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# ALTITUDE DEVELOPMENTAL AND FLIGHT SUPPORT TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-42 THROUGH J4-1901-02)

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ARO, Inc.



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LARGE ROCKET FACILITY
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AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

# NOTICES

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# ALTITUDE DEVELOPMENTAL AND FLIGHT SUPPORT TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-42 THROUGH J4-1901-02)


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## FOREWORD

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

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted between June 19 and July 11, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801 and KA1901. The manuscript was submitted for publication on September 12, 1968.



This technical report has been reviewed and is approved.

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## ABSTRACT

Sixteen firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during four test periods (J4-1801-42 through J4-1901-02) between June 19 and July 11, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application on the S-II stage of the Saturn V vehicle. The firings were conducted utilizing the specially configured low pressure fuel duct designed to simulate the S-II center engine low pressure fuel duct fluid dynamics. The firings were accomplished at pressure altitudes of approximately 100,000 ft at engine start. The primary objective of these firings was to evaluate the augmented spark igniter modified per Rocketdyne Engineering Change Proposal J2-643. Engine components were thermally conditioned to predicted S-II interstage/engine temperatures. Engine operation was satisfactory on all firings except firing 02D, on which ignition was not detected in the augmented spark igniter. Total accumulated firing duration for the four test periods was 197.0 sec.

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## APPENDIXES

I. ILLUSTRATIONS

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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 head, 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 engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range |

### SUBSCRIPTS

| | |
|---|---|
| f | Force |
| m | Mass |
| t | Throat |

# SECTION I
# INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 16 firings reported herein were conducted during test periods J4-1801-42 through J4-1901-02 between June 19 and July 11, 1968, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF).

The main objective of these firings was to evaluate the performance of a modified augmented spark igniter (ASI) system resulting from the apparent failure of the augmented spark igniter propellant system on flight AS-502. The firings were conducted at pressure altitudes ranging from 90,000 to 108,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. The specially configured duct (Ref. 2) designed to simulate the S-II center engine low pressure fuel duct fluid dynamic characteristics was utilized for this test series. Engine components were conditioned to predicted S-II interstage/engine temperatures. Data collected to accomplish the test objectives are presented herein. 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 (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. This engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 $lb_f$ at a mixture (oxidizer-to-fuel) ratio of 5.5. The engine, as received at AEDC, was designated S/N J-2036-1, signifying that it is a rebuilt engine. In rebuilding, modifications were performed to configure the engine identically with engine S/N J-2072, and subsequent engines; in addition, a Photocon® pressure transducer was installed on the oxidizer dome to measure oxidizer injector pressure; and the augmented spark igniter was modified per Rocketdyne Engineering Change Proposal J2-643. An S-IVB battleship stage was used to supply propellants to the engine. The S-IVB low pressure fuel duct was replaced with a specially configured duct (Fig. 4) to simulate S-II stage center engine fuel flow dynamics; however, the standard S-IVB low pressure oxidizer duct remained in use. A schematic of the battleship stage is presented in Fig. 5.

Listings of major engine components and engine orifices for this test series are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

### 2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 6, 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 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at

rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

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

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

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

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

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

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

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

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.
14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

#### 2.1.2 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-$lb_f$-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 conditioning were the thrust chamber, crossover duct, start tank discharge valve, main oxidizer valve second-stage actuator, and low pressure fuel duct. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the start tank discharge valve. Main oxidizer valve conditioning was achieved by opening the prevalves and permitting propellants into the engine. The low pressure fuel duct was conditioned with the heater tape as shown in Fig. 4.

### 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 and a capacitance-type Photocon transducer. 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 and Photocon unit.

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. 7. The sequence of engine events for a normal start and shutdown is presented in Figs. 8a 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. 8c and d.

## SECTION III
## PROCEDURE

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

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

### 4.1.1 General

Sixteen firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test periods J4-1801-42 through J4-1901-02 between June 19 and July 11, 1968. The principle objective of these test periods was to evaluate augmented spark igniter operation utilizing a modified propellant supply system. Secondary objectives included verification of S-II start transients with below minimum engine model specification fuel pump NPSH (Ref. 6) and investigation of oxidizer dome pressure oscillations during the start transient. A Photocon pressure transducer was installed on the oxidizer dome in order to investigate these pressure oscillations.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are shown in Table VII. Calculated engine steady-state performance data are shown in Table VIII. Figure 9 shows engine start conditions for the pump inlets and the start tank for all firings. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firings, engine start and shutdown transients, fuel pump start transient performance, and low pressure fuel duct performance are presented in Figs. 10 through 89. Specific test objectives and a brief summary of results obtained for each firing are presented in the following sections.

### 4.1.2 Firing J4-1801-42A

#### 4.1.2.1 Objectives

Objectives were to evaluate (1) the influence of altitude environment on engine start transient operation by comparing altitude to sea-level acceptance data and (2) the operation of the augmented spark igniter with propellant supply lines orificed for minimum mixture ratio.

#### 4.1.2.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. The influence of altitude environment on engine start transient operation could not be determined because of the difference in fuel lead, thrust chamber temperature, and start tank gas condition at engine start. Actual starting conditions for firing 42A and the sea-level acceptance firing are compared in Table IX. Augmented spark igniter system operation was satisfactory; ignition was detected 276 msec after engine start.

#### 4.1.3 Firing J4-1801-42B

##### 4.1.3.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient utilizing 1380-psia and -270°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) the operation of the modified augmented spark igniter with propellant supply lines orificed for minimum mixture ratio.

##### 4.1.3.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was realized until shortly after oxidizer dome prime, but no adverse effects on engine start transient were observed during the cavitation period. The gas generator outlet temperature experienced a transient peak of 1940°F. The fuel pump stall margin during start tank discharge was 1610 gpm. A comparison with other test results indicates a tendency for higher gas generator transient temperatures and reduced fuel pump stall margin during start tank discharge with low fuel pump NPSH. Augmented spark igniter system operation was satisfactory; ignition was detected 210 msec after engine start.

#### 4.1.4 Firing J4-1801-42C

##### 4.1.4.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) at engine start on the engine start transient utilizing 1380-psia and -270°F start tank conditions and -150°F thrust chamber temperature conditions and (2) the operation of the augmented spark igniter with propellant supply lines orificed for minimum mixture ratio.

##### 4.1.4.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. The minimum fuel pump stall margin during start tank discharge was 1410 gpm (200 gpm lower than on firing 42B because of thrust chamber temperature). Fuel pump cavitation was realized until shortly after oxidizer dome prime, but no adverse effects on the engine start transient were observed during the cavitation period. Thrust chamber temperature did not have a significant effect on fuel pump cavitation, as shown by comparing firings 42B and 42C. Augmented spark igniter system operation was satisfactory; ignition was detected 265 msec after engine start.

#### 4.1.5 Firing J4-1801-42D

##### 4.1.5.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient utilizing 1300-psia and -300°F start tank gas conditions and 150°F thrust chamber temperature at engine start and (2) the operation of the modified augmented spark igniter with propellant supply lines orificed for minimum mixture ratio.

##### 4.1.5.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was realized until shortly after oxidizer dome prime, but no adverse effects on engine start transients were observed. Different start tank gas conditions had an insignificant effect on fuel pump cavitation, as shown by comparison of firings 42C and 42D. Augmented spark igniter system operation was satisfactory; ignition was detected 430 msec after engine start.

#### 4.1.6 Firing J4-1801-42E

##### 4.1.6.1 Objectives

Objectives were to evaluate augmented spark igniter ignition characteristics utilizing maximum fuel pump inlet pressure (41-psia), minimum oxidizer pump inlet pressure (33-psia), and -275°F thrust chamber temperature at engine start with the augmented spark igniter propellant supply lines orificed for minimum mixture ratio.

##### 4.1.6.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Augmented spark igniter system operation was satisfactory; ignition was detected 434 msec after engine start.

#### 4.1.7 Firing J4-1801-43A

##### 4.1.7.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient utilizing 1300-psia and -300°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) the operation of the augmented spark igniter system with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.7.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily met. The fuel pump showed cavitation tendency until shortly after oxidizer dome prime; however, no adverse effects on start transients were noted. Gas generator outlet initial peak temperature was 2080°F. Comparison of this peak temperature with other firings indicates a trend for higher peak temperatures with lower NPSH values. Augmented spark igniter system operation was satisfactory; ignition was detected 228 msec after engine start. Orifice size (i. e., mixture ratio) appeared to have little effect on ignition detect time as compared to firing 42B.

#### 4.1.8 Firing J4-1801-43B

##### 4.1.8.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on fuel pump stall margin during start tank discharge and gas generator outlet temperature transients utilizing 1400-psia and -240°F start tank gas conditions and -150°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.8.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump minimum stall margin during start tank discharge was 1490 gpm. Fuel pump cavitation was observed until shortly after oxidizer dome prime. The gas generator outlet first and second peak temperatures were 2050 and 1850°F, respectively. Augmented spark igniter system operation was satisfactory; ignition was detected 242 msec after engine start. Subsequent firings of this test period were cancelled because the desired start tank pressure could not be obtained.

#### 4.1.9 Firing J4-1901-01A

##### 4.1.9.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on fuel pump stall margin during start tank discharge and gas generator outlet temperature transient utilizing 1380-psia and -270°F start tank gas conditions and -150°F thrust chamber temperature at engine start and (2) the operation of the modified augmented spark igniter system with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.9.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was observed until shortly after oxidizer dome prime; however, no adverse effects on engine start transients were noted. Fuel pump minimum stall margin during start tank discharge was 1490 gpm. Comparison to firing 42B shows a 110°F warmer thrust chamber exhibits a 120 gpm lower stall margin. Gas generator outlet temperature first and second peaks were 2060 and 2120°F, respectively. Augmented spark igniter system operation was satisfactory; ignition was detected 219 msec after engine start. Comparison with firing 43A shows that an increase of 100°F in thrust chamber temperature at engine start has little effect on ignition detect delay.

#### 4.1.10 Firing J4-1901-01B

##### 4.1.10.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient with 1300-psia and -300°F start tank gas conditions and -150°F thrust chamber temperature at engine start and (2) the operation of the modified augmented spark igniter with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.10.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was noted until shortly after oxidizer dome prime; however, no adverse effects on the engine start transients were observed. Fuel pump minimum stall margin was 1510 gpm. Gas generator outlet temperature experienced an initial peak of 2010°F with no second peak. Augmented spark igniter system operation was satisfactory; ignition was detected 376 msec after engine start. Comparison of ignition detect delay on firing 01B with that of firing 01A shows that decreasing oxidizer pump inlet pressure from 45.2 to 33.3 psia increased ignition detect delay time by 160 msec.

#### 4.1.11 Firing J4-1901-01C

##### 4.1.11.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient utilizing 1400-psia and -240°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter system with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.11.2 Results

The planned 7.5-sec duration firing was prematurely terminated at $t_0$ + 3.025 by an erroneous vibration safety cutoff. Start conditions were satisfactorily obtained, and firing duration was sufficient to obtain start transient data. Fuel pump cavitation was observed until shortly after oxidizer dome prime; however, no adverse effects on the engine start transients were noted. Fuel pump minimum stall margin during start tank discharge was 1570 gpm. Comparison of stall margin on firing 01C with that of firing 43B shows that a 110°F decrease in thrust chamber temperature increased fuel pump minimum stall margin by 70 gpm.

As indicated by gas generator chamber pressure, low-grade combustion existed in the gas generator for approximately 75 msec after initial ignition. A similar situation existed on firing 42B for 150 msec after initial gas generator ignition and on firing 43A for 70 msec after initial gas generator ignition. Examination of start conditions shows that a cold thrust chamber (-275°F), low fuel pump NPSH (125-ft), and high start tank gas energy are the most conducive to this abnormal gas generator ignition transient.

Augmented spark igniter system operation was satisfactory; ignition was detected 206 msec after engine start. Comparison of ignition detect delay time on firing 01C with that of firing 01A shows that thrust chamber temperature has little effect on ignition detect delay time.

#### 4.1.12 Firing J4-1901-01D

##### 4.1.12.1 Objectives

Objectives were to evaluate (1) engine start transient utilizing maximum pump inlet pressures (45-psia oxidizer and 41-psia fuel), 1400-psia and -240°F start tank gas conditions, and -150°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter system with propellant supply lines orificed for maximum mixture ratio.

##### 4.1.12.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Comparison of fuel pump operating characteristics with firing 43B shows fuel pump cavitation tendencies to be reduced significantly at high inlet pressures. Gas generator outlet temperature first and second peaks were 1930 and 2050°F, respectively. Augmented spark igniter system operation was satisfactory; and ignition was detected 258 msec after engine start.

#### 4.1.13 Firing J4-1901-01E

##### 4.1.13.1 Objectives

Objectives were to evaluate augmented spark igniter ignition characteristics utilizing maximum fuel pump inlet pressure (41-psia), minimum oxidizer pump inlet pressure (33-psia), and -275°F thrust chamber temperature at engine start with the augmented spark igniter propellant supply lines orificed for maximum mixture ratio.

##### 4.1.13.2 Results

The firing was successfully accomplished, and the requested starting conditions were satisfactorily obtained. Augmented spark igniter system operation was satisfactory; ignition was detected 562 msec after engine start. Comparing ignition detect delay time of firing 01E with firing 01D, it appears that a 13.4-psia decrease in oxidizer pump inlet pressure increased ignition detect delay approximately 300 msec.

#### 4.1.14 Firing J4-1901-02A

##### 4.1.14.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on the engine start transient utilizing 1200-psia and -200°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter with propellant supply lines orificed for minimum mixture ratio.

#### 4.1.14.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was observed until shortly after oxidizer dome prime; however, no adverse effects on the engine start transients were noted. Augmented spark igniter operation was satisfactory; ignition was detected 356 msec after engine start.

### 4.1.15 Firing J4-1901-02B

#### 4.1.15.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on engine start transients and fuel pump stall margin during start tank discharge utilizing 1250-psia and -140°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter system with propellant supply lines orificed for minimum mixture ratio.

#### 4.1.15.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily met. Fuel pump cavitation was observed until shortly after oxidizer dome prime; however, no adverse effects on engine start transients were noted. Fuel pump stall margin during start tank discharge was 1510 gpm. Comparison of stall margin on firing 02B with that of firing 02A shows that a 50-psia decrease in start tank pressure decreased stall margin 100 gpm. Augmented spark igniter operation was satisfactory; ignition was detected 474 msec after engine start.

### 4.1.16 Firing J4-1901-02C

#### 4.1.16.1 Objectives

Objectives were to evaluate (1) the effect of reduced fuel pump NPSH (125-ft) on gas generator outlet temperature transient peaks utilizing 1200-psia and -300°F start tank gas conditions and -275°F thrust chamber temperature at engine start and (2) operation of the modified augmented spark igniter system with propellant supply lines orificed for minimum mixture ratio.

#### 4.1.16.2 Results

The firing was successfully accomplished, and all requested starting conditions were satisfactorily obtained. Fuel pump cavitation was noted until shortly after oxidizer dome prime; however, no adverse effects on engine start transients were observed. Low-grade combustion existed in the gas generator for a period of 75 msec after initial ignition (as indicated by gas generator chamber pressure) because of the cold thrust chamber and low fuel pump NPSH. Gas generator initial peak temperature was 1960°F; no second peak occurred. Augmented spark igniter system operation was satisfactory; ignition was detected 257 msec after engine start.

### 4.1.17 Firing J4-1901-02D

#### 4.1.17.1 Objectives

Objectives were to evaluate augmented spark igniter characteristics with 41-psia fuel pump inlet pressure, 33-psia oxidizer pump inlet pressure, -150°F thrust chamber temperature, and augmented spark igniter propellant supply lines orificed for minimum mixture ratio.

#### 4.1.17.2 Results

All requested starting conditions except start tank pressure were satisfactorily met. Start tank pressure was approximately 30 psia below the target of 1400 psia because of start tank vent and relief valve operation. Augmented spark igniter operation was unsatisfactory because ignition was not detected. The firing was terminated at $t_0 + 0.447$ sec by the engine logic.

## 4.2 ANOMOLIES

An abnormal turbine component chilldown rate following firings 42A and 43A was suspected to be the result of leakage through the fuel pump seals or gas generator fuel poppet. The suspected leakage was apparently eliminated by purging the gas generator and turbine components. The gas generator control valve was replaced before test period J4-1901-01 even though post-test J4-1801-42 and -43 leak checks showed the valve leakage to be within specification.

Oxidizer peak pump speeds during start tank discharge for firings during test period 42 were approximately 8 percent lower than comparable firings on subsequent test periods of this series. No explanation for this is available at this time.

## 4.3 AVERAGE THRUST CHAMBER TEMPERATURE DEVIATION

Testing since July, 1967, has utilized 24 thermocouples in the configuration shown in Ref. 3, by which average thrust chamber temperatures are calculated. This number was reduced to six with the installation of engine J-2036-1. The location of these thermocouples corresponds to the location of six of the previous thermocouples and retains the nomenclature of the corresponding thermocouples. This new configuration is shown in Fig. III-1e of Appendix III. Figure 90 shows the deviation observed on previous tests over the range of conditioning temperatures, when comparing average thrust chamber temperature based on the six remaining thermocouples to the average based on the 24-thermocouple configuration. In general, good agreement existed between the 6- and the 24-thermocouple average except at very warm thrust chamber temperatures.

## 4.4 AUGMENTED SPARK IGNITER SYSTEM OPERATION

The augmented spark igniter system installed for this series of tests utilized the modified propellant supply lines as described in Ref. 3. A 0.125-in.-diam oxidizer supply line orifice was used for all firings of this test series. Minimum augmented spark igniter mixture ratio was obtained for the firings of test periods J4-1801-42 and J4-1901-02 by removing the fuel supply line orifice. Test periods J4-1801-43 and J4-1901-01 utilized a 0.226-in.-diam orifice to provide maximum mixture ratio. Flow calibration by the manufacturer showed minimum mixture ratio to be 0.359 and maximum to be 0.589.

Figure 91 shows augmented spark igniter ignition detect time as a function of oxidizer pump inlet pressure, fuel pump inlet pressure, thrust chamber temperature, and augmented spark igniter mixture ratio. Data indicate that ignition detect delay time is primarily a function of oxidizer pump inlet pressure for the single probe immersion depth utilized. Since mixture ratio, fuel pump inlet pressure, and thrust chamber temperature are varied in a random pattern in both groups of data, it was deduced that the effect of these variables is small compared to the effect of oxidizer pump inlet pressure.

Augmented spark igniter ignition detect delay times experienced during the previous S-II test series (J4-1801-28 through -33, Ref. 2) are compared with ignition detect delay times experienced during this test series in Fig. 92. The modified augmented spark igniter experienced ignition delay times that were approximately 70 msec longer than those experienced during the previous S-II test series with oxidizer pump inlet pressure at engine start in the range of 45 psia. The delay increased to several hundred milliseconds longer as oxidizer pump inlet pressure at engine start was decreased to the range of 33 psia. Ignition detect probe penetration into the augmented spark igniter chamber was the same for the two test series; however, different probes were used for the two test periods. Previous testing at AEDC has shown that ignition detect delay time differs for different probes used under comparable test conditions.

### 4.5 ENGINE OPERATION WITH LESS THAN MINIMUM MODEL SPECIFICATION FUEL PUMP NPSH

#### 4.5.1 Fuel Pump Cavitation

Fuel pump inlet conditions on the majority of firings during this test series resulted in NPSH values below the minimum engine model specification. An examination of fuel pump operating characteristics (head rise and flow coefficients, Appendix V) showed that cavitation existed to some degree during the start transient on all of these firings.

A comparison of fuel pump operating characteristic curves for firings 43B and 01D is shown in Fig. 93. Net positive suction head at engine start was 90 and 575 ft on firings 43B and 01D, respectively. Cavitation occurred on both firings; however, cavitation was more pronounced on the low NPSH firing, primarily because of a reduced flow coefficient.

The effect of thrust chamber temperature on fuel pump cavitation is shown by comparing fuel pump operating characteristic curves on firings 42B and 42C (Fig. 94). Average thrust chamber temperature was -290 and -146°F on firings 42B and 42C, respectively. Although the warmer thrust chamber temperature on firing 42C increased head rise coefficient, thrust chamber temperature had no effect on fuel pump cavitation.

Firings 42C and 42D provide a typical comparison of start tank gas conditions on fuel pump cavitation. Start tank gas conditions were 1380 psia and -270°F on firing 42C and 1300 psia and -300°F on firing 42D. The difference in start tank gas conditions had an insignificant effect on fuel pump cavitation, as shown in Fig. 95.

#### 4.5.2 Gas Generator Outlet Initial Transient Temperature Peak

As reported in Ref. 2, it was found that gas generator outlet temperature initial peak was a function of fuel pump NPSH at engine start with constant starting conditions of -300°F thrust chamber temperature, maximum start tank gas energy, and turbine component temperature of approximately +50°F. Three firings conducted during this series satisfied these starting conditions. These firings (42B, 43A, and 01C) are compared in Fig. 96 with the data from Ref. 2. As shown, the same trend of higher temperatures at lower NPSH exists, even though gas generator orifices are not the same. Orifice sizes are summarized in Fig. 96. Limited data precludes comparisons at other constant starting conditions.

#### 4.5.3 Gas Generator Ignition Transient

During the gas generator ignition transient, low-grade combustion (as indicated by gas generator chamber pressure) was experienced for varying time periods immediately after initial gas generator ignition on certain firings of this test series. Examination of start conditions shows that low fuel pump NPSH (125-ft), very cold thrust chamber (-275°F), and high start tank gas energy are conducive to the most severe case of low-grade combustion. From the data on firings 42B and 42C, for example, it appears that a warmer thrust chamber temperature is probably the most predominate factor in eliminating this condition.

#### 4.5.4 Fuel Pump Stall Margin during Start Tank Discharge

Fuel pump stall margin during start tank discharge is primarily a function of thrust chamber temperature at engine start (Ref. 2). However, at a constant thrust chamber temperature, fuel pump stall margin is reduced as fuel pump NPSH at engine start is reduced (Fig. 97). In Fig. 97, data from this test series were supplemented with data from the previous S-II test series.

#### 4.5.5 Fuel Pump Head Rise and Flow Coefficients

Fuel pump head rise and flow coefficients for this test series are shown compared to those from Ref. 2 in Fig. 98. As in Ref. 2, both head rise and flow coefficient data were reduced at $t_0 + 0.58$ sec. Derivations of the coefficient equations are shown in Appendix V.

In general, data from the two test series show the same trend. However, flow coefficient values are approximately 5 percent higher in the lower NPSH range for the fuel pump installed on engine J-2036-1 (S/N 4073647) than those for the pump on engine J-2047 (S/N 4072328). Flow coefficients exhibit good agreement at the higher NPSH values. Head rise coefficients at the lower NPSH values tend to be approximately 13 percent lower than those of engine J-2047. Head rise coefficients at the higher NPSH values show good agreement.

### 4.6 Photocon Measurement of Oxidizer Injector Pressure during the Start Transient

Data recorded from the Photocon pressure transducer during the start transient of two typical firings of this test series are presented in Fig. 99. Firing 01A had a short period of excessive engine vibration (vibration safety counts recorded for 3 msec) and firing 01B a long period (vibration safety counts recorded for 37 msec) compared with other firings of this test series. These data indicate pressure oscillations at a frequency of 280 ± 20 Hz with peak amplitudes ranging up to approximately 500 psia during oxidizer dome prime.

## SECTION V
## SUMMARY OF RESULTS

The results of the 16 firings of the Rocketdyne J-2 rocket engine conducted between June 19 and July 11, 1968, in Test Cell J-4 are summarized as follows:

1. Modified augmented spark igniter propellant supply line and combustion chamber integrity were satisfactory.
2. Longer augmented spark igniter ignition detect delay times were experienced as oxidizer pump inlet pressure at engine start was reduced from 45 to 33 psia. Ignition was not detected on firing 02D.
3. The influence of thrust chamber temperature, fuel pump inlet pressure, and augmented spark igniter mixture ratio on augmented spark igniter ignition detect delay time is small, compared to the influence of oxidizer pump inlet pressure.
4. Low fuel pump NPSH resulted in (1) fuel pump cavitation until shortly after oxidizer dome prime, (2) the tendency toward higher gas generator outlet first peak temperature, (3) abnormal gas generator ignition transient, (4) a reduction in fuel pump stall margin during start tank discharge, and (5) a reduction in fuel pump flow coefficient and an increase in head rise coefficient.

5. Photocon pressure transducer measurements show oxidizer dome pressure oscillation frequency to be approximately 280 Hz with amplitudes ranging up to 500 psia during oxidizer dome prime.

## REFERENCES


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

2. Kunz, C. H. and Counts, H. J., Jr. "Altitude Testing of the J-2 Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-28 through J4-1801-33)." AEDC-TR-68-160, October 1968.

3. Dougherty, N. S. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-39 through J4-1801-41)." AEDC-TR- , (to be published).

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

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

6. "Engine Model Specification Liquid-Propellant Rocket Engine - Rocketdyne Model J-2." R-2158C3, January 1966.

## APPENDIXES

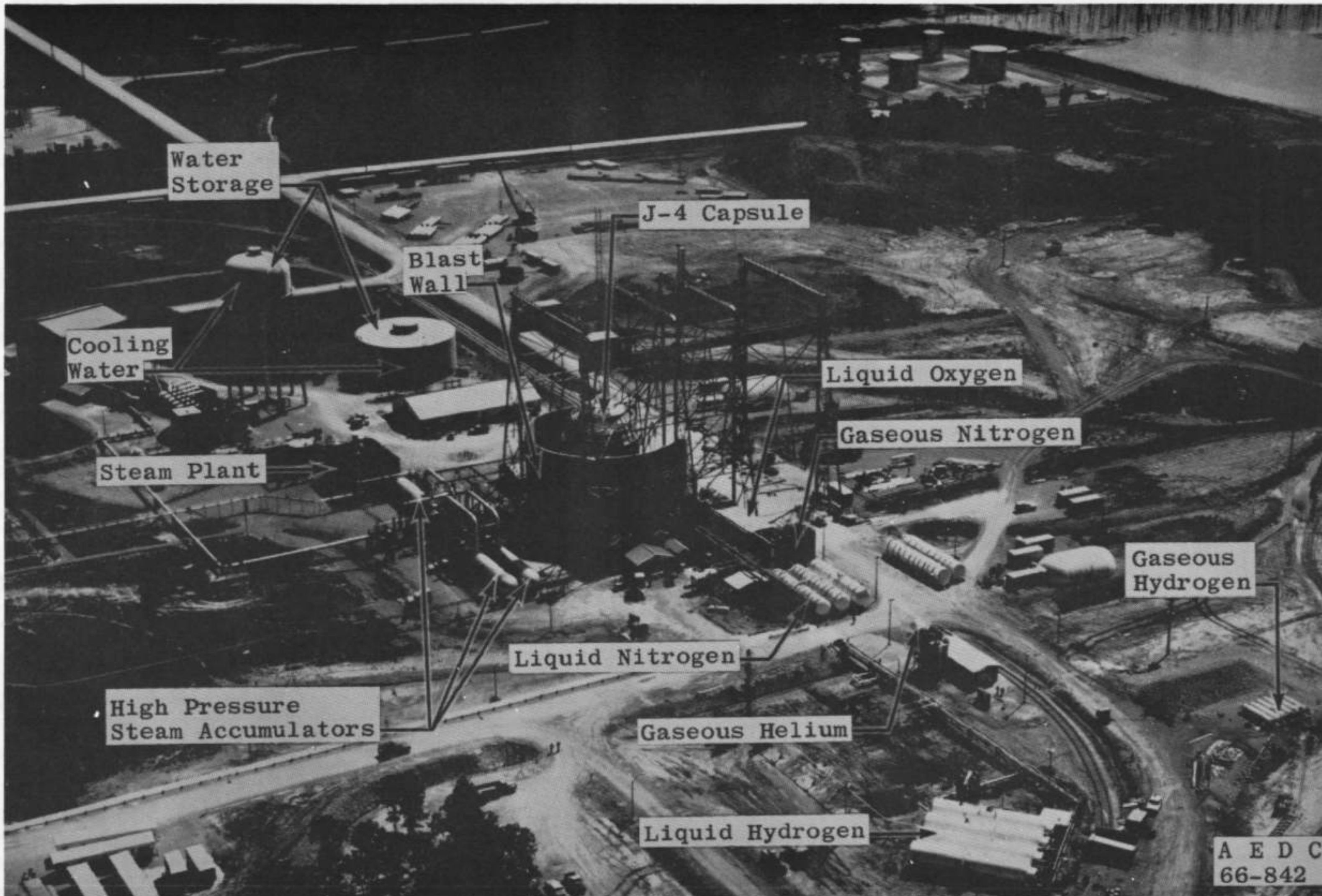



Fig. 1 Test Cell J-4 Complex

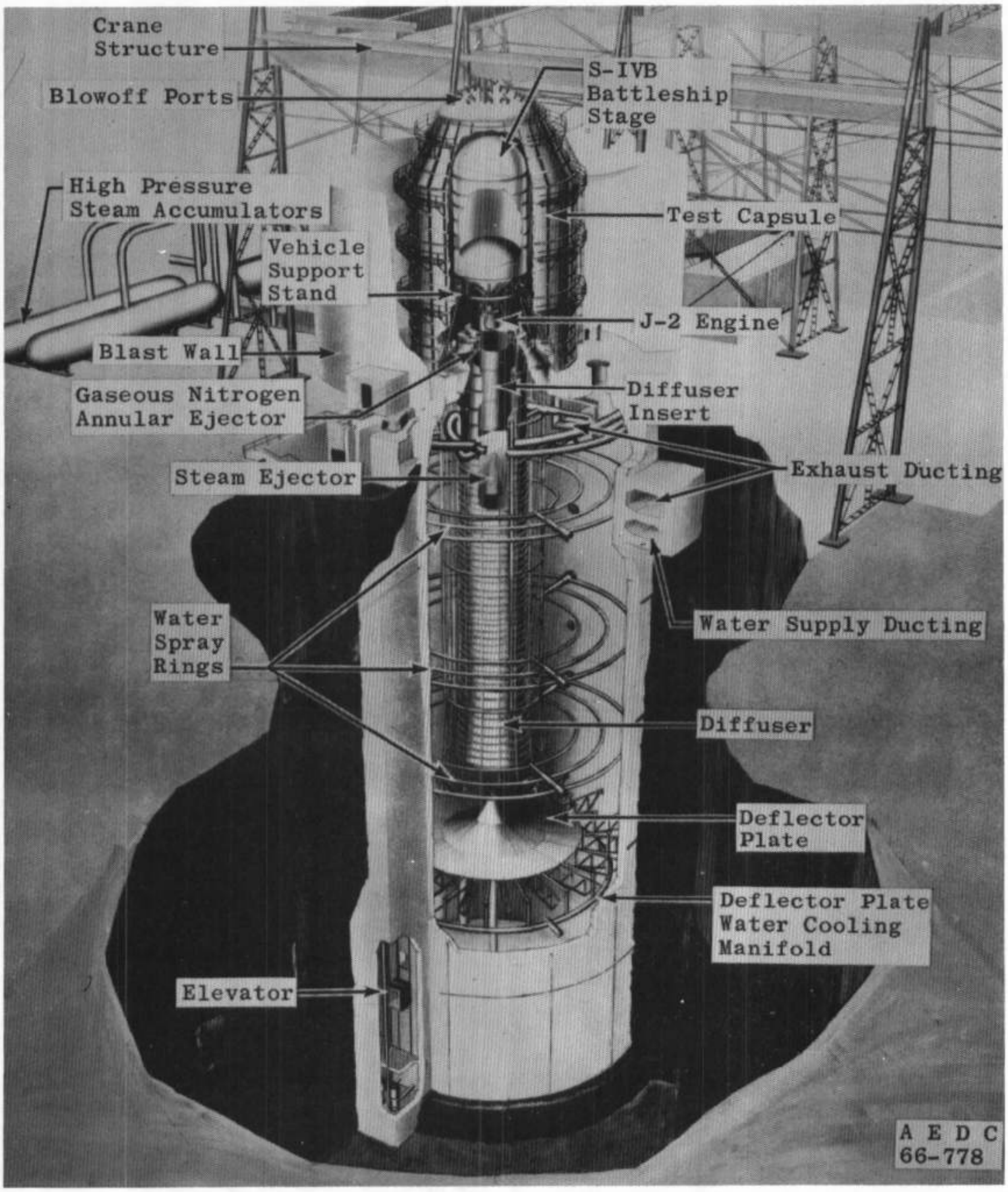



Fig. 2 Test Cell J-4, Artist's Conception

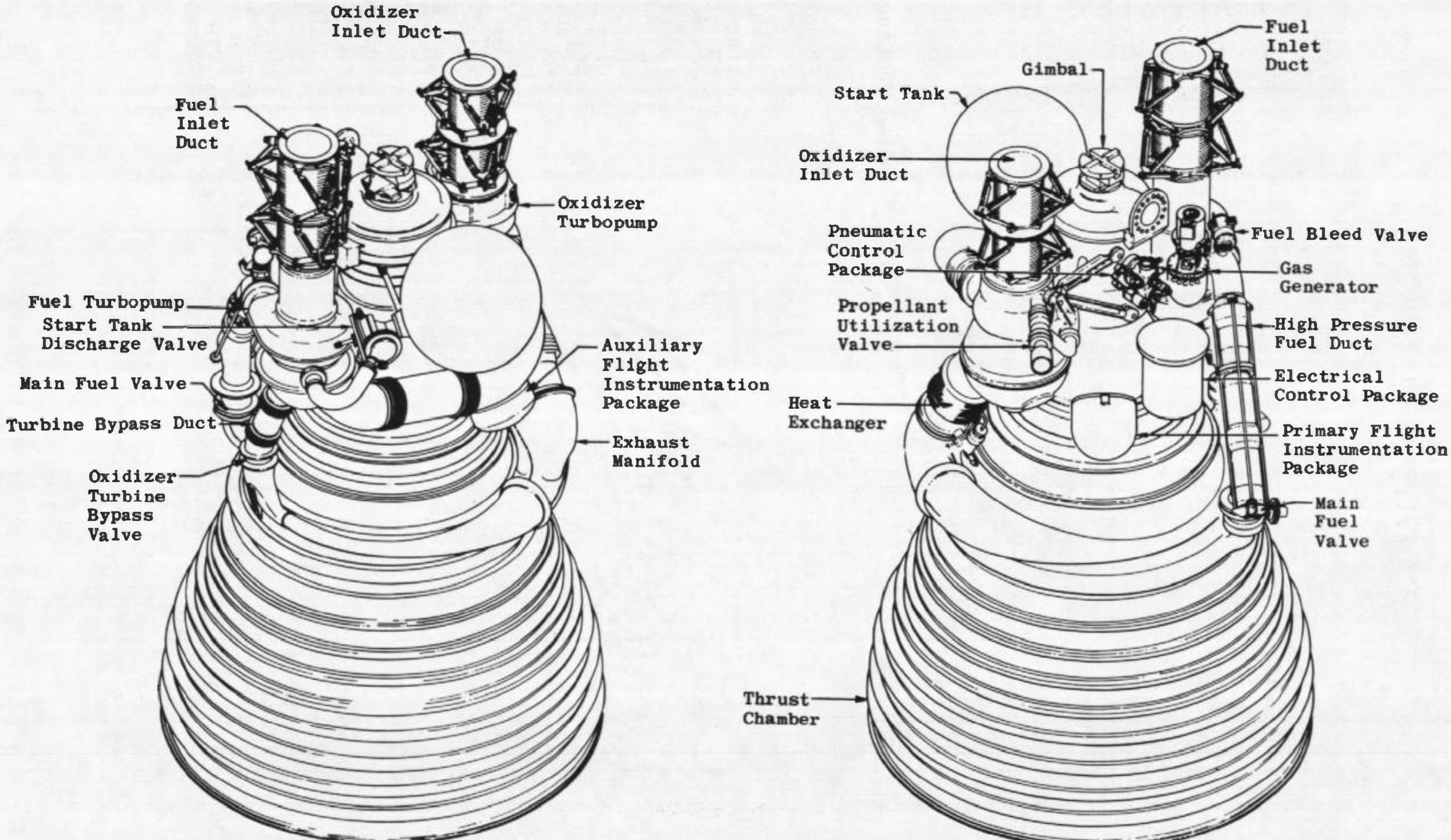
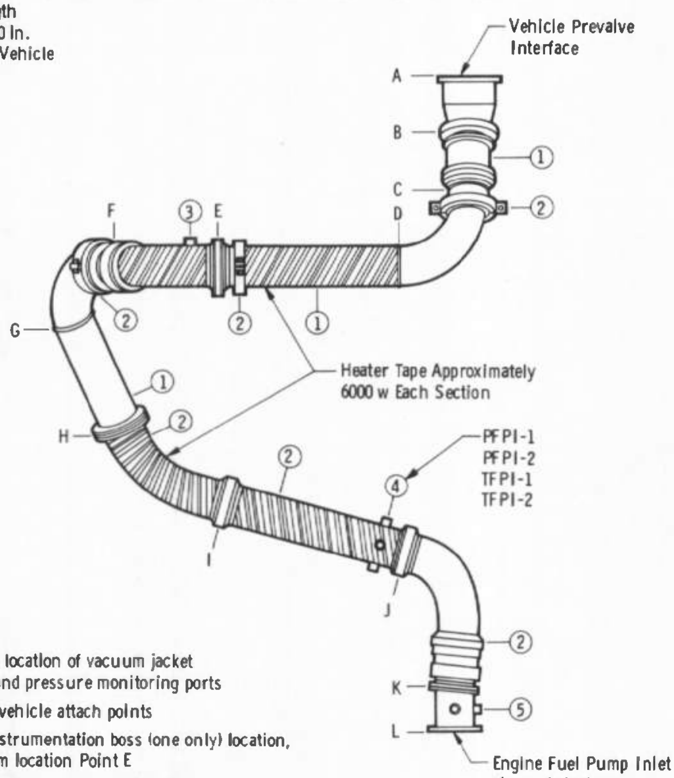



Fig. 3 Engine Details

S II Fuel Duct Configuration for AEDC Test

| Location Point | Approximate Length, In. | Approximate Minimum ID, In. | Type of Insulation: Vac. Jacket | Type of Insulation: Larodyne | Type of Joint: Upper | Type of Joint: Lower |
|---|---|---|---|---|---|---|
| A to B | 13.72 | 7.944 | | X | Marmon Flange | Bolted Flange |
| B to C | 11.00 | 7.950 | X | | Bolted Flange | Bellows |
| C to D | 29.63 | 7.900 | | X | Bellows | Welded |
| D to E | 41.14 | 7.950 | X | | Welded | Bellows |
| E to F | 28.71 | 7.950 | X | | Bellows | Bolted Flange |
| F to G | 26.63 | 7.900 | | X | Bolted Flange | Welded |
| G to H | 29.13 | 7.950 | X | | Welded | Bolted Flange |
| H to I | 44.88 | 7.950 | X | | Bolted Flange | Bellows |
| I to J | 61.18 | 7.950 | X | | Bellows | Bellows |
| J to K | 41.78 | 7.890 | X | | Bellows | Bolted Flange |
| K to L | 9.50 | B.280 | | X | Bolted Flange | Bolted Flange |

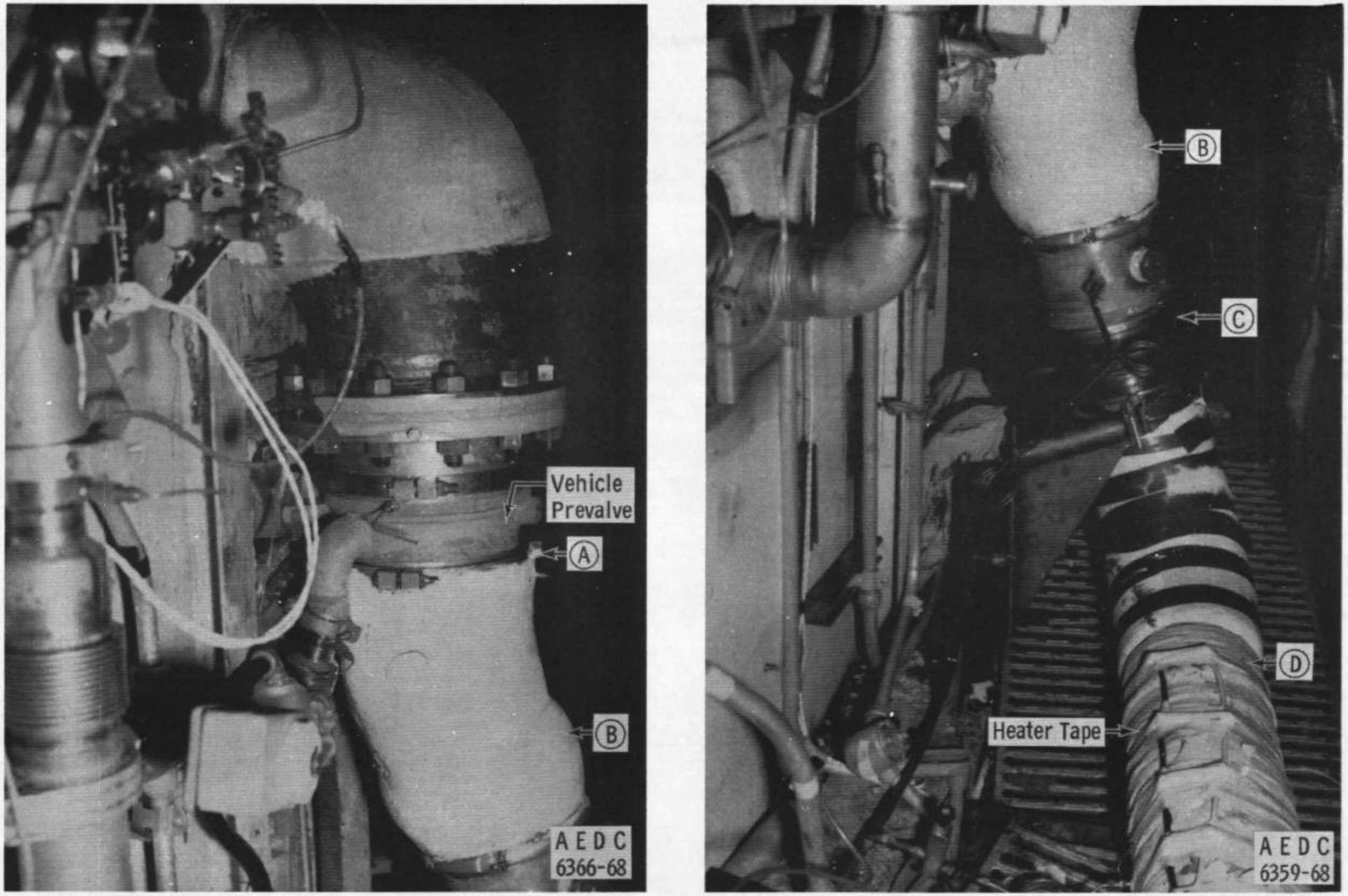
Approximate Total Length
A through L = 337.30 In.
Approximate S II Total Vehicle
Length = 355.08 In.




(1) Approximate location of vacuum jacket evacuation and pressure monitoring ports
(2) Duct to test vehicle attach points
(3) Pressure instrumentation boss (one only) location, 4.85 in. from location Point E
(4) Pressure and temperature instrumentation bosses (2 pr. and 2 temp. at 90-deg spacing), Location, 4.50 in. from location Point J
(5) Pressure and temperature instrumentation bosses (90-deg spacing with one temperature location between two pressure bosses), Location, 6.35 in. from location Point L

a. Schematic

Fig. 4 S-II Center Engine Configuration Low Pressure Fuel Duct




b. Photographs

Fig. 4 Continued

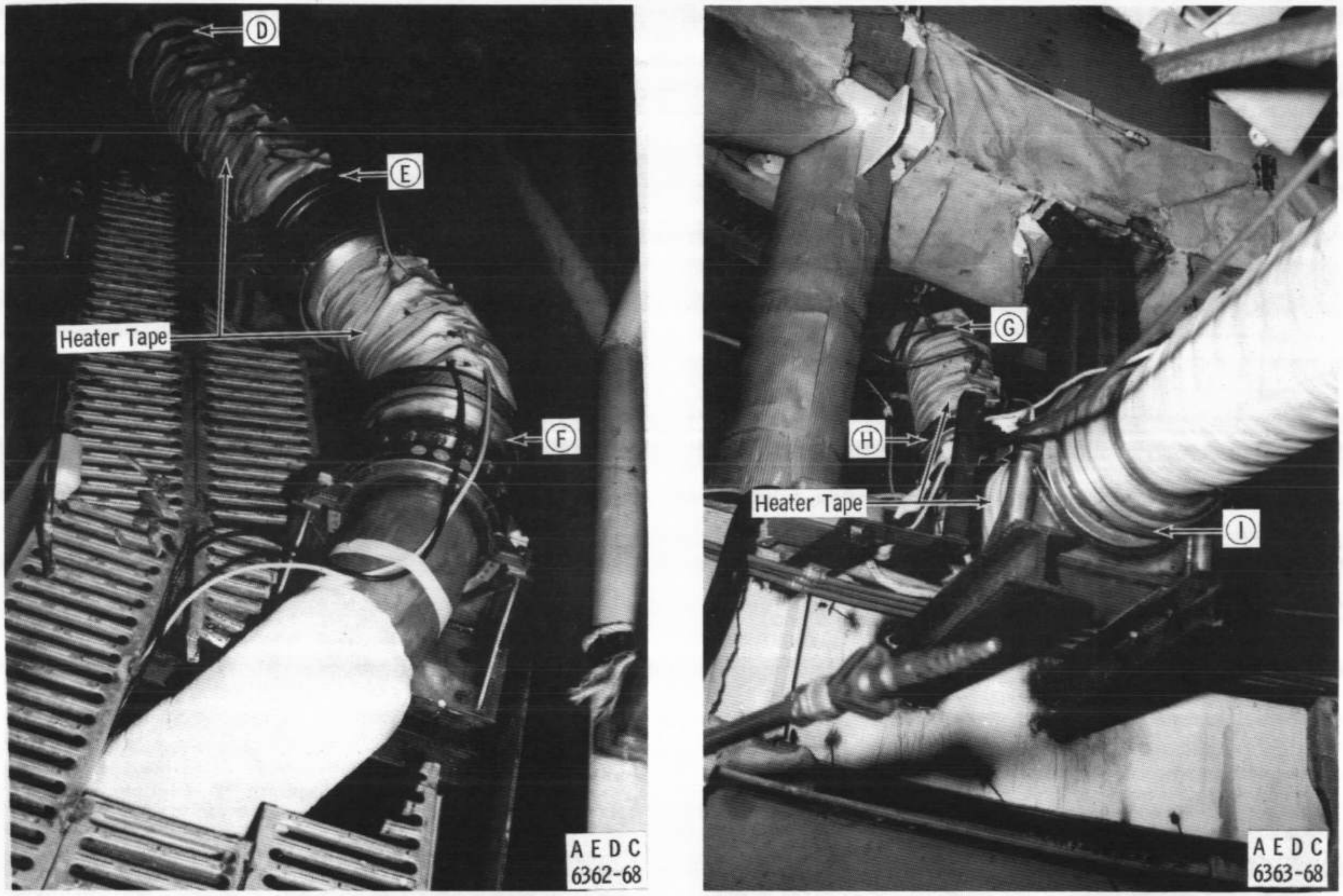
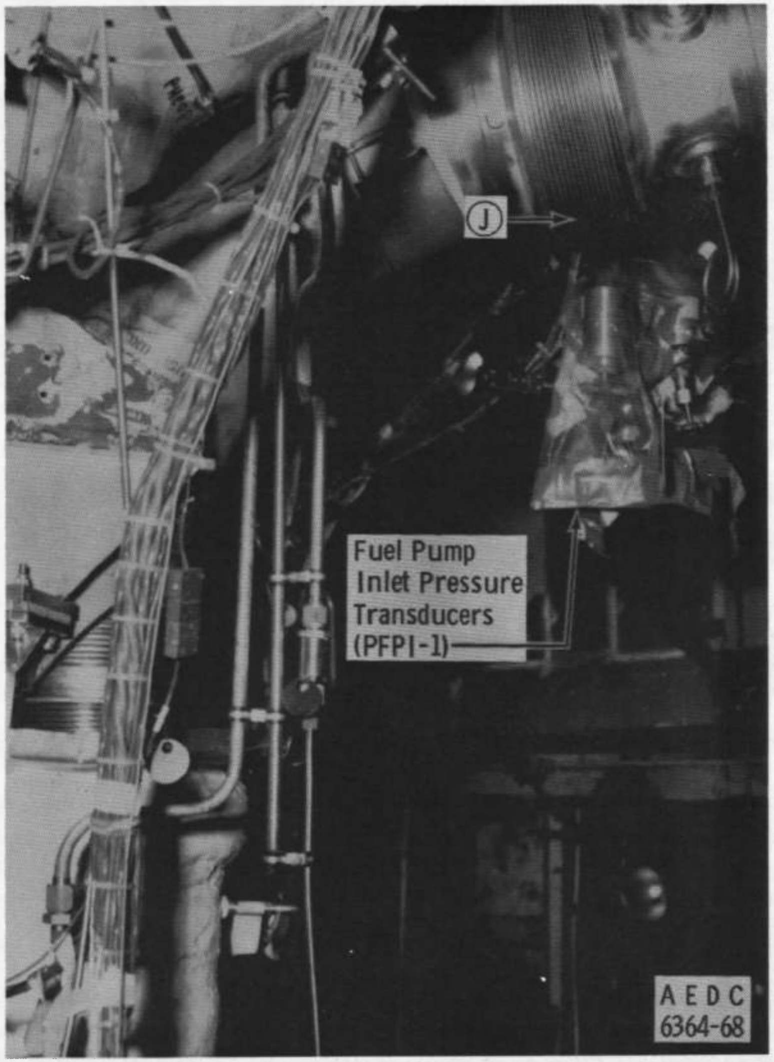



Fig. 4b Continued



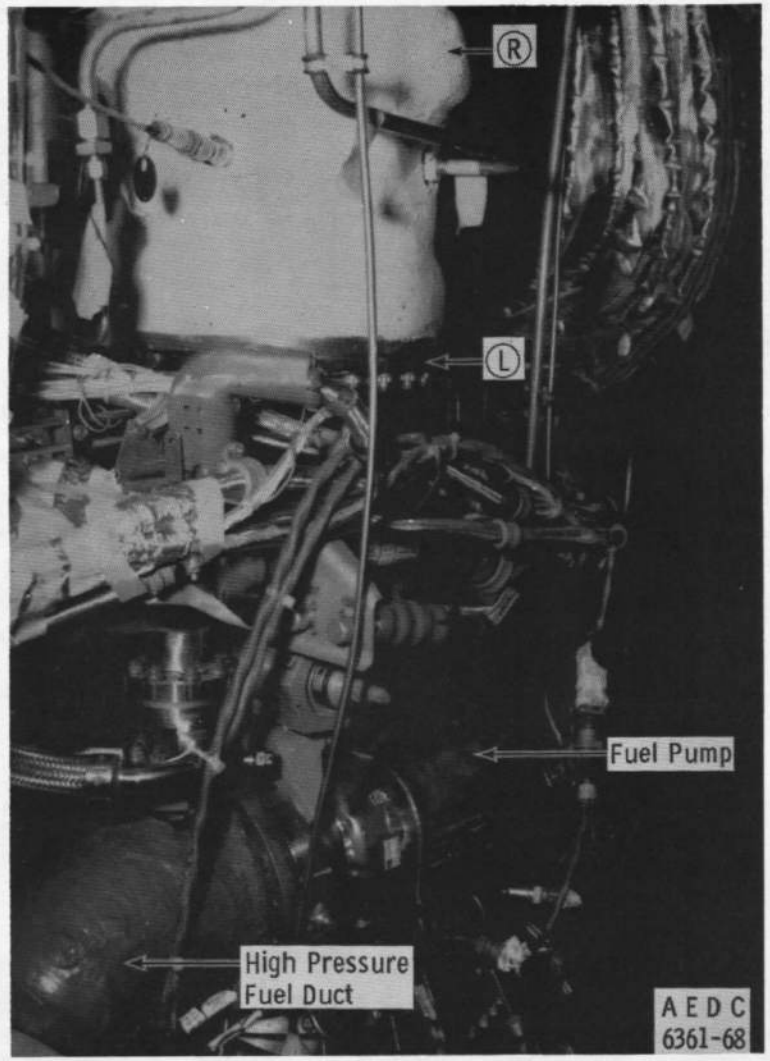




Fig. 4b Concluded

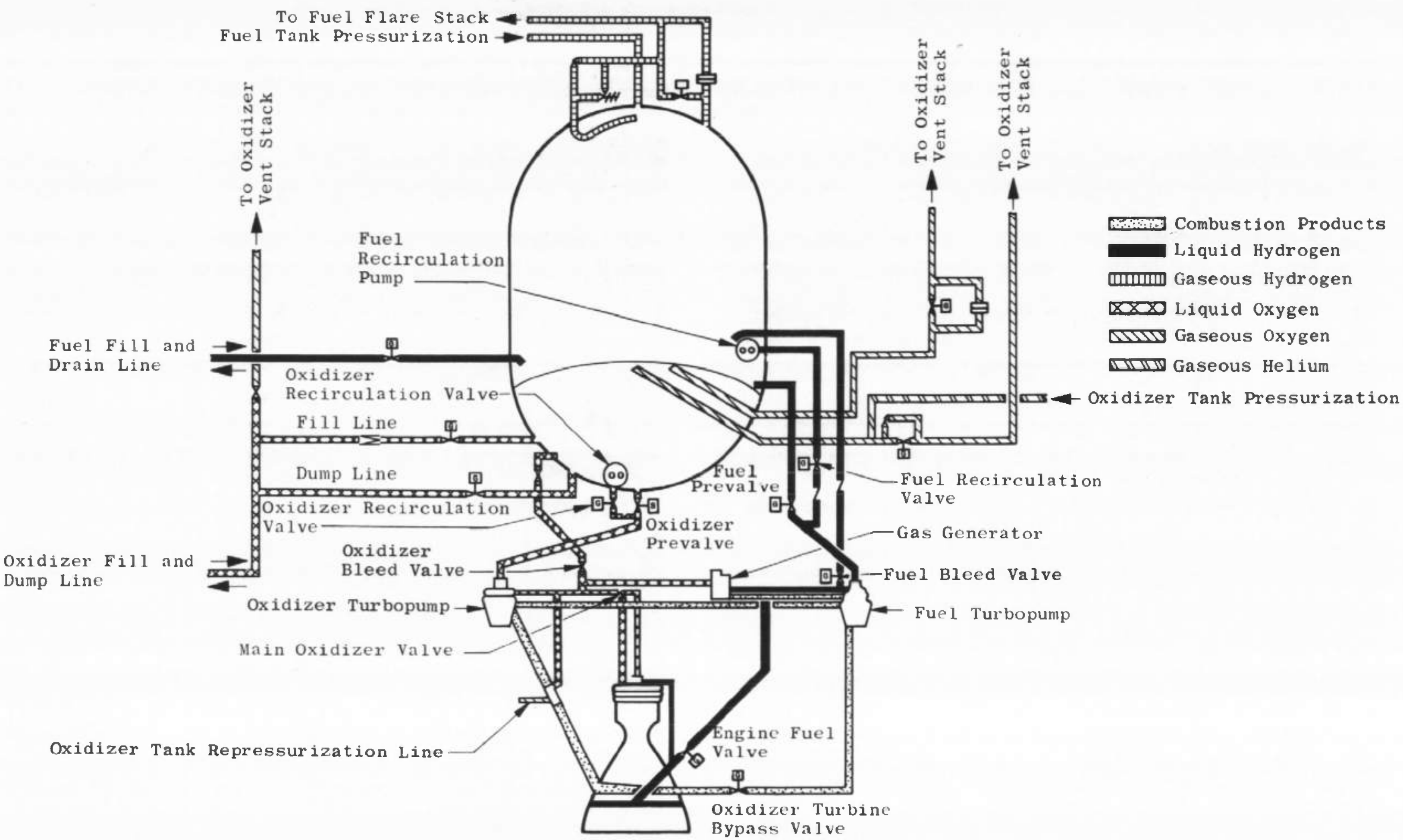



**Fig. 5 S-IVB Battleship Stage/J-2 Engine Schematic**

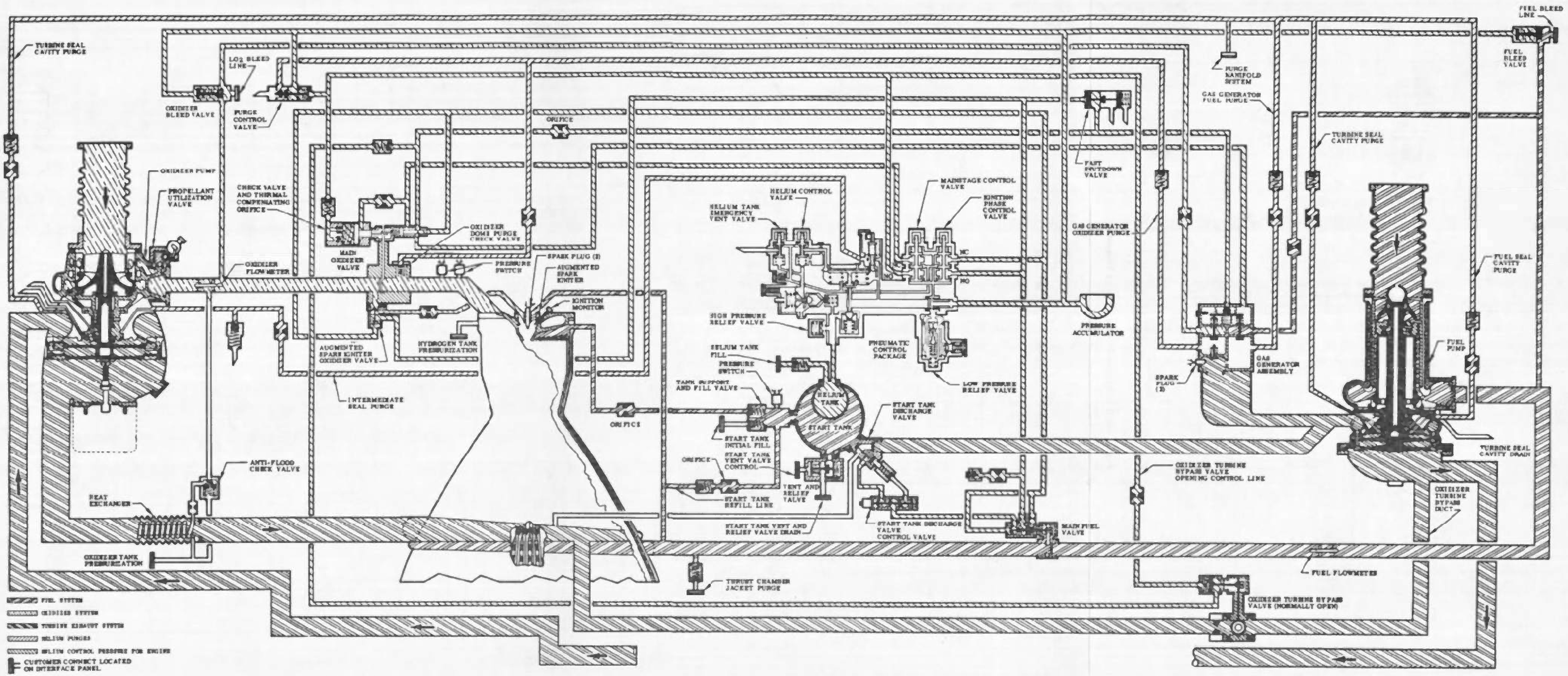



Fig. 5 Engine Schematic

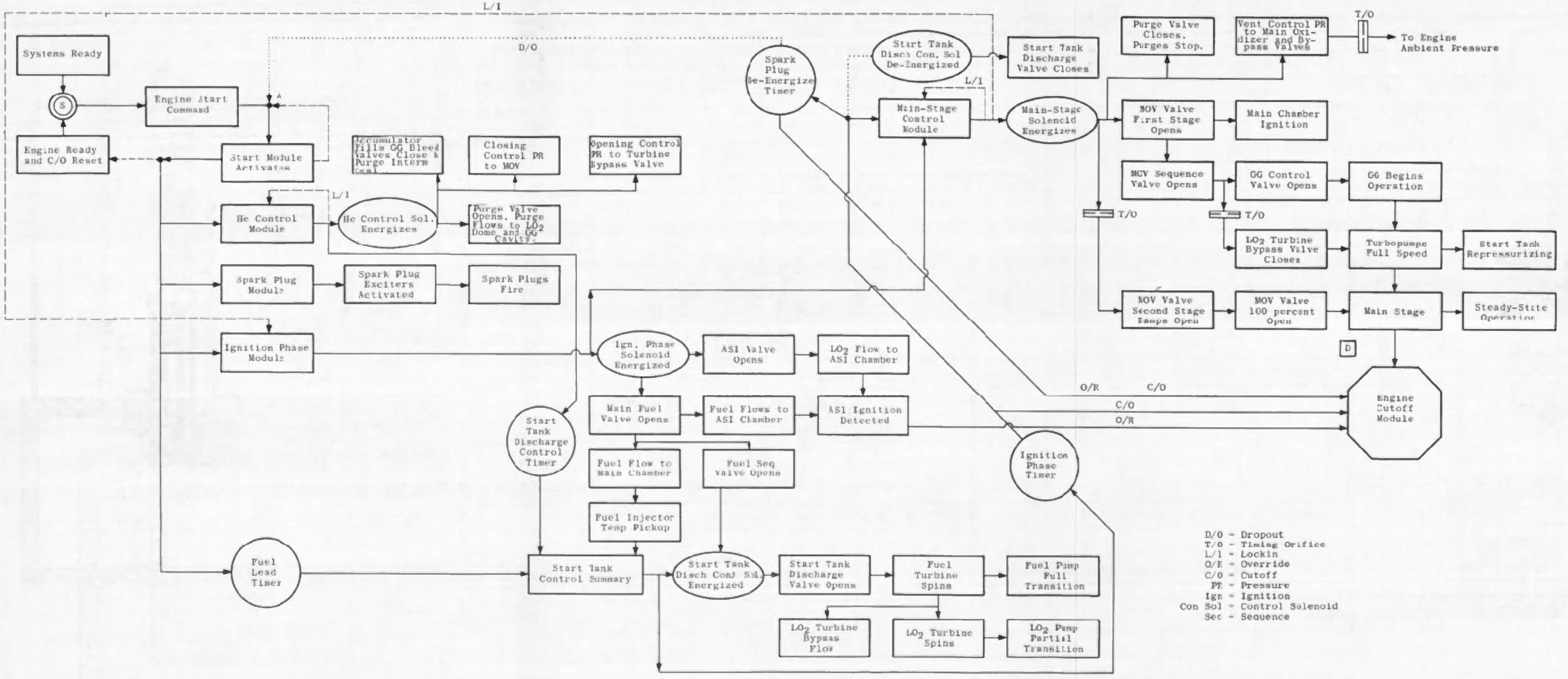
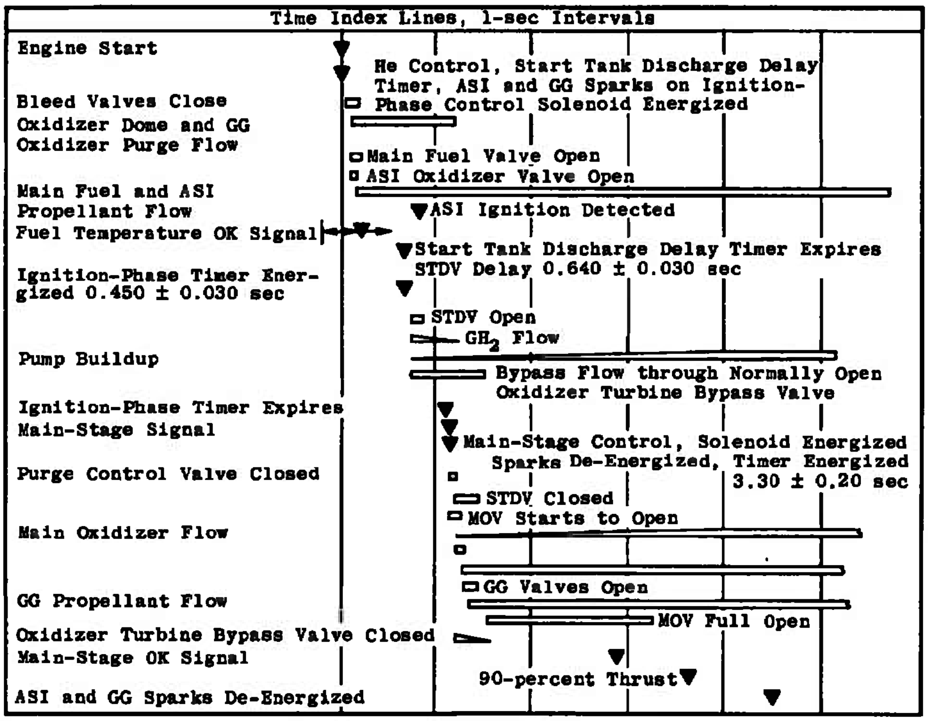
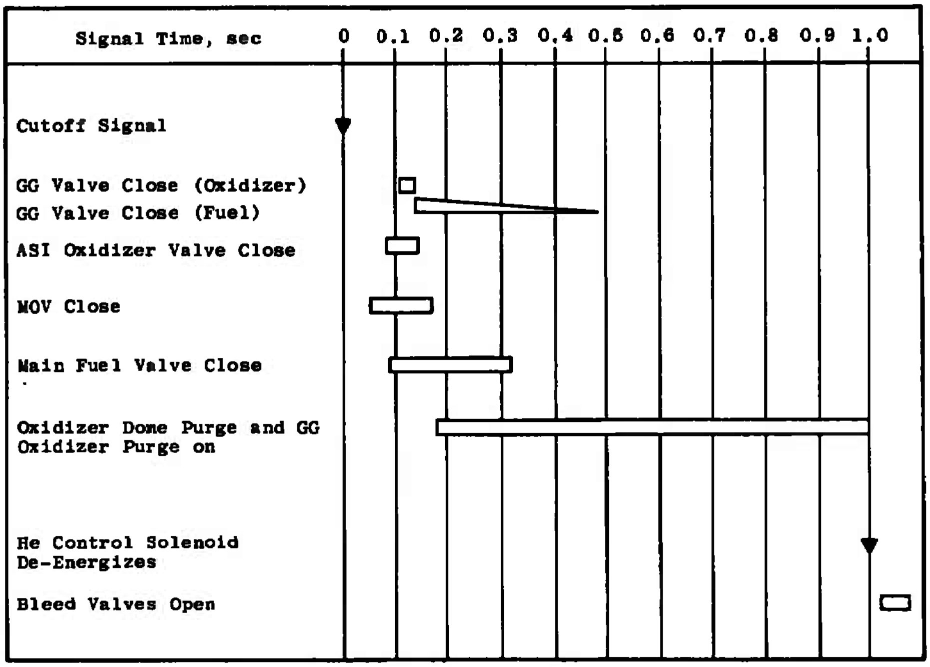



Fig. 6 Engine Start Logic Schematic

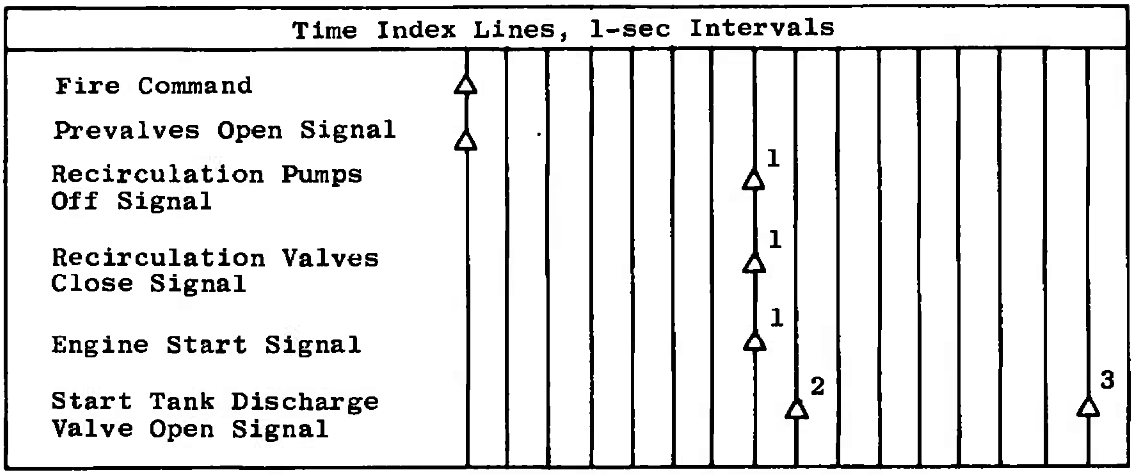



a. Start Sequence



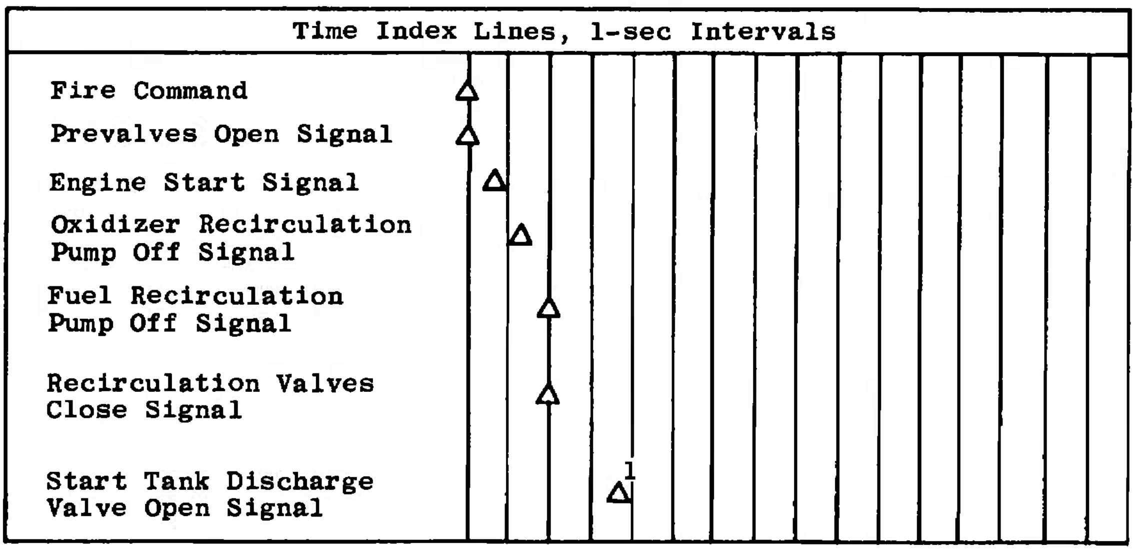

b. Shutdown Sequence

Fig. 8 Start and Shutdown Sequence




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

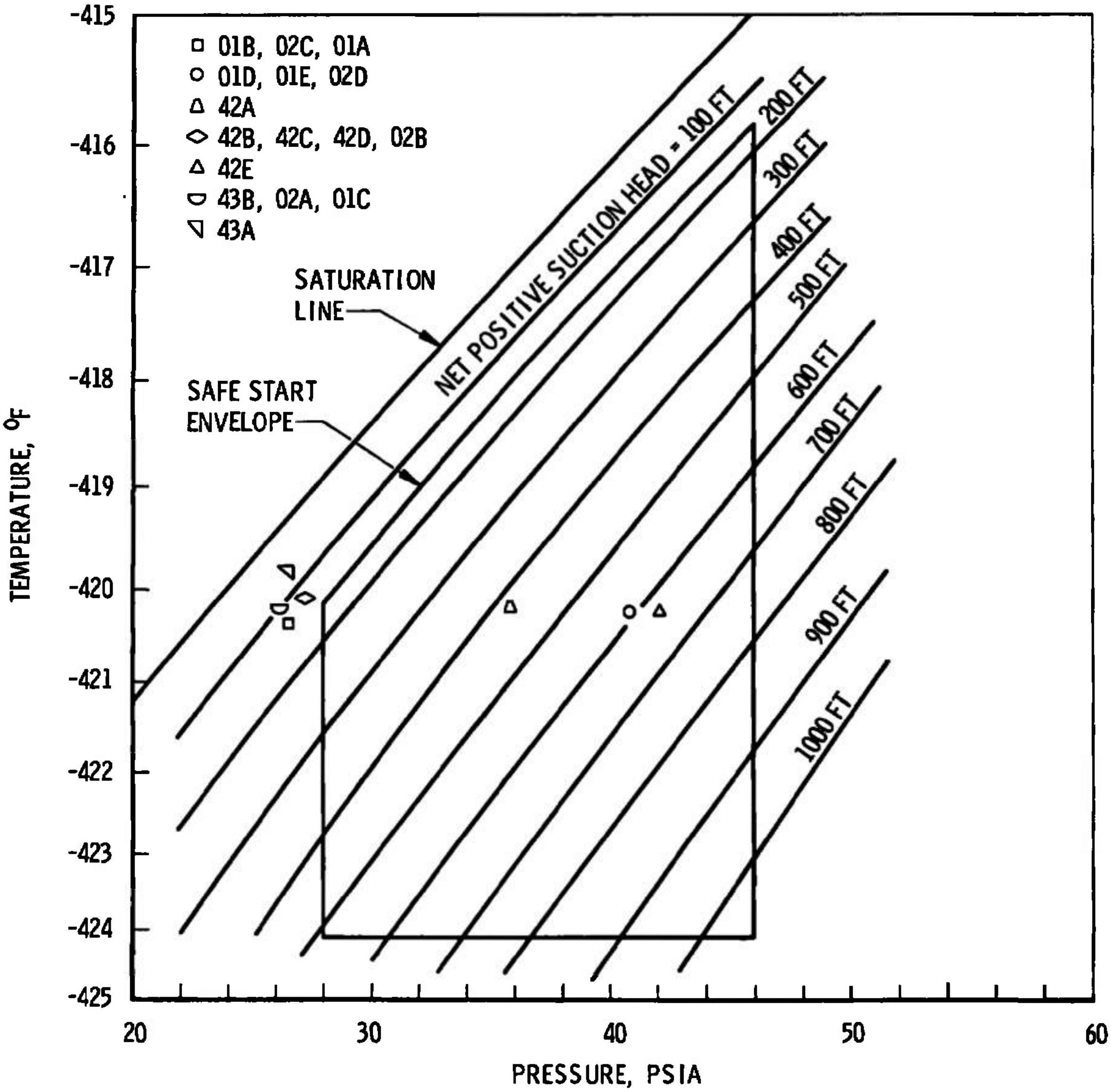
c. Normal Logic Start Sequence




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

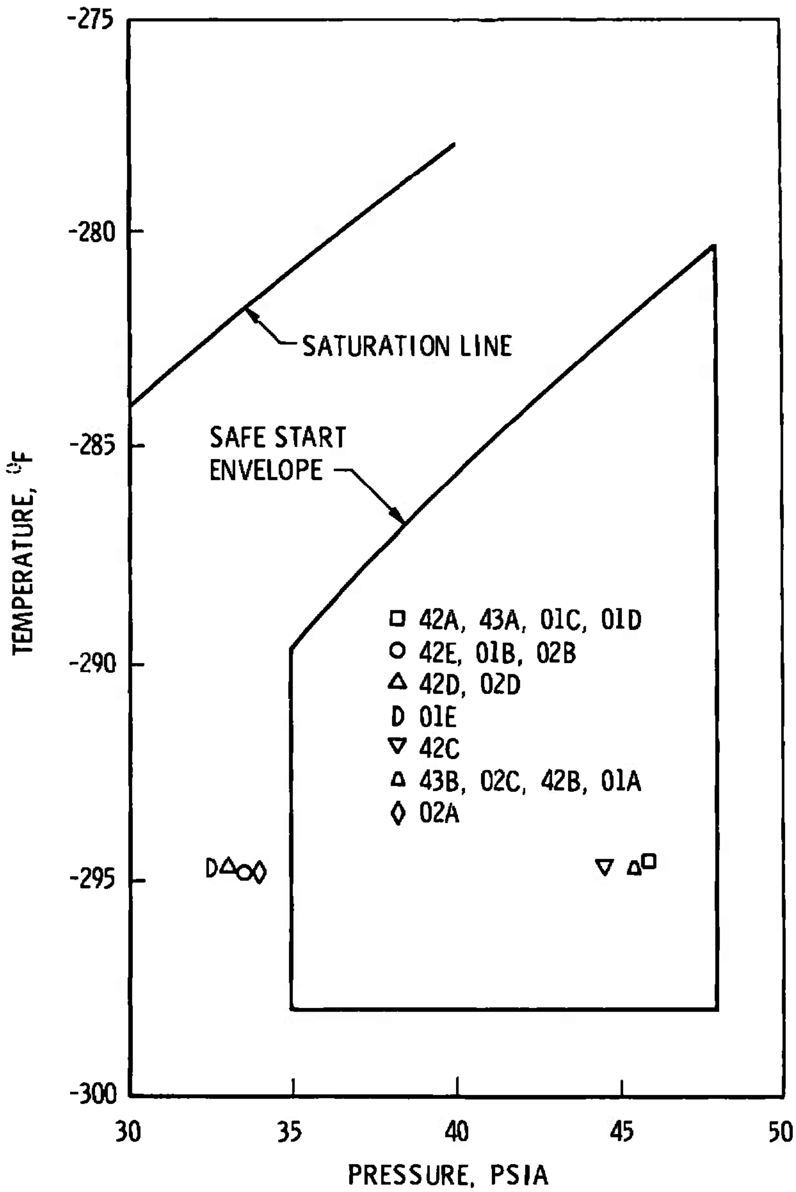
d. Auxiliary Logic Start Sequence

Fig. 8 Concluded



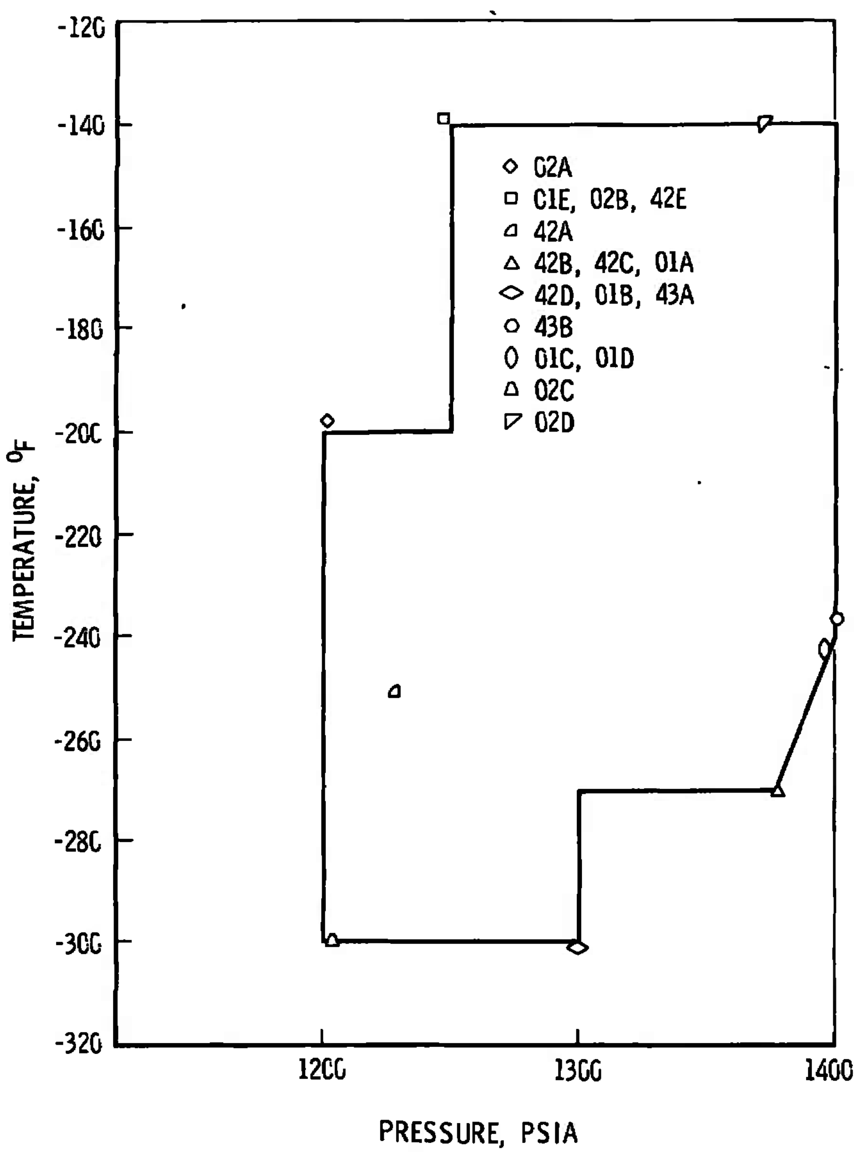

a. Fuel Pump Inlet Start Conditions

Fig. 9 Engine Start Conditions for Pump Inlets and Start Tank



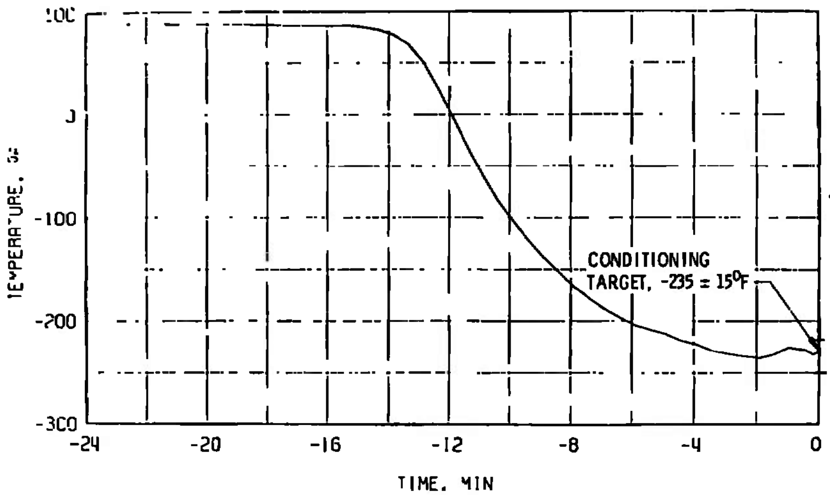

b. Oxidizer Pump Inlet Start Conditions

Fig. 9 Continued

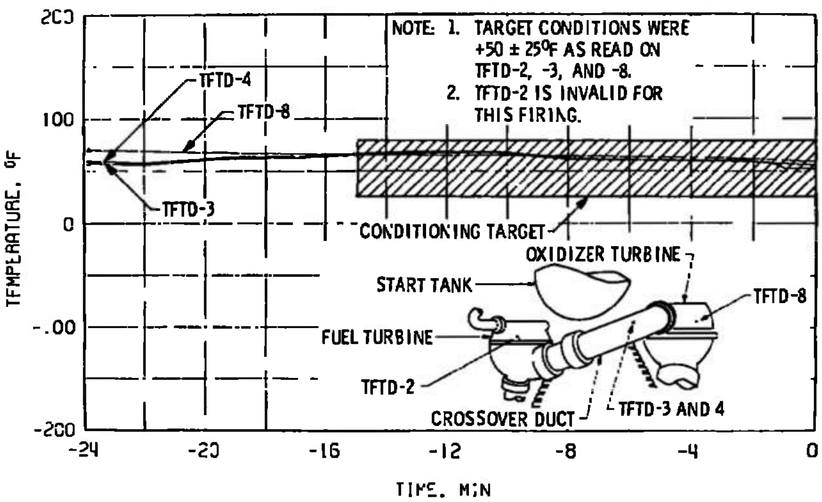



c. Start Tank Start Conditions

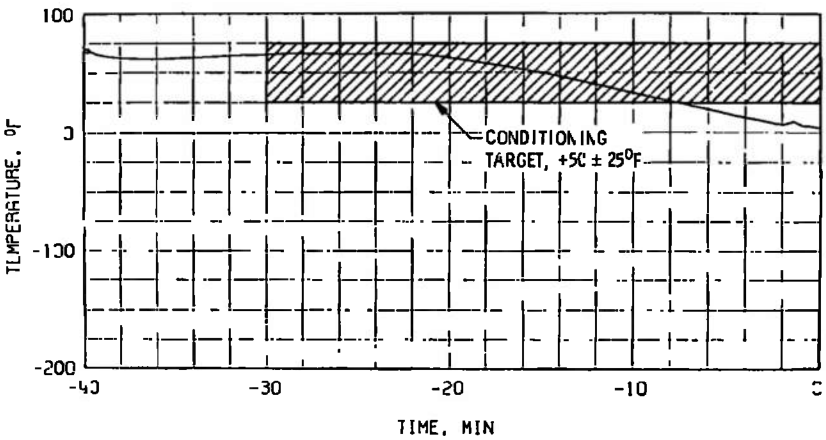
Fig. 9 Concluded




a. Thrust Chamber, TTC-1P

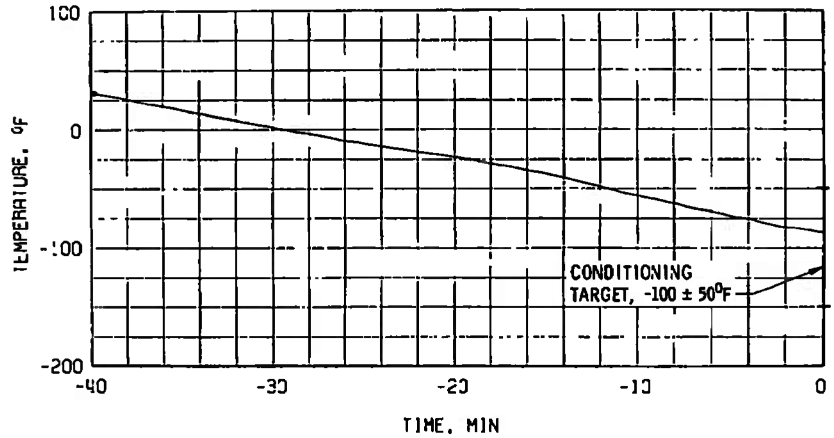



b. Crossover Duct, TFTD

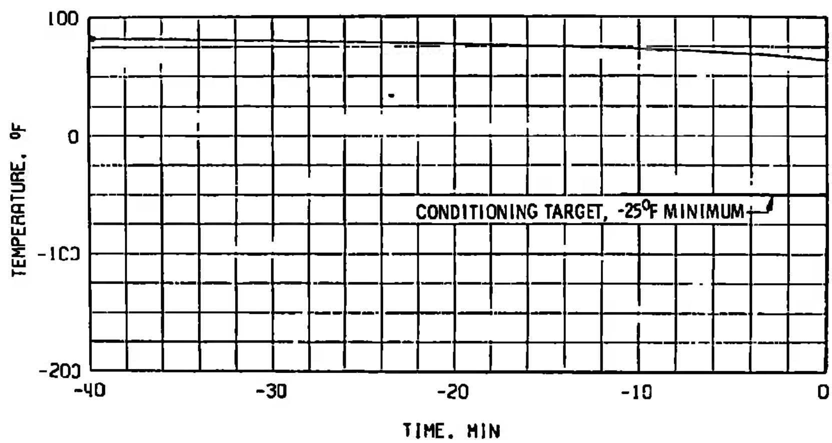



c. Start Tank Discharge Valve, TSTDVOC

Fig. 10 Thermal Conditioning History of Engine Components, Firing 42A




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




e. Gas Generator Control Valve, TGGVRS

Fig. 10 Concluded

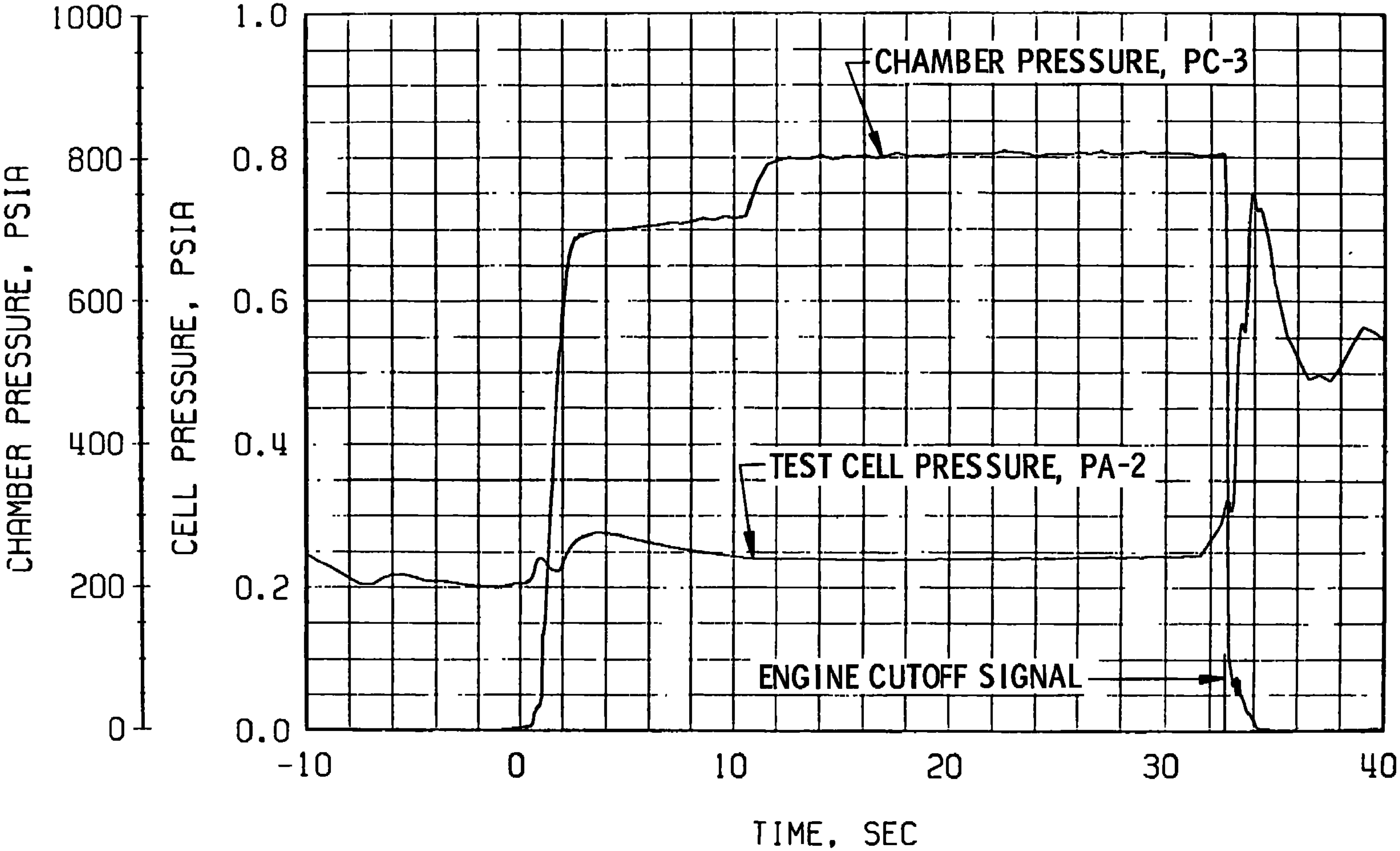
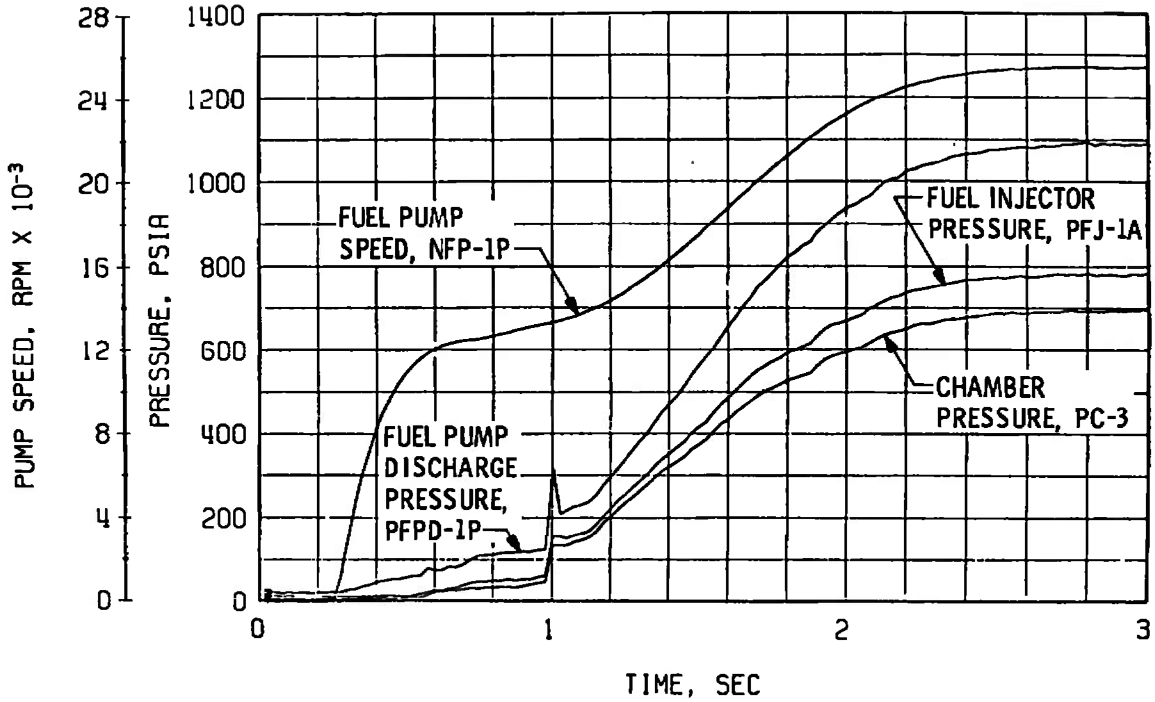
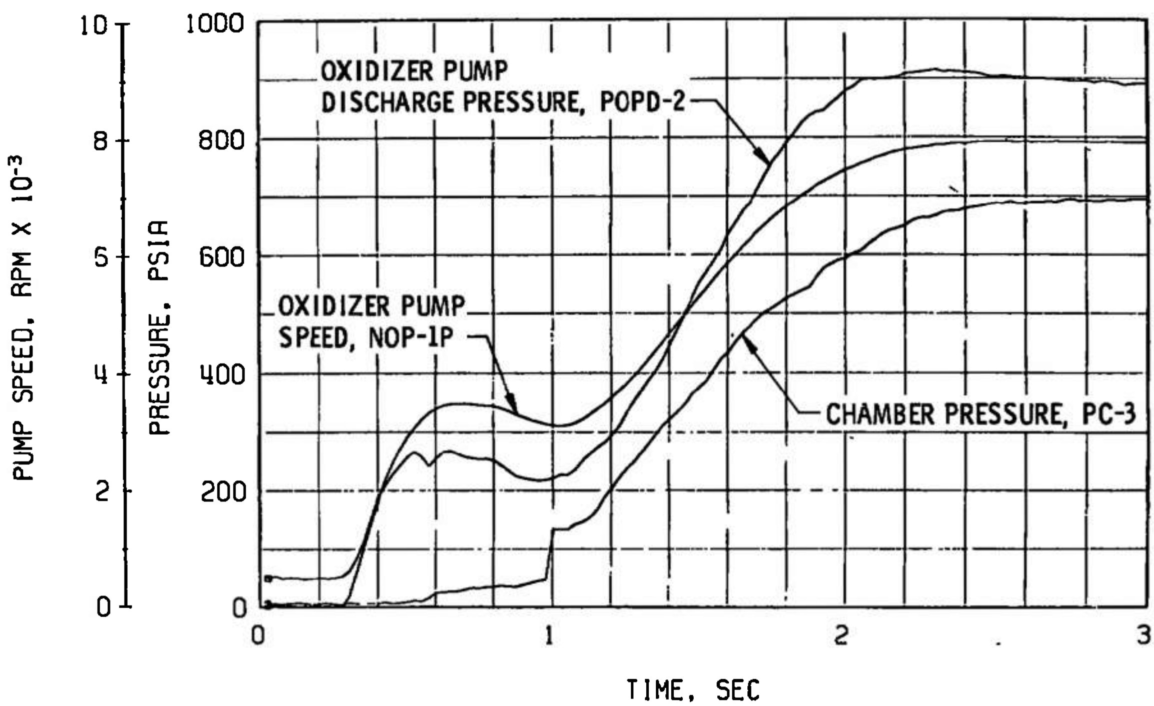



