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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)**

H. J. Counts and C. H. Kunz
ARO, Inc.

November 1968

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Per AF letter 125 July 74 signed William O. Cole.

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.

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This technical report has been reviewed and is approved.

Edgar D. Smith
Major, USAF
AF Representative, LRF
Directorate of Test

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

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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12 July 74, signed
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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 lbf 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 prevalues and main propellant valves at engine shutdown.
9. **Integral Hydrogen Start Tank and Helium Tank** - The integral tanks consist of a 7258-in.³ sphere for hydrogen with a 1000-in.³ sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.
10. **Oxidizer Turbine Bypass Valve** - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.
11. **Main Oxidizer Valve** - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.
12. **Main Fuel Valve** - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

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

2.1.2 S-IVB Battleship Stage

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

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building,

containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 5.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature 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 prevalues 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 pre-valves 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 $+50^{\circ}\text{F}$. 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, August 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

- I. ILLUSTRATIONS**
- II. TABLES**
- III. INSTRUMENTATION**
- IV. METHODS OF CALCULATION (PERFORMANCE PROGRAM)**
- V. METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)**

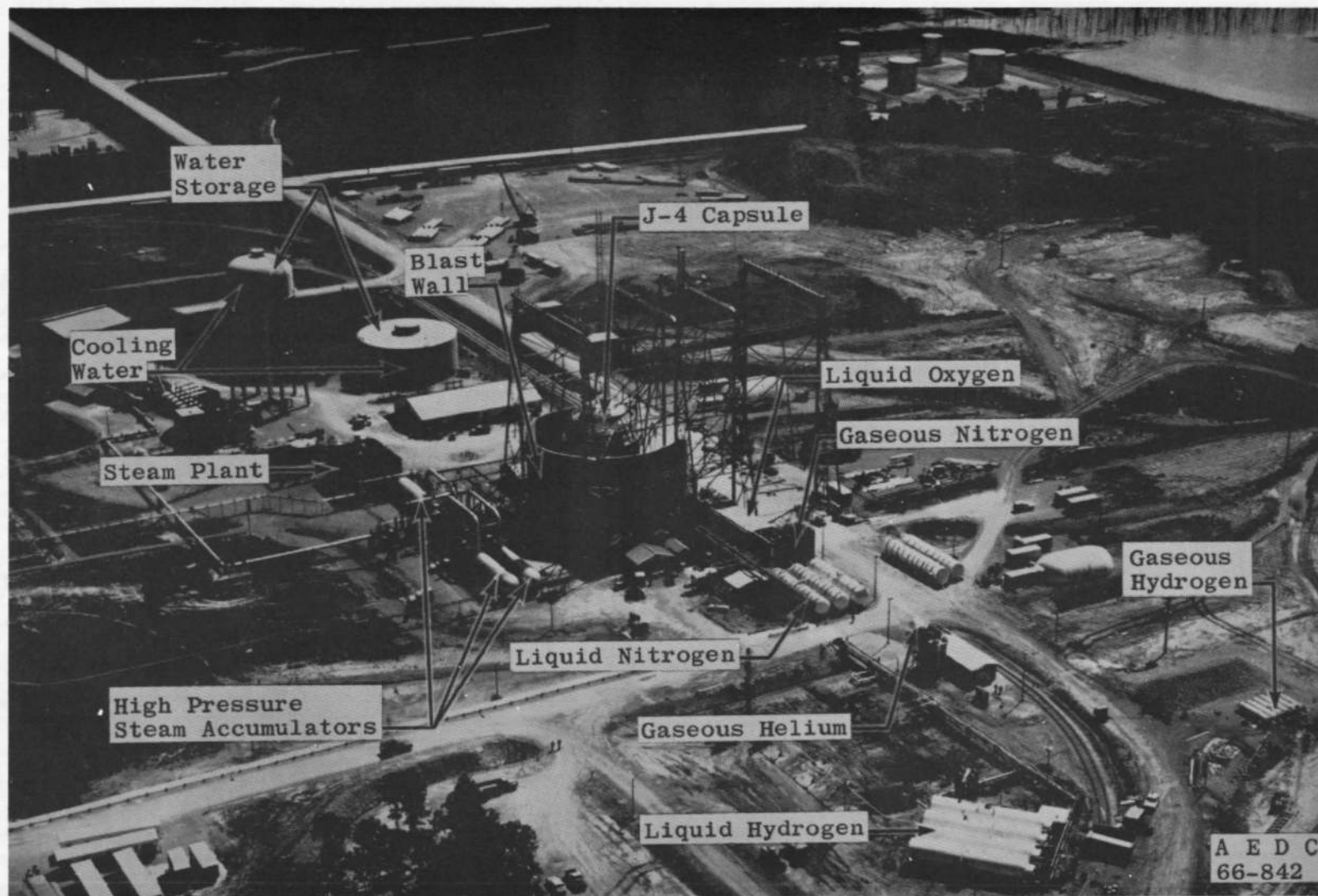


Fig. 1 Test Cell J-4 Complex

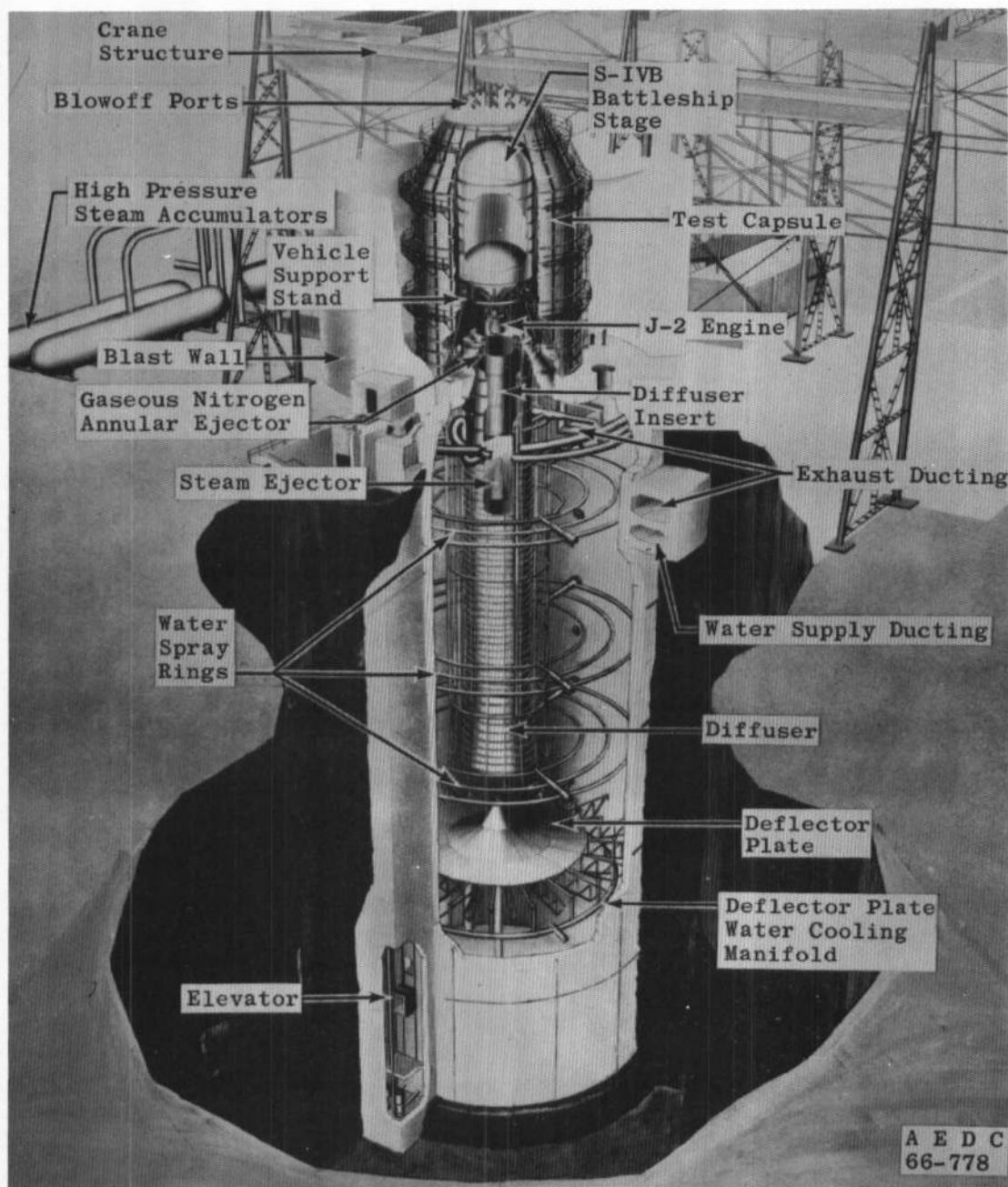


Fig. 2 Test Cell J-4, Artist's Conception

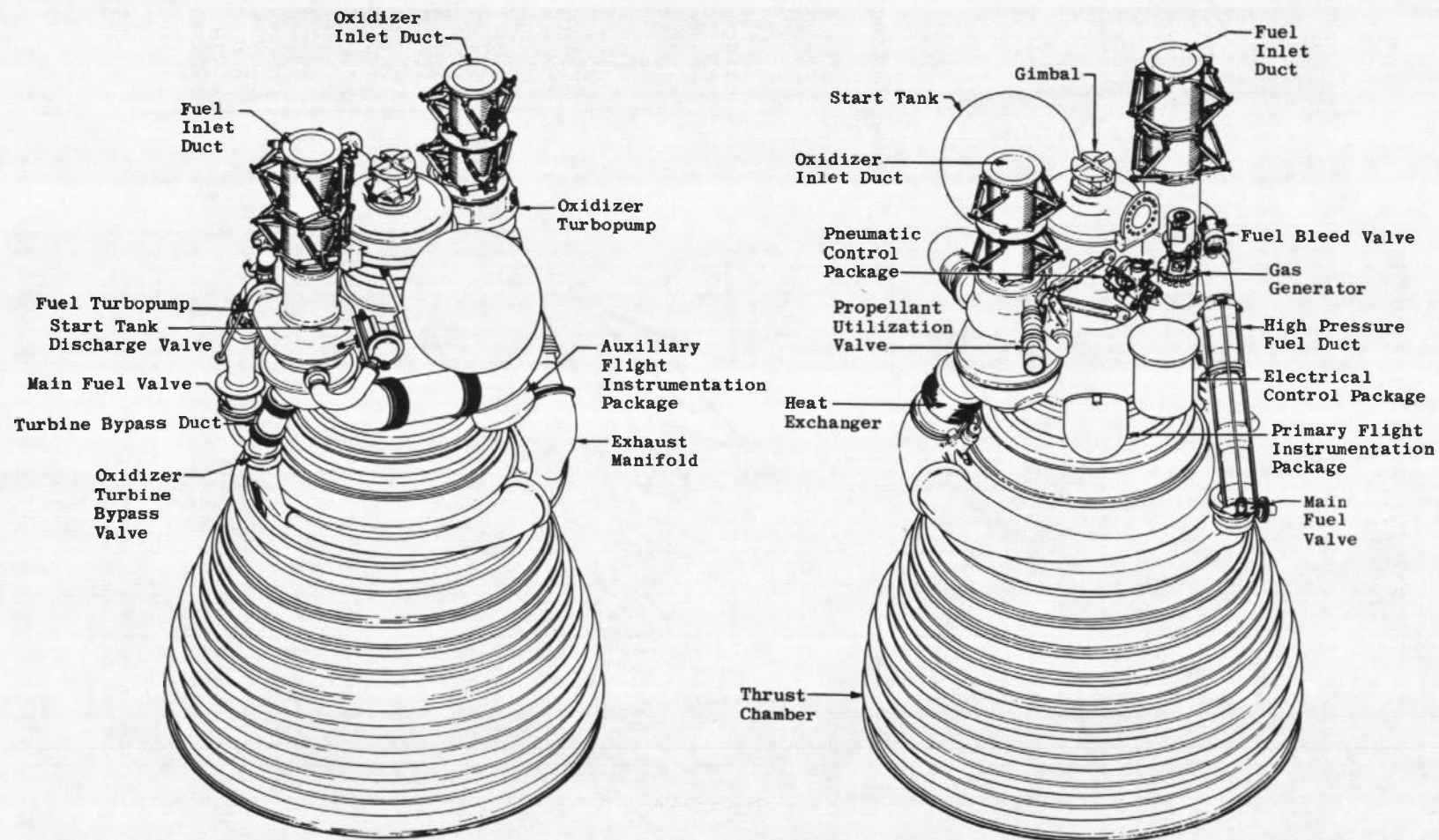


Fig. 3 Engine Details

S-II Fuel Duct Configuration for AE0C Test

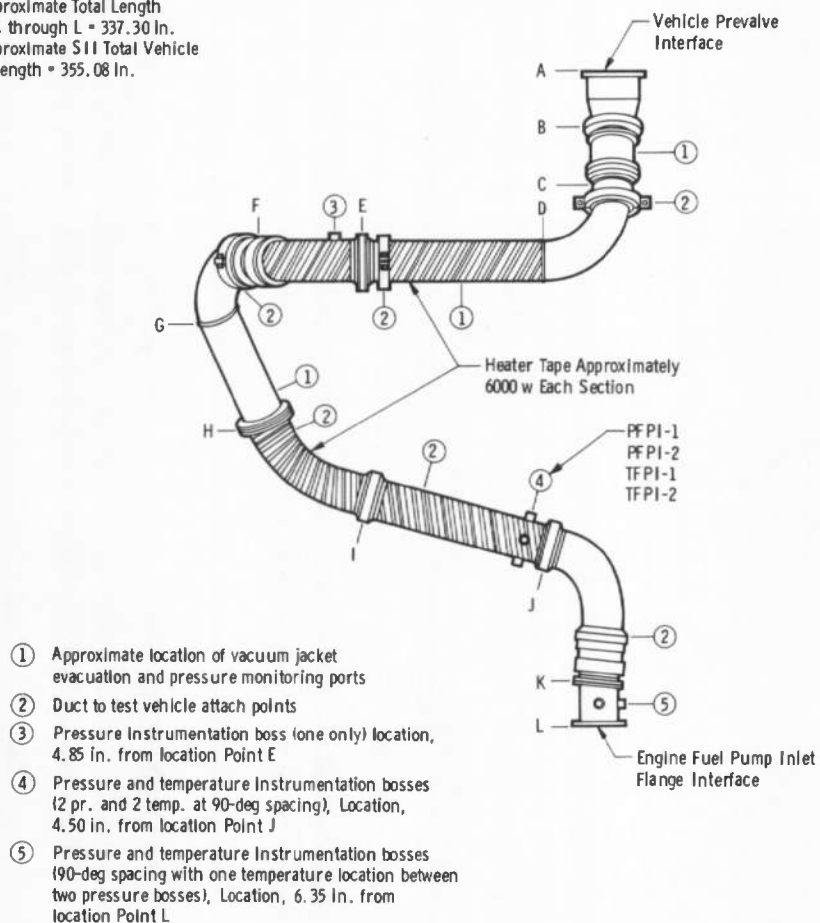
Location Point	Approximate Length, In.	Approximate Minimum ID, In.	Type of Insulation		Type of Joint	
			Vac. Jacket	ILaro-dyne	Upper	Lower
A to B	13.72	7.944		X	Marmon Flange	Bolted Flange
B to C	11.00	7.950	X		Bolted Flange	Bellows
C to D	29.63	7.900		X	Bellows	Welded
D to E	41.14	7.950	X		Welded	Bellows
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	8.280		X	Bolted Flange	Bolted Flange

Approximate Total Length

A through L = 337.30 In.

