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**ALTITUDE DEVELOPMENTAL TESTING OF THE
J-2 ROCKET ENGINE IN PROPULSION ENGINE
TEST CELL (J-4) (TEST J4-1801-04)**

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*Rev AF Letter 74
of 2 (2 July)
Signed William D. Cole*

N. S. Dougherty, Jr.

ARO, Inc.

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ALTITUDE DEVELOPMENTAL TESTING OF THE
J-2 ROCKET ENGINE IN PROPULSION ENGINE
TEST CELL (J-4) (TEST J4-1801-04)

N. S. Dougherty, Jr.

ARO, Inc.

1 Rocket motor J-2

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*Per AF Letter #12
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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 August 3, 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 October 2, 1967.

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This technical report has been reviewed and is approved.

Harold Nelson, Jr.
Captain, USAF
AF Representative, LRF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. A fifth firing attempt was aborted at $t - 1$ sec because the gas generator oxidizer supply line contained liquid-phase oxidizer. The firings were accomplished during test period J4-1801-04 at pressure altitudes ranging from 100,000 to 109,500 ft at engine start at predicted maximum starting energy S-V/S-IVB first burn conditions and maximum and minimum energy orbital restarting conditions. Satisfactory engine operation was obtained. The accumulated firing duration was 95.3 sec.

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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
Q	Volume flow, gal/sec
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 the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range
ΔP	Differential pressure, psi

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I INTRODUCTION

Testing of the Rocketdyne J-2 Rocket Engine (S/N J-2052) using a Douglas Aircraft 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. Test J4-1801-04, reported herein, was conducted on August 3, 1967, and included four engine firings (04A, 04B, 04C, and 04E). A fifth firing attempt (04D) was aborted. The firings were accomplished at pressure altitudes ranging from 100,000 to 109,500 ft (geometric pressure altitude, Z, Ref. 1) at engine start in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-V/S-IVB start condition effects on (1) gas generator and augmented spark igniter chamber ignition characteristics and (2) fuel pump stall margin.

Based on the results of the previous test conducted on July 26, 1967, J4-1801-03 (Ref. 2), a lower thermal conditioning "red line" limit was imposed on the oxidizer supply line to the gas generator. This limit is defined as that condition permitting liquid oxidizer to fill the line beyond the liquid trap, which is designed to preclude the existence of liquid oxidizer in the gas generator at engine start.

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 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.

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 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 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), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 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, crossover duct, pneumatic regulator, and main oxidizer valve closing control line and second-stage actuator. Helium was routed internally through the tubular-walled thrust chamber and crossover duct and externally

over the pneumatic regulator and main oxidizer valve closing control line and second-stage actuator.

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 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. The facility control logic network has the provisions for sequencing the stage prevalves open and recirculation systems off for engine start, as they were during the flight of the vehicle AS-501 S-IVB stage. The normal logic more closely duplicated the start sequence for S-IVB orbital restart; the auxiliary logic mode closely duplicated the start sequence for S-IVB first burn. The two control logics are presented in Figs. 7c and d.

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 various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, pneumatic regulator, main oxidizer valve closing control line, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing. The engine component conditioning system utilized a liquid hydrogen-helium heat exchanger to provide the chilled helium for component conditioning.

An external purge conditioning system for the gas generator oxidizer supply line was provided on engine J-2052 (refer to Rocketdyne Field Directive RFD-32-67). It consisted of a shroud formed by two pliable tubes of 0.016-in. -thick, clear Teflon®, 2.5 in. in diameter, 17 in. long, jointed by an aluminum sleeve. The shroud extended from the oxidizer bleed valve to the gas generator oxidizer inlet. Ambient temperature gaseous nitrogen was supplied to the shroud. A double layer of asbestos insulation and an electric heater, set to control at $-50 \pm 10^{\circ}\text{F}$ and to provide 300 watts of heat addition, were installed on the shroud before the subject test.

The conditioning shroud was designed to provide simulation of ground test environmental (not flight) conditions for the oxidizer line by maintaining approximately 15-psia nitrogen pressure locally over the entire length of the line.

SECTION IV RESULTS AND DISCUSSION

4.1 SUMMARY

During the four firings conducted on August 3, 1967 (test J4-1801-04), a total of 95.3 sec of engine operating time was accumulated. The firings were conducted in the following sequence and for nominal durations of:

04A	30 sec
04C	30 sec
04B	5 sec
04E	30 sec

A fifth firing attempt (04D) followed firing 04E but was aborted at t - 1 sec countdown time.

All of the firings were in support of the J-2 engine developmental program for the S-V/S-IVB launch vehicle. The simulated pressure altitudes at engine start varied from 100,000 to 109,500 ft. Thermal conditioning of the thrust chamber and selected engine components (crossover duct, main oxidizer valve, second-stage actuator cap and closing control line, and pneumatic control package) was accomplished to simulate the J-2 engine thermal conditions predicted for flight. The gas generator oxidizer supply line was thermal conditioned to $-50 \pm 10^{\circ}\text{F}$ for firings 04A, 04B, and 04C. Firing 04E and firing attempt 04D repeated the conditions of firings 04A and 04B, respectively, with the exception that the gas generator oxidizer supply line was not conditioned. Table VI presents the conditioning targets for the engine components and the measured test conditions at engine start. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

Propellant utilization valve excursions to the closed position (changing engine mixture ratio to 5.5) were made during firings 04A, 04C, and 04E to obtain maximum turbine hardware heating during 30 sec of engine operation for simulation of 80-min orbital coast and engine restart at the predicted crossover duct temperature level.

Specific test objectives and a brief summary of results of the firings are as follows:

<u>Firing</u>	<u>Test Objective</u>	<u>Results</u>
04A	Evaluate the effects of S-V/S-IVB first burn thrust chamber resistance on gas generator outlet temperature and evaluate augmented spark igniter operation at maximum starting energy.	No indications of excessive augmented spark igniter chamber temperature. Thrust chamber resistance effect could not be evaluated because necessary gas generator oxidizer supply line thermal conditioning limits were not met.

<u>Firing</u>	<u>Test Objective</u>	<u>Results</u>
04C	Evaluate the effects of minimum starting energy for S-V/S-IVB re-start on fuel pump high level stall margin and thrust chamber pressure buildup time.	Test objectives were met. Fuel pump stall margin was 600 gpm. Buildup time to 550-psia chamber pressure was 2.758 sec.
04B	Evaluate the effects of minimum model specification fuel pump inlet pressure and maximum S-V/S-IVB first orbit restarting energy on engine start transient and fuel pump low level stall margin.	Test objectives were met. Conservative (over 1300-gpm) fuel pump stall margin was maintained in the low level region.
04E	Repeat of firing 04A with all test conditions the same except that the gas generator oxidizer supply line was not conditioned.	All objectives were met. Thrust chamber resistance effect showed roughly a 1:1 increase in gas generator peak temperature for decreased thrust chamber temperature. No indications of excessive augmented spark igniter temperatures.
04D	Repeat of firing 04B with all test conditions the same except that the gas generator oxidizer supply line was not conditioned.	Test was aborted at t - 1 sec countdown time because gas generator oxidizer supply line thermocouples indicated presence of liquid oxidizer beyond the liquid trap.

The presentation of test results in the following sections will consist of a discussion of each firing with pertinent test comparisons essential to the above evaluations. The data presented will be that recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-04A

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 3 sec. Engine start and shutdown transients

are shown in Fig. 9. Table VII presents selected engine valve operating times for start and shutdown. The test cell (engine ambient) pressure altitude at engine start was 100,000 ft. Figure 10 presents engine ambient pressure and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion at about $t_0 + 10$ sec, which changed the engine mixture ratio from 5.0 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 11. The temperature profile of the gas generator oxidizer supply line at engine start is shown in Table VIII. Evaluation of the thrust chamber resistance effect on gas generator outlet peak temperature for maximum S-V/S-IVB starting energy was to be accomplished by duplicating all of the firing 02A conditions (Ref. 5), except for prechilling the thrust chamber 100°F colder. Table IX shows that all of these starting conditions of firings 02A and 04A were similar, except for the warmer gas generator oxidizer supply line temperature profile on firing 04A. Reference 6 states that a colder thrust chamber (reduced thrust chamber resistance to fuel flow) will produce a higher gas generator peak temperature, all other conditions being equal. The peak temperatures on firings 04A and 02A were approximately the same. The expected thrust chamber resistance effect between firings 04A and 02A was apparently negated by the unexpected gas generator oxidizer supply line temperature effect (to which the slight reduction in peak temperature was attributed).

There was no evidence from post-firing physical examination that excessive augmented spark igniter chamber temperatures had occurred. Thus, augmented spark igniter operation was deemed to have been completely satisfactory during this test. Ignition was detected in the igniter chamber 0.215 sec after engine start.

Thrust chamber ignition (defined as the time when thrust chamber pressure reaches 100 psia) occurred at $t_0 + 1.003$ sec. Vibration safety cutoff counts were recorded for 97 msec, beginning at $t_0 + 0.984$ sec. The main oxidizer valve second-stage initial movement occurred at $t_0 + 0.985$ sec. Thrust chamber pressure buildup time to 550 psia was 1.902 sec.¹ All valve operating times were consistent and normal.

¹The 550-psia level was chosen to allow comparison of all firings, either open or null propellant utilization valve position, in buildup time to a distinct level above the "main-stage" pressure switch level.

Although the closing of the gas generator control valve appeared normal, an abnormally high gas generator shutdown transient temperature was recorded (Fig. 9).

The 1860°F gas generator temperature, approximately 4 sec after engine cutoff, indicated possible leakage of oxidizer from the gas generator oxidizer poppet. A leak check conducted approximately 1 hr subsequent to firing 04A, by pressurizing the oxidizer system to 35 psia and operating the recirculation pump for 5 min, revealed that only slight leakage was present.

4.2.2 Firing J4-1801-04C

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 8 sec. Engine start and shutdown transients are shown in Fig. 12. Valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 108,000 ft. Figure 13 presents engine ambient pressure and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion from the open to the closed position at about $t_0 + 11.5$ sec, which changed the engine mixture ratio from 4.4 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 14. Engine start conditions were set for minimum restarting energy within the specified tolerances. Thrust chamber ignition occurred at $t_0 + 1.100$ sec. Vibration safety cutoff counts occurred for 4 msec at $t_0 + 0.544$ sec and for 15 msec at $t_0 + 1.083$ sec. Thrust chamber pressure buildup time to 550 psia was 2.758 sec, the longest buildup time recorded to date in the AEDC test program. The main oxidizer valve began the second-stage ramp at $t_0 + 1.028$ sec. Ignition was detected in the augmented spark igniter chamber 0.332 sec after engine start. All valve operating times were consistent and normal.

Transient fuel pump head/flow data, compared to the stall inception line for the fuel pump, are presented in Fig. 15. The minimum stall margin was approximately 600 gpm, occurring at approximately 19,000 rpm. The fuel pump was rotating at approximately 970 rpm before the start tank discharged (see Fig. 12). This is indicative of the unusually high flow rate of fuel that was attained during the 8-sec fuel lead period by prechilling the thrust chamber to -120°F before

engine start. Figure 15 shows the conservative fuel pump stall margin (approximately 2000 gpm) afforded by the thrust chamber prechill which preceded this firing.

4.2.3 Firing J4-1801-04B

The programmed 5-sec engine firing was accomplished 19 min after firing J4-1801-04C. The crossover duct cooldown rate to the level predicted for 80-min orbital restart is shown in Fig. 16. The propellant utilization valve was in the open position throughout the firing.

Engine start and shutdown transients are shown in Fig. 17. The programmed fuel lead time was 8 sec. All valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 109,500 ft. Figure 18 presents engine ambient pressure and thrust chamber pressure for the duration of the firing. Test conditions at engine start are shown in Table VI. Thermal conditioning history of selected engine components is shown in Fig. 19. The temperature profile of the gas generator oxidizer supply line was similar to that attained on firing 04A (Table VIII). Conservative low level fuel pump stall margin (over 1300-gpm) was maintained, as shown in Fig. 20, with a fuel pump inlet pressure at engine start of 27.6 psia (see Fig. 8a).

Thrust chamber ignition occurred at $t_0 + 0.948$ sec, without the occurrence of excessive vibration. The main oxidizer valve began the second-stage ramp at $t_0 + 1.098$ sec. Thrust chamber pressure buildup time to 550 psia was 1.915 sec. Ignition was detected in the augmented spark igniter chamber 0.259 sec after engine start.

4.2.4 Firing J4-1801-04E

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 3 sec. Engine start and shutdown transients are shown in Fig. 21. Valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 107,000 ft. Figure 22 presents engine ambient and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion from the null position to the closed position at about $t_0 + 10$ sec, which changed the engine mixture ratio from 5.0 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 23. The temperature profile of the gas generator oxidizer supply line at engine start is shown in Table VIII. Table IX shows that all of the firing 04E starting conditions (except thrust chamber temperature) were in close agreement with those attained on firing 02A, permitting isolation of the desired single variable, thrust chamber temperature. The gas generator peak temperature attained during the firing 04E start transient was 2200°F.

Augmented spark igniter operation was deemed satisfactory during this firing, based on no evidence, during post-firing physical examination, of igniter chamber erosion. Ignition was detected in the igniter chamber 0.225 sec after engine start.

Thrust chamber ignition occurred at $t_0 + 0.976$ sec. Vibration safety cutoff counts were recorded for 33 msec, beginning at $t_0 + 0.976$ sec. The main oxidizer valve second-stage initial movement occurred at $t_0 + 0.985$ sec. Thrust chamber pressure buildup time to 550 psia was 1.885 sec.

4.2.5 Firing Attempt J4-1801-04D

The programmed 5-sec engine firing was aborted at 1 sec before the fire command signal because the gas generator oxidizer supply line temperature profile indicated the presence of liquid oxidizer to thermocouple TOBS-2A (Table VIII). An indication of liquid oxidizer at the top of the liquid trap meant that it was possible for liquid to have extended beyond the trap toward the gas generator. Firing 03B (Ref. 2) had resulted in a gas generator overtemperature problem with the same gas generator oxidizer supply line conditions that existed before firing 04D. For this reason, firing 04D was aborted.

The history of the gas generator oxidizer supply line temperature profile following firing 04E, during the 19-min coast period required for crossover duct cooldown to the predicted 80-min restart level, is shown in Fig. 24. This restart was planned with 10 min of propellants-in-engine time. Figure 24 shows the warming trend after oxidizer was expelled following firing 04E. The supply line began to chill down again when the propellant prevalves were opened for the firing 04D restart. The "red line" limit was reached when the oxidizer ullage pressure was increased to the required starting level (48-psia). The warming trend shown during the 115-sec hold at fire command - 1 sec resulted from a last-minute effort to warm the line using the conditioning shroud heater.

4.3 GAS GENERATOR OXIDIZER SUPPLY LINE CONDITIONING

The gas generator oxidizer supply line conditioning system was originally installed on the engine before test J4-1554-26 (conducted April 4, 1967, Ref. 6).

The integrity of the conditioning shroud had significantly degraded before the subject test was conducted. The shroud developed a number of perforations, caused by cracking, and could not be adequately pressurized. The shroud was insulated, and the heater was added, before the subject test, to protect the oxidizer line from being inadvertently chilled by cold helium gas used for conditioning other components in close proximity. The required $-50 \pm 10^{\circ}\text{F}$ environment for firings 04A, 04B, and 04C (refer to Tables VI and VIII) was satisfactorily attained by operating the oxidizer line conditioning system at an increased nitrogen purge supply pressure which yielded a flow rate through the shroud estimated at about 80 scfm. Conditioning, therefore, was accomplished by forced-convection heat addition. For firing 04E and firing attempt 04D, the purge and the heater were turned off (removing the sources of heat addition). Thus, the configuration for these firings was a well-insulated gas generator oxidizer supply line with near vacuum between the oxidizer line and the insulation.

The effect of the differences in conditioning procedure is apparent in the comparisons shown in Table IX. Both firings 04A and 04E repeated the test conditions of firing 03A with the same objective of isolating thrust chamber resistance as the test variable when compared with firing 02A. The gas generator oxidizer supply line configuration for firings 03A and 03B was as shown in Fig. 25 (with the uninsulated shroud), and the nitrogen purge was not utilized. The oxidizer line was exposed to component chill gases used for providing predicted thermal conditions on other components in close proximity. Gas generator oxidizer supply line conditioning was the significant variable between firings 03A, 04A, and 04E. Firing 03A shows a 450°F higher gas generator peak temperature than firing 04A for liquid oxidizer throughout the line at engine start on firing 03A and gaseous oxidizer throughout the line on firing 04A. Firings 04A and 04E show only a 160°F gas generator peak temperature difference (with liquid oxidizer contained in the liquid trap on firing 04E).

Gas generator oxidizer supply line conditioning was the only significant variable between firings 03B and 04B, producing a 500°F gas generator peak temperature increase on firing 03B. Liquid oxidizer extended throughout the oxidizer line at engine start on firing 03B. The line contained only gaseous oxidizer on firing 04B.

4.4 THRUST CHAMBER RESISTANCE EFFECT

Thrust chamber resistance to fuel flow is a variable primarily dependent upon thrust chamber prechill temperature and is defined, for the purposes of this report, as:

$$\frac{\text{Fuel Pump Discharge Pressure-Thrust Chamber Pressure}}{(\text{Fuel Volumetric Flow Rate})^2}$$

Figure 26 shows the resistance values during the fuel lead and gas generator ignition transients for firing 04E compared with firing 02A. These two tests represent the extreme limits in thrust chamber temperature expected at engine start for S-V/S-IVB first burn.

A comparison of the gas generator start transients for firings 04E and 02A is presented in Fig. 27. Figure 27a shows that gas generator oxidizer injector pressures were nearly equal for both tests and that gas generator fuel injector and chamber pressures were slightly higher on firing 02A. Figures 27b and c show the gas generator ignition transient details as the gas generator control valve opened. Gas generator ignition was detected at $t_0 + 0.642$ sec on firing 02A and 20 msec later, at $t_0 + 0.662$ sec on firing 04E. The oxidizer poppet had been open for 25 msec longer before ignition occurred on firing 04E.

The effect of thrust chamber resistance on the gas generator peak temperature is shown to be small for these two firings. Table IX shows that firing 02A test conditions were closely duplicated on firing 04E except for the desired single variable, thrust chamber temperature at engine start. There was a difference of 110°F in thrust chamber temperature at t_0 for these two firings. Gas generator peak temperatures differed by only 120°F, showing roughly a 1:1 correlation between decreased thrust chamber temperature and increased gas generator peak temperature. The assumption has been made that the reorificing of the engine between these two firings had no appreciable effect on this conclusion. Orifice sizes used for these two firings were as follows:

<u>Gas Generator</u>	<u>Firing 02A</u>	<u>Firing 04E</u>	<u>Area Increase, percent</u>
Fuel Orifice Diameter, in.	0.472	0.500	12.1
Oxidizer Orifice Diameter, in.	0.276	0.294	13.5

The difference in gas generator ignition characteristics caused by decreased thrust chamber resistance resulted in a slower thrust chamber pressure buildup rate to main-stage operation on firing 04E than on firing 02A. Thrust chamber pressure buildup time to 550 psia required 31 msec longer on firing 04E as a result of the delayed gas generator ignition and lower gas generator power as bootstrap operation began. Figures 27a and e show the effect that thrust chamber resistance had on engine buildup time. The difference in fuel pump discharge pressure (shaded area in Fig. 27d) for identical fuel pump spinup rates (Fig. 27e) is the result of thrust chamber resistance to fuel flow. The difference in fuel pump speed rise rates shown in Fig. 27e after gas generator ignition is indicative of the slower gas generator power buildup rate on firing 04E. The corresponding difference in fuel pump discharge pressure after gas generator ignition reflects this difference in fuel pump speed.

4.5 ENGINE PERFORMANCE

Engine steady-state performance data are presented in Table X for a 1-sec data average between 29 and 30 sec after t_0 for firings 04A, 04C, and 04E. These data 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. Data from the flight instrumentation sensor for oxidizer turbine inlet pressure (POTI-1A) were nonrecoverable for any of the subject firings. A value of 3.0 psia was added to the oxidizer turbine bypass nozzle (PGBNI) pressure measurement during each of these tests, and this estimated pressure was substituted for the missing POTI-1A measurement. The 3-psi value represented a mean difference between these two values measured during previous firings and the exact difference measured for this particular fuel turbine during test J4-1801-01 (Ref. 7).

The engine was reorificed between tests J4-1801-03 and -04 (see Table II) to compensate for significant reduction in fuel turbine blade area caused by erosion during test J4-1801-03. The normalized performance data (Table X) show that overall engine performance was higher than nominal during firings 04A and 04C and very close to nominal during firing 04E. For rated conditions (not presented in Table X) of 225,000-lbf thrust, 5.50 mixture ratio, and 1200°F fuel turbine inlet temperature, test data show that the oxidizer turbine bypass nozzle and the gas generator oxidizer supply orifice were slightly undersized by 2 and 0.5 percent, respectively. The gas generator fuel supply orifice was correctly sized.

Site data presented in Table X show that combustion chamber pressure and calculated engine thrust were decreased proportionately to lower gas generator chamber pressure during the 1-sec data average of each successive firing. The lower gas generator chamber pressure on successive firings resulted from lowered gas generator mixture ratio (evidenced by corresponding decreased fuel turbine inlet temperature). Calculated fuel turbine efficiency was only slightly below nominal. Calculated oxidizer turbine efficiency was slightly above nominal.

4.6 AUGMENTED SPARK IGNITER OPERATION

Pump inlet pressures were set at the extreme limits of the safe starting regions, high oxidizer and low fuel pressures, for firings 04A, 04B, and 04E (see Fig. 17). These are the conditions most conducive to yield excessive combustion temperature in the augmented spark igniter and erosion of the igniter chamber. A 0.110-in. -diam augmented spark igniter oxidizer supply line orifice was installed for these firings. The absence of any erosion as determined from post-test physical examination was the basis of the conclusion that augmented spark igniter operation was completely satisfactory during these firings. A previous AEDC firing, J4-1554-19 (Ref. 8), produced severe erosion using a 0.150-in. -diam oxidizer supply line orifice with the same relative pump inlet pressures. The subject firings indicate that a 0.110-in. -diam oxidizer supply line orifice precludes the occurrence of the undesirable high igniter chamber temperatures.

4.7 POST-TEST INSPECTION

Following test J4-1801-04, the fuel and oxidizer turbines were disassembled for inspection. This inspection showed the oxidizer turbine to be in satisfactory condition, and it was reinstalled on the engine. However, inspection of the fuel turbine showed that it would have to be replaced. There were five known cracks in the fuel turbine curvic coupling before the subject test. Two additional cracks developed during this test period, and the five original cracks progressed as indicated in Fig. 28.

Measurements of the amount of material that had eroded from the blades of the fuel turbine first stage, taken before and after the subject test, showed that no significant erosion occurred during these four firings. Figure 29 shows the eroded condition of the fuel turbine

as compared with the worst of the eroded blades from the turbine that had been damaged during the anomalous test J4-1554-30.

Because of the suspected oxidizer leakage from the gas generator after engine cutoff of firing 04A, the gas generator control valve was removed from the engine for extensive post-test physical examination by the engine manufacturer.

SECTION V

SUMMARY OF RESULTS

The results of the four J-2 engine firings obtained and the fifth firing attempt on August 3, 1967, in Test Cell J-4 during test period J4-1801-04 are summarized as follows:

1. Variations in gas generator oxidizer supply line pre-fire conditioning were shown to have significant effects of up to 500°F on gas generator outlet peak temperature.
2. A red line limit was established for gas generator oxidizer supply line thermal conditions at engine start. Restart firing attempt 04D was aborted because these conditions were realized.
3. An abnormally high gas generator outlet temperature (1860°F), 4 sec after shutdown of firing 04A, indicated probable leakage from the gas generator oxidizer poppet.
4. A minimum starting energy S-V/S-IVB restart firing was successfully conducted. The minimum high level stall margin for the fuel pump was approximately 600 gpm. Thrust chamber pressure buildup time to the 550-psia level was the slowest to date observed in AEDC altitude testing — 2.758 sec.
5. A maximum starting energy S-V/S-IVB restart firing was made with minimum model specification fuel pump inlet pressure at the crossover duct temperature level predicted for 80-min (first orbit) restart. Conservative low level fuel pump stall margin (over 1300-gpm) was maintained.
6. Thrust chamber resistance to fuel flow was found to have a small effect on gas generator peak temperature during two maximum starting energy S-V/S-IVB first burn firings, which were made at the opposite extremes of thrust chamber pre-chill predicted for S-V flight.

7. Normalized engine steady-state performance data computed for three 30-sec firings (04A, 04C, and 04E) showed that overall engine performance was higher than nominal on firings 04A and 04C and close to nominal on firing 04E.
8. Augmented spark igniter operation was satisfactory during all firings. A 0.110-in. -diam oxidizer supply line orifice was used. Pump inlet pressures were set at engine start of firings 04A, 04B, and 04E for worst-case expected igniter chamber erosion.
9. Vibration safety cutoff counts were measured during thrust chamber ignition of three of the firings (04A, 04C, and 04E) with durations ranging from 15 to 97 msec.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wesler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Kunz, C. H. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-03)." AEDC-TR-67-209, December 1967.
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. Franklin, D. E. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-02)." AEDC-TR-67-192, December 1967.
6. 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-67-145, October 1967.
7. Muse, W. W., and Pillow, C. E. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-01)." AEDC-TR-67-181, December 1967.
8. Simpson, J. N., Cantrell, F. D., and Kunz, C. H. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-12 through J4-1554-19)." AEDC-TR-67-115 (AD820463), September 1967.

APPENDIXES

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

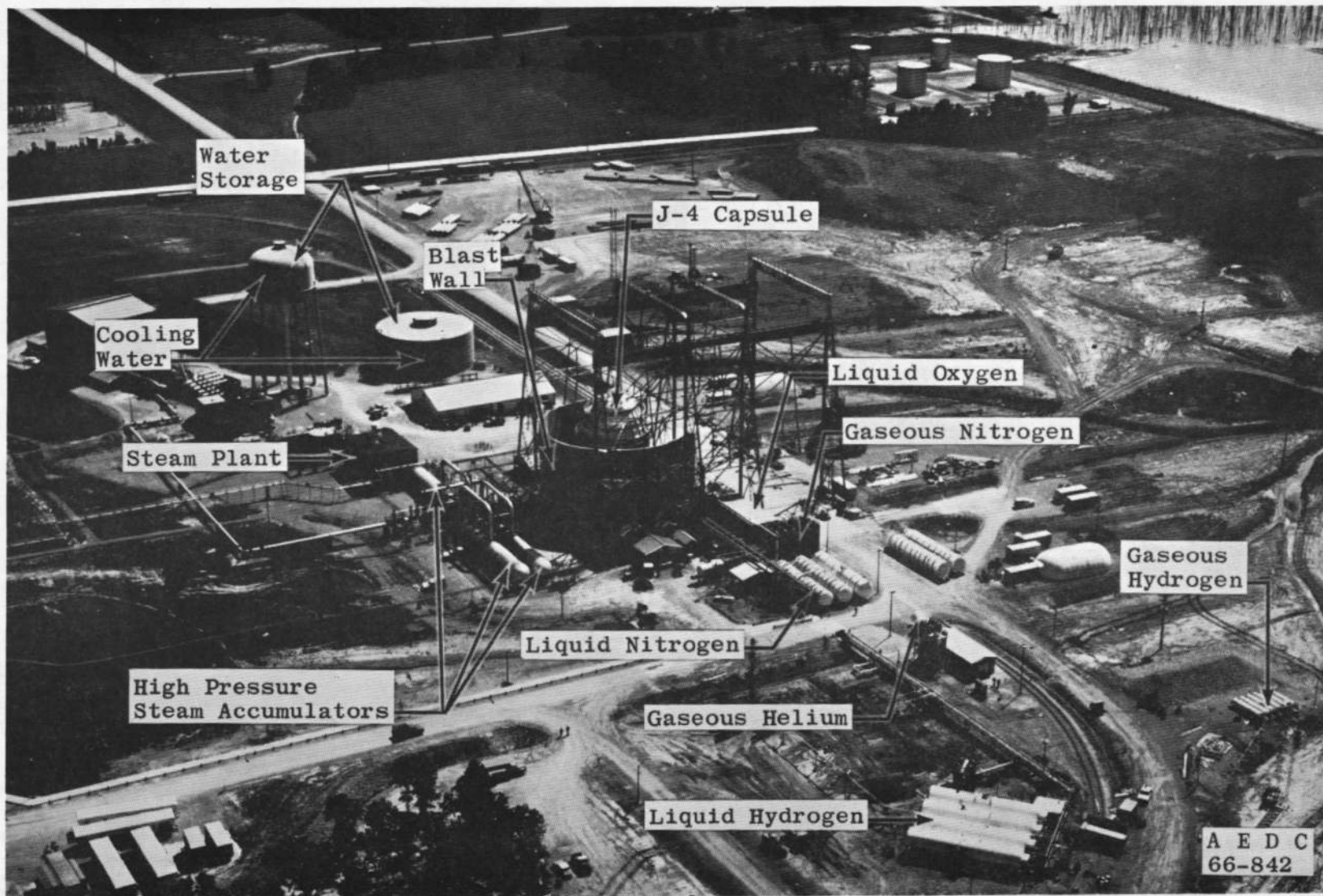


Fig. 1 Test Cell J-4 Complex

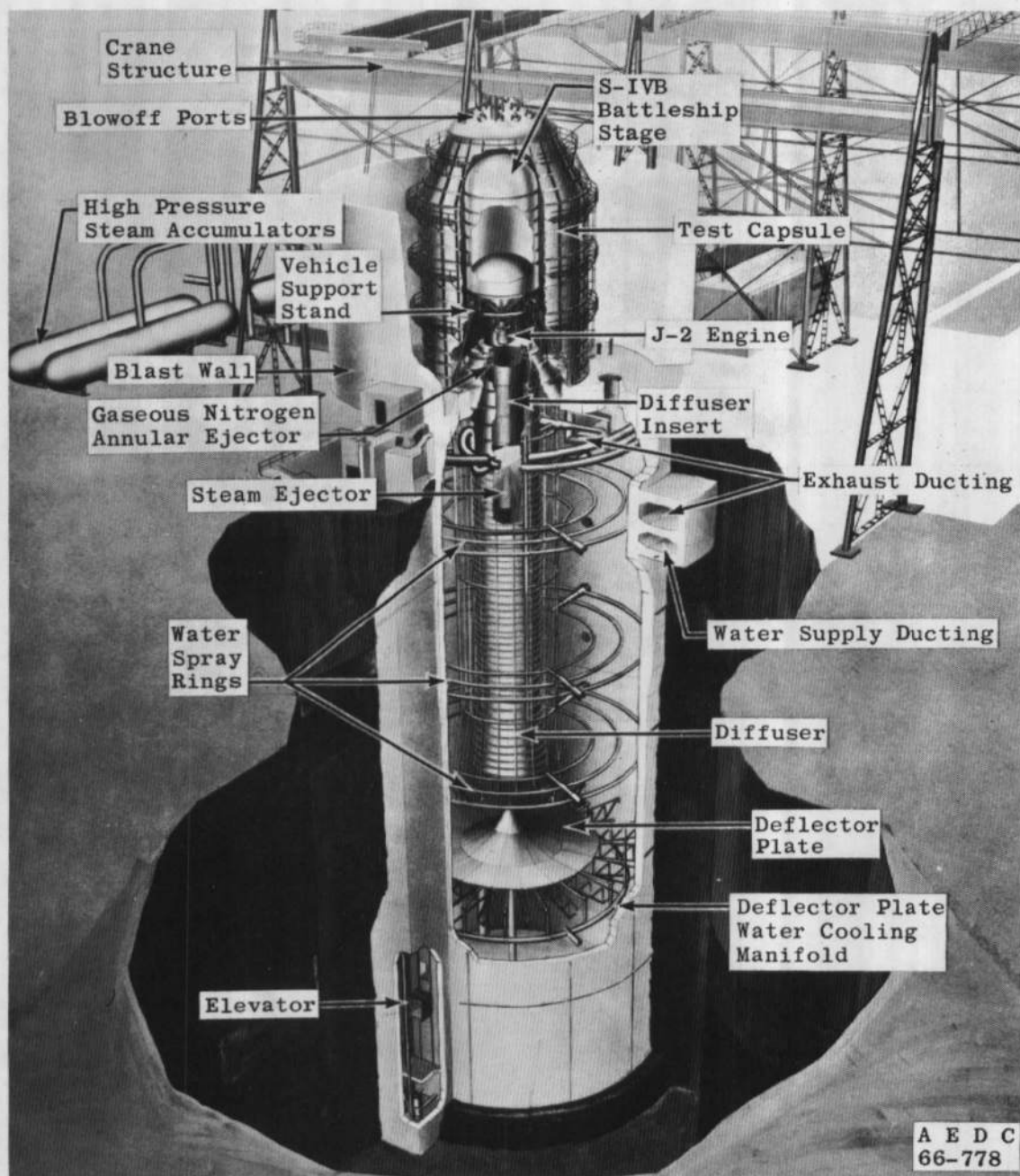


Fig. 2 Test Cell J-4, Artist's Conception

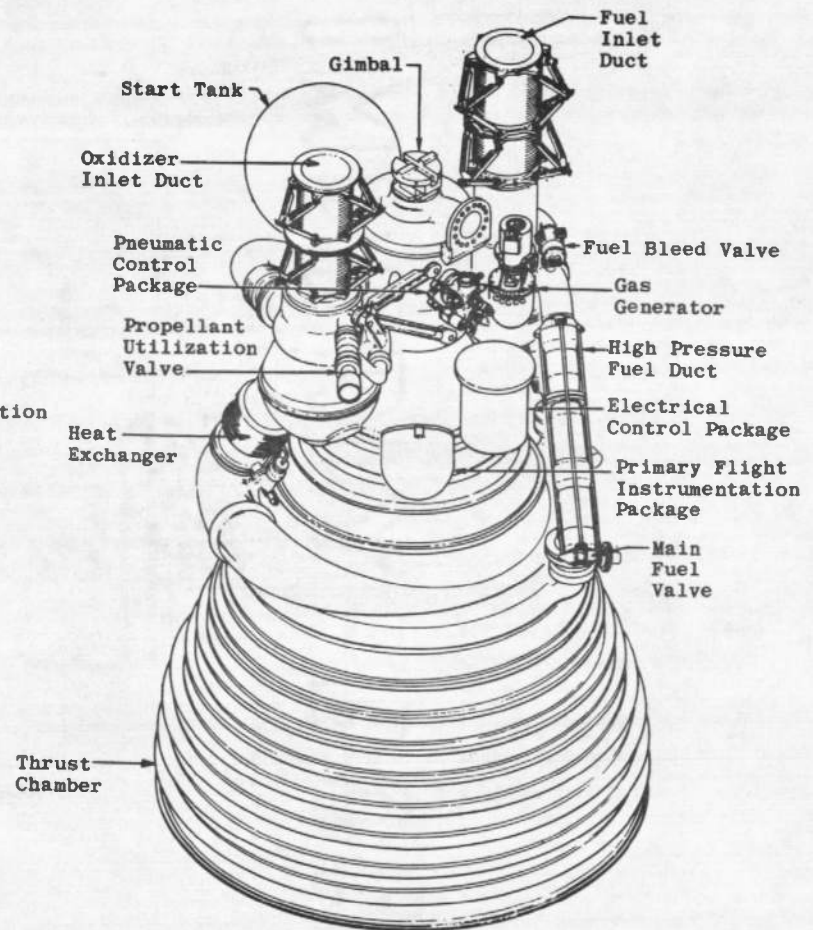
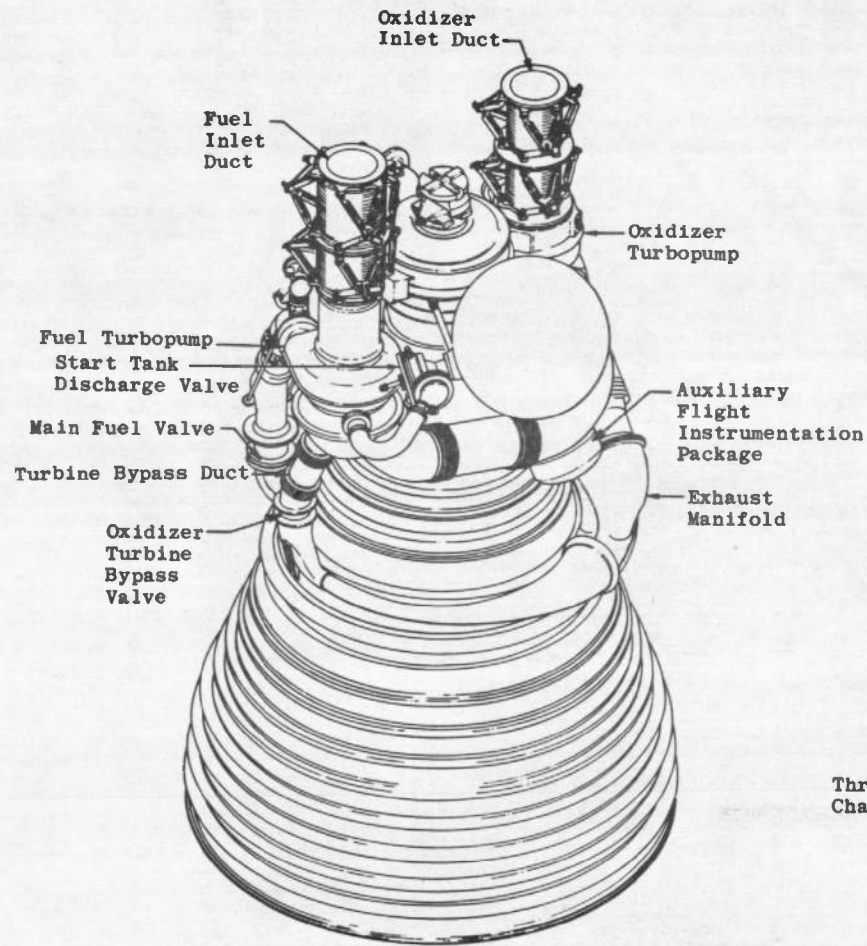


