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FLIGHT SUPPORT TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1901-07 AND J4-1901-08)

J. N. Simpson and C. E. Pillow

ARO, Inc.

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
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FLIGHT SUPPORT TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1901-07 AND J4-1901-08)

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FOREWORD

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

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on August 21 and 27, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1901. The manuscript was submitted for publication on October 24, 1968.

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This technical report has been reviewed and is approved.

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ABSTRACT

Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during two test periods (J4-1901-07 and J4-1901-08) on August 21 and 27, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the Saturn V vehicle. The firings were accomplished at pressure altitudes between 93,000 and 102,000 ft at engine start. The primary objective of these firings was to evaluate transient gas generator temperatures under simulated engine first burn and restart conditions. Transient gas generator temperatures, particularly on engine restarts, were significantly reduced by utilizing a gas generator oxidizer supply line assembly which incorporated a geometrically different bellows section. The supply line assembly utilized on this series of firings had a 1.7 percent greater pressure drop at a flow of 3.5 lb_m/sec. The total accumulated firing duration for these tests was 163 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
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

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The ten firings reported herein were conducted during test periods J4-1901-07 and J4-1901-08 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to investigate engine start transients for both S-IVB first burn, 80-min orbital restarts, and an S-II start utilizing a 230,000-lb_f-thrust configuration engine. The firings were accomplished at pressure altitudes ranging from 93,000 to 102,000 ft (geometric pressure altitude, $\dot{Z}$, Ref. 1) at engine start. Engine components were conditioned to temperatures predicted for an S-IVB first burn, 80-min restart, or S-II start. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. The engine, as received at AEDC, was designated S/N J-2036-1 signifying that it is a rebuilt engine. In rebuilding, modifications were performed to configure the engine identically with engine S/N J-2072 and subsequent engines. 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.

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 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 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 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.
6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel

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

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

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

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

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

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

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

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

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

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

2.1.2 Oxidizer Supply Line to Gas Generator

The gas generator oxidizer supply line assembly (Fig. 3b) utilized on these firings was identical to the assembly utilized on the previous tests (Ref. 2), with the exception of the internal geometry of the flexible bellows section. An X-ray photograph of the bellows section manufactured by the Anaconda American Brass Company is shown in Fig. 3c. An X-ray photograph of the bellows section utilized on the previous tests is shown in Fig. 3d. This bellows section was manufactured by the Avica Corporation. The assemblies P/N 408710 and P/N NA5-260113 are hereafter referred to as the Anaconda and Avica lines, respectively.

2.1.3 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB and S-II 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, start tank discharge valve (firing 08A, only), oxidizer dome (firing 07E, only), and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct, oxidizer dome, and tubular-walled thrust chamber. Helium was routed externally over the start tank discharge valve. Main oxidizer valve conditioning was achieved by opening the prevalves and permitting propellants into the engine.

2.3 INSTRUMENTATION

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

Pressure measurements were made using strain-gage-type and capacitance-type (Photocon®, POJ-3) 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. 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 strain-gage-type pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and the Photocon pressure transducer.

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

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

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, start tank discharge valve (firing 08A, only), oxidizer dome (firing 07E, only), 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.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test periods J4-1901-07 and J4-1901-08 on August 21 and 27, 1968, respectively. The principle objective of these tests was to evaluate transient gas generator temperatures at simulated S-IVB engine first burn and restart conditions.

Initial altitude testing of engine S/N J-2036-1 had resulted in high gas generator transient temperatures (Refs. 2 and 5) relative to the temperatures experienced on the previously tested engine (S/N J-2047, Ref. 6, for typical results). Consequently, the engine manufacturer determined that there are internal dimensional differences between the Anaconda and Avica oxidizer supply lines to the gas generator. These tests were conducted to determine the effect on the engine start transient of the line differences.

The engine was operated 163 sec during tests 07 and 08. This resulted in a total accumulated operating time at AEDC on engine S/N J-2036-1 of 583 sec.

4.2 TEST OBJECTIVES AND RESULTS

Engine configuration changes, Tables III and IV, were performed before each of the tests of this series to obtain the desired objectives. The principle change was the gas generator oxidizer supply line assembly which was replaced before test 07.

In general, these firings investigated the effect of internal geometric differences (Section 2.1.2) of the gas generator oxidizer supply line assembly on transient gas generator temperature. The Anaconda line was utilized on tests 07 and 08; the Avica line was utilized in Ref. 2.

Test requirements and specific conditions at engine start for all firings are presented in Table VI. Start and shutdown operating times of principle engine valves are presented in Table VII. Calculated engine steady-stage performance data are shown in Table VIII. Primary engine starting requirements are shown in Fig. 8.

The following sections will consist of discussions and analysis of selected firings. The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2.1 Firing J4-1901-07A

4.2.1.1 Objectives

Objectives were to perform an S-IVB engine first burn to evaluate augmented spark igniter operation and gas generator transient temperature utilizing high start tank energy, minimum fuel pump inlet pressure, and coldest expected thrust chamber preconditioning.

4.2.1.2 Results

The firing of 32.6-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements except for start tank pressure (17 psi below minimum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 9. Engine start and shutdown transients are shown in Fig. 10. Fuel pump start transient performance is shown in Fig. 11. Engine ambient and combustion chamber pressure histories are shown in Fig. 12. Pressure altitude at engine start was 93,000 ft.

Ignition was detected in the augmented spark igniter 172 msec after engine start. Maximum gas generator transient temperature was 1480°F (first peak). Oxidizer dome prime (chamber pressure = 100 psia) occurred at t_0 + 0.982 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 0.982 sec, and a chamber pressure of 550 psia was attained at t_0 + 1.958 sec. The scheduled propellant utilization valve excursion (null to close) was completed at t_0 + 12.0 sec. Approximately 50 msec of excessive engine vibration (VSC) occurred, beginning at t_0 + 0.972 sec.

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 10). These pressure transients caused an indicated fuel pump stall condition (Fig. 11), but main-stage operation was successfully attained.

4.2.2 Firing J4-1901-07B

4.2.2.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperature with maximum start tank energy.

4.2.2.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 29 min after firing 07A and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 13. Engine start and shutdown transients are shown in Fig. 14. Fuel pump start transient performance is shown in Fig. 15. Engine ambient and combustion chamber pressure histories are shown in Fig. 16. Pressure altitude at engine start was 99,000 ft.

Maximum transient gas generator temperatures were 1210°F (first peak) and 1510°F (second peak). Oxidizer dome prime occurred at t_0 + 0.944 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 1.112 sec, and a chamber pressure of 550 psia was attained at t_0 + 2.050 sec. The propellant utilization valve remained full open as scheduled throughout this firing.

4.2.3 Firing J4-1901-07C

4.2.3.1 Objective

The objective was to perform an S-IVB engine first burn to evaluate augmented spark igniter operation and gas generator transient temperature utilizing low start tank energy, minimum fuel pump inlet pressure, and coldest expected thrust chamber preconditioning.

4.2.3.2 Results

The firing of 32.6-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 17. Engine start and shutdown transients are shown in Fig. 18. Fuel pump start transient performance is shown in Fig. 19. Engine ambient and combustion chamber pressure histories are shown in Fig. 20. Pressure altitude at engine start was 98,000 ft.

Ignition was detected in the augmented spark igniter 172 msec after engine start. Maximum gas generator transient temperature was 1460°F (first peak). Oxidizer dome prime occurred at t_0 + 0.996 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 0.993 sec, and a chamber pressure of 550 psia was attained at t_0 + 1.947 sec. The scheduled propellant utilization valve excursion (null to close) was completed at t_0 + 11.4 sec. Approximately 35 msec of excessive engine vibration (VSC) occurred at oxidizer dome prime.

4.2.4 Firing J4-1901-07D

4.2.4.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperature with maximum start tank energy.

4.2.4.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 27 min after firing 07C and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 21. Engine start and shutdown transients are shown in Fig. 22. Fuel pump start transient performance is shown in Fig. 23. Engine ambient and combustion chamber pressure histories are shown in Fig. 24. Pressure altitude at engine start was 99,000 ft.

Maximum transient gas generator temperatures were 1400°F (first peak) and 1510°F (second peak). Oxidizer dome prime occurred at t_0 + 0.958 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 1.088 sec, and a chamber pressure of 550 psia was attained at t_0 + 2.050 sec. The propellant utilization valve remained full open as scheduled throughout this firing.

4.2.5 Firing J4-1901-07E

4.2.5.1 Objective

The objective was to perform a partial transition test to evaluate the effect of a prechilled oxidizer dome on the engine start transient.

4.2.5.2 Results

The firing of 1.3-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements except for oxidizer pump inlet temperature (1.5°F above maximum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 25. Engine start and shutdown transients are shown in Fig. 26. Fuel pump start transient performance is shown in Fig. 27. Engine ambient and combustion chamber pressure histories are shown in Fig. 28. Pressure altitude at engine start was 101,000 ft.

Ignition was detected in the augmented spark igniter 240 msec after engine start. Maximum gas generator transient temperature was 800°F (first peak). Oxidizer dome prime (initial) occurred at t_0 + 0.967 sec, and initial movement of the second stage of the main oxidizer valve occurred at t_0 + 0.986 sec. The propellant utilization valve remained in the null position as scheduled throughout this firing. Approximately 43 msec of excessive engine vibration (VSC) occurred, beginning at t_0 + 0.952 sec; a second period of 158 msec of excessive engine vibration occurred, beginning at t_0 + 1.117 sec and continuing until shortly after engine cutoff signal (t_0 + 1.250 sec).

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 26). These pressure transients were similar to those experienced on firing 07A, except the initial chamber pressure peak was not as great as on firing 07A. The initial chamber pressure peak on firing 07E resulted in a minimum fuel pump stall margin (Fig. 27) of 1100 gpm at approximately 13,000 rpm, whereas an indicated stall condition occurred during firing 07A.

4.2.6 Firing J4-1901-08A

4.2.6.1 Objective

The objective was to perform an engine start at simulated S-II engine conditions to evaluate the operation of the augmented spark igniter with maximum fuel pump inlet pressure and warmest expected thrust chamber preconditioning.

4.2.6.2 Results

The firing of 32.6-sec duration following a 1.0-sec fuel lead was conducted satisfying test requirements, except for start tank pressure

(15 psi below minimum requested value) and oxidizer pump inlet pressure (0.8 psi above maximum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 29. Engine start and shutdown transients are shown in Fig. 30. Fuel pump start transient performance is shown in Fig. 31. Engine ambient and combustion chamber pressure histories are shown in Fig. 32. Pressure altitude at engine start was 90,000 ft.

Ignition was detected in the augmented spark igniter 504 msec after engine start. Maximum gas generator transient temperature was 930°F (first peak). Oxidizer dome prime occurred at t_0 + 0.997 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 0.975 sec, and a chamber pressure of 550 psia was attained at t_0 + 1.975 sec. The scheduled propellant utilization valve excursion (null to close) was completed at t_0 + 13.3 sec.

This firing was conducted at essentially the same test conditions as was S-II firing 02D (Ref. 5), during which ignition was not detected in the augmented spark igniter. However, the depth of the ignition detect probe into the combustion chamber of the augmented spark igniter had been increased about 0.024 in. between these firings. Ignition detection on firing 08A indicates that combustion probably occurred in the augmented spark igniter on firing 02D but was not satisfactorily detected.

4.2.7 Firing J4-1901-08B

4.2.7.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperatures. This firing repeated firing 07B.

4.2.7.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 28 min after firing 08A and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 33. Engine start and shutdown transients are shown in Fig. 34. Fuel pump start transient performance is shown in Fig. 35. Engine ambient and combustion chamber pressure histories are shown in Fig. 36. Pressure altitude at engine start was 102,000 ft.

Maximum transient gas generator temperatures were 1210°F (first peak) and 1460°F (second peak). Oxidizer dome prime occurred at t_0 + 0.949 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 1.093 sec, and a chamber pressure of 550 psia was attained at t_0 + 2.060 sec. The propellant utilization valve remained full open as scheduled throughout this firing.

Firing 08B, conducted at the same starting conditions as firing 07B, yielded essentially identical start transient results. Maximum transient gas generator temperatures (first peak) agreed; second peak temperatures differed by only 50°F. The time required for chamber pressure to attain 550 psia differed by less than 10 msec.

4.2.8 Firing J4-1901-08C

4.2.8.1 Objective

The objective was to perform an S-IVB engine first burn to evaluate engine start transient at maximum start tank energy and warmest expected thrust chamber preconditioning.

4.2.8.2 Results

The firing of 32.6-sec duration, following a 3.0-sec fuel lead, was conducted which satisfied test requirements except for start tank pressure (23 psi below minimum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 37. Engine start and shutdown transients are shown in Fig. 38. Fuel pump start transient performance is shown in Fig. 39. Engine ambient and combustion chamber pressure histories are shown in Fig. 40. Pressure altitude at engine start was 100,000 ft.

Maximum gas generator transient temperatures were 1380°F (first peak) and 1420°F (second peak). Oxidizer dome prime occurred at t_0 + 0.962 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 0.989 sec, and a chamber pressure of 550 psia was attained at t_0 + 1.850 sec. The scheduled propellant utilization valve excursion (null to close) was completed at t_0 + 6.6 sec (inadvertently premature by 3.4 sec). Approximately 24 msec of excessive engine vibration occurred at oxidizer dome prime.

4.2.9 Firing J4-1901-08D

4.2.9.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate augmented spark igniter operation and gas generator transient temperature with maximum start tank energy.

4.2.9.2 Results

The firing of 7.6-sec duration, following a 7.9-sec fuel lead, was conducted 31 min after firing 08C and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 41. Engine start and shutdown transients are shown in Fig. 42. Fuel pump start transient performance is shown in Fig. 43. Engine ambient and combustion chamber pressure histories are shown in Fig. 44. Pressure altitude at engine start was 100,000 ft.

Ignition was detected in the augmented spark igniter 240 msec after engine start. Maximum gas generator transient temperatures were 1200°F (first peak) and 1460°F (second peak). Oxidizer dome prime occurred at t_0 + 0.962 sec, initial movement of the second stage of the main oxidizer valve occurred at t_0 + 1.097 sec, and a chamber pressure of 550 psia was attained at t_0 + 2.033 sec. The propellant utilization valve remained full open as scheduled throughout this firing.

4.2.10 Firing J4-1901-08E

4.2.10.1 Objective

The objective was to perform a partial transition test to evaluate augmented spark igniter operation and gas generator transient temperature utilizing minimum fuel pump inlet pressure and coldest expected thrust chamber preconditioning.

4.2.10.2 Results

The firing of 1.3-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 45. Engine start and shutdown transients are shown in Fig. 46. Fuel pump start transient performance is shown in Fig. 47. Engine ambient and combustion chamber pressure histories are shown in Fig. 48. Pressure altitude at engine start was 102,000 ft.

Ignition was detected in the augmented spark igniter 165 msec after engine start. Maximum gas generator transient temperature was 1520°F (first peak). Oxidizer dome prime occurred at t_0 + 0.803 sec, and initial movement of the second stage of the main oxidizer valve occurred at t_0 + 1.037 sec. The propellant utilization valve remained in the null position as scheduled throughout this firing.

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 46). These pressure transients were much earlier (about 170 msec) than those experienced on firing 07A, although the initial chamber pressure peak was not as great as on firing 07A. The minimum fuel pump stall margin (Fig. 47) was 1200 gpm at approximately 13, 600 rpm on firing 08E.

4.3 GAS GENERATOR OXIDIZER SUPPLY LINE EFFECT

The effect of internal geometric differences of the gas generator oxidizer supply line assembly on the transient gas generator temperature and steady-state performance is discussed in the following sections. The Anaconda line was utilized on tests 07 and 08 (P/N 408710, S/N 3729063); the Avica line was utilized on tests 03 and 04 (P/N NA5-260113, S/N 045, Ref. 2).

4.3.1 Transient Performance

Specific test conditions at engine start for the S-IVB 80-min orbital coast restart simulations conducted during tests 03 and 04 (three firings) compared closely with S-IVB 80-min orbital coast restart simulations conducted during tests 07 and 08 (three firings). Tabulated below are the ranges of test conditions attained.

Tests	J4-1901-03 and 04	J4-1901-07 and 08
Gas Generator Oxidizer Supply Line Assembly (P/N)	Avica NA5-260113	Anaconda 408710
Fuel Pump Inlet Pressure, psia	27.0 to 40.8	26.7 to 41.0
Fuel Pump Inlet Temperature, °F	-421.1 to -421.3	-421.0 to -421.3
Oxidizer Pump Inlet Pressure, psia	45.0 to 45.8	45.0 to 45.5
Oxidizer Pump Inlet Temperature, °F	-294.8 to -295.2	-294.7 to -295.2
Start Tank Pressure, psia	1291 to 1297	1298 to 1303

Tests	J4-1901-03 and 04	J4-1901-07 and 08
Start Tank Temperature, °F	-262 to -268	-265 to -269
Average Thrust Chamber Temperature, °F, at Engine Start	33 to 45	22 to 29
Average Thrust Chamber Temperature, °F, at t_0	-262 to -349	-277 to -339
Average Turbine System Temperature, °F	296 to 306	293 to 305

The transient gas generator temperatures of tests J4-1901-07 and 08 were combined to form an envelope and are compared with a similar envelope for tests J4-1901-03 and 04 in Fig. 49. The envelope with the lower level of magnitude corresponded with the Anaconda line. This indicated that the Anaconda line reduced the maximum gas generator initial temperature peak about 790°F and the maximum second temperature peak about 680°F.

4.3.2 Steady-State Performance

Gas generator oxidizer line resistance (from the engine bleed valve to gas generator chamber pressure) was calculated for these two sets of firings, normalized to a standard oxidizer flow rate of 3.5 lb_m/sec. These data indicate the Anaconda line resistance (252.1 psid) was 1.7 percent greater than the Avica line resistance.

Steady-state performance data for firings 07A, 07C, 08A, and 08C were calculated (as shown in Appendix IV) and are presented in Table VIII. Selected calculated parameters from the normalized performance were averaged and are compared below to average normalized performance reduced from firings 03A, 03C, 04C, 06A, and 06C (Ref. 2).

Tests	J4-1901-03 through 06	J4-1901-07 and 08
Gas Generator Oxidizer Line	Avica	Anaconda
Thrust, lb_f	227,300	225,500 (-0.8 percent)
Total Engine Weight Flow, lb_m/sec	537.4	534.8 (-0.5 percent)
Total Gas Generator Weight Flow, lb_m/sec	6.99	6.92 (-1.0 percent)

Apparently the engine steady-state operating point was slightly shifted by the change in the gas generator oxidizer supply line assembly which occurred between these sets of firings (as indicated, engine thrust decreased 0.8 percent). The slight performance shift is attributed to the increase in resistance of the gas generator oxidizer supply line.

4.4 POST-TEST INSPECTION

Inspection after the completion of tests J4-1901-07 and 08 revealed no apparent engine component damage.

SECTION V
SUMMARY OF RESULTS

The results of testing the J-2 rocket engine (S/N J-2036-1) in Propulsion Engine Test Cell J-4 during test periods J4-1901-07 and 08 conducted on August 21 and 27, 1968, respectively, are summarized as follows:

1. The gas generator oxidizer supply line assembly (Anaconda) utilized for this series of S-IVB 80-min orbital coast restart simulations reduced the maximum gas generator initial temperature peak about 790°F and the maximum second peak about 680°F, when compared with the tests utilizing the Avica line (Ref. 2). Tne Anaconda line resistance (252.1 psid) was 1.7 percent greater than the Avica line resistance at a flow rate of 3.5 lb_m/sec.
2. Ignition was detected in the augmented spark igniter 504 msec after engine start for an S-II simulation (firing 08A) with maximum fuel pump inlet pressure and warmest expected thrust chamber preconditioning. Ignition was not detected during a previous test (J4-1901-02, Ref. 5) conducted at essentially the same starting conditions as firing 08A. However, the ignition detect probe was 0.024 in. deeper into the combustion chamber of the augmented spark igniter for firing 08A.
3. Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence of firings 07A, 07E, and 08E. These pressure transients caused an indicated fuel pump stall condition during firing 07A, but main-stage operation was successfully attained.

4. The firing with a prechilled oxidizer dome (firing 07E) was characterized by excessive engine vibration (VSC) for 43 msec beginning at t_0 + 0.952 and a second period of 158 msec beginning at t_0 + 1.117 sec, continuing until shortly after engine cutoff signal (t_0 + 1.250 sec).

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

2. Vetter, N. R. "Flight Support Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1901-03 through J4-1901-06)." AEDC-TR-68-238, December 1968.

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

4. Test Facilities Handbook (7th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.

5. Counts, H. J., Jr., and Kunz, C. H. "Altitude Developmental and Flight Support Testing of the J-2 Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-42 through J4-1901-02)." AEDC-TR-68-223, November 1968.

6. Franklin, D. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4)(Tests J4-1801-34, J4-1801-35, and J4-1801-36)." AEDC-TR-68-176, October 1968.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHOD OF CALCULATION (PERFORMANCE PROGRAM)

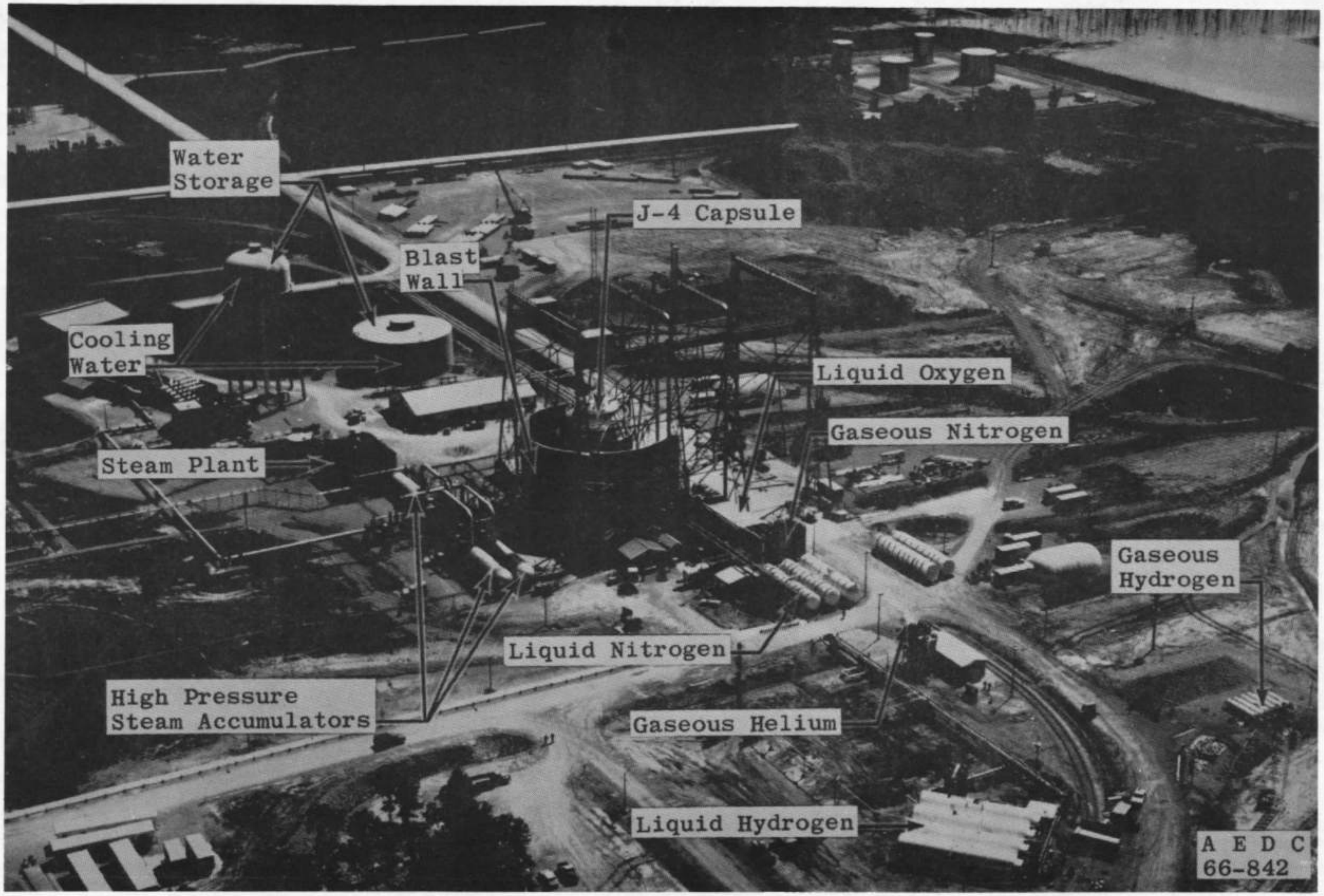


Fig. 1 Test Cell J-4 Complex

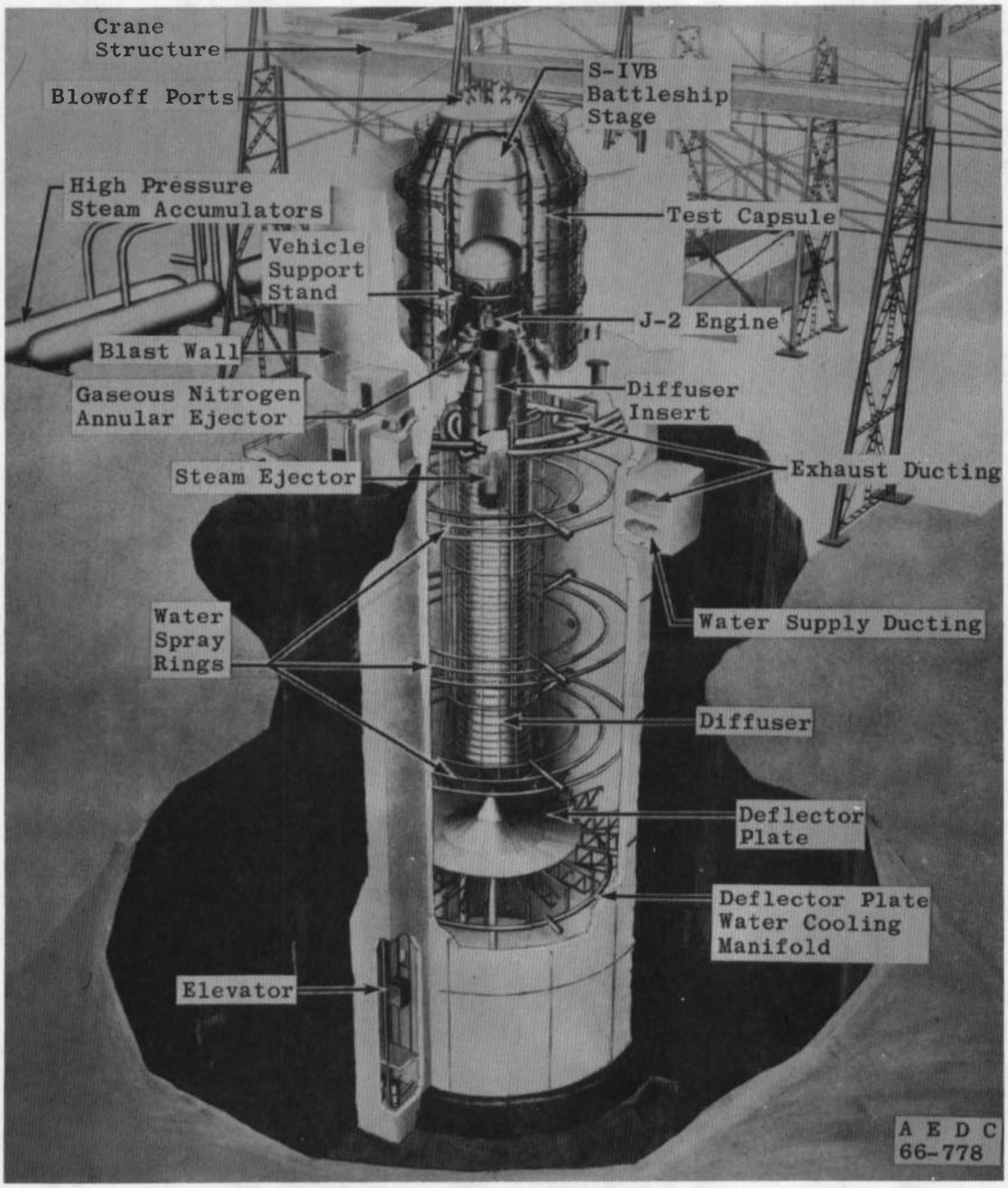
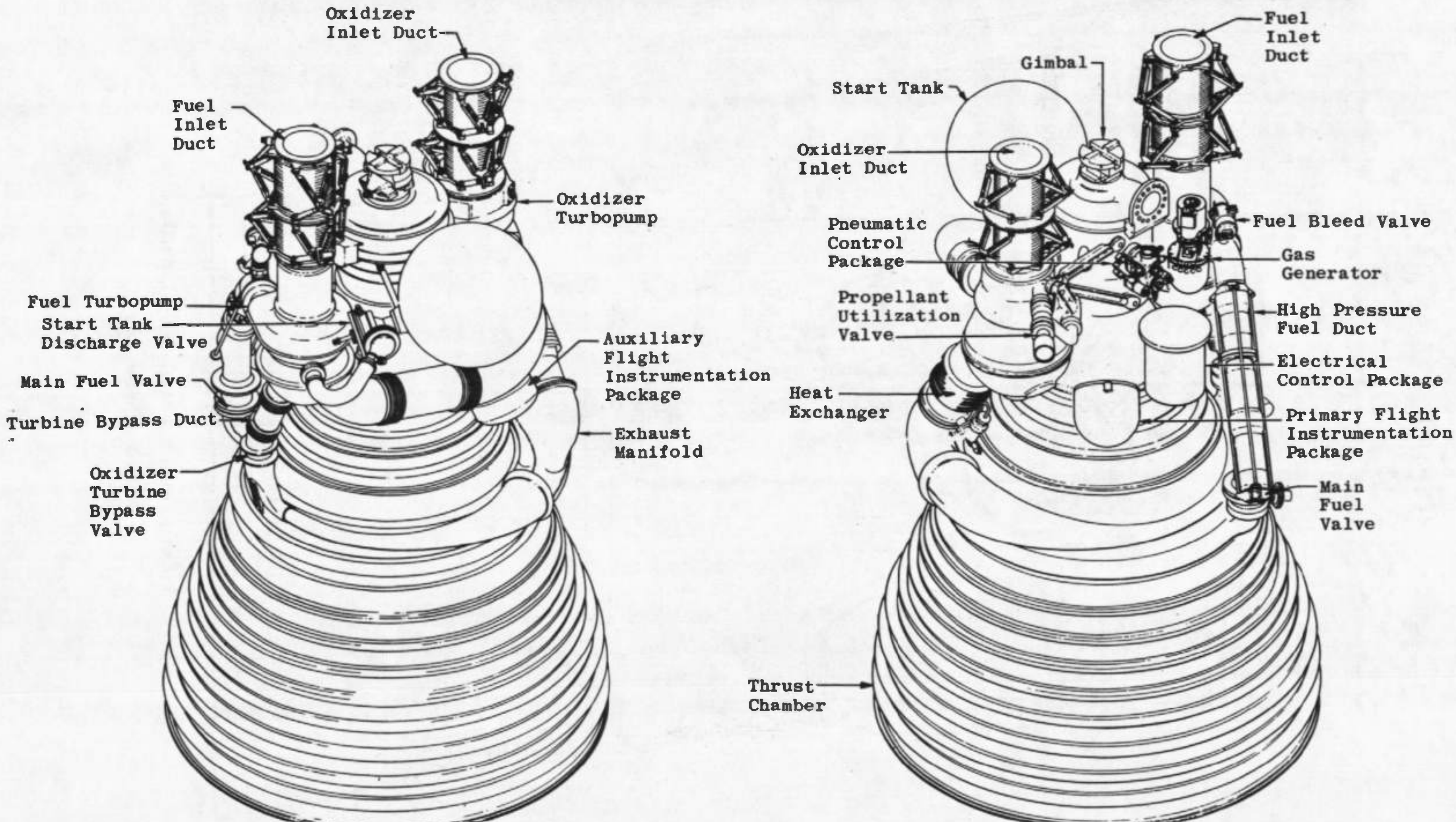
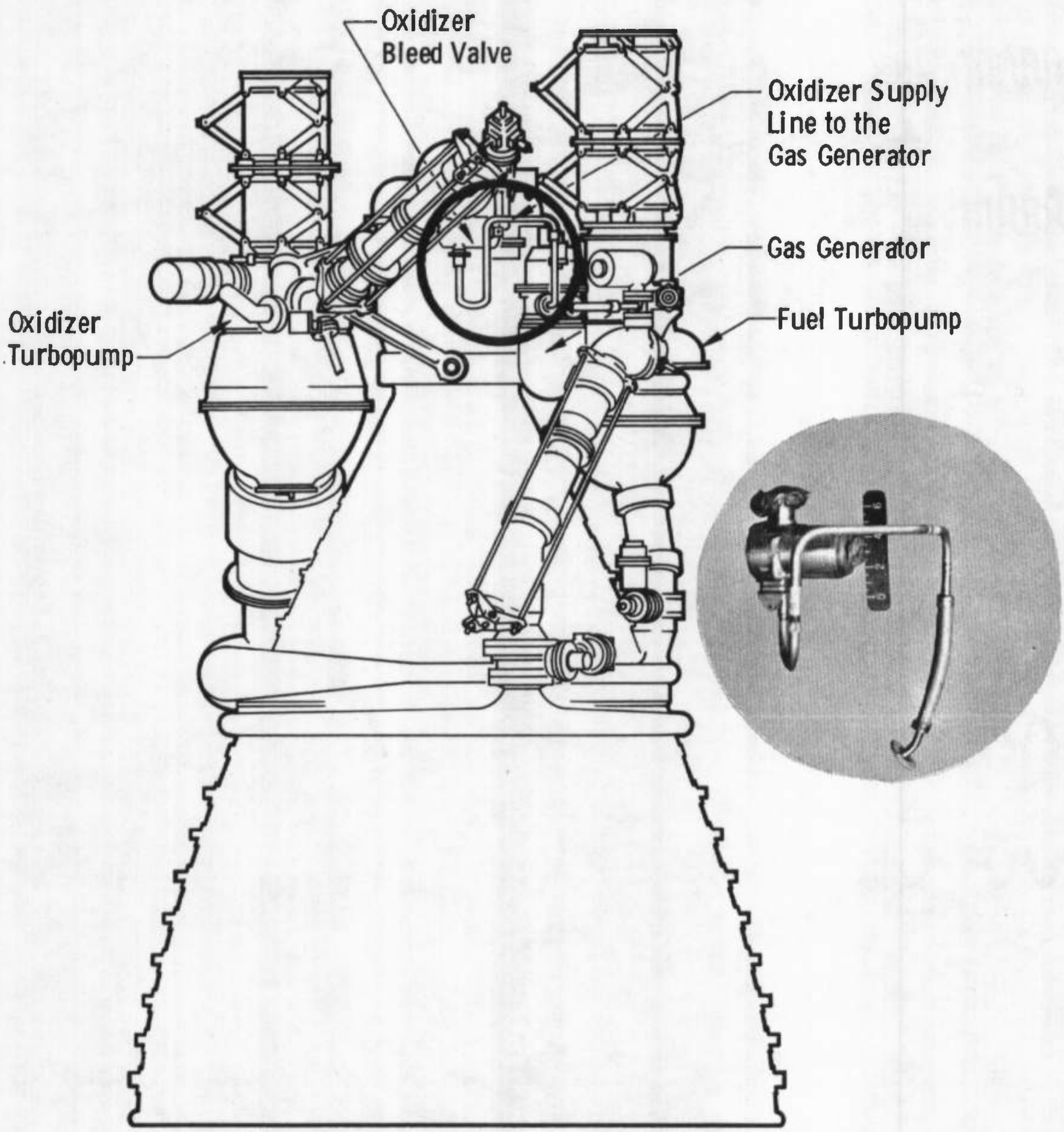


Fig. 2 Test Cell J-4, Artist's Conception

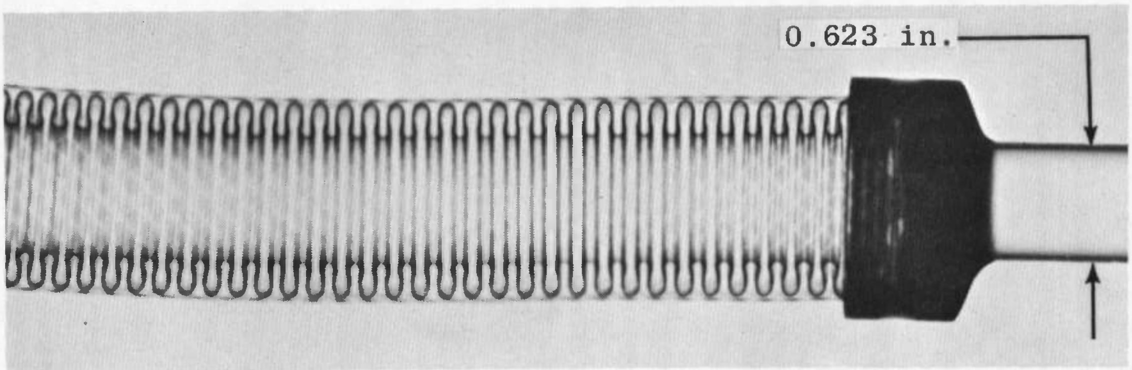


a. Major Engine Components

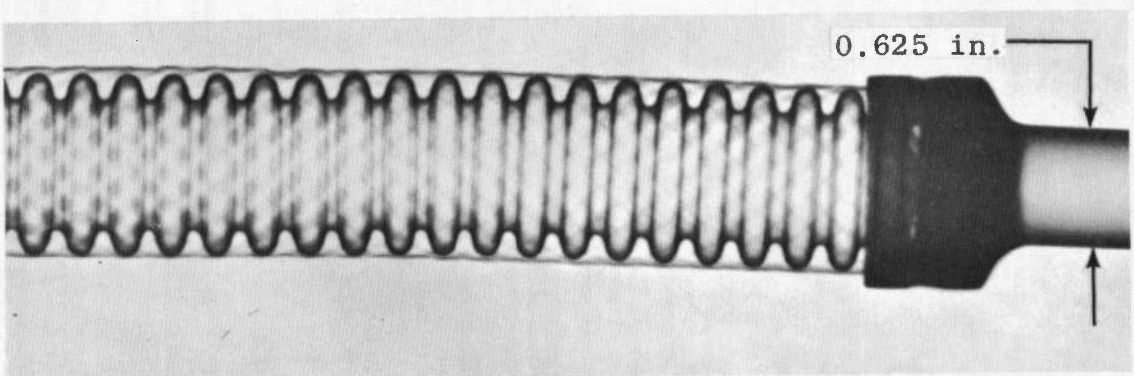
Fig. 3 Engine Details



b. Gas Generator Oxidizer Supply Line Detail
Fig. 3 Continued



c. Gas Generator Oxidizer Supply Line Assembly, Anaconda (P/N 408710, S/N 3729063)



d. Gas Generator Oxidizer Supply Line Assembly, Avica (P/N NA5-260113, S/N 045)
Fig. 3 Concluded

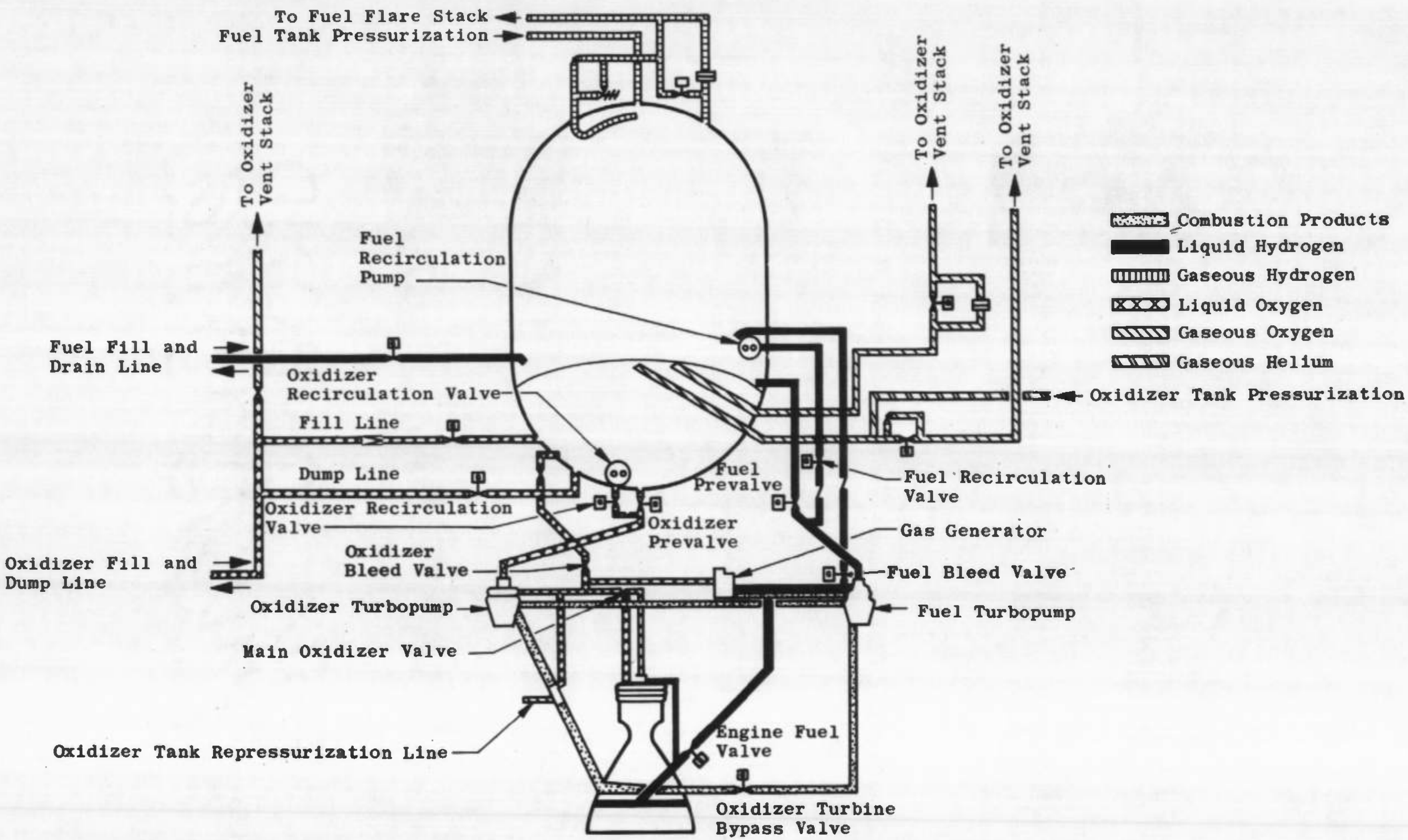


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

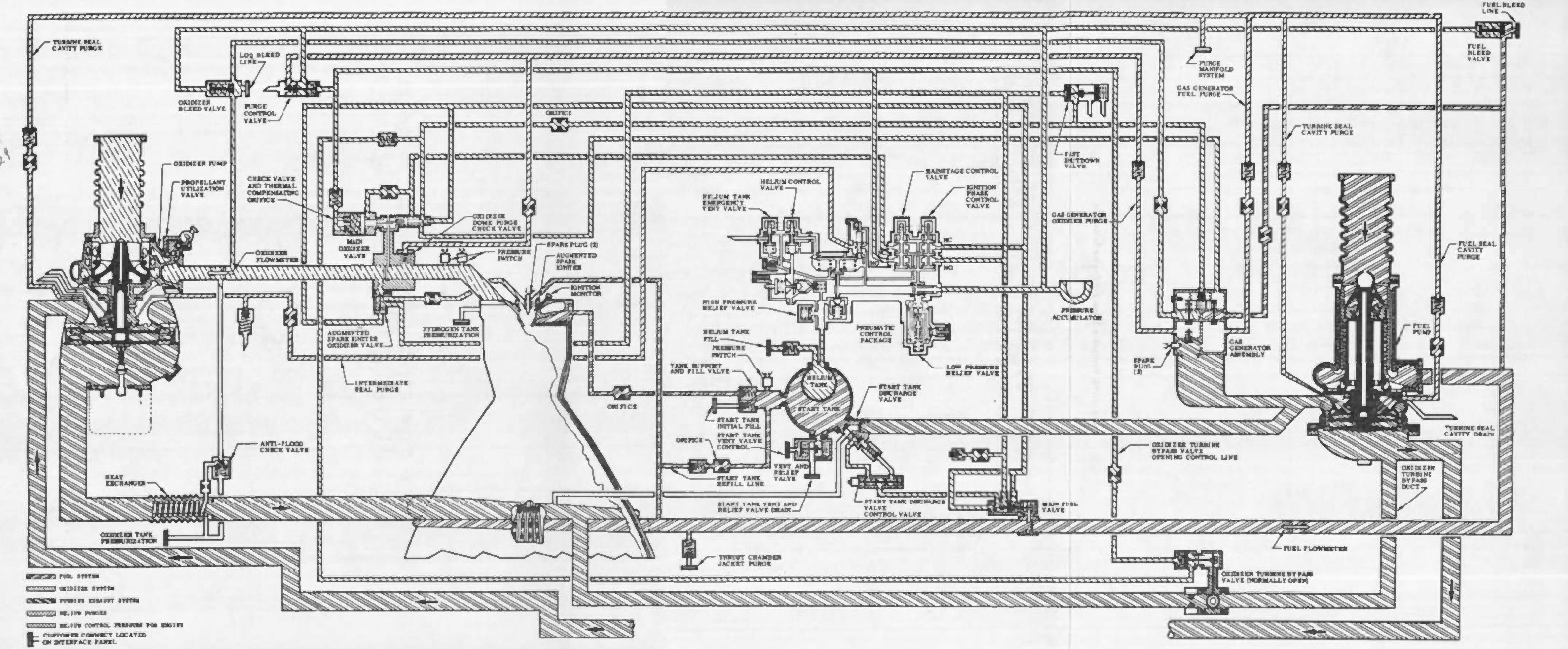


Fig. 5 Engine Schematic

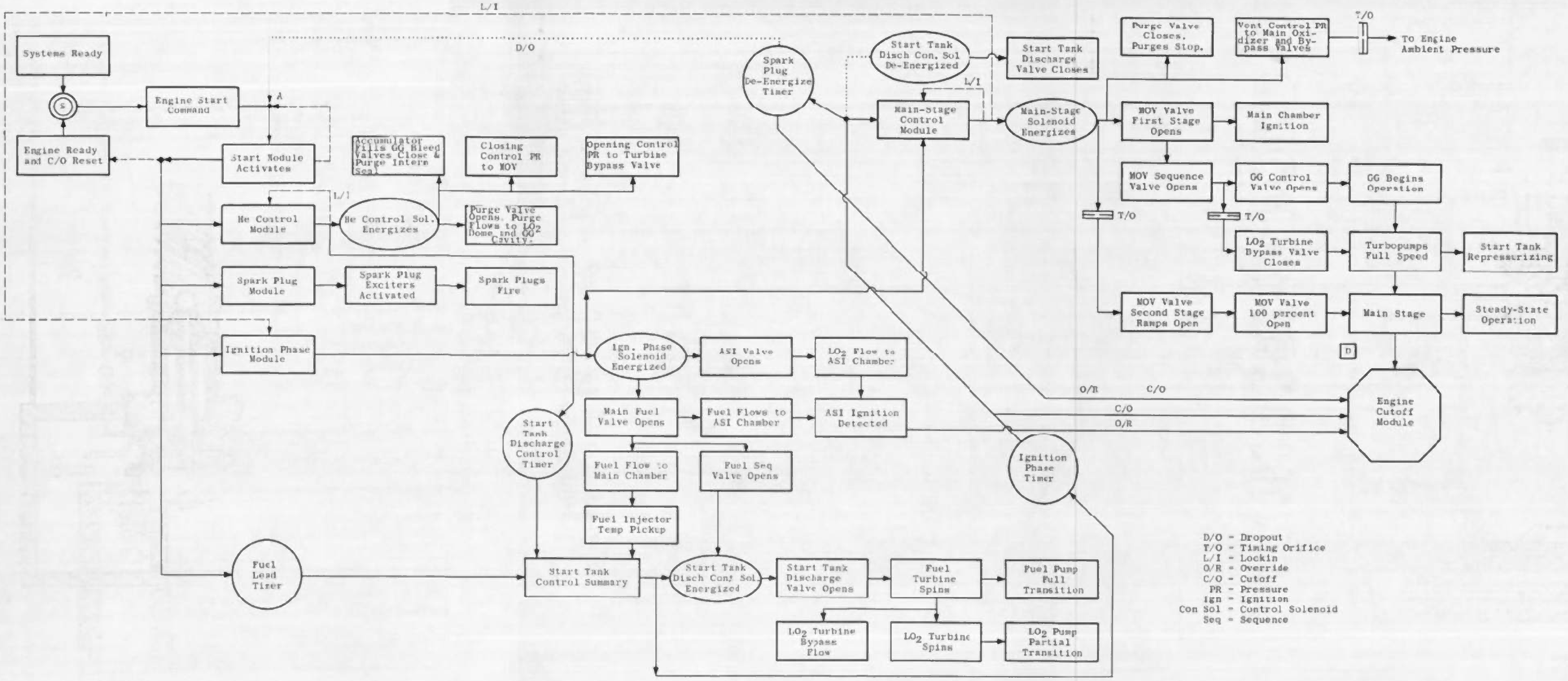
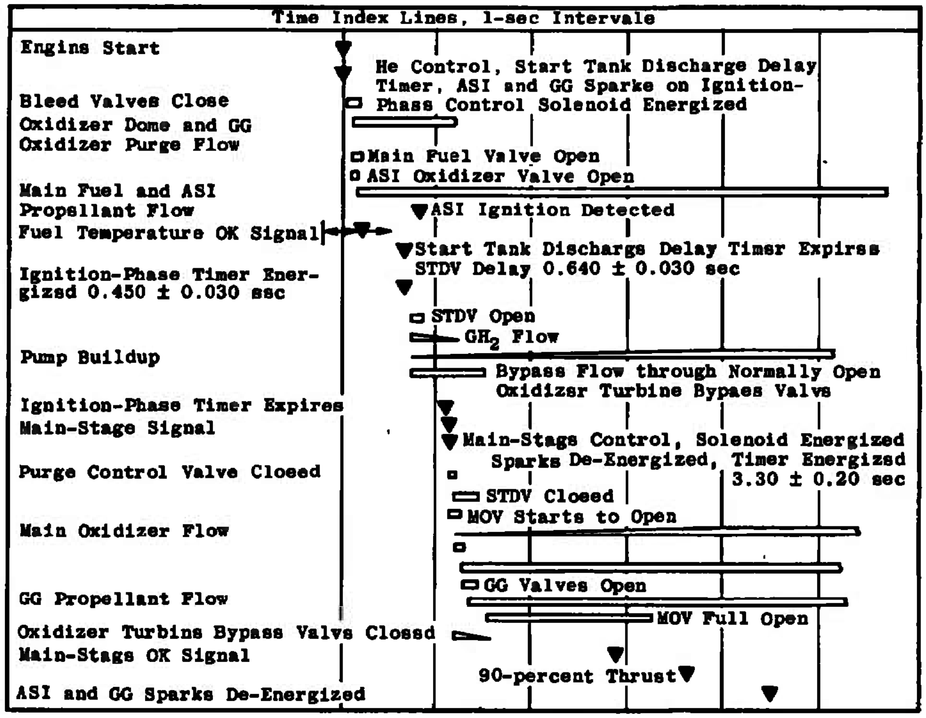
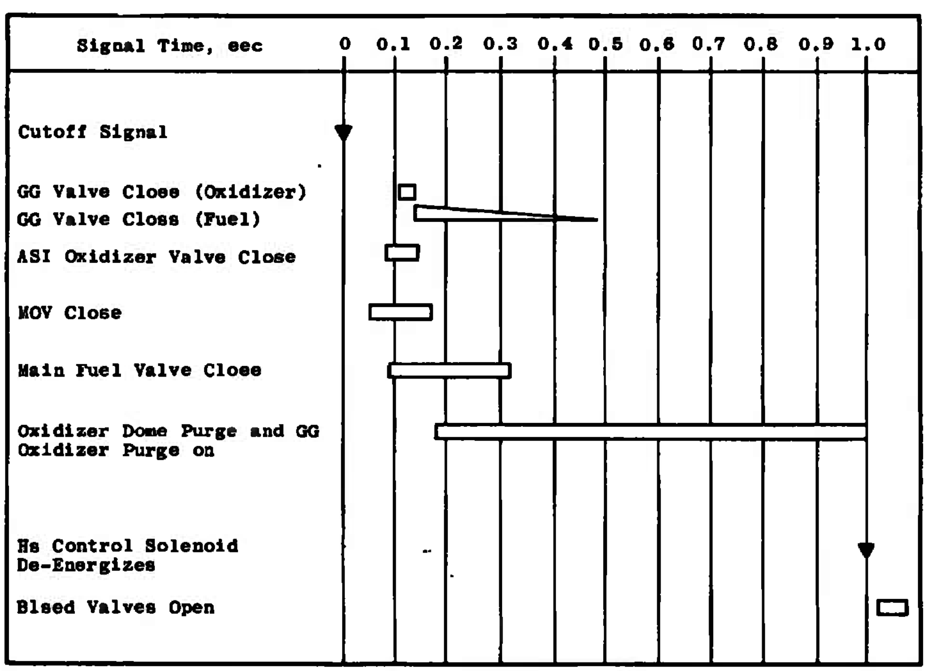


