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S-IVB/V AUXILIARY PROPULSION SYSTEM 90-DAY RECYCLE CAPABILITY TEST REPORT, MODULE I

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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MCDONNELL DOUGLAS CORPORATION

S-IVB/V AUXILIARY PROPULSION SYSTEM 90-DAY RECYCLE CAPABILITY TEST REPORT, MODULE I

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COORDINATED BY: W. L. BROWNING
PROJECT OFFICE-TEST
HUNTINGTON BEACH DEVELOPMENT ENGINEERING
SATURN/APOLLO APPLICATIONS PROGRAMS

PREPARED BY:
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
SATURN S-IVB TEST PLANNING
AND EVALUATION COMMITTEE

PREPARED FOR:
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MODEL DSV-4B

H. B. Mitchell for
APPROVED BY: A. P. O'NEAL
HUNTINGTON BEACH DEVELOPMENT ENGINEERING DIRECTOR
SATURN/APOLLO & APOLLO APPLICATIONS PROGRAMS

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
5301 Bolsa Avenue, Huntington Beach, California 92647 (714) 897-0311

ABSTRACT

This report presents an evaluation of the Auxiliary Propulsion System 90-Day Recycle Capability Test, Module I that was conducted at the Sacramento Test Center from 8 May to 7 October 1968. The test was conducted to verify the capability of the Auxiliary Propulsion System modules to remain in a KSC launch-ready condition for an extended hold period and subsequently to meet performance criteria after vibration.

This test program was conducted under National Aeronautics and Space Administration Contract NAS7-101, Change Orders 1671 and 1987.

DESCRIPTORS

Saturn S-IVB/V Stage

Auxiliary Propulsion System Module

Complex Gamma Test Facility

Sacramento Test Center

Complex Alpha Test Facility

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PREFACE

This report documents the evaluation of the Auxiliary Propulsion System 90-Day Recycle Capability Test on Module I as performed by MDAC-WD personnel at the Sacramento Test Center. The test was initiated on 8 May 1968 and completed 7 October 1968.

The purpose of the test was to demonstrate the capabilities of the S-IVB/V Auxiliary Propulsion System modules to perform a lunar mission duty cycle after having been exposed to propellants for 90 days and then vibrated.

The burp-firings which were part of the KSC prelaunch requirements were found detrimental to the APS module performance and consequently were deleted from the prelaunch requirements.

This report, prepared under National Aeronautics and Space Administration Contract NAS7-101 (Change Orders 1671 and 1987), is issued in accordance with line item FQ-L-70 of report No. SM-41412, General Test Plan.

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SECTION 1

INTRODUCTION

1. INTRODUCTION

This report presents the results and evaluation of the APS 90-day recycle capability test, module 1, that was conducted at the STC Complex Gamma and Alpha Test Facilities.

The test program was conducted in the following sequence:

a. Extended Hold Test (8 May to 22 July 1968)

b. Supplemental Test (27 July to 7 August 1968)

c. Vibration Tests (12 August to 21 August 1968)

d. Lunar Mission Duty Cycle (27 August to 28 August 1968)

e. Disassembly and Inspection (28 August to 7 October 1968).

The information contained in the following sections documents and evaluates the test program that was initiated on 8 May 1968 and completed 7 October 1968. A test schedule is presented in figure 1-1.

1.1 Objective

The purpose of the test was to verify the capability of the APS module to remain in a KSC launch ready condition during an extended hold period and subsequently to meet performance criteria after vibration of the module. KSC prelaunch requirements will be determined by conditions expected during an extended hold with loaded APS module propellant tanks. KSC launch requirements are determined by boost phase vibration conditions and lunar mission duty cycle (LMDC) operation. The test program incorporated these requirements and simulated KSC launch and prelaunch conditions as closely as possible.

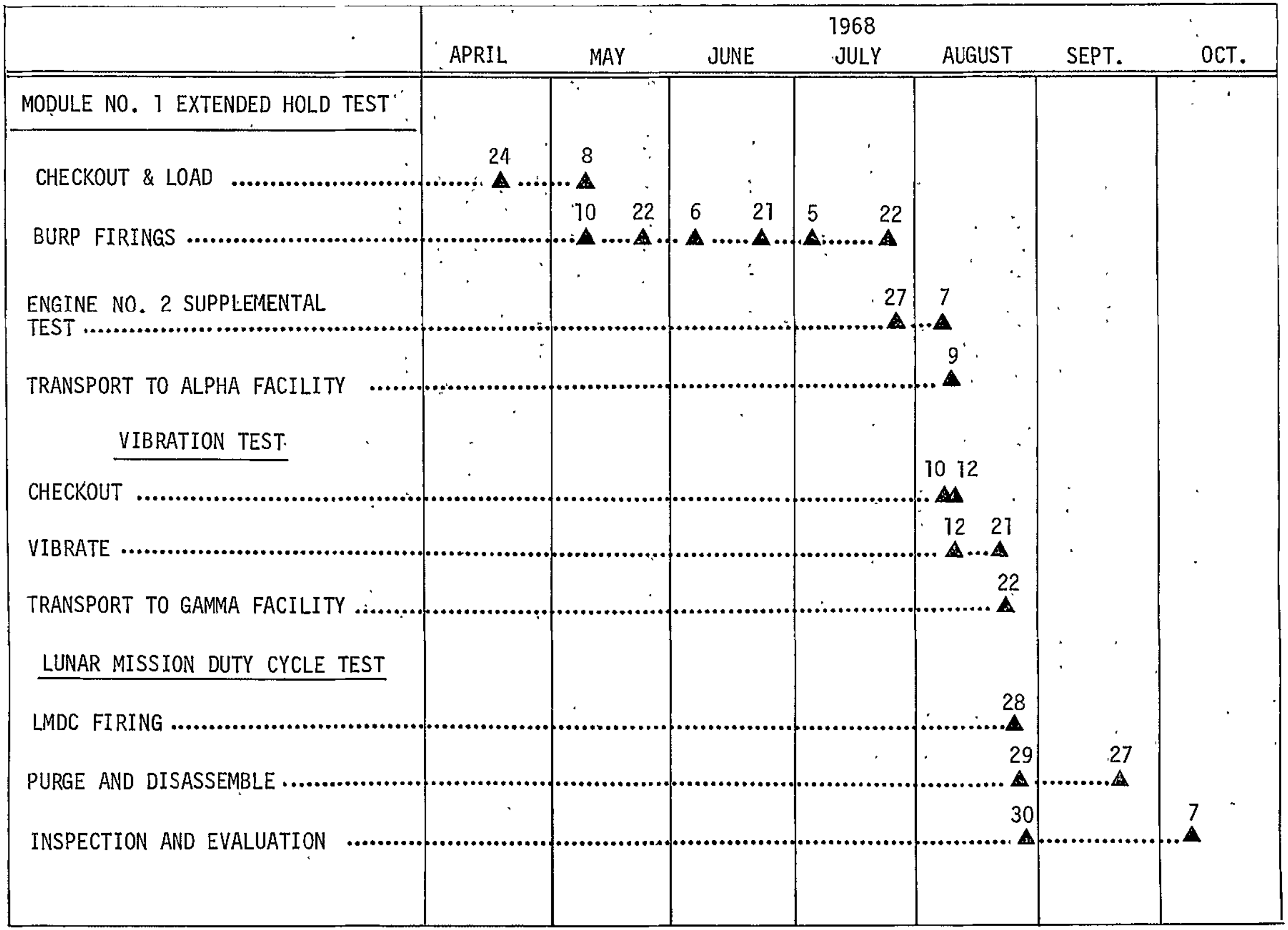


Figure 1-1. APS Recycle Capability Test Schedule

SECTION 2

SUMMARY

2. SUMMARY

The APS module I was subjected to a 90-day recycle capability test that was conducted at the Sacramento Test Center. The test verified the capability of the APS module to remain in a KSC launch ready condition during an extended hold period and subsequently to meet performance criteria after being vibrated.

The following paragraphs describe the anomalies that were noted during the test. Figure 2-1 presents the APS engine chamber pressure history.

2.1 Extended Hold Test

During the extended hold test, APS engines 1 and 3 exhibited a significant degradation of chamber pressure while being burp-fired. The ullage engine (No. 4) performed satisfactorily. Investigation indicated a high probability of a restriction of oxidizer flow in the injector tube inlets, injector tubes, and injectors. Supplementary testing results indicated the anomaly to be directly related to firing the engines for short times at sea-level, with an extended hold between firings.

Results of recent tests conducted by MDAC and MSFC showed detrimental effects of sea level burp-firings on APS engine performance. Consequently, MSFC has concurred with the MDAC recommendation to delete prelaunch burp-firings.

2.2 Supplemental Test Program

A supplemental test was conducted on APS engine No. 2 to determine if APS module and feedline orientation and/or engine burp-firing sequence were contributing factors to the chamber pressure decay observed previously in engines 1 and 3.

The results of this test indicated that feedline orientation and burp-firing sequence had no effect on the chamber pressure degradation phenomenon.

2.3 Vibration Tests

The loaded APS module was installed in a vertical position and subjected to vibration and shock tests (as outlined in the formal qualification test procedure) to simulate launch vibration.

Several discrepancies were noted during and after the tests. These discrepancies were attributed to the following:

a. Overtesting in the radial axis random vibration test levels

b. Duration of the radial axis random vibration test, as specified in the test control document, was excessive

c. Excessive shock test requirements.

2.4 Lunar Mission Duty Cycle

During the LMDC, it was discovered that engine No. 1 was receiving unprogrammed firing pulses. Investigation showed a malfunction of the GSE electrical circuits supplying the pulse signals to the engine. The malfunction was corrected eliminating the spurious pulses.

2.5 Disassembly and Inspection

After completion of the Lunar Mission Duty Cycle (LMDC), the APS module was disassembled and inspected for failures and contamination. The following failures were discovered:

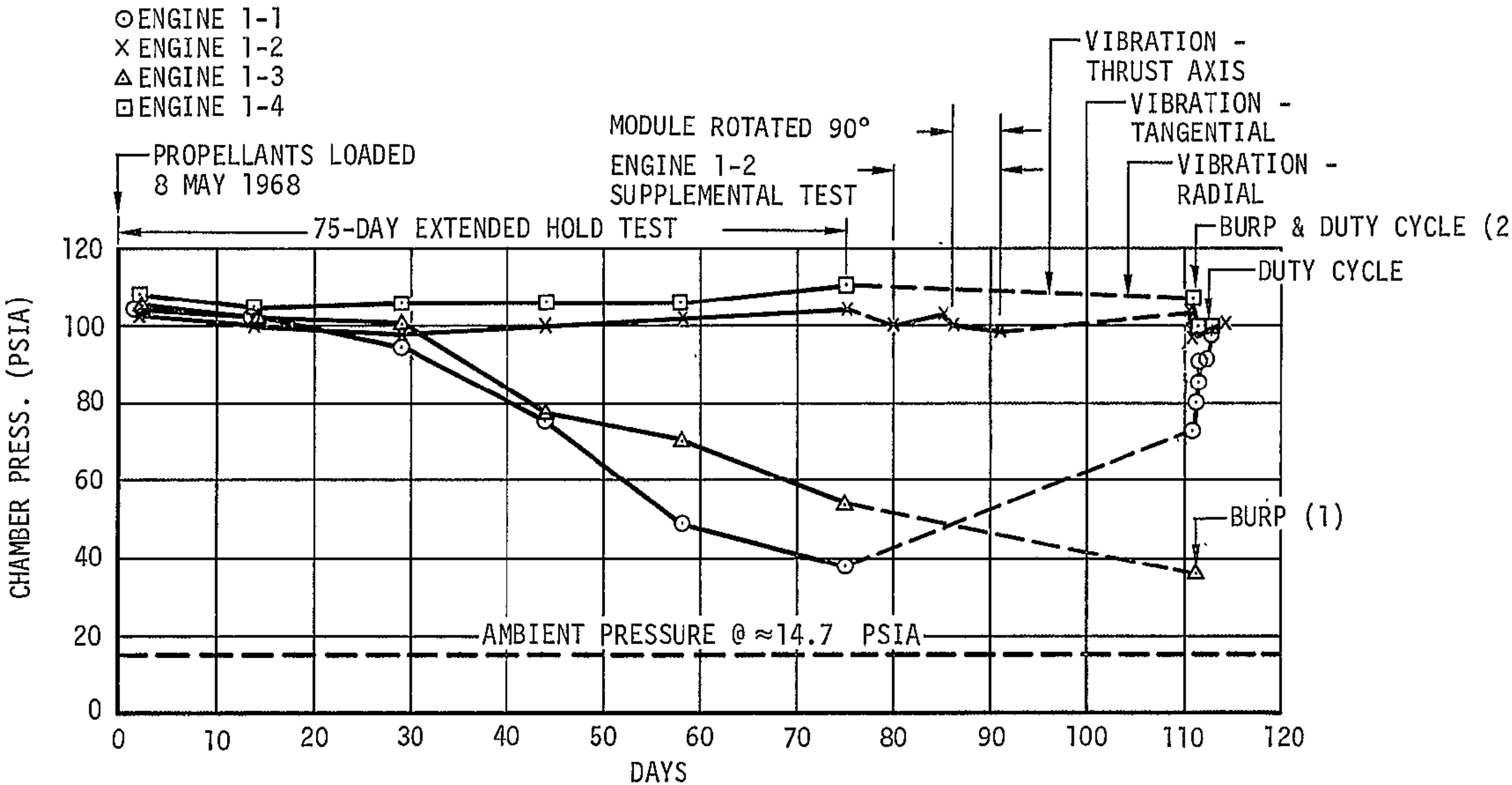
a. A tear approximately 5 in. long was found in the forward end of the oxidizer bladder.

b. A tear approximately 5 in. long was found in the forward end of the fuel bladder.

c. The oxidizer tank diffuser tube had a break completely around the aft end.

The contamination in the APS engines was thought to be caused by the burp-firings which have subsequently been deleted from prelaunch requirements.

The contamination found in the components was attributed to long term exposure but did not affect the functional operation of the APS during the LMDC. Consequently the APS module can tolerate long exposures with no serious detrimental effects to its functional operation.



NOTES:

(1) ENGINE 1-3 WAS NOT COMMANDED TO FIRE DURING LMDC.

(2) DETAILED CHAMBER PRESSURE HISTORY DURING LMDC IS LISTED IN FIGURE 8-4.

(3) LMDC DATA IS VACUUM REFERENCE, ALL OTHER DATA IS AMBIENT REFERENCE.

(4) ENGINE CHAMBER PRESSURE REQUIREMENTS:
  A. VACUUM REF; 101 ±5 PSIA
  B. SEA LEVEL REF, 104 ±5 PSIA

Figure 2-1. APS Engine Chamber Pressure History

SECTION 3

AUXILIARY PROPULSION SYSTEM

3. AUXILIARY PROPULSION SYSTEM

The auxiliary propulsion system (APS) provides attitude control of the stage during all operational phases of S-IVB flight. The system also incorporates a propellant settling capability for damping mainstage propellant transients at the end of the first J-2 engine burn, and for J-2 engine restart after coast. Figure 3-1 is a schematic of the APS and instrumentation.

Subsystem components are contained in two separate modules placed 180 deg apart on the aft skirt. Each module (figure 3-2) contains hypergolic liquid bi-propellant engines, a positive expulsive propellant feed subsystem, and a helium pressurization subsystem. The fuel used by the APS is monomethylhydrazine (MMH) and the oxidizer is inhibited nitrogen tetroxide (N_2O_4). Propellants are stored in two separate tanks equipped with positive expulsive teflon bladders for propellant feed during zero g conditions.

Prior to launch countdown operations, each module is loaded with propellants through connections in the aft end of the module. During loading, the expulsion bladders must initially be in a fully expanded position against the tank wall. A differential pressure is maintained during the preparatory operations to assure that this condition is satisfied.

Propellant loading and recirculation are accomplished simultaneously. Propellant flow is established through the propellant control module transfer valve. The flow then divides, with a portion going to the propellant tank, and a portion circulating through the engine manifolding to eliminate gas from the system. After a full tank is achieved, propellant flow is continued for a short time to assure complete gas elimination. The propellant tank ullage is then established by offloading the required amount of propellant through the transfer valve.

Helium used for propellant expulsion is loaded into the module through a pneumatic service line connected to the stage through the fly-away stage umbilicals.

The APS modules are enabled in flight after the second stage retrorockets have been ignited. The APS provides stage roll control during S-IVB J-2 engine burn. Commands for operation of the APS engines are provided by the instrument unit. Output from a guidance platform indicating measured vehicle attitude is received in the instrument unit (IU), and a comparison is made with the desired or programmed attitude. If a deviation exists, the IU gives the required commands (via a control relay package) to the APS engine injector valves for thrust duration proportional to the magnitude of the deviation.

At J-2 engine cutoff, the APS pitch and yaw controls are activated, and all controls (pitch, yaw, and roll) remain active throughout the coast phase. At J-2 engine restart, the pitch and yaw modes are deactivated. The pitch and yaw modes are reactivated after J-2 engine second-burn cutoff to maintain 3 axes attitude control.

The APS ullage (propellant settling) engines (one in each module) are enabled during the J-2 engine first-burn cutoff transient to prevent undesirable stage propellant movement. Firing continues through the engine cutoff transient decay and the activation of the LH2 tank continuous propulsive vent system. The APS ullage engines are again fired at the end of orbital coast to provide propellant settling during J-2 engine restart.

3.1 Engine Systems

Three 150-lbf thrust attitude control engines and one 70-lbf thrust ullage engine are employed in each APS module. The 150-lbf thrust engines are manufactured by Thomas-Ramo-Woolridge Incorporated. The 70-lbf thrust engine was designed, developed, and manufactured under NASA contract by Rocketdyne Division of North American-Rockwell for the Gemini Program. The 150-lbf thrust engines employ quadruple injector valves for redundant valve action. The 70-lbf Gemini (ullage) engine employs single valves on both the fuel and oxidizer lines.

3.1.1 150-lbf Thrust Attitude Control Engines

Three 150-lbf thrust engines (figure 3-3) are employed in each APS module, and have quadruple propellant injector valves for redundancy. The thrust chamber is an integral part of the engine, and is composed of a combustion chamber, a nozzle throat section, and a nozzle expansion cone.

The injector consists of 12 pairs of unlike-on-unlike doublets arranged to minimize hot spots in the combustion chamber. The valve side of the injector is filled with a silver braze heat sink to reduce injector operating temperature.

The engine was qualified for a total pulse operation of 300 sec. During the 300-sec life requirement, the external wall temperature does not exceed 1,060 deg R, and the maximum valve body external temperature does not exceed 625 deg R. The maximum expected duty cycle requirements on the S-IVB/V is approximately 90 sec.

Engine propellant flow is controlled by a valve assembly which consists of eight solenoid valves arranged in two quad-redundant series-parallel valve arrangement to preclude any operational failure due to a single valve malfunction. A dual failure, such as two valves "failed open" in series or two valves "failed closed" in parallel, must occur to cause a failure.

The injector valves provide positive on/off control of propellant flow upon command from an external power source. Four valves, integral in an assembly, are capable of simultaneous operation and are synchronized to open or close within 3 ms of each other. The opening time for each valve assembly, defined as the time from initiation of open signal to fully open valve package, does not exceed 23 ms.

3.1.2 70-lbf Thrust Ullage Engine

Propellant settling is accomplished by a 70-lbf thrust film-cooled ullage engine (figure 3-4). Propellant flow to the engine is controlled by single solenoid valves: one for fuel and one for oxidizer. Engine operation has been qualified for continuous burn time of approximately 640 sec.

3.2 Propellant Feed System

The propellant feed system (figure 3-5) consists of separate fuel and oxidizer propellant tank assemblies, propellant control modules, and propellant manifolds for distribution of propellants to the engines. Filling of each tank assembly is accomplished through the outer (perforated) tube; the inner (solid wall) tube allows entrained gases in the bladder to be exhausted from the tank as the bladder is filled. Positive expulsion of propellants is accomplished by pressurizing the ullage space between the tank and the bladder.

3.2.1 Propellant Tanks

Each propellant tank (fuel and oxidizer) consists of an outer titanium pressure vessel (cylindrical shell with hemispherical ends of approximately 4,100 cu. in. capacity), an internal teflon bladder, and standpipe assembly (figure 3-5).

The bladder is fabricated of fluorinated ethylene propylene teflon laminated to polytetrafluoroethylene using a spray process resulting in a one-piece seamless unit with a nominal wall thickness of 6 mils. The bladder provides a separation membrane between the pressurization gas (ullage) and the propellant, and also provides a method of transferring propellant under zero g environment. The ullage space between the tank and the bladder is pressurized with helium gas to provide the expulsion pressure necessary for propellant flow.

A concentric tube standpipe assembly is located axially in the center of the tank assembly within the bladder. Propellant passes through perforations in the standpipe during expulsion as well as during filling operations. A vent tube is located within the standpipe assembly to allow removal of gas from inside the bladder.

3.2.2 Propellant Control Modules

The propellant control (figure 3-6) module provides for loading and recirculation of propellants and purging of the propellant systems.

The propellant transfer valve is a direct-operating, normally-closed solenoid valve. The transfer valve cannot be opened by application of power if the subsystem pressure exceeds external pressure by more than 10 psi, and the transfer valve will not close or remain closed if the external pressure exceeds subsystem pressure by more than 40 psi.

The propellant recirculation valve is a direct-acting, normally-closed solenoid valve with two independent poppets and seats. The two-poppet design isolates the engine recirculation line from the tank recirculation line, and all propellant flowing to the engine passes through a 10-micron nominal and 25-micron absolute rated filter.

3.2.3 Recirculation In-Line Filter

The filter assembly (figure 3-7) consists of a body with two in-line male tube fittings containing a filter element. The element is a welded assembly of a perforated support tube covered with corrugations of dutch twill weave wire cloth to provide an absolute filtering of particles greater than 25 microns.

Two filters are used in the fuel and oxidizer propellant recirculation lines to provide filtering of propellant or purge gas flowing through the propellant control module recirculation valve.

3.3 Helium Pressurization System

The helium pressurization system consists of two check valves in series, a helium storage tank, a helium pressure regulator assembly, two quadruple check valves, two filters, and two low pressure helium modules.

The helium storage tank stores helium at an initial pressure of 3,000 $\pm$200 psia. This pressure is reduced to 196 $\pm$3 psia for propellant tank ullage pressurization through a two-regulator module. These regulators are connected in series, and function by sensing the regulator downstream pressure.

Since a common pressurization subsystem is used, quadruple check valves are employed between the regulator and propellant tankage for added assurance that hypergolics will not mix as the result of leaks or normal permeation. The low pressure helium modules provide ground venting capabilities of propellant tank ullage pressure, and a means of establishing pneumatic control of the expulsion bladders during loading and checkout. Command venting capabilities during flight are not provided, although the propellant tanks are protected from overpressurization by relief valves in the low pressure helium modules. All helium entering the regulated pressure area of the subsystem is filtered upstream of the regulators.

3.3.1 High Pressure Helium Tank

The helium tank is a welded titanium assembly consisting of a cylindrical center section and two hemispherical end domes, each containing a female tube fitting boss. The helium tank is a gas reservoir for the propellant positive-expulsion system on the S-IVB/V attitude control system.

3.3.2 Helium Pressure Regulator Module

Helium stored at 3,000 $\pm$200 psia in the high pressure helium tank is fed to a helium regulator module. The helium gas entering the module passes through an internal filter and then through two regulators in series, both of which sense downstream pressure. The first (or primary) regulator regulates the gas pressure to 196 $\pm$3 psig while the redundant secondary regulator regulates the gas pressure to 200 $\pm$3 psig. During normal operation, regulated pressure is maintained by the primary regulator. Should the primary regulator fail, the secondary regulator then begins operation. Each regulator is of fail-open design. Ambient pressure sensing ports, provided on both regulators, furnish the necessary ambient pressure references. Regulator performance is evaluated by pressure transducers installed immediately before and after the regulators. Regulated helium is fed through quadruple check valves and filters to the ullage area of the fuel and oxidizer tanks.

3.3.3 Quadruple Check Valves

Two sets of quadruple check valves are employed in the helium pressurization subsystem; one set in the fuel tank pressurization line, and the other set in the oxidizer tank pressurization line. These check valves prevent contact of fuel and oxidizer vapors in the pressurization subsystem due to permeation through the bladders during normal operation or bladder leaks.

Each set of check valves consist of four check valves connected in a series-parallel arrangement and contained in one enclosure. Failure of a check valve set requires open-failure of two check valves in series or closed-failure of two check valves in parallel.

3.3.4 Low Pressure Helium Module

The low pressure helium module (figure 3-8) consists of a solenoid dump valve and a relief valve. Two low pressure modules are employed in the pressurization subsystem, one module connected to each propellant tank ullage volume. The solenoid dump valve is a normally-closed, direct-acting valve with a dual (redundant) coil. The valve performs no flight function, and is employed only to vent or pressurize the propellant tank ullage during ground servicing and checkout operations.

The purpose of the relief valve is to provide overpressurization protection of the propellant tankage during ground or flight operations.

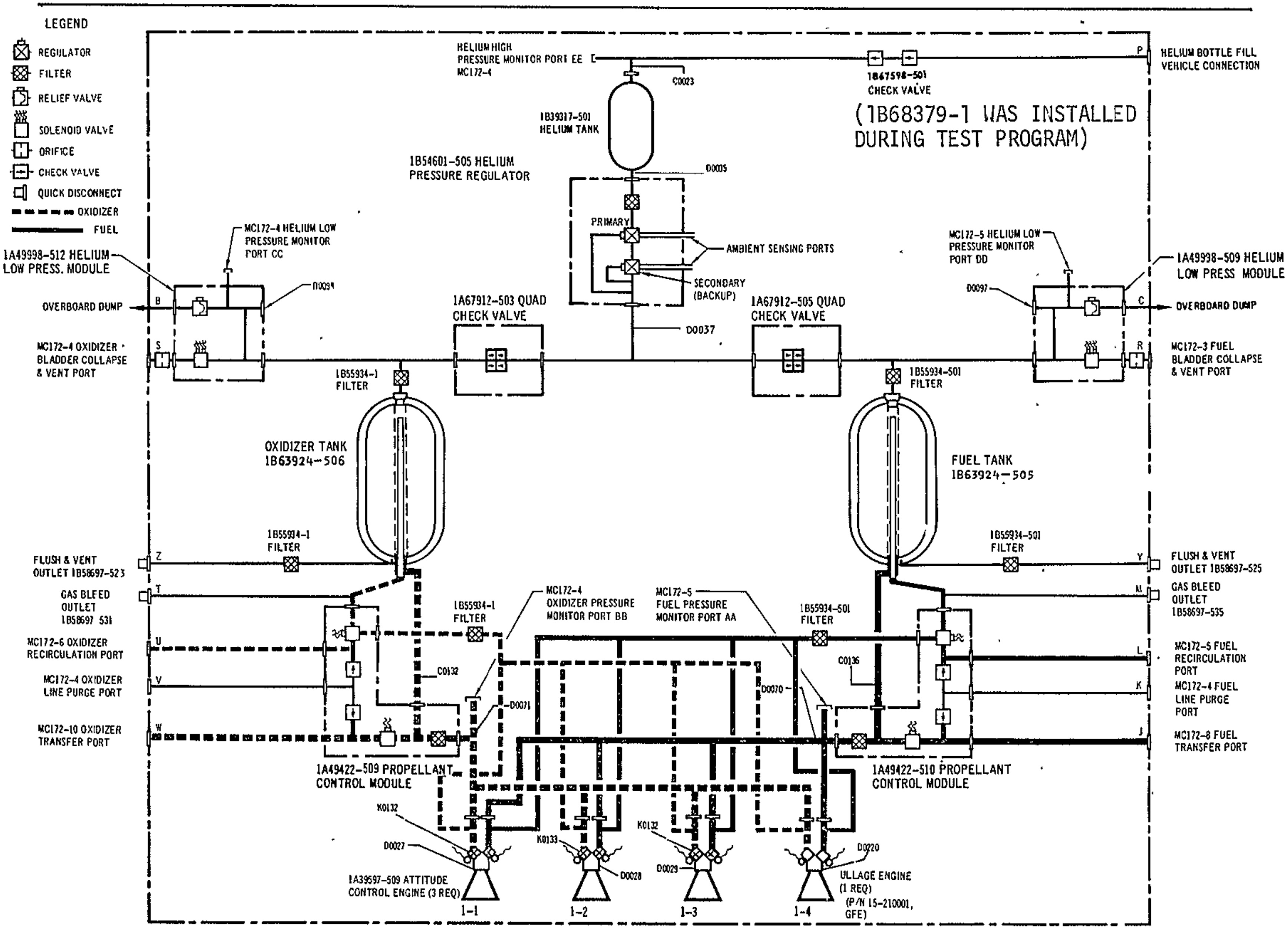


Figure 3-1. S-IVB/V Auxiliary Propulsion System and Instrumentation

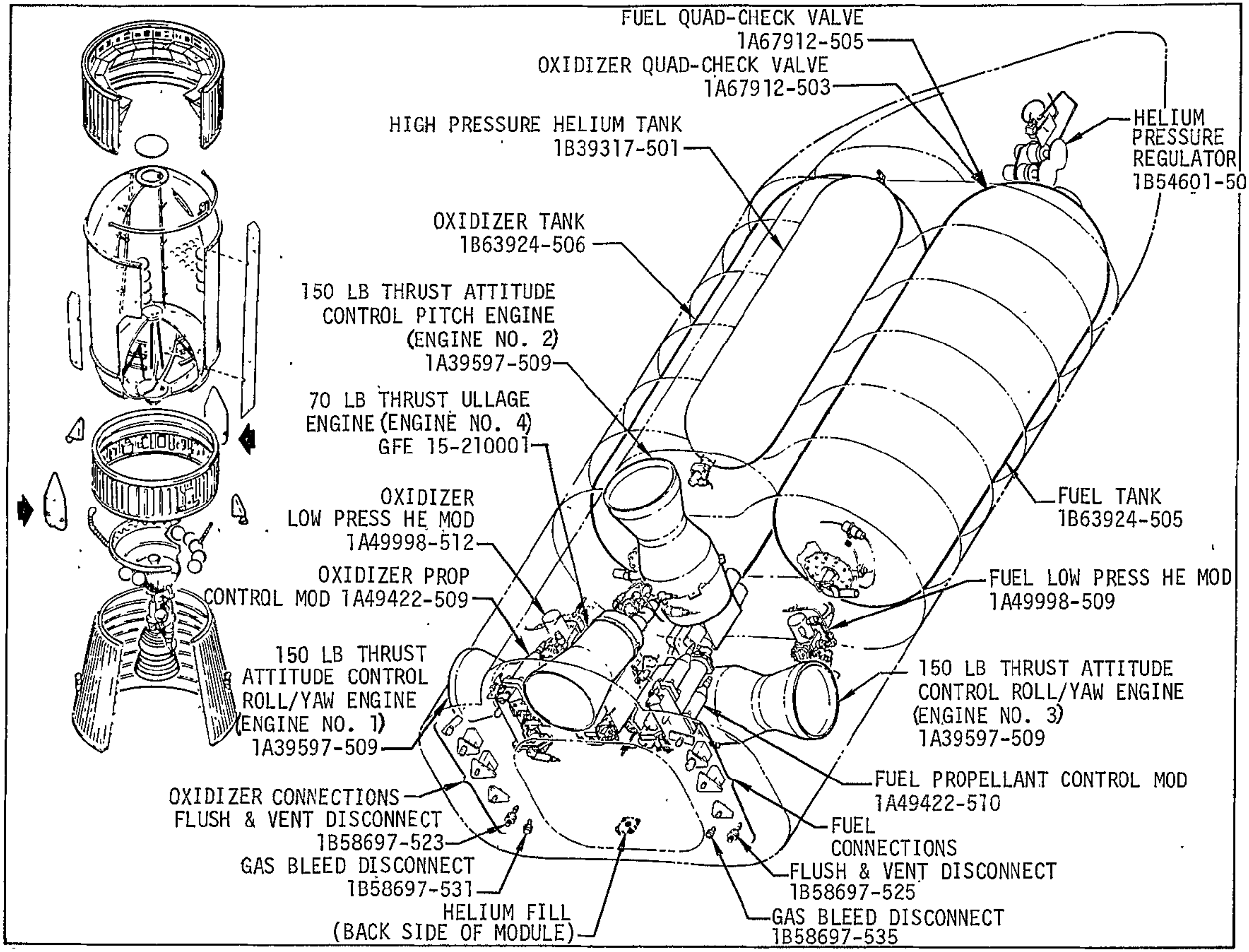


Figure 3-2. S-IVB/V Auxiliary Propulsion System Module

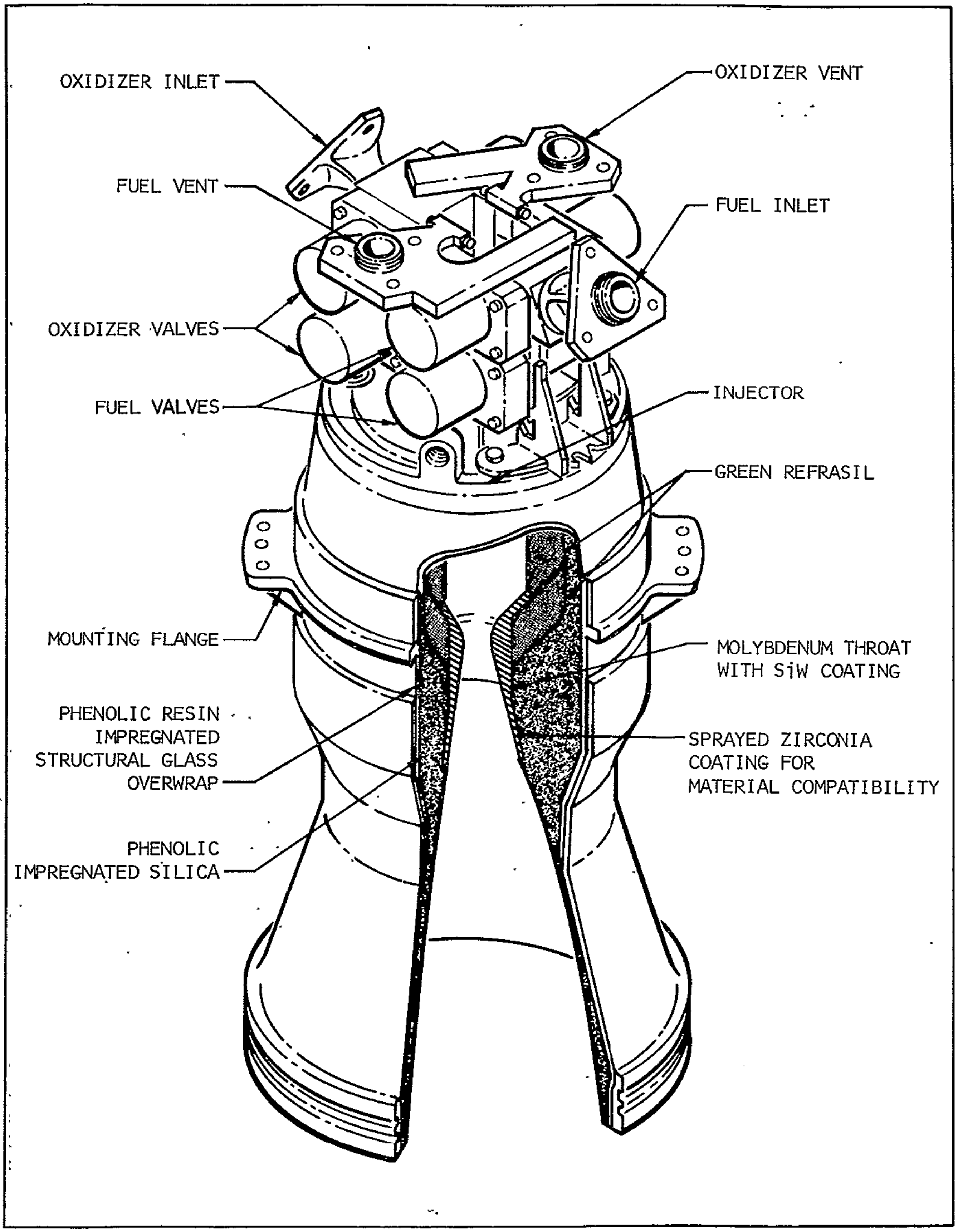


Figure 3-3. 150-lbf-Thrust Attitude Control Engine

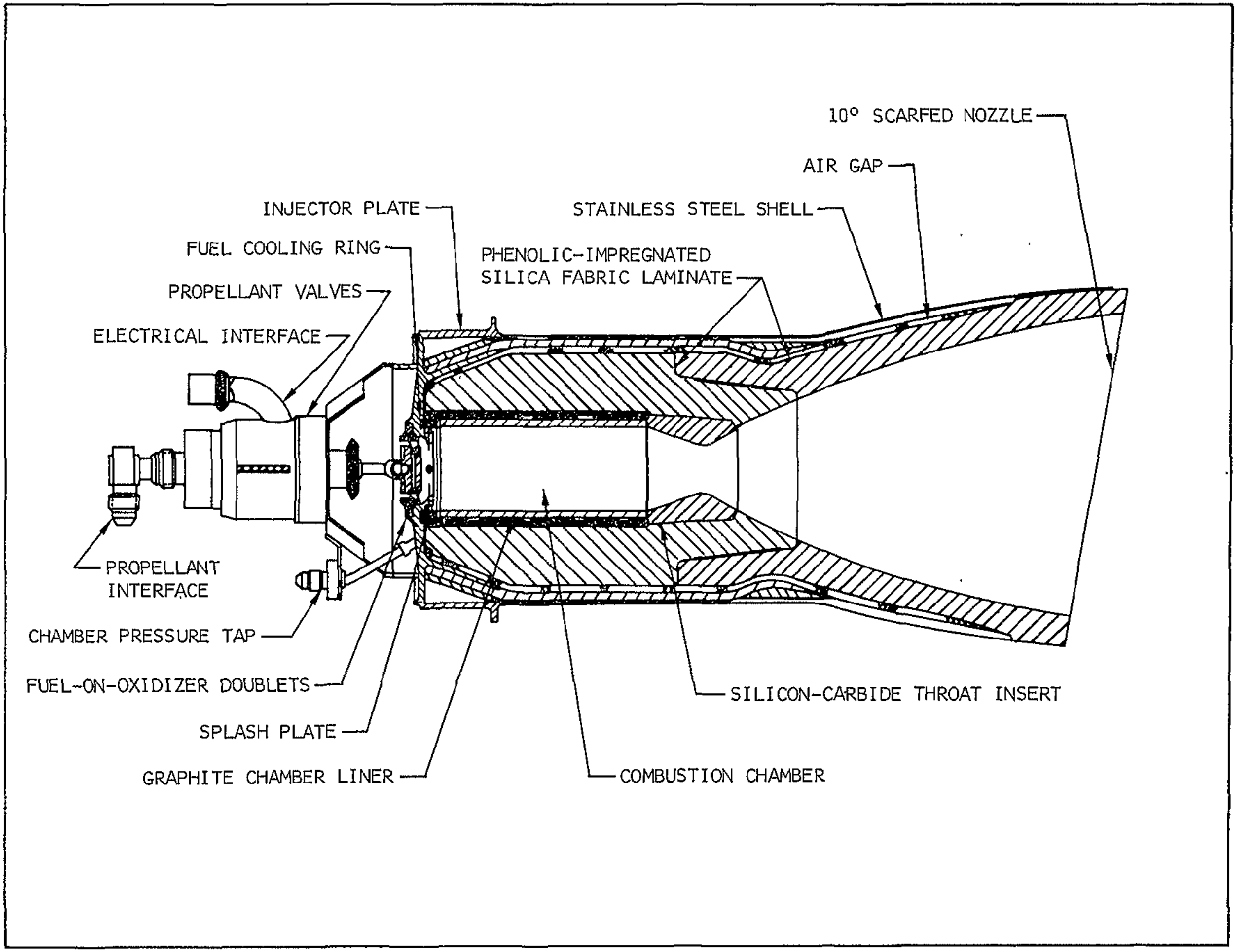


Figure 3-4. 70-lbf-Thrust Ullage Control Engine

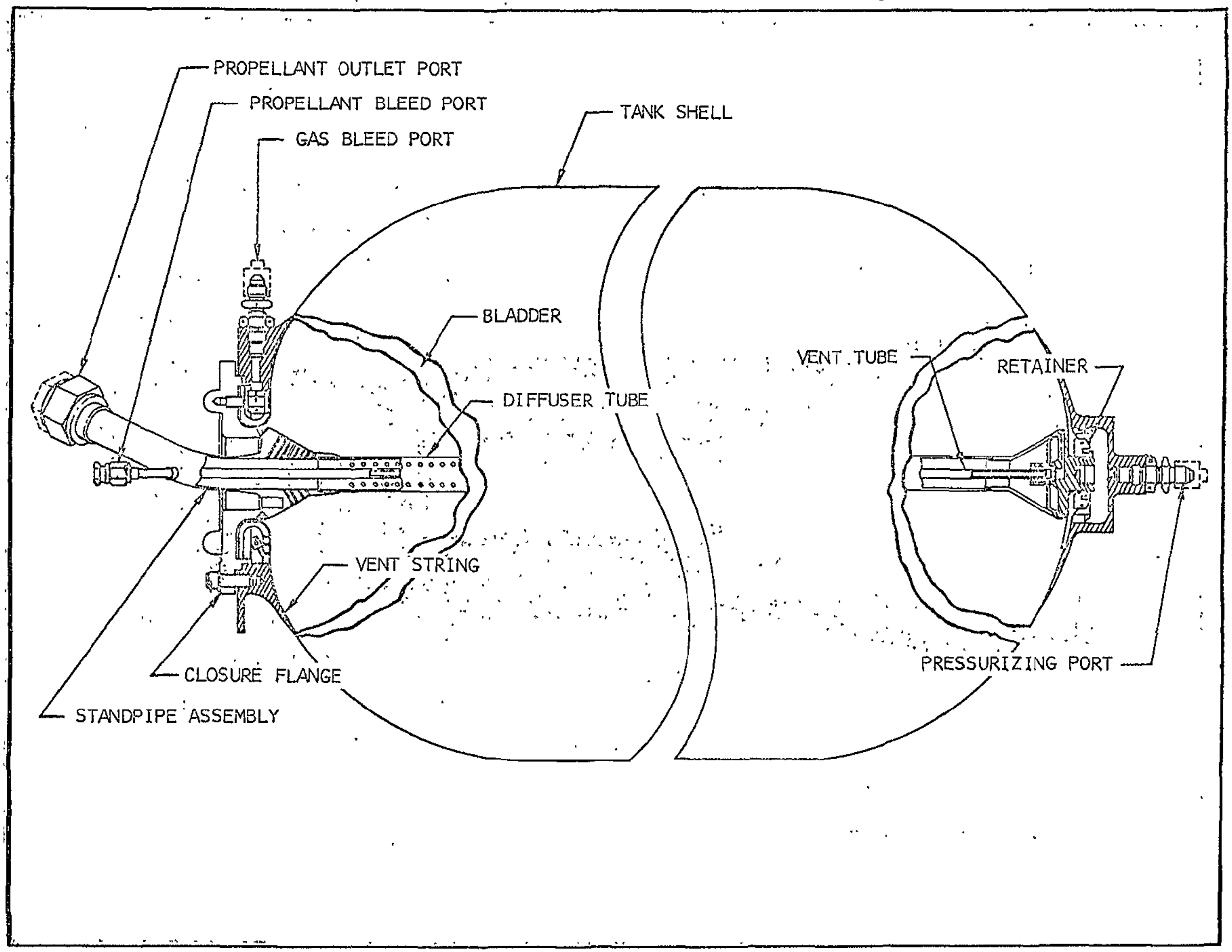


Figure 3-5. Positive Expulsion Propellant Tank

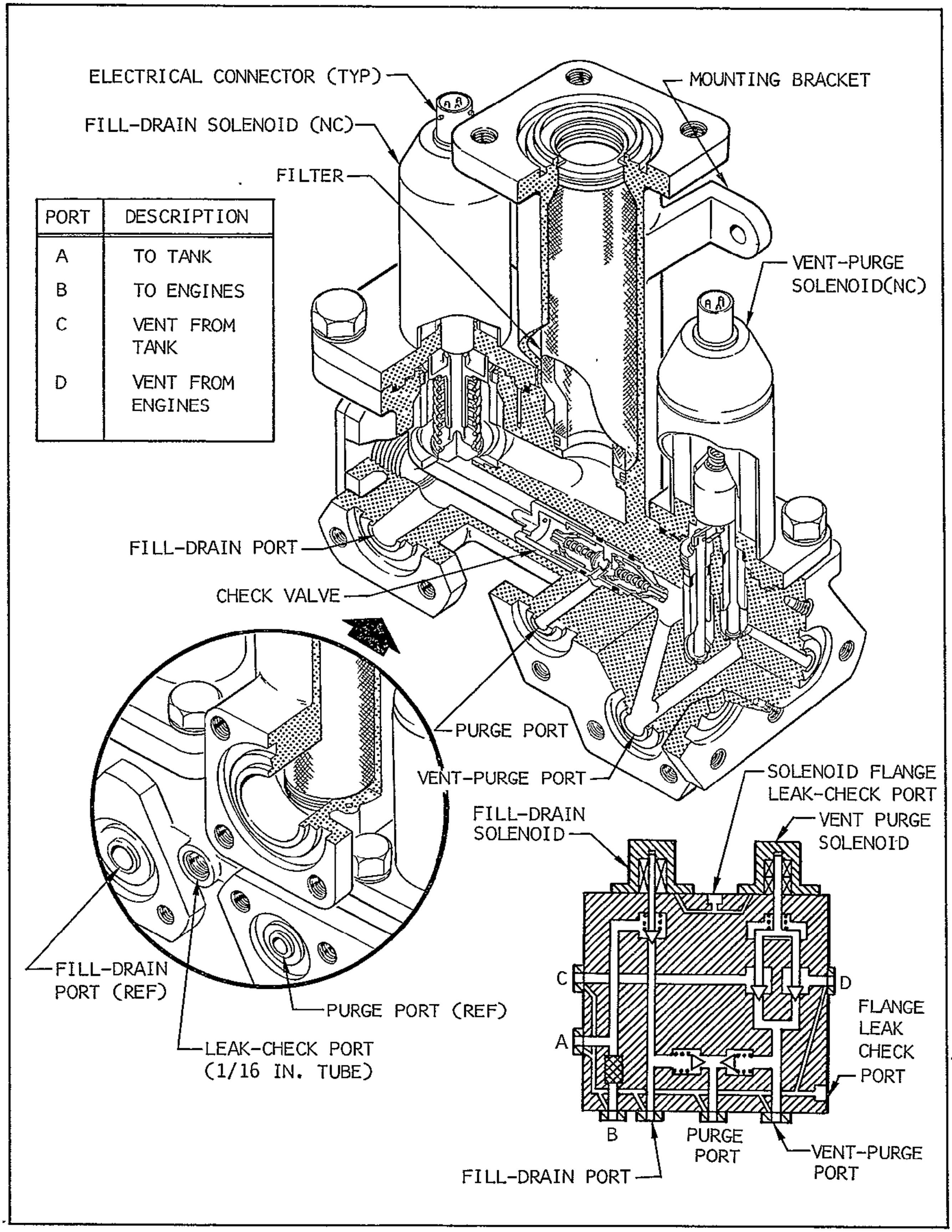


Figure 3-6. Propellant Control Module

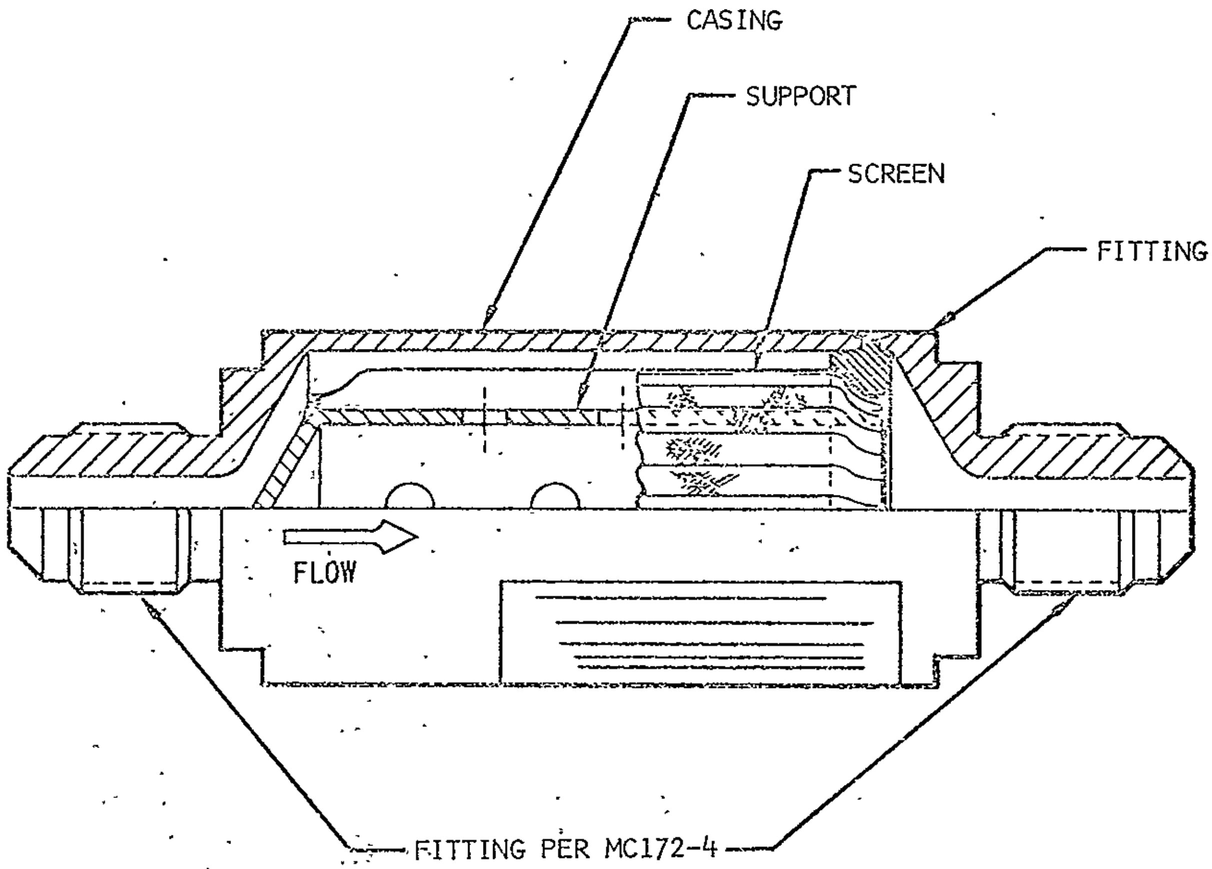


Figure 3-7. 25 Micron Recirculation In-Line Filter

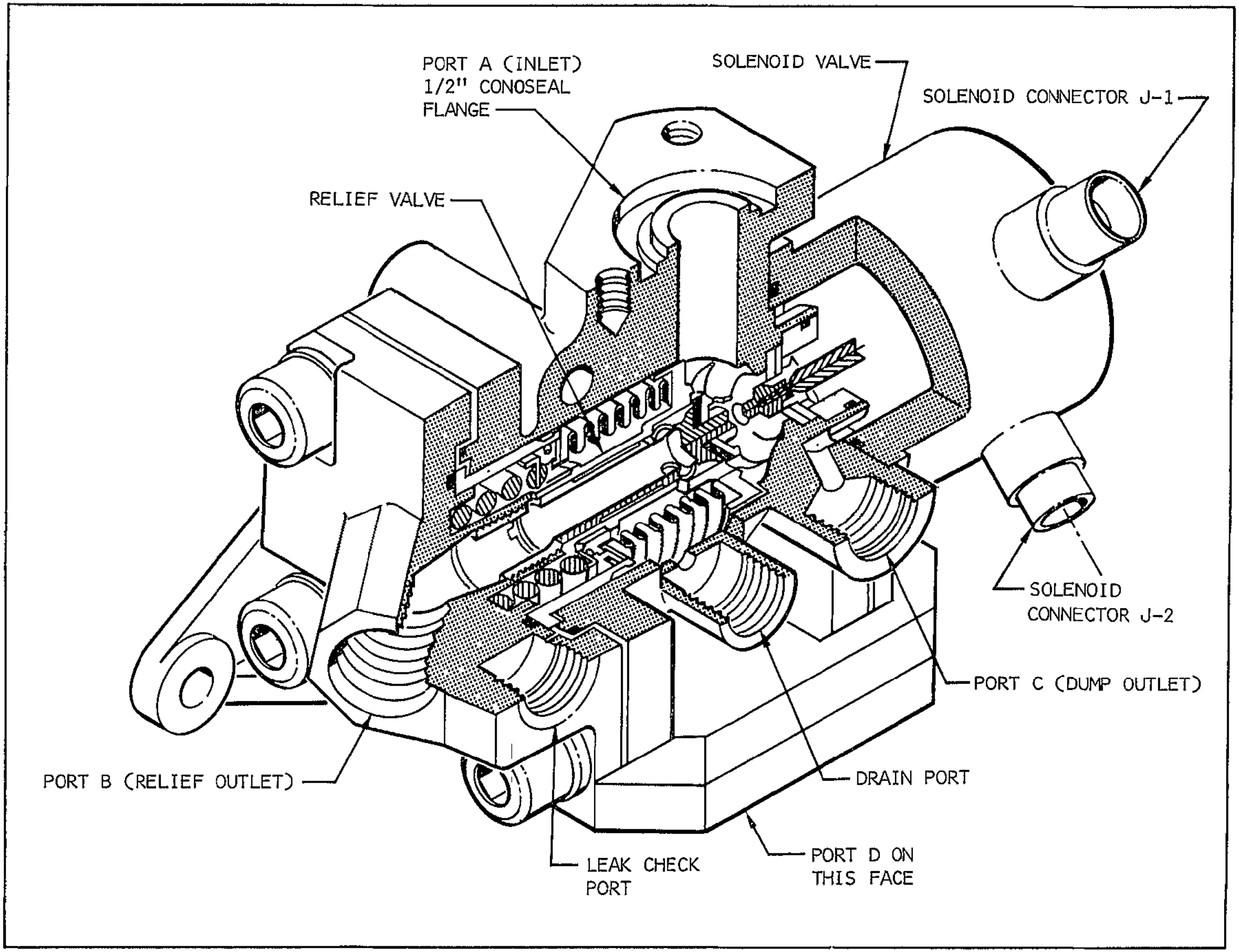


Figure 3-8. Low Pressure Helium Module

SECTION 4

TEST CONFIGURATION

4. TEST CONFIGURATION

The test configuration for line item FQ-L-70 (APS Module No. 1, S/N 507-1, Assembly No. 1A83918-535) is described in the following paragraphs. The components installed on assembly No. 1A83918-535, S/N 507-1 are listed in table 4-1.

4.1 APS Module I

The APS module I was installed in test cell III at Complex Gamma, Sacramento Test Center. The module was attached to a test mounting structure which provided the capability of rotating the module within the test cell. Since the test cell is of open construction, an environmental control unit was required to maintain the module and propellant temperatures within the desired ranges. The environmental control unit was connected to the APS module by a flexible duct and supplied cool or warm air as required through the openings provided in the module fairing.

4.2 Instrumentation

4.2.1 Gamma Test Control Center

The electrical control panels located in the Test Control Center provide for remote operation of the APS module and support equipment. Functions such as purging, pressurizing, and propellant transfer are controlled manually. Engine firing, however, can be controlled manually, semi-automatically, (which requires manual timer setting), or by a completely automatic punched tape system. The Test Control Center, in addition to the meters on the operating consoles, also contains 8 stripchart recorder channels for monitoring critical redline parameters while testing and a 100-channel event recorder to monitor sequence of operations.

All burp-firings were controlled automatically by the 1B70326-21 control tape. The LMDC test was controlled automatically utilizing the 1B70326-21, -9, -11, -13, -11, -13 (in sequence) control tapes. These tapes, in addition to providing automatic engine firing commands, control the analog tape recorder and oscillograph which are located in the Instrumentation Center.

4.2.2 Gamma Instrumentation Center

The Instrumentation Center (IC) contains the major components of the data acquisition system. The data recording capabilities include 42 strip chart channels, 56 oscillograph channels, 90 pulse duration modulation (PDM) channels and 23 frequency modulation (FM) channels. The PDM and FM data are recorded on two 14-track tape recorders. In addition, the IC contains a range time generator, photo camera control panel, master calibration control console, and various signal conditioning equipment.

The instrumentation system consisted of two basic inter-related systems: the ground instrumentation system, and the APS module instrumentation system. All measurements were hardwired to their respective recording equipment and did not utilize telemetry.

4.3 Alpha Facility

The APS module I was transported to the Complex Alpha test facility for the vibration tests while loaded with propellants. The module was mated to a simulated section of an aft skirt which was attached to vibration fixtures. The vibration fixtures were attached to the shaker head of a C-210Y "MB" vibration exciter. The vibration exciter was driven by two "MB" model T999 power amplifiers. Because the test site is of open construction, an environmental control unit was required to maintain the module and propellant temperatures within the desired ranges. The environmental control unit was connected to the APS module by a flexible duct which supplied cool or warm air, as required, through the openings provided in the module fairing.

The electrical control panels located at Alpha Test Control Center provided for remote operation of the APS module and support equipment. Functions such as pressurizing, venting, and the ability to off load propellants in case of emergency were controlled manually. The test control center in addition to the meters on the operation console, also contained strip chart recorder channels for monitoring the critical redline parameters while the APS module was being vibrated.

A small portion of the Alpha Test Control Center instrumentation was used for the vibration test. The data recording equipment used included

10 strip chart channels, 3 dc amplifier channels, 3 signal condition channels, and 13 frequency modulation (FM) channels. The FM data was recorded on two 14-track tape recorders; one primary and one backup recorder. Two 14-track tape recorders were used by EE&S at the vibration site to record twenty-two vibration control accelerometers. In addition, a range time generator, photo camera system, master calibration control console, closed circuit TV, and a video tape recorder were utilized.

4.3.1 Equipment Used at Gamma Site

The facility and ground support equipment used was that shown in drawing 1B70590 and consisted of the following:

Model	1872	Pressure Kit, Fuel
Model	1873	Pressure Kit, Oxidizer
Model	372	Fuel Valve Complex
Model	373	Oxidizer Valve Complex
Model	323	Fuel Mobile Servicer
Model	322	Oxidizer Mobile Servicer
Model	212	Fuel System & Ullage Pressure & ΔP Transducers
Model	213	Oxidizer System & Ullage Pressure & ΔP Transducers
Model	374	Pneumatic Distribution Complex
Model	375	Pneumatic Regulation Complex
Model	592	Test Cells Installation Complete Drawing List
Model	628	Gamma APS Testing Support Equipment
Model	702A	APS Module Monitor Panel Installation Cell III
Model	655	Propulsion Systems Propellant Storage Facilities Drawing List

4.3.2 Equipment Used Without Modification

Model 1872 Pressure Kit, Fuel

Model 1873 Pressure Kit, Oxidizer

Model 372 Fuel Valve Complex

Model 373 Oxidizer Valve Complex

Model 374 Pneumatic Distribution Complex

Model 375 Pneumatic Regulation Complex

Model 702A APS Module Monitor Panel Installation, Cell III

4.3.3 Equipment Requiring Modification

a. Models 212 and 213, Fuel and Oxidizer (respectively) System Pressure, Ullage Pressure, and Pressure Differential Transducers were modified by replacing the 0-50 psia pressure transducers with 0-100 psia transducers (2 in each model). (See MRD Revisions per DCRSEO's 1B60868-A45-1, 1B60 869-A45-1, 1B60871-A45-1, and 1B60872-A45-1.)

b. Model 322 Oxidizer Mobile Servicer was modified by adding a temperature gage to the 1A71460-502 storage tank. (See DCRSEO 1A71460-A45-1A.)

c. Model 323 Fuel Mobile Servicer was modified as follows:

   (1) A temperature gage was added to the 1A71460-502 storage tank (see DCRSEO 1A71460-A45-1A).

   (2) All quick disconnects were eliminated from the interface with facilities plumbing (see DCRSEO 1A71475-A45-4).

d. Model 592 Test Cells Installation Complete Drawing List was modified as follows:

(1) Quick disconnect assemblies were removed from lines attaching to Model 323 interfaces DNE-53, DNE-54 and DNE-55, and the applicable 1B05151 adapter was installed (see CP revision of drawing 1B35359 and variation EO 1B35359 CV).

(2) A hand operated shutoff valve was added between the 1B70021 fuel system panel and the port R facility interface (see the CT revision of drawing 1B35359).

(3) A hand operated shutoff valve was added between the 1B70021 oxidizer system panel and the port S facility interface (see the CJ revision of drawing 1B35362).

(4) A reducer, tube assembly and elbow were added in the Apollo regulator vacuum line to port B (see the CU revision of drawing 1B35359).

(5) A reducer, tube assembly and elbow were added in the Apollo regulator vacuum line to port A (see the CK revision of drawing 1B35362).

(6) Flared tube reducers and associated parts were installed on the oxidizer fill interface, GNE-55 (see variation EO 1B35362 CL).

e. Model 665 Gamma Propulsion System Propellant Storage Facility Drawing List was modified as follows:

(1) Quick Disconnects were removed from the transfer and vent/pressure lines in the oxidizer storage area (see criteria EO 1B35418 H).

(2) Quick Disconnects were removed from the transfer and vent/pressure lines in the fuel storage area, and the applicable 1B05151 adapters were installed (see P revision of drawing 1B35422).

f. Model 628 Gamma APS Testing Support Equipment was modified as follows:

(1) A new tube assembly (1B60985-636) was added to interface the fuel ullage pressure sense line with the low pressure helium module. Installation of APS aft door assemblies makes this tube assembly necessary.

(2) The 1B70021 Sightglass Panel Assembly was modified as follows:

(a) S011356-3 and -4 elbows were removed and replaced with S0089J4-3-6 and S0089J4-4-6 tees, respectively, in the lines leading to APS ports R and S, respectively (see 1B70021 S revision).

(b) The AN919-19S reducers between the fuel and oxidizer transfer umbilicals and the sightglass assembly were changed to S0089J12-8-4 tees, to provide system pressure sense ports such that the 0-60 psig gages at DGE-63 and GGE-63 can be isolated during 200 psig checks (see 1B70021 T revision).

(c) The flowmeters and the short (1B60985-596 and -597) tube assemblies were removed from the fuel and oxidizer fill lines because they were not required, and their removal eliminated several potential leak paths (see 1B70021 U revision).

(3) An additional hand valve was installed on the 1B70754-1 and -501 calibration tank assemblies in order to vent the calibration tanks to permit filling, and to provide a means of pressurizing the calibration tanks when their contents were required for topping off the APS propellant tanks (see 1B70754 H revision).

(4) The 1B68009-1 and -501 Tank Assembly, Gas Removal was modified as follows:

(a) An additional hand valve was added in order to permit bleeding off the excess gas introduced into the propellant tanks to position the bladders against the tank walls during transportation (see DCRSEO 1B68009-A45-1).

(b) The nickel conoseals (S0254NX) were replaced with corrosion resistant steel seals (P/N VSF1015SX) to eliminate a corrosion problem (see DCRSEO 1B68009-A45-2).

(5) The range of all gages in 1B70021 panel was changed from 0-30 psig to 0-60 psig.

4.3.4 Discussion

a. The change of transducers on Models 212 and 213 was necessary to avoid working the transducers at full-range during propellant loading. The 100 psia transducers working in mid-range give improved accuracy and give full information on surge pressures.

b. The quick disconnects were removed from Models 323, 592, and 665 because they were defective. For the same reason, they had been removed previously from the oxidizer mobile servicing unit, Model 322.

c. Temperature gages were added to the propellant storage tanks in Models 322 and 323 because of temperature limitations on the flexing of the APS propellant tank bladders.

d. The hand valves added to Model 592 between the 1B70021 panel and the port R and port S facility interfaces were required to provide control of APS propellant tank ullage venting.

e. The interface connections of Model 592 to the APS vacuum ports A and B were modified because of the requirement that the APS doors be installed.

f. The flared tube reducers and associated parts installed on Model 592 oxidizer fill interface GNE-55 per 1B35362 CL and on fuel fill interface DNE-55 per 1B35359 CV were required to permit unloading the propellant tanks into the respective calibration tanks.

TABLE 4-1
MODULE NO. 1 COMPONENTS
(Sheet 1 of 4)

INITIAL TEST CONFIGURATION			ACTUAL TEST CONFIGURATION	
Item	P/N	Configuration	Configuration	S/N
Pressurization System Installation (1A79373-503)				
Quad Check Valve (Fuel Side	1A67912	-505	-505	1109
Quad Check Valve (Oxid Side)	1A67912	-503	-503	1018
Low Press. He Module (Fuel Side)	1A49998	-509	(-509)	(a) 106G (Replaced 101G)
Low Press. He Module (Oxid Side)	1A49998	-512	(-512)	129G
Helium Pressure Regulator	1B54601	-505	-505	03825M640060
Helium Tank	1B39317	-503 (b)	(b)-501	021
Primary High Pressure He Check Valve	* (d) 1B68379	-1	-1	353
Secondary High Pressure He Check Valve	* (d) 1B68379	-1	-1	354
Disconnect Coupling (Flush and Vent Outlet Oxidizer Ullage)	1B58697	-523	-523	A125
Disconnect Coupling (Flush and Vent Outlet Fuel Ullage)	1B58697	-525	-525	C126
Filter (Oxidizer Tank Ullage Drain Line)	1B55934	-1	-1	1036034
Filter (Oxidizer Ullage Supply)	1B55934	-1	-1	1036037

*Not flight configuration

TABLE 4-1
MODULE NO. 1 COMPONENTS
(Sheet 2 of 4)

INITIAL TEST CONFIGURATION			ACTUAL TEST CONFIGURATION	
Item	P/N	Configuration	Configuration	S/N
Filter (Fuel Tank Ullage Drain Line)	1B55934	-501	-501	1036313
Filter (Fuel Ullage Supply)	1B55934	-501	-501	1036310
<u>Propellant System Installation</u> (1A82258-509)				
Propellant Control Module (Oxid.)	1A49422	-509	-509	0000070
Propellant Control Module (Fuel)	1A49422	-510	-510	(c) 0000255(Rep. 260)
Disconnect Coupling (Gas Bleed Outlet Oxidizer Tank)	1B58697	-531	-531	E112
Disconnect Coupling (Gas Bleed Outlet Fuel Tank)	1B58697	-535	-535	G117
Fuel Tank Assembly (1B39468-503 Tank S/N 23 Plus Blanket)	1B63924	-505	-505	026
Oxidizer Tank (1B39468-504 Tank S/N 18 Plus Blanket)	1B63924	-506	-506	025
Filter (Oxidizer Recirculation)	1B55934	-1	-1	1036306
Filter (Fuel Circulation)	1B55934	-501	-501	1036371
<u>Engine Installation</u> (1A65685-503)				
Attitude Control Engine No. 1	1A39597	-509	(f)-509	731

TABLE 4-1
MODULE NO. 1 COMPONENTS
(Sheet 3 of 4)

INITIAL TEST CONFIGURATION			ACTUAL TEST CONFIGURATION	
Item	P/N	Configuration	Configuration	S/N
Attitude Control Engine No. 2	1A39597	-509	(g)-509	803
Attitude Control Engine No. 3	1A39597	-509	-509	615
Ullage Engine	GFE	15-210001	15-210001	4071857
Transducer (No. 1 Engine)	1A88035	-505	-505	157
Transducer (No. 2 Engine)	1A88035	-505	-505	(e) 179(Rep. 164)
Transducer (No. 3 Engine)	1A88035	-505	-505	161
Transducer	1A88035	-505	-505	169

(a) S/N 101G was removed after thrust vibration and replaced with S/N 106G (Reference Paragraph 6.1.5 of this report).

(b) ECP 2262 R2: Releases 1B39317-503 tank per effectivity 508-515.
WRO 3722 R2: Stage 507-1 and -2 modules allocated for Phase V tests.
ECP 2262 R3: Added 1B39317-503 for effectivity 507 production modules (S/N 507-3 and 507-4).
SEO 1A79373-011 & WRO 3623: For inst'l of 1B39317-501 tank.

(c) FARR No. 500-096-977, dated October 20, 1967, removed S/N 260, which was replaced with S/N 255.

(d) 1B68379-1 is a retorqued 1B51361-1.

(e) FARR No. 500-226-650 dated July 22, 1968 removed S/N 164, which was replaced with S/N 179.

TABLE 4-1
MODULE NO. 1 COMPONENTS
(Sheet 4 of 4)

(f) Engine No. 1 was actually identified on nameplate, photos and report as a -505, but had been subjected to MDC production acceptance test per 1B59663, making it a -509. However, subsequent reidentification to a -509 was not accomplished.

(g) Engine No. 2 was identified incorrectly as a -505 in the Handling and Checkout Drawing 1B73229, sheet 109, paragraph 4.14.2, Item No. 1.

SECTION 5

EXTENDED HOLD TEST

5. EXTENDED HOLD TEST

The extended hold test sequence simulated the KSC procedure and operational sequence. This sequence included the following: pretest inspection, loading of APS module with hypergolic propellants, burp-firing of APS engines on the 3rd day and evaluation of results, simulation of KSC launch pad hold, and burp-firing of the APS engines on the 15th day and evaluation of results. The simulated launch pad hold and burp-firing sequence was repeated every 15 days until the 75-day hold was completed.

During the burp-firings and simulated launches, the helium bottle was pressurized to operating pressure. During the hold periods between the burp-firings and simulated launches, the system was kept at a blanket pressure.

X-rays were taken periodically to determine the position of the bladder and the condition of the internal tankage as set forth in the APS Test Plan, DAC-56590B.

5.1 Pressurization System

Operation of the pressurization system was satisfactory throughout the extended hold test.

During the period from 8 May to 22 July 1968, the helium bottle was pressurized and vented eleven times. The helium sphere was pressurized prior to each of the six burp-firings. Table 5-1 indicates the helium bottle conditions during each of the six burp-firings.

The helium bottle was also pressurized prior to each of the five simulated launches. Table 5-2 indicates the helium bottle pressures and temperatures during the simulated launches.

Analysis of helium bottle pressure and temperature data indicated that there was no helium leakage from the high pressure system during the extended hold test.

5.1.1 Helium Regulator

Figure 5-1 shows history of the regulator outlet pressure during hold periods. The data during the extended hold test indicate that the pressure remained between 55 and 70 psia except at the start and end of the test. The pressure at the start of the test reached a minimum of 15 psia (ambient). This pressure was prior to pressurization of the system and was acceptable. On the last day of the extended hold test, the minimum pressure recorded was 29 psia. This was due to venting of the system following completion of the test, and was acceptable.

Ambient temperature fluctuations during the extended hold periods caused pressure changes that exceeded 65 ± 5 psia and, therefore, necessitated a new allowable pressure range (refer to DAC-56590B). This new range of 45 to 150 psia was never exceeded during the extended hold test.

5.1.2 Fuel Manifold and Ullage Pressures

Figure 5-2 shows the fuel manifold pressure history during hold periods. The manifold pressure, for most of the extended hold test, remained in a range of 65 to 75 psia. Pressures were within the 45 to 150 psia pressure range allowed for hold periods. The pressures at the initiation of hold periods were in the range of 65 ± 5 psia.

Tables 5-1 and 5-2 indicate that the pressures encountered during burp-firings and simulated launches were in the desired range. The manifold and ullage pressures for all burp-firings and simulated launches were in the 203-222 psia range allowed for these parameters.

5.1.3 Oxidizer Manifold and Ullage Pressures

Figure 5-3 shows the pressure history of the oxidizer manifold during hold periods. Most of the pressures were in the range of 70 to 85 psia. This is well within the allowable range of 45 to 150 psia.

The pressures at the initiation of holds or during bubble removal were within tolerance (65 ± 5 psia), except on the 7th, 8th, 15th, 60th, and 65th days of the test when the pressure range was exceeded. Temperature transients within the system were the probable cause of these pressures.

Tables 5-1 and 5-2 show the pressure range for the oxidizer manifold and ullage during pressurized periods. Pressures were within the required range.

5.2 Propellant Systems

5.2.1 Propellant Loading

Loading was initiated on 8 May 1968 in Gamma Test Cell III following a complete APS module checkout. The oxidizer tank was filled and the engine feed lines bled during the loading operations. To provide a space for propellant expansion and tank pressurant, 1.8 gal of propellant were offloaded. The propellant temperature after loading was 542 deg R.

The fuel tank was then filled and the engine feed lines bled. To provide expansion space and a pressurant ullage, 0.4 gal of fuel was offloaded. The fuel temperature after loading was 548 deg R.