**Fig. 11 Engine Ambient and Combustion Chamber Pressures, Firing 42A**

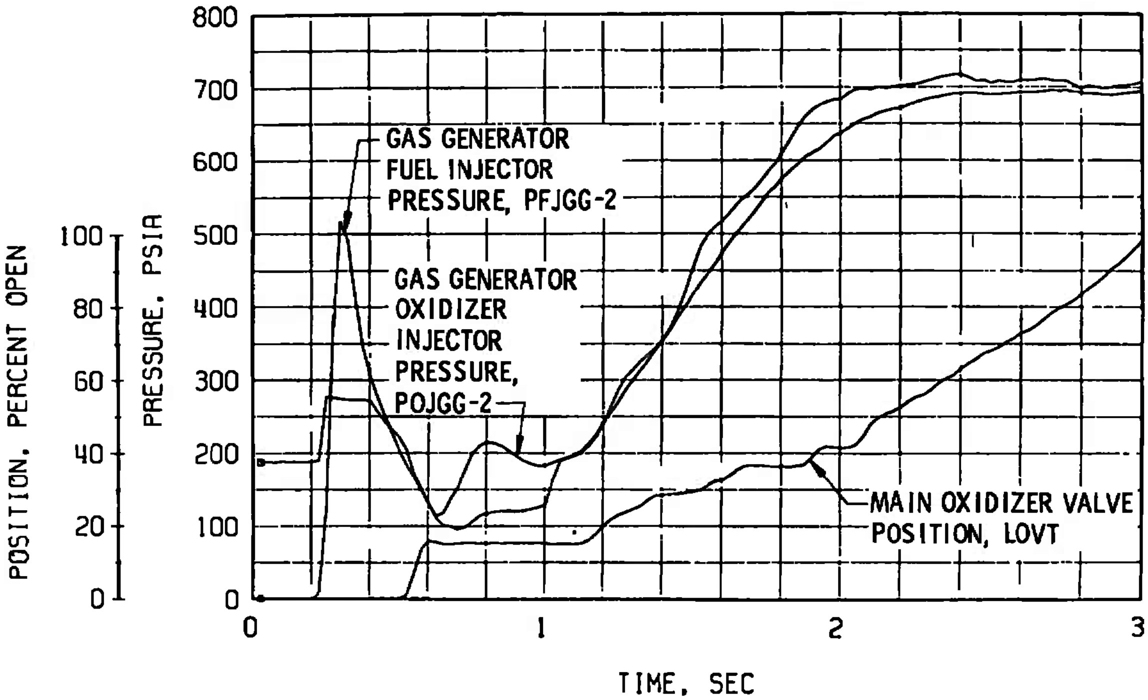



a. Thrust Chamber Fuel System, Start

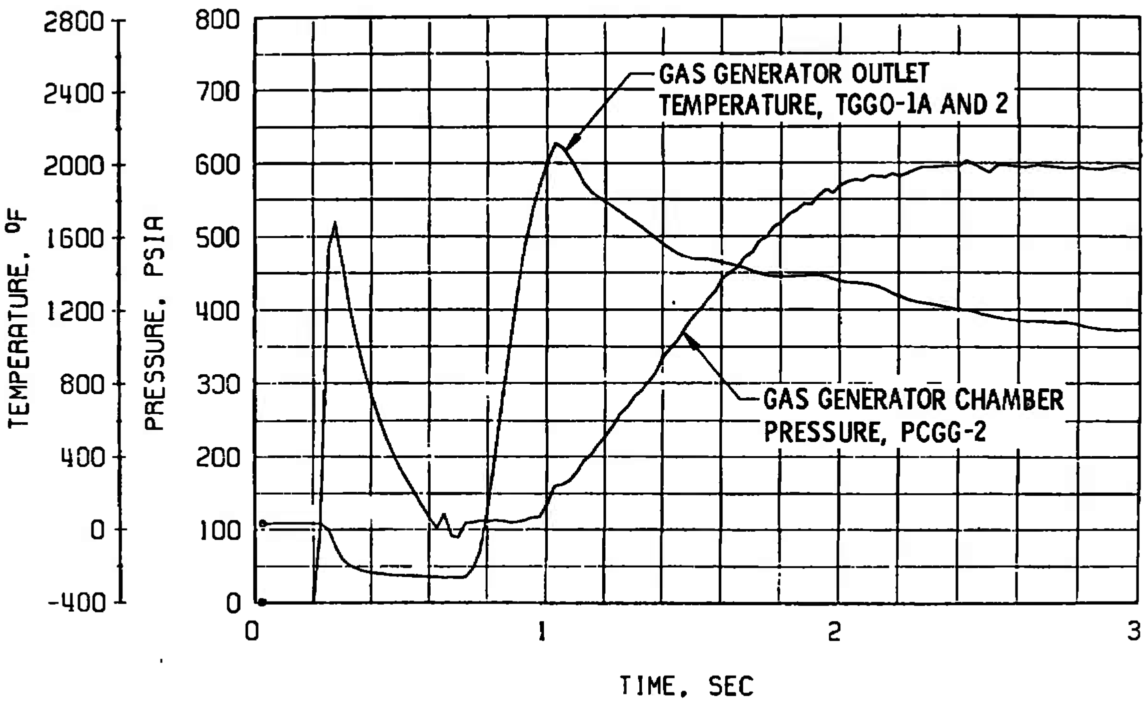



b. Thrust Chamber Oxidizer System, Start

Fig. 12 Engine Transient Operation, Firing 42A

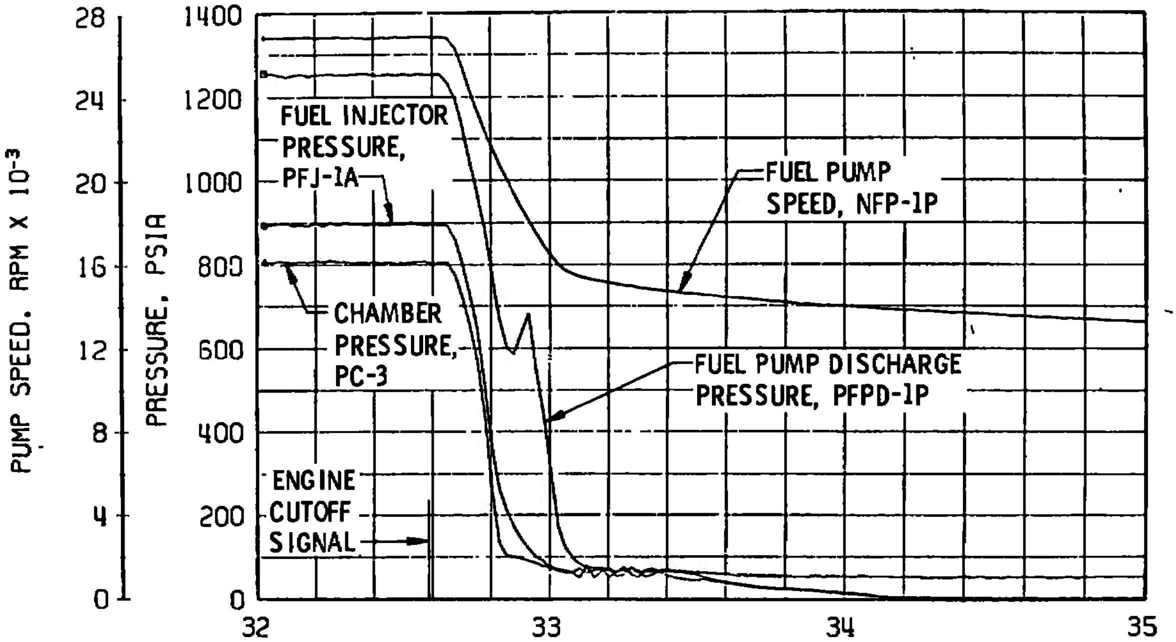



c. Gas Generator Injector Pressure and Main Oxidizer Valve Position, Start

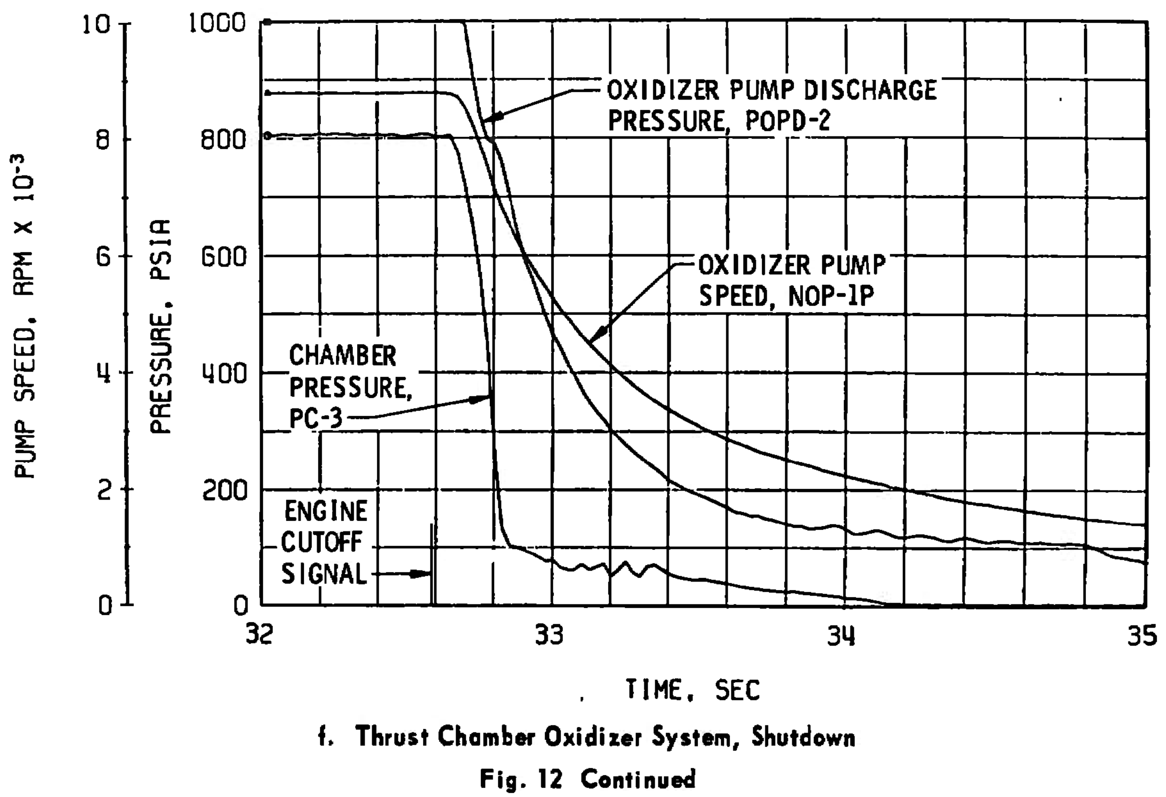



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 12 Continued

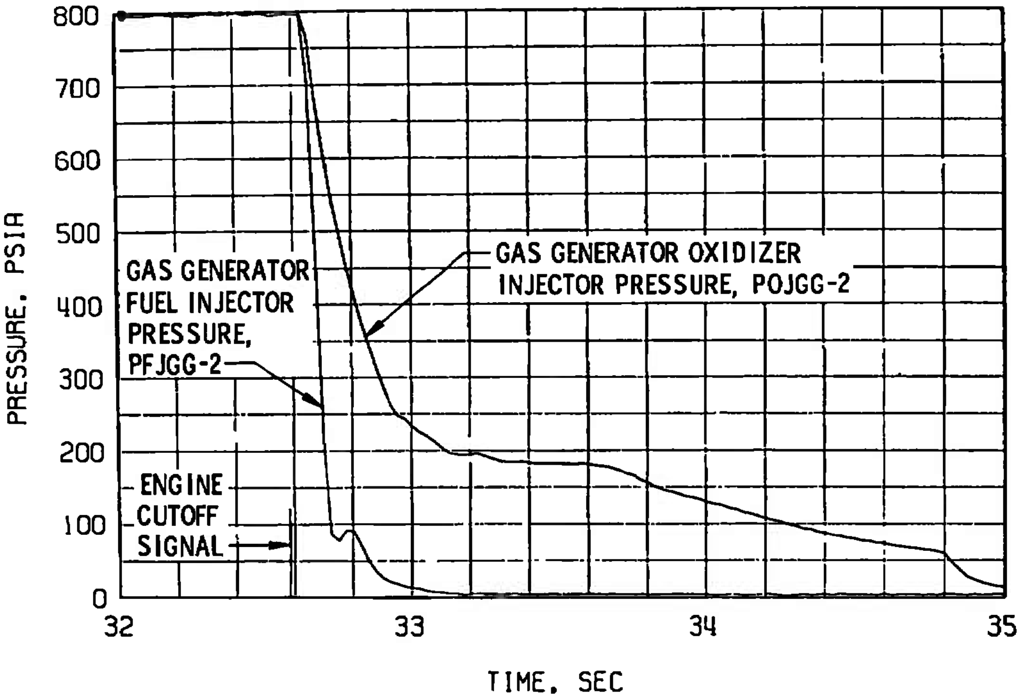



**e. Thrust Chamber Fuel System, Shutdown**

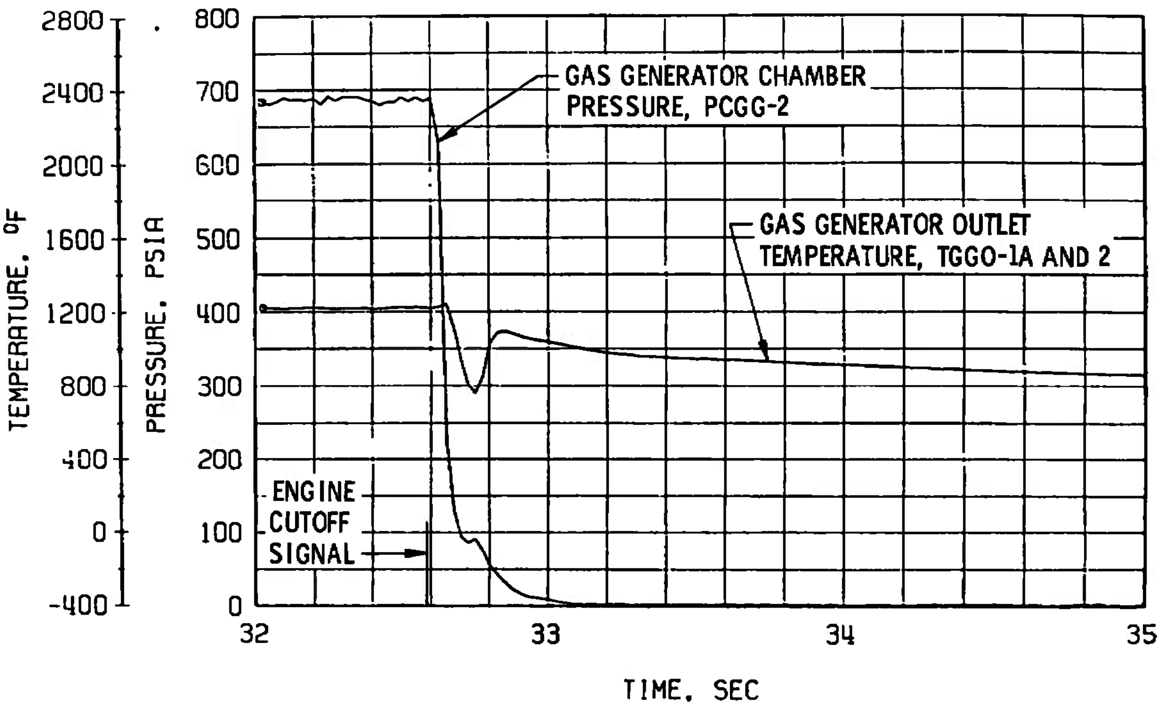



**f. Thrust Chamber Oxidizer System, Shutdown**

**Fig. 12 Continued**




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 12 Concluded

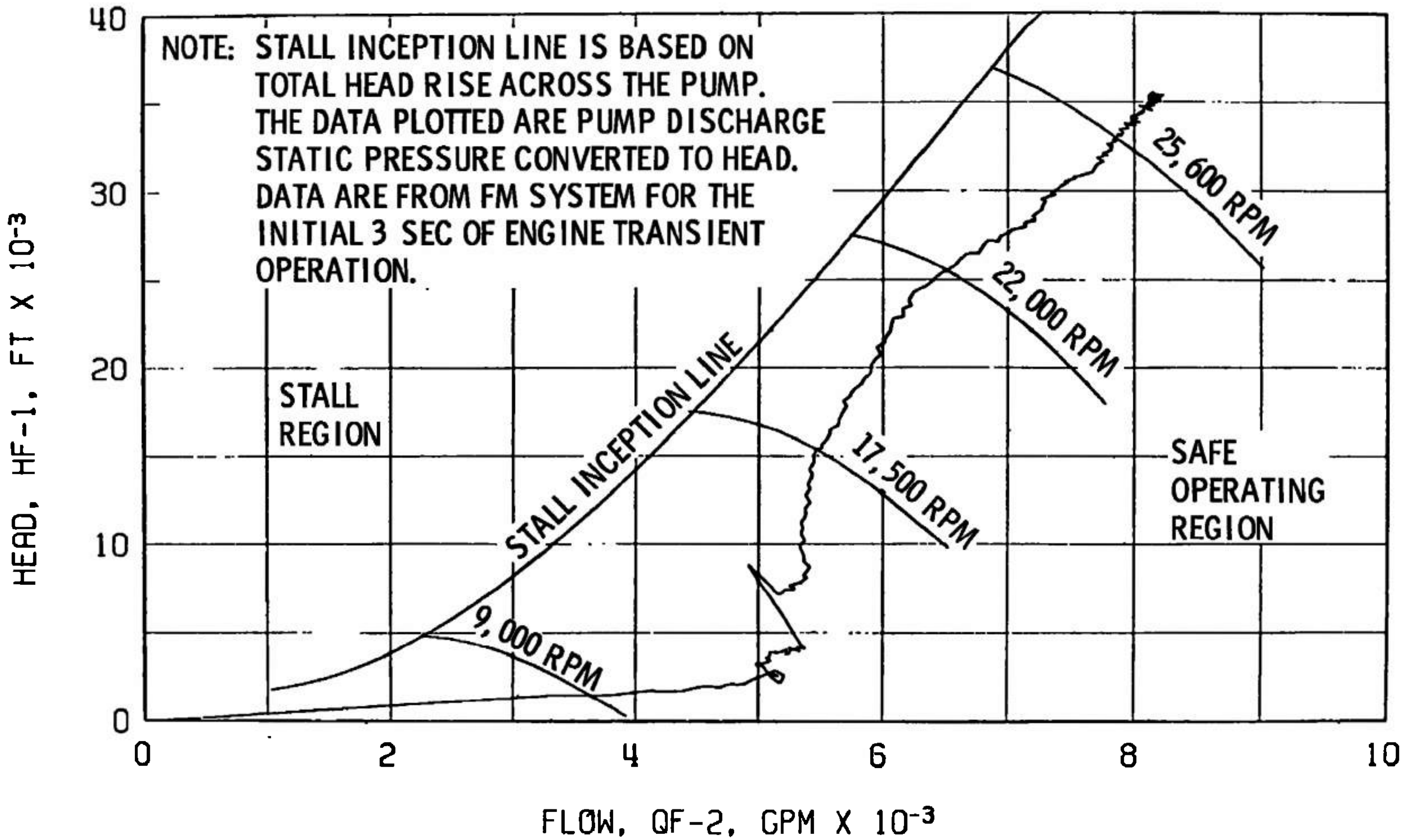
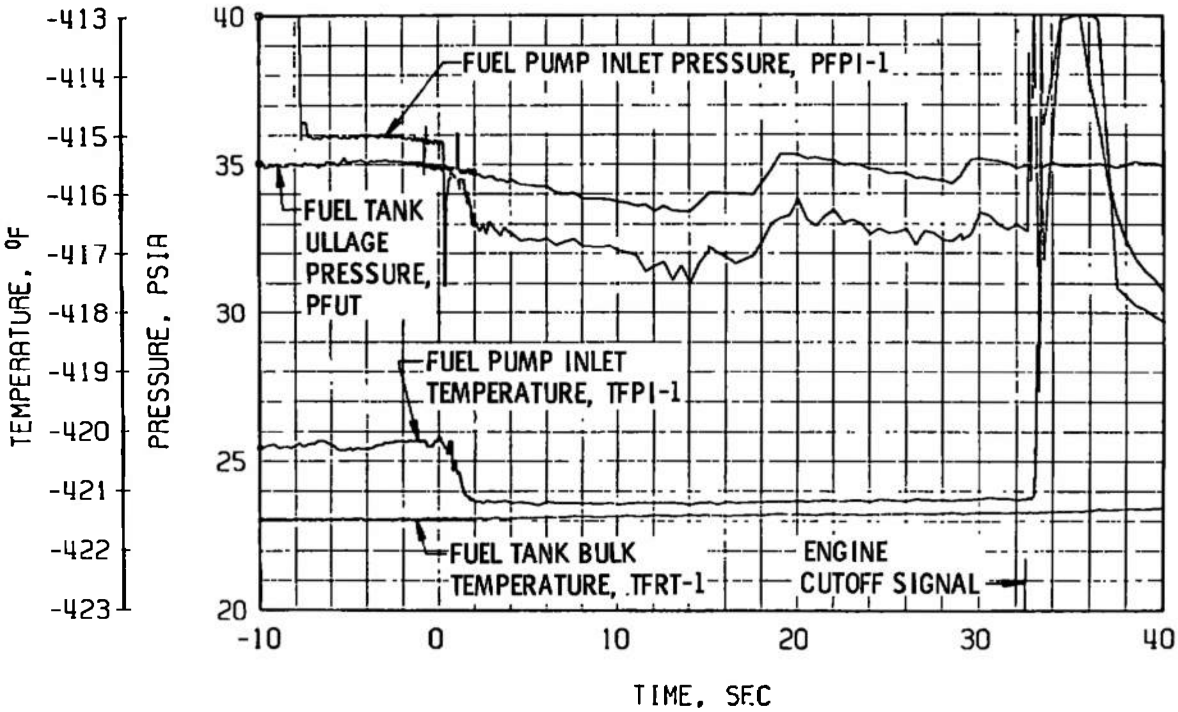
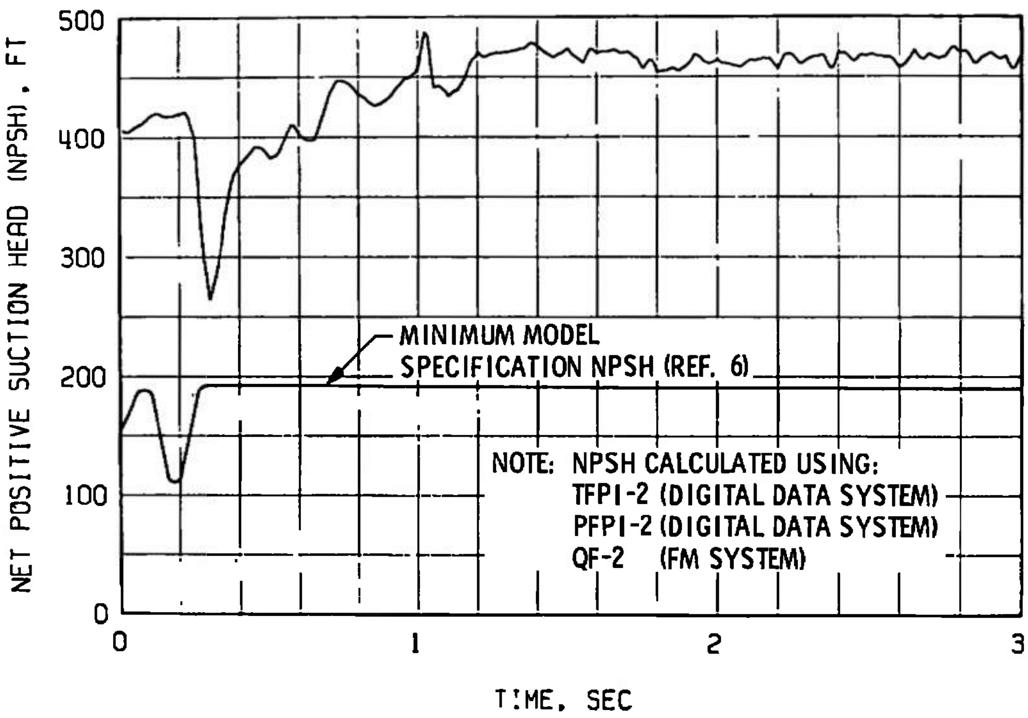



Fig. 13 Fuel Pump Start Transient Performance, Firing 42A

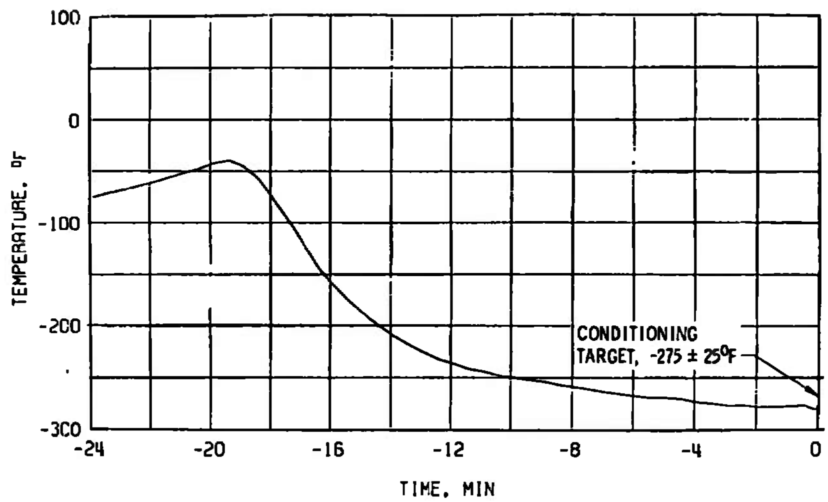



a. Duct Pressure and Temperature Transients

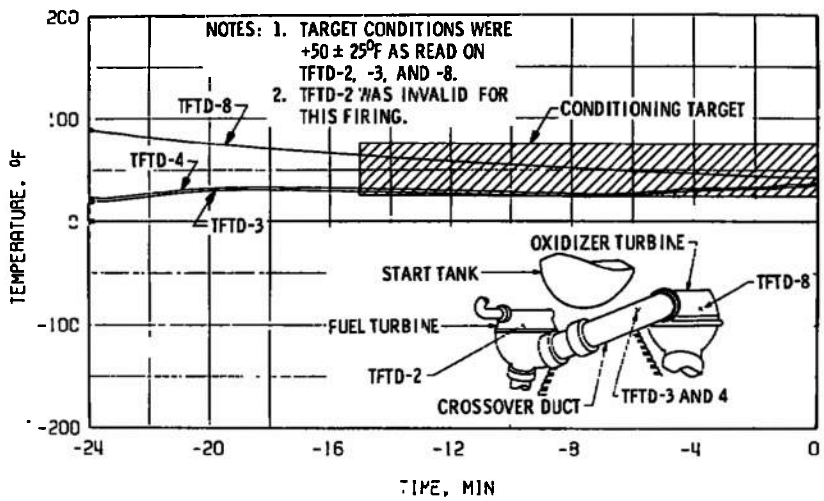



b. Fuel Pump NPSH during Start Transient, Firing 42A

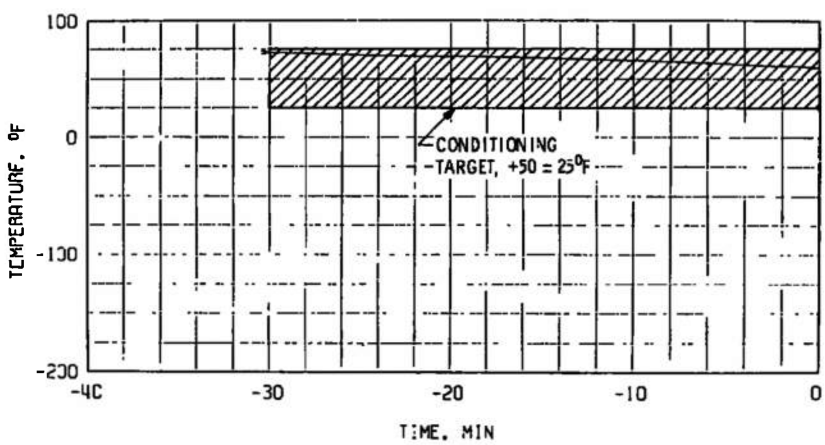
Fig. 14 Fuel Low Pressure Duct Performance, Firing 42A




a. Thrust Chamber, TTC-1P

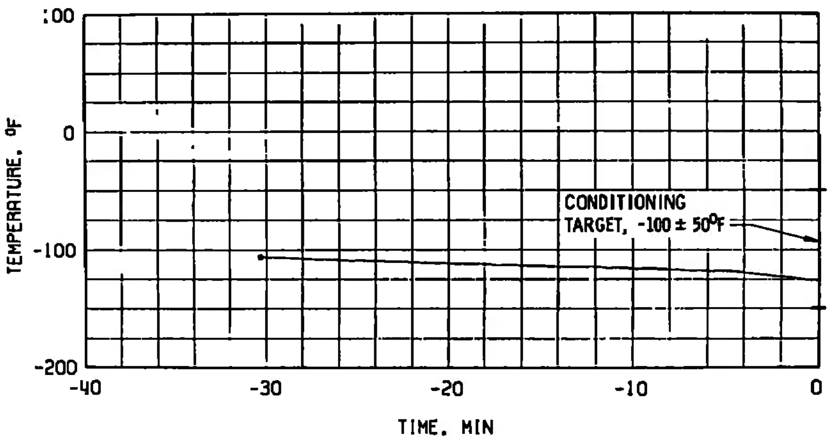



b. Crossover Duct, TFTD

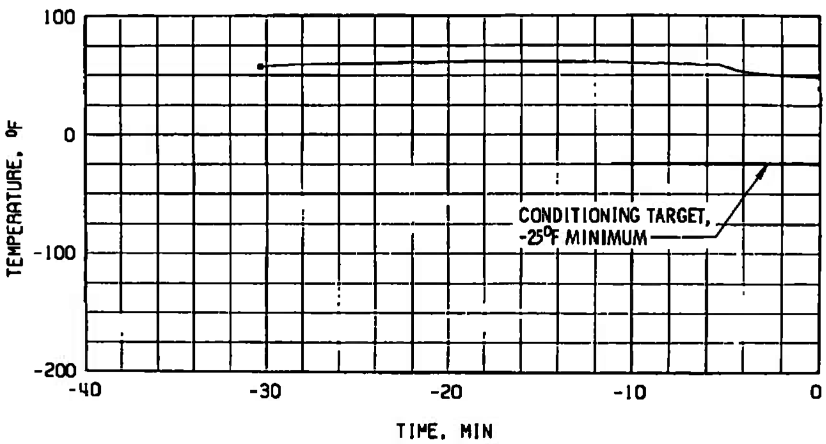



c. Start Tank Discharge Valve, TSTDVOC

Fig. 15 Thermal Conditioning History of Engine Components, Firing 42B




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




e. Gas Generator Control Valve, TGGVRS

Fig. 15 Concluded

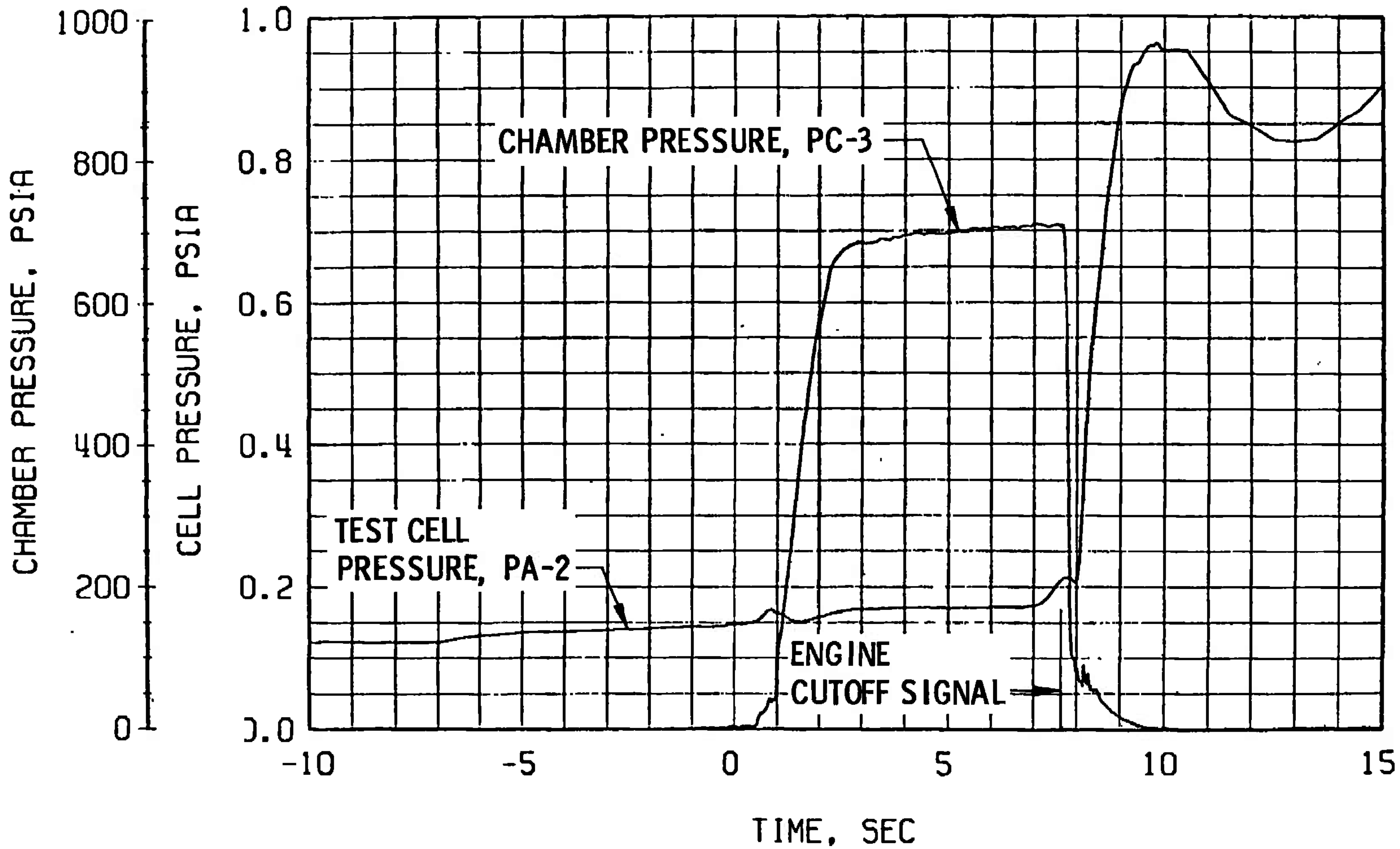
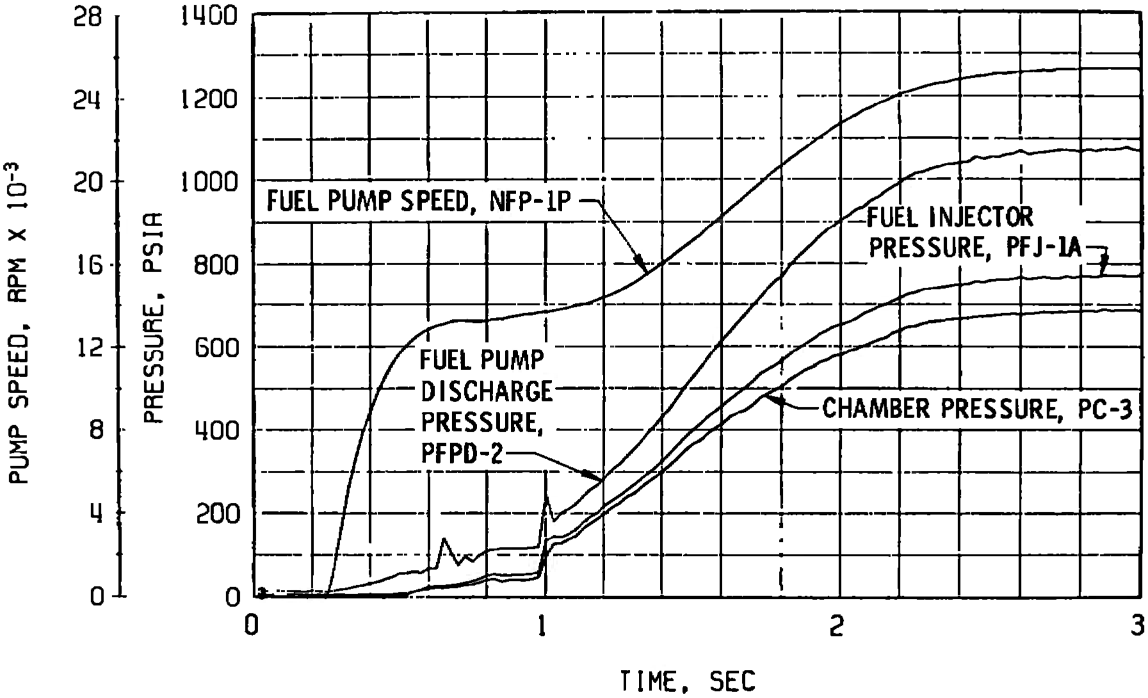
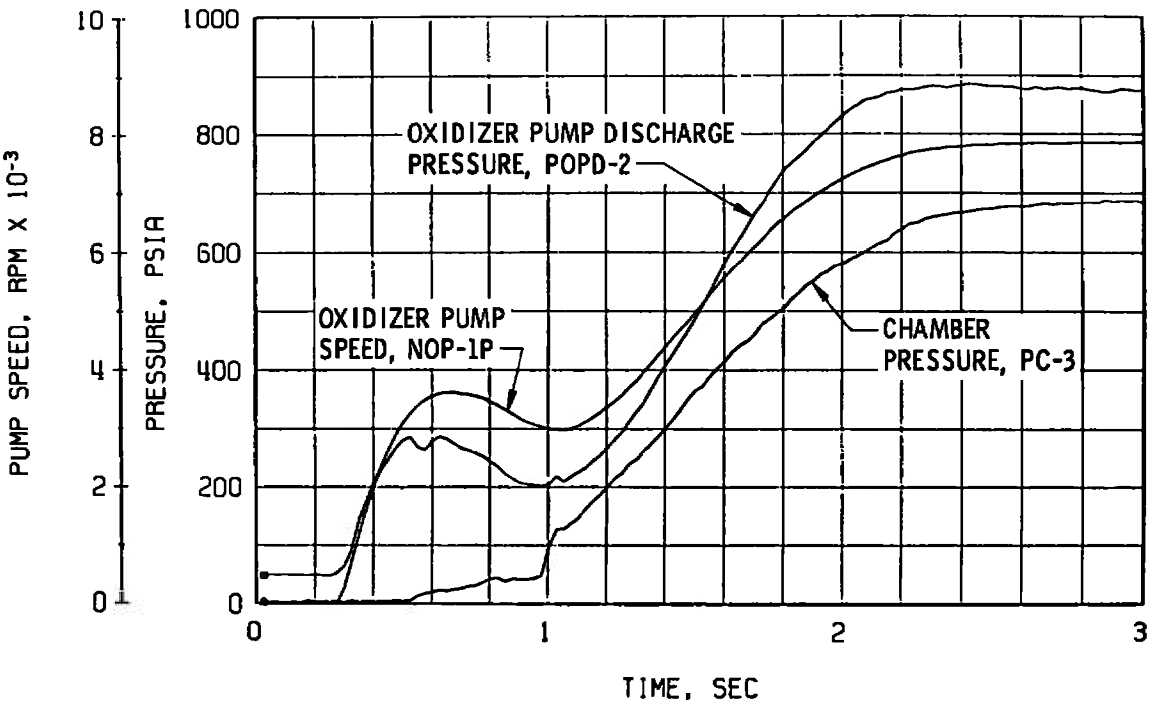



**Fig. 16 Engine Ambient and Combustion Chamber Pressures, Firing 42B**

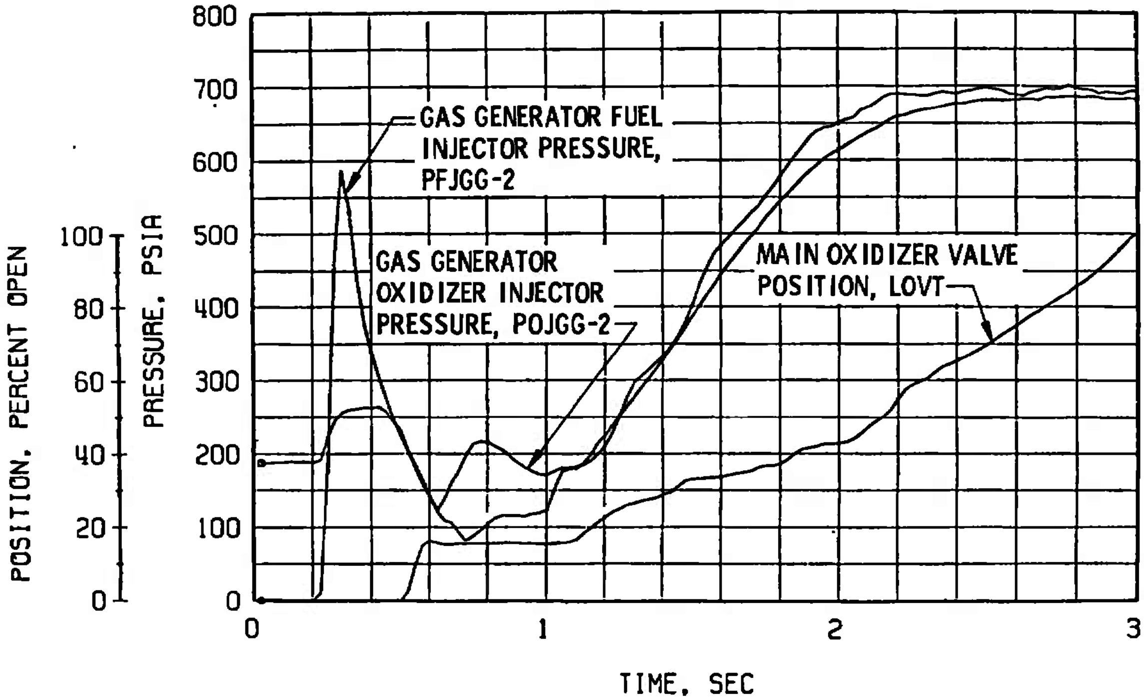



a. Thrust Chamber Fuel System, Start

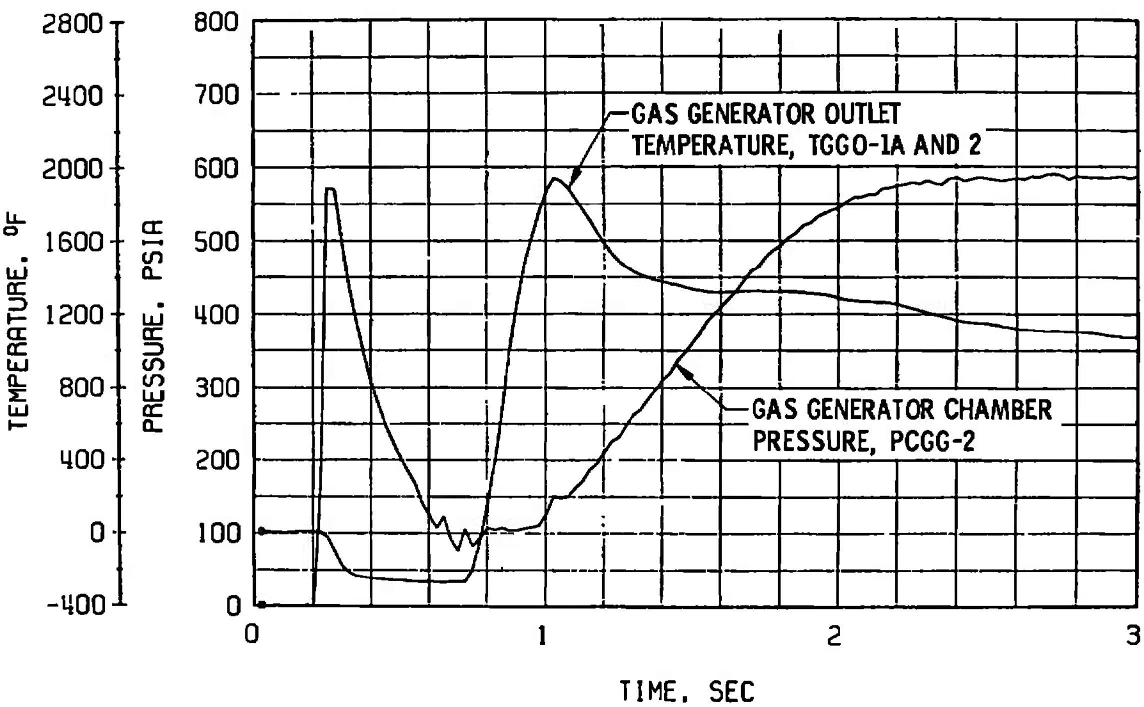



b. Thrust Chamber Oxidizer System, Start

Fig. 17 Engine Transient Operation, Firing 42B

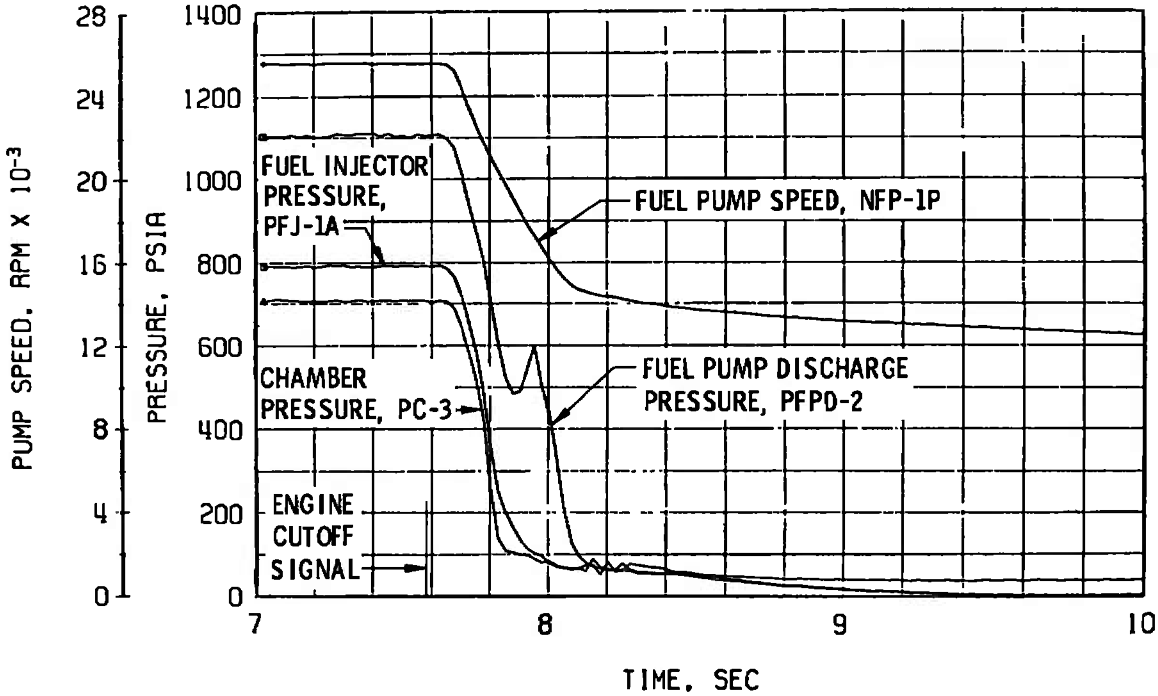



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

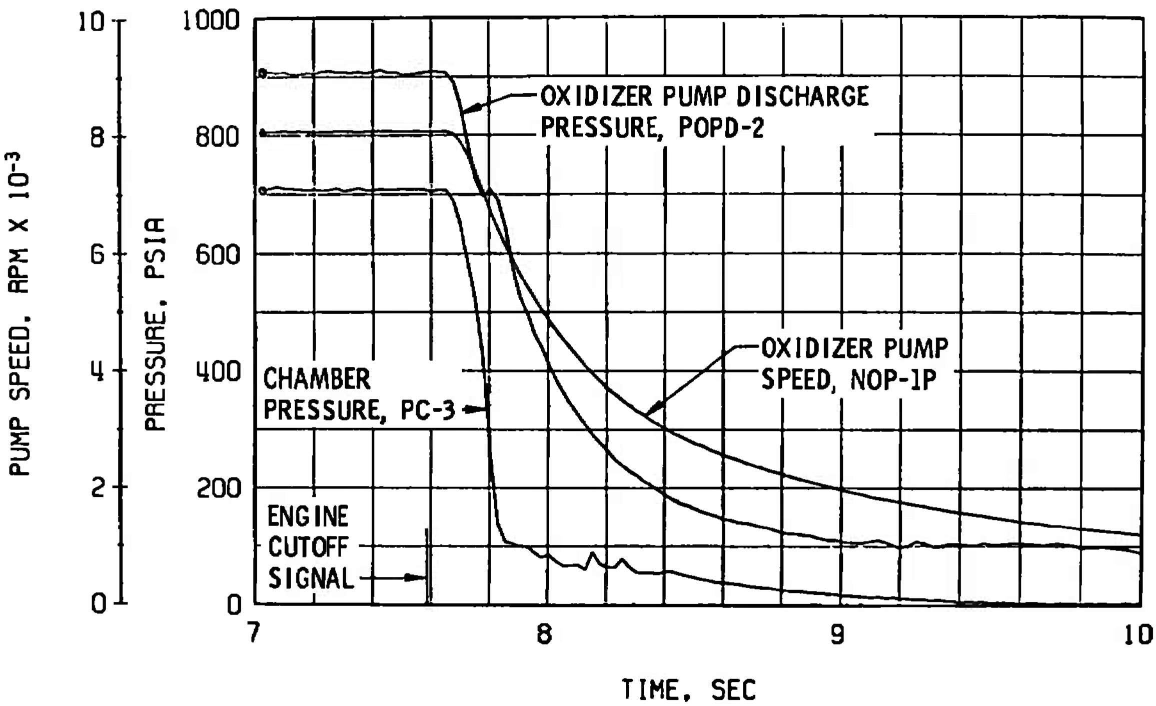



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 17 Continued

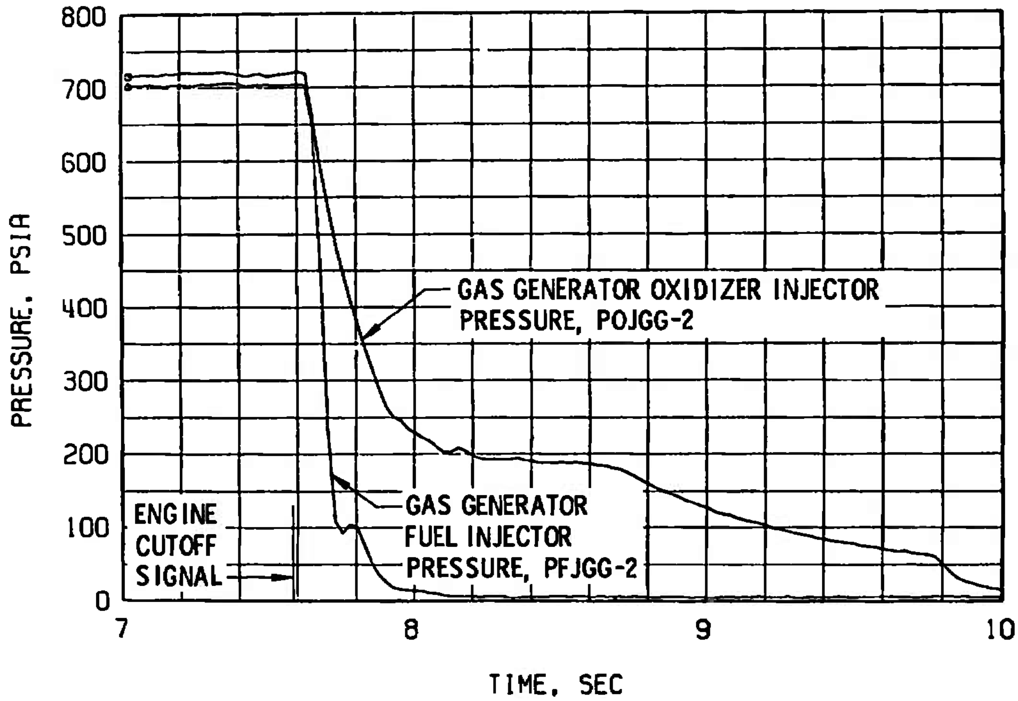



e. Thrust Chamber Fuel System, Shutdown

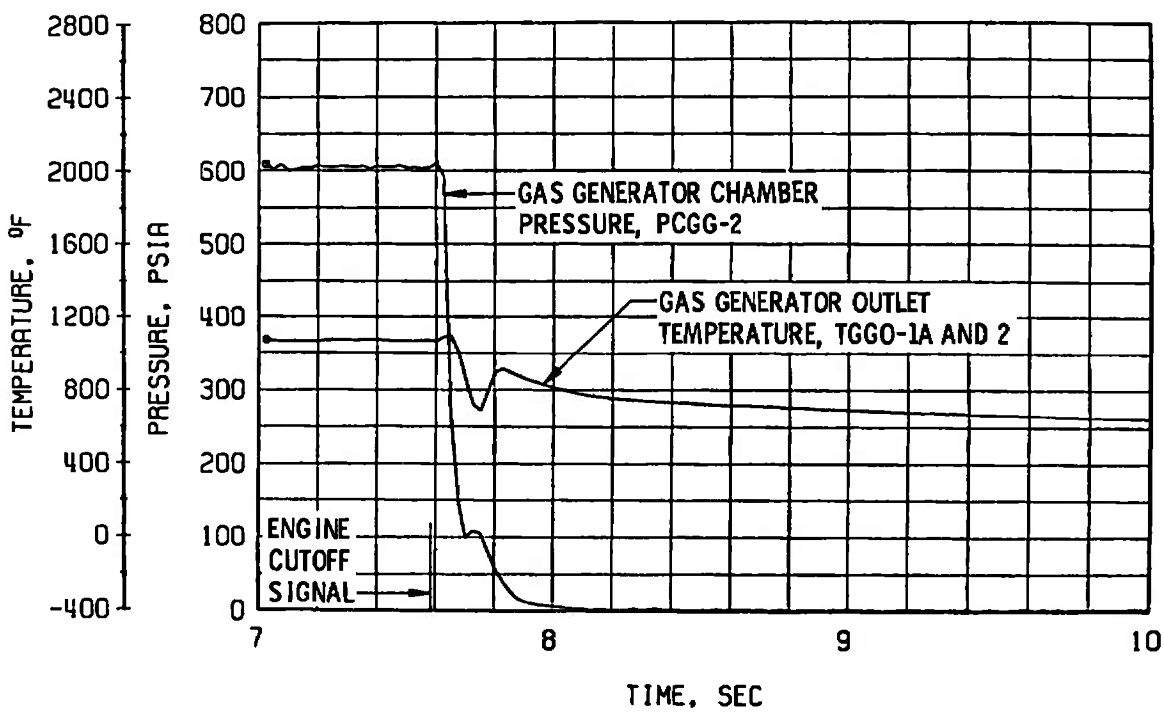



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 17 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 17 Concluded

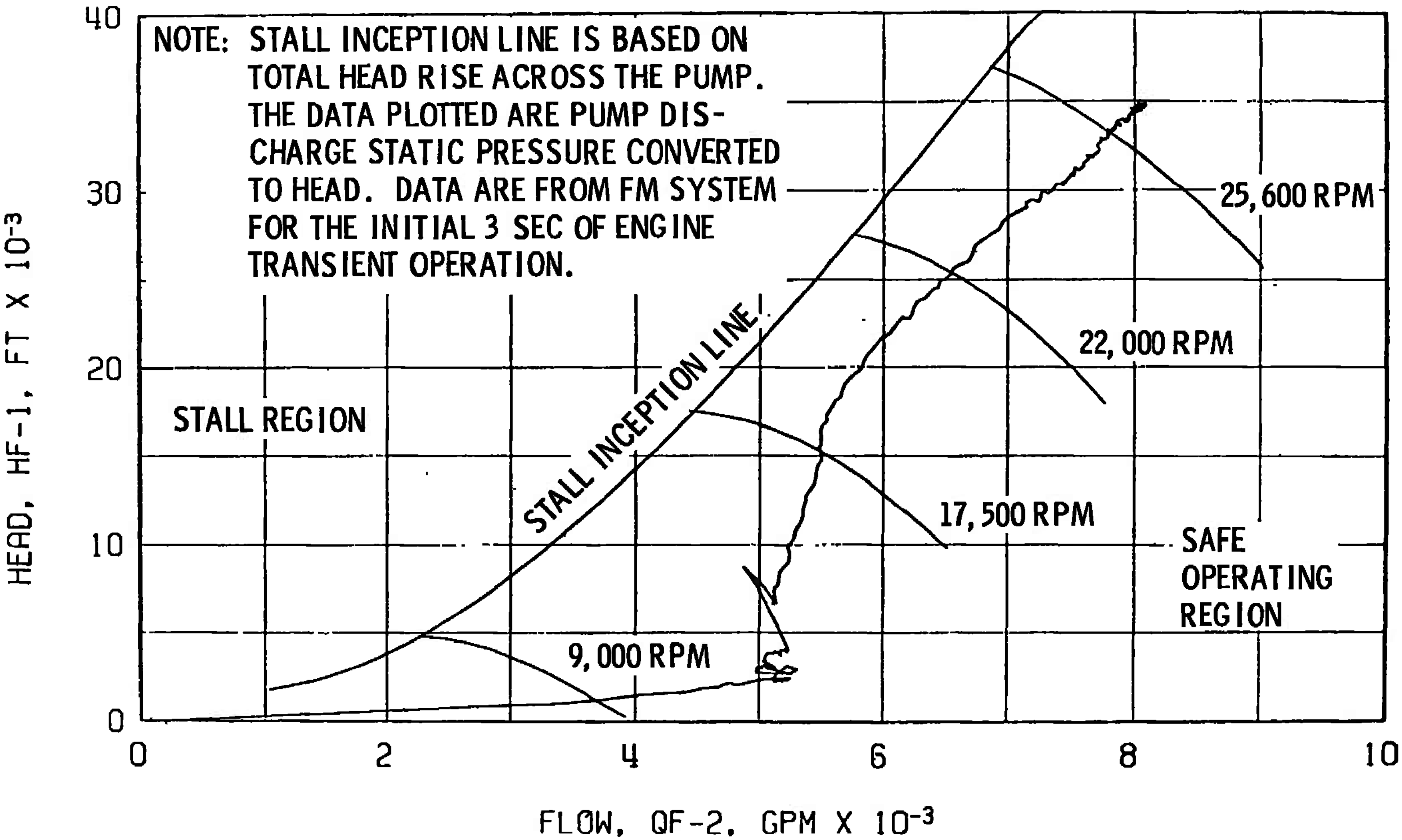
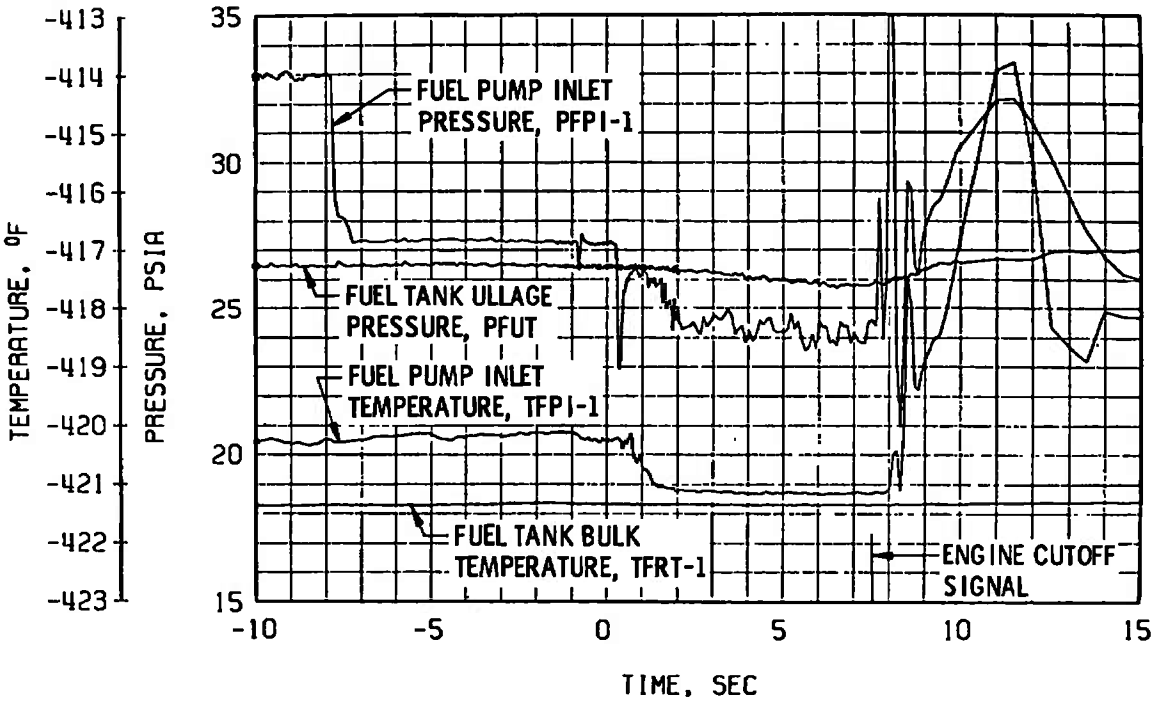
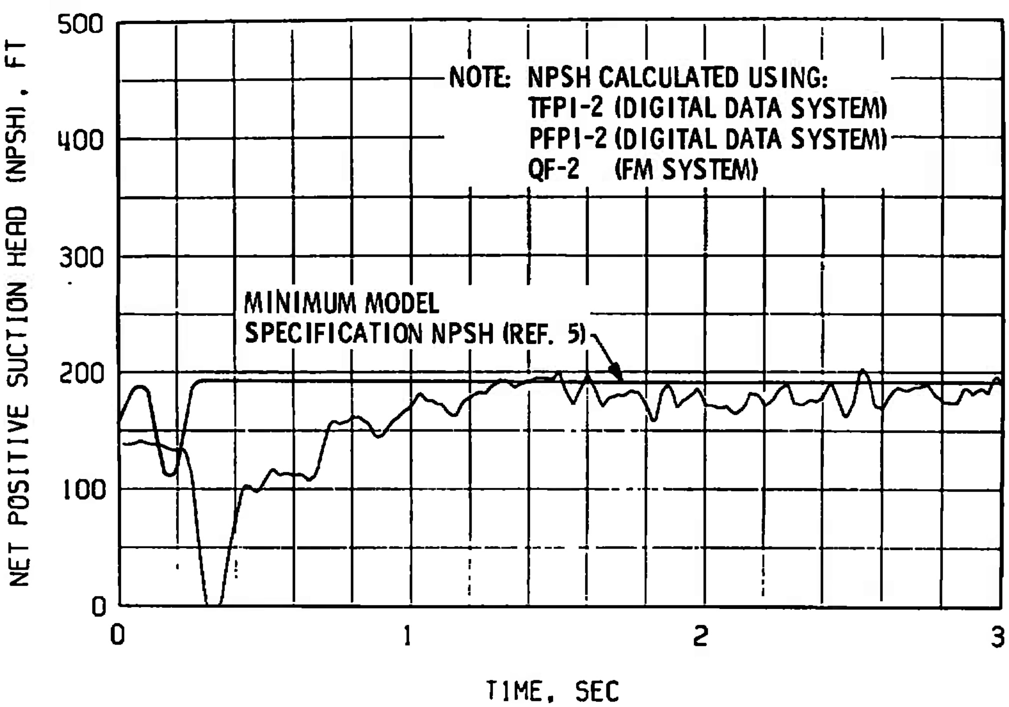



Fig. 18 Fuel Pump Start Transient Performance, Firing 42B

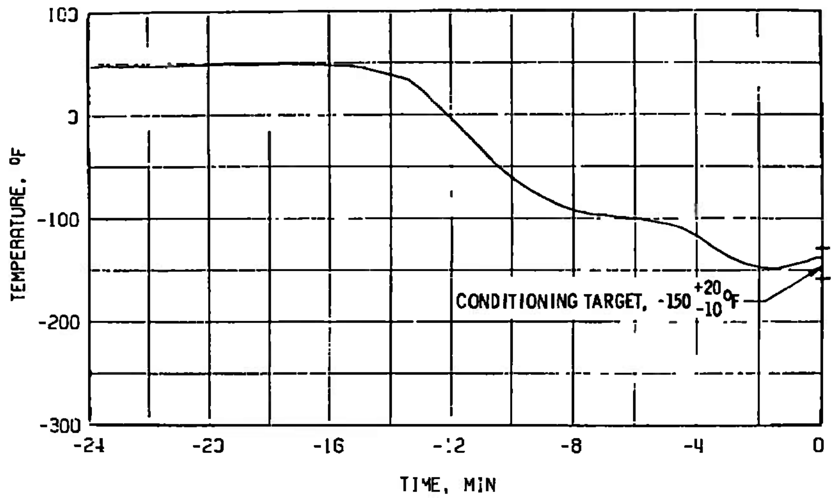



a. Duct Pressure and Temperature Transients

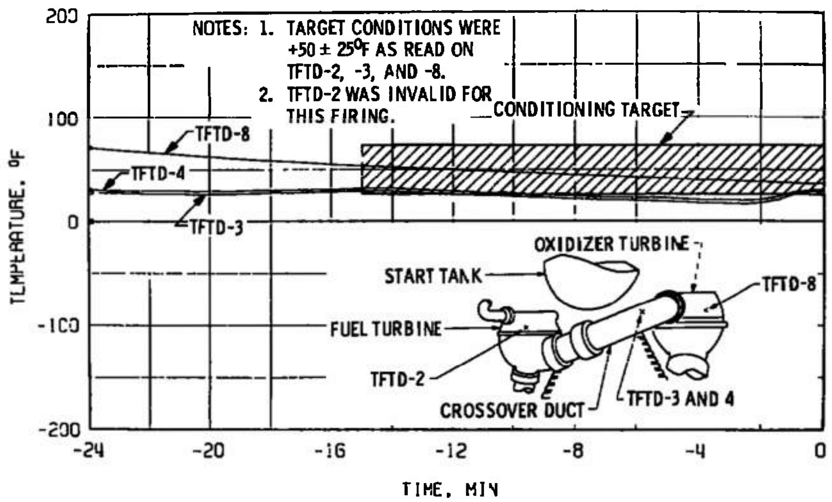



b. Fuel Pump NPSH during Start Transient, Firing 42B

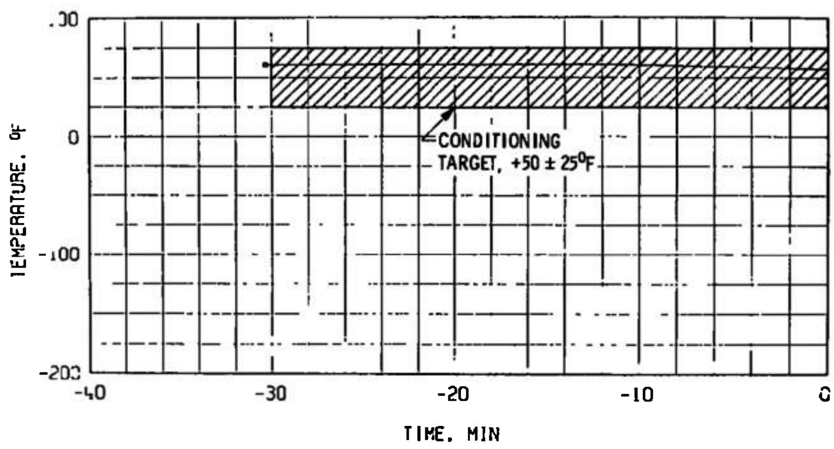
Fig. 19 Fuel Low Pressure Duct Performance, Firing 42B




a. Thrust Chamber, TTC-1P

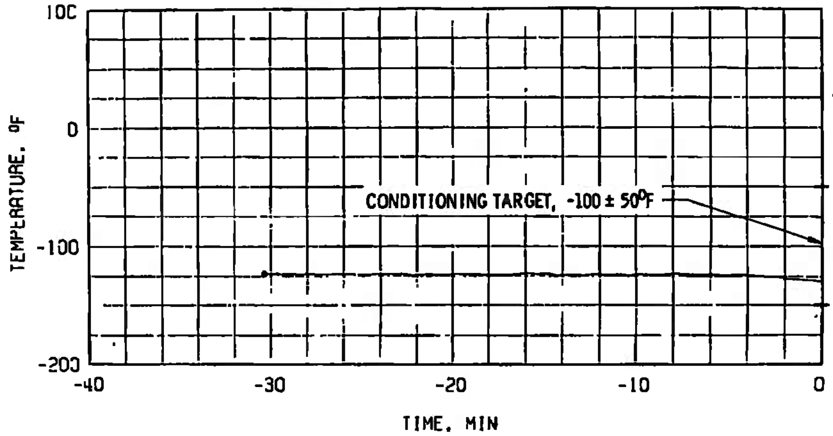



b. Crossover Duct, TFTD

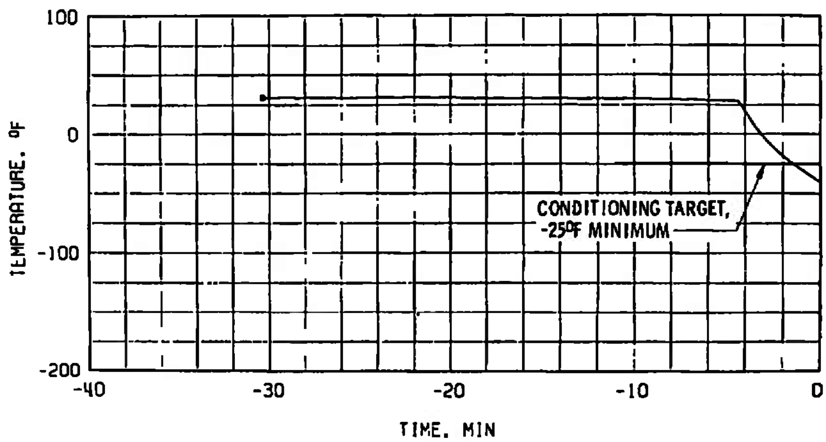



c. Start Tank Discharge Valve, TSTDVOC

Fig. 20 Thermal Conditioning History of Engine Components, Firing 42C




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




e. Gas Generator Control Valve, TGGVRS

Fig. 20 Concluded

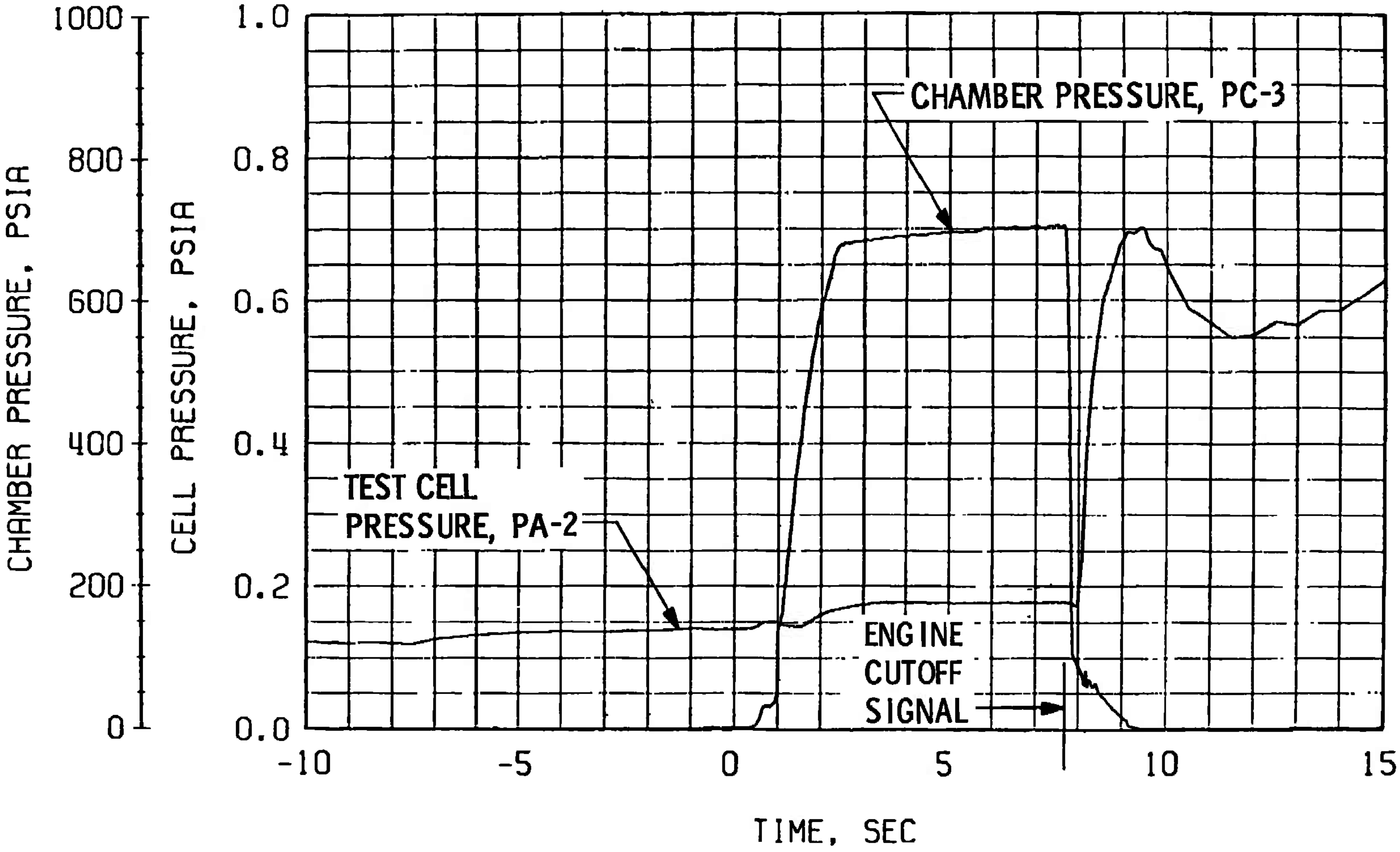
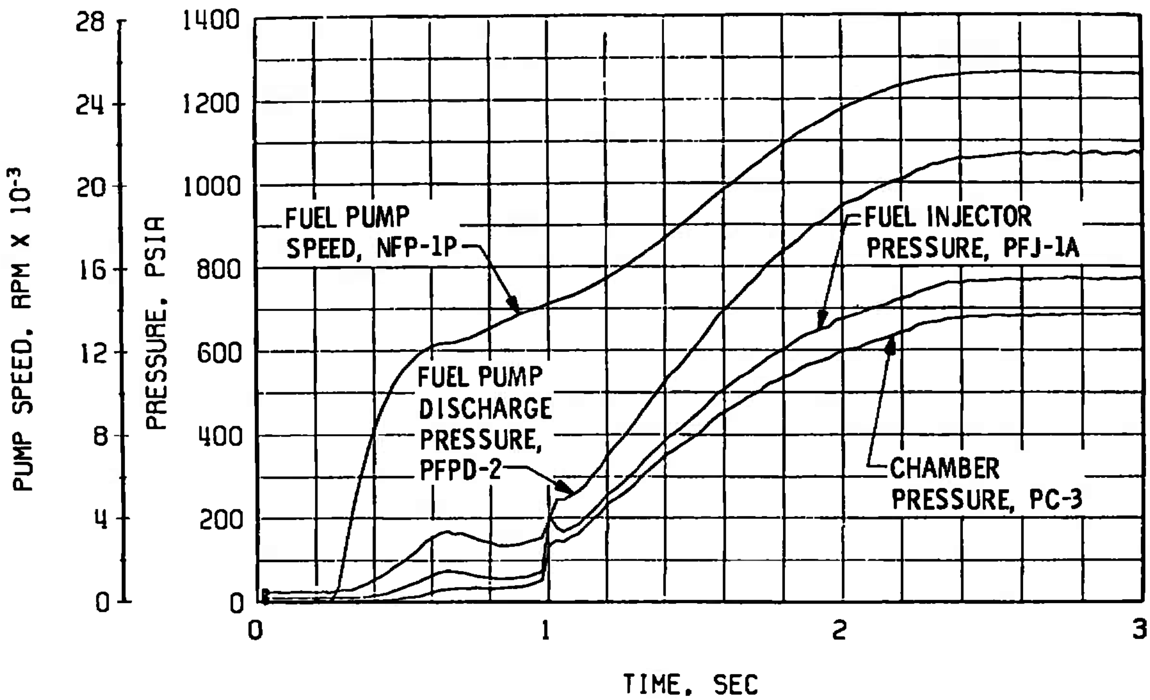
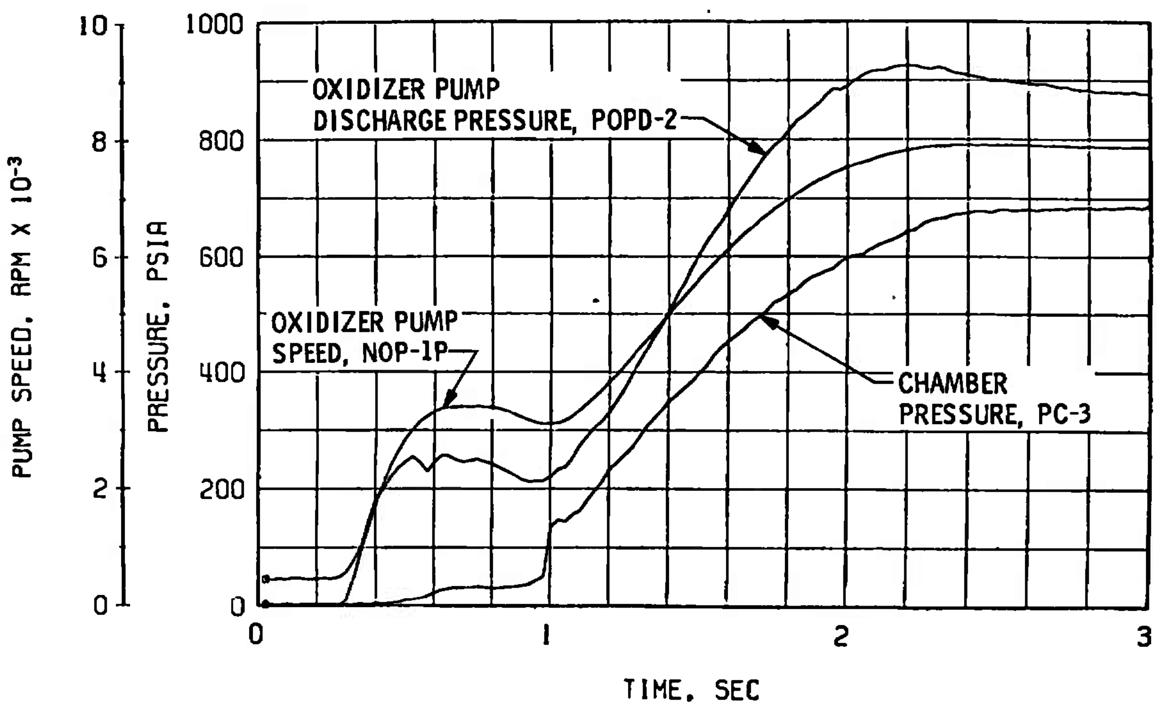



Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 42C

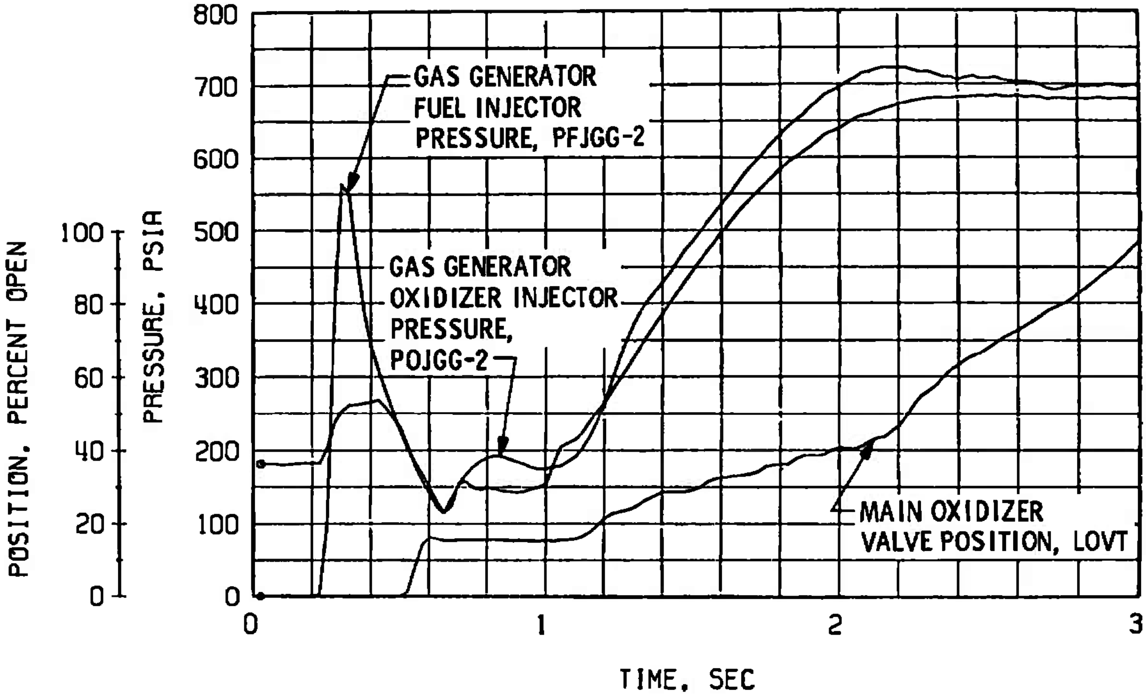



a. Thrust Chamber Fuel System, Start

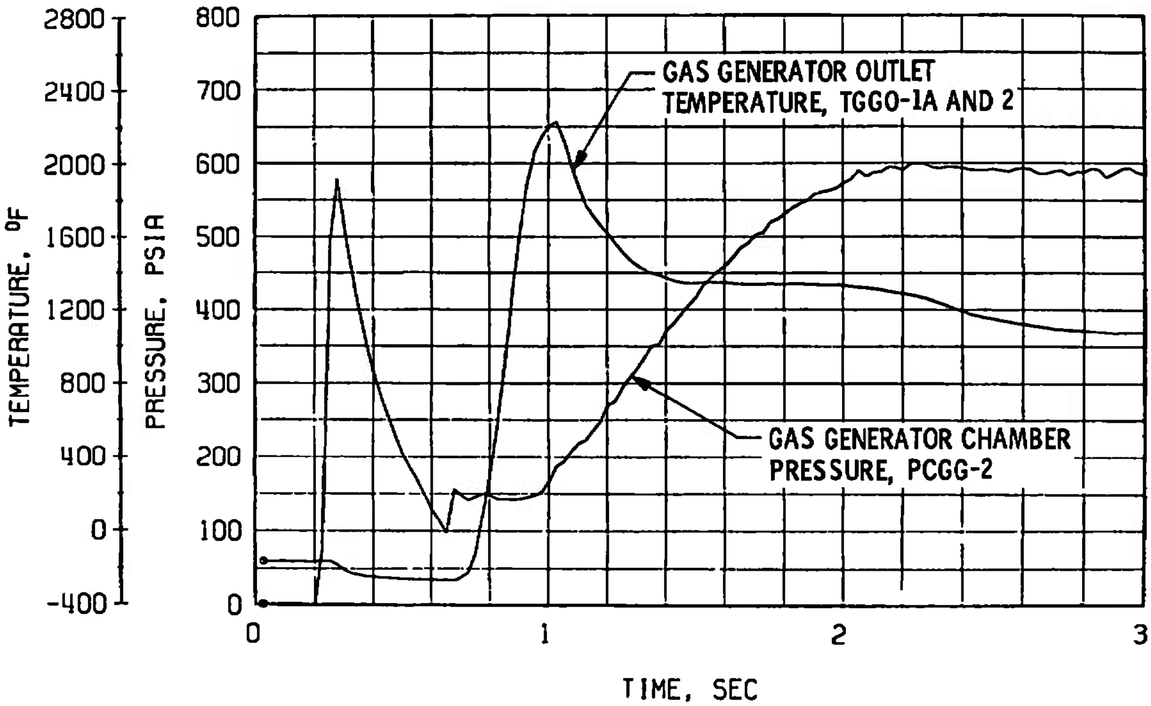



b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 42C

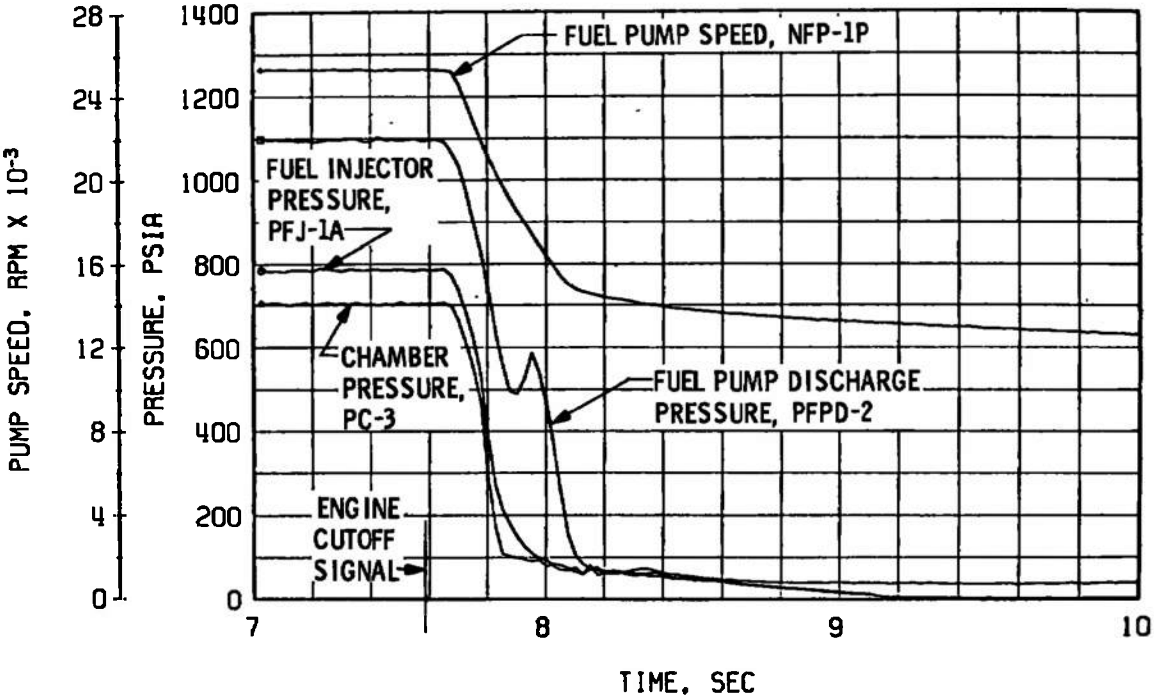



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

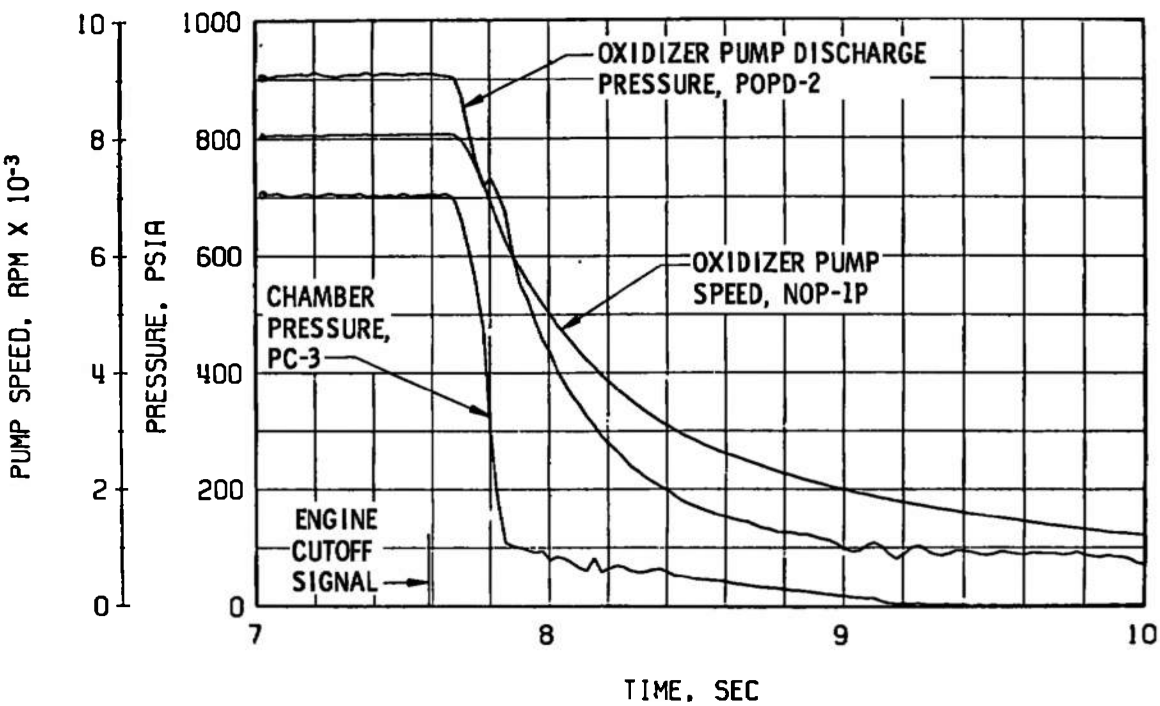



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued

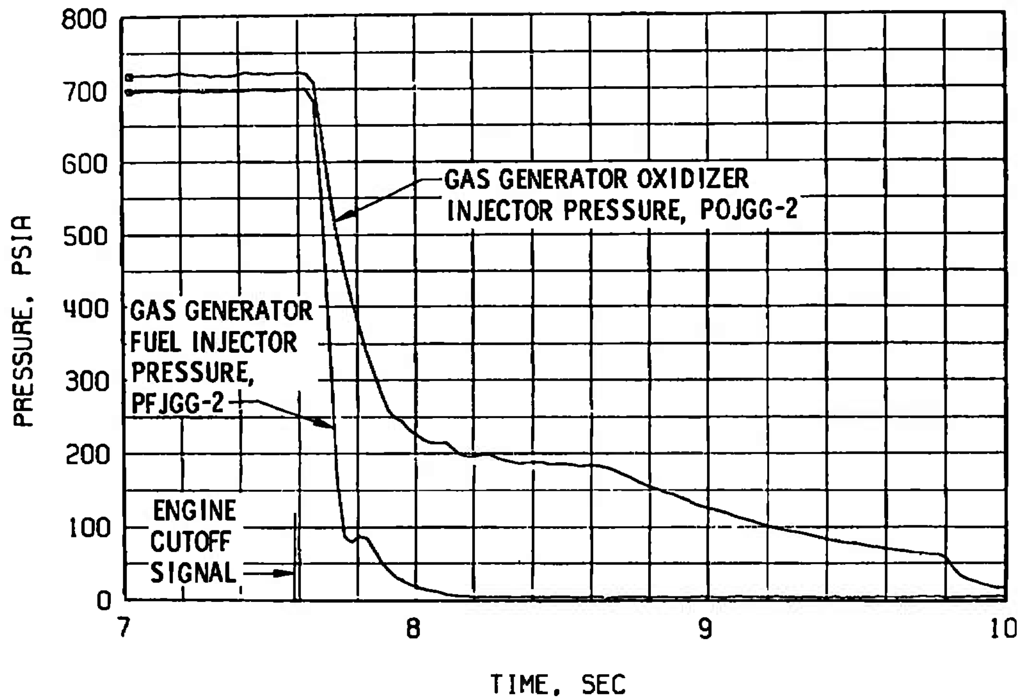



e. Thrust Chamber Fuel System, Shutdown

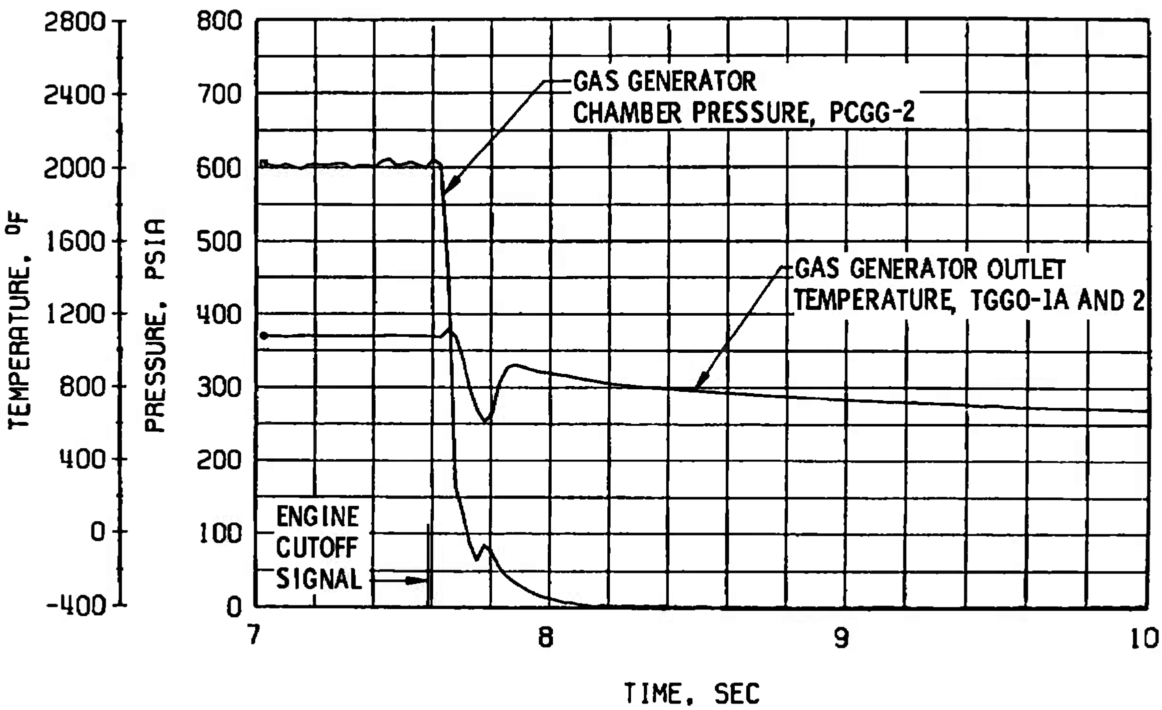



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

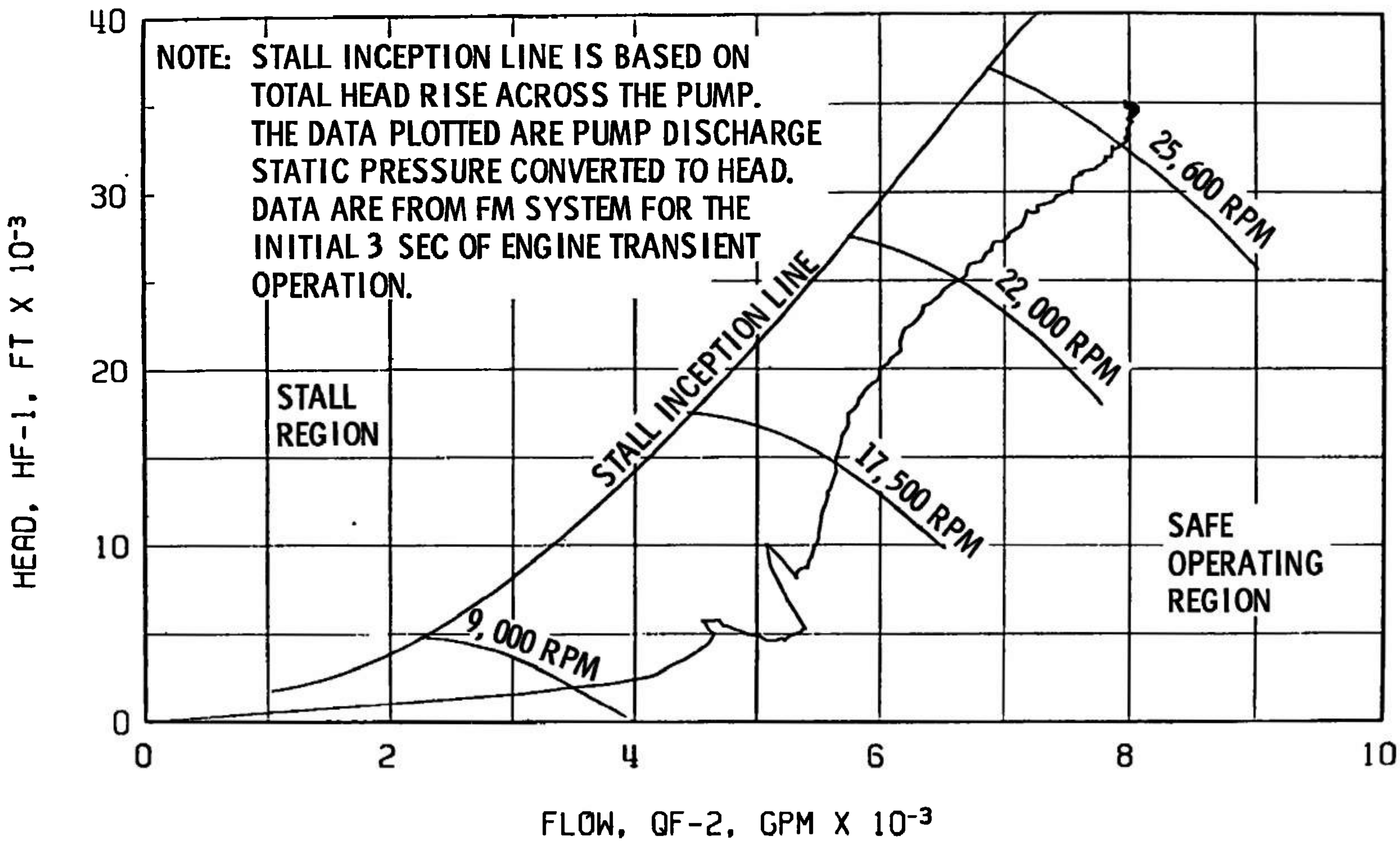
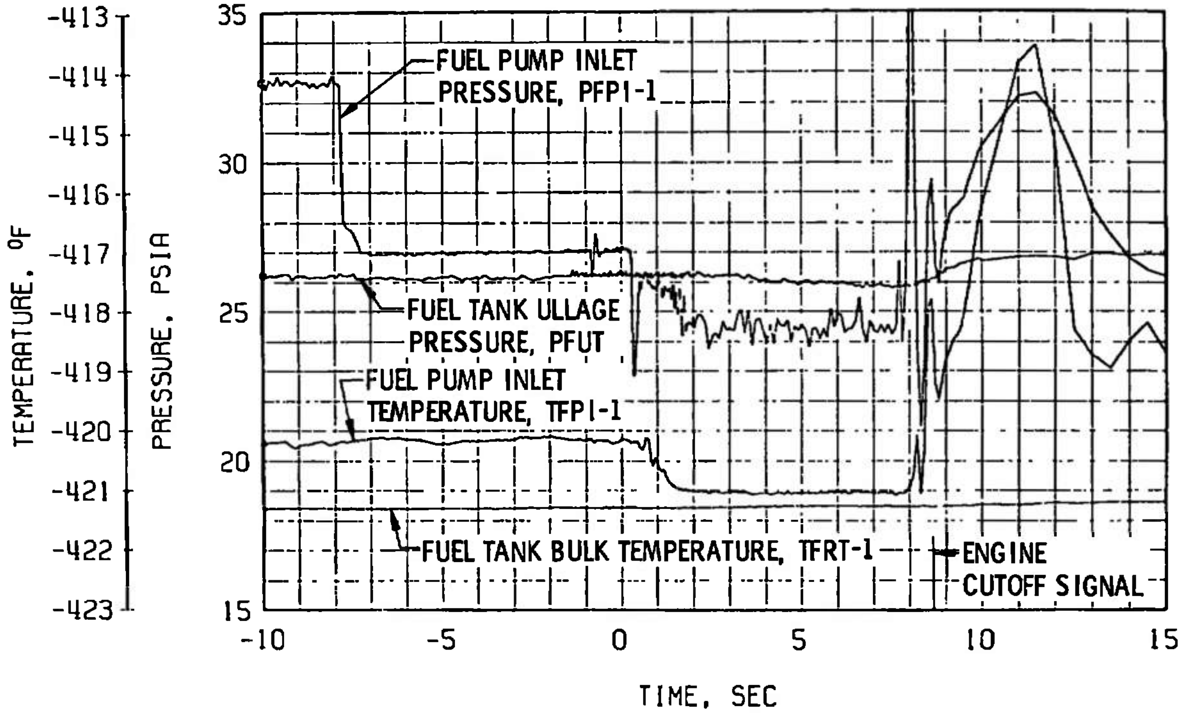
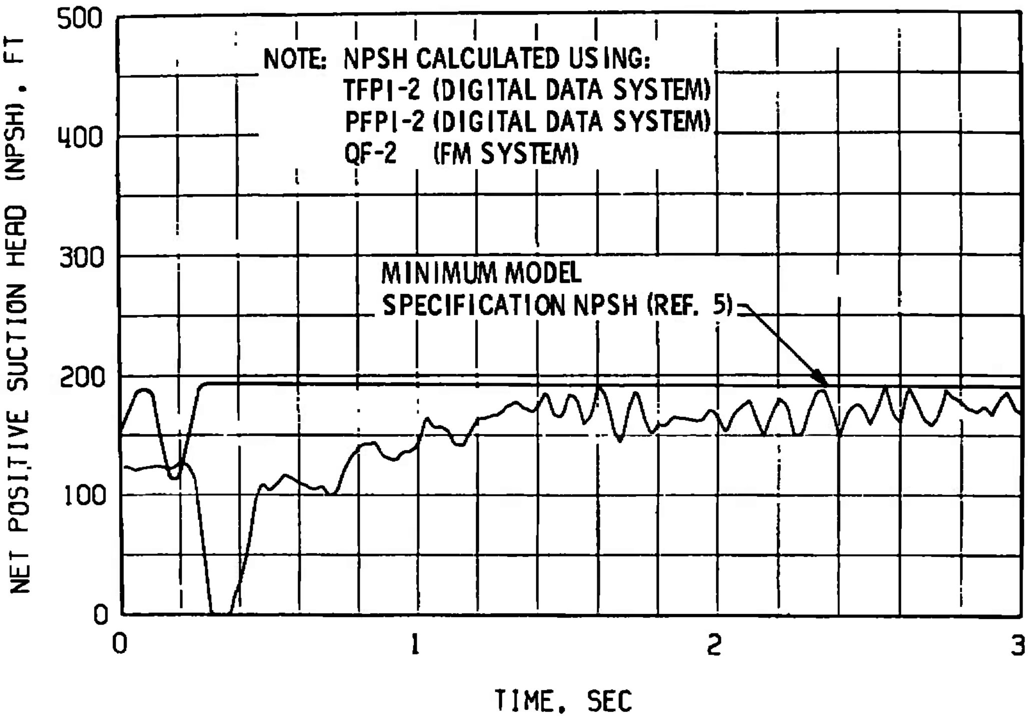



Fig. 23 Fuel Pump Start Transient Performance, Firing 42C

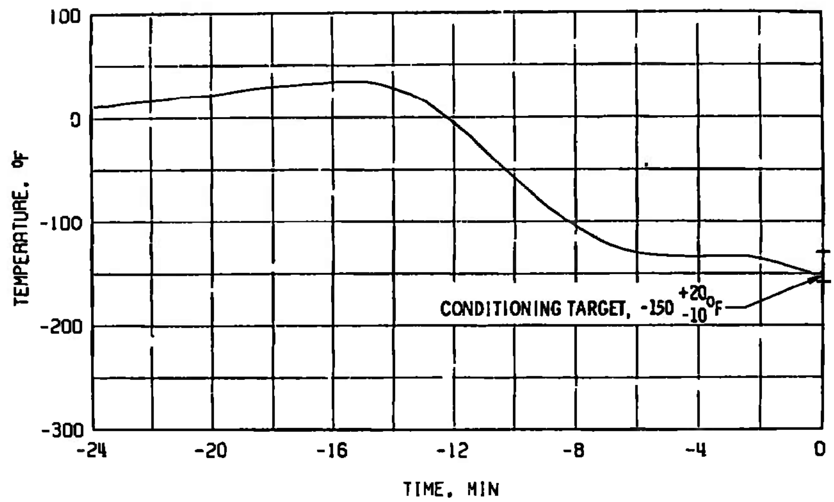



a. Duct Pressure and Temperature Transients

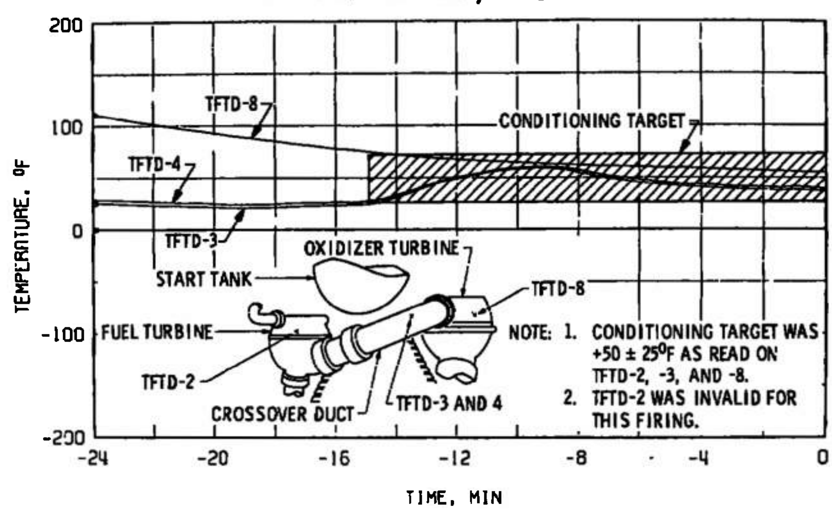



b. Fuel Pump NPSH during Start Transient, Firing 42C

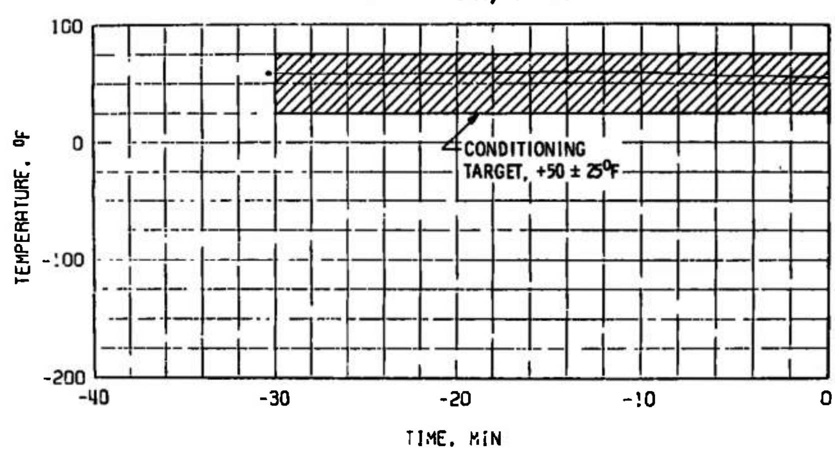
Fig. 24 Fuel Low Pressure Duct Performance, Firing 42C




a. Thrust Chamber, TTC-1P

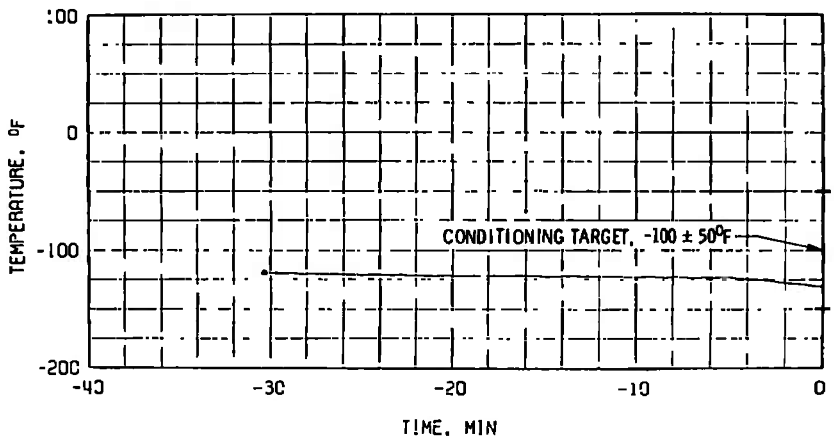



b. Crossover Duct, TFTD

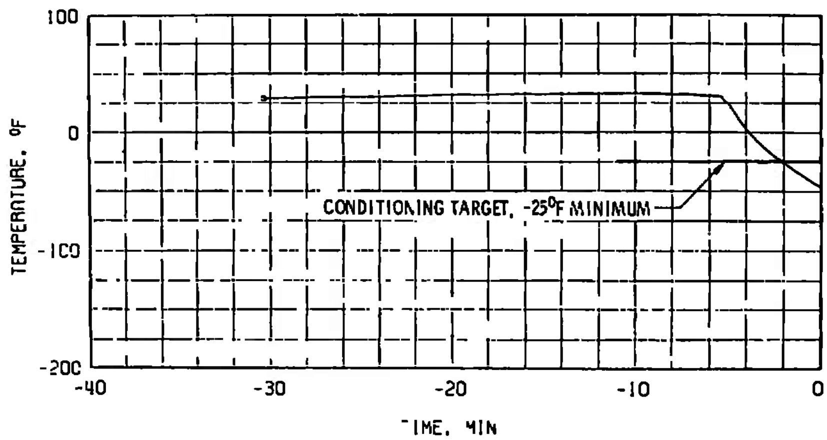



c. Start Tank Discharge Valve, TSTDVOC

Fig. 25 Thermal Conditioning History of Engine Components, Firing 42D




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




e. Gas Generator Control Valve, TGGVRS

Fig. 25 Concluded

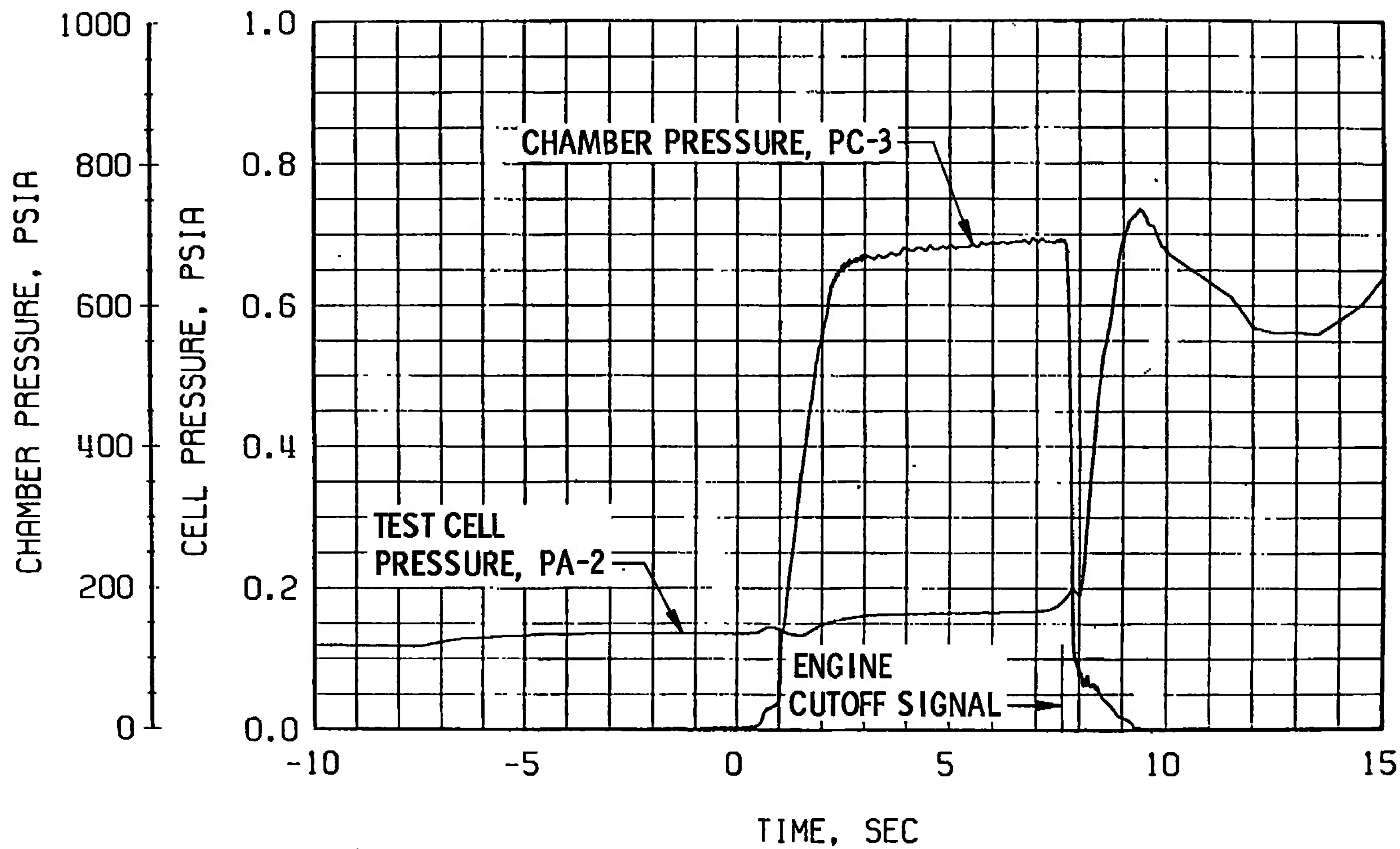
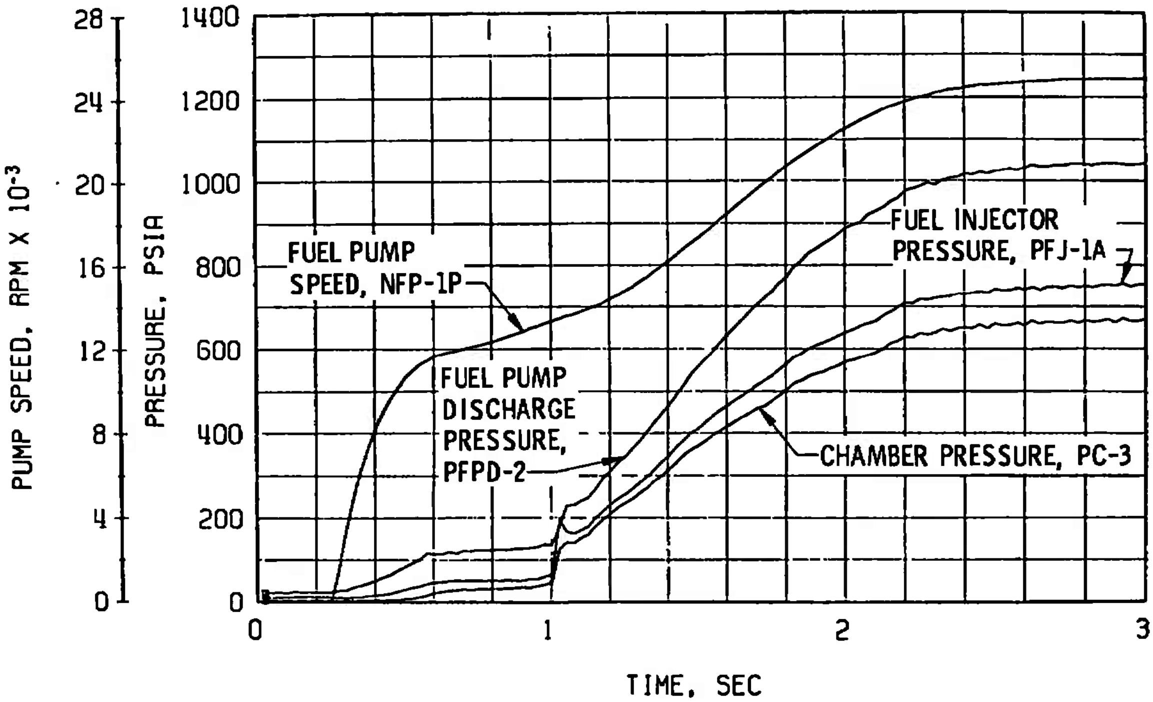
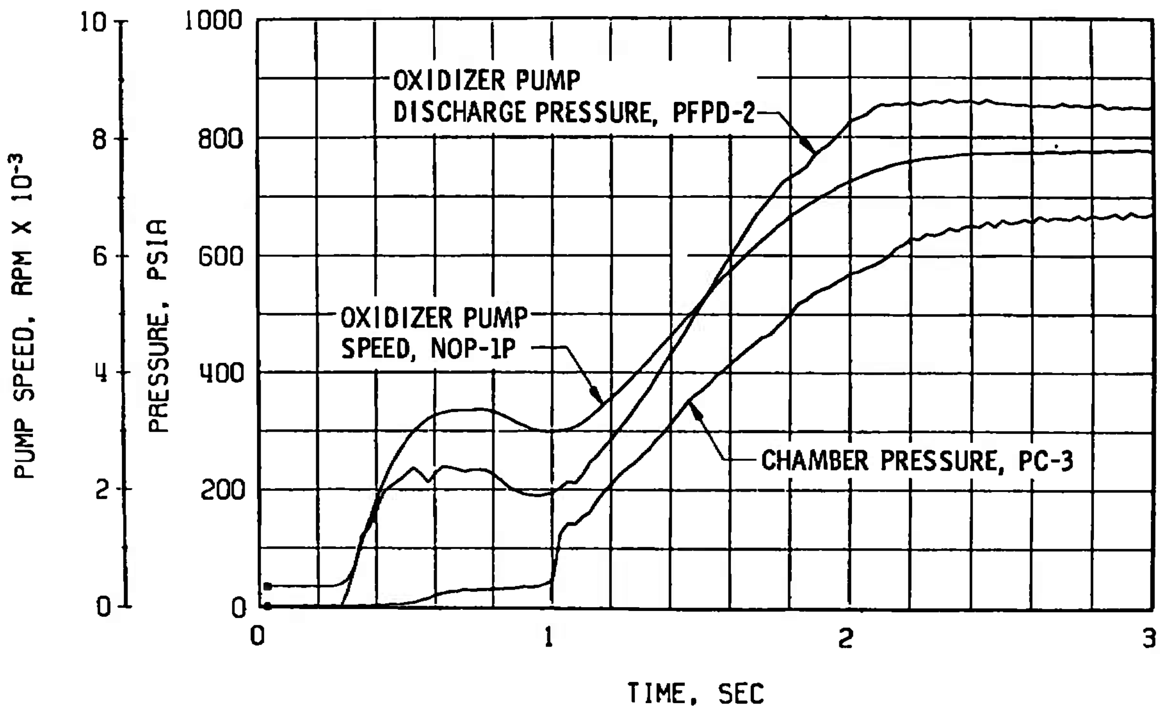



Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 42D

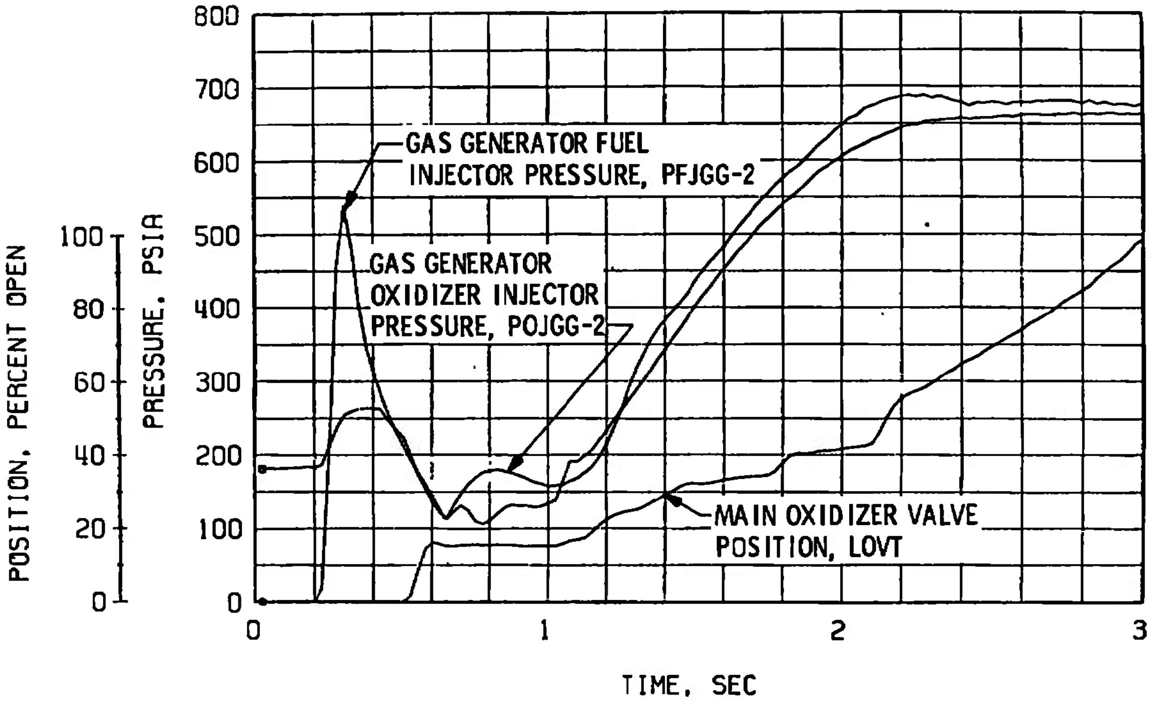



a. Thrust Chamber Fuel System, Start

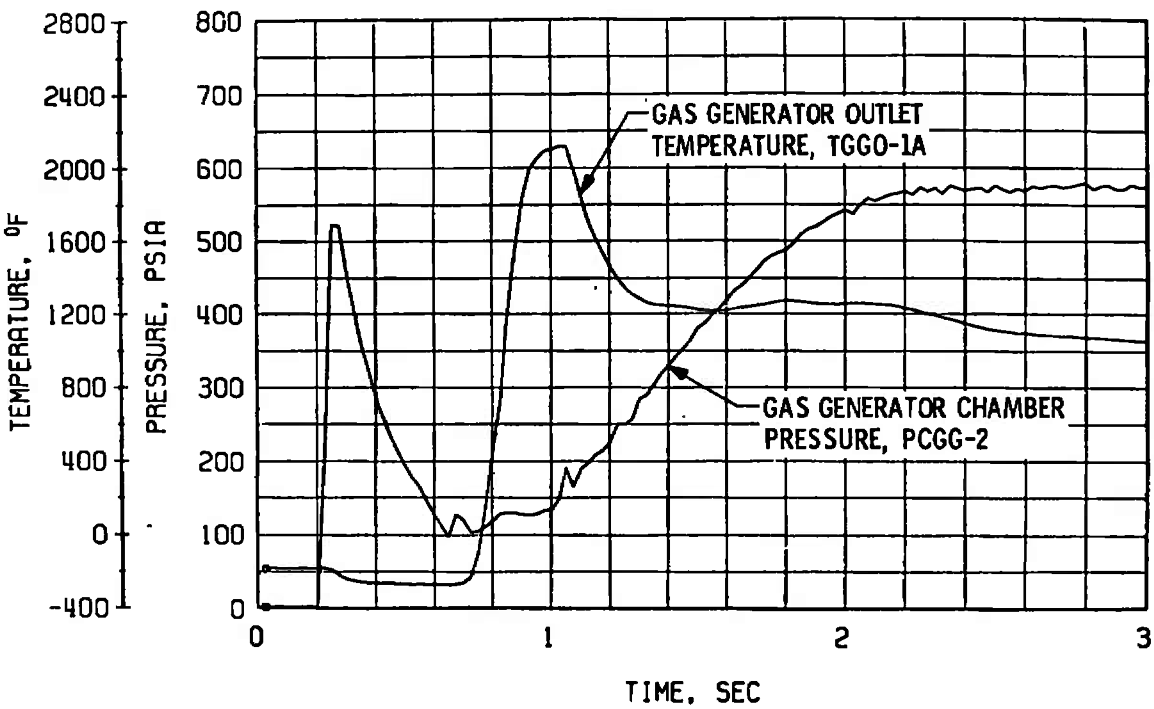



b. Thrust Chamber Oxidizer System, Start

Fig. 27 Engine Transient Operation, Firing 42D

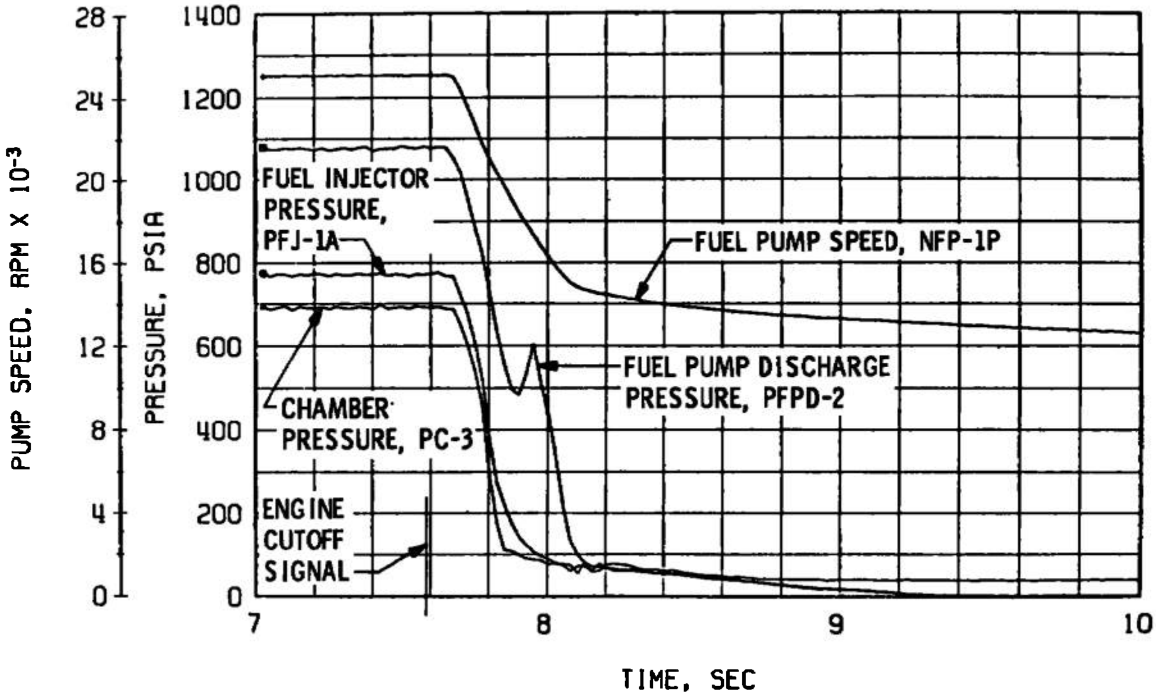



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

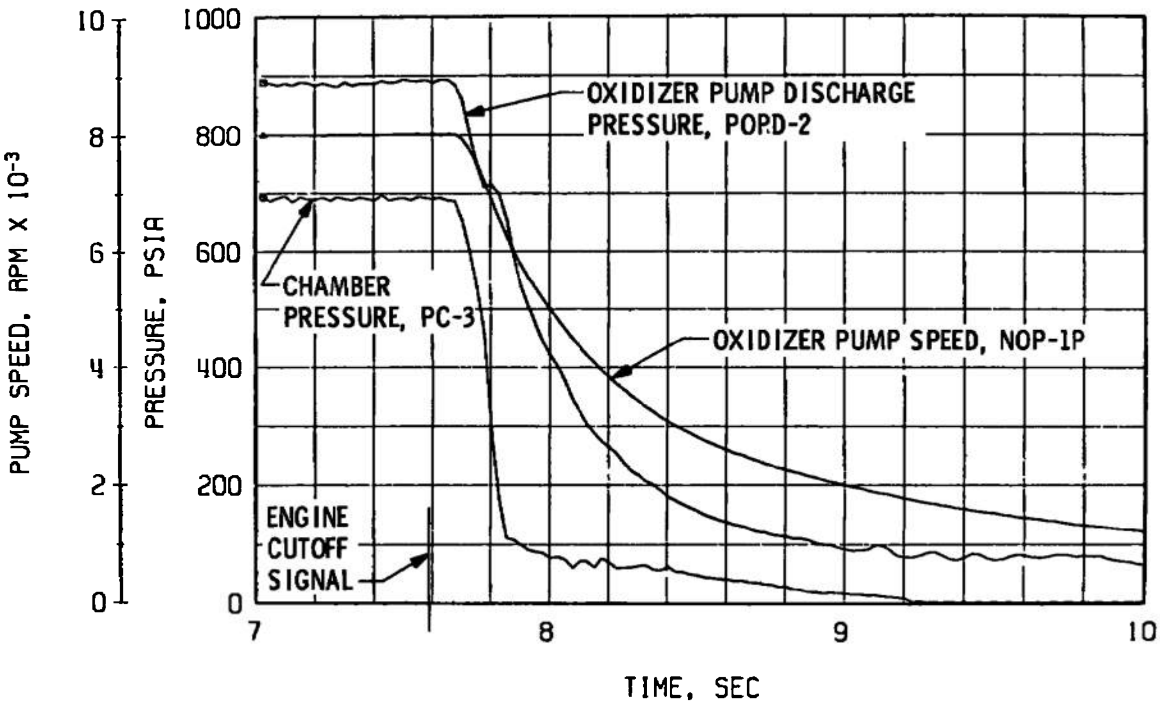



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 27 Continued

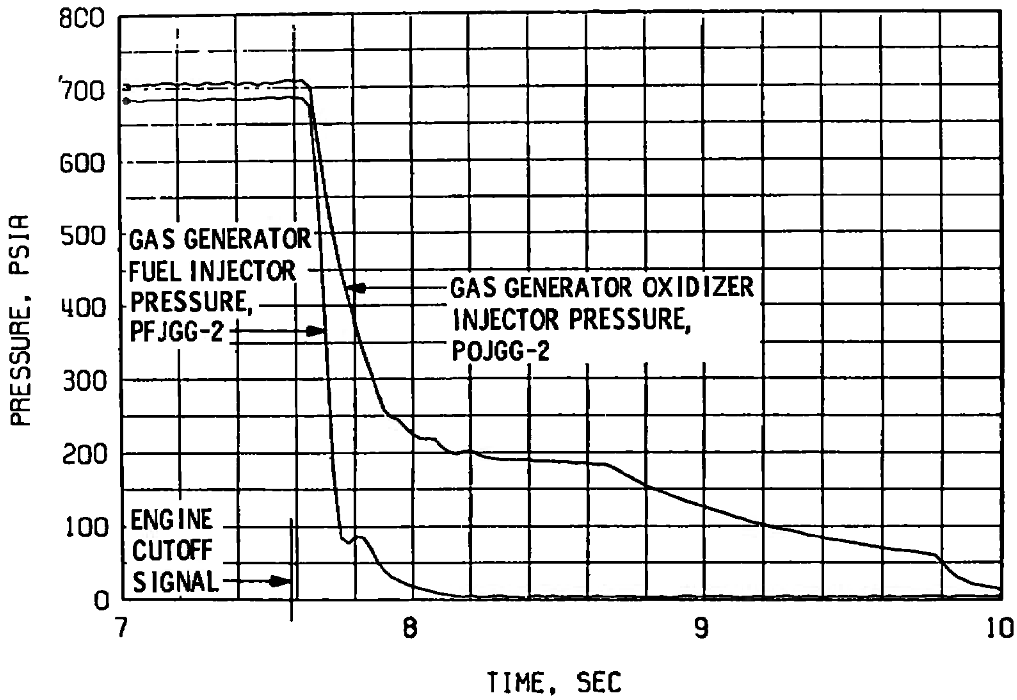



e. Thrust Chamber Fuel System, Shutdown

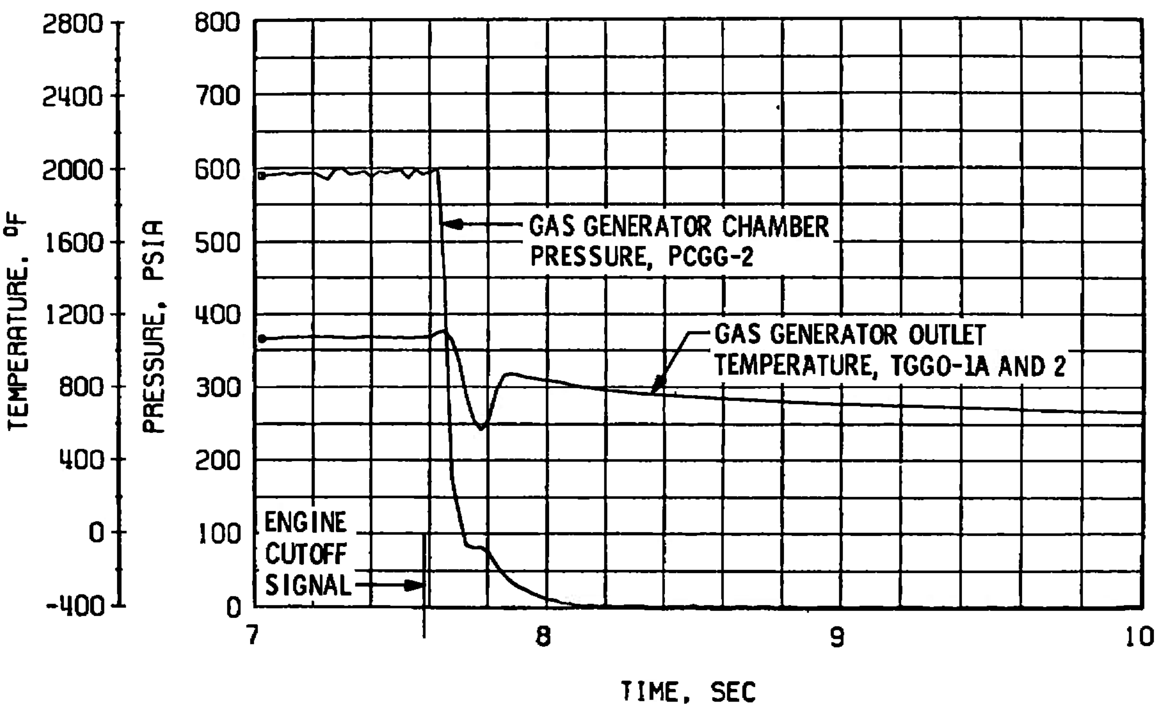



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 27 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 27 Concluded

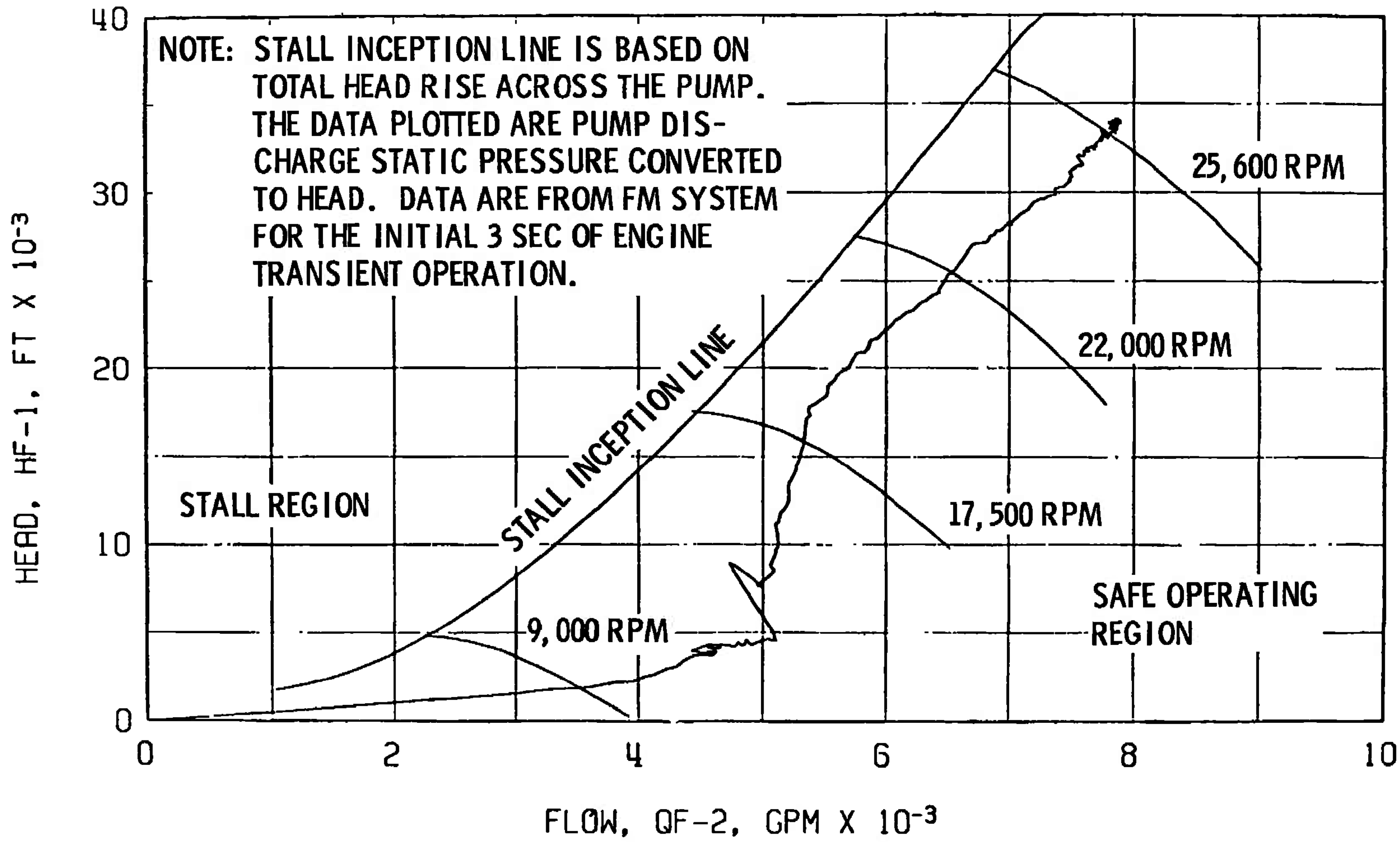
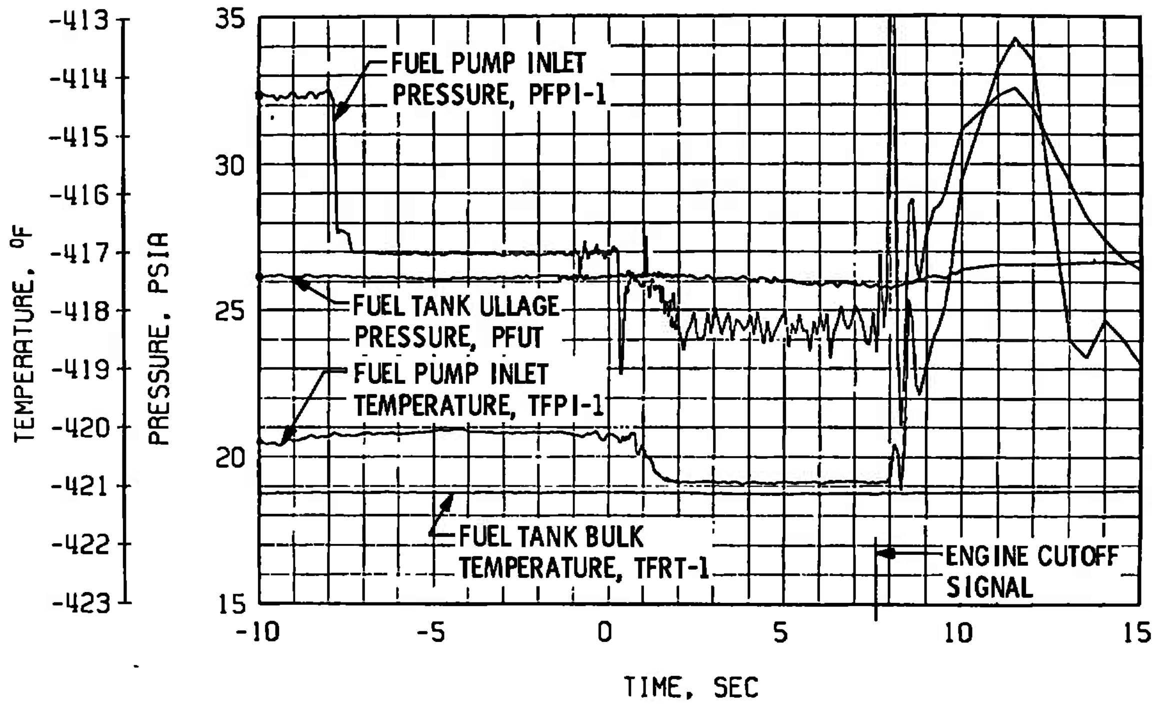
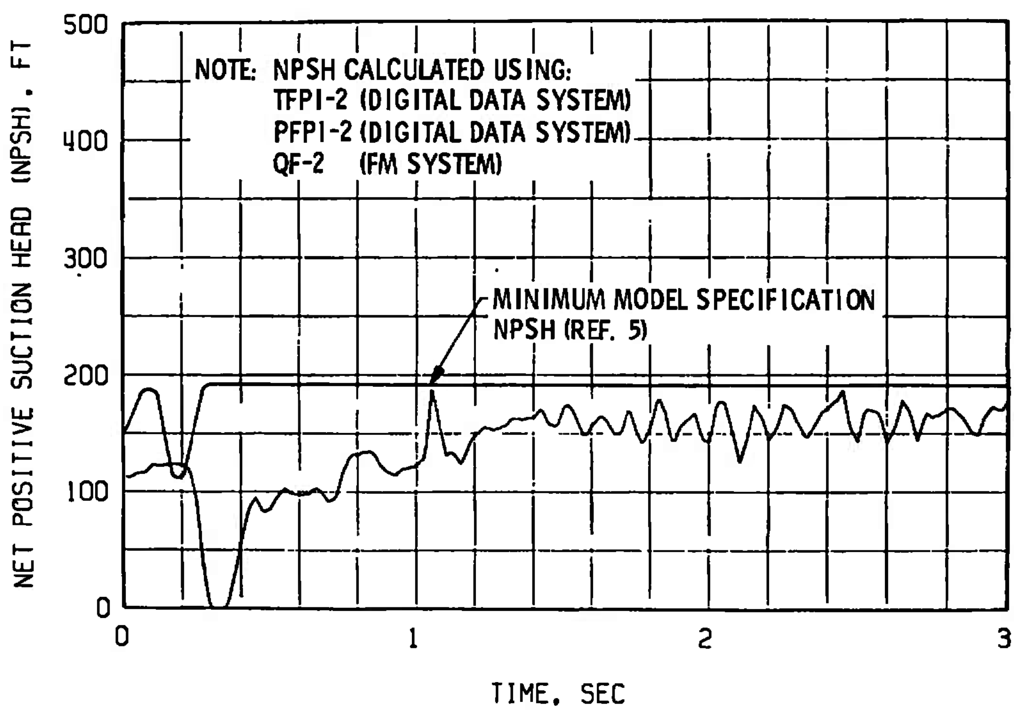



Fig. 28 Fuel Pump Start Transient Performance, Firing 42D

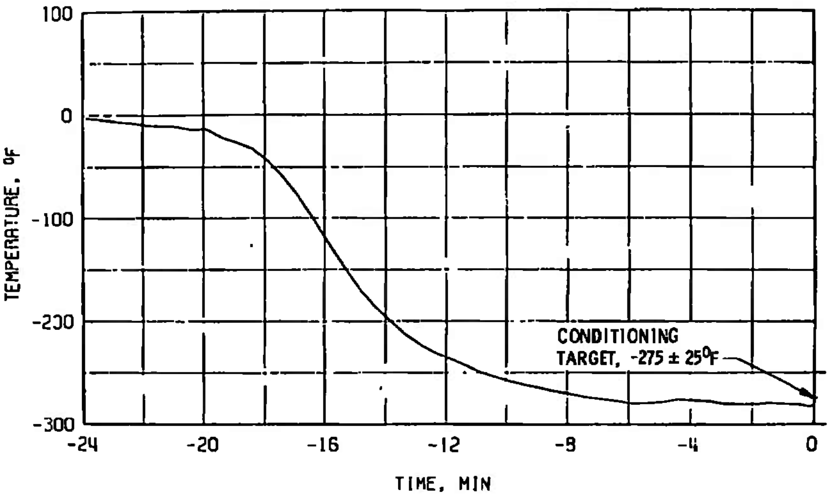



a. Duct Pressure and Temperature Transients

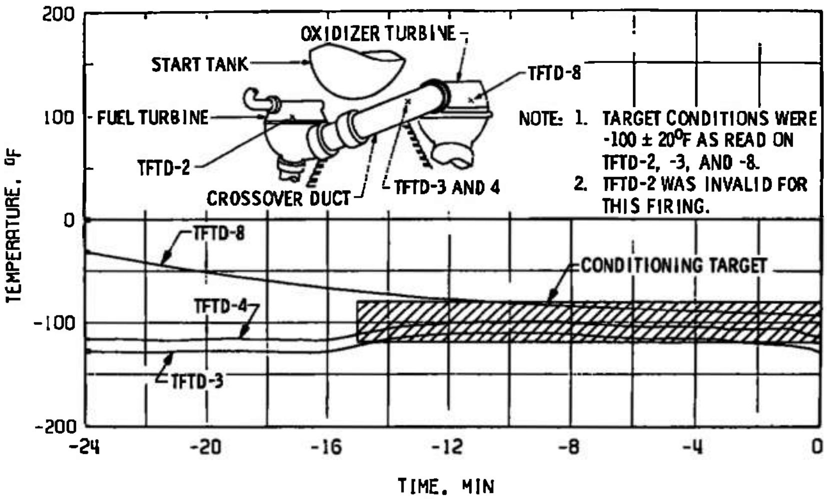



b. Fuel Pump NPSH during Start Transient, Firing 42D

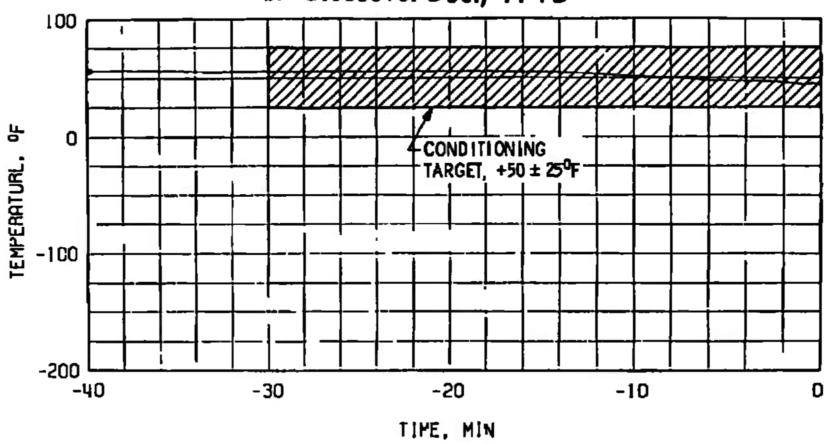
Fig. 29 Fuel Low Pressure Duct Performance, Firing 42D




a. Thrust Chamber, TTC-1P

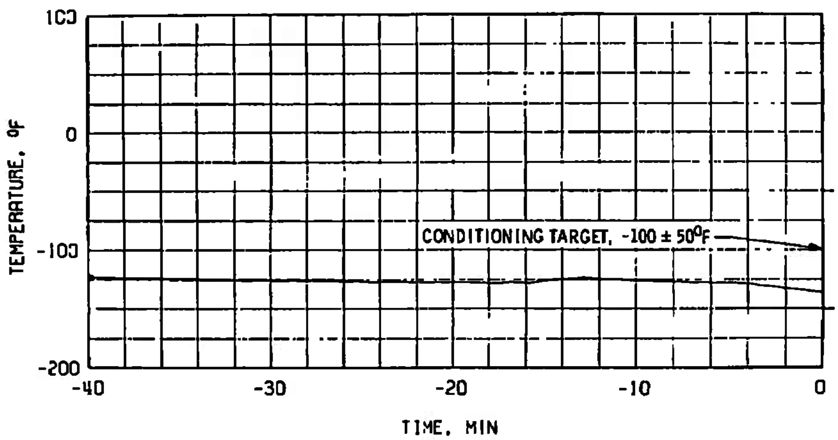



b. Crossover Duct, TFTD

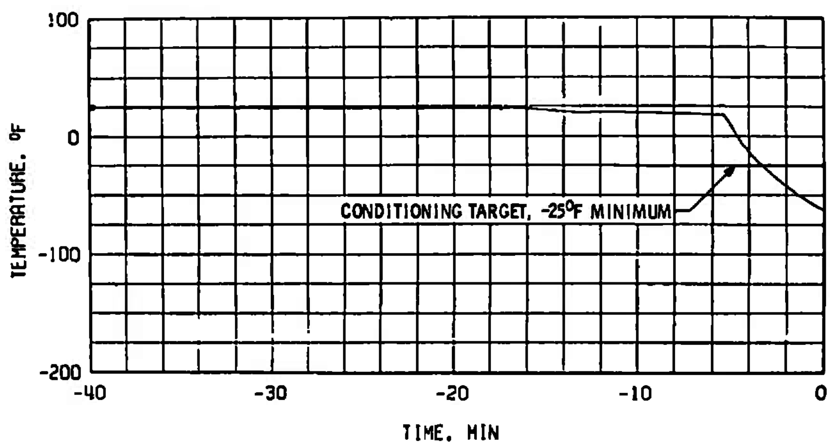



c. Start Tank Discharge Valve, TSTDVOC

Fig. 30 Thermal Conditioning History of Engine Components, Firing 42E




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




e. Gas Generator Control Valve, TGGVRS

Fig. 30 Concluded

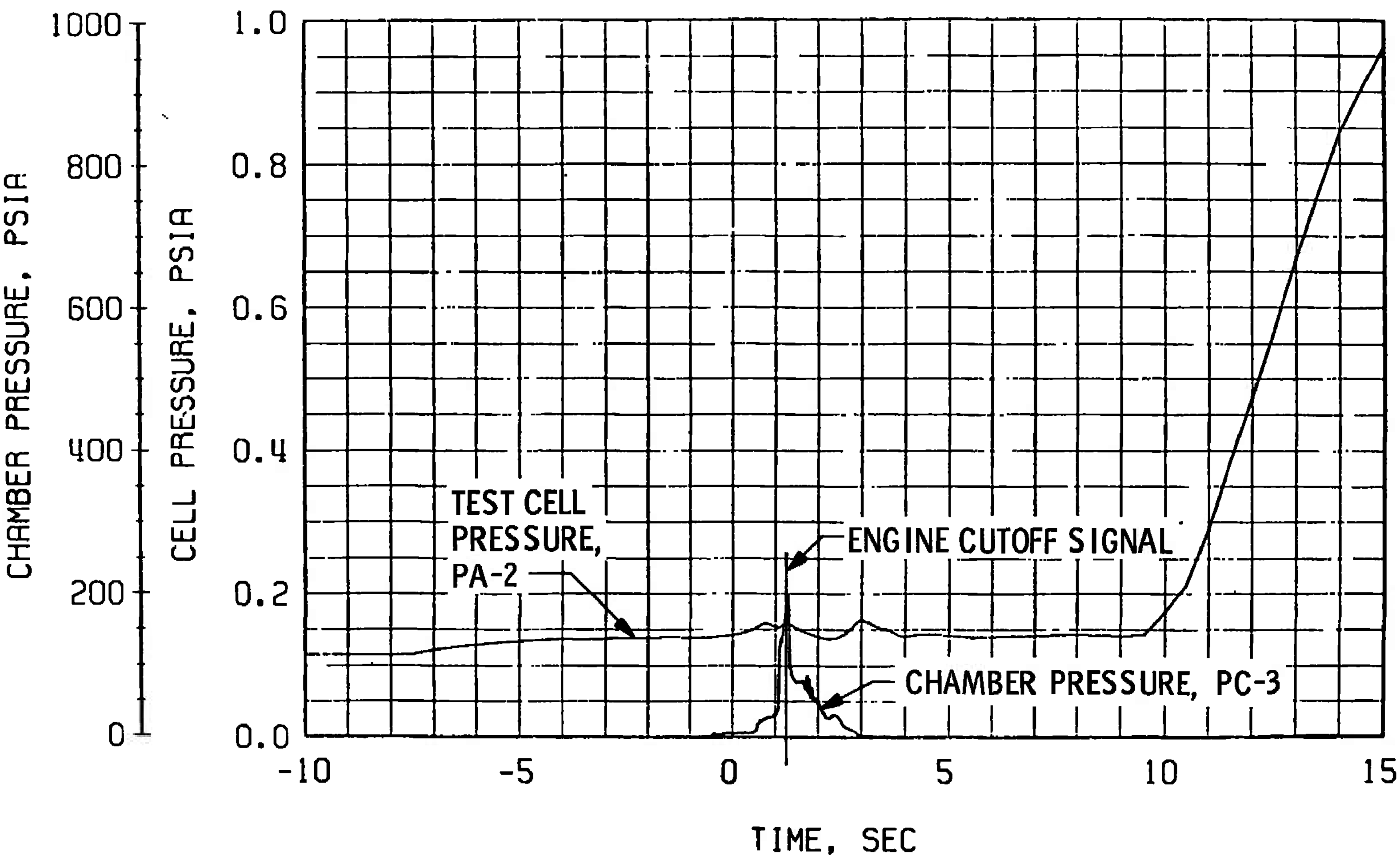
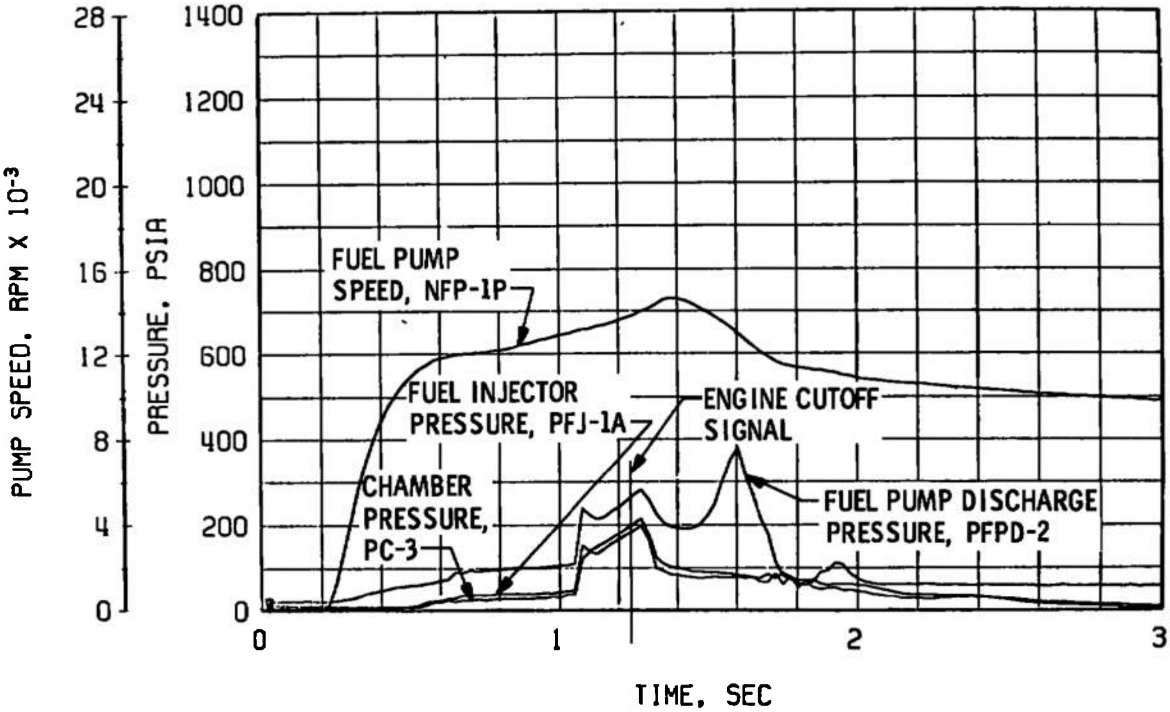
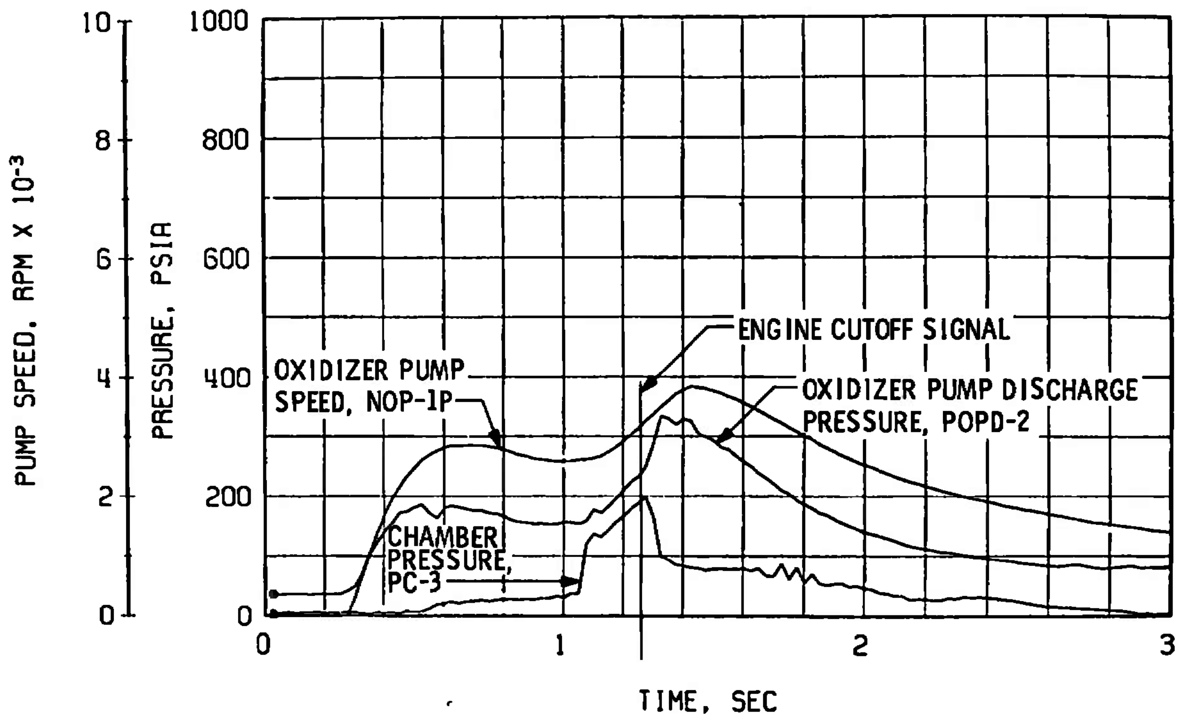



Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 42E

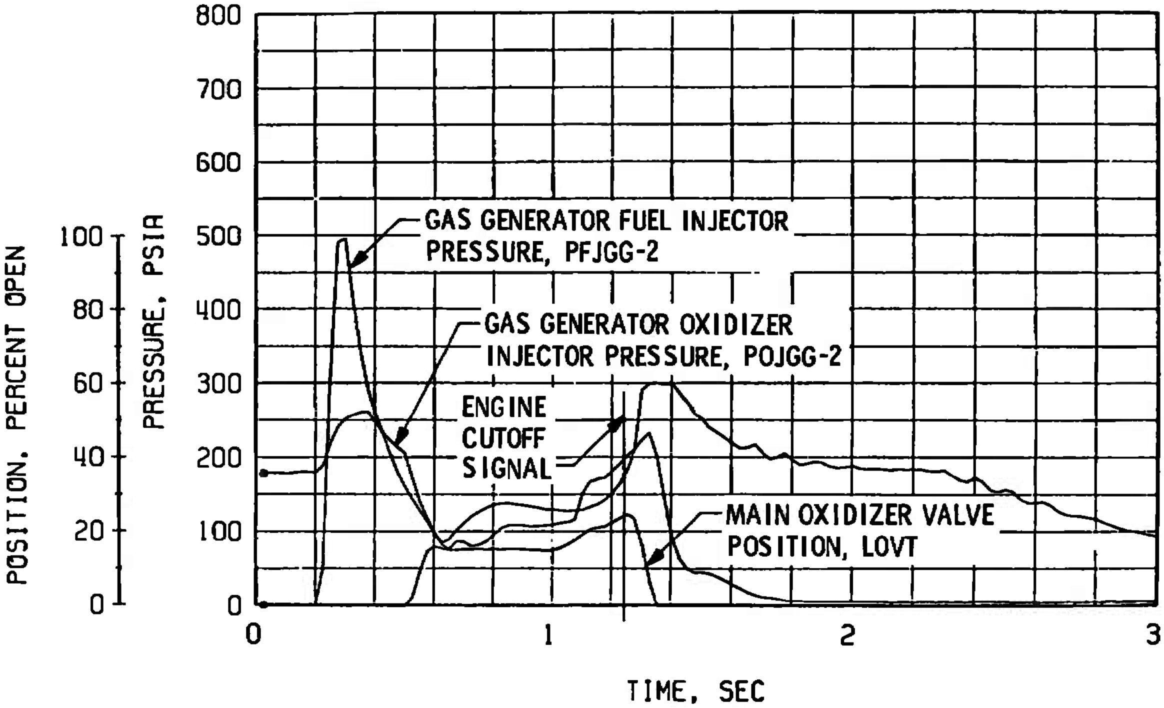



a. Thrust Chamber Fuel System, Start and Shutdown

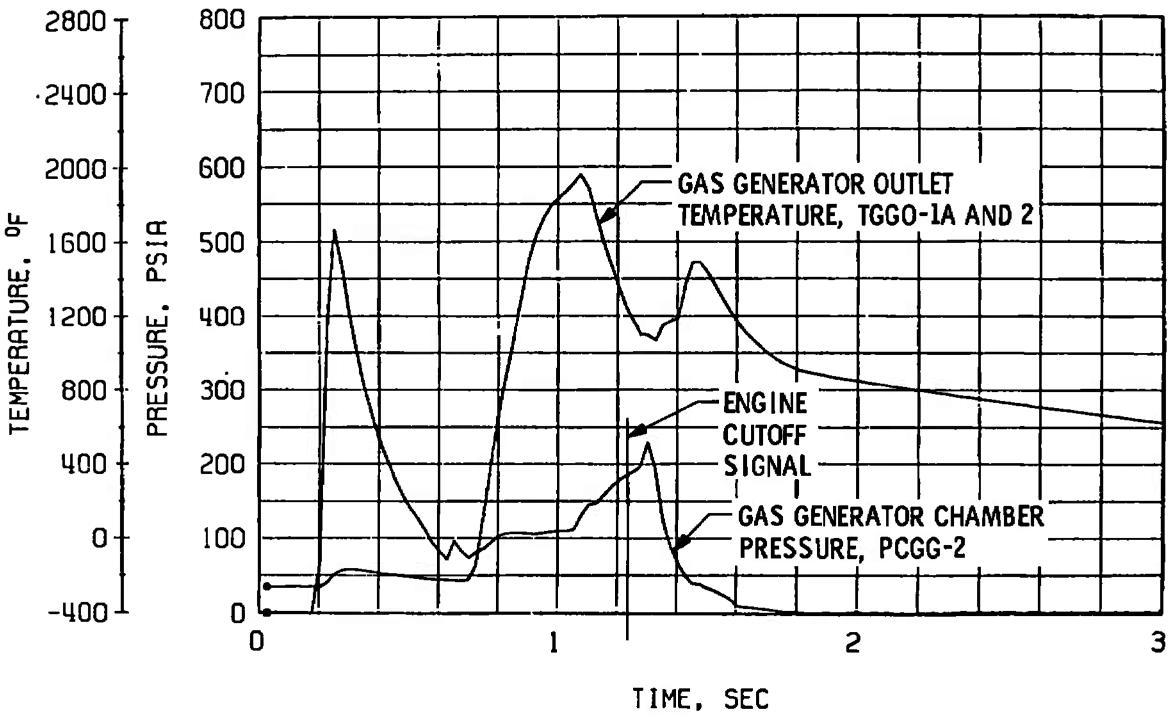



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 32 Engine Transient Operation, Firing 42E




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




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

Fig. 32 Concluded

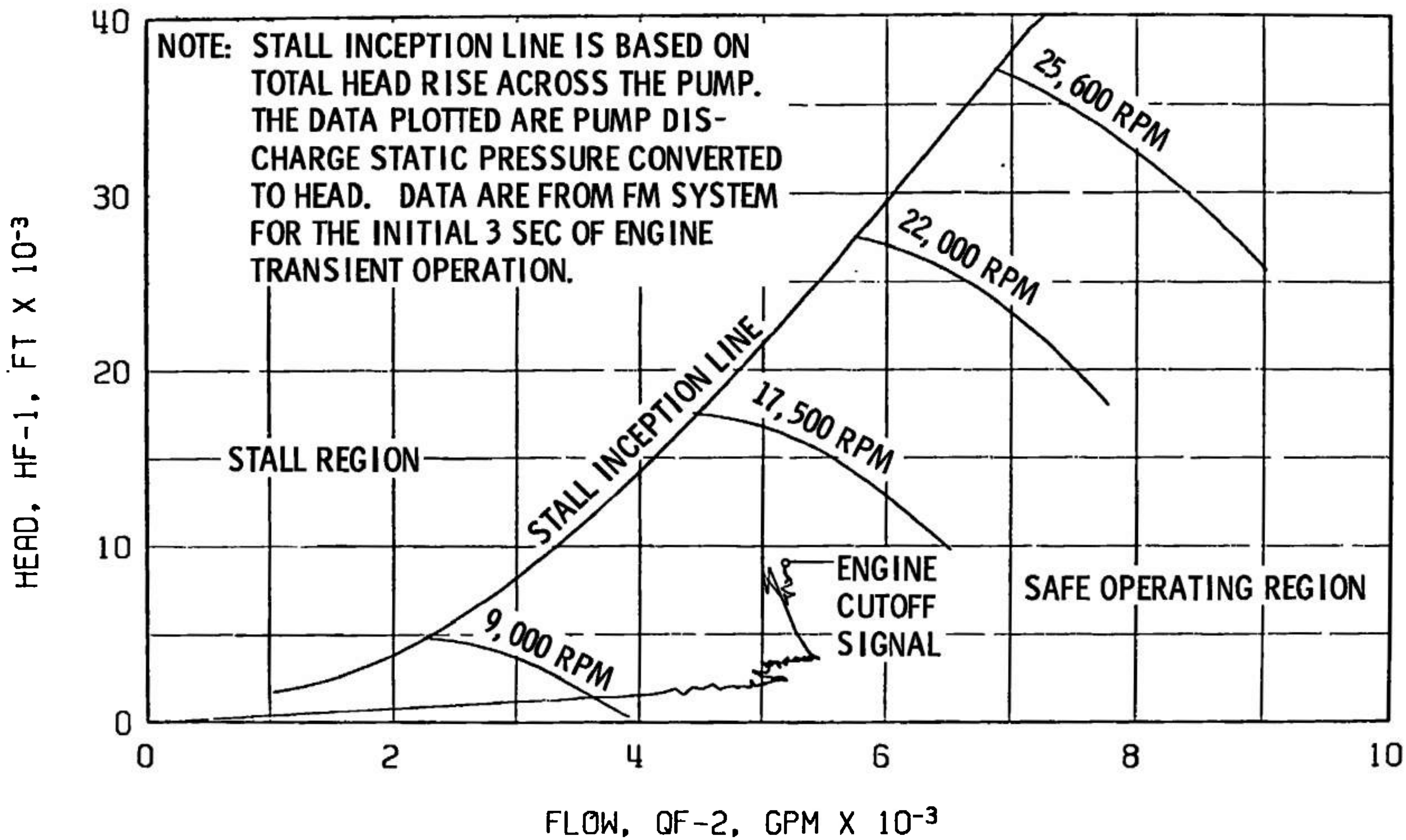
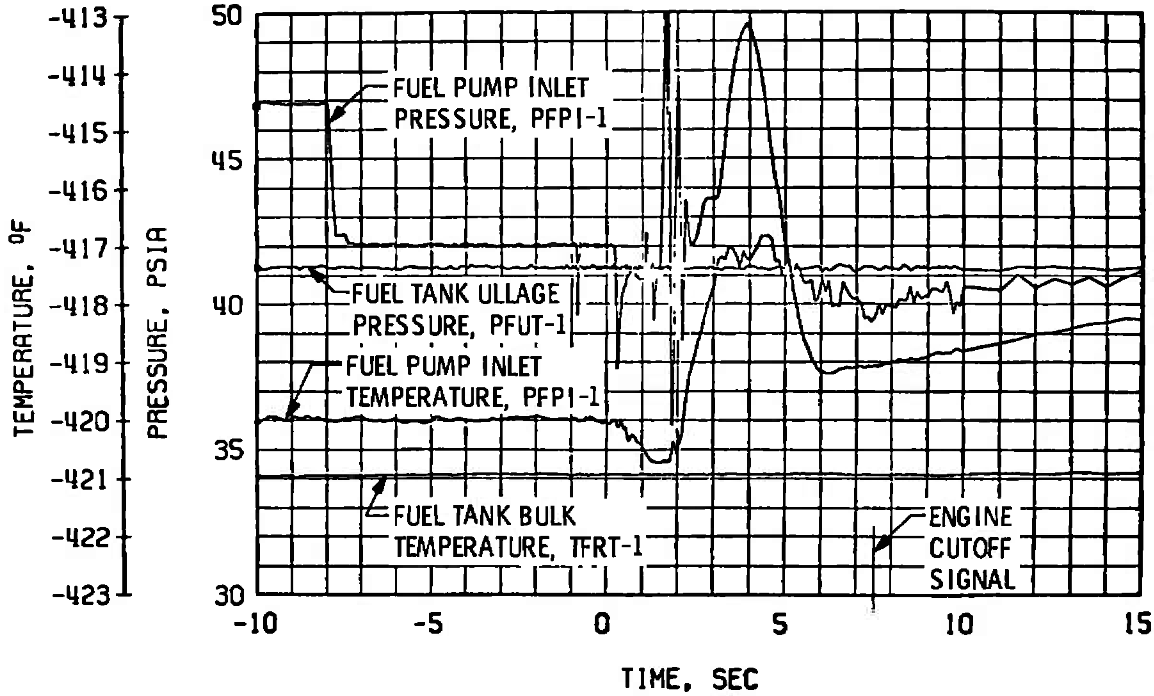
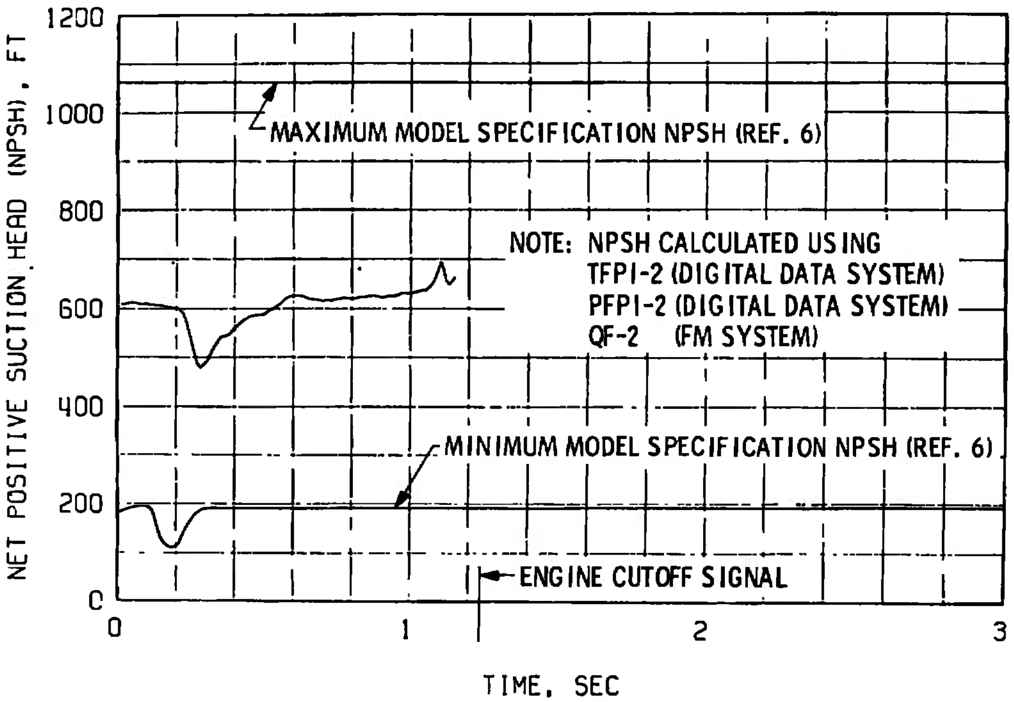



Fig. 33 Fuel Pump Start Transient Performance, Firing 42E

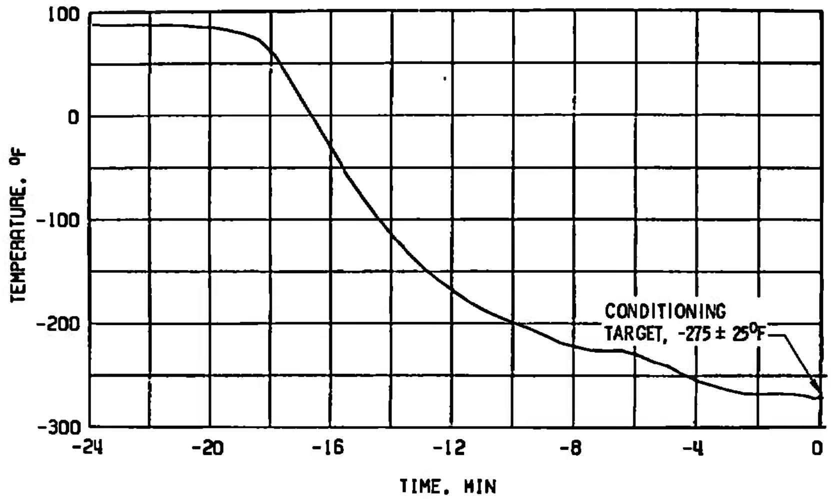



a. Duct Pressure and Temperature Transients

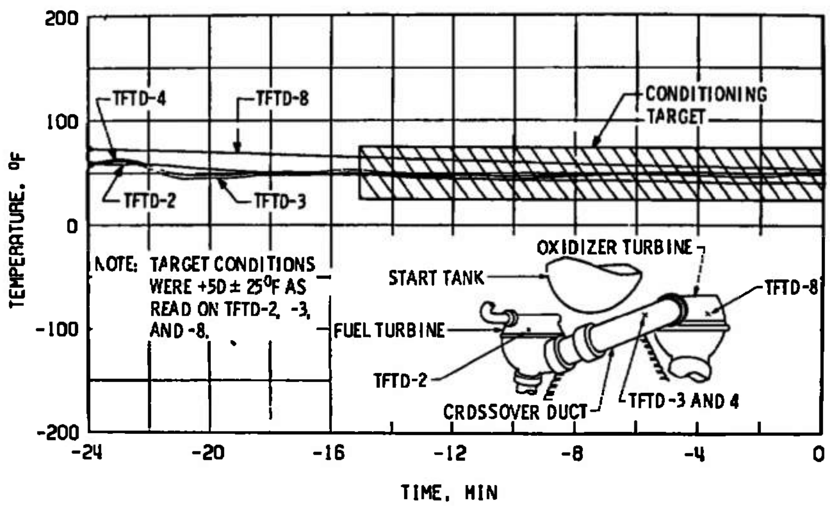



b. Fuel Pump NPSH during Start Transient, Firing 42E

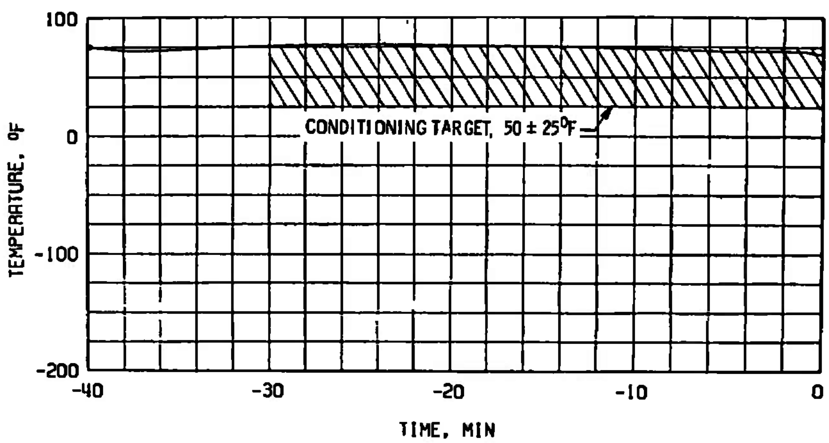
Fig. 34 Fuel Low Pressure Duct Performance, Firing 42E




a. Thrust Chamber, TTC-1P

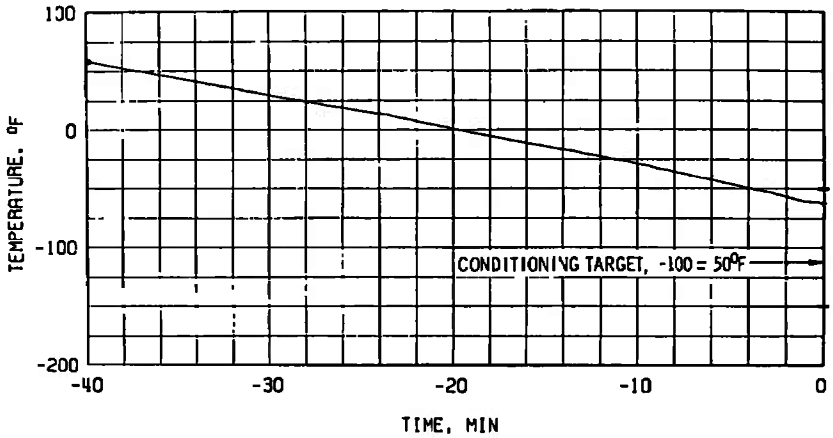



b. Crossover Duct, TFTD

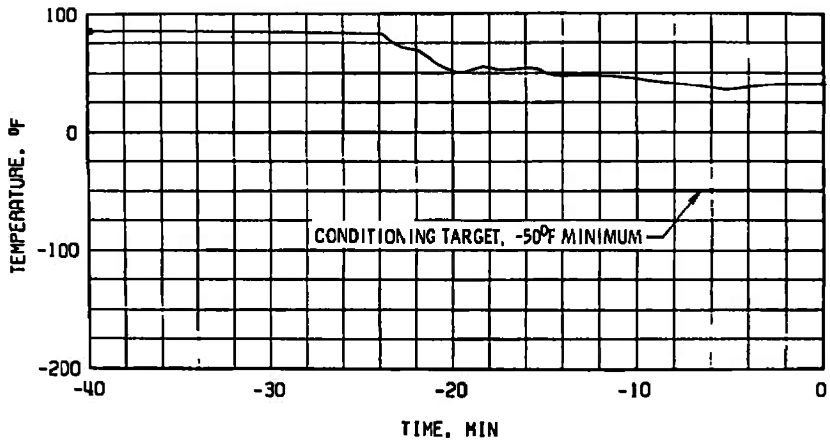



c. Start Tank Discharge Valve, TSTDVOC

Fig. 35 Thermal Conditioning History of Engine Components, Firing 43A




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




e. Gas Generator Control Valve, TGGVRS

Fig. 35 Concluded

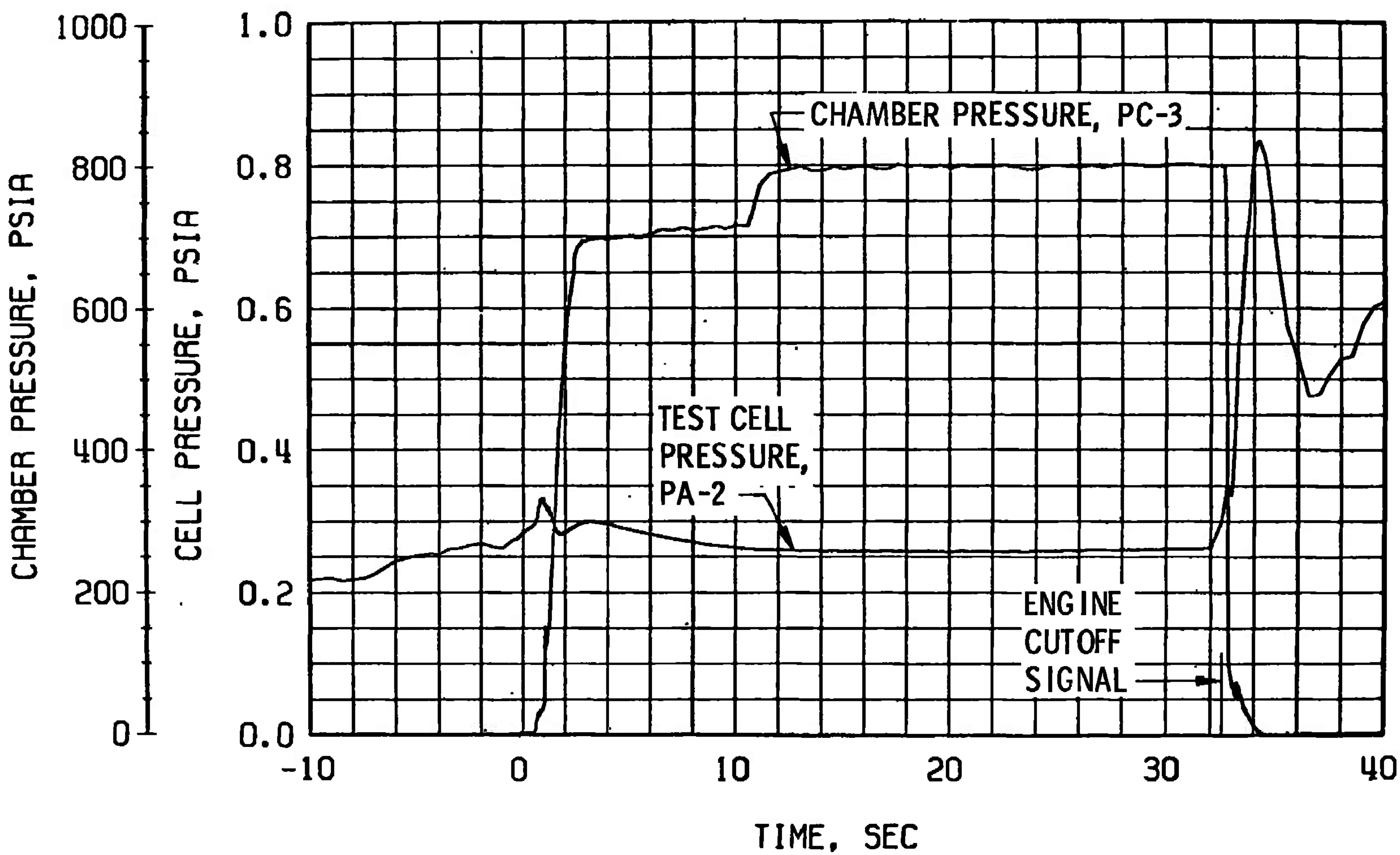
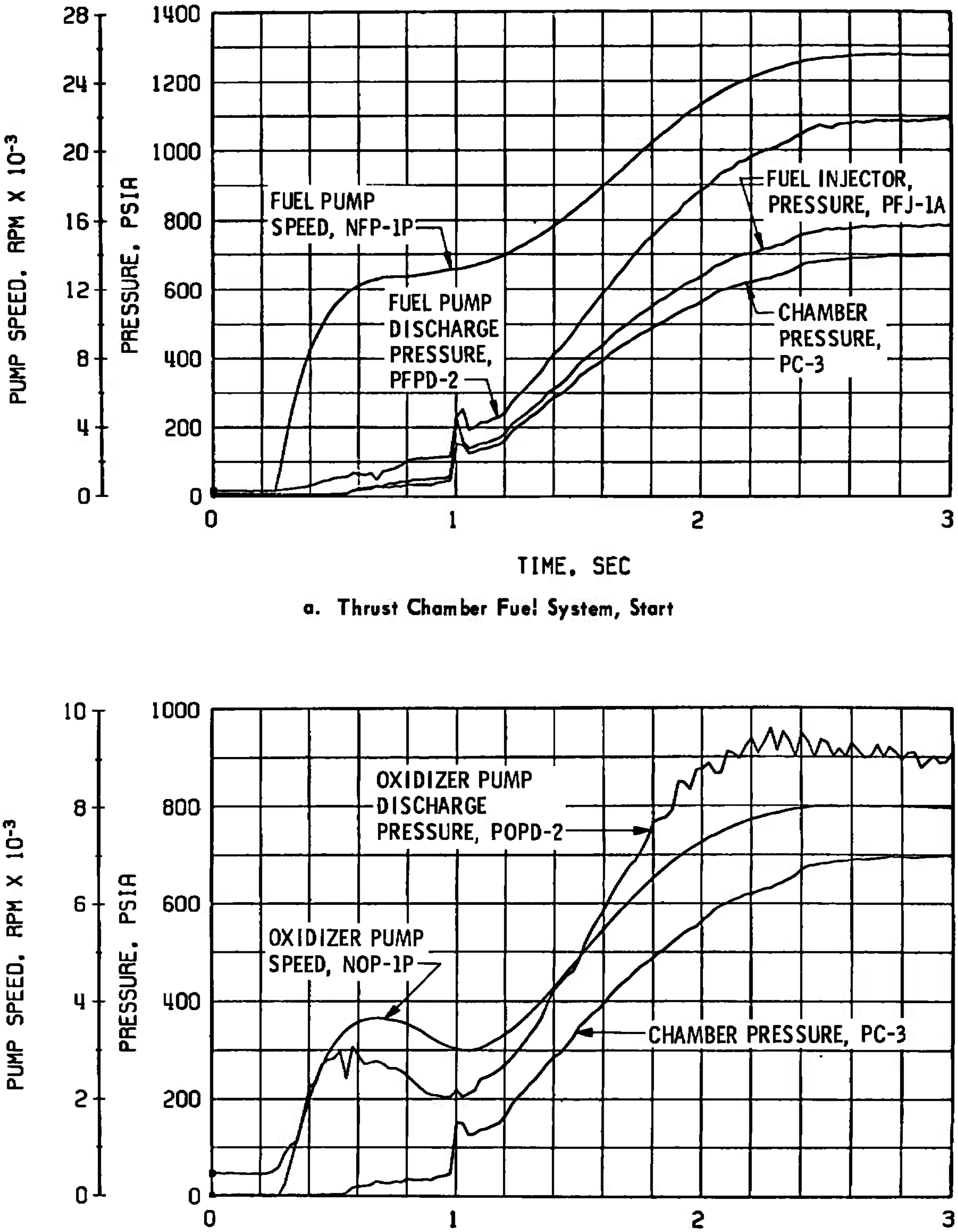



Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 43A

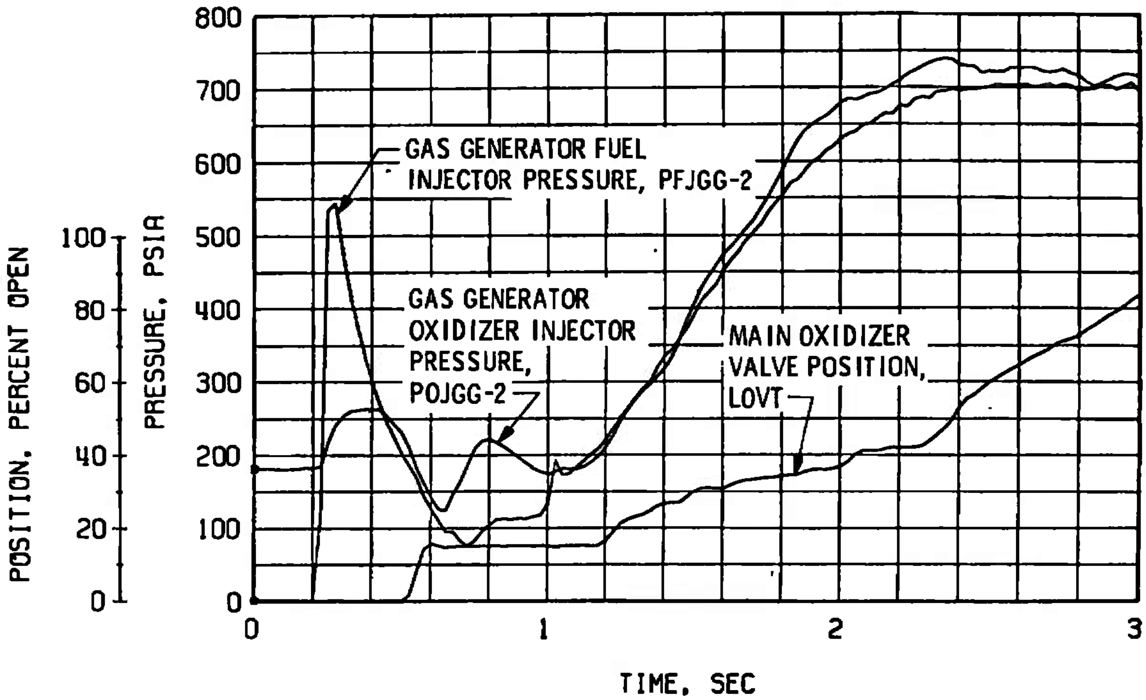



a. Thrust Chamber Fuel System, Start

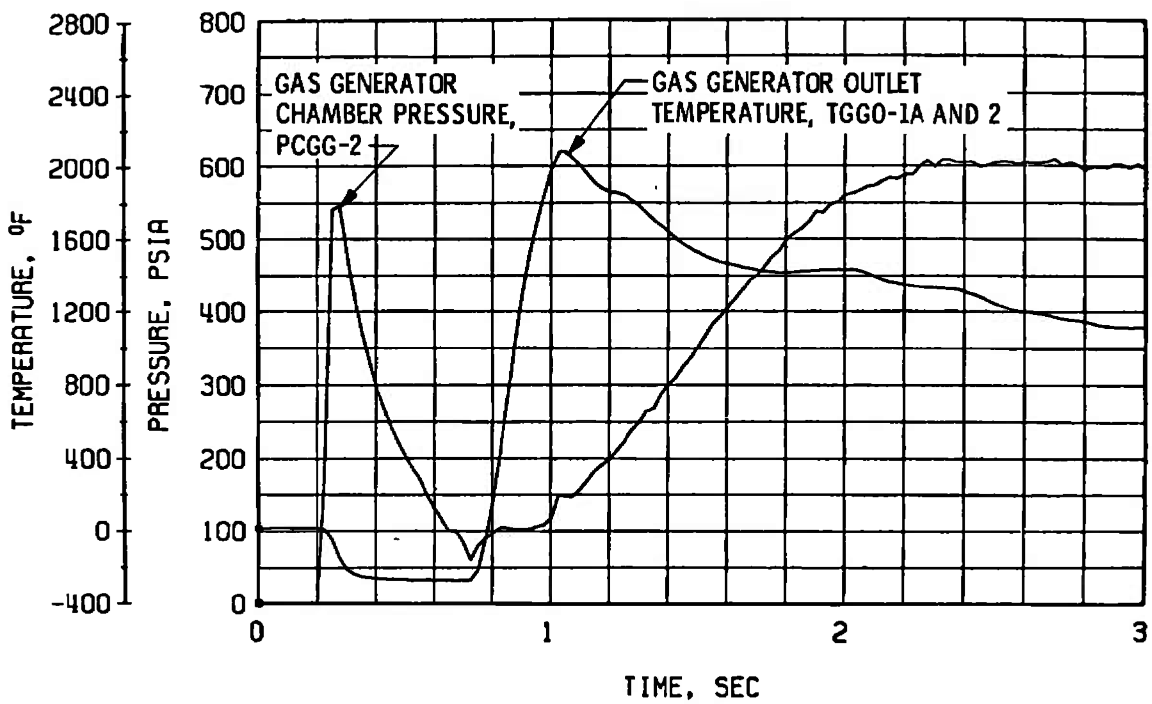


b. Thrust Chamber Oxidizer System, Start

Fig. 37 Engine Transient Operation, Firing 43A

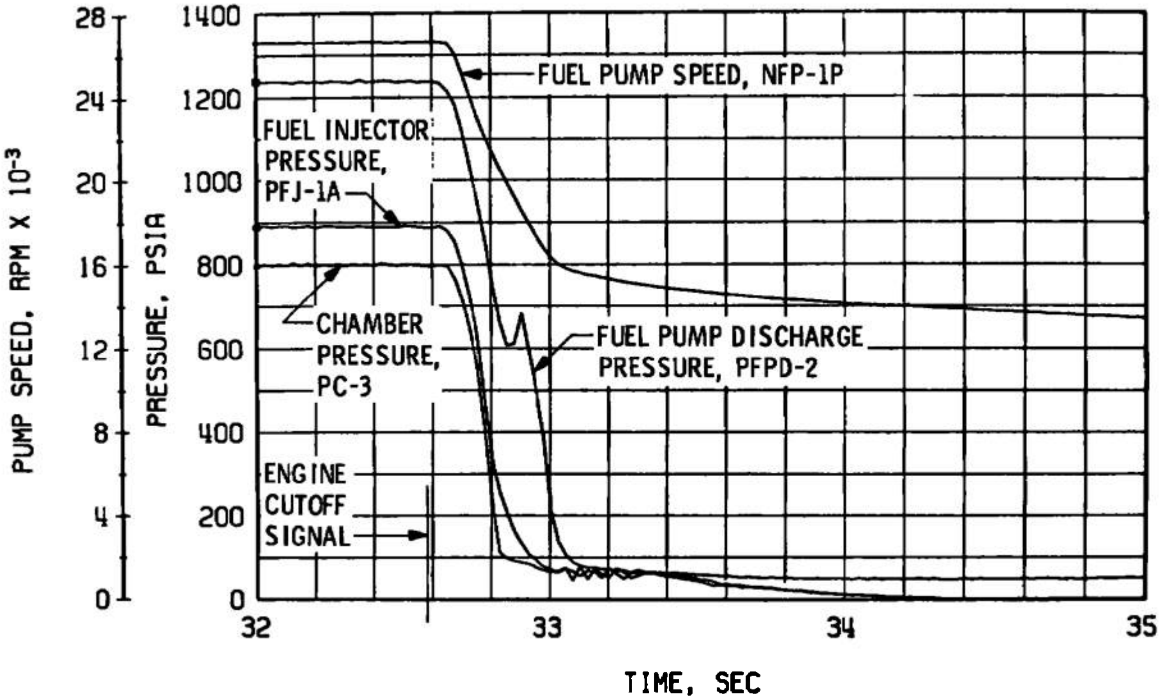



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

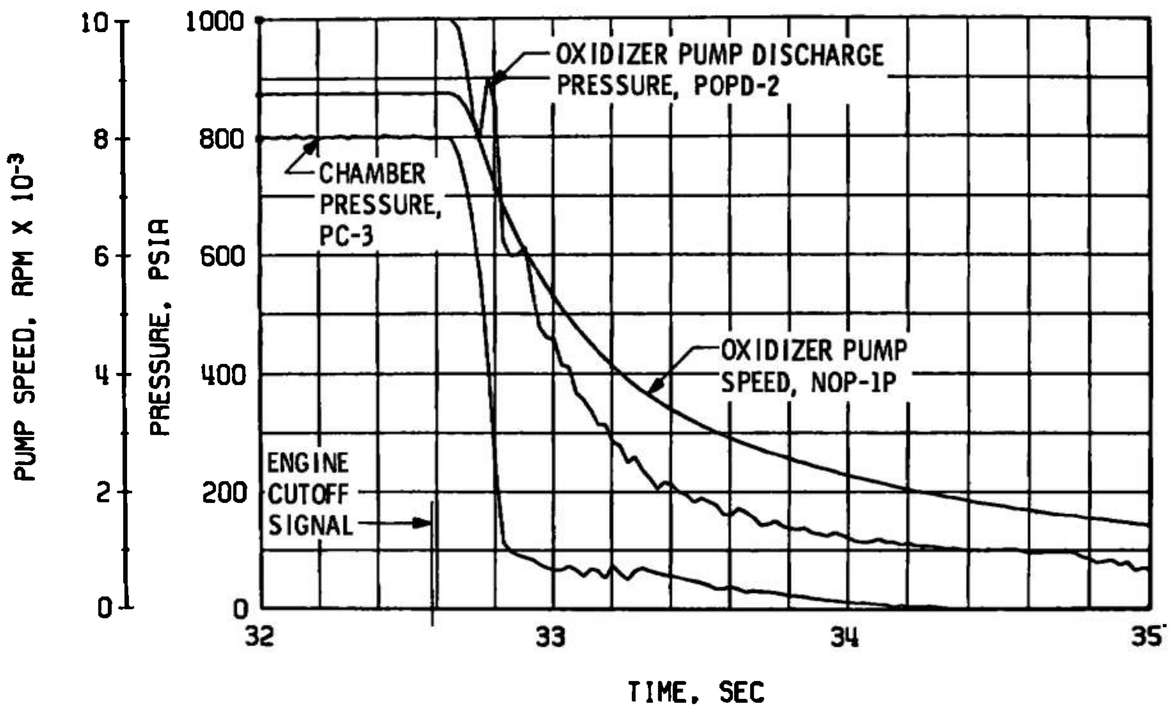



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 37 Continued

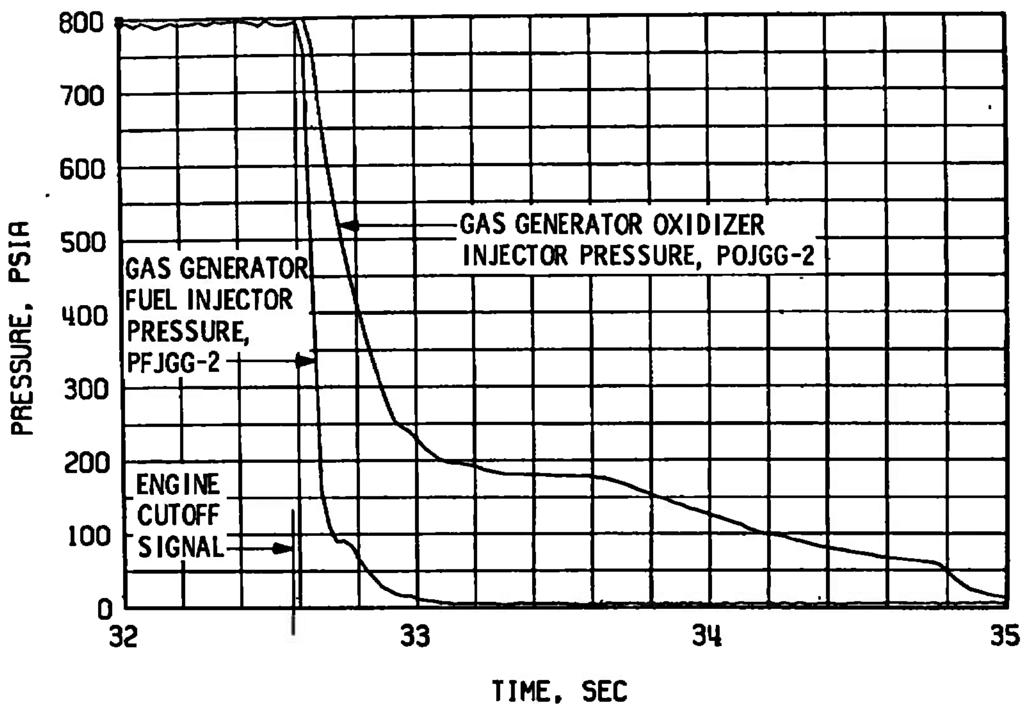



e. Thrust Chamber Fuel System, Shutdown

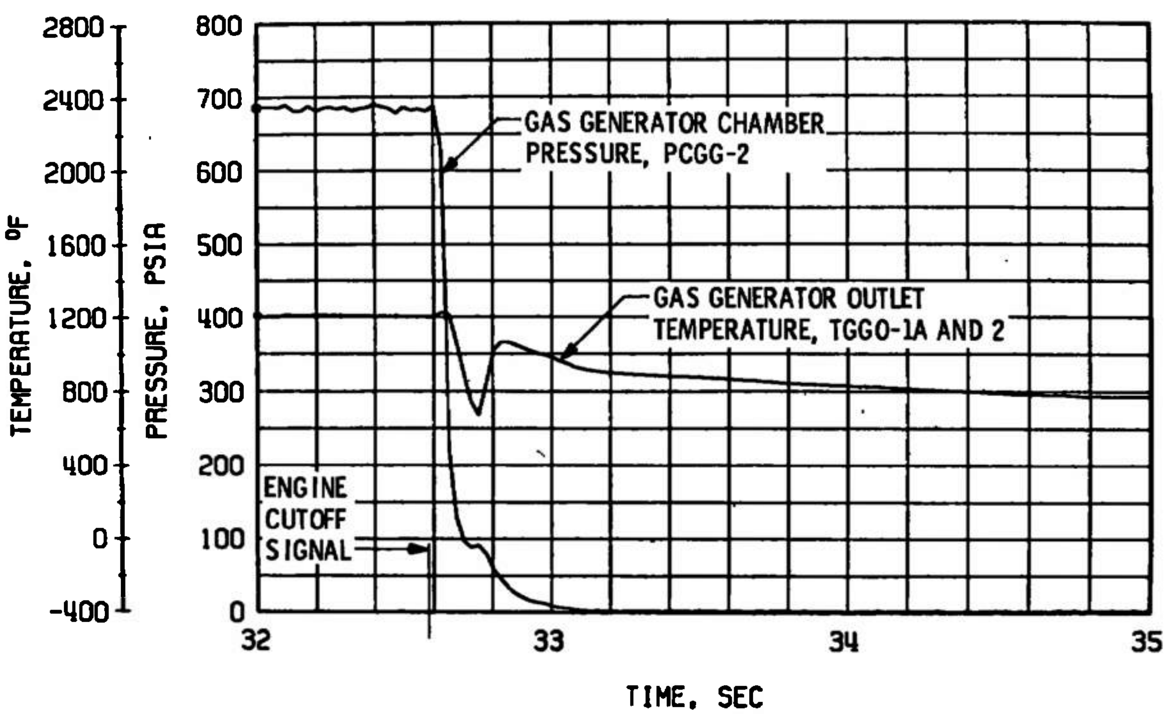



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 37 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 37 Concluded

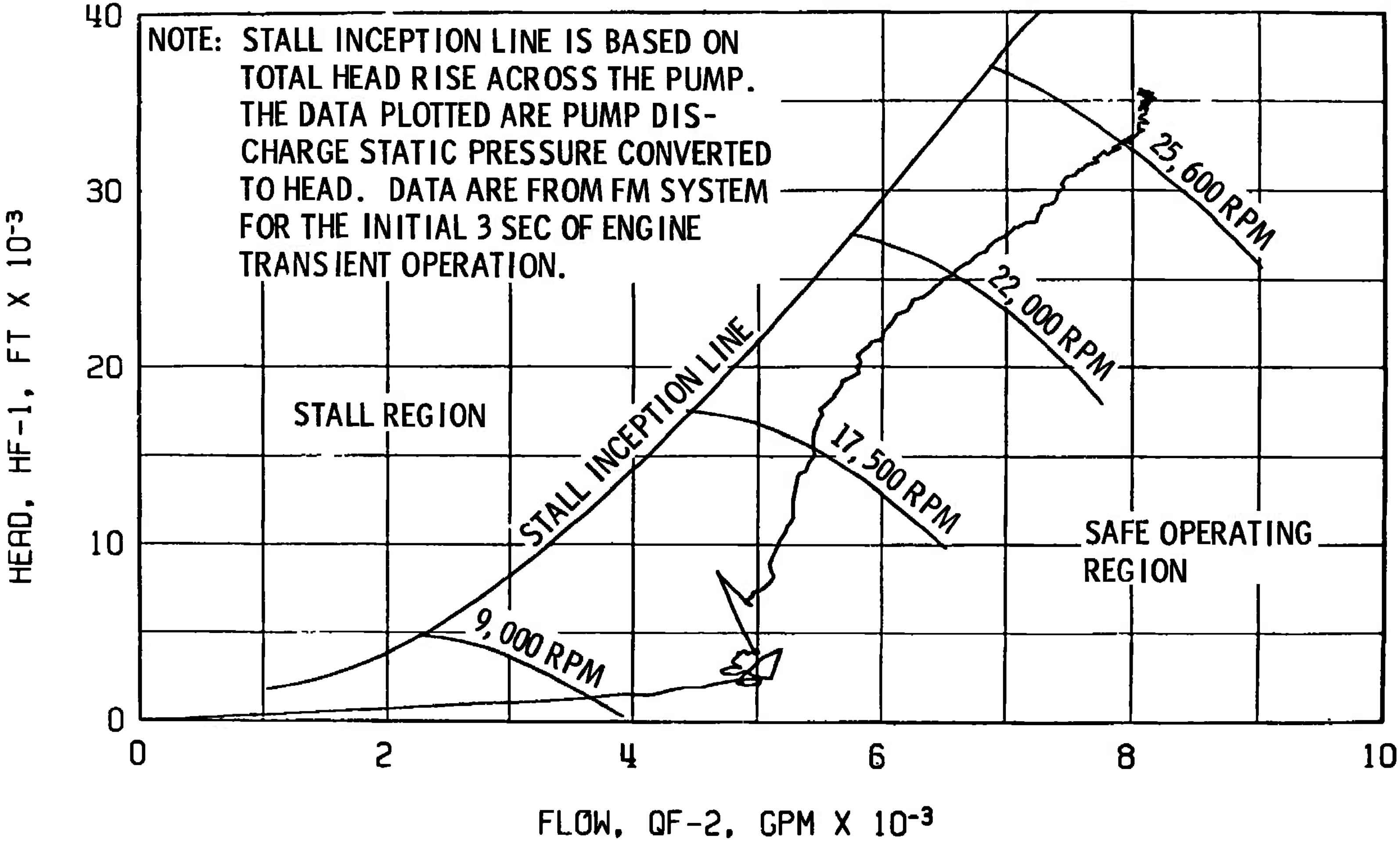
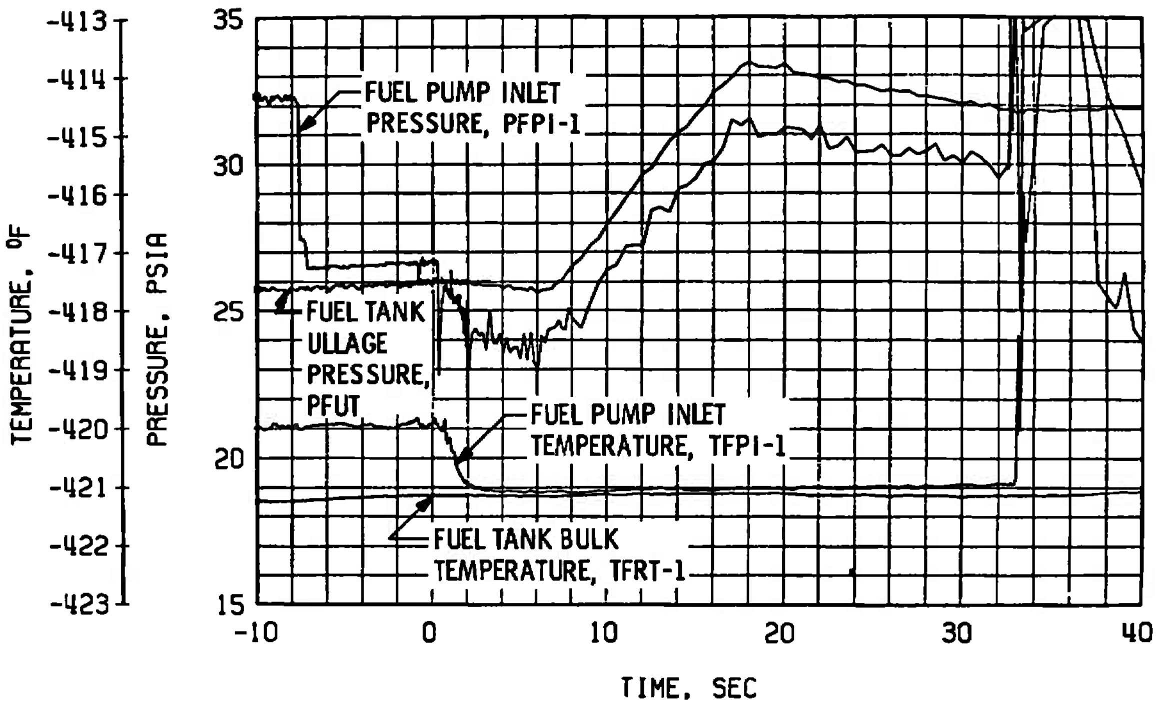
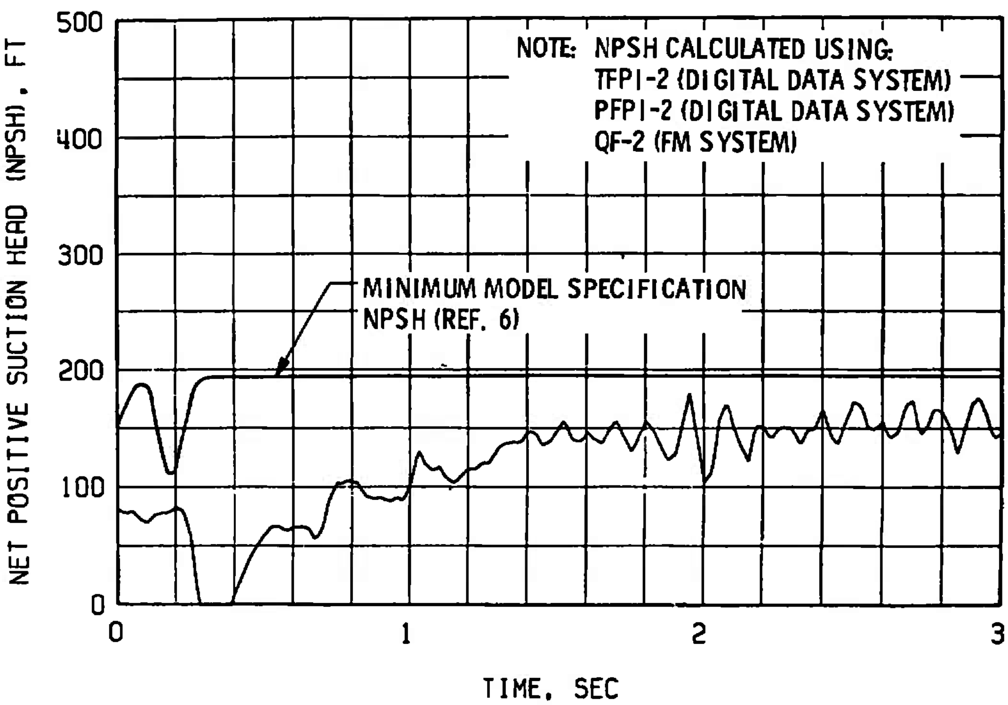



Fig. 38 Fuel Pump Start Transient Performance, Firing 43A

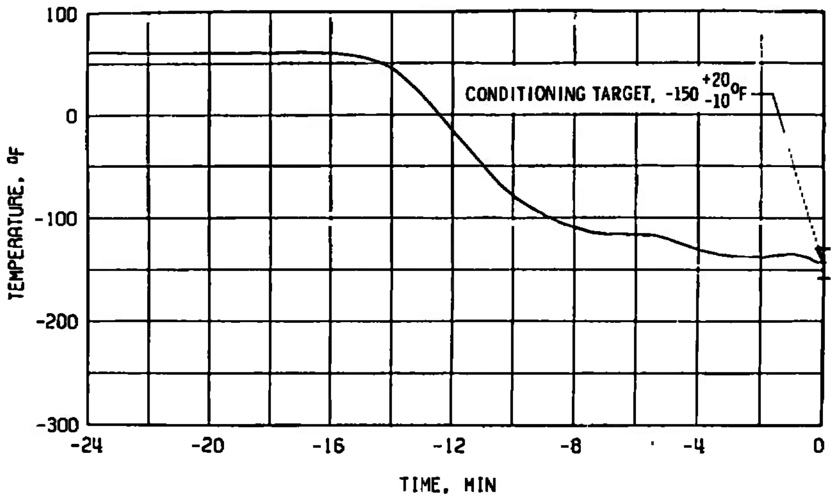



a. Duct Pressure and Temperature Transients

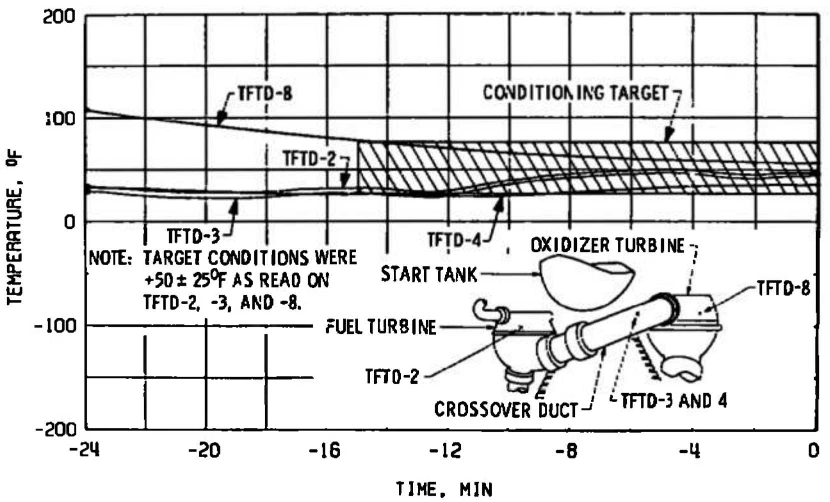



b. Fuel Pump NPSH during Start Transient, Firing 43A

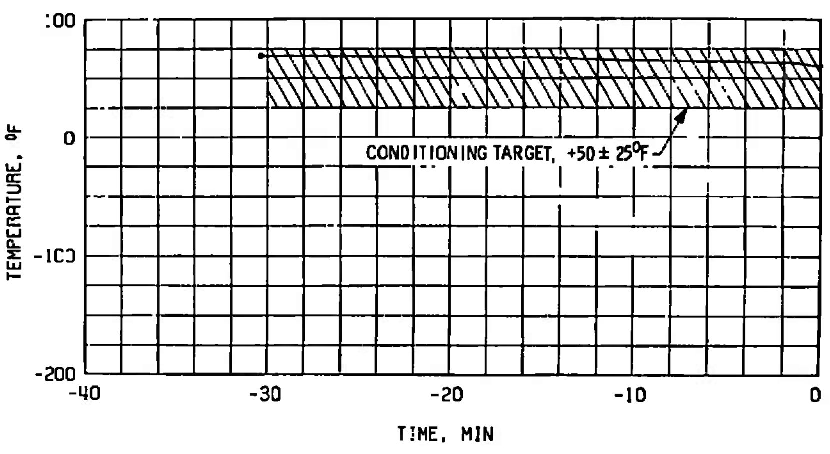
Fig. 39 Fuel Low Pressure Duct Performance, Firing 43A




a. Thrust Chamber, TTC-1P

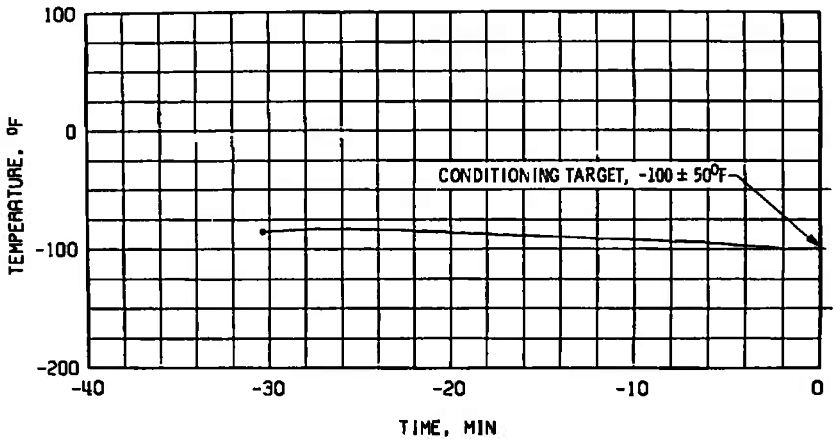



b. Crossover Duct, TFTD

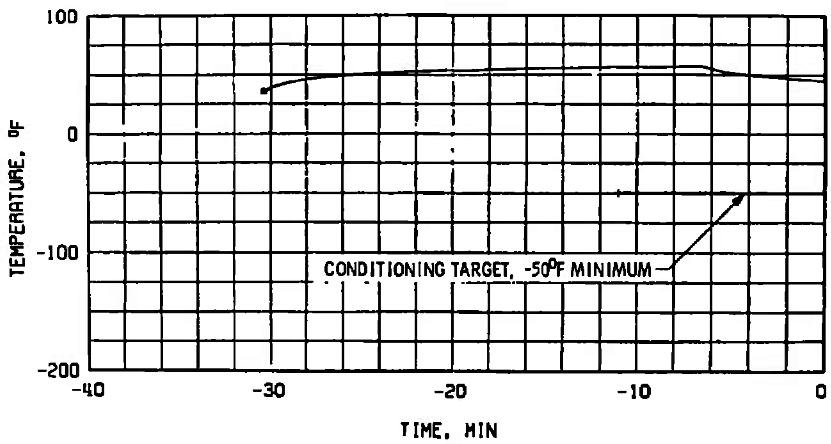



c. Start Tank Discharge Valve, TSTDVOC

Fig. 40 Thermal Conditioning History of Engine Components, Firing 43B




d. Main Oxidizer Second-Stage Actuator, TSOVC-1




e. Gas Generator Control Valve, TGGVRS

Fig. 40 Concluded

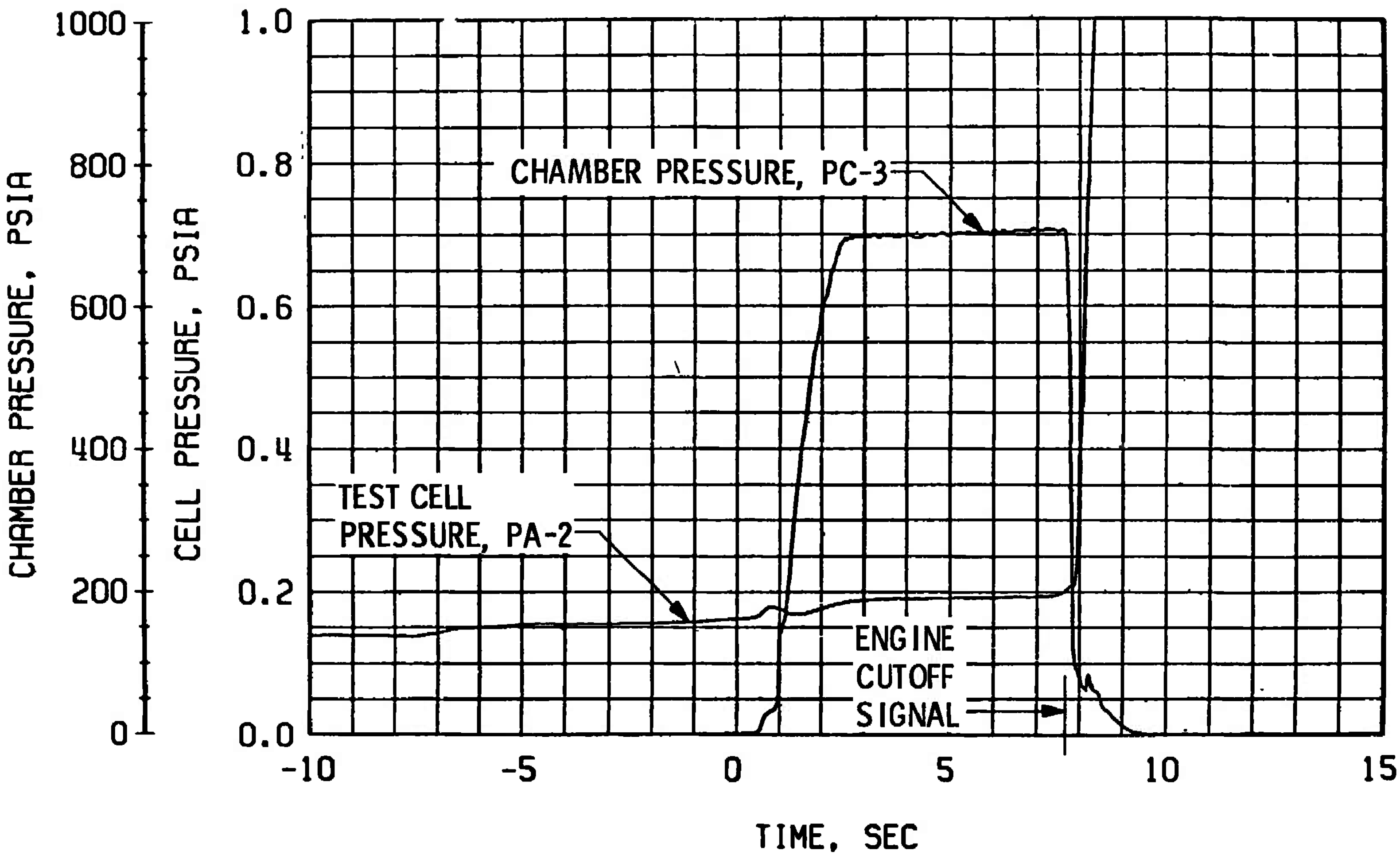
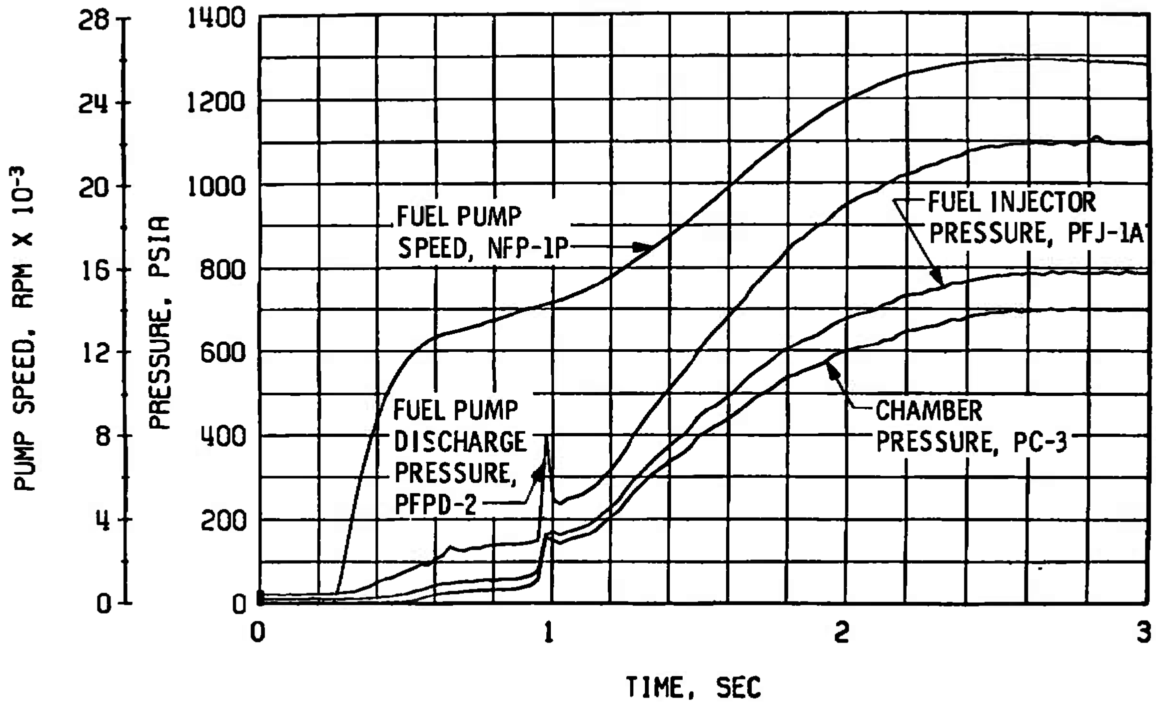
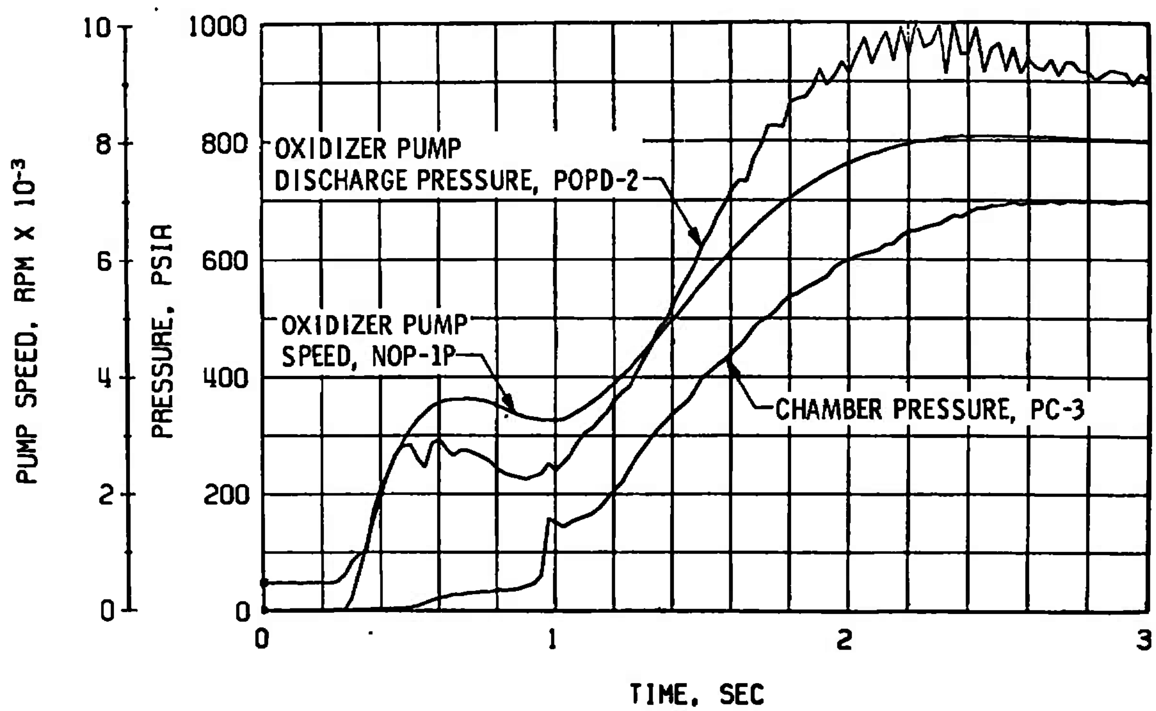