Fig. 6 Engine Start Logic Schematic

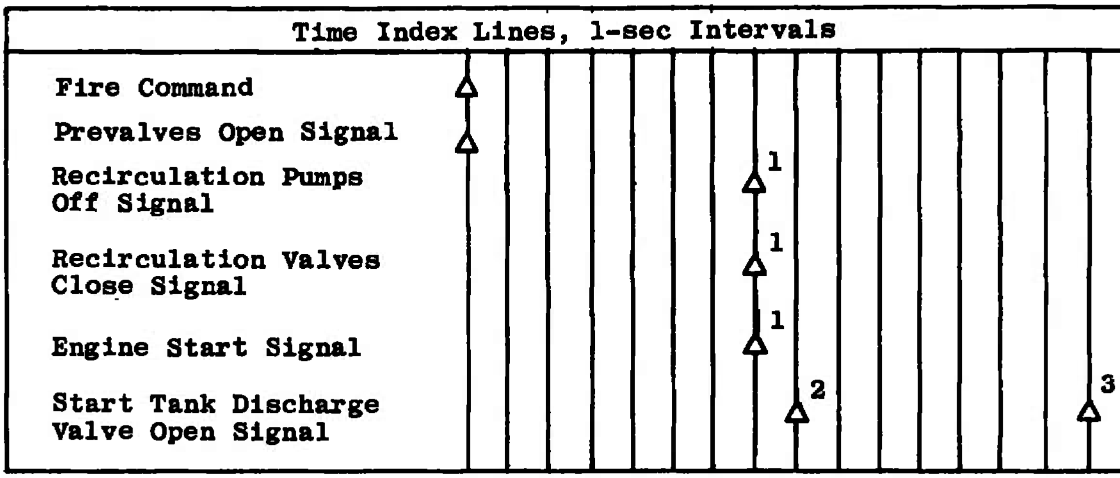


a. Start Sequence



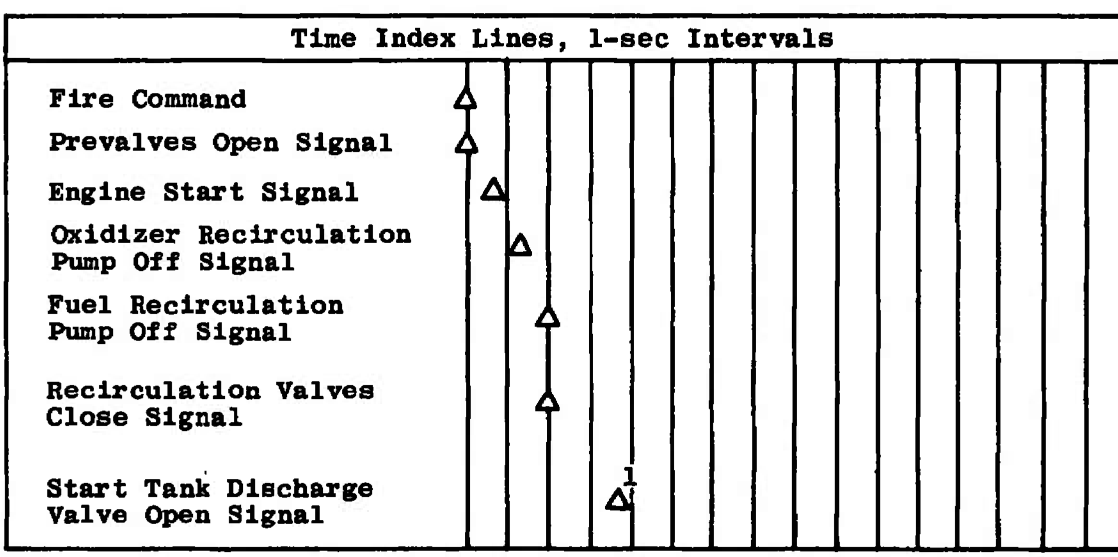
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



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

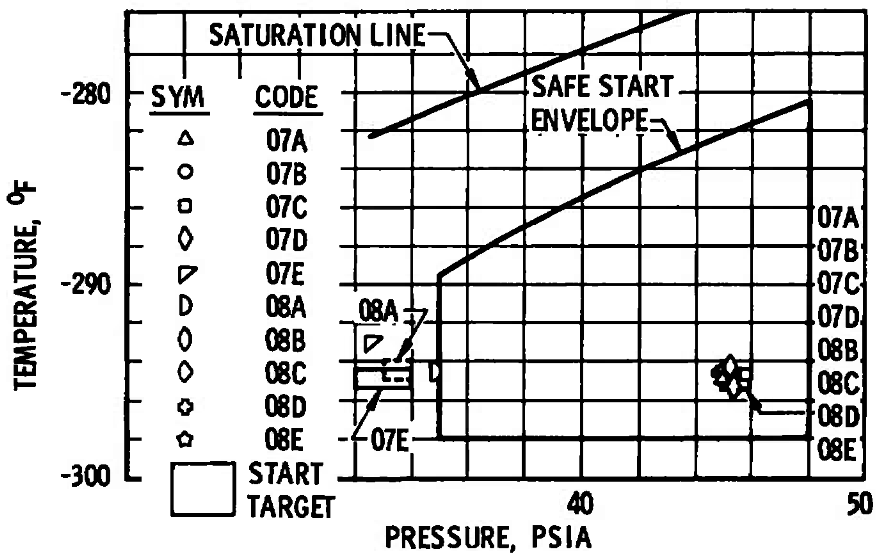
c. "Normal" Start Sequence



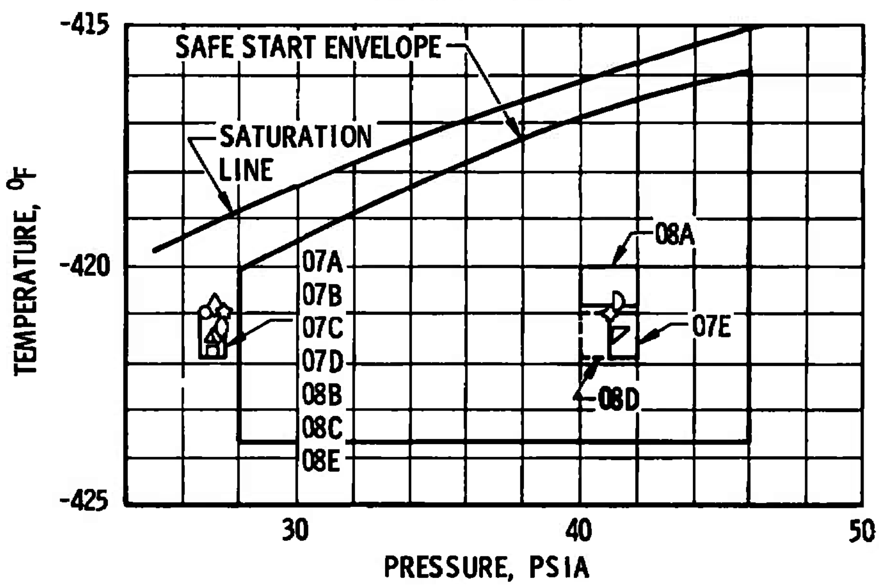
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

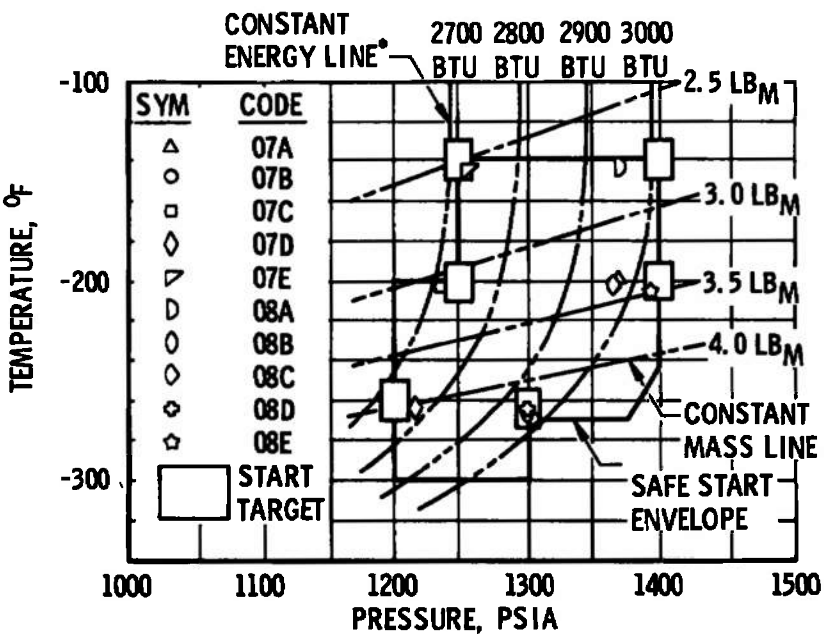


a. Oxidizer Pump Inlet



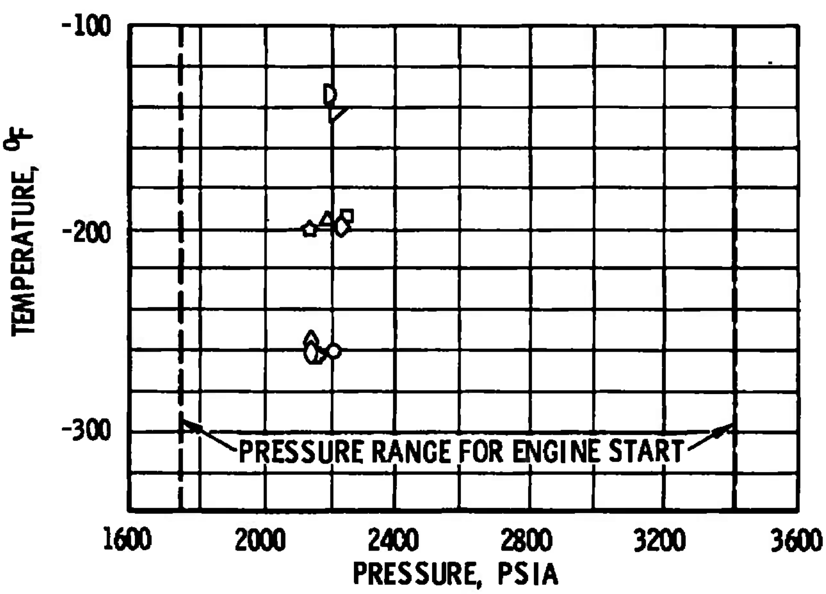
b. Fuel Pump Inlet

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



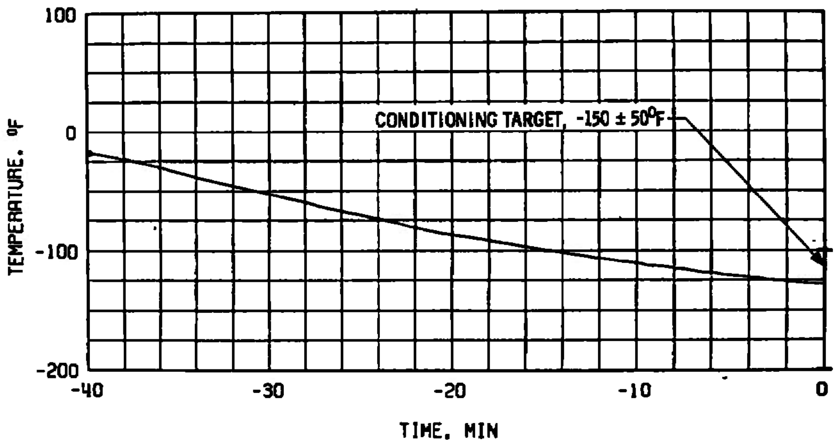
*CALCULATED FROM "TABLE OF THERMAL PROPERTIES OF GASES," NATIONAL BUREAU OF STANDARDS CIRCULAR 564, NOVEMBER 1965.

c. Start Tank

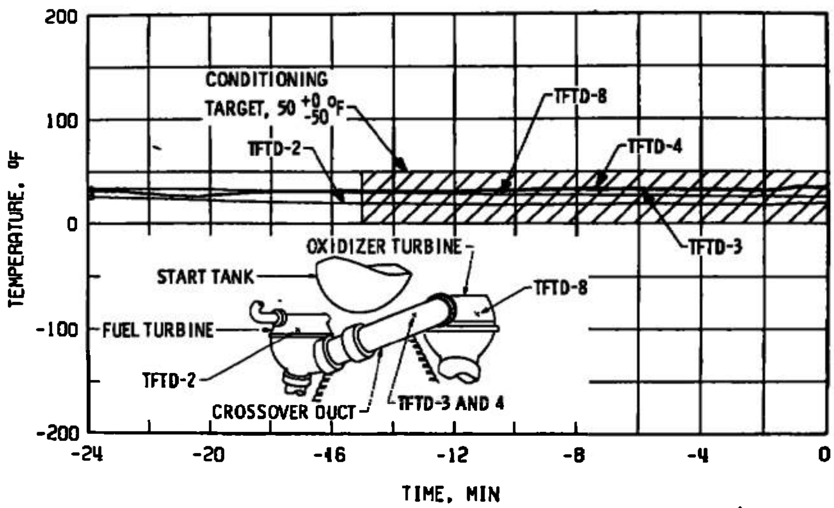


d. Helium Tank

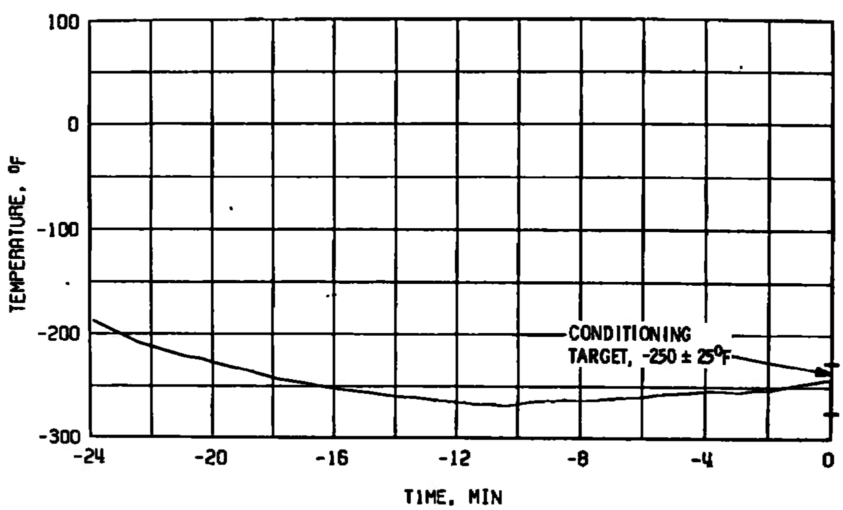
Fig. 8 Concluded



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

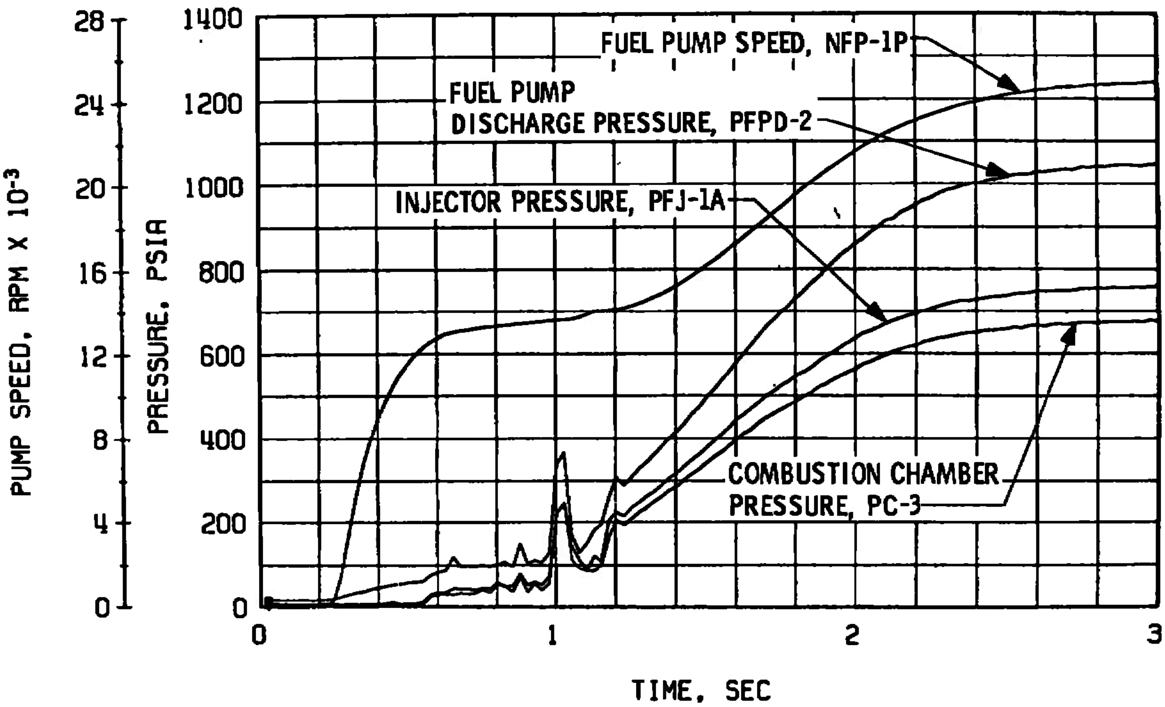


b. Crossover Duct, TFTD

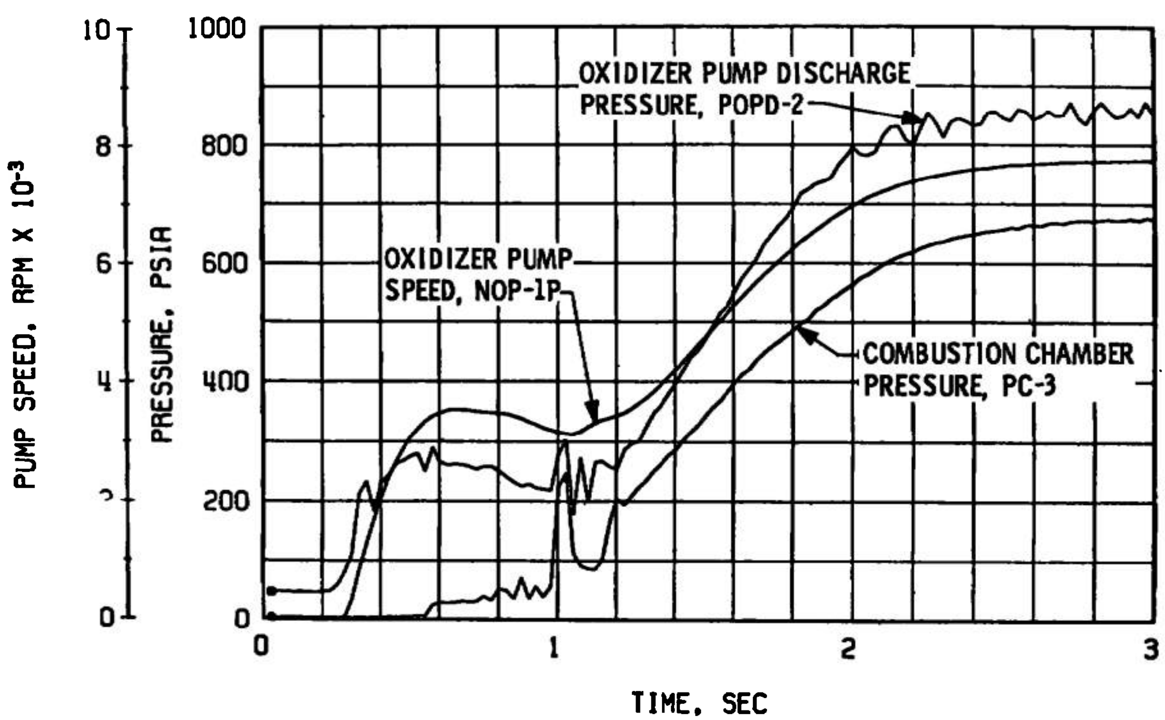


c. Thrust Chamber Throat, TTC-1P

Fig. 9 Thermal Conditioning History of Engine Components, Firing 07A

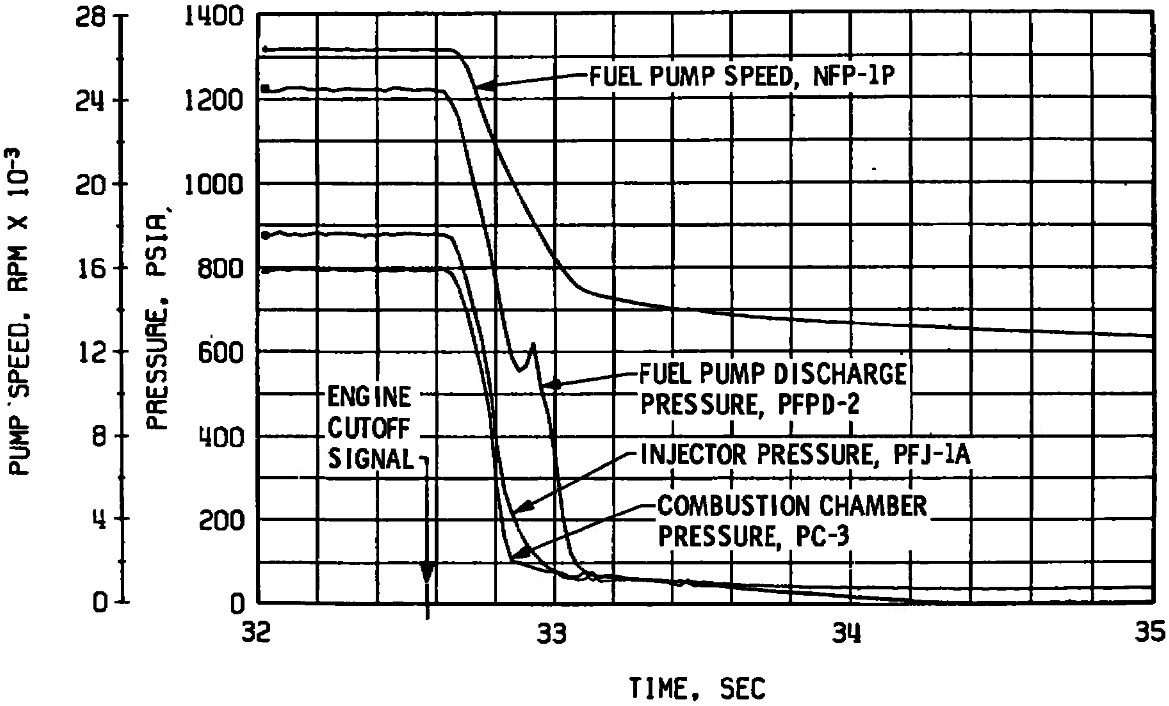


a. Thrust Chamber Fuel System, Start

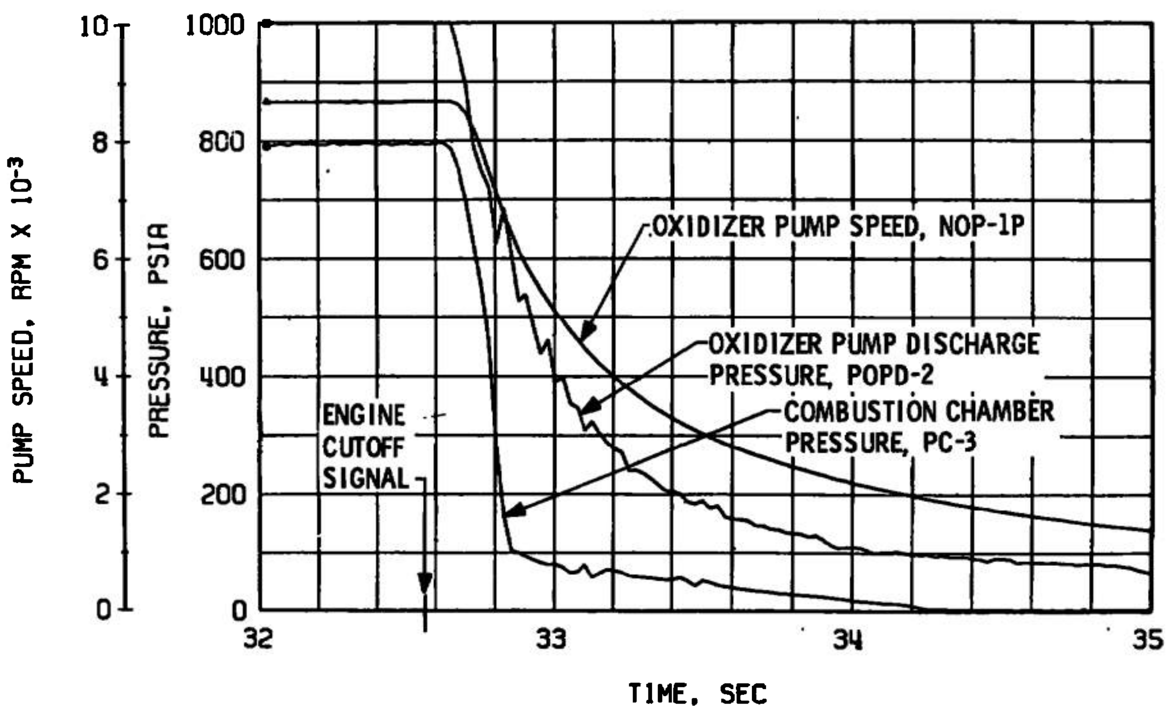


b. Thrust Chamber Oxidizer System, Start

Fig. 10 Engine Transient Operation, Firing 07A

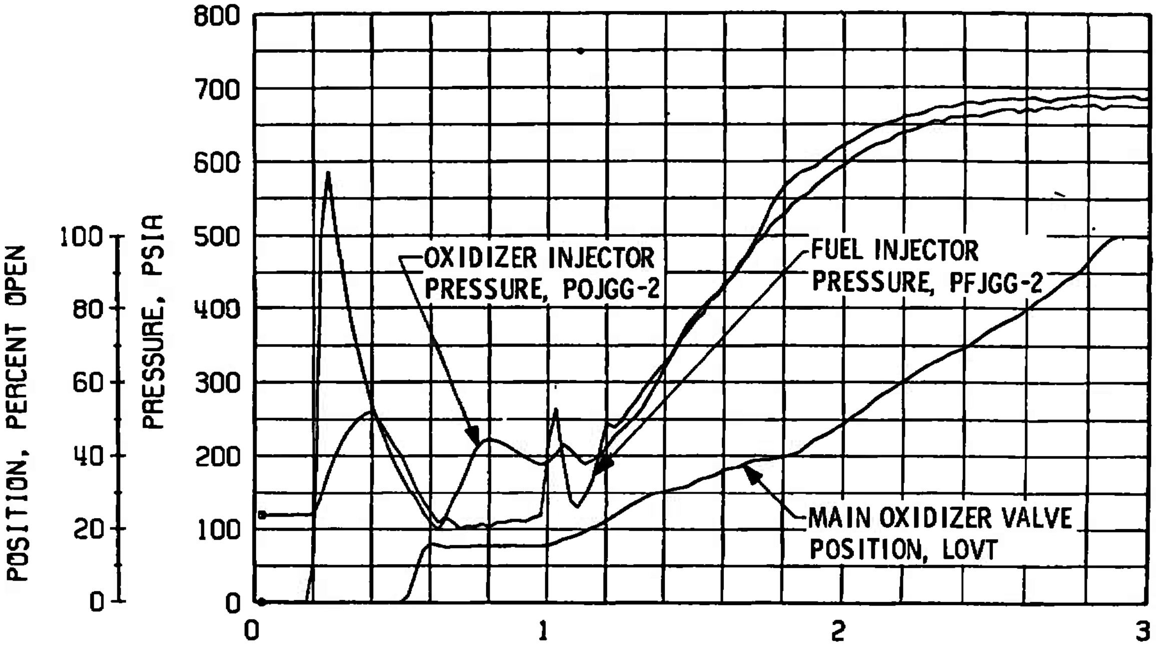


c. Thrust Chamber Fuel System, Shutdown

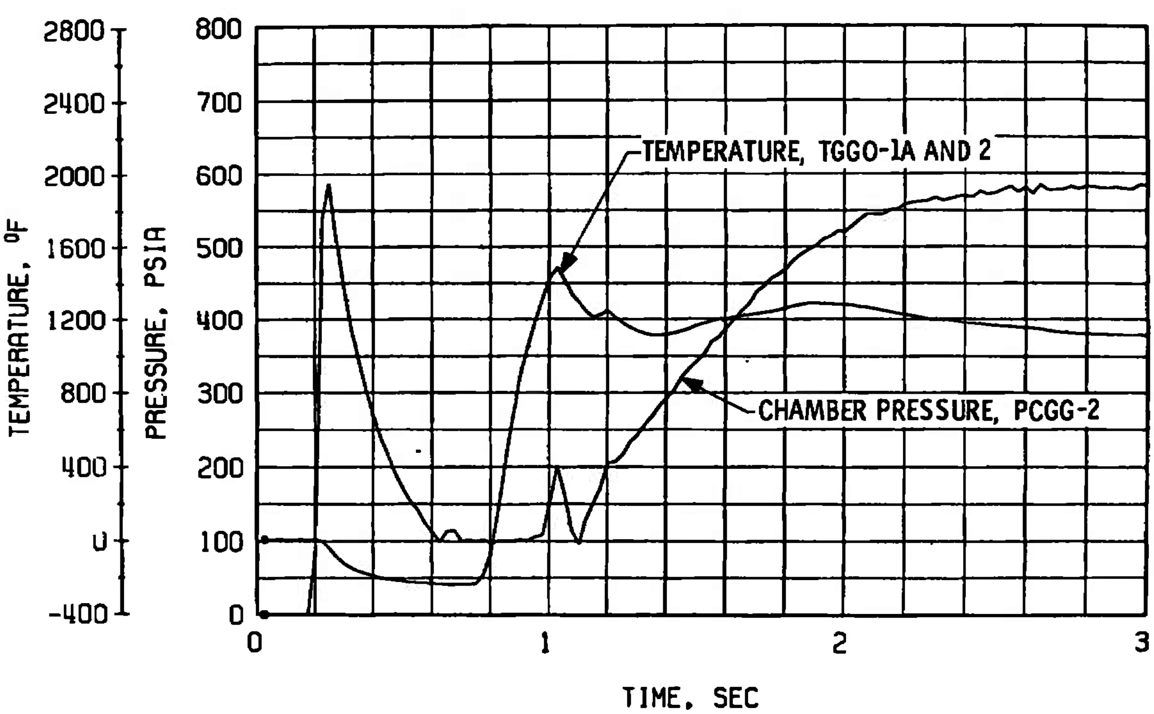


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Continued

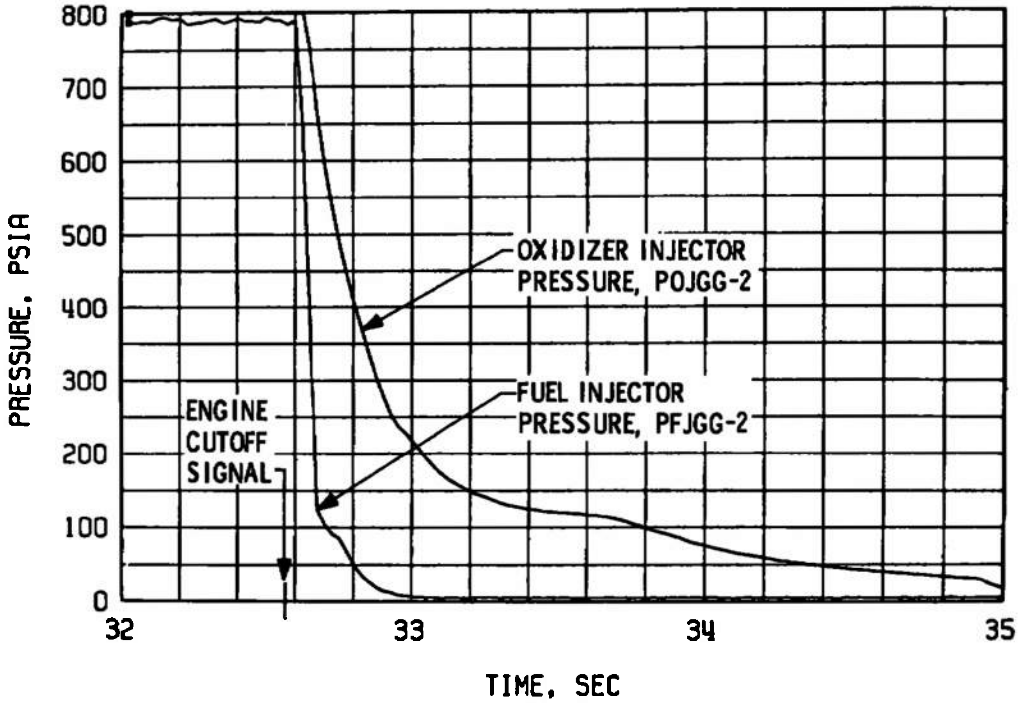


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

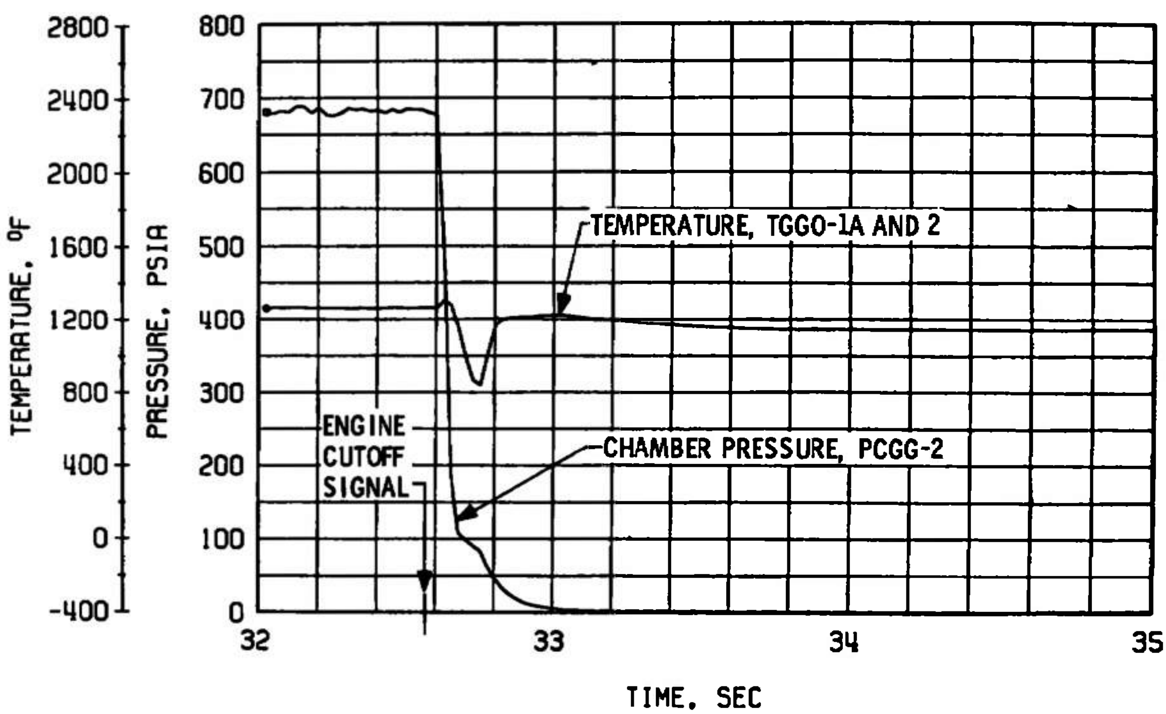


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 10 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded

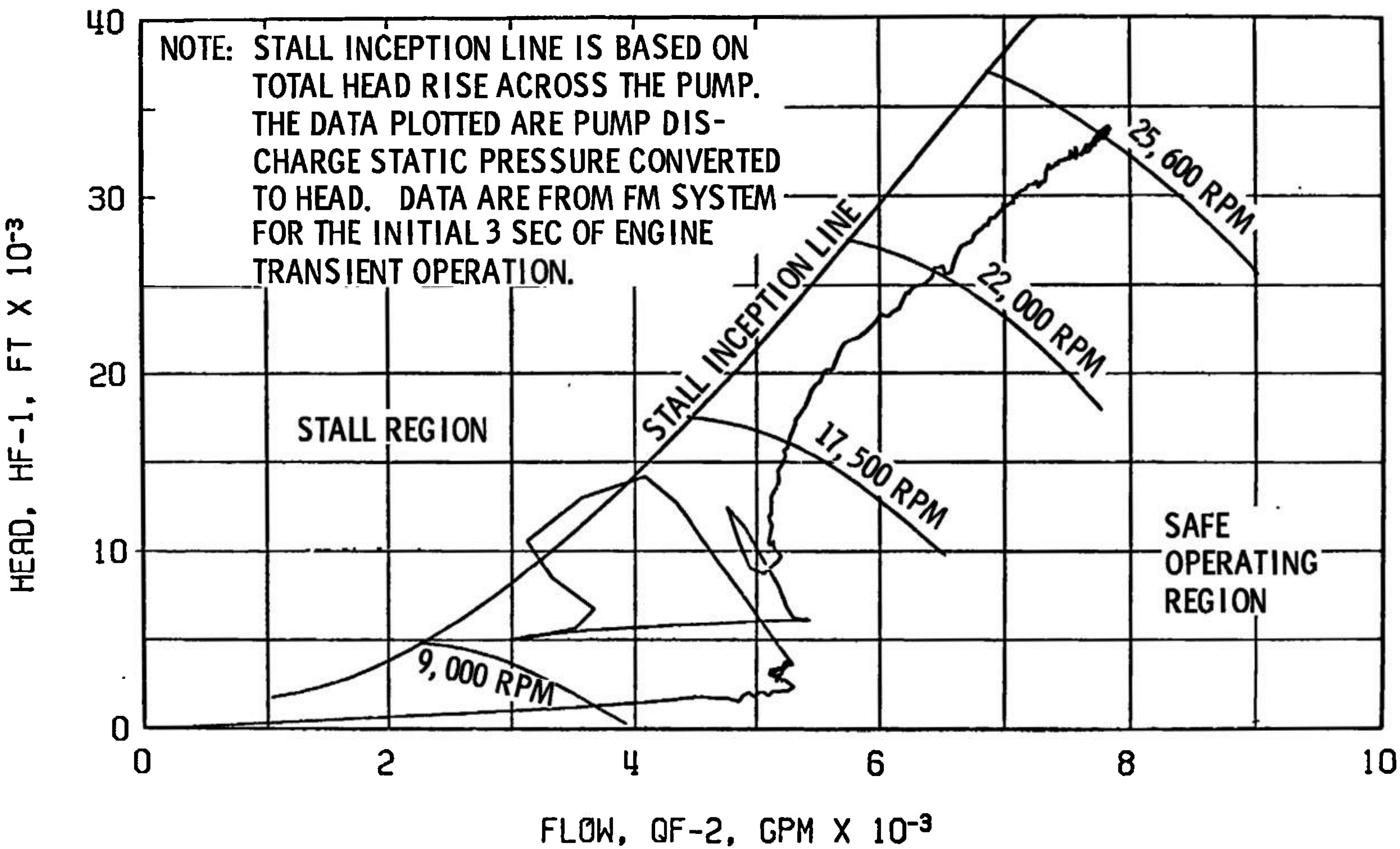


Fig. 11 Fuel Pump Start Transient Performance, Firing 07A

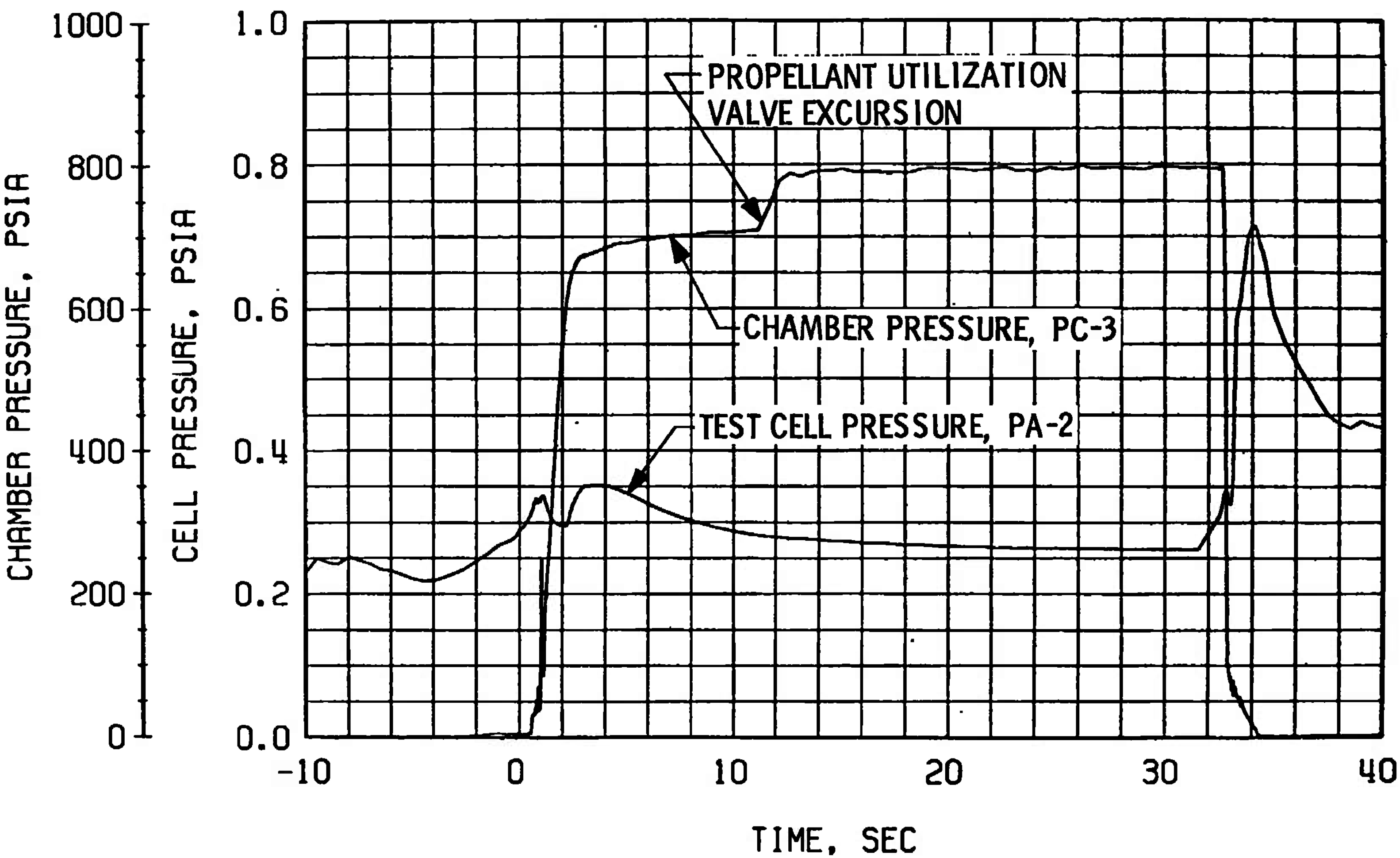
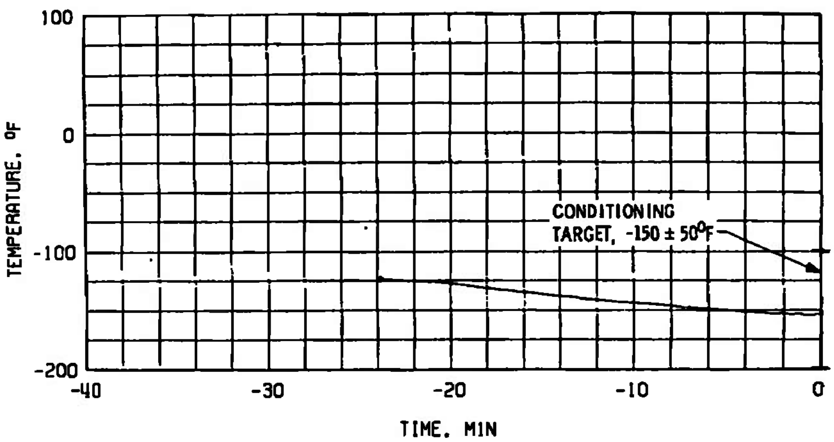
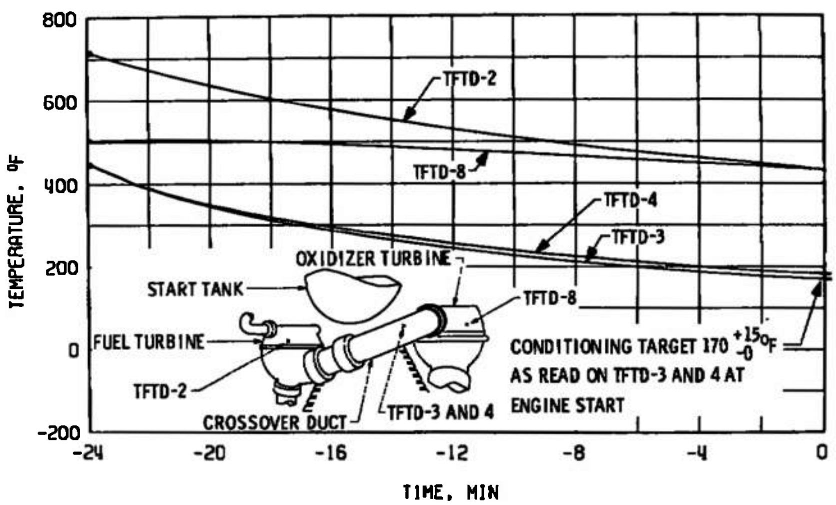


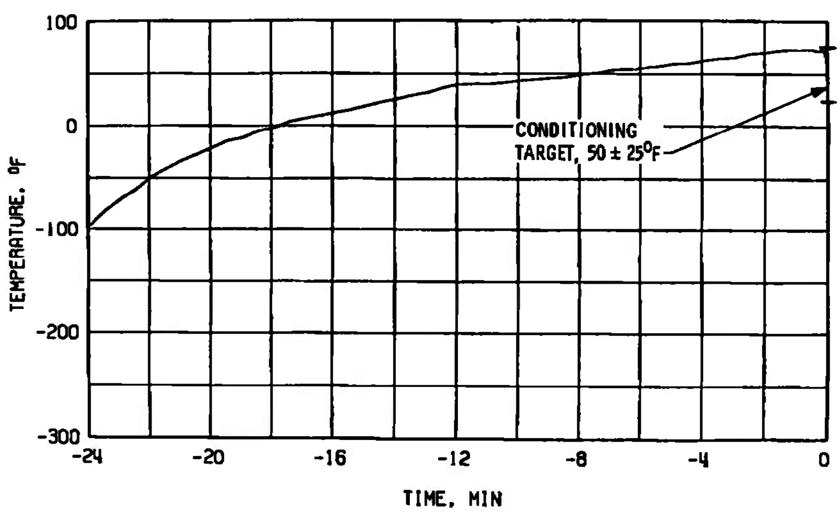
Fig. 12 Engine Ambient and Combustion Chamber Pressure, Firing 07A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

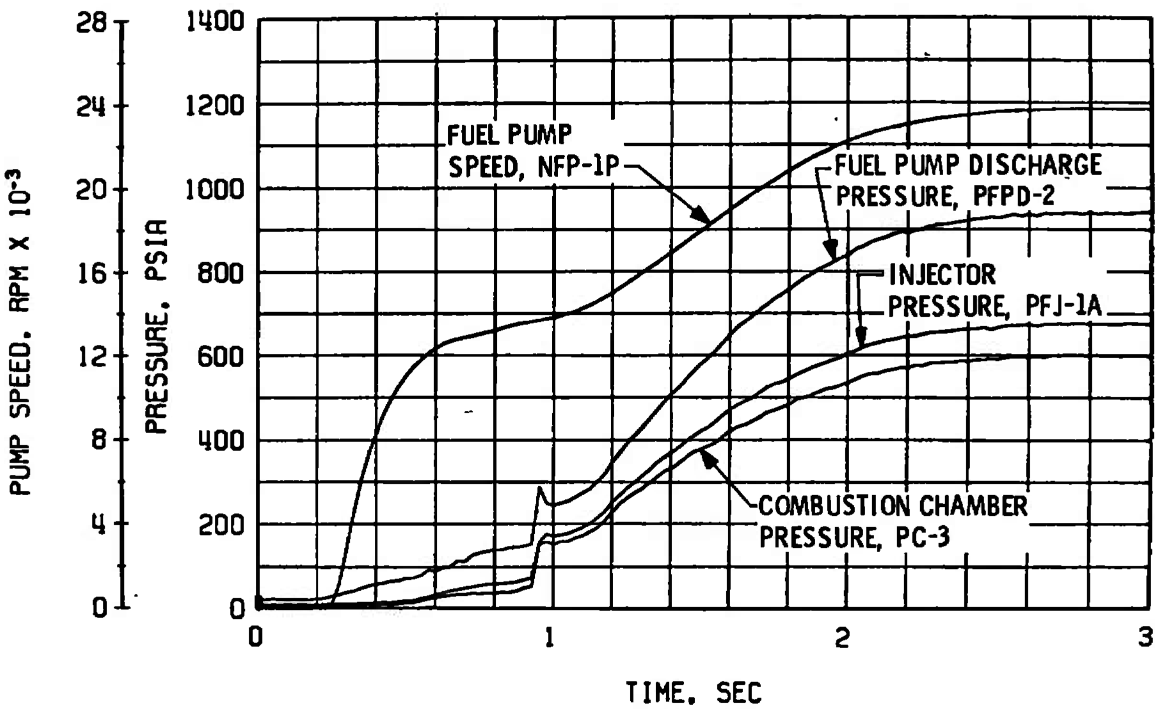


b. Crossover Duct, TFTD

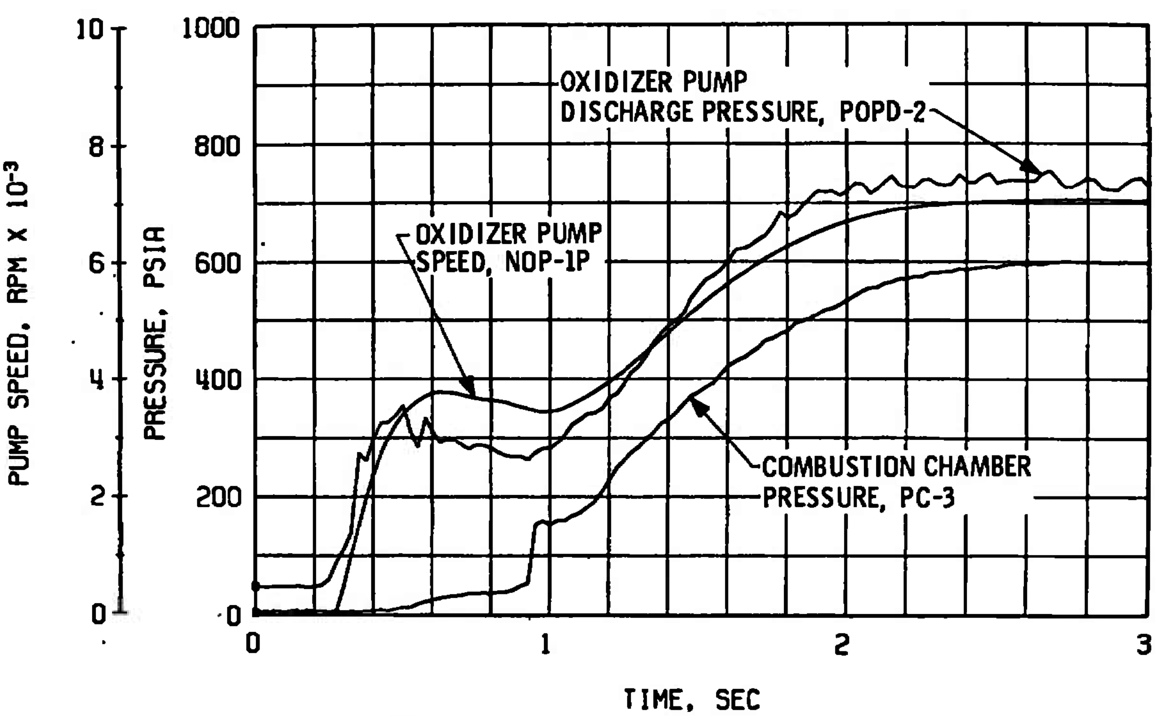


c. Thrust Chamber Throat, TTC-1P

Fig. 13 Thermal Conditioning History of Engine Components, Firing 07B

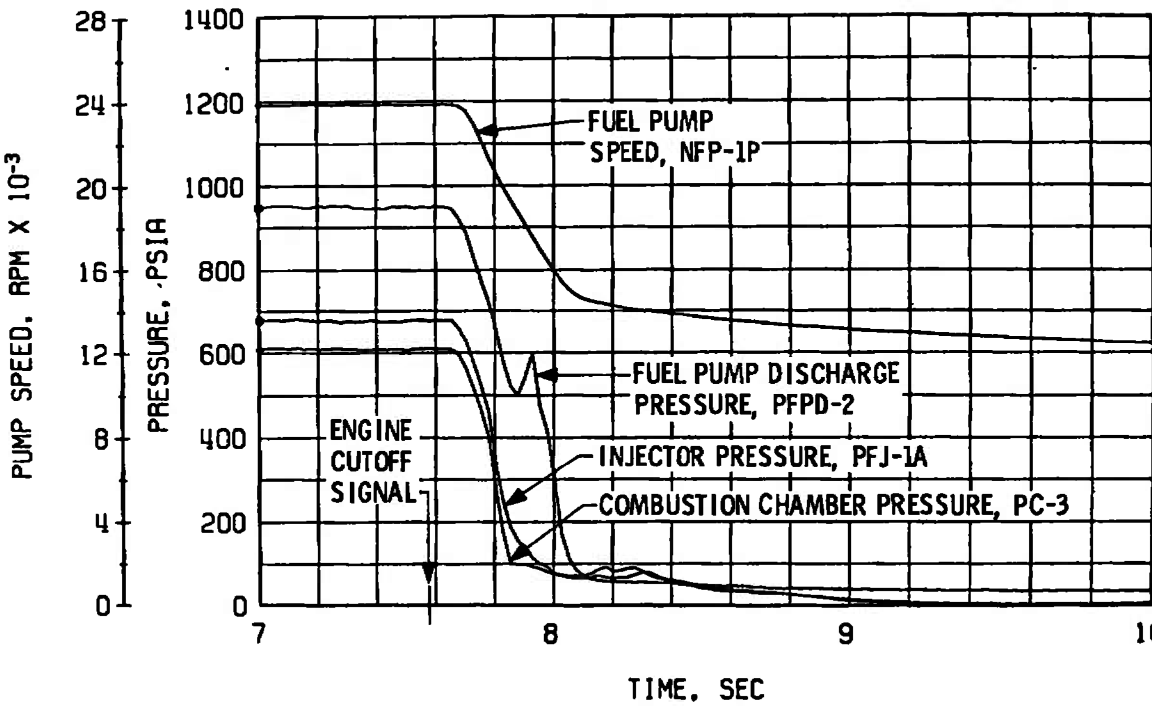


a. Thrust Chamber Fuel System, Start

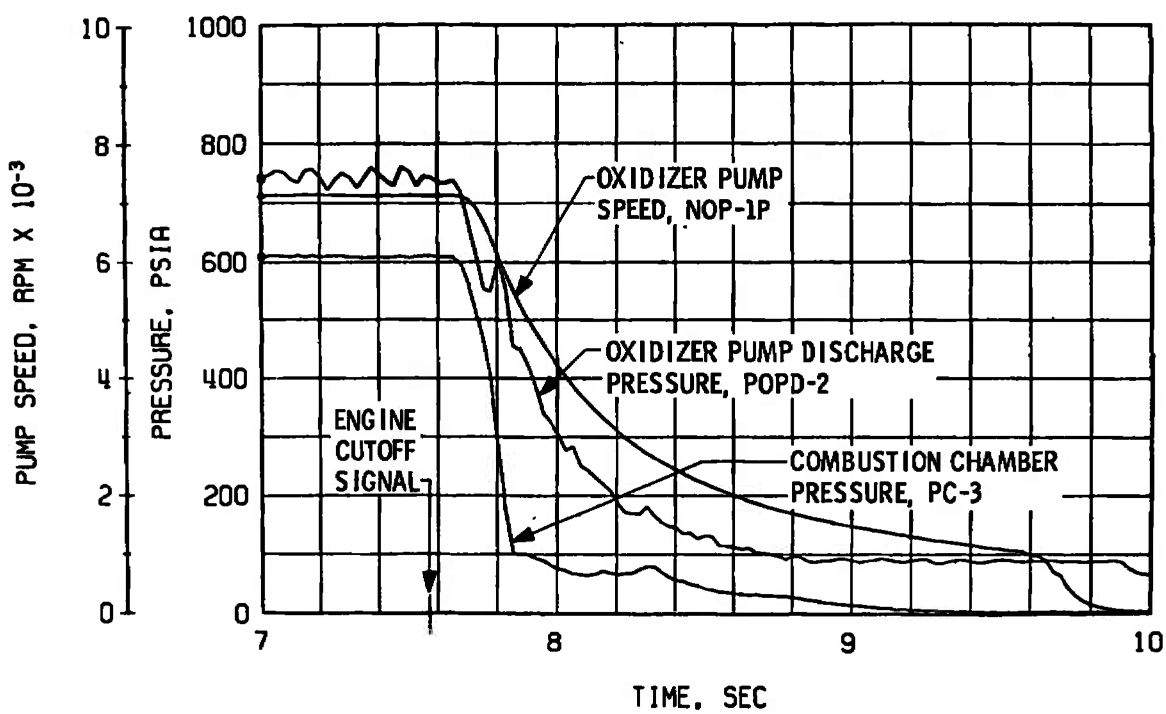


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 07B

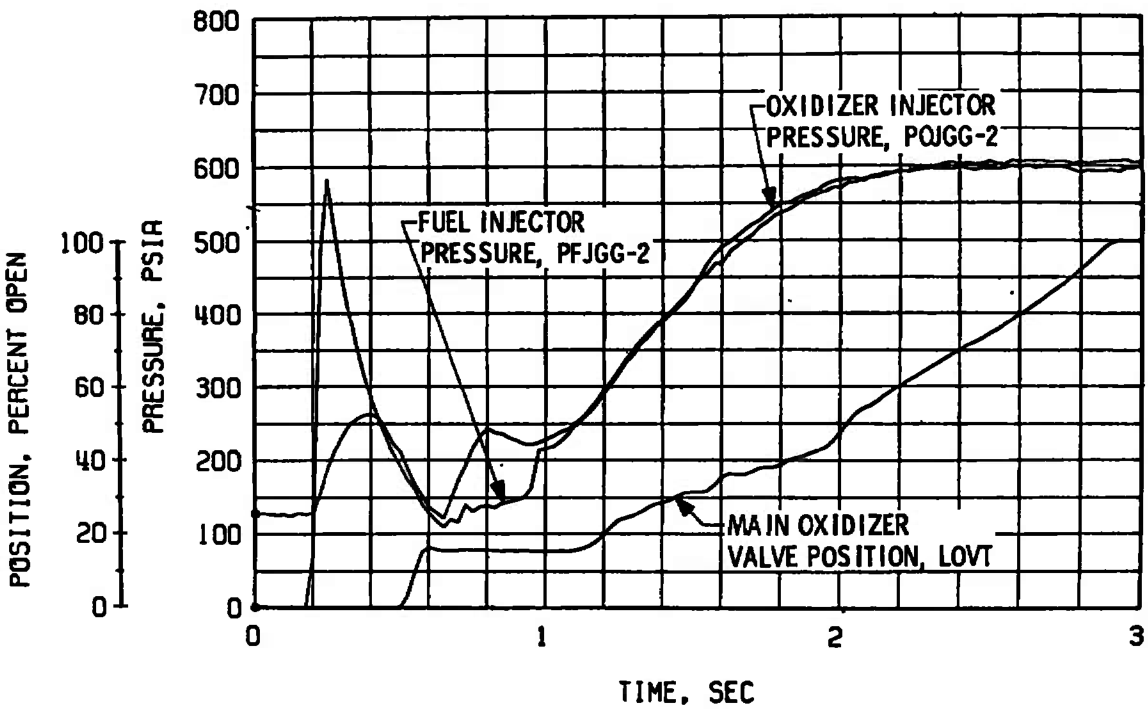


c. Thrust Chamber Fuel System, Shutdown

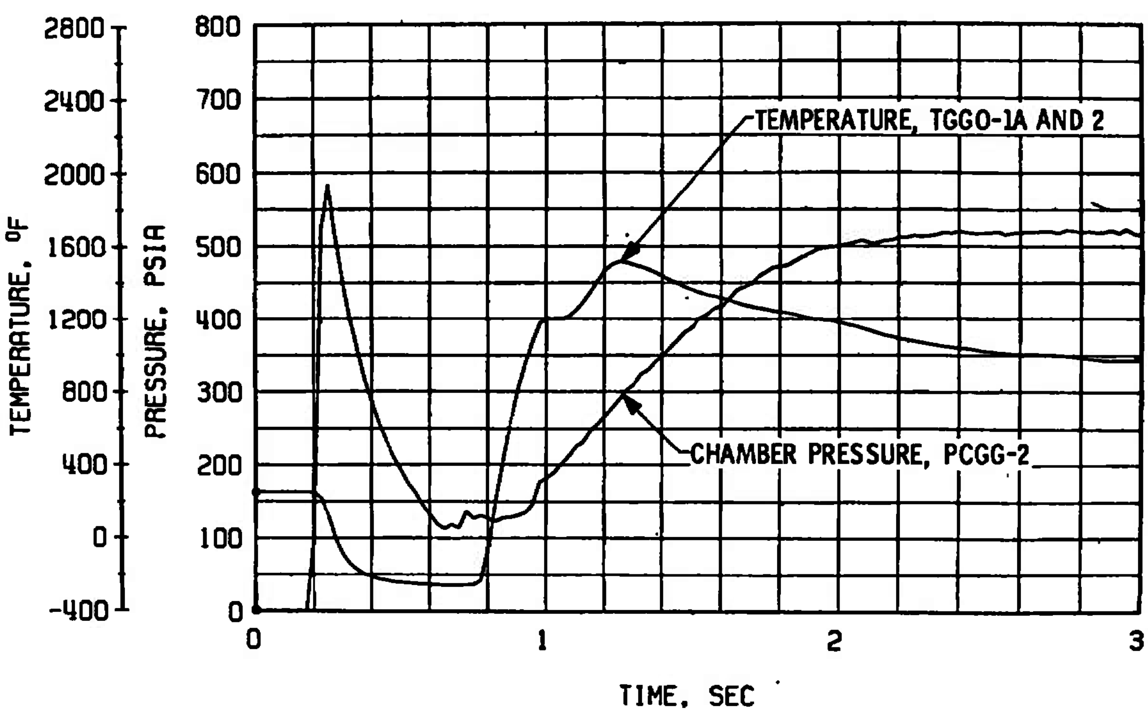


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued.

