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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-07)

C. E. Pillow
ARO, Inc.

FEBRUARY 1968

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

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) 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 AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on September 1, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on November 2, 1967.

This technical report has been reviewed and is approved.

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ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. These firings were accomplished during test period J4-1801-07 at pressure altitudes ranging from 89,000 to 106,000 ft at engine start. The objectives of these S-IVB/S-V firings included the evaluation of the effect of start tank energy on the oxidizer pump spin speed and the effect of thrust chamber temperature on the fuel pump high level stall margin. Firing 07A was conducted with 12 experimental oxidizer pump primary seal drain tubes attached to the engine. The accumulated firing duration for this test period was 66.5 sec.

CONTENTS

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I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that the helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
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-2 rocket engine (S/N J-2052) using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The four firings reported herein were conducted during test period J4-1801-07 on September 1, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to evaluate J-2 engine S-IVB/S-V fuel pump high level stall characteristics, to investigate the effect of start tank energy on the oxidizer turbine spin speed, and to evaluate the performance of the experimental oxidizer pump primary seal drain tubes. These firings were accomplished at pressure altitudes ranging from 89,000 to 106,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start.

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. 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 since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized. Experimental oxidizer pump primary seal drain tubes were installed for this test period to evaluate a proposed modification to the S-II and S-IVB stage engines on vehicle AS-501.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5 through 9, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic lenght (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 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.

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 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total 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 turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy

gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. 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.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. 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 main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. 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.

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

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 Experimental Oxidizer Pump Primary Seal Drain Tubes

Experimental oxidizer pump primary seal drain tubes were attached to the thrust chamber for this test period, specifically to be evaluated during firing 07A. The drain tubes tested were the following (Fig. 9):

1. Drain discharge tube orificed for 100-scfm gaseous oxygen flow, tube 9,
2. Drain discharge tube orificed for 100-scim gaseous oxygen flow, tube 12,
3. Two drain discharge tubes provided with pressure transducers, tubes 10 and 11, and
4. Eight drain discharge tubes of various cap configurations and open at the other end, tubes 1 through 8.

Gaseous oxygen was supplied to tubes 9 and 12 from a facility source at a constant upstream pressure of 45 ± 5 psia. A copper cap was soldered to the discharge end of tubes 9 and 12 (Fig. 9c). The copper caps extended approximately 3 in. beyond the thrust chamber exit into the exhaust plume (Fig. 9a).

Drain discharge tubes 10 and 11 were provided with pressure transducers as shown in Fig. 9a. The exits of these tubes were sealed with stainless steel coin-type caps, silver soldered to the tube ends (Fig. 9c). Both caps extended approximately 3 in. beyond the thrust chamber exit into the exhaust plume (Fig. 9a). A rectangular section was cut out and soldered back into the side of tube 11 to form a blowout port, as shown in Fig. 9c.

There were four different configurations proposed for sealing the discharge end of the oxidizer pump primary seal drain tube. Tubes 1 through 8 were approximately 8 in. long and open at one end. The exits of these tubes were sealed and extended approximately 3 in. beyond the thrust chamber exit into the exhaust plume (Fig. 9b). Each of these tubes were sealed as follows:

Tube Number	Description
1	Stainless steel coin-type cap, soldered, with blowout port
2	Stainless steel coin-type cap, soldered, with blowout port
3	Copper cap, silver soldered
4	Copper cap, silver soldered
5	Stainless steel coin-type cap, soldered
6	Stainless steel coin-type cap, soldered
7	Copper cap, tinned before silver soldering
8	Copper cap, silver soldered

2.1.3 S-IVB Battleship Stage

The S-IVB battleship stage 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 the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. 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 for fuel tank pressurization during S-IVB flight was routed to the facility vent system.

2.2 TEST CELL

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 low 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. 4.

The battleship stage and the J-2 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.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber and the crossover duct. Cold helium was routed internally through the crossover duct and tubular-walled thrust chamber.

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 test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-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. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. 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, load cells, 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.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second 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-2 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 a normal start and shutdown is presented in Fig. 7.

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, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, 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 the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the thrust chamber and turbine crossover duct system was accomplished as required, using the facility-supplied engine component conditioning system. Table V presents the engine purge operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Four firings of the J-2 rocket engine (S/N J-2052) were conducted on September 1, 1967, in support of S-IVB/S-V test objectives. These firings were obtained at pressure altitudes ranging from 89,000 to 106,000 ft at engine start. The accumulated total firing duration of this test period was 66.5 sec.

Thermal conditioning of the thrust chamber and turbine crossover duct system was accomplished to simulate predicted thermal conditions for (1) an S-IVB/S-V first burn mission and (2) an S-IVB/S-V one orbit (80-min) restart mission. Flight AS-501 prevalve sequencing (auxiliary logic start sequence) for a J-2 engine first burn mission was utilized for firing 07A. The oxidizer pump primary seal drain simulation tubes, in support of the S-II and S-IVB stages of vehicle AS-501, were operated during firing 07A. Firing 07D was terminated at t_0 + 1.253 sec by the engine safety cutoff system because of a gas generator outlet temperature of 2425°F.

Conditioning targets for engine components and the measured test conditions at engine start are presented in Table VI. Start and shutdown times of selected engine valves are presented in Table VII. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8. Specific test objectives and a brief summary of results obtained from each firing are presented as follows:

Firing	Test Objectives	Results
07A	Evaluate the effect of warmest (-80°F) predicted thrust chamber on fuel pump high level stall characteristics for an S-IVB/S-V first burn mission; operate oxidizer pump primary seal drain simulation tubes.	A minimum fuel pump stall margin of 650 gpm was measured in the region above 17,500 rpm. Less than 5 psia was measured in tubes 10 and 11 during the firing after the caps burned off.

Firing	Test Objectives	Results
07B	Evaluate the effect of minimum start tank energy (-300°F, 1200 psia) on oxidizer turbine spin speed for an S-IVB one orbit (80-min) restart.	The maximum oxidizer turbine spin speed during start tank discharge was approximately 3800 rpm.
07C	Evaluate the effects of minimum start tank energy and cold crossover duct (-100°F) on fuel pump high level stall margin and thrust chamber pressure buildup time.	A minimum fuel pump stall margin of 650 gpm was measured in the region above 17,500 rpm. Buildup time to a chamber pressure of 550 psia was 2.630 sec.
07D	Evaluate the effects of maximum start tank energy (-300°F, 1300 psia) on the oxidizer turbine spin speed for an S-IVB one orbit (80-min) restart.	The maximum oxidizer turbine spin speed during start tank discharge was 4000 rpm. The firing was terminated at t_0 + 1.253 sec because of a gas generator outlet temperature of 2425°F.

The presentation of the test results in the following sections will consist of a discussion of each engine firing. The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-07A

The duration of firing 07A was for a programmed 30 sec. A 3-sec fuel lead preceded the firing. Flight AS-501 prevalve sequencing (auxiliary logic start sequence) for a J-2 engine first burn mission was utilized. Pre-fire thermal conditioning histories of the thrust chamber and crossover duct are shown in Fig. 10 and 11, respectively.

Start and shutdown transient data for selected primary engine parameters are shown in Fig. 12. Initial main oxidizer valve second-stage movement occurred at t_0 + 0.986 sec with thrust chamber ignition occurring 1.032 sec after t_0. Engine vibration (VSC) of 3 msec was recorded beginning 1.032 sec after t_0. The gas generator outlet temperature peak was 1470°F. Main chamber pressure reached 550 psia at t_0 + 2.020 sec.

Transient fuel pump head/flow data were documented and are compared with the stall inception line provided by the engine manufacturer in Fig. 13. A conservative fuel pump stall margin of 650 gpm was measured at approximately 19,000 rpm.

Engine ambient and combustion chamber pressure histories are shown in Fig. 14. The effect of the propellant utilization valve excursion on combustion chamber pressure was an increase from 680 to 780 psia at approximately t_0 + 12.5 sec. The engine ambient pressure was 0.195 (96,000 ft) at engine start.

Selected engine valve data during the start and shutdown transients are shown in Table VII. All valve operating times were normal.

Engine steady-state performance data are presented in Table VIII. The data presented were computed using the Rocketdyne PAST 640 modification zero performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV.

The oxidizer pump primary seal drain simulation tubes were operated during firing 07A and are discussed in Section 4.2.5.

4.2.2 Firing J4-1801-07B

A successful one orbit (80-min) restart simulation firing was accomplished for a programmed 5-sec duration. An 8-sec fuel lead preceded the firing. This firing was conducted 19 min after engine cutoff of firing 07A in order to provide turbine and crossover duct temperatures (Fig. 15), equivalent to predicted orbital engine restart temperatures 80-min after first burn cutoff. A summary of test requirements and results is presented in Table VI.

Start and shutdown transient data for selected primary engine parameters are shown in Fig. 16. Thrust chamber ignition occurred at t_0 + 0.947 sec with the initial main oxidizer valve second-stage movement at t_0 + 1.080 sec. No engine vibration (VSC) was recorded. The initial gas generator outlet temperature peak was 2120°F with a second peak of 2155°F. Pre-fire temperature history of the thrust chamber is shown in Fig. 17. The maximum spin speed of the oxidizer pump during start tank discharge was 3800 rpm.

Selected engine valve data during the start and shutdown transients are shown in Table VII. All valve operating times were normal.

Engine ambient and combustion chamber pressure histories are shown in Fig. 18. Ambient pressure at engine start was 0.263 psia (89,000 ft).

4.2.3 Firing J4-1801-07C

Firing 07C was successfully accomplished for a programmed 30-sec duration. An 8-sec fuel lead preceded the firing. Start requirements resulted in a restart mission with minimum starting energy. A summary of engine start requirements and test results is presented in Table VI. Pre-fire temperature histories of the thrust chamber and the turbine crossover duct system are shown in Figs. 19 and 20, respectively.

Engine start and shutdown transient data of selected primary engine parameters are shown in Fig. 21. The initial movement of the main oxidizer valve second stage occurred at t_0 + 1.015 sec with thrust chamber ignition occurring at t_0 + 1.070 sec. Engine vibration (VSC) of 24 msec was recorded beginning at t_0 + 1.070 sec. The gas generator outlet temperature peaked to 1565°F.

Transient fuel pump head/flow data were documented and are compared with the stall inception line provided by the engine manufacturer in Fig. 22. A conservative fuel pump stall margin of 650 gpm was measured at approximately 19,000 rpm.

Selected engine valve data during the start and shutdown transients are shown in Table VII. All valve operating times were normal.

Engine ambient and combustion chamber pressure histories are shown in Fig. 23. The chamber pressure increase from 600 to 775 psia reflects the propellant utilization valve excursion at t_0 + 10 sec. The ambient pressure at engine start was 0.122 psia (106,000 ft).

Engine steady-state performance data are presented in Table VIII and indicate that engine operation was nominal. The data presented were computed using the Rocketdyne PAST 640 modification zero performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV.

4.2.4 Firing J4-1801-07D

Firing 07D was a programmed 5-sec duration, one orbit (80-min) restart simulation. An 8-sec fuel lead preceded the firing. This firing was conducted 19 min after engine cutoff of firing 07C in order to provide turbine and crossover duct temperatures (Fig. 24) equivalent to predicted orbital engine restart temperatures 80 min after first burn cutoff. A summary of engine start requirements and results is presented in Table VI.

Start and shutdown transient data for selected primary engine parameters are shown in Fig. 25. Thrust chamber ignition occurred at t_0 + 0.919 sec with initial main oxidizer valve second-stage movement at t_0 + 1.140 sec. No engine vibration (VSC) was recorded. Pre-fire temperature history of the thrust chamber is shown in Fig. 26. The maximum spin speed of the oxidizer pump during start tank discharge was 4000 rpm. Comparison of firing 07D with firing 07B shows that a 100-psia increase in start tank pressure yielded a 200-rpm increase in the maximum oxidizer pump spin speed during start tank discharge.

A premature engine cutoff occurred at t_0 + 1.253 sec because of a high gas generator outlet temperature of 2425°F. This temperature resulted from the high oxidizer pump spin speed during start tank discharge.

Engine ambient and combustion chamber pressure histories are shown in Fig. 27. The ambient pressure at engine start was 0.122 psia (106,000 ft).

4.2.5 Experimental Oxidizer Pump Primary Seal Drain Tubes

The S-II and S-IVB stage engines of vehicle AS-501 will experience static pump inlet pressure increases because of vehicle acceleration during the boost phase of flight. An excessive oxidizer pump primary seal leakage of gaseous oxygen is predicted as a result of this increased static pressure. The present drain configuration will allow this leakage to be exhausted into the vehicle interstage compartments, presenting a potential explosion hazard. A proposed modification to the seal drain, to eliminate leakage during the boost phase, involved extending the drain into the engine exhaust jet and sealing the discharge end. Normal draining of the oxidizer pump primary seal should occur after the engine exhaust gases burned off the sealing cap.

Two of the experimental drain tubes, tubes 9 and 12, were supplied with gaseous oxygen from a facility source to simulate maximum (100-scfm) and minimum (100-scim) predicted leakage flow rates. The purposes of these tubes were to verify that end cap ejection and burn characteristics were satisfactory under the influence of the gaseous oxygen flows.

Pressure measurement data from firing 07A indicated that the cap on tube 9 burned off at approximately t_0 + 6 sec; the cap on tube 12 burned off approximately 1.5 sec later. The pressures measured in the discharge end of tubes 9 and 12 decayed to about 5 and 1 psia, respectively, after the caps burned off. Close-range motion-picture data from firing 07A revealed that the caps separated cleanly from the tubes and were propelled almost vertically downward by the engine exhaust. No further burning of the tubes with the gaseous oxygen resulted after the caps were ejected.

Two experimental drain tubes, tubes 10 and 11, were instrumented to measure pressure recovery after the caps burned off. The purpose of these tubes was to determine the dynamic pressure recovery of the engine exhaust gases in the seal drain tube after the cap burned off. A significant pressure recovery in the drain tube could force hydrogen-rich exhaust gases into the oxidizer pump. Pressure measurement data from firing 07A indicated that the caps on tubes 10 and 11 burned off at approximately t_0 + 3 sec. The pressure in tubes 10 and 11 decayed below 1 psia immediately after the caps burned off. The pressure in tube 11, which was provided with a blowout port, remained less than 1 psia for the duration of firing 07A. However, the pressure in tube 10 increased very gradually throughout firing 07A and at engine cutoff was approximately 5 psia.

The eight additional experimental drain tubes were attached to the thrust chamber to determine the burnoff characteristics of four different methods of sealing the modified drain tubes. The post-test examination revealed that the tubes with stainless steel, coin-type caps were eroded significantly, whereas the copper-capped tubes showed no apparent erosion.

4.3 POST-TEST INSPECTION

Post-test inspection of the J-2 engine revealed that the gas generator outlet temperature probe had been eroded and required replacing. This is the first inspection of this probe since test J4-1801-04. Further inspection revealed that the first-stage fuel turbine blades were eroded slightly but not sufficiently to require replacement of the turbopump assembly.

Post-test photographs of the experimental oxidizer pump primary seal drain tubes (Fig. 28) were taken after four firings had been completed. The photographs show that the stainless steel tubes were eroded significantly. The copper-capped discharge tubes showed no signs of erosion.

SECTION V
SUMMARY OF RESULTS

The results of these four firings of the J-2 engine conducted on September 1, 1967, in Test Cell J-4 are summarized as follows:

1. A first burn mission (firing 07A) with a -80°F thrust chamber yielded a conservative fuel pump stall margin of 650 gpm at approximately 19,000 rpm.

2. Minimum start tank energy (-140°F, 1250-psia) on a first orbit (80-min) restart mission (firing 07C) resulted in a conservative fuel pump stall margin of 650 gpm at about 19,000 rpm.

3. First orbit (80-min) restart (firing 07B) crossover duct temperature (169°F) and minimum start tank energy (-300°F, 1200-psia) produced a maximum oxidizer pump spin speed of 3800 rpm during start tank discharge.

4. An increase in start tank pressure of 100 psia (from 1200 psia and -300°F to 1300 psia and -300°F) resulted in a 200-rpm increase in the oxidizer pump spin speed during start tank discharge on comparable one orbit (80-min) engine restart firings.

5 Firing 07D was prematurely cut off at t_0 + 1.253 sec because of a high gas generator outlet temperature of 2425°F. This temperature resulted from the high oxidizer pump spin speed (4000-rpm) during start tank discharge.

6. Discharge pressures of less than 1 psia were measured for the firing duration in the copper-capped oxidizer pump primary seal drain tubes, tubes 9 and 12, after the caps burned off.

7. A pressure of less than 1 psia was measured for the firing duration in the stainless steel, coin-type, capped tube with a blowout port (tube 11), after the cap burned off. The pressure in tube 10, without a blowout port, increased from less than 1 psia to a level of 5 psia at engine cutoff, after the cap burned off.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Vetter, N. R. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-06)." AEDC-TR-67-215, January 1968.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

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Fig. 1 Test Cell J-4 Complex

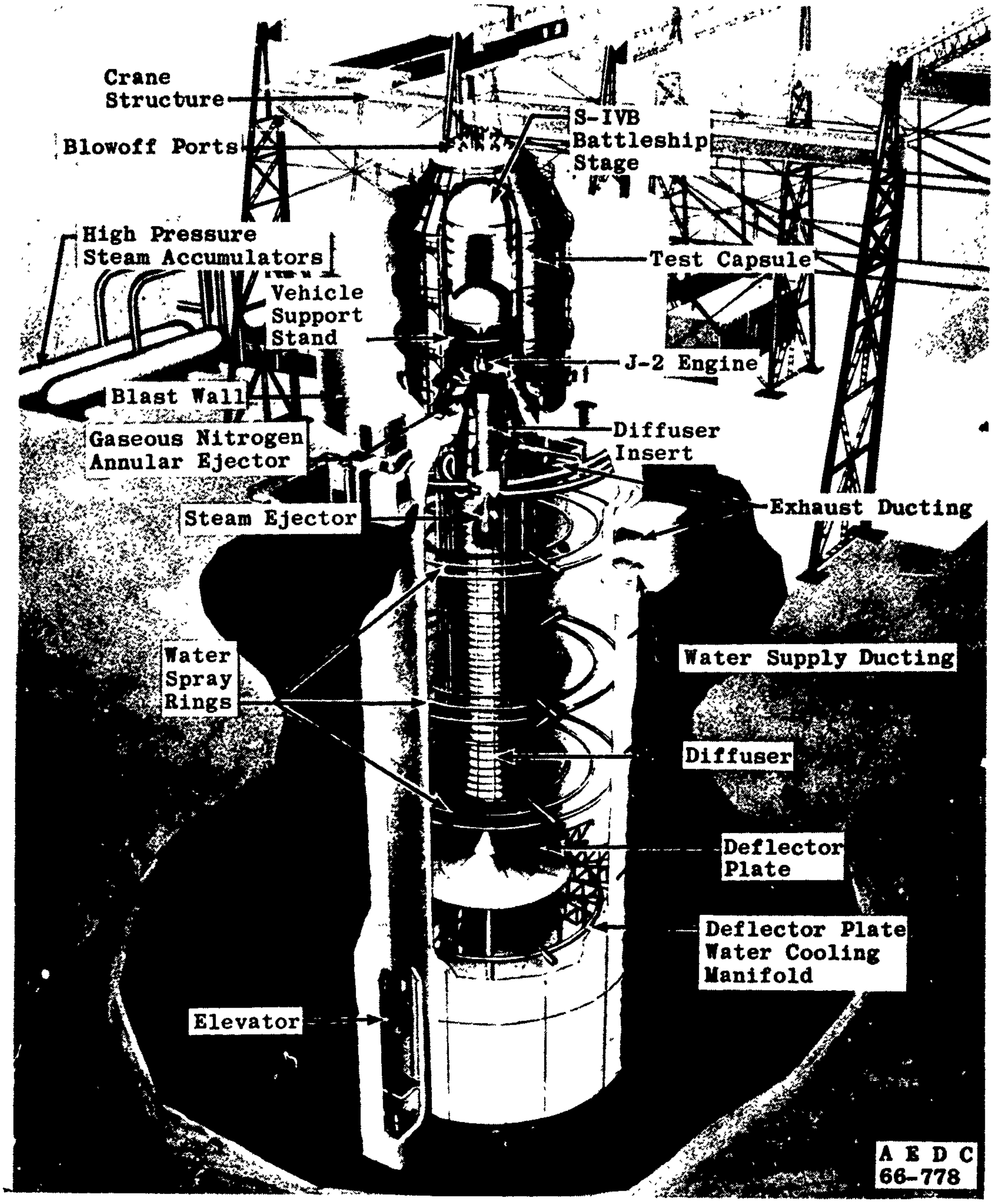


Fig. 2 Test Cell J-4, Artist's Conception

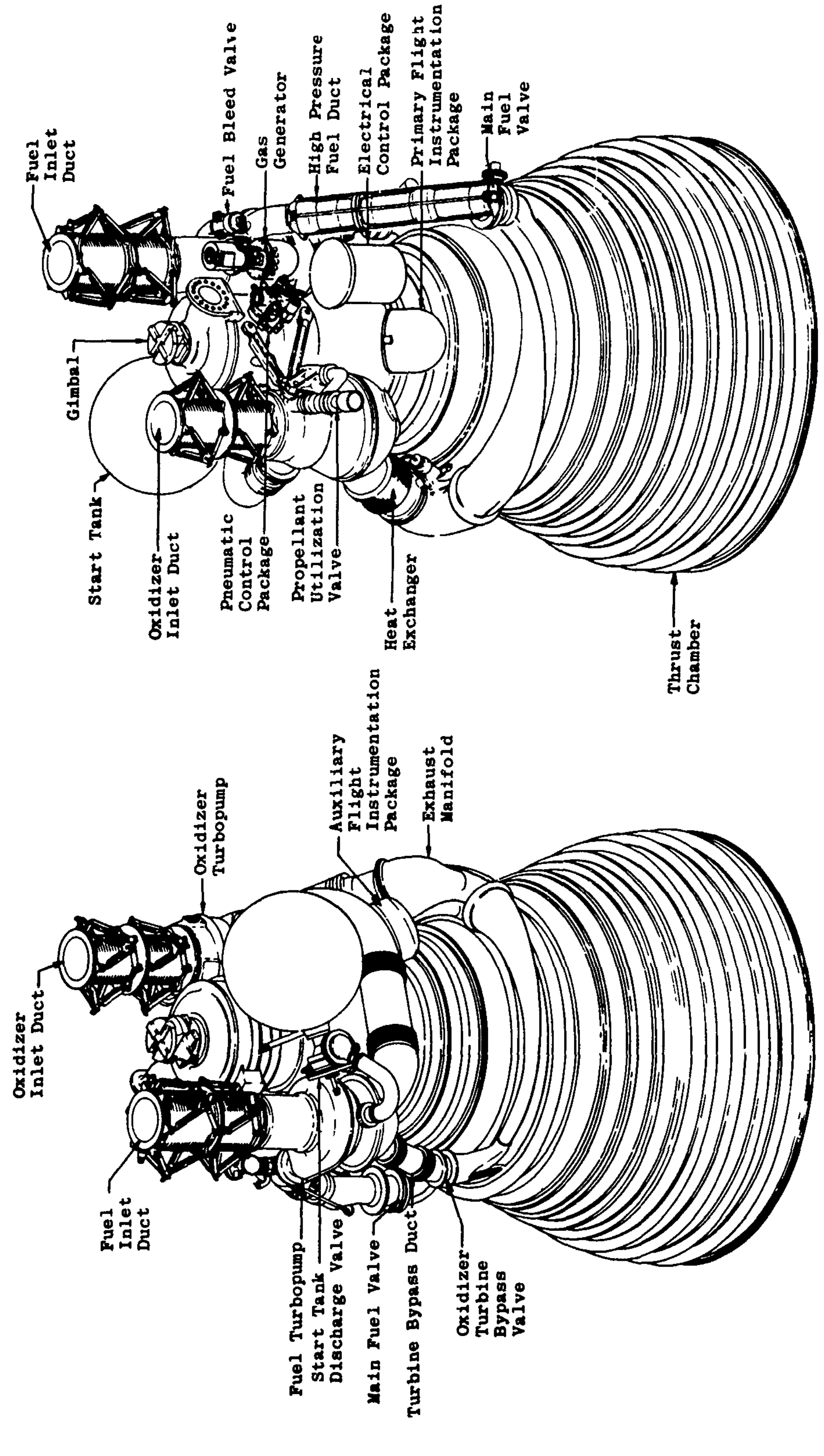


Fig. 3 Engine Details

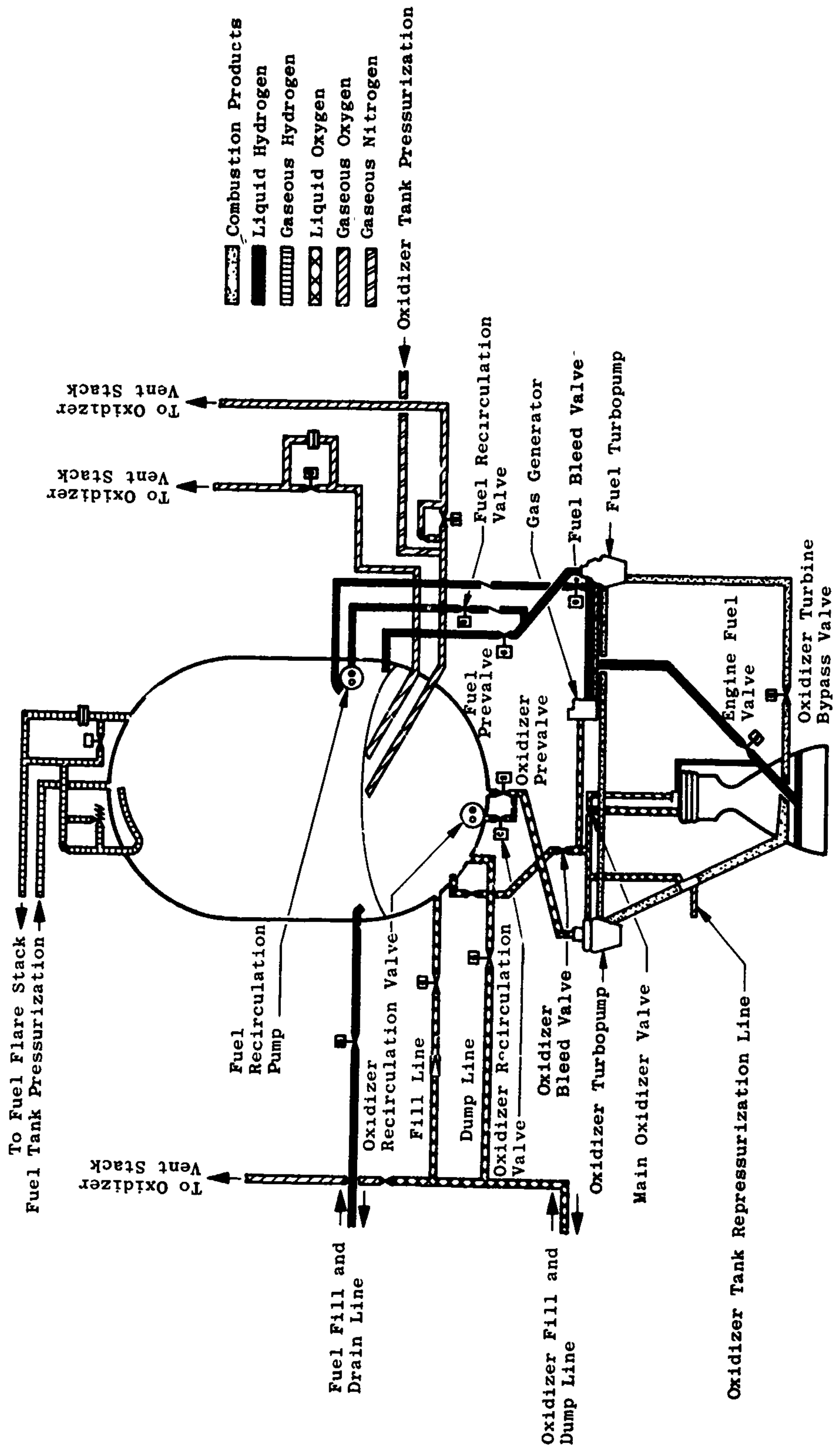
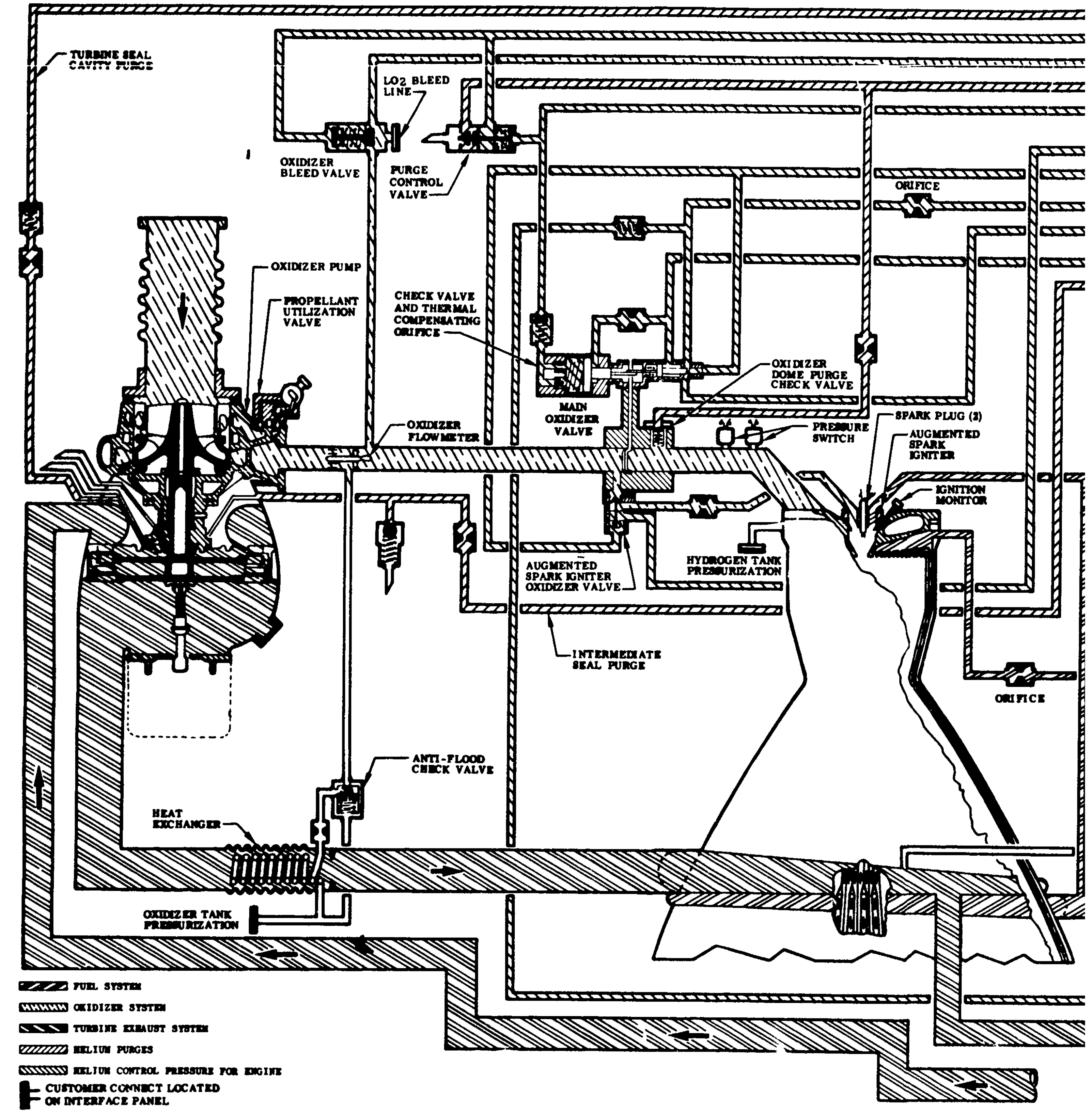


