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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-17, 18, AND 19)

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C. E. Pillow

ARO, Inc.

June 1968

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-17, 18, AND 19)

C. E. Pillow

ARO, Inc.

FOREWORD

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

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American 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 between November 27 and December 7, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on March 13, 1968.

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This technical report has been reviewed and is approved.

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

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

ABSTRACT

Eleven firings of the Rocketdyne J-2 Rocket Engine (S/N J-2047) were conducted in Test Cell J-4 of the Large Rocket Facility. Pressure altitudes ranged from 90,000 to 110,000 ft at engine start. These were S-II Stage, Vehicles 502 and 503, verification tests to investigate fuel pump operation at net positive suction head below the minimum model specifications at engine start, and to evaluate the effect of heavier oxidizer turbine wheels on engine start transients. Selected engine components were thermally conditioned to targets predicted for the S-II stage engines. The accumulated firing duration for these tests was 130 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
NPSH	Net positive suction heat, ft
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 in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The eleven firings reported herein were in support of the S-II Stage, Vehicles 502 and 503, for the NASA Apollo Program. They were conducted during test periods J4-1801-17 through J4-1801-19 between November 27 and December 7, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate fuel pump operation at net positive suction head values below the minimum model specifications, Ref. 1, and to evaluate the effect of heavier oxidizer turbine wheels on the engine start transient. These firings were accomplished at pressure altitudes ranging from 90, 000 to 110, 000 ft (geometric pressure altitude, Z, Ref. 2) at engine start, and with predicted S-II interstage/engine temperature conditions as the targets for conditioning selected engine components.

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of the previous test period are presented in Ref. 3.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (S/N J-2047) (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine used liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225, 000 lb_f at an oxidizer-to-fuel mixture ratio of 5. 5. An S-IVB battleship stage with flight-type S-IVB stage pressure propellant supply ducts was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized. The requirement to measure side-load forces was deleted beginning with test J4-1801-17. Side-load forces for subsequent tests were restrained with stiff members mounted in the gimbal actuator positions.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 4) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

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

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

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

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

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

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage 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 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 and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

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. 5.

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 conditions were the thrust chamber, crossover duct, start tank discharge valve, and the main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the start tank discharge valve. The main oxidizer valve second-stage actuator was conditioned by the oxidizer within the valve and ambient helium blown over the component as required to attain the conditioning target.

2.3 INSTRUMENTATION

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

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

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

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

2.4 CONTROLS

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

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, start tank discharge valve, 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

Eleven firings of the J-2 rocket engine (S/N J-2047) were conducted between November 27 and December 7, 1967, during test periods J4-1801-17, 18, and 19. Each of these firings was in support of S-II Stage, Vehicles 502 and 503, verification to evaluate fuel pump operation at low propellant net positive suction head and the effect heavier oxidizer turbine wheels have on the engine start transient. Testing was accomplished at pressure altitudes ranging from 90,000 to 110,000 ft at engine start. Total accumulated firing duration for these tests was 130 sec.

Selected engine components were thermally conditioned to targets predicted for the S-II stage engines. Conditioning targets for the engine components and the measured test conditions at engine start are shown in Table VI. Engine start conditions for the pump inlets, start tank, and helium tank are shown in Fig. 8. Specific test objectives and a brief summary of results obtained from each firing are presented as follows:

Firing	Test Objectives	Results
17A	S-II start simulation to evaluate the minimum fuel pump stall margin at reduced net positive suction head, the maximum pressure buildup time of the thrust chamber to 550 psia with minimum starting energy.	A minimum fuel pump stall margin of 700 gpm was measured at approximately 19,000 rpm. Thrust chamber pressure buildup to 550 psia occurred at $t_0 + 2.177$ sec. The test was prematurely terminated at $t_0 + 27.56$ sec.
18A	S-II start simulation to evaluate the minimum fuel pump stall margin at reduced net positive suction head, and the thrust chamber pressure buildup time to 550 psia with minimum starting energy.	A minimum fuel pump stall margin of 600 gpm was measured at approximately 18,000 rpm. Thrust chamber pressure buildup to 550 psia occurred at $t_0 + 2.241$ sec.

Firing	Test Objectives	Results
18B	S-II start simulation to evaluate fuel pump stall margin during start tank discharge with low fuel pump net positive suction head, gas generator temperature with warmest expected (-150°F) thrust chamber, and augmented spark igniter operation.	There were no apparent fuel pump stall tendencies during start tank discharge. The initial gas generator outlet temperature peak was 1725°F with a second peak of 1405°F. No erosion of the augmented spark igniter chamber was detected.
18C	S-II start simulation to evaluate fuel pump operation at reduced net positive suction head, gas generator peak temperature, and augmented spark igniter operation with cold (-250°F) thrust chamber. Determine effect of heavier oxidizer turbine wheels on start transient by comparison with firing J4-1801-15B.	No apparent fuel pump stall tendencies were noted. The initial gas generator outlet temperature peak was 1900°F with a second peak of 1360°F. No erosion of the augmented spark igniter chamber was detected. Peak oxidizer turbine speed during start tank discharge was approximately 40 rpm lower on firing 18C than on firing 15B.
18D	S-II start simulation to evaluate engine start transient with maximum predicted flight fuel pump inlet pressure and coldest (-250°F) thrust chamber; compare with 18C to determine start tank temperature relation with peak gas generator outlet temperature.	Maximum predicted flight fuel pump inlet pressure had no apparent effect on the engine start transient. The peak gas generator outlet temperature was 1855°F, or approximately 0.5°F decrease in gas generator outlet temperature peak for each 1.0°F increase in start tank temperature.
18E	S-II start simulation to evaluate fuel pump operation during start tank discharge with low propellant net positive suction head at engine start.	A conservative fuel pump stall margin was maintained during start tank discharge.
19A	S-II start simulation to evaluate fuel pump operation at reduced net positive suction head.	A minimum fuel pump stall margin of 650 gpm was measured at approximately 19,000 rpm.

Firing	Test Objectives	Results
19B	S-II start simulation to evaluate fuel pump operation at reduced net positive suction head, the effect of heavier oxidizer turbine wheels on start transient by comparing with firing J4-1801-16B, and augmented spark igniter operation with maximum starting energy and warm (-150°F) thrust chamber.	The fuel pump stall margin was conservative throughout the firing. Peak oxidizer turbine speed during start tank discharge was 75 rpm lower on firing 19B than on firing 16B. No apparent erosion of the augmented spark igniter chamber was detected.
19C	S-II start simulation to evaluate fuel pump operation at reduced net positive suction head, gas generator outlet temperature, and augmented spark igniter operation with maximum starting energy and warm (-150°F) thrust chamber.	No apparent fuel pump stall tendencies were observed throughout the firing. The peak gas generator outlet temperature was 1675°F. There was no erosion of the augmented spark igniter chamber detected.
19D	S-II start simulation to evaluate the effect of heavier oxidizer turbine wheels on the gas generator outlet temperature peak with coldest (-250°F) thrust chamber.	The peak gas generator outlet temperature was 1960°F.
19E	S-II start simulation to evaluate fuel pump operation with low propellant net positive suction head during start tank discharge.	A conservative fuel pump stall margin was recorded during start tank discharge.

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

4.2 TEST RESULTS

4.2.1 Firing J4-1801-17A

The programmed 30-sec engine firing was prematurely terminated at $t_0 + 27.56$ sec when the oxidizer pump inlet pressure exceeded the maximum operating safety limit. This was not an engine anomaly, but resulted from pressurization of the oxidizer tank above the requested level by the facility system. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients of selected primary engine parameters are shown in Fig. 9. Selected engine valve operating times during start and shutdown are shown in Table VII.

The pressure altitude at engine start was 93,000 ft. Engine ambient pressure and combustion chamber pressure histories during this firing are shown in Fig. 10. The chamber pressure rise from 690 to 780 psia at approximately t_0 + 16.5 sec reflects the propellant utilization valve movement from the null to closed positions. This changed the engine mixture ratio from 5.0 to 5.5.

Selected engine components were thermally conditioned to conditions predicted for the S-II stage engines. Temperature histories of the main oxidizer valve second-stage actuator, start tank discharge valve, crossover duct, and thrust chamber prefire 17A are shown in Fig. 11.

Thrust chamber ignition (chamber pressure = 100 psia) was recorded at t_0 + 1.027 sec. Main-stage operation (chamber pressure = 550 psia) was achieved at t_0 + 2.177 sec. The main oxidizer valve second stage began to move at t_0 + 0.961 sec. Engine vibration (VSC) was recorded for 20 msec beginning at t_0 + 1.026 sec.

The maximum gas generator outlet temperature during the start transient was 1500°F. There was no second temperature peak. The gas generator control valve began to operate prematurely as shown in Fig. 12. The remaining firings were cancelled because of this anomaly. Posttest inspection revealed that "opening" pressure was leaking past a seal in the main oxidizer valve sequence valve which tended to prematurely open the gas generator control valve.

Fuel pump head/flow data are compared with manufacturer-supplied stall inception data in Fig. 13. A minimum fuel pump stall margin of 700 gpm was recorded at approximately 19,000 rpm.

Steady state engine performance data are tabulated in Table VIII. Test data were averaged from 24 to 25 sec and input in the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and program computations are presented in Appendix IV.

4.2.2 Firing J4-1801-18A

The programmed 30-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in

Table VI. The engine start and shutdown transients are shown in Fig. 14. Selected engine valve operating times during start and shutdown are shown in Table VII.

The pressure altitude at engine start was 91,000 ft. Engine ambient and combustion chamber pressure histories during the firing are shown in Fig. 15. At t_0 + 13.5 sec, the propellant utilization valve was operated to change the engine mixture ratio from 5.0 to 5.5 as shown by the combustion chamber pressure increase from 680 to 775 psia.

Selected engine components were thermally conditioned to conditions predicted for the S-II stage engines. Temperature conditioning histories of the main oxidizer valve second-stage actuator, start tank discharge valve, crossover duct, and thrust chamber prefire 18A are shown in Fig. 16.

Thrust chamber ignition (chamber pressure = 100 psia) was recorded at t_0 + 1.042 sec with the main oxidizer valve second-stage initial movement beginning at t_0 + 0.964 sec. Engine vibration (VSC) was recorded for 32 msec beginning at t_0 + 1.031 sec. Combustion chamber pressure buildup to 550 psia (main-stage operation) occurred 2.241 sec after t_0. The maximum gas generator outlet temperature was 1345°F with no second peak.

Fuel pump transient head/flow data are compared with stall inception data supplied by the manufacturer in Fig. 17. A minimum fuel pump stall margin of 600 gpm was measured at approximately 18,000 rpm.

Steady-state engine performance data are tabulated in Table VIII. Test data were averaged from 29 to 30 sec and input in the Rocketdyne, PAST 640, modification zero, performance computer program. Engine test measurements required by the program and program computations are presented in Appendix IV.

4.2.3 Firing J4-1801-18B

A programmed 5-sec duration was achieved for this firing. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients of selected engine parameters are shown in Fig. 18. Selected engine valve operating times are tabulated in Table VII. Temperature conditioning histories of selected engine components, prefire 18B, are shown in Fig. 19. The pressure altitude at engine start was 106,000 ft. Engine ambient pressure and combustion chamber pressure histories are shown in Fig. 20. The propellant utilization valve was in the null position (mixture ratio = 5.0) during this firing.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 0.962 sec. The initial main oxidizer valve second-stage movement began at t_0 + 1.028 sec. Engine vibration (VSC) was recorded for 64 msec beginning at t_0 + 0.960 sec. Main-stage operation (chamber pressure = 550 psia) was achieved at t_0 + 1.930 sec. The initial gas generator outlet temperature was 1725°F with a prolonged second peak of 1405°F, as shown in Fig. 18.

Fuel pump transient head/flow data are compared with stall inception data in Fig. 21. A conservative stall margin was maintained throughout the firing.

4.2.4 Firing J4-1801-18C

The programmed 5-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients of selected engine parameters are shown in Fig. 22. Selected engine valve operating times are tabulated in Table VII. Temperature conditioning histories of selected components, prefire 18C, are shown in Fig. 23. The pressure altitude at engine start was 106,000 ft. Engine ambient and combustion chamber pressure histories during engine operation are shown in Fig. 24. This firing was conducted with the propellant utilization valve in the null position (mixture ratio = 5.0).

Firing 18C compares closely with test conditions for firing J4-1801-15B, Ref. 6, with the following exceptions:

1. 18C had heavier oxidizer turbine wheels, and
2. 18C had a larger oxidizer turbine bypass valve nozzle (1.430 versus 1.319 in.).

This close similarity permitted evaluation of the effect heavier oxidizer turbine wheels have on the engine start transient before the oxidizer turbine bypass valve began to close. The oxidizer turbine bypass valve began to close at t_0 + 0.670 sec on firing 18C, and t_0 + 0.668 sec on firing 15B. During start tank discharge and before the bypass valve began to close, the peak oxidizer pump speed was 3565 rpm, approximately 40 rpm less than occurred on firing 15B, as shown in Fig. 22.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 0.977 sec. Engine vibration (VSC) was recorded for 138 msec beginning at t_0 + 0.976 sec. The initial main oxidizer valve second-stage movement began at t_0 + 1.031 sec. Main-stage operation (chamber pressure = 550 psia) was achieved at t_0 + 2.016 sec. The peak gas generator outlet temperature was 1900°F with a second peak of 1360°F as shown in Fig. 22.

Comparison of test data from firings 18B and 18C revealed that the thrust chamber throat temperature was approximately 100°F colder on firing 18C. This resulted in about 175°F hotter peak gas generator outlet temperature on firing 18C.

Fuel pump performance is shown in Fig. 25. Transient head/flow data are compared with stall inception data and show that a conservative stall margin was maintained throughout the firing.

4.2.5 Firing J4-1801-18D

The programmed 5-sec firing was successfully achieved. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients are shown in Fig. 26. Selected engine valve operating times during start and shutdown transients are tabulated in Table VII. The pressure altitude at engine start was 106,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 27. Temperature conditioning histories of selected engine components prefire 18D are shown in Fig. 28.

Comparison of firing 18C with 18D revealed that no significant change in the start transients resulted from the high fuel pump inlet pressure. Start tank temperature was approximately 100°F warmer on firing 18D. This resulted in approximately a 45°F lower gas generator outlet temperature peak on firing 18D.

Thrust chamber ignition occurred at t_0 + 0.988 sec. The main oxidizer valve second stage began to move at t_0 + 1.035 sec during engine vibration (VSC). Engine vibration (VSC) was recorded for 46 msec beginning at t_0 + 0.986 sec. Main-stage operation was achieved at t_0 + 1.933 sec.

Transient fuel pump performance is shown in Fig. 29. Transient head/flow data show that a conservative stall margin was maintained throughout the firing.

4.2.6 Firing J4-1801-18E

A programmed firing with 400 msec of main-stage operation was successfully conducted. Conditioning requirements and test results at engine start are shown in Table VI. The start and shutdown transients of selected engine parameters are shown in Fig. 30. Selected engine valve operating times are tabulated in Table VII. The pressure altitude at engine start was 105,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 31. Temperature conditioning histories of selected engine components prefire 18E are shown in Fig. 32.

Transient fuel pump performance is shown in Fig. 33. Transient head/flow data show that a conservative stall margin was observed during start tank discharge.

4.2.7 Firing J4-1801-19A

The programmed 32.5-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients are shown in Fig. 34. Selected engine valve operating times are tabulated in Table VII. Selected engine components were thermally conditioned prefire 19A to conditions predicted for the S-II stage engines, as shown in Fig. 35.

The pressure altitude at engine start was 90,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 36. The propellant utilization valve was operated at t_0 + 12.5 sec to change the engine mixture ratio from 5.0 to 5.5. This is shown by the increase from 680 to 740 psia in combustion chamber pressure.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 1.035 sec. Main-stage operation was achieved at t_0 + 2.208 sec (chamber pressure = 550 psia). The initial main oxidizer valve second-stage movement occurred at t_0 + 0.995 sec. Engine vibration (VSC) was recorded for 35 msec beginning at t_0 + 1.035 sec. The maximum gas generator outlet temperature recorded was 1285°F.

Transient fuel pump head/flow data are compared with the stall inception line in Fig. 37. A minimum fuel pump stall margin of 650 gpm was recorded at approximately 19,000 rpm.

Steady-state engine performance data are tabulated in Table VIII. Test data were averaged from 29 to 30 sec and input in the Rocketdyne past 640, modification zero, computer performance program. Engine test measurements required by the program and program computations are presented in Appendix IV.

4.2.8 Firing J4-1801-19B

The programmed 7.6-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients are shown in Fig. 38. Selected engine valve operating times during start and shutdown transients are tabulated in Table VII. Selected engine components were thermally conditioned prefire 19B to conditions predicted for the S-II stage engines, as shown in Fig. 39.

The pressure altitude at engine start was 106,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 40. The propellant utilization valve was positioned to provide an engine mixture ratio of 5.0.

Firing 19B compared closely with the test conditions for firing J4-1801-16B, Ref. 3, with the following exceptions:

1. 19B had heavier oxidizer turbine wheels, and
2. 19B had a larger oxidizer turbine bypass valve nozzle (1.430 versus 1.319 in.).

This close similarity permitted evaluation of the effect heavier oxidizer turbine wheels have on the engine start transient before the oxidizer turbine valve began to close. The oxidizer turbine bypass valve began to close at t_0 + 0.684 sec on firing 19B and at t_0 + 0.655 sec on firing 16B. During start tank discharge and before the bypass valve began to close, the peak oxidizer pump speed was 3590 rpm, approximately 75 rpm less than occurred on firing 16B, as shown in Fig. 38.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 0.965 sec. Main-stage operation was achieved at t_0 + 1.950 sec (chamber pressure = 550 psia). The initial main oxidizer valve second-stage actuator movement occurred at t_0 + 1.076 sec. The maximum gas generator outlet temperature recorded was 1610°F. Engine vibration (VSC) was recorded for 20 msec beginning at t_0 + 0.964 sec.

Transient fuel pump head/flow data are compared with the stall inception line in Fig. 41. A conservative stall margin was observed throughout the firing.

4.2.9 Firing J4-1801-19C

The programmed 7.6-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients are shown in Fig. 42. Selected engine valve operating times during start and shutdown transients are tabulated in Table VII. Selected engine components were thermally conditioned prefire 19C to conditions predicted for the S-II stage engines, as shown in Fig. 43.

The pressure altitude at engine start was 106,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 44. The propellant utilization valve was positioned to provide an engine mixture ratio of 5.0.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 0.957 sec. Main-stage operation was achieved at t_0 + 1.939 sec (chamber pressure = 550 psia). The initial main oxidizer valve second-stage actuator movement occurred at t_0 + 1.075 sec. The maximum gas generator outlet temperature recorded was 1675°F. Engine vibration (VSC) was recorded for 20 msec beginning at t_0 + 0.955 sec.

Transient fuel pump head/flow data are compared with the stall inception line in Fig. 45. A conservative stall margin was observed throughout the firing.

4.2.10 Firing J4-1801-19D

The programmed 7.6-sec firing was successfully accomplished. Conditioning requirements and test results at engine start are shown in Table VI. The engine start and shutdown transients are shown in Fig. 46. Selected engine valve operating times during start and shutdown transients are tabulated in Table VII. Selected engine components were thermally conditioned prefire 19D to conditions predicted for the S-II stage engines as shown in Fig. 47.

The pressure altitude at engine start was 110,000 ft. Engine ambient and combustion chamber pressure histories are shown in Fig. 48. The propellant utilization valve was positioned to provide an engine mixture ratio of 5.0.

Thrust chamber ignition (chamber pressure = 100 psia) occurred at t_0 + 0.990 sec. Main-stage operation was achieved at t_0 + 2.058 sec (chamber pressure = 550 psia). The initial main oxidizer valve second-stage actuator movement occurred at t_0 + 1.024 sec. The maximum gas generator outlet temperature recorded was 1960°F. Engine vibration (VSC) was recorded for 35 msec beginning at t_0 + 0.984.

Transient fuel pump head/flow data are compared with the stall inception line in Fig. 49. A conservative stall margin was observed throughout the firing.

4.2.11 Firing J4-1801-19E

A programmed firing with 400 msec of main-stage operation was successfully conducted. Conditioning requirements and test results at engine start are shown in Table VI. The start and shutdown transients of selected engine parameters are shown in Fig. 50. Valve operating times of selected engine components are tabulated in Table VII. Temperature conditioning histories of the main oxidizer valve second-stage actuator, start tank discharge valve, crossover duct, and thrust chamber throat prefire 19E are shown in Fig. 51. The engine ambient and combustion start tank discharge valve, crossover duct, and thrust chamber throat prefire 19E are shown in Fig. 51. The engine ambient and combustion chamber pressure histories are shown in Fig. 52. The pressure altitude at engine start was 110,000 ft.

Transient fuel pump performance is shown in Fig. 53. Comparison of transient head/flow data with the stall inception line revealed that a conservative stall margin was maintained during start tank discharge.

The gas generator control valve was inadvertently conditioned to -185°F. This resulted in abnormal delay and opening times of the gas generator poppets, as shown in Fig. 54.

4.2.12 Posttest Inspection

Leak checks performed posttest J4-1801-17 revealed that the start tank discharge valve was leaking and required replacing before test J4-1801-18. Visual inspection of the augmented spark igniter chamber revealed no apparent erosion. Improper gas generator control valve operation during firing 17A resulted in the removal and checking of the main oxidizer valve and the oxidizer turbine bypass valve. A leaking seal in the main oxidizer valve sequence valve was found to be allowing "opening" pressure to prematurely operate the gas generator control valve.

Visual examination after tests 18 and 19 detected no apparent erosion of the augmented spark igniter chamber.

SECTION V
SUMMARY OF RESULTS

The results of these eleven firings of the J-2 Rocket Engine conducted during Tests J4-1801-17, 18, and 19 between November 27 and December 7, 1967, in Test Cell J-4 are summarized as follows:

1. The increased inertia of the heavier oxidizer turbine wheels resulted in a decrease of less than 75 rpm in peak turbine speed during start tank discharge, before the oxidizer turbine bypass valve began to close.
2. A decrease in thrust chamber throat temperature from -153 to -250°F resulted in approximately a 175°F increase in initial peak gas generator outlet temperature.
3. Maximum predicted fuel pump inlet pressure of 38.2 psia resulted in no apparent change in the engine start transient.

4. An increase in start tank temperature from -242 to -145°F at a constant pressure of 1400 psia resulted in approximately a 45°F decrease in initial peak gas generator outlet temperature.

5. All firings with low fuel pump net positive suction head maintained conservative fuel pump stall margins.

6. There was no apparent erosion of the augmented spark igniter chamber.

REFERENCES

1. "Engine Model Specification Liquid-Propellant Rocket Engine - Rocketdyne Model J-2," R-2158cS, January 1966.

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

3. Kunz, C. H. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-16)." AEDC-TR-68-43, April 1968.

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

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

6. Counts, H. J., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-13 through J4-1801-15)." AEDC-TR-68-16, February 1968.

APPENDIXES

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

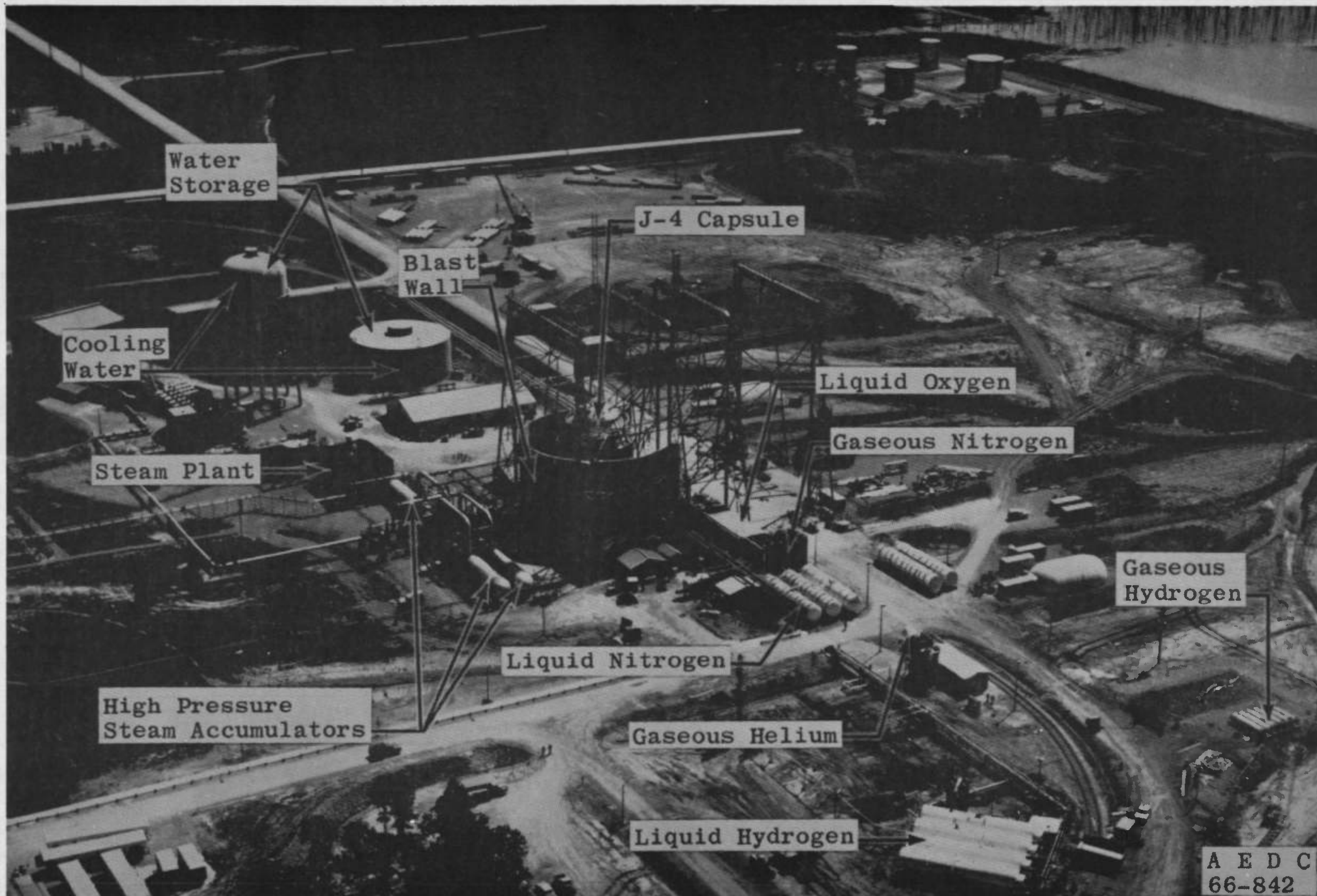


Fig. 1 Test Cell J-4 Complex

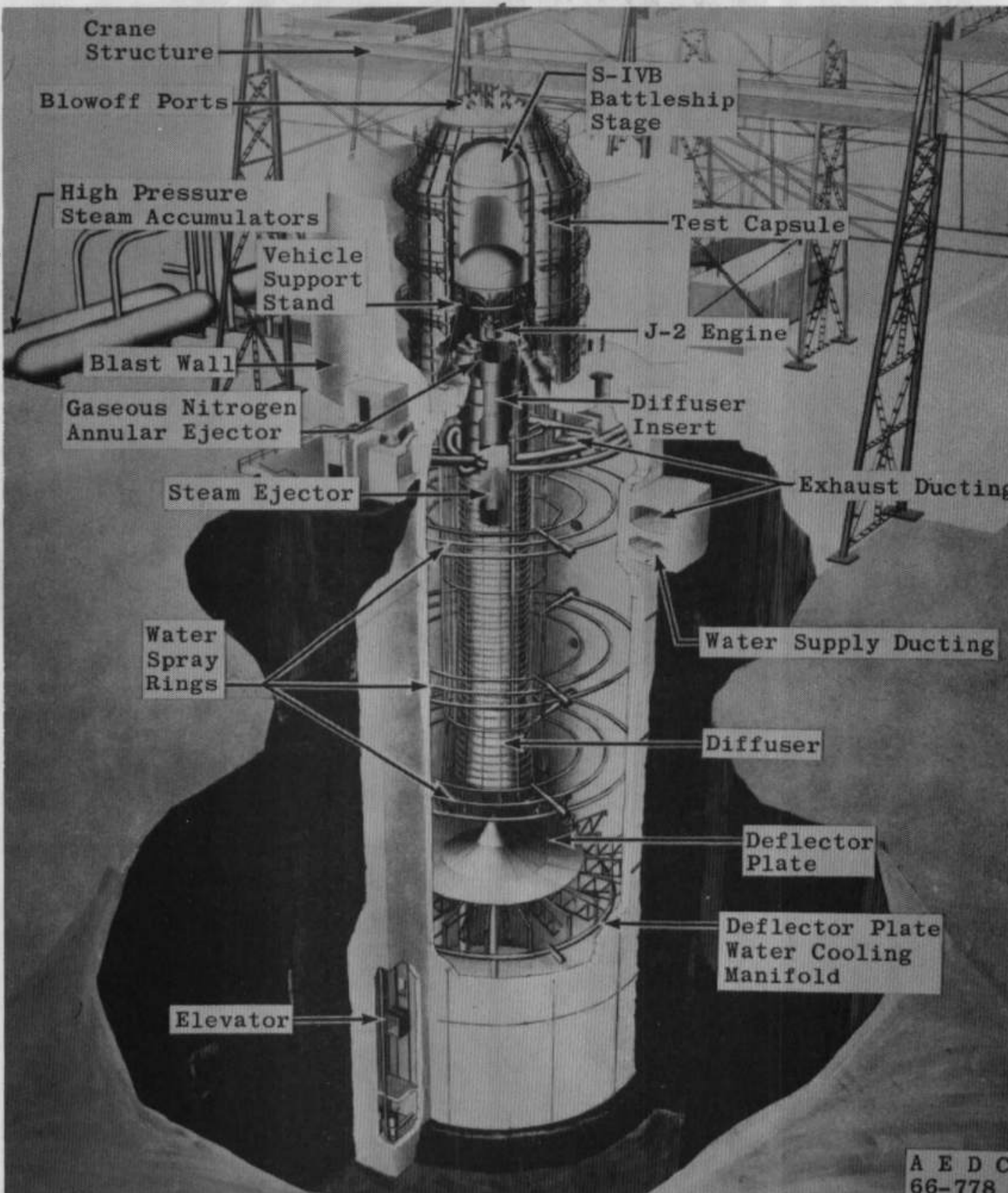


Fig. 2 Test Cell J-4, Artist's Conception

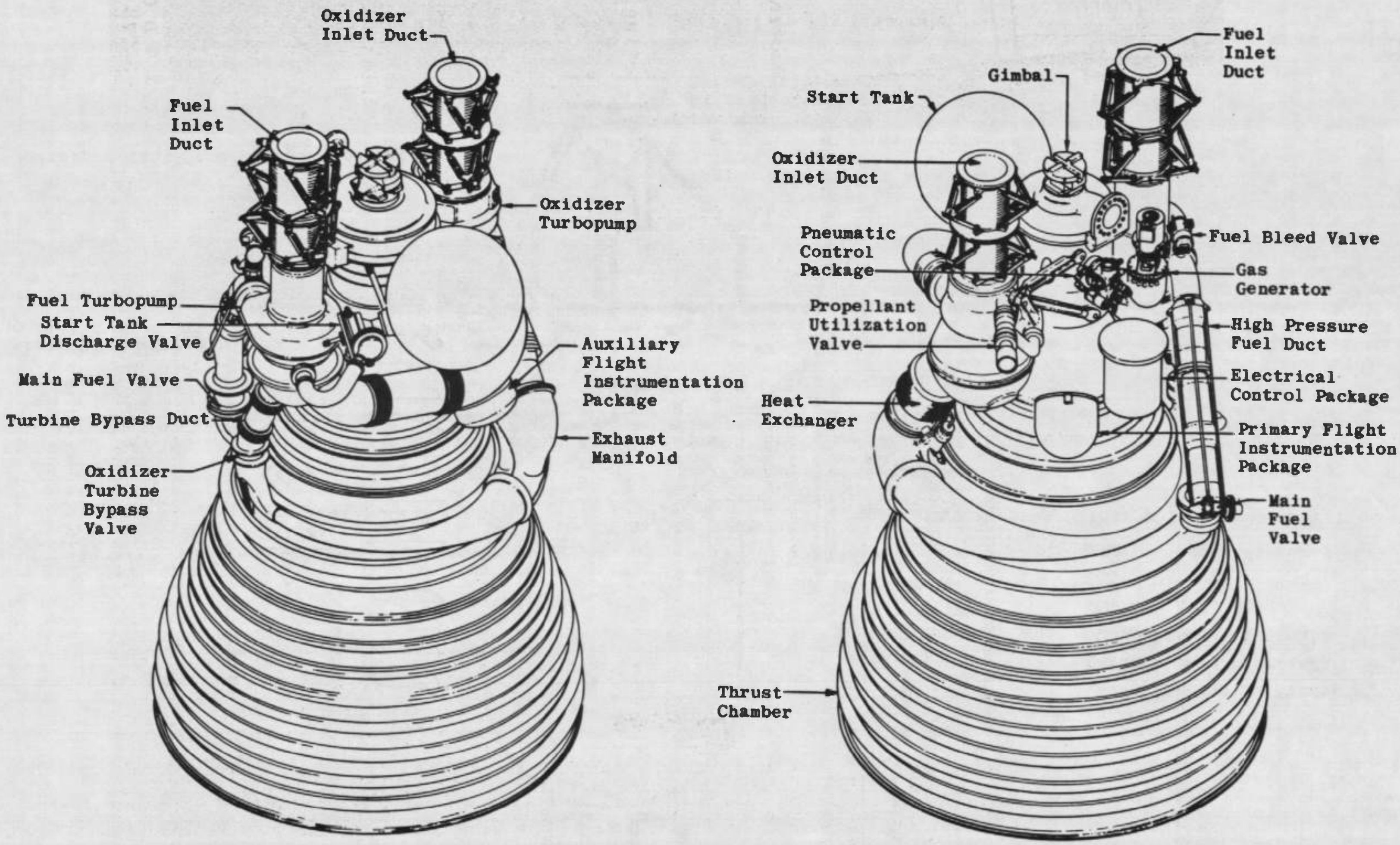


Fig. 3 Engine Details

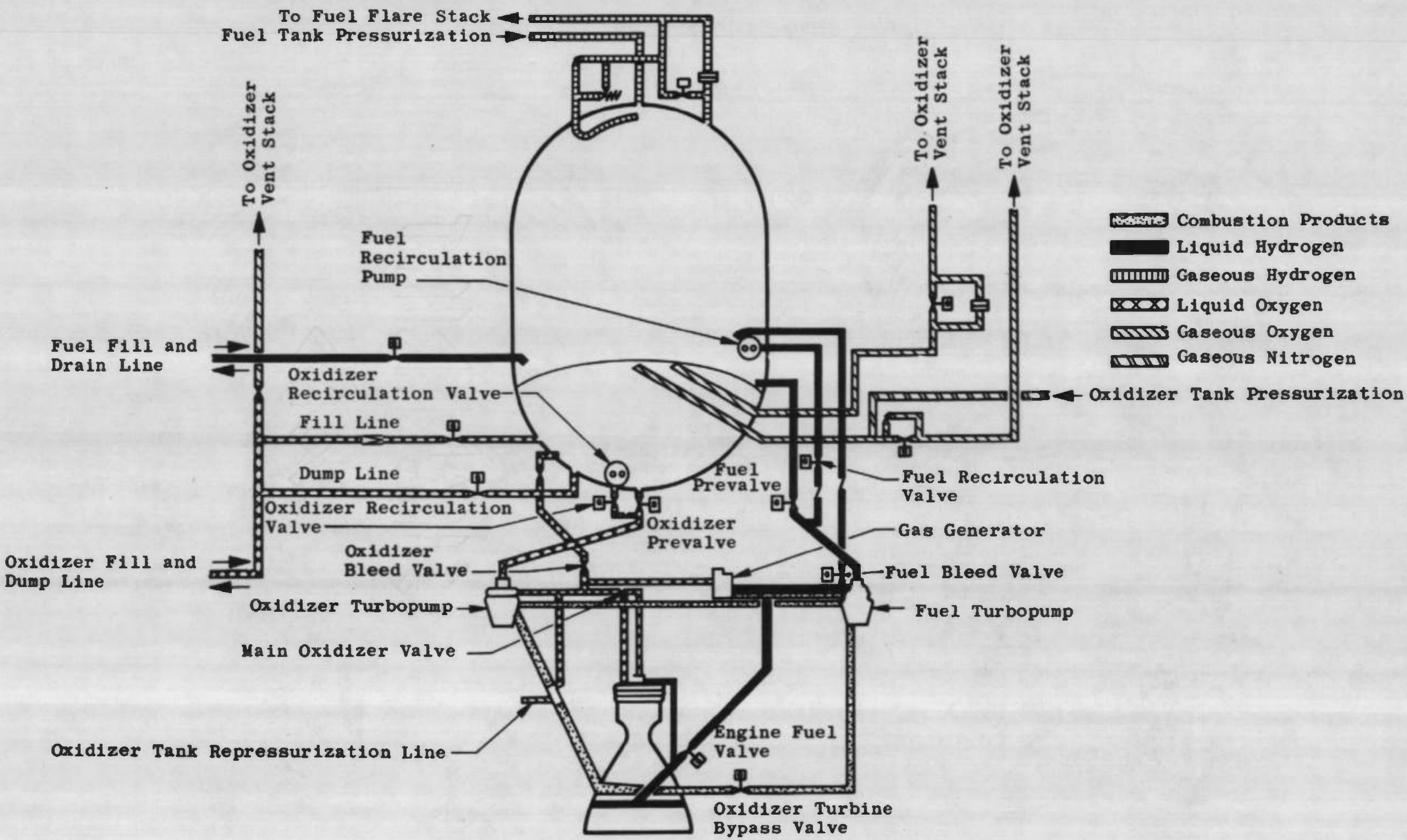


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

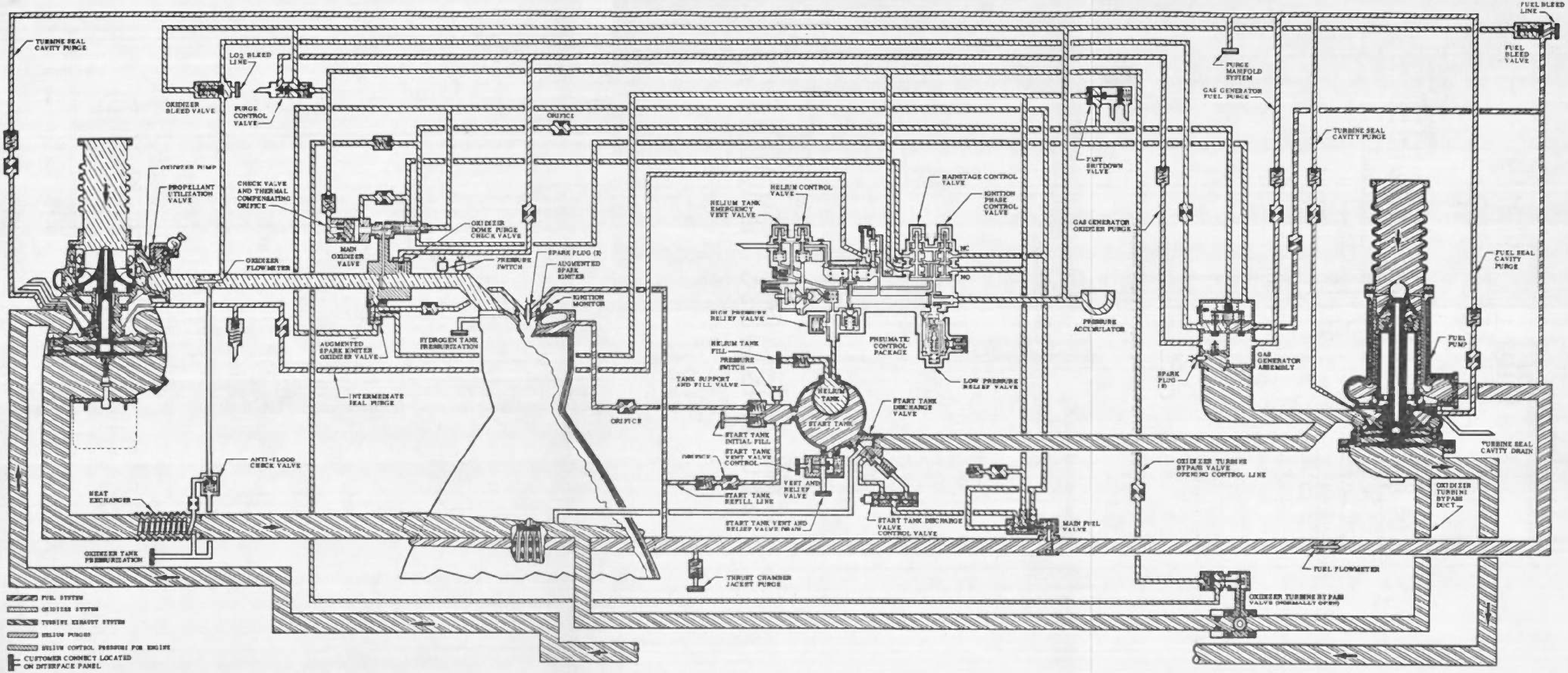
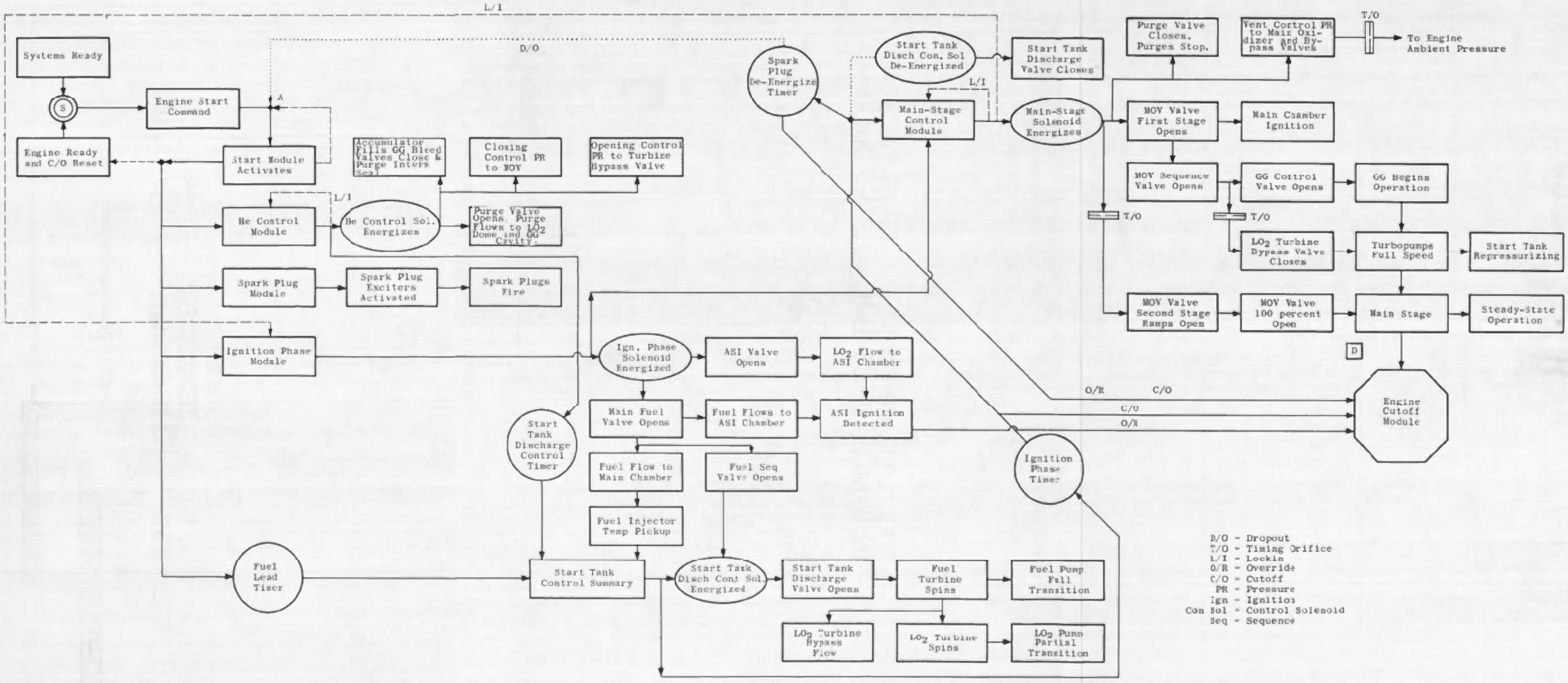
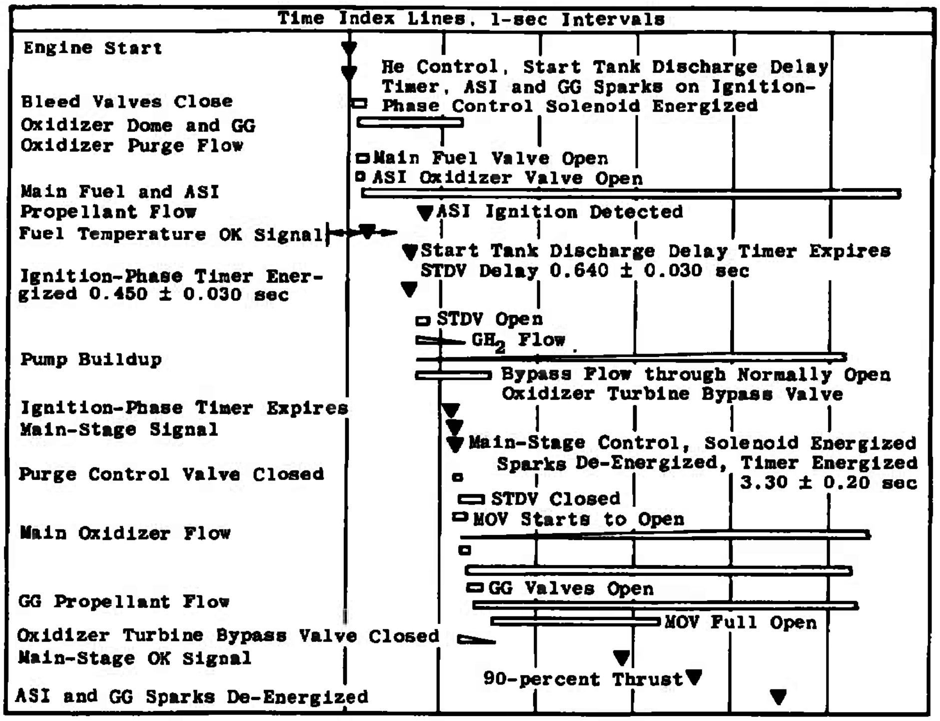


Fig. 5 Engine Schematic

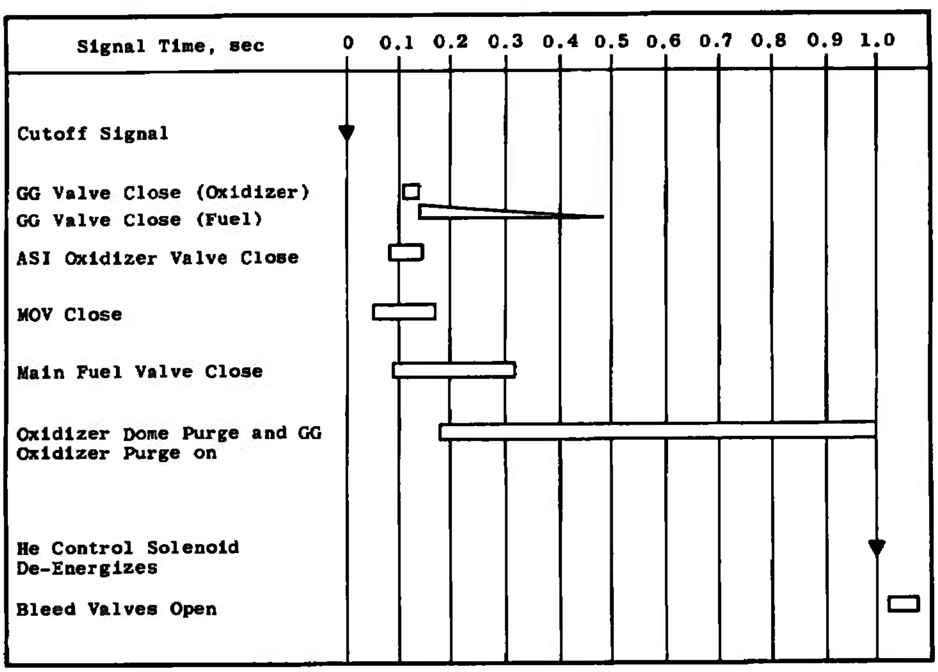


D/O - Dropout
T/O - Timing Orifice
L/I - Lockin
O/R - Override
C/O - Cutoff
PR - Pressure
Ign - Ignition
Con Sol - Control Solenoid
Seq - Sequence

Fig. 6 Engine Start Logic Schematic

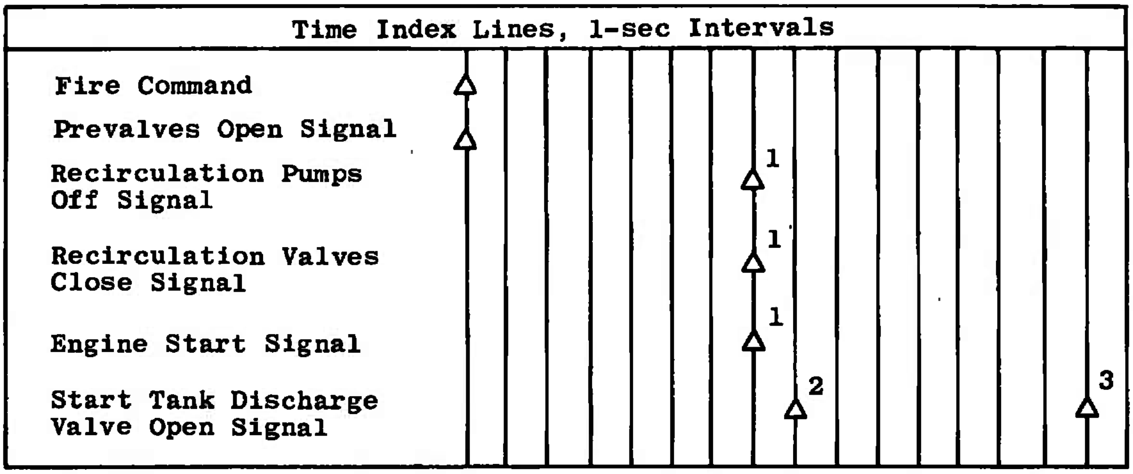


a. Start Sequence



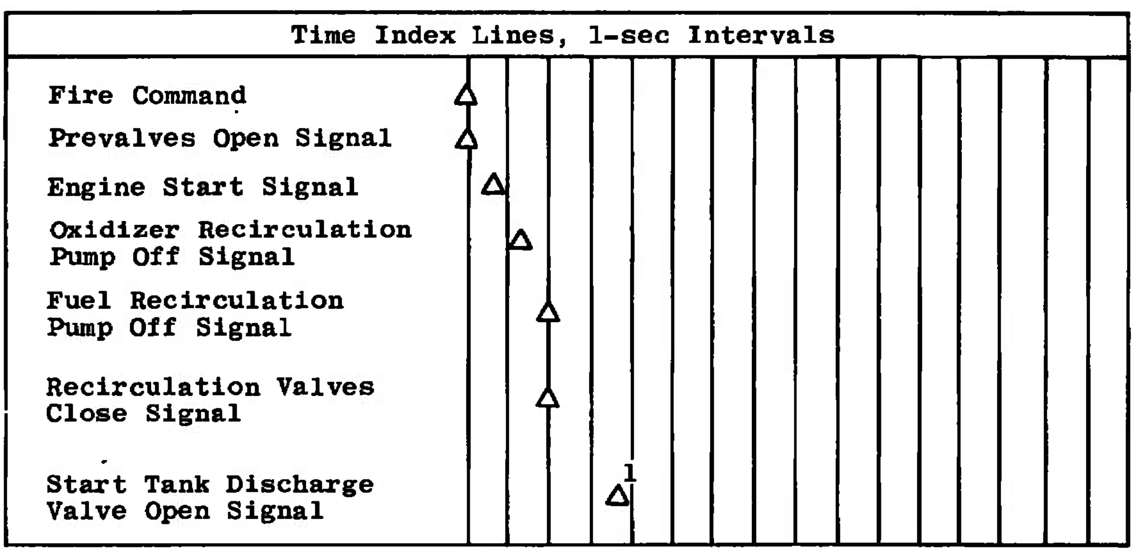
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1] Nominal Occurrence Time (Function of Prevalves Opening Time)
[2] 1-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3] 8-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

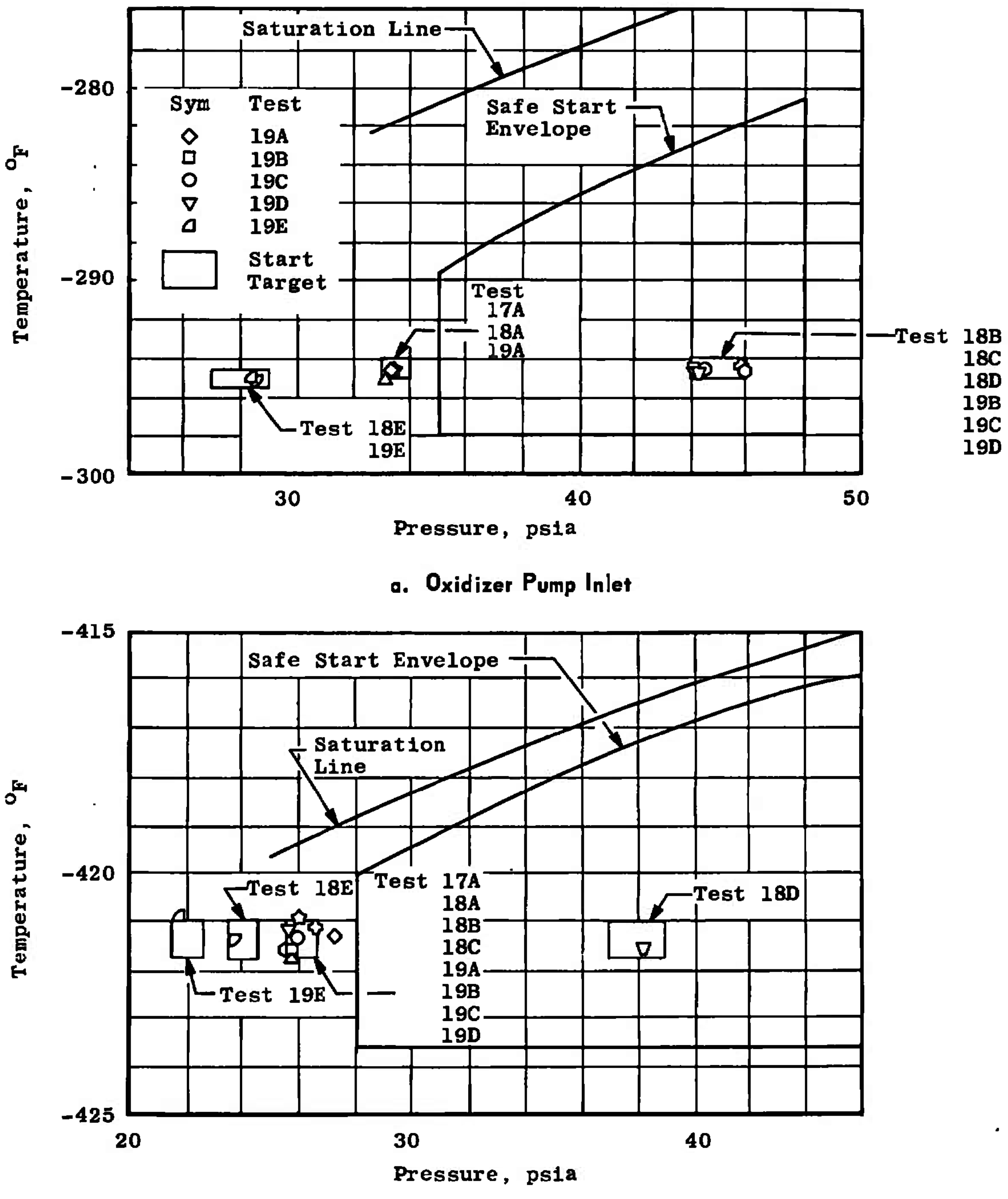
c. Normal Logic Start Sequence



[1] 3-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

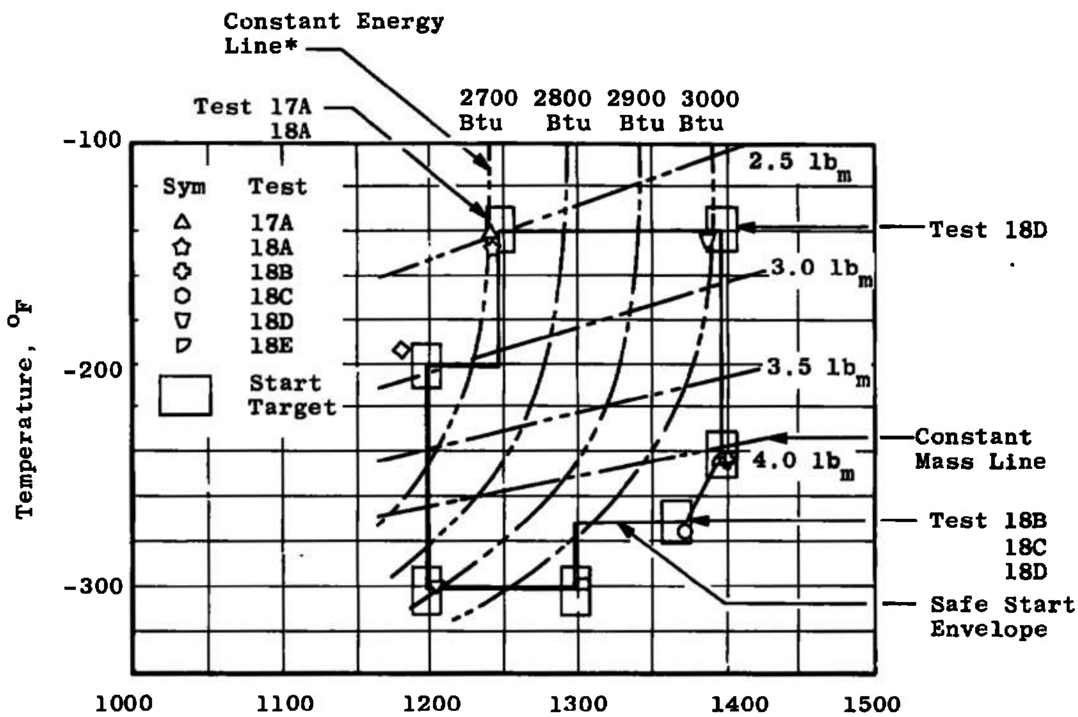
Fig. 7 Concluded



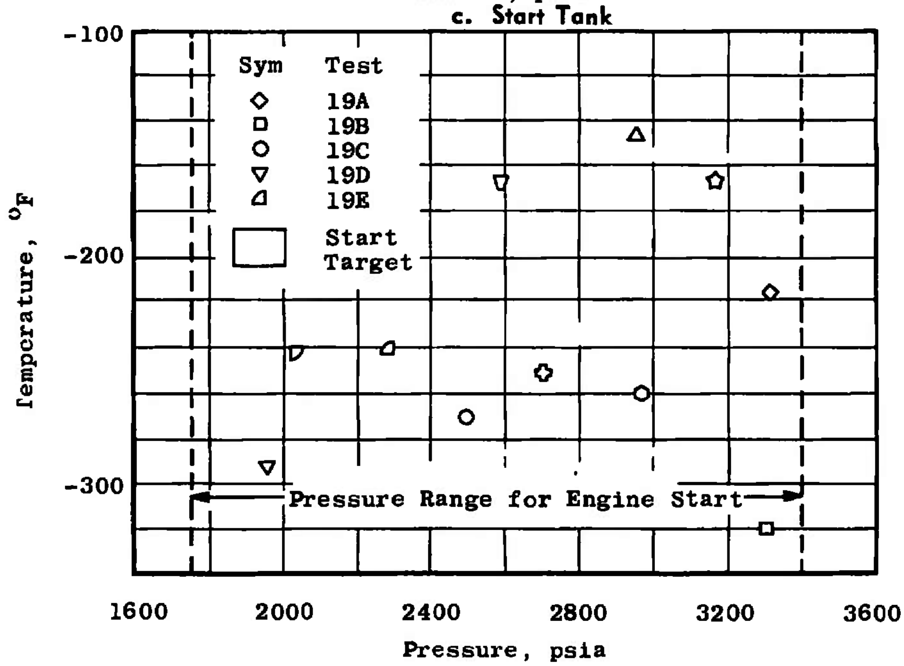
a. Oxidizer Pump Inlet

b. Fuel Pump Inlet

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



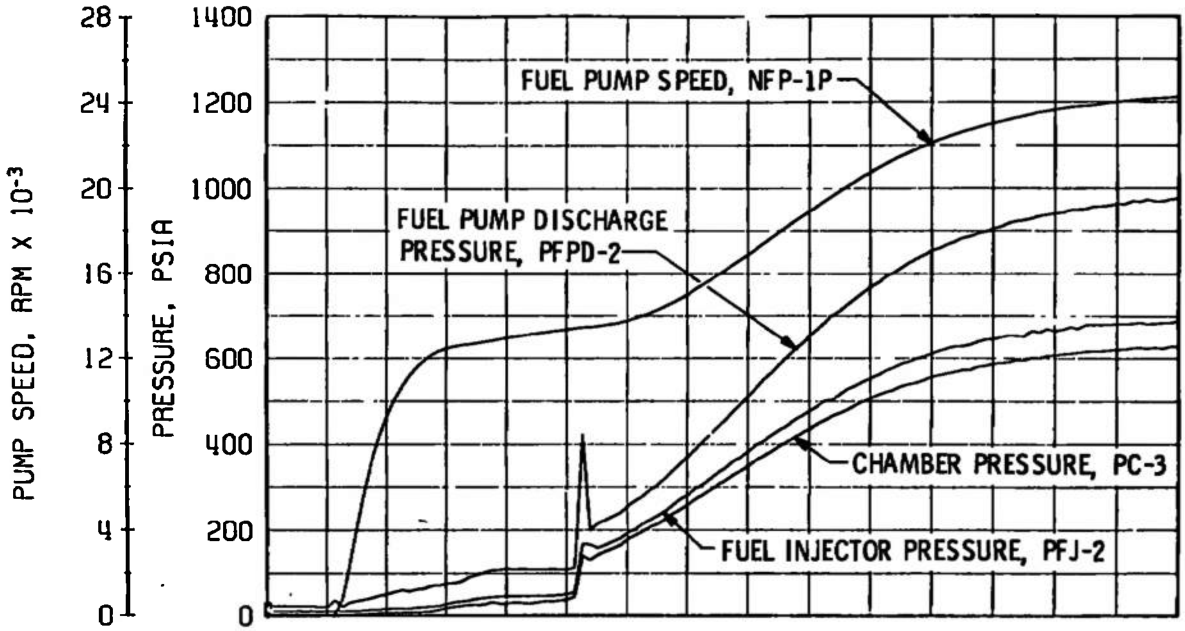
c. Start Tank



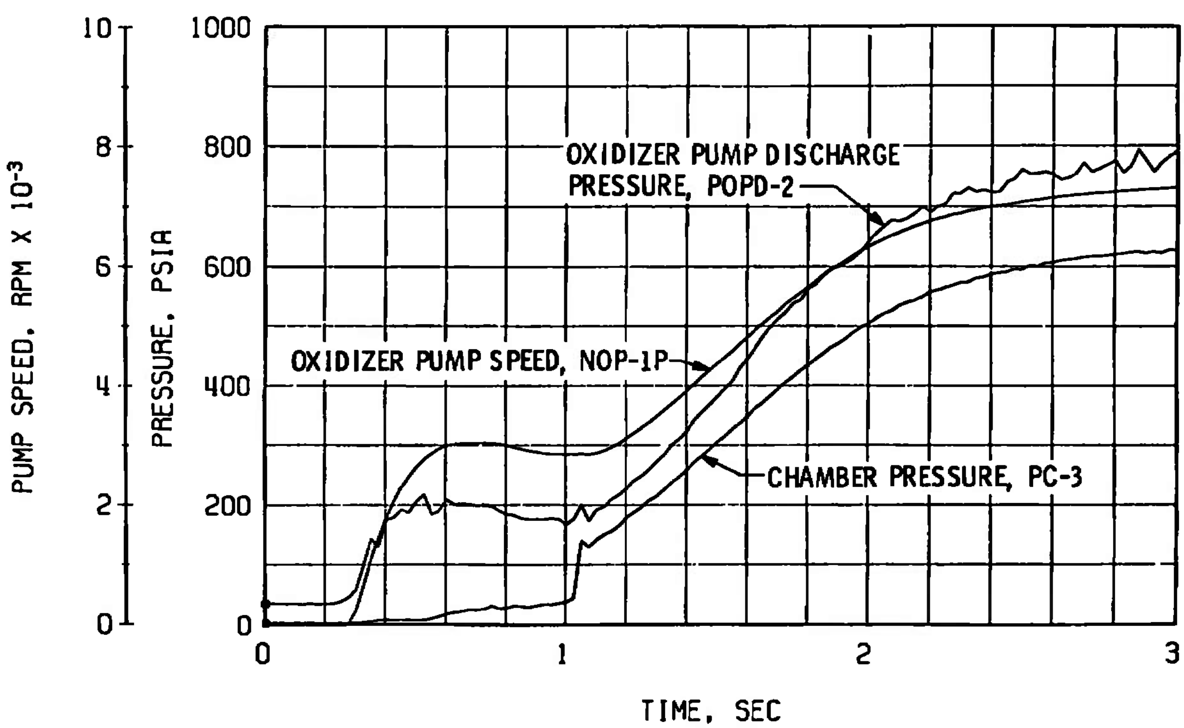
*Calculated from "Table of Thermal Properties of Gases" National Bureau of Standards Circular 564, November 1965.

