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**ALTITUDE DEVELOPMENTAL TESTING OF THE
J-2 ROCKET ENGINE IN PROPULSION ENGINE
TEST CELL (J-4) (TESTS J4-1801-11 AND J4-1801-12)**

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Per AF Letter dated 12 July 74 Signed William D. Cole

D. E. Franklin and C. R. Tinsley

ARO, Inc.

January 1968

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**LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
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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 AF 40(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 manufacturer of the S-IVB stage. The testing reported herein was conducted on October 9 and 17, 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 22, 1967.

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This technical report has been reviewed and is approved.

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ABSTRACT

Three firings of the Rocketdyne J-2 rocket engine S/N J-2047 were conducted in Test Cell J-4 of the Large Rocket Facility. Four firings were originally scheduled for each of the two test periods. However, because of problems developing with the augmented spark igniter ignition detect probe, only one firing for each test period was successfully conducted, and a third firing attempt was aborted. The firings were accomplished during test periods J4-1801-11 and -12 at pressure altitudes ranging from 98,000 to 104,000 ft at engine start. The objectives of these tests were to (1) evaluate the effect of altitude environment on engine operation by a comparison of Rocketdyne sea-level acceptance test (624061) data with AEDC altitude test data and (2) evaluate engine transient operation with conditions simulating an S-IVB/S-V two orbit restart and compare results with engine J-2052 data for similar conditions.

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NOMENCLATURE

A	Area, in. ²
ASI	Augmented spark igniter
ES	Engine start, designated as the time that 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 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 engine installed at the beginning of the program, S/N J-2052, was removed before test 11 and replaced with engine S/N J-2047. The performance rating of both engines is identical. Accumulated firing time on engine J-2052 at AEDC was 1402 sec, accomplished in 89 engine starts before replacement. The three firings reported herein were conducted during test periods J4-1801-11 and -12 on October 9 and 17, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). Primary test objectives were to (1) compare altitude test data at AEDC with Rocketdyne sea-level acceptance test (test 624061) data for J-2047 and (2) evaluate engine transient operation for conditions simulating an S-IVB/S-V two orbit restart and compare results with engine J-2052 for similar conditions. These firings were conducted at pressure altitudes ranging from 98,000 to 104,000 ft (geometric pressure altitude, Z, Ref. 1).

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during these tests have been previously supplied to the sponsor, and copies are on file at AEDC. The results of the previous test period are reported 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 lbf 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 between

tests 11 and 12 are presented in Tables III and IV, respectively. Thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, 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 length (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 port 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 prevalues 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 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 pre-valves, 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 venting 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), 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 S-IVB 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 as required. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning.

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 Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III PROCEDURE

Pre-operational 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 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

A total of three firings of the J-2 rocket engine (S/N-2047) were conducted on October 9 and 17, 1967, during test periods J4-1801-11 and -12 in support of S-IVB/S-V test objectives. These firings were obtained at pressure altitudes ranging from 98,000 to 104,000 ft at engine start. The total firing duration for the two test periods was 60.6 sec.

The primary objectives of tests 11 and 12 were to (1) obtain transient and steady-state performance data for comparison with Rocketdyne sea-level test 624061 and (2) evaluate engine transient operation for conditions simulating an S-IVB/S-V two orbit restart. Firing 11A did not satisfy test objectives since an orifice retainer ring, used for sea-level testing, was inadvertently left in the oxidizer turbine bypass line. Failure of the augmented spark igniter ignition detect probe during firings 11A and 12A also precluded successful completion of test objectives. Ambient thrust chamber and crossover duct temperature conditions were specified for engine start on firings 11A and 12A; the crossover duct was conditioned on firing 12B to simulate thermal conditions expected for an S-IVB/S-V two orbit restart.

Specific test objectives and a brief summary of results for the firings are presented in the following sections. Table VI presents conditioning targets and the measured test conditions at engine start. The oxidizer and fuel pump inlets, start tank, and helium tank conditions at engine start are shown in Fig. 8.

<u>Firing</u>	<u>Test Objectives</u>	<u>Results</u>
11A	Conduct a 30-sec firing of J-2 engine S/N J-2047 to obtain data for comparison with sea-level acceptance test data.	A 30-sec firing was successfully completed. Major objectives were not attained because of the presence of the orifice retainer ring in the oxidizer turbine bypass line used for sea-level testing. The augmented spark igniter ignition detect probe failed during this firing, resulting in cancellation of the remaining scheduled firings.

<u>Firing</u>	<u>Test Objectives</u>	<u>Results</u>
12A	Repeat of firing 11A. The orifice retainer ring in the oxidizer turbine bypass line was removed before test 12.	A 30-sec firing was successfully completed. Test objectives were satisfactorily met.
12B	Evaluate vehicle AS-501 engine modifications for an S-IVB/S-V two orbit restart simulation utilizing maximum start energy expected for the two orbit condition.	This firing was prematurely terminated at $t_0 + 0.454$ sec. The ignition detect signal did not occur before expiration of the ignition phase timer as required by the engine logic. This was caused by an electrical short circuit of the ignition detect probe. None of the test objectives were met.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-11A

Firing 11A was 30.07 sec in duration with a propellant utilization valve excursion from null position to full closed at approximately $t_0 + 10$ sec. The fuel lead duration was 7.97 sec. A pre-firing history of the crossover duct and thrust chamber temperatures are shown in Fig. 9.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 10. Thrust chamber ignition occurred at $t_0 + 0.986$ sec; engine vibrations were observed for 14 msec beginning at $t_0 + 0.980$ sec. Combustion chamber pressure buildup to 550 psia occurred at $t_0 + 1.878$ sec. The gas generator outlet temperature initial and second peaks were 2070 and 2230°F, respectively. The main oxidizer valve, second-stage, initial movement occurred at $t_0 + 1.27$ sec with a second-stage ramp time of 1.847 sec. Considering the engine start conditions for firing 11A, the gas generator outlet temperatures and the oxidizer valve second-stage delay time were excessive. This was caused by a high starting energy to the oxidizer turbine, caused by an orifice retainer ring (Fig. 11) in the oxidizer turbine bypass line. The retainer ring, which was not removed after sea-level testing, reduced the cross-sectional area of the bypass line by 48 percent. The oxidizer turbine speed peaked at 3890 rpm during start tank discharge. Data presented in Ref. 5 indicate that for thermal conditions similar to those obtained

for firing 11A, the peak oxidizer turbine speed during start tank discharge should be approximately 3300 rpm, or approximately 15 percent less than actually measured with the orifice retainer ring installed.

The augmented spark igniter ignition detect event occurred 0.265 sec after the engine start command but failed to de-energize after shutdown. The probe was not shimmed as on some recent tests, which resulted in maximum extension of the probe into the augmented spark igniter chamber. This, coupled with the excessive combustion temperatures resulting from a high energy supply to the oxidizer turbine, evidently caused the probe to fail. The ignition detect voltage amplifier indicated probe failure occurred at $t_0 + 0.982$ sec. Three other firings scheduled for this test period were cancelled because of the failure.

Combustion chamber pressure and engine ambient pressure for the firing duration are shown in Fig. 12. Pressure altitude at engine start was 101,000 ft.

Start transient fuel pump head/flow data are compared with the nominal stall inception curve (provided by the engine manufacturer) in Fig. 13. The minimum stall margin, in the high-speed region, was 1050 gpm at approximately 22,000 rpm.

A summary of selected engine valve operating times for start and shutdown is presented in Table VII. Valve operations appeared normal.

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

4.2.2 Firing J4-1801-12A

The programmed 30-sec firing, preceded by an 8-sec fuel lead, was successfully accomplished with a propellant utilization valve excursion from the null to the full-closed position at approximately $t_0 + 11$ sec. A thermal history of the crossover duct and thrust chamber throat before engine start is presented in Fig. 14.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 15. Second-stage movement of the main oxidizer valve began at $t_0 + 1.046$ sec with a valve travel time of 2.050 sec. Thrust chamber ignition occurred at $t_0 + 1.042$ sec with 20 msec of engine vibration (VSC). The gas generator outlet temperature peaked at 1425°F with a second peak of 1540°F. Combustion chamber pressure buildup to

550 psia occurred at $t_0 + 1.975$ sec. Engine ambient pressure and combustion chamber pressure during the firing are presented in Fig. 16. Pressure altitude at engine start was 98,000 ft.

Start transient fuel pump head/flow data are compared with the nominal stall inception curve (Fig. 17)(provided by the engine manufacturer), which indicates a conservative stall margin was maintained during the engine starting transient.

A summary of the engine valve operating times for both start and shutdown is presented in Table VII. Valve operations were normal with the exception of the oxidizer turbine bypass valve closing. The valve traveled to approximately 80 percent closed in 245 msec, whereas the travel time from 80 to 90 percent closed was 130 msec (normal travel time from 80 percent closed to fully closed is approximately 70 msec). However, the valve closing time was well within specified limits.

Augmented spark igniter ignition was detected 254 msec after engine start. At $t_0 + 1.053$ sec, the time corresponding approximately to the expiration of 20 msec of engine vibration, the signal from the augmented spark igniter ignition detect probe de-energized and remained de-energized throughout the remainder of this firing. This anomaly was observed before firing 12B. However, temporary loss of the ignition detect event has been experienced during previous firings (Ref. 6).

Engine start transients for both AEDC altitude (J4-1801-12A) and Rocketdyne sea-level (624061) firings are presented in Fig. 18. The engine start conditions were similar, as shown in Table IX. Figure 18 reveals that the oxidizer pump peak speed was approximately 1200 rpm higher during start tank discharge for the sea-level firing, with the orifice in the oxidizer turbine bypass line, than for the altitude firing. As a result, the oxidizer pump discharge pressure during start tank discharge was approximately 165 psi higher for the sea-level firing. Thrust chamber ignition was delayed approximately 110 msec for the altitude firing.

The main oxidizer valve employed in the sea-level firing was replaced before altitude testing. Figure 18 shows that for the altitude firing the main oxidizer valve second-stage ramp time was longer than that of the sea-level firing. This longer second-stage ramp time for the altitude firing contributed to a higher gas generator power and a faster buildup to steady-state operation. The gas generator outlet temperature at altitude exceeded that at sea level by a maximum of 1100°F during the start transient (Fig. 18d).

Figure 19 shows that a more conservative stall margin was maintained for the altitude firing. This stall margin difference is attributed primarily to the main oxidizer valve second-stage ramp time.

Engine steady-state performance data from AEDC firing 12A and Rocketdyne sea-level firing 624061 are presented in Table VIII. In general, all performance parameters for the two firings agreed within approximately ± 1 percent.

The difference in fuel turbine efficiency, fuel and oxidizer turbine pressure ratios, and fuel and oxidizer turbine weight flows for firings 11A and 12A may have been caused by the orifice retainer ring left installed during firing 11A.

4.2.3 Firing J4-1801-12B

The programmed 5-sec firing, preceded by an 8-sec fuel lead, was terminated prematurely at $t_0 + 0.454$ sec. The augmented spark igniter ignition detect event did not occur before expiration of the ignition phase timer, as required by the engine logic, and resulted in engine cutoff. Electrical checks revealed that the ignition detect probe was electrically short circuited to ground.

Thermal conditioning of the crossover duct and a thermal history of the thrust chamber throat before engine start are presented in Fig. 20. Pressure altitude at engine start was 104,000 ft. Chamber pressure peaked at 20 psia, approximately $t_0 + 0.73$ sec. A summary of pertinent engine valve operating times is presented in Table VII.

4.3 POST-TEST INSPECTION

Inspection of the augmented spark igniter chamber after tests 11 and 12 indicated no chamber erosion. The ignition detect probe failed during tests 11 and 12 and was replaced after each test.

SECTION V SUMMARY OF RESULTS

The results of these three firings of the J-2 engine conducted on October 9 and 17, 1967, in Test Cell J-4 are summarized as follows:

1. Altitude test (firing 12A) data for J-2 engine S/N J-2047 from AEDC were compared with Rocketdyne sea-level test (624061) data. The major differences observed were
 - a. thrust chamber ignition occurred 110 msec later at altitude, and
 - b. the combustion chamber pressure attained 550 psia approximately 330 msec sooner, and the stall margin was more conservative at altitude (attributed to a longer main oxidizer valve ramp time).
2. The gas generator outlet temperature first and second peaks were 2070 and 2230°F for firing 11A with an orifice retainer ring in the oxidizer turbine bypass line. Gas generator outlet temperature initial and second peaks were 1425 and 1540°F for firing 12A with the retainer ring removed.
3. The minimum fuel pump stall margin was 1050 gpm, occurring during firing 11A.
4. The augmented spark igniter ignition detect probe failed during two firings (11A and 12A). No augmented spark igniter chamber erosion was observed during post-test inspection.
5. In general, all performance parameters for altitude and sea-level firings agreed within approximately ± 1 percent.

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1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Rafferty, C. A. "Altitude Development Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-10)." AEDC-TR-68-5 (to be published).
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.
5. Collier, M. R., and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1554-26)." AEDC-TR-67-115, September 1967.
6. Simpson, J. N., and Tinsley, C. R. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-08)." AEDC-TR-67-240, January 1968.

APPENDIXES

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

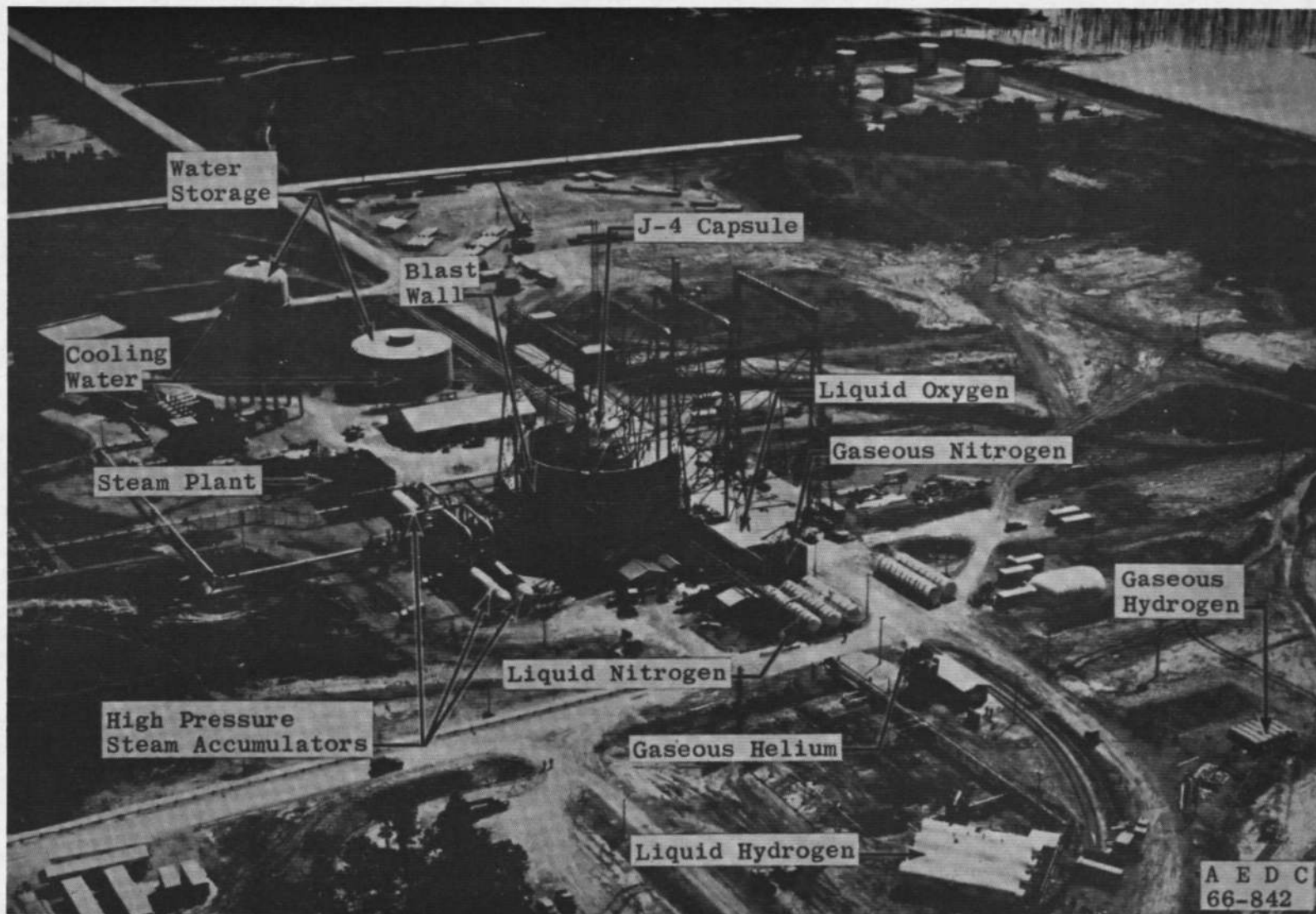


Fig. 1 Test Cell J-4 Complex

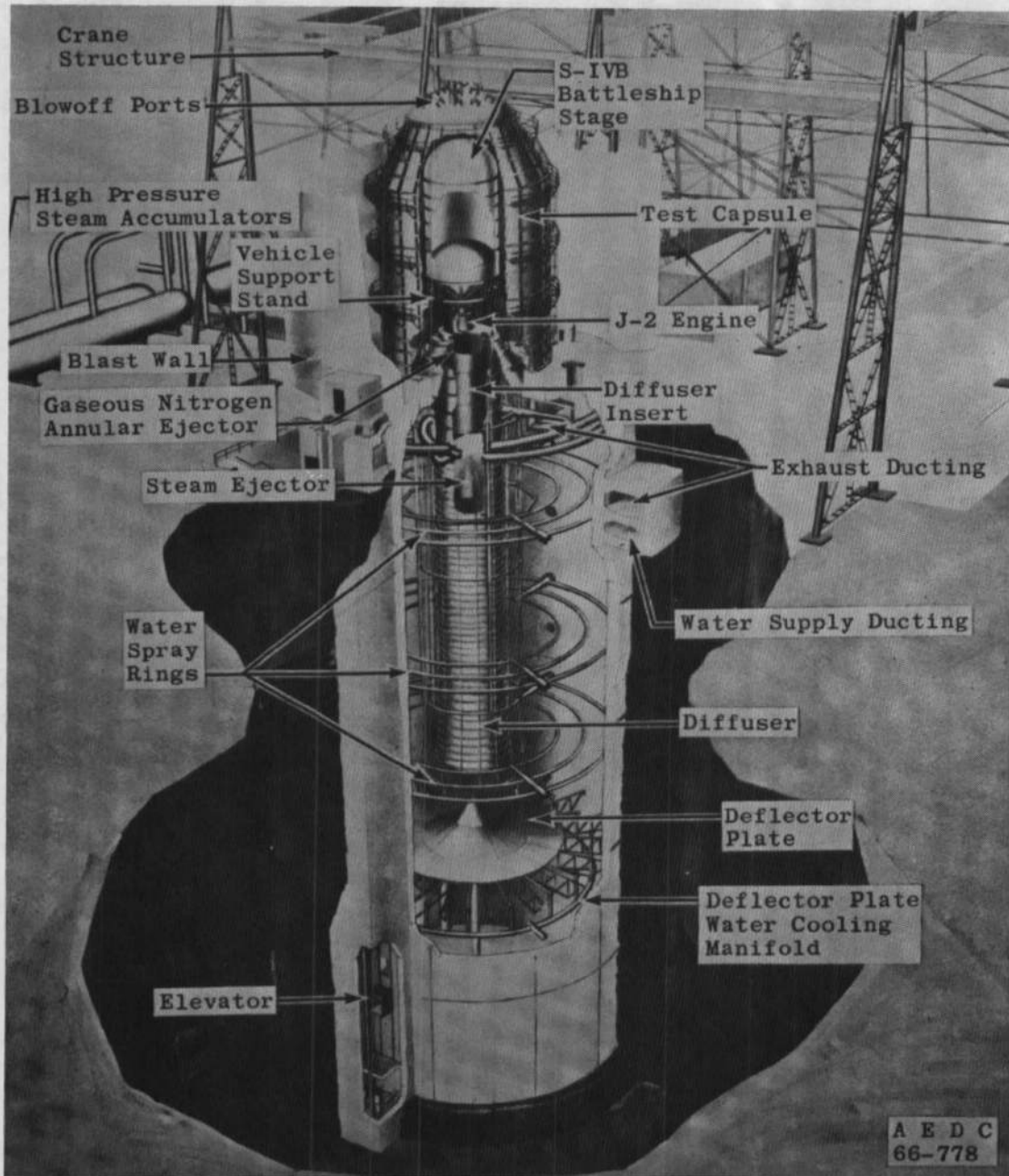


Fig. 2 Test Cell J-4, Artist's Conception

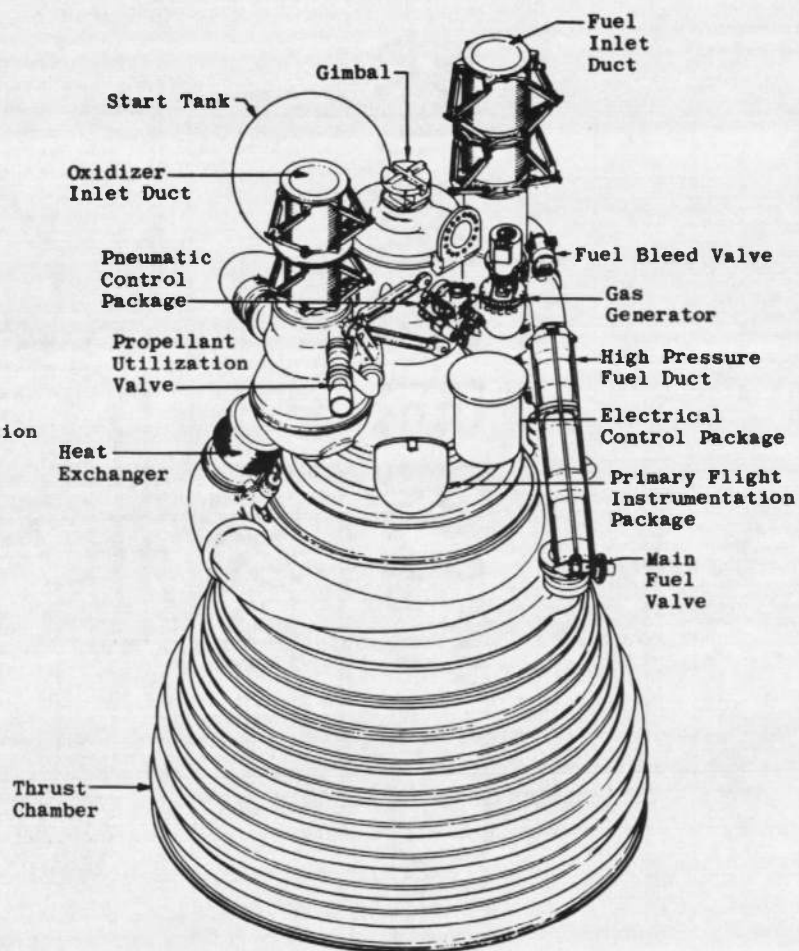
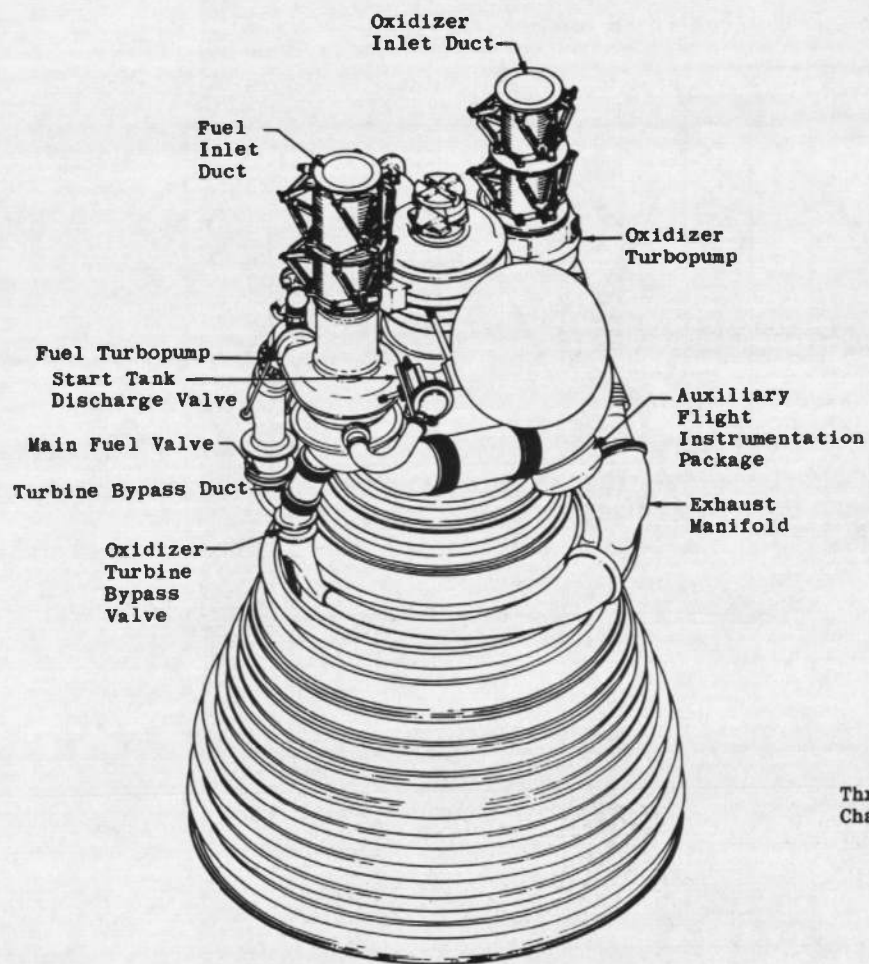