At the completion of the 75-day hold period, it was necessary to replenish the propellant tank levels to make up for propellants utilized in burp-firings and bubble extractions prior to simulated launch holds. A total of 1.7 gal oxidizer and 1.3 gal fuel were added on 22 July in preparation for vibration testing.

On 24 July 1968, after the oxidizer tank (P/N 1B 63924-506, S/N 025) had been loaded with N_2O_4 for 77 days, Two cu. in. of liquid N_2O_4 were found on the ullage side of the oxidizer bladder. Subsequent bladder leak tests showed a bladder leakage of only 7 sccm of helium. Since the liquid N_2O_4 could have been formed from the condensation of N_2O_4 vapor which normally permeates the bladder, the bladder was considered acceptable and the test program was continued.

A supplemental test program was initiated following the topping operations. As a result of the additional engine tests and bubble extractions, it was again necessary to replenish the propellant levels prior to vibration. Therefore, on 8 August 1968, 1.0 gal of oxidizer and 0.5 gal of fuel were loaded in preparation for vibration testing.

5.2.2 Fuel Temperature

Figure 5-2 presents the fuel temperature history throughout the extended hold test. Temperature ranged from 520 to 554 deg R.

The allowable temperature range for the fuel during hold periods is 520 to 560 deg R, with the exception of the period between propellant tank bubble removal and launch abort which is 547 ± 5 deg R.

All of the fuel temperature readings were within the specified range for holds (540 to 560 deg R), and in the 547 ± 5 deg R range for the bladder bleed to launch abort period.

5.2.3 Oxidizer Temperature

Figure 5-3 presents the temperature history of the oxidizer throughout the extended hold test. The allowable range for oxidizer temperature is 520 to 560 deg R, except for the period between the bleeding of the propellant tank bladders and the launch abort, when the allowable range is 547 ± 5 deg R.

The oxidizer temperature fell below the minimum of 520 deg R on the 9th, 10th, 11th, 12th, 55th, 61st, and 75th days of the test. The maximum excursion below 520 deg R was 2 deg R, which is well within the resolution accuracy of the measurement.

The requirement of 547 ± 5 deg R in the period between bubble bleed and launch abort was achieved throughout the test.

5.3 Engine Performance

All four engines were burp-fired on 10 May 1968, and approximately every 15 days thereafter.

The pulse series for engines 1, 2, and 3 consisted of one burp-firing of 250 ms followed by two burp-firings of 65 ms duration. The pulse series for engine No. 4 consisted of one burp-firing of 550 ms duration. The chamber pressure levels observed during the burp-firings are listed in table 5-3 and illustrated in figure 5-4.

5.3.1 Engine No. 1

Engine chamber pressures from the first two burp-firings (10 and 22 May, 1968) were within the expected range. However, on the 3rd burp-firing (6 June 1968), the chamber pressures were from 4 to 6 psi lower than the expected minimum specification. This degradation continued through the 4th, 5th, and 6th firings. During the 6th firings, the chamber pressure of the 250 ms pulse was 38 psia. The two short 65 ms pulses did not achieve steady-state.

5.3.2 Engine No. 2

The chamber pressures from the first two burp-firings were within the expected range. On the 3rd burp-firings, the chamber pressures from the first two pulses were 1 psi lower than the minimum. The pressure recovered to the expected levels in the 4th, 5th, and 6th firings. During the 6th burp-firing, the chamber pressure transducer (P/N 1A88035-505, S/N 164) exhibited a 30 psi shift. The transducer was replaced with transducer S/N 179 and the discrepant part returned to the vendor for failure analysis.

5.3.3 Engine No. 3

The chamber pressure had a significant degradation at the 4th burp-firing. The chamber pressures were 79, 78, and 77 psia. This decay continued through the 6th firing, at which time the chamber pressure was 54 psia.

5.3.4. Engine No. 4

The ullage engine performed satisfactorily throughout the six firings. The chamber pressures ranged from 104 to 110 psia.

5.3.5 Valve Current

The valve current analysis consisted of the timing measurement (table 5-4), and comparison from the current traces of the following:

a. Command signal to the time when the valve started to open.

b. Command signal to the time when the valve was fully open.

c. Travel time of valve poppet.

d. Command signal to steady-state amperage.

e. Command signal to oxidizer pressure when it started to rise.

f. Command signal to fuel pressure when it started to rise.

g. Command signal to chamber pressure initiation.

Following the command signal from the first pulse of the first burp-firing, all the downstream valves started to open first (9.0 to 11.0 ms). This was due to the lack of initial propellant back pressure inside the valve. The upstream valves, working against a 200 psia manifold pressure, took nearly twice as long as the downstream valves (18.0 to 19.5 ms). The actual valve travel time in both cases was from 2 to 3 ms. Within this period the valve current decreased due to the back electromotive force induced by the valve poppet travel. The time required from the electrical signal to the steady-state amperage varied from 25 to 32 ms. The time required from the electrical signal to the oxidizer and fuel manifold pressure rise was 18 ms.

The time delay from the electrical signal to the chamber pressure rise initiation was 38 ms for the first pulse. This was about 10 ms longer than the later pulses. The longer delay is believed to be due to the propellant flow through an initially empty flow passage.

The opening sequence of the upstream and downstream valves for the second and subsequent pulses did not follow a set pattern. This could be due to the differential pressure across the individual valve poppet at the instant the poppet started to lift.

The amount of this differential pressure could be affected by the amount of propellant trapped in the valve from the previous operation, interim valve leakages between operations, and other mechanical and electrical variables.

The maximum and minimum time required to open the valve (from electrical signal to a fully opened position) and the maximum and minimum time to the initial chamber pressure of each pulse series, are listed in table 5-5. Each pulse series consists of three pulses each from engines 1, 2, and 3. It was noted that the maximum valve opening time varied in a narrow range of 1.5 ms.

The valve current traces indicated a time lag from the initiation of the electrical signal to the fully open position of the solenoid operated propellant valves. The maximum opening time from the May 22 burp-firings (normal chamber pressure) was 18.0 ms for the fuel valve, and 18.5 ms for the oxidizer valve. The maximum opening time from the July 22 burp-firings (low chamber pressures) was 18.5 ms for the fuel valve, and 19.0 ms for the oxidizer valve. These delay times are below the maximum lag time of 23 ms in TAPCO SPEC #03-10060, Revision E, of the engine manufacturer. The valve current traces from all four engines showed proper valve operation throughout the firings.

Between the time when the valve reached its fully open position and the maximum valve current, a small "blip" or perturbation appeared on the current traces from all six burp-firings. Immediately following the maximum valve amperage, these "blips" were also noted during the 1st burp-firings. These "blip" occurrences are illustrated in table 5-6. Although the cause of these "blips" is not known, they did not seem to be related to the chamber pressure degradation.

5.4 Conclusion

The APS module performed satisfactorily throughout the extended hold test with the exception of the engine chamber degradation that was experienced during the burp-firings.

APS engines 1 and 3 exhibited a significant degradation of chamber pressure while being burp-fired. Investigation indicated that a restriction of oxidizer flow in the injector tube inlets, injector tubes, and injectors was caused by contamination. This contamination was attributed to moisture being introduced into the APS engines during the hold periods between burp-firings.

The results of recent tests conducted by MDAC and MSFC showed detrimental effects of sea-level burp-firings on APS engine performance. Consequently MSFC has concurred with the MDAC recommendation to delete prelaunch burp-firings.

TABLE 5-1
BURP - FIRING DATA SUMMARY

DATE (BURP-FIRING)	TIME HELD HR:MIN:SEC	HELIUM BOTTLE PRESS (PSIA)	HELIUM BOTTLE TEMP (°R)	REG* OUTLET PRESS (PSIA)	OXID* MANIF PRESS (PSIA)	OXID* ULLAGE PRESS (PSIA)	FUEL* MANIF PRESS (PSIA)	FUEL* ULLAGE PRESS (PSIA)	OXID TEMP (°R)	FUEL TEMP (°R)
5-10-68 (1)	00:38:00	2,843	557	205-208	205-209	205-209	209-210	205-208	543	544
5-22-68 (2)	2:15:40	2,835	542	203-207	206-210	205-208	207-211	204-209	530	530
6-6-68 (3)	2:23:40	2,870	548	205-209	208-210	204-208	208-210	204-208	534	535
6-21-68 (4)	2:27:00	2,880	560	205-210	210-214	208-214	206-210	204-206	540	539
7-5-68 (5)	Not Available	2,940	580	204-206	206-216	205-216	206-210	202-207	550	550
7-22-68 (6)	2:44:00	2,905	555	203-209	210-216	210-216	210-214	210-212	530	530

*Ambient Reference

TABLE 5-2
SIMULATED LAUNCH DATA SUMMARY

DATE (SIM LAUNCH)	TIME HELD HR:MIN:SEC	HELIUM BOTTLE PRESS (PSIA)	HELIUM BOTTLE TEMP (°R)	REG* OUTLET PRESS (PSIA)	OX* MANIF PRESS (PSIA)	OX* ULLAGE PRESS (PSIA)	FUEL* MANIF PRESS (PSIA)	FUEL* ULLAGE PRESS (PSIA)	OX TEMP (°R)	FUEL TEMP (°R)
5-15-68 (1)	00:37:00	3,115	571	206-208	206-210	204-208	207-210	204-208	544	546
5-27-68 (2)	00:43:00	2,960	562	205-208	208-214	208-210	208-209	203-204	547	550
6-11-68 (3)	00:44:20	3,080	580	204-208	208-210	204-210	207-210	204-206	548	549
6-26-68 (4)	00:42:20	2,920	566	205-209	208-212	208-210	208-210	204-206	546	548
7-10-68 (5)	00:46:00	2,955	563	205-207	208-211	207-209	208-212	206-208	549	550

*Ambient Reference

TABLE 5-3
CHAMBER PRESSURE HISTORY

		DAYS FROM PROPELLANT LOADING (8 MAY 1968)					
		2 (5-10-68)	14 (5-22-68	29 (6-6-68)	44 (6-21-68)	58 (7-5-68)	75 (7-22-68)
ENG 1-1 (PSIA)	250 ms	105	103	95	75	50	38
	65 ms	104	102	93	77	48	35
	65 ms	104	102	93	76	48	35
ENG 1-2 (PSIA)	250 ms	104	102	98	100	103	104*
	65 ms	100	101	98	100	102	104*
	65 ms	103	102	100	100	101	104*
ENG 1-3 (PSIA)	250 ms	104	102	101	79	71	54
	65 ms	104	104	101	78	71	54
	65 ms	104	102	101	77	71	54
ENG 1-4 (PSIA)	500 ms	107	104	106	106	106	110
PROP TEMP (°F)	OXID	83	76	76	92	100	88
	FUEL	84	82	76	90	93	88
MAN PRESS (PSIA)	OXID	208	209	208	212	212	210
	FUEL	207	209	209	209	210	215

*With transducer shift (trend only)

TABLE 5-4 (Sheet 1 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 1 (5/10/68)							
First Pulse (ENG 1) (P_c = 105.0)							
F 1-A	15.5	18.5	3.0	31.0			
F 1-B	7.5	9.5	2.0	26.0			
F 1-C	17.0	19.5	2.5	31.0			
F 1-D	7.0	9.0	2.0	25.0	18.0	18.0	38.0
O 1-1	16.0	19.0	3.0	32.0			
O 1-2	8.5	11.0	2.5	26.0			
O 1-3	15.0	18.0	3.0	31.0			
O 1-4	8.5	11.0	2.5	27.0			
Second Pulse (ENG 1) (P_c = 103.8)							
F 1-A	8.0	10.5	2.5	26.0			
F 1-B	14.0	17.0	3.0	30.0			
F 1-C	8.0	11.0	3.0	27.0			
F 1-D	14.0	16.5	2.5	30.0	18.0	18.0	26.5
O 1-1	8.5	12.0	3.5	27.0			
O 1-2	15.0	18.5	3.5	32.0			
O 1-3	10.0	13.0	3.0	27.0			
O 1-4	15.0	18.5	3.5	33.0			
Third Pulse (ENG 1) (P_c = 103.8)							
F 1-A	10.0	12.5	2.5	27.0			
F 1-B	14.0	16.5	2.5	30.0			
F 1-C	7.5	10.5	3.0	26.0			
F 1-D	13.5	16.5	3.0	31.0	14.0	17.0	26.0
O 1-1	11.0	14.0	3.0	27.0			
O 1-2	15.5	19.0	3.5	32.0			
O 1-3	9.5	12.5	3.0	27.0			
O 1-4	15.5	18.5	3.0	31.0			
First Pulse (ENG 2) (P_c = 103.8)							
F 2-A	15.5	18.5	3.0	31.0			
F 2-B	10.0	12.5	2.5	27.0			
F 2-C	17.0	19.5	2.5	32.0			
F 2-D	7.0	9.0	2.0	25.0	18.0	19.0	38.0
O 2-1	16.0	19.0	3.0	32.0			
O 2-2	7.0	9.5	2.5	27.0			
O 2-3	15.0	18.5	3.5	30.0			
O 2-4	8.0	10.0	2.0	27.0			

VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
			BURP-FIRING NO. 1 (5/10/68) (Continued)				
Second Pulse (ENG 2) (P_c = 100.0)							
F 2-A	9.5	12.5	3.0	27.0			
F 2-B	15.0	17.5	2.5	31.0			
F 2-C	10.0	13.0	3.0	28.0			
F 2-D	15.0	17.5	2.5	31.0	16.5	19.0	25.5
O 2-1	8.0	11.5	3.5	27.0			
O 2-2	14.0	17.5	3.5	30.0			
O 2-3	14.0	17.0	3.0	29.0			
O 2-4	9.5	12.5	3.0	27.0			
Third Pulse (ENG 2) (P_c = 102.5)							
F 2-A	8.0	11.0	3.0	27.0			
F 2-B	14.5	17.5	3.0	31.0			
F 2-C	10.0	12.5	2.5	27.0			
F 2-D	14.5	17.0	2.5	31.0	16.5	19.0	25.0
O 2-1	8.5	11.5	3.0	27.0			
O 2-2	14.5	17.5	3.0	31.0			
O 2-3	14.0	17.0	3.0	31.0			
O 2-4	9.5	12.5	3.0	27.0			
First Pulse (ENG 3) (P_c = 103.8)							
F 3-A	15.0	18.5	3.5	31.0			
F 3-B	6.5	8.5	2.0	25.0			
F 3-C	17.0	19.5	2.5	32.0			
F 3-D	8.0	10.0	2.0	26.0	17.5	18.5	37
O 3-1	15.0	18.0	3.0	32.0			
O 3-2	7.0	9.5	2.5	27.0			
O 3-3	14.0	17.0	3.0	28.0			
O 3-4	9.0	12.5	3.5	26.0			
Second Pulse (ENG 3) (P_c = 103.8)							
F 3-A	11.5	14.0	2.5	27.0			
F 3-B	11.5	14.0	2.5	27.0			
F 3-C	7.5	10.5	3.0	26.0			
F 3-D	12.0	14.5	2.5	27.0	12.5	14.5	26
O 3-1	9.5	12.5	3.0	27.0			
O 3-2	15.5	19.0	3.5	31.0			
O 3-3	10.0	13.0	3.0	26.0			
O 3-4	15.0	18.0	3.0	30.0			

TABLE 5-4 (Sheet 3 of 15
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 1 (5/10/68) (Continued)							
Third Pulse (ENG 3) (P_c = 103.8)							
F 3-A	7.5	10.5	3.0	26.0			
F 3-B	13.5	16.5	3.0	30.0			
F 3-C	8.0	10.5	2.5	27.0			
F 3-D	13.5	16.0	2.5	28.0	16.5	16.5	25.5
O 3-1	8.5	11.5	3.0	26.0			
O 3-2	15.0	18.5	3.5	31.0			
O 3-3	14.5	17.5	3.0	31.0			
O 3-4	9.0	12.0	3.0	26.0			
First Pulse (ENG 4) (P_c = 106.6)							
F 4	13.0	15.0	2.0	31.0			
O 4	13.5	15.5	2.0	32.0	16.0	16.0	20.5
BURP-FIRING NO. 2 (5/22/68)							
First Pulse (ENG 1) (P_c = 102.7)							
F 1-A	15.0	17.5	2.5	30.0			
F 1-B	10.0	13.0	3.0	27.0			
F 1-C	15.0	18.0	3.0	30.0			
F 1-D	10.0	13.5	3.5	27.0	18.0	18.0	27.0
O 1-1	15.5	18.5	3.0	30.0			
O 1-2	10.5	14.0	3.5	28.0			
O 1-3	15.0	18.5	3.5	30.0			
O 1-4	9.0	13.0	4.0	27.0			
Second Pulse (ENG 1) (P_c = 101.5)							
F 1-A	14.0	16.5	2.5	30.0			
F 1-B	9.0	12.0	3.0	28.0			
F 1-C	8.0	11.0	3.0	26.0			
F 1-D	14.0	16.5	2.5	26.0	14.5	14.5	24.5
O 1-1	11.5	14.5	3.0	27.0			
O 1-2	15.0	18.0	3.0	30.0			
O 1-3	8.5	11.5	3.0	26.0			
O 1-4	14.0	17.5	3.5	30.0			

TABLE 5-4 (Sheet 4 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 2 (5/22/68) (Continued)							
Third Pulse (ENG 1) (P_c = 101.5)							
F 1-A	8.0	11.0	3.0	26.0			
F 1-B	13.5	16.5	3.0	30.0			
F 1-C	8.0	10.5	2.5	26.0			
F 1-D	13.5	16.0	2.5	30.0	17.0	17.0	24.5
O 1-1	9.5	12.5	3.0	27.0			
O 1-2	15.5	18.5	3.0	31.0			
O 1-3	9.0	12.5	3.5	27.0			
O 1-4	14.5	17.5	3.0	31.0			
First Pulse (ENG 2) (P_c = 102.0)							
F 2-A	15.0	17.5	2.5	31.0			
F 2-B	7.0	10.0	3.0	26.0			
F 2-C	15.0	18.0	3.0	31.0			
F 2-D	11.0	13.5	3.5	27.0	15.0	17.0	25.0
O 2-1	14.0	16.5	2.5	31.0			
O 2-2	10.5	13.5	3.0	27.0			
O 2-3	13.5	16.5	3.0	30.0			
O 2-4	8.5	11.5	3.0	27.0			
Second Pulse (ENG 2) (P_c = 100.7)							
F 2-A	14.5	17.5	3.0	31.0			
F 2-B	8.5	11.5	3.0	26.0			
F 2-C	15.0	17.5	2.5	31.0			
F 2-D	10.5	13.5	3.0	28.0	16.0	18.0	25.0
O 2-1	8.5	12.0	3.5	27.0			
O 2-2	14.5	17.5	3.0	30.0			
O 2-3	14.5	17.5	3.0	30.0			
O 2-4	8.5	11.5	3.0	27.0			
Third Pulse (ENG 2) (P_c = 102.0)							
F 2-A	14.5	17.0	2.5	31.0			
F 2-B	7.5	10.5	3.0	26.0			
F 2-C	8.0	11.0	3.0	27.0			
F 2-D	15.0	17.5	2.5	31.0	16.5	16.5	25.0
O 2-1	8.0	11.0	3.0	26.0			
O 2-2	14.0	17.0	3.0	30.0			
O 2-3	14.0	17.0	3.0	31.0			
O 2-4	8.5	11.5	3.0	27.0			

TABLE 5-4 (Sheet 5 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 2 (5/22/68) (Continued)							
First Pulse (ENG 3) (P_c = 102.3)							
F 3-A	13.0	16.0	3.0	30.0			
F 3-B	9.0	11.5	2.5	27.0			
F 3-C	12.5	15.5	3.0	31.0			
F 3-D	11.5	14.0	2.5	28.0	18.0	16.0	27.5
O 3-1	14.0	17.0	3.0	31.0			
O 3-2	10.5	13.0	2.5	27.0			
O 3-3	14.5	17.5	3.0	30.0			
O 3-4	9.0	12.5	3.5	27.0			
Second Pulse (ENG 3) (P_c = 103.6)							
F 3-A	14	16.5	2.5	30.0			
F 3-B	8.5	11.5	3.0	28.0			
F 3-C	9.0	12.0	3.0	27.0			
F 3-D	13.5	16.0	2.5	30.0	16.0	16.0	25.5
O 3-1	14.5	17.5	3.0	31.0			
O 3-2	10.5	13.5	3.0	28.0			
O 3-3	14.5	17.0	3.5	30.0			
O 3-4	9.0	12.0	3.0	27.0			
Third Pulse (ENG 3) (P_c = 102.3)							
F 3-A	13.5	16.0	2.5	30.0			
F 3-B	8.5	11.5	3.0	27.0			
F 3-C	8.0	10.5	2.5	27.0			
F 3-D	13.0	15.5	2.5	30.0	17.0	14.0	25.0
O 3-1	14.0	17.0	3.0	31.0			
O 3-2	10.5	13.5	3.0	27.0			
O 3-3	14.0	17.0	3.0	29.0			
O 3-4	9.0	12.0	3.0	26.0			
First Pulse (ENG 4) (P_c = 104.1)							
F 4	12.5	14.0	1.5	31.0			
O 4	13.5	15.5	2.0	32.0	16.5	17.5	21.5

TABLE 5-4 (Sheet 6 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 3 (6/6/68)							
First Pulse (ENG 1) (P_c = 95.2)							
F 1-A	15.5	18.0	2.5	31.0			
F 1-B	8.5	11.5	3.0	27.0			
F 1-C	15.5	18.5	3.0	31.0			
F 1-D	10.0	12.5	2.5	27.0	18.5	18.5	28.0
O 1-1	16.0	19.0	3.0	31.0			
O 1-2	10.0	13.5	3.5	28.0			
O 1-3	15.5	19.0	2.5	31.0			
O 1-4	9.0	12.5	3.5	27.0			
Second Pulse (ENG 1) (P_c = 92.7)							
F 1-A	8.0	11.5	3.5	27.0			
F 1-B	14.0	16.5	2.5	31.0			
F 1-C	8.0	11.0	3.0	26.0			
F 1-D	14.0	16.5	2.5	31.0	17.0	17.0	25.0
O 1-1	9.0	12.5	3.5	27.0			
O 1-2	15.0	18.0	3.0	31.0			
O 1-3	9.5	13.0	3.5	27.0			
O 1-4	14.5	18.0	3.5	32.0			
Third Pulse (ENG 1) (P_c = 92.7)							
F 1-A	8.0	10.5	2.5	26.0			
F 1-B	13.0	16.0	3.0	31.0			
F 1-C	7.5	10.5	3.0	25.0			
F 1-D	13.0	16.0	3.0	30.0	16.5	16.5	23.5
O 1-1	8.5	12.0	3.5	26.0			
O 1-2	14.0	17.0	3.0	30.0			
O 1-3	9.0	12.0	3.0	27.0			
O 1-4	14.0	17.0	3.0	31.0			
First Pulse (ENG 2) (P_c = 97.5)							
F 2-A	15.0	17.5	2.5	32.0			
F 2-B	7.5	10.5	3.0	27.0			
F 2-C	15.5	18.0	2.5	32.0			
F 2-D	10.0	13.0	3.0	28.0	15.5	18.5	27.5
O 2-1	13.5	16.5	3.0	31.0			
O 2-2	11.5	14.5	3.0	30.0			
O 2-3	14.0	16.5	2.5	31.0			
O 2-4	9.0	12.5	3.5	28.0			

TABLE 5-4 (Sheet 7 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
			BURP-FIRING NO. 3 (6/6/68) (Continued)				
Second Pulse (ENG 2) (P_c = 97.5)							
F 2-A	14.5	17.0	2.5	31.0			
F 2-B	8.0	11.0	3.0	27.0			
F 2-C	10.0	13.0	3.0	27.0			
F 2-D	14.0	17.0	3.0	31.0	17.0	17.0	24.5
O 2-1	8.5	12.0	3.5	27.0			
O 2-2	14.5	17.5	3.0	31.0			
O 2-3	14.0	17.5	3.5	31.0			
O 2-4	8.5	11.5	3.5	27.0			
Third Pulse (ENG 2) (P_c = 100.0)							
F 2-A	15.0	18.0	3.0	31.0			
F 2-B	8.0	11.0	3.0	27.0			
F 2-C	9.5	12.5	3.0	27.0			
F 2-D	14.5	17.0	2.5	31.0	18.0	18.0	25.5
O 2-1	9.0	12.0	3.0	27.0			
O 2-2	15.0	18.0	3.0	27.0			
O 2-3	15.0	18.0	3.0	31.0			
O 2-4	9.5	12.5	3.0	28.0			
First Pulse (ENG 3) (P_c = 101.0)							
F 3-A	15.0	18.0	3.0	31.0			
F 3-B	8.0	11.0	3.0	27.0			
F 3-C	16.0	19.0	3.0	32.0			
F 3-D	10.0	13.0	3.0	27.0	17.5	17.5	27.5
O 3-1	15.0	18.0	3.0	32.0			
O 3-2	10.5	13.5	3.0	30.0			
O 3-3	1.50	18.0	3.0	31.0			
O 3-4	9.5	13.0	3.5	28.0			
Second Pulse (ENG 3) (P_c = 101.0)							
F 3-A	12.5	15.5	3.0	30.0			
F 3-B	8.0	11.0	3.0	26.0			
F 3-C	7.5	10.5	3.0	26.0			
F 3-D	12.5	15.0	2.5	29.0	17.0	15.0	25.0
O 3-1	14.0	17.0	3.0	31.0			
O 3-2	9.5	12.5	3.0	28.0			
O 3-3	14.0	17.0	3.0	31.0			
O 3-4	8.5	12.0	3.5	27.0			

VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 3 (6/6/68) (Continued)							
Third Pulse (ENG 3) (P_c = 101.0)							
F 3-A	13.0	15.5	2.5	31.0			
F 3-B	8.5	11.0	2.5	27.0			
F 3-C	8.0	11.0	3.0	27.0			
F 3-D	13.0	15.5	2.5	31.0	17.0	15.0	25.0
O 3-1	14.5	17.5	3.0	31.0			
O 3-2	10.0	13.0	3.0	28.0			
O 3-3	14.5	17.5	3.0	31.0			
O 3-4	9.5	12.5	3.0	27.0			
First Pulse (ENG 4) (P_c = 105.6)							
F 4	13.5	16.0	2.5	34.0			
O 4	12.5	14.5	2.0	33.0	17.0	16.0	22.5
BURP-FIRING NO. 4 (6/21/68)							
First Pulse (ENG 1) (P_c = 75.0)							
F 1-A	15.5	18.0	2.5	31.0			
F 1-B	8.0	11.0	3.0	27.0			
F 1-C	15.5	18.5	3.0	32.0			
F 1-D	10.0	13.0	3.0	27.0	18.0	18.0	26.0
O 1-1	15.5	18.5	3.0	31.0			
O 1-2	11.0	14.0	3.0	30.0			
O 1-3	15.5	18.5	3.0	31.0			
O 1-4	10.0	13.5	3.5	28.0			
Second Pulse (ENG 1) (P_c = 77.0)							
F 1-A	13.0	15.5	2.5	31.0			
F 1-B	9.0	12.0	3.0	27.0			
F 1-C	12.5	15.5	2.5	30.0			
F 1-D	11.5	14.0	2.5	30.0	18.0	15.0	25.0
O 1-1	15.5	18.5	3.0	30.0			
O 1-2	12.0	14.5	2.5	30.0			
O 1-3	10.0	13.0	3.0	27.0			
O 1-4	15.5	18.0	2.5	31.0			

TABLE 5-4 (Sheet 9 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 4 (6/21/68) (Continued)							
Third Pulse (ENG 1) (P_c = 76.0)							
F 1-A	8.5	11.0	2.5	27.0			
F 1-B	13.5	16.5	3.0	31.0			
F 1-C	8.5	11.5	3.0	27.0			
F 1-D	13.5	16.0	2.5	31.0	18.0	16.0	25.0
0 1-1	10.5	13.5	3.0	27.0			
0 1-2	15.0	18.0	3.0	31.0			
0 1-3	10.0	13.5	3.5	27.0			
0 1-4	15.0	18.5	3.5	31.0			
First Pulse (ENG 2) (P_c = 100.0)							
F 2-A	7.5	10.0	2.5	27.0			
F 2-B	15.5	18.5	3.0	32.0			
F 2-C	16.0	19.0	3.0	32.0			
F 2-D	11.0	14.5	3.5	30.0	13.0	18.5	24.5
0 2-1	10.5	14.0	3.5	28.0			
0 2-2	13.5	16.5	3.0	30.0			
0 2-3	12.0	15.5	3.5	30.0			
0 2-4	11.0	14.5	3.5	30.0			
Second Pulse (ENG 2) (P_c = 100.0)							
F 2-A	15.0	18.0	3.0	31.0			
F 2-B	9.0	11.5	2.5	27.0			
F 2-C	15.5	18.0	2.5	31.0			
F 2-D	9.5	12.5	3.0	27.0	12.5	17.5	25.0
0 2-1	10.5	13.5	3.0	28.0			
0 2-2	15.5	18.5	3.0	31.0			
0 2-3	9.5	12.5	3.0	27.0			
0 2-4	14.5	18.0	3.5	31.0			
Third Pulse (ENG 2) (P_c = 100.0)							
F 2-A	14.5	17.0	2.5	31.0			
F 2-B	8.0	10.5	2.5	26.0			
F 2-C	10.5	13.0	2.5	27.0			
F 2-D	14.5	17.5	3.0	31.0	15.0	16.0	24.0
0 2-1	14.0	17.0	3.0	31.0			
0 2-2	10.5	14.0	3.5	27.0			
0 2-3	13.5	16.5	3.0	30.0			
0 2-4	9.0	12.0	3.0	27.0			

VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
			BURP-FIRING NO. 4 (6/21/68) (Continued)				
First Pulse (ENG 3) (P_c = 79.0)							
F 3-A	13.5	16.5	3.0	31.0			
F 3-B	7.5	10.5	3.0	26.0			
F 3-C	9.0	12.0	3.0	28.0			
F 3-D	13.0	16.0	3.0	31.0	16.5	15.5	25.0
O 3-1	14.5	17.5	3.0	31.0			
O 3-2	10.5	14.0	3.5	27.0			
O 3-3	10.0	13.0	3.0	27.0			
O 3-4	15.0	18.0	3.0	31.0			
Second Pulse (ENG 3) (P_c = 78.0)							
F 3-A	13.0	16.0	3.0	30.0			
F 3-B	8.5	11.0	2.5	27.0			
F 3-C	8.0	11.0	3.0	28.0			
F 3-D	13.5	16.0	2.5	30.0	13.0	15.0	21.5
O 3-1	13.0	15.5	2.5	30.0			
O 3-2	11.5	14.5	3.0	29.0			
O 3-3	11.0	14.0	3.0	28.0			
O 3-4	12.0	15.0	3.0	29.0			
Third Pulse (ENG 3) (P_c = 77.0)							
F 3-A	13.5	16.0	2.5	27.0			
F 3-B	8.0	10.5	2.5	25.0			
F 3-C	9.5	12.0	2.5	27.0			
F 3-D	13.0	16.0	3.0	30.0	16.0	17.5	24.0
O 3-1	13.0	16.0	3.0	28.0			
O 3-2	9.5	12.0	2.5	26.0			
O 3-3	13.0	15.5	2.5	28.0			
O 3-4	9.0	11.5	2.5	26.0			
First Pulse (ENG 4) (P_c = 106.0)							
F 4	12.5	14.5	2.0	31.0			
O 4	11.0	13.0	2.0	31.0	15.5	13.5	20.5

0

TABLE 5-4 (Sheet 11 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 5 (7/5/68)							
First Pulse (ENG 1) (P_c = 50.0)							
F 1-A	16.0	19.0	3.0	31.0			
F 1-B	8.5	11.5	3.0	27.0			
F 1-C	16.0	19.0	3.0	31.0			
F 1-D	12.0	15.0	3.0	27.0	19.0	21.0	27.0
O 1-1	11.0	14.0	3.0	27.0			
O 1-2	16.0	19.0	3.0	31.0			
O 1-3	8.0	11.0	3.0	26.0			
O 1-4	16.0	19.0	3.0	31.0			
Second Pulse (ENG 1) (P_c = 48.0)							
F 1-A	14.0	17.0	3.0	31.0			
F 1-B	9.0	12.0	3.0	27.0			
F 1-C	8.0	11.0	3.0	27.0			
F 1-D	14.5	17.5	3.0	27.0	13.5	15.0	21.0
O 1-1	9.0	12.0	3.0	26.0			
O 1-2	15.0	18.0	3.0	30.0			
O 1-3	9.0	12.0	3.0	27.0			
O 1-4	15.0	18.0	3.0	30.0			
Third Pulse (ENG 1) (P_c = 48.0)							
F 1-A	14.5	17.0	2.5	30.0			
F 1-B	8.0	11.0	3.0	27.0			
F 1-C	7.5	10.5	3.0	26.0			
F 1-D	15.0	2.5	31.0	17.0	17.0	25.0	
O 1-1	15.0	18.0	3.0	31.0			
O 1-2	10.5	13.5	3.0	27.0			
O 1-3	8.5	12.0	3.5	26.0			
O 1-4	15.0	18.0	3.0	31.0			
First Pulse (ENG 2) (P_c = 103.0)							
F 2-A	7.5	10.5	3.0	26.0			
F 2-B	14.5	17.5	3.0	31.0			
F 2-C	10.5	13.0	2.5	27.0			
F 2-D	14.5	17.5	3.0	31.0	18.0	18.0	25.5
O 2-1	11.0	14.0	3.0	27.0			
O 2-2	15.0	18.0	3.0	31.0			
O 2-3	14.5	17.5	3.0	30.0			
O 2-4	10.0	13.0	3.0	28.0			

TABLE 5-4 (Sheet 12 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 5 (7/5/68) (Continued)							
Second Pulse (ENG 2) (P_c = 102.0)							
F 2-A	8.5	11.5	3.0	26.0			
F 2-B	14.5	17.0	2.5	31.0			
F 2-C	14.5	17.0	2.5	30.0			
F 2-D	9.5	13.0	3.5	27.0	17.5	17.5	26.5
O 2-1	9.5	13.0	3.5	28.0			
O 2-2	15.5	18.5	3.0	31.0			
O 2-3	14.5	17.0	2.5	31.0			
O 2-4	9.0	12.0	3.0	27.0			
Third Pulse (ENG 2) (P_c = 101.0)							
F 2-A	15.0	18.0	3.0	31.0			
F 2-B	8.5	11.5	3.0	27.0			
F 2-C	9.5	12.5	3.0	28.0			
F 2-D	15.0	18.0	3.0	31.0	16.0	16.0	26.0
O 2-1	14.5	17.5	3.0	31.0			
O 2-2	11.0	14.0	3.0	29.0			
O 2-3	14.0	17.0	3.0	30.0			
O 2-4	9.0	12.5	3.5	27.0			
First Pulse (ENG 3) (P_c = 71.0)							
F 3-A	13.0	16.0	3.0	31.0			
F 3-B	7.5	10.0	2.5	26.0			
F 3-C	8.0	11.0	3.0	26.0			
F 3-D	12.5	15.5	3.0	30.0	13.5	15.0	23.0
O 3-1	11.0	14.0	3.0	28.0			
O 3-2	11.5	14.5	3.0	30.0			
O 3-3	12.0	15.0	3.0	29.0			
O 3-4	10.0	13.0	3.0	28.0			
Second Pulse (ENG 3) (P_c = 71.0)							
F 3-A	7.5	10.5	3.0	27.0			
F 3-B	13.0	16.0	3.0	31.0			
F 3-C	7.5	10.5	3.0	27.0			
F 3-D	13.0	16.0	3.0	31.0	17.0	15.0	23.5
O 3-1	9.0	12.0	3.0	26.0			
O 3-2	14.0	17.0	3.0	31.0			
O 3-3	13.5	16.5	3.0	30.0			
O 3-4	9.0	12.5	3.5	29.0			

TABLE 5-4 (Sheet 13 of 15)
VALVE CURRENT TIMINGS

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 5 (7/5/68) (Continued)							
THIRD Pulse (ENG 3) (P_c = 71.0)							
F 3-A	14.5	17.0	2.5	32.0			
F 3-B	8.5	11.0	2.5	27.0			
F 3-C	15.0	17.5	2.5	32.0			
F 3-D	10.0	12.5	2.5	29.0	16.0	16.0	24.0
O 3-1	14.0	17.0	3.0	30.0			
O 3-2	10.5	13.0	2.5	30.0			
O 3-3	13.5	16.5	3.0	30.0			
O 3-4	13.5	16.5	3.0	30.0			
FIRST Pulse (ENG 4) (P_c = 106.0)							
F 4	13.5	15.5	2.0	33.0			
O 4	12.5	14.0	1.5	31.0	16.5	16.5	21.5
BURP-FIRING NO. 6 (7/22/68)							
First Pulse (ENG 1) (P_c = 38.0)							
F 1-A	15.5	18.5	3.0	31.0			
F 1-B	8.5	11.5	3.0	27.0			
F 1-C	15.5	18.5	3.0	31.0			
F 1-D	9.5	12.5	3.0	27.0	17.0	17.0	27.0
O 1-1	16.0	19.0	3.0	31.0			
O 1-2	10.0	13.0	3.0	28.0			
O 1-3	15.5	18.5	3.0	31.0			
O 1-4	9.5	13.0	3.5	28.0			
Second Pulse (ENG 1) (P_c = 35.0)							
F 1-A	14.0	16.5	2.5	31.0			
F 1-B	8.5	11.5	3.0	27.0			
F 1-C	9.0	11.5	2.5	26.0			
F 1-D	14.0	16.5	2.5	31.0	15.0	16.0	23.5
O 1-1	9.0	12.0	3.0	27.0			
O 1-2	14.5	17.5	3.0	31.0			
O 1-3	9.0	12.0	3.0	26.0			
O 1-4	14.0	17.5	3.5	31.0			

VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
BURP-FIRING NO. 6 (7/22/68) (Continued)							
Third Pulse (ENG 1) (P_c = 35.0)							
F 1-A	14.0	17.0	3.0	30.0			
F 1-B	10.0	13.0	3.0	27.0			
F 1-C	8.5	11.0	2.5	27.0			
F 1-D	14.0	17.0	3.0	31.0	15.0	15.0	23.5
O 1-1	15.5	18.5	3.0	31.0			
O 1-2	10.5	13.5	3.0	27.0			
O 1-3	9.0	12.0	3.0	27.0			
O 1-4	16.0	19.0	3.0	31.0			
First Pulse (ENG 2) (P_c = 104.0)							
F 2-A	8.0	10.5	2.5	26.0			
F 2-B	15.5	18.5	3.0	32.0			
F 2-C	16.0	18.5	2.5	32.0			
F 2-D	9.5	12.5	3.0	27.0	14.5	17.5	24.5
O 2-1	13.0	16.0	3.0	31.0			
O 2-2	12.0	15.0	3.0	28.0			
O 2-3	13.5	16.5	3.0	30.0			
O 2-4	9.0	12.0	3.0	27.0			
Second Pulse (ENG 2) (P_c = 104.0)							
F 2-A	15.0	18.0	3.0	31.0			
F 2-B	7.5	10.5	3.0	26.0			
F 2-C	15.5	18.0	2.5	31.0			
F 2-D	8.0	11.0	3.0	27.0	14.0	17.0	22.5
O 2-1	14.0	17.0	3.0	31.0			
O 2-2	10.5	13.5	3.0	27.0			
O 2-3	13.5	16.5	3.0	28.0			
O 2-4	8.5	11.5	3.0	26.0			
Third Pulse (ENG 2) (P_c = 104.0)							
F 2-A	10.5	13.5	3.0	28.0			
F 2-B	15.0	17.5	2.5	31.0			
F 2-C	15.0	17.5	2.5	31.0			
F 2-D	8.5	11.5	3.0	27.0	14.0	16.0	24.5
O 2-1	10.0	13.5	3.5	27.0			
O 2-2	15.5	18.5	3.0	31.0			
O 2-3	15.0	18.0	3.0	31.0			
O 2-4	9.0	12.0	3.0	27.0			

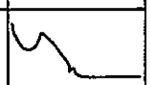
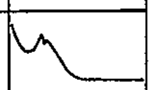
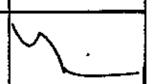
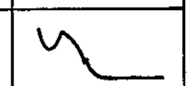
TABLE 5-4 (Sheet 15 of 15)
VALVE CURRENT TIMINGS

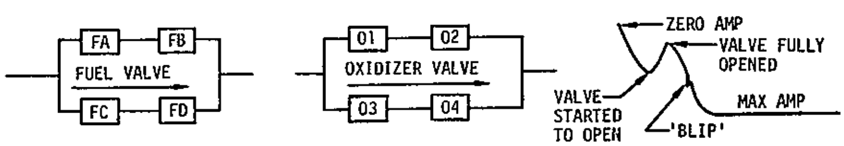
VALVE	SIGNAL TO START TO OPEN (ms)	SIGNAL TO FULLY OPEN (ms)	TRAVEL TIME (ms)	SIGNAL TO STEADY-STATE (MS)	SIGNAL TO OXIDIZER PRESSURE START TO RISE (ms)	SIGNAL TO FUEL PRESSURE START TO RISE (ms)	SIGNAL TO CHAMBER PRESSURE INITIATION (ms)
				BURP-FIRING NO. 6 (7/22/68) (Continued)			
First Pulse (ENG 3) (P_c = 54.0)							
F 3-A	15.0	17.5	2.5	31.0			
F 3-B	8.0	10.5	2.5	26.0			
F 3-C	15.5	18.5	3.0	30.0			
F 3-D	9.5	12.5	3.0	28.0	17.0	17.0	26.5
O 3-1	14.5	17.5	3.0	30.0			
O 3-2	10.0	13.0	3.0	28.0			
O 3-3	14.5	17.5	3.0	31.0			
O 3-4	9.5	12.5	3.0	28.0			
Second Pulse (ENG 3) (P_c = 54.0)							
F 3-A	13.5	16.5	3.0	31.0			
F 3-B	8.5	11.0	2.5	27.0			
F 3-C	8.0	11.0	3.0	27.0			
F 3-D	13.5	16.0	2.5	32.0	17.0	15.0	24.5
O 3-1	15.0	17.5	2.5	32.0			
O 3-2	10.0	13.0	3.0	28.0			
O 3-3	15.0	18.0	3.0	31.0			
O 3-4	9.5	12.5	3.0	29.0			
Third Pulse (ENG 3) (P_c = 54.0)							
F 3-A	15.0	18.0	3.0	31.0			
F 3-B	8.0	11.0	3.0	27.0			
F 3-C	15.5	18.0	2.5	31.0			
F 3-D	8.5	11.0	2.5	27.0	16.5	16.5	23.5
O 3-1	10.5	18.5	3.0	28.0			
O 3-2	15.0	18.0	3.0	32.0			
O 3-3	14.5	17.5	3.0	31.0			
O 3-4	9.0	12.0	3.0	27.0			
First Pulse (ENG 4) (P_c = 110.0)							
F 4	12.5	14.0	1.5	32.0			
O 4	14.2	16.0	2.0	32.0	15.5	14.0	21.0

TABLE 5-5
VALVE OPENING TIME AND CHAMBER PRESSURE INITIATION

BURP FIRING	PROP	SIGNAL TO FULLY OPEN (ms)		SIGNAL TO P_c INITIATION (ms)	
		MAX	MIN	MAX	MIN
1	Fuel	19.5	8.5	38.0	25.0
	Oxid	19.0	9.5		
2	Fuel	18.0	10.0	27.5	24.5
	Oxid	18.5	11.0		
3	Fuel	19.0	10.5	28.0	23.5
	Oxid	19.0	11.5		
4	Fuel	19.0	10.0	26.0	21.5
	Oxid	18.5	11.5		
5	Fuel	19.0	10.0	27.0	21.0
	Oxid	19.0	11.0		
6	Fuel	18.5	10.5	27.0	22.5
	Oxid	19.0	11.5		

TABLE 5-6
VALVE CURRENT PERTURBATIONS

BURP FIRING	PULSE NO	ENG NO	VALVE NO	VALVE CURRENT TRACE
1	1	1	FD	
	1	1	02	
	1	2	02	
	1	2	04	
	1	3	FB	
2	1	1	02	
	1	3	02	
3	1	1	02	
	2	1	03	
4	1	1	02	
	2	1	02	
	3	1	02	
	1	3	02	
	3	3	02	
5	2	1	02	
	3	1	02	
	1	2	02	
	2	3	02	
	3	3	02	
6	2	1	02	
	2	1	04	
	3	1	01	
	3	1	02	
	1	3	02	
	2	3	02	
	3	3	02	



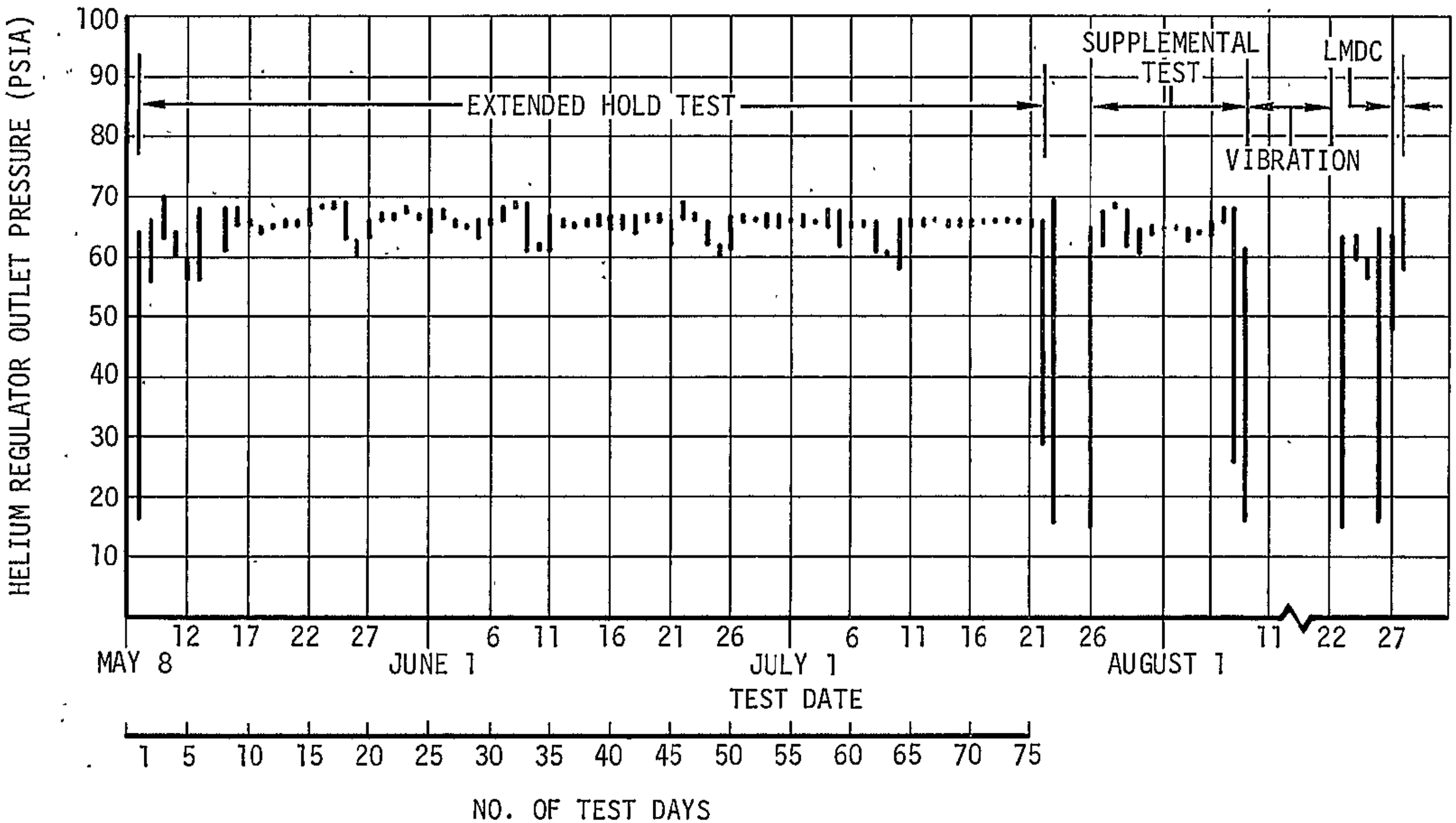


Figure 5-1. Helium Regulator Outlet Pressure History

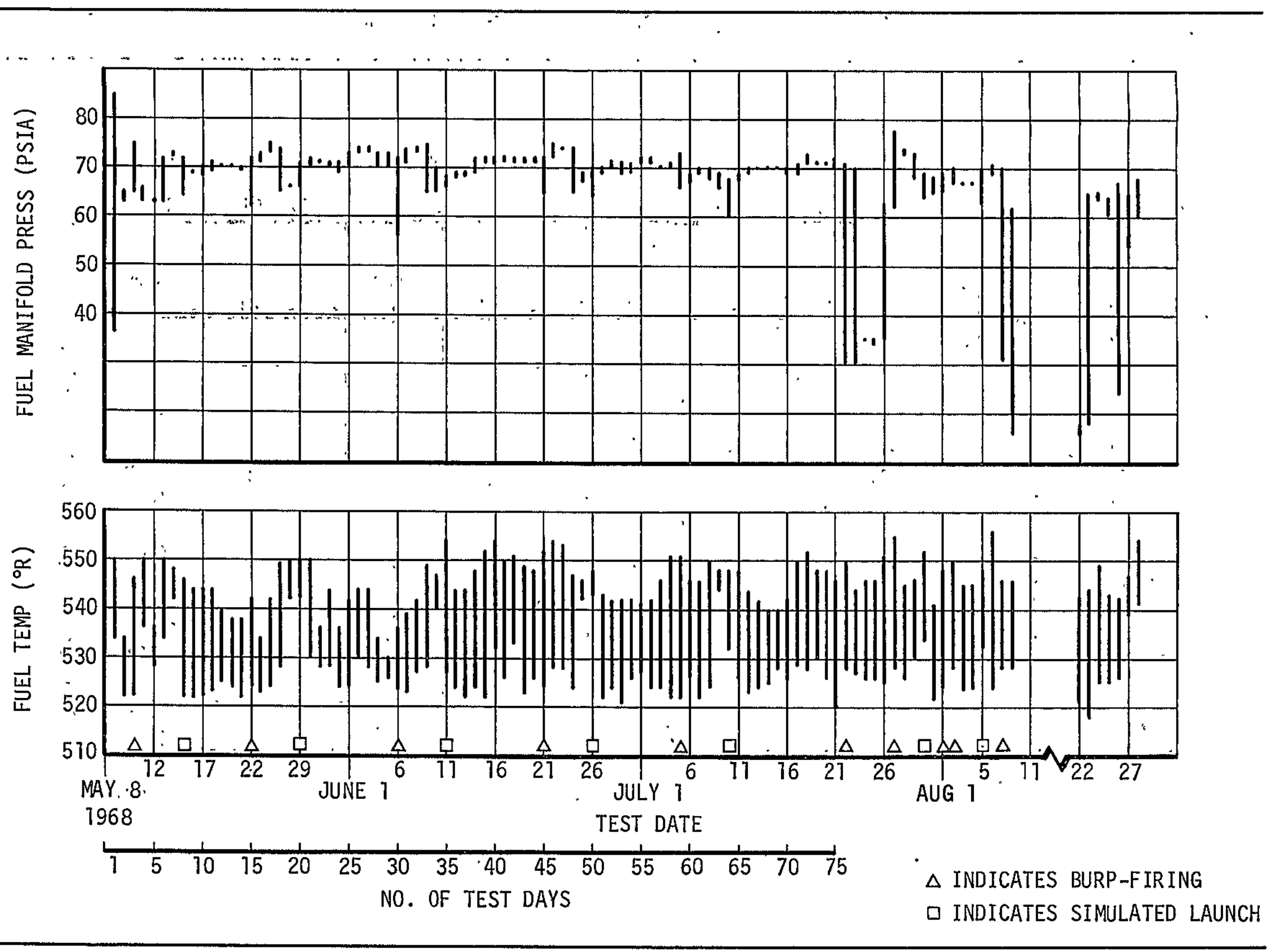


Figure 5-2. Fuel Temperature and Manifold Pressure Histories

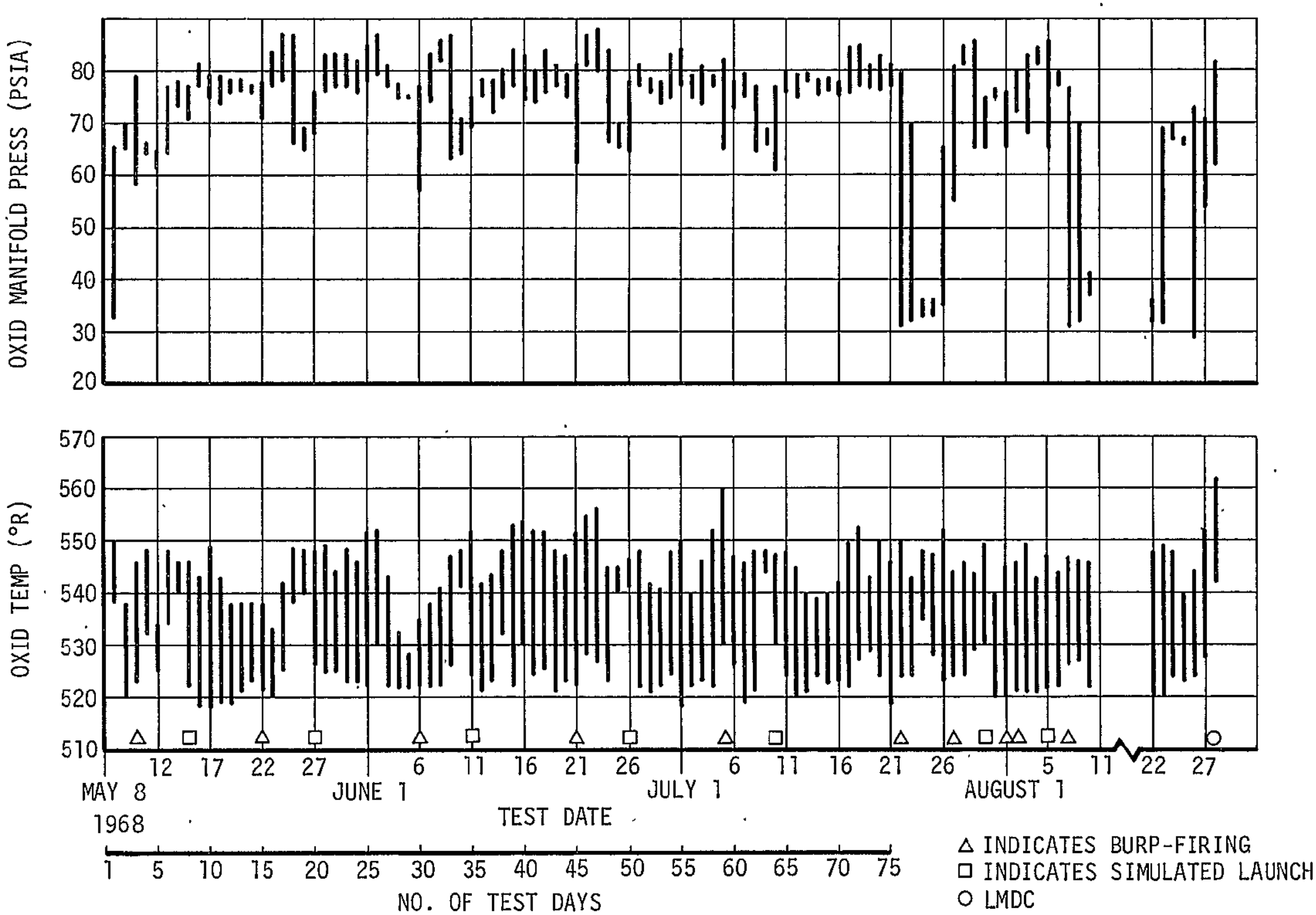


Figure 5-3. Oxidizer Temperature and Manifold Pressure Histories

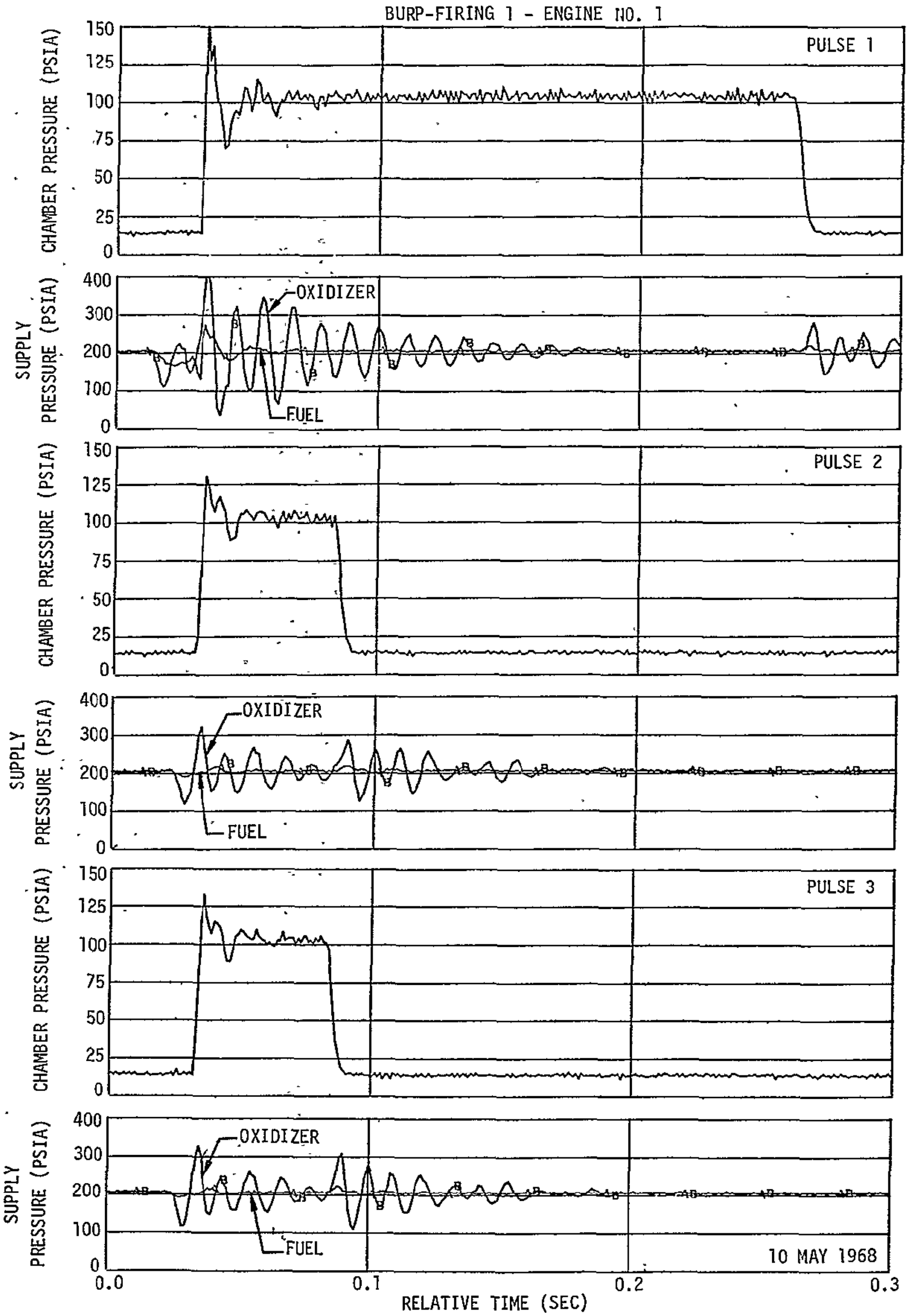


Figure 5-4. Chamber Pressure Levels (Sheet 1 of 24)

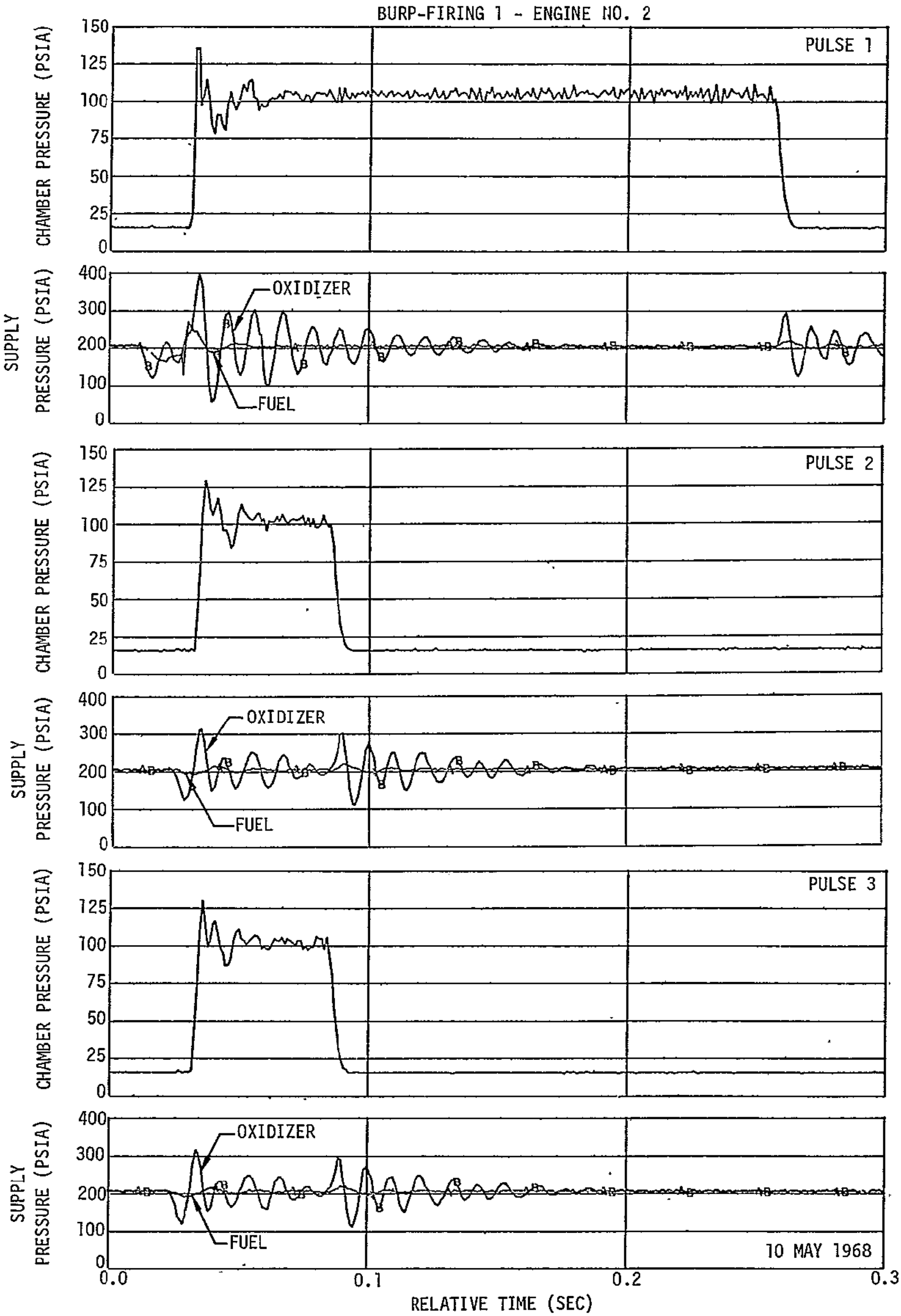


Figure 5-4. Chamber Pressure Levels (Sheet 2 of 24)

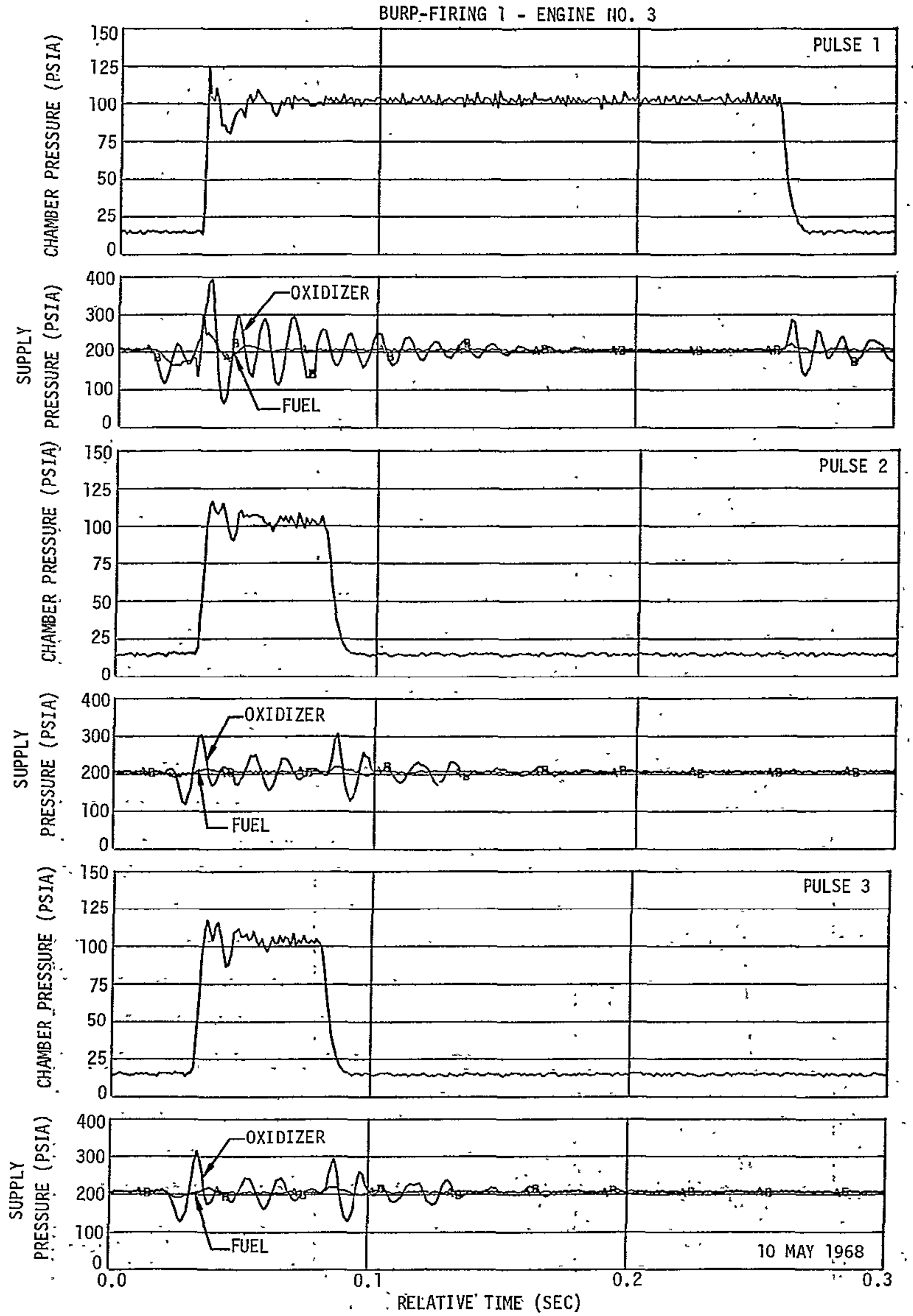


Figure 5-4. Chamber Pressure Levels (Sheet 3 of 24)

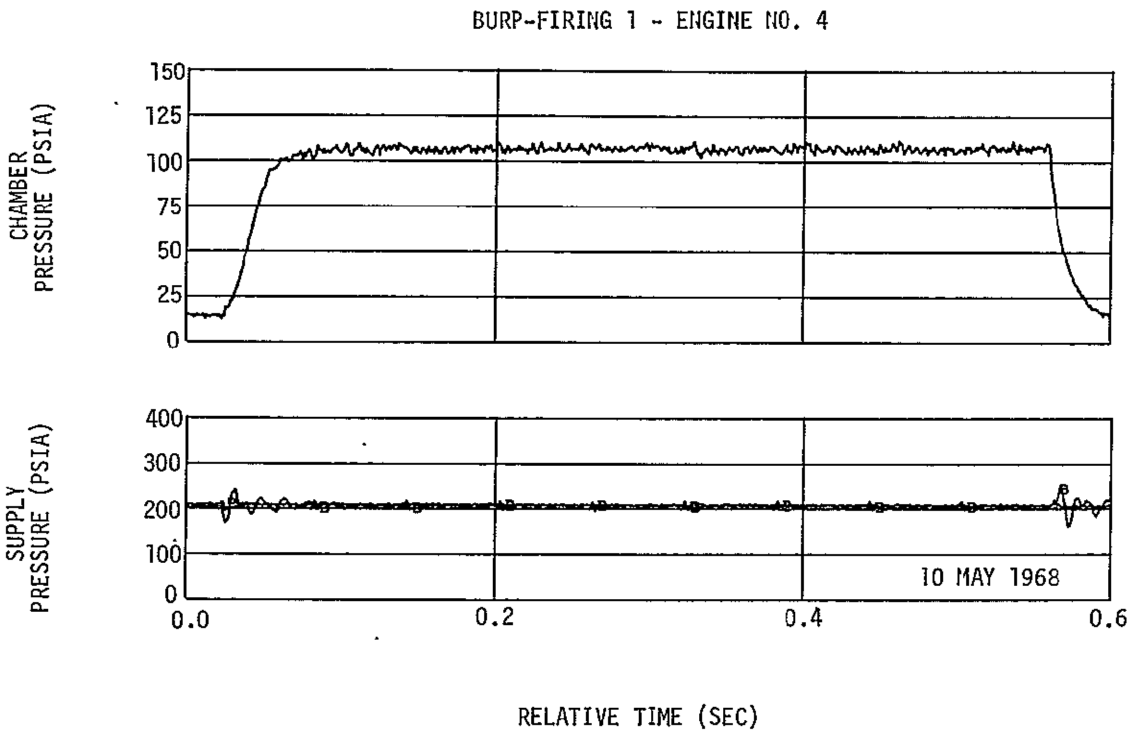


Figure 5-4. Chamber Pressure Levels (Sheet 4 of 24)

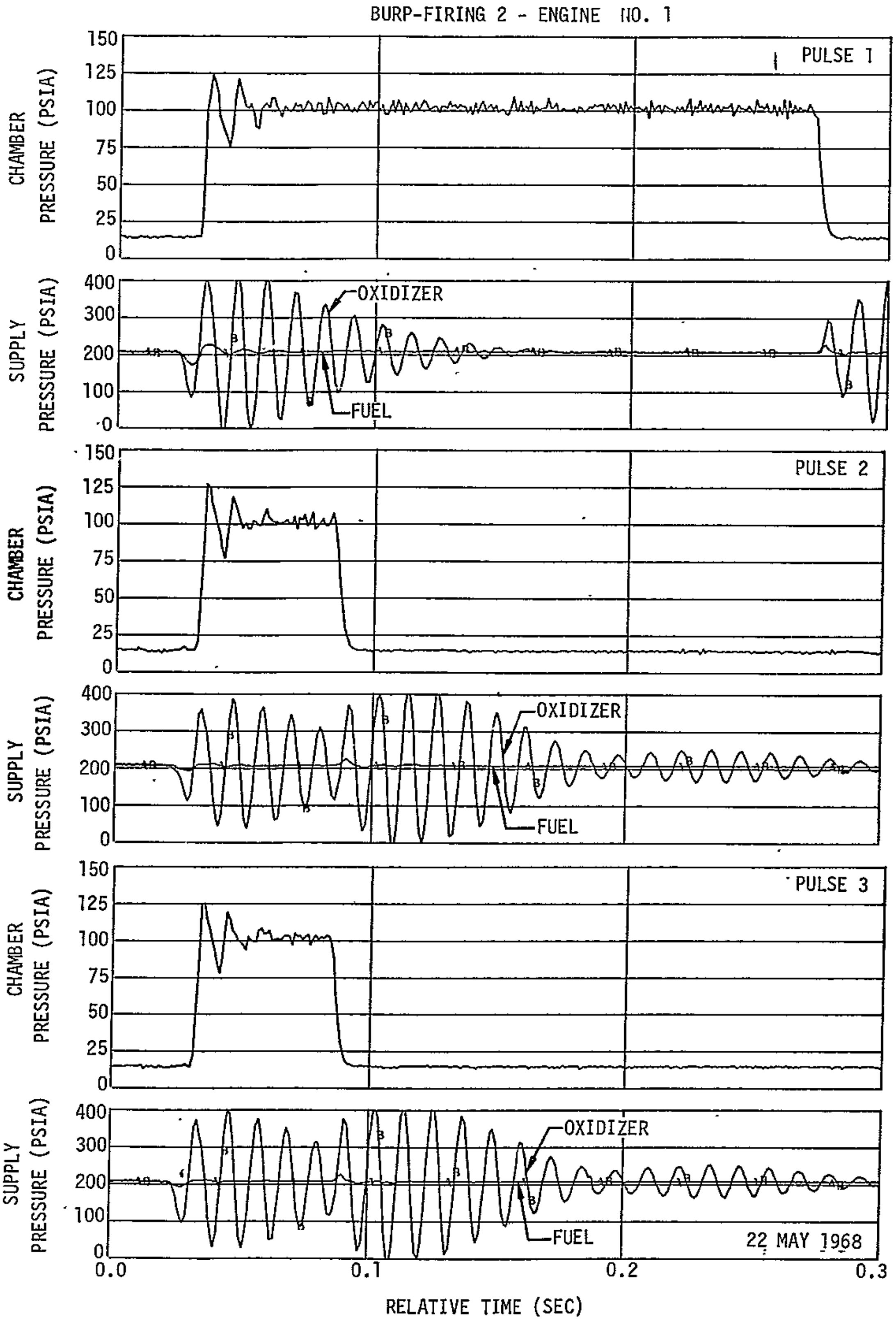


Figure 5-4. Chamber Pressure Levels (Sheet 5 of 24)