Fig. 4 S-IVB Battleship Stage/J-2 Rocket Engine Schematic


TURBINE SEAL CAVITY PURGE
LO2 BLEED LINE
OXIDIZER BLEED VALVE
PURGE CONTROL VALVE
ORIFICE
OXIDIZER PUMP
PROPELLANT UTILIZATION VALVE
CHECK VALVE AND THERMAL COMPENSATING ORIFICE
OXIDIZER DOME PURGE CHECK VALVE
MAIN OXIDIZER VALVE
OXIDIZER FLOWMETER
PRESSURE SWITCH
SPARK PLUG (2)
AUGMENTED SPARK IGNITER
IGNITION MONITOR
AUGMENTED SPARK IGNITER OXIDIZER VALVE
HYDROGEN TANK PRESSURIZATION
INTERMEDIATE SEAL PURGE
ORIFICE
ANTI-FLOOD CHECK VALVE
HEAT EXCHANGER
OXIDIZER TANK PRESSURIZATION
FUEL SYSTEM
OXIDIZER SYSTEM
TURBINE EXHAUST SYSTEM
HELIUM PURGES
HELIUM CONTROL PRESSURE FOR ENGINE
CUSTOMER CONNECT LOCATED ON INTERFACE PANEL

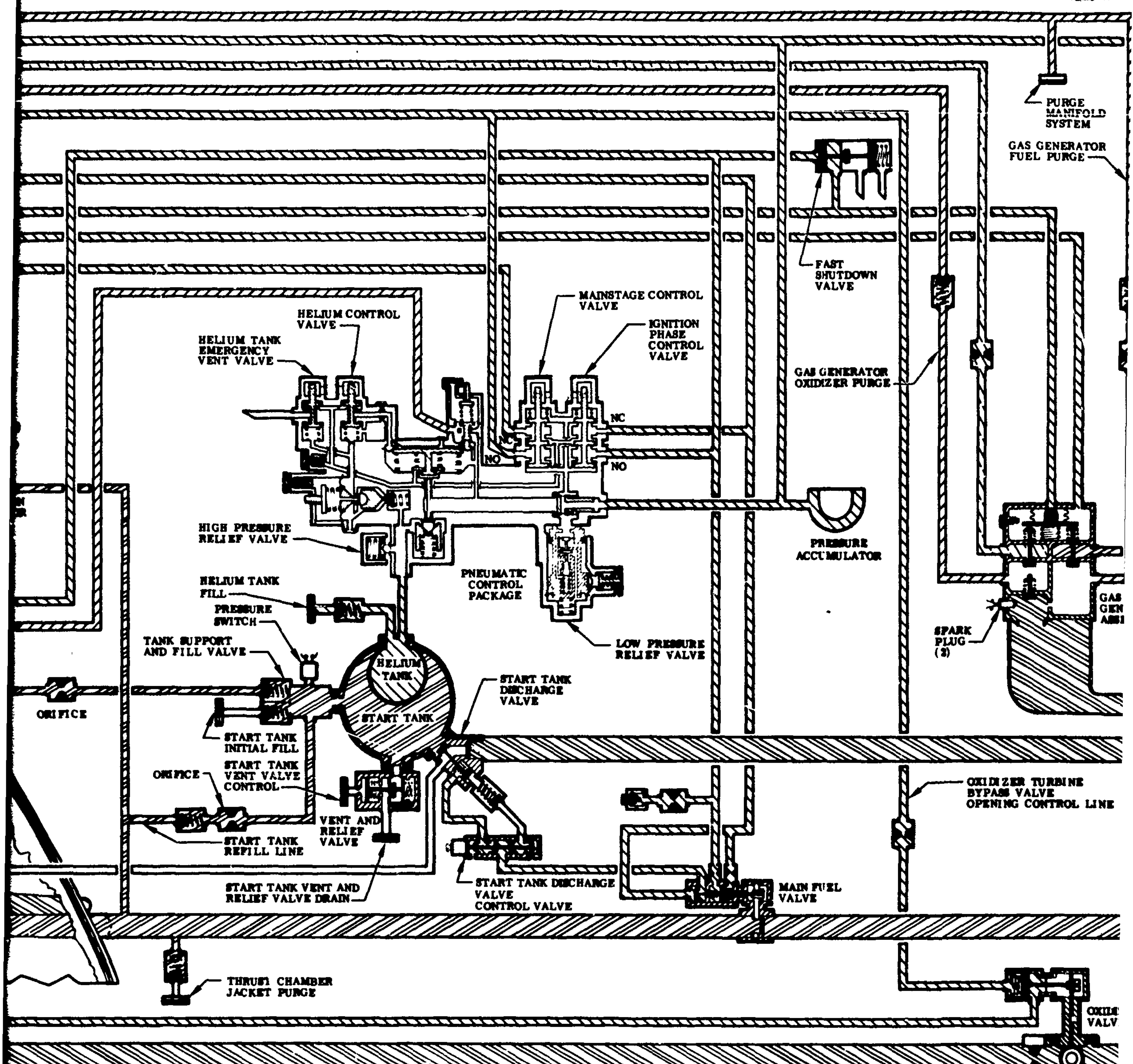
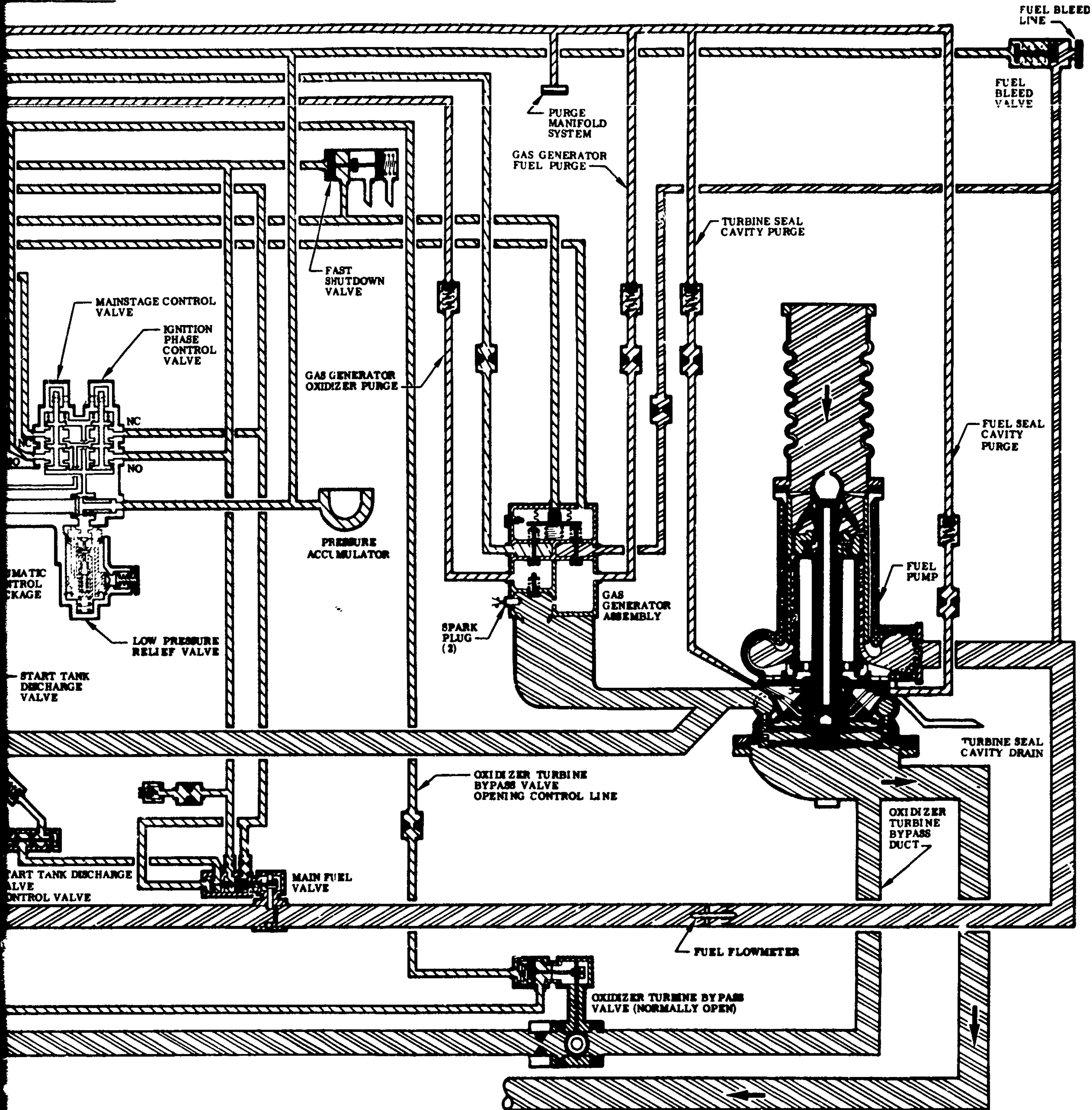
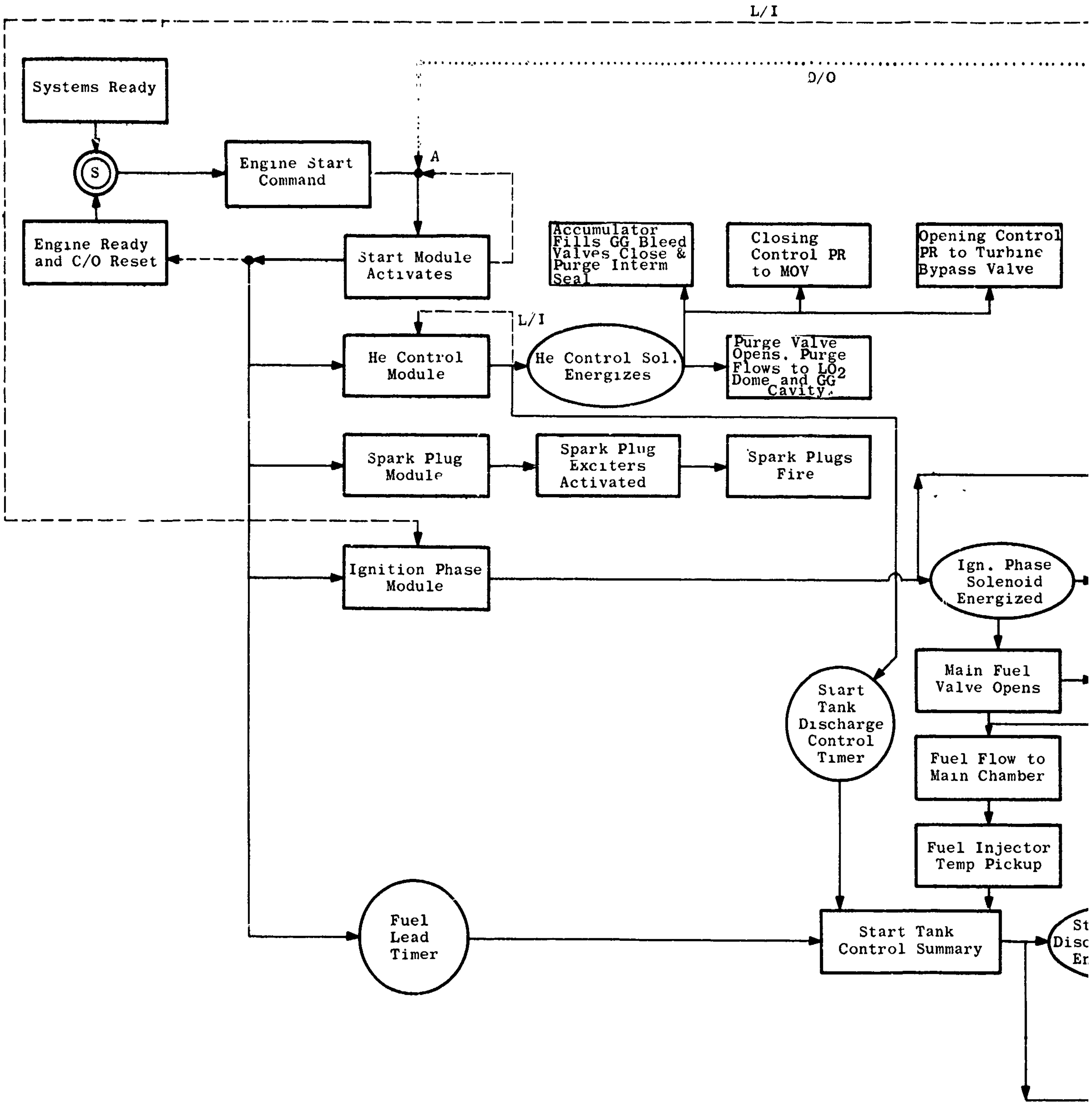


Fig. 5 Engine Schematic


FUEL BLEED LINE
FUEL BLEED VALVE
PURGE MANIFOLD SYSTEM
GAS GENERATOR FUEL PURGE
TURBINE SEAL CAVITY PURGE
FAST SHUTDOWN VALVE
MAINSTAGE CONTROL VALVE
IGNITION PHASE CONTROL VALVE
NC
NO
GAS GENERATOR OXIDIZER PURGE
FUEL SEAL CAVITY PURGE
PRESSURE ACCUMULATOR
FUEL PUMP
GAS GENERATOR ASSEMBLY
SPARK PLUG (2)
LOW PRESSURE RELIEF VALVE
START TANK DISCHARGE VALVE
TURBINE SEAL CAVITY DRAIN
OXIDIZER TURBINE BYPASS VALVE OPENING CONTROL LINE
OXIDIZER TURBINE BYPASS DUCT
MAIN FUEL VALVE
FUEL FLOWMETER
OXIDIZER TURBINE BYPASS VALVE (NORMALLY OPEN)

1


L/I
D/O
Systems Ready
S
Engine Start Command
A
Engine Ready and C/O Reset
Start Module Activates
Accumulator Fills GG Bleed Valves Close & Purge Interm Seal
Closing Control PR to MOV
Opening Control PR to Turbine Bypass Valve
L/I
He Control Module
He Control Sol. Energizes
Purge Valve Opens. Purge Flows to LO_2 Dome and GG Cavity.
Spark Plug Module
Spark Plug Exciters Activated
Spark Plugs Fire
Ignition Phase Module
Ign. Phase Solenoid Energized
Main Fuel Valve Opens
Start Tank Discharge Control Timer
Fuel Flow to Main Chamber
Fuel Injector Temp Pickup
Fuel Lead Timer
Start Tank Control Summary

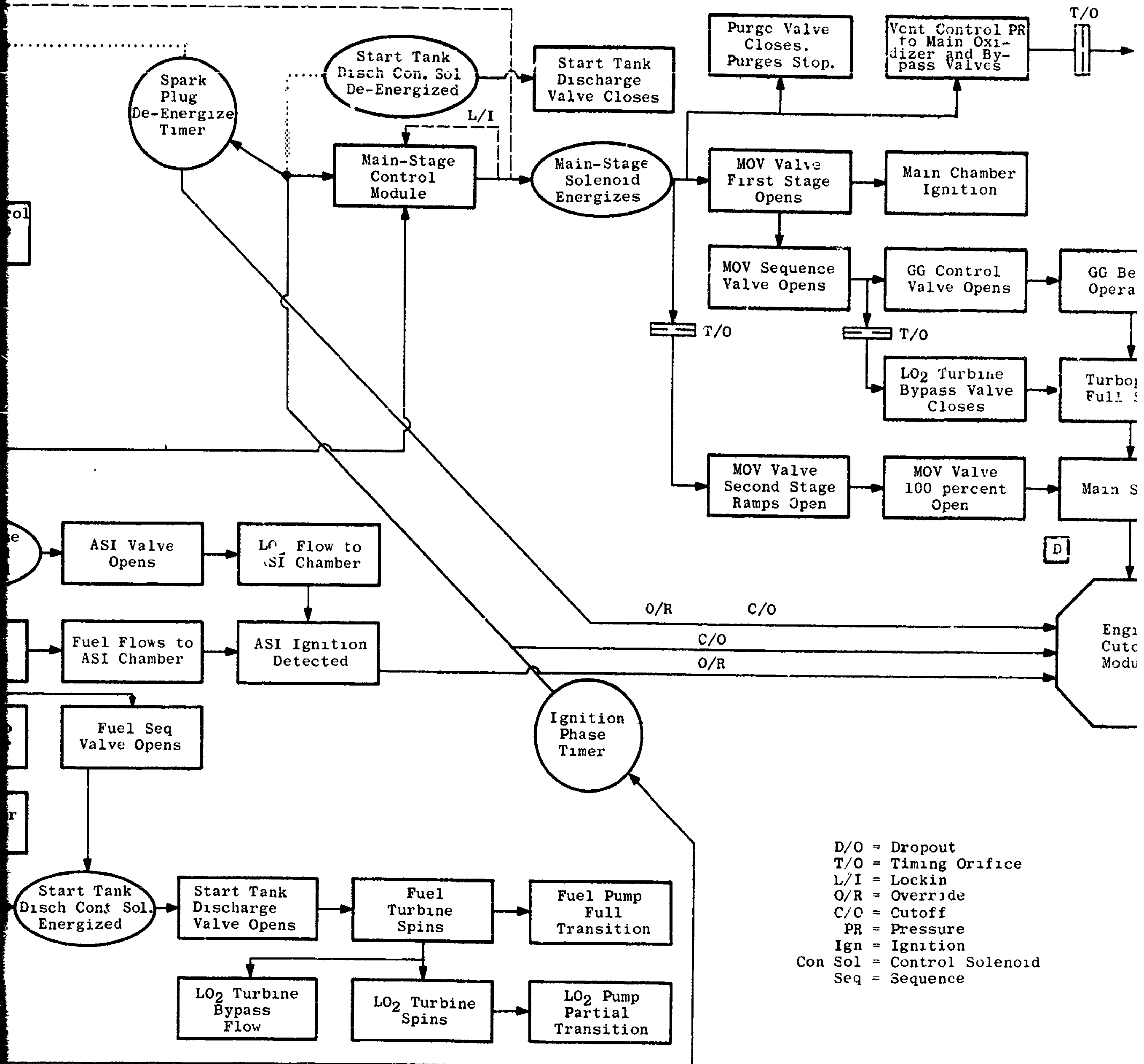
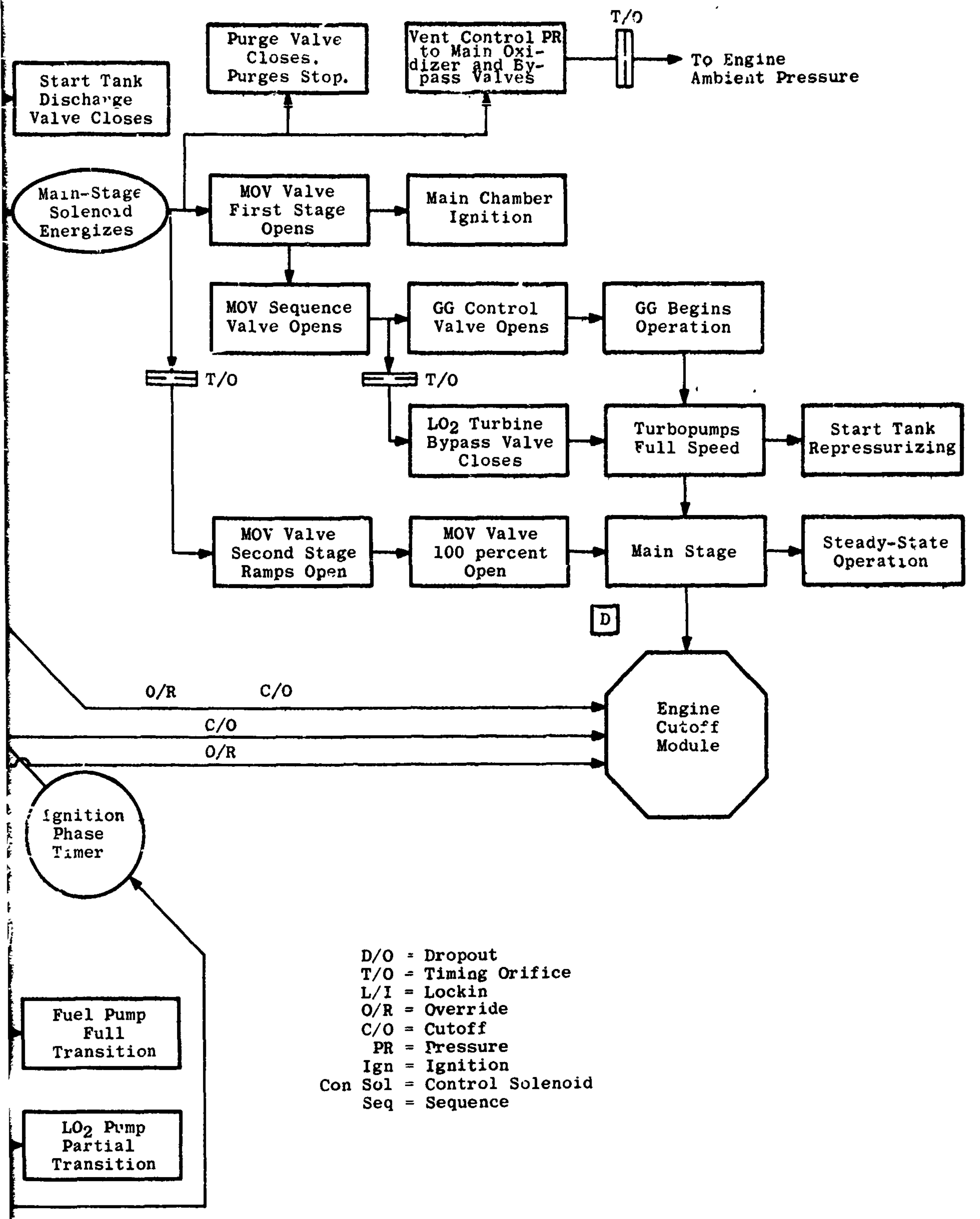
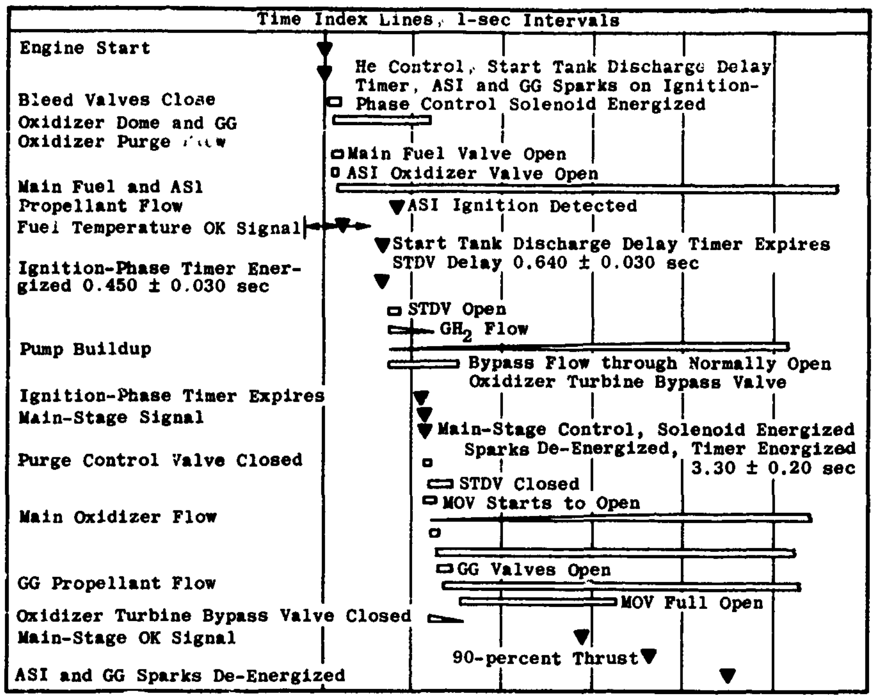


Fig. 6 Engine Start Logic Schematic

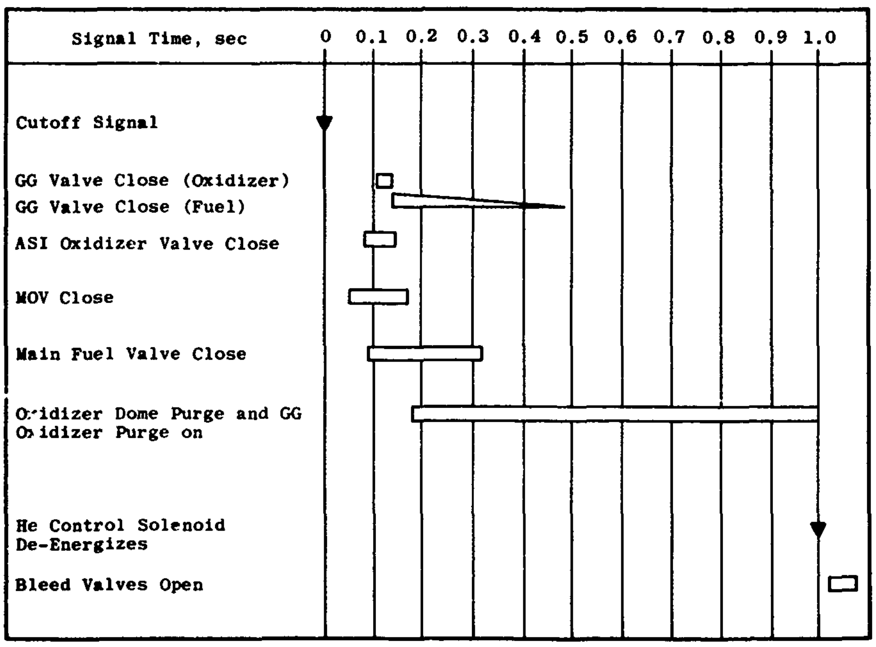
3



D/O = Dropout
T/O = Timing Orifice
L/I = Lockin
O/R = Override
C/O = Cutoff
PR = Pressure
Ign = Ignition
Con Sol = Control Solenoid
Seq = Sequence

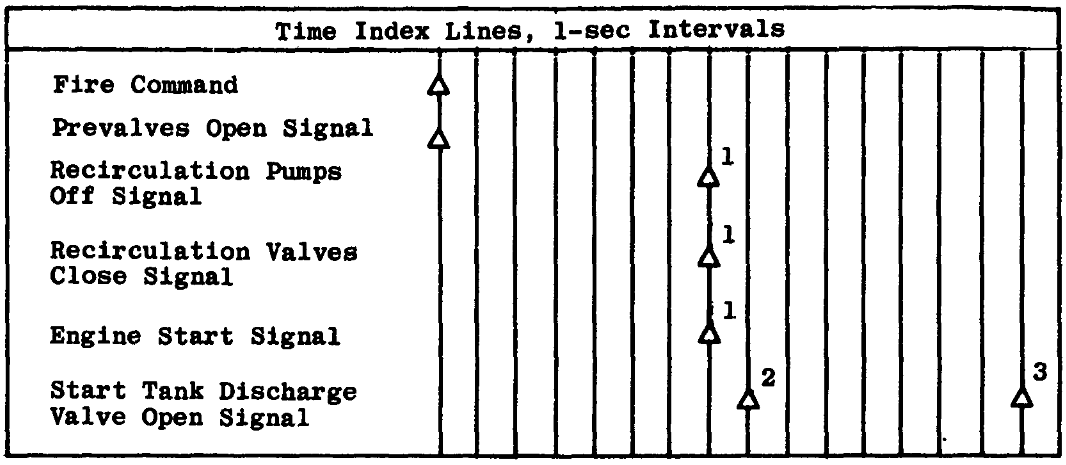


a. Start Sequence



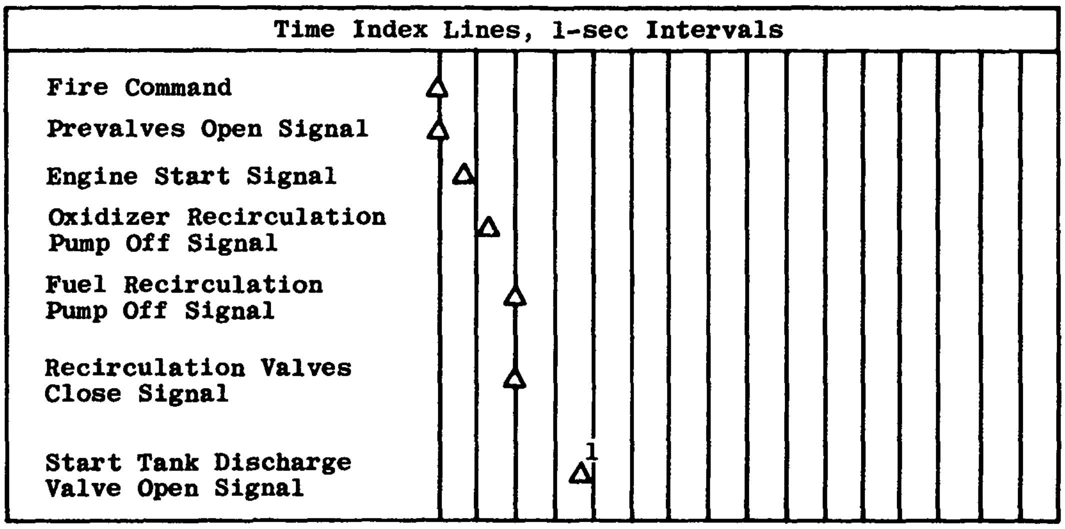
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