Fig. 3 Engine Details

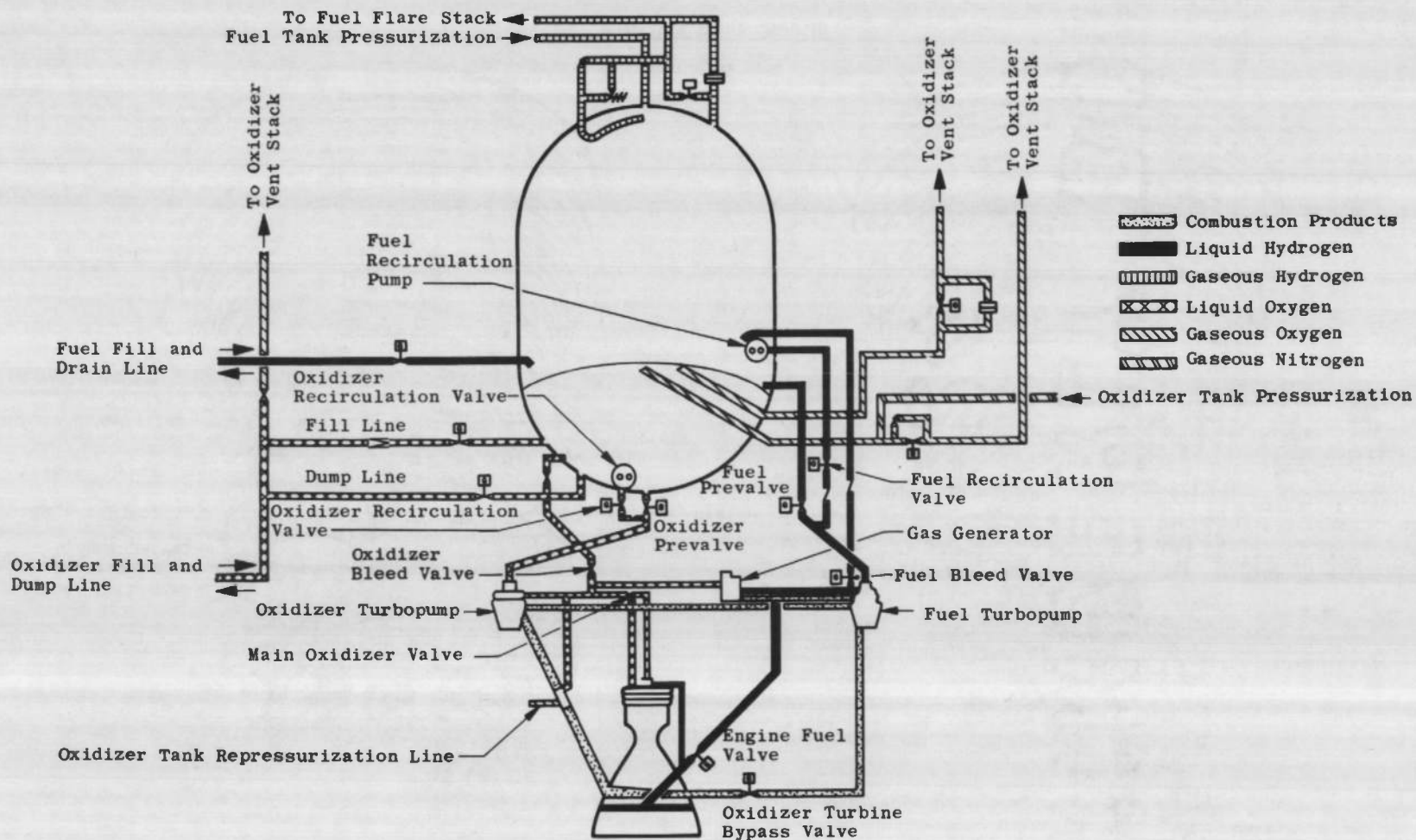
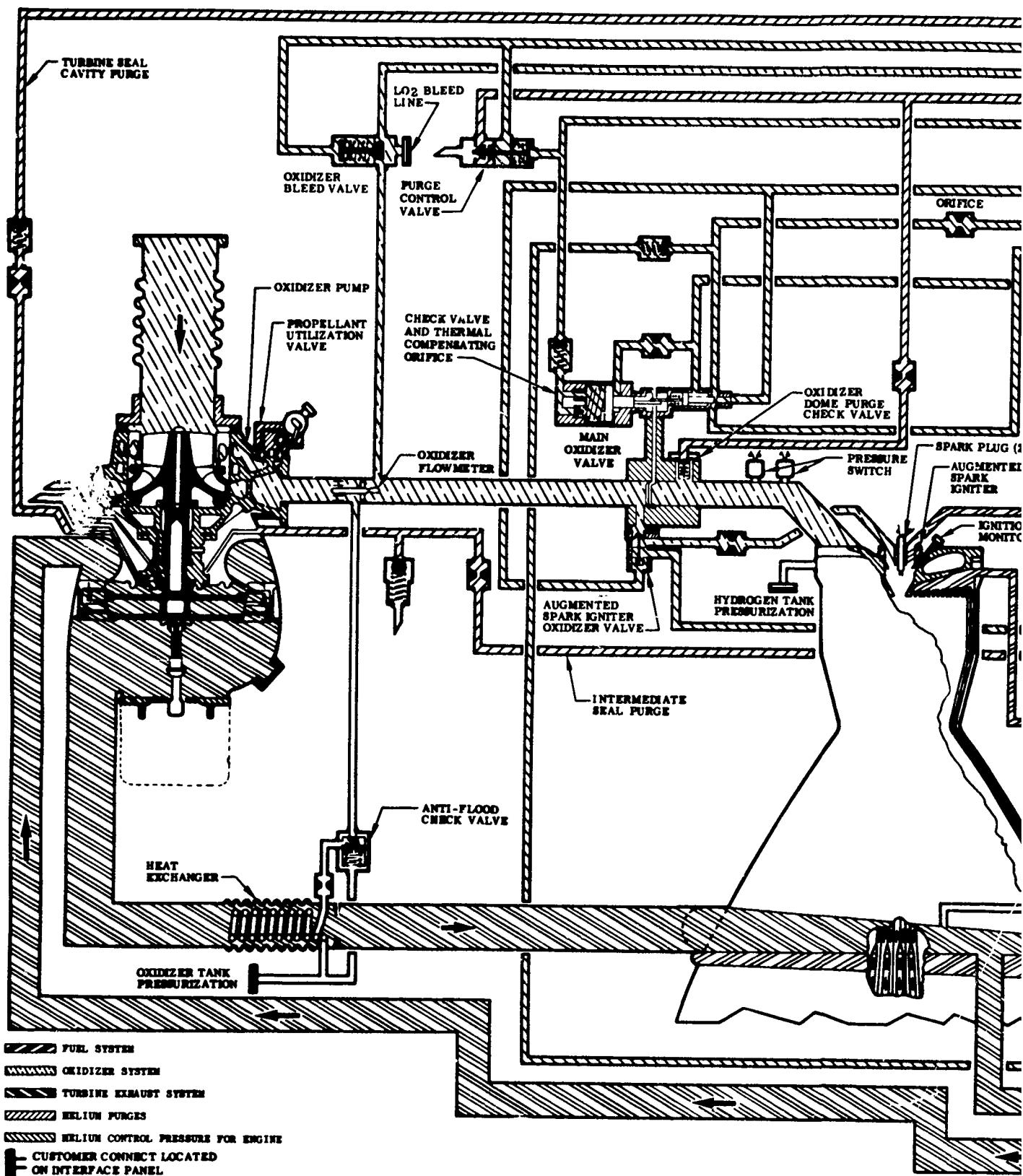
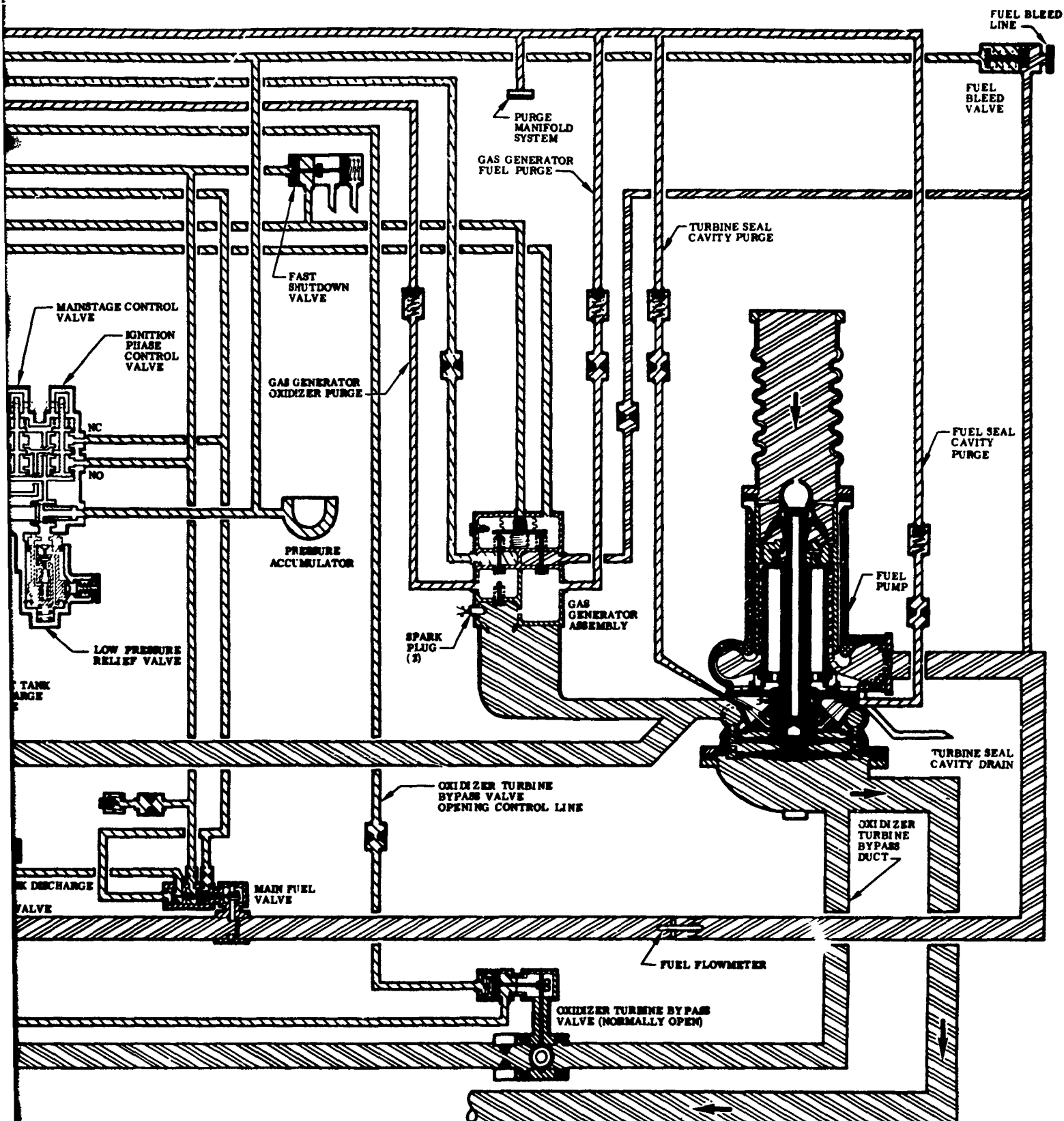
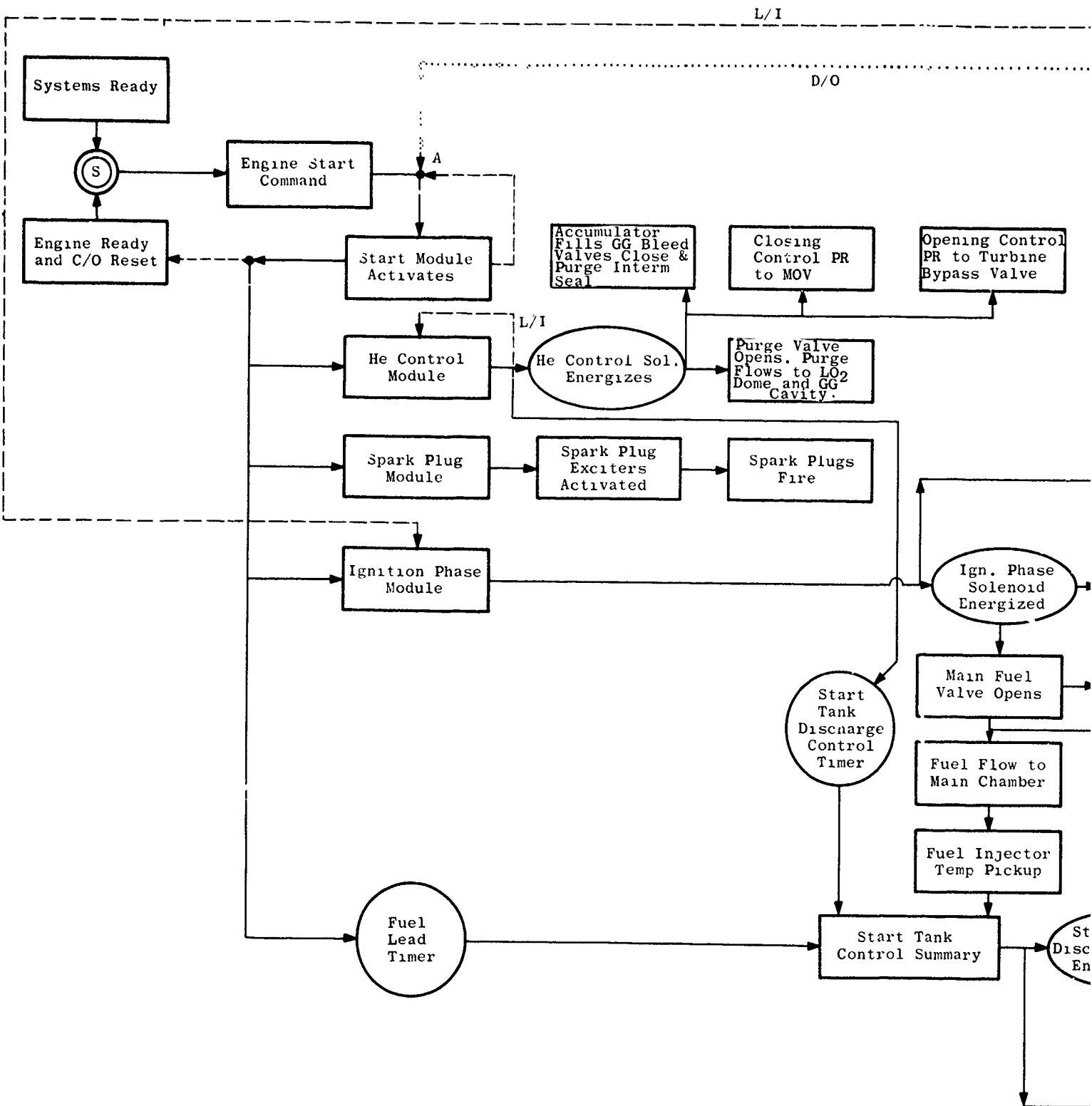


Fig. 4 S-IVB Battleship Stage/J-2 Rocket Engine Schematic









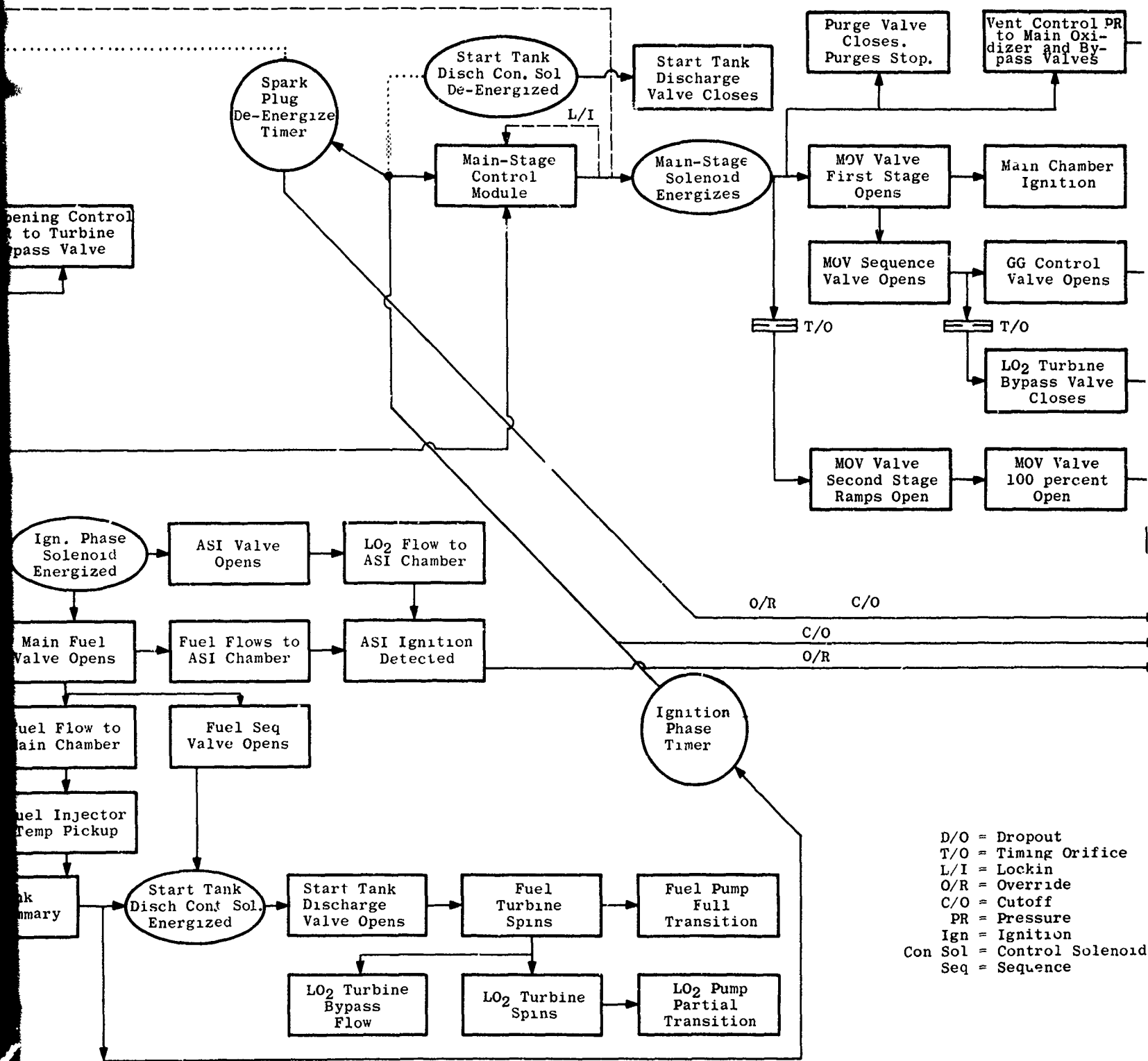
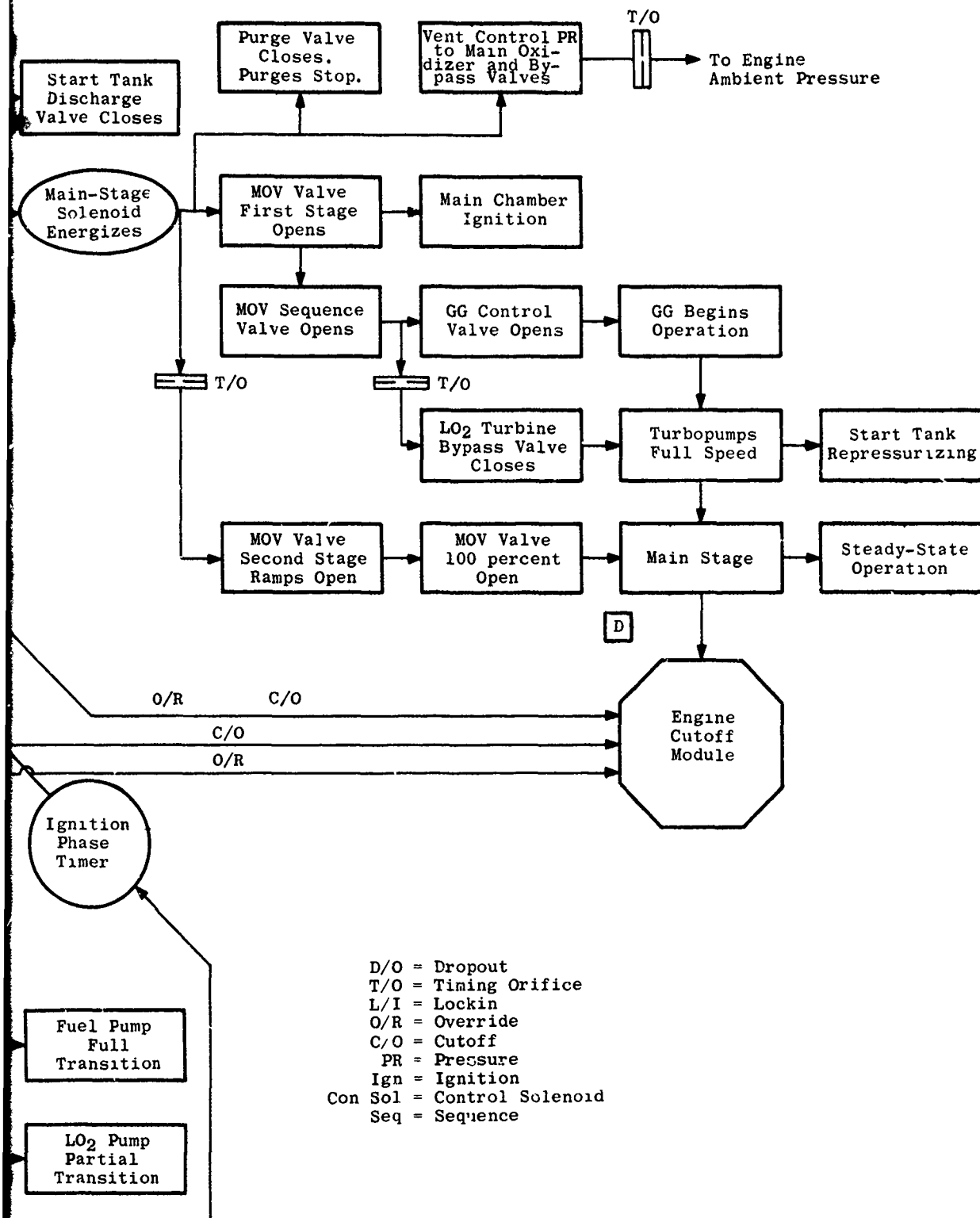