Fig. 41 Engine Ambient and Combustion Chamber Pressures, Firing 43B

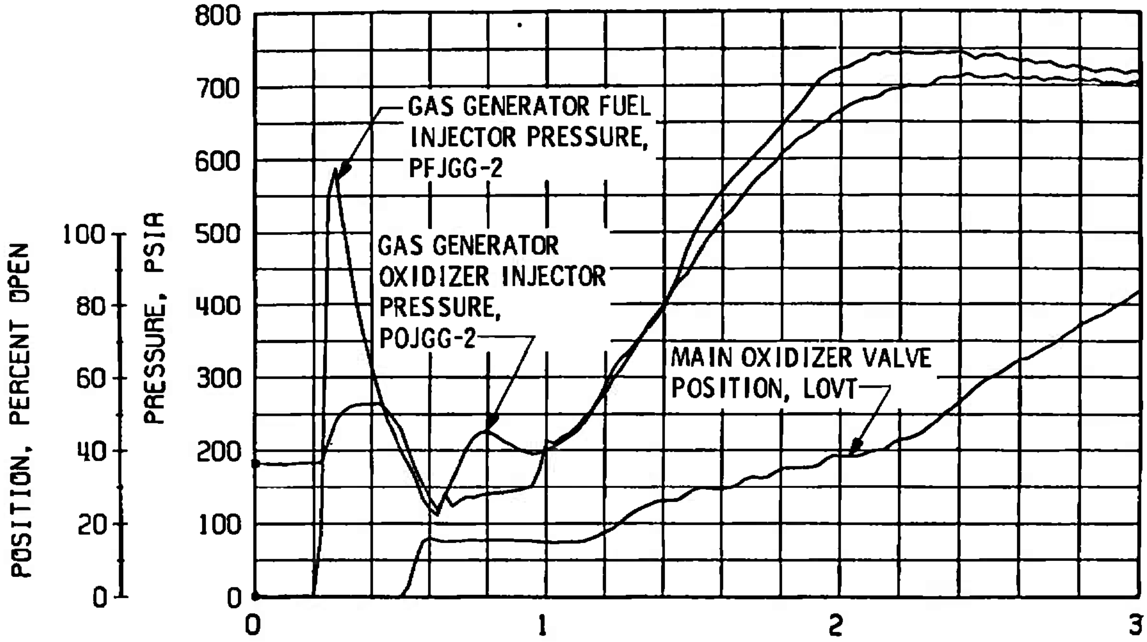



a. Thrust Chamber Fuel System, Start

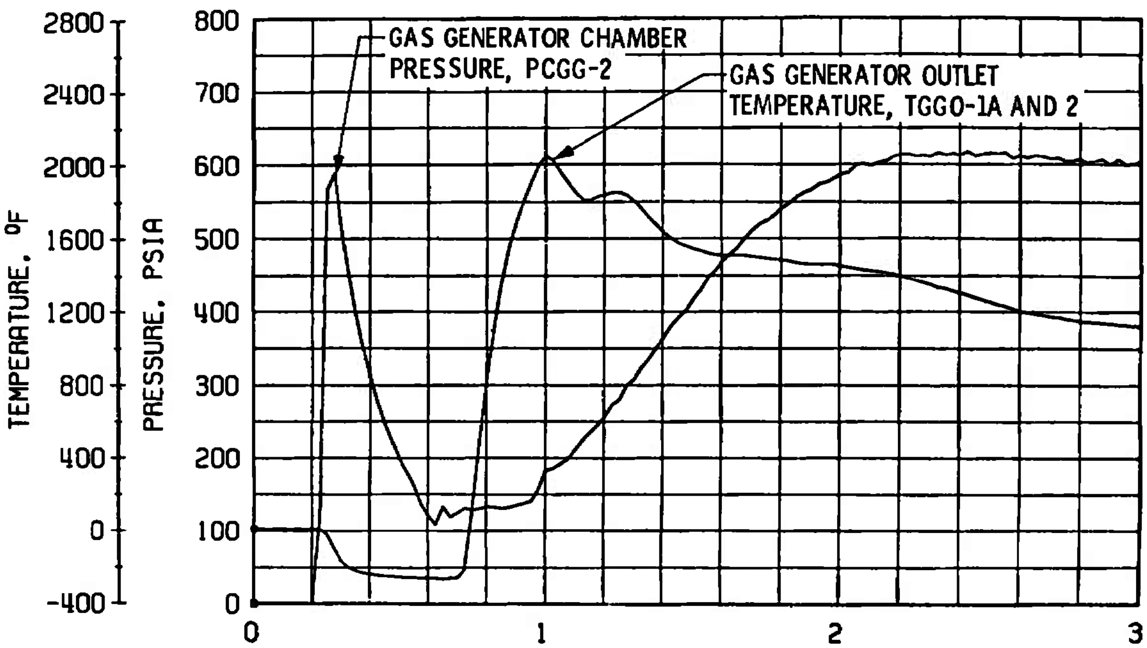



b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 43B

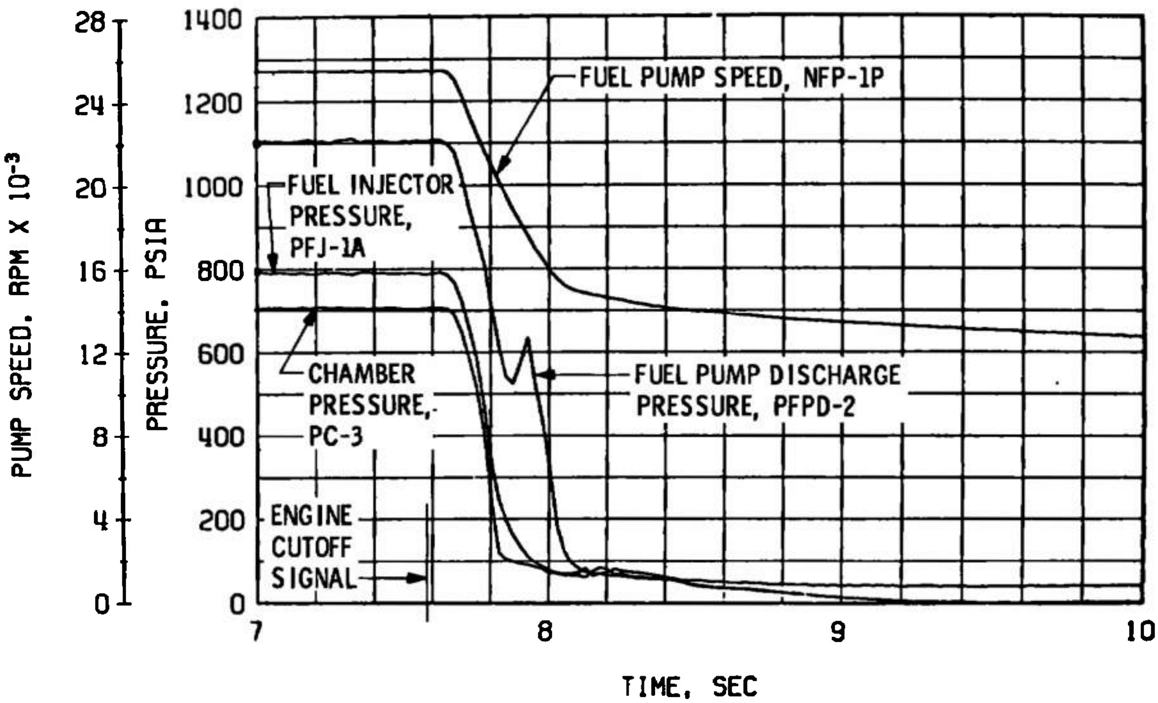



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

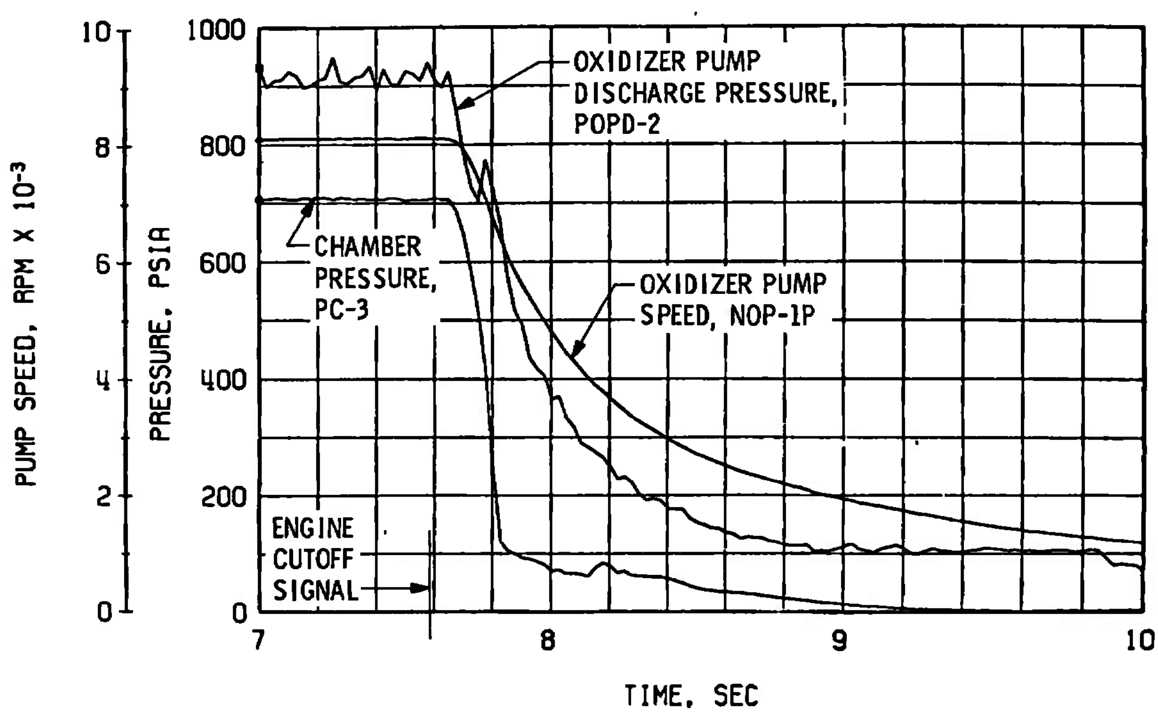



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued

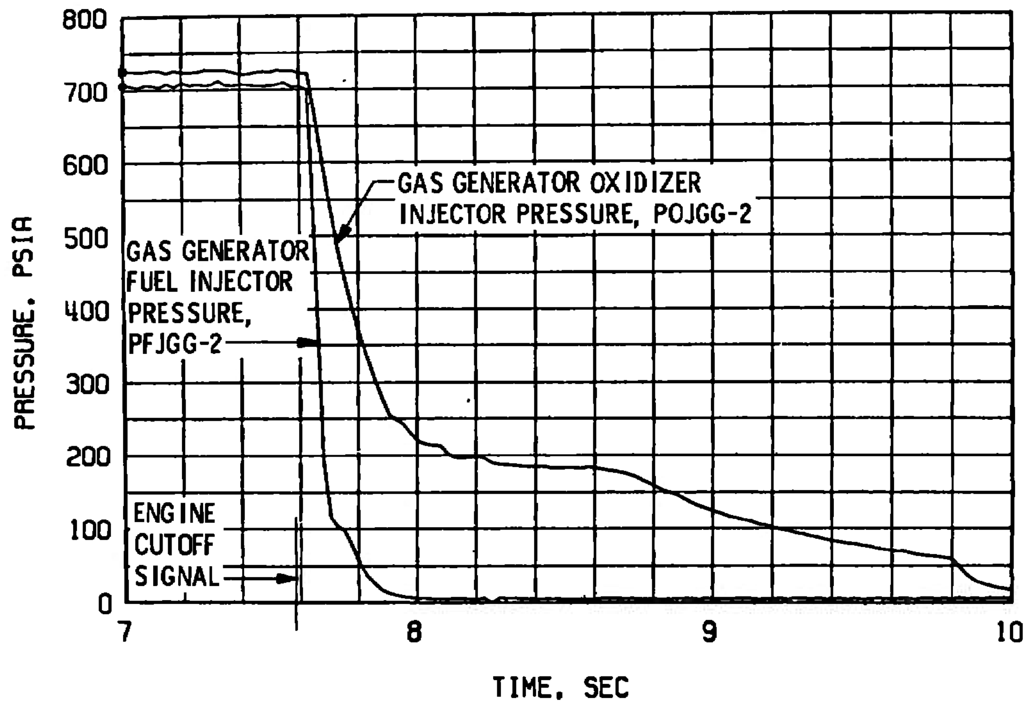



e. Thrust Chamber Fuel System, Shutdown

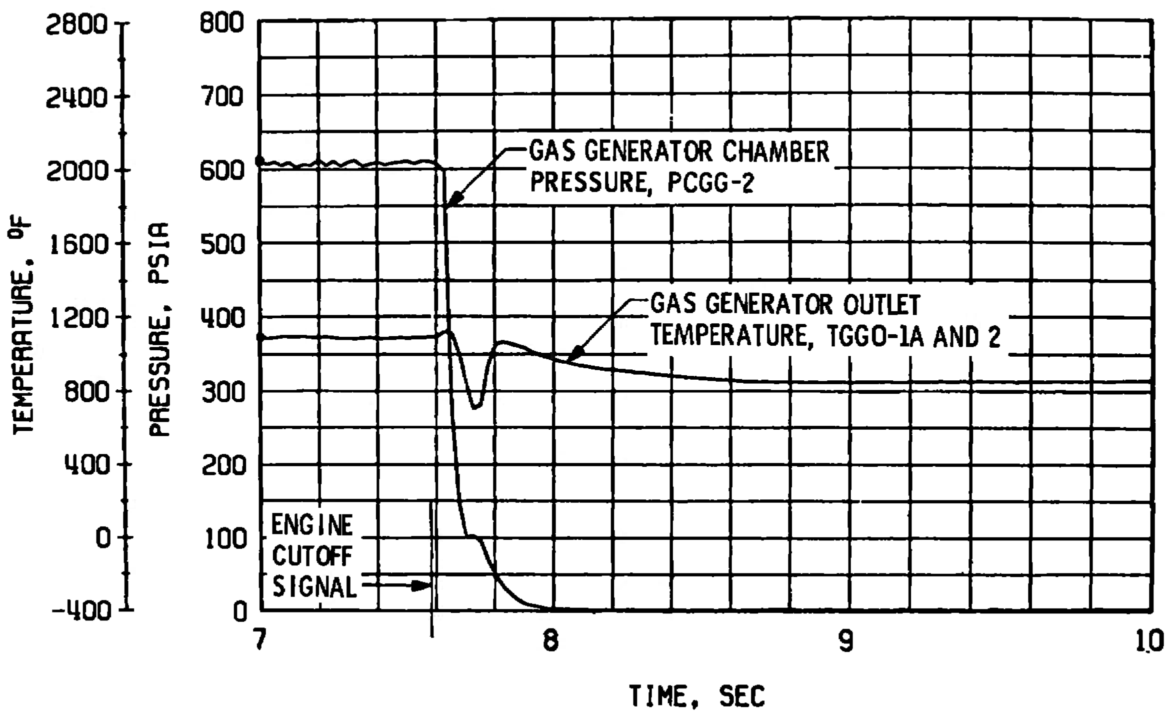



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

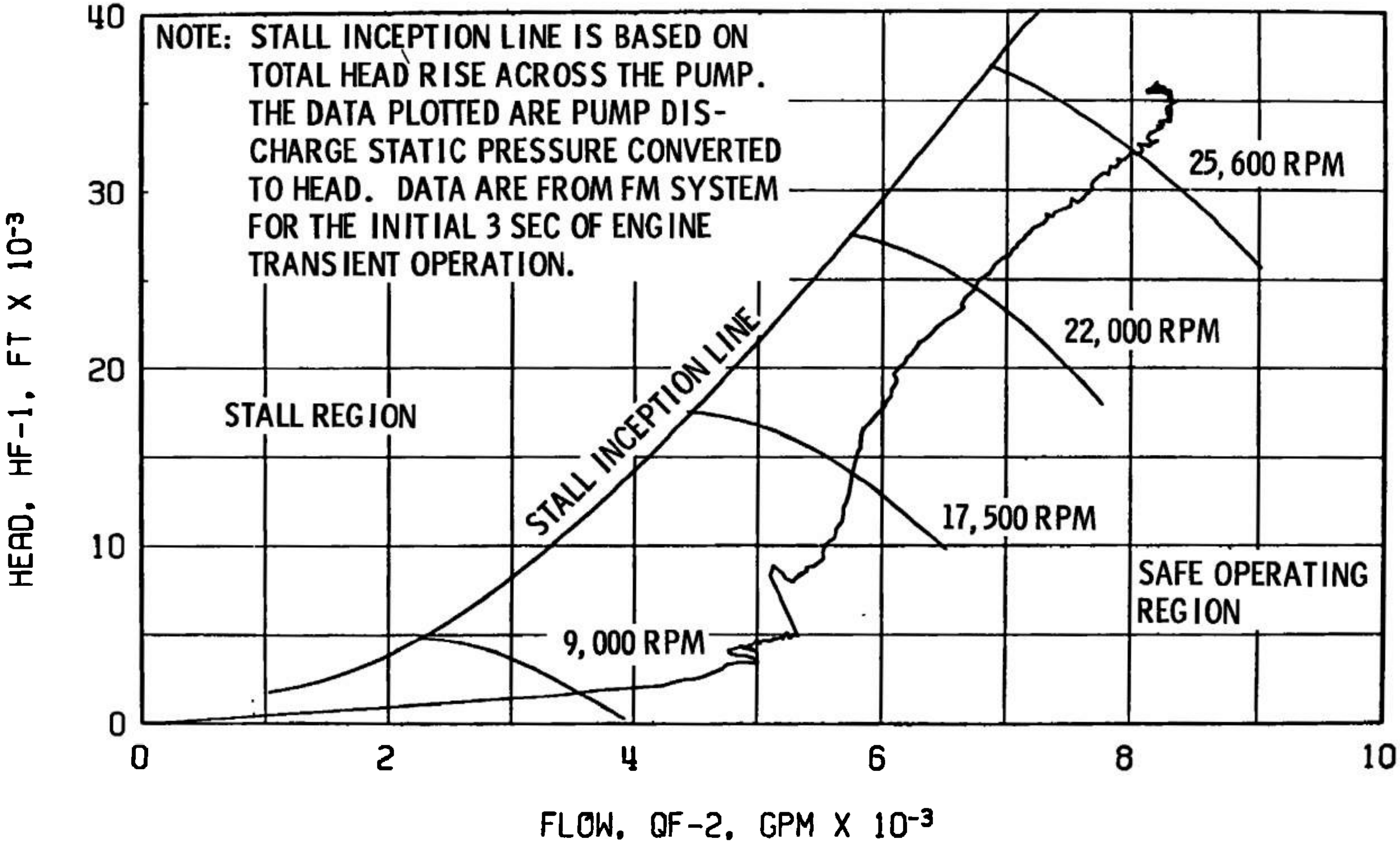
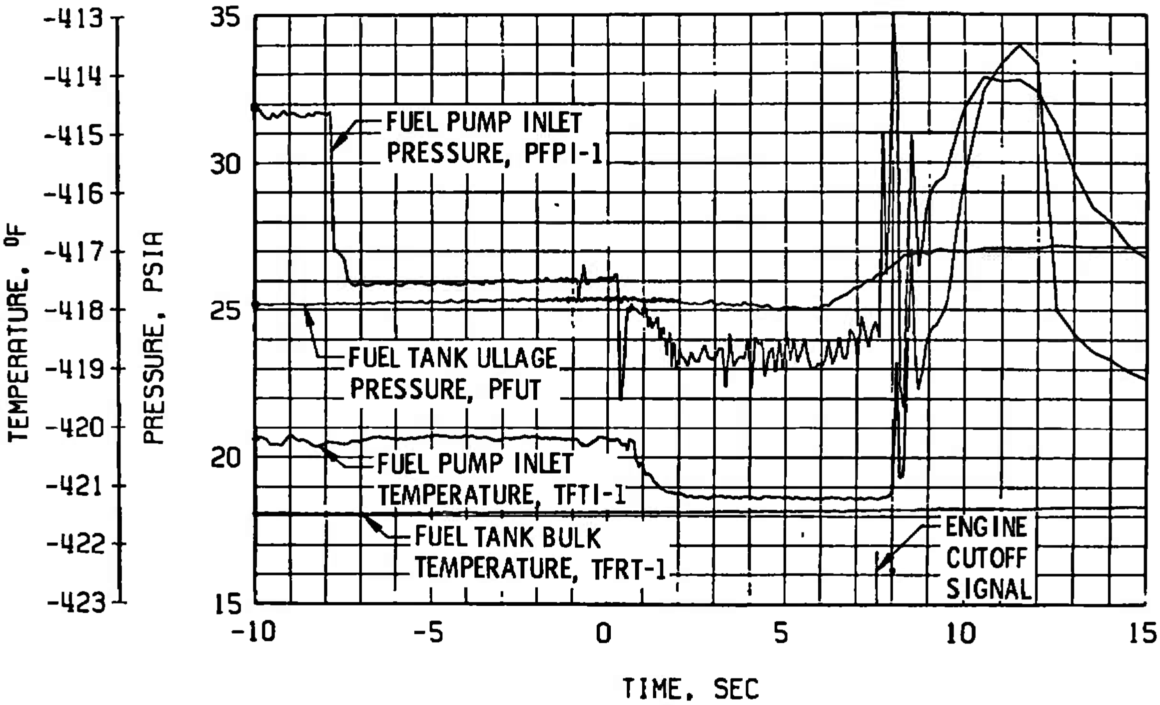
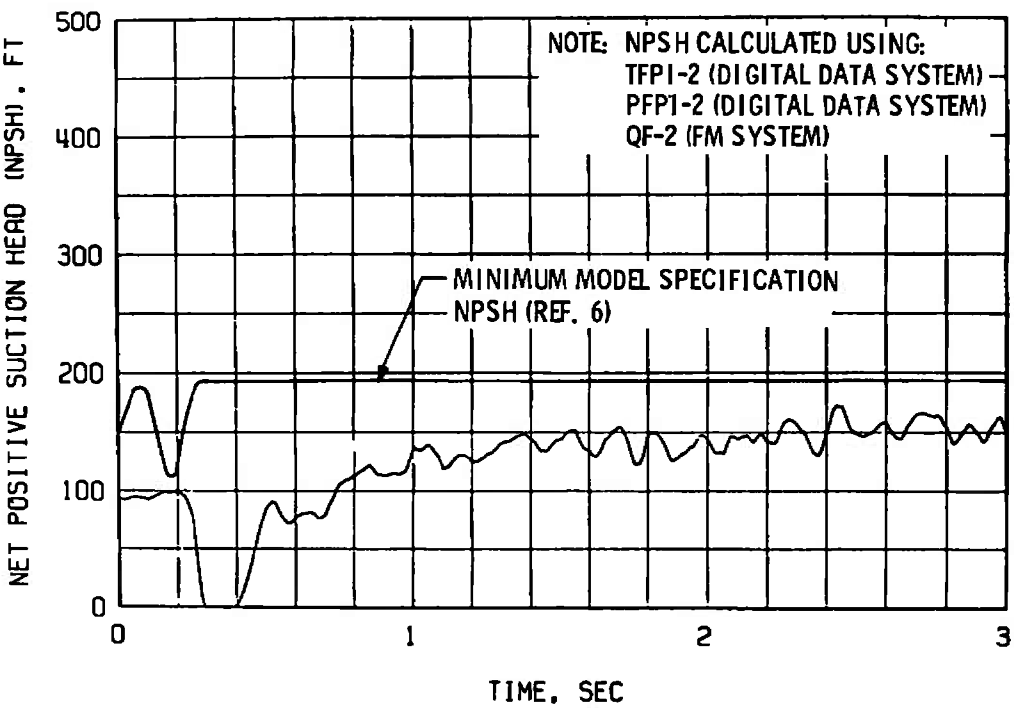



Fig. 43 Fuel Pump Start Transient Performance, Firing 43B

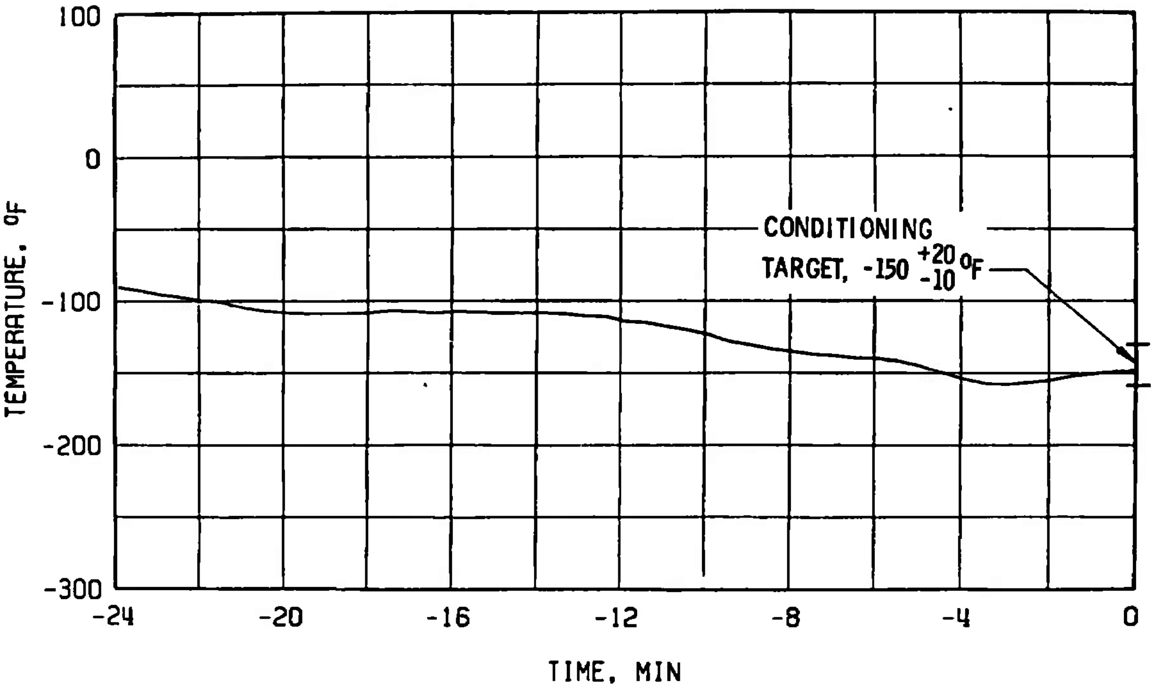



a. Duct Pressure and Temperature Transients

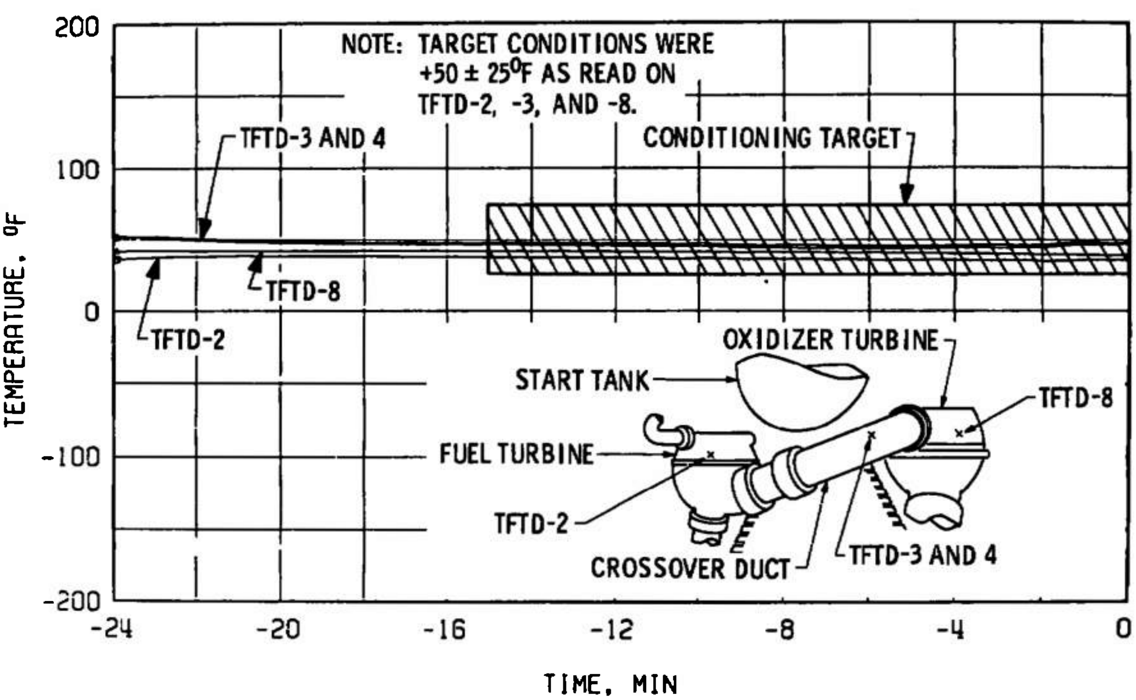



b. Fuel Pump NPSH during Start Transient, Firing 43B

Fig. 44 Fuel Low Pressure Duct Performance, Firing 43B

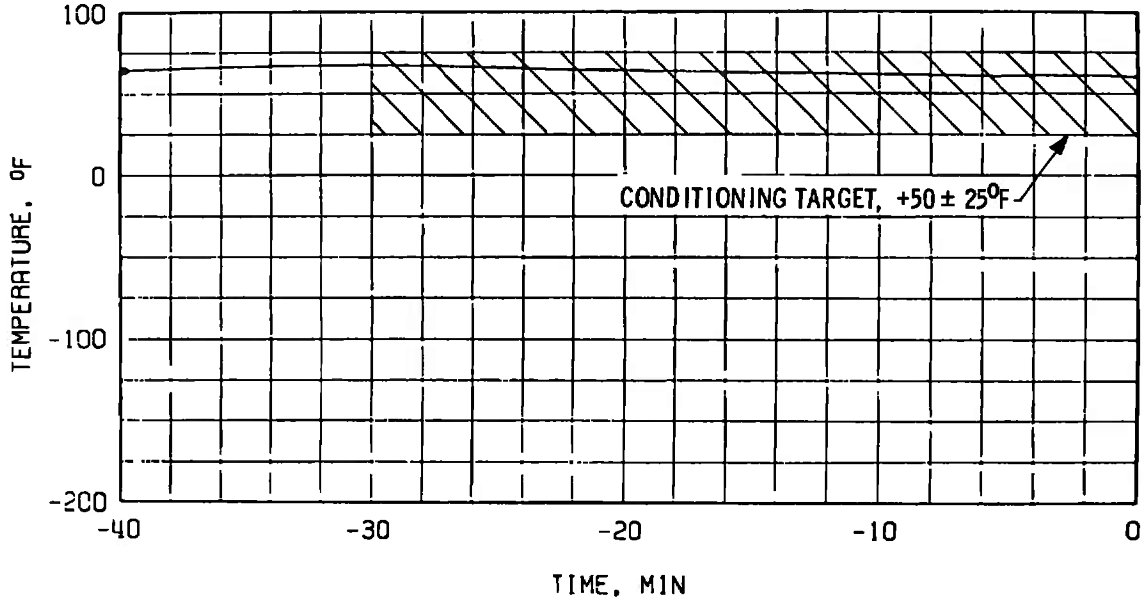



a. Thrust Chamber, TTC-1P

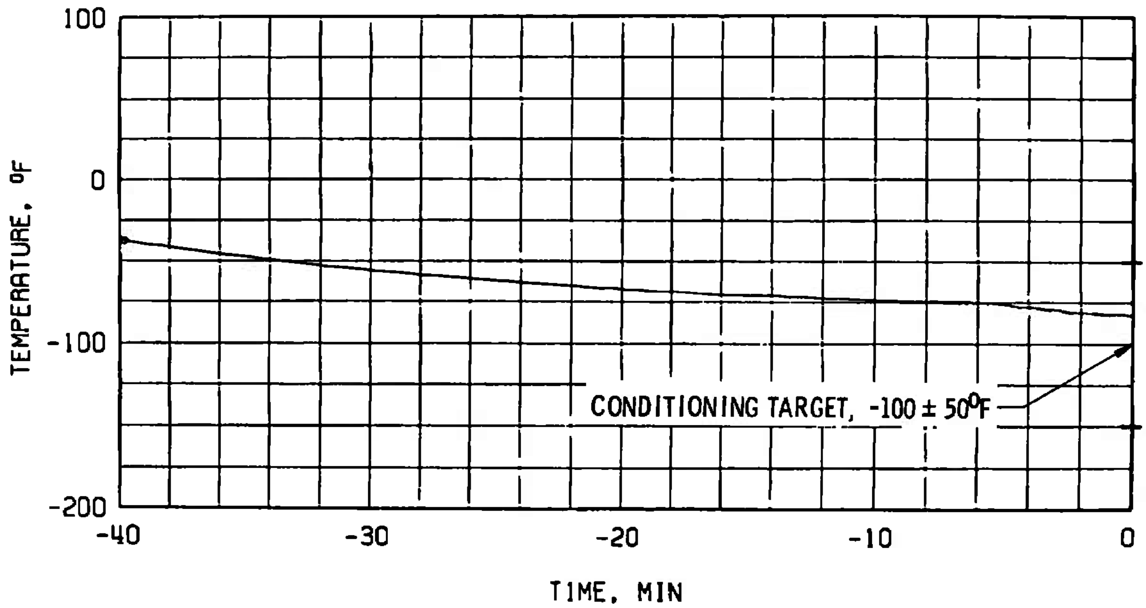



b. Crossover Duct, TFTD

Fig. 45 Thermal Conditioning History of Engine Components, Firing 01A




c. Start Tank Discharge Valve, TSTDVOC




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

Fig. 45 Concluded

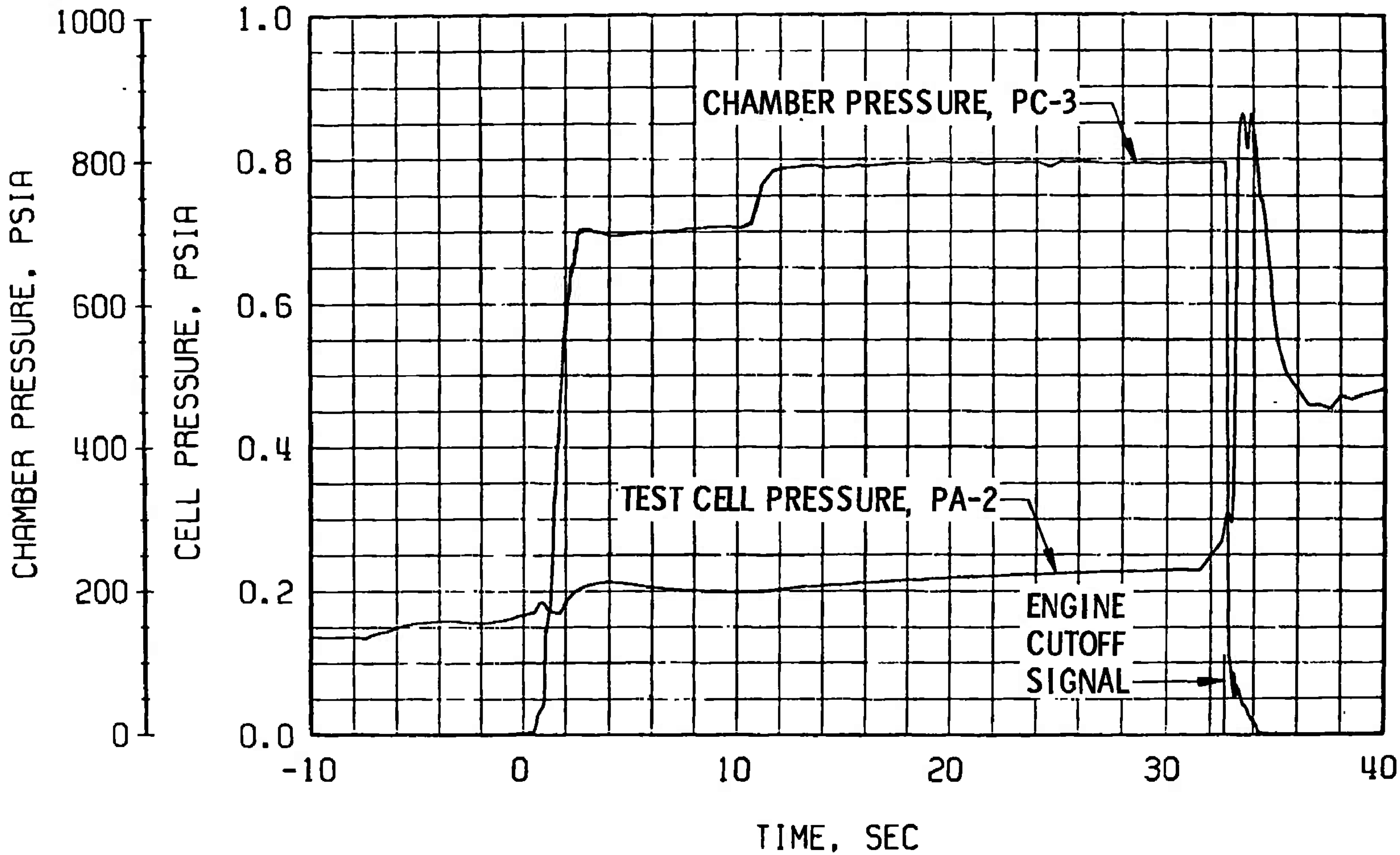
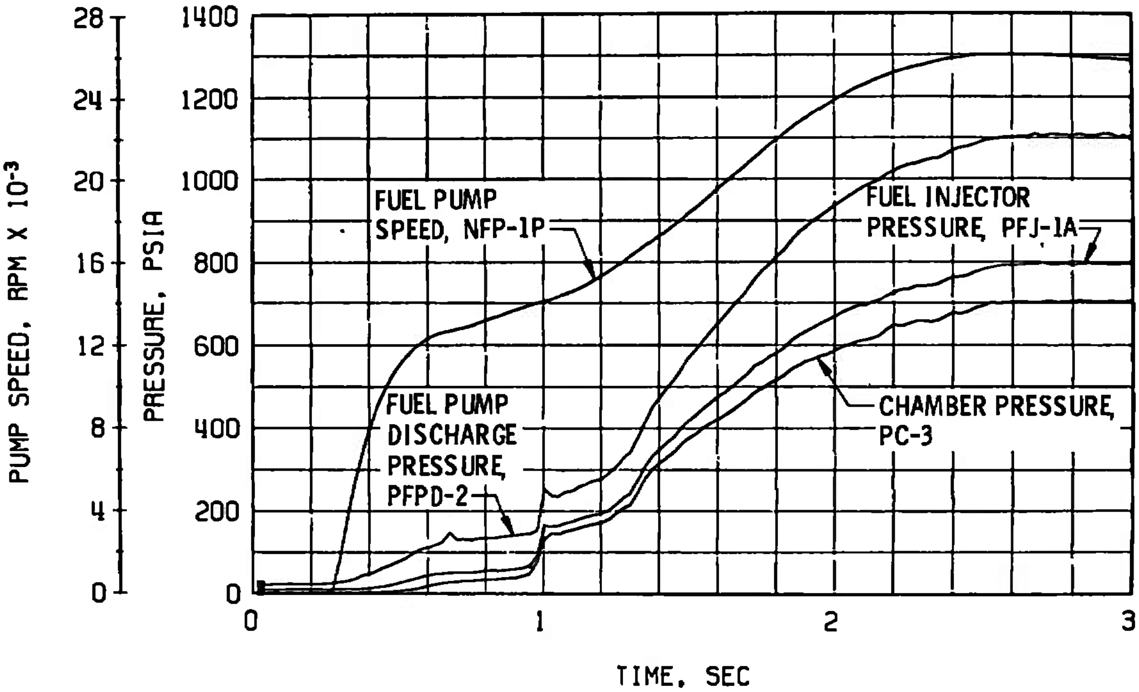
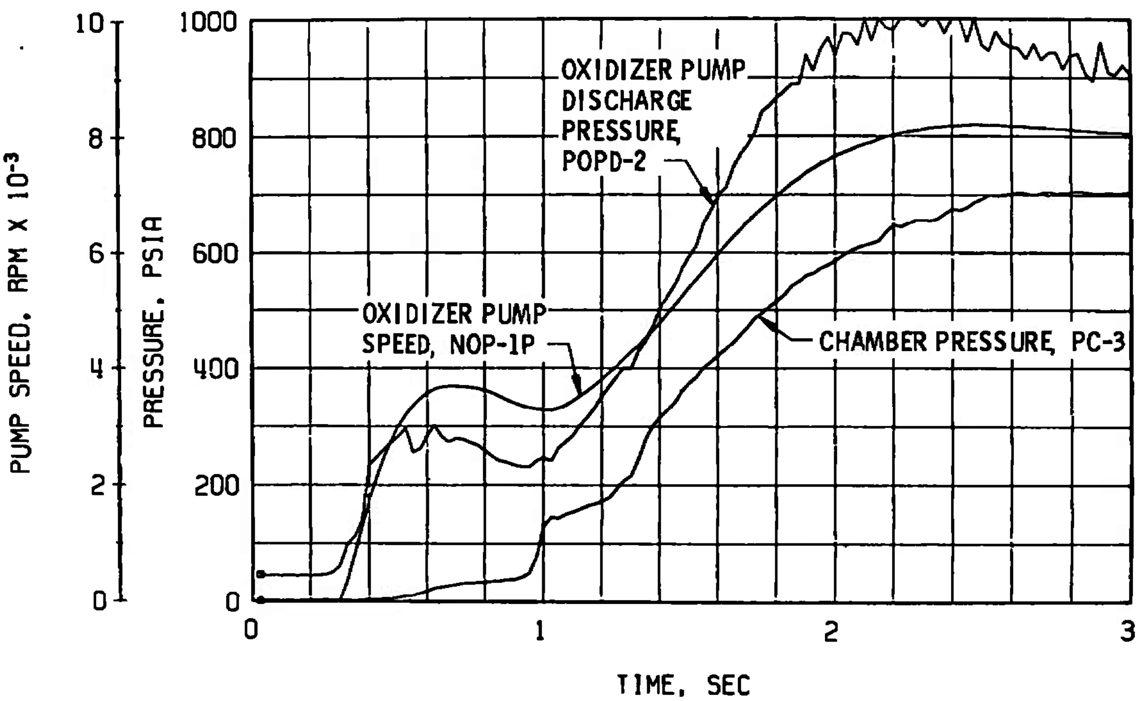



Fig. 46 Engine Ambient and Combustion Chamber Pressures, Firing 01A

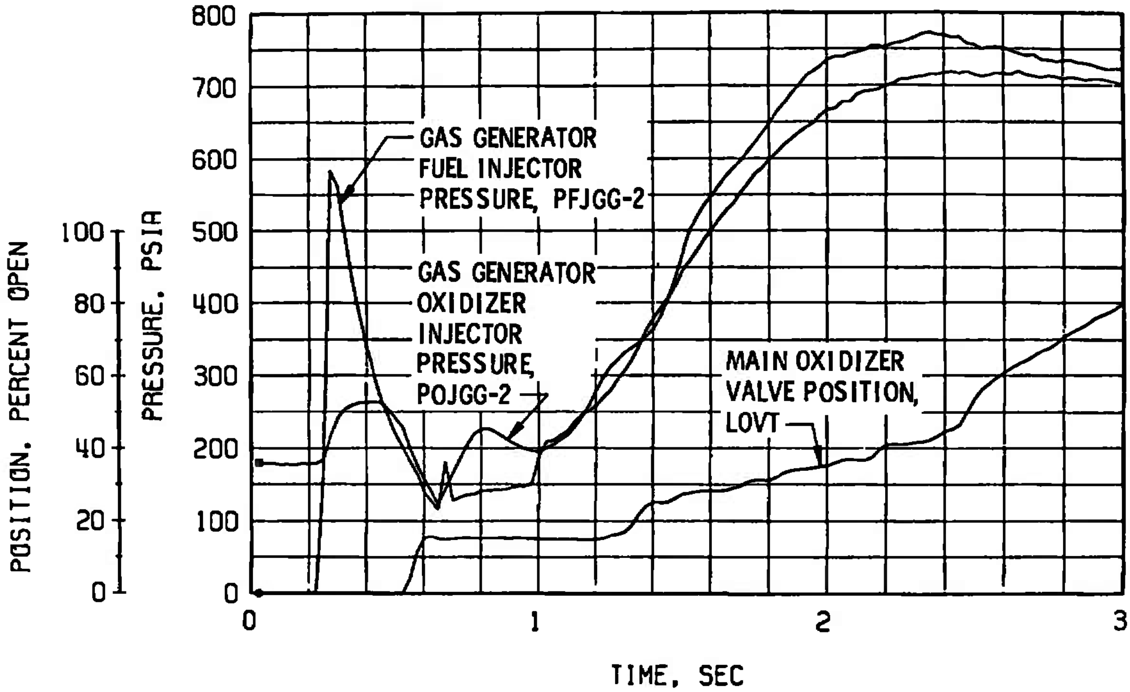



a. Thrust Chamber Fuel System, Start

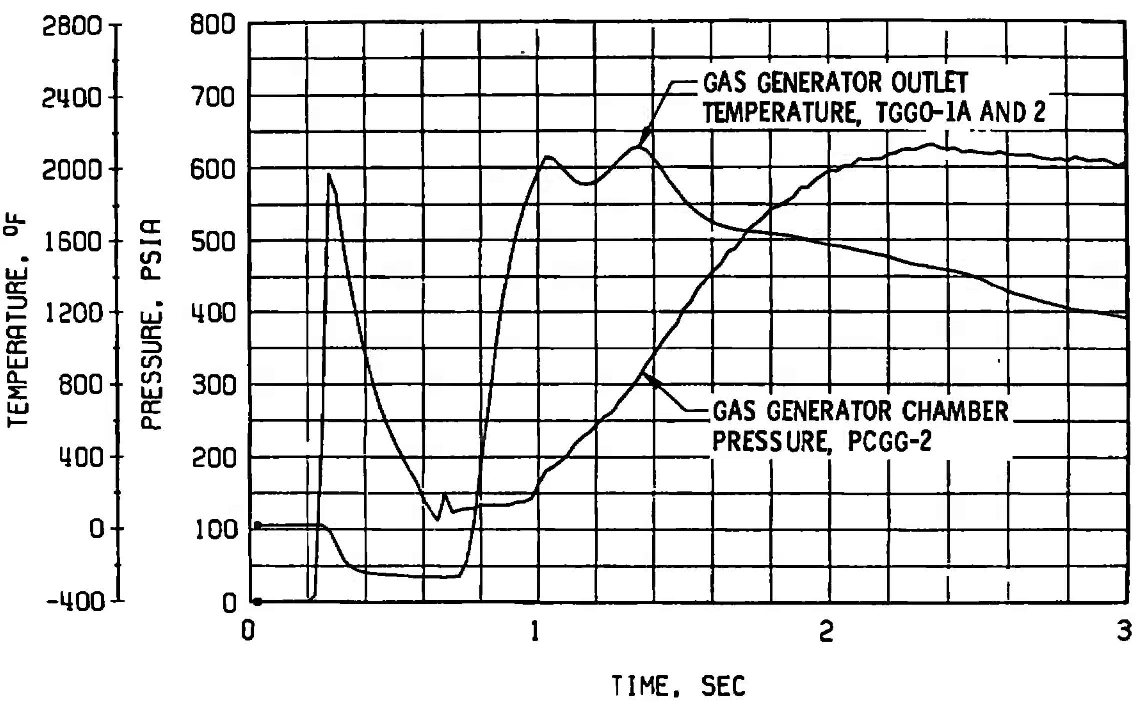



b. Thrust Chamber Oxidizer System, Start

Fig. 47 Engine Transient Operation, Firing 01A

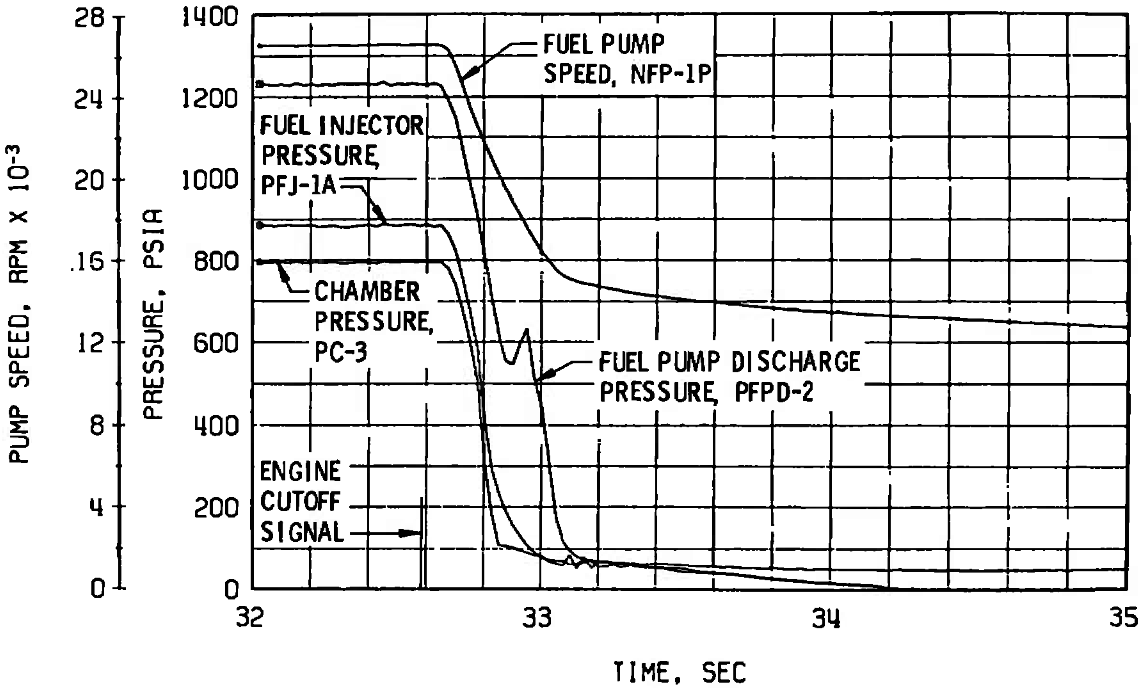



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

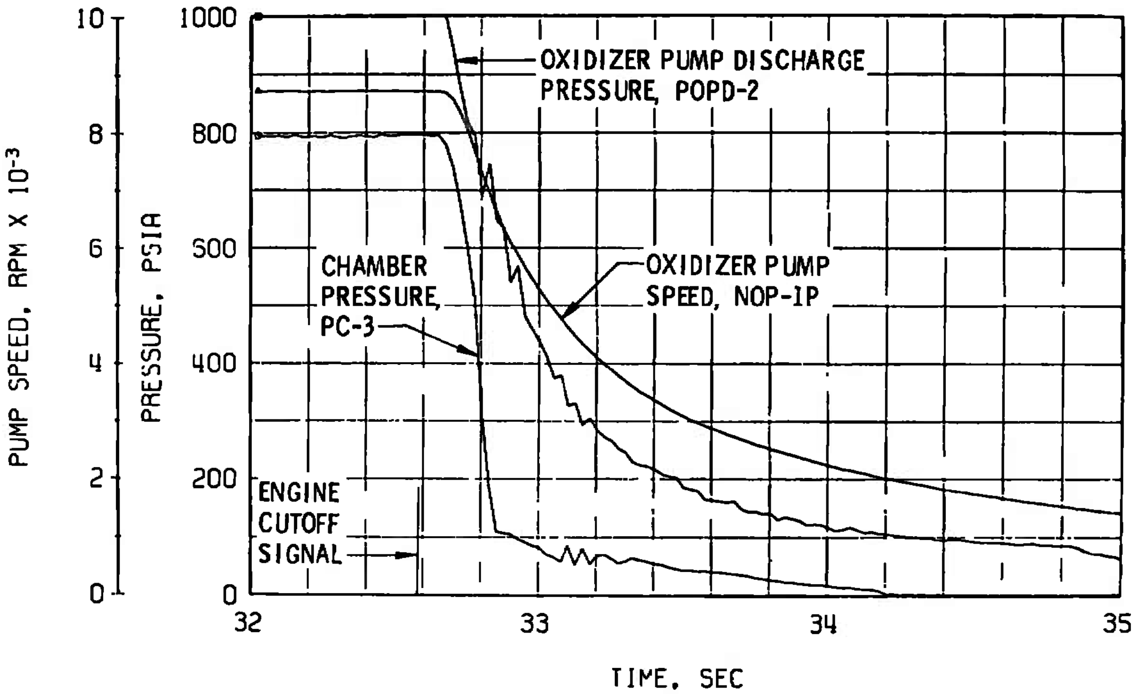



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 47 Continued

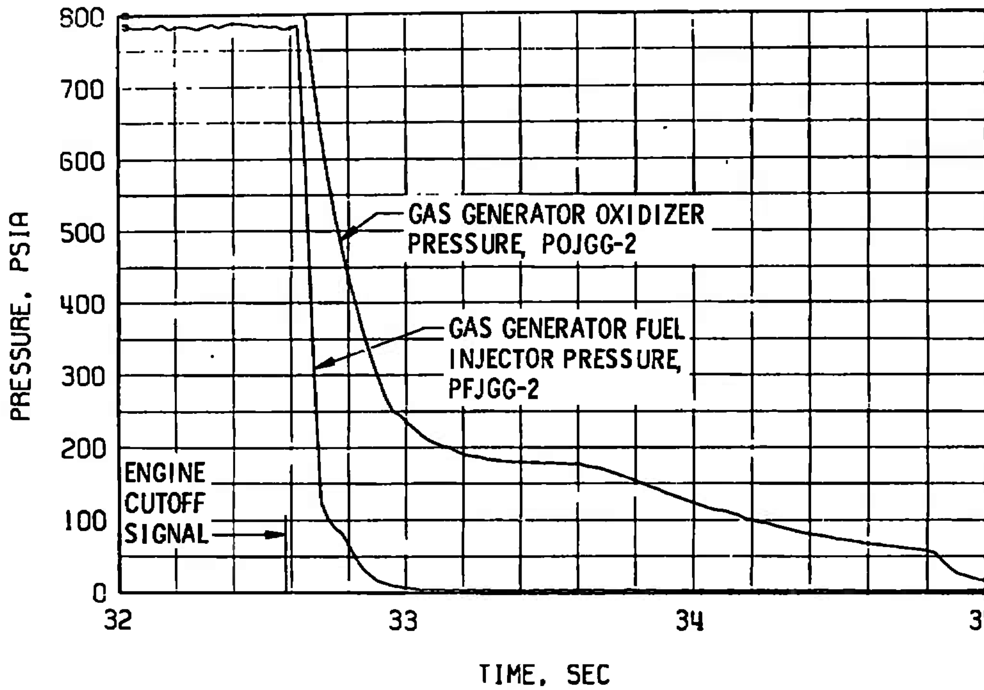



e. Thrust Chamber Fuel System, Shutdown

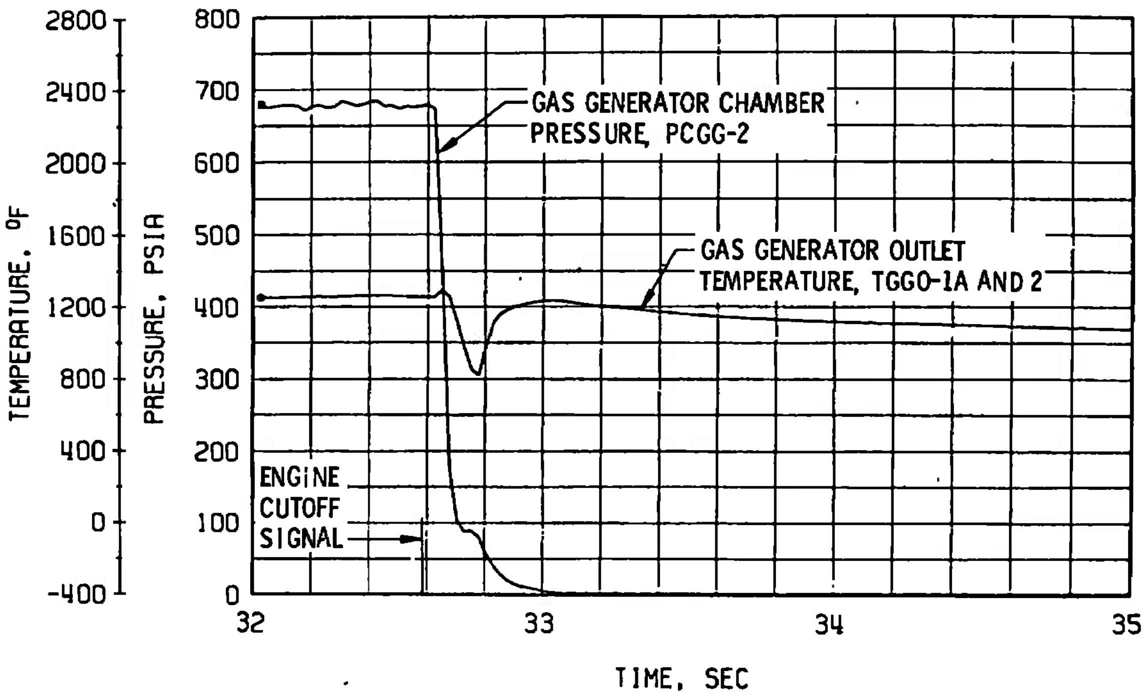



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 47 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 47 Concluded

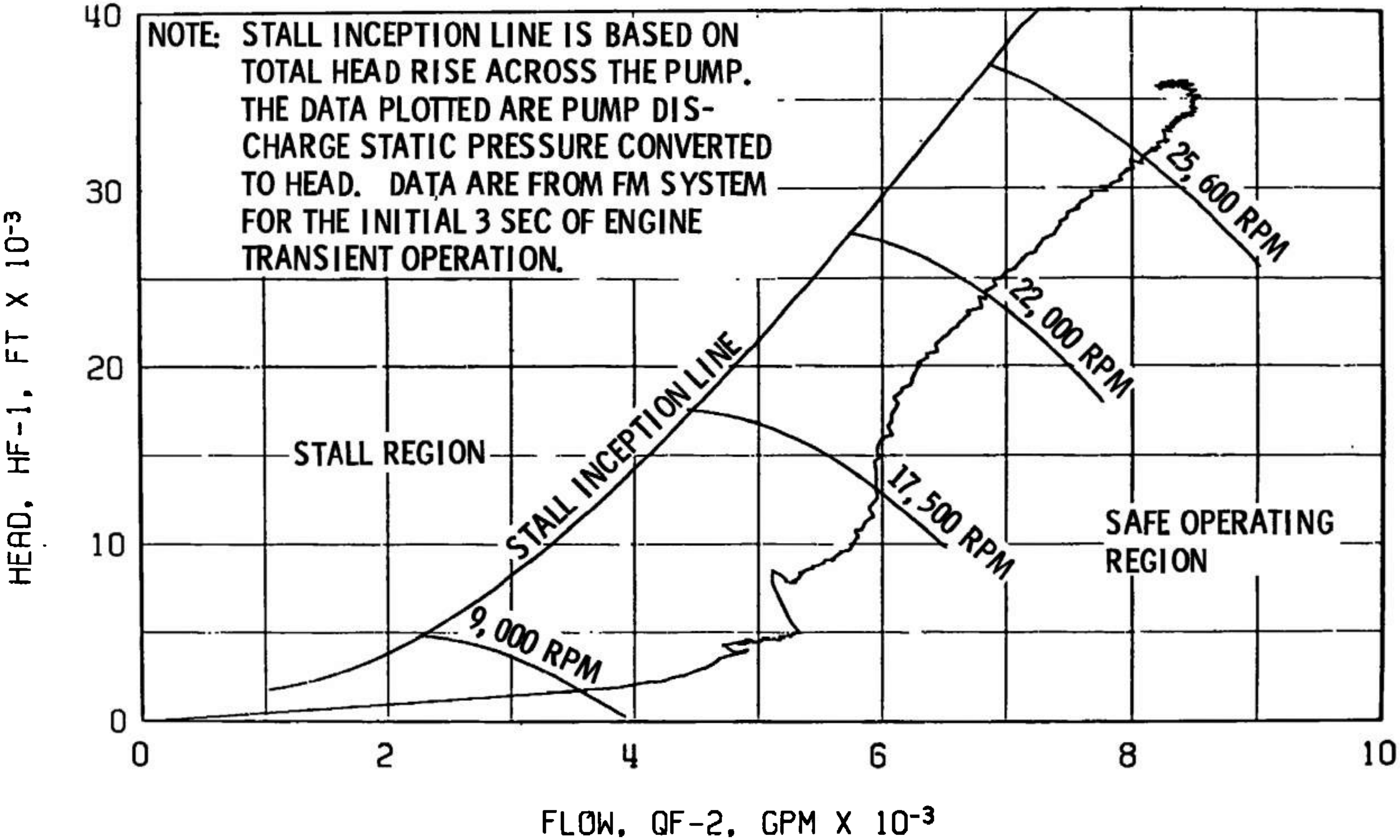
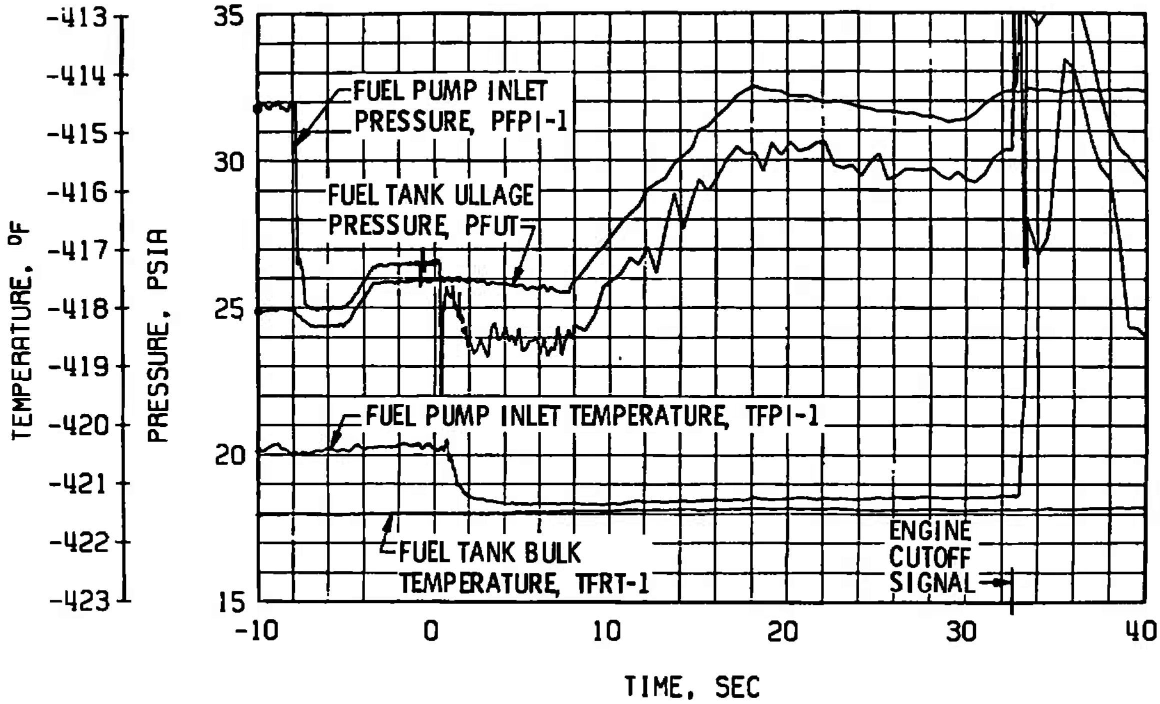
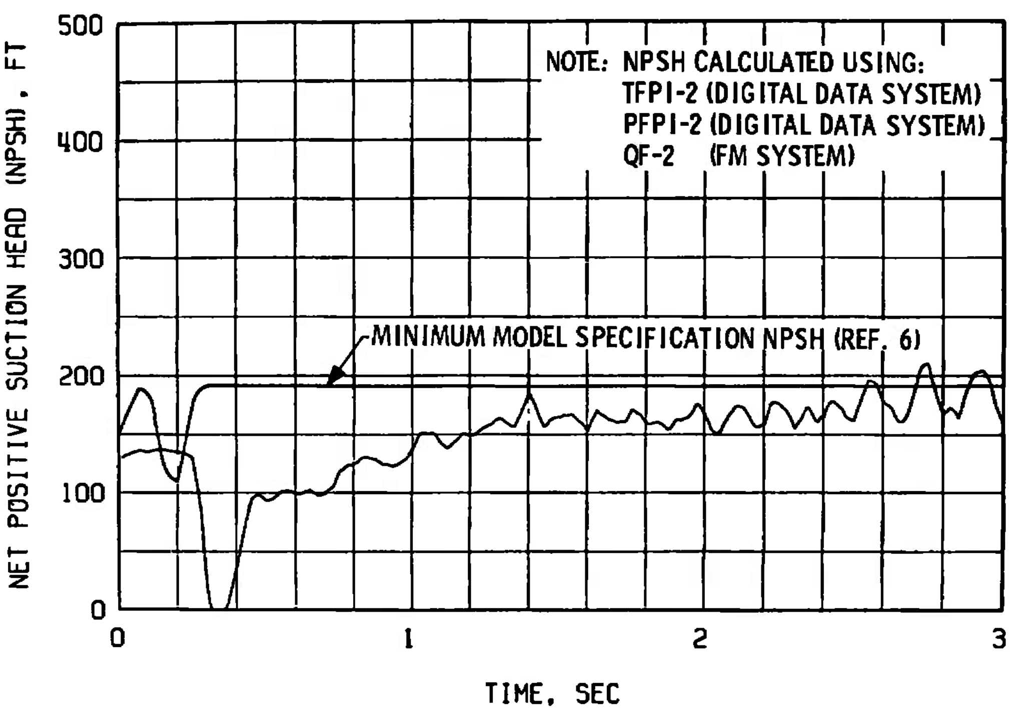



Fig. 48 Fuel Pump Start Transient Performance, Firing 01A

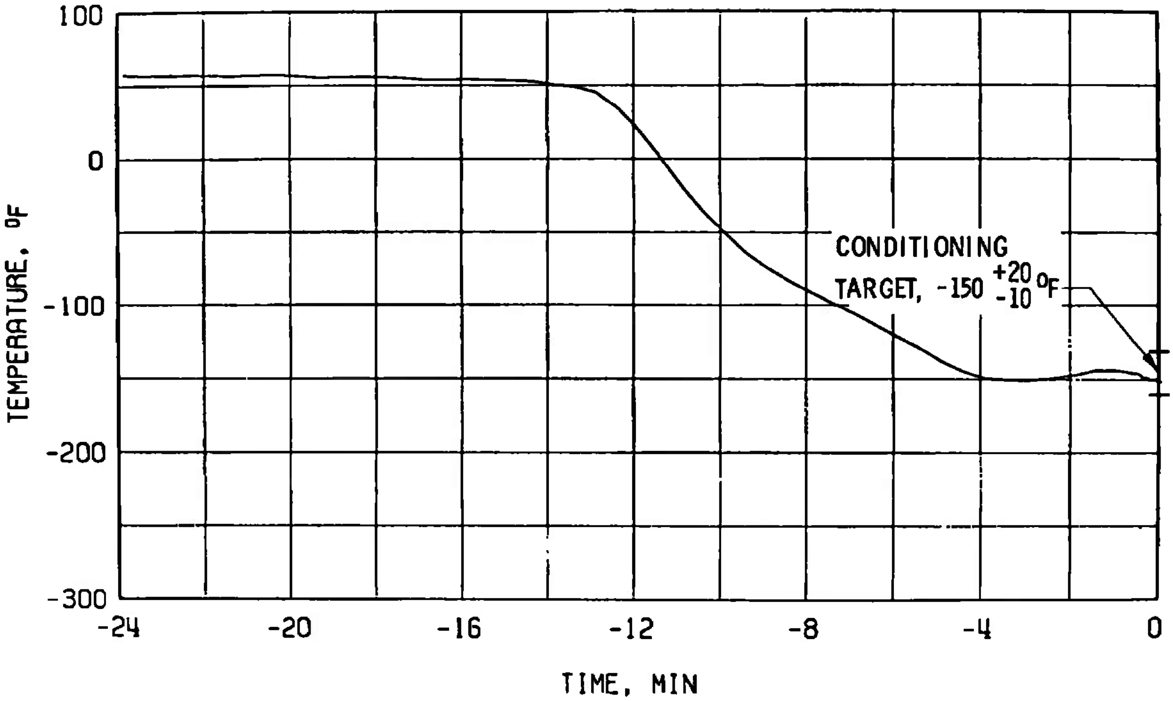



a. Duct Pressure and Temperature Transients

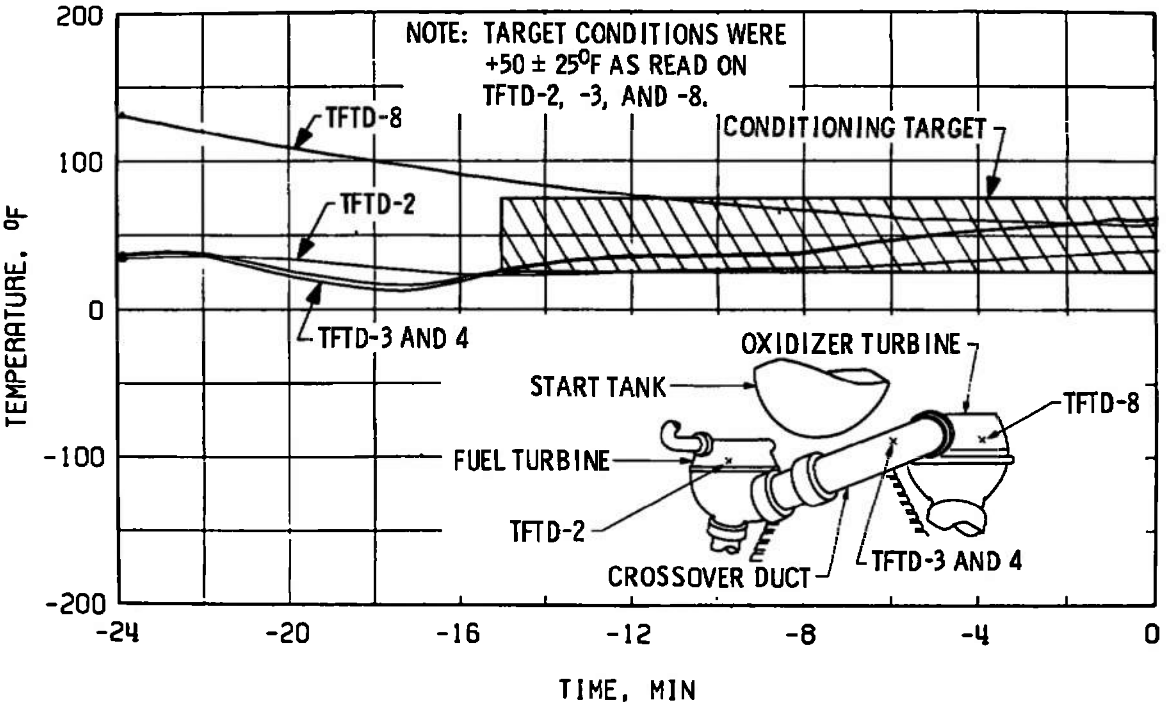



b. Fuel Pump NPSH during Start Transient, Firing 01A

Fig. 49 Fuel Low Pressure Duct Performance, Firing 01A

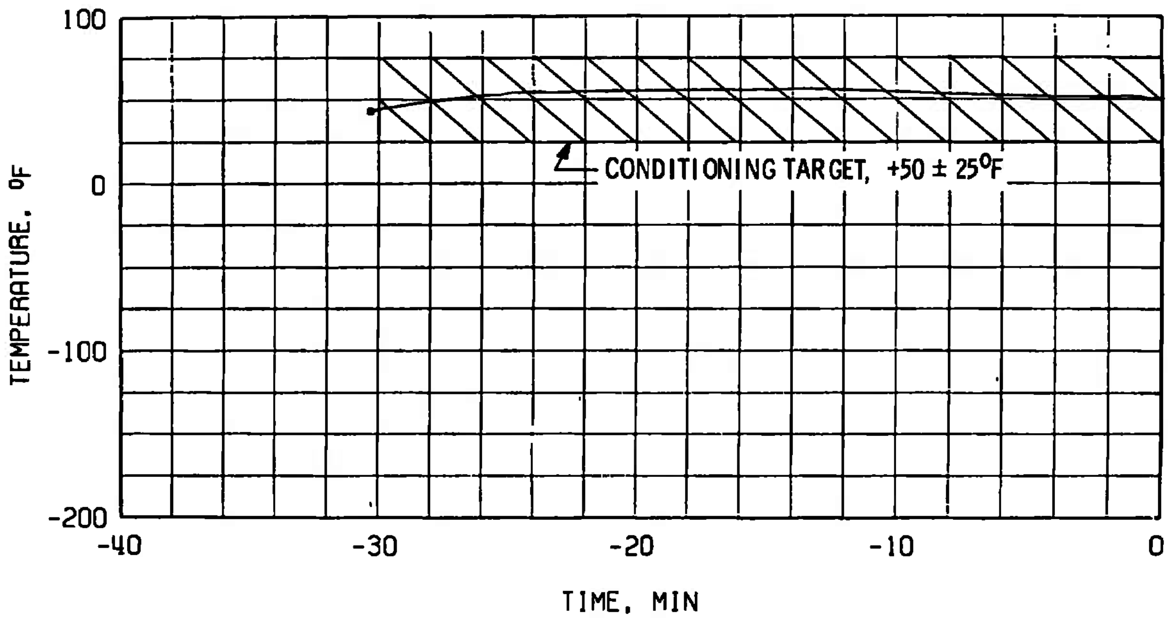



a. Thrust Chamber, TTC-1P

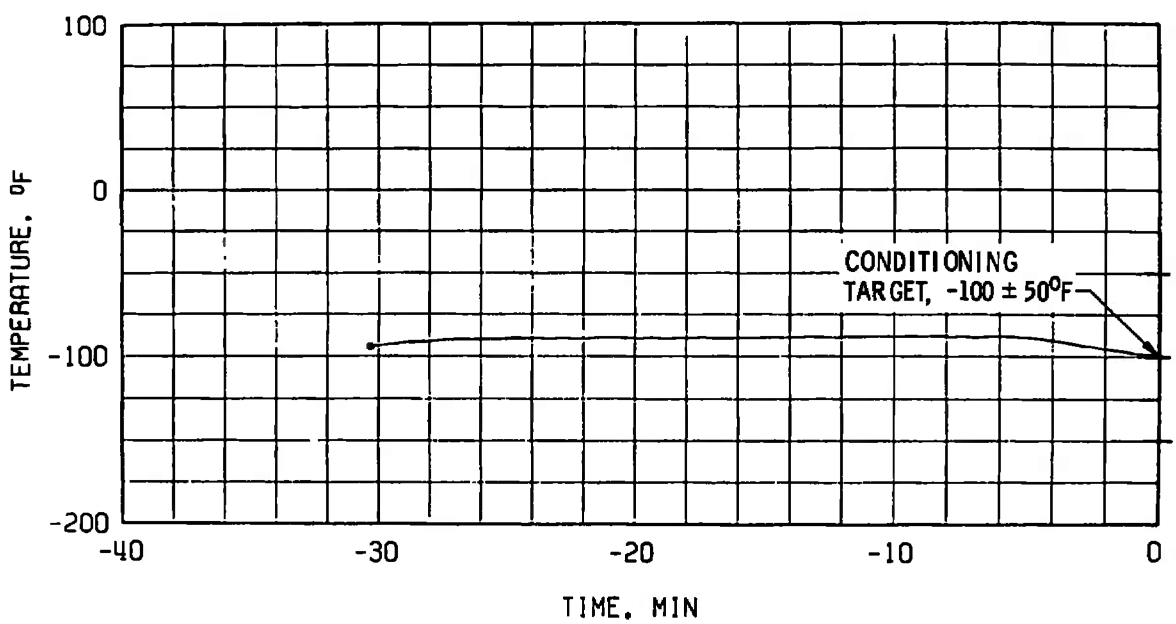



b. Crossover Duct, TFTD

Fig. 50 Thermal Conditioning History of Engine Components, Firing 01B




c. Start Tank Discharge Valve, TSTDVOC




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

Fig. 50 Concluded

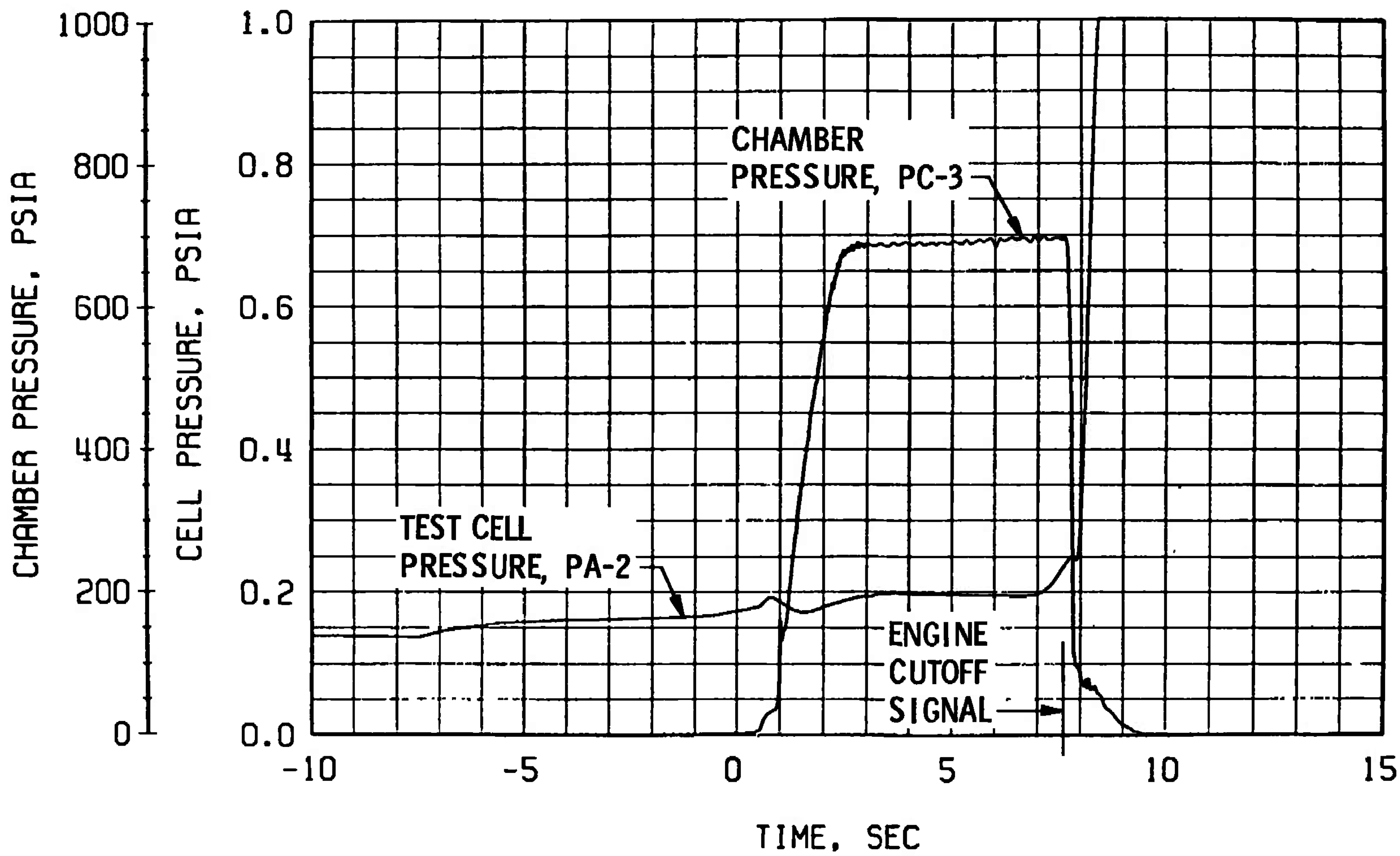
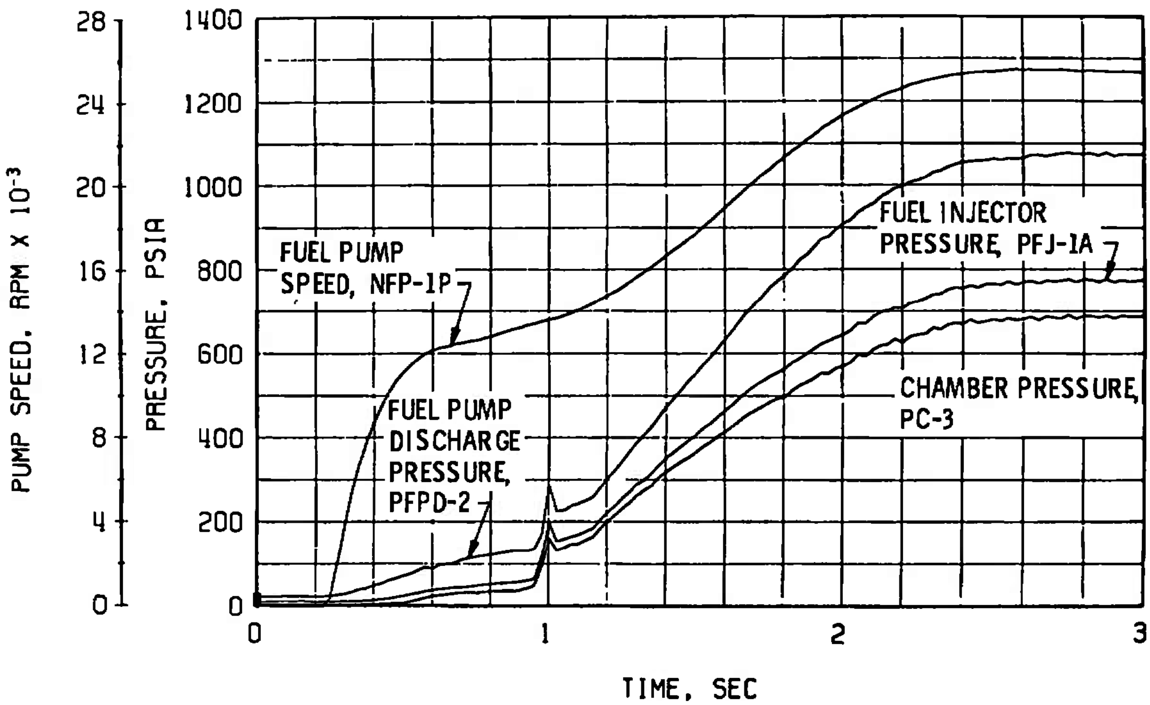
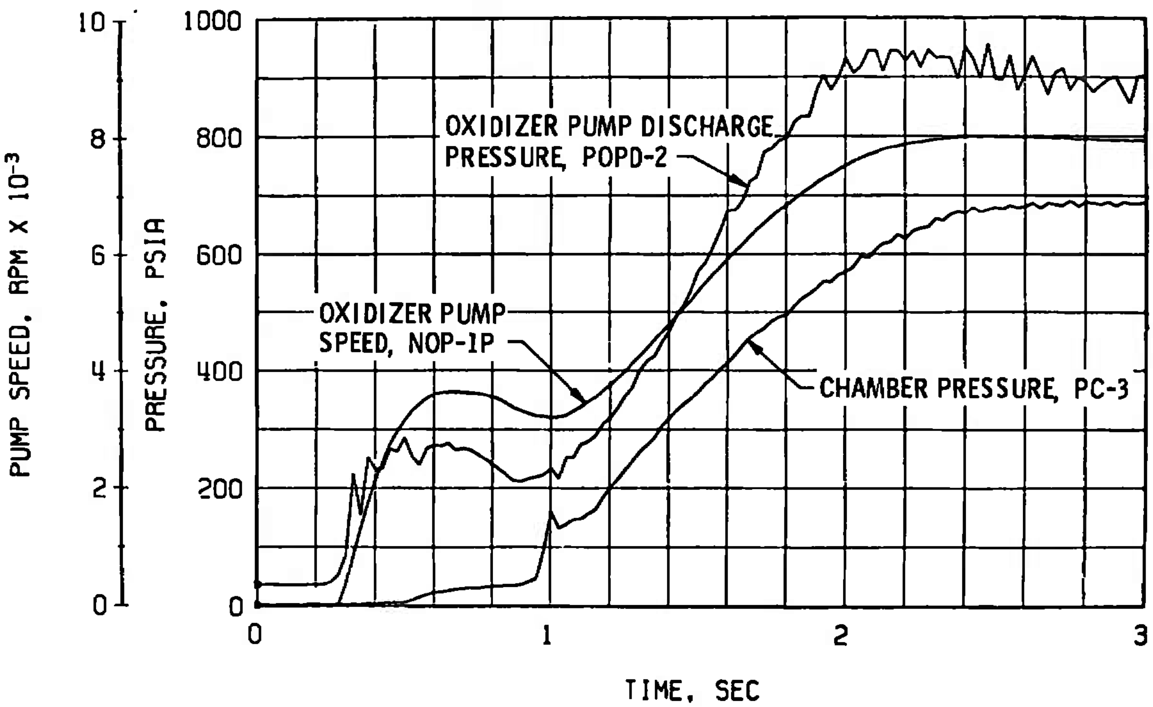



Fig. 51 Engine Ambient and Combustion Chamber Pressures, Firing 01B

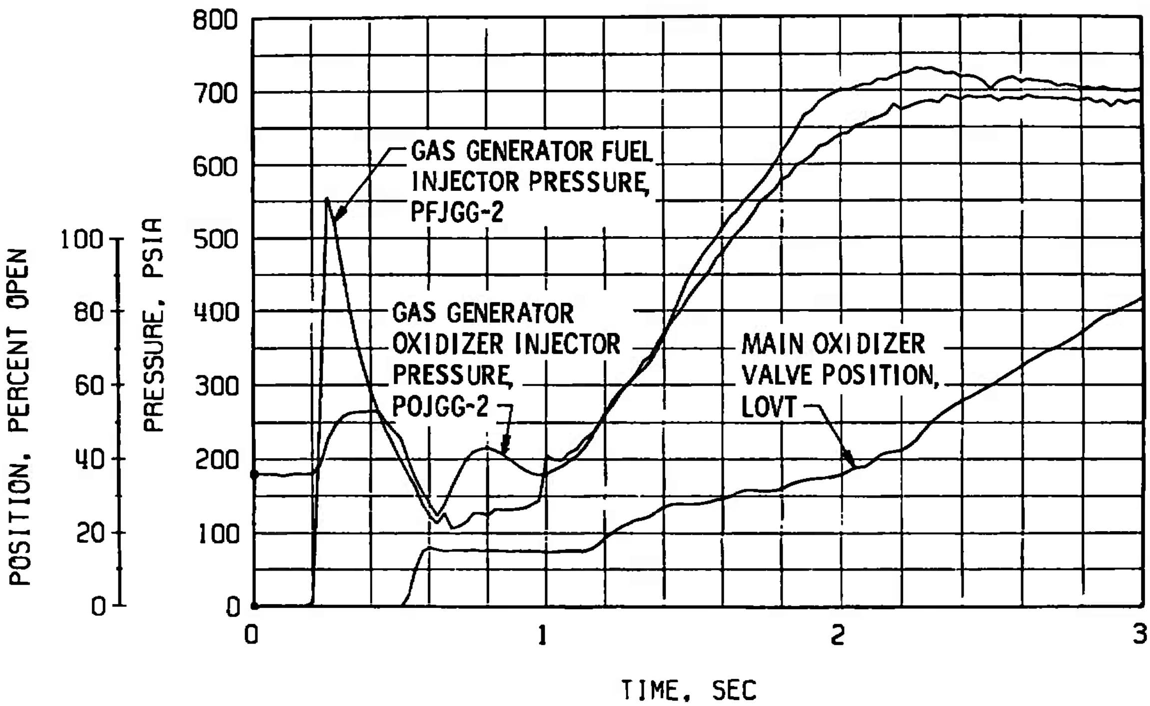



a. Thrust Chamber Fuel System, Start

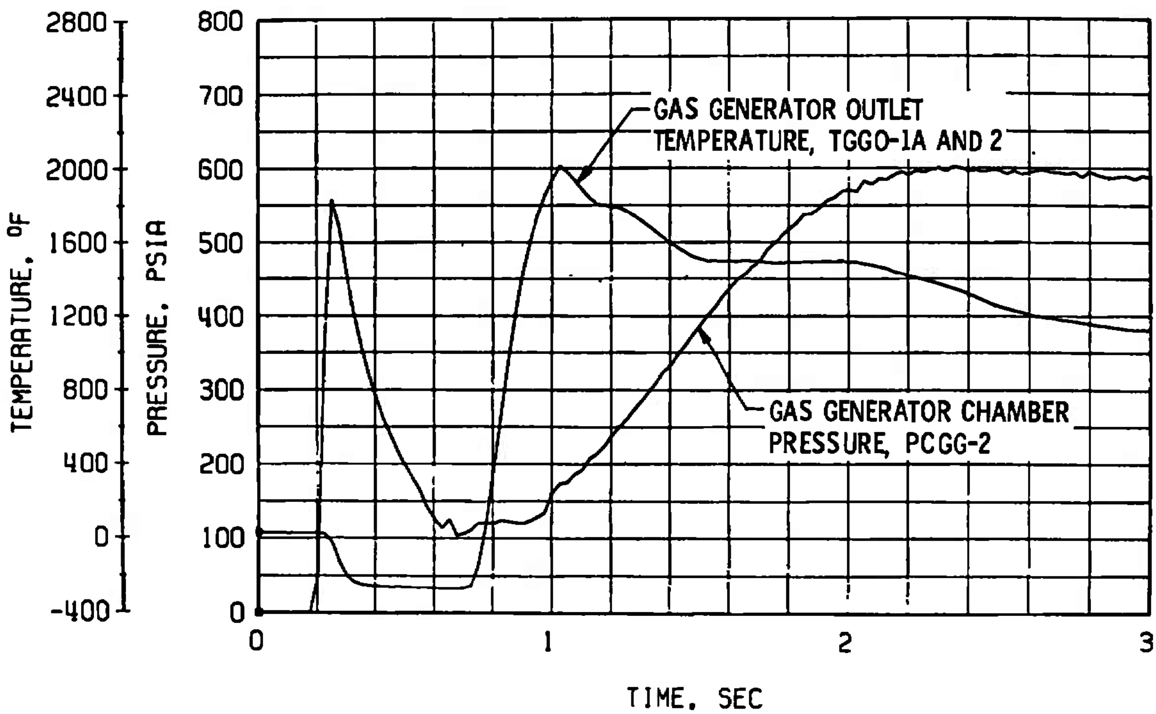



b. Thrust Chamber Oxidizer System, Start

Fig. 52 Engine Transient Operation, Firing 01B

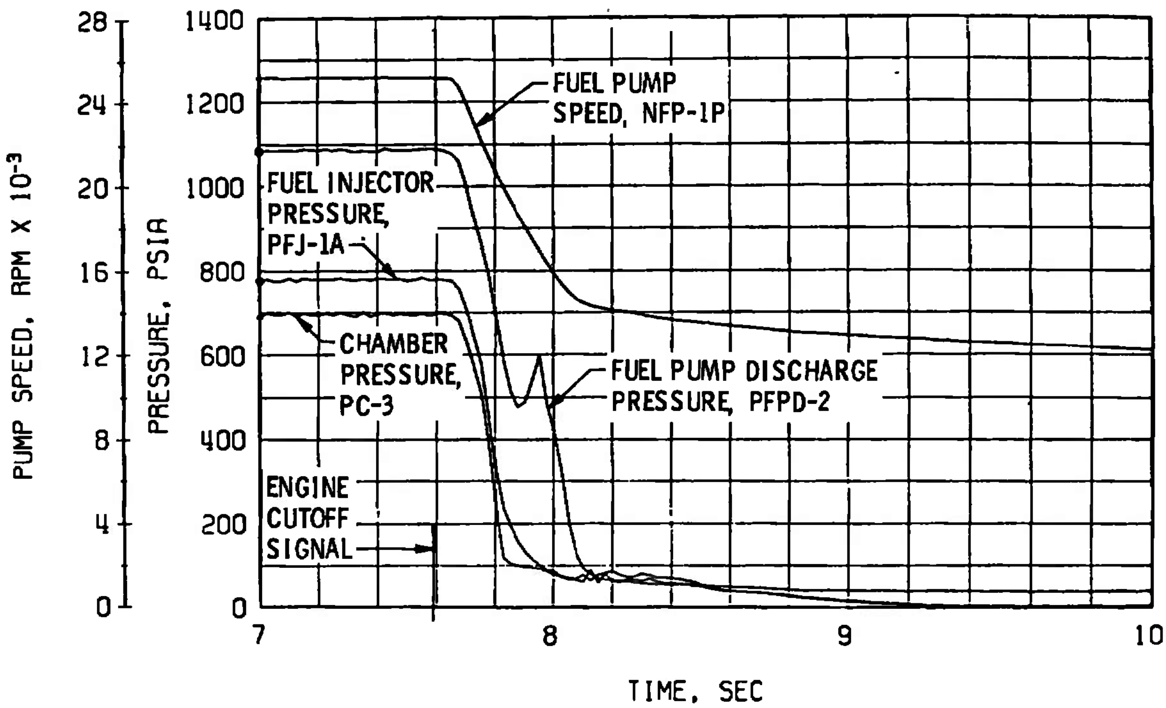



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

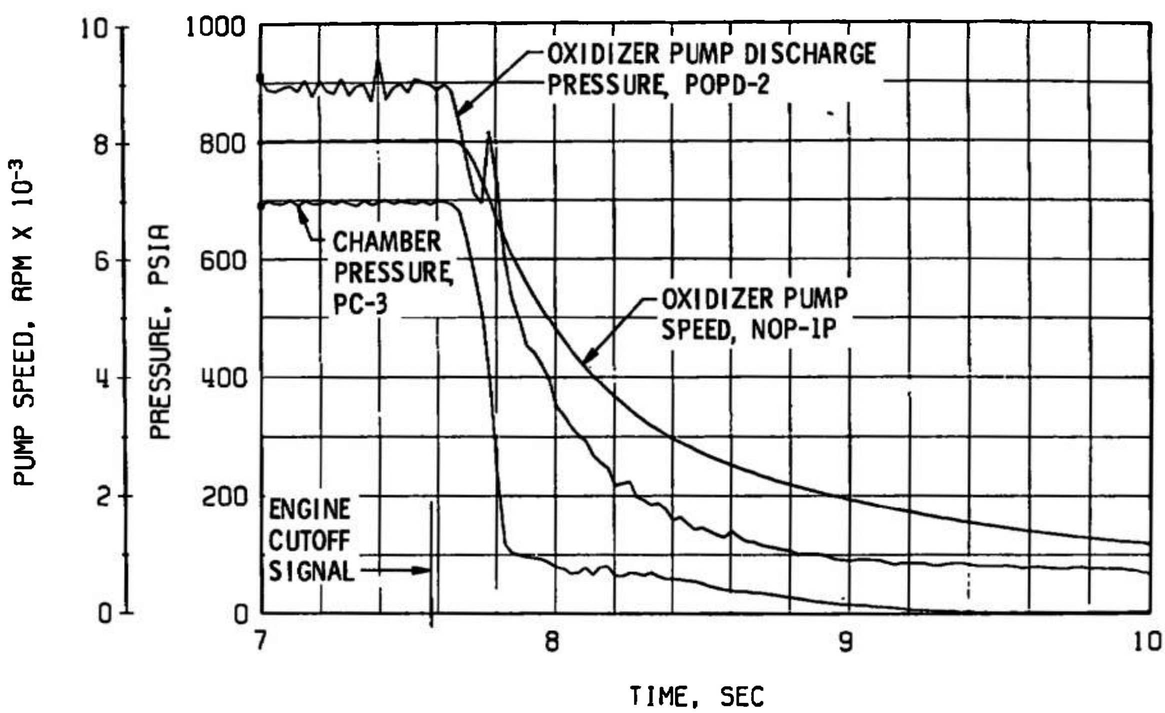



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 52 Continued

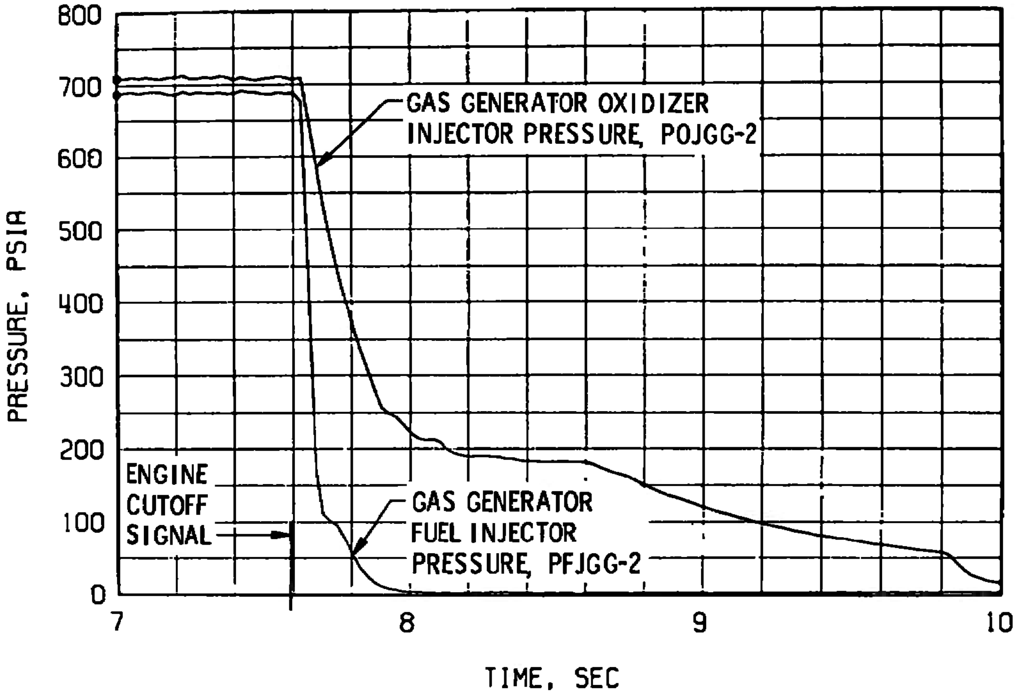



e. **Thrust Chamber Fuel System, Shutdown**

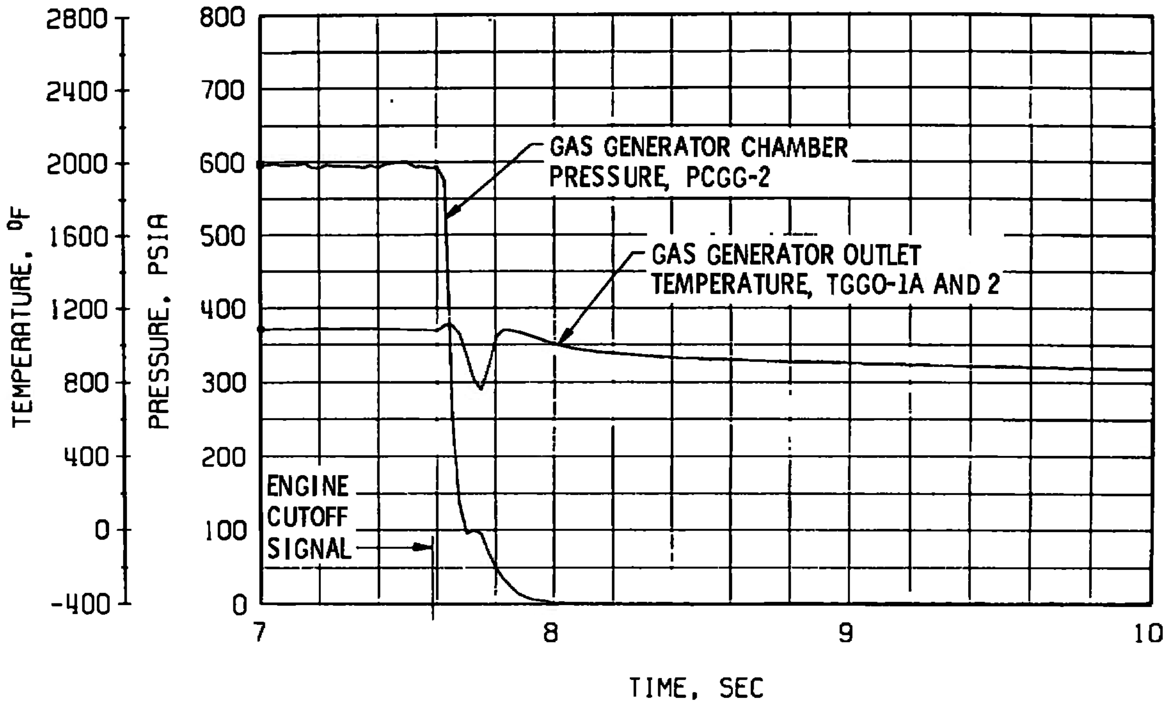



f. **Thrust Chamber Oxidizer System, Shutdown**

**Fig. 52 Continued**




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 52 Concluded

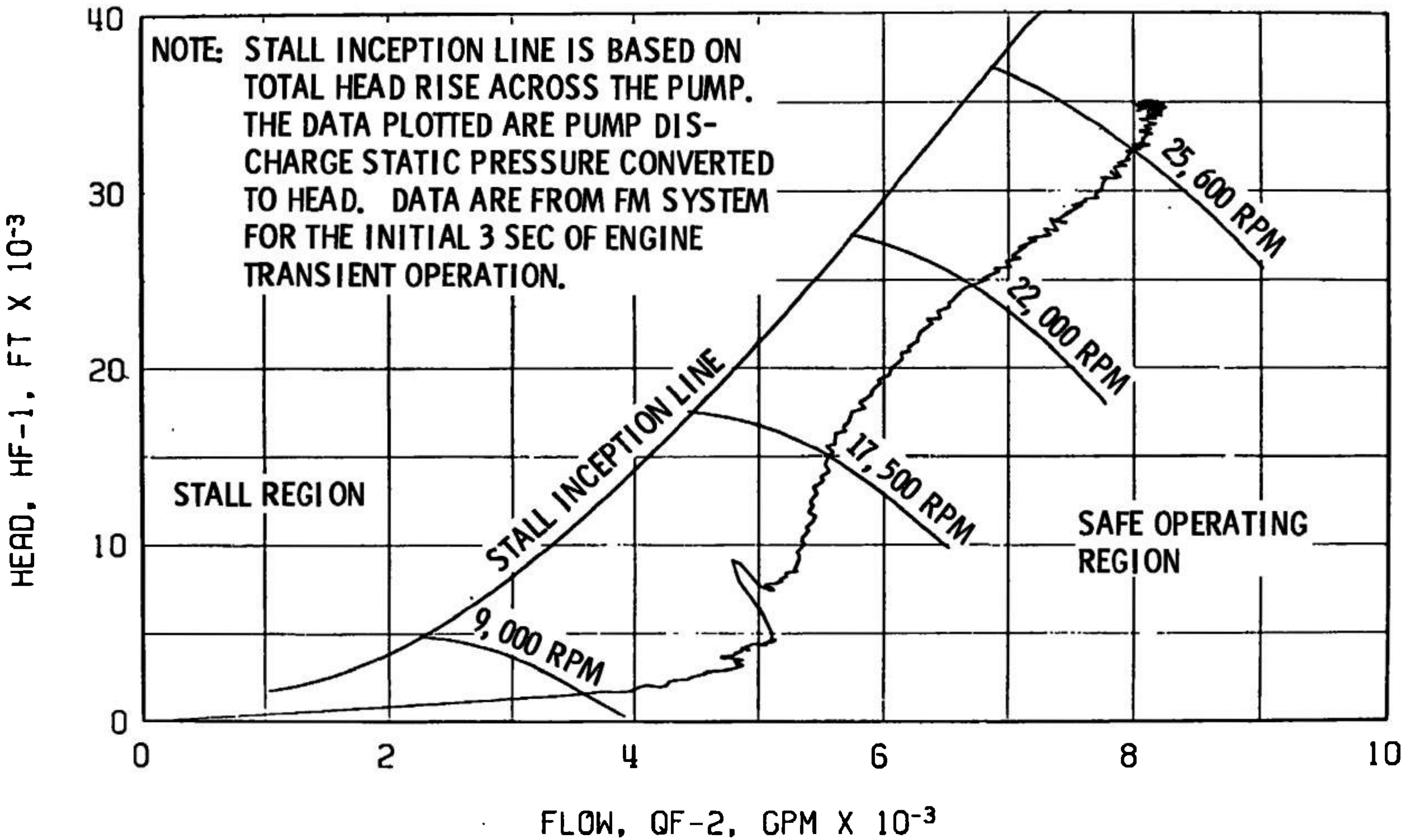
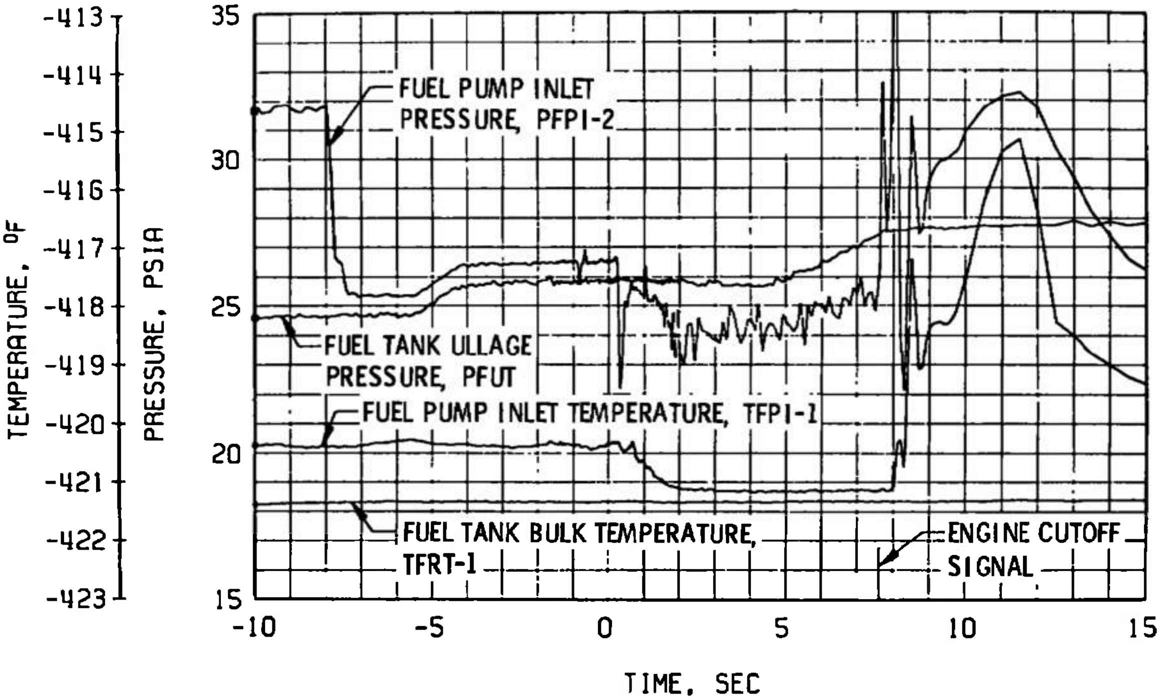
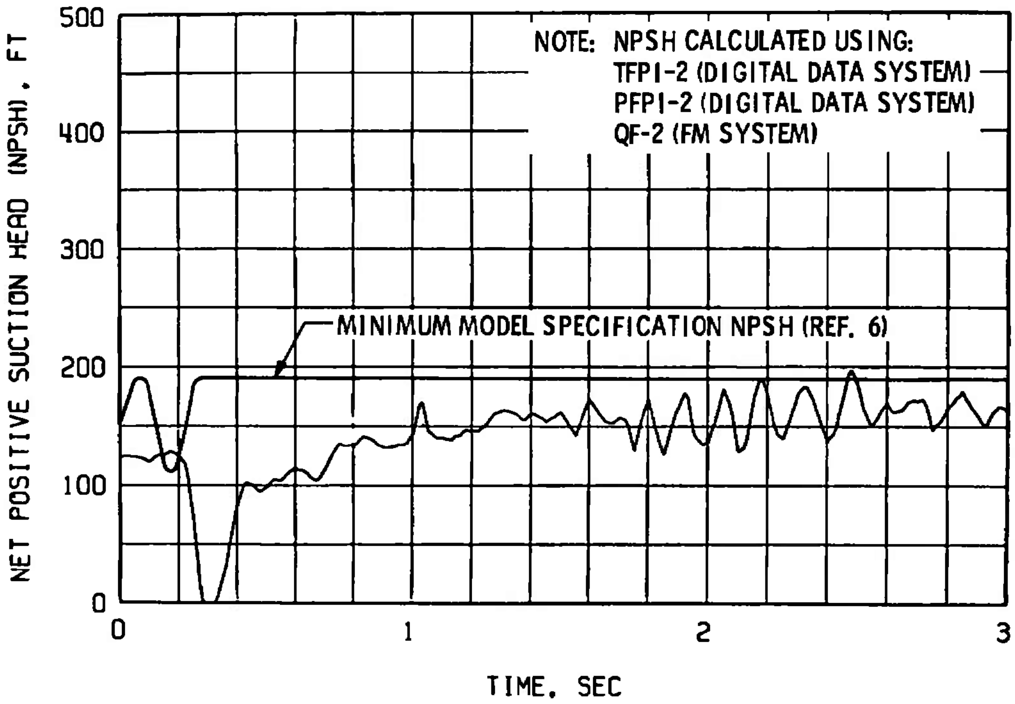