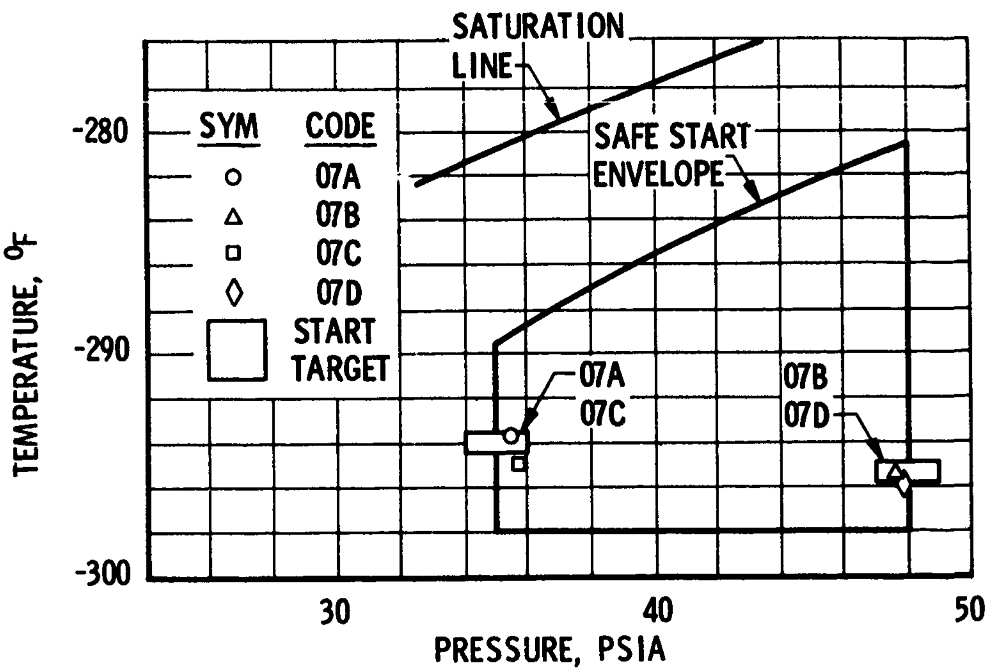
c. "Normal" Start Sequence



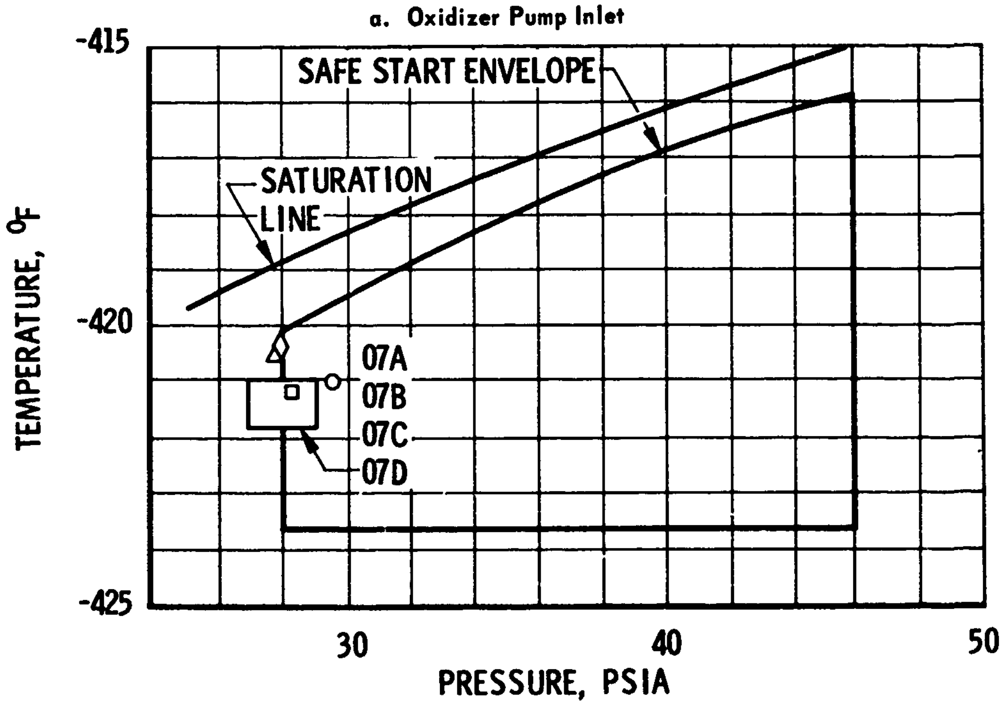
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

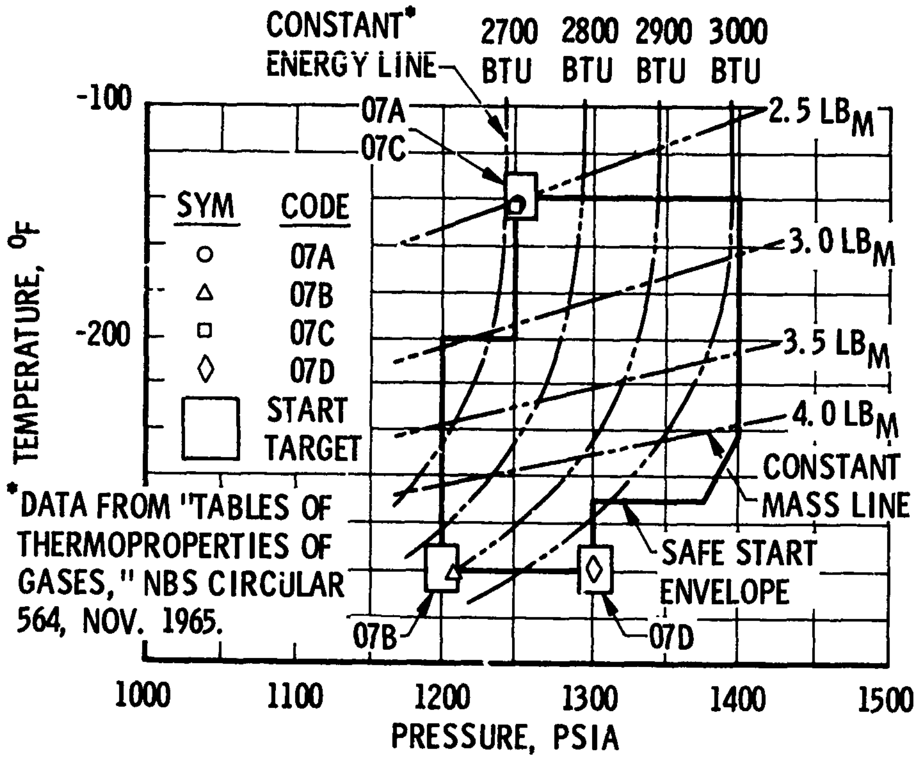


a. Oxidizer Pump Inlet

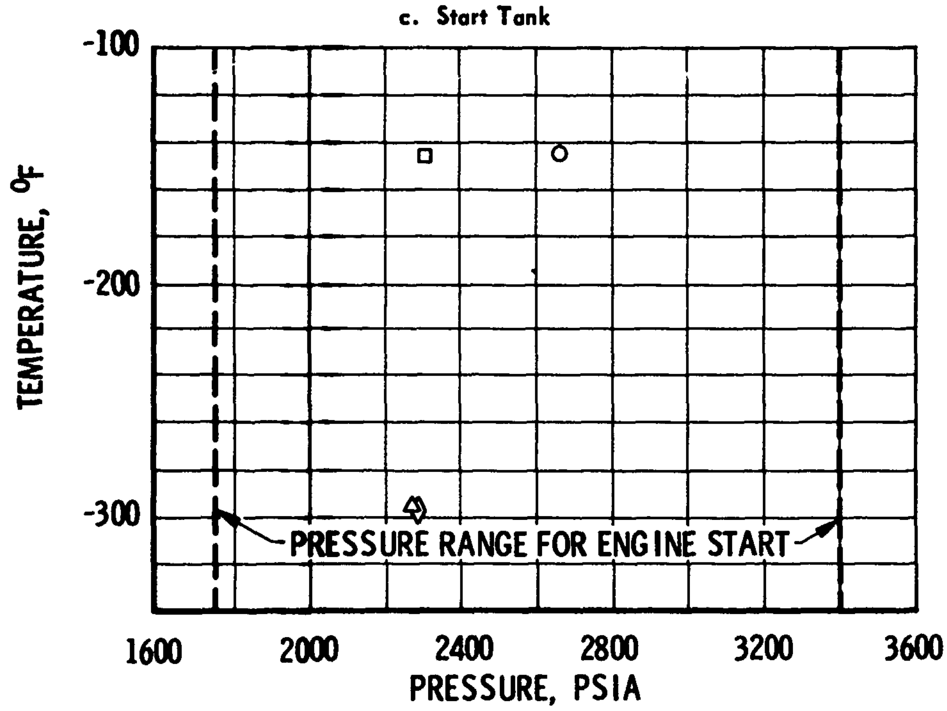


b. Fuel Pump Inlet

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

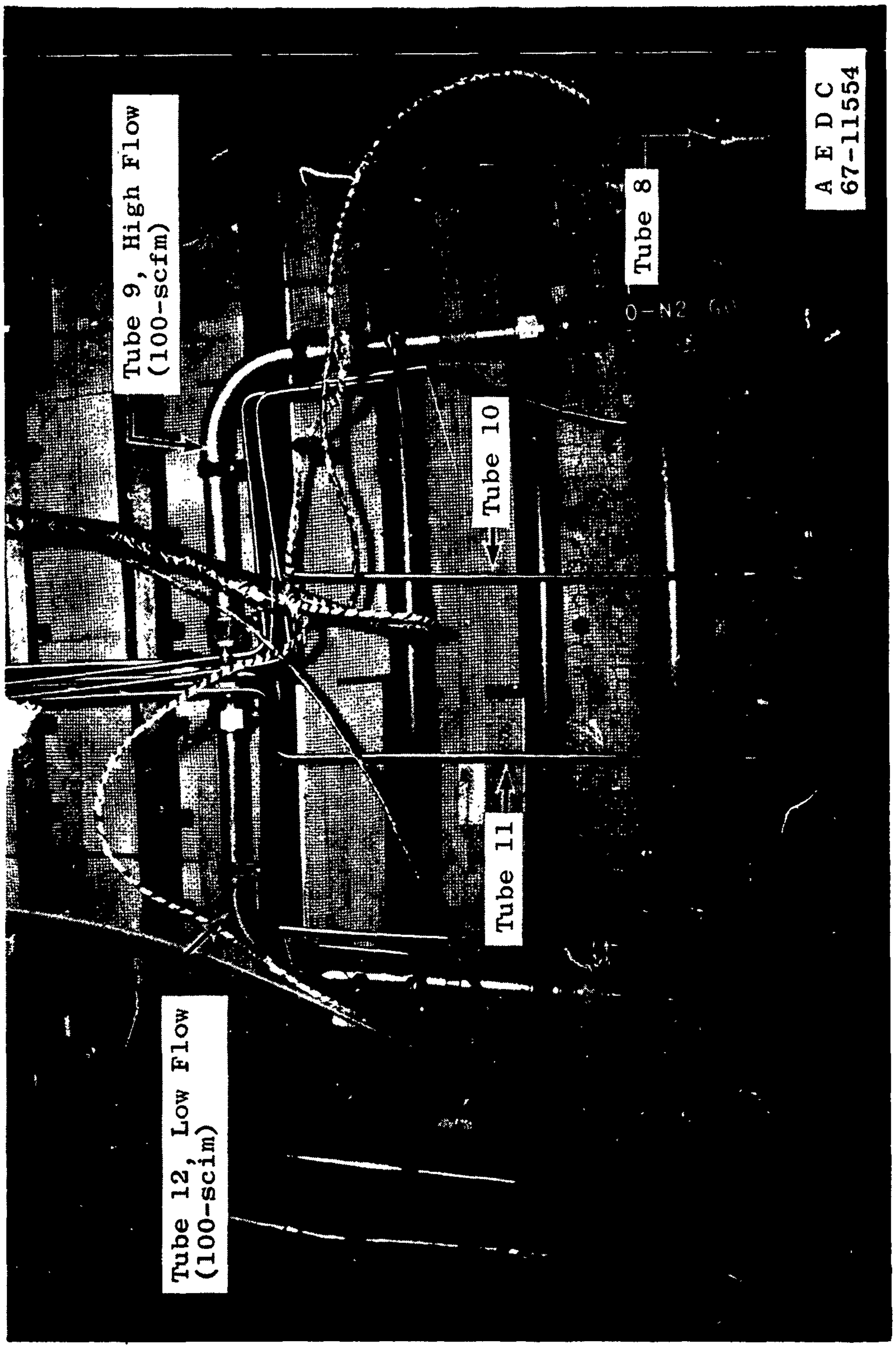


c. Start Tank



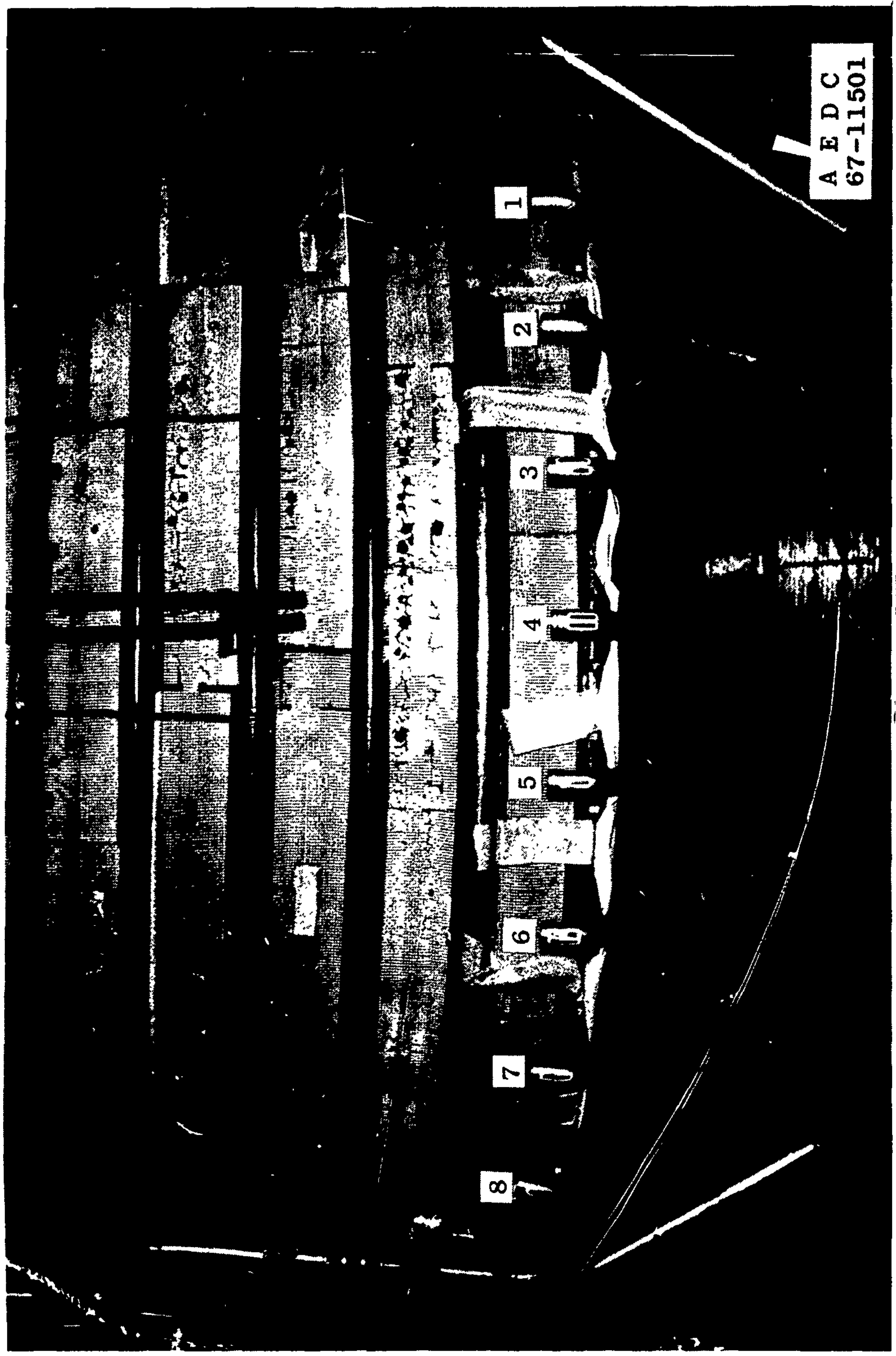
d. Helium Tank

Fig. 8 Concluded



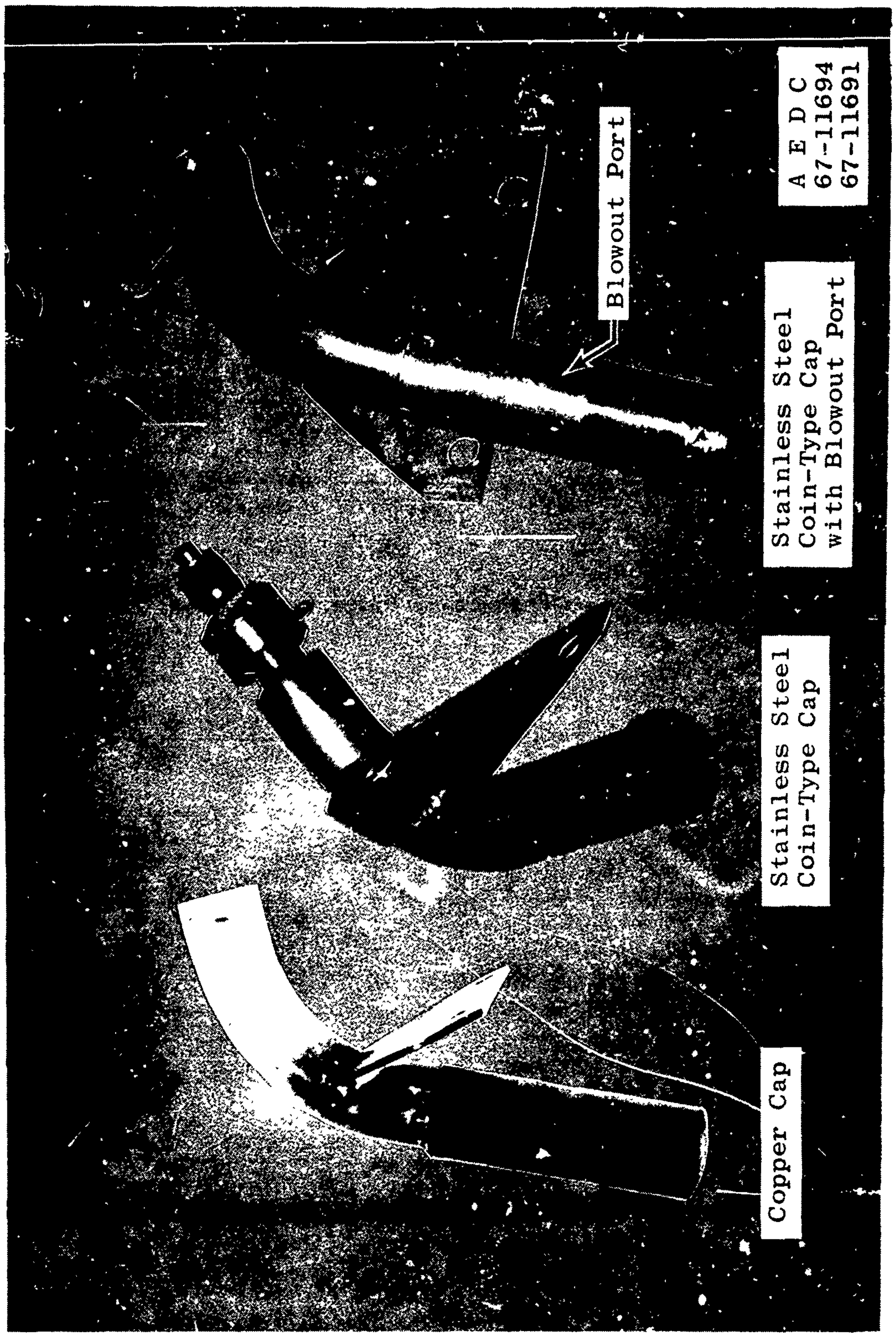
a. Drain Simulation Tubes, 8 through 12

Fig. 9 Experimental Oxidizer Pump Primary Seal Drain Tubes



b. Drain Simulation Tubes, 1 through 8

Fig. 9 Continued



c. Cap Configurations

Fig. 9 Concluded

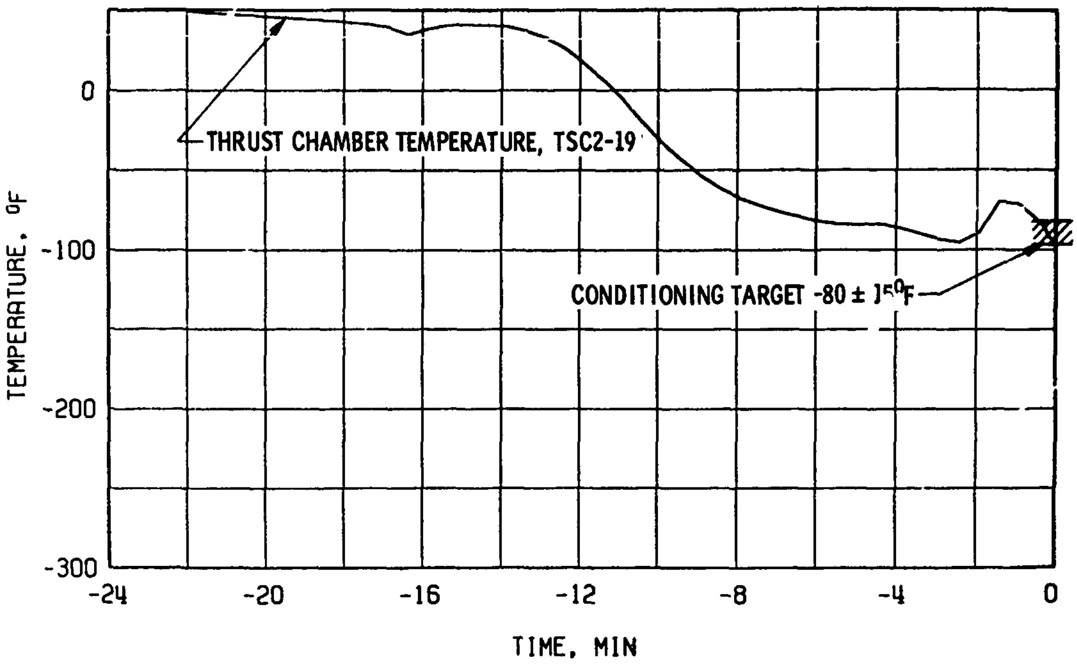


Fig. 10 Thrust Chamber Temperature History, Pre-Firing 07A

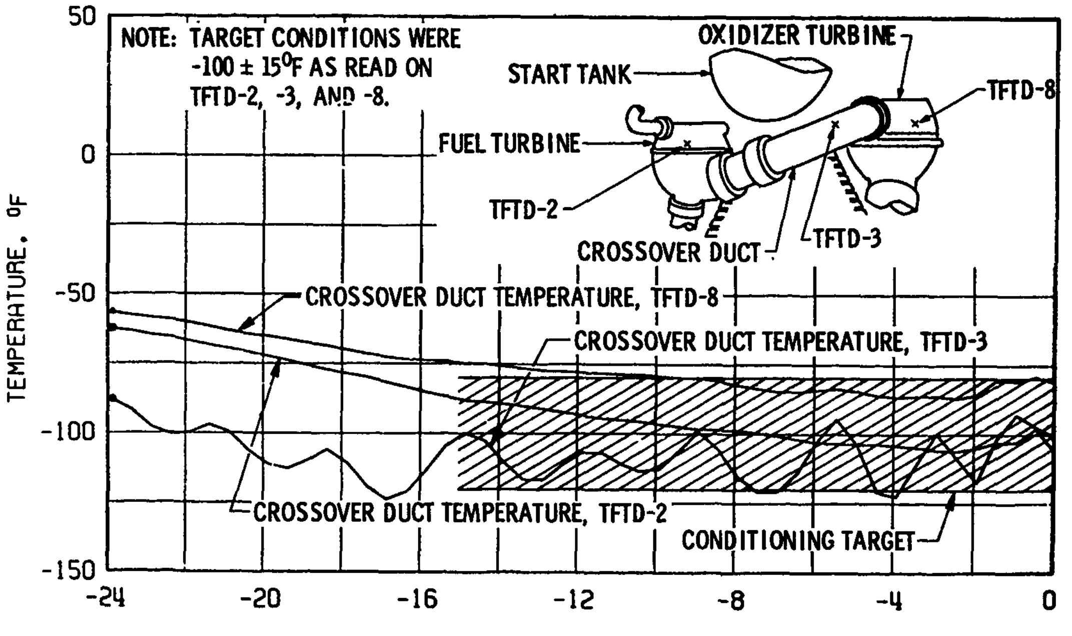
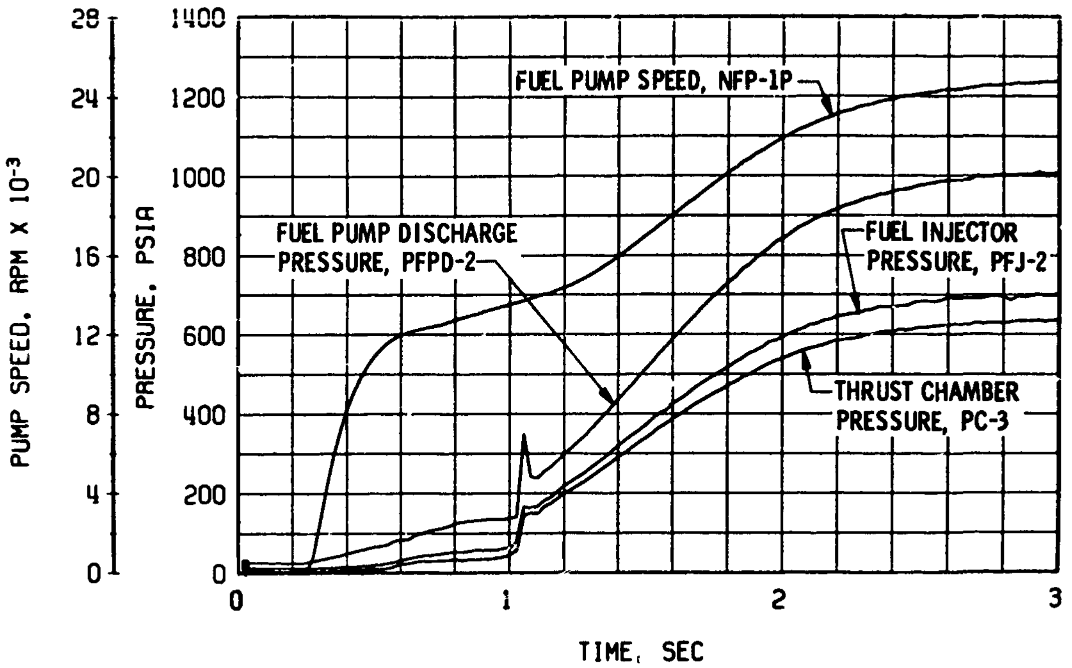
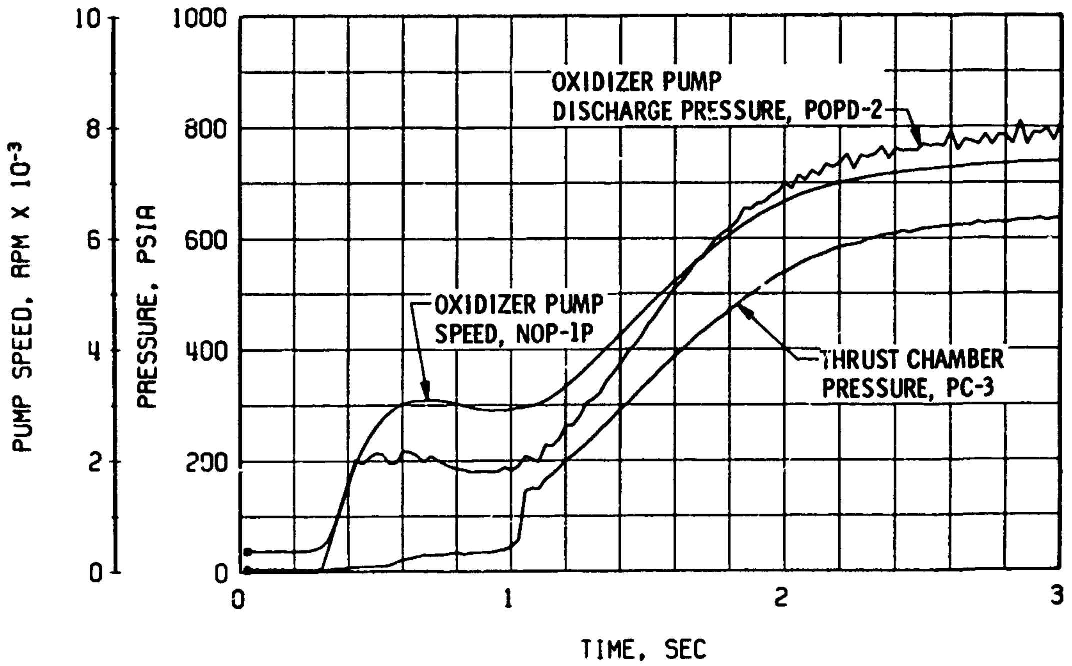