Fig. 6 Engine Start Logic Schematic



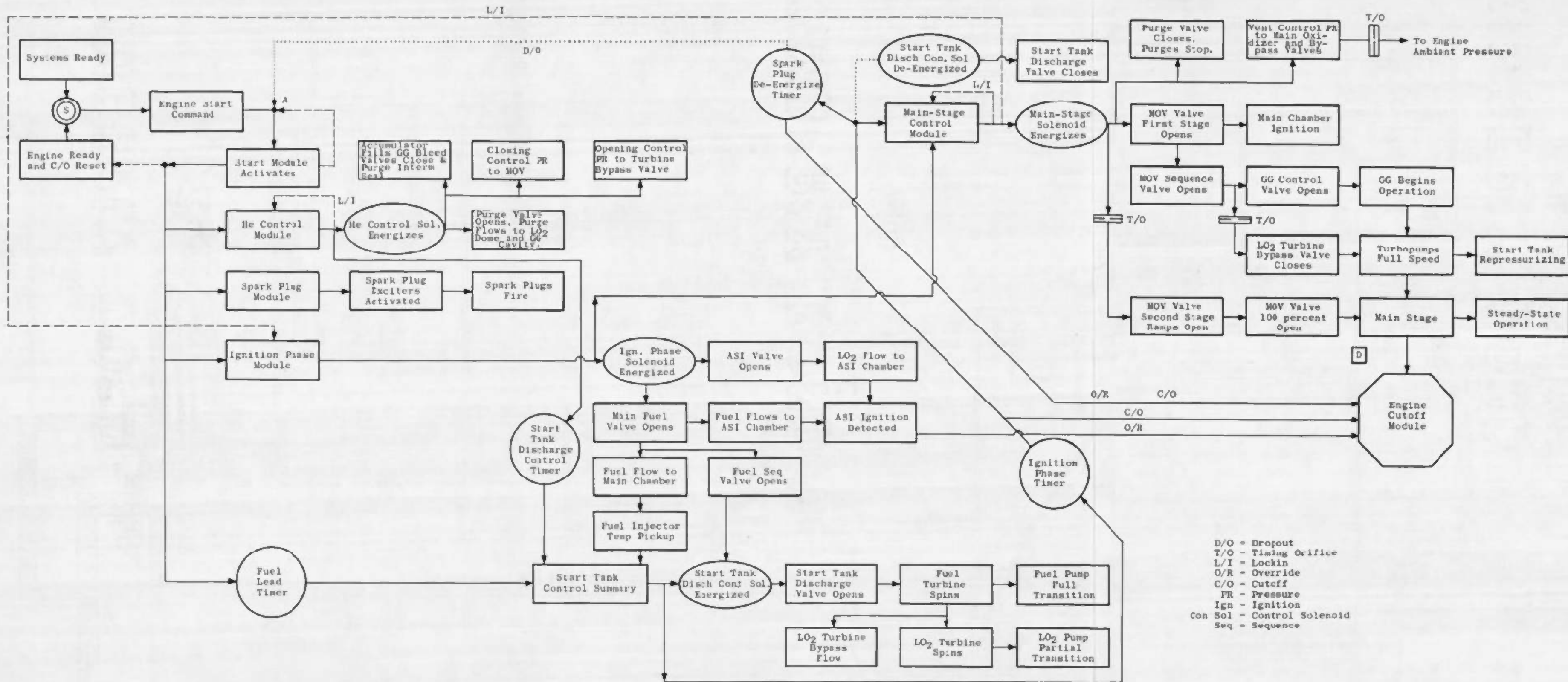
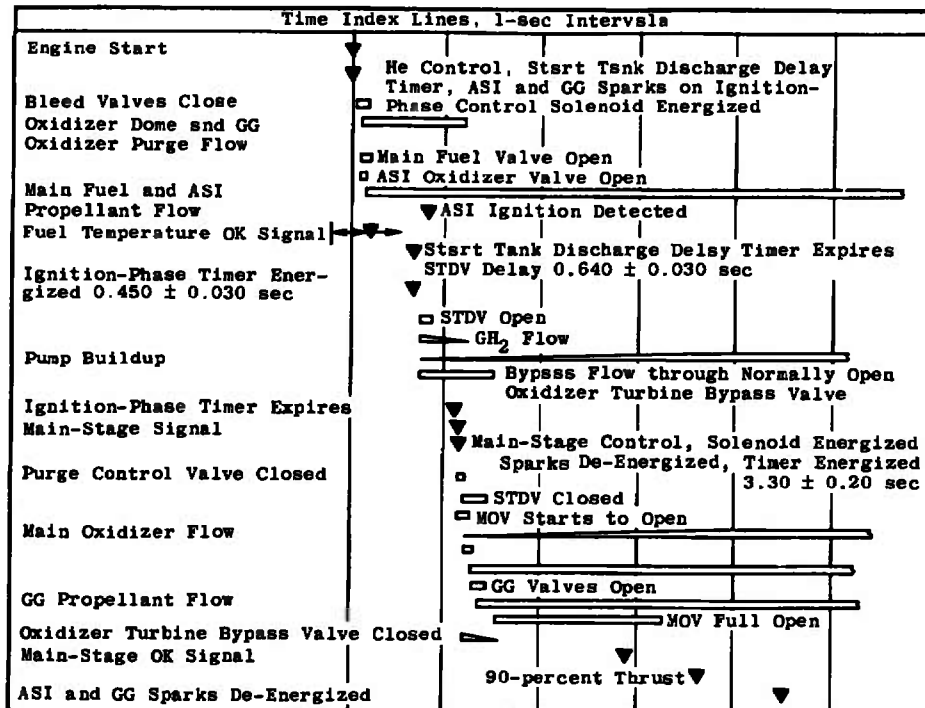
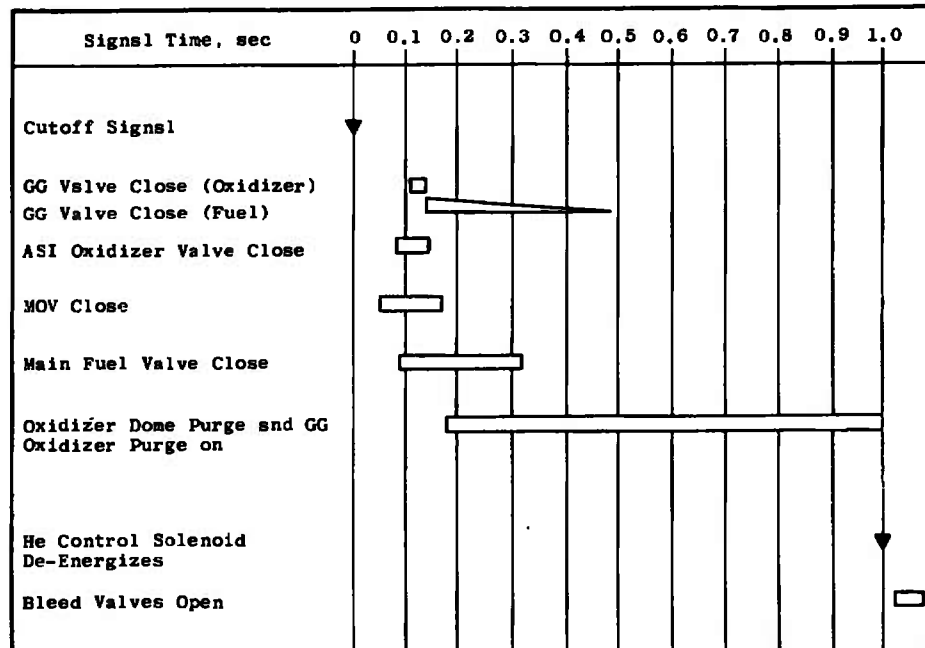


Fig. 6 Engine Start Logic Schematic

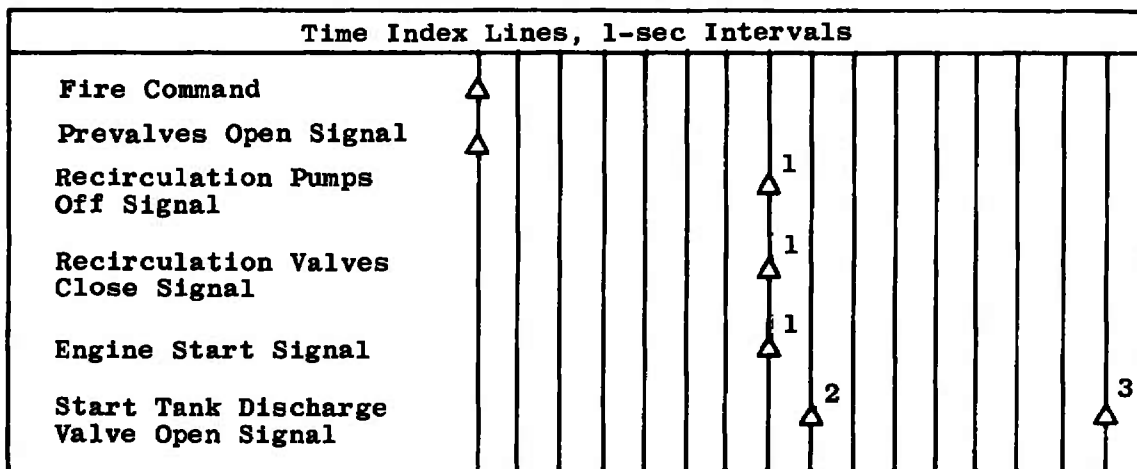


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

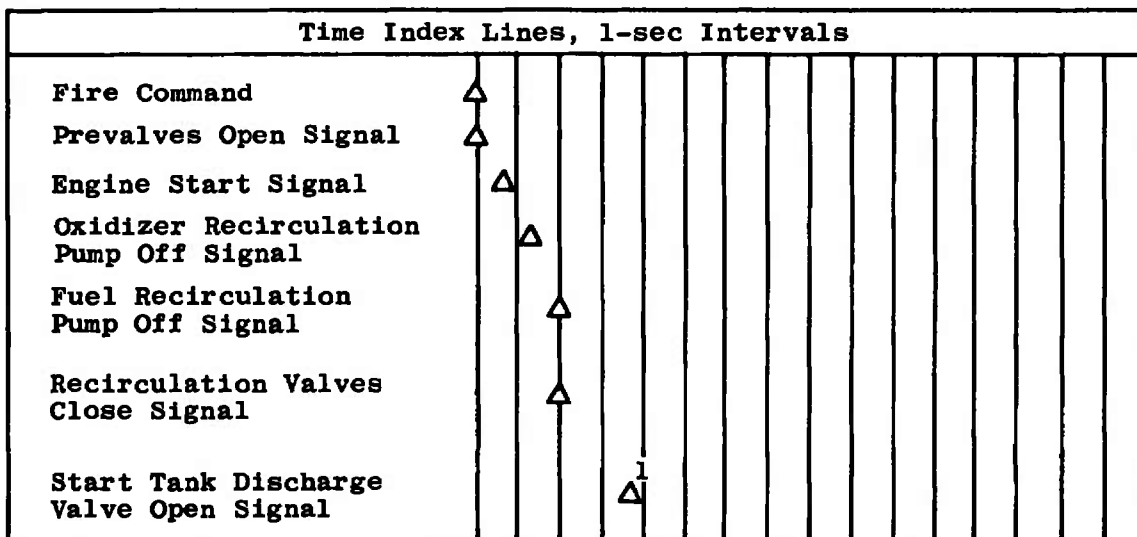


¹Nominal Occurrence Time (Function of Prevalves Opening Time)

²One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

³Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

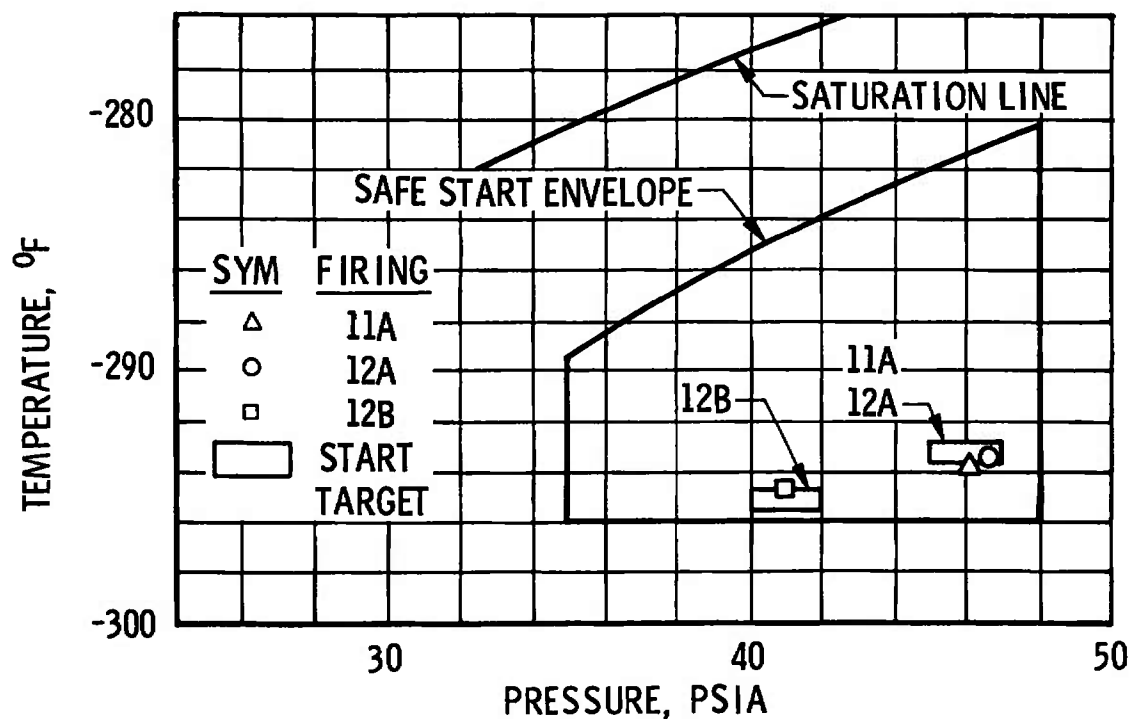
c. "Normal" Start Sequence



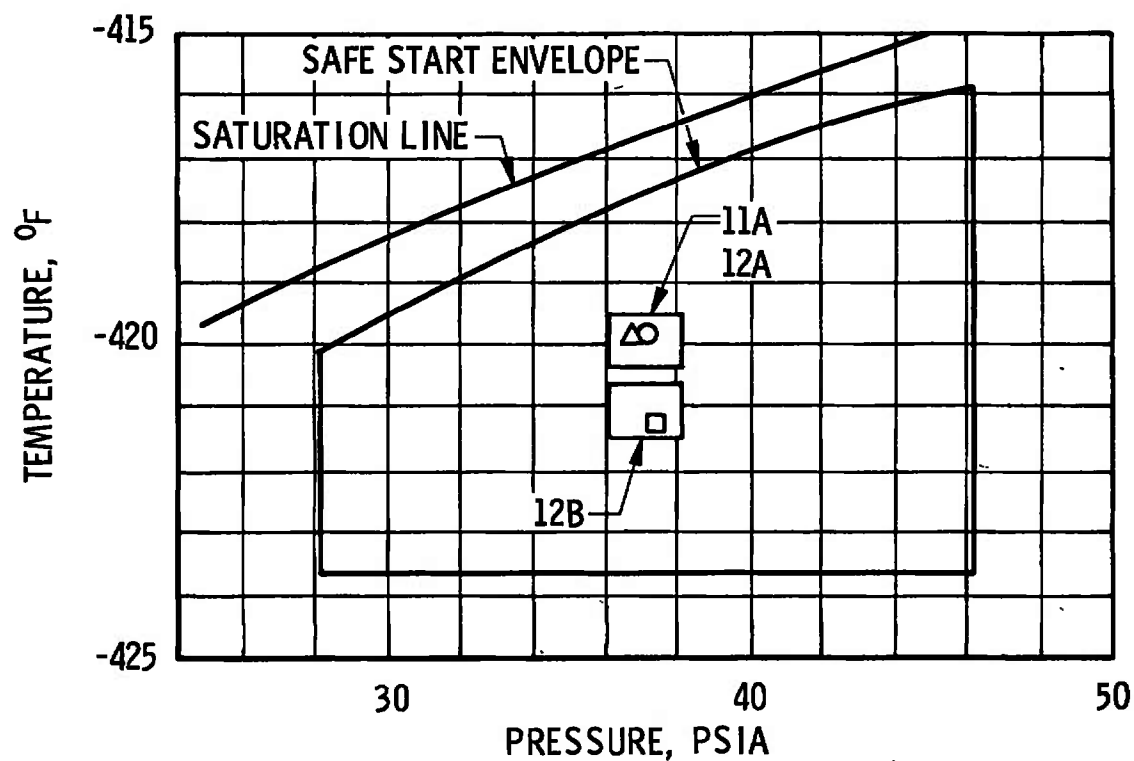
¹Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

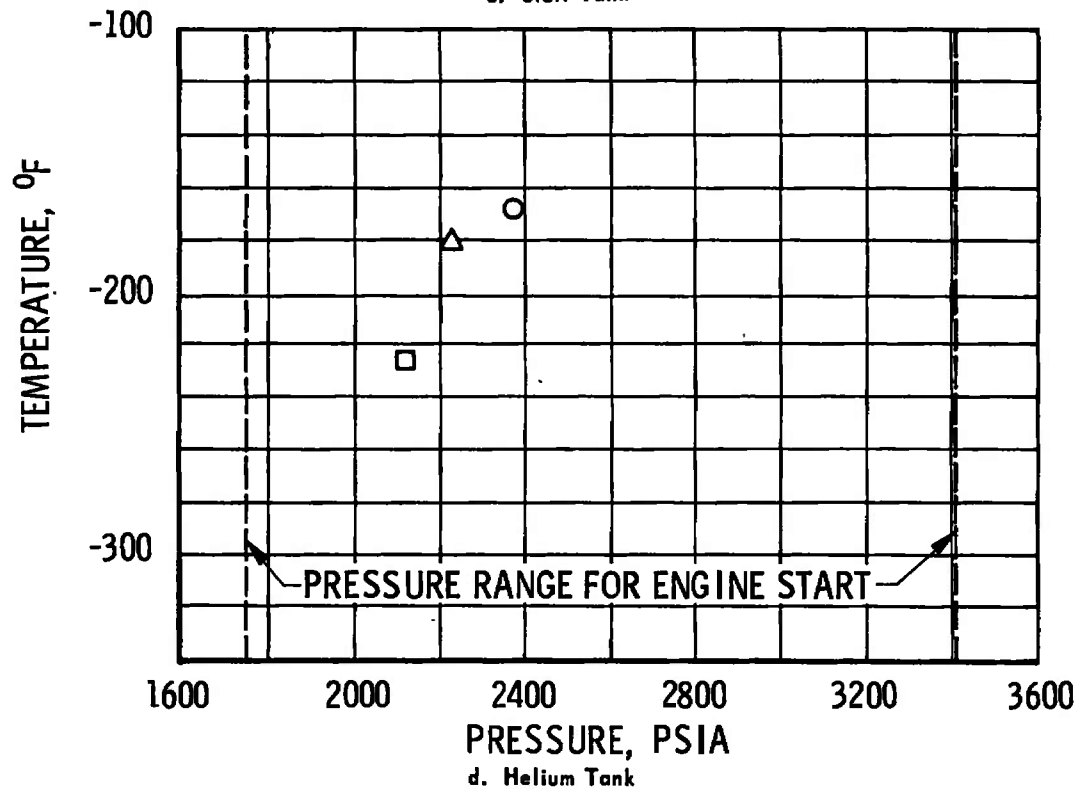
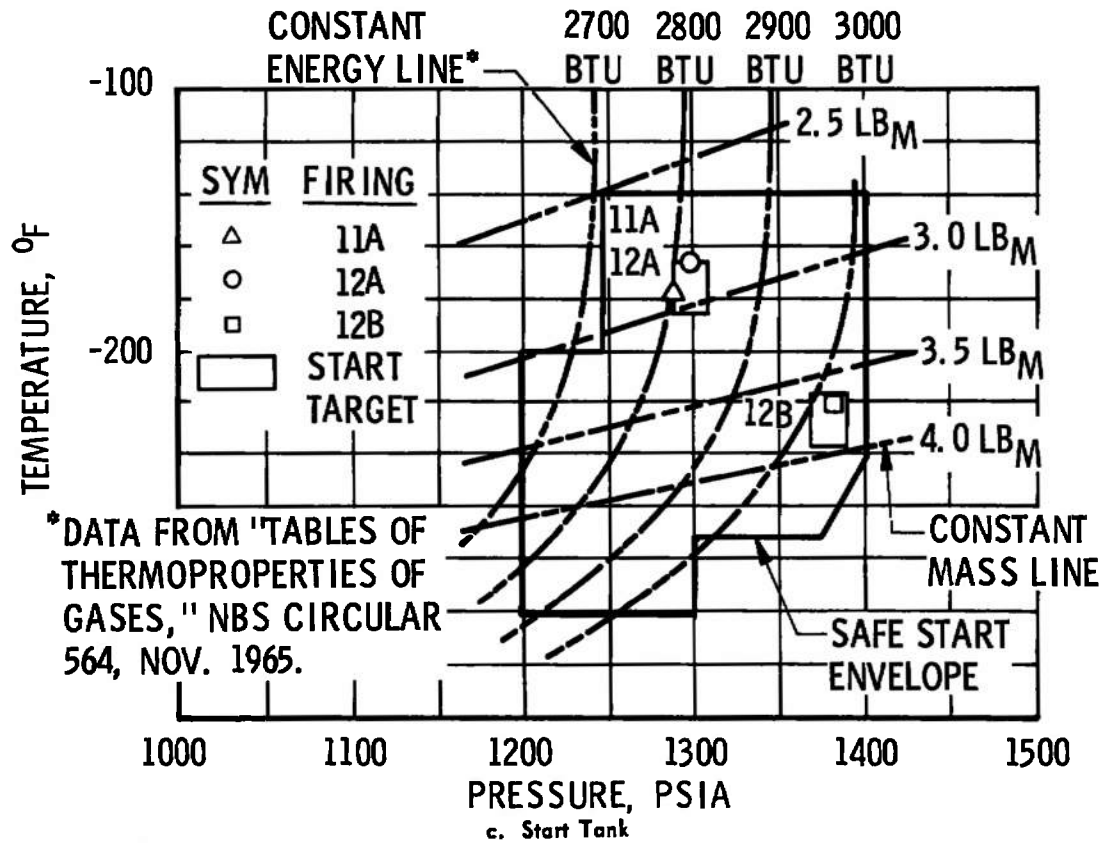


