UNCLASSIFIED

AD NUMBER
AD847562
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Critical Technology; FEB 1969. Other requests shall be referred to National Aeronautics and Space Administration, Marshall Space Flight Center (I-B-J), Huntsville, AL 35812. This document contains export-controlled technical data.**
AUTHORITY
USAEDC ltr, 12 Jul 1974.

THIS PAGE IS UNCLASSIFIED

AEDC-TR-69-44

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-01 THROUGH J4-1902-04)

N. R. Vetter
ARO, Inc.

February 1969

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812.

...public release
Per A F letter dtd 12 July 74
Signed William O. Co

LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

AEDC-TR-69-44

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-01 THROUGH J4-1902-04)

N. R. Vetter

ARO, Inc.

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812.

This d ... public release ... Per AF Letter dtd 12 July, 74 signed William O. Cole

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc., (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted between December 5, 1968, and January 10, 1969, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1902. The manuscript was submitted for publication on January 24, 1969.

This technical report has been reviewed and is approved.

Edgar D. Smith
Major, USAF
AF Representative, LRF
Directorate of Test

Roy R. Croy, Jr.
Colonel, USAF
Director of Test

ABSTRACT

Five firings of the Rocketdyne J-2S rocket engine (S/N J-111A) were conducted in Test Cell J-4 of the Large Rocket Facility between December 5, 1968, and January 10, 1969. These firings were accomplished during test periods J4-1902-01 through J4-1902-04 at pressure altitudes of approximately 100,000 ft at engine start to investigate engine idle-mode operation, transition from idle mode to main stage, and steady-state operation at main stage. The engine started successfully in all cases and two planned transitions from idle mode to main stage were accomplished. The thrust chamber and injector were damaged extensively during a 288.5-sec duration idle-mode firing (04A).

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, $in.^2$
ASI	Augmented spark igniter
CCP	Customer connect panel
EBW	Exploding bridge wire
FM	Frequency modulation
MFV	Main fuel valve
MOV	Main oxidizer valve
O/F	Propellant mixture ratio, oxidizer to fuel, by weight
SPTS	Solid-propellant turbine starter
T/C	Thrust chamber

t_0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress since December, 1968, at AEDC. The five firings reported herein were conducted during test periods J4-1902-01 through J4-1902-04 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to verify previously obtained test data on the performance of the simplified J-2 engine under simulated altitude conditions. The firings were accomplished at pressure altitudes ranging from 86,000 to 101,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Data collected to accomplish the test objectives are presented herein.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lb_f and mixture ratio of 2.5 or at main stage at any precalibrated thrust level between 230,000 and 265,000 lb_f at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5, Ref. 2) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat diameter of 12.192 in., a characteristic length (L*) of 35.4, and a divergent nozzle with an expansion ratio of 40. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 $in.^2$, respectively. The oxidizer portion is compartmentalized, the outer compartment supplying oxidizer during main-stage operation only. The porous material, forming the injector face, allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self lubricated and nominally produces, at the 265,000-lb_f-thrust rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump - The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self lubricated and nominally produces, at the 265,000-lb_f-thrust rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the

oxidizer high pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at the 10-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to the main-stage operating level.

8. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package - The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank - The helium tank has a volume of 4000 in.^{3} and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve - The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve - The idle-mode valve is a pneumatically operated ball-type valve which supplies liquid oxygen to the idle-mode compartment of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve - The hot gas tapoff valve is a pneumatically operated butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter - The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting systems.

2.2 TEST CELL

Propulsion Engine Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 3.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

Systems were provided for temperature conditioning of engine components. Cold helium from a liquid hydrogen-helium heat exchanger was routed externally over the main fuel valve to provide the required temperature. Temperature-conditioned nitrogen from liquid nitrogen-steam vaporizers was routed through shrouds surrounding the solid-propellant turbine starters to provide the required temperatures.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and the capacitance-type pressure transducer.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 40 samples per second (50 samples per second for firing 04A) and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Figs. 7a and b.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers.

Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the solid-propellant turbine starters were installed, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for engine main-stage operation. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five firings of the Rocketdyne J-2S rocket engine (S/N J-111A) were conducted between December 5, 1968, and January 10, 1969, during test periods J4-1902-01 through J4-1902-04. These firings comprised the initial testing of the J-2S engine at altitude conditions; pressure altitude at engine start ranged from 86,000 to 101,000 ft.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 8 shows engine start conditions for propellant pump inlets and helium tank. Accumulated firing durations were 593.8 sec in idle mode and 39.1 sec of main-stage operation.

Data presented in subsequent sections are from the digital data acquisition system except where indicated otherwise. Propellant flow rates are based on engine flowmeter calibration constants supplied by the engine manufacturer: 5.50 and 2.00 cycles/gal for the oxidizer and fuel flowmeters, respectively.

4.2 TEST RESULTS

4.2.1 Firing J4-1902-01A

Firing 01A was a 172.3-sec duration idle-mode firing to evaluate (1) thrust chamber chilldown rate, (2) augmented spark igniter performance, (3) engine mixture ratio, (4) helium consumption rate, and (5) engine integrity. Engine ambient and combustion chamber pressures are shown in Fig. 9; pressure altitude at engine start was 99,000 ft. At t_0 + 42 sec a facility malfunction resulted in an engine ambient pressure and temperature level which adversely affected engine performance. Data beyond t_0 + 42 sec which are not considered representative of J-2S engine operation at altitude conditions are not presented.

Thrust chamber chilldown rate as indicated by external skin thermocouples at the engine throat and exit is shown in Fig. 10. Augmented spark igniter performance is shown in Fig. 11; ignition was detected at t_0 + 0.364 sec. Engine propellant flow rate and mixture ratio data in Fig. 12 were based on pump discharge temperatures and pressures and a manual reduction of the flowmeter cyclic outputs as recorded on an oscillogram. Included in Fig. 12 are engine inlet and combustion chamber pressures. Helium consumption and engine integrity data are presented in Sections 4.2.7 and 4.2.8, respectively.

4.2.2 Firing J4-1902-02A

This was a 32.2-sec duration main-stage firing to evaluate (1) engine start and shutdown transients, (2) steady-state operation, (3) solid-propellant turbine starter performance, (4) oxidizer system pressure surges, and (5) engine-generated side loads. Pressure altitude at engine start was 99,000 ft; engine ambient and combustion chamber pressures are shown in Fig. 13. The ambient pressure increase beginning at t_0 + 7 sec was caused by inadvertant operation of the facility annular ejector.

Engine start and shutdown transients and steady-state operation were satisfactory, as shown in Fig. 14. At t_0 + 7 sec a propellant utilization valve excursion was made to produce a mixture ratio of 5.44

and a peak combustion chamber pressure of 1215 psia at t_0 + 27 sec. Solid-propellant turbine starter performance is shown in Fig. 15. Combustion pressure measurement was not recovered, but satisfactory starter performance is shown by the propellant pump start transients (Fig. 14). A maximum oxidizer system pressure of 1460 psia (230 psi above the operating level) was measured at the oxidizer pump discharge at t_0 + 33.45 sec as shown in Fig. 16. Engine-generated side loads were less than 1200 lb_f, as shown in Fig. 17. The indicated levels before engine start result from tare loads caused by engine propellant supply line pressures and temperatures; the indicated oscillations before engine start result from the operation of facility steam and cooling water systems. Fuel pump start transient performance is shown in Fig. 18.

4.2.3 Firing J4-1902-03A

This firing consisted of 76.2 sec of idle-mode operation followed by a transition to main stage. Primary objectives were to evaluate (1) thrust chamber chilldown, (2) augmented spark igniter performance, (3) idle-mode mixture ratio, (4) engine transition from idle-mode to main-stage operation, (5) solid-propellant turbine starter performance, and (6) oxidizer system pressure surges. Pressure altitude at engine start was 86,000 ft; engine ambient and combustion chamber pressures are shown in Fig. 19.

Thrust chamber chilldown data are indicated in Fig. 20. The thrust chamber chilldown rate compares closely with that indicated for firing 01A. Augmented spark igniter performance is shown in Fig. 21; ignition was detected at t_0 + 0.481 sec compared to 0.364 sec for firing 01A. Engine propellant flow rate and mixture ratio data in Fig. 22 were calculated in the same manner as those presented for firing 01A. Engine inlet and combustion chamber pressures are included in Fig. 22.

Transition from idle-mode to main-stage operation is shown in Fig. 23. Transition was satisfactory and compares favorably with firing 02A. Solid-propellant turbine starter performance (Fig. 24) was consistent with that obtained during firing 02A. Combustion pressure (Fig. 24a) was as predicted by the engine manufacturer. The burn duration was 2.4 sec, and the maximum pressure was 3420 psia. A maximum oxidizer system pressure (Fig. 25) of 1340 psia was measured at the oxidizer pump discharge at t_0 + 83.38 sec. This was 120 psi less than that measured during firing 02A.

Fuel pump start transient performance is shown in Fig. 26. Data analysis indicated a possible degradation in the fuel pump balance piston rings, and the engine manufacturer requested that no further main-stage testing be conducted until the pump could be repaired or replaced.

4.2.4 Firing J4-1902-03B

Firing 03B was a 55.8-sec duration idle-mode firing to evaluate (1) thrust chamber chilldown, (2) augmented spark igniter performance, and (3) engine mixture ratio. Engine ambient and combustion chamber pressures are shown in Fig. 27; pressure altitude at engine start was 101,000 ft.

Thrust chamber chilldown rate (Fig. 28) compared favorably with that obtained for firings 01A and 03A. Augmented spark igniter performance was satisfactory, as shown in Fig. 29; ignition was detected at t_0 + 0.371 sec. Engine propellant flow rate and mixture ratio data shown in Fig. 30 were calculated as stated in Section 4.2.1. Engine inlet and combustion chamber pressures are included in Fig. 30.

4.2.5 Firing J4-1902-04A

Firing 04A was a 288.5-sec duration idle-mode firing to evaluate (1) thrust chamber chilldown rate, (2) augmented spark igniter performance, and (3) engine mixture ratio. Pressure altitude at engine start was 98,000 ft; engine ambient and combustion chamber pressures are shown in Fig. 31.

Thrust chamber chilldown rate, as shown in Fig. 32, was lower than that measured for firings 01A, 03A, and 03B. The time required to reach a stable temperature was approximately 35 sec, some 10 sec longer than required for firings 01A, 03A, and 03B. Augmented spark igniter performance is shown in Fig. 33; ignition was detected at t_0 + 0.412 sec. Engine propellant flow rate and mixture ratio data shown in Fig. 34 were calculated as stated in Section 4.2.1. Engine inlet and combustion chamber pressures are included in Fig. 34.

Post-test inspection showed that the engine had been damaged extensively during this firing. The injector face had been burned through in two separate places (Fig. 35a), and the ends of several oxidizer posts had been burned and distorted. The combustion chamber tubes (upstream of the throat) in approximately 28 isolated areas had been ruptured and distorted with no evidence of heat damage (Fig. 35b).

Data analysis showed severe pressure perturbations in the combustion chamber and propellant systems beginning at t_0 + 158 sec and recurring at random time intervals until approximately t_0 + 252 sec, at which time combustion chamber pressure decreased to 4.5 psia and remained stable until engine shutdown at t_0 + 288.5 sec. The data shown in Fig. 36 are typical of the pressure perturbations as recorded by the digital data acquisition system. A pressure increase of 412 psi was reduced from the oscillogram recording of oxidizer injector pressure POJ-2 at t_0 + 158.20 sec. No failure analysis is attempted in this report.

4.2.6 Idle-Mode Mixture Ratio

Figure 37 shows idle-mode mixture ratio predicted by the engine manufacturer as a function of propellant pump inlet pressures. The predicted mixture ratio assumes saturated liquids at the pump inlets. The measured mixture ratio data are from manual reductions of flowmeter cyclic outputs over 0.5-sec increments as recorded on an oscillogram. The symbols (Fig. 37) are predicted mixture ratio as a function of measured pump inlet pressures. The numbers in parentheses are measured mixture ratio. A portion of the erratic nature of the data in Fig. 37 is attributed to the fact that propellant quality at the oxidizer flowmeter is not known in all cases. The times shown (Fig. 37) were chosen to represent data for which the oxidizer pump discharge pressures and temperatures indicated 100-percent liquid, except firing 03A, for which liquid was not indicated until after shutdown. For firing 04A, liquid was not indicated before t_0 + 140 sec. In all cases shown, the fuel pump discharge pressures and temperatures indicated 100-percent liquid.

4.2.7 Helium Consumption

Figure 38 shows temperature and pressure in the engine-mounted helium tank as functions of time for the five firings in this testing period. Helium consumption rate as indicated by a mass change averaged 0.001 lb_m/sec for idle-mode operation and 0.002 lb_m/sec for main-stage operation.

4.2.8 Engine Integrity

The main oxidizer valve was replaced following firing 01A because of a leaking idler arm shaft seal. The oxidizer dome purge check valve was repaired because of reverse flow following firing 01A and was replaced following firing 03B. The oxidizer idle-mode line purge check valve was replaced following firing 01A because of reverse flow.

Following firing 02A, the seal between the main oxidizer valve and the high pressure oxidizer supply duct was replaced because of leakage. At this time the oxidizer dome purge check valve was repaired to eliminate reverse flow.

Analysis of data from firing 03A indicated that the fuel pump balance piston rings had degraded to a degree that required repair or pump replacement before any further main-stage operation.

Inspection following firing 04A showed that the engine thrust chamber and injector had been damaged extensively and would require replacement.

SECTION V
SUMMARY OF RESULTS

Results of testing the J-2S rocket engine in Test Cell J-4 during test periods J4-1902-01 through J4-1902-04 between December 5, 1968, and January 10, 1969, are summarized as follows:

1. Augmented spark igniter performance was satisfactory, and engine start was successful in all cases.
2. Transition from idle-mode to main-stage operation was successful in all cases.
3. Engine-generated side loads during transition to main-stage operation were less than 1200 lb_f.
4. Possible degradation of the fuel pump balance piston rings occurred during main-stage firing 03A.
5. The engine thrust chamber and injector were damaged extensively during a 288.5-sec duration idle-mode firing (04A).
6. Thrust chamber temperatures reached a steady-state idle-mode operating level within 40 sec after engine start.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. "J-2S Interface Criteria." Rocketdyne Document J-7211, October 16, 1967.
3. Test Facilities Handbook (7th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.
4. "Engine Model Specification Oxygen/Hydrogen Liquid-Propellant Rocket Engine Rocketdyne Model J-2S." Rocketdyne Document R-2158dS, August 21, 1968.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION

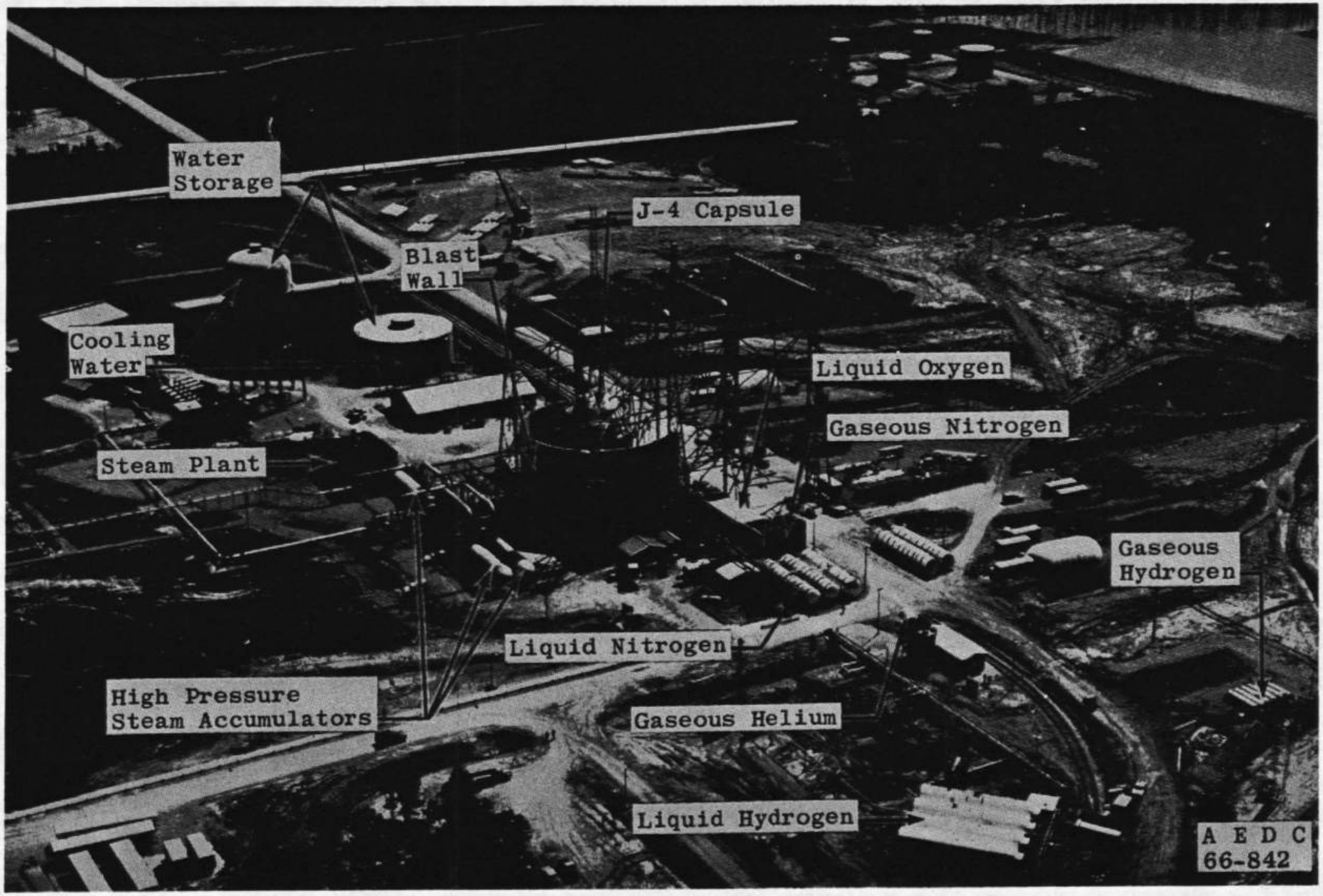


Fig. 1 Test Cell J-4 Complex

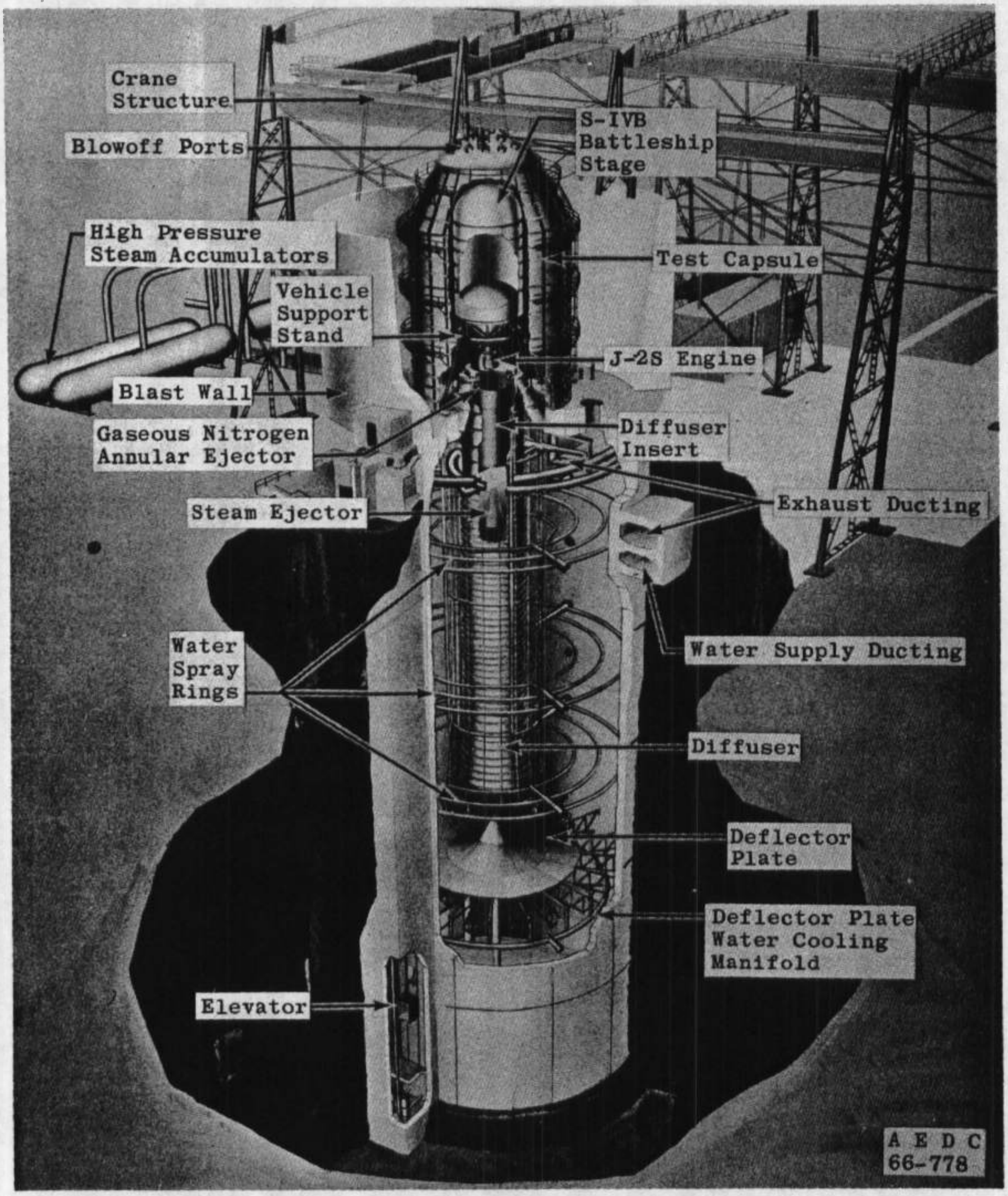


Fig. 2 Test Cell J-4, Artist's Conception

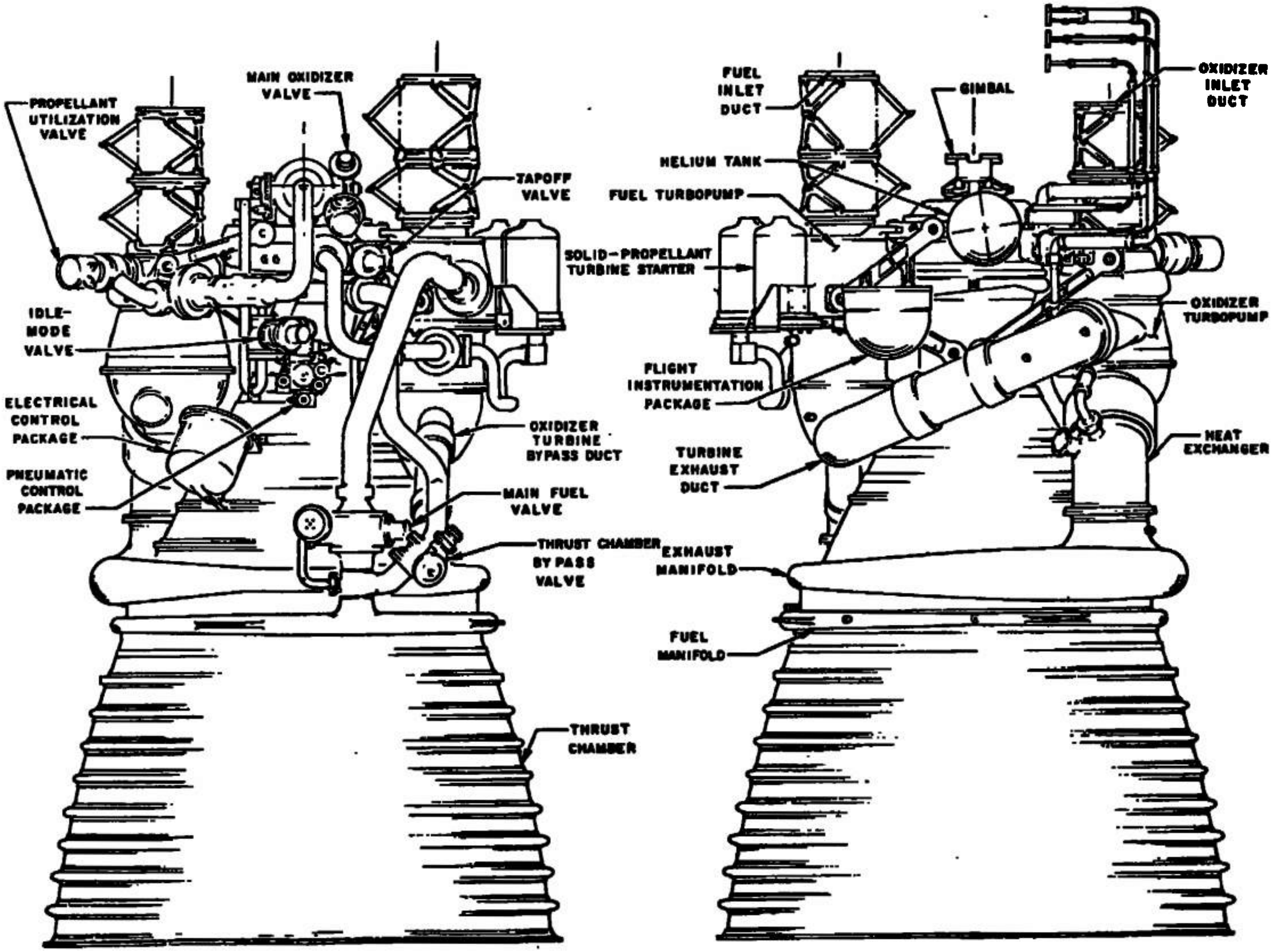


Fig. 3 J-2S Engine General Arrangement

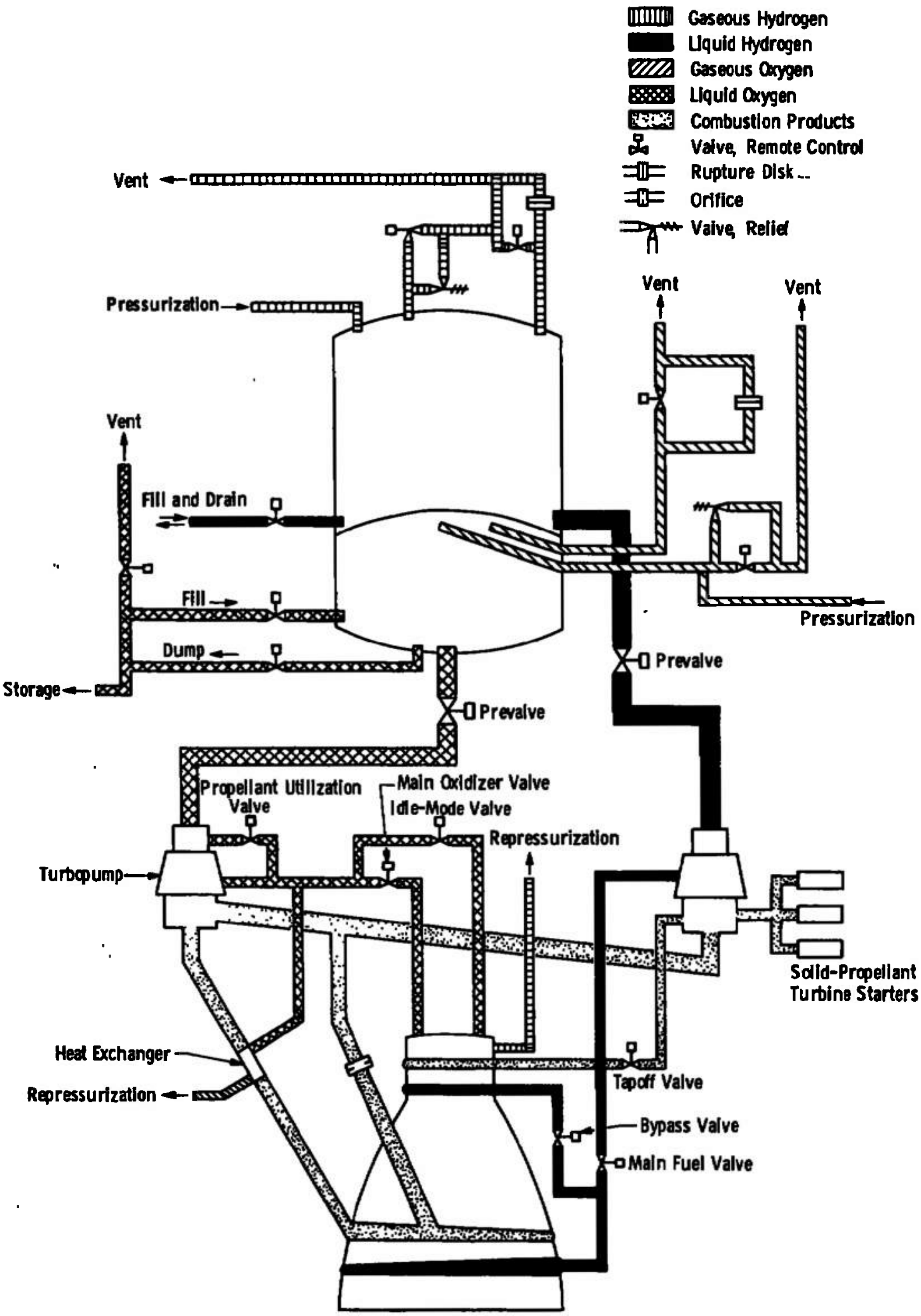
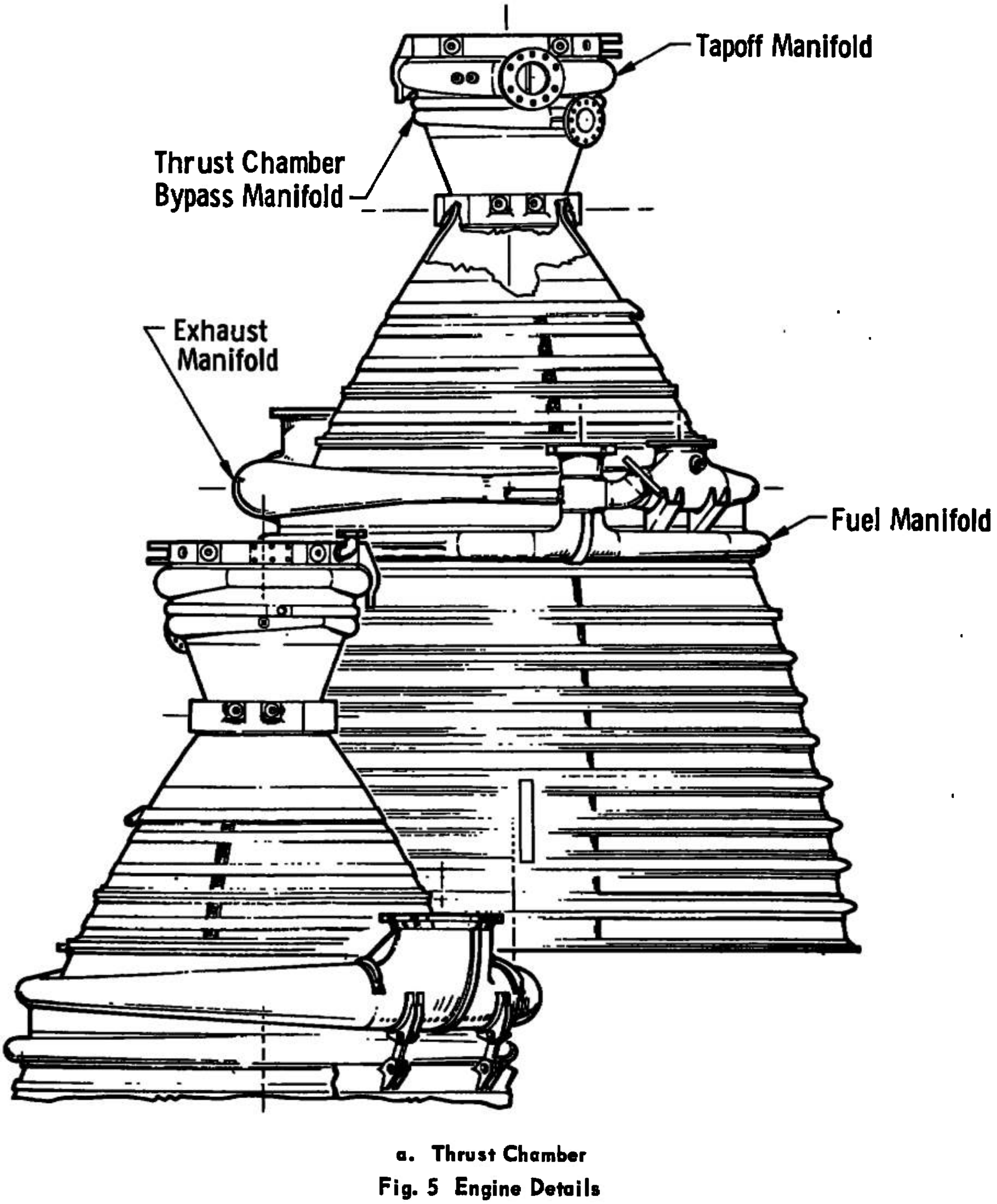
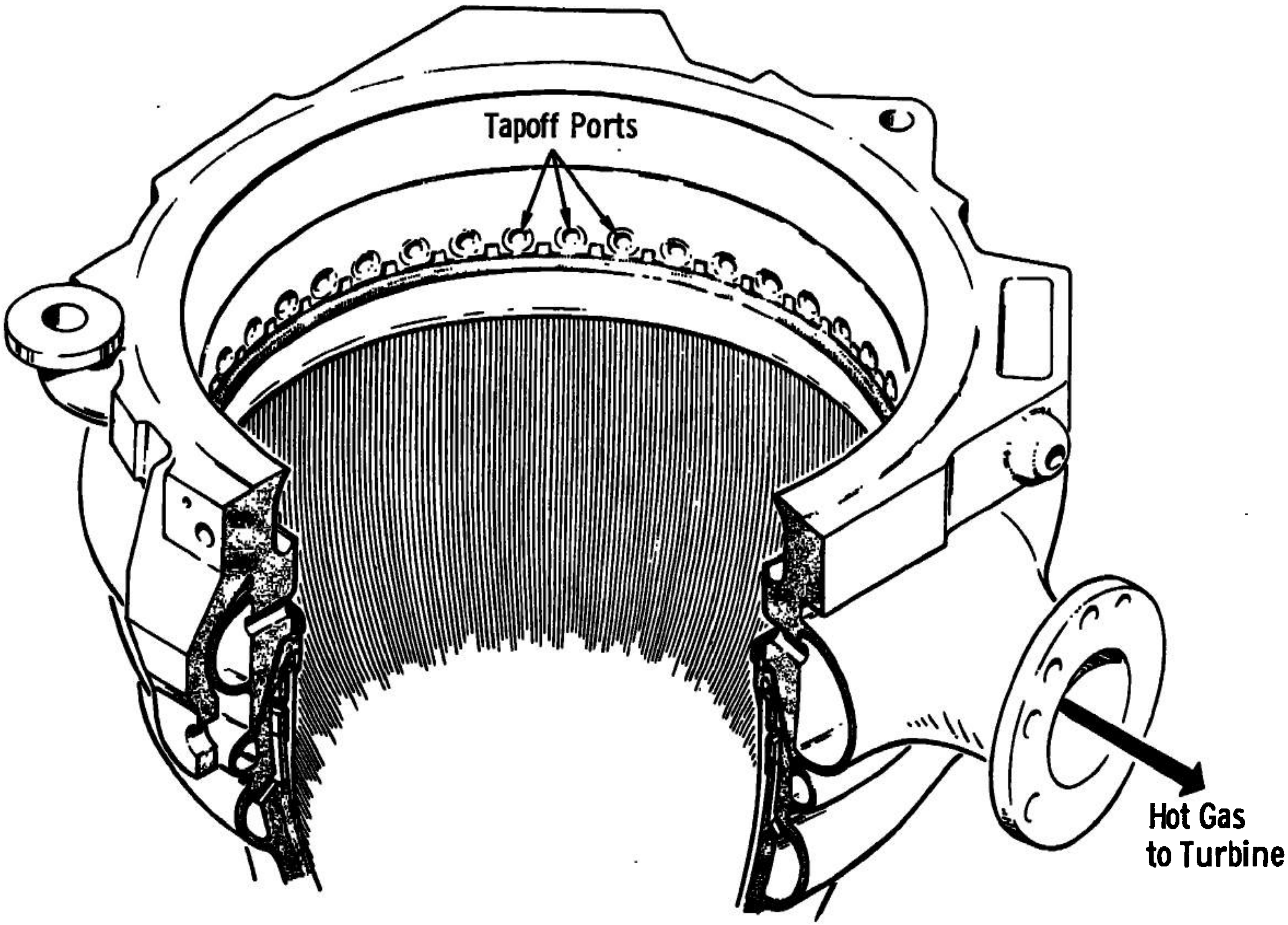


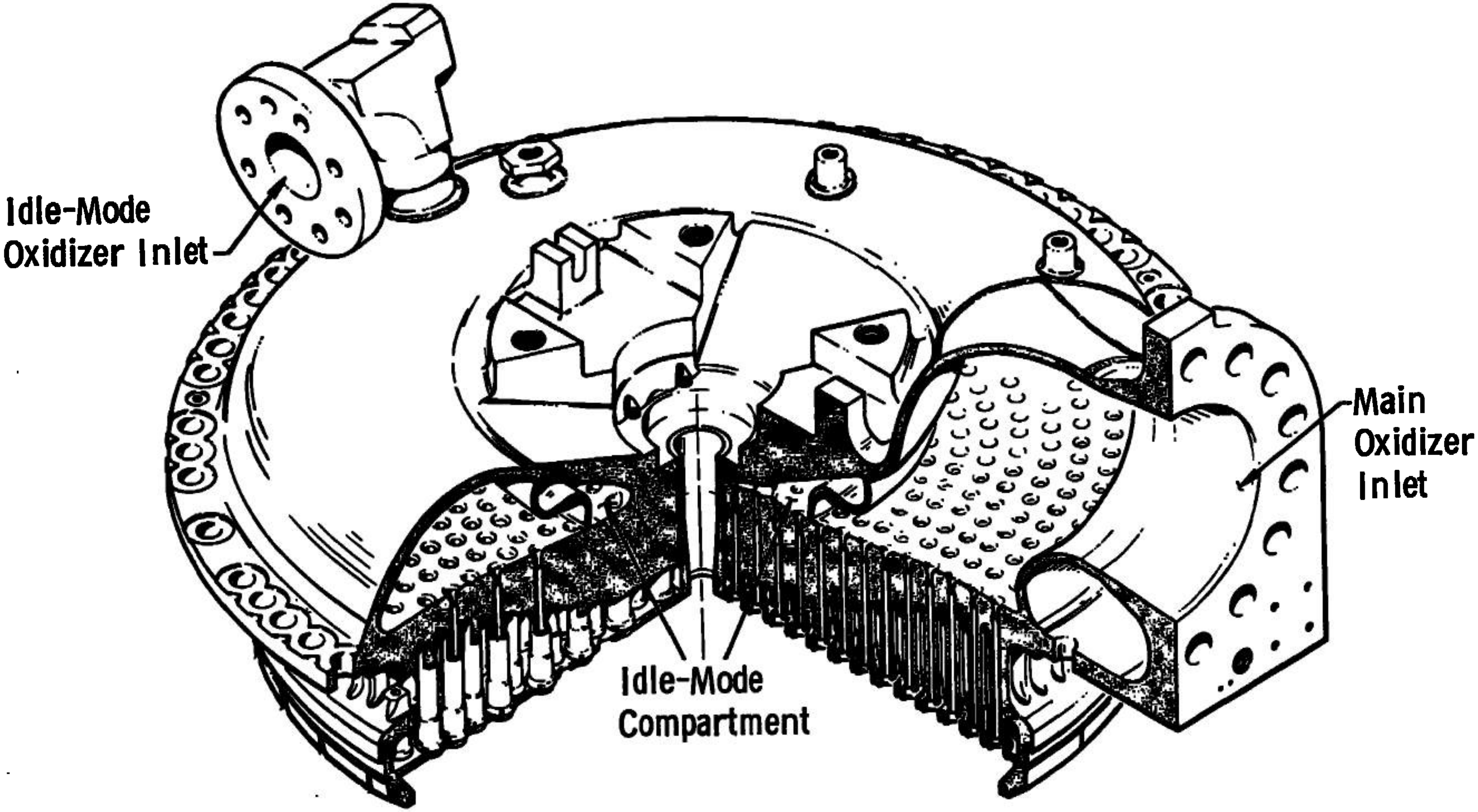
Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