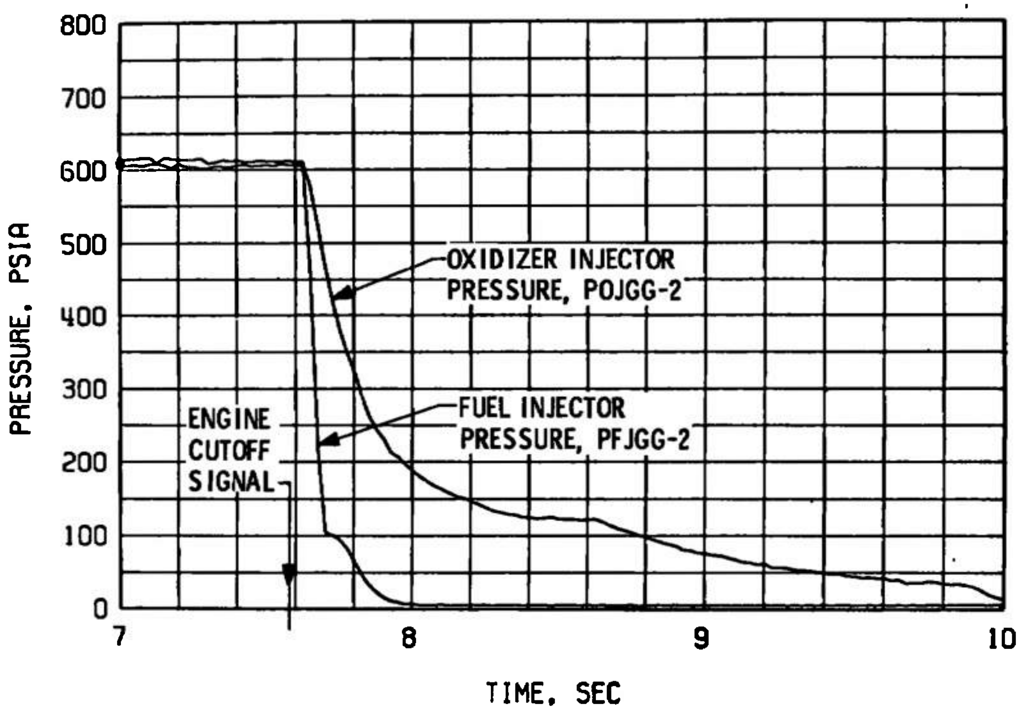


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

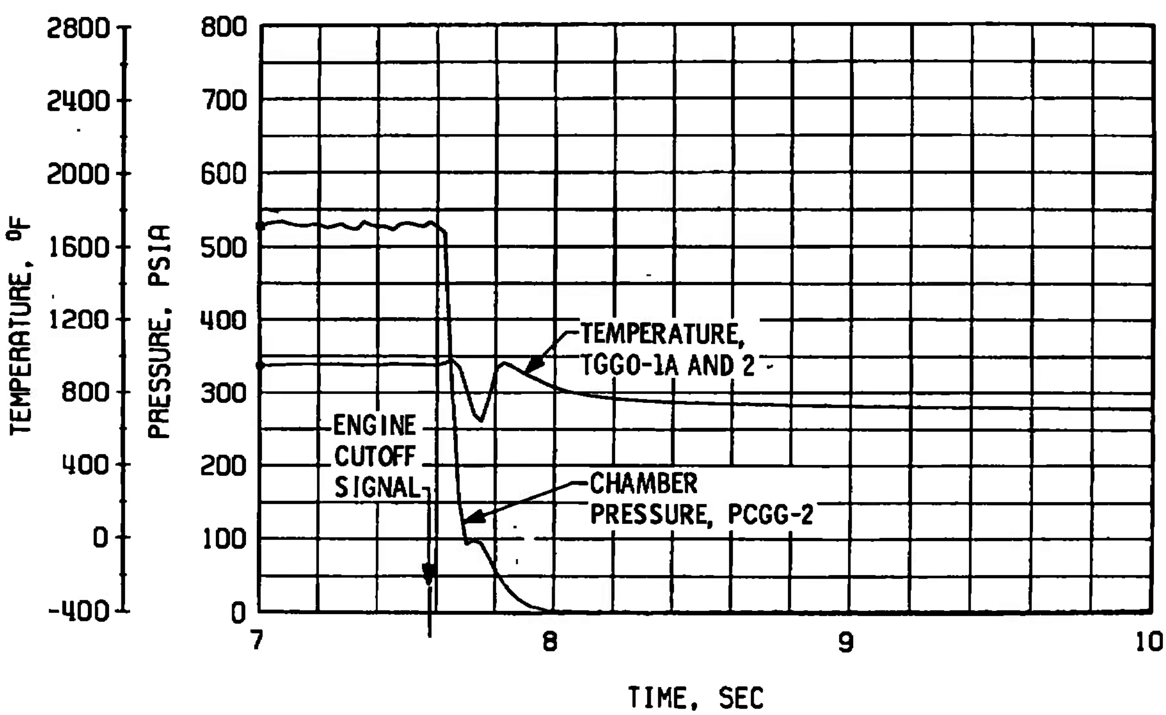


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued



g. Gas Generator Injector Pressure, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded

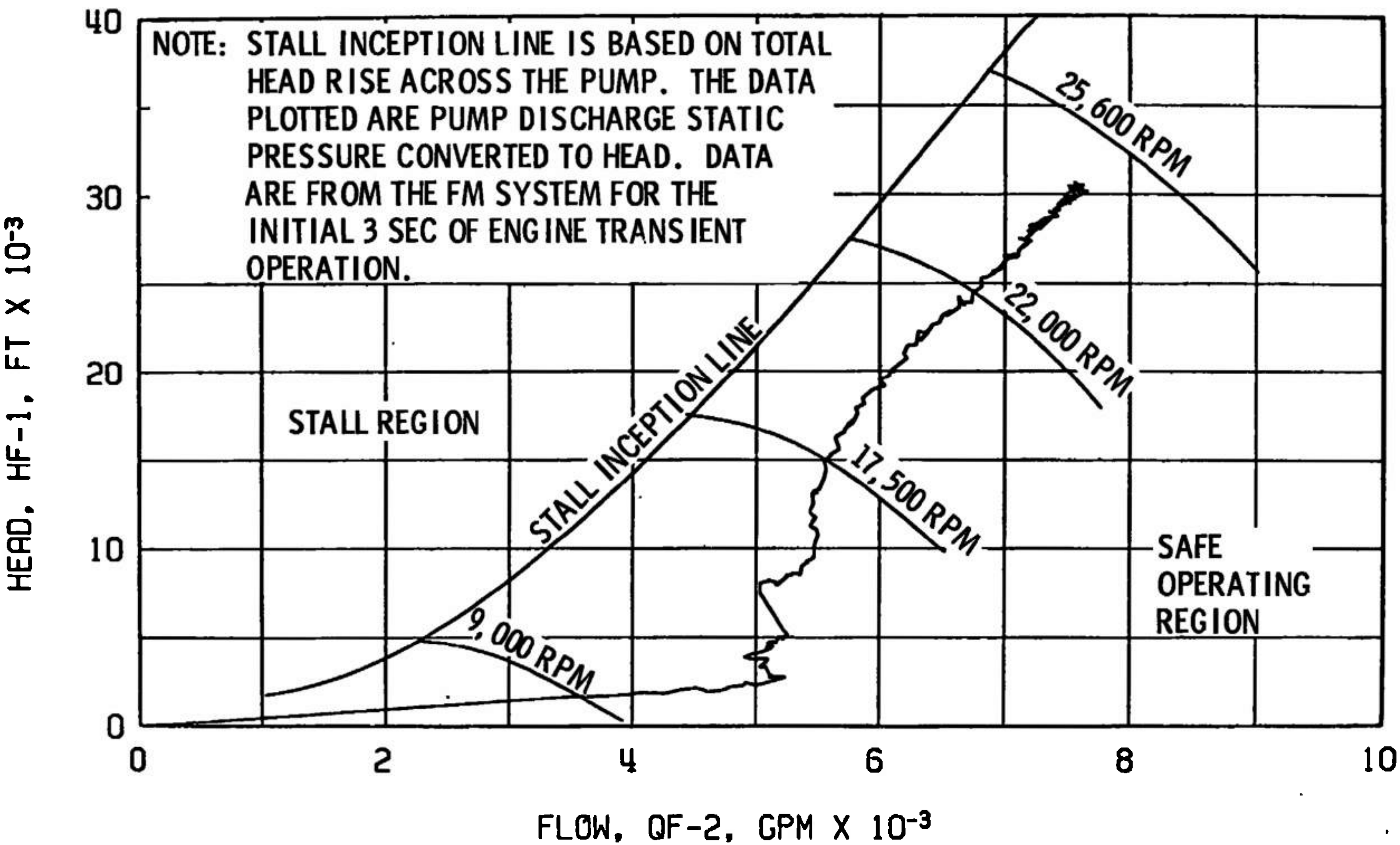


Fig. 15 Fuel Pump Start Transient Performance, Firing 07B

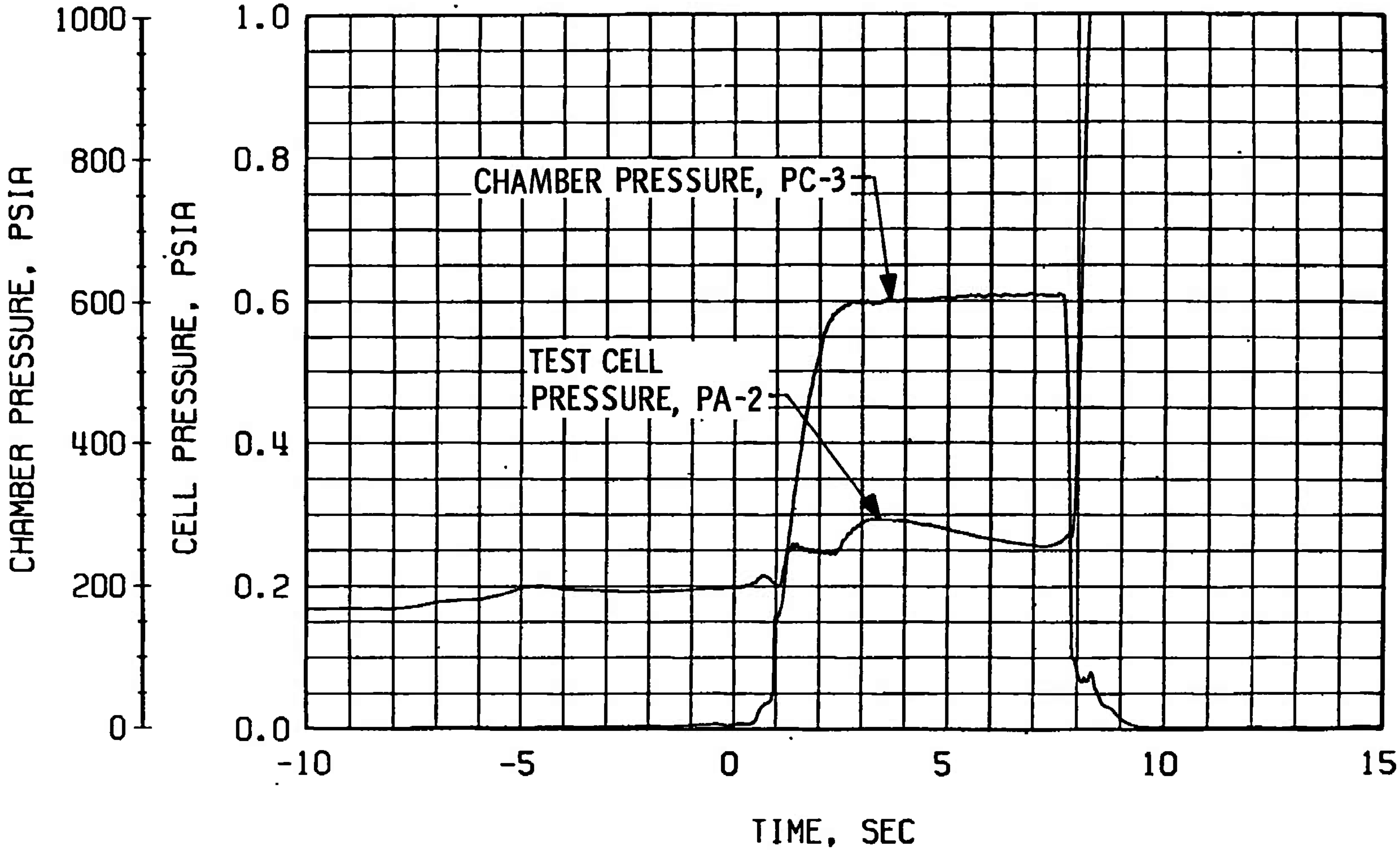
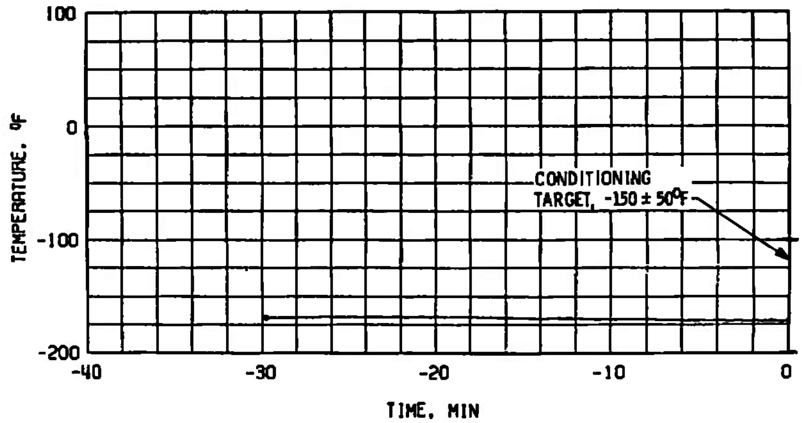
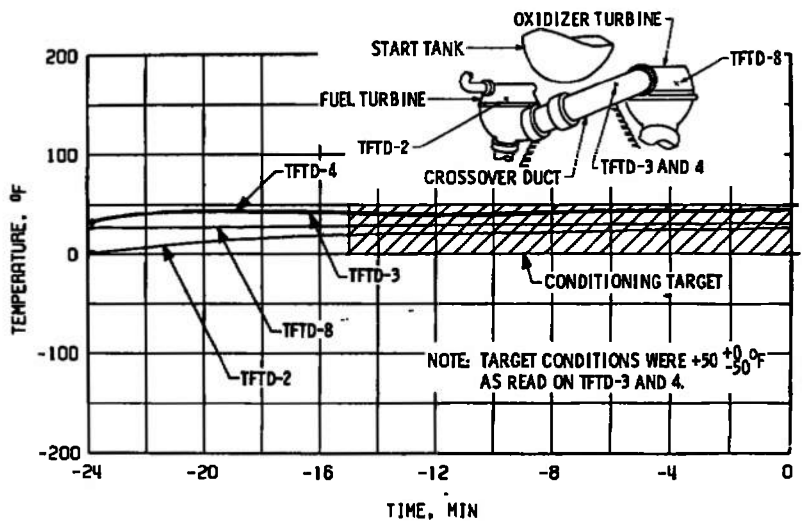


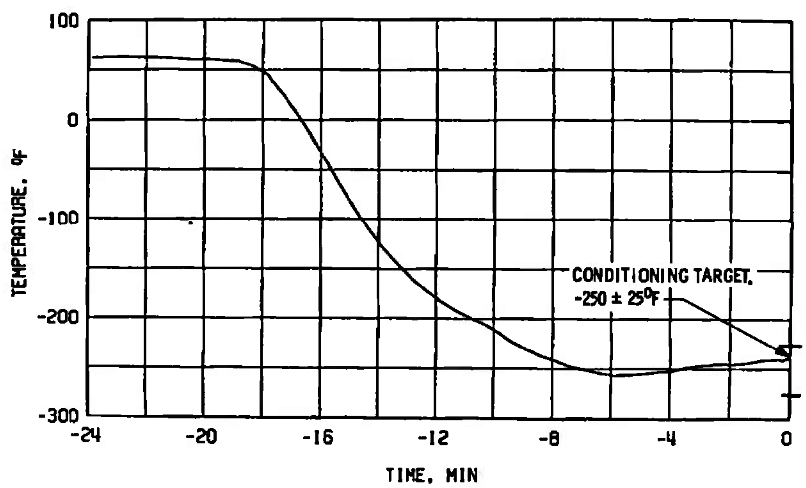
Fig. 16 Engine Ambient and Combustion Chamber Pressure, Firing 07B



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

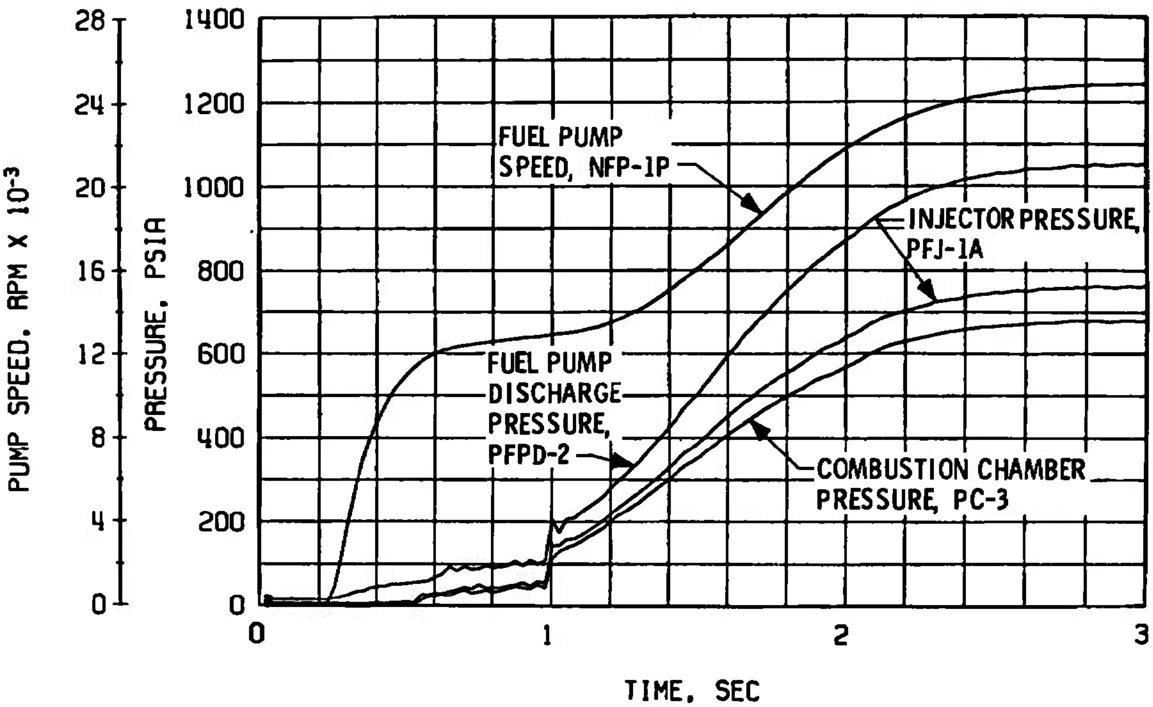


b. Crossover Duct, TFTD

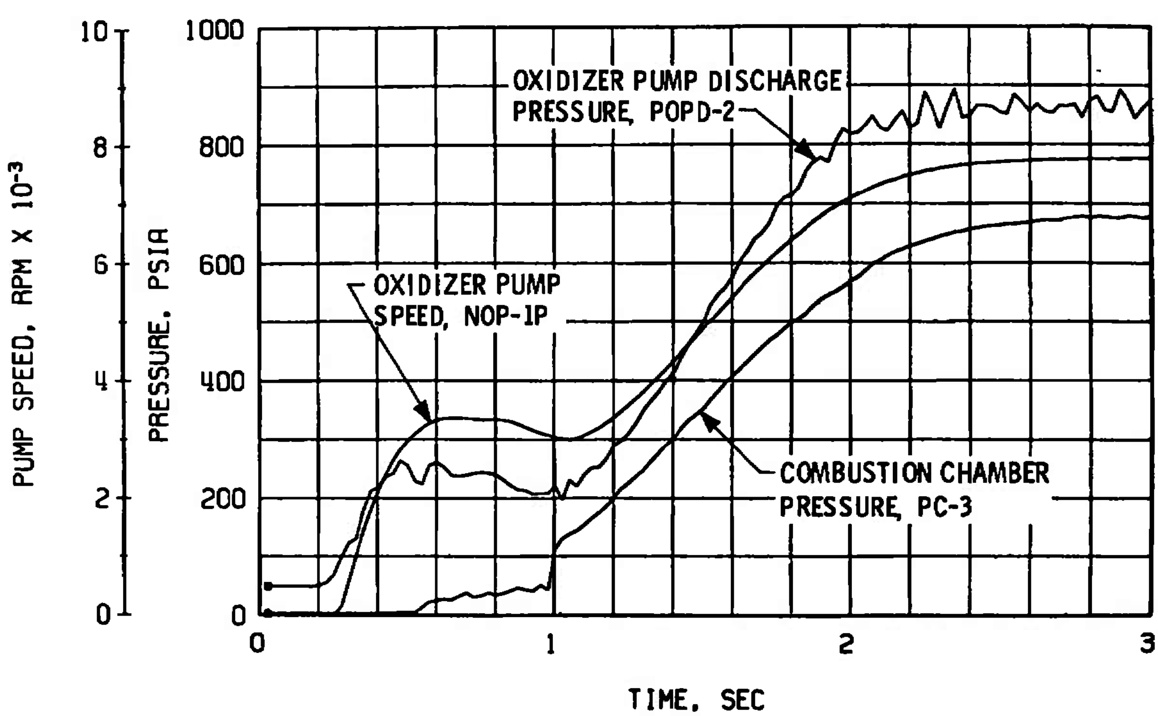


c. Thrust Chamber Throat, TTC-1P

Fig. 17 Thermal Conditioning History of Engine Components, Firing 07C

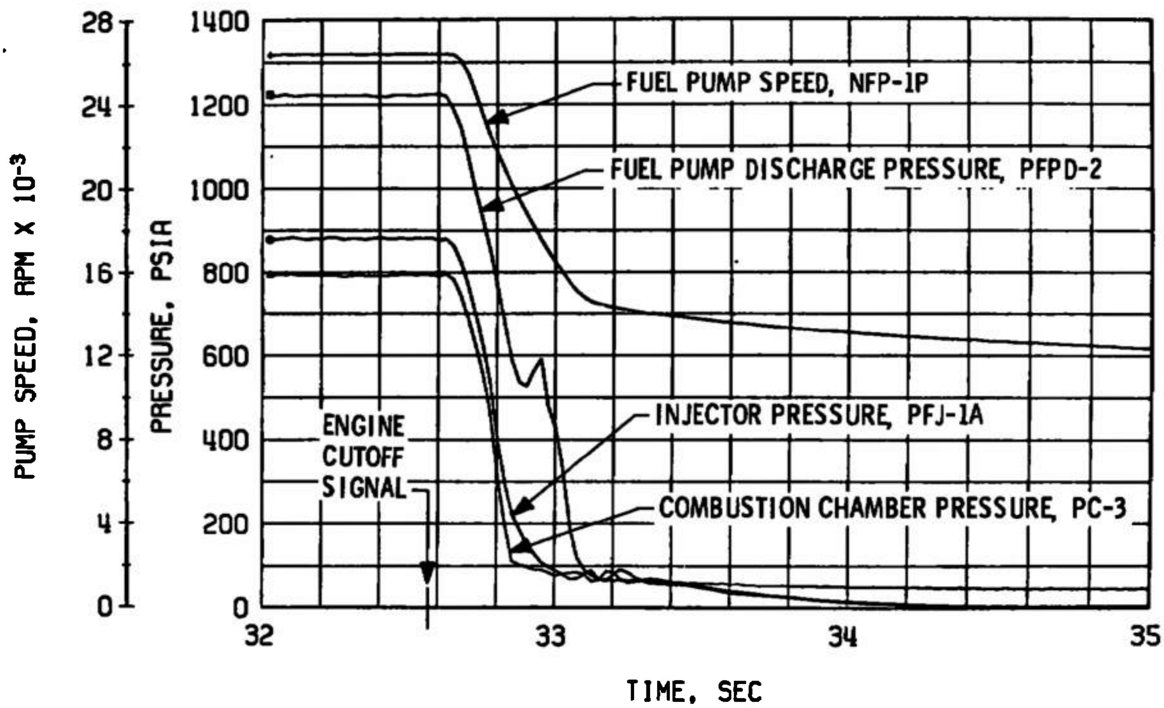


a. Thrust Chamber Fuel System, Start

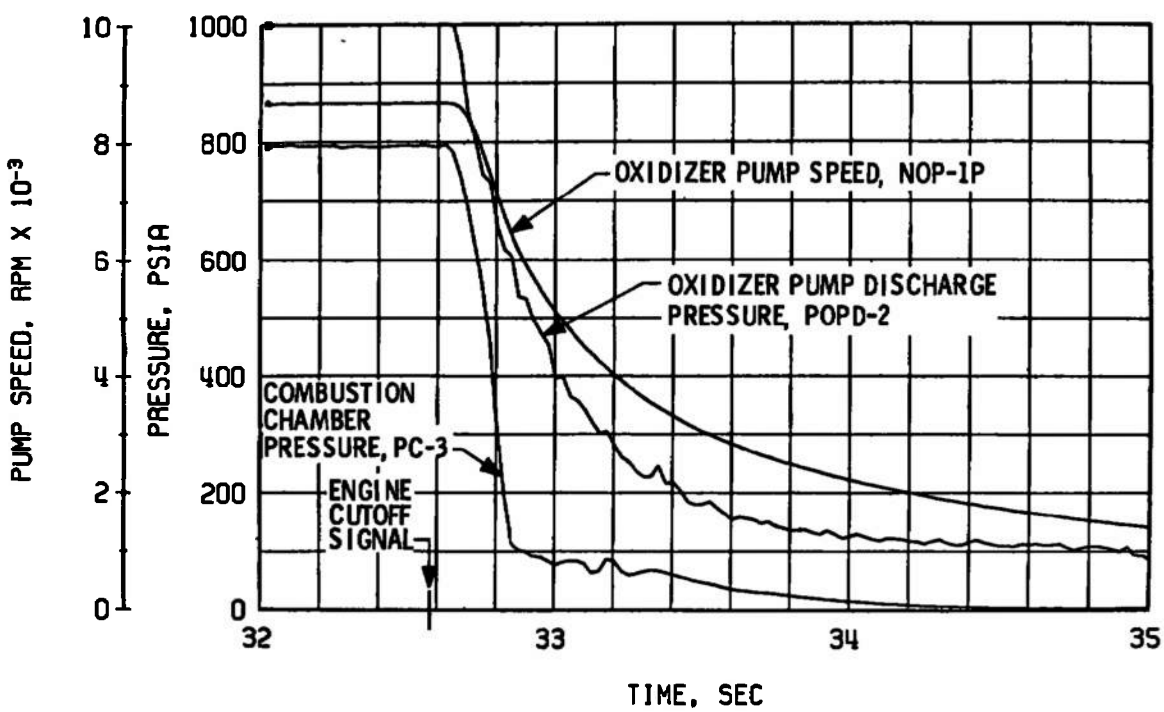


b. Thrust Chamber Oxidizer System, Start

Fig. 18 Engine Transient Operation, Firing 07C

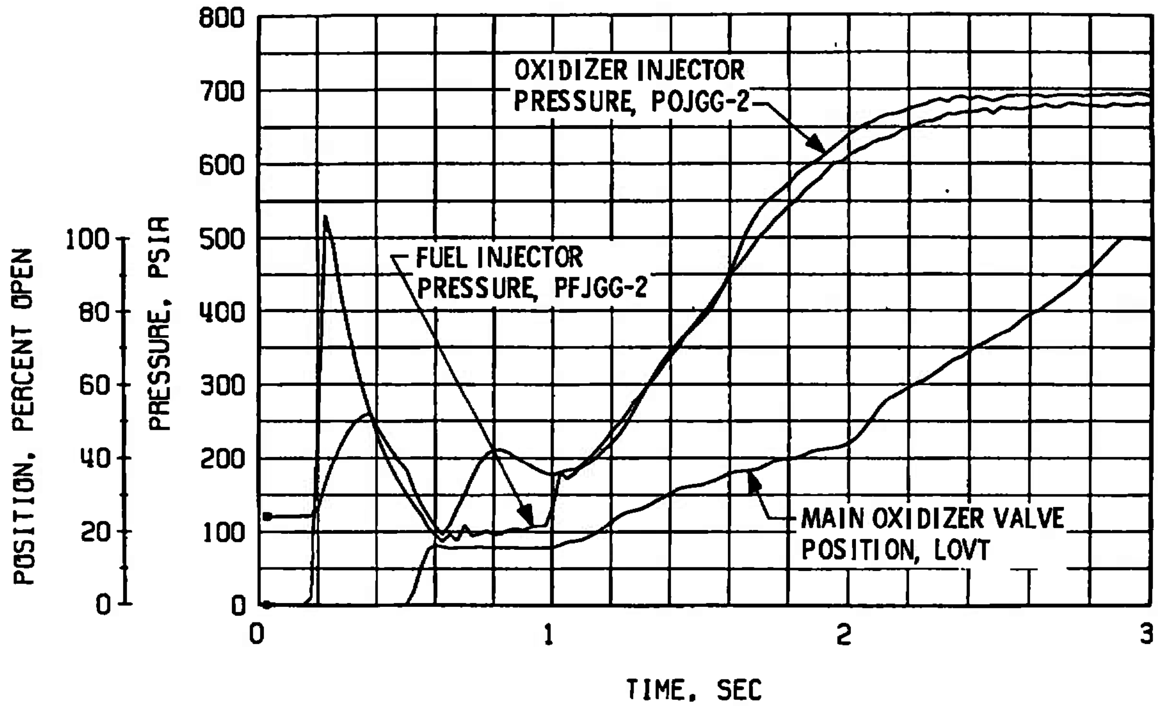


c. Thrust Chamber Fuel System, Start

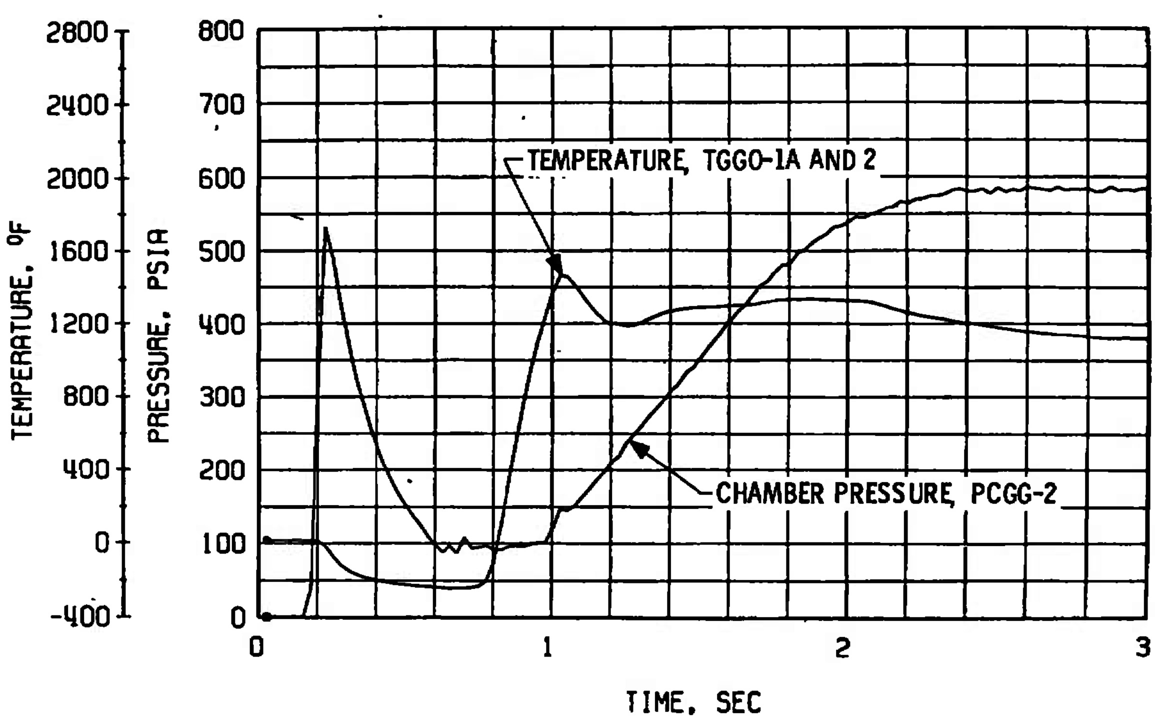


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 18 Continued

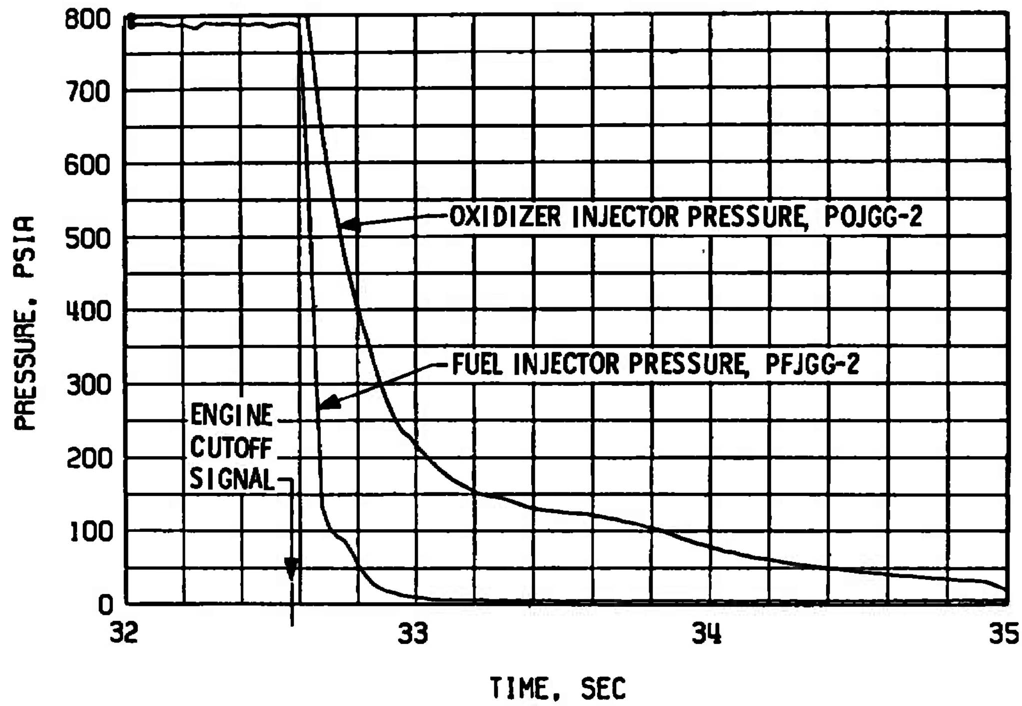


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

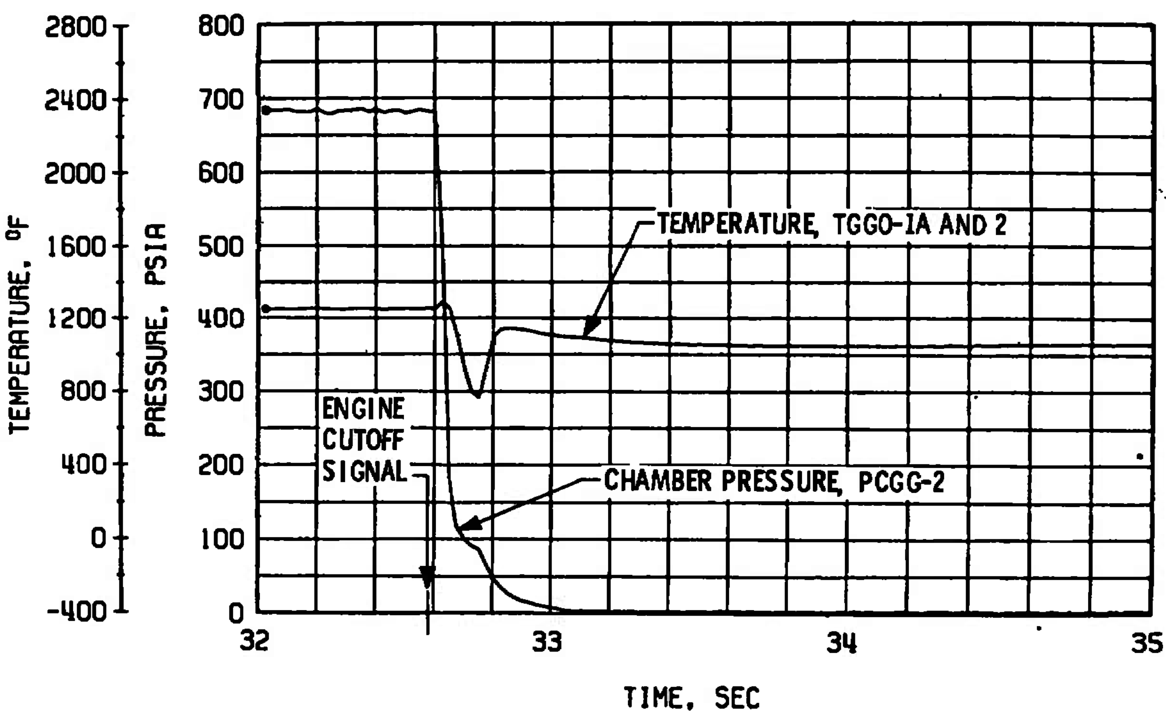


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 18 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 18 Concluded

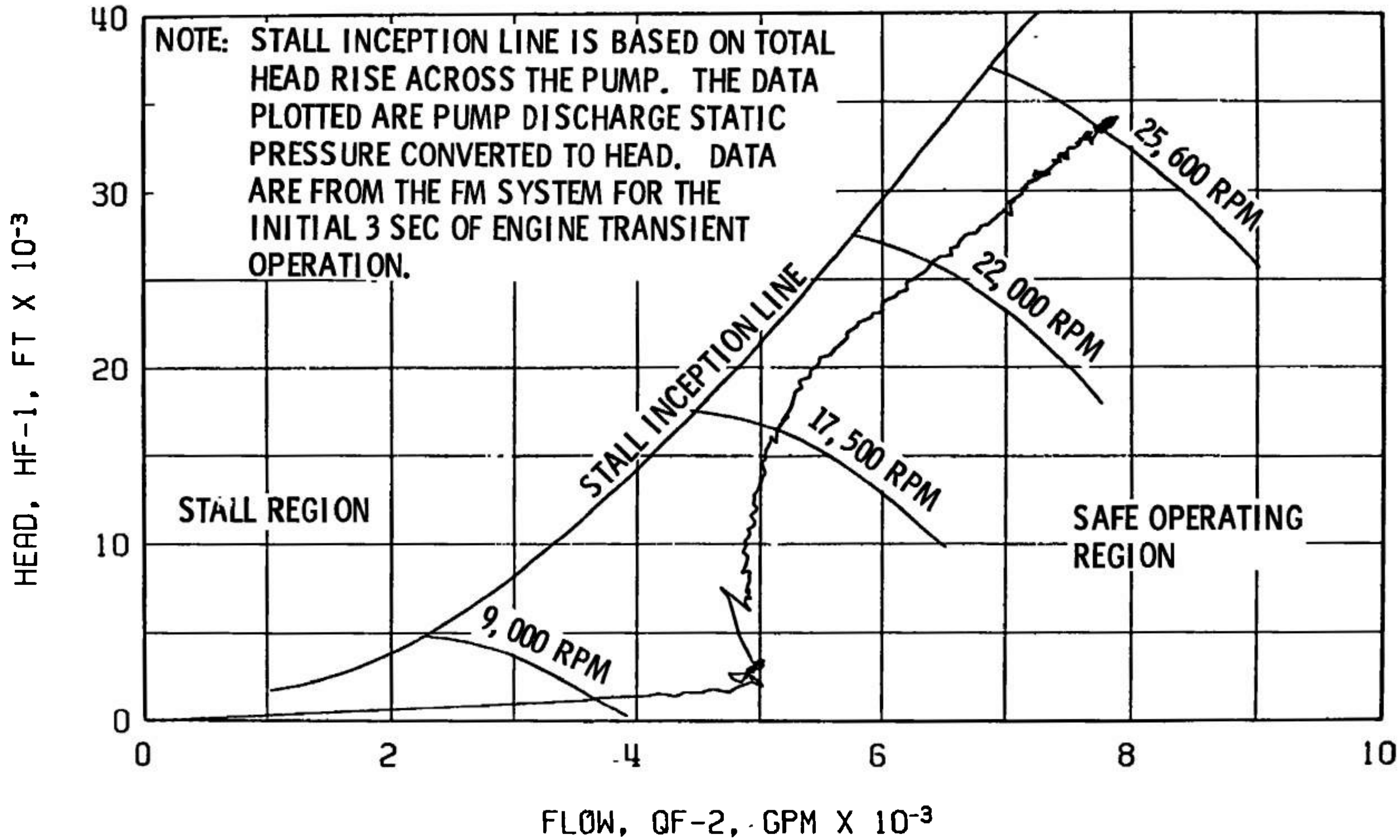


Fig. 19 Fuel Pump Start Transient Performance, Firing 07C

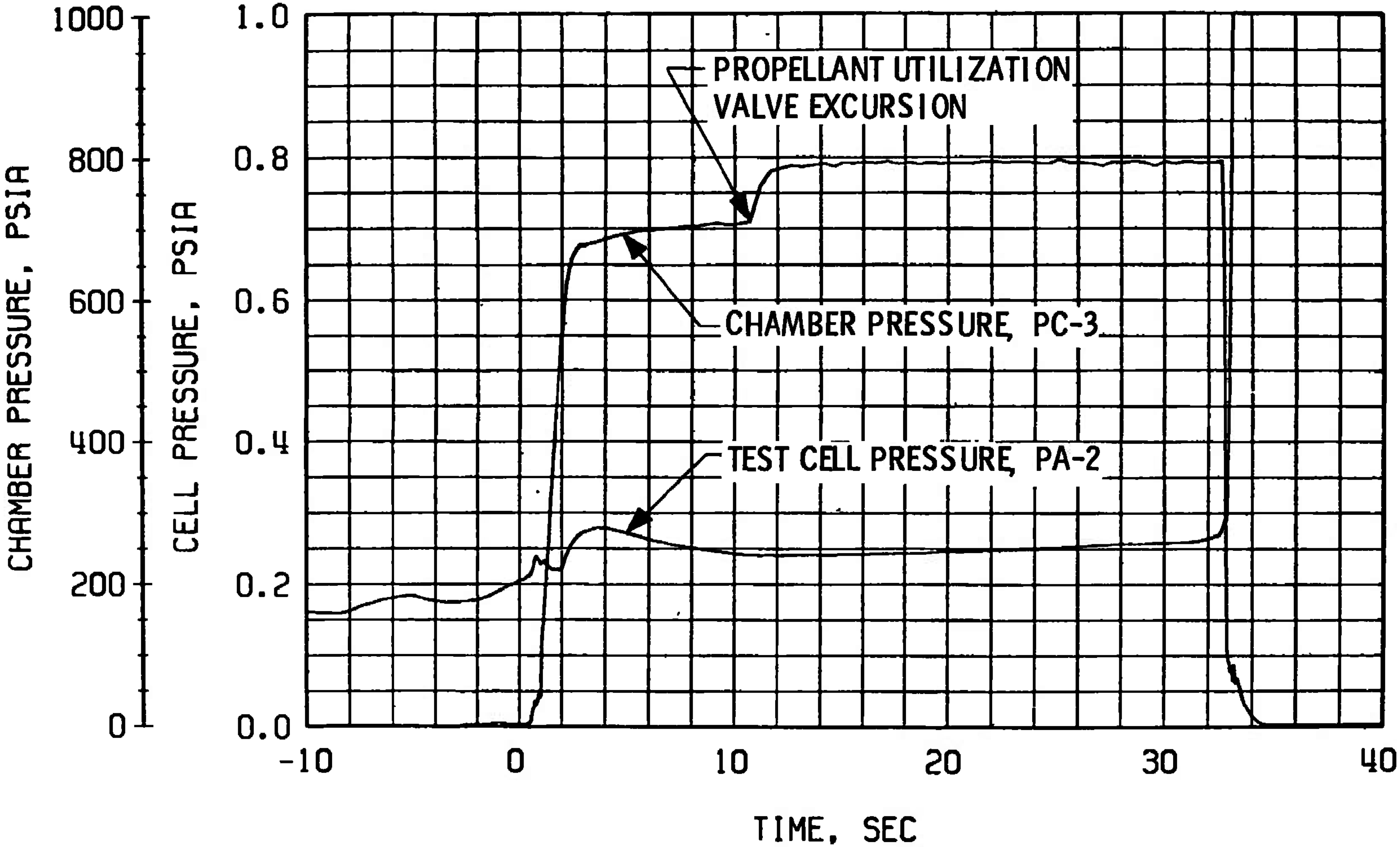
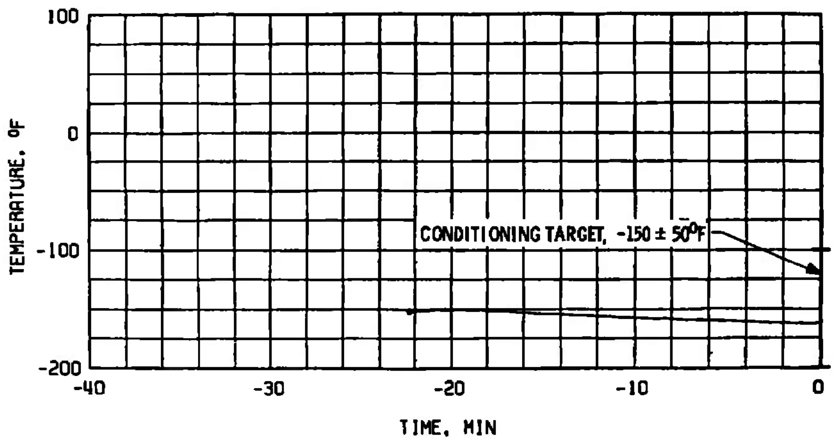
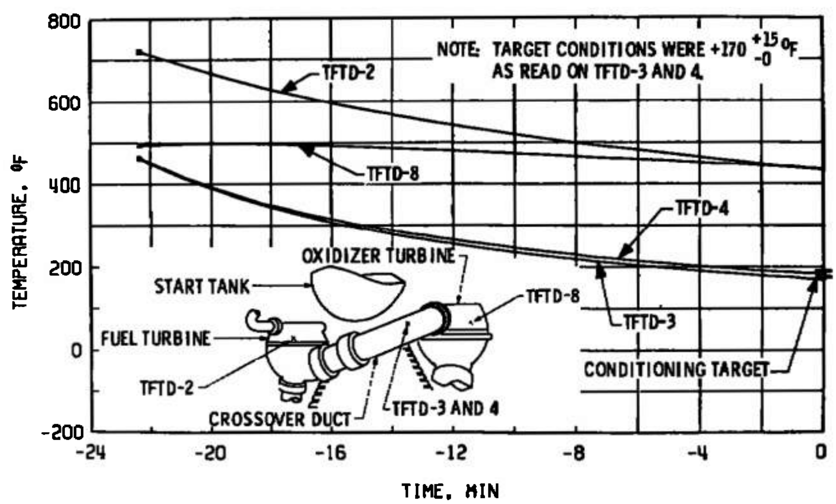