Fig. 11 Crossover Duct Temperature History, Pre-Firing 07A

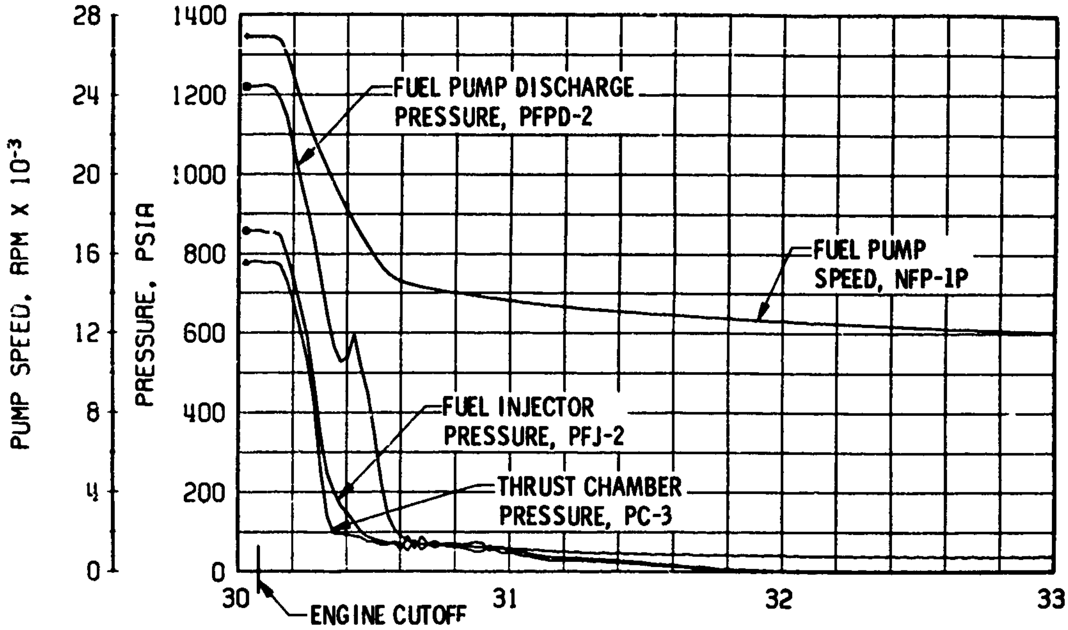


a. Thrust Chamber Fuel System, Start

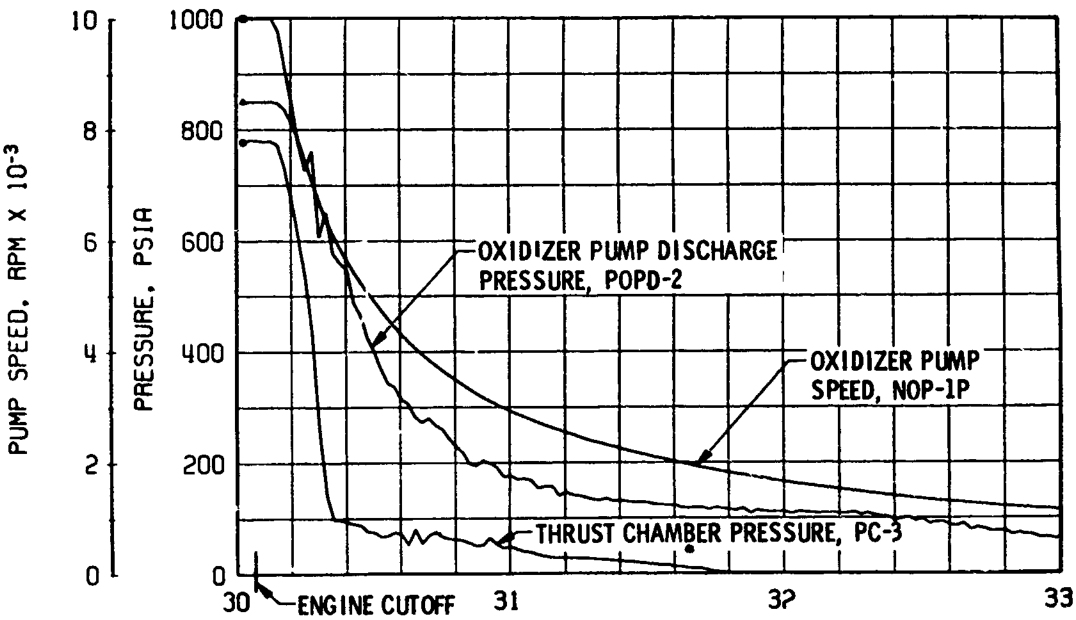


b. Thrust Chamber Oxidizer System, Start

Fig. 12 Engine Transient Operation, Firing 07A

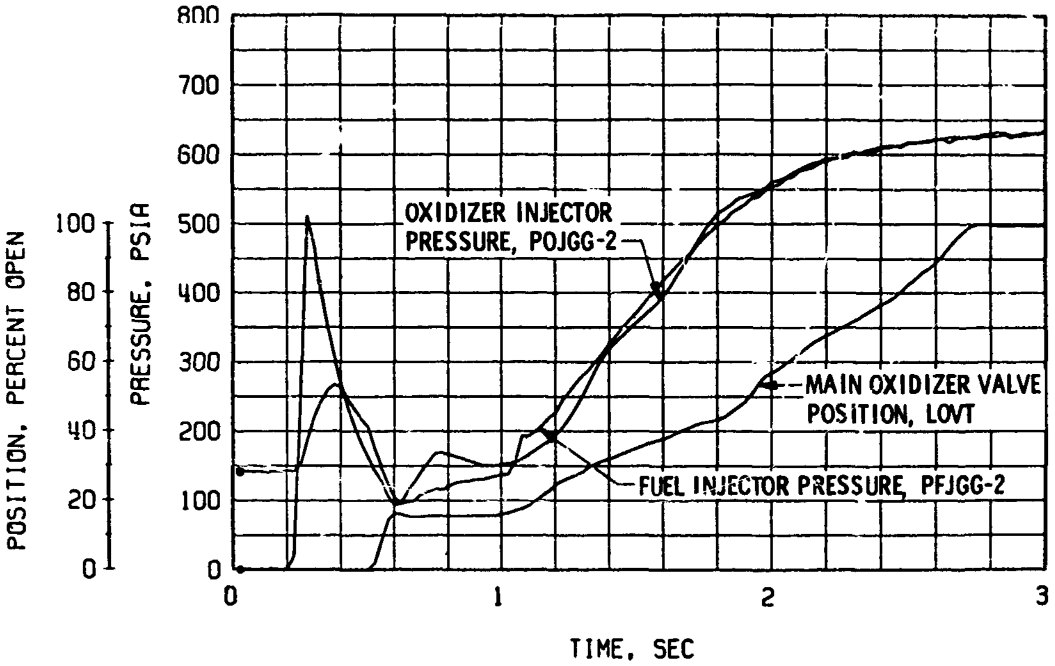


c. Thrust Chamber Fuel System, Cutoff

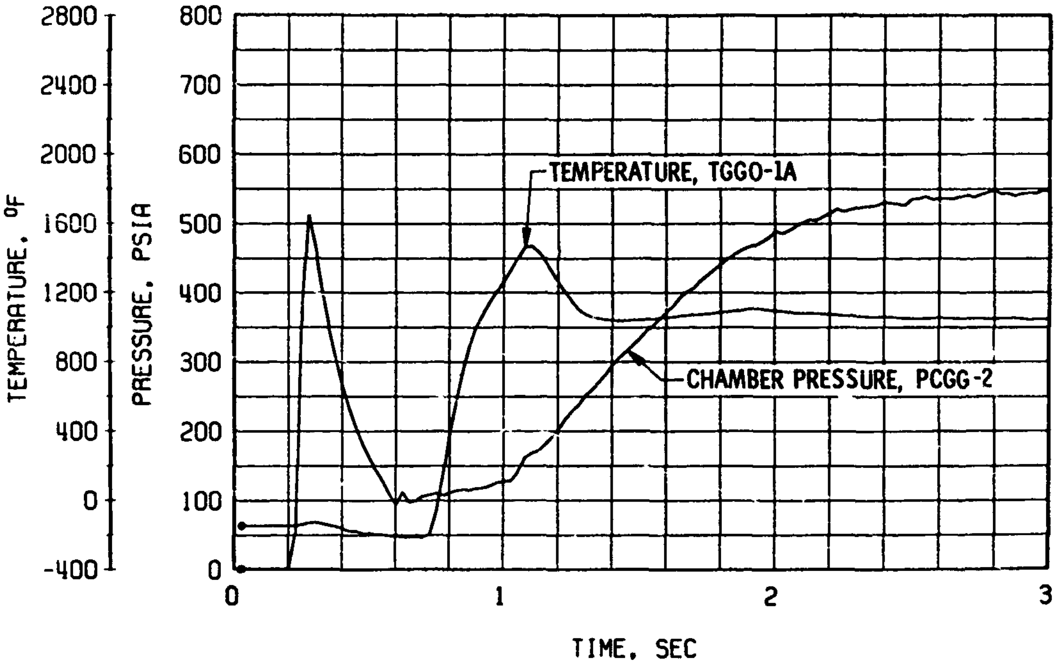


d. Thrust Chamber Oxidizer System, Cutoff

Fig. 12 Continued

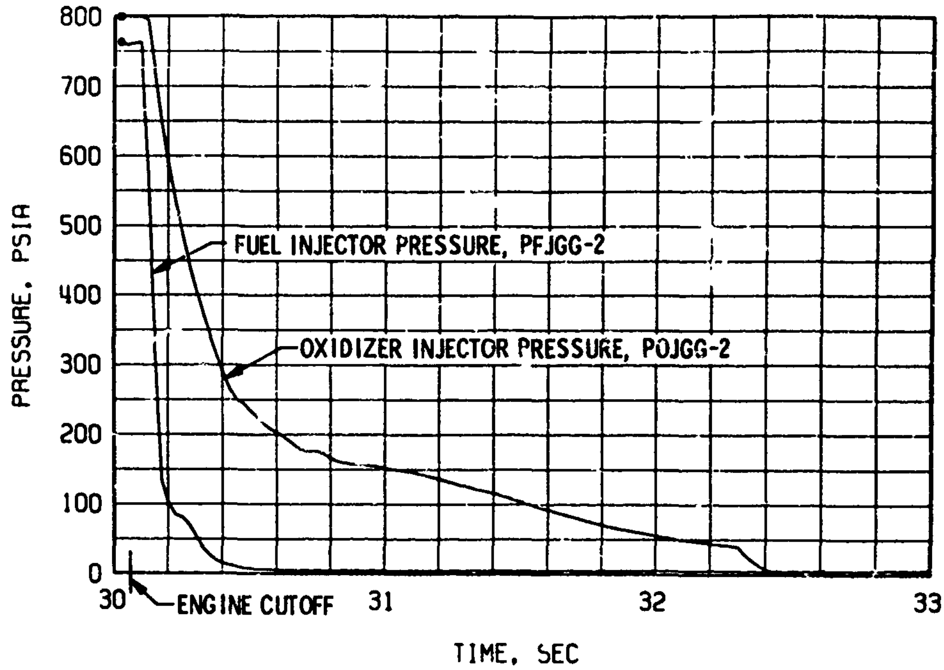


e. Gas Generator Injector Pressures, Start

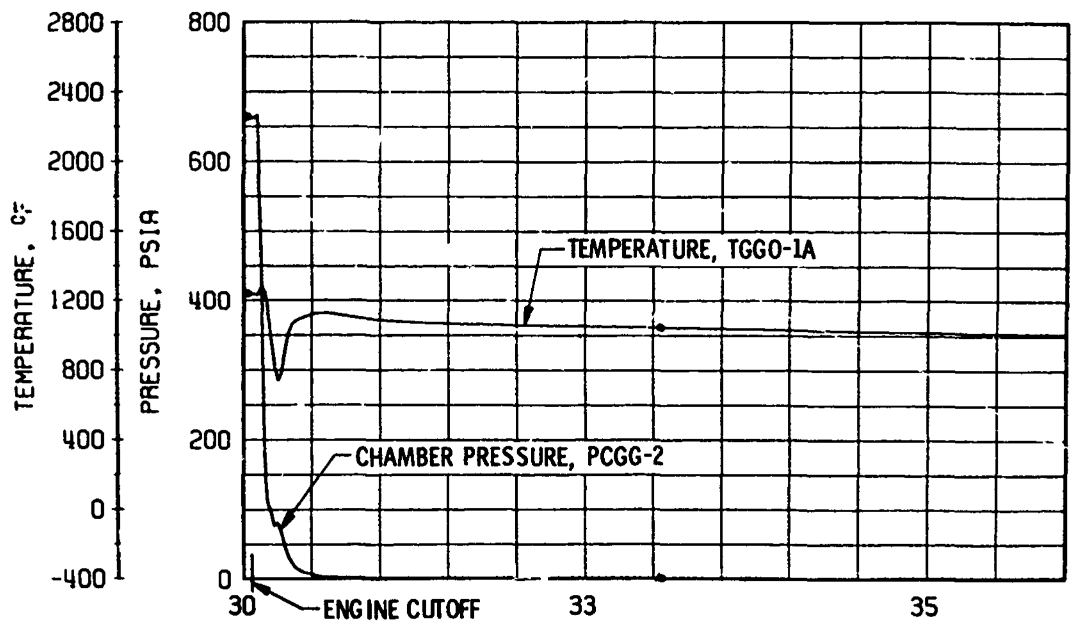


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 12 Continued



g. Gas Generator Injector Pressures, Cutoff



h. Gas Generator Chamber Pressure and Temperature, Cutoff

Fig. 12 Concluded

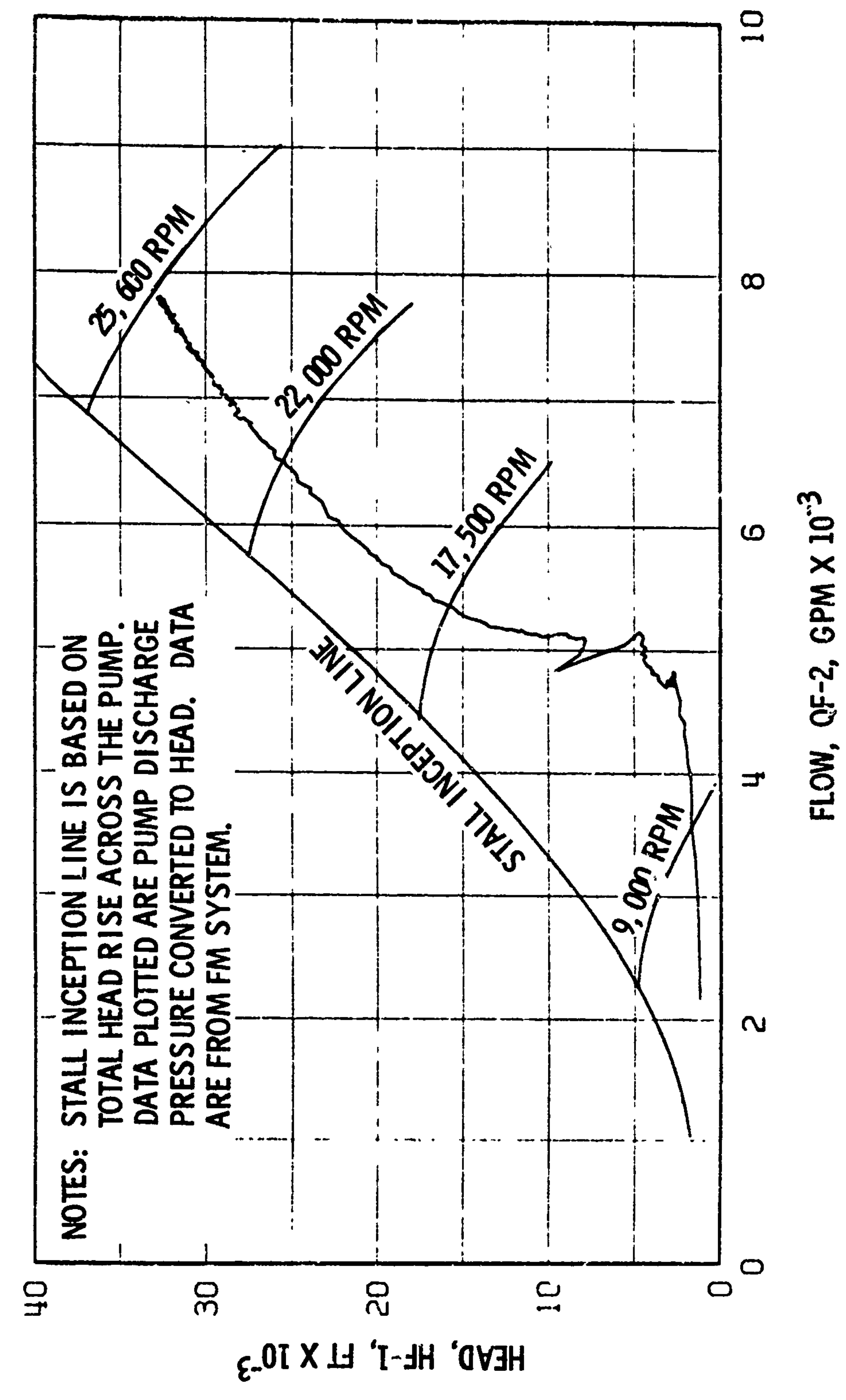


Fig. 13 Fuel Pump Start Transient Performance, Firing 07A

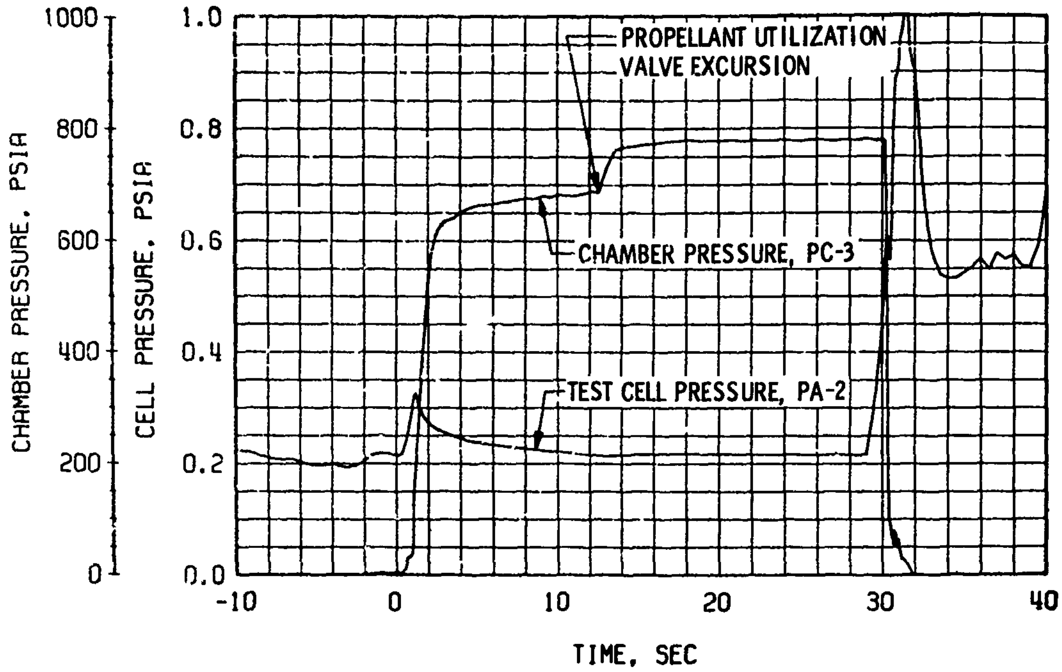


Fig. 14 Engine Ambient and Combustion Chamber Pressure Histories, Firing 07A

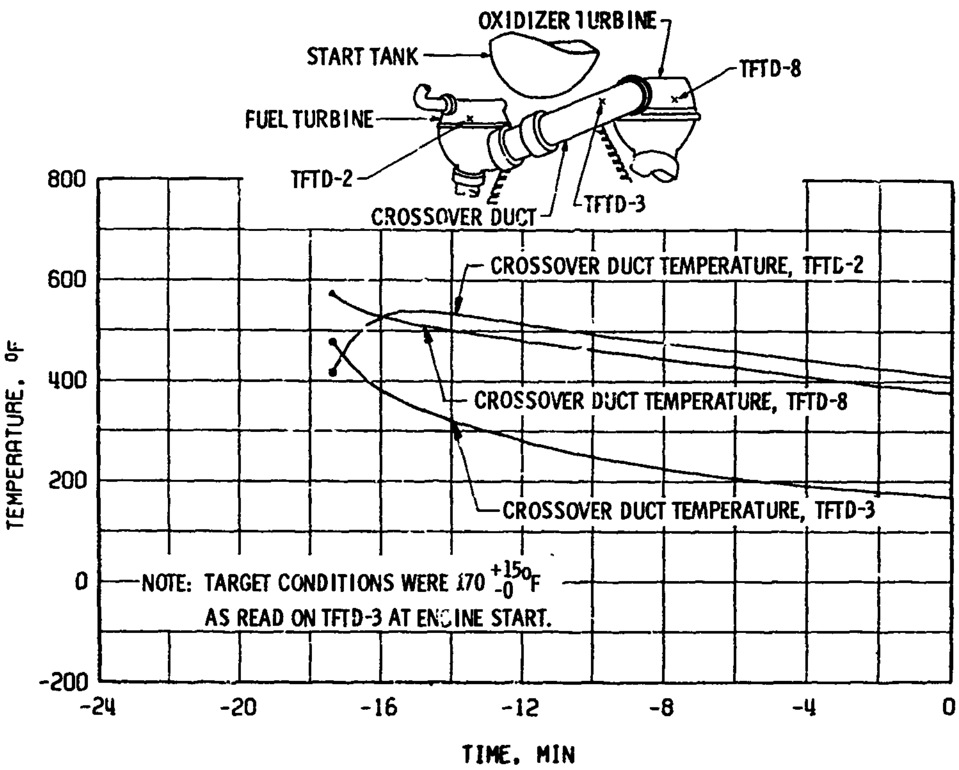
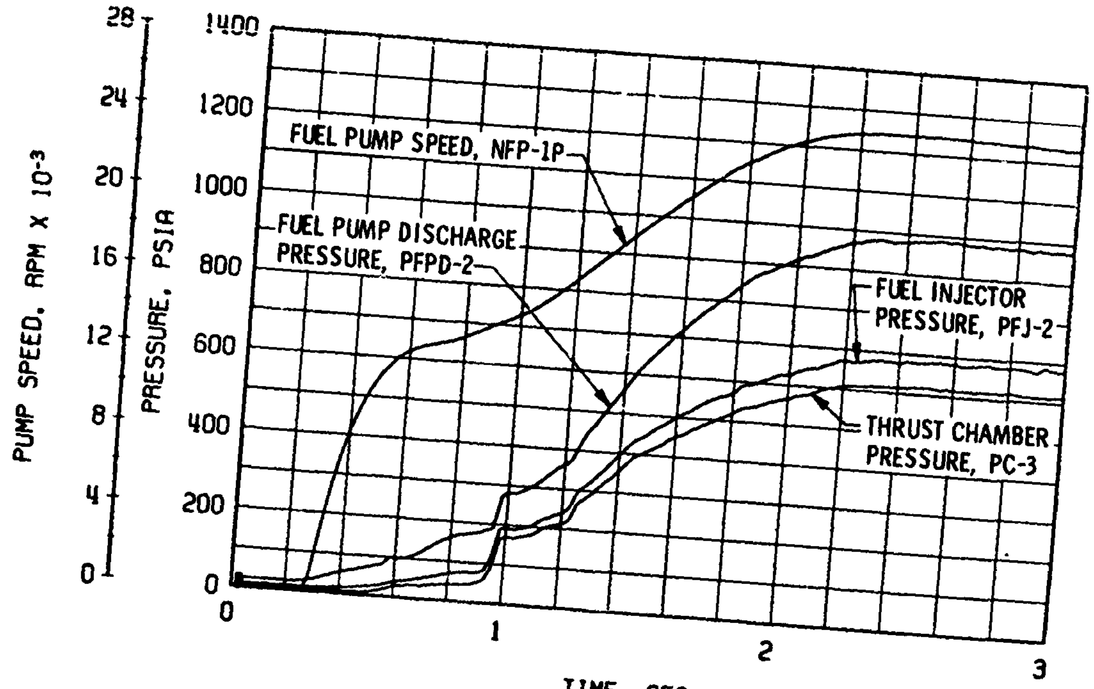
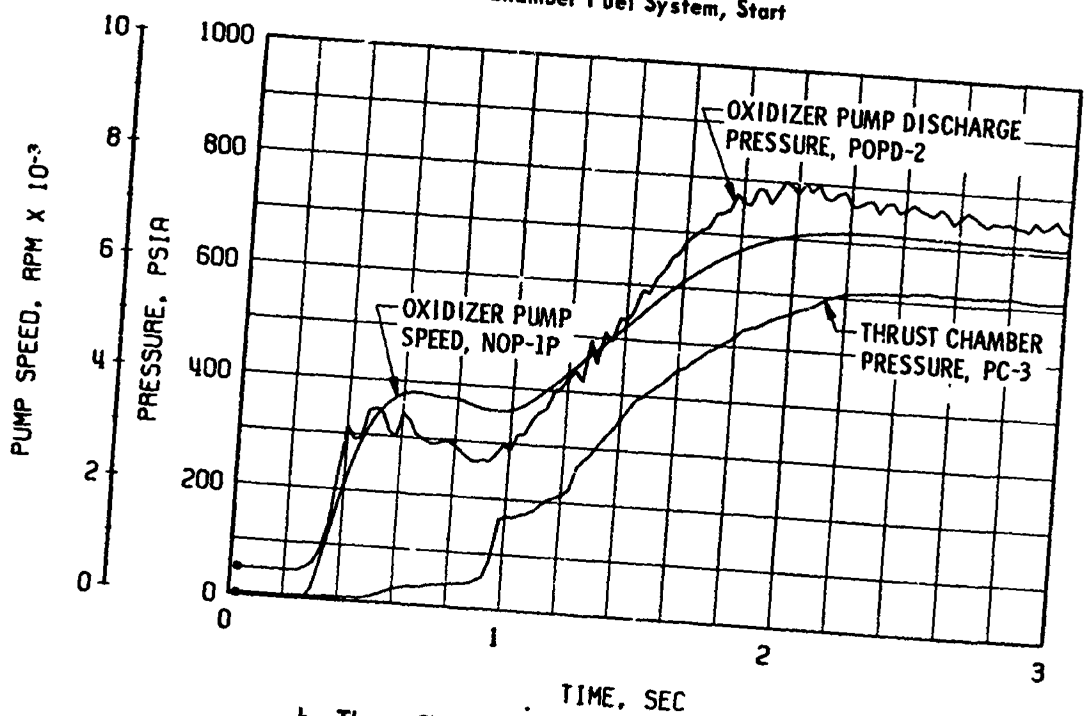