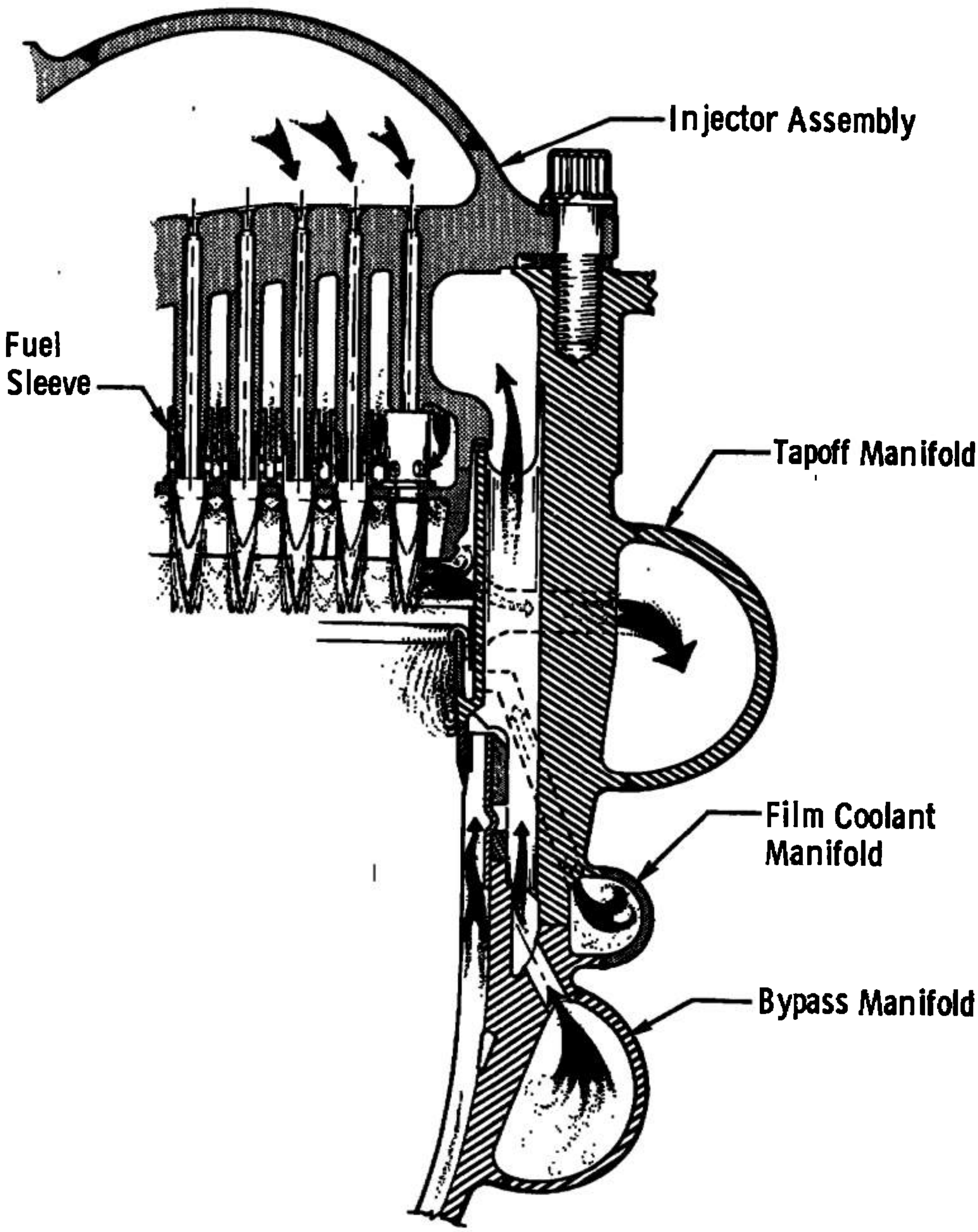
a. Thrust Chamber
Fig. 5 Engine Details



b. Combustion Chamber
Fig. 5 Continued



c. Injector
Fig. 5 Continued



d. Injector to Chamber
Fig. 5 Concluded

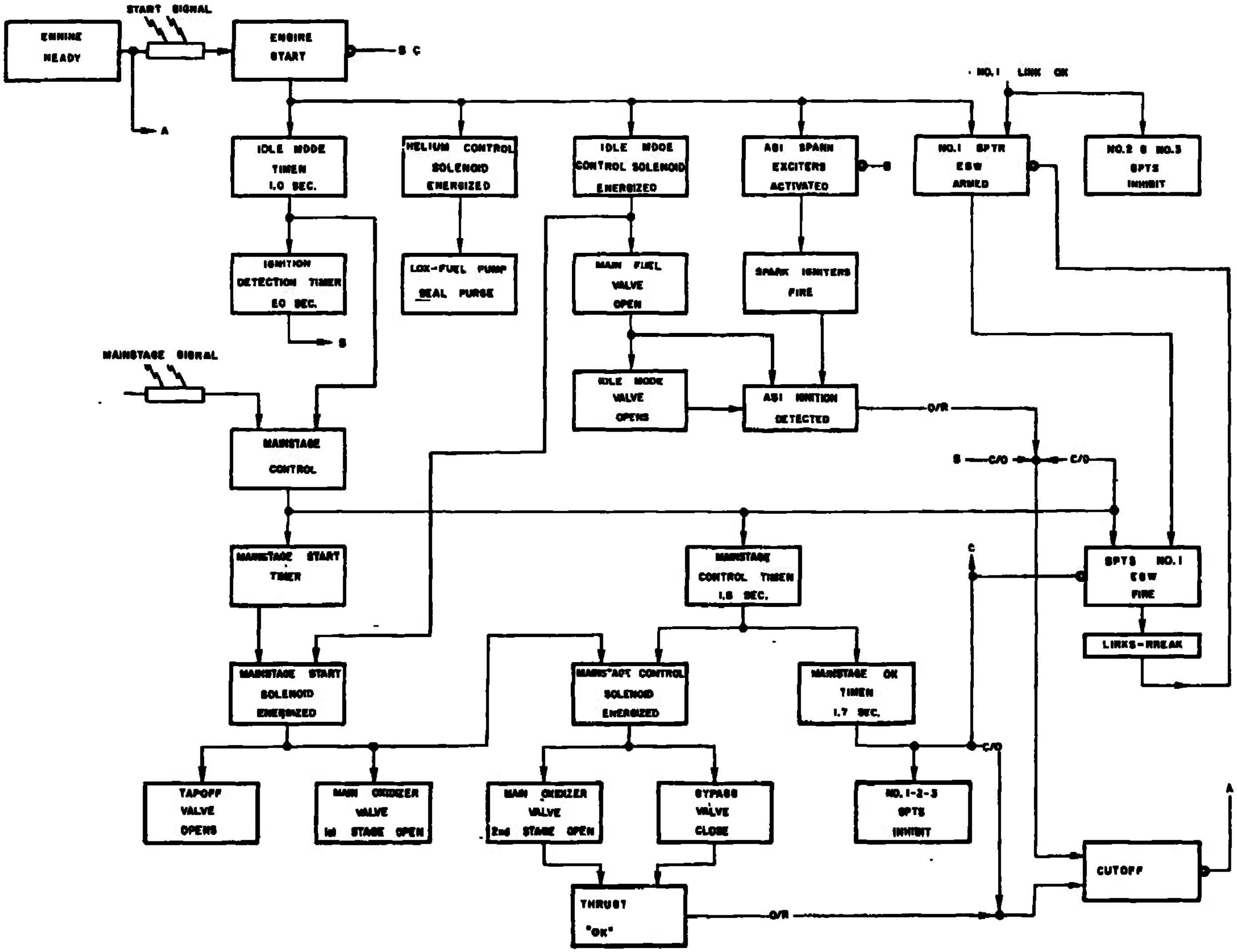
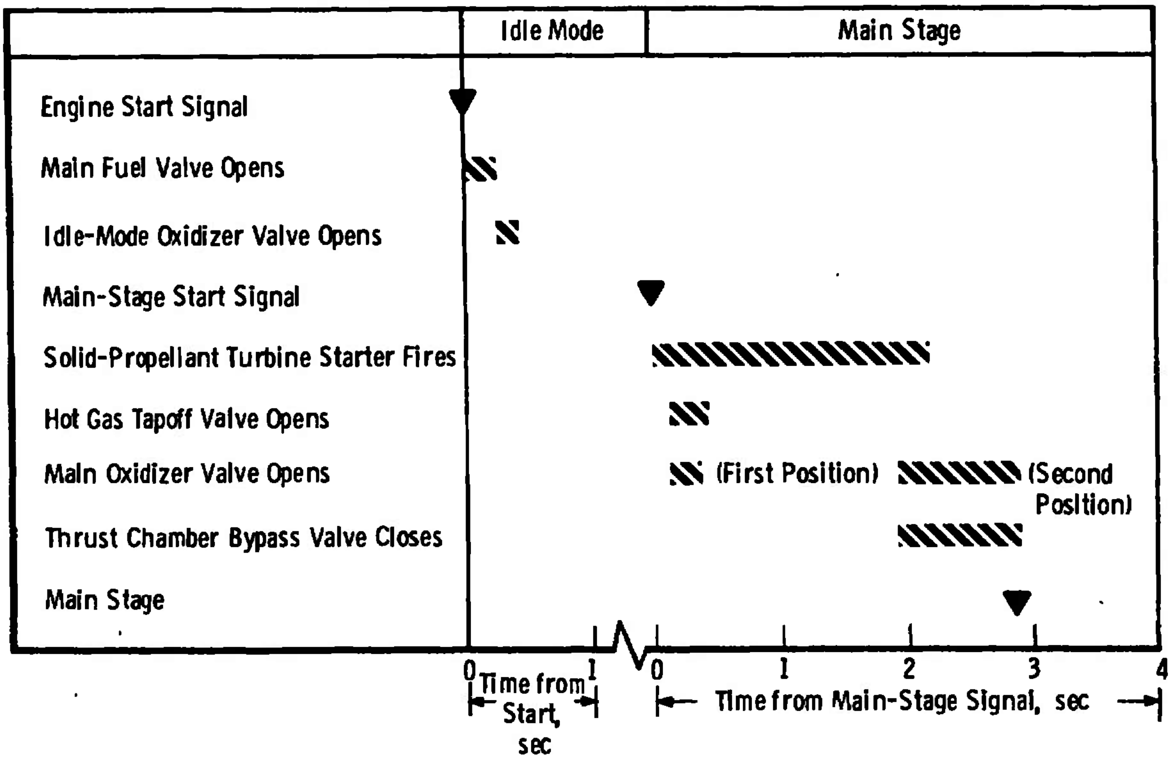
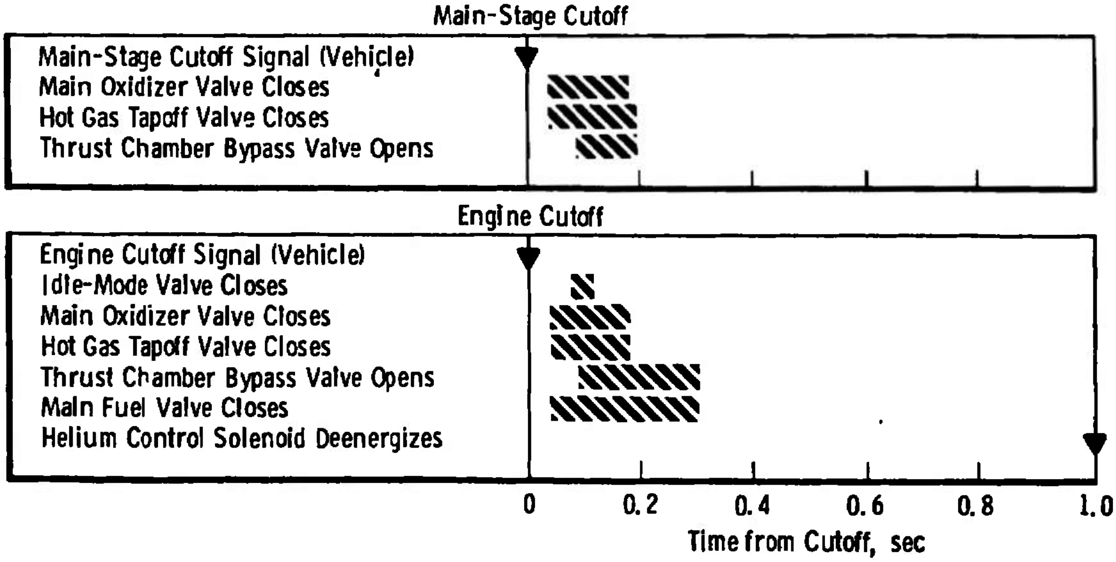


Fig. 6 Engine Start Logic Schematic

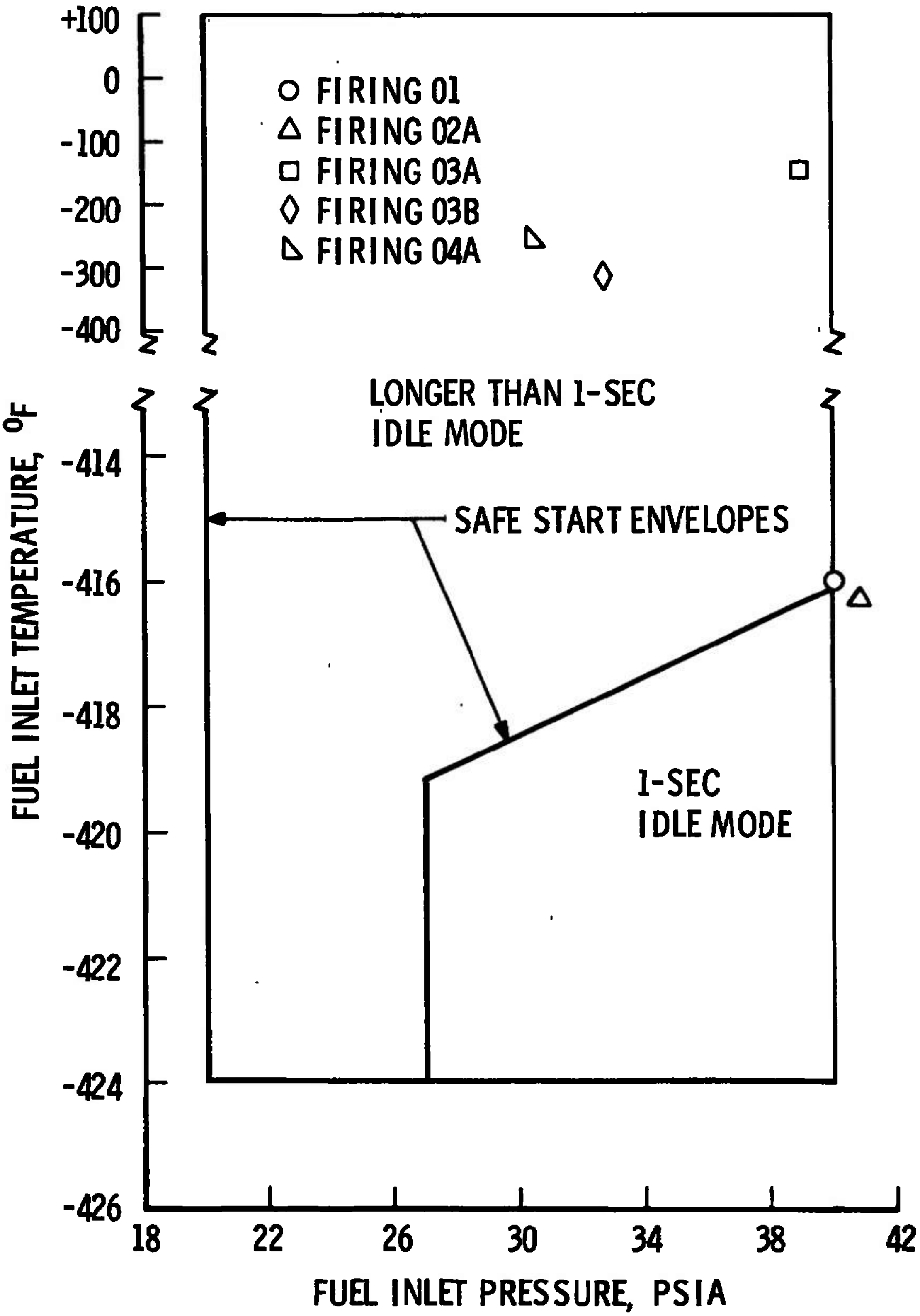


a. Start Sequence



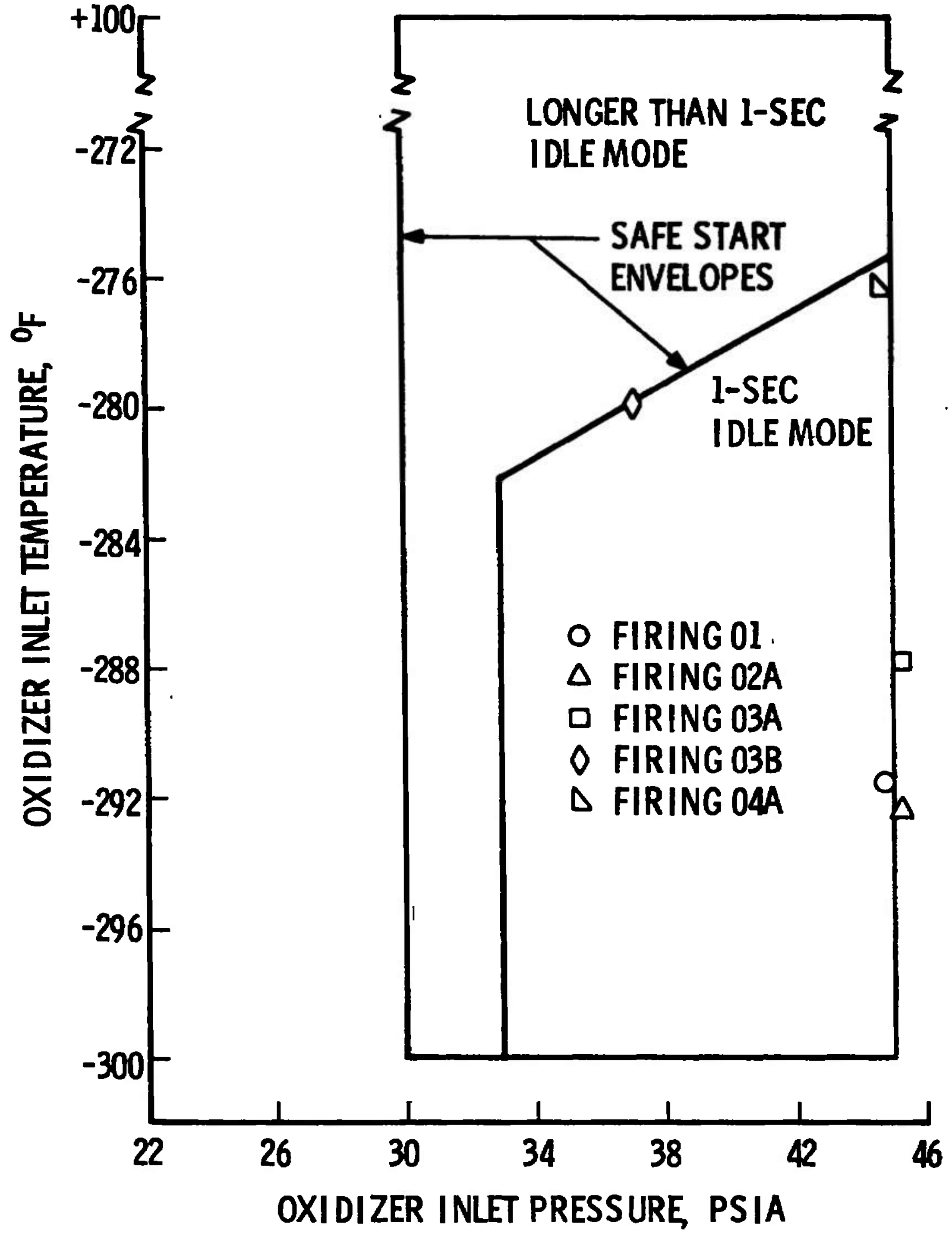
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

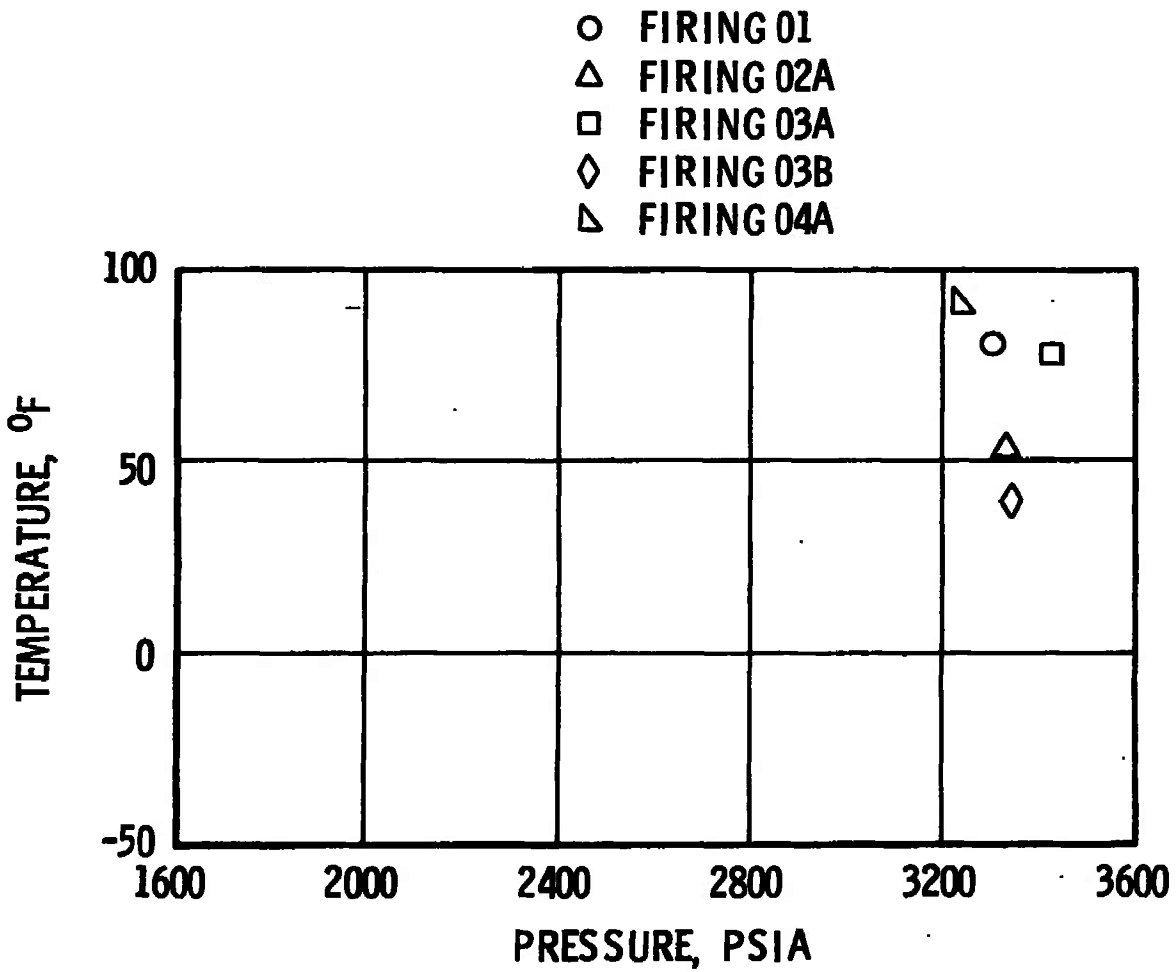


a. Fuel Pump

Fig. 8 Engine Start Conditions for Propellant Pump Inlets and Helium Tank



b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank

Fig. 8 Concluded

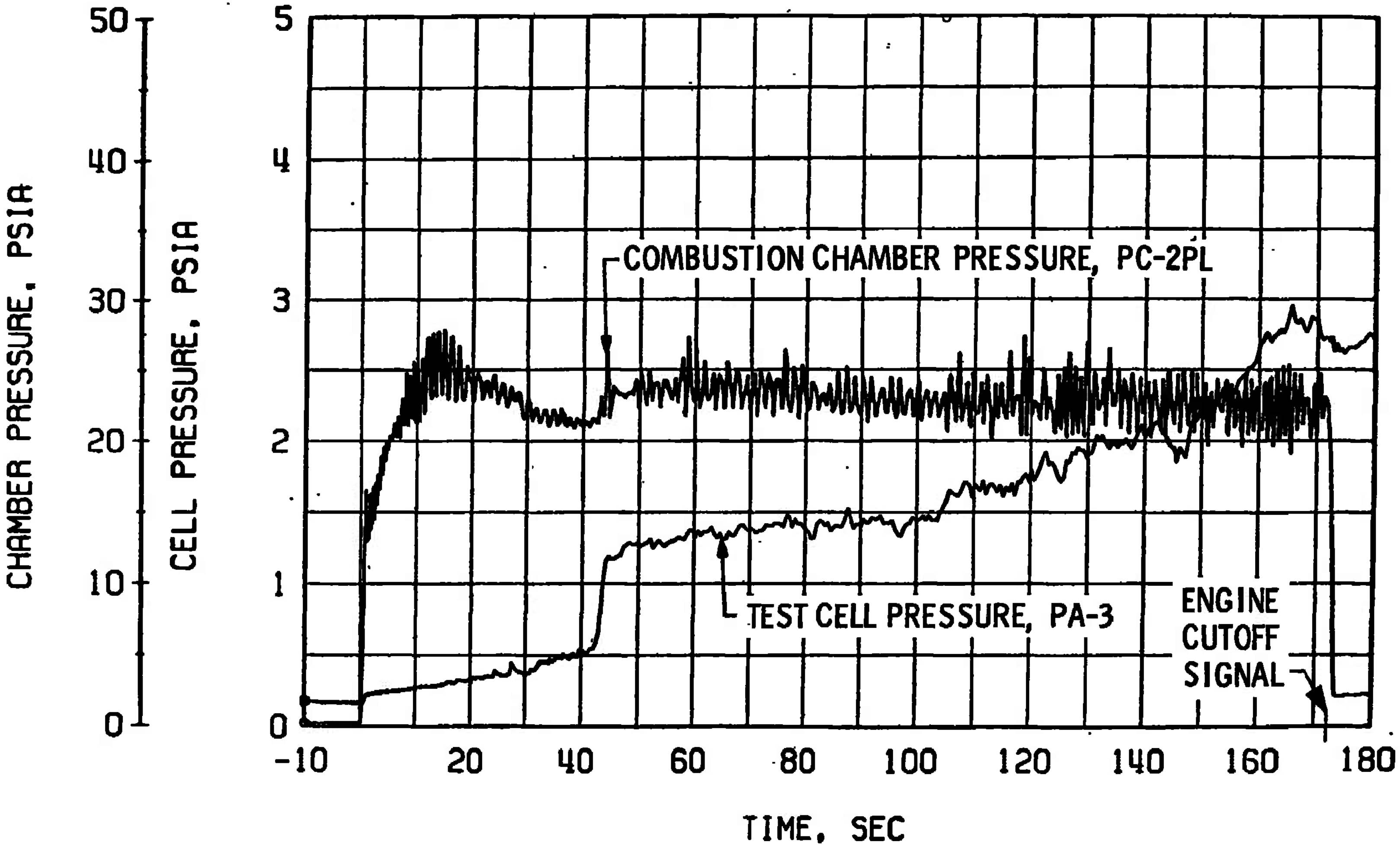


Fig. 9 Engine Ambient and Combustion Chamber Pressure, Firing 01A

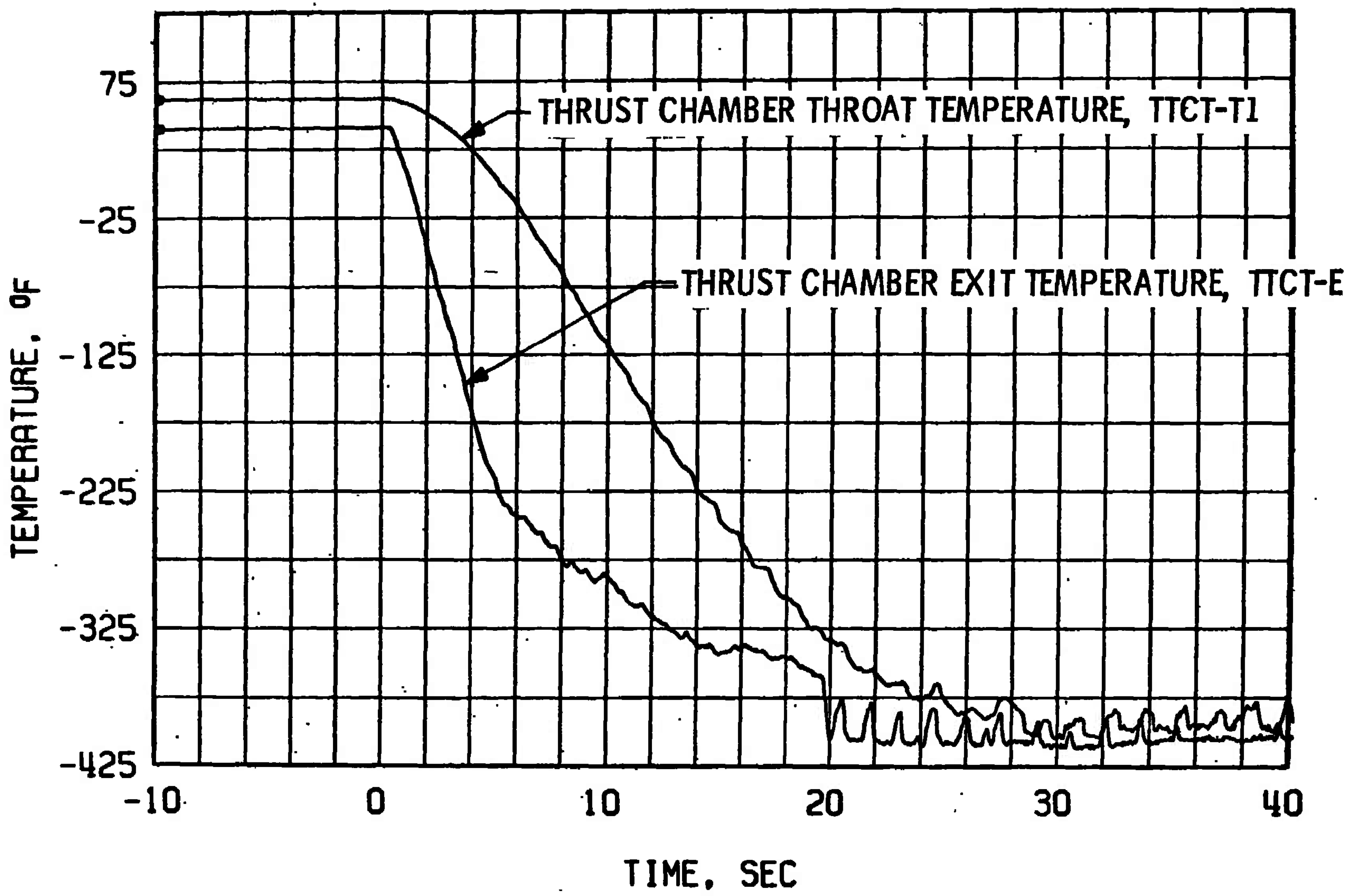


Fig. 10 Thrust Chamber Chilldown, Firing 01A

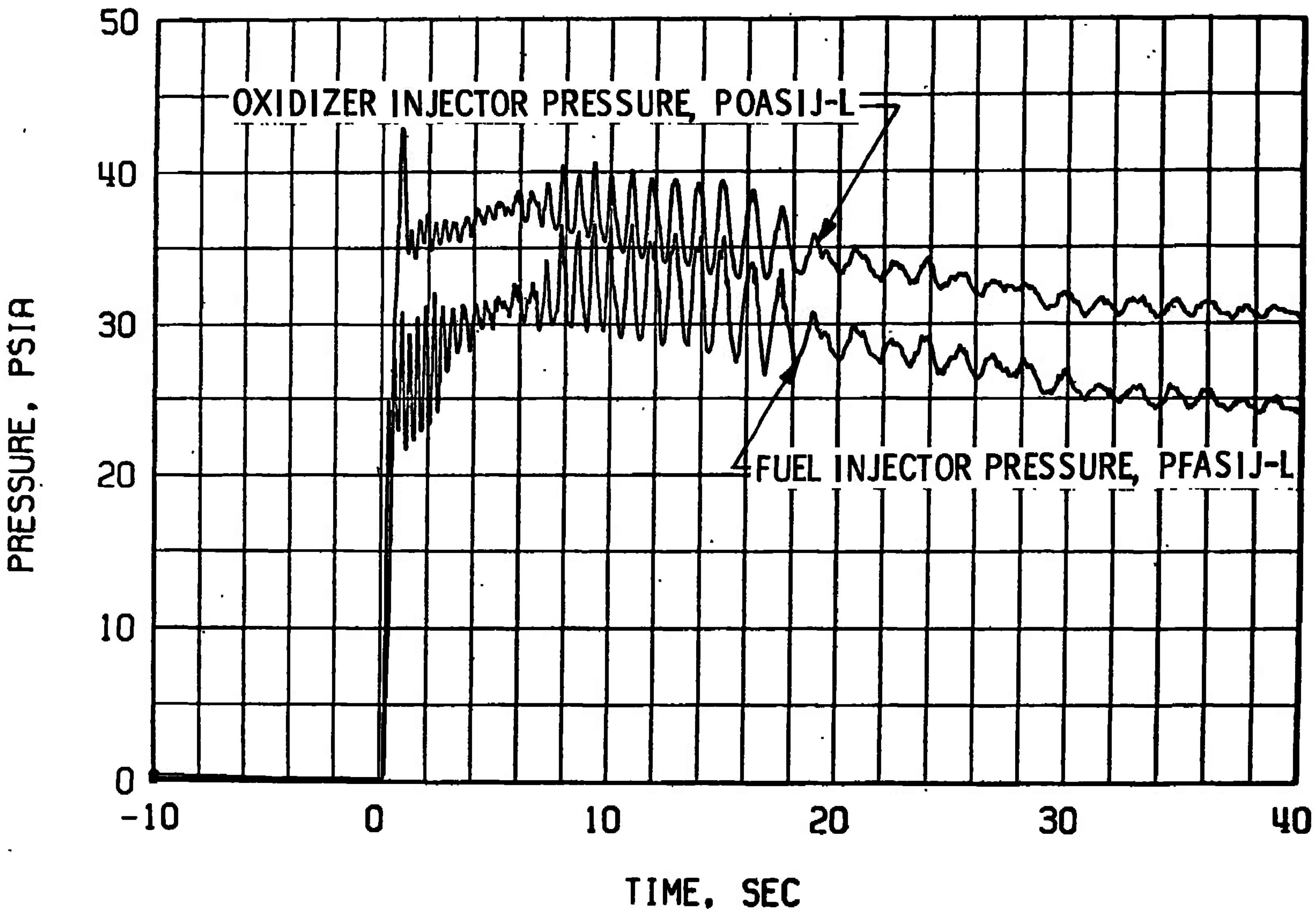
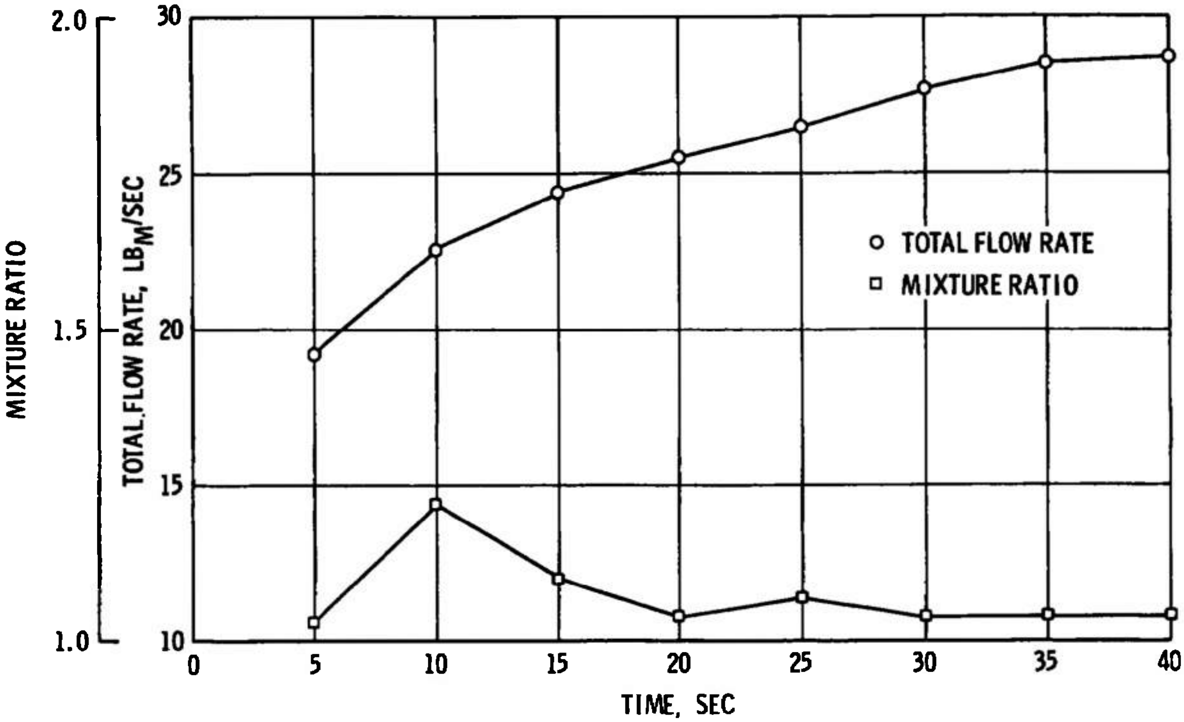
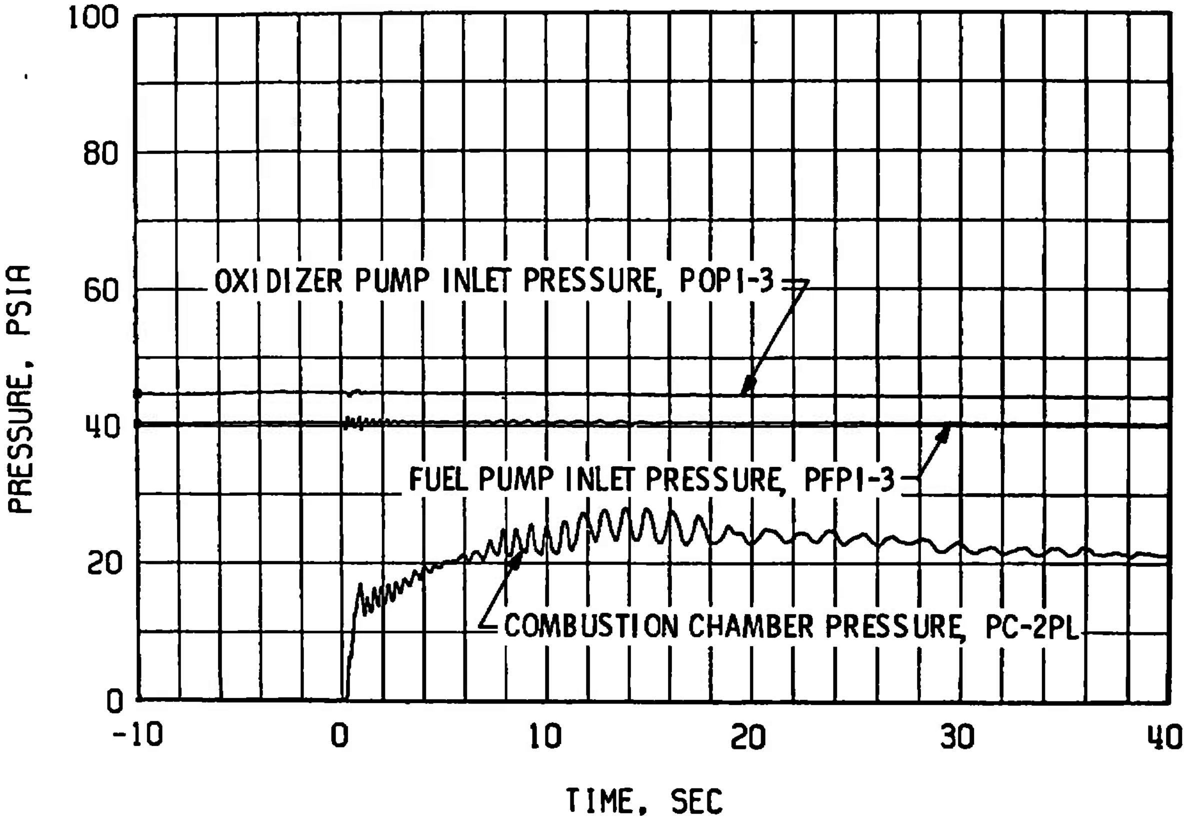