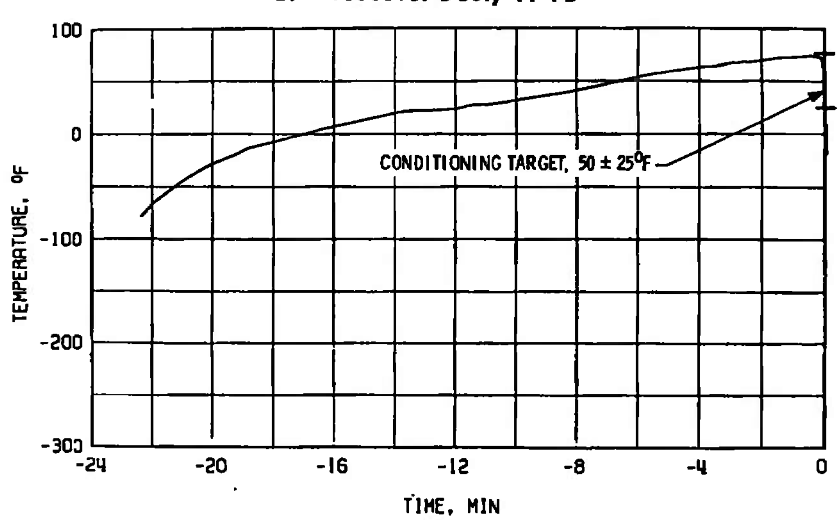
Fig. 20 Engine Ambient and Combustion Chamber Pressure, Firing 07C



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

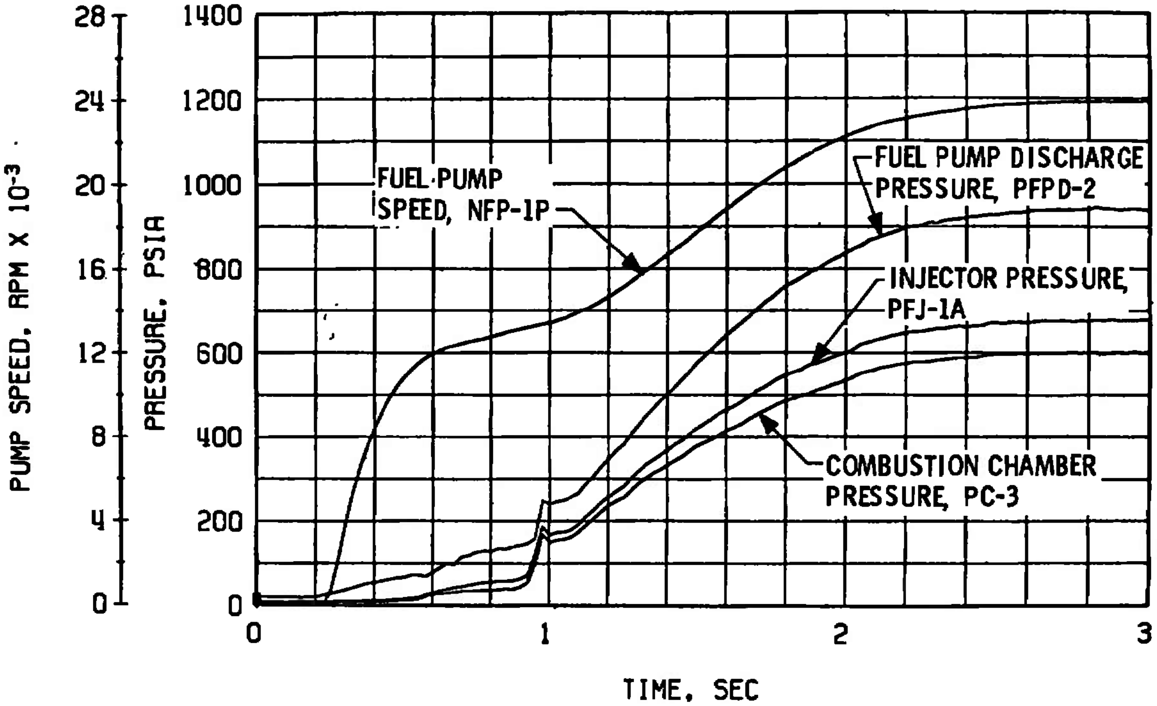


b. Crossover Duct, TFTD

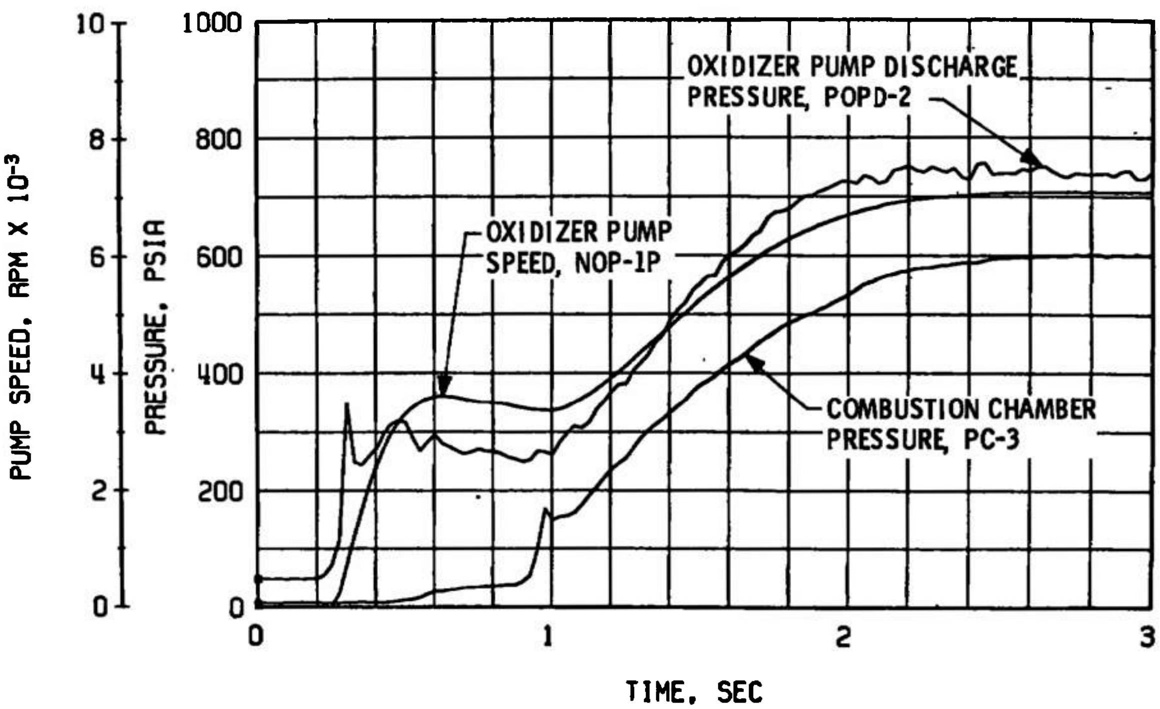


c. Thrust Chamber Throat, TTC-1P

Fig. 21 Thermal Conditioning History of Engine Components, Firing 07D

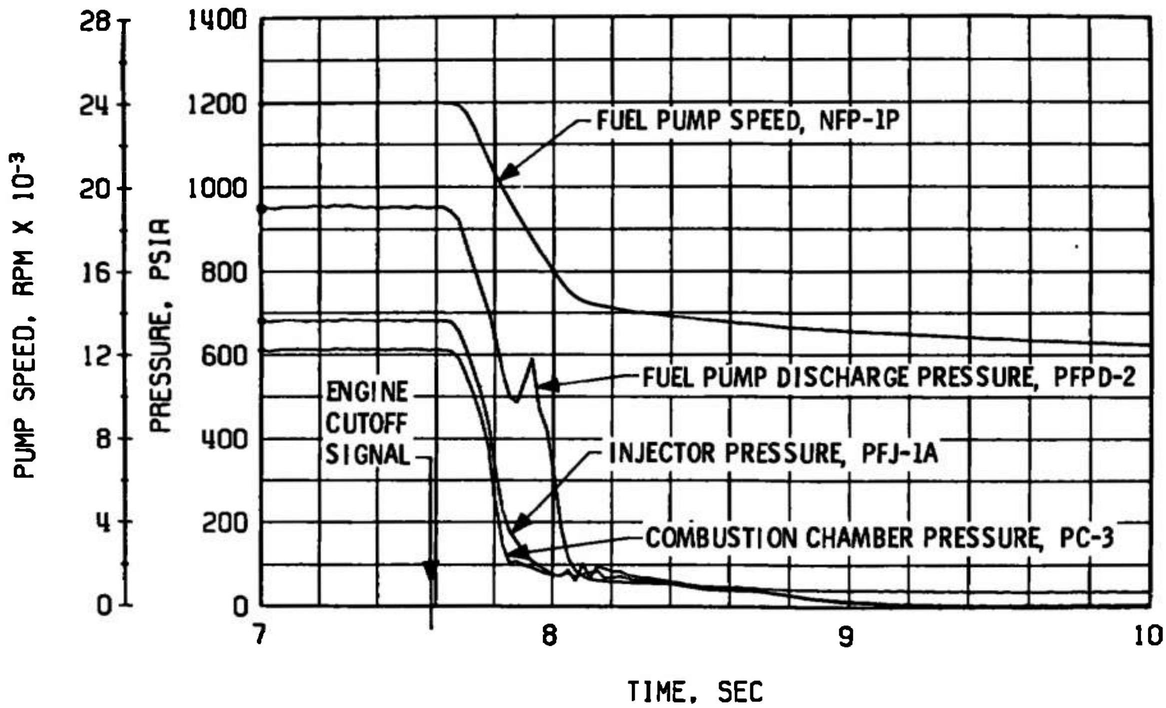


a. Thrust Chamber Fuel System, Start

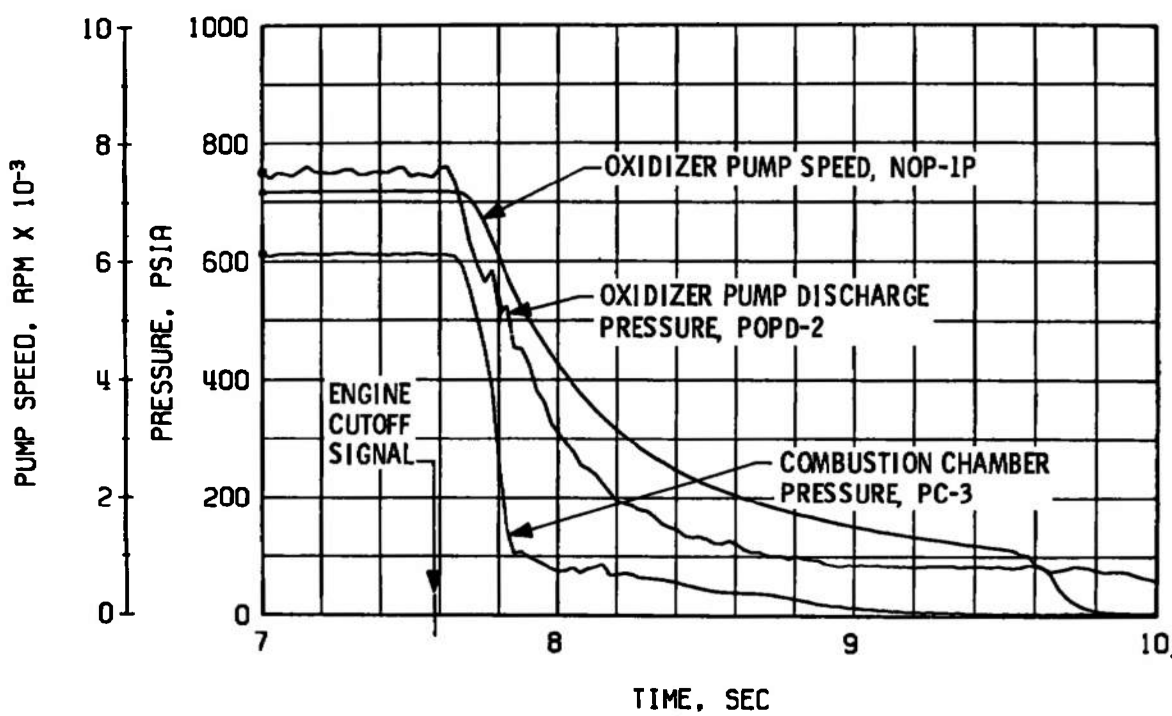


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 07D

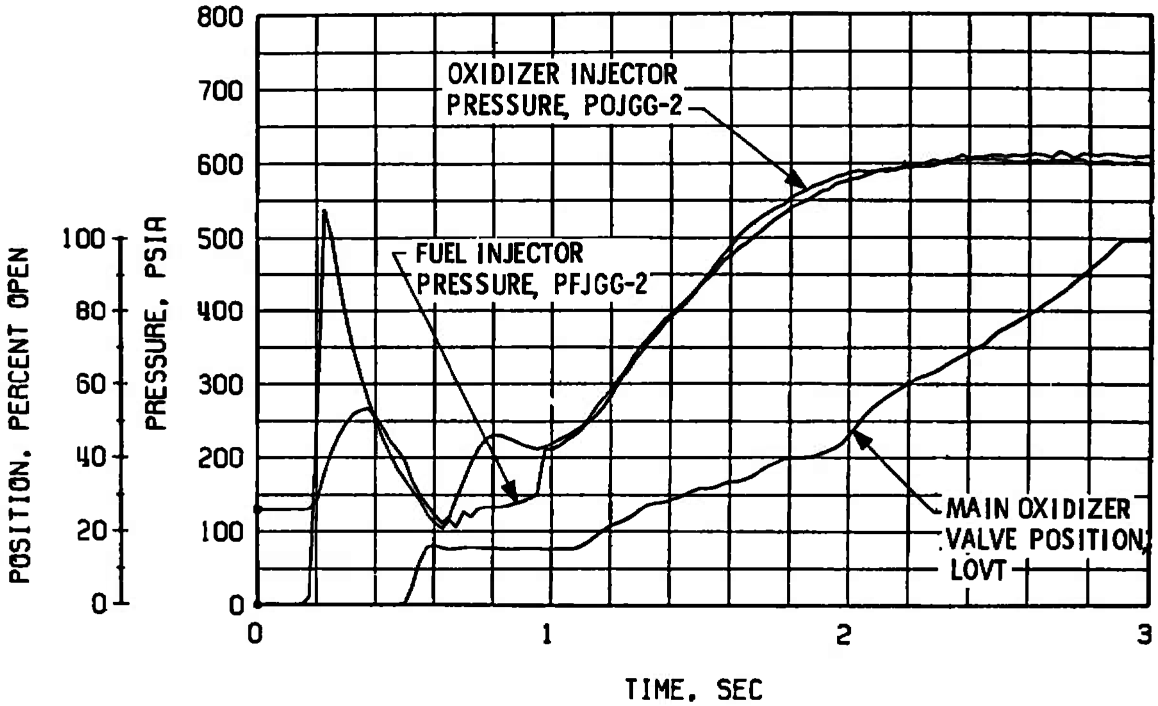


c. Thrust Chamber Fuel System, Shutdown

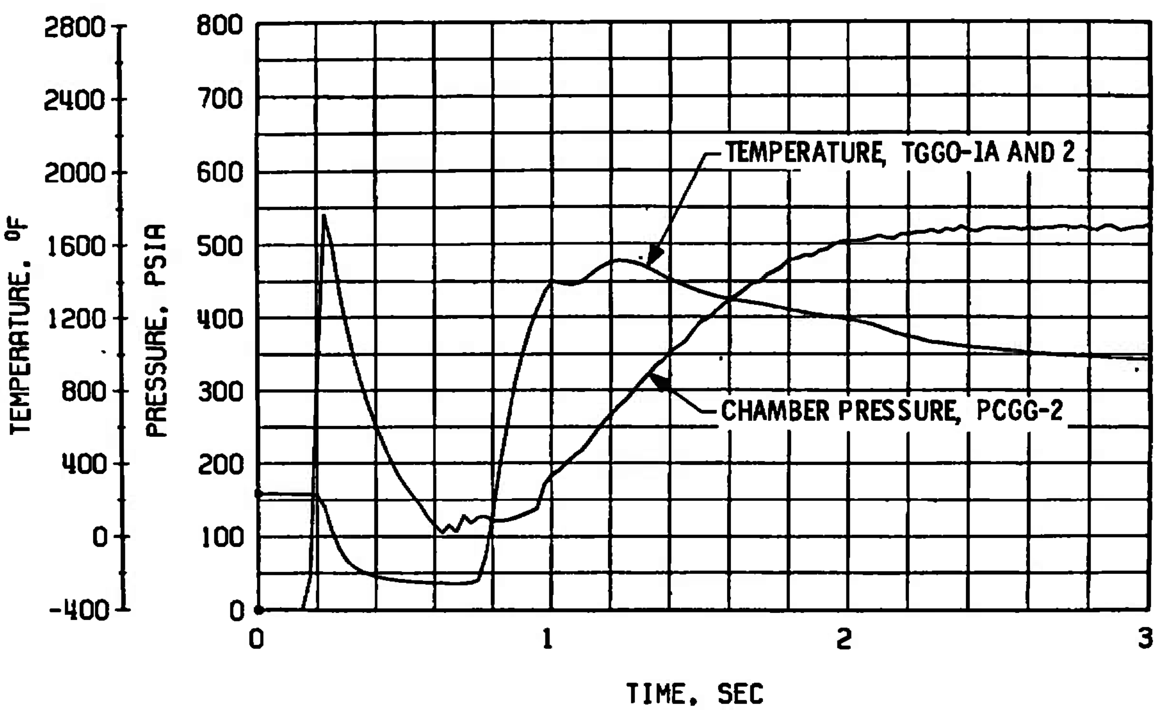


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued

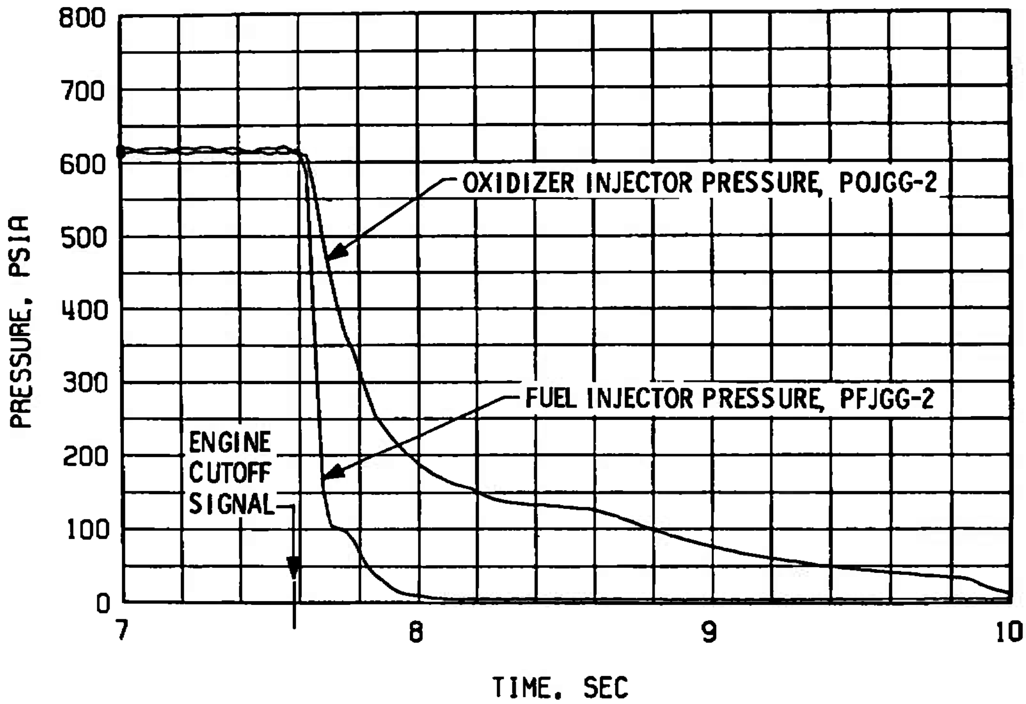


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

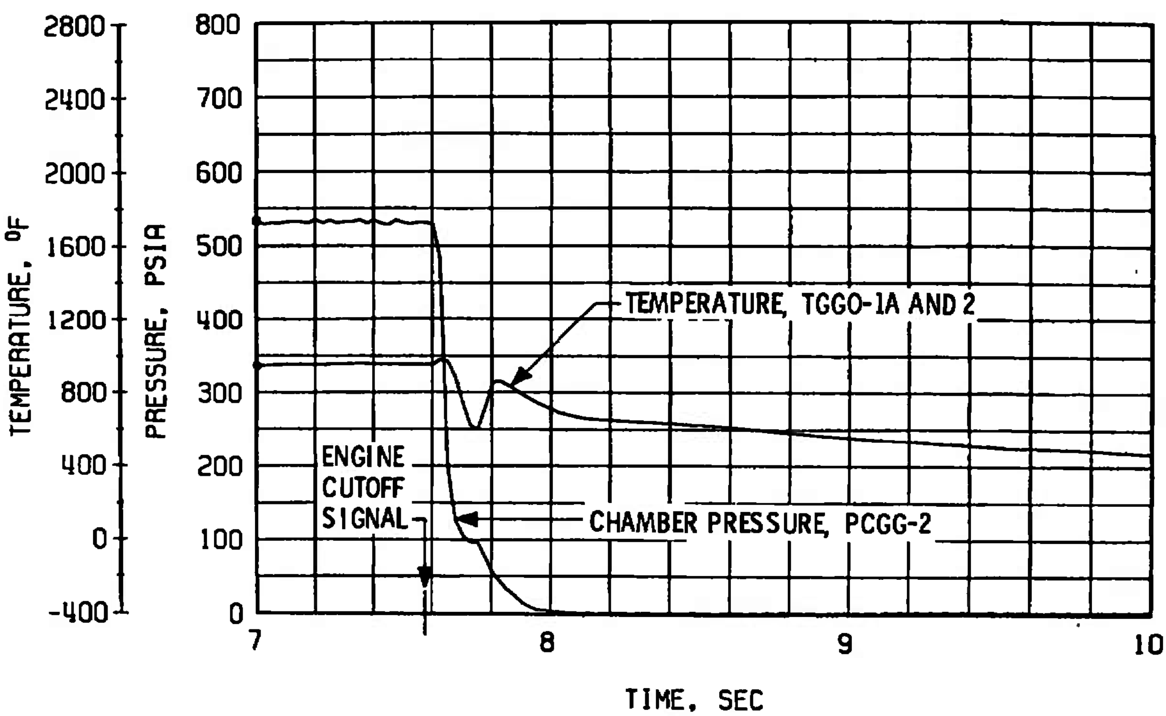


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

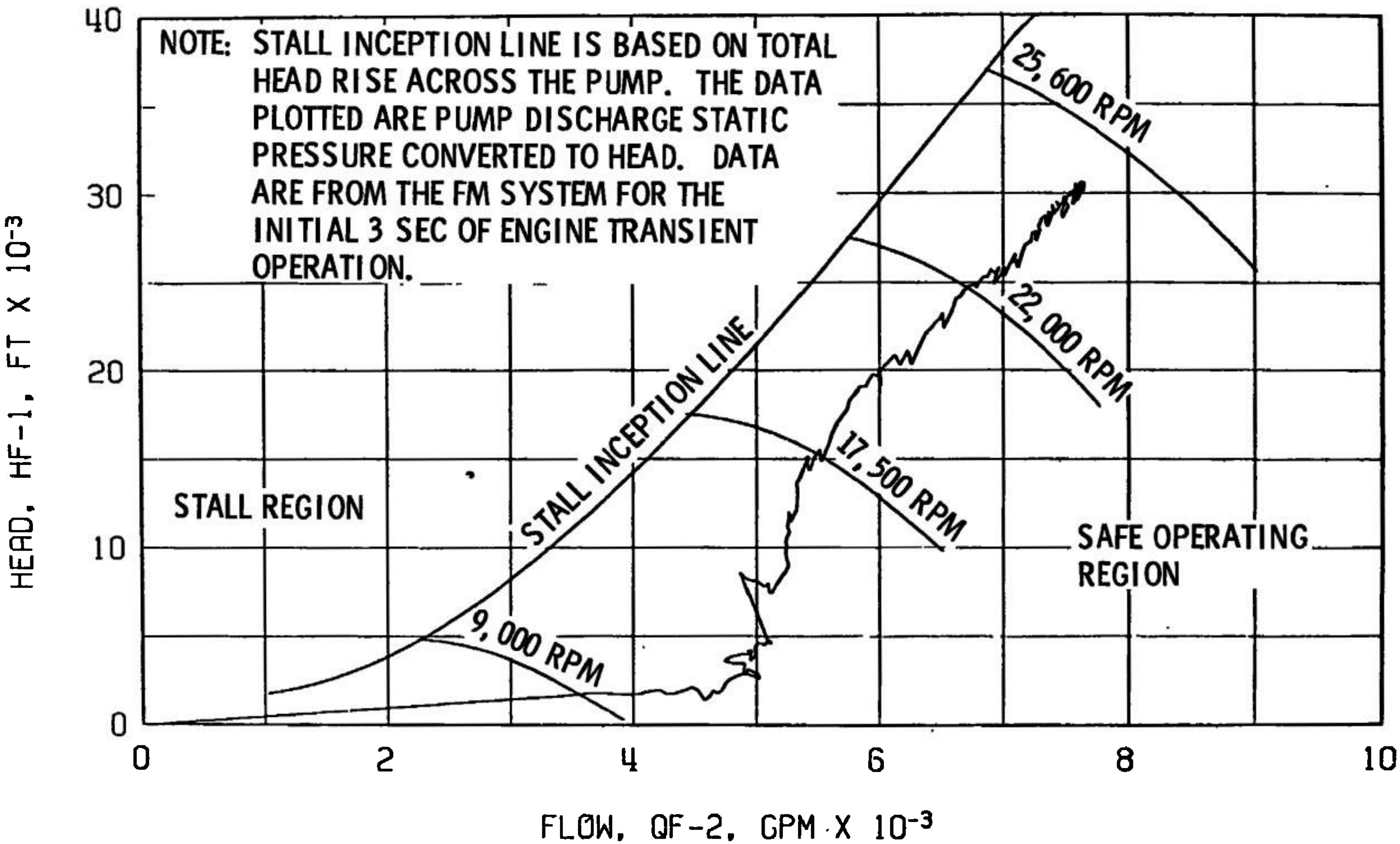


Fig. 23 Fuel Pump Start Transient Performance, Firing 07D

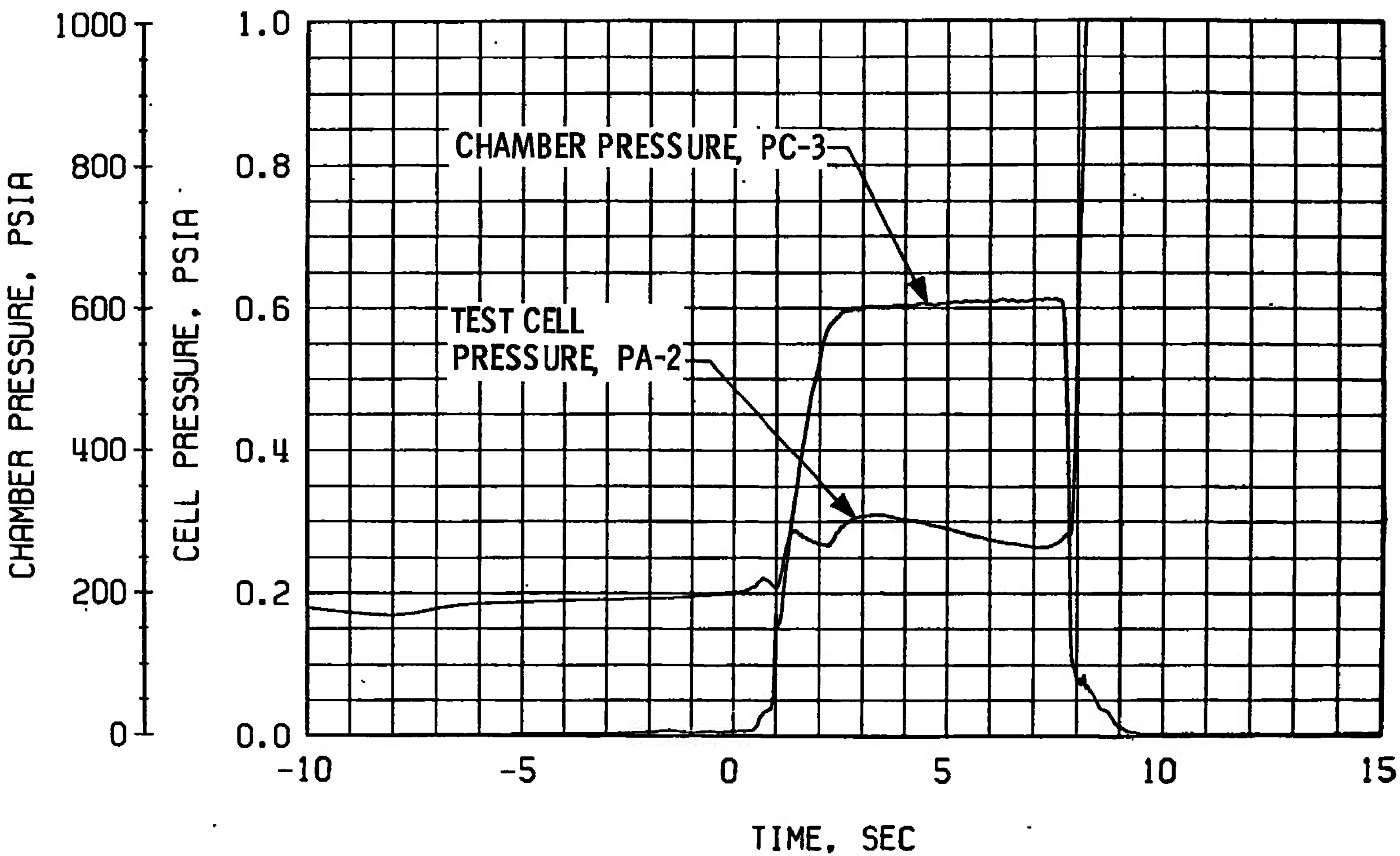
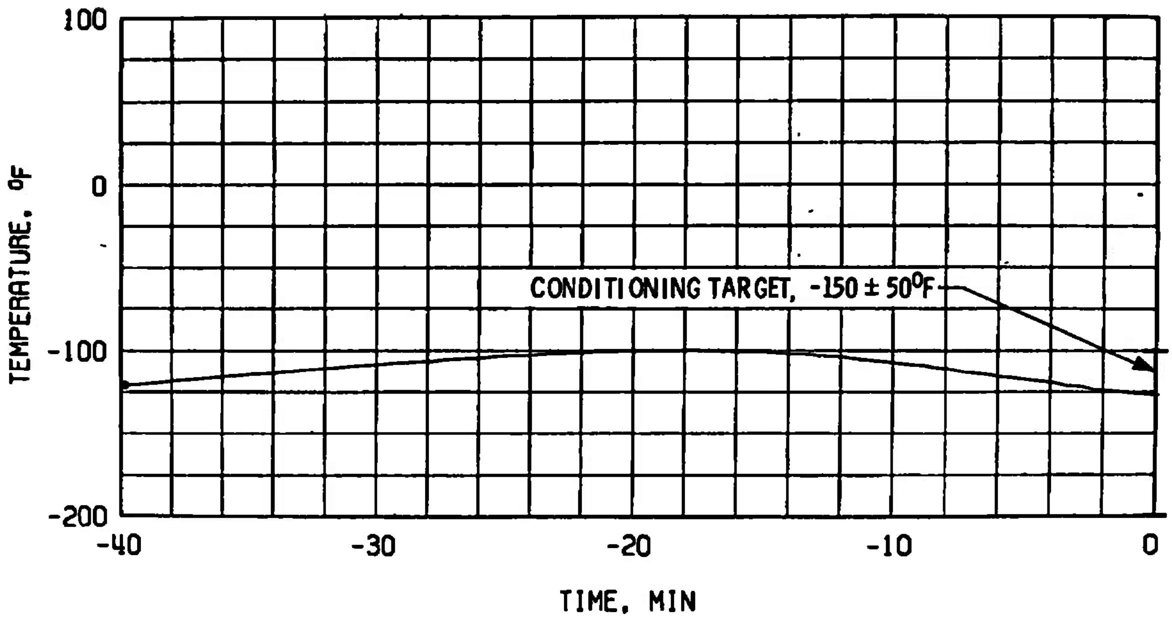
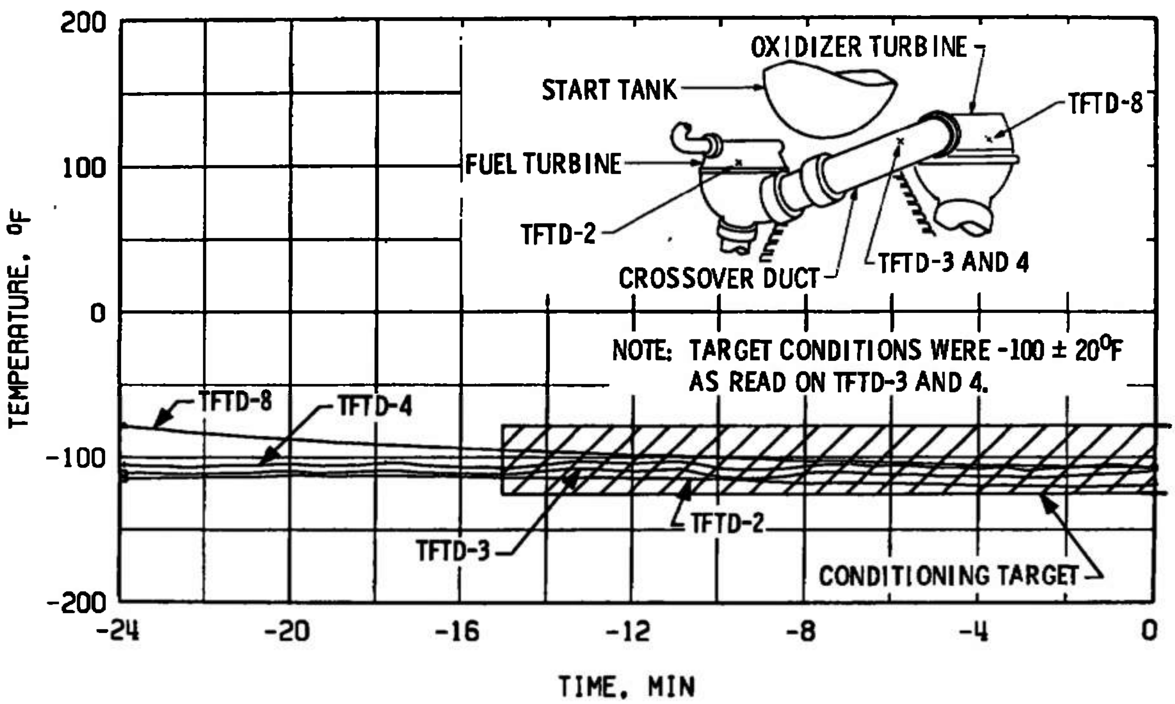


Fig. 24 Engine Ambient and Combustion Chamber Pressure, Firing 07D

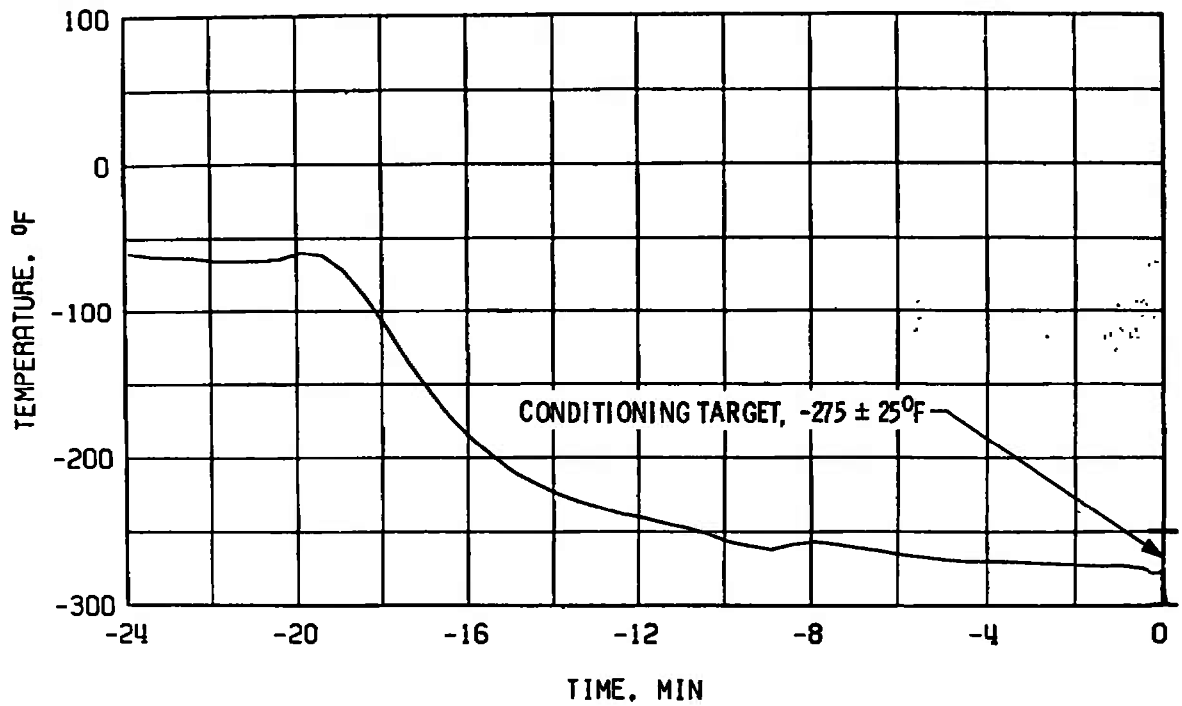


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

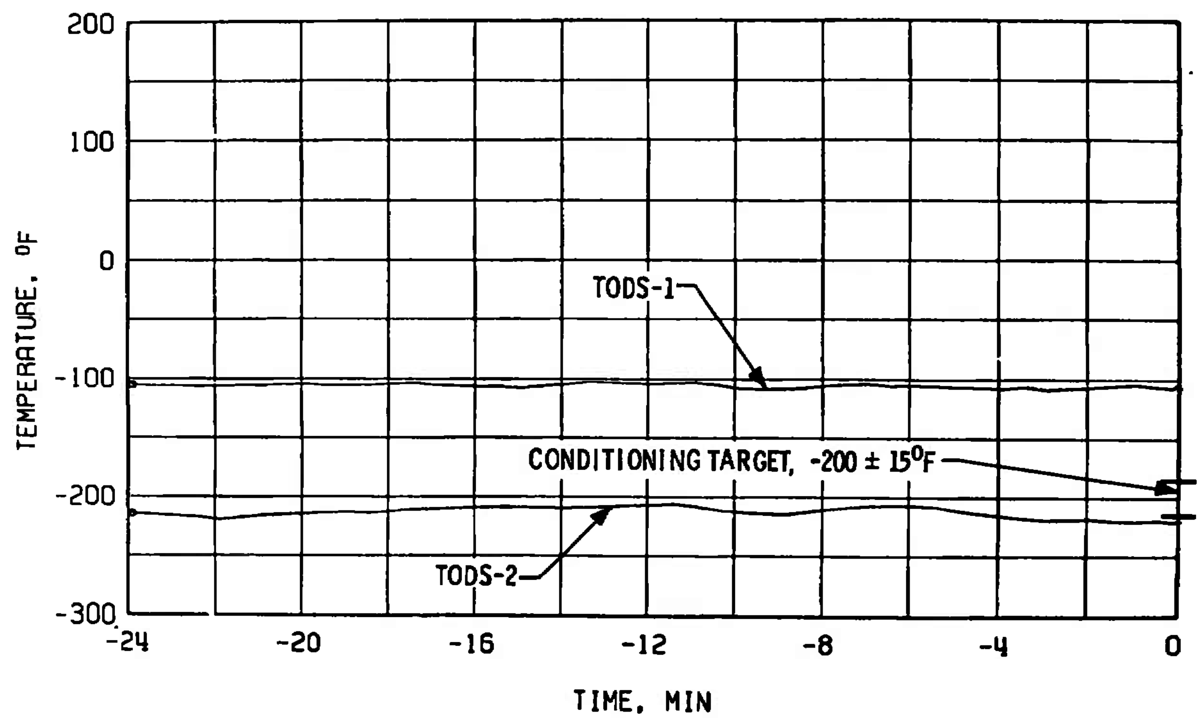


b. Crossover Duct, TFTD

Fig. 25 Thermal Conditioning History of Engine Components, Firing 07E

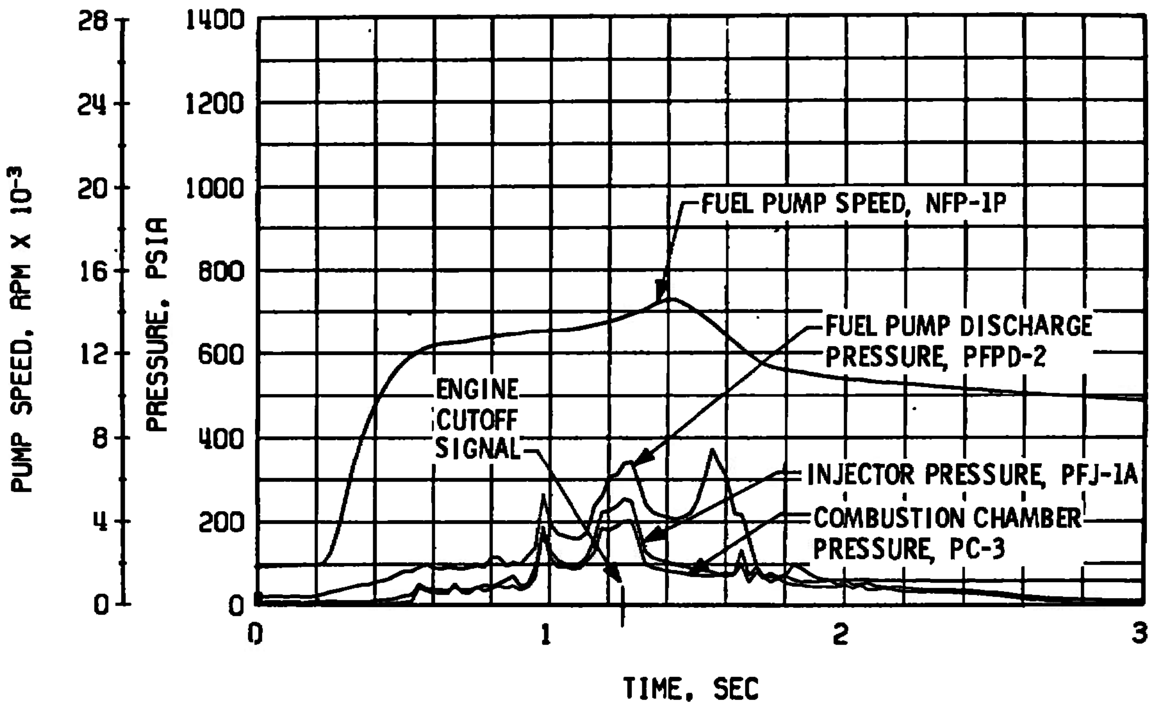


c. Thrust Chamber Throat, TTC-1P

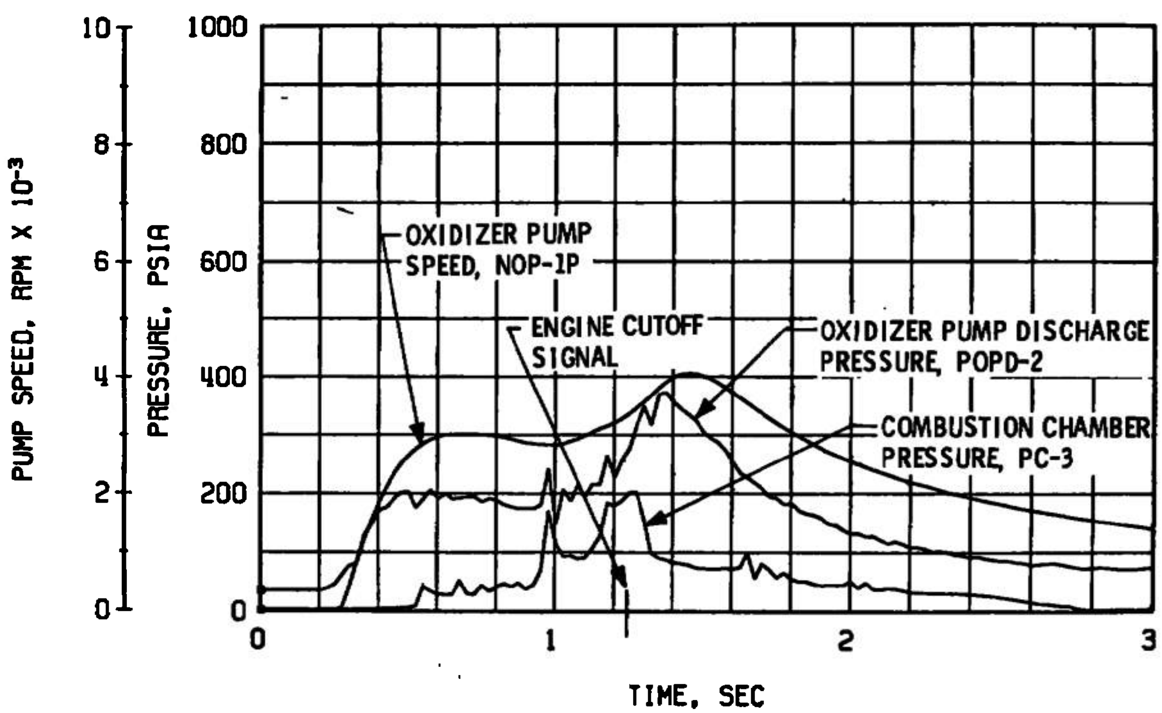


d. Oxidizer Dome, TODS

Fig. 25 Concluded

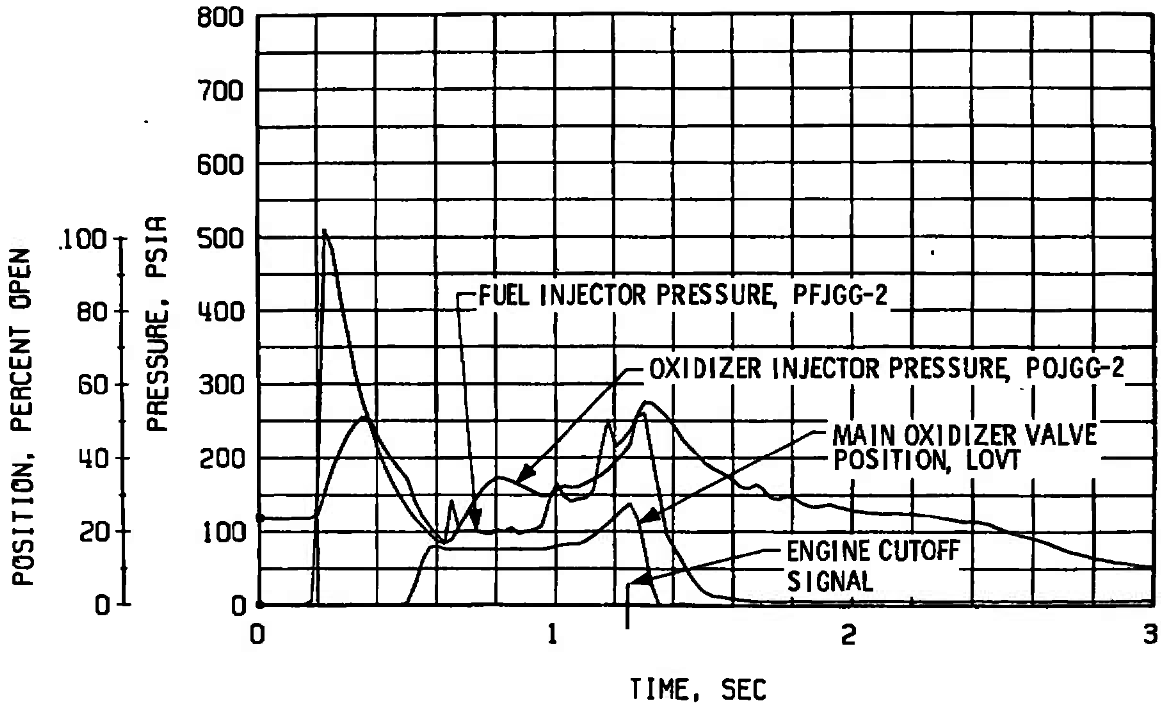


a. Thrust Chamber Fuel System, Start and Shutdown

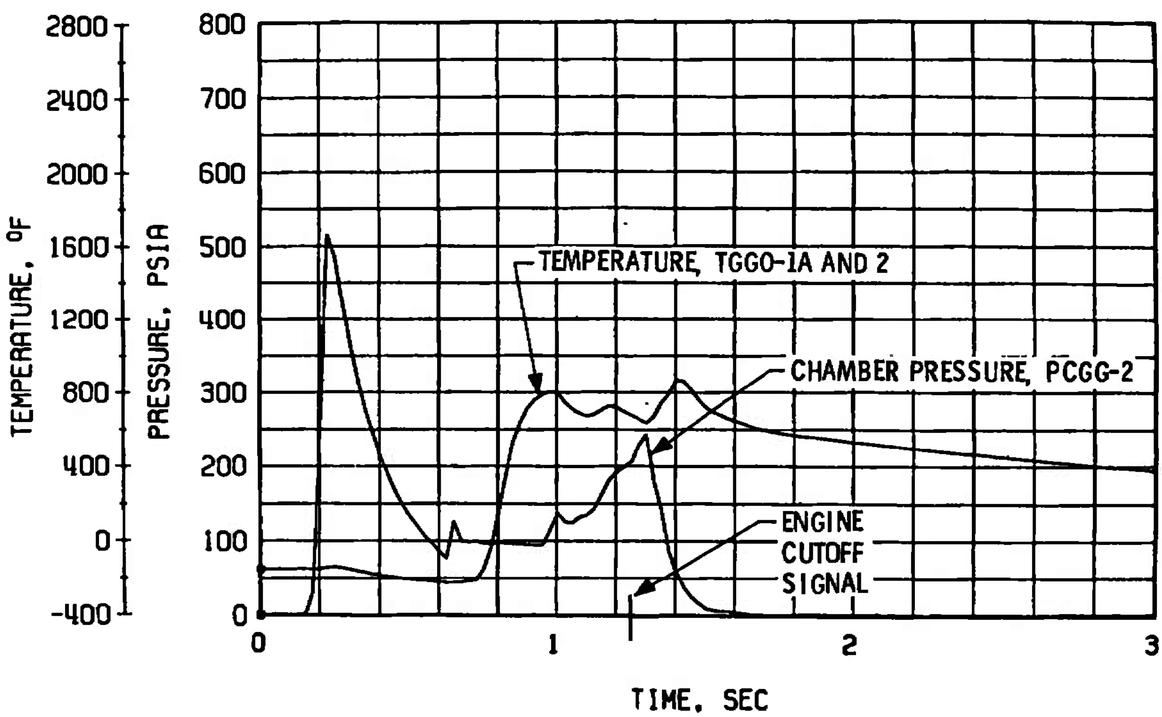


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 26 Engine Transient Operation, Firing 07E