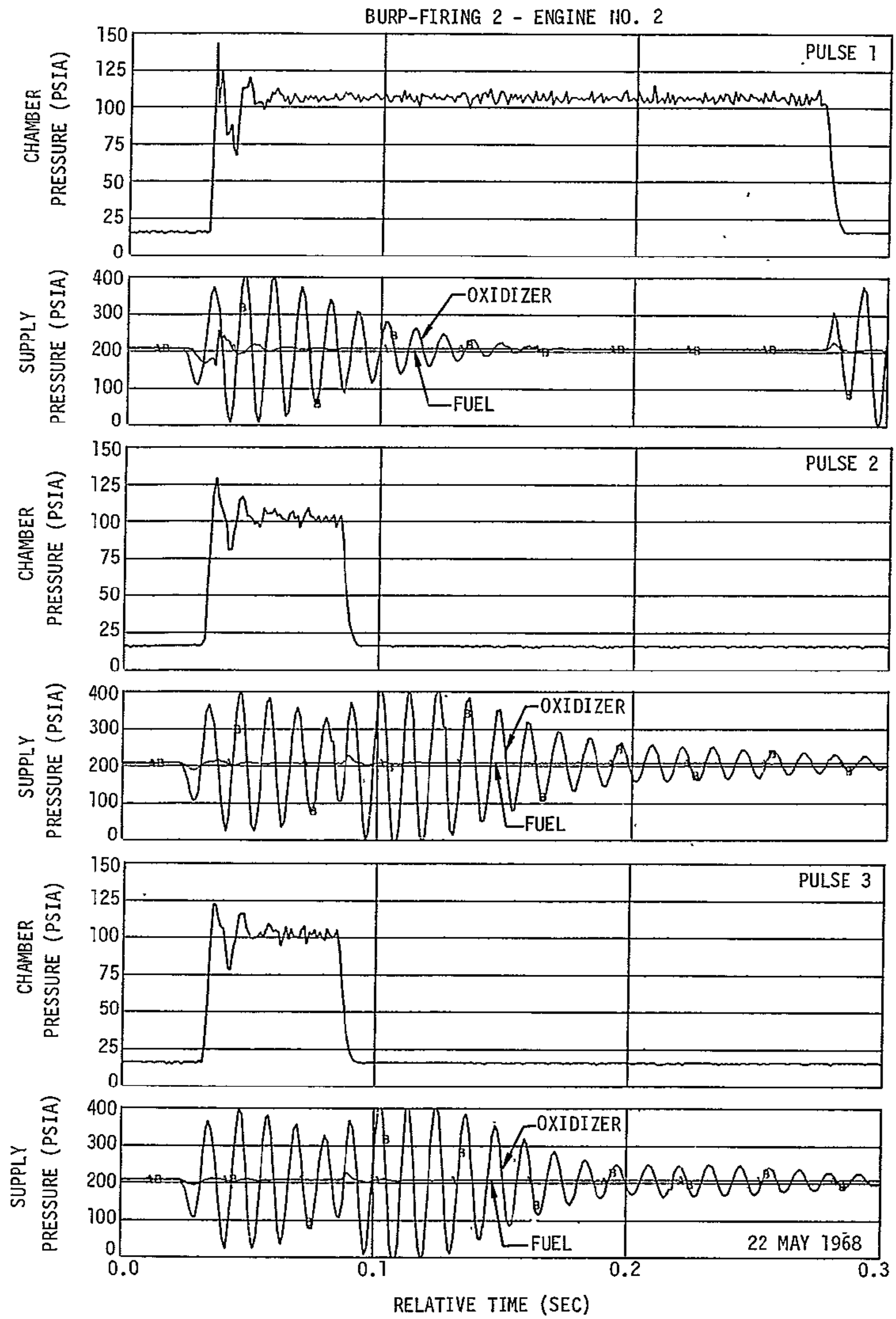


Figure 5-4. Chamber Pressure Levels (Sheet 6 of 24)

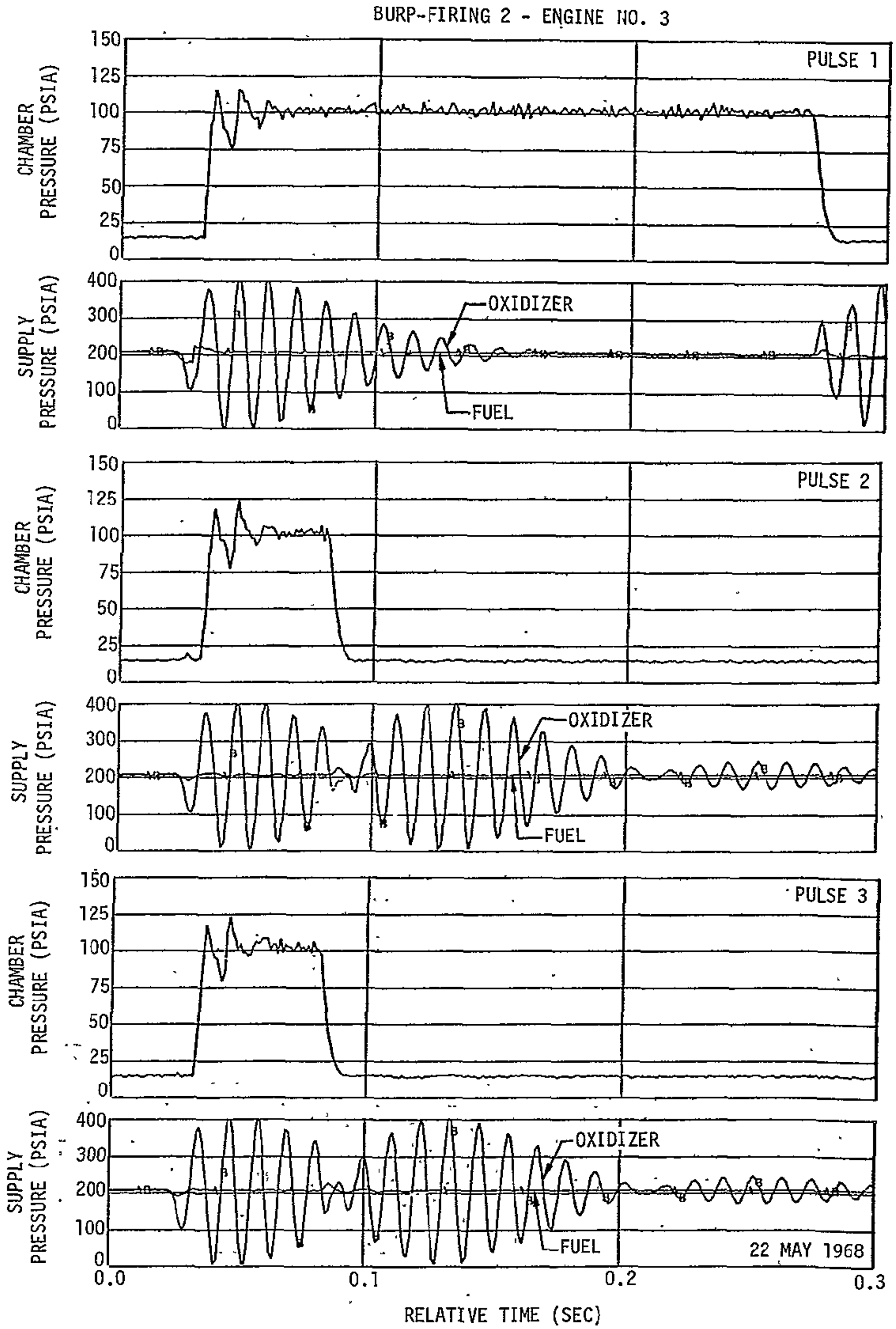


Figure 5-4. Chamber Pressure Levels (Sheet 7 of 24)

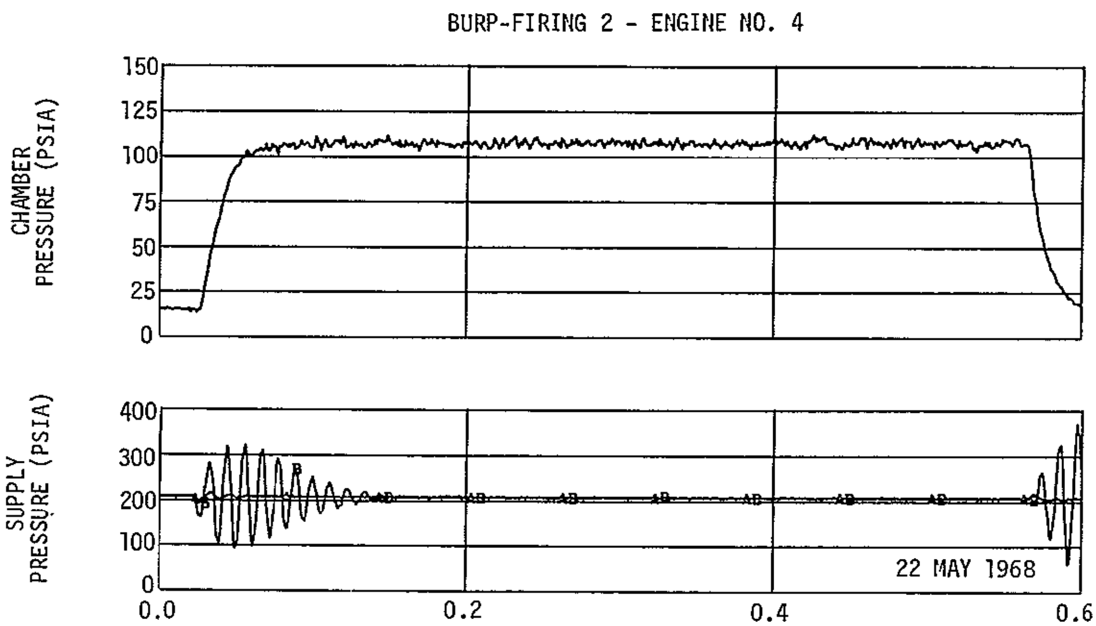


Figure 5-4. Chamber Pressure Levels (Sheet 8 of 24)

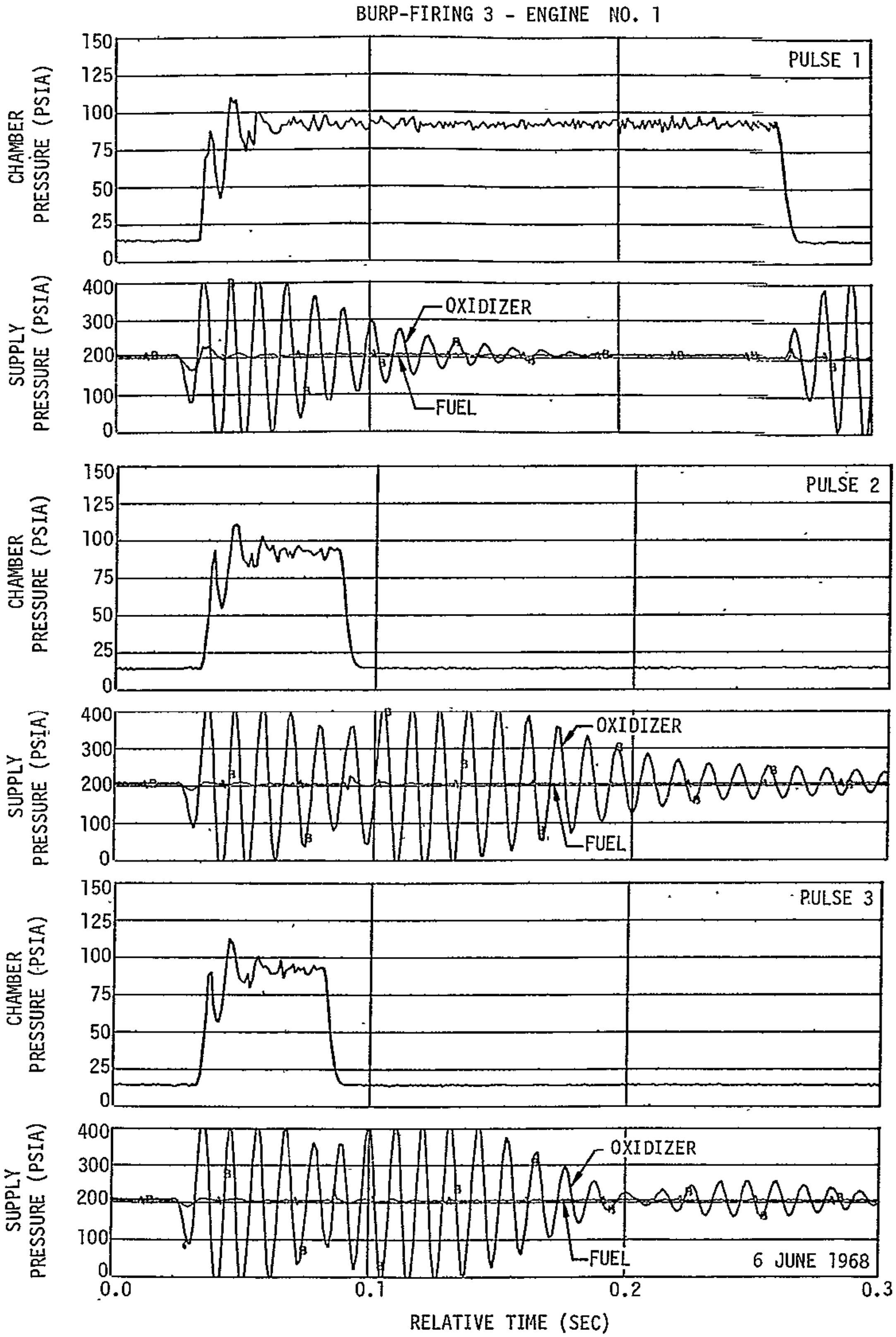


Figure 5-4. Chamber Pressure Levels (Sheet 9 of 24)

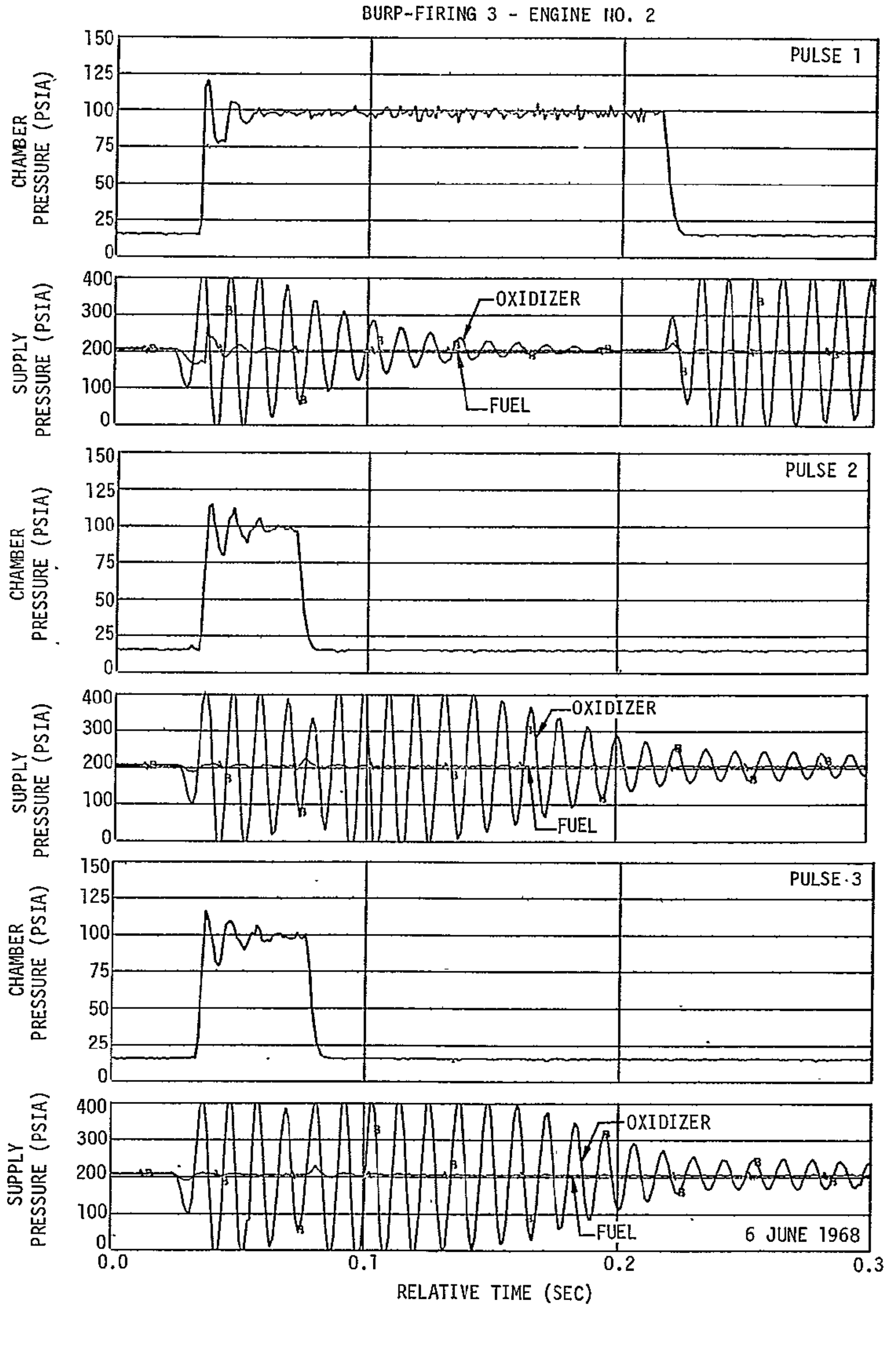


Figure 5-4. Chamber Pressure Levels (Sheet 10 of 24)

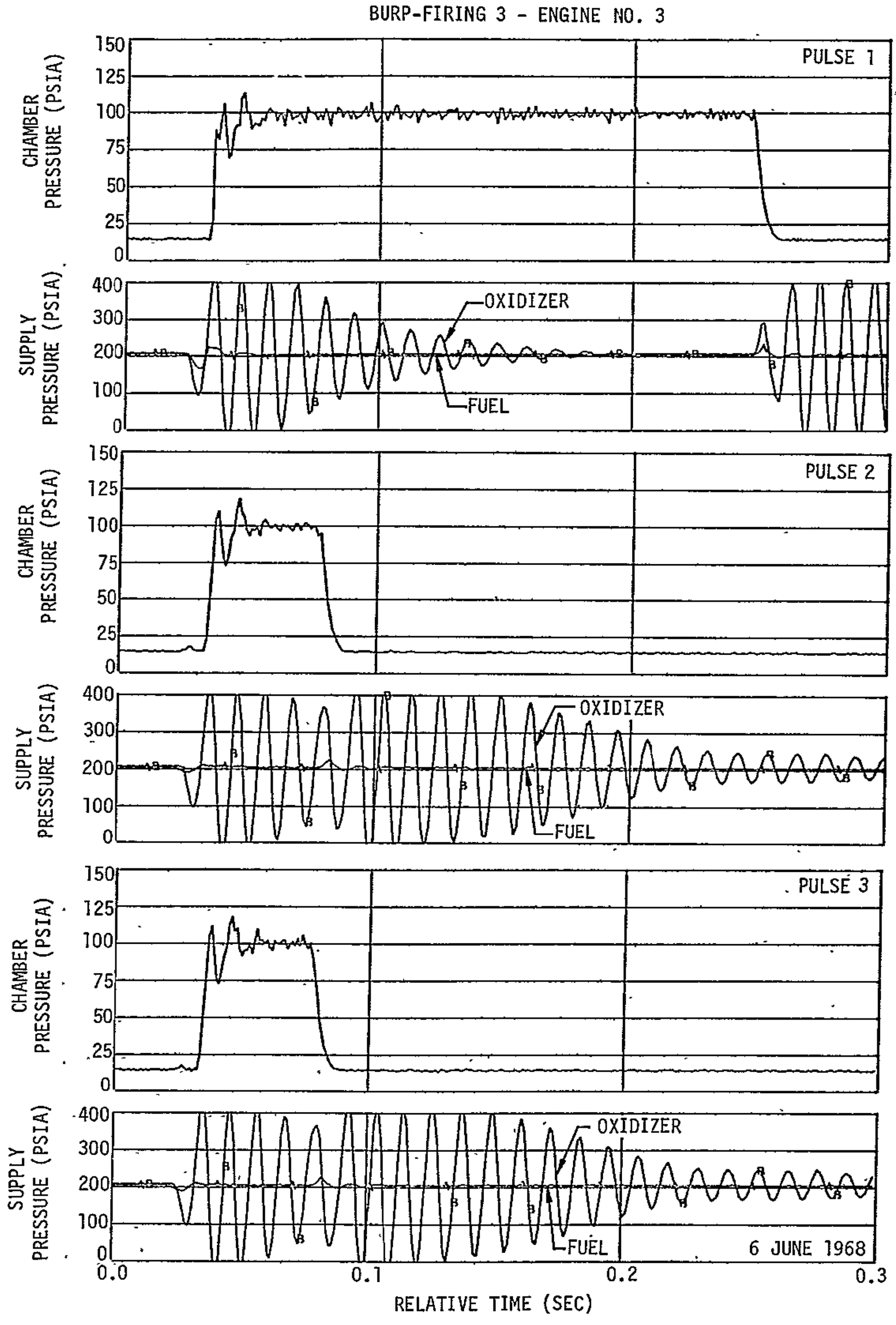


Figure 5-4. Chamber Pressure Levels (Sheet 11 of 24)

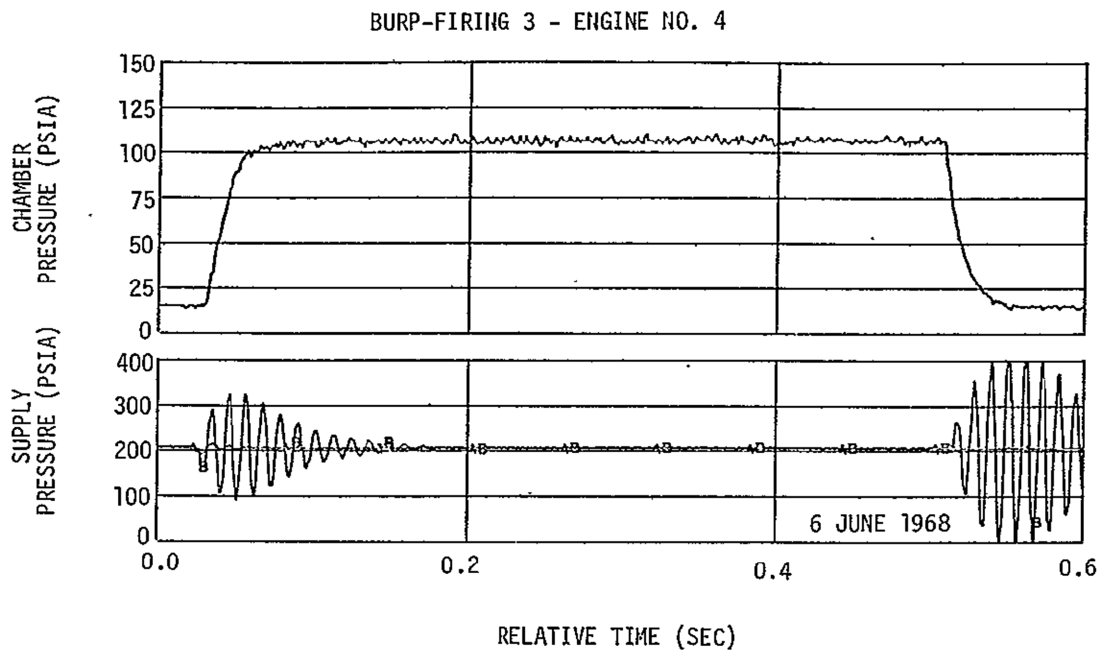


Figure 5-4. Chamber Pressure Levels (Sheet 12 of 24)

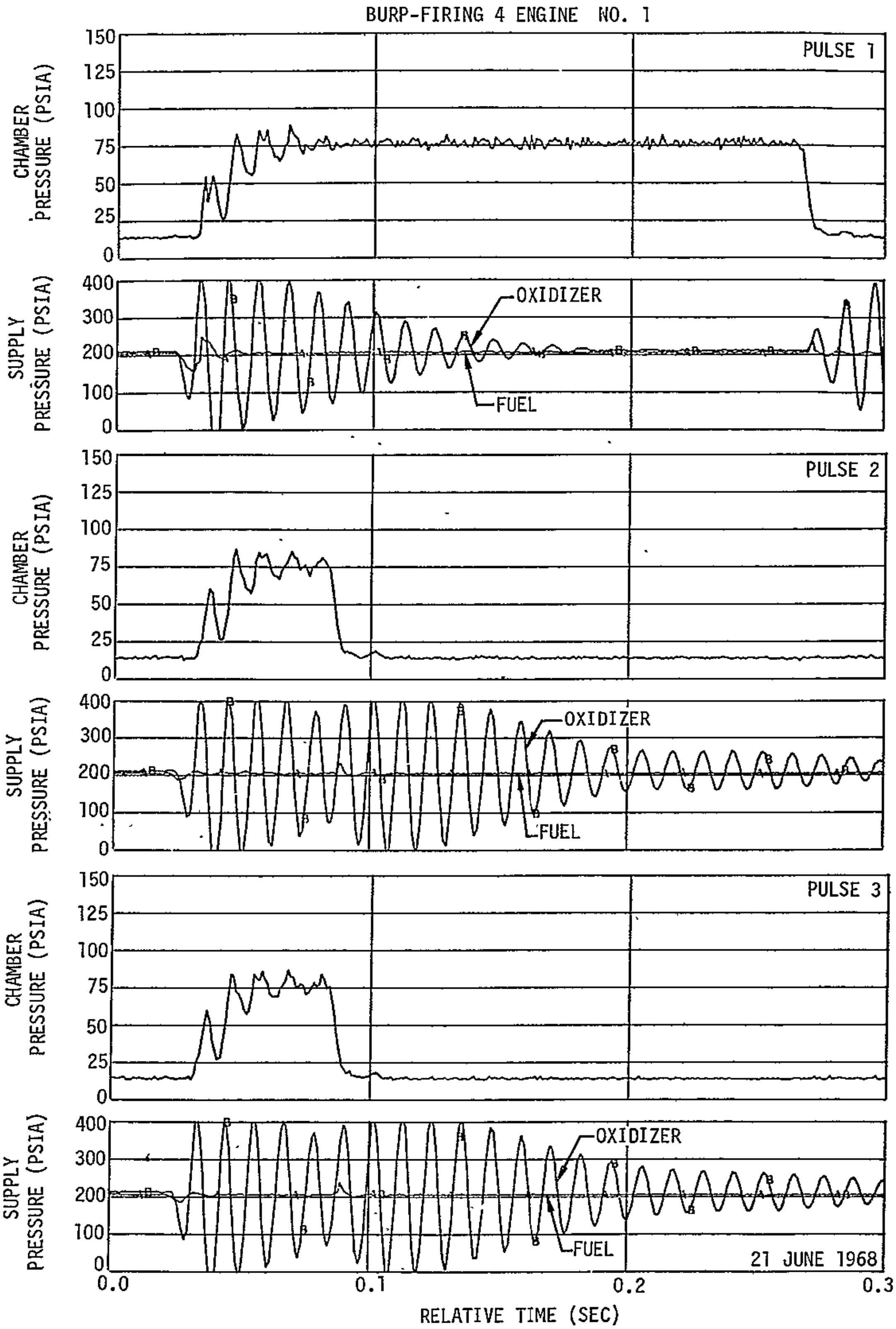


Figure 5-4. Chamber Pressure Levels (Sheet 13 of 24)

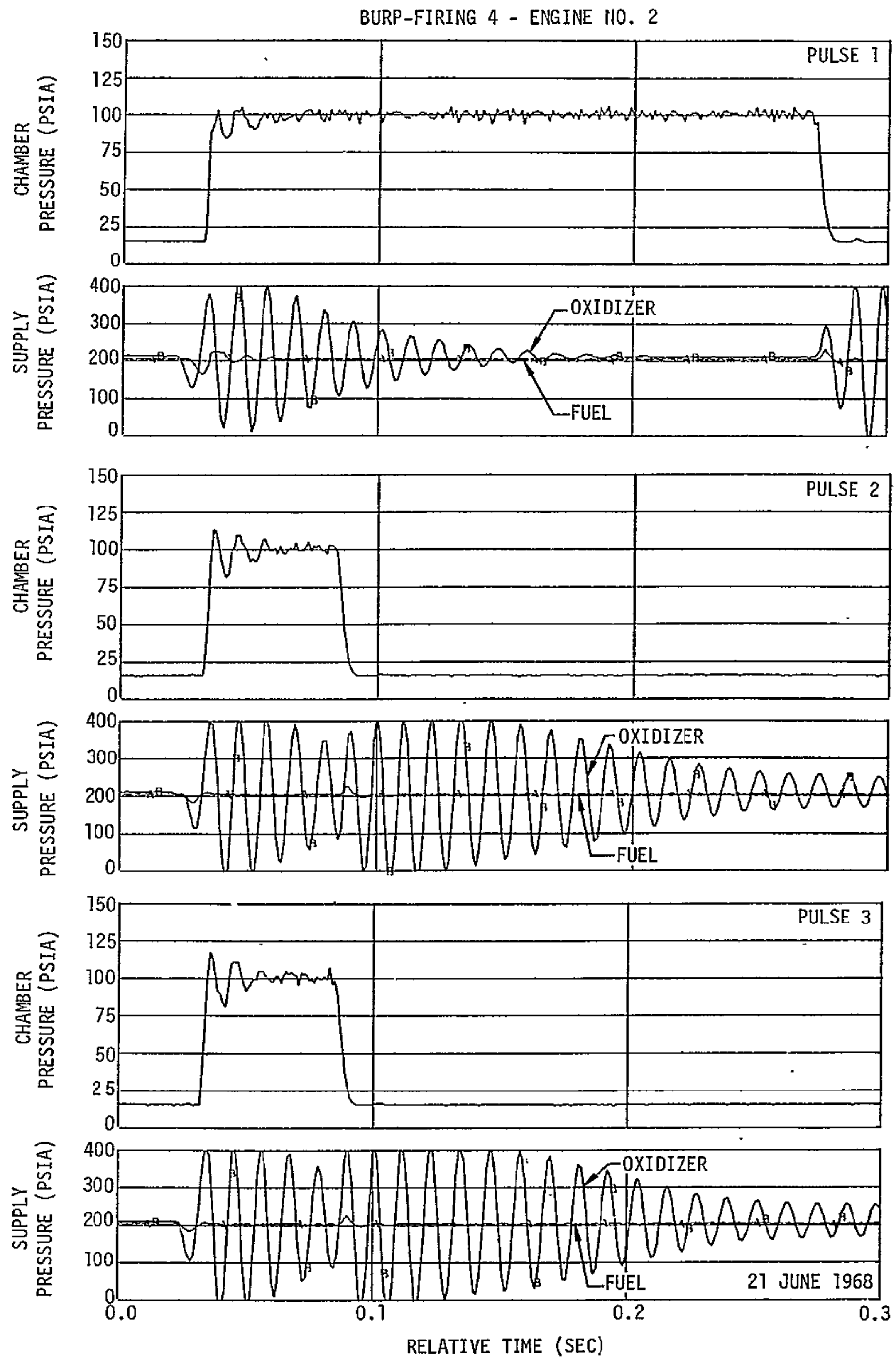


Figure 5-4. Chamber Pressure Levels (Sheet 14 of 24)

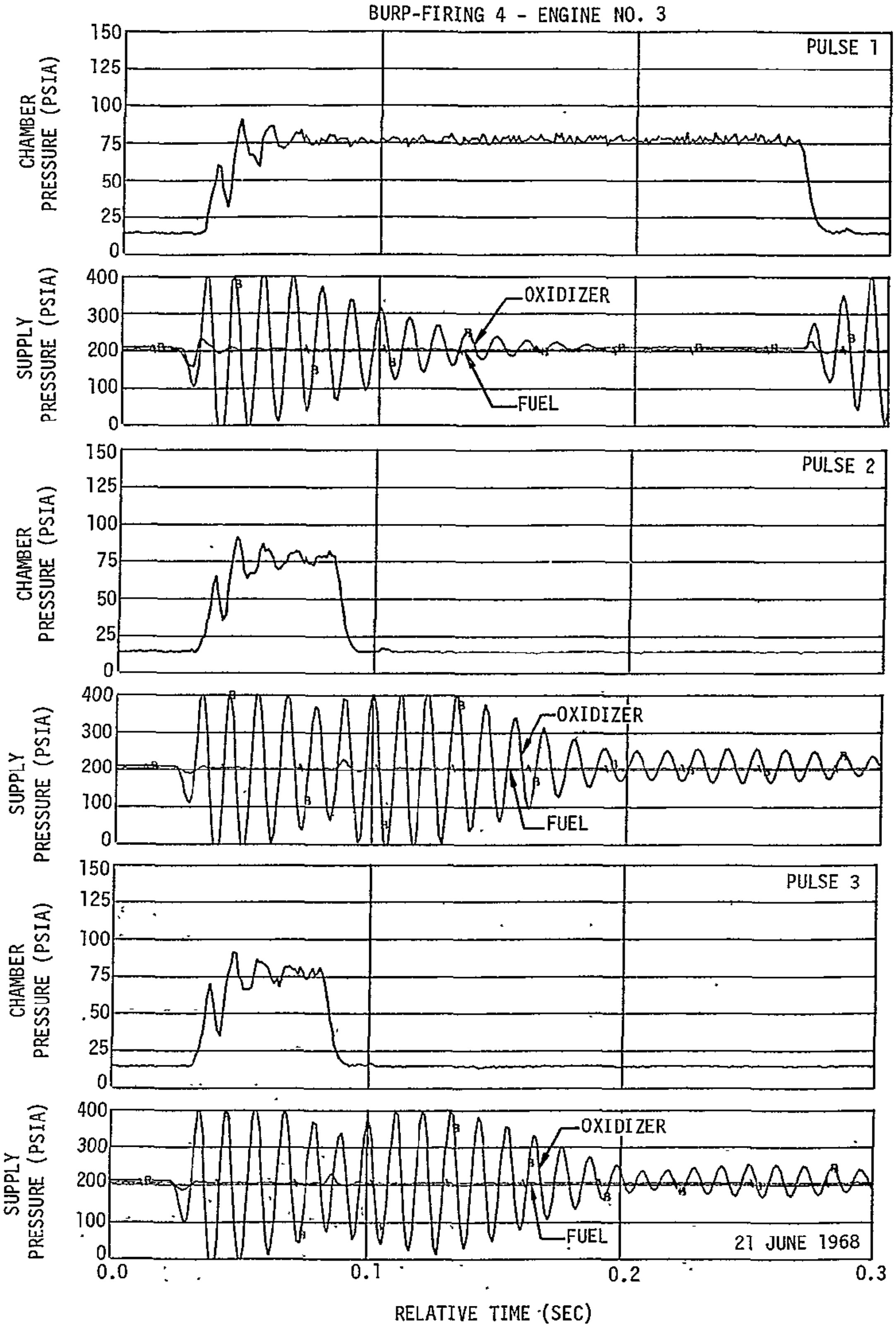


Figure 5-4. Chamber Pressure Levels (Sheet 15 of 24)

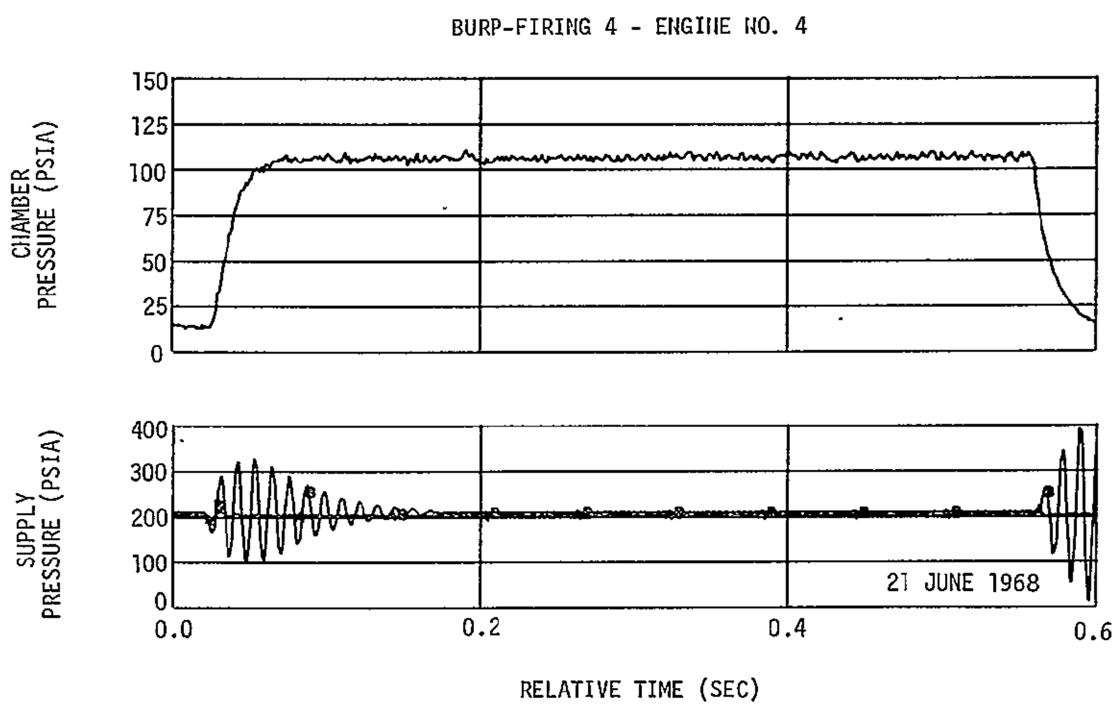


Figure 5-4. Chamber Pressure Levels (Sheet 16 of 24)

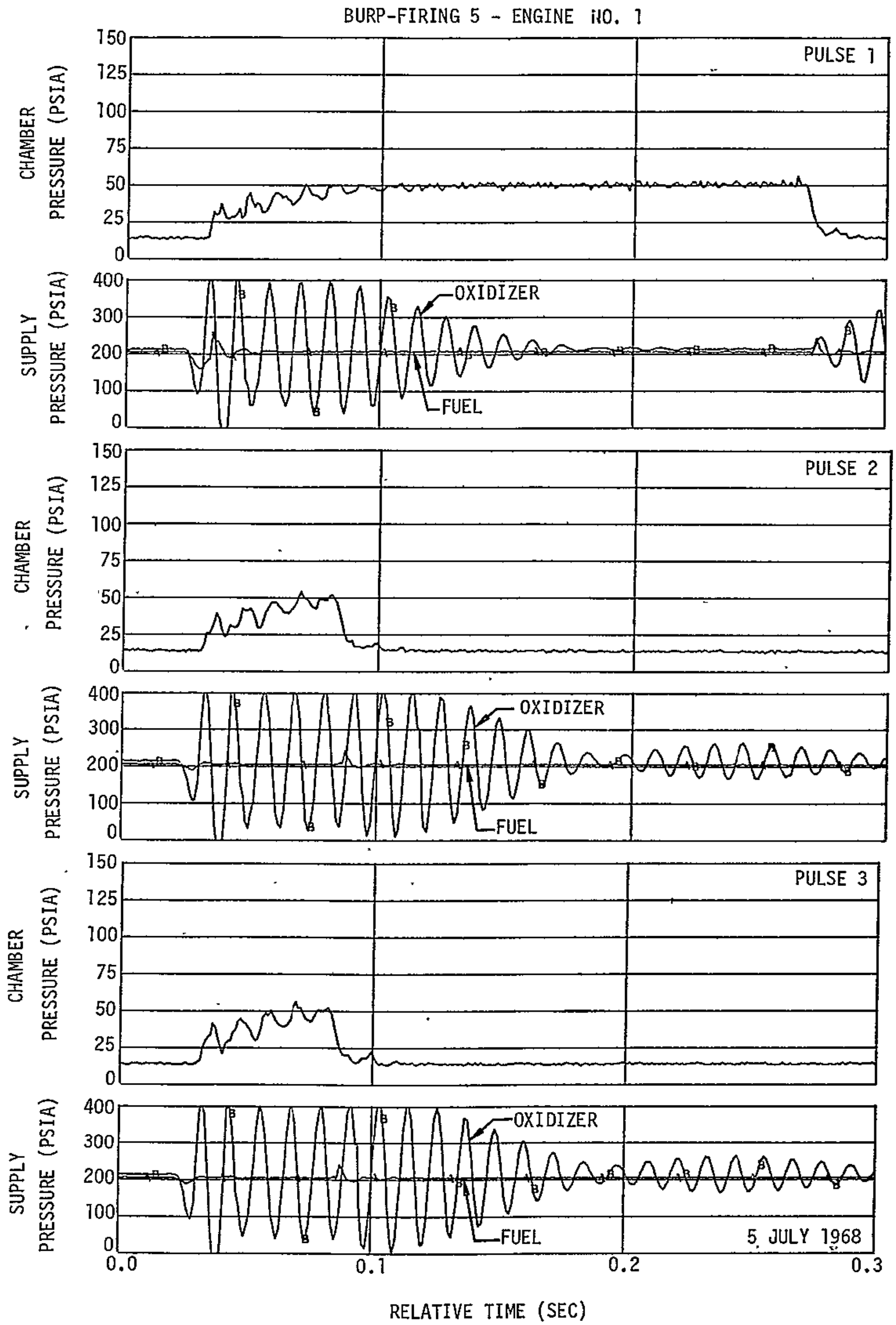


Figure 5-4. Chamber Pressure Levels (Sheet 17 of 24)

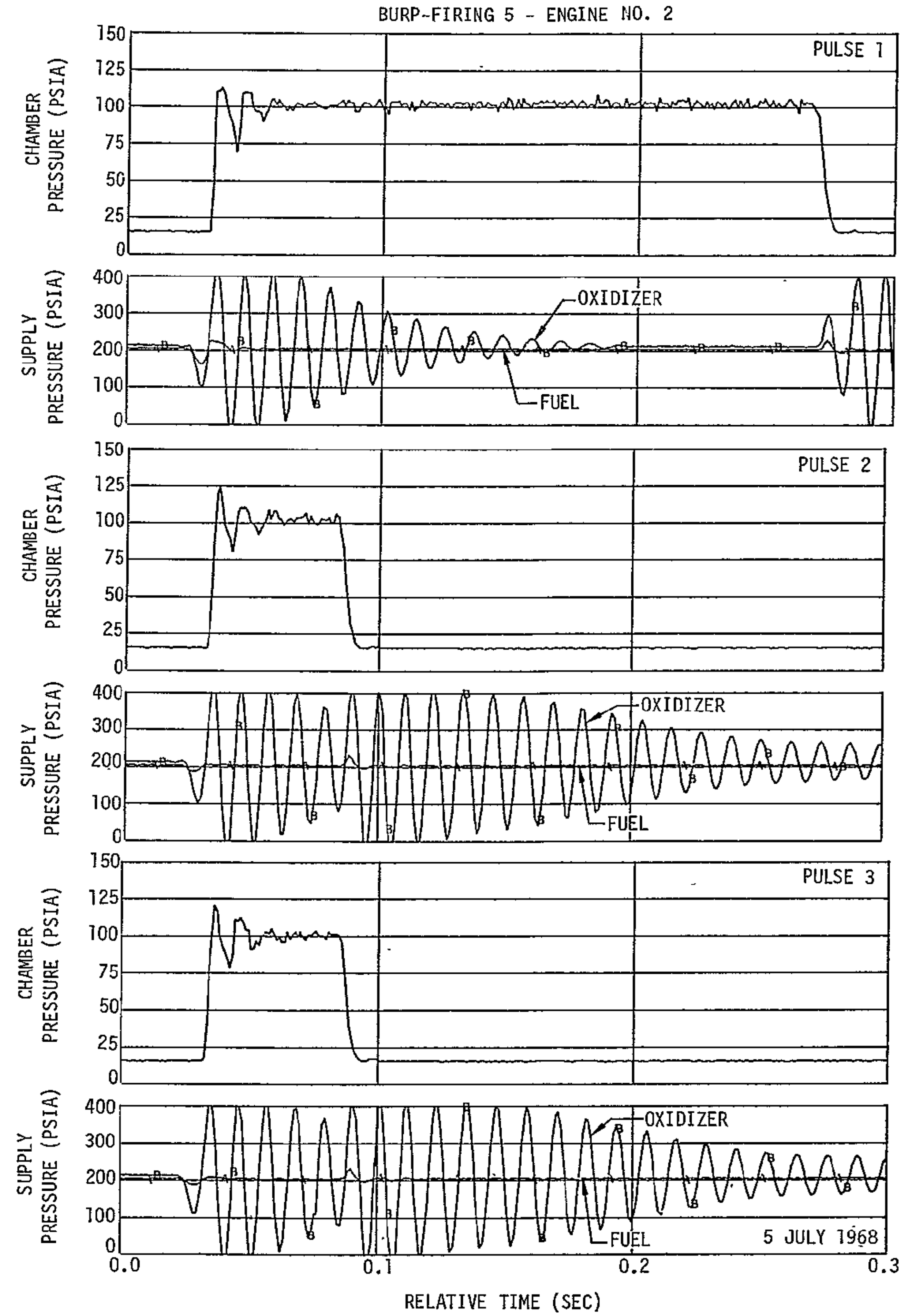


Figure 5-4. Chamber Pressure Levels (Sheet 18 of 24)

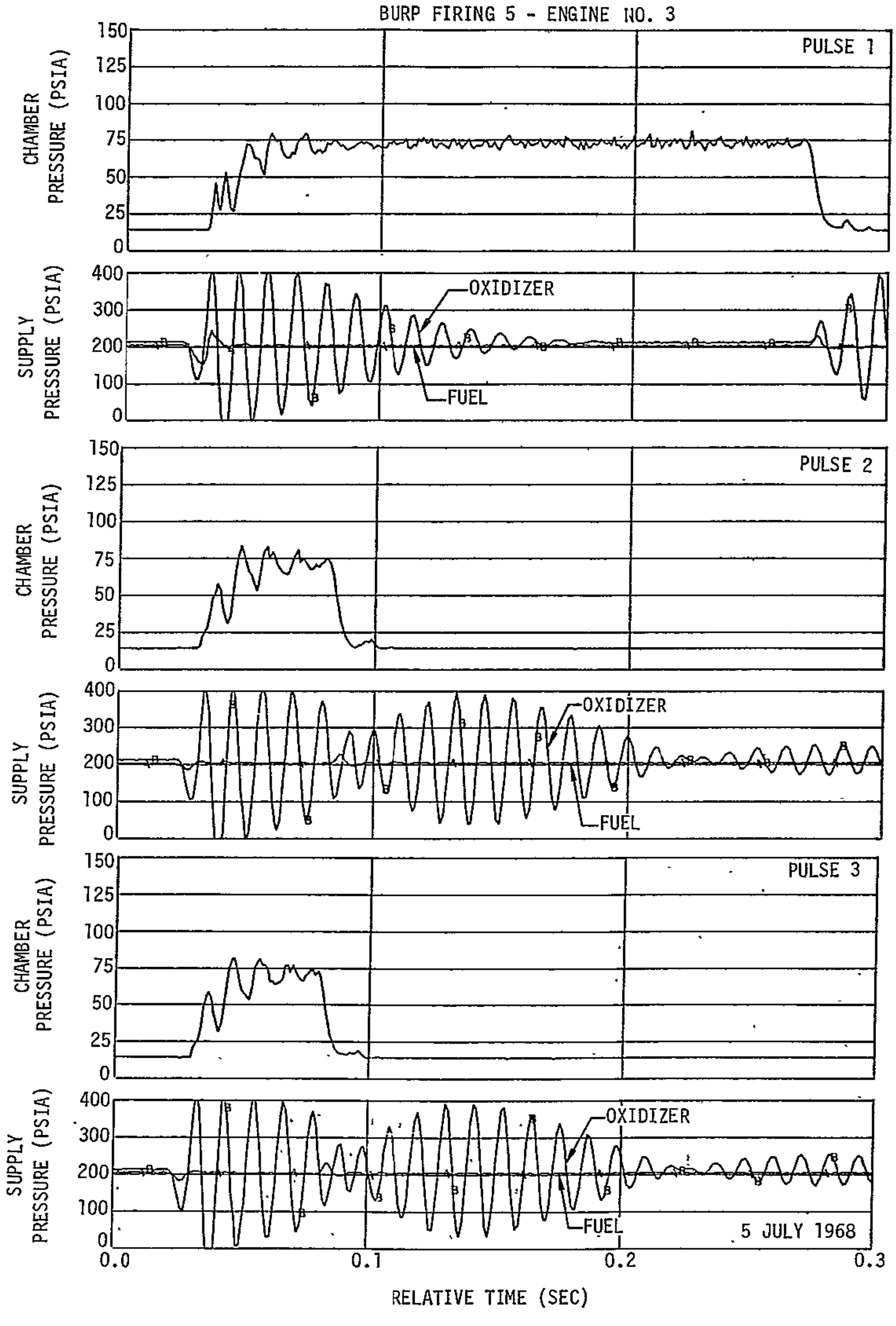


Figure 5-4. Chamber Pressure Levels (Sheet 19 of 24)

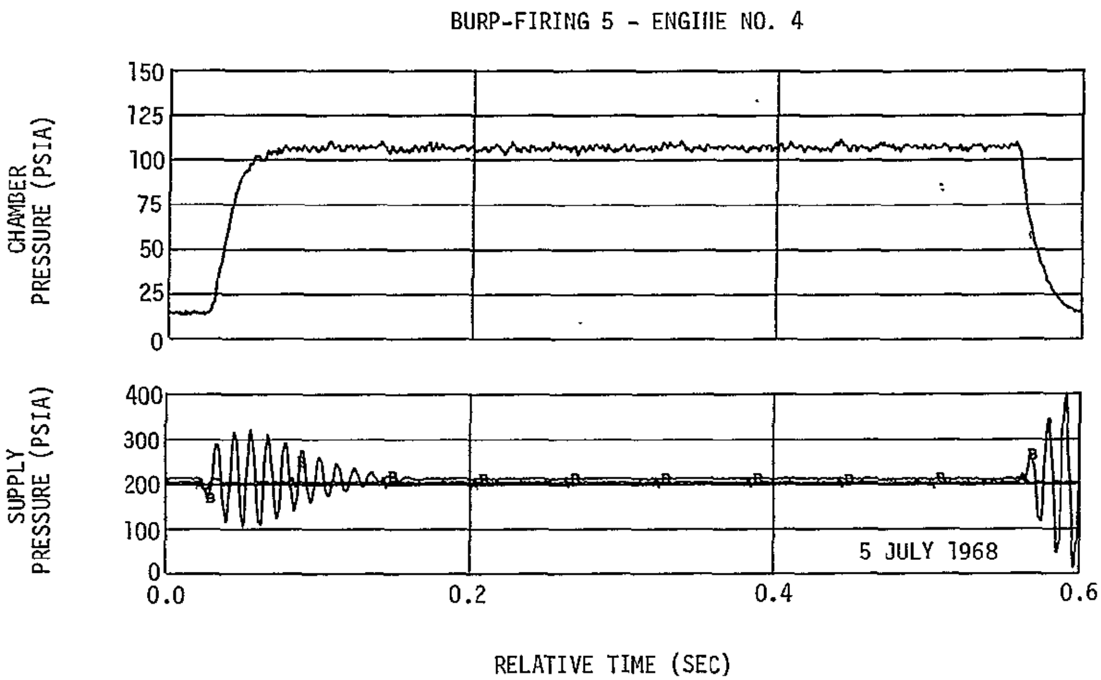


Figure 5-4. Chamber Pressure Levels (Sheet 20 of 24)

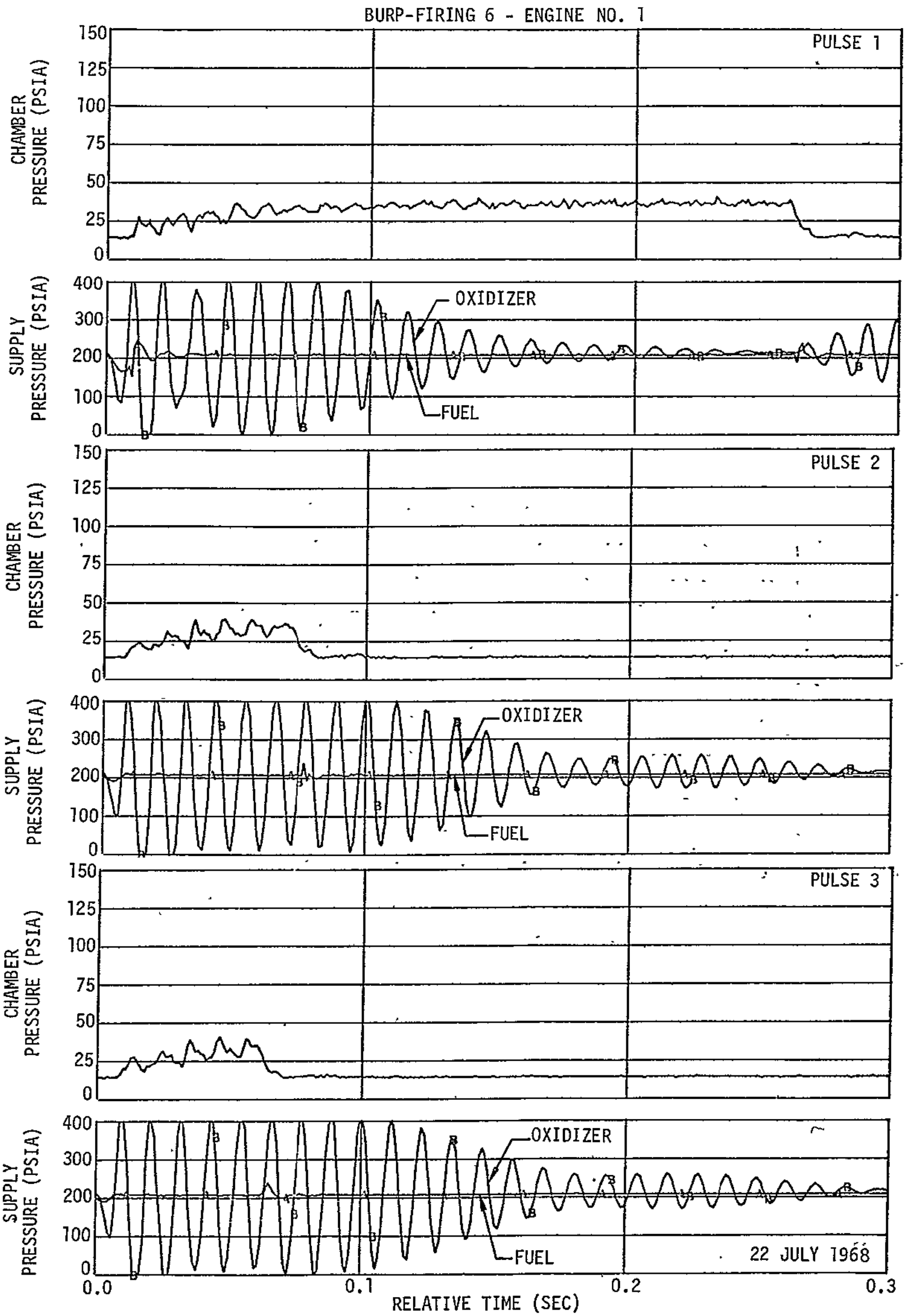


Figure 5-4. Chamber Pressure Levels (Sheet 21 of 24)

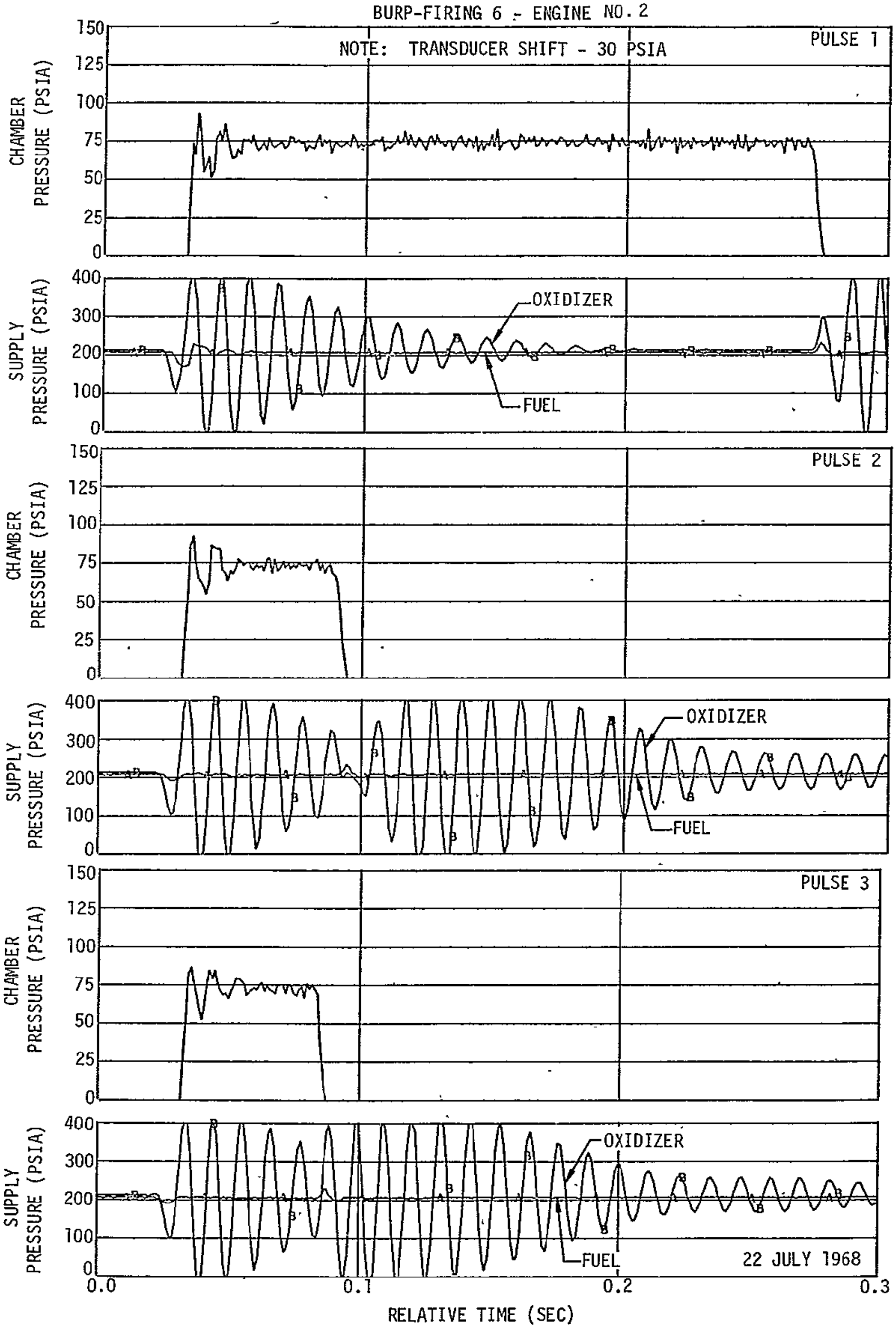


Figure 5-4. Chamber Pressure Levels (Sheet 22 of 24)

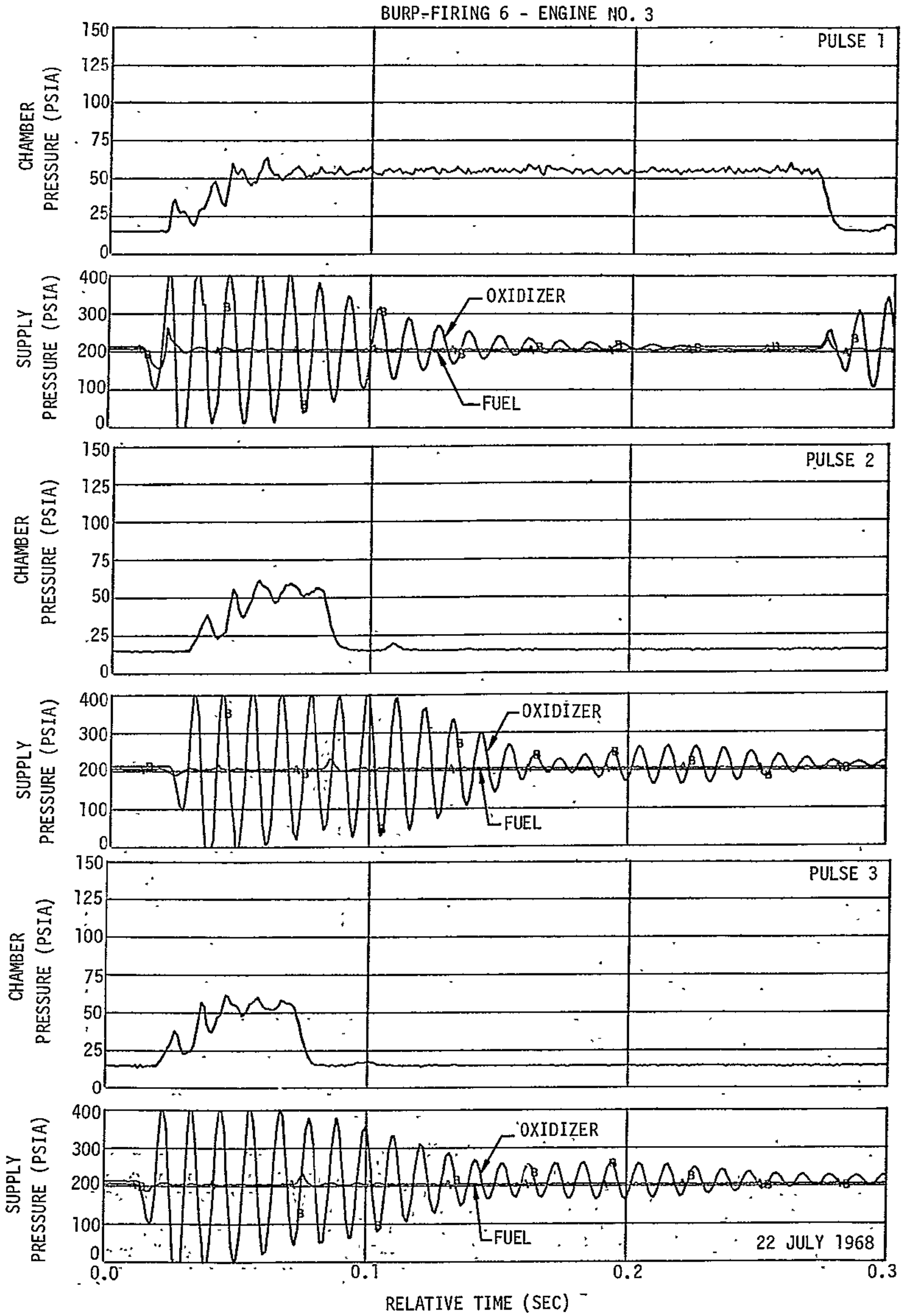


Figure 5-4. Chamber Pressure Levels (Sheet 23 of 24)

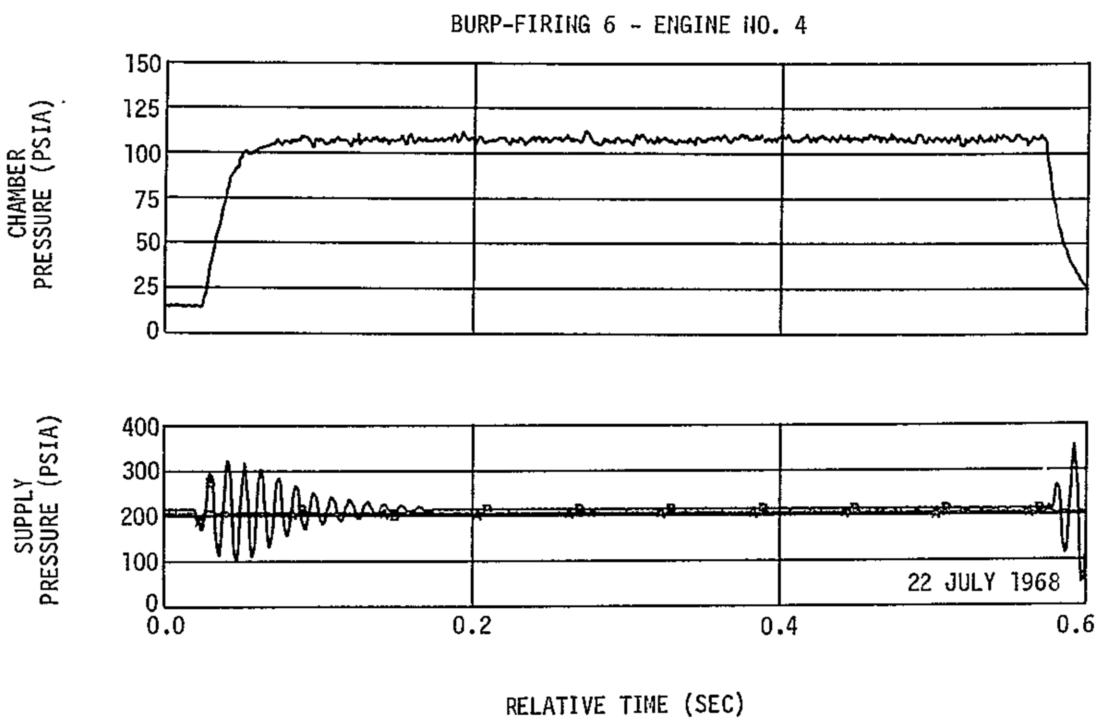


Figure 5-4. Chamber Pressure Levels (Sheet 24 of 24)

SECTION 6

SUPPLEMENTAL TEST

6. SUPPLEMENTAL TEST

A supplemental test was conducted on engine No. 2 between July 27 and August 7, 1968. The purpose of the test was to determine if APS module and feedline orientation and/or engine firing sequence were contributing factors to the chamber pressure decay observed previously in engines 1 and 3.

The test was divided into two phases. The first phase consisted of firing engine No. 2 with the module in the normal vertical position.

Phase two consisted of rotating the module 90 deg counter-clockwise and then burp-firing engine No. 2. Phase two was to be run only if no significant pressure decay was noted during phase one.

6.1 Pressurization System

During the supplemental test the helium bottle was pressurized six times. These six pressurizations corresponded to four burp-firings and two simulated launches. Due to the brevity of the firings, no attempt was made to fully load the helium bottle. The initial bottle pressures ranged between 550 to 3,120 psia. The temperature range was 437 to 595 deg R. To prevent bladder damage, the module was rotated to the normal vertical position prior to depressurizations.

6.1.1 Helium Regulator

After pressurization, the regulator outlet pressure ranged from 204 to 210 psia with ambient reference. During the hold period, the pressure ranged from 26 to 69 psia with ambient reference. The low reading of 26 psia occurred on the last day of the supplemental test and was due to venting the helium bottle to obtain hold conditions.

6.1.2 Fuel Manifold and Ullage Pressure

After pressurization, the fuel manifold pressure ranged from 208 to 214 psia with ambient reference. During the hold period the pressure ranged from 31 to 78 psia. Again the low reading of 31 psia was due to venting the high pressure system. The ullage pressure ranged from 204 to 212 psia during pressurization and 26 to 76 psia during the hold period.

6.1.3 Oxidizer Manifold and Ullage Pressure

After pressurization, the pressure ranged from 206 to 213 psia with ambient reference. During the hold period, the pressure ranged from 31 to 86 psia. The low reading of 31 psia occurred on the last day of the test and was due to venting the high pressure system. The high pressure reading of 86 psia occurred on 29 July and 5 August. On both days, however, the manifold pressure was vented to 65 psia, thus minimizing the period above 80 psia. After pressurization, the ullage pressure ranged from 205 to 212 psia. During the hold period the pressure ranged from 28 to 81 psia, with the low value recorded following the venting of the system on the last day of the test.

6.1.4 Propellant Temperatures

The oxidizer temperature ranged from 520 to 549 deg R and the fuel temperature ranged from 522 to 556 deg R.

6.2 Engine No. 2 Performance

Engine No. 2 was first burp-fired for 250 ms followed by two 65 ms pulses. The APS module was in the normal vertical position. The chamber pressures of the three pulses were 100, 100, and 99 psia. The engine was burp-fired again on 1 August 1968, with the module still in the vertical position. The chamber pressures were 103, 102, and 102 psia. At the conclusion of this burp-firing, the module was rotated 90 deg to the horizontal (oxidizer propellant control module down) position. However, problems with the rotating gear assembly required that the module be returned to the vertical position for overnight storage.

On 2 August 1968, the module was rotated to the horizontal position and engine No. 2 burp-fired. The chamber pressures of the three pulses were 104, 100, and 97 psia. The module was then rotated back to the vertical position and maintained in that position until 6 August 1968, when it was rotated to the horizontal position.

On 7 August 1968, engine No. 2 was again burp-fired with the APS module in the horizontal position. The chamber pressures of the three pulses were 102, 97, and 96 psia. Following the burp-firing, the module was rotated to the vertical position, removed from the test stand, and shipped to Complex Alpha for the vibration tests.

6.2.1 Valve Current

The valve opening sequence, timing, delay, and signal to chamber pressure initiation of engine No. 2 pulses are listed in table 6-2. The delay times are within Specification No. 03-10060, Revision E of the engine manufacturer.

6.3 Conclusion

The results of the supplemental test (table 6-1) indicated that feedline orientation and/or burp-firing sequence had no effect on the engine chamber pressure degradation.

TABLE 6-1
CHAMBER PRESSURE HISTORY

		DAYS FROM PROPELLANT LOADING (8 MAY 1968)			
		80 (7-27-68)	85 (8-1-68)	86 (8-2-68)	91 (8-7-68)
Eng No. 2 (psia)	250 ms	100.0	103.0	104.0	102.0
	65 ms	100.0	102.0	100.0	97.0
	65 ms	99.0	102.0	97.0	96.0
Prop Temp (F°)	Oxid	84	68	80	70
	Fuel	95	70	86	71
Man Press (psia)	Oxid	210	209	209	208
	Fuel	211	211	209	208

TABLE 6-2
VALVE OPENING TIME AND
CHAMBER PRESSURE INITIATION

ENG	DATE	SIGNAL TO FULL OPEN (ms)		SIGNAL TO Pc INITIATION (ms)		VALVE CURRENT PERTURBATION
		MAX	MIN	MAX	MIN	
1-2	7-27	18.0	12.0	27.5	25.0	None
	8-1	17.5	11.0	25.0	24.5	Note*
	8-2	18.0	12.0	26.0	24.0	None
	8-7	18.5	11.5	25.0	24.0	None

*At the second and third pulse (both 65 ms) a very small blip was noted on oxidizer valve No. 03 after the valve was fully closed. The distrubance was similar to the ones illustrated in burp-firing No. 6, table 5-6.

SECTION 7

VIBRATION TESTS

7. VIBRATION TESTS

The APS module I was transported to the Complex Alpha test facility for the vibration tests while loaded with propellants. During transportation, the maximum allowable dynamic loading of 1.5 g was not exceeded. Acceleration measurements were made in the thrust, tangential, and radial axes.

Installation of APS module I began on 9 August 1968. The vibration tests commenced on 12 August 1968.

The module was subjected to sinusoidal vibration tests, random vibration tests, and shock tests in the thrust, tangential, and radial axes. The specification levels and durations were as outlined in the formal qualification test procedure S-IVB/V APS Vibration, P/N 1A83918-535, Drawing No. 1T31583, Change C. The vibration and shock tests were accomplished with the APS loaded with hypergolic propellants. The helium system was pressurized to 3,000 ±200 psi. The test specimen consisted of a complete APS module installation on a portion of aft skirt vehicle structure which in turn was mounted on a rigid fixture in the thrust, tangential, and radial axes (figure 7-1). Twenty-four accelerometers were used to monitor the input and response of the test specimen. Table 7-1 lists the locations and the sensing axis of each of the accelerometers. Accelerometer locations are shown in figure 7-2.