d. Helium Tank

Fig. 8 Concluded

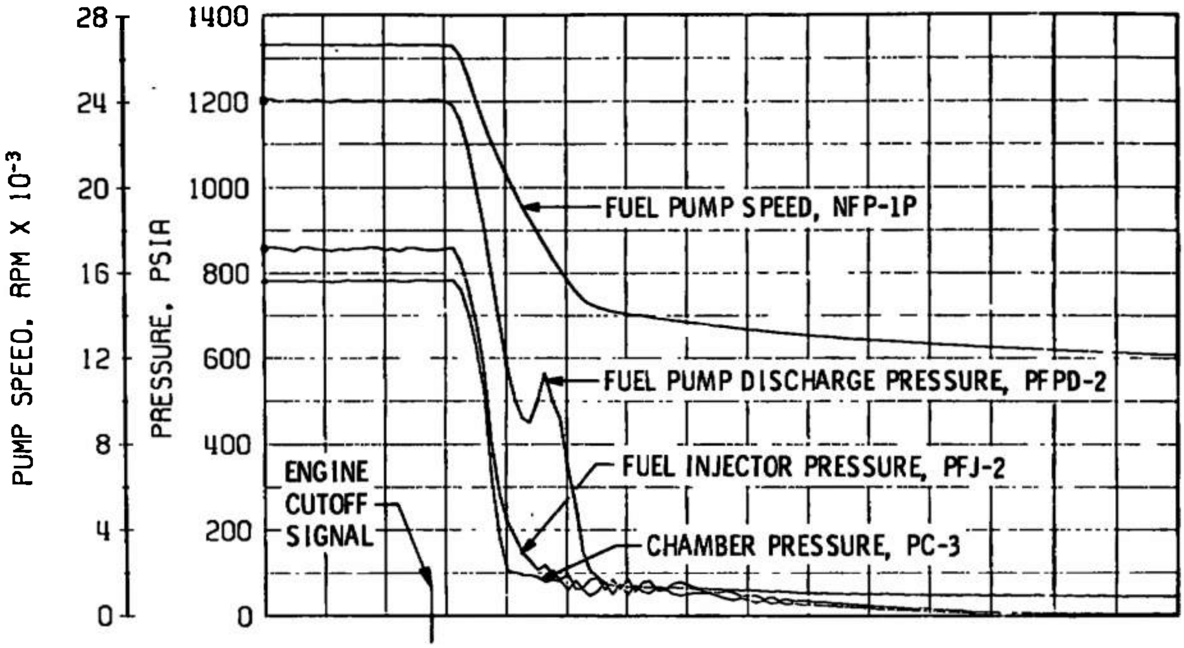


a. Thrust Chamber Fuel System, Start

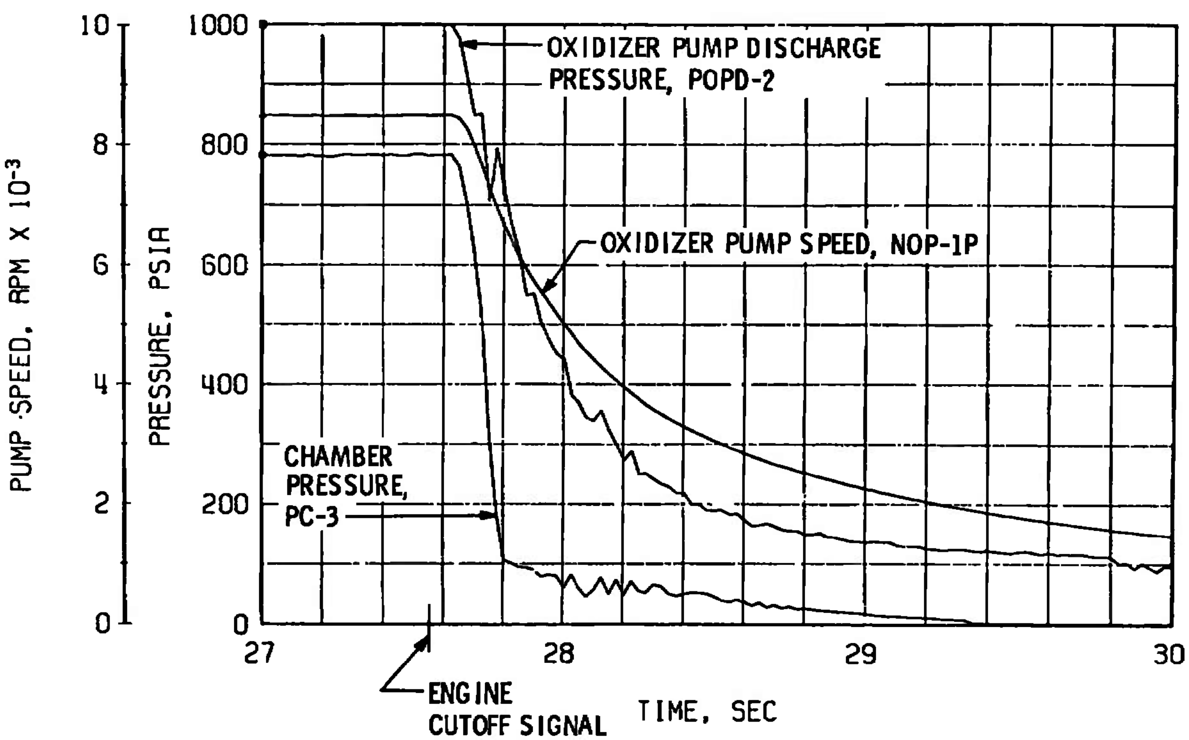


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 17A

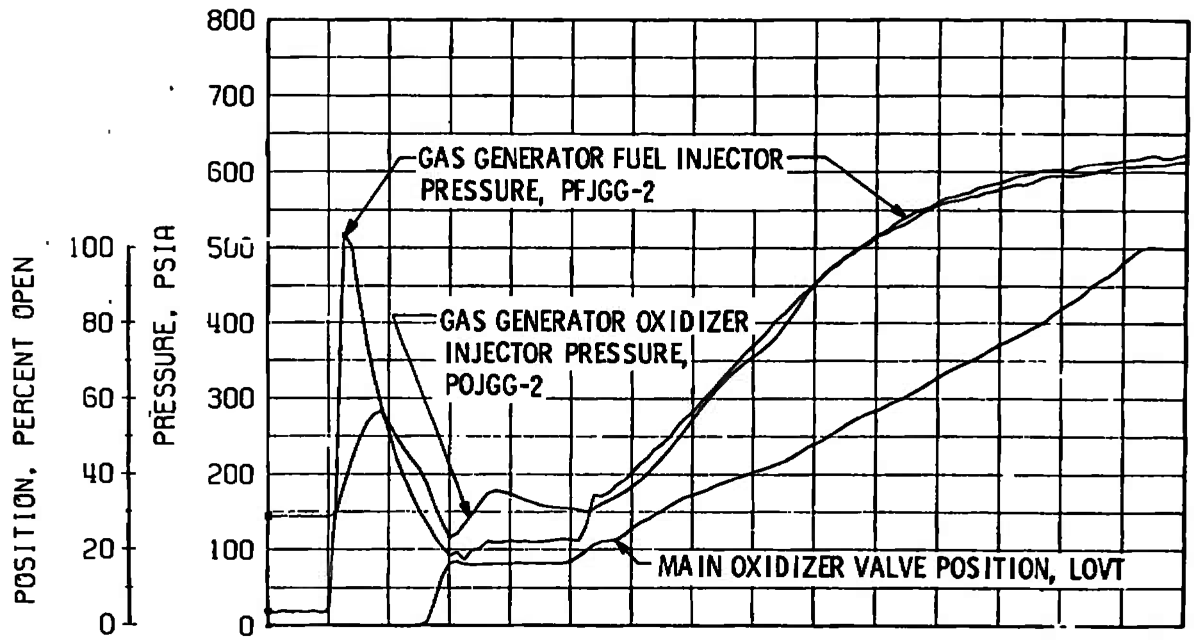


c. Thrust Chamber Fuel System, Shutdown

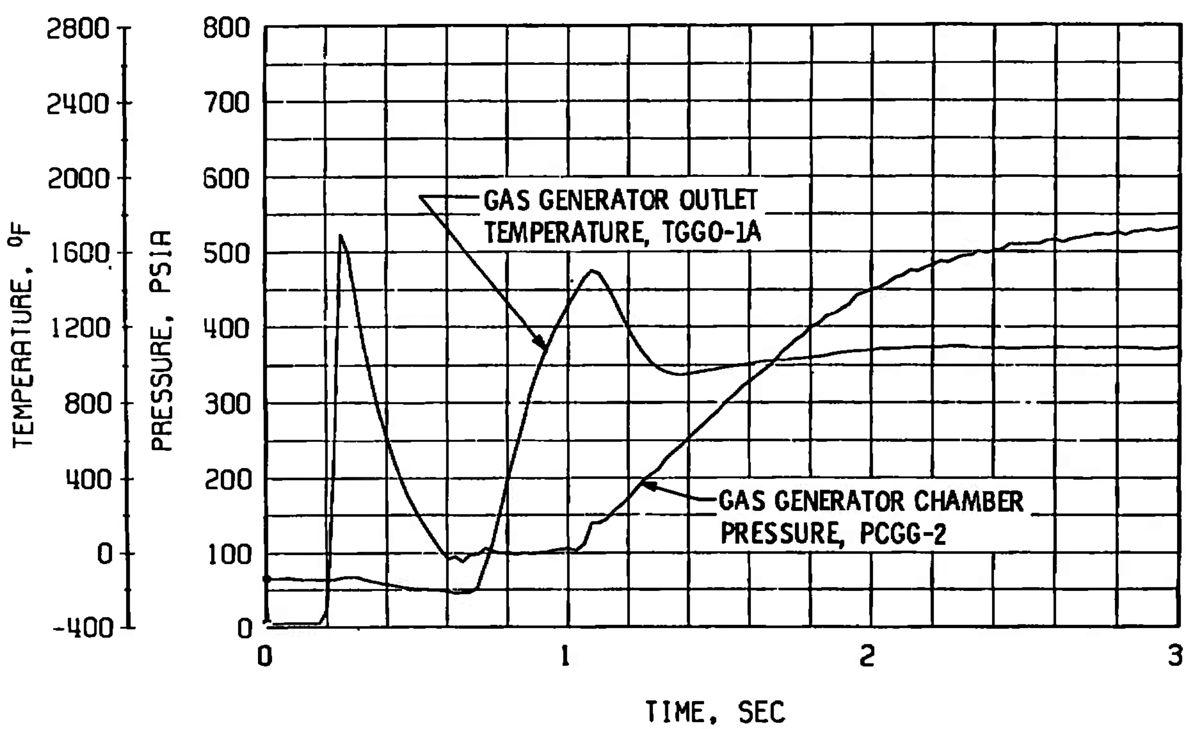


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued

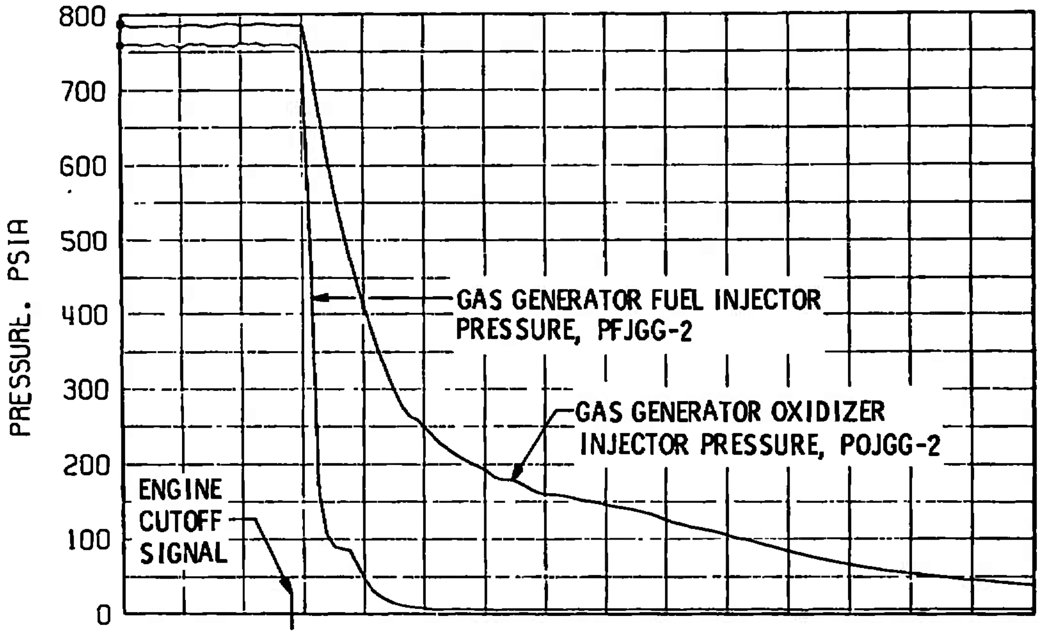


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

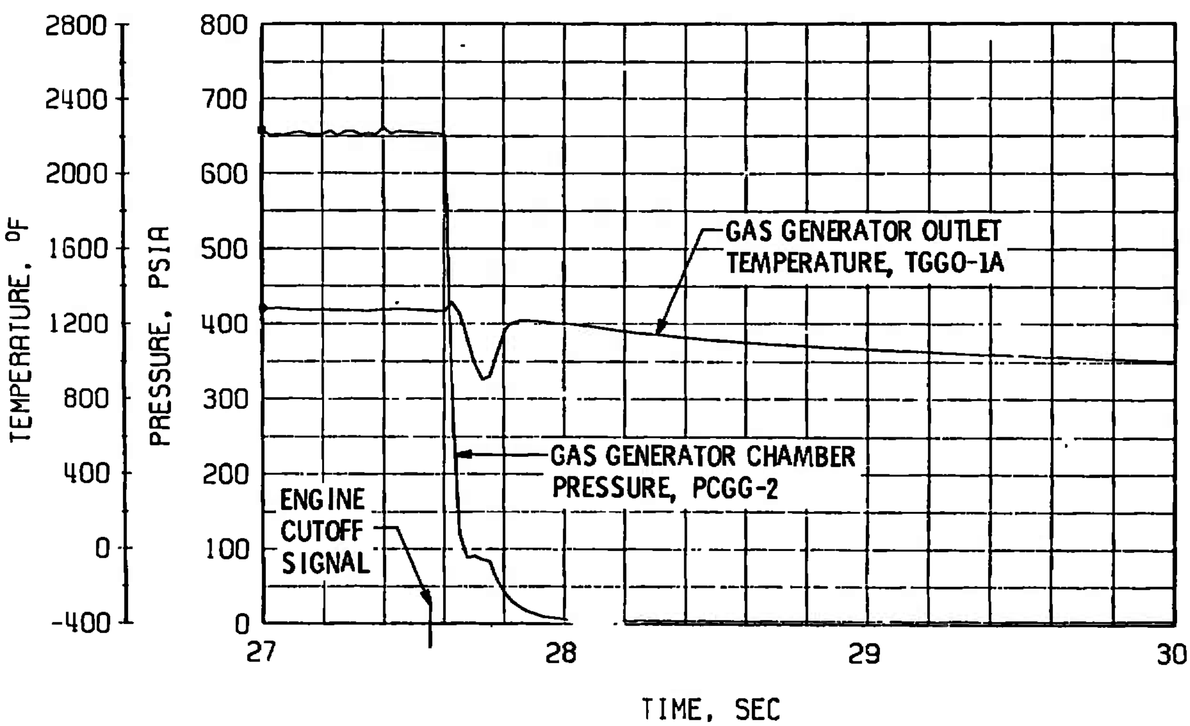


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 9 Concluded

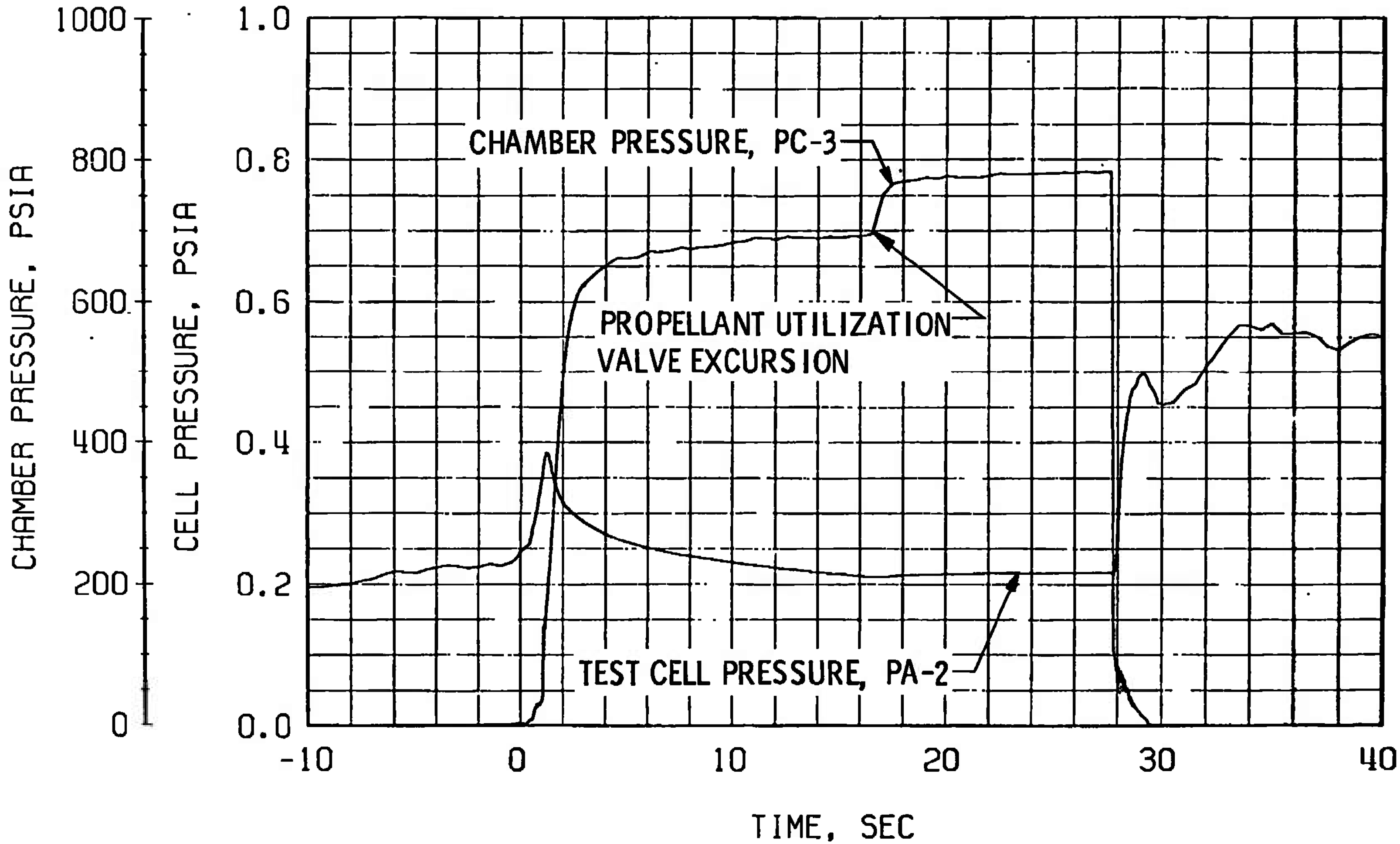
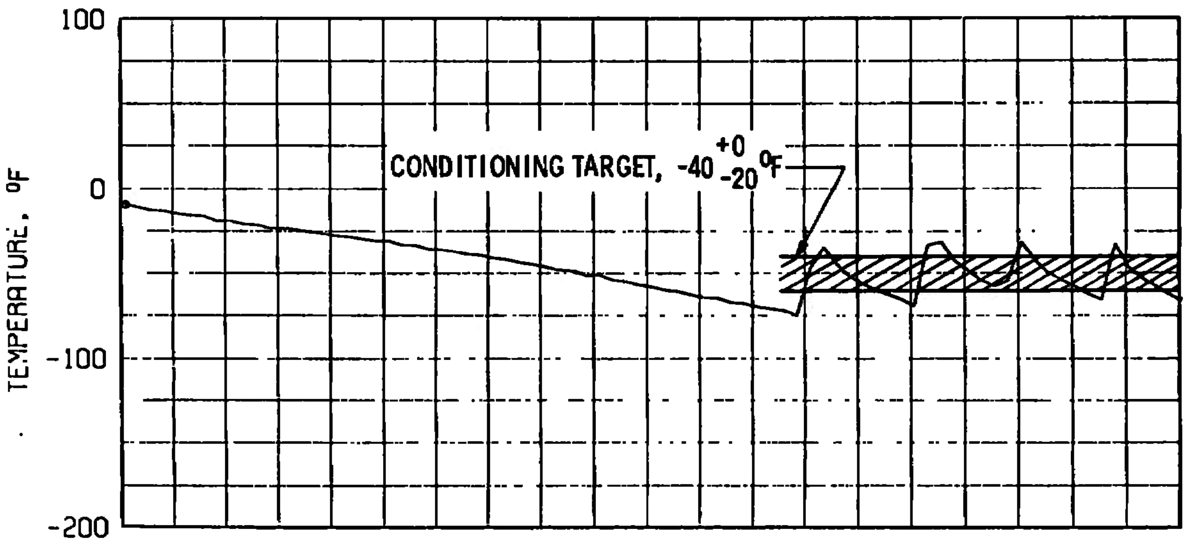
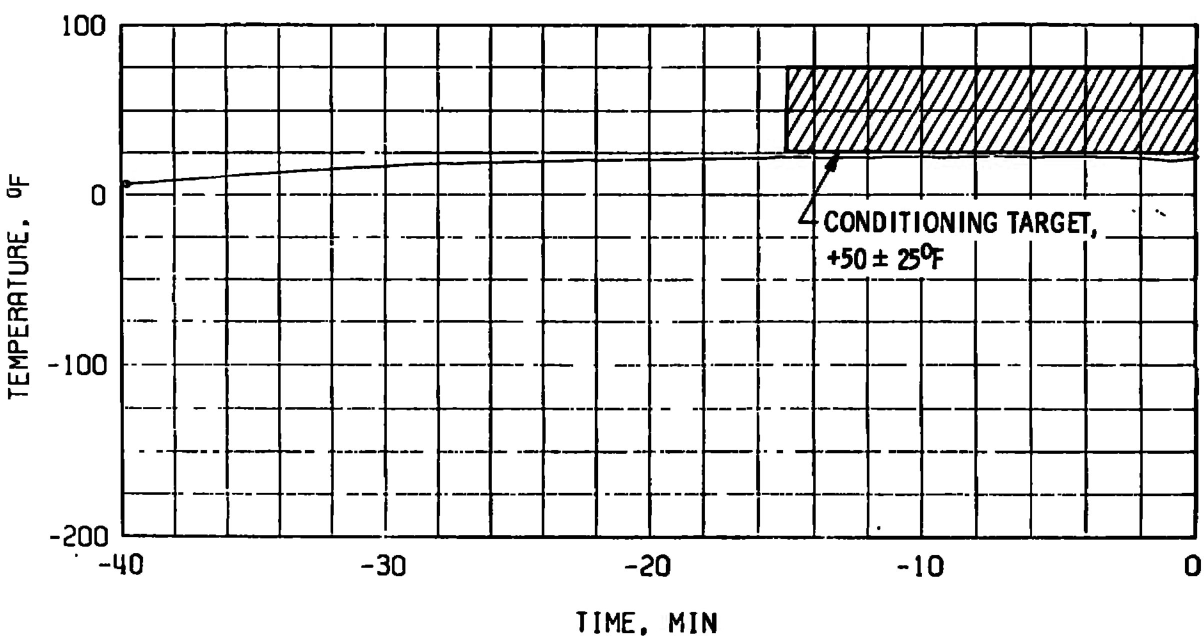


Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 17A

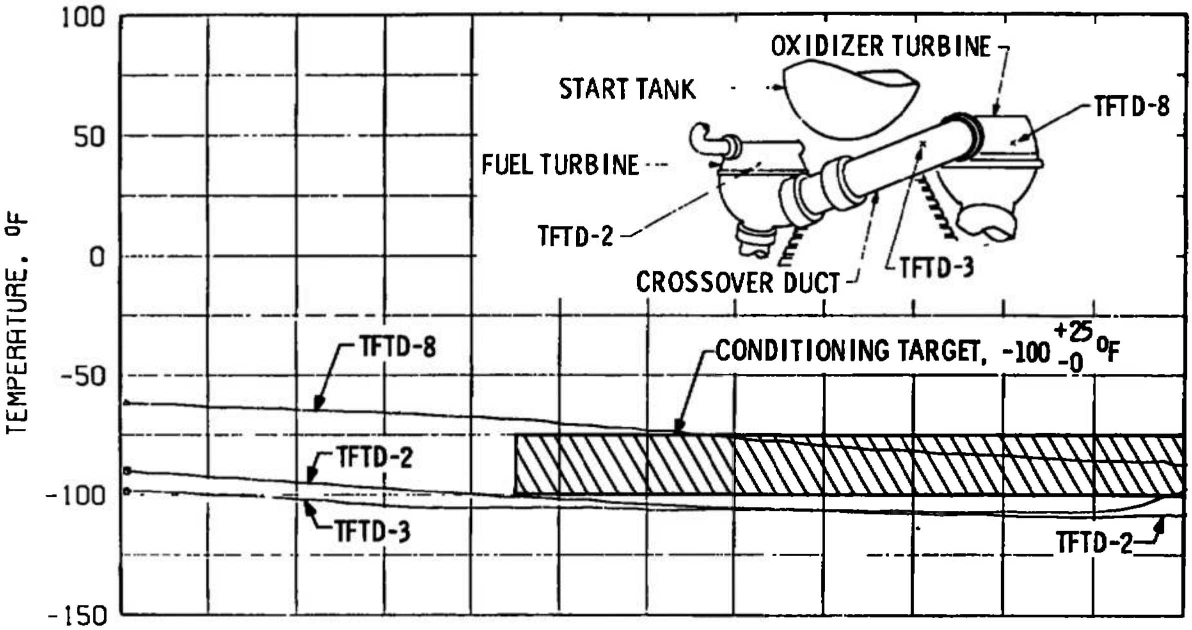


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

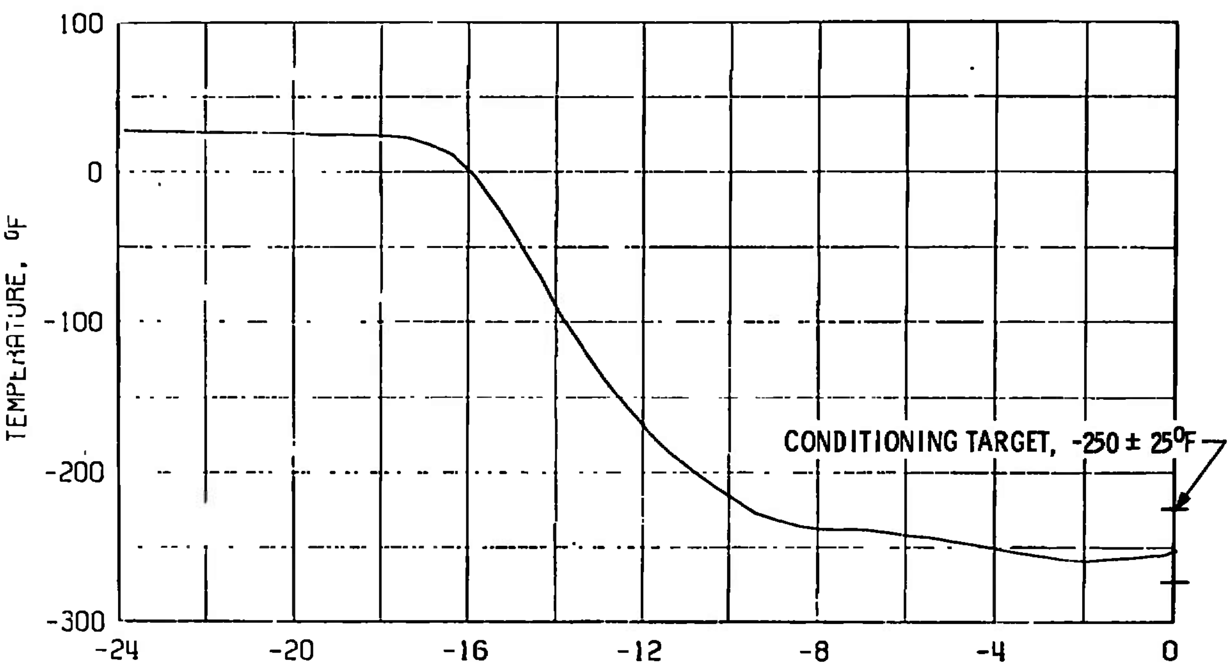


b. Start Tank Discharge Valve, TSTDVOC

Fig. 11 Thermol Conditioning History of Engine Components, Firing 17A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 11 Concluded

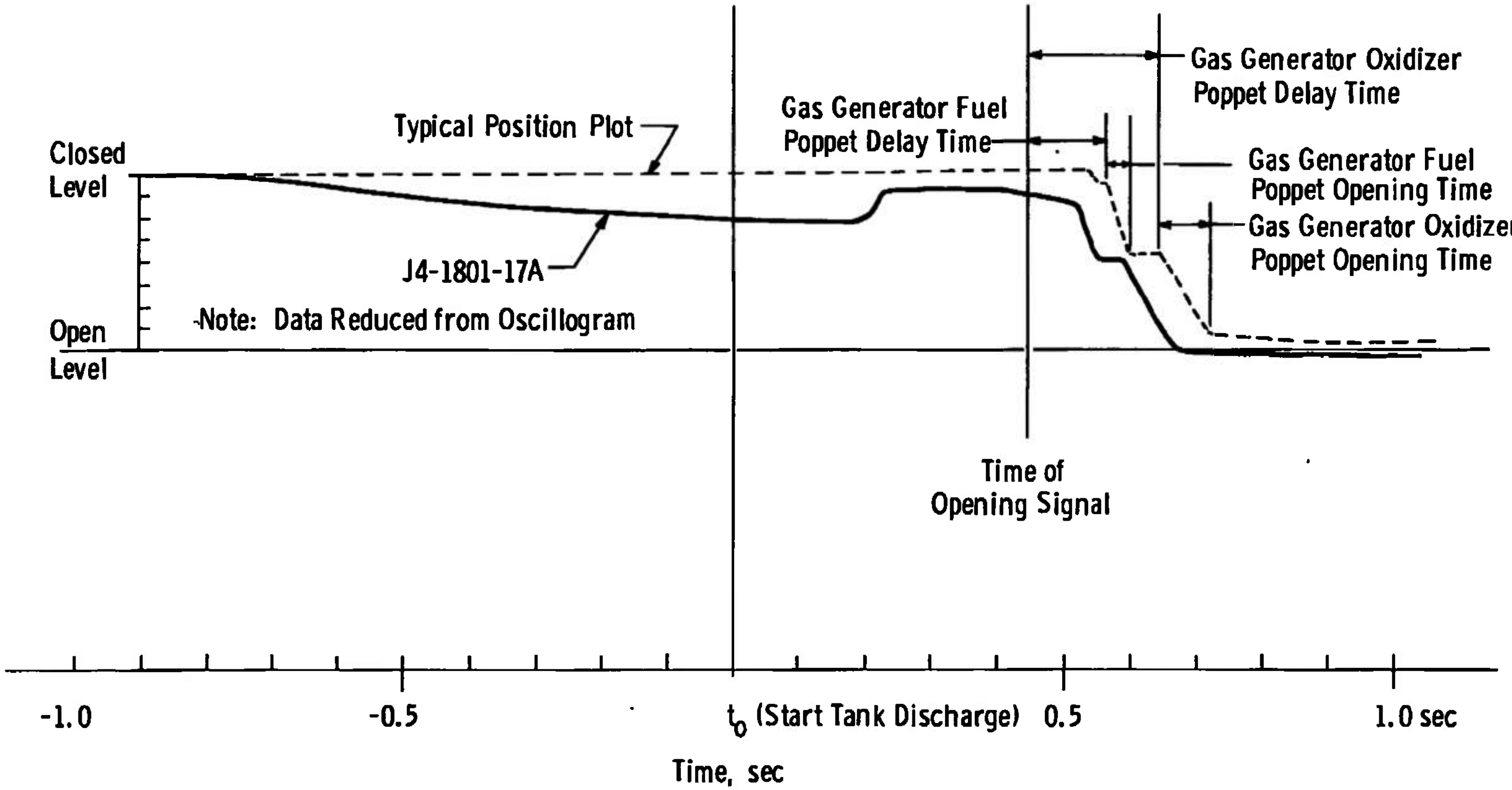


Fig. 12 Gas Generator Control Valve Position, Firing 17A

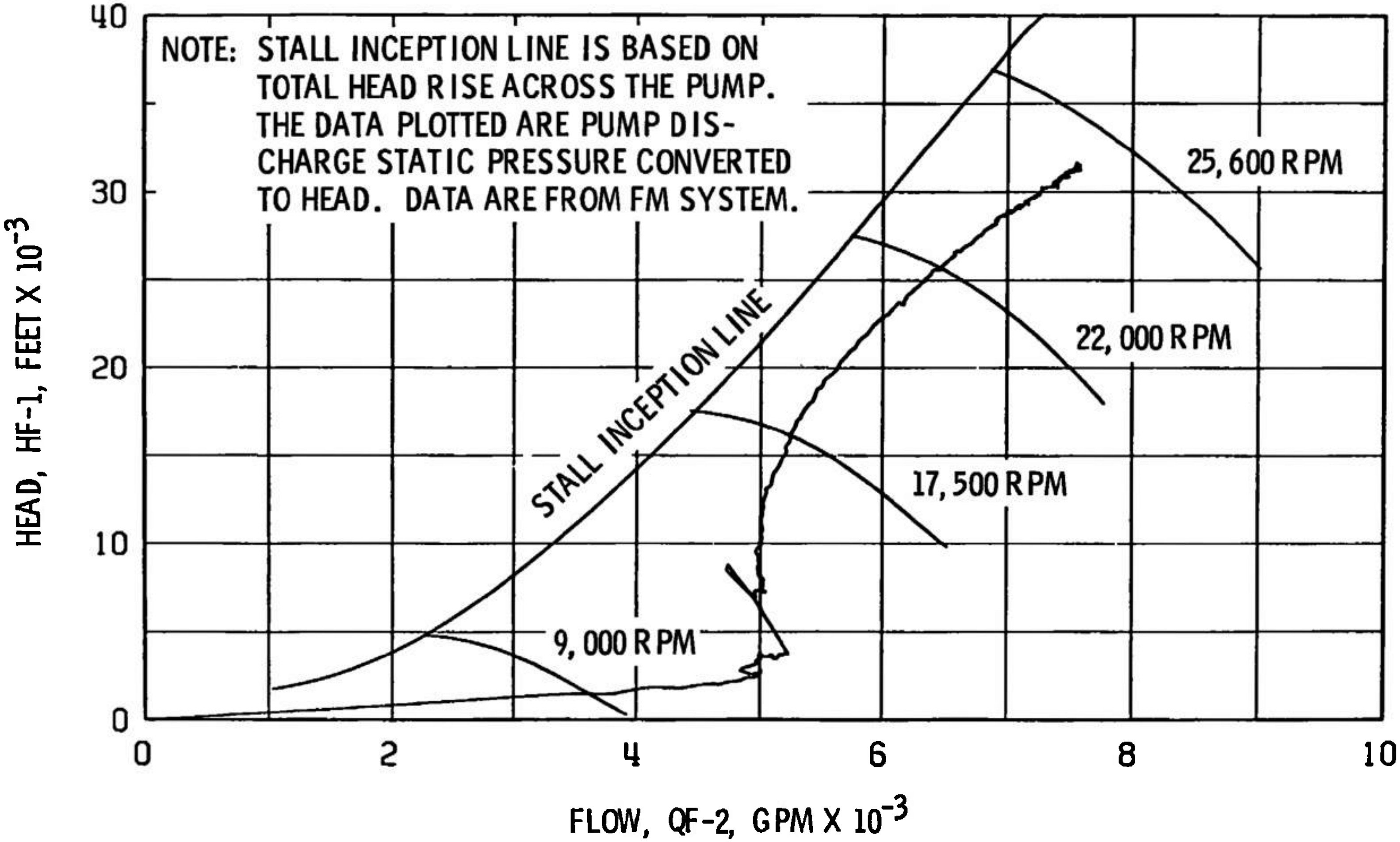
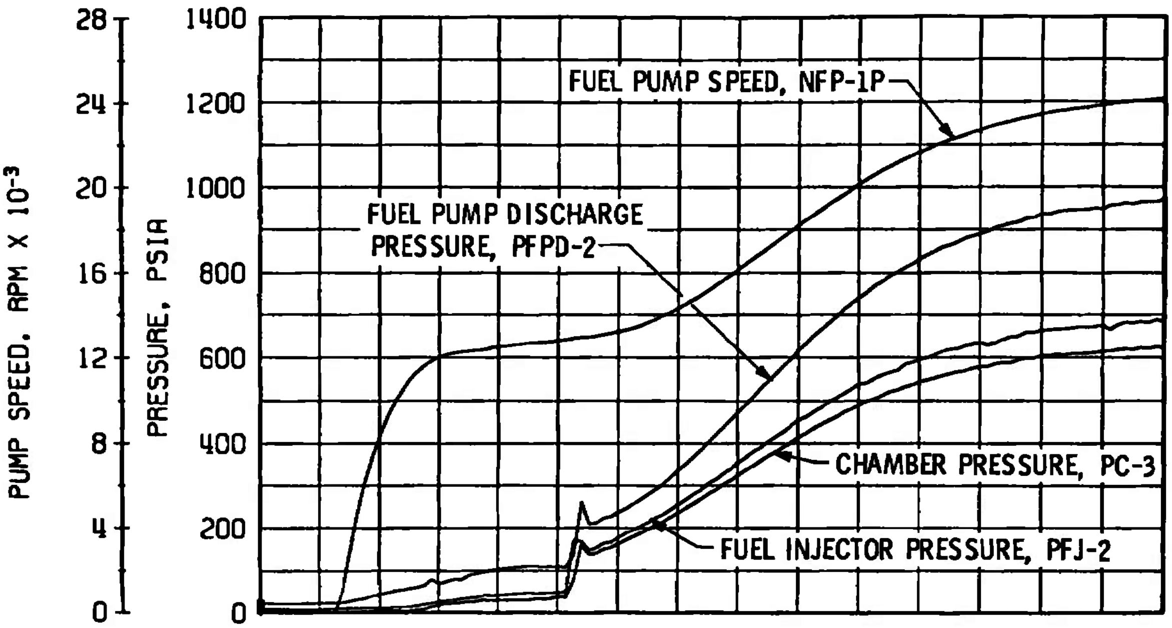
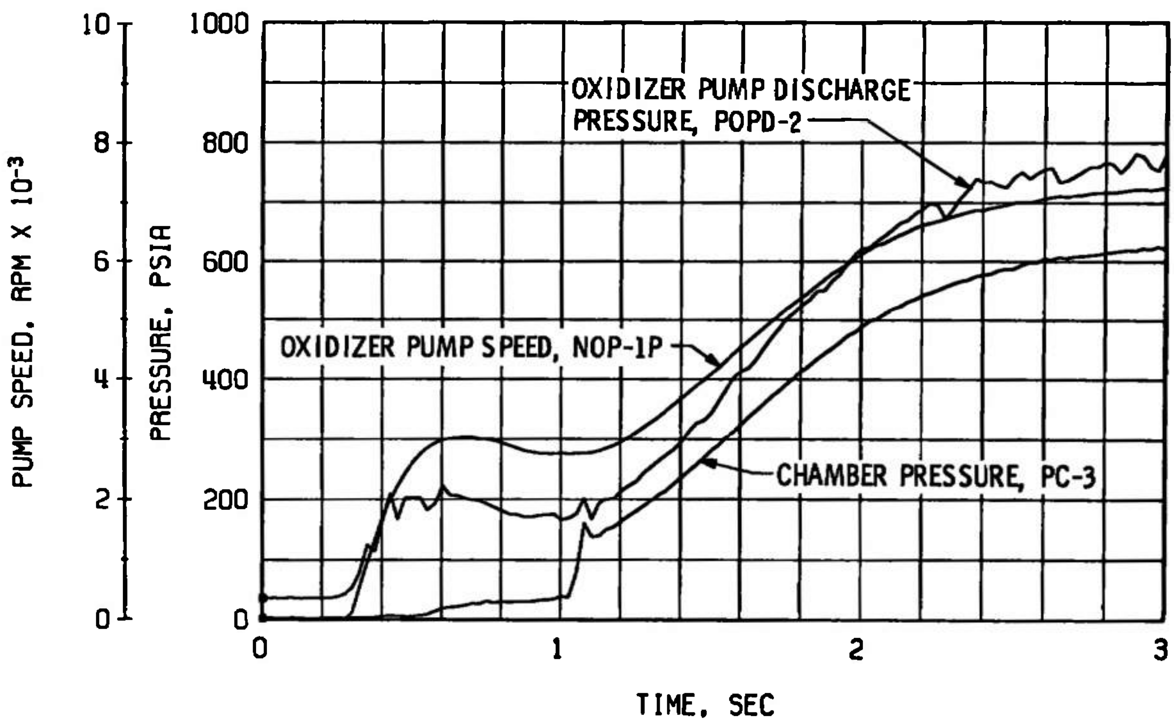


Fig. 13 Fuel Pump Start Transient Performance, Firing 17A

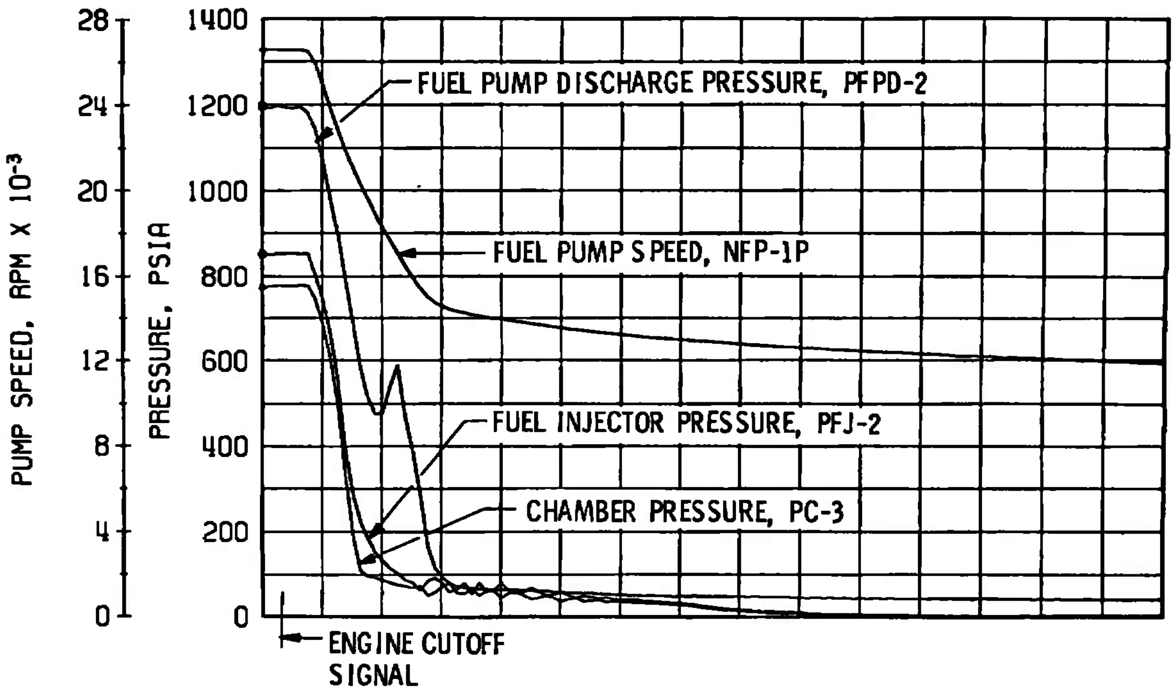


a. Thrust Chamber Fuel System, Start

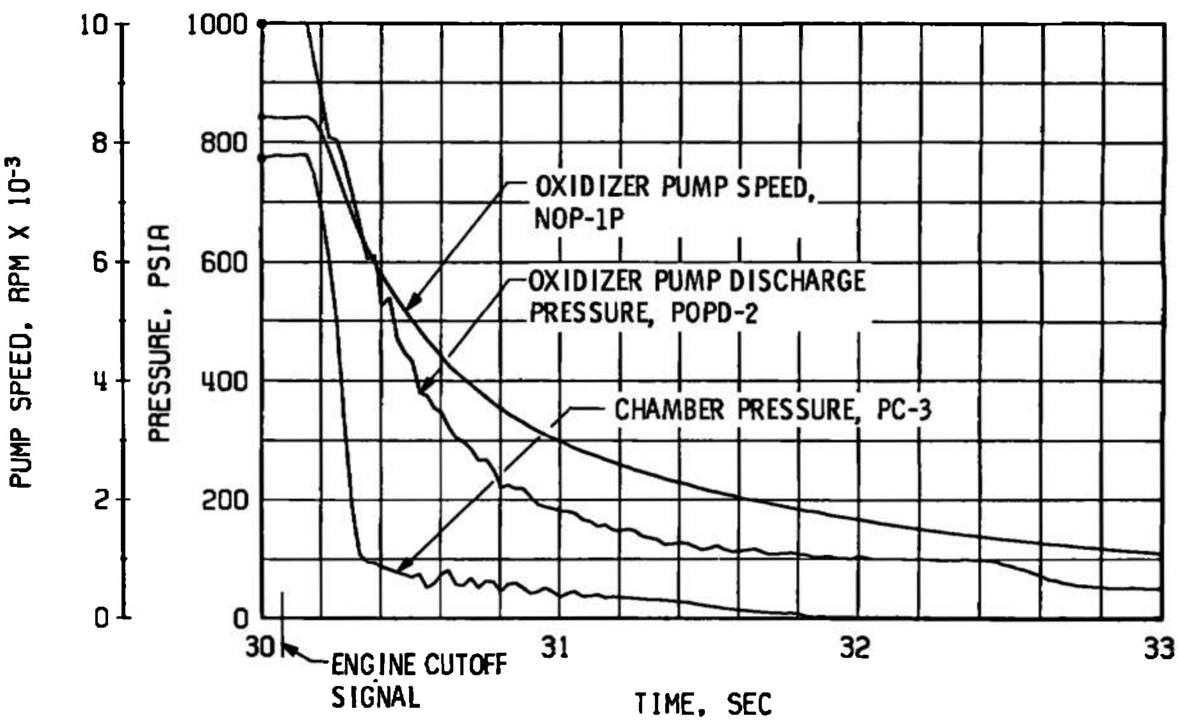


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 18A

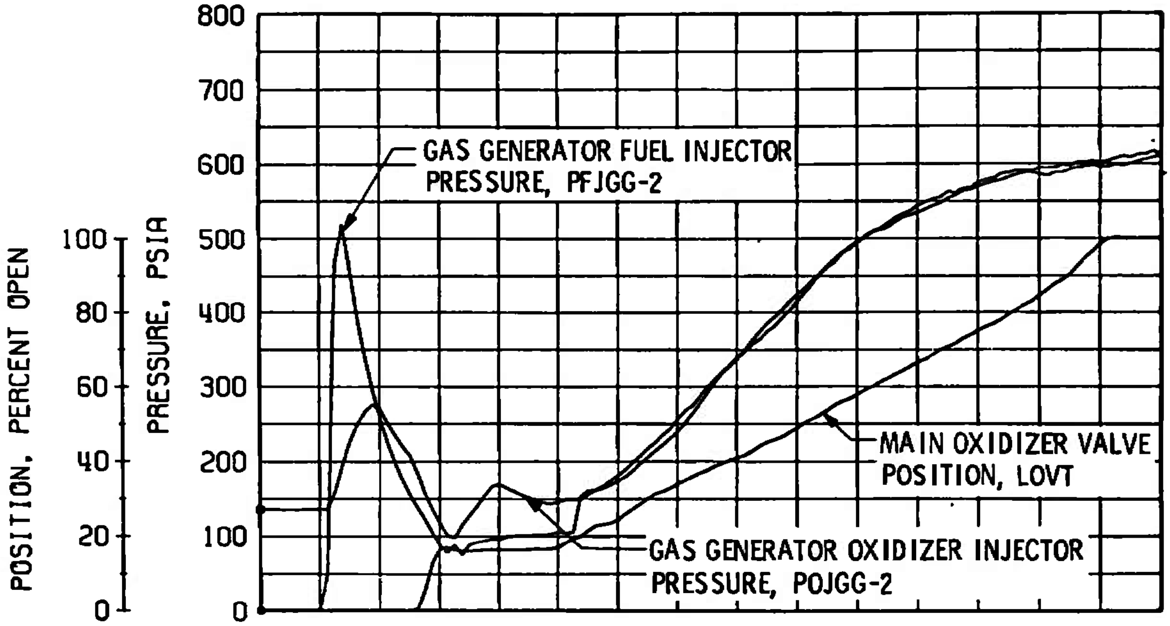


c. Thrust Chamber Fuel System, Shutdown

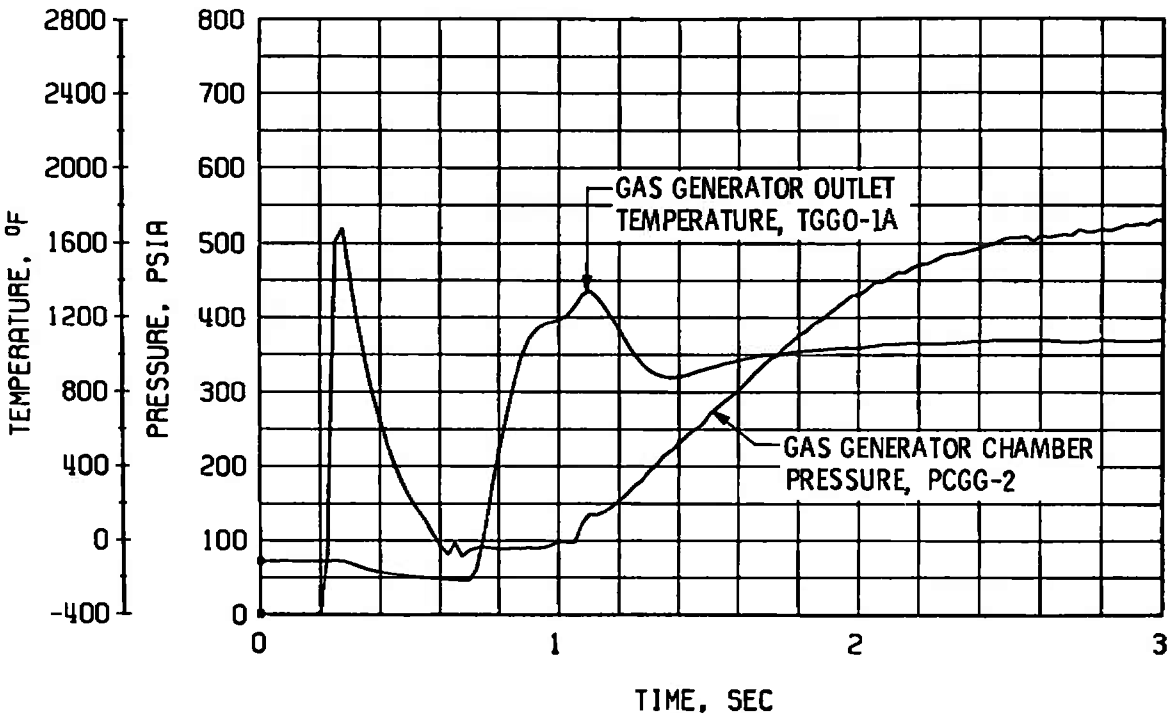


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued

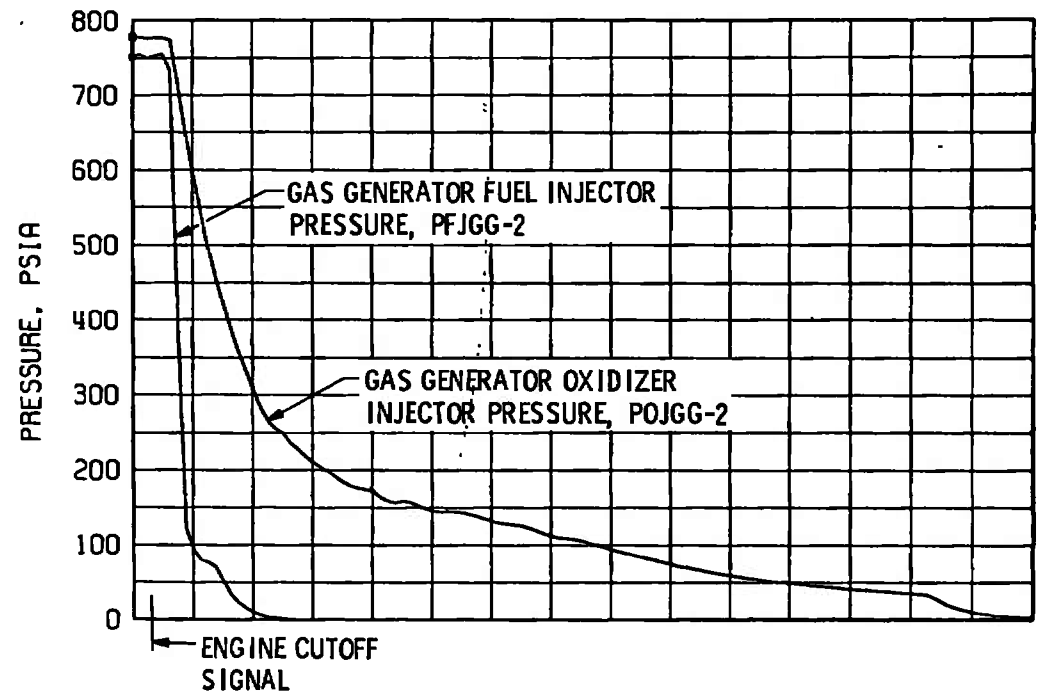


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

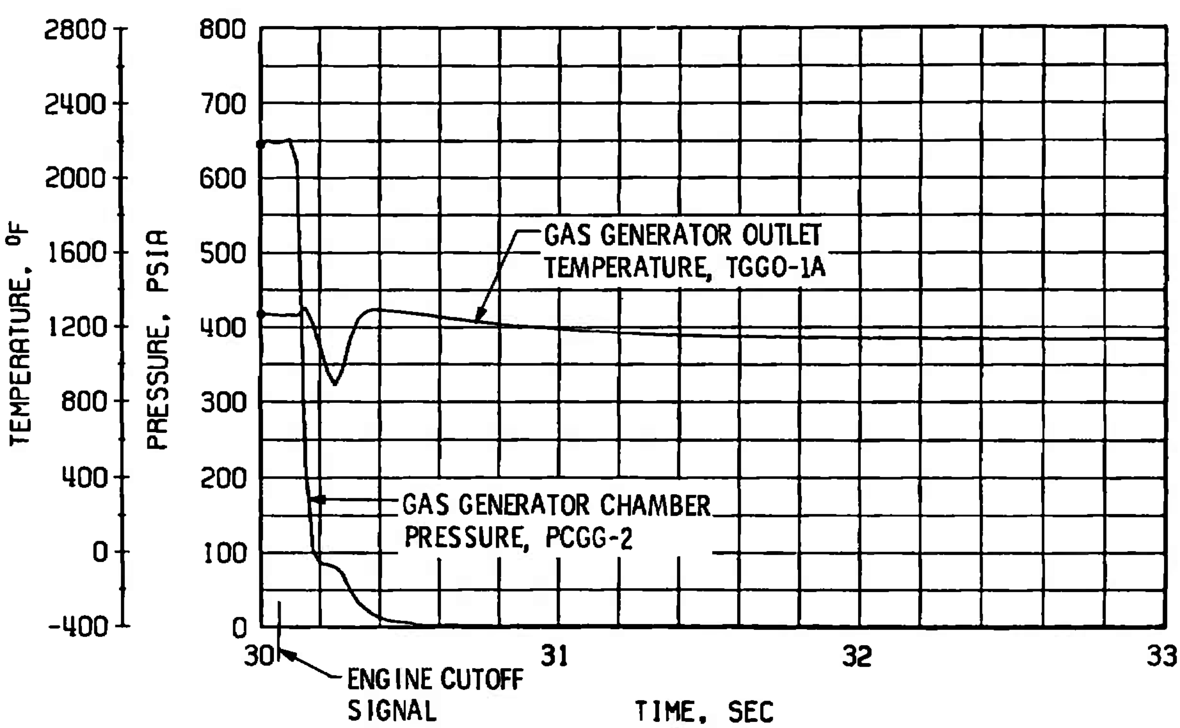


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 14 Concluded

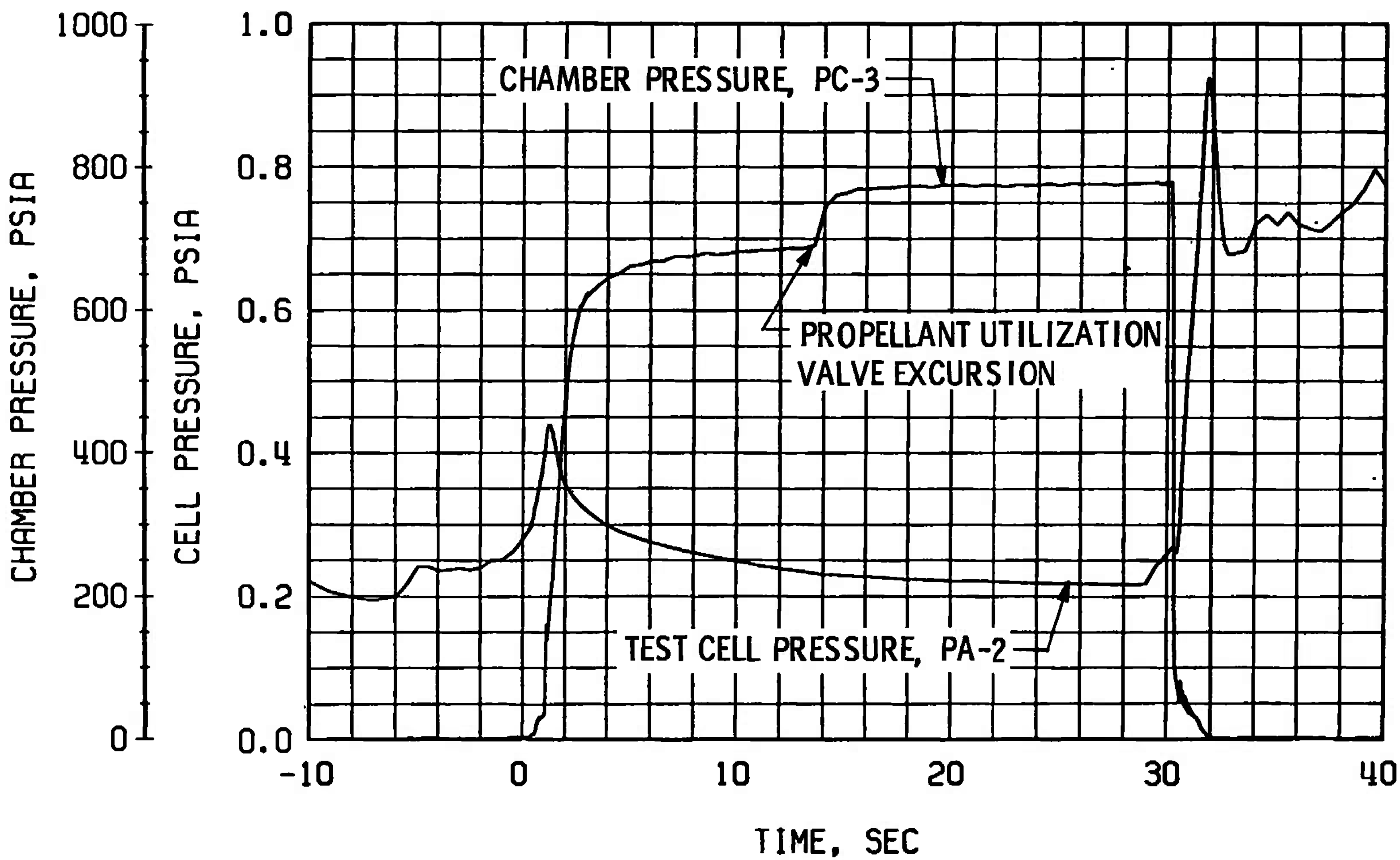
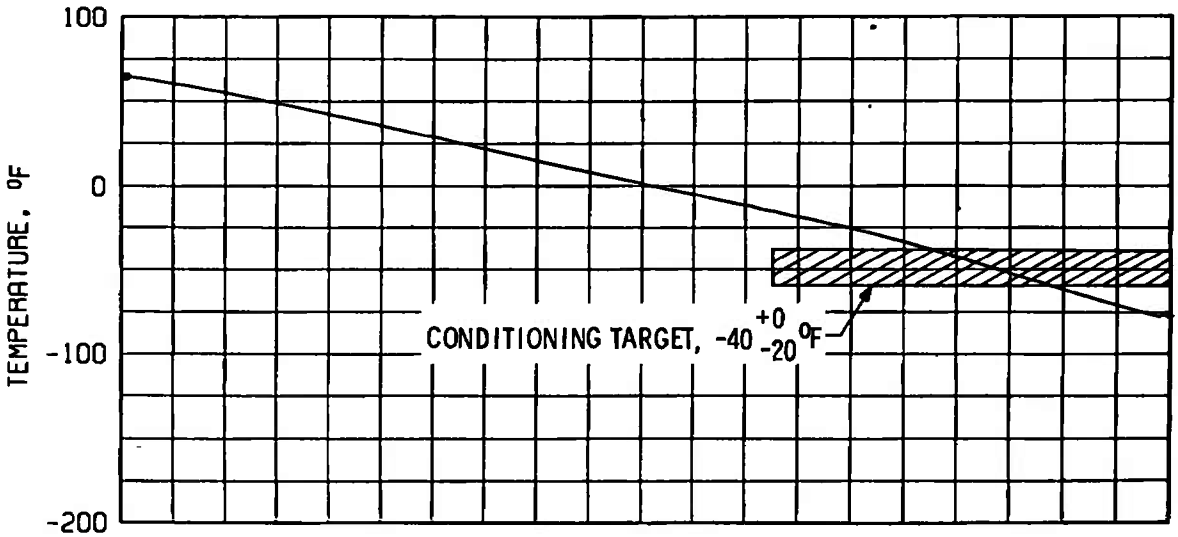
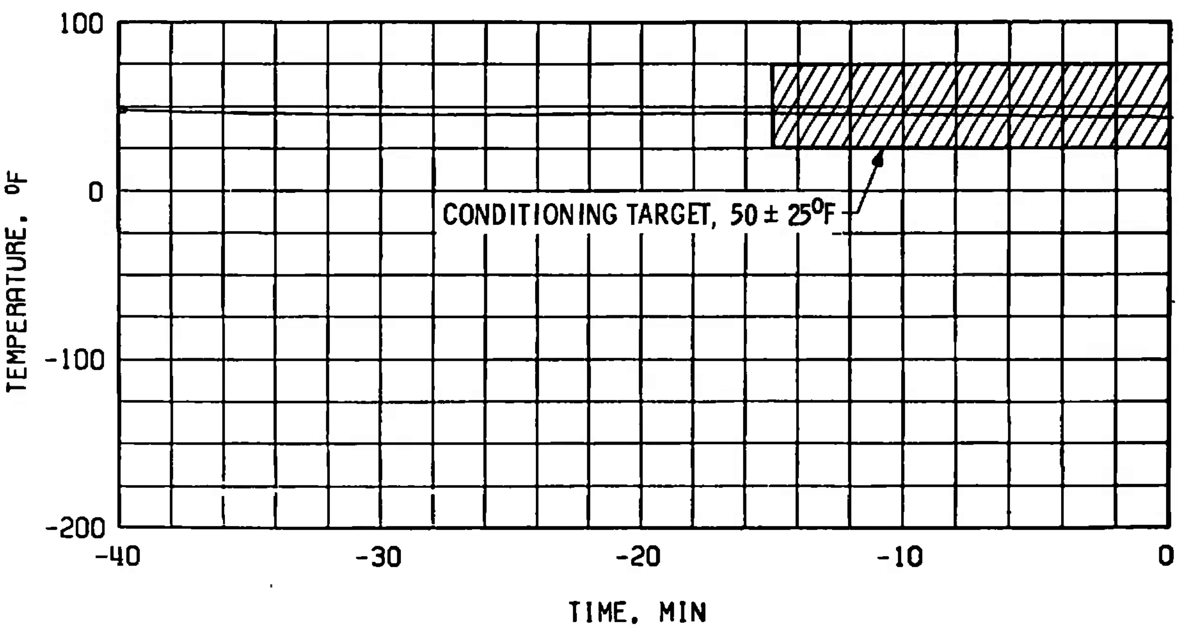