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



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

Fig. 26 Concluded

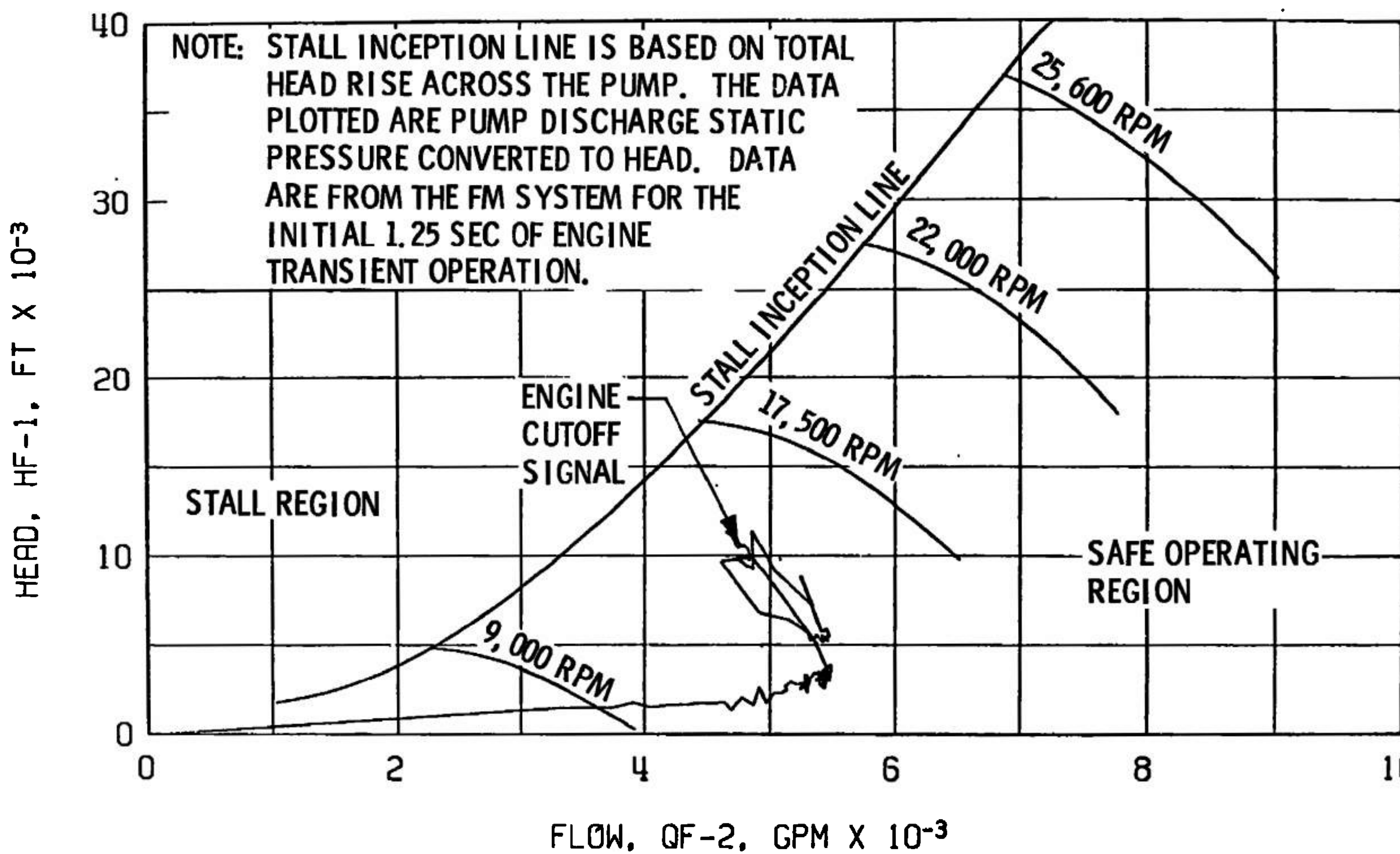


Fig. 27 Fuel Pump Start Transient Performance, Firing 07E

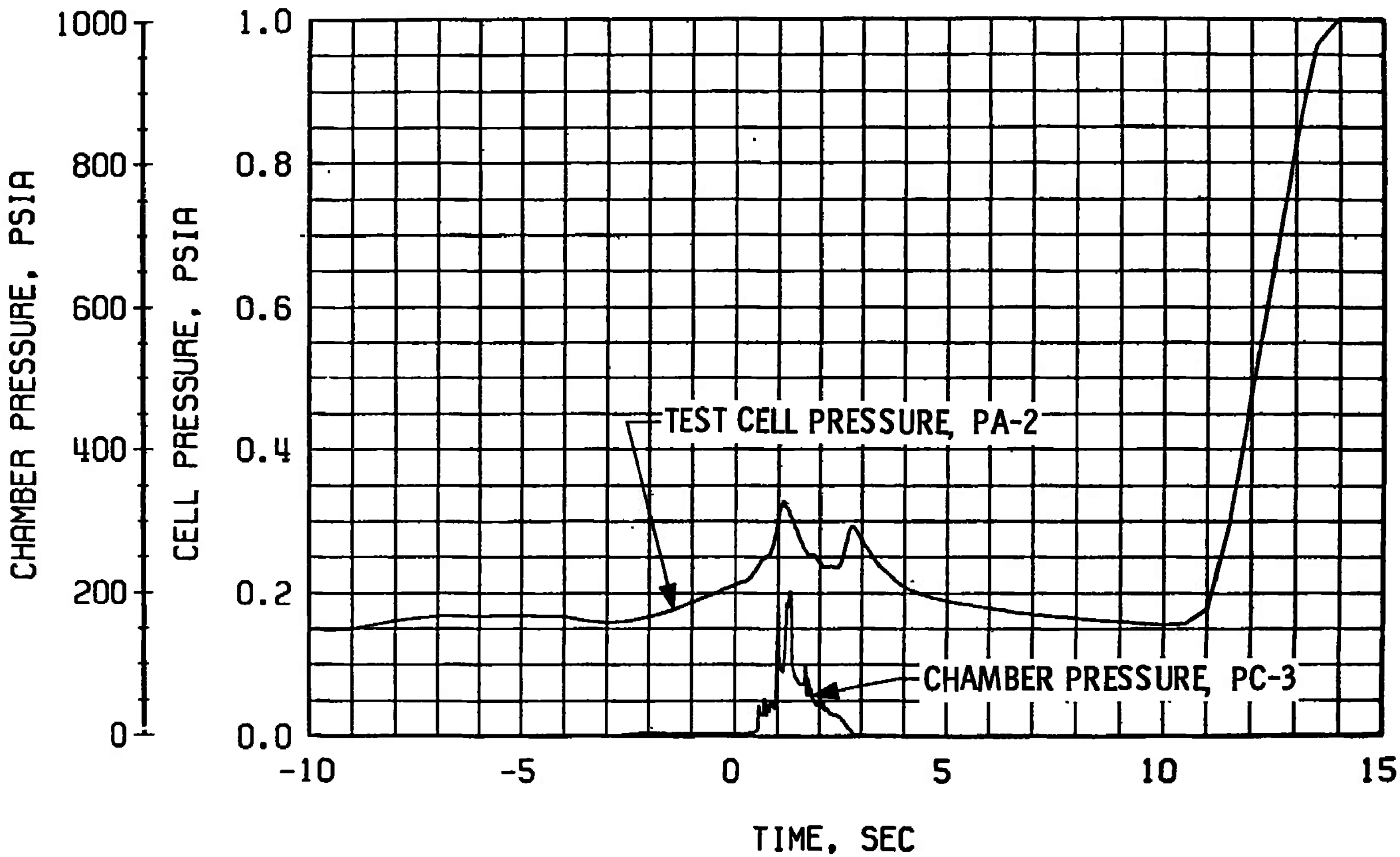
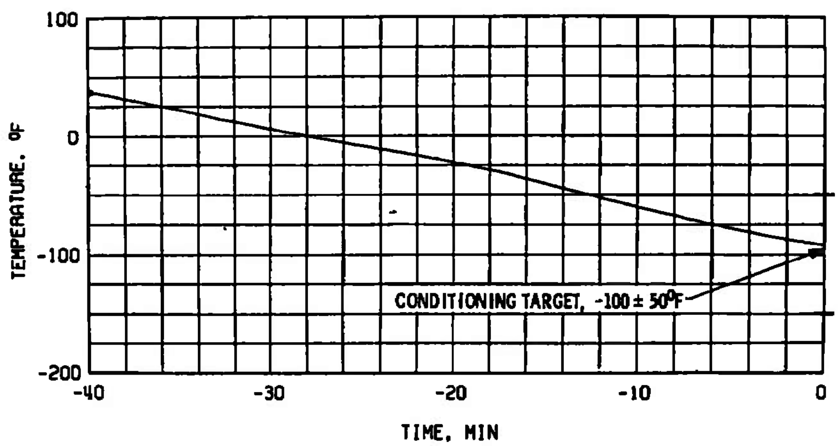
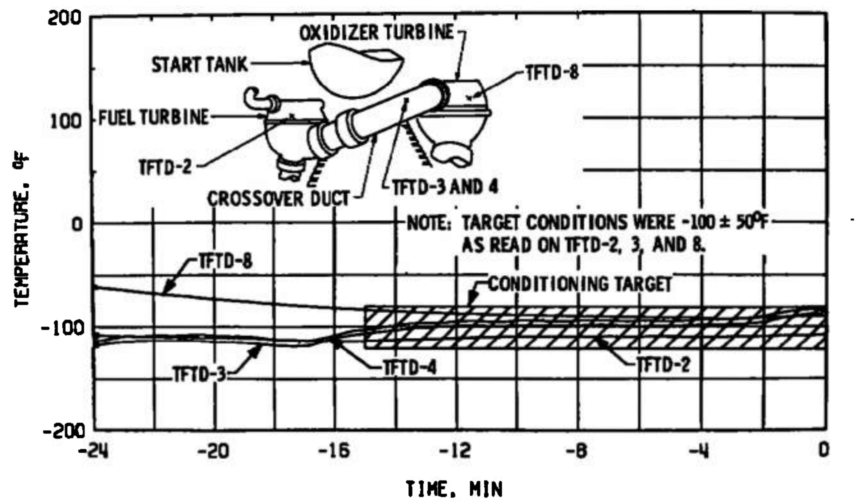


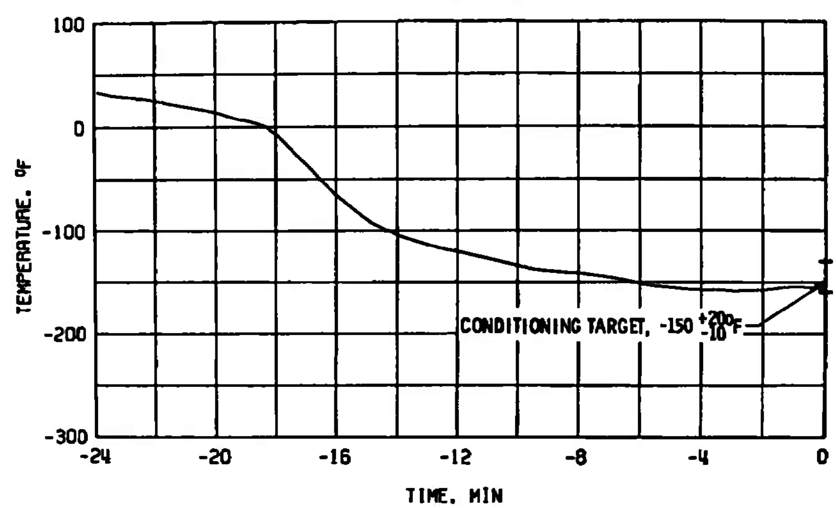
Fig. 28 Engine Ambient and Combustion Chamber Pressure, Firing 07E



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

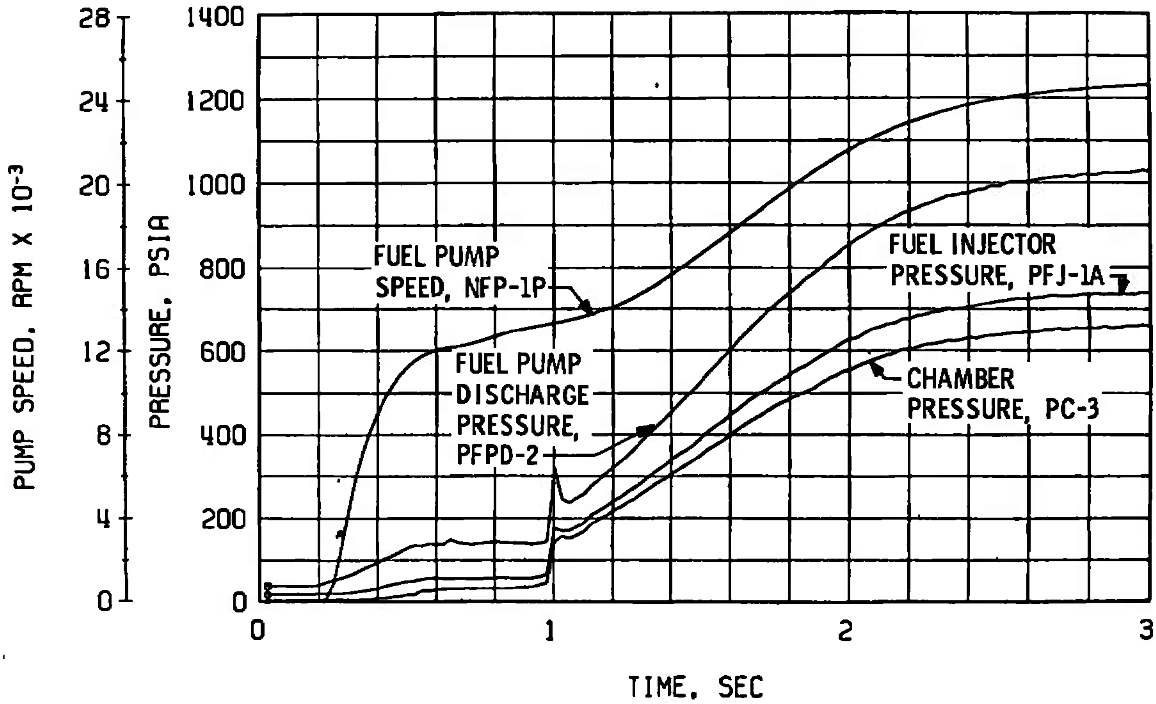


b. Crossover Duct, TFTD

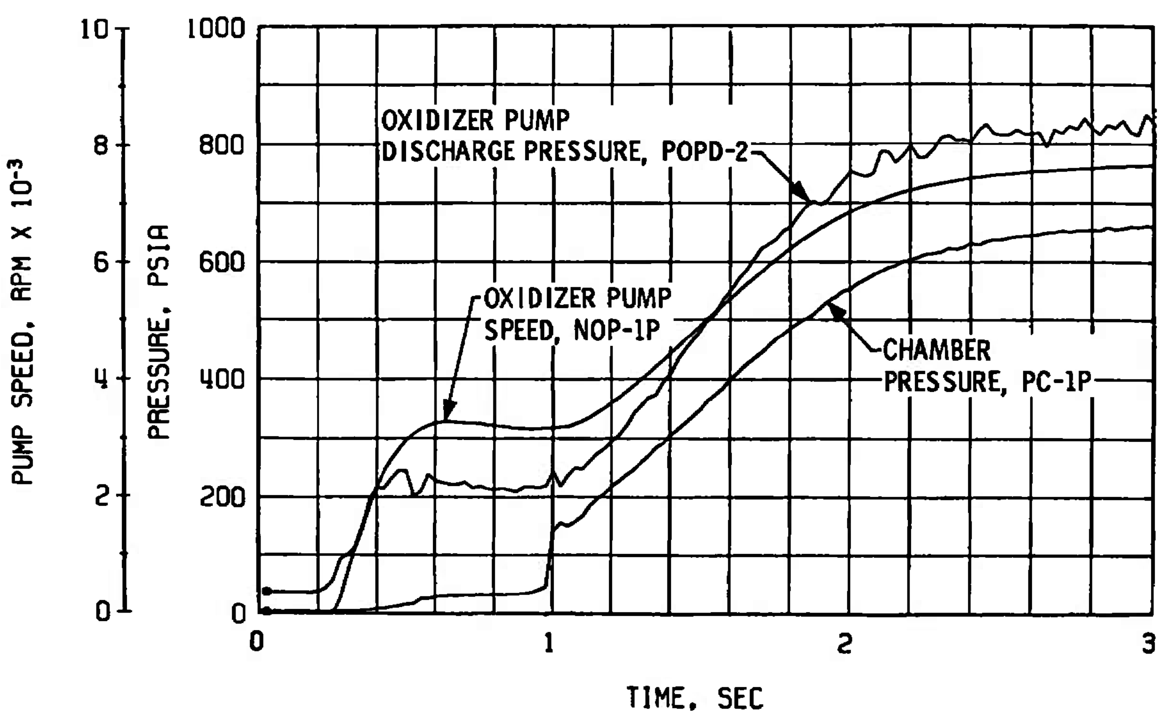


c. Thrust Chamber, TTC-1P

Fig. 29 Thermal Conditioning History of Engine Components, Firing 08A

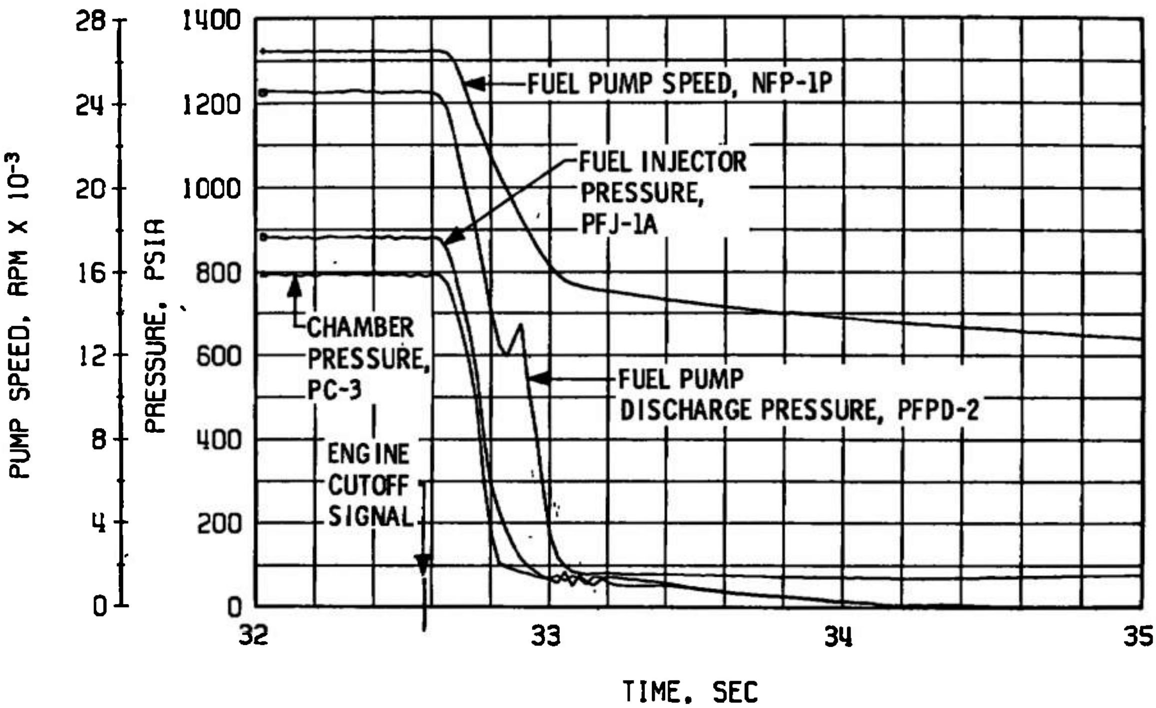


a. Thrust Chamber Fuel System, Start

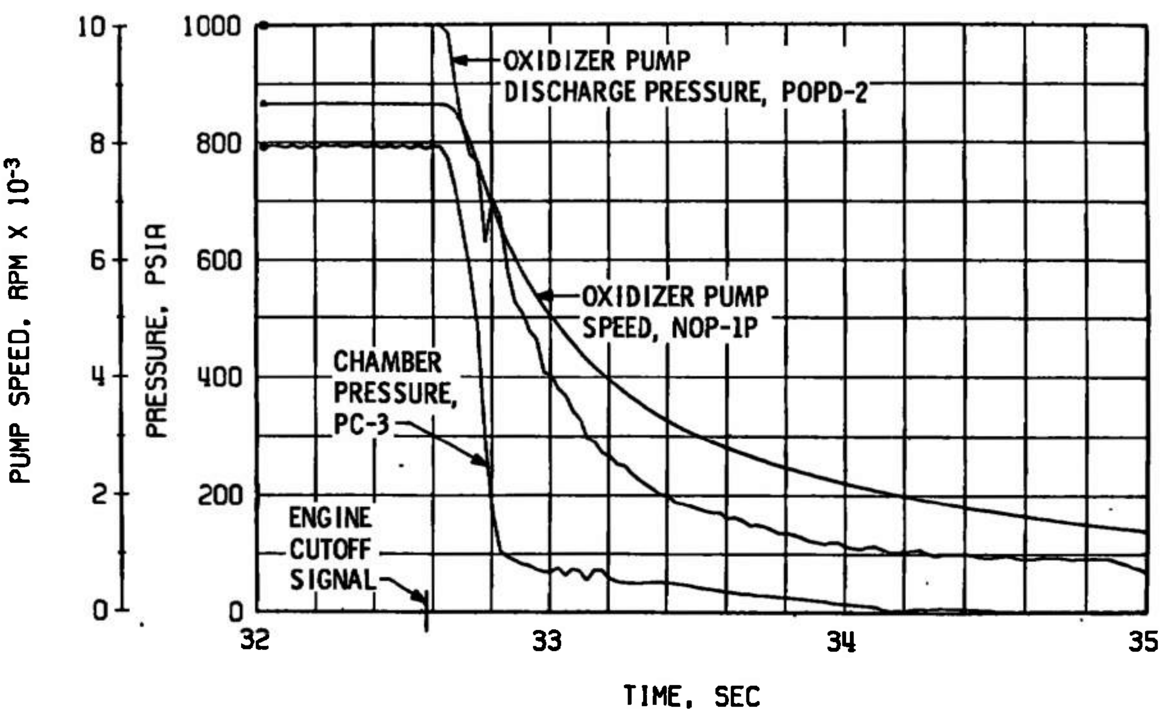


b. Thrust Chamber Oxidizer System, Start

Fig. 30 Engine Transient Operation, Firing 08A

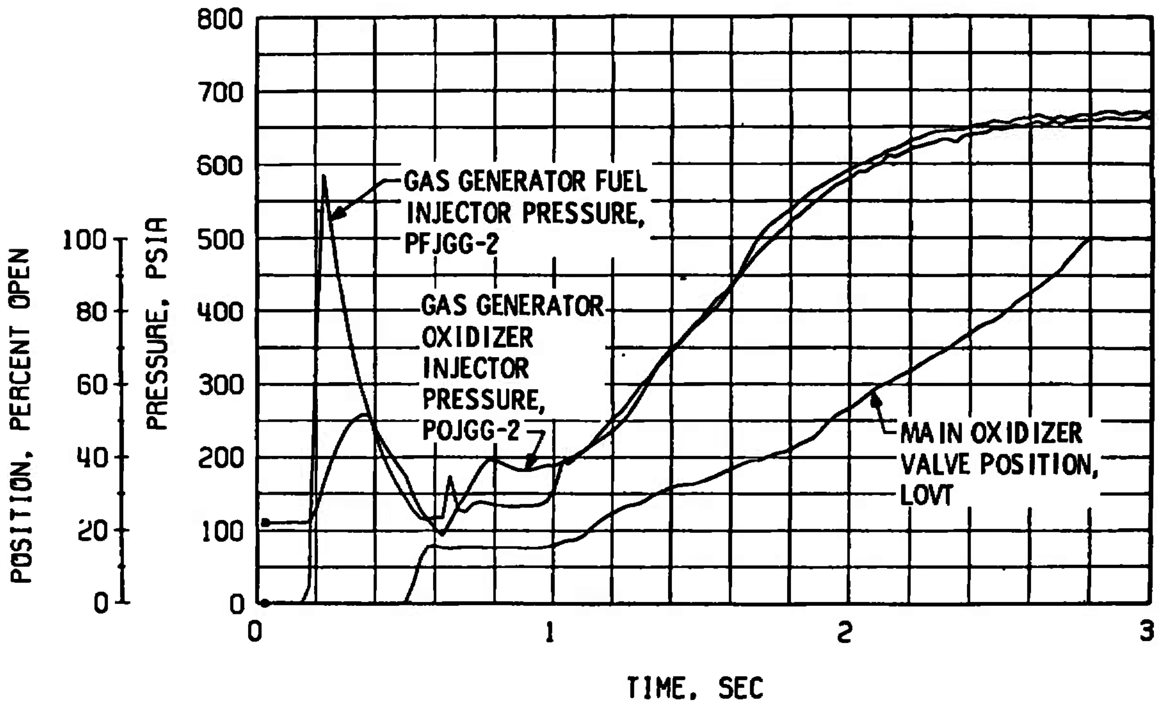


c. Thrust Chamber Fuel System, Shutdown

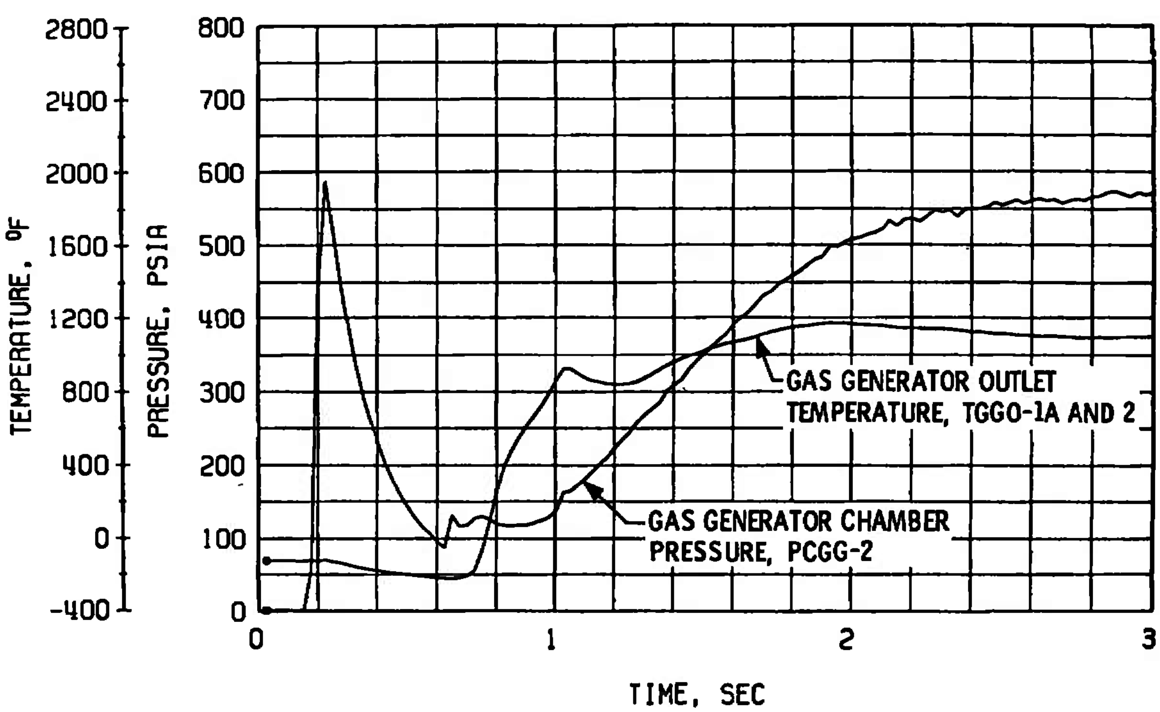


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 30 Continued

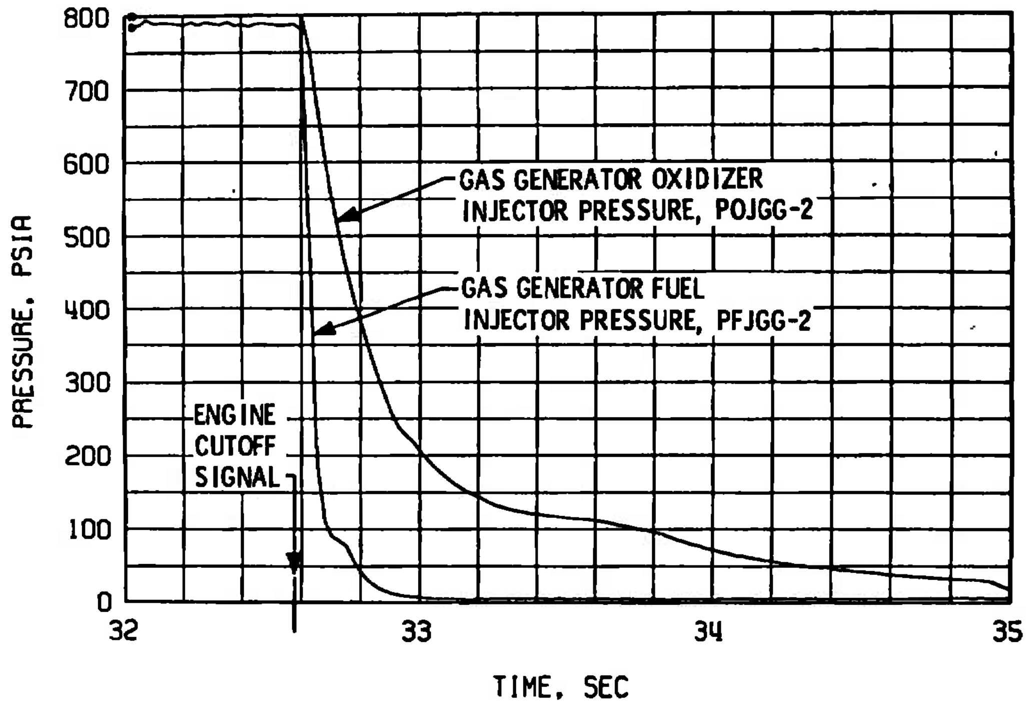


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

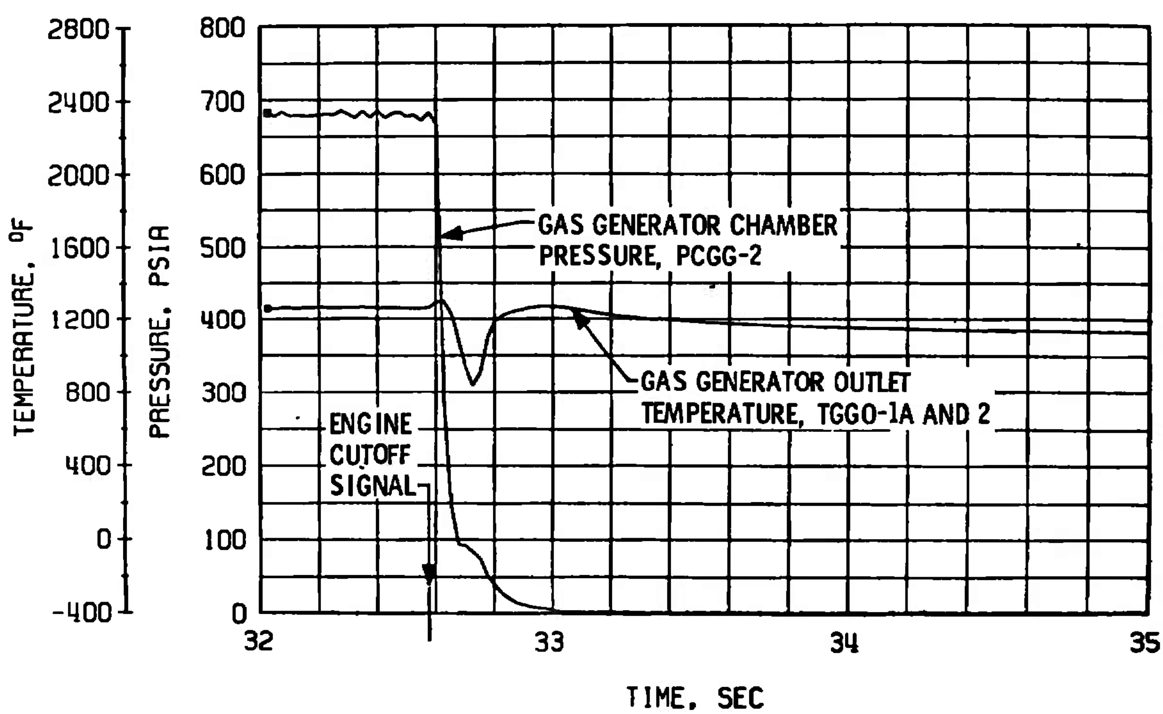


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 30 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 30 Concluded

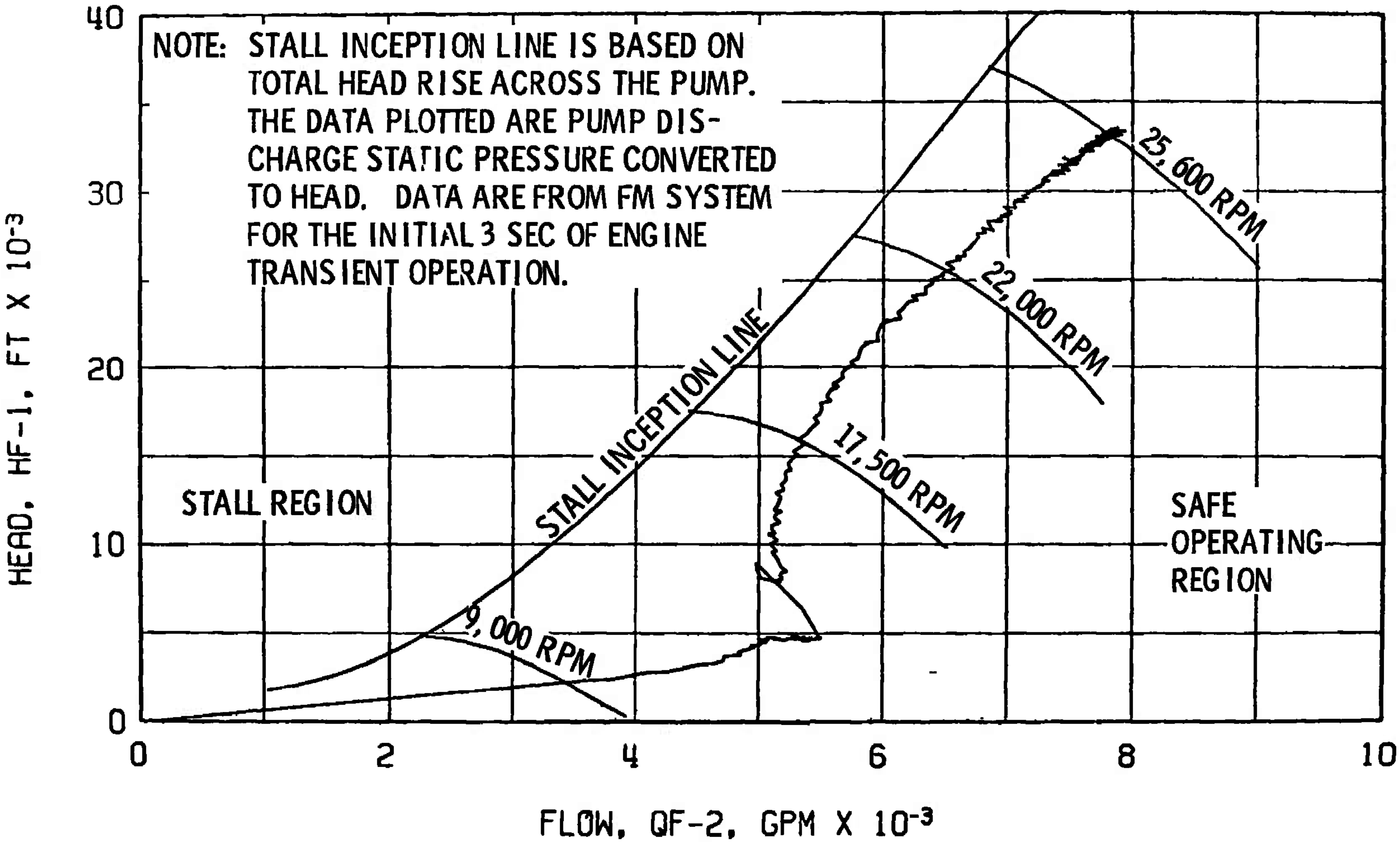


Fig. 31 Fuel Pump Start Transient Performance, Firing 08A

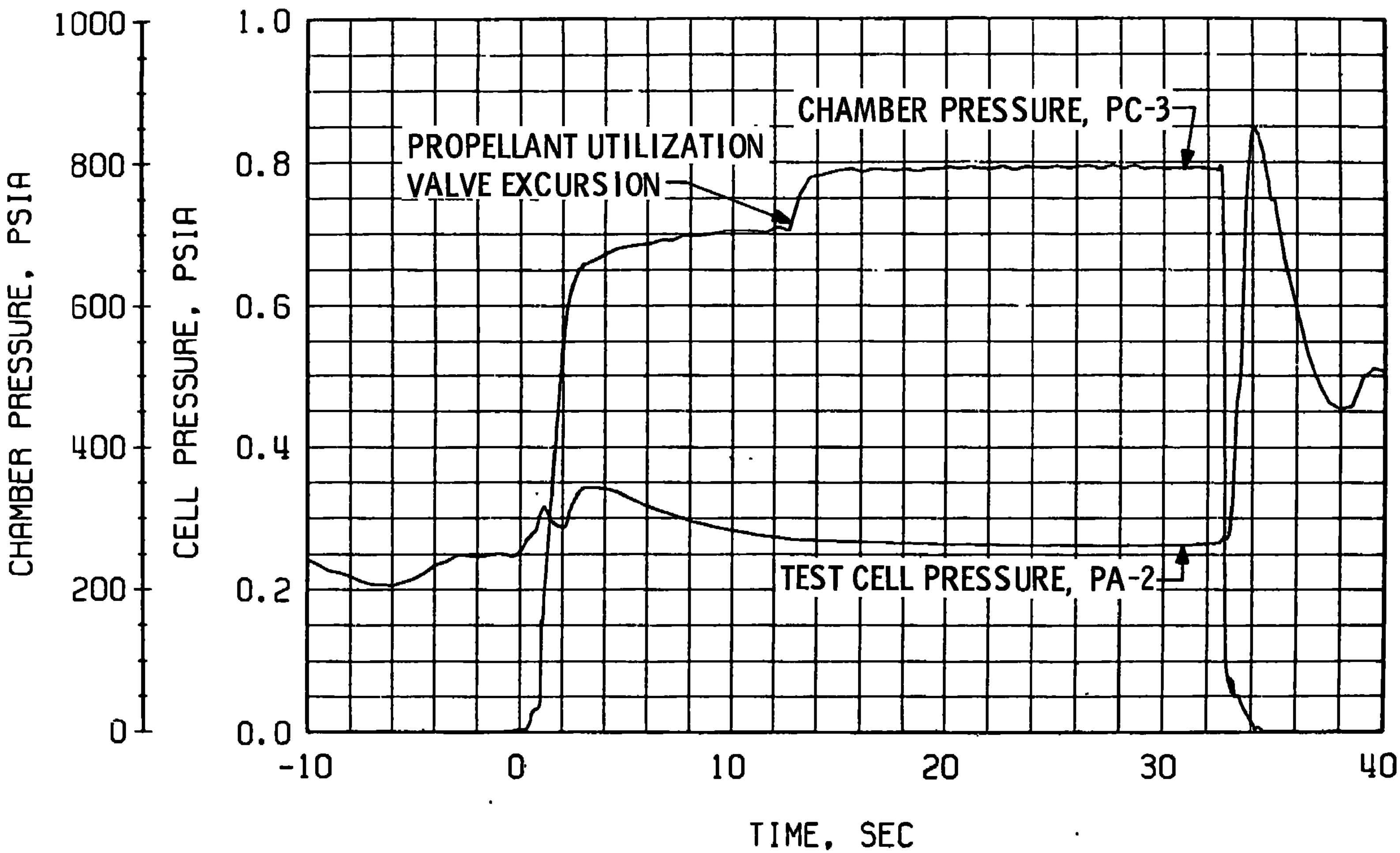
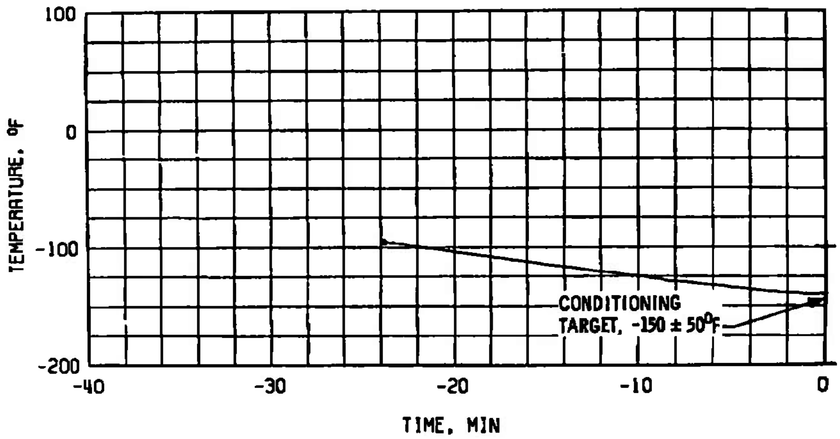
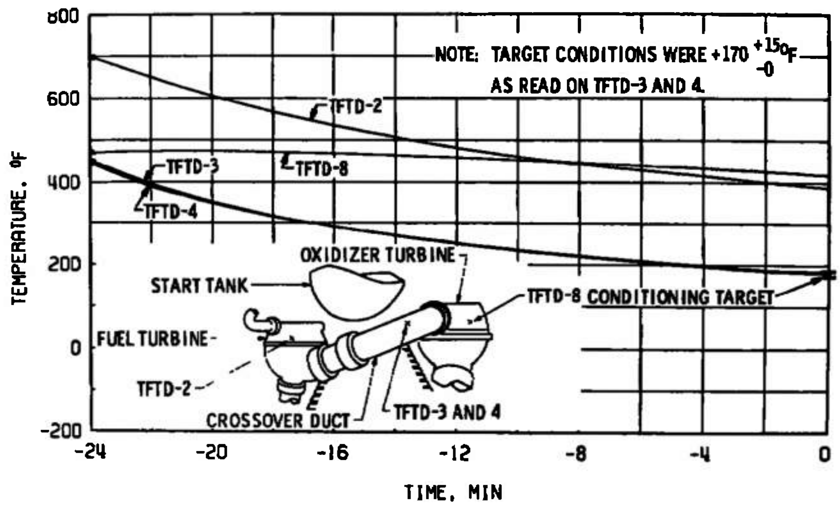


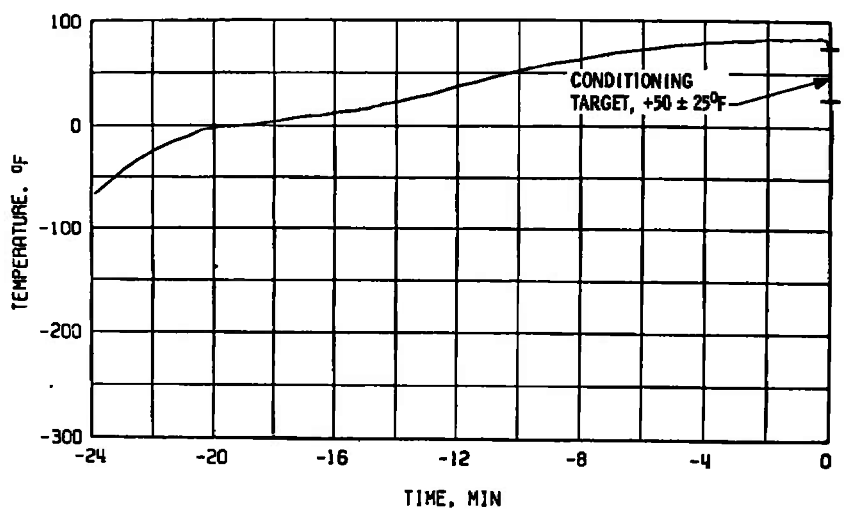
Fig. 32 Engine Ambient and Combustion Chamber Pressure, Firing 08A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