Although eight discrepancies were noted during and after the vibration tests, MDAC-WD attributes these discrepancies to one or more of the following:

a. An overtest in the radial axis random vibration test levels

b. Duration of the radial axis random vibration test, as specified in the test control document, was excessive.

c. Excessive shock test requirements.

The tests are described in the following paragraphs.

7.1 Thrust Axis Tests

A chronological history of the thrust axis tests is presented in table 7-2.

7.1.1 Sinusoidal Sweep Test

The APS module was subjected to a logarithmic sinusoidal sweep vibration test at the following levels:

1 oct/min 3-7 Hz
3 oct/min 7-20 Hz
Upsweep Only
3-4 Hz at 0.24 in. double amplitude displacement
4-7 Hz at 0.2 g 0-peak
7-20 Hz at 0.1 g 0-peak

The input was controlled from accelerometer location No. 1. No malfunction or failure was noted during or after this test. Filtered acceleration data for this test are presented in figure 7-3. The control data were plotted from the oscillograph trace of the filtered control signal. Response data plots were produced by computer analysis of the unfiltered data. Sixteen data samples were used to generate the curves for each plot.

7.1.2 Random Vibration Test

The APS module was subjected to random vibration excitation in the frequency range from 20 to 2,000 cps at the following levels:

Duration: 3 min/axis

20 to 30 Hz at +6 db/octave
30 to 100 Hz at 0.01 g^2/Hz
100 to 200 Hz at +6 db/octave
200 to 1,000 Hz at 0.05 g^2/Hz
1,000 to 2,000 Hz at -3 db/octave

Control was accomplished by averaging the outputs from accelerometers 1 and 2 with a Spectral Dynamics MAC-V averaging device. No malfunction or failure was noted during or after this test. Accelerometer data for this test are presented in figure 7-4.

7.1.3 Shock Test

The APS was subjected to three half-sine wave shocks in one direction at a level of 20 g peak with a duration of 10 ±2 ms. The input was controlled at accelerometer location No. 1. The signal from the control accelerometer was filtered using a 200 Hz low pass filter; control data are presented in figure 7-5. A shock spectrum analysis of shock No. 2 is shown in figure 7-6.

After completion of this test, the fuel low pressure helium module (P/N 1A49998-509, S/N 1019) failed to close on command after being opened to vent the fuel ullage from 203 psia to 145 psia and was replaced with module No. 1A49998-509, S/N 106G. The failed module was sent to the Gamma facility for disassembly and contamination was found in several areas of the solenoid.

Since the APS low pressure helium modules do not operate in flight it is impossible for a "hang open" type of failure to occur in flight. The failure experienced is a direct result of long term hold-type of contamination.

On 15 August 1968, during the post thrust axis tests inspection, the oxidizer and fuel tank aft mounts (P/N 1B51329-1 and -2) were found to have minor cracks and chips near the end fasteners (figure 7-7).

These discrepancies were recorded but since the mounts were still structurally sound and provided satisfactory support to the APS propellant tanks, they were not removed and the tests were continued without further problems.

7.2 Tangential Axis Tests

A chronological history of the tangential axis tests is presented in table 7-2.

7.2.1 Sinusoidal Sweep Test

The APS module was subjected to a logarithmic sinusoidal sweep vibration test at the following levels:

3 oct/min from 1.5 to 20 Hz (upsweep only)

1.5 to 2.5 Hz at 0.04 g 0-peak

2.5 to 3.5 Hz at 0.125 in. double amplitude displacement

3.5 to 20 Hz at 0.08 g 0-peak

The input was controlled from accelerometer location No. 1. No malfunction or failure was noted during or after the test. The accelerometer No. 1 (control) and accelerometer No. 2 data for this test are presented in figure 7-8. No other response data are presented because of the extremely high tape noise level.

7.2.2 Random Vibration Test

The test described in paragraph 7.1.2 was repeated in the tangential axis with no malfunction or failure noted during or after the test. Accelerometer data for this test are presented in figure 7-9.

7.2.3 Shock Test

The test described in paragraph 7.1.3 was repeated in the tangential axis with no malfunction or failure noted before or after the test. Control accelerometer data for this test are presented in figure 7-10. A shock spectrum analysis of shock No. 2 is shown in figure 7-11.

7.3 Radial Axis Tests

A chronological history of the radial axis tests is presented in table 7-2.

7.3.1 Sinusoidal Sweep Test

The APS module was subjected to a logarithmic sinusoidal sweep vibration test at the levels shown in paragraph 7.2.1.

The input was controlled from accelerometer location No. 1. No malfunction or failure was noted during or after this test. Filtered acceleration data for this test are presented in figure 7-12. The control data were plotted from the oscillograph trace of the filtered control signal. Response data plots were produced from computer analysis of the unfiltered data. Sixteen data samples were used to generate the curves for each response plot.

7.3.2 Shock Test

The test described in paragraph 7.1.3 was repeated in the radial axis with no malfunction or failure noted before or after the tests. Control accelerometer data for this test are presented in figure 7-13. A shock spectrum analysis of shock No. 2 is shown in figure 7-14.

7.3.3 Random Vibration Test

The APS module was subjected to random vibration excitation in the frequency range from 20 to 2,000 cps at the following levels:

Duration: 2 min and 1 min

20 to 170 Hz at 0.1 g^2/Hz
170 to 280 Hz at +6.5 db/octave
280 to 1,000 Hz at 0.31 g^2/Hz
1,000 to 2,000 Hz at -12 db/octave

The input was controlled by averaging the outputs from accelerometers 1 and 2 with a Spectral Dynamics MAC-V averaging device.

Several charge amplifiers of the data acquisition system overheated prior to the radial axis random vibration tests. No data were obtained during the first two minutes of testing from accelerometers 3, 4, 6, 7, 8, 9, 16, 19, 23, and 24. During the last minute of testing no data were obtained from accelerometers 5, 10, 11, 12, 15, 16, 17, 19, 22, 23, and 24.

After 2 min of radial axis random vibration testing, a system leak check was performed, which revealed a major leak in the oxidizer tank bladder. Subsequent data evaluation indicated that a pressure fluctuation occurred 63 sec into the run probably due to the bladder failure. Vibration data for this test period are presented in figure 7-15.

The additional 1 min of the required random vibration test was then performed. At the conclusion of this test, the following discrepancies were noted:

a. Major leak in the fuel bladder.

b. Three of the eight bolts that secure the APS aft attach fittings to the aft skirt structure were loose or broken. Galling occurred at the interface of the attach fittings and the structure fittings.

c. Leakage from a crack in the flare of the helium pressurization tube assembly.

d. The vibration isolators that support the engine chamber pressure transducer amplifiers were damaged.

e. Breaks on oxidizer diffuser tube at the base of the closure flange of the oxidizer tank diffuser tube.

f. One of the six screws mounting the engine No. 2 chamber pressure transducer had fallen out and the lock washers were missing.

g. Engine No. 4 chamber pressure transducer was faulty at the 80 percent calibration step.

h. Deterioration of control signal from accelerometer No. 1.

The following paragraphs describe these discrepancies in detail.

7.3.3.1 Oxidizer Bladder

See paragraph 9.1.1.

7.3.3.2 Fuel Bladder

See paragraph 9.1.2.

7.3.3.3 APS Aft Attach Fittings

On 23 August 1968, during post radial axis inspection, the APS aft attach fittings were found to have several discrepancies. The left and right hand aft attach fittings (P/N 1B51321-1 and P/N 1B51321-2) are each mounted to the vehicle aft skirt (simulated aft skirt in this test) with four bolts (figure 7-16).

The upper left hand bolt of the left aft attach fitting was sheared off at the vehicle side and the head of the bolt was not found. The fractured surface of this bolt is shown in figure 7-17. Analysis revealed that it was a 160,000 psi bolt that failed due to reverse fatigue bending.

The NAS 679C4 self-locking nut on the lower left hand bolt of the left attach fitting was loose from the mating bolt and the threads of the bolt were damaged (figure 6-8). This was a 160,000 psi bolt which was probably damaged as a result of high tension loading. The NAS 679C4 nut on the lower right hand bolt of the right aft attach fitting was also loose and the bolt threads were worn smooth (figure 7-18). This bolt was checked out by Rockwell Hardness Test and proved to be a 125,000 psi bolt (requires a 160,000 psi bolt).

Both of the sockets on the aft attach fittings were scored. Figure 7-19 shows the socket on the right hand aft attach fitting which is typical for both sockets.

A review of the vibration test data revealed that the duration of the radial axis random vibration test, as specified in the test control document, was excessive. Based on this information and the fact that one bolt did not meet the engineering requirements, it was concluded that the failures were not caused by a design deficiency.

7.3.3.4 Helium Pressurization Tube Assembly

On 21 August 1968, the helium pressurization tube assembly (P/N 1B52299-1) indicated a leak during the radial post axis checkout (leak test). This tube assembly connects the filter, attached to the oxidizer quadruple check valve, to the ullage side of the oxidizer tank. The leaking tube was replaced and sent to Materials and Methods/Research and Engineering (MM&RE) for failure analysis and testing was continued.

The leak (at the B-nut connection to the filter) was discovered during the radial post axis checkout when two bolts were removed from each door on the APS module and the interior of the APS was monitored (sniffed) for leakage using a propellant detector. Oxidizer leakage was indicated at this time (no leakage was indicated on an identical test performed prior to the 1-min radial random vibration test). After the leak was verified, the APS doors were removed and a small orange oxidizer vapor cloud was observed coming from the tube assembly "B-nut" connector which attaches to the oxidizer filter. The leak was caused by a small crack on the flare section of the tube (figure 7-20). Investigation by MM&RE revealed that the tube assembly conformed to engineering requirements and the failure was a normal fatigue failure which would be expected in the area adjacent to the flare section of the tube. A review of vibration data revealed that the duration of the radial axis random vibration test, as specified in the test control document, was excessive. Consequently, engineering concludes that the failure was caused by this overtest and not by any design deficiencies in the tube assembly or in the mounting of the tube assembly.

7.3.3.5 Chamber Pressure Transducer Amplifier Vibration Isolators

On 22 August 1968 during the post radial axis inspection, the rubber vibration isolators (91070-2) which support the engine P_c transducer amplifier mounting brackets (P/N 1B63478-1) were found to be damaged (figure 7-21). The anomalies were documented and the test program continued without further problems.

After analyzing the vibration data, it was concluded that the damage to the plate and rubber grommets was caused by the radial random vibration overtest and not by any design deficiency.

7.3.3.6 Oxidizer Tank Diffuser Tube

See paragraph 9.1.3.

7.3.3.7 Control Signal Deterioration

The character of the control signal from accelerometer No. 1 deteriorated considerably during this test, probably as a result of the aft attach fitting bolt failures. The signal deterioration is shown in figure 7-22.

7.4 Conclusion

An analysis of the vibration test data was performed to determine the major resonance frequencies of the APS module and how the test vibration levels compare to flight vibration levels at these frequencies. This analysis revealed that in the radial axis, all significant resonances of the APS occurred below 100 Hz, with the maximum response occurring at 50 Hz (figure 7-23).

Figure 7-24 presents a comparison of vibration data measured in the radial direction at the aft and forward APS attach points during S-IVB liftoff, Mach 1/max q, and during test of module 1. These figures show that a severe overtest occurred at the APS aft attach point at frequencies below 60 Hz, and at the APS forward attach point at frequencies between 35 and 60 Hz. This overtest was as much as 1.9 times the specification level (on an RMS basis) at the aft attach point, and as much as 2.1 times the specification level at the forward attach point.

The duration of the specified radial axis random vibration test (3 min) was excessive when compared with the duration of the maximum expected liftoff environment (approximately 16 sec) from which the low frequency portion of the test specification (as shown in figure 7-24) was based.

In addition, the shock pulse of 10 ms duration used in this test exactly coupled with the critical response frequency of the APS, and consequently produced the maximum possible shock response of the components. A review of the shock data measured at the APS attach fittings during flight indicated that the most severe shock encountered was of much shorter duration, and would not significantly excite the APS.

Figure 7-25 presents a comparison of radial axis shock spectrum plots for the aft and forward APS attach points. Shock spectra shown are from S-IVB separation (worst case flight shock) and from module 1 testing. This comparison indicates that the response to the shock test in the 45 to 70 Hz frequency range was approximately 10 times more severe than that which could be produced by a flight shock.

TABLE 7-1
ACCELEROMETER LOCATIONS AND ORIENTATIONS

LOC NO.	MEASUREMENT LOCATION	RESPONSE AXIS		
		THRUST	TANG.	RADIAL
1	Control (Input - APS - Lower Right Attach Point*)	Thrust	Tang.	Radial
2	Alt Control (Input - APS - Upper Right Attach Point*)	Thrust	Tang.	Radial
3	Input - Quad. Check Valve and Helium Press Regulator	Thrust	Tang.	Radial
4	Shaker Head	Thrust	Tang.	Radial
5	Input - Fuel Low Press Helium Mod. (Ullage Vent Valve)	Thrust	Tang.	Radial
6	Input - Propellant Control Module (Fuel)	Thrust	Tang.	Radial
7	Aft Response - Prop. Tank (Oxidizer)	Thrust	Tang.	Radial
8	Input - APS - Lower Right Attach Point*	Radial	Radial	Thrust
9	Response - Fuel Low Press. Helium Mod.	Thrust	Tang.	Radial
10	Input - Engine No. 4 (Ullage)	Thrust	Tang.	Radial
11	Forward Input - Engine No. 1 (Roll)	Thrust	Tang.	Radial
12	Forward Input - Engine No. 2 (Attitude Control)	Thrust	Tang.	Radial
13	Input - APS - Lower Left Attach Point*	Thrust	Tang.	Radial
14	Input - APS - Upper Left Attach Point*	Thrust	Tang.	Radial
15	Aft Input - Helium Tank	Thrust	Tang.	Radial
16	Forward Response - Propellant Tank (Fuel)	Thrust	Thrust	Thrust
17	Forward Response - APS Module	Thrust	Tang.	Radial
18	Forward Input - Propellant Tank (Oxidizer)	Thrust	Tang.	Radial
19	Forward Response - Propellant Tank (Oxidizer)	Thrust	Thrust	Thrust
20	Forward Response - Propellant Tank (Oxidizer)	Radial	Radial	Radial
21	Forward Response - Propellant Tank (Oxidizer)	Tang.	Tang.	Tang.
22	Aft Input - Propellant Tank (Oxidizer)	Thrust	Tang.	Radial
23	Forward Response - Propellant Tank (Fuel)	Radial	Radial	Radial
24	Forward Response - Propellant Tank (Fuel)	Tang.	Tang.	Tang.

*As viewed from outside the vehicle

TABLE 7-2
CHRONOLOGICAL HISTORY

DATE	EVENT
	THRUST AXIS
8-9-68	APS moved from gamma to alpha site.
8-10-68	Checked out accelerometers on bare shaker head
8-11-68	Mounted accelerometers and APS in thrust axis
8-12-68	Sine sweep test
8-13-68	Random and shock tests
	TANGENTIAL AXIS
8-14-68	Rotated fixture to tangential axis
8-15-68	Reoriented accelerometers and mounted APS
8-16-68	Sine and random tests
8-17-68	Shock test
	RADIAL AXIS
8-18-68	Rotated fixture to radial axis
8-19-68	Reoriented accelerometer and mounted APS and sine sweep test
8-20-68	Shock and random (first 2 minutes) tests
8-21-68	Random (last minute) test

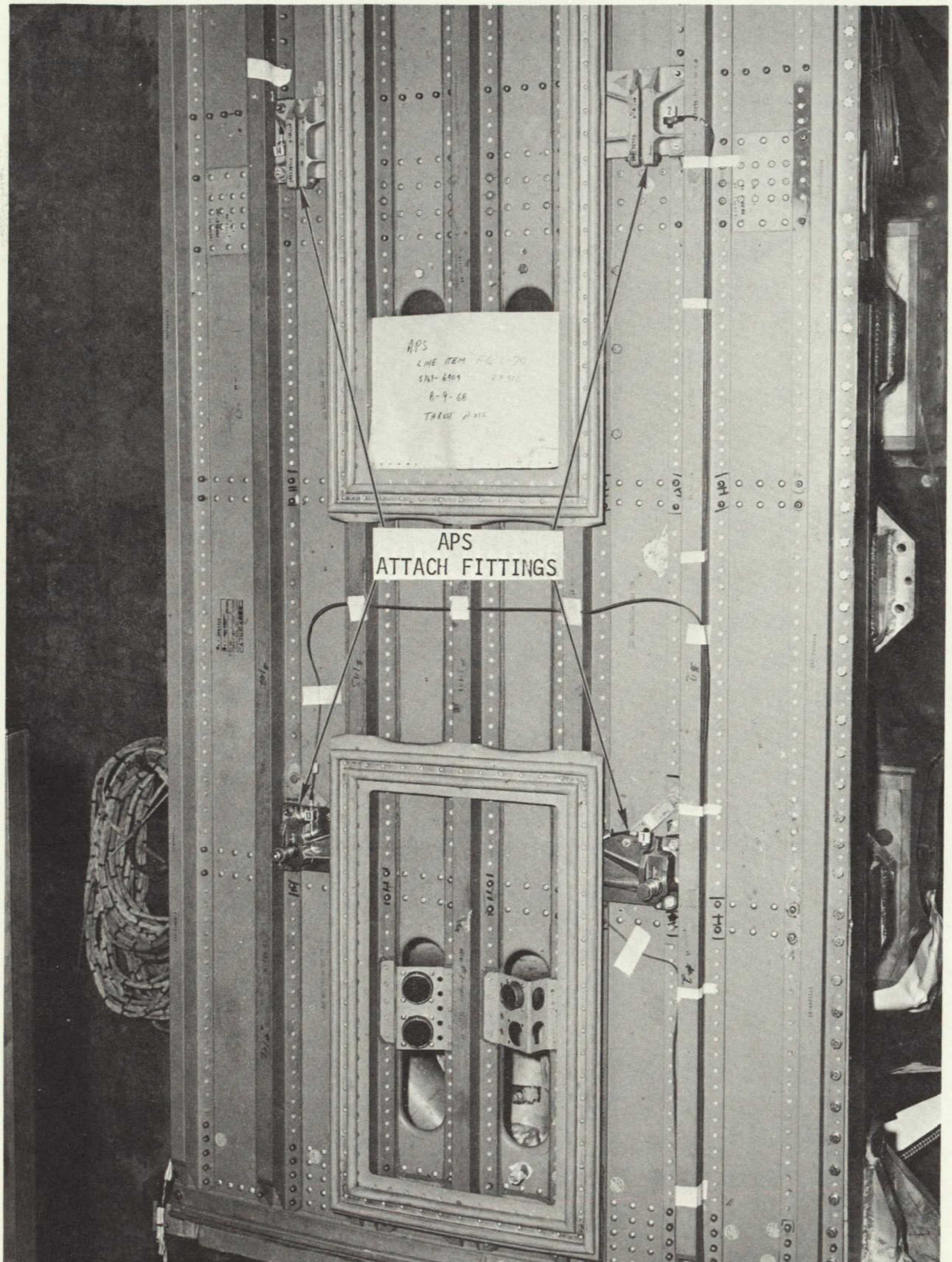


Figure 7-1. Vibration Test Setup (Sheet 1 of 4)

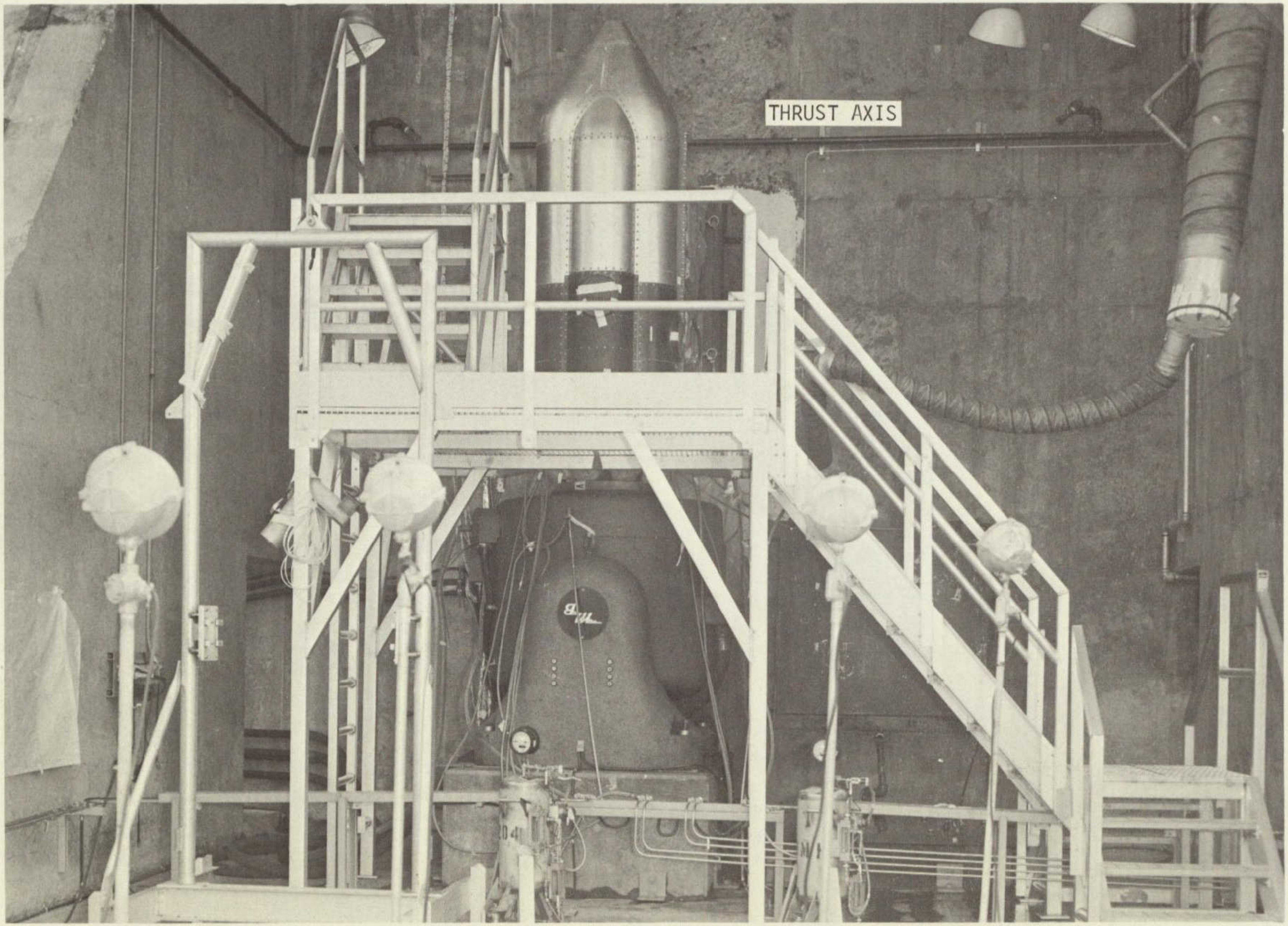


Figure 7-1. Vibration Test Setup (Sheet 2 of 4)

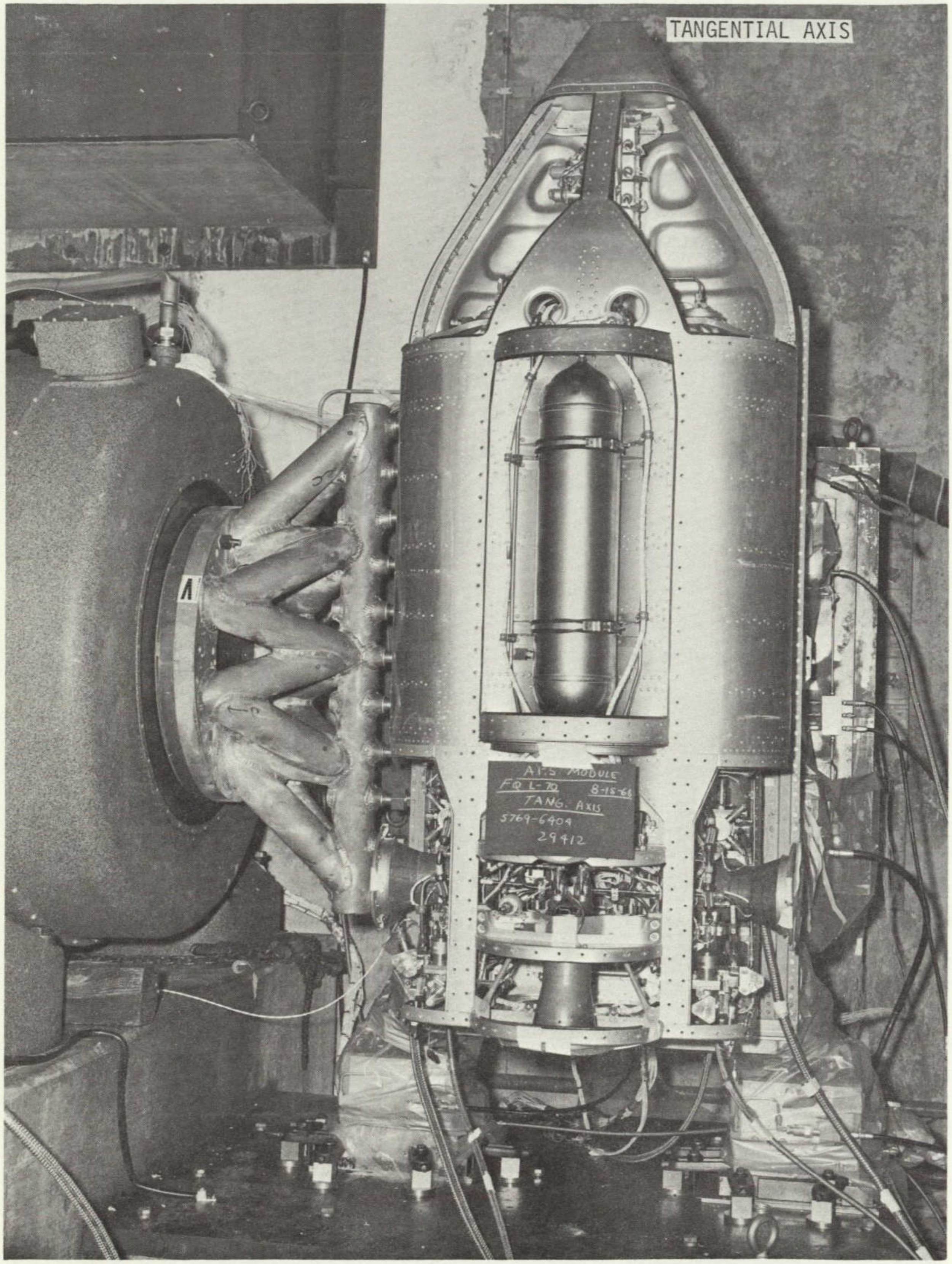


Figure 7-1. Vibration Test Setup (Sheet 3 of 4)

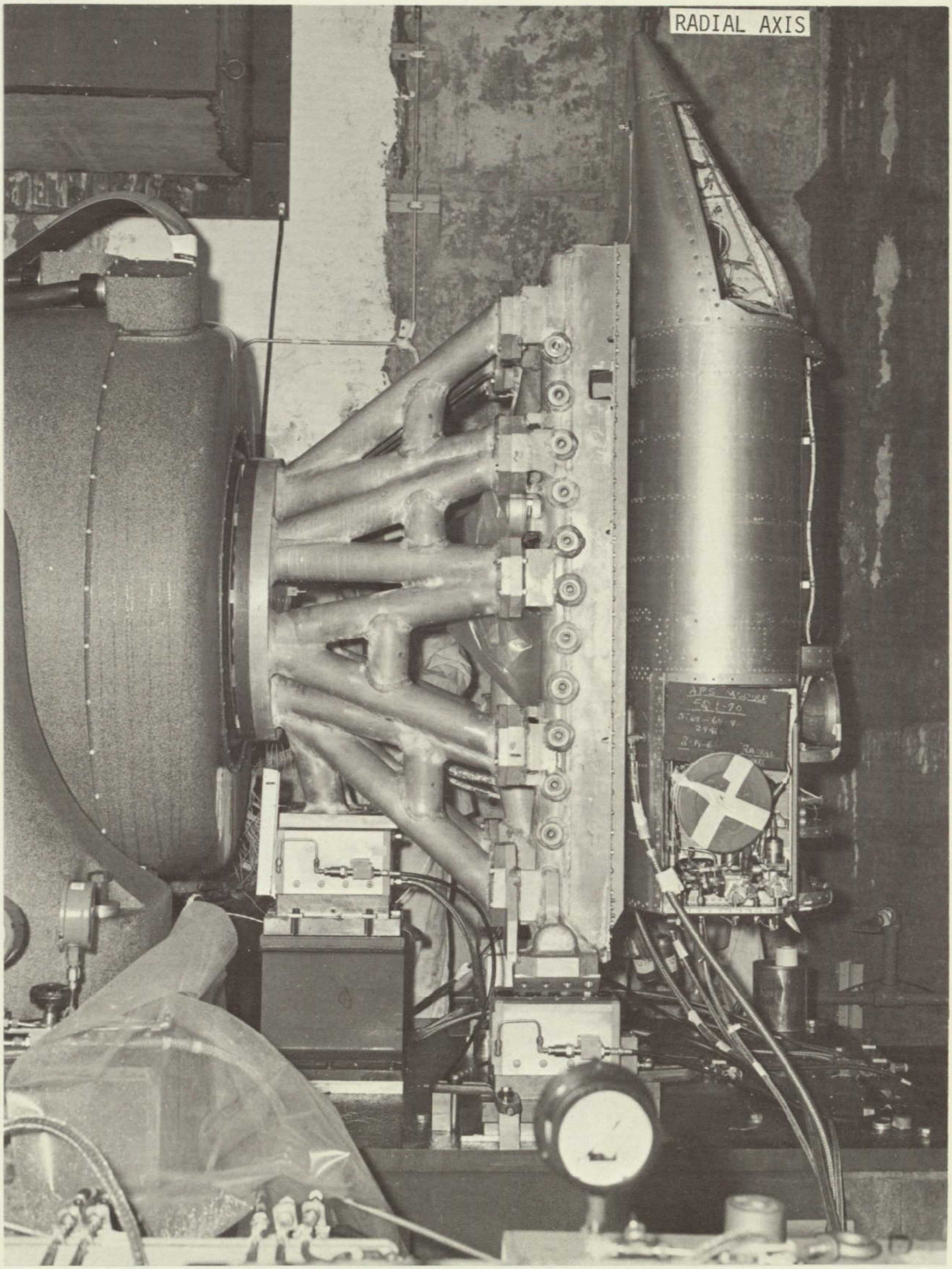


Figure 7-1. Vibration Test Setup (Sheet 4 of 4)

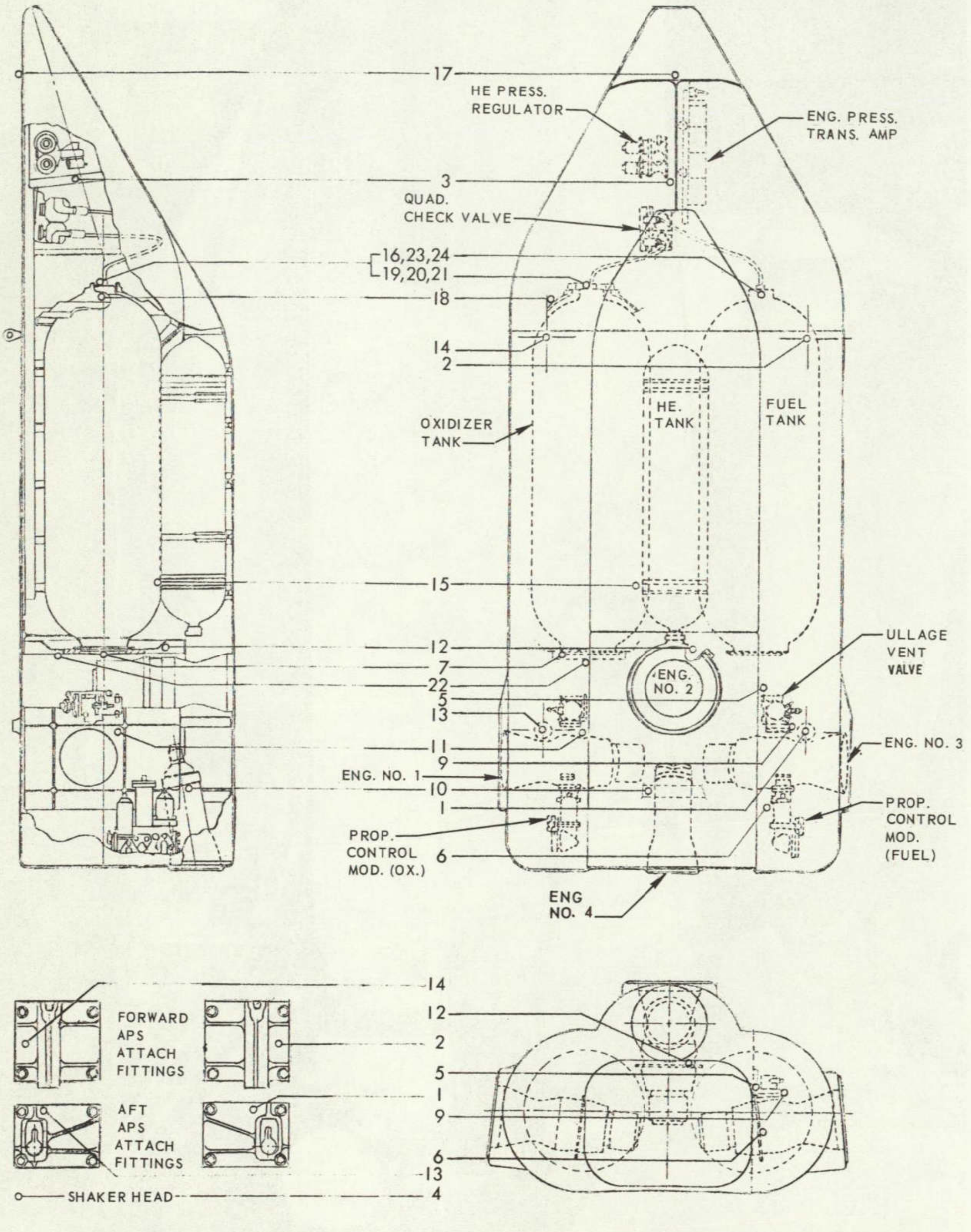


Figure 7-2. Accelerometer Locations

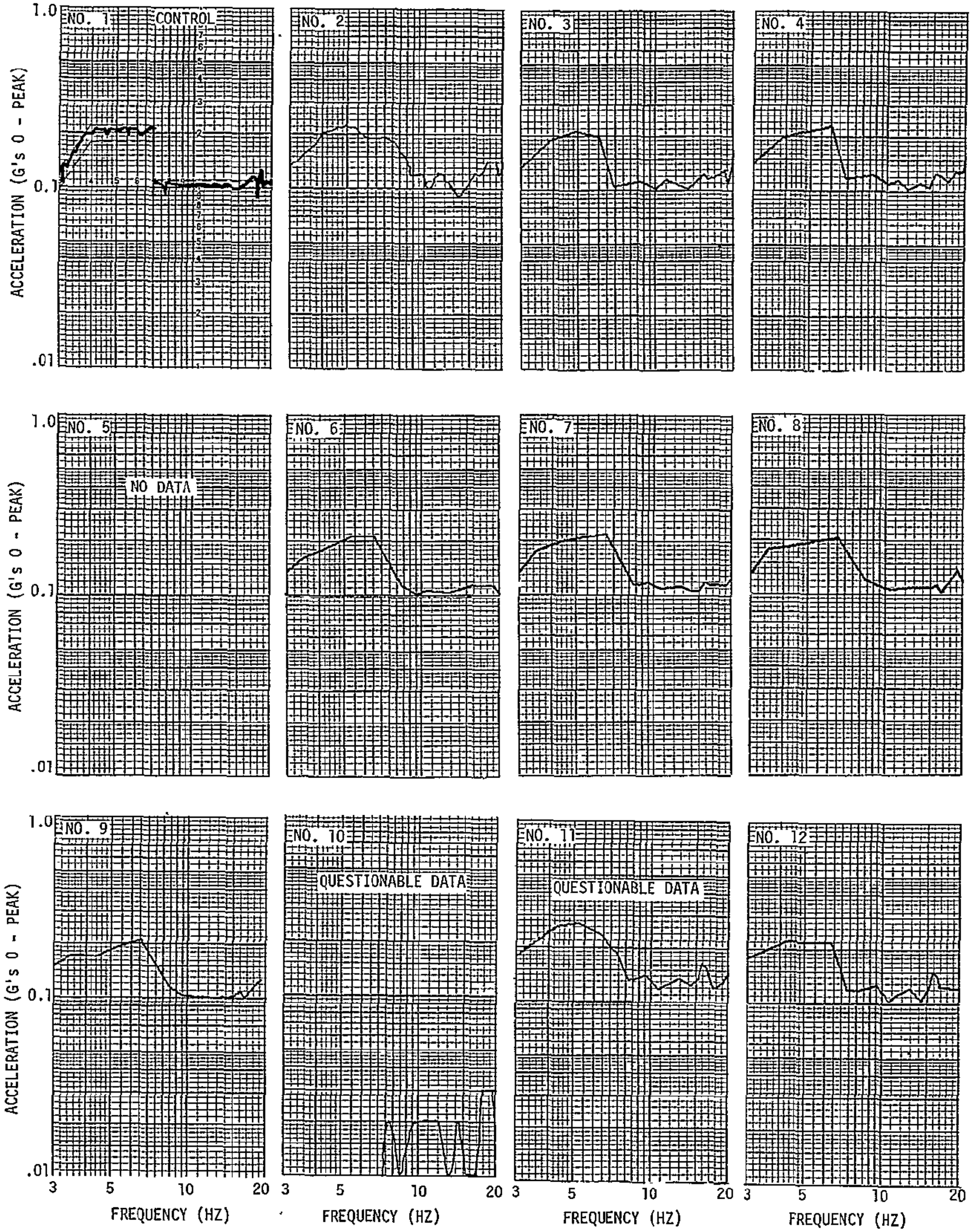


Figure 7-3. Thrust Axis Sinusoidal Sweep Filtered Data (Sheet 1 of 2)

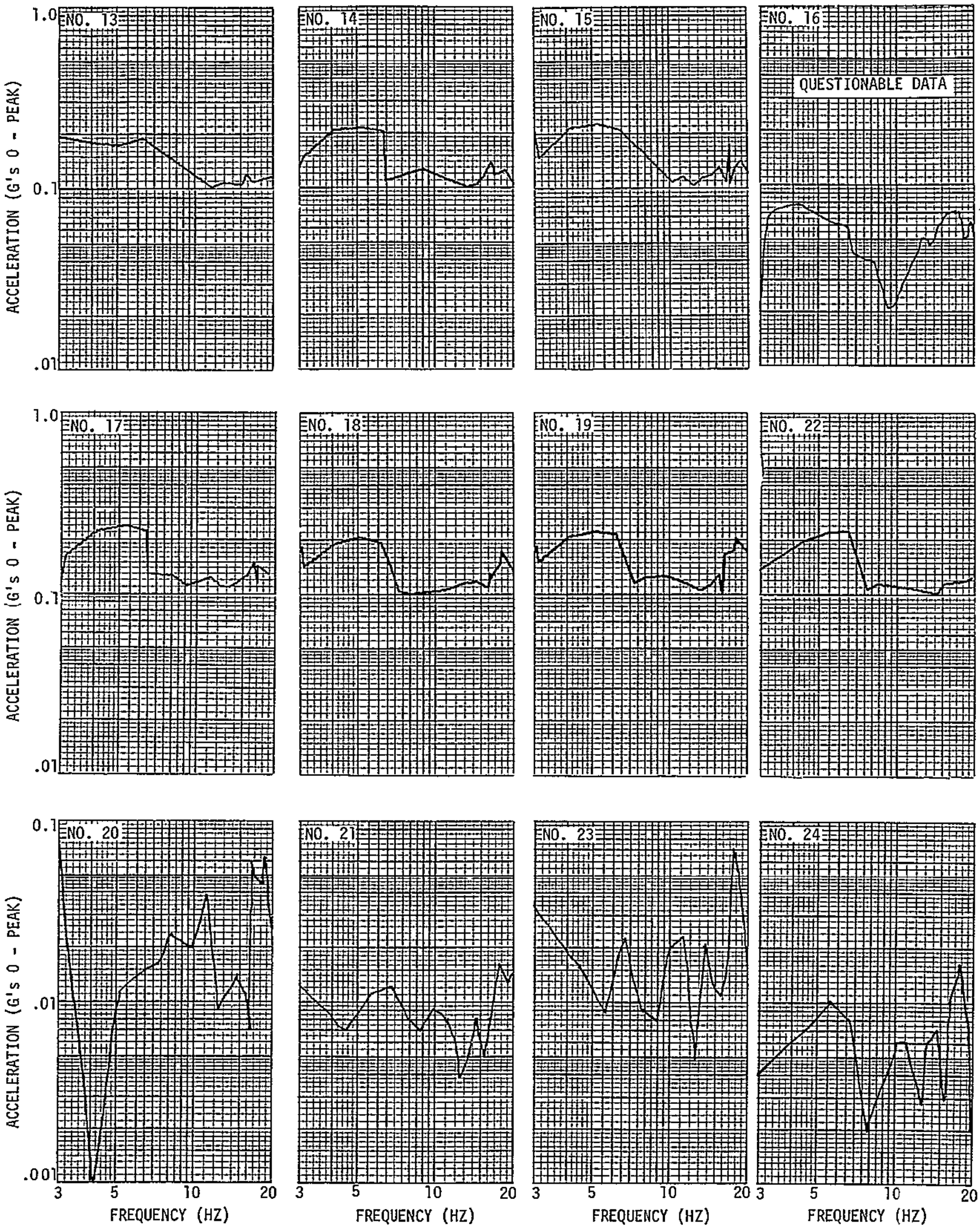


Figure 7-3. Thrust Axis Sinusoidal Sweep Filtered Data (Sheet 2 of 2)

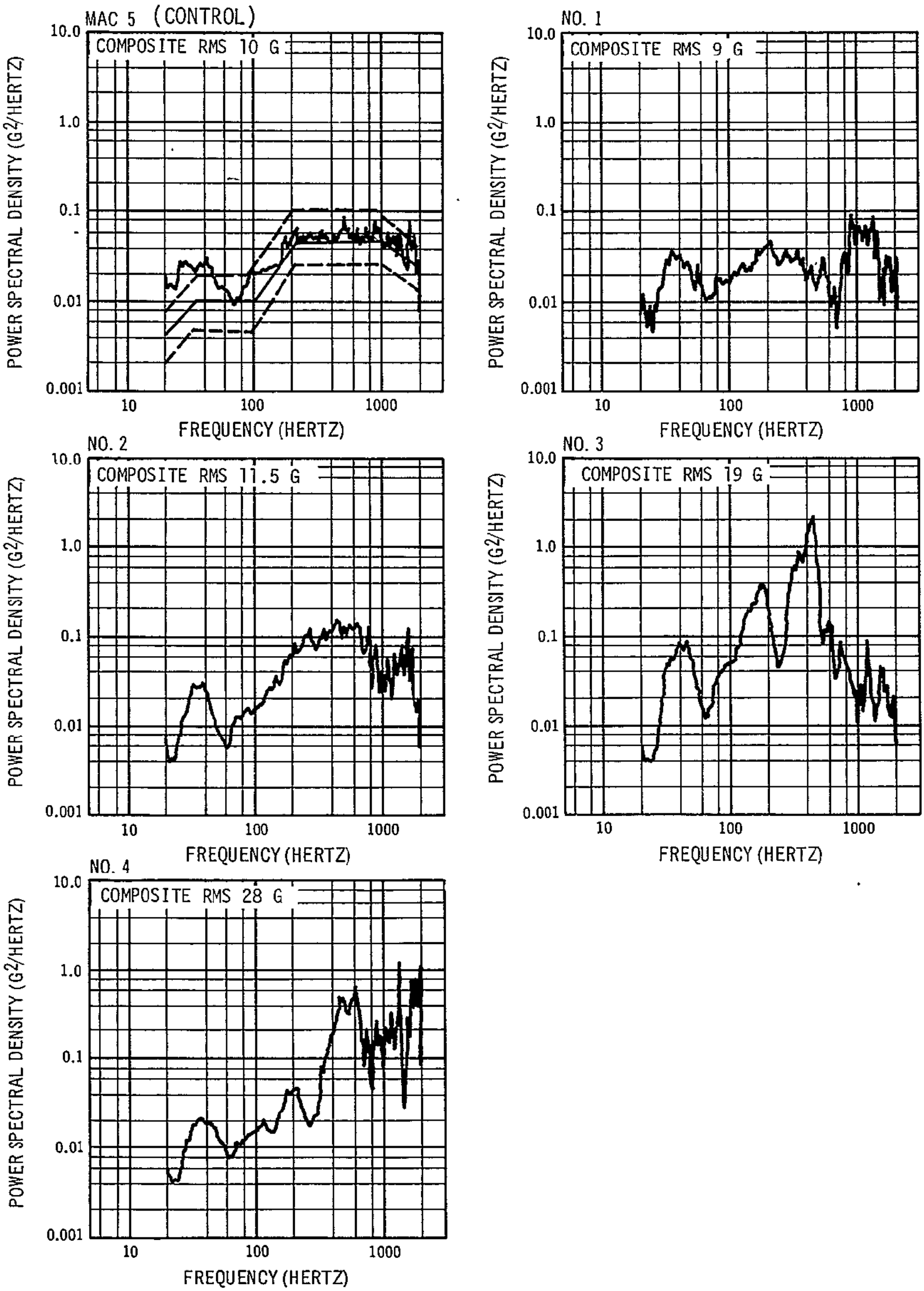


Figure 7-4. Thrust Axis Random Vibration (Sheet 1 of 5)

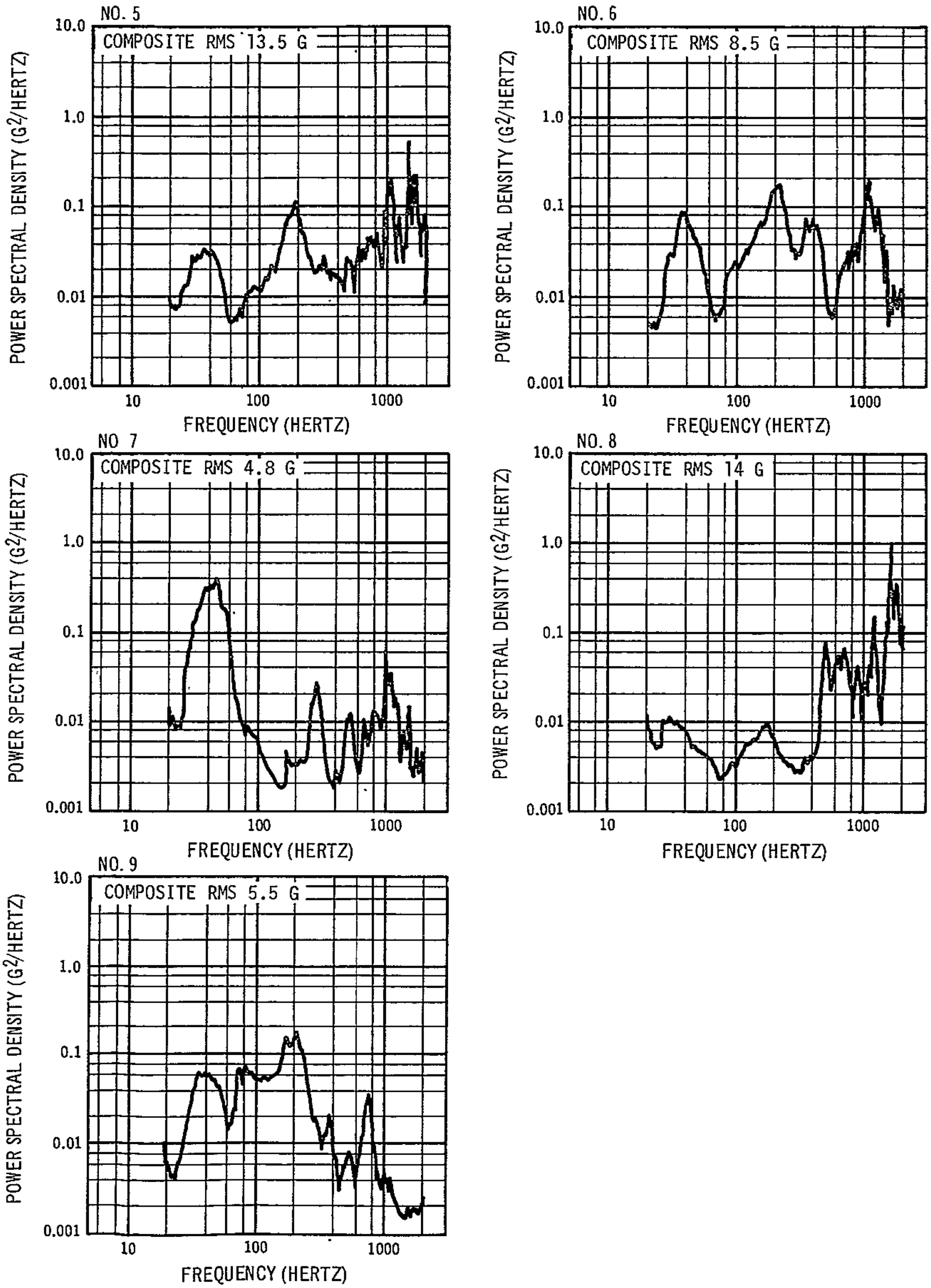


Figure 7-4. Thrust Axis Random Vibration (Sheet 2 of 5).

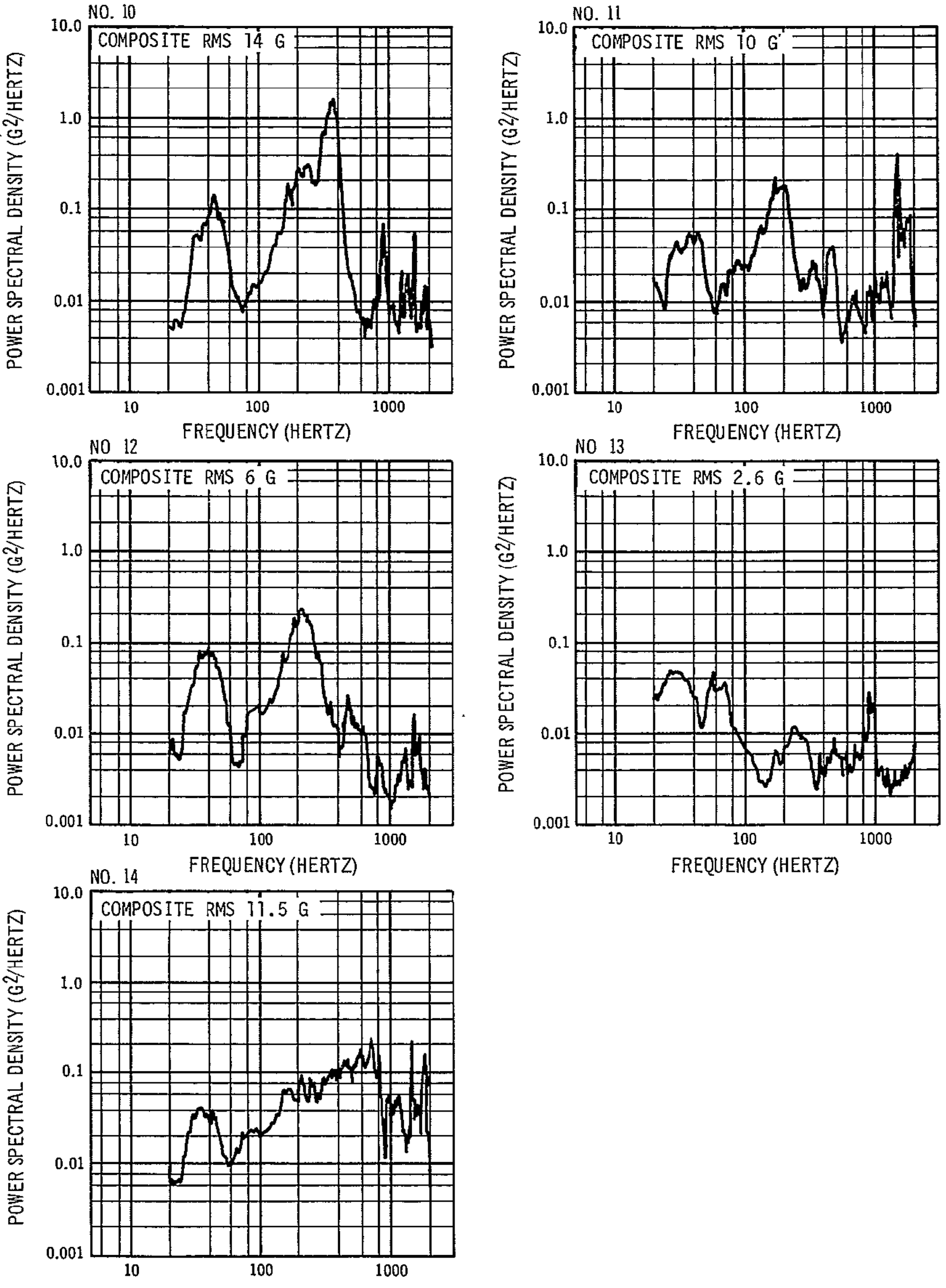


Figure 7-4. Thrust Axis Random Vibration (Sheet 3 of 5)

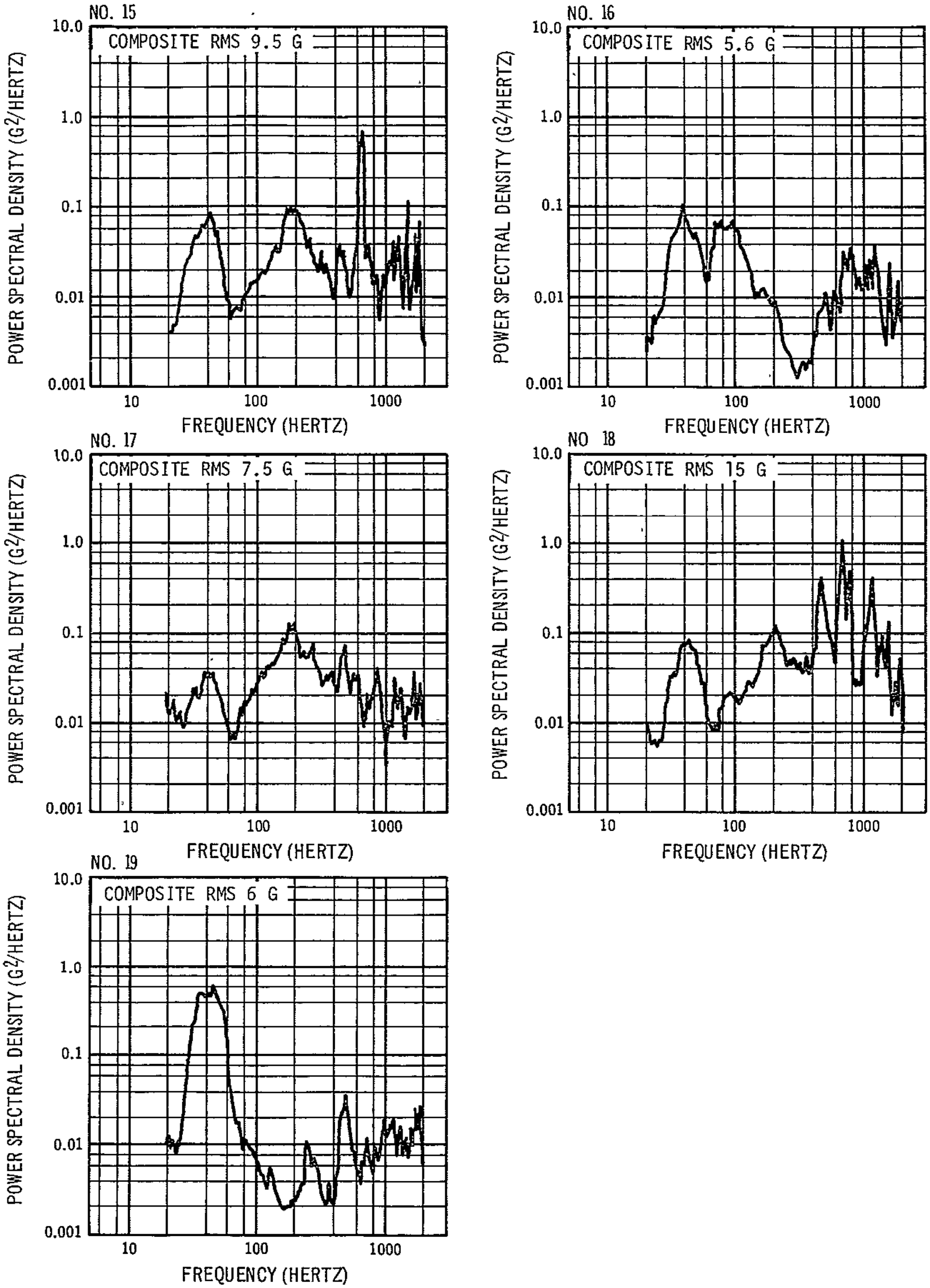


Figure 7-4. Thrust Axis Random Vibration (Sheet 4 of 5)

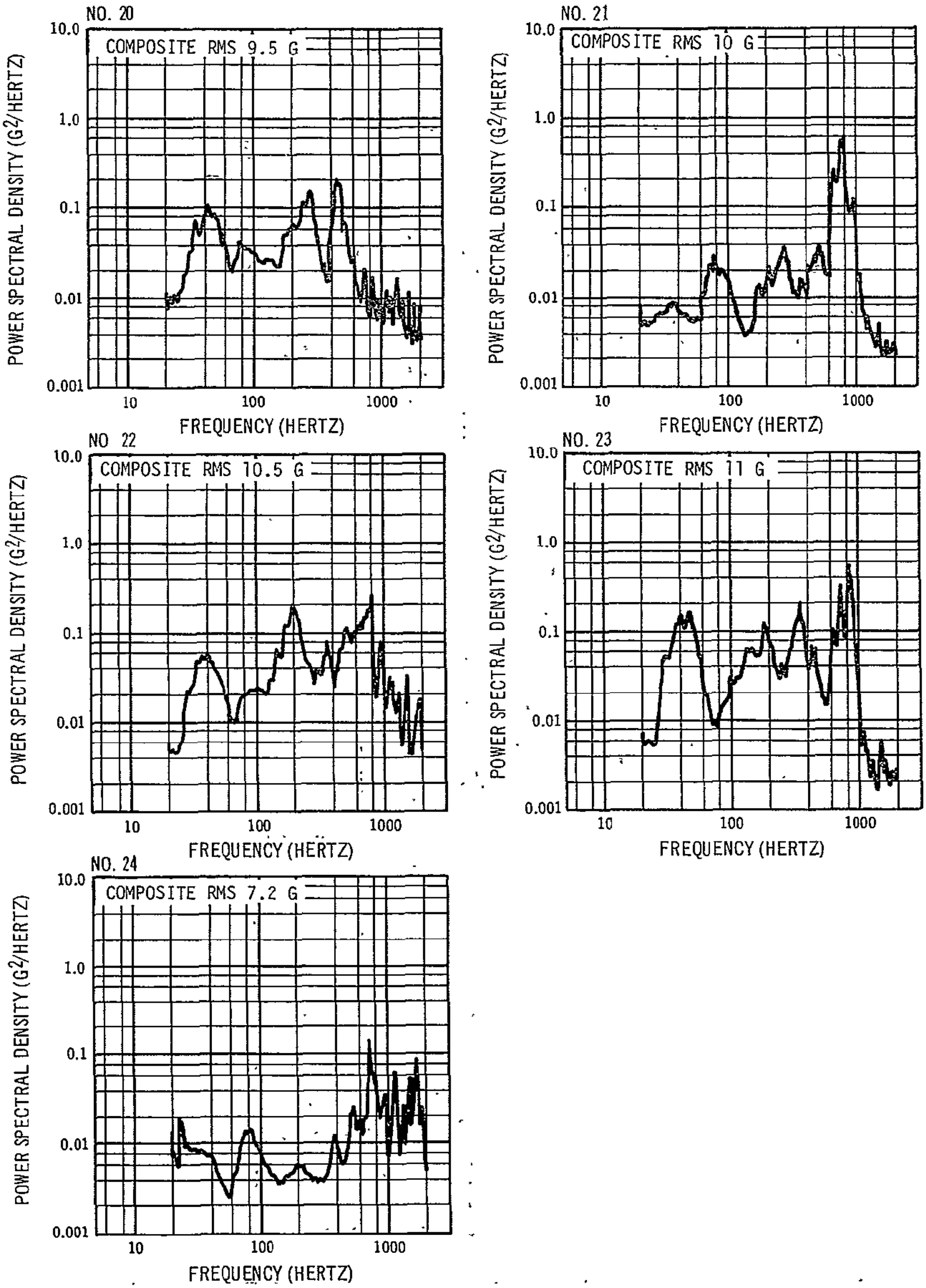


Figure 7-4. Thrust Axis Random Vibration (Sheet 5 of 5)

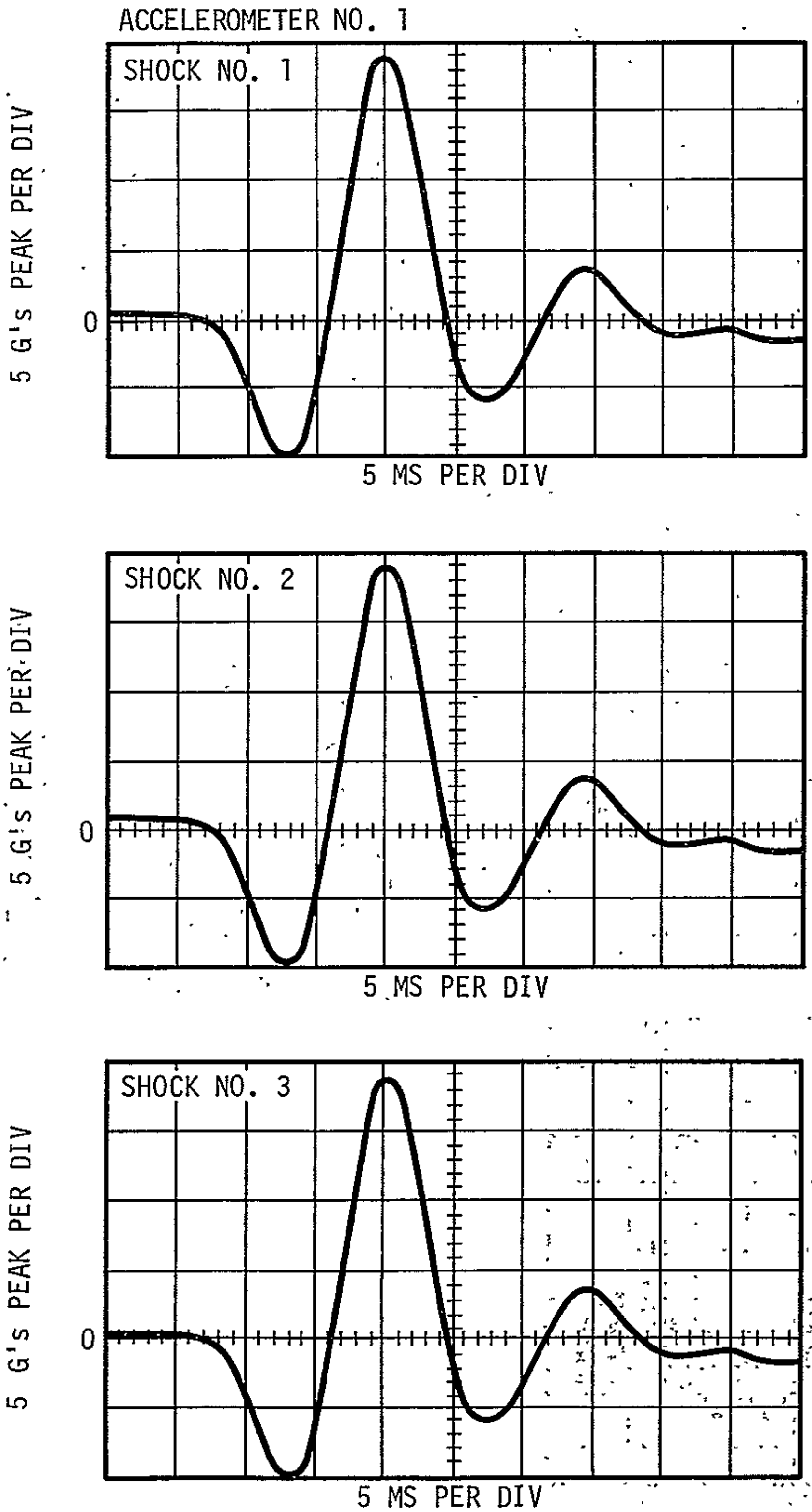
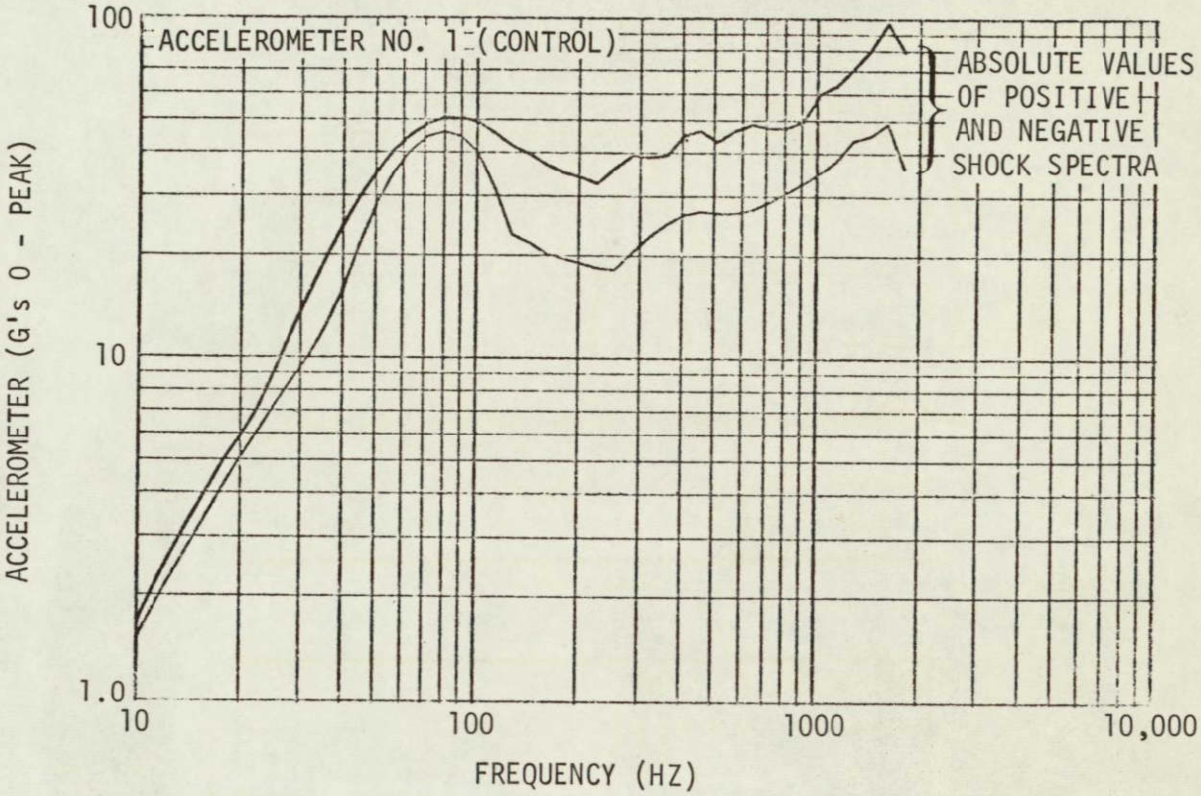


Figure 7-5. Thrust Axis Shock



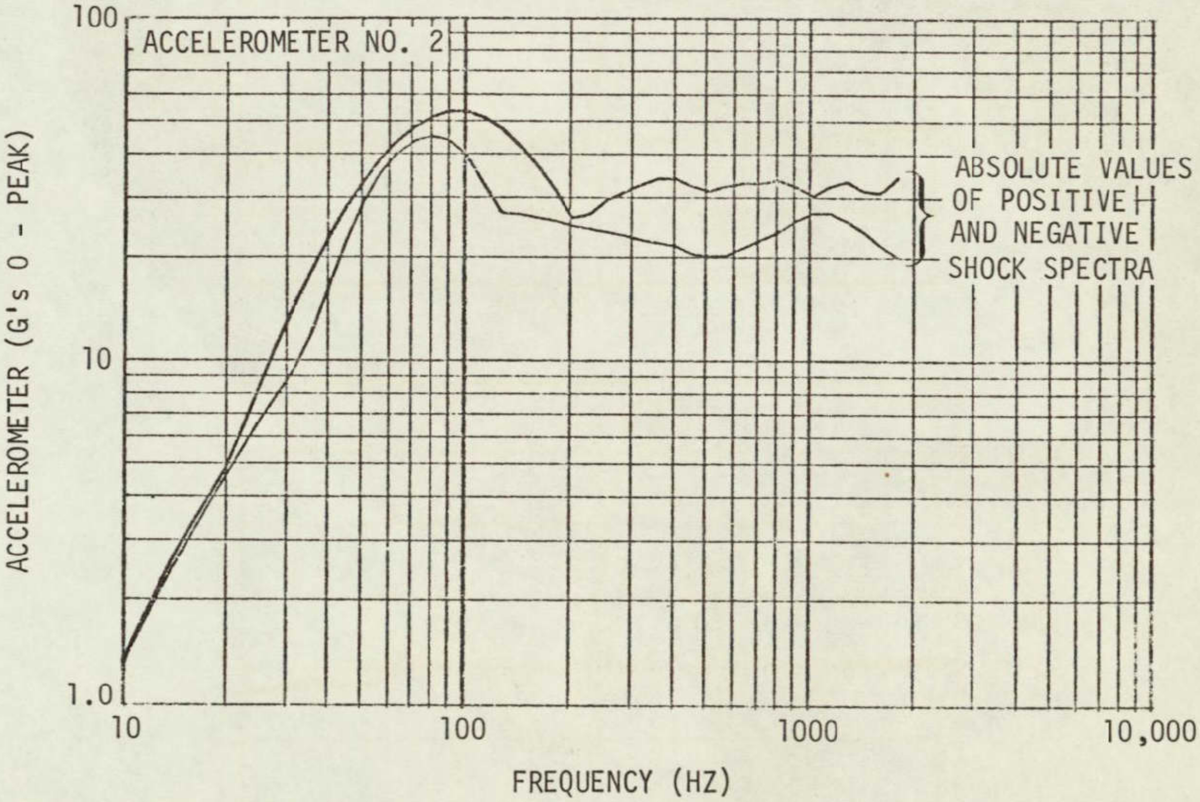


Figure 7-6. Shock Spectrum Analysis - Thrust Axis Shock No. 2

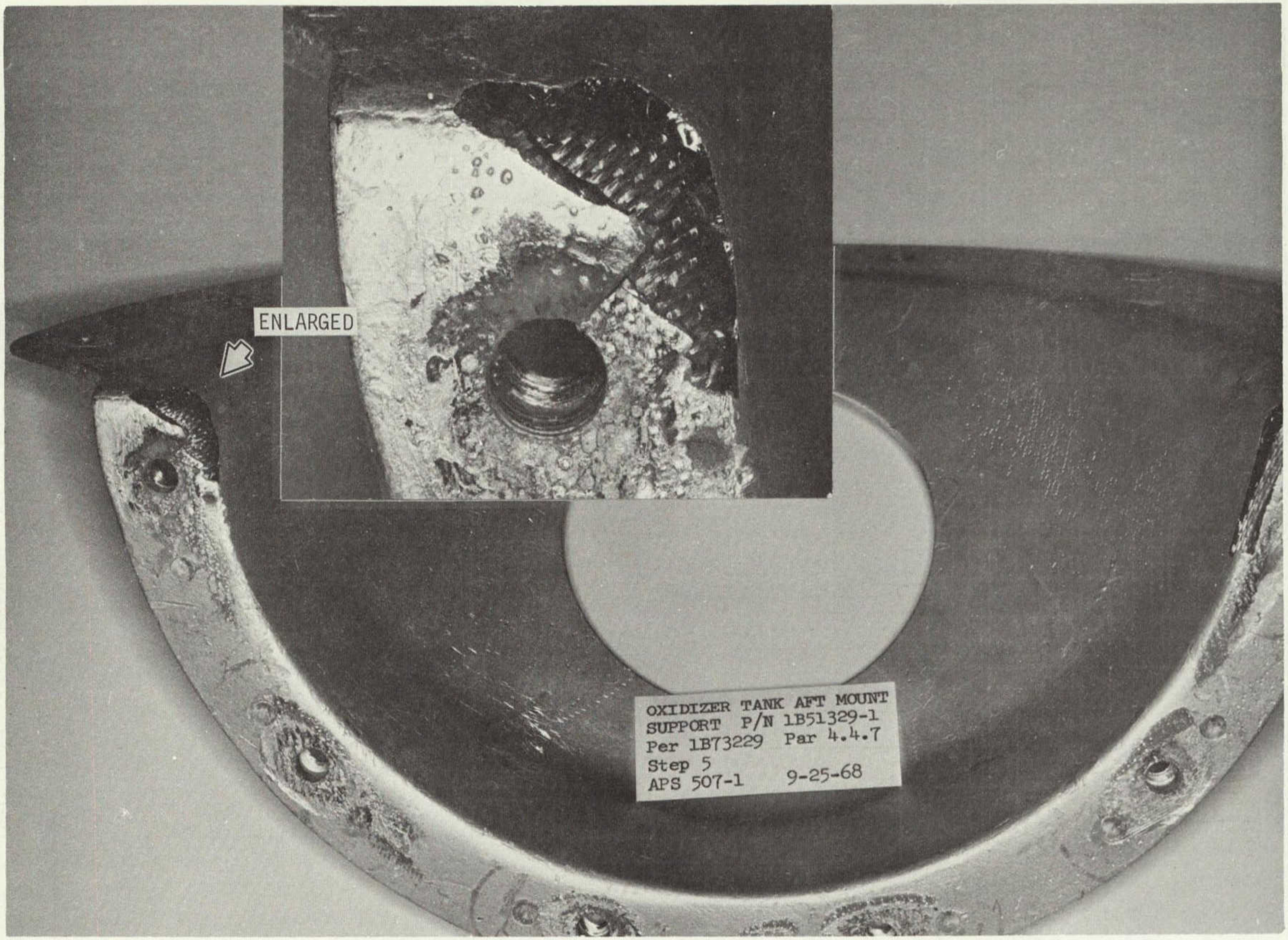


Figure 7-7. Propellant Tank Aft Mount Support (Typical)