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 18A

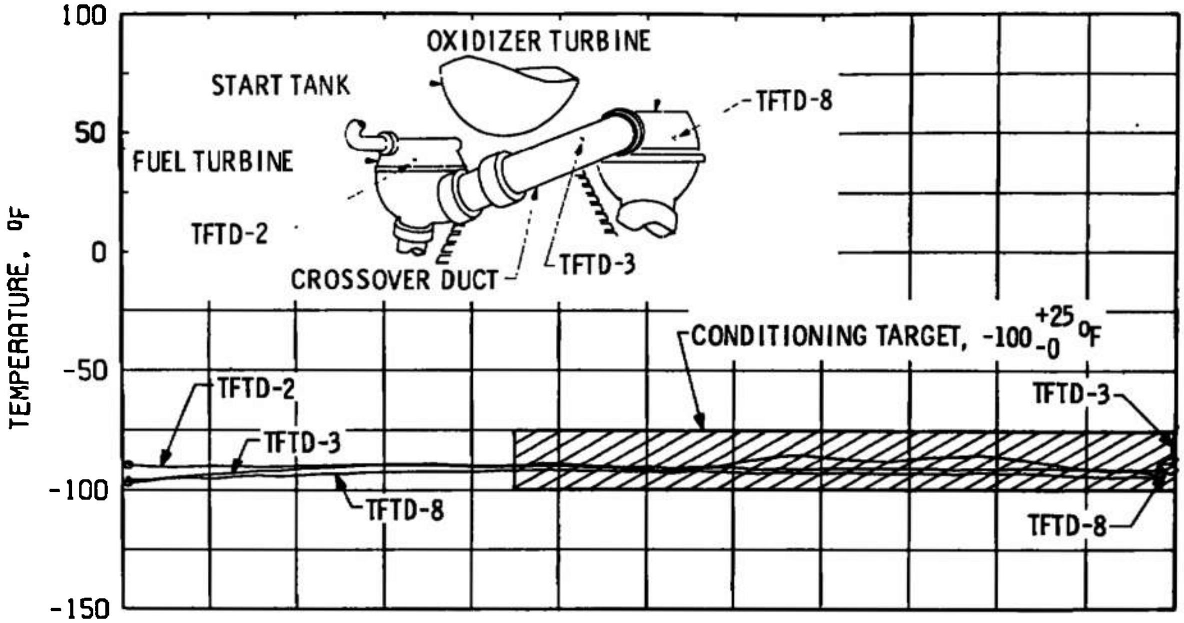


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

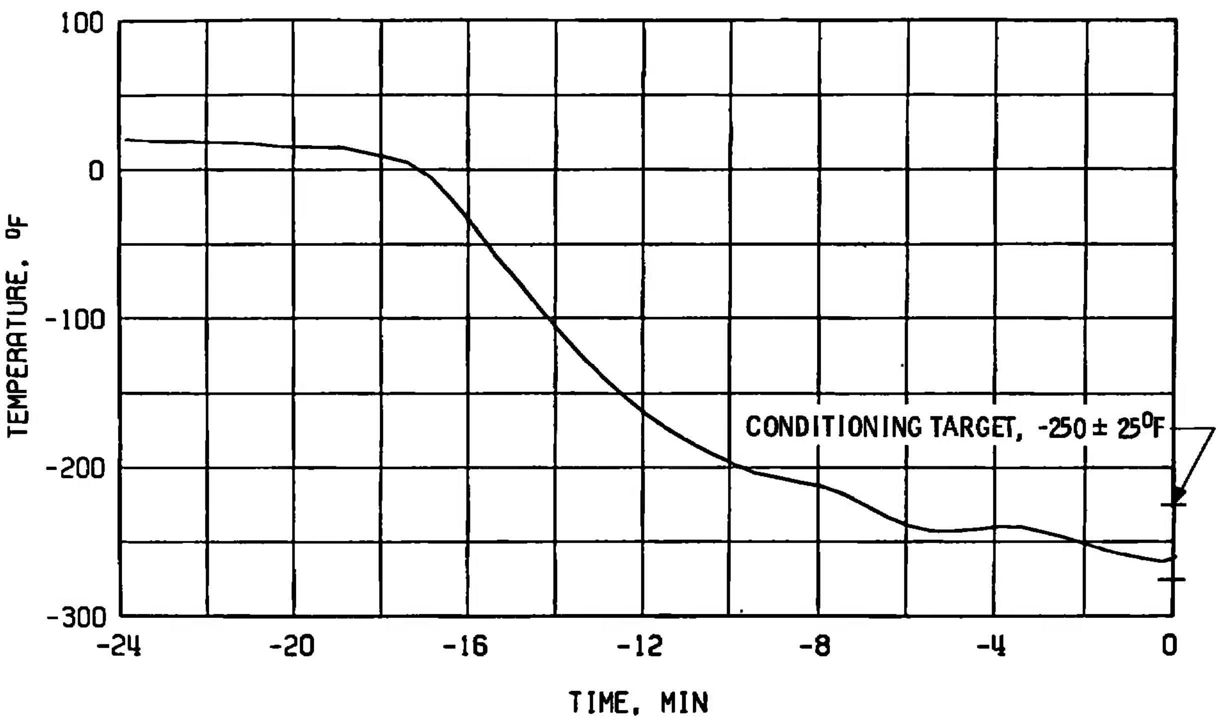


b. Start Tank Discharge Valve, TSTDVOC

Fig. 16 Thermal Conditioning History of Engine Components, Firing 18A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 16 Concluded

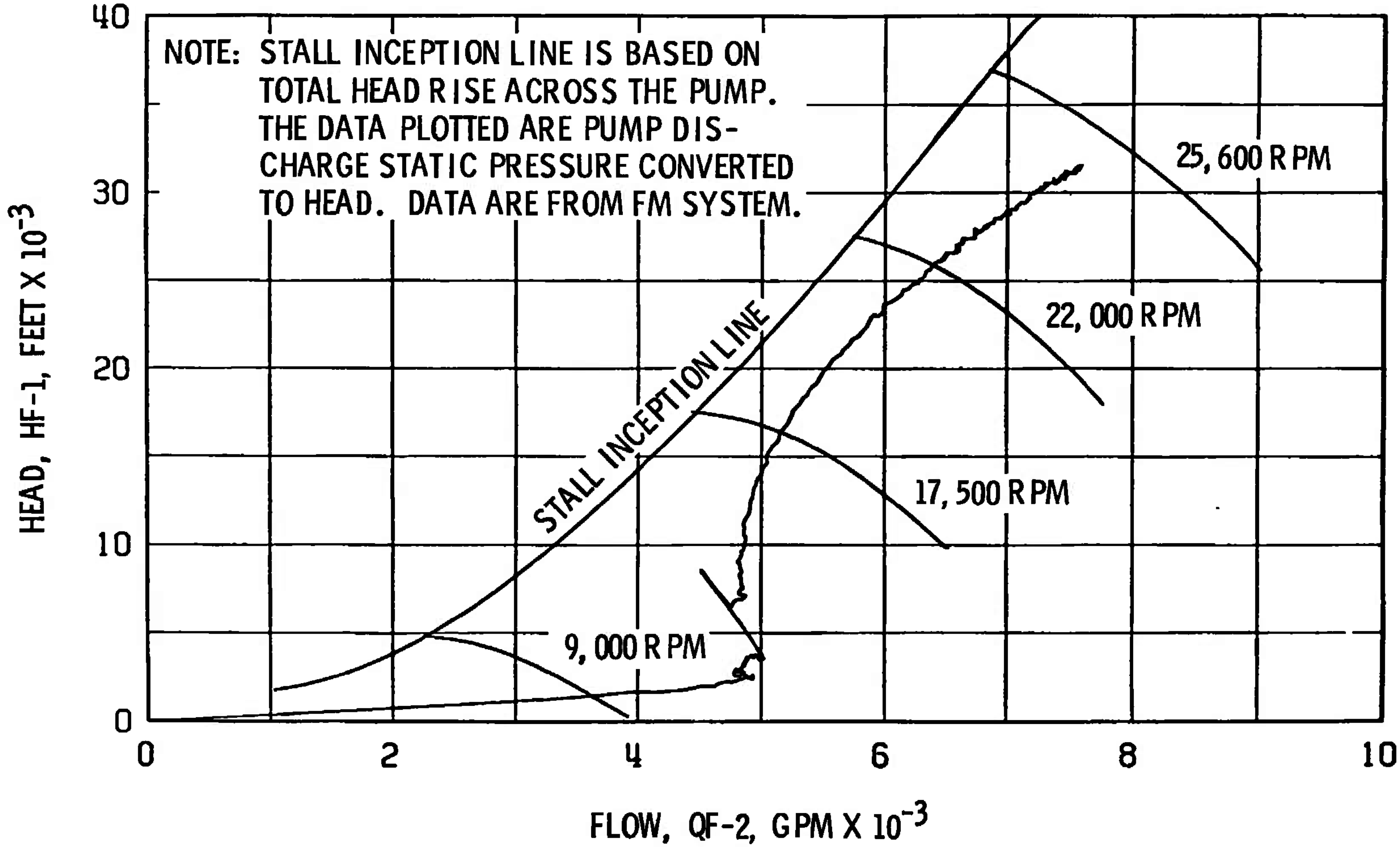
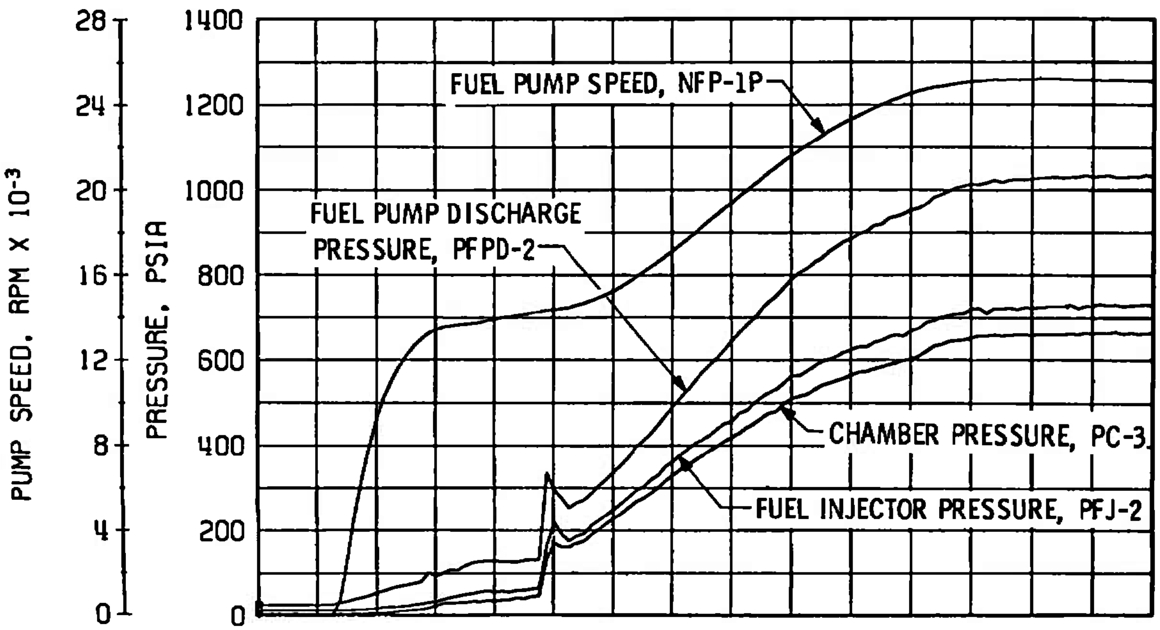
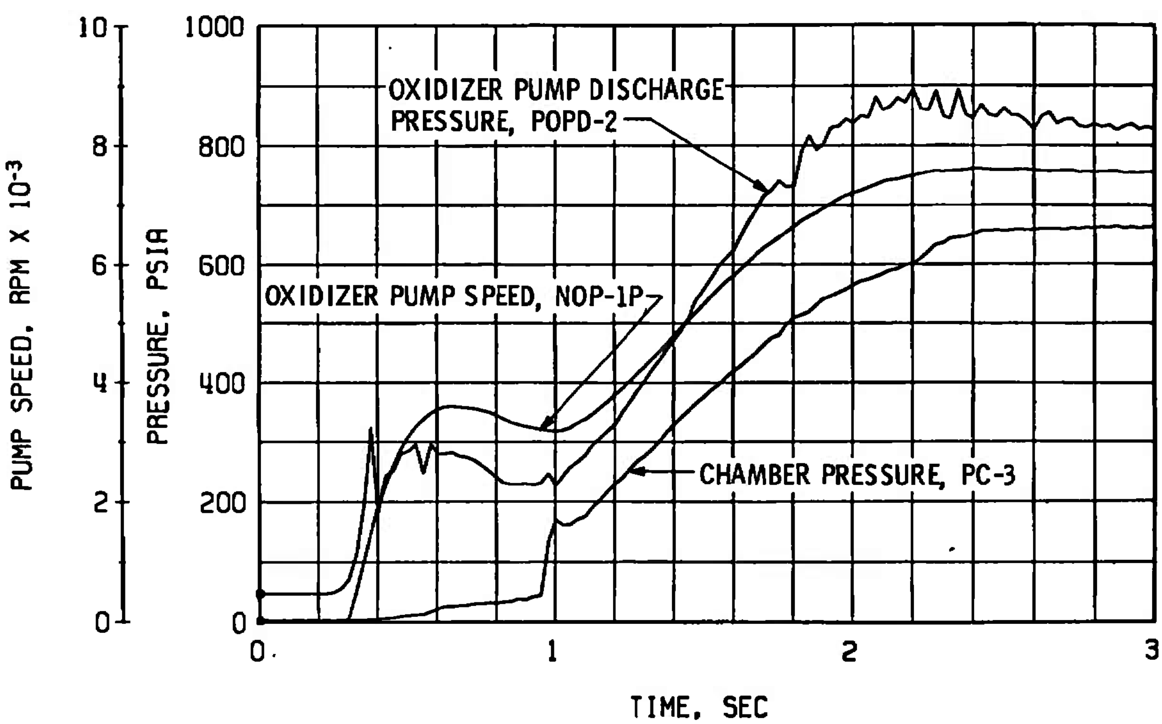


Fig. 17 Fuel Pump Start Transient Performance, Firing 18A

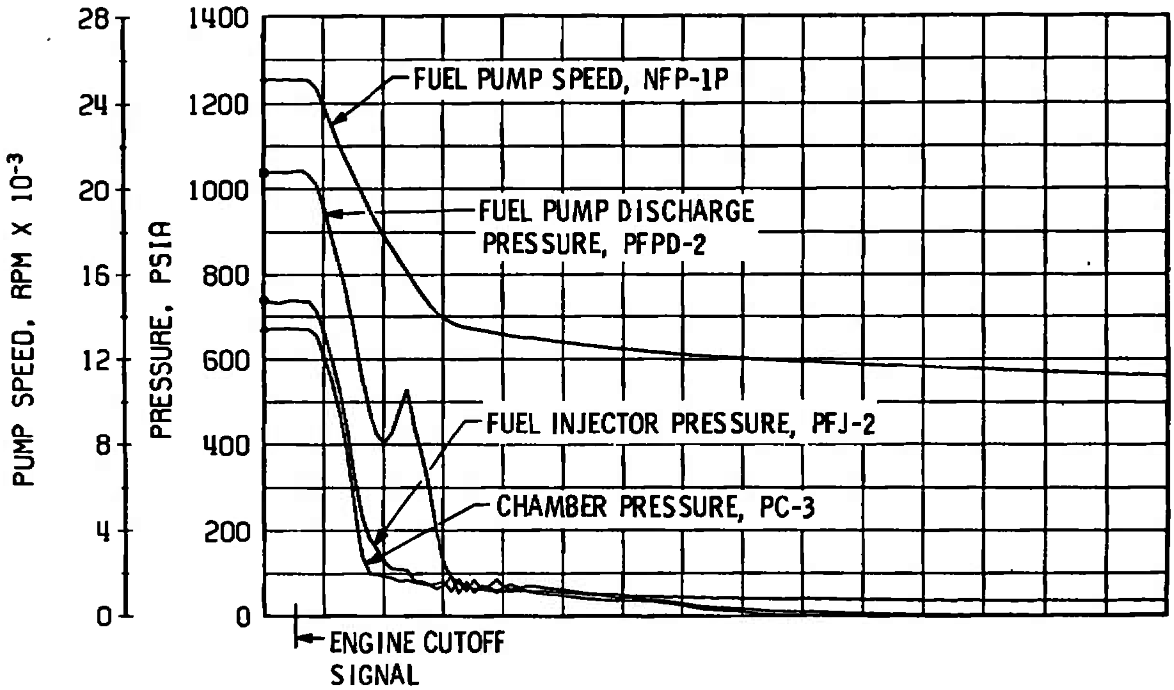


a. Thrust Chamber Fuel System, Start

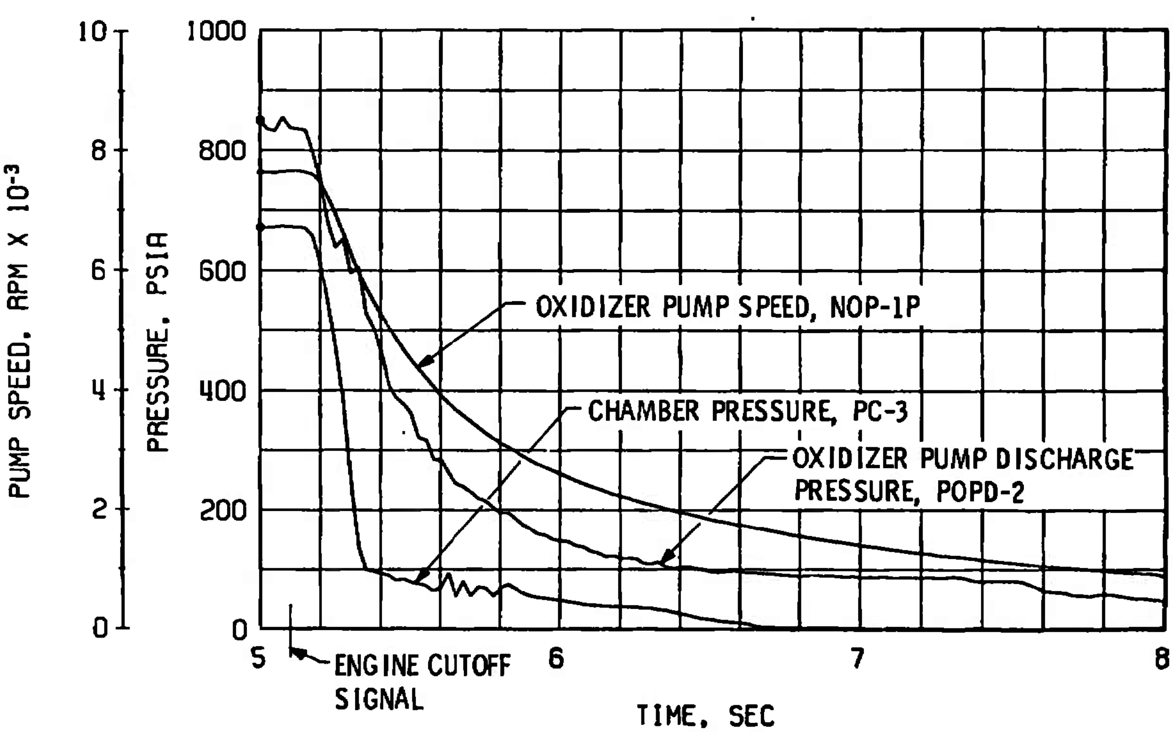


b. Thrust Chamber Oxidizer System, Start

Fig. 18 Engine Transient Operation, Firing 18B

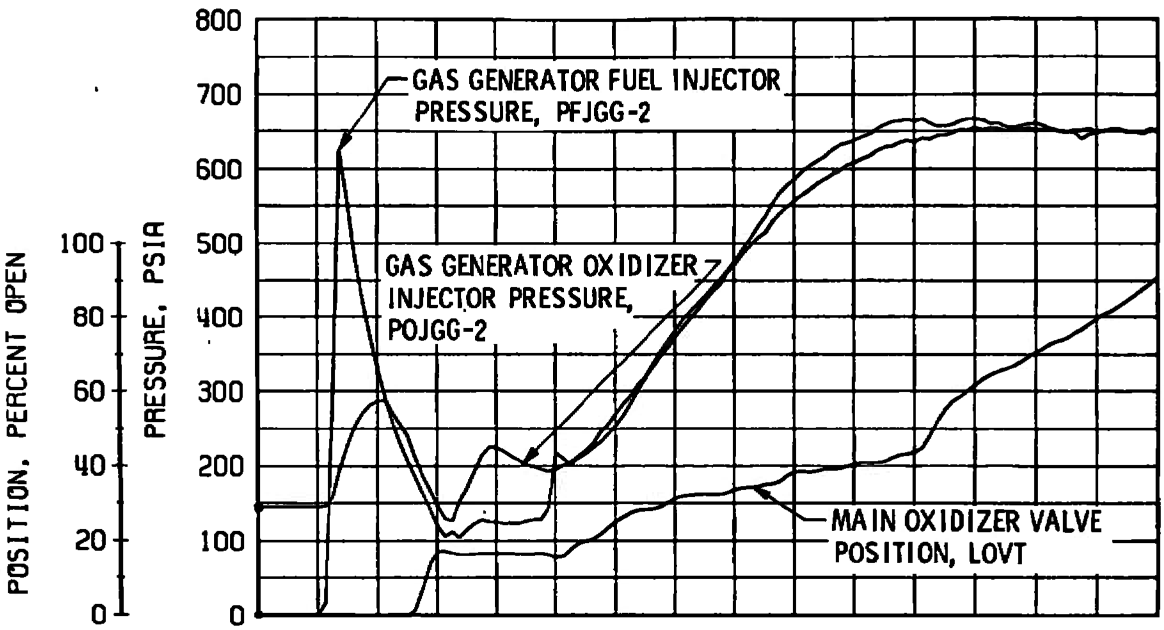


c. Thrust Chamber Fuel System, Shutdown

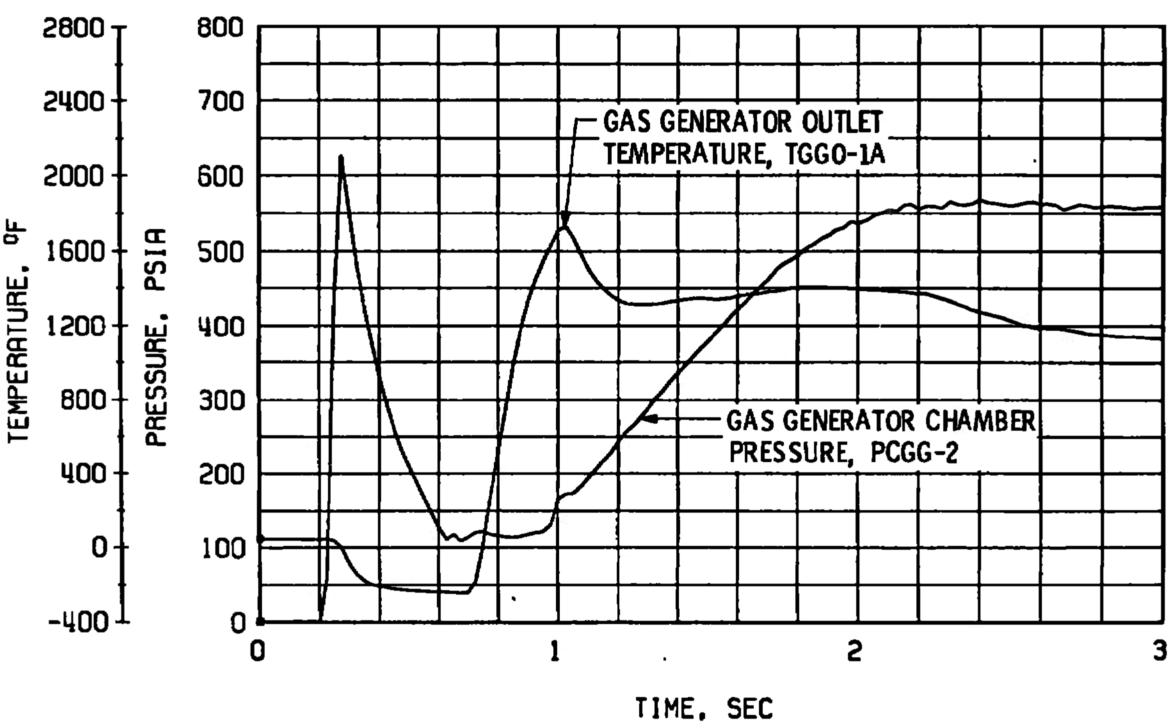


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 18 Continued

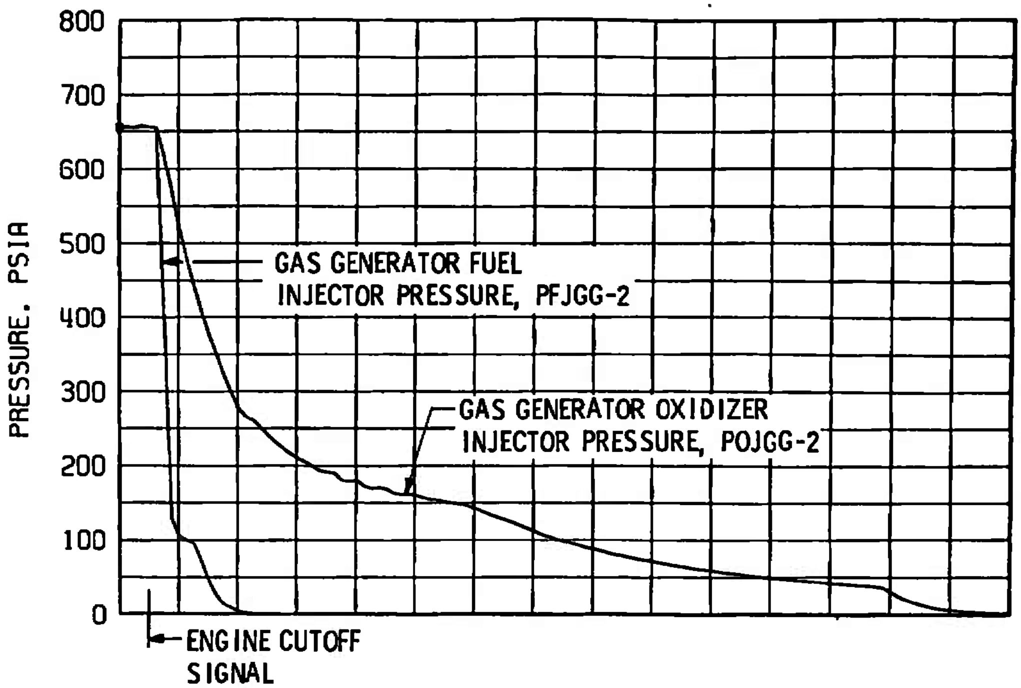


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

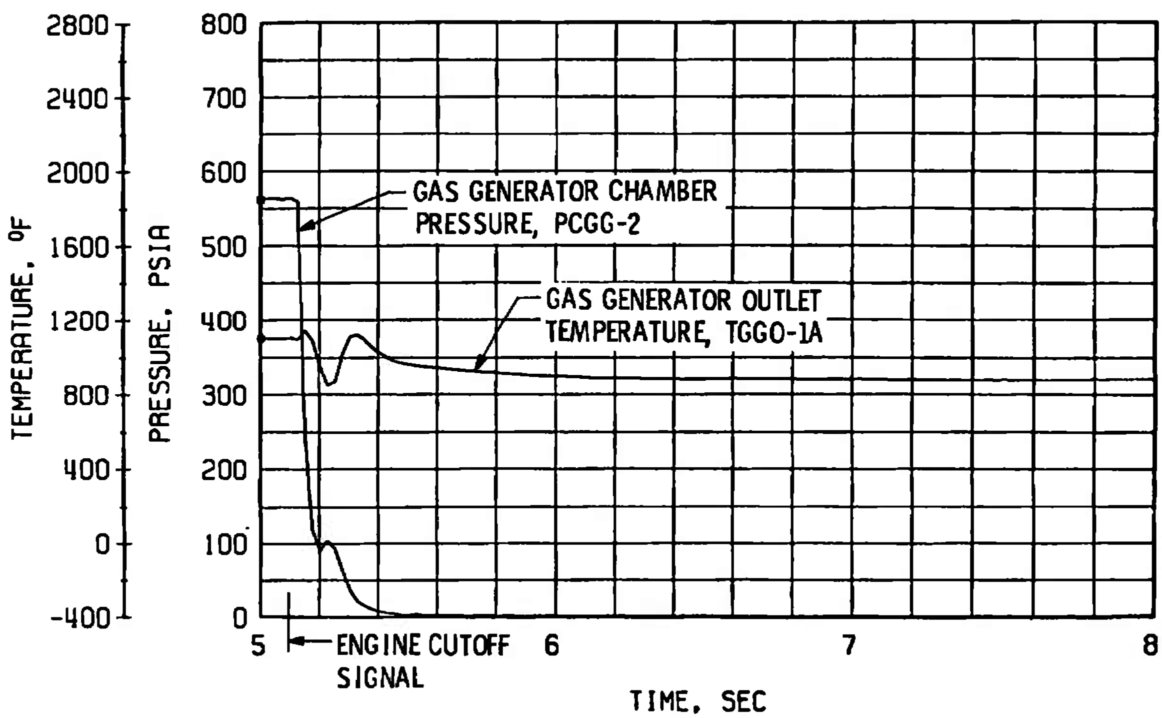


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 18 Continued

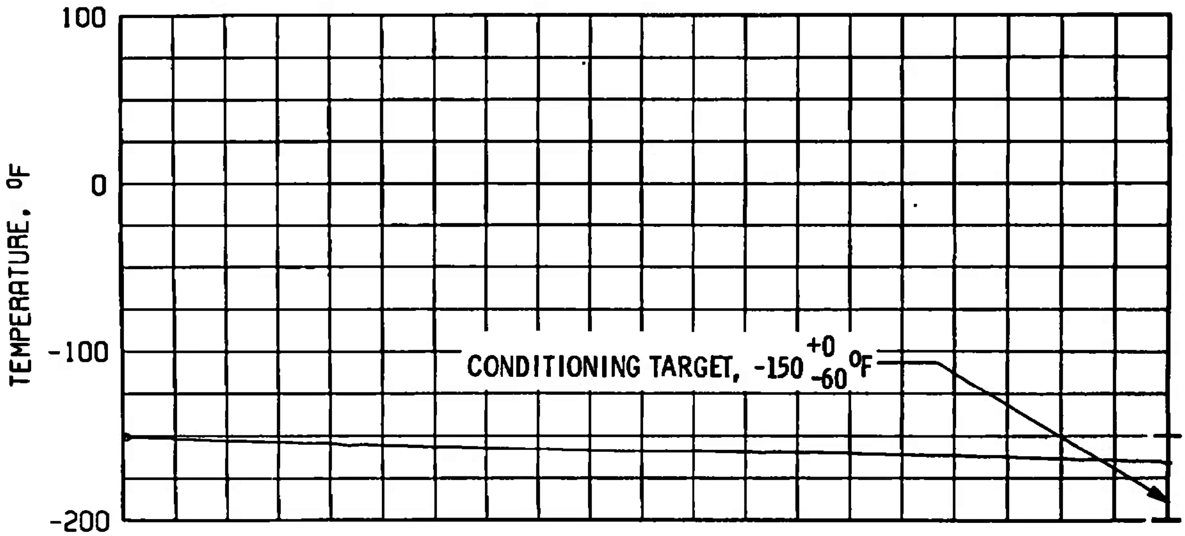


g. Gas Generator Injector Pressures, Shutdown

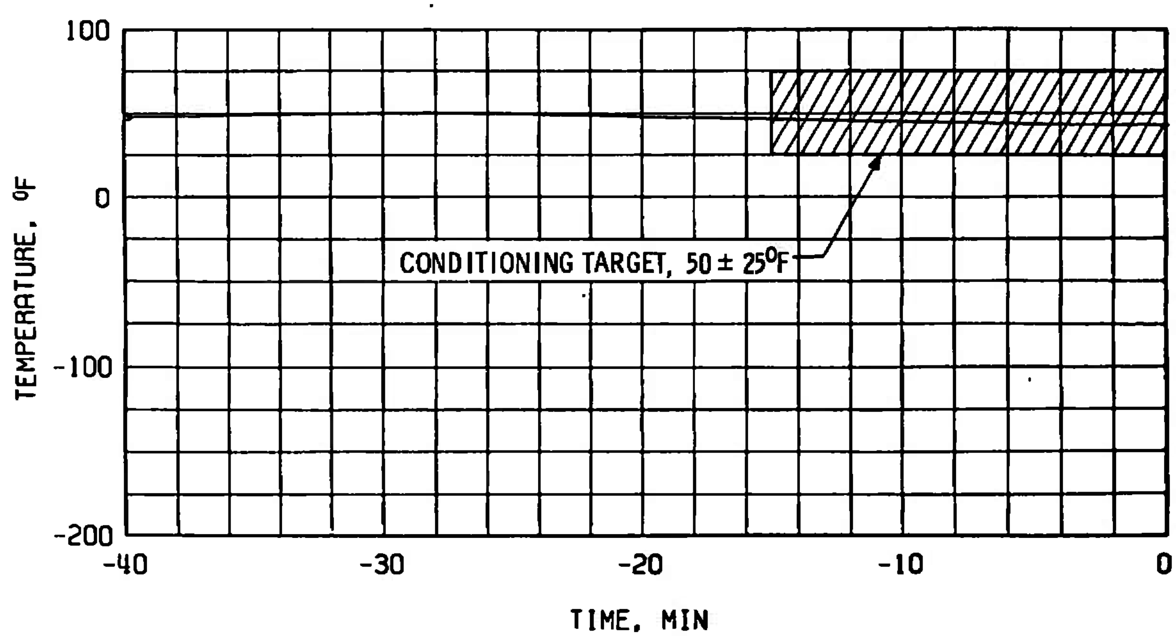


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 18 Concluded

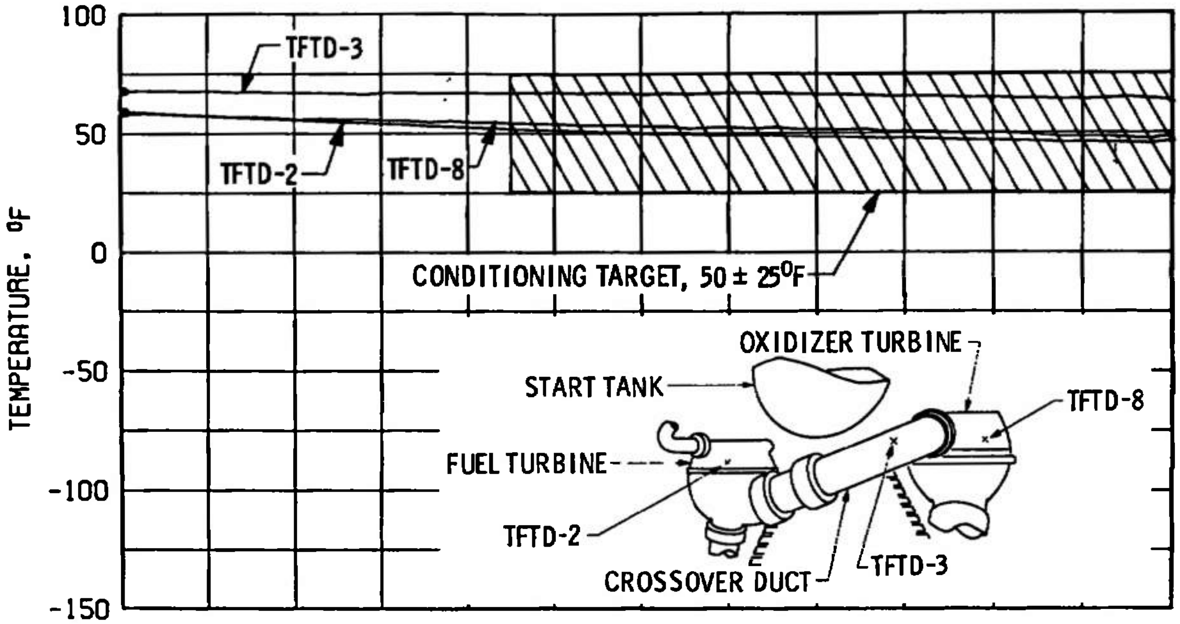


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

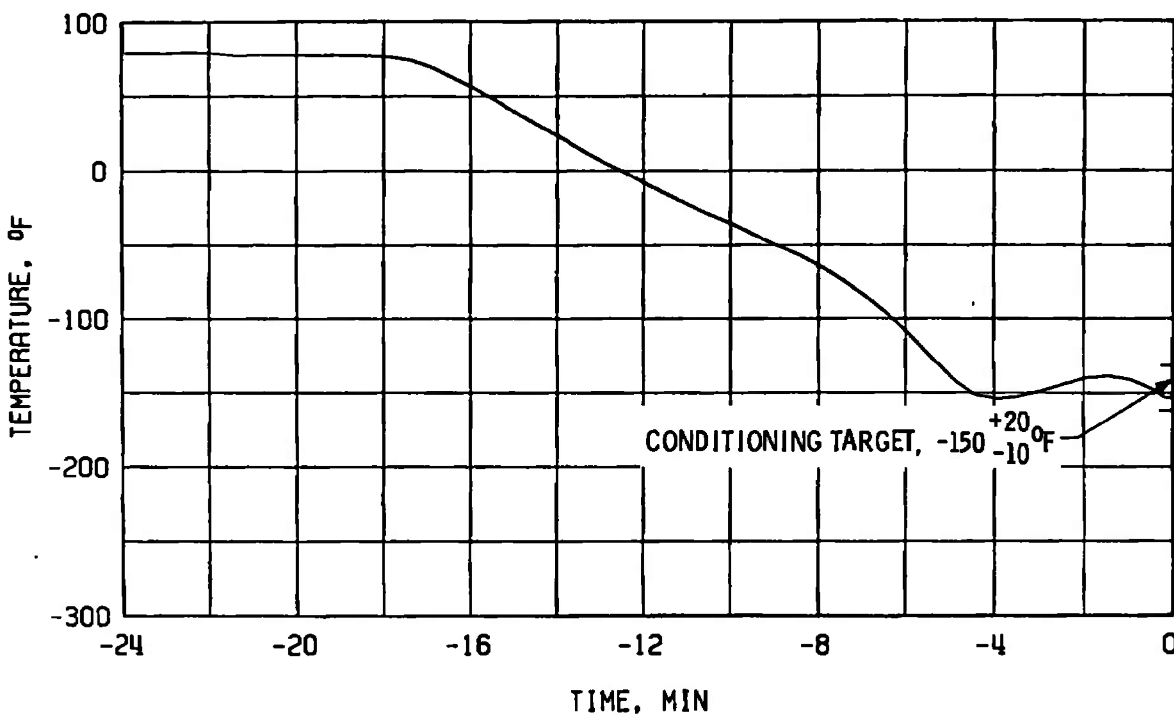


b. Start Tank Discharge Valve, TSTDVOC

Fig. 19 Thermal Conditioning History of Engine Components, Firing 18B



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 19 Concluded

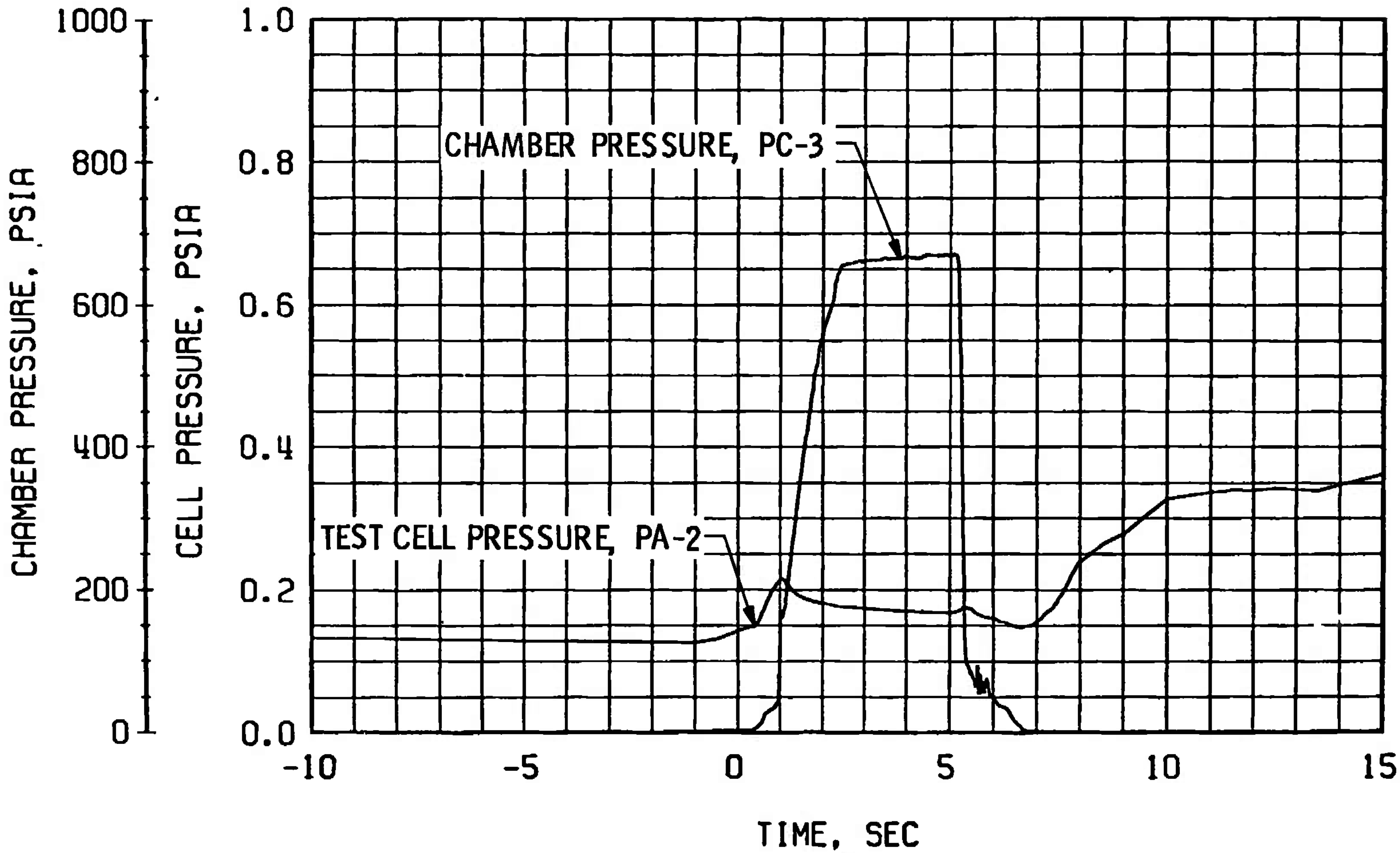


Fig. 20 Engine Ambient and Combustion Chamber Pressures, Firing 18B

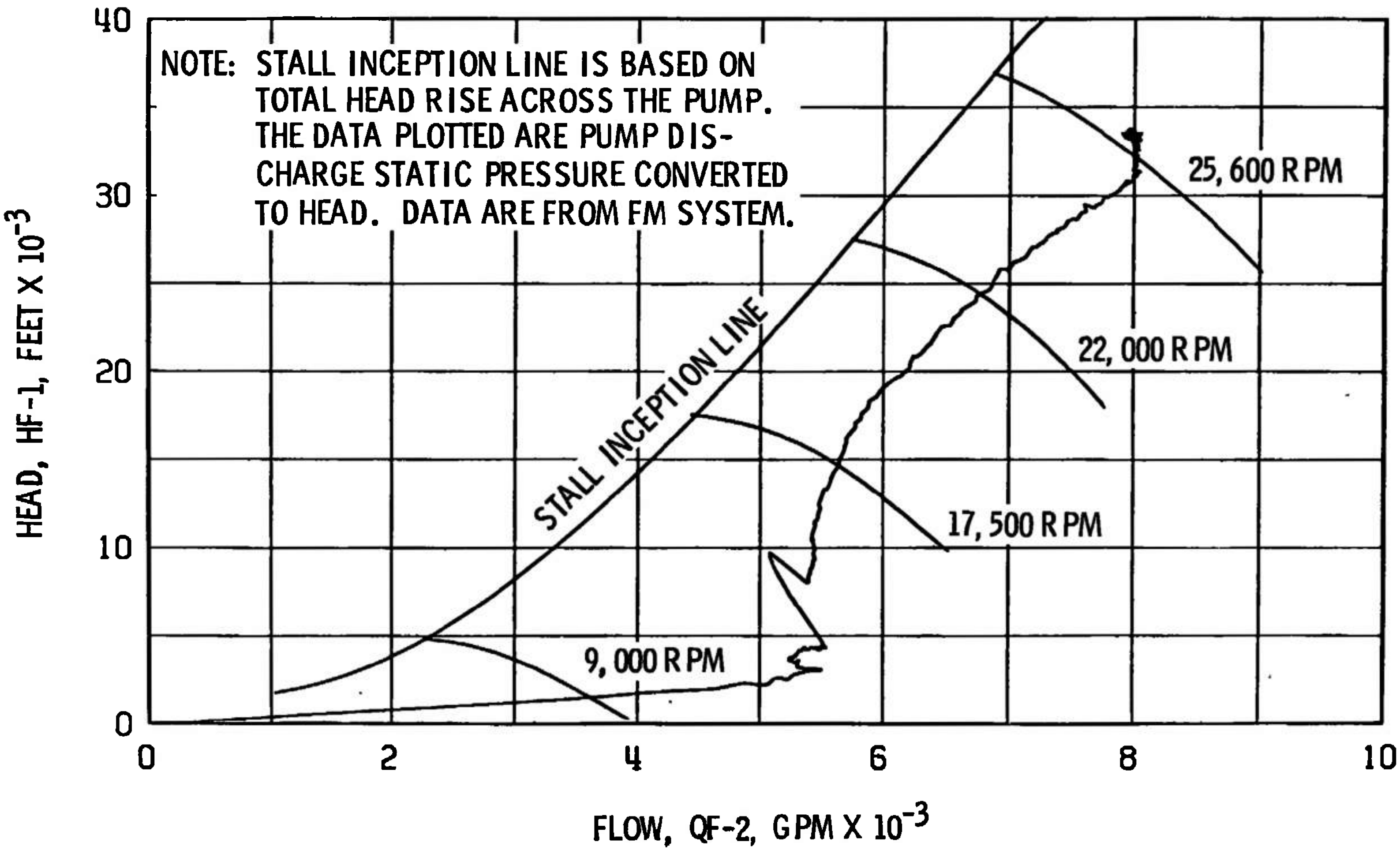
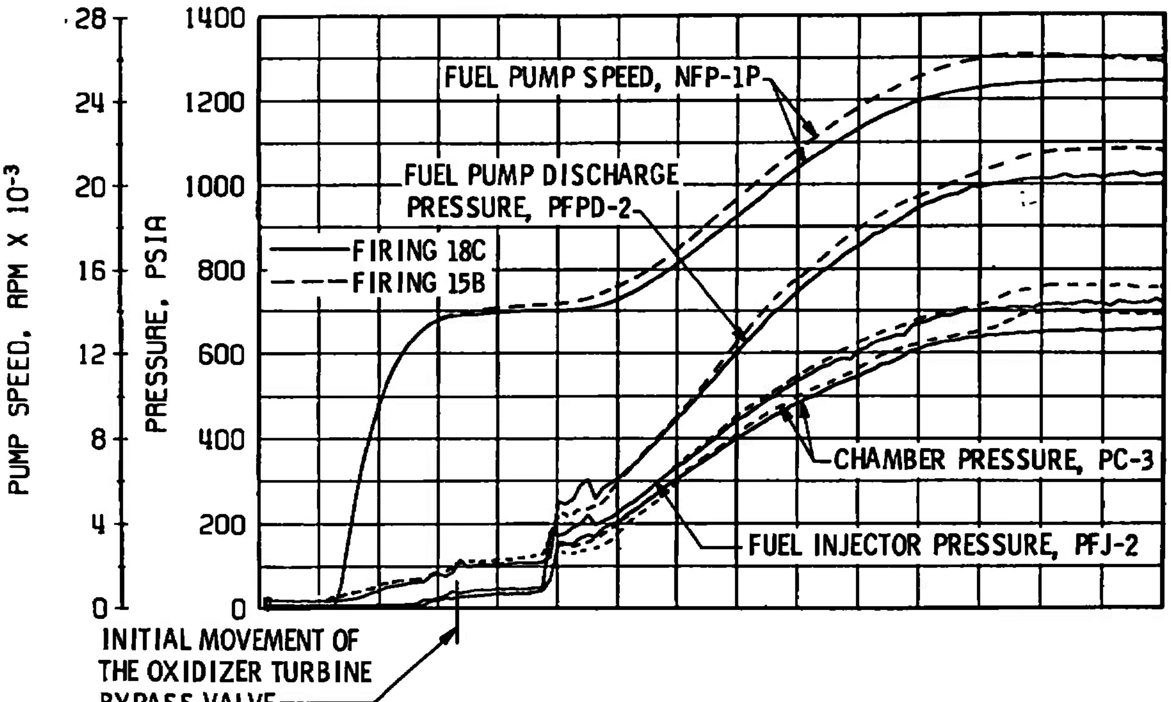
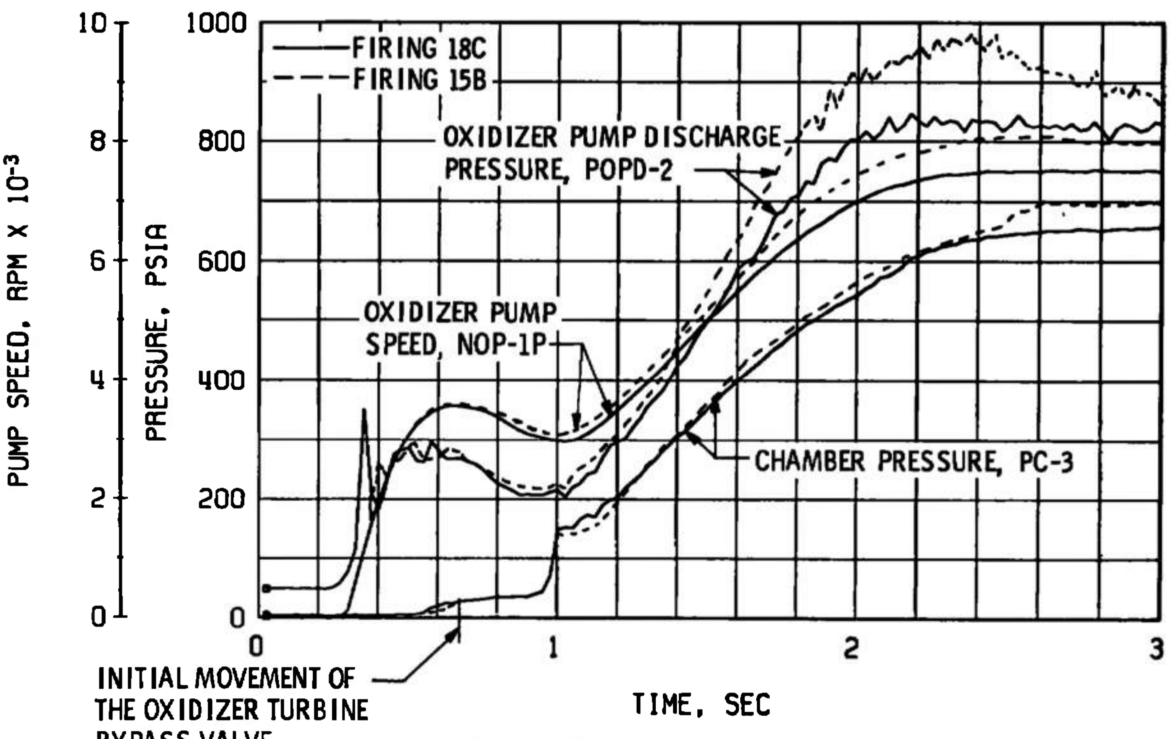