Fig. 53 Fuel Pump Start Transient Performance, Firing 01B

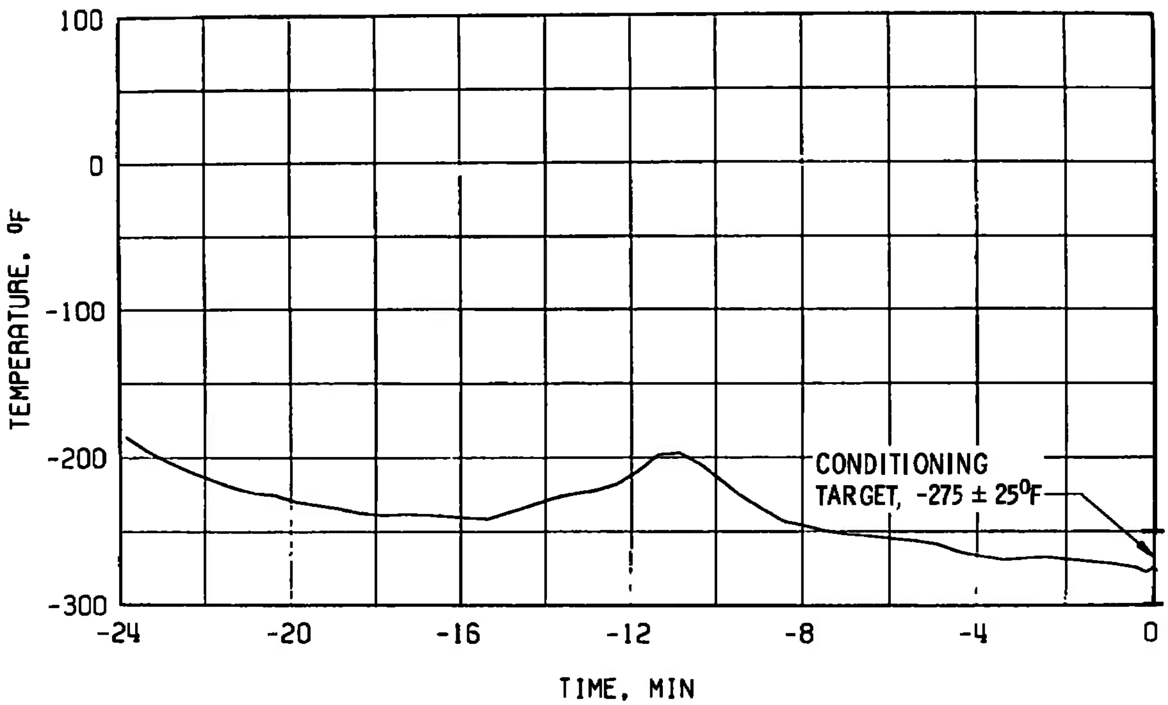



a. Duct Pressure and Temperature Transients

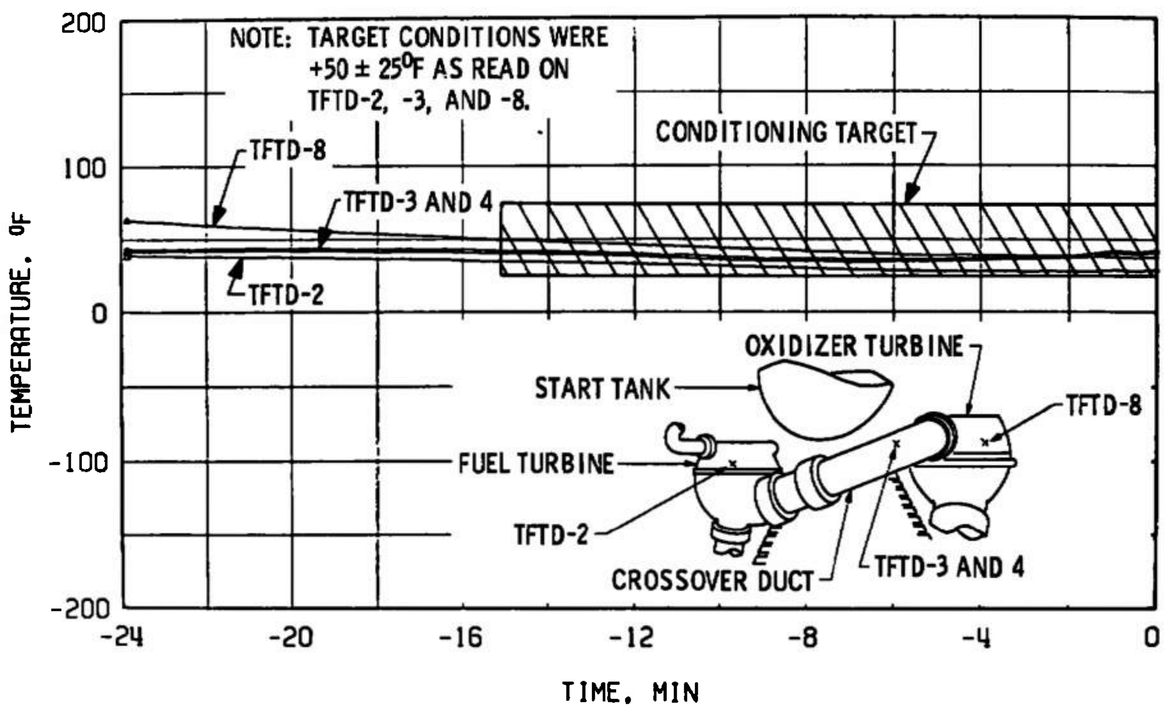



b. Fuel Pump NPSH during Start Transient, Firing 01B

Fig. 54 Fuel Low Pressure Duct Performance, Firing 01B

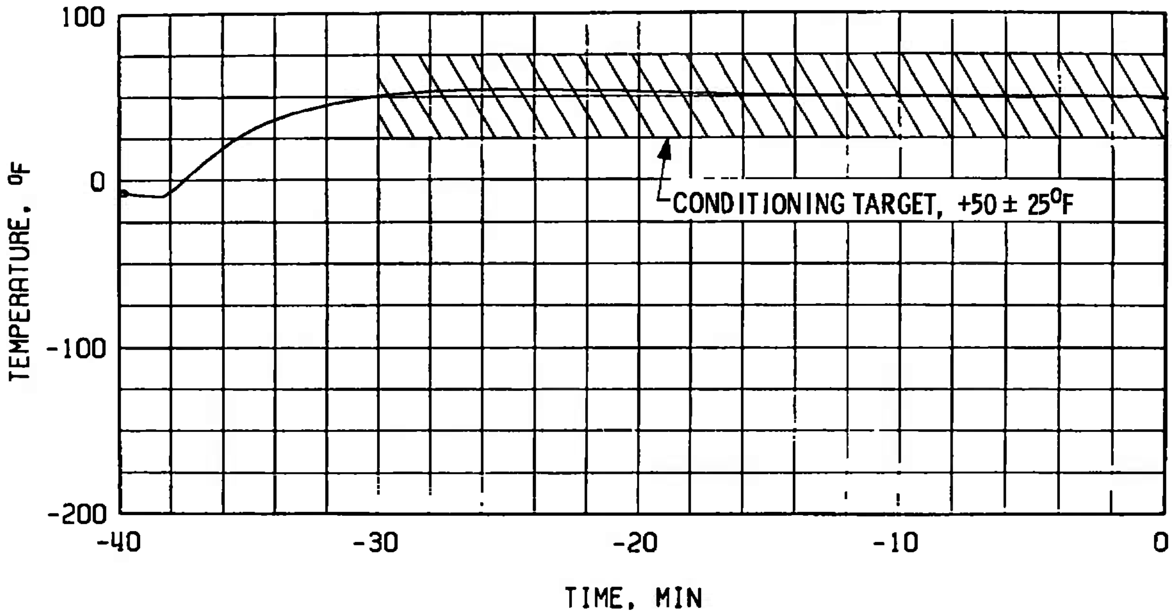



a. Thrust Chamber, TTC-1P

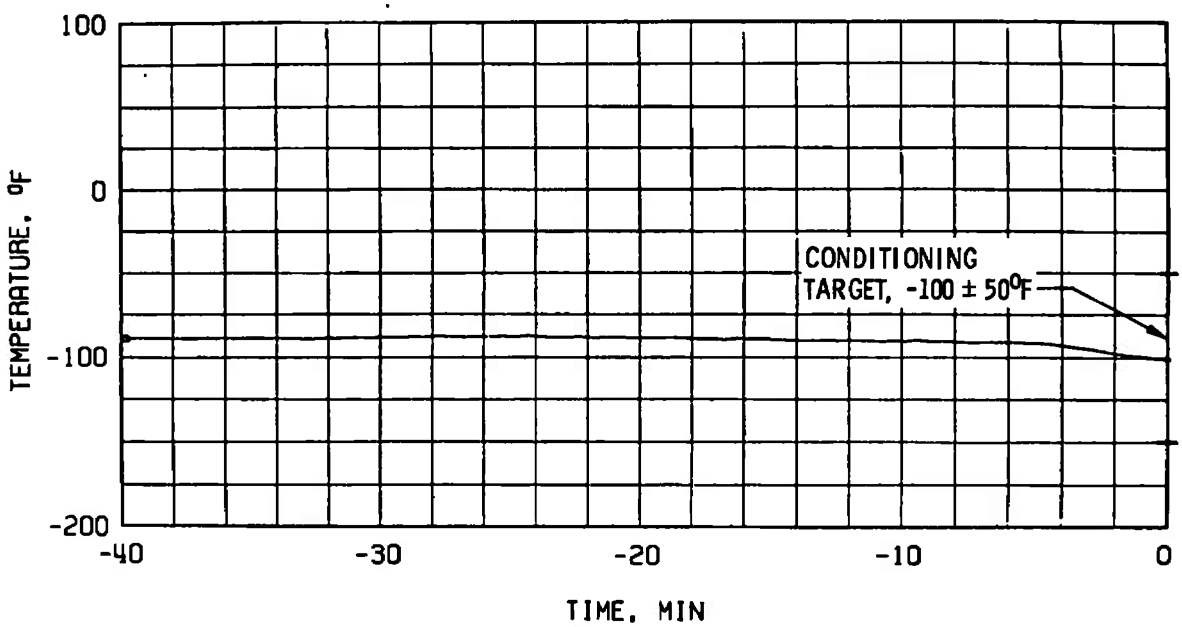



b. Crossover Duct, TFTD

Fig. 55 Thermal Conditioning History of Engine Components, Firing 01C




c. Start Tank Discharge Valve, TSTDVOC




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

Fig. 55 Concluded

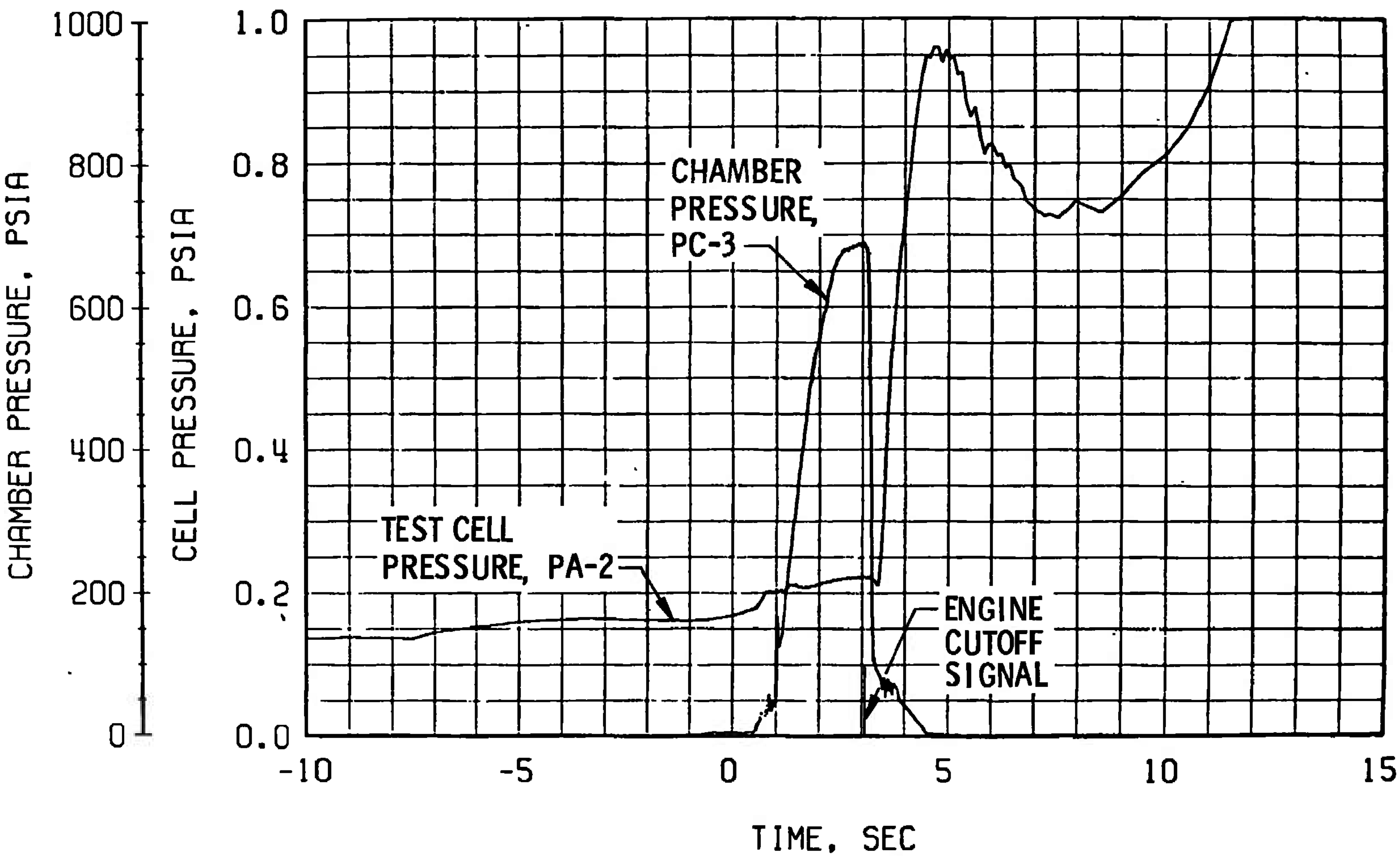
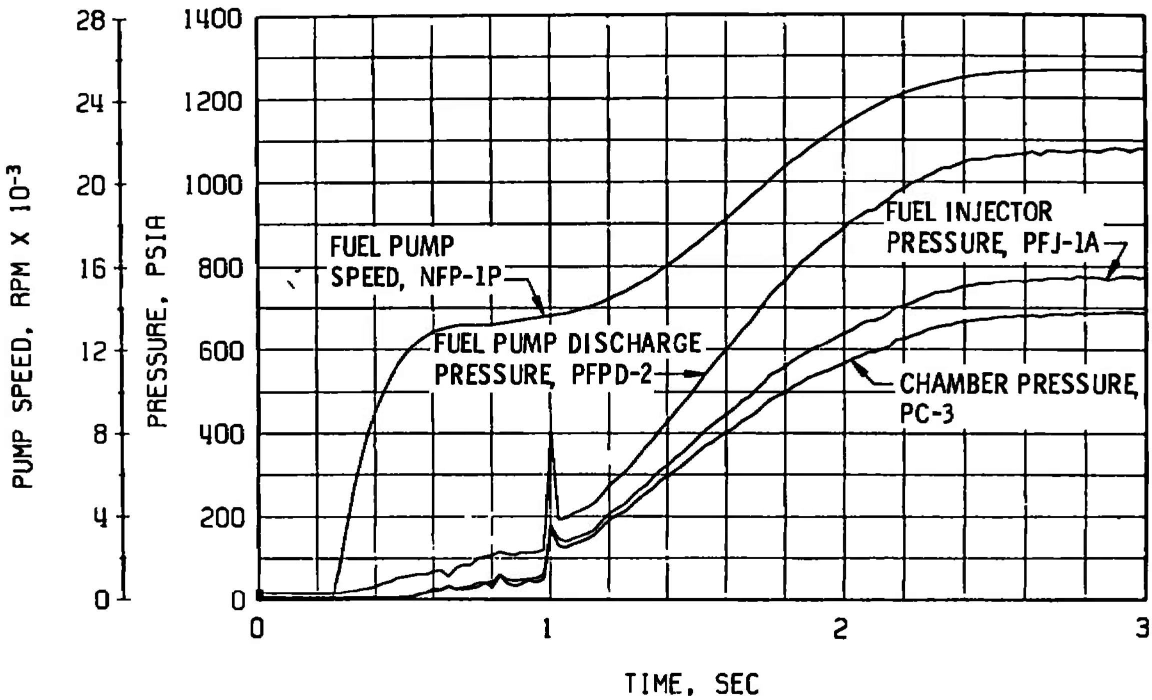
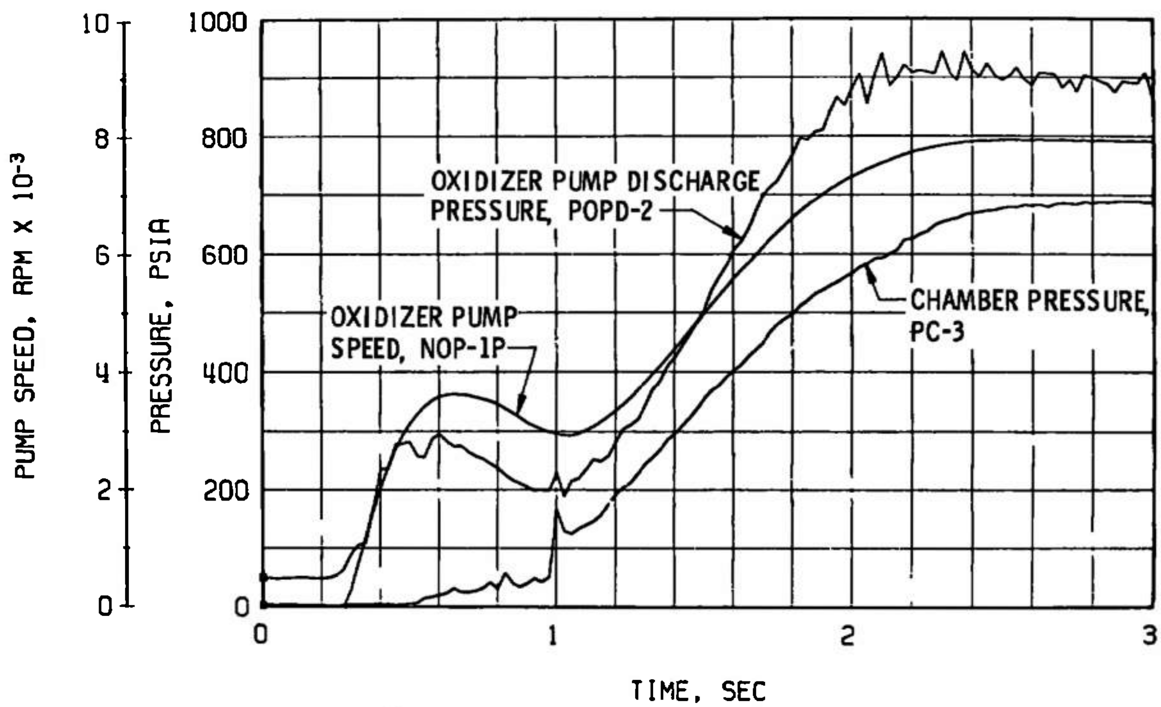



Fig. 56 Engine Ambient and Combustion Chamber Pressures, Firing 01C

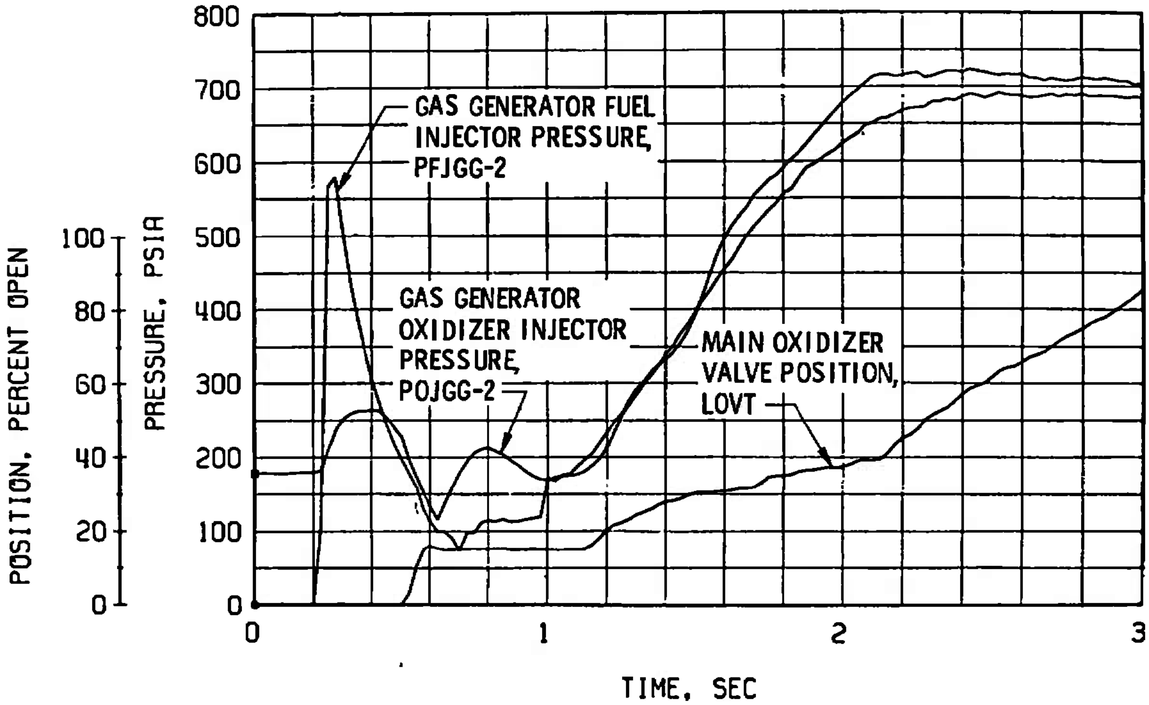



a. Thrust Chamber Fuel System, Start

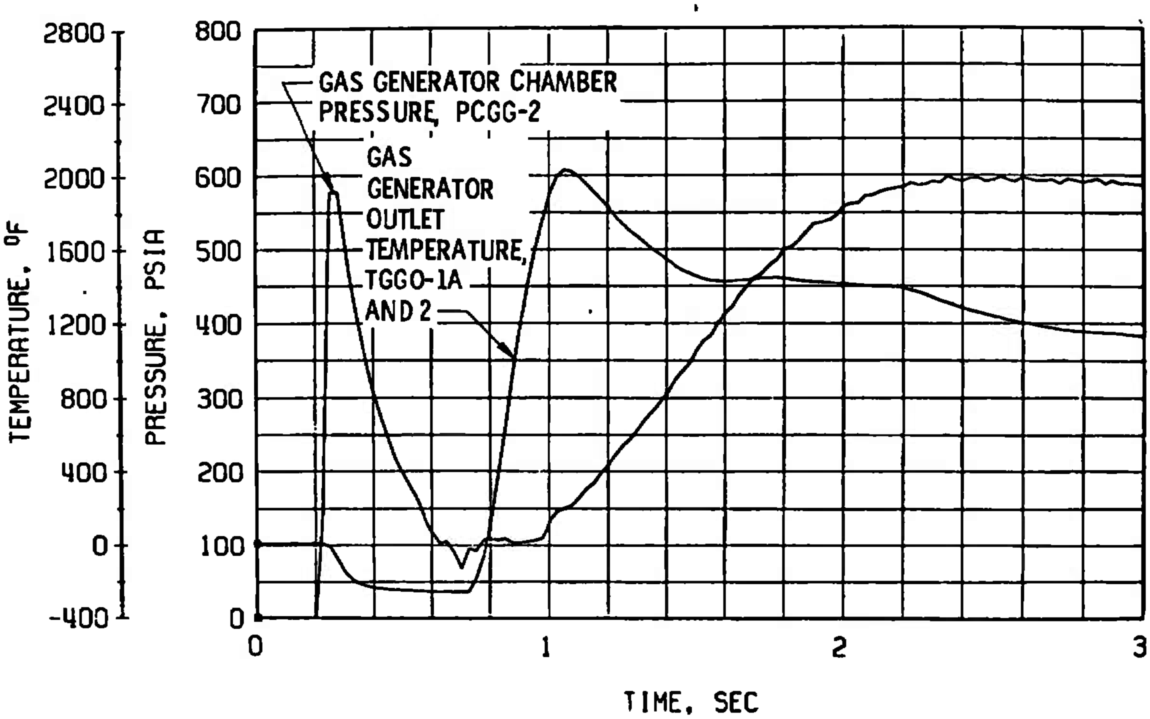



b. Thrust Chamber Oxidizer System, Start

Fig. 57 Engine Transient Operation, Firing 01C

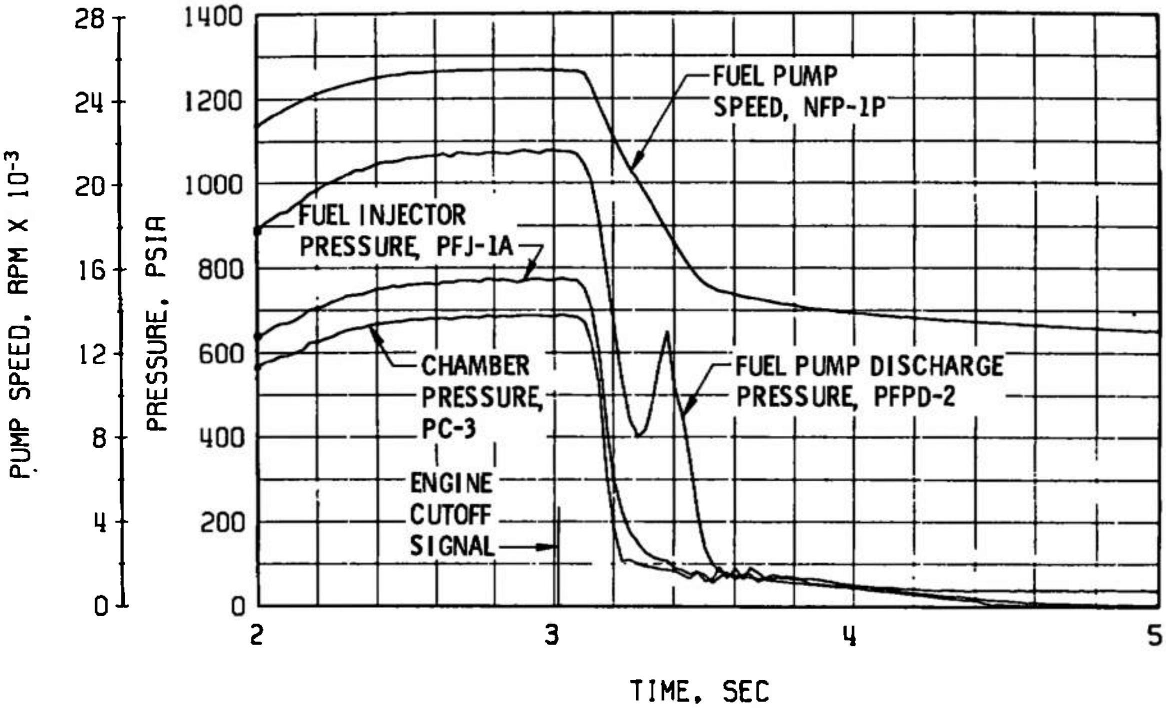



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

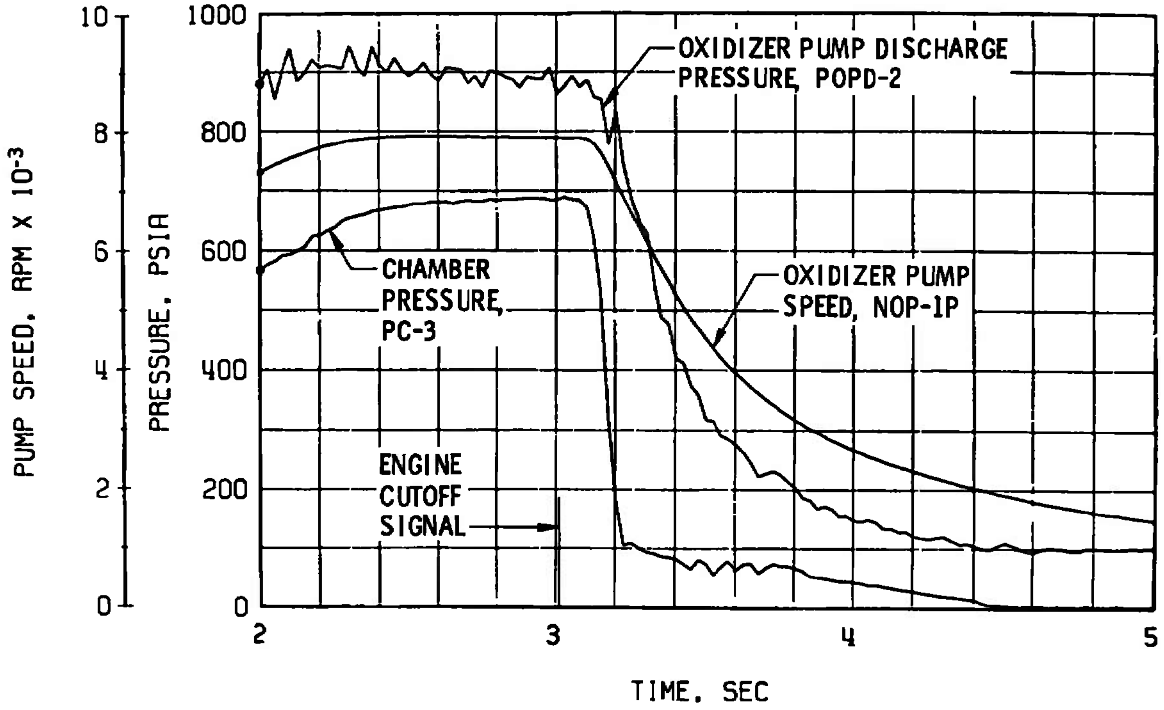



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 57 Continued

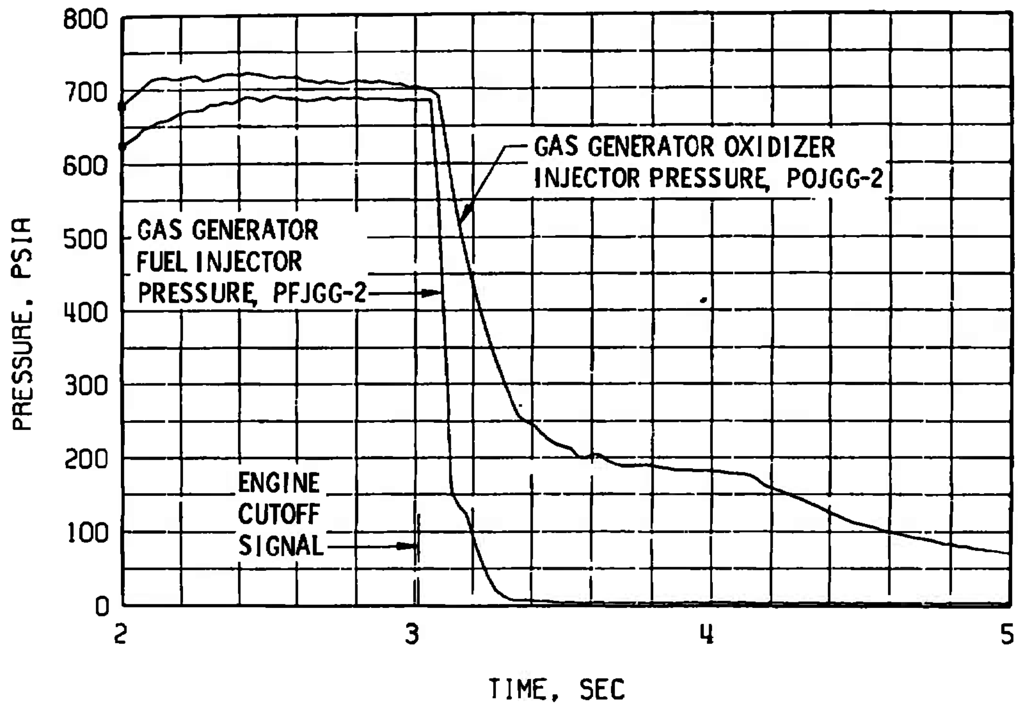



e. Thrust Chamber Fuel System, Shutdown

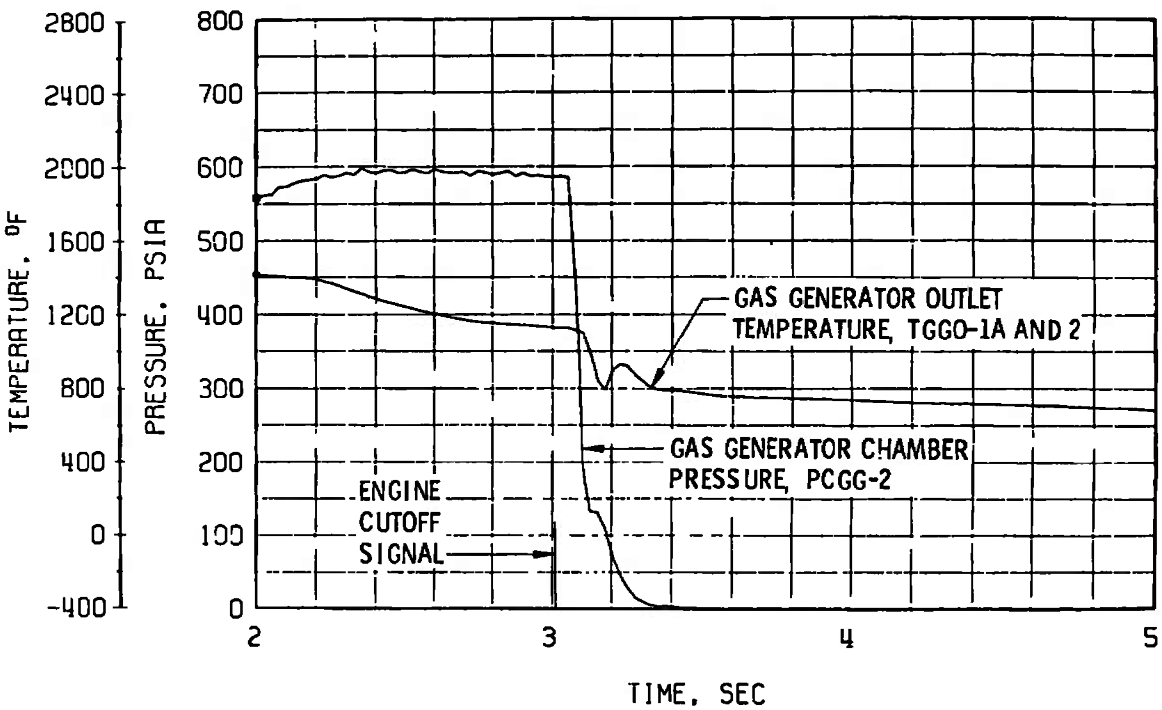



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 57 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 57 Concluded

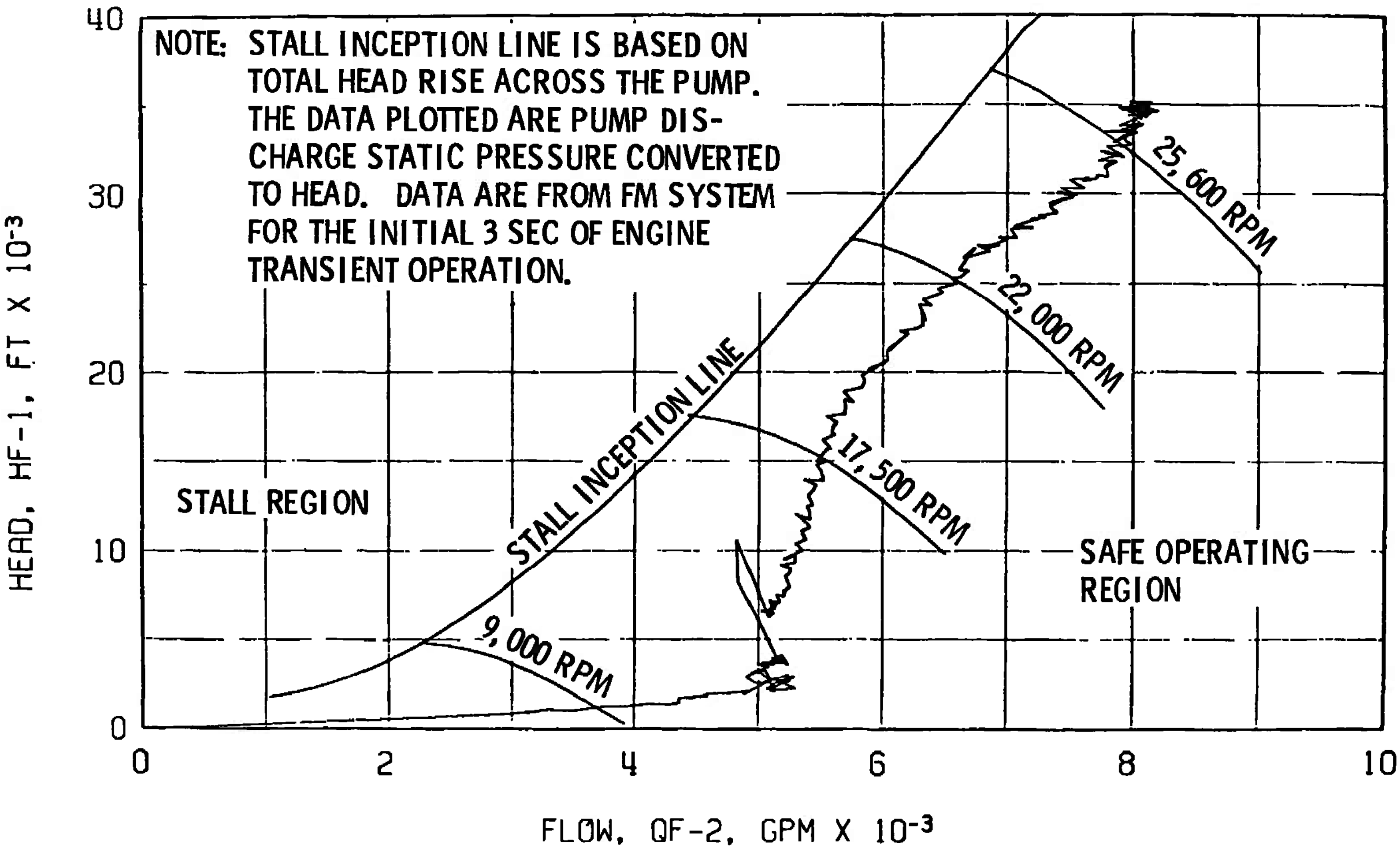
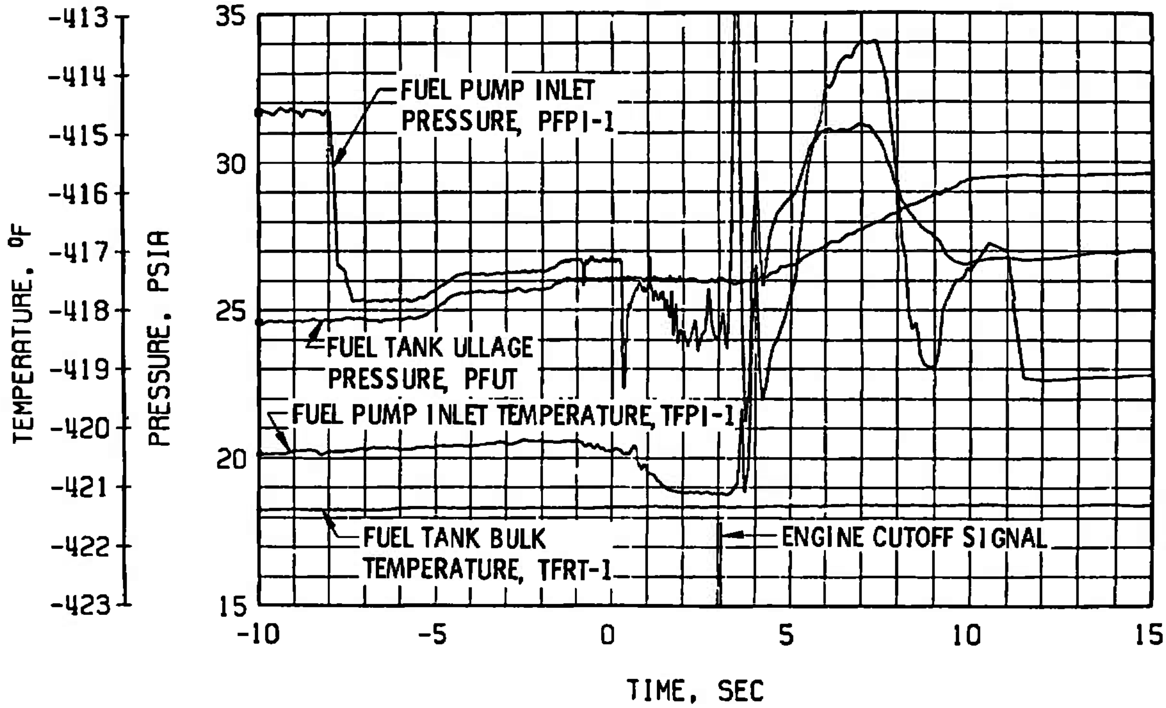
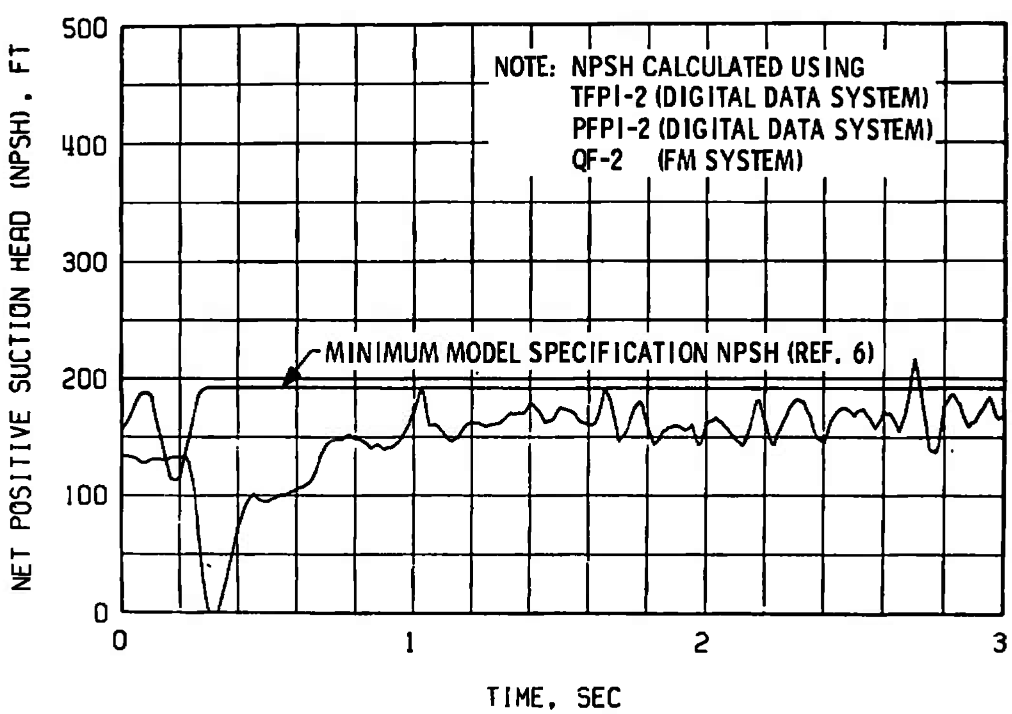



Fig. 58 Fuel Pump Start Transient Performance, Firing 01C

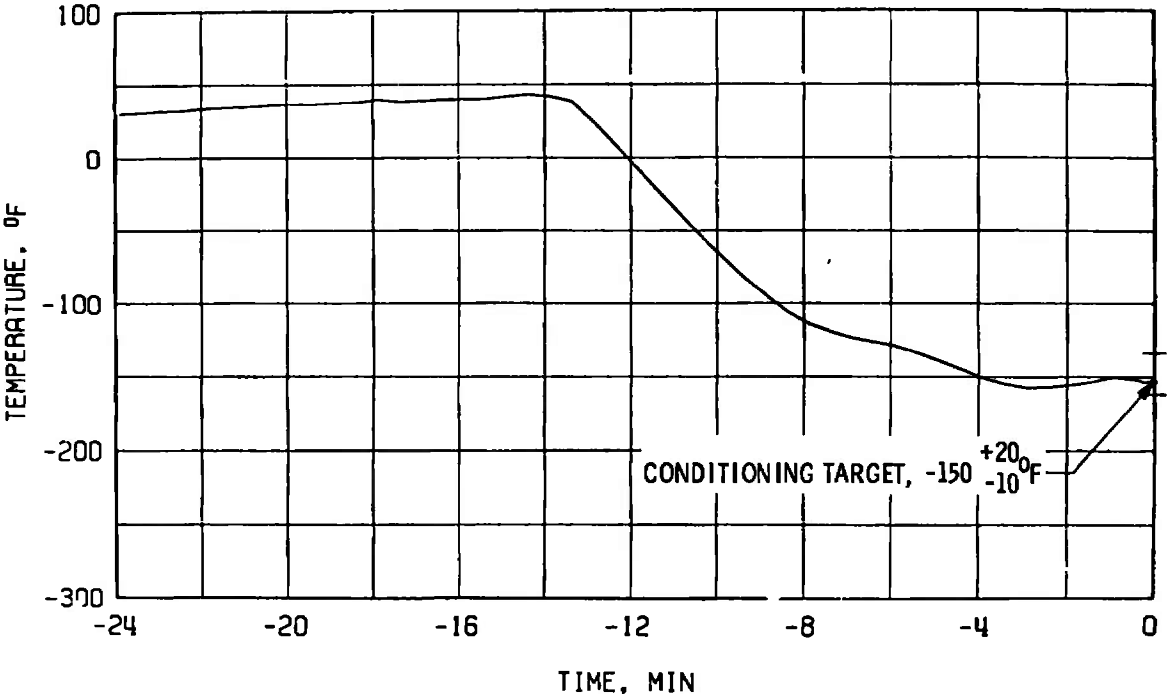



a. Duct Pressure and Temperature Transients

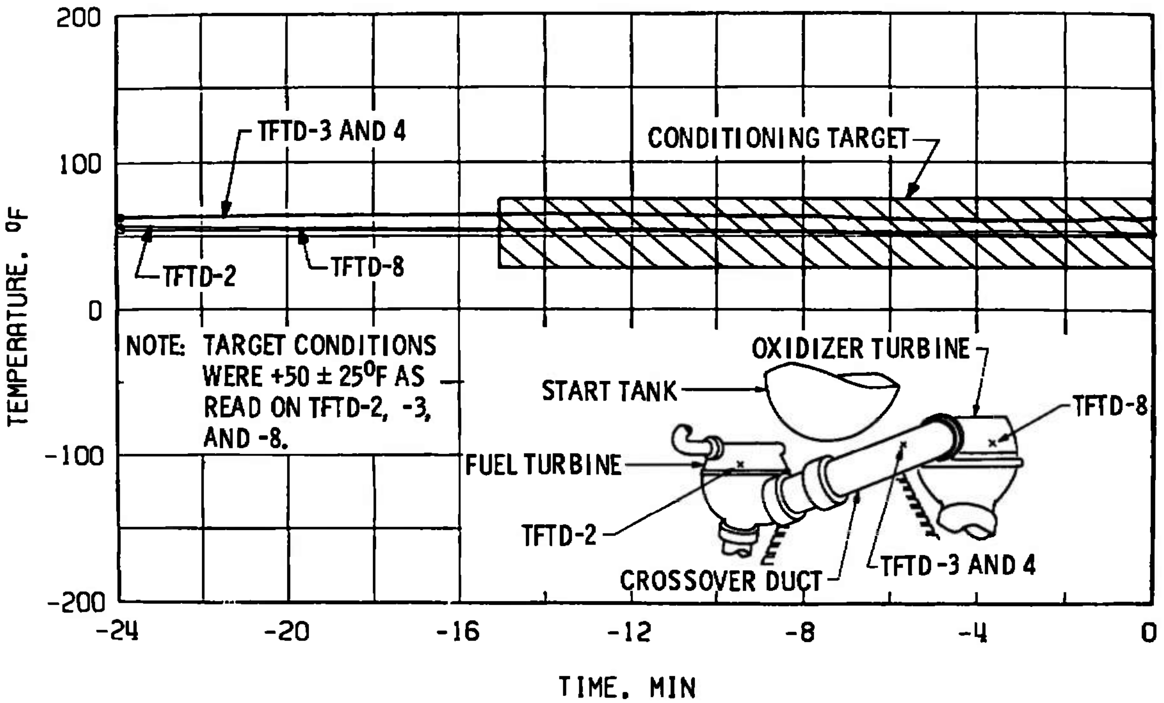



b. Fuel Pump NPSH during Start Transient, Firing 01C

Fig. 59 Fuel Low Pressure Duct Performance, Firing 01C

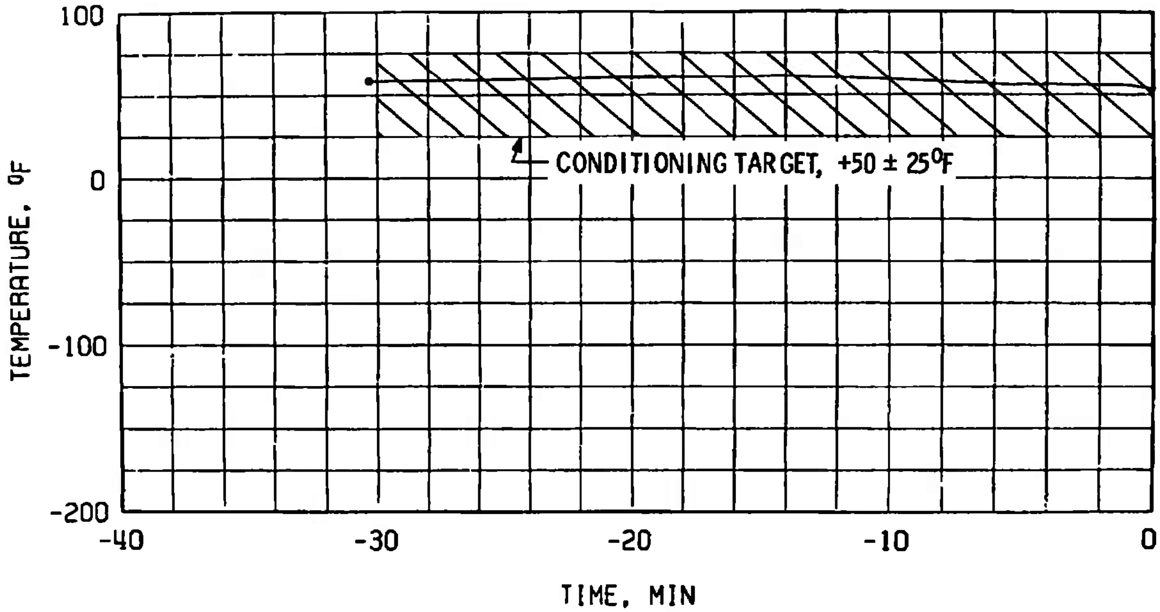



a. Thrust Chamber, TTC-1P

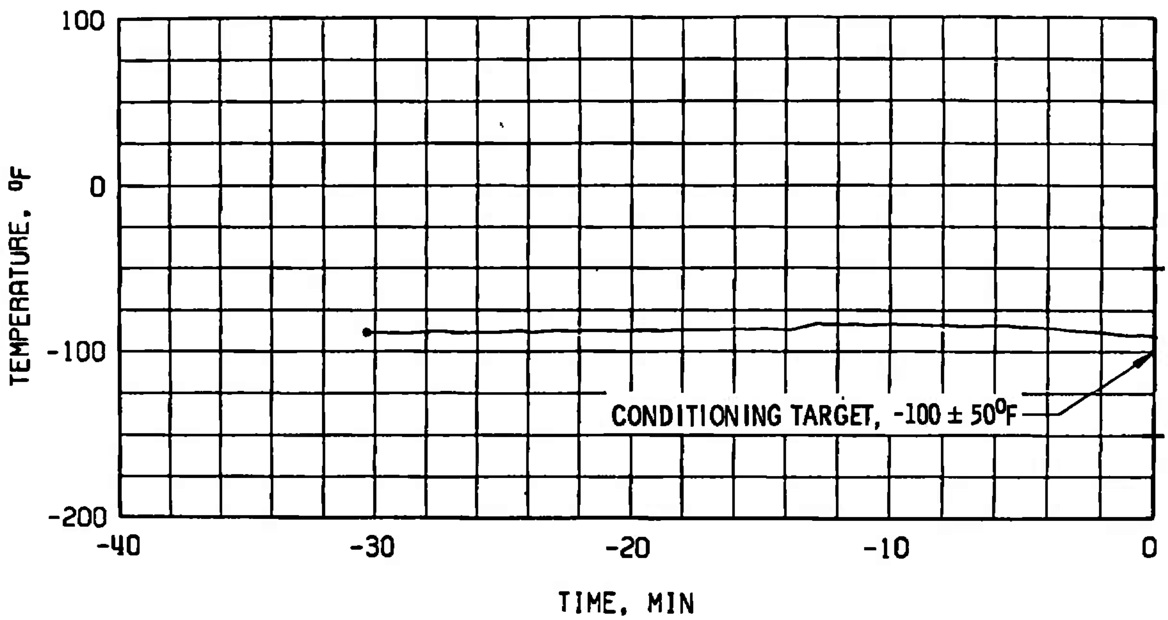



b. Crossover Duct, TFTD

Fig. 60 Thermal Conditioning History of Engine Components, Firing 01D




c. Start Tank Discharge Valve, TSTDVOC




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

Fig. 60 Concluded

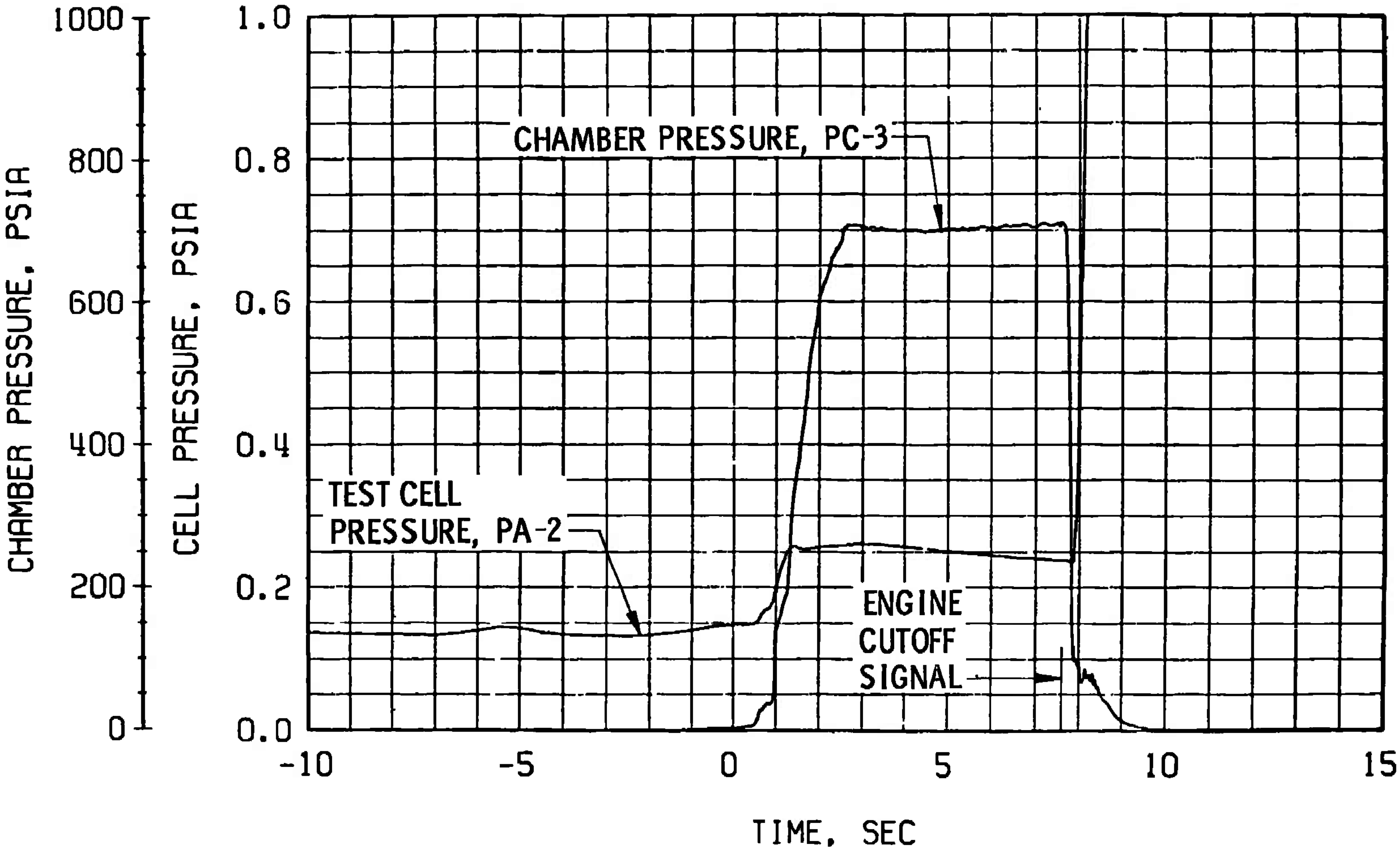
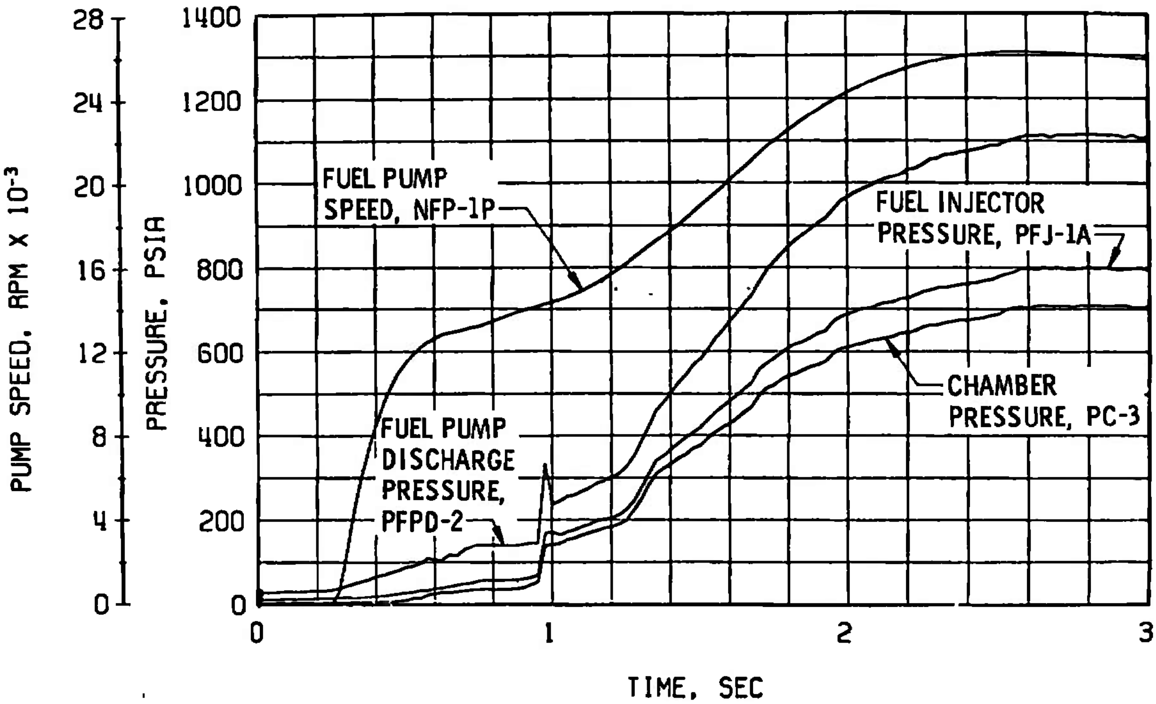
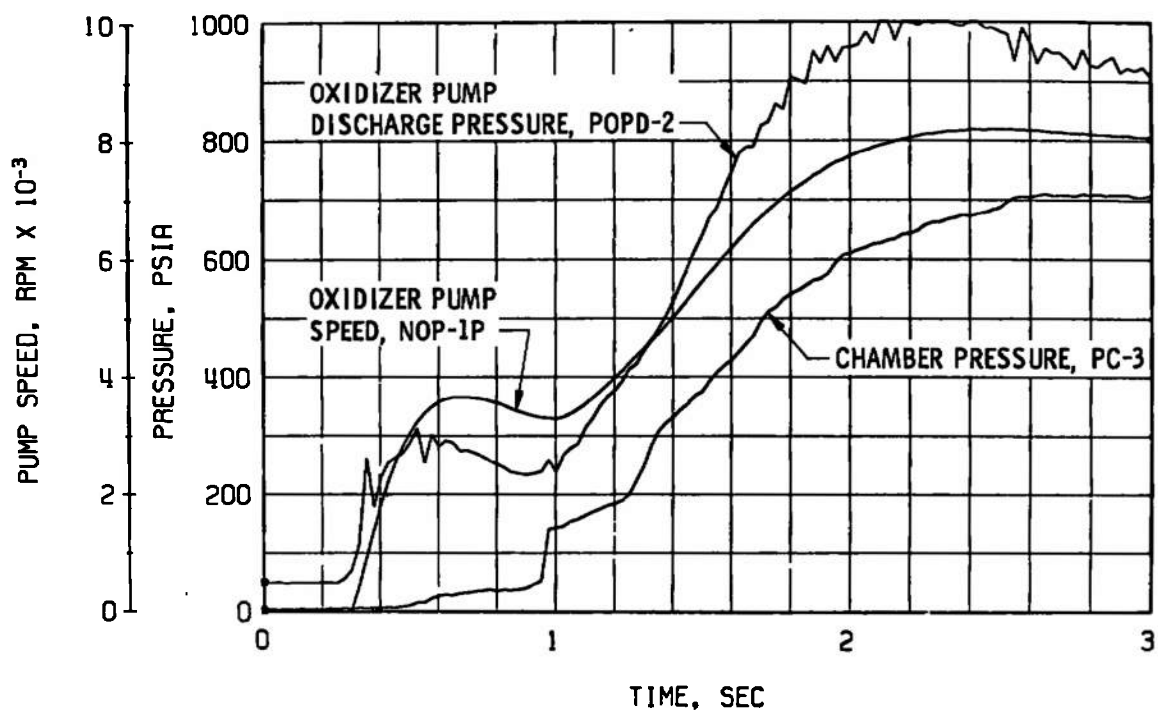



Fig. 61 Engine Ambient and Combustion Chamber Pressures, Firing 01D

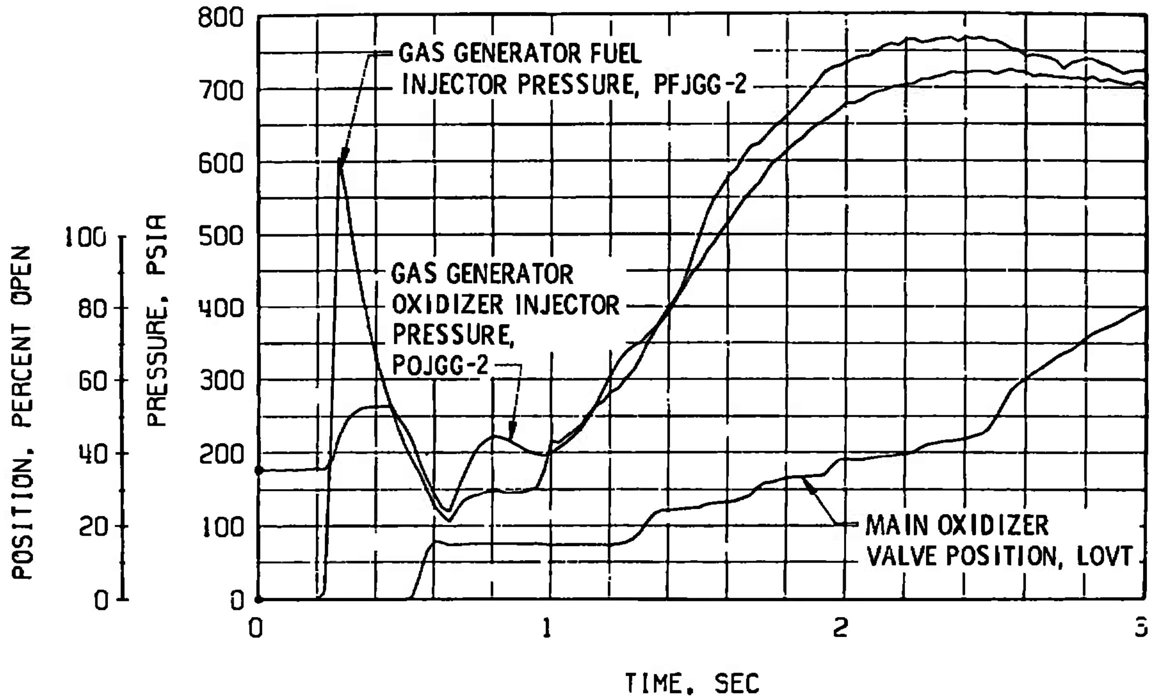



a. Thrust Chamber Fuel System, Start

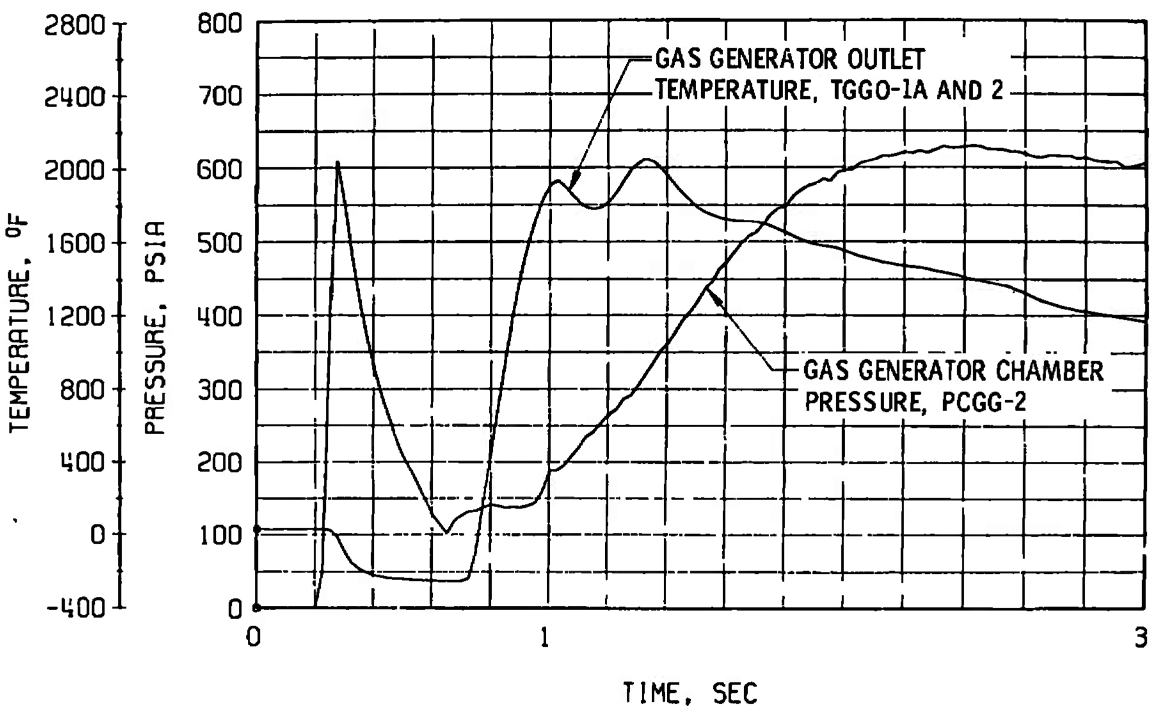



b. Thrust Chamber Oxidizer System, Start

Fig. 62 Engine Transient Operation, Firing 01D

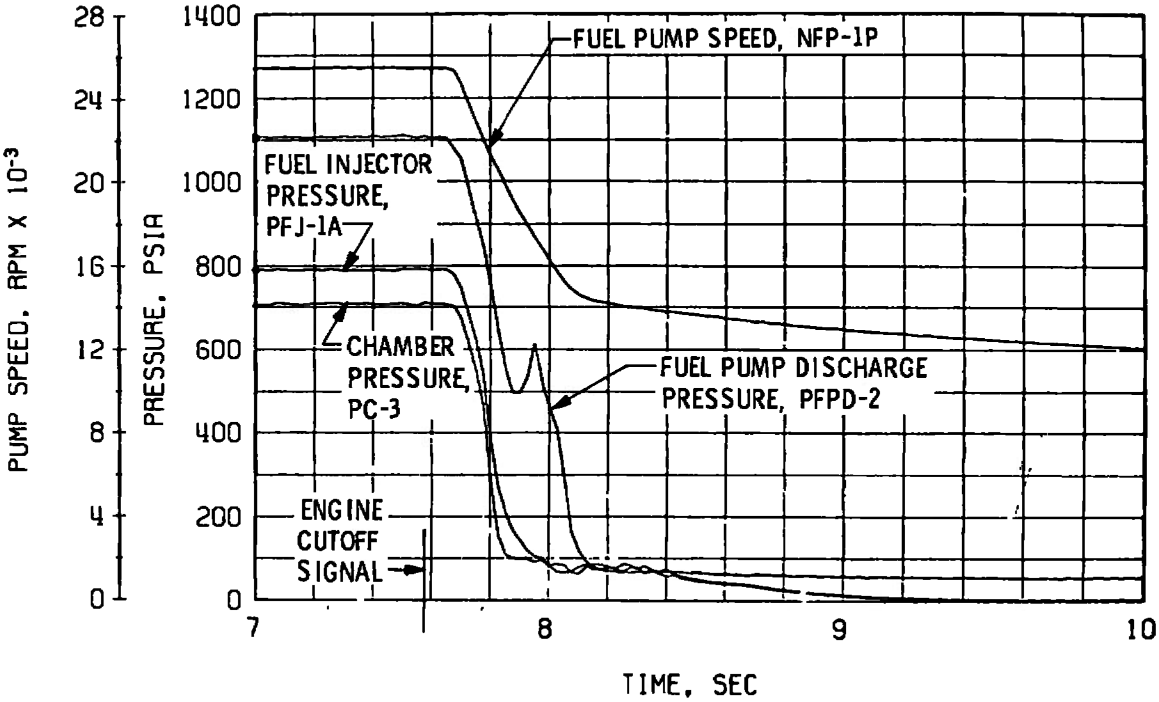



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

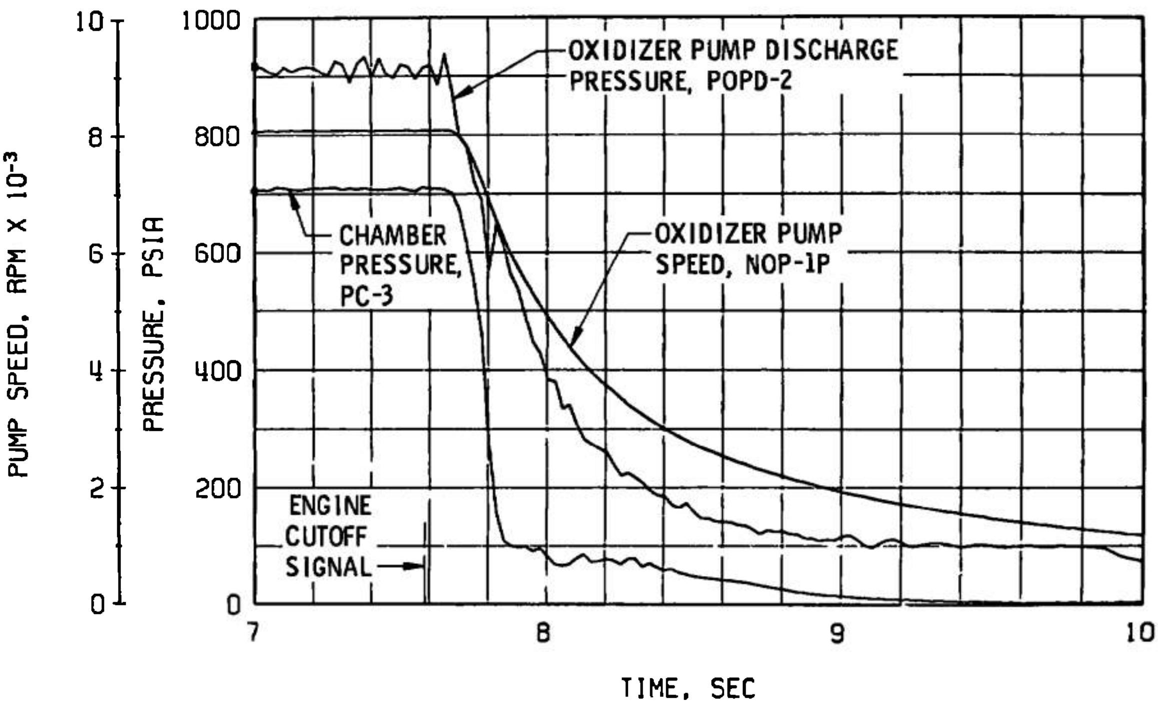



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 62 Continued

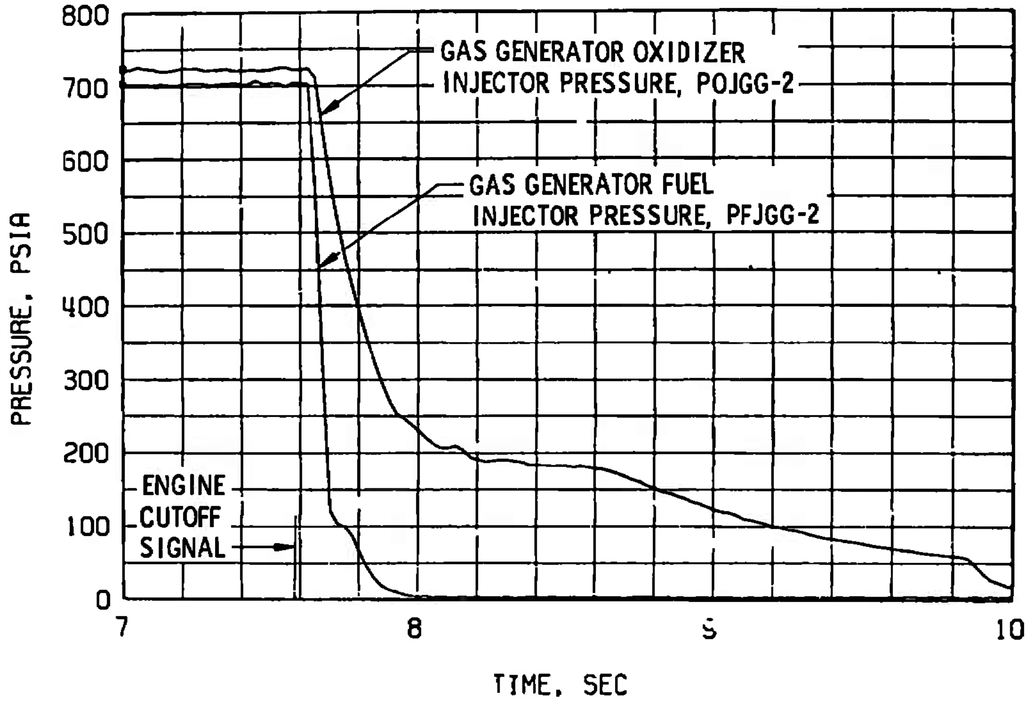



e. Thrust Chamber Fuel System, Shutdown

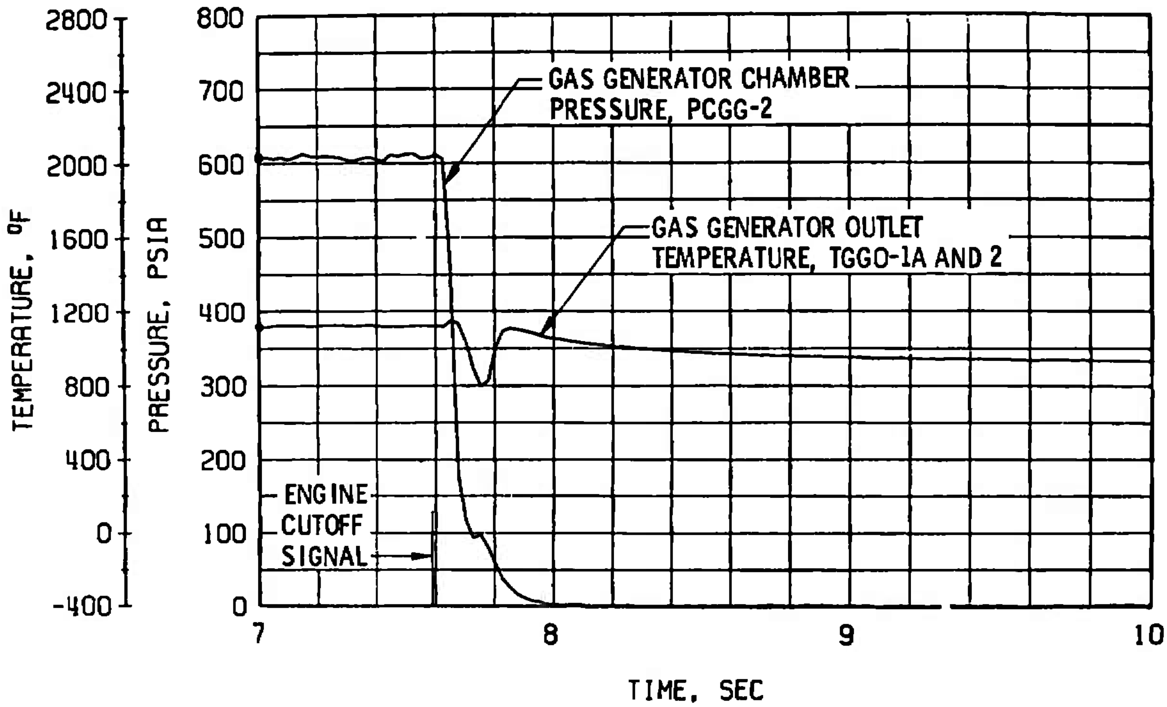



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 62 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 62 Concluded

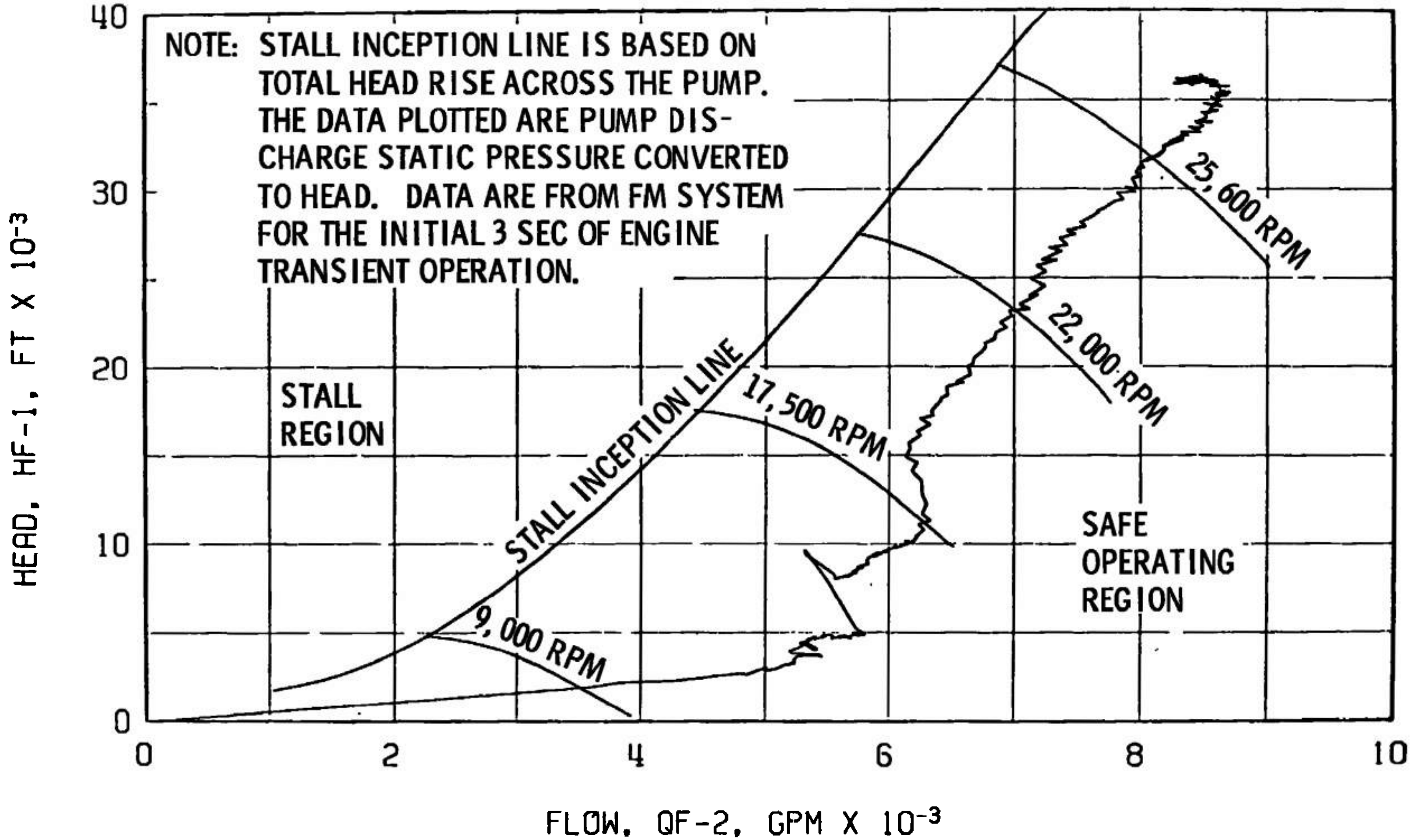
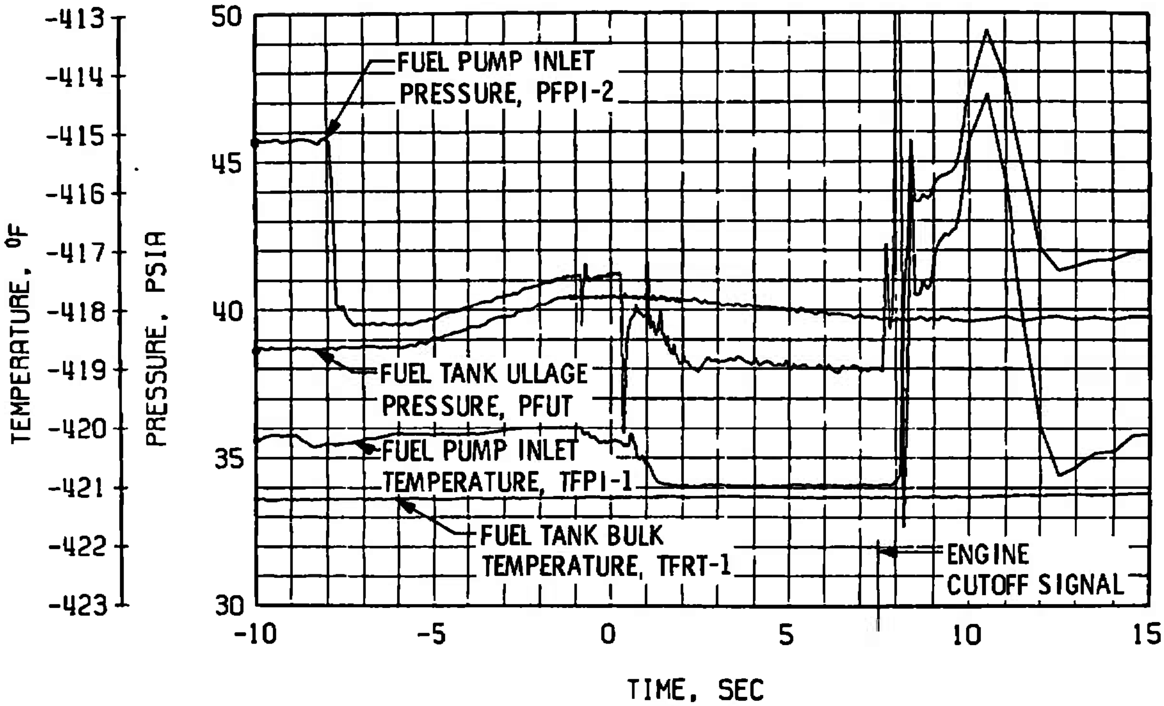
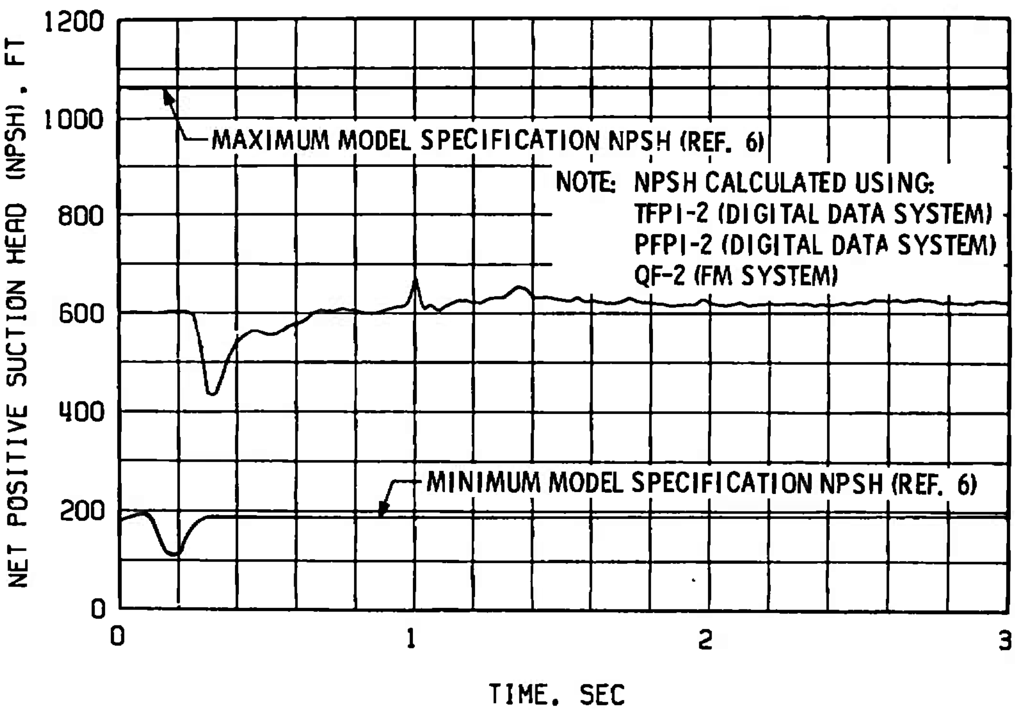



Fig. 63 Fuel Pump Start Transient Performance, Firing 01D

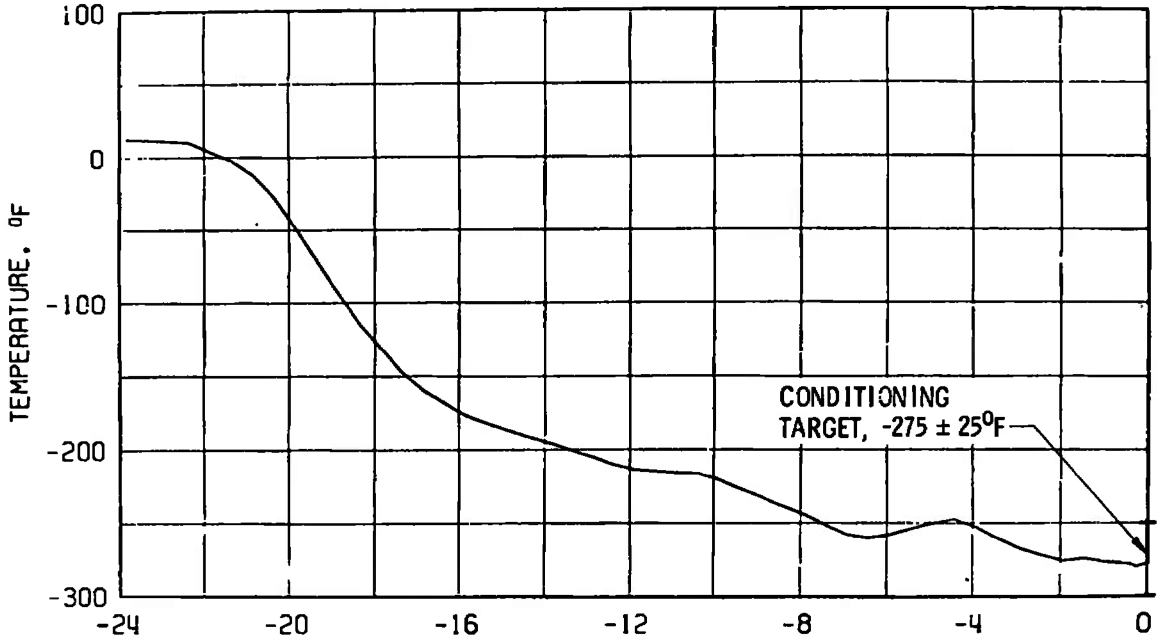



a. Duct Pressure and Temperature Transients

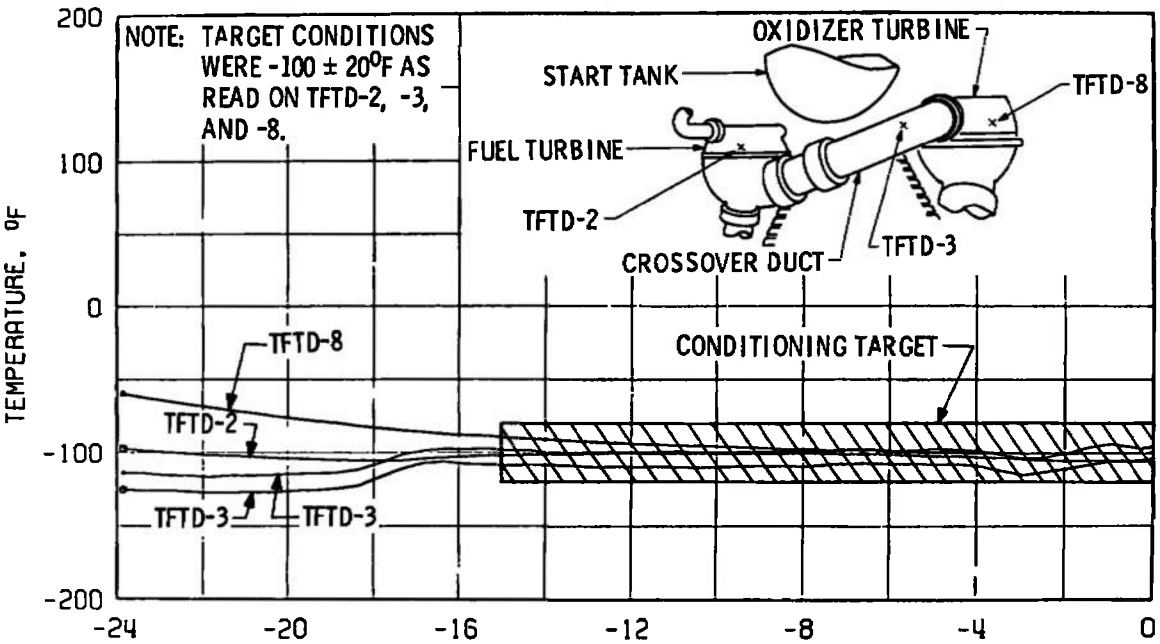



b. Fuel Pump NPSH during Start Transient, Firing 01D

Fig. 64 Fuel Low Pressure Duct Performance, Firing 01D

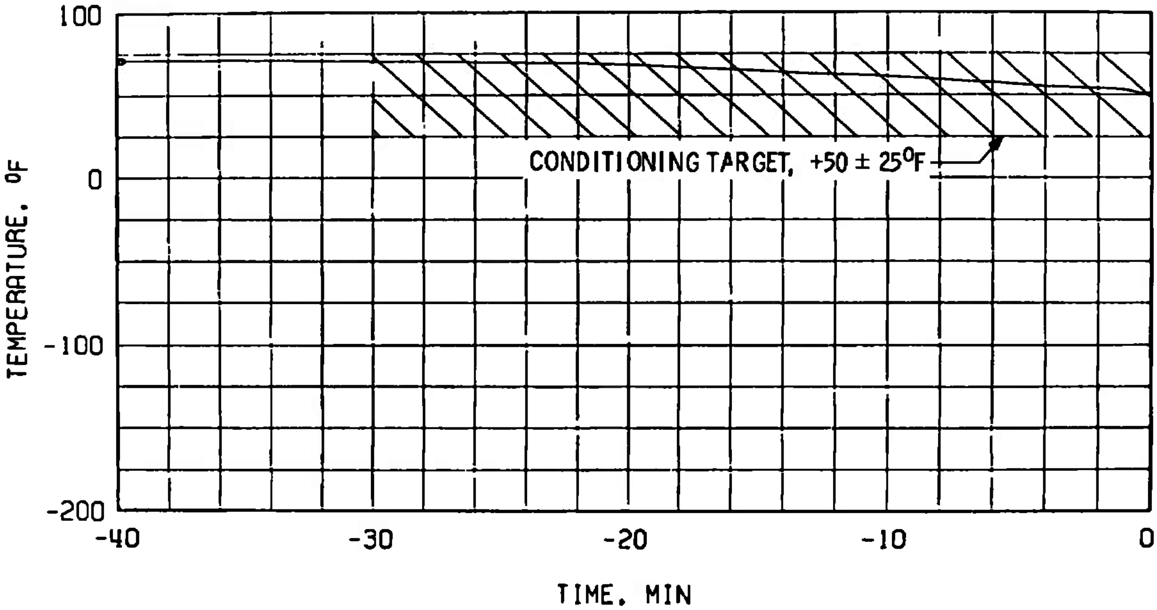



a. Thrust Chamber Throat, TTC-1P

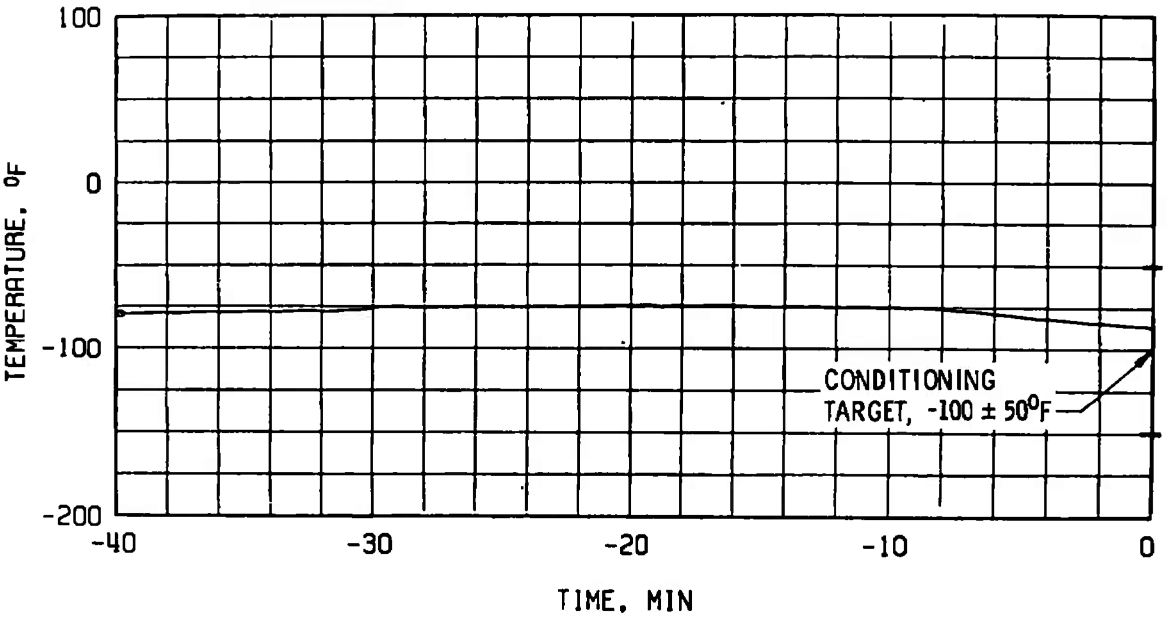



b. Crossover Duct, TFTD

Fig. 65 Thermal Conditioning History of Engine Components, Firing 01E




c. Start Tank Discharge Valve, TSTDVOC




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

Fig. 65 Concluded

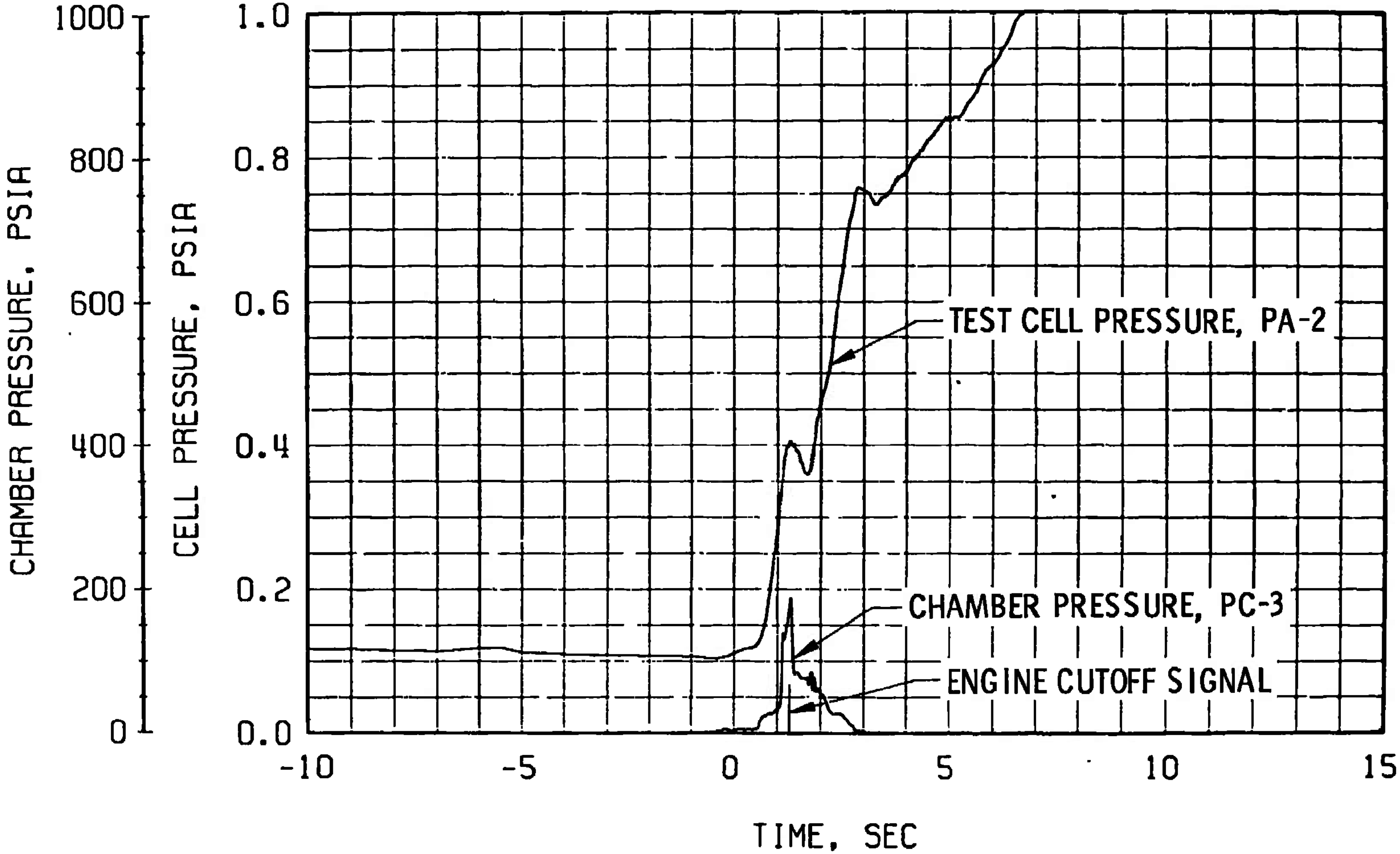
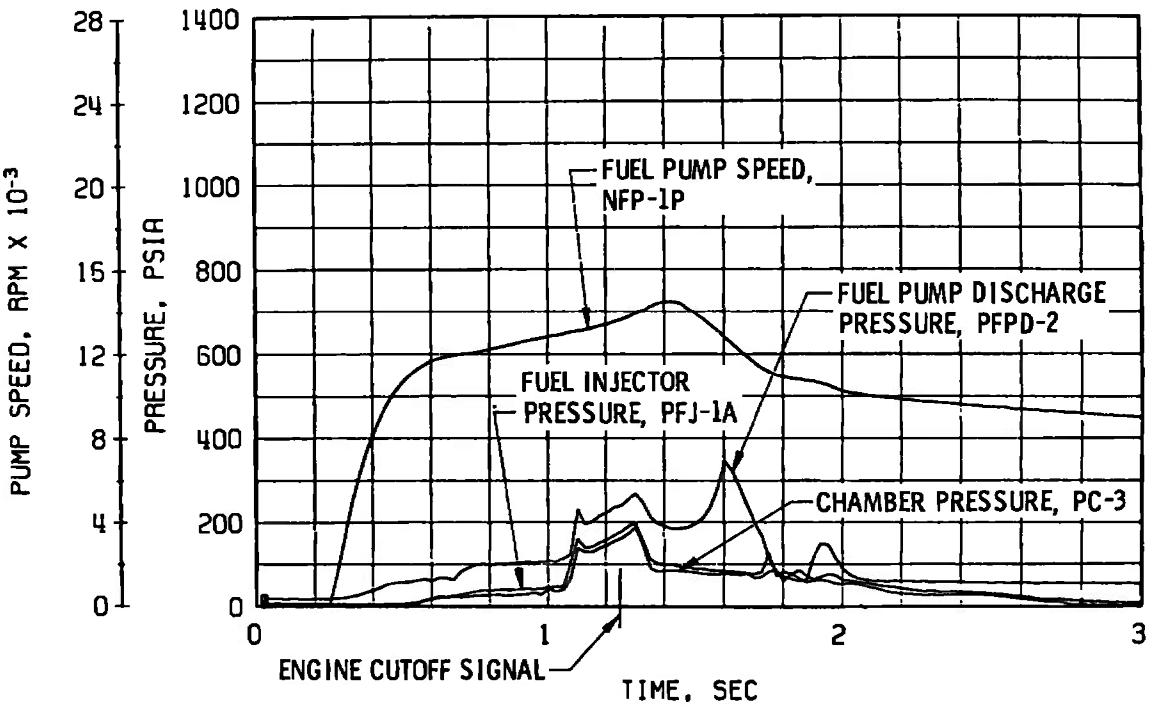
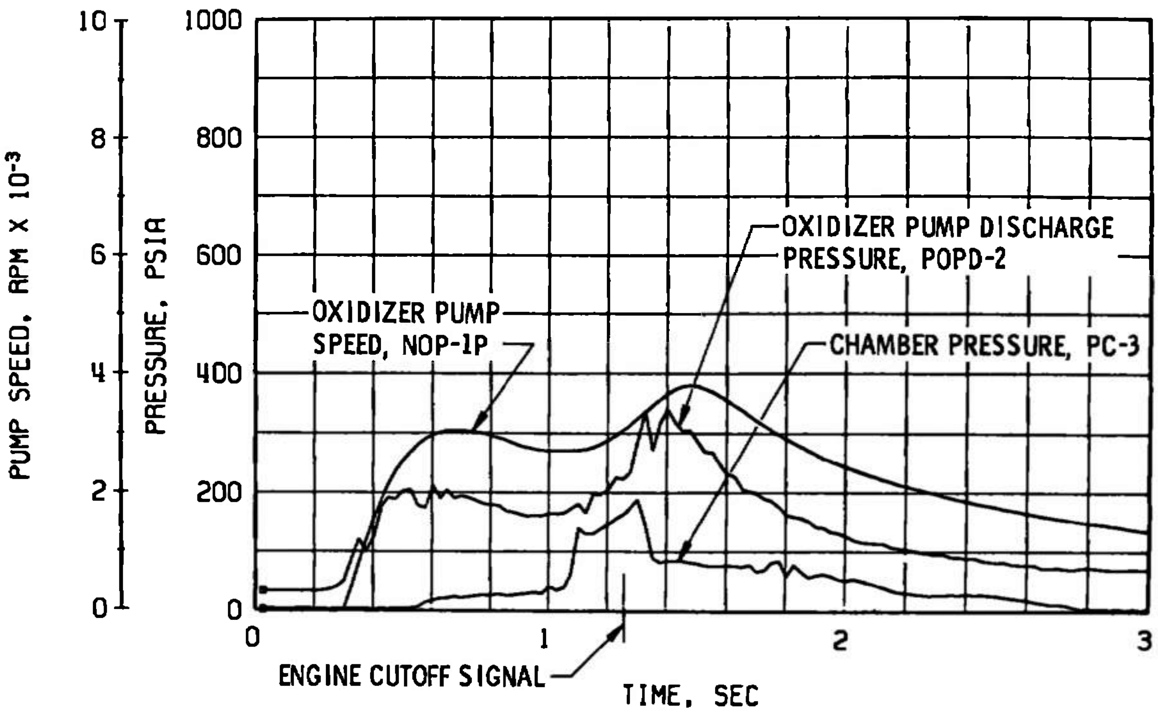