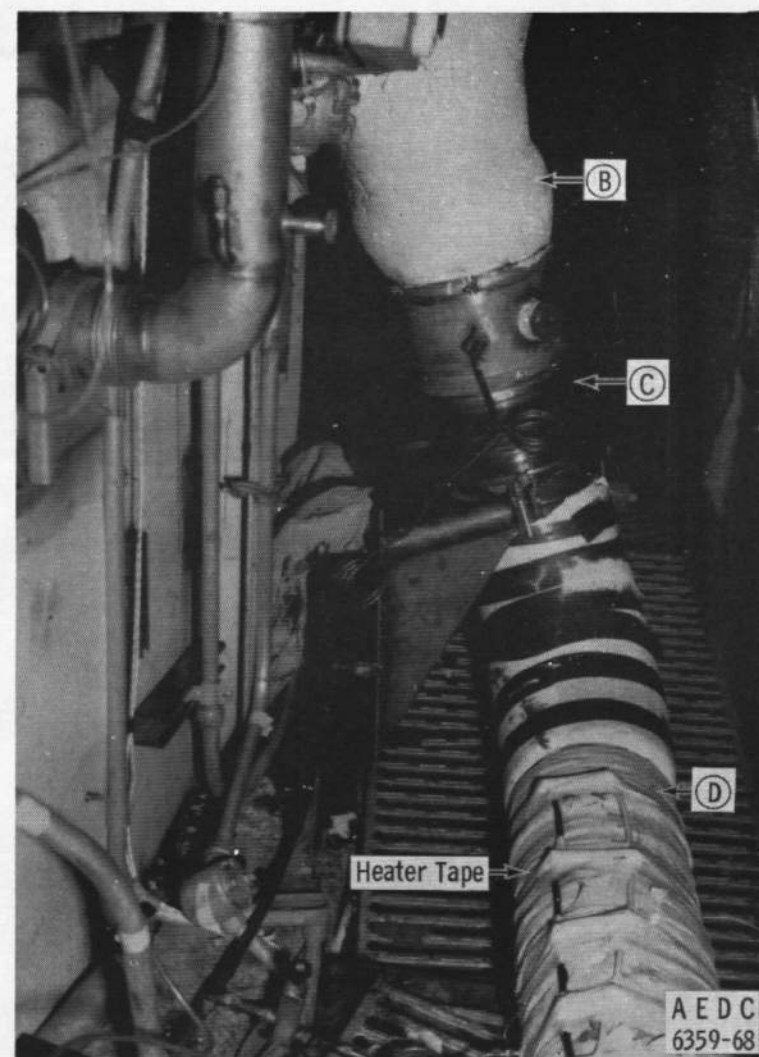
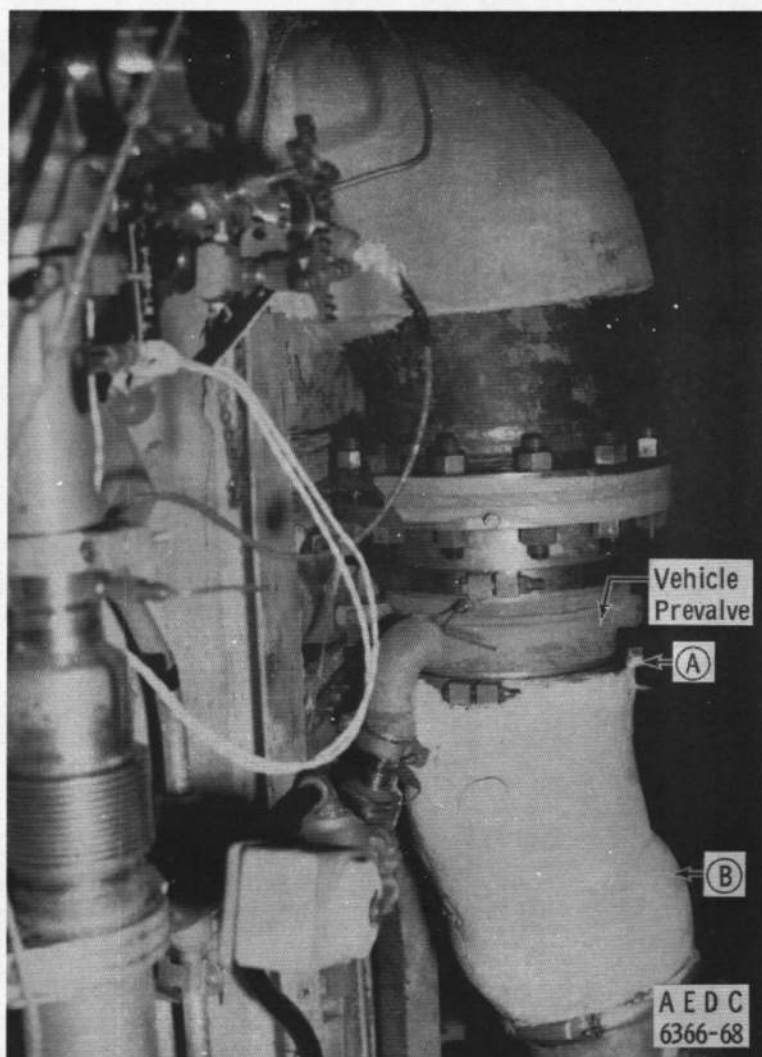
Approximate S-II Total Vehicle

Length = 355.08 In.