Fig. 11 Augmented Spark Igniter Performance, Firing 01A



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 12 Propellant System Performance during Idle Mode, Firing 01A

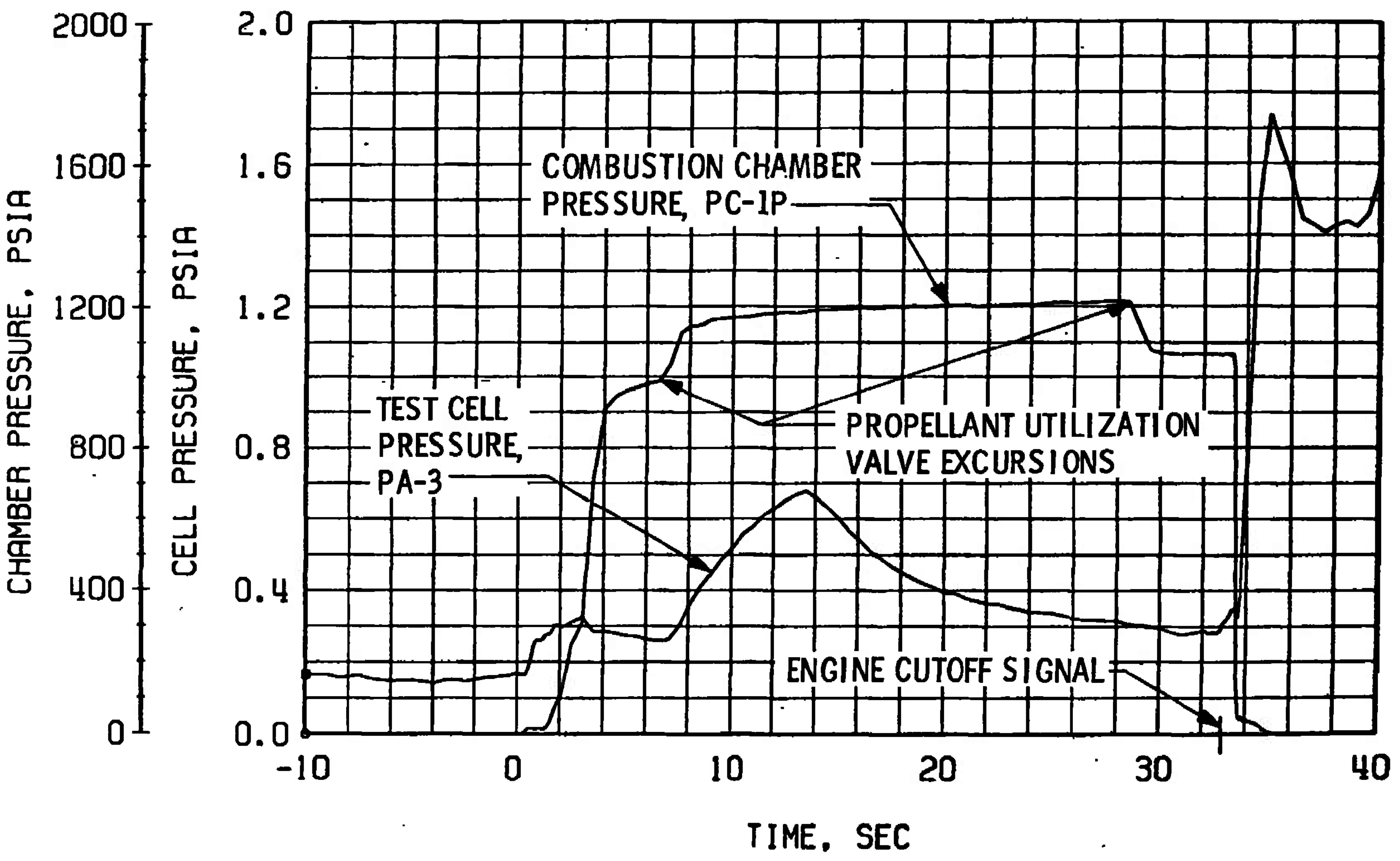
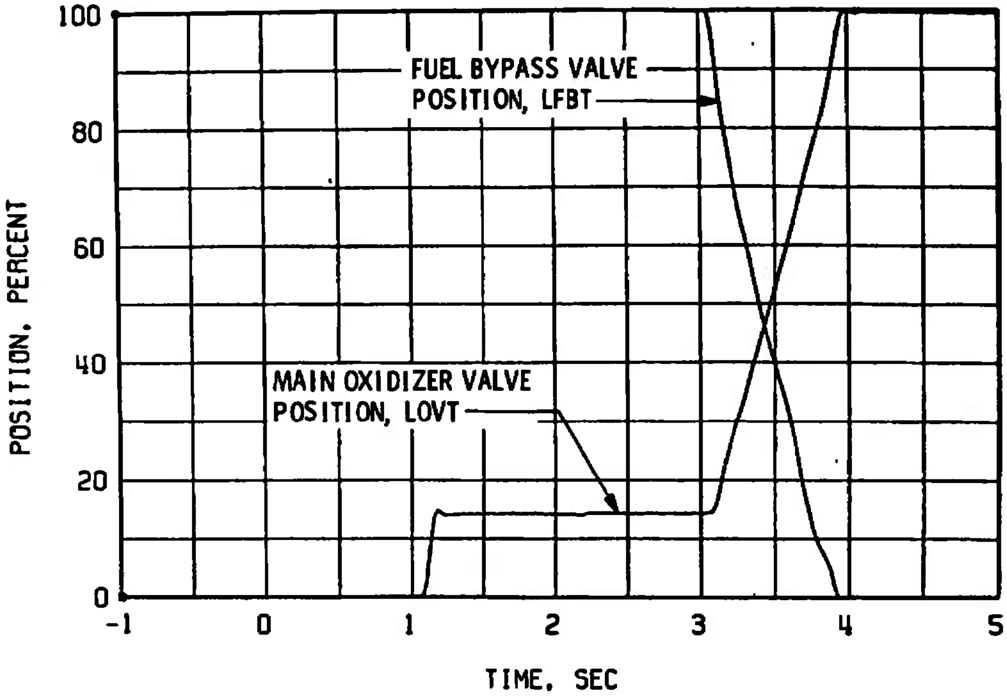
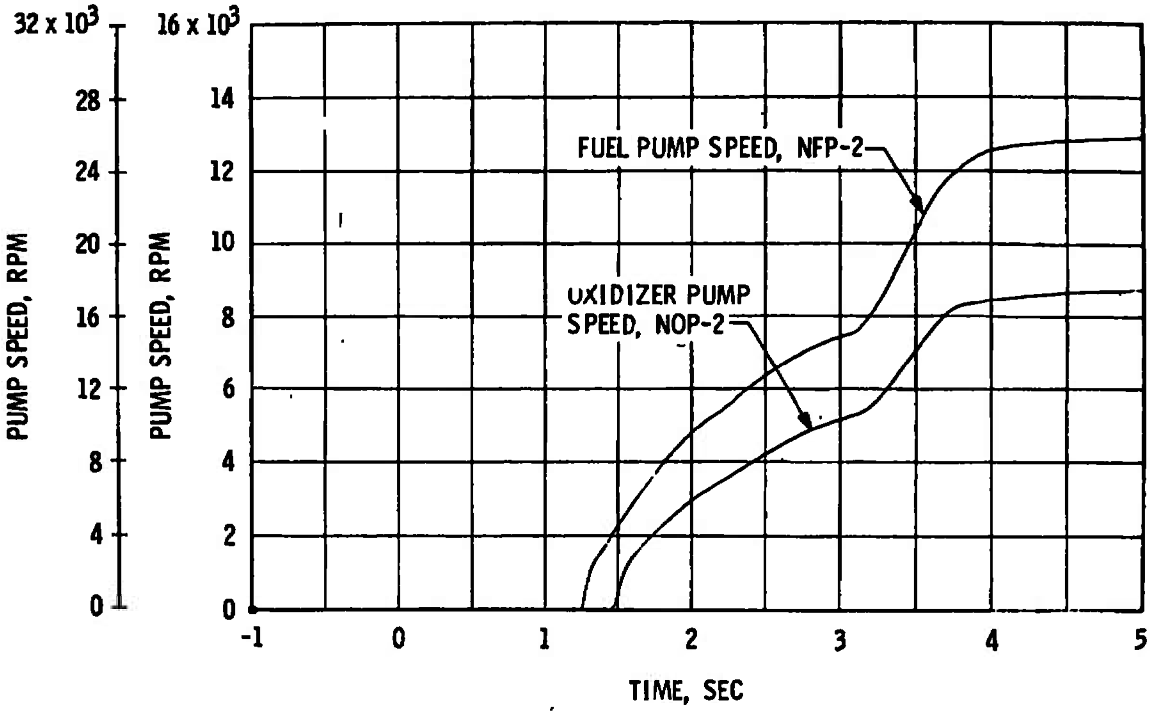