Fig. 15 Crossover Duct Temperature History, Pre-Firing 07B

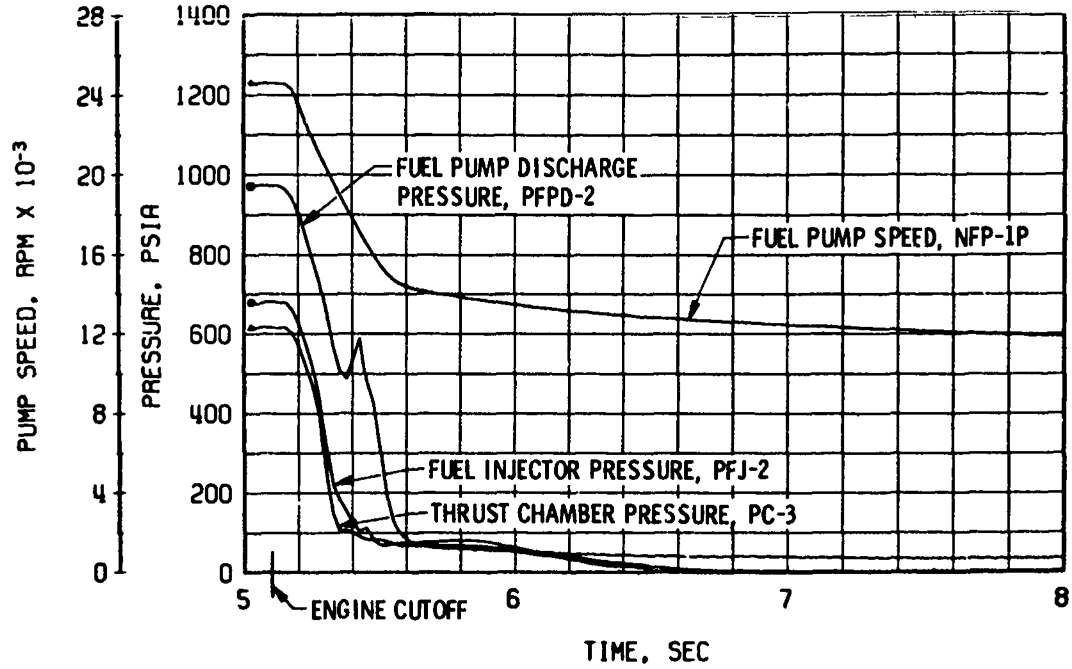


a. Thrust Chamber Fuel System, Start

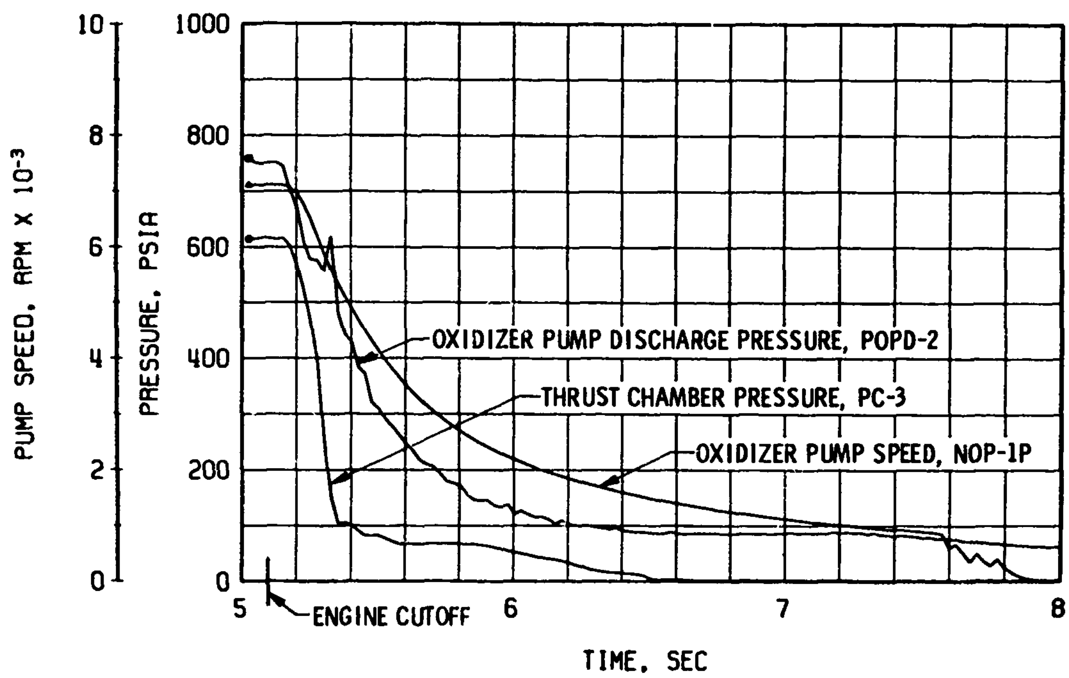


b. Thrust Chamber Oxidizer System, Start

Fig. 16 Engine Transient Operation, Firing 07B

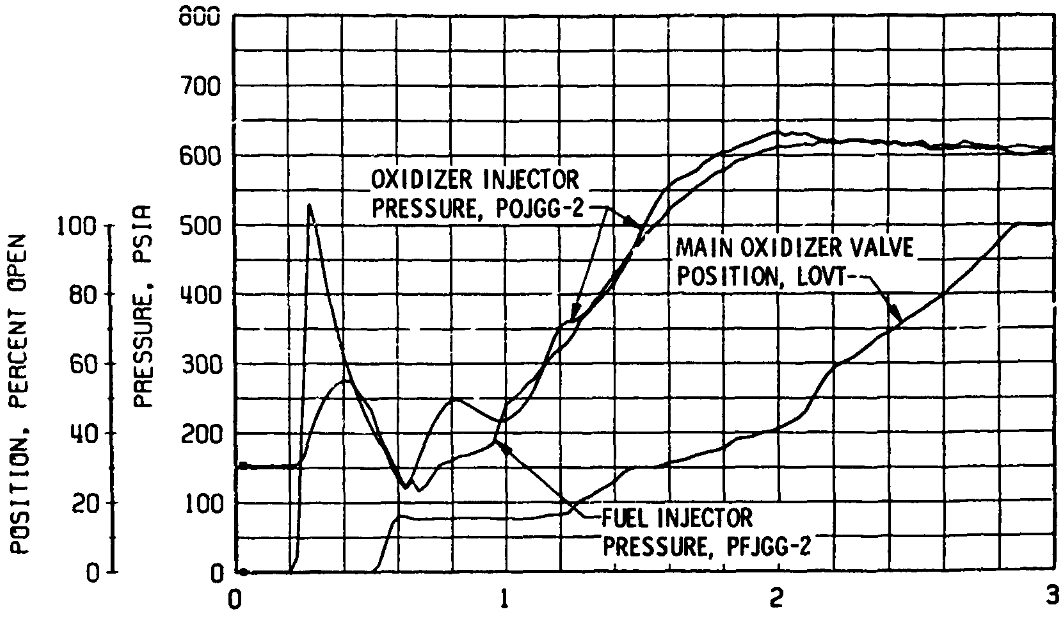


c. Thrust Chamber Fuel System, Cutoff

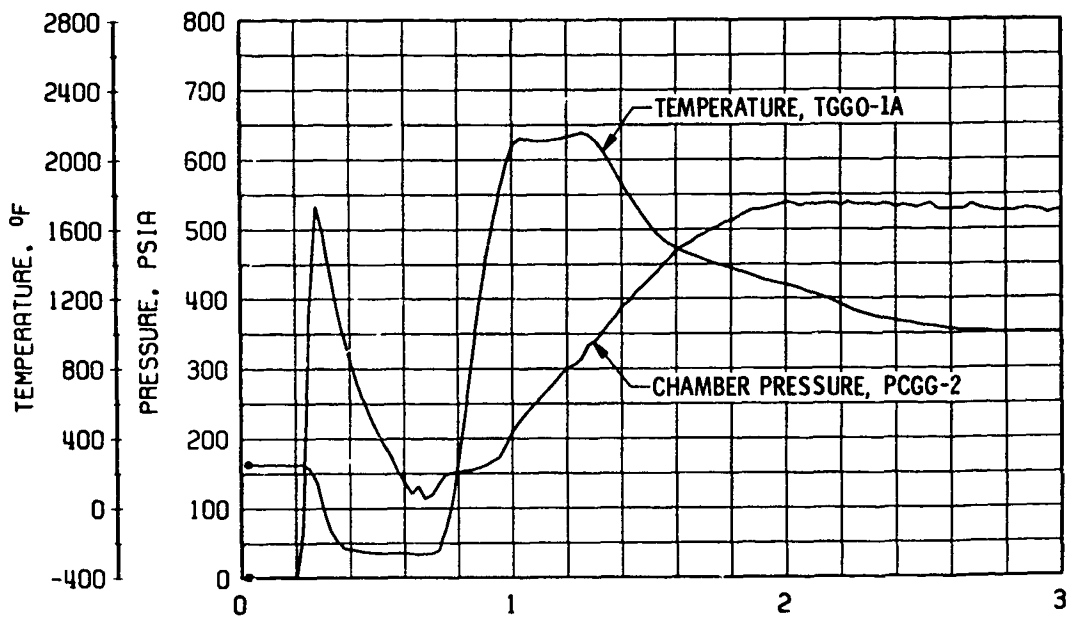


d. Thrust Chamber Oxidizer System, Cutoff

Fig. 16 Continued

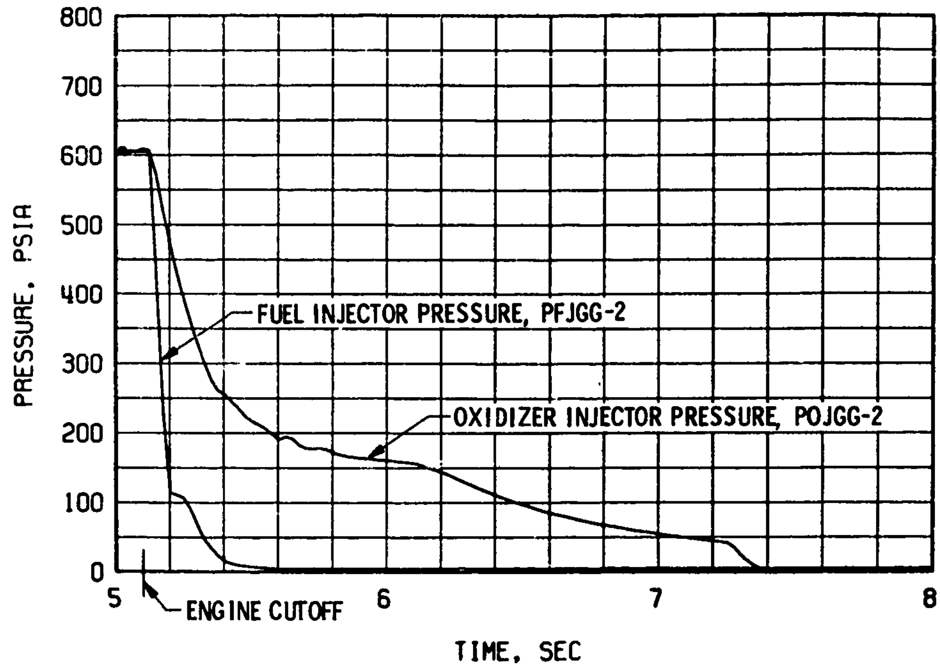


e. Gas Generator Injector Pressures, Start

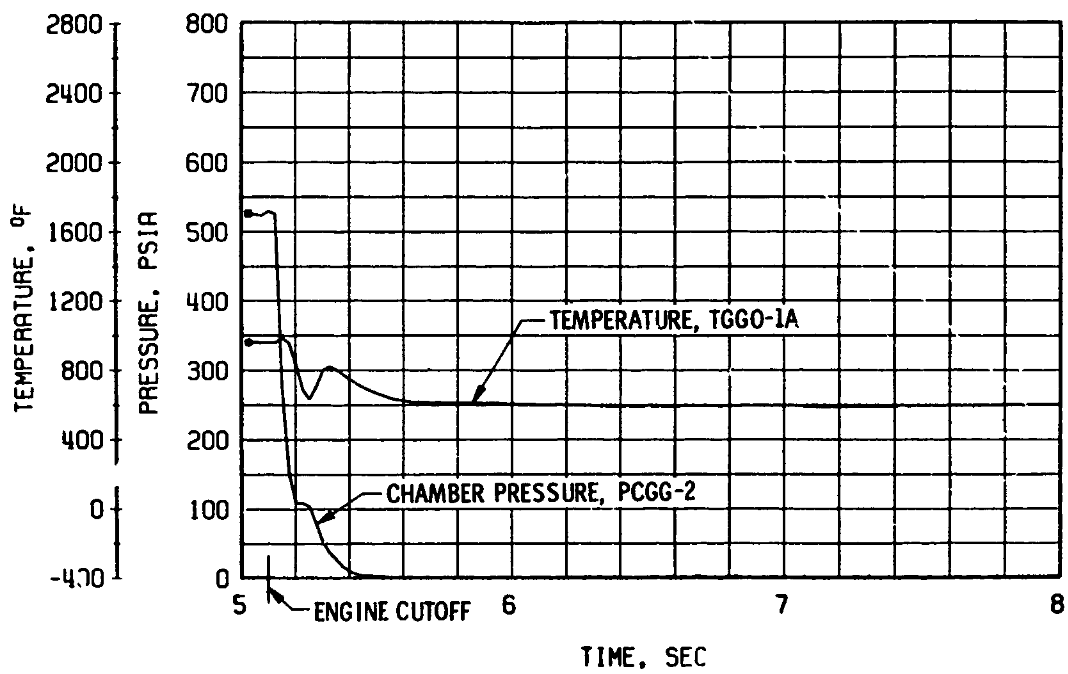


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 16 Continued



g. Gas Generator Injector Pressures, Cutoff



h. Gas Generator Chamber Pressure and Temperature, Cutoff

Fig. 16 Concluded

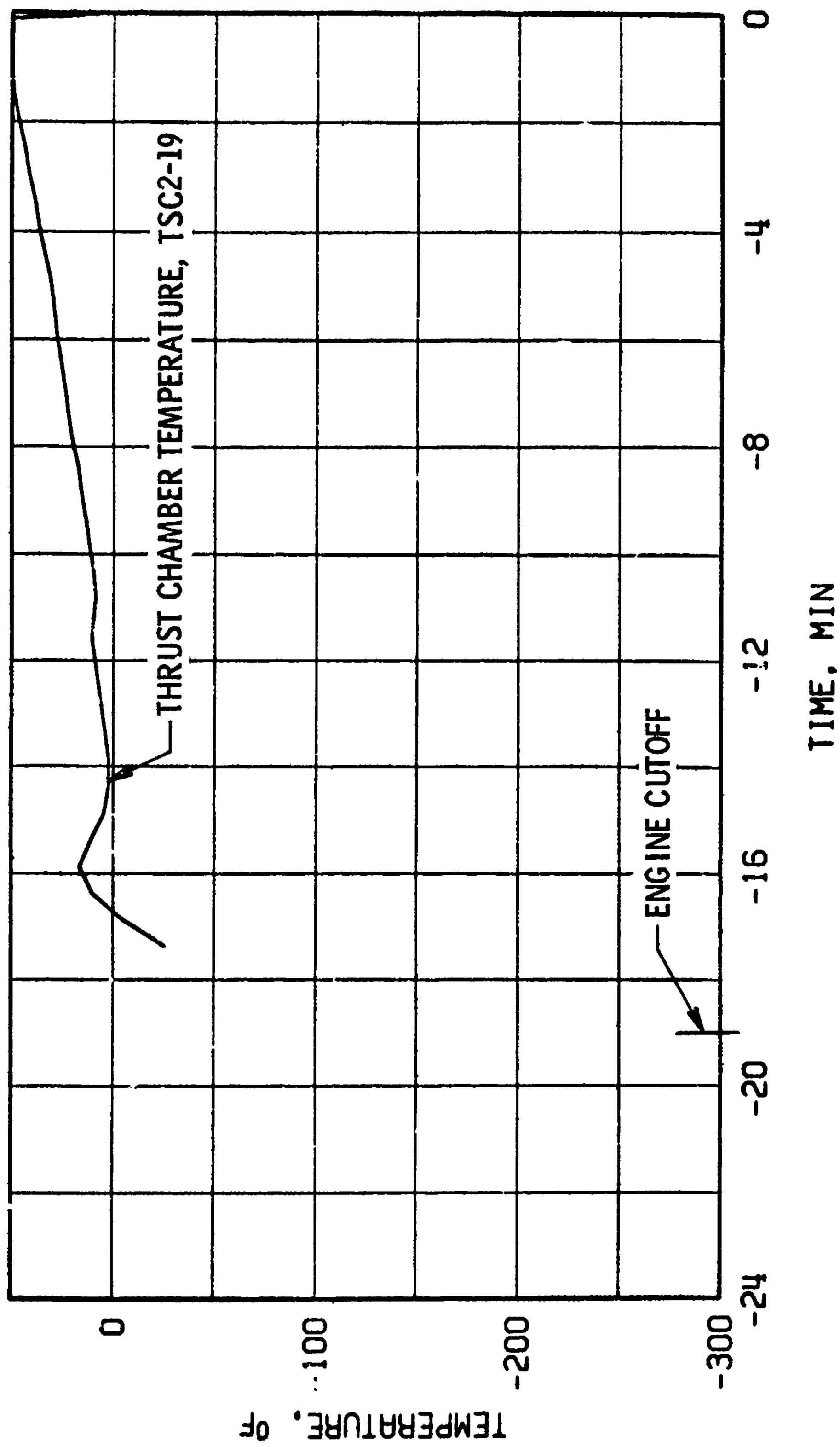


Fig. 17 Thrust Chamber Temperature History, Pre-Firing 07B

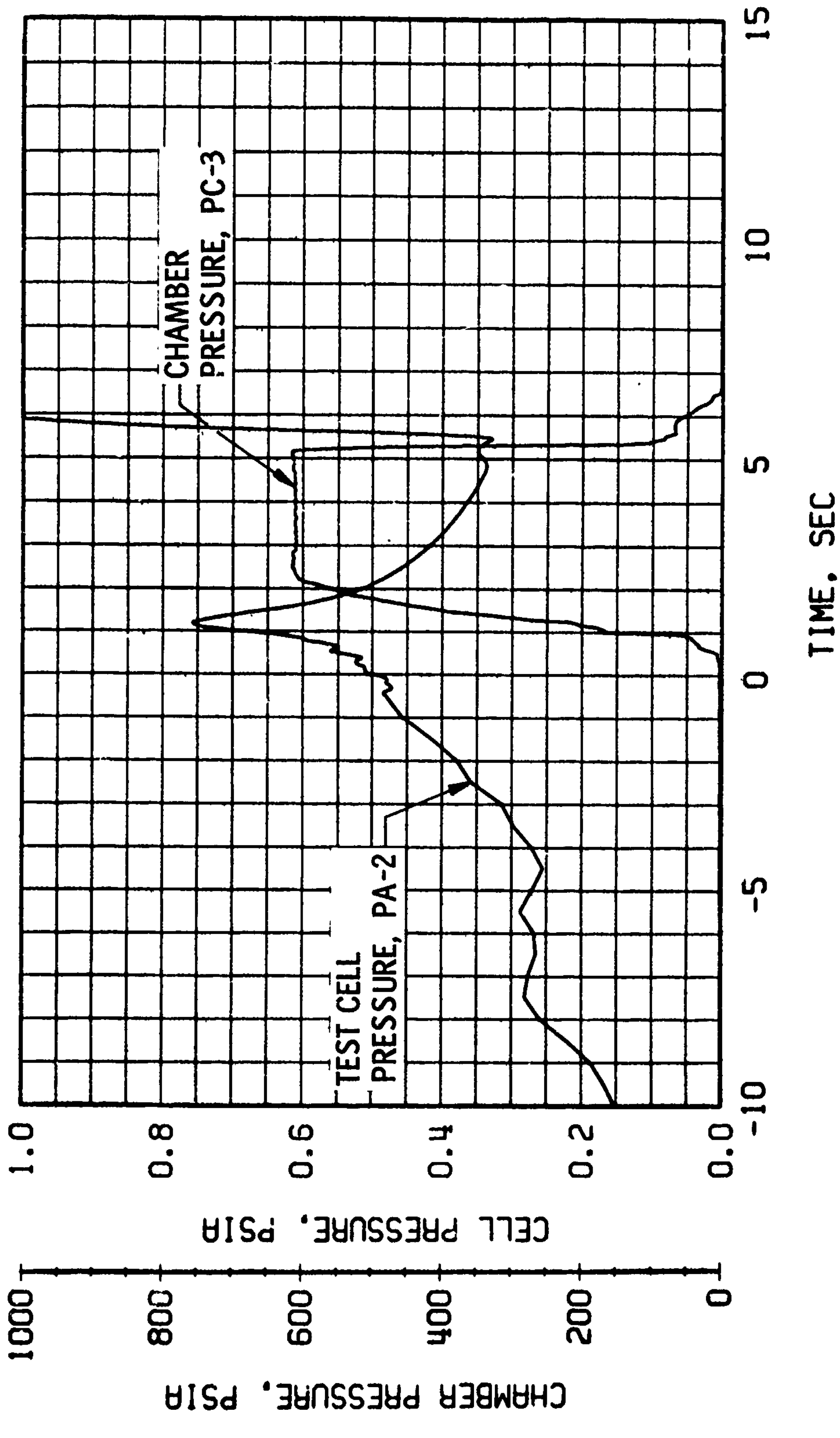


Fig. 18 Engine Ambient and Combustion Chamber Pressure Histories, Firing 07B

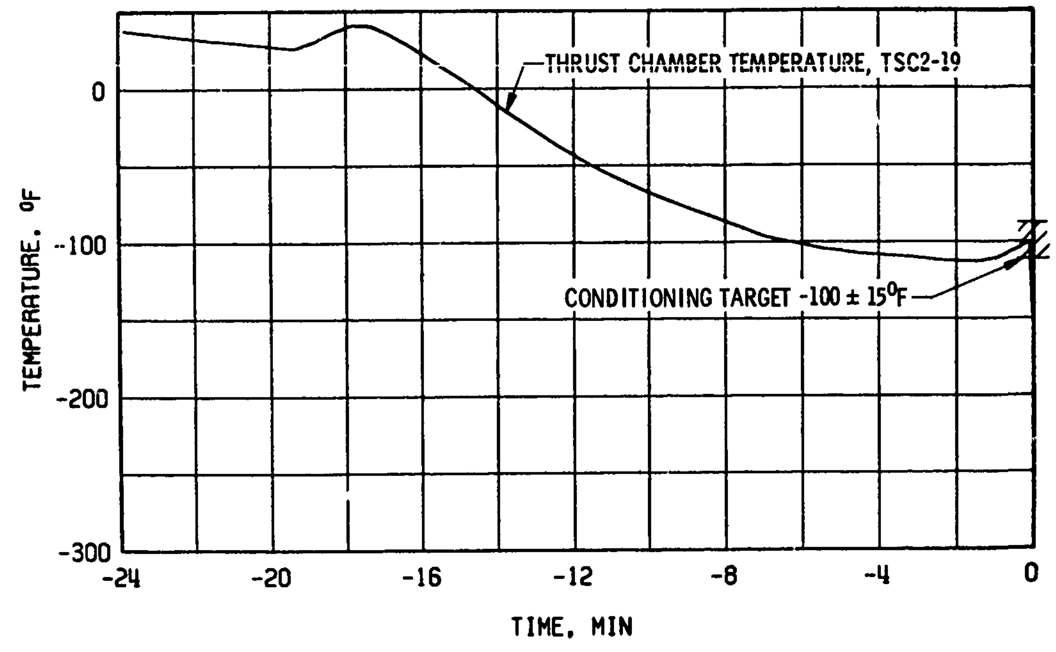


Fig. 19 Thrust Chamber Temperature History, Pre-Firing 07C

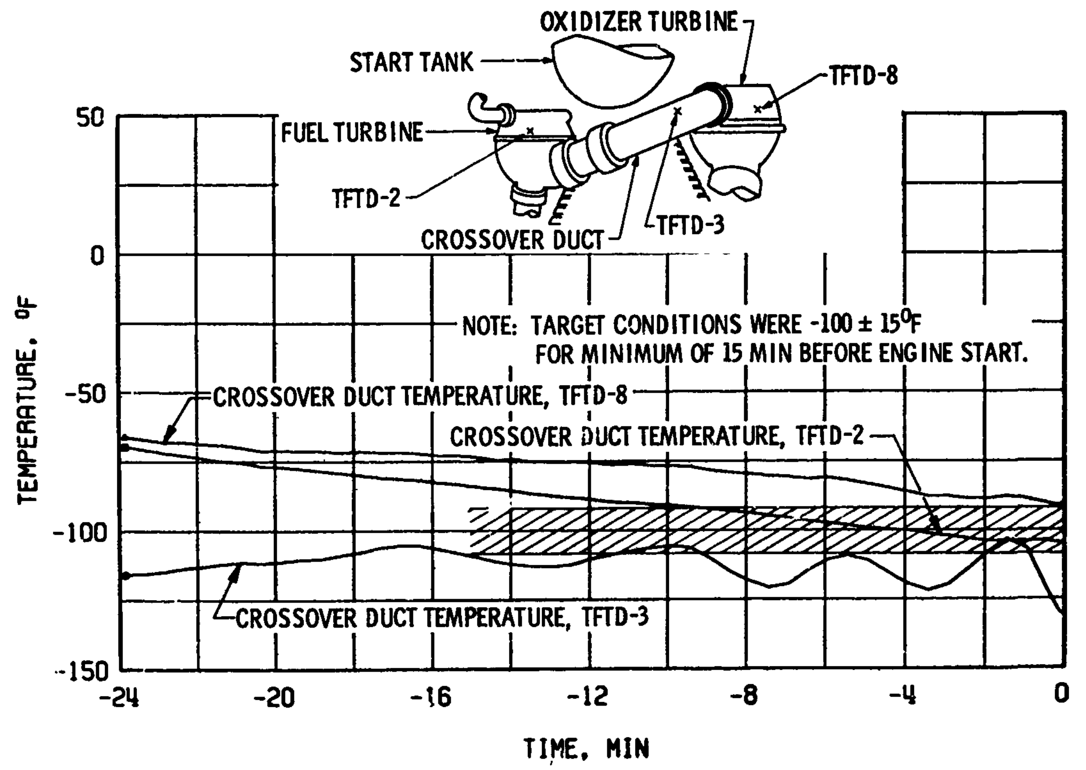
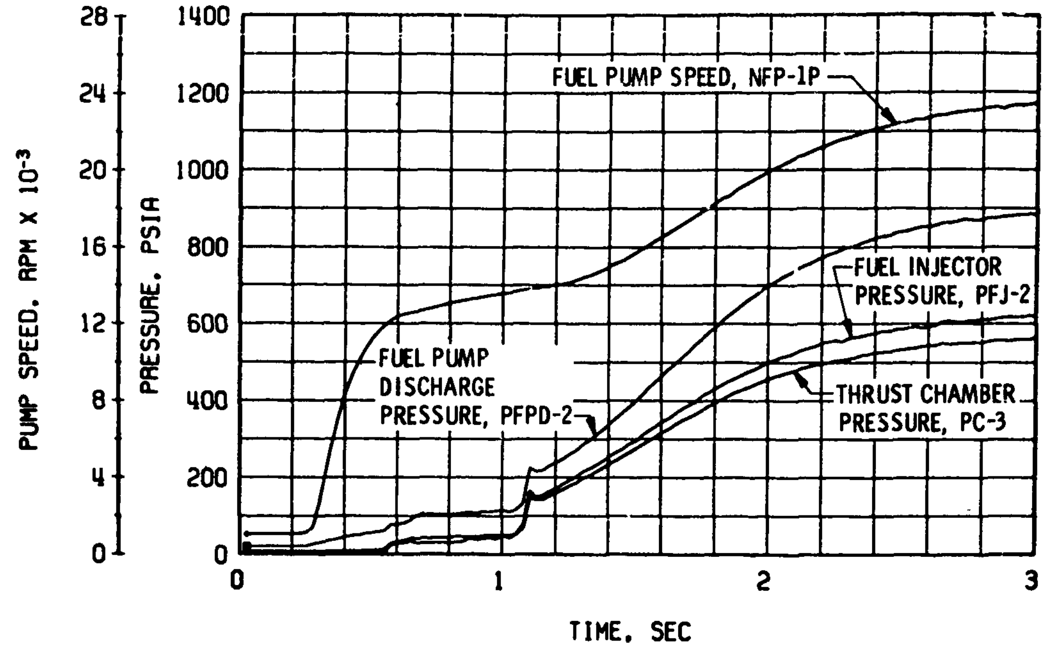
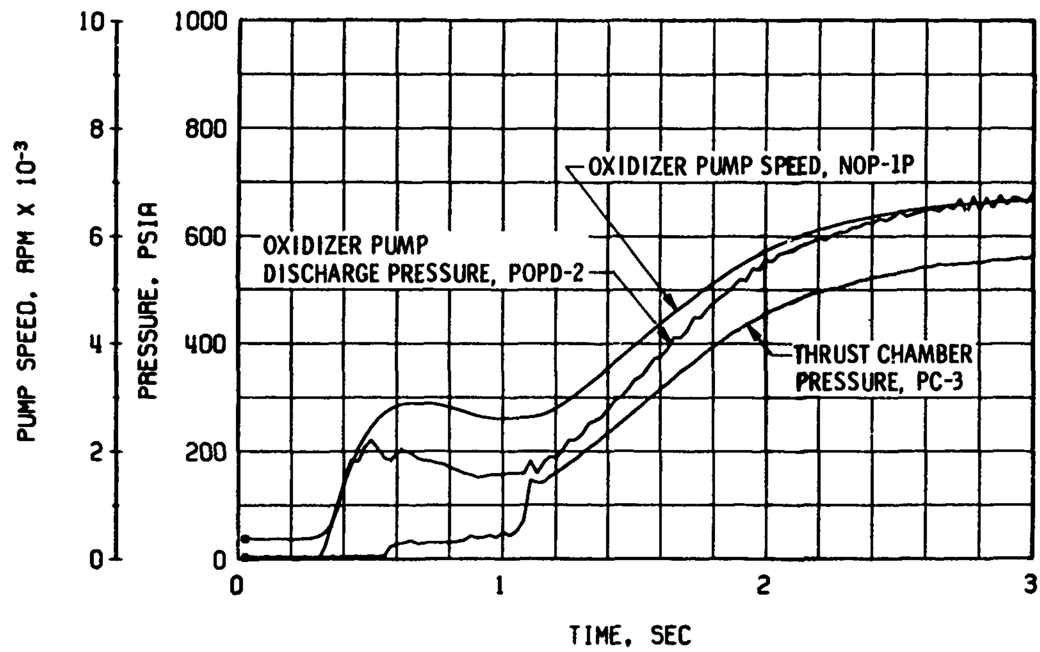