a. Schematic

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



b. Photographs
Fig. 4 Continued

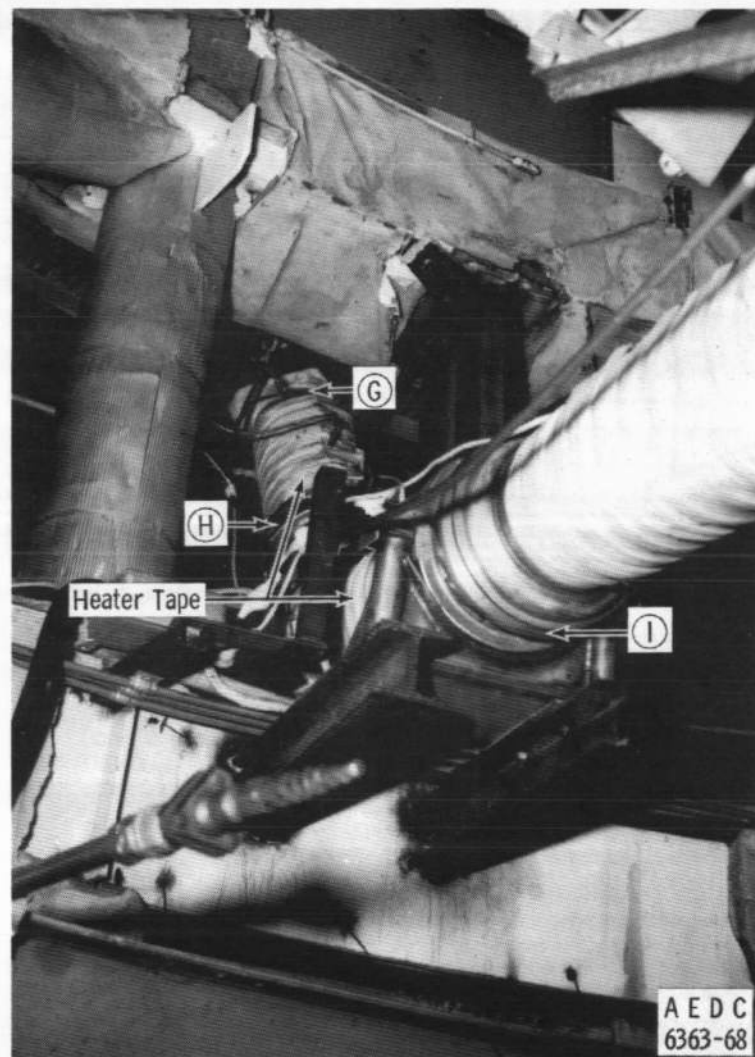
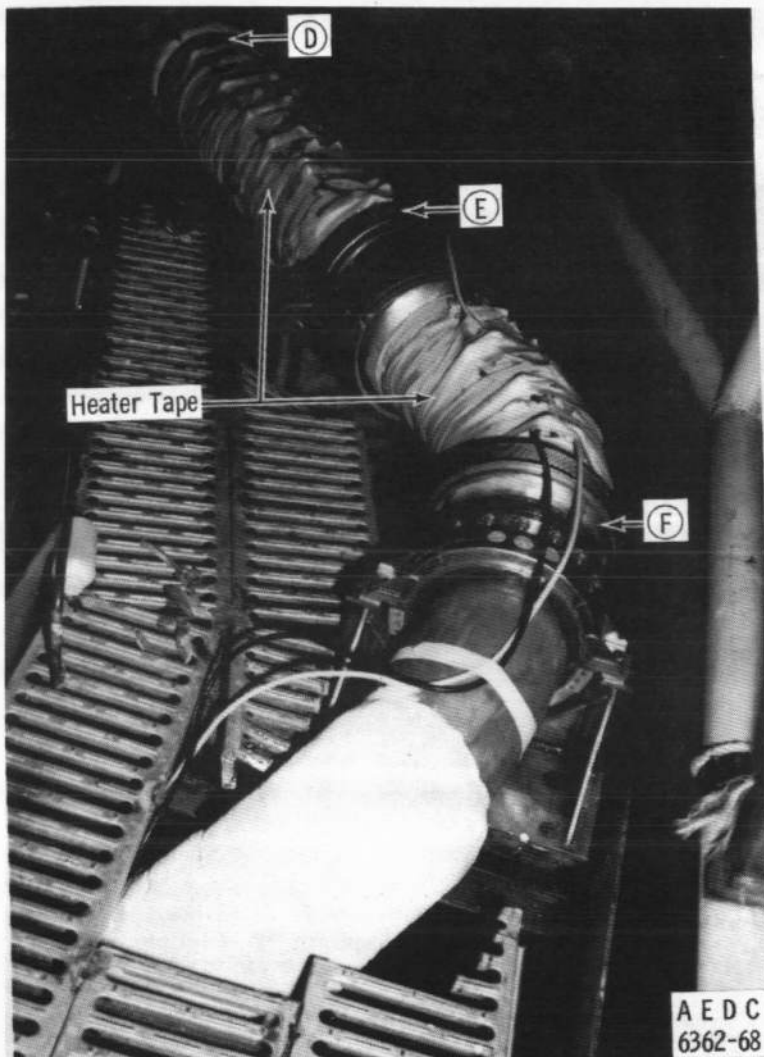