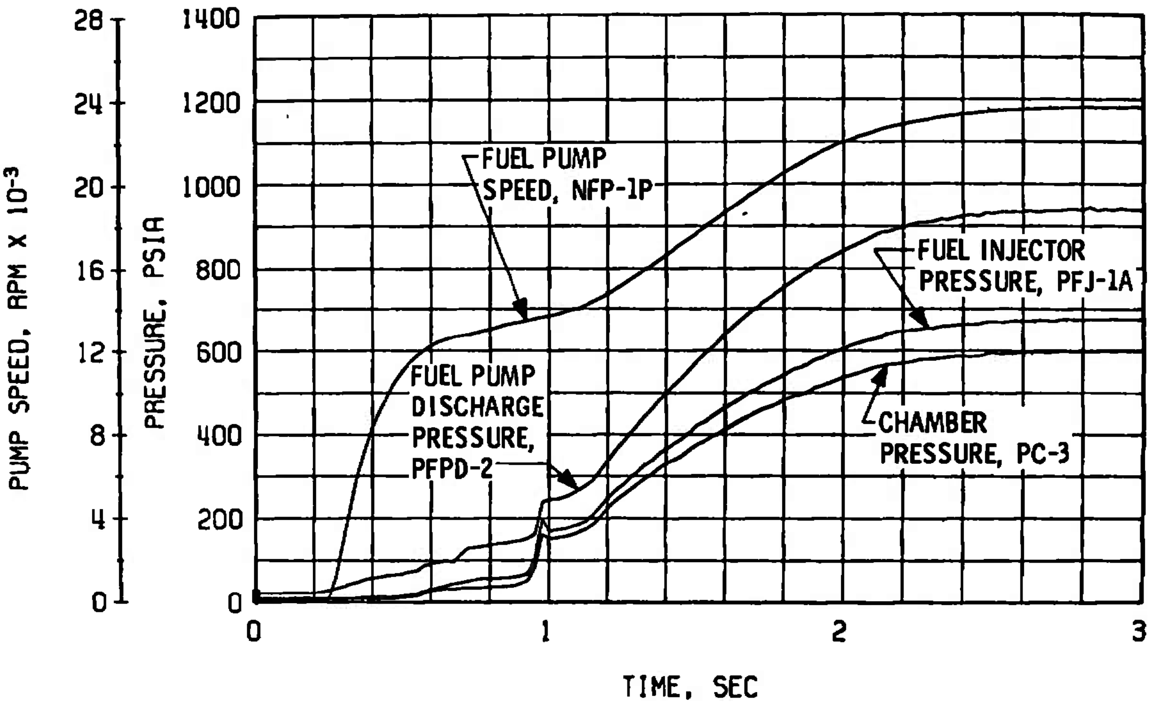


b. Crossover Duct, TFTD

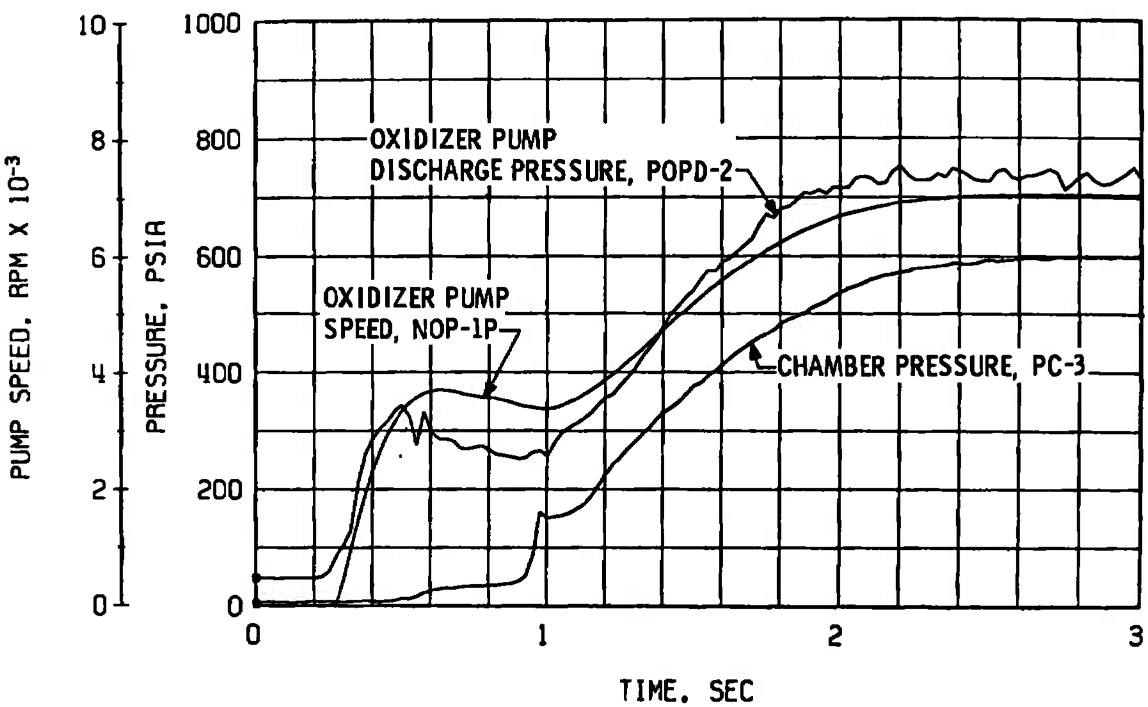


c. Thrust Chamber, TTC-1P

Fig. 33 Thermal Conditioning History of Engine Components, Firing 08B

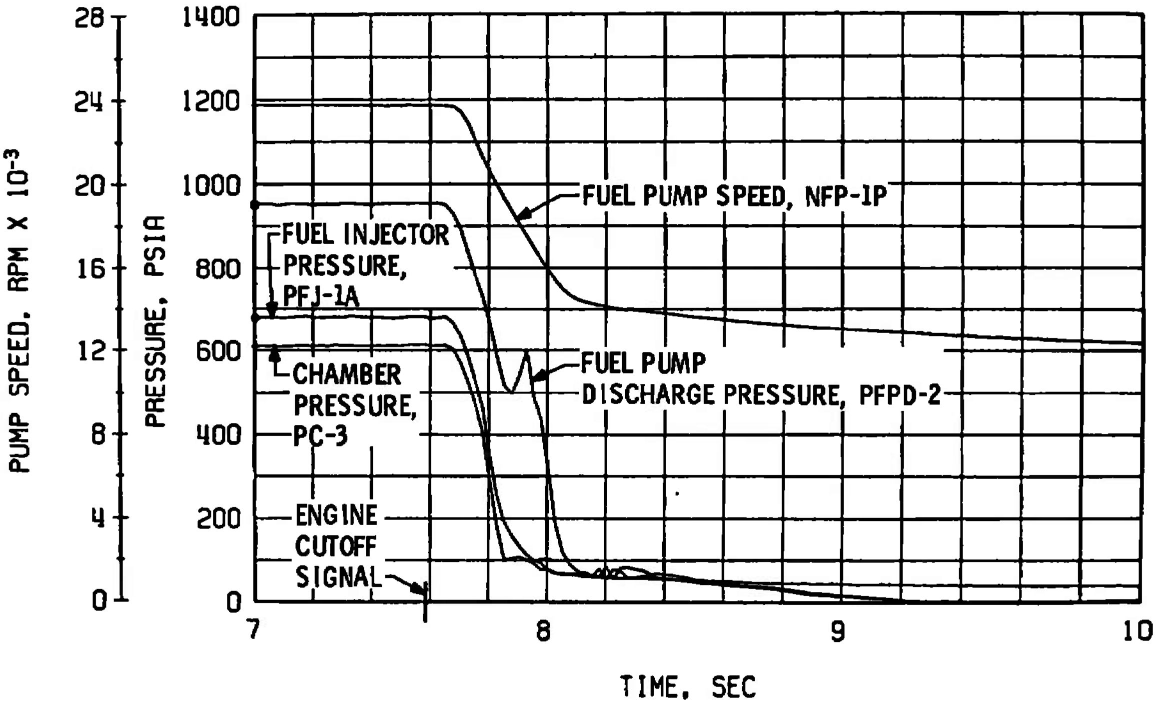


a. Thrust Chamber Fuel System, Start

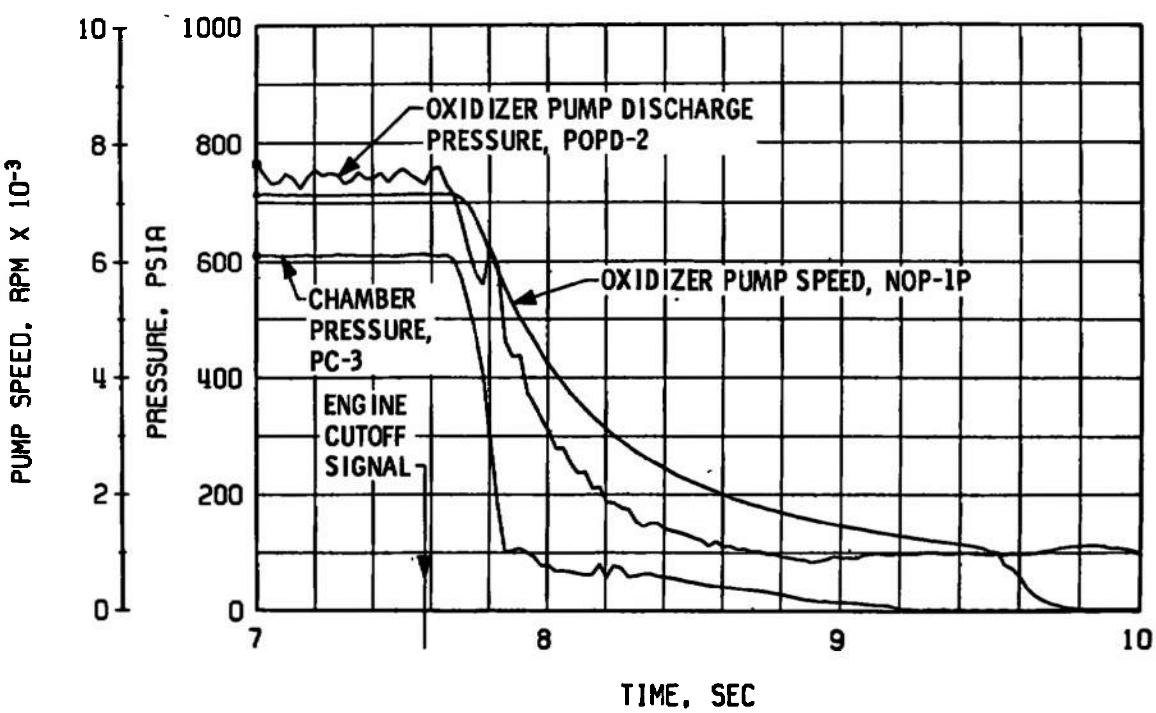


b. Thrust Chamber Oxidizer System, Start

Fig. 34 Engine Transient Operation, Firing 08B

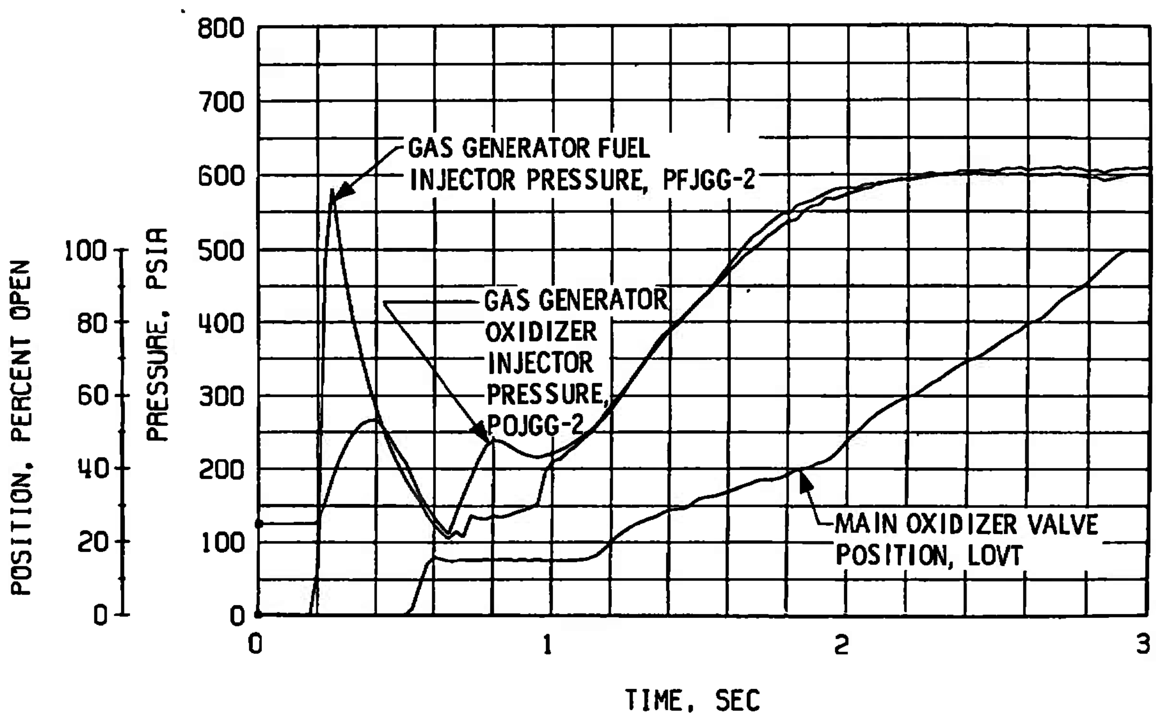


c. Thrust Chamber Fuel System, Shutdown

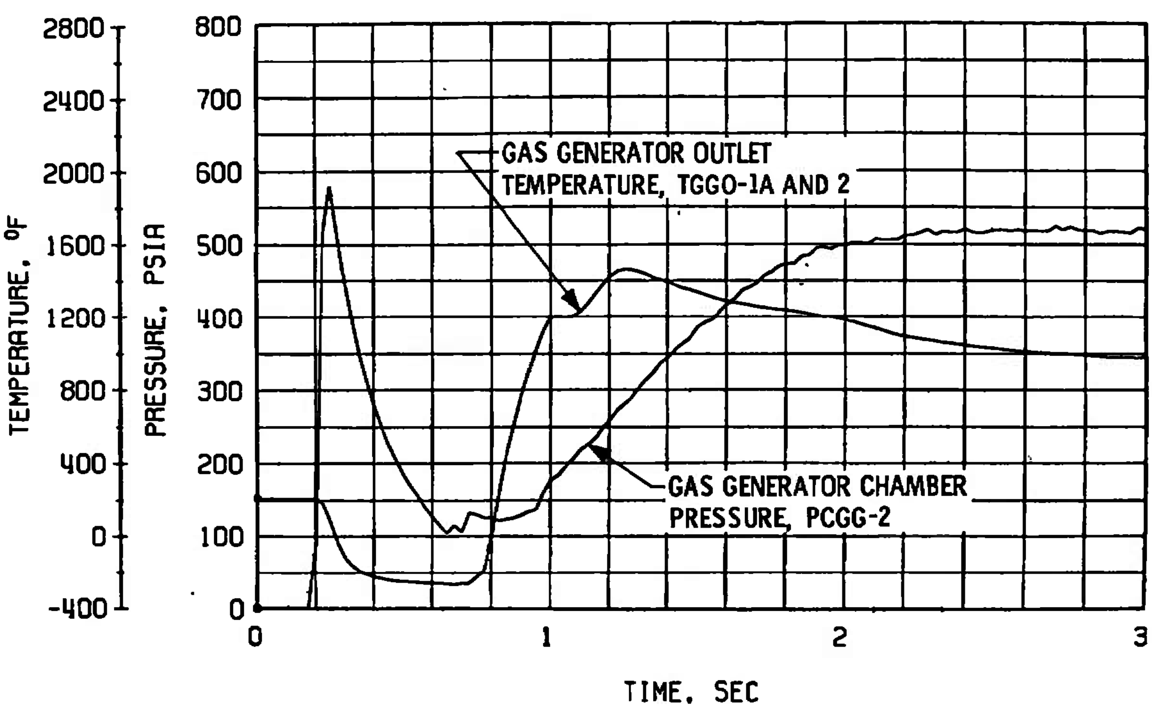


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 34 Continued

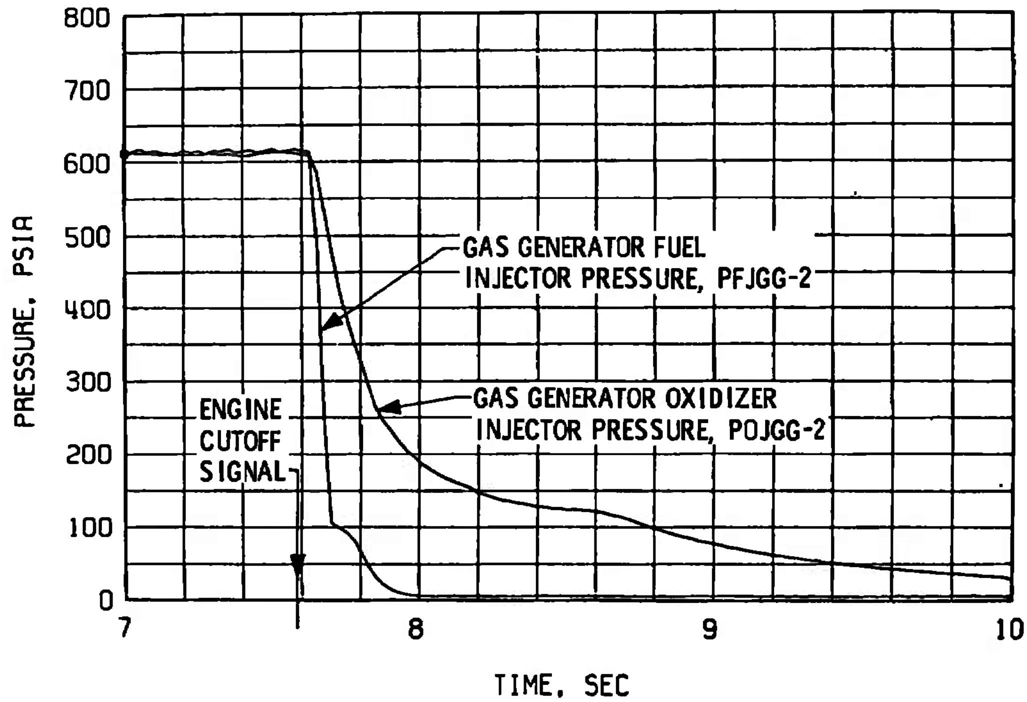


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

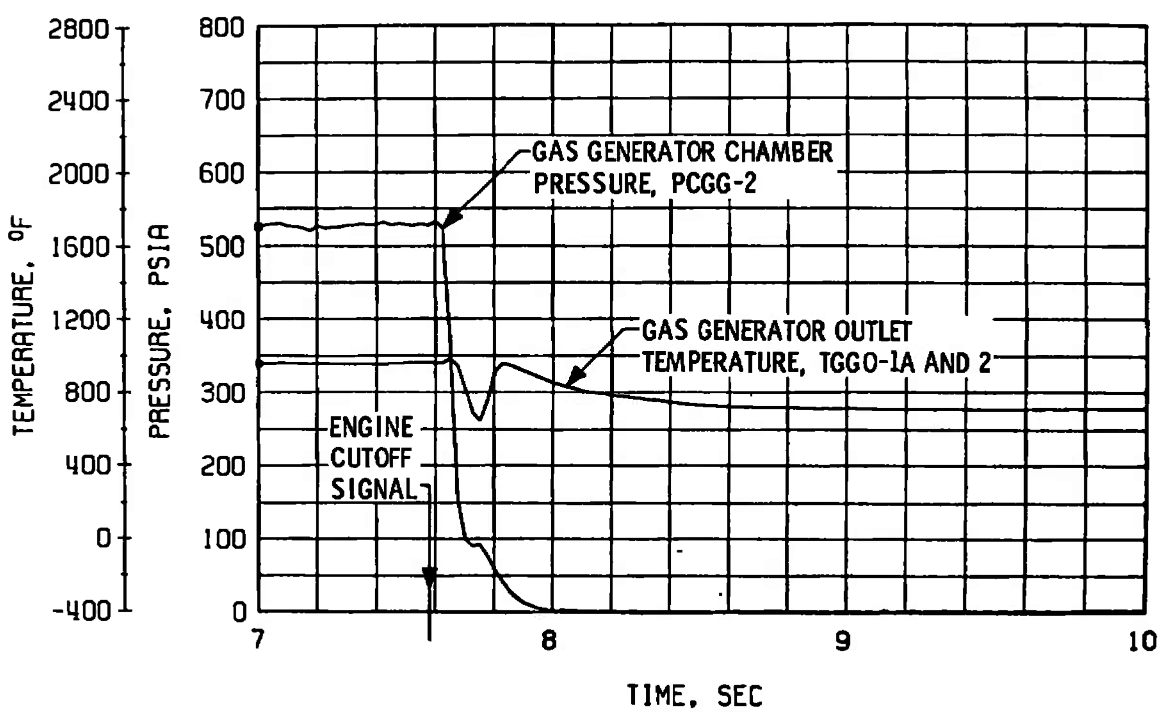


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 34 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 34 Concluded

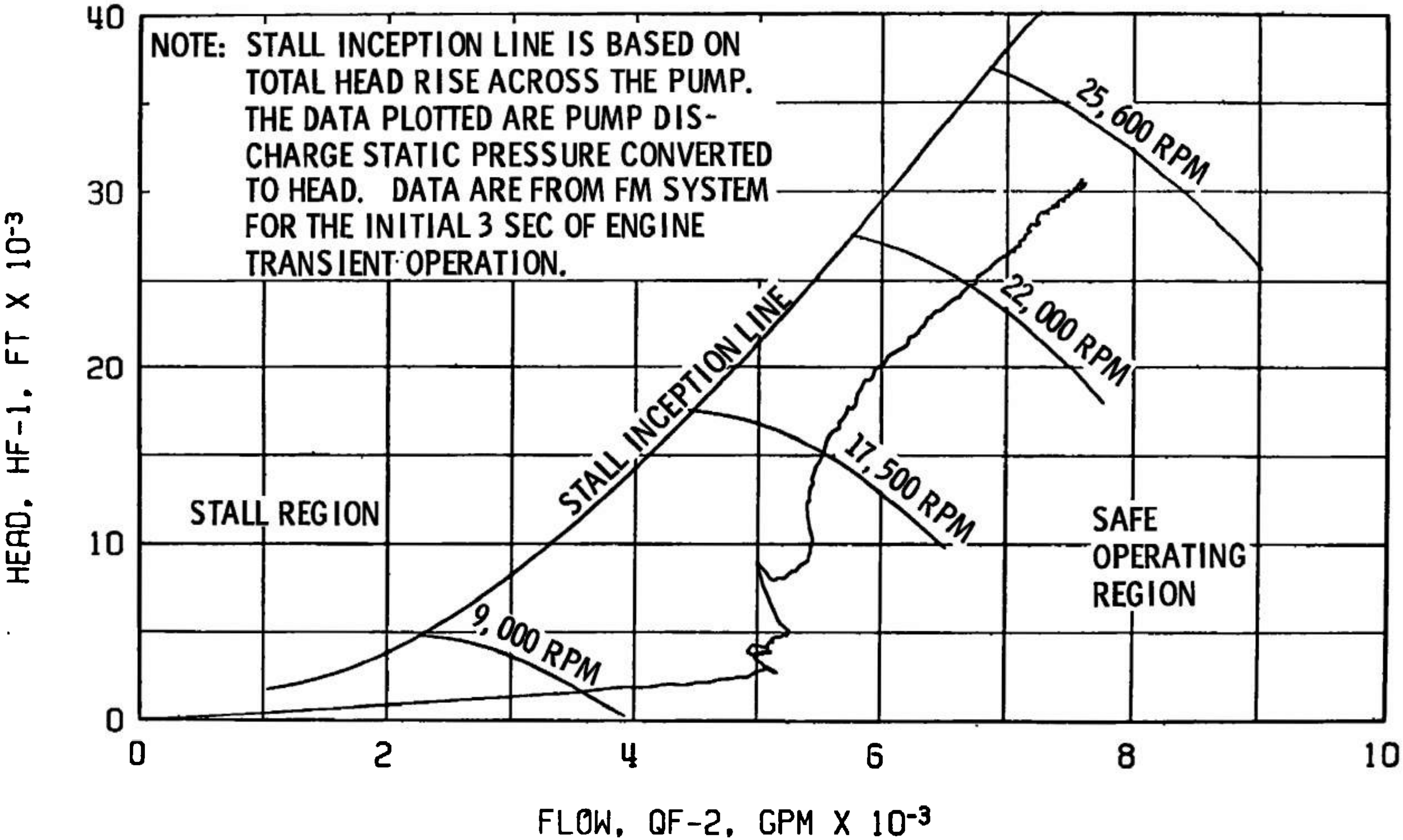


Fig. 35 Fuel Pump Start Transient Performance, Firing 08B

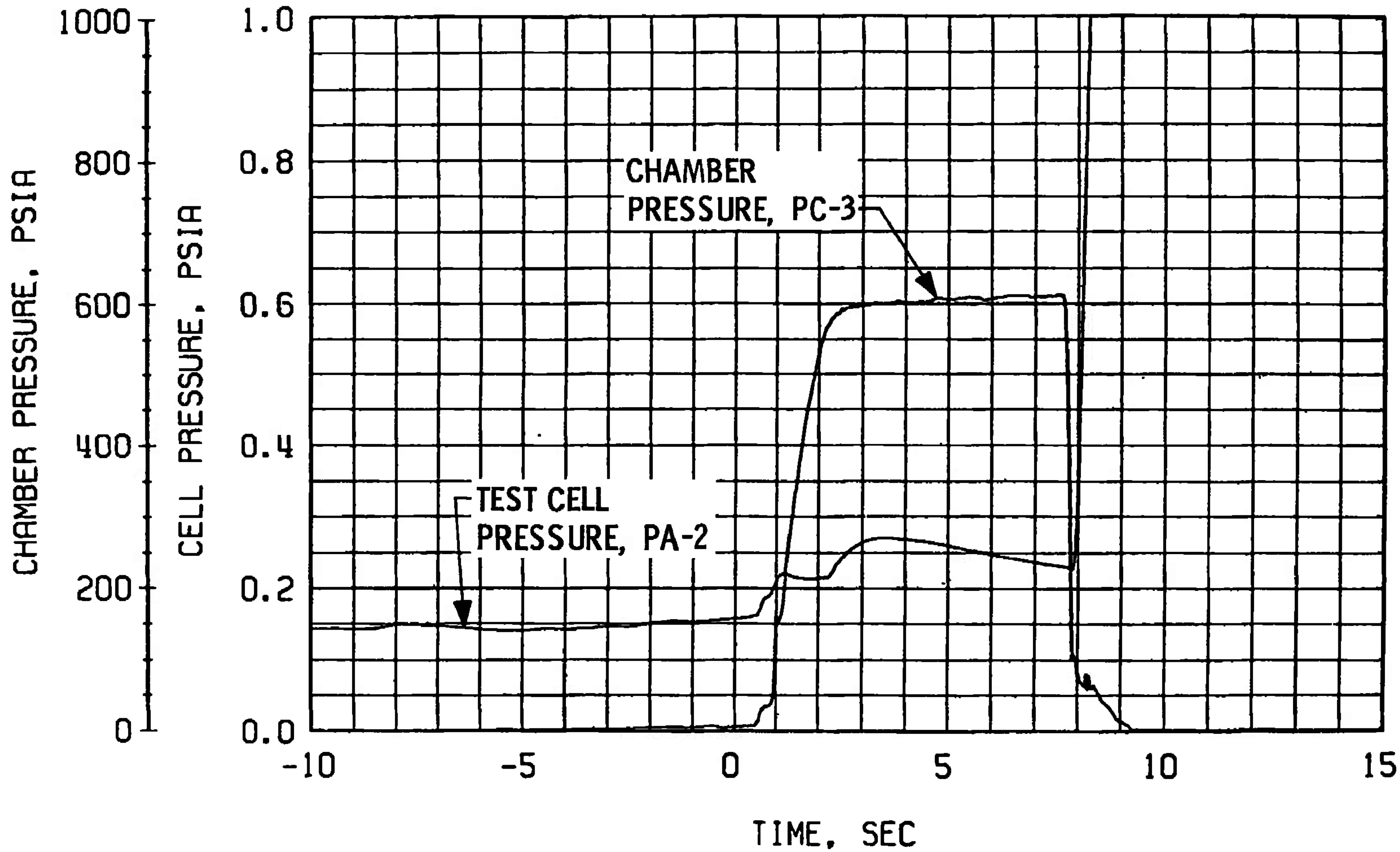
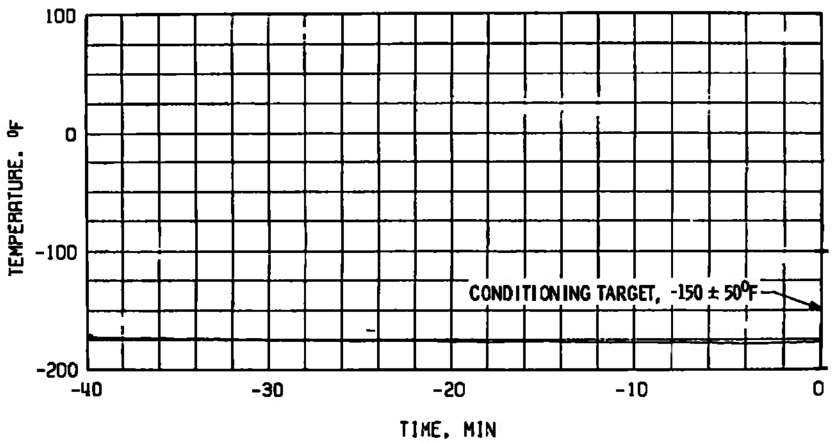
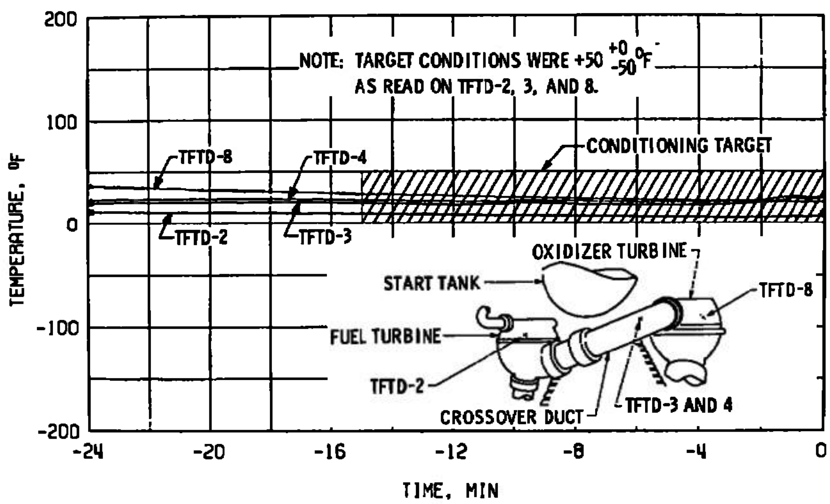


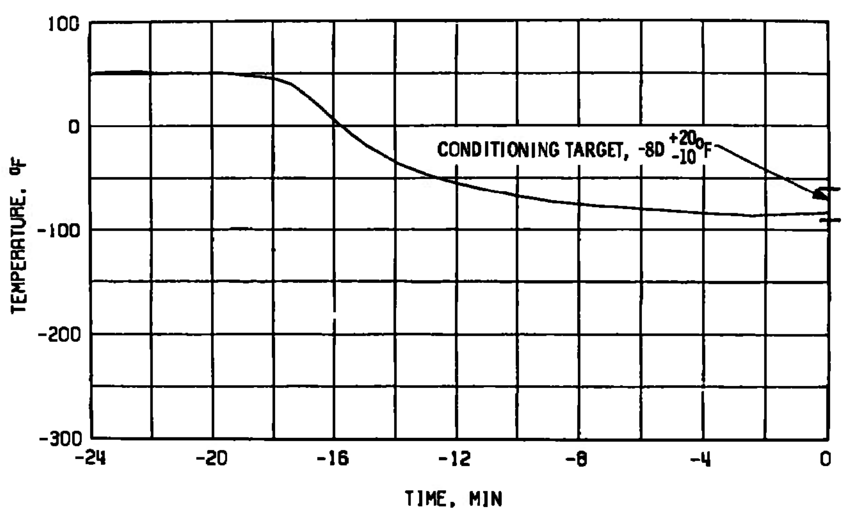
Fig. 36 Engine Ambient and Combustion Chamber Pressure, Firing 08B



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

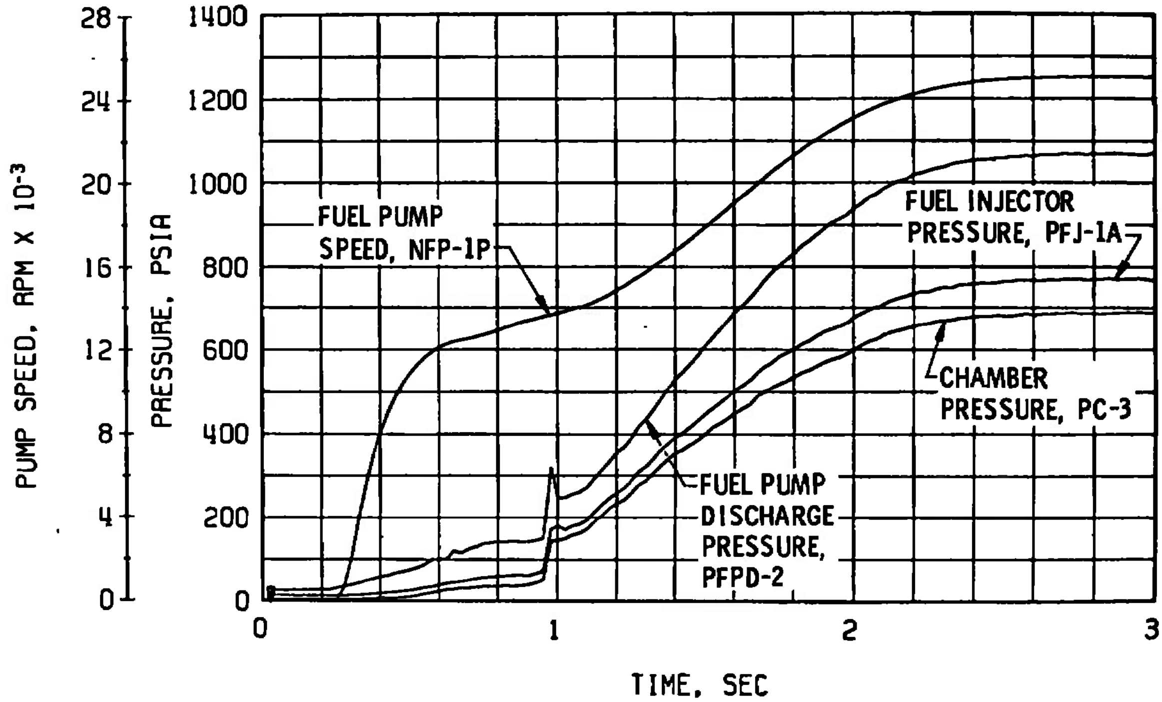


b. Crossover Duct, TFTD

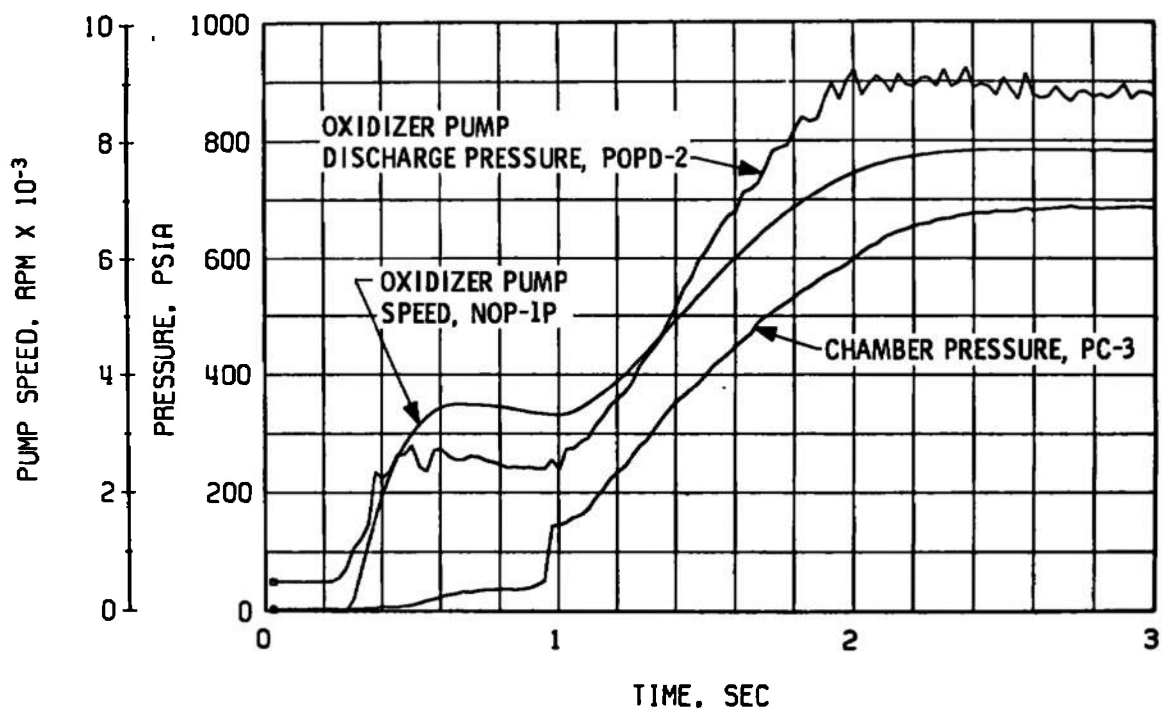


c. Thrust Chamber, TTC-1P

Fig. 37 Thermal Conditioning History of Engine Components, Firing 08C

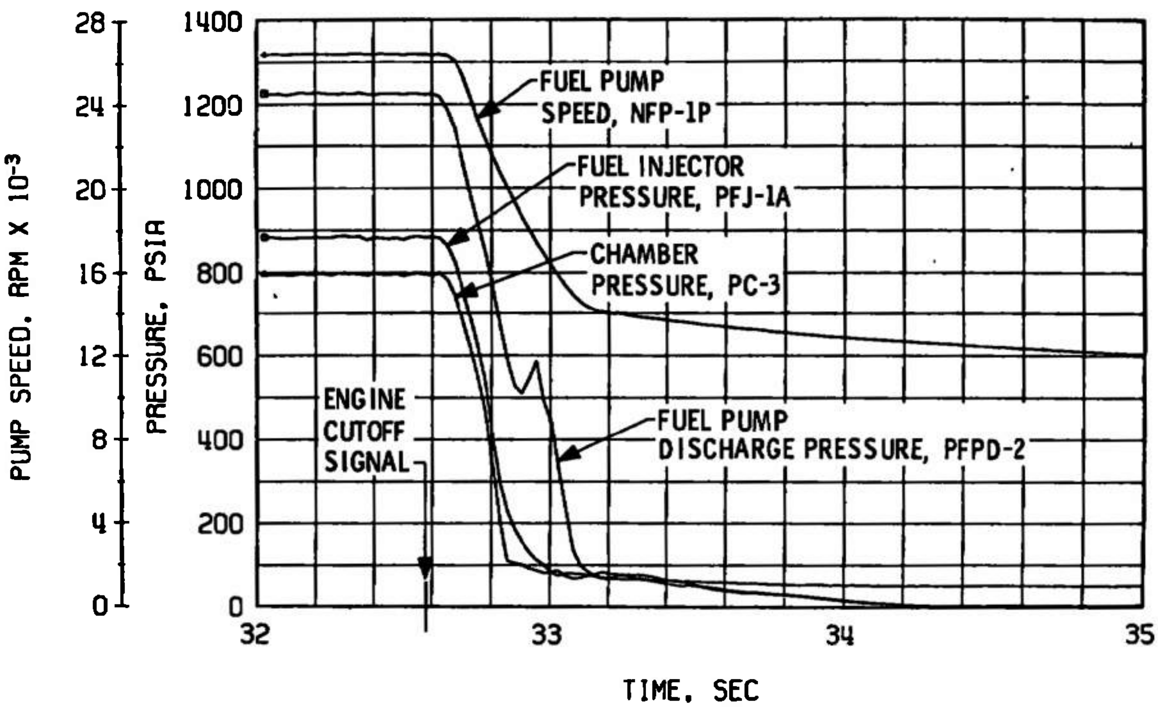


a. Thrust Chamber Fuel System, Start

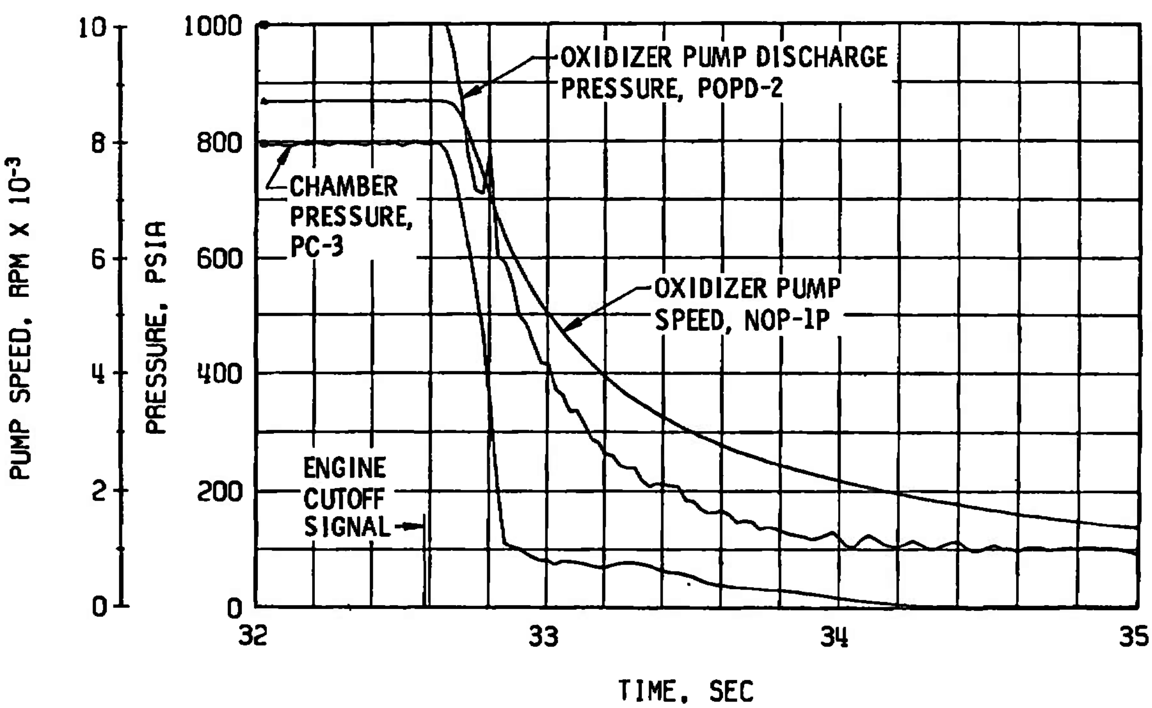


b. Thrust Chamber Oxidizer System, Start

Fig. 38 Engine Transient Operation, Firing 08C

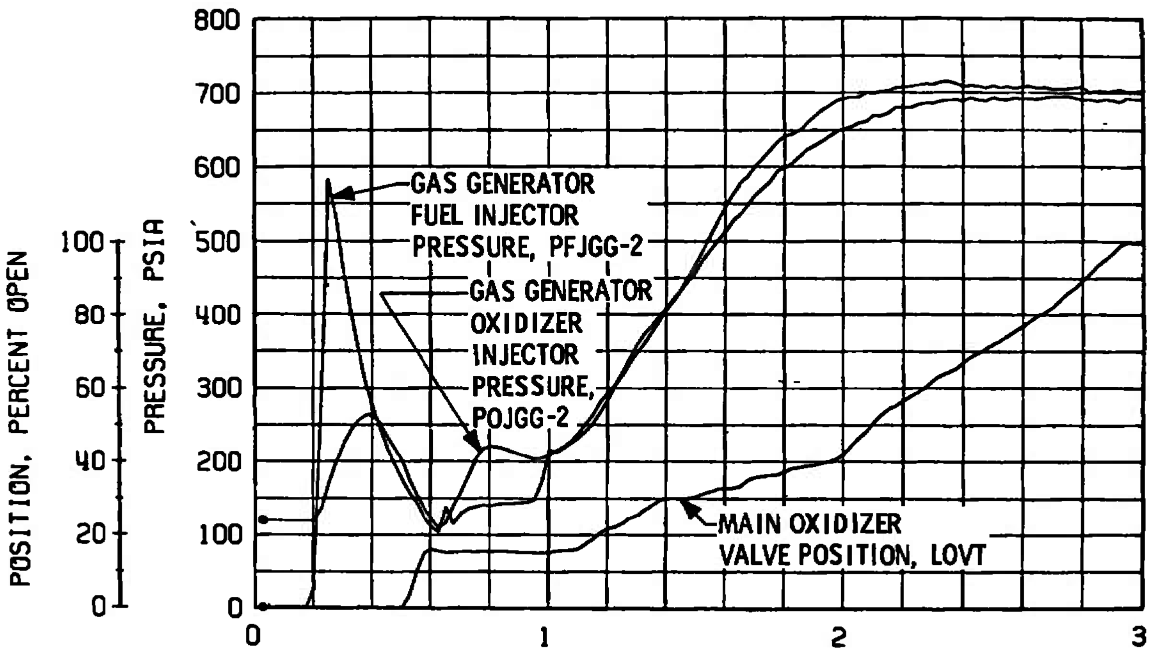


c. Thrust Chamber Fuel System, Shutdown

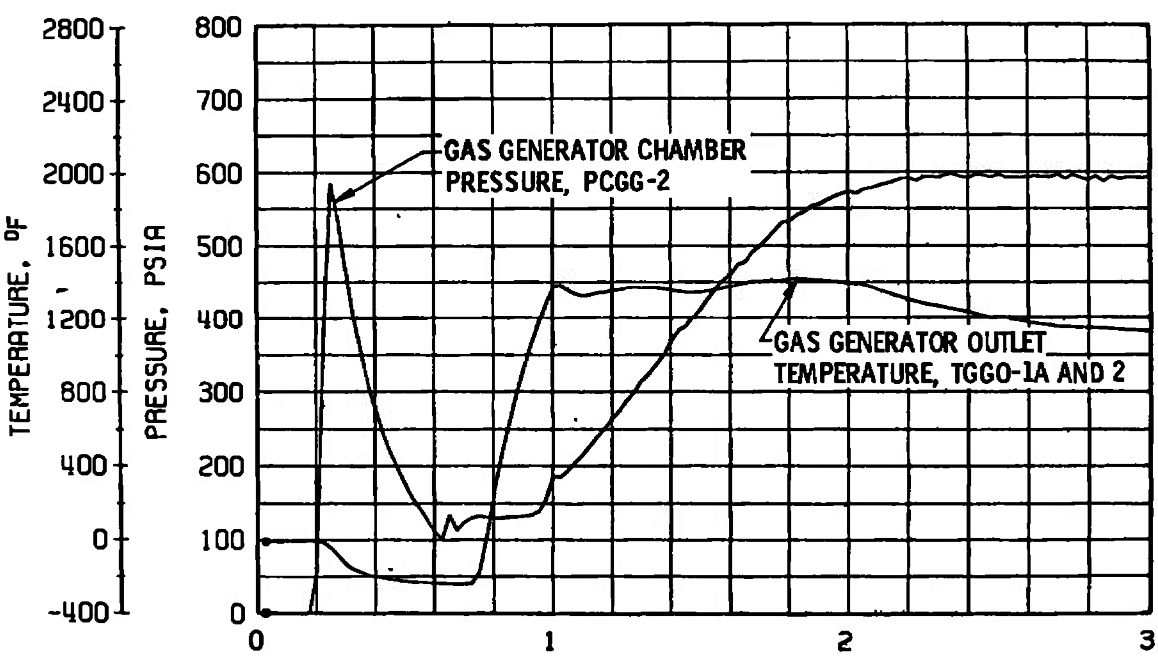


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 38 Continued

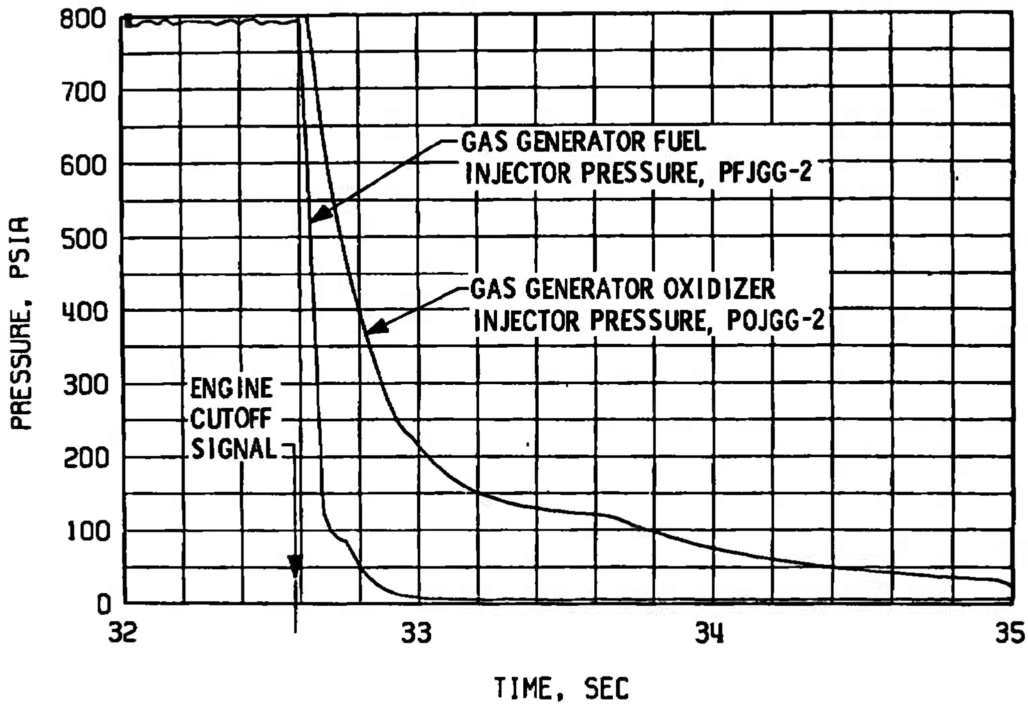


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

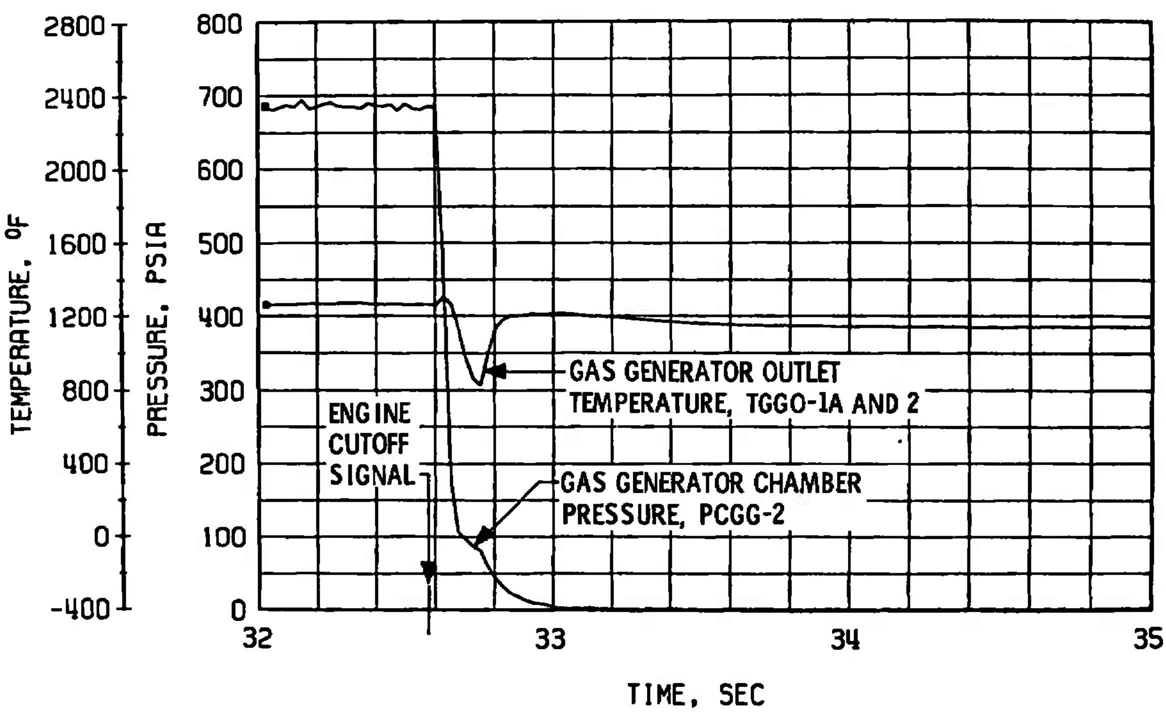


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 38 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 38 Concluded

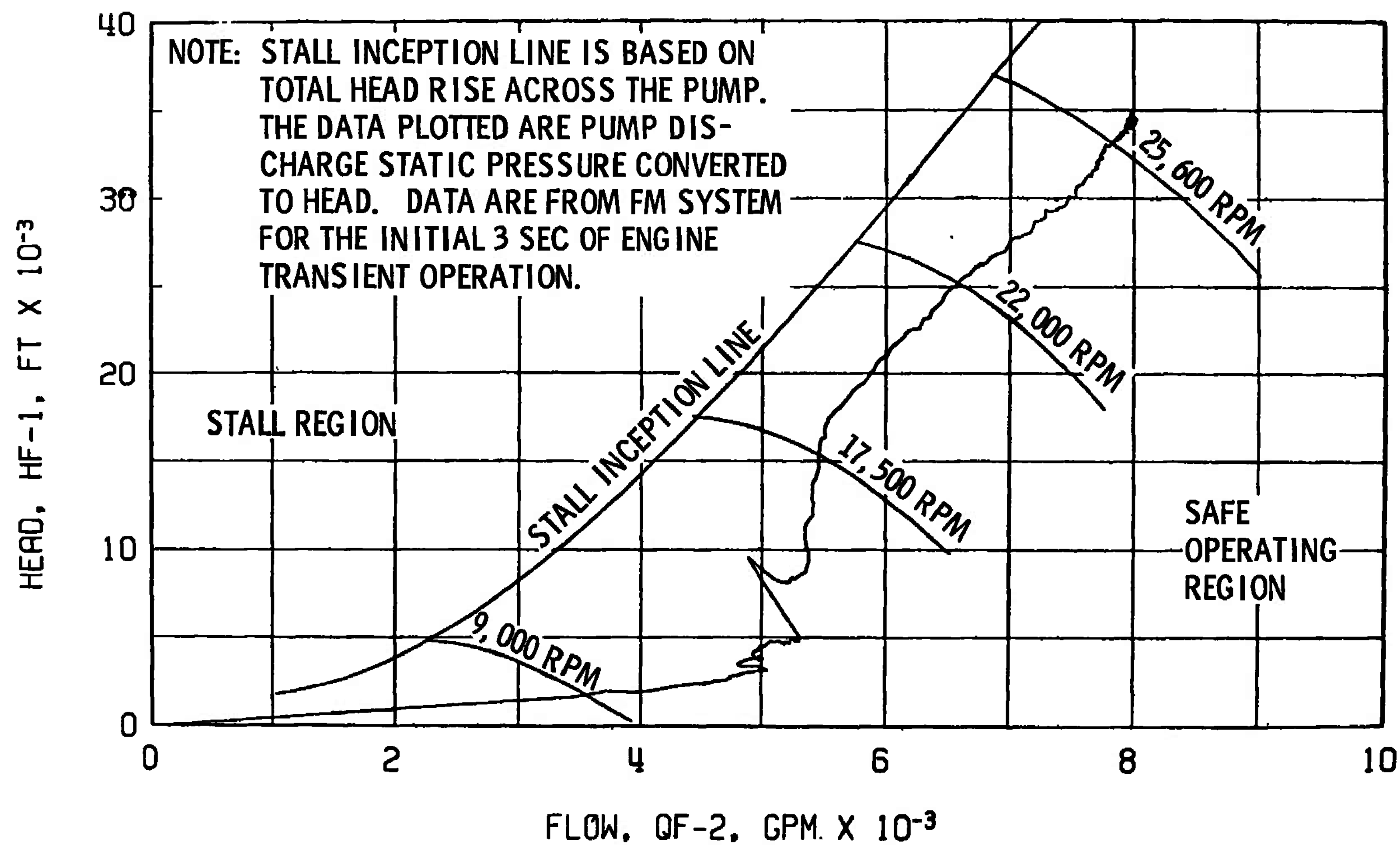


Fig. 39 Fuel Pump Start Transient Performance, Firing 08C

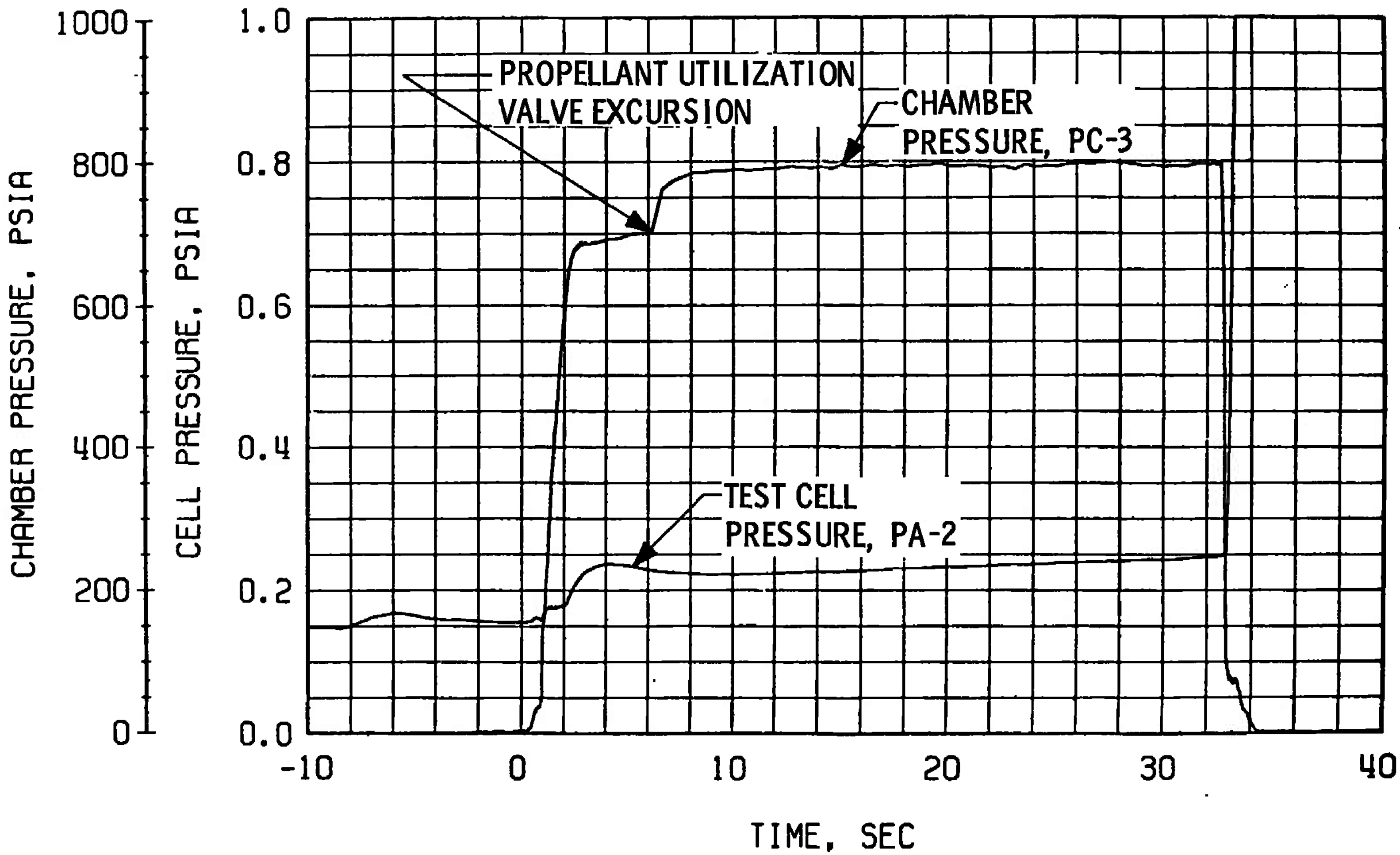
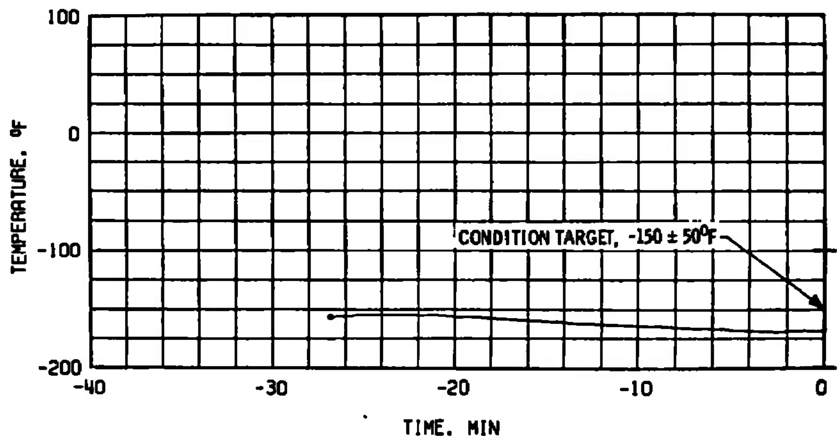
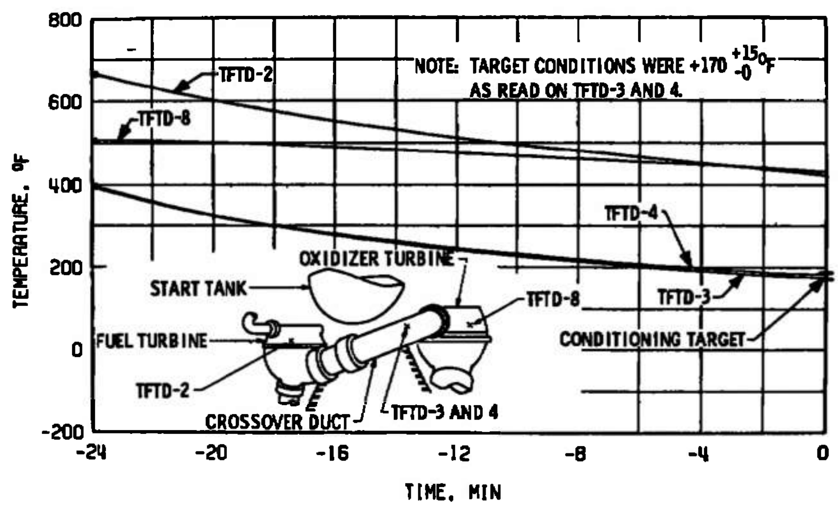


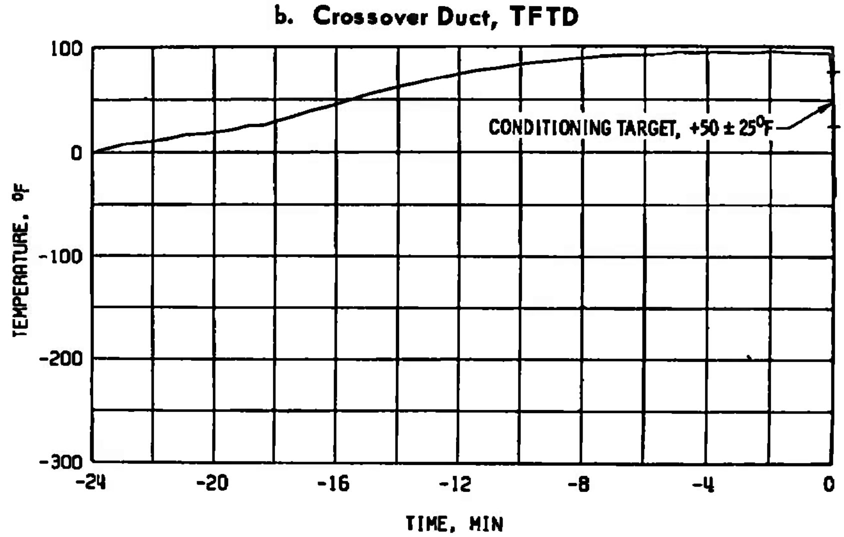
Fig. 40 Engine Ambient and Combustion Chamber Pressure, Firing 08C