Fig. 20 Crossover Duct Temperature History, Pre-Firing 07C

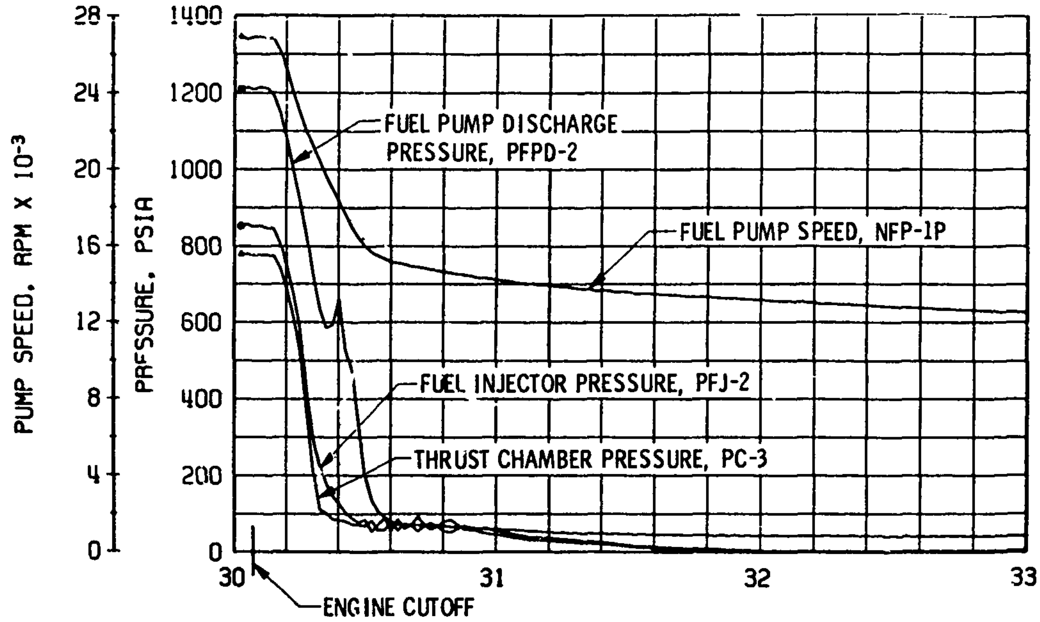


a. Thrust Chamber Fuel System, Start

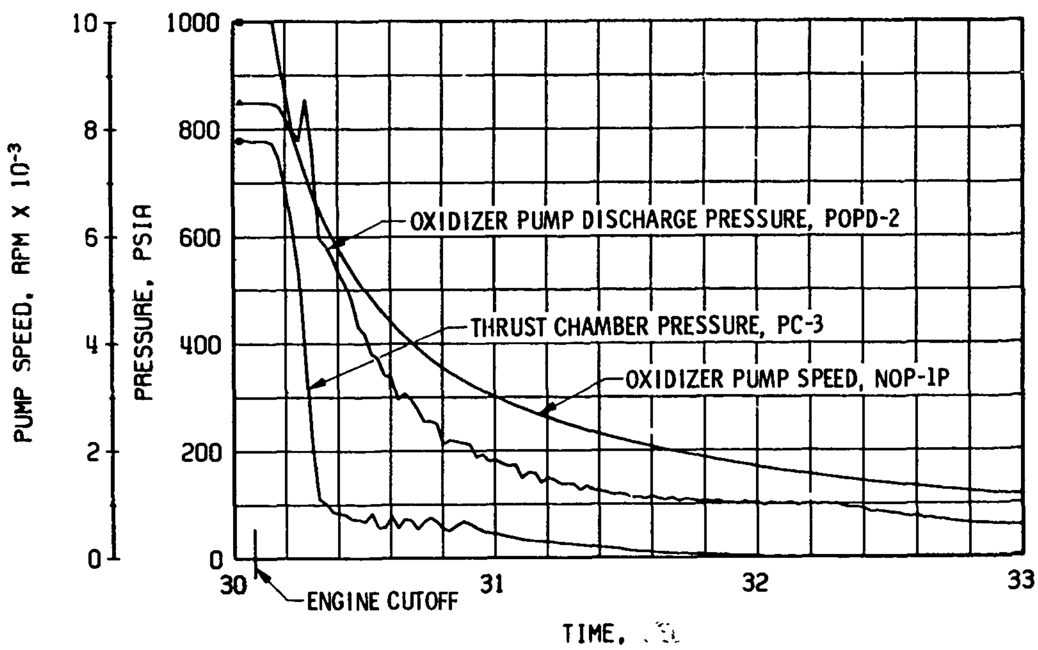


b. Thrust Chamber Oxidizer System, Start

Fig. 21 Engine Transient Operations, Firing 97C

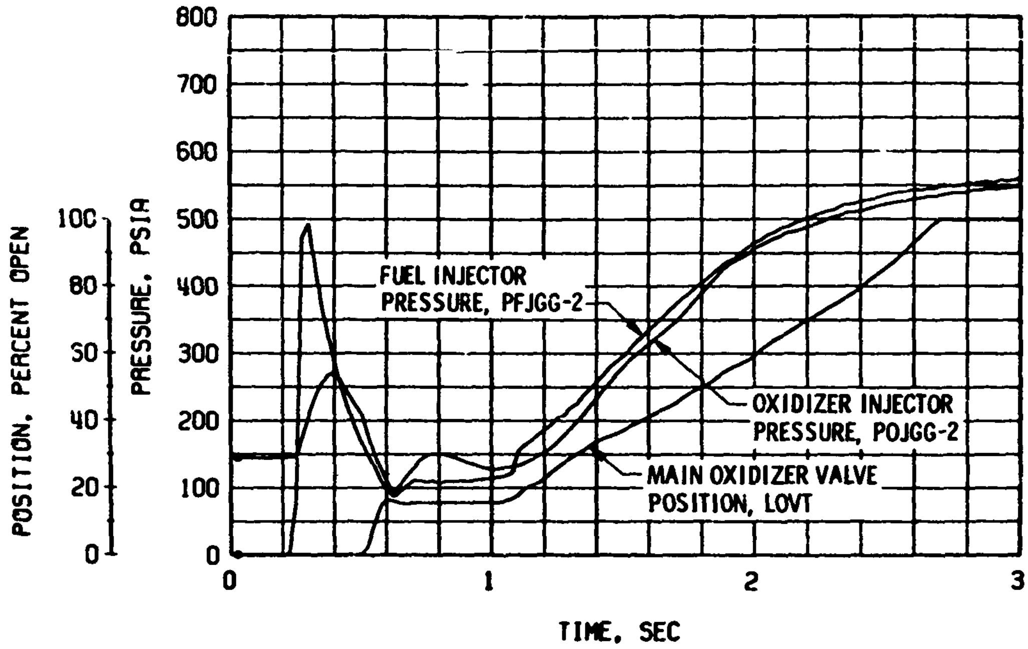


c. Thrust Chamber Fuel System, Cutoff

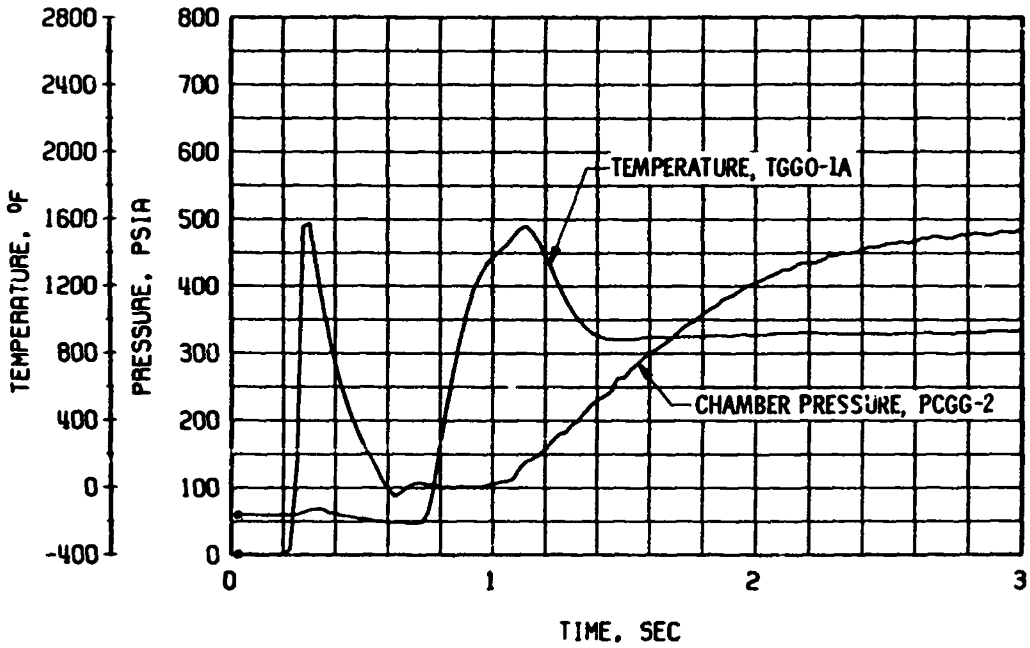


d. Thrust Chamber Oxidizer System, Cutoff

Fig. 21 Continued

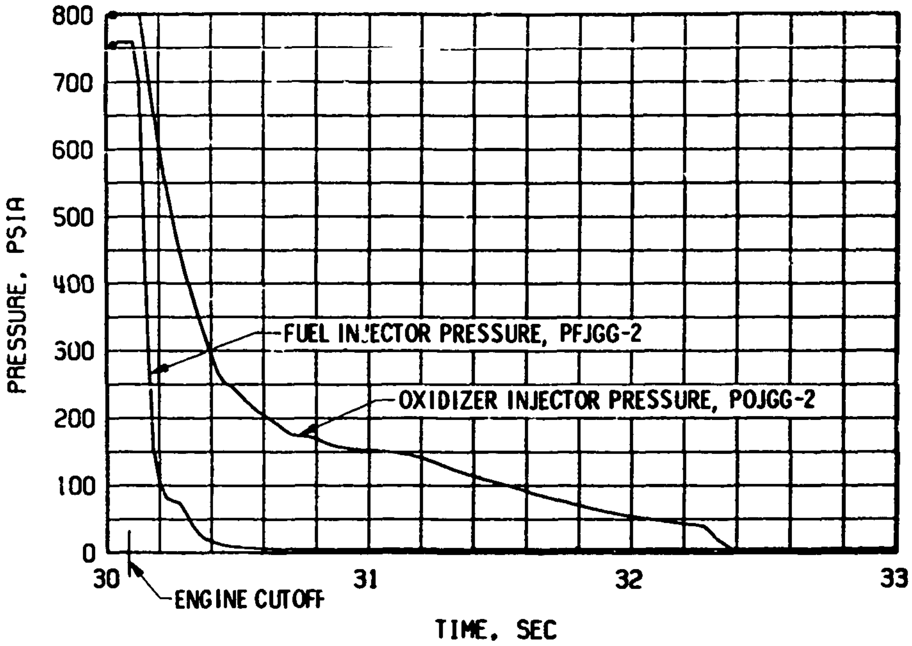


e. Gas Generator Injector Pressures, Start

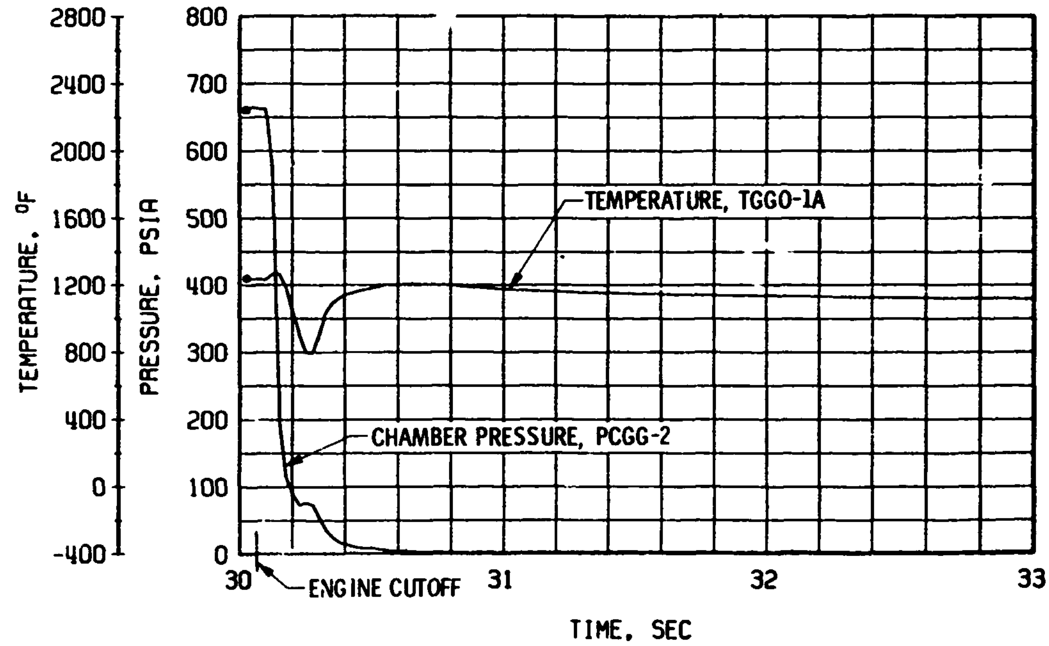


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 21 Continued



g. Gas Generator Injector Pressures, Cutoff



h. Gas Generator Chamber Pressure and Temperature, Cutoff

Fig. 21 Concluded

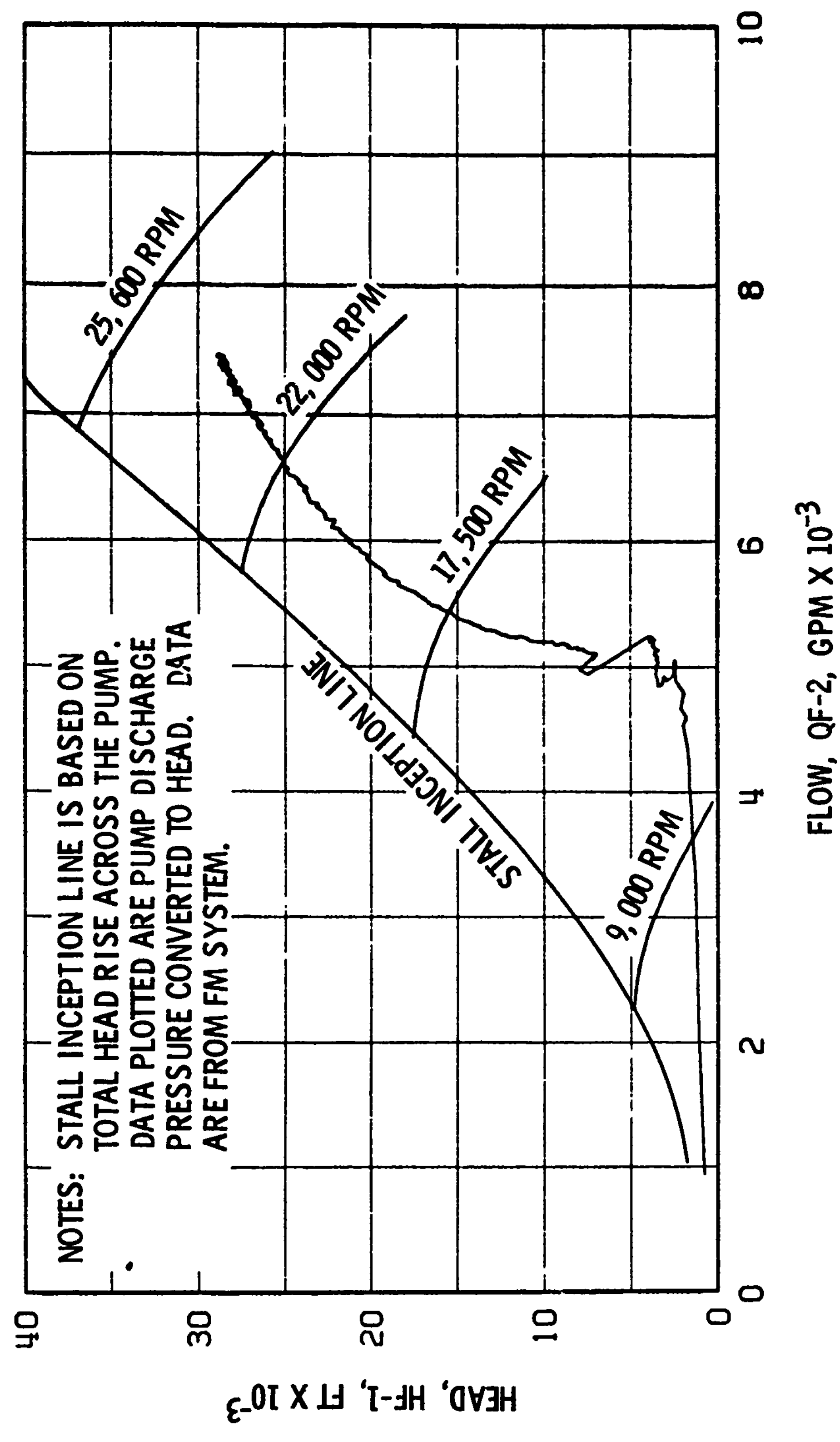


Fig. 22 Fuel Pump Start Transient Performance, Firing 07C

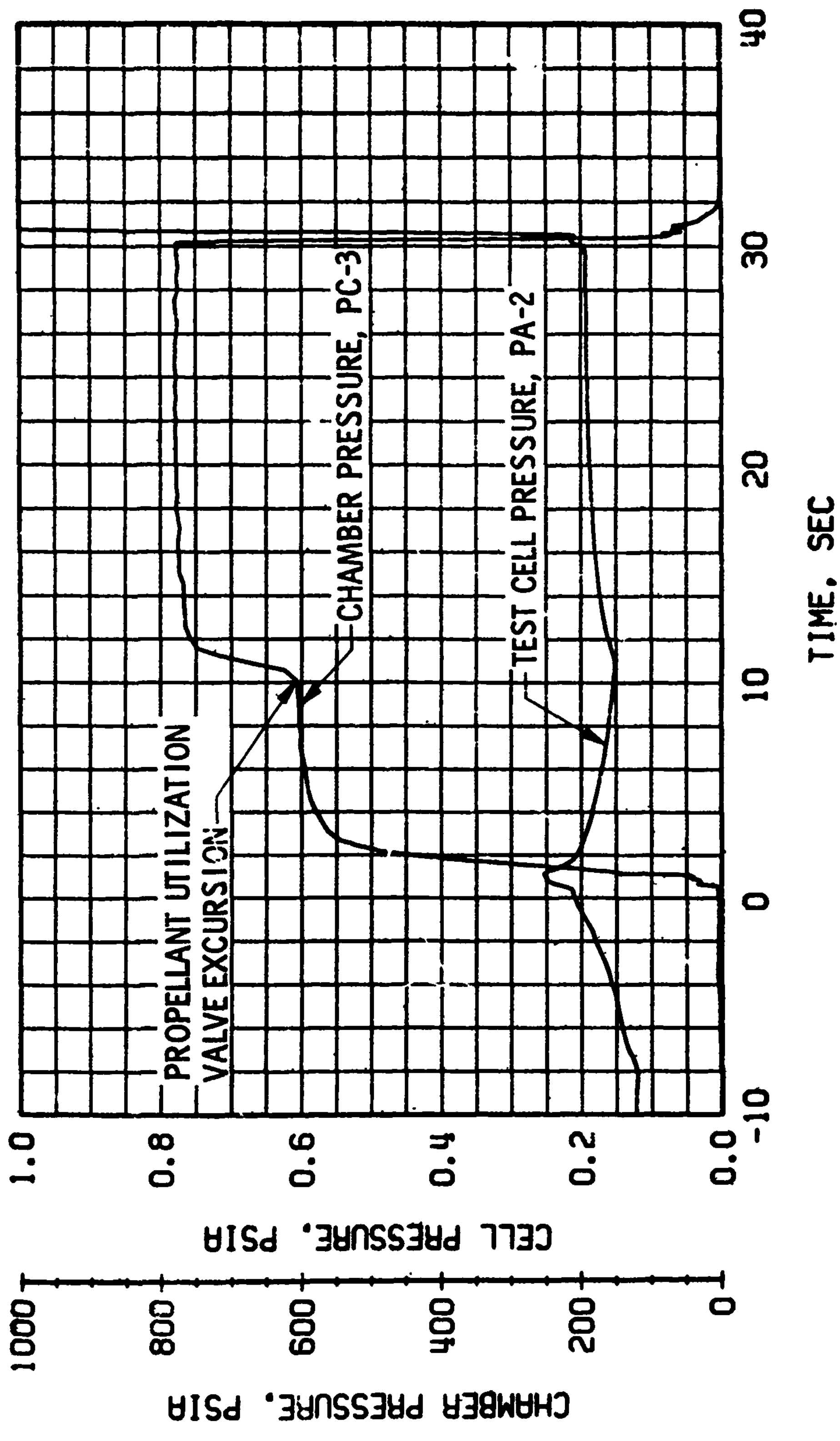


Fig. 23 Engine Ambient and Combustion Chamber Pressure Histories, Firing 07C

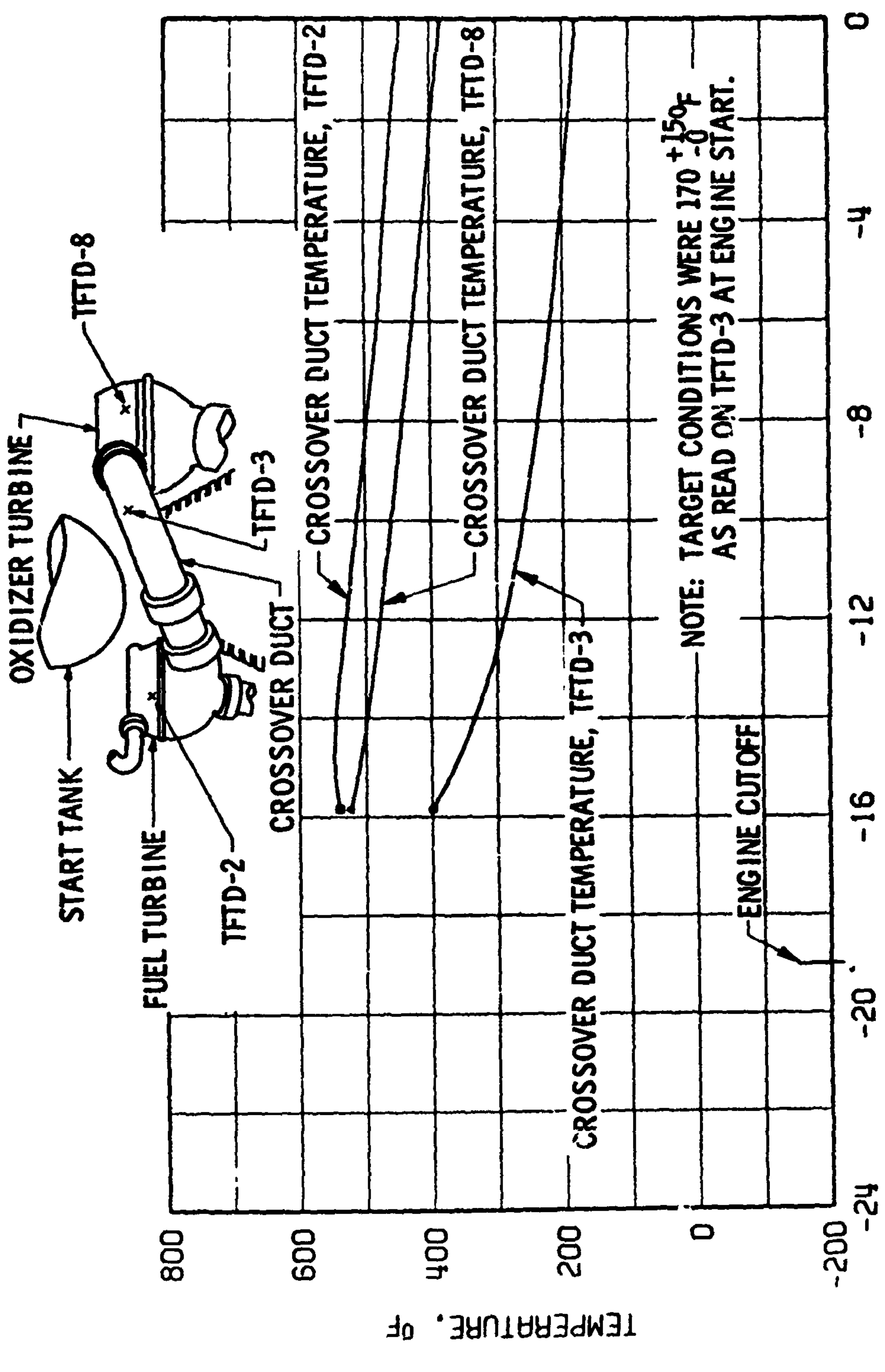
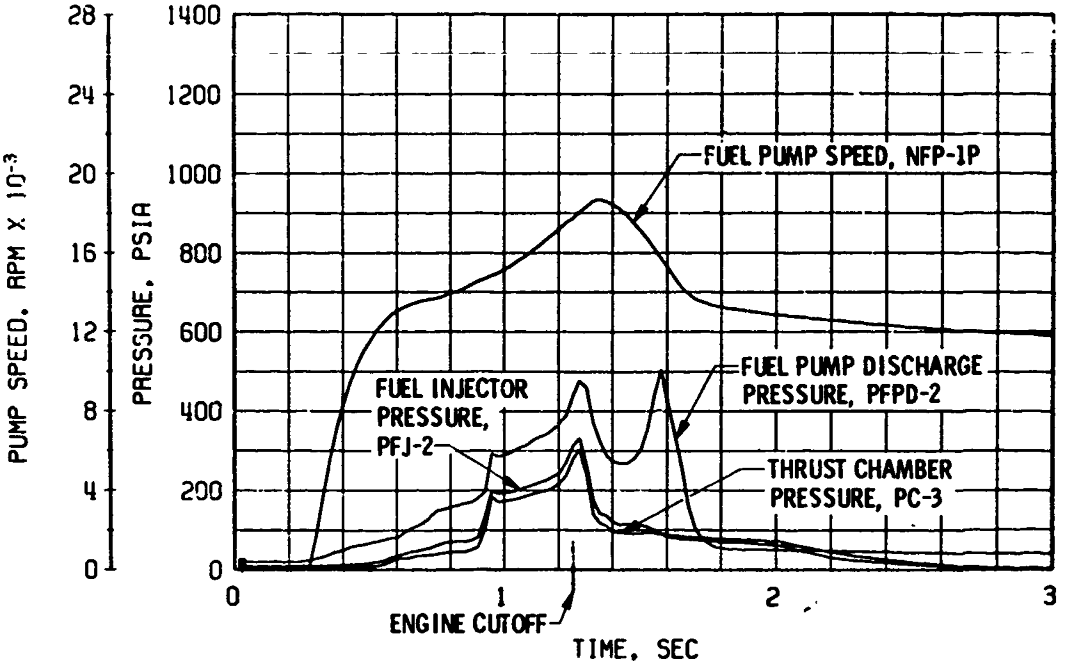
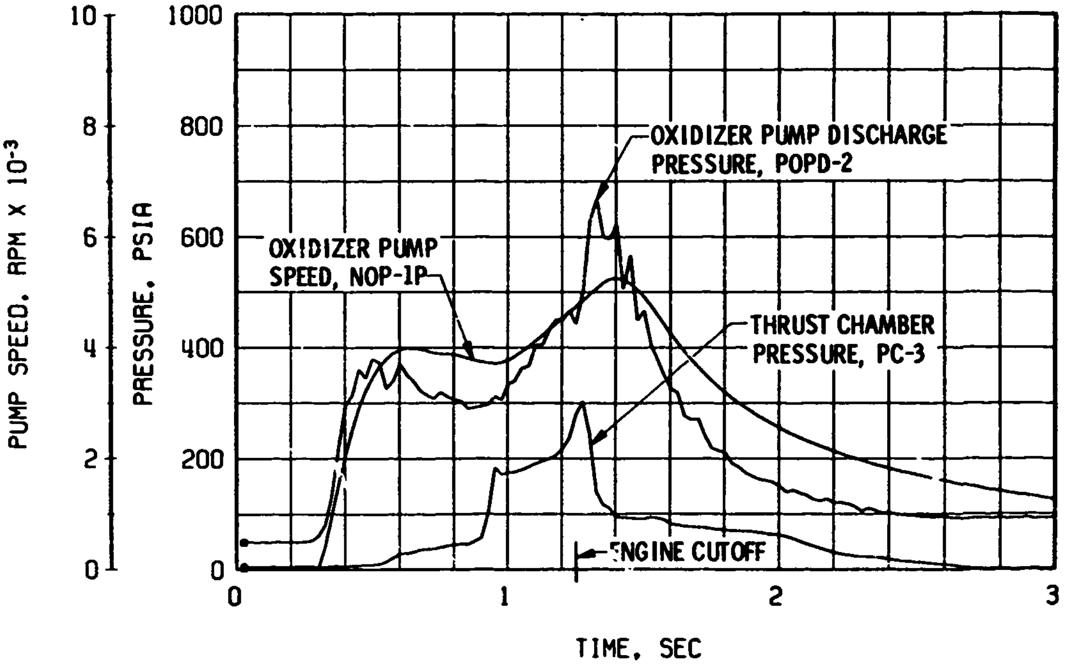