Fig. 4b Continued

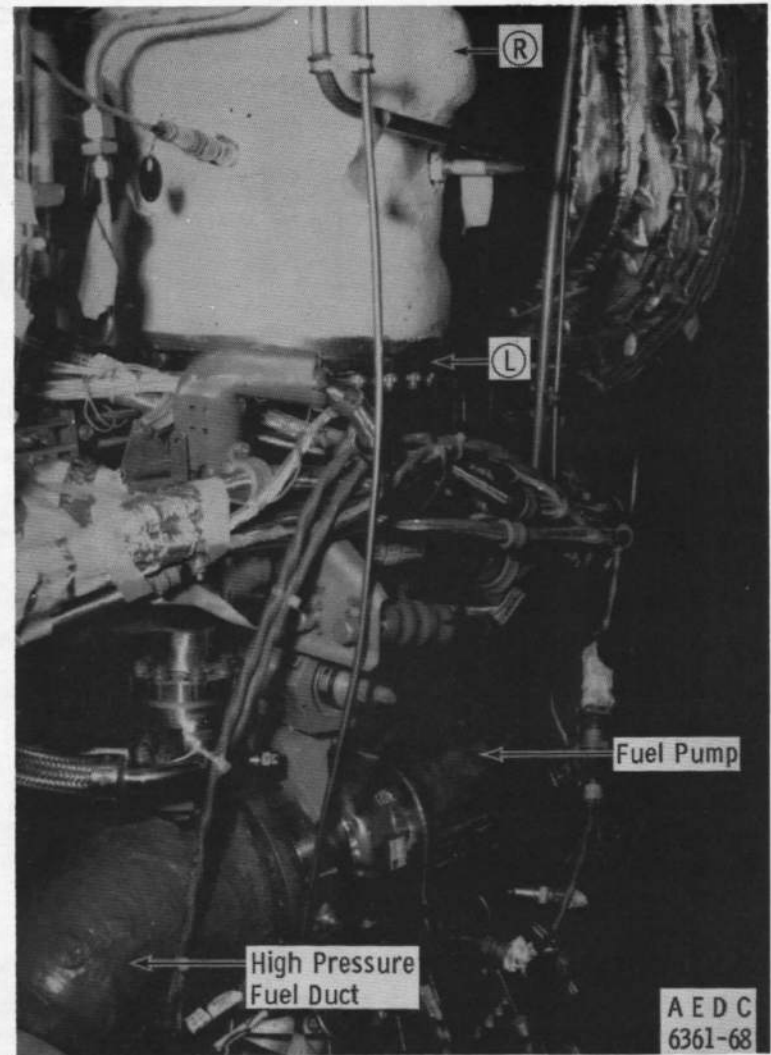
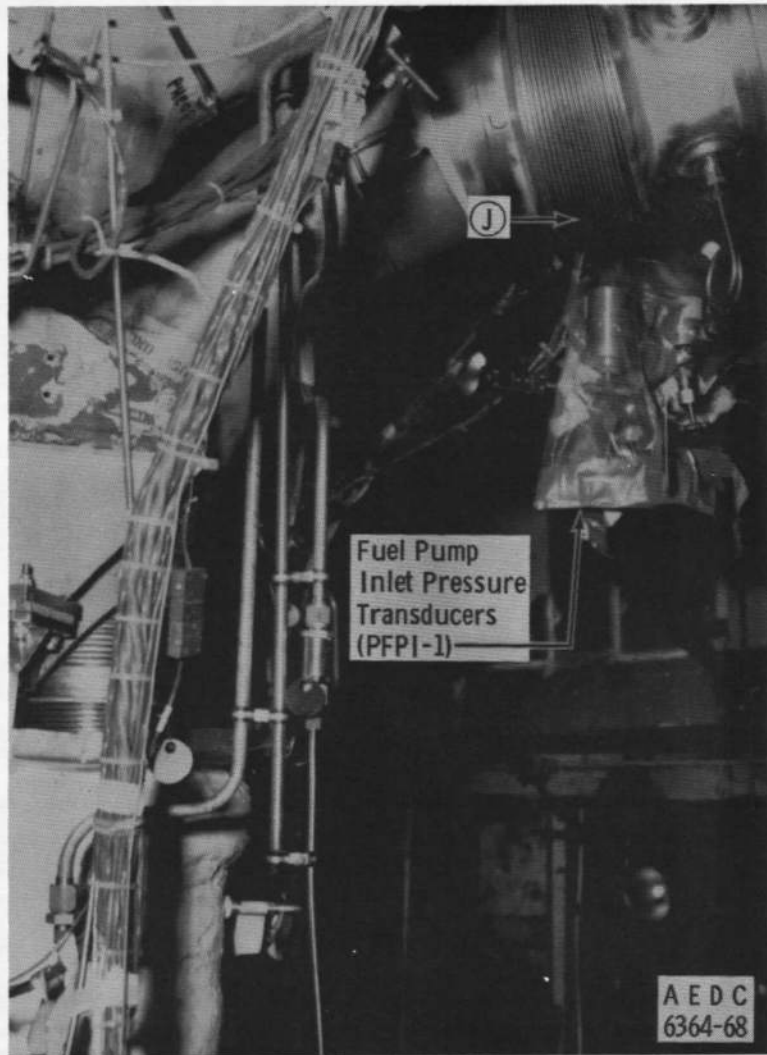