Fig. 13 Engine Ambient and Combustion Chamber Pressure, Firing 02A

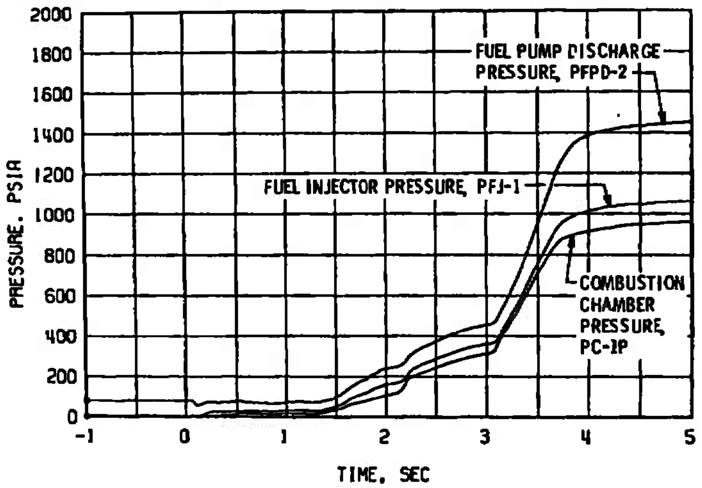


a. Main Oxidizer and Fuel Bypass Valves, Start

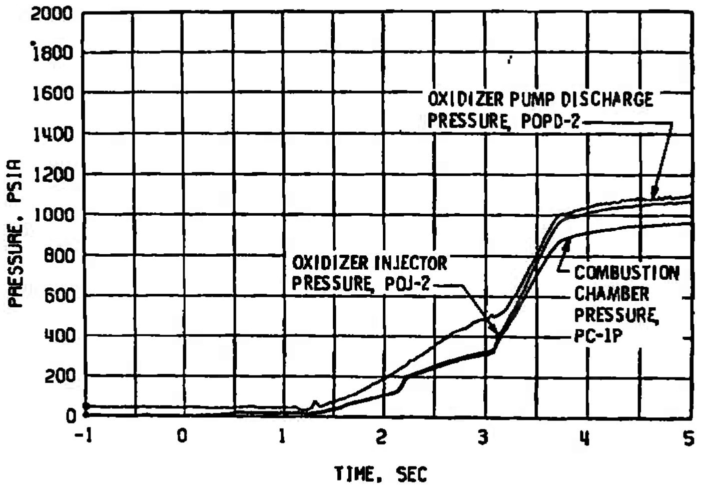


b. Propellant Pumps, Start

Fig. 14 Engine Transient Operation, Firing 02A

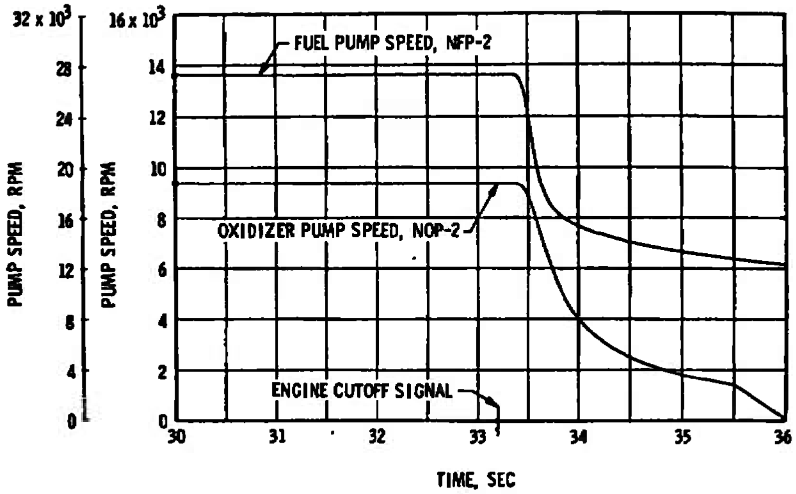


c. Fuel System, Start

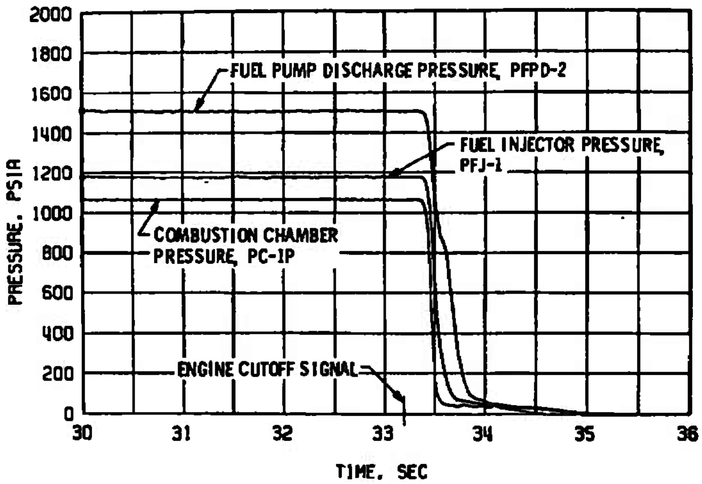


d. Oxidizer System, Start

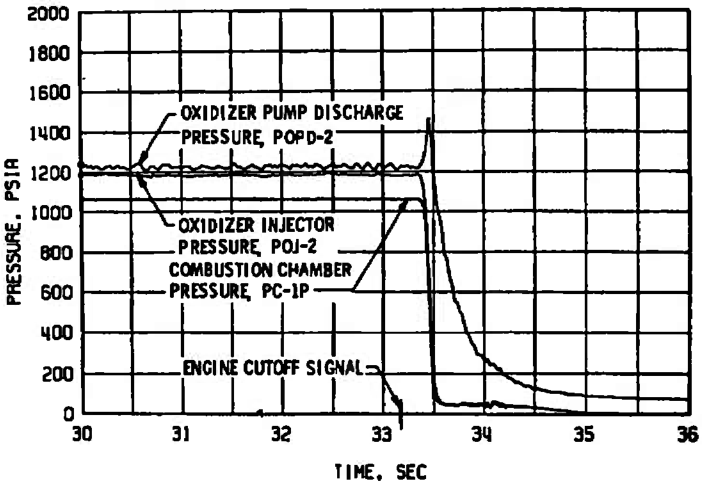
Fig. 14 Continued



e. Propellant Pumps, Shutdown

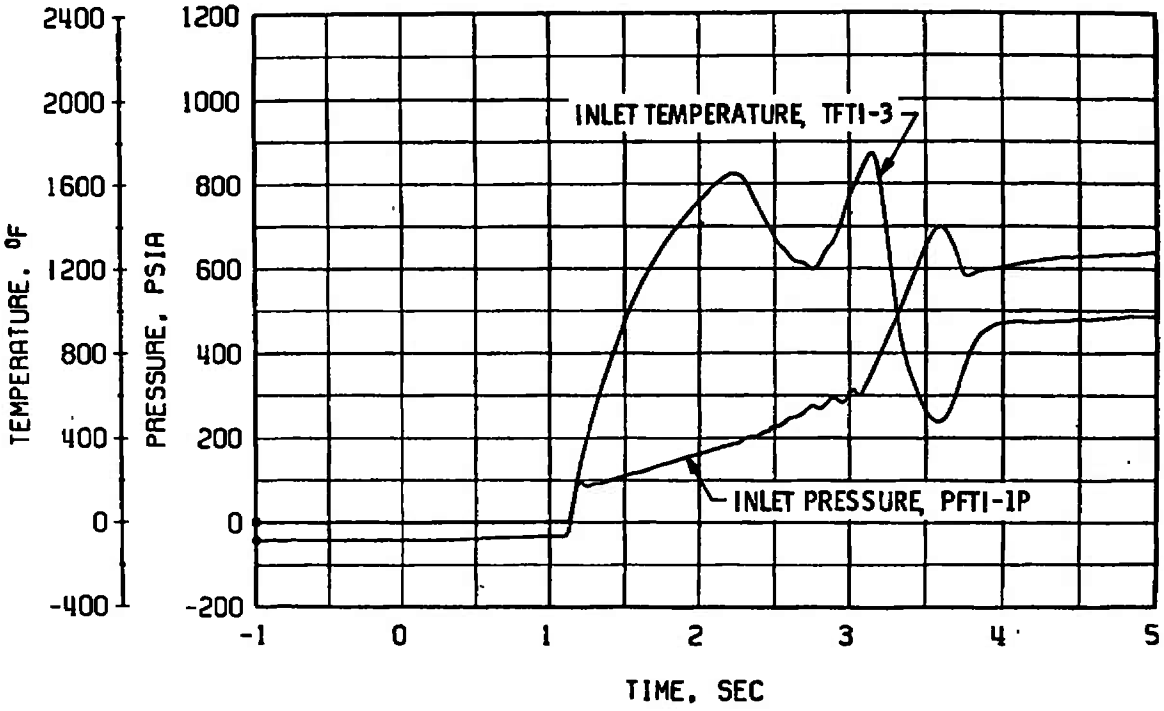


f. Fuel System, Shutdown

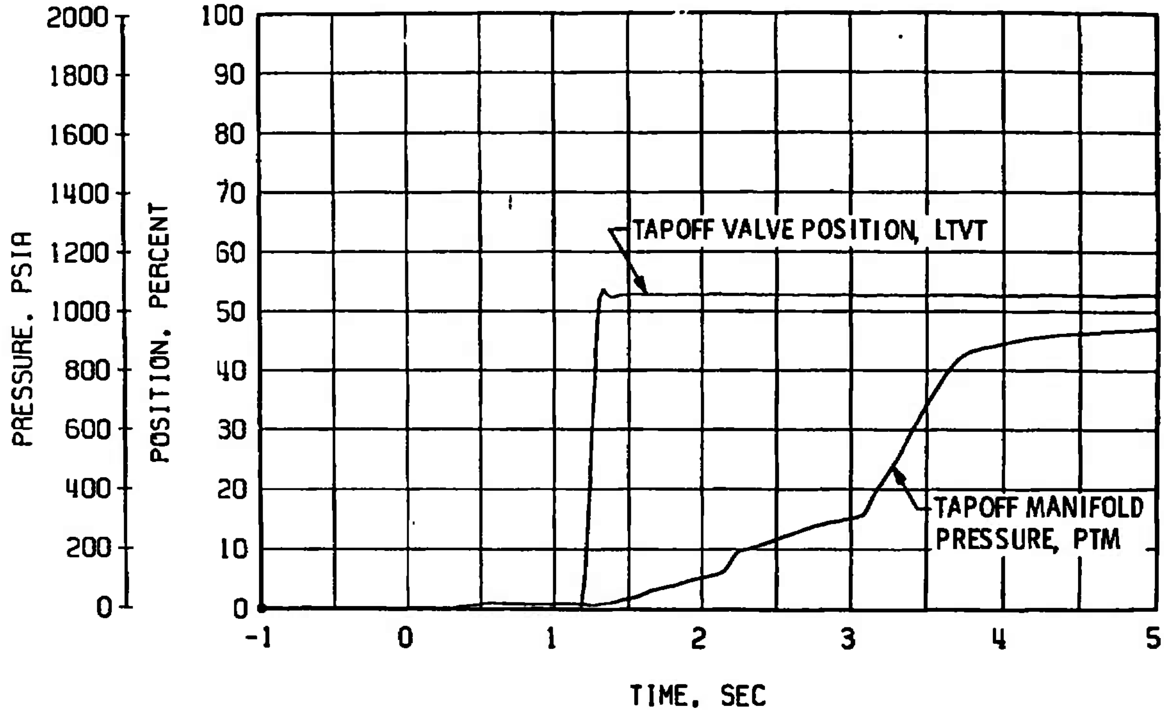


g. Oxidizer System, Shutdown

Fig. 14 Concluded

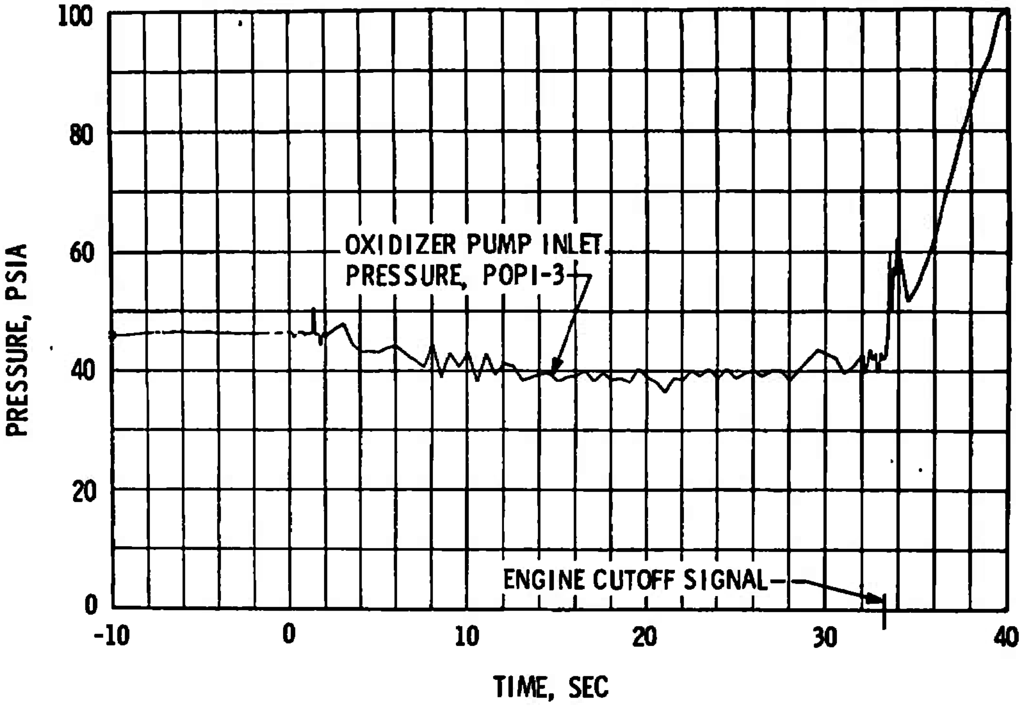


a. Fuel and Turbine Inlet Temperature and Pressure

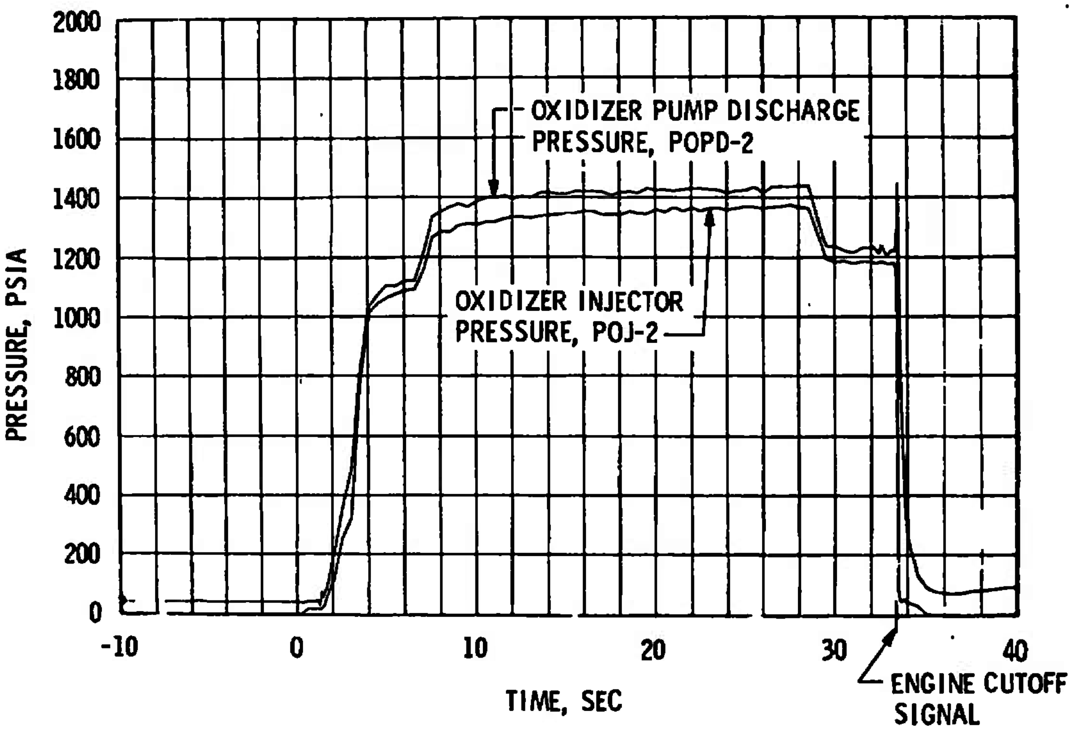


b. Tapoff Valve Position and Manifold Pressure

Fig. 15 Solid-Propellant Turbine Starter Performance, Firing 02A



a. Pump Inlet Pressure



b. Pump Discharge and Injector Pressure

Fig. 16 Oxidizer System Pressures, Firing 02A

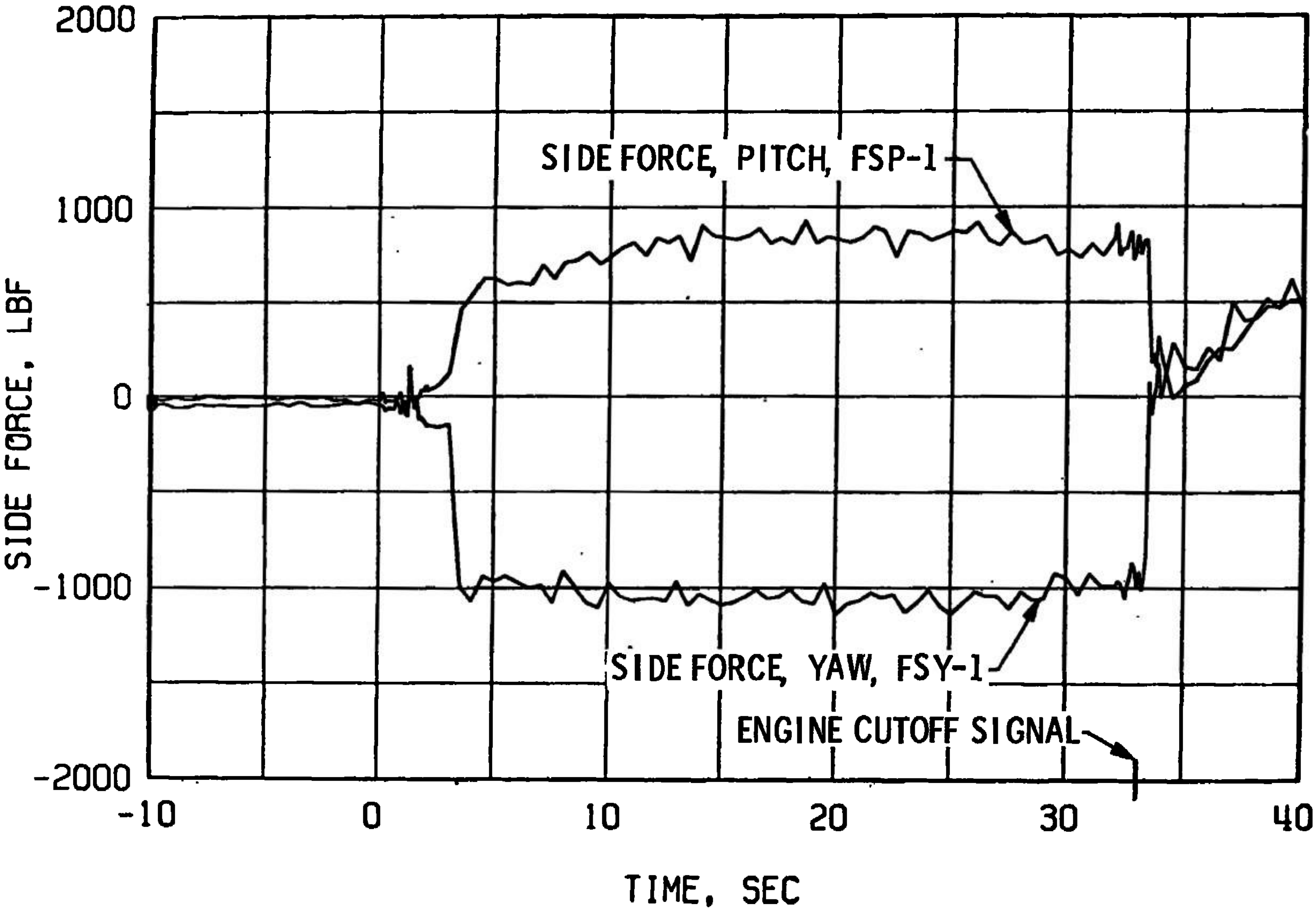


Fig. 17 Engine-Generated Side Loads, Firing 02A

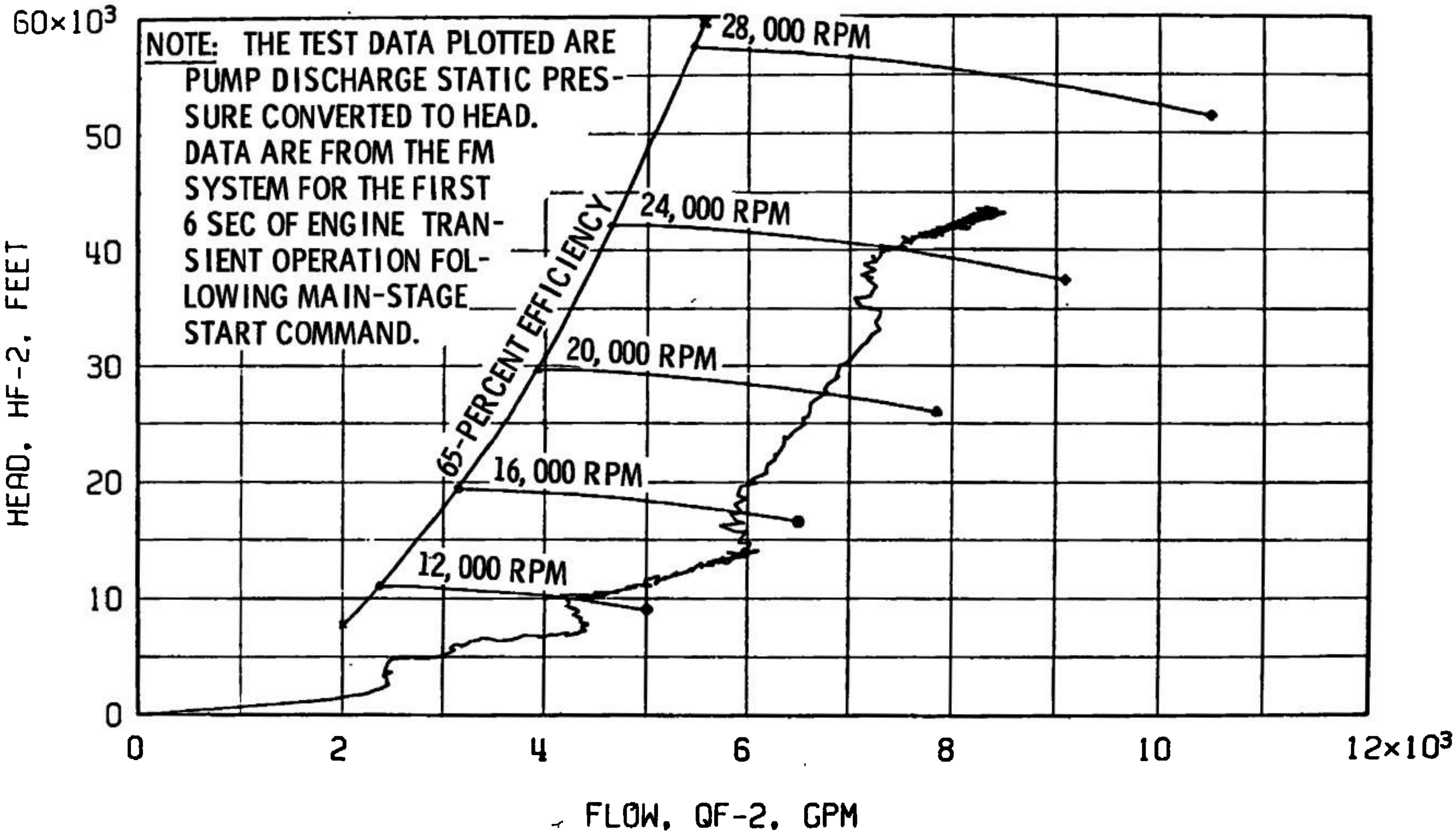


Fig. 18 Fuel Pump Start Transient Performance, Firing 02A

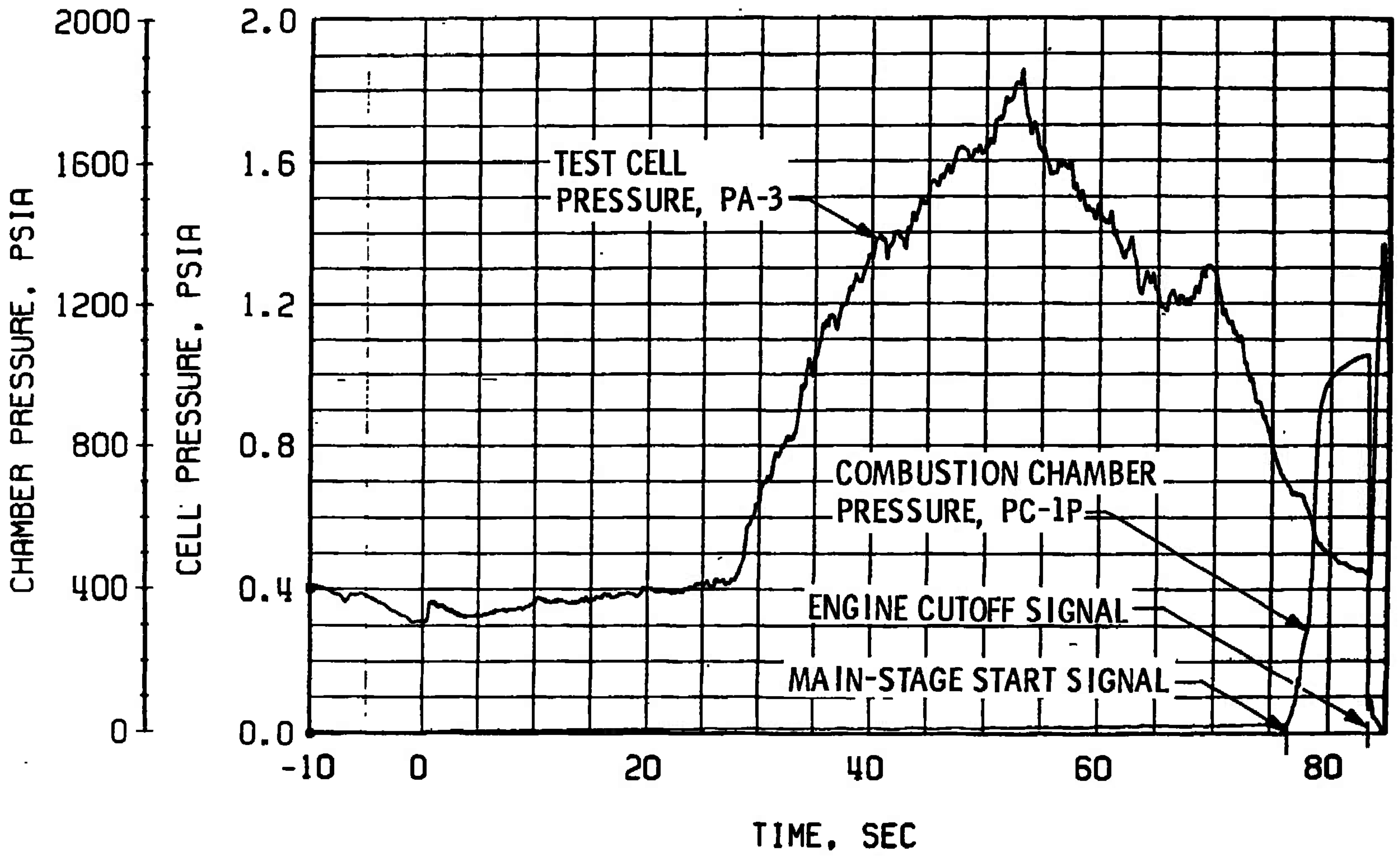


Fig. 19 Engine Ambient and Combustion Chamber Pressure, Firing 03A

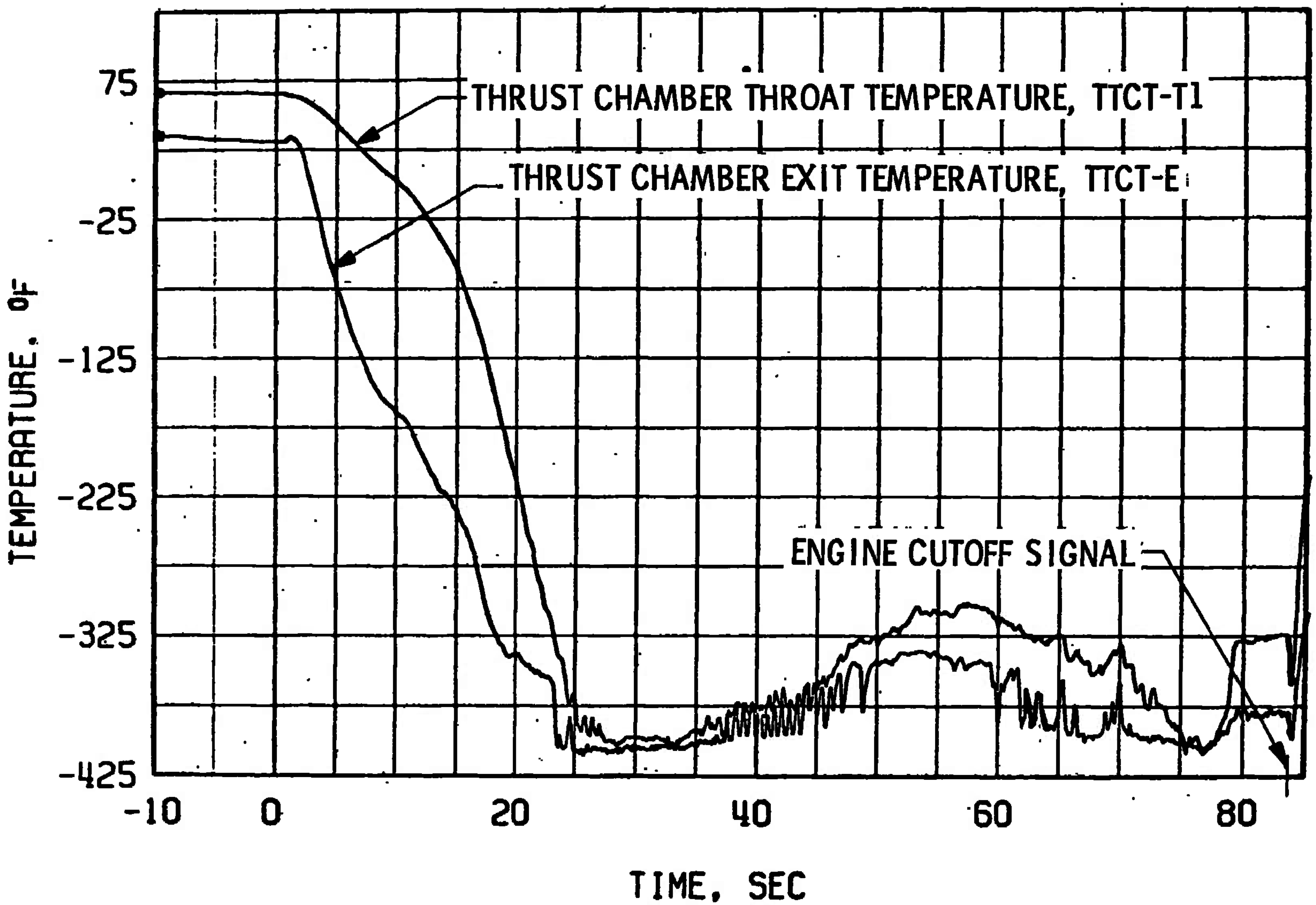


Fig. 20 Thrust Chamber Chilldown, Firing 03A

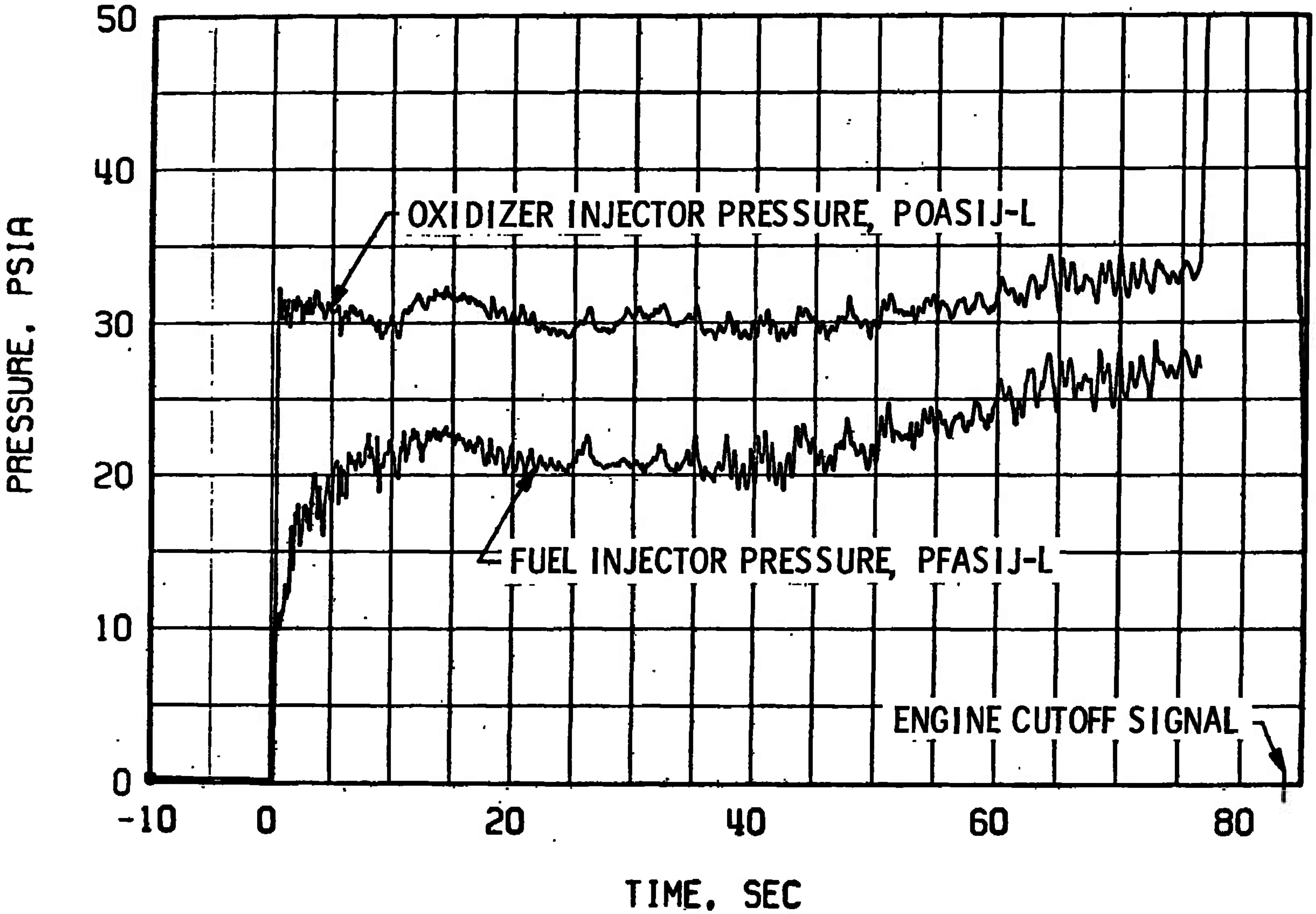
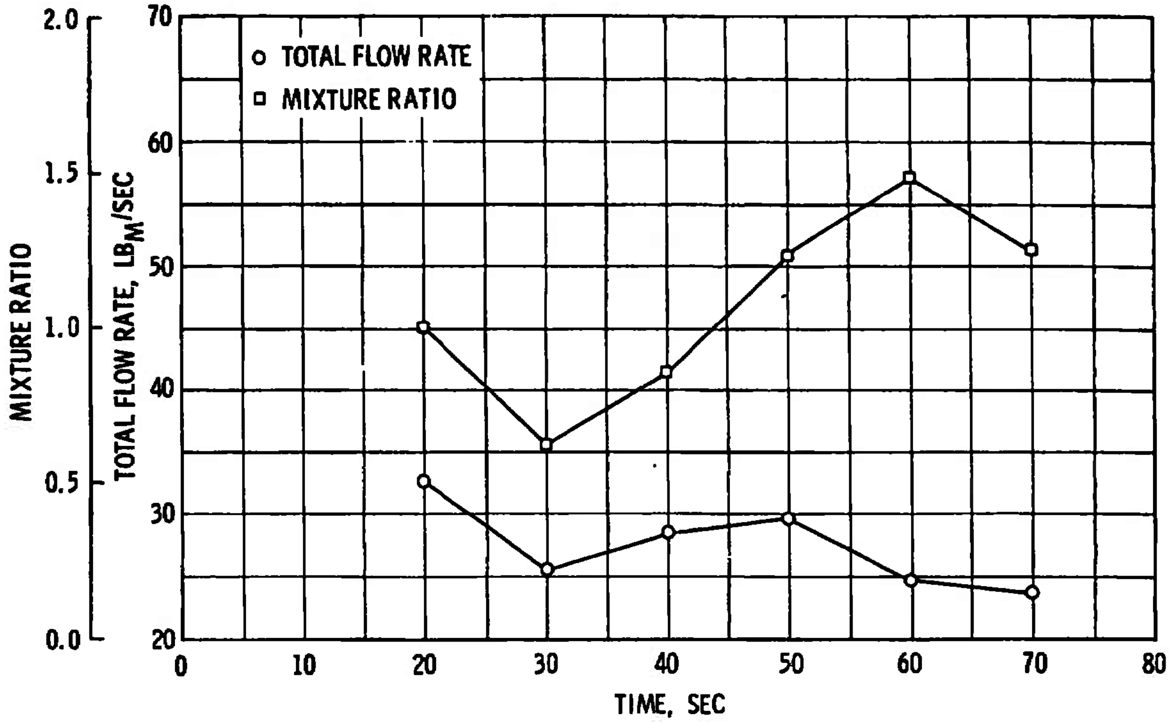
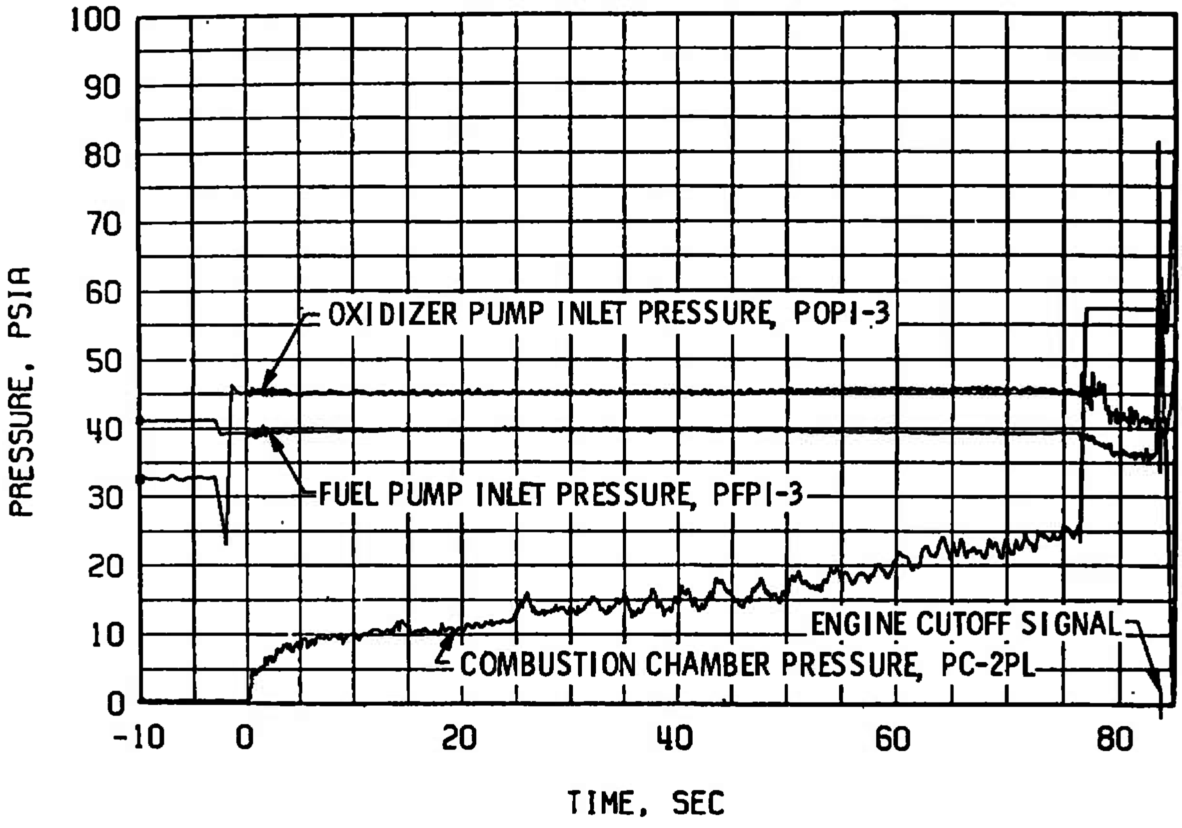