Fig. 21 Fuel Pump Start Transient Performance, Firing 18B

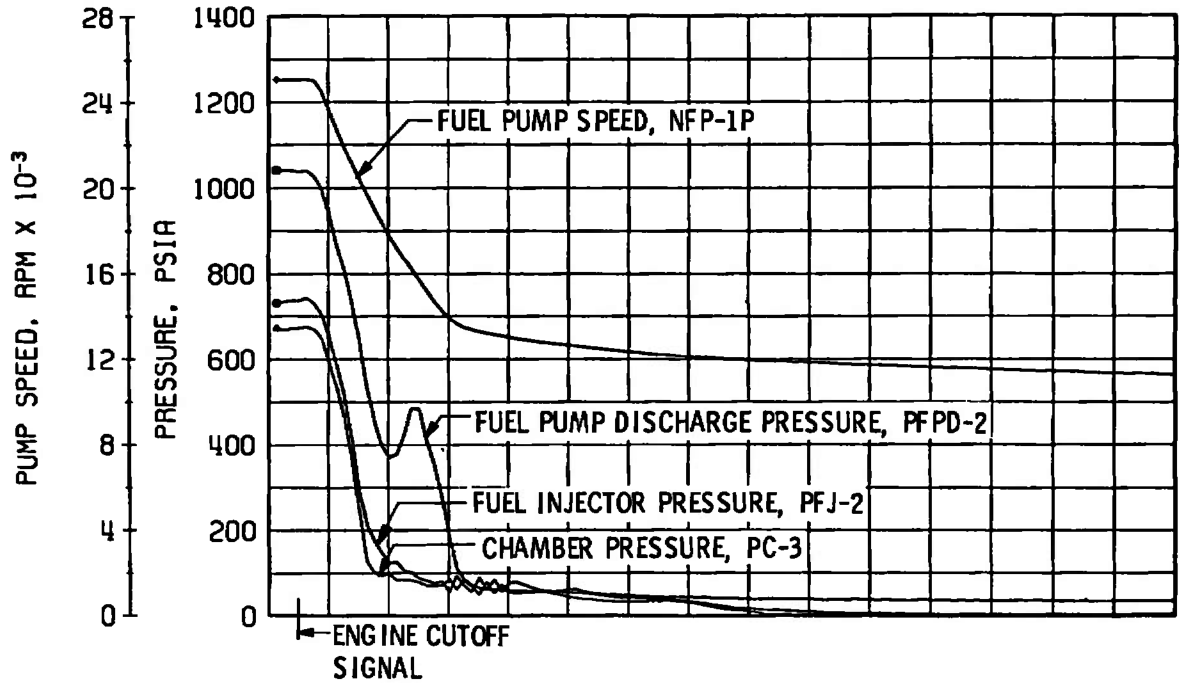


a. Thrust Chamber Fuel System, Start

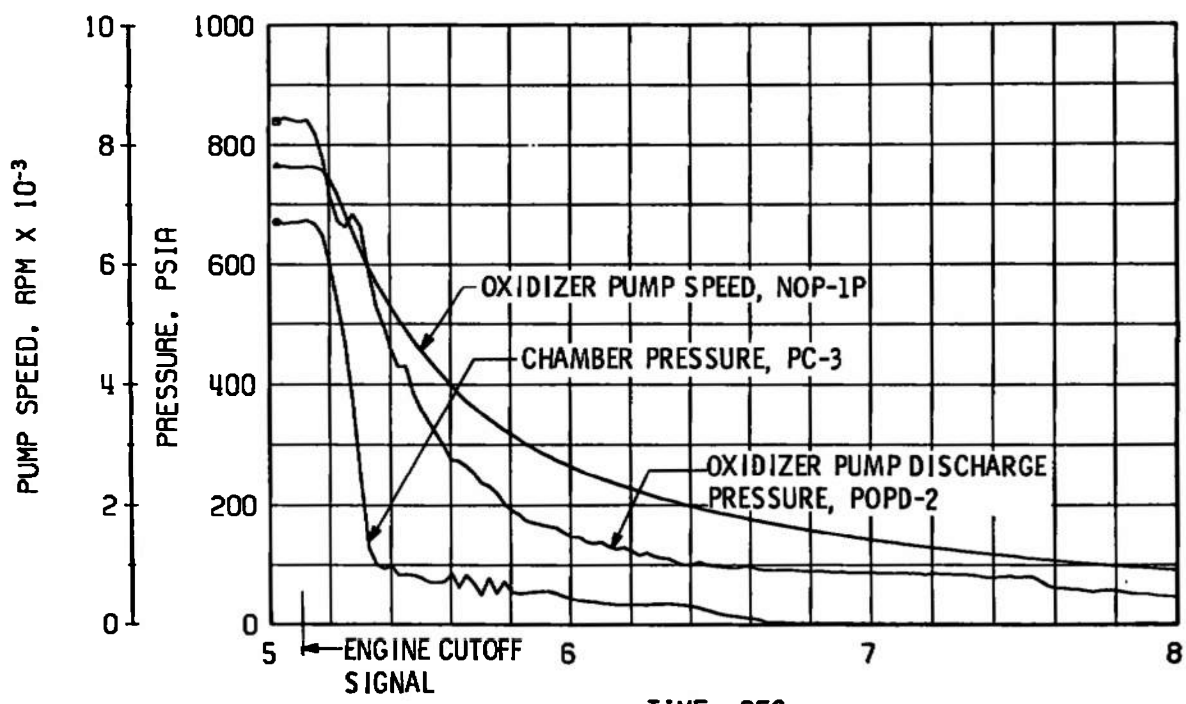


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 18C

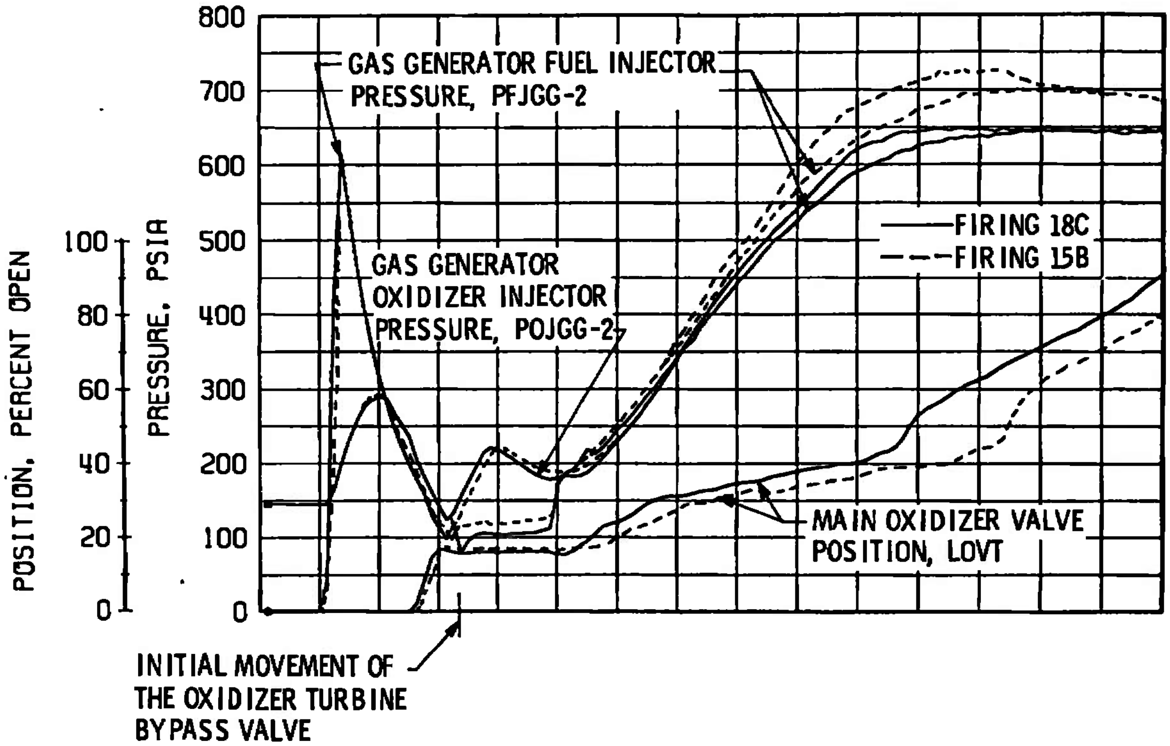


c. Thrust Chamber Fuel System, Shutdown

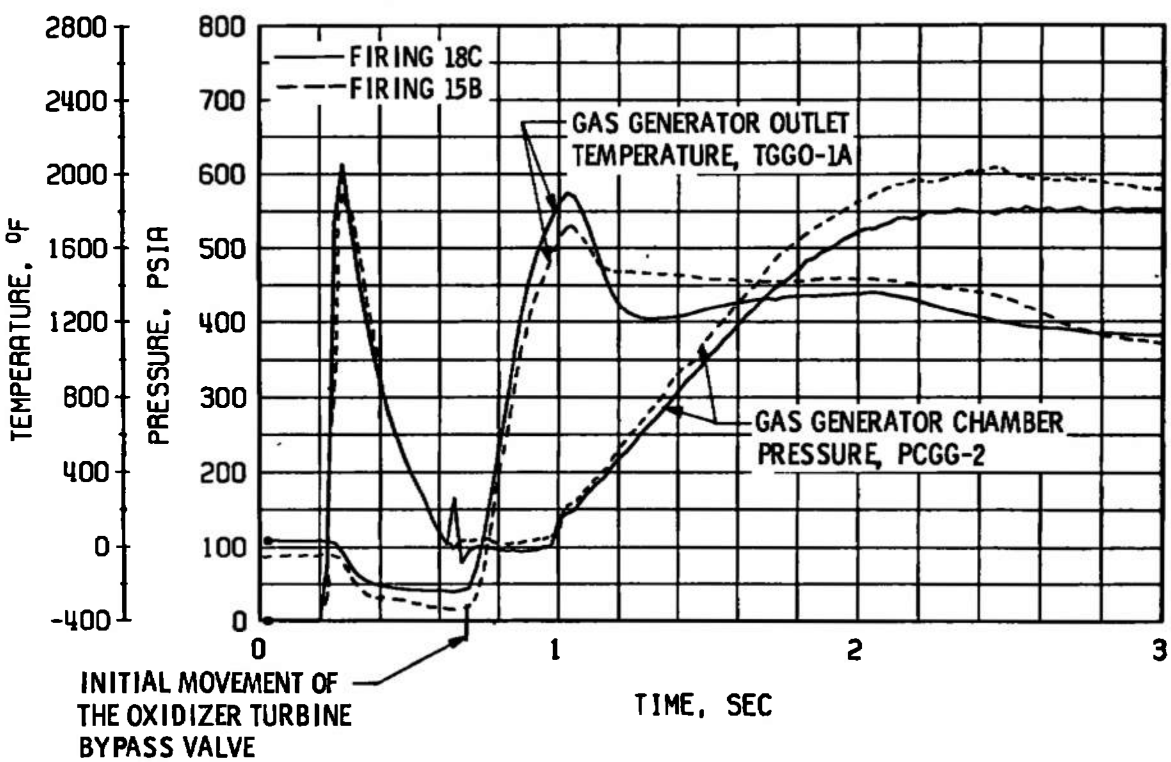


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued

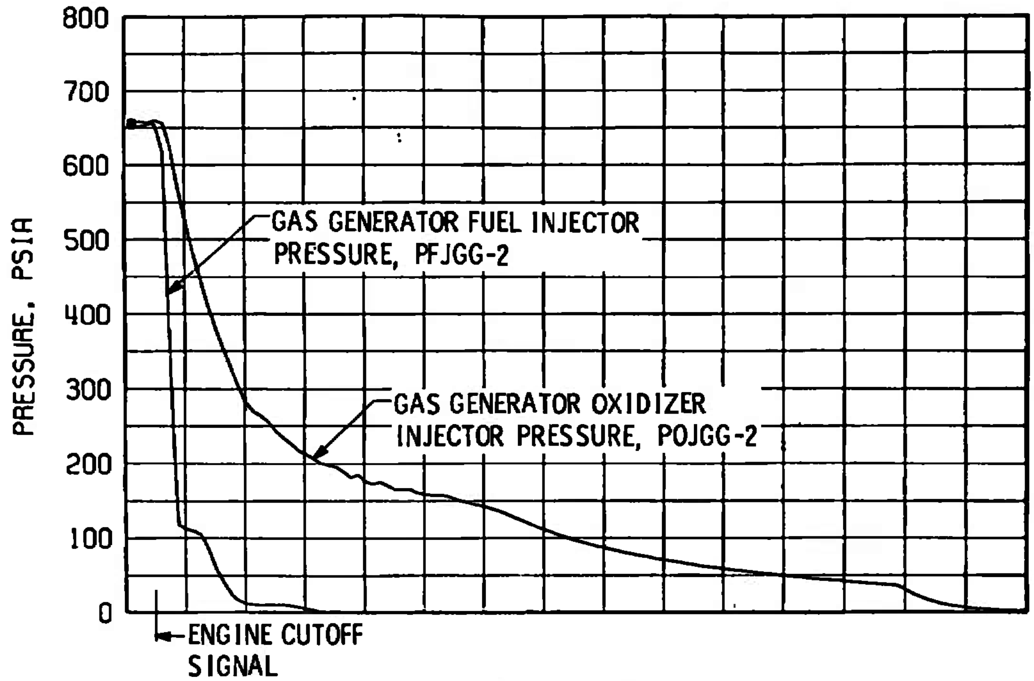


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

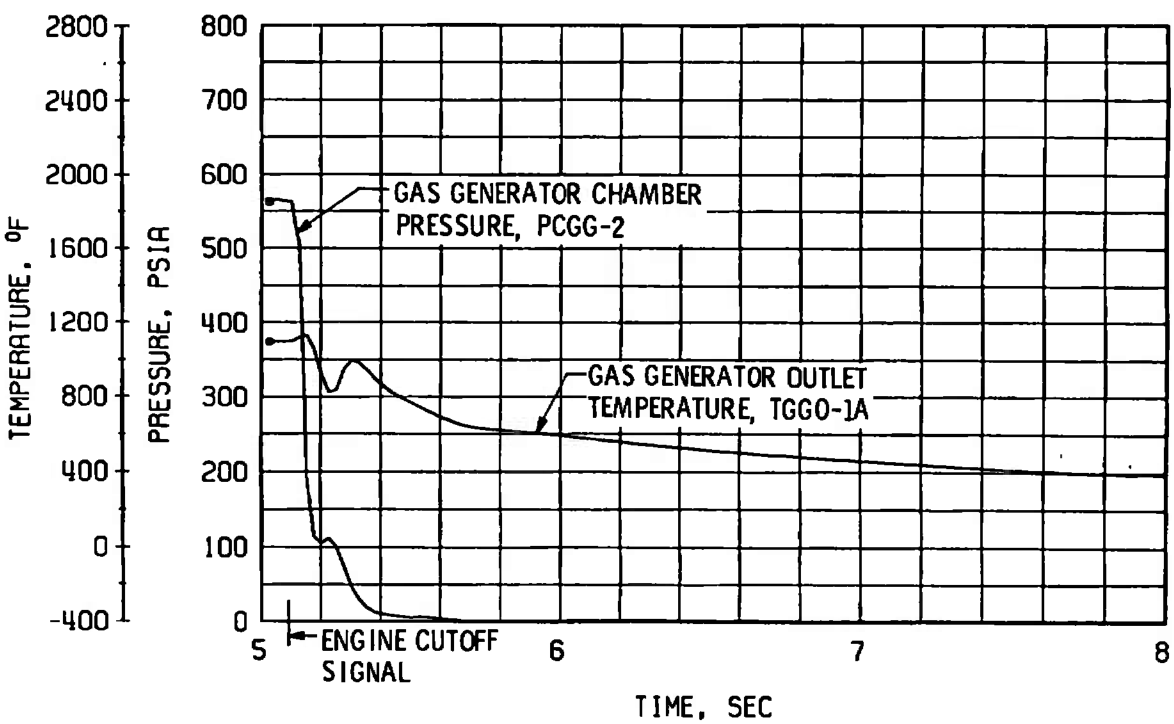


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued

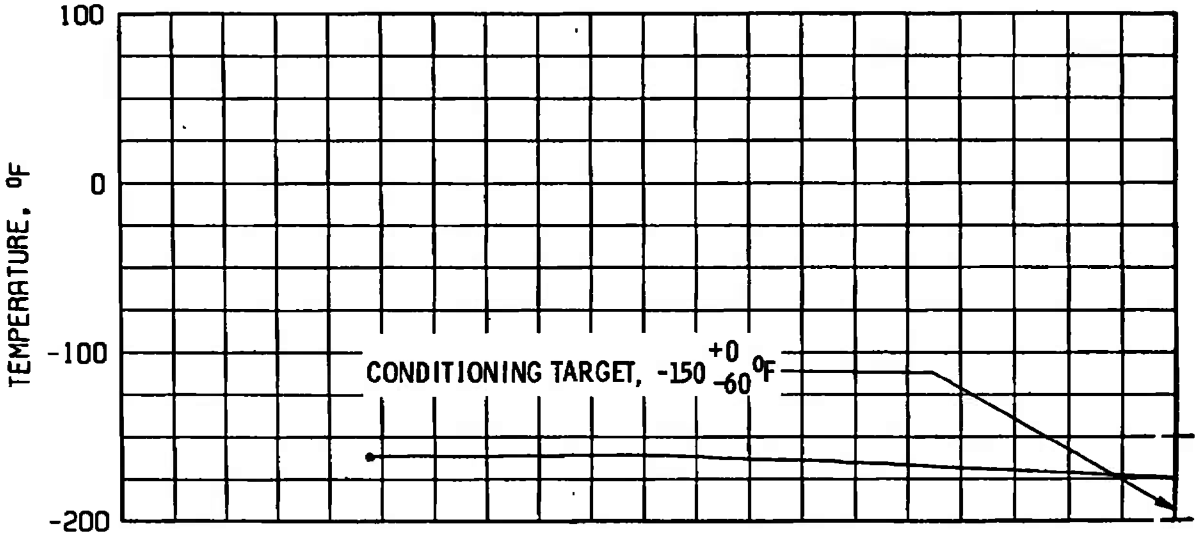


g. Gas Generator Injector Pressures, Shutdown

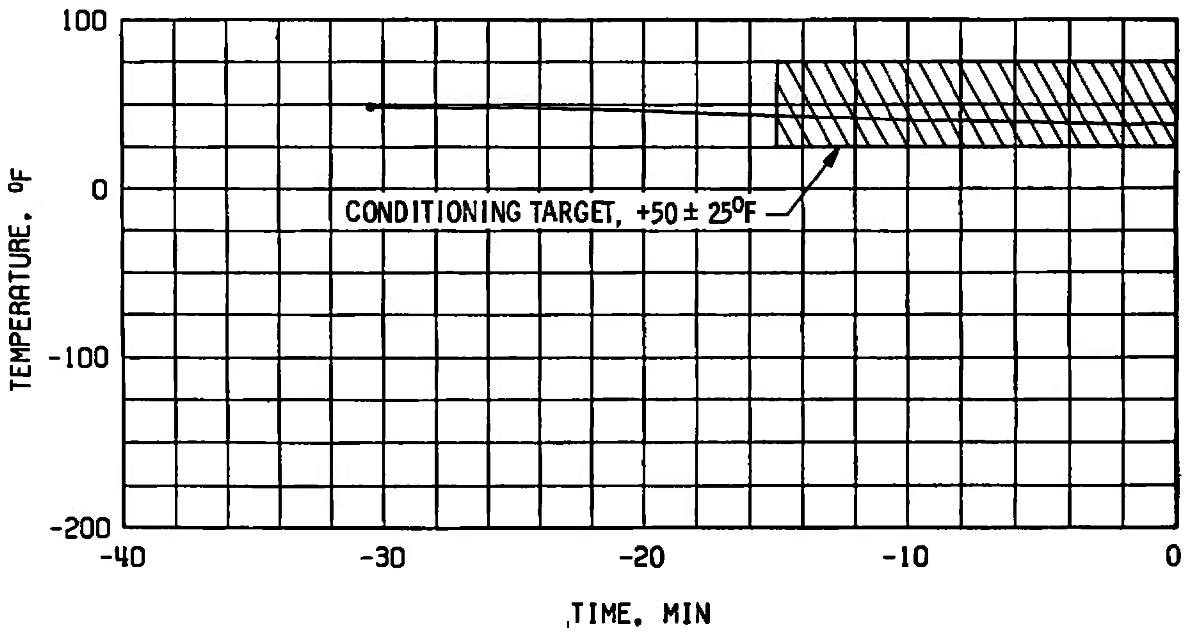


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

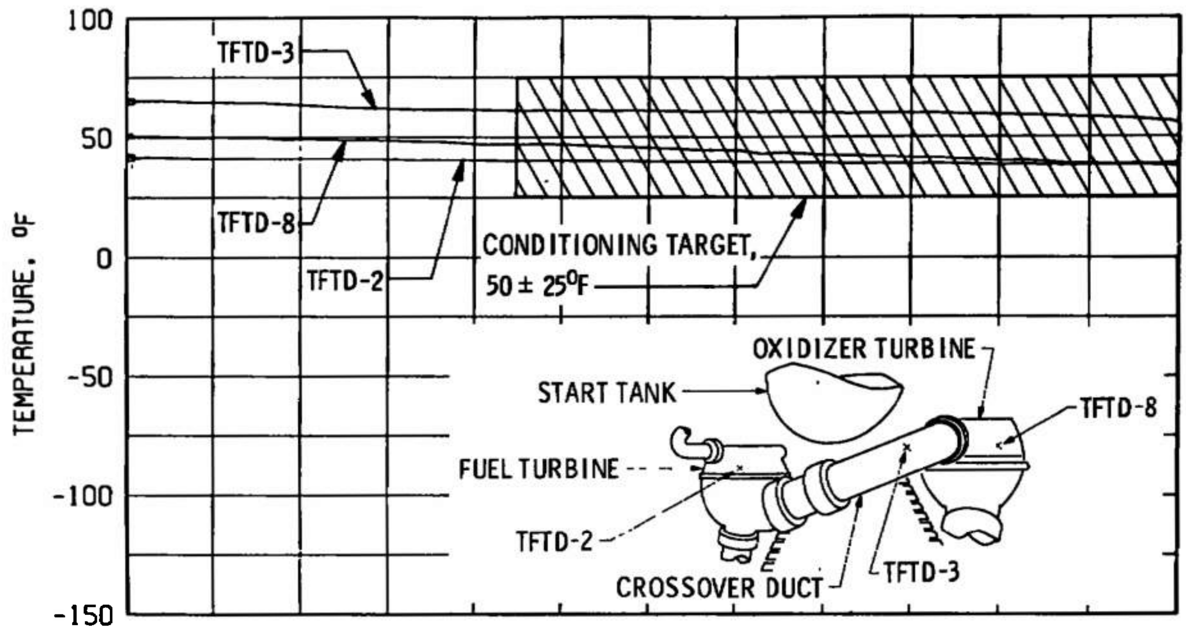


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

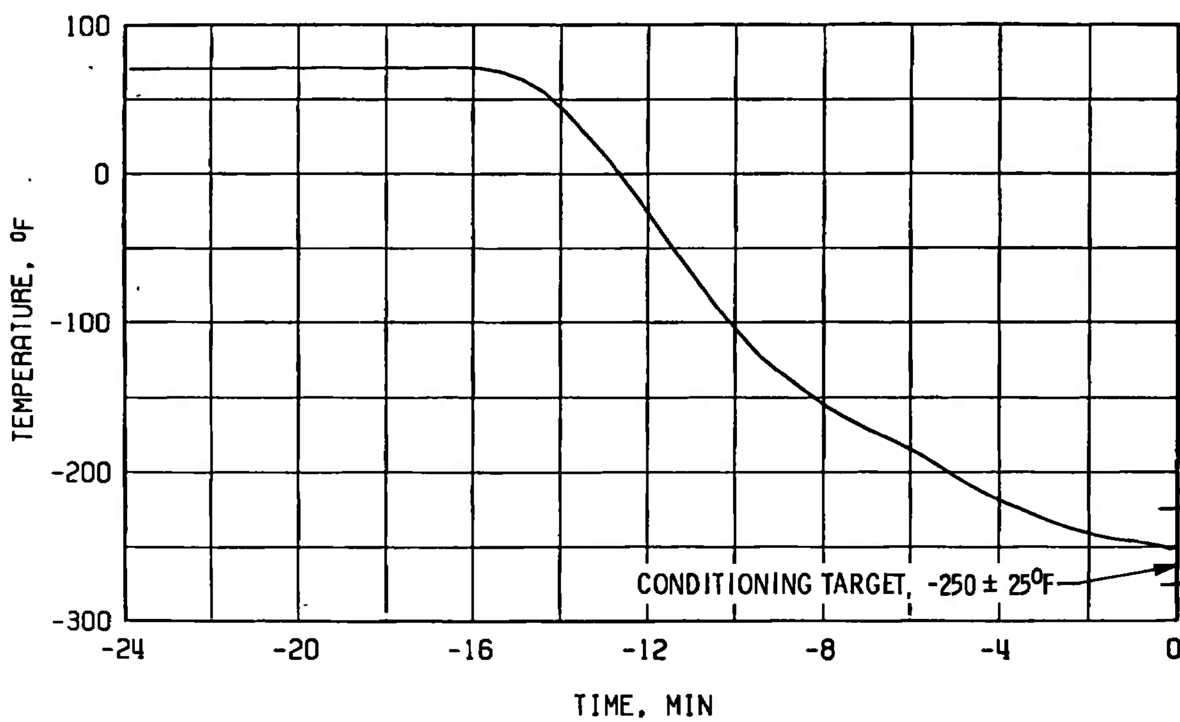


b. Start Tank Discharge Valve, TSTDVOC

Fig. 23 Thermal Conditioning History of Engine Components, Firing 18C



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 23 Concluded

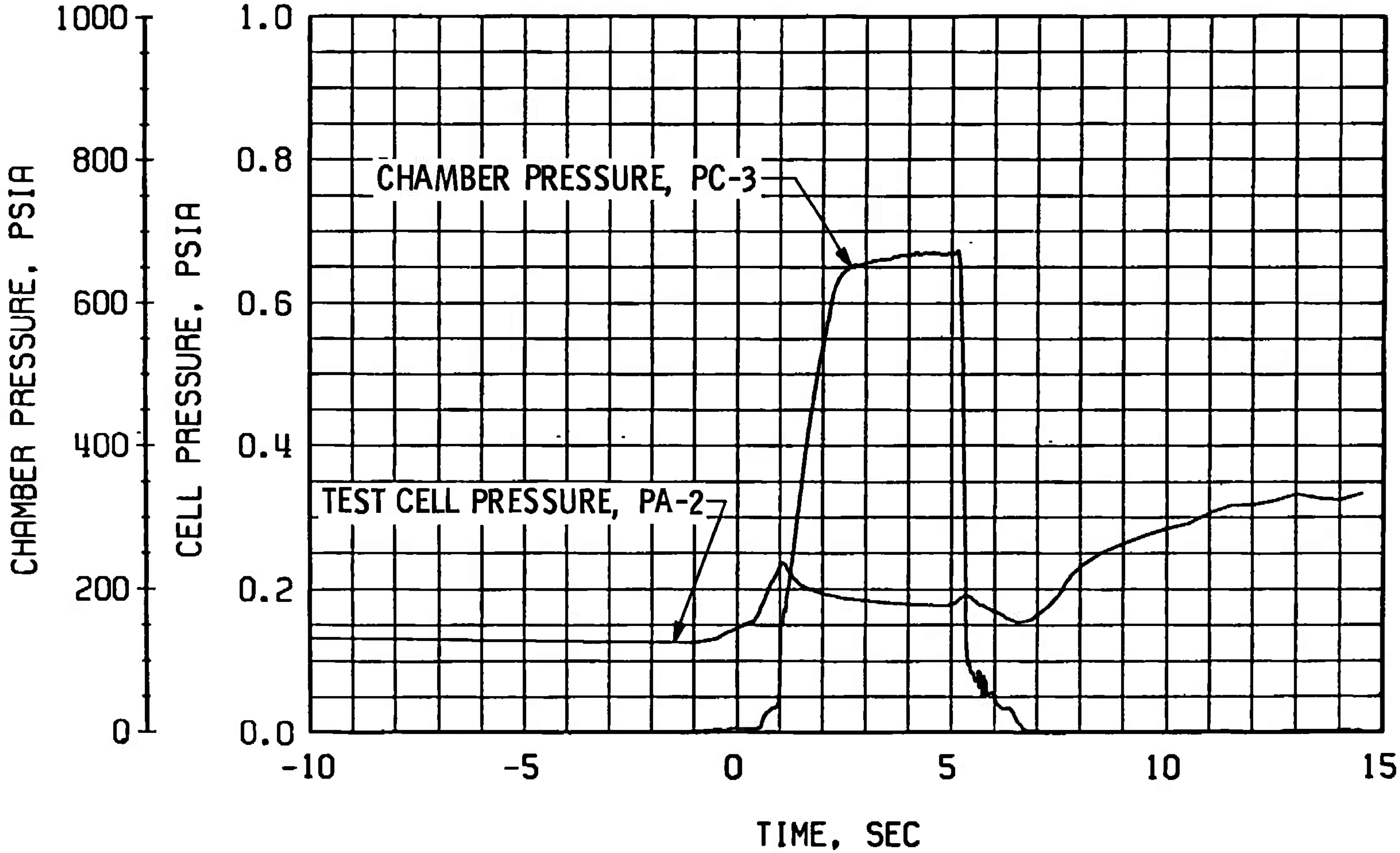


Fig. 24 Engine Ambient and Combustion Chamber Pressures, Firing 18C

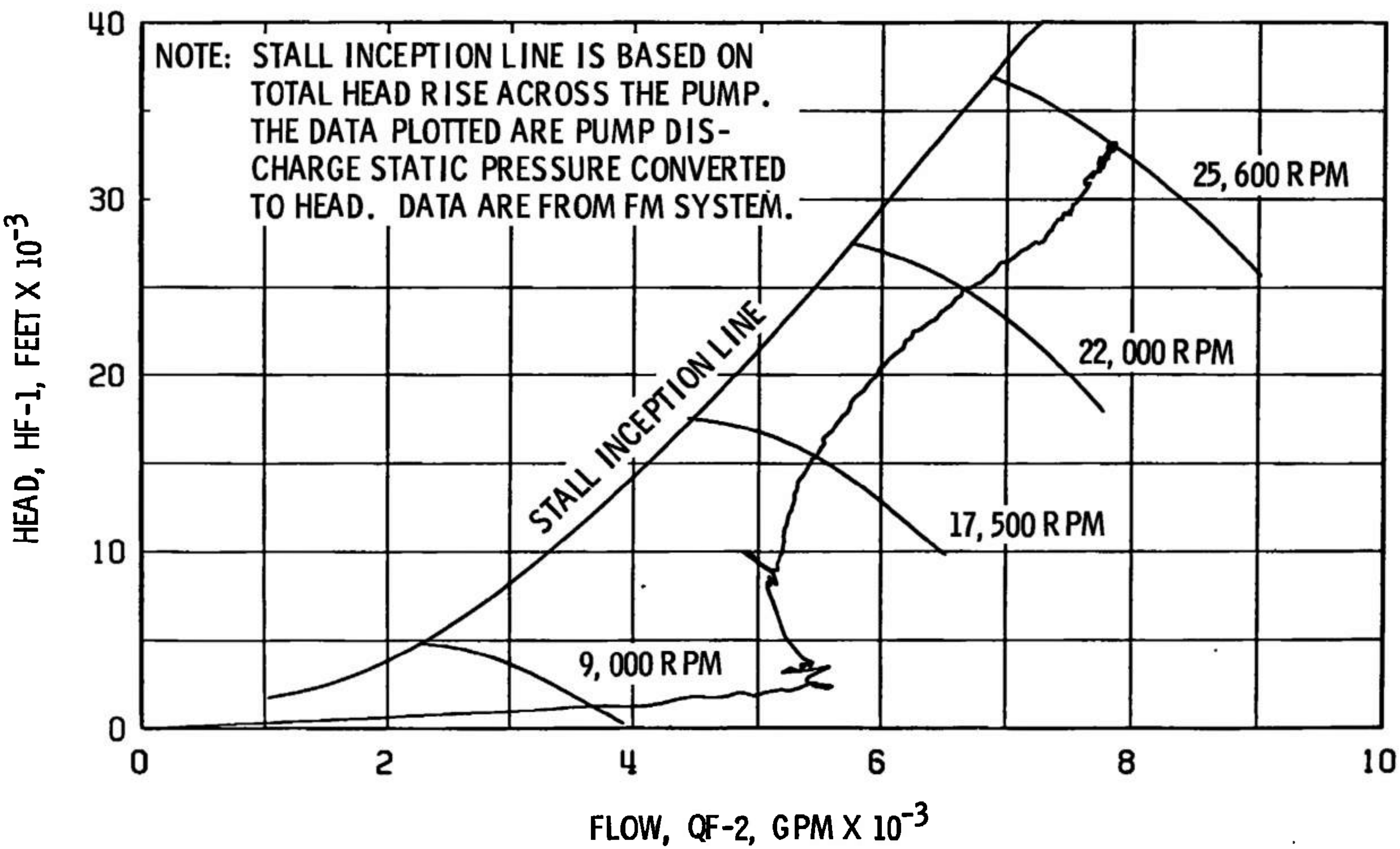
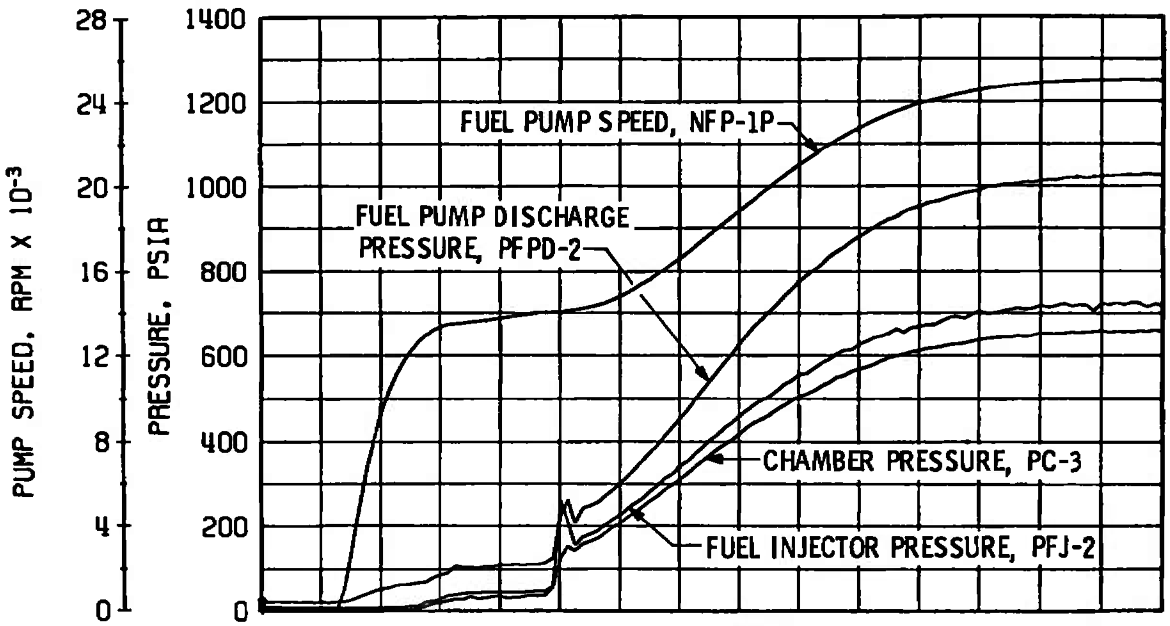
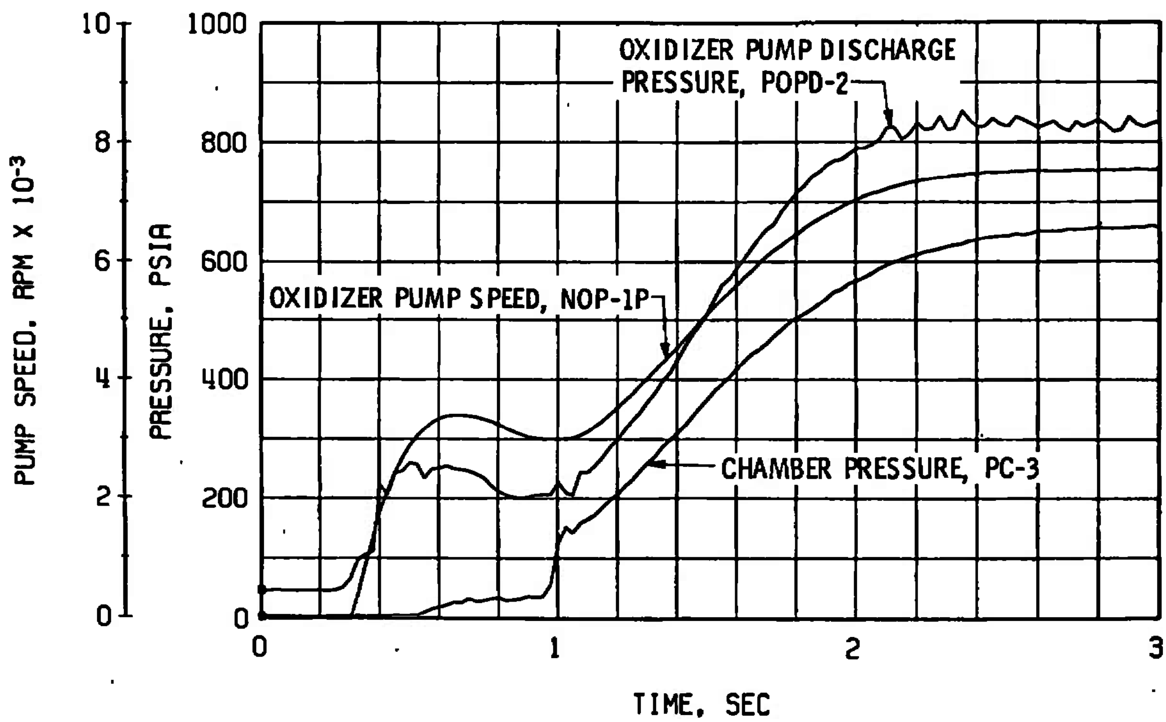


Fig. 25 Fuel Pump Start Transient Performance, Firing 18C

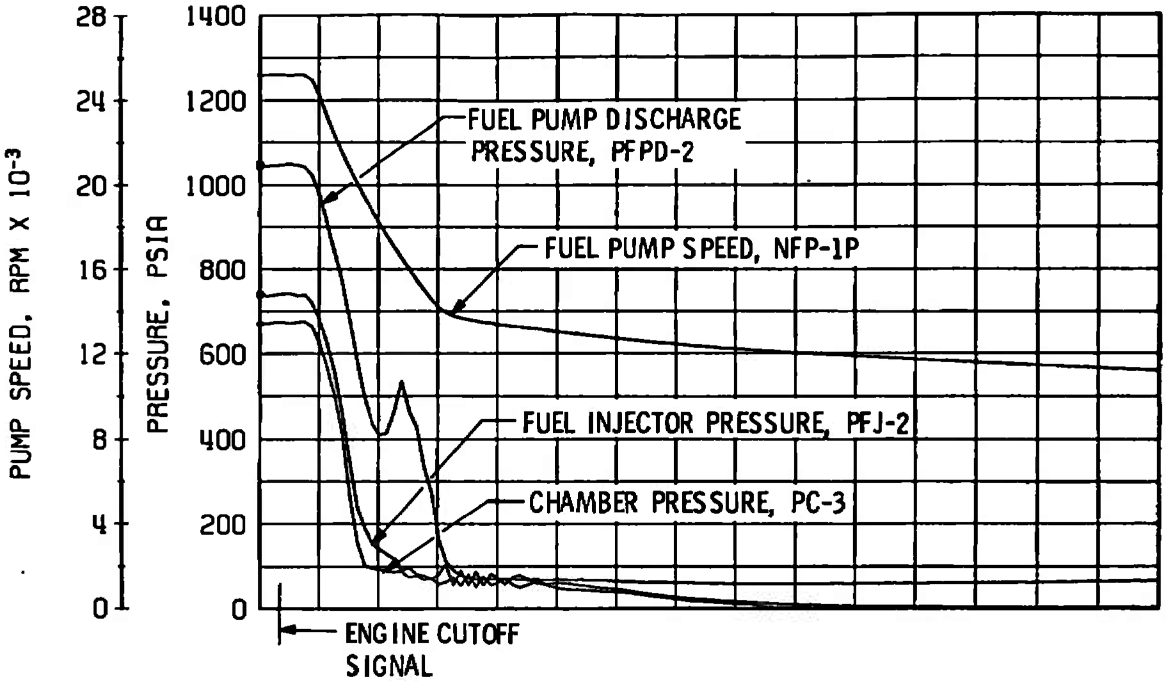


a. Thrust Chamber Fuel System, Start

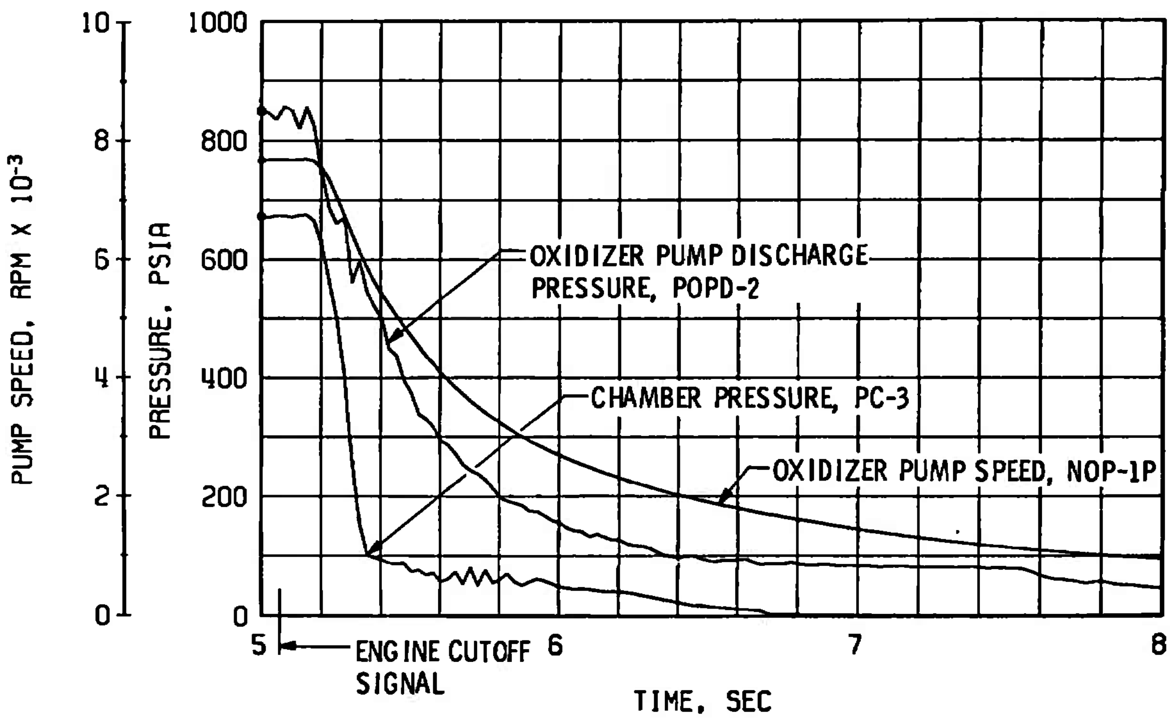


b. Thrust Chamber Oxidizer System, Start

Fig. 26 Engine Transient Operation, Firing 18D

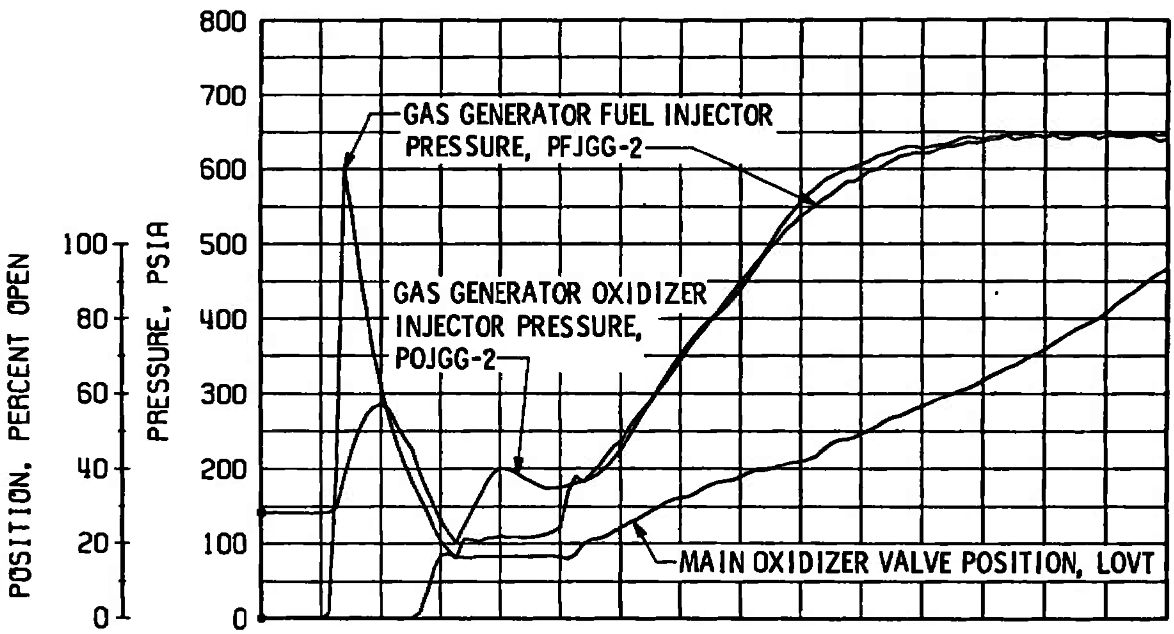


c. **Thrust Chamber Fuel System, Shutdown**

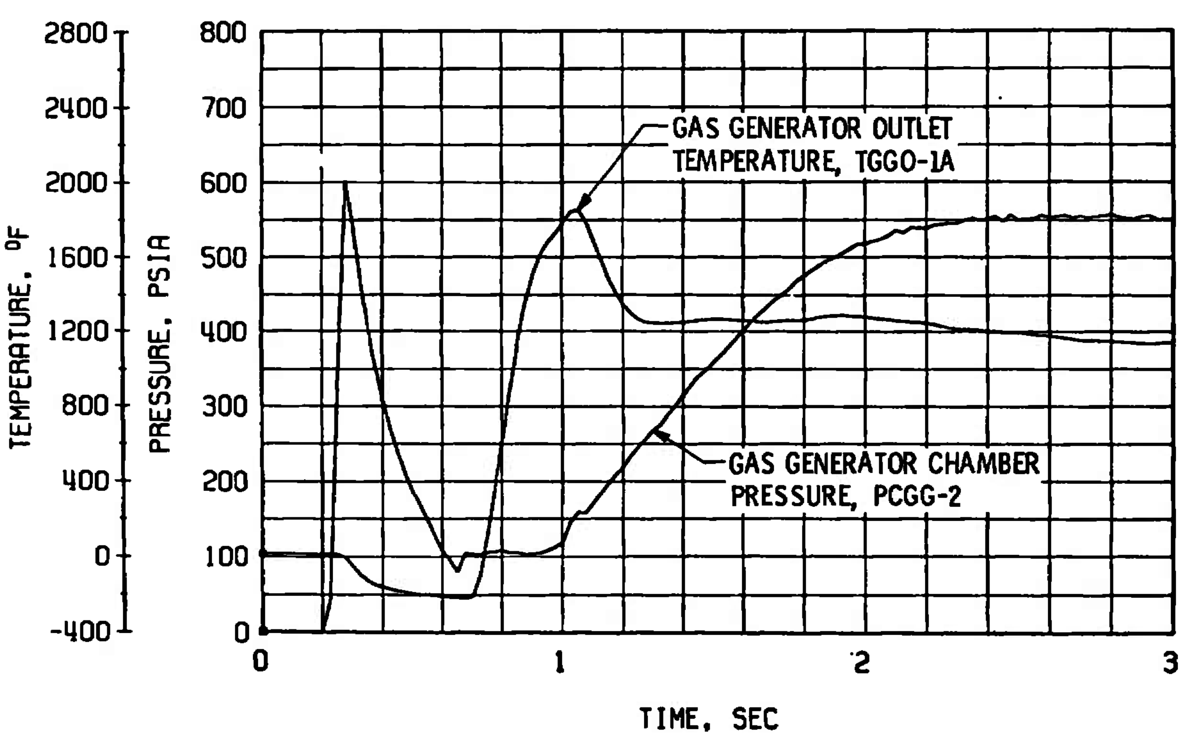


d. **Thrust Chamber Oxidizer System, Shutdown**

Fig. 26 Continued

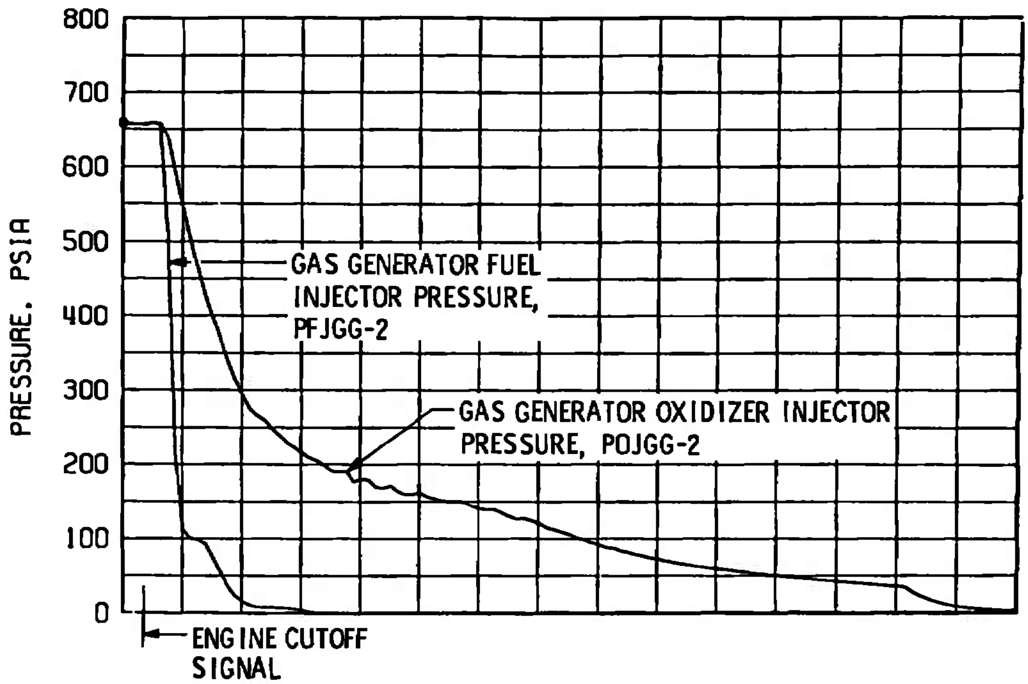


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

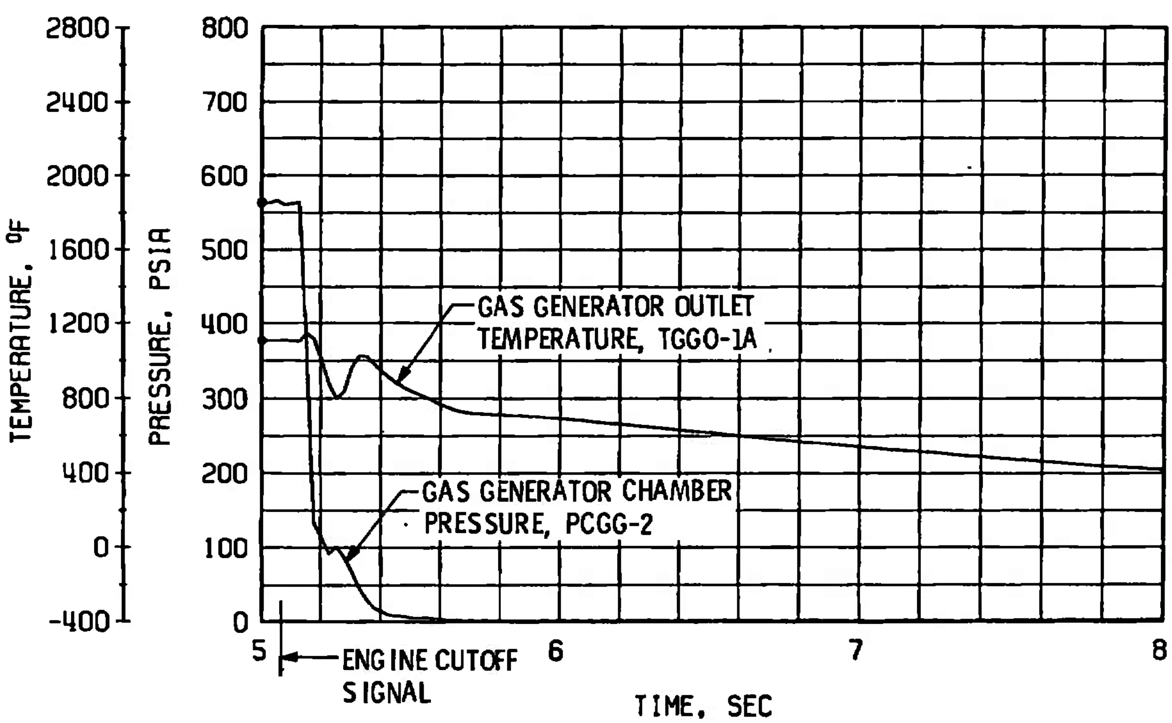


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 26 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 26 Concluded

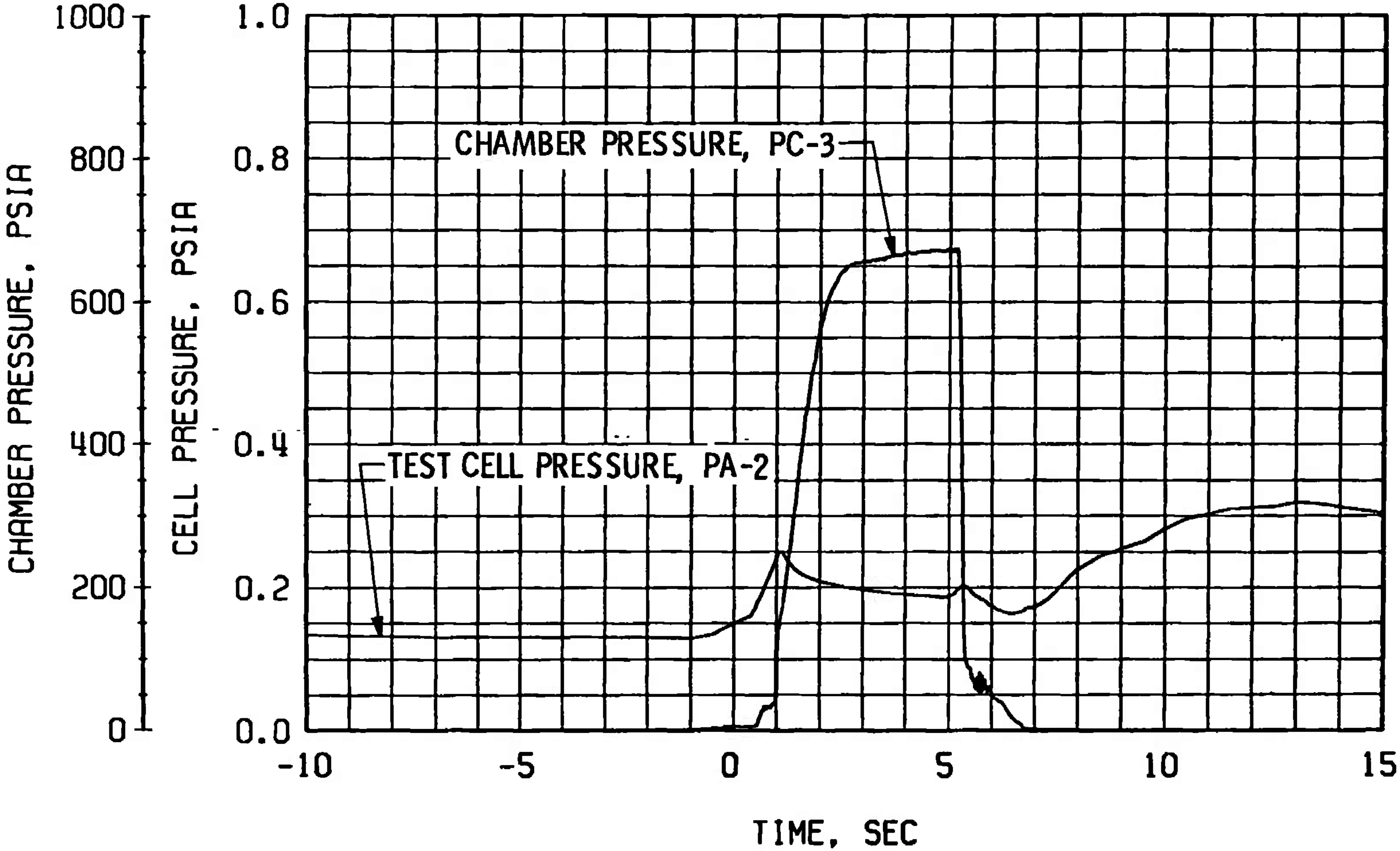
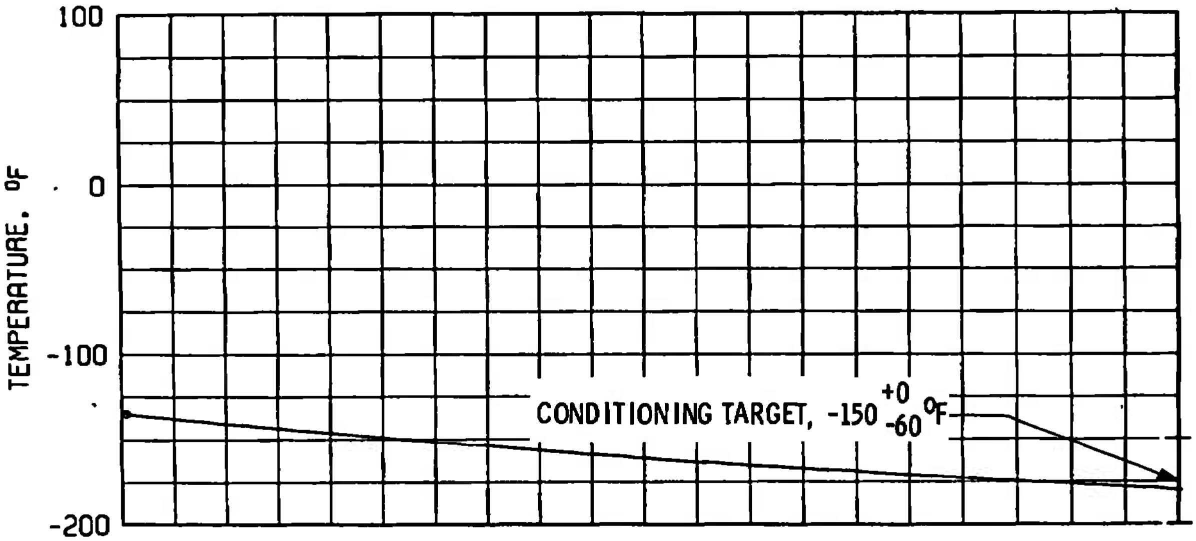
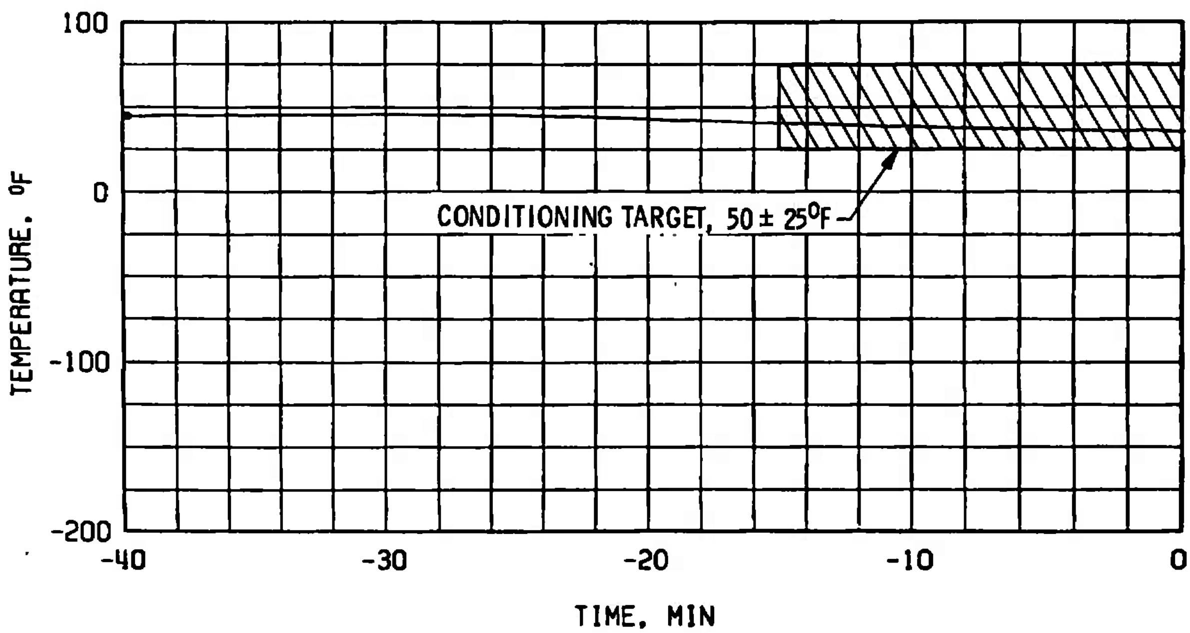


Fig. 27 Engine Ambient and Combustion Chamber Pressures, Firing 18D

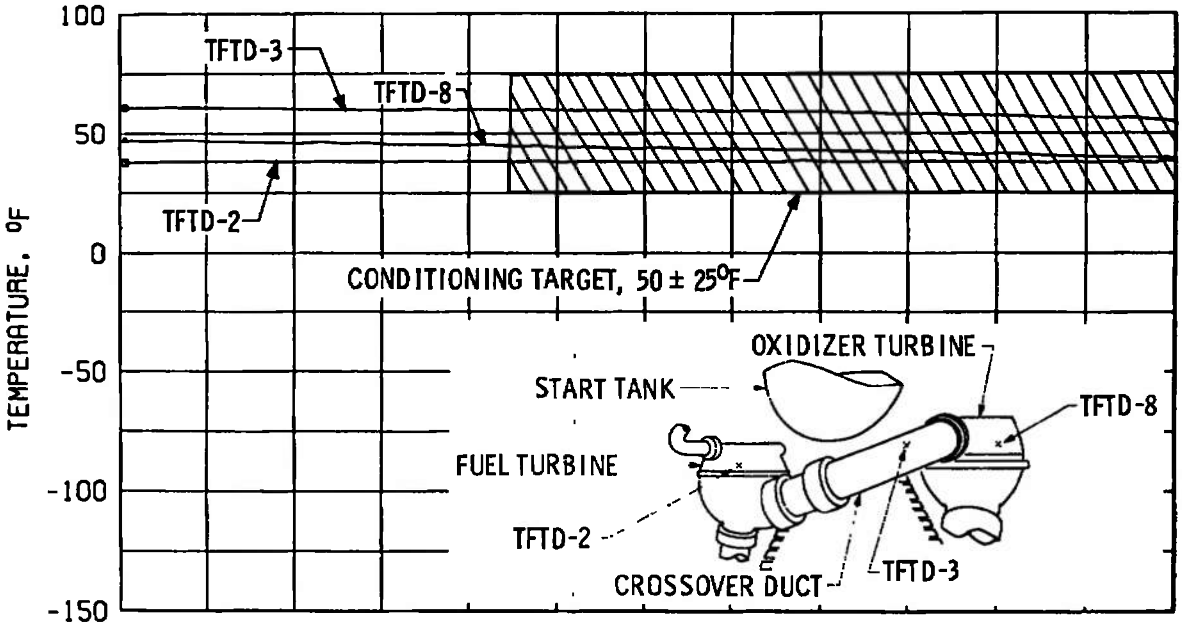


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

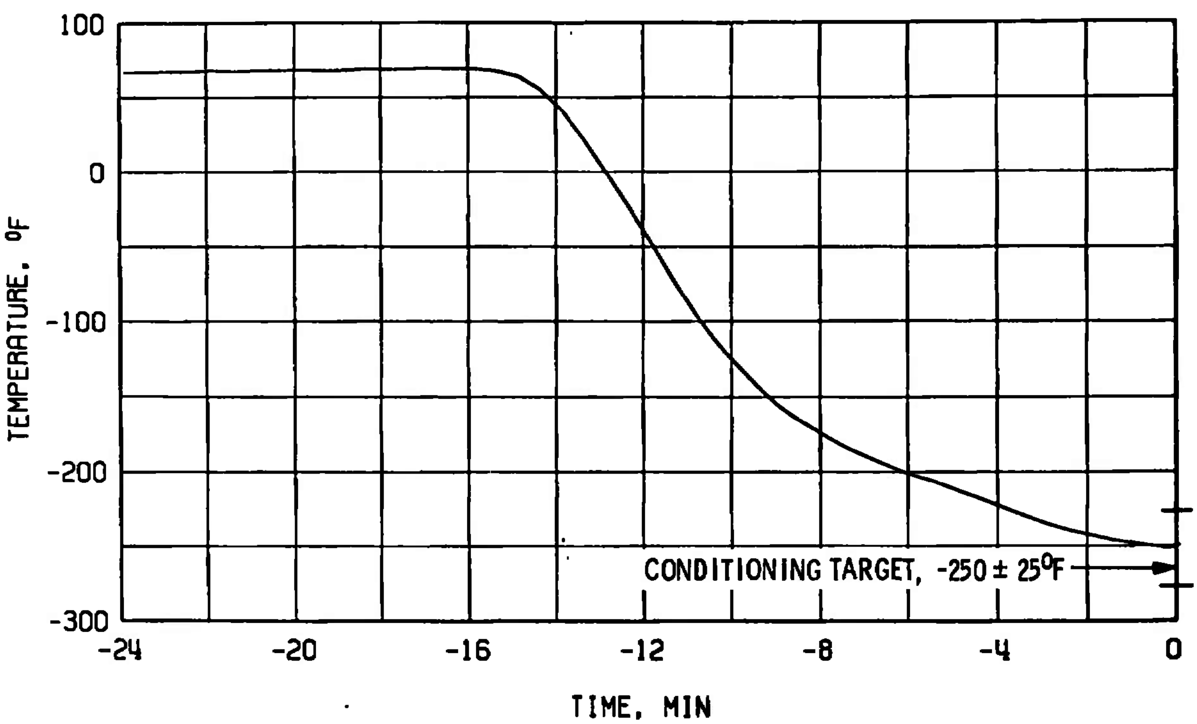


b. Start Tank Discharge Valve, TSTDVOC

Fig. 28 Thermal Conditioning History of Engine Components, Firing 18D



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 28 Concluded

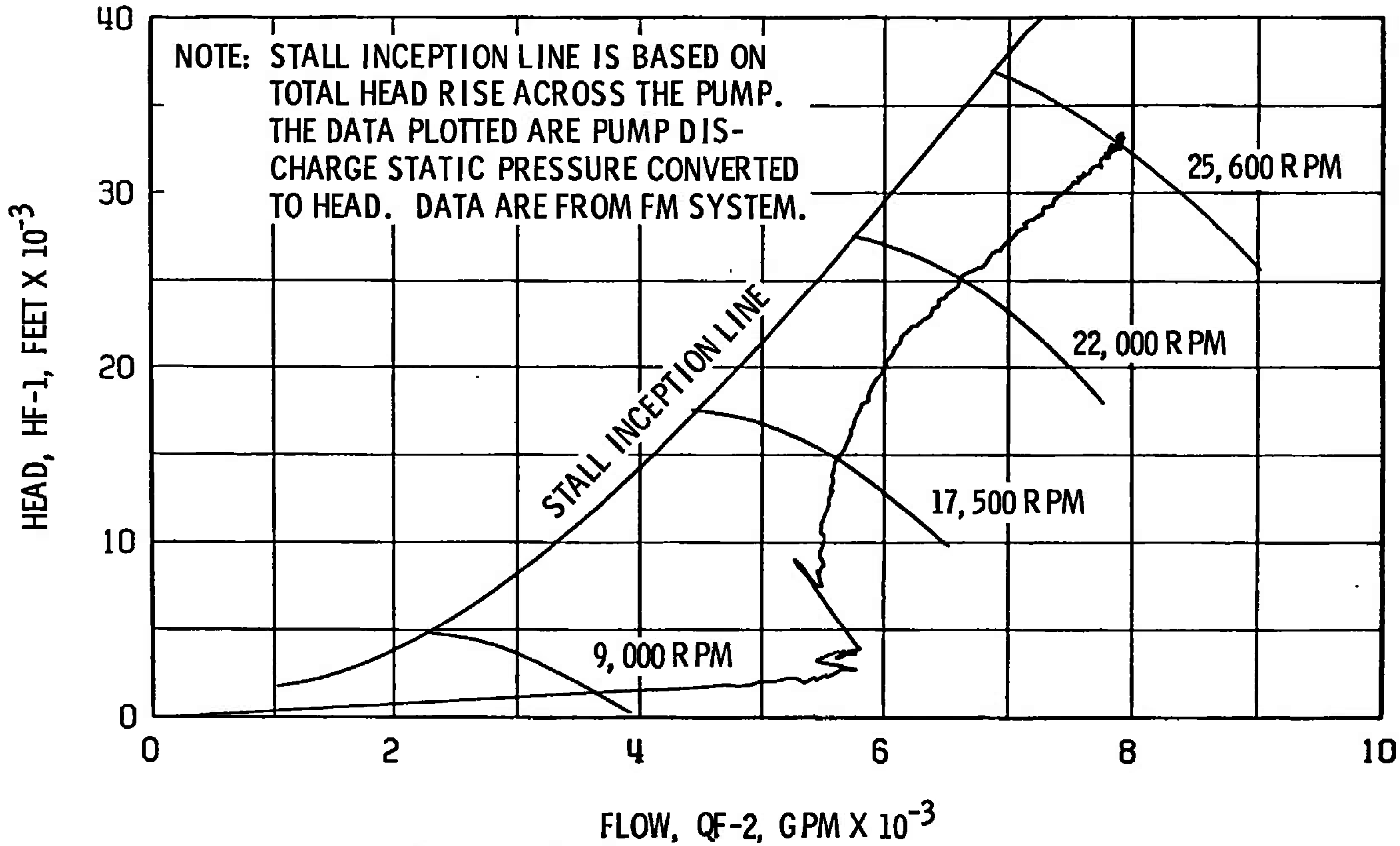
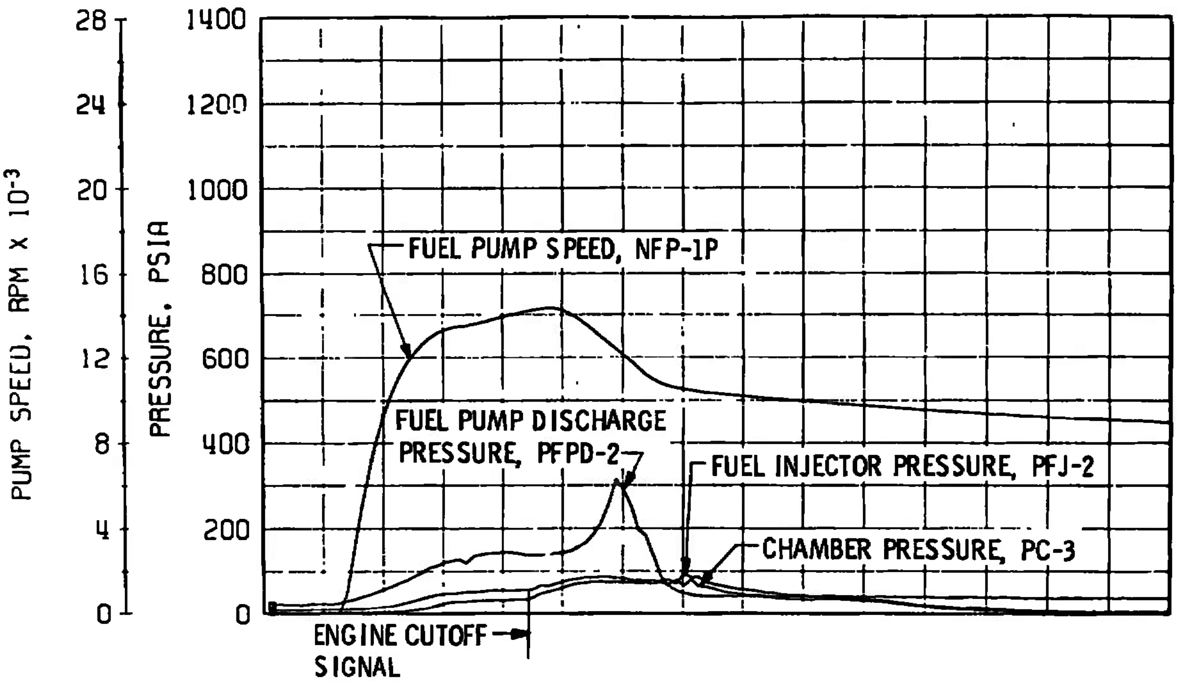
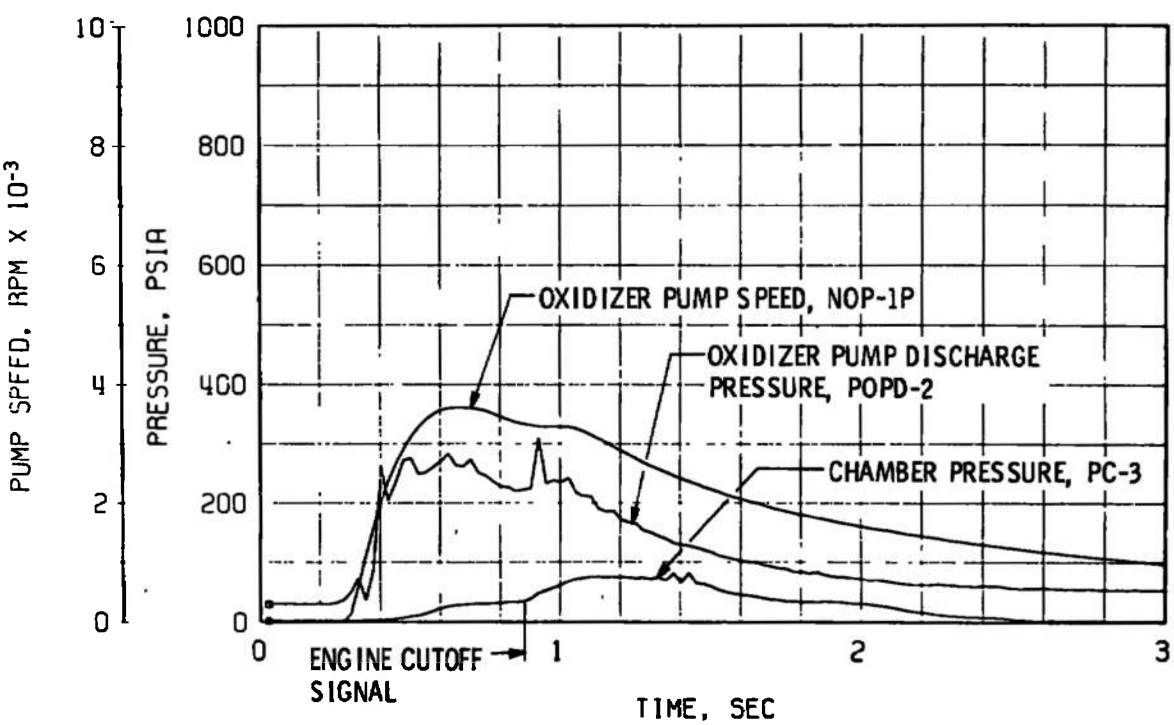