Fig. 4b Concluded

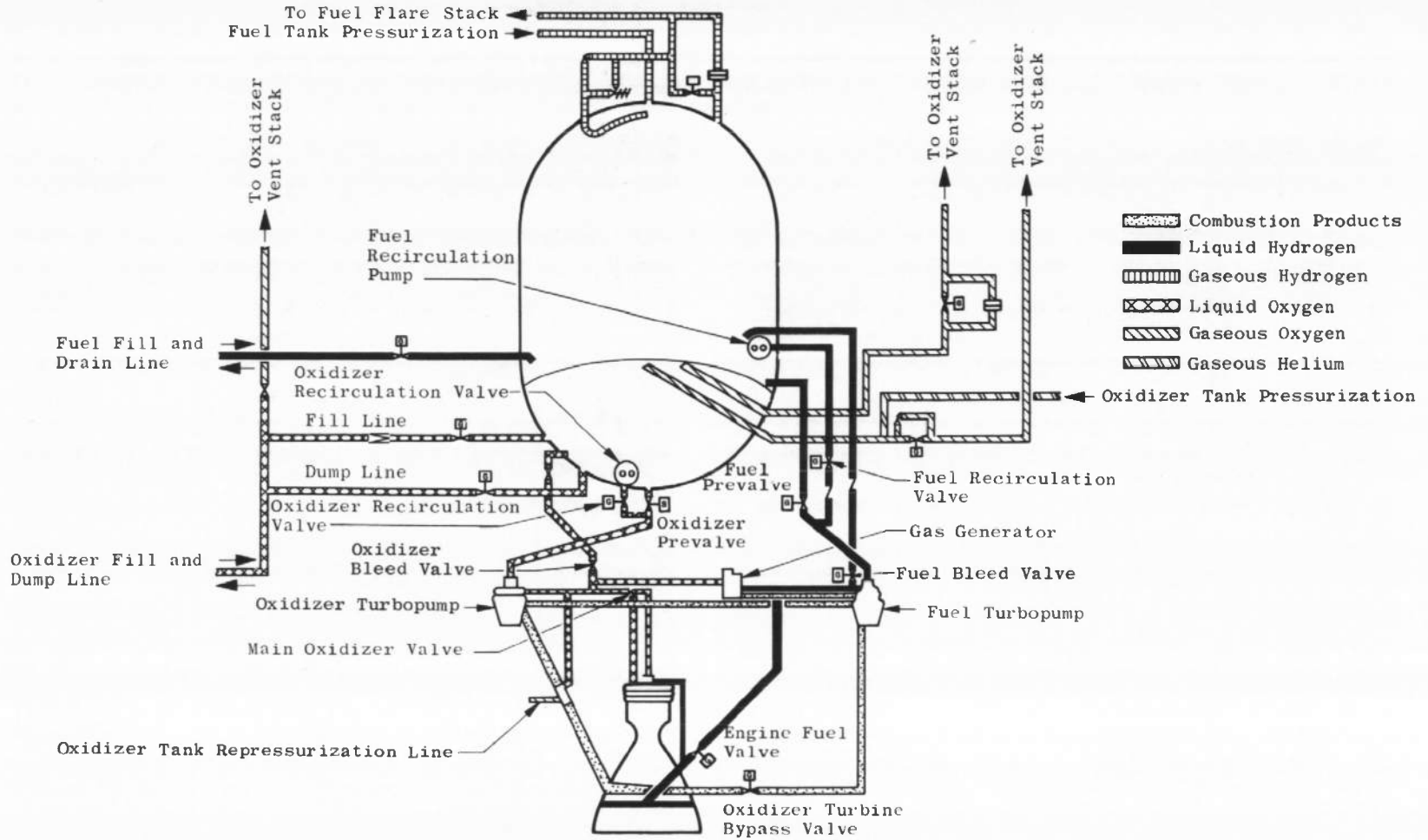
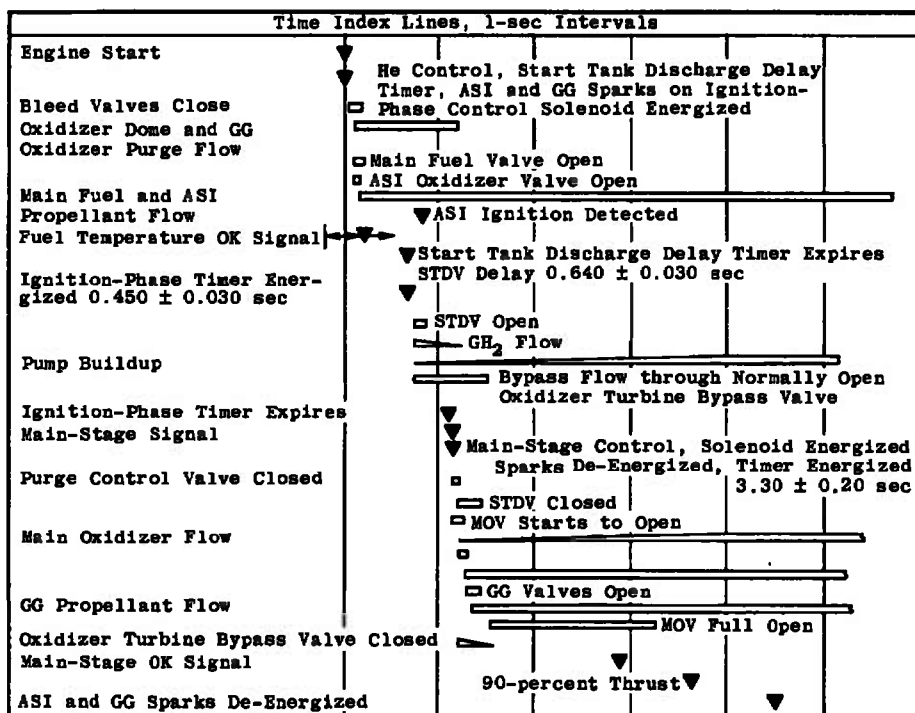
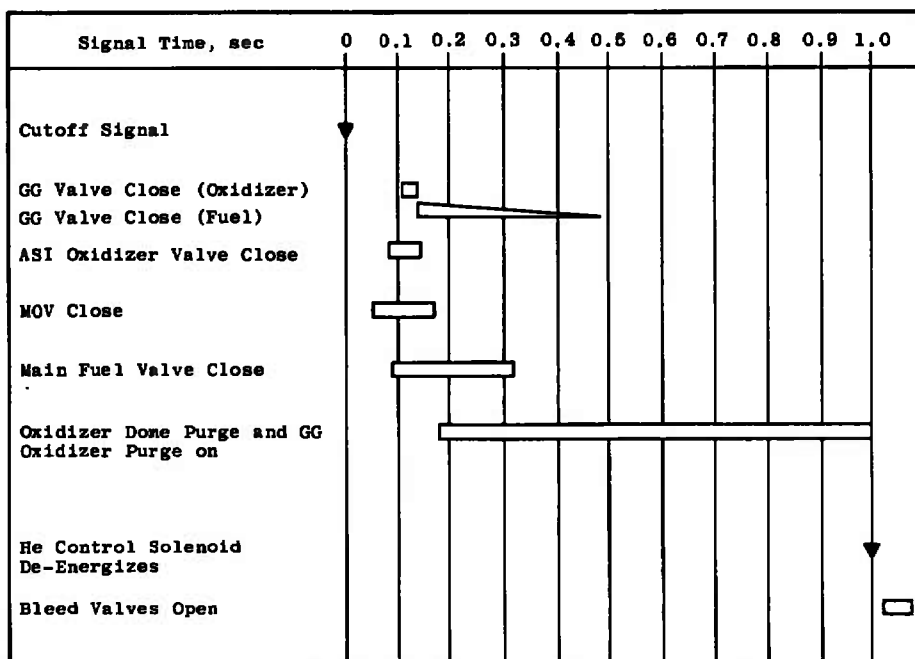