Fig. 3 Engine Details

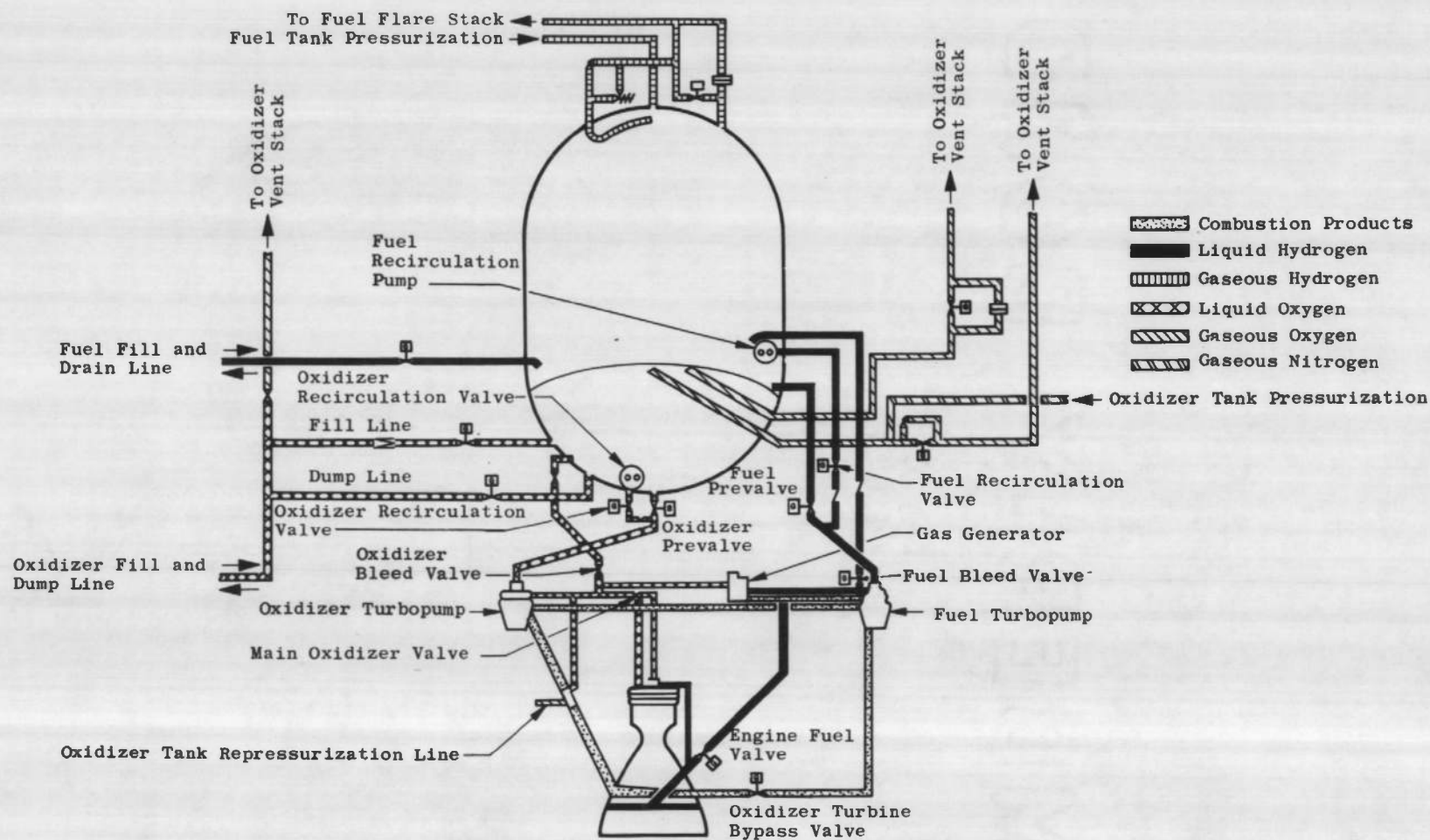


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

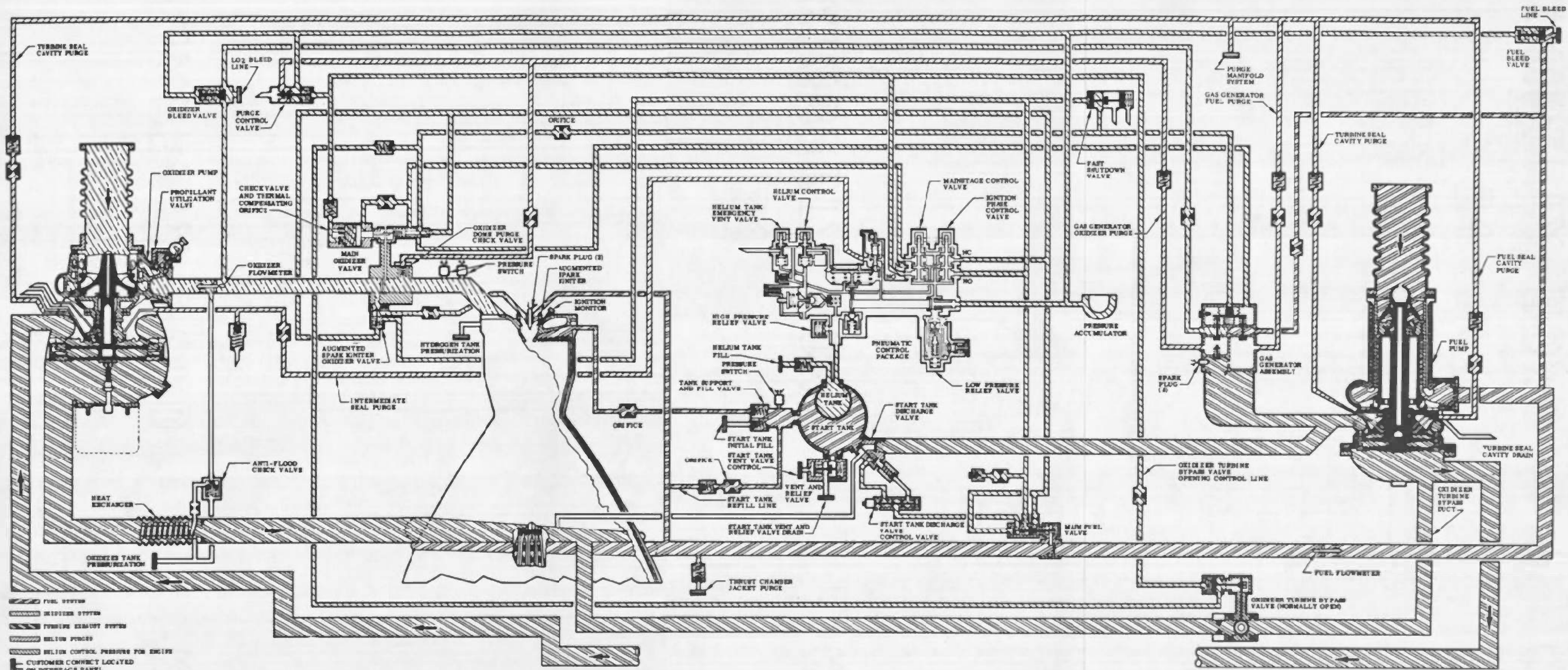


Fig. 5 Engine Schematic

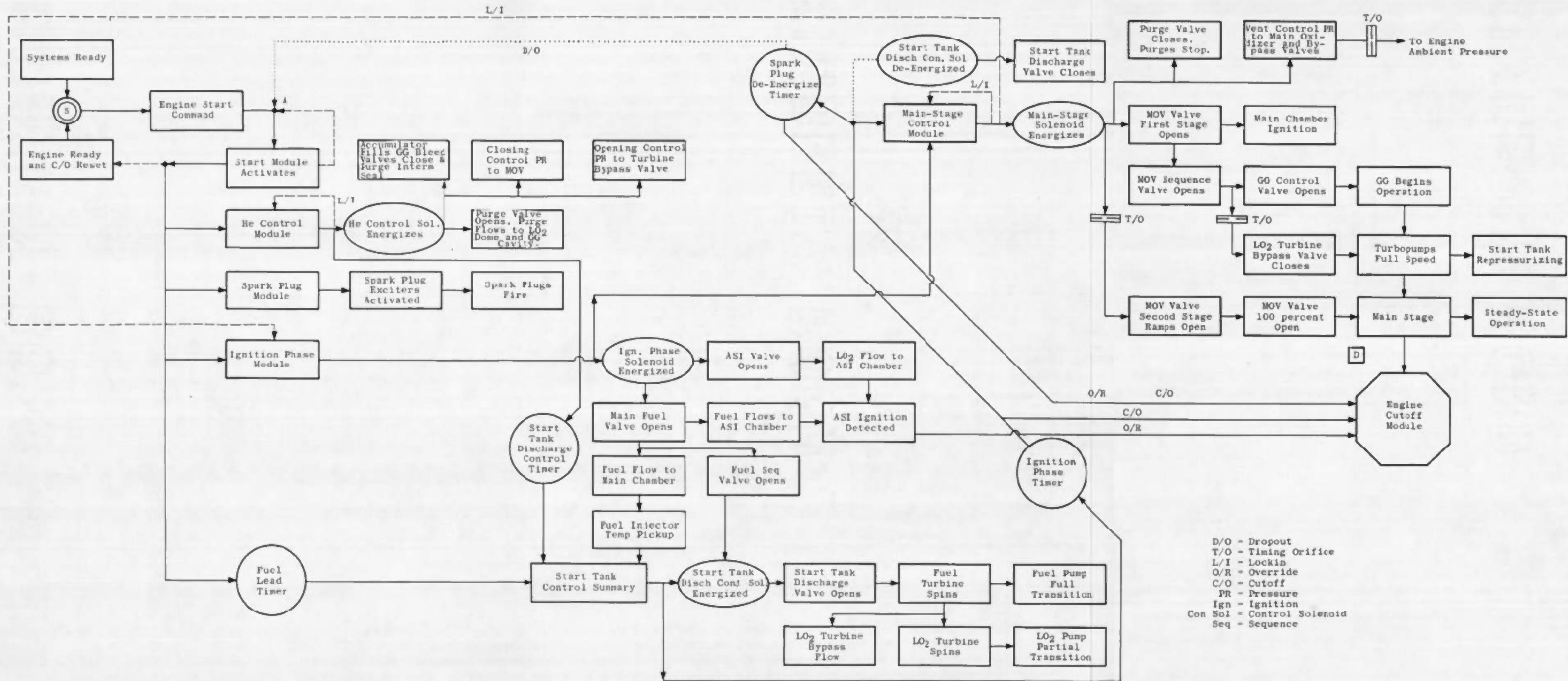
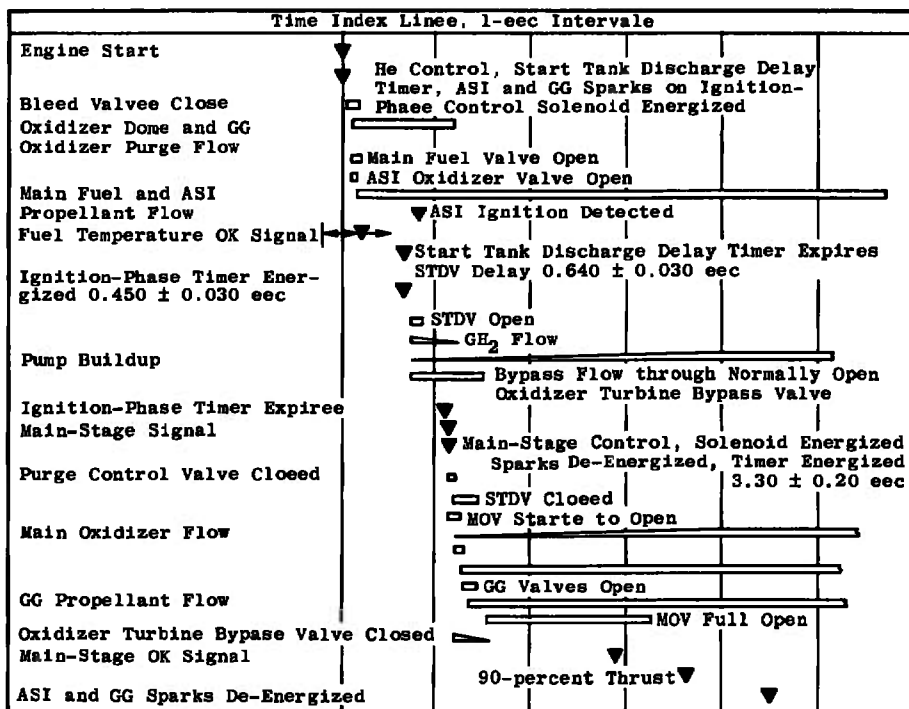
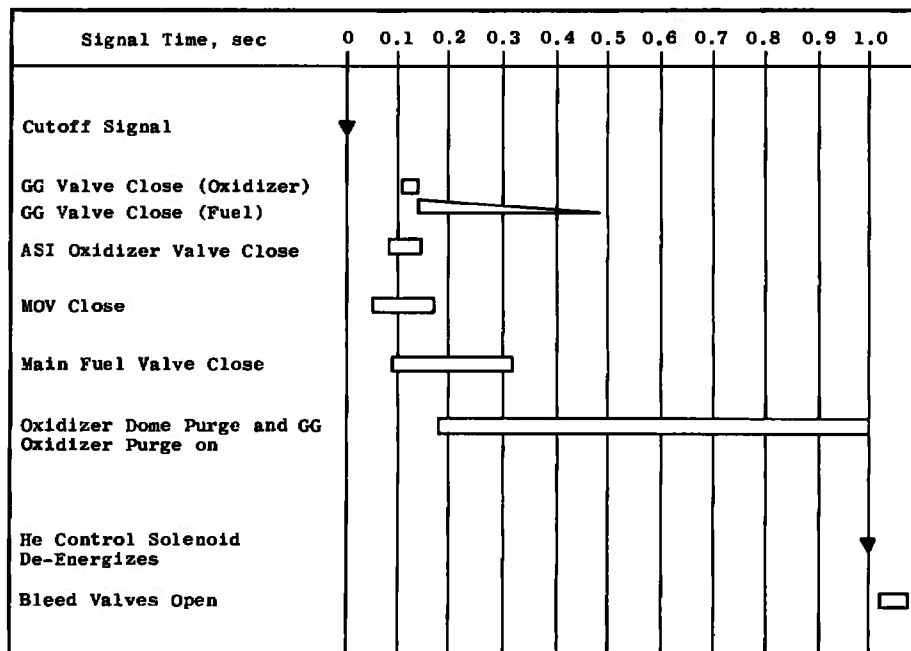


Fig. 6 Engine Start Logic Schematic

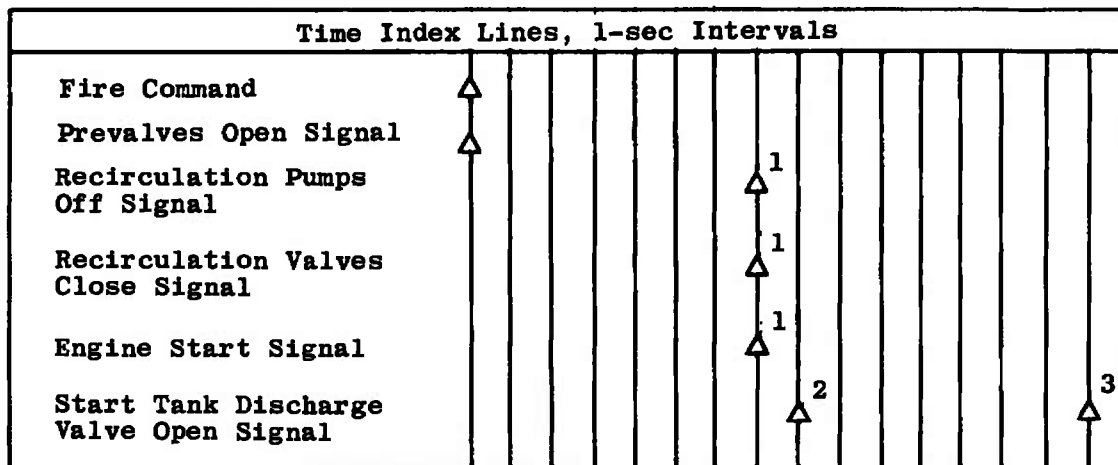


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

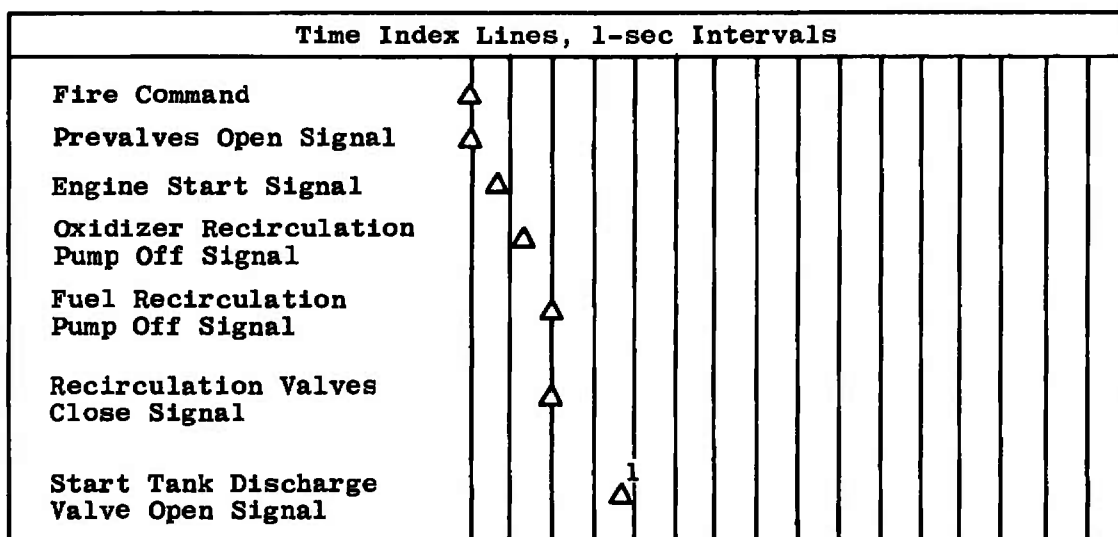


¹Nominal Occurrence Time (Function of Prevalves Opening Time)

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)

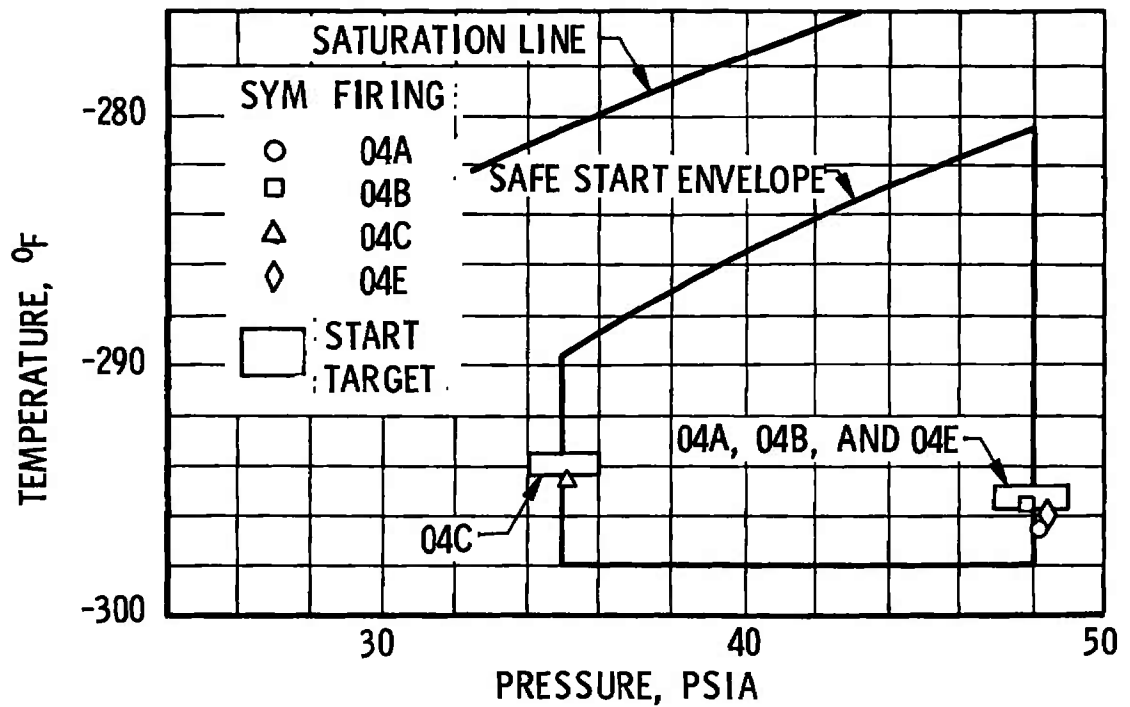
c. Normal Logic Start Sequence



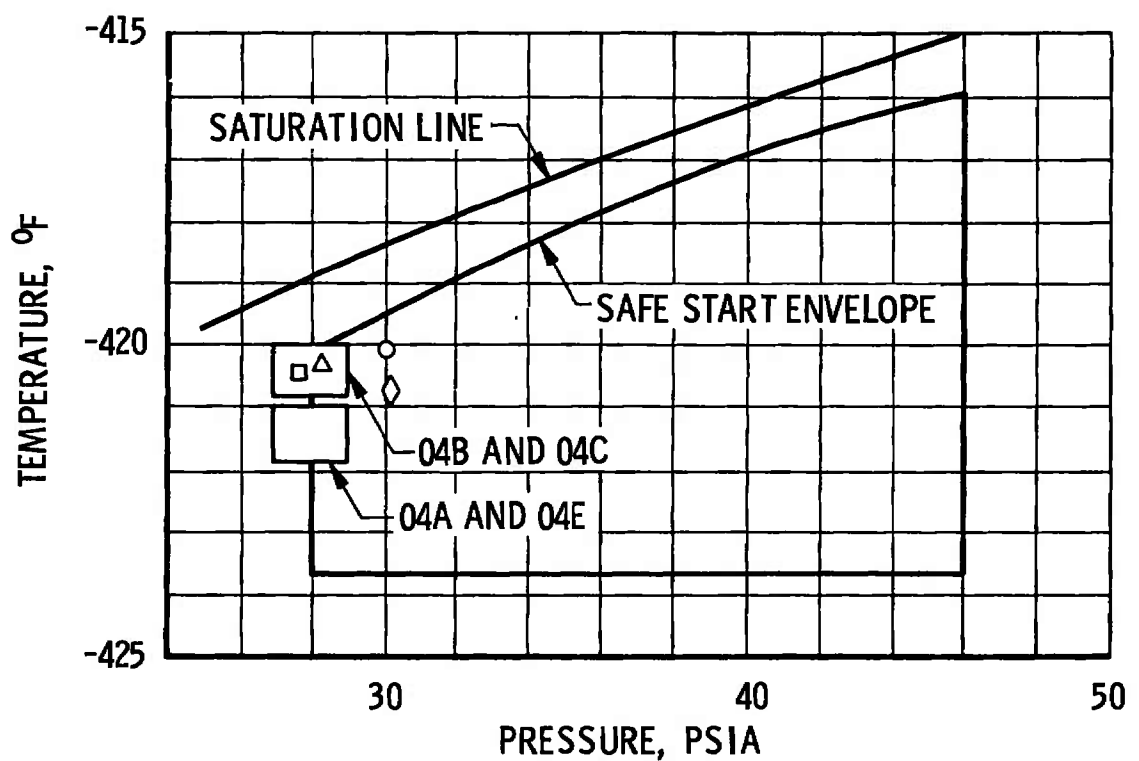
¹Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

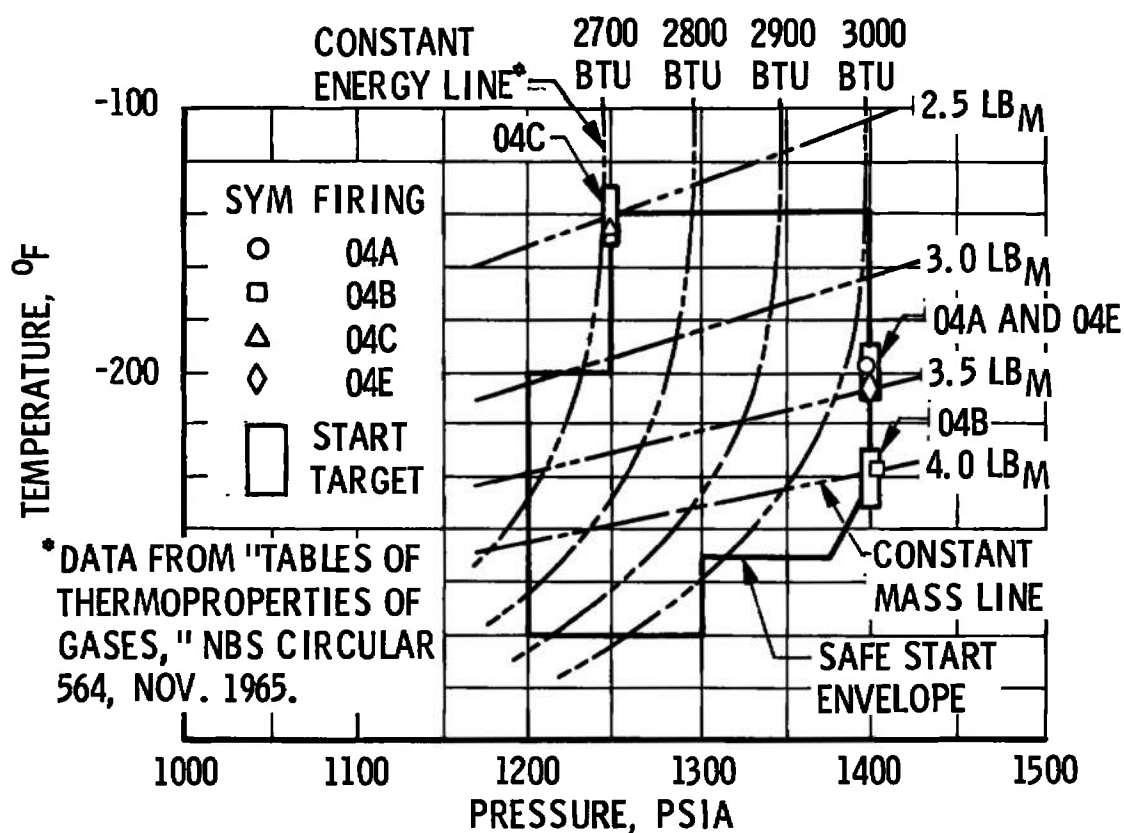


a. Oxidizer Pump Inlet

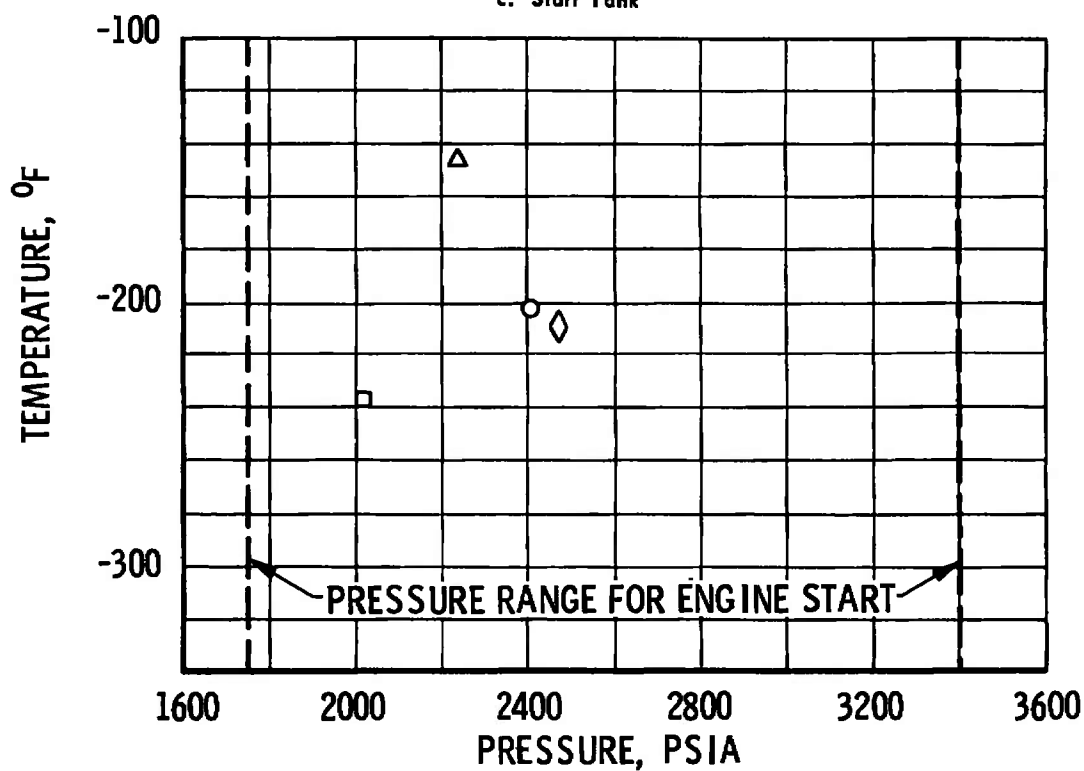


b. Fuel Pump Inlet

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

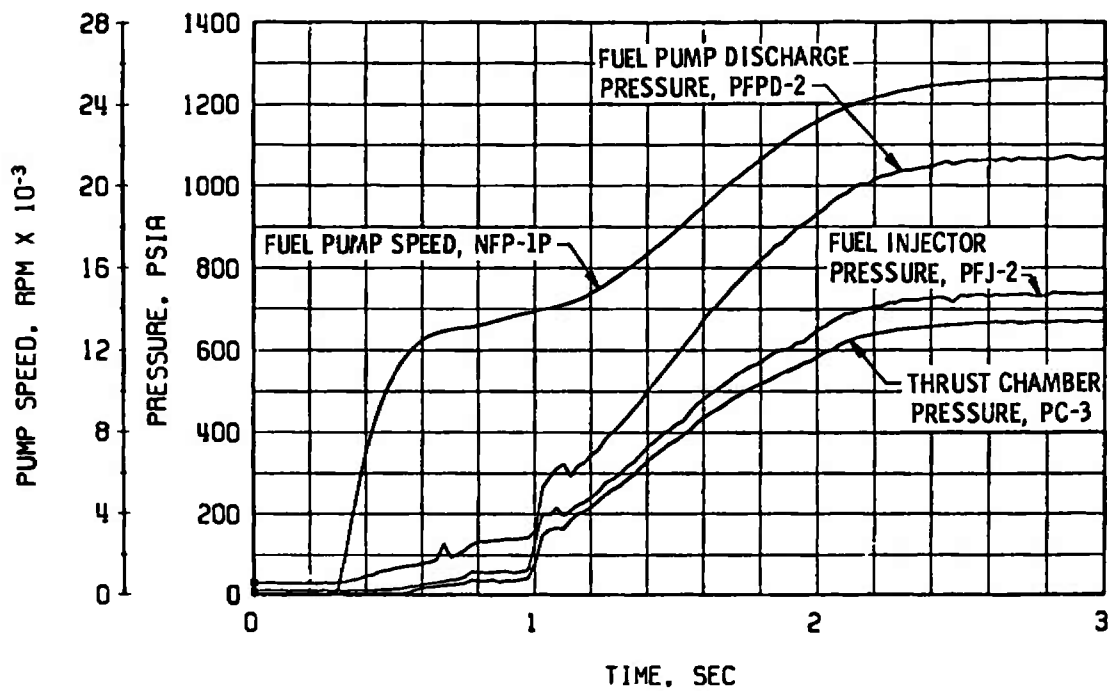


c. Start Tank

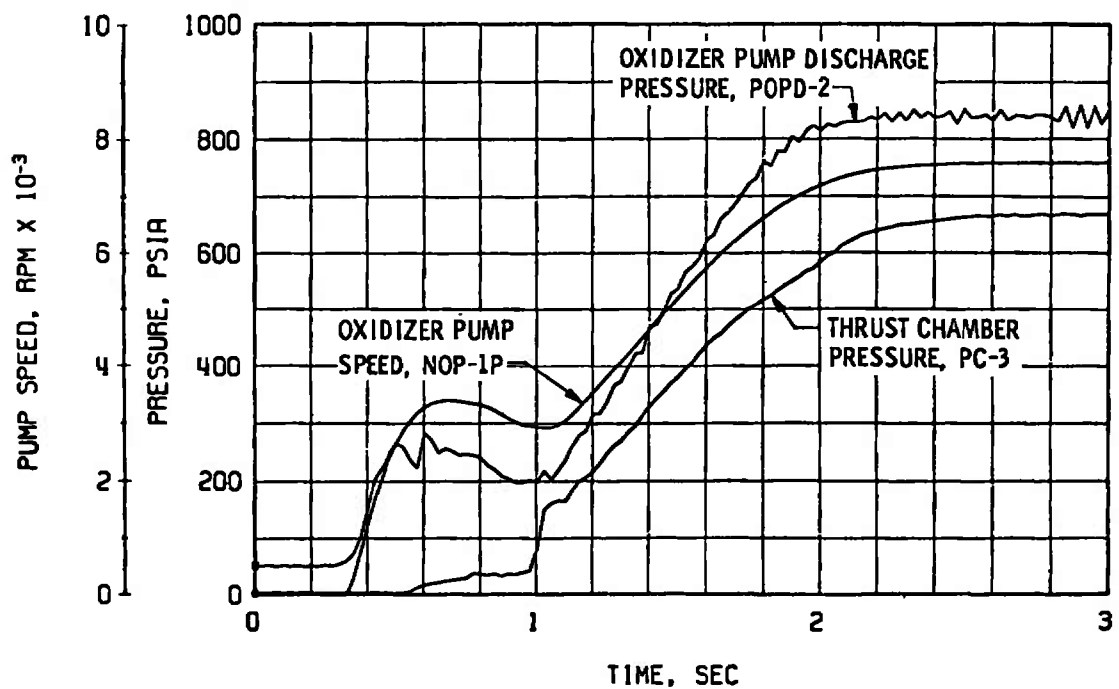


d. Helium Tank

Fig. 8 Concluded

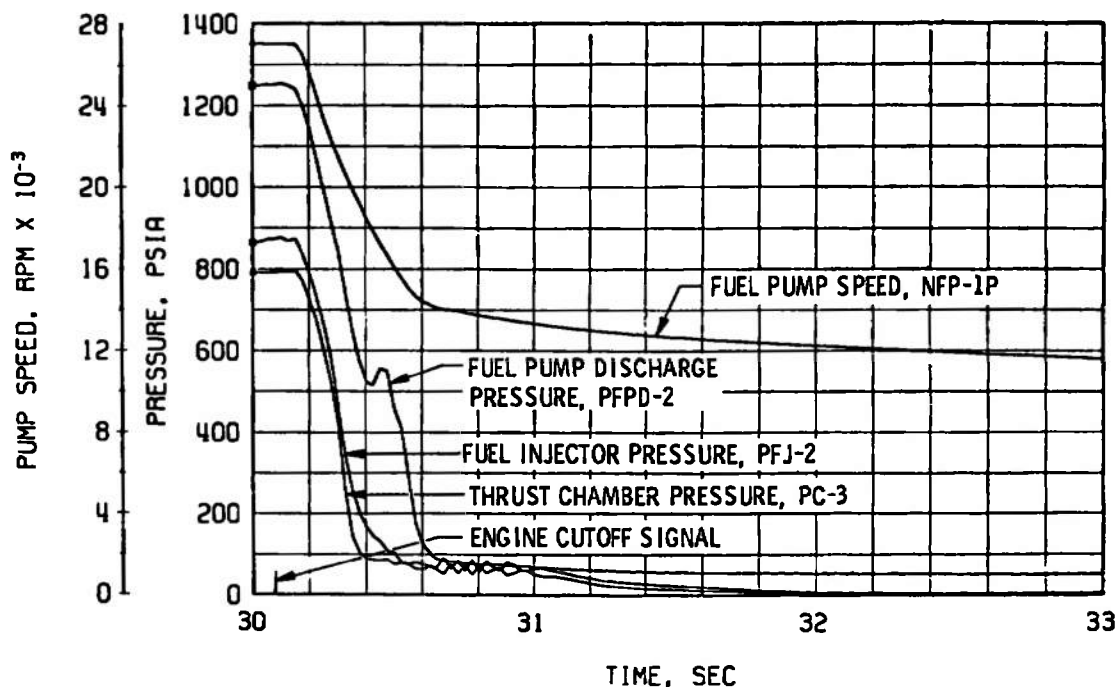


a. Start Transient, Thrust Chamber Fuel System

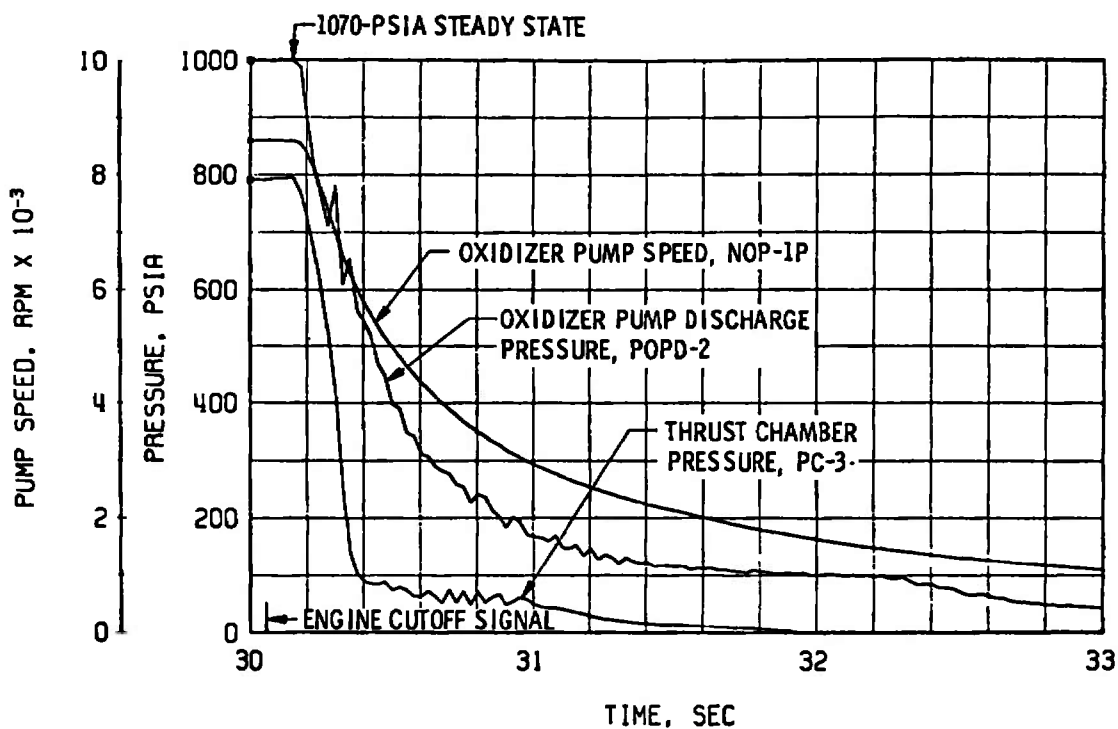


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 9 Engine Transient Operation, Firing 04A