**Fig. 66 Engine Ambient and Combustion Chamber Pressures, Firing 01E**

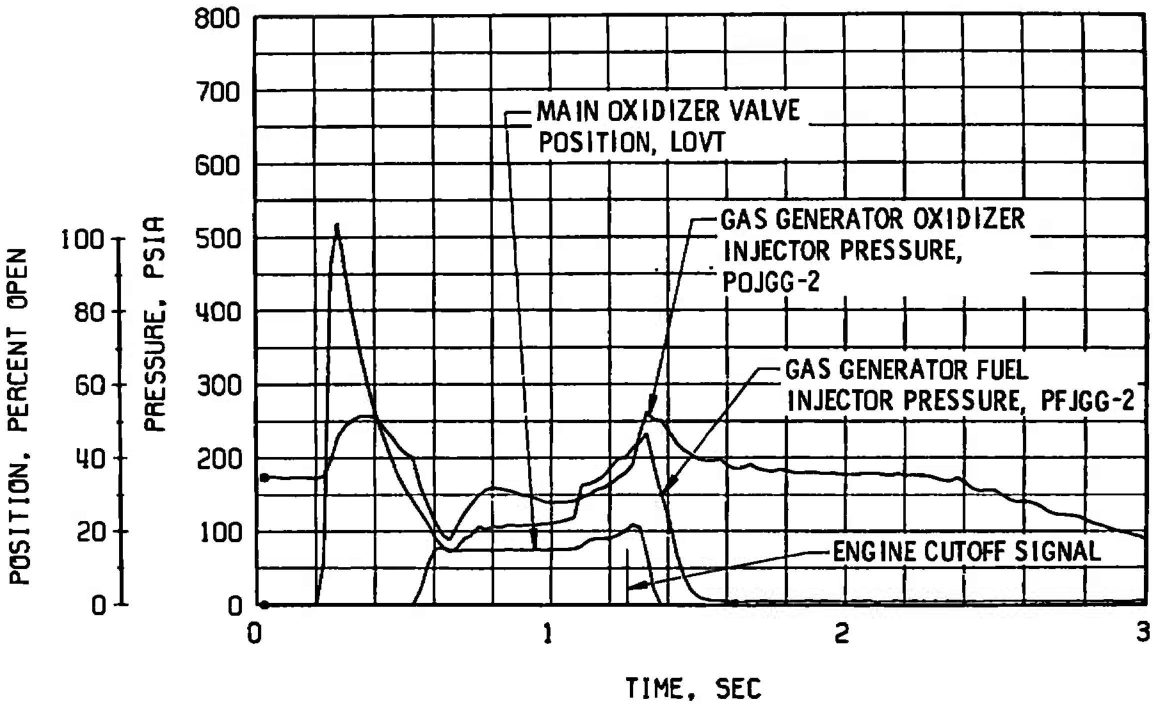



a. Thrust Chamber Fuel System, Start and Shutdown

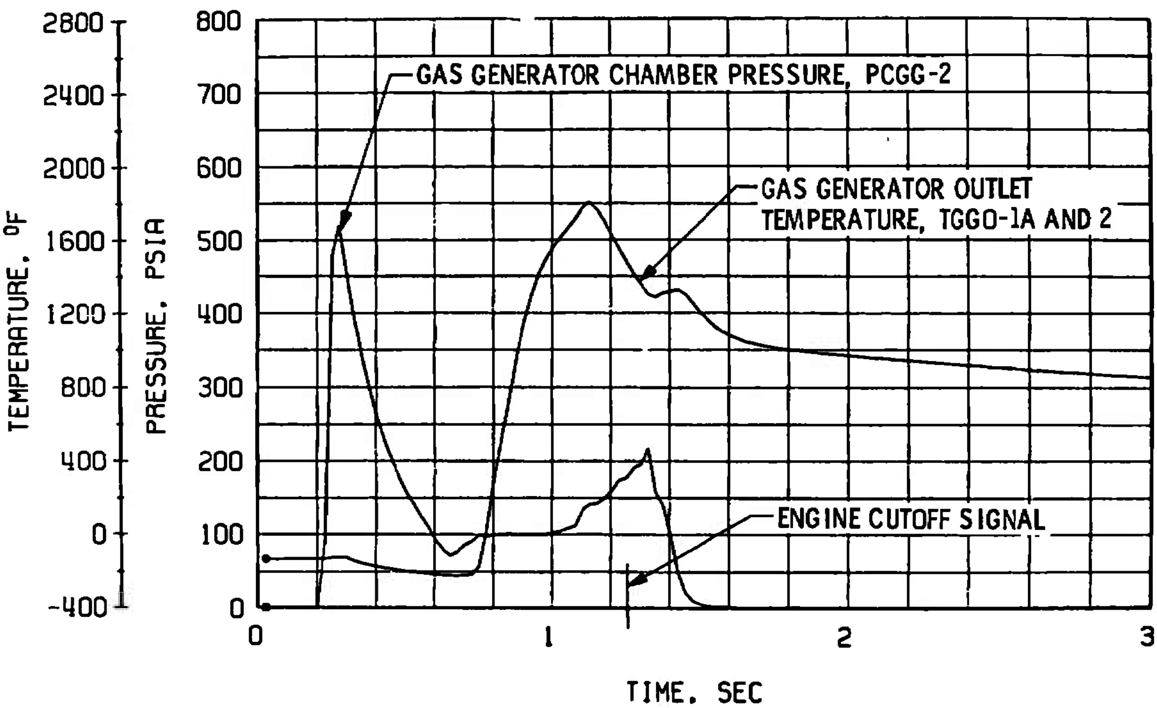



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 67 Engine Transient Operation, Firing 01E




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




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

Fig. 67 Concluded

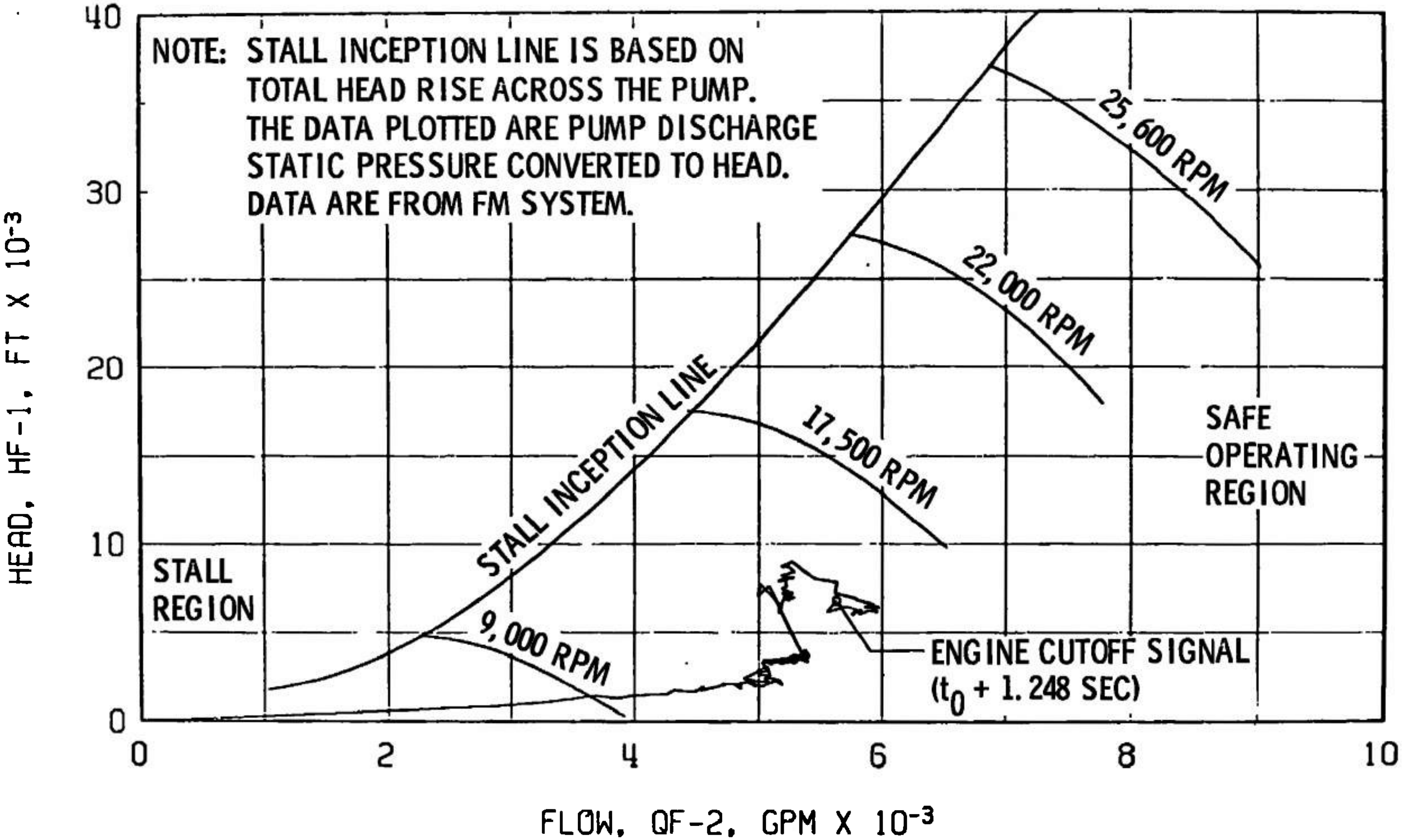
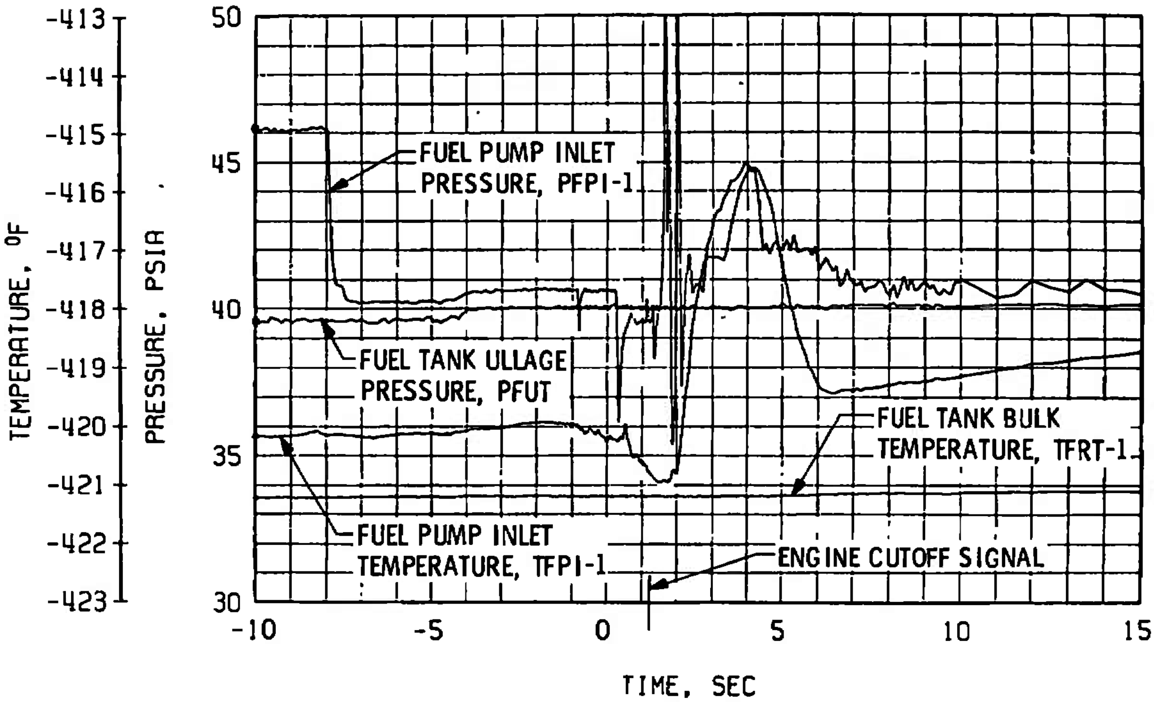
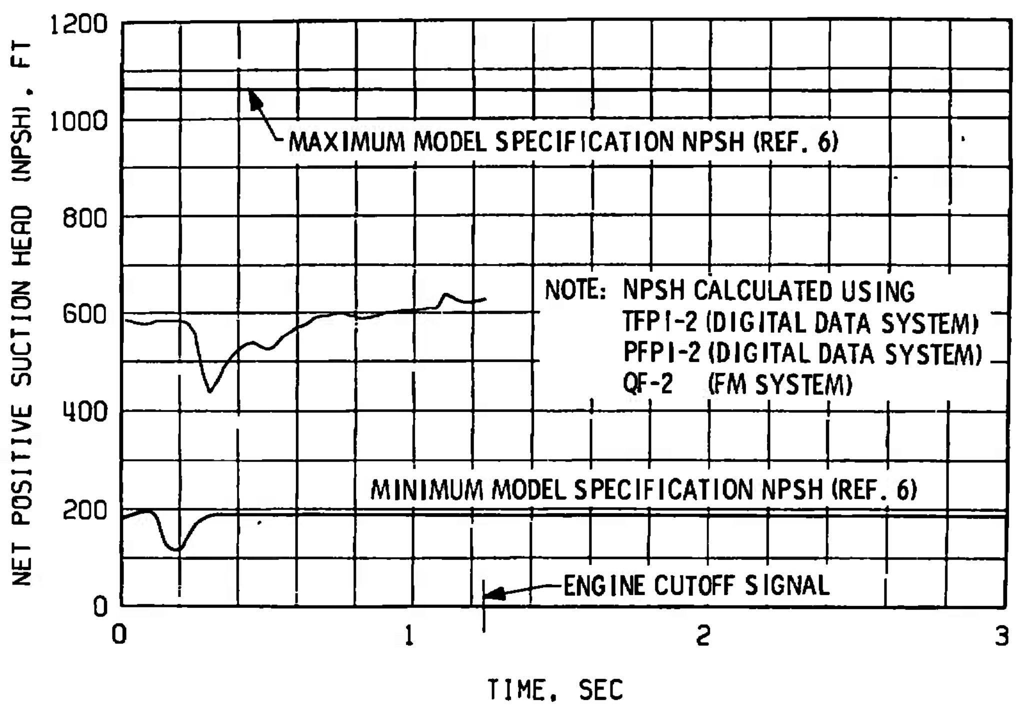



Fig. 68 Fuel Pump Start Transient Performance, Firing 01E

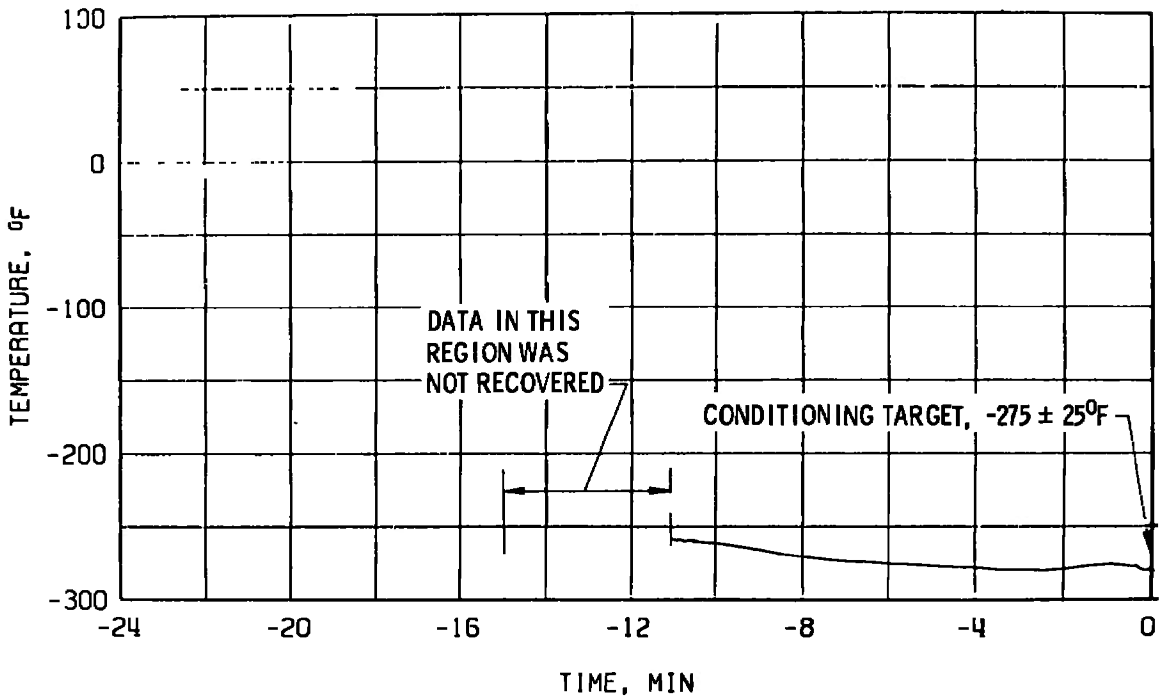



a. Duct Pressure and Temperature Transients

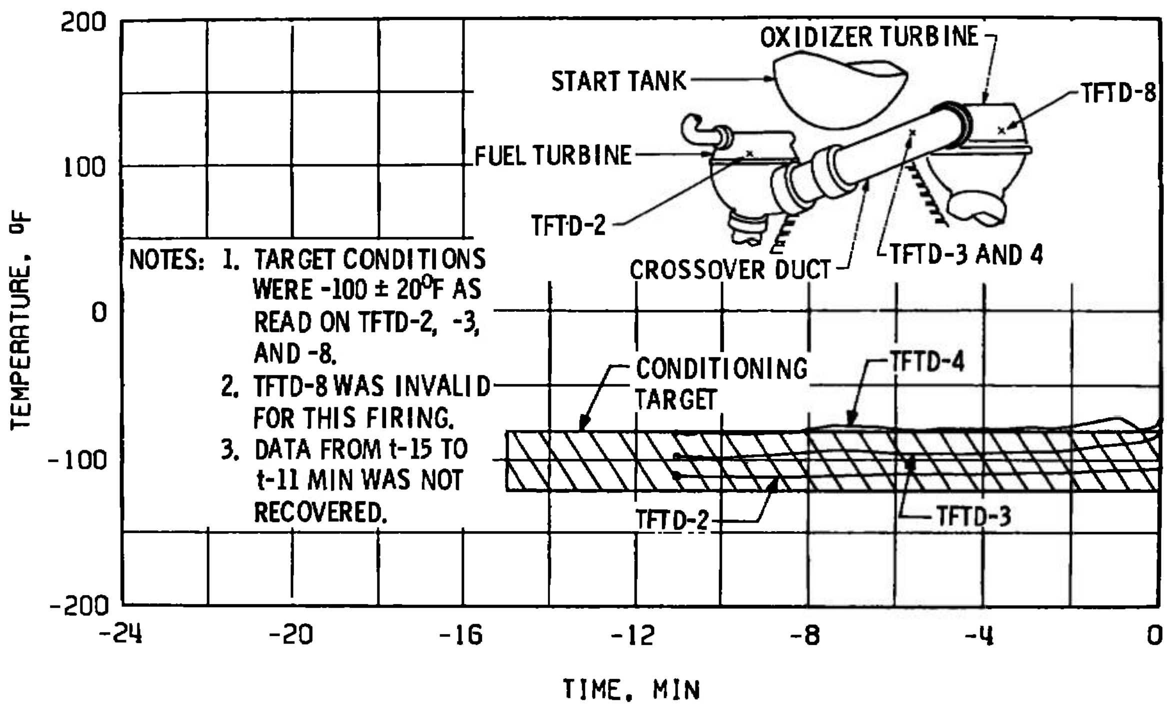



b. Fuel Pump NPSH during Start Transient, Firing 01E

Fig. 69 Fuel Low Pressure Duct Performance, Firing 01E

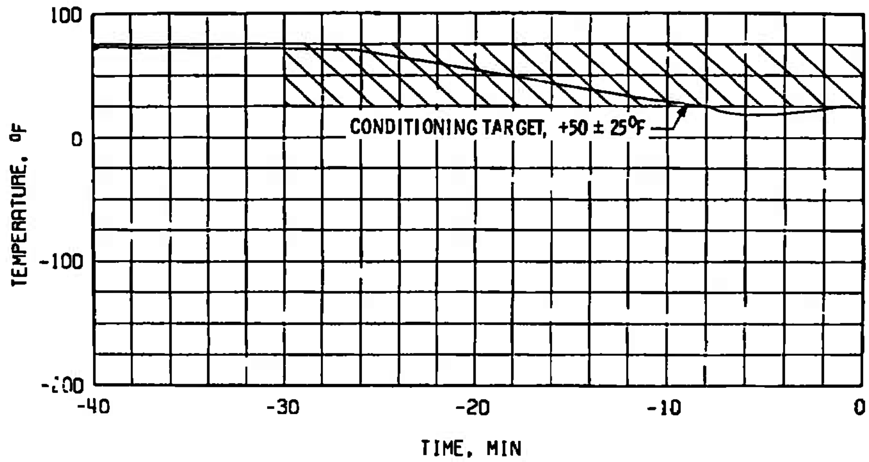



a. Thrust Chamber, TTC-1P

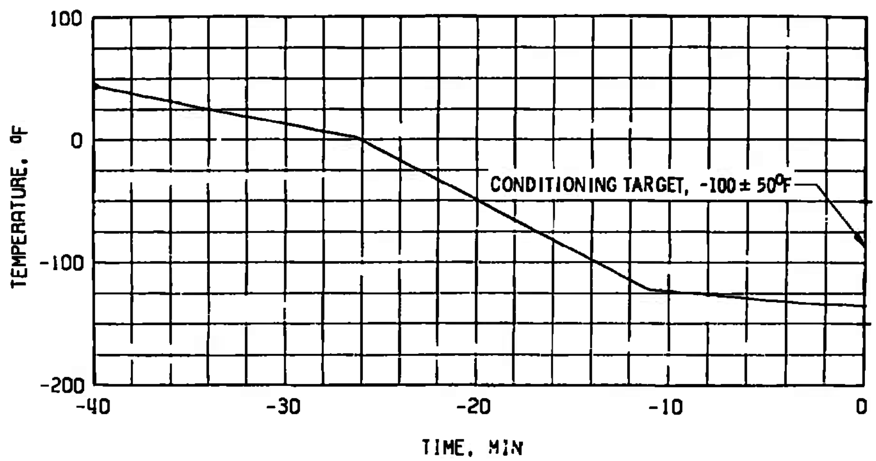



b. Crossover Duct, TFTD

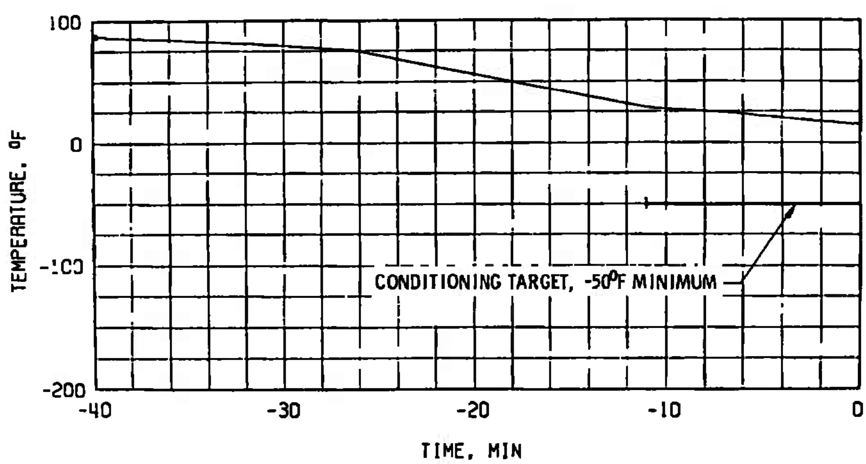
Fig. 70 Thermal Conditioning History of Engine Components, Firing 02A




c. Start Tank Discharge Valve, TSTDVOC




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




e. Gas Generator Control Valve, TGGVRS

Fig. 70 Concluded

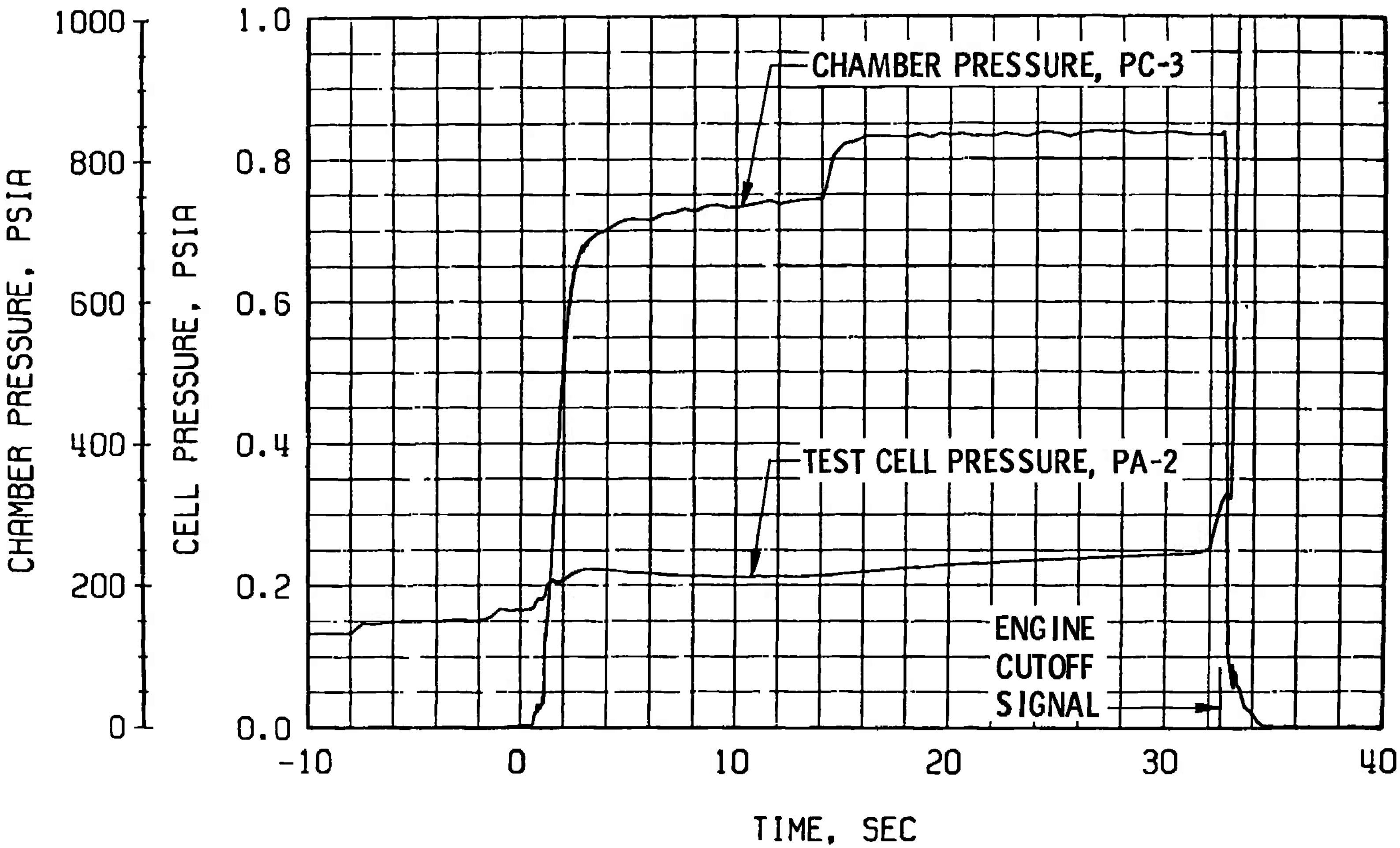
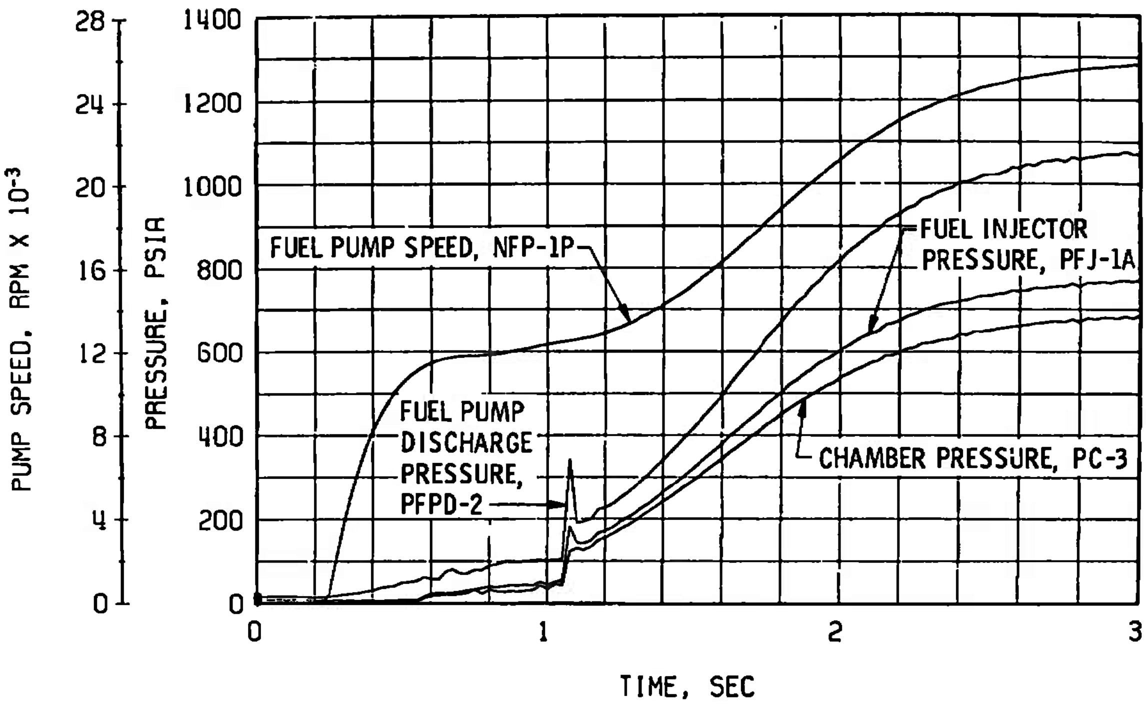
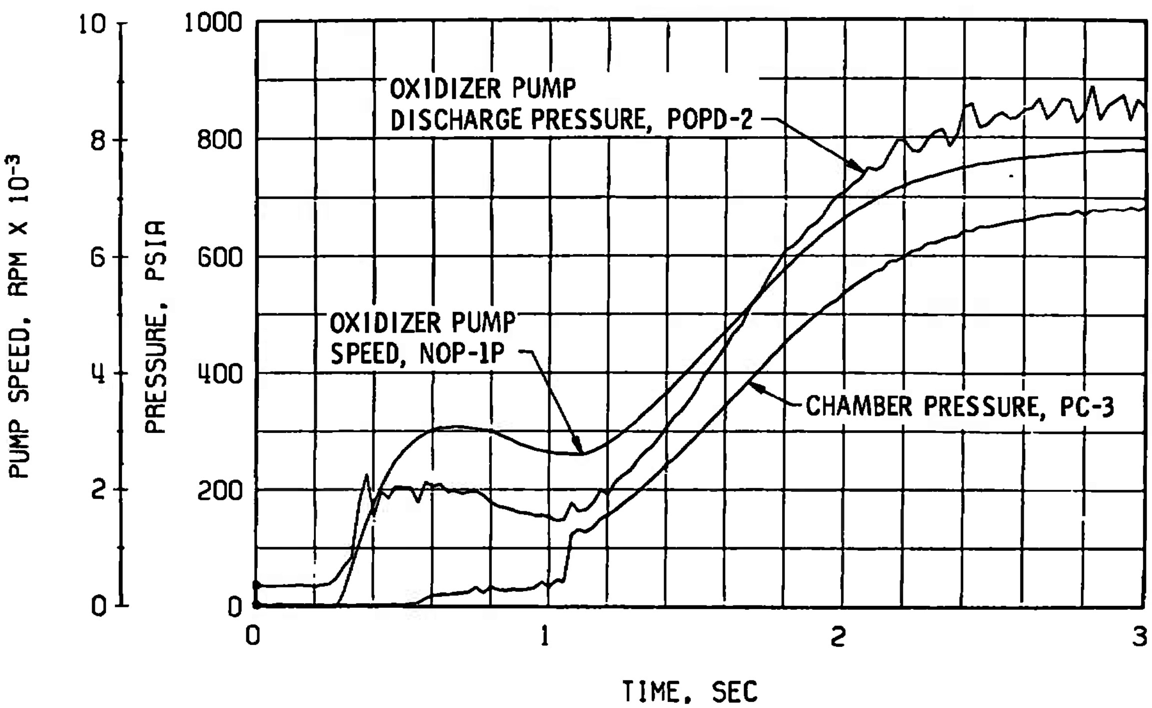



**Fig. 71 Engine Ambient and Combustion Chamber Pressures, Firing 02A**

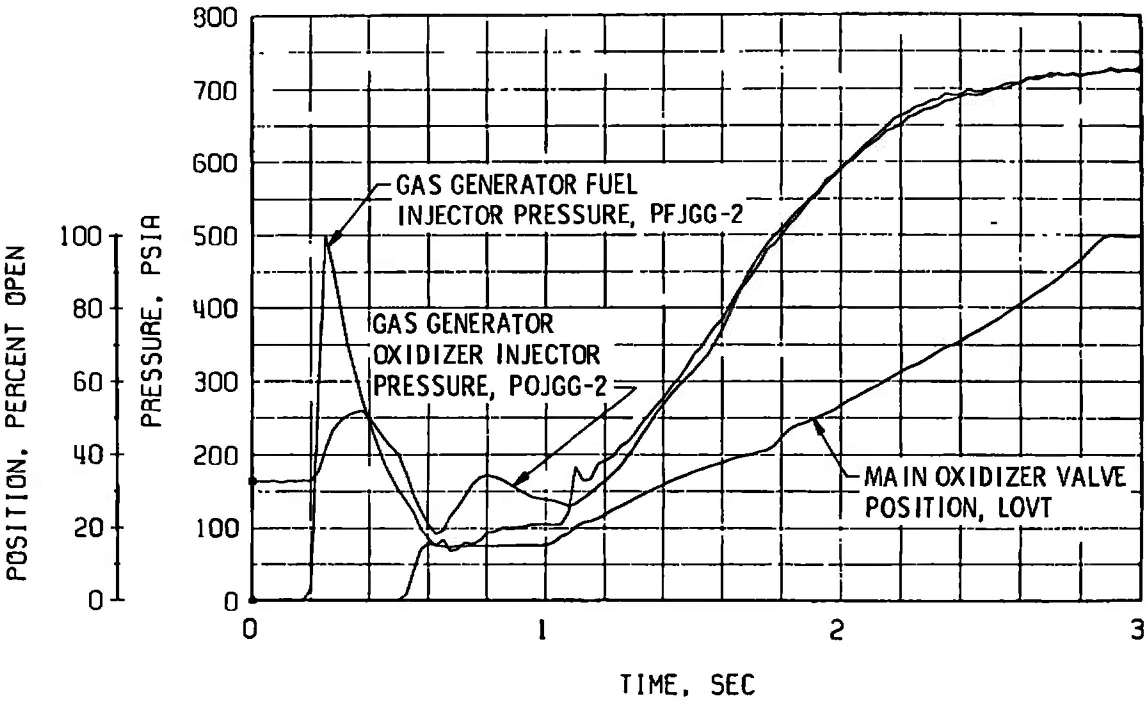



a. Thrust Chamber Fuel System, Start

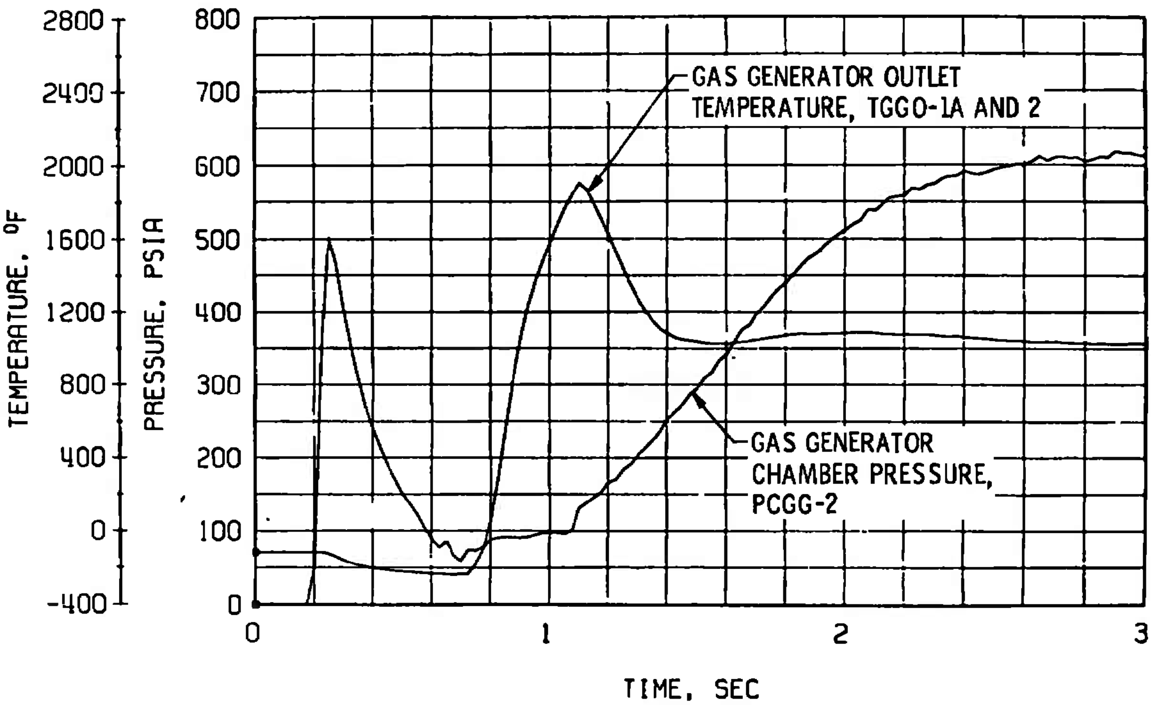



b. Thrust Chamber Oxidizer System, Start

Fig. 72 Engine Transient Operation, Firing 02A

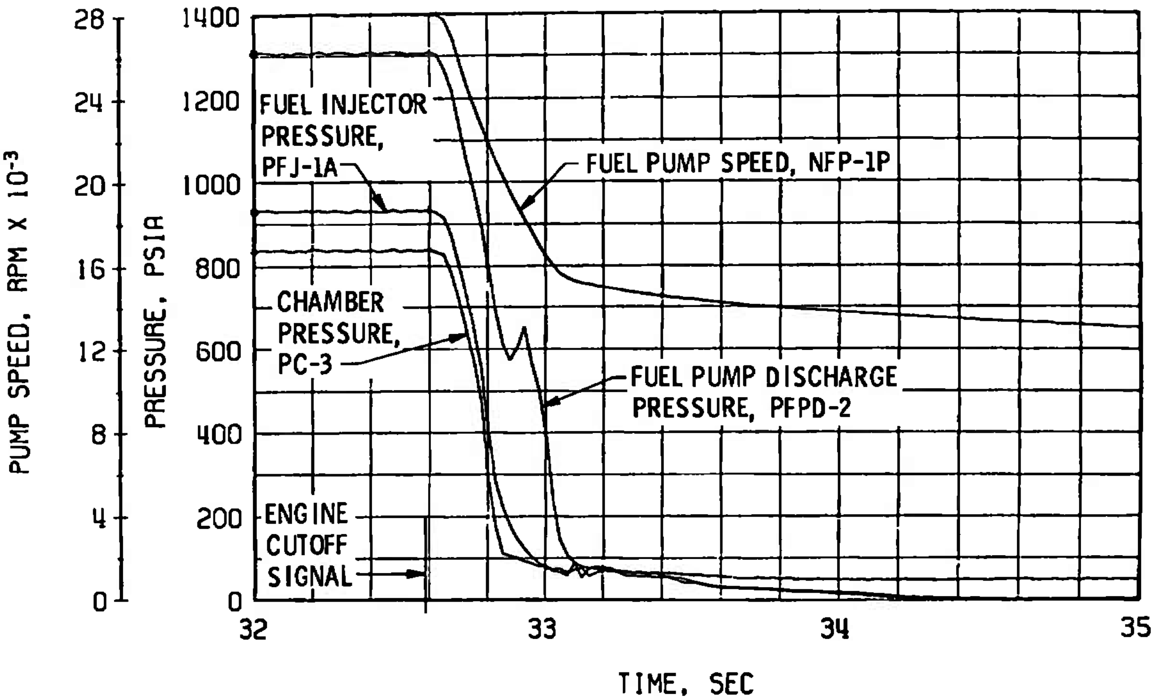



c. Gas Generator Injectar Pressures and Main Oxidizer Valve Position, Start

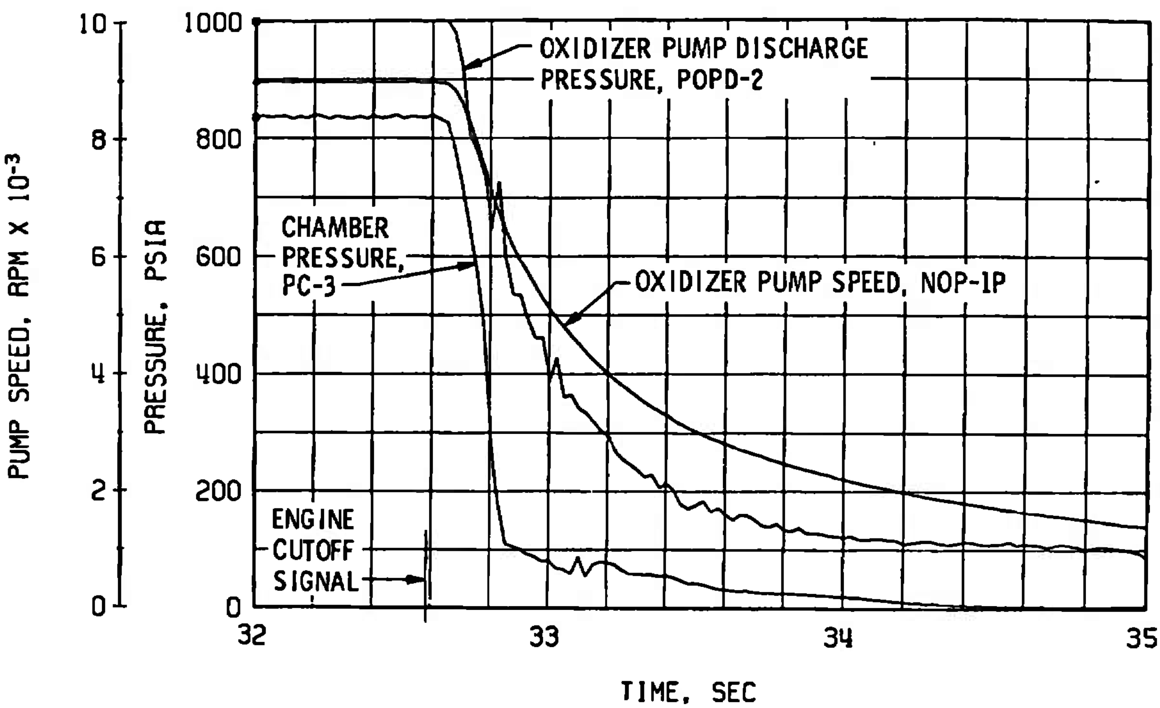



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 72 Continued

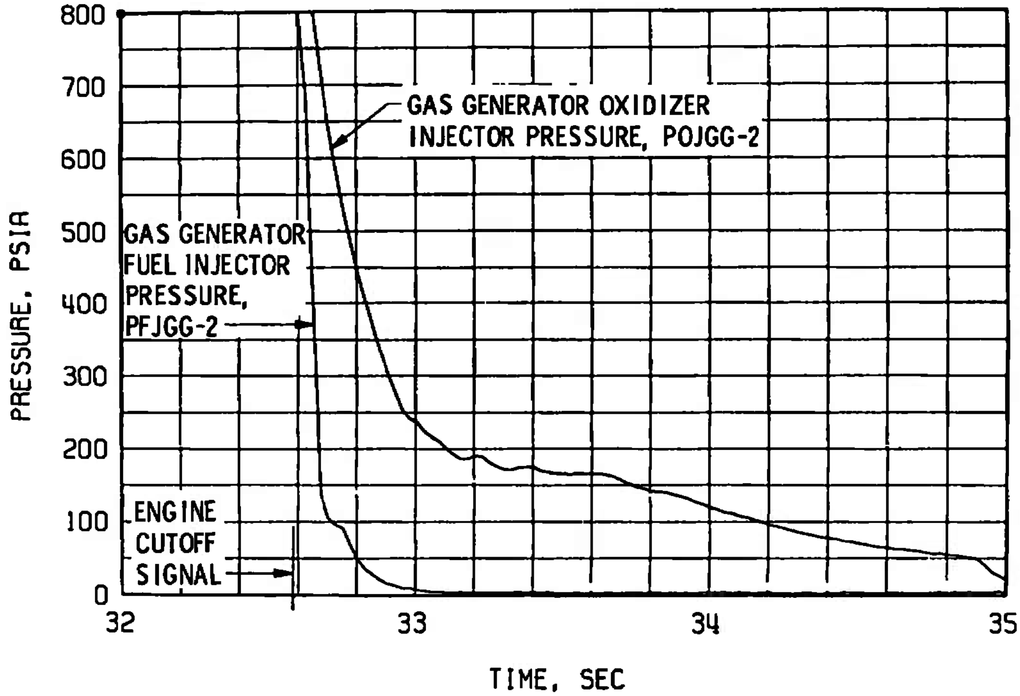



e. Thrust Chamber Fuel System, Shutdown

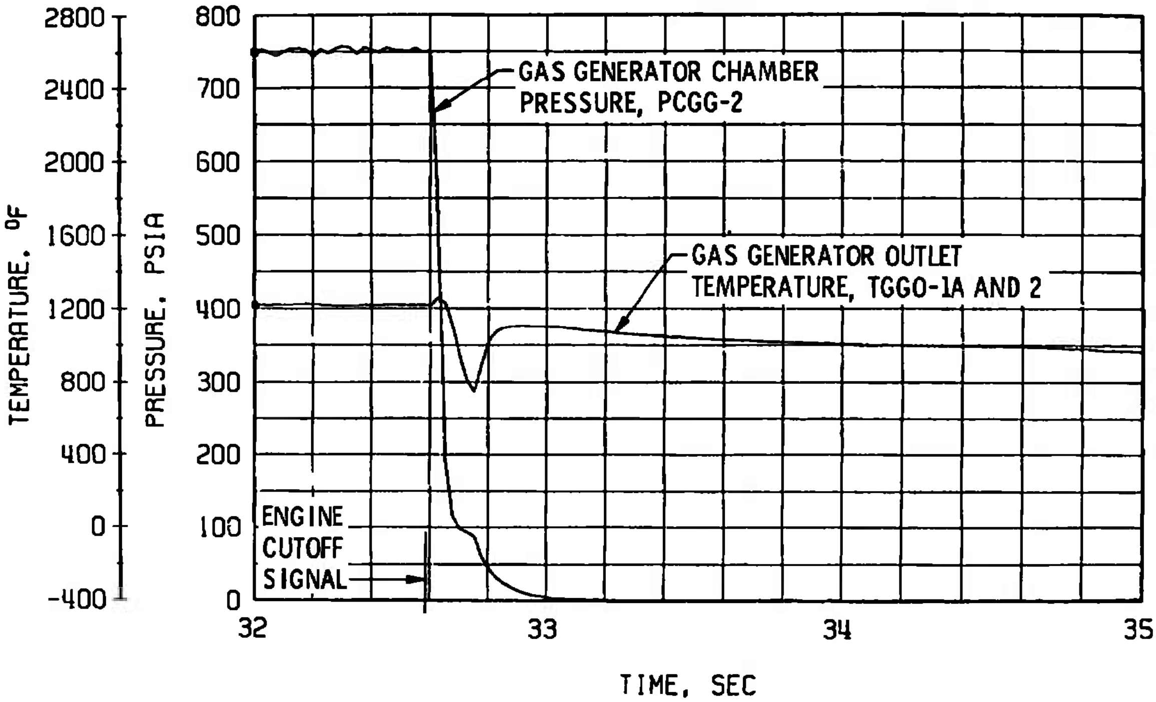



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 72 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 72 Concluded

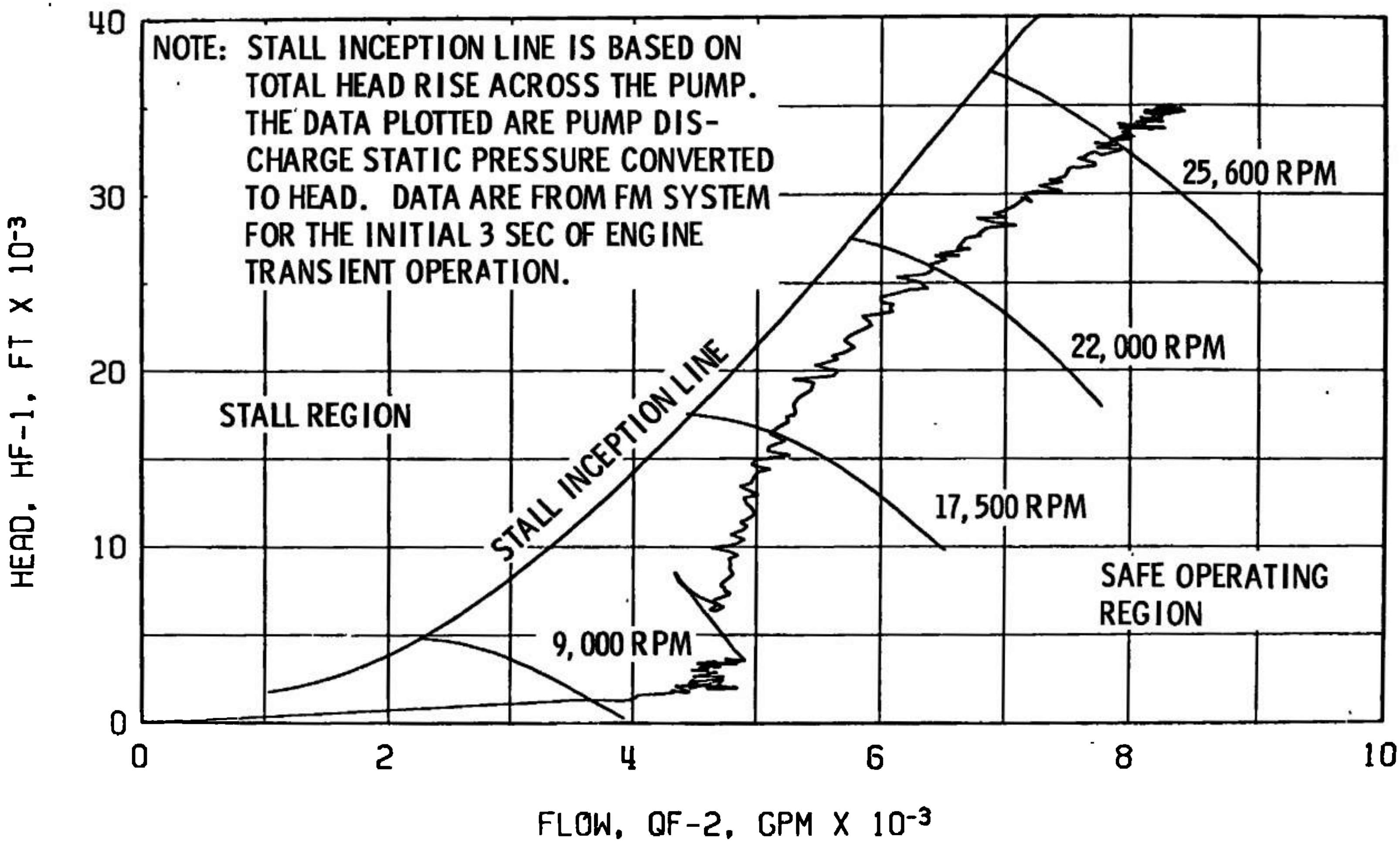
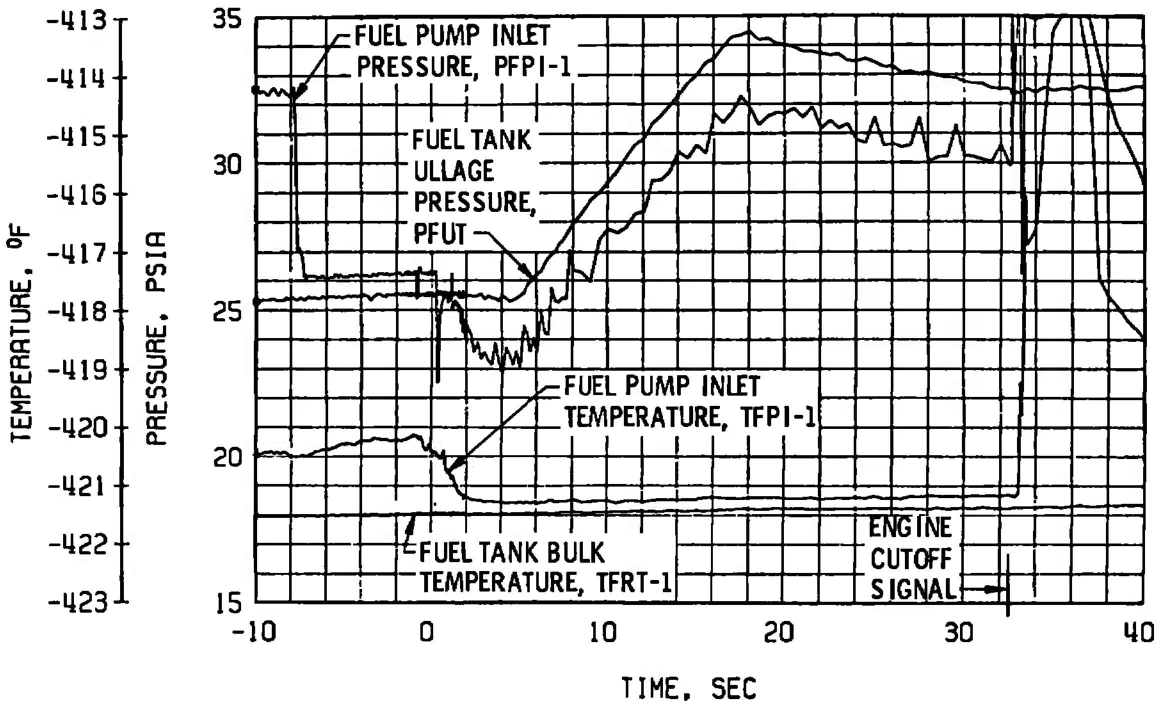
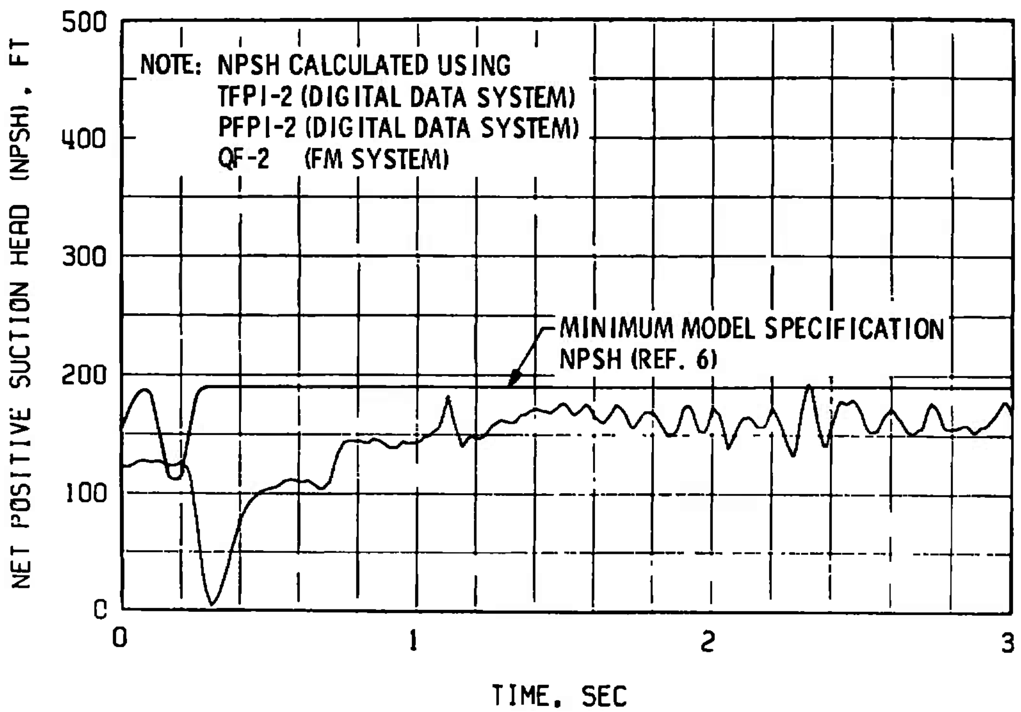



Fig. 73 Fuel Pump Start Transient Performance, Firing 02A

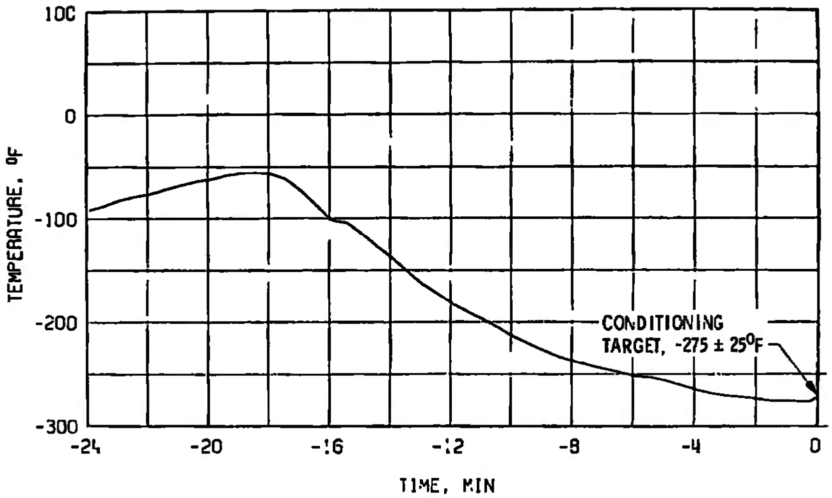



a. Duct Pressure and Temperature Transients

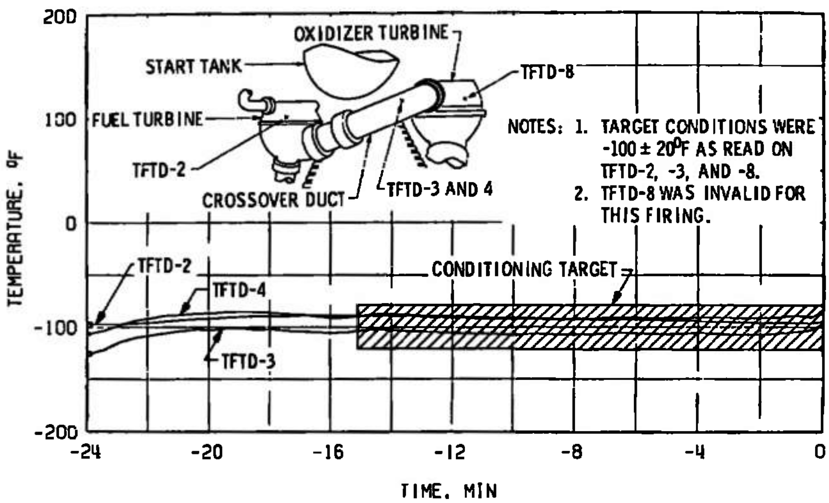



b. Fuel Pump NPSH during Start Transient, Firing 02A

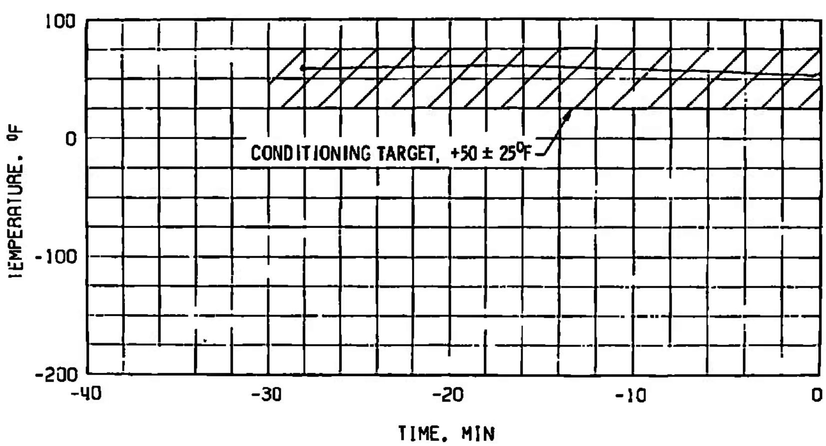
Fig. 74 Fuel Low Pressure Duct Performance, Firing 02A




a. Thrust Chamber, TTC-1P

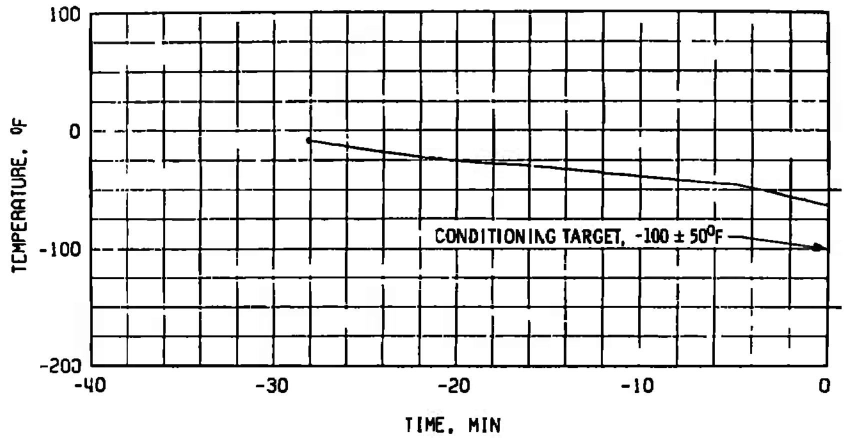



b. Crossover Duct, TFTD

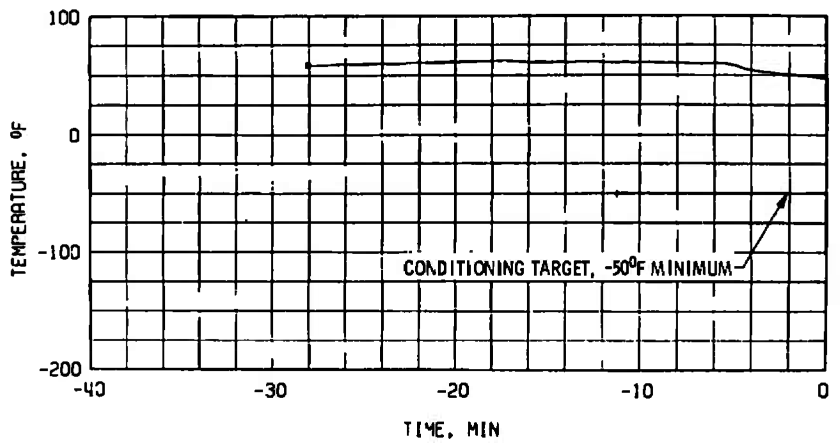



c. Start Tank Discharge Valve, TSTDVOC

Fig. 75 Thermal Conditioning History of Engine Components, Firing 02B




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




e. Gas Generator Control Valve, TGGVRS

Fig. 75 Concluded

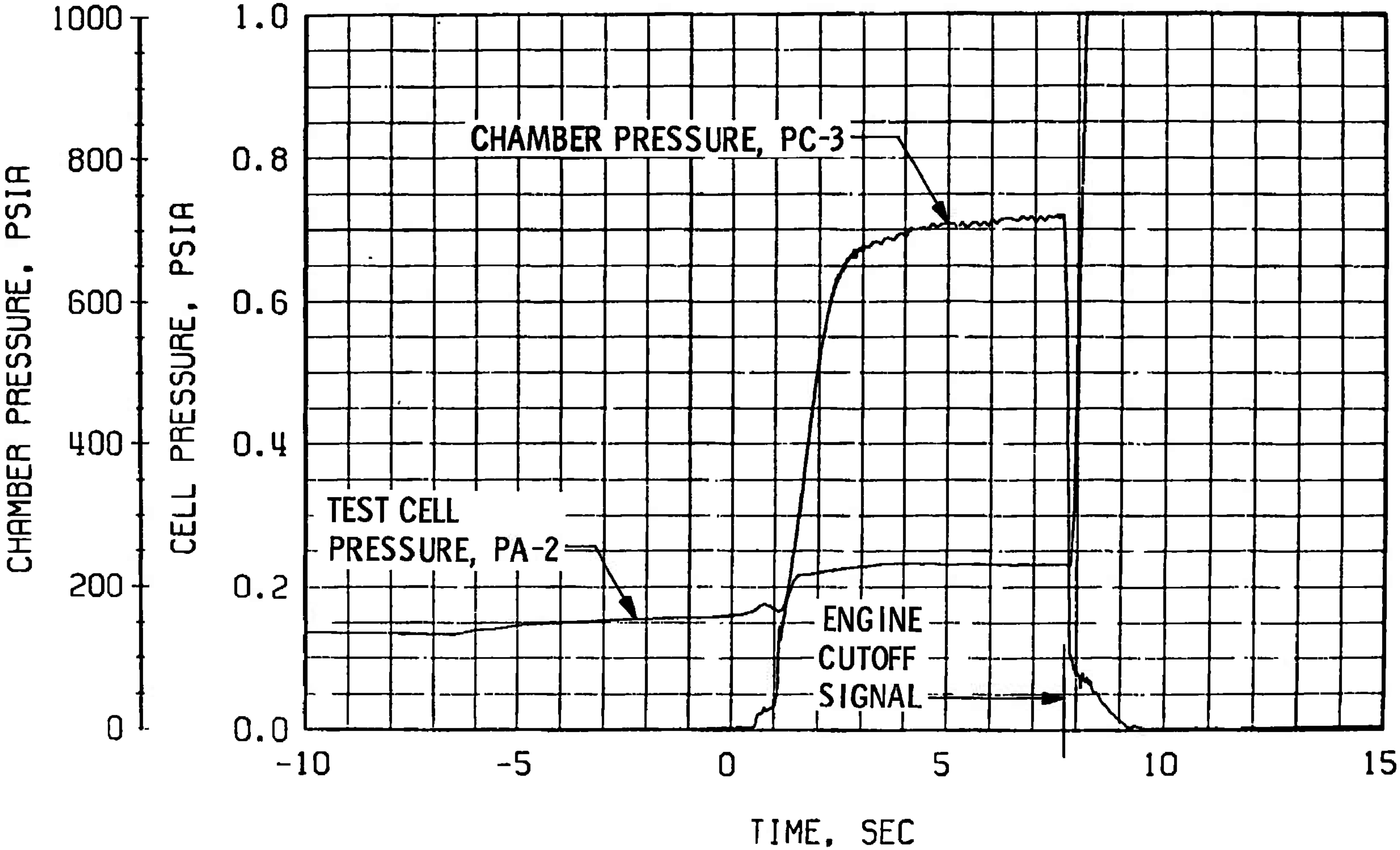
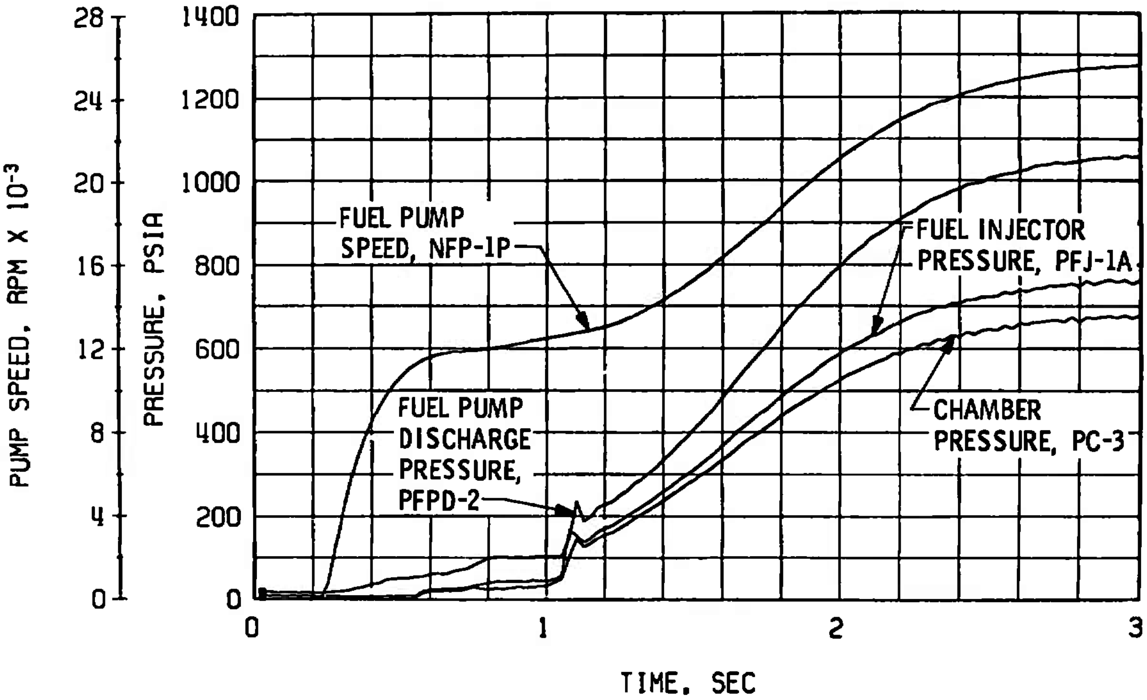
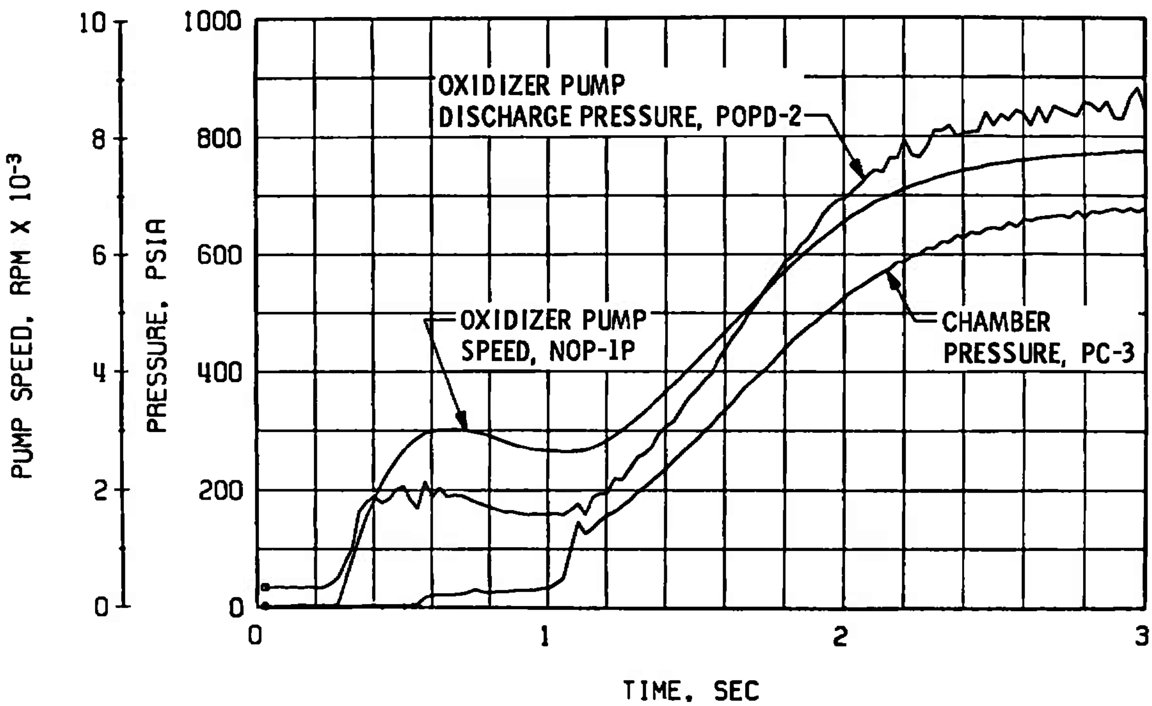



Fig. 76 Engine Ambient and Combustion Chamber Pressures, Firing 02B

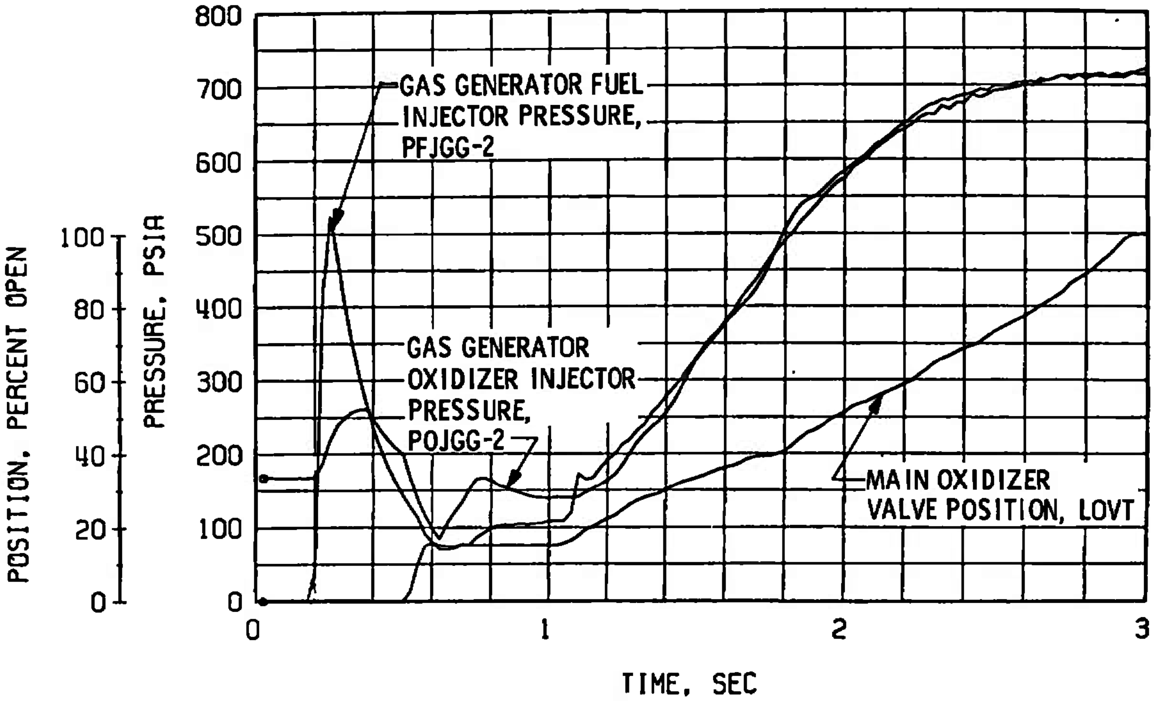



a. Thrust Chamber Fuel System, Start

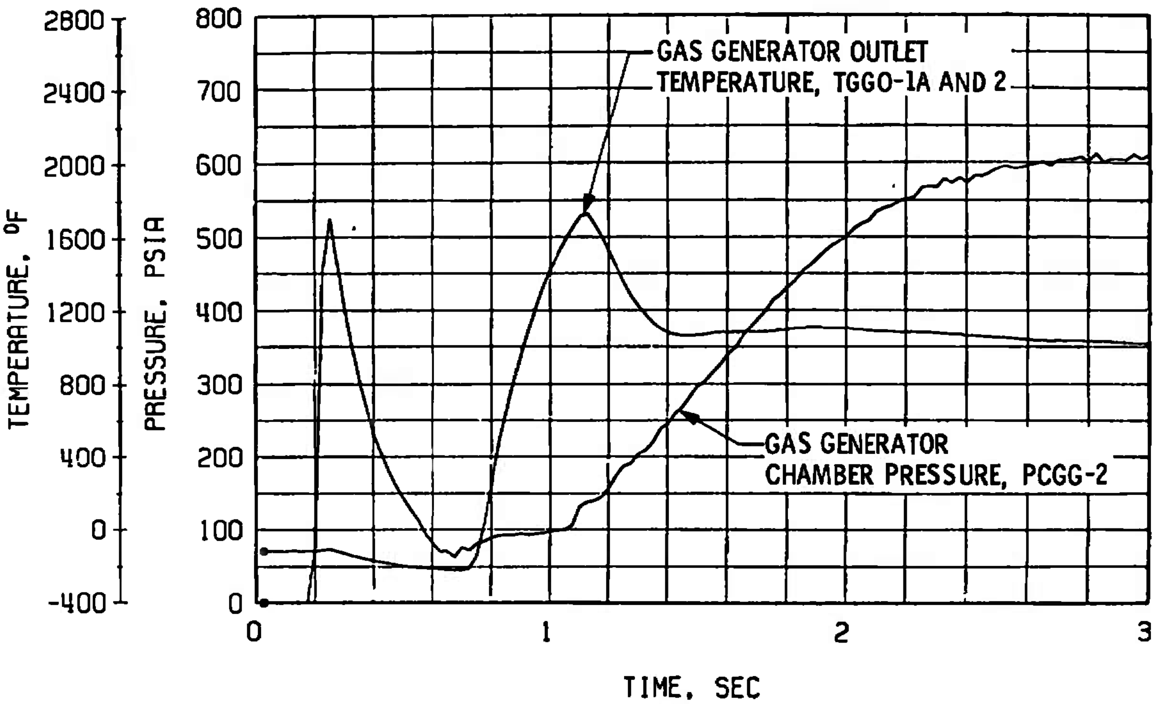



b. Thrust Chamber Oxidizer System, Start

Fig. 77 Engine Transient Operation, Firing 02B

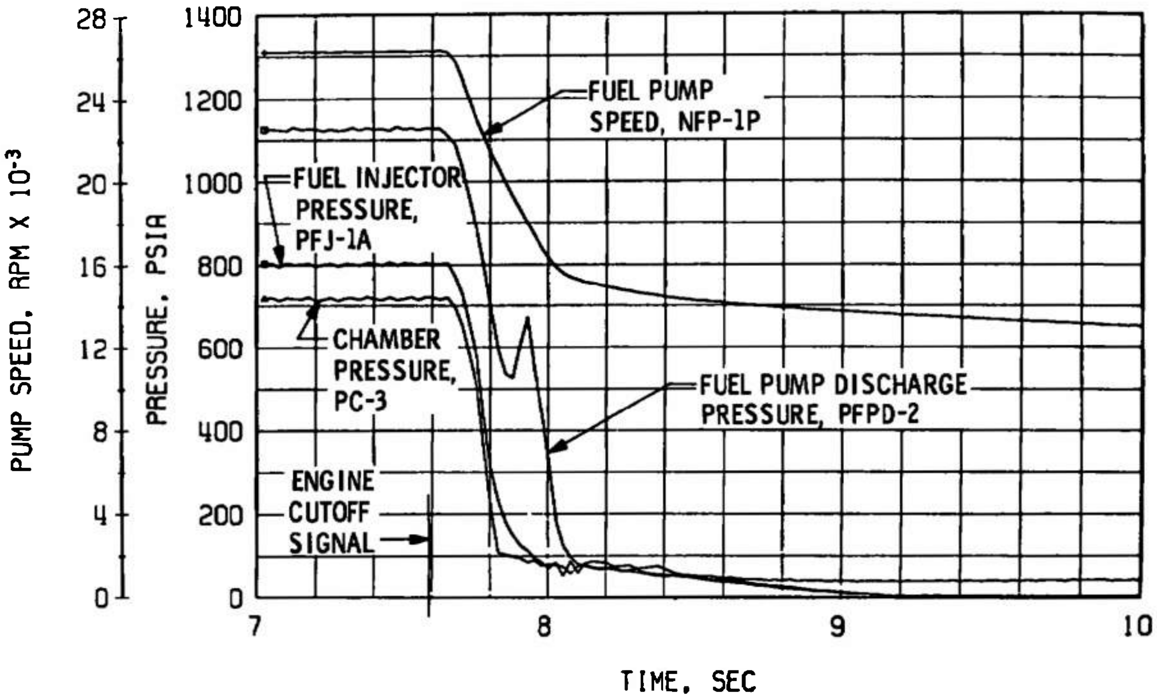



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

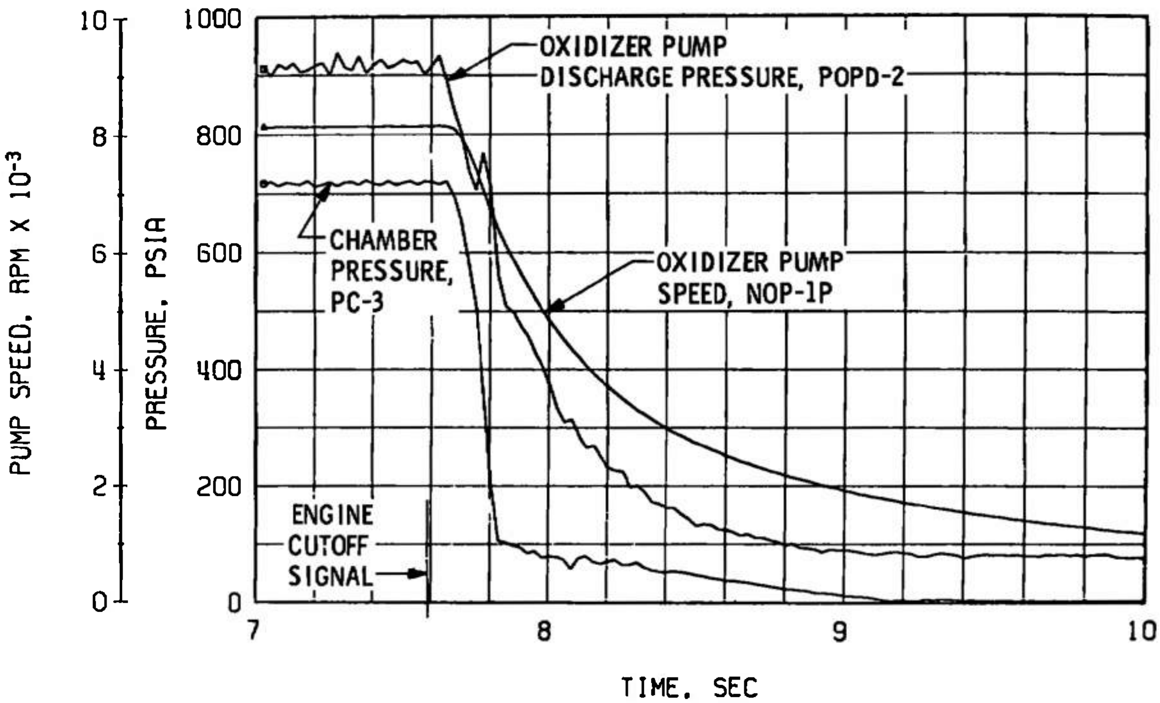



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 77 Continued

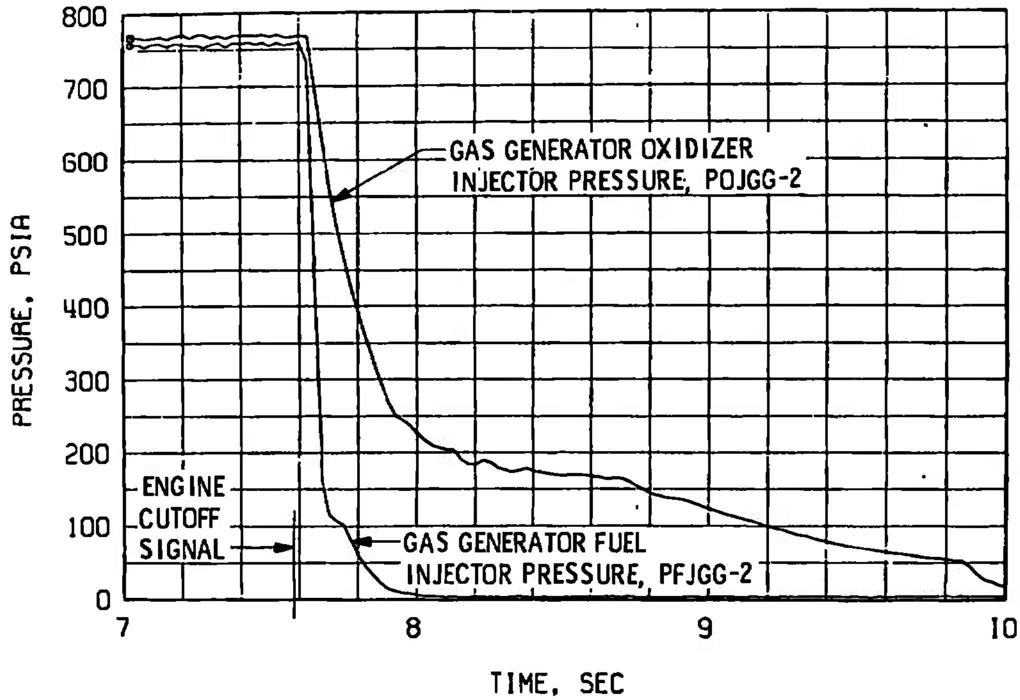



e. Thrust Chamber Fuel System, Shutdown

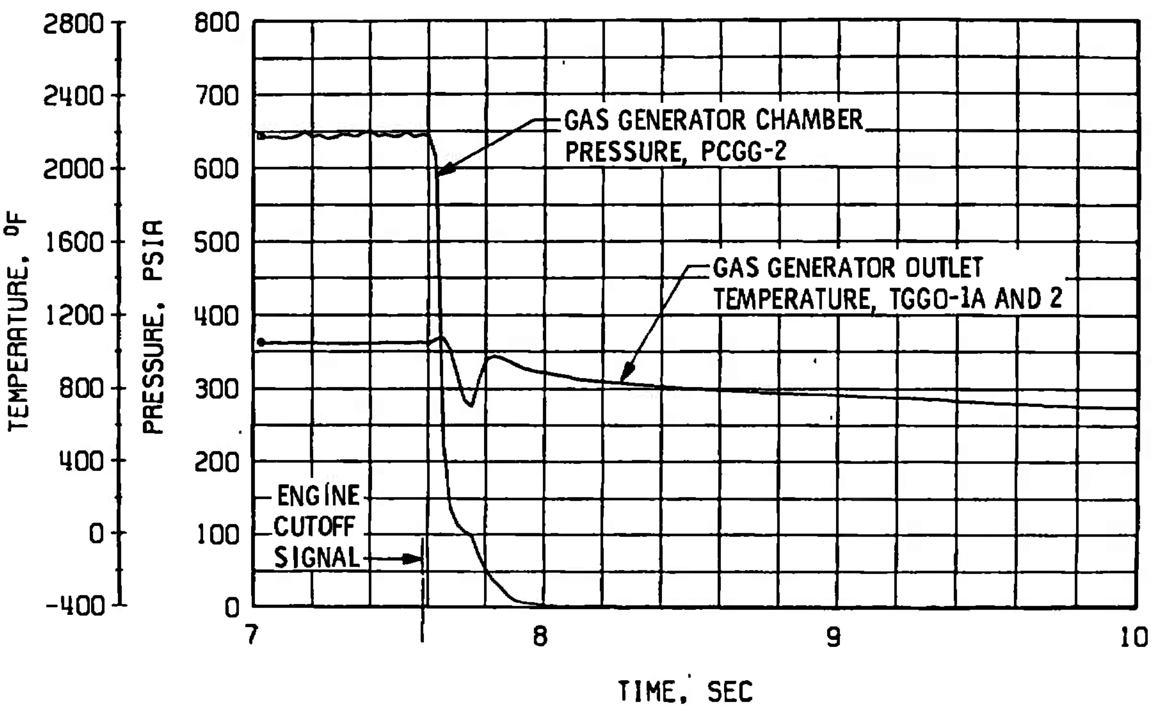



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 77 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 77 Concluded

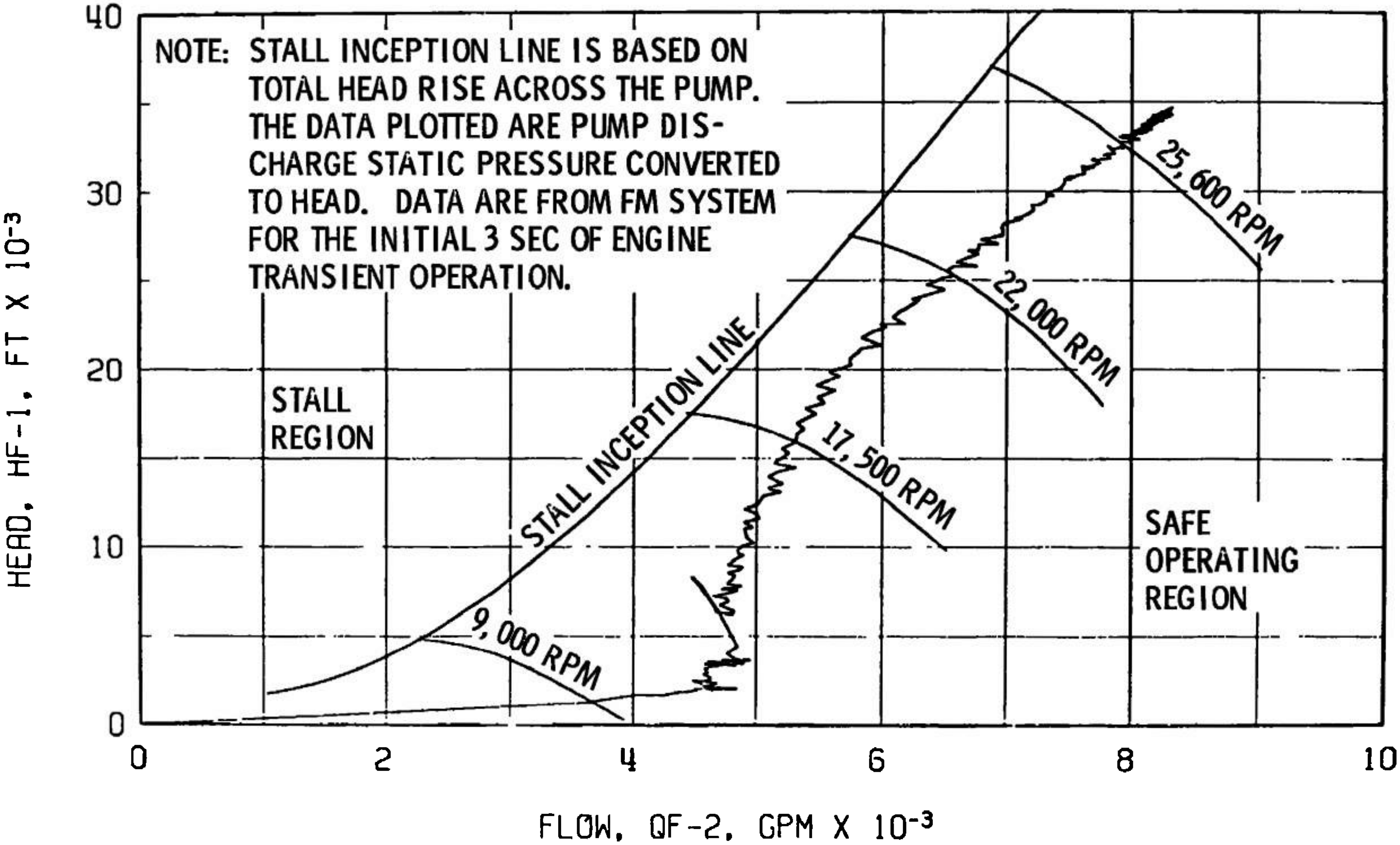
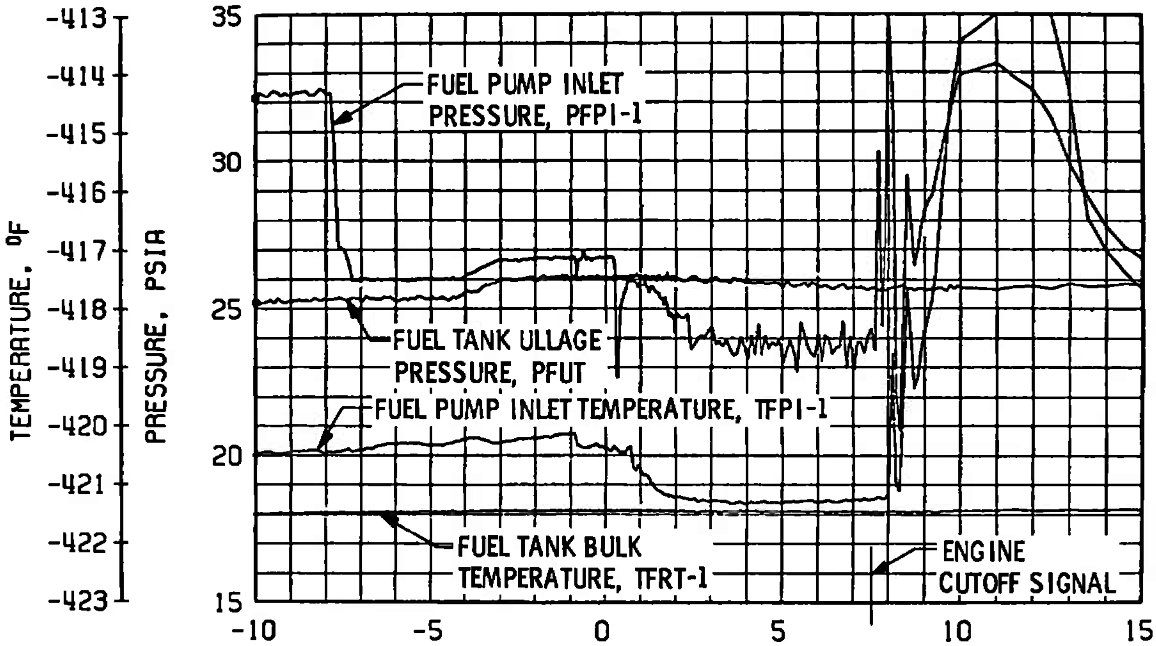
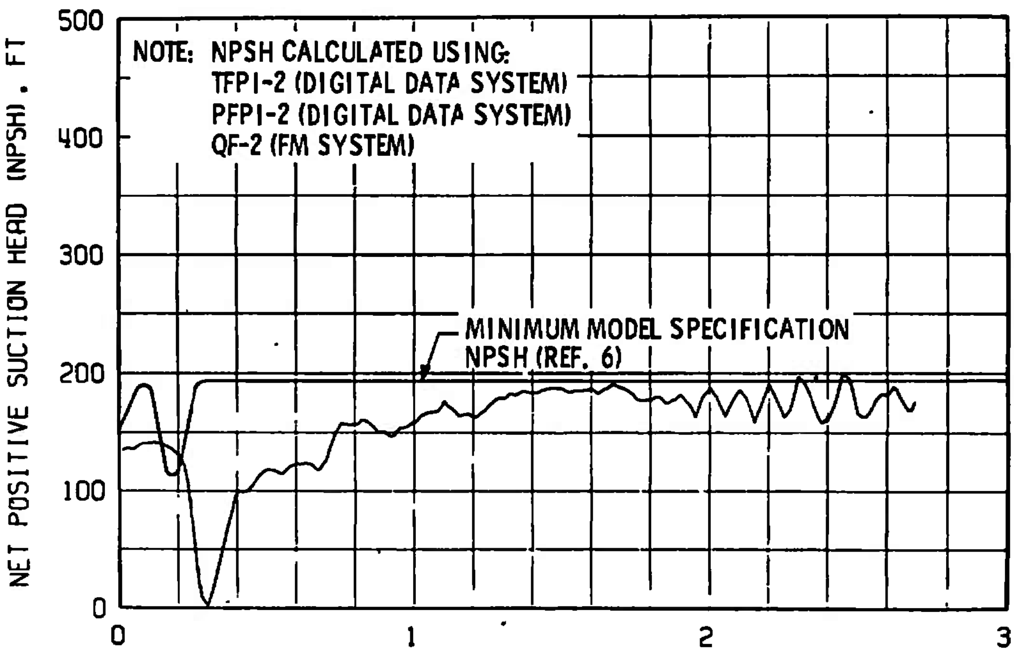