Fig. 29 Fuel Pump Start Transient Performance, Firing 18D

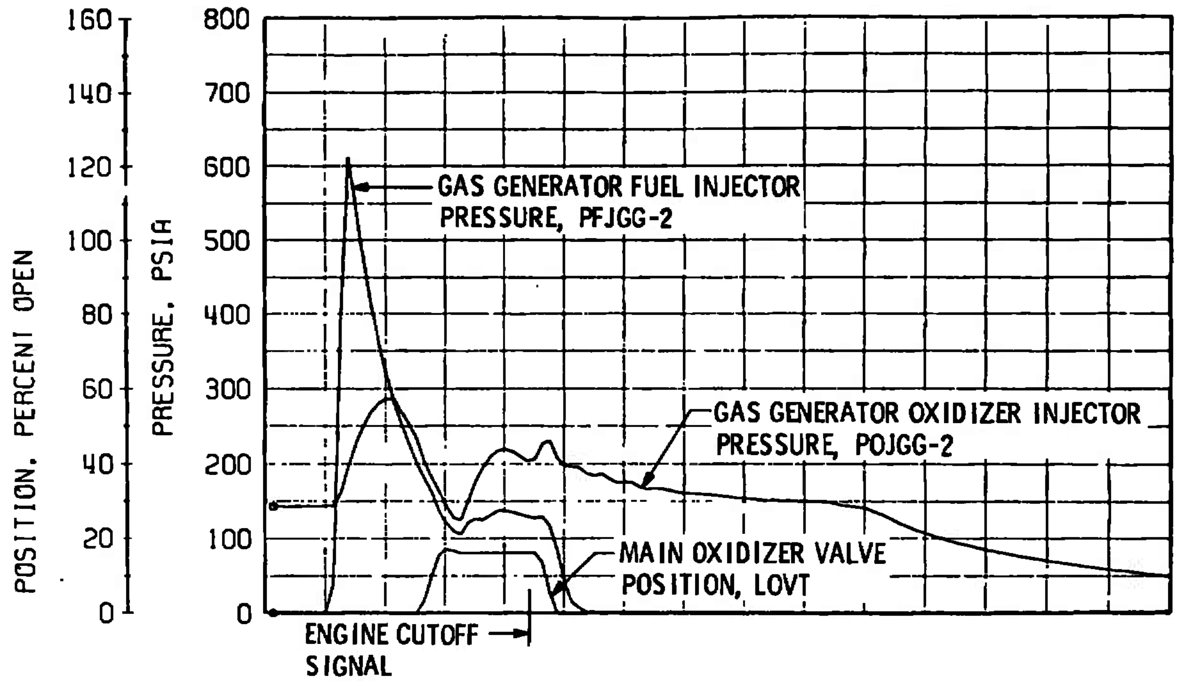


a. Thrust Chamber Fuel System

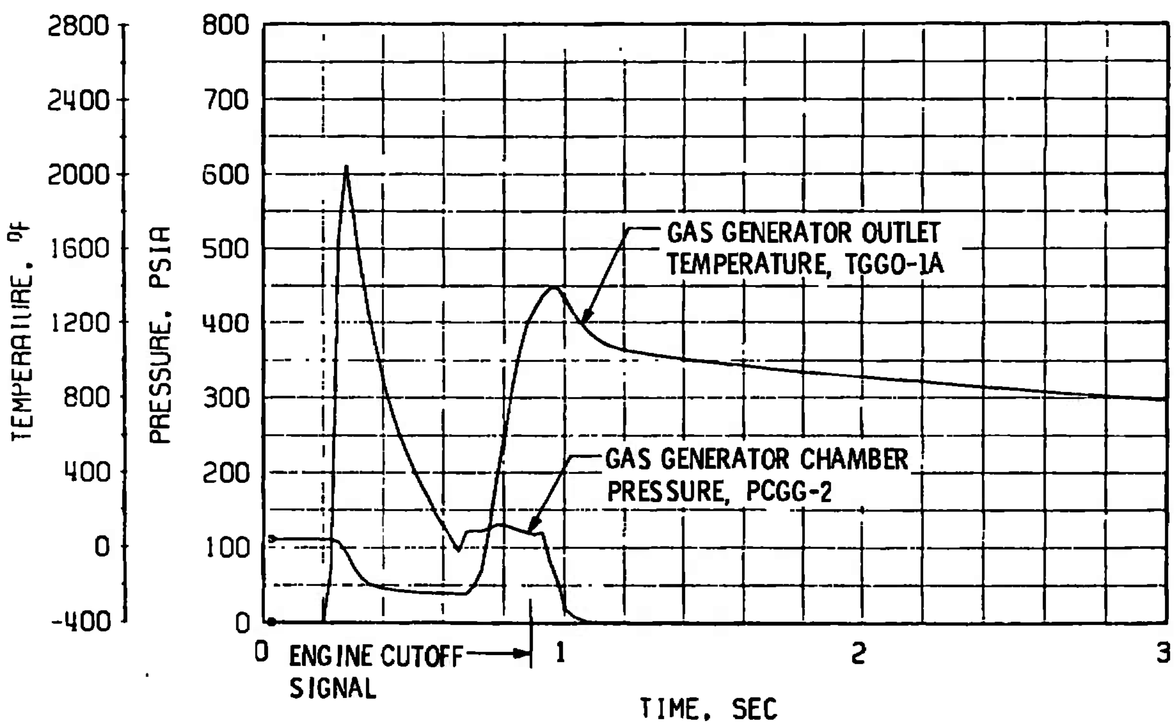


b. Thrust Chamber Oxidizer System

Fig. 30 Engine Transient Operation, Firing 18E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position



d. Gas Generator Chamber Pressure and Temperature

Fig. 30 Concluded

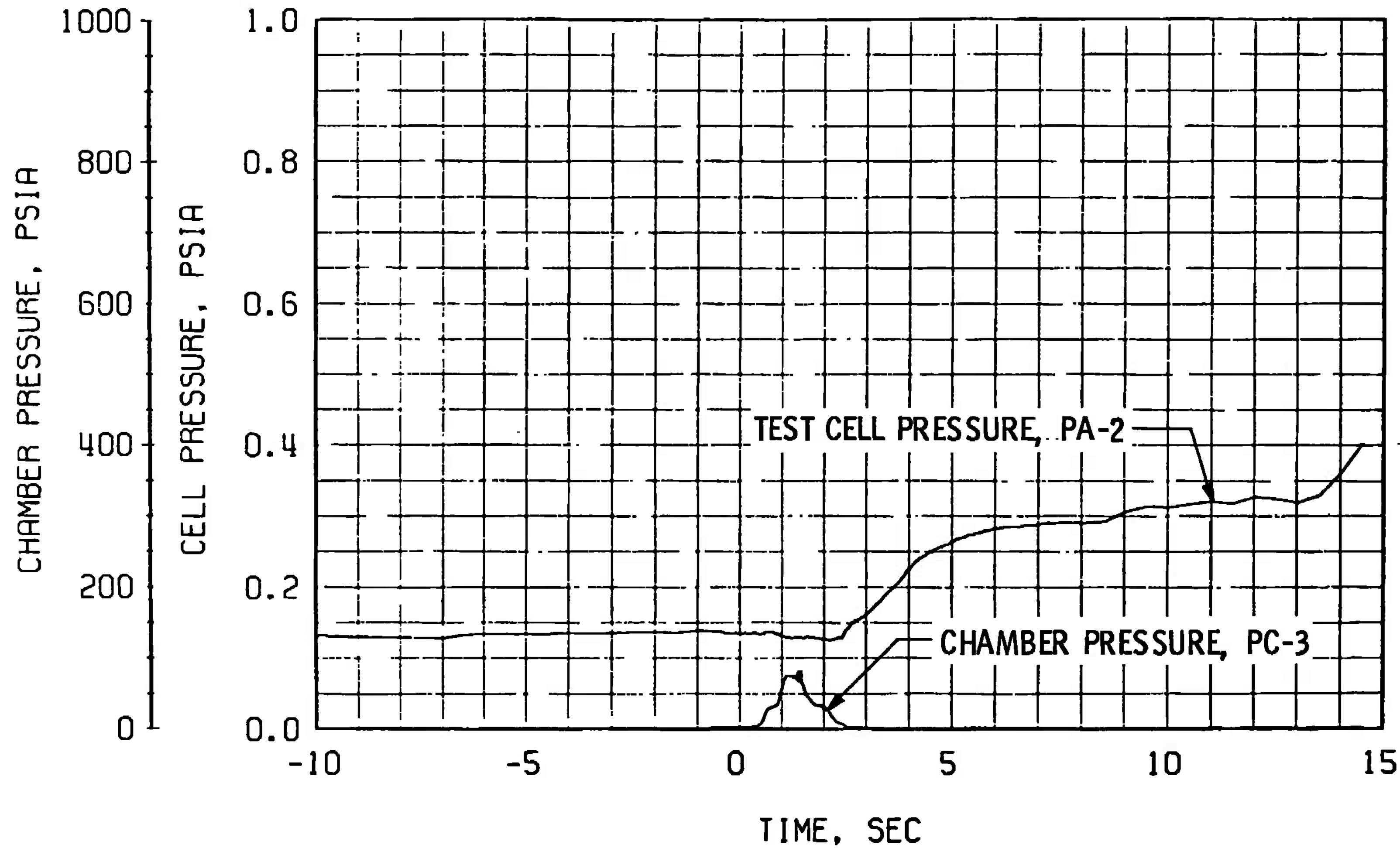
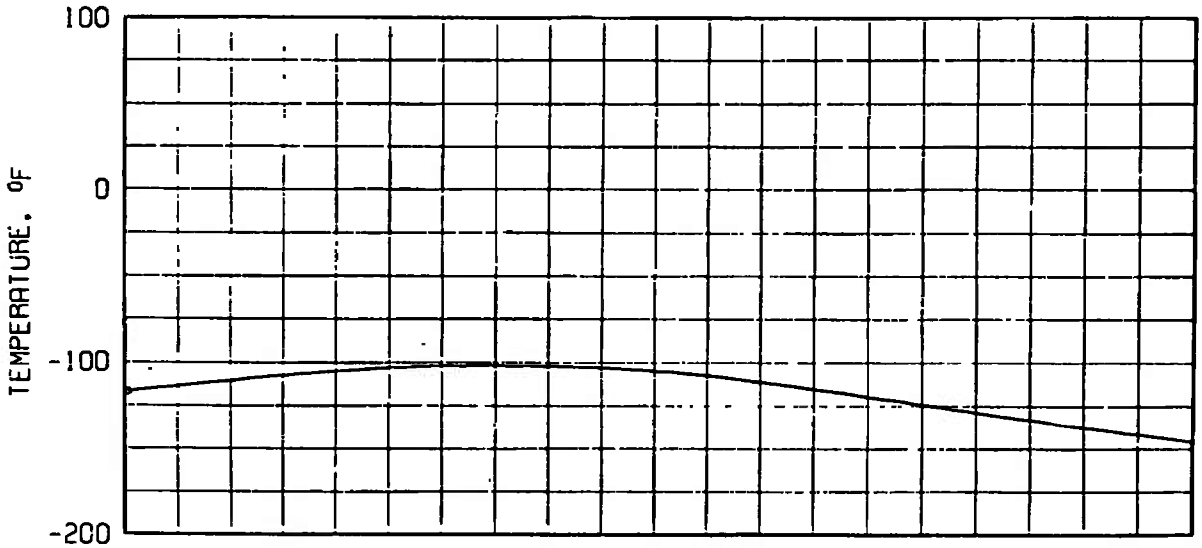
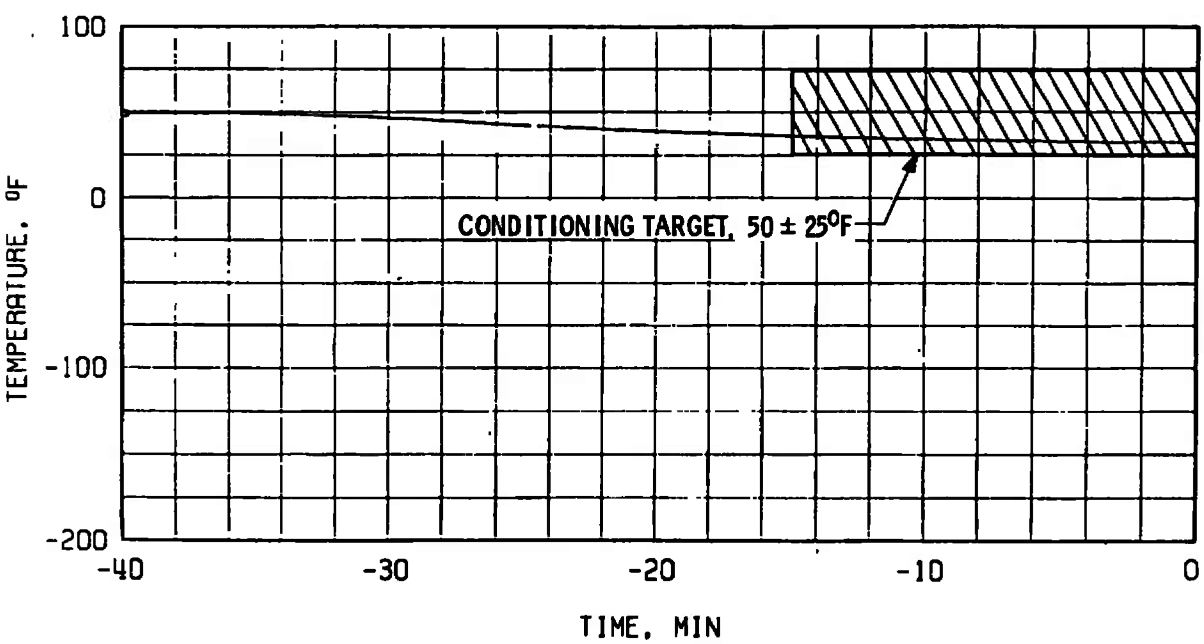


Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 18E

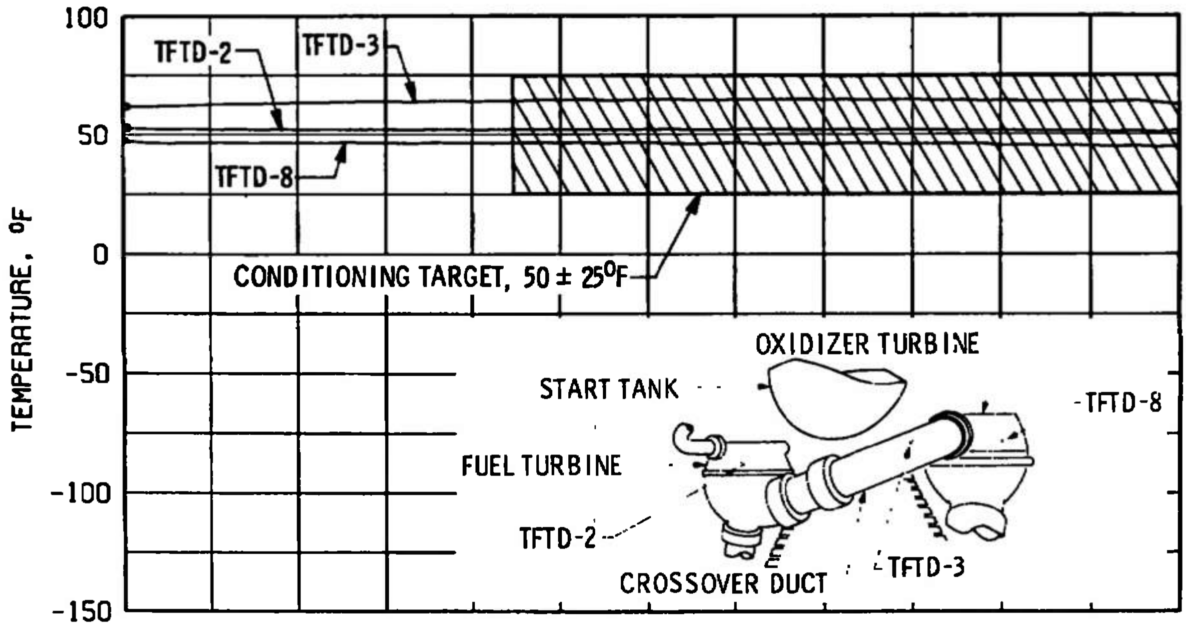


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

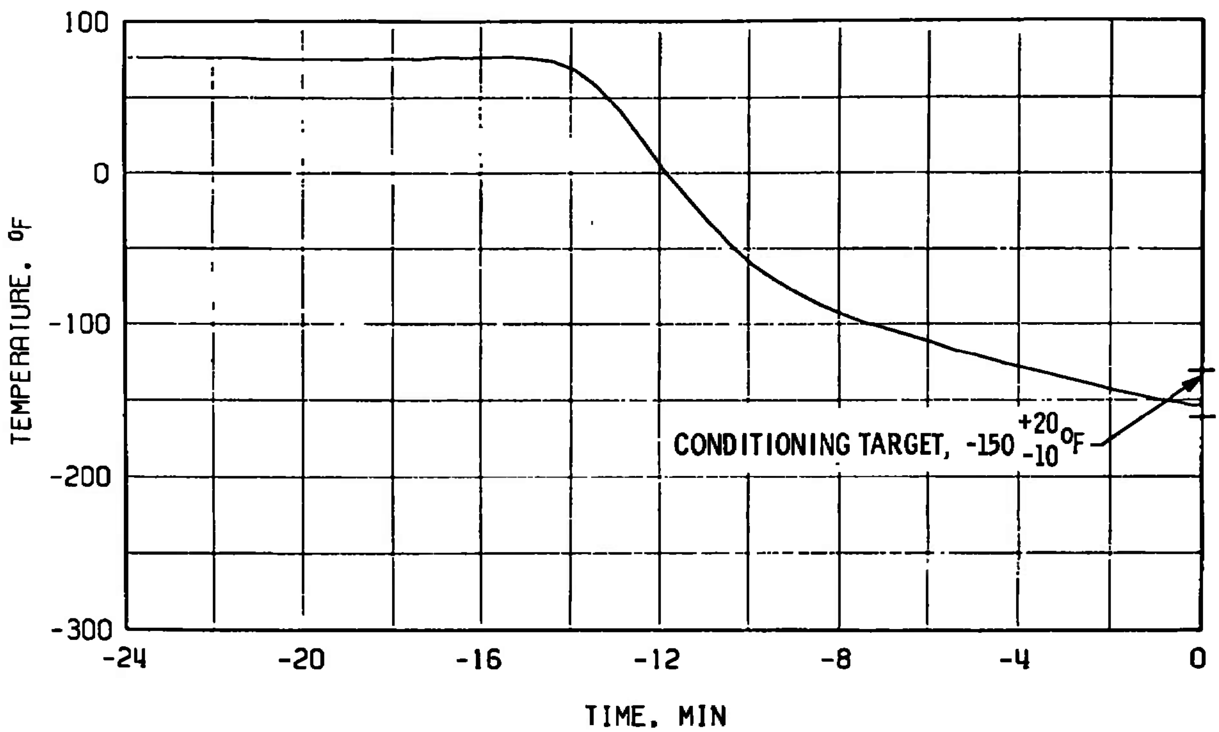


b. Start Tank Discharge Valve, TSTDVOC

Fig. 32 Thermal Conditioning History of Engine Components, Firing 18E



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 32 Concluded

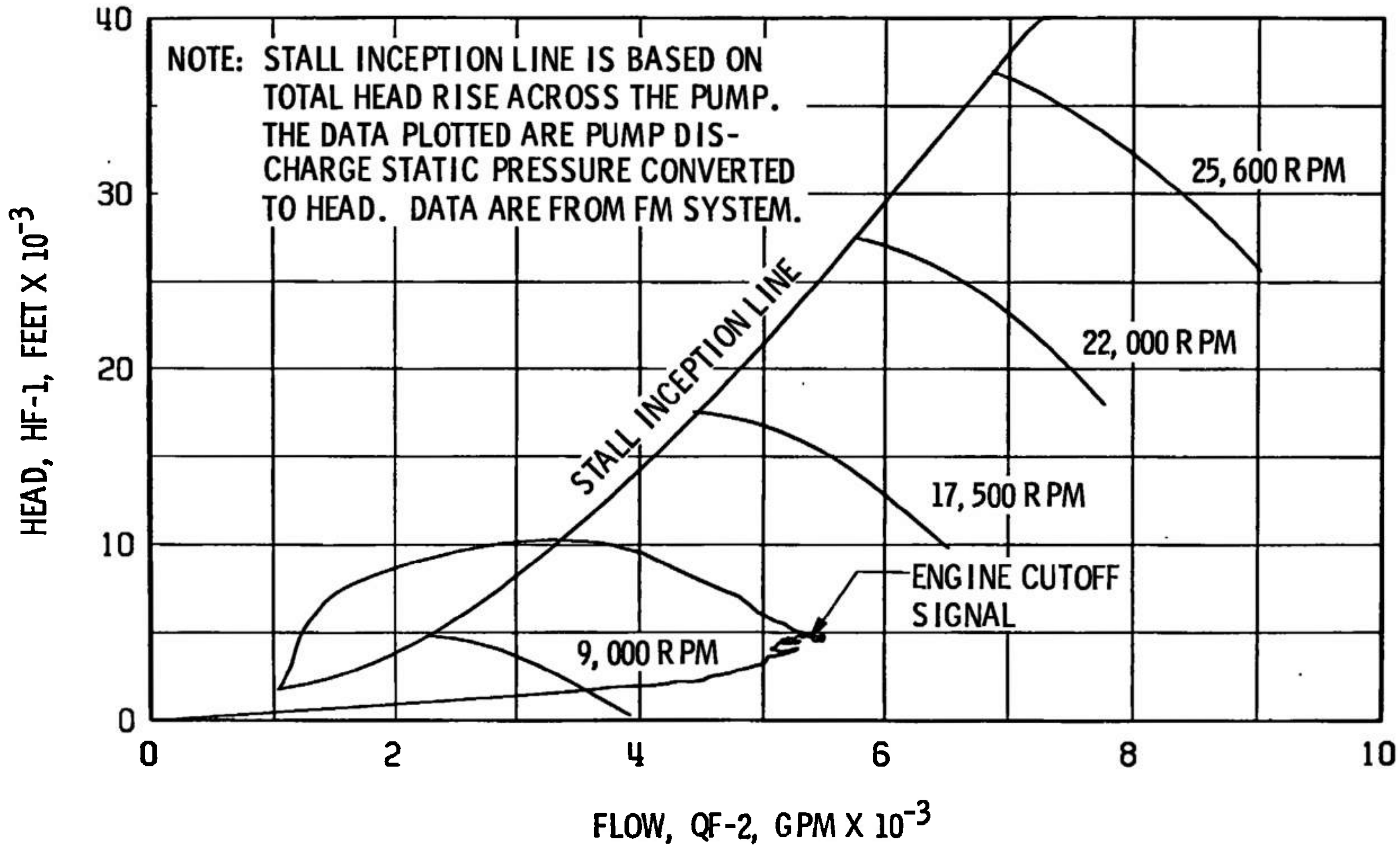
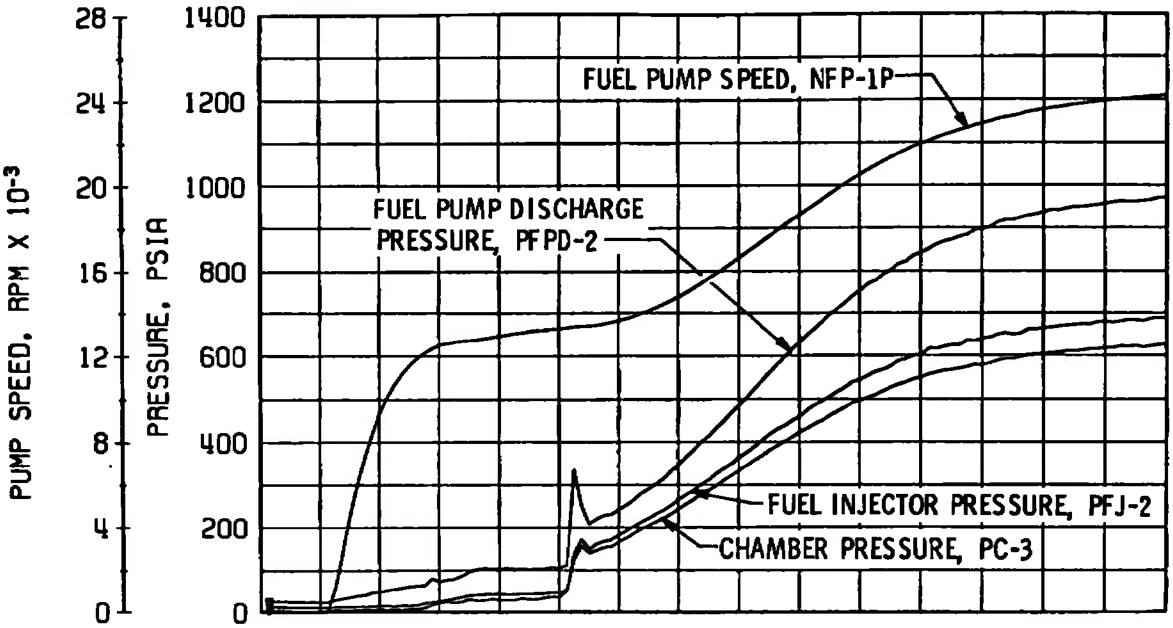
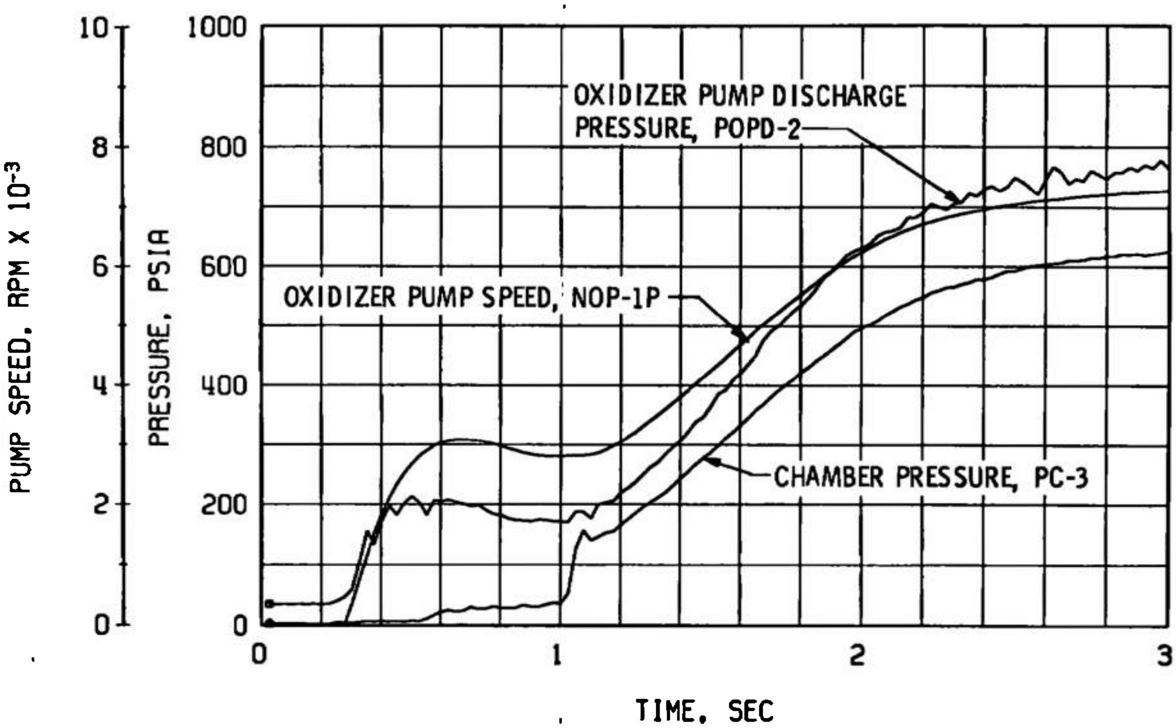


Fig. 33 Fuel Pump Start Transient Performance, Firing 18E

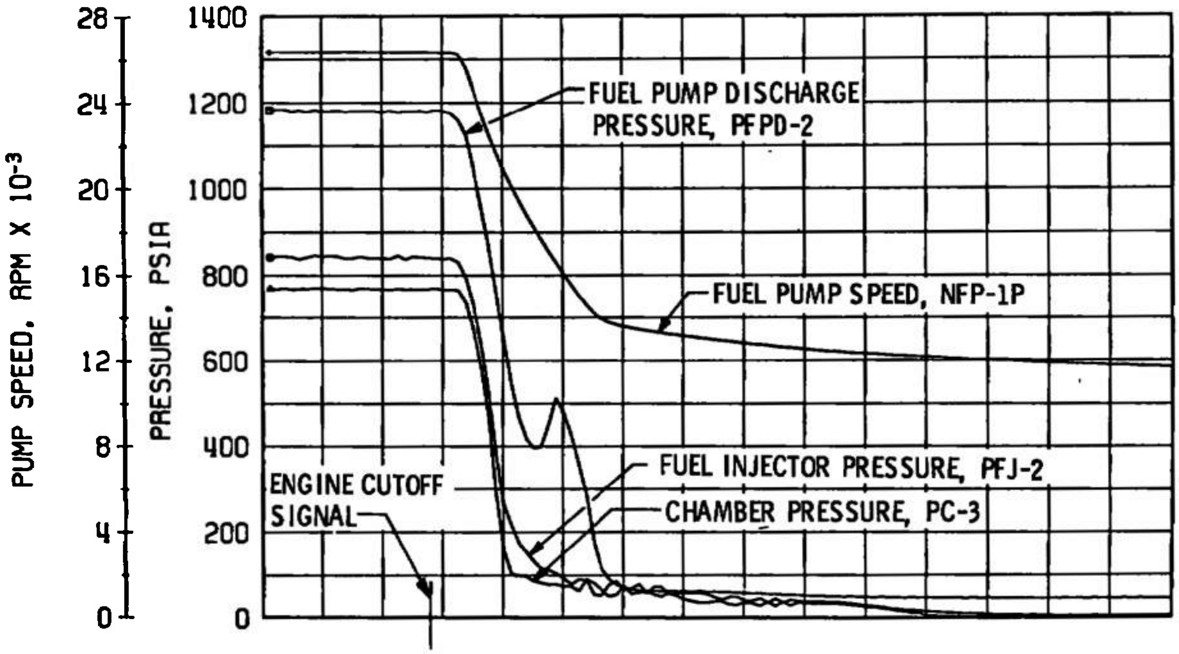


a. Thrust Chamber Fuel System, Start

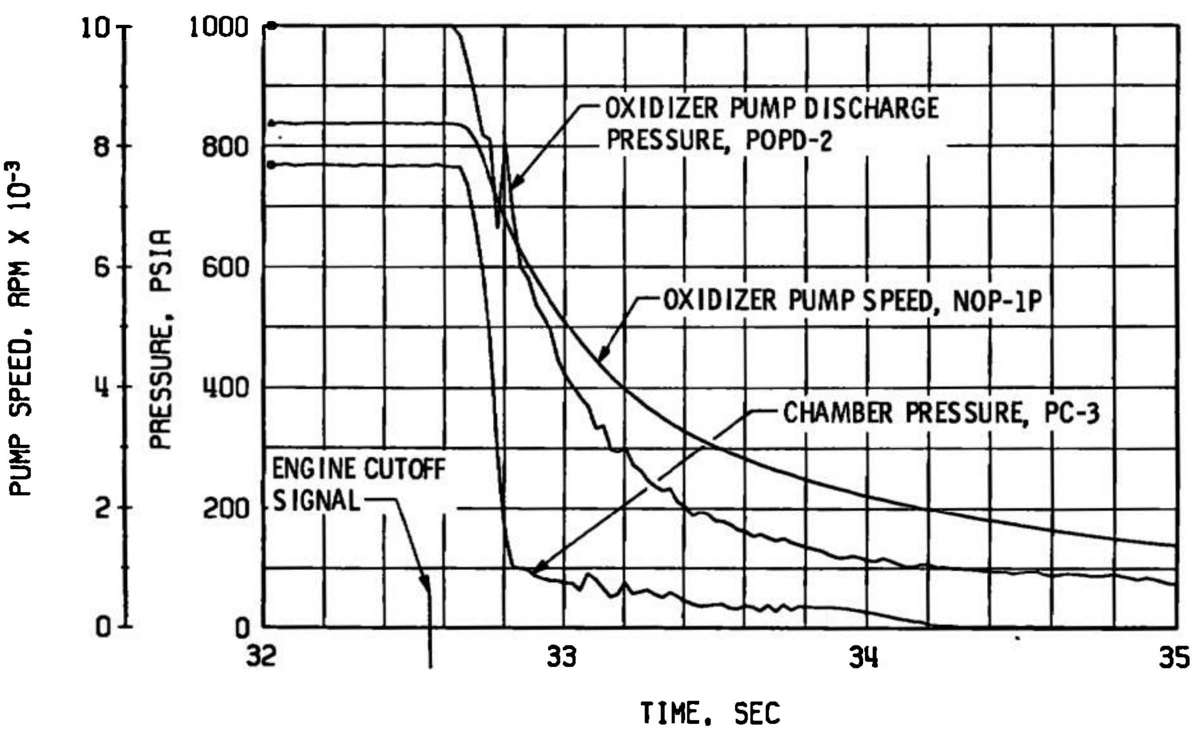


b. Thrust Chamber Oxidizer System, Start

Fig. 34 Engine Transient Operation, Firing 19A

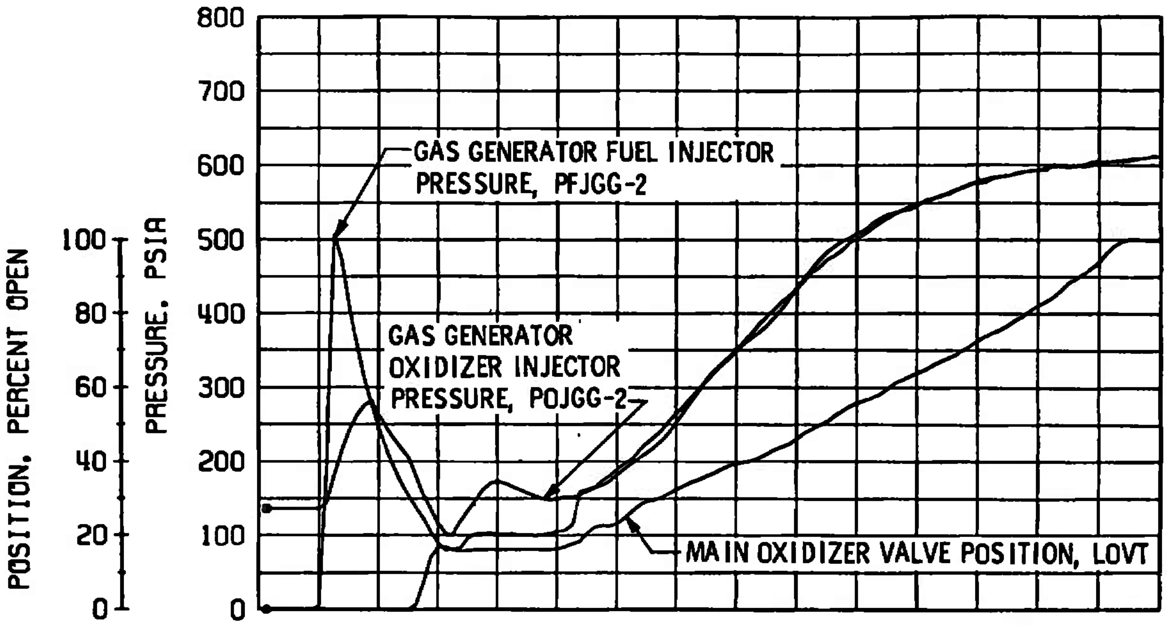


c. Thrust Chamber Fuel System, Shutdown

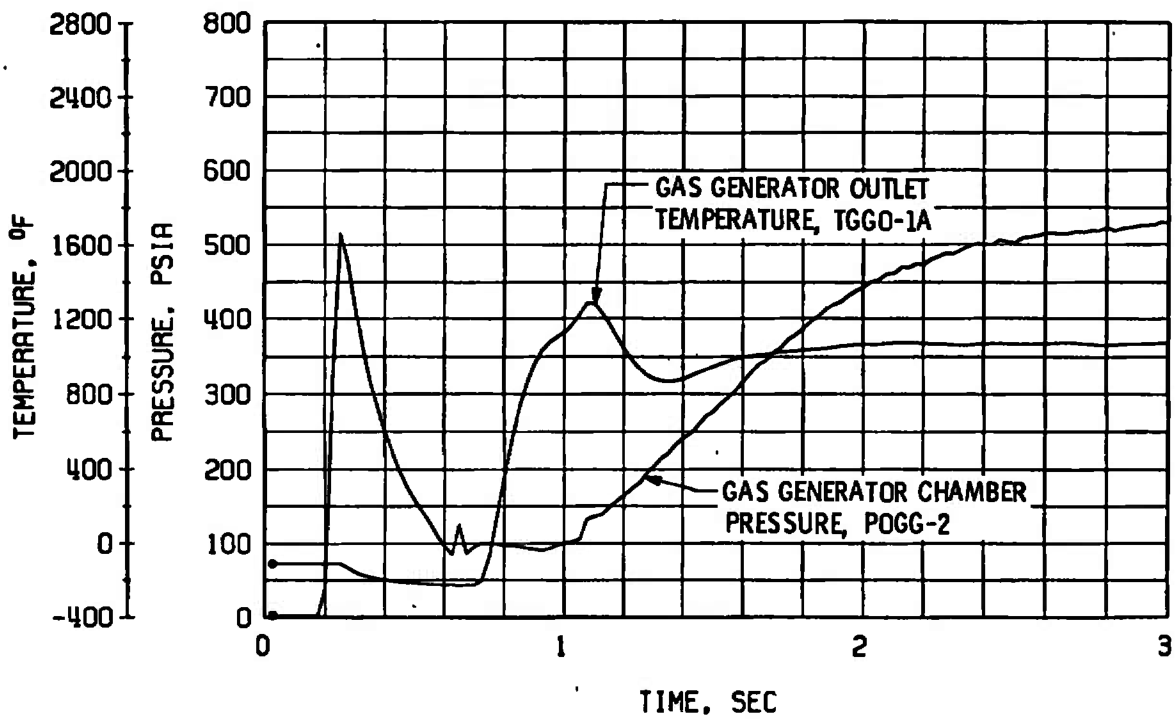


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 34 Continued

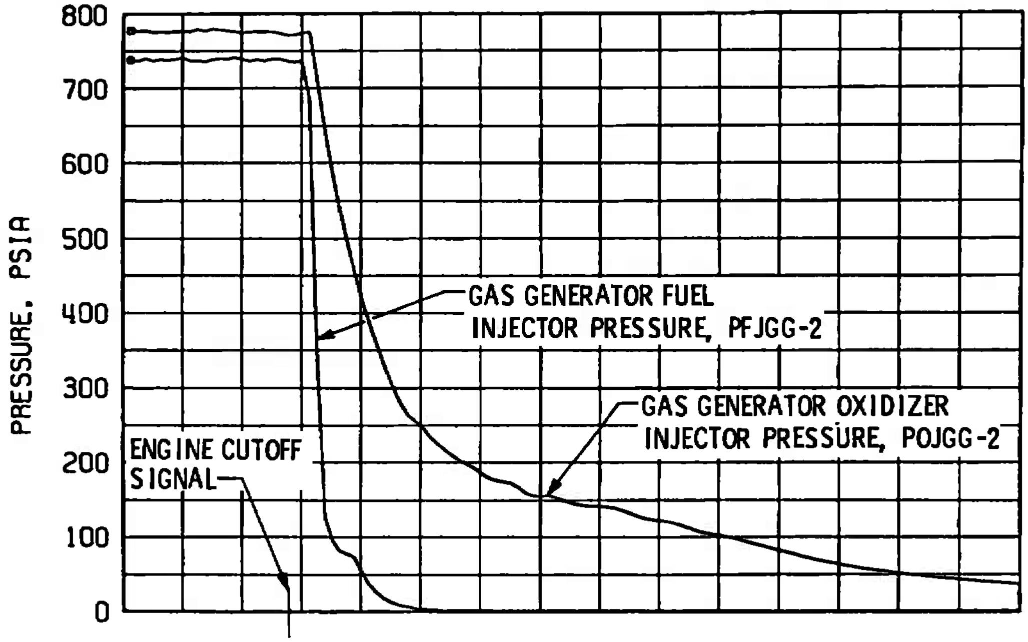


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

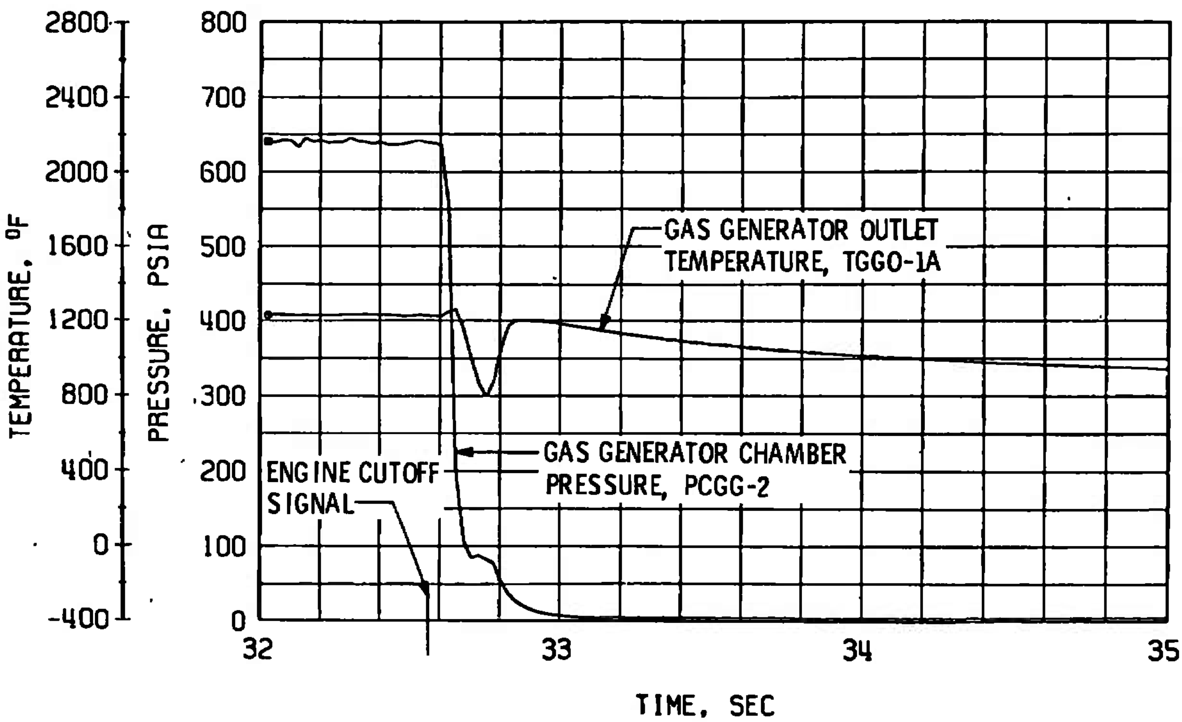


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 34 Continued

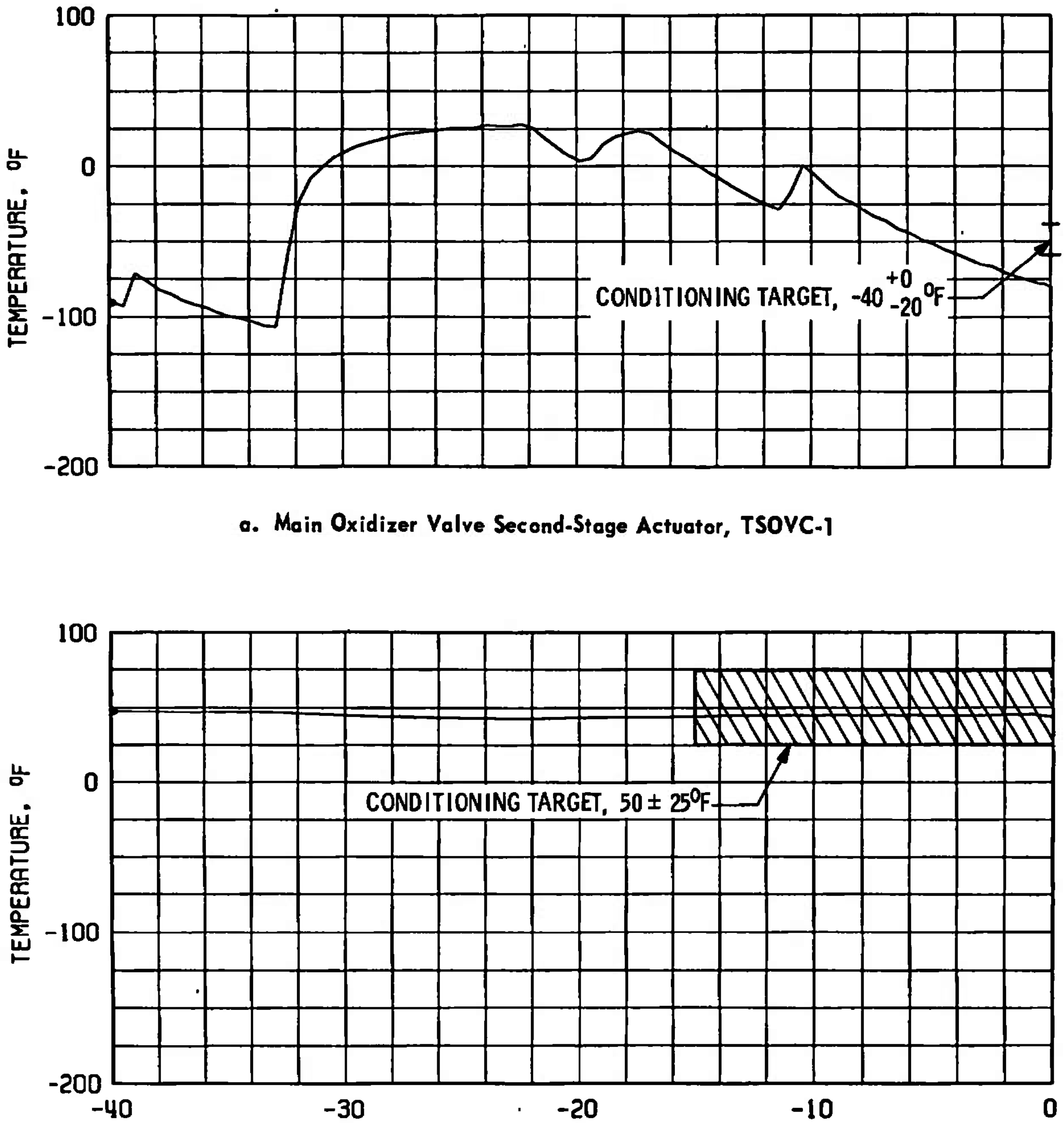


g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

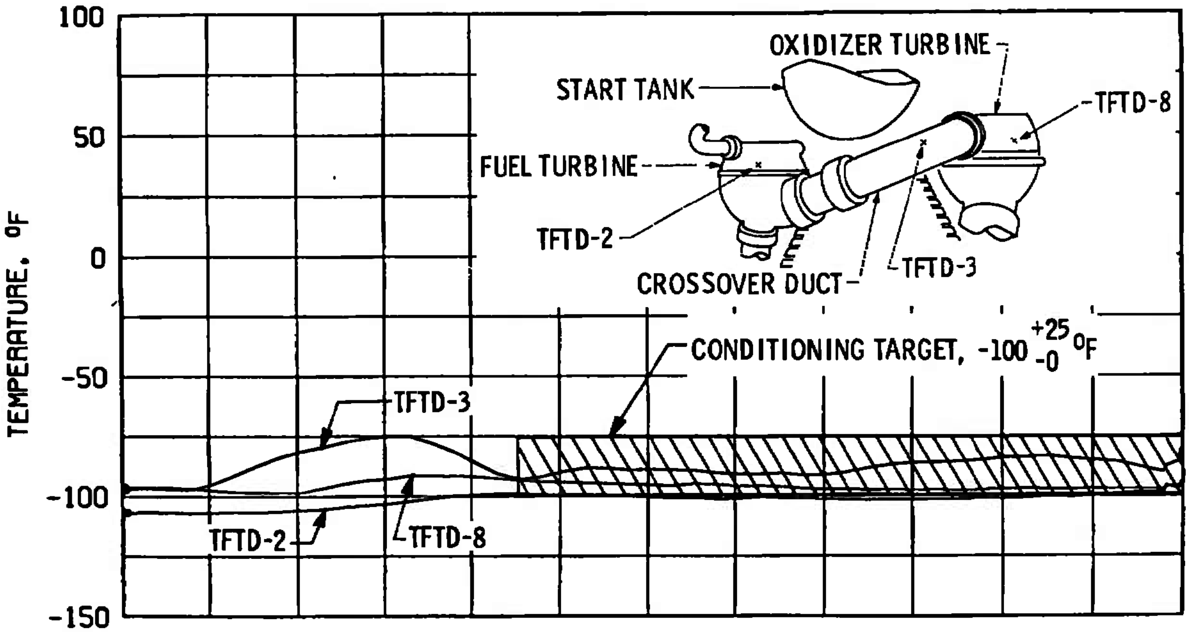
Fig. 34 Concluded



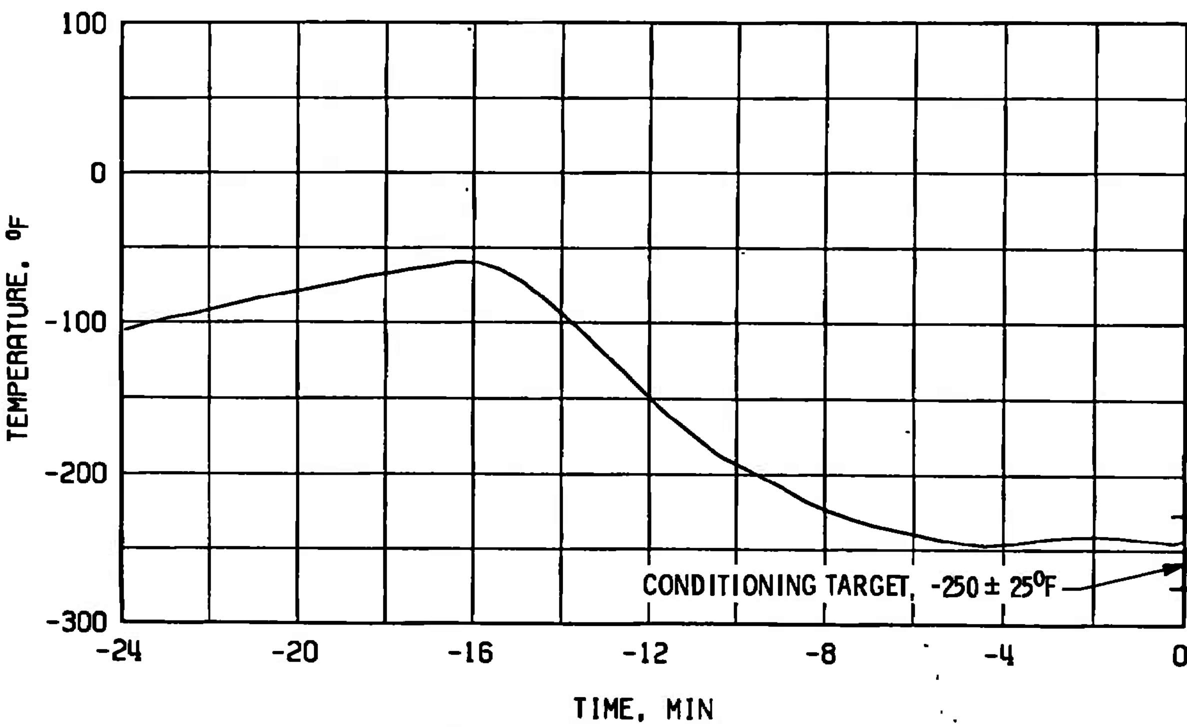
a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

b. Start Tank Discharge Valve, TSTDVOC

Fig. 35 Thermal Conditioning History of Engine Components, Firing 19A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 35 Concluded

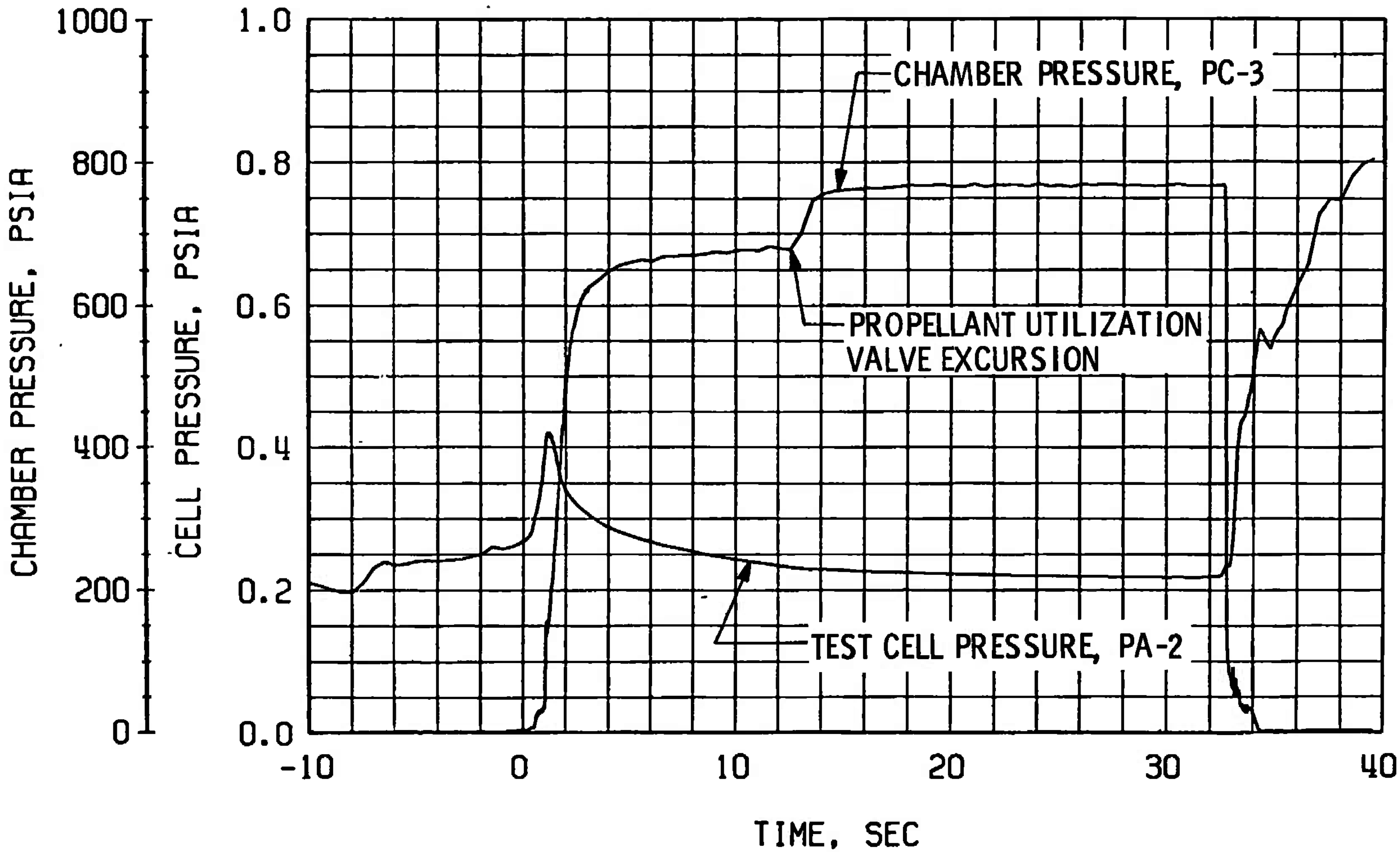


Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 19A

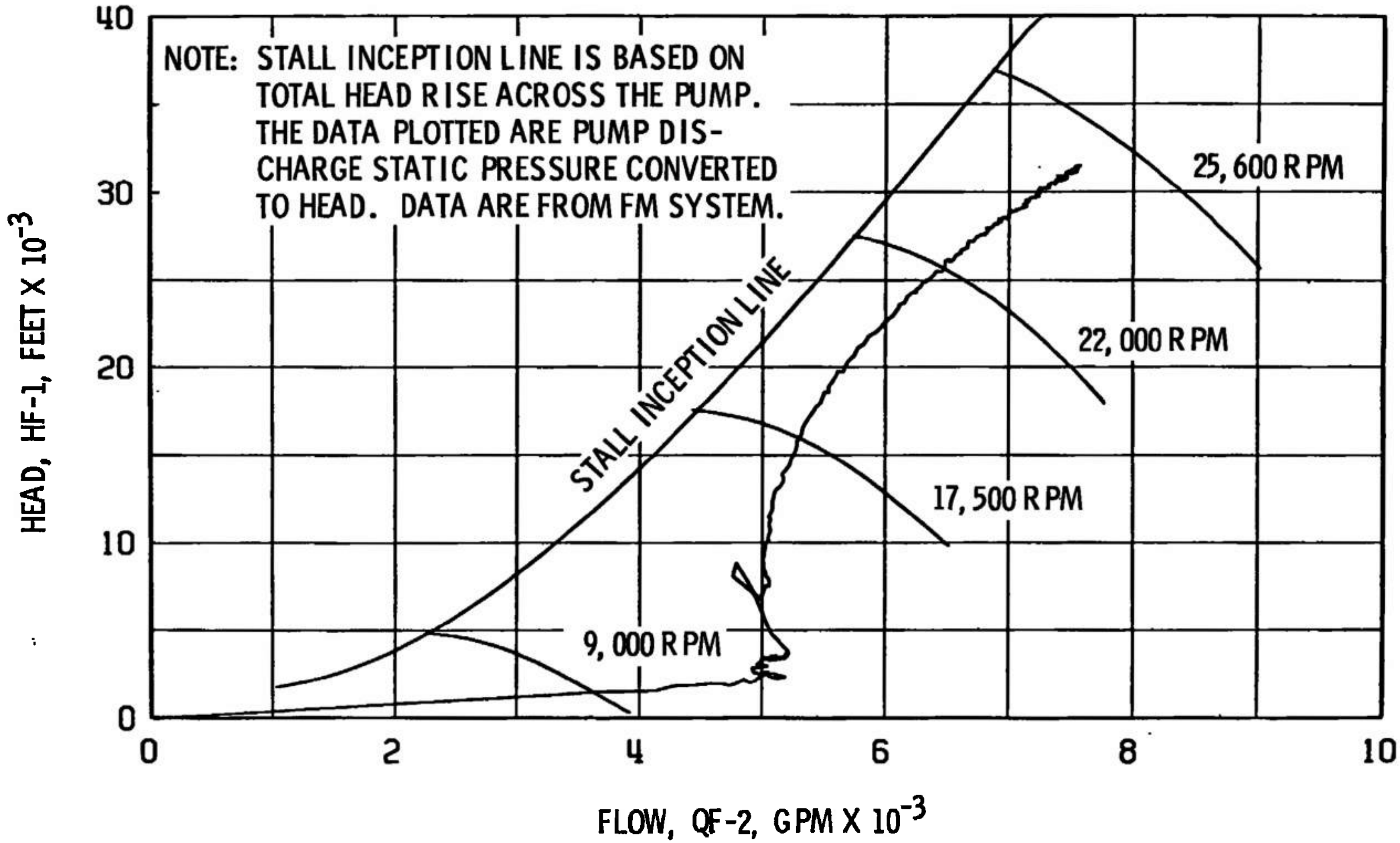
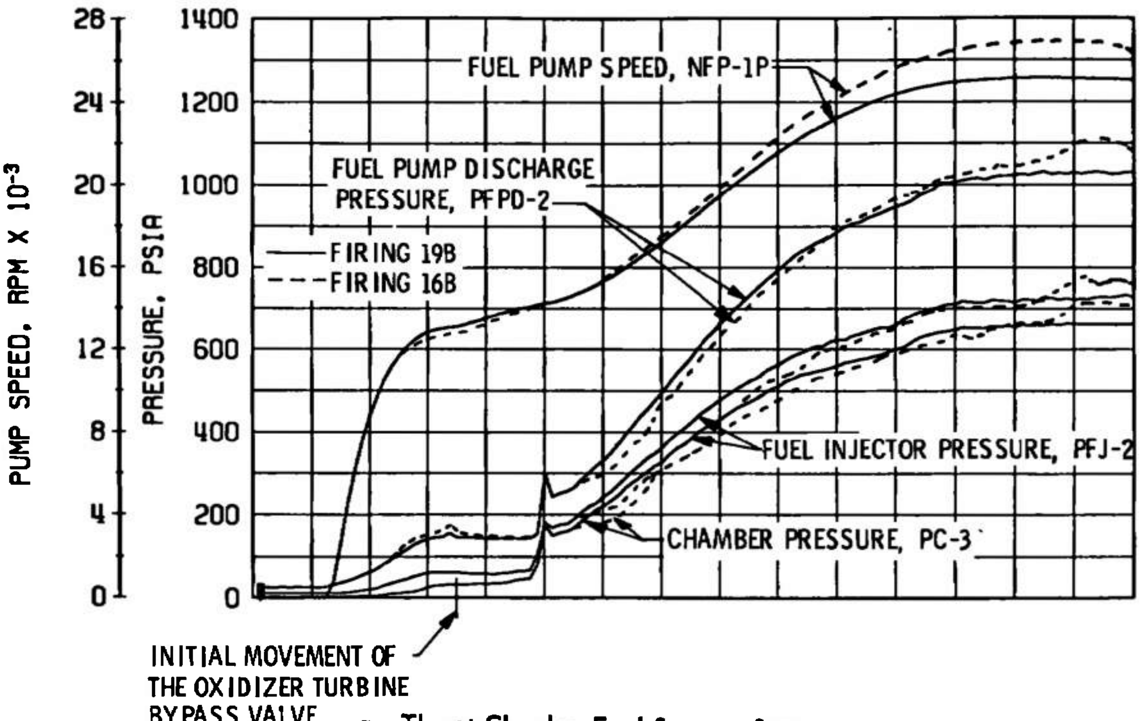
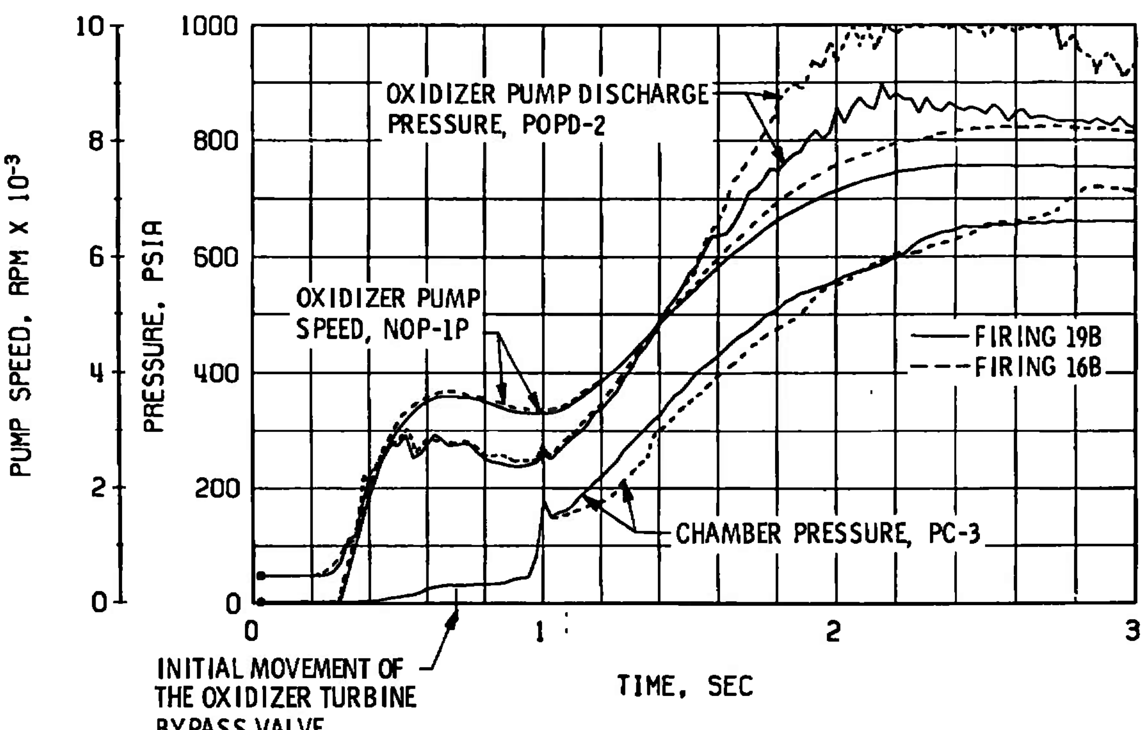