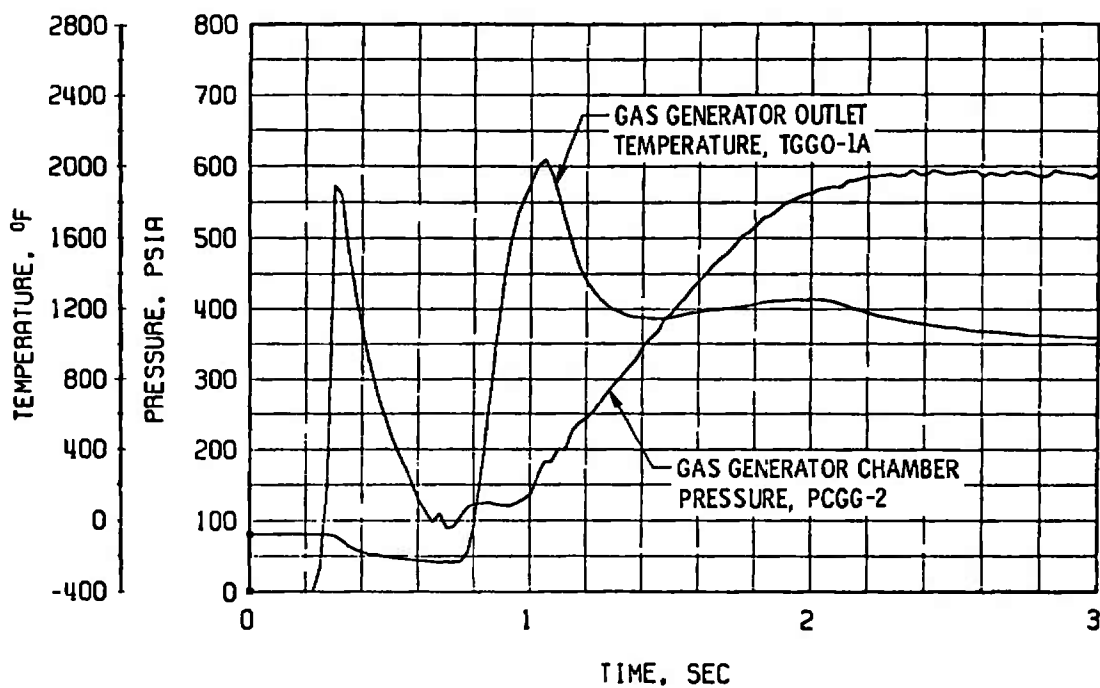
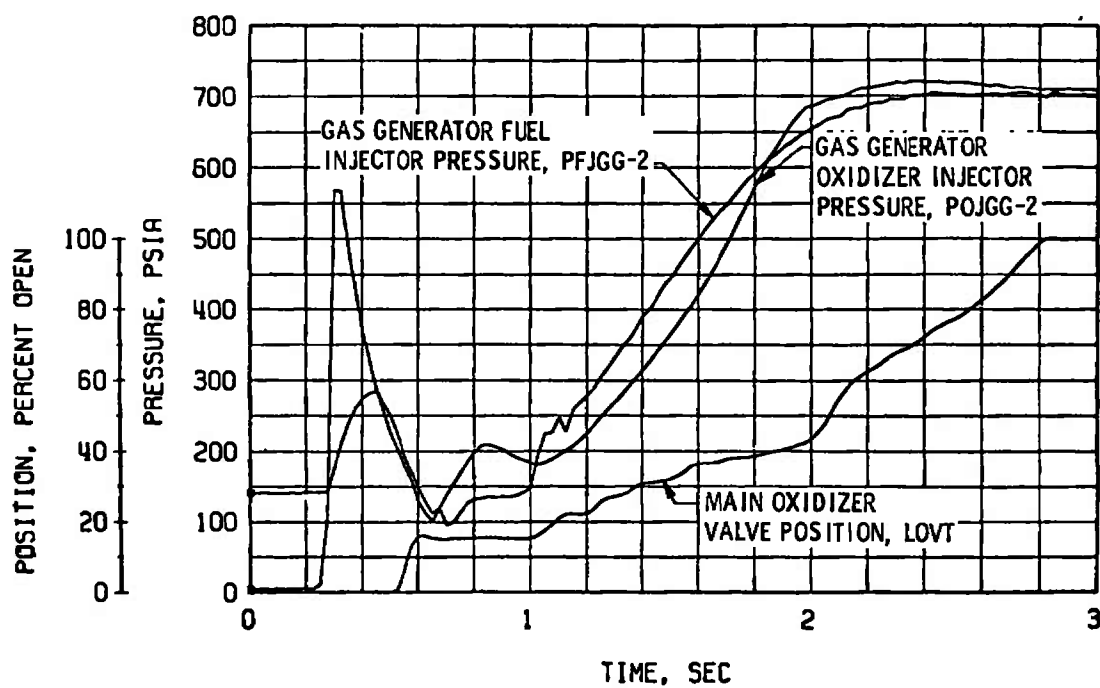


c. Shutdown Transient, Thrust Chamber Fuel System



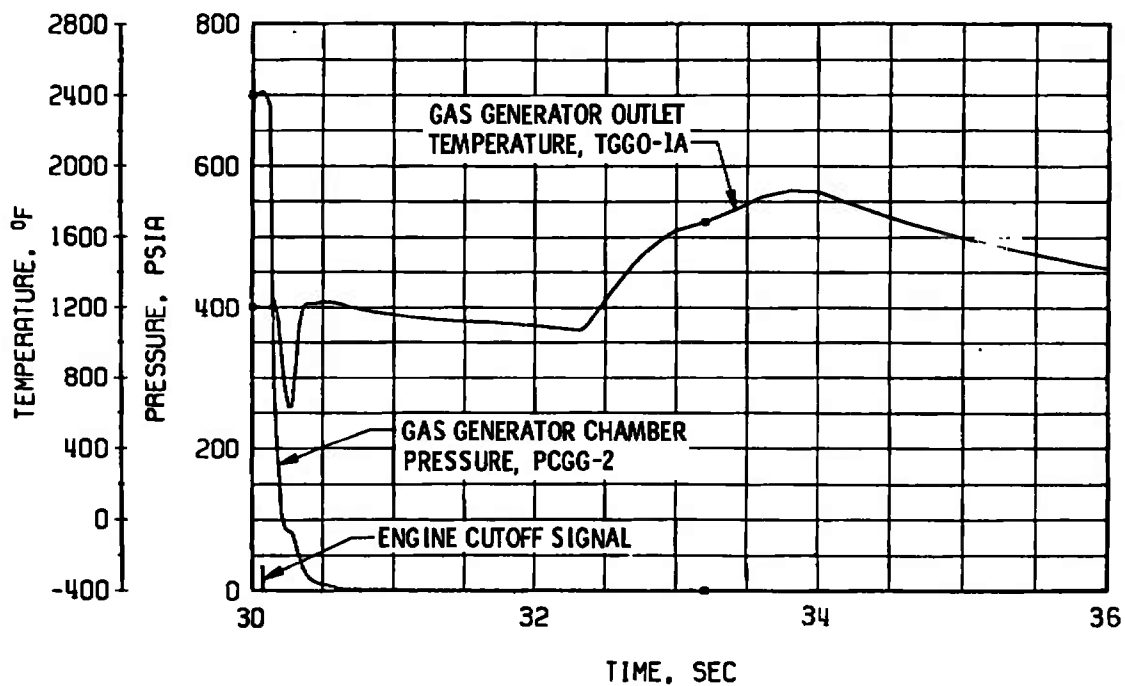
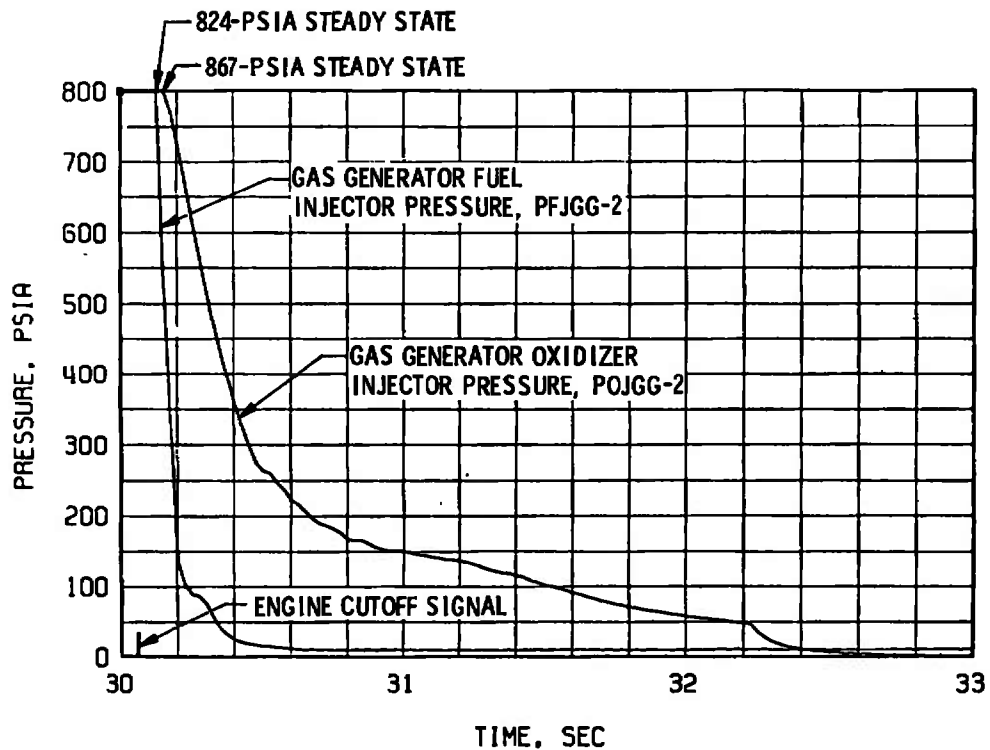
d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 9 Continued



e. Start Transient, Gas Generator

Fig. 9 Continued



f. Shutdown Transient, Gas Generator

Fig. 9 Concluded

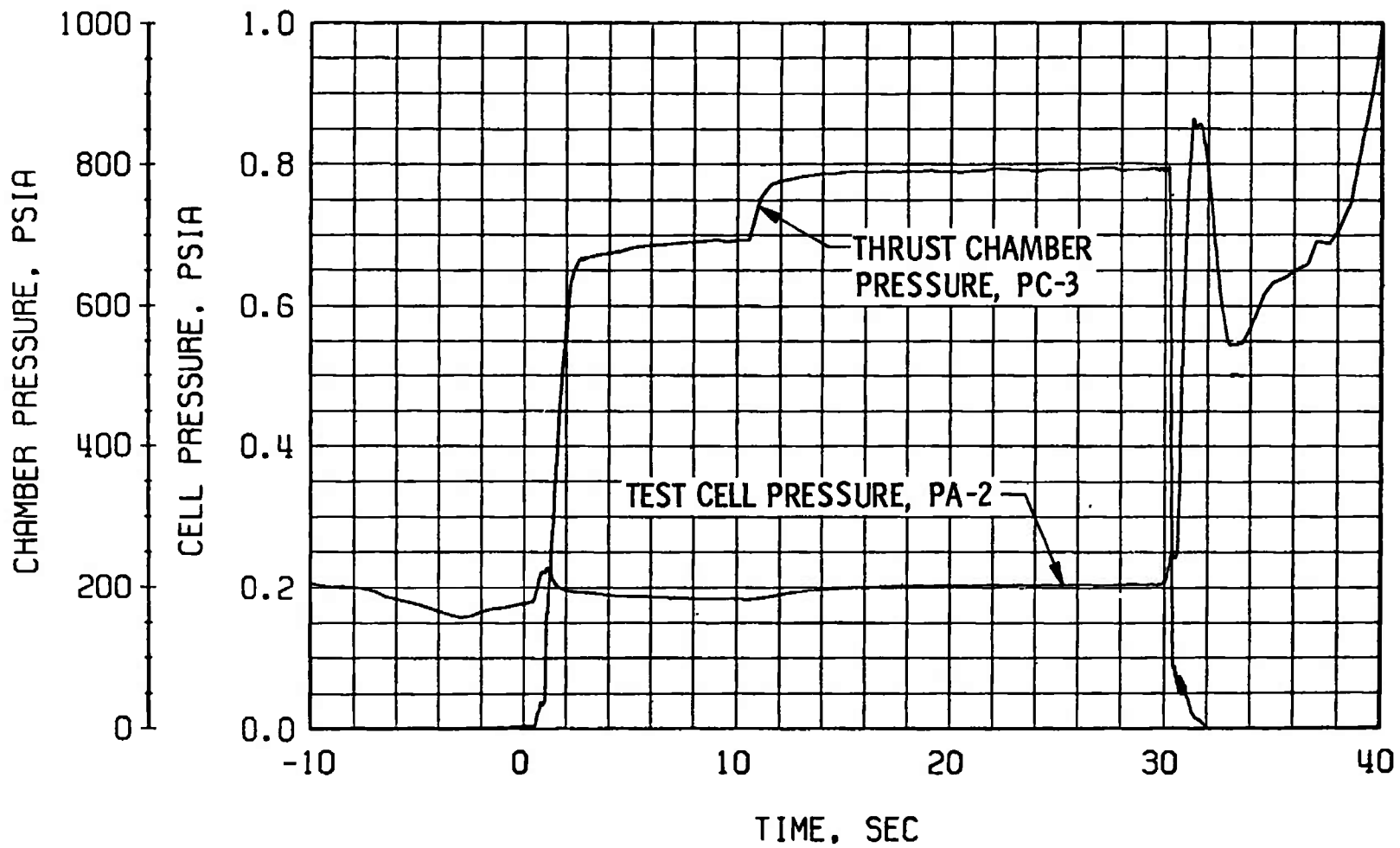
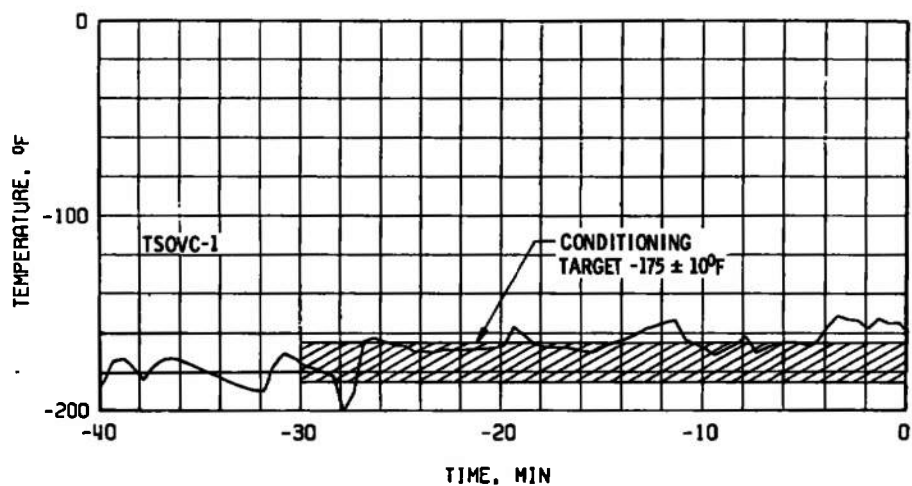
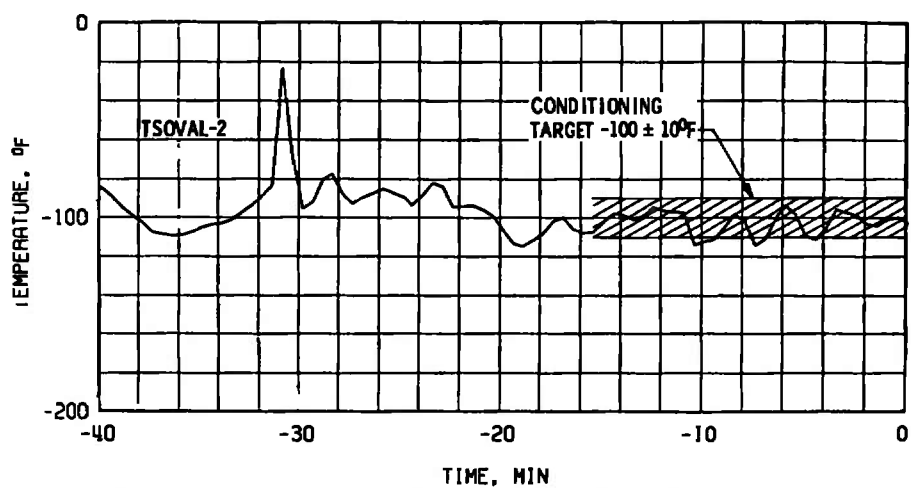


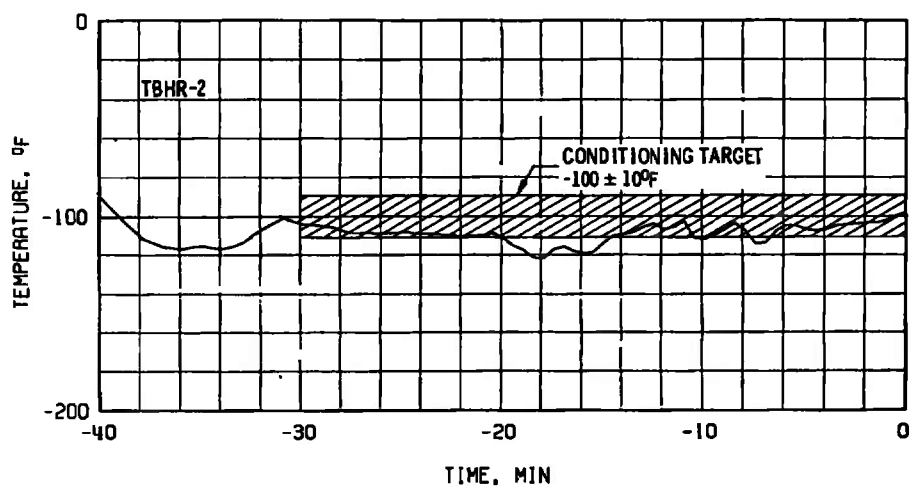
Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 04A



a. Main Oxidizer Valve Second-Stage Actuator Conditioning

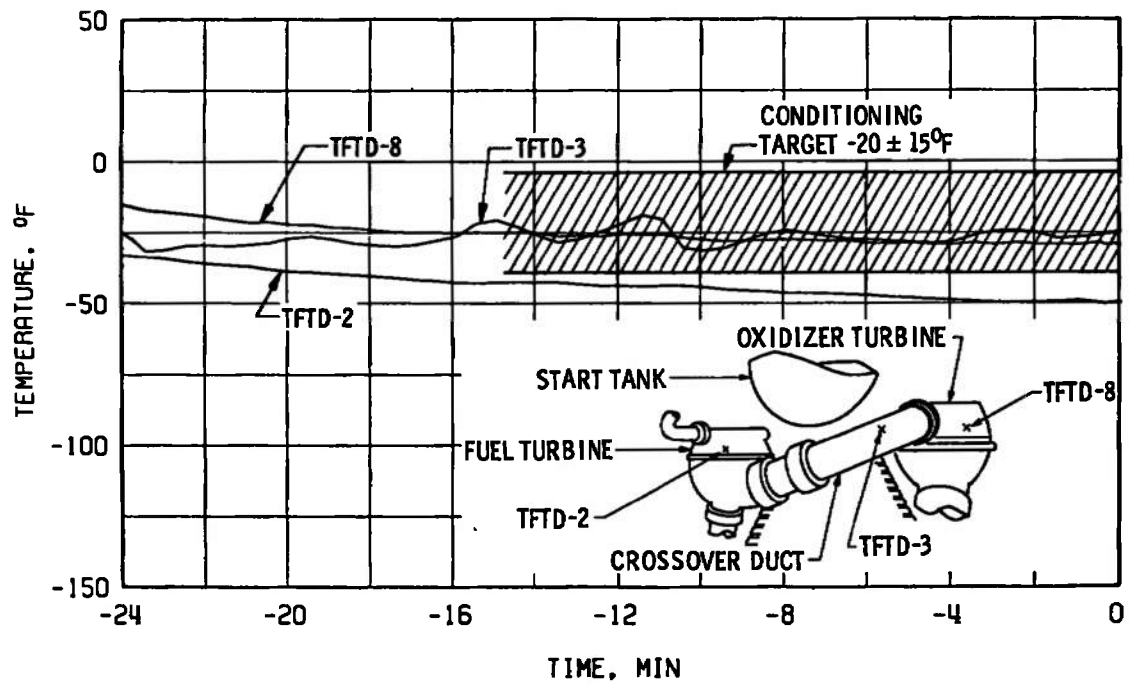


b. Main Oxidizer Valve Closing Control Line Conditioning

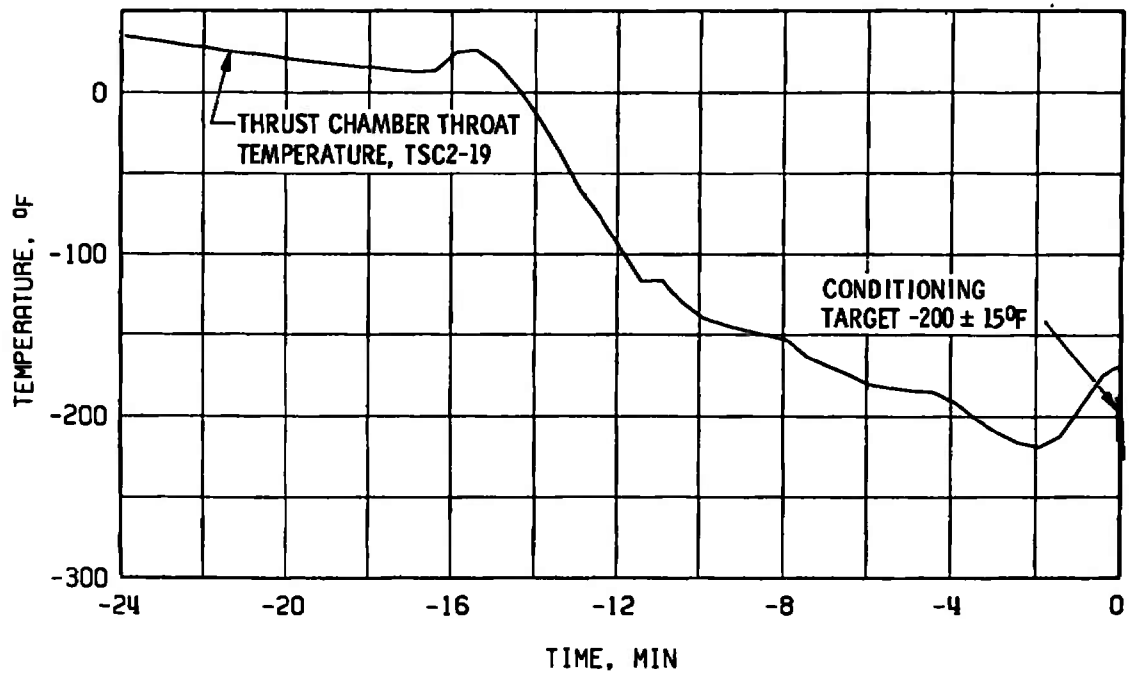


c. Pneumatic Control Package Conditioning

Fig. 11 Thermal Conditioning History of Engine Components, Firing 04A

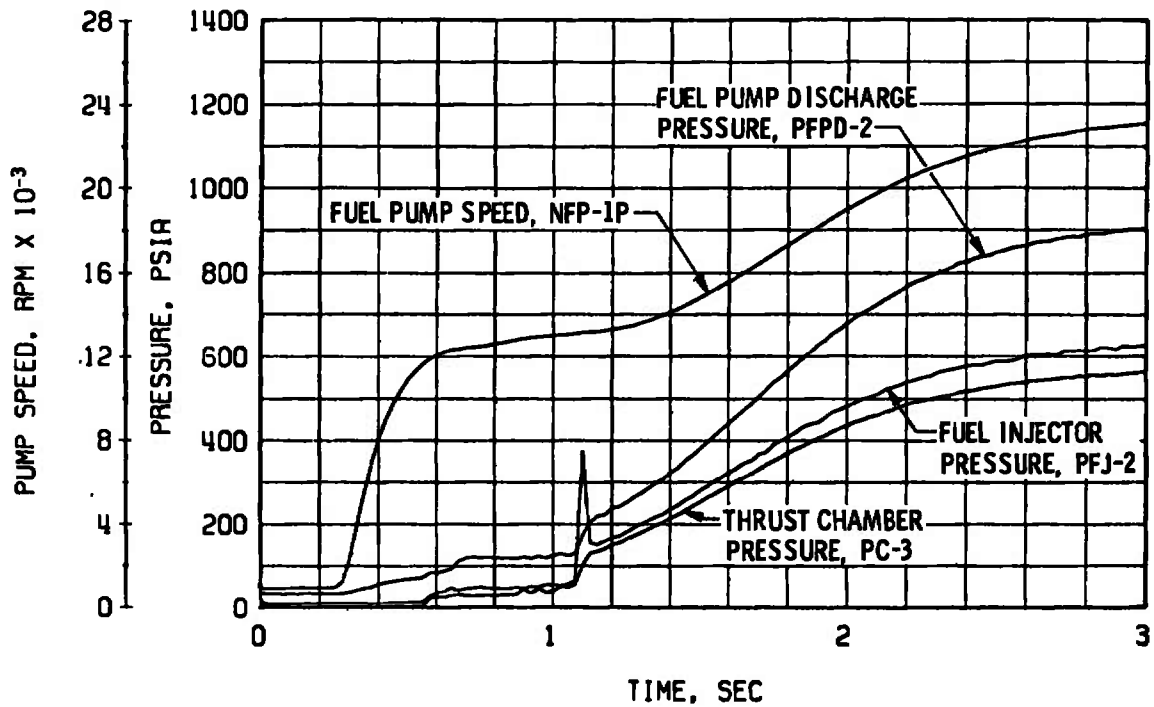


d. Crossover Duct Conditioning

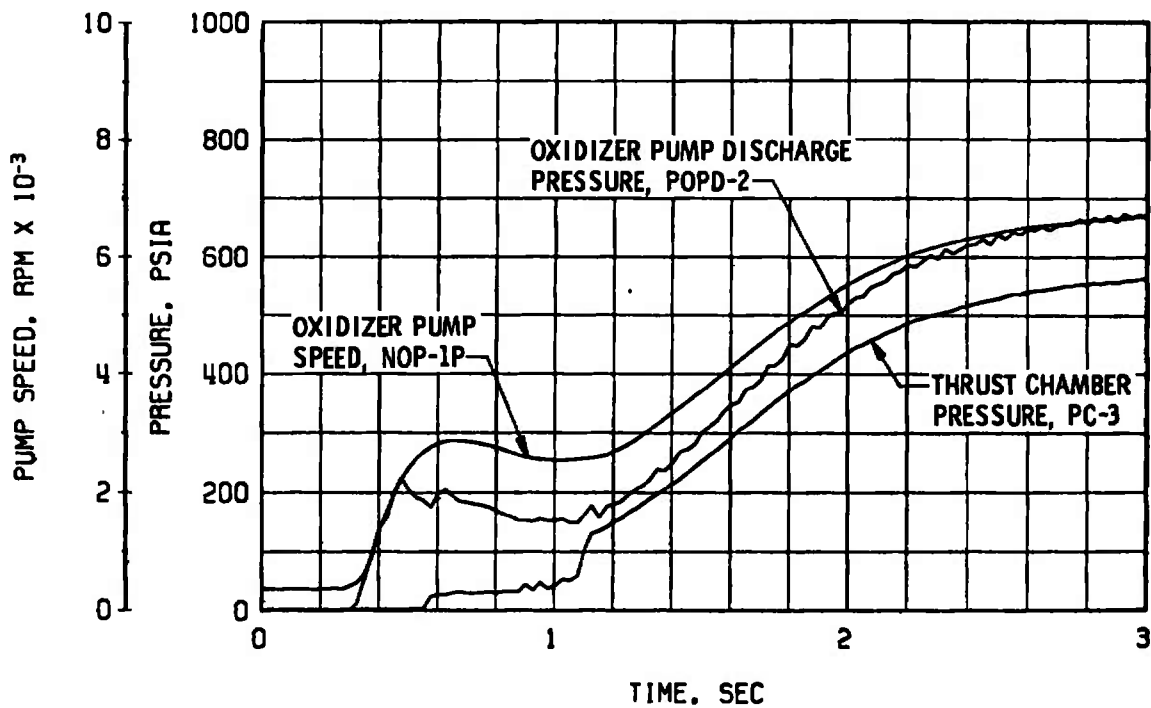


e. Thrust Chamber Conditioning

Fig. 11 Concluded

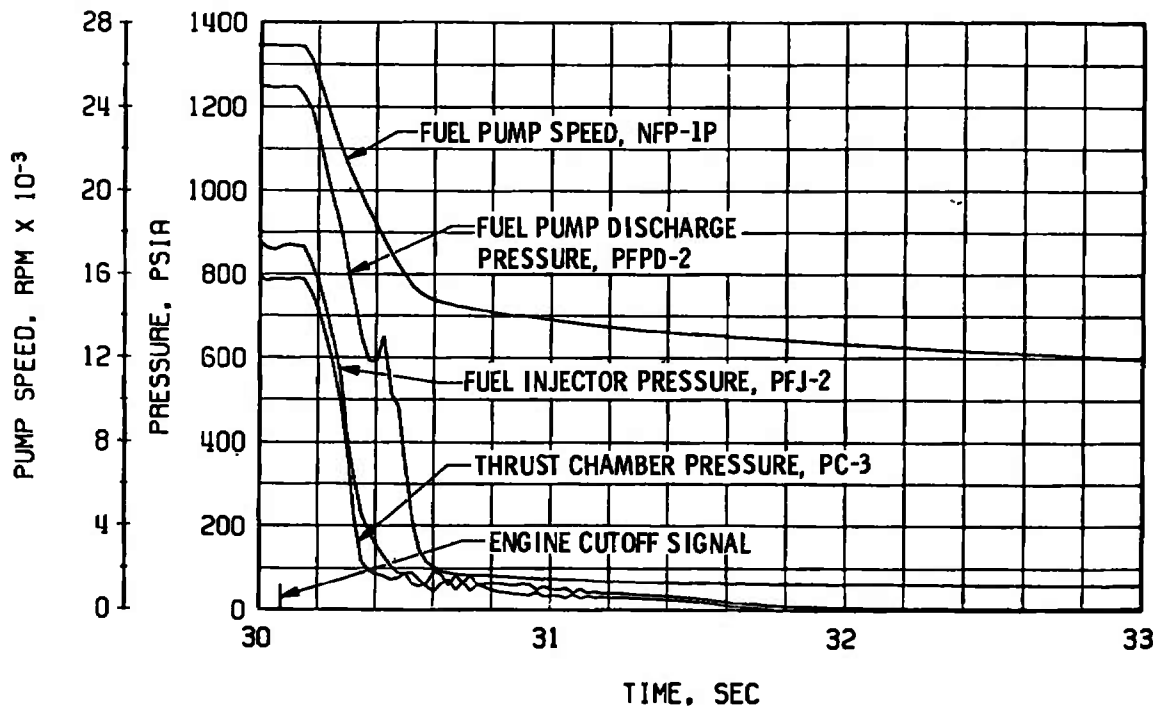


a. Start Transient, Thrust Chamber Fuel System

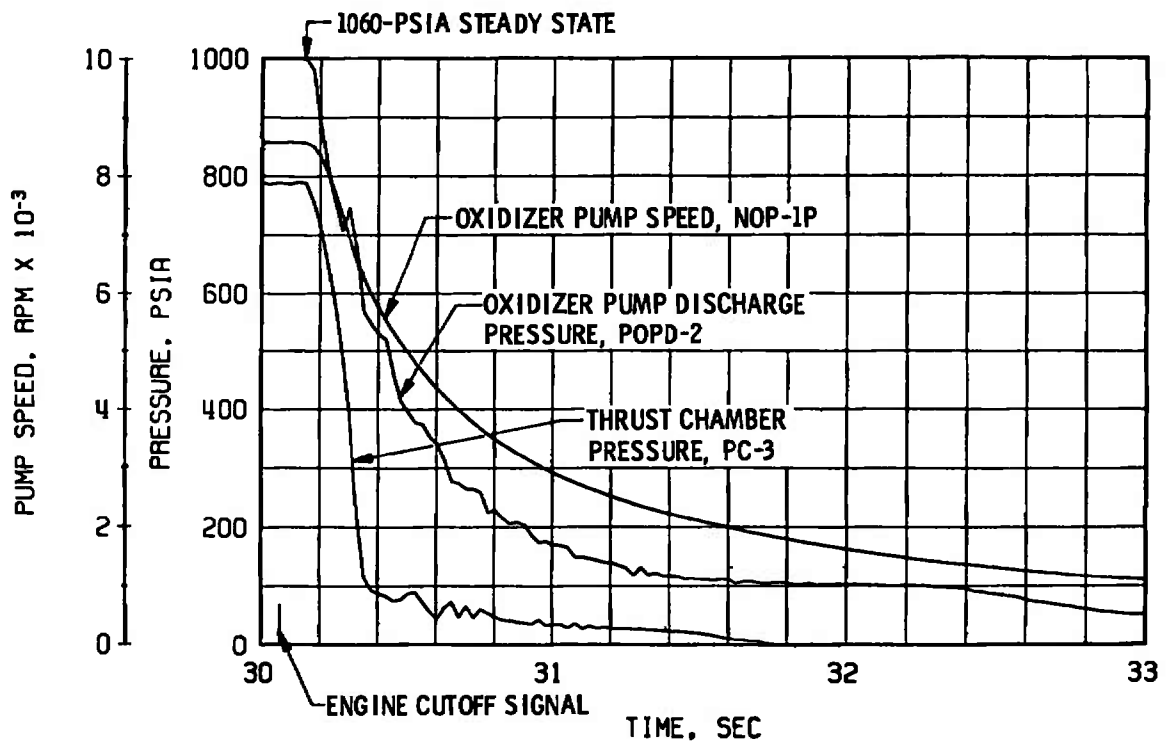


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 12 Engine Transient Operation, Firing 04C