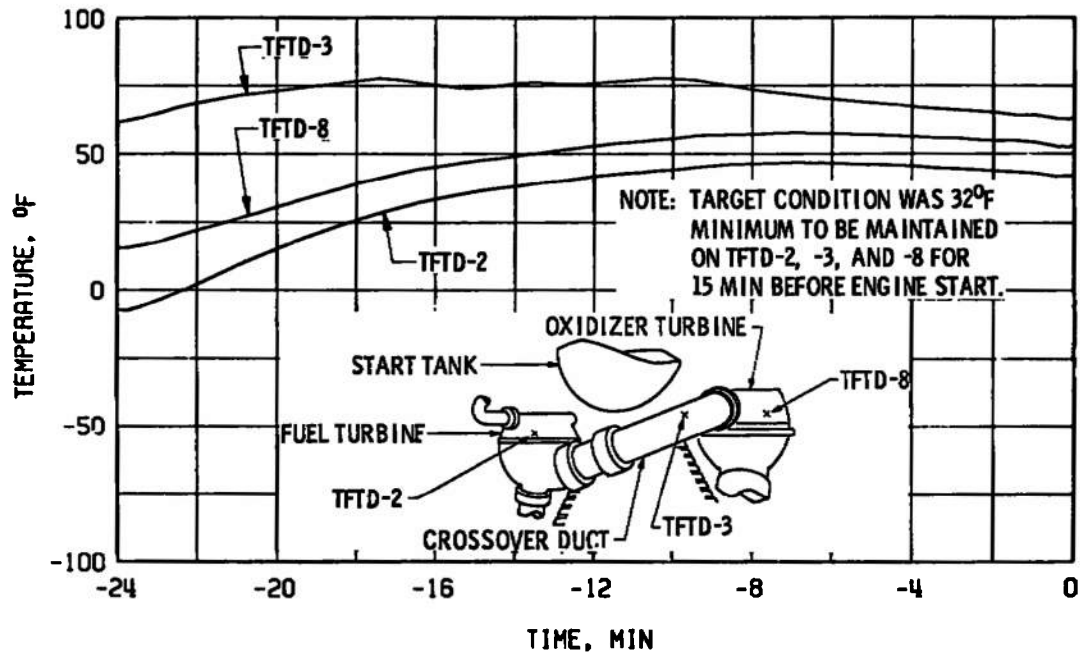
a. Oxidizer Pump Inlet



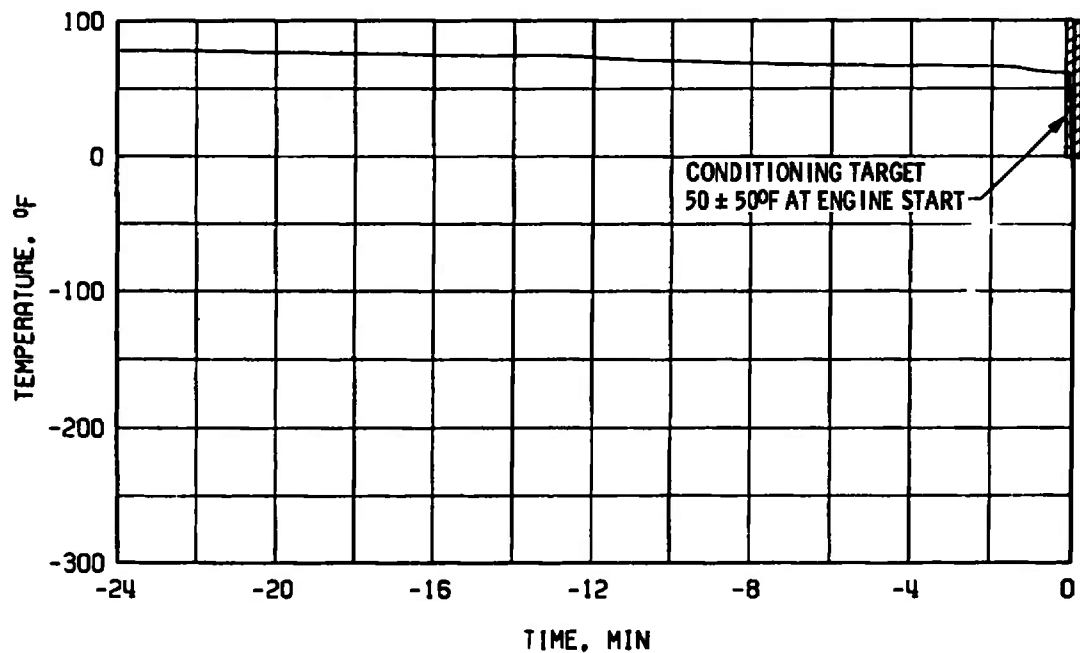
b. Fuel Pump Inlet

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



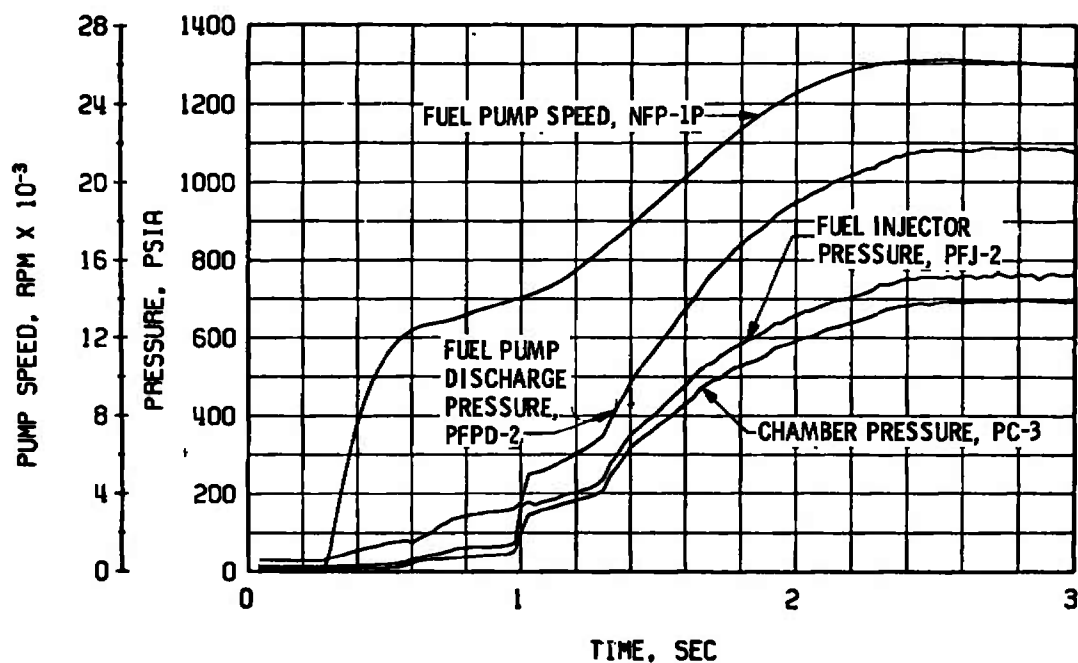


a. Crossover Duct, TFTD

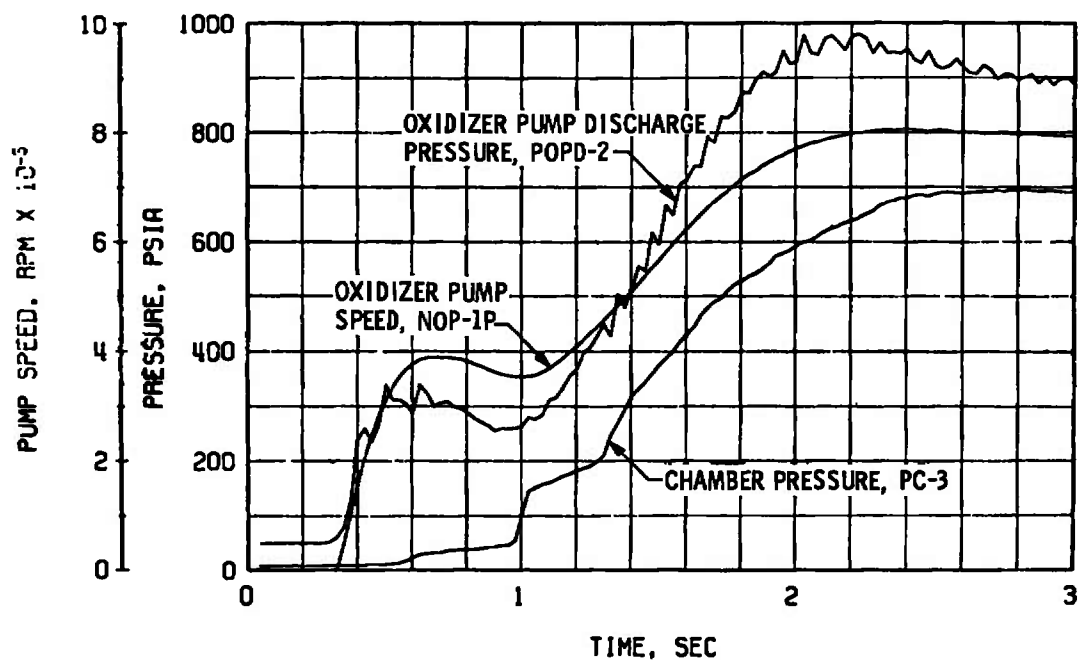


b. Thrust Chamber Throat, TSC2-19

Fig. 9 Thermal Conditioning History of Engine Components, Firing 11A

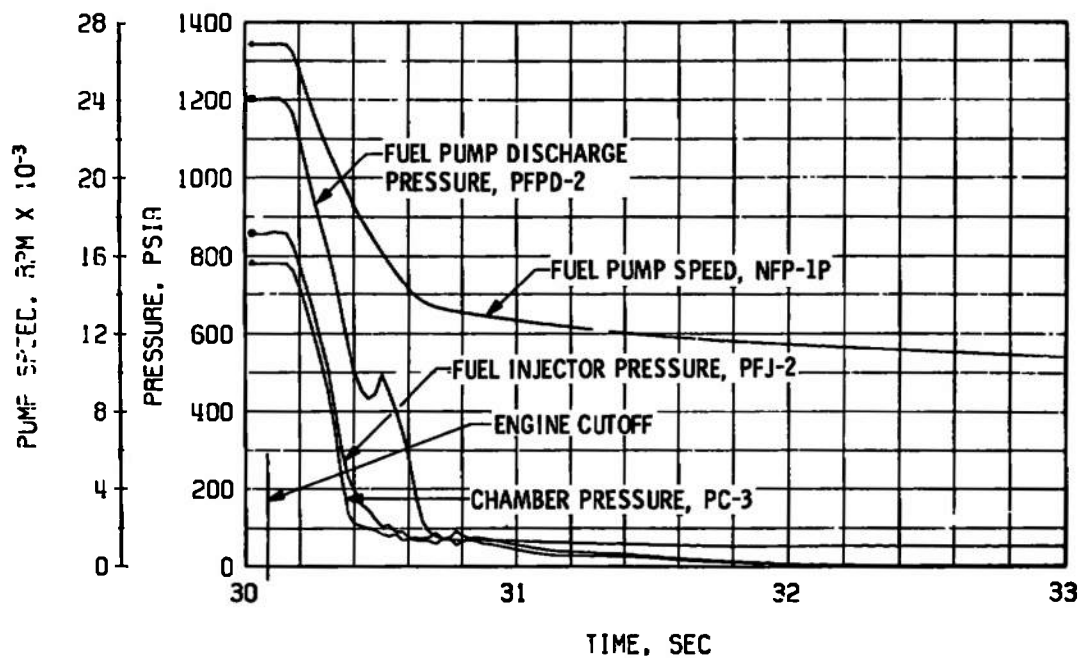


a. Thrust Chamber Fuel System, Start

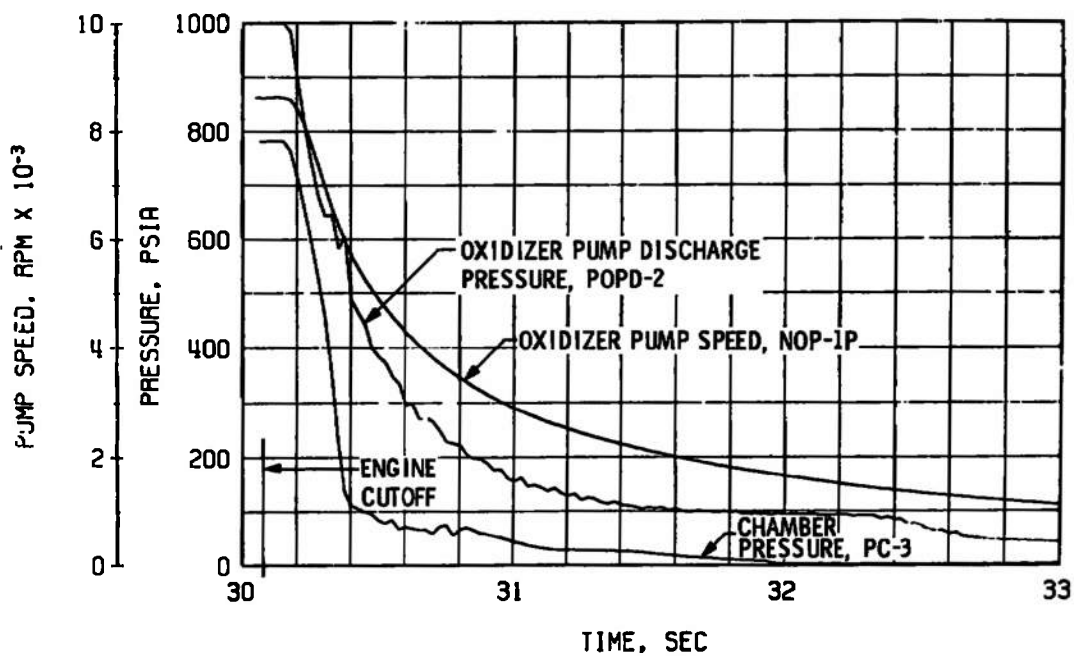


b. Thrust Chamber Oxidizer System, Start

Fig. 10 Engine Transient Operation, Firing 11A

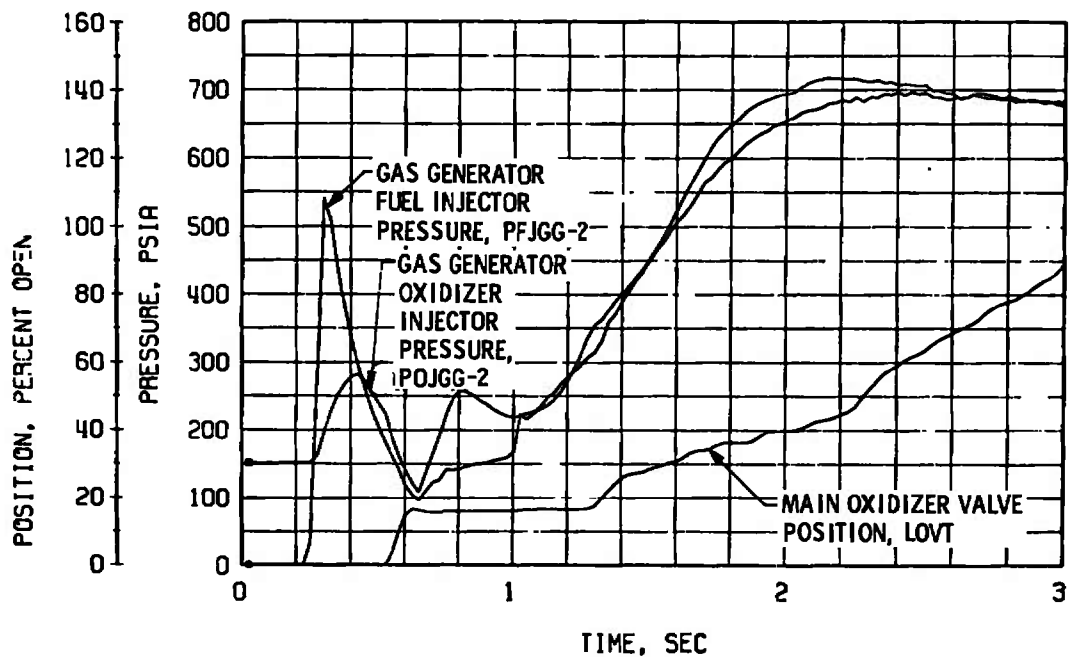


c. Thrust Chamber Fuel System, Shutdown

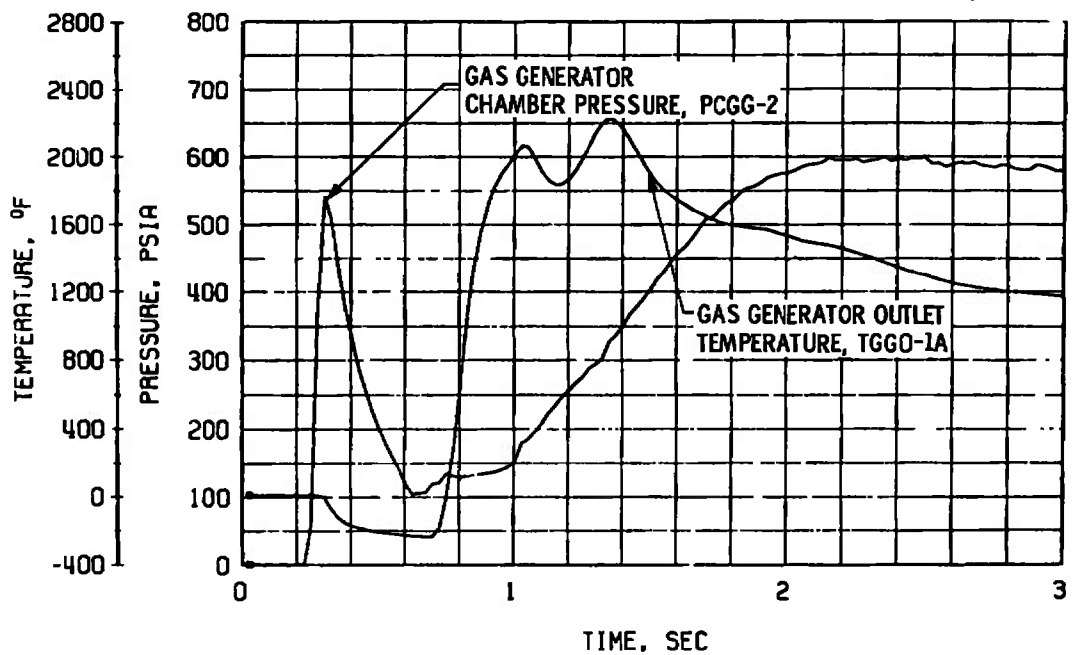


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Continued

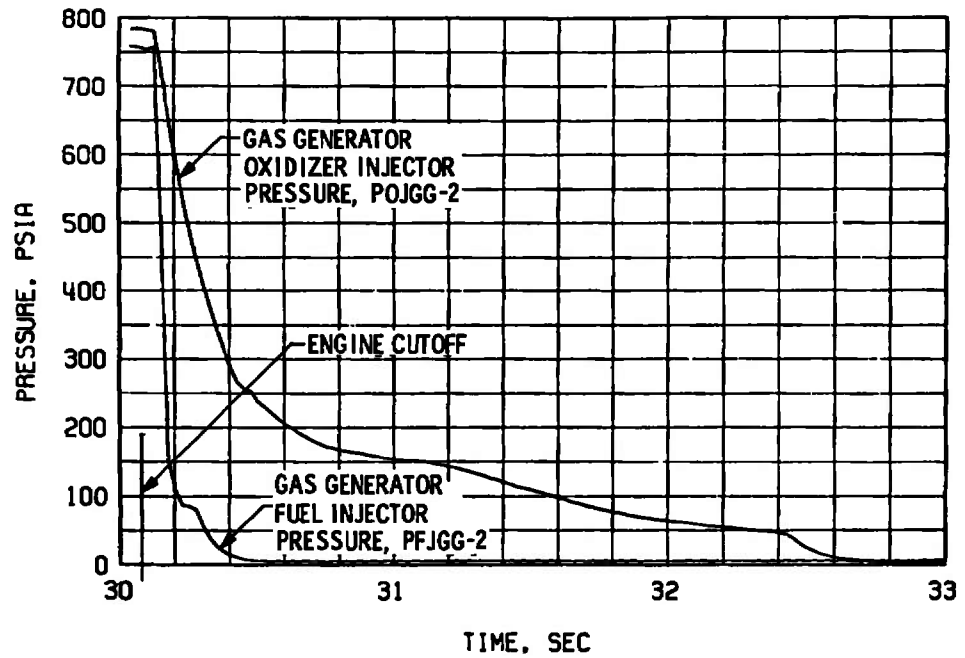


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

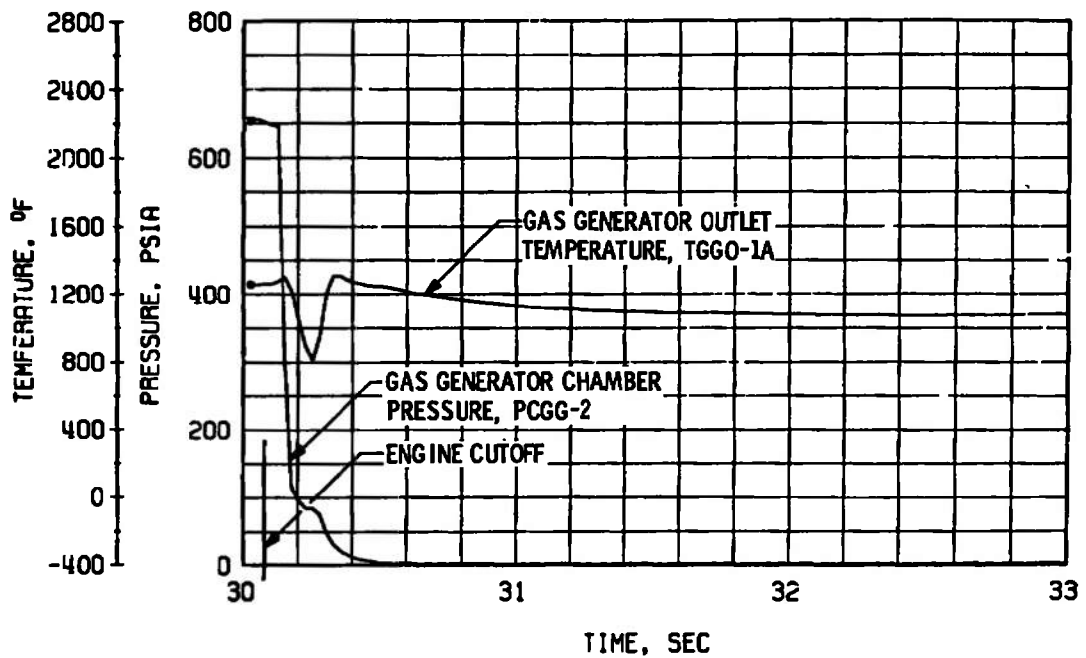


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 10 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded

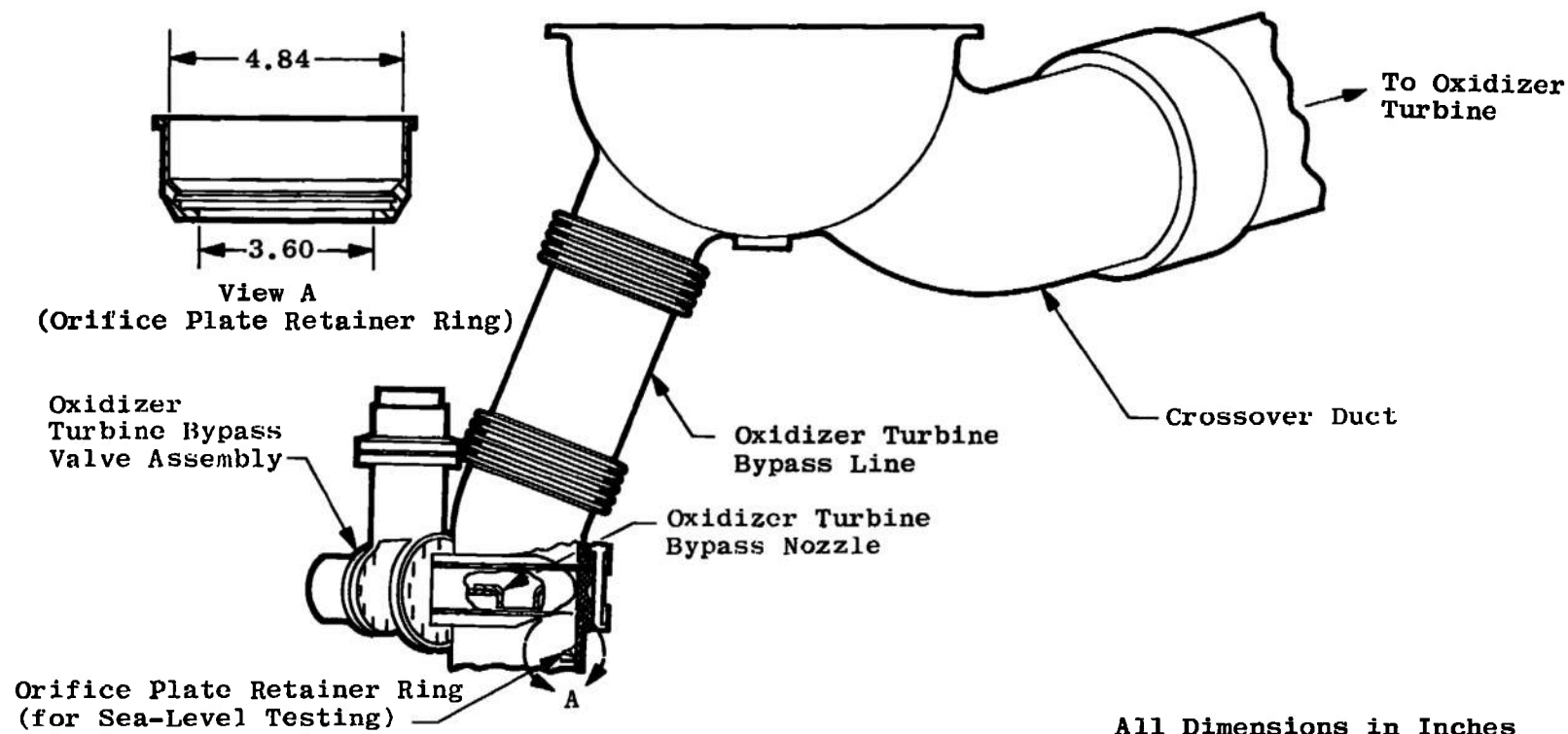


Fig. 11 Fuel Turbine Exhaust Duct

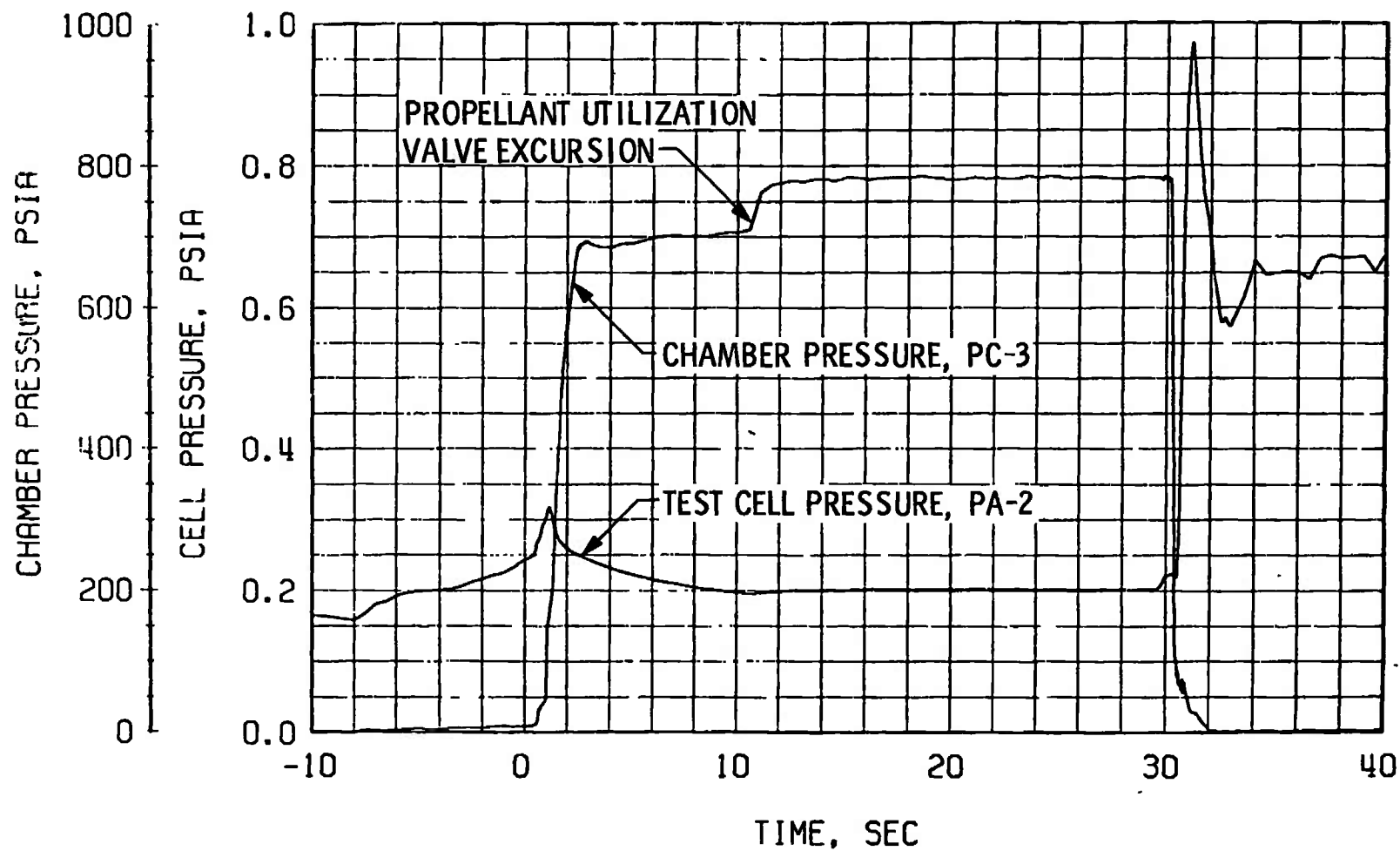


Fig. 12 Engine Ambient and Combustion Chamber Pressures, Firing 11A

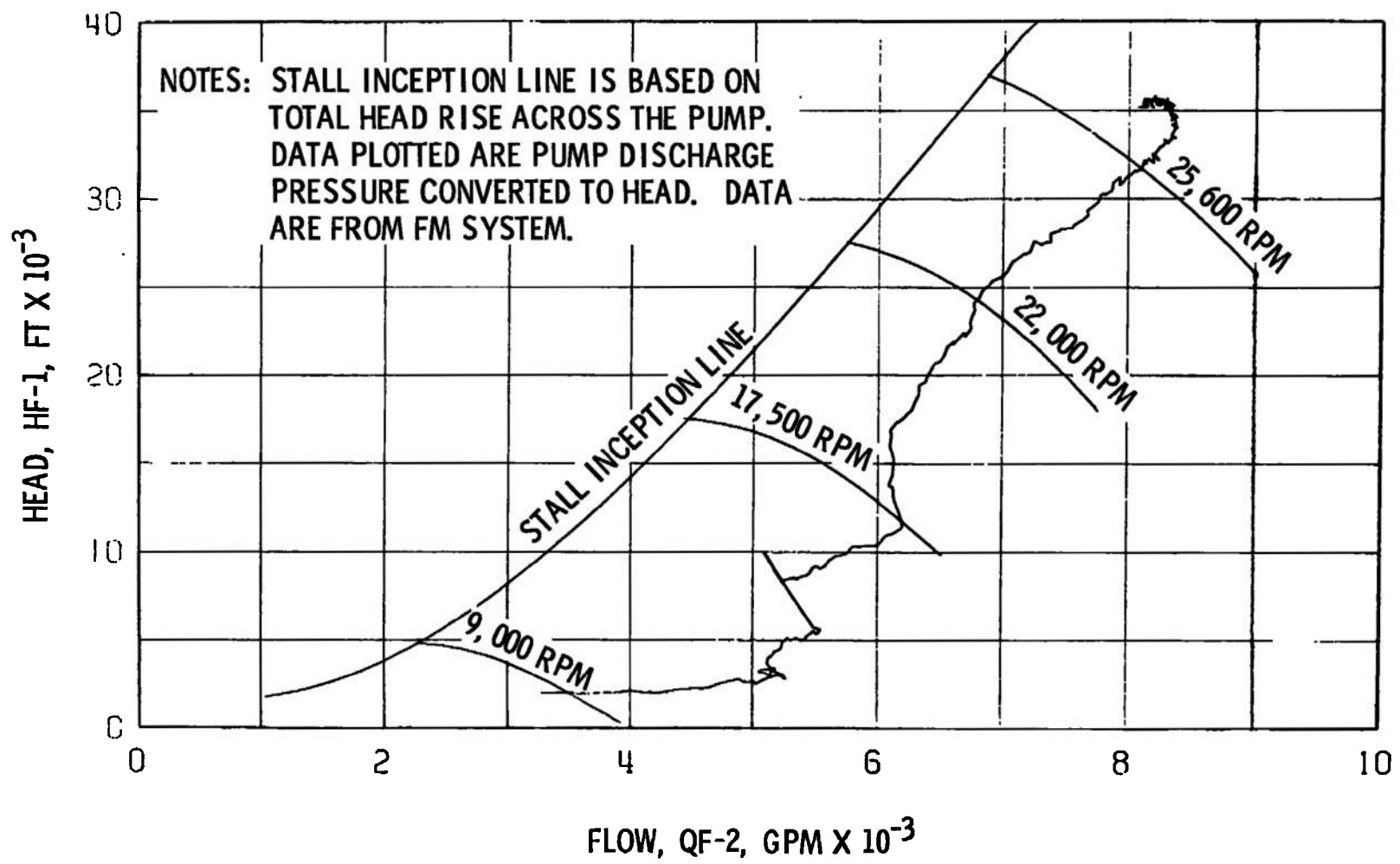


Fig. 13 Fuel Pump Start Transient Performance, Firing 11A

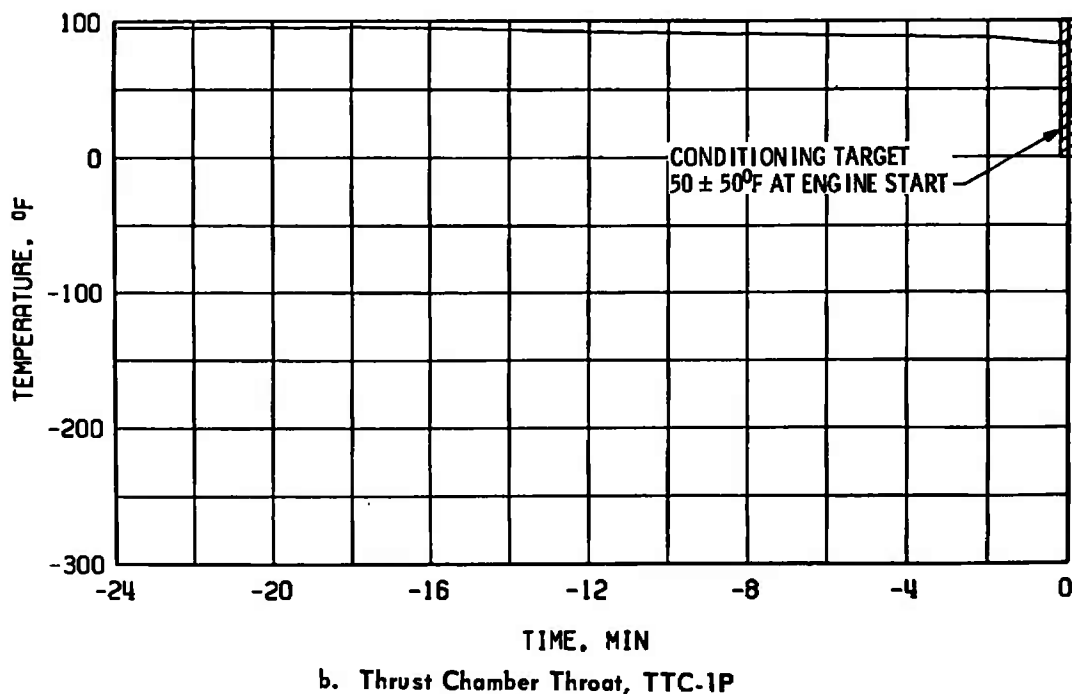
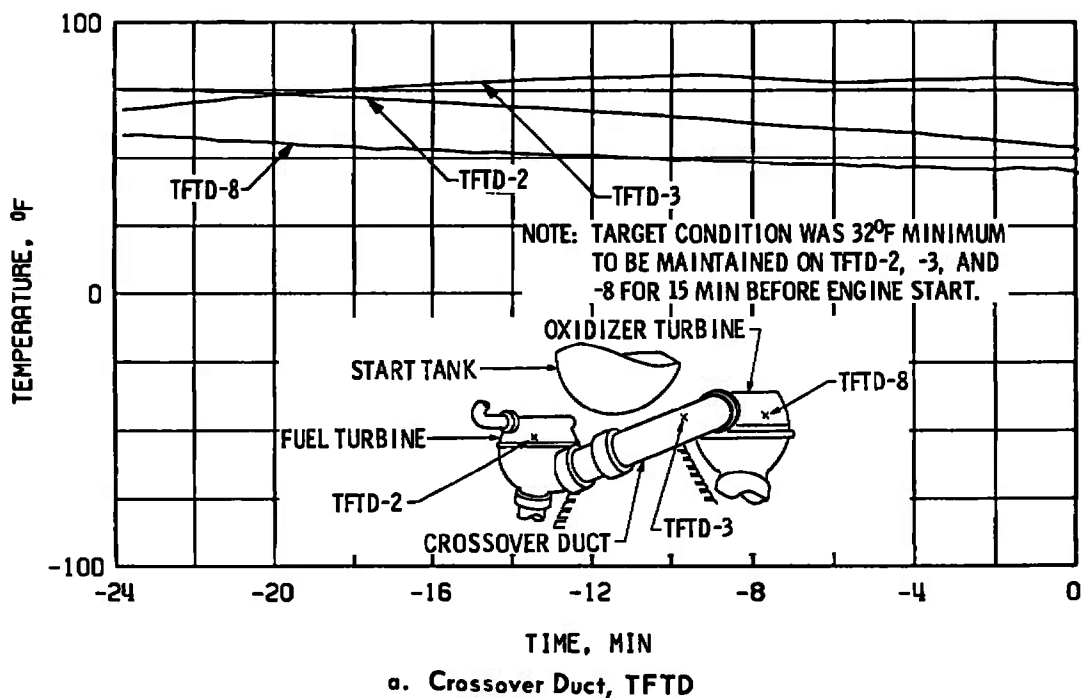
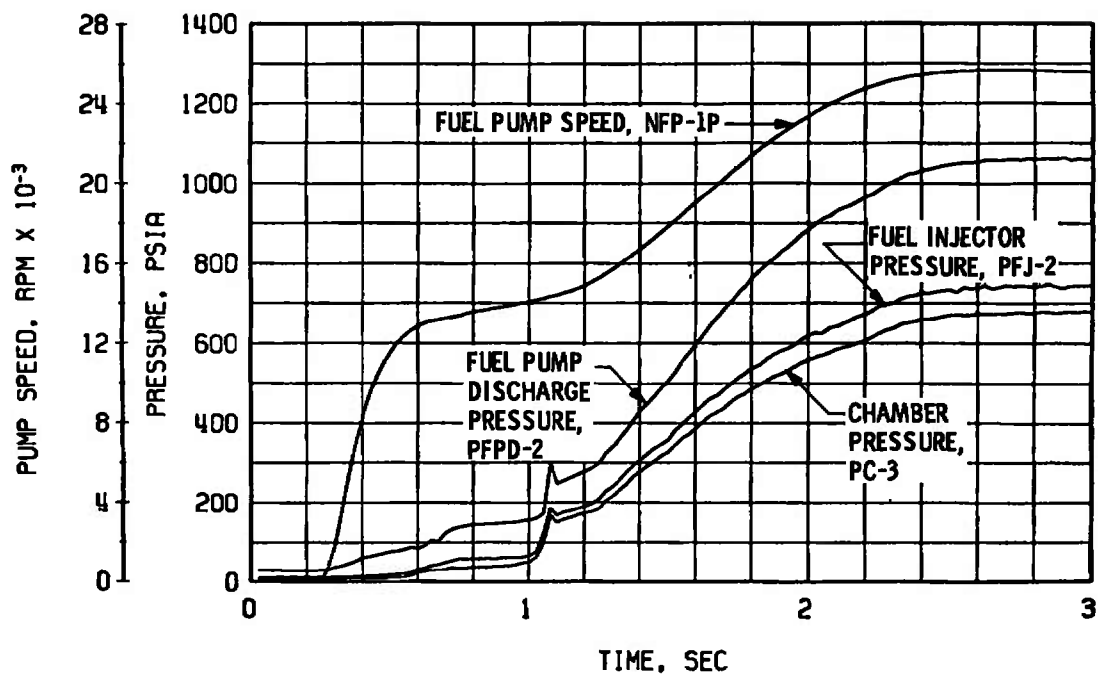
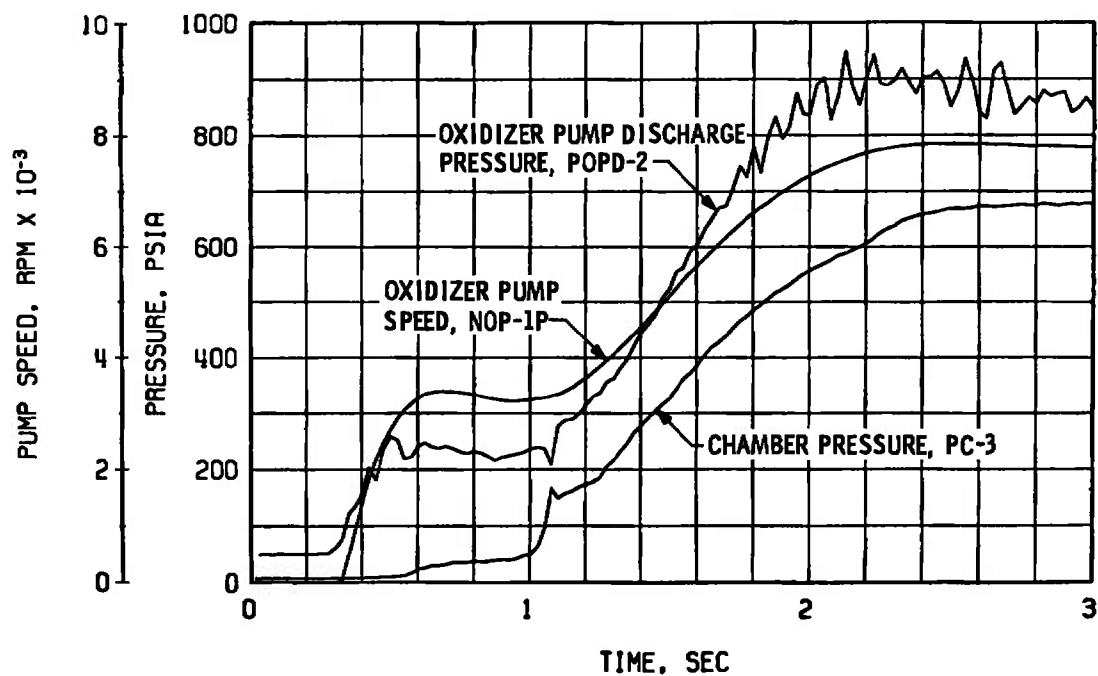