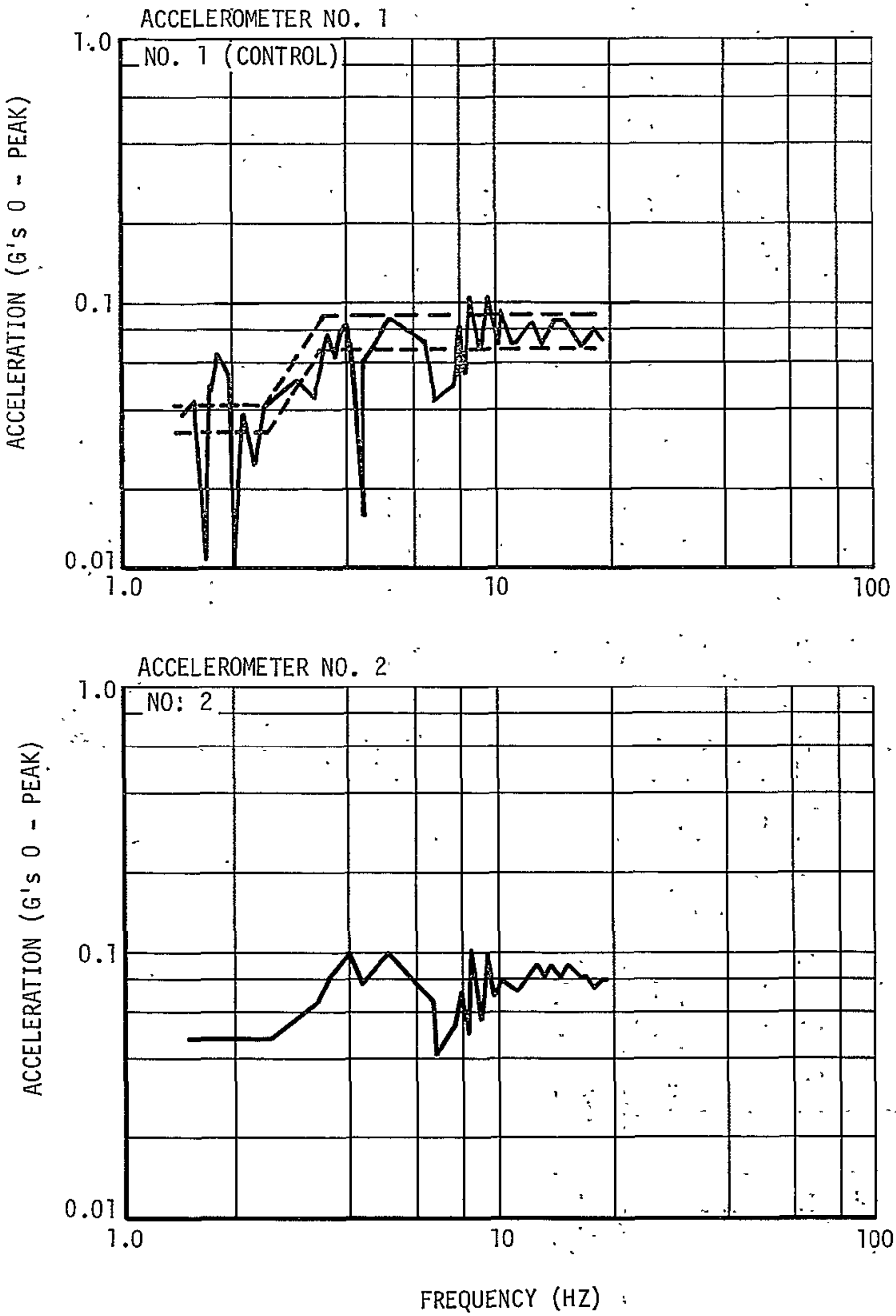


Figure 7-8. Tangential Axis Sinusoidal Sweep

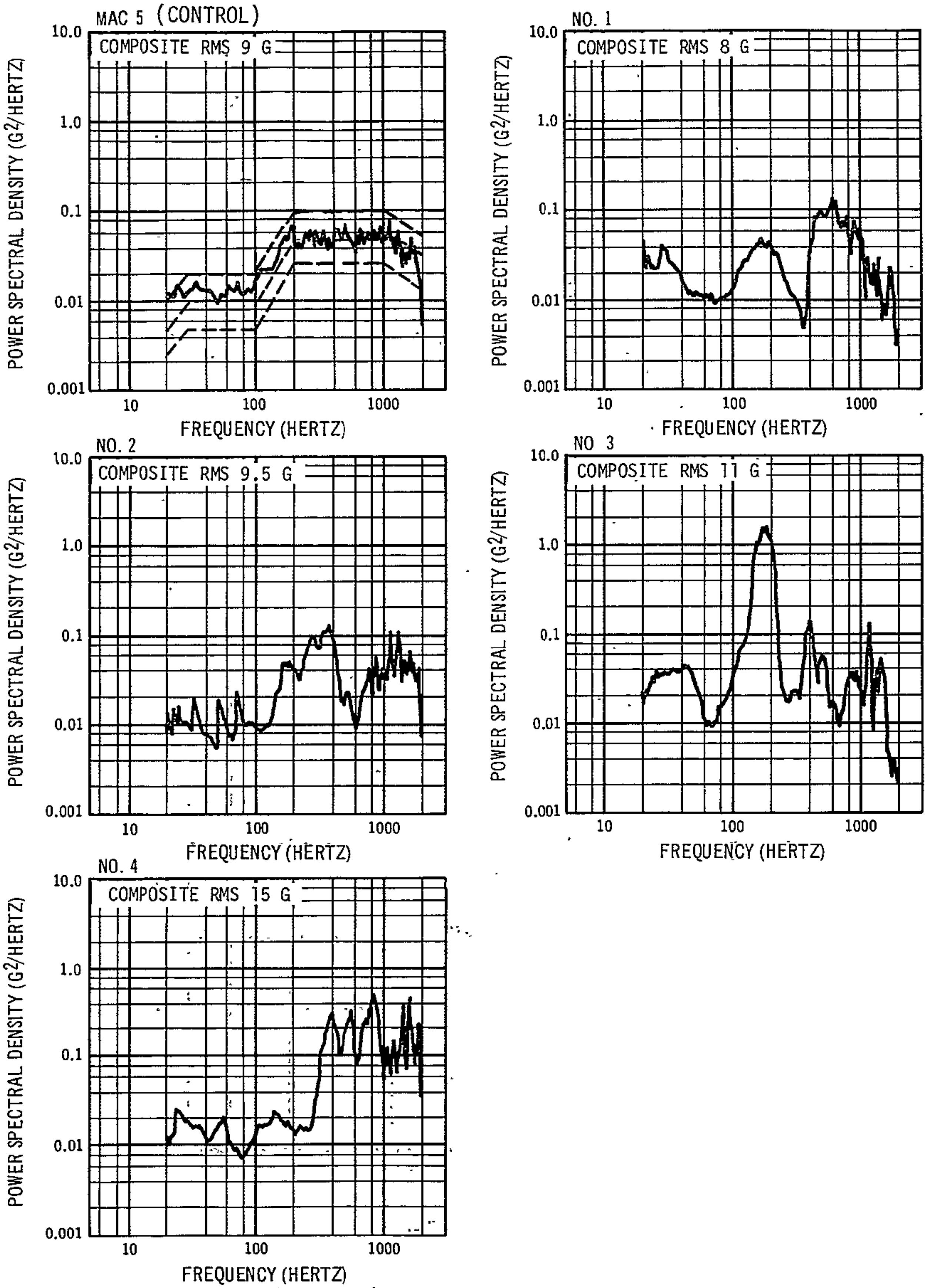


Figure 7-9. Tangential Axis Random Vibration (Sheet 1 of 5)

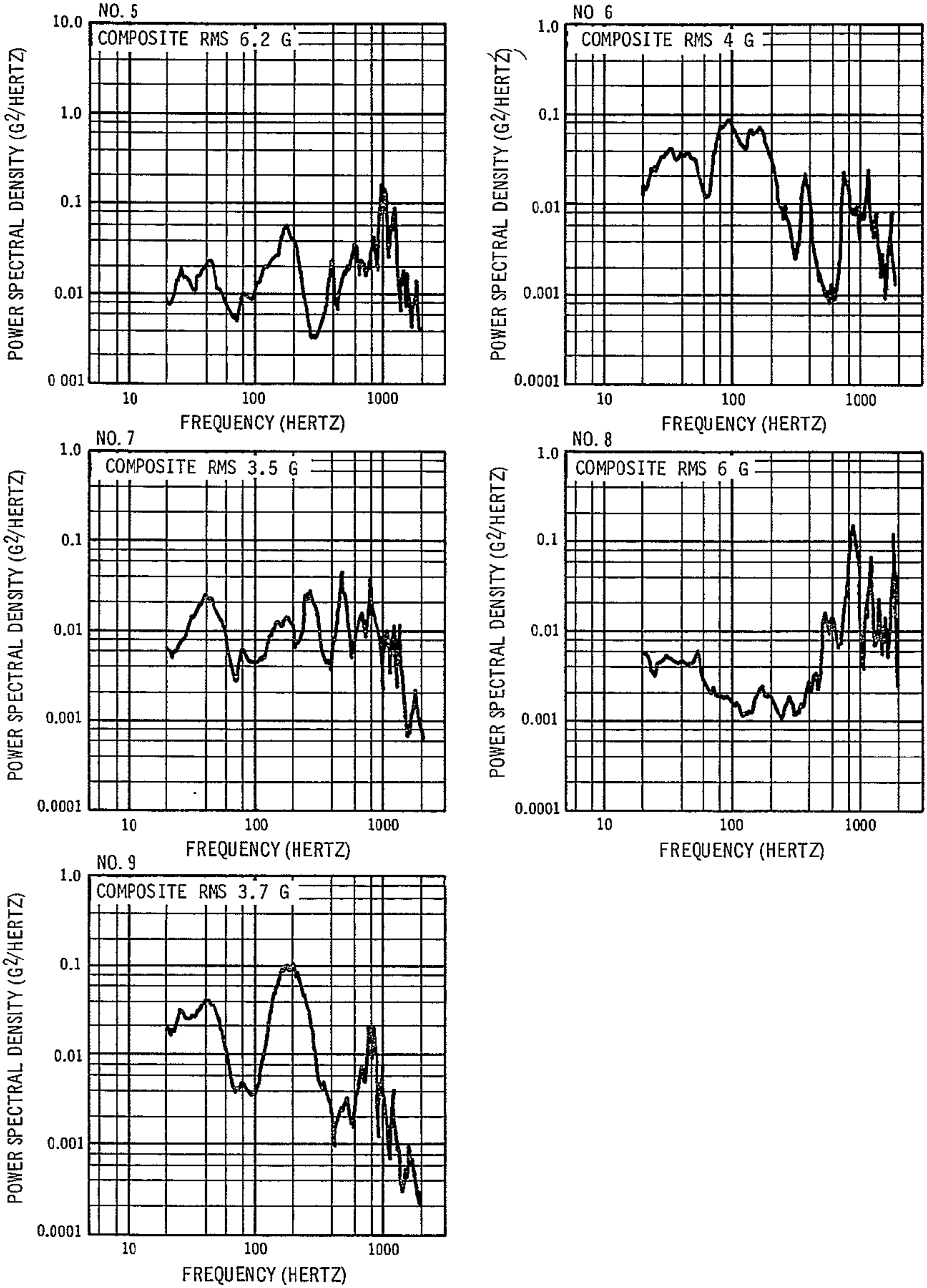


Figure 7-9. Tangential Axis Random Vibration (Sheet 2 of 5)

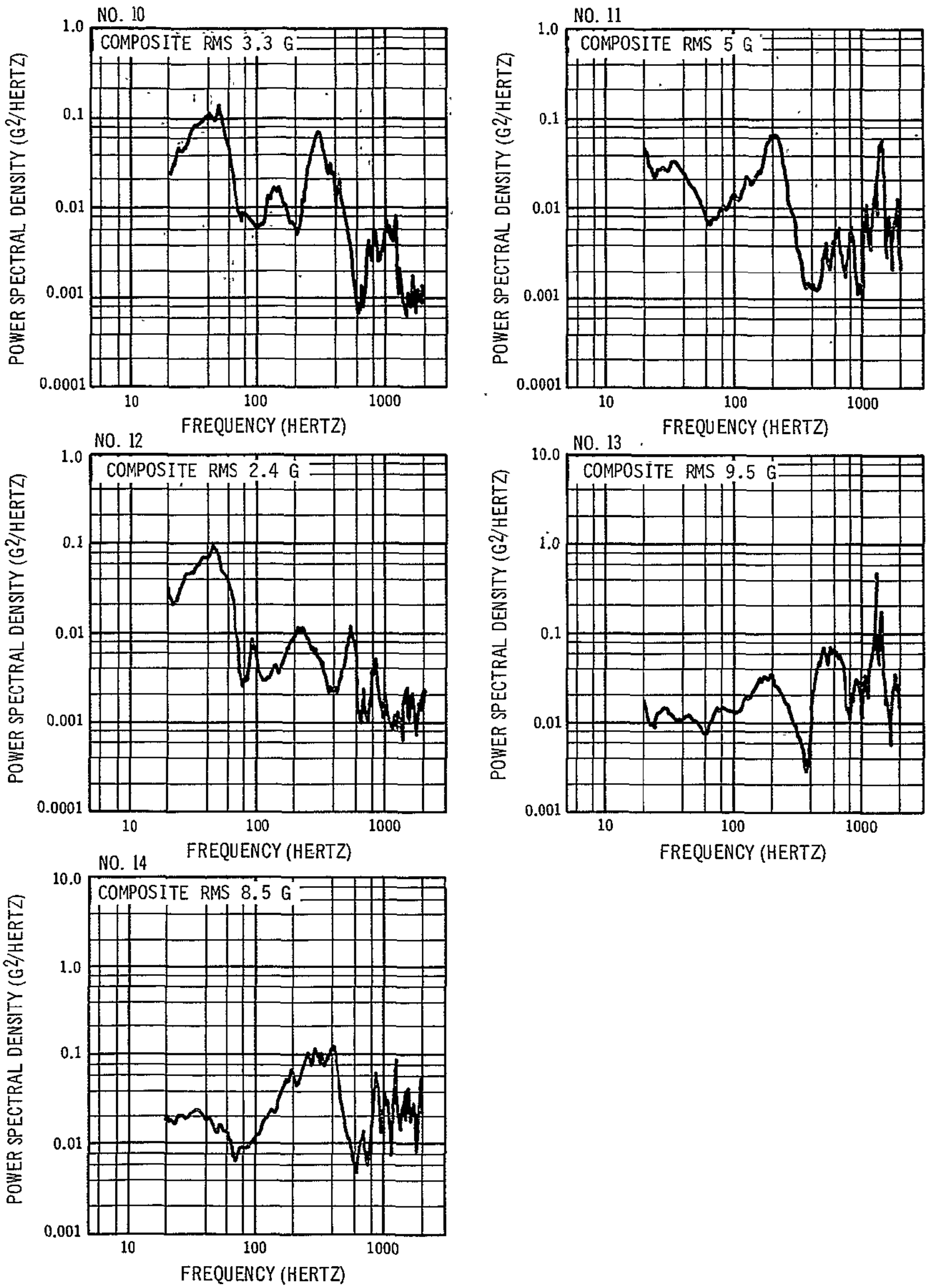


Figure 7-9. Tangential Axis Random Vibration (Sheet 3 of 5)

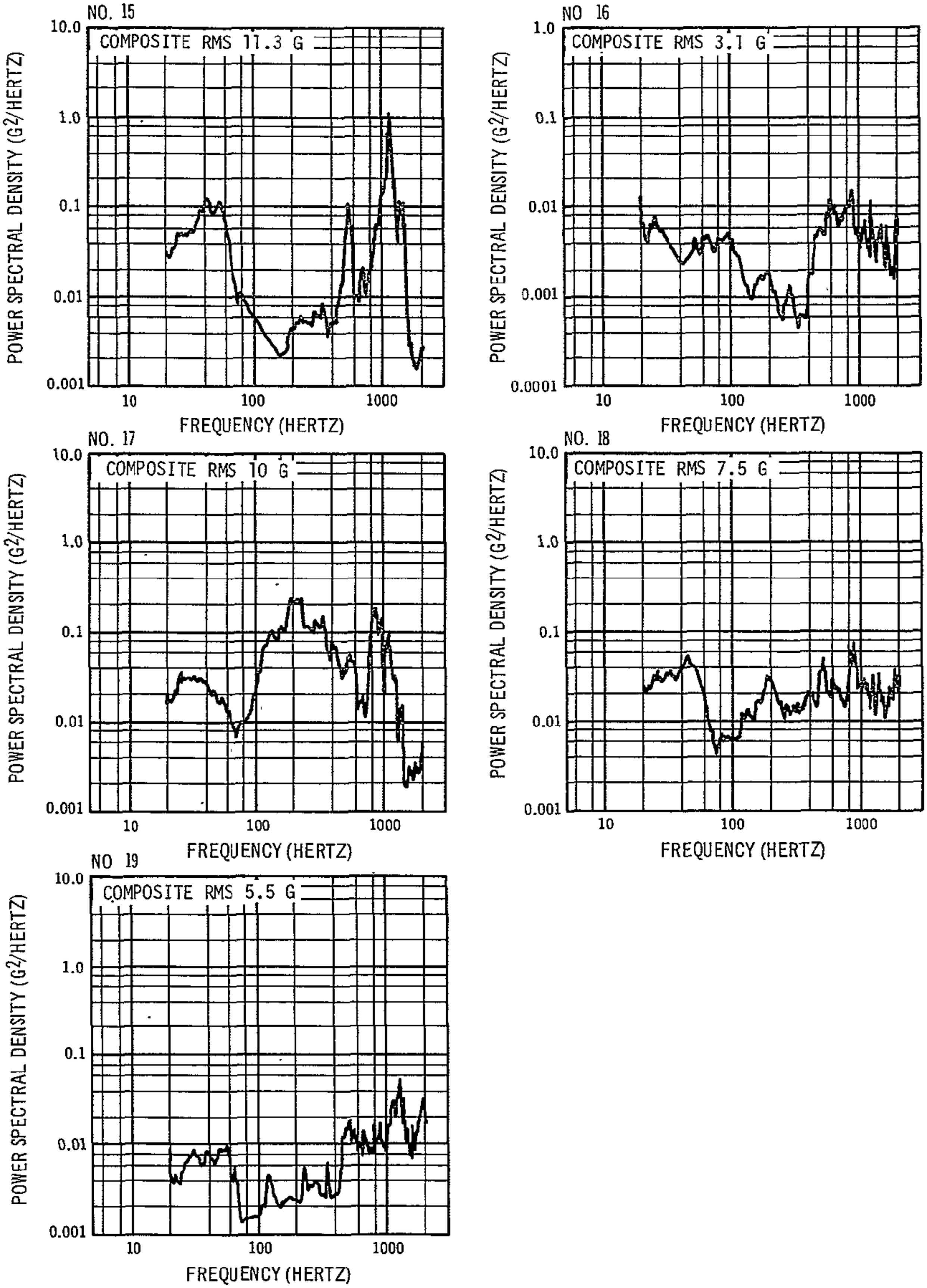


Figure 7-9. Tangential Axis Random Vibration (Sheet 4 of 5)

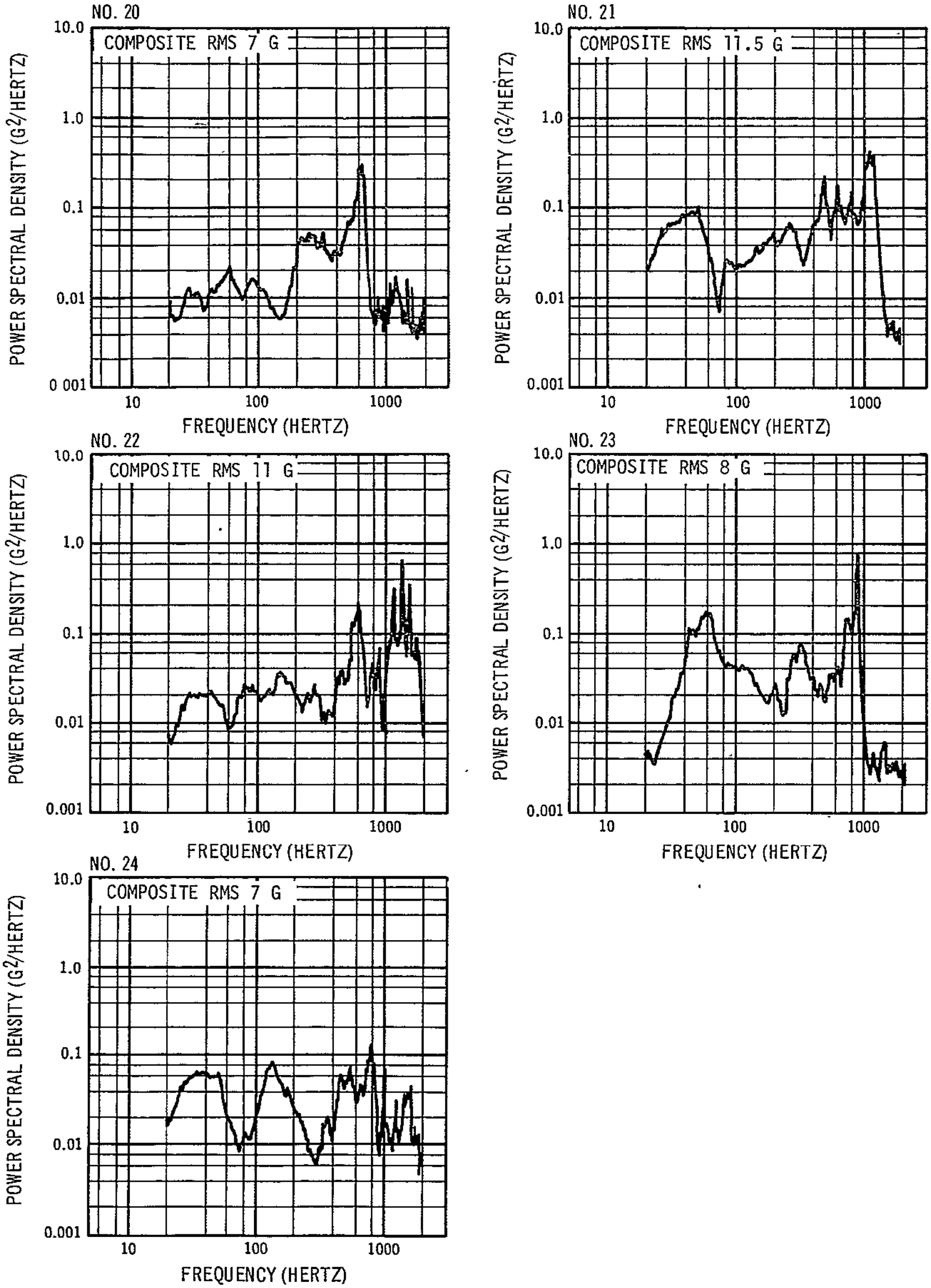


Figure 7-9. Tangential Axis Random Vibration (Sheet 5 of 5)

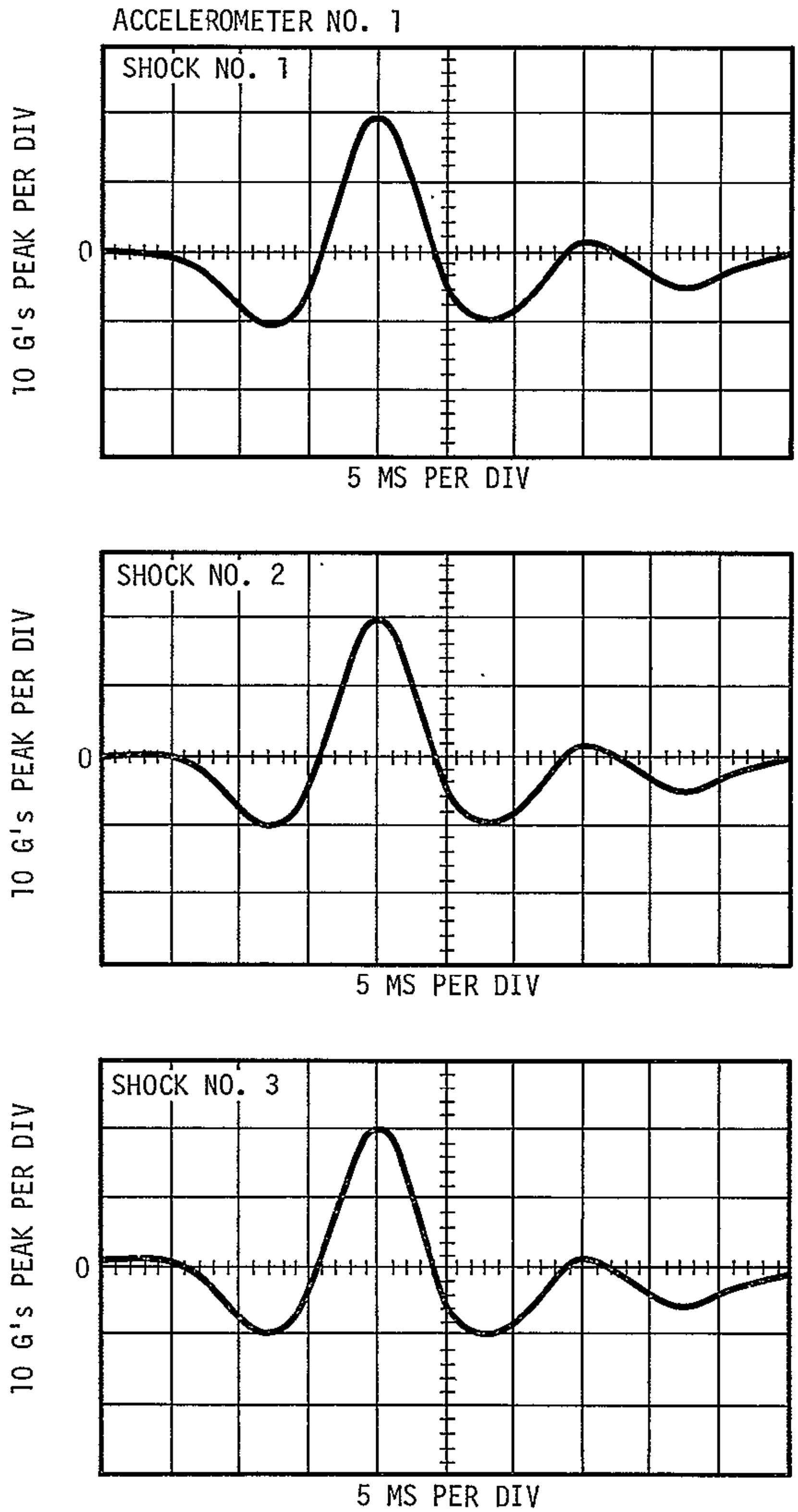
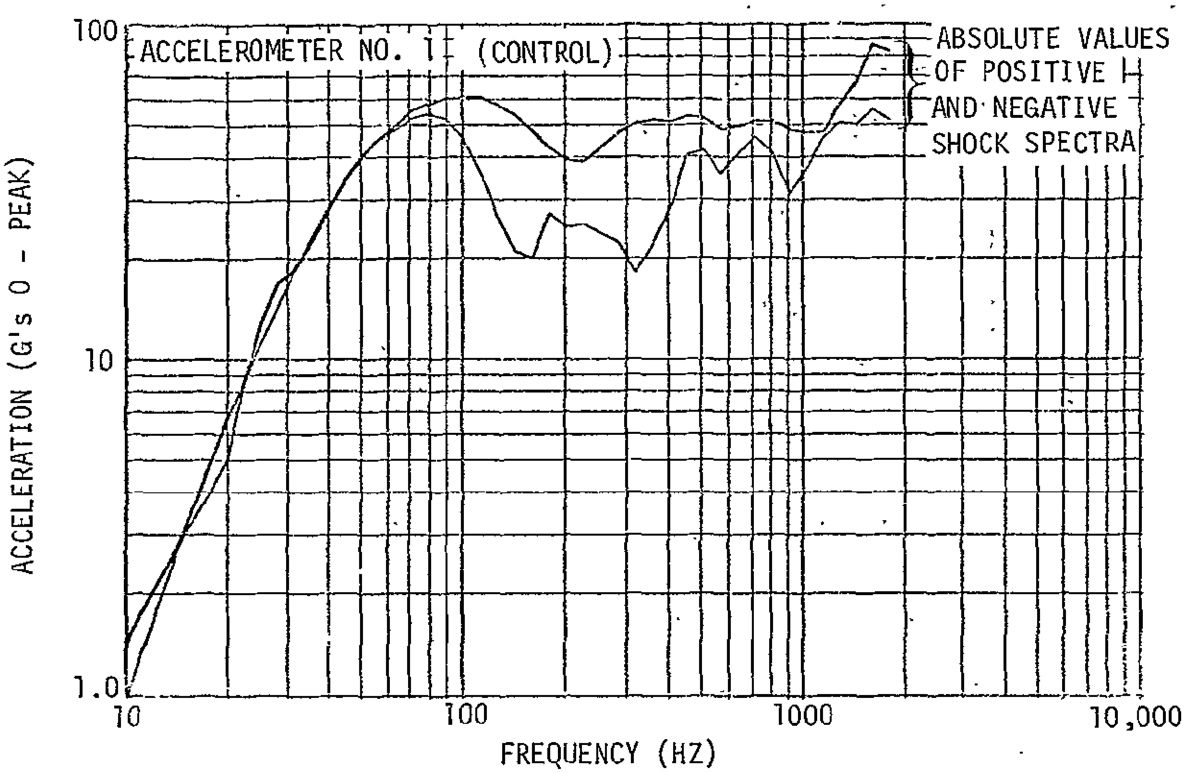


Figure 7-10. Tangential Axis Shock



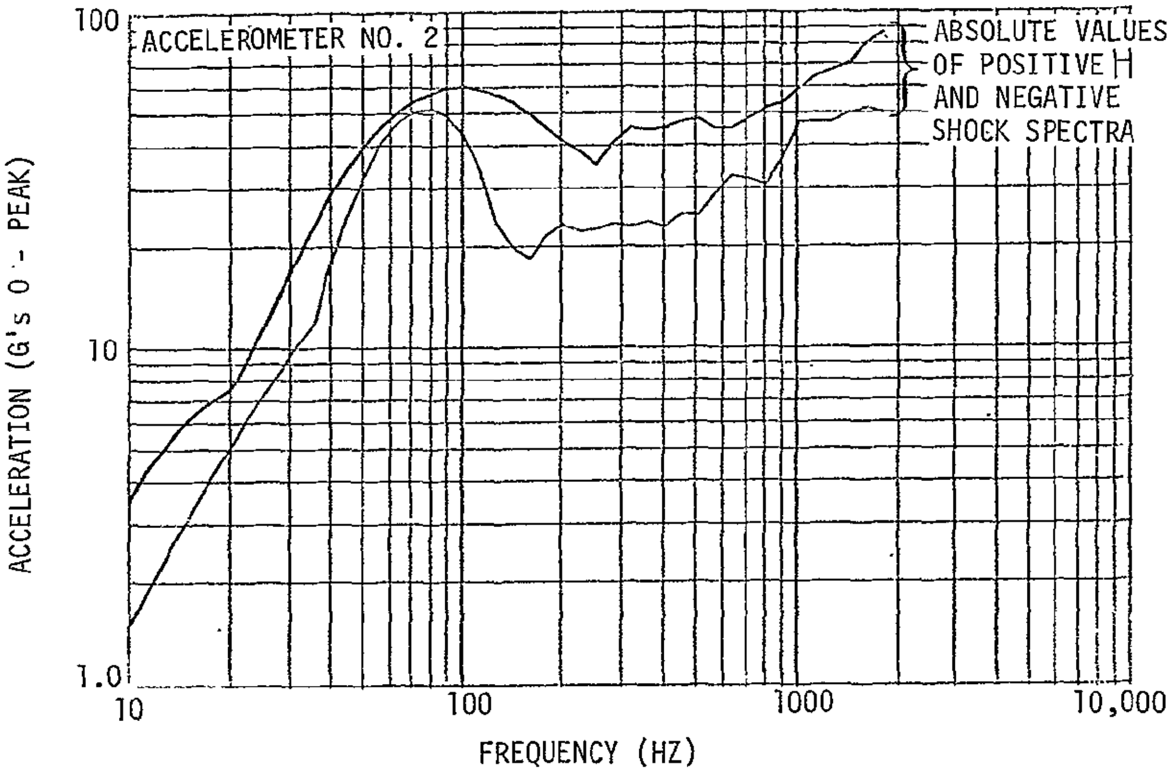


Figure 7-11. Shock Spectrum Analysis - Tangential Axis Shock No. 2

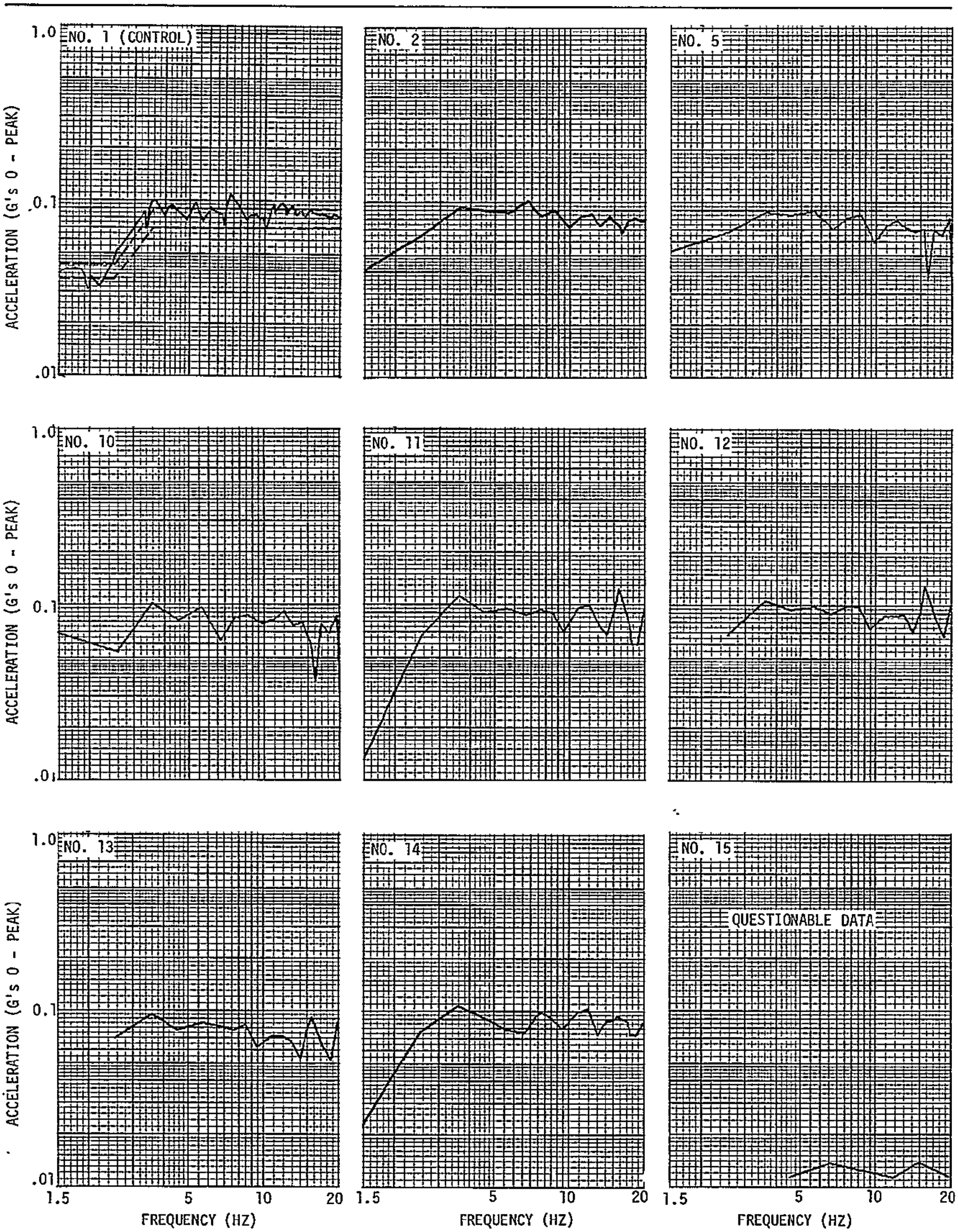


Figure 7-12. Radial Axis Sinusoidal Sweep (Sheet 1 of 2)

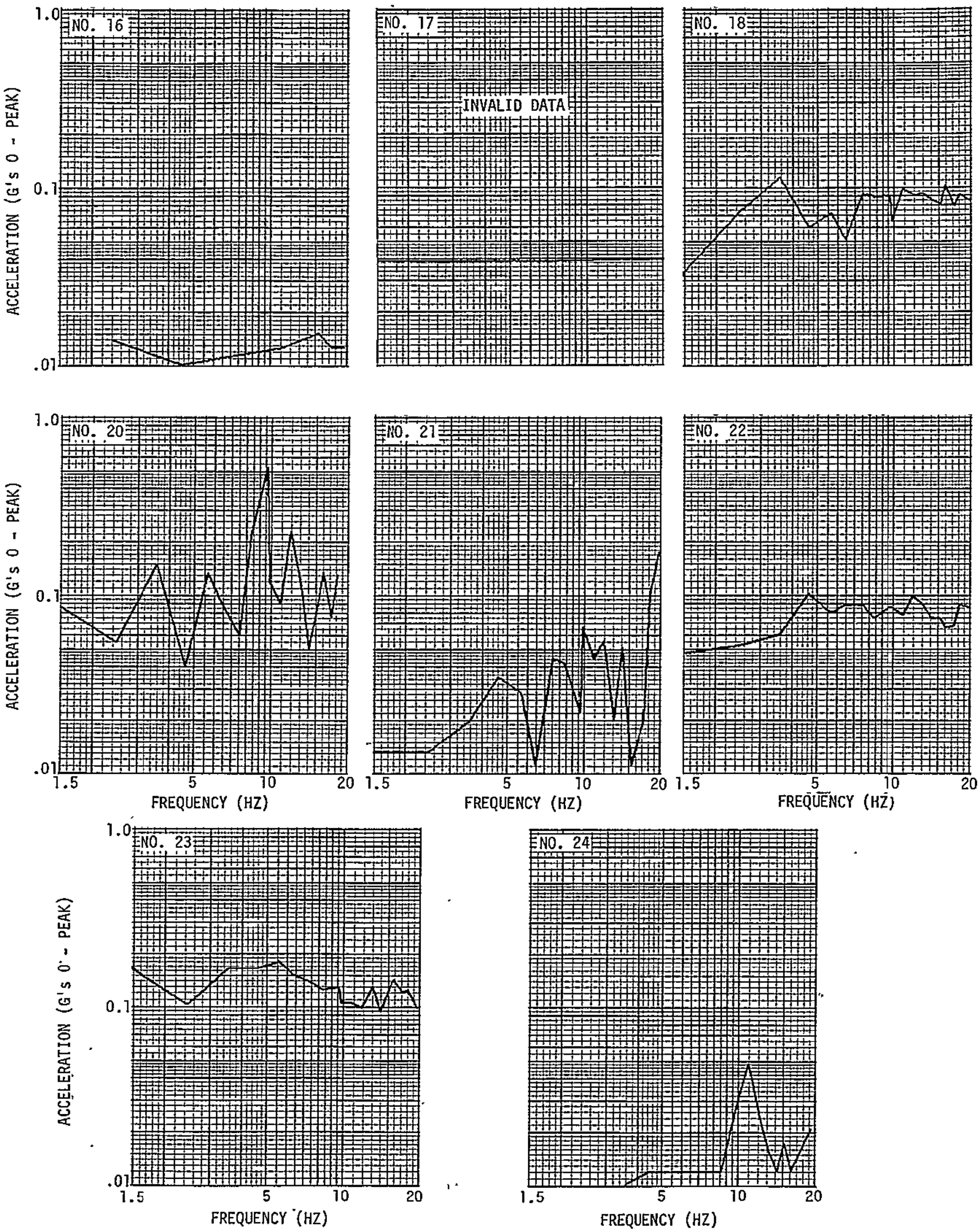


Figure 7-12. Radial Axis Sinusoidal Sweep (Sheet 2 of 2)

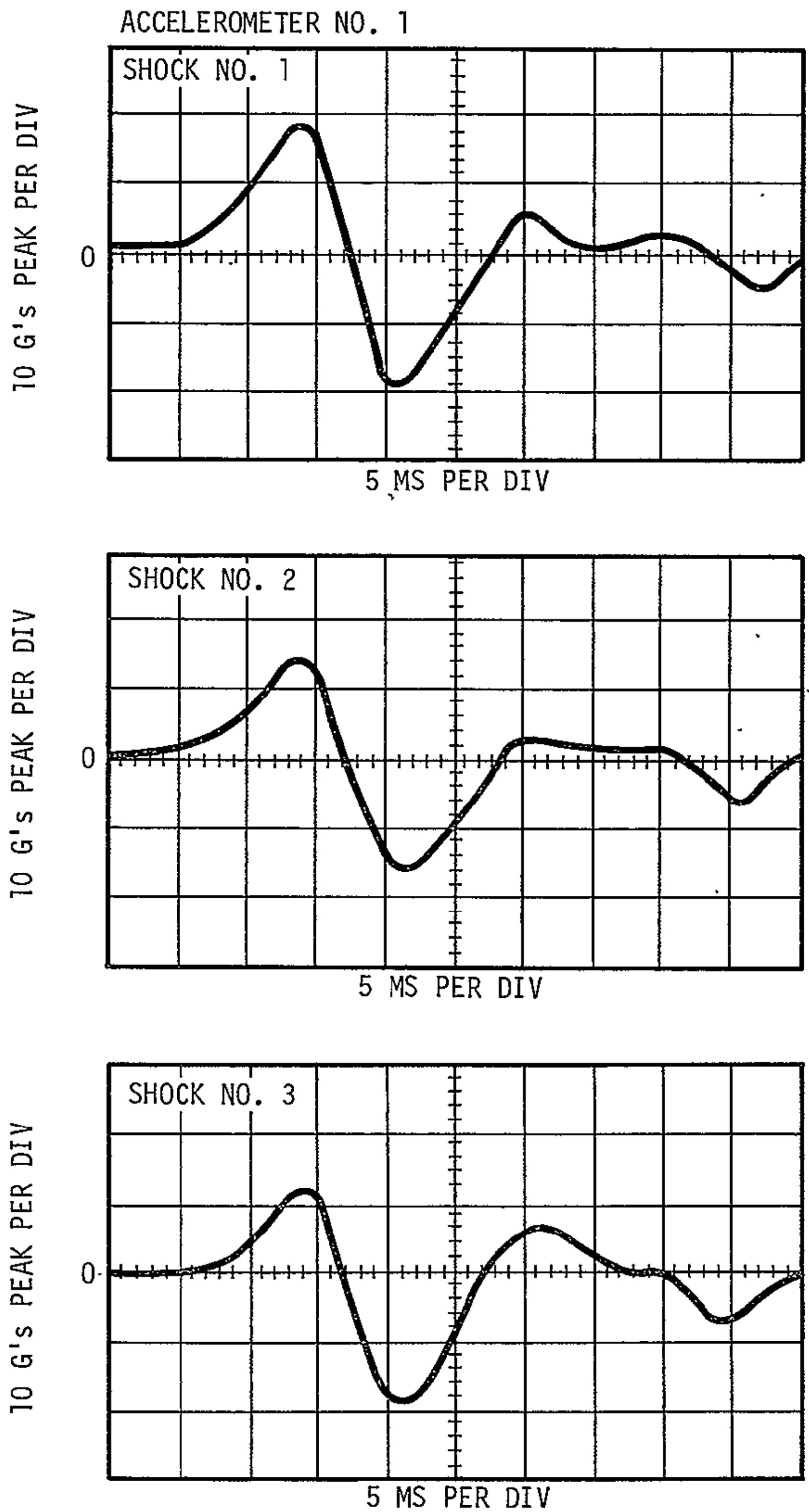
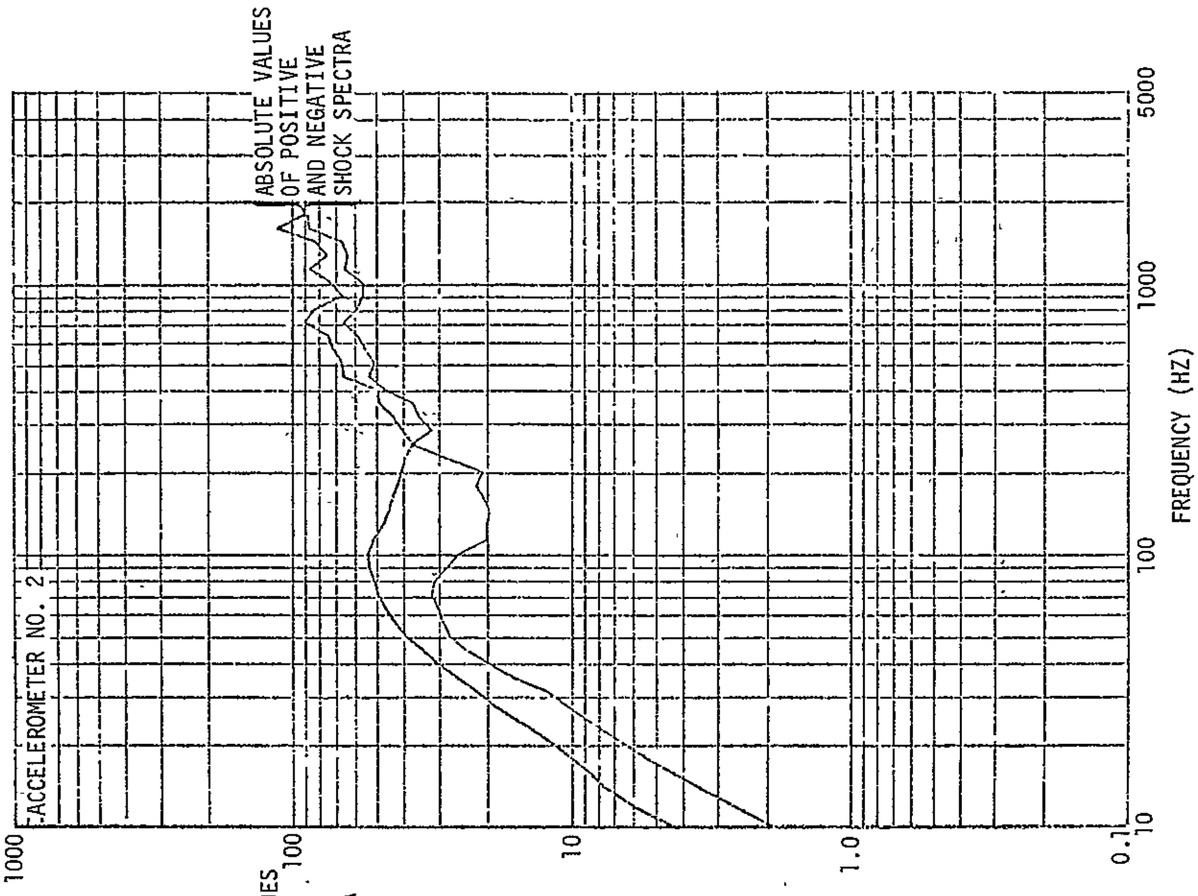


Figure 7-13. Radial Axis Shock



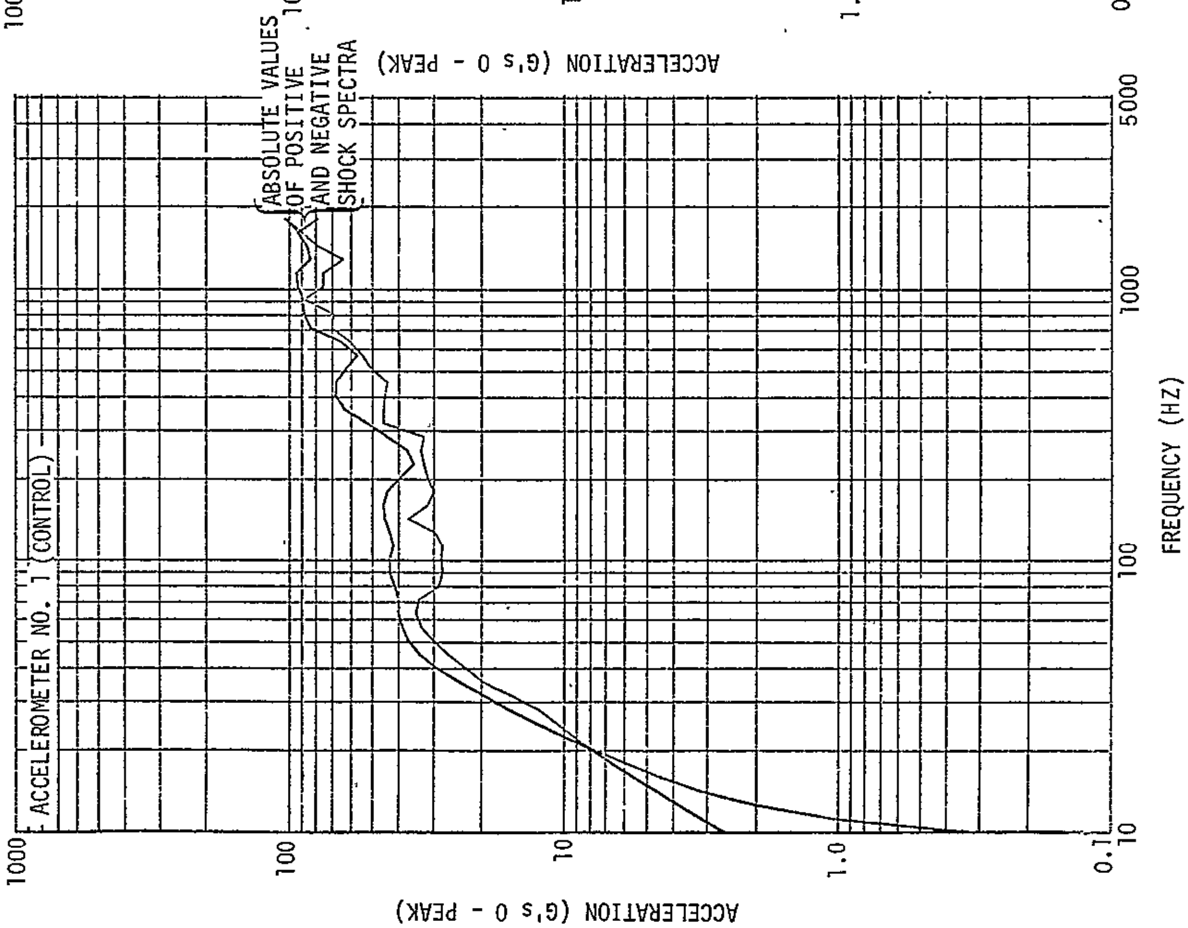


Figure 7-14. Shock Spectrum Analysis - Radial Axis Shock No. 2

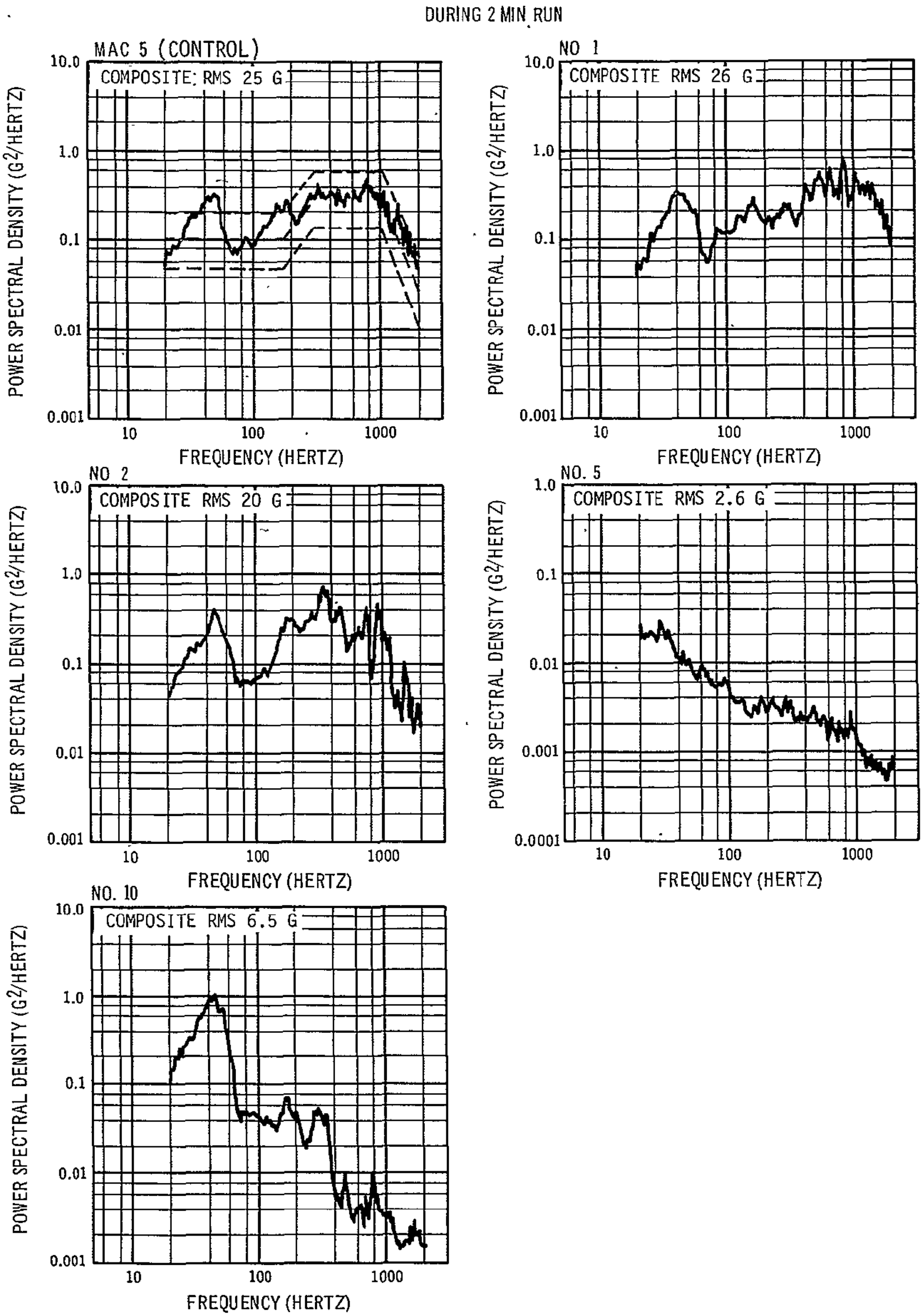


Figure 7-15. Radial Axis Random Vibration (Sheet 1 of 6)

DURING 2 MIN RUN

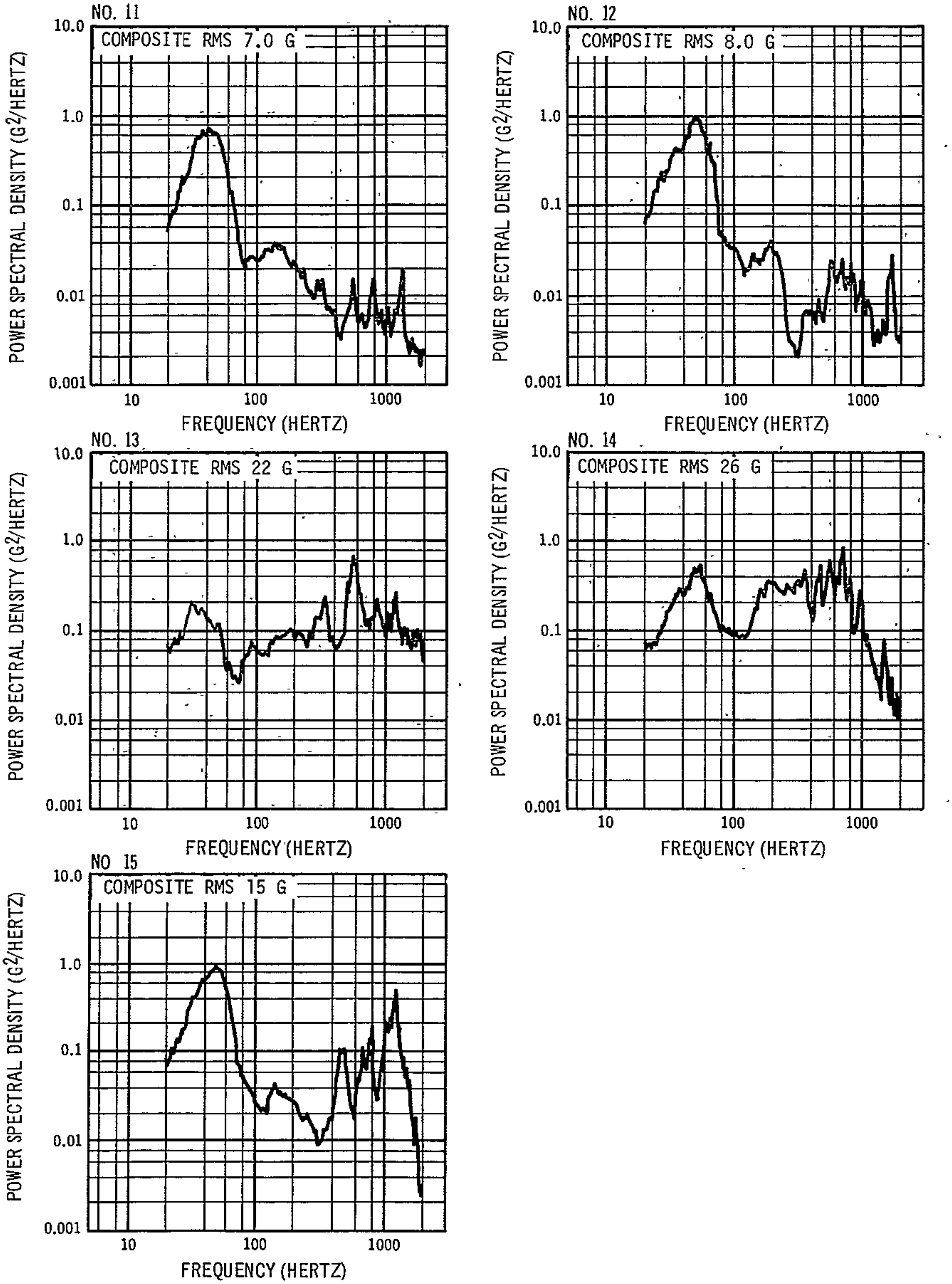


Figure 7-15. Radial Axis Random Vibration (Sheet 2 of 6)

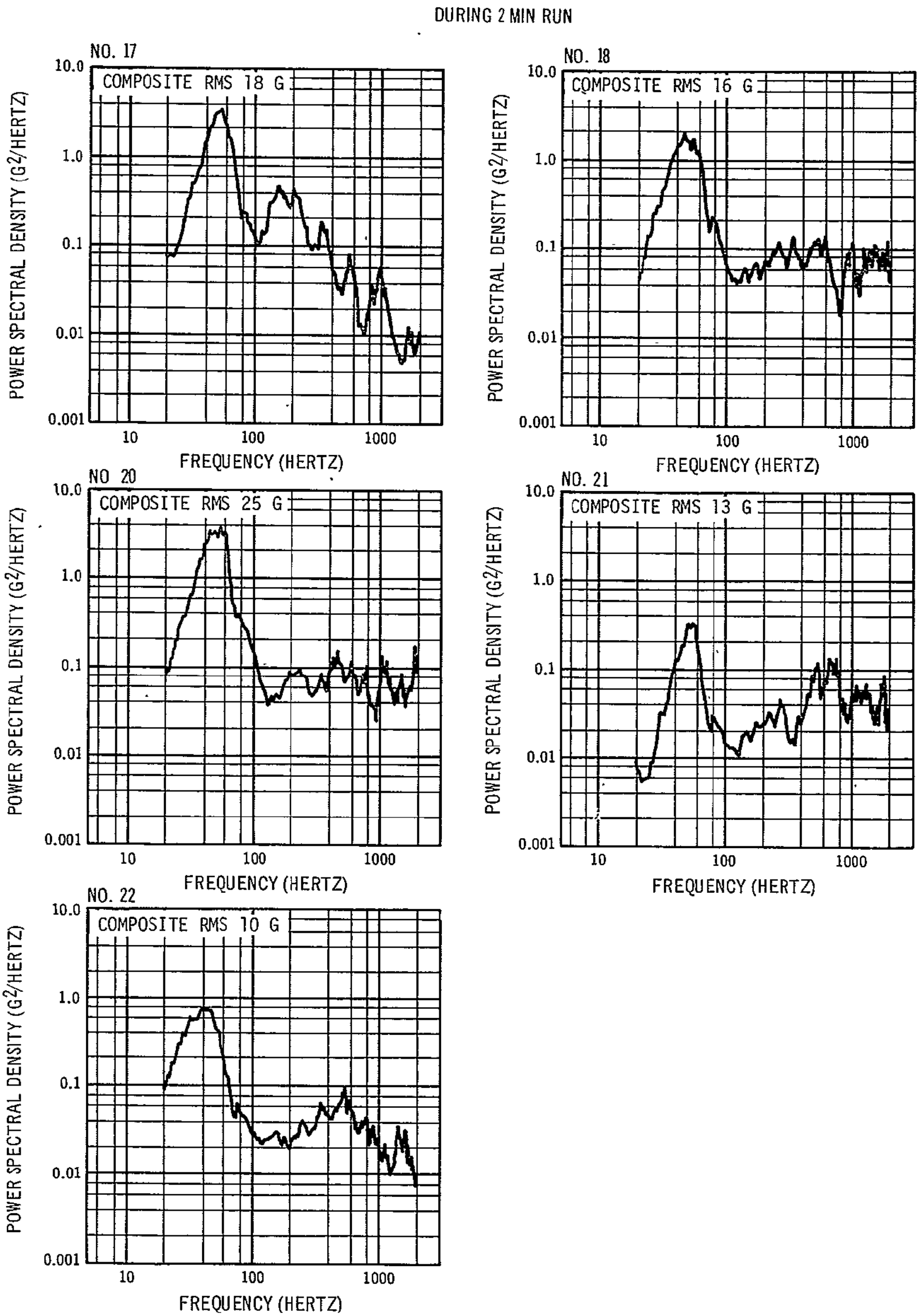


Figure 7-15. Radial Axis Random Vibration (Sheet 3 of 6)

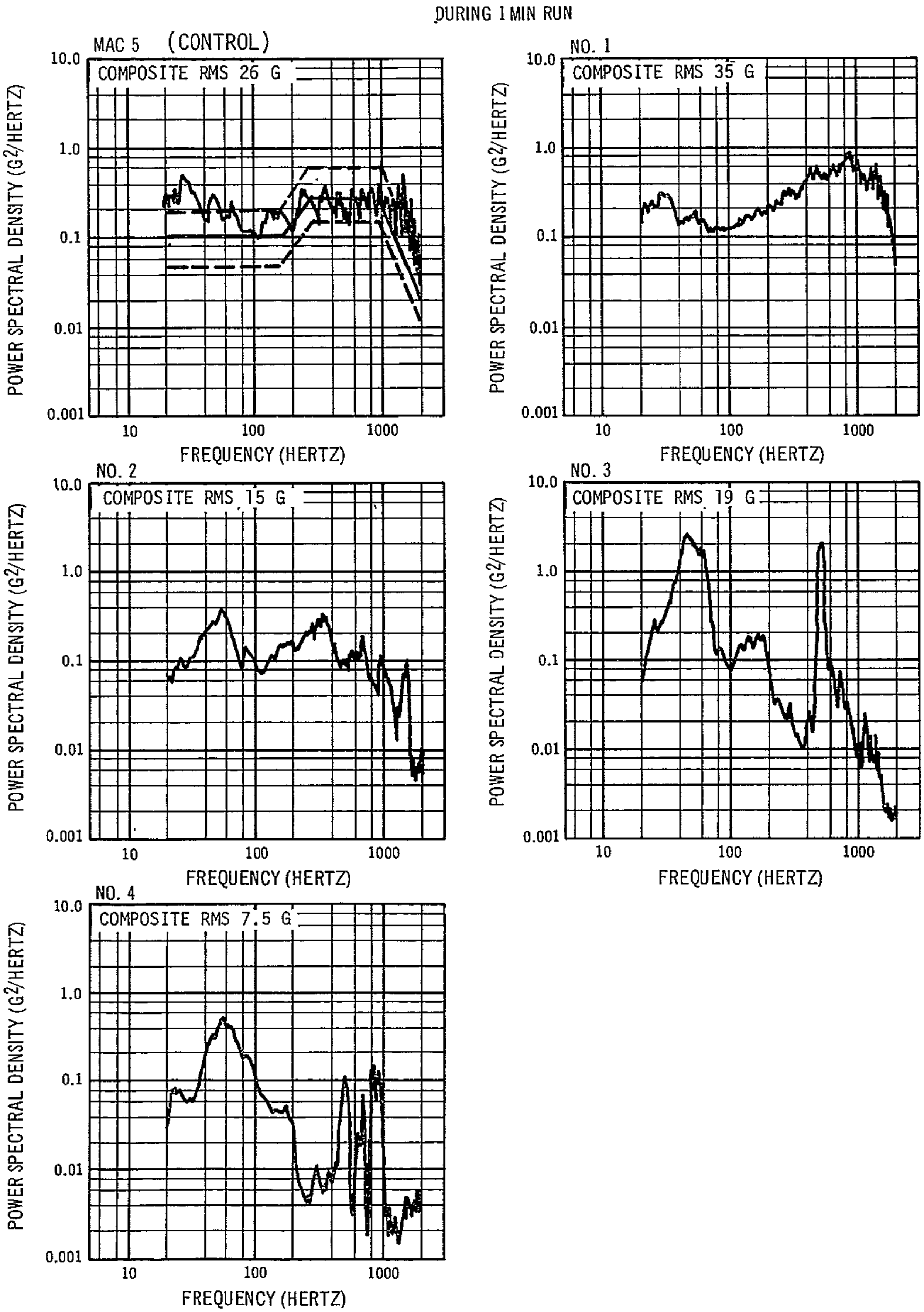


Figure 7-15. Radial Axis Random Vibration (Sheet 4 of 6)

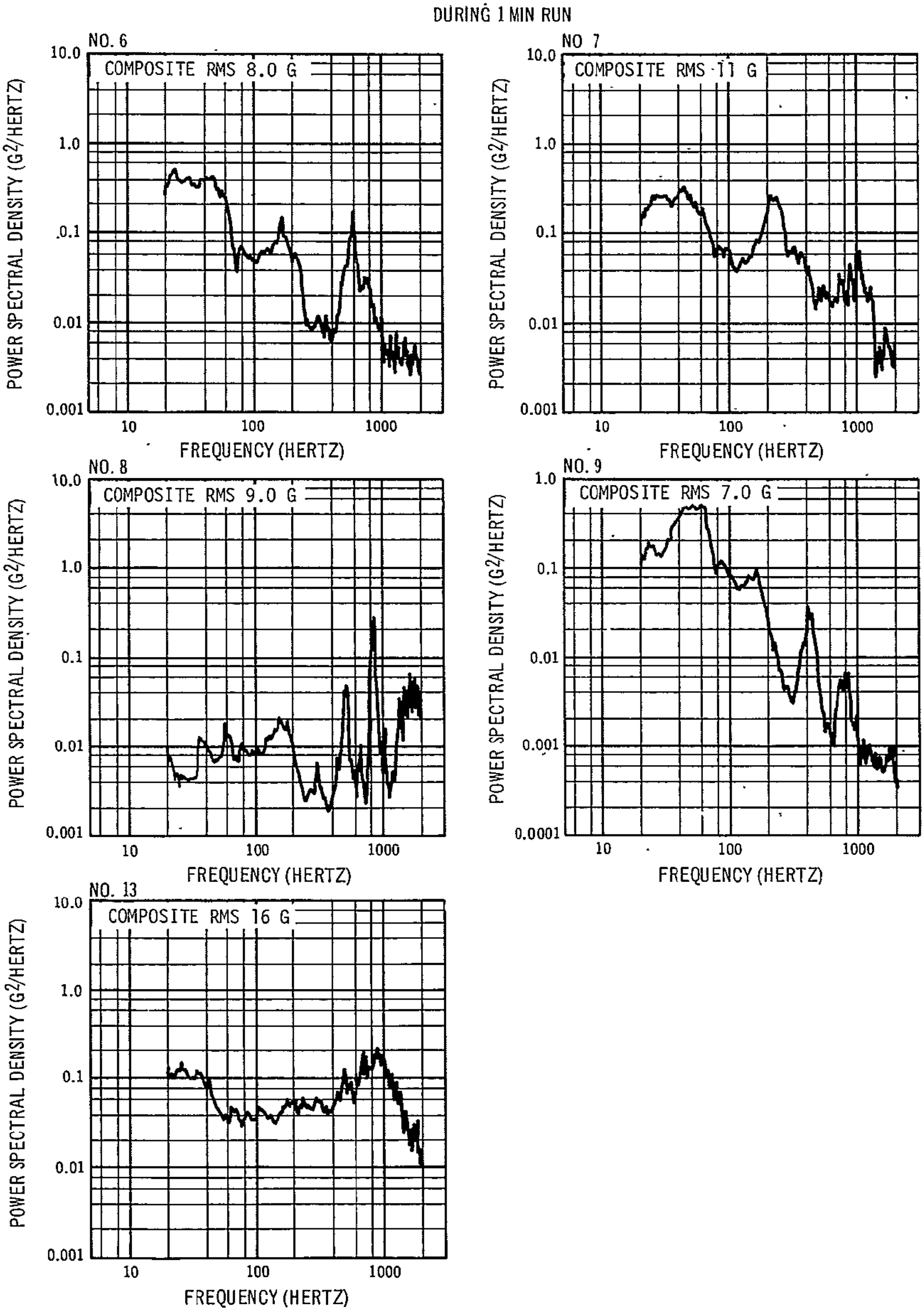


Figure 7-15. Radial Axis Random Vibration (Sheet 5 of 6)