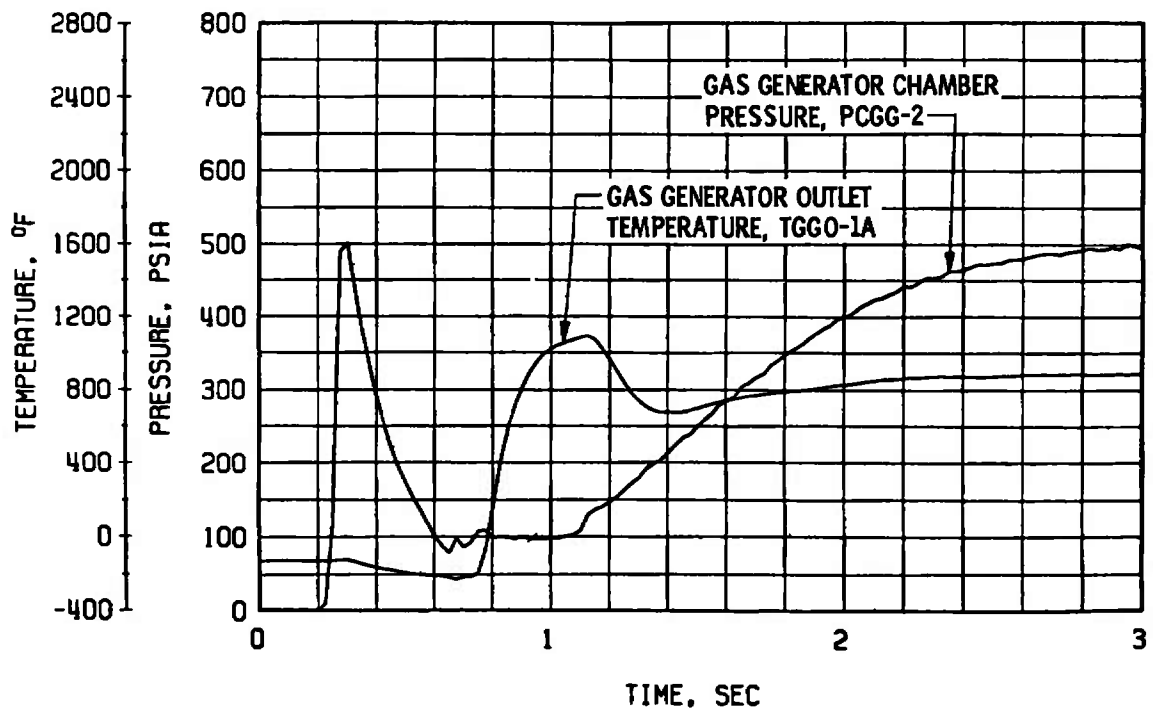
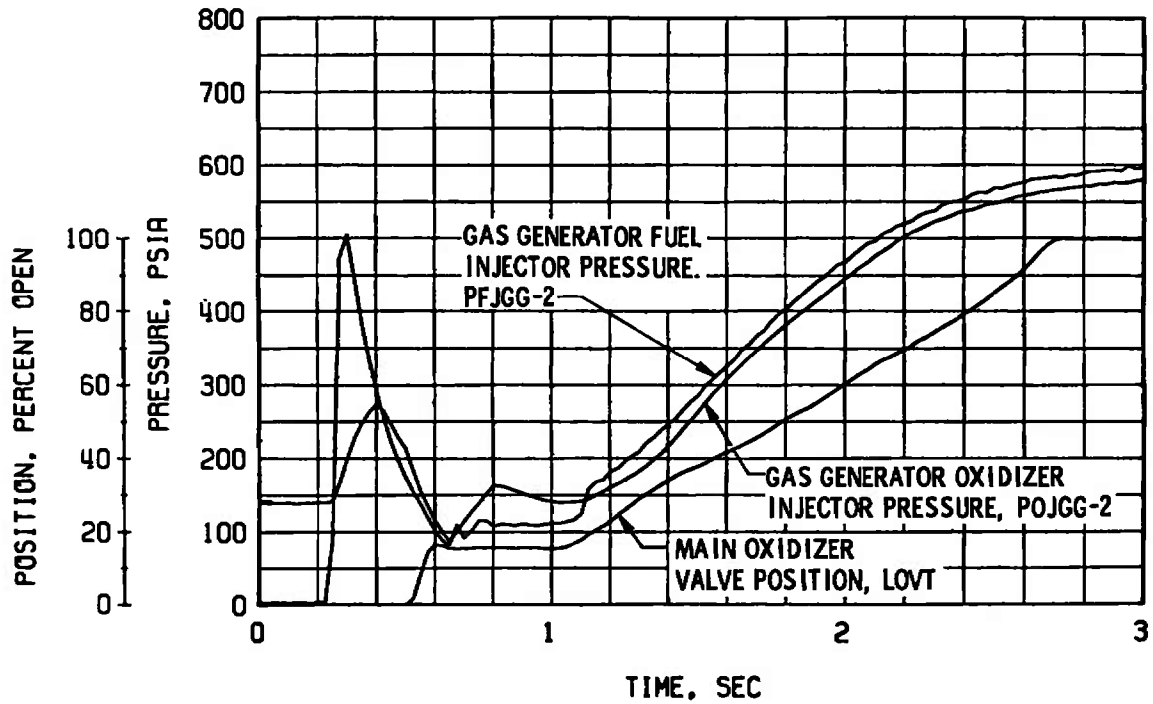


c. Shutdown Transient, Thrust Chamber Fuel System



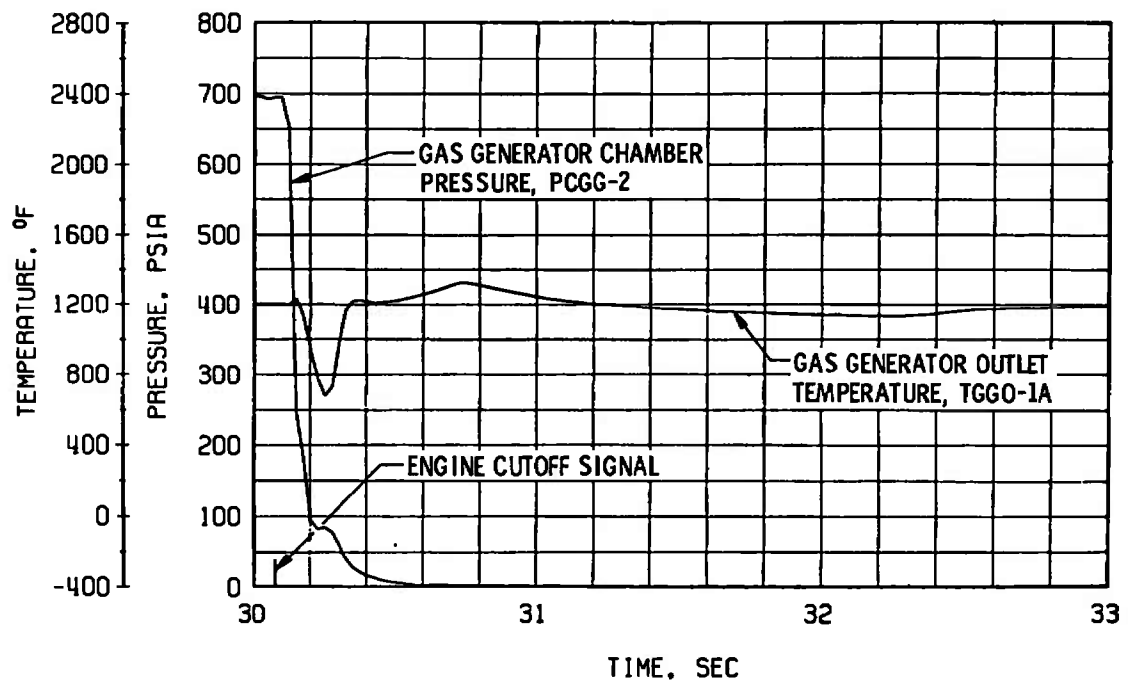
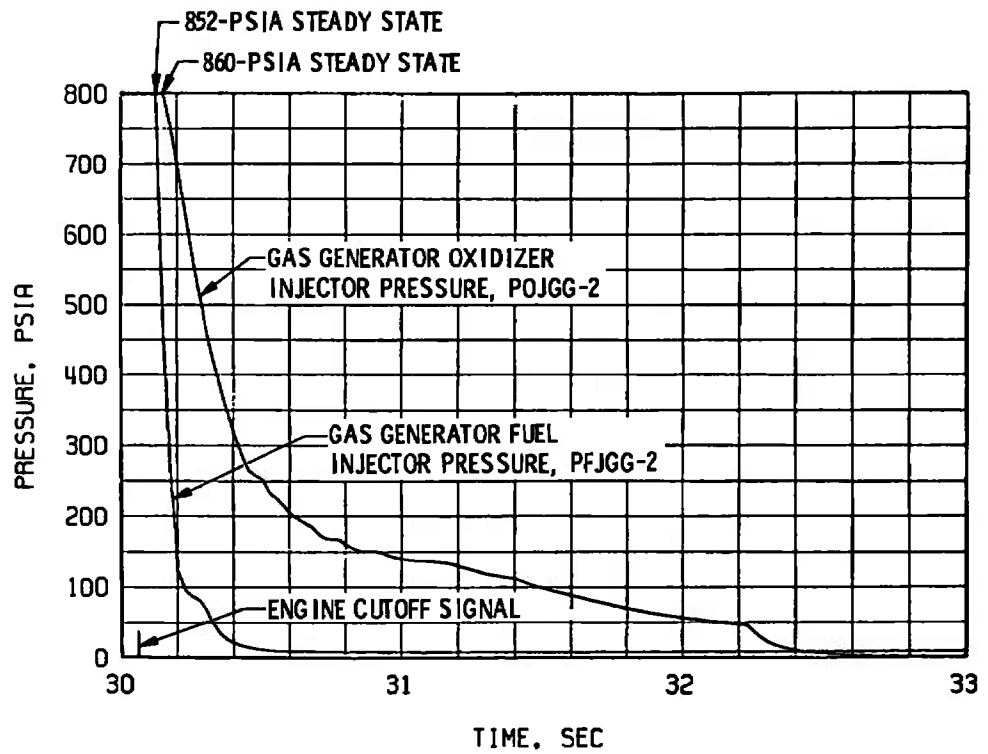
d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 12 Continued



e. Start Transient, Gas Generator

Fig. 12 Continued



f. Shutdown Transient, Gas Generator

Fig. 12 Concluded

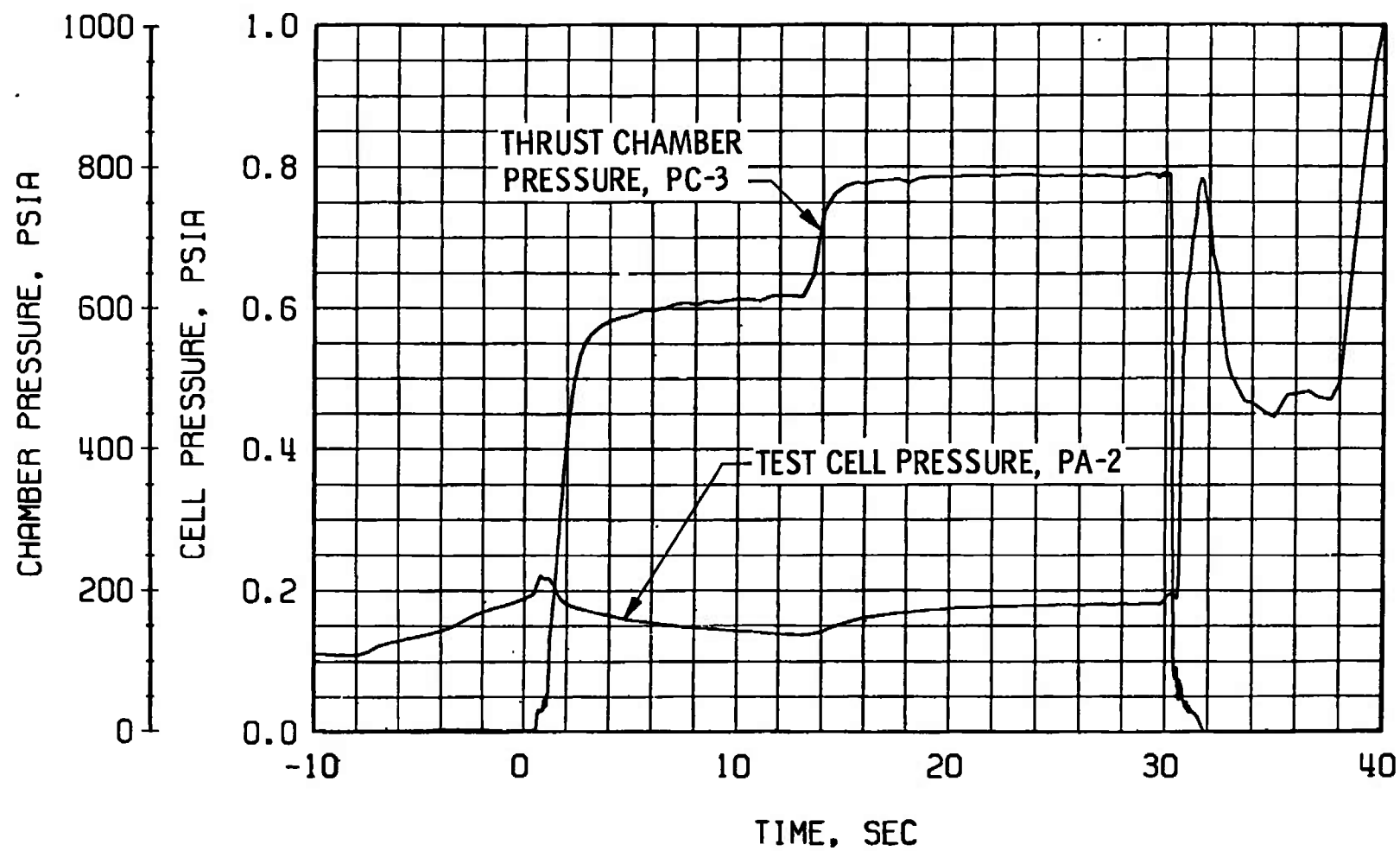
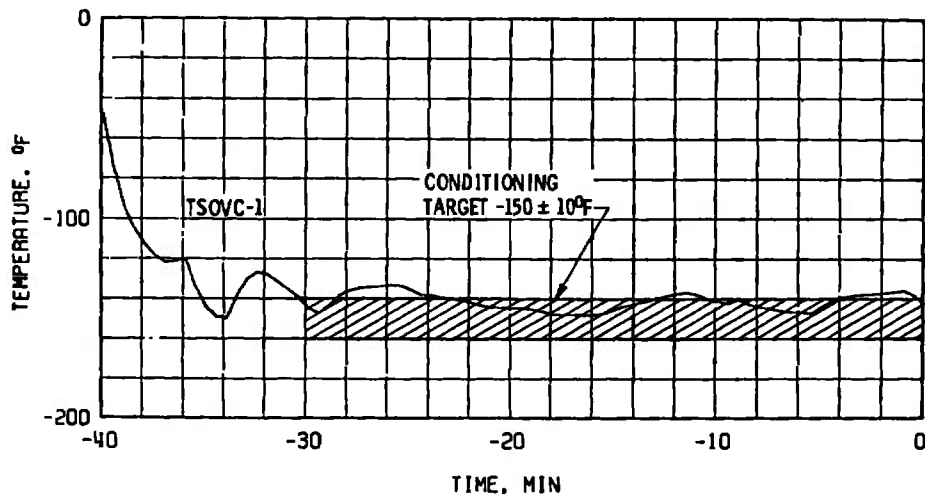
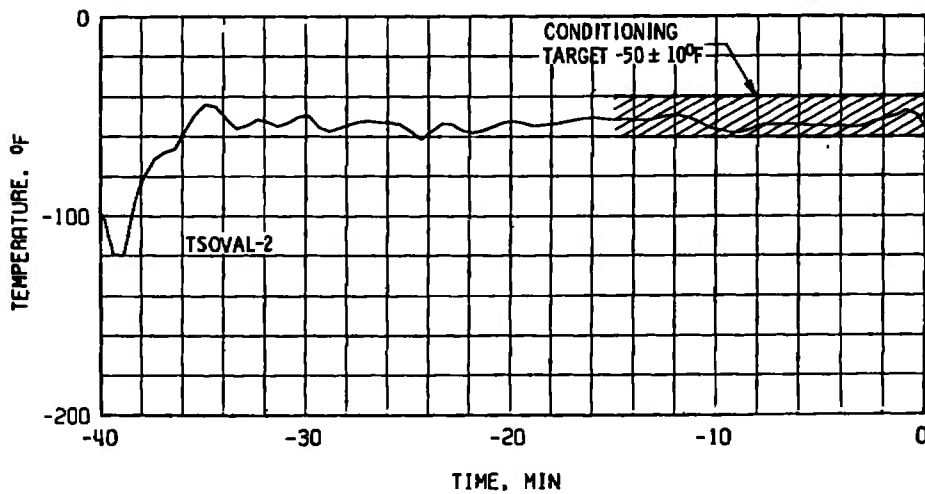


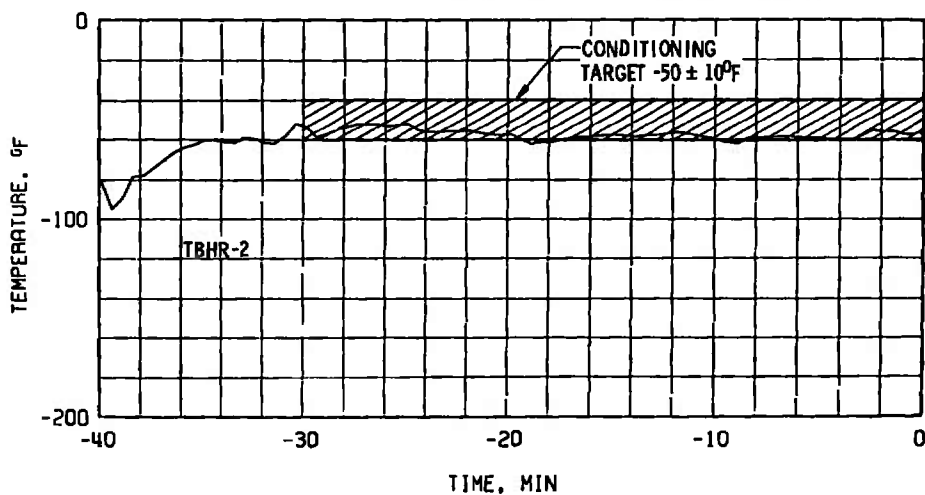
Fig. 13 Engine Ambient and Combustion Chamber Pressures, Firing 04C



a. Main Oxidizer Valve Second-Stage Actuator Conditioning

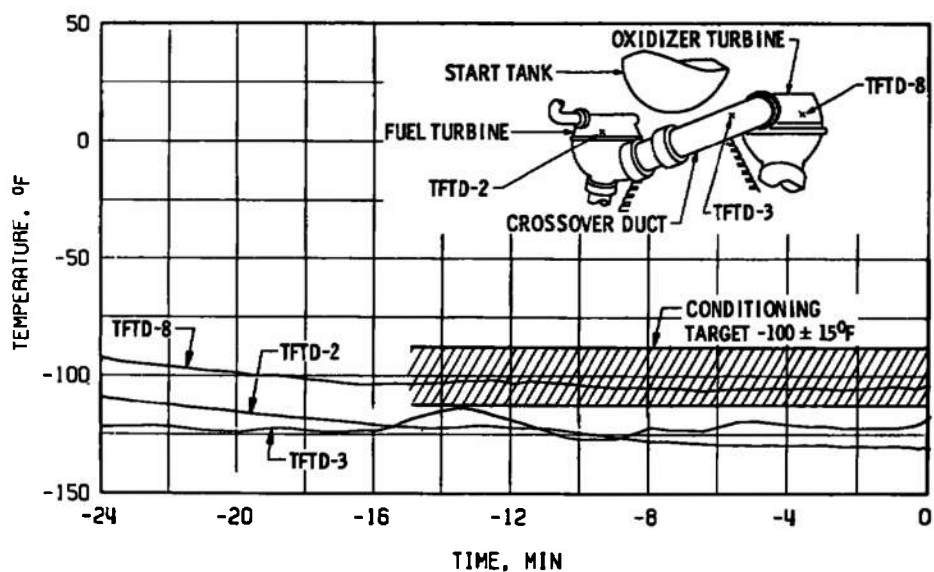


b. Main Oxidizer Valve Closing Control Line Conditioning

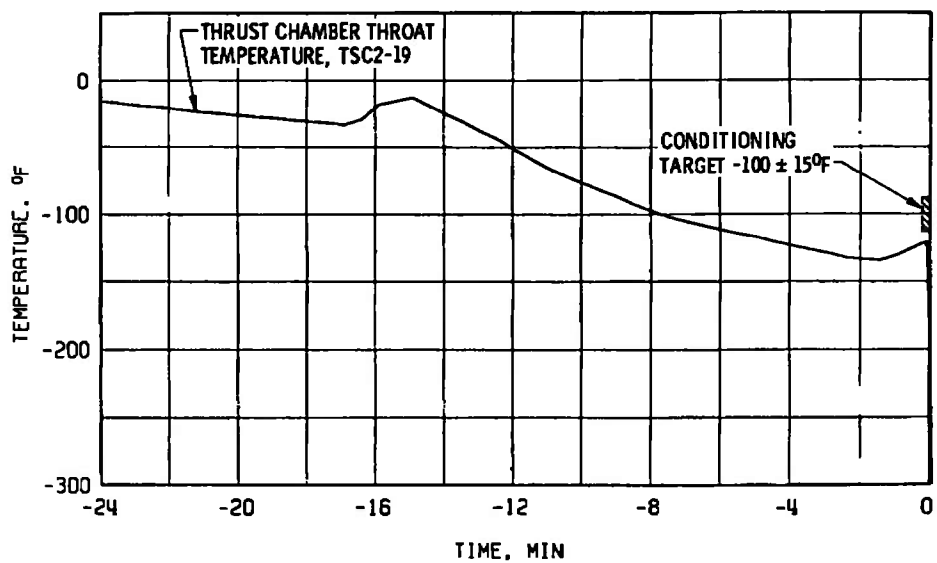


c. Pneumatic Control Package Conditioning

Fig. 14 Thermal Conditioning History of Engine Components, Firing 04C



d. Crossover Duct Conditioning



e. Thrust Chamber Conditioning

Fig. 14 Concluded

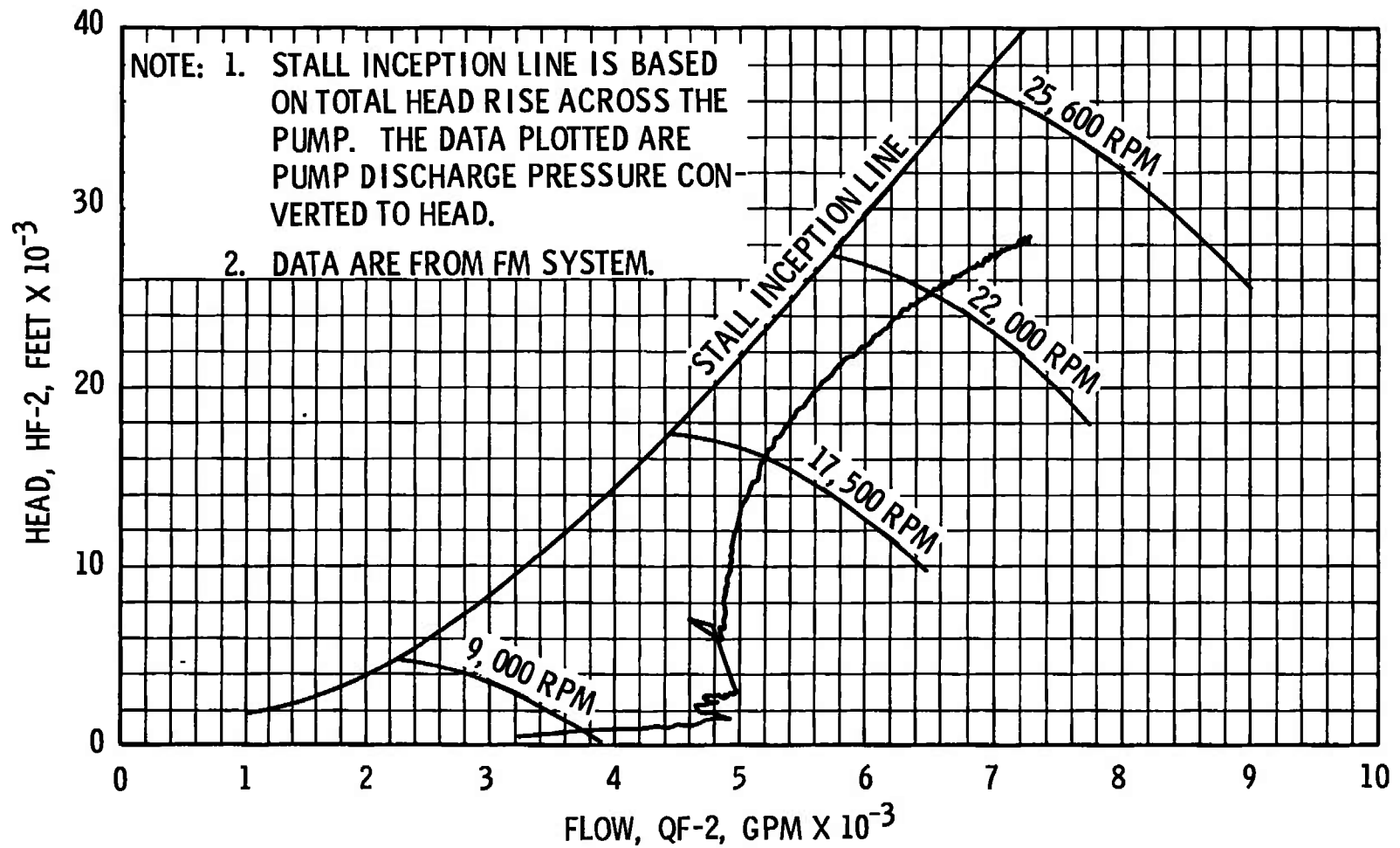


Fig. 15 Fuel Pump Start Transient Performance, Firing 04C

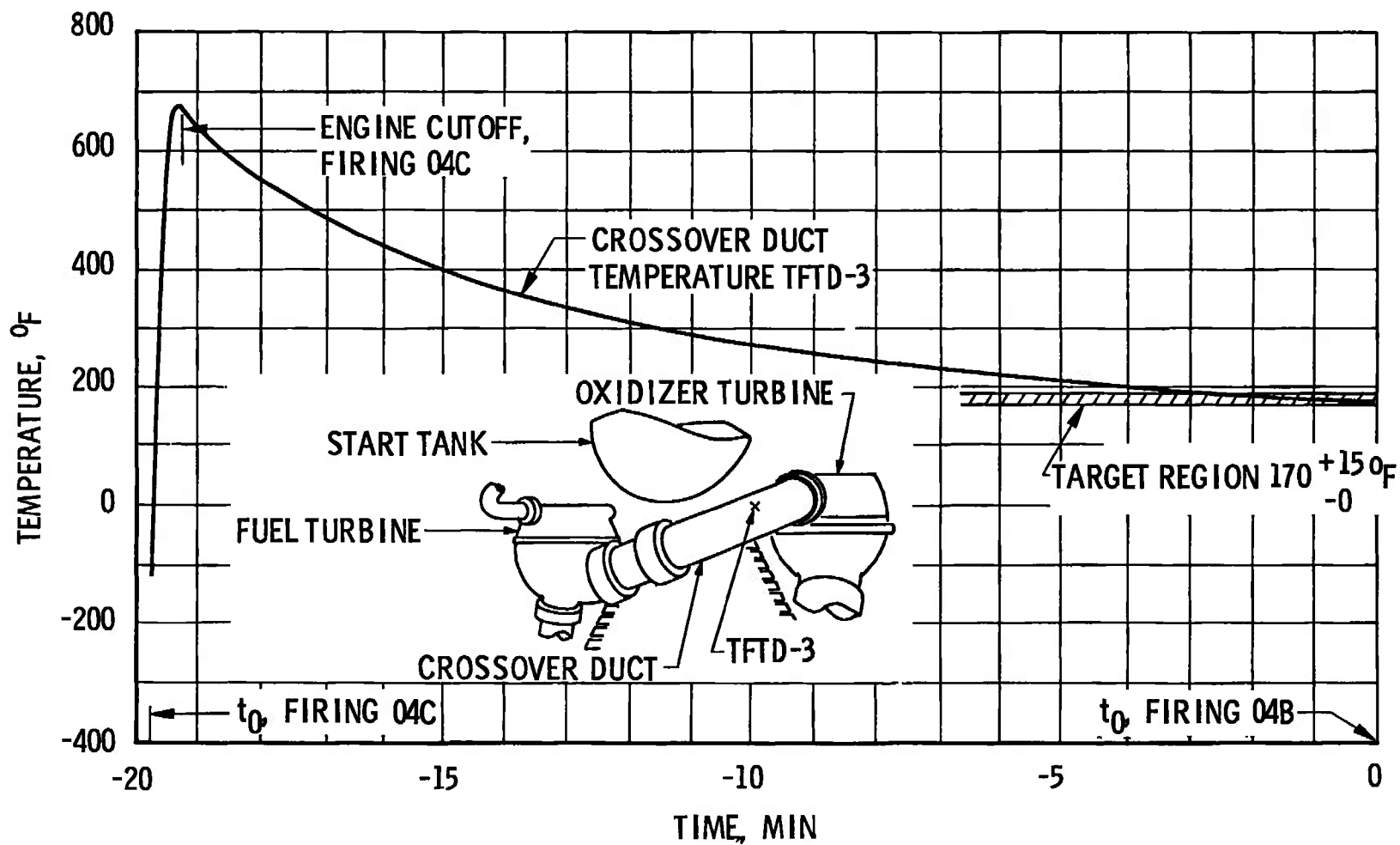
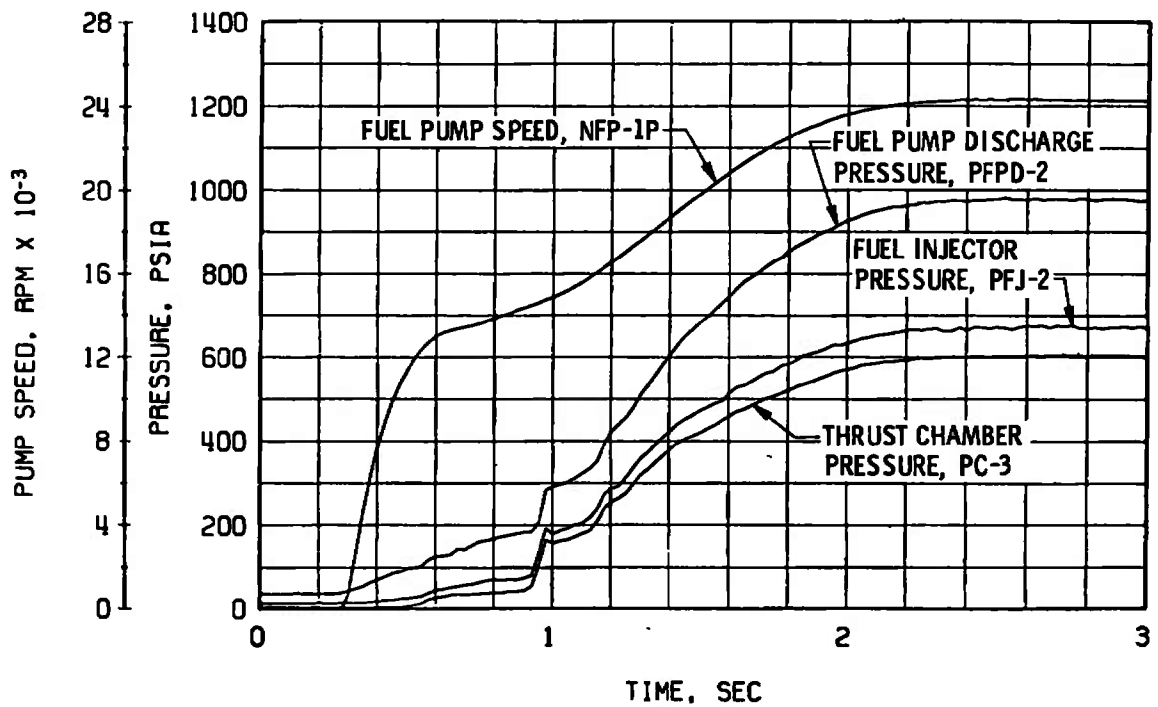
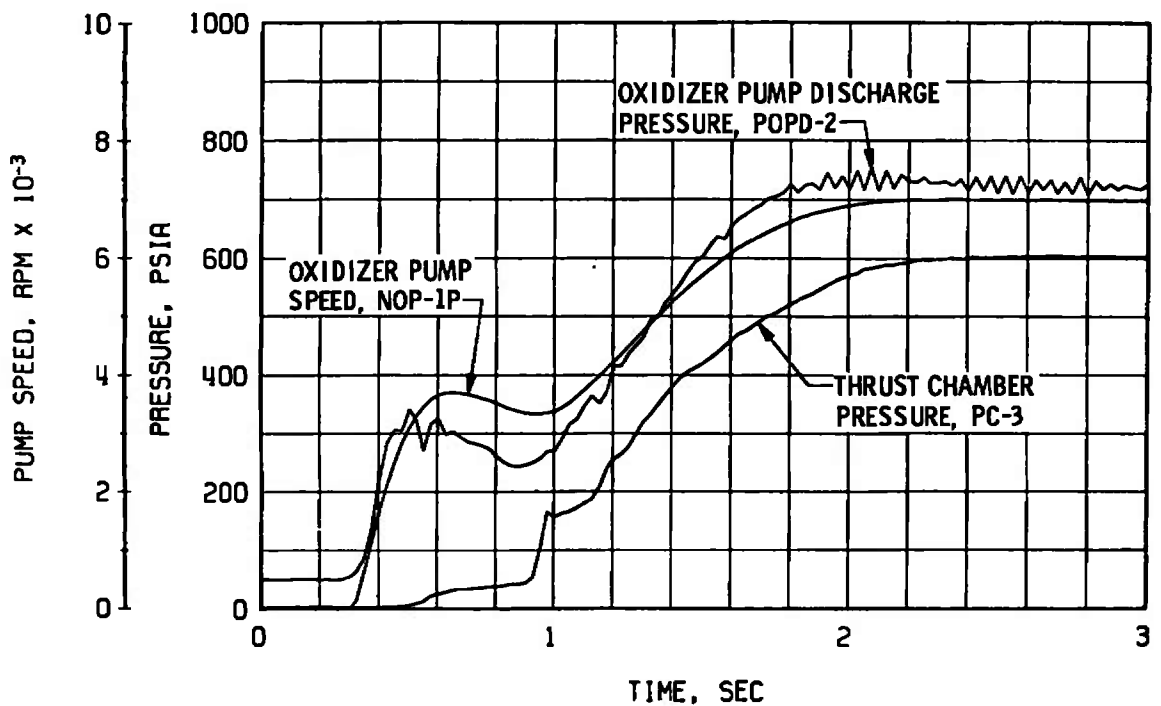