Fig. 37 Fuel Pump Start Transient Performance, Firing 19A

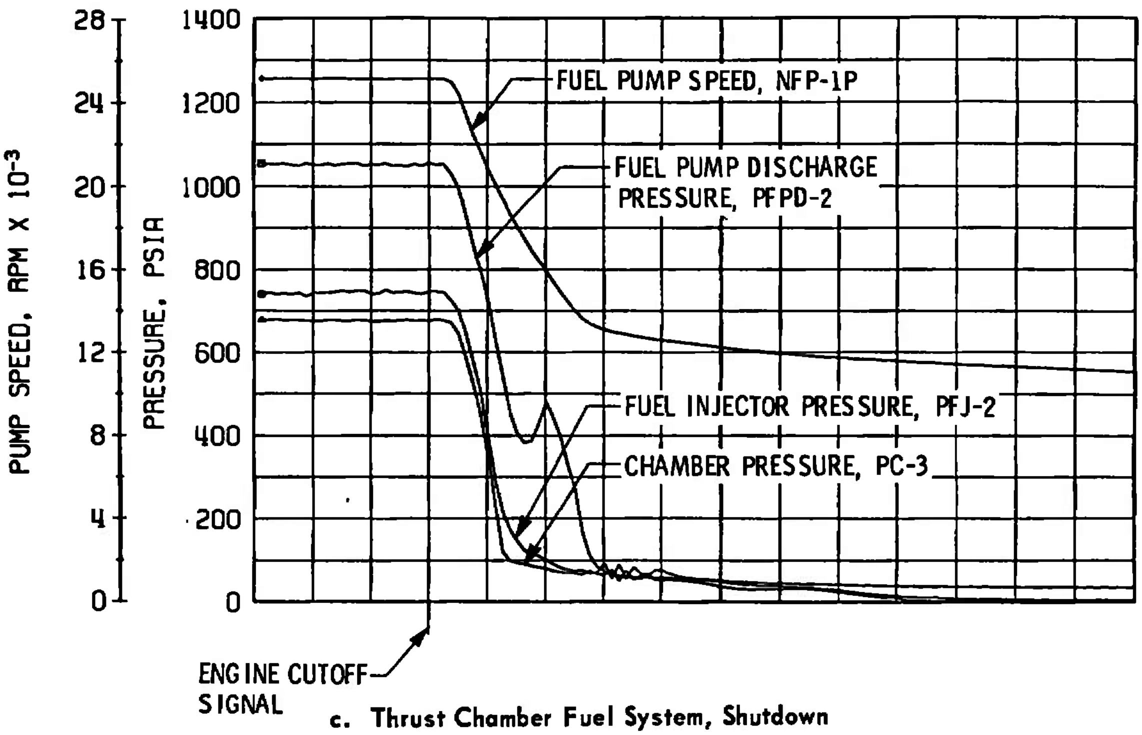


a. Thrust Chamber Fuel System, Start

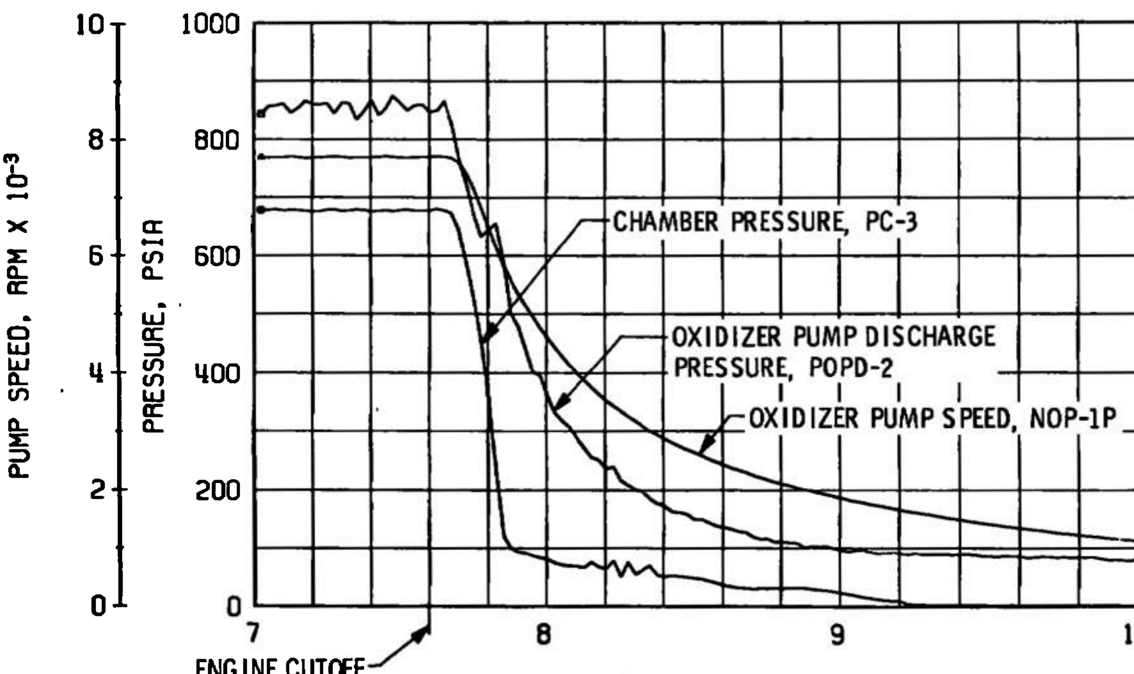


b. Thrust Chamber Oxidizer System, Start

Fig. 38 Engine Transient Operation, Firing 19B

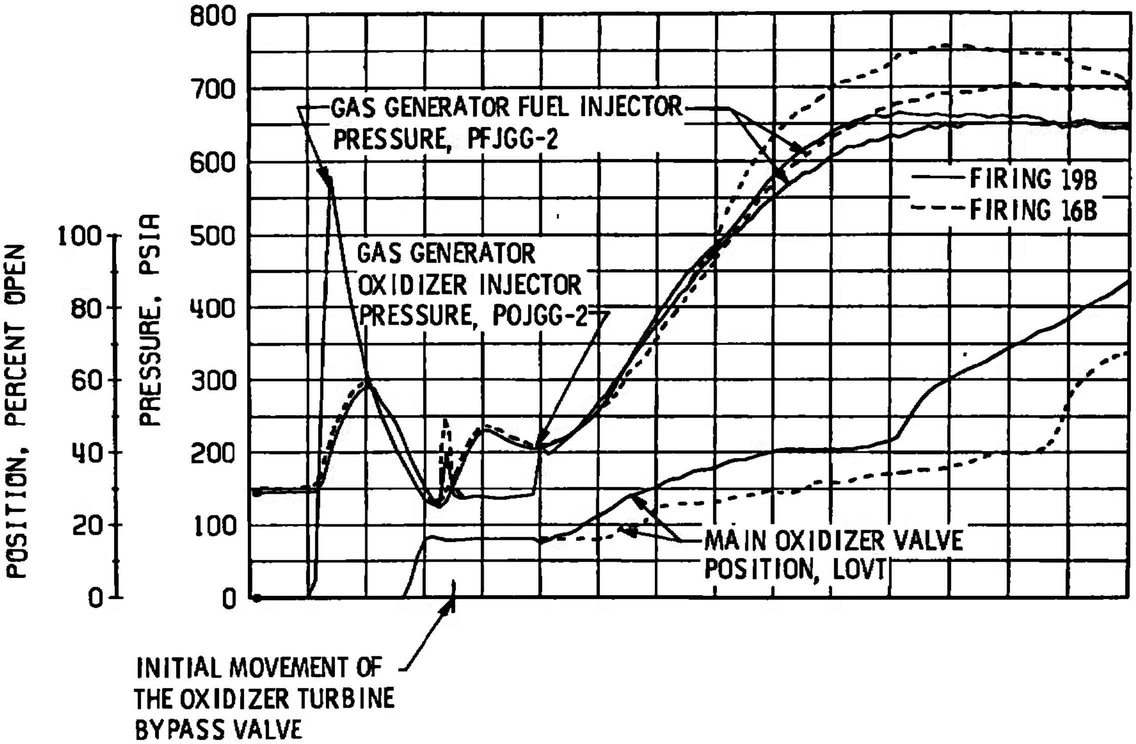


c. Thrust Chamber Fuel System, Shutdown

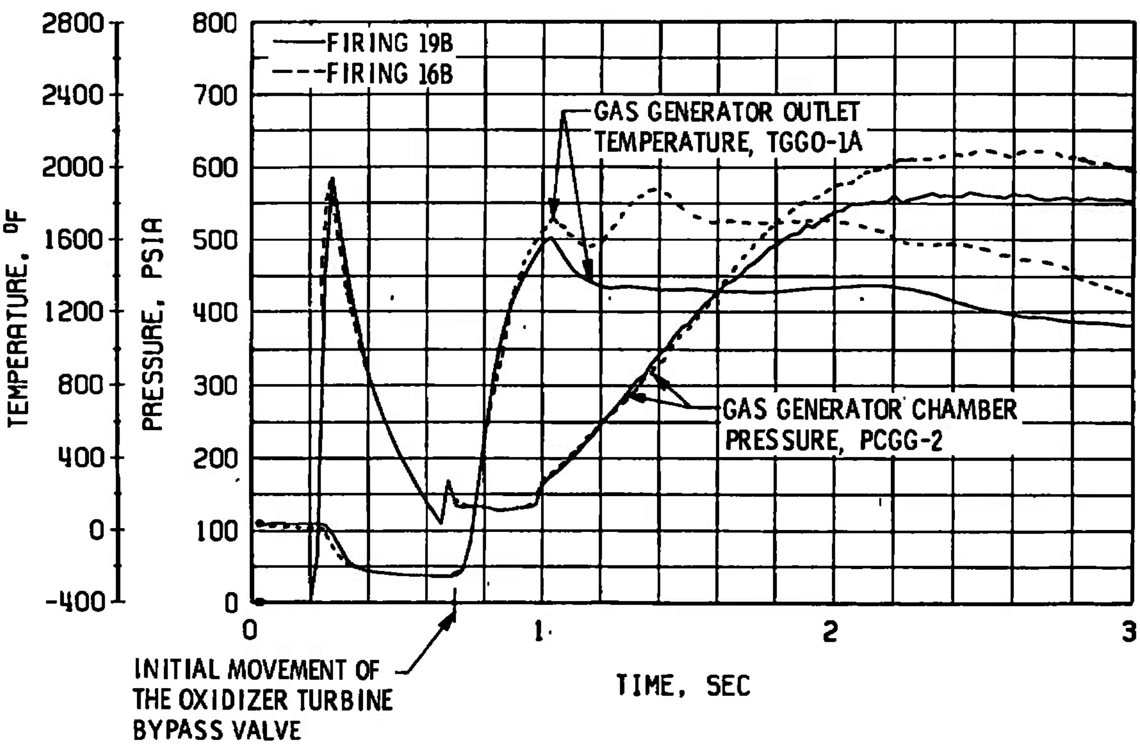


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 38 Continued

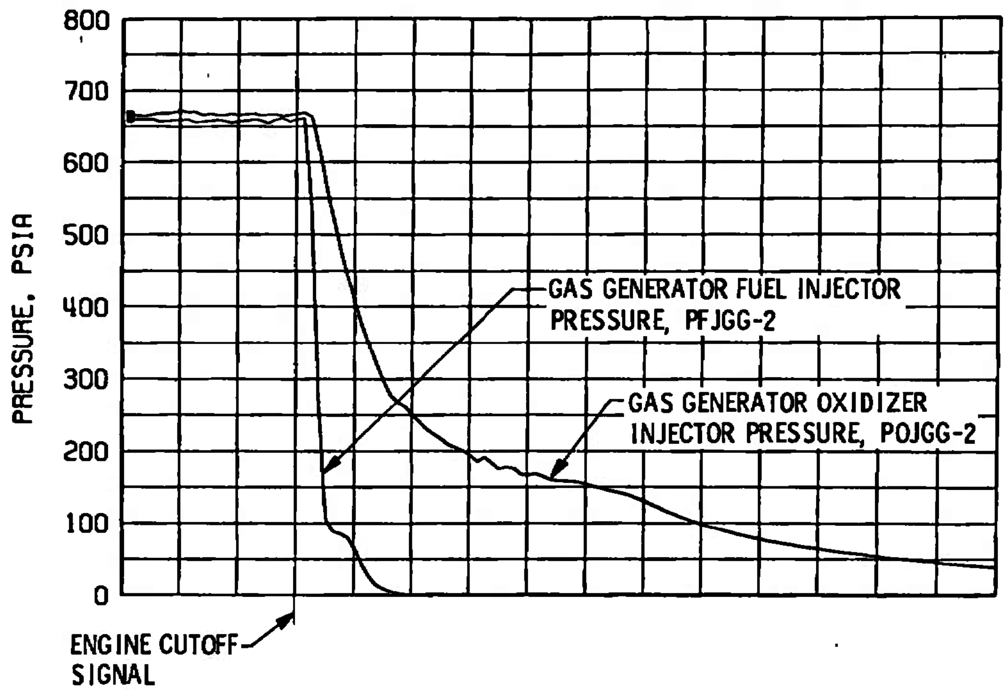


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

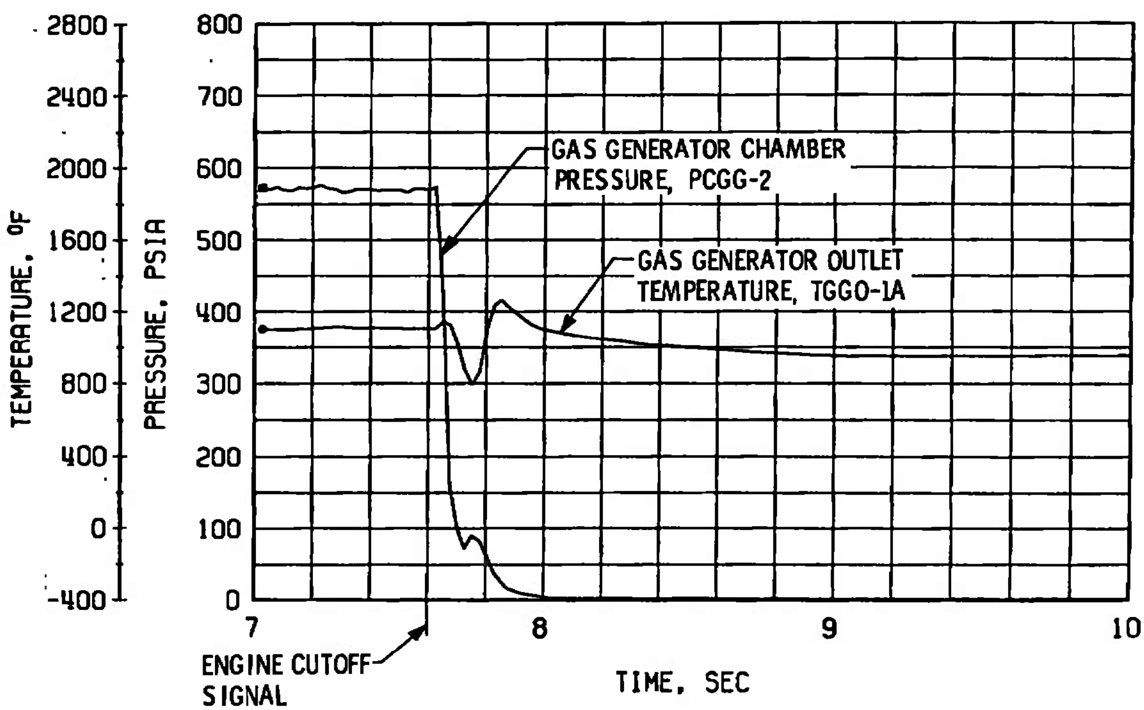


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 38 Continued

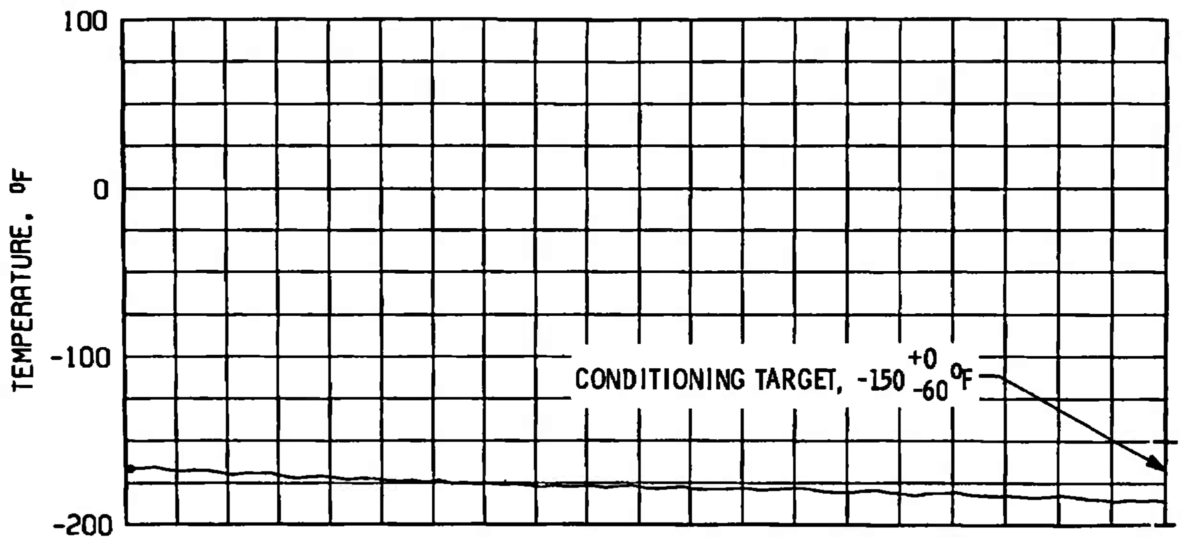


g. Gas Generator Injector Pressures, Shutdown

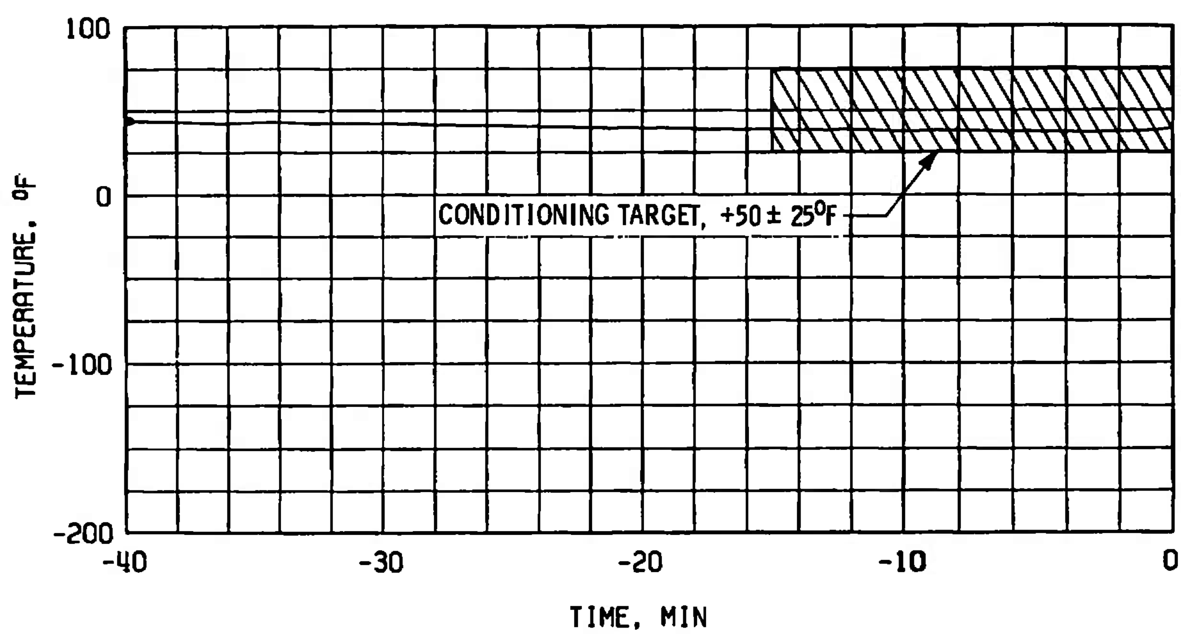


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 38 Concluded

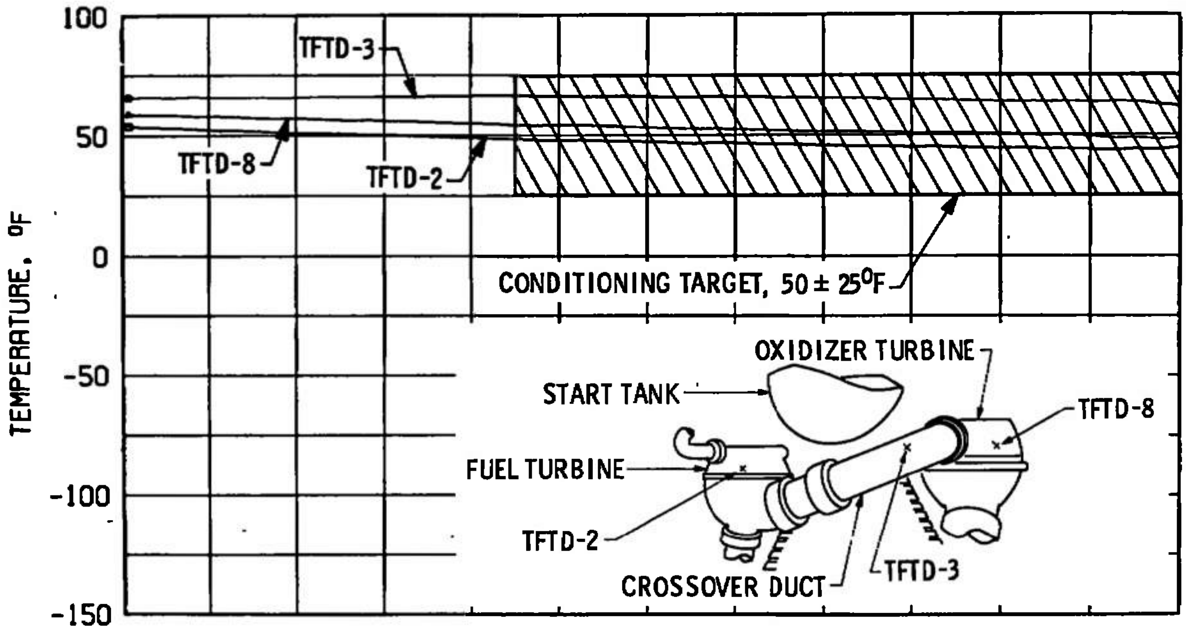


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

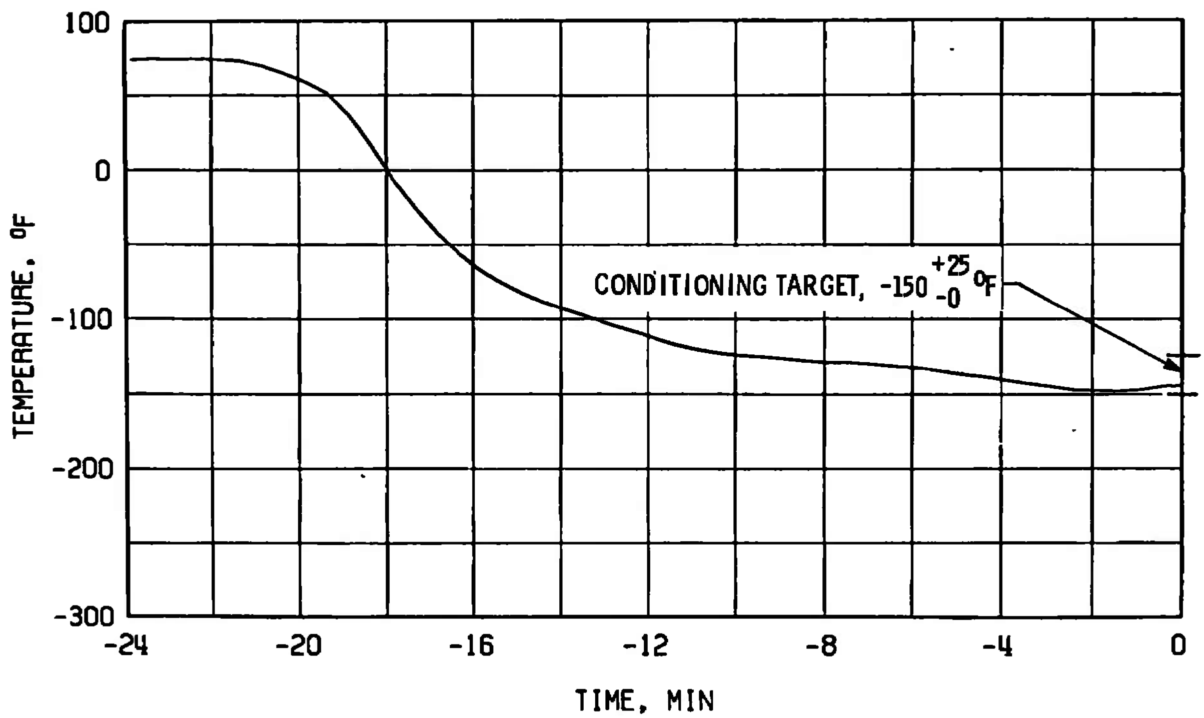


b. Start Tank Discharge Valve, TSTDVOC

Fig. 39 Thermal Conditioning History of Engine Components, Firing 19B



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 39 Concluded

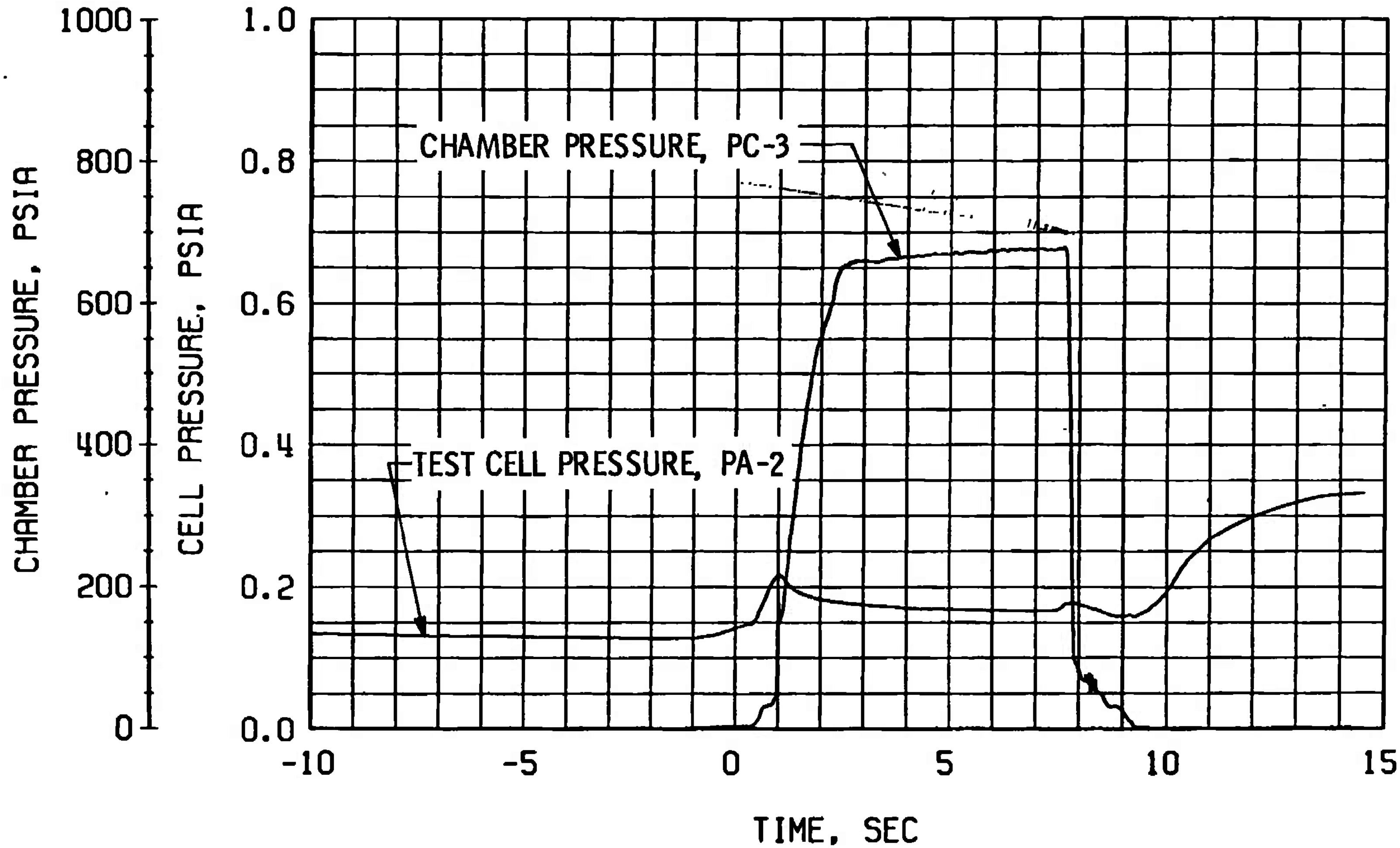


Fig. 40 Engine Ambient and Combustion Chamber Pressures, Firing 19B

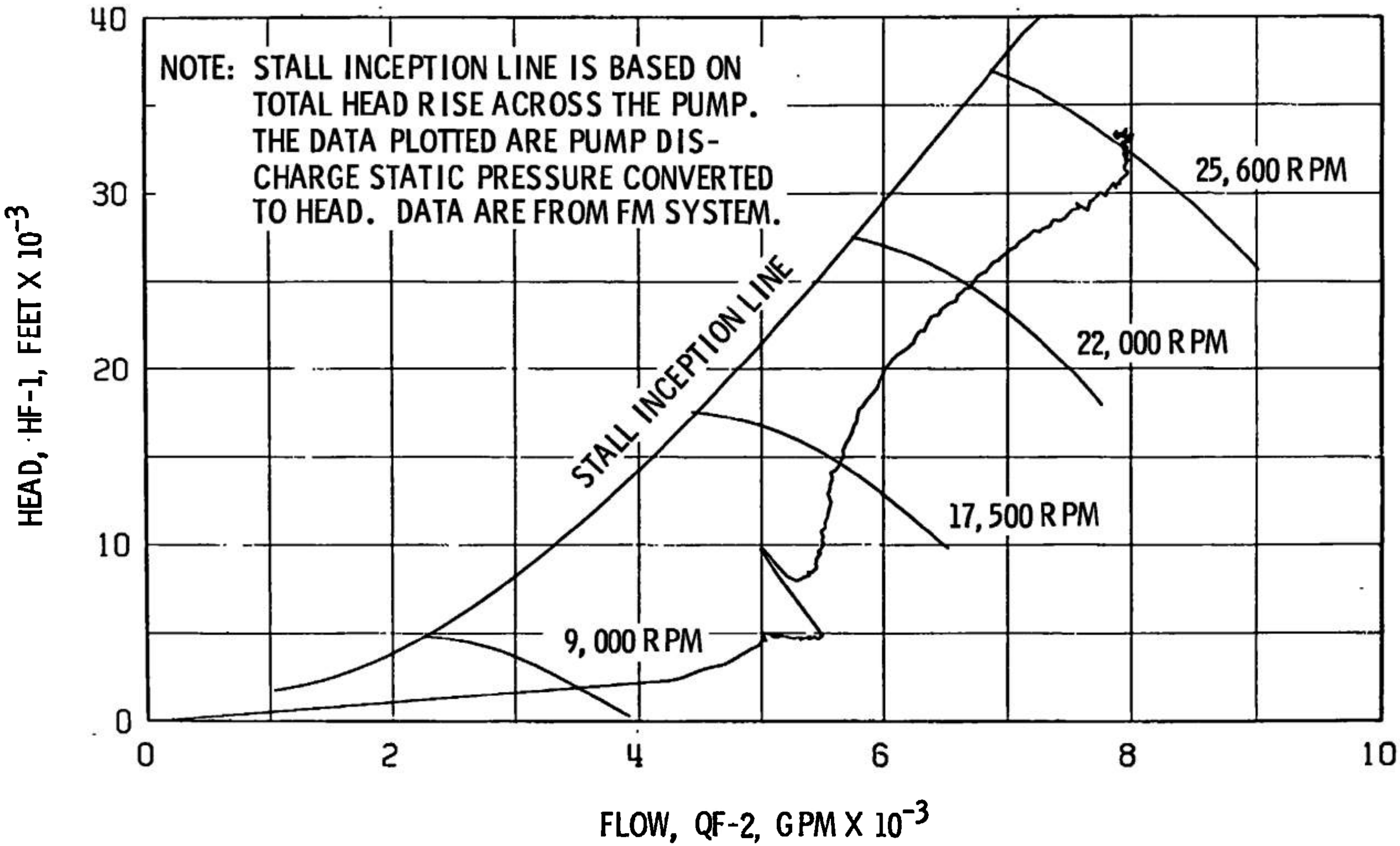
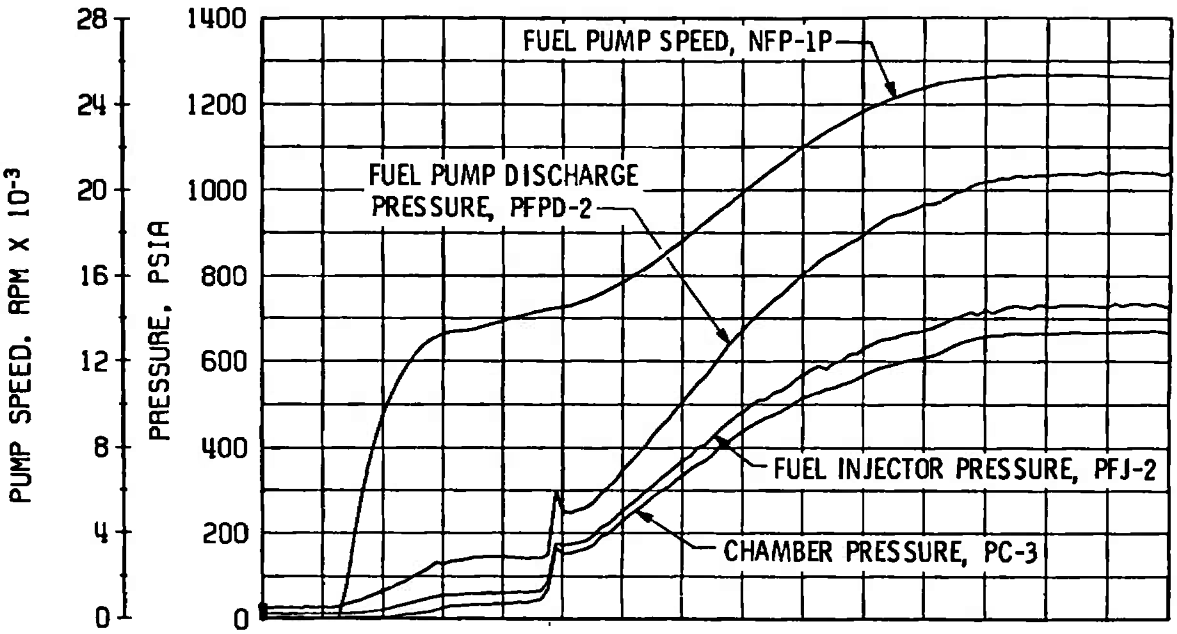
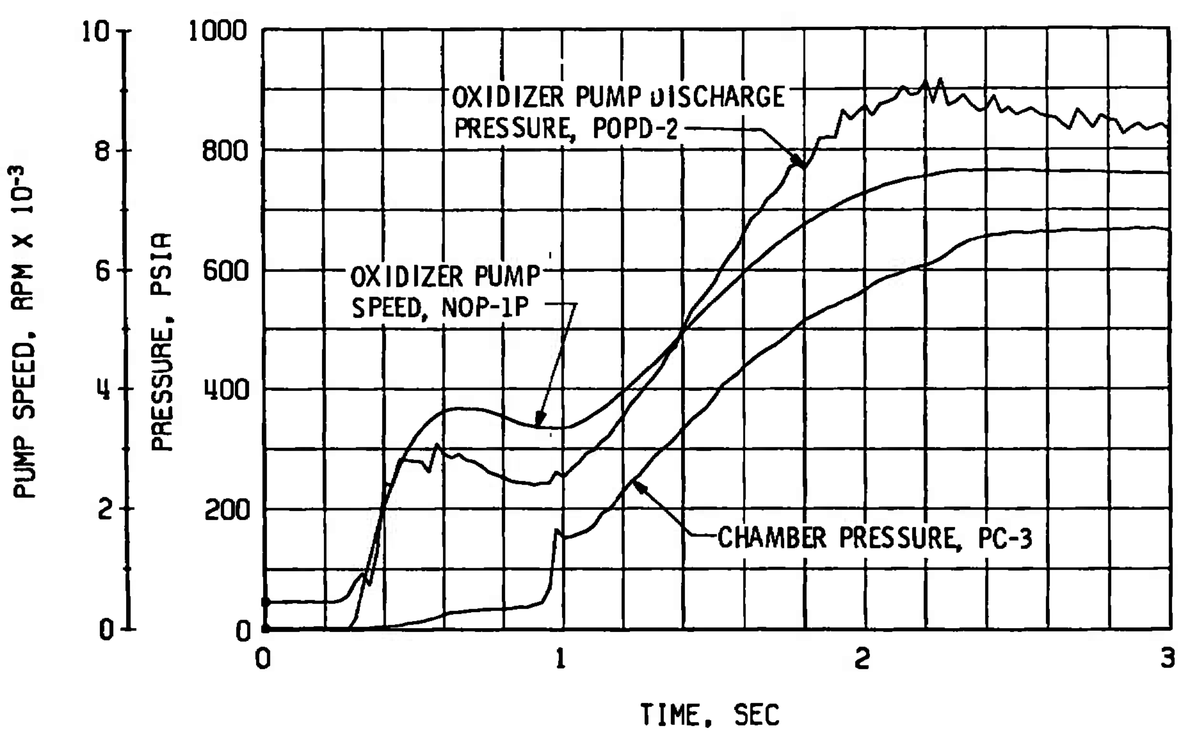