Fig. 78 Fuel Pump Start Transient Performance, Firing 02B

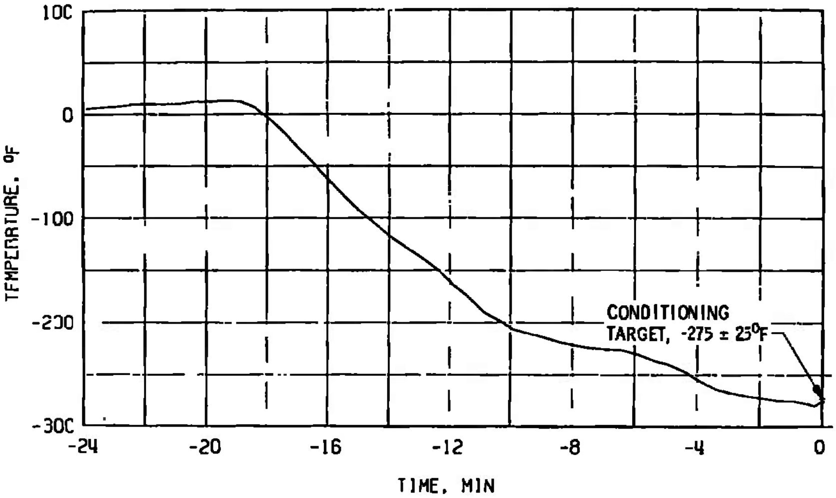



a. Duct Pressure and Temperature Transients

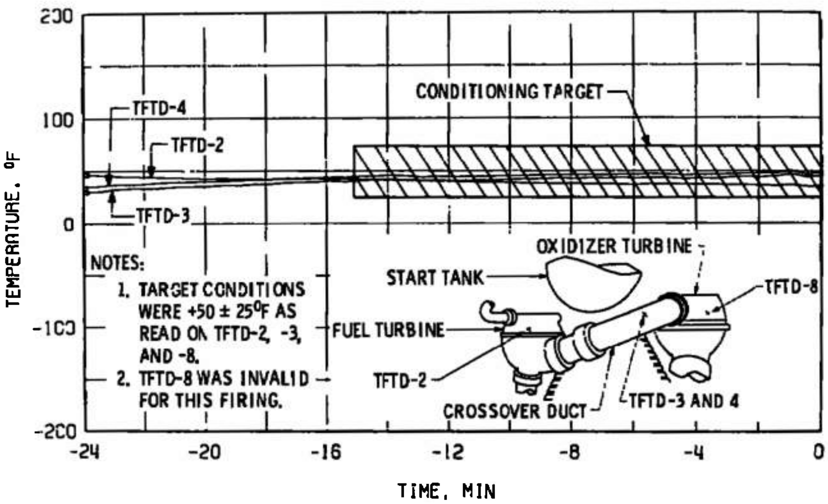



b. Fuel Pump NPSH during Start Transient, Firing 02B

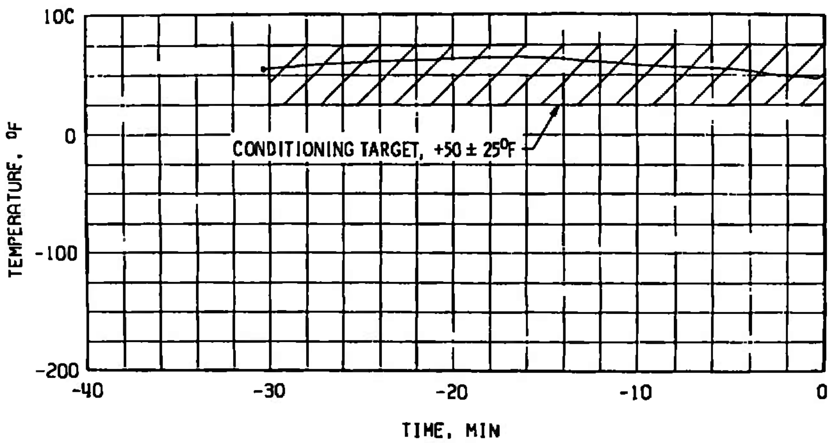
Fig. 79 Fuel Low Pressure Duct Performance, Firing 02B




a. Thrust Chamber, TTC-1P

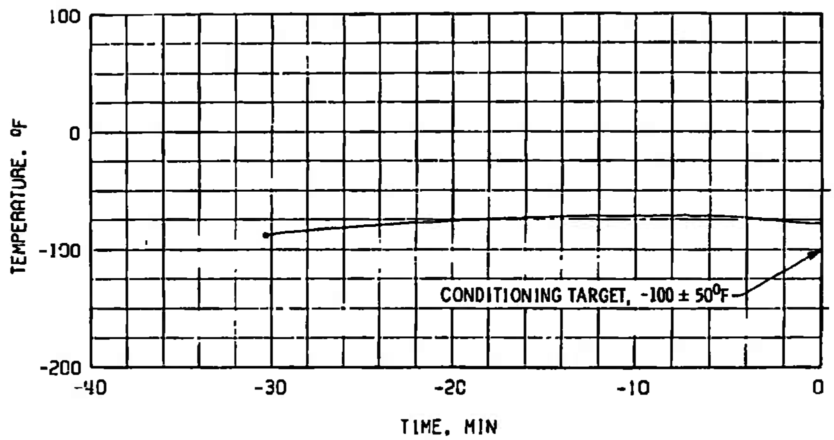



b. Crossover Duct, TFTD

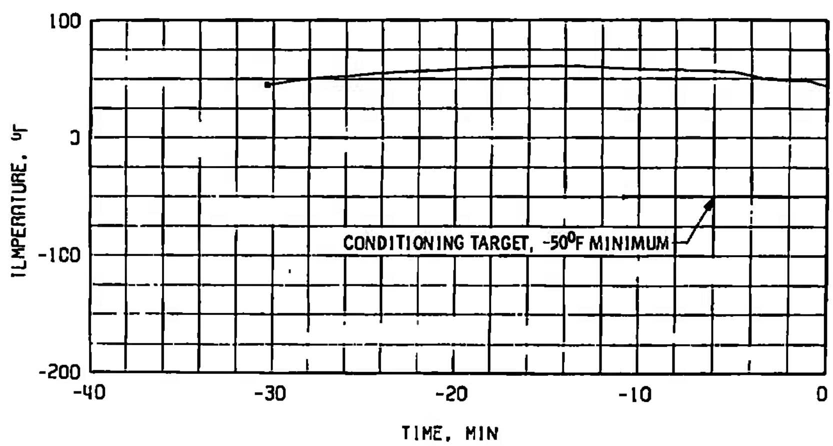



c. Start Tank Discharge Valve, TSTDVOC

Fig. 80 Thermal Conditioning History of Engine Components, Firing 02C




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




e. Gas Generator Control Valve, TGGVRS

Fig. 80 Concluded

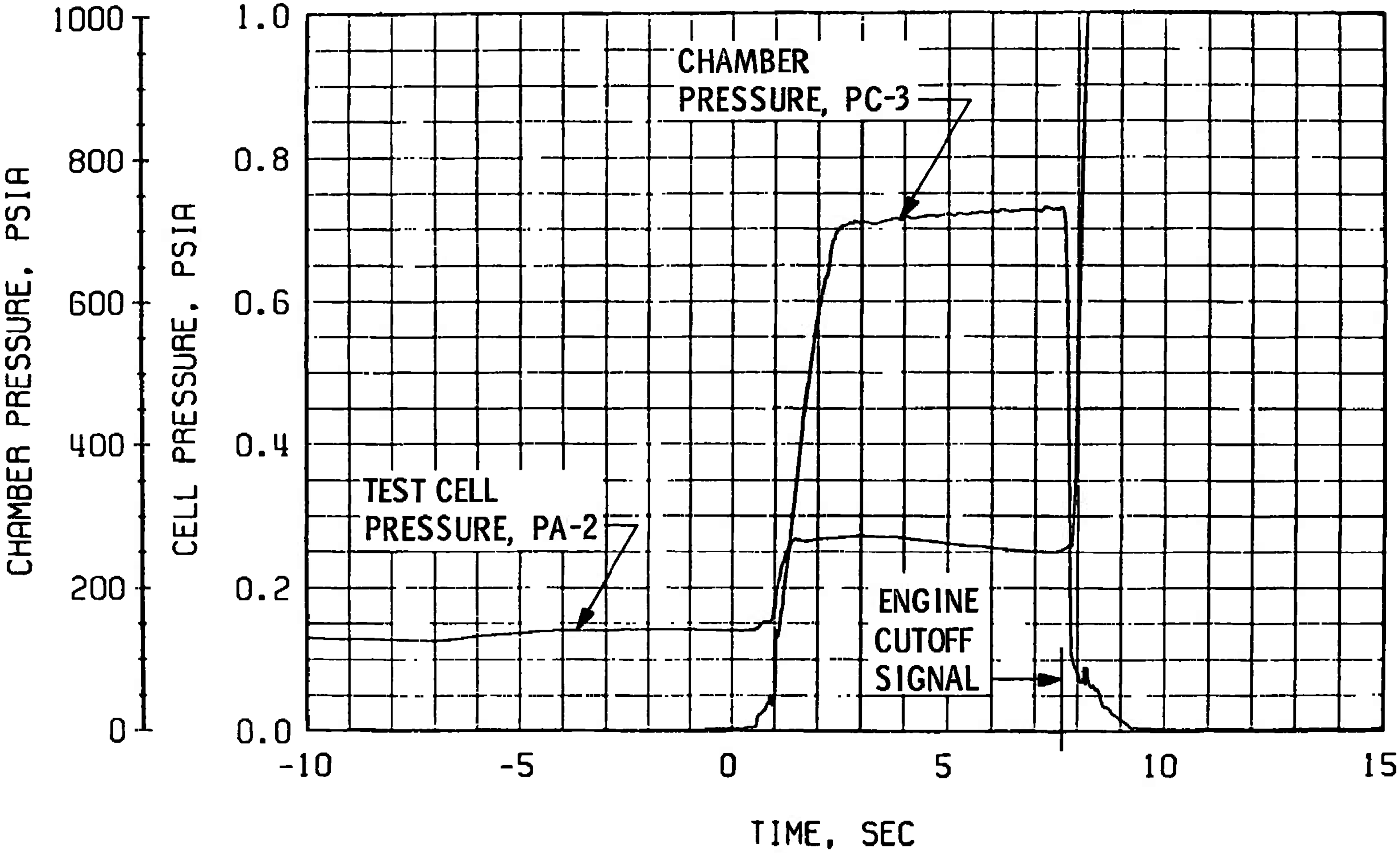
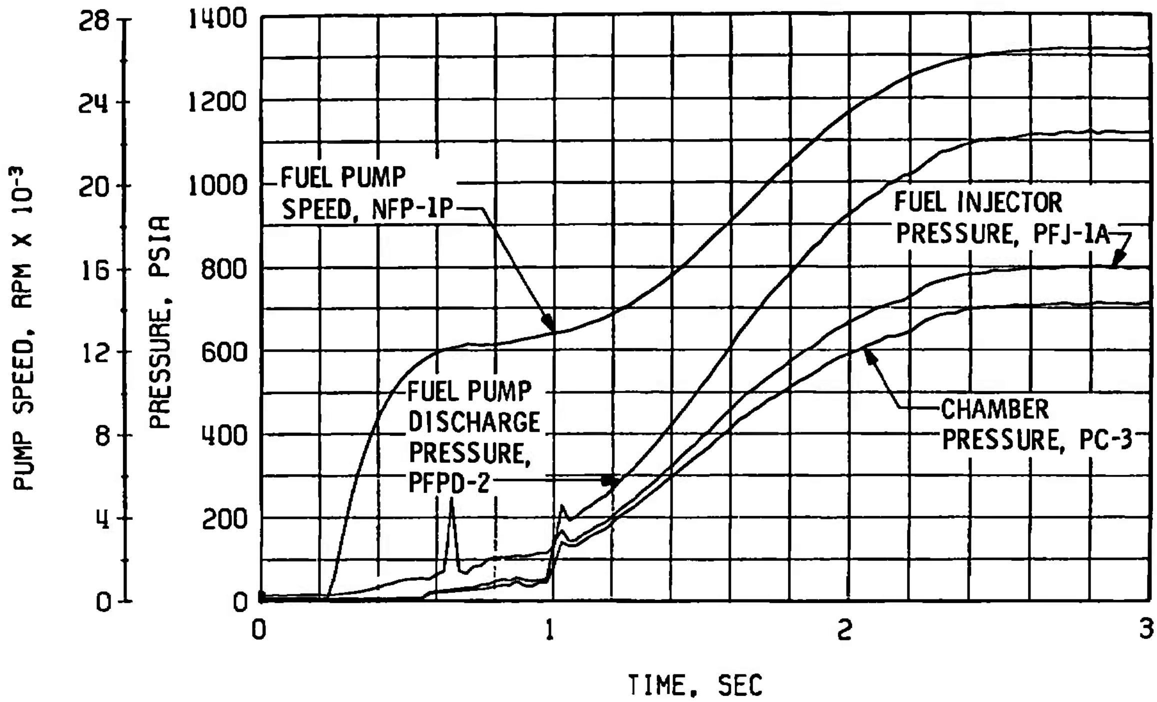
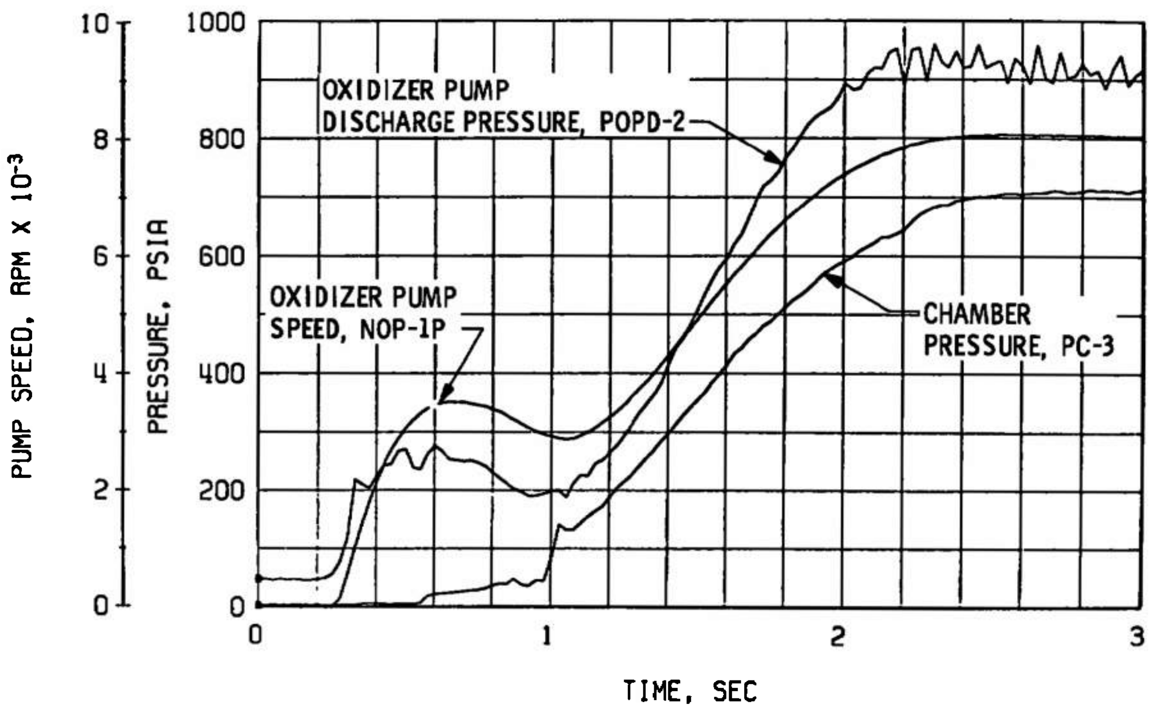



Fig. 81 Engine Ambient and Combustion Chamber Pressures, Firing 02C

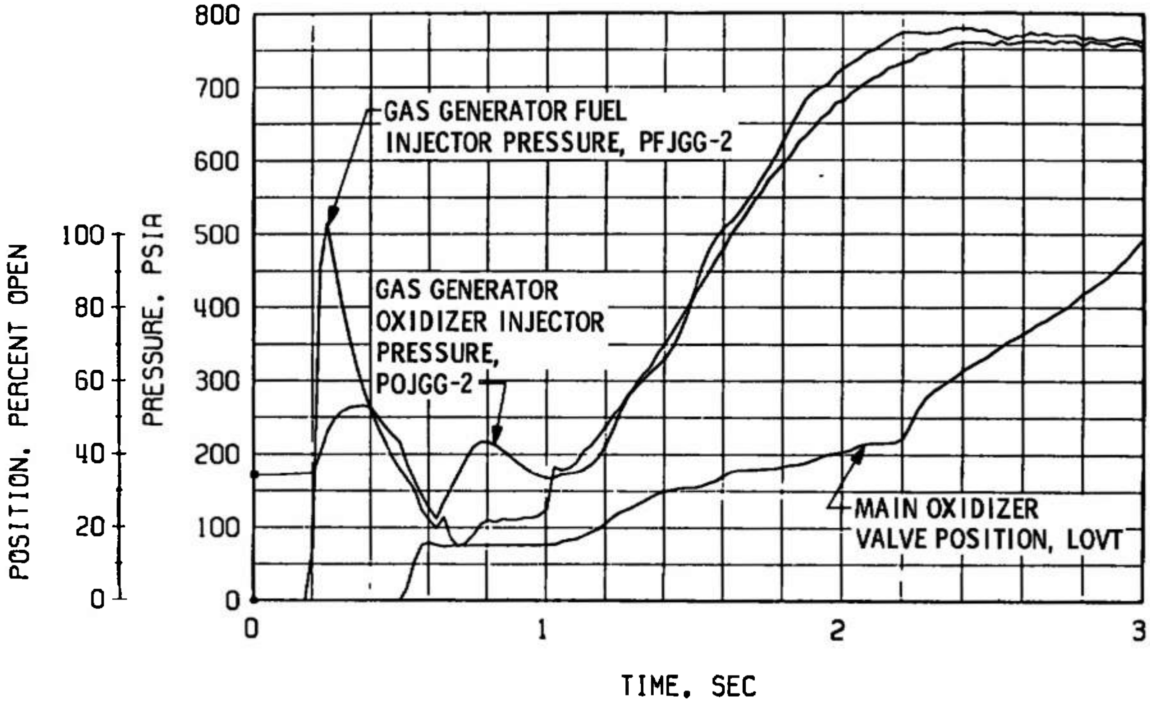



a. Thrust Chamber Fuel System, Start

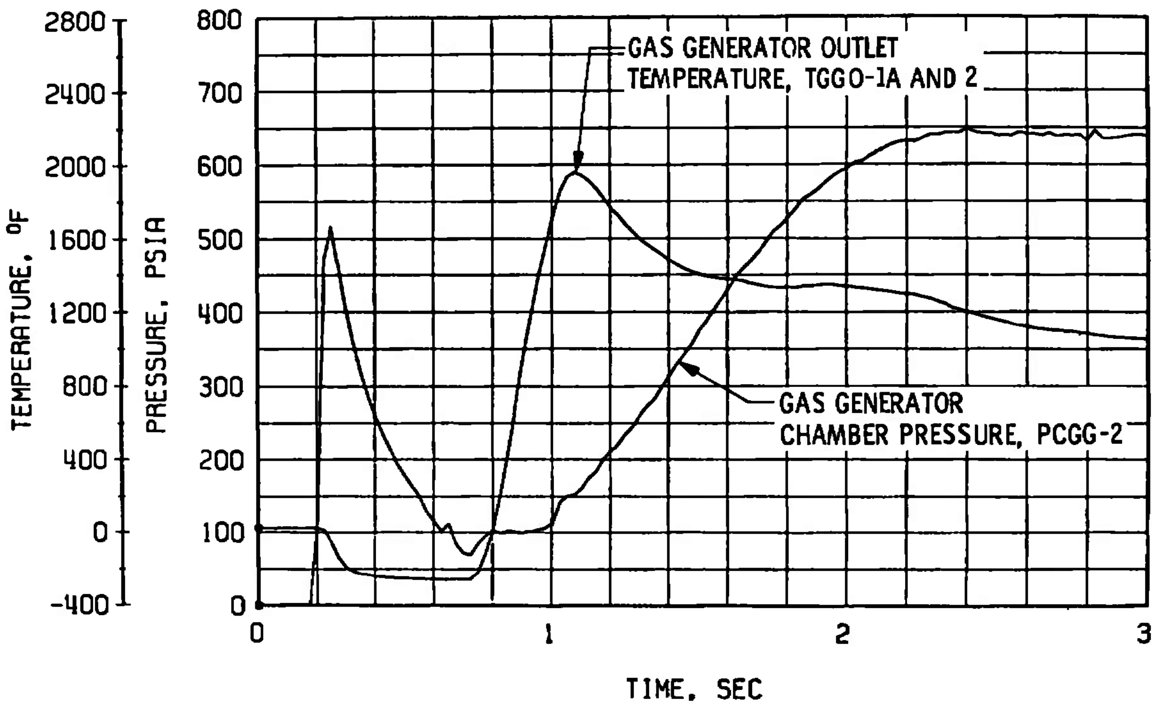



b. Thrust Chamber Oxidizer System, Start

Fig. 82 Engine Transient Operation, Firing 02C

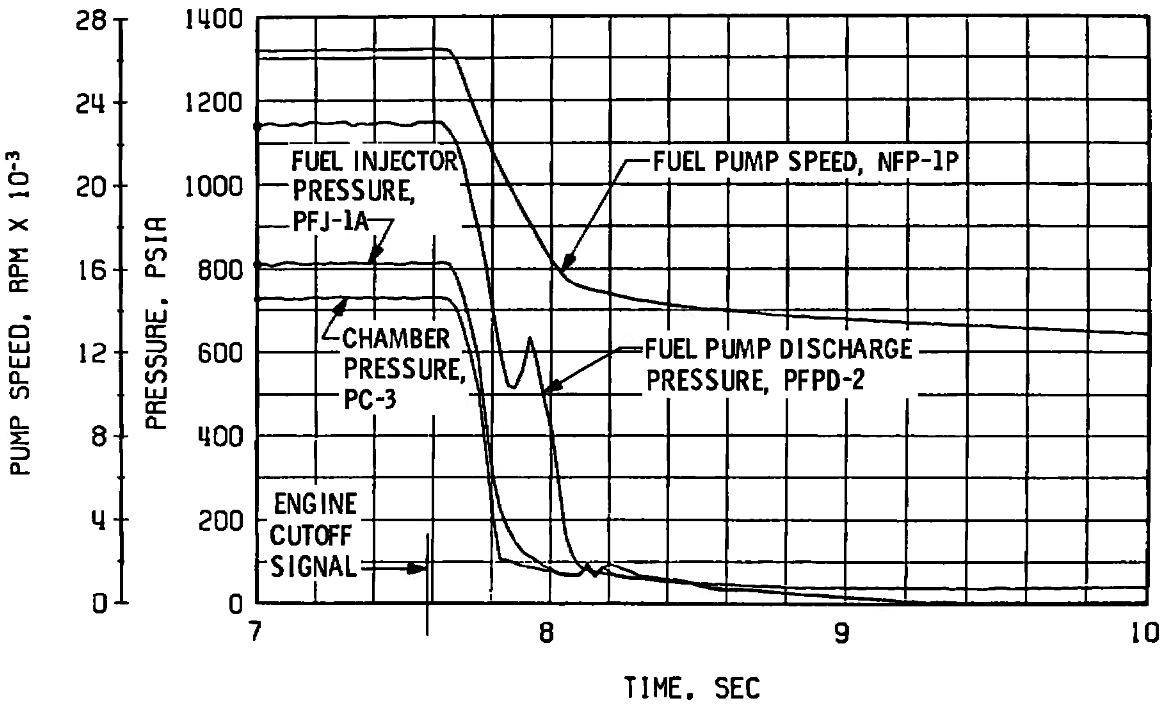



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

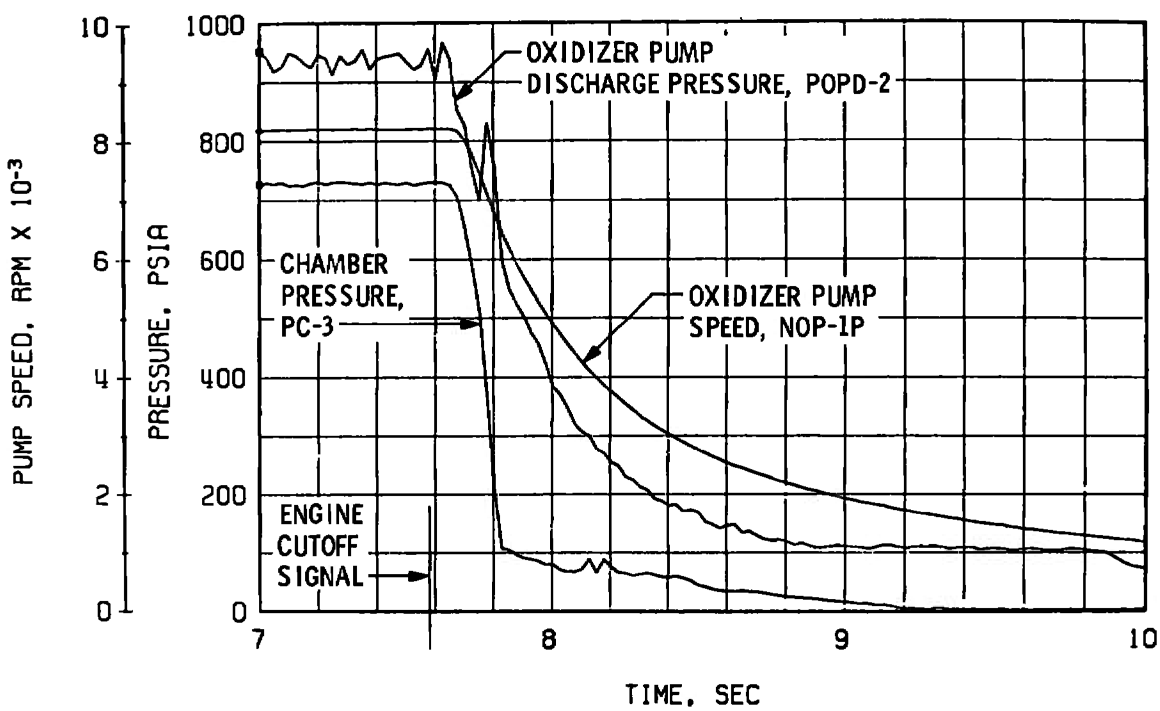



d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 82 Continued

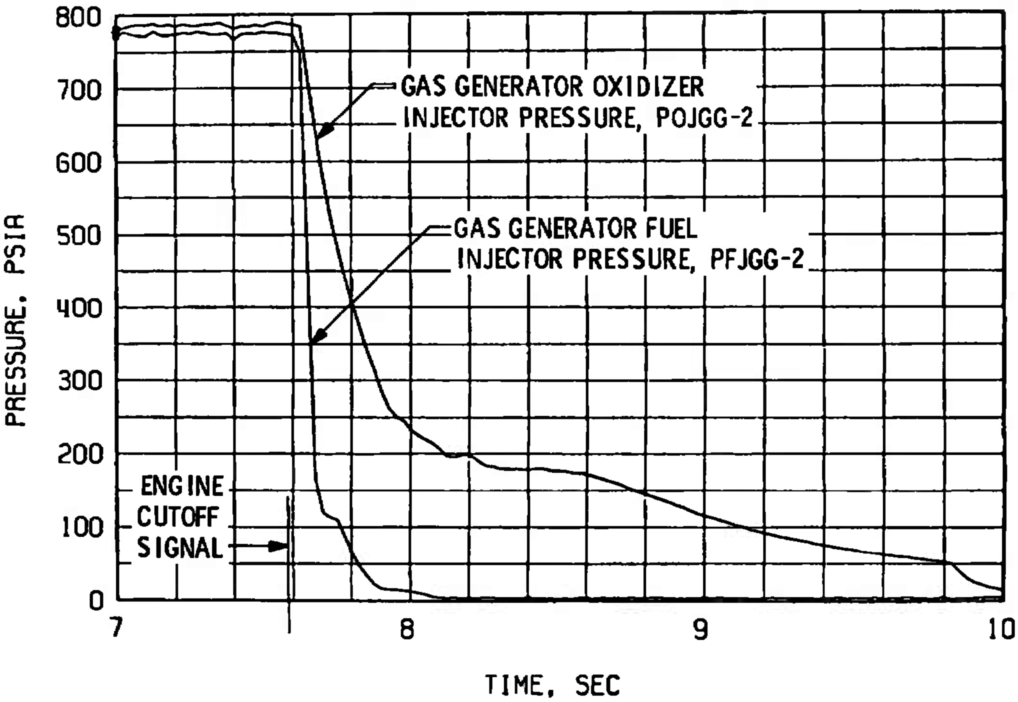



e. Thrust Chamber Fuel System, Shutdown

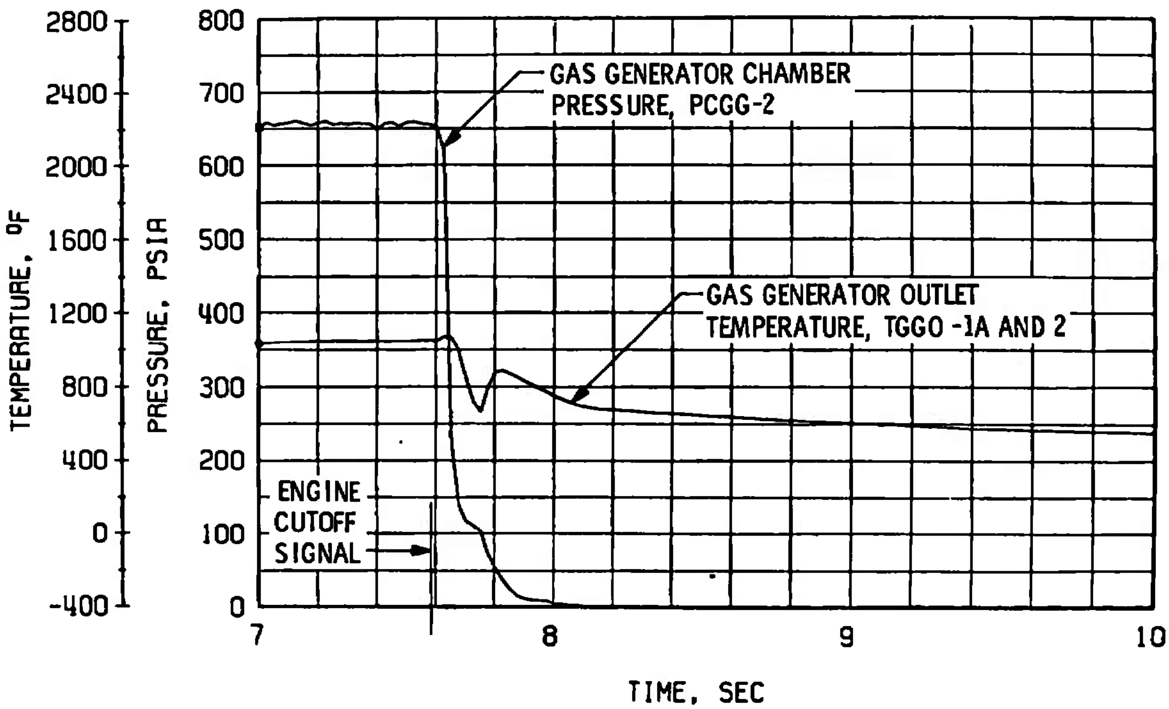



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 82 Continued




g. Gas Generator Injector Pressures, Shutdown




h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 82 Concluded

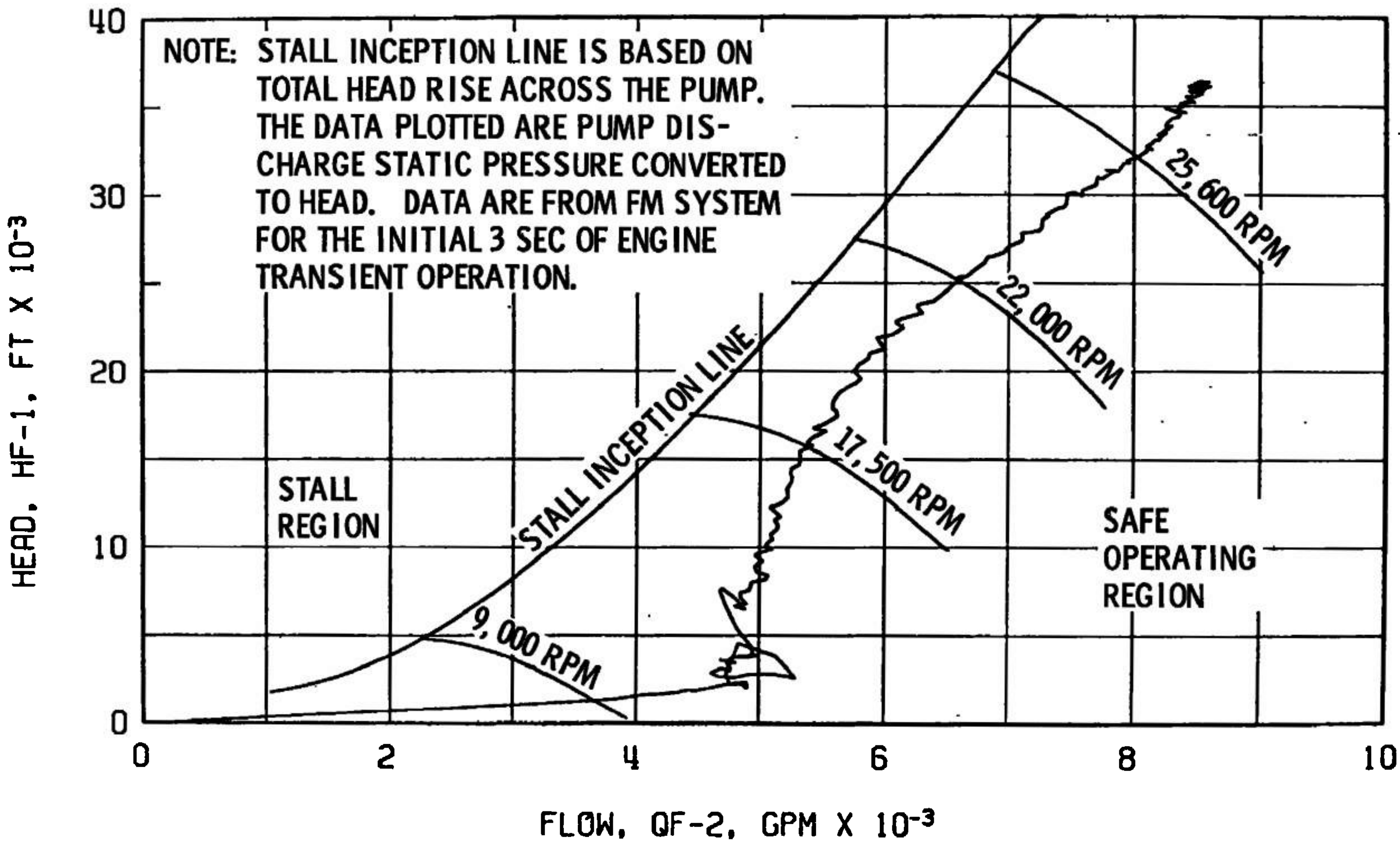
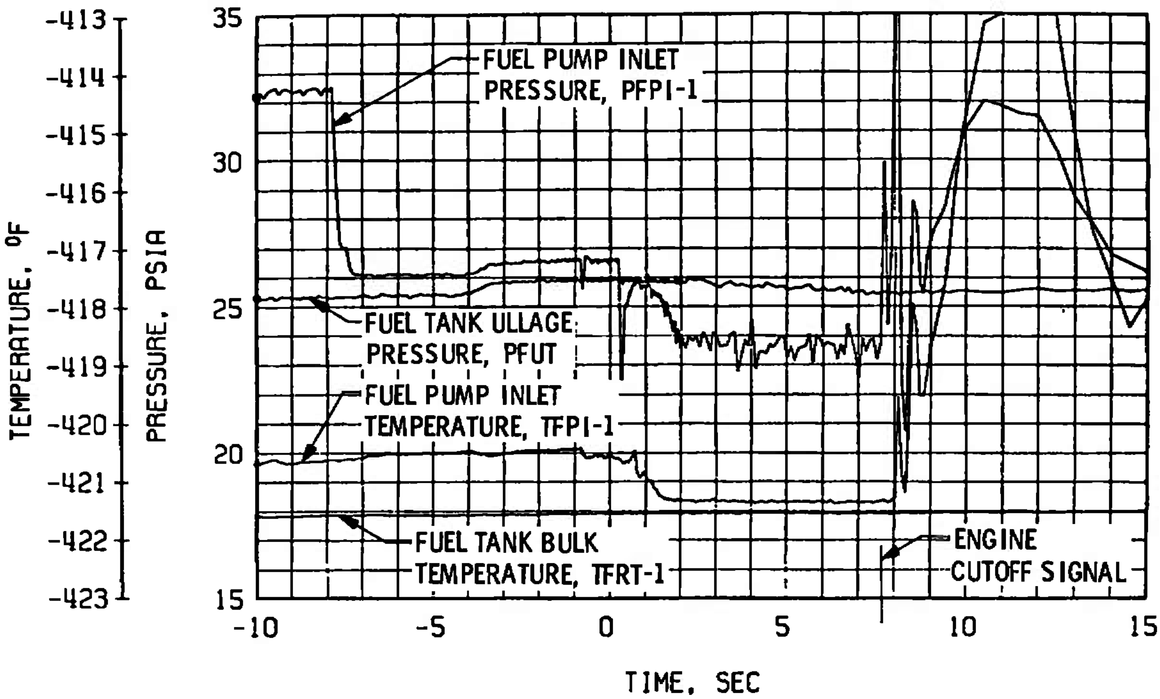
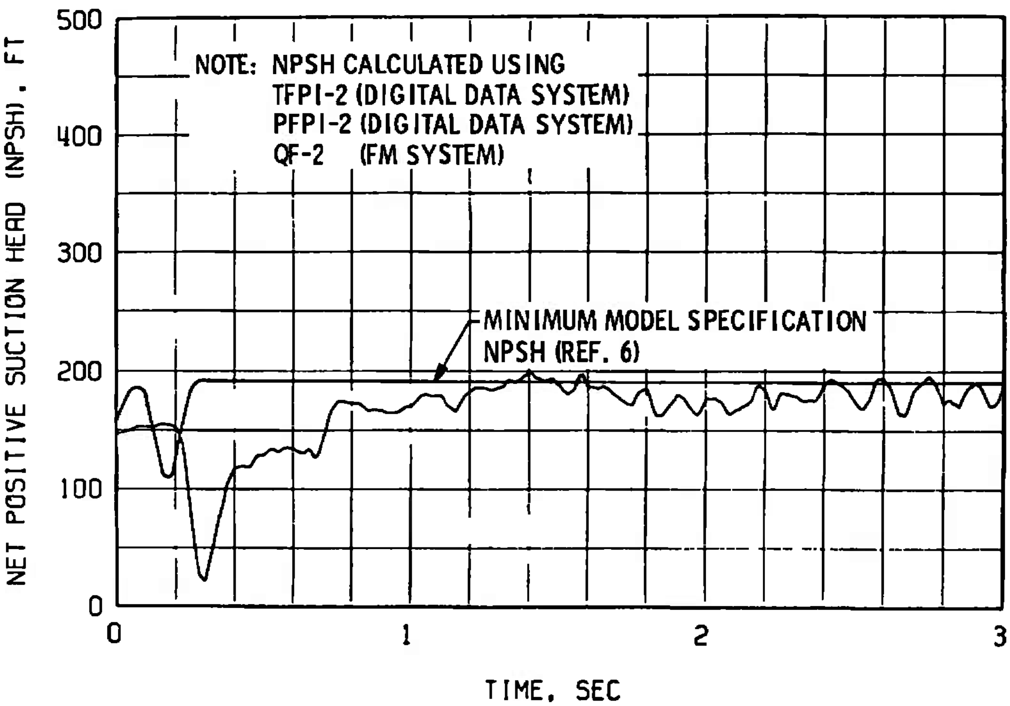



Fig. 83 Fuel Pump Start Transient Performance, Firing 02C

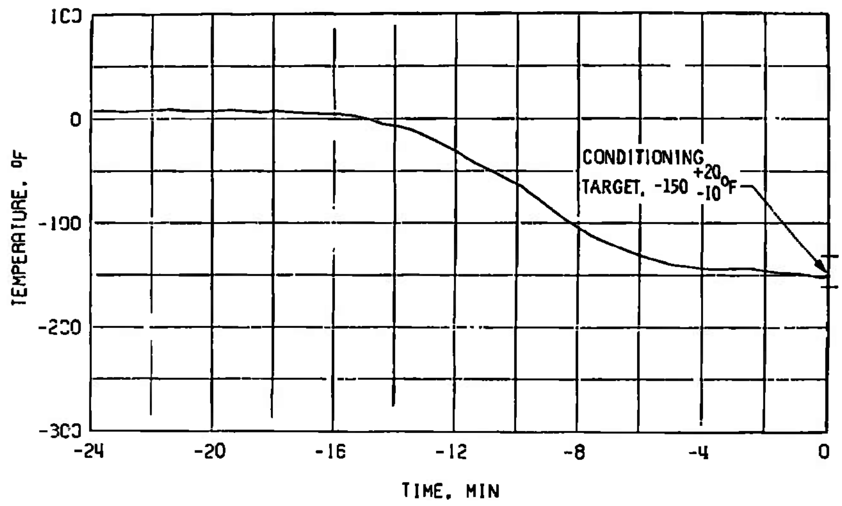



a. Duct Pressure and Temperature Transients

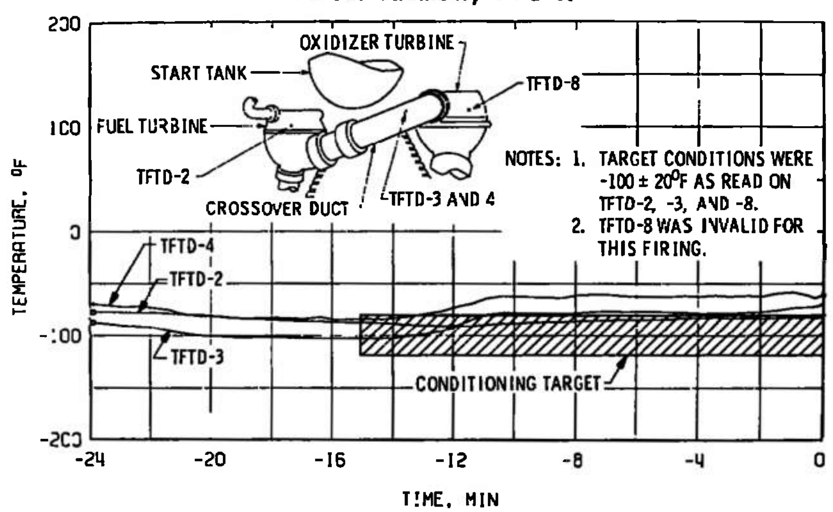



b. Fuel Pump NPSH during Start Transient, Firing 02C

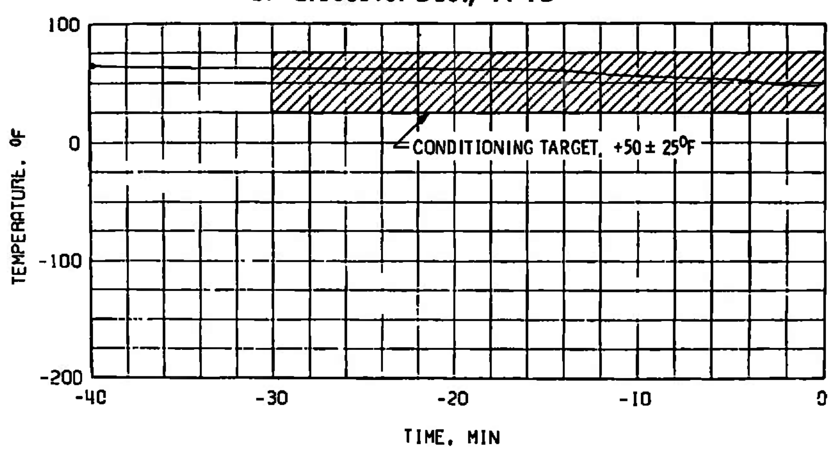
Fig. 84 Fuel Low Pressure Duct Performance, Firing 02C




a. Thrust Chamber, TTC-1P

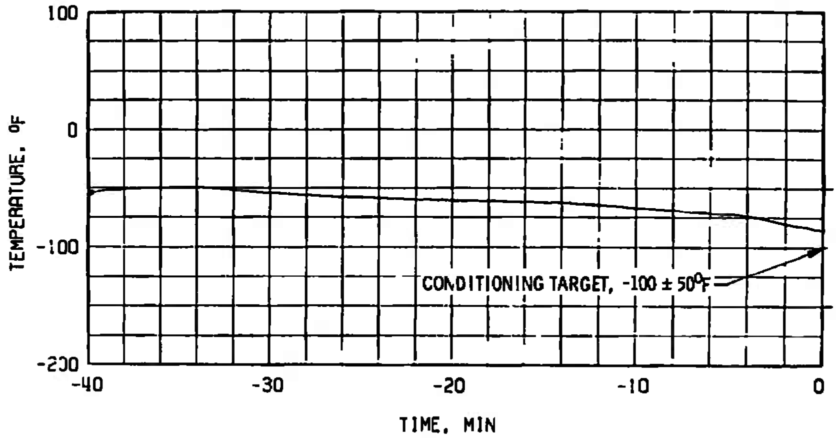



b. Crossover Duct, TFTD

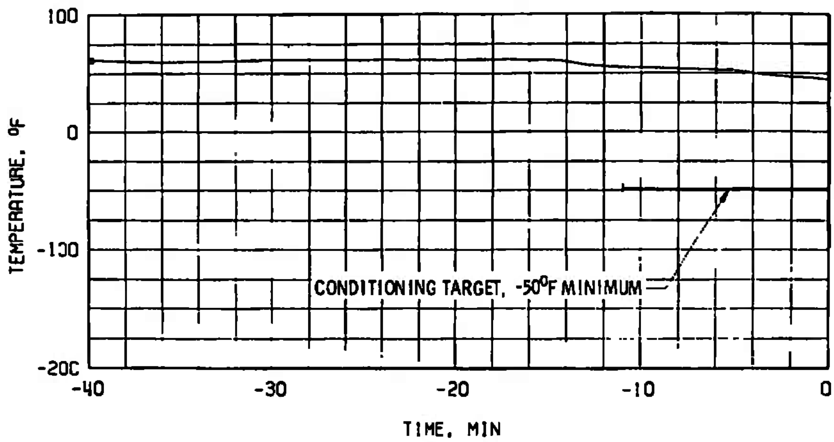



c. Start Tank Discharge Valve, TSTDVOC

Fig. 85 Thermal Conditioning History of Engine Components, Firing 02D




**d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1**




**e. Gas Generator Control Valve, TGGVRS**

**Fig. 85 Concluded**

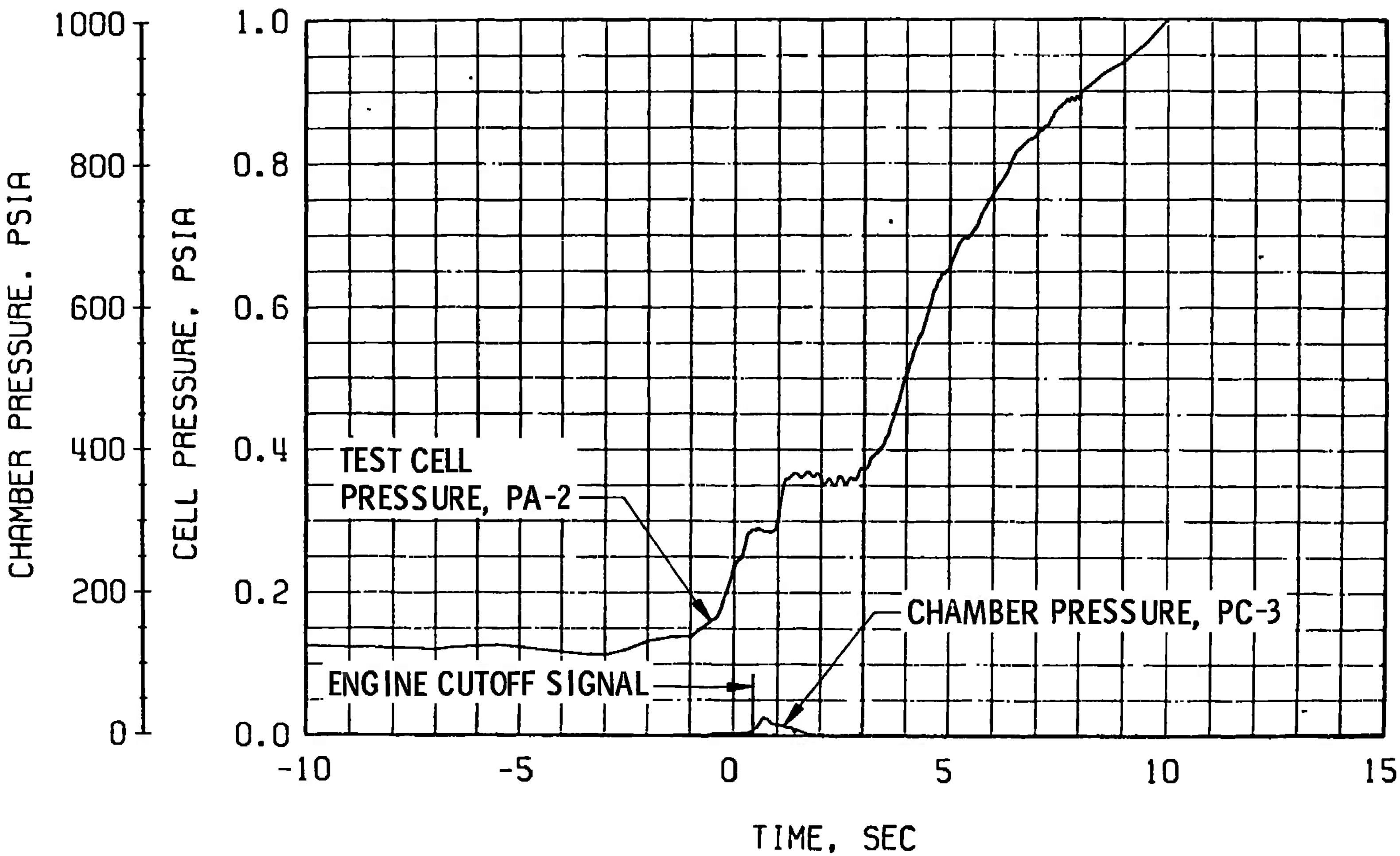
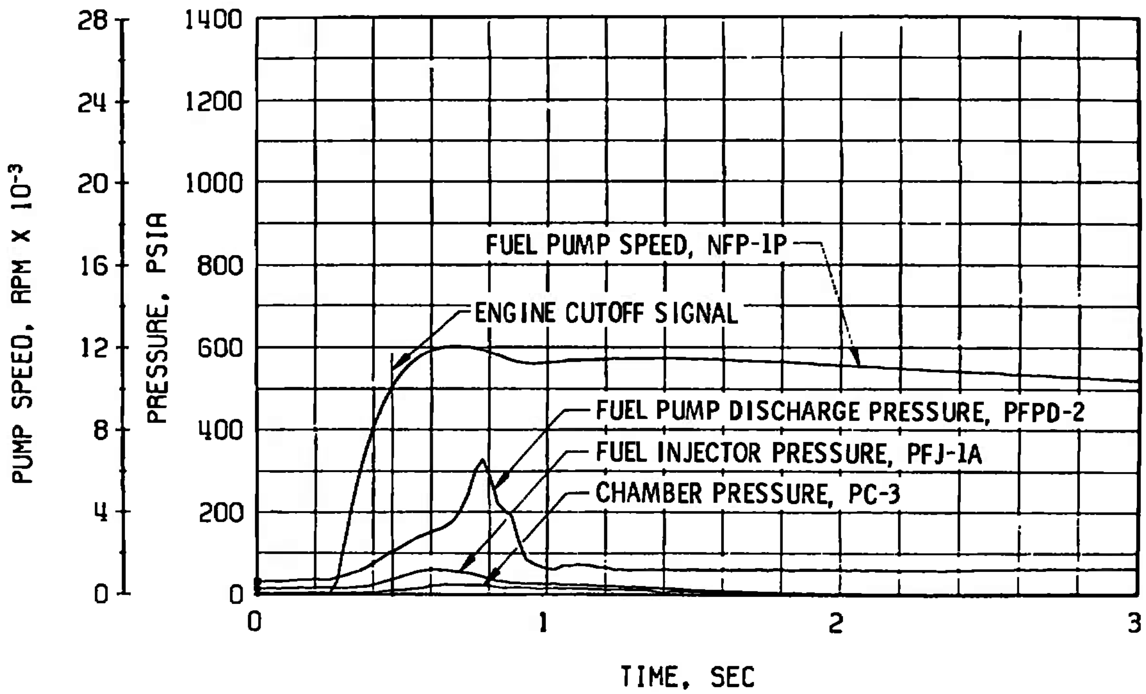
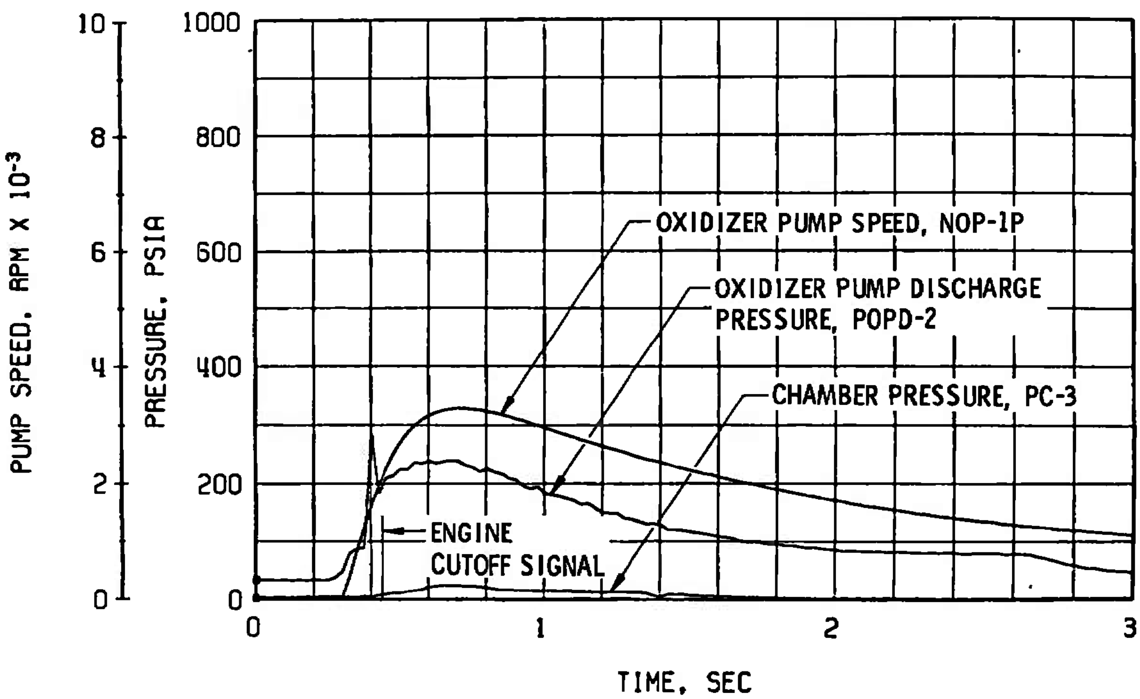



Fig. 86 Engine Ambient and Combustion Chamber Pressures, Firing 02D

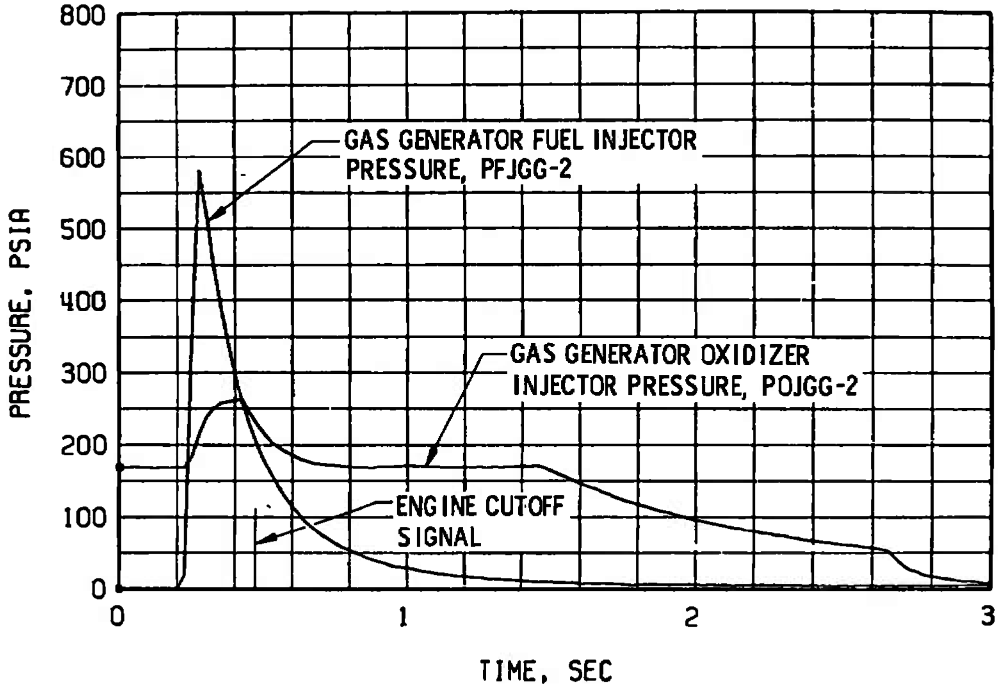



a. Thrust Chamber Fuel System, Start and Shutdown

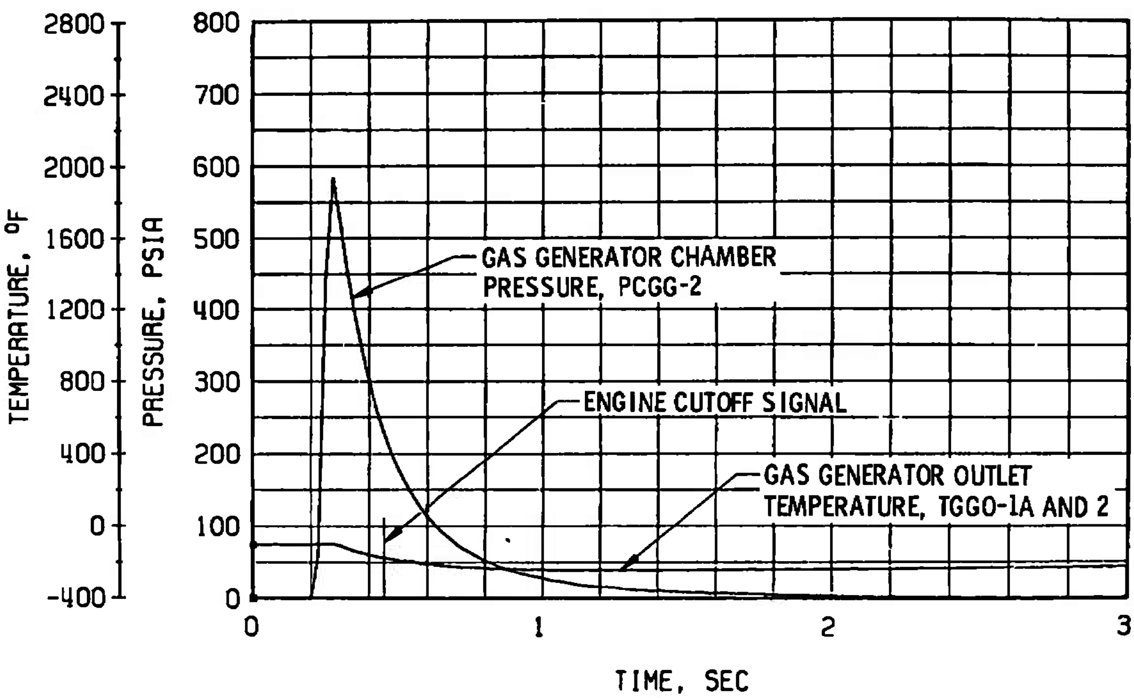



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 87 Engine Transient Operation, Firing 02D




c. Gas Generator Injector Pressures, Start and Shutdown




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

Fig. 87 Concluded

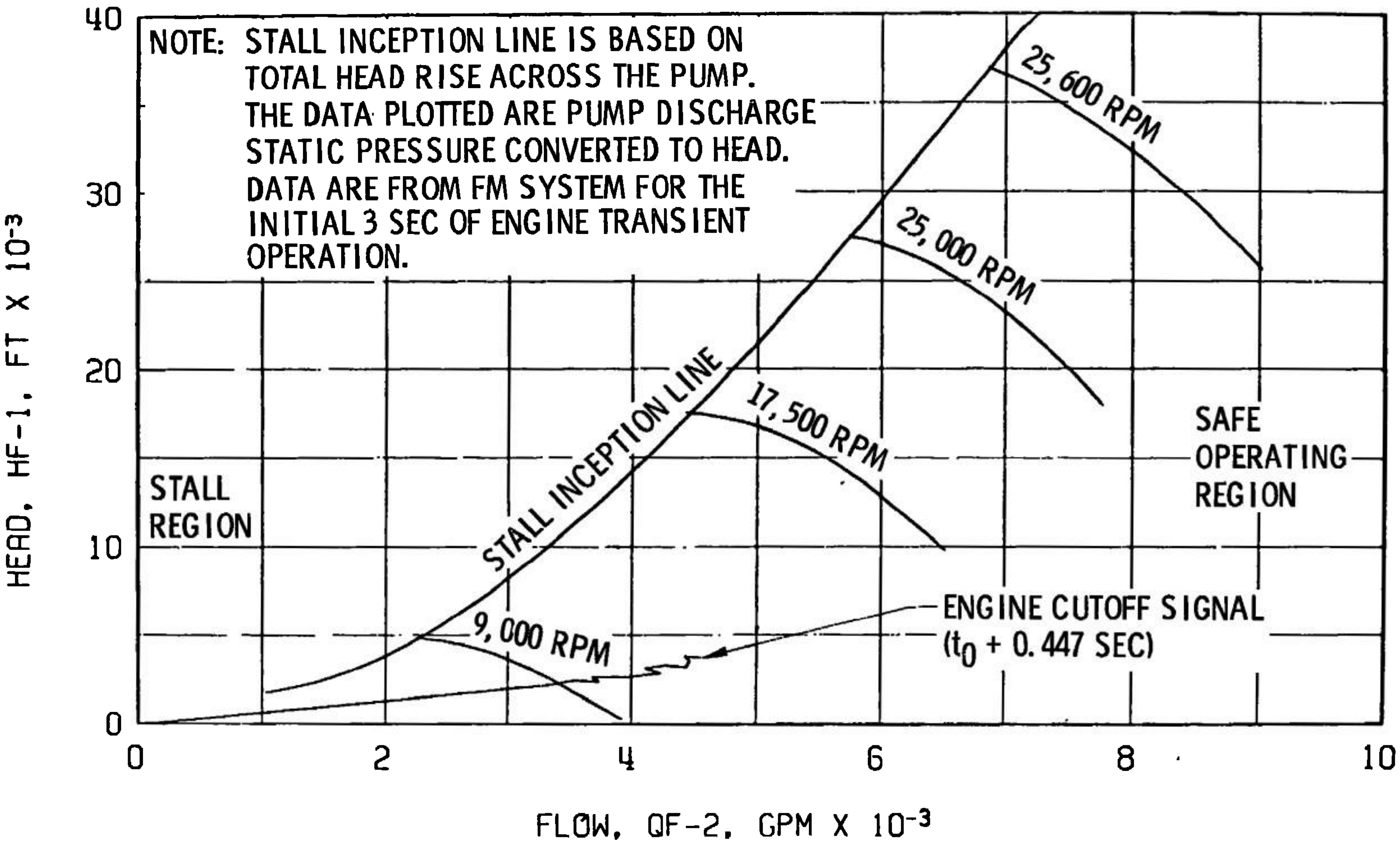
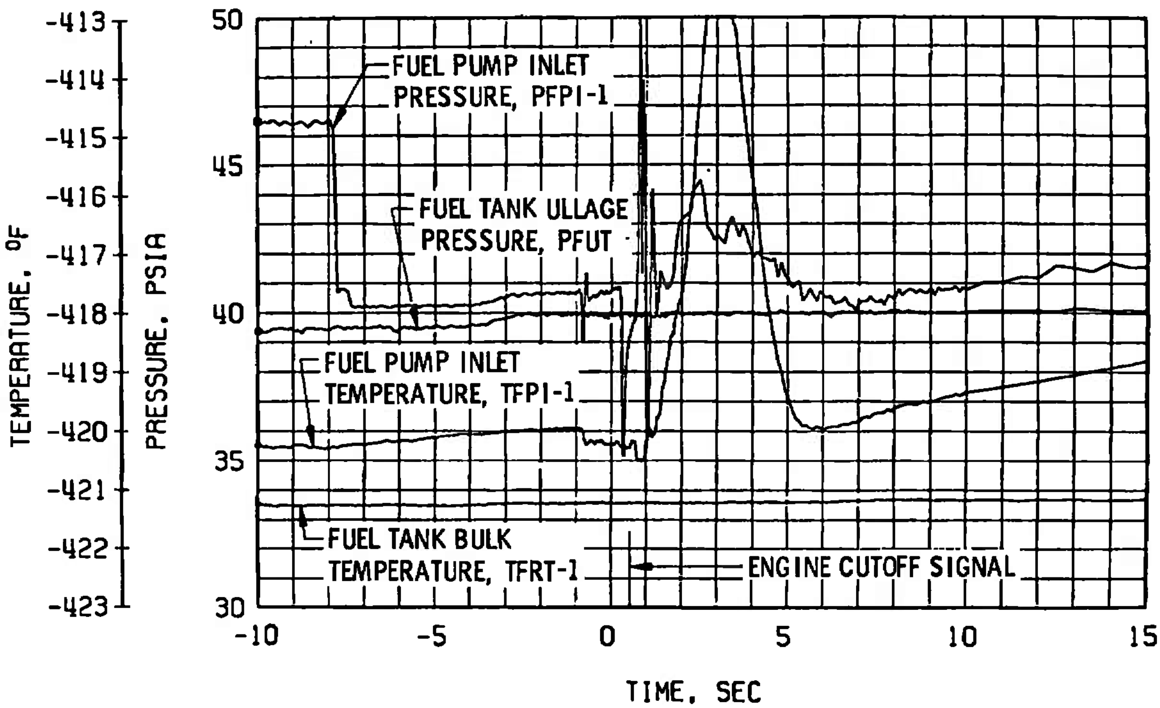
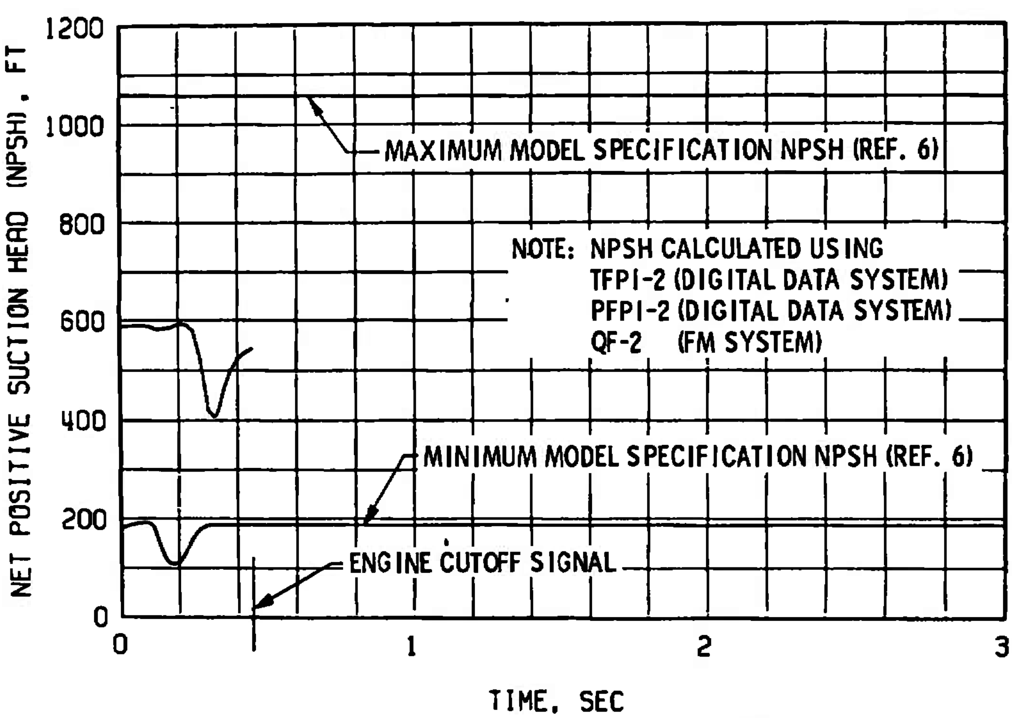



Fig. 88 Fuel Pump Start Transient Performance, Firing 02D




a. Duct Pressure and Temperature Transients




b. Fuel Pump NPSH during Start Transient, Firing 02D

Fig. 89 Fuel Low Pressure Duct Performance, Firing 02D

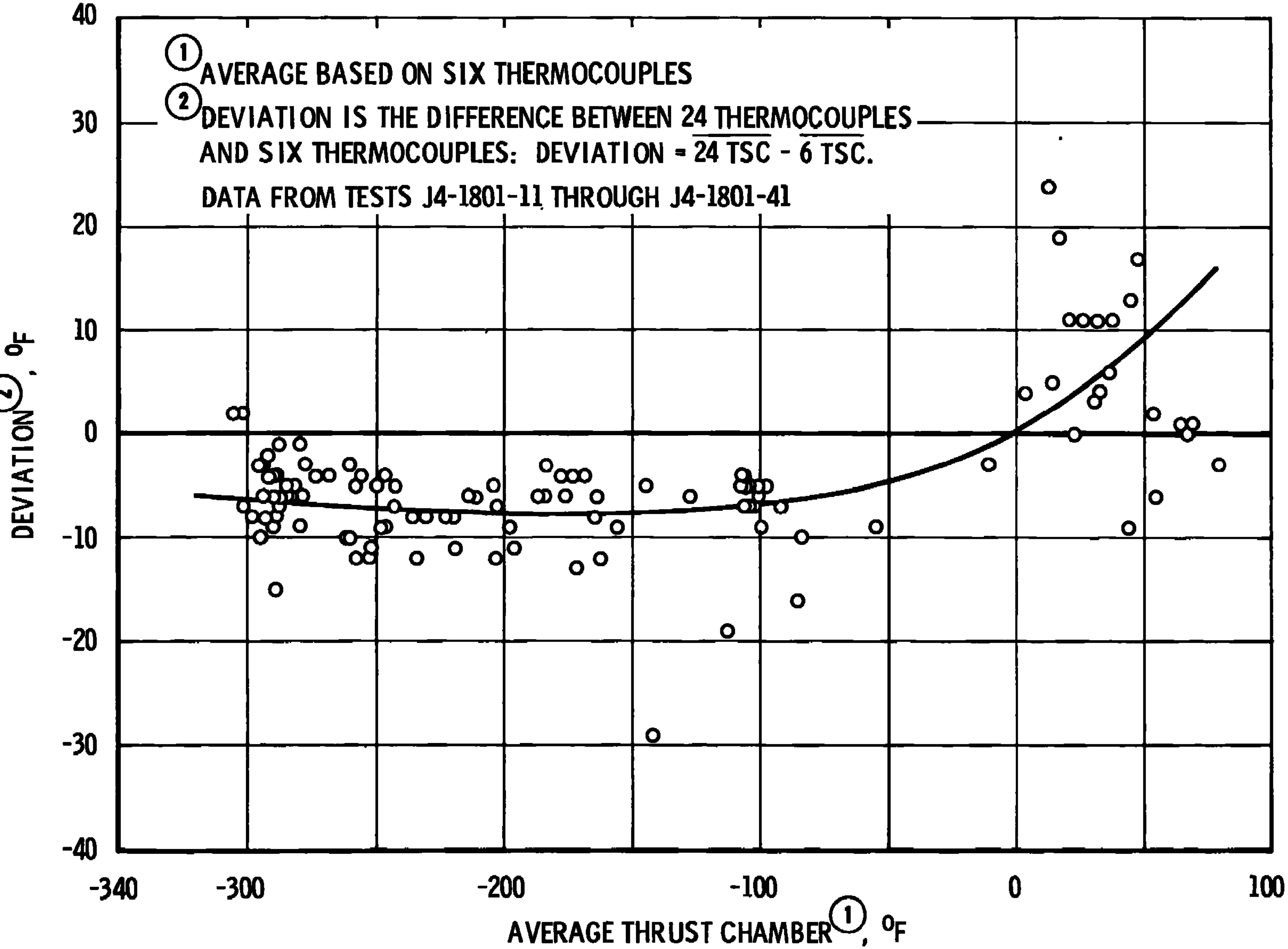



**Fig. 90 Expected Deviation in Comparing Thrust Chamber Average Temperature Utilizing 6- and 24-Thermocouple Averages**

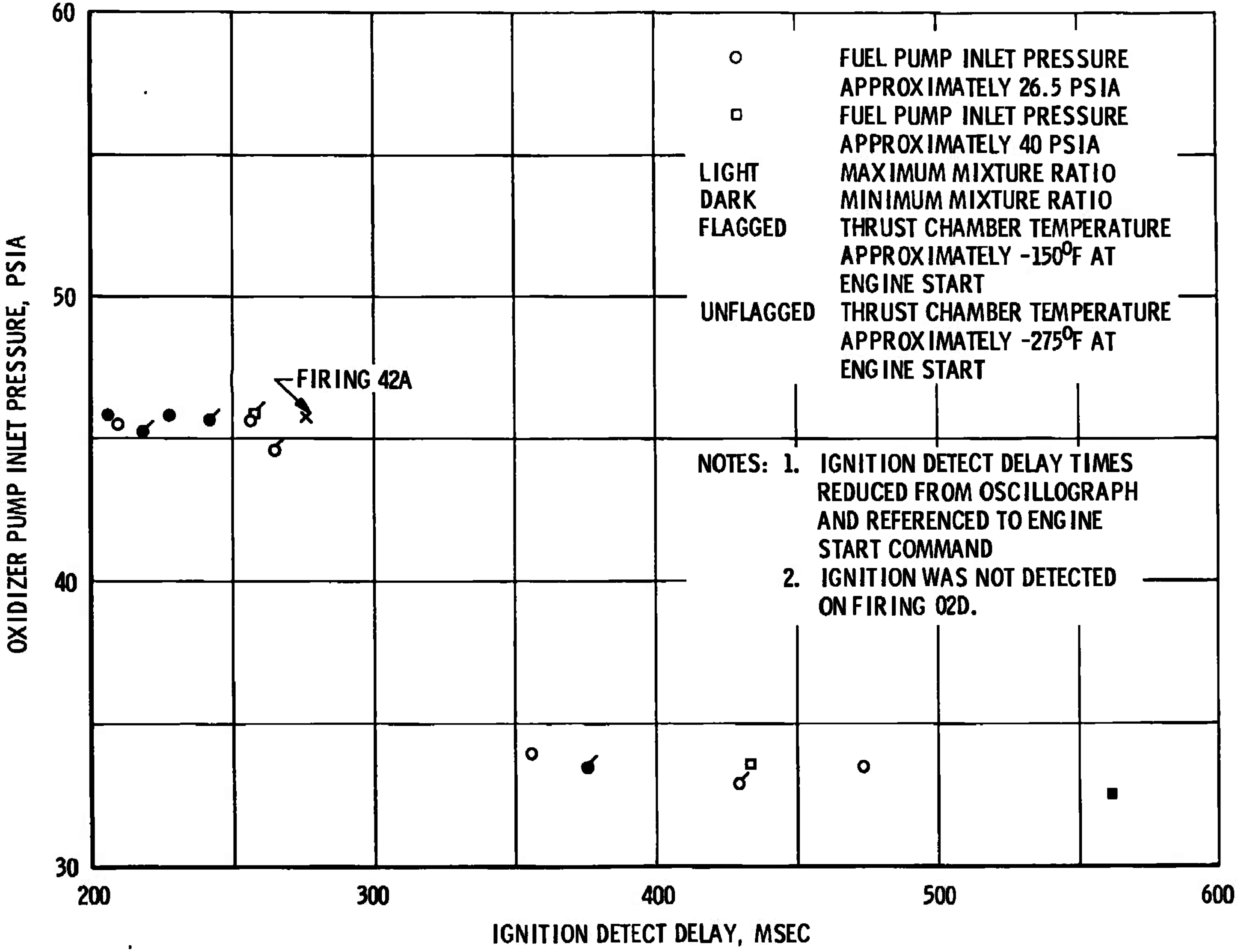



**Fig. 91 Oxidizer Pump Inlet Pressure Effect on Augmented Spark Igniter Ignition Detect Delay Time**

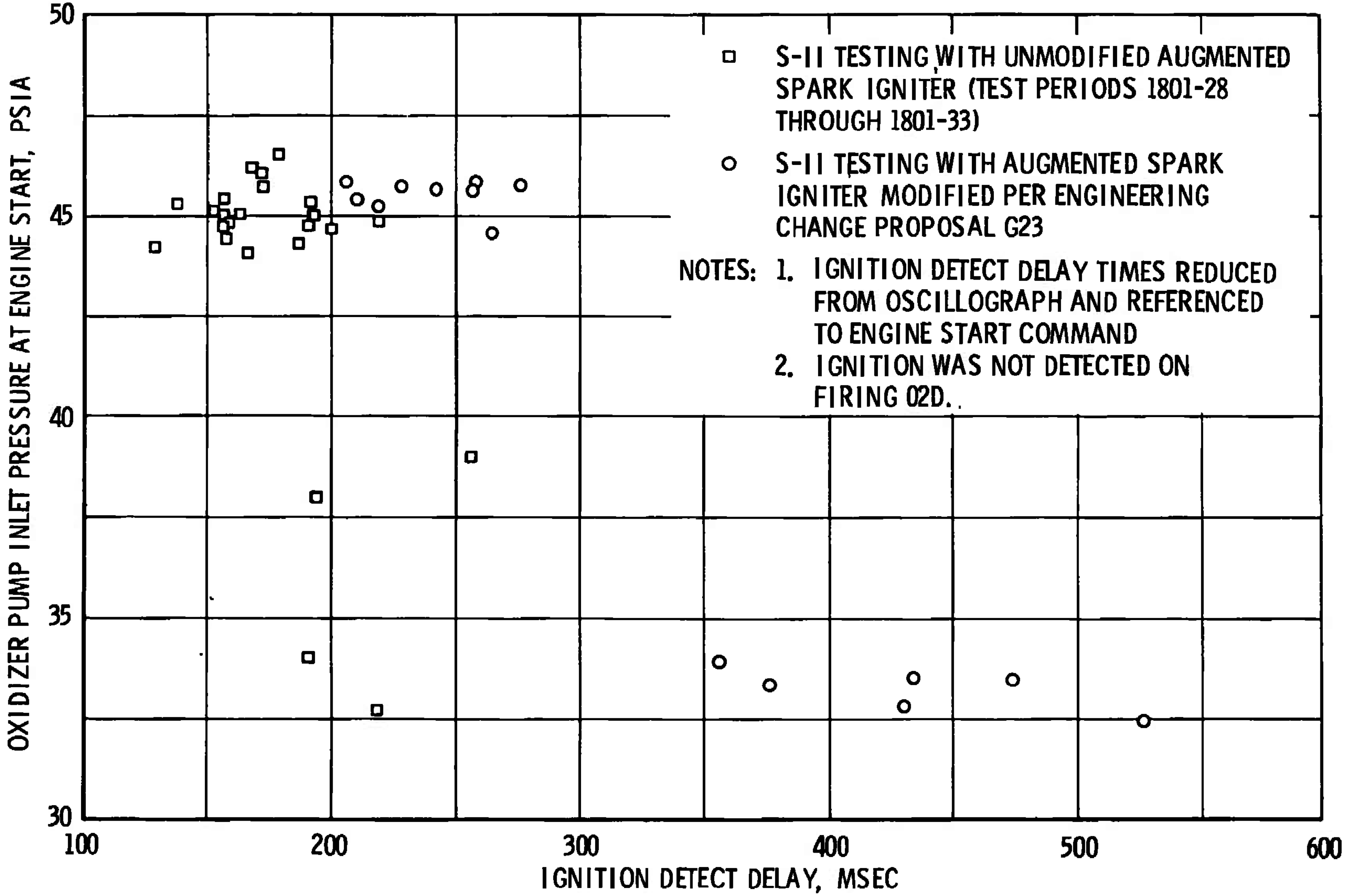



**Fig. 92 Comparison of Augmented Spark Igniter Ignition Detect Delay for Test Periods J4-1801-42 through J4-1901-02 and J4-1801-28 through J4-1801-33**

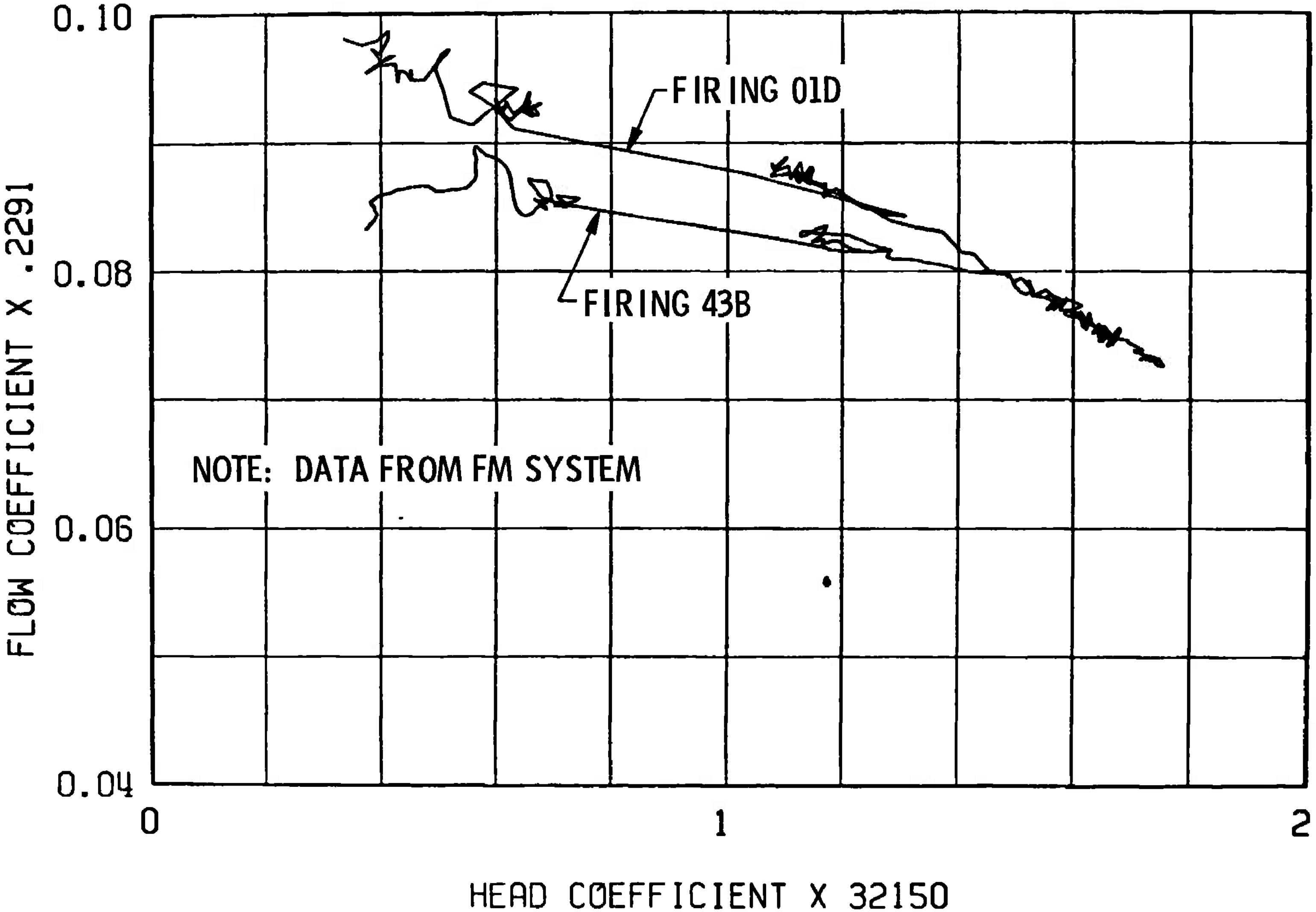



Fig. 93 Fuel Pump Operating Characteristics, Firings 43B and 01D

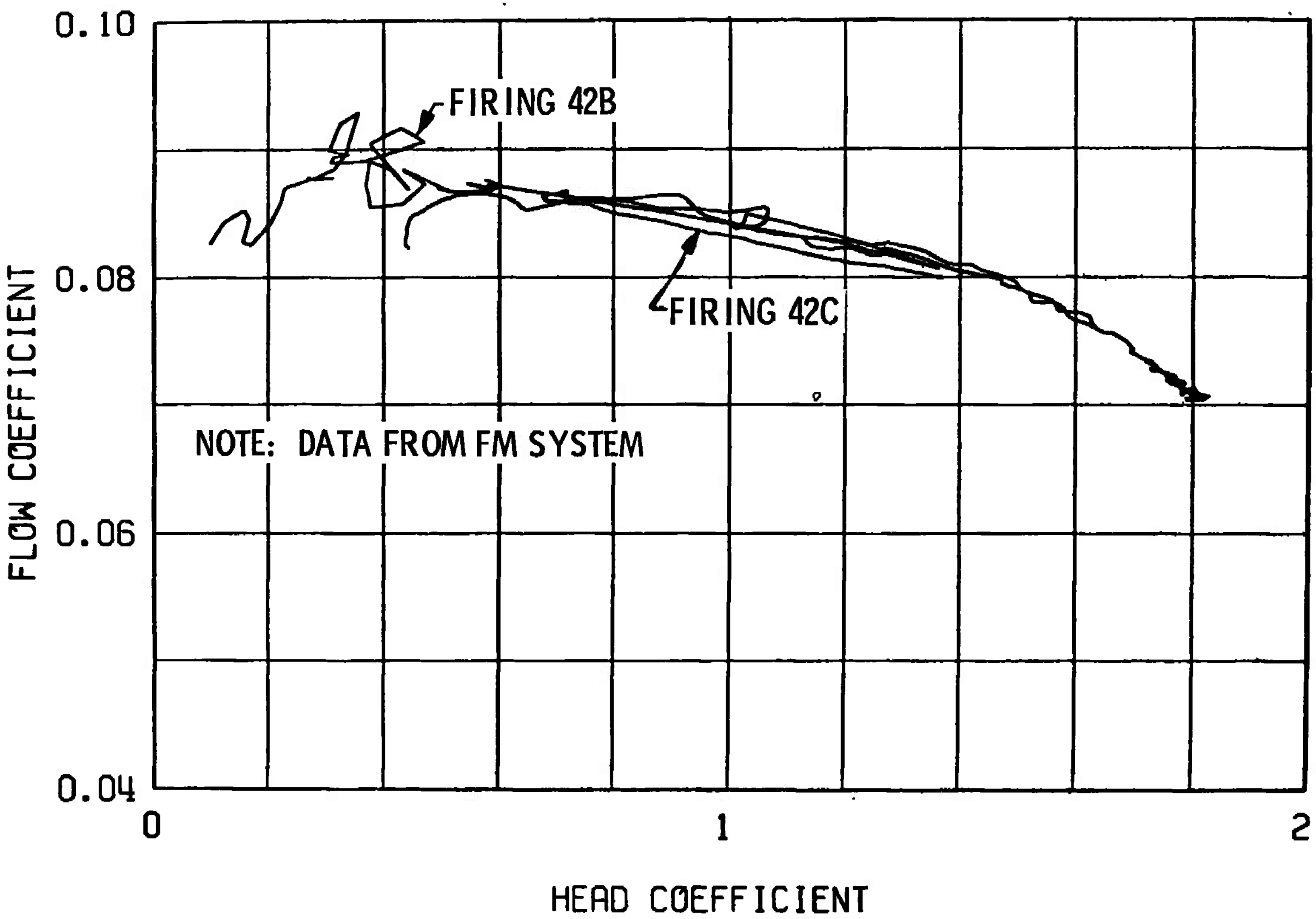



Fig. 94 Fuel Pump Operating Characteristics, Firings 43B and 42C

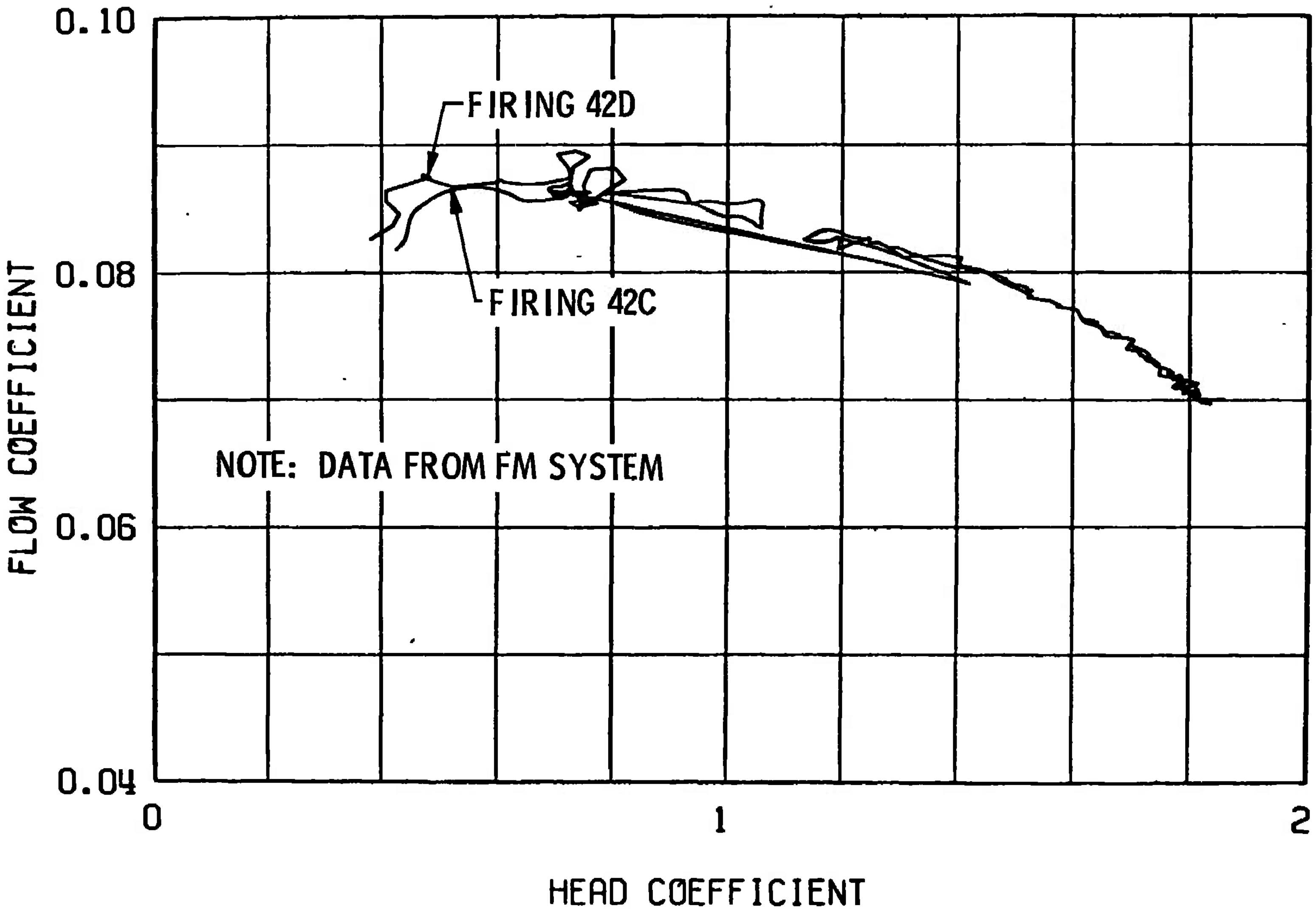
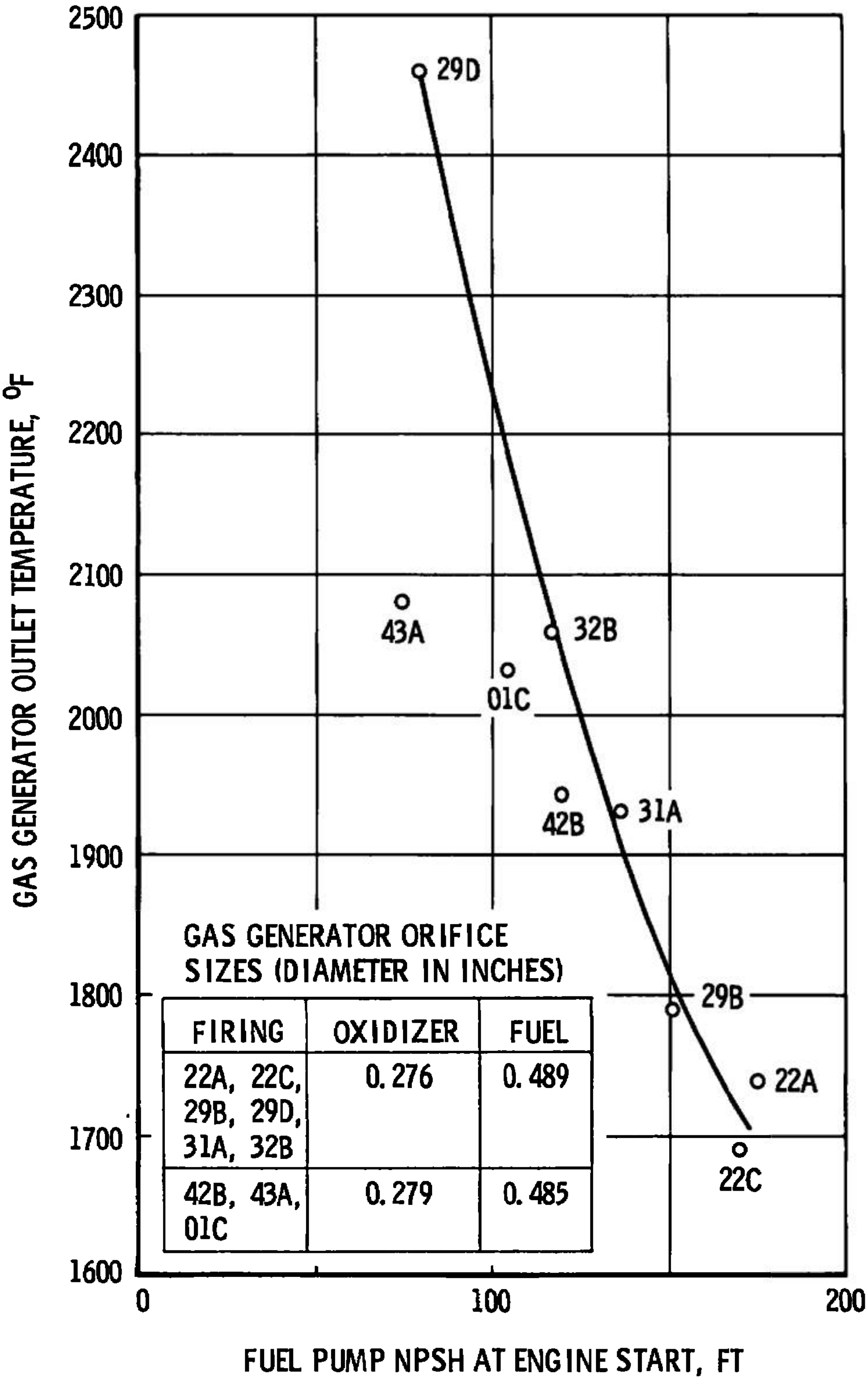



Fig. 95 Fuel Pump Operating Characteristics, Firings 42D and 42C




| FIRING | OXIDIZER | FUEL |
|---|---|---|
| 22A, 22C, 29B, 29D, 31A, 32B | 0.276 | 0.489 |
| 42B, 43A, 01C | 0.279 | 0.485 |

Fig. 96 Fuel Pump NPSH Influence on Gas Generator Initial Peak Temperature

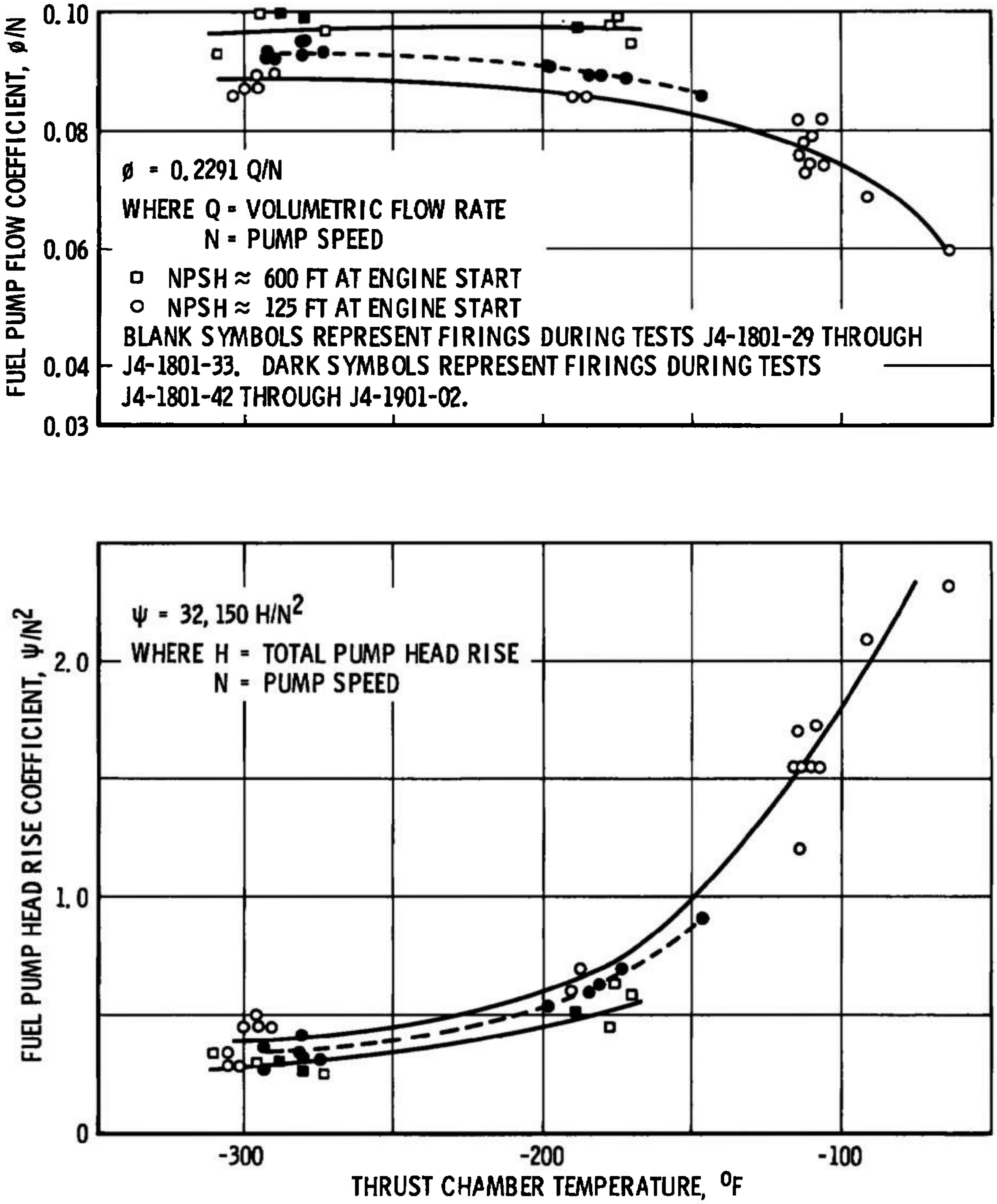



**Fig. 97 Fuel Pump NPSH Influence on Fuel Pump Stall Margin during Start Tank Discharge**

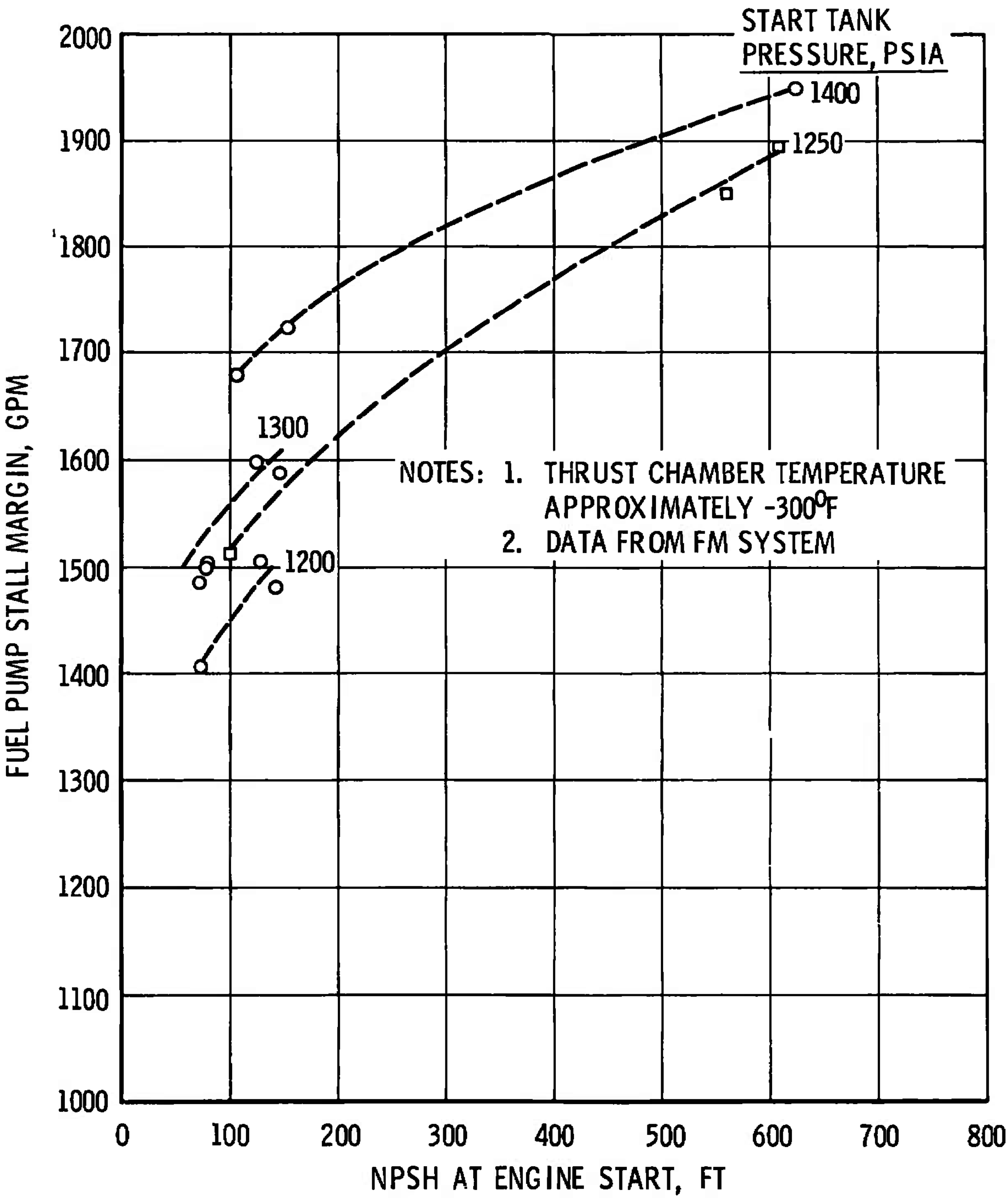



**Fig. 98 Fuel Pump NPSH and Thrust Chamber Temperature Effect on Fuel Pump Flow and Head Rise Coefficients**

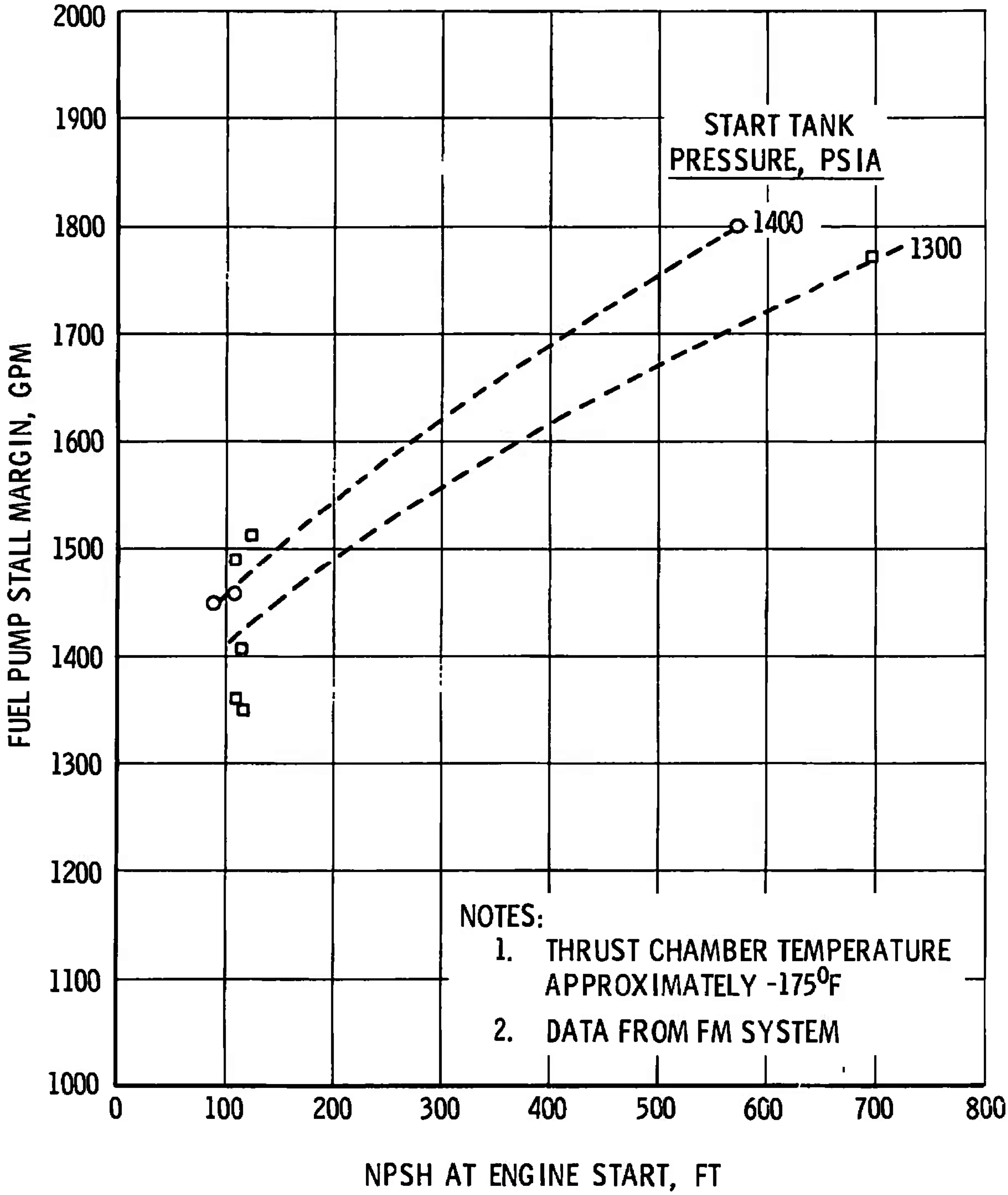
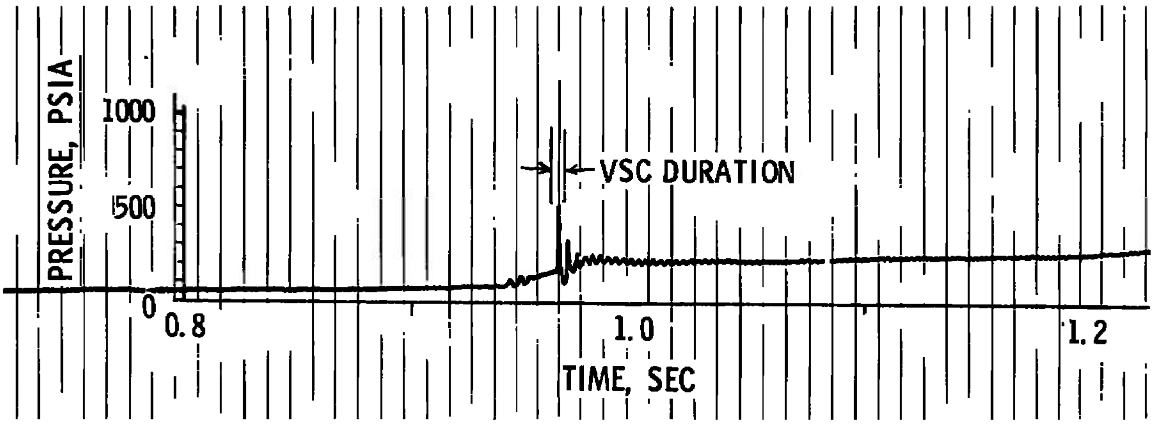
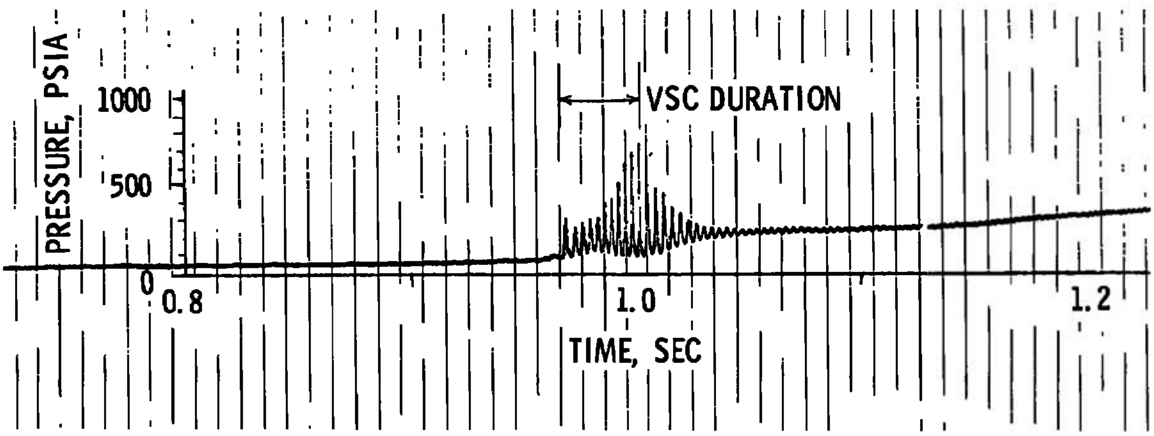