Fig. 16 Crossover Duct Cooldown Rate between Firings 04C and 04B

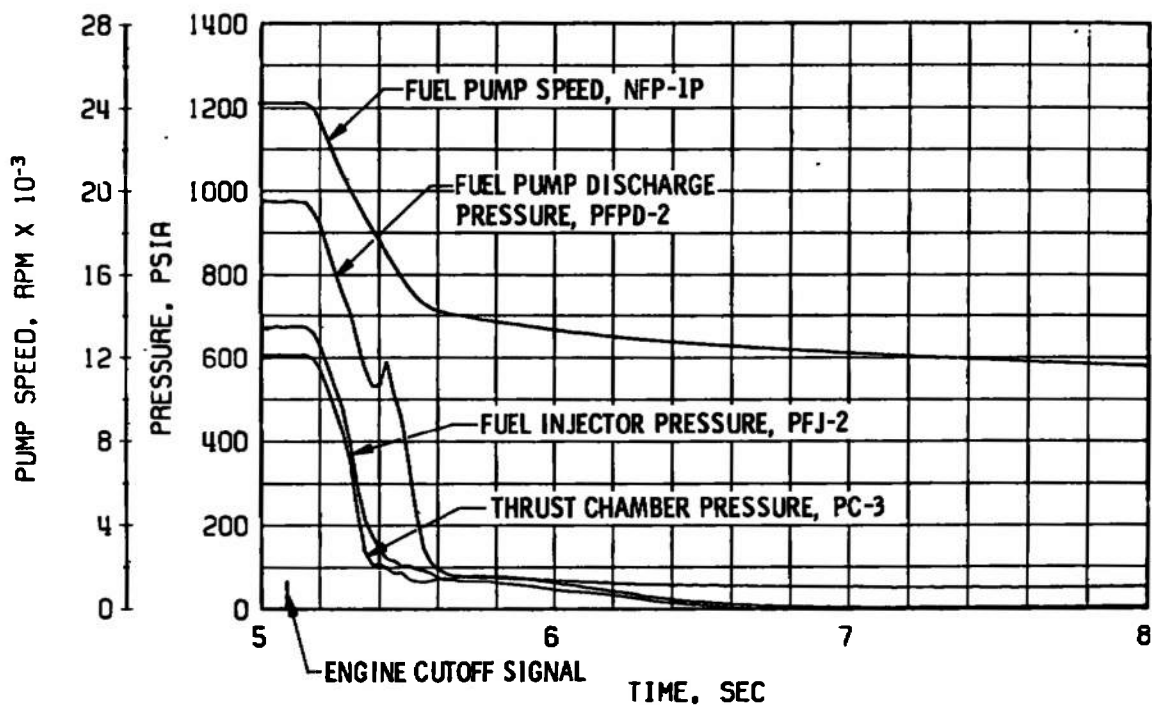


a. Start Transient, Thrust Chamber Fuel System

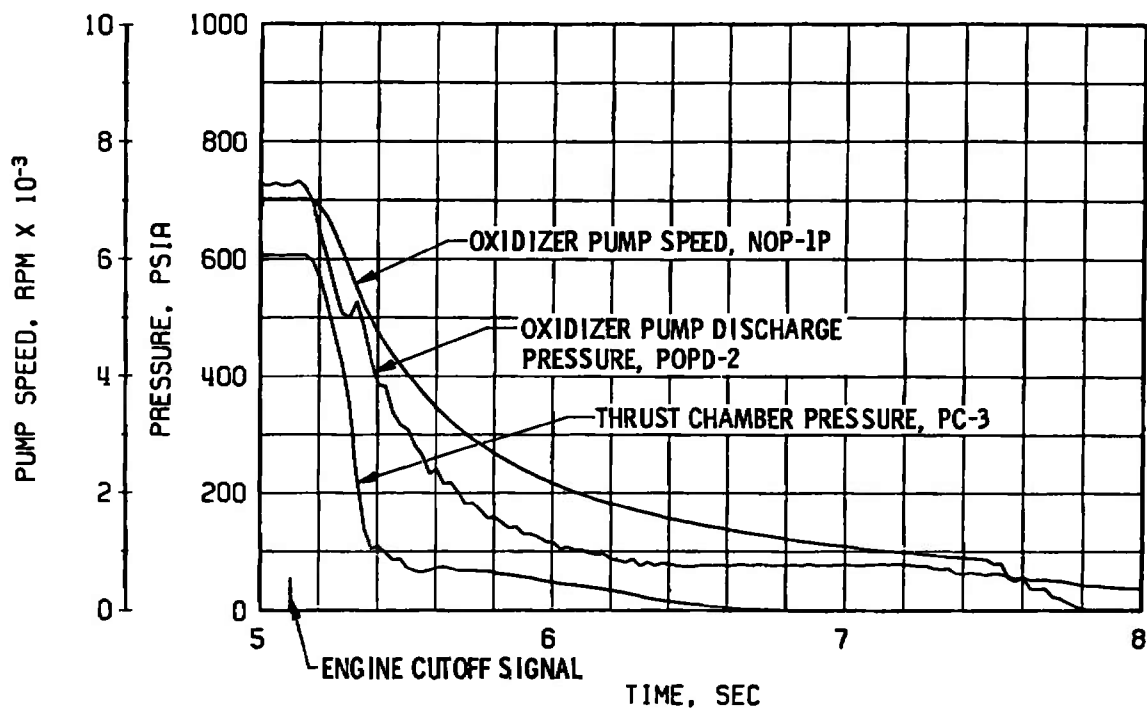


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 17 Engine Transient Operation, Firing 04B

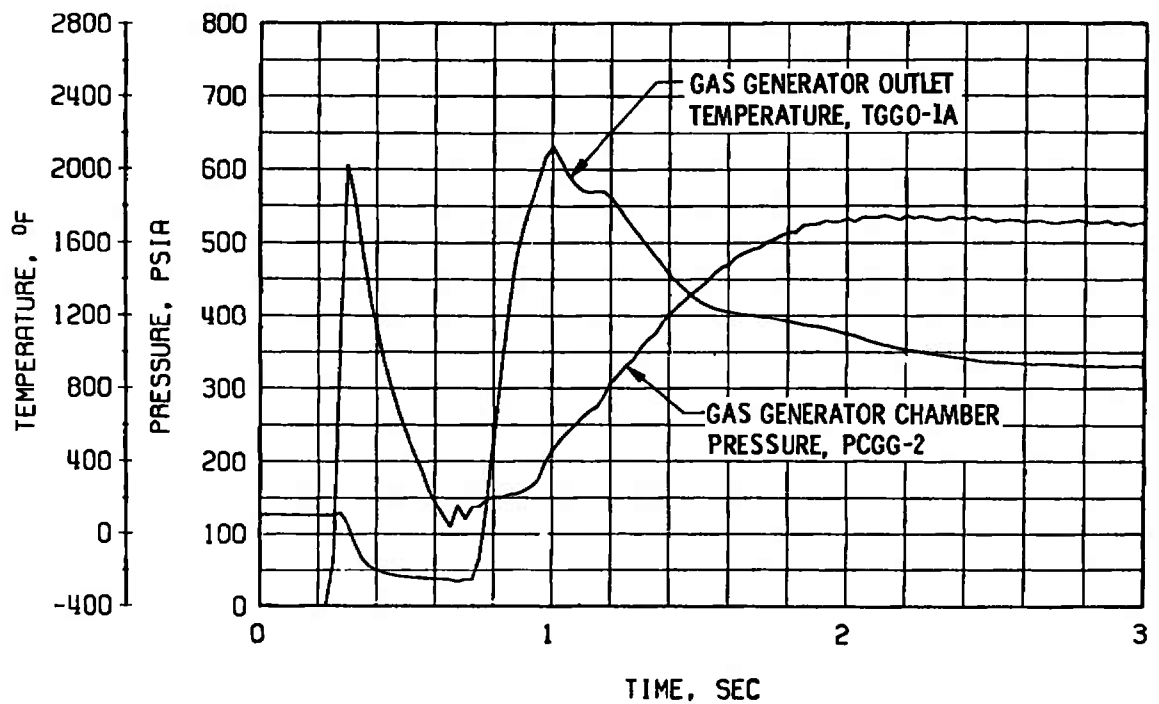
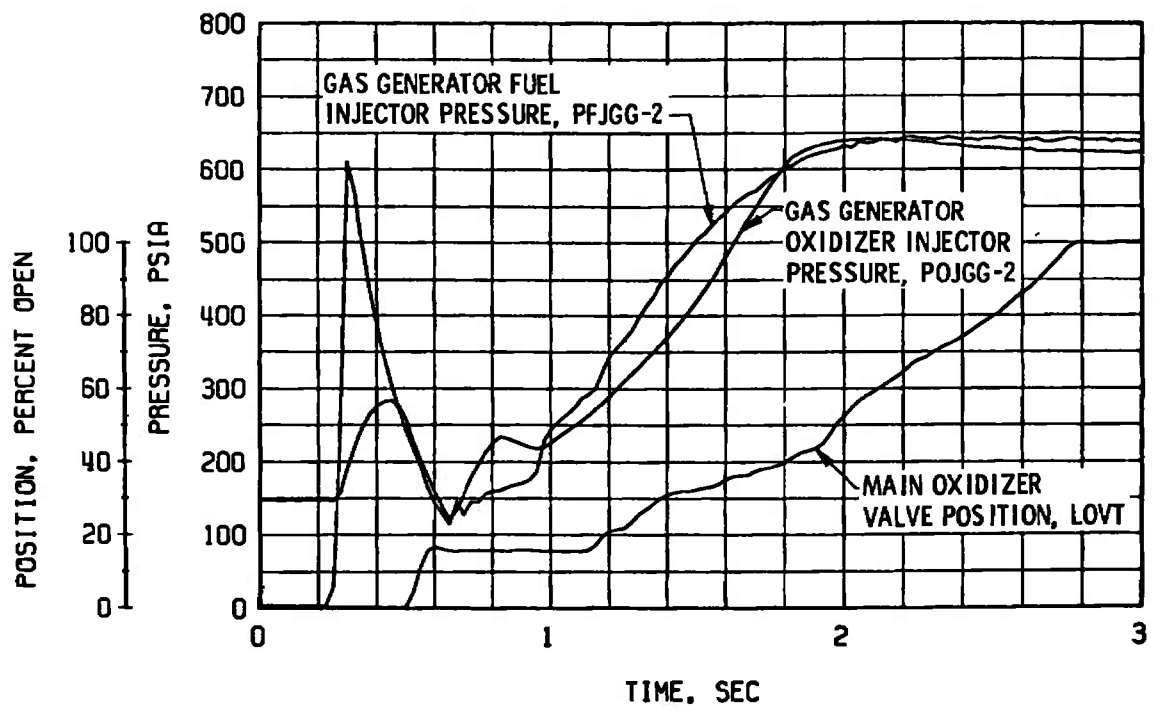


c. Shutdown Transient, Thrust Chamber Fuel System



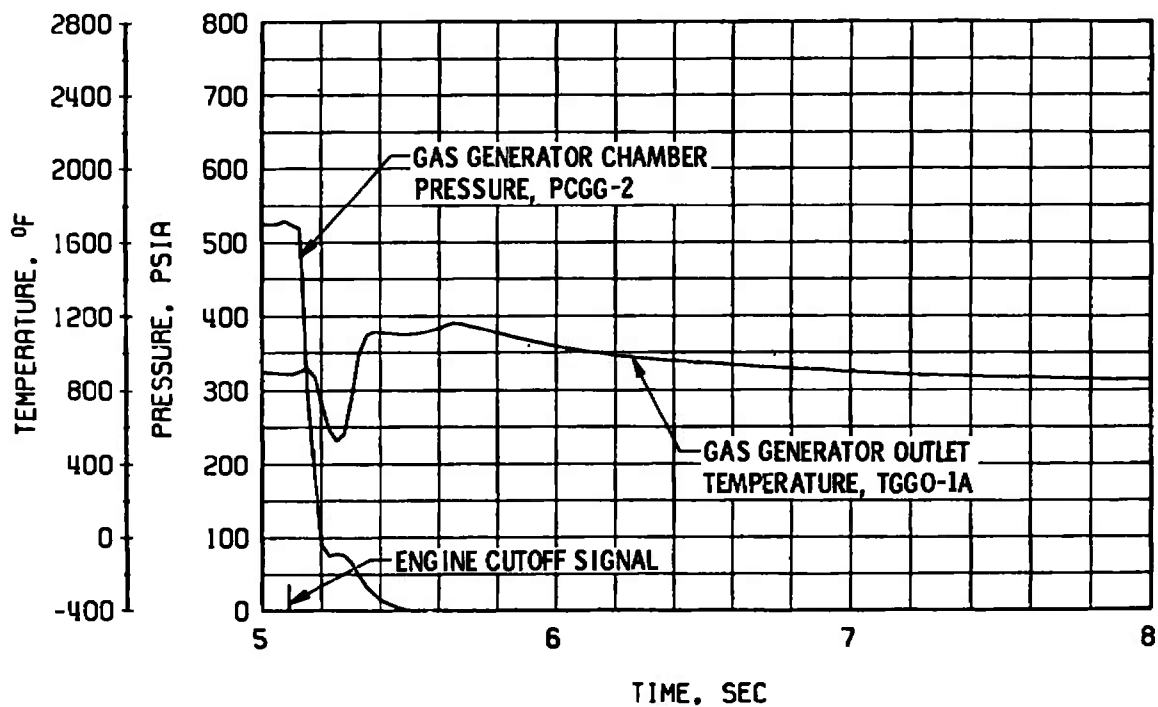
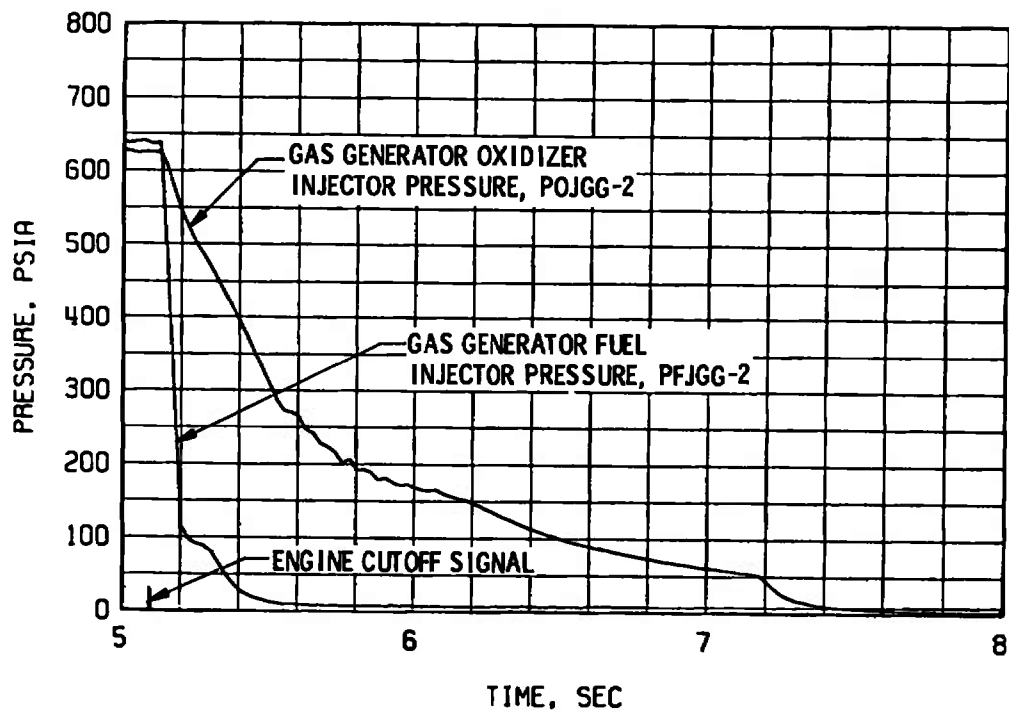
d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 17 Continued



e. Start Transient, Gas Generator

Fig. 17 Continued



f. Shutdown Transient, Gas Generator

Fig. 17 Concluded

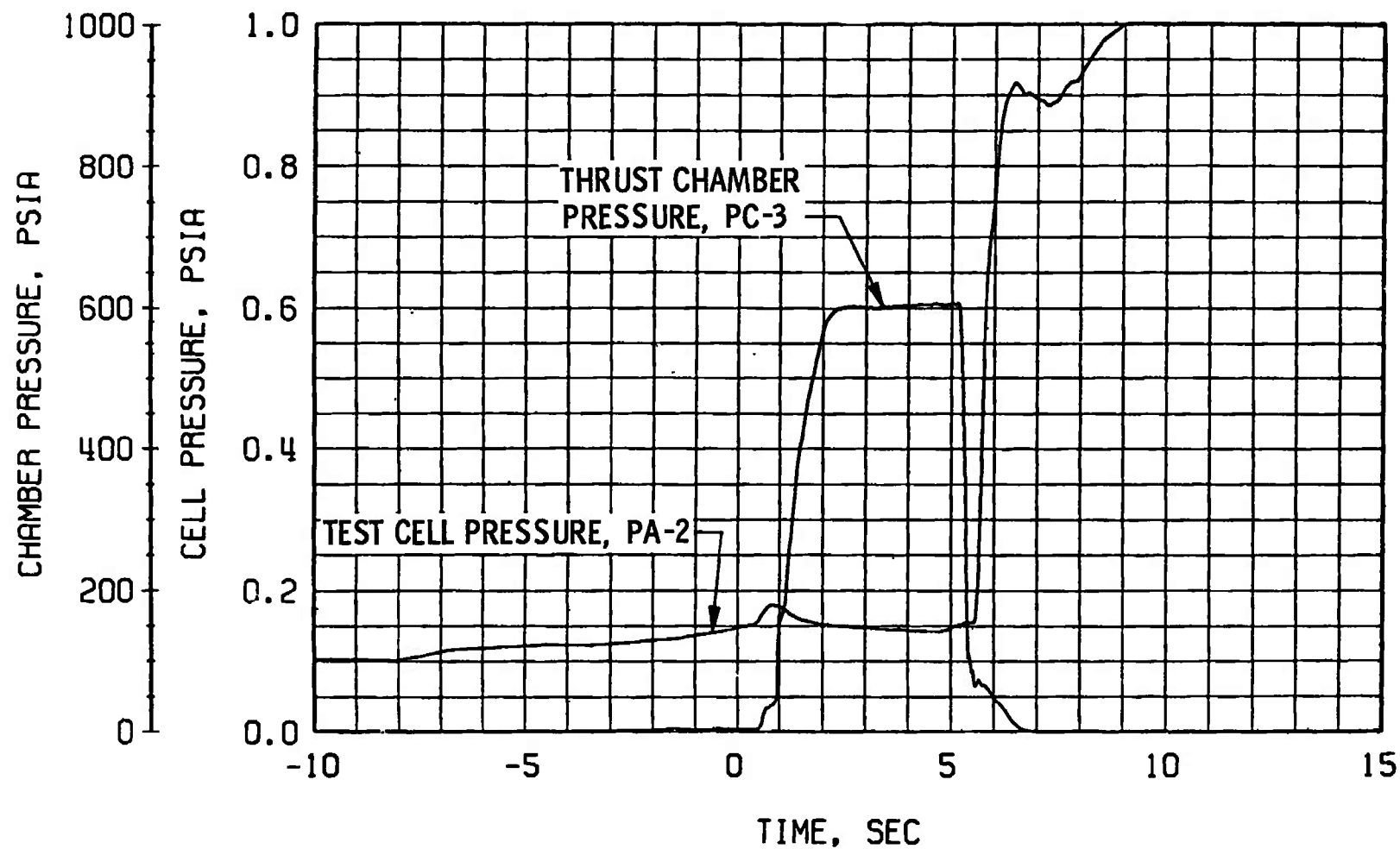
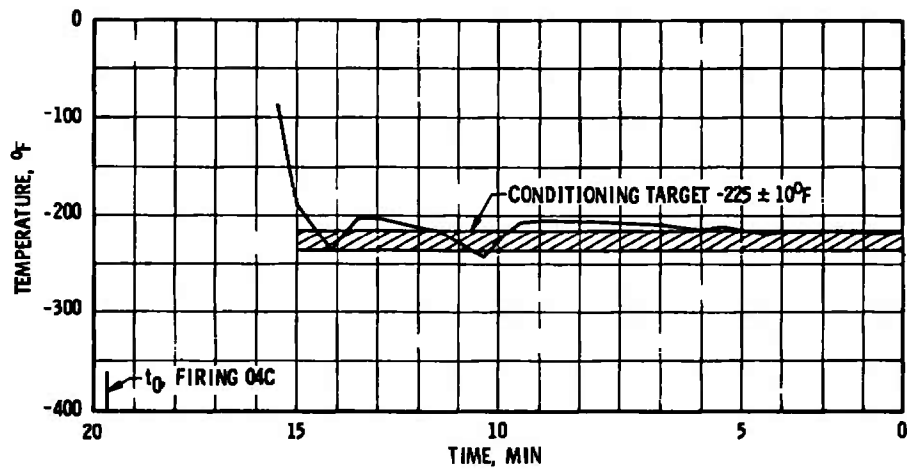
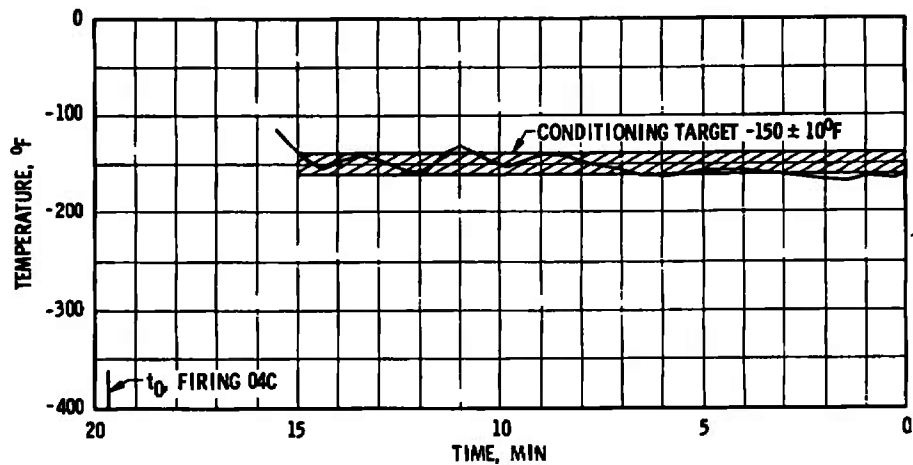


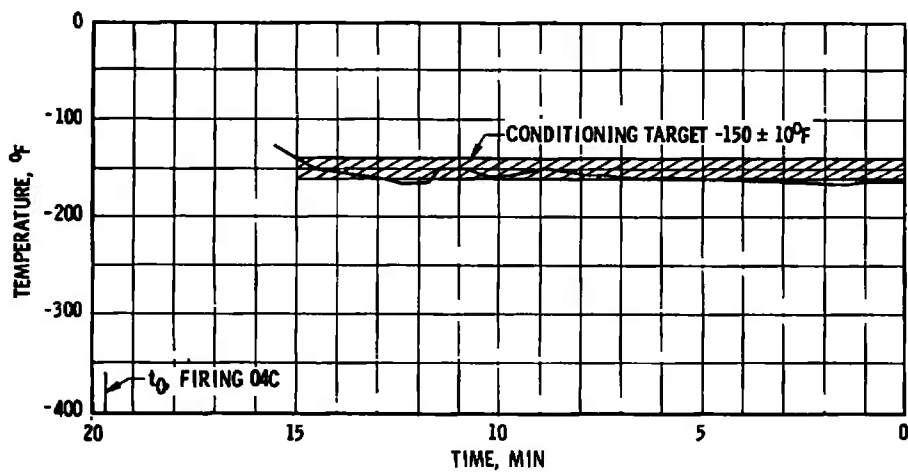
Fig. 18 Engine Ambient and Combustion Chamber Pressures, Firing 04B



a. Main Oxidizer Valve Second-Stage Actuator Conditioning



b. Main Oxidizer Valve Closing Control Line Conditioning



c. Pneumatic Control Package Conditioning

Fig. 19 Thermal Conditioning History of Engine Components, Firing 04B

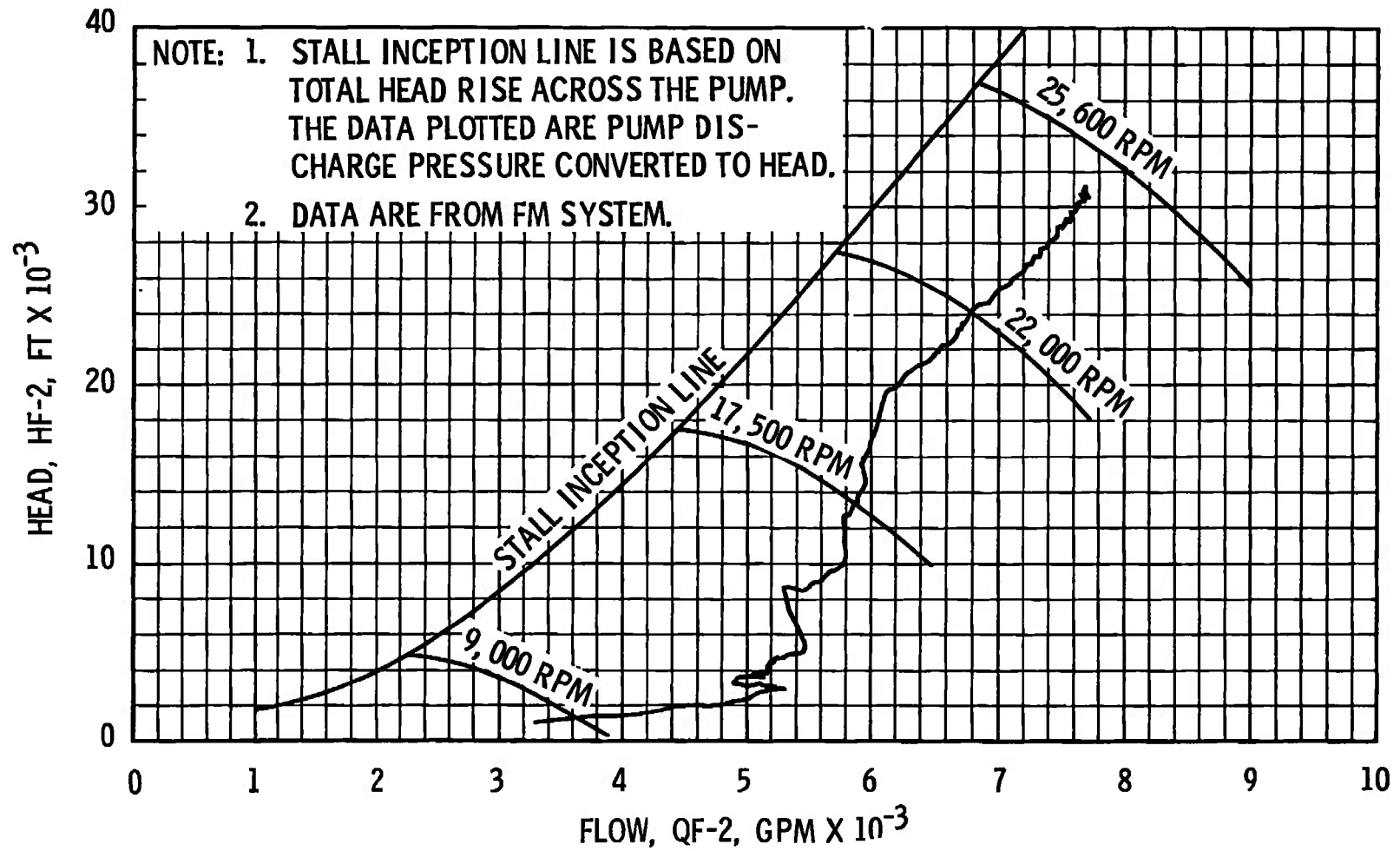
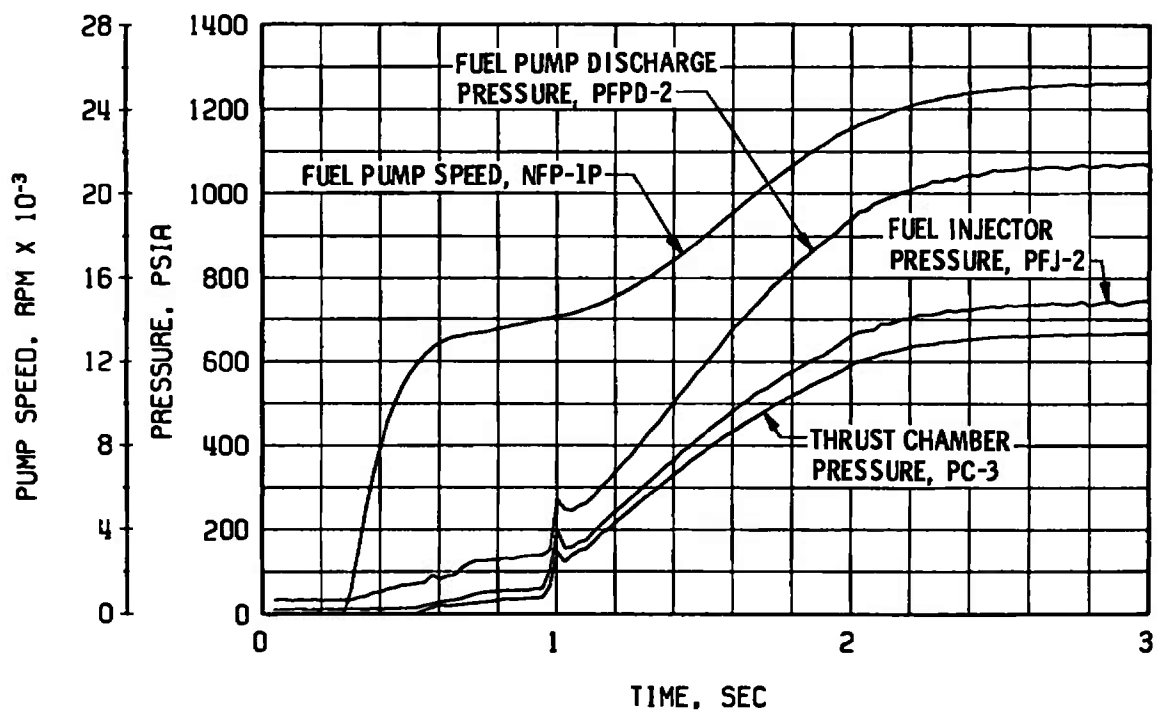
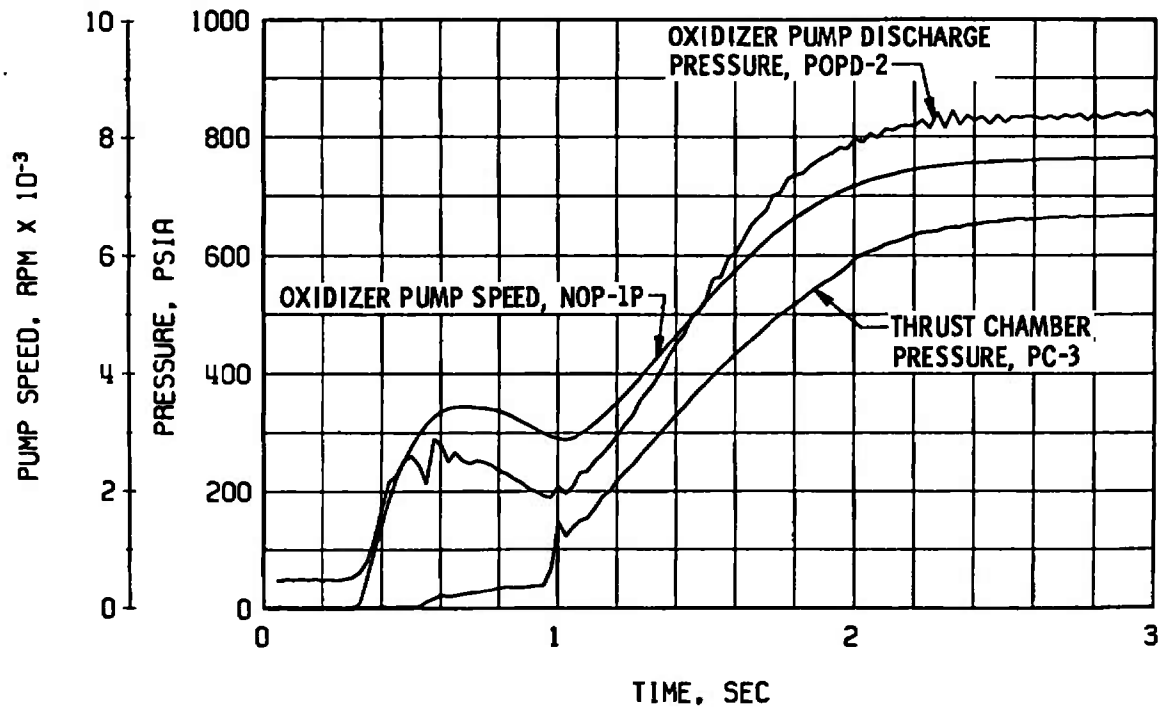


Fig. 20 Fuel Pump Start Transient Performance, Firing 04B

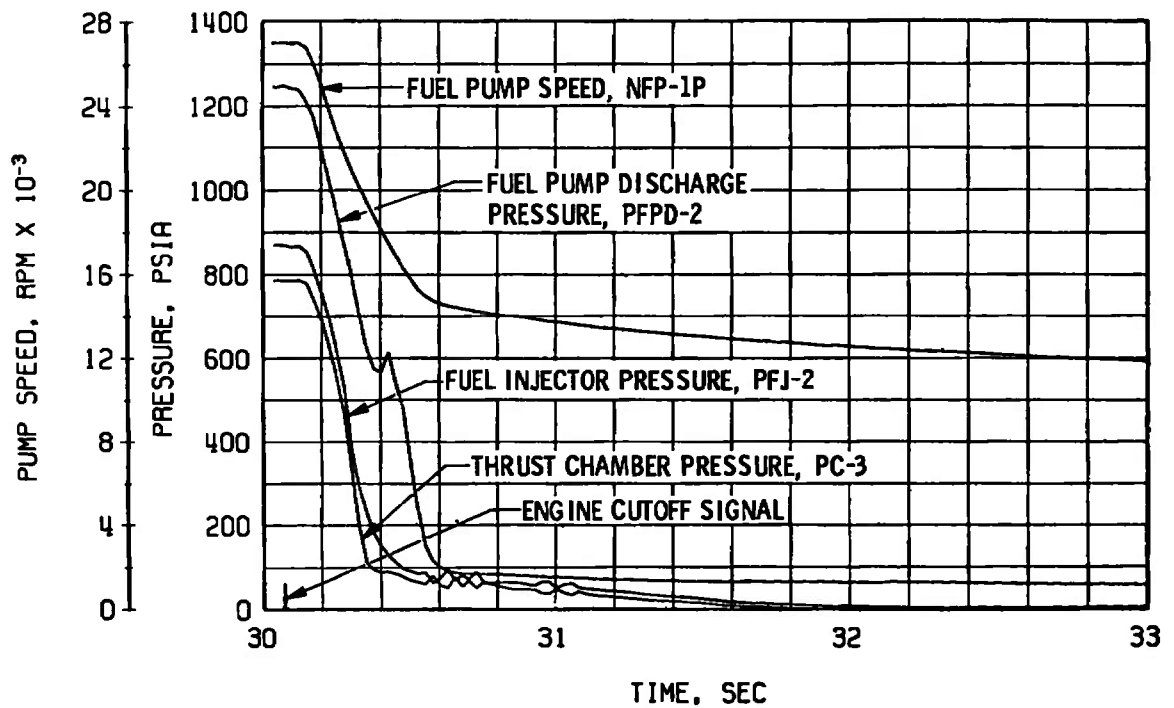


a. Start Transient, Thrust Chamber Fuel System

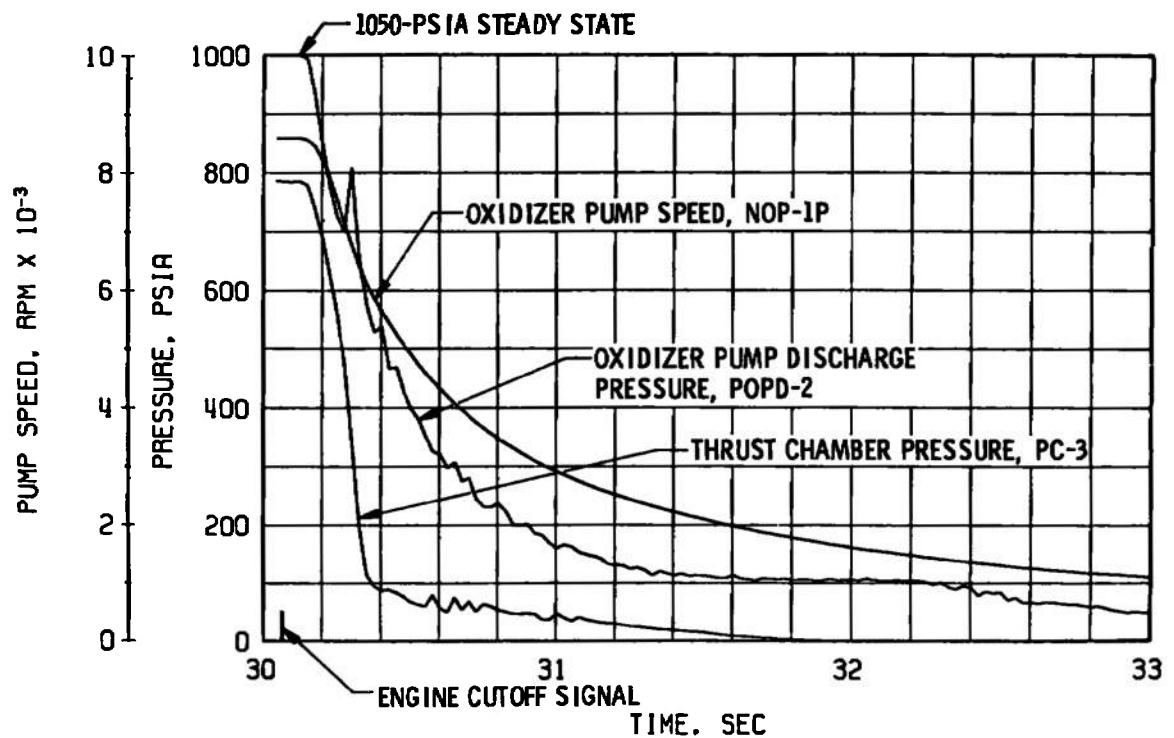


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 21 Engine Transient Operation, Firing 04E