Fig. 21 Augmented Spark Igniter Performance, Firing 03A

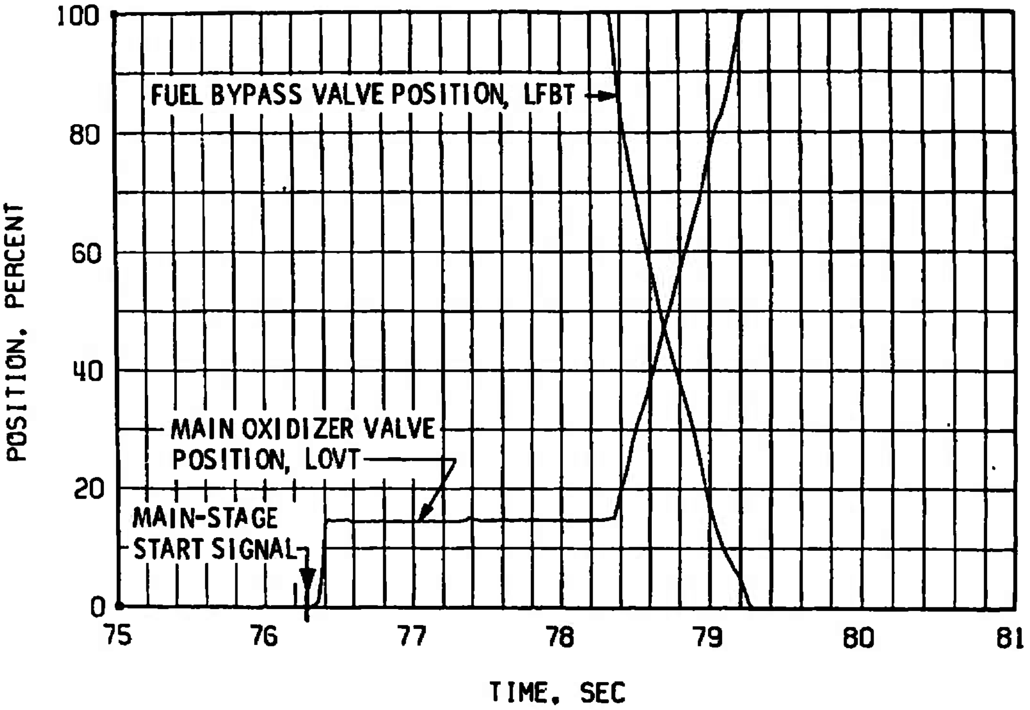


a. Total Flow Rate and Mixture Ratio

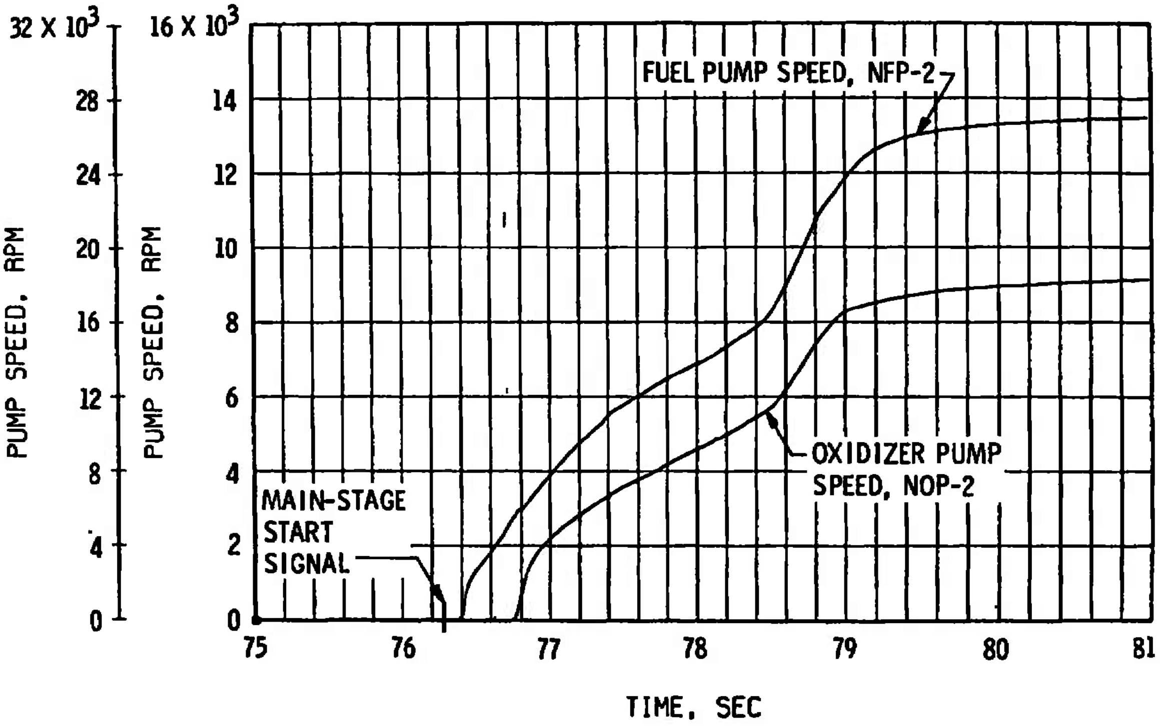


b. Pump Inlet and Combustion Chamber Pressures

Fig. 22 Propellant System Performance during Idle Mode, Firing 03A

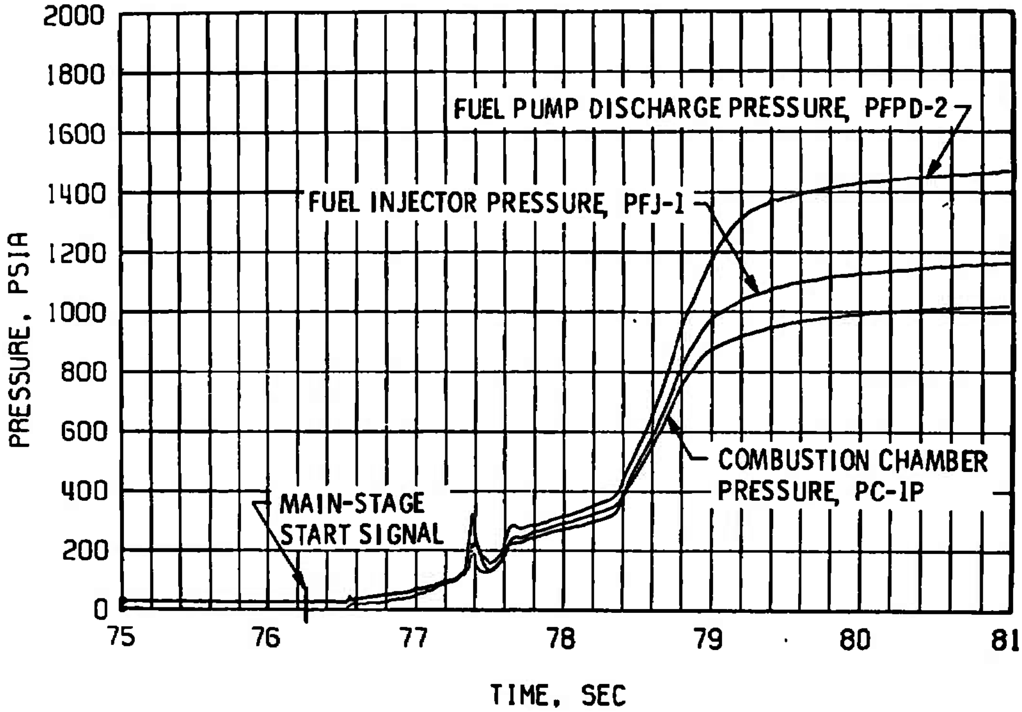


a. Main Oxidizer and Fuel Bypass Valves, Start

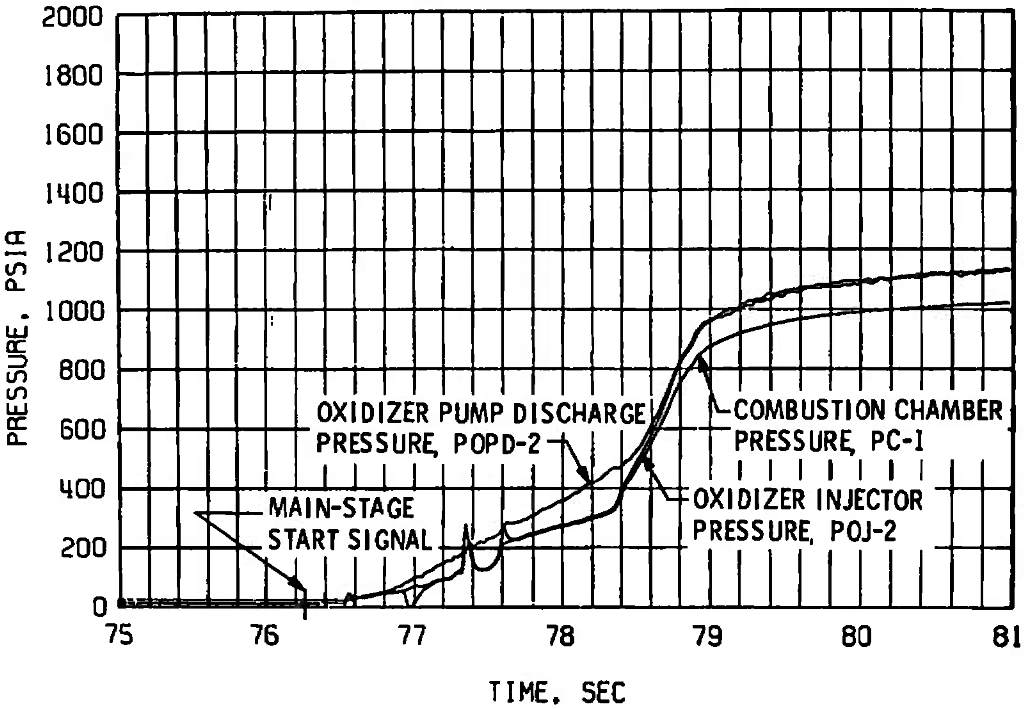


b. Propellant Pumps, Start

Fig. 23 Engine Transient Operation, Firing 03A

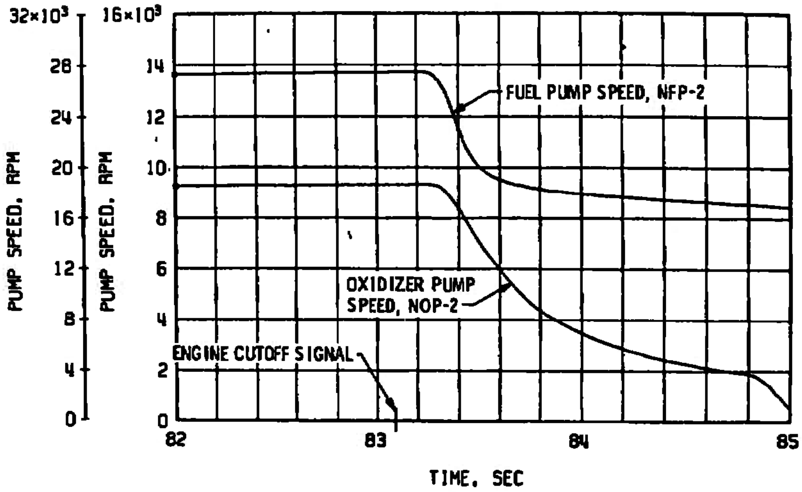


c. Fuel System, Start

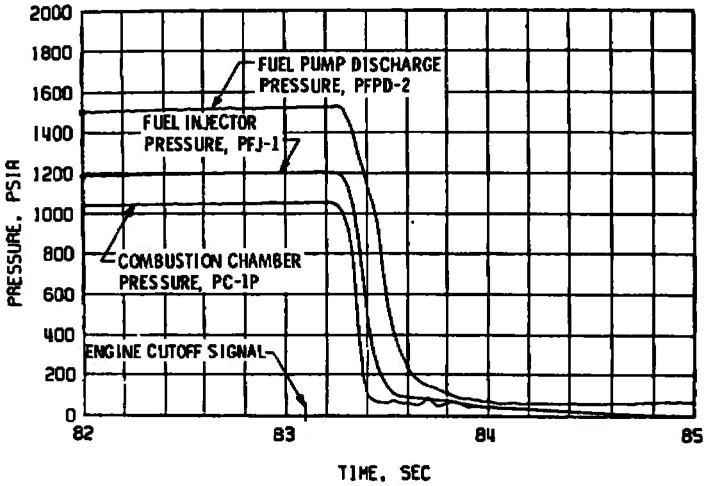


d. Oxidizer System, Start

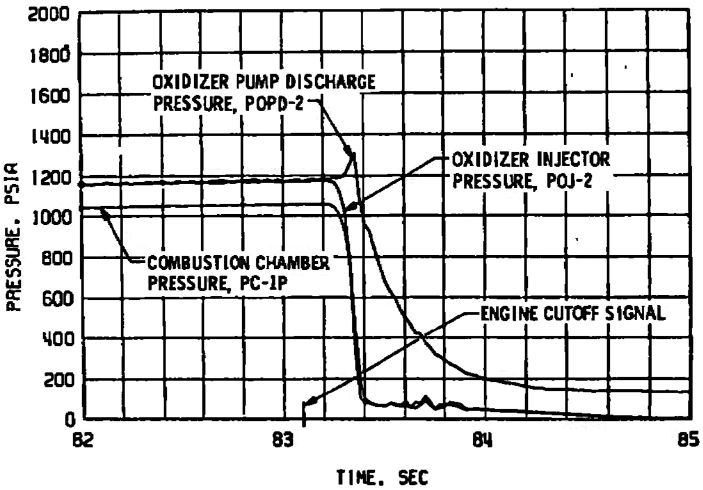
Fig. 23 Continued



e. Propellant Pumps, Shutdown

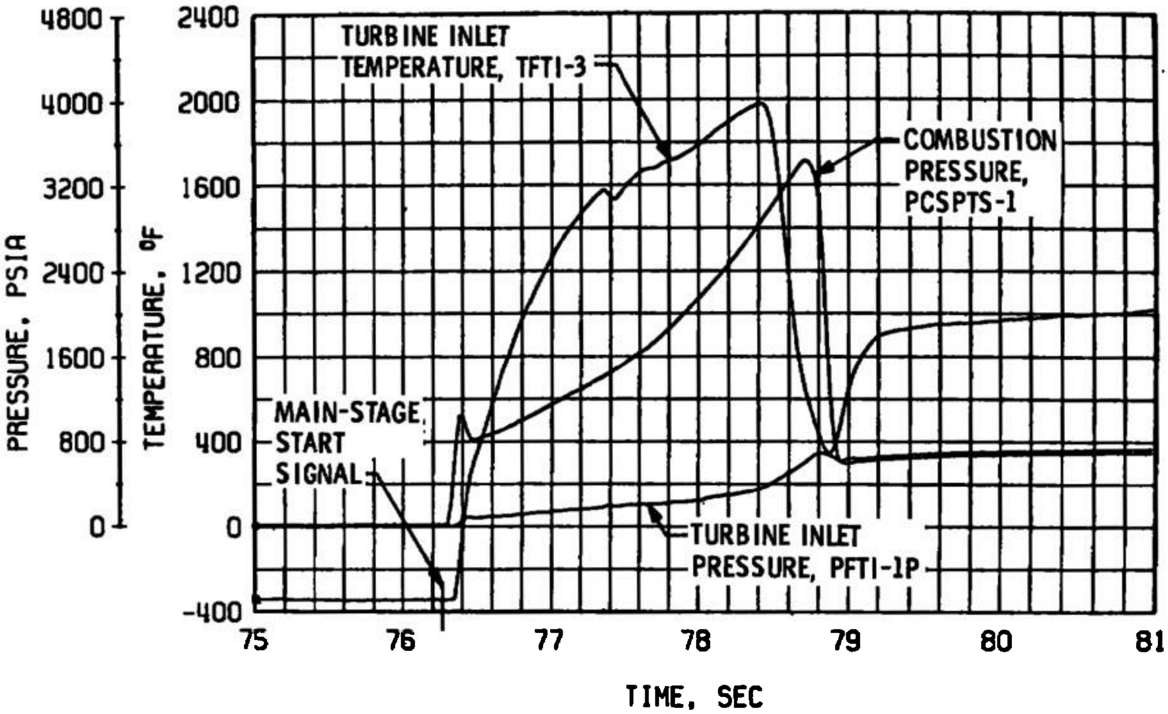


f. Fuel System, Shutdown

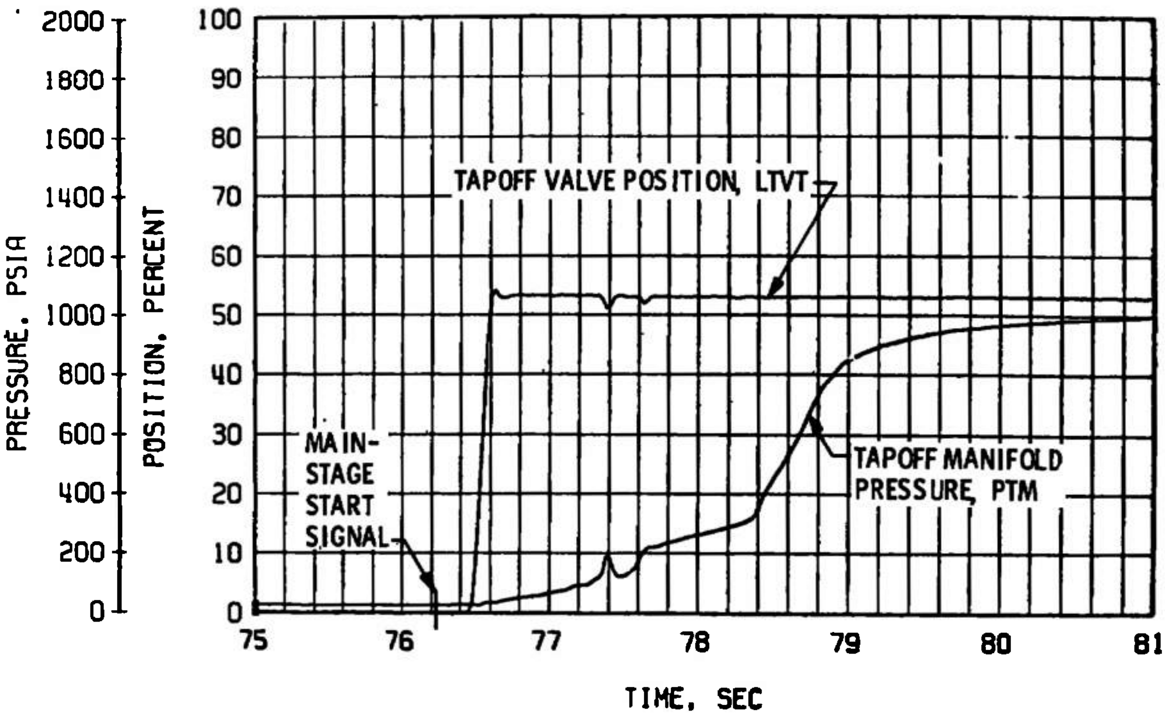


g. Oxidizer System, Shutdown

Fig. 23 Concluded

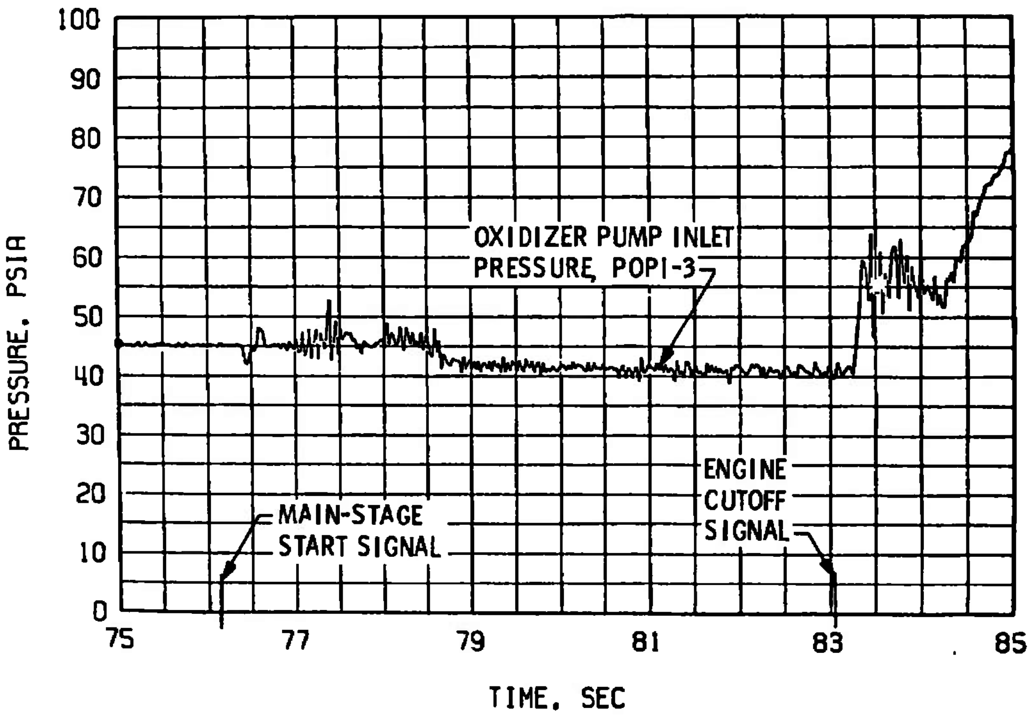


a. Combustion Pressure and Fuel Tubine Inlet Temperature and Pressure

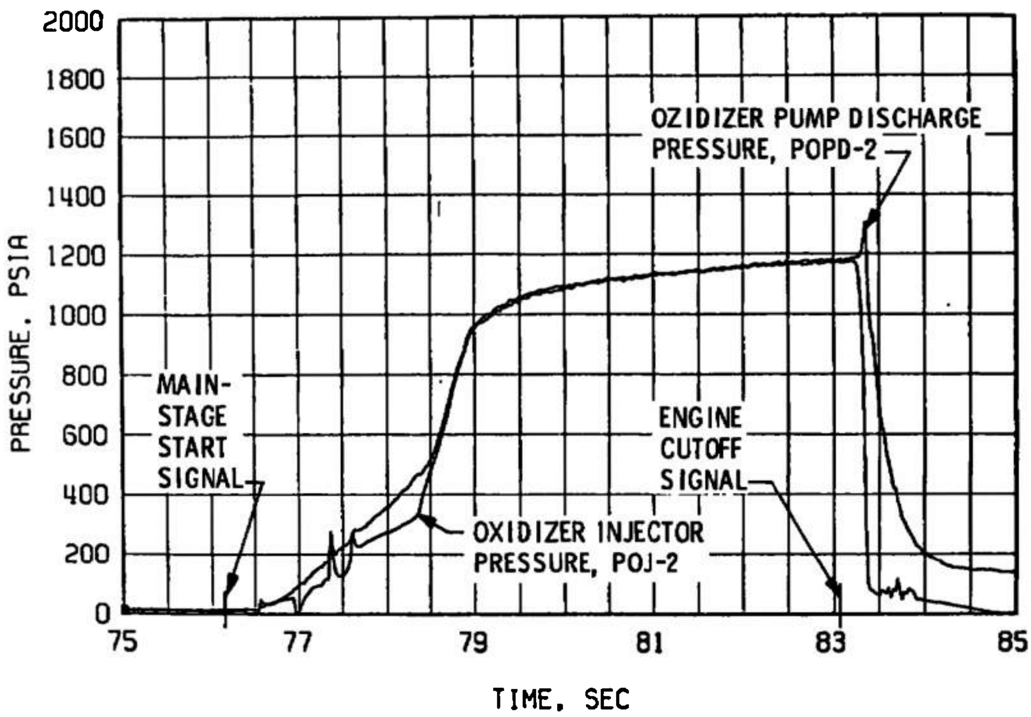


b. Tapoff Valve Position and Manifold Pressure

Fig. 24 Solid-Propellant Turbine Starter Performance, Firing 03A



a. Pump Inlet Pressure



b. Pump Discharge and Injector Pressure

Fig. 25 Oxidizer System Pressures, Firing 03A

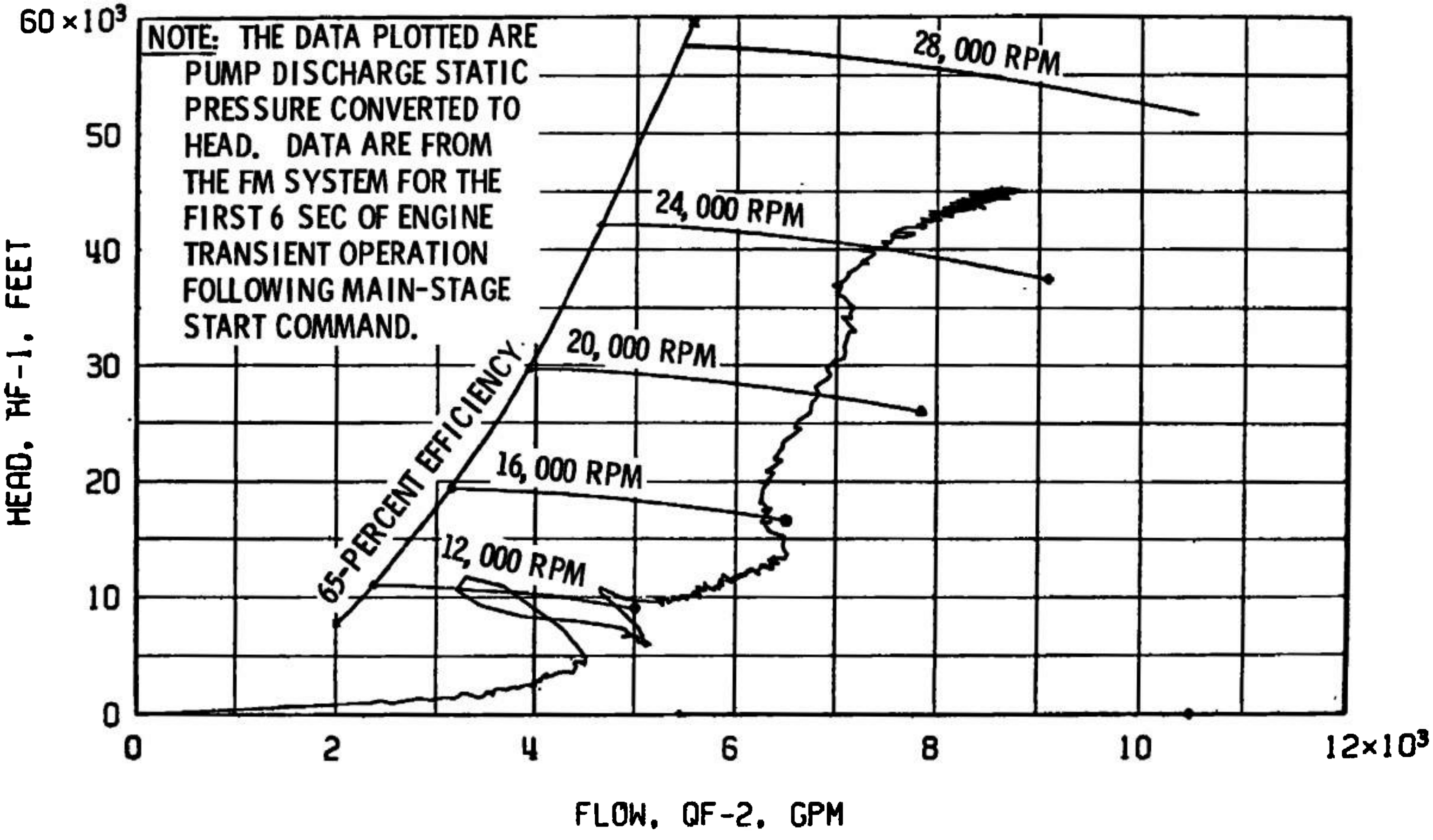


Fig. 26 Fuel Pump Start Transient Performance, Firing 03A

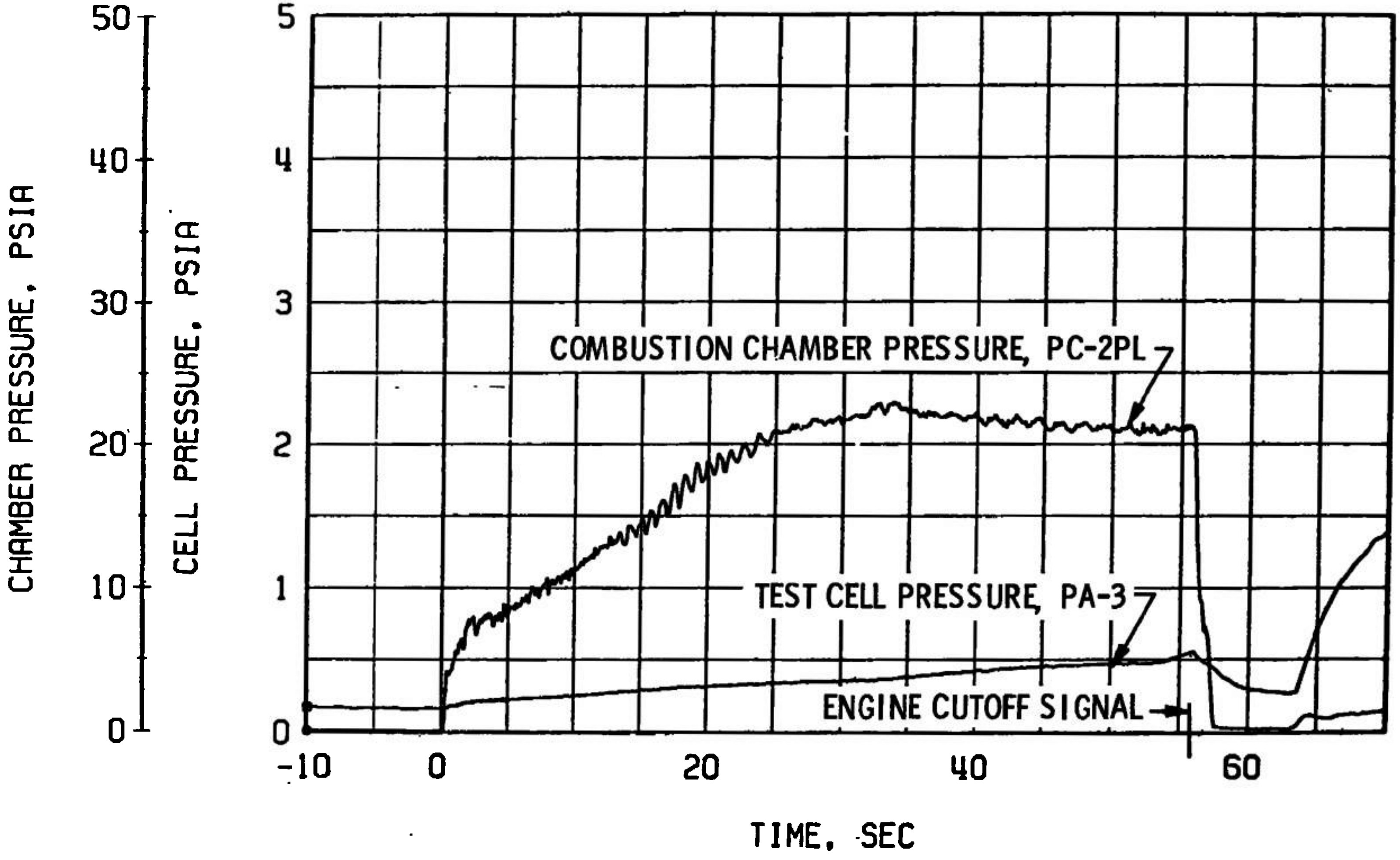


Fig. 27 Engine Ambient and Combustion Chamber Pressure, Firing 03B

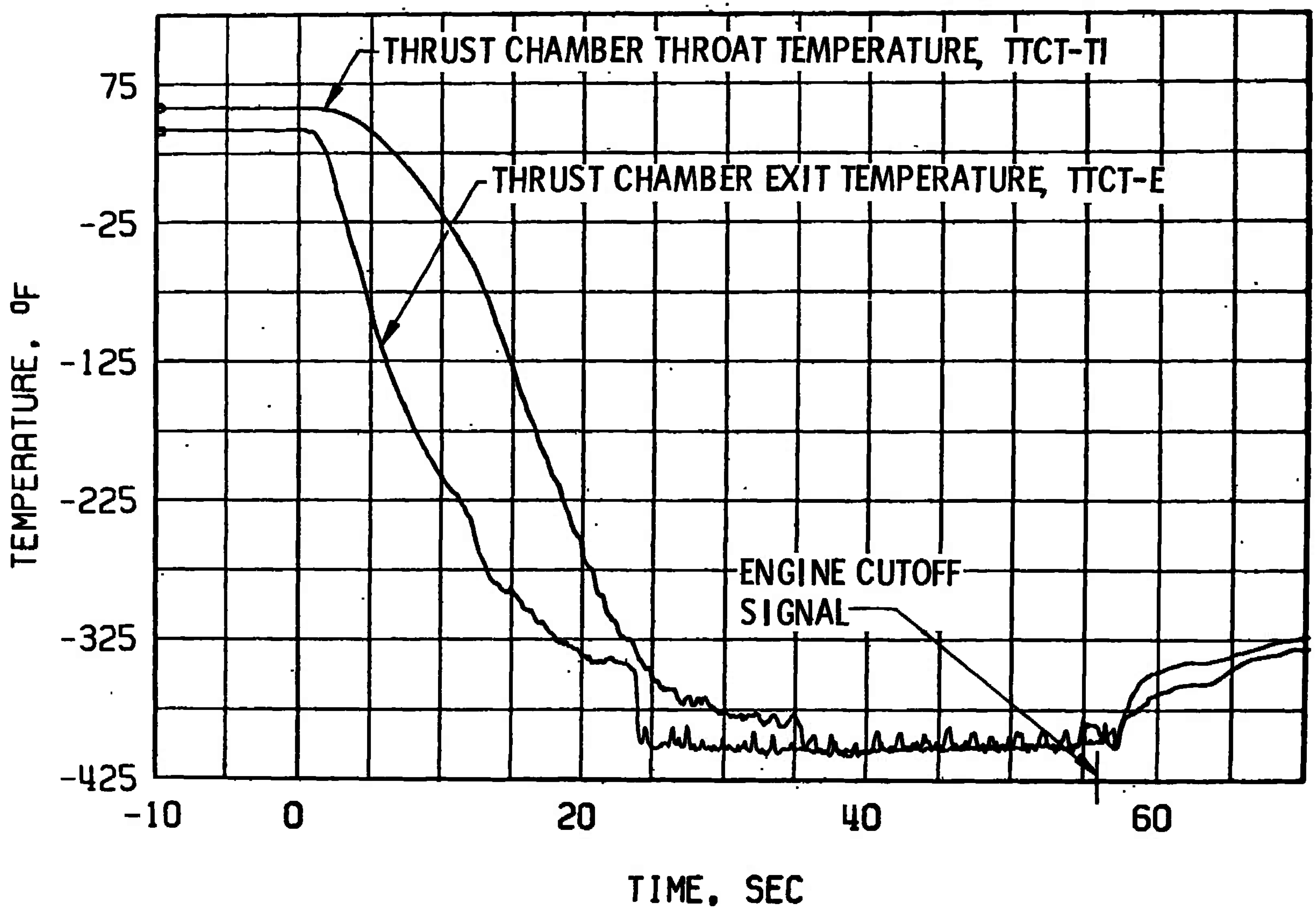


Fig. 28 Thrust Chamber Childown, Firing 03B

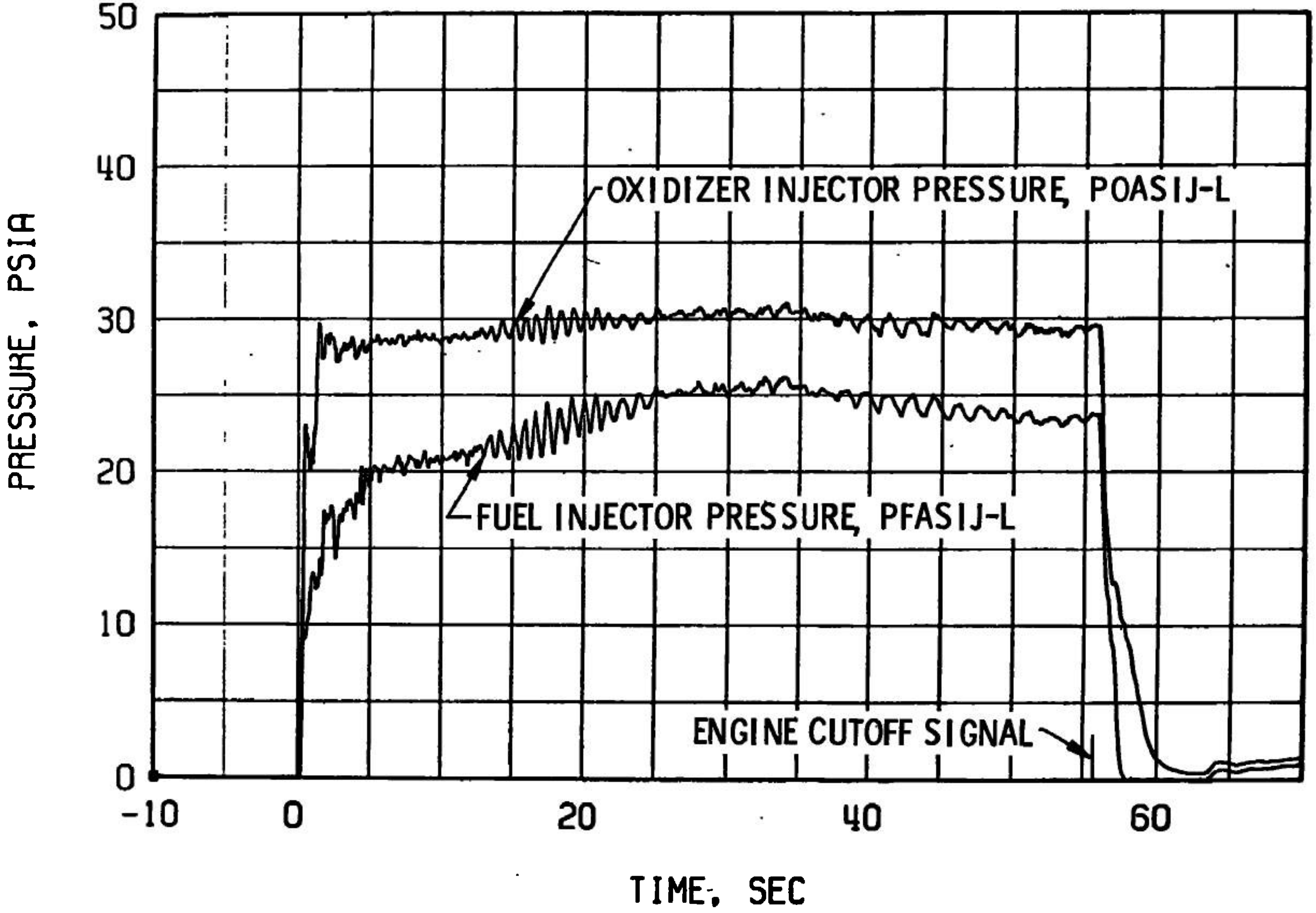
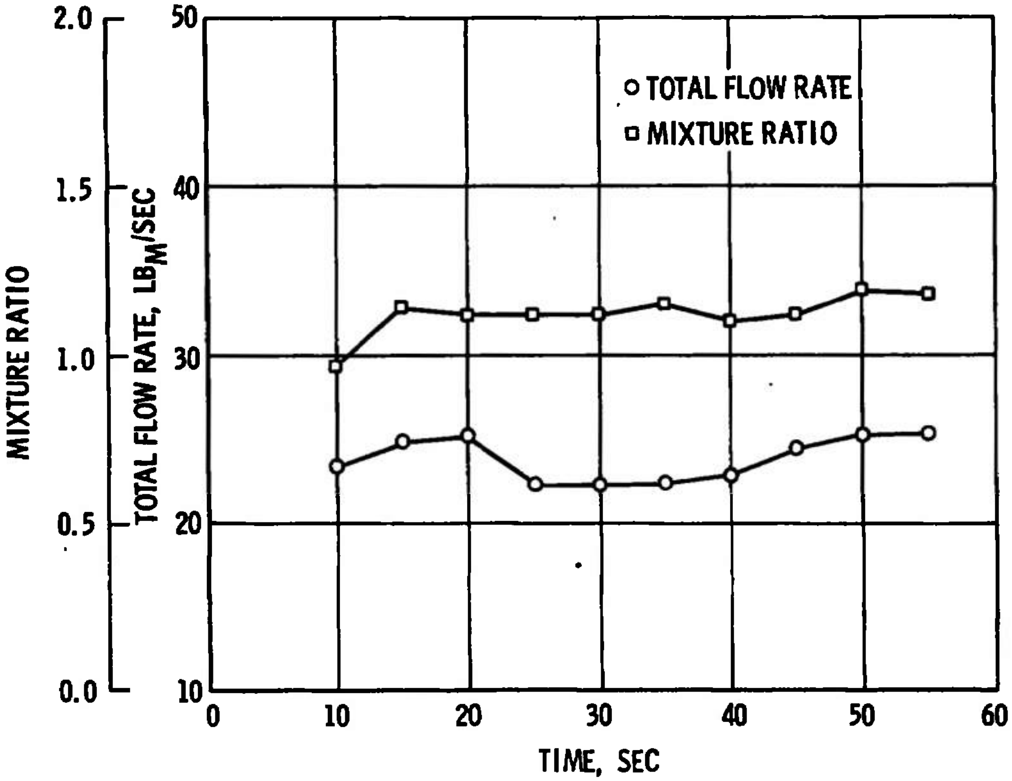
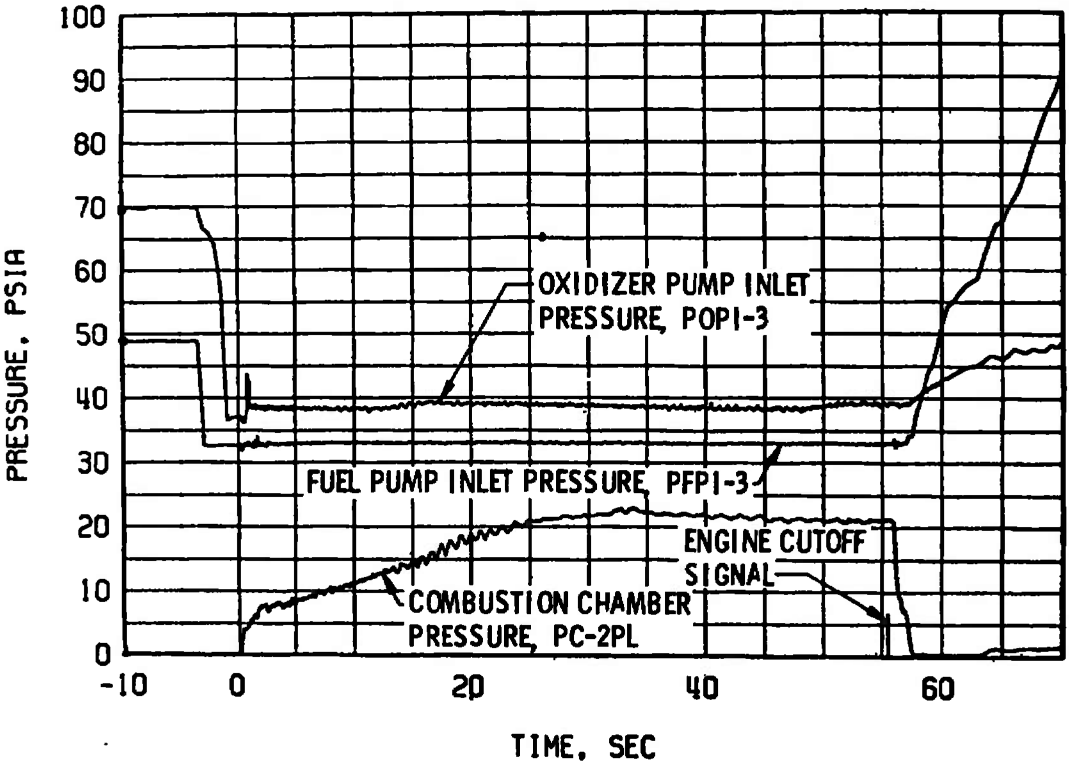


Fig. 29 Augmented Spark Igniter Performance, Firing 03B



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressure

Fig. 30 Propellant System Performance during Idle Mode, Firing 03B

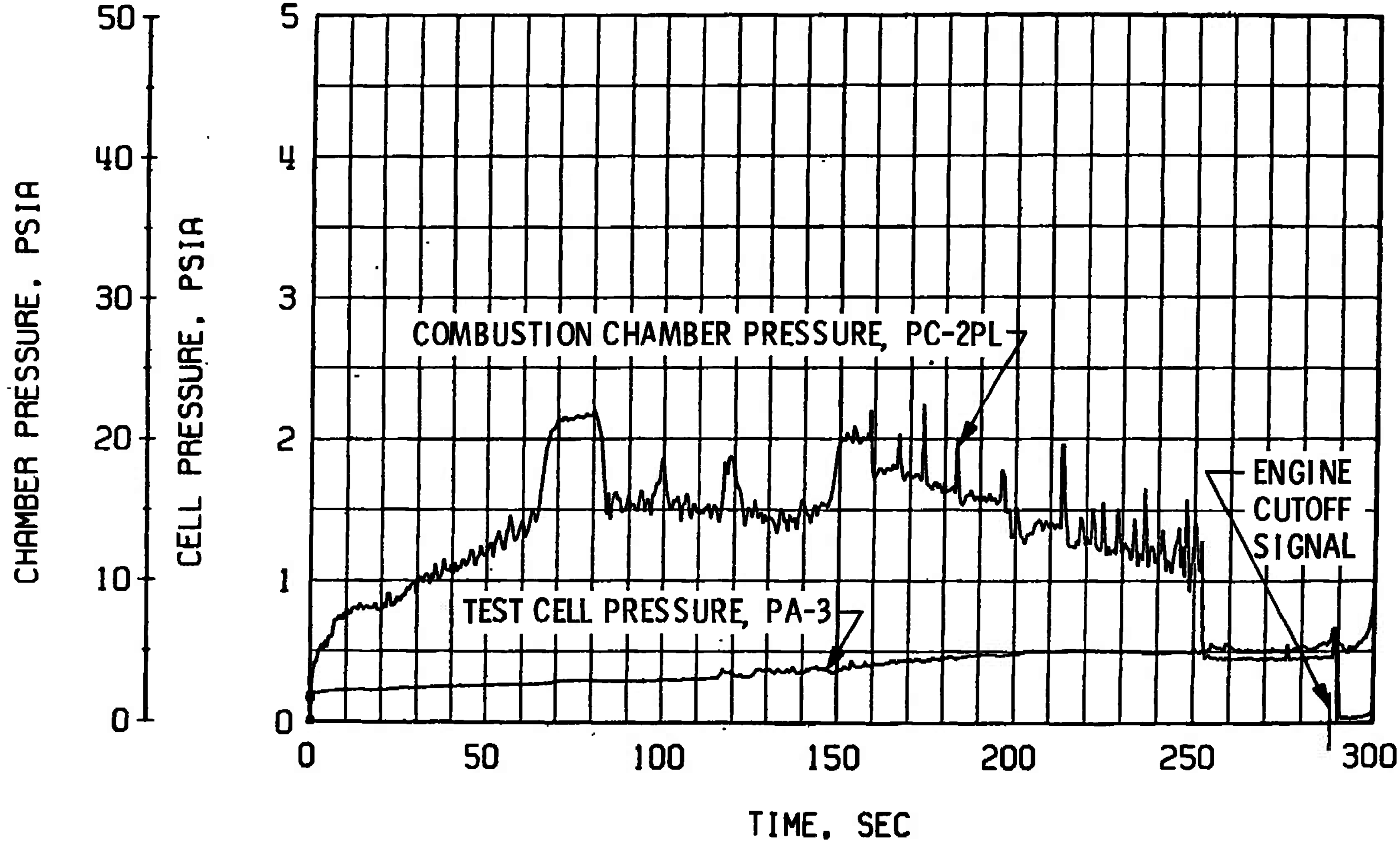


Fig. 31 Engine Ambient and Combustion Chamber Pressure, Firing 04A

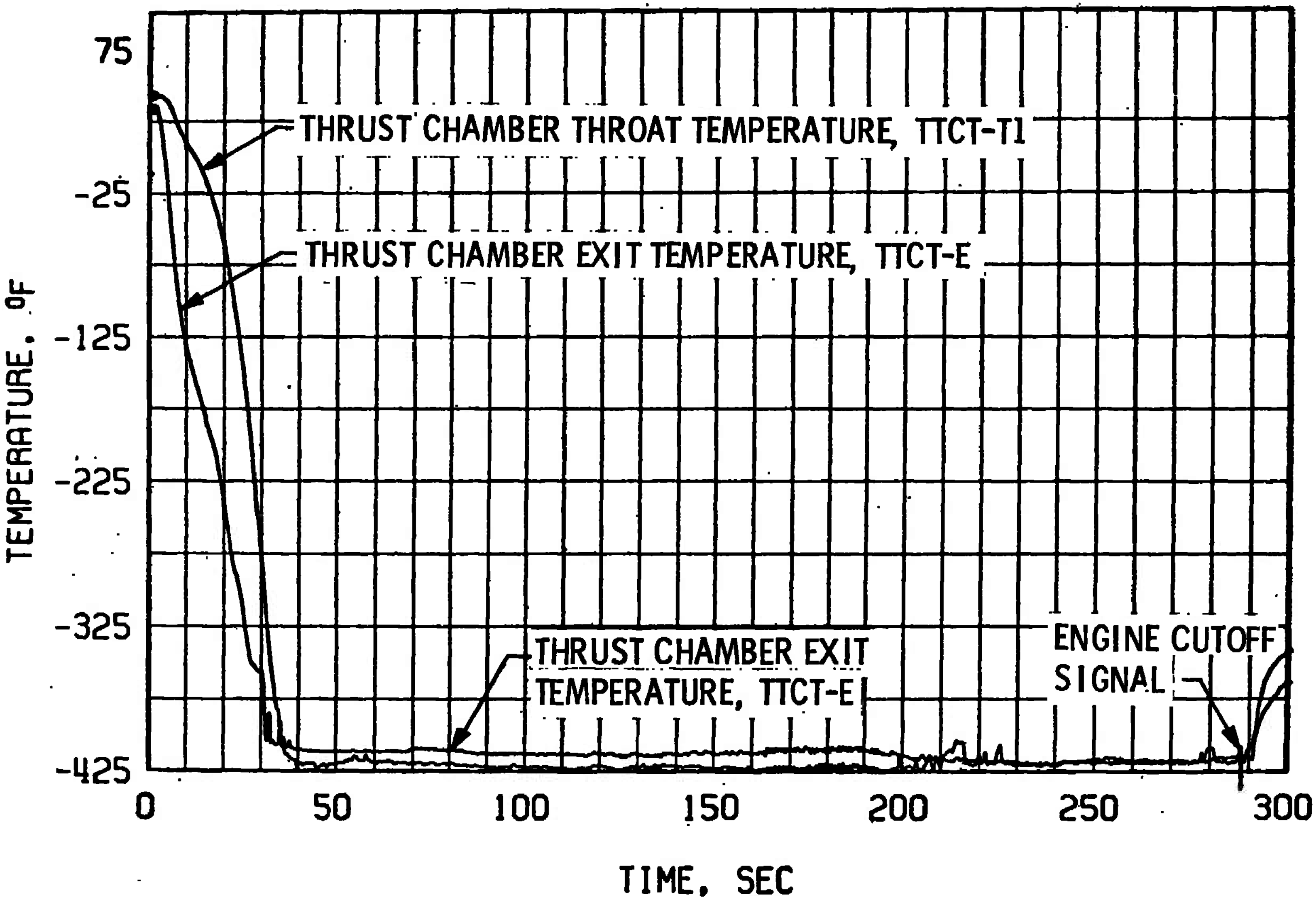


Fig. 32 Thrust Chamber Childown, Firing 04A

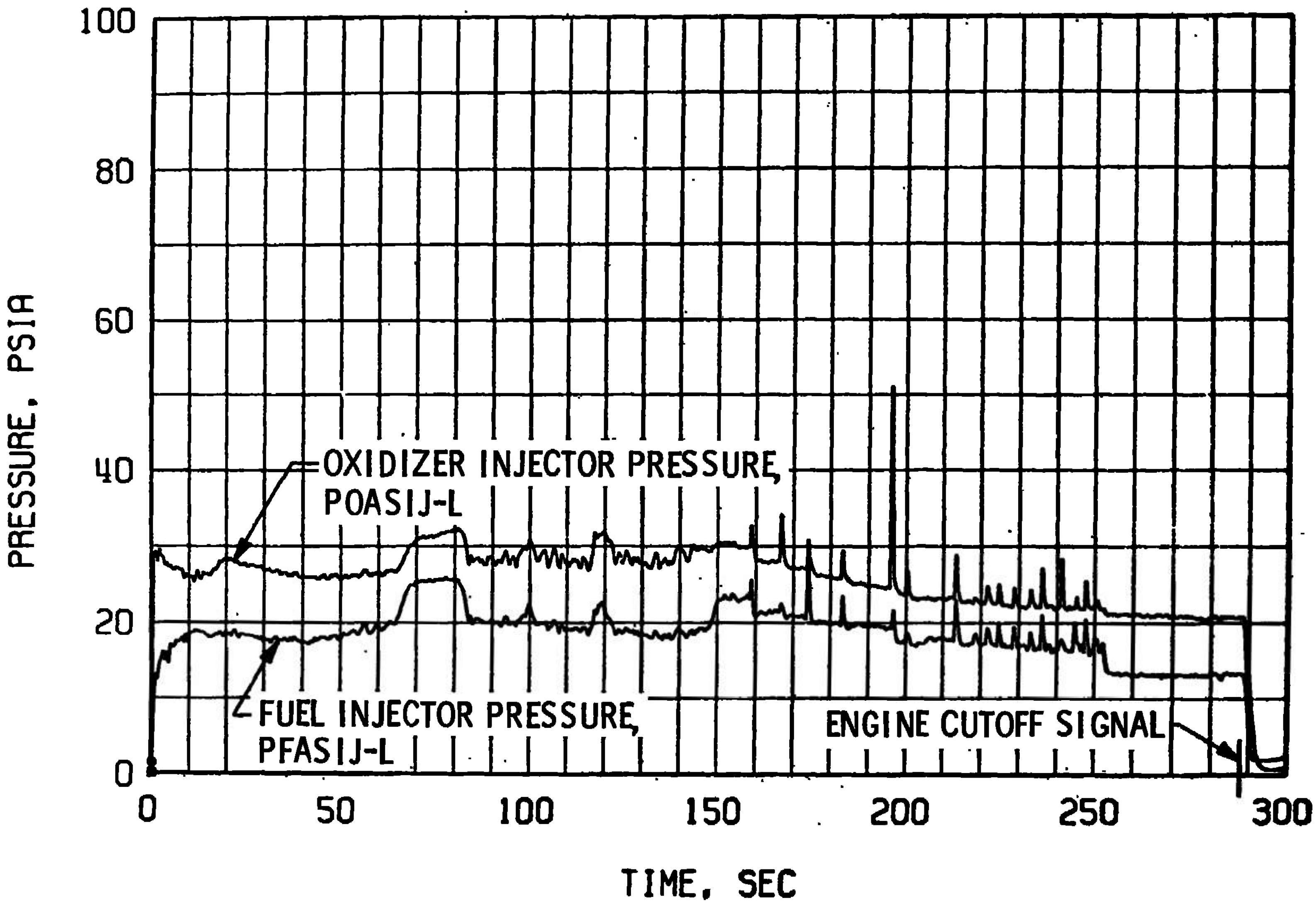
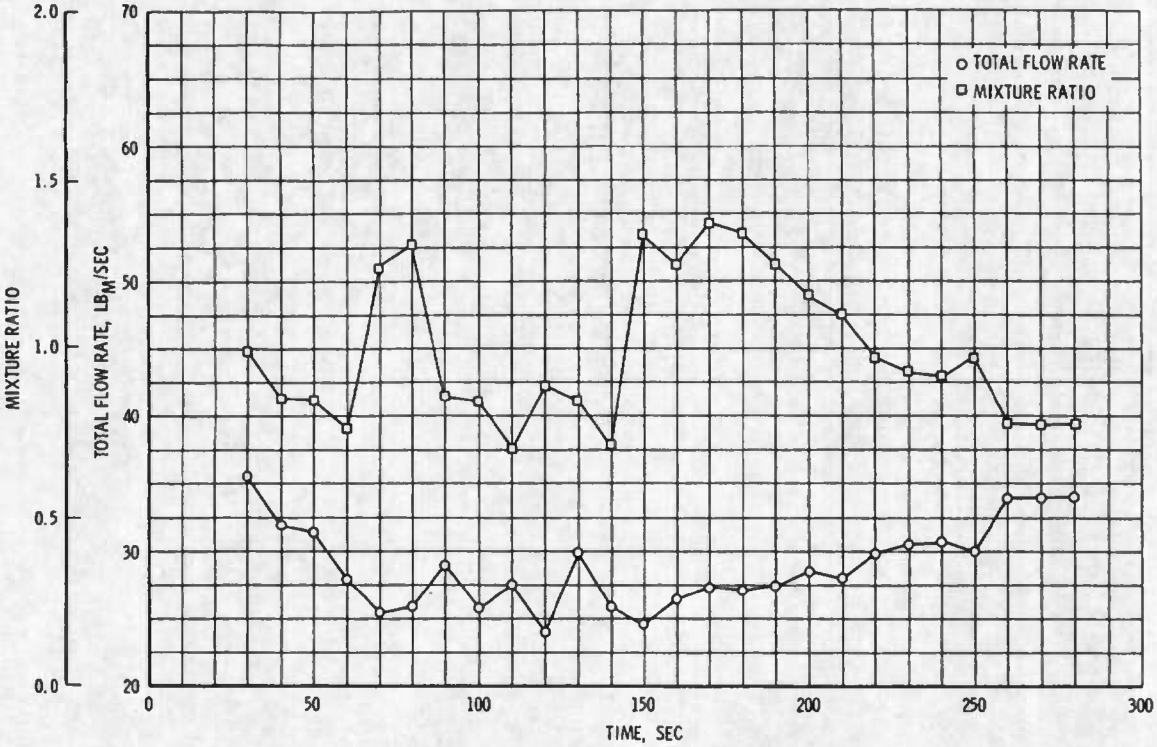
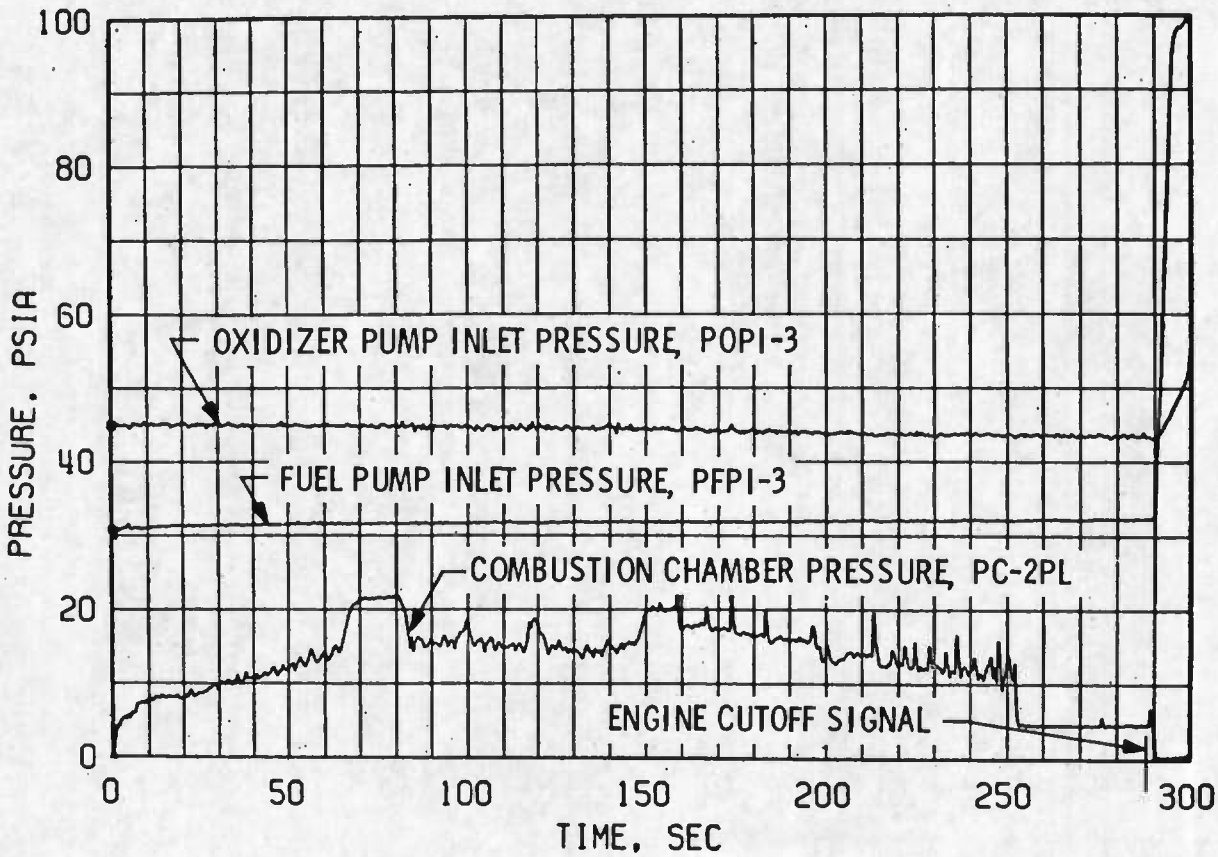


Fig. 33 Augmented Spark Igniter Performance, Firing 04A

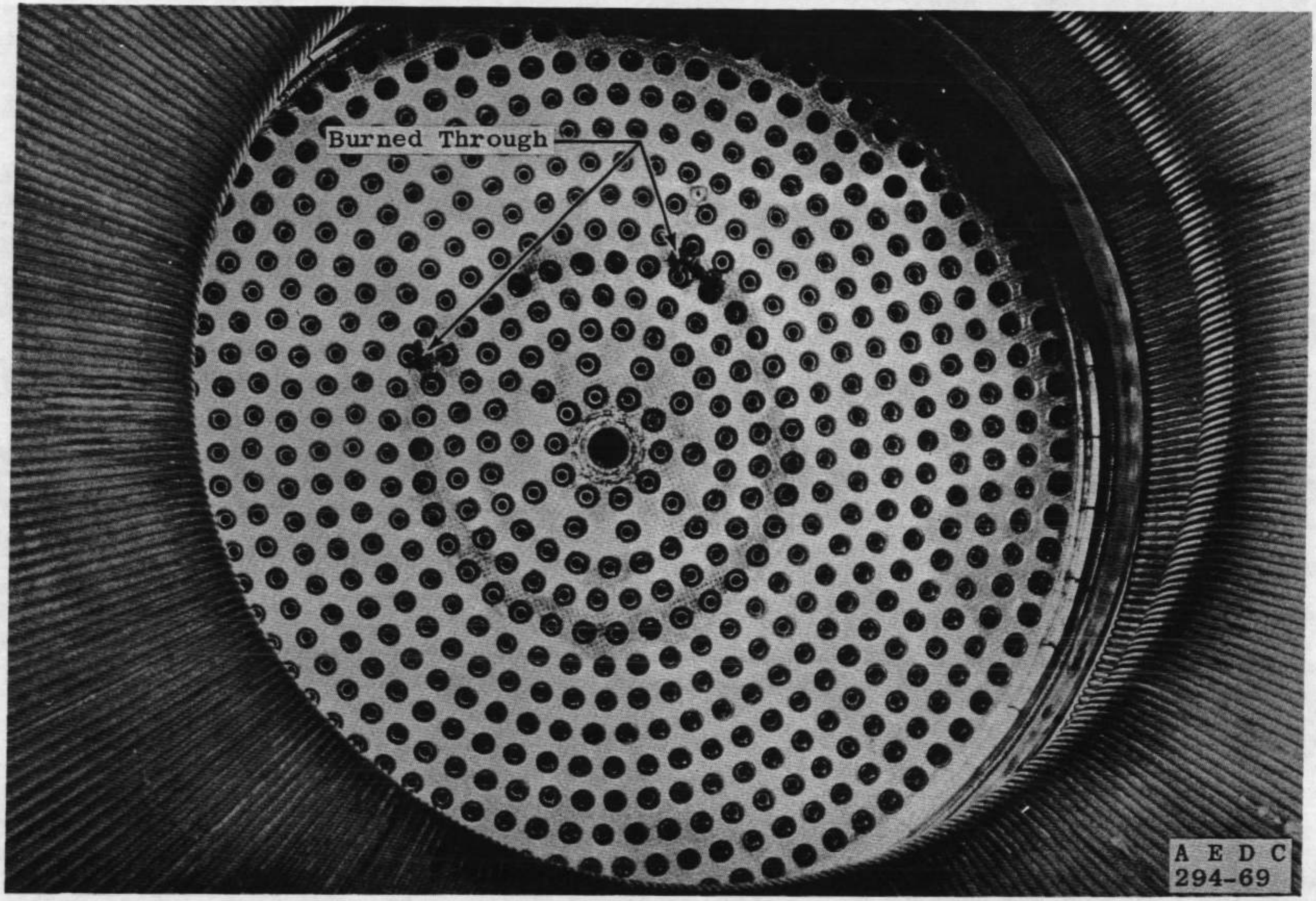


a. Total Flow Rate and Mixture Ratio



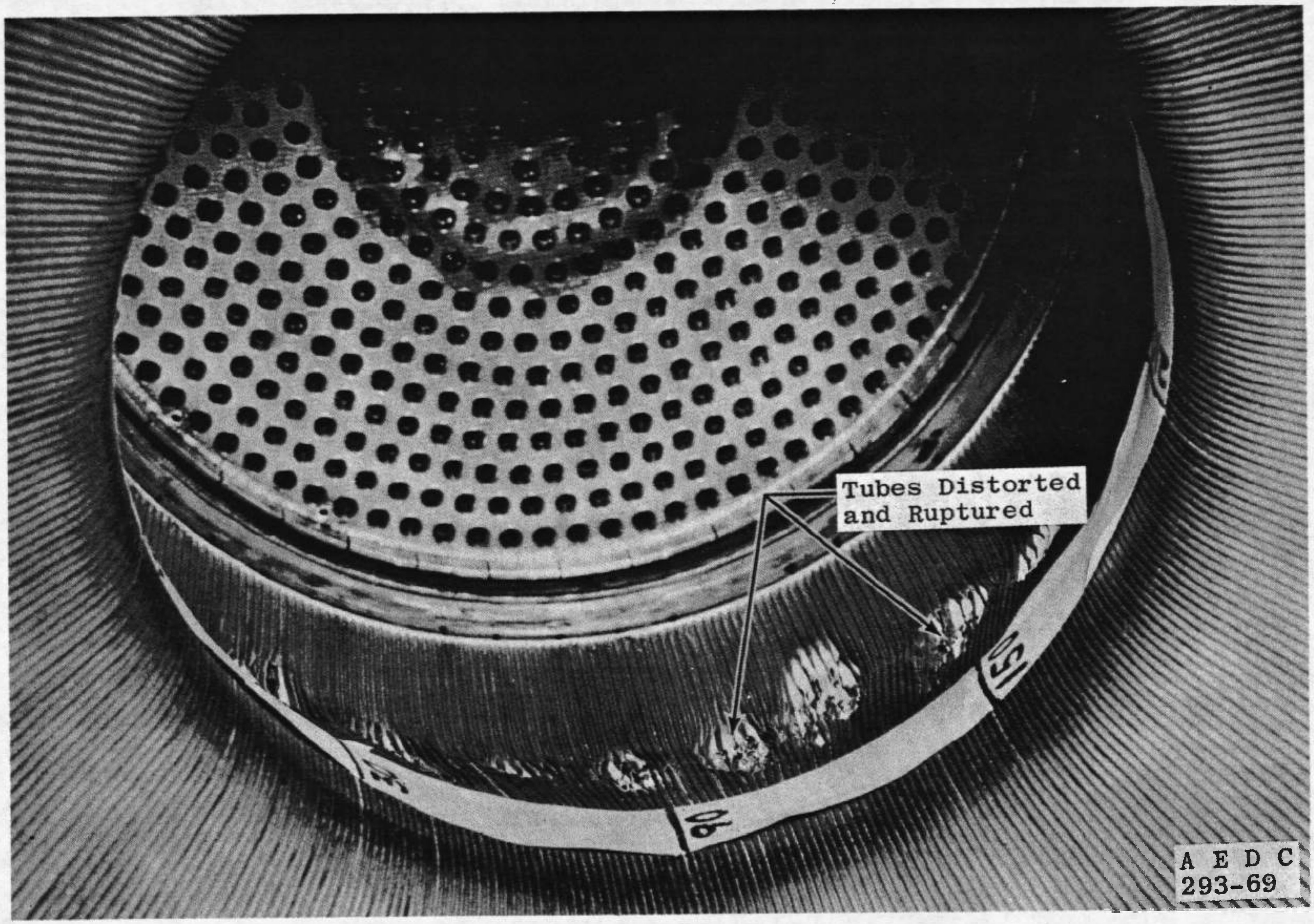
b. Pump Inlet and Combustion Chamber Pressures