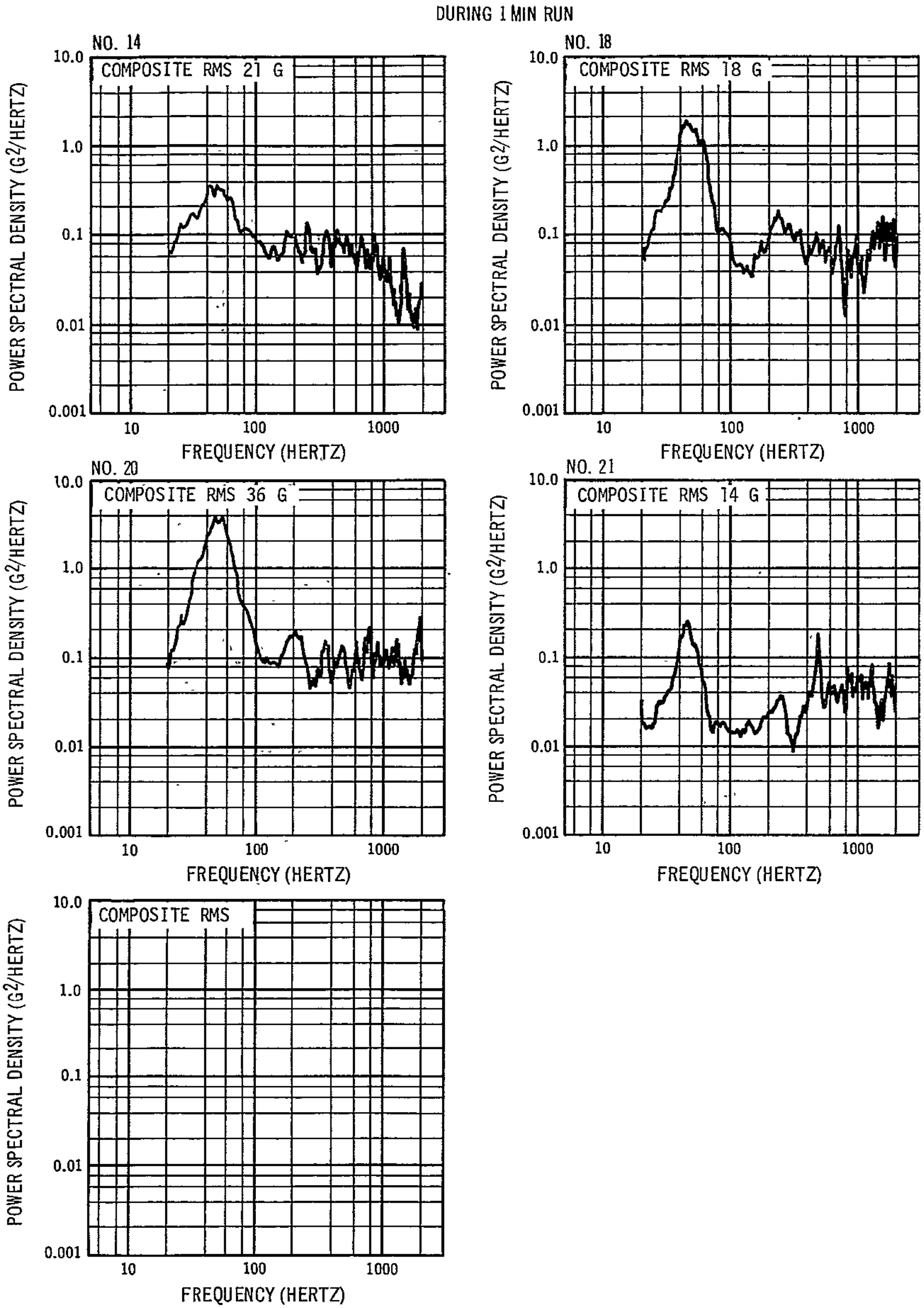


Figure 7-15. Radial Axis Random Vibration (Sheet 6 of 6)

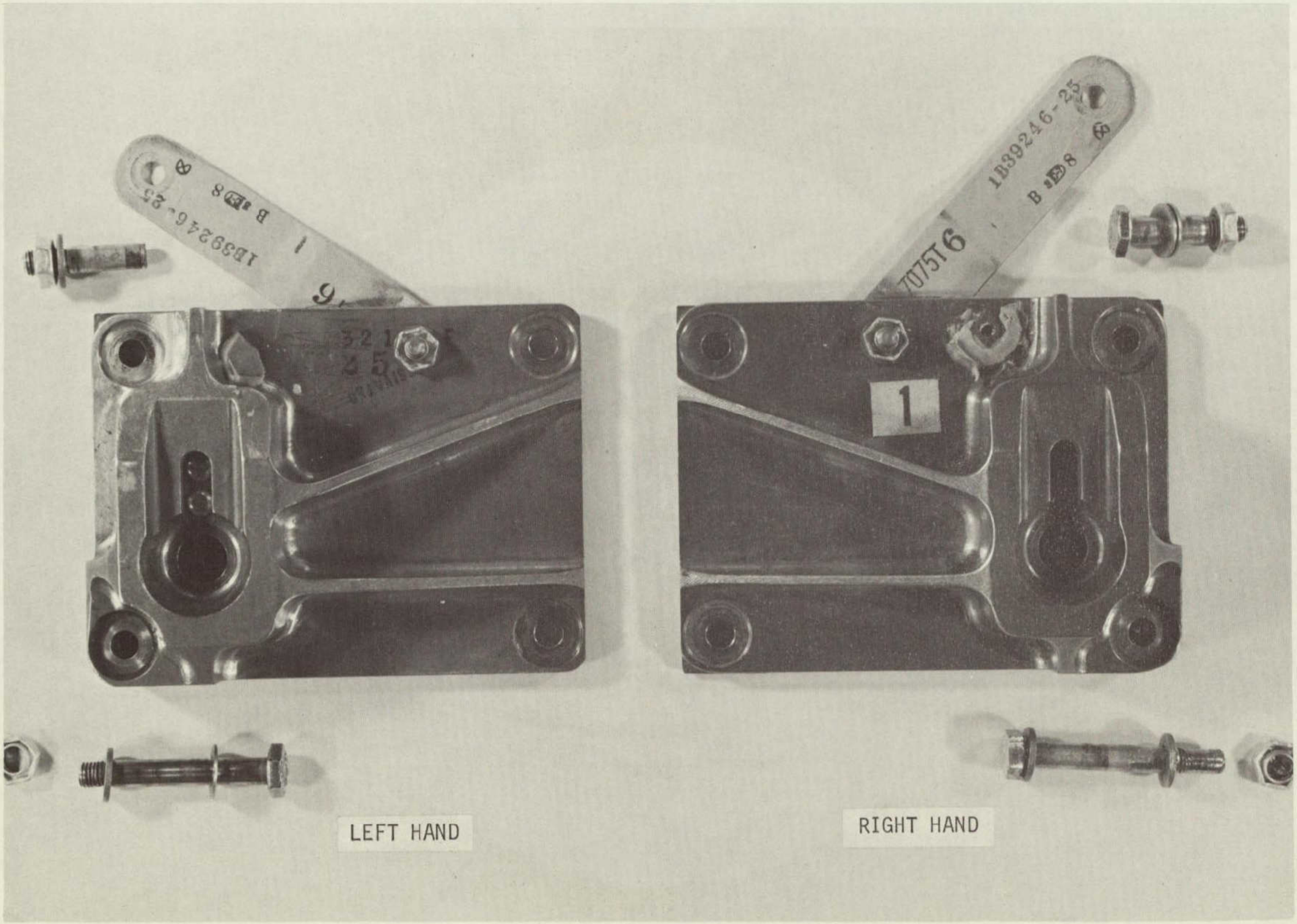


Figure 7-16. APS Aft Attach Fittings

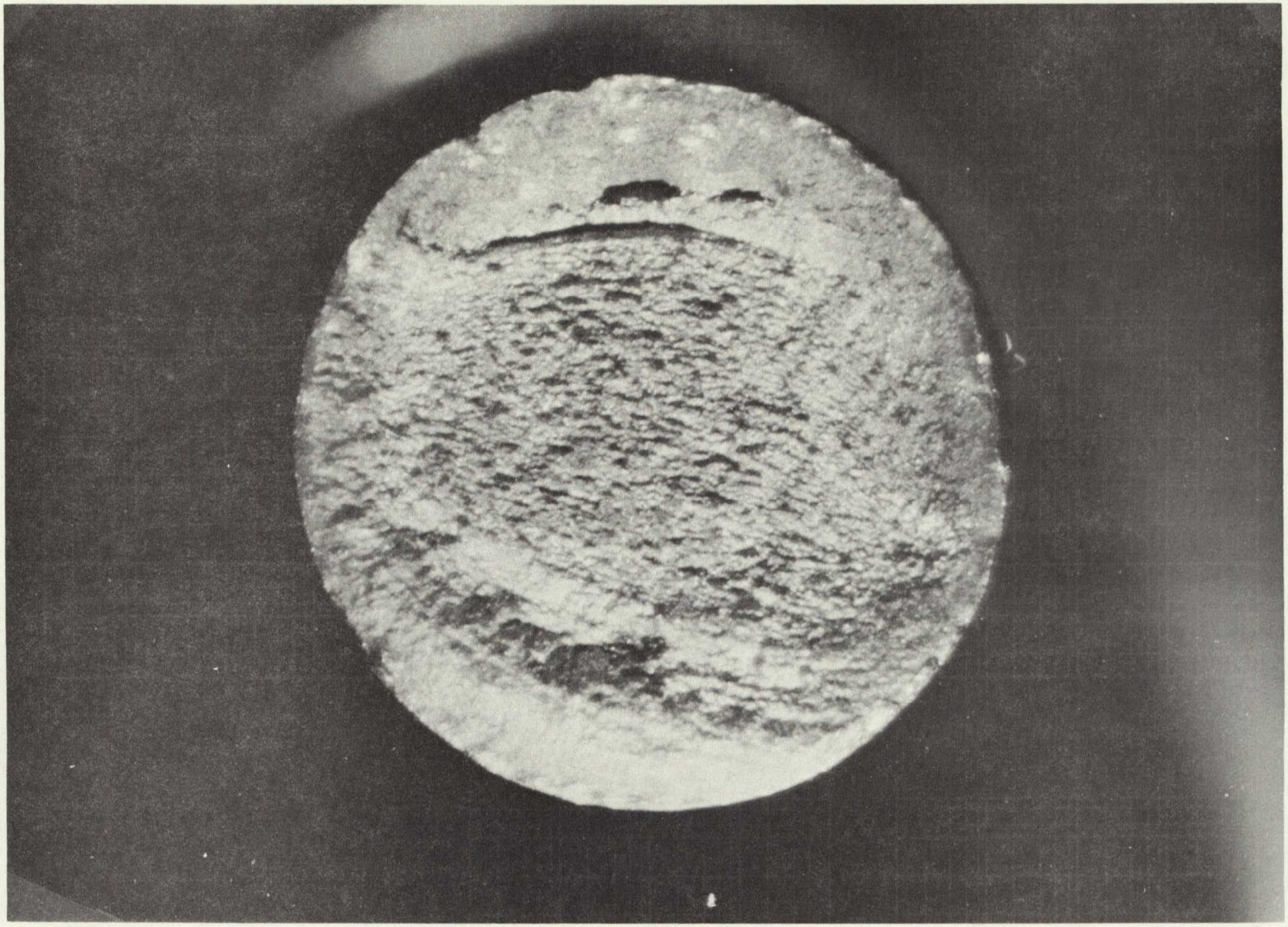


Figure 7-17. Aft Attach Fitting Bolt

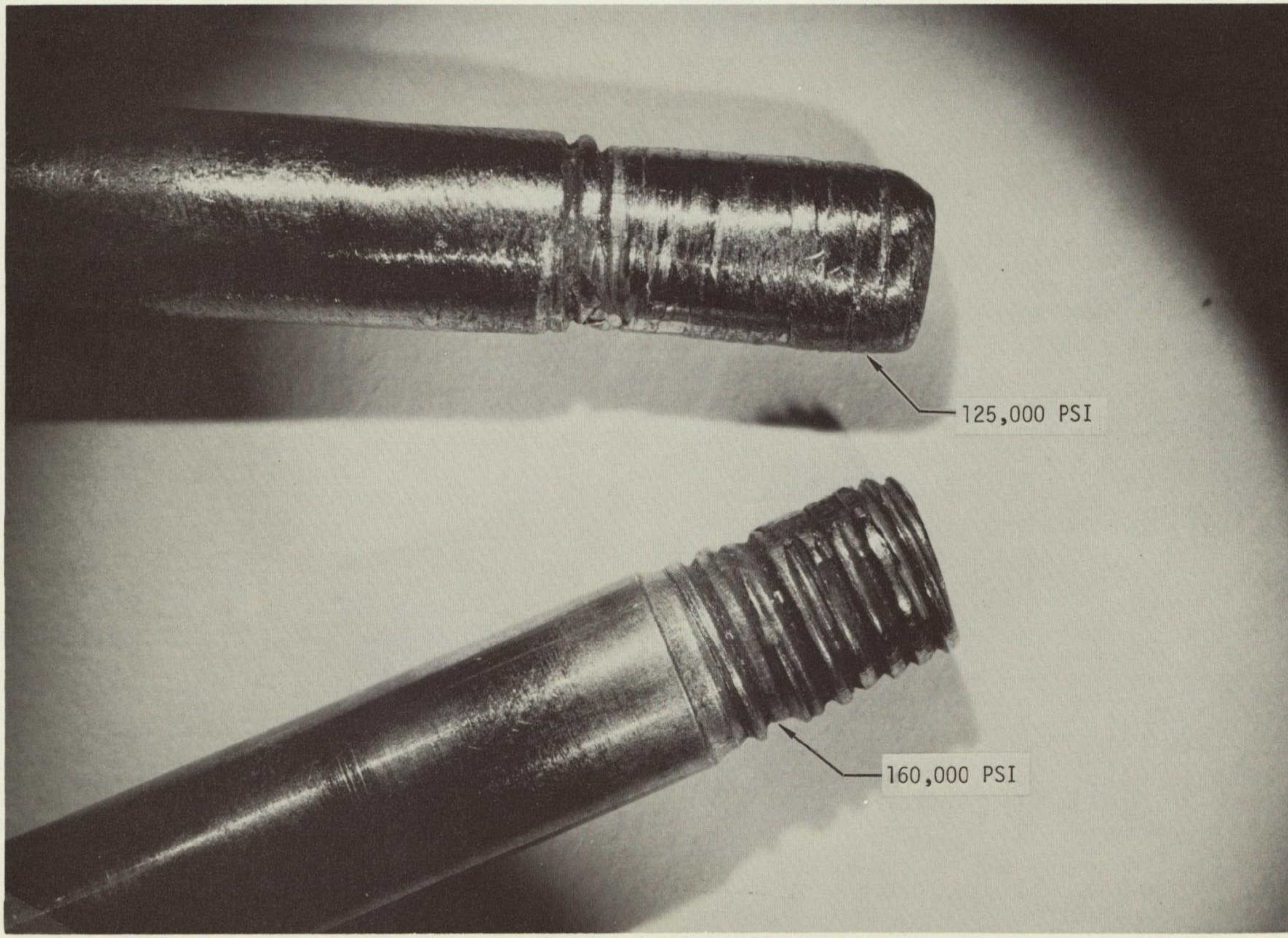


Figure 7-18. Aft Attach Fitting Bolts

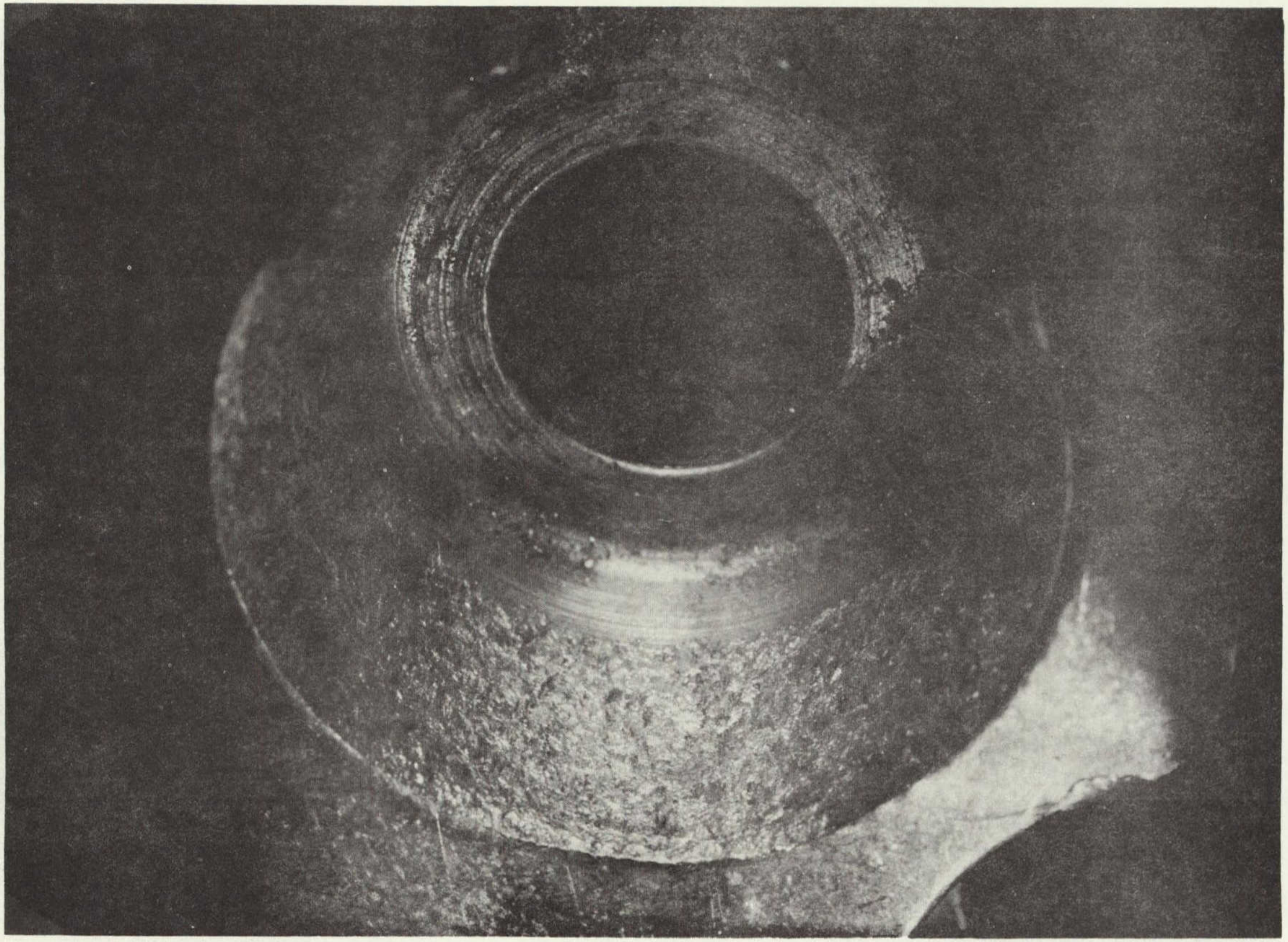


Figure 7-19. Aft Attach Fitting Socket

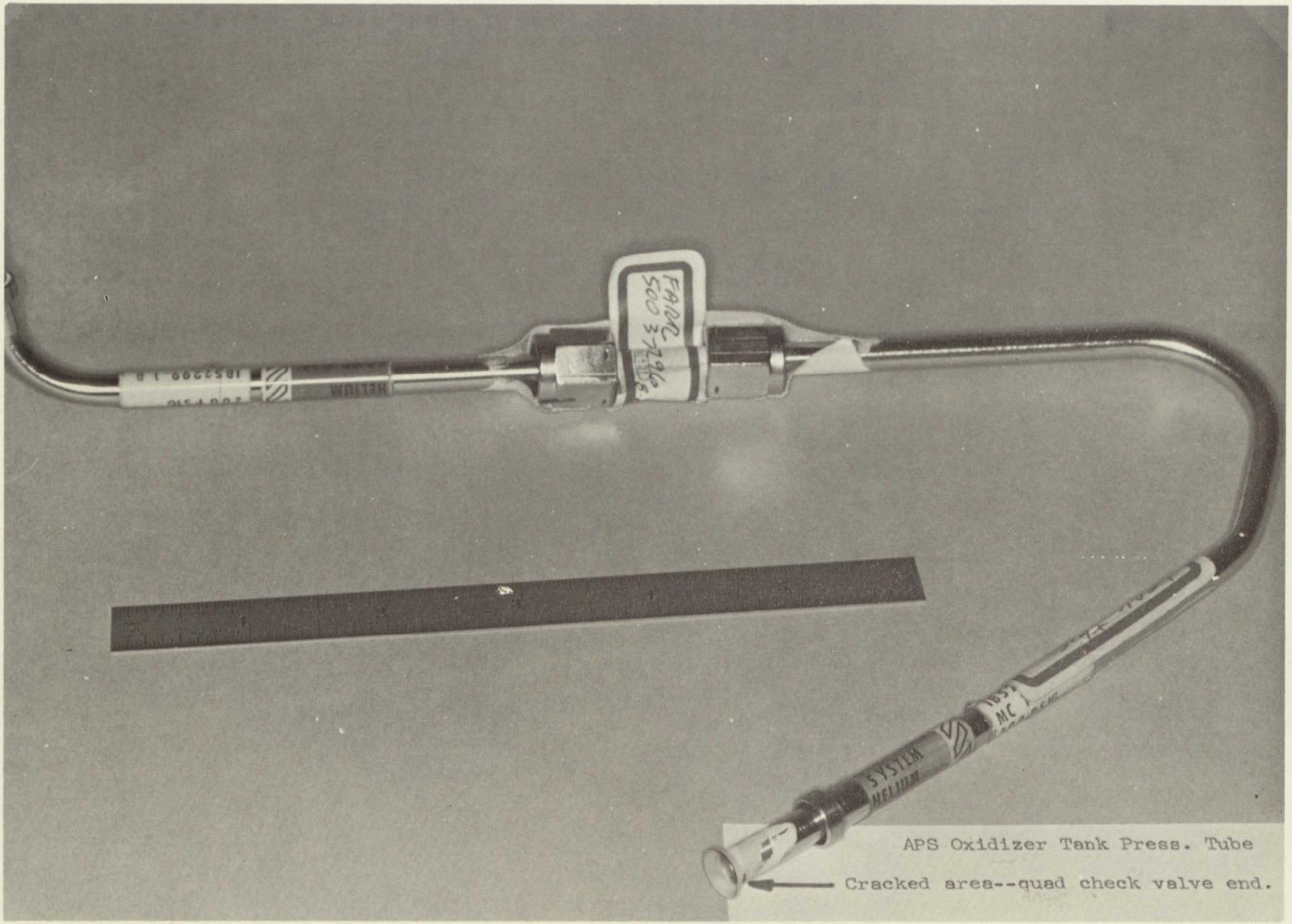


Figure 7-20. Helium Pressurization Tube Assembly (Sheet 1 of 2)

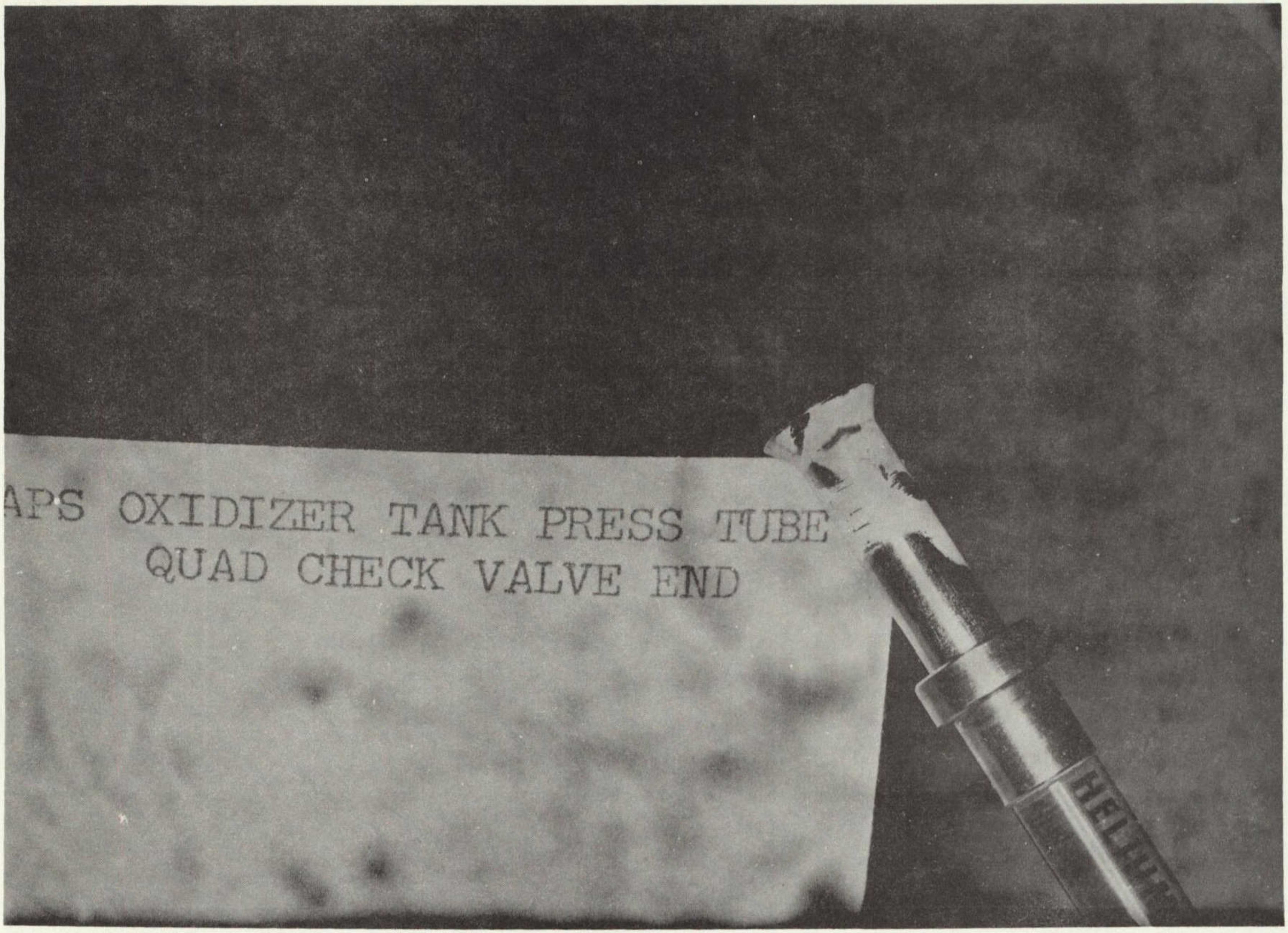


Figure 7-20. Helium Pressurization Tube Assembly (Sheet 2 of 2)

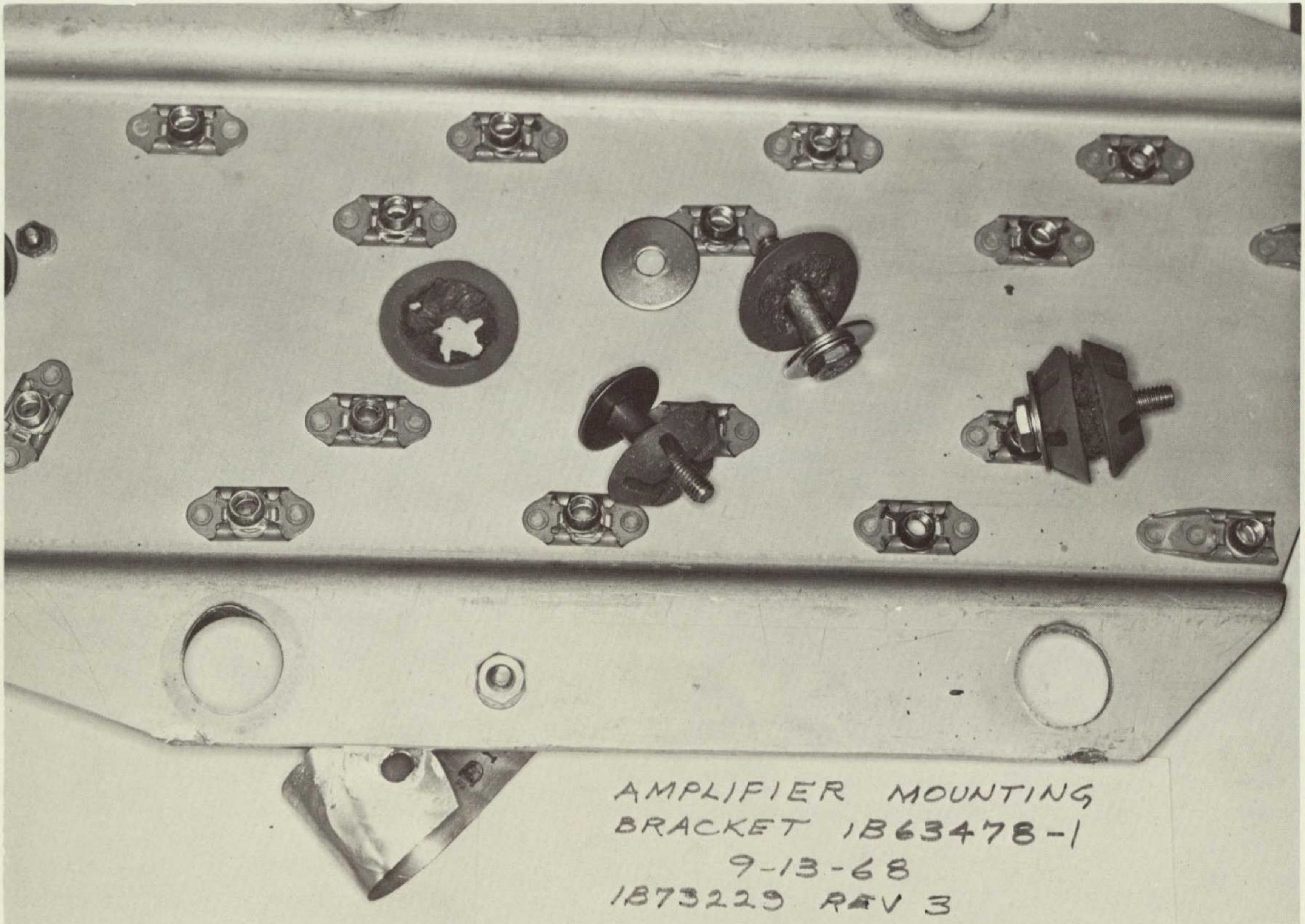
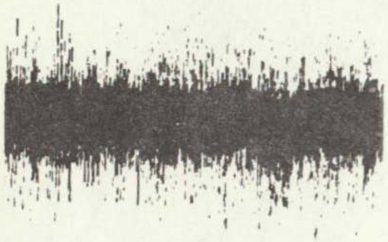
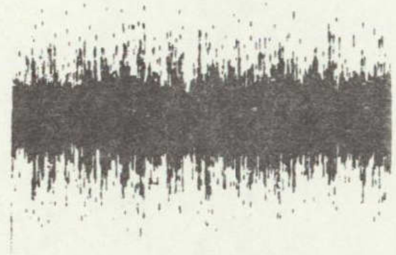


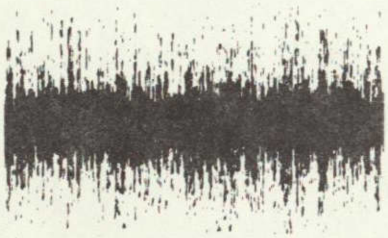
Figure 7-21. Amplifier Mounting Bracket



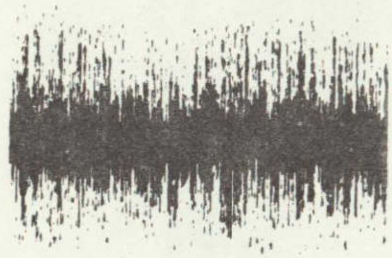
15 SEC INTO RUN
(2 MIN)



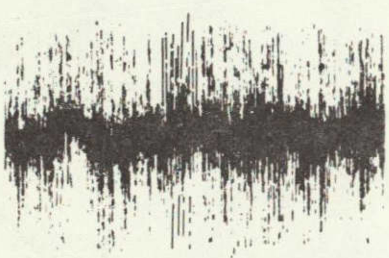
30 SEC INTO RUN
(2 MIN)



60 SEC INTO RUN
(2 MIN)



115 SEC INTO RUN
(2 MIN)



150 SEC INTO RUN
(1 MIN)

165 SEC INTO RUN
(1 MIN)

NOTE: TOTAL TEST TIME WAS 180 SEC

Figure 7-22. Random Vibration Radial Axis - Signal Deterioration Control #1

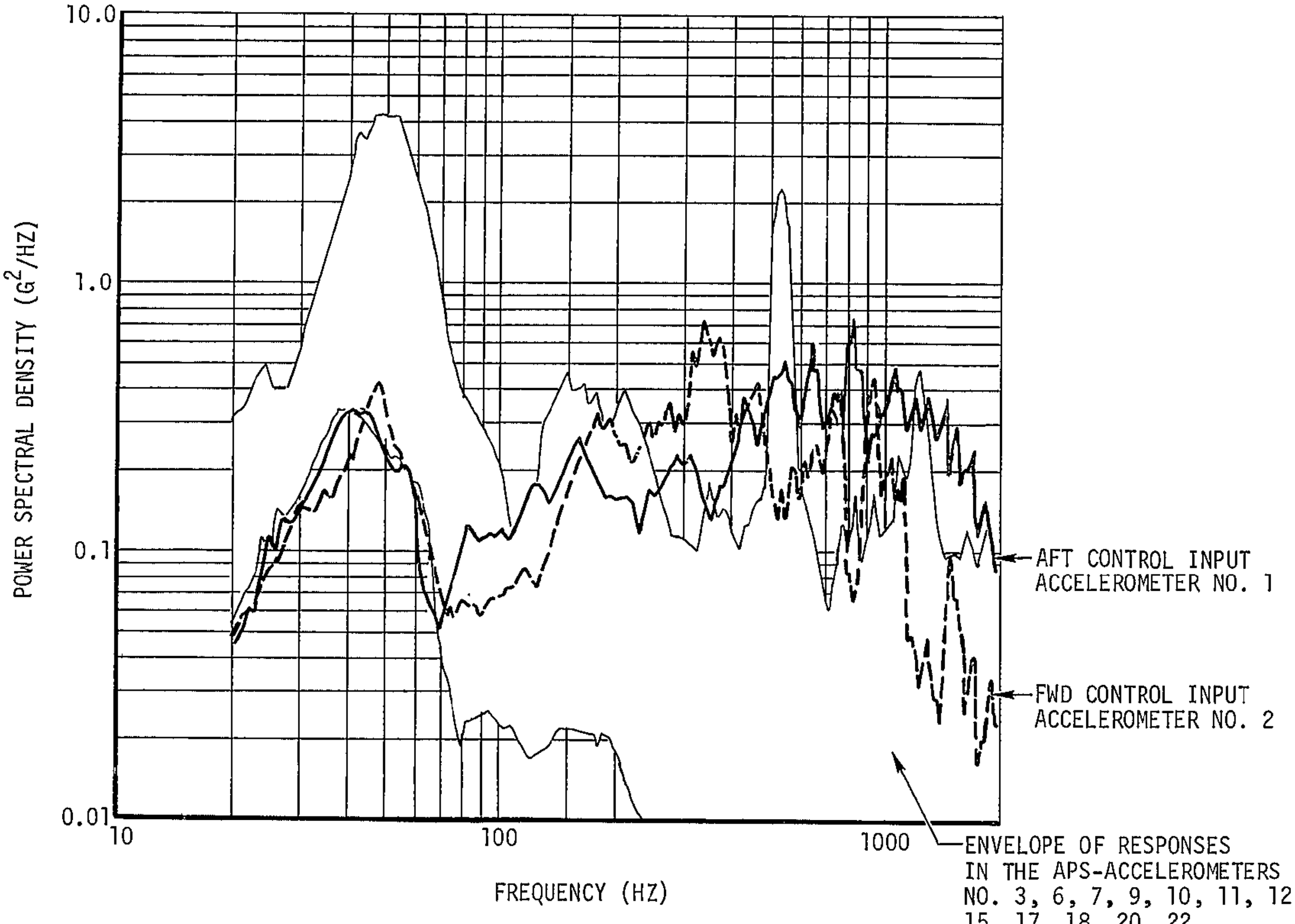


Figure 7-23. Comparison of Input & Responses Data - Radial Axis

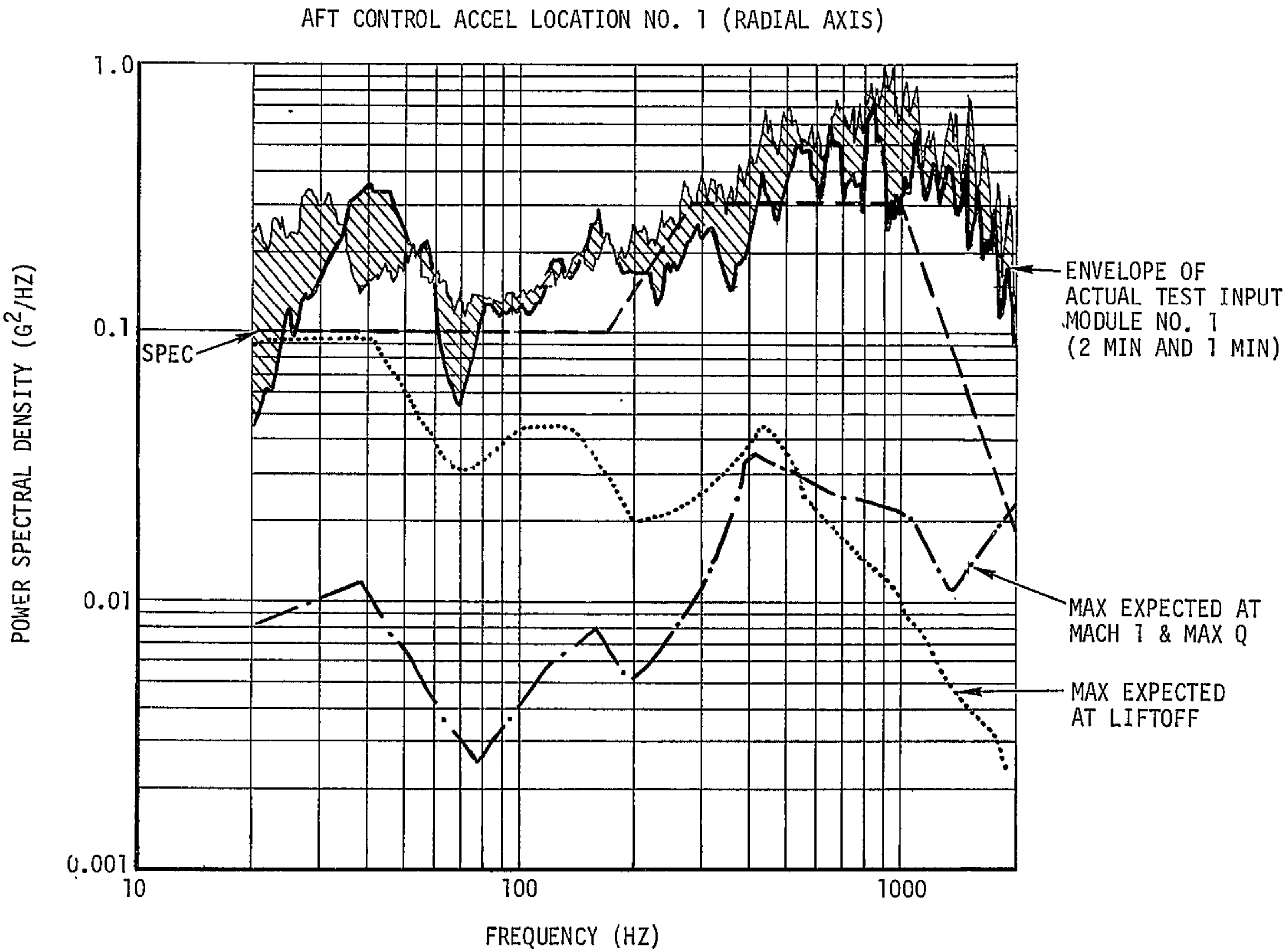


Figure 7-24. Comparison of Specification Test Data with Maximum Expected Flight Environment (Sheet 1 of 2)

FORWARD CONTROL ACCEL LOCATION NO. 2 (RADIAL AXIS)

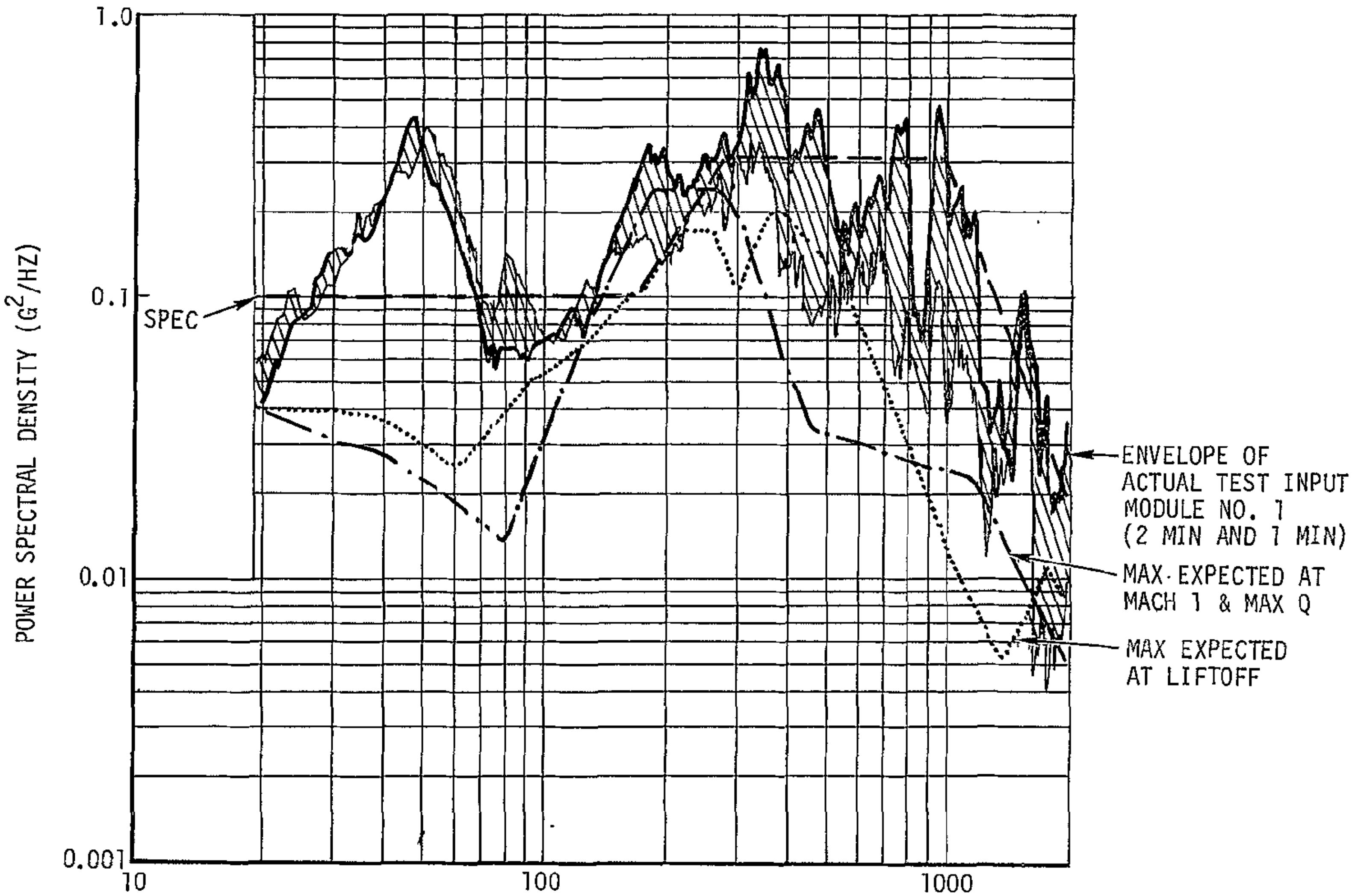


Figure 7-24. Comparison of Specification Test Data with Maximum Expected Flight Environment (Sheet 2 of 2)

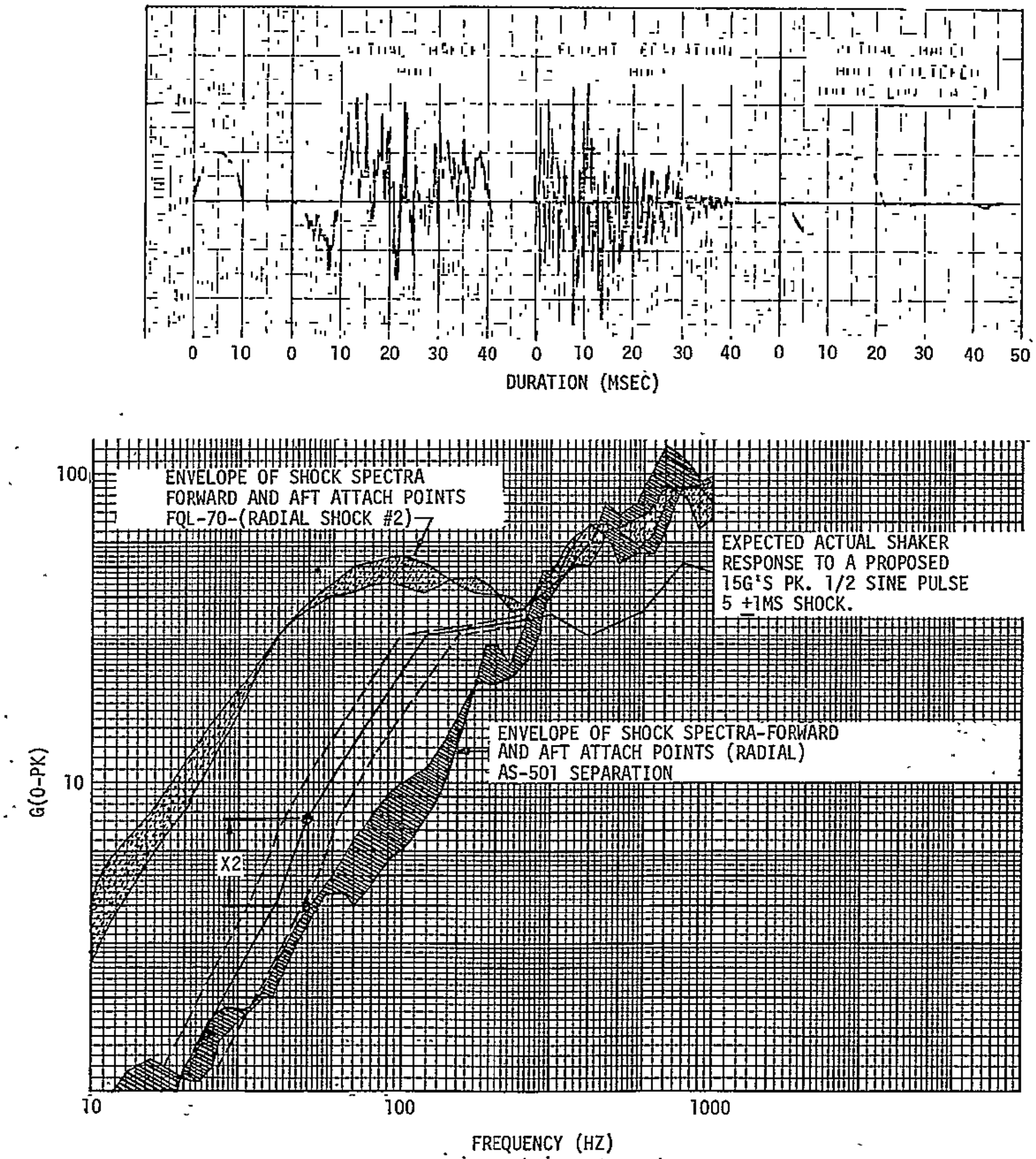


Figure 7-25. Comparison of Radial Axis Shock Spectra

SECTION 8

LUNAR MISSION DUTY CYCLE

8. LUNAR MISSION DUTY CYCLE

The APS module was transported to the Gamma test site while loaded with propellants. During transportation, the maximum allowable dynamic loading of 1.5 g's was not exceeded.

The simulated lunar mission duty cycle (LMDC) test was conducted on APS module 1 on 27 and 28 August 1968, at Complex Gamma, STC. Engine No. 3 was electrically disabled to preserve the evidence which would determine the cause of the low chamber pressure in engines 1 and 3 that occurred during the burp-firings of the extended hold test.

The LMDC test consisted of a clearing burst, burp-firings, and a 6.5 hr duration firing program (figure 8-1) controlled automatically by punched tape. The program was divided into four major stage flight phases: first J-2 engine burn, earth orbital coast, second J-2 engine burn, and translunar coast. APS operation during the two J-2 engine burn periods was limited to counteracting induced roll moments. The 4.5 hr earth orbital coast was subdivided into 22 coast periods, 21 maneuvers, and the J-2 engine chilldown. The 2-hr translunar coast consisted of initial convergence, LOX and LH2 blowdown, and limit cycle control operations. The APS operation for the first J-2 engine burn and a portion of the earth orbital coast (a total of 2 hr and 50 min) was completed 27 August 1968. The remainder of the earth orbital coast, second J-2 engine burn, and the translunar coast was completed 28 August 1968.

The following paragraphs describe the test performance.

8.1 Pressurization System

8.1.1 High Pressure System

Figure 8-2 presents the history of helium bottle pressure, temperature, and calculated helium mass during the simulated LMDC.

Pressurization of the helium bottle on 27 August 1968 was initiated at 0901 hr and reached a maximum pressure of 3,185 psia at 0908 hr. The temperature in the bottle increased from 543 to 591 deg R during pressurization. During the 40 min prior to the first engine firings, the bottle conditions stabilized at 550 deg R and 2,975 psia. The calculated helium mass in the bottle, based on these conditions, was .987 lbm.

After the engine clearing burst and burp-firings, it was determined that the firing cables should be rewired to their initial configuration before continuing with the duty cycle. This required the depressurization of the helium bottle at 1003 hr. The bottle was vented to 90 psia in 10 min and 16 sec. The lowest helium temperature recorded during the vent was 431 deg R.

The second helium bottle pressurization started at 1100 hr on 27 August. The maximum pressure reached was 3,185 psia at 1107 hr. During pressurization, the temperature in the bottle increased from 528 to 584 deg R. Prior to the first engine firings, temperature and pressure in the helium bottle stabilized at 569 deg R and 3,130 psia, respectively. Based on these conditions, the helium mass in the bottle was 1.005 lbm.

As shown in figure 8-2, the bottle pressure decreased rapidly between 1127 and 1138 hr. During this time the ullage engine and two attitude control engines were firing, causing the rapid reduction of helium pressure from 3,045 psia to 2,730 psia.

During the duty cycle, it was discovered that engine No. 1 was receiving unprogrammed firing pulses. A hold in the test was called and the engine No. 1 firing GSE relay was replaced. This did not eliminate the problem so another hold for trouble-shooting was called.

Prior to depressurization (to trouble-shoot the engine No. 1 firing problem) the helium bottle pressure was 2,520 psia. The helium temperature was 560 deg R. The mass of helium remaining in the bottle was .842 lbm indicating a usage of .163 lbm during the day's firing.

Following the resolution of the engine firing problem, the LMDC was continued on 28 August 1968. Pressurization of the helium bottle began at 1030 hr and was completed at 1037 hr. The maximum pressure and temperature recorded were 2,600 psia and 600 deg R. Prior to the first engine firing on 28 August the helium bottle conditions stabilized at 2,590 psia and 590 deg R. Using these values, the calculated helium mass was .815 lbm.

An ullage engine firing from 1329 to 1335 hr accounted for the rapid decrease in bottle pressure from 2,340 psia to 1,775 psia (figure 8-2). Prior to venting the helium bottle at the conclusion of the LMDC, the bottle conditions were 1,670 psia and 569 deg R. This is equivalent to .518 lbm of helium. Thus, .297 lbm of helium was used during the portion of the LMDC conducted on 28 August 1968, and .460 lbm was consumed for the total test.

Venting of the bottle from 1,670 psia to 80 psia was initiated at 1553 hr and completed in 5 min 40 sec. The lowest temperature recorded during the vent was 424 deg R.

Analysis of the helium bottle data prior to the initial engine firings on 27 and 28 August 1968 showed that no helium leakage occurred in the high pressure system.

8.1.2 Low Pressure System

The operation of the low pressure system was satisfactory throughout the LMDC.

8.1.2.1 Helium Regulator

During hold periods on 27 August 1968, the helium regulator outlet pressure remained between 48 and 64 psia. When the system was pressurized on 27 August 1968, and referenced to ambient, the pressure range was 203-207 psia; and when referenced to vacuum, the range was 190-193 psia. The system was referenced to a vacuum during engine firings except for the engine clearing burst and burp-firings.

During a hold period on 28 August 1968, the regulator outlet pressure remained between 58 to 70 psia. Prior to the first engine firing (ambient regulator reference), the regulator remained between 200 to 205 psia. During engine firings, the regulator remained between 190-194 psia. The specification value for regulator outlet pressure is 196 ±3 psia with vacuum reference and 211 ±3 psia with sea level reference. It was apparent that some of the regulator outlet pressures were below these values from 1 to 3 psia. These apparent low readings are attributed to instrumentation accuracy. The transducer used to record these values had a 0-400 psia range. The normal accuracy of data from such a transducer is approximately one percent of full range or ±4 psi.

8.1.2.2 Fuel Manifold and Ullage Pressure

Figure 8-3 presents the history of the fuel manifold pressures during the LMDC. The supply manifold pressure remained in the 54 to 65 psia range during the hold periods on 27 August 1968. After system pressurization on 27 August 1968, the range was 201 to 204 psia referenced to ambient, and 185 to 199 psia referenced to vacuum. During hold periods on 28 August 1968, the manifold pressure ranged from 60 to 68 psia. After pressurization on 28 August 1968, the supply manifold pressure was maintained at 200 to 205 psia referenced to ambient, and 190 to 198 psia referenced to vacuum.

Figure 8-3 shows the effect of referencing the regulator to a vacuum. The pressurizations of the helium bottle at 1100 hr on 27 August 1968, and 1030 hr on 28 August 1968, were performed with the regulator referenced to sea level. The regulator was then referenced to a vacuum. As soon as the engines commenced firing and a demand was placed on the regulator, the supply pressures dropped approximately 15 psi. The difference in the rate of the drop was due to the difference in the amount of engine firings.

The ullage pressure remained in the 60-68 psia range during the hold periods. During pressurization on 27 August 1968, the ullage pressure ranged from 204 to 207 psia referenced to ambient and 190 to 191 psia referenced to vacuum. During pressurization on 28 August 1968, the ullage pressure ranged from 204 to 206 psia referenced to ambient, and 189 to 192 psia referenced to vacuum.

8.1.2.3 Oxidizer Manifold and Ullage Pressure

Figure 8-3 presents the history of the oxidizer manifold pressure during the LMDC. The oxidizer manifold pressure was maintained at 54 to 82 psia during hold periods on 27 and 28 August 1968. After pressurization on 27 August the range was 200 to 212 psia referenced to ambient, and 188 to 195 psia referenced to vacuum. After pressurization on 28 August 1968, the manifold pressure ranged from 201 to 209 psia referenced to ambient, and 189 to 196 psia referenced to vacuum.

As in the case of the fuel manifold pressure, decreases in oxidizer manifold pressure were exhibited on 27 August 1968, at 1126 hr and on 28 August 1968, at 1103 hr. The reasons for these decreases in pressure are the same as those described in paragraph 8.1.2.2 (i.e, switch from ambient regulator reference to vacuum regulator reference).

The oxidizer ullage pressure ranged from 56 to 78 psia during hold periods on 27 and 28 August 1968. After pressurization on 27 August 1968, the ullage pressure ranged from 206 to 208 psia referenced to ambient, and 188 to 197 psia referenced to vacuum.

8.2 Propellant Utilization

8.2.1 Fuel System

Prior to initiation of the LMDC, the fuel tank was topped by the addition of approximately 2.1 gal of MMH. Interpretation of fuel tank x-rays indicated the fuel bladder contained 120.3 lbm of fuel with a 6.1 percent ullage prior to the engine firing bursts. Following the LMDC, x-rays indicated 23.5 lbm of fuel remained in the system. Thus, a total of 96.8 lbm of fuel was used during the LMDC.

The quantity of fuel used, determined from the helium usage, was 104 lbm. This value agrees with the value determined from the x-rays. Both agree with the propellant usage obtained from past LMDC tests performed at the Gamma test site.

8.2.2 Oxidizer System

Prior to the LMDC, 2.0 gal of oxidizer were added to the oxidizer tank. Interpretation of tank x-rays showed that the oxidizer bladder contained 189.4 lbm of oxidizer with a 9.8 percent ullage. Following the LMDC, x-rays indicated 53.9 lbm of oxidizer remained in the system. Thus, a total of 135.5 lbm of oxidizer, which gives an average engine mixture ratio of 1.4 to 1, was used during the LMDC.

The quantity of oxidizer used, determined from the helium usage, was 146 lbm. This value agrees reasonably well with the x-ray method and with previous LMDC tests.

8.3 Engine Performance

The LMDC firings consisted of a clearing burst, burp-firing from each of the four engines, and 6.5 hr firing simulating the LMDC. Engine chamber pressures during the LMDC are presented in figure 8-4.

The regulator setting for all previous burp-firings was referenced to ambient; for the LMDC, it was referenced to vacuum. Referencing to vacuum reduces the propellant supply pressure to the engine by 15 psi which will result in a chamber pressure loss of from 5 to 7 psi. The initial supply pressure after referencing to vacuum remains at the ambient reference pressure and provides higher chamber pressures until engine firing reduces the line pressure to the intended vacuum referenced pressure.

8.3.1 Clearing Burst

A single burp-firing of 500 ms to clear any possible gas ingestion in the propellant lines (required because of possible ingestion of gas at Alpha site) was first scheduled for engine No. 2. The chamber pressure history of this engine had been considered good from previous burp-firings. The oscillograph of this clearing burst showed a fairly smooth chamber pressure trace at 102 psia, indicating little or no gas in the lines.

8.3.2 Burp-Firings

The chamber pressure history from the extended hold portion of the test indicated that engine No. 1 had the lowest performance. Prior to the LMDC burp-firings, the electrical connectors to engines 1 and 3 were switched so that engine No. 3 would receive the heavier duty cycle firings. It was intended that engine No. 1 would be deactivated following the burp-firings; however, the burp-firing data of engine No. 1 exhibited an improved chamber pressure of 75 psia and engine No. 3 chamber pressure reduced to 36 psia. In keeping with the original philosophy of deactivating the lowest performing engine while maintaining a high duty cycle on the active engine, the electrical connectors of engines 1 and 3 were returned to their original configuration and engine No. 3 was deactivated for the LMDC.

The chamber pressure from engine No. 2 remained at 102 psia, and the chamber pressure from engine No. 4 was 107 psia.

The burp-firings from each engine consisted of one 250 ms pulse followed by two 65 ms pulses separated by 750 ms off-times for each of the three attitude control engines. The ullage control engine during burp-firing was scheduled for 550 ms. The burp-firing results are presented in table 8-1.

8.3.3 Engine No. 1

The first group of pulses was performed by engine No. 1 for 165 sec simulating roll control during the first J-2 engine burn. The chamber pressure of this group of pulses ranged from 73 to 76 psia. As the firing continued into the coast period, the chamber pressure of this engine gradually improved. By the end of the day, after 2 hr and 50 min into the duty cycle, the chamber pressure had increased to 91 psia.

Spurious short pulses were noted from the chamber pressure and valve current traces intermittently throughout the first day. Investigation of this problem showed a malfunction of the GSE electrical circuits supplying the pulse signals to engine No. 1. The malfunction was corrected and no spurious pulses were noted the following day.

The chamber pressure from the remaining earth orbital coast period during the second day, showed continued improvement to a high of 96 psia. During the final 2 hr of the translunar coast period, the Pc stayed between 96 to 97 psia.

8.3.4 Engine No. 2

The chamber pressure of engine No. 2 was from 96 to 101 psia the first day. The high chamber pressure of 99 to 101 psia from a group of pulses at the beginning of the LMDC was due to initially high manifold pressures. As the regulator downstream pressure eventually referenced to vaccum, the chamber pressure reduced to 96 to 98 psia.

The performance of this engine remained at the high level of 96 to 102 psia during the second day. The 6 psi difference was believed to be due to the following:

a. Pulse width - longer pulses at a steady state condition generally had higher chamber pressure.

b. Single and multiple pulses - a single pulse was free from any injection pressure disturbances at the time of initiation. A multiple pulse was initiated at 500 ms or less from the end of the previous pulse where some transient oscillations still existed in the propellant lines resulting in a slightly higher chamber pressure for a short pulse.

c. Differences in calibration and measurements.

d. Supply pressure variations during test.

8.3.5 Engine No. 3

Previous testing performed on module 1 during the extended hold test indicated that chamber pressure of engines 1 and 3 had decreased to 35 psia and 54 psia, respectively; as a function of time and burp-firings. The cause of this pressure loss was deemed important by both MDAC and NASA and it was mutually decided that engine No. 1 would be deactivated during the LMDC test so as not to disturb or destroy the cause of the low chamber pressure. Agreement was also made to connect engine No. 3 to the electrical control cable of engine No. 1 and therefore subject it to the engine No. 1 firing program during the LMDC test.

During the burp-firing, prior to the LMDC, it was discovered that engine No. 1 chamber pressure had increased to 75 psia while engine No. 3 chamber pressure had decreased to 36 psia. The electrical connectors were returned to their original position, then engine No. 3, instead of engine No. 1, was electrically disabled to preserve the evidence which would determine cause of the low chamber pressure in engines 1 and 3.

8.3.6 Engine No. 4

This engine ran for 91 sec following the simulated first J-2 engine burn. The chamber pressure was at a steady 100 psia. The second ullage engine burn prior to the simulated J-2 engine restart ran for 330 sec at 100 psia.

On 30 August 1968, during the LMDC post-test inspection, a black substance was discovered leaking from engine No. 4 (P/N 15-210001, S/N 4071857).

Further investigation revealed that the substance was a sealant used to seal the engine nozzle to the mounting structure. The leakage did not affect the operation of the engine and was considered acceptable by engineering.

8.3.7 Valve Currents

The valve current traces and the command signals of the LMDC pulses were examined to cross-check with the chamber pressure oscillographs at an identical scale. The spurious pulses previously noted from the chamber pressures were identified and checked against the valve current traces.

It was noted from these short spurious pulses that when the command signal duration was longer than 17 ms, oxidizer manifold pressure oscillations and a short chamber pressure spike were observed. Below 13 ms the oxidizer manifold pressure oscillations and the chamber pressure spike were absent. The latter could be due to the minimum time required to open the oxidizer valve which was slightly longer than that of the fuel valve, as indicated in table 5-5. The command signals between 13 and 16 ms did not consistently generate these chamber pressure spikes.

The valve opening sequence, timing delay, and signal to chamber pressure initiation of the LMDC pulses, were within the time frames of the 75-Day Extended Hold.

Valve current perturbations discussed in paragraph 5.3.4 were noted occasionally from oxidizer valves 2, 3, and 4 of engine No. 1 throughout the LMDC firing. No valve current perturbations were observed on engines 2 and 4.

8.4 Conclusion

The APS module performed satisfactorily during all phases of the LMDC. There was no indication of engine chamber pressure degradation although engine No. 1, which had exhibited a low chamber pressure prior to the LMDC, gradually improved.

TABLE 8-1
CHAMBER PRESSURE HISTORY LMDC BURP-FIRINGS

		BURP-FIRINGS	
		NO. OF DAYS	
		111 (8-27-68)	112 (8-28-68)
ENG 1-3 (PSIA)	250 ms	36	NO BURP-FIRINGS
	65 ms	34	
	65 ms	34	
ENG 1-2 (PSIA)	250 ms	103	
	65 ms	102	
	65 ms	102	
ENG 1-1 (PSIA)	250 ms	75	
	65 ms	72	
	65 ms	73	
ENG 1-4 (PSIA)	550 ms	107	
		Duty Cycle	Duty Cycle
ENG 1-1 (PSIA)		73 to 91	92 to 97
ENG 1-2 (PSIA)		96 to 101	96 to 102
ENG 1-3		Did Not Fire	Did Not Fire
ENG 1-4 (PSIA)		100	100
PROP TEMP (°F)	OXID	88	100
	FUEL	82	93
MANIF PRESS (PSIA)	OXID	196	195
	FUEL	185	191

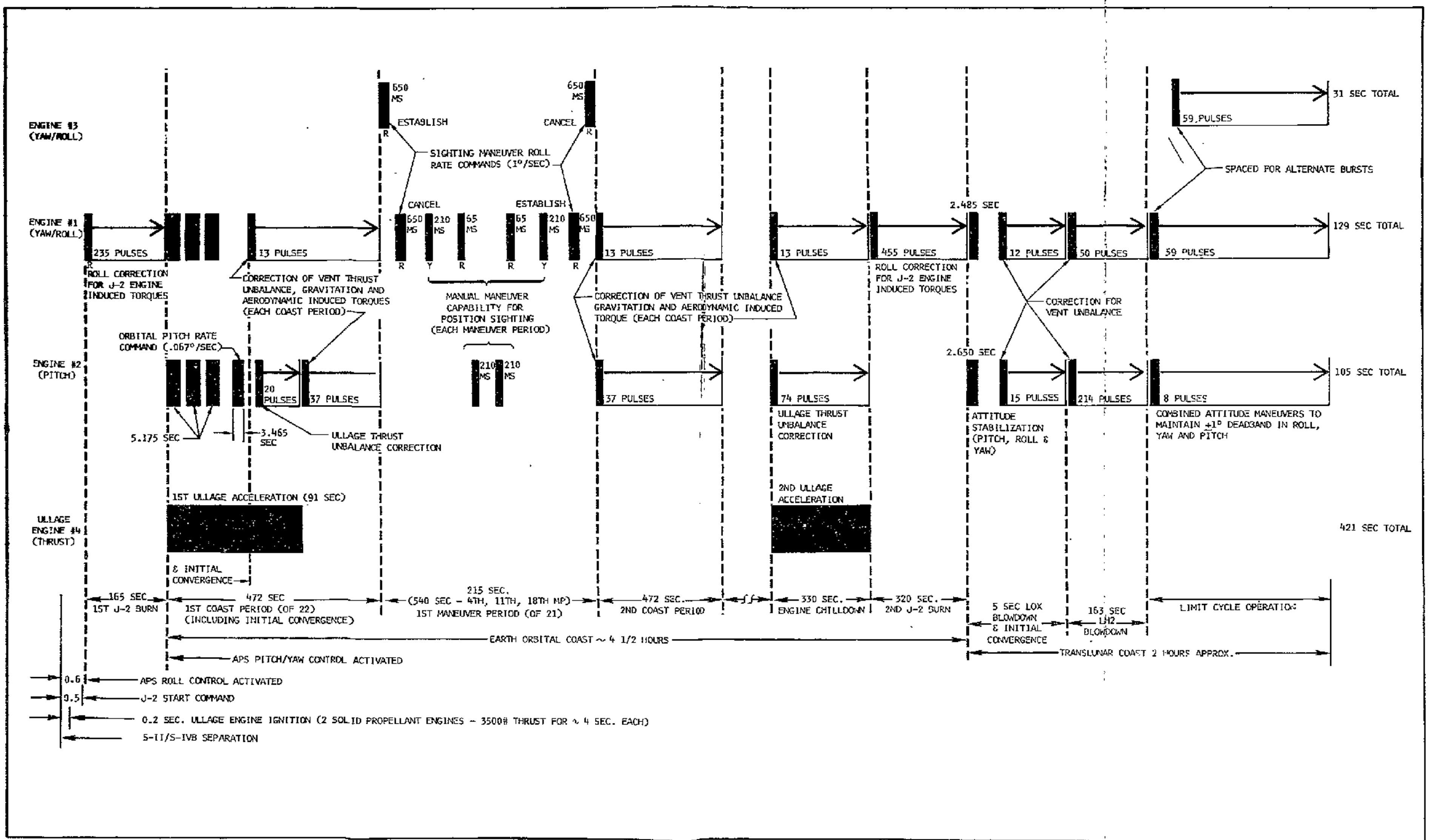


Figure 8-1. 6 1/2 Hour Lunar Mission Duty Cycle Firing Program

FOLDOUT FRAME 1

FOLDOUT FRAME 2

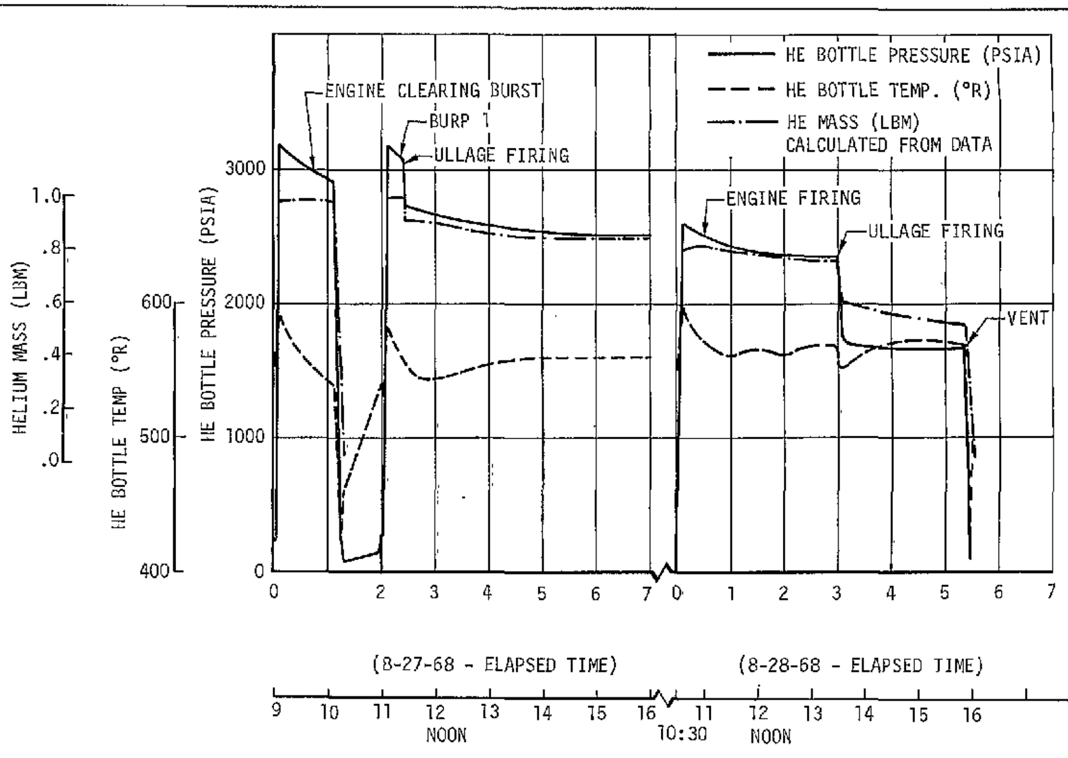


Figure 8-2. LMDC Helium Bottle Data

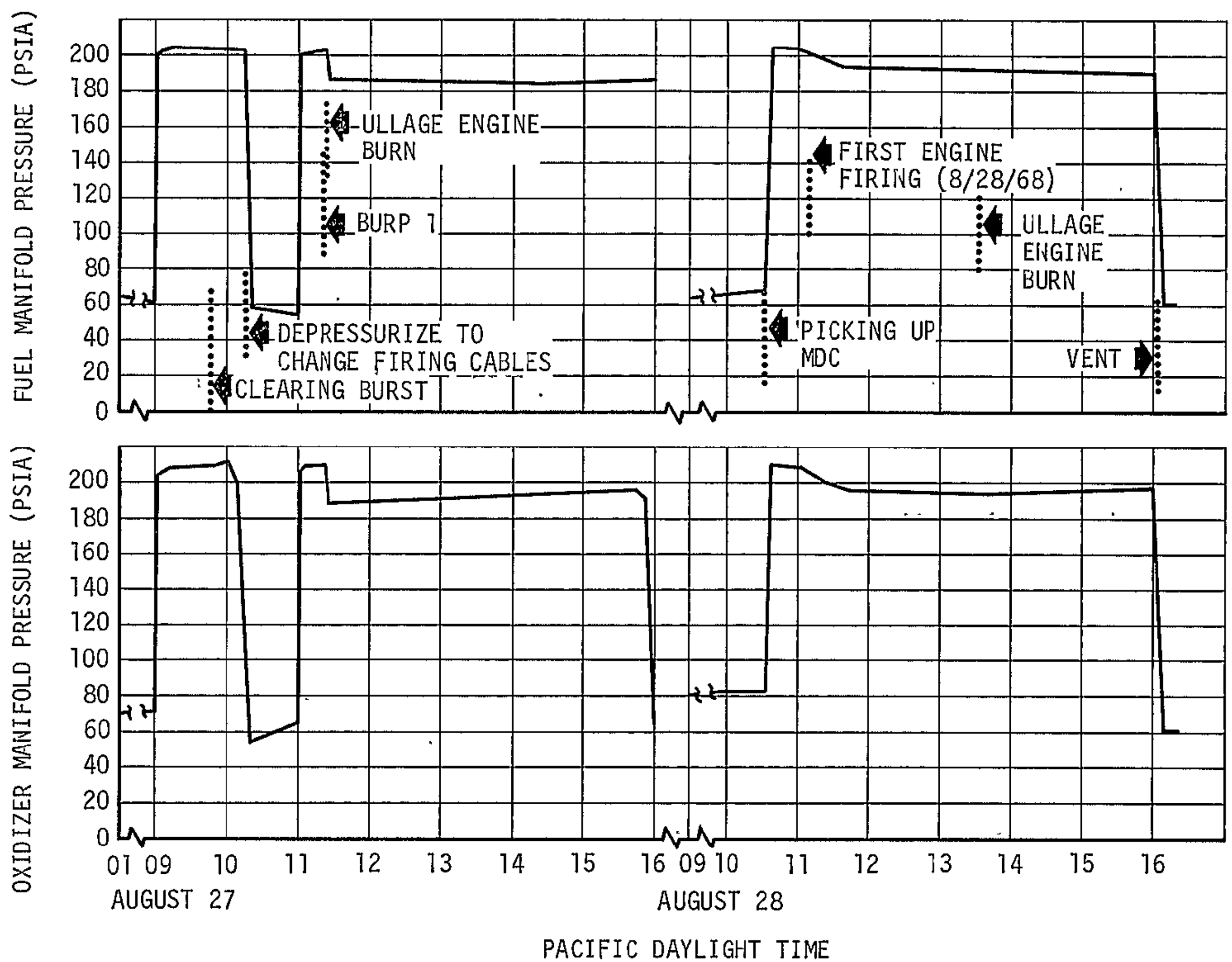
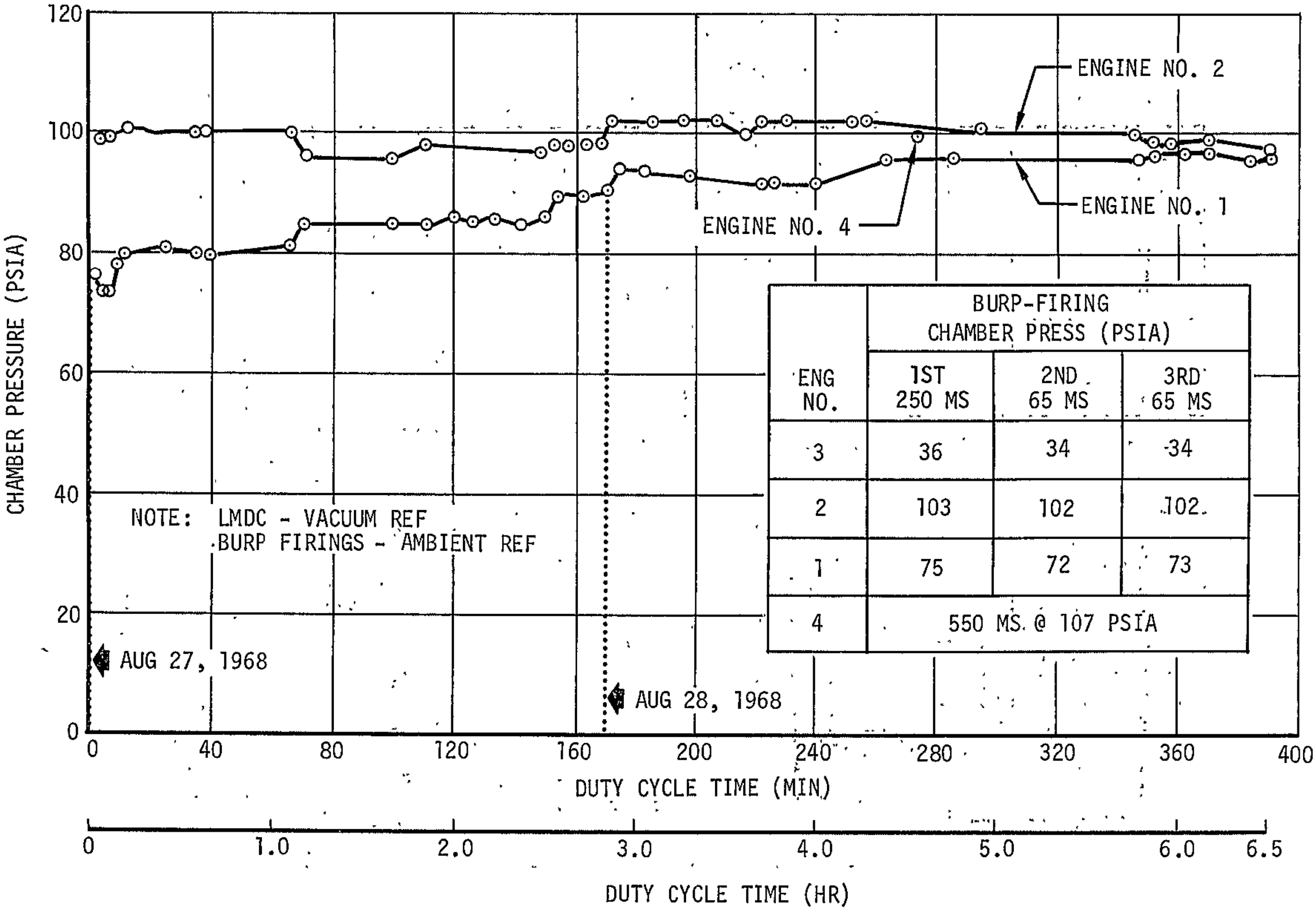


Figure 8-3. LMDC Fuel and Oxidizer Manifold Pressure



ENG NO.	BURP-FIRING CHAMBER PRESS (PSIA)		
	1ST 250 MS	2ND 65 MS	3RD 65 MS
3	36	34	34
2	103	102	102
1	75	72	73
4	550 MS @ 107 PSIA		

Figure 8-4. Chamber Pressure History During LMDC

SECTION 9

DISASSEMBLY AND INSPECTION

9. DISASSEMBLY AND INSPECTIONS

This section describes the results of the disassembly and inspection of APS module I conducted in accordance with Phase V APS Disassembly and Inspection Procedure, 1B73229, from 28 August to 7 October.