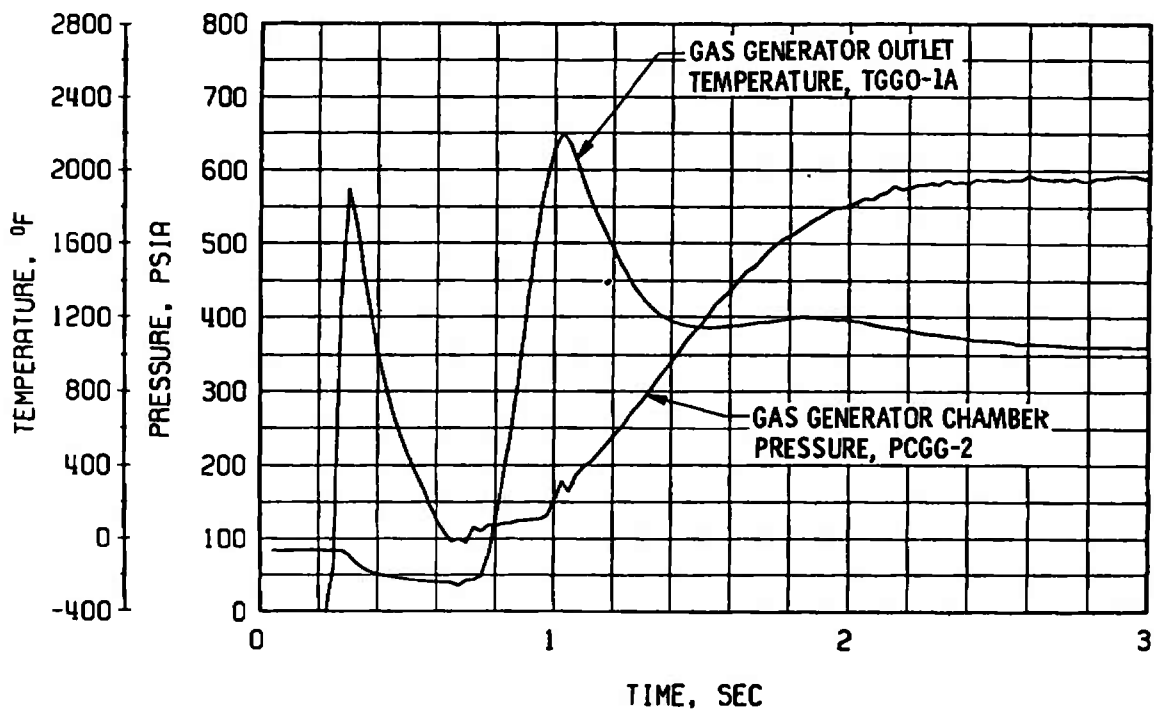
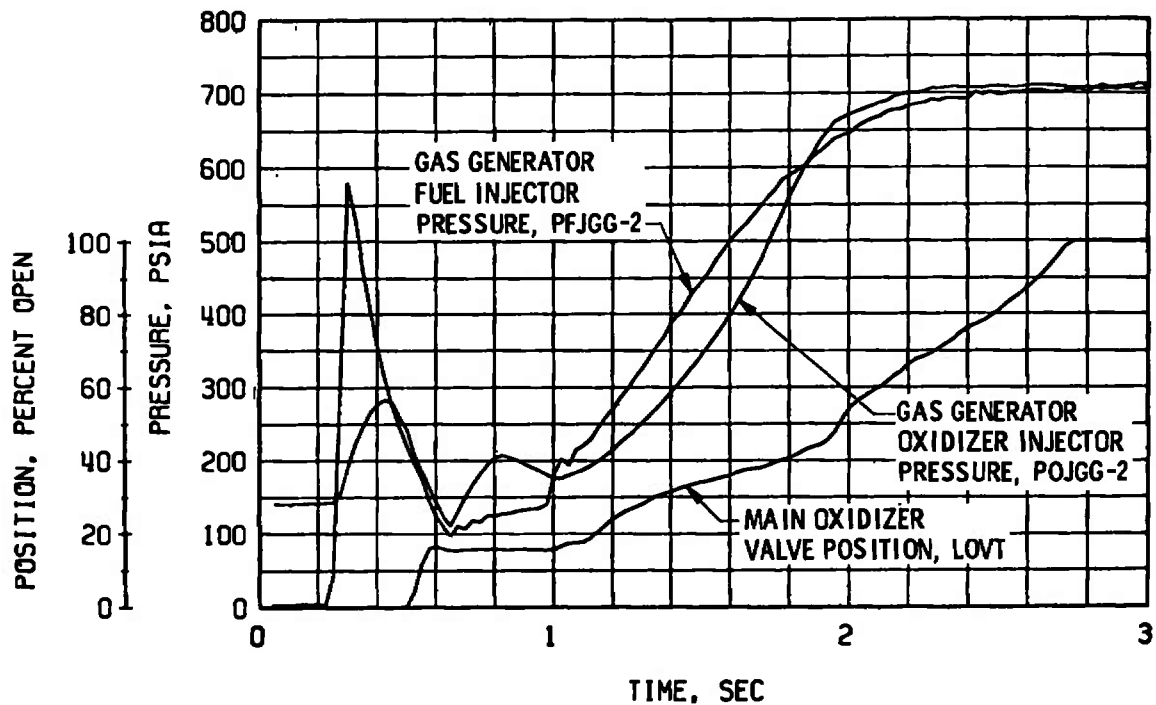


c. Shutdown Transient, Thrust Chamber Fuel System



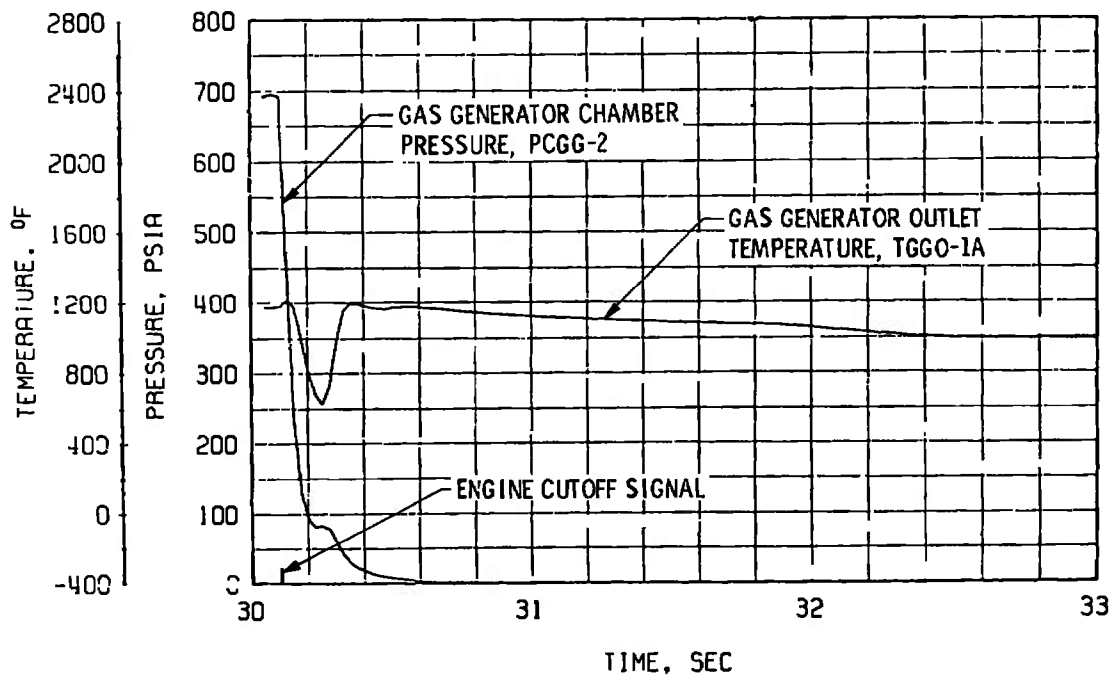
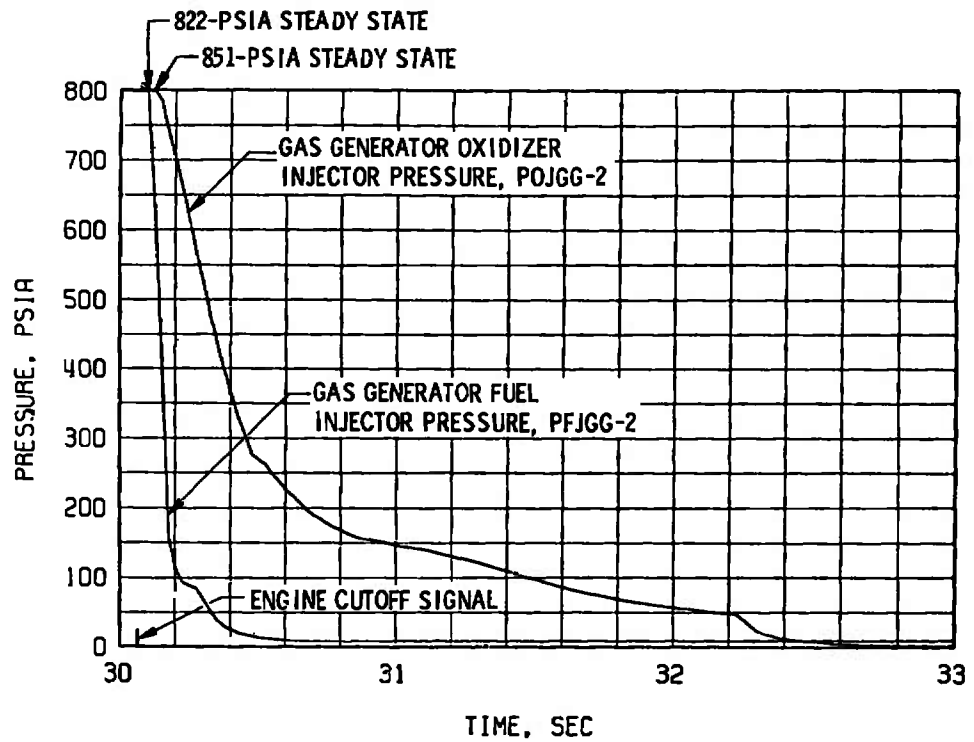
d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 21 Continued



e. Start Transient, Gas Generator

Fig. 21 Continued



f. Shutdown Transient, Gas Generator

Fig. 21 Concluded

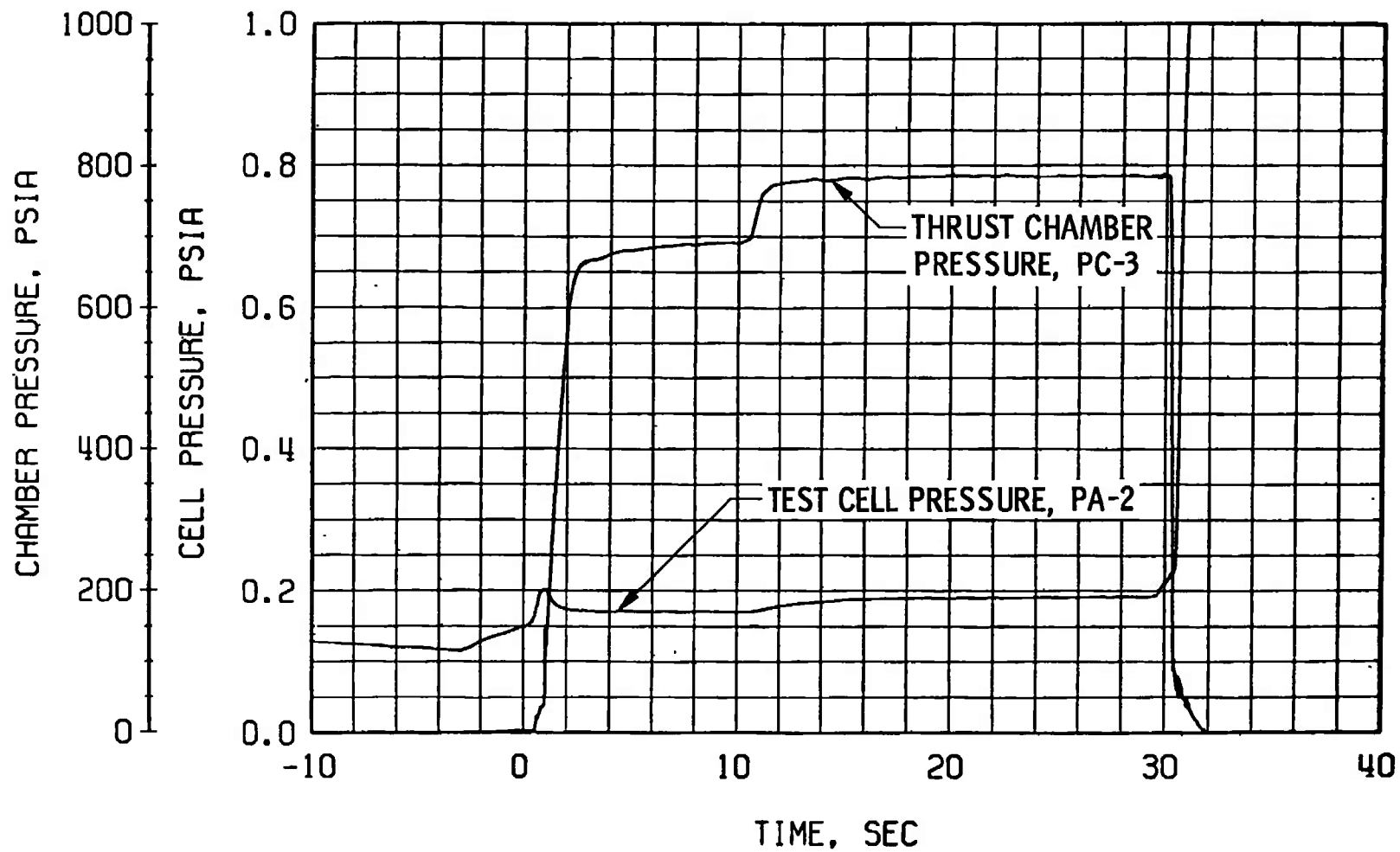
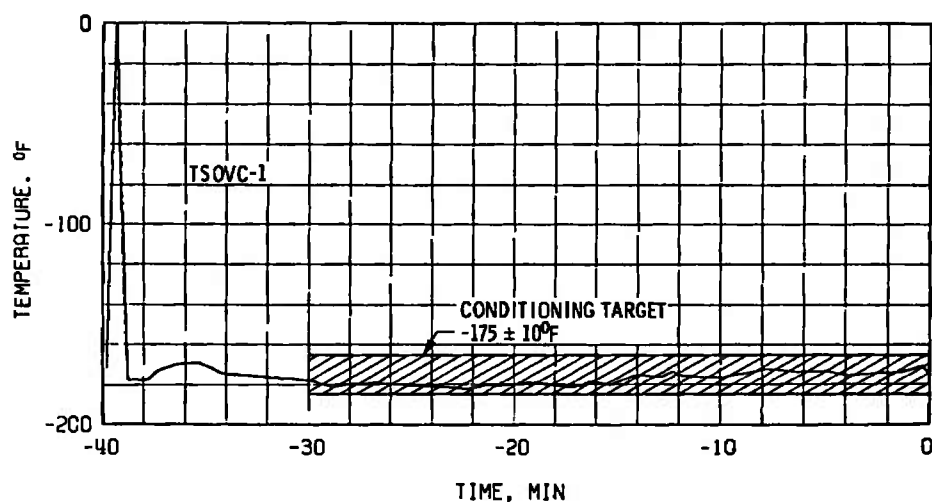
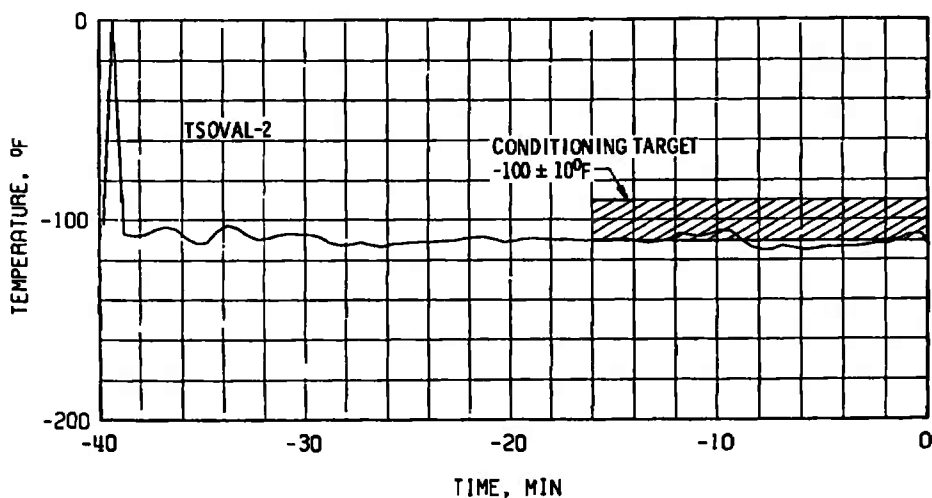


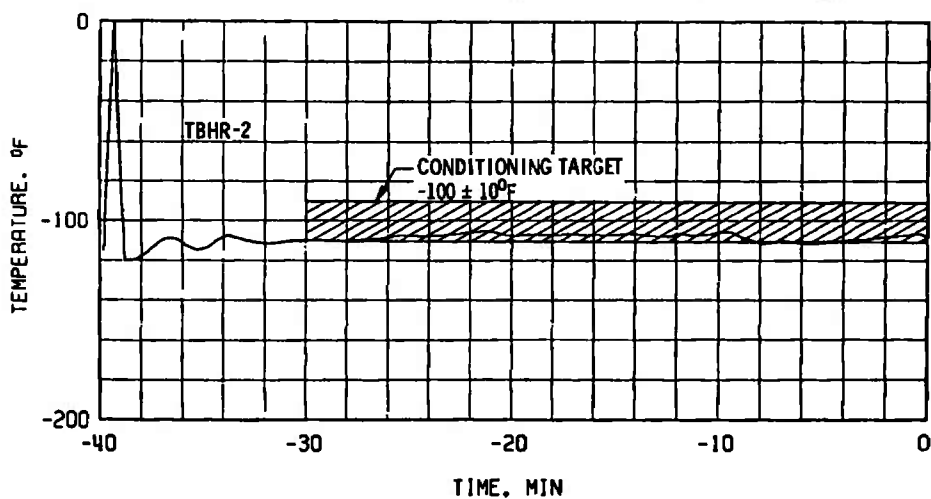
Fig. 22 Engine Ambient and Combustion Chamber Pressures, Firing 04E



a. Main Oxidizer Valve Second-Stage Actuator Conditioning

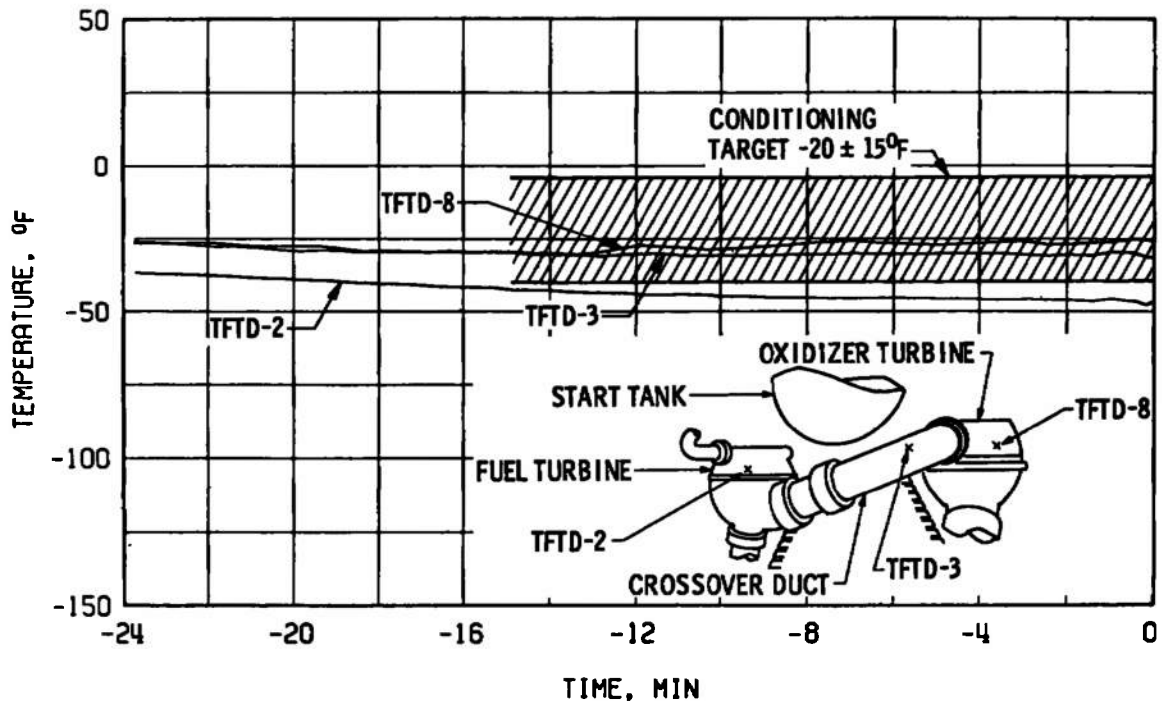


b. Main Oxidizer Valve Closing Control Line Conditioning

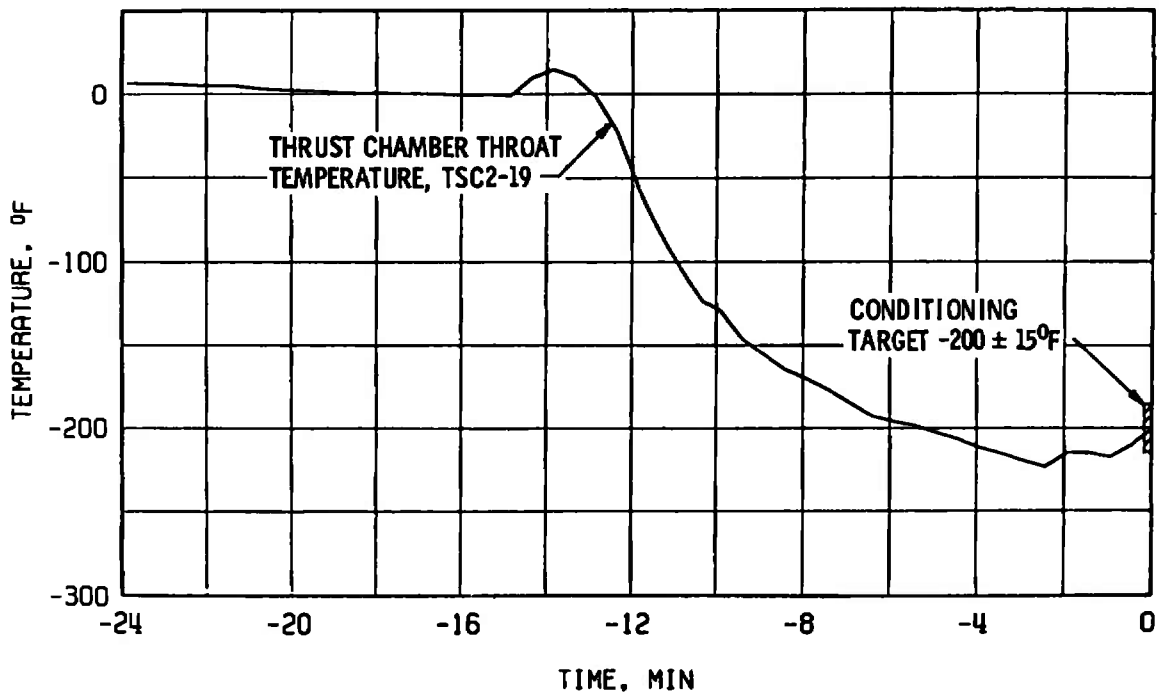


c. Pneumatic Control Package Conditioning

Fig. 23 Thermal Conditioning History of Engine Components, Firing 04E

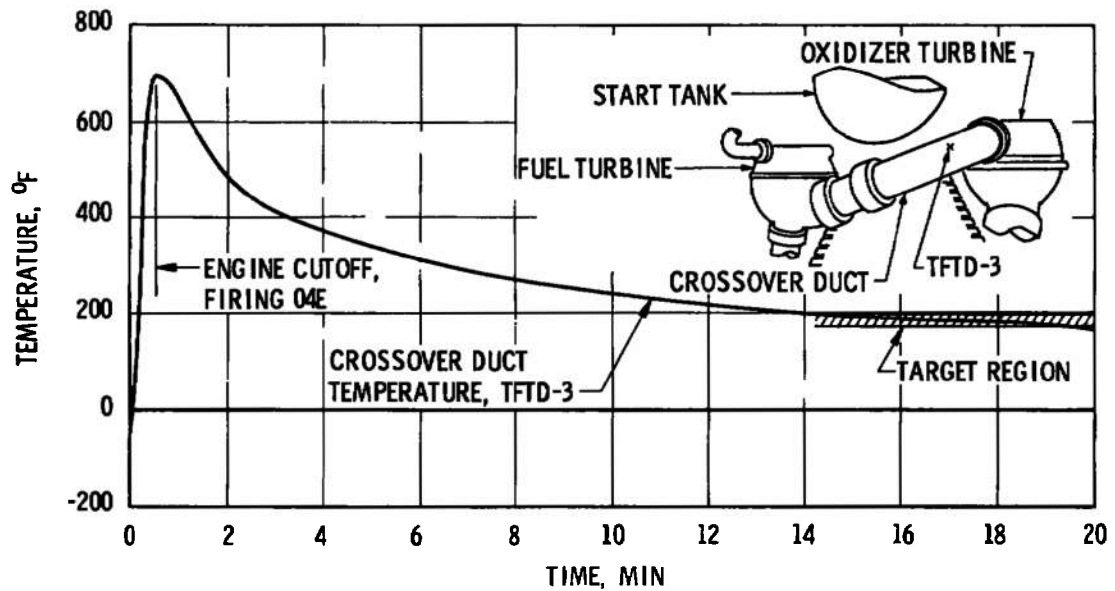


d. Crossover Duct Conditioning

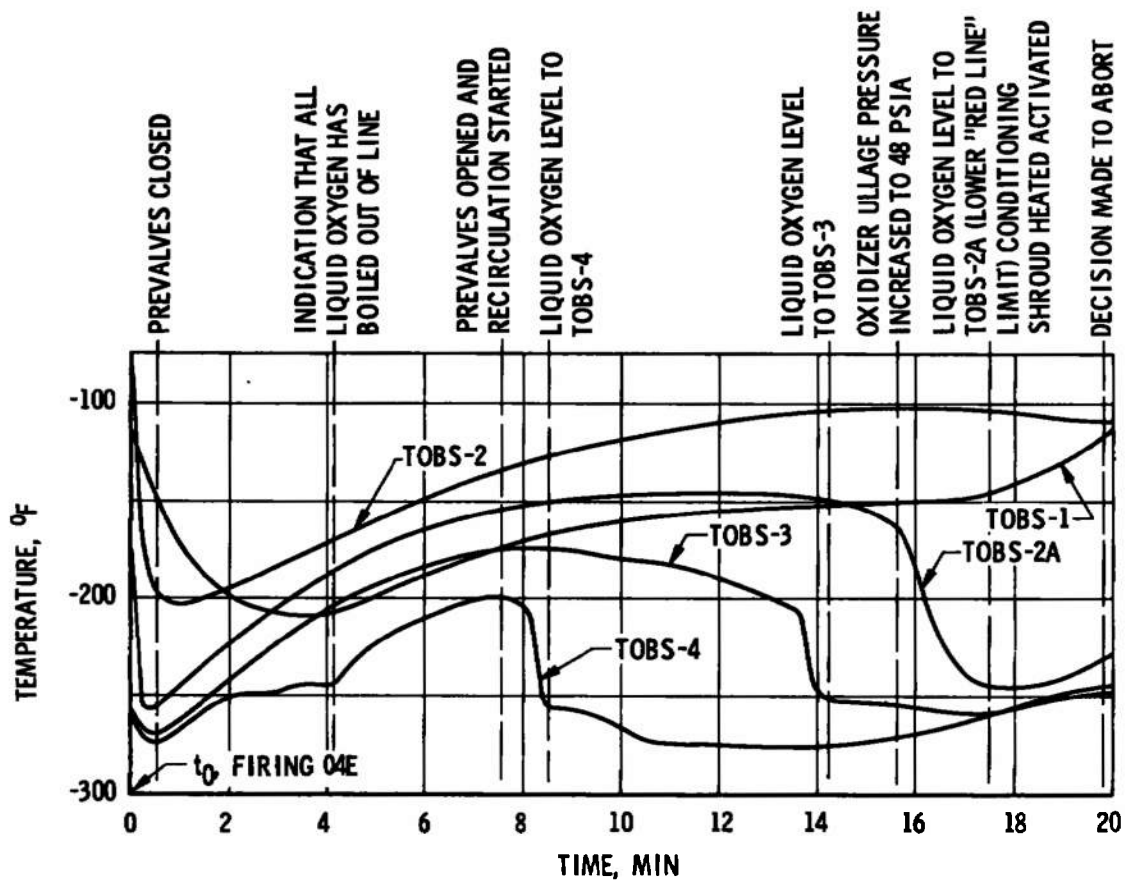


e. Thrust Chamber Conditioning

Fig. 23 Concluded



a. Crossover Duct Cooldown Rate between Firings 04E and 04D



b. Gas Generator Oxidizer Supply Line Temperature History between Firings 04E and 04D
 Fig. 24 Gas Generator Oxidizer Supply Line Temperature History between Firing 04E and Firing Attempt 04D

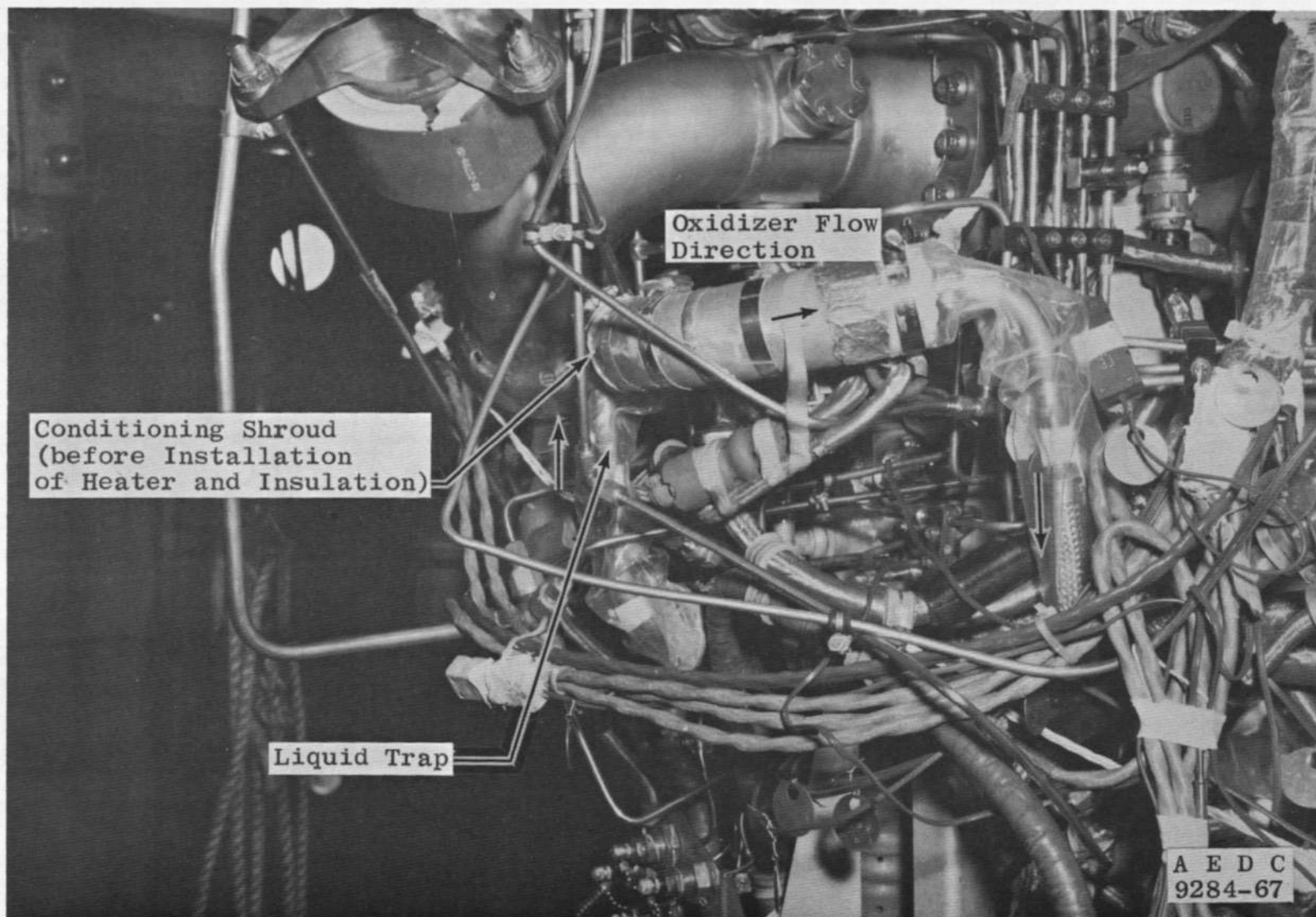


Fig. 25 Gas Generator Oxidizer Supply Line Conditioning Shroud

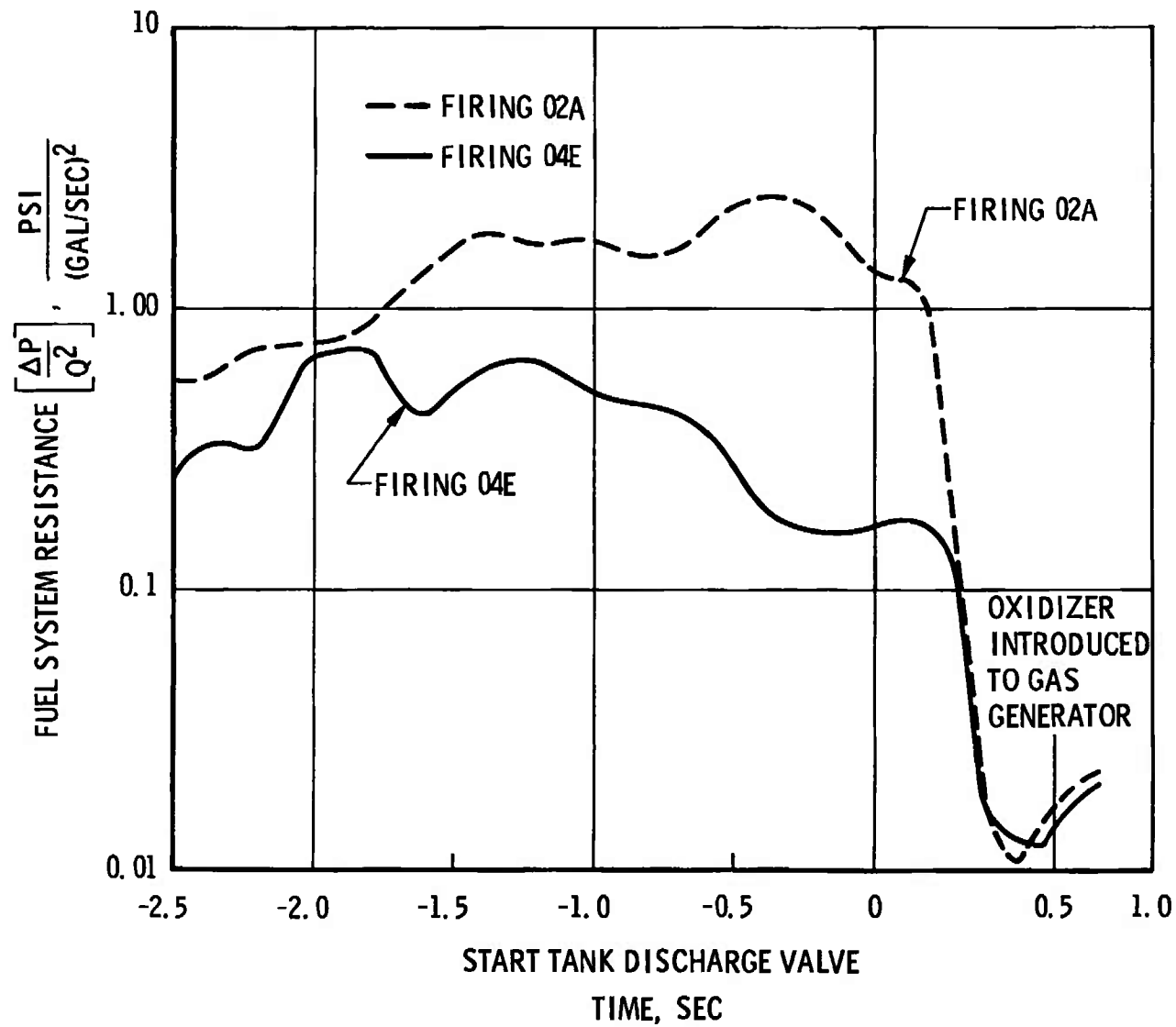


Fig. 26 Fuel System Resistance during Fuel Lead and Gas Generator Ignition Transient for Firings 04E and 02A