Fig. 34 Propellant System Performance during Idle Mode, Firing 04A

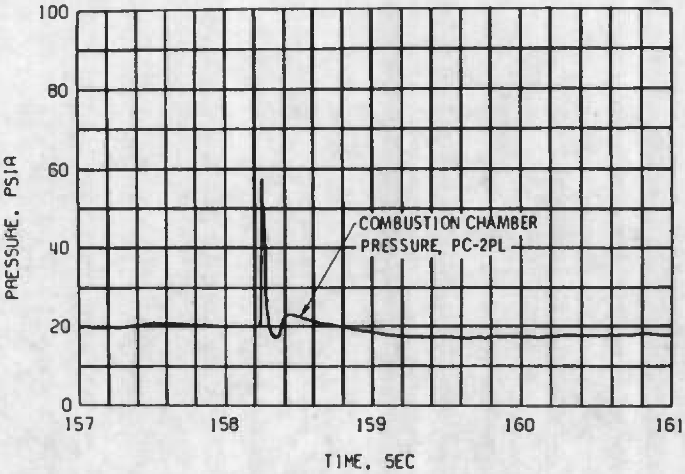


a. Injector

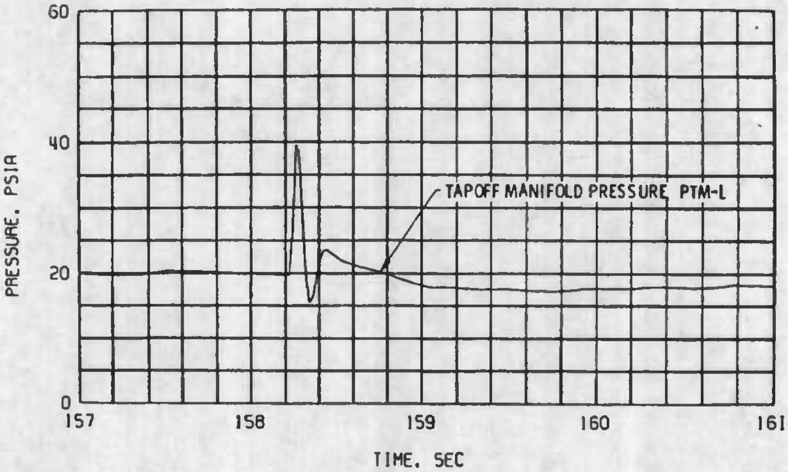
Fig. 35 Engine Damage, Firing 04A



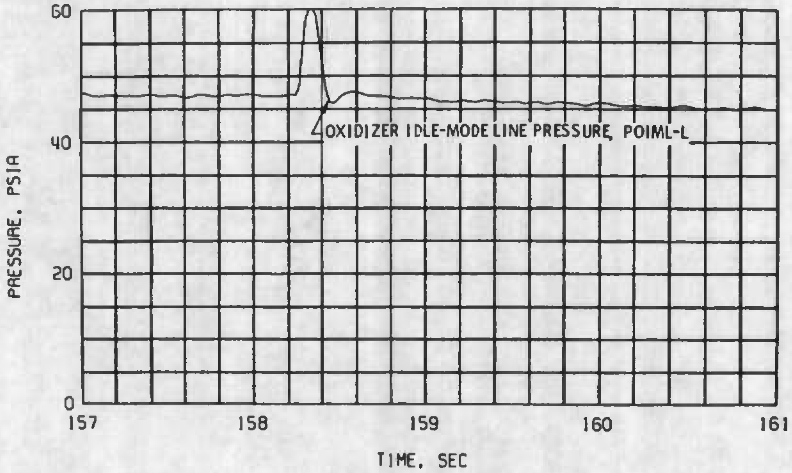
b. Thrust Chamber
Fig. 35 Concluded



a. Combustion Chamber

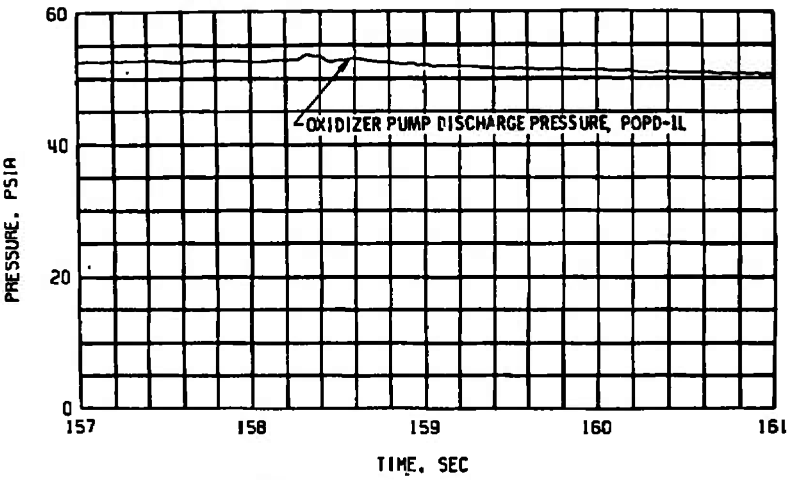


b. Tapoff Manifold

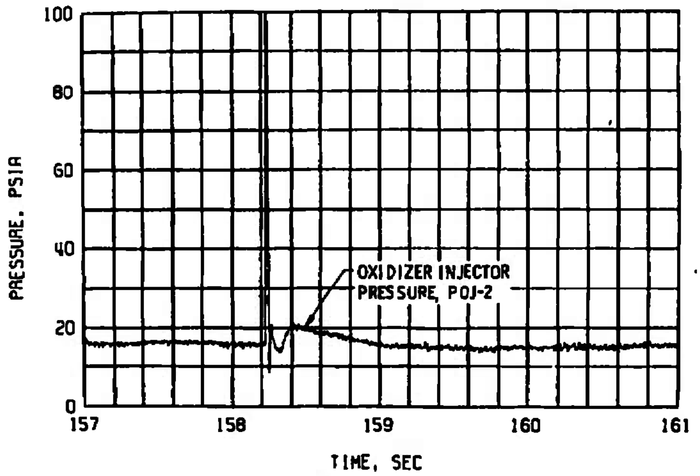


c. Oxidizer Idle-Mode Line

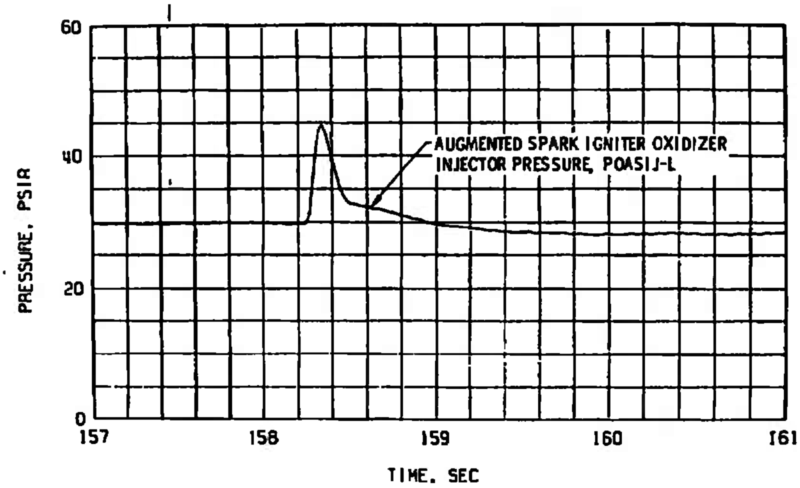
Fig. 36 Pressure Perturbations, Firing 04A



d. Oxidizer Pump Discharge

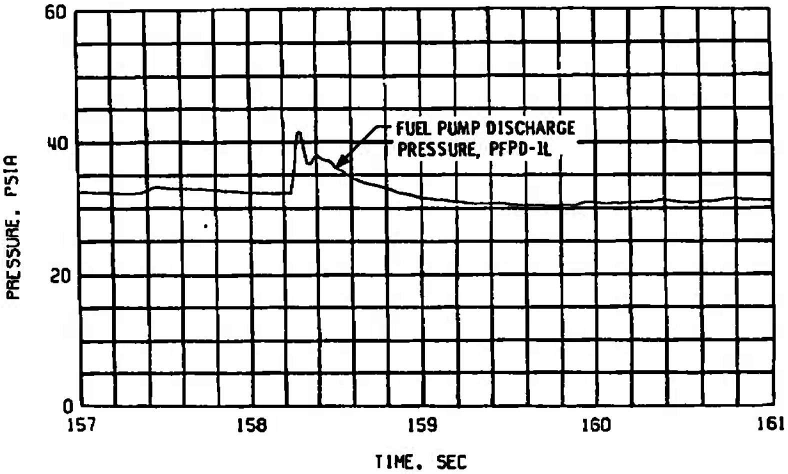


e. Oxidizer Injector

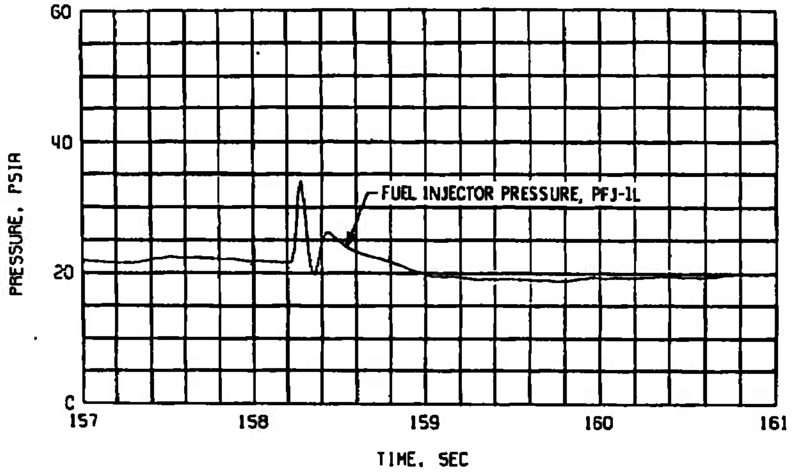


f. Augmented Spark Igniter Injector, Oxidizer

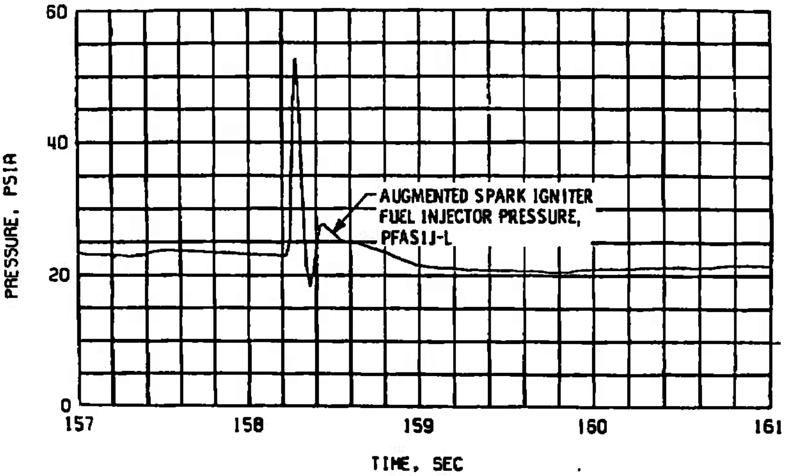
Fig. 36 Continued



g. Fuel Pump Discharge



h. Fuel Injector



i. Augmented Spark Igniter Injector, Fuel

Fig. 36 Concluded

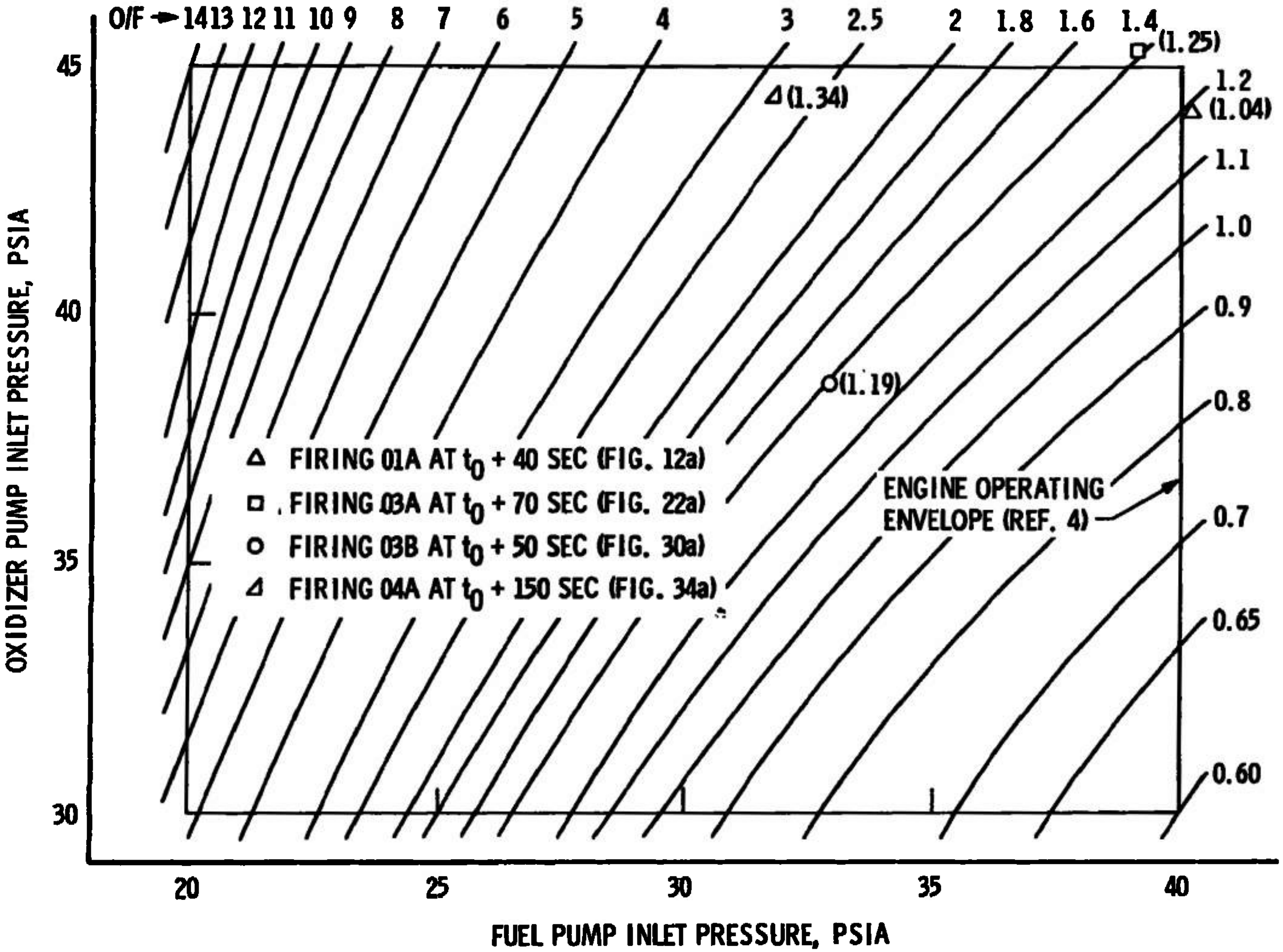
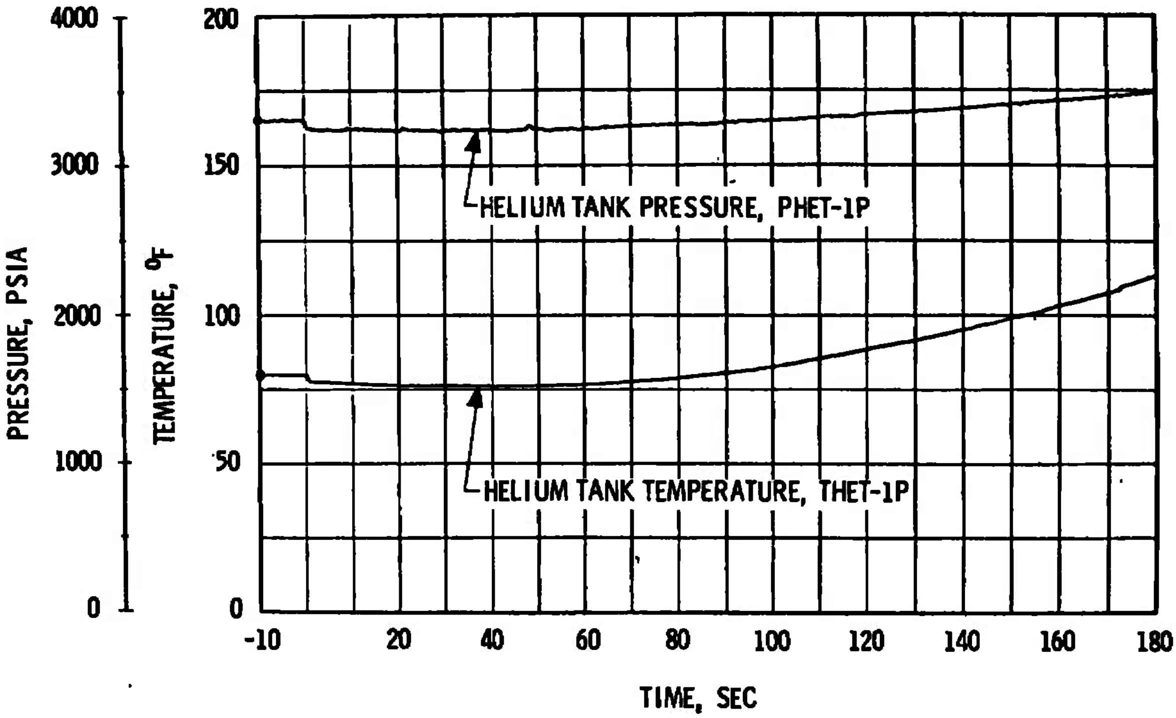
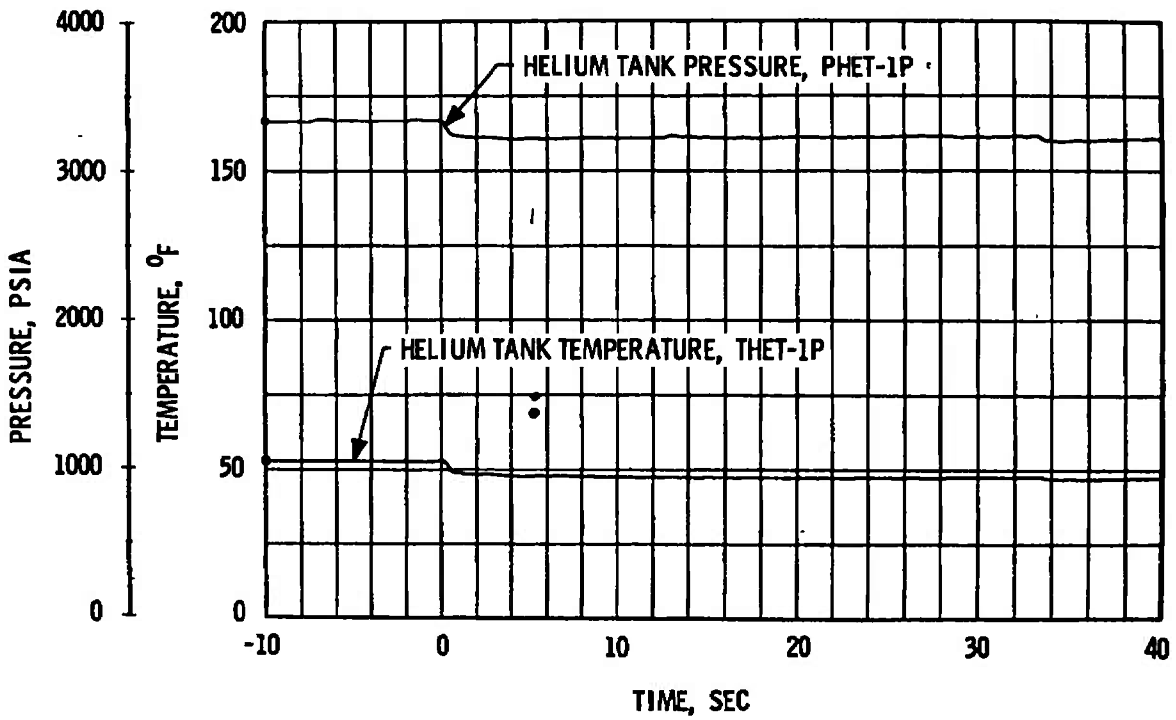


Fig. 37 Idle-Mode Mixture Ratio, Predicted and Measured

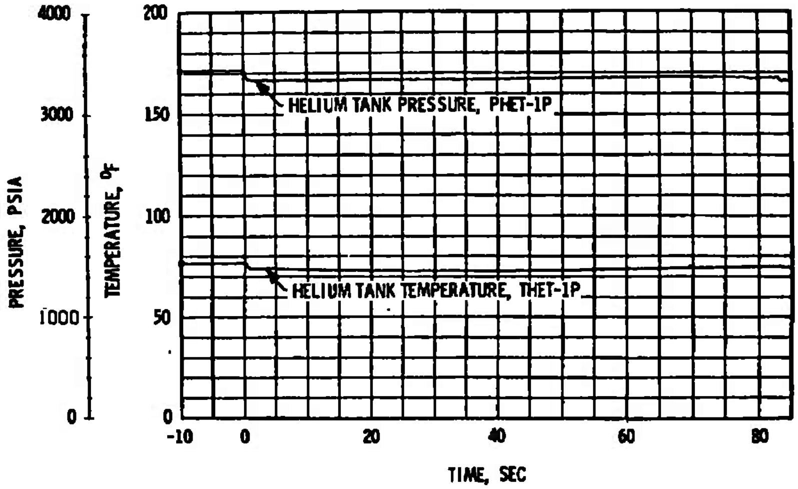


a. Firing 01A

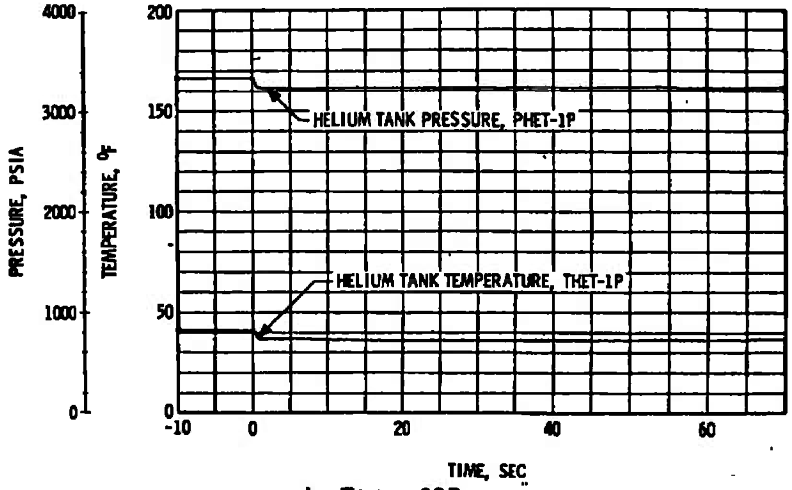


b. Firing 02A

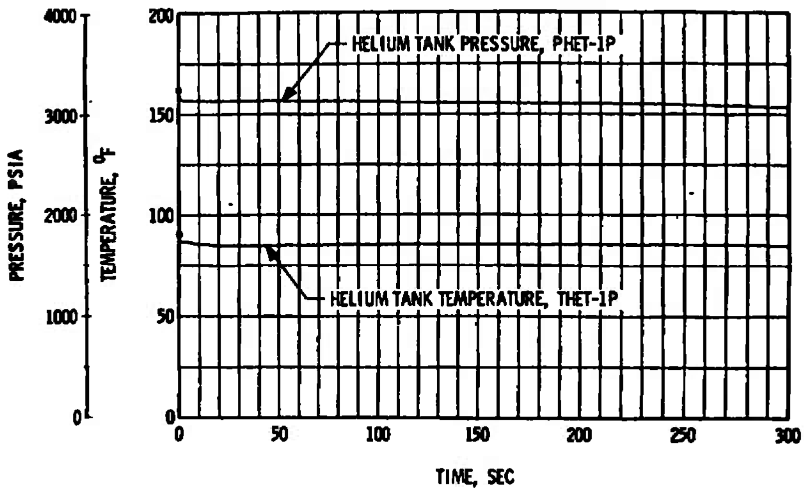
Fig. 38 Helium Tank Pressures and Temperatures



c. Firing 03A



d. Firing 03B



e. Firing 04A

Fig. 38 Concluded

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1902-01)

Part Name	P/N	S/N
Thrust Chamber Body Assembly	99-210620	4094417
Thrust Chamber Injector Assembly	99-210610-71	4087379
Augmented Spark Igniter Assembly	652050	4097350
Ignition Detector Probe No. 1	3243-2	041
Ignition Detector Probe No. 2	500750	7202262
Fuel Turbopump Assembly	99-461500	R001-0B
Oxidizer Turbopump Assembly	99-460430	S001-0
Main Fuel Valve	99-411320x3	8900881
Main Oxidizer Valve	99-411225	8900815
Idle-Mode Valve	99-411385	8900816
Thrust Chamber Bypass Valve	99-411180	8900806
Hot Gas Tapoff Valve	99-557824x2	8900847
Propellant Utilization Valve	99-251455x5	8900911
Electrical Control Package	99-503670	4098176
Engine Instrumentation Package	99-704641	4097437
Pneumatic Control Package	99-558330	8900817
Restart Control Assembly	99-503680	4097867
Helium Tank Assembly	80097-1	0002
Oxidizer Flowmeter	251216	4096874
Fuel Flowmeter	251225	4096875
Fuel Inlet Duct Assembly	409900-11	6631788
Oxidizer Inlet Duct Assembly	409899-11	4052289
Fuel Pump Discharge Duct	99-411078	417
Oxidizer Pump Discharge Duct	99-411077	417
Thrust Chamber Bypass Duct	99-411079	417
Fuel Turbine Exhaust Bypass Duct	307879-11	02143580
Hot Gas Tapoff Duct	99-411080-51	7239769
Solid-Propellant Turbine Starters Manifold	99-210921	7216433
Heat Exchanger and Oxidizer Turbine Exhaust Duct	307887	2142922
Crossover Duct	307879-11	02143580

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, Inches Unless Otherwise Noted	Test Effective	Comments
Oxidizer Turbine Bypass Nozzle	99-210924	1.960	J4-1902-01	
Main Oxidizer Valve Closing Control Line	99-411279	0.0443 208.5 scfm	J4-1902-01 J4-1902-02	Thermostatic Orifices
Augmented Spark Igniter Oxidizer Supply Line	99-558365-87	0.100	J4-1902-01	
Augmented Spark Igniter Fuel Supply Line				No Orifice Installed

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1902-01 AND J4-1902-04)

Modification Number	Completion Date	Description of Modification
	Pre-Test	
R 086729	12/3/68	Insulation of Fuel Film Coolant Line and the Augmented Spark Igniter Fuel Line
	Test J4-1902-01 12/5/68	
R 121031	12/16/68	Replaced Main Oxidizer Valve Closing Control Orifice, 208.5 scfm (Thermostatic Orifice)
	Test J4-1902-02 12/18/68	
R 121114	12/30/68	Installed Fuel Pump Volute Seal Drain Line
	Test J4-1902-03 1/3/69	
	None	
	Test J4-1902-04 1/10/69	

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1902-01 AND J4-1902-04)

Replacement	Completion Date	Component Replaced
	Test J4-1902-01 12/5/68	
P/N 557755-11 S/N 2137550	12/16/68	Oxidizer Idle-Mode Line Purge Check Valve, P/N 557755-11 S/N 2137547
P/N 99-411225X4 S/N 8900929	12/16/68	Main Oxidizer Valve, P/N 99-411225 S/N 8900815
	Test J4-1902-02 12/18/68	
	None	
	Test J4-1902-03 1/3/69	
P/N 554175 S/N 7224310	1/7/69	Oxidizer Dome Purge Check Valve, P/N 554175 S/N 2138996
	Test J4-1902-04 1/10/69	

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Purge	Requirement	Solid-Propellant Turbine Starter Installed	Air-On	Propellant Drop	Engine Start	Cutoff	Coast Period	Propellant Drop	Restart	Cutoff (Last Firing)
Oxidizer Dome and Idle-Mode Compartment	Nitrogen, 600 ± 25 psia; 100 to 200°F at CCP 150 scfm (e)									15 min
Thrust Chamber Jacket, Film Coolant and Turbopump Purges	Helium, 150 ± 25 psia; 100 to 150°F at CCP (125 scfm)		(b) (c)		(a)	15 min (b) (c)		(a)	15 min	
Solid-Propellant Turbine Starter Conditioning	Nitrogen, -50 to +140°F	No. 1, 2, and 3				Remaining Solid-Propellant Turbine Starter Installed				
Main Fuel Valve Conditioning	Helium, -300°F to Ambient			d						

(a) Engine-Supplied Liquid Oxygen Pump Intermediate Seal Cavity Purge
(b) Any Time Facility Water On
(c) 30 min before Propellant Drop
(d) Initiate Main Fuel Valve Conditioning 30 min before Engine Start for those Firings with Temperature Requirements
(e) 100 to 150°F for Firing 04A

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number		J4-1902-01A		J4-1902-02A		J4-1902-03A		J4-1902-03B		J4-1902-04A	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day		--- / ---	12/5/68 / 1612 hr	--- / ---	12/18/68 / 2026 hr	--- / ---	1/3/69 / 1449 hr	--- / ---	1/3/69 / 1931 hr	--- / ---	1/10/69 / 1416 hr
Pressure Altitude at t_0, ft (Ref. 1)		100,000	99,000	100,000	99,000	100,000	86,000	100,000	101,000	100,000	98,000
Idle-Mode Duration Pre-Main Stage, sec[1]		200	172.310	1.0	0.996	80	76.243	100	55.758	200 Minimum	288.542
Main-Stage Duration, sec[1]		---	---	32.5	32.242	7.5	6.852	---	---	---	---
Idle-Mode Duration Post-Main Stage, sec[1]		---	---	---	---	---	---	---	---	---	---
Fuel Pump Inlet Pressure at t_0, psia		40.0 ± 1.0	40.1	$40.0^{+1.0}_{-0}$	40.9	40.0 ± 1.0	30.0	33.0 ± 1.0	32.8	30.0 ± 1.0	30.4
Fuel Pump Inlet Temperature at t_0, °F		---	-416.0	---	-416.6	---	-147.7	---	-311.4	---	-255.8
Fuel Tank Bulk Temperature at t_0, °F		-422.4 ± 0.4	-422.5	-422.4 ± 0.4	-422.4	-422.4 ± 0.4	-422.6	-422.4 ± 0.4	-422.3	-422.4 ± 0.4	-422.6
Oxidizer Pump Inlet Pressure at t_0, psia		45.0 ± 1.0	44.7	45.0 ± 1.0	45.2	45.0 ± 1.0	45.2	38.0 ± 1.0	37.1	45.0 ± 1.0	44.7
Oxidizer Pump Inlet Temperature at t_0, °F		---	-291.8	---	-292.4	---	-287.8	---	-279.8	---	-278.3
Oxidizer Tank Bulk Temperature at t_0, °F		-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-295.6	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.0
Helium Tank Conditions at t_0	Pressure, psia	3450^{+0}_{-200}	3302	3450^{+0}_{-200}	3333	3450^{+0}_{-200}	3427	3450^{+0}_{-200}	3329	3450^{+0}_{-200}	3240
	Temperature, °F	---	+80	---	+53	---	+77	---	+41	---	+90
Main Fuel Valve Temperature at t_0, °F		---	+96	-100^{+0}_{-50}	-146	---	+94	---	+76	---	+104
Augmented Spark Igniter Ignition Detected, sec (Ref. t_0)[1]		---	0.364	---	0.425	---	0.481	---	0.371	---	0.412
Propellant Utilization Valve Position at t_0		Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Propellant Utilization Valve Excursion, Position/Time		--- / ---	--- / ---	Closed / t_0 + 6.0	Closed / t_0 + 7.0	--- / ---	--- / ---	--- / ---	--- / ---	--- / ---	--- / ---
		--- / ---	--- / ---	Null / t_0 + 27.5	Null / t_0 + 28.5	--- / ---	--- / ---	--- / ---	--- / ---	--- / ---	--- / ---
Solid-Propellant Turbine Starter	Part Number	---	---	---	99803527-11	---	99803527-11	---	---	---	---
	Serial Number	---	---	---	RT000001	---	RT000002	---	---	---	---
	Temperature at t_0, °F	---	---	+50 ± 10	Not Recovered	+50 ± 10	+44	---	---	---	---
	Burn Time, sec	---	---	---	---	---	2.4	---	---	---	---
	Maximum Pressure, psia	---	---	---	---	---	3420	---	---	---	---

[1] Data Reduced from Oscillogram

TABLE VII
ENGINE VALVE TIMINGS

Test J4-1902-	Firing	Start																	
		Main Fuel Valve			Idle-Mode Oxidizer Valve			Hot Gas Tapoff Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Thrust Chamber Bypass Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
01	A	0.0	0.071	0.112	0.0	0.200	0.059	---	---	---	---	---	---	---	---	---	---	---	---
	Final Sequence	0.0	0.047	0.074	0.0	0.125	0.044	0.094	0.155	0.110	0.994	0.076	0.033	2.890	0.160	0.620	2.980	0.166	0.611
02	A	0.0	0.053	0.062	0.0	0.130	0.035	0.996	0.170	0.105	0.996	0.060	0.032	2.870	0.188	0.877	2.970	0.157	0.860
	Final Sequence	0.0	0.045	0.067	0.0	0.122	0.045	0.992	0.155	0.110	0.992	0.090	0.040	2.892	0.205	0.822	2.692	0.150	0.925
03	A	0.0	0.053	0.059	0.0	0.124	0.034	76.243	0.164	0.124	76.243	0.075	0.032	76.126	0.180	0.878	78.129	0.150	0.010
	B	0.0	0.053	0.058	0.0	0.125	0.033	---	---	---	---	---	---	---	---	---	---	---	---
	Final Sequence	0.0	0.049	0.071	0.0	0.129	0.041	0.992	0.162	0.116	0.992	0.079	0.039	2.879	0.192	0.811	2.879	0.173	0.782
04	A	0.0	0.050	0.057	0.0	0.122	0.044	---	---	---	---	---	---	---	---	---	---	---	---
	Final Sequence	0.0	0.050	0.074	0.0	0.137	0.043	---	---	---	---	---	---	---	---	---	---	---	---

Test J4-1902-	Firing	Shutdown														
		Main Oxidizer Valve			Hot Gas Tapoff Valve			Main Fuel Valve			Idle-Mode Oxidizer Valve			Thrust Chamber Bypass Valve		
		Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
01	A	---	---	---	---	---	---	172.302	0.065	0.245	172.302	0.065	0.137	---	---	---
	Final Sequence	7.049	0.084	0.146	7.049	0.094	0.210	7.048	0.069	0.249	7.049	0.075	0.118	7.049	0.248	0.220
02	A	33.244	0.069	0.150	33.244	0.094	0.225	33.244	0.090	0.304	33.244	0.084	0.160	33.244	0.264	0.200
	Final Sequence	9.666	0.099	0.144	9.668	0.097	0.179	9.669	0.085	0.237	9.899	0.077	0.119	9.668	0.238	0.221
03	A	63.095	0.092	0.146	63.005	0.085	0.220	83.095	0.092	0.261	63.095	0.071	0.112	83.095	0.281	0.164
	B	---	---	---	---	---	---	55.756	0.070	0.252	55.756	0.069	0.151	---	---	---
	Final Sequence	7.970	0.081	0.142	7.870	0.088	0.217	16.288	0.099	0.254	16.288	0.067	0.119	7.870	0.232	0.219
04	A	---	---	---	---	---	---	286.547	0.073	0.258	268.547	0.071	0.132	---	---	---
	Final Sequence	---	---	---	---	---	---	8.134	0.071	0.254	9.134	0.070	0.119	---	---	---

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1902-01 through J4-1902-04 is tabulated in Tables III-1 and III-2. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST FOR MAIN-STAGE OPERATION