Fig. 14 Thermal Conditioning History of Engine Components, Firing 12A

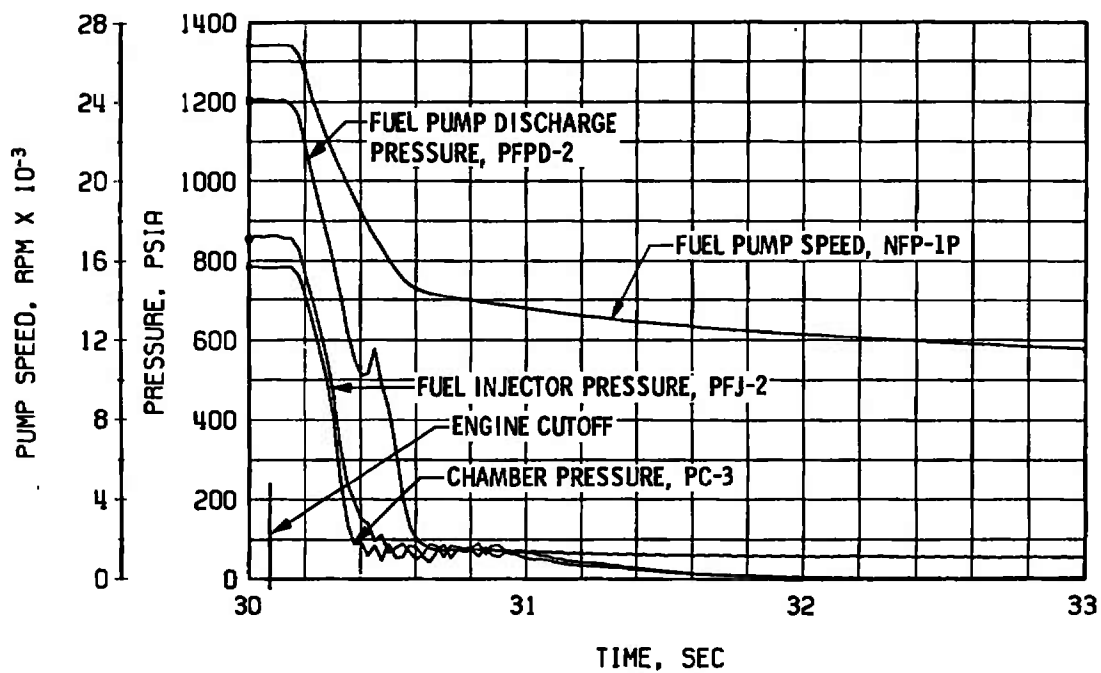


a. Thrust Chamber Fuel System, Start

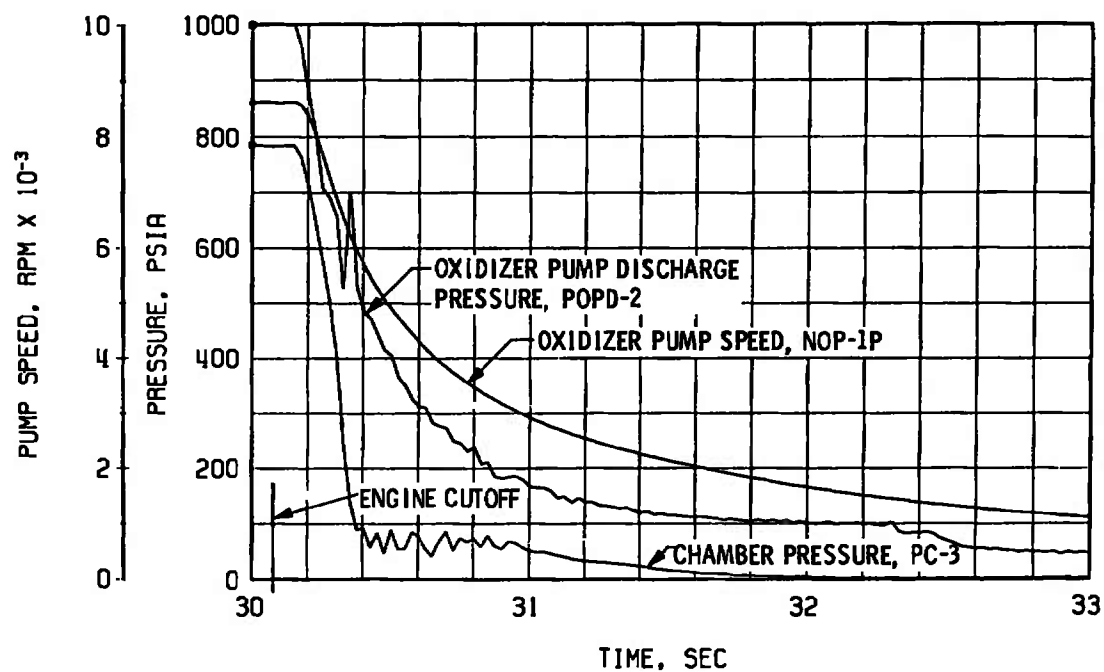


b. Thrust Chamber Oxidizer System, Start

Fig. 15 Engine Transient Operation, Firing 12A

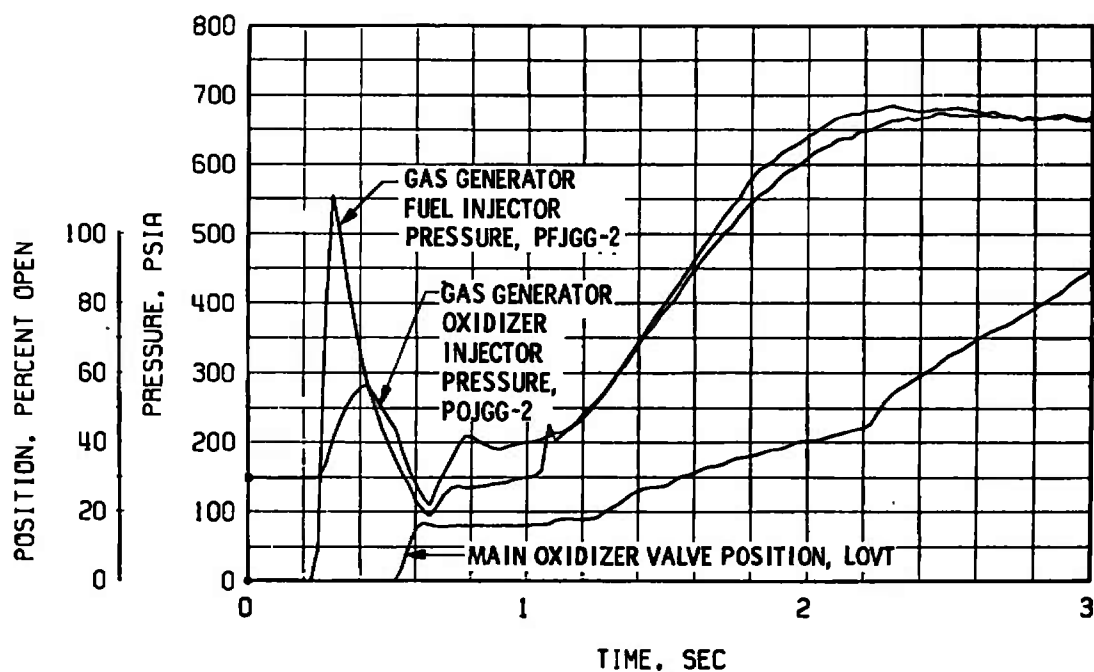


c. Thrust Chamber Fuel System, Shutdown

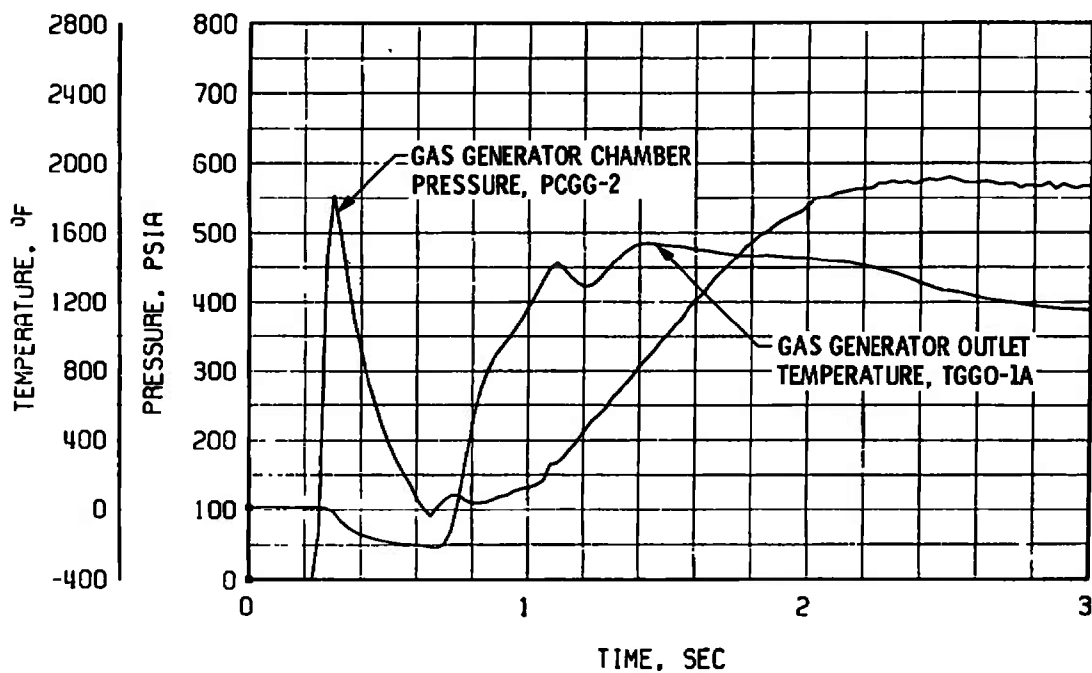


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 15 Continued

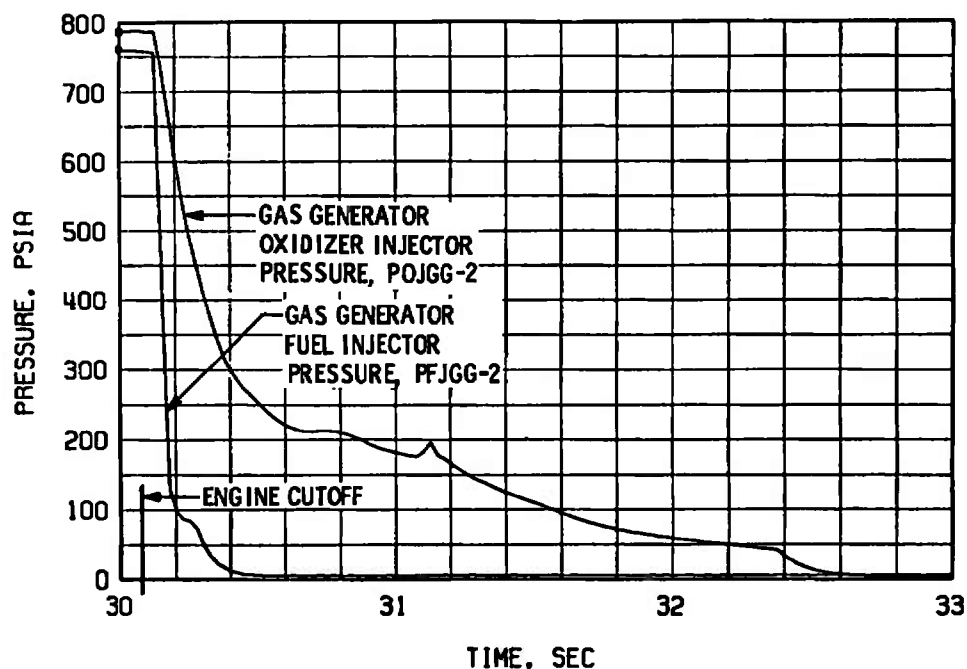


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

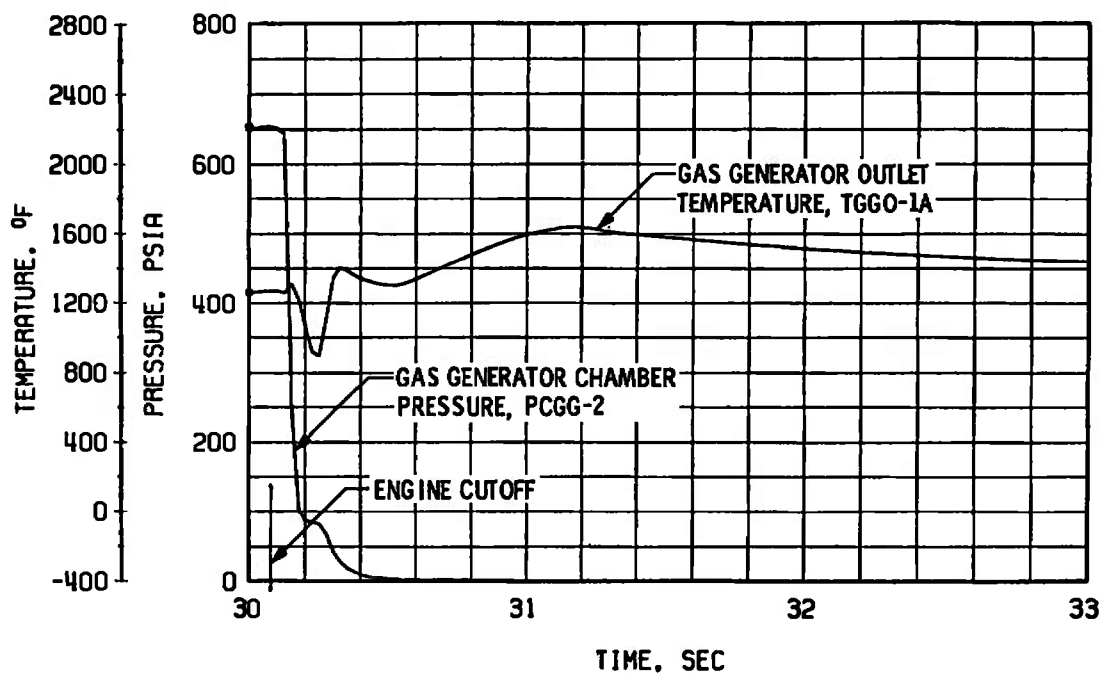


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 15 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 15 Concluded

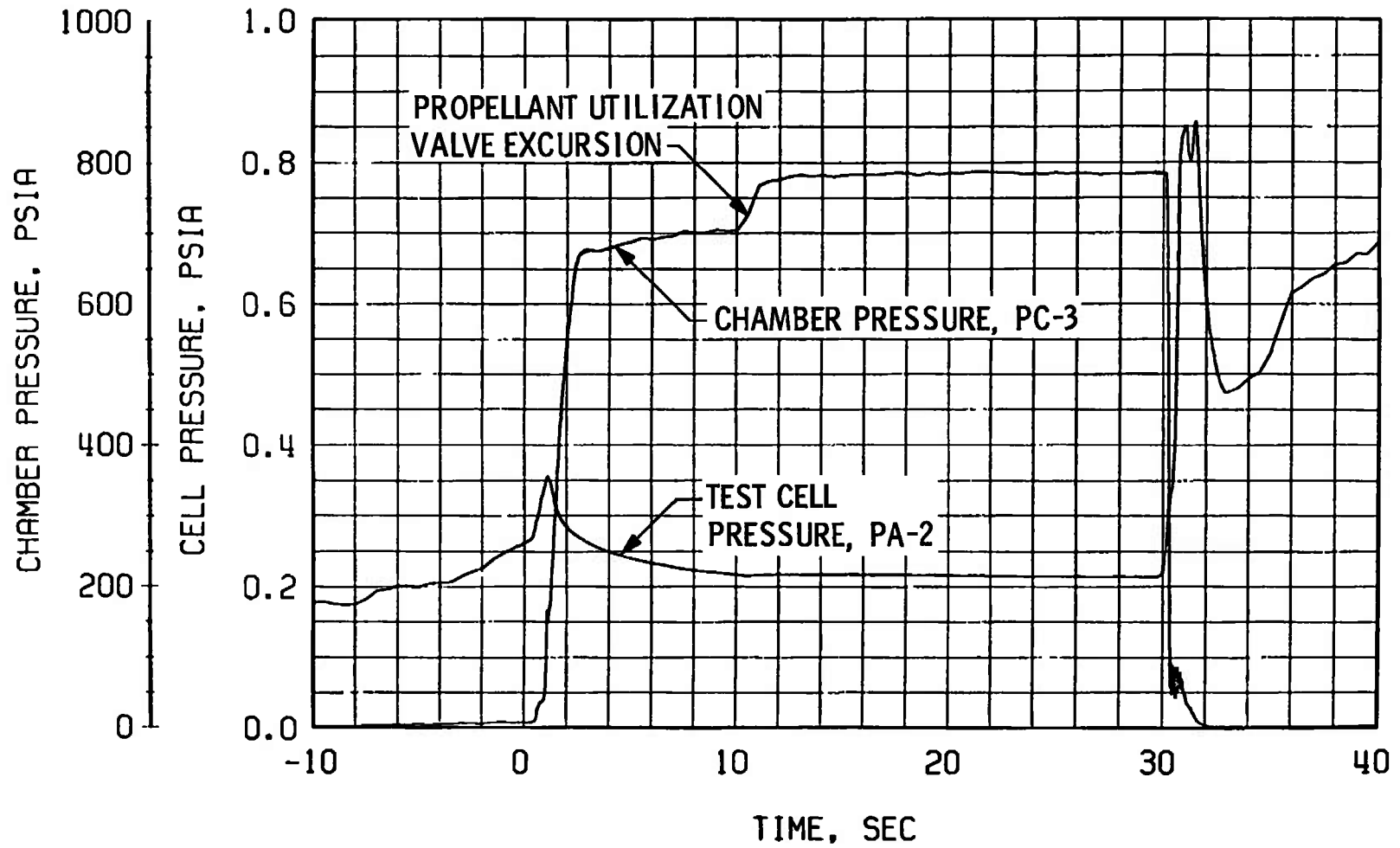


Fig. 16 Engine Ambient and Combustion Chamber Pressures, Firing 12A

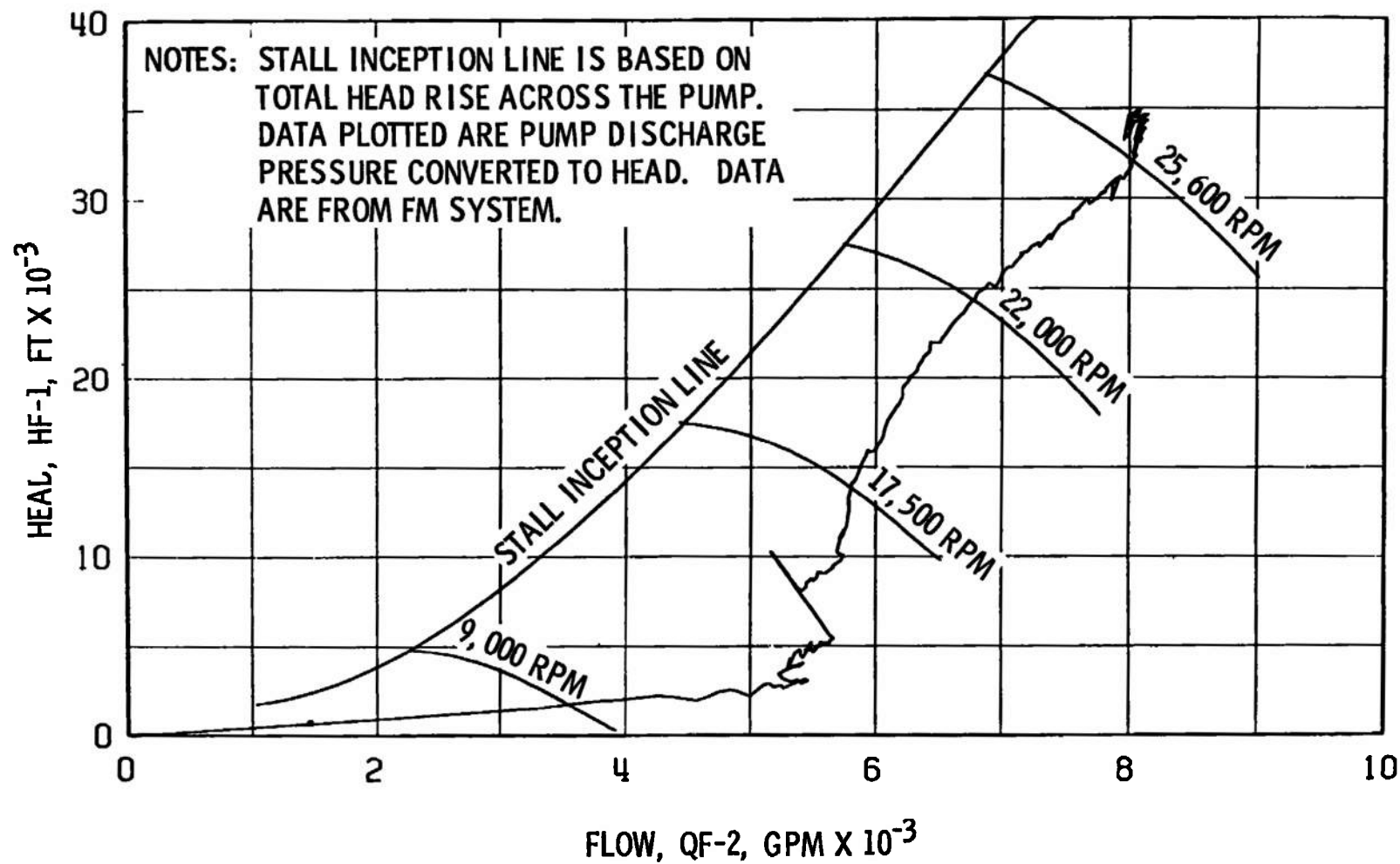
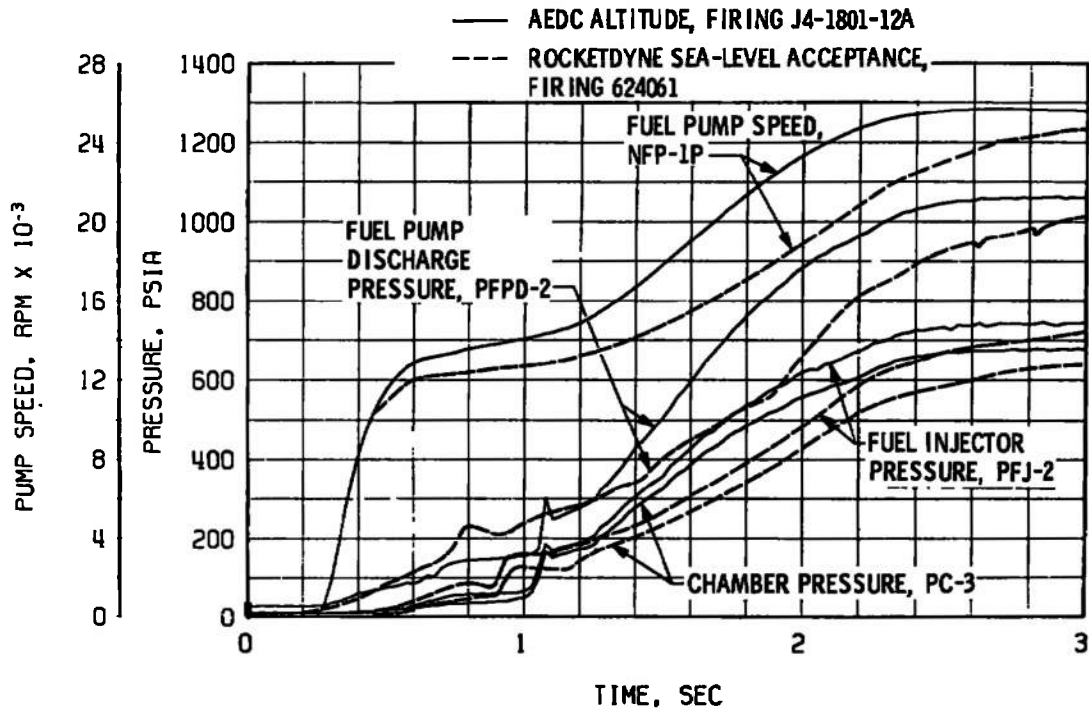
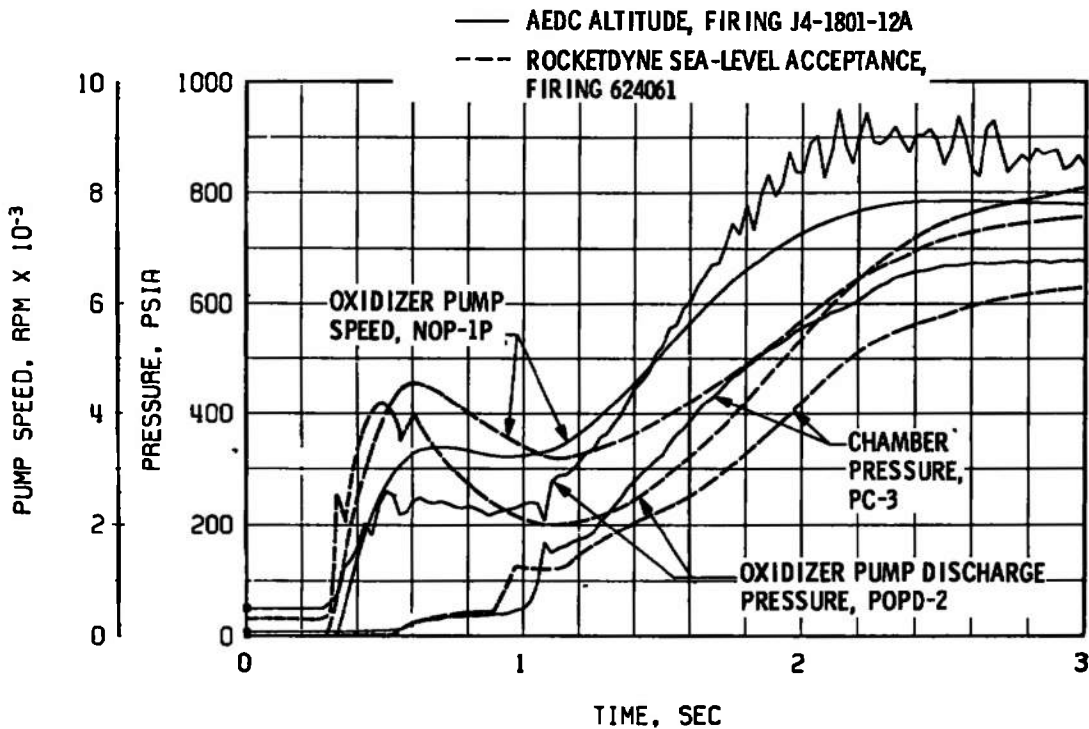