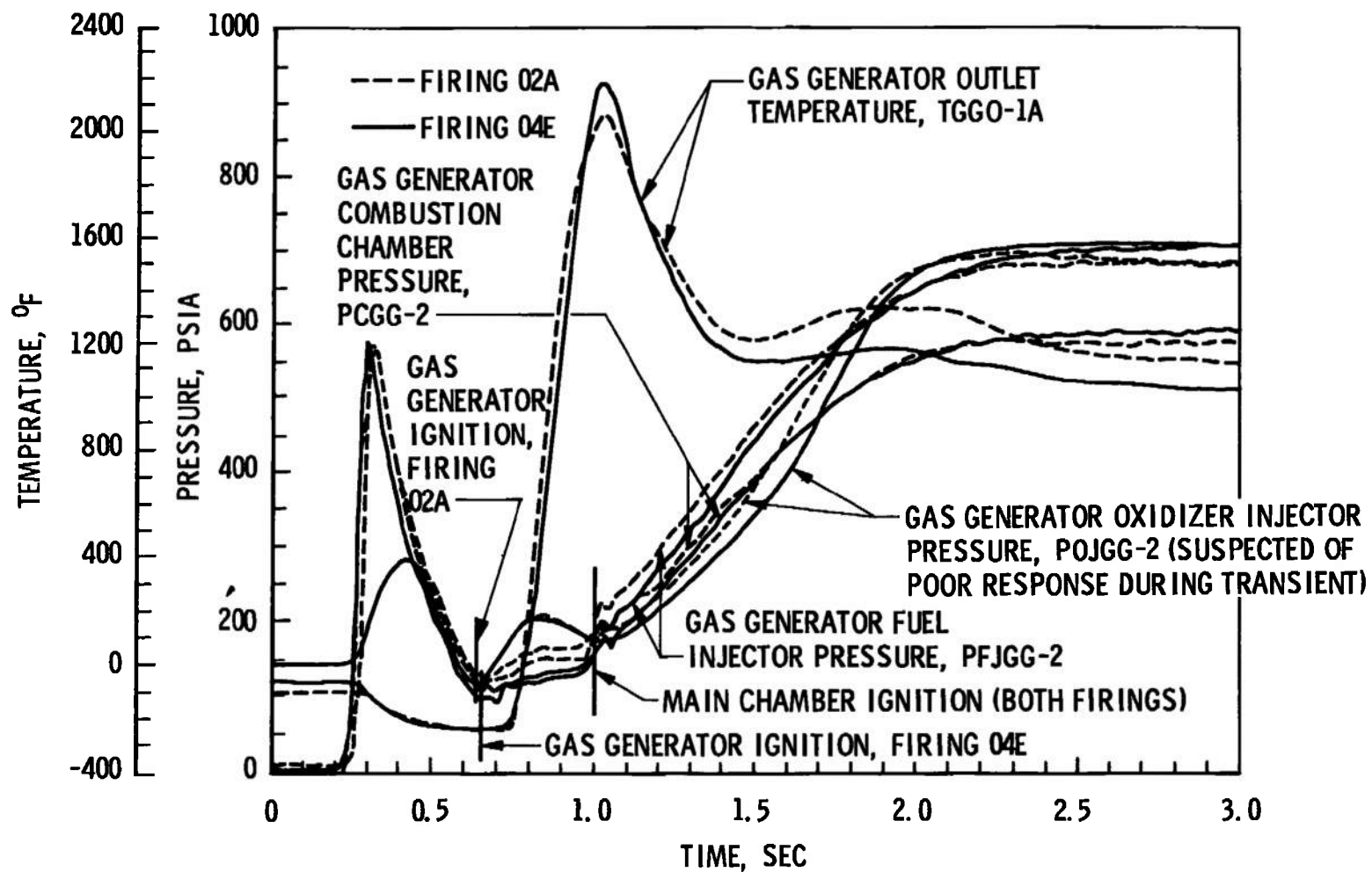
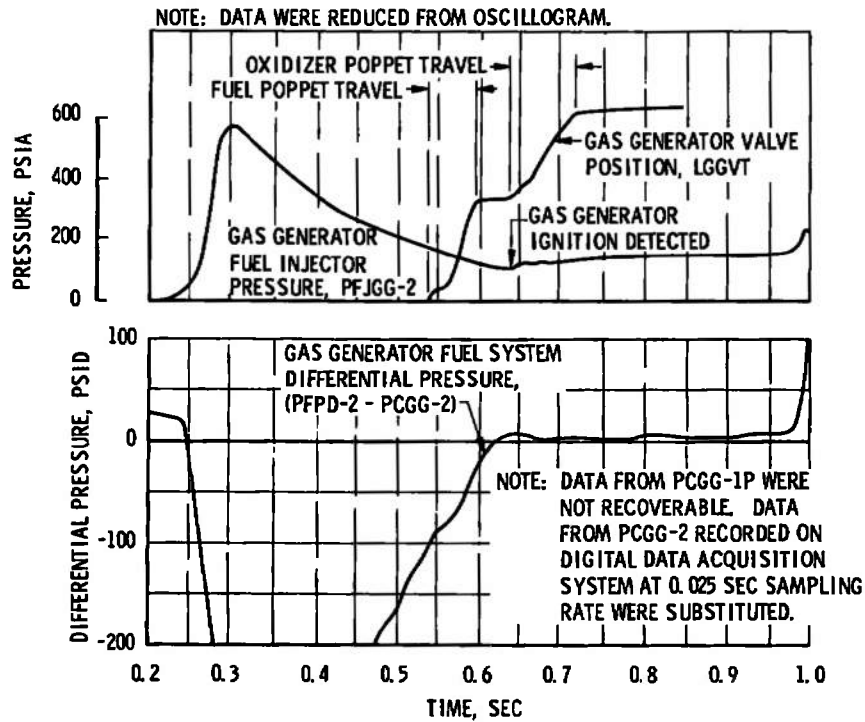
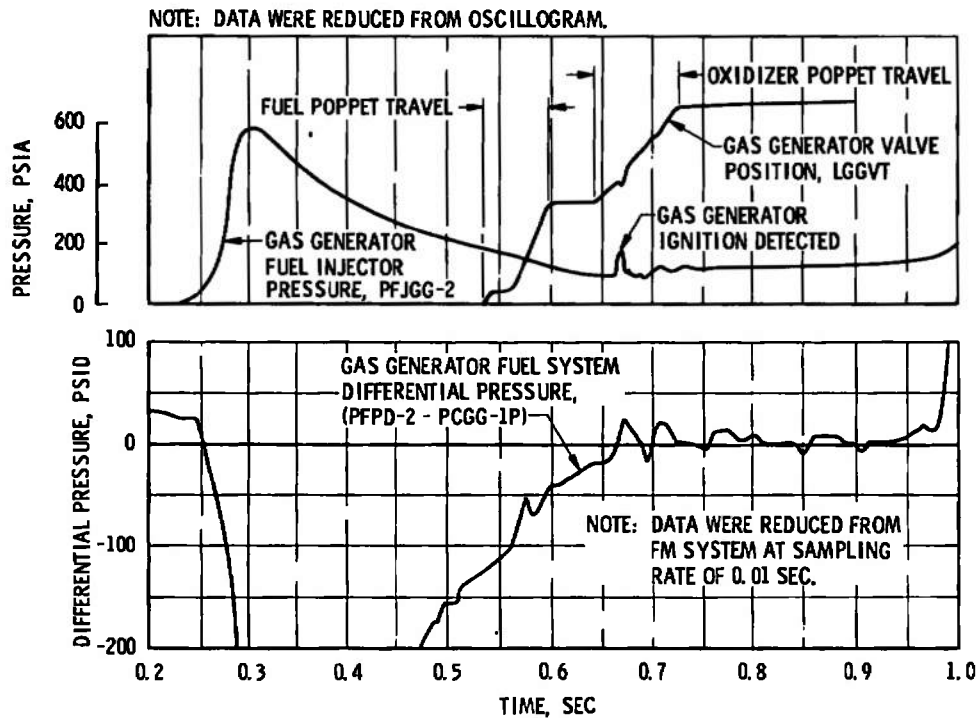


Fig. 27 Gas Generator Start Transient Comparison, Firings 04E and 02A
 a. Comparison of Gas Generator Pressures and Temperature, Firings 04E and 02A

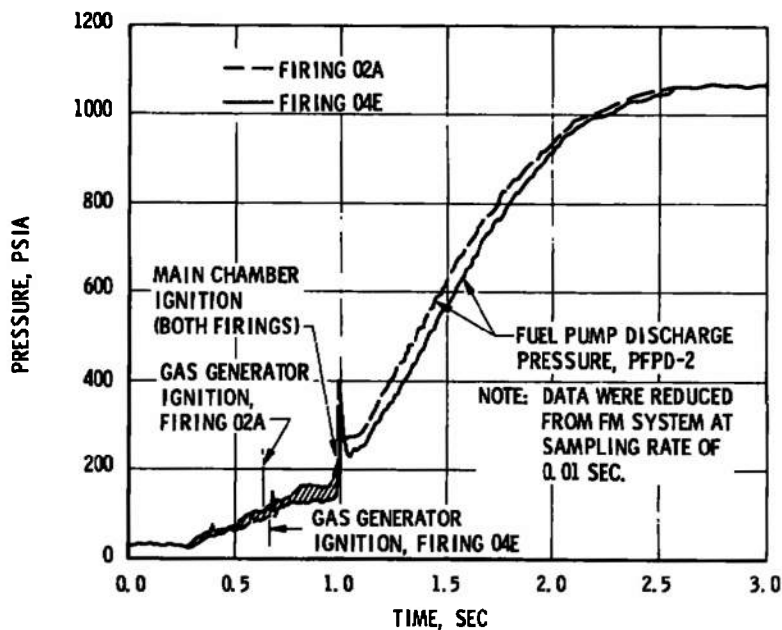


b. Gas Generator Ignition Transient, Firing 02A

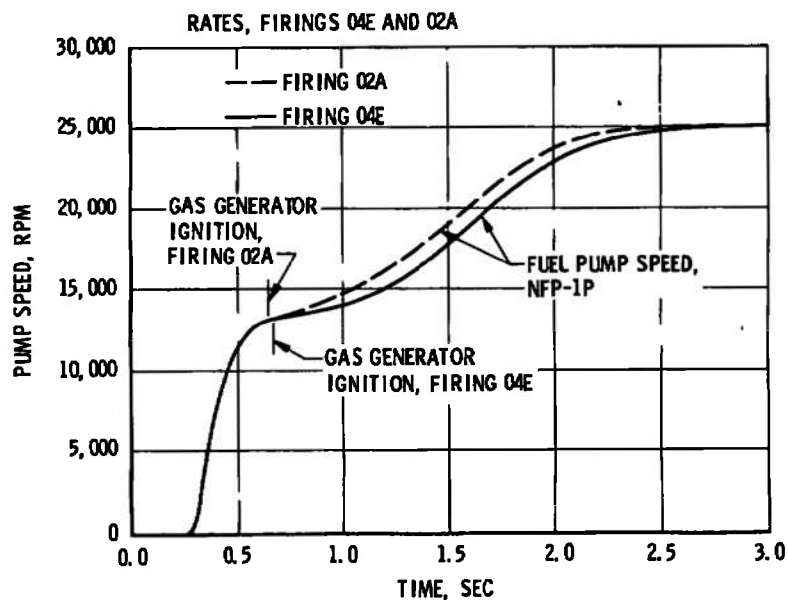


c. Gas Generator Ignition Transient, Firing 04E

Fig. 27 Continued



d. Comparison of Fuel Pump Discharge Pressure Buildup Rates, Firings 04E and 02A



e. Comparison of Fuel Pump Speed Buildup Rates, Firings 04E and 02A

Fig. 27 Concluded

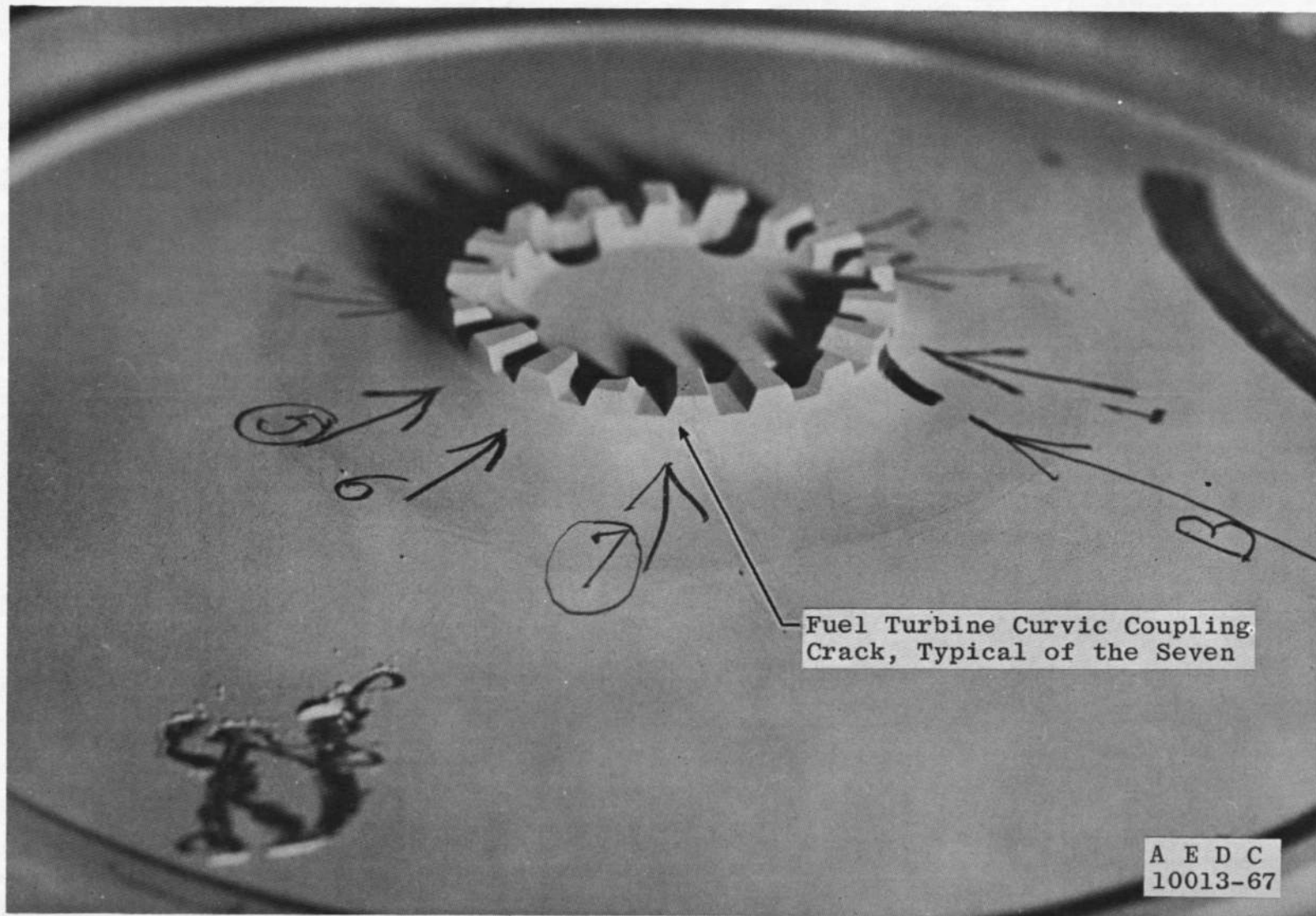


Fig. 28 Fuel Turbine Curvic Coupling Condition, Post-Test J4.1801.04

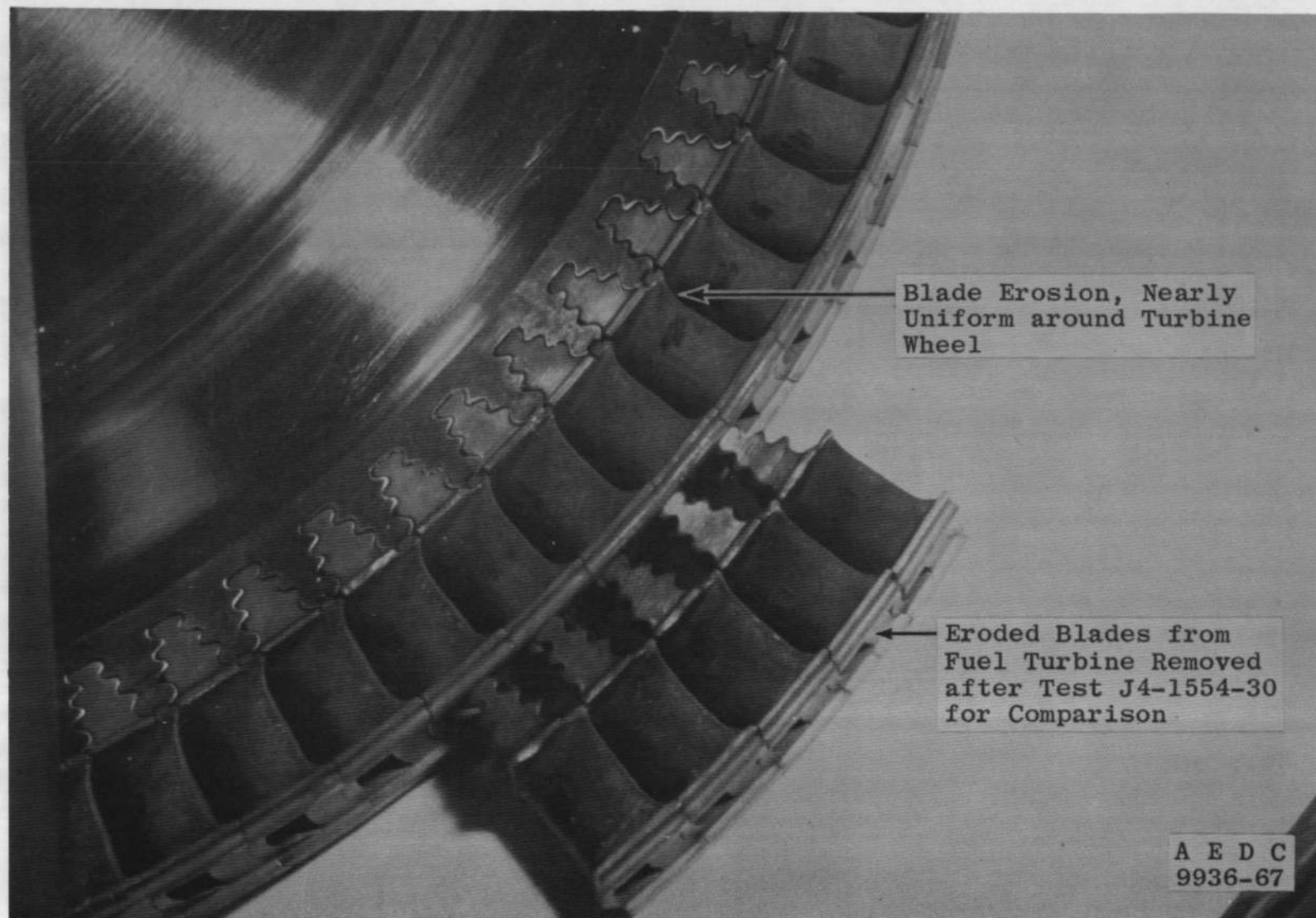


Fig. 29 Fuel Turbine Blade Condition, Post-Test J4-1801-04

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	459000-161	4062324
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	2008734
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	411031	4089563
Gas Generator Control Valve	309040	4078714
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	342270
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	Date Effective	Comments
Gas Generator Oxidizer Supply Line	RD251-4106	0.294 in.	July 31, 1967	
Augmented Spark Igniter Oxidizer Supply Line	406361	0.110 in.	July 12, 1967	
Main Oxidizer Valve Closing Control	410437	8.34 scfm	July 11, 1967	Thermostatic
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.571 in.	July 31, 1967	
Gas Generator Fuel Supply Line	RD251-4107	0.500 in.	July 31, 1967	
Oxidizer Turbine Exhaust Manifold	RD251-9004	9.99 in.	January 18, 1966	Installed on engine before receipt at AEDC

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-03 AND J4-1801-04)

Model Number	Completion Date	Description of Modification												
RFD*-58-67	July 31, 1967	Reorificing of Engine as Follows: <table> <tr> <td><u>Location</u></td><td><u>From</u></td><td><u>To</u></td></tr> <tr> <td>Gas Generator Fuel, in.</td><td>0.489</td><td>0.500</td></tr> <tr> <td>Gas Generator Oxidizer, in.</td><td>0.284</td><td>0.294</td></tr> <tr> <td>Oxidizer Turbine Bypass Valve, in.</td><td>1.430</td><td>1.571</td></tr> </table>	<u>Location</u>	<u>From</u>	<u>To</u>	Gas Generator Fuel, in.	0.489	0.500	Gas Generator Oxidizer, in.	0.284	0.294	Oxidizer Turbine Bypass Valve, in.	1.430	1.571
<u>Location</u>	<u>From</u>	<u>To</u>												
Gas Generator Fuel, in.	0.489	0.500												
Gas Generator Oxidizer, in.	0.284	0.294												
Oxidizer Turbine Bypass Valve, in.	1.430	1.571												
RFD-59-67	August 1, 1967	Addition of Gas Generator Opening Control Line Flange Thermocouple TSGGOC												
RFD-46-1-67	August 1, 1967	Deletion of Start Tank Discharge Valve Closing Control Line Thermocouple TSTDVCC												
RFD-60-67	August 1, 1967	Installation of Heater and Insulation on Gas Generator Oxidizer Bootstrap Line												
RFD-44-2-67	August 1, 1967	Addition of Oxidizer Bootstrap Line Thermocouple TOBS-2B												

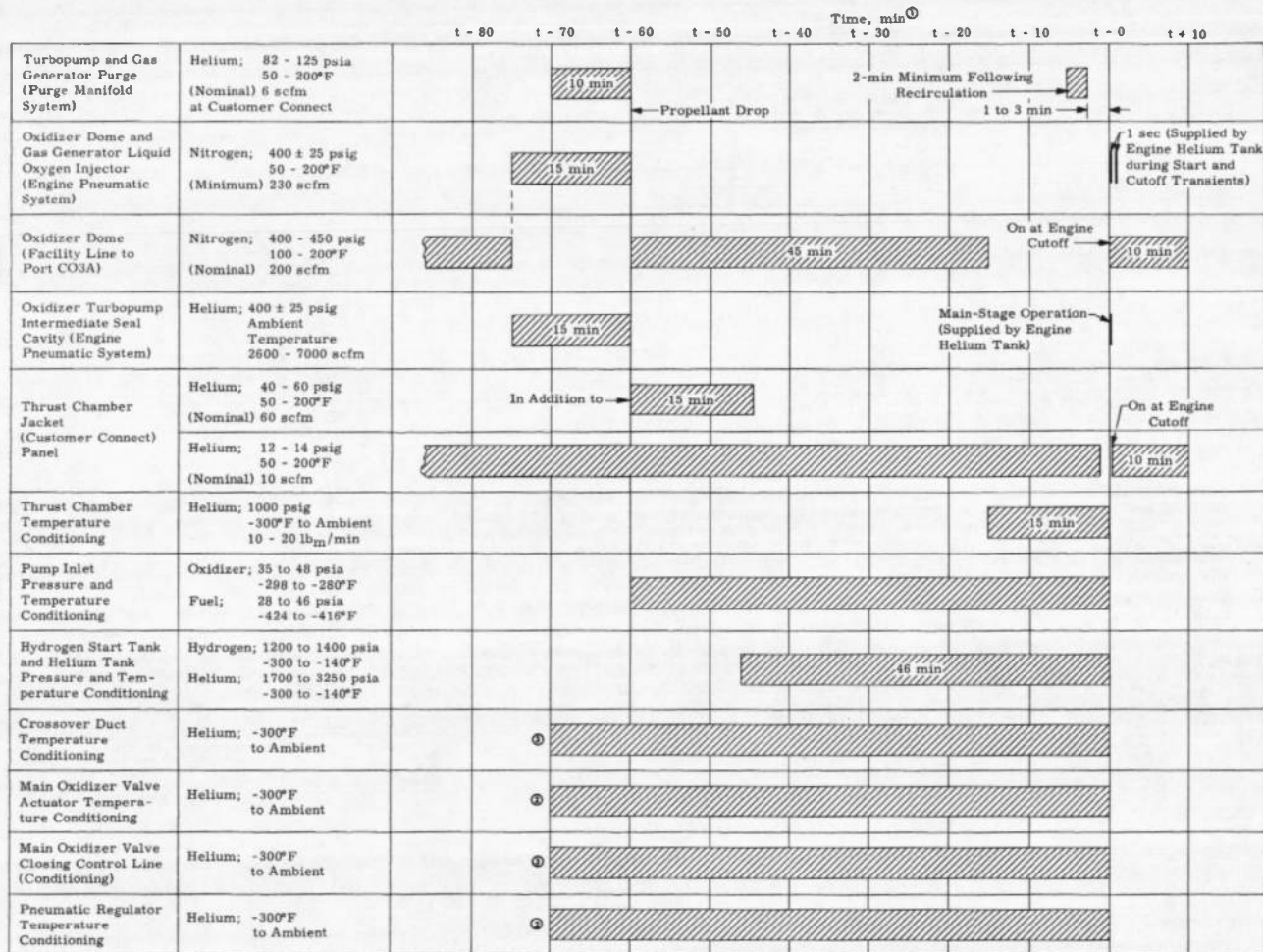
*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-03 AND J4-1801-04)

Model Number	Completion Date	Component Replaced
UCR*-007972	August 4, 1967	Gas Generator Outlet Temperature Transducer
UCR-007973	August 5, 1967	Fuel Turbine Inlet Temperature Transducer

*UCR - Rocketdyne Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE



① Times are adjusted for one and two orbit simulation firings

② Component conditions to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

③ Component conditions to be maintained within limits for last 15 min before engine start.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-		04A		04C		04B		04E	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1242/August 3, 1967		1510/August 3, 1967		1530/August 3, 1967		2034/August 3, 1967	
Pressure Altitude at Engine Start, ft (Ref. 1)		---	100,000	---	106,000	---	109,500	---	107,000
Firing Duration, sec ^①		30.0	30.07	30.0	30.07	5.0	5.09	30.0	30.07
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28.0 ± 1.0	30.0	28.0 ± 1.0	28.3	28.0 ± 1.0	27.8	28.0 ± 1.0	30.2
	Temperature, °F	-420.4 ± 0.4	-420.1	-420.4 ± 0.4	-420.3	-421.4 ± 0.4	-420.5	-420.4 ± 0.4	-420.7
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	48.0 ± 1.0	48.1	35.0 ± 1.0	35.1	48.0 ± 1.0	47.9	48.0 ± 1.0	48.4
	Temperature, °F	-285.3 ± 0.4	-286.5	-284.0 ± 0.4	-284.6	-285.3 ± 0.4	-285.5	-285.3 ± 0.4	-286.0
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1385	1250 ± 10	1248	1400 ± 10	1409	1400 ± 10	1388
	Temperature, °F	-200 ± 10	-197	-140 ± 10	-144	-240 ± 10	-238	-200 ± 10	-206
Helium Tank Conditions at Engine Start	Pressure, psia	---	2412	---	2219	---	2090	---	2475
	Temperature, °F	---	-202	---	-148	---	-235	---	-210
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-200 ± 15	-189	-100 ± 15	-121	---	51	-200 ± 15	-201
	Average	---	-175	---	-121	---	8	---	-197
Crossover Duct Temperature at Engine Start, °F ^②	TFTD-2	-20 ± 15	-50	-100 ± 15	-131	---	417	-20 ± 15	-47
	TFTD-3	---	-25	---	-120	+15 - 0	176	---	-26
	TFTD-8	---	-30	---	-105	---	371	---	-32
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F ^②		-100 ± 10	-102	-50 ± 10	-55	-150 ± 10	-160	-100 ± 10	-113
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F ^②		-175 ± 10	-158	-150 ± 10	-142	-225 ± 10	-221	-175 ± 10	-176
Pneumatic Control Package Temperature at Engine Start, °F ^②		-100 ± 10	-100	-50 ± 10	-57	-150 ± 10	-163	-100 ± 10	-108
Fuel Lead Time, sec ^③		3	3.007	8	7.995	8	7.980	3	3.008
Propellant In Engine Time, min		80	118	20	88	10	11	80	74
Propellant Recirculation Time, min		10	10.5	10	11	10	11	10	16.5 10.5
Sequencing Logic		Auxiliary	Auxiliary	Normal	Normal	Normal	Normal	Auxiliary	Auxiliary
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	-50 ± 10	④	-50 ± 10	④	-50 ± 10	④	Duplication of Firing 02A Conditions	④
	TOBS-2	---		---		---			
	TOBS-3	---		---		---			
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	-54	---	-58	---	-57	---	-75
Gas Generator Control Valve Opening Control Temperature at Engine Start, °F		---	-105	---	-82	---	-127	---	-118
Vibration Safety Count Duration (maec) and Occurrence Time (sec) from Start Tank Discharge Valve		---	87 at 0.984	---	4 at 0.544 15 at 1.083	---	None	---	33 at 0.878
Gas Generator Outlet Temperature, °F	Initial Peak	---	2038	---	1094	---	2121	---	2201
	Second Peak	---	None	---	None	---	None	---	None
Thrust Chamber Ignition Time, sec (Ref. t_0) ($P_c = 3 - 100$ psia) ^⑤		---	1.003	---	1.100	---	0.848	---	0.878
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ^⑤		---	0.885	---	1.028	---	1.098	---	0.985
Main-Stage Pressure No. 2, sec (Ref. t_0) ^⑤		---	1.638	---	2.041	---	1.588	---	1.631
550-psia Chamber Pressure Attained, sec (Ref. Start Tank Discharge Valve)		---	1.802	---	2.758	---	1.915	---	1.885

Notes: ① Data reduced from oscillogram.

② Component conditioning to be maintained within limits for last 15 min before engine start.

③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

④ See Table VIII.

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
-04A	0	0.155	0.149	0.445	0.097	0.263	-3.007	0.058	0.062	0.445	0.054	0.049	0.445	0.540	1.939	0.445	0.090	0.060	0.445	0.194	0.075	0.445	0.238	0.284
-04B	0	0.154	0.152	0.443	0.091	0.258	-7.880	0.059	0.057	0.443	0.052	0.045	0.443	0.655	1.644	0.443	0.091	0.090	0.443	0.205	0.087	0.443	0.237	0.290
-04C	0	0.147	0.134	0.447	0.089	0.268	-7.995	0.046	0.067	0.447	0.053	0.047	0.447	0.591	1.649	0.447	0.091	0.058	0.447	0.199	0.079	0.447	0.250	0.299
-04E	0	0.160	0.150	0.445	0.091	0.268	-3.008	0.055	0.063	0.445	0.052	0.049	0.445	0.540	1.725	0.445	0.090	0.060	0.445	0.185	0.086	0.445	0.243	0.310
Pre-Fire Final Sequence	0	0.099	0.106	0.447	0.093	0.249	-1.010	0.047	0.062	0.447	0.049	0.045	0.447	0.577	1.712	0.447	0.073	0.045	0.447	0.139	0.056	0.447	0.210	0.287

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 Closing Time, sec
-04A	30.07	0.124	0.292	30.07	0.086	0.189	30.07	0.068	0.034	30.07	0.019	0.025	30.07	0.270	0.538
-04B	5.09	0.108	0.317	5.09	0.077	0.199	5.09	0.073	0.023	5.09	0.022	0.029	5.09	0.254	0.538
-04C	30.07	0.112	0.307	30.07	0.078	0.185	30.07	0.072	0.021	30.07	0.018	0.021	30.07	0.278	0.573
-04E	30.07	0.121	0.325	30.07	0.083	0.199	30.07	0.068	0.030	30.07	0.020	0.026	39.07	0.268	0.568
Pre-Fire Final Sequence	---	0.099	0.239	---	0.053	0.128	---	0.090	0.028	---	0.063	0.018	---	0.229	0.594

- 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.

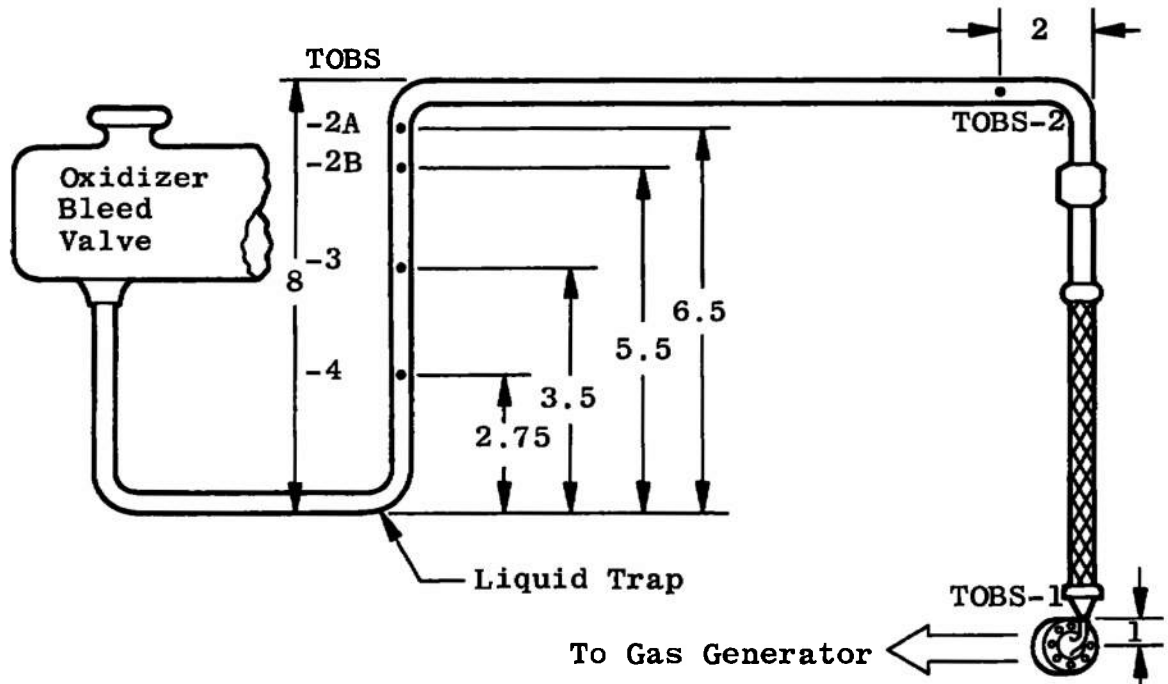


TABLE VIII
GAS GENERATOR OXIDIZER SUPPLY LINE TEMPERATURES AT ENGINE START

Parameter	04A	04C	04B	04E	04D
TOBS-1, °F	-37	-23	-43	-112	-129
TOBS-2, °F	-39	-26	-38	-73	-109
TOBS-2A, °F	-52	-34	-53	-176	-240
TOBS-2B, °F	-46	-31	-45	-162	-163
TOBS-3, °F	-83	-58	-88	-254	-251
TOBS-4, °F	-174	-112	-182	-258	-249

Note: Thermocouple TOBS-2B was suspected of poor contact with the line.

**TABLE IX
TEST CONDITION COMPARISONS**

Firing Number J4-1801-		02A	04A	03A	04E	03B	04B	04D*
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28.3	30.0	29.6	30.2	28.3	27.6	---
	Temperature, °F	-420.4	-420.1	-420.6	-420.7	-420.6	-420.5	---
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	47.7	48.1	48.6	48.4	47.8	47.9	---
	Temperature, °F	-295.8	-296.5	-294.6	-296.0	-294.3	-295.5	---
Start Tank Conditions at Engine Start	Pressure, psia	1395	1395	1394	1399	1401	1409	1399
	Temperature, °F	-203	-197	-203	-206	-243	-236	-239
Thrust Chamber Temperature, °F	Throat at Engine Start	-115	-169	-186	-201	110	51	73
	Average at t_0	-147	-231	-243	-257	-182	-176	---
Crossover Duct Temperature at Engine Start	TFTD-3, °F	-17	-25	-38	-32	181	176	179
Main Oxidizer Valve Closing Control Line Temperature at Engine Start		-96	-102	-132	-113	-163	-160	-171
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start		-166	-159	-299	-176	-321	-221	-252
Pneumatic Control Package Temperature at Engine Start		-116	-100	-95	-108	-178	-163	-168
Gas Generator Oxidizer Supply Line Temperature, °F	TOBS-1	-76	-37	-134	-112	-126	-43	-129
	TOBS-2	-50	-39	-159	-73	-182	-38	-109
	TOBS-2A	---	-52	-249	-176	-265	-53	-240
	TOBS-3	-252	-83	-261	-254	-262	-88	-251
	TOBS-4	-248	-174	-256	-258	-253	-182	-249
Propellant in Engine Time, min		116	118	143	74	10	11	12
Oxidizer Recirculation Time, min		11	10.5	11	16.5 10.5	10	11	12
Oxidizer System Pressurized, min		2	2	2	1 2	2.4	2.5	4.5
Fuel Lead Time, sec		3.000	3.007	3.002	3.008	7.992	7.980	---
Actual Coast Time before Engine Restart (80-min Simulation), min		N/A	N/A	N/A	N/A	19	19	19
Gas Generator Peak Temperature, °F		2080	2040	2490	2200	**2650	2120	---

*Conditions shown for $t - 1$ sec countdown time when firing 04D was aborted.