Fig. 24 Crossover Duct Temperature History, Pre-Firing 07D

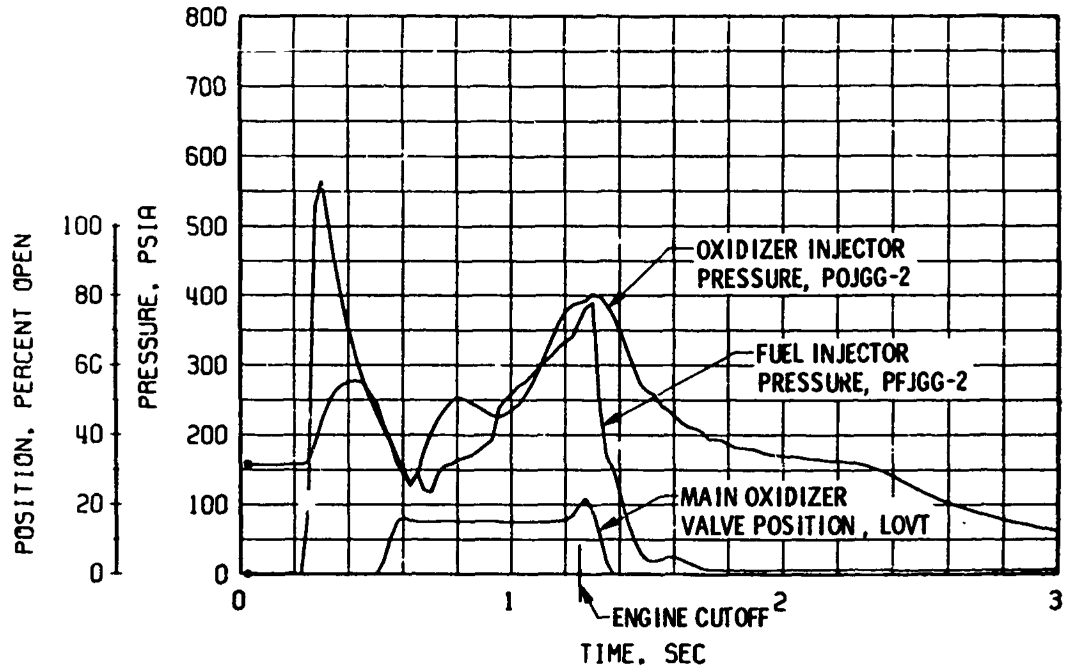


a. Thrust Chamber Fuel System, Start and Cutoff

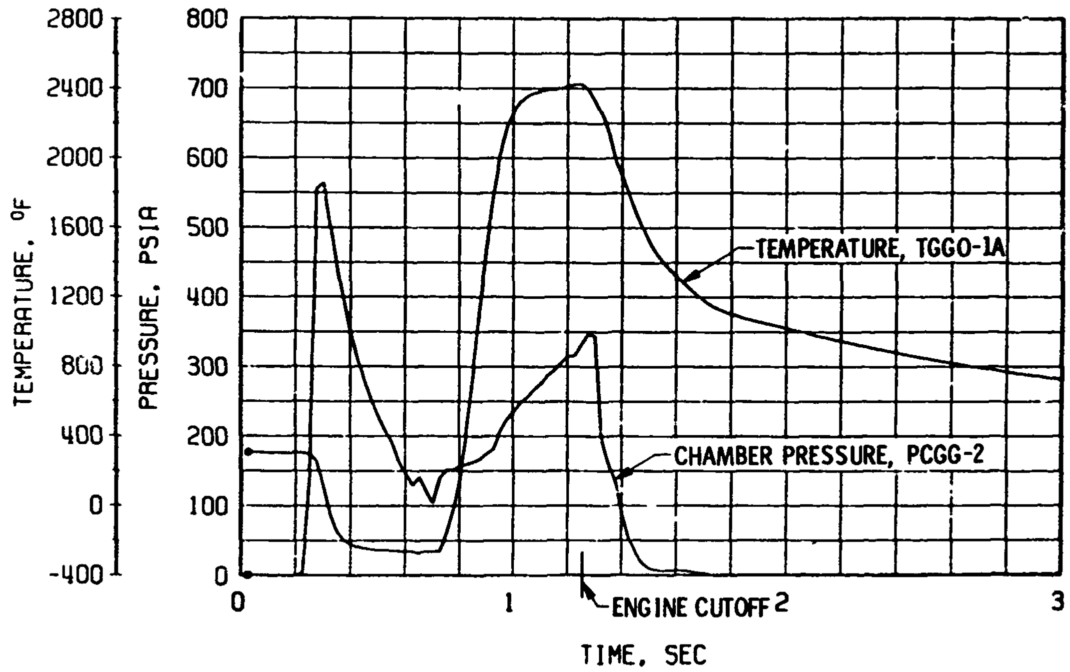


b. Thrust Chamber Oxidizer System, Start and Cutoff

Fig. 25 Engine Transient Operation, Firing 07D



c. Gas Generator Injector Pressures, Start and Cutoff



d. Gas Generator Chamber Pressure and Temperature, Start and Cutoff

Fig. 25 Concluded

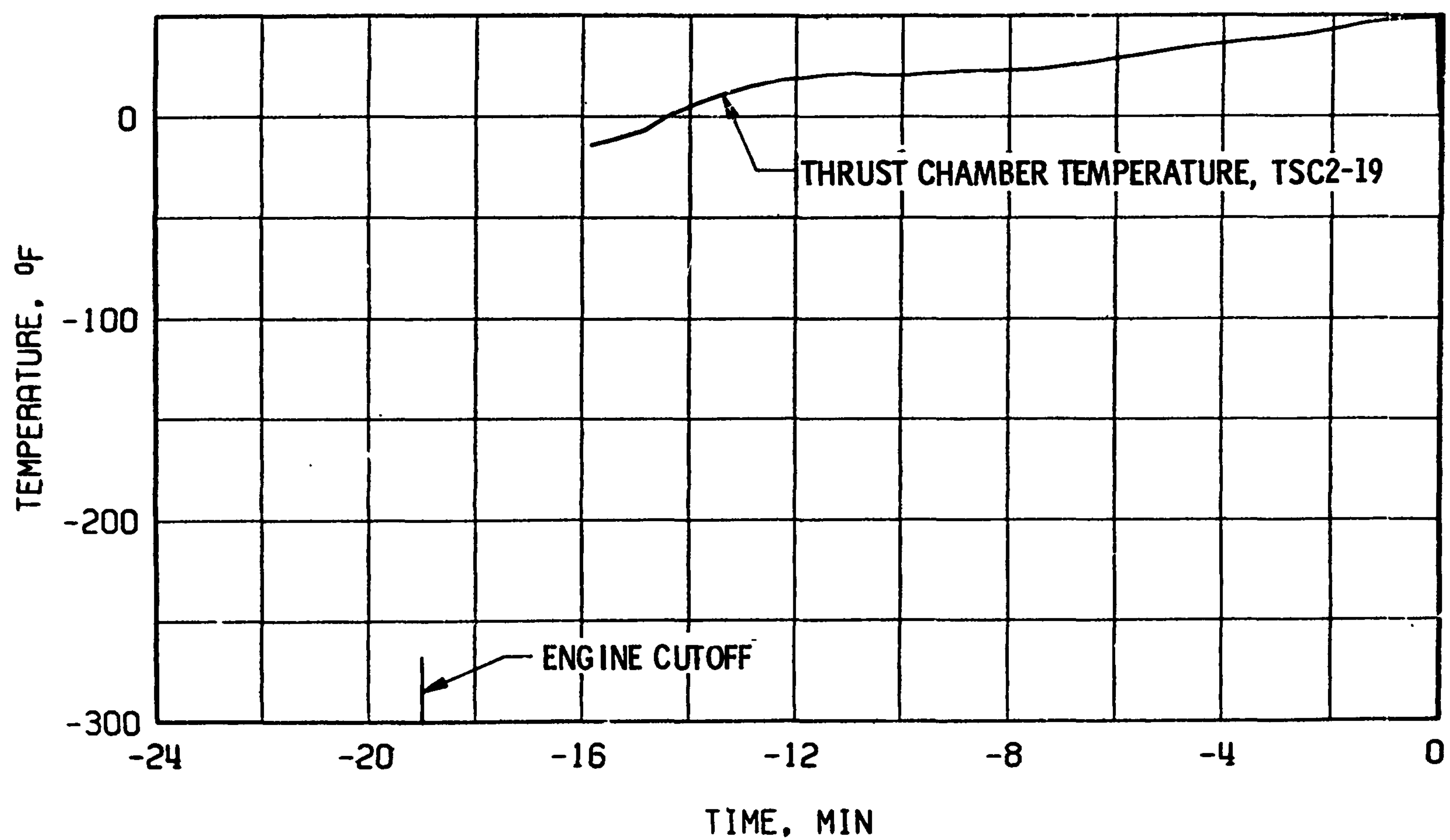


Fig. 26 Thrust Chamber Temperature History, Pre-Firing 07D

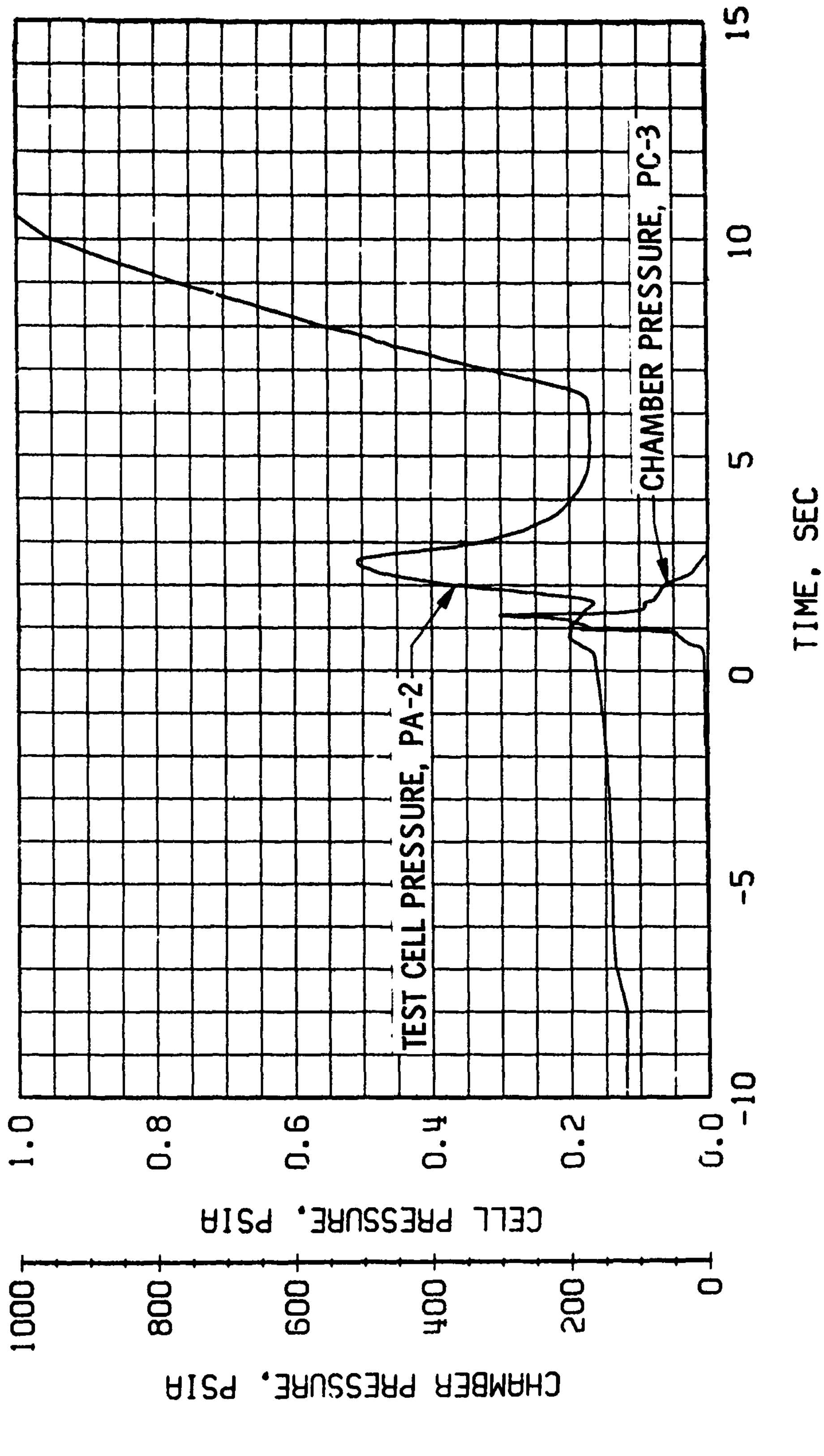


Fig. 27 Engine Ambient and Combustion Chamber Pressure Histories, Firing 07D

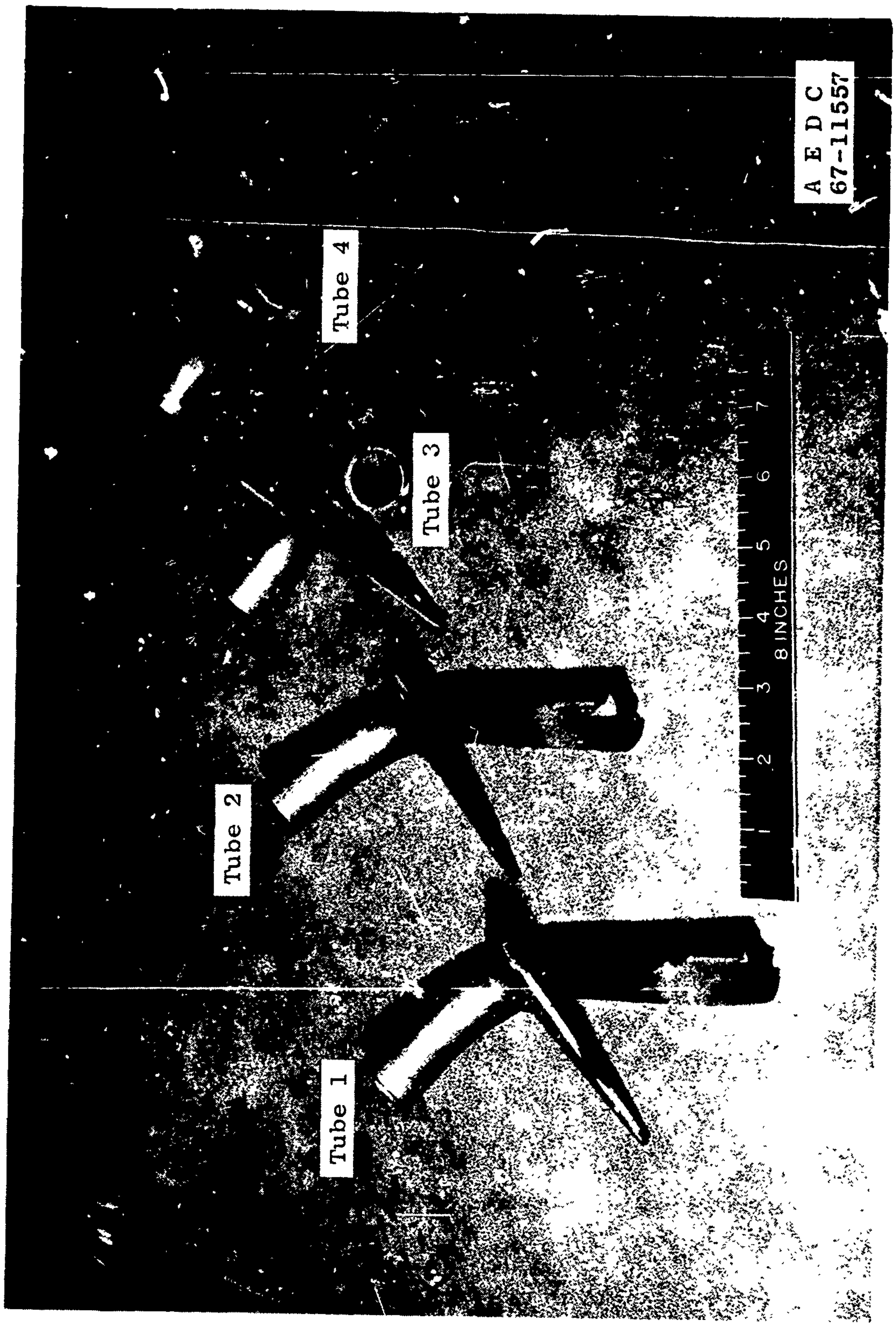


Fig. 28 Experimental Oxidizer Pump Primary Seal Drain Tubes, Post-Test Condition

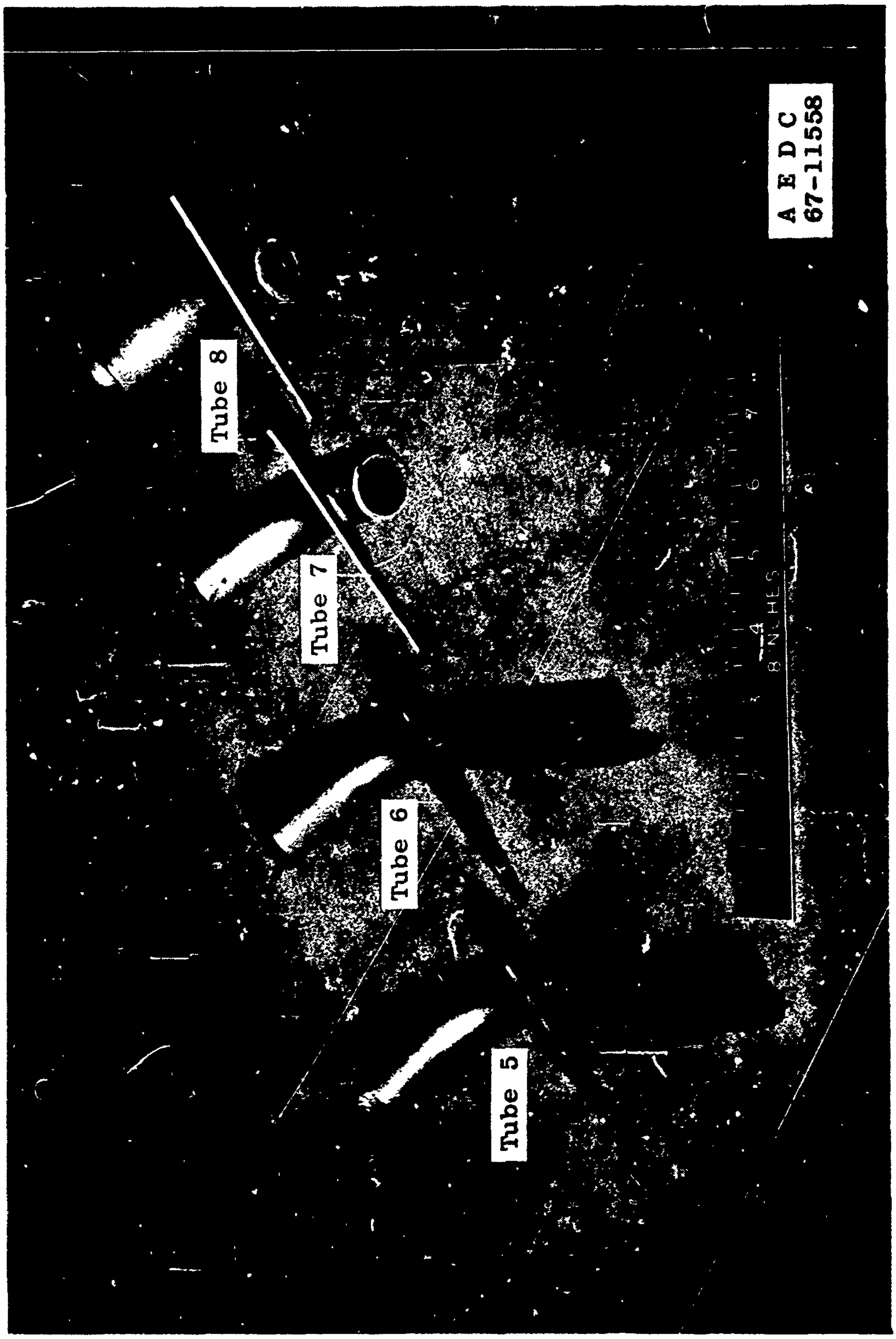


Fig. 28 Continued

Fig. 28 Concluded

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-181	4062085
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	4066541
Pneumatic Control Assembly	556947	4079720
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	409969	4072594
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Phase Control Valve	558069	8275775
Helium Control Valve	106012000	3793-0
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XEOR915389	211

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Installation Date	Comments
Main Oxidizer Valve Closing Control	410437	8.65 scfm	August 28, 1967	RFD*-AEDC 17-1-67 Supplement
Gas Generator Fuel	RD251-4107	0.480 in.	August 18, 1967	FTP † Replacement
Gas Generator Oxidizer	RD251-4106	0.281 in.	August 18, 1967	FTP Replacement
Oxidizer Turbine Bypass Nozzle	RD273-8002	1.571 in.	July 31, 1967	RFD-AEDC 58-67
Oxidizer Turbine Exhaust Orifice	RD251-9004	10.0 in.	January 18, 1967	Size Verification
Augmented Spark Igniter Oxidizer	406361 None	0.137 in. 0.125 in.	August 10, 1967	RFD-AEDC-62-67

*RFD - Rocketdyne Field Directive

† FTP - Fuel Turbopump Assembly

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-06 AND J4-1801-07)

Modification Number	Completion Date	Description of Modification
RFD*-64-67	August 30, 1967	Installation of Oxidizer Pump Primary Seal Drain Simulation System
---	August 30, 1967	Augmented Spark Igniter Ignition Detect Probe Depth Increased 0.085 in. to Return Probe Depth to the Standard

*RFD - Rocketdyne Field Directive

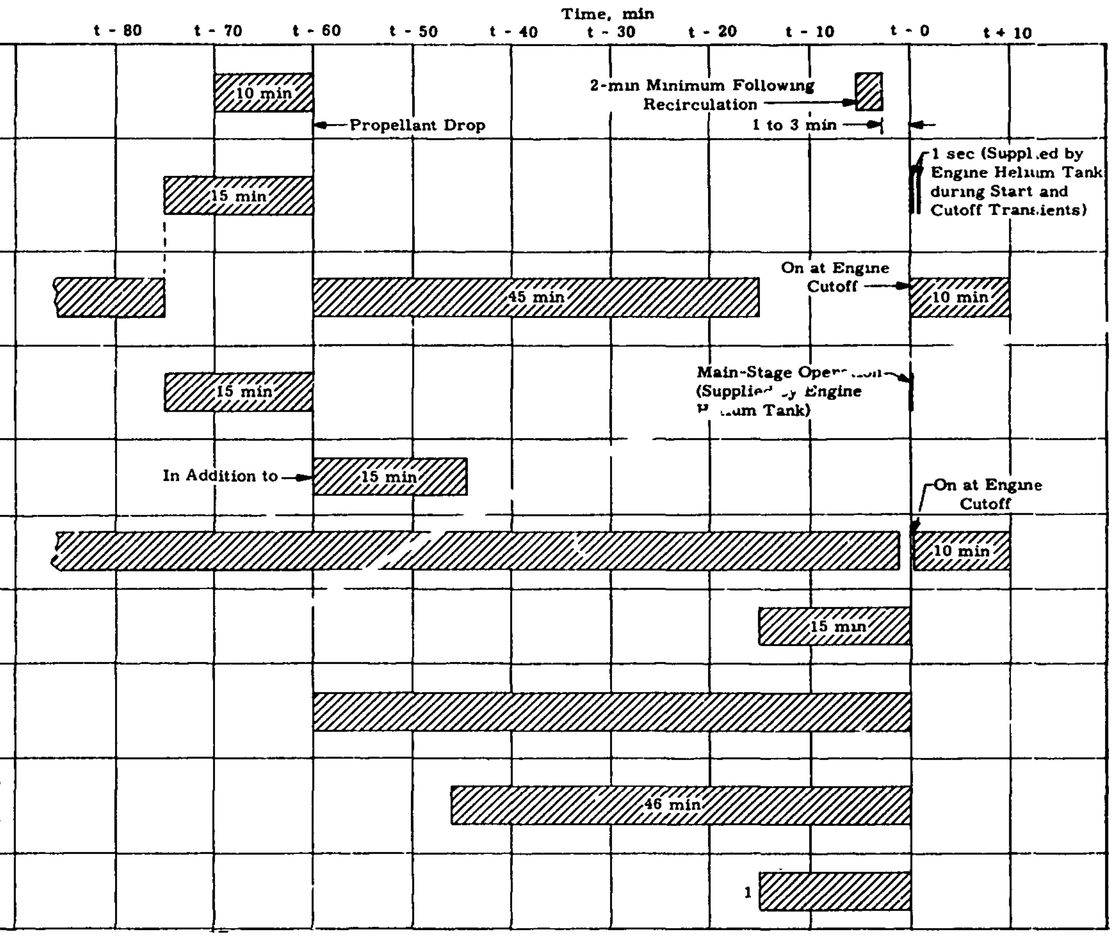
TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-06 AND J4-1801-07)

Replacement	Completion Date	Component Replaced
UCR*-007397	August 23, 1967	Gas Generator Outlet Temperature Transducer

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium, 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen, 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen, 400 - 450 psig 100 - 200°F (Nominal) 200 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium, 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect) Panel	Helium, 40 - 60 psig 50 - 200°F (Nominal) 60 scfm
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280 F Fuel; 28 to 46 psia -424 to -416°F
Hydrogen St. rt Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium, 1700 to 3250 psia -300 to -140°F
Crossover Duct Temperature Conditioning	Helium, -300°F to Ambient



[1]Conditioning temperature to be maintained for the last 15 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-		07A Target	07A Actual	07B Target	07B Actual	07C Target	07C Actual	07D Target	07D Actual
Time of Day, hr/Firing Date		1113/September 1, 1967		1132/September 1, 1967		1405/September 1, 1967		1424/September 1, 1967	
Pressure Altitude at Engine Star (Ref 1)		100,000	96,000	100,000	89,000	100,000	106,000	100,000	106 000
Firing Duration, sec ①		30	30 070	5	5 087	30	30.070	5	1 253
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28 ± 1	29 6	28 ± 1	27 8	28 ± 1	28 2	28 ± 1	27 9
	Temperature, °F	-421 4 ± 0 4	-421 1	-421 4 ± 0 4	-420 6	-421 4 ± 0 4	-421.2	-421.4 ± 0 4	-420.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	35 ± 1	35.4	48 ± 1	47 6	35 ± 1	35.7	48 ± 1	47 9
	Temperature, °F	-294 0 ± 0 4	-293 8	-295 3 ± 0 4	-295 3	-294 0 ± 0 4	-295.0	-295 3 ± 0 4	-295 9
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1248	1200 ± 10	1207	1250 ± 10	1245	1300 ± 10	1300
	Temperature, °F	-140 ± 10	-142	-300 ± 10	-301	-140 ± 10	-142	-300 ± 10	-299
Helium Tank Conditions at Engine Start	Pressure, psia	---	2660	---	2270	---	2300	---	2275
	Temperature, °F	--	-144	---	-294	---	-145	---	-296
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat (TSC2-19)	-80 ± 15	-93	---	53	-100 ± 15	-100	---	49
	Average	---	-112	---	35	---	-103	---	30
Crossover Duct Temperature Conditions at Engine Start, °F ②	TFTD-2	-100 ± 15	-101	---	408	-100 ± 15	-105	---	445
	TFTD-3	-100 ± 15	-107	170^{+15}_{-0}	169	-100 ± 15	-131	170^{+15}_{-0}	180
	TFTD-8	-100 ± 15	-81	---	375	-100 ± 15	-91	---	384
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	21	---	22	---	13	---	22
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		---	-94	---	-130	---	-46	---	-100
Pneumatic Control Package Temperature at Engine Start, °F		---	58	---	41	---	16	---	10
Fuel Lead Time, sec ①		3 0 ± 0 1	3 010	8 0 ± 0 1	8 003	8 0 ± 0 1	8 004	8 0 ± 0 1	8 004
Propellant in Engine Time, min		60	61	---	12	20	25	---	12
Propellant Recirculation Time, min		10	11	10	12	10	14	10	12
Prevalve Sequencing Logic		Auxiliary	Auxiliary	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	---	34	- -	-24	---	36	---	-17
Start Tank Discharge Valve Body Temperature at Engine Start, °F		---	10	---	1	---	-34	---	-30
Gas Generator Control Valve Body Temperature at Engine Start, °F		---	49	---	8	---	2	---	-27
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 ①		--- / ---	3 / 1 032	--- / ---	--- / ---	--- / ---	24 / 1 070	--- / ---	--- / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1470	---	2120	---	1565	---	2425
	Second Peak	---	---	---	2155	---	---	---	---
Thrust Chamber Ignition Time, sec (P_c = 100 psia) (Ref t_0) ①		---	1 032	---	0 947	---	1 070	---	0 919
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref t_0) ①		---	0 986	---	1 080	---	1.015	---	1.140
Main-Stage Pressure No 2, sec (Ref t_0) ①		---	1 770	---	1 624	---	2.005	---	---
550-psia Chamber Pressure Attained, sec (Ref t_0) ①		---	2 020	---	1.931	---	2 630	---	---
Propellant Utilization Valve Position at Engine Start, deg (Engine Start at t_0 + 10 sec)		Null / Closed	Null / Closed	Open / ---	Open / ---	Open / Closed	Open / Closed	Open / ---	Open / ---

Notes ① Data reduced from oscillogram
② Component conditioning to be maintained within limits for last 15 min before engine start

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening 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	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
07A	0	0 145	0 136	0.446	0 095	0 253	-3.010	0 050	0 067	0 446	0 058	0 050	0.446	0 540	1 716	0.446	0 110	0 020	0 446	0 166	0 058	0 446	0 250	0 280
07B	0	0.150	0.134	0 445	0.095	0 253	-8.003	0 050	0 064	0 445	0 056	0 056	0 445	0.625	1 750	0 445	0 116	0 020	0 445	0.182	0 064	0 445	0 232	0 287
07C	0	0.142	0 138	0.445	0.099	0.250	-8 004	0.050	0 056	0 445	0 054	0 046	0 445	0 570	1 645	0 445	0 108	0 025	0 445	0.170	0 062	0 445	0 239	0 284
07D	0	0.157	0 146	0 445	0 098	0 257	-8 004	0 050	0.061	0 445	0 055	0 050	0 445	0 695	---	0 445	0 114	0 024	0 445	0 188	0.070	0 445	0 230	0 288
Pre-Fire Final Sequence	0	0 097	0 108	0 444	0 092	0.250	-1 009	0 043	0 069	0 444	0 047	0 046	0 444	0.552	1 629	0 444	0 077	0 034	0 444	0 132	0 052	0 444	0 219	0.299