Fig. 41 Fuel Pump Start Transient Performance, Firing 19B

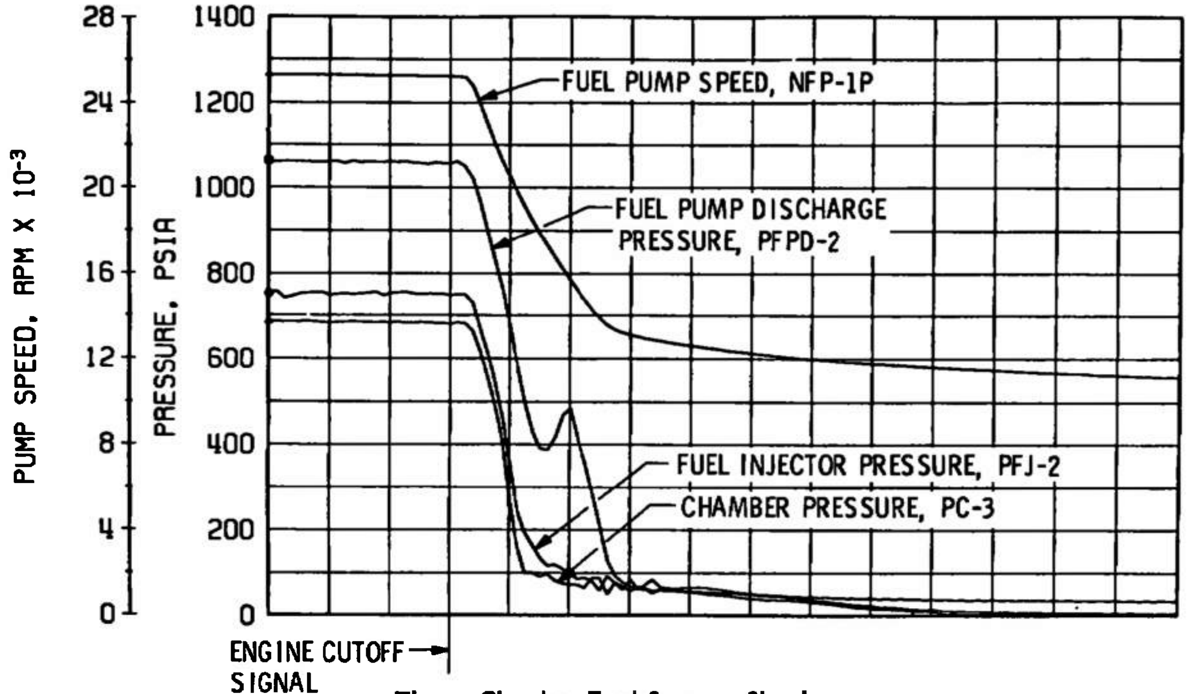


a. Thrust Chamber Fuel System, Start

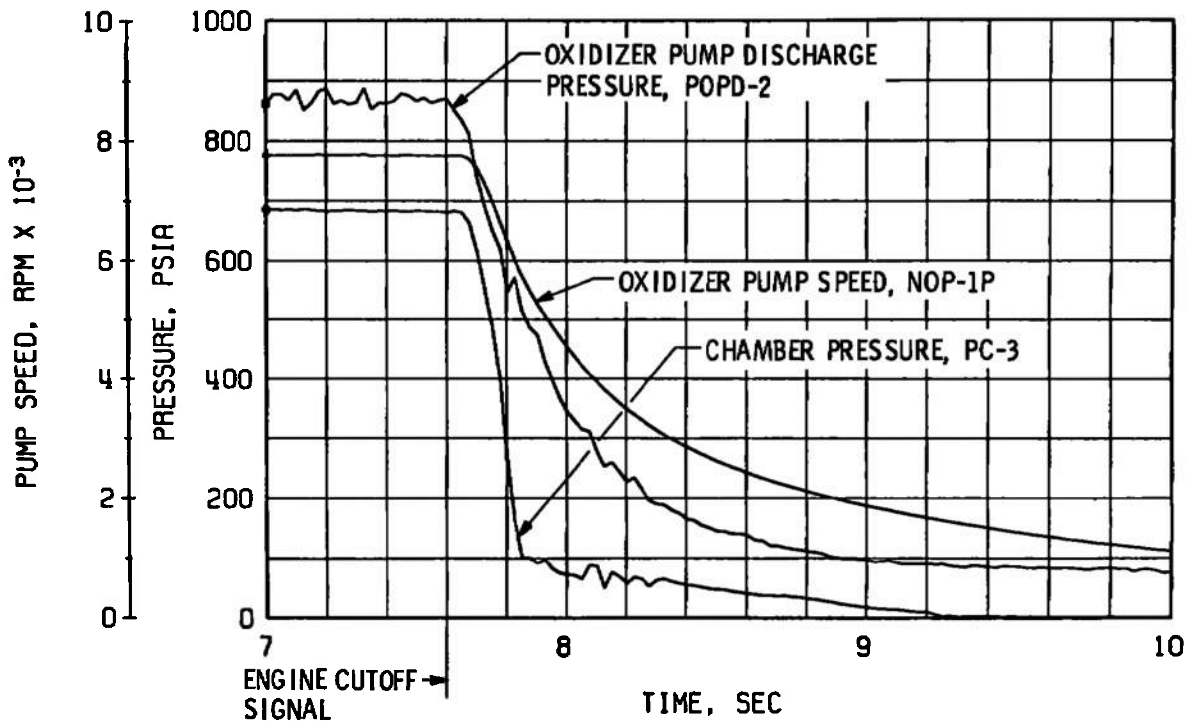


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 19C

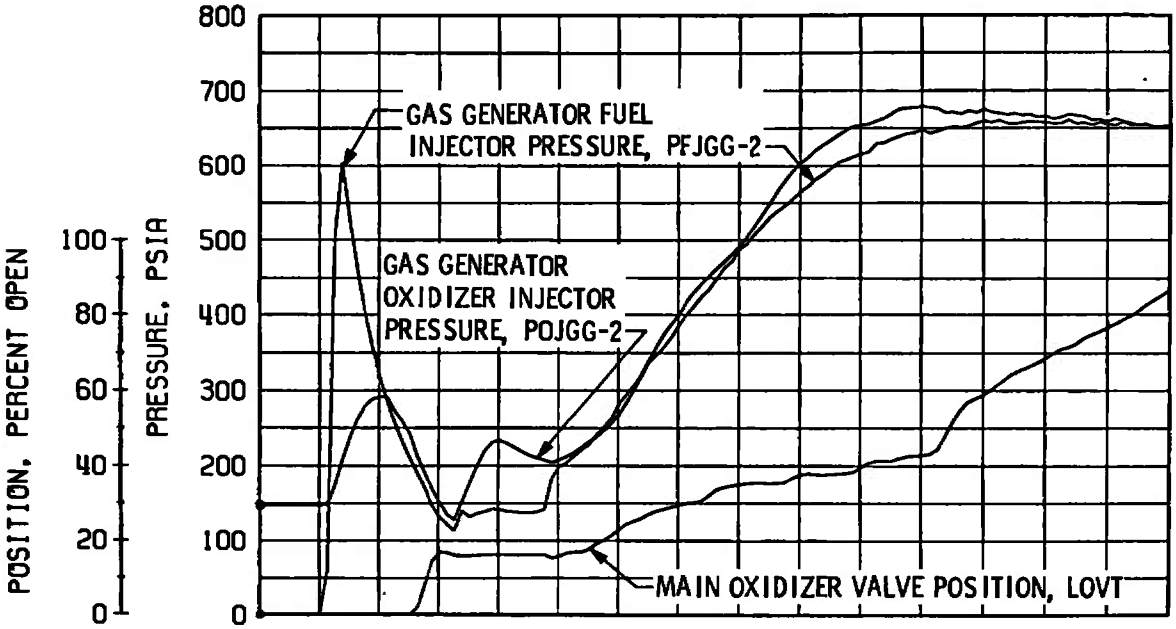


c. Thrust Chamber Fuel System, Shutdown

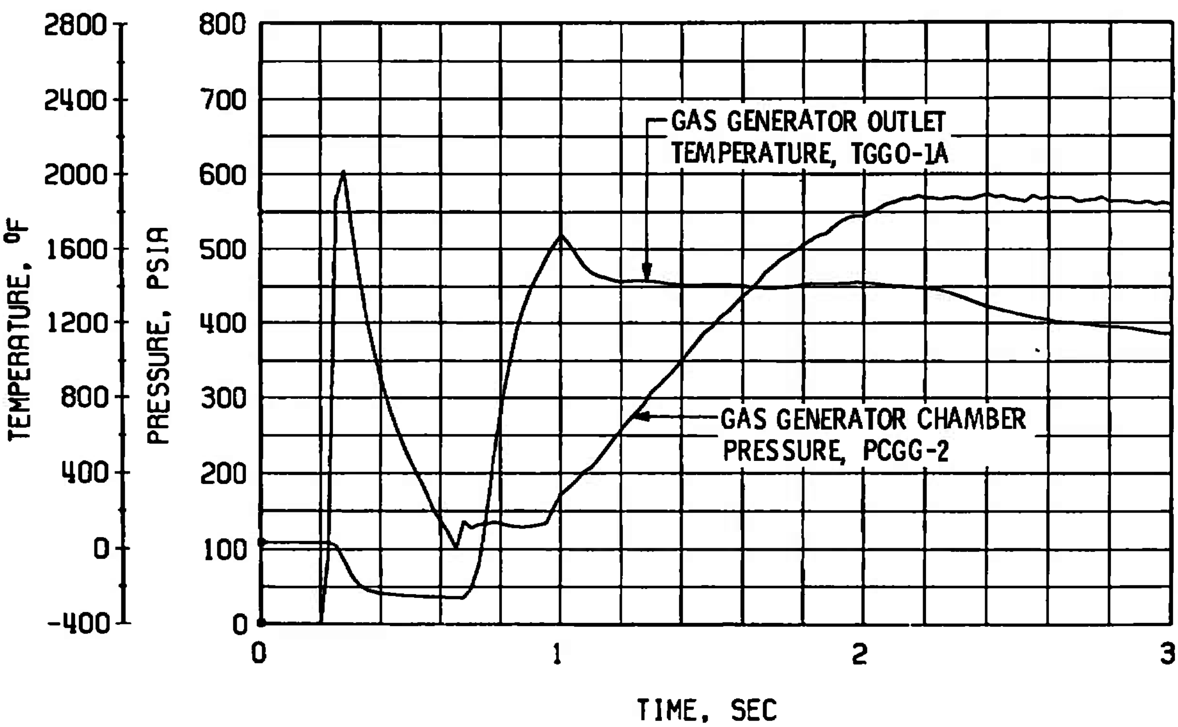


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued

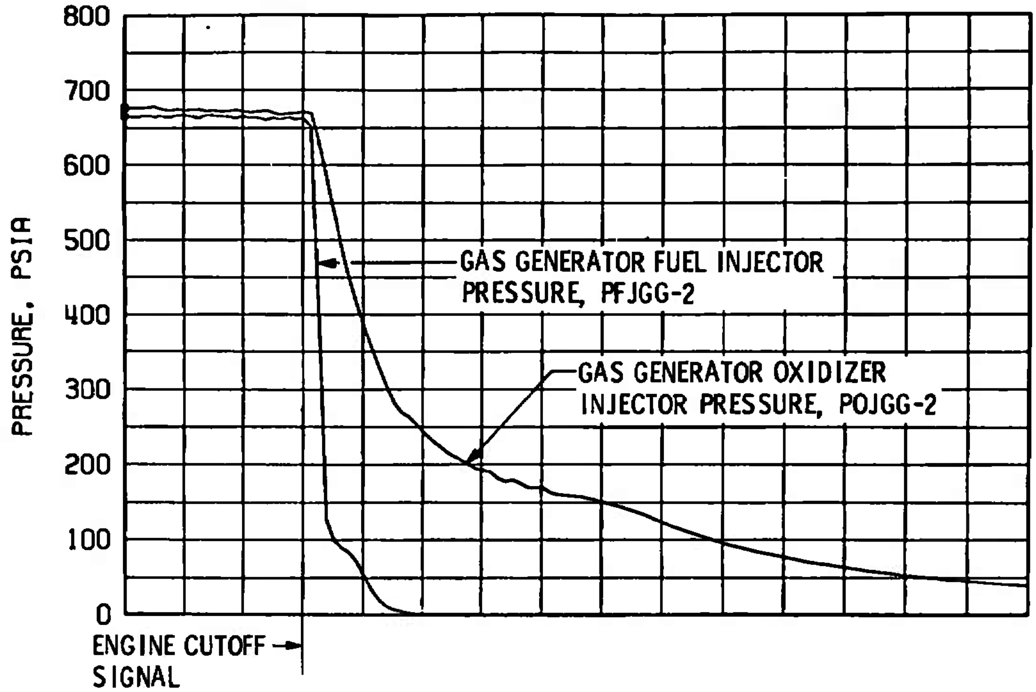


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

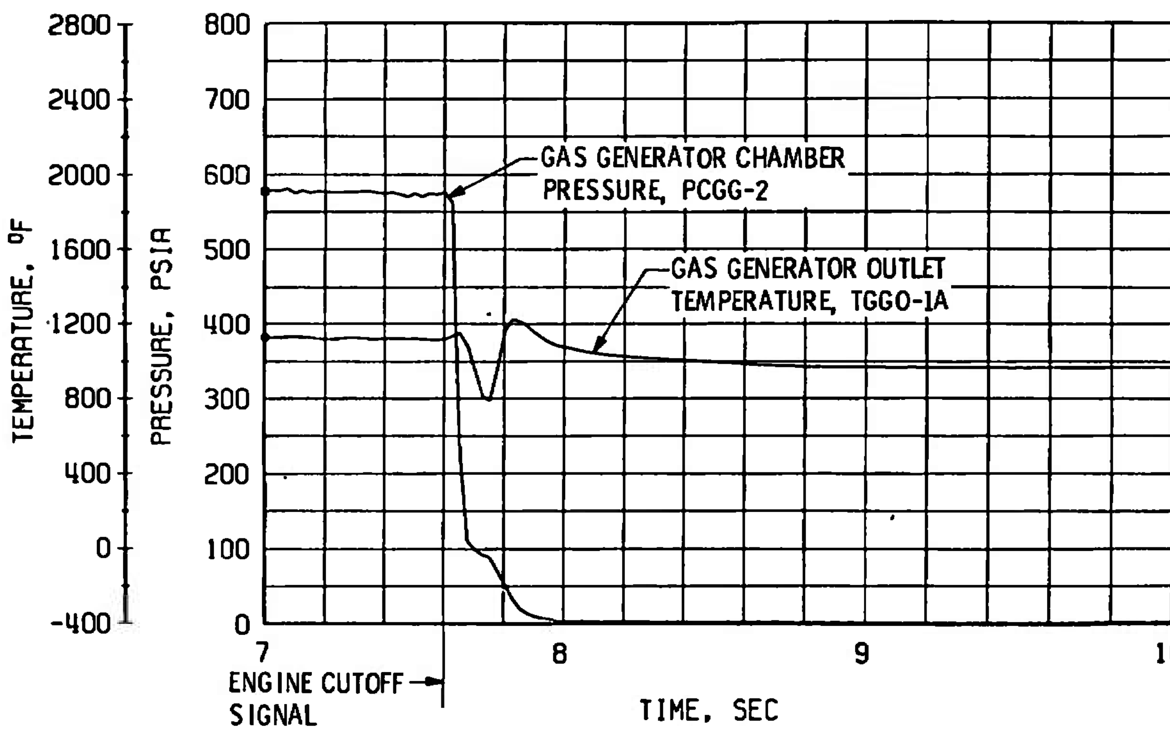


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued

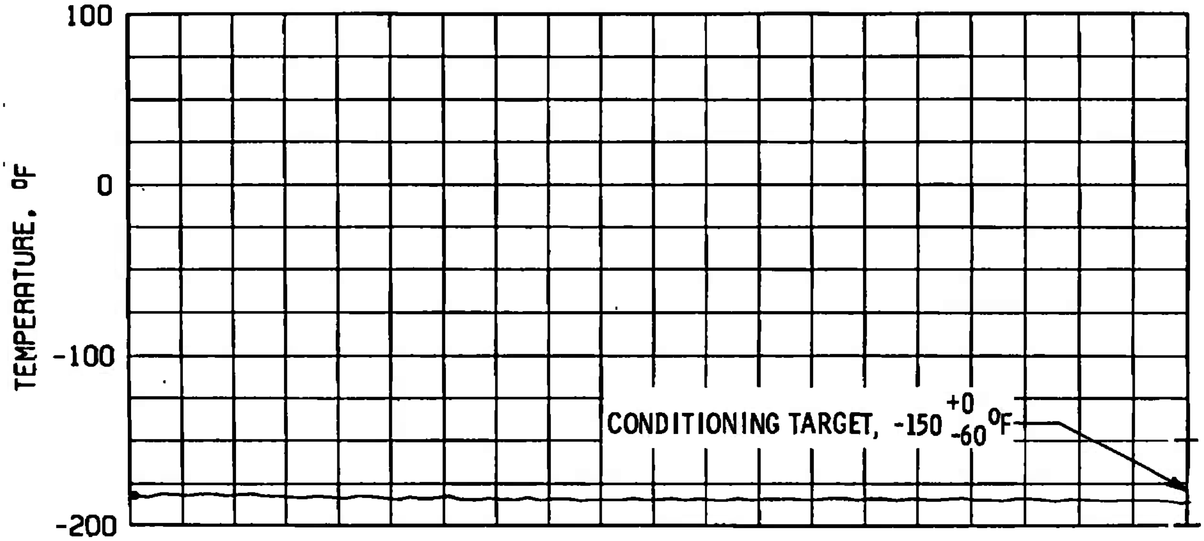


g. Gas Generator Injector Pressures, Shutdown

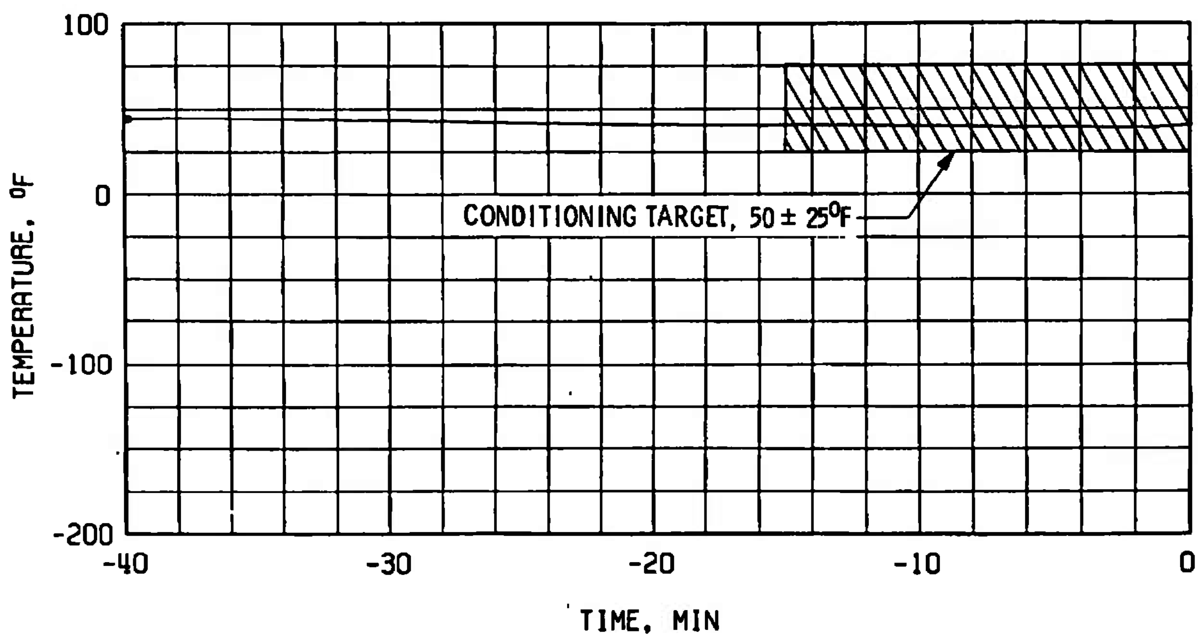


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

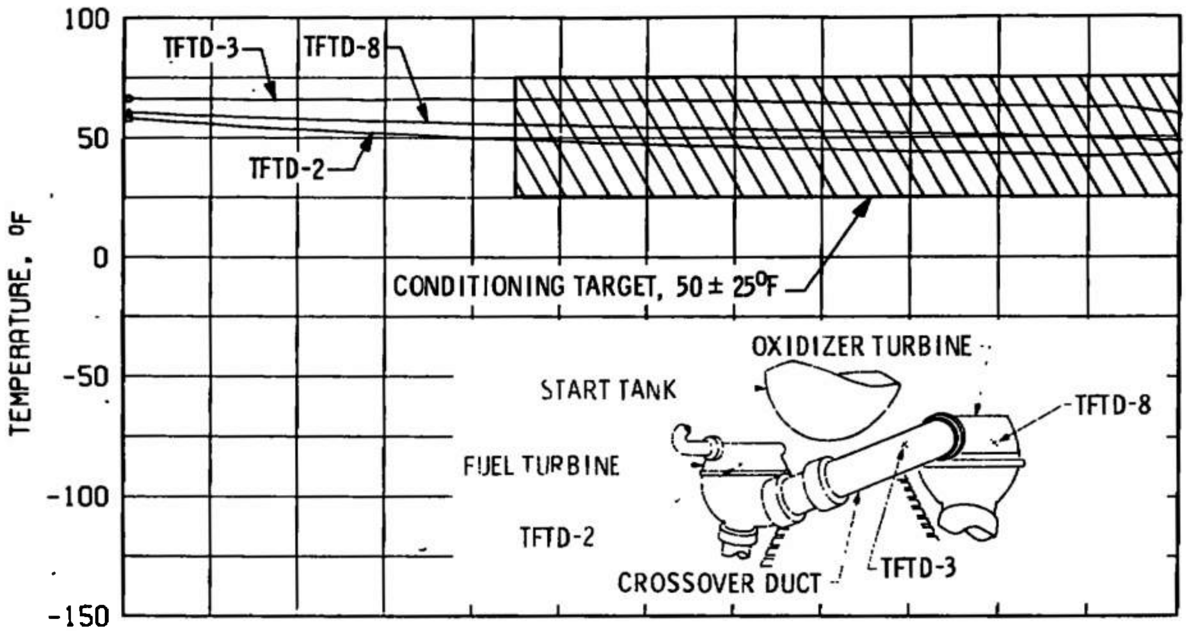


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

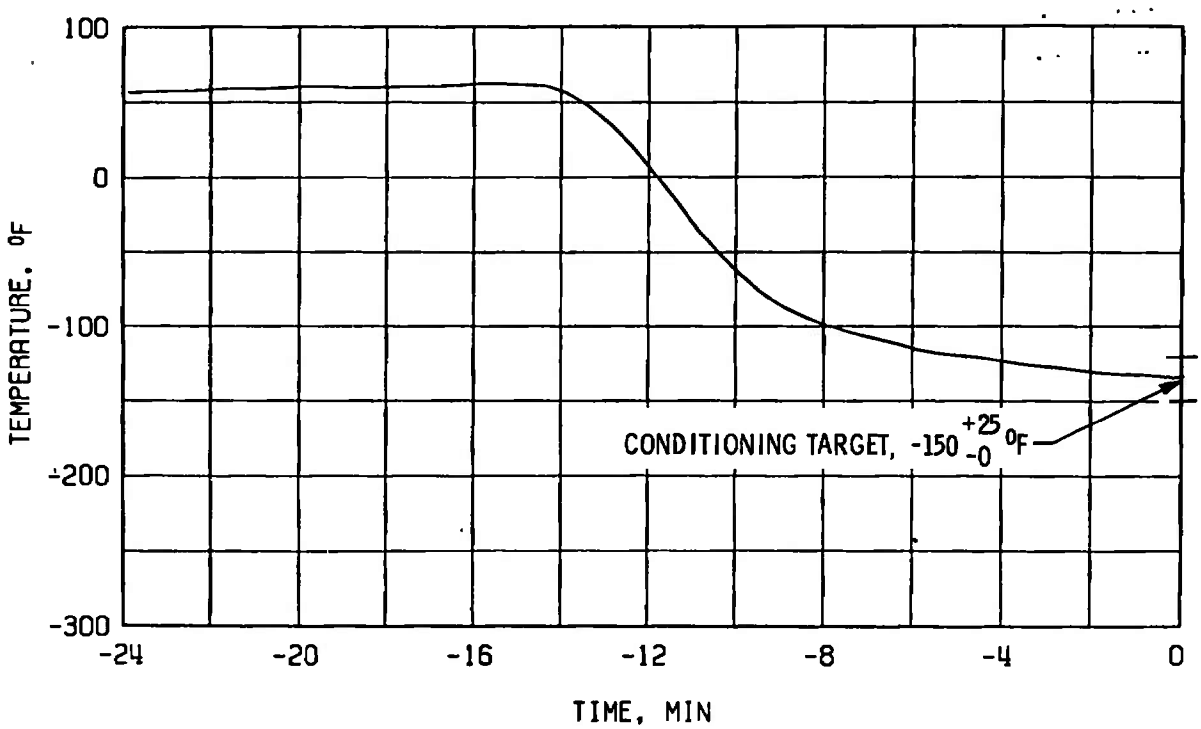


b. Start Tank Discharge Valve, TSTDVOC

Fig. 43 Thermal Conditioning History of Engine Components, Firing 19C



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 43 Concluded

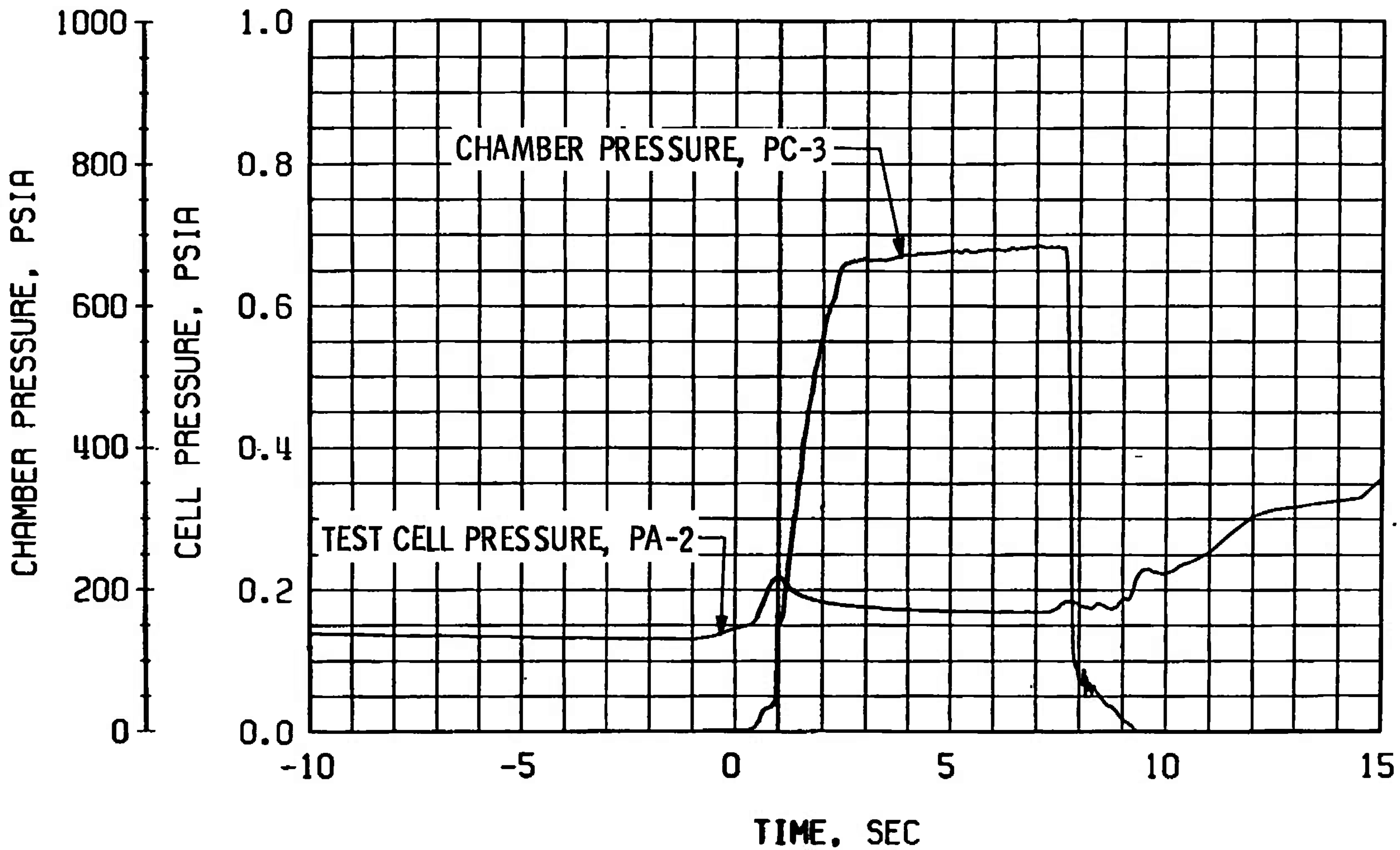


Fig. 44 Engine Ambient and Combustion Chamber Pressures, Firing 19C

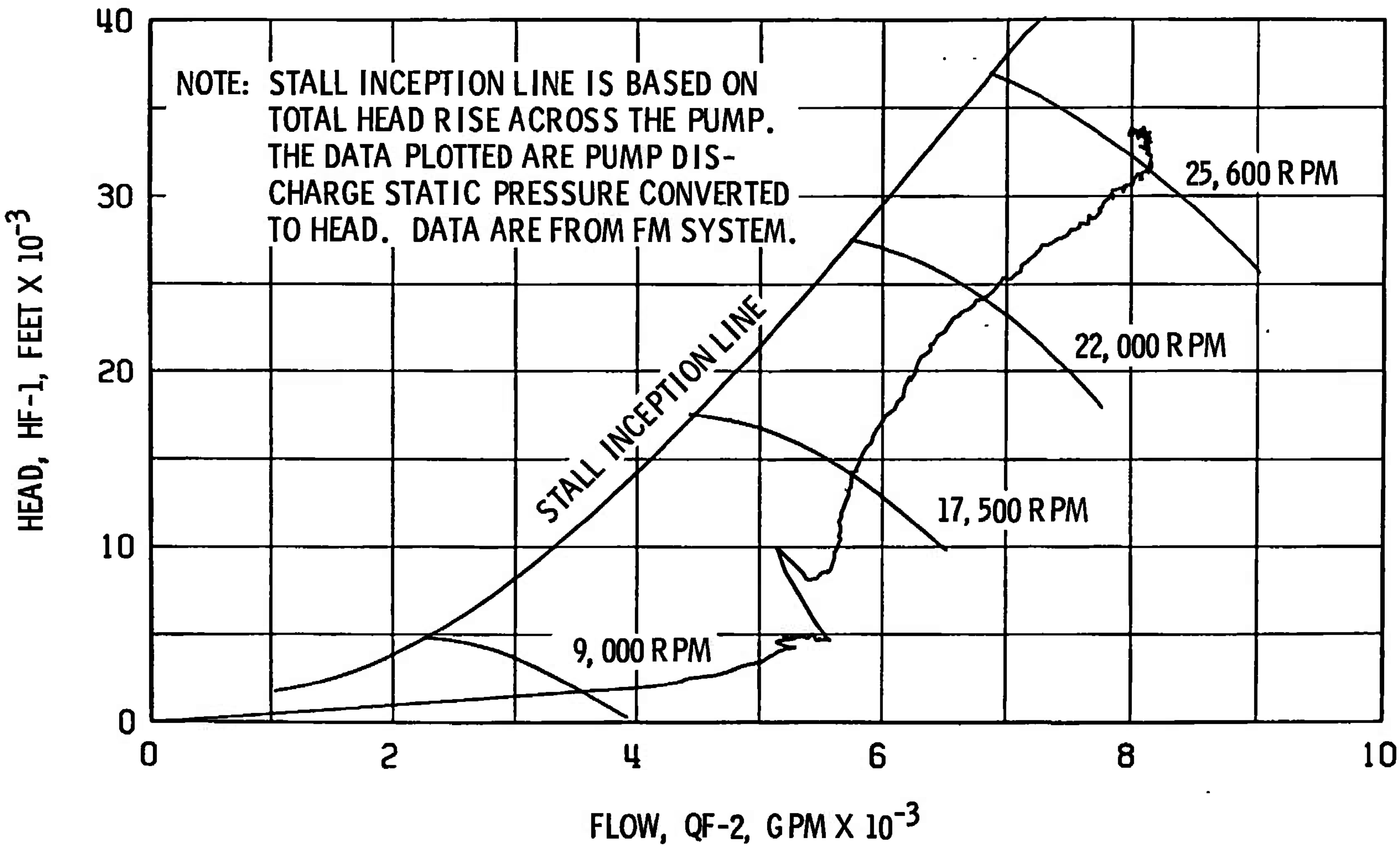
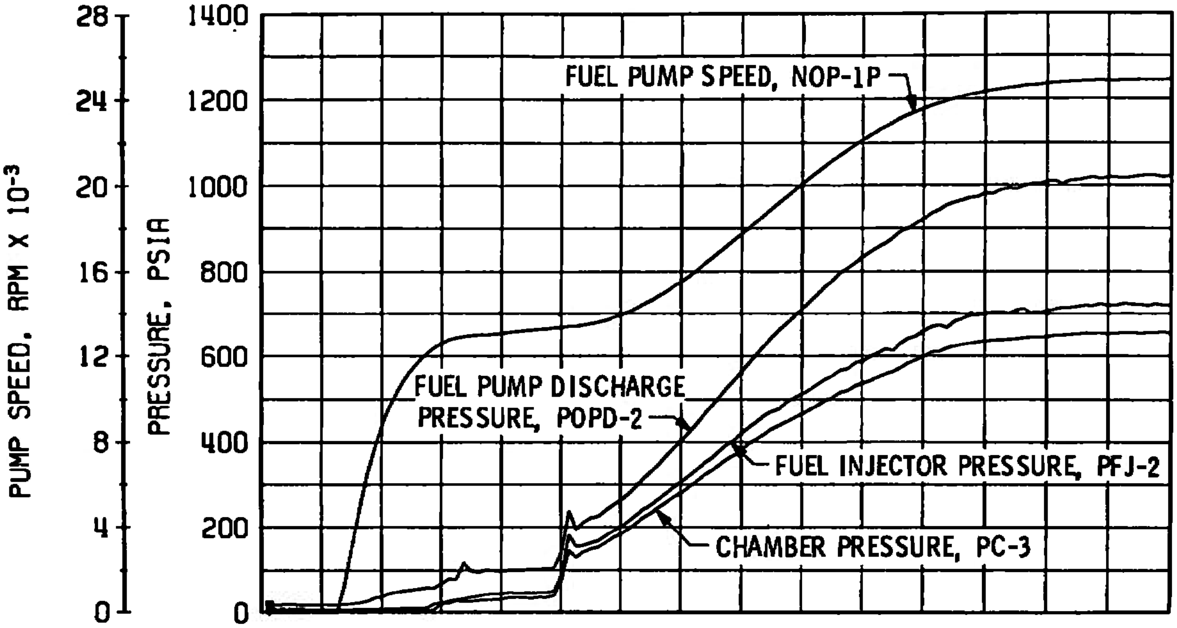
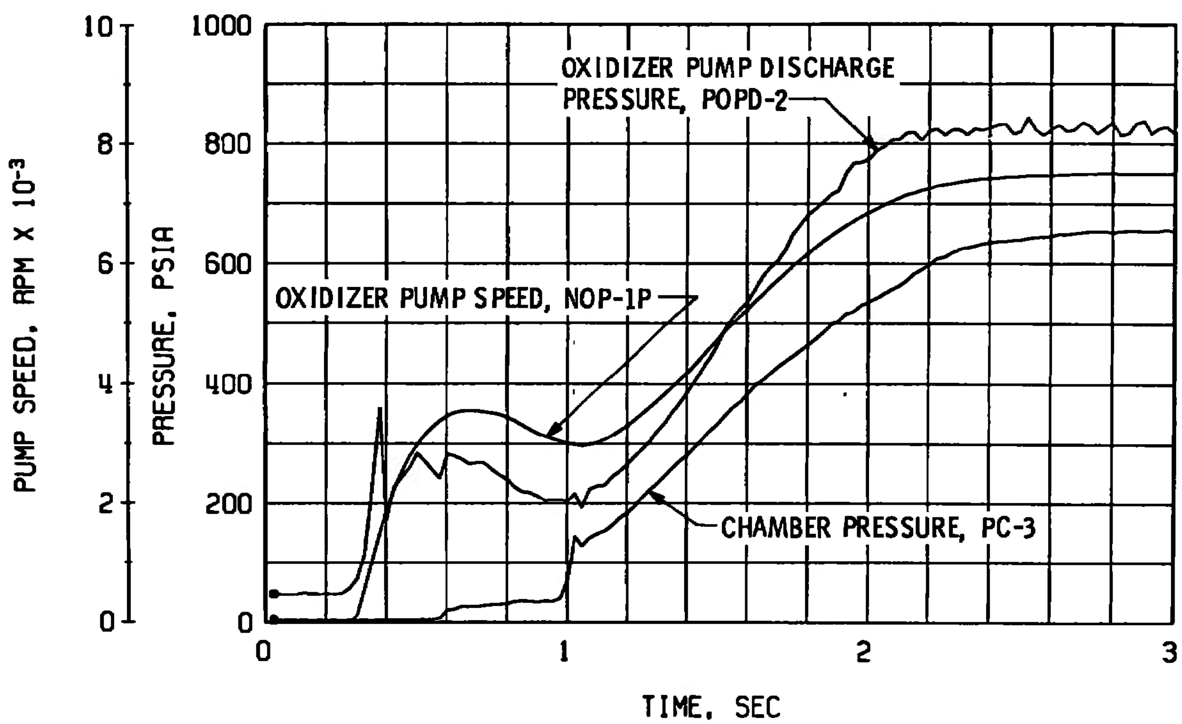


Fig. 45 Fuel Pump Start Transient Performance, Firing 19C

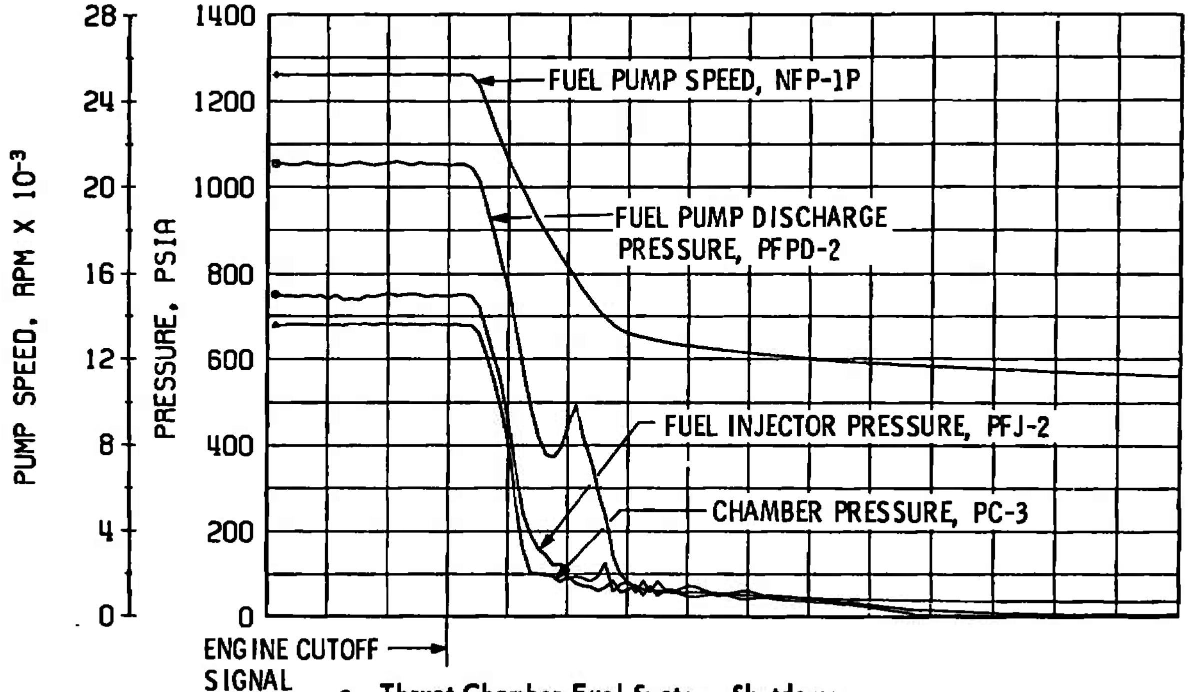


a. Thrust Chamber Fuel System, Start

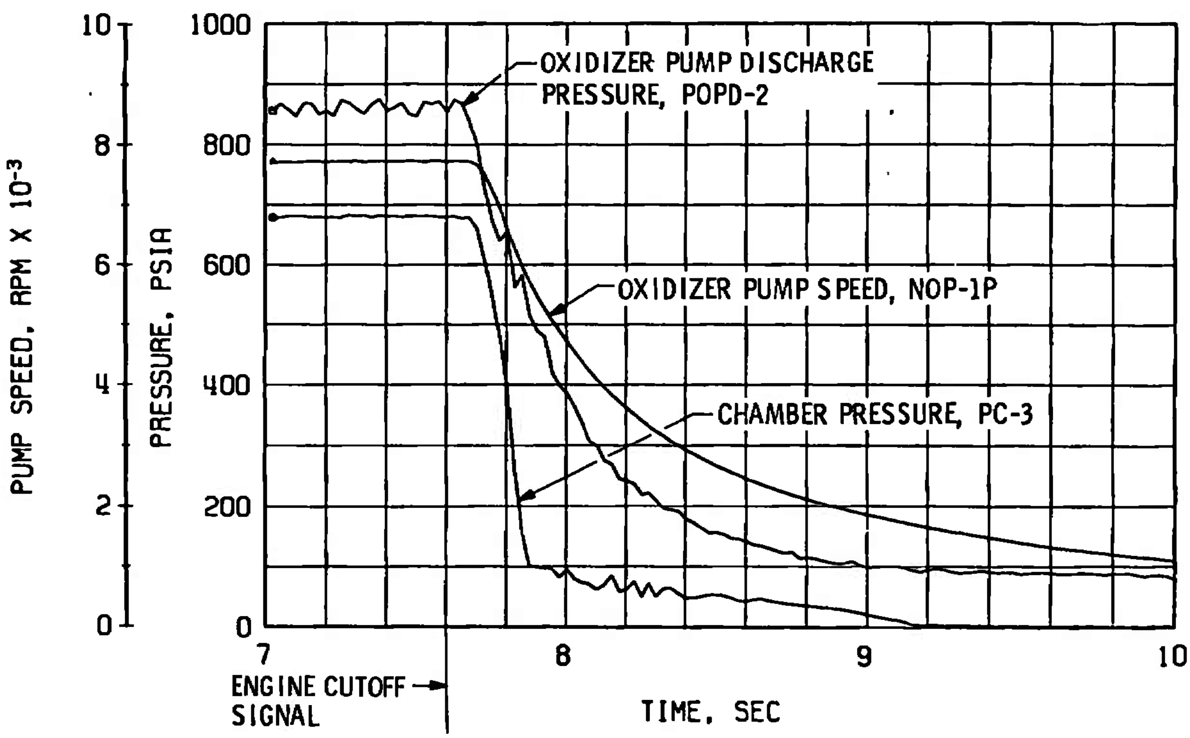


b. Thrust Chamber Oxidizer System, Start

Fig. 46 Engine Transient Operation, Firing 19D

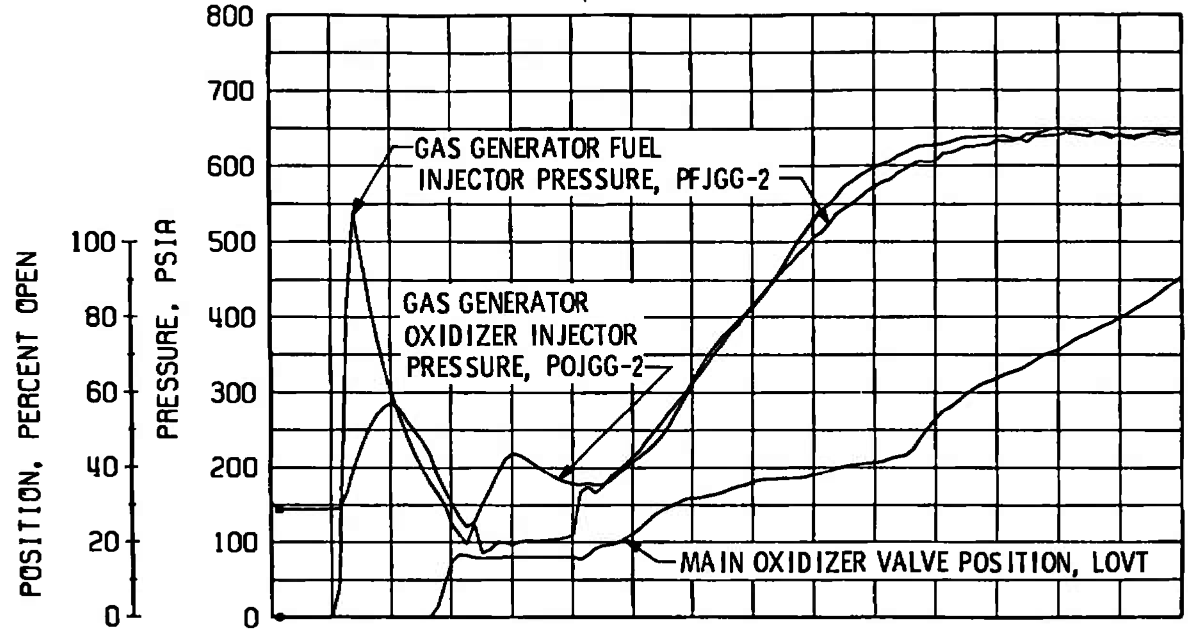


c. Thrust Chamber Fuel System, Shutdown

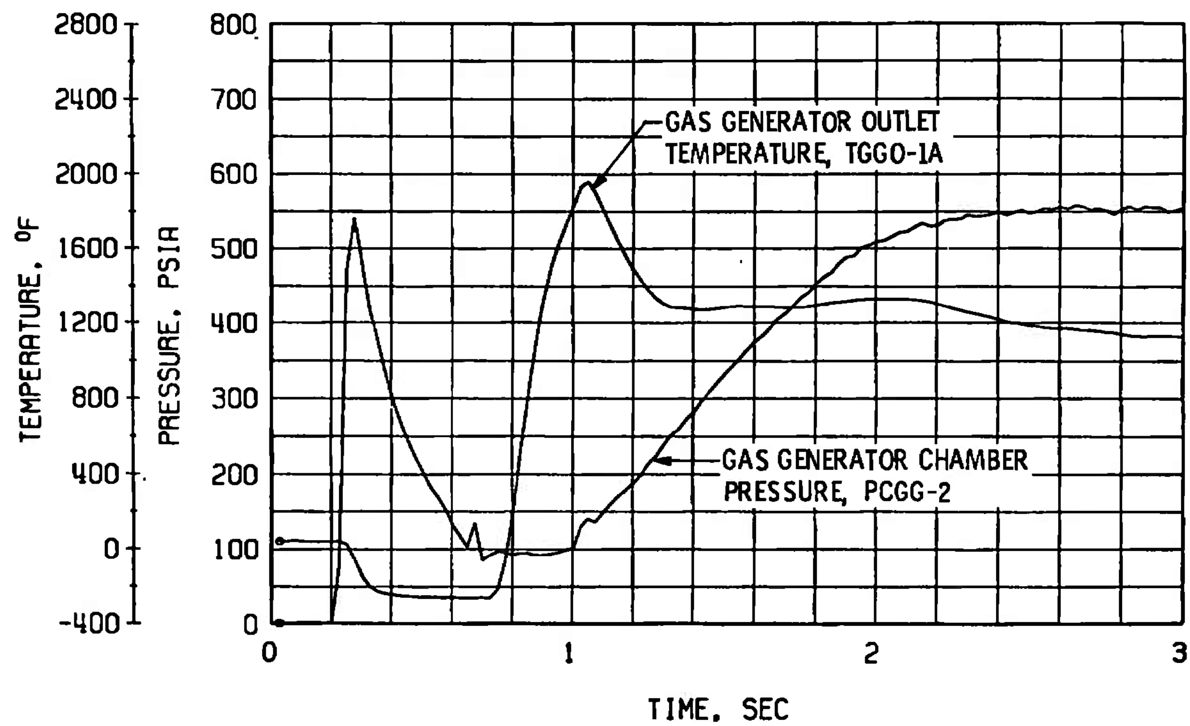


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 46 Continued

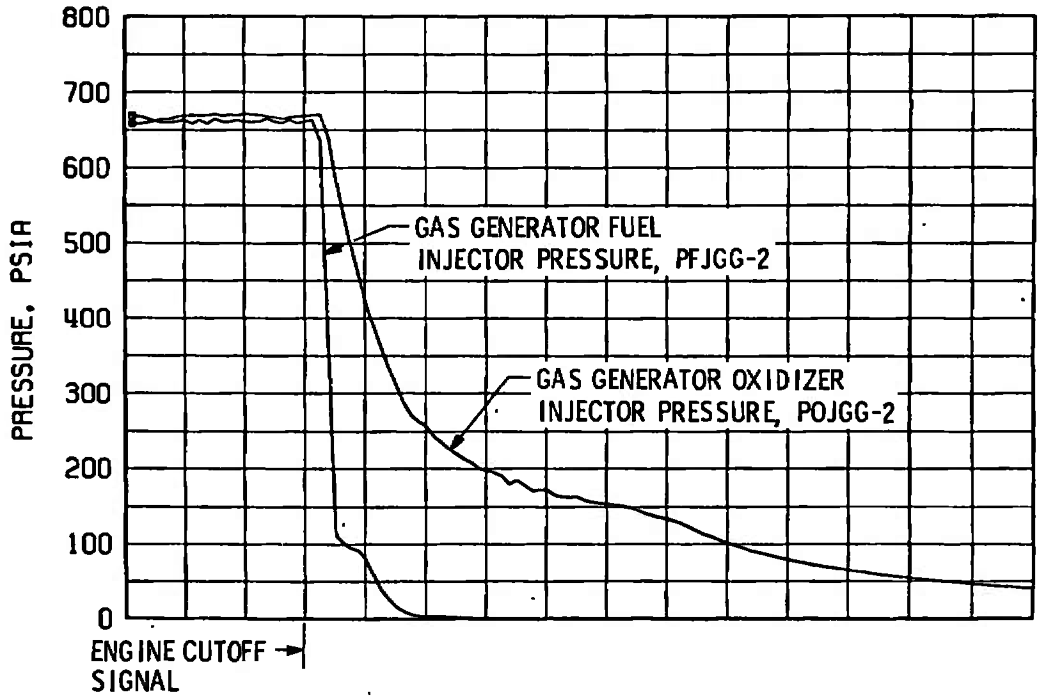


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

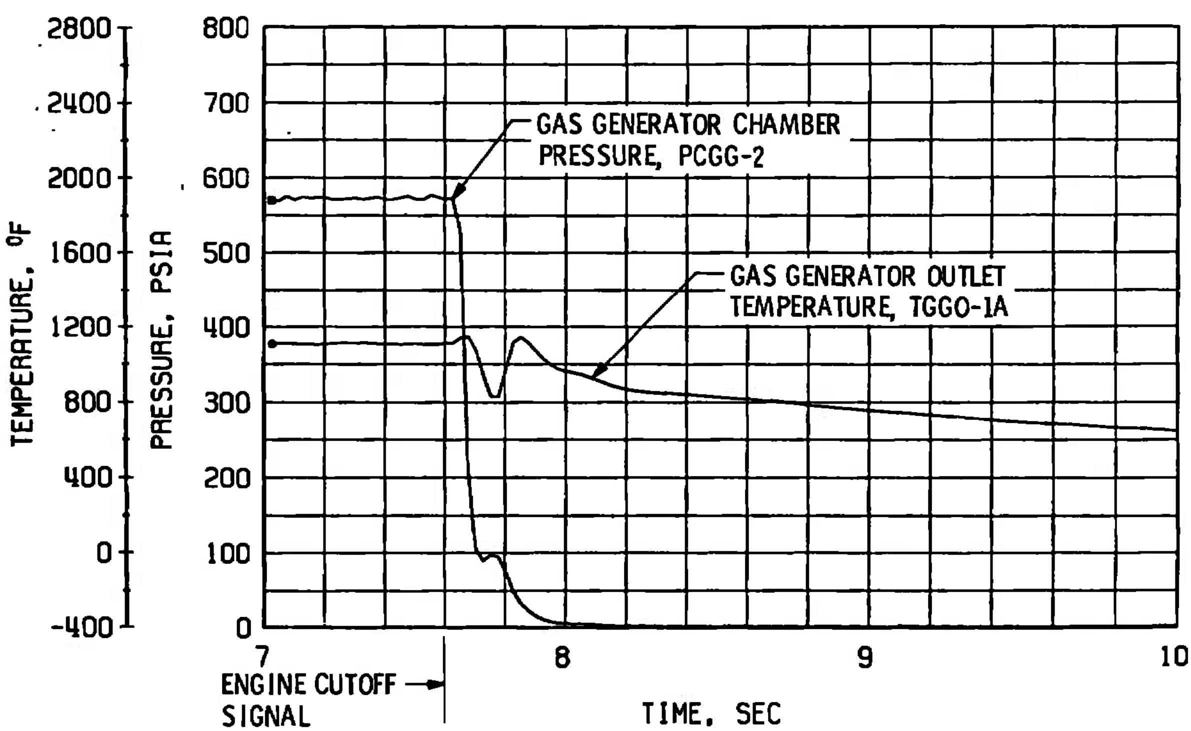


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 46 Continued

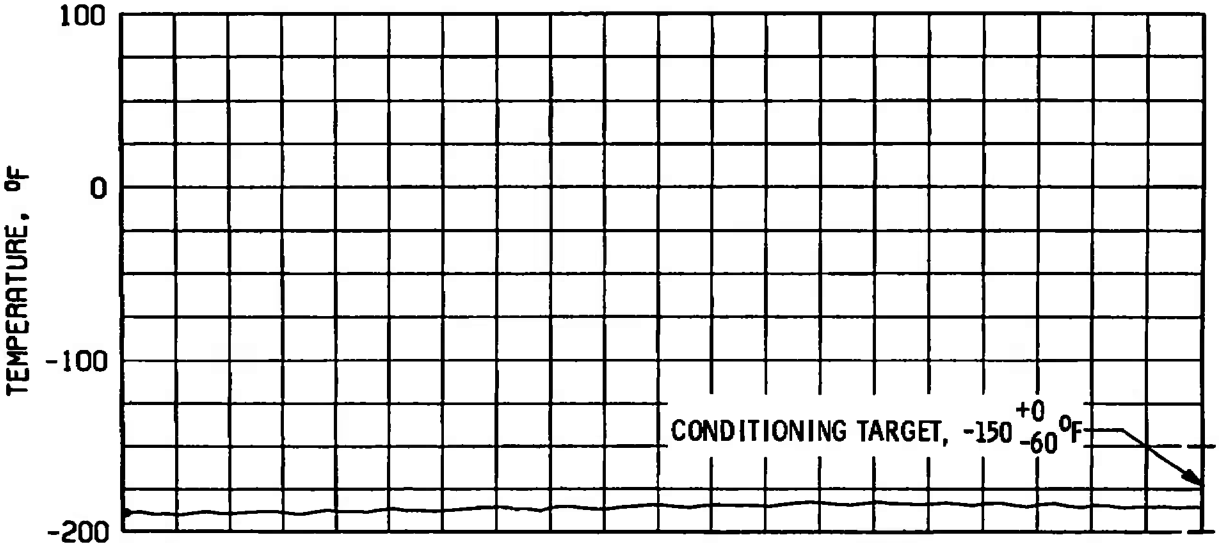


g. Gas Generator Injector Pressures, Shutdown

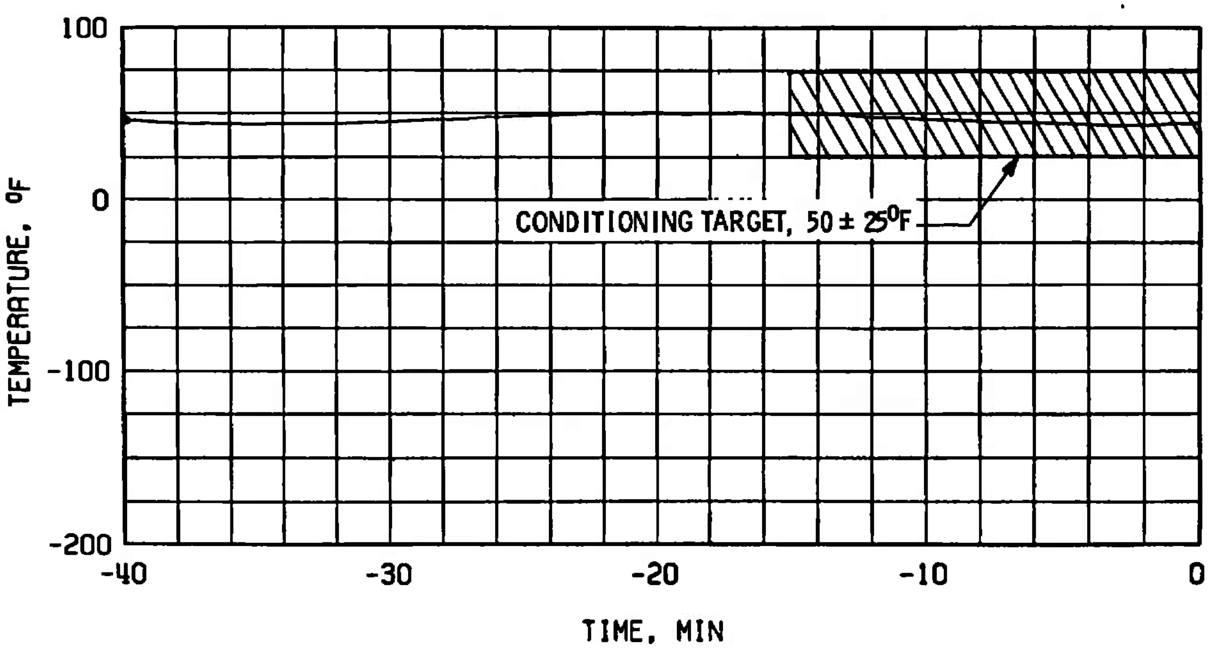


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 46 Concluded

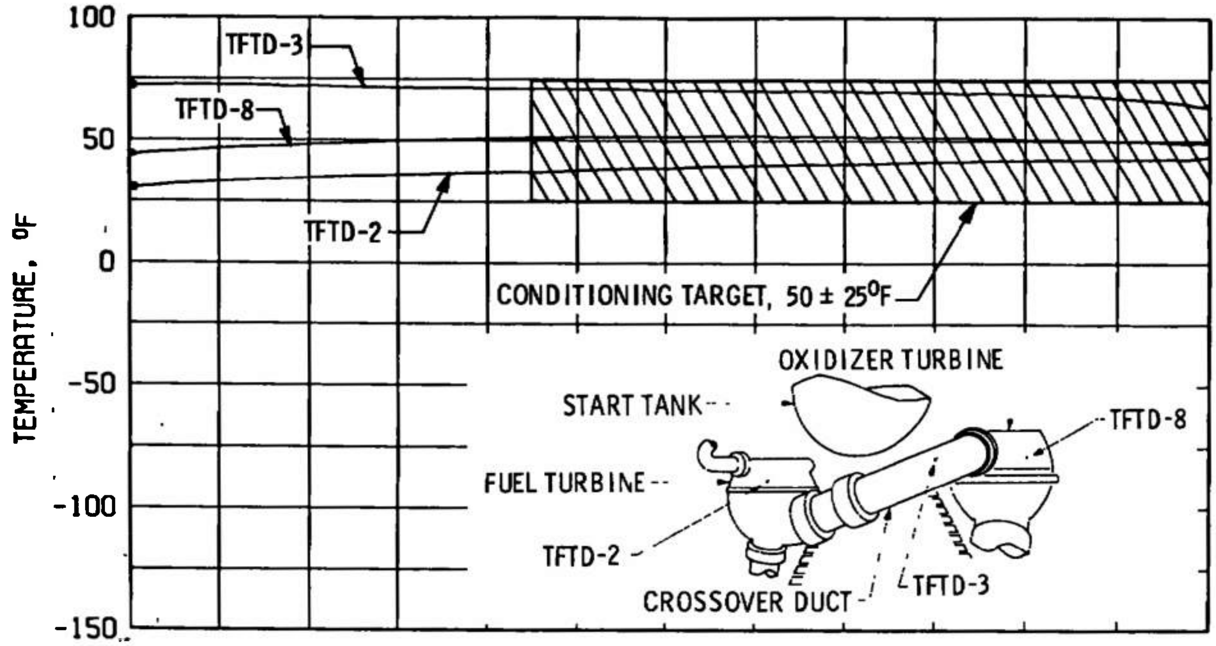


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

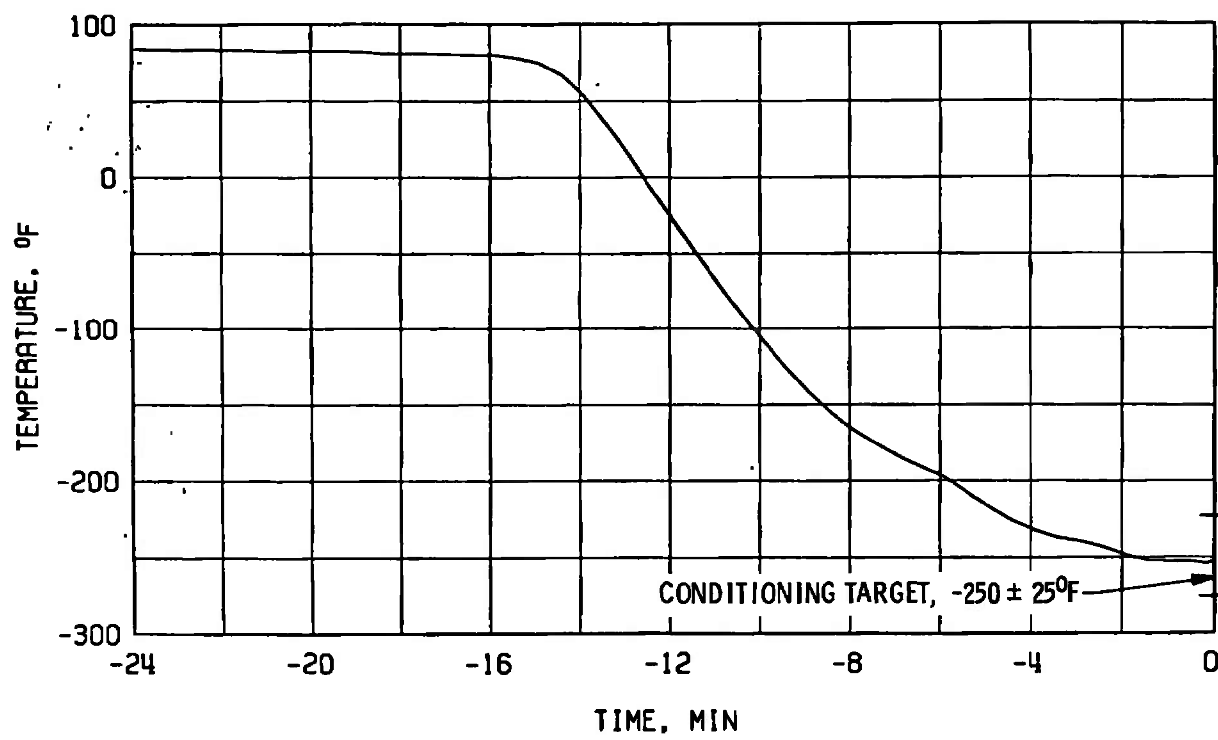


b. Start Tank Discharge Valve, TSTDVOC

Fig. 47 Thermal Conditioning History of Engine Components, Firing 19D



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 47 Concluded

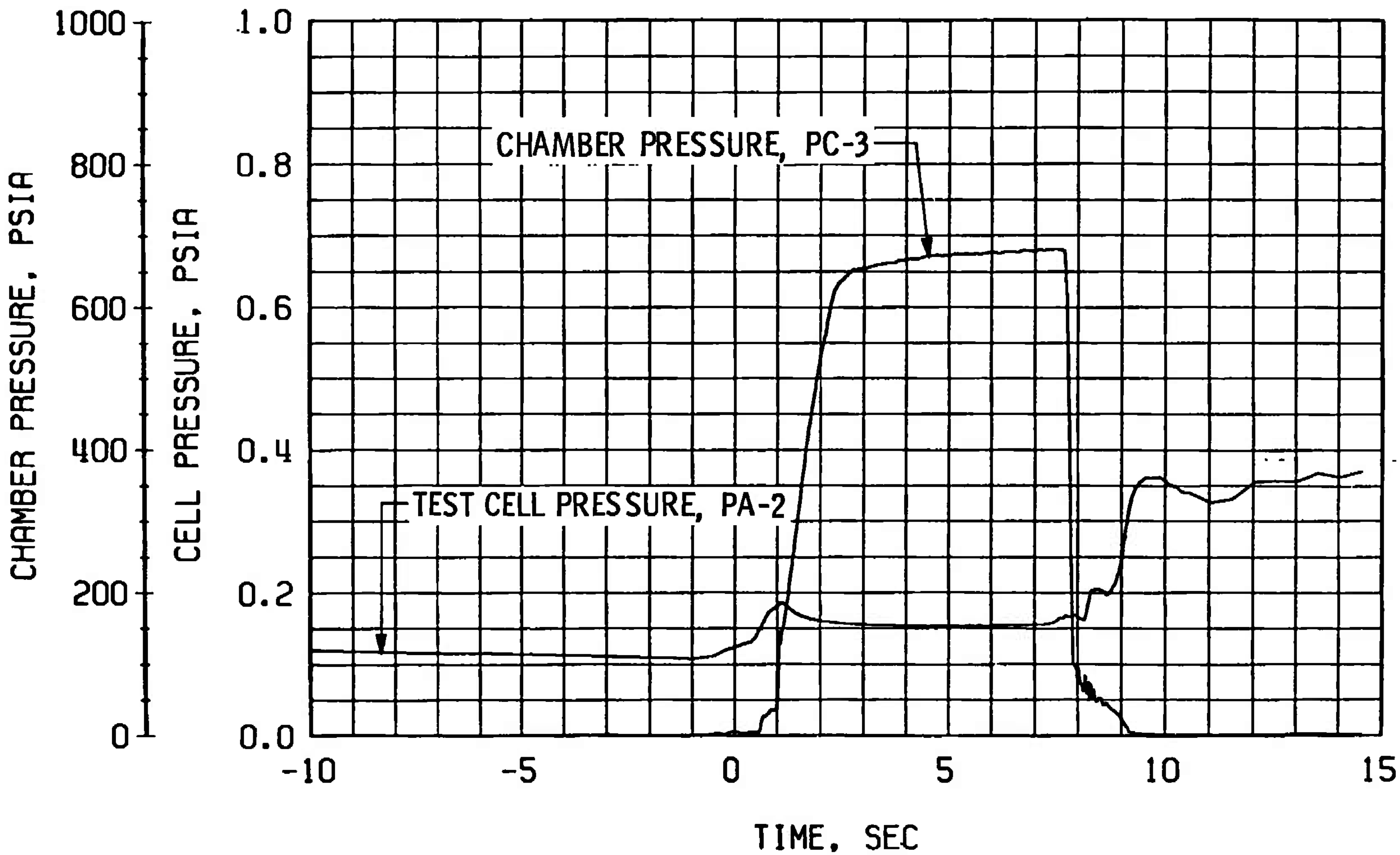


Fig. 48 Engine Ambient and Combustion Chamber Pressures, Firing 19D

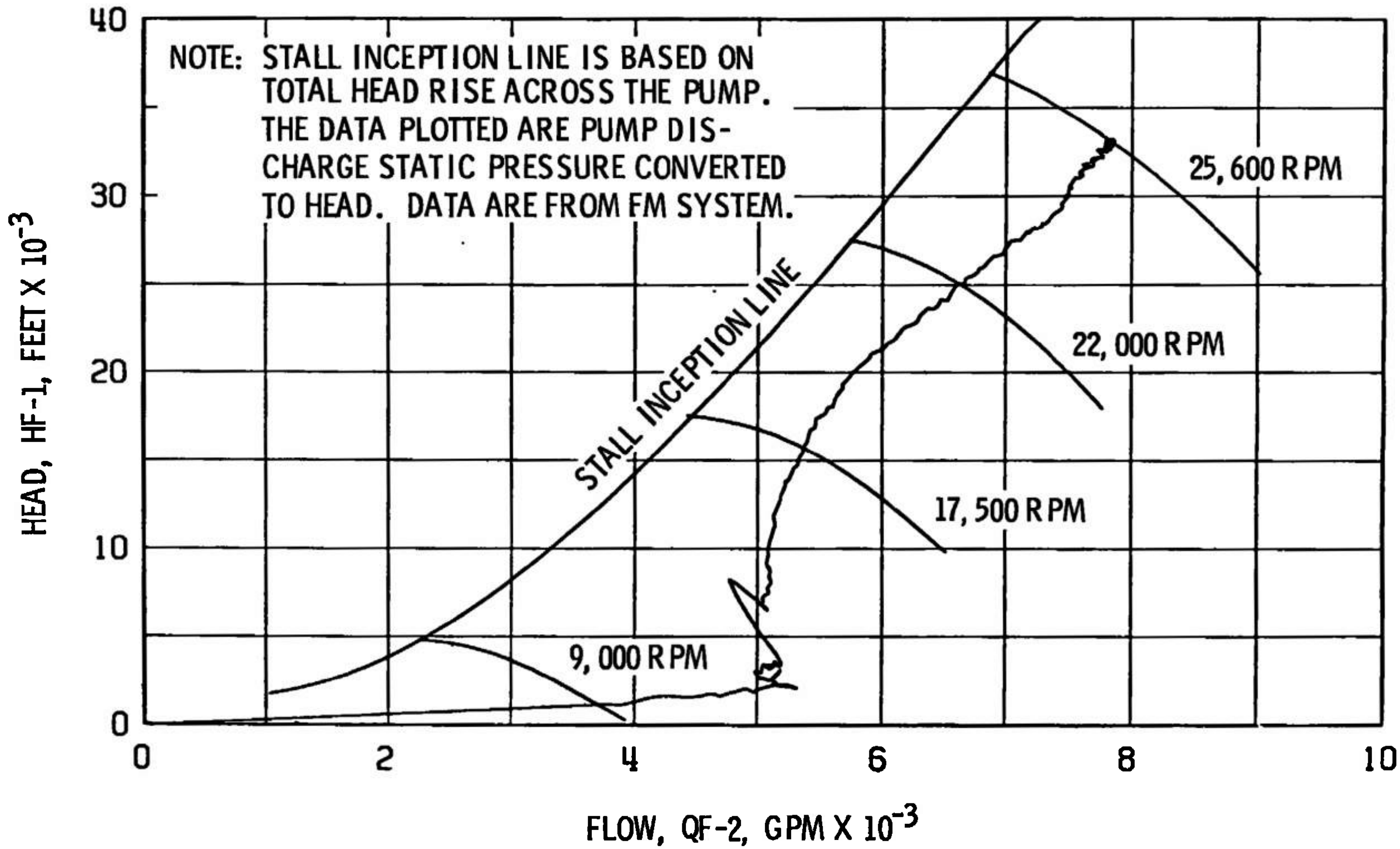
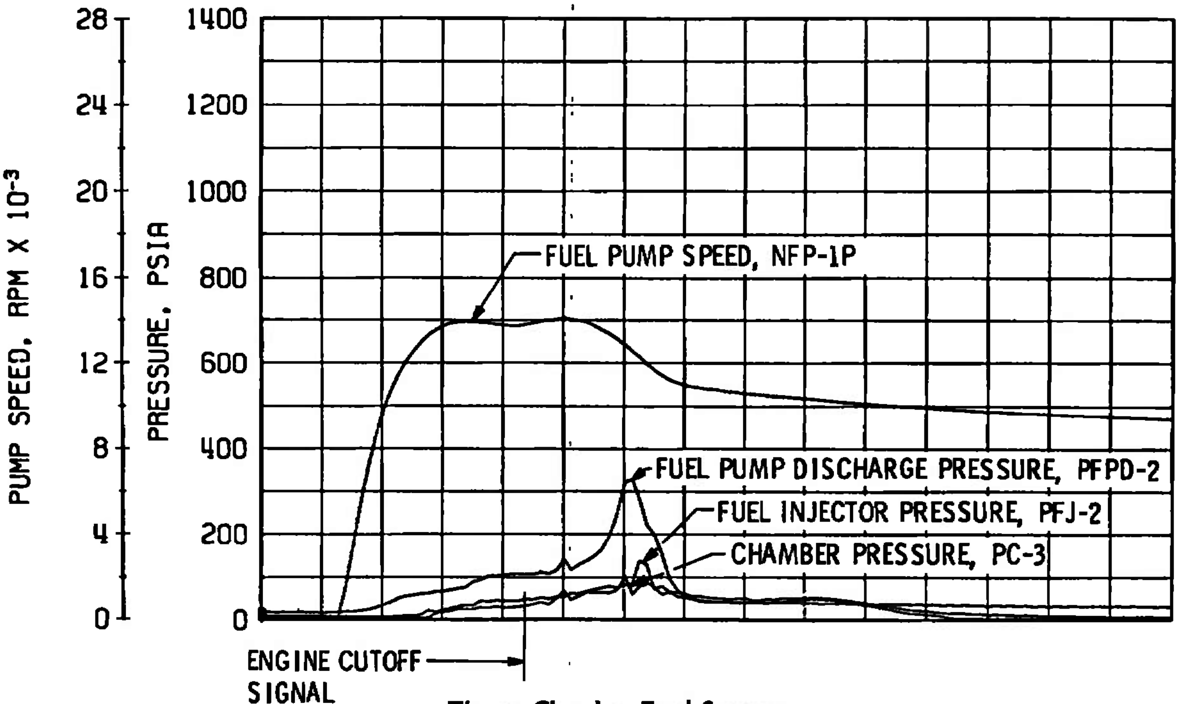
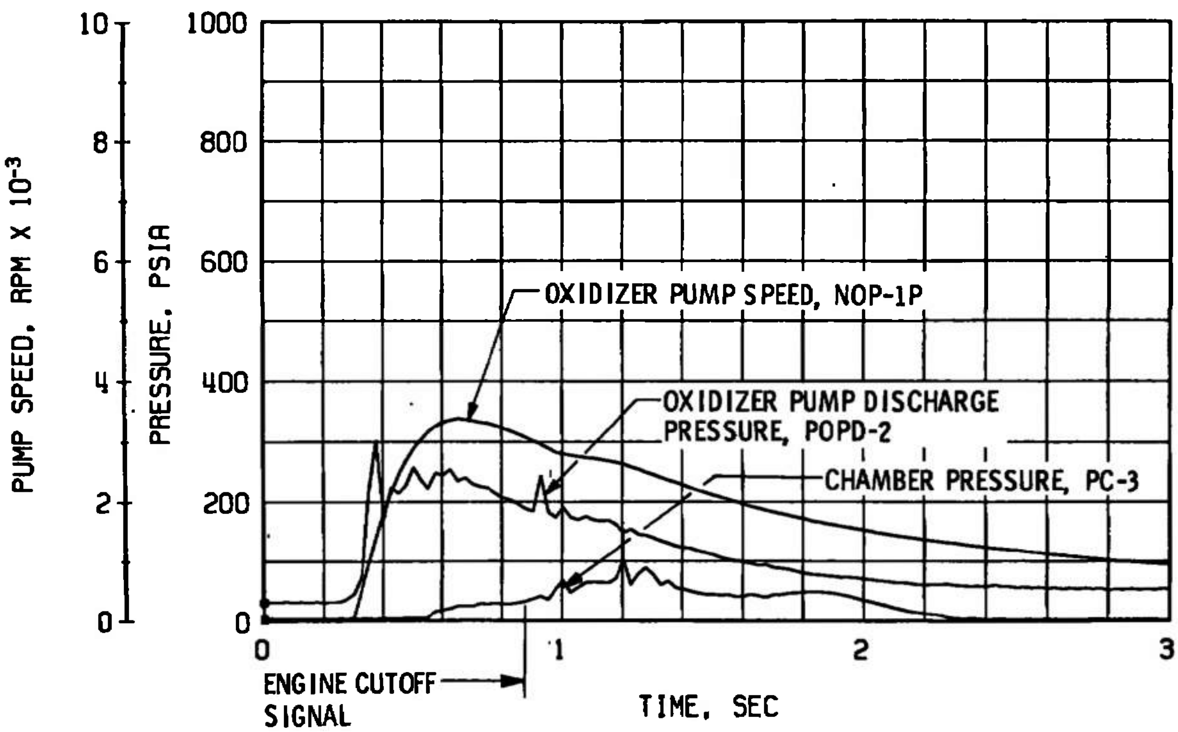