**The gas generator temperature sensing probe failed, producing engine cutoff at $t_0 + 1.25$ sec.

TABLE X
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		04A		04C		04E	
Time		29.5		29.5		29.5	
		Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lbf	230,900	228,100	229,600	227,500	228,600	225,600
	Chamber Pressure, psia	778.1	766.8	773.3	764.5	770.8	758.3
	Mixture Ratio	5.616	5.547	5.572	5.537	5.585	5.540
	Oxidizer Weight Flow, lb _m /sec	461.7	453.2	457.3	451.2	458.9	450.5
	Fuel Weight Flow, lb _m /sec	82.2	81.7	82.0	81.5	82.2	81.3
	Total Weight Flow, lb _m /sec	543.9	534.9	539.3	532.7	541.1	531.8
Thrust Chamber Performance	Mixture Ratio	5.834	5.766	5.788	5.755	5.802	5.760
	Total Weight Flow, lb _m /sec	536.6	527.6	532.0	525.4	533.8	524.5
	Characteristic Velocity, ft/sec	7948	7966	7967	7975	7914	7924
Fuel Turbopump Performance	Pump Efficiency, percent	72.4	72.4	72.4	72.4	72.7	72.7
	Pump Speed, rpm	27,022	26,656	26,863	26,567	27,003	26,650
	Turbine Efficiency, percent	58.2	58.0	58.1	57.9	59.3	59.1
	Turbine Pressure Ratio	7.36	7.36	7.35	7.35	7.30	7.24
	Turbine Inlet Temperature, °F	1278	1238	1266	1234	1252	1217
	Turbine Weight Flow, lb _m /sec	7.35	7.30	7.28	7.25	7.30	7.24
Oxidizer Turbopump Efficiency	Pump Efficiency, percent	80.4	80.3	80.4	80.3	80.3	80.3
	Pump Speed, rpm	8591	8534	8577	8516	8586	8522
	Turbine Efficiency, percent	45.7	45.6	46.1	46.0	45.8	45.8
	Turbine Pressure Ratio	2.73	2.73	2.72	2.72	2.73	2.73
	Turbine Inlet Temperature, °F	806	777	792	771	783	759
	Turbine Weight Flow, lb _m /sec	6.37	6.33	6.31	6.28	6.32	6.26
Gas Generator Performance	Mixture Ratio	0.986	0.962	0.979	0.961	0.971	0.950
	Chamber Pressure, psia	700.2	684.4	693.0	679.2	693.1	676.4

Site - Test Data

Normalized - Test Data Corrected to Standard Pump Inlet and Engine Ambient Vacuum Conditions

APPENDIX III INSTRUMENTATION

The instrumentation for AEDC test J4-1801-04 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					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>Position</u>		<u>Percent Open</u>					
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 (Pot Output Voltage)		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
	<u>Pressure</u>		<u>psia</u>					
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	Augmented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-1P	Gas Generator Chamber		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
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 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 Line		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 Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Vent Line		0 to 1000	x				
PGBNI	Bypass Nozzle Inlet	TG8	0 to 200	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Helium 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		

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>Oscillograph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
<u>Pressure</u>								
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				
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				
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				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x			x	
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				

TABLE III-1 (Continued)

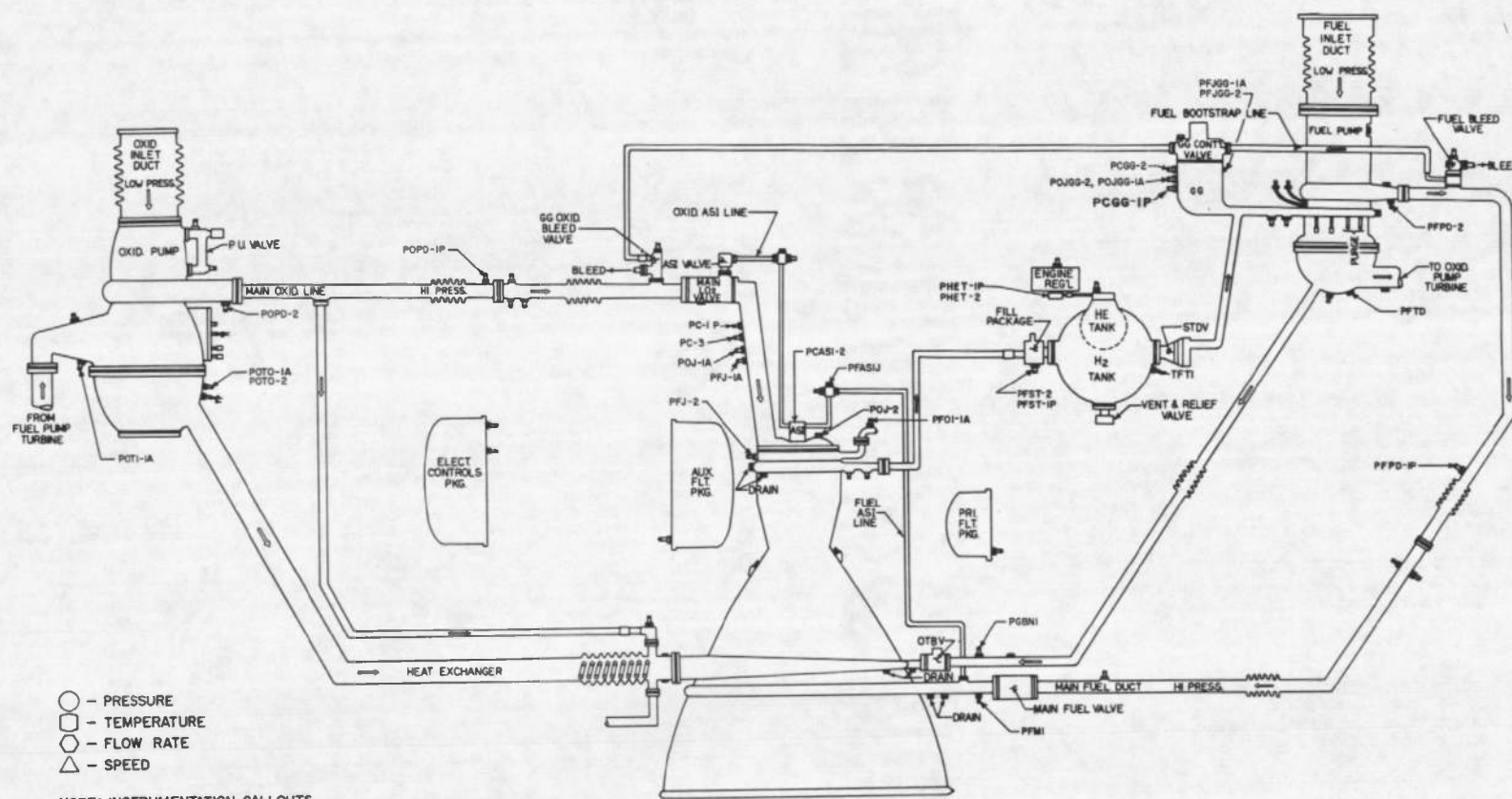
<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro- SADIC</u>	<u>Magnetic Tape</u>	<u>Oscillo- graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
	<u>Temperatures</u>		<u>°F</u>					
TECP-1P	Electrical Control Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	1FT1	-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				
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 2000	x	x	x		
THET-1P	Helium Tank	NNTI	-350 to +100	x				x
TMOV	Main Oxidizer Valve Actuator Conditioning		-325 to +200	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				
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				

TABLE III-1 (Continued)

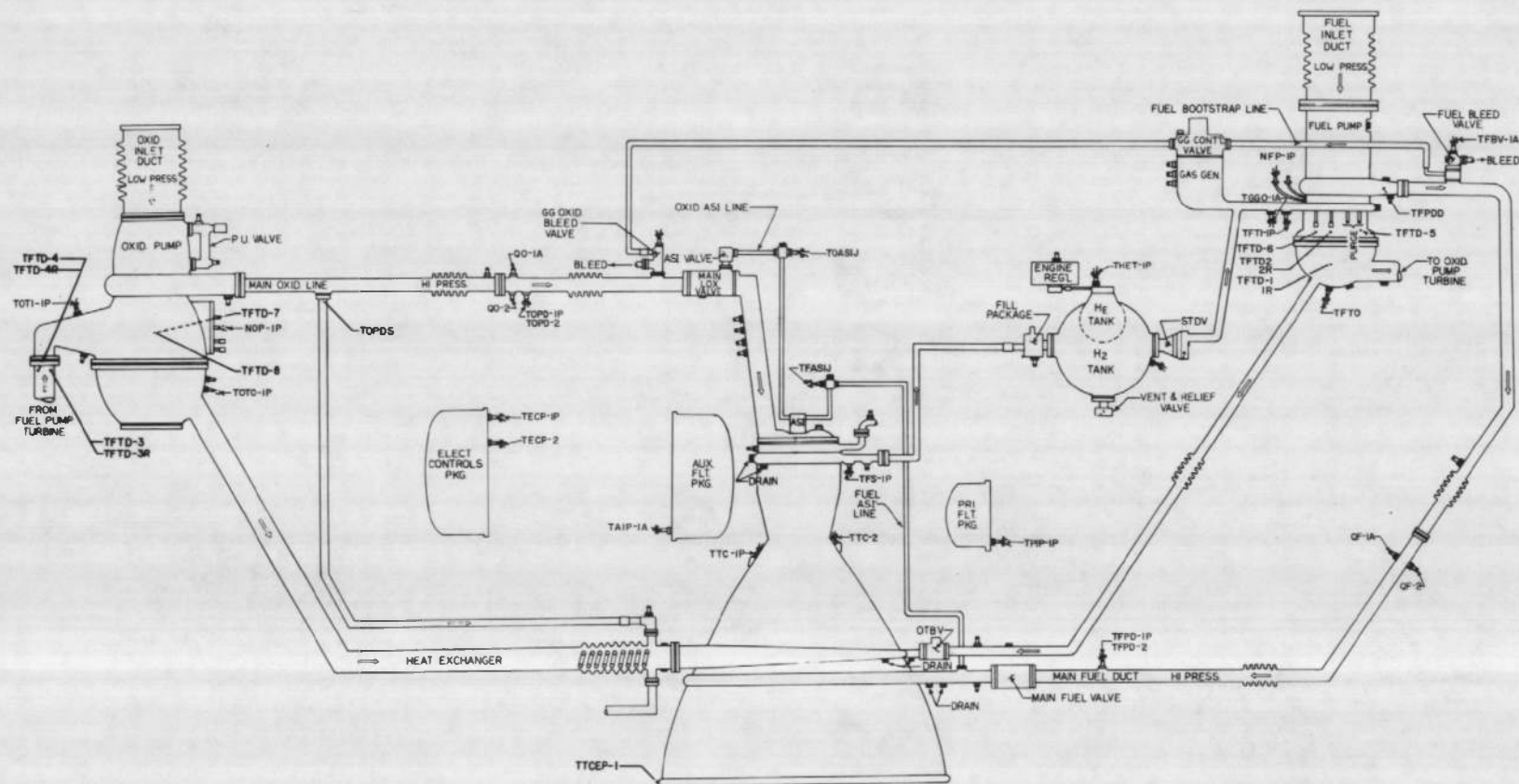
AEDC Code	Parameter	Tsp No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
<u>Temperatures</u>			<u>*F</u>					
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	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
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return Line		-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	Prechill 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				
TSOB	Skin Oxidizer Bootstrap Shroud		-200 to +100	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				

TABLE III-1 (Concluded)

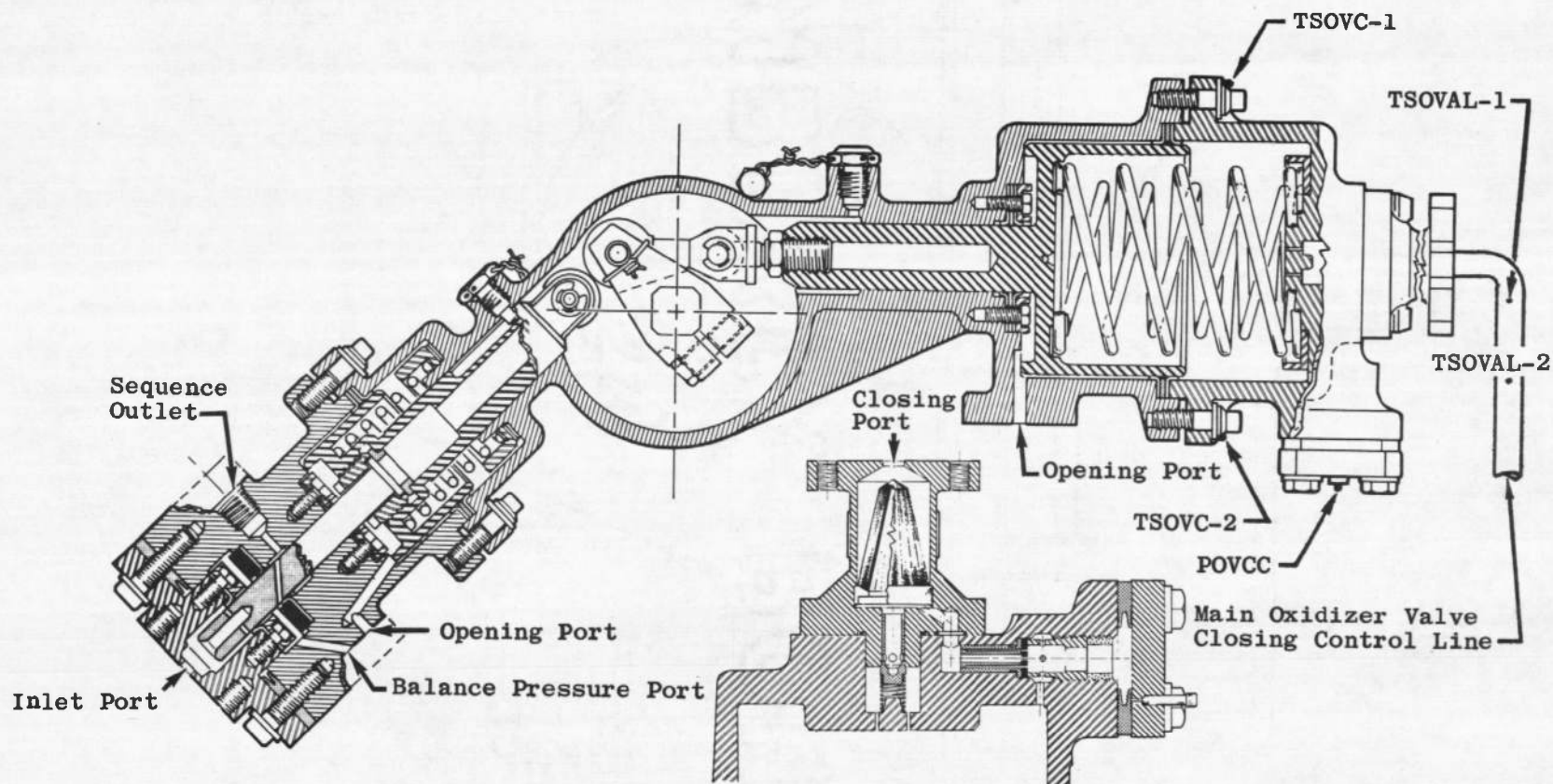
<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro- SADIC</u>	<u>Magnetic Tape</u>	<u>Oscillo- graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
<u>Temperatures</u>			<u>°F</u>					
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSTC	Start Tank Conditioning Upstream (PCV-N2-He)		-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			x	
TSGGOC	Gas Generator Opening Control Port		-350 to +100	x				
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
<u>Vibrations</u>			<u>g</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 100	x				
RTCEP	Thrust Chamber Exhaust Plume		0 to 7	x			x	



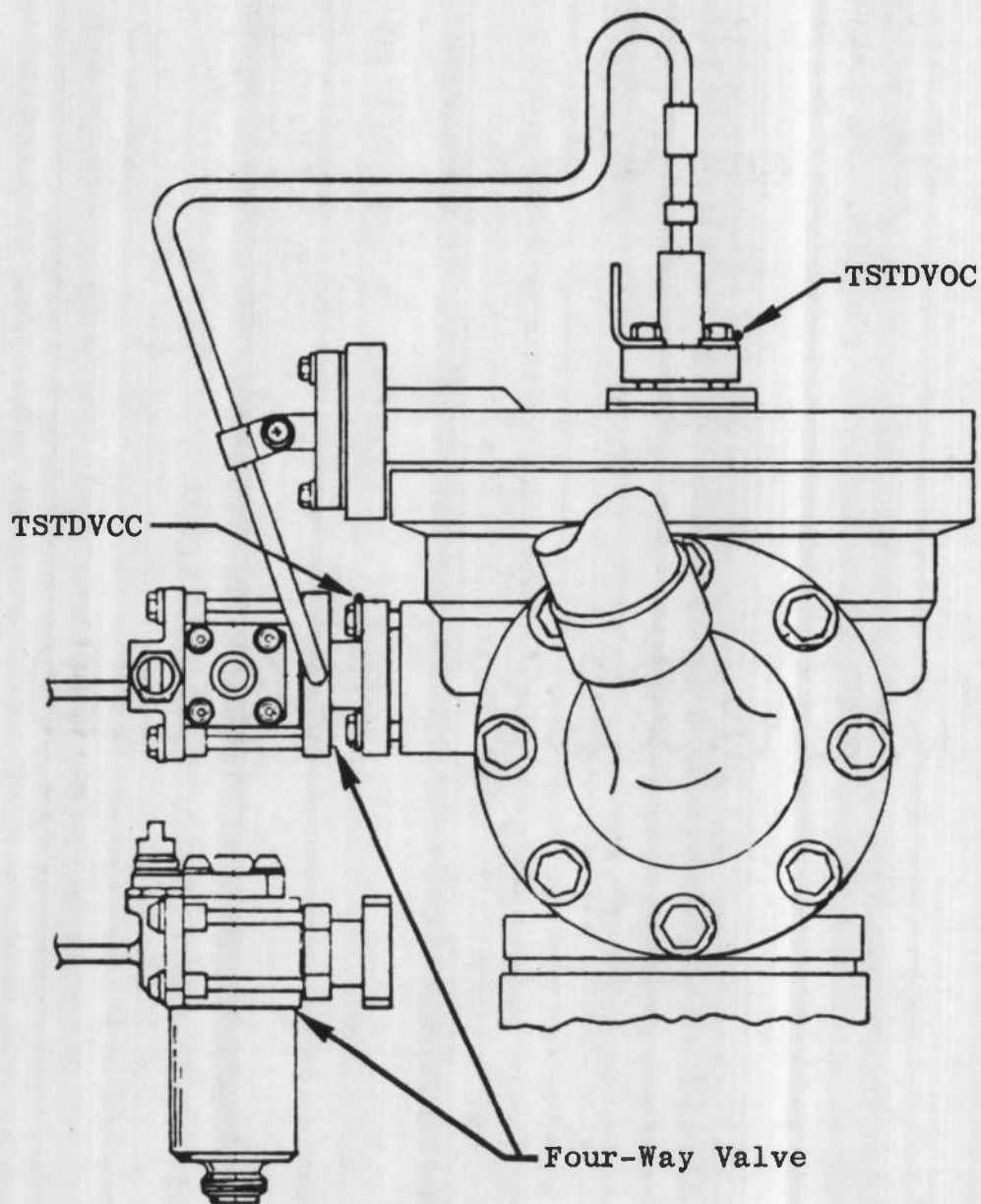
a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations



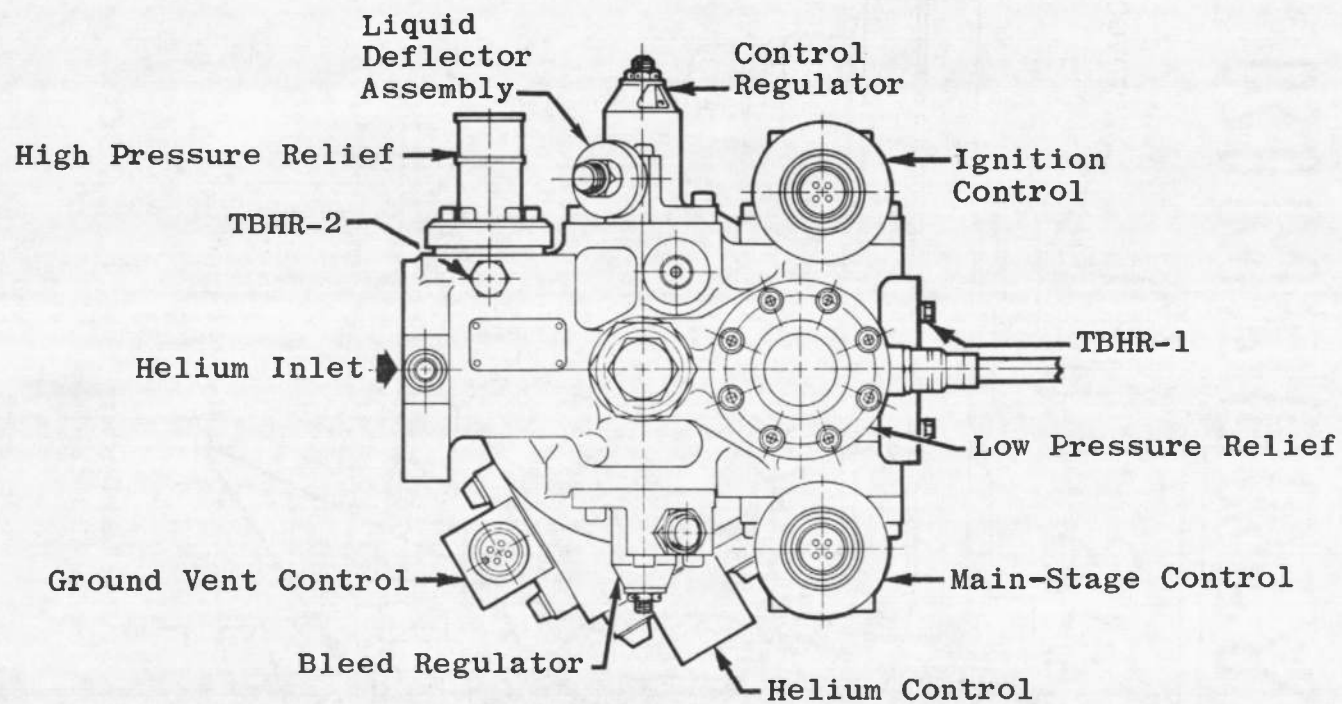
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

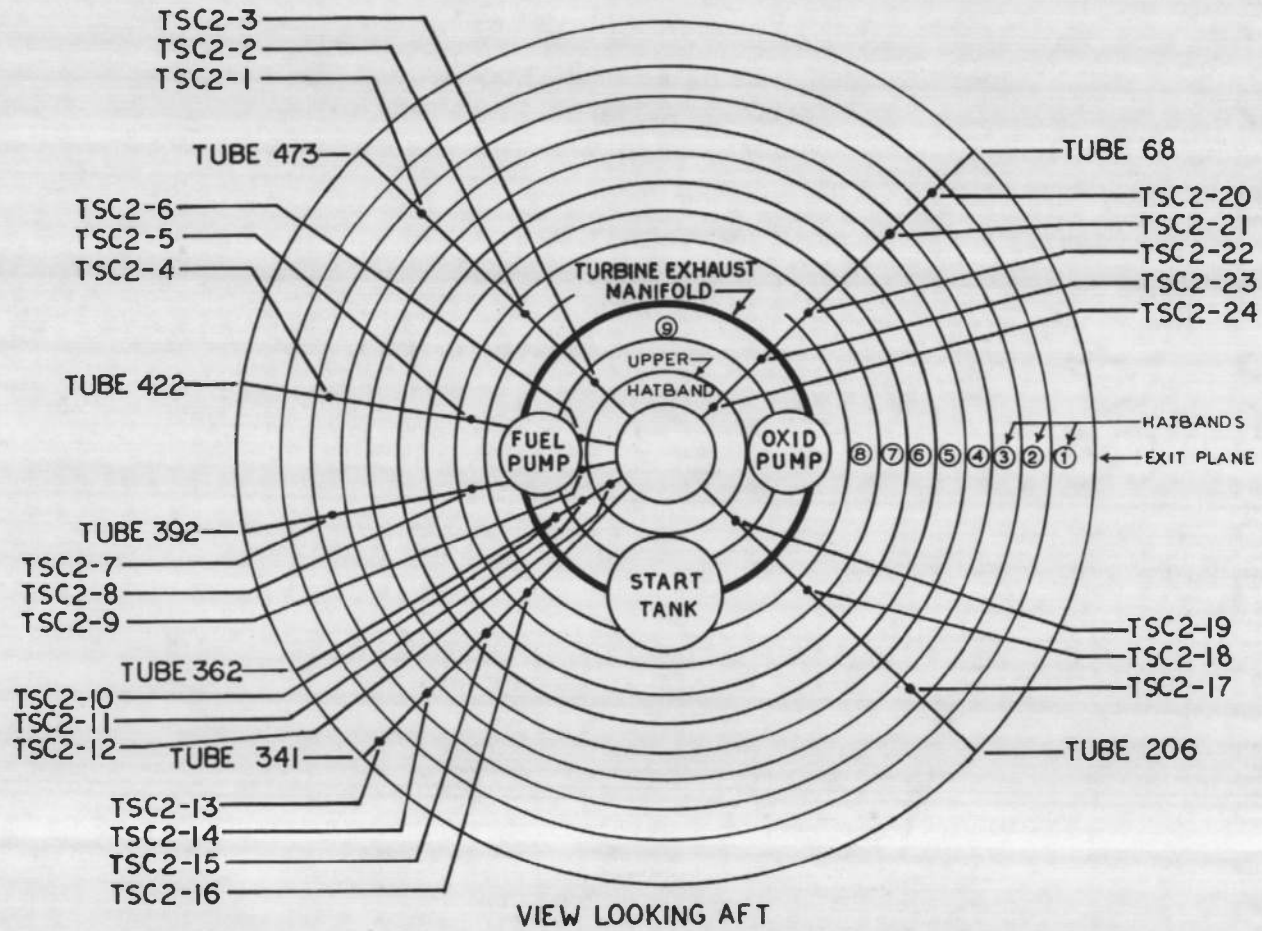


d. Start Tank Discharge Valve
Fig. III-1 Continued

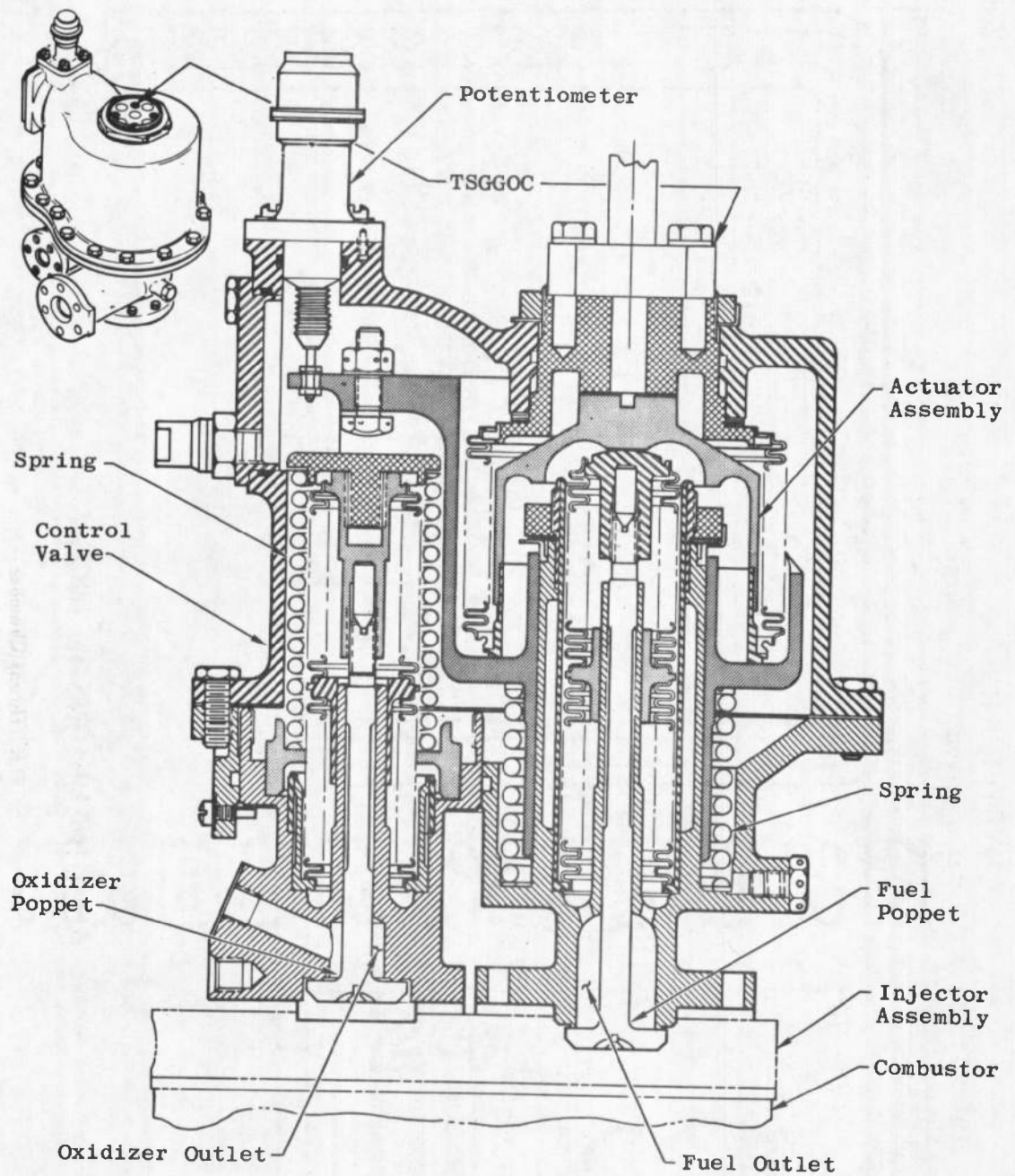


Top View

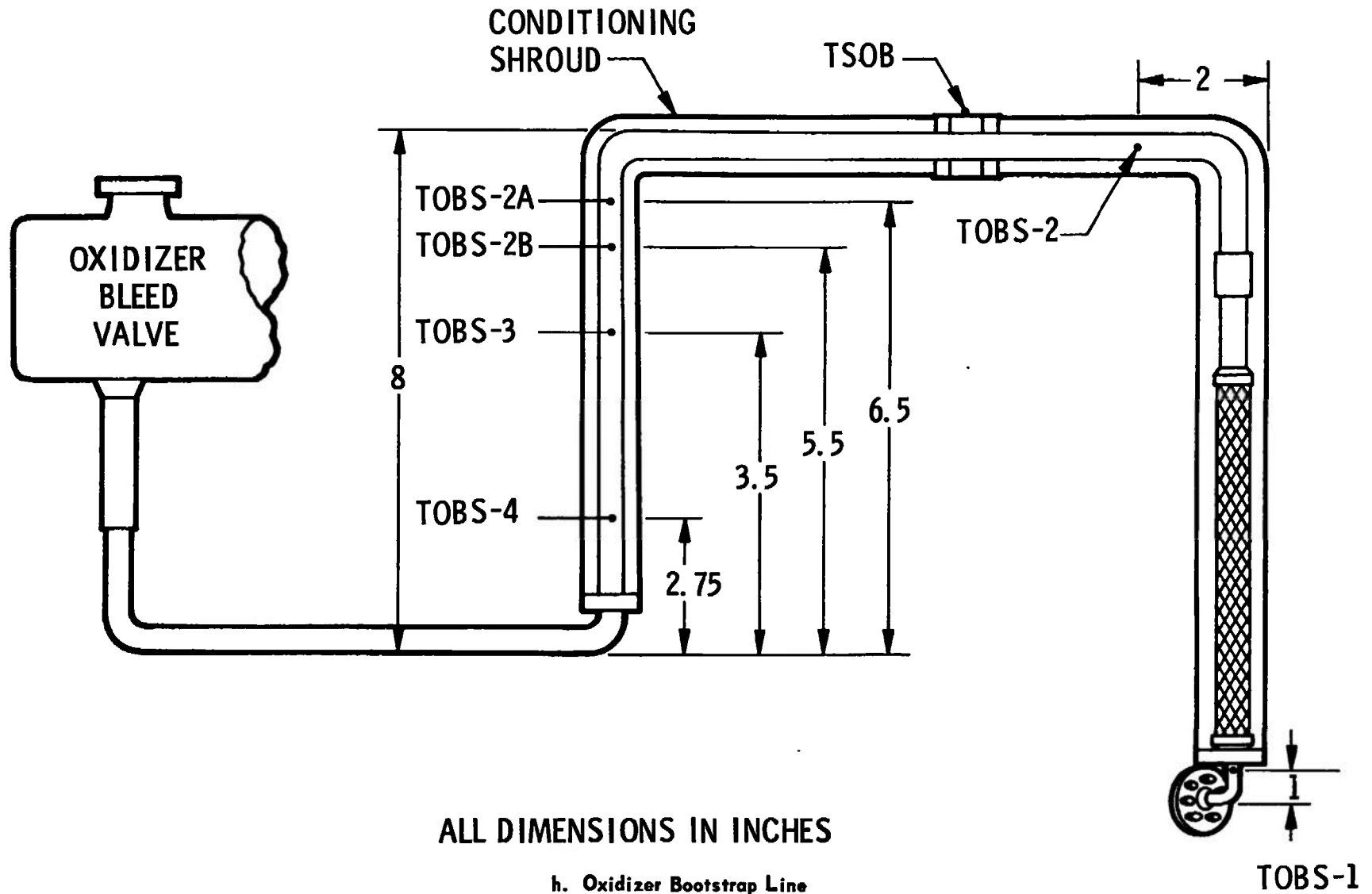
e. Helium Regulator
Fig. III-1 Continued

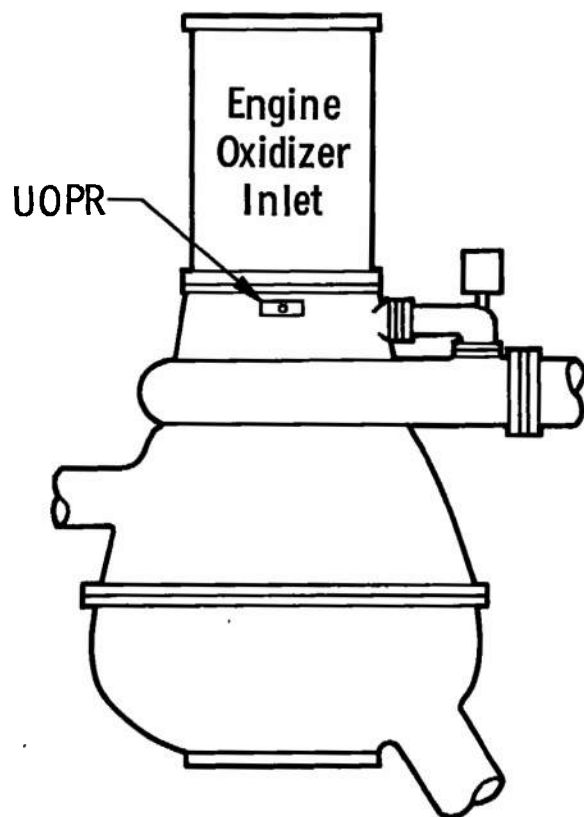


f. Thrust Chamber
Fig. III-1 Continued

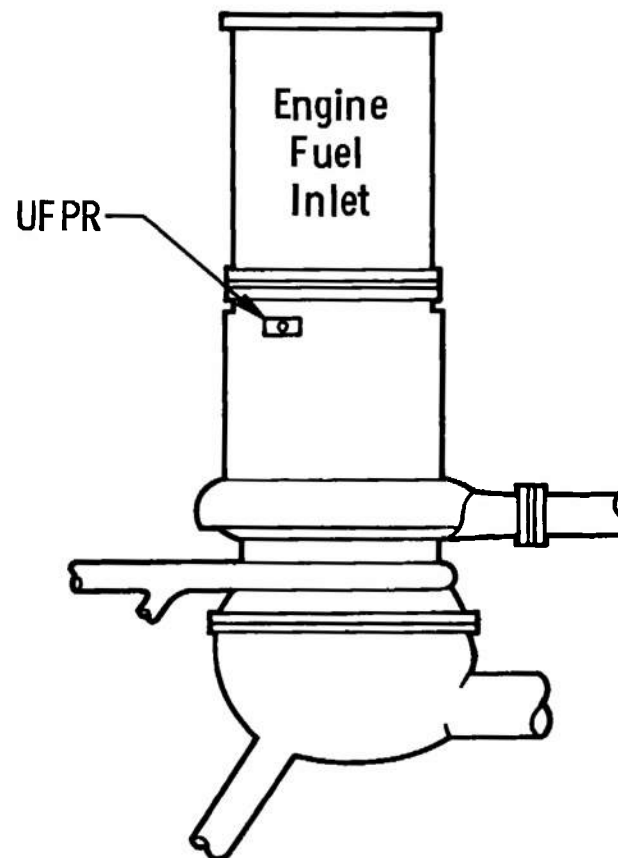


g. Gas Generator Control Valve
 Fig. III-1 Continued





View of Engine Looking North



i. Engine Inlets
Fig. III-1 Concluded

**APPENDIX IV
METHODS OF CALCULATIONS
(PERFORMANCE PROGRAM)**

TABLE IV-1

TEST MEASUREMENTS REQUIRED BY PERFORMANCE PROGRAM

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.

$$\begin{aligned}P_{IO} &= 39 \text{ psia} \\P_{IF} &= 30 \text{ psia} \\ \rho_{IO} &= 70.79 \text{ lb/ft}^3 \\ \rho_{IF} &= 4.40 \text{ lb/ft}^3 \\ T_{IO} &= -295.212^\circ\text{F} \\ T_{IF} &= -422.547^\circ\text{F}\end{aligned}$$

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

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

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

$$P_{RNC} = f(\beta_{NB}, \gamma_{H_2})$$

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

$$\gamma_{H_2}, M_{H_2} = f(T_{H_2R}, R_G)$$

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

$$K_{13} = 0.7854$$

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

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

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

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H_2R}}{D_{TEF}^4 M_{H_2}} \left(\frac{\gamma_{H_2}-1}{\gamma_{H_2}} \right) \right]^{\frac{\gamma_{H_2}}{\gamma_{H_2}-1}}$$

$$K_8 = 38.8983$$

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

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

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

$$B_2 = 3.2267$$

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

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

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

$$K_8 = 38.8983$$

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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14.	KEY WORDS	LINK A		LINK B		LINK C	
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	J-2 rocket engines altitude testing performance gas generator ignition characteristics fuel pump stall margin						
	1 Rocket motors -- J-2						
	2 " " -- Performance						
	3 " " -- Ignition						
	4 " " -- Fuel pump stall.						
	5 " " -- Ignition						
	16-3						