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

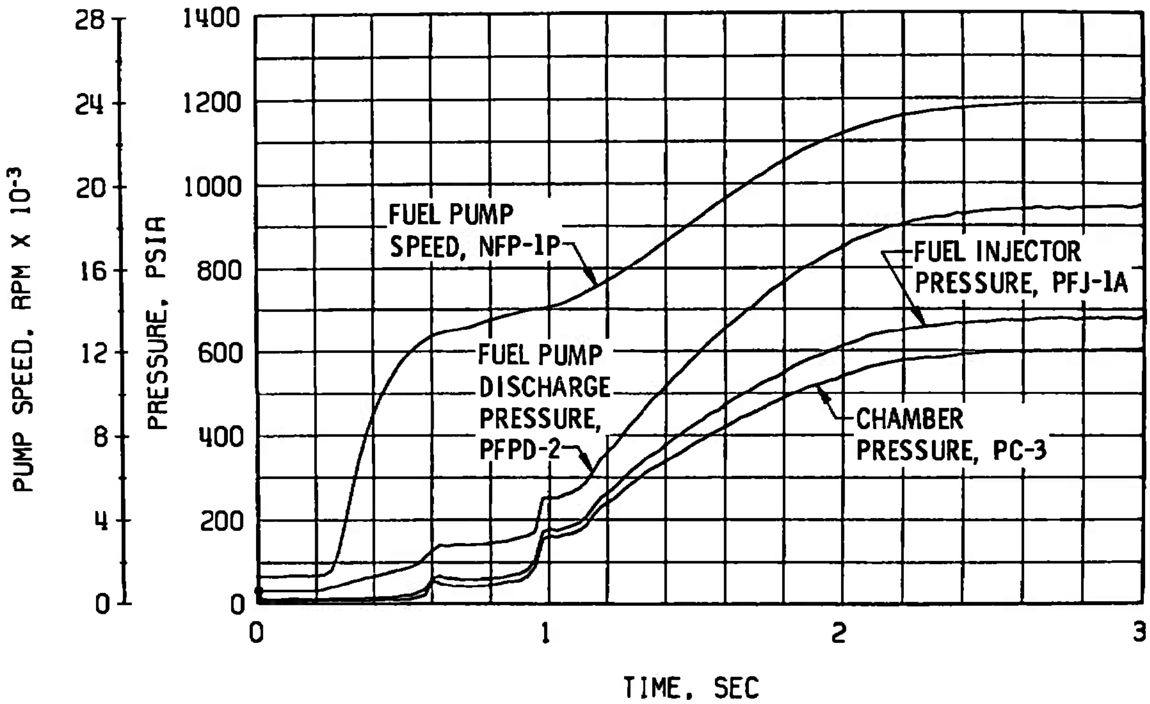


b. Crossover Duct, TFTD

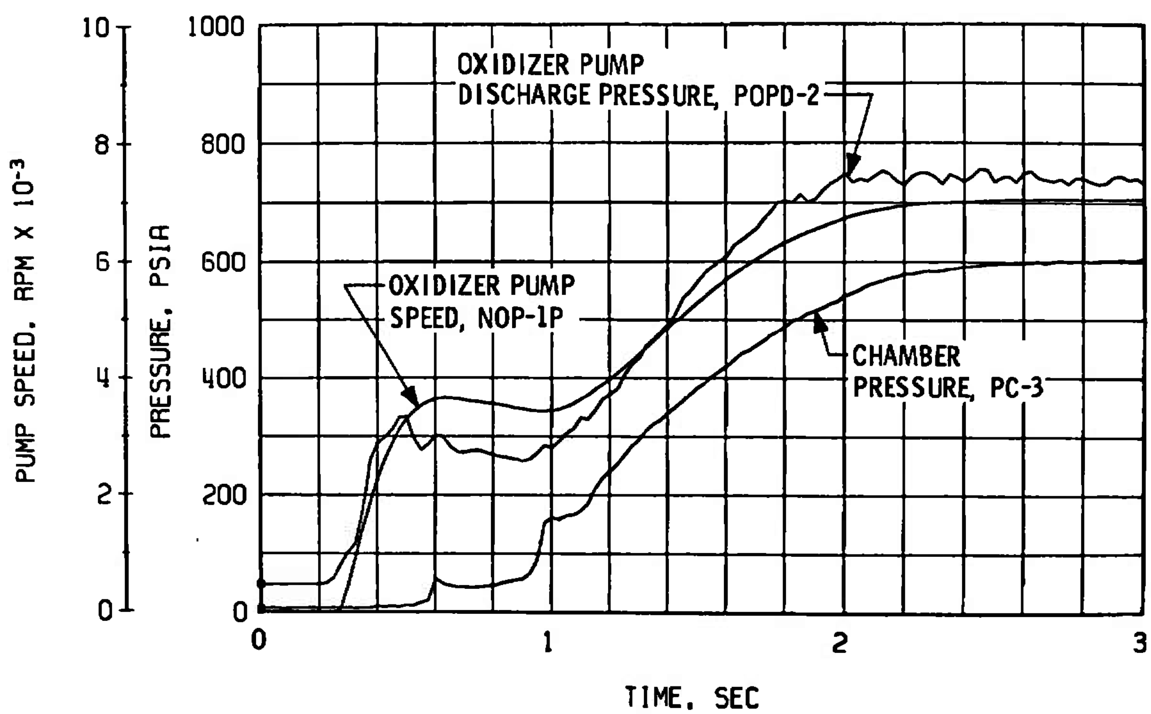


c. Thrust Chamber, TTC-1P

Fig. 41 Thermal Conditioning History of Engine Components, Firing 08D

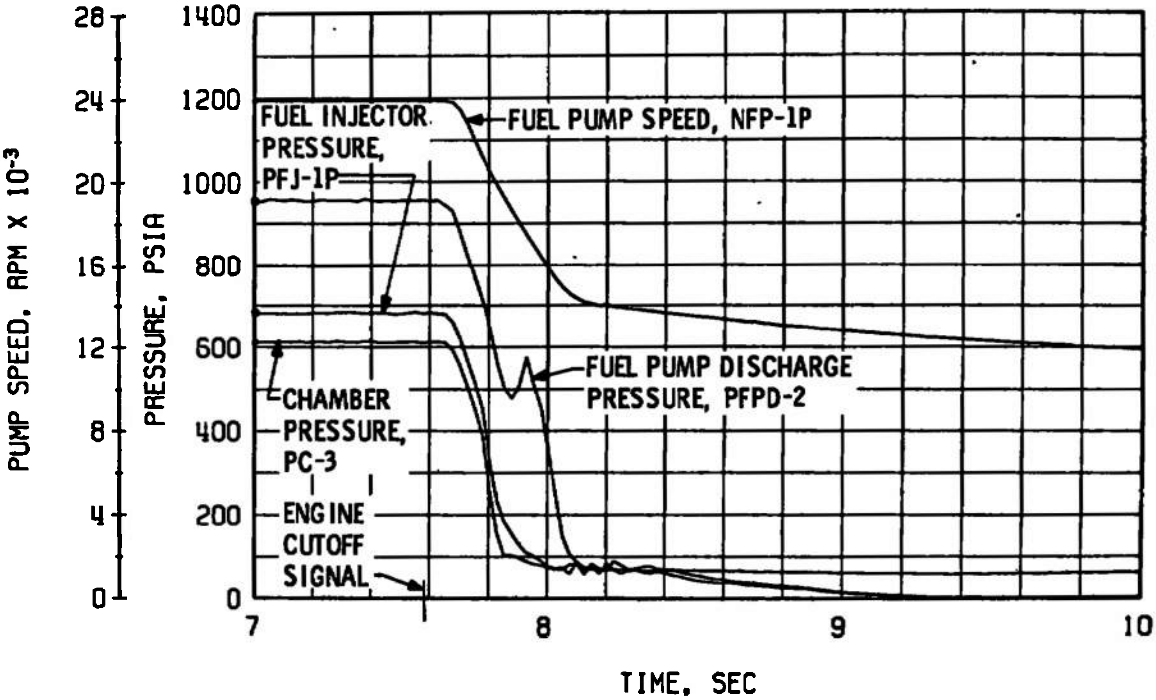


a. Thrust Chamber Fuel System, Start

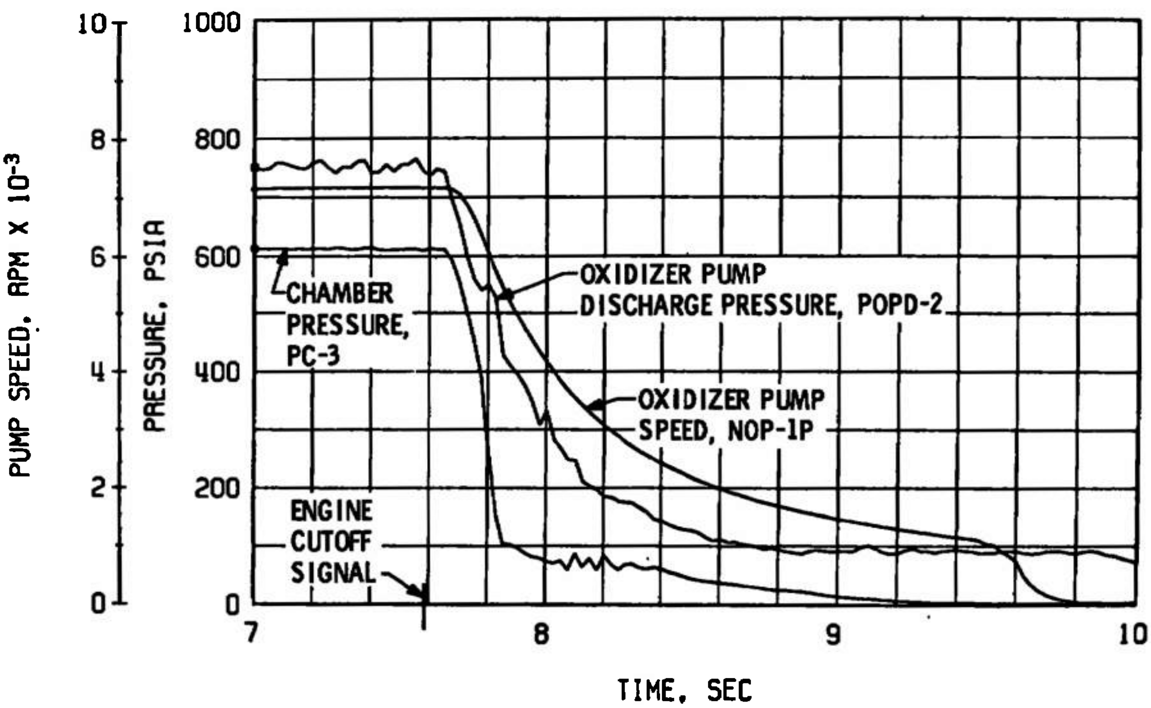


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 08D

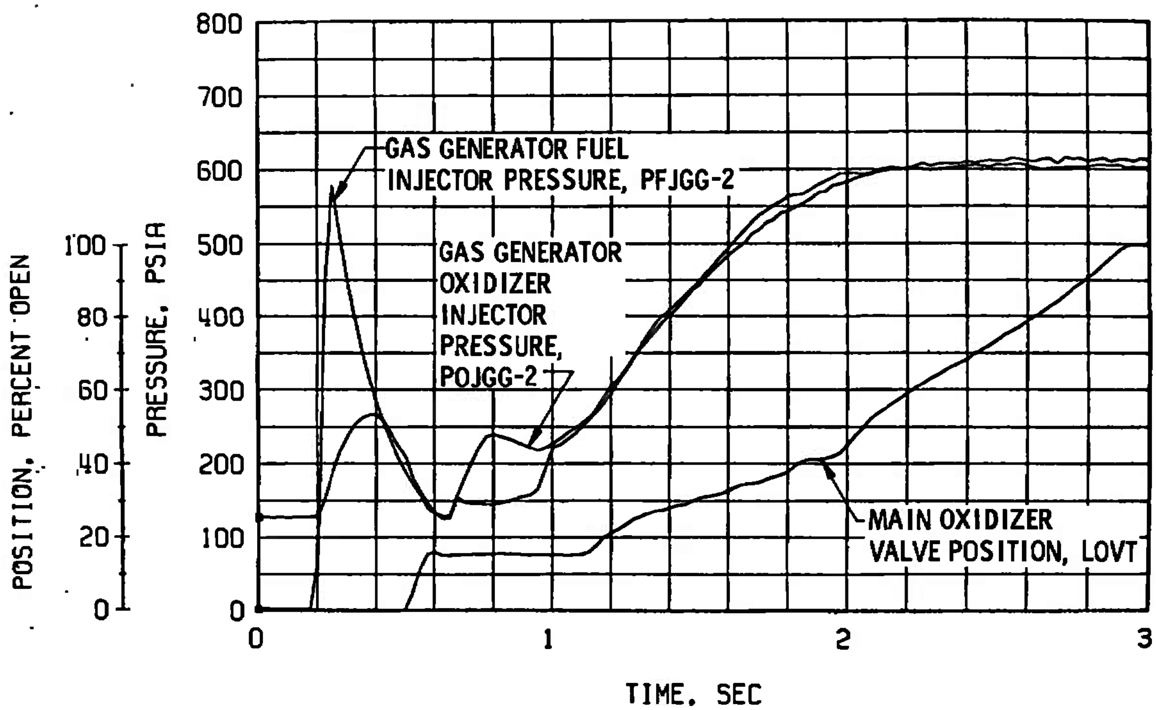


c. Thrust Chamber Fuel System, Shutdown

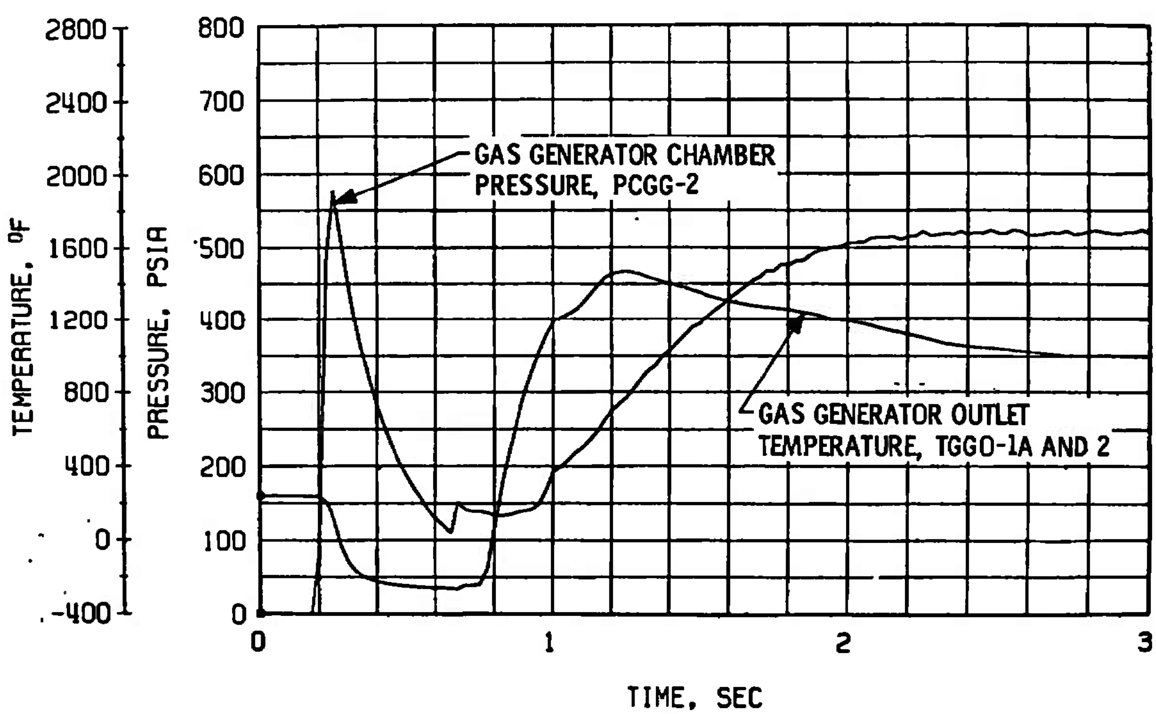


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued

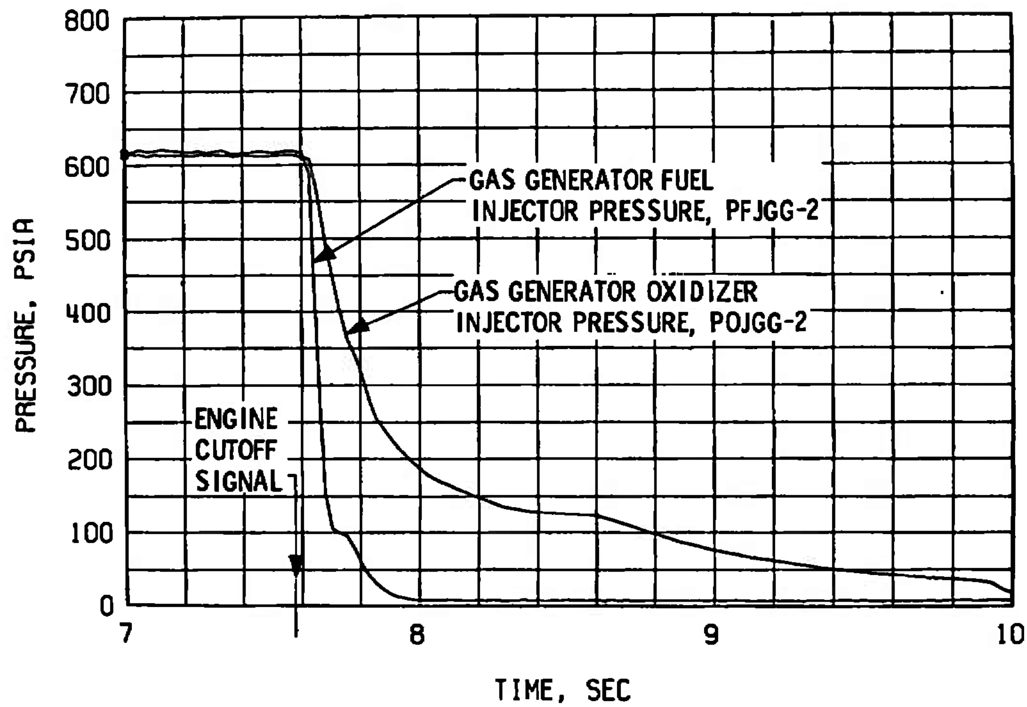


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

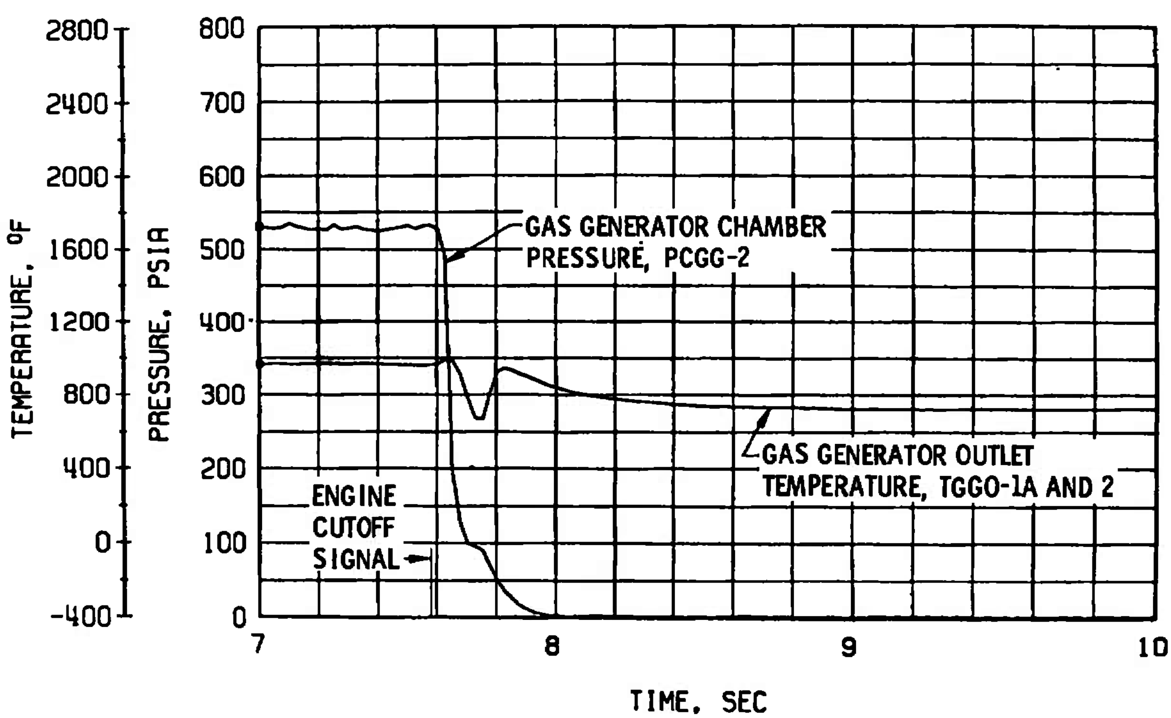


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

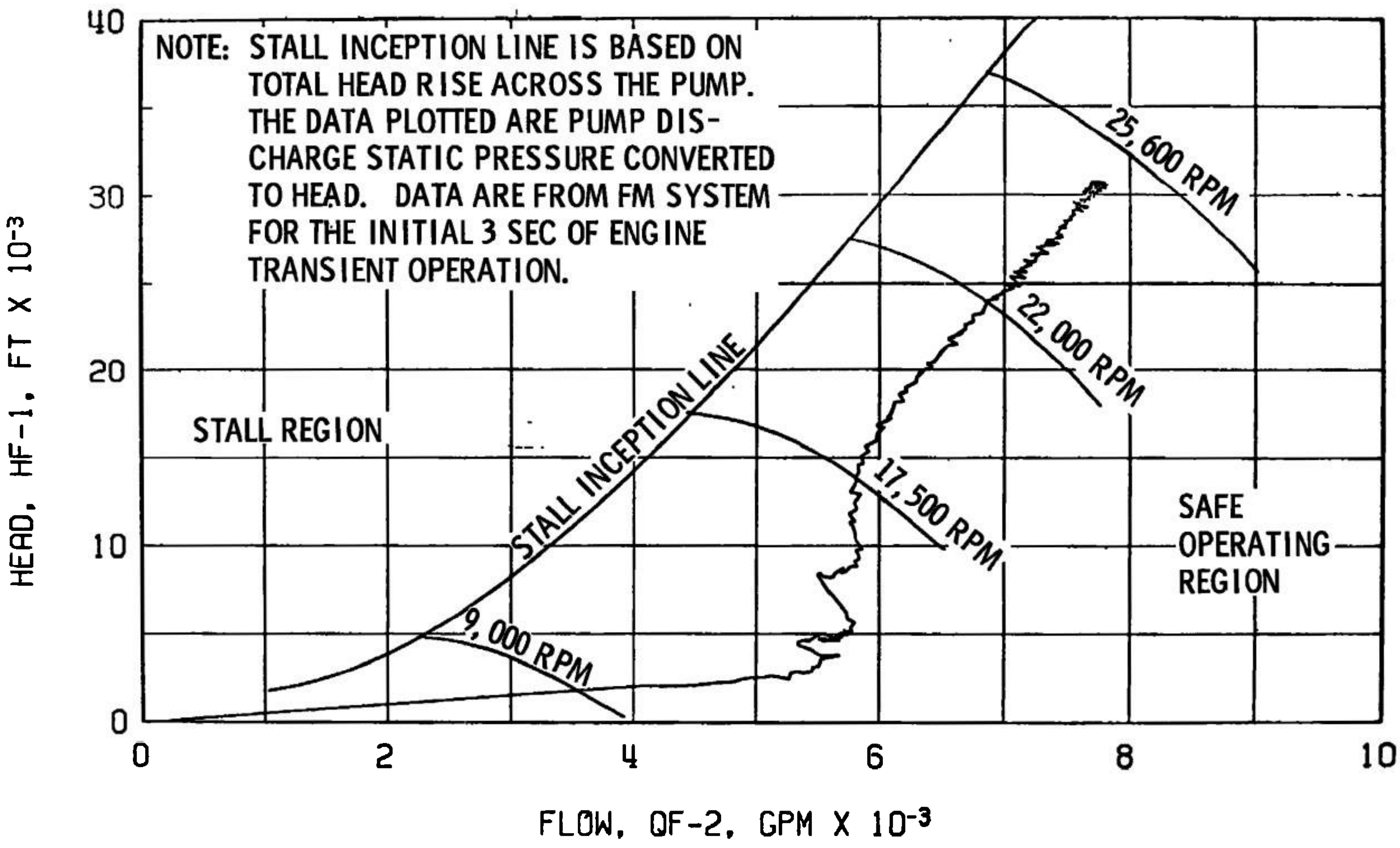


Fig. 43 Fuel Pump Start Transient Performance, Firing 08D

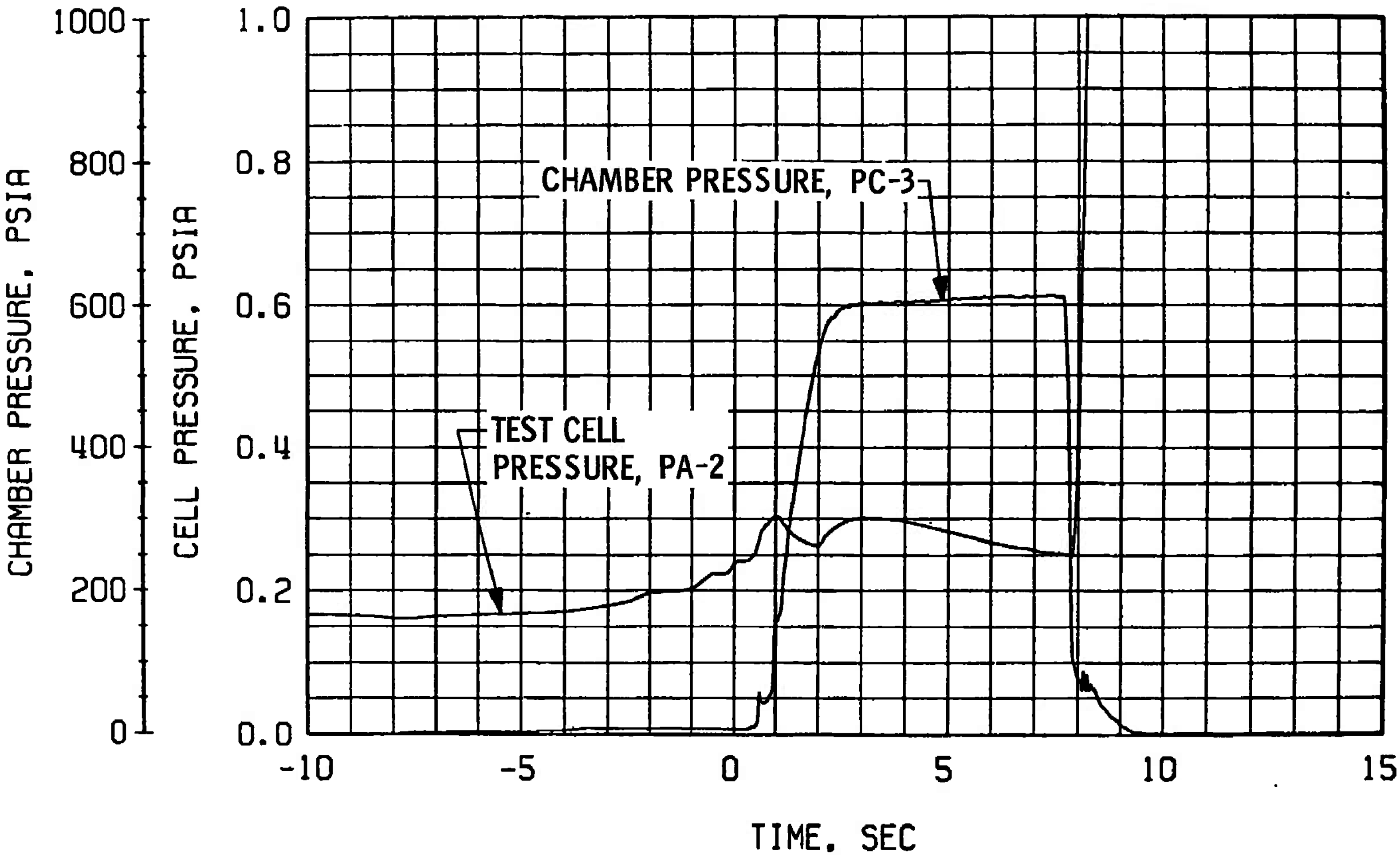
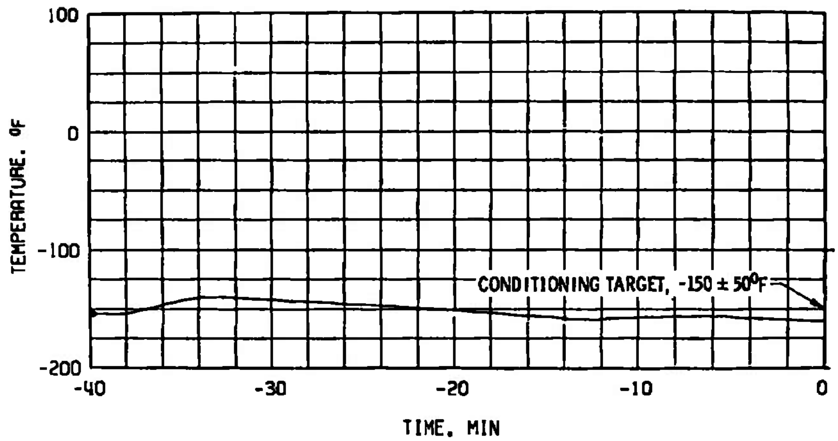
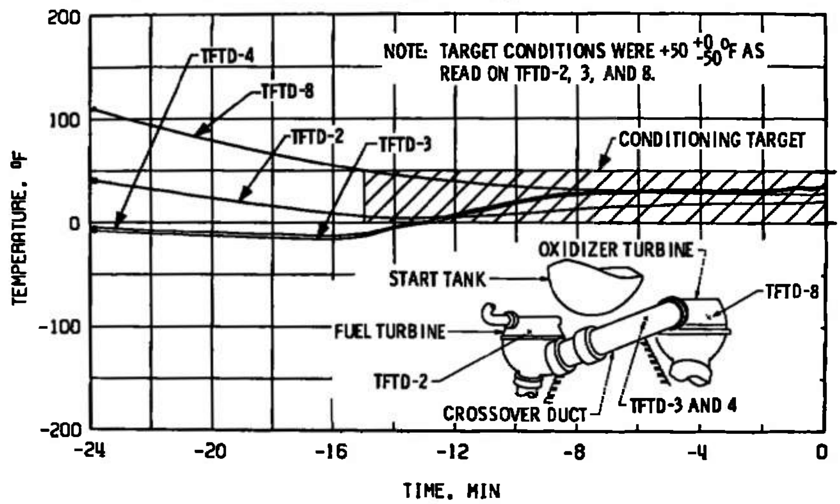


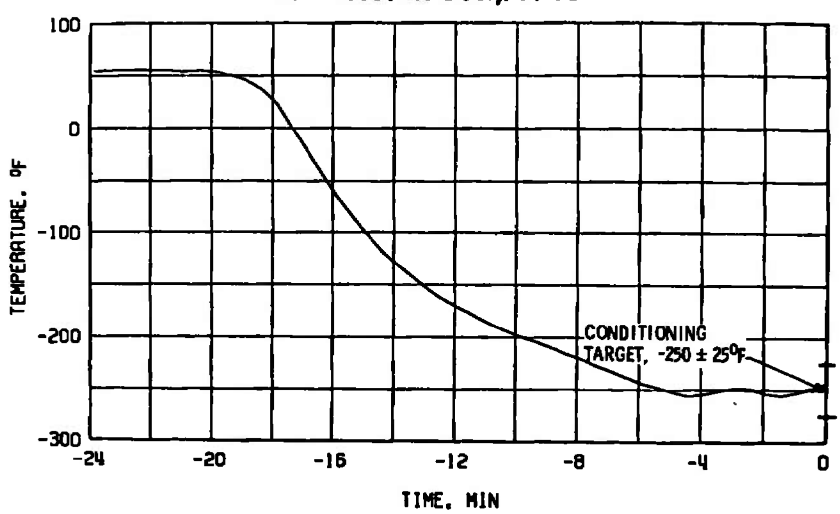
Fig. 44 Engine Ambient and Combustion Chamber Pressure, Firing 08D



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

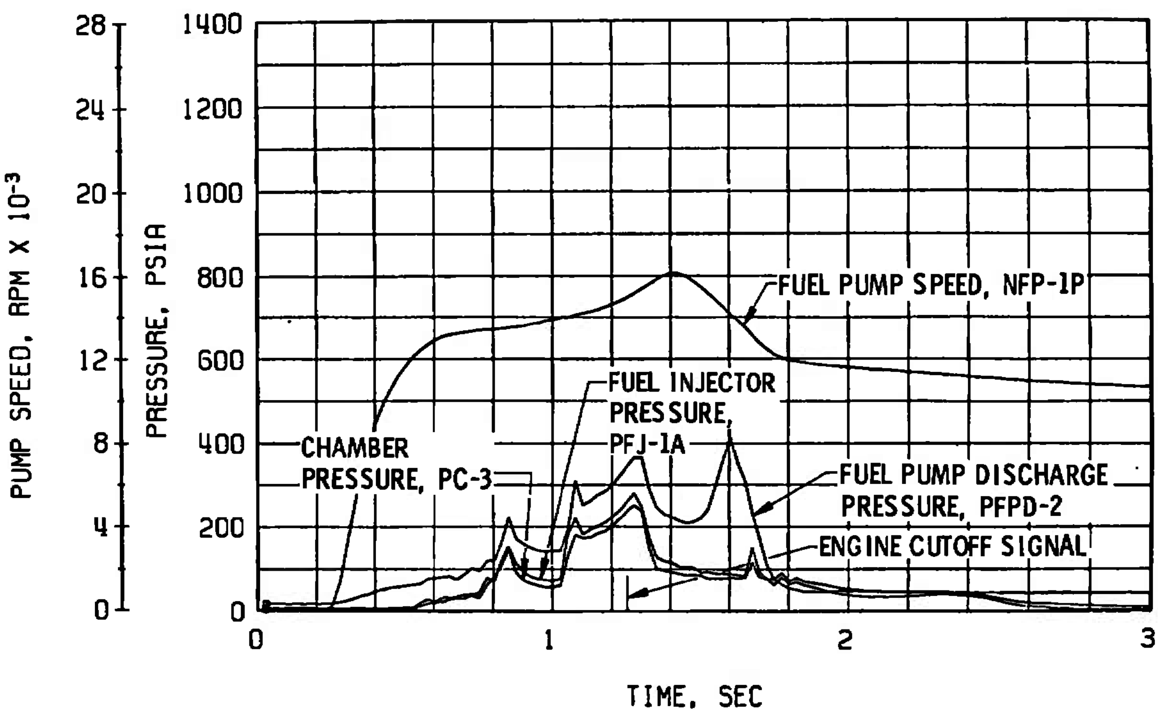


b. Crossover Duct, TFTD

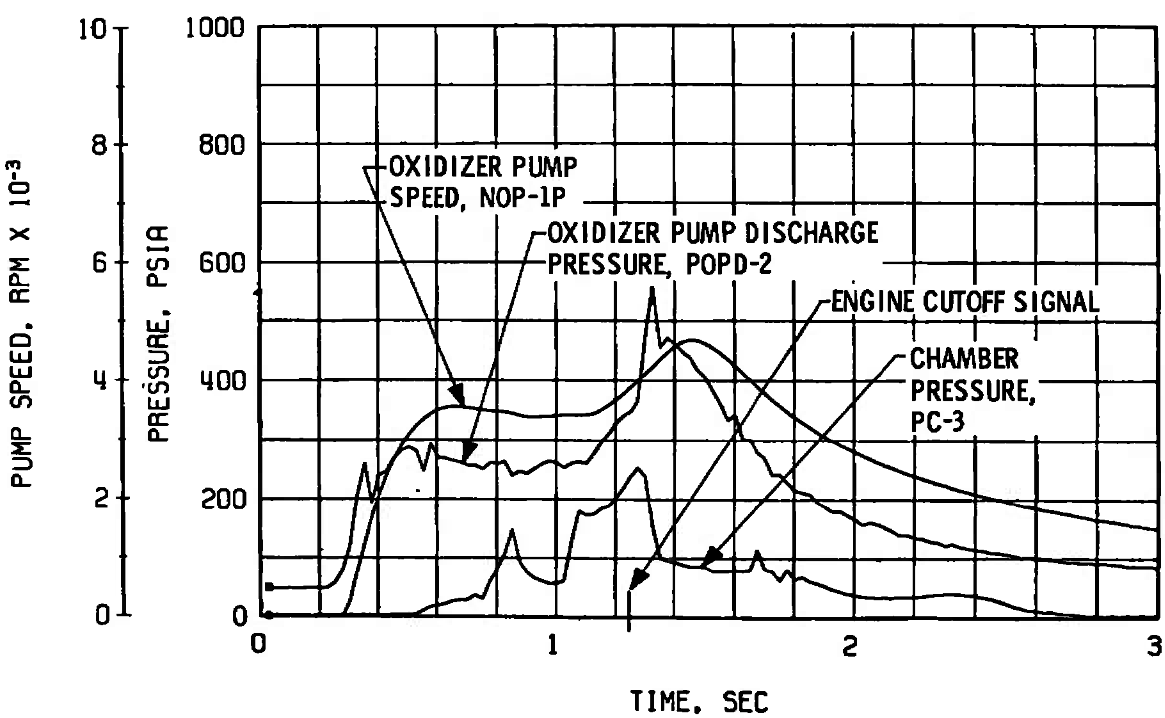


c. Thrust Chamber TTC-1P

Fig. 45 Thermal Conditioning History of Engine Components, Firing 08E

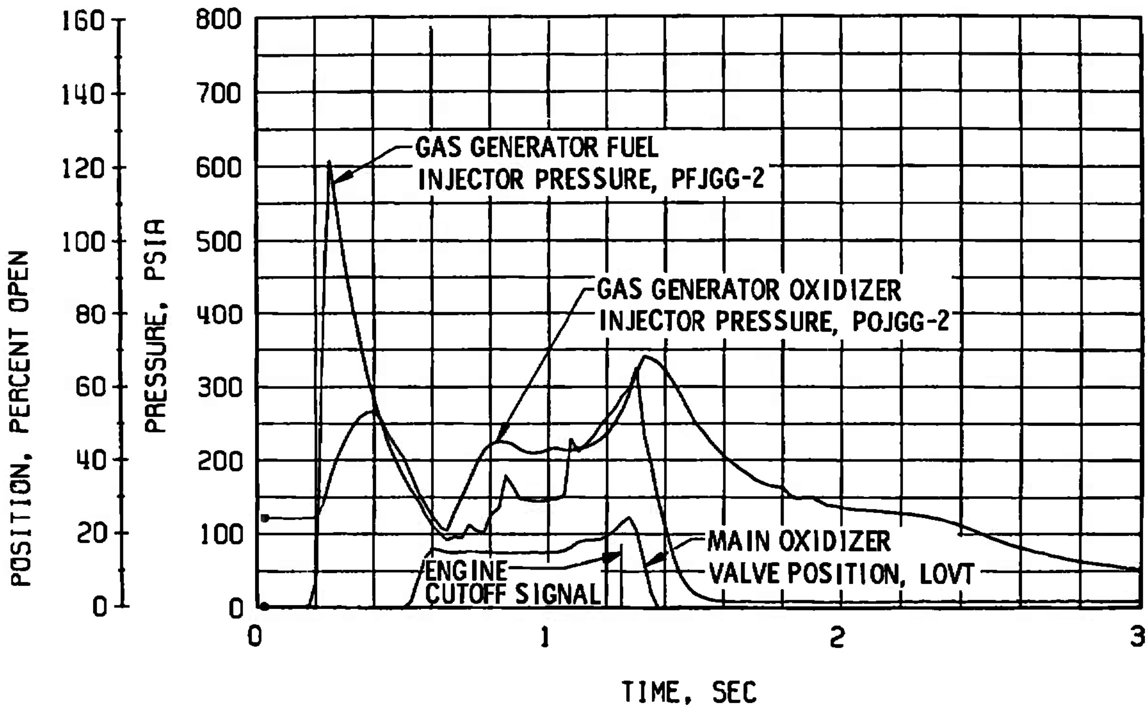


a. Thrust Chamber Fuel System, Start and Shutdown

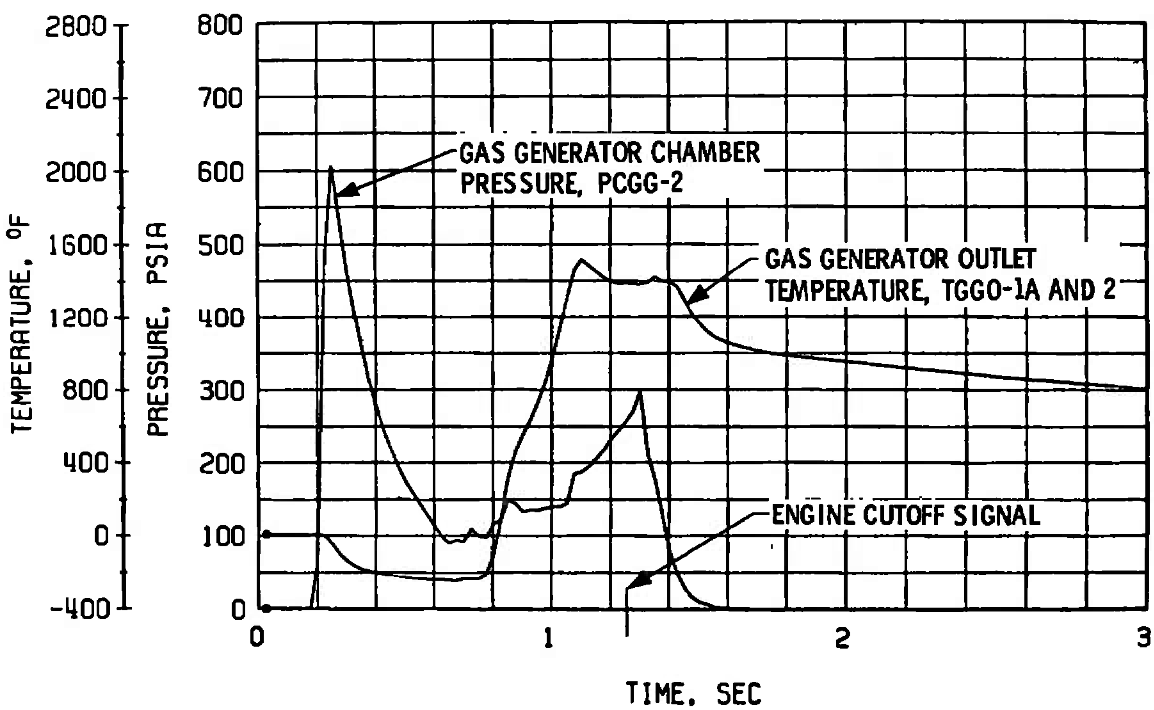


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 46 Engine Transient Operation, Firing 08E



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



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

Fig. 46 Concluded

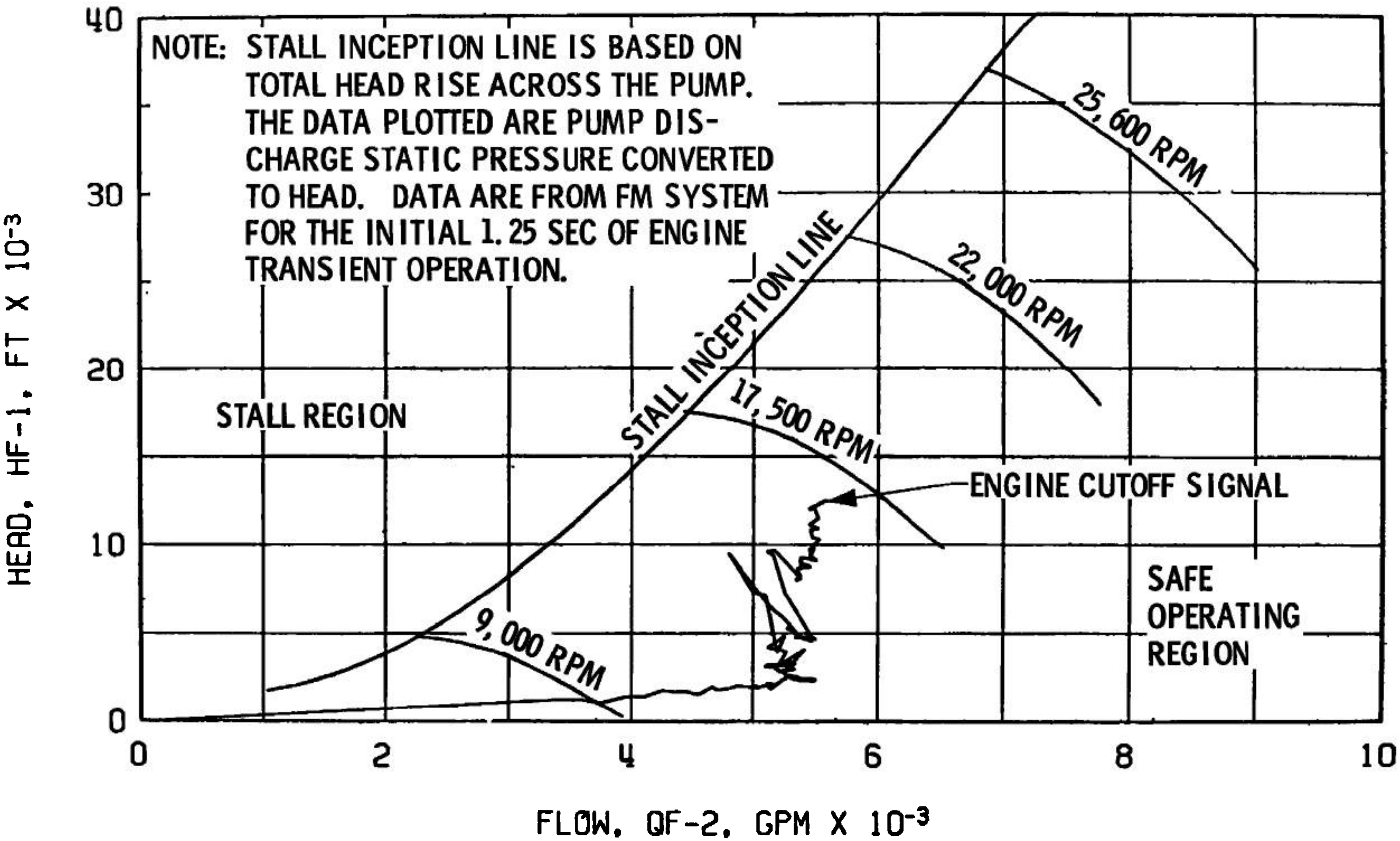


Fig. 47 Fuel Pump Start Transient Performance, Firing 08E

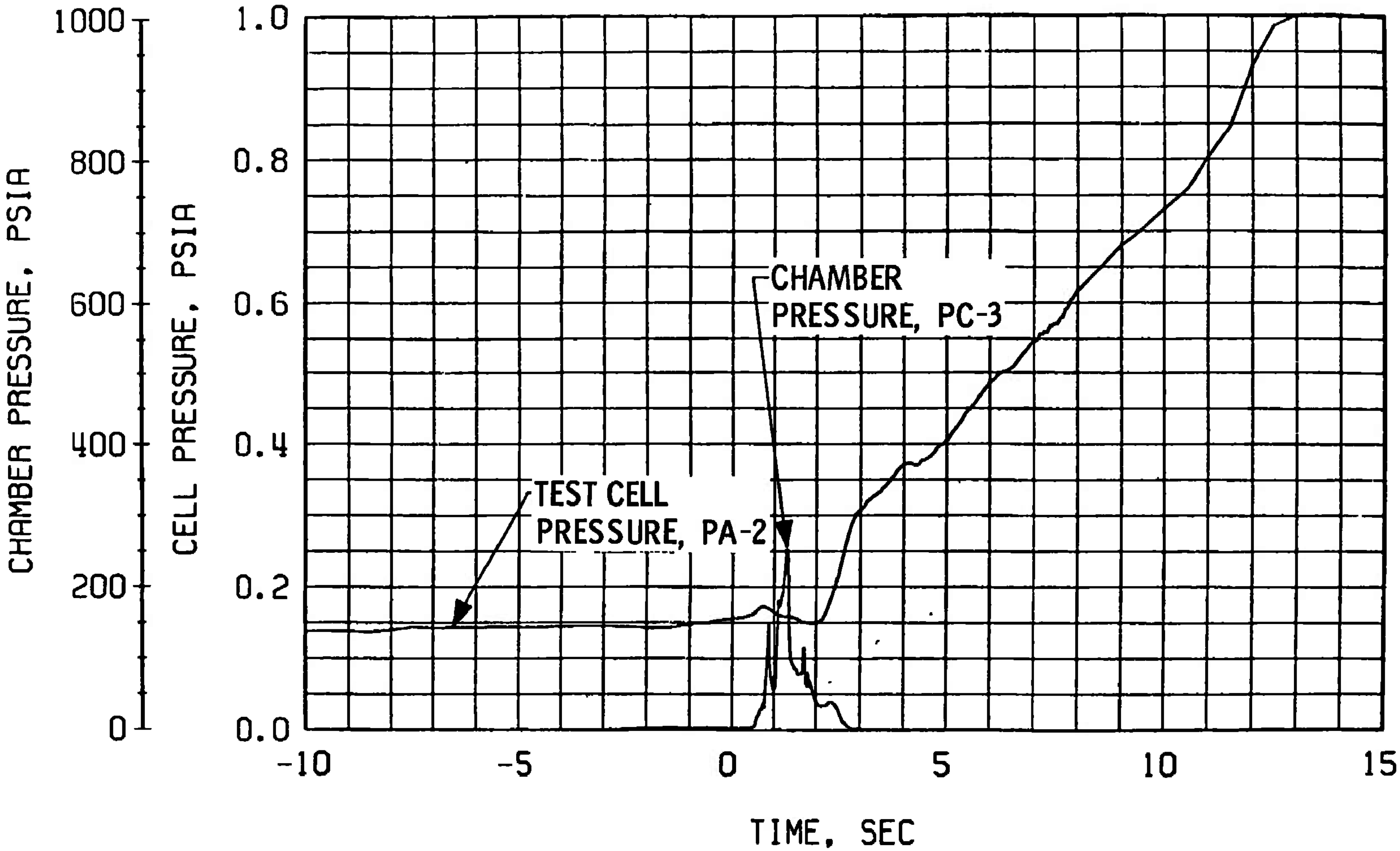


Fig. 48 Engine Ambient and Combustion Chamber Pressure, Firing 06L

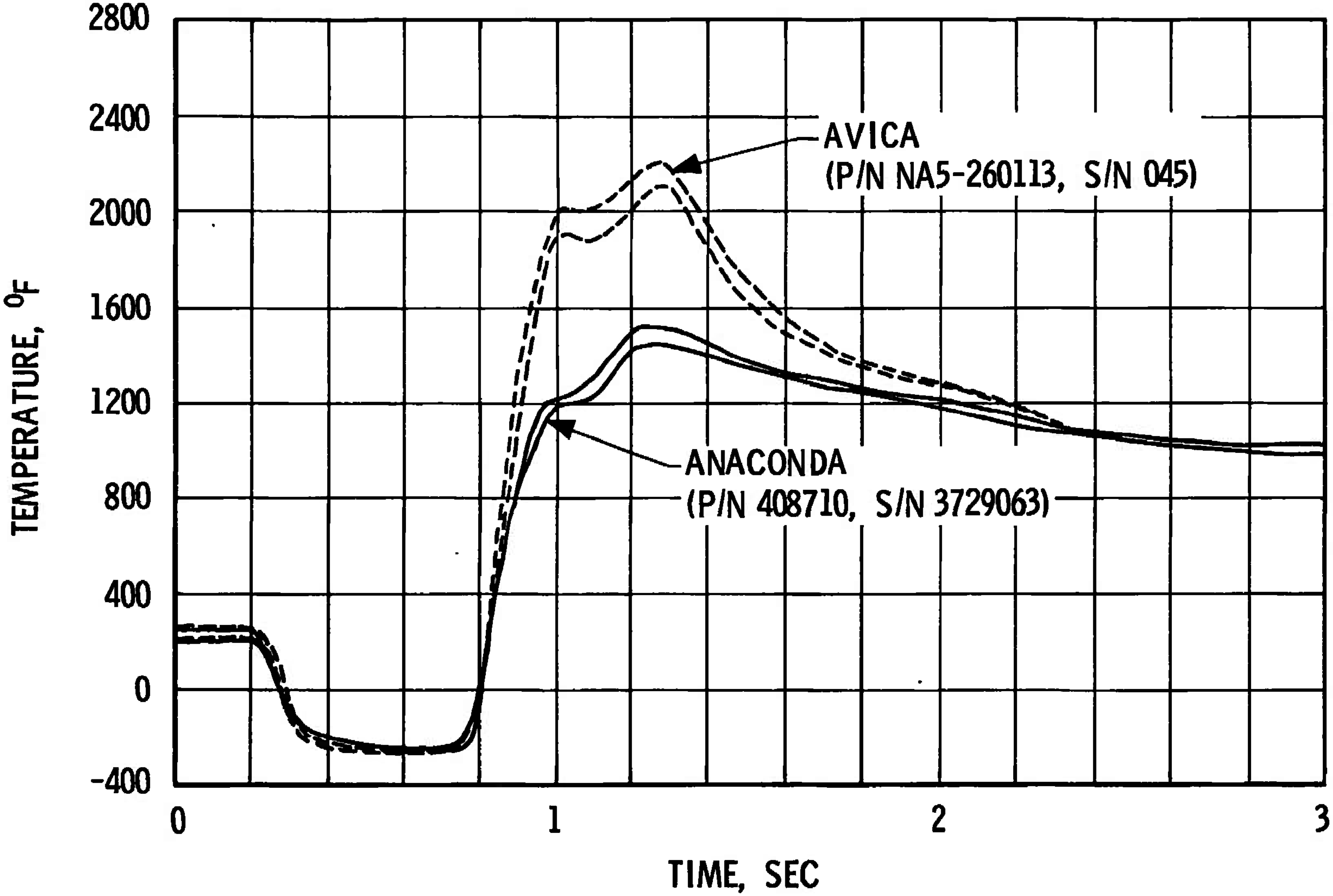


Fig. 49 Transient Gas Generator Temperature Envelopes for the Anaconda and Avica Gas Generator Oxidizer Supply Line Assemblies

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Augmented Spark Igniter Assembly	309360-91	4071414
Augmented Spark Igniter Oxidizer Valve	308880	4079065
Auxiliary Flight Instrumentation Package	704090-21	4075163
Electrical Control Package	502670-51	4081748
Fuel Bleed Valve	309034	4084042
Fuel Flowmeter	251225	4074110
Fuel Injector Temperature Transducer	NA5-27441	AA013283F66
Fuel Turbopump Assembly	460390-181	4073647
Gas Generator Control Valve	309040-31	4078292
Gas Generator Fuel Injector and Combustor Assembly	308360-11	4090408
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4092975
Helium Control Valve	NA5-27273	372452
Helium Regulator Assembly	558130-111	4061139
Helium Tank Vent Control Valve	NA5-27273	379313
Ignition Phase Control Valve	558069	8313398
Main Fuel Valve	409920	4074288
Main Oxidizer Valve	411031-21	4072666
Main-Stage Control Valve	558069	8284312
Oxidizer Bleed Valve	309029	4076750
Oxidizer Flowmeter	251216	4075154
Oxidizer Turbine Bypass Valve	409940	4073096
Oxidizer Turbopump Assembly	458175-111	6610105
Pressure-Actuated Purge Control Valve	558126	4073862
Pressure-Actuated Shutdown Valve Assembly	558127-11	4074549
Primary Flight Instrumentation Package	704095-21	4074730
Propellant Utilization Valve	251351-51	4075182
Restartable Ignition Detect Probe	NA5-27298T2	203
Start Tank	307579	0098
Start Tank Discharge Valve	304386	4086957
Start Tank Fill/Refill Valve	557998	4091617
Start Tank Vent and Relief Valve	557848	4080517
Thrust Chamber Body	15-205875	4062445
Thrust Chamber Injector Assembly	XEOR-933703	4089721