**Fig. 98 Concluded**




a. Firing 01A




b. Firing 01B

Fig. 99 Typical Oxidizer Dome Pressure Oscillations Recorded during Oxidizer Dome Prime by the Photocon Transducer

# TABLE I
## MAJOR ENGINE COMPONENTS

| Part Name | P/N | S/N |
|---|---|---|
| Augmented Spark Igniter Assembly | 206280-161 | 4084016 |
| Augmented Spark Igniter Oxidizer Valve | 308880 | 4079065 |
| Auxiliary Flight Instrumentation Package | 704090-21 | 4075163 |
| Electrical Control Package | 502670-51 | 4081748 |
| Fuel Bleed Valve | 309034 | 4084042 |
| Fuel Flowmeter | 251225 | 4074110 |
| Fuel Injector Temperature Transducer | NA5-27441 | AA013283F66 |
| Fuel Turbopump Assembly | 460390-181 | 4073647 |
| Gas Generator Control Valve | 309040-31 | 4055754 |
| Gas Generator Fuel Injector and Combustor | 308360-11 | 4090408 |
| Gas Generator Oxidizer Injector and Poppet Assembly | 303323 | 4092975 |
| Gas Generator Oxidizer Supply Line | NA5-260113 | 045 |
| Helium Control Valve (Three-Way) | NA5-27273 | 372452 |
| Helium Regulator Assembly | 558130-111 | 4061139 |
| Helium Tank Vent Control Valve (Three-Way) | NA5-27273 | 379313 |
| Ignition Phase Control Valve (Four-Way) | 558069 | 8313398 |
| Main Fuel Valve | 409920 | 4074288 |
| Main Oxidizer Valve | 411031-21 | 4072666 |
| Main-Stage Control Valve (Four-Way) | 558069 | 8284312 |
| Oxidizer Bleed Valve | 309029 | 4078081 |
| Oxidizer Flowmeter | 251216 | 4075154 |
| Oxidizer Turbine Bypass Valve | 409940 | 4073096 |
| Oxidizer Turbopump Assembly | 458175-111 | 6610105 |
| Pressure-Actuated Purge Control Valve | 558126 | 4073862 |
| Pressure-Actuated Shutdown Valve Assembly | 558127-11 | 4074549 |
| Primary Flight Instrumentation Package | 704095-21 | 4074730 |
| Propellant Utilization Valve | 251351-51 | 4075182 |
| Restartable Ignition Detect Probe | 500750 | 2125567 |
| Start Tank | 307579 | 0098 |
| Start Tank Discharge Valve | 306875-21 | 4093386 |
| Start Tank Fill/Refill Valve | 557998 | 4091617 |
| Start Tank Vent and Relief Valve | 557848 | 4080517 |
| Thrust Chamber Body | 15-205875 | 4062445 |
| Thrust Chamber Injector Assembly | 208021-11 | 4089721 |

# TABLE II

## SUMMARY OF ENGINE ORIFICES

| Orifice Name | Part Number | Diameter (Inches Unless Otherwise Noted) | Date Effective | Comments |
|---|---|---|---|---|
| Gas Generator Fuel Supply Line | RD251-4107<br>RD251-4107 | 0.485<br>0.524 | July 5, 1968[1] | --- |
| Gas Generator Oxidizer Supply Line | RD251-4132<br>RD251-4132 | 0.279<br>0.304 | July 5, 1968[1] | --- |
| Oxidizer Turbine Bypass Valve Nozzle | RD273-8002<br>RD273-8002 | 1.424<br>1.600 | July 5, 1968[1] | --- |
| Main Oxidizer Closing Control Line | 410437-082<br>410437-0760<br>710437-083 | 8.20 scfm<br>7.60 scfm<br>8.30 scfm | June 21, 1968[1]<br>July 5, 1968 | Thermostatic Orifices |
| Oxidizer Turbine Exhaust Manifold | RD251-9004 | 10.00 | [1] | --- |
| Augmented Spark Igniter Oxidizer Supply Line | 309358 | 0.125 | June 9, 1968 | --- |
| Augmented Spark Igniter/ Fuel Supply Line | --- | 0.266 | July 5, 1968 | --- |

[1] As delivered to AEDC

**TABLE III**

**ENGINE MODIFICATIONS**

**(BETWEEN TEST PERIODS J4-1801-42 AND J4-1901-02)**

| Modification Number | Completion Date | Description of Modification |
|---|---|---|
| RFD[1]- AEDC 33-68 | June 20, 1968 | Augmented Spark Igniter Fuel Orifice Installation |
| RFD-AEDC 34-68 | June 21, 1968 | Retiming Main Oxidizer Valve to 1900 $\pm\,^{20}_{10}$ msec |
| Test J4-1801-43 | | June 26, 1968 |
| | None | |
| Test J4-1901-01 | | July 3, 1968 |
| RFD-AEDC 1-68 | July 5, 1968 | Retiming Main Oxidizer Valve to 1750 ± 20 msec |
| RFD-AEDC 33-1-68 | July 5, 1968 | Deletion of Augmented Spark Igniter Fuel Orifice |
| RFD-AEDC 36-68 | July 5, 1968 | Engine Reorificing |

[1]RFD - Rocketdyne Field Directive

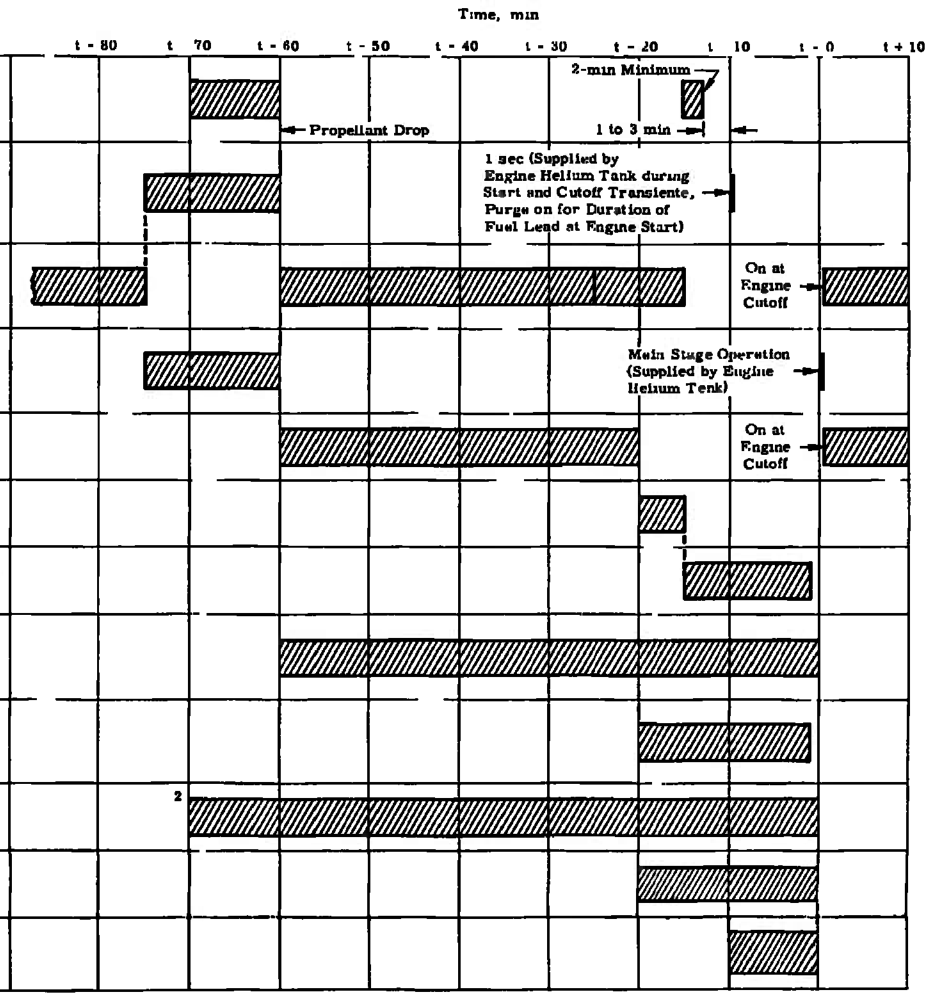
TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TEST PERIODS J4-1801-42 AND J4-1901-02)

| Replacement | Completion Date | Component Replaced |
|---|---|---|
| | June 19, 1968 | Fuel Turbine Inlet Temperature Probe |
| | June 19, 1968 | Gas Generator Outlet Temperature Probe |
| Test J4-1801-43 | | June 26, 1968 |
| | June 26, 1968 | Fuel Turbine Inlet Temperature Probe |
| | June 26, 1968 | Gas Generator Outlet Temperature Probe |
| UCR[1] 005138 | June 29, 1968 | Gas Generator Control Valve |
| Test J4-1901-01 | | July 3, 1968 |
| | July 3, 1968 | Gas Generator Outlet Temperature Probe |

[1]UCR - Unsatisfactory Condition Report

# TABLE V
## ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

| | |
|---|---|
| Turbopump and Gas Generator Purge (Purge Manifold System) | Helium, 82 - 130 psia; 50 - 200°F (Nominal 6 scfm at Customer Connect |
| Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System) | Helium, 1400 psig; 50 100°F (Nominal 230 scfm at Customer Connect) |
| Oxidizer Dome (Facility Line to Port CO3A) | Nitrogen, 415 - 675 psia; 100 - 200°F; 175 - 230 scfm |
| Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System) | Helium, 1400 psig; 50 - 200°F; 2600 - 7000 scfm |
| Thrust Chamber Jacket (Customer Connect Panel) | Nitrogen, 165 - 215 psia; 100 200°F; Nominal 100 scfm |
| | Helium, 55 - 200 psia; Ambient Temperature |
| Thrust Chamber Temperature Conditioning | Helium, 1000-psia Maximum; Temperature as Required |
| 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 - 1400 psia; -140 to -300°F; Helium, 1700 - 3250 psia; -140 to -300°F |
| Crossover Duct Temperature | Helium, -300°F to Ambient |
| Start Tank Discharge Valve Temperature Conditioning | Helium - Ambient |
| Low Pressure Fuel Duct | Heater Tape; 12, 000 watts |




[1]Required on Tests 31 and 32 only
[2]Conditioning Temperature to be Maintained for the Last 30 min of Pre-Fire

## TABLE VI
## SUMMARY OF TEST REQUIREMENTS AND RESULTS

| Firing Number | | J4-1801-42A[4][5] Target | J4-1801-42A[4][5] Actual | J4-1801-42B[4][5] Target | J4-1801-42B[4][5] Actual | J4-1801-42C[4][5] Target | J4-1801-42C[4][5] Actual | J4-1801-42D[4][5] Target | J4-1801-42D[4][5] Actual | J4-1801-42E[4] Target | J4-1801-42E[4] Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time of Day, hr/Firing Date | | 1252 | 6/19/68 | 1424 | 6/19/68 | 1531 | 6/19/68 | 1620 | 6/19/68 | 1719 | 6/19/68 |
| Pressure Altitude at Engine Start, ft (Ref. 1) | | 100,000 | 95,000 | 100,000 | 103,000 | 100,000 | 103,000 | 100,000 | 104,000 | 100,000 | 104,000 |
| Firing Duration, sec[1] | | 32.500 | 32.572 | 7.500 | 7.585 | 7.500 | 7.586 | 7.500 | 7.588 | 1.250 | 1.243 |
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | $35.0^{+1}_{-0}$ | 35.6 | $28.5^{+1}_{-0}$ | 27.2 | $28.5^{+1}_{-0}$ | 27.0 | $28.5^{+1}_{-0}$ | 27.1 | 41 ± 1 | 42.1 |
| | Temperature, °F | -420.4 ± 0.4 | -420.2 | -420.4 ± 0.4 | -420.1 | -420.4 ± 0.4 | -420.1 | -420.4 ± 0.4 | -420.1 | -420.4 ± 0.4 | -420.0 |
| | NPSH, ft | 410 | 416 | 126 | 120 | 125 | 115 | 125 | 115 | 810 | 810 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | 46.0 ± 1 | 45.7 | $45.0^{+1}_{-0}$ | 45.4 | $46.0^{+1}_{-0}$ | 44.5 | $33.0^{+1}_{-0}$ | 32.8 | $33^{+1}_{-0}$ | 33.5 |
| | Temperature, °F | -294.5 ± 0.4 | -294.4 | -294.5 ± 0.4 | -294.5 | -294.5 ± 0.4 | -294.5 | -294.5 ± 0.4 | -294.4 | -294.5 ± 0.4 | -294.4 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1225 ± 10 | 1229 | 1380 ± 10 | 1378 | 1380 ± 10 | 1380 | 1300 ± 10 | 1300 | 1250 ± 10 | 1248 |
| | Temperature, °F | -250 ± 10 | -260 | -270 ± 10 | -270 | -270 ± 10 | -268 | -300 ± 10 | -303 | -140 ± 10 | -138 |
| Helium Tank Conditions at Engine Start | Pressure, psia | --- | 2118 | --- | 2077 | --- | 2120 | --- | 2140 | --- | 2494 |
| | Temperature, °F | --- | -245 | --- | -264 | --- | -264 | --- | -297 | --- | -139 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | Throat | -235 ± 15 | -229 | -275 ± 25 | -278 | $-150^{+20}_{-10}$ | -137 | $-150^{+20}_{-10}$ | -150 | -275 ± 25 | -281 |
| | Average | --- | -245 | --- | -290 | --- | -148 | --- | -173 | --- | -280 |
| Crossover Duct Temperature at Engine Start, °F[2] | TFTD-2 | +50 ± 25 | --- | +50 ± 25 | --- | +50 ± 25 | --- | +50 ± 25 | --- | -100 ± 20 | --- |
| | TFTD-3 | ↓ | 56 | ↓ | 36 | ↓ | 29 | ↓ | 37 | ↓ | -129 |
| | TFTD-5 | ↓ | 59 | ↓ | 43 | ↓ | 38 | ↓ | 55 | ↓ | -94 |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F | | -100 ± 50 | -88 | -100 ± 50 | -128 | -100 ± 50 | -130 | -100 ± 50 | -131 | -100 ± 50 | -137 |
| Fuel Lead Time, sec[1] | | 1.000 | 1.002 | 1.000 | 1.004 | 1.000 | -1.003 | 1.000 | 1.003 | 1.000 | 1.001 |
| Propellant in Engine Time, min | | [3] | 67 | [3] | 47 | [3] | 66 | [3] | 49 | [3] | 89 |
| Propellant Recirculation Time, min | | 10 | 11 | 10 | 10 | 10 | 10.5 | 10 | 10 | 10 | 10 |
| Start Sequence Logic | | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F | TOBS-1 | --- | 82 | --- | 61 | --- | 20 | --- | 15 | --- | 5 |
| | TOBS-2 | --- | 35 | --- | 46 | --- | 45 | --- | 43 | --- | 40 |
| | TOBS-2B | --- | 56 | --- | 60 | --- | 58 | --- | 57 | --- | 54 |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F | | 50 ± 25 | 3 | 50 ± 25 | 56 | 50 ± 25 | 57 | 50 ± 25 | 55 | 50 ± 25 | 45 |
| Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from $t_0$ | | --- / --- | 21 / 0.977 | --- / --- | 29 / 0.983 | --- / --- | 14 / 0.985 | --- / --- | 14 / 1.015 | --- / --- | 36 / 1.058 |
| Gas Generator Outlet Temperature, °F | Initial Peak | --- | 2107 | --- | 1943 | --- | 2226 | --- | 2118 | --- | 1959 |
| | Second Peak | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fuel Pump Stall Margin during Start Tank Discharge, gpm | | --- | 1800 | --- | 1810 | --- | 1410 | --- | 1420 | --- | 1900 |
| Augmented Spark Ignition Detect Delay Time from Engine Start, msec[1] | | --- | 275 | --- | 210 | --- | 285 | --- | 430 | --- | 434 |
| Thrust Chamber Ignition ($P_c$ = 100 psia) Time, sec (Ref. $t_0$)[1] | | --- | 0.978 | --- | 0.987 | --- | 0.985 | --- | 1.015 | --- | 1.057 |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. $t_0$)[1] | | --- | 1.110 | --- | 1.007 | --- | 1.080 | --- | 1.024 | --- | 0.958 |
| Main-Stage Pressure No. 2, sec (Ref. $t_0$)[1] | | --- | 1.610 | --- | 1.873 | --- | 1.580 | --- | 1.854 | --- | --- |
| Time Chamber Pressure Attains 550 psia, sec (Ref. $t_0$)[1] | | --- | 1.886 | --- | 1.903 | --- | 1.845 | --- | 1.945 | --- | --- |
| Propellant Utilization Valve Position, Engine Start/$t_0$ + 10 sec | | Null / Closed | Null / Closed | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- |
| Gas Generator Control Valve Temperature at Engine Start, °F | | -25 Minimum | 64 | -25 Minimum | 46 | -25 Minimum | 41 | -25 Minimum | -48 | -25 Minimum | -84 |

[1] Data reduced from oscillograph.
[2] Component conditioning to be maintained within limits for last 15 min before engine start.
[3] Propellant-in-engine time is dependent on main oxidizer valve conditioning requirements; minimum time is 30 min.
[4] Stall approach monitor activated.
[5] Turbine overspeed trip activated.

## TABLE VI (Continued)

| Firing Number | | J4-1801-43A Target | J4-1801-43A Actual | J4-1801-43B[4] Target | J4-1801-43B[4] Actual | J4-1901-01A[4][5] Target | J4-1901-01A[4][5] Actual | J4-1901-01B[4][5] Target | J4-1901-01B[4][5] Actual | J4-1901-01C[4] Target | J4-1901-01C[4] Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time of Day, hr/Firing Date | | 1056 | 6/20/68 | 1215 | 6/26/68 | 1136 | 7/3/68 | 1248 | 7/3/68 | 1356 | 7/3/68 |
| Pressure Altitude at Engine Start, ft (Ref. 1) | | 100,000 | 90,000 | 100,000 | 101,000 | 100,000 | 101,000 | 100,000 | 100,000 | 100,000 | 101,000 |
| Firing Duration, sec[1] | | 32.500 | 32.57 | 7.500 | 7.59 | 32.500 | 32.575 | 7.500 | 7.588 | 7.500 | 3.025 |
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 26.5 ± 0.5 | 26.6 | 26.5 ± 0.5 | 20.0 | 26.5 ± 0.5 | 20.5 | 26.5 ± 0.5 | 20.5 | 20.5 ± 0.5 | 20.7 |
| | Temperature, °F | -420.4 ± 0.4 | -419.6 | -420.4 ± 0.4 | -420.2 | -420.4 ± 0.4 | -420.3 | -420.4 ± 0.4 | -420.4 | -420.4 ± 0.4 | -420.2 |
| | NPSH, ft | 125 | 75 | 125 | 90 | 125 | 110 | 125 | 125 | 125 | 105 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | $45^{+1}_{-0}$ | 45.6 | $45^{+1}_{-0}$ | 45.6 | $45.0^{+1}_{-0}$ | 45.2 | $33.0^{+1}_{-0}$ | 33.0 | $45.0^{+1.0}_{-0}$ | 45.6 |
| | Temperature, °F | -204.5 ± 0.4 | -204.4 | -294.5 ± 0.4 | -294.8 | -204.5 ± 0.4 | -204.3 | -294.5 ± 0.4 | -294.5 | -204.5 ± 0.4 | -294.4 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1300 ± 10 | 1304 | 1400 ± 10 | 1400 | 1300 ± 10 | 1302 | 1300 ± 10 | 1302 | 1400 ± 10 | 1396 |
| | Temperature, °F | -300 ± 10 | -300 | -240 ± 10 | -236 | -270 ± 10 | -271 | -300 ± 10 | -304 | -240 ± 10 | -243 |
| Helium Tank Conditions at Engine Start | Pressure, psia | --- | 2116 | --- | 2145 | --- | 2134 | --- | 2118 | --- | 2525 |
| | Temperature, °F | --- | -300 | --- | -238 | --- | -270 | --- | -205 | --- | -242 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | Throat | -275 ± 25 | -209 | $-150^{+20}_{-10}$ | -142 | $-150^{+20}_{-10}$ | -140 | $-150^{+20}_{-10}$ | -150 | -275 ± 25 | -275 |
| | Average | --- | -201 | --- | -164 | --- | -160 | --- | -107 | --- | -293 |
| Crossover Duct Temperature at Engine Start, °F[2] | TFTD-2 | 50 ± 25 | 41 | 50 ± 25 | 34 | +50 ± 25 | 36 | 50 ± 25 | 40 | 50 ± 25 | 20 |
| | TFTD-3 | ↓ | 49 | ↓ | 45 | ↓ | 47 | ↓ | 81 | ↓ | 41 |
| | TFTD-6 | ↓ | 54 | ↓ | 56 | ↓ | 39 | ↓ | 50 | ↓ | 36 |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F | | -100 ± 50 | -63 | -100 ± 50 | -100 | -100 ± 50 | -84 | -100 ± 50 | -100 | -100 ± 50 | -101 |
| Fuel Lead Time, sec[1] | | 1.000 | 0.000 | 1.000 | 0.008 | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| Propellant in Engine Time, min | | [3] | 61 | [3] | 37 | [3] | 98 | [3] | 72 | [3] | 69 |
| Propellant Recirculation Time, min | | 10 | 10 | 10 | 11 | 10 | 11 | 10 | 10 | 10 | 10 |
| Start Sequence Logic | | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F | TOBS-1 | --- | 46 | --- | 40 | --- | 35 | --- | 20 | --- | 23 |
| | TOBS-2 | --- | 36 | --- | 27 | --- | 25 | --- | 20 | --- | 17 |
| | TOBS-2B | --- | 50 | --- | 46 | --- | 41 | --- | 44 | --- | 43 |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F | | 50 ± 25 | 00 | +50 ± 25 | 61 | 50 ± 25 | 60 | 50 ± 25 | 50 | 50 ± 25 | 46 |
| Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from $t_0$ | | --- / --- | 27 / 0.963 | --- / --- | 5 / 0.004 | --- / --- | 3 / 0.964 | --- / --- | 37 / 0.964 | --- / --- | 15 / 0.066 |
| Gas Generator Outlet Temperature, °F | Initial Peak | --- | 2060 | --- | 2051 | --- | 2059 | --- | 2014 | --- | 2032 |
| | Second Peak | --- | --- | --- | 1840 | --- | 2115 | --- | --- | --- | --- |
| Fuel Pump Stall Margin during Start Tank Discharge, gpm | | --- | 1460 | --- | 1490 | --- | 1490 | --- | 1510 | --- | 1570 |
| Augmented Spark Ignition Detect Delay Time from Engine Start, msec[1] | | --- | 228 | --- | 242 | --- | 219 | --- | 378 | --- | 206 |
| Thrust Chamber Ignition ($P_c$ = 100 psia) Time, sec (Ref. $t_0$)[1] | | --- | 0.962 | --- | 0.064 | --- | 0.986 | --- | 0.967 | --- | 0.980 |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. $t_0$)[1] | | --- | 1.156 | --- | 1.120 | --- | 1.182 | --- | 1.125 | --- | 1.125 |
| Main-Stage Pressure No. 2, sec (Ref. $t_0$)[1] | | --- | 1.001 | --- | 1.616 | --- | 1.032 | --- | 1.653 | --- | 1.694 |
| Time Chamber Pressure Attains 550 psia, sec (Ref. $t_0$)[1] | | --- | 1.072 | --- | 1.720 | --- | 1.076 | --- | 1.923 | --- | 1.951 |
| Propellant Utilization Valve Position, Engine Start/$t_0$ + 10 sec | | Null / Closed | Null / Closed | Null / --- | Null / --- | Null / Closed | Null / Closed | Null / --- | Null / --- | Null / --- | Null / --- |
| Gas Generator Control Valve Temperature at Engine Start, °F | | -50 Minimum | 40 | -50 Minimum | 48 | -50 Minimum | --- | -50 Minimum | --- | -50 Minimum | --- |

[1] Data reduced from oscillograph.
[2] Component conditioning to be maintained within limits for last 15 min before engine start.
[3] Propellant-in-engine time is dependent on main oxidizer valve conditioning requirements; minimum time is 30 min.
[4] Stall approach monitor activated.
[5] Turbine overspeed trip activated.

## TABLE VI (Concluded)

| Firing Number | | J4-1901-01D (4)(5) Target | J4-1901-01D (4)(5) Actual | J4-1901-01E (5) Target | J4-1901-01E (5) Actual | J4-1901-02A (4)(5) Target | J4-1901-02A (4)(5) Actual | J4-1901-02B (4) Target | J4-1901-02B (4) Actual | J4-1401-02C (5) Target | J4-1401-02C (5) Actual | J4-1901-02D (4)(5) Target | J4-1901-02D (4)(5) Actual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time of Day, hr/Firing Date | | 1500 | 7/3/66 | 1603 | 7/3/66 | 1136 | 7/11/66 | 1333 | 7/11/66 | 1425 | 7/11/66 | 1616 | 7/11/66 |
| Pressure Altitude at Engine Start, ft (Ref. 1) | | 100,000 | 103,000 | 100,000 | 106,000 | 100,000 | 99,000 | 100,000 | 101,000 | 100,000 | 103,000 | 100,000 | 103,000 |
| Firing Duration, sec (1) | | 7.500 | 7.590 | 1.250 | 1.248 | 32.500 | 32.573 | 7.500 | 7.587 | 7.500 | 7.590 | 1.250 | 0.447 |
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 41.0 ± 1.0 | 41.1 | 41.0 ± 1.0 | 40.5 | 26.5 ± 0.5 | 26.3 | 26.5 ± 0.5 | 26.7 | 26.5 ± 0.5 | 26.6 | 41.0 ± 1.0 | 40.7 |
| | Temperature, °F | -420.4 ± 0.4 | -420.0 | -420.4 ± 0.4 | -420.0 | -420.4 ± 0.4 | -420.2 | -420.4 ± 0.4 | -420.1 | -420.4 ± 0.4 | -420.4 | -420.4 ± 0.4 | -420.0 |
| | NPSH, ft | 510 | 575 | 410 | 560 | 125 | 95 | 125 | 100 | 125 | 130 | 610 | 560 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | $45.0^{+1}_{-0}$ | 45.6 | $33.0^{+1}_{-0}$ | 32.4 | $33.0^{+1}_{-0}$ | 33.9 | $33^{+1}_{-0}$ | 33.4 | $45^{+1}_{-0}$ | 45.5 | $33^{+1}_{-0}$ | 33.0 |
| | Temperature, °F | -294.5 ± 0.4 | -294.3 | -294.5 ± 0.4 | -294.5 | -294.5 ± 0.4 | -294.6 | -294.5 ± 0.4 | -294.6 | -294.5 ± 0.4 | -294.6 | -294.5 ± 0.4 | -294.6 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1400 ± 10 | 1397 | 1250 ± 10 | 1250 | 1200 ± 10 | 1203 | 1250 ± 10 | 1247 | 1200 ± 10 | 1205 | 1400 ± 10 | 1372 |
| | Temperature, °F | -240 ± 10 | -240 | -140 ± 10 | -135 | -200 ± 10 | -196 | -140 ± 10 | -137 | -300 ± 10 | -300 | -140 ± 10 | -142 |
| Helium Tank Conditions at Engine Start | Pressure, psia | --- | 2265 | --- | 2655 | --- | 2227 | --- | 2217 | --- | 2189 | --- | 2154 |
| | Temperature, °F | --- | -239 | --- | -137 | --- | -196 | --- | -129 | --- | -302 | --- | -142 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | Throat | $-150^{+20}_{-10}$ | -152 | -275 ± 25 | -276 | -275 ± 25 | -260 | -275 ± 25 | -272 | -275 ± 25 | -275 | $-150^{+20}_{-10}$ | -151 |
| | Average | --- | -165 | --- | -266 | --- | -260 | --- | -274 | --- | -293 | --- | -153 |
| Crossover Duct Temperature at Engine Start, °F (1) | TFTD-2 | 50 ± 25 | 51 | -100 ± 20 | -106 | -100 ± 20 | -105 | -100 ± 20 | -95 | +50 ± 25 | +36 | -100 ± 20 | -61 |
| | TFTD-3 | ↓ | 62 | ↓ | -103 | ↓ | -61 | ↓ | -95 | ↓ | +46 | ↓ | -66 |
| | TFTD-5 | ↓ | 53 | ↓ | -100 | ↓ | -92 | ↓ | --- | ↓ | --- | ↓ | --- |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F | | -100 ± 50 | -92 | -100 ± 50 | -57 | -100 ± 50 | -135 | -100 ± 50 | -63 | -100 ± 50 | -76 | -100 ± 50 | -65 |
| Fuel Lead Time, sec (1) | | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.003 | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| Propellant in Engine Time, min | | (3) | 64 | (3) | 63 | (3) | 96 | (3) | 114 | (3) | 51 | (3) | 64 |
| Propellant Recirculation Time, min | | 10 | 10 | 10 | 13 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Start Sequence Logic | | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F | TOBS-1 | --- | 26 | --- | 22 | --- | 25 | --- | 53 | --- | 51 | --- | 46 |
| | TOBS-2 | --- | 17 | --- | 13 | --- | 15 | --- | 35 | --- | 52 | --- | 34 |
| | TOBS-2B | --- | 44 | --- | 42 | --- | 50 | --- | 55 | --- | 53 | --- | 51 |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F | | 50 ± 25 | 53 | 50 ± 25 | 50 | 50 ± 25 | 25 | 50 ± 25 | 55 | 50 ± 25 | 51 | 50 ± 25 | 51 |
| Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from $t_0$ | | --- / --- | 24 / 0.945 | --- / --- | 32 / 1.050 | --- / --- | 29 / 1.051 | --- / --- | 26 / 1.071 | --- / --- | 31 / 0.966 | --- / --- | --- / --- |
| Gas Generator Outlet Temperature, °F | Initial Peak | --- | 1932 | --- | 1605 | --- | 1901 | --- | 1724 | --- | 1959 | --- | --- |
| | Second Peak | --- | 2046 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fuel Pump Stall Margin during Start Tank Discharge, gpm | | --- | 1920 | --- | 1650 | --- | 1610 | --- | 1510 | --- | 1510 | --- | --- |
| Augmented Spark Ignition Detect Delay Time from Engine Start, msec (1) | | --- | 255 | --- | 562 | --- | 356 | --- | 474 | --- | 257 | --- | --- |
| Thrust Chamber Ignition ($P_c$ = 100 psia) Time, sec (Ref. $t_0$) (1) | | --- | 0.953 | --- | 1.055 | --- | 1.063 | --- | 1.071 | --- | 0.996 | --- | --- |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. $t_0$) (1) | | --- | 1.200 | --- | 1.036 | --- | 0.687 | --- | 1.023 | --- | 1.011 | --- | --- |
| Main-Stage Pressure No. 2, sec (Ref. $t_0$) (1) | | --- | 1.621 | --- | --- | --- | 1.766 | --- | 1.513 | --- | 1.647 | --- | --- |
| Time Chamber Pressure Attains 550 psia, sec (Ref. $t_0$) (1) | | --- | 1.635 | --- | --- | --- | 2.040 | --- | 2.059 | --- | 1.686 | --- | --- |
| Propellant Utilization Valve Position, Engine Start/$t_0$ + 10 sec | | Null / --- | Null / --- | Null / --- | Null / --- | Null / Closed | Null / Closed | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- | Null / --- |
| Gas Generator Control Valve Temperature at Engine Start, °F | | -50 Minimum | --- | -50 Minimum | --- | -50 Minimum | 15 | -50 Minimum | 47 | -50 Minimum | 44 | -50 Minimum | 44 |

(1) Data reduced from oscillograph.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Propellant-in-engine time is dependent on main oxidizer valve conditioning requirements; minimum time is 30 min.
(4) Stall approach monitor activated.
(5) Turbine overspeed trip activated.

# TABLE VII
## ENGINE VALVE TIMINGS

| Firing Number J4-1901- | Start: Start Tank Discharge Valve | | | | | | Main Fuel Valve | | | Main Oxidizer Valve, First Stage | | | Main Oxidizer Valva, Second Stage | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, aec | Tima of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valva Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Tima of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Tima, sec | Valva Opening Tima, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Cloaing Time, sec |
| 42A | 0.0 | 0.140 | 0.126 | 0.451 | 0.101 | 0.249 | -1.002 | 0.088 | 0.092 | 0.451 | 0.055 | 0.045 | 0.451 | 0.666 | 1.879 | 0.451 | 0.102 | 0.027 | 0.451 | 0.175 | 0.069 | 0.451 | 0.220 | 0.290 |
| 42B | 0.0 | 0.140 | 0.137 | 0.450 | 0.099 | 0.229 | -1.004 | 0.080 | 0.092 | 0.450 | 0.054 | 0.047 | 0.450 | 0.557 | 1.958 | 0.450 | 0.103 | 0.025 | 0.450 | 0.191 | 0.094 | 0.450 | 0.218 | 0.280 |
| 42C | 0.0 | 0.137 | 0.129 | 0.450 | 0.090 | 0.227 | -1.003 | 0.090 | 0.117 | 0.450 | 0.058 | 0.048 | 0.450 | 0.832 | 1.928 | 0.450 | 0.109 | 0.029 | 0.450 | 0.184 | 0.099 | 0.450 | 0.220 | 0.290 |
| 42D | 0.0 | 0.135 | 0.129 | 0.450 | 0.090 | 0.230 | -1.003 | 0.077 | 0.119 | 0.450 | 0.055 | 0.048 | 0.450 | 0.578 | 1.983 | 0.450 | 0.110 | 0.028 | 0.450 | 0.187 | 0.082 | 0.450 | 0.223 | 0.290 |
| 42E | 0.0 | 0.130 | 0.125 | 0.450 | 0.090 | 0.238 | -1.001 | 0.081 | 0.122 | 0.450 | 0.055 | 0.050 | 0.450 | 0.580 | --- | 0.450 | 0.109 | 0.029 | 0.450 | 0.191 | 0.083 | 0.450 | 0.220 | 0.300 |
| 43A | 0.0 | 0.138 | 0.120 | 0.451 | 0.099 | 0.220 | -0.999 | 0.088 | 0.092 | 0.451 | 0.058 | 0.042 | 0.451 | 0.703 | 2.043 | 0.451 | 0.103 | 0.028 | 0.451 | 0.188 | 0.092 | 0.451 | 0.218 | 0.265 |
| 43B | 0.0 | 0.139 | 0.129 | 0.449 | 0.094 | 0.239 | -0.998 | 0.073 | 0.113 | 0.449 | 0.057 | 0.047 | 0.449 | 0.973 | 2.097 | 0.449 | 0.108 | 0.029 | 0.449 | 0.198 | 0.089 | 0.449 | 0.215 | 0.290 |
| 01A | 0.0 | 0.140 | 0.125 | 0.450 | 0.093 | 0.229 | -1.001 | 0.090 | 0.100 | 0.450 | 0.052 | 0.049 | 0.450 | 0.752 | 1.999 | 0.450 | 0.105 | 0.032 | 0.450 | 0.180 | 0.080 | 0.450 | 0.205 | 0.318 |
| 01B | 0.0 | 0.134 | 0.125 | 0.449 | 0.090 | 0.233 | -1.001 | 0.091 | 0.112 | 0.449 | 0.052 | 0.047 | 0.449 | 0.872 | 2.090 | 0.449 | 0.105 | 0.030 | 0.449 | 0.178 | 0.074 | 0.449 | 0.200 | 0.305 |
| 01C | 0.0 | 0.139 | 0.125 | 0.449 | 0.090 | 0.233 | -1.001 | 0.080 | 0.122 | 0.449 | 0.055 | 0.048 | 0.449 | 0.878 | --- | 0.449 | 0.104 | 0.031 | 0.449 | 0.190 | 0.070 | 0.449 | 0.229 | 0.284 |
| 01D | 0.0 | 0.141 | 0.130 | 0.449 | 0.091 | 0.231 | -1.001 | 0.087 | 0.118 | 0.449 | 0.053 | 0.047 | 0.449 | 0.751 | 2.018 | 0.449 | 0.108 | 0.030 | 0.449 | 0.193 | 0.085 | 0.449 | 0.221 | 0.310 |
| 01E | 0.0 | 0.135 | 0.120 | 0.450 | 0.090 | 0.239 | -1.001 | 0.071 | 0.131 | 0.450 | 0.053 | 0.048 | 0.450 | 0.592 | --- | 0.450 | 0.105 | 0.030 | 0.450 | 0.178 | 0.073 | 0.450 | 0.222 | 0.298 |
| 02A | 0.0 | 0.136 | 0.123 | 0.452 | 0.094 | 0.239 | -1.001 | 0.098 | 0.094 | 0.452 | 0.054 | 0.051 | 0.452 | 0.542 | 1.870 | 0.452 | 0.104 | 0.029 | 0.452 | 0.172 | 0.074 | 0.452 | 0.232 | 0.290 |
| 02B | 0.0 | 0.139 | 0.118 | 0.450 | 0.089 | 0.238 | -1.004 | 0.083 | 0.100 | 0.450 | 0.055 | 0.044 | 0.450 | 0.571 | 1.900 | 0.450 | 0.102 | 0.031 | 0.450 | 0.172 | 0.079 | 0.450 | 0.228 | 0.295 |
| 02C | 0.0 | 0.135 | 0.129 | 0.449 | 0.090 | 0.238 | -1.001 | 0.119 | 0.088 | 0.449 | 0.049 | 0.048 | 0.449 | 0.582 | 1.970 | 0.449 | 0.101 | 0.029 | 0.449 | 0.199 | 0.079 | 0.449 | 0.227 | 0.295 |
| 02D | 0.0 | 0.139 | 0.129 | 0.449 | --- | --- | -1.001 | 0.118 | 0.078 | 0.449 | --- | --- | 0.449 | --- | --- | 0.449 | --- | --- | 0.449 | --- | --- | 0.449 | --- | --- |
| Final Sequence Run | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 42 | 0.0 | 0.099 | 0.105 | 0.449 | 0.098 | 0.241 | -1.003 | 0.052 | 0.110 | 0.448 | 0.050 | 0.043 | 0.448 | 0.595 | 1.805 | 0.448 | 0.080 | 0.034 | 0.448 | 0.140 | 0.090 | 0.448 | 0.200 | 0.290 |
| 43 | 0.0 | 0.099 | 0.102 | 0.450 | 0.093 | 0.241 | -1.001 | 0.050 | 0.110 | 0.450 | 0.051 | 0.043 | 0.450 | 0.948 | 1.917 | 0.450 | 0.091 | 0.032 | 0.450 | 0.138 | 0.092 | 0.450 | 0.200 | 0.299 |
| 01 | 0.0 | 0.095 | 0.104 | 0.449 | 0.095 | 0.240 | -1.001 | 0.052 | 0.099 | 0.449 | 0.050 | 0.044 | 0.449 | 0.847 | 1.909 | 0.449 | 0.082 | 0.035 | 0.449 | 0.138 | 0.069 | 0.449 | 0.208 | 0.283 |
| 02 | 0.0 | 0.099 | 0.107 | 0.449 | 0.109 | 0.249 | -1.000 | 0.052 | 0.112 | 0.448 | 0.051 | 0.048 | 0.448 | 0.833 | 1.760 | 0.448 | 0.142 | 0.069 | 0.448 | 0.081 | 0.038 | 0.449 | 0.202 | 0.290 |

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

# TABLE VII (Concluded)

| Firing Number J4-1801- | Shutdown | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Main Fuel Valve | | | Main Oxidizer Valve | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
| | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec |
| 42A | 32.572 | 0.107 | 0.301 | 32.572 | 0.081 | 0.182 | 32.572 | 0.065 | 0.025 | 32.572 | 0.030 | 0.010 | 32.572 | 0.249 | 0.700 |
| 42B | 7.585 | 0.118 | 0.338 | 7.585 | 0.078 | 0.189 | 7.585 | 0.074 | 0.015 | 7.685 | 0.035 | 0.015 | 7.585 | 0.234 | 0.500 |
| 42C | 7.588 | 0.117 | 0.336 | 7.586 | 0.073 | 0.176 | 7.588 | 0.088 | 0.023 | 7.586 | 0.038 | 0.019 | 7.588 | 0.244 | 0.500 |
| 42D | 7.688 | 0.118 | 0.332 | 7.588 | 0.079 | 0.187 | 7.688 | 0.084 | 0.025 | 7.588 | 0.037 | 0.022 | 7.588 | 0.243 | 0.510 |
| 42E | 1.243 | 0.110 | 0.317 | 1.243 | --- | --- | 1.243 | 0.095 | 0.025 | 1.243 | 0.049 | 0.027 | 1.243 | 0.155 | 0.580 |
| 43A | 32.674 | 0.104 | 0.293 | 32.574 | 0.077 | 0.198 | 32.574 | 0.075 | 0.017 | 32.574 | 0.033 | 0.019 | 32.574 | 0.255 | 0.550 |
| 43B | 7.685 | 0.111 | 0.307 | 7.585 | 0.077 | 0.187 | 7.585 | 0.080 | 0.015 | 7.585 | 0.035 | 0.015 | 7.585 | 0.240 | 0.530 |
| 01A | 32.573 | 0.112 | 0.320 | 32.573 | 0.080 | 0.183 | 32.573 | 0.070 | 0.015 | 32.573 | 0.030 | 0.017 | 32.573 | 0.250 | 0.551 |
| 01B | 7.588 | 0.120 | 0.334 | 7.588 | 0.074 | 0.167 | 7.588 | 0.071 | 0.017 | 7.588 | 0.034 | 0.013 | 7.588 | 0.240 | 0.533 |
| 01C | 3.025 | 0.118 | 0.335 | 3.025 | --- | --- | 3.025 | 0.070 | 0.021 | 3.025 | 0.034 | 0.012 | 3.025 | 0.221 | 0.560 |
| 01D | 7.690 | 0.118 | 0.336 | 7.590 | 0.079 | 0.159 | 7.590 | 0.072 | 0.020 | 7.590 | 0.032 | 0.017 | 7.590 | 0.242 | 0.551 |
| 01E | 1.248 | 0.113 | 0.311 | 1.248 | --- | --- | 1.248 | 0.079 | 0.021 | 1.248 | 0.043 | 0.019 | 1.248 | 0.160 | 0.595 |
| 02A | 32.573 | 0.114 | 0.327 | 32.573 | 0.088 | 0.184 | 32.573 | 0.076 | 0.010 | 32.573 | 0.030 | 0.013 | 32.673 | 0.268 | 0.590 |
| 02B | 7.587 | 0.109 | 0.310 | 7.587 | 0.077 | 0.155 | 7.587 | 0.087 | 0.010 | 7.587 | 0.033 | 0.014 | 7.587 | 0.248 | 0.594 |
| 02C | 7.590 | 0.112 | 0.330 | 7.590 | 0.072 | 0.162 | 7.590 | 0.065 | 0.010 | 7.690 | 0.032 | 0.014 | 7.590 | 0.250 | 0.570 |
| 02D | 0.447 | 0.106 | 0.272 | 0.447 | --- | --- | 0.447 | --- | --- | 0.447 | --- | --- | 0.447 | --- | --- |
| Final Sequence Run | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 42 | 4.884 | 0.080 | 0.225 | 4.664 | 0.050 | 0.127 | 4.664 | 0.095 | 0.035 | 4.664 | 0.082 | 0.020 | 4.864 | 0.218 | 0.601 |
| 43 | 7.128 | 0.082 | 0.226 | 7.128 | 0.064 | 0.120 | 7.128 | 0.094 | 0.035 | 7.128 | 0.062 | 0.023 | 7.128 | 0.220 | 0.582 |
| 01 | 7.188 | 0.083 | 0.229 | 7.188 | 0.060 | 0.124 | 7.186 | 0.092 | 0.040 | 7.188 | 0.060 | 0.023 | 7.186 | 0.221 | 0.588 |
| 02 | --- | 0.082 | 0.227 | --- | 0.057 | 0.123 | --- | 0.095 | 0.038 | --- | 0.059 | 0.026 | --- | 0.210 | 0.585 |

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

# TABLE VIII
## ENGINE PERFORMANCE

| Firing Number | | J4-1801-42A | | J4-1801-43A | | J4-1901-01A | | J4-1801-02A | | Rocketdyne Sea-Level Acceptance Test No. 313-019 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Site | Normalized | Site | Normalized | Site | Normalized | Site | Normalized | Site | Normalized |
| Overall Engine Performance | Thrust, $lb_f$ | 231,707 | 230,589 | 229,656 | 228,842 | 228,299 | 227,217 | 241,500 | 239,948 | 171,188 | 231,743 |
| | Chamber Pressure, psia | 793 | 785 | 766 | 780 | 782 | 774 | 624 | 615 | 799 | 769 |
| | Mixture Ratio | 5.568 | 5.588 | 5.711 | 5,897 | 5.692 | 5,682 | 5.432 | 5.415 | 5.497 | 5.478 |
| | Fuel Weight Flow, $lb_m$/sec | 83.7 | 82,9 | 61.6 | 81,1 | 81.5 | 80.9 | 86.6 | 88.1 | 65.0 | 84,2 |
| | Oxidizer Weight Flow, $lb_m$/sec | 486,3 | 461.8 | 486.0 | 461.8 | 484.0 | 459.7 | 482,6 | 476.9 | 467,3 | 461,2 |
| | Total Weight Flow, $lb_m$/sec | 550.0 | 544.8 | 547.6 | 542,9 | 545.5 | 540,6 | 571.4 | 565,0 | 552.3 | 545,3 |
| Thrust Chamber Performance | Mixture Ratio | 5.776 | 5.779 | 5,931 | 5.920 | 5.905 | 5.897 | 5.842 | 5.626 | 5.701 | 5.682 |
| | Total Weight Flow, $lb_m$/sec | 543.0 | 537.7 | 540.6 | 535,9 | 538.6 | 533.7 | 563,6 | 557.3 | 545 | 538 |
| | Characteristic Velocity, ft/sec | 8001.2 | 7999,3 | 7971,8 | 7973.7 | 7952.0 | 7953,0 | 6007.4 | 8010,6 | 6026 | 8032 |
| Fuel Turbopump Performance | Pump Efficiency, percent | 74.2 | 74.2 | 74.1 | 74,1 | 74.2 | 74.2 | 73.6 | 73.8 | 73.5 | 73,5 |
| | Pump Speed, rpm | 26,869 | 26,623 | 26,636 | 26,388 | 26,520 | 26,295 | 27,966 | 27,695 | 27,119 | 27,002 |
| | Turbine Efficiency, percent | 62,3 | 62.1 | 60.8 | 60.6 | 60.0 | 59.9 | 62,2 | 62,1 | 63,2 | 63,1 |
| | Turbine Pressure Ratio | 7,22 | 7,22 | 7,24 | 7.23 | 7.25 | 7.25 | 7.55 | 7.55 | 7,22 | 7.22 |
| | Turbine Inlet Temperature, °F | 1225 | 1204 | 1210 | 1166 | 1253 | 1230 | 1223 | 1198 | 1210 | 1201 |
| | Turbine Weight Flow, $lb_m$/sec | 7,05 | 7.02 | 7.01 | 7.00 | 8.93 | 6.91 | 7.75 | 7,72 | 7,11 | 7,03 |
| Oxidizer Turbopump Performance | Pump Efficiency, percent | 80,4 | 60.3 | 60.4 | 60.3 | 80.4 | 80.3 | 60.5 | 80.4 | 80.3 | 80.2 |
| | Pump Speed, rpm | 8773 | 8723 | 8742 | 8695 | 8713 | 8663 | 0984 | 8910 | 6797 | 6749 |
| | Turbine Efficiency, percent | 49.7 | 49.6 | 49.6 | 49.6 | 49,2 | 49.2 | 50.8 | 50.7 | 50.7 | 50.5 |
| | Turbine Pressure Ratio | 2.62 | 2,62 | 2.61 | 2,61 | 2.61 | 2,61 | 2,63 | 2,63 | 2,60 | 2.80 |
| | Turbine Inlet Temperature, °F | 804 | 769 | 798 | 761 | 820 | 804 | 770 | 752 | 769 | 770 |
| | Turbine Weight Flow, $lb_m$/sec | 6,25 | 6,23 | 6,23 | 6,21 | 6,15 | 6.13 | 6.89 | 6,65 | 6,3 | 6,2 |
| Gas Generator Performance | Mixture Ratio | 0.954 | 0,942 | 0.948 | 0.931 | 0.971 | 0.956 | 0.953 | 0.939 | 0.945 | 0.940 |
| | Chamber Pressure, psia | 884,3 | 679.5 | 879.5 | 675.6 | 676.0 | 871.7 | 752.8 | 748.4 | 689 | 681 |

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

TABLE IX
SUMMARY OF ENGINE START CONDITIONS FOR AEDC ALTITUDE FIRING J4-1801-42A AND SEA-LEVEL ACCEPTANCE TEST

| Parameter | | Rocketdyne Test 313-019 | KA1801-42A |
|---|---|---|---|
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 37.5 | 35.8 |
| | Temperature, °F | -419.6 | -420.2 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | 46.7 | 45.7 |
| | Temperature, °F | -295.5 | -294.4 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1261 | 1229 |
| | Temperature, °F | -172 | -250 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | TTC-1P | 54 | -229 |
| Fuel Turbine Inlet Temperature at Engine Start, °F | --- | 1201 | --- |
| Fuel Lead Time, sec | --- | 8 | 1 |
| Propellant Utilization Valve Position at Engine Start | --- | Null | Null |

# APPENDIX III
## INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-42 through J4-1901-02 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1. The instrumentation applies to all tests except as noted.

## TABLE III-1
## INSTRUMENTATION LIST

| AEDC Code | Parsmeter | Tap No. | Range | Micro-sadic | Magnetic Tape | Oscillo-graph | Strip Chsrt | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | **Current** | | **amp** | | | | | |
| ICC | Control | | 0 to 30 | x | | x | | |
| IIC | Ignition | | 0 to 30 | x | | x | | |
| | **Event** | | | | | | | |
| EASIOV | Augmented Spark Igniter Oxidizer Valve Open | | Open/Closed | x | | x | | |
| EECL | Engine Cutoff Lockin | | On/Off | x | | x | | |
| EECO | Engine Cutoff Signal | | On/Off | x | x | x | | |
| EES | Engine Start Command | | On/Off | x | | x | | |
| EFBVC | Fuel Bleed Valve Cloaed Limit | | Open/Closed | x | | | | |
| EFPVC/O | Fuel Prevalve Closed/Open Limit | | Closed/Open | x | | | | |
| EHCS | Helium Control Solenoid | | On/Off | x | | x | | |
| EID | Ignition Detected | | On/Off | x | | x | | |
| EIPCS | Ignition Phase Control Solenoid | | On/Off | x | | x | | |
| EMCS | Msin-Stage Control Solenoid | | On/Off | x | | x | | |
| EMP-1 | Main-Stage Presaure No. 1 | | On/Off | x | | x | | |
| EMP-2 | Main-Stage Preaaure No. 2 | | On/Off | x | | x | | |
| EOBVC | Oxidizer Bleed Valve Cloaed Limit | | Open/Cloaed | x | | | | |
| EOPVC | Oxidizer Prevalve Closed Limit | | Closed | x | | x | | |
| EOPVO | Oxidizer Prevalve Open Limit | | Open | x | | x | | |
| ESTDCS | Start Tsnk Discharge Control Solenoid | | On/Off | x | x | x | | |
| RASIS-1 | Augmented Spark Igniter Spark No. 1 | | On/Off | | | x | | |
| RASIS-2 | Augmented Spark Igniter Spsrk No. 2 | | On/Off | | | x | | |
| RGGS-1 | Gas Generator Spark No. 1 | | On/Off | | | x | | |
| RGGS-2 | Gas Generator Spark No. 2 | | On/Off | | | x | | |
| | **Flows** | | **gpm** | | | | | |
| QF-1A | Fuel | PFF | 0 to 9000 | x | | x | | |
| QF-2 | Fuel | PFFA | 0 to 9000 | x | x | x | | |
| QF-1SAM | Fuel Flow Sial. Approach Monitor | | 0 to 9000 | x | | x | | |
| QFRP | Fuel Recirculation | | 0 to 160 | x | | | | |
| QO-1A | Oxidizer | POF | 0 to 3000 | x | | x | | |
| QO-2 | Oxidizer | POFA | 0 to 3000 | x | x | x | | |
| QORP | Oxidizer Recirculation | | 0 to 50 | x | | | x | |
| | **Position** | | **Percent Open** | | | | | |
| LFVT | Main Fuel Valve | | 0 to 100 | x | | x | | |
| LGGVT | Gaa Generator Valve | | 0 to 100 | x | | x | | |
| LOTBVT | Oxidizer Turbine Bypass Valve | | 0 to 100 | x | | x | | |
| LOVT | Main Oxidizer Valve | | 0 to 100 | x | | x | | |
| LPUTOP | Propellant Utilization Valve | | 0 to 100 | x | | x | x | |
| LSTDVT | Start Tank Discharge Valve | | 0 to 100 | x | | x | | |
| | **Pressure** | | **psia** | | | | | |
| PA1 | Test Cell | | 0 to 0.5 | x | | x | | |
| PA2 | Test Cell | | 0 to 1.0 | x | | | | |
| PA3 | Test Cell | | 0 to 5.0 | x | | | x | |

## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap No. | Range | Micro-sadic | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Pressure | | psia | | | | | |
| PC-1P | Thrust Chamber | CG1 | 0 to 1000 | x | | | x | |
| PC-3 | Thrust Chamber | CG1A | 0 to 1000 | x | x | x | | |
| PCBO-1 | Constant Bleed Orifice | | 0 to 50 | x | | | | |
| PCDP | Crossover Duct Purge | | 0 to 100 | x | | | | |
| PCGG-1P | Gas Generator Chamber Pressure | | 0 to 1000 | x | | x | | |
| PCGG-2 | Gas Generator Chamber | GG1A | 0 to 1000 | x | | | | |
| PFBL-3 | Fuel Bleed Line | | 0 to 500 | x | | x | | |
| PFJ-1A | Main Fuel Injection | CF2 | 0 to 1000 | x | | x | | |
| PFJGG-1A | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | | | |
| PFGG-2 | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | x | | |
| PFPC-1A | Fuel Pump Balance Piston Cavity | PF5 | 0 to 1000 | x | | | | |
| PFPD-1P | Fuel Pump Discharge | PF3 | 0 to 1500 | x | | | | |
| PFPD-2 | Fuel Pump Discharge | PF2 | 0 to 1500 | x | x | x | | |
| PFPI-1 | Fuel Pump Inlet | | 0 to 100 | x | | x | | x |
| PFPI-2 | Fuel Pump Inlet | | 0 to 100 | x | | x | | x |
| PFPI-3 | Fuel Pump Inlet | | 0 to 200 | | x | | | |
| PFPPSD-1 | Fuel Pump Primary Seal Drain | | 0 to 200 | x | | | | |
| PFRPO | Fuel Recirculation Pump Outlet | | 0 to 60 | x | | | | |
| PFRPR | Fuel Recirculation Pump Return | | 0 to 50 | x | | | | |
| PFST-1P | Fuel Start Tank | TF1 | 0 to 1500 | x | | x | | |
| PFST-2 | Fuel Start Tank | TF1 | 0 to 1500 | x | | | | x |
| PFUT | Fuel Tank Ullage | | 0 to 100 | x | | | | |
| PFVI | Fuel Tank Pressurization Line Nozzle Inlet | | 0 to 1000 | x | | | | |
| PFVL | Fuel Tank Pressurization Line Nozzle Throat | | 0 to 1000 | x | | | | |
| PHECMO | Pneumatic Control Module Outlet | | 0 to 750 | x | | | | |
| PHEOP | Oxidizer Recirculation Pump Purge | | 0 to 150 | x | | | | |
| 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 | | | | |
| POJ-1A | Main Oxidizer Injection | CO3 | 0 to 1000 | x | | x | | |
| POJ-2 | Main Oxidizer Injection | CO3A | 0 to 1000 | x | | x | | |
| POJ3 | Main Oxidizer Injection | | 0 to 2000 | | x | | | |
| POJGG-1A | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | x | | |
| POJGG-2 | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | | | |
| POPBC-1A | Oxidizer Pump Bearing Coolant | PO7 | 0 to 500 | x | | | | |
| POPD-1P | Oxidizer Pump Discharge | PO3 | 0 to 1500 | x | | | | |
| POPD-2 | Oxidizer Pump Discharge | PO2 | 0 to 1500 | x | x | x | | |
| POPI-1 | Oxidizer Pump Inlet | | 0 to 100 | x | | | | x |
| POPI-2 | Oxidizer Pump Inlet | | 0 to 200 | x | | | | x |
| POPI-3 | Oxidizer Pump Inlet | | 0 to 100 | | | x | | |

## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap No. | Range | Micro-sadic | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Pressure | | psia | | | | | |
| POPSC-1A | Oxidizer Pump Primary Seal Cavity | PO6 | 0 to 50 | x | | | | |
| PORPO | Oxidizer Recirculation Pump Outlet | | 0 to 115 | x | | | | |
| PORPR | Oxidizer Recirculation Pump Return | | 0 to 100 | x | | | | |
| POTI-1A | Oxidizer Turbine Inlet | TG3 | 0 to 200 | x | | | | |
| POTO-1A | Oxidizer Turbine Outlet | TG4 | 0 to 100 | x | | | | |
| POUT | Oxidizer Tank Ullage | | 0 to 100 | x | | | | |
| POVCC | Main Oxidizer Valve Closing Control | | 0 to 500 | x | | | | |
| POVI | Oxidizer Tank Pressurization Line Nozzle Inlet | | 0 to 1000 | x | | | | |
| POVL | Oxidizer Tank Pressurization Line Nozzle Throat | | 0 to 1000 | x | | | | |
| PPUVI-1A | Propellant Utilization Valve Inlet | PO8 | 0 to 1500 | x | | | | |
| PPUVO-1A | Propellant Utilization Valve Outlet | PO9 | 0 to 500 | x | | | | |
| PTCFJP | Thrust Chamber Fuel Jacket Purge | | 0 to 100 | x | | | | |
| PTCP | Thrust Chamber Purge | | 0 to 1000 | x | | | | |
| PTPP | Turbopump and Gas Generator Purge | | 0 to 250 | x | | | | |
| | Speeds | | rpm | | | | | |
| NFP-1P | Fuel Pump | PFV | 0 to 30,000 | x | x | x | | |
| NFRP | Fuel Recirculation Pump | | 0 to 15,000 | x | | | | |
| NOP-1P | Oxidizer Pump | POV | 0 to 12,000 | x | x | x | | |
| NORP | Oxidizer Recirculation Pump | | 0 to 15,000 | x | | | | |
| | Strain | | µin./in. | | | | | |
| SGFASI-1[2] | Augmented Spark Igniter Fuel Line | | ±1500 | | x | | | |
| SGFASI-2[2] | Augmented Spark Igniter Fuel Line | | ±1500 | | x | | | |
| SGFASI-3 | Augmented Spark Igniter Fuel Line | | ±1500 | | x | | | |
| SGFASI-4 | Augmented Spark Igniter Fuel Line | | ±1500 | | x | | | |
| SGOASI-1 | Augmented Spark Igniter Oxidizer Line | | ±1500 | | x | | | |
| SGOASI-2[1] | Augmented Spark Igniter Oxidizer Line | | ±1500 | | x | | | |
| SGOASI-3 | Augmented Spark Igniter Oxidizer Line | | ±750 | | 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 | | | | |
| TCDP | Crossover Duct Purge | | -150 to +150 | x | | | | |
| TECP-1P | Electrical Controls Package | NST1A | -300 to +200 | x | | | x | |

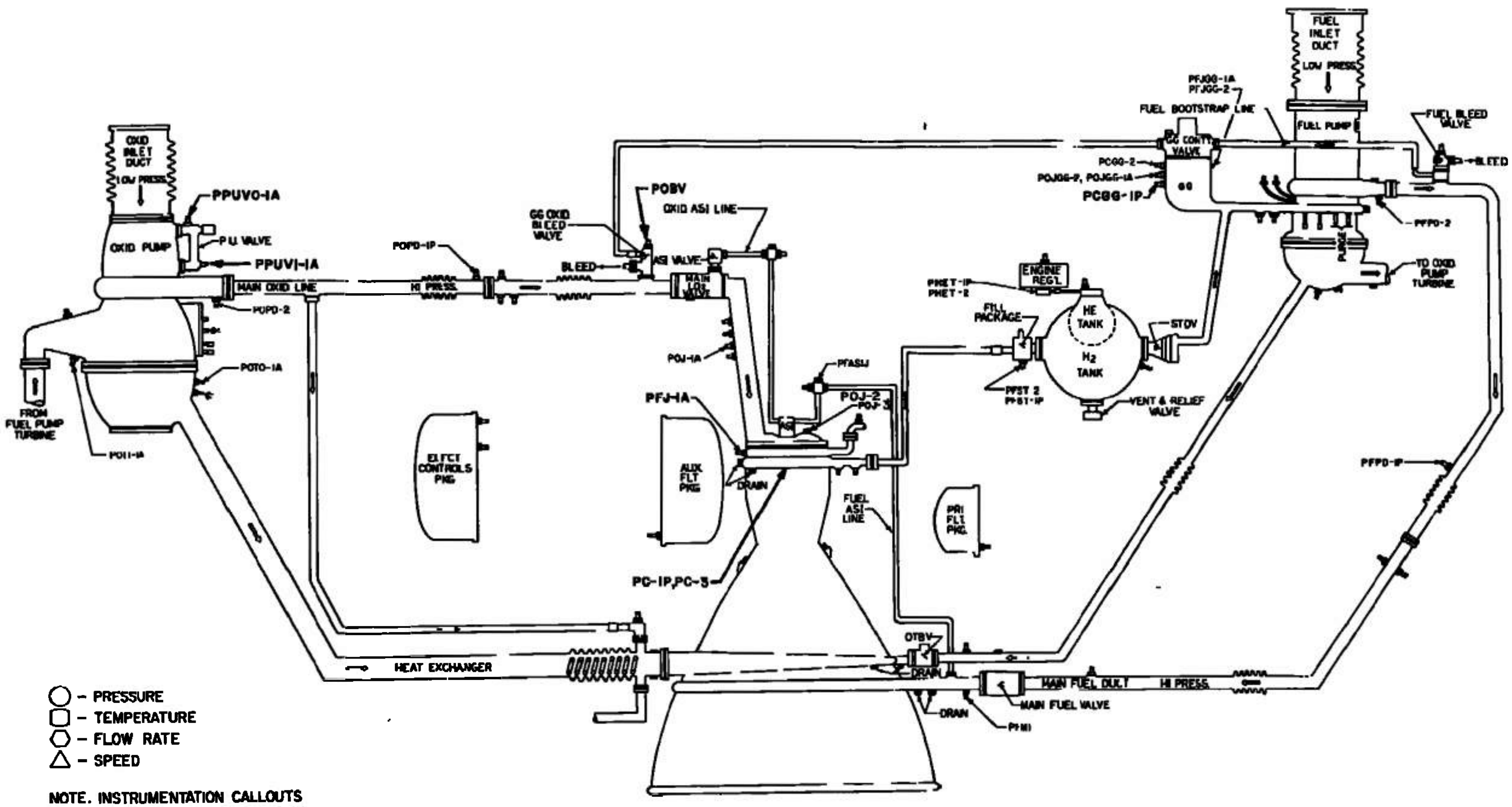
## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap No. | Range | Micro-sadic | Magnetic Tape | Oscillograph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Temperatures | | °F | | | | | |
| TFASIL-4 | Augmented Spark Igniter Line | | -425 to +500 | 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 | | |
| TFPD-1P | Fuel Pump Discharge | PFT1 | -425 to -400 | x | x | x | | |
| TFPD-2 | Fuel Pump Discharge | PFT1 | -425 to -400 | x | | | | |
| TFPI-1 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFPI-2 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFPI-3 | Fuel Pump Inlet | | -425 to -400 | x | | | | |
| TFRPO | Fuel Recirculation Pump Outlet | | -425 to -350 | x | | | | |
| TFRPR | Fuel Recirculation Pump Return Line | | -425 to -250 | x | | | | |
| TFRT-1 | Fuel Tank | | -425 to -410 | x | | | | |
| TFRT-3 | Fuel Tank | | -425 to -410 | x | | | | |
| TFST-1P | Fuel Start Tank | TFT1 | -350 to +100 | x | | | | |
| TFST-2 | Fuel Start Tank | TFT1 | -350 to +100 | x | | | | x |
| TFTD-2 | Fuel Turbine Discharge Duct | | -200 to -1000 | x | | | x | |
| TFTD-3 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | x | |
| TFTD-4 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | | |
| TFTD-8 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | x | |
| TFTO | Fuel Turbine Outlet | TFT2 | 0 to 1800 | x | | | | |
| TFTSD-1 | Fuel Turbine Seal Drain Line | | -300 to +100 | x | | | | |
| TGGO-1A & 2 | Gas Generator Outlet | GGT1 | 0 to 2500 | x | | x | x | |
| TGGVRS | Gas Generator Valve Retaining Screw | | -100 to +100 | x | | | x | |
| THET-1P | Helium Tank | NNT1 | -350 to +100 | x | | | | x |
| TNODP | Liquid Oxygen Dome Purge | | 0 to -300 | x | | | | |
| TOASIL-1 | Augmented Spark Igniter Oxidizer Line Skin | | -425 to +500 | x | | | | |
| TOBS-1 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2B | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBV-1A | Oxidizer Bleed Valve | GOT2 | -300 to -250 | x | | | | |
| TODS-1 | Oxidizer Dome Skin | | -300 to +100 | x | | | | |
| TODS-2 | Oxidizer Dome Skin | | -300 to +100 | x | | | | |
| TOPB-1A | Oxidizer Pump Bearing Coolant | POT4 | -300 to -250 | x | | | | |
| TOPD-1P | Oxidizer Pump Discharge | POT3 | -300 to -250 | x | | x | x | |
| TOPD-2 | Oxidizer Pump Discharge | POT3 | -300 to -250 | x | | | | |
| TOPI-1 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TOPI-2 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TORPO | Oxidizer Recirculation Pump Outlet | | -300 to -250 | x | | | | |
| TORPR | Oxidizer Recirculation Pump Return | | -300 to -140 | x | | | | |
| TORT-1 | Oxidizer Tank | | -300 to -287 | x | | | | |

## TABLE III-1 (Concluded)

| AEDC Code | Parameter | Tap No. | Range | Micro-sadic | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| TORT-1B | Oxidizer Tank | | -300 to -287 | x | | | | |
| TORT-3 | Oxidizer Tank | | -300 to -287 | x | | | | |
| TOTI-1P | Oxidizer Turbine Inlet | TGT3 | -300 to 1200 | x | | | x | |
| TOTO-1P | Oxidizer Turbine Outlet | TGT4 | 0 to 1000 | x | | | | |
| TOVL | Oxidizer Tank Pressurization Line Nozzle Throat | | -300 to +100 | x | | | | |
| TPIP-1P | Primary Instrument Package | | -300 to +200 | x | | | | |
| TSC2-1 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-12 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-13 | Thrust Chamber Skin | | -300 to -500 | x | | | x | |
| TSC2-17 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-20 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-24 | Thrust Chamber Skin | | -300 to -500 | x | | | | |
| TSOVC-1 | Oxidizer Valve Actuator Cap | | -325 to +150 | x | | | x | |
| TSTDVDL[5] | Start Tank Discharge Valve Drain Line | | -100 to +200 | x | | | | |
| TSTDVOC | Start Tank Discharge Valve Opening Control Port | | -300 to +200 | x | | | x | |
| TTC-1P | Thrust Chamber Jacket (Control) | CS1 | -425 to +500 | x | | | x | |
| TTC-2 | Thrust Chamber Jacket | | -425 to -500 | x | | | x | |
| TTPP | Turbopump Purge | | -150 to +150 | x | | | x | |
| TXOC | Crossover Duct Conditioning | | -325 to +200 | x | | | | |
| | Vibrations | | g's | | | | | |
| UASIF-1 | Augmented Spark Igniter Fuel Orifice Block | | ±150 | | x | | | |
| USAIV-1 | Augmented Spark Igniter Oxidizer Valve | | ±150 | | x | | | |
| UASIV-3[3] | Augmented Spark Igniter Oxidizer Valve | | ±150 | | x | | | |
| UFPR | Fuel Pump Radial 90 deg | | ±300 | | x | x | | |
| UMFV-1 | Main Fuel Valve | | ±150 | | x | | | |
| UMFV-2[1] | Main Fuel Valve | | ±150 | | x | | | |
| UMFV-3[3] | Main Fuel Valve | | ±150 | | x | | | |
| UOPR | Oxidizer Pump Radial 90 deg | | ±200 | | x | | | |
| UOTBV-1 | Oxidizer Turbine Bypass Valve | | ±150 | | x | | | |
| UTCD-1 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-2 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-4 | Thrust Chamber Dome | | ±1000 | | | x | | |
| U1VSC | No. 1 Vibration Safety Counts | | On/Off | | | x | | |
| U2VSC | No. 2 Vibration Safety Counts | | On/Off | | | x | | |
| | Voltage | | volts | | | | | |
| VCB | Control Bus | | 0 to 36 | x | | x | | |
| VIB | Ignition Bus | | 0 to 36 | x | | x | | |
| VIDA | Ignition Detect Amplifier | | 9 to 16 | x | | x | | |
| VPUTEP | Propellant Utilization Valve Excitation | | 0 to 5 | x | | | | |

Notes:
1. Deleted after firing 42.
2. Not required for firing 43.
3. Added beginning with firing 43.
4. Deleted after firing 43.
5. Added beginning with firing 02.

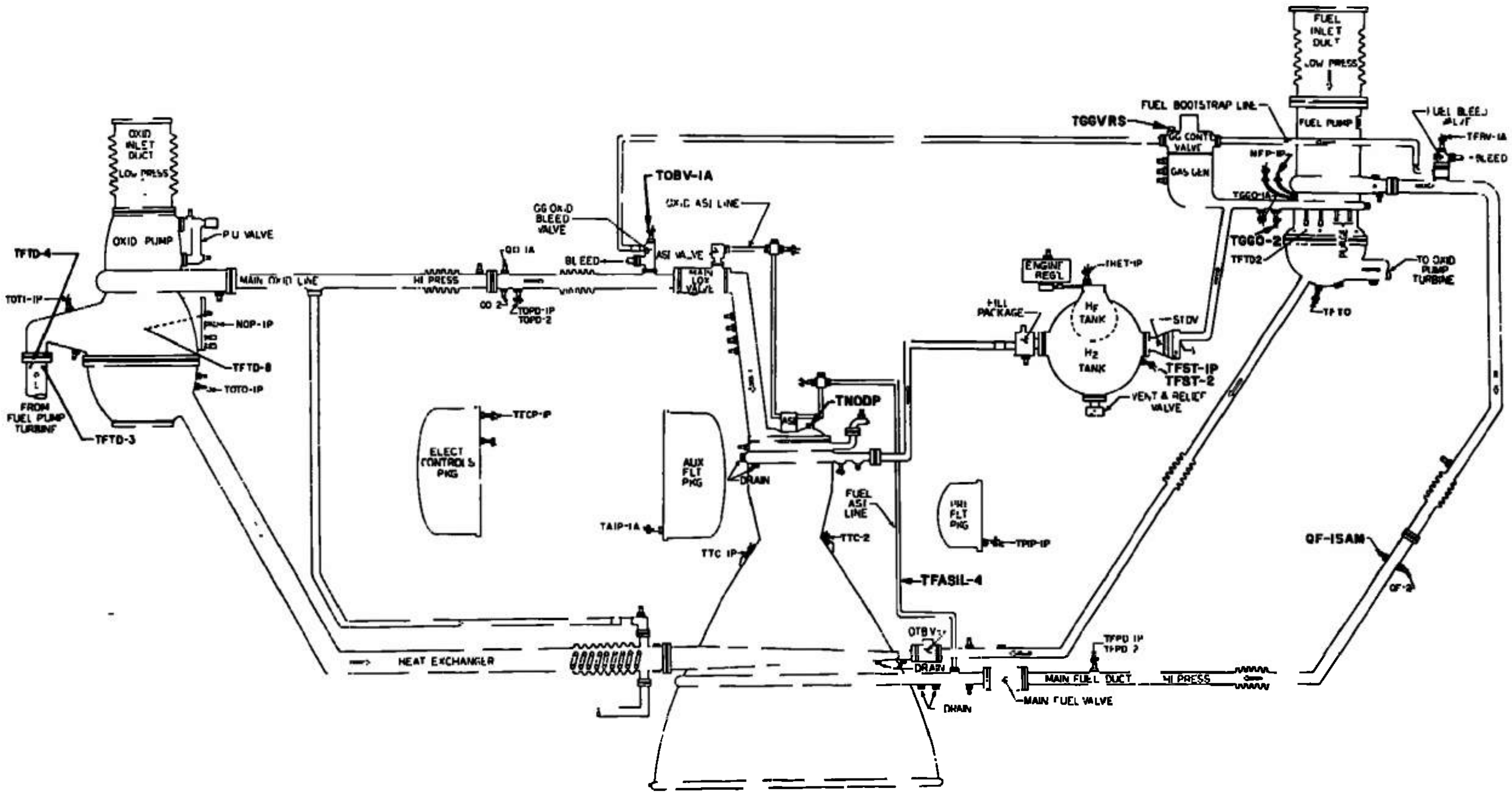



○ - PRESSURE
□ - TEMPERATURE
⬡ - FLOW RATE
△ - SPEED

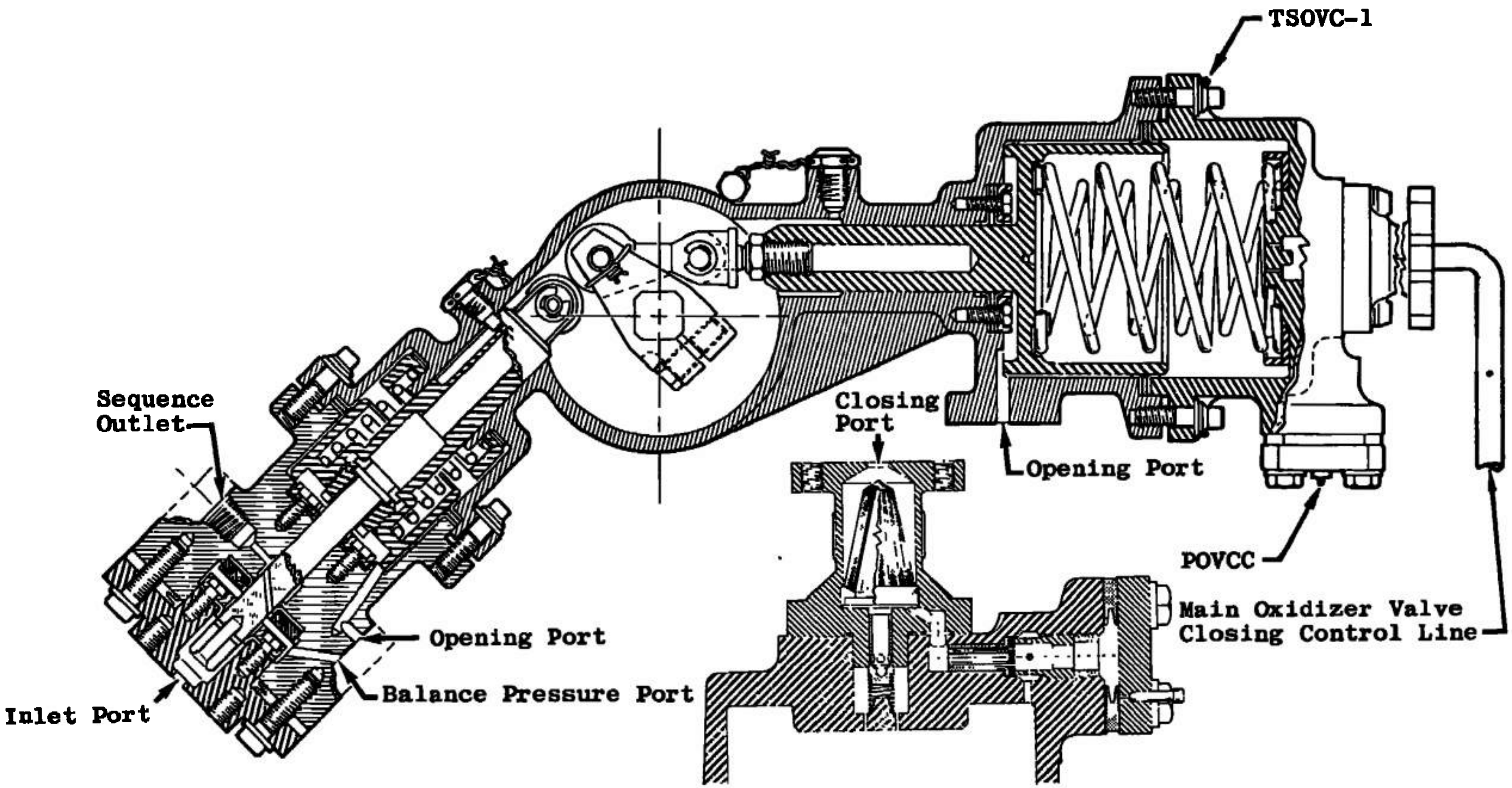
NOTE. INSTRUMENTATION CALLOUTS REFER TO ITEM NUMBERS IN TABLE IV

**a. Engine Pressure Tap Locations**

**Fig. III-1 Instrumentation Locations**

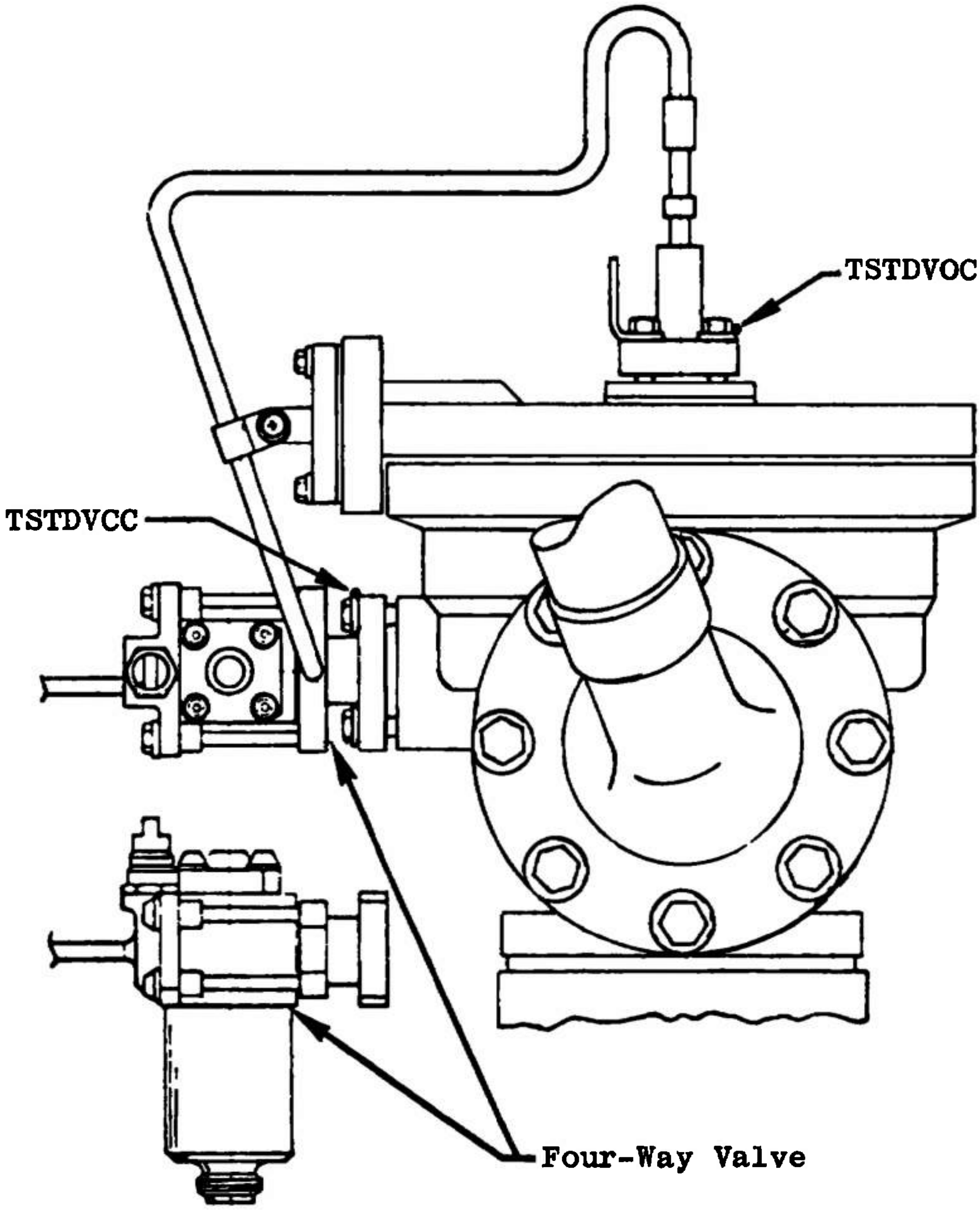



b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued

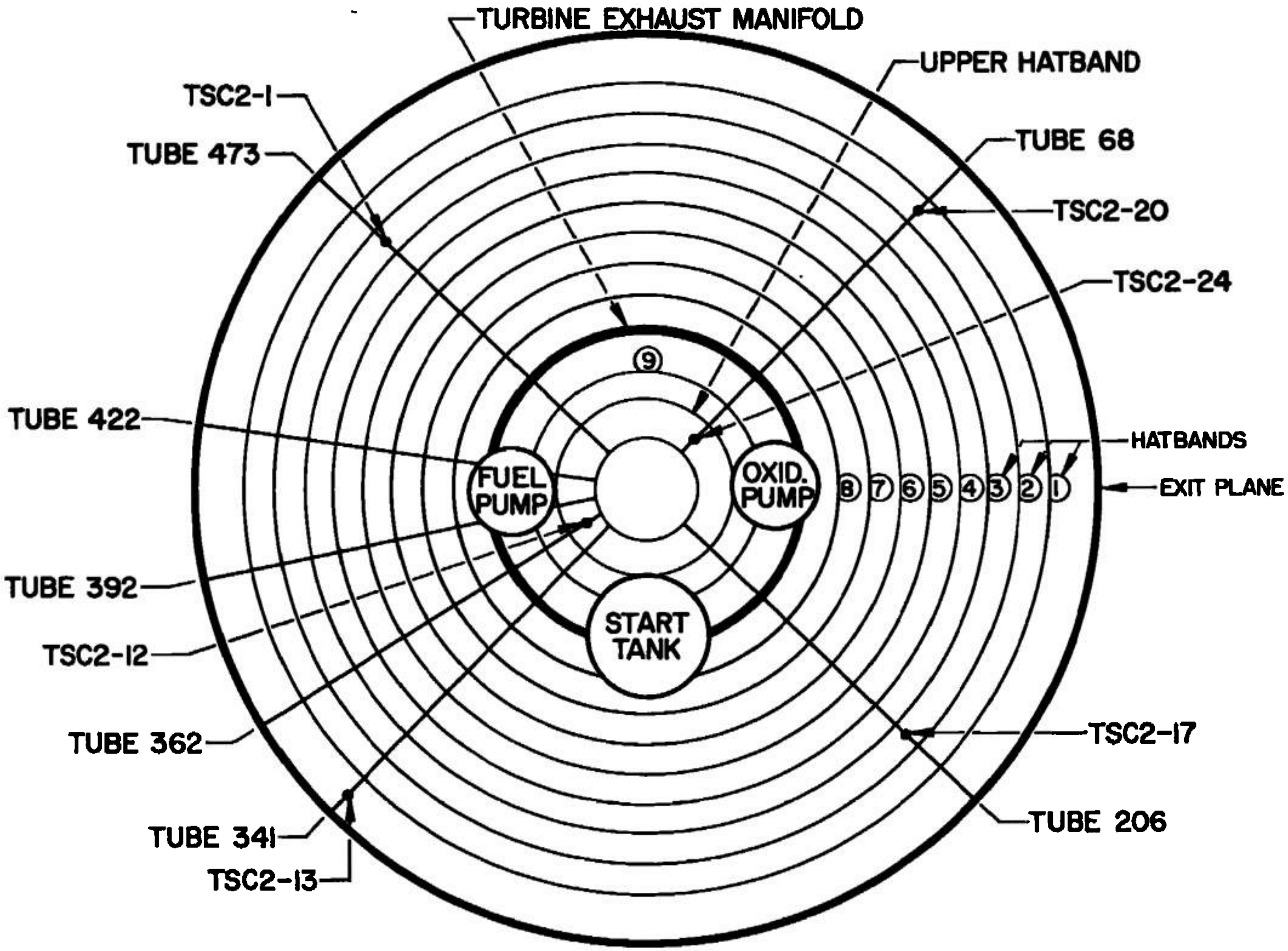



c. Main Oxidizer Valve

Fig. III-1 Continued



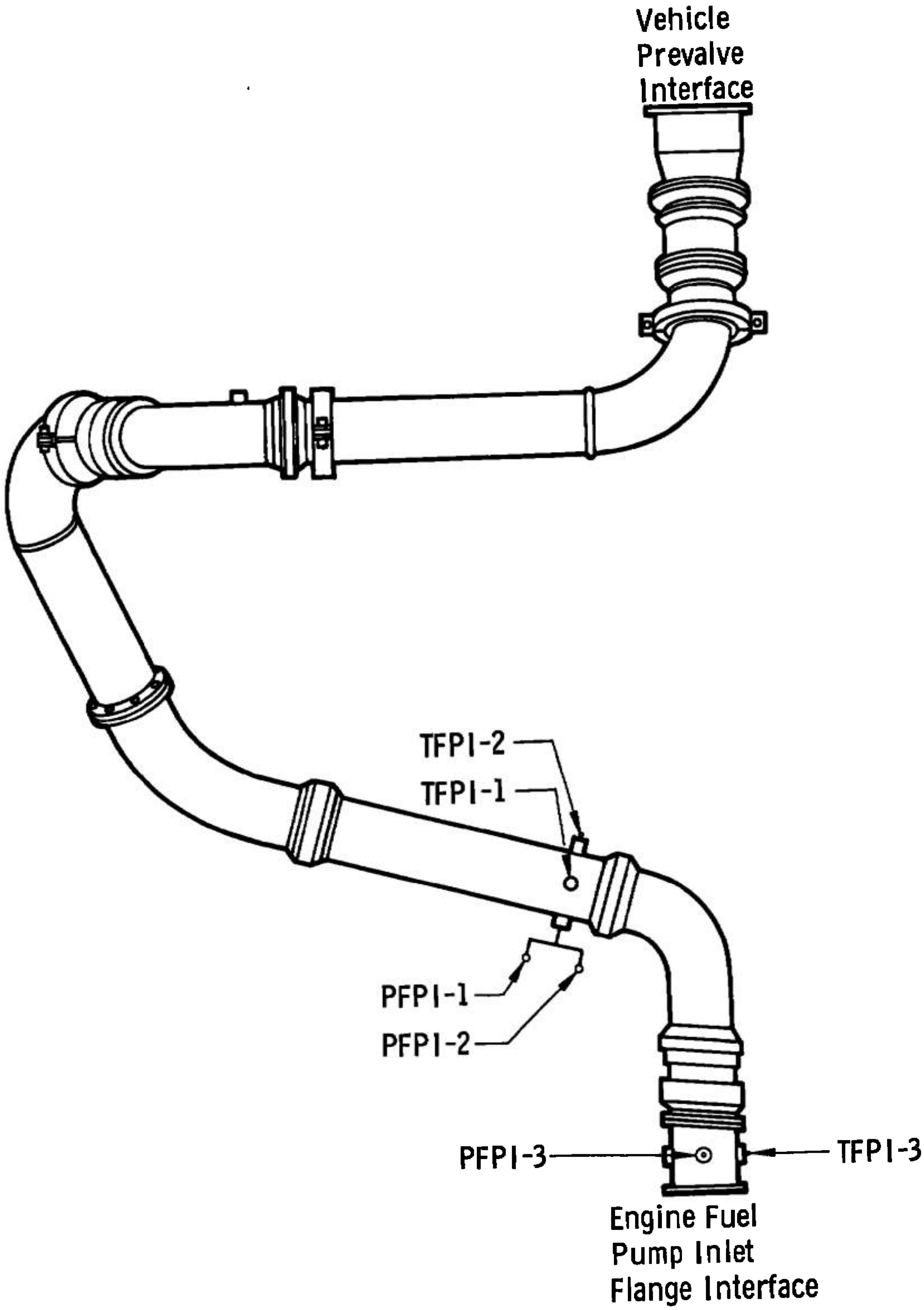

d. Start Tank Discharge Valve
Fig. III-1 Continued




VIEW LOOKING AFT

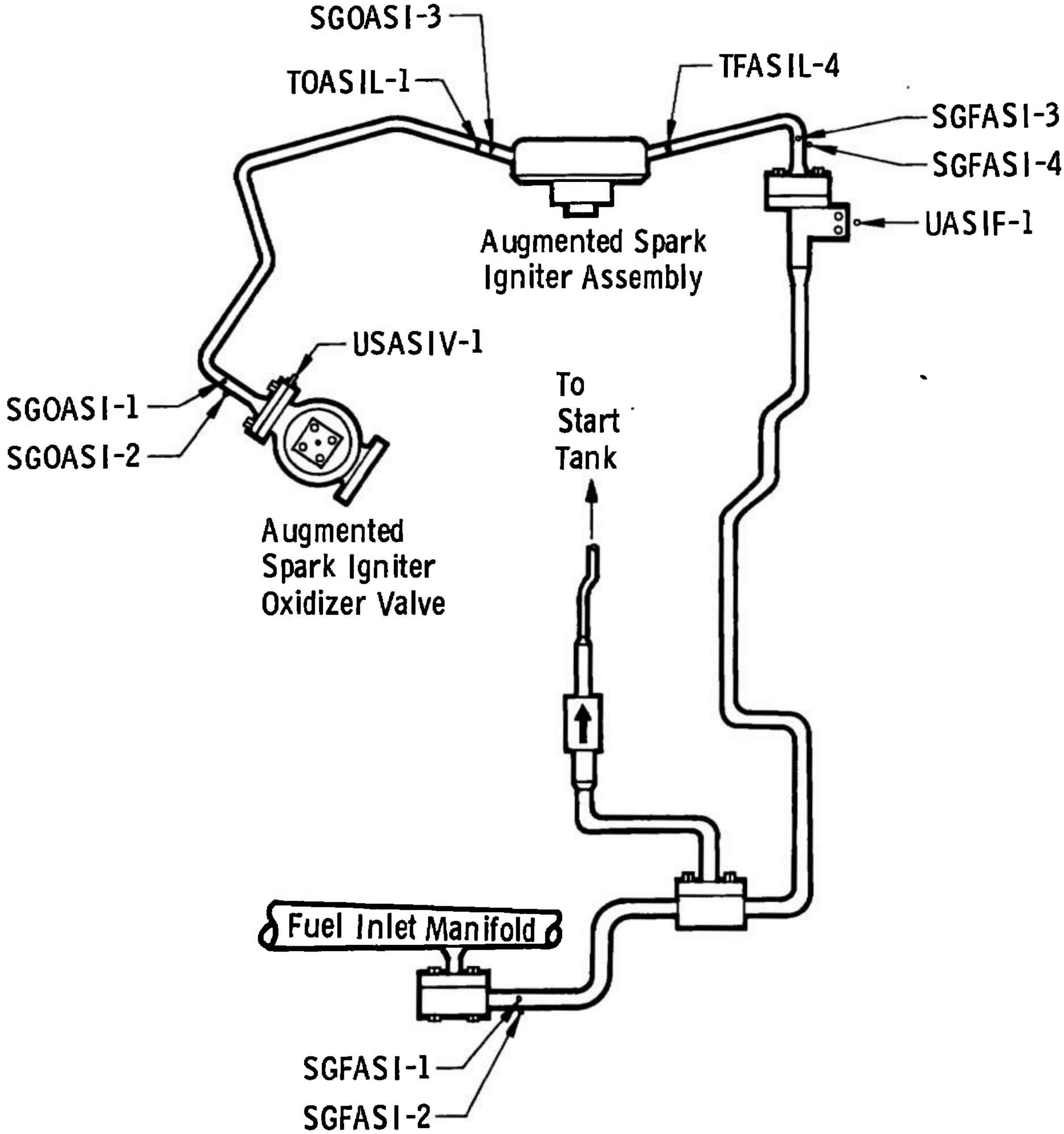
e. Thrust Chamber

Fig. III-1 Continued



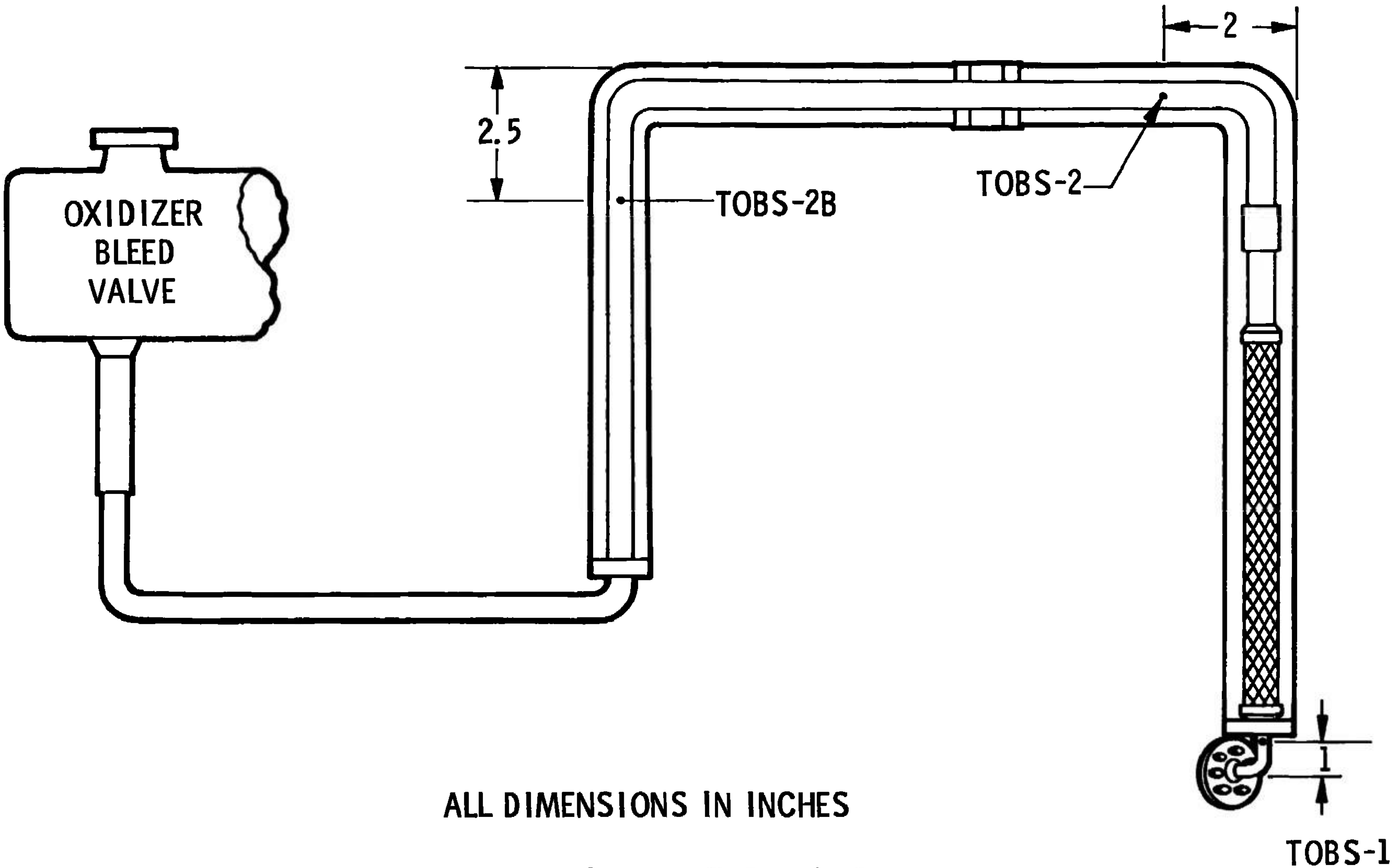

f. Low Pressure Fuel Duct

Fig. III-1 Continued




g. Augmented Spark Igniter Propellant Lines

Fig. III-1 Continued




h. Gas Generator Oxidizer Supply Line

Fig. III-1 Concluded

# APPENDIX IV
## METHODS OF CALCULATION (PERFORMANCE PROGRAM)

### TABLE IV-1
### PERFORMANCE PROGRAM DATA INPUTS

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

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

## NOMENCLATURE

| | |
|---|---|
| A | Area, in.$^2$ |
| B | Horsepower |
| C | Coefficient |
| C* | Characteristic velocity, ft/sec |
| D | Diameter, in. |
| F | Thrust, $lb_f$ |
| H | Head, ft |
| h | Enthalpy, Btu/$lb_m$ |
| I | Impulse |
| M | Molecular weight |
| N | Speed, rpm |
| P | Pressure, psia |
| Q | Flow rate, gpm |
| R | Resistance, sec$^2$/ft$^3$-in.$^2$ |
| r | Mixture ratio, O/F |
| T | Temperature, °F |
| TC* | Theoretical characteristic velocity, ft/sec |
| W | Weight flow, lb/sec |
| Z | Differential pressure, psi |
| $\beta$ | Ratio |
| $\gamma$ | Ratio of specific heats |
| $\eta$ | Efficiencies |
| $\theta$ | Degrees |
| $\rho$ | Density, lb/ft$^3$ |

### SUBSCRIPTS

| | |
|---|---|
| A | Ambient |
| AA | Ambient at thrust chamber exit |
| B | Bypass nozzle |

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

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

## PERFORMANCE PROGRAM EQUATIONS

### THRUST

Thrust Chamber, Vacuum

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

Empirical Determination from Curve Fit of Thrust versus $P_C$

Thrust Chamber

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

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

$P_{AA}$ = Measured Cell Pressure

Engine, Vacuum

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

Engine

$$F_E = F_C$$

### MIXTURE RATIO

Engine

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

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

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

Thrust Chamber

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

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

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

$W_{XO}$ = Standard 0.9 lb/sec

$W_{XF}$ = Standard 2.1 lb/sec

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

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

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

$$K_7 = 32.174$$

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

$$P_{IO}\ STD = 39\ psia$$
$$P_{IF}\ STD = 30\ psia$$
$$\rho_{IO}\ STD = 70.79\ lb/ft^3$$
$$\rho_{IF}\ STD = 4.40\ lb/ft^3$$
$$T_{IO}\ STD = -295.2°F$$
$$T_{IF}\ STD = 422.5°F$$

**SPECIFIC IMPULSE**

Engine

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

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

Engine, Vacuum

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

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

Chamber

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

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

Chamber, Vacuum

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

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

**CHARACTERISTIC VELOCITY**

Thrust Chamber

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

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

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

$$K_7 = 32.174$$

Nozzle

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

$$K_6 = 1.086$$

Nozzle, Vacuum

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

$$K_6 = 1.086$$

**THRUST COEFFICIENT**

Engine

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

Engine, Vacuum

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

**DEVELOPED PUMP HEAD**

Oxidizer

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

$K_4 = 144$

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

Fuel

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

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

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

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

Fuel and Oxidizer Vacuum

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

**PUMP EFFICIENCIES**

Fuel, Isentropic

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

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

Oxidizer, Isentropic

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

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

$$Y_O = 1.000$$

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

**TURBINES**

Oxidizer, Efficiency

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

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

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

$$\text{if } P_{OO} \geq 1010$$

$$\text{set } P_{OO} = 1010$$

$$\ell n \, R_v = A + B \, (\theta_{PUVO}) - C(\theta_{PUVO})^3 + D \, (e)^{\frac{\theta_{PUVO}}{7}} + E \, \theta_{PUVO} \, (e)^{\frac{\theta_{PUVO}}{7}} + F \left[ (e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

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

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

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

$$D = 1.234$$

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

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

Fuel, Efficiency

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

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

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

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

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

$$K_{10} = 1.415$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} \doteq B_{PO}$$

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

$$K_5 = 0.001818$$

Fuel, Developed Horsepower

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

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

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

Fuel, Weight Flow

$$W_{TF} = W_T$$

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

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

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

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

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

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

$$K_{13} = 0.7854$$

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

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

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

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

$$K_8 = 38.90$$

**GAS GENERATOR**

Mixture Ratio

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

$$A_1 = 0.2575$$

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

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

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

$$T_{H1} = T_{T1FM}$$

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.

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

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

# APPENDIX V
## METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)

### FLOW COEFFICIENT, $\phi$

$$\phi \sim \frac{V_f}{V_T}$$

where $V_f$ = Absolute fluid velocity at inducer inlet, ft/sec

$$V_f = \frac{Q}{(448.9)\ A}$$

$Q$ = Flow rate, gpm

$A$ = Inducer annulus area, $ft^2$ (specified as 0.2856 $ft^2$ by Rocketdyne)

$$V_f = \frac{Q}{128.2}$$

and $V_T$ = Absolute velocity of inducer rotor tip, ft/sec

$$V_T = \left(\frac{\pi}{60}\right)(D_T)\ (N)$$

$N$ = Pump speed, rpm

$D_T$ = Inducer rotor tip diameter, ft (specified as 0.653 ft by Rocketdyne)

Therefore,

$$\phi = \left[\frac{1}{(128.2)\ (0.0340)}\right]\ \frac{Q}{N}$$

$$\phi = 0.2291\ \frac{Q}{N}$$

### HEAD RISE COEFFICIENT

$$\Psi \sim \frac{H}{(V_{T^1})^2} = \frac{(H)(g)}{(V_{T^1})^2}$$

where $H$ = Total pump head rise, ft

$g$ = 32.174 $ft/sec^2$

and $V_{T^1}$ = Absolute velocity of pump rotor tip, ft/sec

$$V_{T^1} = \left(\frac{\pi}{60}\right)(D_{T^1})\ (N)$$

$N$ = Pump speed, rpm

$D_{T^1}$ = Pump rotor tip diameter, ft (specified as 0.6043 ft by Rocketdyne)

$$V_{T^1} = 0.03164N$$

Therefore,

$$\Psi = \left[\frac{32.174}{(0.03164)^2}\right]\ \frac{H}{N^2}$$

$$\Psi = 32{,}150\,\frac{H}{N^2}$$

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13. ABSTRACT


Sixteen firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during four test periods (J4-1801-42 through J4-1901-02) between June 19 and July 11, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application on the S-II stage of the Saturn V vehicle. The firings were conducted utilizing the specially configured low pressure fuel duct designed to simulate the S-II center engine low pressure fuel duct fluid dynamics. The firings were accomplished at pressure altitudes of approximately 100,000 ft at engine start. The primary objective of these firings was to evaluate the augmented spark igniter modified per Rocketdyne Engineering Change Proposal J2-643. Engine components were thermally conditioned to predicted S-II interstage/engine temperatures. Engine operation was satisfactory on all firings except firing 02D, on which ignition was not detected in the augmented spark igniter. Total accumulated firing duration for the four test periods was 197.0 sec.

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| altitude testing | | | | | | |
| Saturn | | | | | | |
| spark ignition | | | | | | |
| engine operation | | | | | | |

1. Rocket motors -- J-2
2 Missles -- Saturn
3 Rocket motors -- Performance
4 " " -- Ignition
~~5~~ ~~Spark ignition~~
6. Igniters

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