After completion of the Lunar Mission Duty Cycle (LMDC), the APS module 1 was disassembled and inspected for failures and contamination. The disassembly consisted of a teardown of the module and its components and included the cutting of welded assemblies. The following paragraphs describe the failures, anomalies, and contamination found during the disassembly:

9.1 Failures

A failure is defined as any discrepancy which could possibly cause loss of mission. The failures that were found after disassembly of module 1 are listed in Table 9-1 chronologically. The following paragraphs describe the failures:

9.1.1 Oxidizer Bladder

On 13 September, 1968, the oxidizer bladder was removed from the oxidizer tank. The vendor bladder part No., XN8339-471080-3A, S/N 139-3 was verified and the bladder inspected. A tear approximately 6 in long was found in the forward end (ullage area) of the bladder (figure 9-1). After the failure was verified, the bladder was returned to the vendor for a failure analysis (see appendix 1). The vendor's failure analysis indicated that the failure was caused by stress resulting from application of sudden-type loadings on the bladder rather than by fatigue.

The cycle record for this bladder indicated 7.6 cycles up until the time of failure.

Subsequent analysis of the vibration data revealed that the duration of the radial axis random vibration test, as specified in the test control document, was excessive.

9.1.2 Fuel Bladder

On 13 September 1968, the fuel bladder was removed from the fuel tank. The vendor bladder part No. P/N XN8339-4171080-3A, S/N 129-3, was verified and the bladder inspected. A tear approximately 5 in. long was found in the forward end (ullage area) of the bladder (figure 9-2). After the failure was verified the bladder was returned to the vendor for a failure analysis (see appendix 1). The vendor failure analysis indicated that the failure was caused by stress resulting from application of sudden-type loadings on the bladder rather than by fatigue.

The cycle record for this bladder indicated 7.5 cycles through August 19.

Subsequent analysis of the vibration data revealed that the duration of the radial axis random vibration test, as specified in the test control document, was excessive.

9.1.3 Oxidizer Tank Diffuser Tube

On 13 September 1968, the oxidizer propellant tank, P/N 1B63924-506, S/N 025 was disassembled and the diffuser tube was found to be broken (figure 9-3). This break extended completely around the aft end of the diffuser tube where the tube was welded to the cone section of the mounting plate. The break allowed the tube to separate at the aft end and hit against the internal recirculation tube which extends through the center of the diffuser tube. The diffuser tube assembly was sent to MM & RE for analysis. The failure was shown to have been caused by fatigue or high cycle low stress. The parts were inspected for conformance to the vendor's engineering drawings; no out of tolerance or out of specification conditions were found. Subsequent analysis of the vibration data revealed that the duration of the radial axis random vibration test, as specified in the test control document, was excessive.

9.2 Anomalies

An anomaly is defined as a discrepancy which is undesirable and not normal but which would not cause loss of mission. Anomalies that were found after disassembly of module 1 are listed in table 6-1 chronologically. The following paragraphs describe the anomalies. A contamination analysis is presented in table 9-2.

9.2.1. Fuel Low Pressure Helium Module (1A49998-509, S/N 106G)

The fuel low pressure helium module (figure 9-4) was disassembled and the following discrepancies noted:

a. Several scratches were found on the relief valve poppet, but they did not affect operation.

b. The solenoid area was splattered with a black substance. Function of the solenoid was not affected. Analysis showed this substance to be a plastic polymer, appearing to be some form of rust combined with MMH polymer.

c. Three dead flies were found in the module; two downstream of the relief valve, and one upstream of the relief valve.

d. Liquid droplets in fuel ullage vent line were analyzed as a combination of MMH and rust.

e. Solenoid plunger rhodium flash plate worn approximately 120 deg radial ring. No metallic particles found.

9.2.2 Fuel Low Pressure Helium Module (1A49998-509, S/N 101G)

The fuel low pressure helium module (S/N 101G) was originally installed in the 507-1 APS, but was replaced by S/N 106G after failure. Inspection of S/N 101G after disassembly revealed contamination as follows:

a. A large amount of brown and black residue on the solenoid-to-body flange.

b. Black residue on the plunger assembly.

MM&RE analysis showed the contamination to be mainly MMH, nitrates, and gold and iron oxides.

9.2.3 Oxidizer Low Pressure Helium Module

The oxidizer low pressure helium module (1A49998-512, S/N 129G) was disassembled and the following discrepancies noted:

a. Brown particles and residue in inlet and relief side (figure 9-5), with analysis reported as aluminum metal, possibly corroded or discolored, and in the solenoid side as primarily a complex iron-nickel-oxide-nitrate compound.

9.2.4 Fuel Propellant Control Module

The fuel propellant control module (1A49422-510, S/N 000025) was disassembled and the following minor discrepancies noted:

a. Rust-like corrosion on the weld attaching the L1 solenoid flange to its mount flange.

b. A small quantity of seal lubricant on the facility lines purge check valve poppets.

c. Several very small black tar-like deposits on the underside of the recirculation solenoid plunger. This was similar to minor contamination found on the fuel quad check valve and was possibly a form of MMH.

9.2.5 Oxidizer Propellant Control Module

The oxidizer propellant control module (1A49422-509, S/N 0000070) was disassembled and the following discrepancies noted:

a. The pressure transducer mounting flange (mount #MT625) was discolored with a stain having the appearance of rust. The transducer had been removed three days prior to this inspection and moisture had accumulated on the flange, subsequently analyzed as rust.

b. Longitudinal scratches were noted on the fill solenoid plunger with matching scratches on the bore. No burrs, particles, or other evidence of contamination were present in the area of the solenoid.

c. Several particles of teflon-like consistency were found in the recirculation solenoid and analyzed as LOX compatible lubricant per DPM 3329-1.

d. Yellow crystal formation on temperature transducer flange was analyzed as LOX compatible lubricant per DPM 3329-1.

9.2.6 Fuel Quad Check Valve

The fuel quad check valve (1A67912-505, S/N 1109) was disassembled and the following discrepancies noted:

a. A large quantity of a black liquid substance was found downstream of the upstream check valves between series check valve and in the outlet flange of the valve (figure 9-6). This appeared to be the same type of liquid found in the fuel low pressure helium module and the tube assembly between the fuel quad check valve and the fuel low pressure helium module and was analyzed as a form of MMH.

b. Two wear rings noted around upstream "A" check valve guide. No metallic particles were found.

9.2.7 Oxidizer Quad Check Valve

The oxidizer quad check valve (1A67912-503, S/N 1018) was disassembled and no contamination or major discrepancies were noted.

On 4 September 1968, the oxidizer quadruple check valve (P/N 1A67912-503, S/N 1018) indicated a leak slightly above that allowable. The check valve leaked 3.5 sccm over a 5-min period with a differential pressure of 5 psid from outlet port to inlet port. The allowable leakage is 3.0 sccm over a 5-min period with a differential pressure of 5 psid from outlet port to inlet port. Leakage measured during hold periods with 50 psi differential pressure was zero.

It was concluded that the leakage was at low pressure and in no way affected the operation of the APS module.

9.2.8 Fuel Propellant Tank Assembly

The fuel propellant tank assembly (1B63924-505, S/N 026) was disassembled and the following discrepancies noted:

a. Ruptured fuel bladder (see paragraph 9.1.2).

b. Contamination in the form of black specks was noted inside the aft end of the bladder. Identification and analysis of this contaminant was not conclusive.

9.2.9 Oxidizer Propellant Tank Assembly

The oxidizer propellant tank assembly (1B63924-506, S/N 025) was disassembled and the following discrepancies noted:

a. Ruptured oxidizer bladder, broken diffuser tube, and bent standpipe (see paragraph 9.1.1).

b. No contamination was noted.

9.2.10 Helium Pressure Regulator

The helium pressure regulator (1B54601-505, S/N 03825M640060) was disassembled and no contamination or discrepancies noted, other than corrosion on secondary regulator sense tube assembly at weld-on exterior of regulator, and an odor of hypergolics about the regulator assembly.

9.2.11 Engine No. 1

Engine No. 1 (1A39597-509, S/N 731) was disassembled and the following items noted:

a. Oxidizer and fuel valves were clean of contaminants.

b. A dry green substance was found underneath the oxidizer engine trim orifice at the injector tube inlet (figure 9-7). Analysis of this deposit is reported as a possible complex iron-nickel-nitrate compound. This deposit was similar to that found in engine No. 3, except that it was in a drier condition.

c. Injector outlets were clean of contaminants.

d. A black carbon-like residue was found on the threads and male fitting end of the P_c sensor.

e. Removal of P_c elbows indicated fitting contained large deposits of black gummy substance in volume adjacent to P_c sensor male fitting.

f. Both fuel and oxidizer valve package inlet screens were clean and free of contamination and corrosion.

9.2.12 Engine No. 2

Engine No. 2 (1A39597-509, S/N 803) was disassembled and the following items noted:

a. Oxidizer and fuel valves were free of contamination, except for a small metal chip found in the fuel valve immediately above the conoseal flange.

b. Both oxidizer and fuel valve package inlet screens were clean and free of contamination and corrosion.

c. A soot-like residue existed on the upper (as mounted in the APS) half of the divergent nozzle.

d. Very slight traces of a dark soot-like deposit were noted at the oxidizer injector face to orifice interface.

e. A black carbon-like residue was found on the threads and male fitting end of the P_c sensor.

f. The P_c elbow contained a black coke-like smudge on its complete interior surface.

9.2.13 Engine No. 3

Engine No. 3 (1A39597-509, S/N 615) was disassembled and the following items noted:

a. A small chip was noted on the teflon seat face of valve plunger L1.

b. A light trace of seal lube was noted on the L1 solenoid body seal.

c. A small gold-colored particle was noted on the L5 teflon seat.

d. Several very small particles were imbedded in plunger L6 seal face.

e. The area under the oxidizer trim orifice was found to have a jelly-like substance that seemed to have completely blocked the 12 oxidizer feed tube inlets (figure 9-8). After removing the trim orifice, which also contained some contamination on the downstream side, it was found that all but two oxidizer tube openings were blocked by a green liquid that appeared to be nickel nitrate - $N_i(NO_3)_2$ (figure 9-9).

f. After removing the silver alloy heat sink and the oxidizer tube and flange assembly, 5 of the 12 oxidizer tubes were split (figure 9-10) with the following results:

Tube No. 1 Wet - residual oxidizer

Tube No. 2 Wet - residual oxidizer

Tube No. 5 - Small hard black deposit on tube inner surface.

Tube No. 6 - Clean and dry

Tube No. 12 - Wet black liquid deposit. A wet chemical test, using Dimethyl Glyoxime, indicated the presence of nickel.

g. Some deposits were noted at the oxidizer tube to injector interface plates. Figure 9-11 shows four such tubes, ranging from clean to partially blocked.

h. The fuel trim orifice and orifice cavity were free of contamination.

i. The fuel flow divider was free of contamination other than several minute black deposits noted at the point of impingement.

j. The fuel flow divider cavity and the 12 fuel injector orifices were clean and clear; however, some residual fuel was noted in this area.

k. A dark, heavy residue was noted on the injector face (figure 9-12).

l. The combustion chamber and throat insert were free of contamination except injector face, chamber side, showed a black residue at the top and a white residue at the bottom. These were classified as probable combustion products.

9.2.14 Engine No. 4

Engine No. 4 (P/N 15-210001, S/N 4071857) was disassembled and the following items noted:

a. A brown hard residue was forced out of the four vent holes in the exit nozzle shroud. This was analyzed as refrasil resin liquefied by the engine temperature.

b. A dark brown heavy liquid (similar to MMH) was noted within the oxidizer injector cavity.

c. The same type of heavy liquid residue (similar to MMH) was noted on the fuel injector face as found in the oxidizer injector cavity.

d. Several white whisker-like particles were found downstream of the oxidizer filter, analyzed as LOX compatible lubricant (DPM 3329-1)

e. Removal of P_c sensor line indicated yellow oil-like liquid on engine port threads and line flare end (similar to MMH).

f. A mixture of small metal shavings and MMH was observed in the fuel valve.

9.2.15 High Pressure Helium Check Valves

The primary (upstream) and secondary (downstream) high pressure helium check valves (1B68379-1, S/N's 353 and 354 respectively) were disassembled and the following anomalies (common to both valves with respect to discrepancies and contamination) noted:

a. Poppet spring ends scarred. The spring was not deformed and appeared to function properly.

b. Valve poppet had a wear ring around it where poppet had contacted the shoulder of the valve body.

c. No metallic particles were found.

9.2.16 Filters, Oxidizer System

The following filters were disassembled and no major evidence of contamination or discrepancies found:

Filter	S/N	Service
1B55934-1	10306034	Oxidizer Tank Ullage Drain Line
1B55934-1	1036047	Oxidizer Ullage Supply
1B55934-1	1036306*	Oxidizer Recirculation

*Minor discrepancies:

(a) Filter element nicked by grinder during disassembly

(b) Metal chip attached to body at filter inlet. Apparently from original machining of valve body.

9.2.17 Filters, Fuel System

The following filters were disassembled and no major evidence of contamination or discrepancies found:

Filter	S/N	Service
1B55934-501	1036313	Fuel Tank Ullage Drain Line
1B55934-501	1036310	Fuel Ullage Supply
1B55934-501	1036371	Fuel Recirculation

9.2.18 Helium Tank Assembly

The helium tank assembly (1B39317-501, S/N 021) was disassembled and the following contamination and discrepancies noted:

a. Greenish-yellow crystal formation on the inner surface of the temperature transducer flange (1B40623-1). Analyzed as discolored LOX compatible lubricant - DPM 3329-1.

b. MC249C4N elbow not torqued properly.

c. Dark stains inside helium tank. Contamination not analyzed in absence of sample.

9.3 Conclusion

Subsequent analysis of the vibration data revealed that the duration of the radial axis random vibration test, as specified in the test control document was excessive.

The contamination in the APS engines was thought to be caused by the burp-firings which have subsequently been deleted from prelaunch requirements.

The contamination found in the components was attributed to long term exposure but did not affect the functional operation of the APS during the LMDC. Consequently the APS module can tolerate long exposures with no serious detrimental effects to its functional operation.

TABLE 9-1 (Sheet 1 of 2)
FAILURES AND ANOMALIES

SEQUENCE	DATE (1968)	PROBLEM	WHEN OBSERVED	CLASS	DISPOSITION
1	6-6	Eng No. 1 P_c Degradation	30th day of hold	Anomaly	Continued test
2	6-21	Eng No. 3 P_c Degradation	45th day of hold	Anomaly	Continued test
3	7-25	Bladder N_2O_4 Leak	77th day of hold	Anomaly	Continued test
4	7-26	Eng No. 2 Transducer Shift	80th day of hold	Anomaly	Replaced - Continued with new component
5	8-12	Missing Door Hdw	Pre-Vib Insp	Anomaly	Continued test
6	8-12	Eng No. 3 Cover Crack	Pre-Vib Insp	Anomaly	Continued test
7	8-13	Fuel Vent Valve Hang Up	Thrust Post-Axis Insp	Anomaly	Continued test with new component
8	8-15	Chipped Tank Supports	Thrust Post-Axis Insp	Anomaly	Continued test
9	8-18	Missing Clamp	Tangential Post-Axis Insp	Anomaly	Corrected - Continued Test
10	8-20	Oxid Bladder Leak	Radial Post 2-min Random Checkout	Failure	Continued test at disassembly
11	8-21	Fuel Bladder Leak	Radial Post-Axis Checkout	Failure	Continued test at disassembly
12	8-21	He Press Line Crack	Radial Post-Axis Checkout	Failure	Replaced, continued test with new tube assembly
13	8-22	Transducer Amplifier Shock Mounts	Radial Post-Axis Checkout	Anomaly	Continued test
14	8-23	Attach Fittings	Radial Post-Axis Checkout	Failure	Continued test

TABLE 9-1 (Sheet 2 of 2)
FAILURES AND ANOMALIES

SEQUENCE	DATE (1968)	PROBLEM	WHEN OBSERVED	CLASS	DISPOSITION
15	8-27	GSE Malfunction	During LMDC	Anomaly	Corrected - Continued test
16	8-30	Eng No. 4 Sealant Leak	Post Fire Insp	Anomaly	Continued test
17	9-4	Oxid Quad Chk Leak	Post Fire Checkout	Anomaly	Continued test
18	9-10	Missing Transducer Screw	Disassembly & Insp	Anomaly	No further test required
19	9-13	Oxid Bladder Diffuser Tube	Disassembly & Insp	Failure	Failure analysis required-No further test required

TABLE 9-2 (Sheet 1 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Chamber Pressure Transducer Mounts, ENG #1,2&3 1B38510-501	Firing Chamber	Black, carbon-like residue	Inconclusive	No major elements	Not able to identify	Chloride-trace nitrate-trace nickel-negative	Visually similar to nickel nitrate ($Ni[NO_3]_2$) but "Wet" tests gave a negative nickel test. Probably combustion products
He Tank Temperature Transducer Flange 1B40623-1	Helium	Greenish-yellow residue	Similar to fluorocarbon lubricant PR 240 AC DPM 3329-1				Discolored LOX compatible lubricant - DPM 3329-1
Oxidizer System Transducer 1B 31413-1 P/N 2091-4001, S/N 1284	Oxidizer	(1) White grease residue (2) Brown residue	(1) and (2) fluorocarbon lubricant PR 240 AC DPM 3329-1				(1) LOX compatible lubricant, DPM 3329-1 (2) Discolored LOX compatible lubricant - DPM 3329-1.
Helium Low Pressure Module - Oxidizer Relief Side & Inlet Side 1A49998-512 Solenoid Plunger	Helium	(1) Brown particles & residue (2) Not described	(1) Inconclusive (2) Inconclusive	(1) Major-aluminum (2) Principal iron & nickel, hi minor-gold	(1) Aluminum metal (2) Primarily Fe_2O_3 and $NiFe_2O_4$	(1) Nitrate faint trace (2) Chloride trace, nitrate-strong	(1) Aluminum metal, possibly corroded or discolored. (2) Primarily a complex iron-nickel-oxide-nitrate compound.
Engine #3 Oxidizer Injector Tube #1	Oxidizer	Green liquid	Inconclusive			Nickel-positive	Visually appears to be nickel nitrate-$Ni(NO_3)_2$

TABLE 9-2 (Sheet 2 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Engine #3 Oxidizer	Oxidizer	Green solid crystals	Inconclusive			Nickel & iron-positive, nitrate positive	Appears to be nickel nitrate-$Ni(NO_e)_2$ & possibly iron nitrate $Fe(NO_3)_2$ or $Fe(NO_3)_3$
Engine #3 Oxidizer Injector Ports	Oxidizer	Green crystals	Inconclusive	Principal-iron, nickel major-chromium	Possibly iron oxide Fe_2O_3 no positive identification	Nitrate-very strong, nickel-positive, iron-slightly positive, chloride & sulfate-negative.	Appears to be nickel nitrate-$Ni(NO_3)_2$, possibly iron nitrate $Fe(NO_3)_2$ or $Fe(NO_3)_3$ or possibly iron oxide Fe_2O_3.
Engine #3 Fuel Injector Port	Fuel	Liquid	Some H_2O, rest was inconclusive				Some water, the rest was inconclusive.
Hard Line 1B65680-1	Oxidizer	White grease	Fluorocarbon lubricate (PR 240 AC) DPM 3329-1				LOX compatible lubricant DPM 3329-1
Engine #3 Oxidizer Injector Tube #2	Oxidizer	Green liquid	Inconclusive				Visually appears to be nickel nitrate-$Ni(NO_3)_2$
Engine #3 Fuel Trim Orifice Injector Side	Fuel	Brown liquid	Some Similarity to MMH			MMH Positive	Similar to MMH

TABLE 9-2 (Sheet 3 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Helium Transducer MT 646-1A67863-521	Helium					Not enough sample to identify	Not enough sample to identify.
GSE Flowmeter Oxidizer	Oxidizer	Green crystals		Principal-iron, nickel major-silicon	Deliquescent-could not be identified	Insufficient sample	Possibly a complex iron-nickel-nitrate
Engine #4 Chamber Pressure Sense Line,1B57441-1	Firing Chamber	Dark brown liquid	Similar to MMH			MMH-positive, nickel & iron negative	Similar to MMH
Fuel Ullage Vent Line - 1B55640-1	Fuel	Black liquid	Some similarity to MMH			MMH & iron positive nickel - negative	Could be combination of MMH and rust.
Oxidizer Pressure control Module-Recirc Solenoid Housing	Oxidizer	White grease particles	Similar to fluorocarbon lubricant (PR 240 AC) DPM 3329-1				LOX compatible lubricant DPM 3329-1
Oxidizer Pressure Control Module-Recirc Inlet Flange	Oxidizer	White grease residue	Fluorocarbon lubricant (PR 240 AC) DPM 3329-1				LOX compatible lubricant DPM 3329-1

TABLE 9-2 (Sheet 4 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Oxidizer Pressure Control Module-MT 625	Oxidizer	Reddish-brown solie residue				Iron-positive, nickel - negative	Appears to be rust
Oxidizer Pressure Control Module-Temp. Probe Flange	Oxidizer	White grease residue	Fluorocarbon lubricant (PR 240 AC) DPM 3329-1			Iron and nickel - negative	LOX compatible lubricant DPM 3329-1
Engine #1 Oxidizer Injector Ports	Oxidizer	Green crystals		Principal-iron & nickel, major chromium, hi minor-gold	Deliquescent could not be identified	Chloride-trace, sulfate-negative, nitrate-strong	Possibly a complex iron-nickel-nitrate
Engine #3 Injector Face (Plastic Section) Chamber Side	Firing chamber	Black residue top, white residue - bottom		Principal-iron & nickel major - aluminum chromium & silicon	Crystalline portion is iron sulfide (Fe_3S_4)	Chloride & sulfate-negative, nitrate-trace	Probably combustion products.
Fuel Bladder Bell P/N 8339-471080-3 S/N 129-3	Fuel	No description		Major-silicon, hi minor-iron & aluminum	Amorpous-could not be identified	Chloride & nitrate-trace, sulfate-negative	No conclusion.

TABLE 9-2 (Sheet 5 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Hard Line-Helium System 1B59953-1	Helium	No description				Not enough to identify	Not enough to identify.
Hard Line-Helium System 1B59856-1-plus attached elbow	Helium	1. Elbow-solid 2. Hard line-brown residue	1. Some type of halocarbon grease			2. Iron-positive	1. Some type of halocarbon 2. Possibly rust
Oxidizer-Low Pressure Helium Module-Vent Poppet	Oxidizer	No description					Sample lost enroute to Santa Monica for analysis-no results.
Fuel Low Pressure Helium Module-Solenoid Pole Piece	Fuel	Brown solid residue	An inorganic type spectrum.			Nickel-negative iron-positive	Visually looks like rust-microscopically looks like a plastic polymer-could be some form of rust combined with MMH polymer
Fuel Quad Check Valve 1A67912-505N S/N 1109	Fuel	Black liquid	Spectrum contaminated with moisture-inconclusive	Major-Manganese & iron, hi minor-nickel & chromium	Liquid could not be identified	MMH-positive, chloride & sulfate-netative, nitrate-very strong	Possibly a form of MMH
Helium Tank Assembly 1B39317-501 S/N 021	Helium	No description					No sample

TABLE 9-2 (Sheet 6 of 6)
CONTAMINATION ANALYSIS OF APS MODULE 1

PART AND PART NO.	SYSTEM	DESCRIPTION OF CONTAMINANT	ANALYSES				CONCLUSION
			INFRARED	EMISSION SPECTROGRAPH	X-RAY	"WET" CHEMICAL	
Fuel Valve-P/N 409405-S/N 8821169-Engine #4	Fuel	Small metal shavings				MMH positive	Indication of MMH on the metal shavings
Engine #4 Oxidizer Valve P/N 409404-S/N 8821940	Oxidizer	No description					Not enough sample to analyze.
Engine #4 Injector Face Plate	Oxidizer	Brown oily residue	Hydrocarbon residue				No conclusion
Engine #1 Oxidizer Trim Orifice	Oxidizer	Green crystals		Major-silver, hi minor-copper	Deliques-cent could not be identified	Iron & nickel-positive, chloride-negative, sulfate & nitrate-very strong	Possibly a complex iron-nickel-nitrate compound.
Fuel Low Pressure Helium Module-Solenoid Flange	Fuel	Brown residue scraped off gold plating				Iron-posi-tive, nickel-negative	Indicates rust

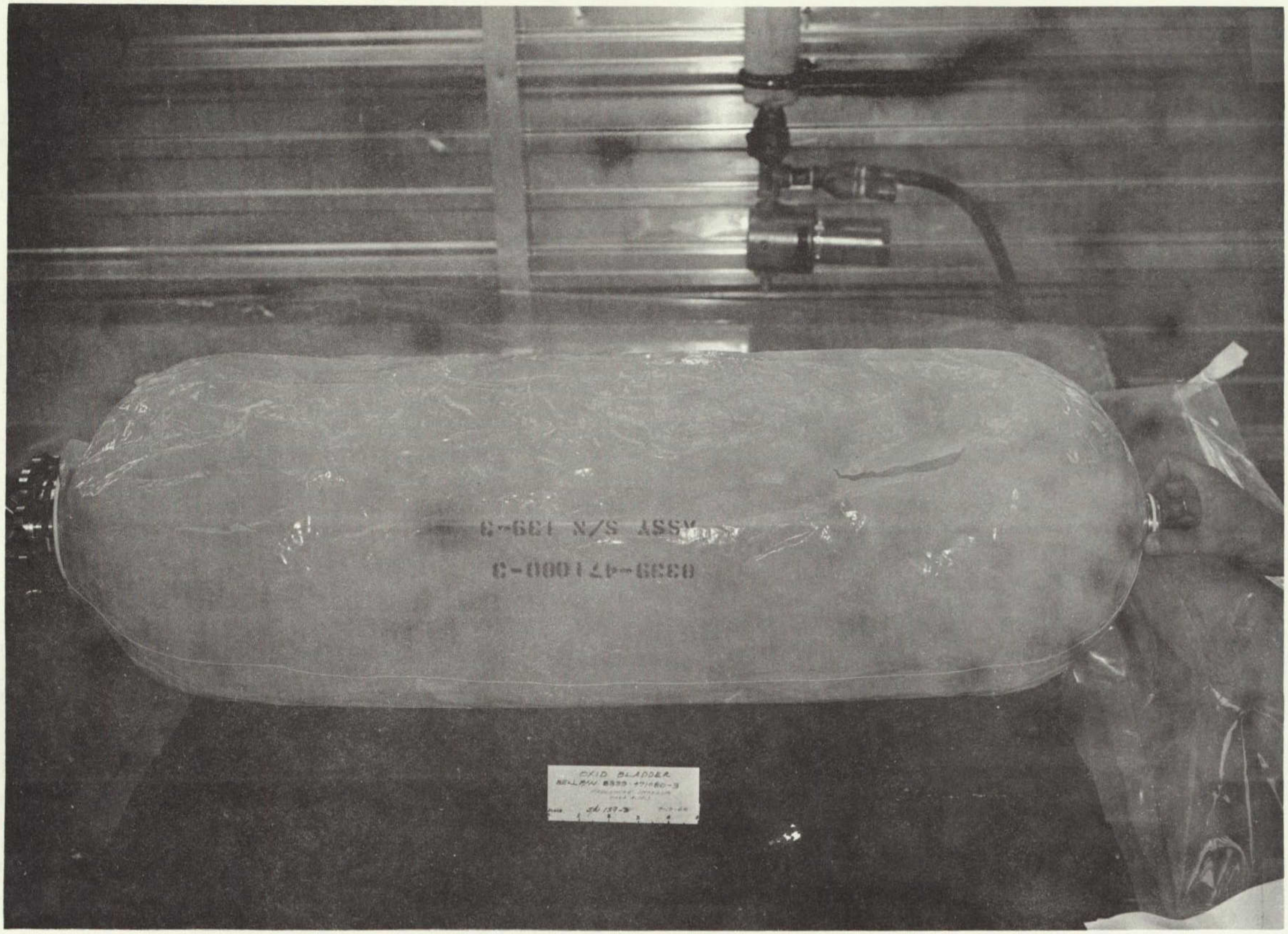


Figure 9-1. Oxidizer Bladder (Sheet 1 of 2)

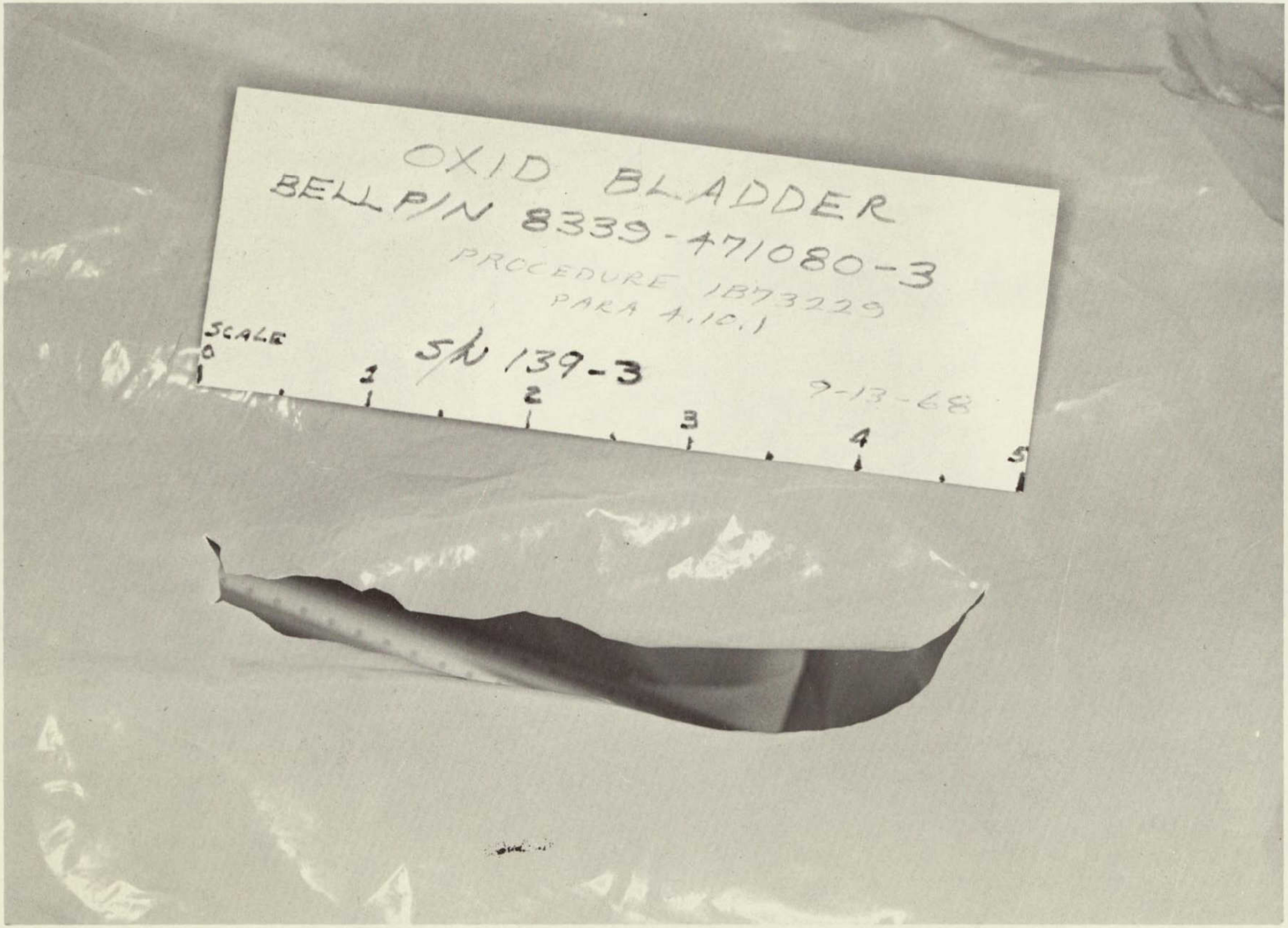


Figure 9-1. Oxidizer Bladder (Sheet 2 of 2)

Figure 9-2. Fuel Bladder (Sheet 1 of 2)

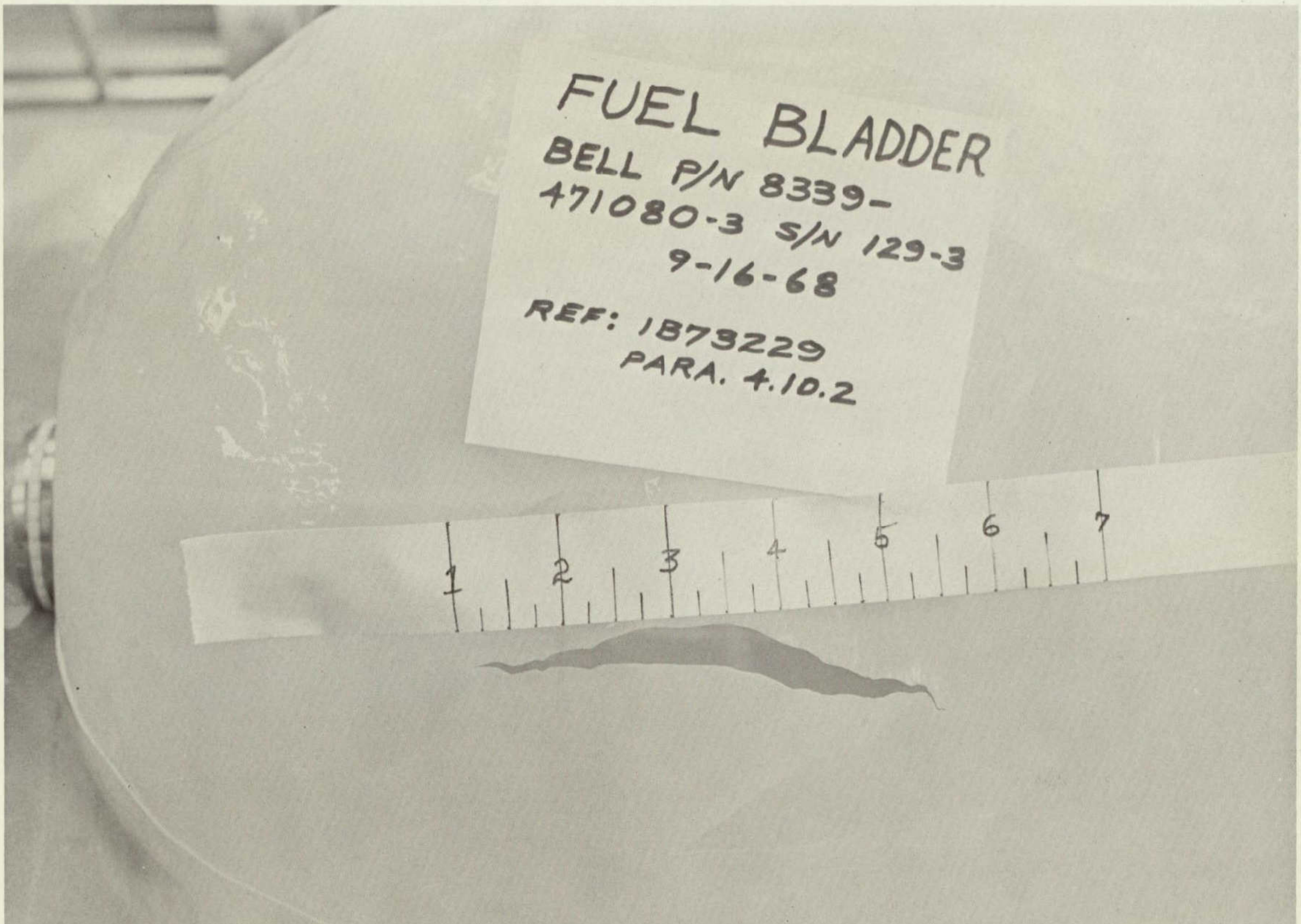


Figure 9-2. Fuel Bladder (Sheet 2 of 2)

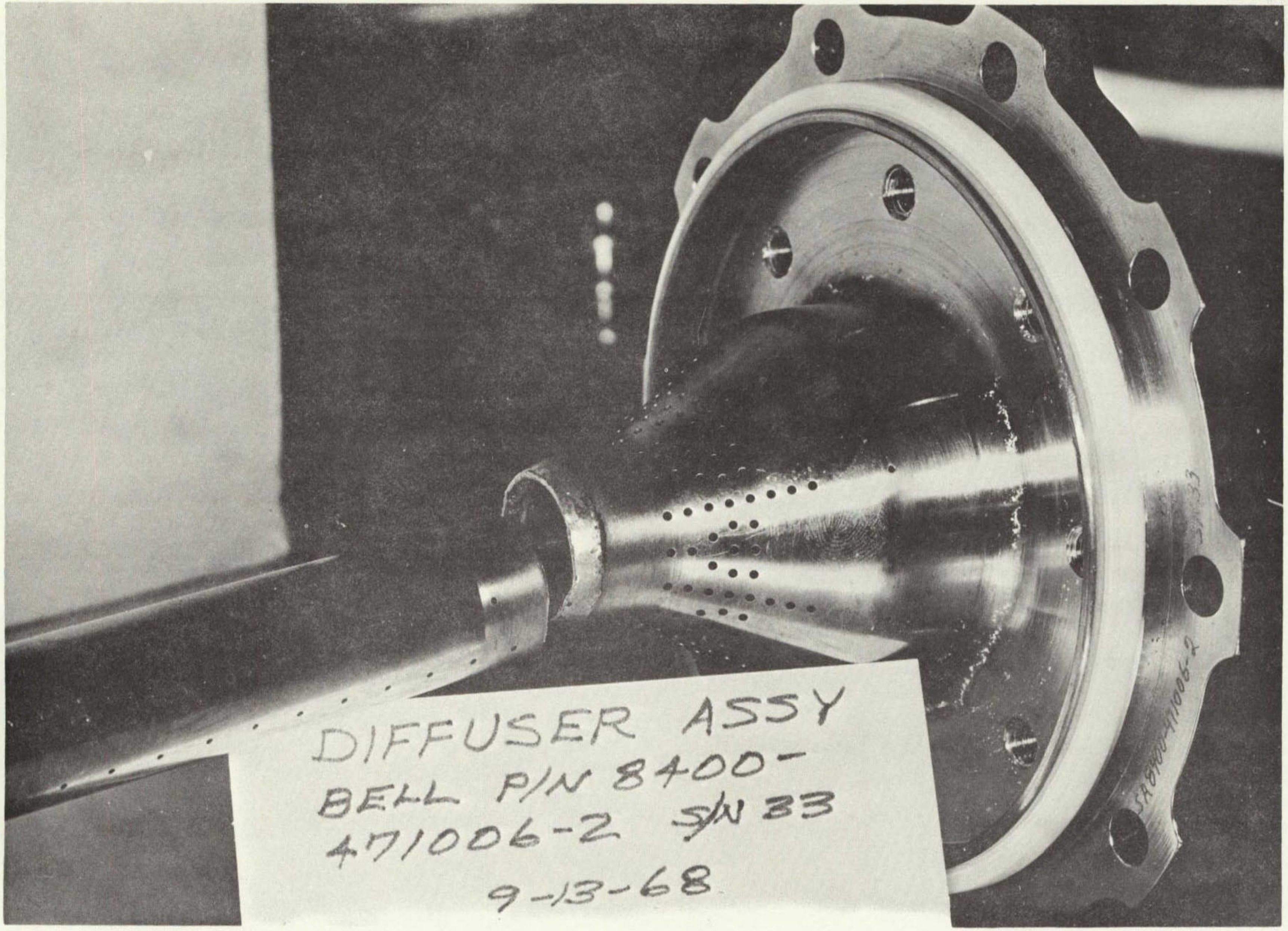


Figure 9-3. Oxidizer Tank Diffuser Tube (Sheet 1 of 2)

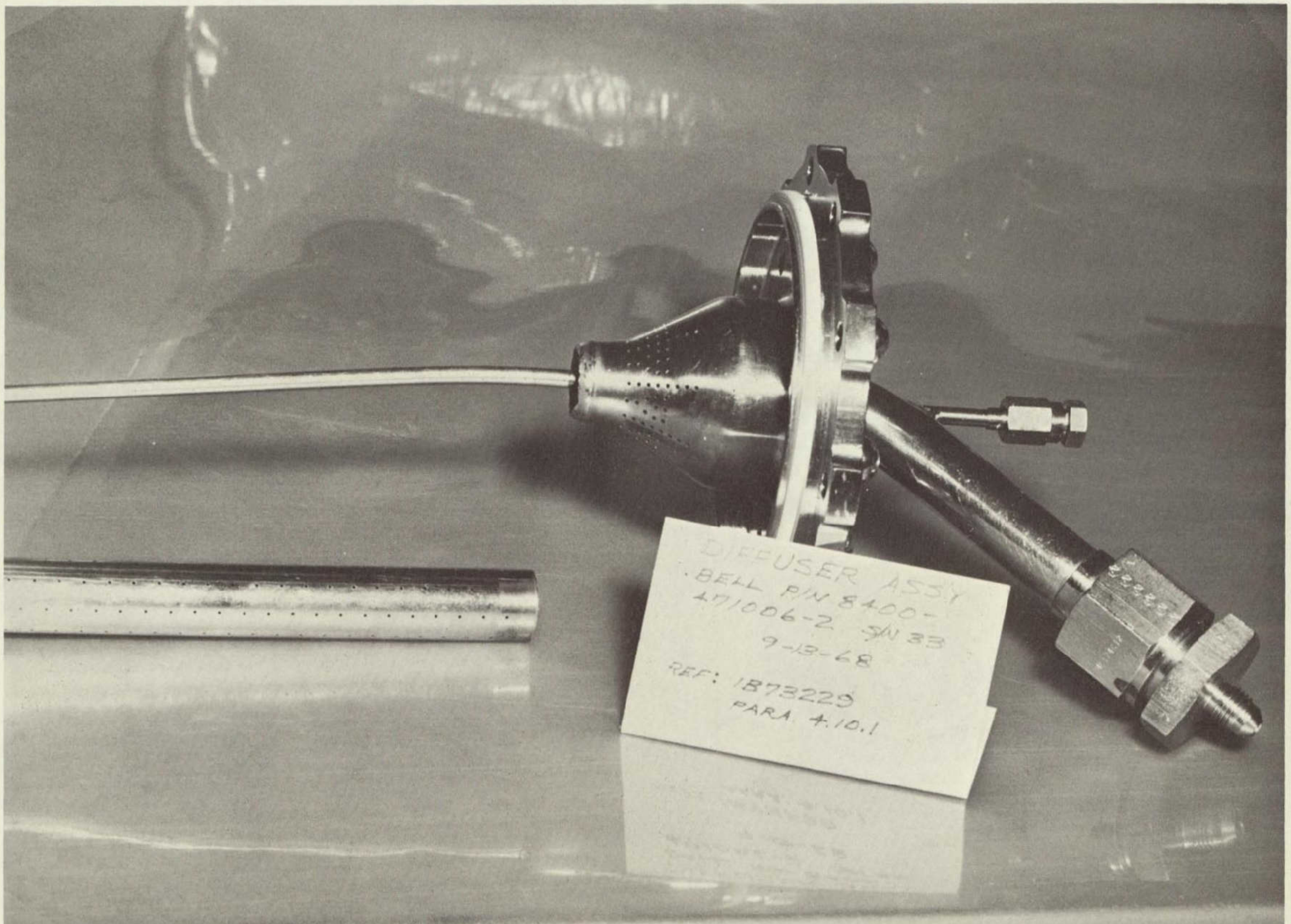


Figure 9-3. Oxidizer Tank Diffuser Tube (Sheet 2 of 2)

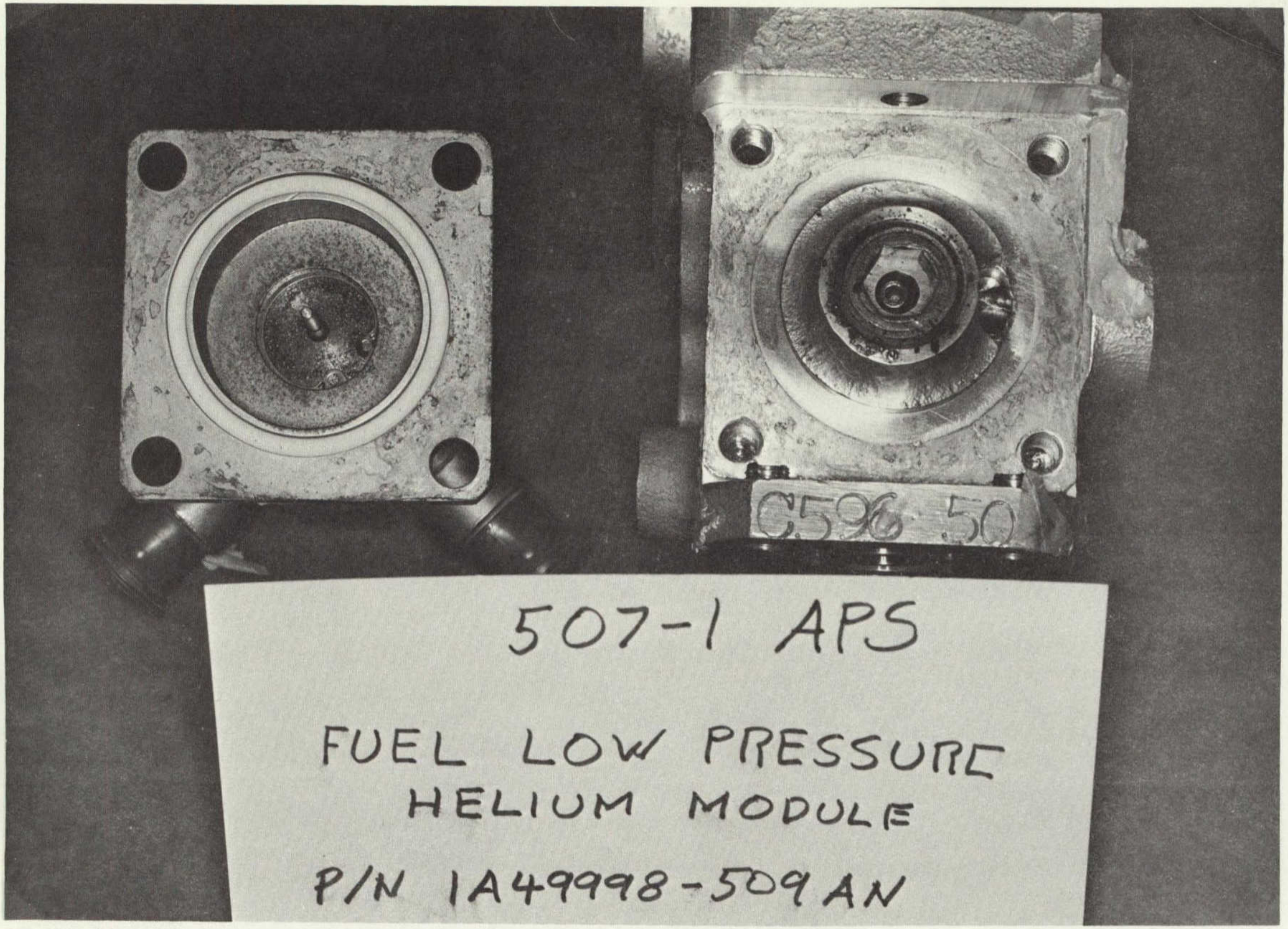


Figure 9-4. Fuel Low Pressure Helium Module

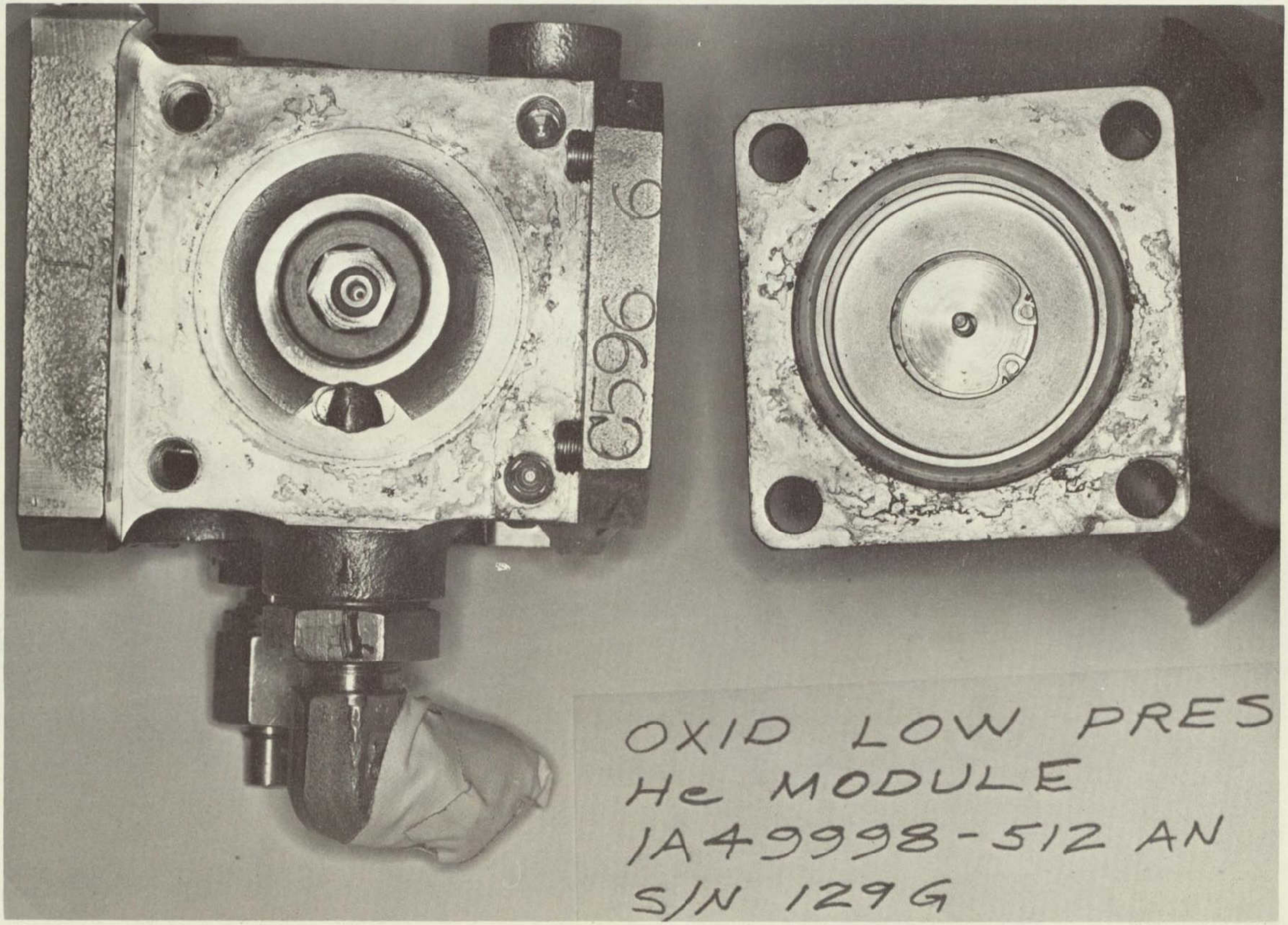


Figure 9-5. Oxidizer Low Pressure Helium Module

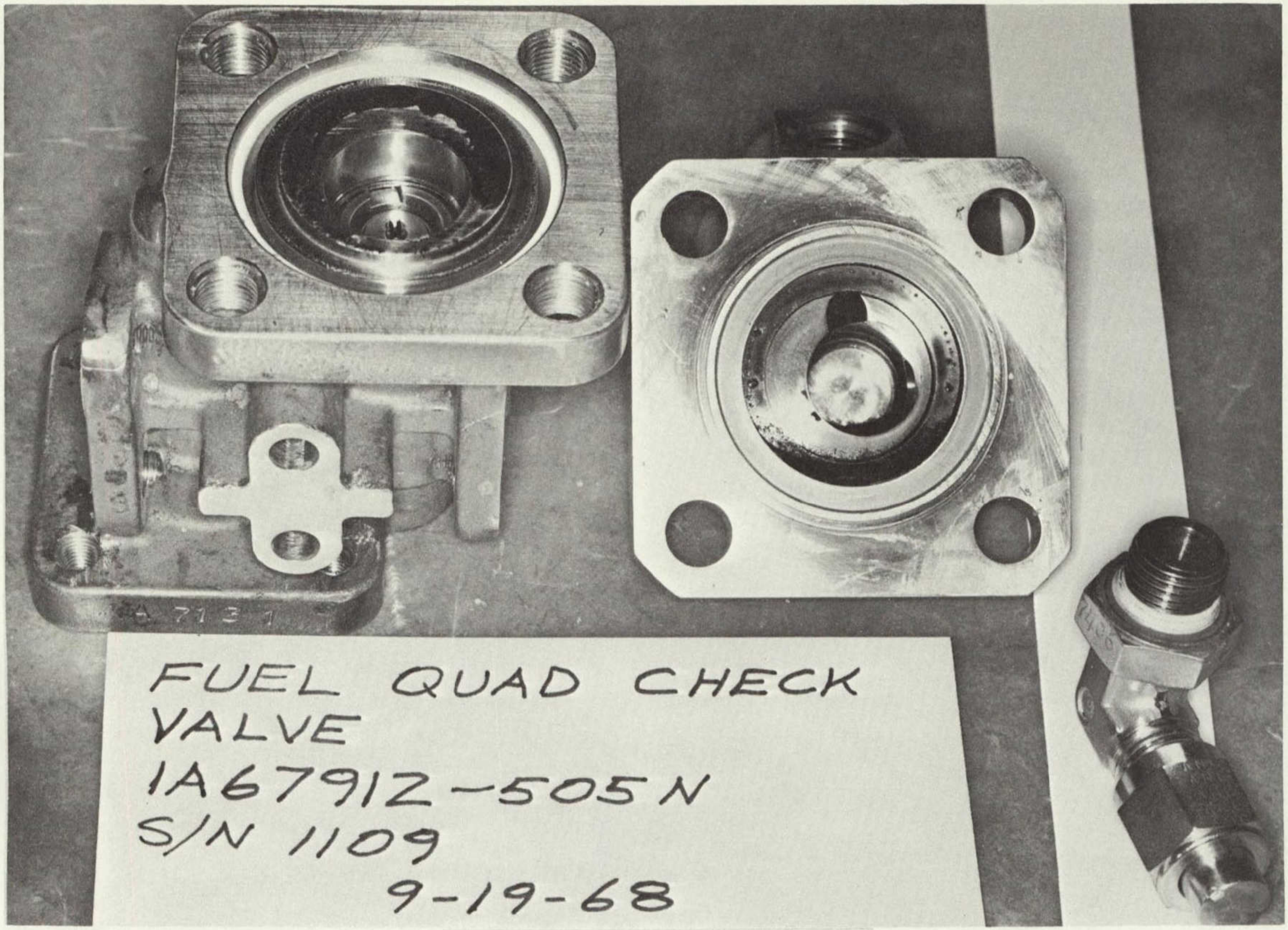


Figure 9-6. Fuel Quad Check Valve

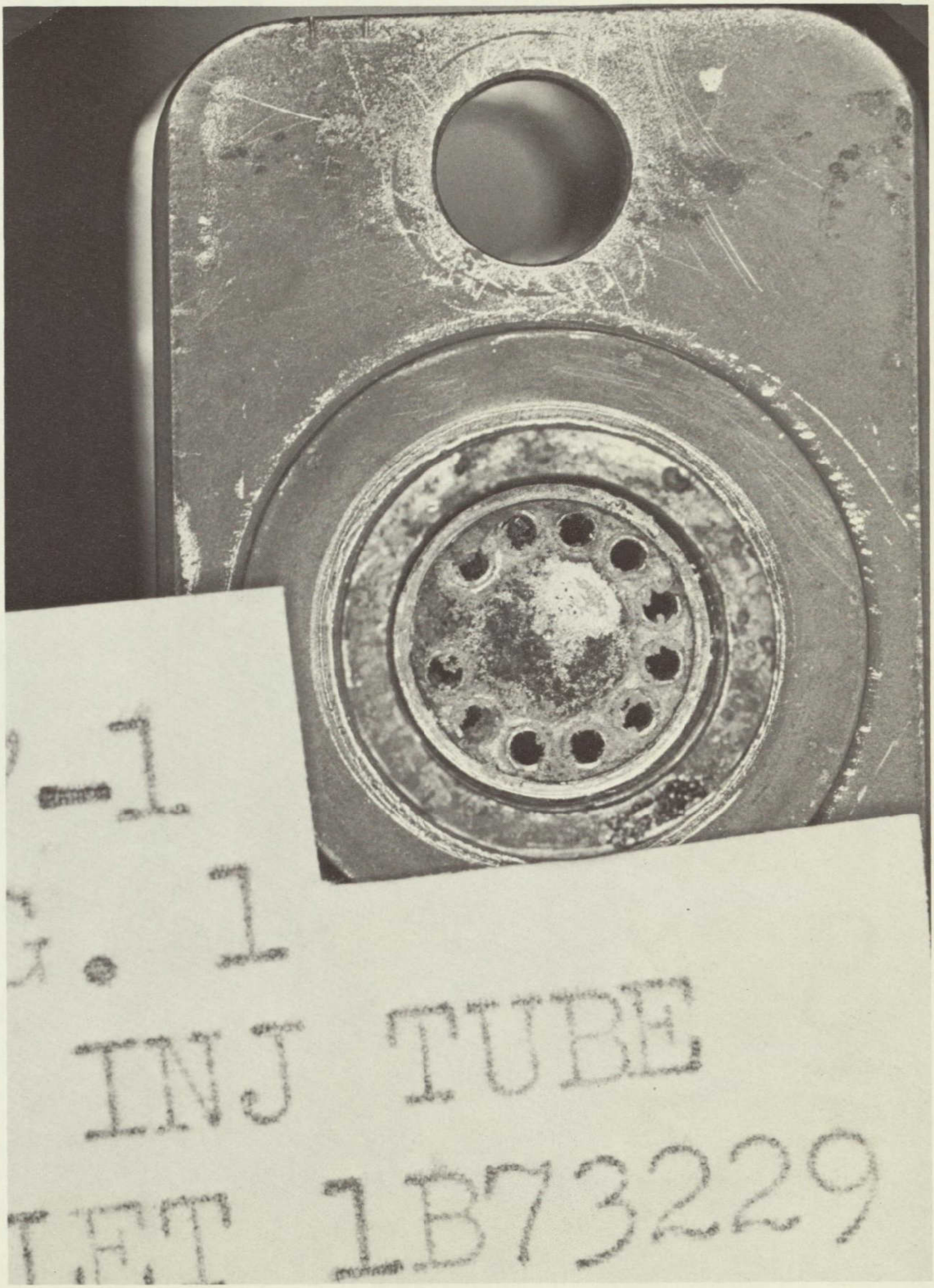


Figure 9-7. Oxidizer Injector Tube Inlet

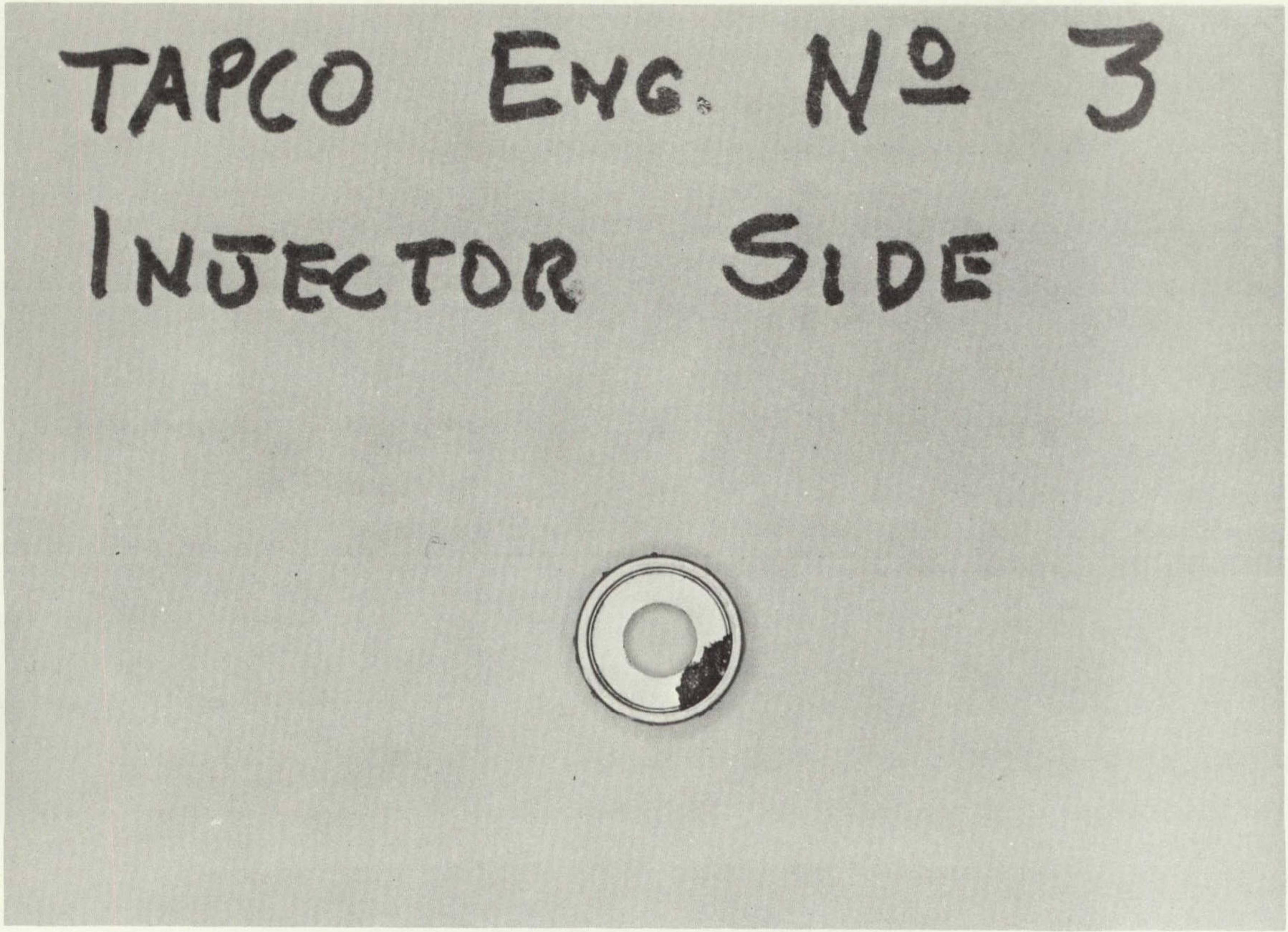


Figure 9-8. Oxidizer Trim Orifice (Sheet 1 of 2)

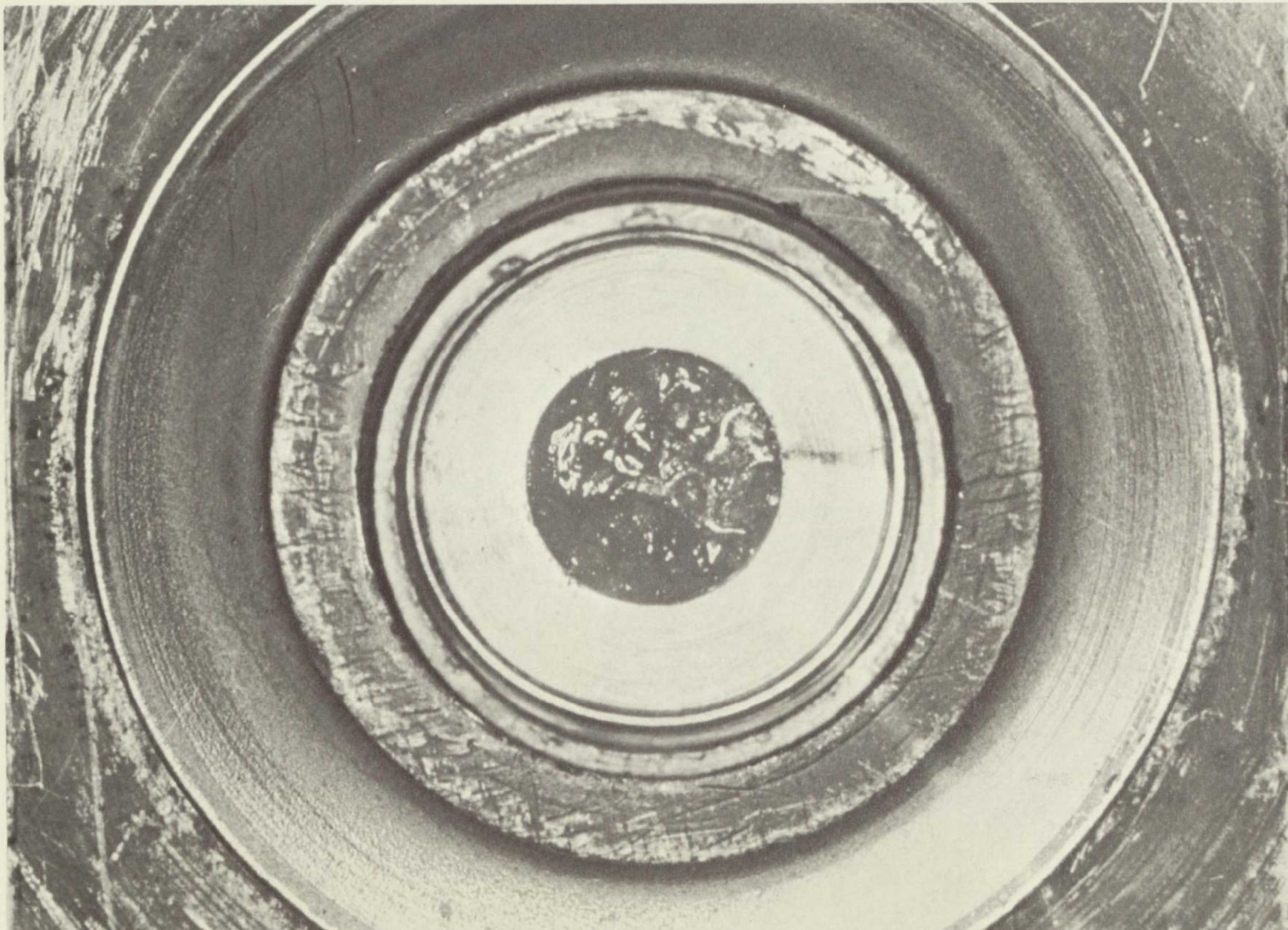


Figure 9-8. Oxidizer Trim Orifice (Sheet 2 of 2)