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.488 in.	July 15, 1968	Per RFD AEDC-38-68
Gas Generator Oxidizer Supply Line	RD251-4106	0.284 in.	July 15, 1968	Per RFD AEDC-38-68
Gas Generator Control Valve-Opening Control at Main Oxidizer Valve Sequence Outlet Port	RD251-4115	0.045 in.	August 16, 1968	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.520 in.	July 15, 1968	Per RFD AEDC-38-68
Main Oxidizer Valve Closing Control Line	410437	8.40 scfm	August 16, 1968	Thermostatic Orifice Per RFD AEDC-12-68
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.00 in.	1	
Augmented Spark Igniter Oxidizer Supply Line	309358	0.125 in.	June 9, 1968	Per RFD AEDC-24-68
Augmented Spark Igniter Fuel Supply Line	309355	0.302 in.	August 1, 1968	Per RFD AEDC-41-68

1 As delivered to AEDC
RFD - Rocketdyne Field Directive

TABLE III
ENGINE MODIFICATIONS

Modification Number	Completion Date	Description of Modification
RFD[1] AEDC 45-68	August 16, 1968	Insulation of Fuel Supply Line to Augmented Spark Igniter
RFD AEDC 12-68	August 16, 1968	Retiming Main Oxidizer Valve to $1700\,^{+20}_{-10}$ msec
RFD AEDC 42-68	August 16, 1968	Retiming Gas Generator Oxidizer Valve Opening Delay to $140\,^{-5}_{-0}$
Test J4-1901-07 8/21/68		
RFD AEDC 45-68	August 23, 1968	Deleted Requirements for Referenced RFD (Removed Insulation from Fuel Supply Line to Augmented Spark Igniter)
RFD AEDC 35-A-67	August 23, 1968	Deleted Requirements for Referenced RFD and Installed Seal P/N 408767-3 beneath Ignition Detect Probe of Augmented Spark Igniter
Test J4-1901-08 8/27/68		

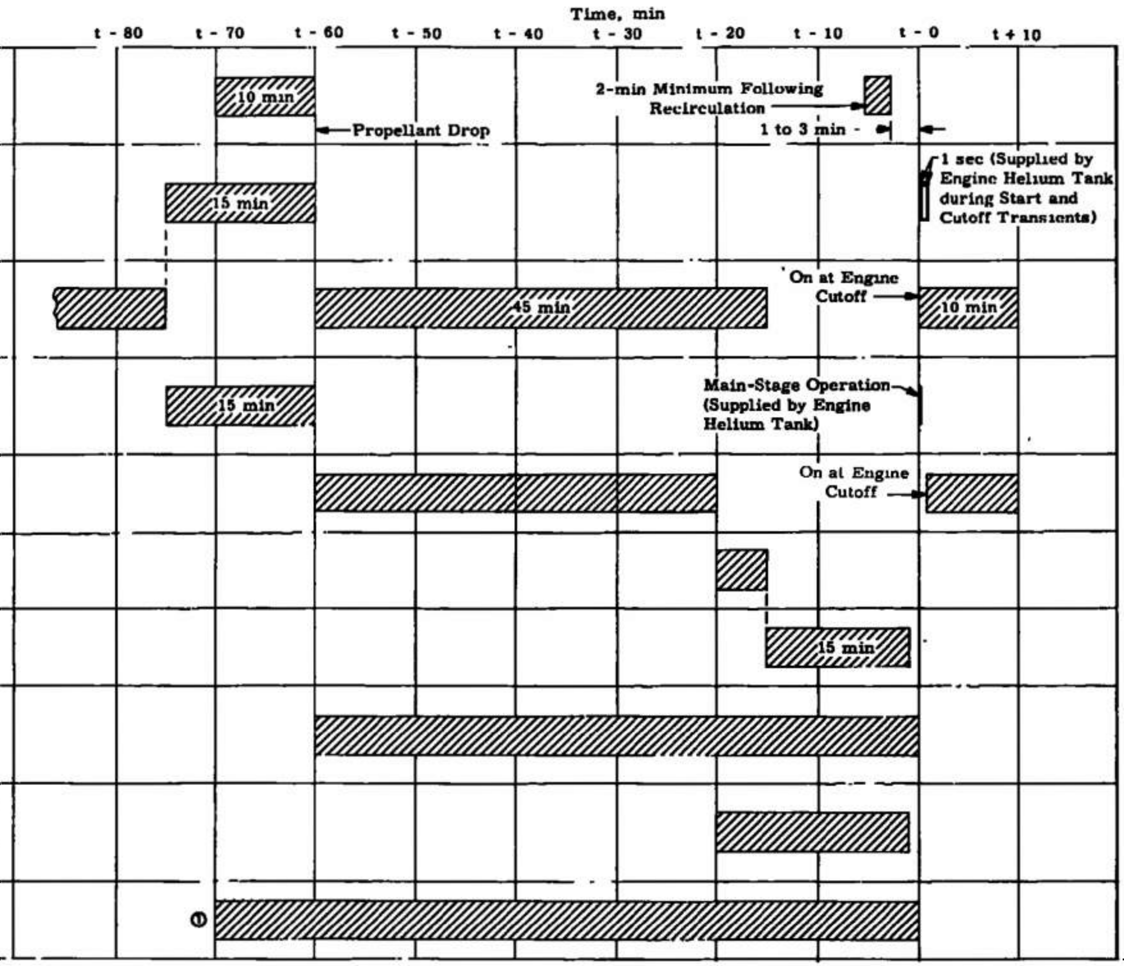
[1]RFD-Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS

Replacement	Completion Date	Component Replaced
P/N 408710 S/N 3729063	August 16, 1968	Gas Generator Oxidizer Supply Line P/N NA5-260113 S/N 045
P/N 309029 S/N 4076750	August 16, 1968	Oxidizer Bleed Valve P/N 309029 S/N 4078081
Test J4-1901-07 8/21/68		
None		
Test J4-1901-08 8/27/68		

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium, 82 - 130 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Helium, 1600 psig 50 - 100°F (Nominal) 230 scfm at Customer Connect
Oxidizer Dome (Facility Line to Port COA3)	Nitrogen, 415 - 675 psia 100 - 200°F 175 - 230 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 1400 psig 50 - 200°F 2600 to 7000 scim
Thrust Chamber Jacket (Customer Connect, Panel)	Nitrogen, 165 - 215 psia 100 - 200°F (Nominal) 100 scfm
	Helium; 55 - 200 psia Ambient Temperature
Thrust Chamber Temperature Conditioning	Helium, 1000 psia Maximum
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -140 to -300°F Helium; 1700 to 3250 psia -140 to 300°F
Crossover Duct Temperature Conditioning	Helium, -300°F to Ambient



①Conditioning Temperature to be Maintained for the Last 15 min of Pre-Fire

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number: J4-1901-07		A Target	A Actual	B Target	B Actual	C Target	C Actual	D Target	D Actual	E Target	E Actual
Time of Day, hr/Firing Date		1050	8/21/68	1119	8/21/68	1541	8/21/68	1609	8/21/68	1740	8/21/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	92,500	100,000	99,000	100,000	98,000	100,000	99,000	100,000	100,500
Firing Duration, sec[1]		32.5	32,573	7.5	7.587	32.5	32.573	7.5	7,586	1.25	1.250
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.5^{+1}_{-0}	27.0	28.5^{+1}_{-0}	28.7	28.5^{+1}_{-0}	26.9	25.5^{+1}_{-0}	27.0	41.0^{+1}_{-2}	41.3
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.0	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-420.8	-421.4 ± 0.4	-421.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0^{+1}_{-0}	45.1	45.0^{+1}_{-0}	45.4	45.0^{+1}_{-0}	45.6	45.0^{+1}_{-0}	45.3	33.0 ± 1	32.5
	Temperature, °F	-295.0 ± 0.4	-295.0	-295.0 ± 0.4	-294.9	-295.0 ± 0.4	-294.6	-295.0 ± 0.4	-294.4	-249.0 ± 0.4	-293.1
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1373	1300 ± 10	1303	1250 ± 10	1235	1200 ± 10	1213	1250 ± 10	1254
	Temperature, °F	-200 ± 10	-199	-265 ± 10	-289	-200 ± 10	-202	-260 ± 10	-264	-140 ± 10	-144
Helium Tank Conditions at Engine Start	Pressure, psia	---	2171	---	2184	---	2238	---	2122	---	2201
	Temperature, °F	---	-198	---	-261	---	-193	---	-258	---	-142
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-250 ± 25	-242	50 ± 25	+72	-250 ± 25	-240	50 ± 25	+74	-275 ± 25	-278
	Average Engine Start/t_0	---	-244/-343	---	+23/-277	---	-259/-353	---	+17/-283	---	-260/-385
Crossover Duct Temperature at Engine Start, °F[2]	TFTD-2	50^{+0}_{-50}	+20	---	+434	50^{+0}_{-50}	+28	---	+433	-100 ± 20	-118
	TFTD-3/4	50^{+0}_{-50}	+34/+35	170^{+15}_{-0}	+170/+183	50^{+0}_{-50}	+44/+46	170^{+15}_{-0}	+170/+162	-100 ± 20	-107/-103
	TFTD-6	50^{+0}_{-50}	+26	---	+432	50^{+0}_{-50}	+31	---	+434	-100 ± 20	-106
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F[3]		-150 ± 50	-128	-150 ± 50	-153	-150 ± 50	-172	-150 ± 50	-183	-150 ± 50	-127
Fuel Lead Time, sec[1]		3.0	3.021	8.0	7,934	3.0	3.019	8.0	7.935	3.0	3.021
Propellant in Engine Time, min		30	66	---	29	30	262	---	27	30	25
Propellant Recirculation Time, min		10	10	10	10	10	10	10	12.5	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	---	+30	---	+6	---	+21	---	+1	---	+17
	TOBS-2	---	+44	---	+4	---	+24	---	-5	---	-20
	TOBS-2B	---	+46	---	+43	---	+42	---	+38	---	+43
Start Tank Discharge Valve Body Temperature at Engine Start, °F		---	+38	---	-8	---	+3	---	-23	---	-33
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0		--- / ---	50 / 0.972	--- / ---	4 / 0.940	--- / ---	35 / 0.967	--- / ---	7 / 0.950	--- / ---	43/0.952 / 158/1.170
Gas Generator Outlet Temperature, °F	Initial Peak	---	1480	---	1210	---	1480	---	1400	---	800
	Second Peak	---	1250	---	1510	---	---	---	1510	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)[1]		---	0.962	---	0.944	---	0.996	---	0.958	---	0.967
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)[1]		---	0.982	---	1.112	---	0.993	---	1.086	---	0.966
Main-Stage Pressure No. 2, sec (Ref. t_0)[1]		---	1.888	---	1.876	---	1.668	---	1.586	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)		---	1.958	---	2.050	---	1.947	---	2.050	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / ---	Open / ---	Null / Closed	Null / Closed	Open / ---	Open / ---	Null / ---	Null / ---

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.

TABLE VI (Concluded)

Firing Number: J4-1901-09		A Target	A Actual	B Target	B Actual	C Target	C Actual	D Target	D Actual	E Target	E Actual
Time of Day, hr/Firing Date		1046	8/27/68	1114	8/27/68	1316	8/27/68	1347	8/27/68	1443	8/27/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	90,000	100,000	102,000	100,000	100,000	100,000	100,000	100,000	102,000
Firing Duration, sec①		32.5	32.572	7.5	7.587	32.5	32.572	7.5	7.588	1.25	1.250
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	41.0 ± 1	41.3	26.5^{+1}_{-0}	27.3	26.5^{+1}_{-0}	27.1	41.0 ± 1	41.0	26.5^{+1}_{-0}	27.4
	Temperature, °F	-420.4 ± 0.4	-420.7	-421.4 ± 0.4	-421.3	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.0	-421.4 ± 0.4	-421.0
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	34.9	45.0^{+1}_{-0}	45.5	45.0^{+1}_{-0}	45.5	45.0^{+1}_{-0}	45.0	45.0^{+1}_{-0}	45.2
	Temperature, °F	-294.5 ± 0.4	-294.5	-295.0 ± 0.4	-295.2	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-294.7	-295.0 ± 0.4	-294.6
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1374	1300 ± 10	1299	1400 ± 10	1367	1300 ± 10	1298	1400 ± 10	1406
	Temperature, °F	-140 ± 10	-145	-265 ± 10	-269	-200 ± 10	-203	-265 ± 10	-295	-200 ± 10	-204
Helium Tank Conditions at Engine Start	Pressure, psia	---	2172	---	2124	---	2223	---	2149	---	2104
	Temperature, °F	---	-133	---	-291	---	-199	---	-267	---	-200
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-150^{+20}_{-10}	-154	50 ± 25	+82	-90^{+20}_{-10}	-83	50 ± 25	+94	-250 ± 25	-244
	Average Engine Start/t_0	---	-149/-175	---	+22/-284	---	-93/-195	---	+29/-338	---	-264/-359
Crossover Duct Temperature at Engine Start, °F②	TFTD-2	-100 ± 20	-107	---	+388	50^{+0}_{-50}	+7	---	+422	50^{+0}_{-50}	+21
	TFTD-3/-4	-100 ± 20	-84/-81	170^{+15}_{-0}	+180/+185	50^{+0}_{-50}	+25/+26	170^{+15}_{-0}	+175/+183	50^{+0}_{-50}	+35/+35
	TFTD-8	-100 ± 20	-90	---	+419	50^{+0}_{-50}	+21	---	+431	50^{+0}_{-50}	+28
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F③		-100 ± 50	-92	-150 ± 50	-141	-150 ± 50	-177	-150 ± 50	-169	-150 ± 50	-190
Fuel Lead Time, sec①		1.0	1.000	8.0	7.934	3.0	3.021	8.0	7.931	3.0	3.017
Propellant in Engine Time, min		30	64	---	28	30	121	---	31	30	31
Propellant Recirculation Time, min		10	10	10	11.5	10	10	10	14	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	---	+28	---	+8	---	+12	---	-1	---	+19
	TOBS-2	---	+29	---	0	---	-4	---	-6	---	+6
	TOBS-2B	---	+40	---	+32	---	+34	---	+28	---	+38
Start Tank Discharge Valve Body Temperature at Engine Start, °F		50 ± 25	+62	---	+7	---	-40	---	-49	---	+34
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0		--- / ---	18 / 0.995	--- / ---	5 / 0.950	--- / ---	24 / 0.862	--- / ---	241 / 0.589	--- / ---	46/0.798 / 36/1.034
Gas Generator Outlet Temperature, °F	Initial Peak	---	930	---	1210	---	1380	---	1200	---	1520
	Second Peak	---	---	---	1460	---	1420	---	1460	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)①		---	0.997	---	0.949	---	0.992	---	0.962	---	0.903
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	0.975	---	1.093	---	0.989	---	1.097	---	1.037
Main-Stage Pressure No. 2, sec (Ref. t_0)①		---	1.714	---	1.888	---	1.598	---	1.679	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)		---	1.875	---	2.060	---	1.850	---	2.033	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / ---	Open / ---	Null / Closed	Null / Closed	Open / ---	Open / ---	Null / ---	Null / ---

Notes: ①Data reduced from oscillogram.
②Component conditioning to be maintained within limits for last 16 min before engine start.
③Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, which is longer.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1901-07	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
A	0.0	0.127	0.115	0.450	0.124	0.248	-3.021	0.093	0.097	0.450	0.053	0.050	0.450	0.532	1.874	0.450	0.104	0.033	0.450	0.178	0.083	0.450	0.217	0.278
B	0.0	0.132	0.121	0.450	0.131	0.248	-7.934	0.079	0.114	0.450	0.055	0.052	0.450	0.662	1.773	0.450	0.112	0.034	0.450	0.194	0.091	0.450	0.212	0.287
C	0.0	0.128	0.112	0.448	0.129	0.251	-3.019	0.082	0.107	0.448	0.058	0.053	0.448	0.545	1.883	0.448	0.109	0.031	0.448	0.186	0.084	0.448	0.218	0.283
D	0.0	0.132	0.117	0.449	0.134	0.249	-7.935	0.079	0.122	0.449	0.055	0.058	0.449	0.639	1.788	0.449	0.112	0.032	0.449	0.194	0.095	0.449	0.214	0.279
E	0.0	0.134	0.116	0.450	0.134	0.281	-3.021	0.073	0.108	0.450	0.054	0.057	0.450	0.536	---	0.450	0.108	0.036	0.450	0.193	0.110	0.450	0.218	0.287
Final Sequence	0.0	0.091	0.089	0.450	0.131	0.236	-0.998	0.059	0.102	0.450	0.054	0.042	0.450	0.602	1.880	0.450	0.088	0.032	0.450	0.143	0.073	0.450	0.202	0.278

Firing Number J4-1901-07	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
A	32.573	0.108	0.323	32.573	0.087	0.174	32.573	0.067	0.020	32.573	0.030	0.016	32.573	0.256	0.536
B	7.593	0.099	0.315	7.593	0.074	0.184	7.583	0.074	0.016	7.593	0.035	0.014	7.593	0.227	0.494
C	32.573	0.113	0.348	32.573	0.089	0.190	32.573	0.074	0.023	32.573	0.033	0.014	32.573	0.252	0.521
D	7.588	0.101	0.329	7.588	0.076	0.179	7.588	0.076	0.016	7.588	0.034	0.013	7.588	0.226	0.488
E	1.250	0.097	0.291	1.250	---	---	1.250	0.089	0.026	1.250	0.049	0.021	1.250	0.164	0.574
Final Sequence	6.174	0.076	0.224	8.174	0.061	0.122	6.174	0.094	0.038	8.174	0.059	0.028	6.174	0.222	0.581

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 VII (Concluded)

Firing Number J4-1901-08	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
A	0.0	0.123	0.112	0.450	0.125	0.243	-1.000	0.081	0.107	0.450	0.054	0.048	0.450	0.525	1.810	0.450	0.104	0.031	0.450	0.184	0.081	0.450	0.223	0.281
B	0.0	0.129	0.117	0.449	0.125	0.250	-7.934	0.078	0.114	0.449	0.055	0.049	0.449	0.644	1.791	0.449	0.108	0.032	0.449	0.183	0.092	0.449	0.218	0.284
C	0.0	0.135	0.126	0.448	0.130	0.266	-3.021	0.082	0.114	0.448	0.056	0.054	0.448	0.541	1.924	0.448	0.109	0.032	0.448	0.188	0.092	0.448	0.219	0.286
D	0.0	0.138	0.123	0.450	0.138	0.254	-7.831	0.079	0.124	0.450	0.056	0.054	0.450	0.647	1.808	0.450	0.111	0.031	0.450	0.186	0.081	0.450	0.216	0.287
E	0.0	0.127	0.113	0.448	0.123	0.245	-3.017	0.086	0.109	0.448	0.053	0.051	0.448	0.589	---	0.448	0.105	0.031	0.448	0.187	0.086	0.448	0.205	0.279
Final Sequence	0.0	0.089	0.093	0.450	0.128	0.241	-0.997	0.053	0.111	0.450	0.050	0.047	0.450	0.597	1.688	0.450	0.085	0.037	0.450	0.142	0.074	0.450	0.204	0.273

Firing Number J4-1801-08	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
A	32.572	0.104	0.298	32.572	0.080	0.167	32.572	0.064	0.022	32.572	0.029	0.013	32.572	0.257	0.576
B	7.587	0.101	0.314	7.587	0.079	0.173	7.587	0.074	0.023	7.587	0.034	0.016	7.587	0.233	0.527
C	32.572	0.113	0.352	32.572	0.085	0.182	32.572	0.069	0.020	32.572	0.030	0.014	32.572	0.244	0.529
D	7.588	0.109	0.336	7.588	0.083	0.178	7.588	0.076	0.026	7.588	0.036	0.014	7.588	0.226	0.487
E	1.250	0.101	0.317	1.250	---	---	1.250	0.081	0.023	1.250	0.043	0.018	1.250	0.158	0.529
Final Sequence	6.188	0.077	0.228	6.169	0.064	0.121	6.168	0.095	0.039	6.169	0.061	0.025	6.169	0.226	0.592

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

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1901-		07A		07C		08A		08C	
		Site	Normalized	Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	227,488	225,043	227,226	224,991	227,713	225,541	228,564	226,522
	Chamber Pressure, psia	779.6	767.0	778.8	766.9	780.3	768.5	782.8	771.7
	Mixture Ratio	5.657	5.658	5.659	5.661	5.618	5.639	5.613	5.626
	Fuel Weight Flow, lb_m/sec	81.37	80.08	81.49	80.26	81.99	80.58	82.20	80.94
	Oxidizer Weight Flow, lb_m/sec	460.3	453.1	461.1	454.4	460.6	454.4	461.4	455.4
	Total Weight Flow, lb_m/sec	541.7	533.2	542.6	534.6	542.6	535.0	543.6	536.3
Thrust Chamber Performance	Mixture Ratio	5.868	5.873	5.872	5.877	5.826	5.851	5.821	5.837
	Total Weight Flow, lb_m/sec	534.7	526.3	535.6	527.7	535.6	528.1	536.6	529.4
	Characteristic Velocity, ft/sec	7991	7988	7968	7965	7984	7976	7996	7990
Fuel Turbopump Performance	Pump Efficiency, percent	73.7	73.7	73.9	73.9	73.9	73.9	73.8	73.8
	Pump Speed, rpm	26,349	26,162	26,377	26,185	26,453	26,166	26,362	26,192
	Turbine Efficiency, percent	58.5	58.4	58.4	58.3	59.1	58.8	58.9	58.8
	Turbine Pressure Ratio	7.32	7.32	7.36	7.36	7.32	7.32	7.33	7.33
	Turbine Inlet Temperature, °F	1265	1247	1254	1236	1266	1245	1265	1250
	Turbine Weight Flow, lb_m/sec	6.97	6.90	6.99	6.93	6.96	6.90	6.99	6.93
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.3	80.3	80.3	80.3	80.3	80.3	80.3
	Pump Speed, rpm	8667	8595	8663	8589	8667	8598	8679	8612
	Turbine Efficiency, percent	49.0	48.8	49.0	48.8	49.4	49.2	49.4	49.2
	Turbine Pressure Ratio	2.58	2.58	2.58	2.58	2.59	2.59	2.57	2.57
	Turbine Inlet Temperature, °F	843.5	830.3	833.7	820.5	834.6	820.4	841.3	830.2
	Turbine Weight Flow, lb_m/sec	6.09	6.03	6.12	6.06	6.08	6.03	6.11	6.06
Gas Generator Performance	Mixture Ratio	0.978	0.967	0.972	0.961	0.979	0.967	0.979	0.969
	Chamber Pressure, psia	681.1	672.0	682.4	673.9	680.5	672.6	683.3	675.5

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

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1901-07 and J4-1901-08 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
1CC	Control		0 to 30	x		x		
1IC	Ignition		0 to 30	x		x		
	Event							
EASIOV	Augmented Spark Igniter Oxidizer Valve		Open/Closed	x		x		
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				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	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		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-1SAM	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				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x		x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x				
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCBO-1	Constant Bleed Orifice		0 to 50	x				
PCDP	Crossover Duct Purge		0 to 100	x				
PCGG-1P	Gas Generator Chamber		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFBL	Fuel Bleed Line		0 to 100	x		x		
PFJ-1A	Main Fuel Injection	CF2	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		
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		x
PFPI-2	Fuel Pump Inlet		0 to 100	x		x		x

TABLE III-1 (Continued)

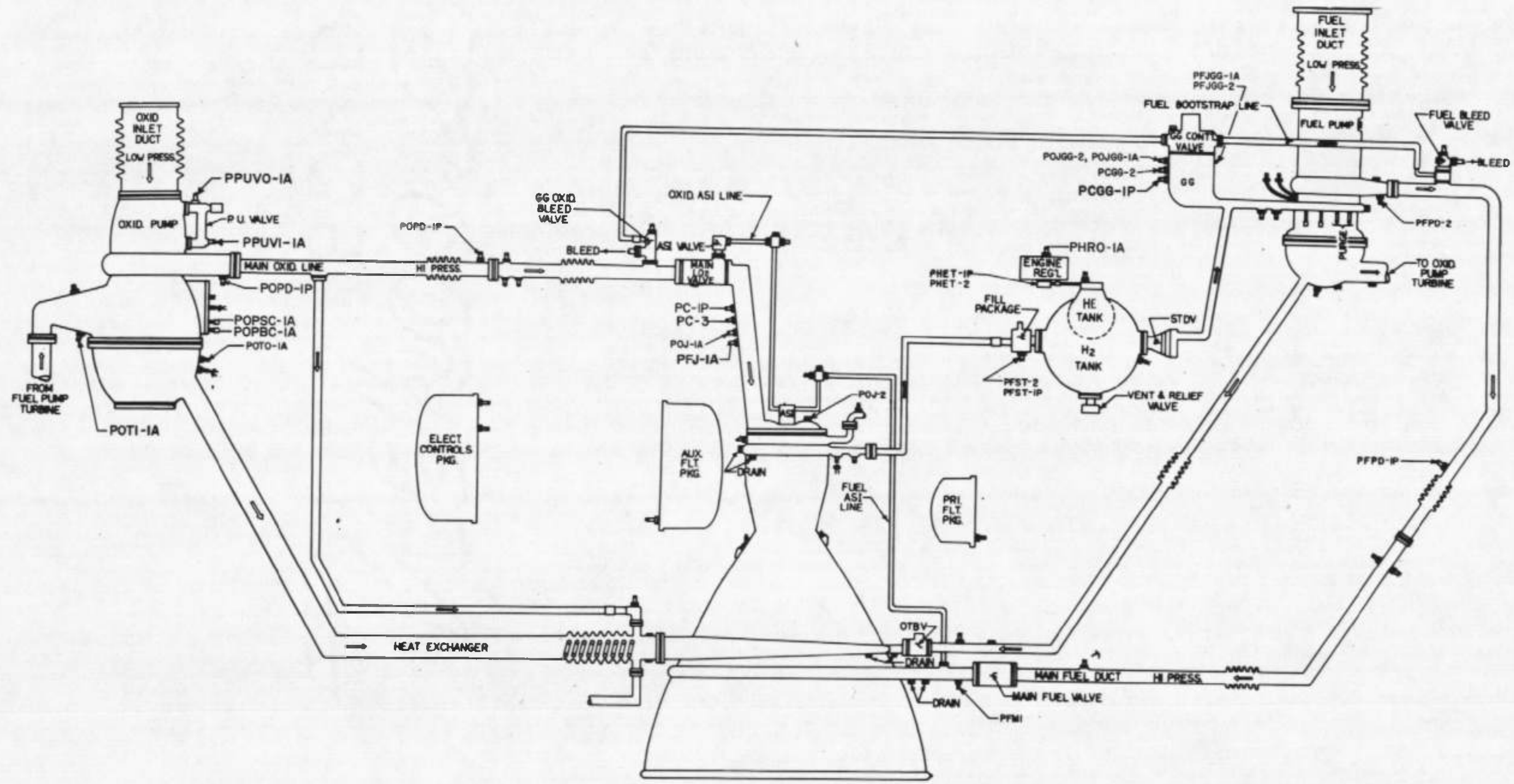
AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PFPI-3	Fuel Pump Inlet		0 to 200		x			
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
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				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJ-3	Main Oxidizer Injection		0 to 2000		x			
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
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				
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1500	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 1000	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TAIPAA	Auxiliary Instrument Package Area Ambient		-200 to +500	x				
TCDP	Crossover Duct Purge		-150 to +150	x				

TABLE III-1 (Continued)

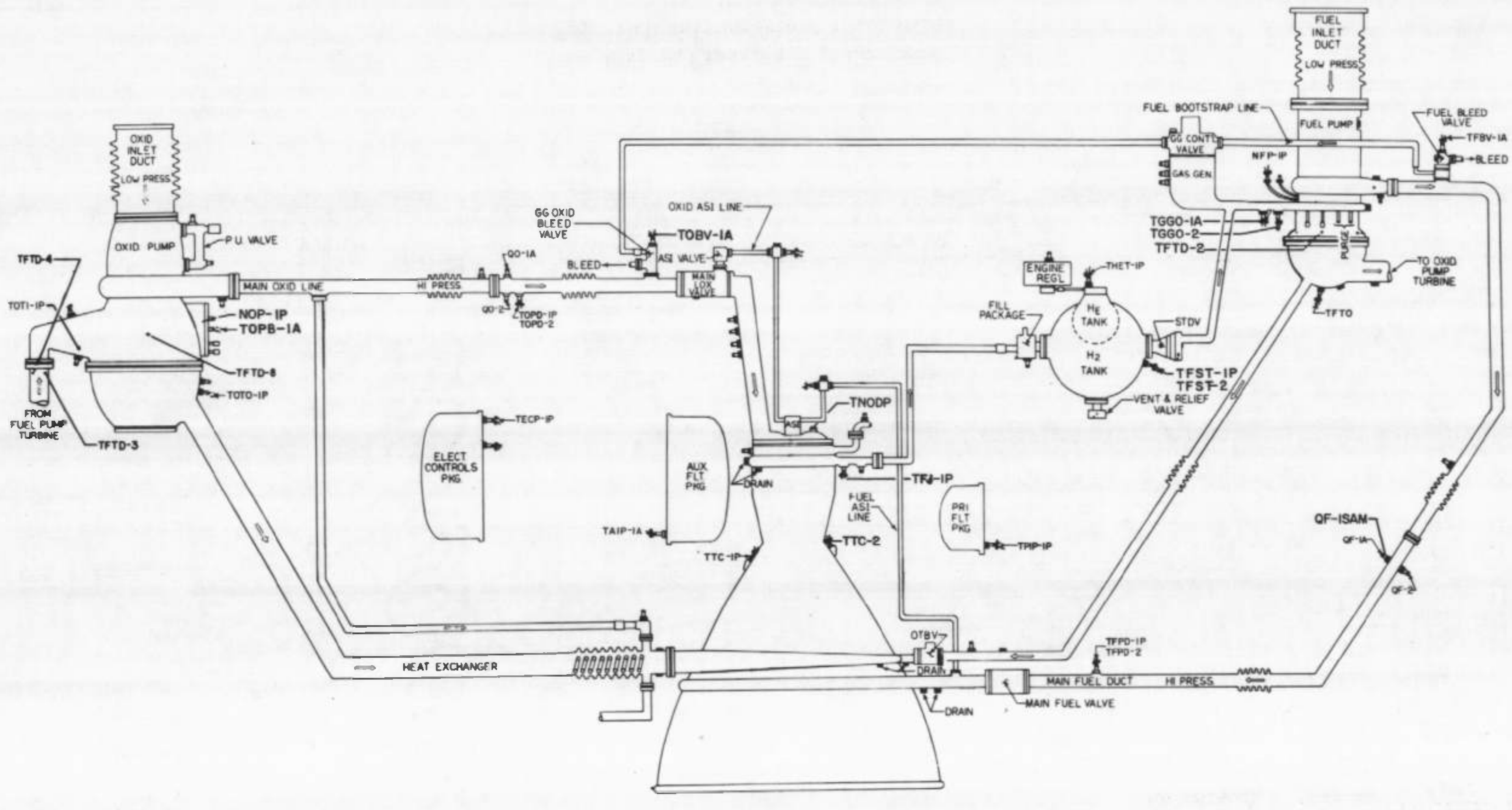
AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TEHAA	Engine Handler Attach Area Ambient		-200 to +500	x				
TFASIL-2	Augmented Spark Igniter Fuel Line Skin		-400 to +300	x				
TFASIL-4	Augmented Spark Igniter Fuel Line Skin		-425 to +500	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFDAA	Fuel High Pressure Duct Area Ambient		-200 to +500	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x		x		
TFJ-2	Main Fuel Injection		-450 to +250	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	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 -350	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	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-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTO	Fuel Turbine Outlet	TGT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A and 2	Gas Generator Outlet	GGT1	0 to 2500	x		x	x	
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x				
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	Oxidizer Dome Purge		0 to +300	x				
TOASIL-1	Augmented Spark Igniter Oxidizer Line Skin		-425 to +500	x				
TOASIL-2	Augmented Spark Igniter Oxidizer Line Skin		-400 to +300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TODAA	Oxidizer Dome Area Ambient		-200 to +500	x				
TODS-1	Oxidizer Dome Skin		-300 to +100	x			x	
TODS-2	Oxidizer Dome Skin		-300 to +100	x			x	
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	-300 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPIPAA	Primary Instrument Package Area Ambient		-200 to +500	x				

TABLE III-1 (Concluded)

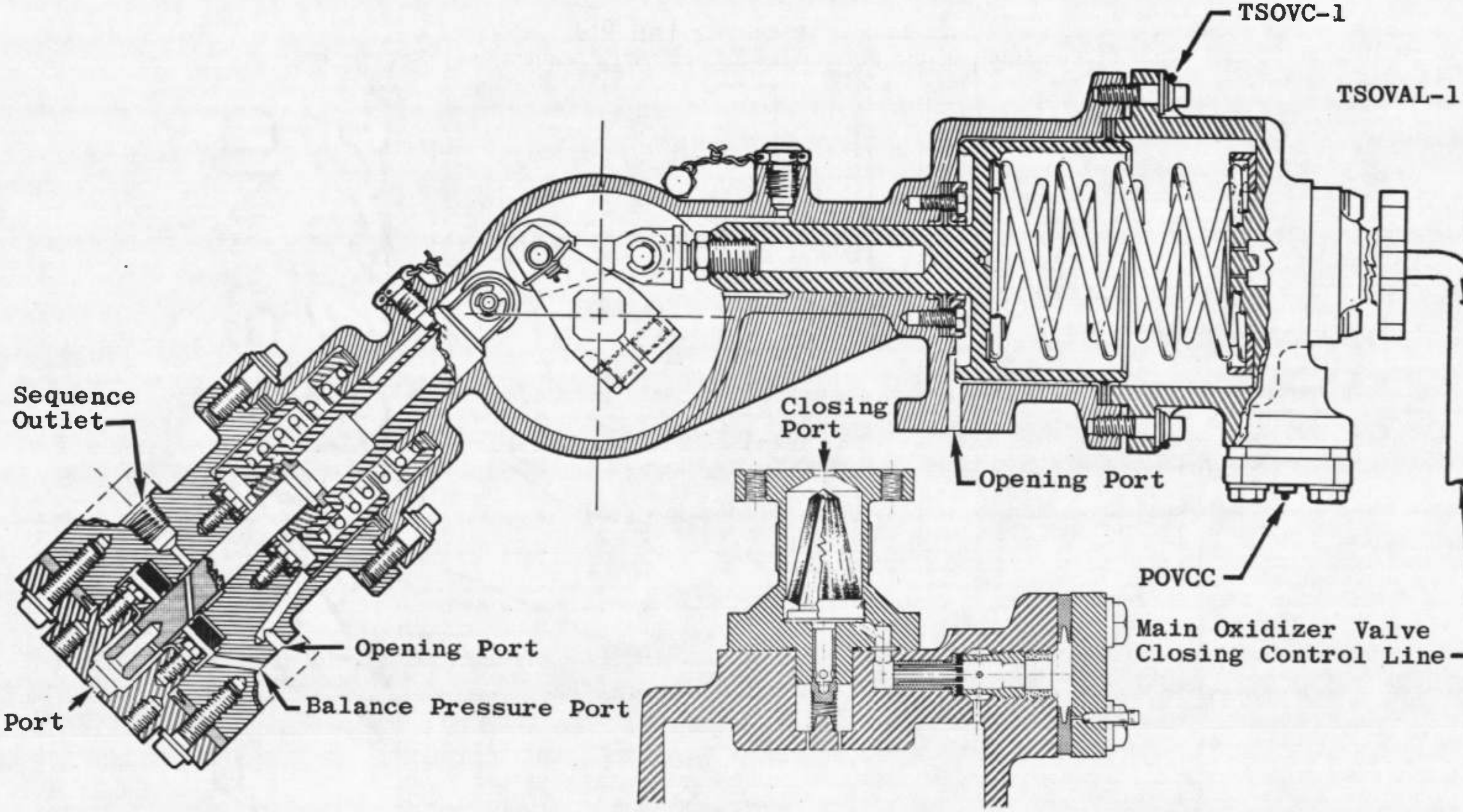
AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVC-1	Oxidizer Valve Actuator Cap	NST1	-325 to +150	x			x	
TSTDVAA	Start Tank Discharge Valve Area Ambient		-200 to +500	x				
TSTDVDL	Start Tank Discharge Valve Drain Line Port		-100 to +200	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-300 to +200	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTC-2	Thrust Chamber Jacket	CS1A	-425 to +100	x				
TTCP	Thrust Chamber Purge		-346 to +504	x				
TTPP	Turbopump Purge		-150 to +150	x			x	
	Vibrations		g's					
USAIF-1	Augmented Spark Igniter Fuel Orifice Block Tangential		±150		x			
UASIV-1	Augmented Spark Igniter Oxidizer Valve Axial		±150		x			
UASIV-3	Augmented Spark Igniter Oxidizer Valve Tangential		±150		x			
UFPR	Fuel Pump Radial 90 deg		±300		x	x		
UMFV-1	Main Fuel Valve Radial		±150		x			
UMFV-3	Main Fuel Valve Tangential		±150		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UOTBV-1	Oxidizer Turbine Bypass Valve Axial		±150		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x			
UTCD-4	Thrust Chamber Dome		±1000			x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibrstion Safety Counts		On/Off			x		
U3VSC	No. 3 Vibration Safety Counts		On/Off			x		
	Voltage		volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 6	x				



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

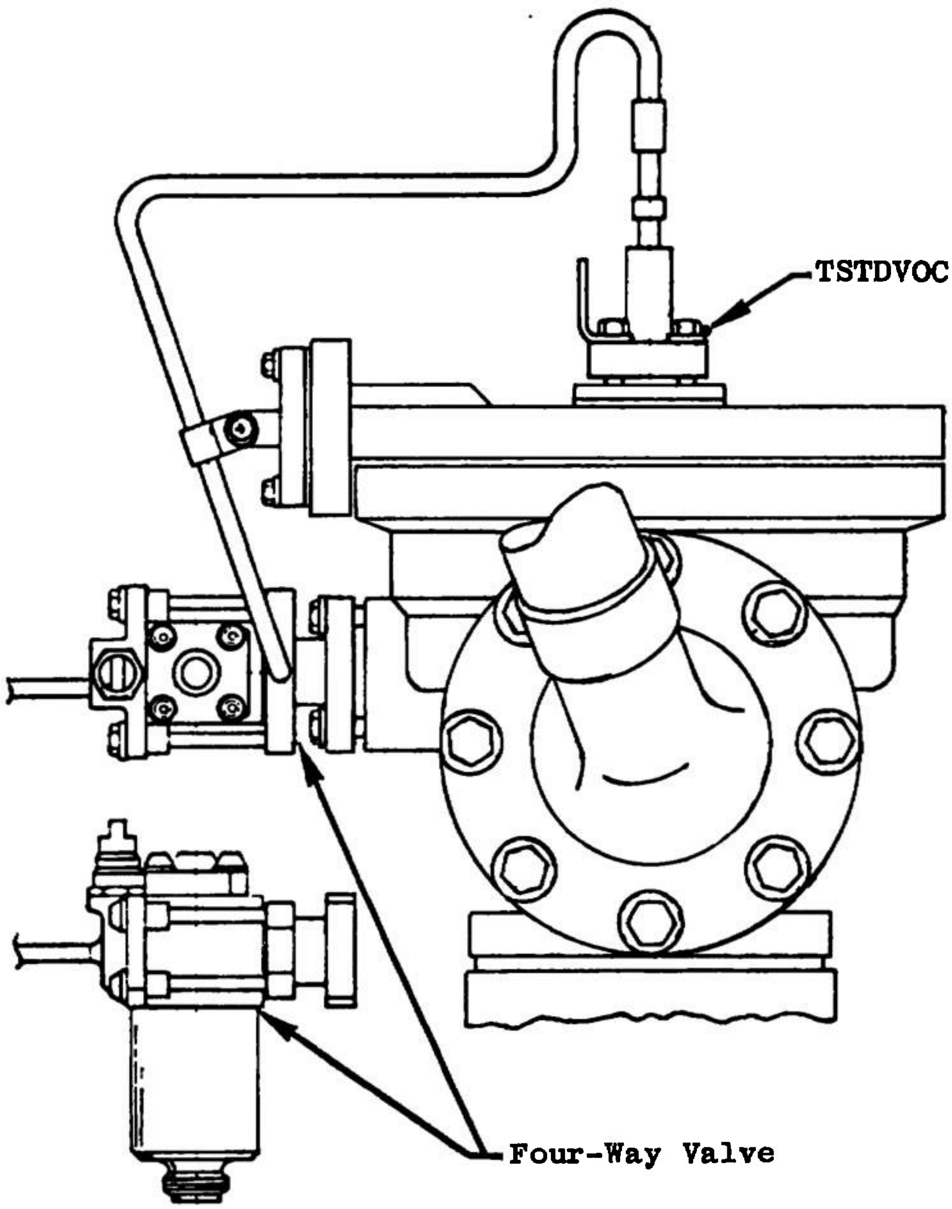


b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued

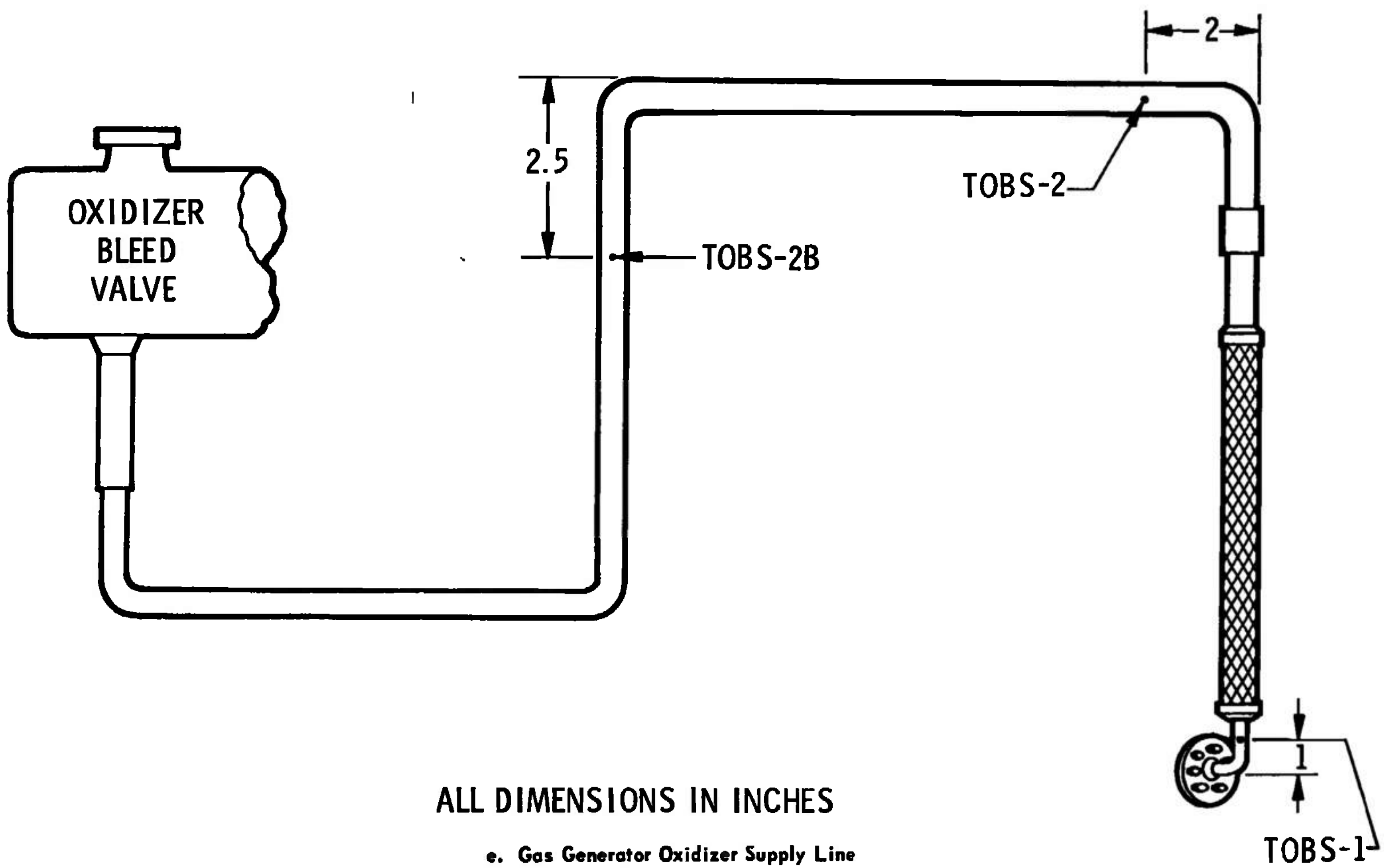


c. Main Oxidizer Valve

Fig. III-1 Continued



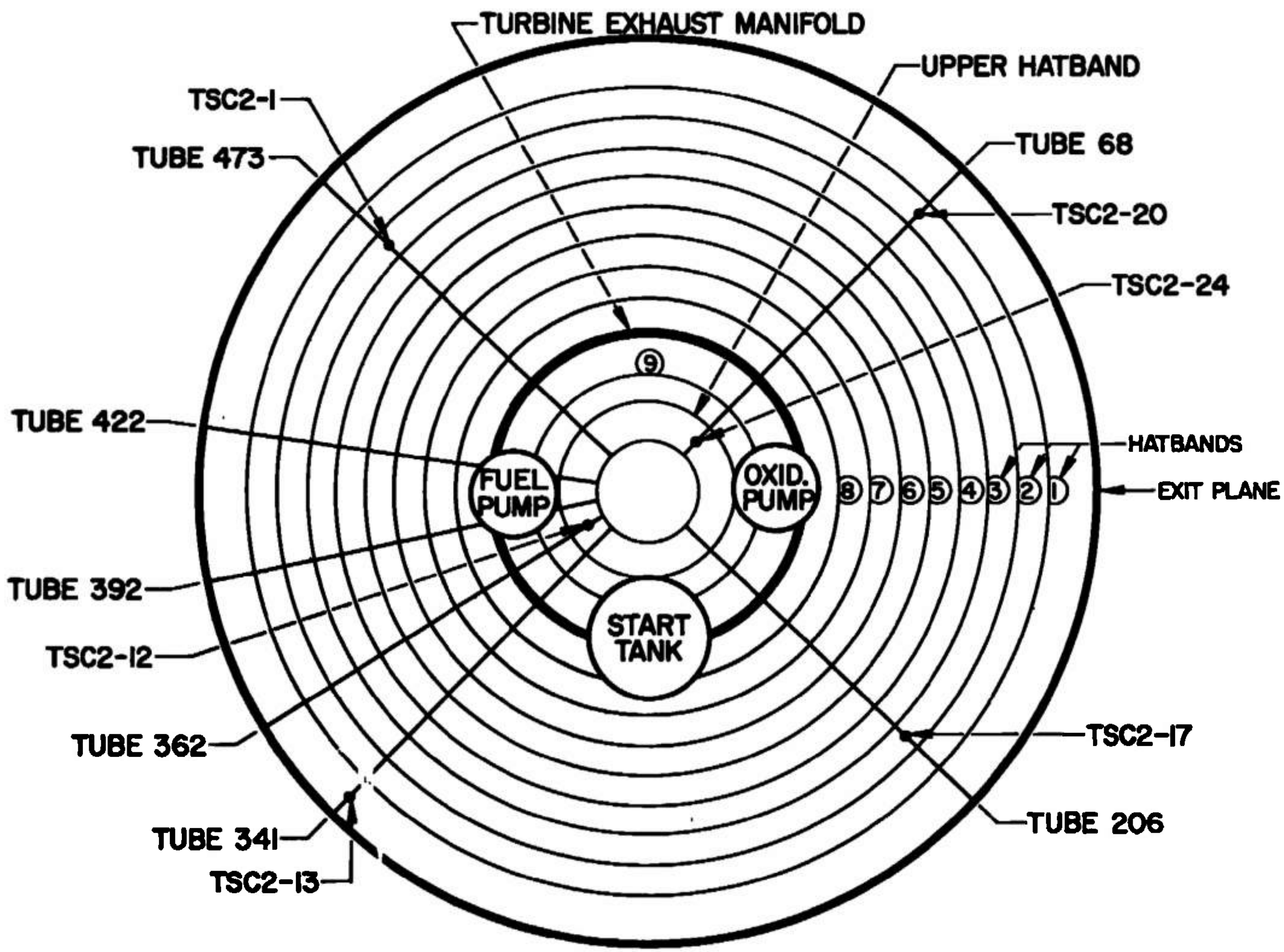
d. Start Tank Discharge Valve
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

e. Gas Generator Oxidizer Supply Line

Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber

Fig. III-1 Concluded

APPENDIX IV
METHOD OF CALCULATION (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

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

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

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower
C	Coefficient
C*	Characteristic velocity, ft/sec
D	Diameter, in.
F	Thrust, lb_f
H	Head, ft
h	Enthalpy, Btu/lb_m
I	Impulse
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
$\dot{R}$	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio, O/F
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Differential pressure, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiencies
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
FM	Fuel measured
FV	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
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
TO	Turbine oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

THRUST

Thrust Chamber, Vacuum

$$F_{CV} = C\,(P_C)^2 + B\,(P_C) + A$$

Empirical Determination from Curve Fit of Thrust versus P_C

Thrust Chamber

$$F_C = F_{CV} - P_{AA}\,A_e$$

$$A_e = A_{em} + 12.8$$

P_{AA} = Measured Cell Pressure

Engine, Vacuum

$$F_{EV} = F_{CV}$$

Engine

$$F_E = F_C$$

MIXTURE RATIO

Engine

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

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

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

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} = Standard 0.9 lb/sec

W_{XF} = Standard 2.1 lb/sec

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

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

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

$$K_7 = 32.174$$

Normalized engine and thrust chamber vacuum data calculated as measured, except all flows are normalized using standard inlet pressures, temperatures, and densities listed below:

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

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

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

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

$$T_{IO}\ STD = -295.2°F$$

$$T_{IF}\ STD = 422.5°F$$

SPECIFIC IMPULSE

Engine

$$I_{SE} = \frac{F_E}{\dot{W}_E}$$

$$\dot{W}_E = \dot{W}_{EO} + \dot{W}_{EF}$$

Engine, Vacuum

$$I_{SEV} = \frac{F_{EV}}{\dot{W}_{EV}}$$

$\dot{W}_{EV} = \dot{W}_E$ Normalized using standard inlet pressures, temperatures, and densities

Chamber

$$I_{SC} = \frac{F_C}{\dot{W}_C}$$

$$\dot{W}_C = \dot{W}_{CO} + \dot{W}_{CF}$$

Chamber, Vacuum

$$I_{SCV} = \frac{F_{CV}}{\dot{W}_{CV}}$$

$\dot{W}_{CV} = \dot{W}_C$ Normalized using standard inlet pressures, temperatures, and densities

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\ P_C\ A_t}{\dot{W}_C}$$

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

$$C^*_V = \frac{K_7\ P_{CV}\ A_t}{\dot{W}_{CV}}$$

$$K_7 = 32.174$$

Nozzle

$$C^*_N = \frac{C^*}{K_6}$$

$$K_6 = 1.086$$

Nozzle, Vacuum

$$C^*_{NV} = \frac{C^*_V}{K_6}$$

$$K_6 = 1.086$$

THRUST COEFFICIENT

Engine

$$C_F = \frac{F_C}{P_C A_t}$$

Engine, Vacuum

$$C_{FV} = \frac{F_{CV}}{P_C A_t}$$

DEVELOPED PUMP HEAD

Oxidizer

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

$$K_4 = 144$$

ρ = National Bureau of Standards Values f(P,T)

Fuel

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

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

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

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

Fuel and Oxidizer Vacuum

Conditions normalized using standard inlet pressures, temperatures, and densities.

PUMP EFFICIENCIES

Fuel, Isentropic

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

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

Oxidizer, Isentropic

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

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

$$Y_O = 1.000$$

$$K_{40} = -5.053 \qquad K_{50} = 3.861 \qquad K_{60} = 0.0733$$

TURBINES

Oxidizer, Efficiency

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

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

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

if $P_{OO} \geq 1010$

set $P_{OO} = 1010$

$$\ell n\, R_v = A + B\,(\theta_{PUVO}) + C(\theta_{PUVO})^2 + D\,(e)^{\frac{\theta_{PUVO}}{7}} + E\,\theta_{PUVO}\,(e)^{\frac{\theta_{PUVO}}{7}} + F\left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$A = 5.566 \times 10^{-1}$

$B = 1.500 \times 10^{-2}$

$C = 7.941 \times 10^{-6}$

$D = 1.234$

$E = -7.255 \times 10^{-2}$

$F = 5.069 \times 10^{-2}$

Fuel, Efficiency

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

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

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

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

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

$$K_{10} = 1.415$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO}$$

$$B_{PO} = K_5 \left(\frac{W_{PO}\ H_O}{\eta_O}\right)$$

$$K_5 = 0.001818$$

Fuel, Developed Horsepower

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

$$B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

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

Fuel, Weight Flow

$$W_{TF} = W_T$$

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

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

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

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

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

$$A_{NB} = K_{13}\ (D_{NB})^2$$

$$K_{13} = 0.7854$$

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

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

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

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

$K_8 = 38.8983$

GAS GENERATOR

Mixture Ratio

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

$A_1 = 0.2575$

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

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

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

$T_{H1} = T_{TIFM}$

Flows

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

$A_2 = 4.4226 \times 10^3$

$B_2 = 3.2267$

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

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

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

$K_8 = 38.8983$

Note: P_{TIF} is determined by iteration.

$T_{H1R} = T_{T1FM} + 460$

$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{H1R}, r_G)$

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13 ABSTRACT

Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during two test periods (J4-1901-07 and J4-1901-08) on August 21 and 27, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the Saturn V vehicle. The firings were accomplished at pressure altitudes between 93,000 and 102,000 ft at engine start. The primary objective of these firings was to evaluate transient gas generator temperatures under simulated engine first burn and restart conditions. Transient gas generator temperatures, particularly on engine restarts, were significantly reduced by utilizing a gas generator oxidizer supply line assembly which incorporated a geometrically different bellows section. The supply line assembly utilized on this series of firings had a 1.7 percent greater pressure drop at a flow of 3.5 lb_m/sec. The total accumulated firing duration for these tests was 163 sec.

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liquid propellants						
altitude simulation						
flight simulation						
startup						
performance tests						
performance evaluation						

1. Rocket motors -- J-2

2 " " -- Performance

AFSC
Arnold AFS Tenn