Fig. 49 Fuel Pump Start Transient Performance, Firing 19D

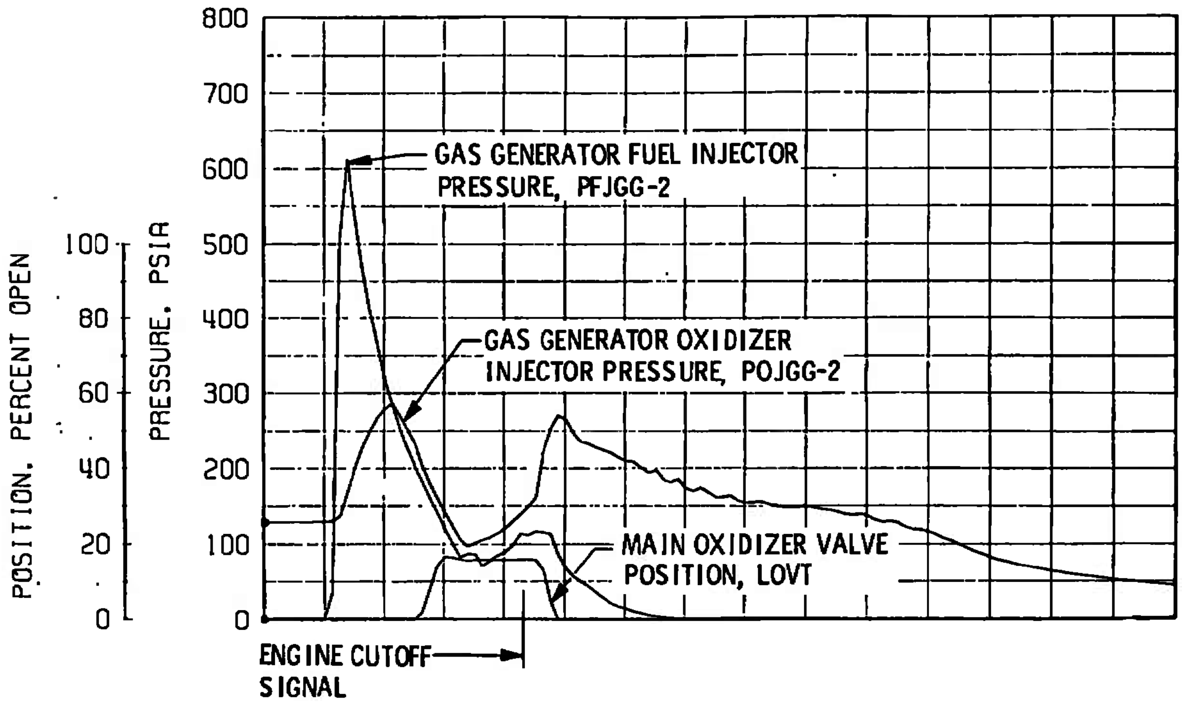


a. Thrust Chamber Fuel System

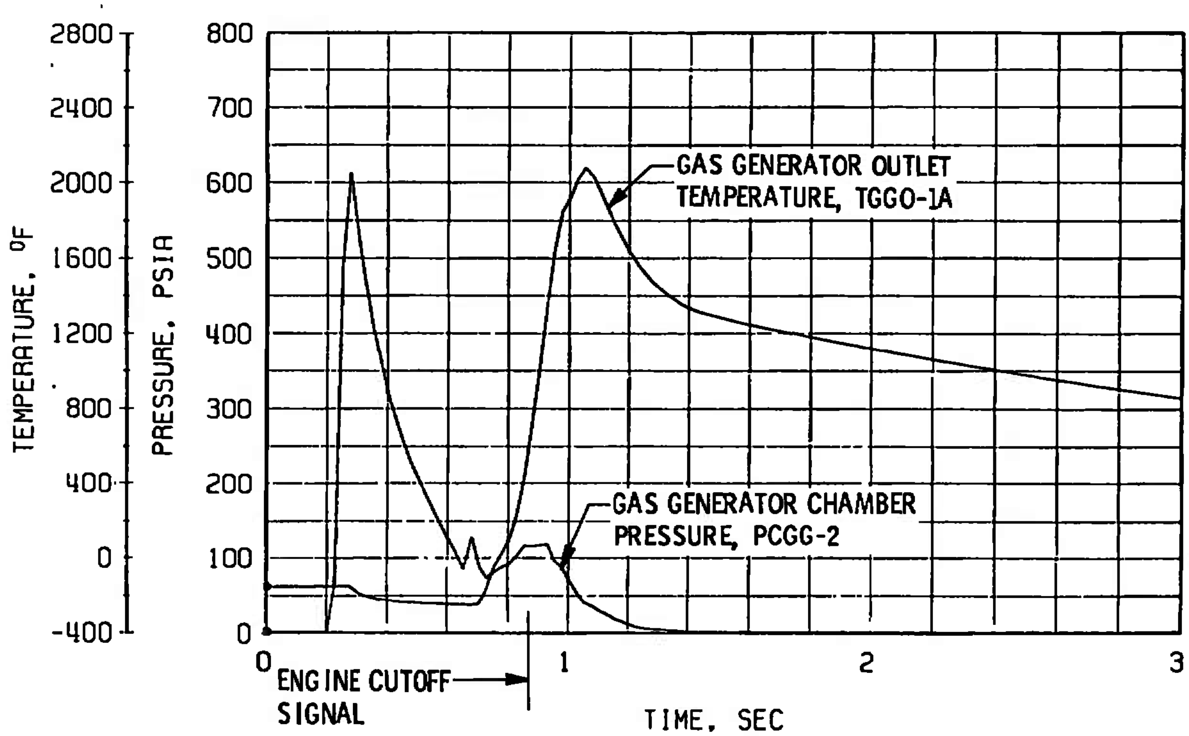


b. Thrust Chamber Oxidizer System

Fig. 50 Engine Transient Operation, Firing 19E

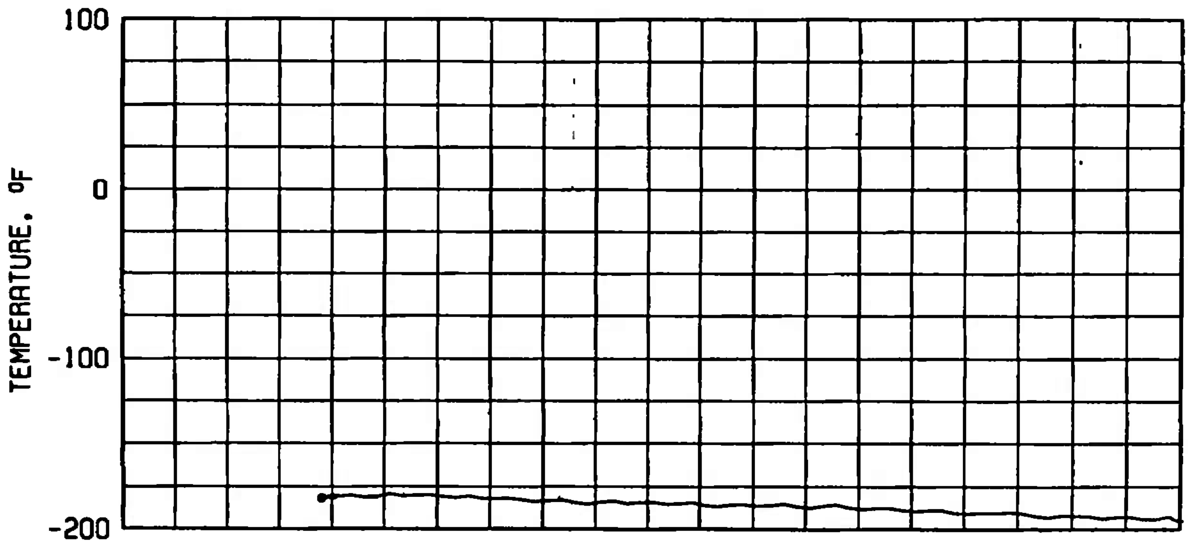


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position

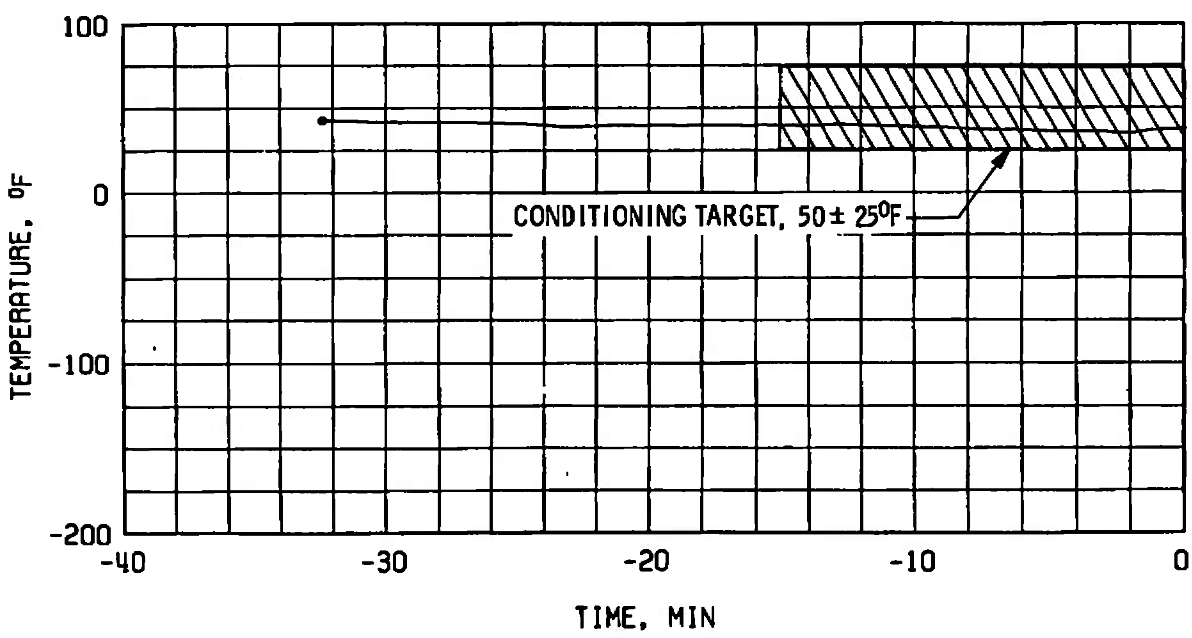


d. Gas Generator Chamber Pressure and Temperature

Fig. 50 Concluded

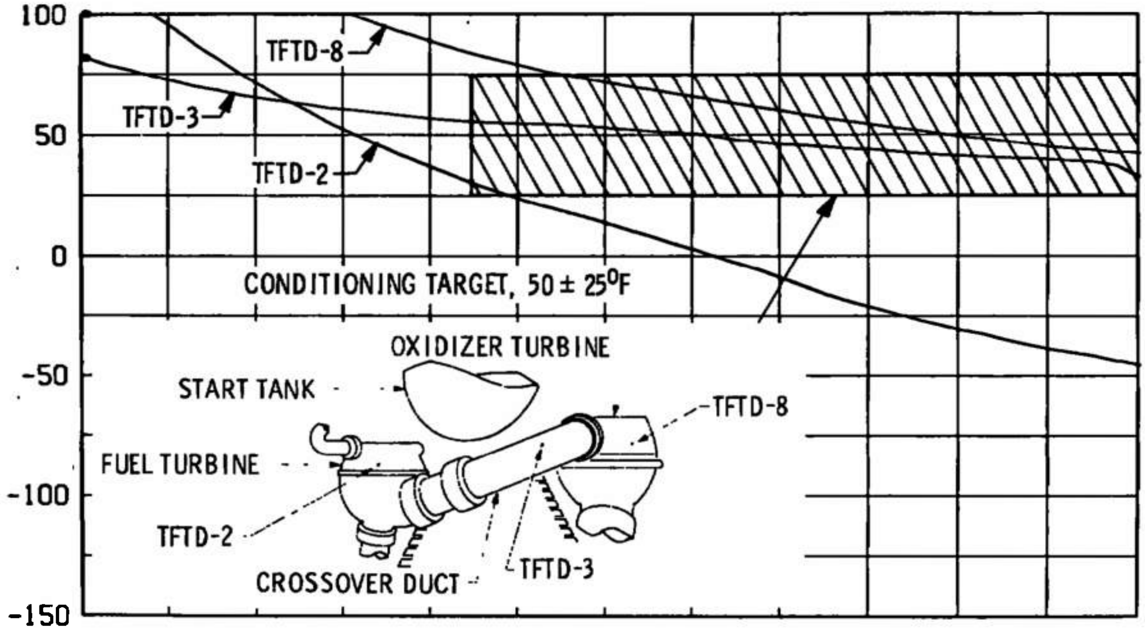


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

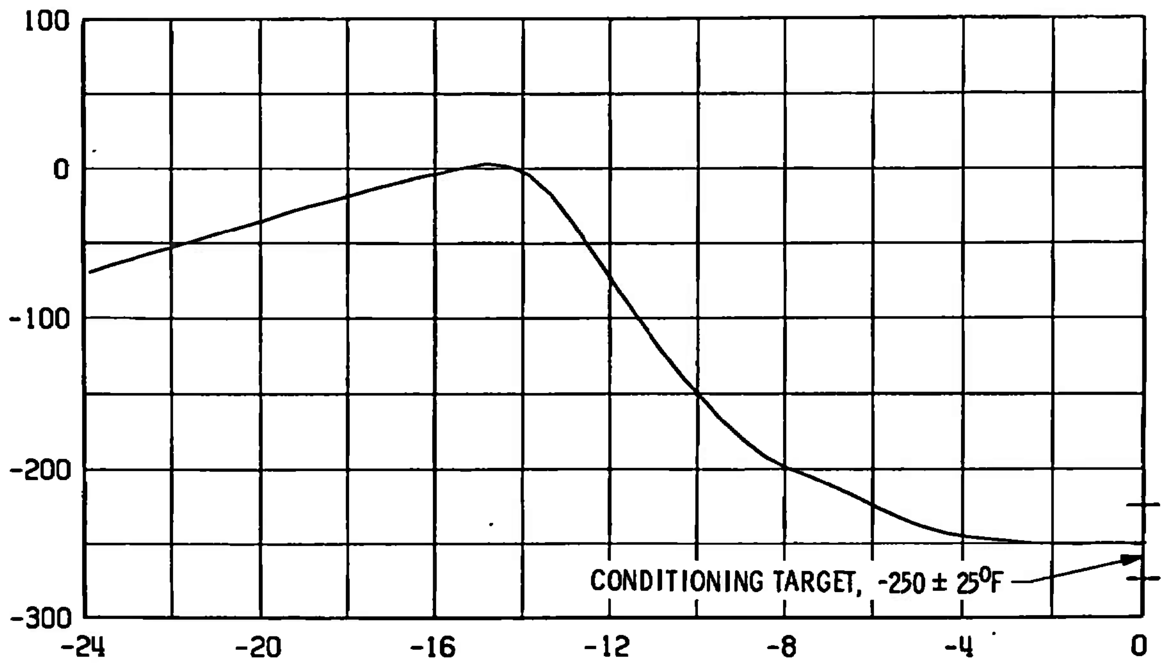


b. Start Tank Discharge Valve, TSTDVOC

Fig. 51 Thermal Conditioning History of Engine Components, Firing 19E



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 51 Concluded

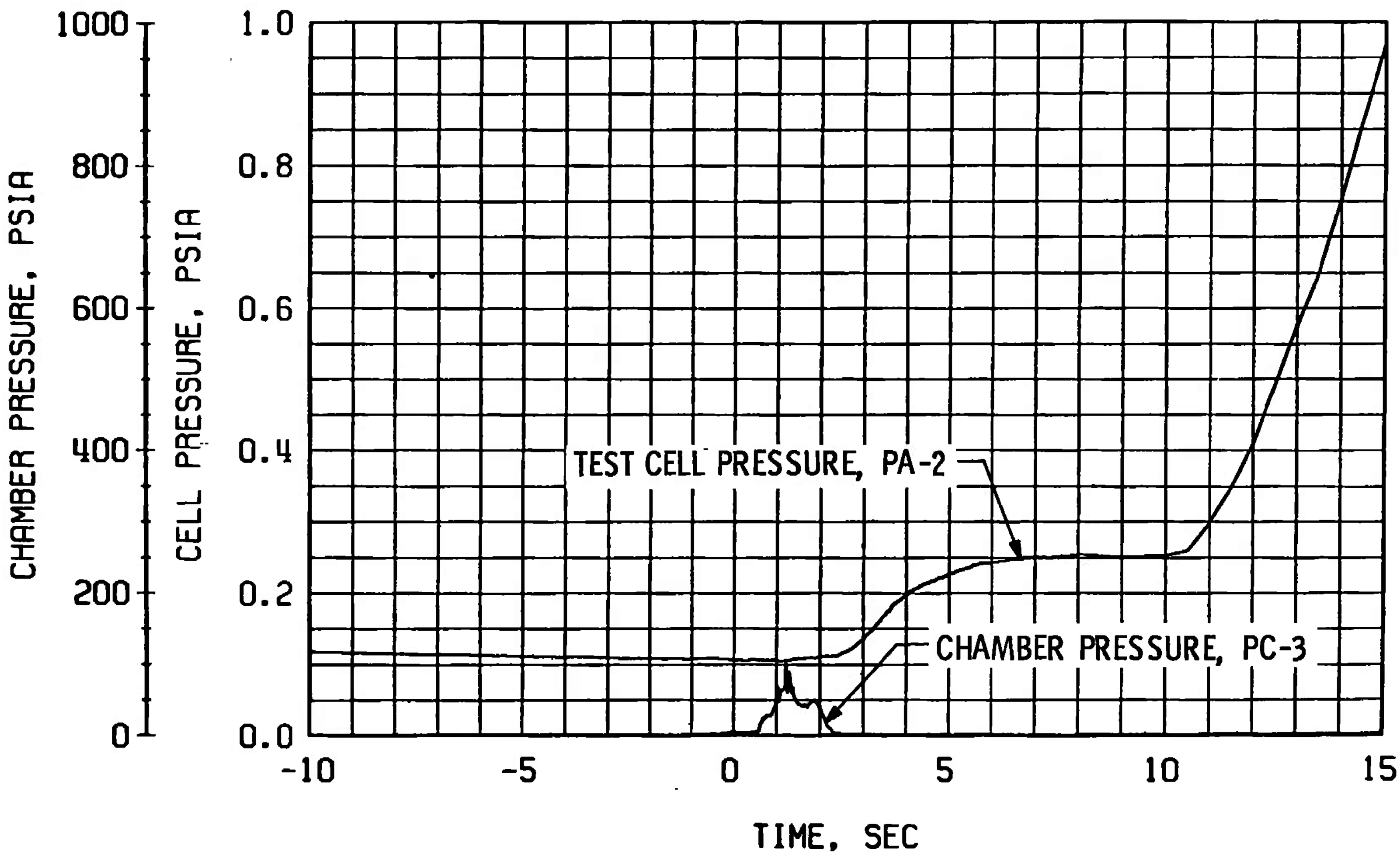


Fig. 52 Engine Ambient and Combustion Chamber Pressures, Firing 19E

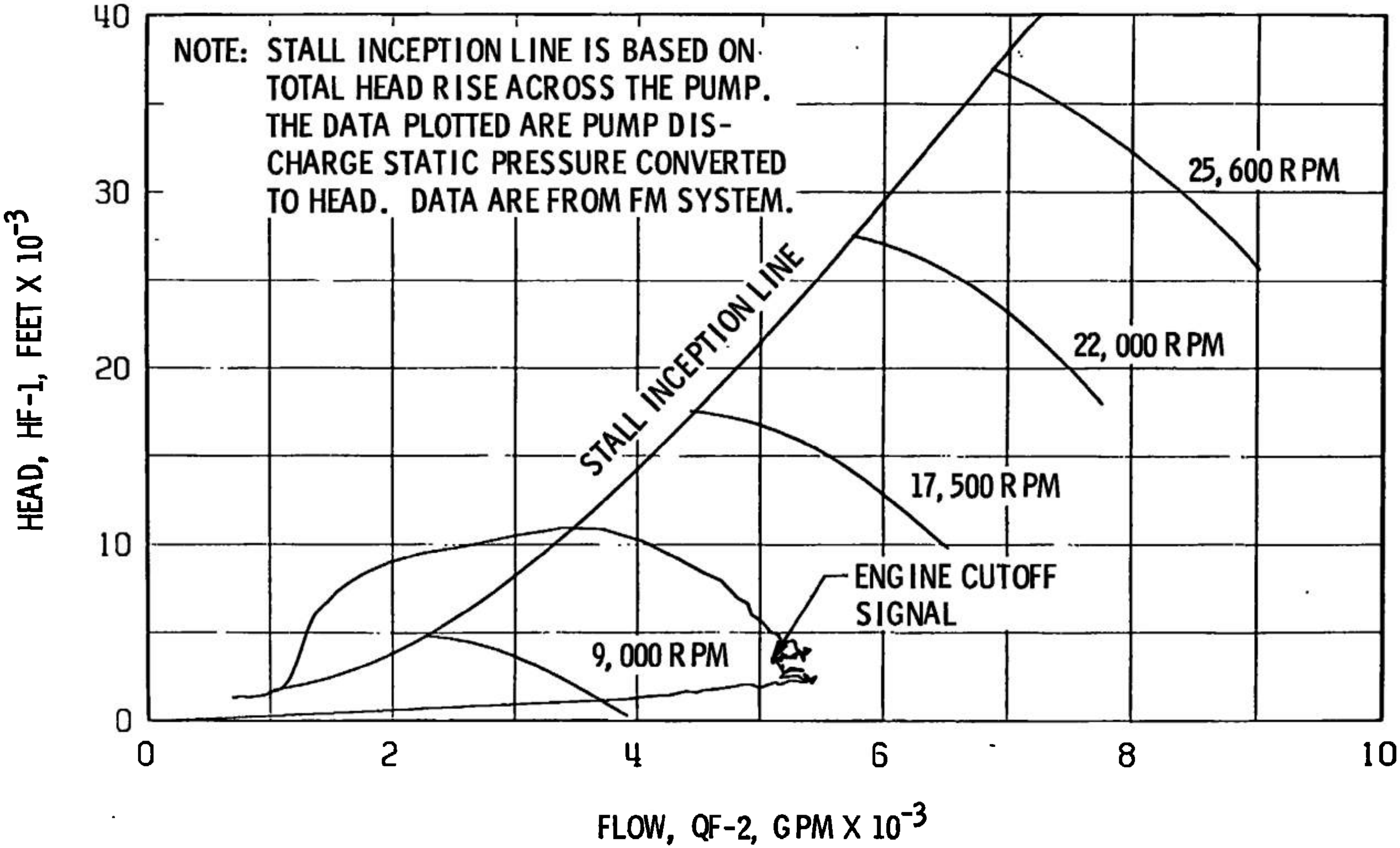


Fig. 53 Fuel Pump Start Transient Performance, Firing 19E

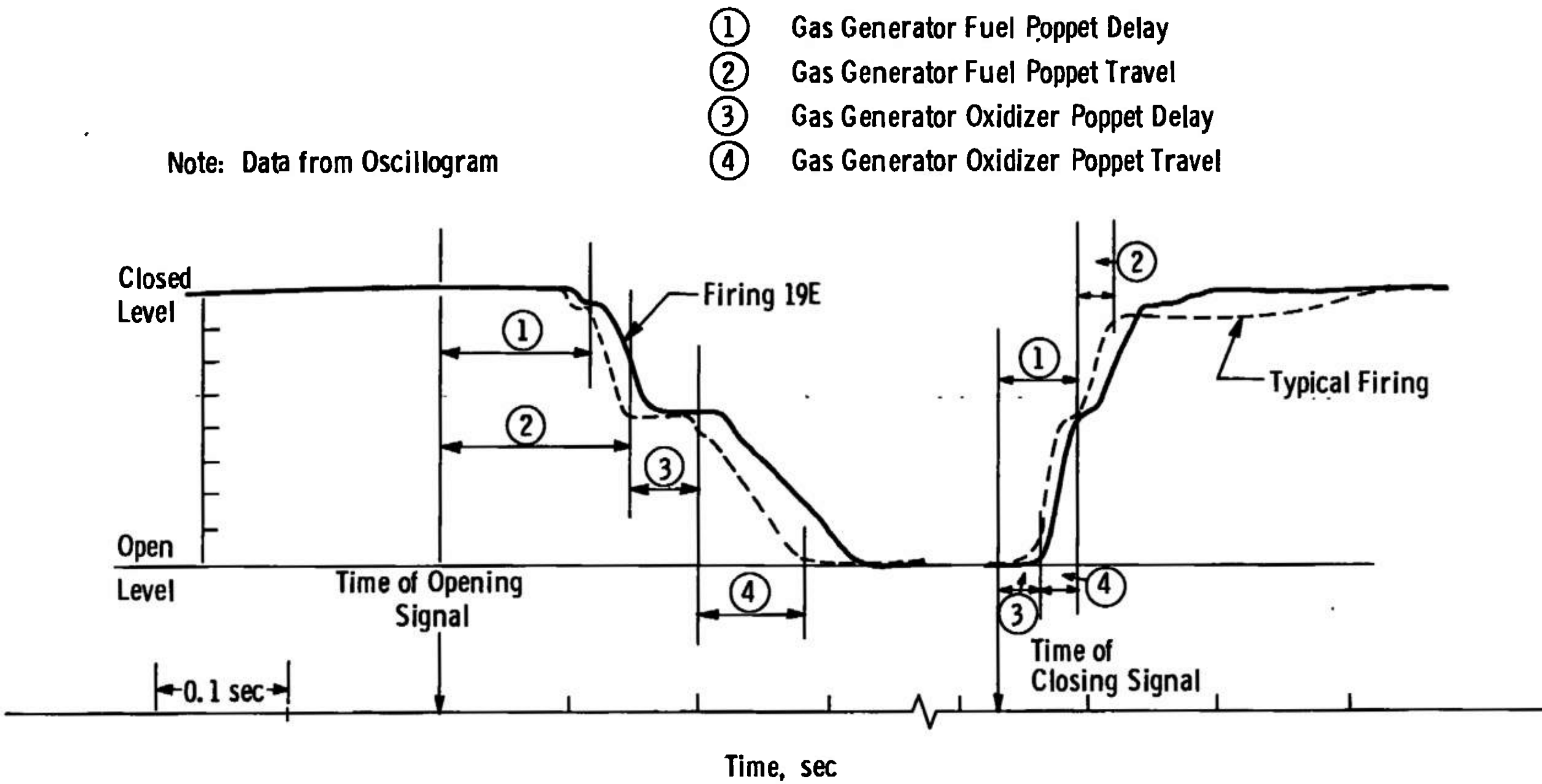


Fig. 54 Gas Generator Control Valve Postition, Firing 19E

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	459000-171	4078258
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0036
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4076827
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	409973	4077271
Gas Generator Control Valve	309040	4076768
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve	409930	4081831
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure Actuated Purge Control Valve	557823	4075865
Pressure Actuated Shutdown Valve	557817	4067200
Start Tank Fill/Refill Valve	558000	4072399
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	329

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.468		Installed on engine before shipment to AEDC
Gas Generator Oxidizer Supply Line	RD251-4106	0.268		Installed on engine before shipment to AEDC
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430	November 17, 1967	Accomplished to lower engine performance to model specifications
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.0		Installed on engine before shipment to AEDC
Main Oxidizer Valve Closing Control Line	556443	0.0267	October 18, 1967	Nonthermostatic
Augmented Spark Igniter Oxidizer Supply Line	406361	0.150	October 20, 1967	Sized per S-II specifications

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-17 AND J4-1801-19)

Modification Number	Completion Date	Description of Modification
	Test J4-1801-17 11/27/67	
RFD[1] 78-67	November 22, 1967	Replaced oxidizer turbopump turbine wheels with heavier turbine wheels
	Test J4-1801-18 12/1/67	
None		
	Test J4-1801-19 12/7/67	
None		

[1] RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-17 AND J4-1801-19)

Replacement	Completion Date	Comment Replaced
	Test J4-1801-17 11/27/67	
UCR[1]-007330	November 16, 1967	Fuel Turbine Shaft Seal
	Test J4-1801-18 12/1/67	
UCR-007332	November 28, 1967	Main Oxidizer Valve
UCR-007335	November 29, 1967	Start Tank Discharge Valve
UCR-007336	November 29, 1967	Oxidizer Turbine Bypass Valve
	Test J4-1801-19 12/7/67	
None		

[1] UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

		Time, min (t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10)
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min Propellant Drop 2-min Minimum Following Recirculation 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min On at Engine Cutoff 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to 15 min
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	On at Engine Cutoff 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	[1]
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient	
Start Tank Discharge Valve Temperature Conditioning	Helium; -300°F to Ambient	46 min

[1]Conditioning temperature to be maintained for the last 15 min of prefire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1901-			17A Target	17A Actual	18A Target	18A Actual	18B Target	18B Actual	18C Target	18C Actual	18D Target	18D Actual
Firing Date/Time of Day, hr			11-27-67	08:40	12-1-67	10:58	12-1-67	12:22	12-1-67	14:02	12-1-67	15:52
Pressure Altitude at Engine Start, ft			100,000	93,000	100,000	11,000	100,000	106,000	100,000	104,000	100,000	106,000
Firing Duration, sec (1)			30.0	27.58	30.0	30.07	5.0	5.09	5.0	5.09	5.0	5.09
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia		33.5^{+1}_{-0}	33.7	33.5^{+1}_{-0}	33.9	33.5^{+1}_{-0}	34.3	33.5^{+1}_{-0}	33.3	38.0 ± 1	38.2
	Temperature, °F		-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-420.9	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.6	-421.4 ± 0.4	-421.8
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia		33^{+1}_{-0}	33.1	33.0^{+1}_{-0}	32.5	45.0 ± 1	45.7	45.0 ± 1	48.0	45.1 ± 1	44.5
	Temperature, °F		-294.5 ± 0.4	-295.1	-294.5 ± 0.4	-294.7	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.0	-294.5 ± 0.4	-294.9
Start Tank Conditions at Engine Start	Pressure, psia		1250 ± 10	1244	1250 ± 10	1248	1400 ± 10	1405	1400 ± 10	1403	1400 ± 10	1390
	Temperature, °F		-140 ± 10	-141	-140 ± 10	-148	-240 ± 10	-243	-240 ± 10	-242	-140 ± 10	-145
Helium Tank Conditions at Engine Start	Pressure, psia		---	2943	---	3160	---	2695	---	2987	---	3380
	Temperature, °F		---	-145	---	-164	---	-248	---	-258	---	-165
Thrust Chamber Temperature Conditions at Engine Start, °F		Throat, TTC-1P	-250 ± 15	-252	-250 ± 25	-260	-150^{+20}_{-10}	-153	-250 ± 25	-250	-250 ± 25	-249
		Average	---	-257	---	-270	---	-239	---	-298	---	-294
Crossover Duct Temperature at Engine Start, °F (2)		TPTD-2	-100^{+25}_{-0}	-100	-100^{+25}_{-0}	-87	30 ± 25	40	30 ± 25	30	30 ± 25	30
		TPTD-3	-100^{+25}_{-0}	-98	-100^{+25}_{-0}	-76	30 ± 15	63	30 ± 25	36	30 ± 25	33
		TPTD-8	-100^{+25}_{-0}	-88	-100^{+25}_{-0}	-92	30 ± 15	40	30 ± 25	38	30 ± 25	39
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F			---	-10	---	0	---	-5	---	-11	---	-5
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F			-40^{+0}_{-20}	-66	-40^{+0}_{-20}	-78	-150^{+0}_{-60}	-160	-150^{+0}_{-60}	-175	-150^{+0}_{-60}	-180
Fuel Lead Time, sec (1)			1.0 ± 0.1	1.001	1.0 ± 0.1	1.002	1.0 ± 0.1	1.002	1.0 ± 0.1	1.002	1.0 ± 0.1	1.000
Propellant in Engine Time, min			40	72	40	51	60	62	60	99	60	61
Propellant Recirculation Time, min			10	12	10	13	10	13	10	10	10	11
Prevalve Sequencing Logic			Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start	TOBS-2A		---	4	---	14	---	10	---	11	---	12
Start Tank Discharge Valve Body Temperature at Engine Start, °F (2)			50 ± 25	32	50 ± 25	42	50 ± 25	43	50 ± 25	18	50 ± 25	33
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 (1)			--- / ---	20 / 1.028	--- / ---	32 / 1.031	--- / ---	64 / 0.980	--- / ---	131 / 0.970	--- / ---	46 / 0.986
Gas Generator Outlet Temperature, °F	Initial Peak		---	1300	---	1345	---	1735	---	1900	---	1855
	Second Peak		---	---	---	---	---	1405	---	1360	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)			---	1.027	---	1.042	---	0.962	---	0.977	---	0.888
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)			---	0.961	---	1.004	---	1.038	---	1.031	---	1.035
Main-Stage Pressure No. 2 "O.K.", sec (Ref. t_0) (1)			---	1.812	---	1.662	---	1.632	---	1.692	---	1.643
550-psia Chamber Pressure Attained, sec (Ref. t_0)			---	2.177	---	1.241	---	1.930	---	2.016	---	1.932
Propellant Utilization Valve Position at Engine Start, Engine Start/t_0 + 10 sec			Null / Closed	Null / Closed	Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Firing Number, J4-1901-			18E Target	18E Actual	19A Target	19A Actual	19B Target	19B Actual	19C Target	19C Actual	19D Target	19D Actual	19E Target	19E Actual
Firing Date/Time of Day, hr			12-1-67	17:31	12-7-67	12:14	12-7-67	11:31	12-7-67	14:30	12-7-67	18:28	12-7-67	19:02
Pressure Altitude at Engine Start, ft			100,000	105,000	100,000	90,000	100,000	106,000	100,000	106,000	100,000	110,000	100,000	110,100
Firing Duration, sec (1)			M/S ± 0.4	M/S ± 0.4	32.5	32.38	7.5	7.50	7.5	7.58	7.5	7.50	M/S + 0.4	M/S + 0.43
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia		33.5^{+1}_{-0}	33.0	33.5^{+1}_{-0}	27.3	25.5^{+1}_{-0}	25.7	21.5^{+1}_{-0}	25.9	25.5^{+1}_{-0}	25.7	21.5^{+1}_{-0}	21.1
	Temperature, °F		-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.3	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.1	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-420.9
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia		28.0 ± 1	28.4	33^{+1}_{-0}	33.3	45 ± 1	44.1	45 ± 1	44.4	45 ± 1	44.1	28 ± 1	28.1
	Temperature, °F		-295.0 ± 0.4	-295.1	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.4	-294.5 ± 0.4	-294.3	-294.5 ± 0.4	-294.6	-295.0 ± 0.4	-295.0
Start Tank Conditions at Engine Start	Pressure, psia		1400 ± 10	1403	1200 ± 10	1182	1100 ± 10	1306	1370 ± 10	1378	1200 ± 10	1208	1400 ± 10	1403
	Temperature, °F		-240 ± 10	-243	-200 ± 10	-194	-300 ± 10	-298	-270 ± 10	-274	-300 ± 10	-299	-240 ± 10	-241
Helium Tank Conditions at Engine Start	Pressure, psia		---	3025	---	3316	---	3290	---	2495	---	1852	---	3290
	Temperature, °F		---	-242	---	-216	---	-330	---	-272	---	-292	---	-240
Thrust Chamber Temperature Conditions at Engine Start, °F		Throat, TTC-1P	-150^{+20}_{-10}	-153	-250 ± 25	-243	-150^{+25}_{-0}	-144	-150^{+25}_{-0}	-134	-250 ± 25	-252	-250 ± 25	-230
		Average	---	-208	---	-253	---	-182	---	-193	---	-294	---	-231
Crossover Duct Temperature at Engine Start, °F (2)		TPTD-2	30 ± 25	31	-100^{+25}_{-0}	-85	20 ± 25	45	30 ± 25	43	30 ± 25	43	30 ± 25	-46
		TPTD-3	30 ± 25	63	-100^{+25}_{-0}	-81	30 ± 25	61	30 ± 25	59	30 ± 25	63	30 ± 25	33
		TPTD-8	30 ± 25	45	-101^{+25}_{-0}	-97	10 ± 25	48	30 ± 25	48	30 ± 25	49	30 ± 25	43
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F			---	11	---	-6	---	-4	---	-6	---	11	---	-22
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F			---	-148	-40^{+0}_{-20}	-81	-150^{+0}_{-60}	-186	-150^{+0}_{-60}	-187	-150^{+0}_{-60}	-186	---	164
Fuel Lead Time, sec (1)			1.0 ± 0.1	1.003	1.0 ± 0.1	1.00	1.0 ± 0.1	1.001	1.0 ± 0.1	1.001	1.0 ± 0.1	1.001	1.0 ± 0.1	1.001
Propellant in Engine Time, min			30	37	40	107	60	77	60	60	60	238	30	35
Propellant Recirculation Time, min			10	11	10	12	10	16	10	10	10	10	10	10
Prevalve Sequencing Logic			Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start	TOBS-2A		---	15	---	19	---	15	---	13	---	24	---	8
Start Tank Discharge Valve Body Temperature at Engine Start, °F (2)			50 ± 25	32	50 ± 25	42	50 ± 25	39	50 ± 25	40	30 ± 25	43	10 ± 25	27
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 (1)			--- / ---	--- / ---	--- / ---	35 / 1.028	--- / ---	20 / 0.964	--- / ---	20 / 0.915	--- / ---	35 / 0.984	--- / ---	--- / 1.2
Gas Generator Outlet Temperature, °F	Initial Peak		---	1390	---	1285	---	1610	---	1875	---	1960	---	2060 at t_0 + 1.050
	Second Peak		---	---	---	---	---	---	---	---	---	1320	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) (1)			---	N/A	---	1.035	---	0.965	---	0.957	---	0.990	---	N/A
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)			---	N/A	---	0.995	---	1.076	---	1.075	---	1.024	---	N/A
Main-Stage Pressure No. 2 "O.K.", sec (Ref. t_0) (1)			---	N/A	---	1.830	---	1.598	---	1.596	---	1.720	---	N/A
550-psia Chamber Pressure Attained, sec (Ref. t_0)			---	N/A	---	2.208	---	1.950	---	1.939	---	2.058	---	N/A
Propellant Utilization Valve Position at Engine Start, Engine Start/t_0 + 10 sec			Null / ---	Null / ---	Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes: (1) Data reduced from oscillogram.

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

TABLE VII
ENGINE VALVE TIMINGS

Start

Firing Number J4-1001-	Start Tank Discharge 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	Main Fuel Valve: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
17A	0	0.132	0.123	0.448	0.093	0.215	-1.001	0.053	0.062
B									
C									
D									
Final Sequence	0.0	0.093	0.112	0.448	0.098	0.213	-1.004	0.045	0.070
18A	0.0	0.142	0.120	0.447	0.091	0.239	-1.002	0.050	0.069
18B	0.0	0.144	0.133	0.447	0.087	0.236	-1.002	0.055	0.065
18C	0.0	0.142	0.138	0.445	0.090	0.230	-1.002	0.055	0.066
18D	0.0	0.146	0.130	0.445	0.088	0.234	-1.009	0.055	0.064
18E	0.0	0.145	0.135	0.444	0.090	0.235	-1.003	0.056	0.060
Final Sequence	0.0	0.100	0.112	0.448	0.094	0.248	-1.000	0.048	0.072
19A	0.0	0.138	0.115	0.450	0.089	0.217	-1.000	0.065	0.075
19B	0.0	0.142	0.124	0.448	0.088	0.215	-1.000	0.064	0.068
19C	0.0	0.142	0.133	0.446	0.090	0.230	-1.001	0.056	0.066
19D	0.0	0.142	0.121	0.449	0.087	0.212	-1.001	0.059	0.072
19E	0.0	0.146	0.130	0.445	0.088	0.238	-1.003	0.068	0.060
Final Sequence	0.0	0.097	0.110	0.448	0.094	0.215	-1.005	0.044	0.070

Start (continued)

Firing Number J4-1001-	Main Oxidizer Valve First Stage: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Main Oxidizer Valve Second Stage: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Gas Generator Fuel Poppet: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Gas Generator Oxidizer Poppet: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Oxidizer Turbine Bypass Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
17A	0.448	0.044	0.064	0.448	0.511	1.855	0.444	N/A	N/A	0.448	0.143	0.078	0.448	0.223	0.278
B															
C															
D															
Final Sequence	0.418	0.050	0.058	0.448	0.480	1.400	0.448	0.076	0.034	0.448	0.130	0.070	0.448	0.100	0.278
18A	0.417	0.060	0.045	0.447	0.517	1.810	0.447	0.109	0.029	0.447	0.180	0.073	0.447	0.238	0.270
18B	0.417	0.061	0.063	0.447	0.581	2.078	0.447	0.118	0.026	0.447	0.190	0.076	0.447	0.225	0.266
18C	0.415	0.060	0.051	0.445	0.586	2.080	0.445	0.116	0.030	0.446	0.180	0.077	0.445	0.225	0.270
18D	0.415	0.059	0.057	0.445	0.590	2.030	0.445	0.119	0.030	0.445	0.191	0.086	0.445	0.230	0.270
18E	0.444	0.066	0.063	0.444	N/A	N/A	0.444	0.115	0.032	0.444	0.197	0.084	0.444	0.230	N/A
Final Sequence	0.448	0.063	0.063	0.448	0.487	1.466	0.448	0.090	0.030	0.440	0.147	0.062	0.448	0.222	0.260
19A	0.450	0.056	0.056	0.450	0.541	1.860	0.450	0.111	0.027	0.450	0.181	0.082	0.450	0.236	0.275
19B	0.446	0.063	0.055	0.448	0.630	2.103	0.446	0.120	0.028	0.446	0.195	0.087	0.446	0.238	0.260
19C	0.445	0.060	0.062	0.445	0.630	2.125	0.445	0.120	0.028	0.445	0.194	0.087	0.445	0.230	0.270
19D	0.449	0.060	0.060	0.449	0.575	2.079	0.449	0.120	0.026	0.449	0.194	0.075	0.449	0.220	0.275
19E	0.445	0.067	0.060	0.445	N/A	N/A	0.443	0.127	0.033	0.443	0.211	0.100	0.443	0.230	N/A
Final Sequence	0.448	0.049	0.058	0.448	0.495	1.440	0.448	0.090	0.034	0.448	0.149	0.070	0.448	0.219	0.270

Shutdown

Firing Number J4-1001-	Main Fuel Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Main Oxidizer Valve: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Gas Generator Fuel Poppet: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Gas Generator Oxidizer Poppet: Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Oxidizer Turbine Bypass Valve: Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
17A	27.557	0.127	0.336	27.557	0.048	0.180	27.547	0.060	0.033	27.557	0.026	0.016	27.557	0.058	0.320
B															
C															
D															
Final Sequence	6.176	0.083	0.235	6.176	0.050	0.125	6.176	0.060	0.025	6.176	0.055	0.020	6.176	0.200	0.525
18A	30.074	0.128	0.110	30.074	0.050	0.159	30.016	0.052	0.030	30.074	0.030	0.012	30.074	0.230	0.490
18B	5.091	0.130	0.138	5.090	0.050	0.194	5.091	0.055	0.027	5.090	0.032	0.014	5.090	0.215	0.425
18C	5.089	0.132	0.170	5.088	0.062	0.104	5.081	0.055	0.022	5.089	0.032	0.013	5.088	0.210	0.400
18D	5.089	0.134	0.146	5.089	0.056	0.180	5.081	0.063	0.022	5.089	0.033	0.015	5.089	0.205	0.300
18E	0.875	0.100	0.182	0.875	N/A	N/A	0.871	0.070	0.030	0.875	0.040	0.020	0.875	N/A	N/A
Final Sequence	10.100	0.085	0.135	10.100	0.050	0.125	10.160	0.078	0.032	10.100	0.052	0.020	10.100	0.212	0.524
19A	32.578	0.136	0.361	32.578	0.053	0.171	32.578	0.054	0.038	32.578	0.029	0.013	32.578	0.233	0.460
19B	7.594	0.130	0.370	7.594	0.063	0.190	7.591	0.056	0.024	7.594	0.032	0.018	7.594	0.220	0.440
19C	7.593	0.132	0.348	7.593	0.061	0.188	7.553	0.057	0.030	7.593	0.032	0.012	7.503	0.222	0.438
19D	7.597	0.138	0.374	7.597	0.061	0.180	7.597	0.056	0.026	7.597	0.032	0.015	7.597	0.212	0.426
19E	0.874	0.100	0.340	0.874	N/A	N/A	0.874	0.073	0.037	0.874	0.033	0.027	0.874	N/A	N/A
Final Sequence	7.142	0.080	0.238	7.142	0.053	0.124	7.142	0.077	0.028	7.143	0.052	0.021	7.142	0.205	0.500

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 valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.
5. N/A - not applicable.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1901-		17A		18A		19A	
		Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	228,905	225,365	229,790	225,065	223,900	222,305
	Chamber Pressure, psia	767.9	753.9	762.4	753.5	752.9	744.9
	Mixture Ratio	5.468	5.435	5.491	5.441	5.490	5.471
	Fuel Weight Flow, lb_m/sec	81.95	80.83	81.58	81.03	80.49	79.79
	Oxidizer Weight Flow, lb_m/sec	449.10	439.32	447.15	440.88	441.99	439.54
	Total Weight Flow, lb_m/sec	530.05	520.16	528.73	521.91	522.15	516.33
Thrust Chamber Performance	Mixture Ratio	5.962	5.930	5.677	5.637	5.687	5.970
	Total Weight Flow, lb_m/sec	523.4	513.5	522.07	515.29	515.6	509.8
	Characteristic Velocity, ft/sec	8030	8036	7994	8004	7993	7997
Fuel Turbopump Performance	Pump Efficiency, percent	75.0	75.0	75.3	75.3	75.1	75.1
	Pump Speed, rpm	29,935	26,415	26,537	26,324	26,319	26,132
	Turbine Efficiency, percent	59.9	59.9	59.9	59.8	60.4	60.3
	Turbine Pressure Ratio	7.26	7.29	7.30	7.30	7.22	7.22
	Turbine Inlet Temperature, °F	1256	1232	1246	1220	1211	1191
	Turbine Weight Flow, lb_m/sec	6.99	9.92	6.66	9.62	6.53	9.49
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.1	80.3	80.2	80.3	80.2
	Pump Speed, rpm	8475	8405	8419	8365	8377	8323
	Turbine Efficiency, percent	47.6	47.4	47.2	47.2	47.3	47.2
	Turbine Pressure Ratio	2.65	2.64	2.65	2.95	2.93	2.63
	Turbine Inlet Temperature, °F	909	791	807	799	799	784
	Turbine Weight Flow, lb_m/sec	5.93	5.86	5.91	5.88	5.79	5.76
Gas Generator Performance	Mixture Ratio	0.973	0.959	0.967	0.951	0.946	0.934
	Chamber Pressure, psia	653.0	643.2	649.0	642.9	632.7	627.5

Note: 1) Site data is calculated from test data.
2) Normalized data is test data corrected to standard pump inlet and engine ambient pressure conditions.
3) Input data is test data averaged from 29 to 39 sec.
4) Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-17, 18, and 19 are tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature OK		On/Off	x		x		
EFPVC/$\bar{O}$	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
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	0-9000	x		x		
QF-2	Fuel	PFFA	0-9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0-9000	x		x		
QFRP	Fuel Recirculation		0- 160	x				
QO-1A	Oxidizer	POF	0-3000	x		x		
QO-2	Oxidizer	POFA	0-3000	x	x	x		
QORP	Oxidizer Recirculation		0- 50	x			x	
	Heat Flux		$\frac{w}{Sr.-cm^2}$					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0-7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Dishcarge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		**psia**					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASU	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFM1	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 100	x				
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1	Fuel Turbine Seal Purge Line		0 to 100	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				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		**psia**					
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank 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 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		**rpm**					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		**°F**					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to -200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x				

TABLE III-1 (Continued)

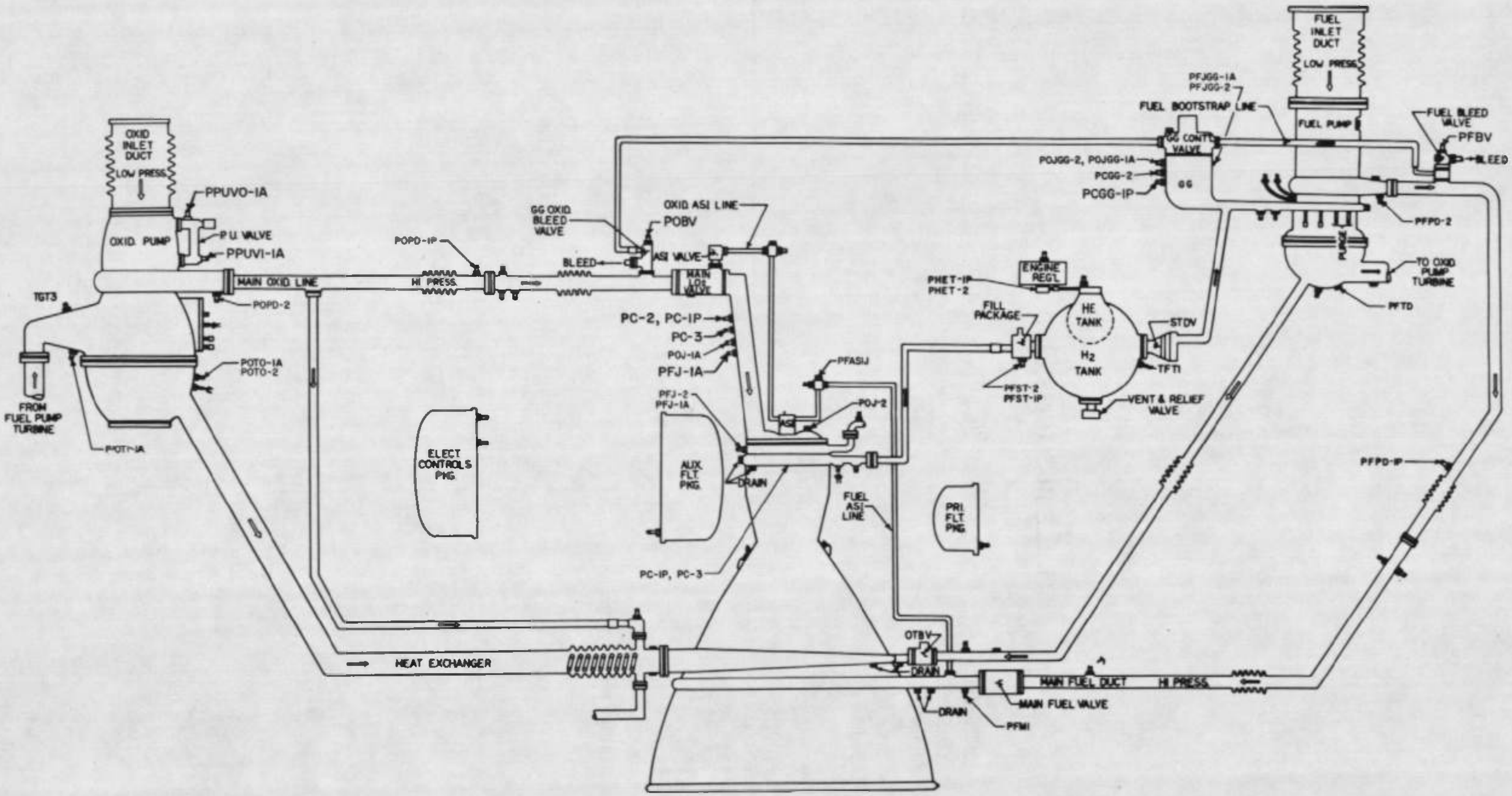
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-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-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +930	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to -1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x		
THET-1P	Helium Tank	NNTI	-350 to +100	x				x
TNODP	LOX Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
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	0 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				
TPCC	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to -500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to -300	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x			x	
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x			x	
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				

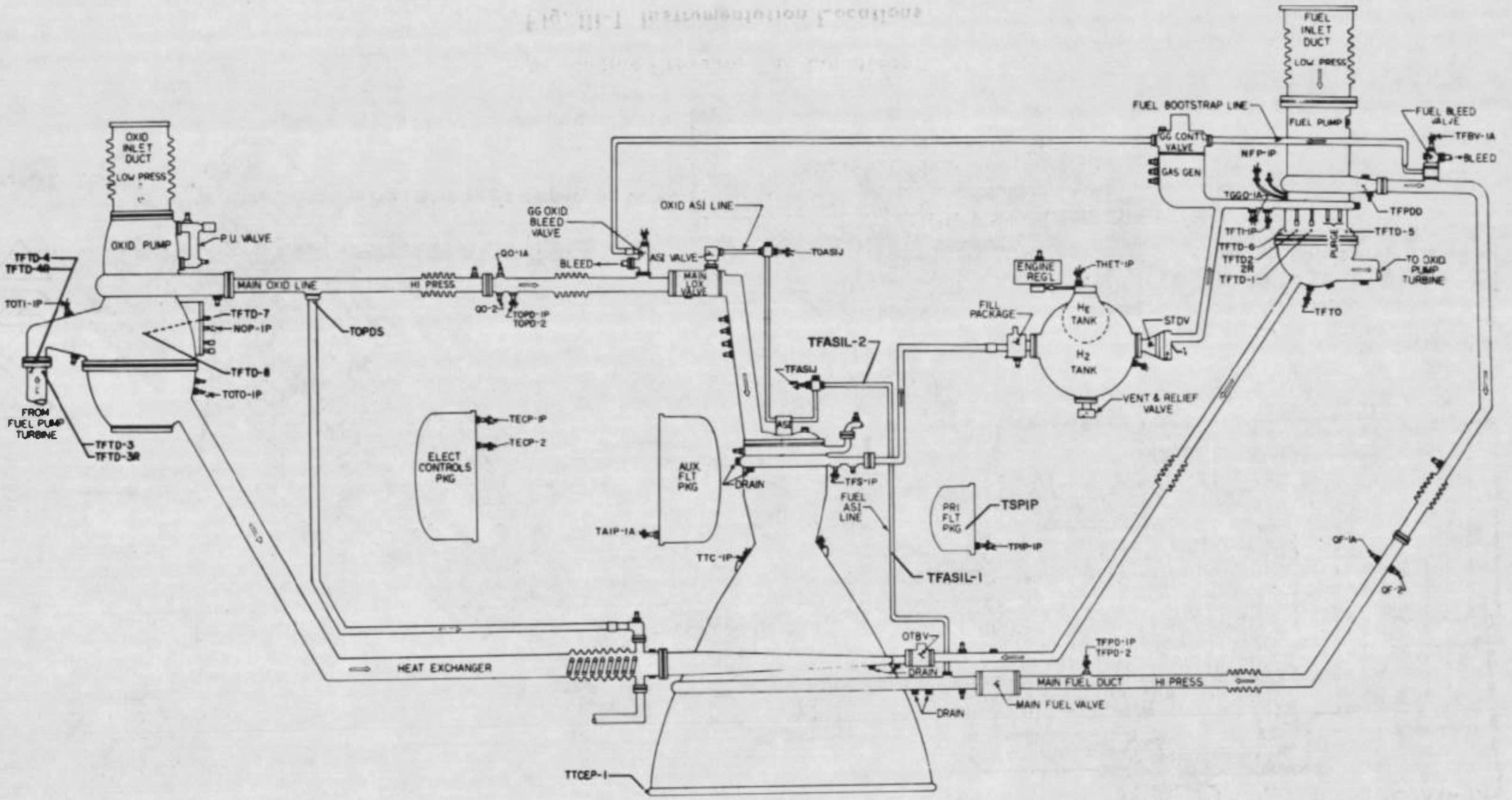
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Vibrations		g_{rms}					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		v					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



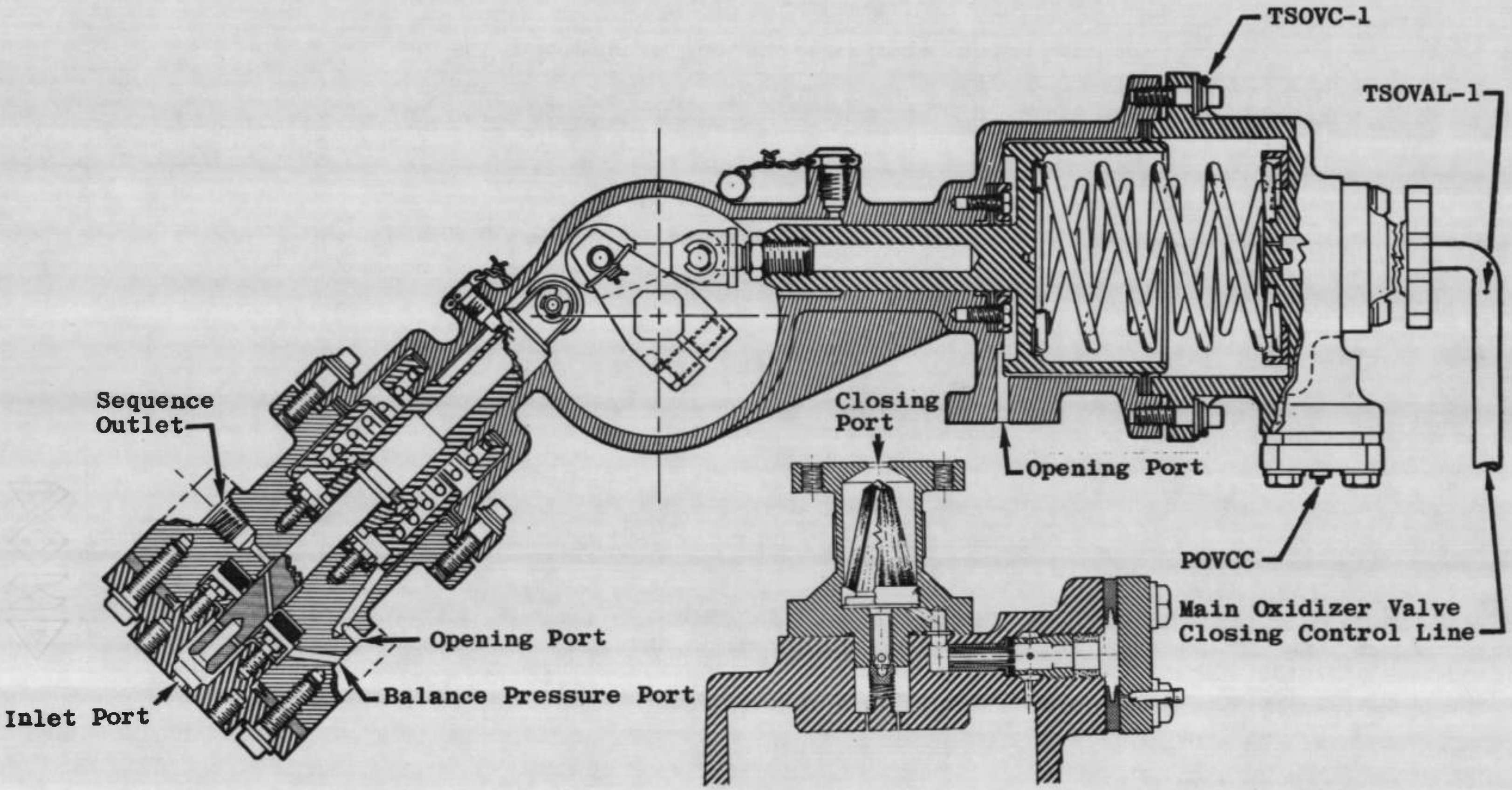
a. Engine Pressure Tap Locations

Fig. III-1 Instrumentation Locations

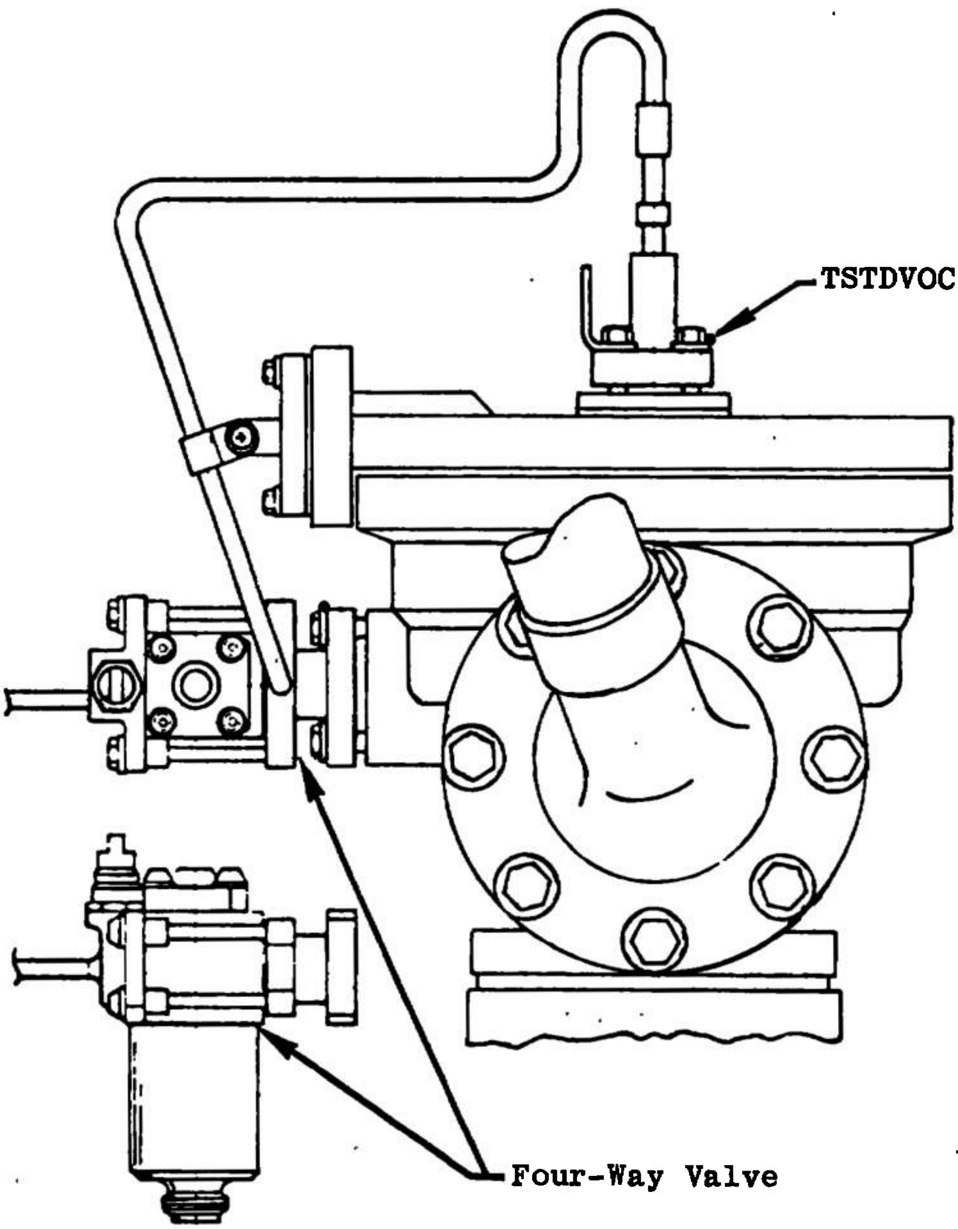


b. Engine Temperature, Flow, and Speed Instrumentation Locations

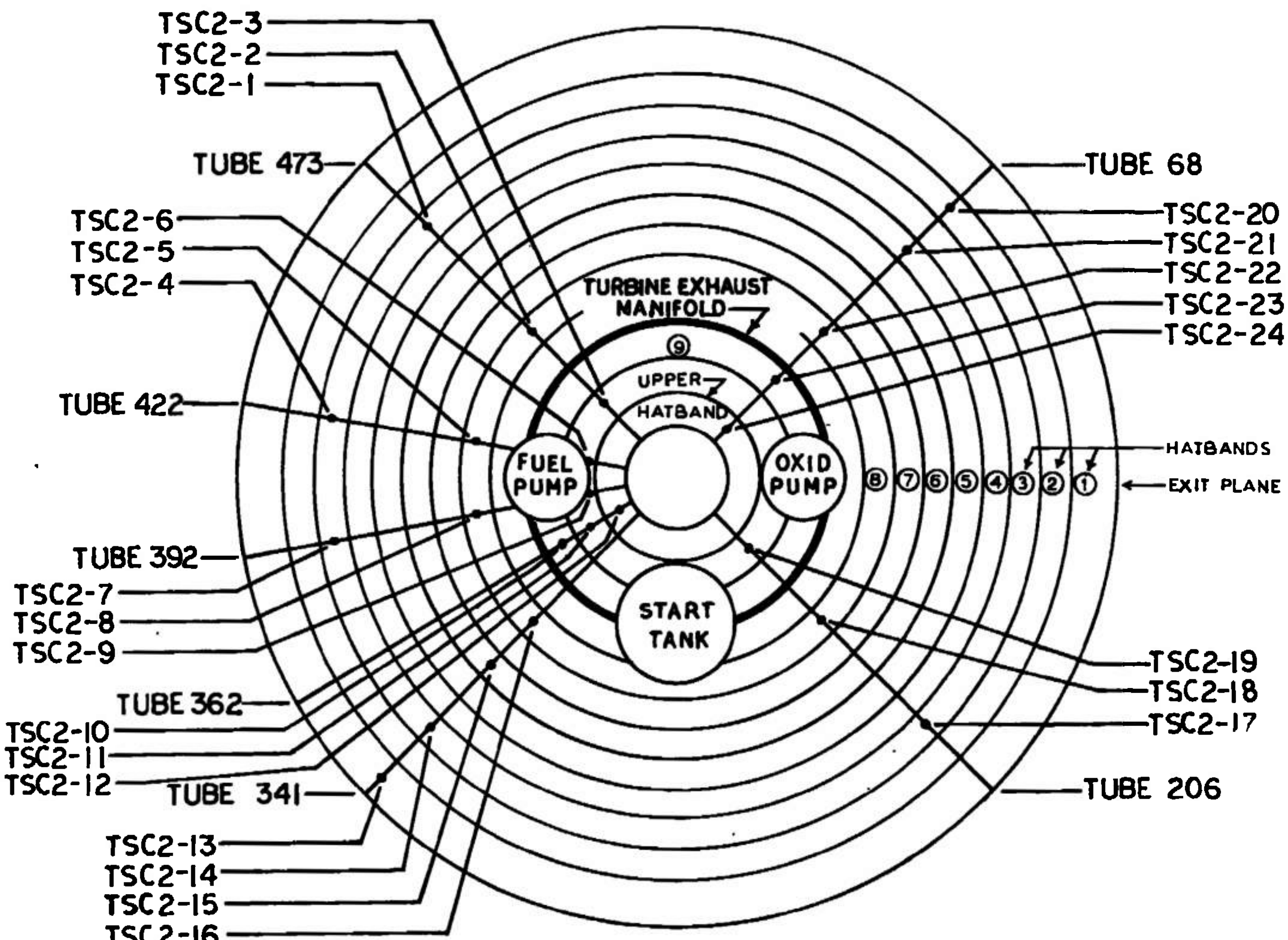
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued



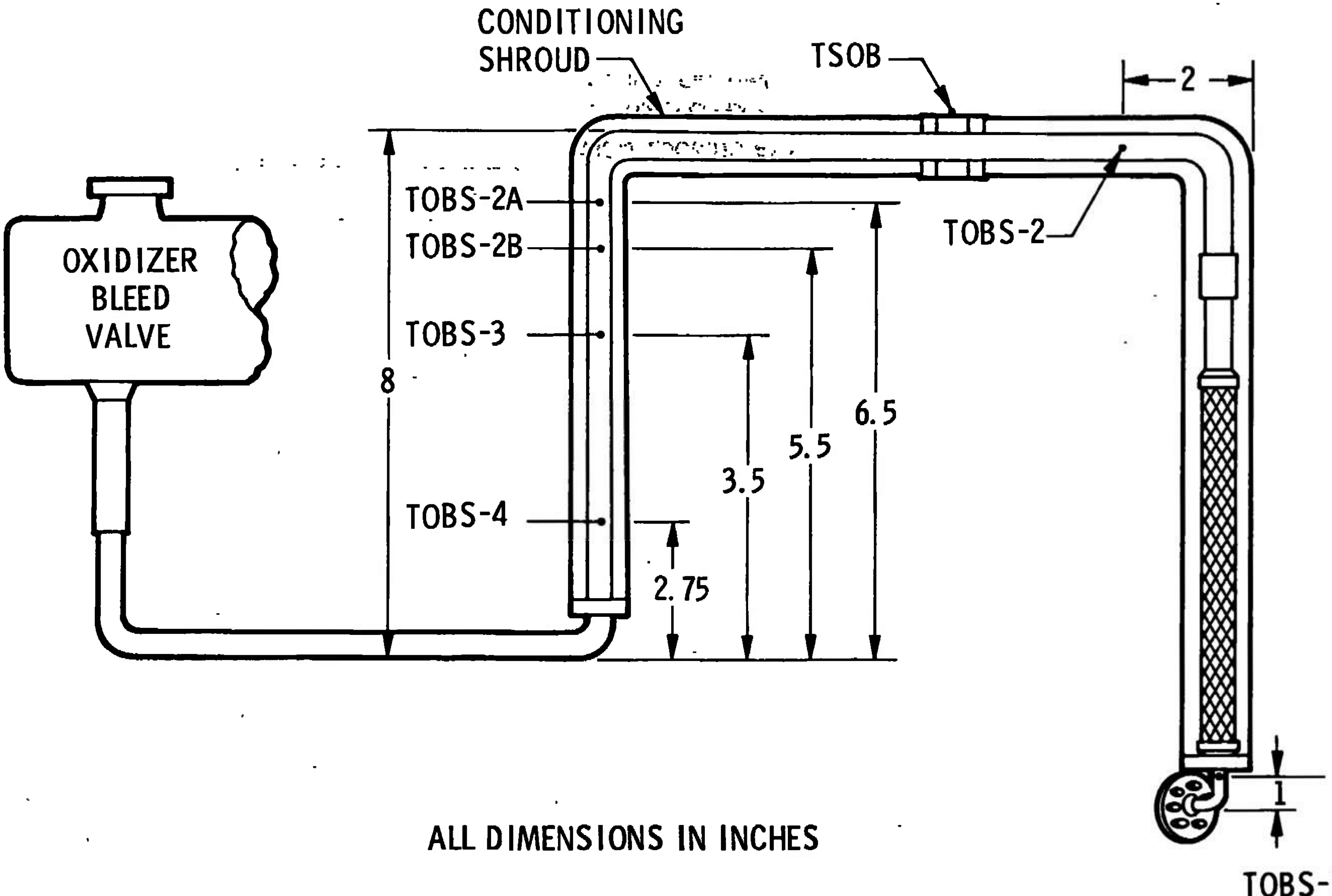
d. Start Tank Discharge Valve
Fig. III-1 Continued



VIEW LOOKING AFT

e. Thrust Chamber

Fig. III-1 Continued



f. Gas Generator Oxidizer Supply Line
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

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

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

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R'	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

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

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

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

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

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

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

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

Thrust Chamber

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

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

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

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

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

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

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

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

$$K_7 = 32.174$$

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

CHARACTERISTIC VELOCITY

Thrust Chamber

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

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

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

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

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

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

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

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

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

Oxidizer

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

$$K_4 = 144$$

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

Fuel

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

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

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

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

PUMP EFFICIENCIES

Fuel, Isentropic

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

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

Oxidizer, Isentropic

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

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

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

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

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

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

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

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

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

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

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

$$D_3 = 1.2343$$

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

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

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

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

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

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

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

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

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

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

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

$$K_{56} = -15$$

Fuel, Developed Horsepower

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

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

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

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

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

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

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

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

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

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

$$K_{13} = 0.7854$$

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

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

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

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

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

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

$$A_1 = 0.2575$$

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

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

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

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

Flows

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

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

$$B_2 = 3.2267$$

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

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

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

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

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

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

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13. ABSTRACT

Eleven firings of the Rocketdyne J-2 Rocket Engine (S/N J-2047) were conducted in Test Cell J-4 of the Large Rocket Facility. Pressure altitudes ranged from 90,000 to 110,000 ft at engine start. These were S-II Stage, Vehicles 502 and 503, verification tests to investigate fuel pump operation at net positive suction head below the minimum model specifications at engine start, and to evaluate the effect of heavier oxidizer turbine wheels on engine start transients. Selected engine components were thermally conditioned to targets predicted for the S-II stage engines. The accumulated firing duration for these tests was 130 sec.

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2. " " -- Perform
4. " " -- Pump perform
5. Pumps -- Perform

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