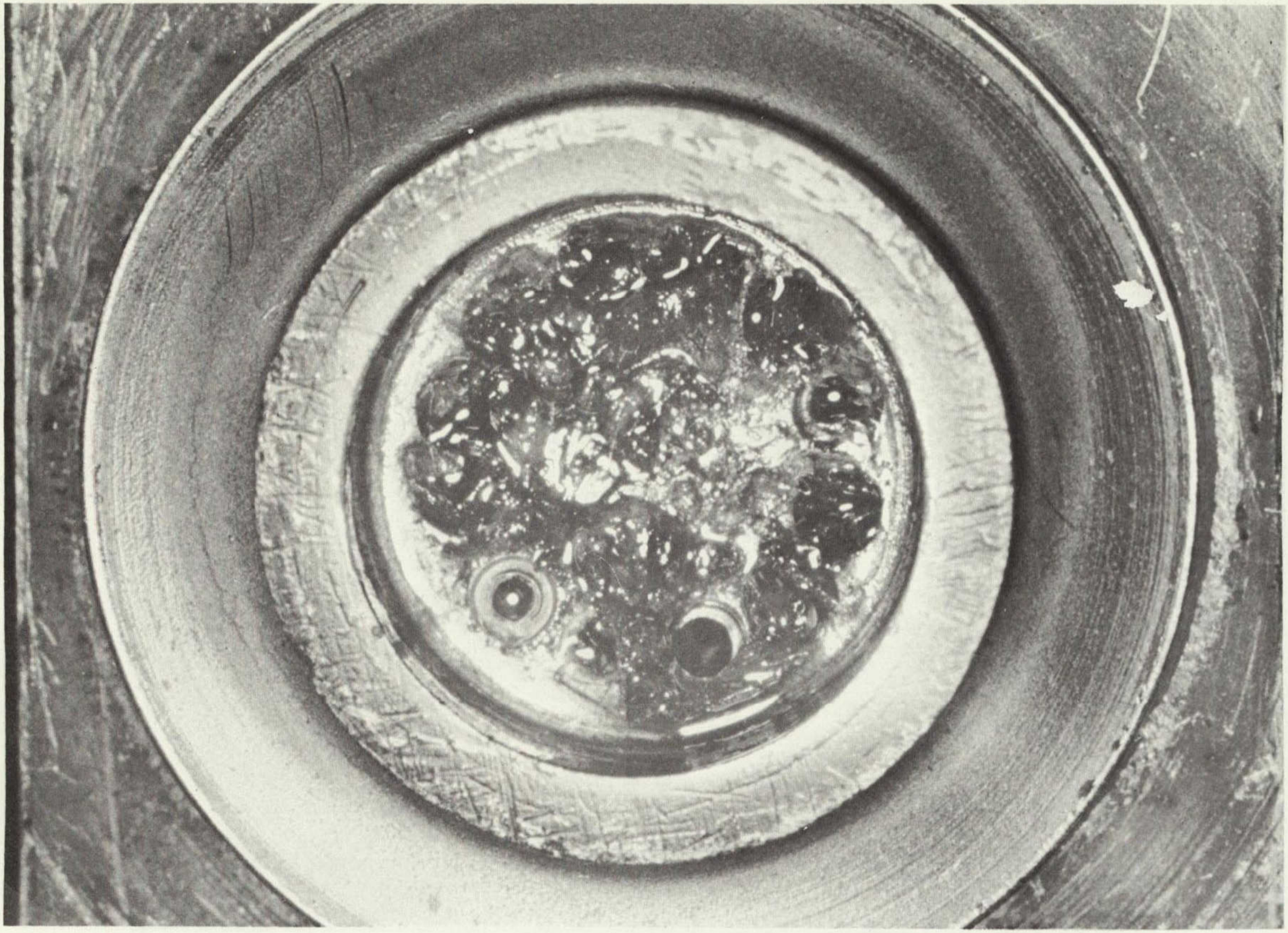


Figure 9-9. Oxidizer Injector Tube (Sheet 1 of 2)

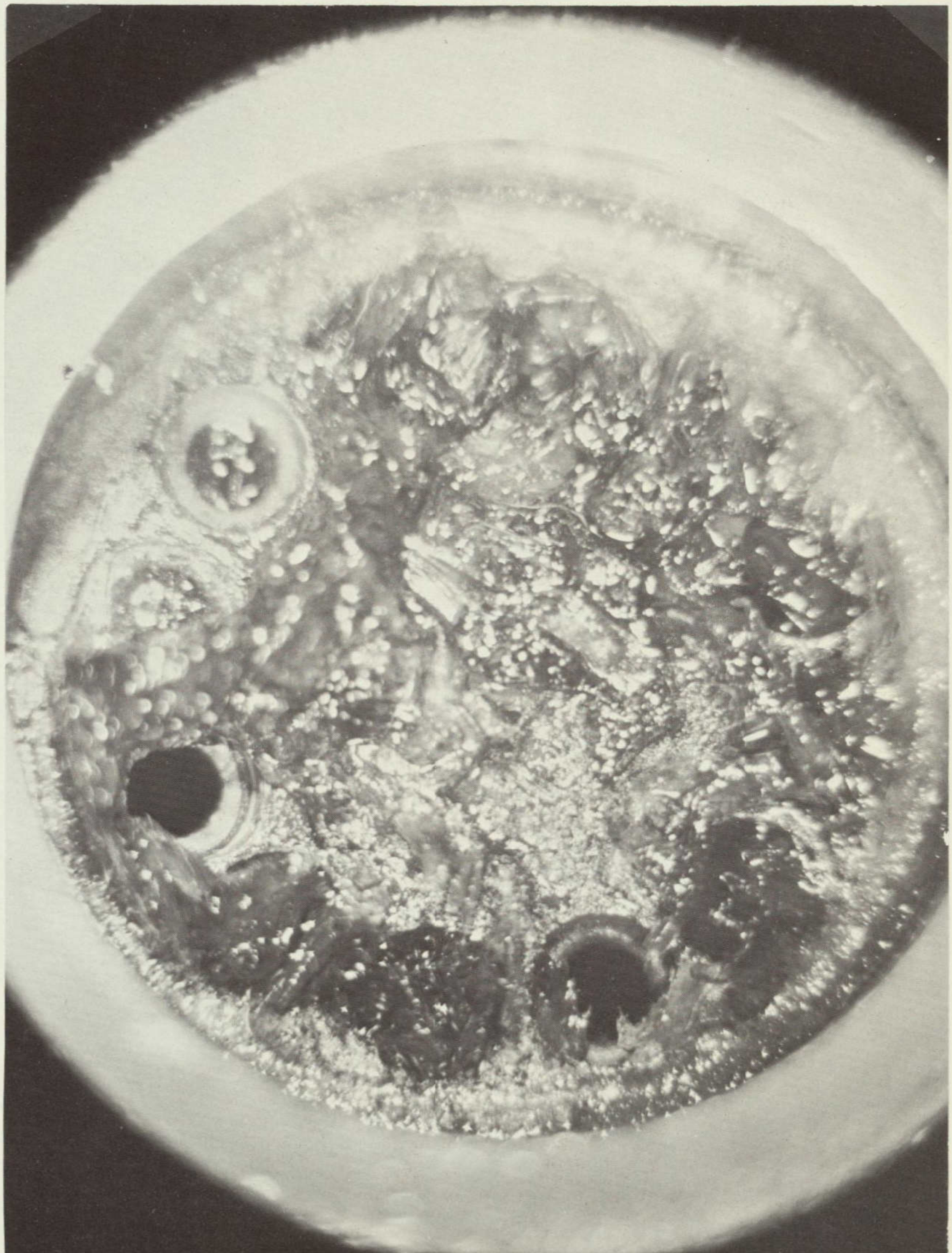


Figure 9-9. Oxidizer Injector Tube (Sheet 2 of 2)

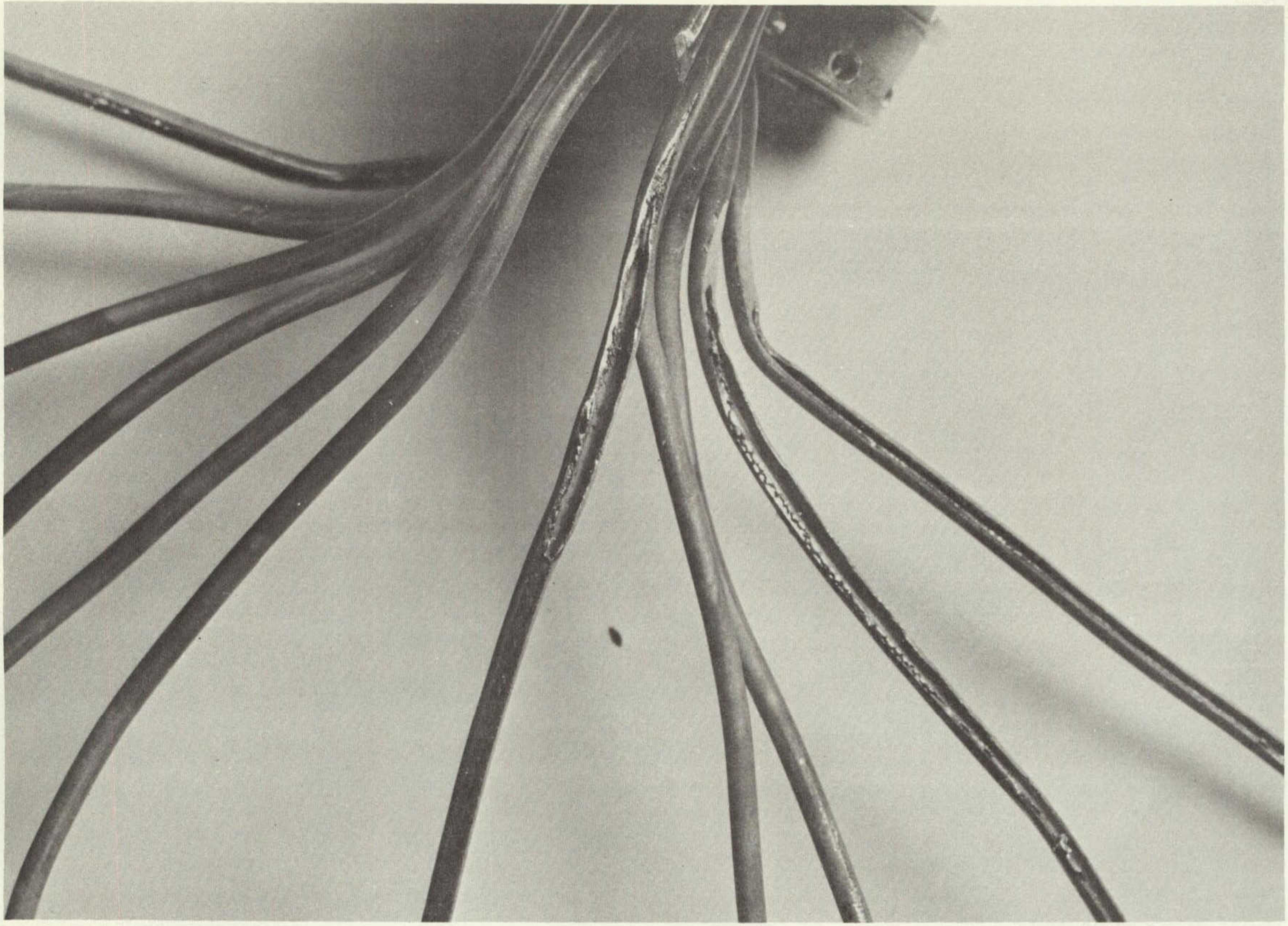


Figure 9-10. Oxidizer Injector Tube (Split)

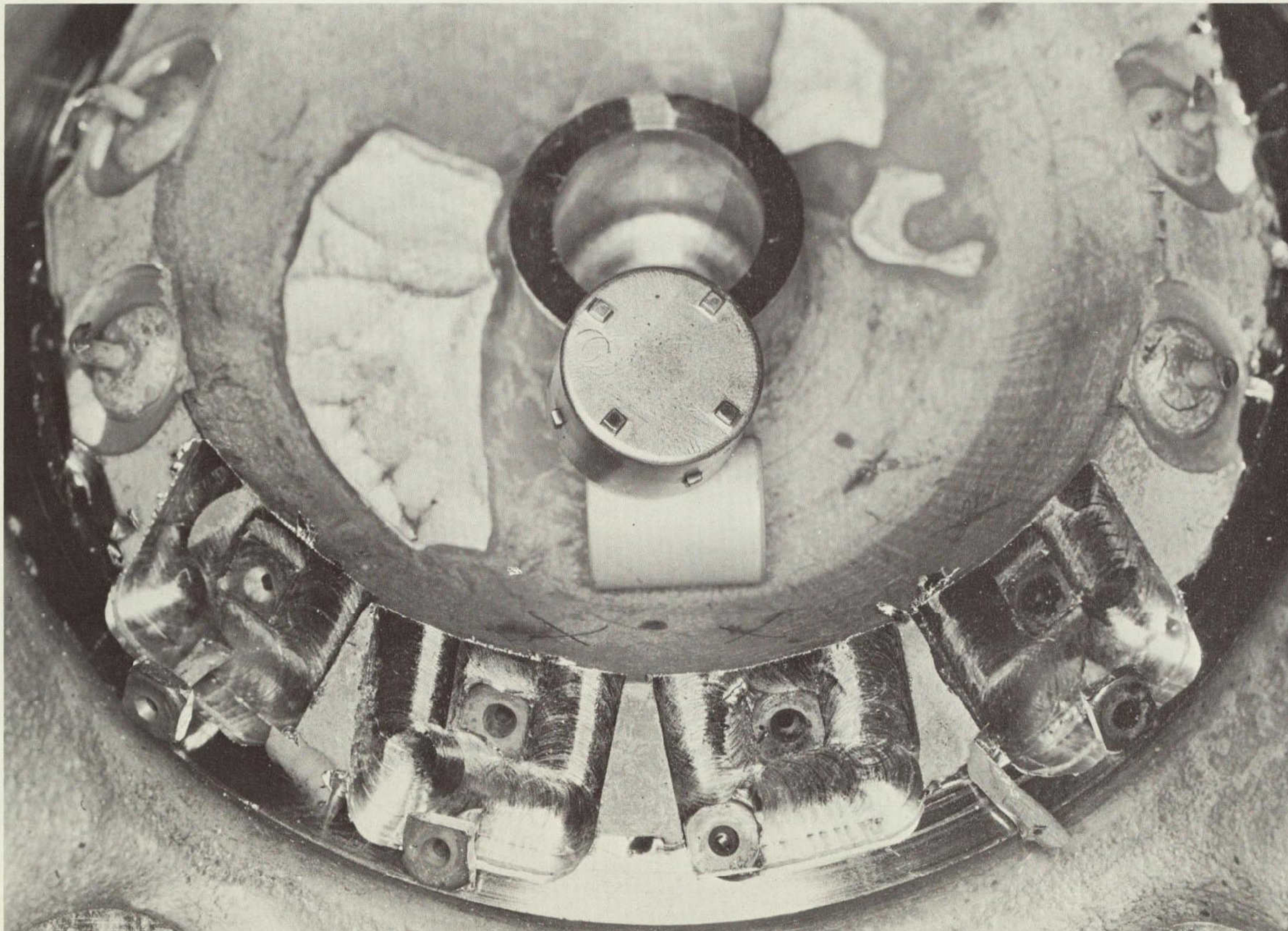


Figure 9-11. Oxidizer Tube Interfaces

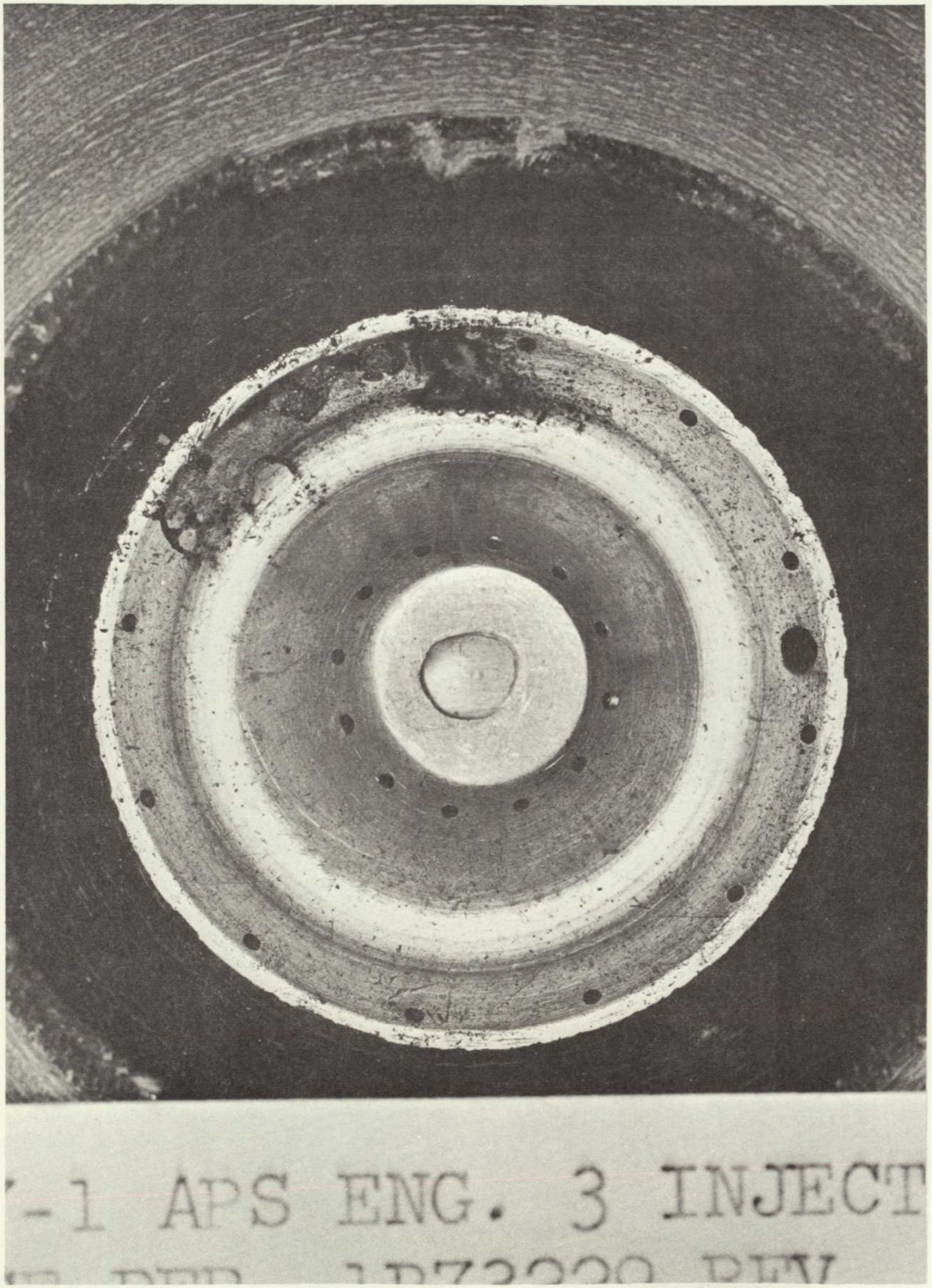


Figure 9-12. Injector Face

SECTION 10

INSTRUMENTATION SYSTEM

10. INSTRUMENTATION SYSTEM

The instrumentation system consisted of two basic interrelated systems: the ground instrumentation system, and the APS module and facilities control system which make up the instrumentation network at the Complex Gamma and Alpha sites. The instrumentation system operated well during all phases of testing with few discrepancies noted. All measurements were hardwired to their respective recording equipment and did not utilize telemetry. APS instrumentation requirements are listed in table 10-1.

Overall instrumentation system performance and efficiency, based on the total number of measurements recorded, was as follows:

	FM	S/C	PDM	OSC
Total Parameter Usage*	810	460	660	640
Total Discrepancies	13	37	11	32
Measurement System Efficiency	98.4%	96.2%	98.4	95.5
Overall Measurement System Efficiency	97.0%			

*Total number of parameters used times each sampling period.

All measurements, with minor exceptions, provided valid data. Some measurements, although considered partial data, were sufficient to warrant the measurement valid.

10.1 Ground Instrumentation System

The ground instrumentation system was satisfactory throughout the test. There were approximately eleven stripchart failures but they were minor in nature and were easily corrected. All critical measurements were backed up on redundant stripchart recorders which accounted for no loss of data due to instrumentation failure.

During the LMDC test the oscillograph used in recording the valve current signatures had a clutch problem which varied the speed at which the data were recorded. The clutch mechanism was readjusted during the test with no loss of data.

A record amplifier failed in the FR600 tape recorder during CD 664001, run 1. The channel that was lost contained system time. No data were lost, but timing correlation was made more difficult. The unit was repaired prior to the next run.

10.2 APS Module Instrumentation

The following paragraphs describe the anomalies noted in the APS module instrumentation.

D0035 Pressure Helium Tank P/N 1A72913-567, S/N 340-2

The helium tank pressure transducer exhibited dropouts when the helium tank was pressurized. This anomaly occurred on many of the pressurization cycles conducted during the burp-firing and abort tests. FARR Tag 500-226-528 was issued on 27 May 1968, in order to document the anomaly. The problem was not considered serious and the transducer was allowed to remain in the module until all testing was completed.

D0027 Chamber Pressure No. 1 P/N 1A88035-505, S/N 157

There were no lock washers under the screw heads on the transducer. No FARR Tag was issued.

D0028 Chamber Pressure No. 2 P/N 1A88035-505, S/N 179

One screw was missing and two screws were loose. No lock washers were under any of the screw heads on the transducer. No FARR Tag was issued.

D0220 Chamber Pressure No. 4 P/N 1A88035-505, S/N 169

The transducer failed during post LMDC test calibration in the following areas:

a. Input current was 53 ma; should be 50 ma maximum

b. Output ripple was 1.5 mv; should be 2.5 mv maximum

c. The 80 percent calibration step was 0.474 vdc; should be 4.0 $\pm$0.05 vdc + amb

These discrepancies were noted on FARR Tag 500-597-038.

C0023 Temperature Helium Tank P/N 1A67863-521, S/N 1157

The probe had spots of material on it that were analyzed and found to be Dupont Krytox, a LOX compatible lubricant. This material can be expected to be found in the module systems and is not considered a problem. No FARR Tag was issued.

D0028 Press - Attitude Control Chamber No. 2 P/N 1A88035-505, S/N 164

This transducer exhibited negative shift of 4 percent during instrumentation setup on 30th and 45th days and during burp-firings (CD 664000, run 12). This problem was tracked during the hold periods where it repeated itself. The decision was finally made to replace the transducer prior to run 13. The new transducer functioned properly during the remaining tests.

D0220 Press - Ullage Control Chamber No. 4 P/N 1A88035-505, S/N 169

The transducer failed to calibrate at the 80 percent step during the tangential axis vibrations (CD 654052, run 2). The 80 percent cal step returned during the radial axis vibration. It is suspected that the calibrate relay contact had malfunctioned and during continuous vibration the relay contact was vibrated into operation. Upon final inspection of the module, it was noted that the bracket which mounts the chamber pressure amplifiers was vibrated loose. Two of the four shock mounts were completely gone and the other two were very loose. The mounting holes were badly scored, indicating that the shock mounts must have broken early in the radial axis random vibration test.

D0071 Press - Oxidizer Supply Manifold P/N 1B31413-1 S/N 1284

The oxidizer supply manifold pressure showed a high amount of ringing whenever the engine feed valves were cycled ON or OFF (figure 5-4). During the shock phase of vibration the effects were the highest with pressure increases of up to 310 psia.

The transducer had a white waxy deposit in the port area. Lab analysis showed a deposit of Dupont Krytox, a LOX compatible lubricant. This deposit could have come through the module propulsion system and is not considered a problem. However, the transducer was rejected during post-test calibration because of being outside the static error band limit of 1.0 percent. The static error was 1.35 percent.

It was noted that the oxidizer system transducers were damped with a Halo-carbon 208 oil which has about the same viscosity as water. The fuel system transducers were damped with Dow Corning 510 lubricant which has a much higher viscosity. This may account for the wide difference in the ringing effect of the manifold pressures during engine firings. The oxidizer manifold pressure had a much higher amplitude of ringing compared with the fuel measurement.

D0070 Press-Fuel Supply Manifold P/N 1B31377-1, S/N 1105

The transducer still had fuel (MMH) inside. Lab analysis showed no fuel in the dampening oil (DC 510 silicon oil). Residual fuel being inside the transducer is not considered a problem and can be expected.

D0097 Press-Fuel Tank Ullage P/N 1B31377-1, S/N 1152

The transducer failed post-test calibration in static error band. Static error was 1.15 percent, it must be less than 1.0 percent.

10.3 Conclusion

The instrumentation system performance was satisfactory throughout the test.

TABLE 10-1
APS INSTRUMENTATION REQUIREMENTS

MEAS NO.	TITLE	FUNCTION		DISPLAY			
		BLUE LINE	RED LINE	STRIP CHART	METER	OSCG	ANAL TAPE
C0023-414	Temp - APS He Press Tank (He Tank Inlet) 1A67863-521 S/N 1157			X	X		X
C0132-414	Temp - Attitude Control, Oxid, (Oxid Supply Manifold) 1A67863-515 S/N 1139	X	X	X			X
C0136-414	Temp - Attitude Control, Fuel, (Fuel Supply Manifold) 1A67863-525 S/N 1152	X	X	X			X
D0027-414	Press - Attitude Control Chamber No. 1 1A88035-505 S/N 157	X		X			X
D0028-414	Press - Attitude Control Chamber No. 2 1A88035-505 S/N 164	X		X			X
D0029-414	Press - Attitude Control Chamber No. 3 1A88035-505 S/N 161	X		X			X
D0035-414	Press - Attitude Control He Press Tank 1A72913-567 S/N 340-2	X	X	X	X		X
D0037-414	Press - He Reg Outlet, 1B31413-1 S/N 1313			X			X
D0097-414	Press - Fuel Tank Ullage Vol, PN 1B31377-1 S/N 1152	X	X	X	X		X
D0098-414	Press - Oxid Tank Ullage Vol, 1B31413-1 S/N 1229	X	X	X	X		X
D0070-414	Press - Fuel Supply Manifold, 1B31377-1 S/N 1105	X	X	X	X		X
D0071-414	Press - Oxidizer Supply Manifold, 1B31413 S/N 1284	X	X	X	X		X
D0220-414	Press - Ullage Control Chamber No. 4 1A88035-505 S/N 169	X		X			X

SECTION 11

ELECTRICAL CONTROL SYSTEM

11. ELECTRICAL CONTROL SYSTEM

The electrical control system performed as required with only a few minor difficulties. The following paragraphs discuss the discrepancies that occurred during this series of tests.

During the third burp-firing (CD 664000, run 6) the control tape reader was out of alignment causing the firing "On" and "Off" pulses to be short. This problem was corrected prior to the next series of burp-firings.

During the sixth burp-firing (CD 664000, run 12) the firing pulse "On" - "Off" times were slightly longer than normal (up to 15 ms on the "on" time and 65 ms on the "Off" time). The problem was attributed to the tape reader used in the operation of the automatic firing program. This problem was not considered serious and was corrected by minor mechanical adjustments.

The APS module oxidizer feed valves 1-2, 1-4, and 3-2 appeared to be slow in fully opening. This was not considered a problem as the time involved was not significant. The phenomenon was not observed in later firings. No corrective action was taken.

The automatic APS module engine fire control system failed on engine No. 1 during the running of the second 1B70326-13 control tape in the LMDC sequence (CD 664001, run 1). As a result, the test was suspended and then resumed the following day after the problem was corrected. The anomaly was associated with double firing of engine No. 1 when only one firing was programmed. Subsequent investigation revealed a faulty flip-flop logic card in the engine No. 1 circuitry. The logic card part number is 1A69461-1, S/N 379. The problem was documented on FARR Tag A256654. The faulty logic card was replaced and the system was verified for proper operation.

APPENDIX 1

VENDOR FAILURE INVESTIGATION

MODEL 8400

REPORT OF FAILURE INVESTIGATION

8339-471080-3 BLADDERS
S/N 129-3 AND S/N 139-3

BELL AEROSYSTEMS COMPANY
REPORT NO. 8400-928016

15 November 1968

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (CONT)

REPORT OF FAILURE INVESTIGATION -
TWO BLADDERS RETURNED BY McDONNELL-DOUGLAS

Reference: A. Replacement P.O. No. 8S34205

B. M/DC Failure and Rejection Report No. 500-226-692, Oxidizer Bladder

C. M/DC Failure and Rejection Report No. 500-226-684, Fuel Bladder

D. Bell letter 404:68:1025-1:WJD, dated 25 October 1968, "Preliminary Report on Two Bladders Returned by McDonnell-Douglas for Investigation"

1.0 INTRODUCTION

This is the final report of the failure investigation authorized by Reference A and preliminarily reported in Reference D. This investigation was performed on two teflon bladders, Bell Part No. 8339-471080-3, Serial Nos. 139-3 (Oxidizer), and 129-3 (Fuel). These bladders were returned to Bell following their failure and subsequent disassembly at M/DC, as described in References B and C.

2.0 BACKGROUND

The M/DC Failure and Rejection Reports (References B and C) state that the units were loaded and subjected to a 90-day storage test with an indication of leakage across the oxidizer bladder on the 77th day. Following the storage test, the system containing the units was subjected to vibration and shock testing. After completion of radial axis random sweep, bladder leakage was of sufficient magnitude to make it impossible to reposition either fuel or oxidizer bladder. A lunar mission cycle duty firing was accomplished subsequent to this and prior to disassembly of the tanks at M/DC.

The tank assemblies were disassembled and examined at M/DC and the bladders subsequently sent to Bell for evaluation. M/DC noted that the fuel bladder tear had been enlarged by hand prior to shipment to Bell.

3.0 FAILURE ANALYSIS METHOD

3.1 Review of Fabrication Records:

A review of all fabrication and assembly records pertaining to the involved bladders and tanks was made.

3.2 Macroscopic Examination:

The bladders, as received, were visually examined and photographs were taken. The general condition of each was noted and the location and dimensions of the failure were defined.

3.3 Microscopic Examination:

The failure areas were cut out of the bladders, examined, and photographed microscopically. The edges were studied carefully to locate the probable failure origin point.

Suspected areas were microtomed and microscopically examined for determination of the fracture edge characteristics and classification of failure mode. This classification was made by optical comparison both to previously experienced bladder and laboratory induced failures, and to laboratory failures induced as part of this investigation.

4.0 RESULTS OF FAILURE ANALYSIS

4.1 Review of Fabrication Records:

A complete review of the bladder and tank fabrication and assembly records disclosed no discrepancies which could have contributed to the failures.

4.2 Macroscopic Examination:

Figures 1 and 2 show the overall failure quadrants and generally good condition of the bladders. The only unusual feature is the circumferential creasing slightly above the tangency point on the retainer end hemisphere of bladder S/N 139-3, shown in Figure 1. Also, evidence of circumferential folding was noted in at least three places on the cylindrical portion of this bladder, but no creasing was evident.

The general failure appearance of both bladders was remarkably similar, disregarding the hand torn enlargement in S/N 129-3 (performed at Douglas). Figures 1 and 2 show both failures to be in the same quadrant at nearly identical locations. Measurement showed them each to be approximately 4.5 inches long and 2.5 inches below the reference line running through the part number/serial number labeling. The tear in S/N 139-3 (Oxidizer) began 10.3 inches from the retainer end hole and that in S/N 129-3 began 9.6 inches from the hole.

4.3 Microscopic Examination:

Figures 3 and 4 are typical microscopic cross-sectional views of both failures and are very similar in appearance. All sections taken along the lengths of the failures appeared similar and no failure origin points could be determined.

The figures show the failures to be characterized by:

a. TFE break without elongation

b. FEP break with only slight elongation

c. No delamination of layers

d. Freedom from striations

Thickness measurements were made in the regions adjacent to the failure in both bladders. These dimensions were:

BLADDER	FEP (Mils)	TFE (Mils)	TOTAL (Mils)
S/N 129-3 (Fuel)	3.1	3.0	6.1
S/N 139-3 (Oxidizer)	3.3	3.2	6.5

The freedom from striations and the TFE break without elongation are definite indications that the failures did not result from fatigue damage such as vibratory motion of a single or a buckled fold. Such a break, which is brittle in nature, can occur when low temperature is combined with severe stresses, or when the bladder material is subjected to an extremely high strain rate due to a sudden shock load. Since verbal communication with M/DC Engineering disclosed that no low temperatures were imposed on the test units, it was hypothesized that the failures were probably due to shock loading.

Since exact testing, servicing and handling histories of the affected tanks at M/DC were not sufficiently known to either substantiate or refute the above hypothesis, it was necessary to initiate the failure analysis with a comparison of the failed areas with Bell's photo library of in-service bladder failures and laboratory-induced failures.

The only failure library specimens which resembled the bladder failures were of the low temperature type; there were no specimens identified as illustrating a failure caused by shock mechanism. During verbal communication with M/DC Engineering, Bell was informed that no adverse temperature conditions existed during testing or due to servicing, such as rapid venting of the tanks. Thus, with low temperature eliminated as a possible mechanism, it became necessary to perform laboratory tests to verify that a shock mechanism was involved in the bladder failures.

4.4 Failure Reproduction Testing:

Laboratory testing to reproduce the S/N 129-3 and S/N 139-3 failures involved three basic failure mechanisms:

a. Tensile shock
b. Flexure without support followed by tensile shock
c. Tearing

Failure reproduction by shock was performed by connecting a 40-pound weight to one end of a 1/2 inch wide 6-mil laminate specimen which was clamped at the other end. The weight was dropped a distance of one foot. Figure 6 is a microtome section through a shock failure. Note the similarity to the failures shown in Figures 3 and 4 in that there is no TFE elongation, slight FEP elongation, and no delamination. Polarized light examination showed no bi-refringence.

Figure 7 shows a failure produced by a shock load on a 6-mil laminate specimen preconditioned with 25,000 single flexure cycles (unsupported). This is also very similar to that of Figures 3 and 4.

It is thought that a bladder failure once started could propagate by tearing either through handling during removal from the tank or from stress during subsequent testing. Specimens of 6-mil laminate material were notched and then subjected to a steady tearing action. Sections of this tear were microtomed and examined. Figure 8 is a typical photo-micrograph of a tear and is also very similar to the actual failures (Figures 3 and 4).

Figure 9 is included for comparative purposes as a typical fracture cross section from a 6-mil bladder known to have failed due to vibration induced fatigue. It is readily seen that there are striations and necking down in both TFE and FEP layers, none of which are evident in the bladder failures involved in this investigation.

4.5 Additional Findings:

4.5.1 Circumferential Crease: Although it was not involved in the bladder failure, the circumferential hard crease in the upper hemisphere of Oxidizer Bladder S/N 139-3 was of interest because of its uniqueness. The crease was cross sectioned and studied. This section (shown in Figure 5) shows little or no damage in the material from the hard crease. Polarized light showed some birefringence which was indicative of some residual stress in the crease.

4.5.2 Additional Damage: A close study of the failure area of bladder S/N 139-3 revealed the presence of a .32 inch long slit near the primary failure, as reported by M/DC in Reference B. In addition, four small failures varying from .076 to .137 inches in length were found located in short creases near one end of the primary failure. Two of the smaller failures contained total rupture through both bladder laminates, while the other two consisted of failure of the inner (TFE) laminate only. The appearance of these failures, in cross section, was very similar to the primary failure. The locations of these additional failures are shown as small dots on Figure 1. Due to the similarity of appearance, photographs of these areas were not included in this report. It is not known whether these failures occurred at the same time as the primary failure or whether they were generated during subsequent servicing or handling. There was no evidence of similar damage in the Fuel Bladder S/N 129-3.

5.0 CONCLUSION

The following conclusions have been reached based upon the failure investigation results:

a. There were no failure-contributive deficiencies in the bladders S/N 129-3 and S/N 139-3.

b. Failure was not due to fatigue but rather due to a sudden, shock type load with possible subsequent enlargement by tearing.

6.0 DISCUSSION

Although verbal information from M/DC concerning the test histories of the failed bladders does not indicate such, it must be concluded from all available evidence at Bell that the bladder failures were due to an over-test condition during dynamic testing which resulted in a shock type load on the affected tanks. This conclusion is supported by the reported failure of the oxidizer diffuser tube during the same test. Using minimum allowable values for material thickness and physical properties, it would require an impulse of 148g to fail the diffuser in shock loading, and it would require more than 2 x 10^5 cycles at 92.5g or 10^7 cycles at 69g to fail the diffuser in fatigue. Any of these conditions would appear to be far in excess of normal testing requirements.

It is not definitely known how the 7 SCCM helium leakage rate across the oxidizer bladder after 77 days of the 90-day storage period, as reported in Reference B, was determined. Bell feels that the validity of such a test, with the tank loaded with oxidizer, is questionable. However, assuming that the leakage rate is valid, it would not be indicative of bladder failure since leakage through a failure even of "pinhole" size would be many times that value. Such a rate could be caused by bladder damage incurred by repetitious local movement of the bladder, possibly during M/DC repositioning procedures.

The reported presence of liquid N_2O_4 on the gas side of the bladder can be explained by alternate heating and cooling of the tank shell due to ambient temperature changes at the test site. Since the ullage volume outside the oxidizer bladder becomes saturated with propellant vapor within a short period of time after propellant loading, any subsequent temperature fluctuations of the shell will cause condensation during temperature decay periods, followed by non-saturation (with additional permeation through the bladder) during subsequent temperature increases.

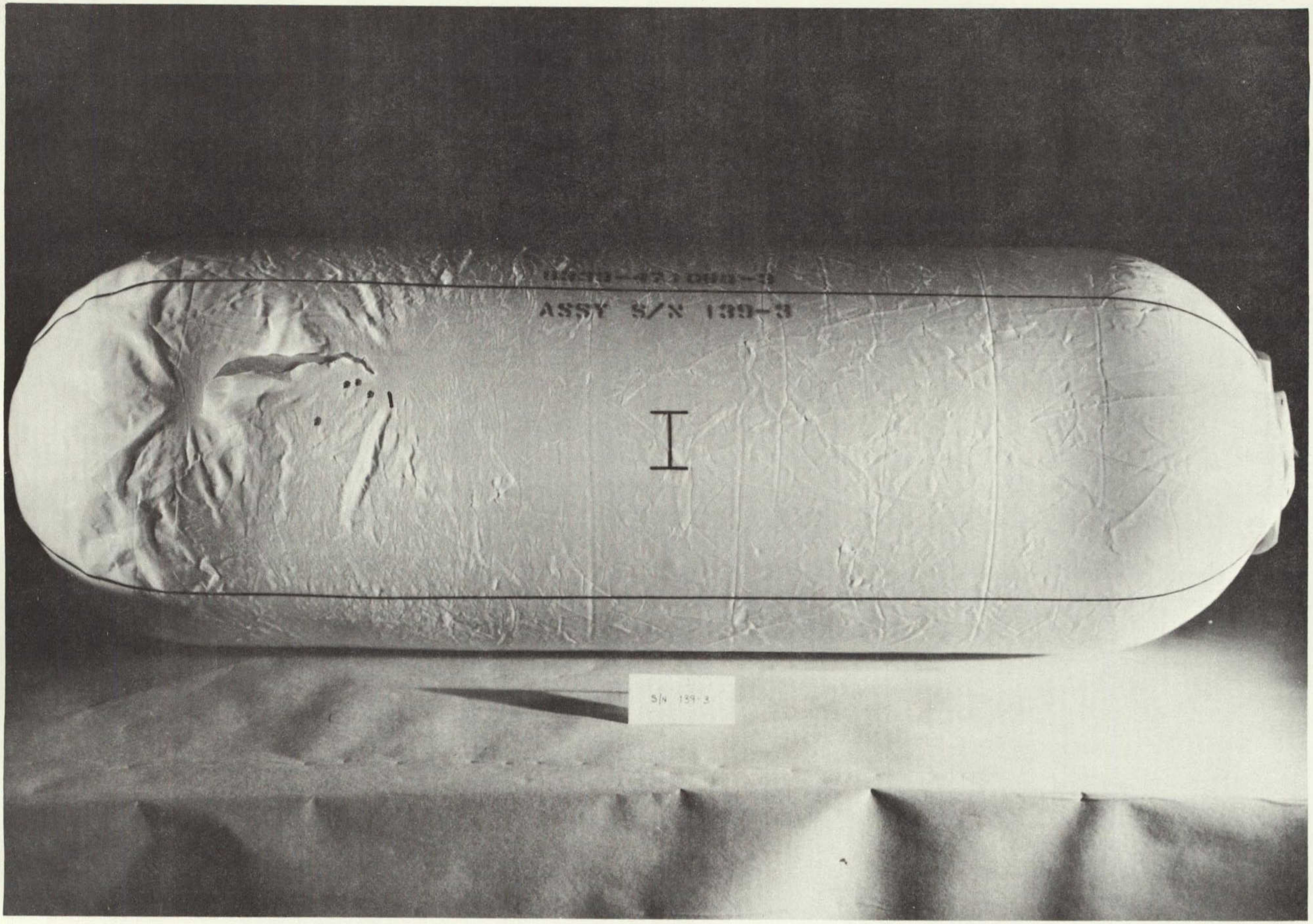


FIGURE 1 - OVERALL VIEW OF FAILURE QUADRANT - OXIDIZER BLADDER

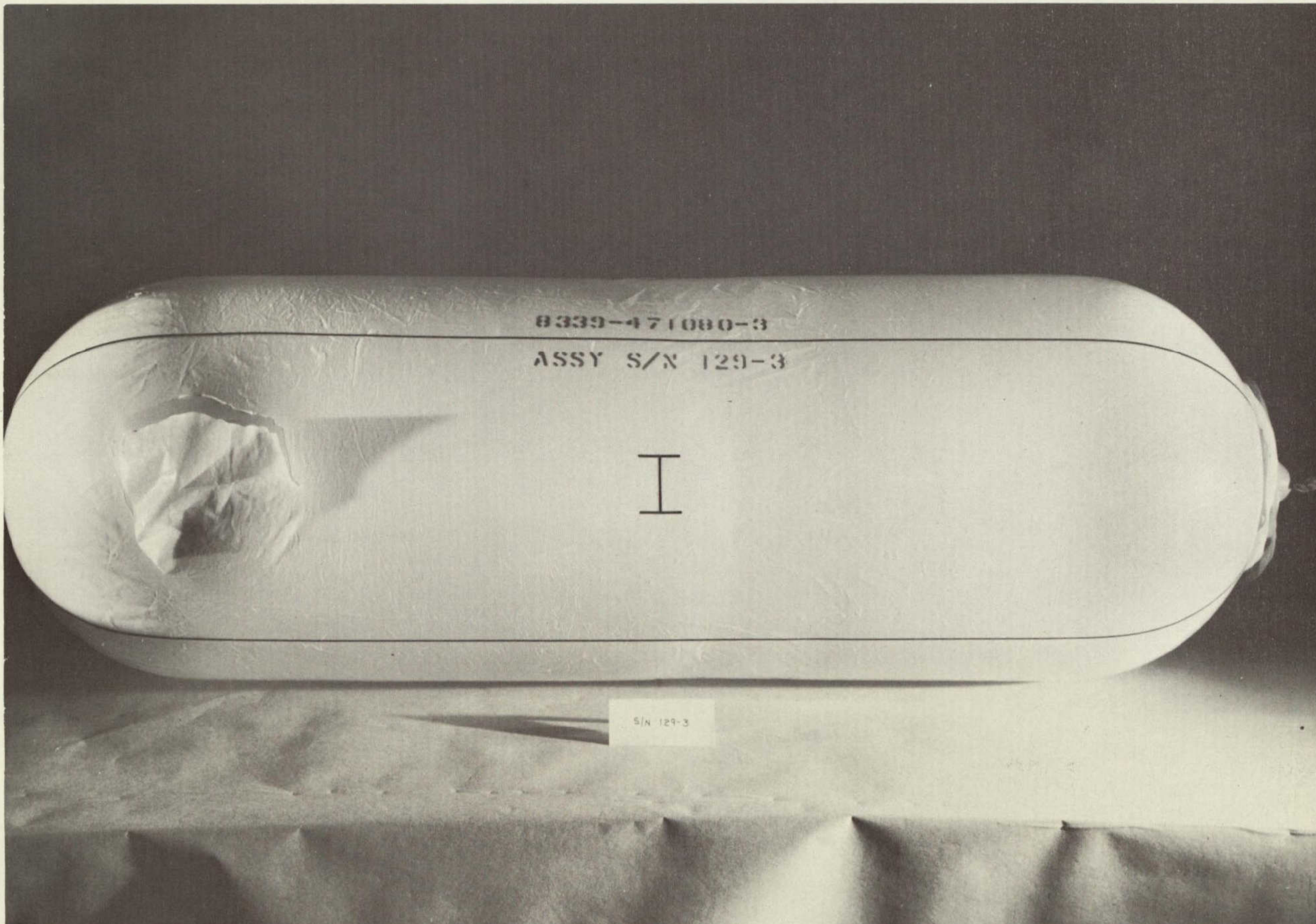


FIGURE 2 - OVERALL VIEW OF FAILURE QUADRANT - FUEL BLADDER

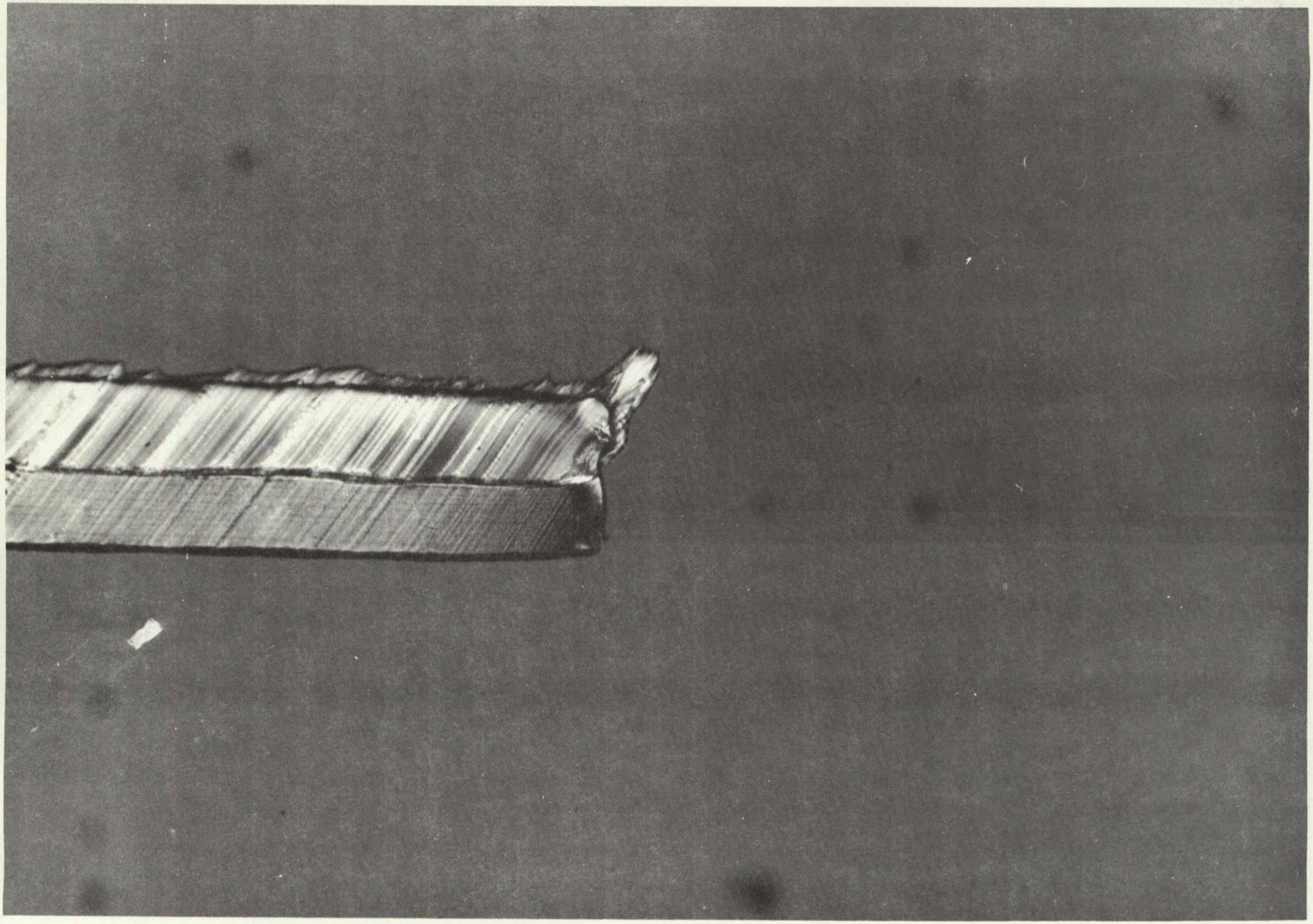


FIGURE 3 - TYPICAL SECTION, S/N 139-3 MAG: APPROX. 200X

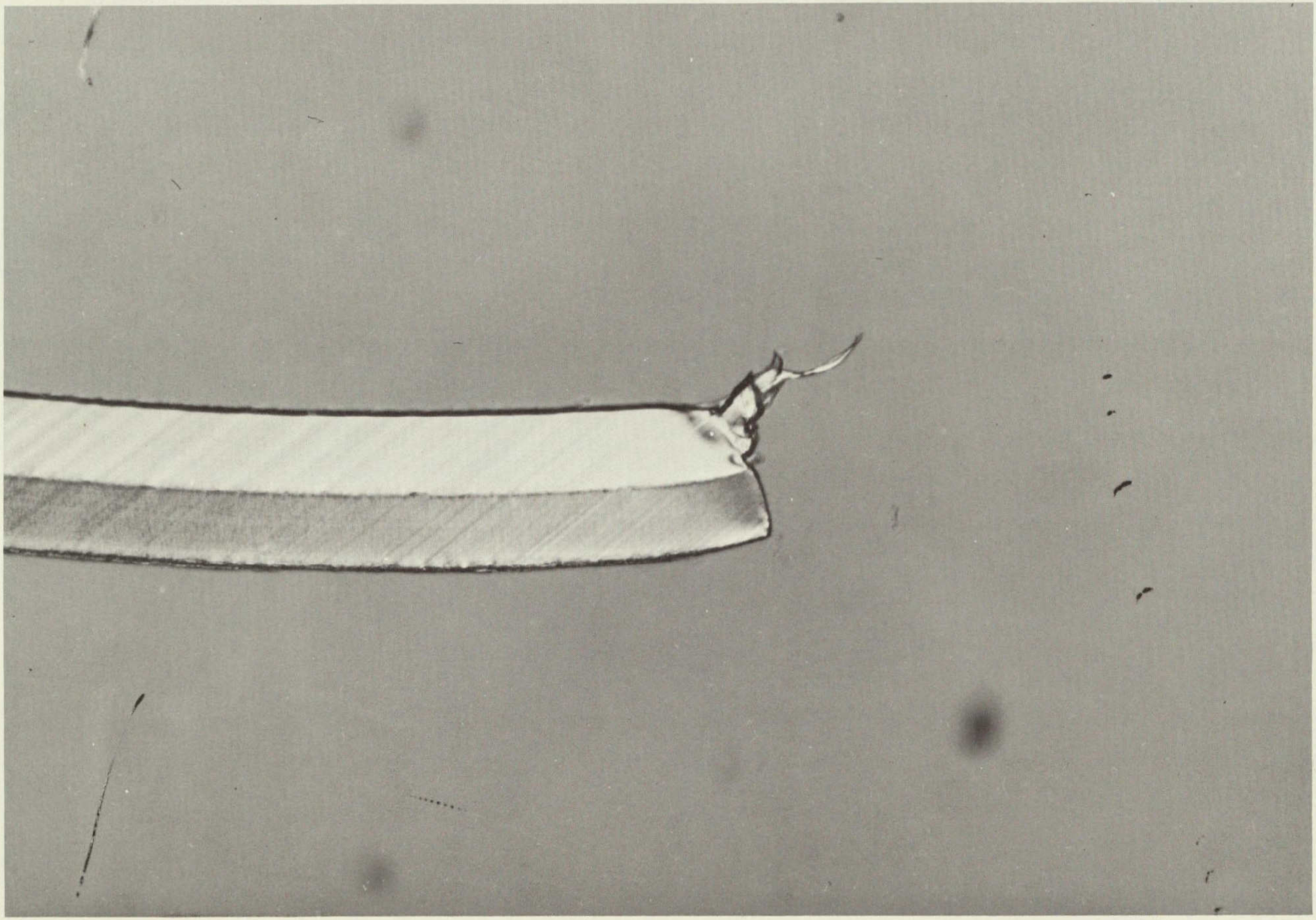


FIGURE 4 - TYPICAL SECTION, S/N 129-3 MAG: APPROX. 200X

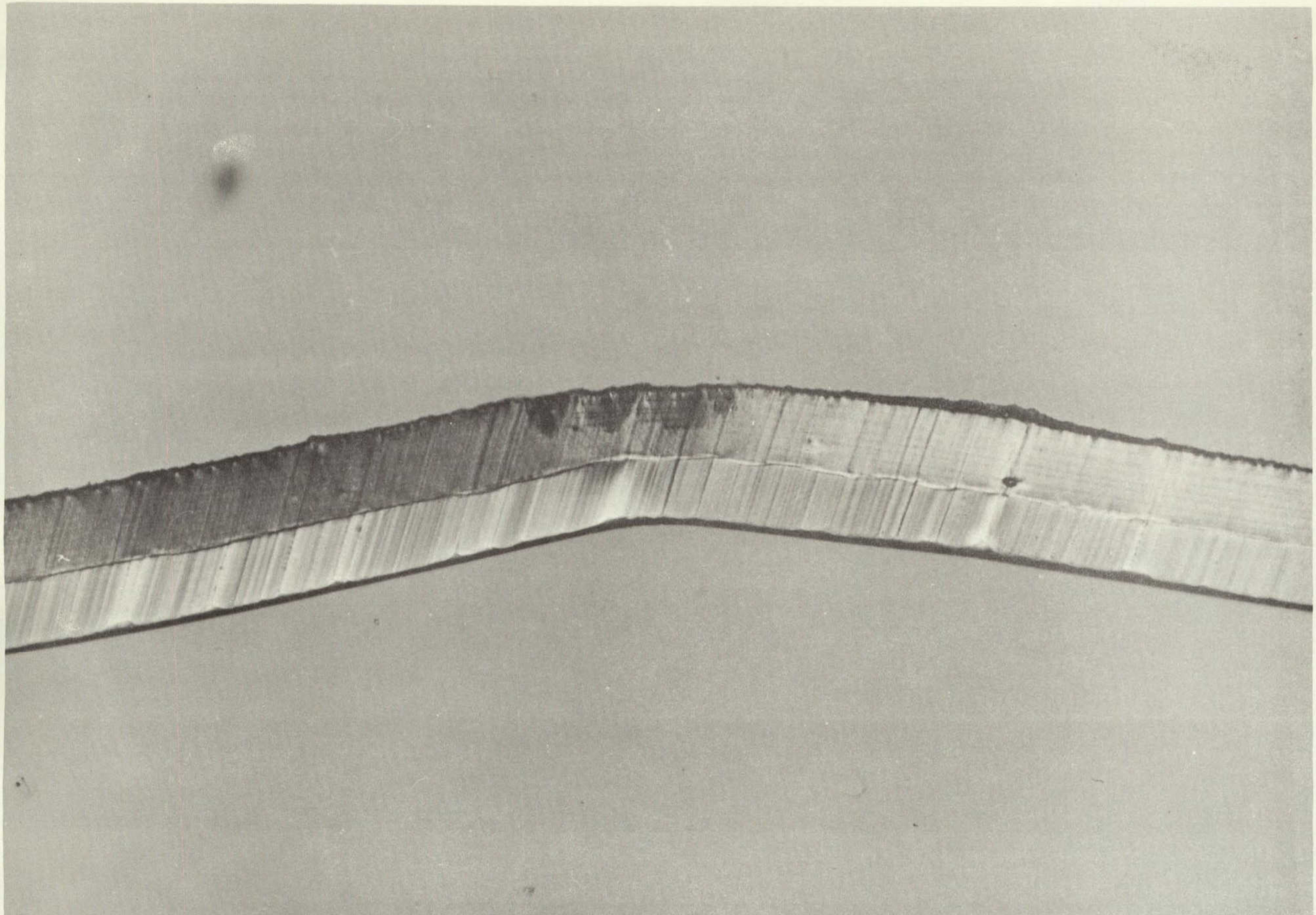


FIGURE 5 - SECTION THRU HARD CREASE IN S/N 139-3 (QUAD. II)   MAG: APPROX. 170X

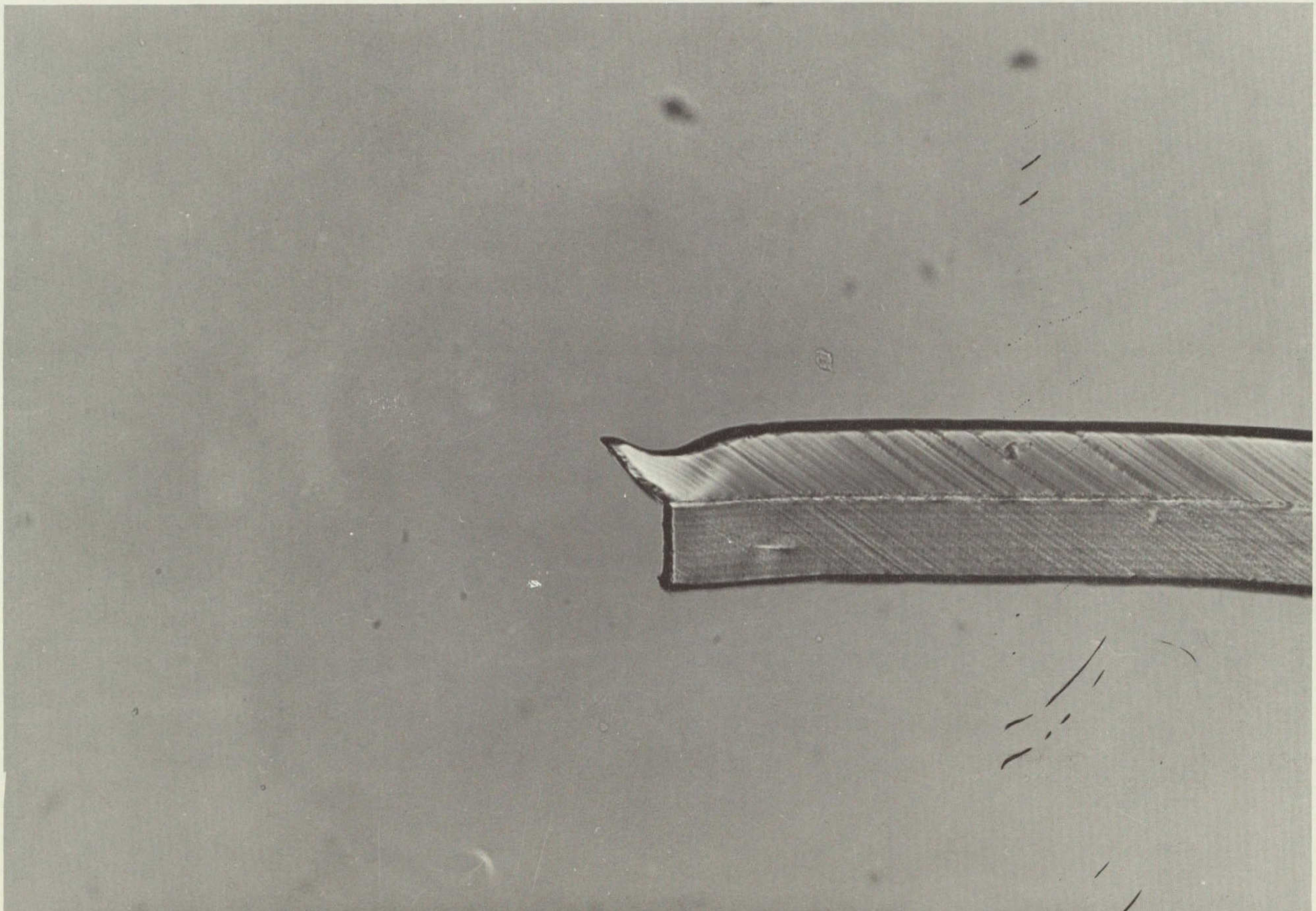


FIGURE 6 - TEFLON LAMINATE (6 MIL) - SHOCK TEST

MAG: APPROX. 200X

AP 1-19

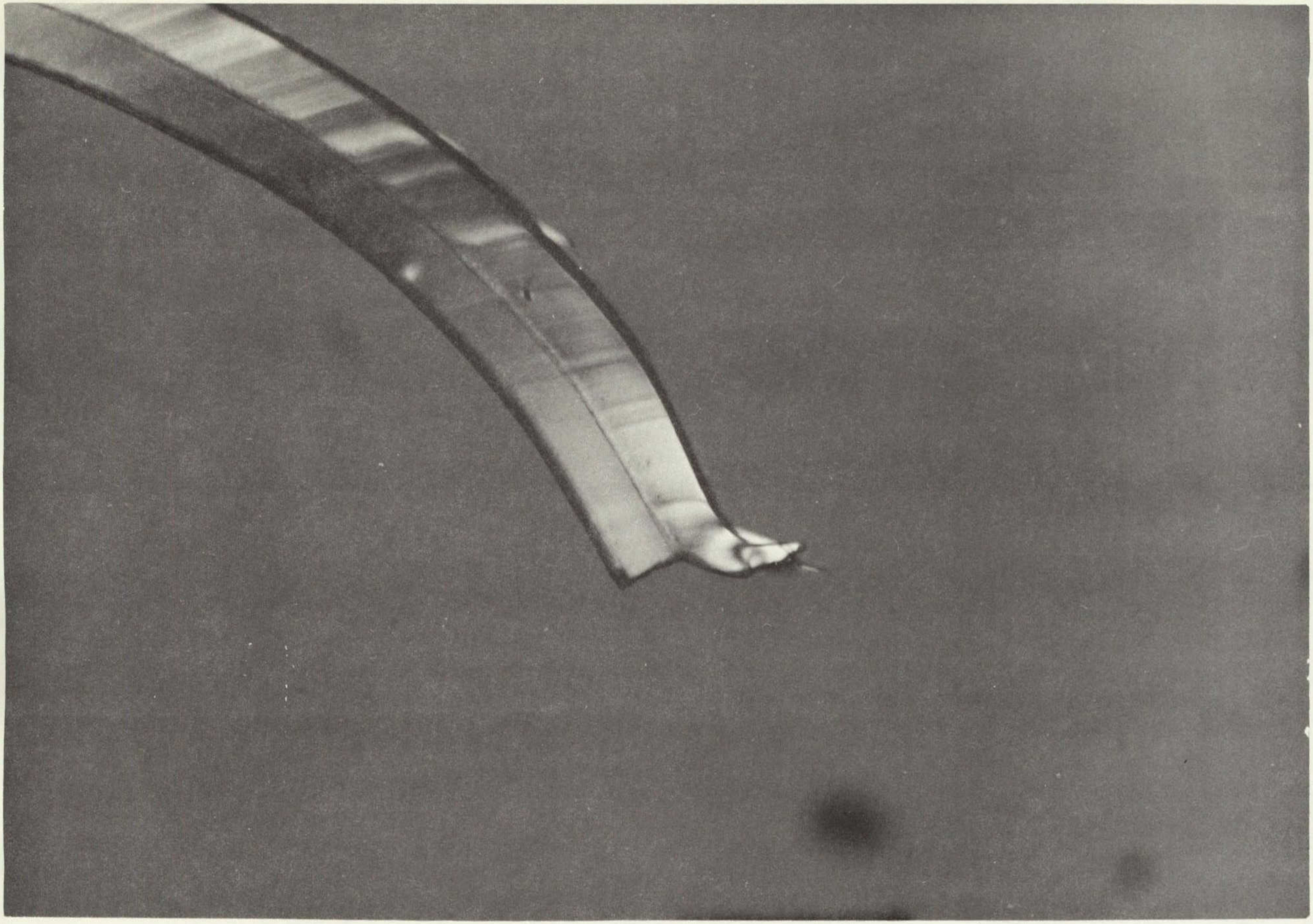


FIGURE 7 - TEFLON LAMINATE (6 MIL) - FOLD PLUS SHOCK TEST

MAG: APPROX. 200X

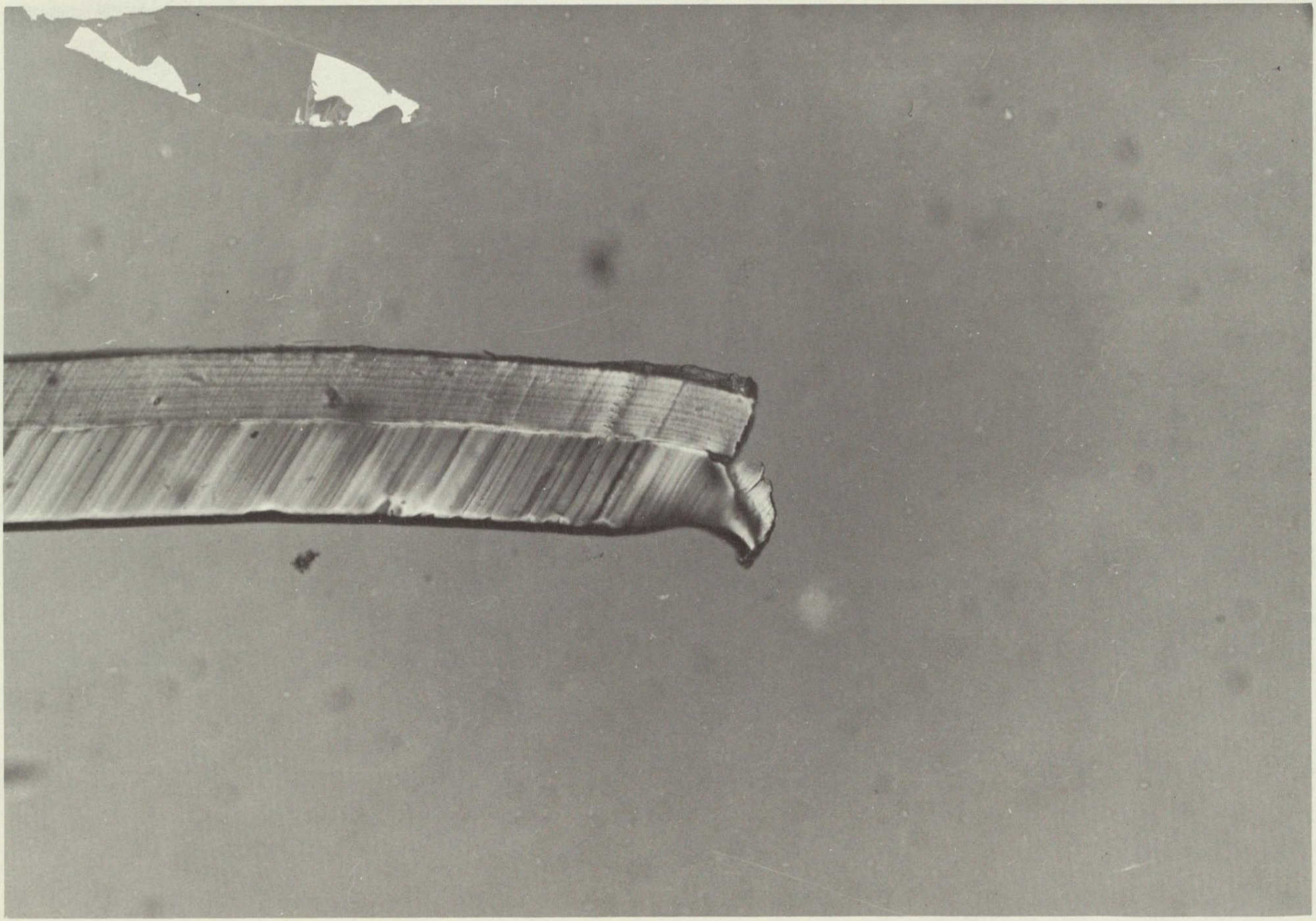


FIGURE 8 - SECTION THRU TEFLON LAMINATE (6 MIL) - TEAR TEST MAG: APPROX. 200X

AP 1-21

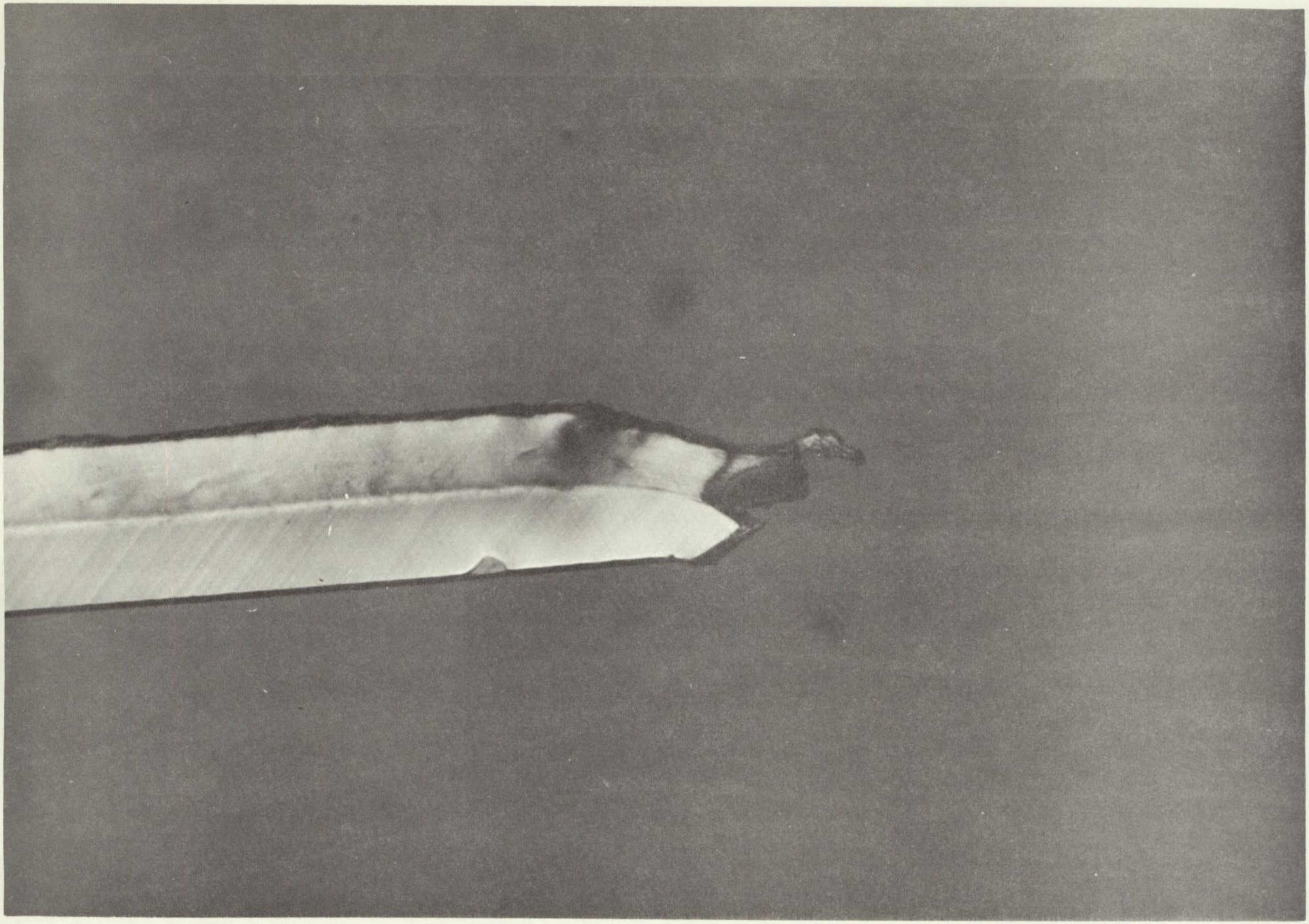


FIGURE 9 - TEFLON LAMINATE (6 MIL) - FATIGUE FAILURE MAG: APPROX. 200X

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