Fig. 17 Fuel Pump Start Transient Performance, Firing 12A

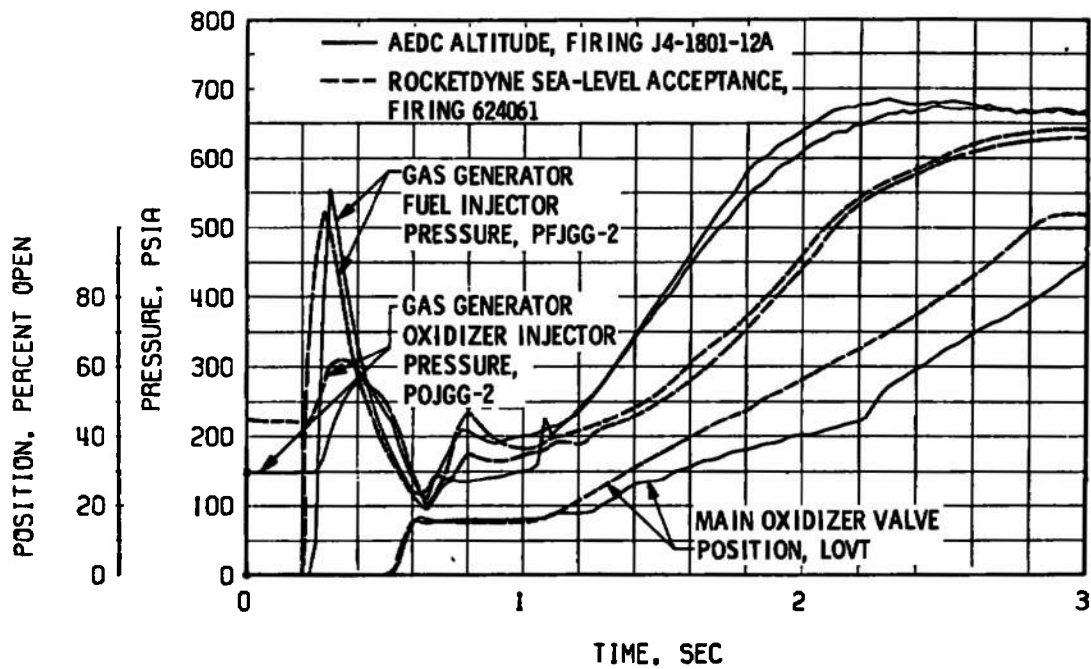


a. Thrust Chamber Fuel System

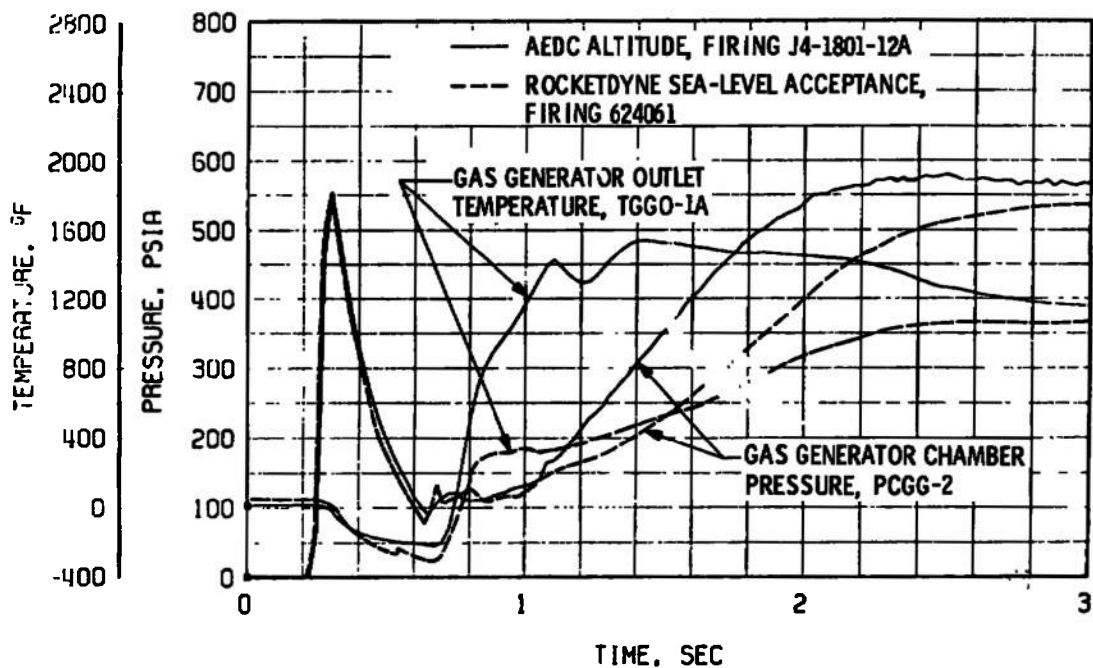


b. Thrust Chamber Oxidizer System

Fig. 18 Comparison of Altitude and Sea-Level Engine Start Transient Operation



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Temperature

Fig. 18 Concluded

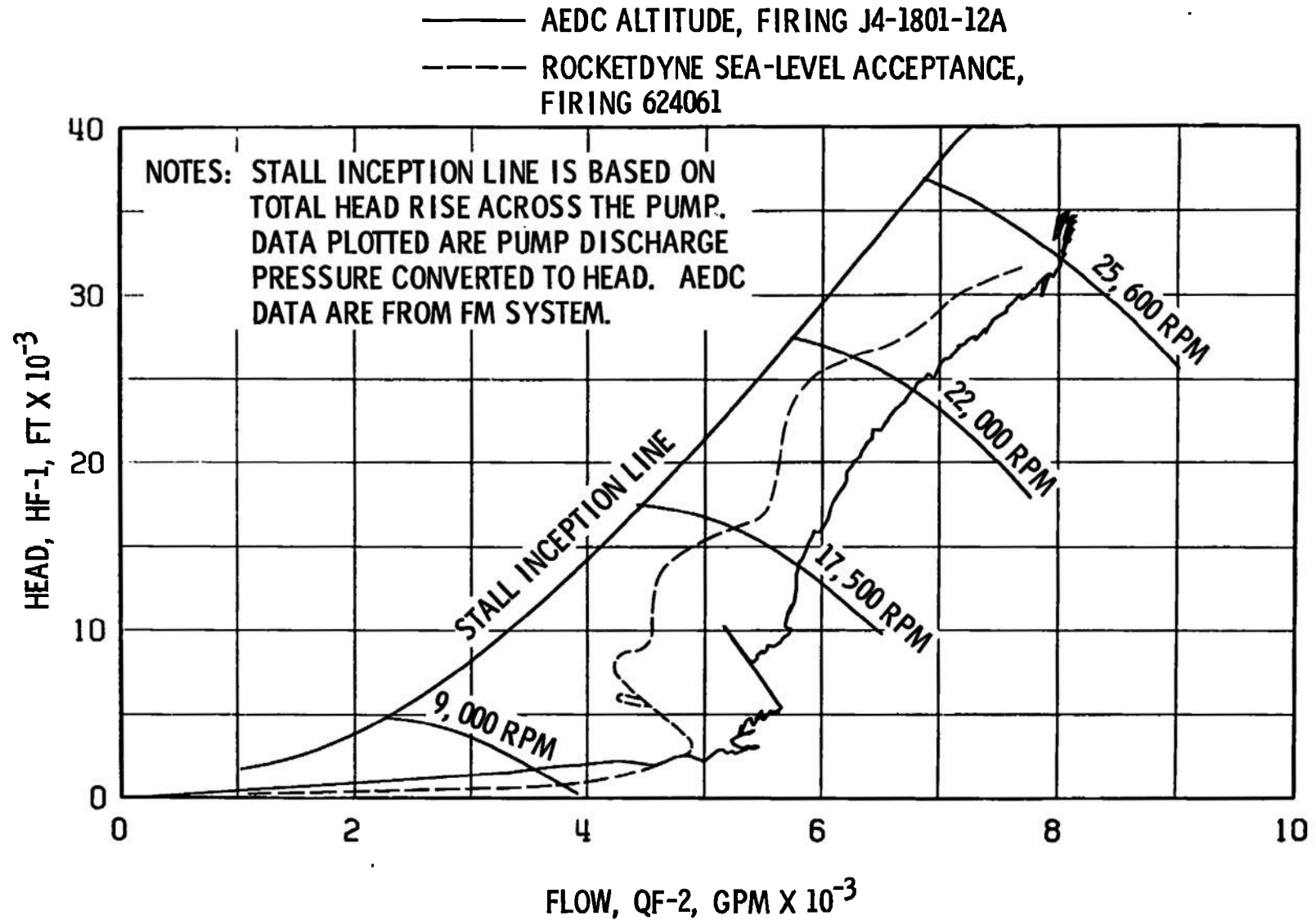
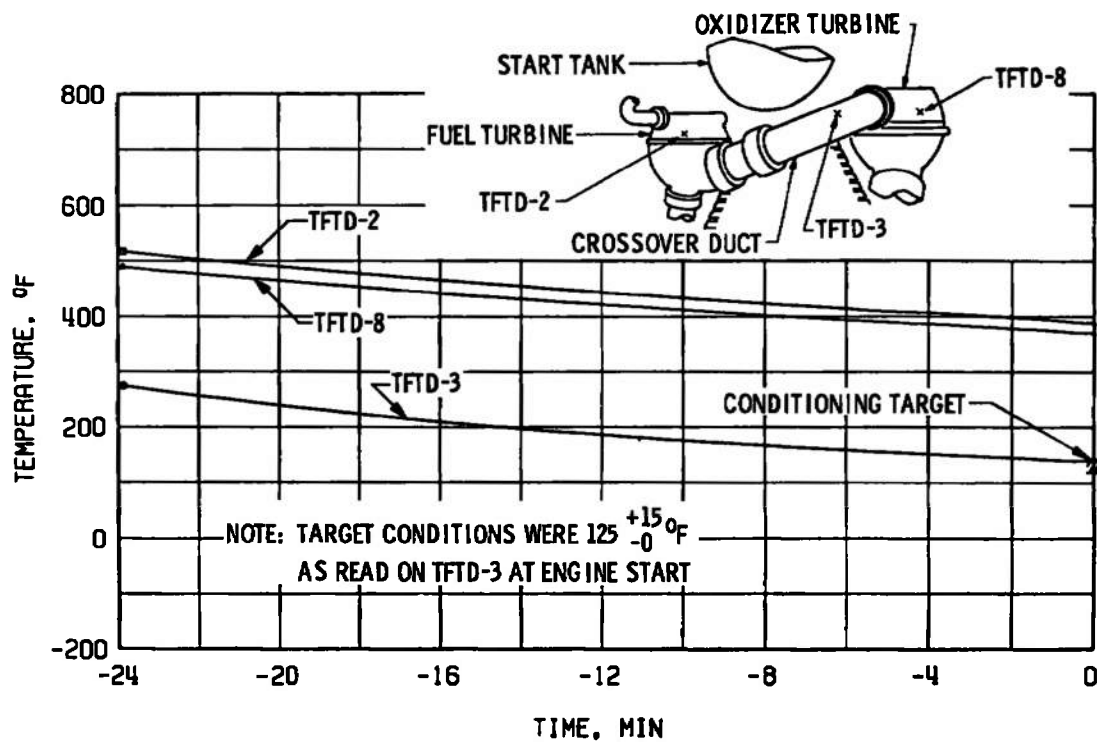
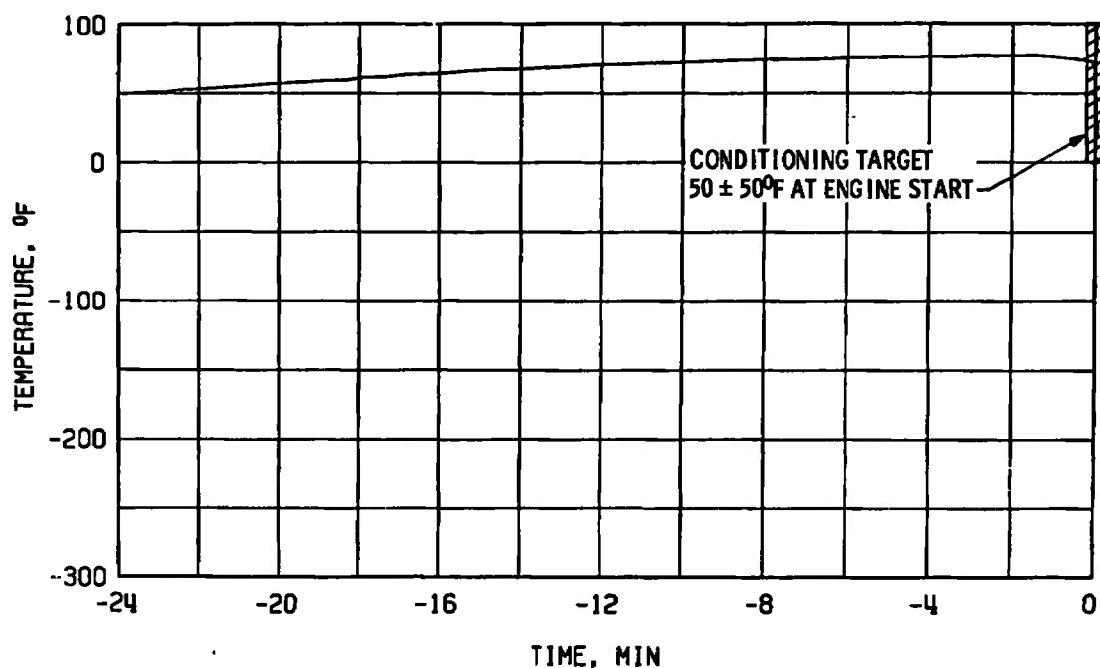


Fig. 19 Comparison of Altitude and Sea-Level Fuel Pump Start Transient Performance



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TTC-1P

Fig. 20 Thermal Conditioning History of Engine Components, Firing 12B

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	459000-171	4078258
Oxidizer Turbopump Assembly	458175-71	6616135
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4078827
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	411039X4	4045142
Gas Generator Control Valve	309040	4076768
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve	409930	4079685
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
P/A Shutdown Valve Assembly	557817	4067200
P/A Purge Control Valve	557823	4075865
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe (Test 11)	XERO-915389	211
Restartable Ignition Detect Probe (Test 12)	NA5-27298T2	324

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in. (Except as Noted)	Date Effective	Comments
Gas Generator Fuel	RD251-4107	0.468	*	Thermostatic Orifice
Gas Generator Oxidizer	RD251-4106	0.268	*	
Oxidizer Turbine Bypass Valve	RD273-8002	1.319	*	
Main Oxidizer Valve	410437-082	8.27 scfm	October 7, 1967 per RFD71-67	
Oxidizer Turbine Exhaust	RD251-9004	10.000	*	
Augmented Spark Igniter Oxidizer	406361-3	0.125	September 21, 1967 per ECP J2-575	

*Installed before engine delivery to AEDC.

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-11 AND J4-1801-12)

Modification	Completion Date	Description of Modification
RFD*-AEDC-35-2-67	October 10, 1967	Installed a 0.085-in. shim under the augmented spark igniter ignition detect probe.
	October 10, 1967	Replaced the gas generator outlet temperature probe, P/N NA5-27342T4, S/N 546, with P/N NA5-27342T4, S/N 572 required by normal maintenance procedures that specifies replacement each time the probe indicates a temperature in excess of 1800°F.
ECP J2-408	October 10, 1967	Removed oxidizer turbine bypass line orifice retainer ring.

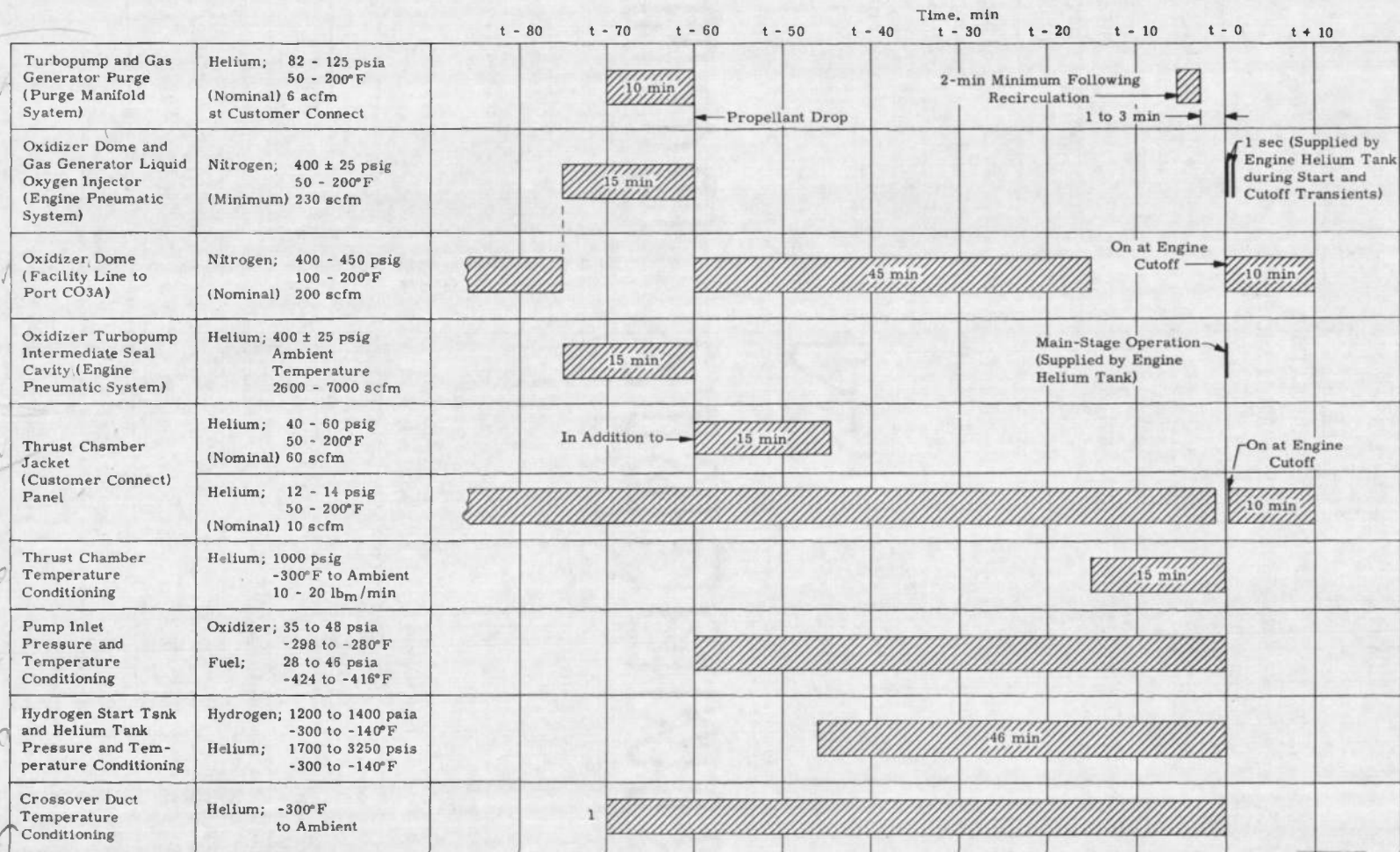
*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-11 AND J4-1801-12)

Replacement	Completion Date	Component Replaced
UCR*-007310	October 10, 1967	Augmented Spark Igniter Ignition Detect Probe

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE



¹Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-		11A		12A		12B	
		Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1344/October 11, 1967		0957/October 17, 1967		1037/October 17, 1967	
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	101,000	100,000	96,000	100,000	---
Firing Duration, sec ^①		30.0	30.071	30.0	30.076	5.0	0.454
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	37.0 ± 1.0	36.7	37.0 ± 1.0	37.2	37.0 ± 1.0	37.2
	Temperature, °F	-420.0 ± 0.4	-419.6	-420.0 ± 0.4	-416.6	-421.1 ± 0.4	-421.3
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	46.0 ± 1.0	46.2	46.0 ± 1.0	46.9	41.0 ± 1.0	40.6
	Temperature, °F	-293.5 ± 0.4	-294.3	-293.5 ± 0.4	-293.7	-295.3 ± 0.4	-294.5
Start Tank Conditions at Engine Start	Pressure, psia	1300 ± 10	1260	1300 ± 10	1269	1360 ± 10	1361
	Temperature, °F	-175 ± 10	-176	-175 ± 10	-166	-225 ± 10	-220
Helium Tank Conditions at Engine Start	Pressure, psia	---	2222	---	2387	---	2230
	Temperature, °F	---	-160	---	-166	---	-225
Thrust Chamber Temperature Conditions at Engine Start, t ₀ , °F	Throat ^②	50 ± 50	61 -257	50 ± 50	83 29	50 ± 50	73 19
	Average	---	76 -257	---	69 -268	---	67 -262
Crossover Duct Temperature at Engine Start, °F	TFTD-2	Ambient ^③	42	Ambient ^③	54	---	368
	TFTD-3	Ambient ^③	63	Ambient ^③	77	±125 ⁺¹⁵ -0	139
	TFTD-8	Ambient ^③	52	Ambient ^③	45	---	371
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	36.5	---	50.6	---	46.4
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		---	-147.0	---	-66.7	---	-68.1
Fuel Lead Time, sec ^①		6	7.969	8	-7.666	8	-7.966
Propellant in Engine Time, min		60	254	60	67	---	---
Propellant Recirculation Time, min		10	10	10	14	10	11.5
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	---	36.4	---	74.4	---	26.9
	TOBS-2	---	26.7	---	83.7	---	16.0
	TOBS-3	---	---	---	34.4	---	5.6
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	-25	---	10	---	-27
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t ₀ ^①		---	14 0.960	---	20 1.040	---	---
Gas Generator Outlet Temperature, °F	Initial Peak	---	2070	---	1426	---	---
	Second Peak	---	2230	---	1536	---	---
Thrust Chamber Ignition Time, sec (Ref. t ₀) (PC-3 = 100 psia) ^①		---	0.986	---	1.042	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t ₀) ^①		---	1.266	---	1.046	---	---
Main-Stage Pressure No. 2, sec (Ref. t ₀) ^①		---	1.607	---	1.713	---	---
550-psia Chamber Pressure Attained, sec (Ref. t ₀)		---	1.676	---	1.675	---	---
Propellant Utilization Valve Position at Engine Start; Engine Start/t ₀ + 10 sec		Null Closed	Null Closed	Null Closed	Null Closed	Open ---	Open ---

Notes: ^①Data reduced from oscillogram.^②Crossover duct temperature must be above 32°F for 15 min before engine start.^③Thrust chamber throat temperature is from TSC2-16 on firing 11A and from TTC-1P on firings 12A and 12B.

**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
11A	0	0.154	0.144	0.447	0.102	0.259	-7.969	0.058	0.072	0.447	0.057	0.063	0.447	0.822	1.847	0.447	0.109	0.028	0.447	0.181	0.079	0.447	0.225	0.307
12A	0	0.150	0.146	0.454	0.095	0.250	-7.986	0.054	0.065	0.454	0.053	0.057	0.454	0.592	2.050	0.454	0.107	0.026	0.454	0.176	0.072	0.454	0.217	0.386
12B	0	0.160	0.157	---	---	---	-7.866	0.049	0.066	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Final Sequence, Test 11	0	0.097	0.108	0.449	0.091	0.248	-1.018	0.047	0.065	0.448	0.044	0.058	0.449	0.502	1.692	0.449	0.072	0.042	0.449	0.138	0.063	0.449	0.200	0.311
Final Sequence, Test 12	0	0.089	0.110	0.450	0.092	0.247	-1.014	0.045	0.070	0.450	0.047	0.052	0.450	0.590	1.680	0.450	0.090	0.031	0.450	0.145	0.063	0.450	0.205	0.277

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 Closing Signal	Valve Delay Time, sec	Valve Opening Time, sec
11A	30.071	0.142	0.373	30.071	0.101	0.187	30.071	0.059	0.025	30.071	0.030	0.016	30.071	0.269	0.541
12A	30.076	0.125	0.318	30.076	0.081	0.181	30.076	0.051	0.074	30.076	0.030	0.012	30.076	0.284	0.458
12B	0.454	0.091	0.281	---	---	---	---	---	---	---	---	---	---	---	---
Final Sequence, Test 11	---	0.081	0.241	---	0.066	0.134	---	0.081	0.051	---	0.054	0.021	---	0.224	0.708
Final Sequence, Test 12	---	0.082	0.238	---	0.072	0.130	---	0.079	0.026	---	0.055	0.020	---	0.234	0.687

- 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

AEDC-TR-67-278

Firing Number J4-1801-		11A		12A		624061
		Site	Normalized	Site	Normalized	Normalized, Averaged from 59 to 60 sec
Overall Engine Performance	Thrust, lbf	228,708	227,716	229,626	228,296	226,825
	Chamber Pressure, psia	767.8	761.8	770.7	763.5	759.2
	Mixture Ratio	5.555	5.520	5.608	5.564	5.559
	Fuel Weight Flow, lb _m /sec	81.4	81.1	80.98	80.66	81.4
	Oxidizer Weight Flow, lb _m /sec	452.3	447.9	454.14	448.80	452.2
	Total Weight Flow, lb _m /sec	533.7	529.0	535.12	529.46	533.5
Thrust Chamber Performance	Mixture Ratio	5.753	5.720	5.807	5.764	5.760
	Total Weight Flow, lb _m /sec	527.1	522.4	528.54	522.88	526.8
	Characteristic Velocity, ft/sec	7974.1	7983.0	7982.1	7993.2	7890
Fuel Turbopump Performance	Pump Efficiency, percent	74.9	74.9	75.0	75.0	72.4
	Pump Speed, rpm	26,871	26,551	26,856	26,504	27,009
	Turbine Efficiency, percent	61.4	61.2	62.0	61.7	62.1
	Turbine Pressure Ratio	7.10	7.09	7.01	7.01	7.10
	Turbine Inlet Temperature, °F	1258.3	1228.3	1262.3	1228.9	1251
	Turbine Weight Flow, lb _m /sec	6.64	6.64	6.58	6.57	6.74
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.2	80.1	80.2	80.2	80.1
	Pump Speed, rpm	8626	8567	8620	8562	8641
	Turbine Efficiency, percent	48.9	48.8	49.0	49.0	48.3
	Turbine Pressure Ratio	2.60	2.60	2.62	2.63	2.60
	Turbine Inlet Temperature, °F	819.6	798.2	822.5	798.7	818
	Turbine Weight Flow, lb _m /sec	5.98	5.98	5.93	5.92	6.08
Gas Generator Performance	Mixture Ratio	0.974	0.956	0.977	0.957	0.970
	Chamber Pressure, psia	648.0	644.8	642.8	638.9	657.3

- Note: 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 except as noted.
 4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

TABLE IX
SUMMARY OF ENGINE START CONDITIONS FOR AEDC ALTITUDE
FIRING J4-1801-12A AND SEA-LEVEL ACCEPTANCE TEST 624061

Parameter		624061	KA1801-12A
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	36.6	37.0
	Temperature, °F	-419.7	-419.8
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	46.3	46.8
	Temperature, °F	-293.5	-293.7
Start Tank Conditions at Engine Start	Pressure, psia	1299	1299
	Temperature, °F	-175	-166
Thrust Chamber Temperature Conditions at Engine Start/ t_0 , °F		+75/+45	+83/+29
Fuel Turbine Inlet Temperature at Engine Start, °F		+30	+13
Fuel Lead Time, sec		8	8
Propellant Utilization Valve Position at Engine Start		Null	Null