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine 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
07A	30 070	0.122	0 316	30 070	0.080	0 175	30.070	0 075	0.010	30 070	0 033	0 011	30 070	0 265	0 550
07B	5 087	0.113	0 305	5 087	0 066	0.180	5.087	0 075	0 016	5.087	0 035	0.016	5.087	0 230	0.496
07C	30 070	0 110	0 285	30.070	0 073	0.166	30 070	0 072	0.016	30 070	0.033	0.014	30 070	0.264	0.540
07D	1.253	0.104	0 294	1.253	0 020	0.065	1.253	0.080	0.018	1.253	0 040	0 018	1 253	0 155	0 570
Pre-Fire Final Sequence	9.372	0 089	0.247	9.372	0.062	0 131	9.372	0 090	0 050	9 372	0 044	0 052	9 372	0.235	0 587

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 reduced from oscillogram

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		07A		07C	
		Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lbf	226,000	225,000	226,000	223,000
	Chamber Pressure, psia	765	756	762	751
	Mixture Ratio	5.412	5.381	5.398	5.377
	Fuel Weight Flow, lb_m/sec	82.80	82.08	82.89	81.85
	Oxidizer Weight Flow, lb_m/sec	448.08	441.63	447.4	440.2
	Total Weight Flow, lb_m/sec	530.88	523.71	530.29	522.01
Thrust Chamber Performance	Mixture Ratio	5.612	5.582	5.597	5.578
	Total Weight Flow, lb_m/sec	523.83	516.71	523.28	515.07
	Characteristic Velocity, ft/sec	8007	8014	7985	7989
Fuel Turbopump Performance	Pump Efficiency, percent	73.7	73.7	73.5	73.5
	Pump Speed, rpm	26,923	26,714	26,864	26,667
	Turbine Efficiency, percent	59.4	59.2	59.3	59.2
	Turbine Pressure Ratio	7.44	7.44	7.45	7.44
	Turbine Inlet Temperature, °F	1255	1232	1244	1222
	Turbine Weight Flow, lb_m/sec	7.05	7.00	7.01	6.94
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.2	80.2	80.1
	Pump Speed, rpm	8508	8431	8490	8419
	Turbine Efficiency, percent	46.5	46.3	46.5	46.3
	Turbine Pressure Ratio	2.68	2.68	2.67	2.67
	Turbine Inlet Temperature, °F	782	765	773	759
	Turbine Weight Flow, lb_m/sec	6.12	6.08	6.09	6.03
Gas Generator Performance	Mixture Ratio	0.972	0.958	0.966	0.953
	Chamber Pressure, psia	658	652	654	645

Notes: 1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-07 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
	Sparks							
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Forces		lb_f					
FSP-1	Side Load (Pitch)		±20,000	x		x		
FSY-1	Side Load (Yaw)		±20,000	x		x		
	Heat Flux		$\frac{watts}{Sr.\ cm^2}$					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0 to 7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCASI-2	Augumented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		**psia**					
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injectior	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
POPSD-H1	LO_2 Pump Seal Drain Simulator (High Flow)		0 to 50	x				
POPSD-H2	LO_2 Pump Seal Drain Simulator (High Flow)		0 to 50	x				
POPSD-L1	LO_2 Pump Seal Drain Simulator (Low Flow)		0 to 50	x				
POPSD-L2	LO_2 Pump Seal Drain Simulator (Low Flow)		0 to 50	x				
POPSD-P1	LO_2 Pump Seal Drain Simulator (Plugged)		0 to 50	x				
POPSD-P2	LO_2 Pump Seal Drain Simulator (Plugged)		0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				

TABLE III-1 (Continued)

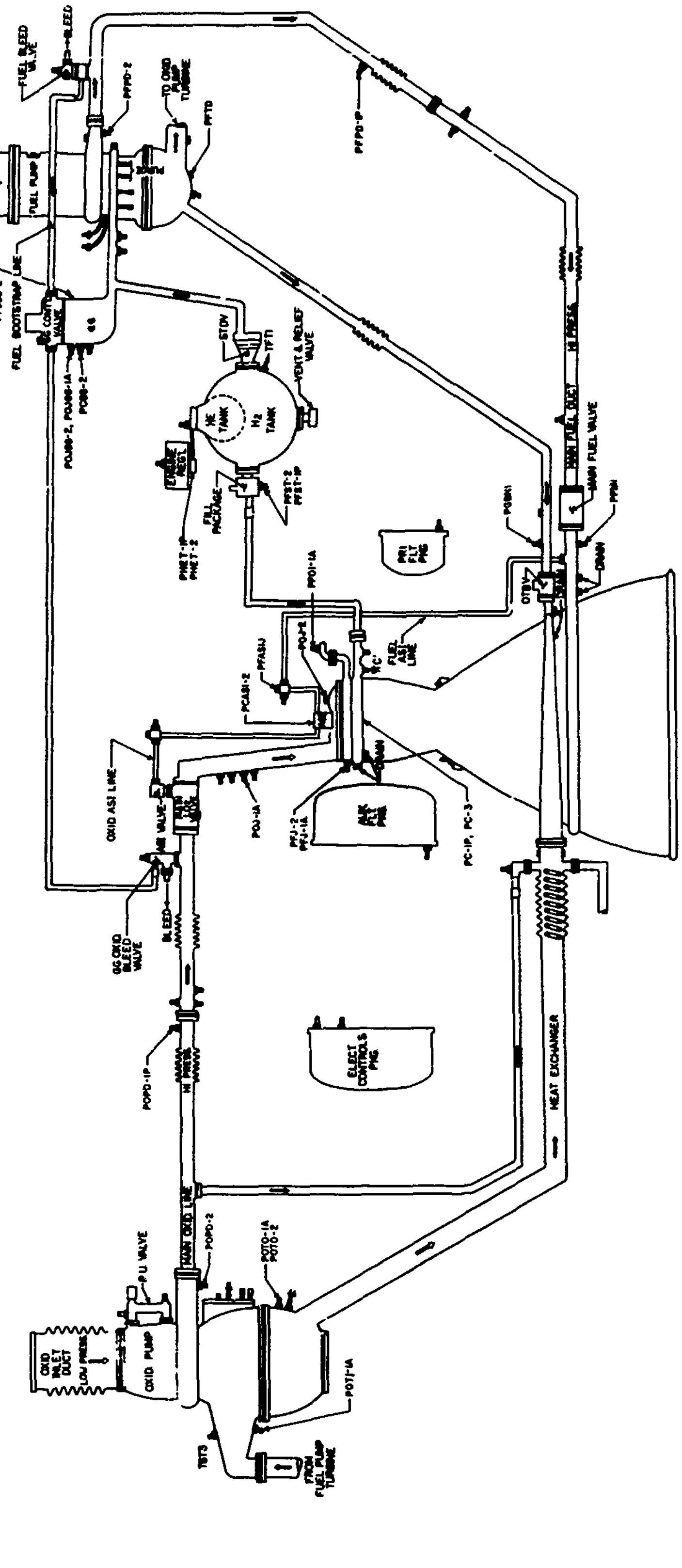
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		**psia**					
PFUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		**rpm**					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		**°F**					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x			x	
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x			x	
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x			x	
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPB-1A	Fuel Pump Bearing		-425 to -325	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x		
THET-1P	Helium Tank	NST1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TNODP	LO_2 Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TOPSD-H1	Oxidizer Pump Seal Drain Simulator (High Flow)		0 to 500	x				
TOPSD-H2	Oxidizer Pump Seal Drain Simulator (High Flow)		0 to 500	x				
TOPSD-L1	Oxidizer Pump Seal Drain Simulator (Low Flow)		0 to 500	x				
TOPSD-L2	Oxidizer Pump Seal Drain Simulator (Low Flow)		0 to 500	x				
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Pre-Chill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSECP	Engine Control Package Skin		-50 to +250	x				
TSGGOC	Gas Generator Opening Control Port		-350 to +100	x				
TSOB	Oxidizer Bootstrap Shroud Skin		-200 to +100	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSPIP	Primary Instrument Package Skin		-50 to +250	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				

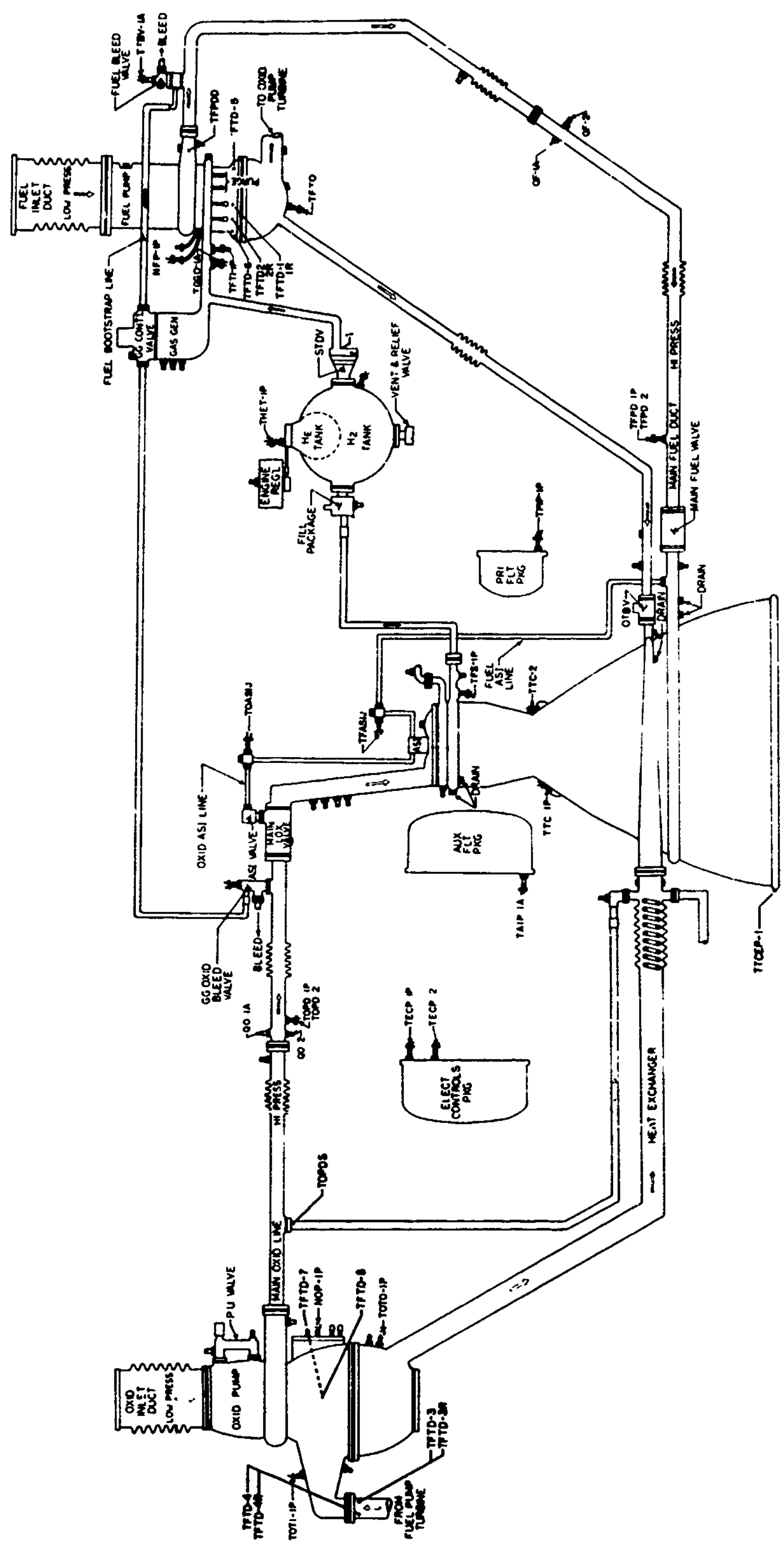
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x				
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g's					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



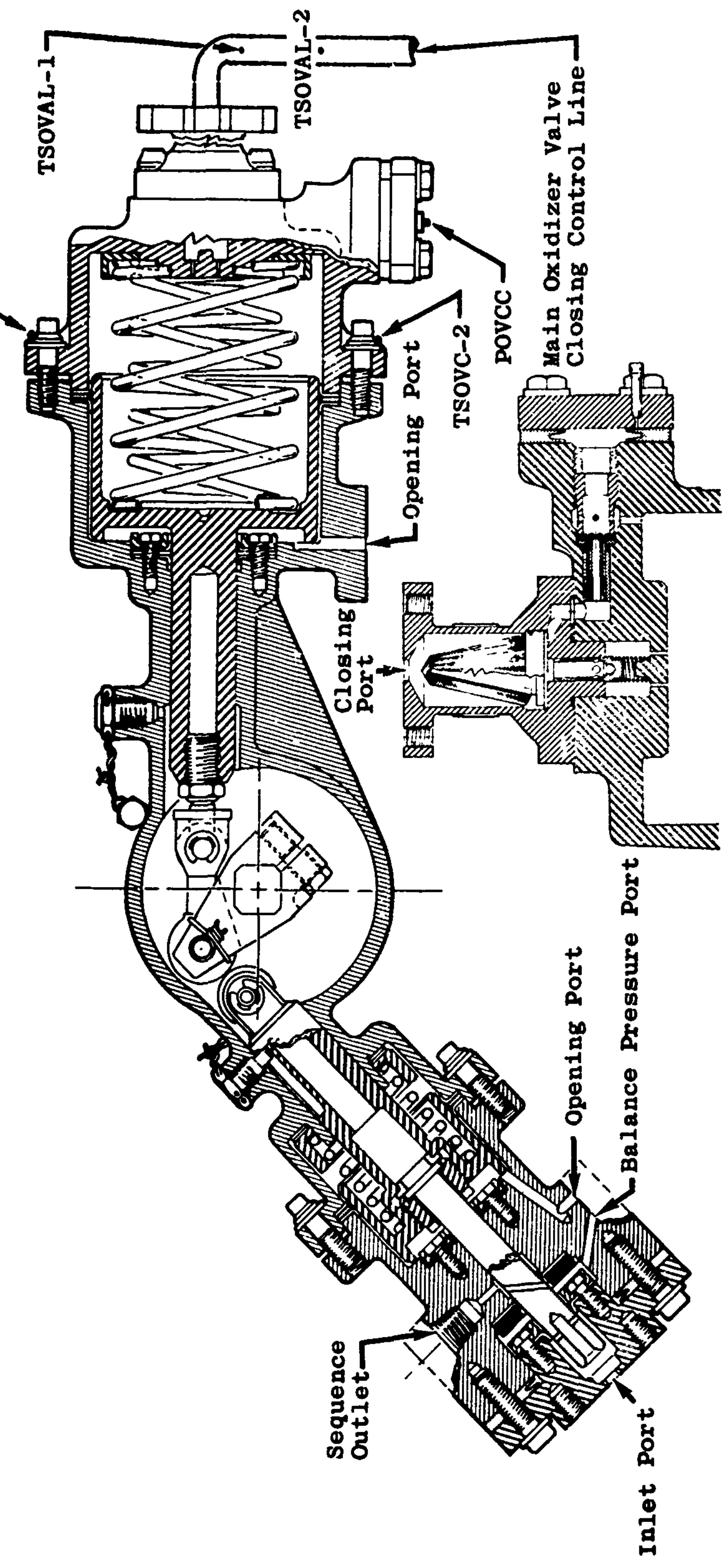
a. Engine Pressure Tap Locations

Fig. III-1 Instrumentation Locations



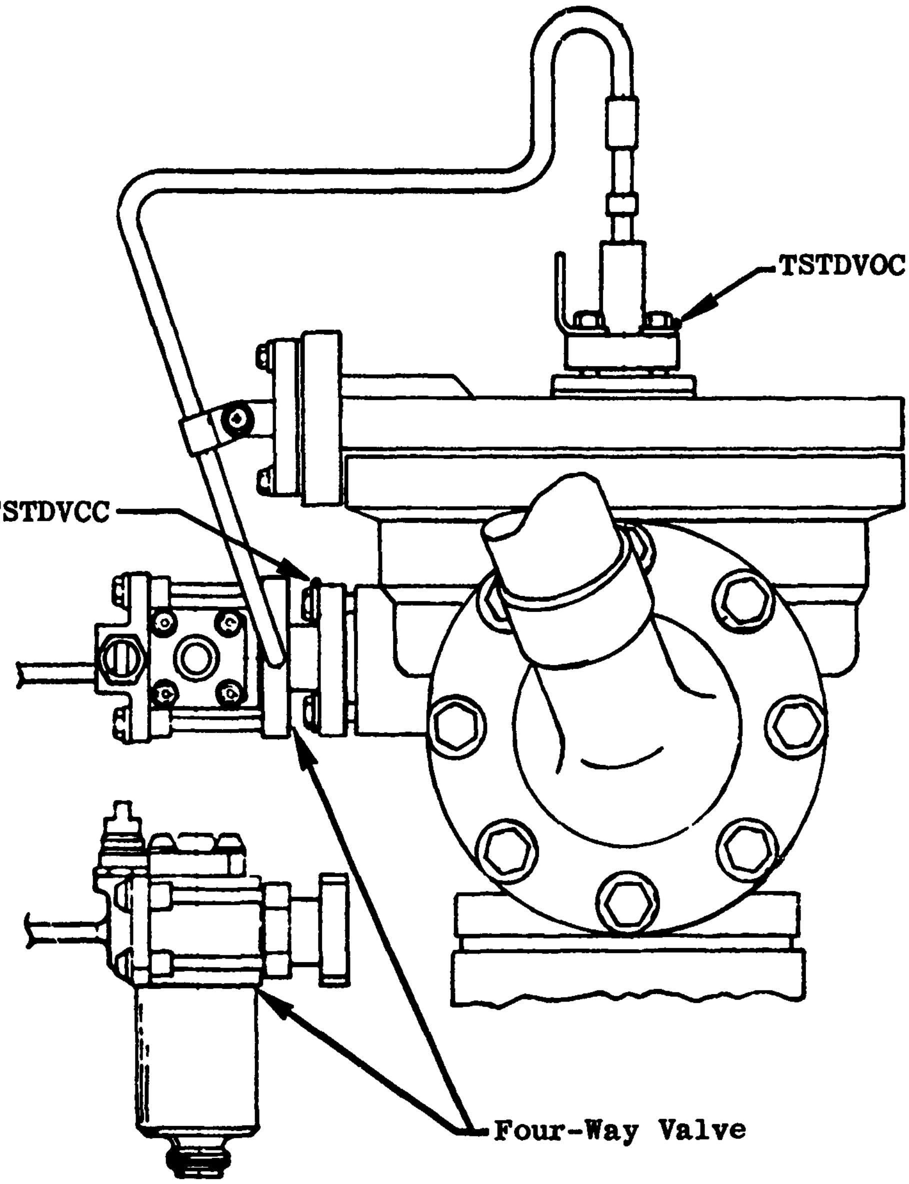
b. Engine Temperature, Flow, and Speed Instrumentation Locations

Fig. III-1 Continued

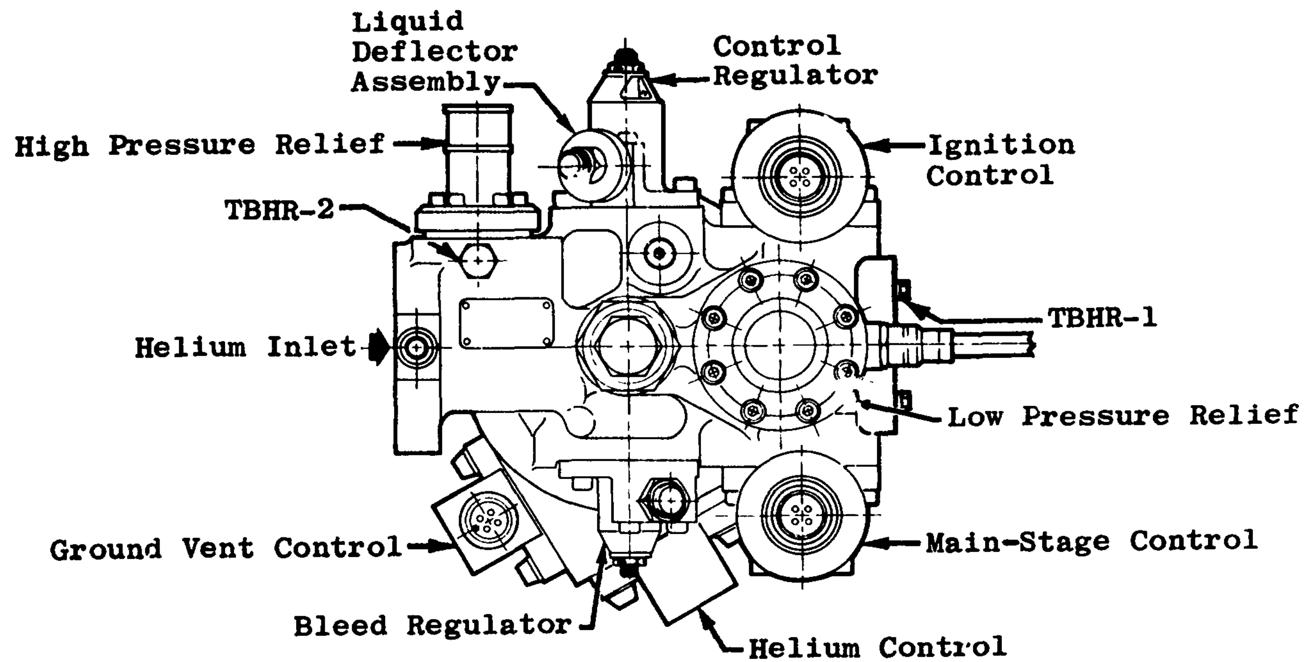


c. Main Oxidizer Valve

Fig. III-1 Continued



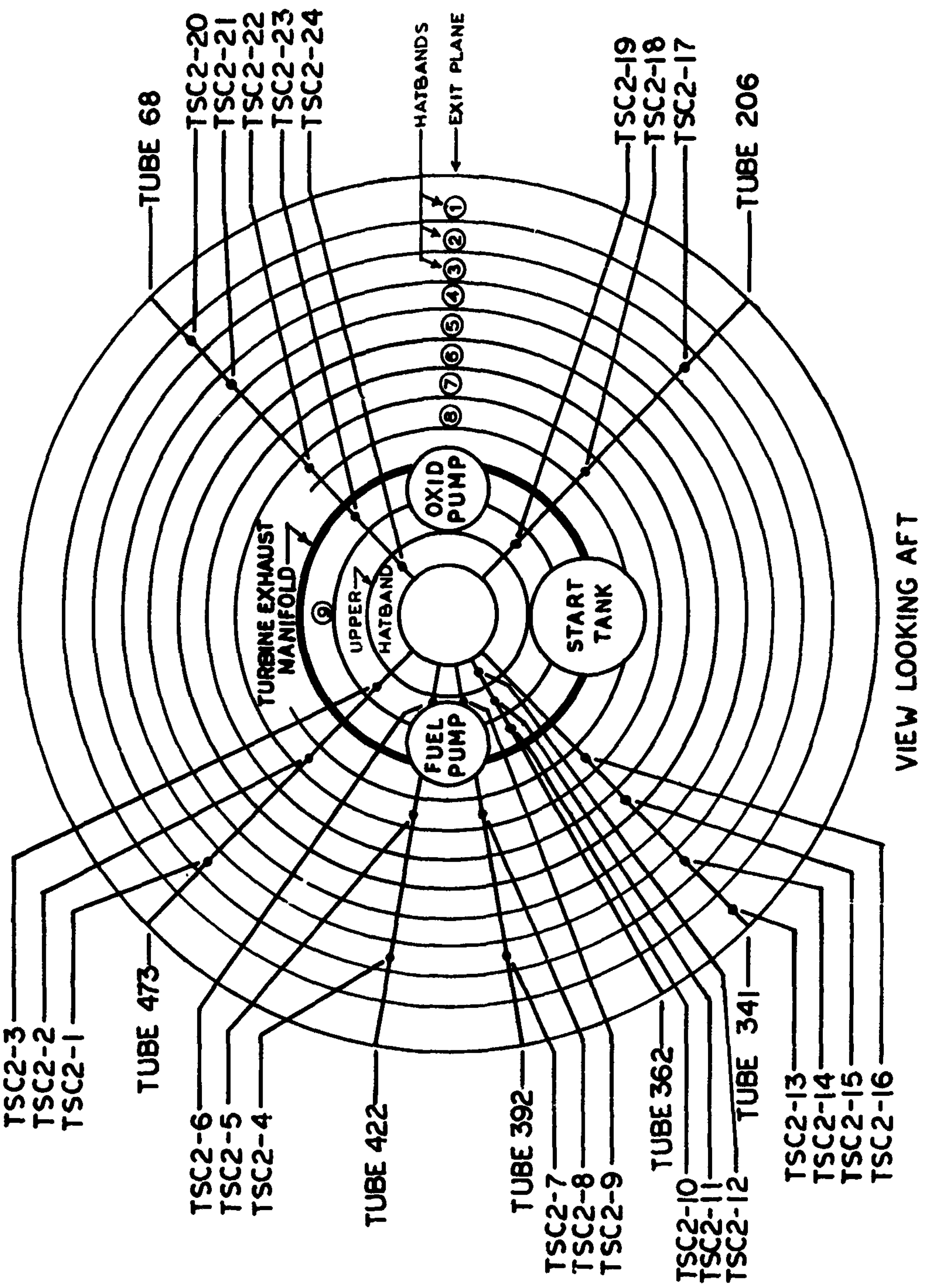
d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

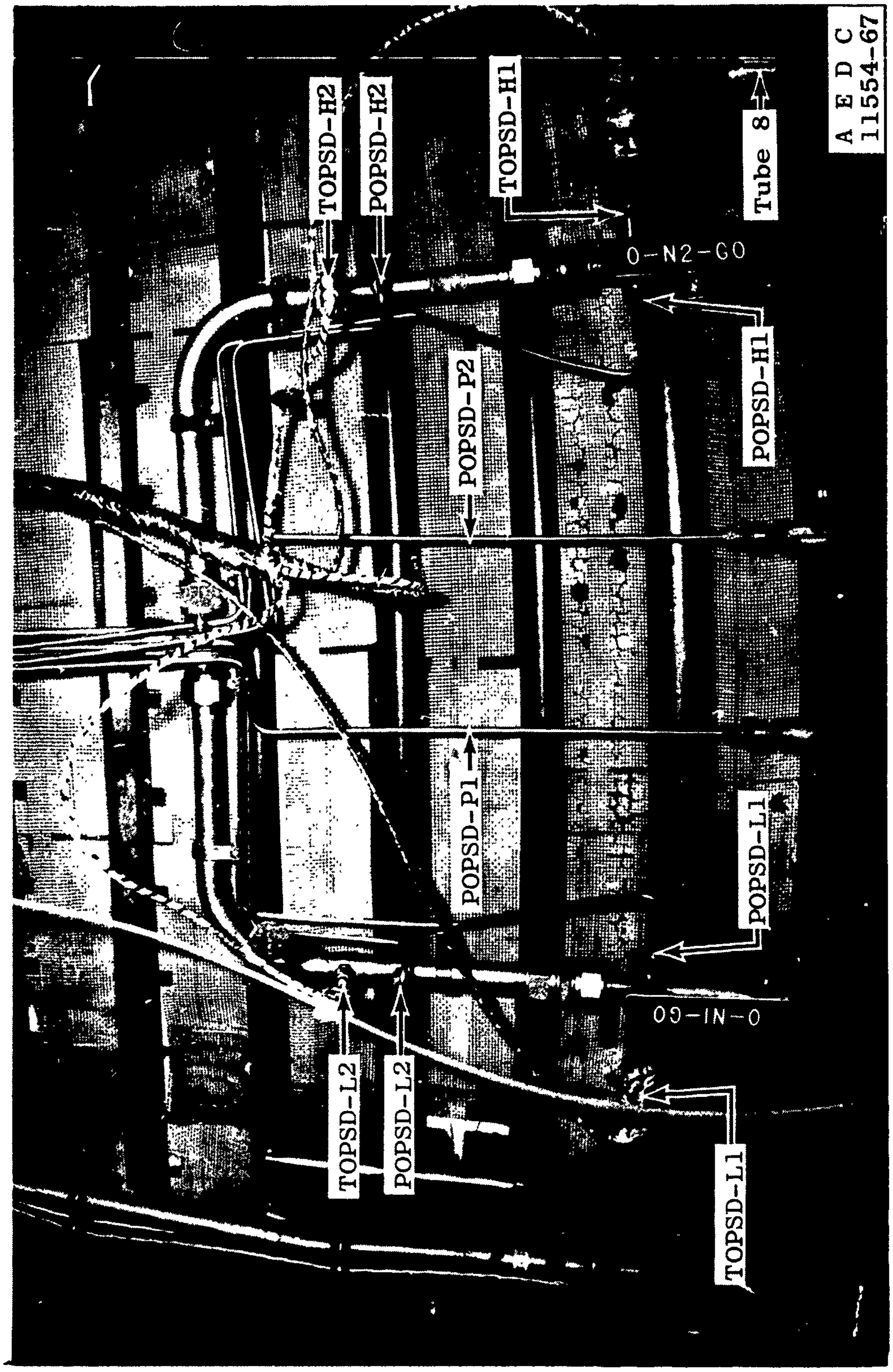
e. Helium Regulator

Fig. III-1 Continued



f. Thrust Chamber

Fig. III-1, Continued



g. Oxidizer Pump Primary Seal Drain Simulation Tubes

Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF} A_{TIF} K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7 P_c A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\, \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

IF $P_{OO} \geq 1010$ Set $P_{OO} = 1010$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}}$$

$$+ E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \Delta h_f W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2}-1} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2}-1}{\gamma_{H2}}}\right] \frac{A_{NB} \; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS}\left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4_{TEF} M_{H2}} \left(\frac{\gamma_{H2}-1}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4_{TIF}\, M_{H1}} \; \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. These firings were accomplished during test period J4-1801-07 at pressure altitudes ranging from 89,000 to 106,000 ft at engine start. The objectives of the test included the evaluation of the effect of start tank energy on the oxidizer pump spin speed and the effect of thrust chamber temperature on the fuel pump high level stall margin. Firing 07A was conducted with 12 experimental oxidizer pump primary seal drain tubes attached to the engine. The accumulated firing duration for this test period was 66.5 sec.

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