AEDC Code	Parameter	Tap No	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Current		**amp**						
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter No 1 Spark		On/Off					x	
EASIS-2	Augmented Spark Igniter No. 2 Spark		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EESCO	Programmed Duration Cutoff		On/Off					x	
EFBVO	Fuel Bleed Valve Open Limit		On/Off					x	
EFPCO	Fuel Pump Overspeed Cut-off		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EFUA	Exploding Bridge Wire Firing Units Armed		On/Off					x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EID	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier No. 1		On/Off					x	
EIDA-2	Ignition Detect Amplifier No. 2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off	x		x		x	
EMCO	Main-Stage Cutoff Signal		On/Off	x		x			
EMCS	Main-Stage Control Solenoid Energized		On/Off	x		x		x	
EMD-1	No. 1 Main-Stage "OK" Depressurized		On/Off	x		x		x	
EMD-2	No. 2 Main-Stage "OK" Depressurized		On/Off	x		x		x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed Limit		On/Off					x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	No. 1 Main-Stage "OK" Pressurized		On/Off	x		x		x	
EMP-2	No. 2 Main-Stage "OK" Pressurized		On/Off	x				x	
EMPCO	Main-Stage Pressure Cutoff Signal		On/Off					x	
EMS	Main-Stage Start Signal		On/Off					x	
EMSCO	Main-Stage Programmed Duration Cutoff		On/Off					x	
EMSS	Main-Stage Start Solenoid Energized		On/Off	x	x	x		x	
EOSVO	Oxidizer Bleed Valve Open Limit		On/Off					x	
EOCO	Observer Cutoff Signal		On/Off					x	
EOPCO	Oxidizer Pump Overspeed Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
EOTCO	Fuel Turbine Overtemperature Cutoff		On/Off					x	
ERASIS-1	Augmented Spark Igniter No. 1 Spark Rate		On/Off			x			
ERASIS-2	Augmented Spark Igniter No. 2 Spark Rate		On/Off			x			
ES1M1	No. 1 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 1 Monitor		On/Off	x		x			
ES1M2	No. 1 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 2 Monitor		On/Off	x		x			
ES2M1	No. 2 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 1 Monitor		On/Off	x		x			
ES2M2	No. 2 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 2 Monitor		On/Off	x		x			
ES3M1	No. 3 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 1 Monitor		On/Off	x		x			
ES3M2	No. 3 Solid-Propellant Turbine Starters Exploding Bridge Wire No. 2 Monitor		On/Off	x		x			
ESAMCO	Stall Approach Monitor Cutoff		On/Off					x	
ESPTS	Solid-Propellant Turbine Starter Initiated		On/Off					x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
ESR-1	No. 1 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESR-2	No. 2 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESR-3	No. 3 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESTCO	Start "OK" Timer Cutoff Signal		On/Off					x	
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts No. 1		On/Off			x			
EVSC-2	Vibration Safety Counts No. 2		On/Off			x			
EVSC-3	Vibration Safety Counts No. 3		On/Off			x			
	Flows		gpm						
QF-1	Engine Fuel Flow	PFF	0 to 11,000	x					
QF-2	Engine Fuel Flow	PFFa	0 to 11,000	x	x	x			
QF-3	Engine Fuel Flow	PFF	0 to 11,000		x	x			
QF-1SAM	Fuel Flow Stall Approach Monitor			x		x			
QO-1	Engine Oxidizer Flow	POF	0 to 3600	x					
QO-2	Engine Oxidizer Flow	POFa	0 to 3600	x	x	x			
QO-3	Engine Oxidizer Flow	POF	0 to 3600		x	x			
	Forces		lb_f						
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000	x		x			
	Position		Percent Open						
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LOVT	Main Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 volts	x		x	x		
LTVT	Hot Gas Tapoff Valve		0 to 100	x		x			
	Pressure		psia						
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure		psia						
PC-1P	Thrust Chamber	CG1	0 to 1500	x					
PC-2P	Thrust Chamber	CG1a-2	0 to 1500	x		x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x			x		
PCSPTS-1	Solid-Propellant Turbine Starter No. 1 Chamber	PTS-1	0 to 5000	x		x			
PCSPTS-2	Solid-Propellant Turbine Starter No. 2 Chamber	PTS-2	0 to 5000	x		x			
PCSPTS-3	Solid-Propellant Turbine Starter No. 3 Chamber	PTS-3	0 to 5000	x		x			
PFASIJ	Augmented Spark Igniter Fuel Injection	CF4	0 to 2000	x					
PFASIJ-L	Augmented Spark Igniter Fuel Injection	CF4	0 to 50	x					
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500	x					
PFCO	Film Coolant Orifice	CF5	0 to 2000	x					
PFCO-L	Film Coolant Orifice	CF5	0 to 50	x					
PFJ-1	Fuel Injection	CF2	0 to 1500	x		x			
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50	x					
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000	x		x	x		
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000	x		x	x		
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500	x			x		
PFPD-2	Fuel Pump Discharge	PF2	0 to 3000	x	x	x			
PFPI-1	Fuel Pump Inlet	PF1	0 to 100	x			x		x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			x
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000	x			x		
PFPS	Fuel Pump Interstage	PF6	0 to 1000	x		x			
PFPSI	Fuel Pump Shroud Inlet		0 to 2500	x			x		
PFTI-1P	Fuel Trubine Inlet	TG1	0 to 1000	x		x			
PFTO	Fuel Trubine Outlet	TG2	0 to 200	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Preseure		psia						
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500	x					
PFUT	Fuel Ullage Tank		0 to 100	x					
PFVC	Fuel Repressurization at Customer Connect Panel		0 to 2000	x					
PFVI	Fuel Repreesurization Nozzle Inlet	KHF1	0 to 2000	x					
PFVL	Fuel Represeurization Nozzle Throat	KHF2	0 to 1000	x					
PHEA	Helium Accumulator	NN3	0 to 750	x					
PHES	Helium Supply		0 to 5000	x					
PHET-1P	Helium Tank	NN1-1	0 to 5000	x					x
PHET-2P	Helium Tank	NN1-3	0 to 5000	x					
PHRO-1P	Helium Regulator Outlet	NN2	0 to 750	x					
PHODP	Oxidizer Dome Purge at Cuetomer Connect Panel		0 to 750	x					
POASIJ	Augmented Spark Igniter Oxidizer Injection	I03	0 to 1500	x		x			
POASIJ-L	Augmented Spark Igniter Oxidizer Injection	I03	0 to 50	x					
POIML	Oxidizer Idle-Modo Line	PO10	0 to 2000	x					
POIML-L	Oxidizer Idle-Mode Line	PO10	0 to 50	x					
POJ-1	Oxidizer Injection	CO3	0 to 1500	x					
POJ-2	Oxidizer Injection	CO3a	0 to 2000	x		x			
POJ-3	Oxidizer Injection Manifold	CO3b	0 to 5000		x				
POPBC	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x					
POPD-1L	Oxidizer Pump Discharge	PO3	0 to 50	x					
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 2500	x					
POPD-2	Oxidizer Pump Discharge	PO2	0 to 3000	x	x	x			
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1a	0 to 100	x	x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x					
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200	x					
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100	x					
POUT	Oxidizer Ullage Tank		0 to 100	x					
POVC	Oxidizer Repreesurization at Cuetomer Connect Panel		0 to 2000	x					
POVI	Oxidizer Represeurization Nozzle Inlot	KHO1	0 to 1500	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure		**psia**						
POVL	Oxidizer Repressurization Nozzle Throat	KH02	0 to 1000	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					
PPUVI	Propellant Utilization Valve Inlet	P08	0 to 2000	x					
PPUVO	Propellant Utilization Valve Outlet	P09	0 to 1000	x					
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTEM	Turbine Exhaust Manifold	TG5	0 to 50	x					
PTM	Tapoff Manifold	GG2b	0 to 1500	x					
PTM-L	Tapoff Manifold	GG2b	0 to 50	x					
	Speeds		**rpm**						
NFP-1	Fuel Pump	PPV	0 to 33000		x				
NFP-2	Fuel Pump	PPV	0 to 33000	x		x			
NFP-3	Fuel Pump	PPV	0 to 33000			x			
NOP-1	Oxidizer Pump	POV	0 to 12000		x				
NOP-2	Oxidizer Pump	POV	0 to 12000	x		x			
NOP-3	Oxidizer Pump	POV	0 to 12000			x			
	Temperatures		**°F**						
TA-1	Test Cell North		-50 to 800	x					
TA-2	Test Cell East		-50 to 800	x					
TA-3	Test Cell South		-50 to 800	x					
TA-4	Test Cell West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200	x					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to 100	x		x			
TFD-Avg	Fire Detection Average		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500	x					
TFJ-1P	Fuel Injection	CFT2	-425 to 100	x					
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x			
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to -375	x			x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -390	x	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures		°F						
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTC-1	Fuel Turbine Cone		-400 to 1800	x					
TFTC-2	Fuel Turbine Cone		-400 to 1800	x					
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400	x			x		
TFTI-4	Fuel Turbine Inlet	GGT2 and GG2	-300 to 2000	x		x	x		
TFVC	Fuel Repressurization at Customer Connect Panel		-300 to -100	x					
TFVL	Fuel Repressurization Nozzle Inlet	KHFT1	-300 to -100	x					
THET-1P	Helium Tank	NNT1	-200 to 150	x					x
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100	x			x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x			x		
TNODP	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
TOIML	Oxidizer Idle Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x					
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TORT-1	Oxidizer Run Tank		-300 to -285	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x					
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x					
TOTSDL	Oxidizer Turbine Seal Drain Line		-100 to 1000	x					
TOVC	Oxidizer Repressurization at Customer Connect Panel		-200 to 500	x					
TOVL	Oxidizer Repressurization Nozzle Inlet	KHOT1	-200 to 500	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures		°F						
TPTU	Photocon Cooling Water (Upstream)		0 to 300	x					
TSCGA-1	Solid-Propellant Turbine Starter No. 1 Conditioning Gas		-100 to 200	x					
TSCGA-2	Solid-Propellant Turbine Starter No. 2 Conditioning Gas		-100 to 200	x					
TSCGA-3	Solid-Propellant Turbine Starter No. 3 Conditioning Gas		-100 to 200	x					
TSCMF-1	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TSCMF-2	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TSCMF-3	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TTCP	Thrust Chamber Purge		-250 to 200	x					
TTCT-E	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	x			x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
	Vibrations		g's						
UFPR	Fuel Pump	PZA-1	450 peak		x				
UFTR	Fuel Turbine	V123-2	450 peak		x				
UOPR	Oxidizer Pump	PZA-2	300 peak		x				
UTCD-1	Thrust Chamber Dome	FZA-1a	1400 peak		x	x			
UTCD-2	Thrust Chamber Dome	FZA-2	1400 peak		x	x			
UTCD-3	Thrust Chamber Dome	FZA-3	300 peak		x	x			
	Voltage		volts						
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	x					
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5	x					

TABLE III-2
INSTRUMENTATION LIST FOR IDLE-MODE OPERATION

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Current		amp						
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event		Counts						
EASIS-1	Augmented Spark Igniter No. 1 Spark		On/Off					x	
EASIS-2	Augmented Spark Igniter No. 2 Spark		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EESCO	Programmed Duration Cutoff		On/Off					x	
EFBVO	Fuel Bleed Valve Open Limit		On/Off					x	
EFPCO	Fuel Pump Overspeed Cutoff		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EFUA	Exploding Bridge Wire Firing Units Armed		On/Off					x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EID	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier No. 1		On/Off					x	
EIDA-2	Ignition Detect Amplifier No. 2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off					x	
EMCS	Main-Stage Control Solenoid Energized		On/Off					x	
EMD-1	No. 1 Main-Stage "OK" Depressurized		On/Off					x	
EMD-2	No. 2 Main-Stage "OK" Depressurized		On/Off					x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed Limit		On/Off					x	
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	No. 1 Main-Stage "OK" Pressurized		On/Off					x	
EMP-2	No. 2 Main-Stage "OK" Pressurized		On/Off					x	
EMPCO	Main-Stage Pressure Cutoff Signal		On/Off					x	
EMS	Main-Stage Start Signal		On/Off					x	
EMSCO	Main-Stage Programmed Duration Cutoff		On/Off					x	
EMSS	Main-Stage Start Solenoid Energized		On/Off					x	
EOBVO	Oxidizer Bleed Valve Open Limit		On/Off					x	
EOCO	Observer Cutoff Signal		On/Off					x	

TABLE III-2 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EOPCO	Oxidizer Pump Overspeed Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
EOTCO	Fuel Turbine Over-Temperature Cutoff		On/Off					x	
ERASIS-1	Augmented Spark Igniter No. 1 Spark Rate		On/Off			x			
ERASIS-2	Augmented Spark Igniter No. 2 Spark Rate		On/Off			x			
ESAMCO	Stall Approach Monitor Cutoff		On/Off					x	
ESPTS	Solid-Propellant Turbine Starter Initiated		On/Off					x	
ESR-1	No. 1 Solid-Propellant Turbine Starter Ready		On/Off					x	
ESR-2	No. 2 Solid-Propellant Turbine Starter Ready		On/Off					x	
ESR-3	No. 3 Solid-Propellant Turbine Starter Ready		On/Off					x	
ESTCO	Start "OK" Timer Cutoff Signal		On/Off					x	
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts No. 1		On/Off			x			
EVSC-2	Vibration Safety Counts No. 2		On/Off			x			
EVSC-3	Vibration Safety Counts No. 3		On/Off			x			
	Flows		gpm						
QF-1	Engine Fuel Flow	PFF	0 to 11,000	x					
QF-2	Engine Fuel Flow	PFFa	0 to 11,000	x		x			
QF-3	Engine Fuel Flow	PFF	0 to 11,000			x			
QF-1SAM	Fuel Flow Stall Approach Monitor			x		x			
QO-1	Engine Oxidizer Flow	POF	0 to 3600	x					
QO-2	Engine Oxidizer Flow	POFa	0 to 3600	x		x			
QO-3	Engine Oxidizer Flow	POF	0 to 3600			x			
	Forces		lb_f						
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000	x		x			
	Position		Percent Open						
LPVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 volts	x		x	x		
	Pressure		psia						
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x			
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x			x		
PFASIJ-L	Augmented Spark Igniter Fuel Injection	CF4	0 to 50	x					

TABLE III-2 (Continued)

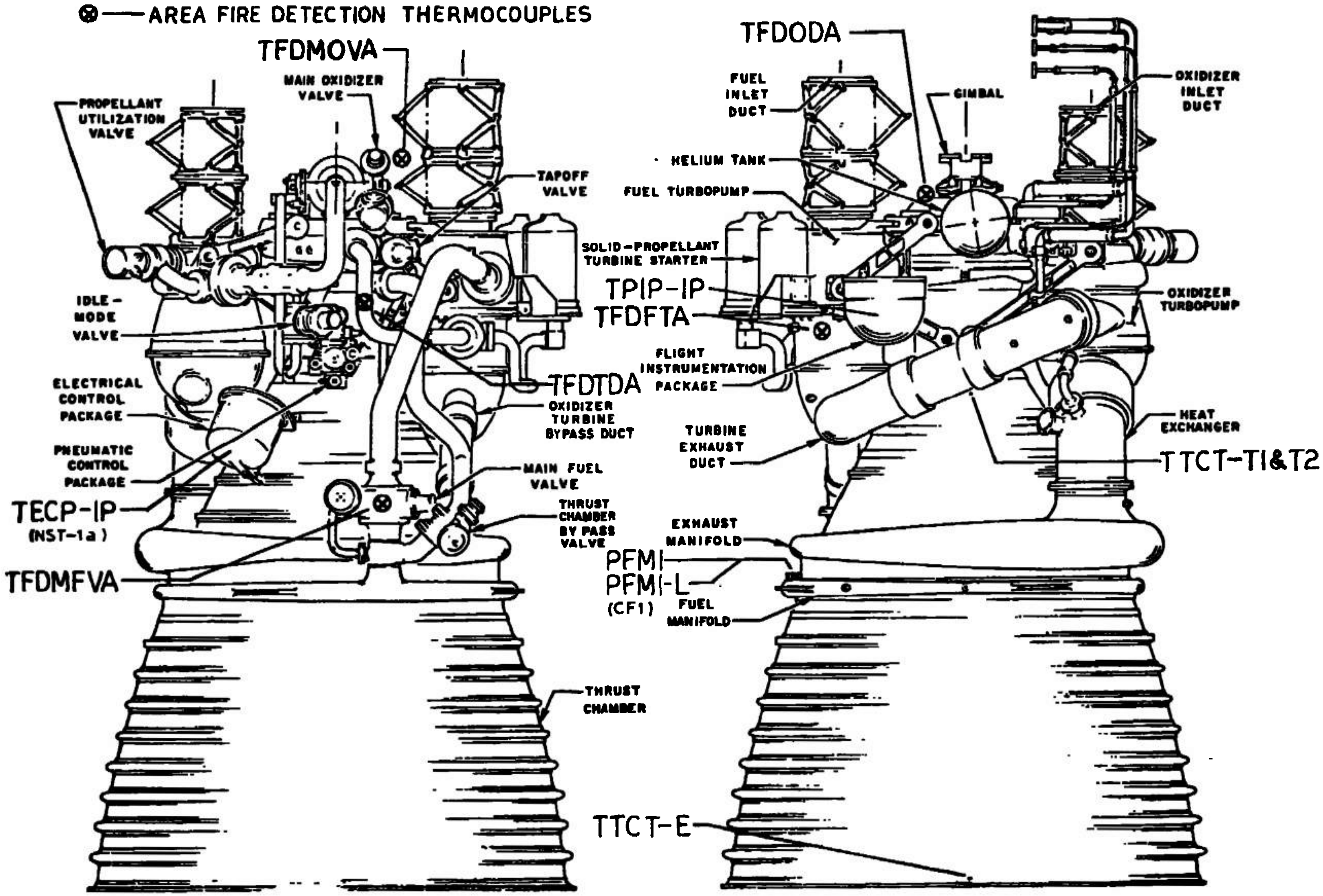
AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure								
PFCO-L	Film Coolant Orifice	CF5	0 to 50	x					
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50	x					
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPI-1	Fuel Pump Inlet	PF1	0 to 100	x			x		x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			
PFUT	Fuel Ullage Tank		0 to 100	x					
PHEA	Helium Accumulator	NN3	0 to 750	x					
PHES	Helium Supply		0 to 5000	x					
PHET-1P	Helium Tank	NN1-1	0 to 5000	x					x
PHET-2P	Helium Tank	NN1-3	0 to 5000	x					
PHRO-1P	Helium Regulator Outlet	NN2	0 to 750	x					
PNODP	Oxidizer Dome Purge at Customer Connect Panel		0 to 750	x					
POASIJ-L	Augmented Spark Igniter Oxidizer Injection	IO3	0 to 50	x					
POIML-L	Oxidizer Idle-Mode Line	PO10	0 to 50	x					
POJ-2	Oxidizer Injectinn	CO3a	0 to 2000	x		x			
POPD-1L	Oxidizer Pump Discharge	PO3	0 to 50	x					
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1a	0 to 100	x	x	x			
POUT	Oxidizer Ullage Tank		0 to 100	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTM-L	Tapoff Manifold	GG2b	0 to 50	x					
	Speeds		**rpm**						
NFP-2	Fuel Pump	PPV	0 to 33,000			x			
NFP-3	Fuel Pump	PPV	0 to 33,000			x			
NOP-2	Oxidizer Pump	POV	0 to 12,000			x			
NOP-3	Oxidizer Pump	POV	0 to 12,000			x			
	Temperatures		**°F**						
TA-1	Test Cell North		-50 to 800	x					
TA-2	Test Cell East		-50 to 800	x					
TA-3	Test Cell South		-50 to 800	x					
TA-4	Test Cell West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200	x					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to 100	x		x			
TFD-AVG	Fire Detection Average		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					

TABLE III-2 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures								
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					
TFDOOA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500	x					
TFJ-1P	Fuel Injection	CFT2	-425 to 100	x					
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x			
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to -375	x			x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -390	x	x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400	x			x		
TFTI-4	Fuel Turbine Inlet	GG2 and GGT2	-300 to 2000	x		x	x		
THET-1P	Helium Tank	NNT1	-200 to 150	x					x
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100	x			x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x			x		
TNODP	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
TOIML	Oxidizer Idle-Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x					
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TORT-1	Oxidizer Run Tank		-300 to -285	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTSDL	Oxidizer Turbine Seal Drain Line		-100 to 1000	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					
TPTU	Photocon Cooling Water (Upstream)		0 to 300	x					
TTCP	Thrust Chamber Purge		-250 to 200	x					
TTCT-E	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	x			x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
	Vibrations		**g's**						
UFPR	Fuel Pump	PZA-1	450 Peak		x				
UFTR	Fuel Turbine	V123-2	450 Peak		x				
UOPR	Oxidizer Pump	PZA-2	300 Peak		x				
UTCD-1	Thrust Chamber Dome	FZA-1a	1400 Peak		x	x			
UTCD-2	Thrust Chamber Dome	FZA-2	1400 Peak		x	x			
UTCD-3	Thrust Chamber Dome	FZA-3	300 Peak		x	x			

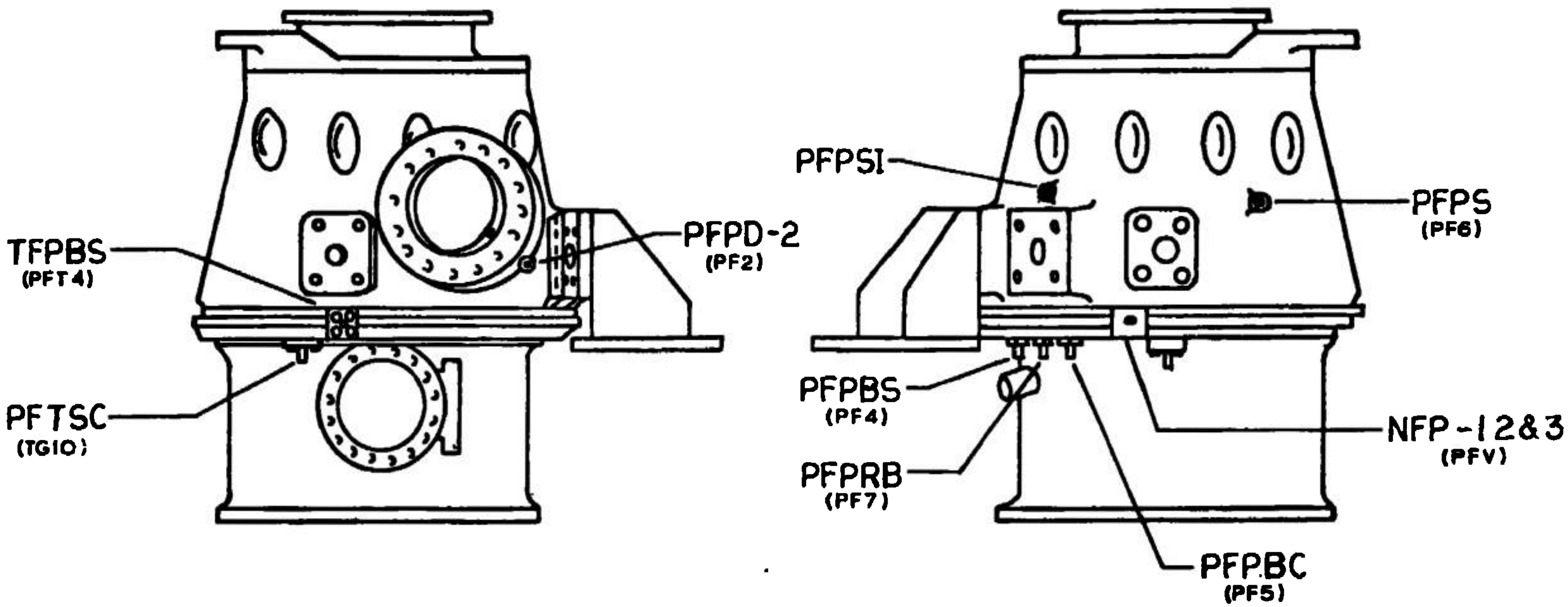
TABLE III-2 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Voltage		Volts						
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	x					

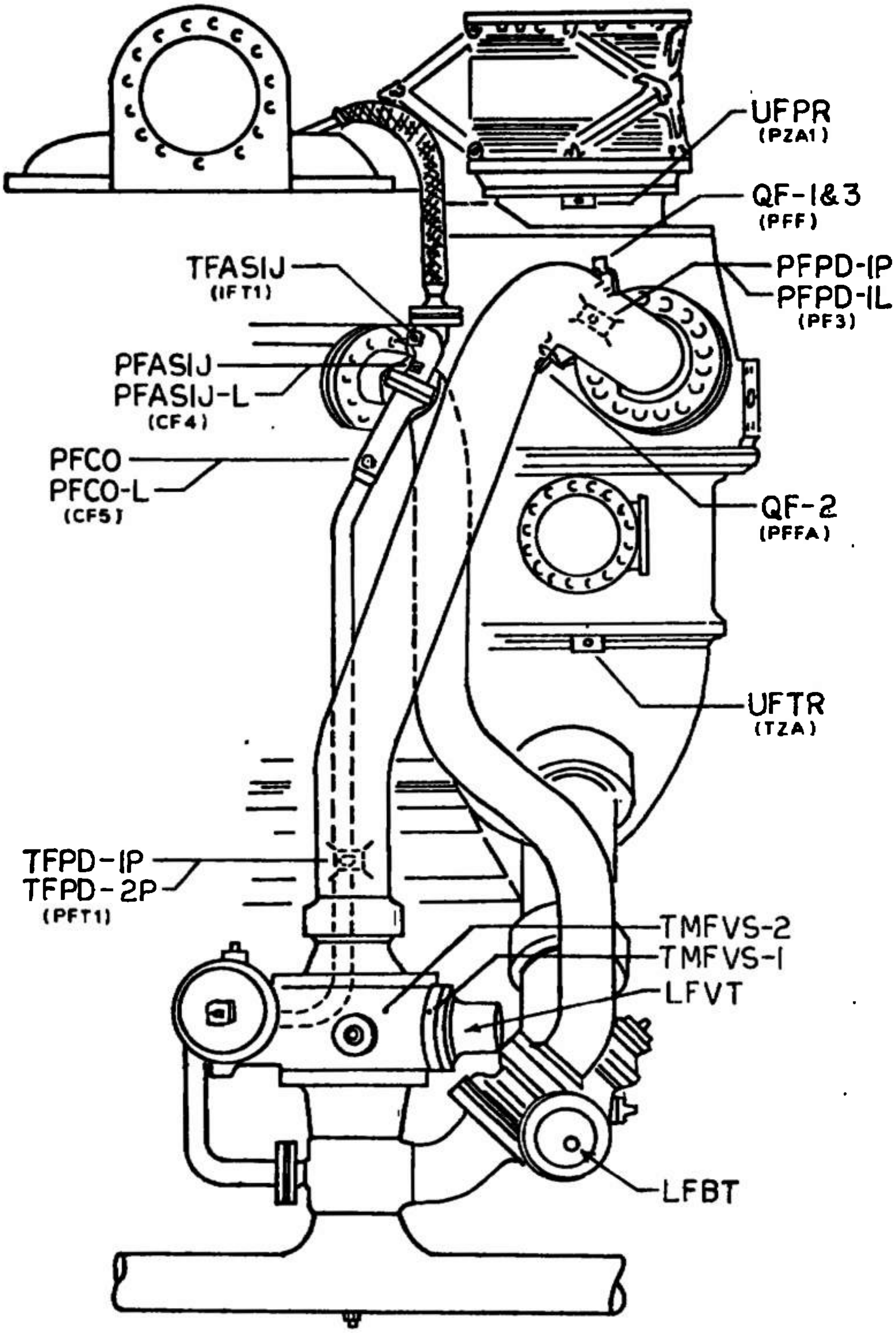


a. General Arrangement

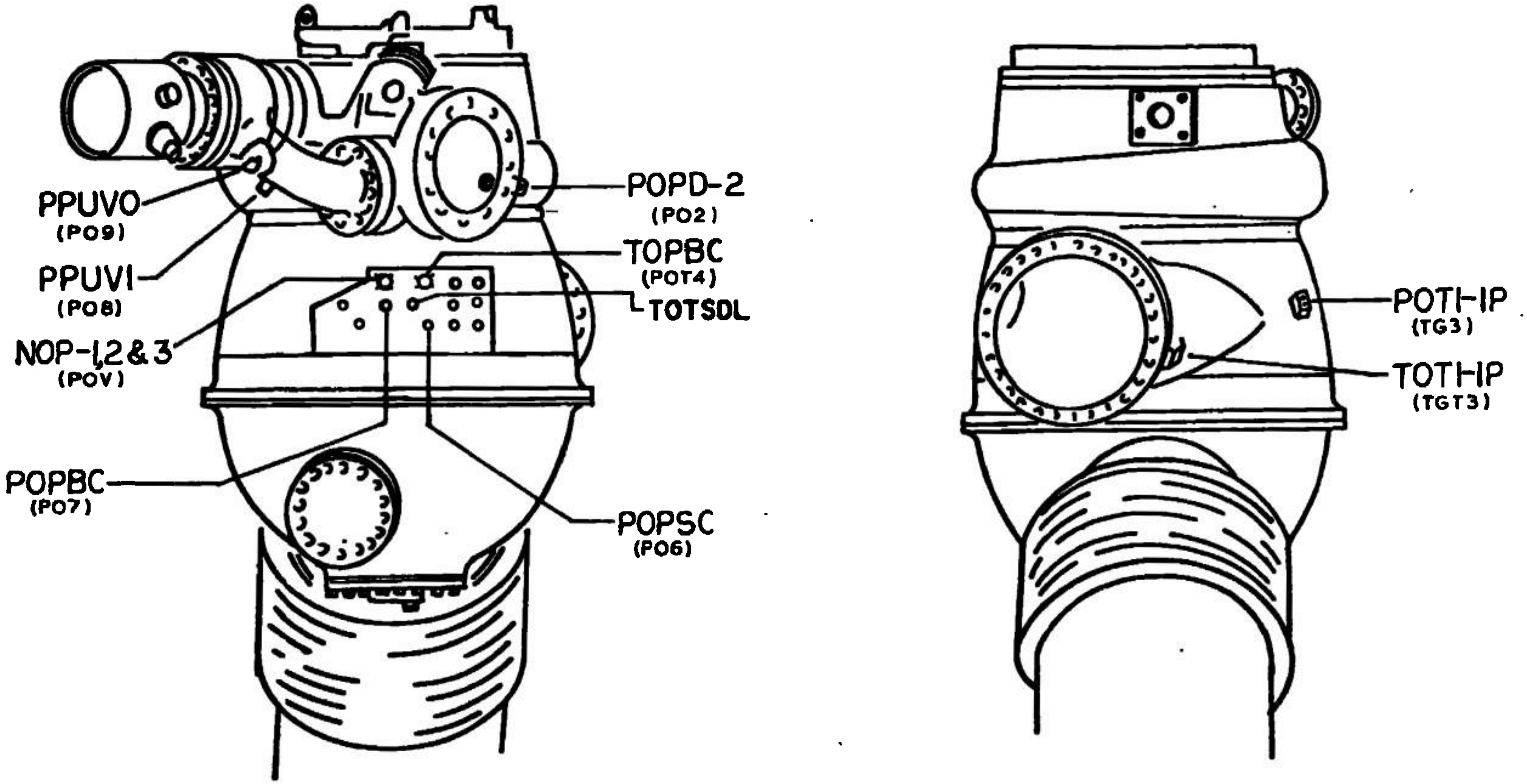
Fig. III-1 Selected Sensor Locations



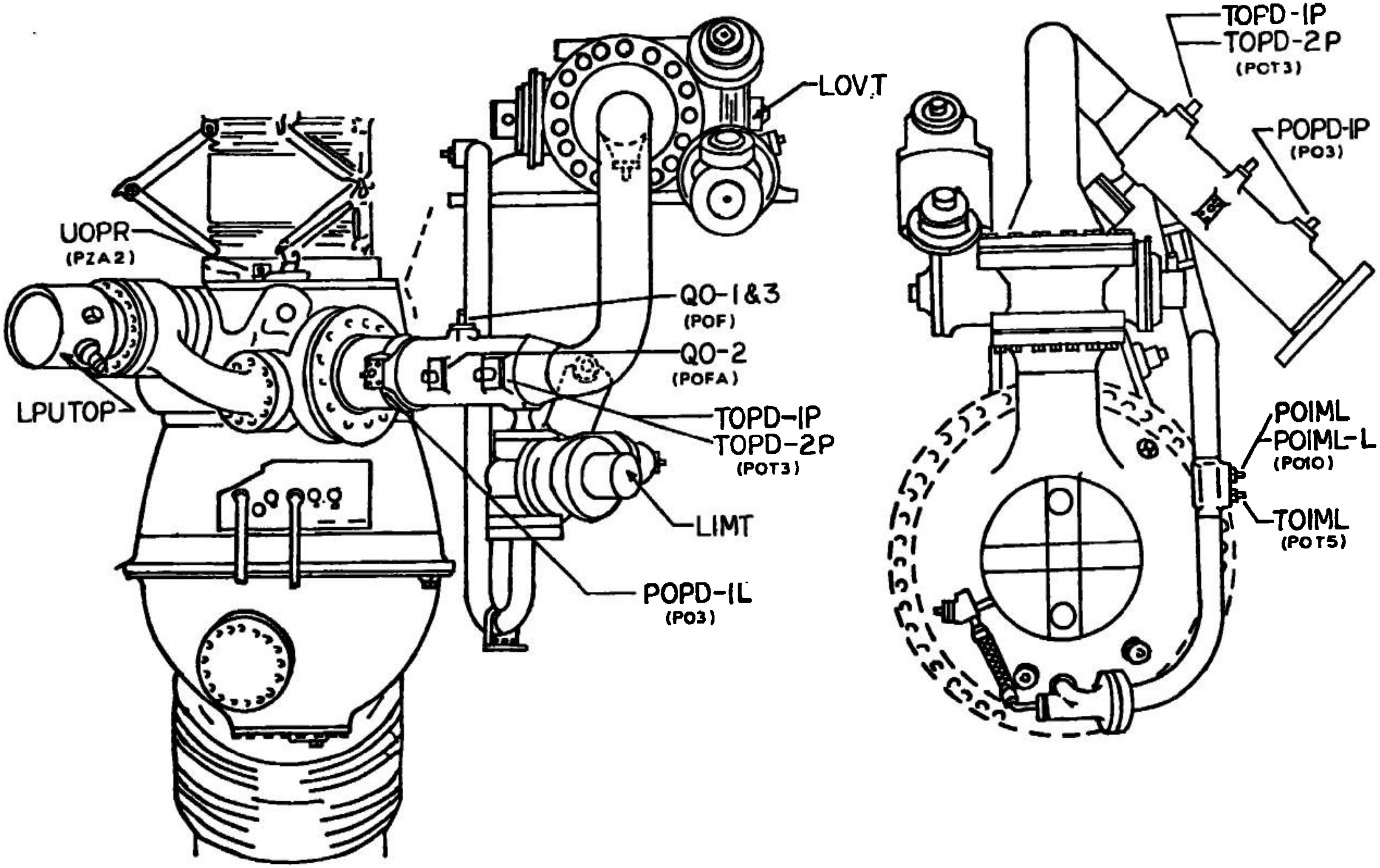
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



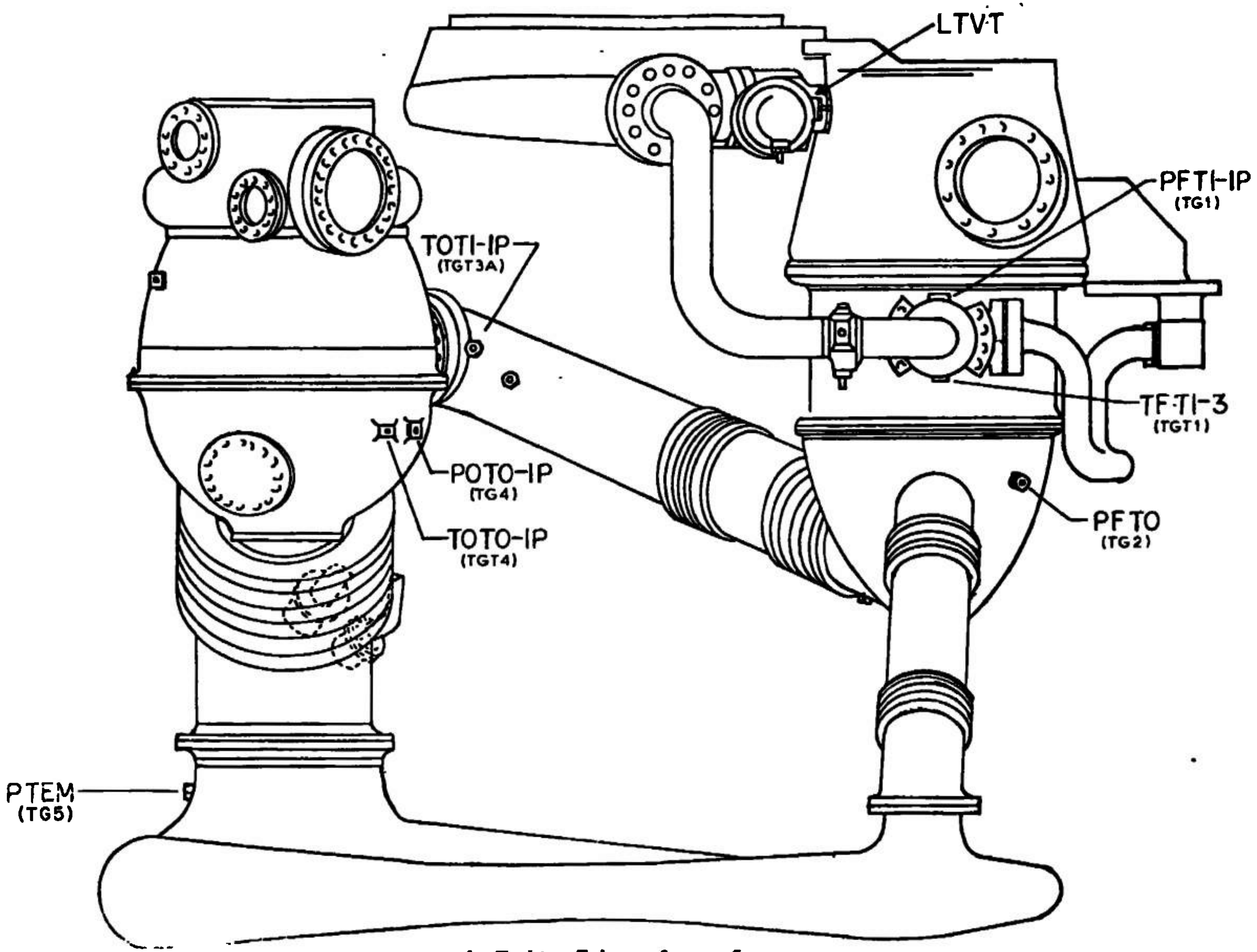
c. Fuel System Sensor Locations
Fig. III-1 Continued