APPENDIX III INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-11 and J4-1801-12 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro- SADIC</u>	<u>Magnetic Tape</u>	<u>Oscillo- graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
	<u>Current</u>		<u>amp</u>					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	<u>Event</u>							
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		
	<u>Sparks</u>							
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		
	<u>Flows</u>		<u>gpm</u>					
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	
	<u>Forces</u>		<u>lbf</u>					
FSP-1	Side Load (Pitch)		±20,000	x		x		
FSY-1	Side Load (Yaw)		±20,000	x		x		
	<u>Heat Flux</u>		<u>watts Sq. cm²</u>					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0 to 7	x				
	<u>Position</u>		<u>Percent Open</u>					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOIBVT	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		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro- SADIC	Magnetic Tape	Oscillo- graph	Strip Chart	X-Y Plotter
	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		
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASLI	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 Injection	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 Throat		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Inlet		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				

TABLE III-1 (Continued)

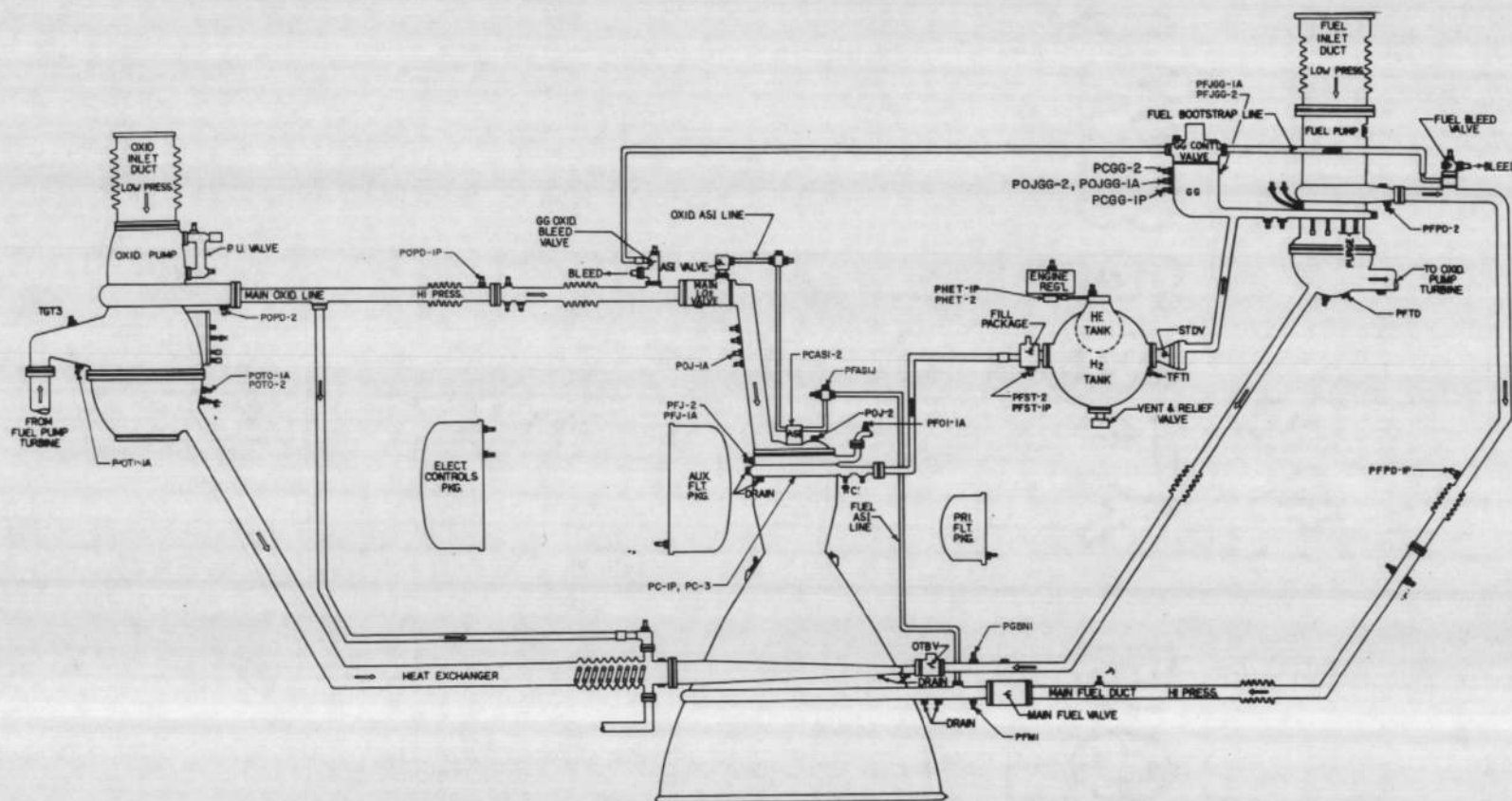
<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro- SADIC</u>	<u>Magnetic Tape</u>	<u>Oscillo- graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
	<u>Pressure</u>		<u>psia</u>					
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 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				
PPUVI-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				
	<u>Speeds</u>		<u>rpm</u>					
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				
	<u>Temperatures</u>		<u>°F</u>					
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				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASLJ	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		
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				

TABLE III-1 (Continued)

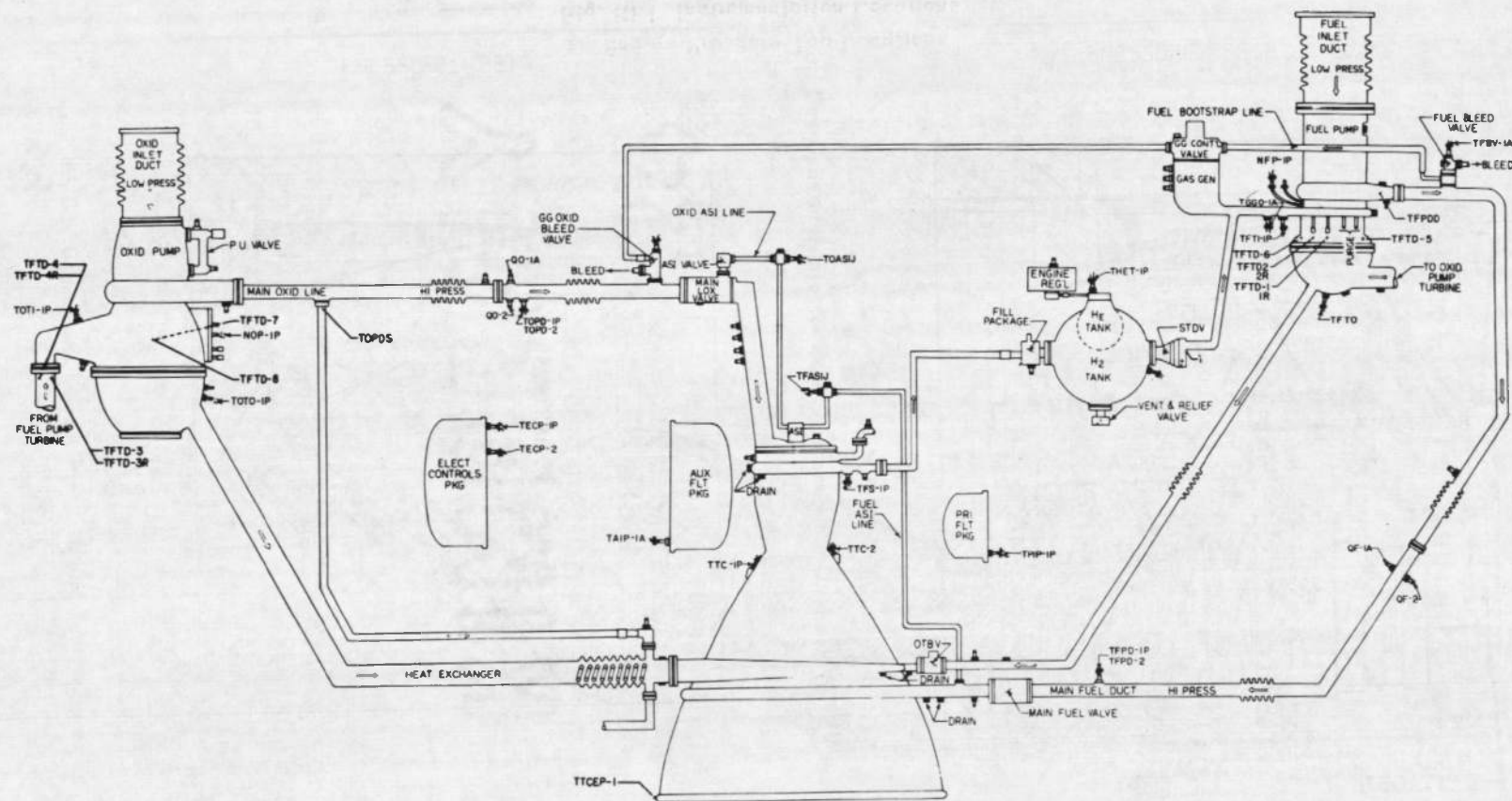
AEDC Code	Parameter	Tap No.	Range	Micro- SADIC	Magnetic Tape	Oscillo- graph	Strip Chart	X-Y Plotter
	<u>Temperatures</u>		<u>°F</u>					
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	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-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	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				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				
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				
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				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				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				
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				

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
<u>Temperatures</u>			<u>°F</u>					
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				
TSC2-11	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				
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				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
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				
<u>Vibrations</u>			<u>g's</u>					
UFPR	Fuel Pump Radial 90°		±200		x			
UOPR	Oxidizer Pump Radial 90°		±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		
<u>Voltage</u>			<u>volts</u>					
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		
VPUTEF	Propellant Utilization Valve Excitation		0 to 5	x				

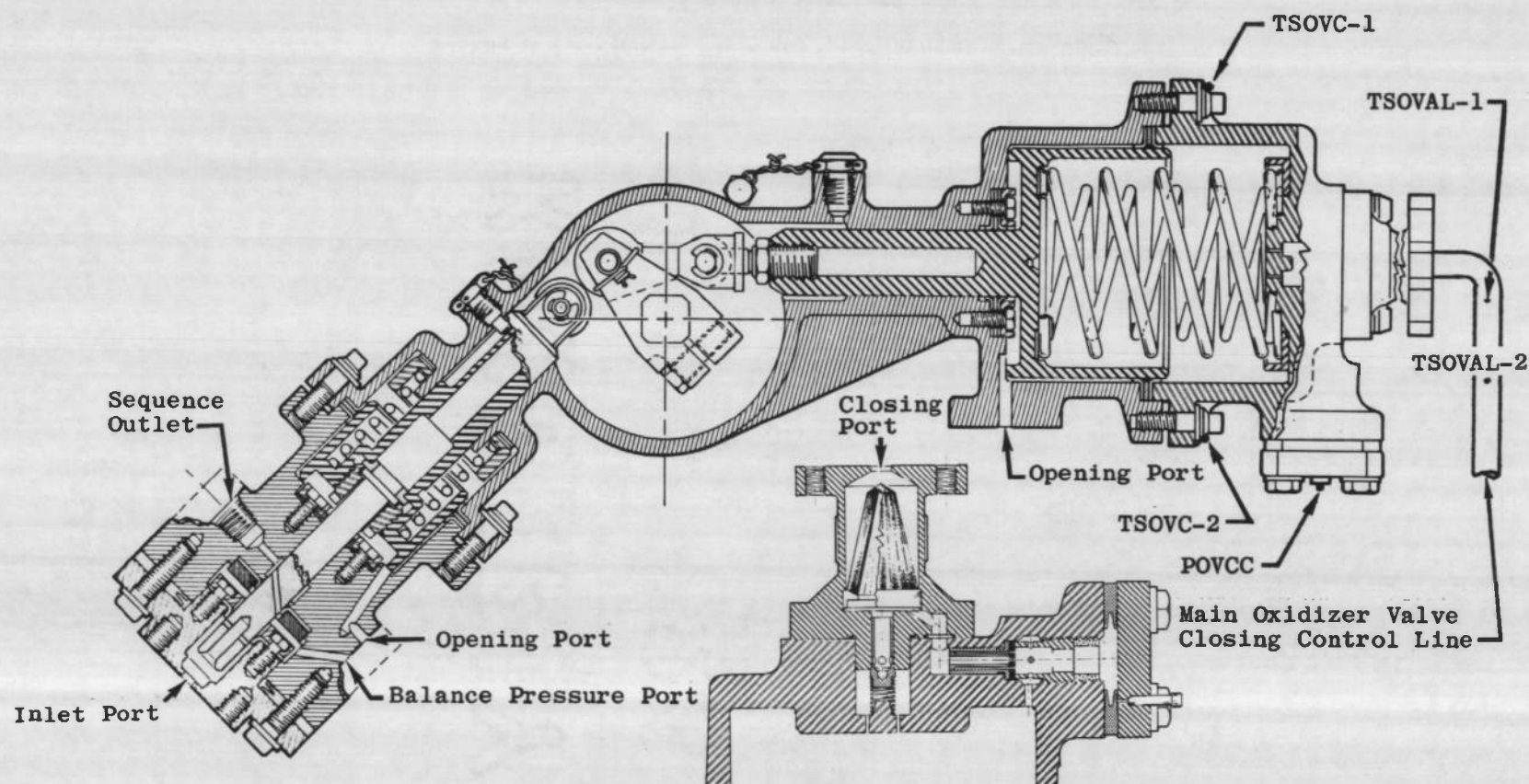


a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations

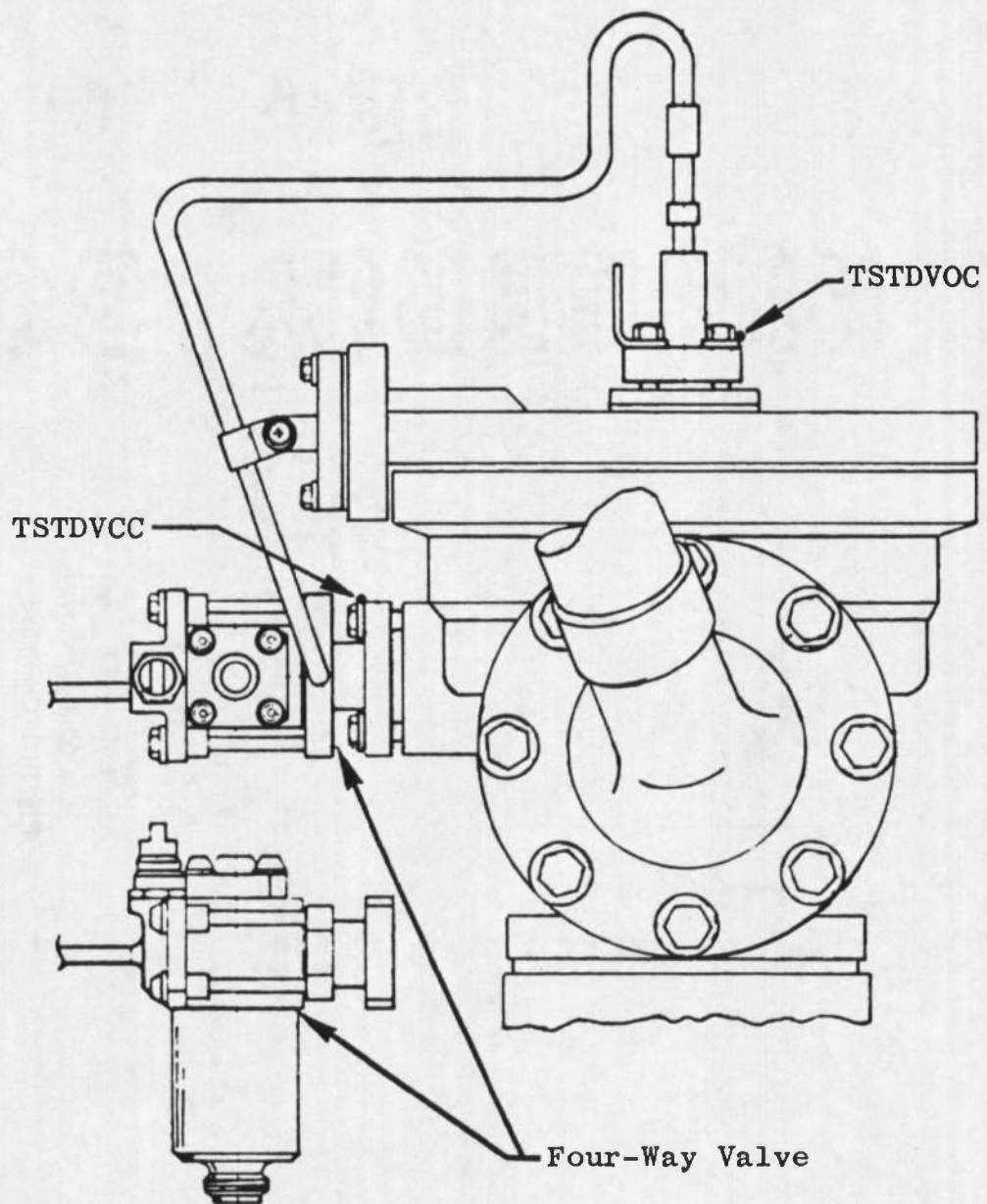


b. Engine Temperature, Flow, and Speed Instrumentation Locations

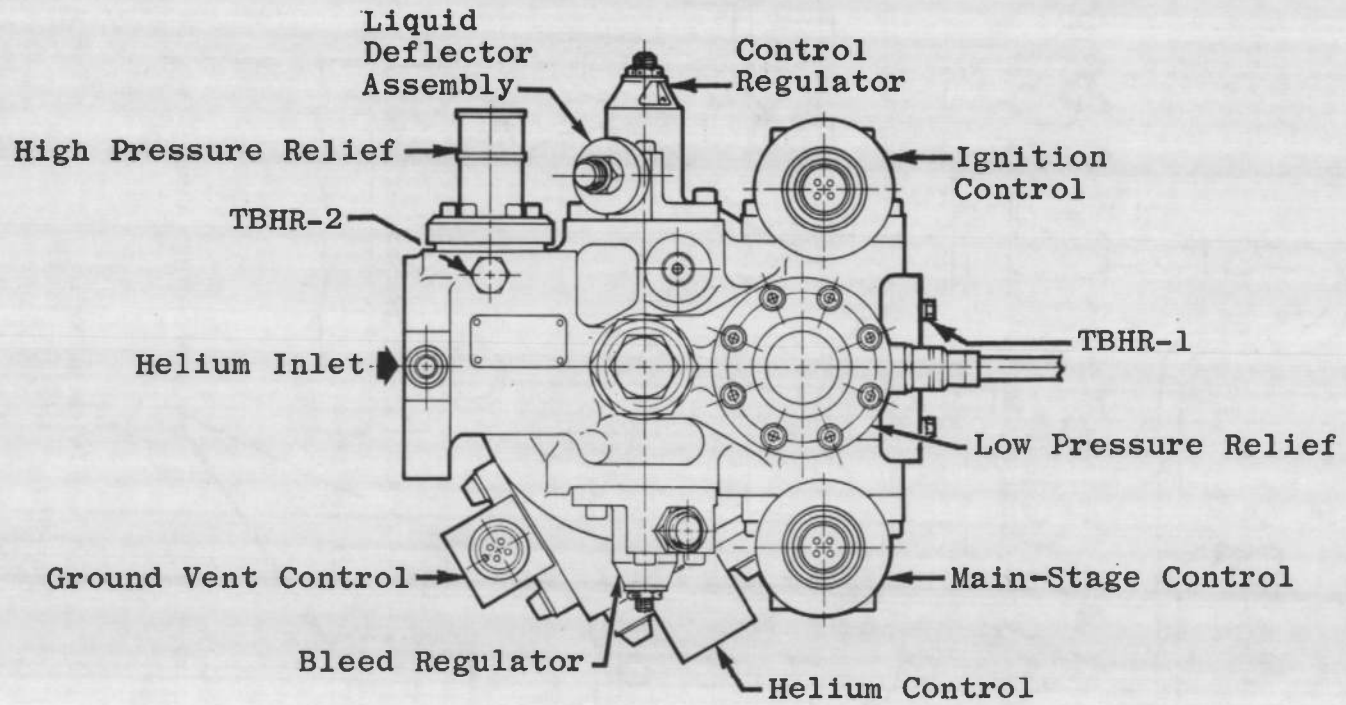
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

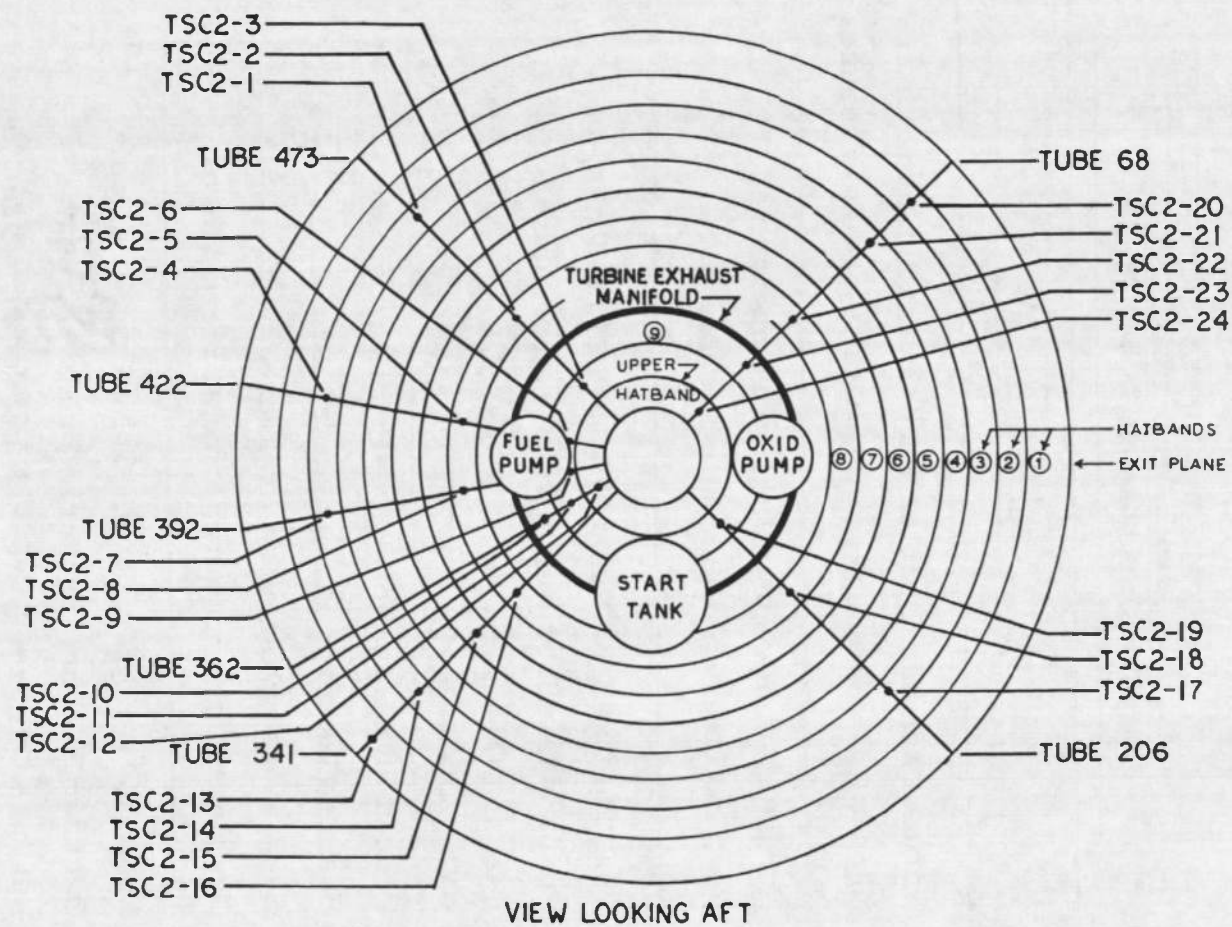


d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulator
Fig. III-1 Continued



f. Thrust Chamber
Fig. III-1 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

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

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

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

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

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

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

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

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

$$K_7 = 32.174$$

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

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.

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

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

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

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

$$T_{IO} = -295.212^\circ\text{F}$$

$$T_{IF} = -422.547^\circ\text{F}$$

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

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

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

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

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

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

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

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

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

$$D_3 = 1.2343$$

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

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

$$\theta_{PUVO} = 16.5239$$

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

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

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

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

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

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

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

$$K_{13} = 0.7854$$

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

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

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

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

$$K_8 = 38.8983$$

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.

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

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

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