d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued

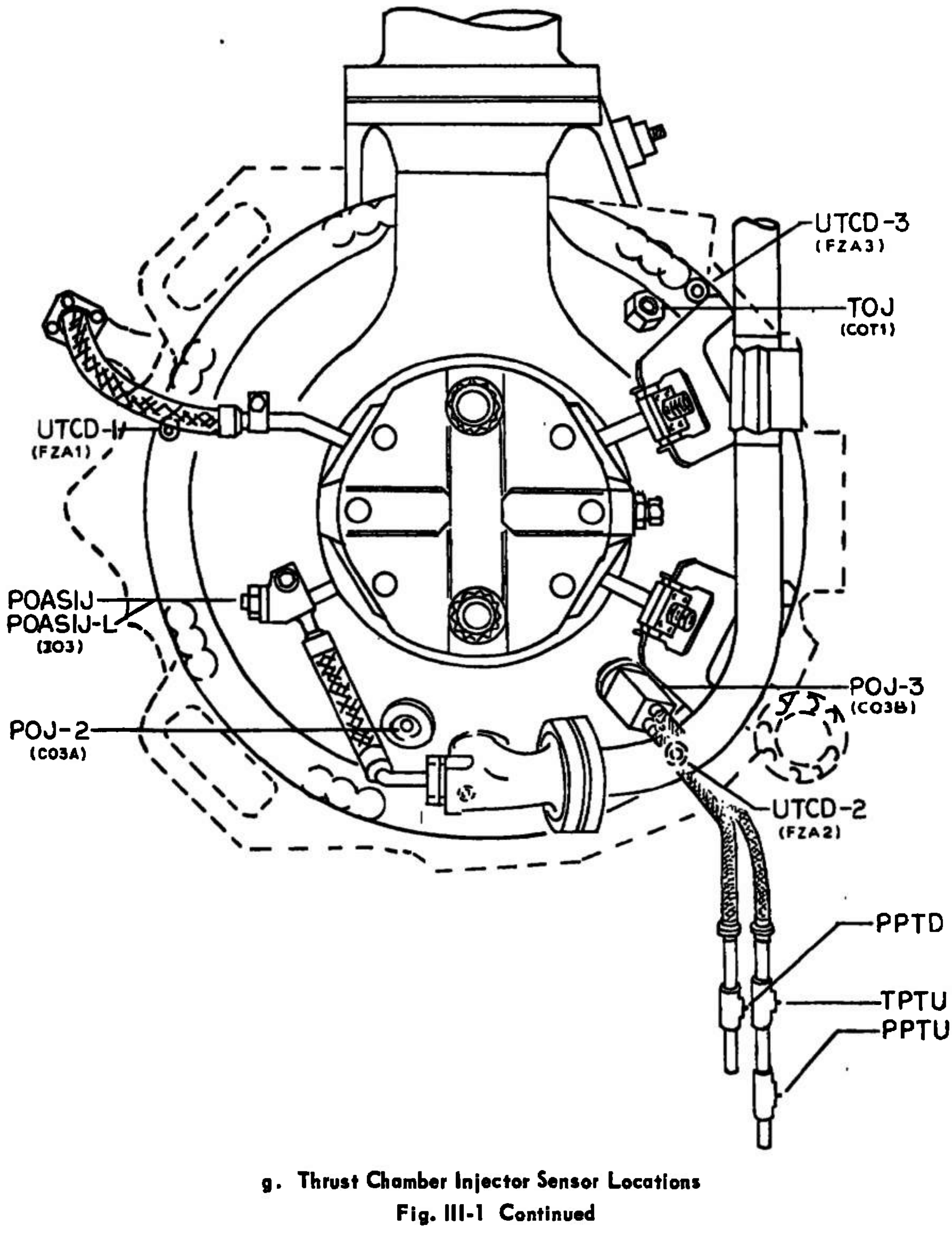


e. Oxidizer System Sensor Locations
Fig. III-1 Continued

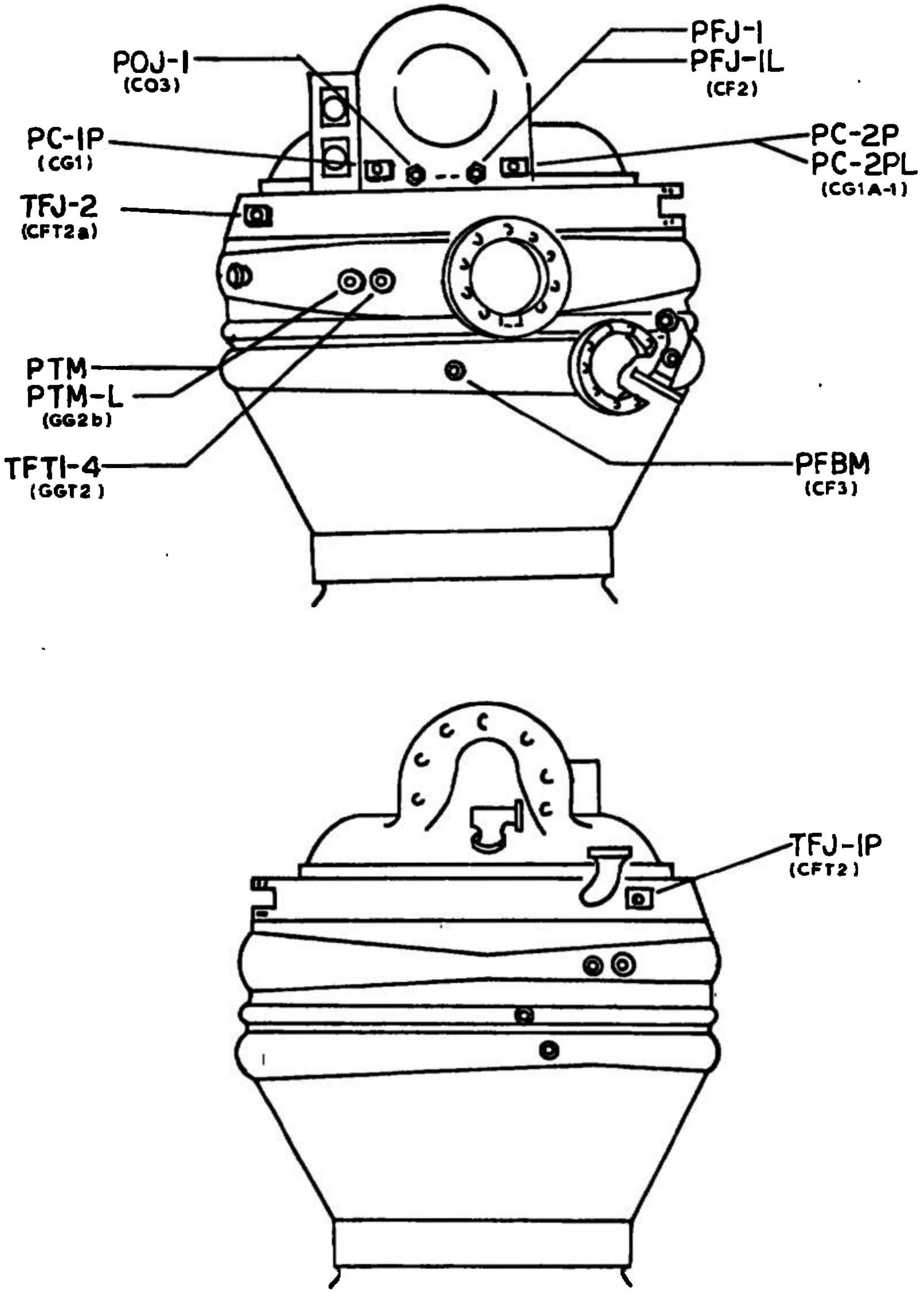


f. Turbine Exhaust System Sensor

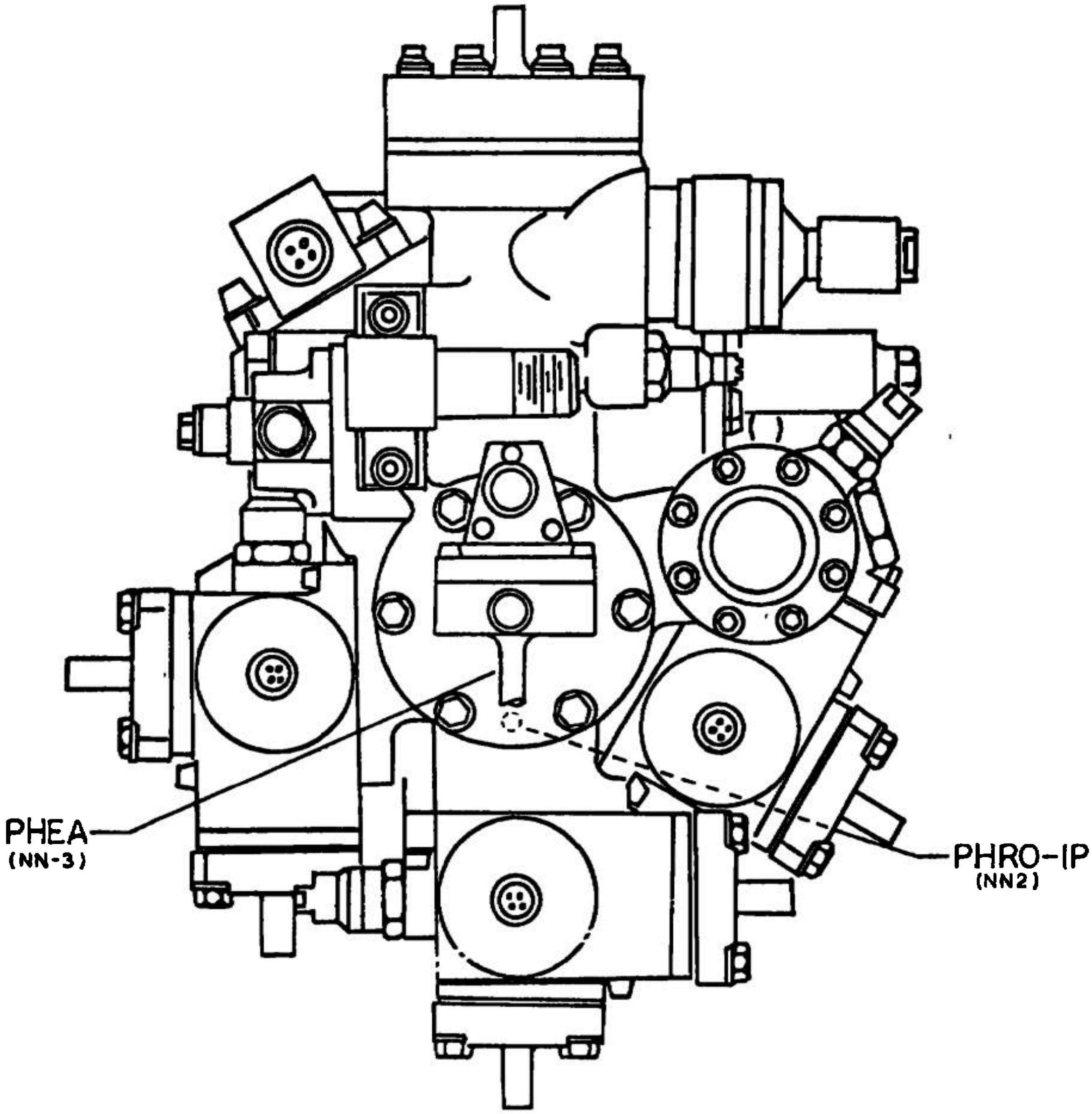
Fig. III-1 Continued



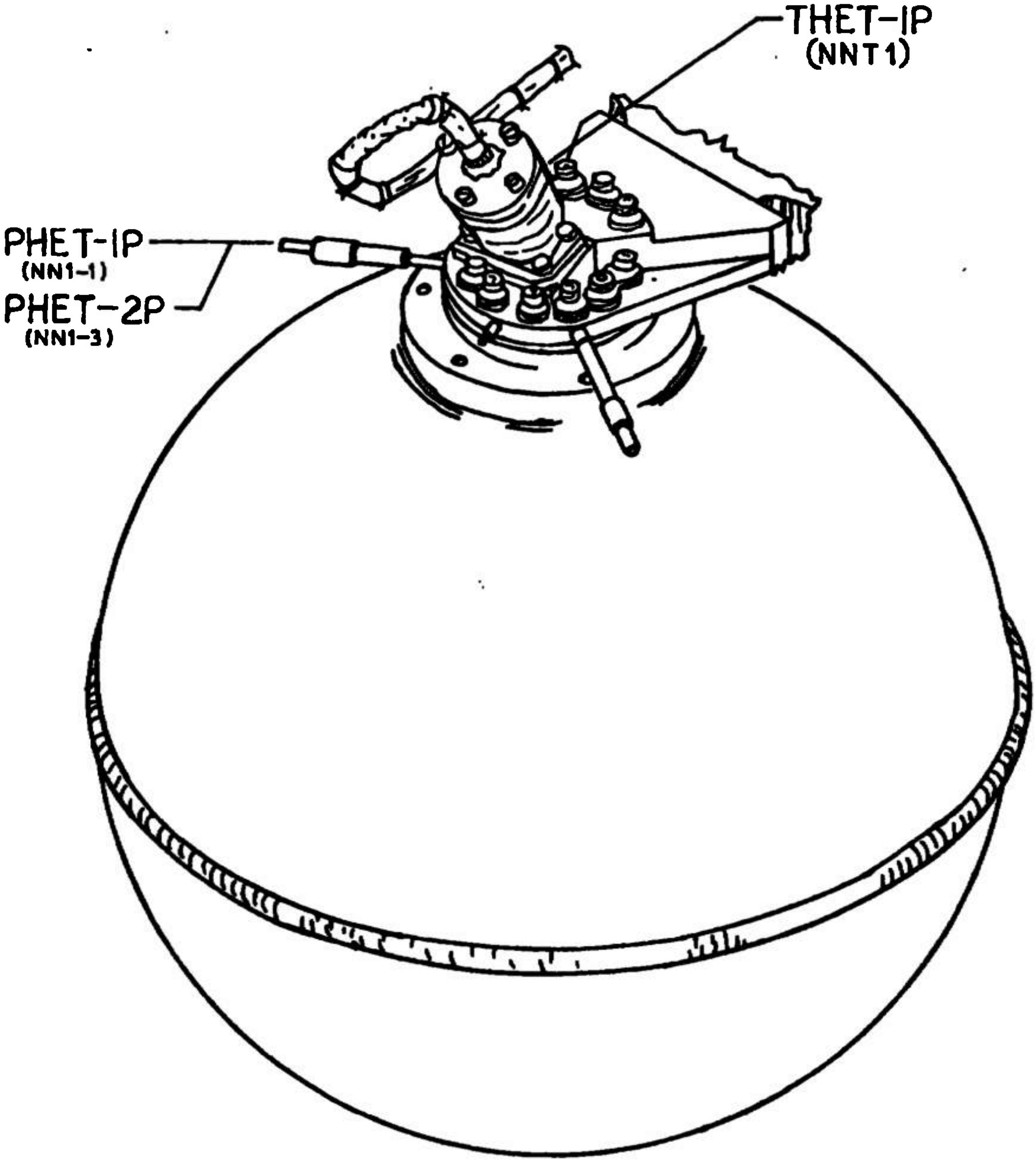
g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



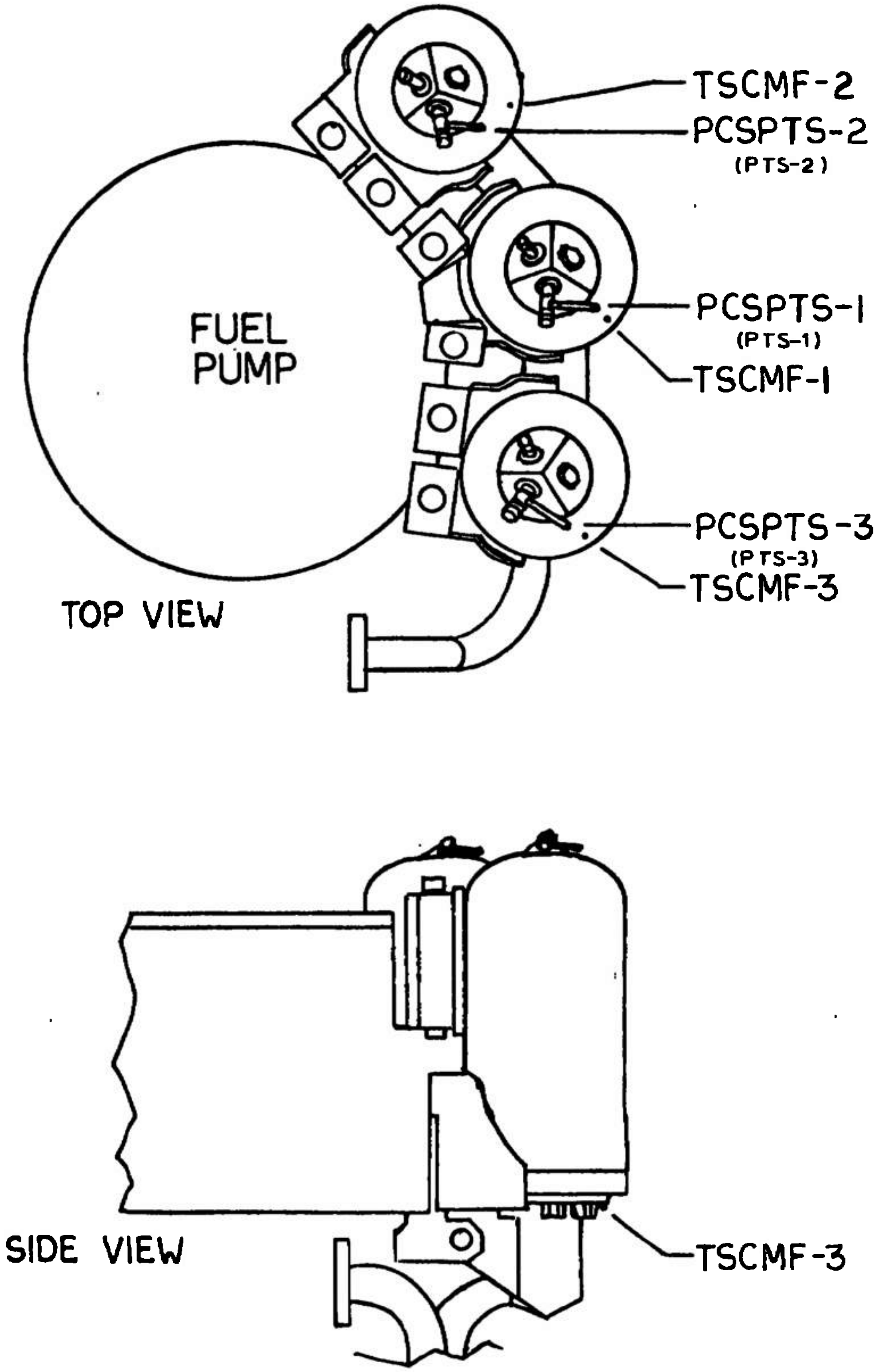
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



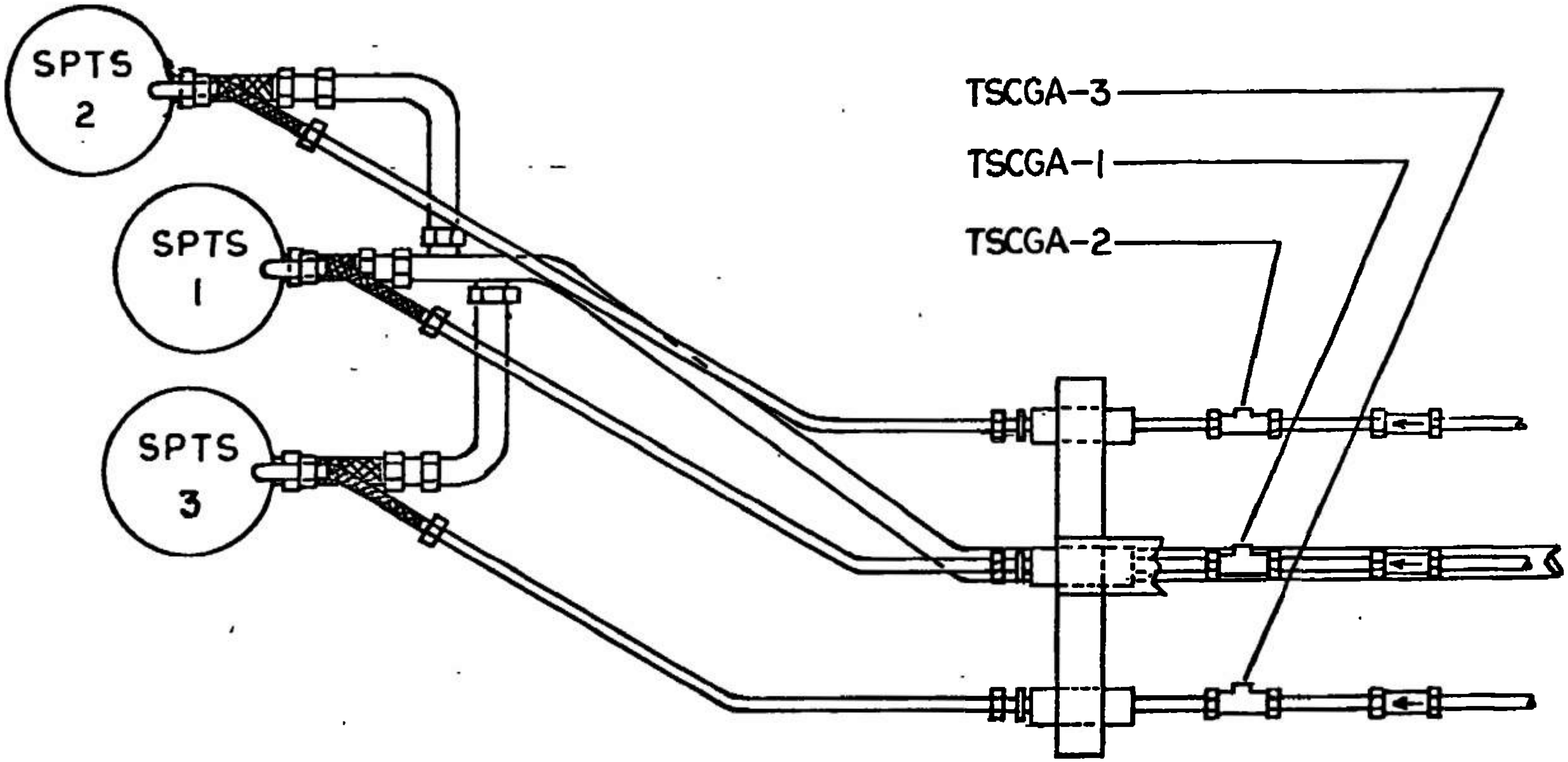
i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



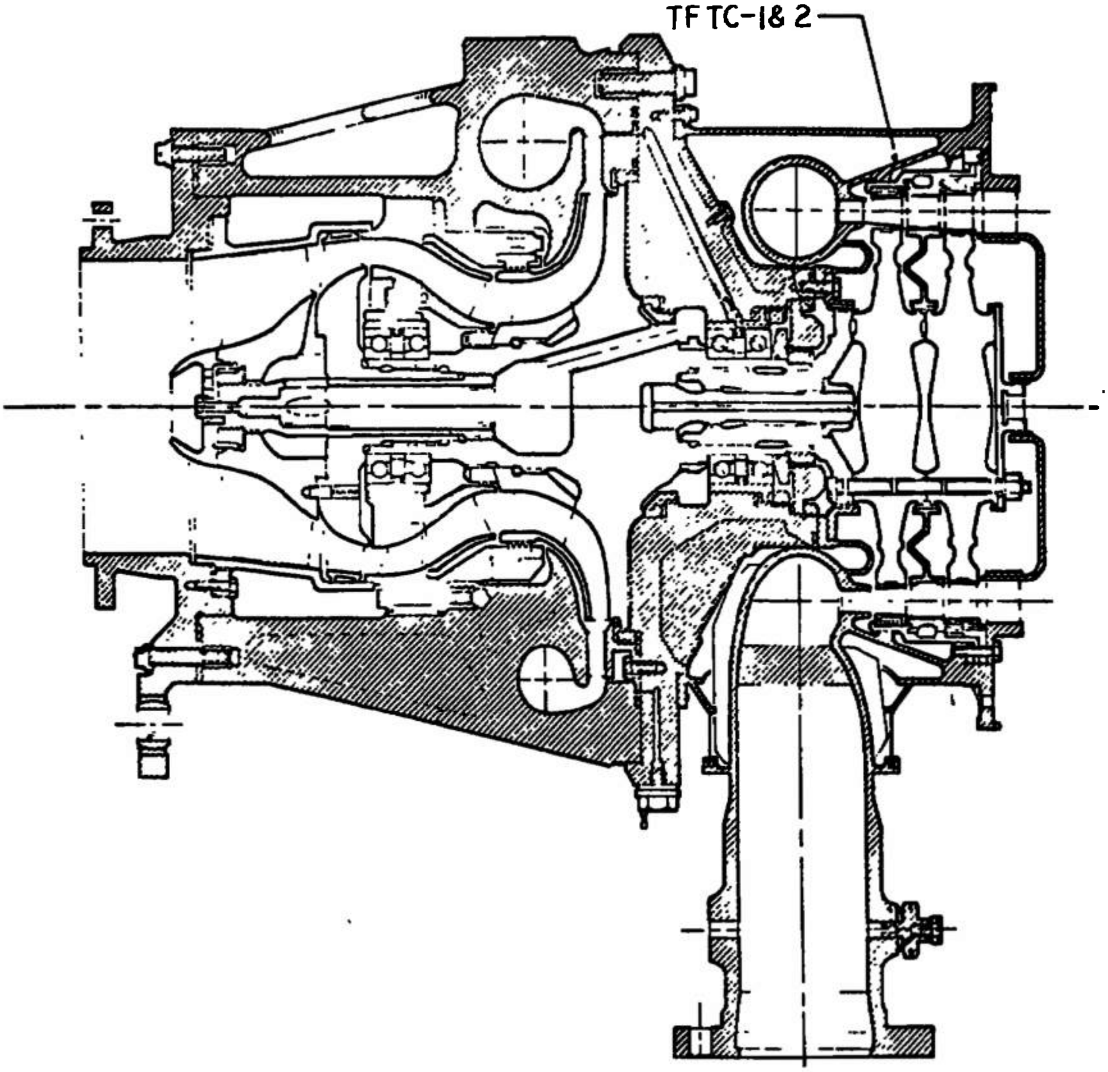
j. Helium Tonk Sensor Locations
Fig. III-1 Continued



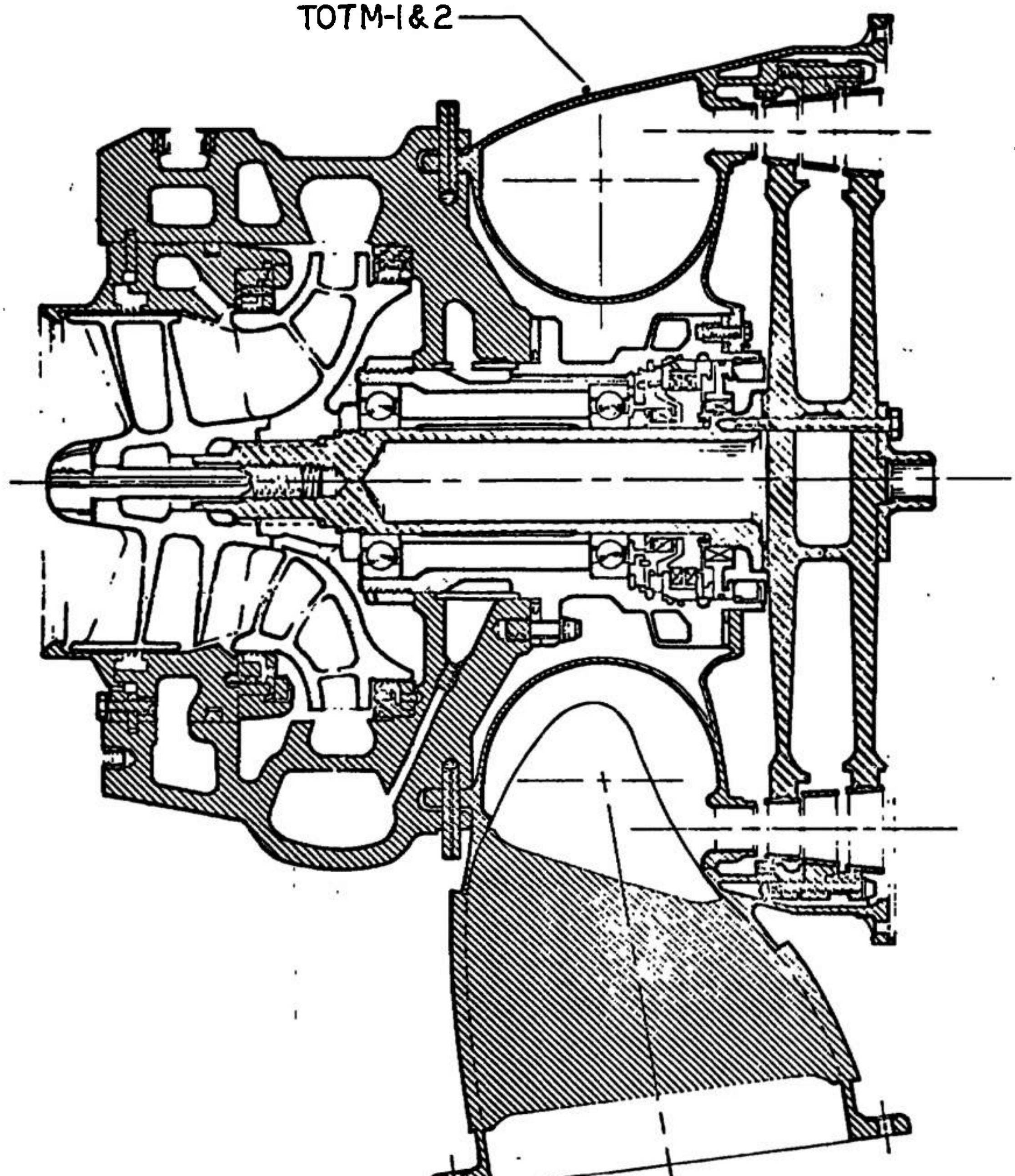
k. Solid-Propellant Turbine Starter Sensor Locations
Fig. III-1 Continued



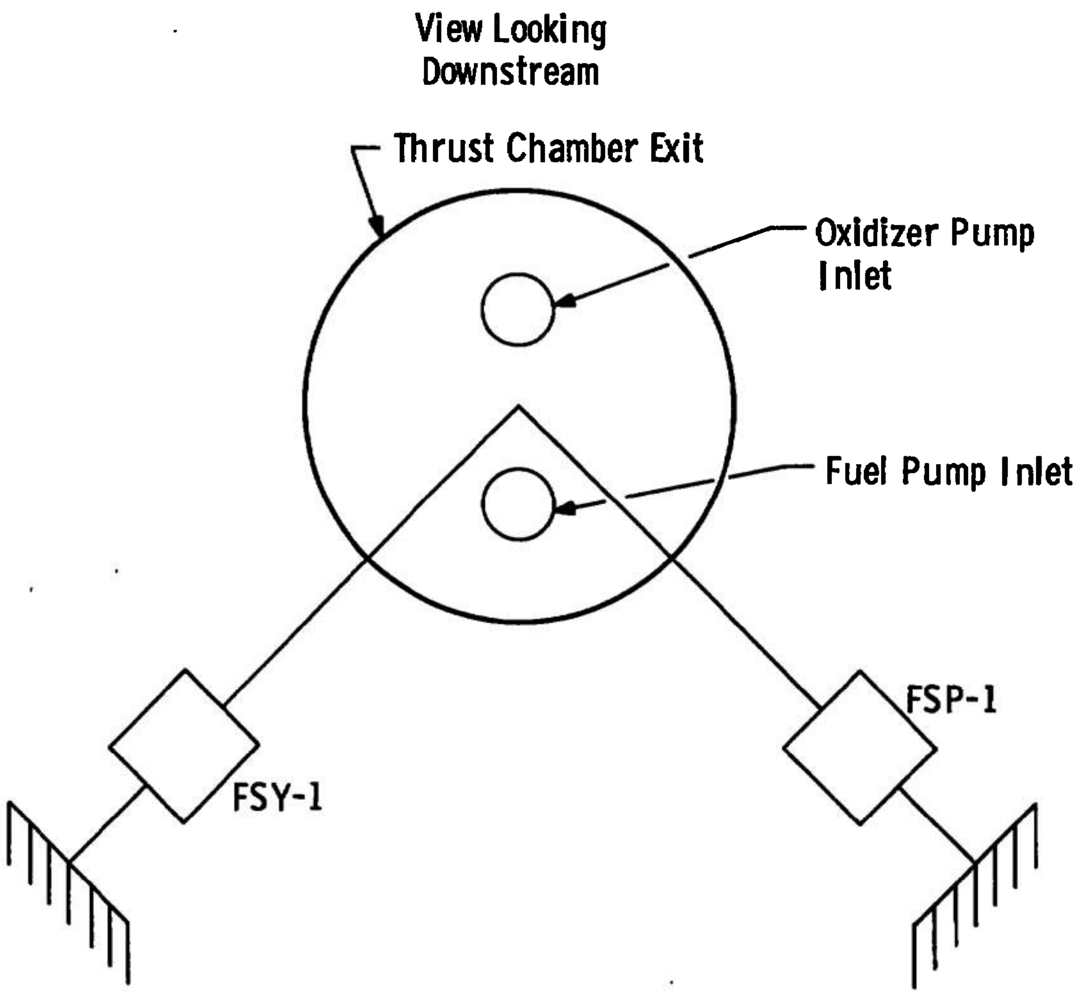
I. Solid-Propellant Turbine Starter Conditioning System Sensor Locations
Fig. III-1 Continued



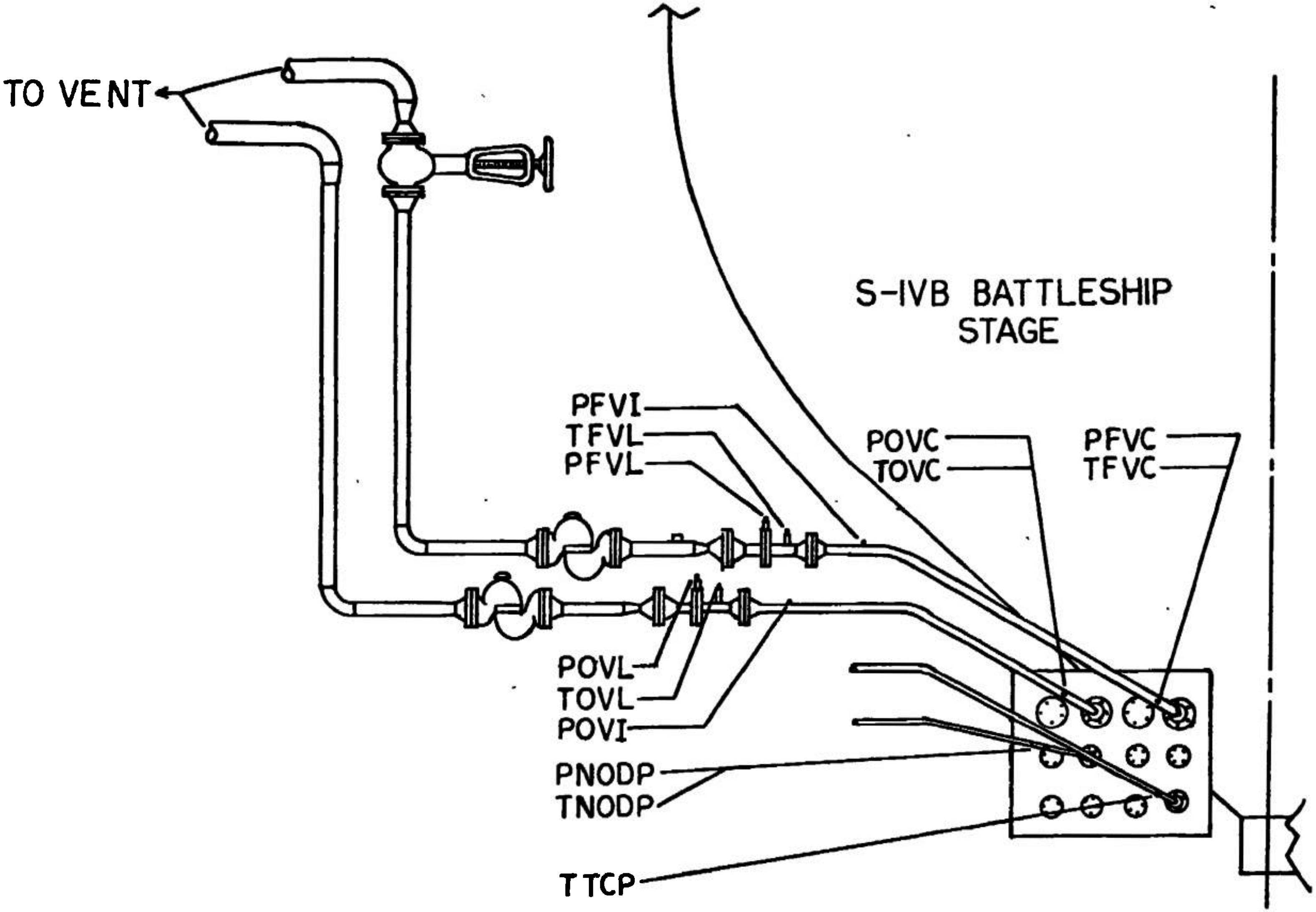
m. Fuel Turbine Sensor Locations
Fig. III-1 Continued



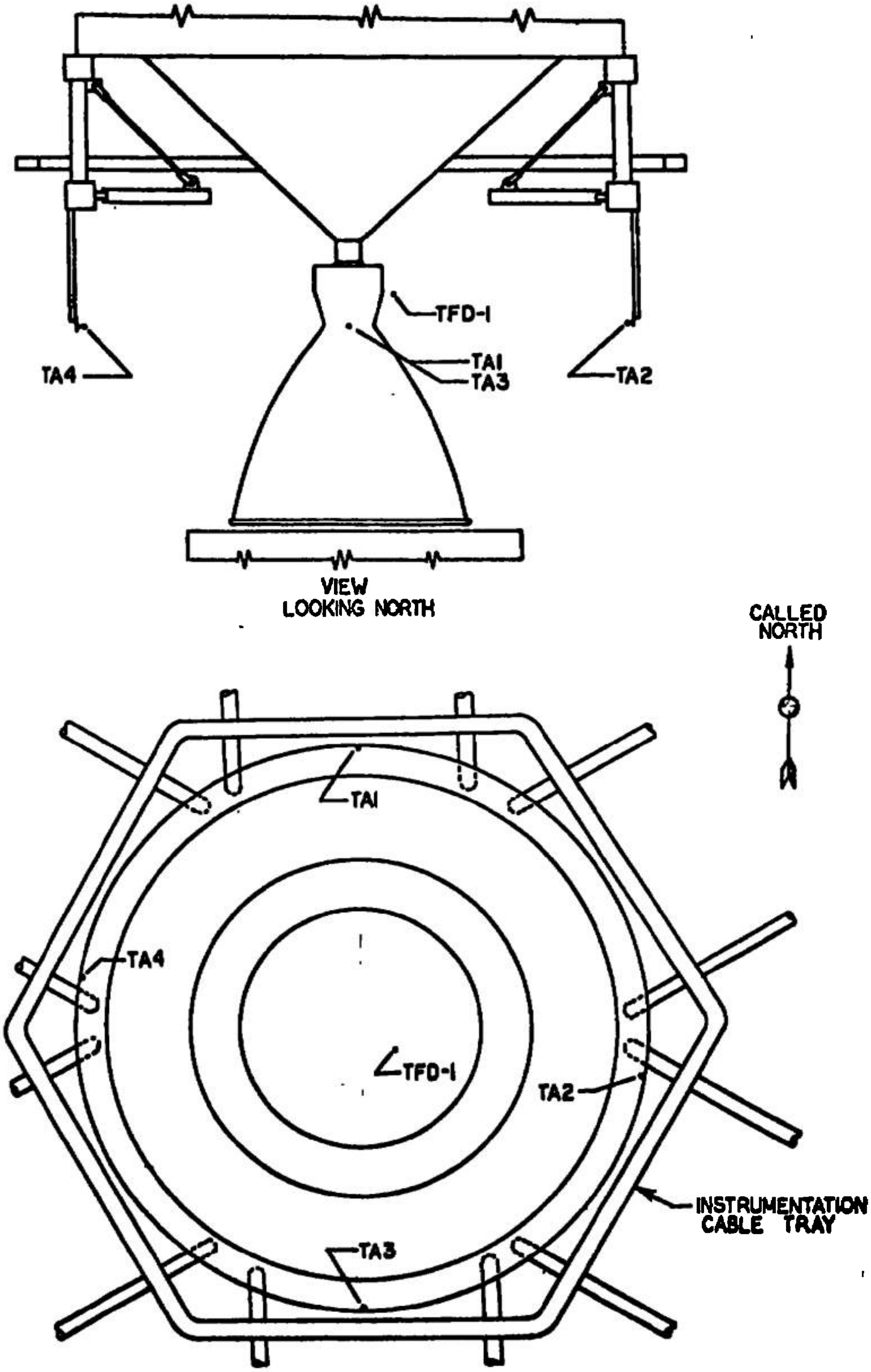
n. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



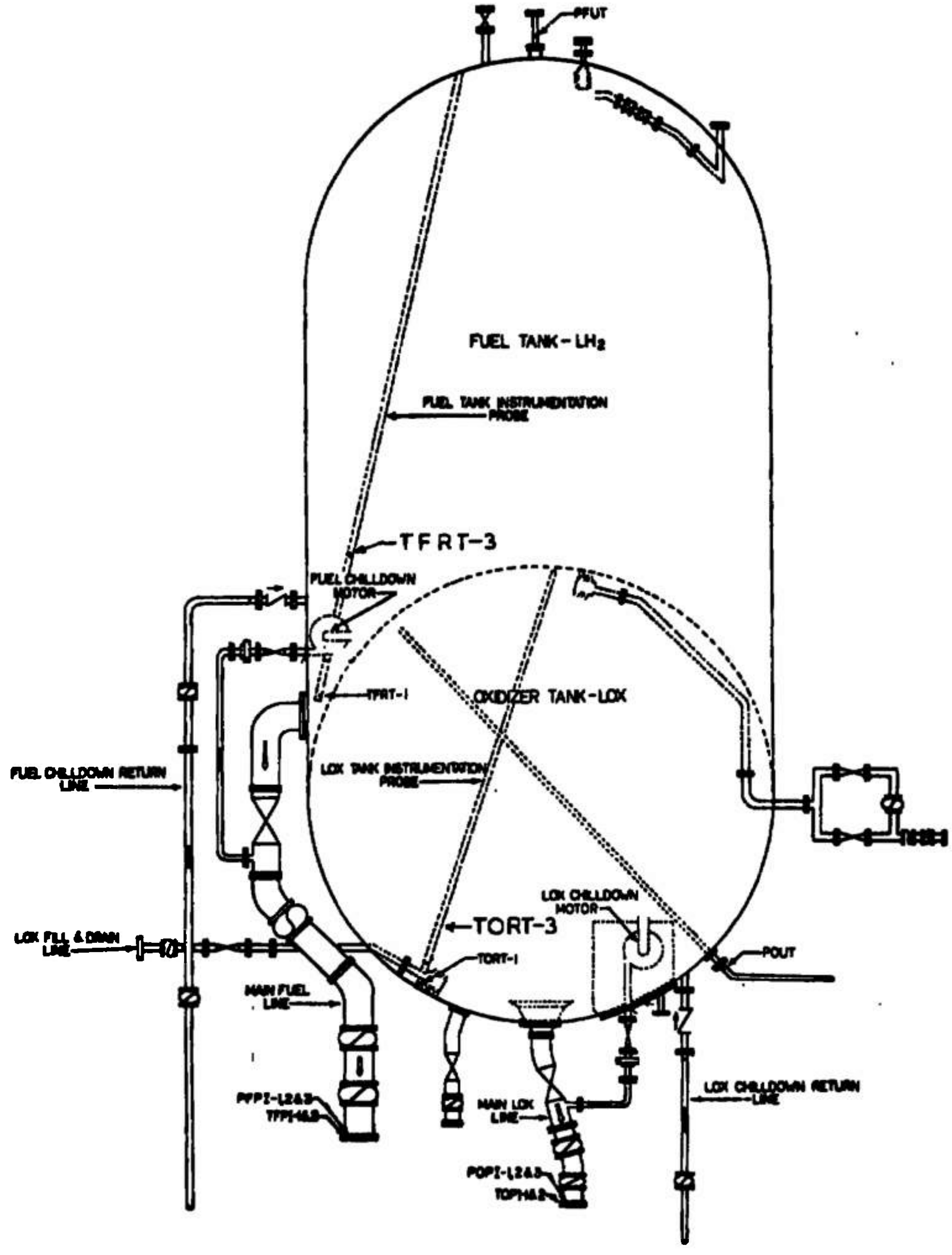
a. Side Load Forces Sensor Locations
Fig. III-1 Continued



p. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



q. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



r. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Arnold Engineering Development Center
ARO, Inc., Operating Contractor
Arnold Air Force Station, Tennessee

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-01 THROUGH J4-1902-04)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
December 5, 1968 through January 10, 1969 - Interim Report

5. AUTHOR(S) (First name, middle initial, last name)
N. R. Vetter, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1969	113	4

8a. CONTRACT OR GRANT NO. F40600-69-C-0001

b. PROJECT NO. 9194

c. System 921E

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AEDC-TR-69-44

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
N/A

10. DISTRIBUTION STATEMENT
Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812.

11. SUPPLEMENTARY NOTES
Available in DDC.

12. SPONSORING MILITARY ACTIVITY
NASA, Marshall Space Flight Center (I-E-J)
Huntsville, Alabama 35812

13. ABSTRACT

Five firings of the Rocketdyne J-2S rocket engine (S/N J-111A) were conducted in Test Cell J-4 of the Large Rocket Facility between December 5, 1968, and January 10, 1969. These firings were accomplished during test periods J4-1902-01 through J4-1902-04 at pressure altitudes of approximately 100,000 ft at engine start to investigate engine idle-mode operation, transition from idle mode to main stage, and steady-state operation at main stage. The engine started successfully in all cases and two planned transitions from idle mode to main stage were accomplished. The thrust chamber and injector were damaged extensively during a 288.5-sec duration idle-mode firing (04A).

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812.

This document ... release ... its distribution is unlimited. Per AF letter dtd 12 July 74 signed William O. Cole

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J-2S rocket engines						
Saturn						
liquid propellants						
altitude simulation						
flight simulation						
startup						
performance tests						
performance evaluation						
damage						

1. Rocket motors -- J-2S -- Performance

2. " "

3. -

16-3

AFSC
Arnold AFS Tenn

UNCLASSIFIED
Security Classification