Fig. 5 S-IVB Battleship Stage/J-2 Engine Schematic

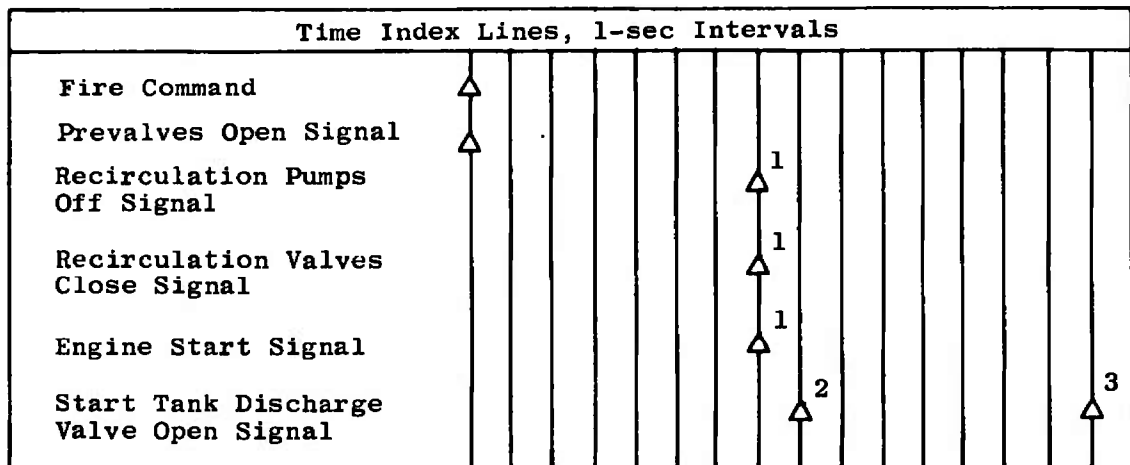


a. Start Sequence



b. Shutdown Sequence

Fig. 8 Start and Shutdown Sequence

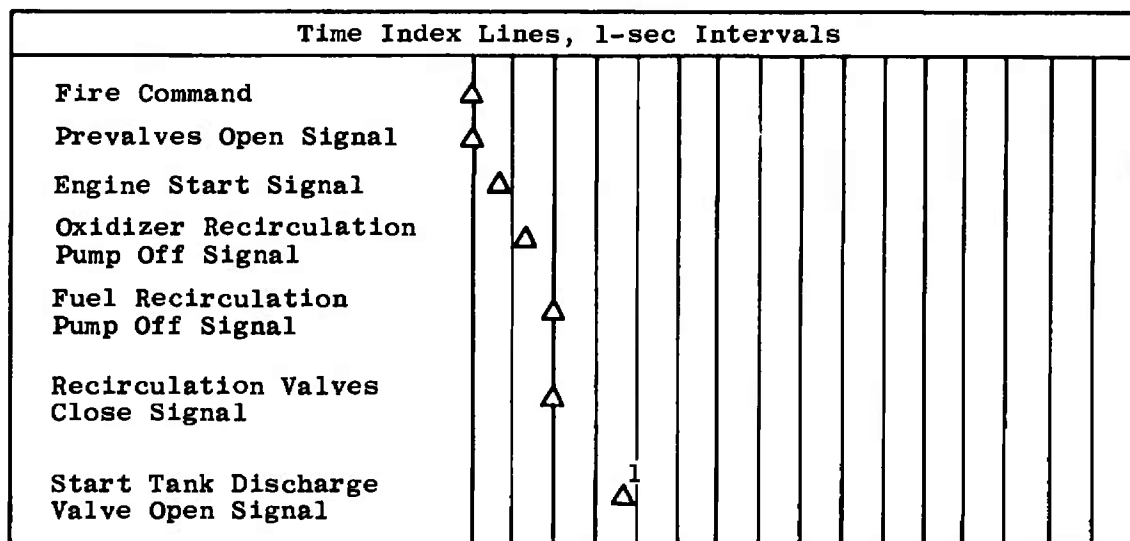


¹Nominal Occurrence Time (Function of Prevalves Opening Time)

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

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

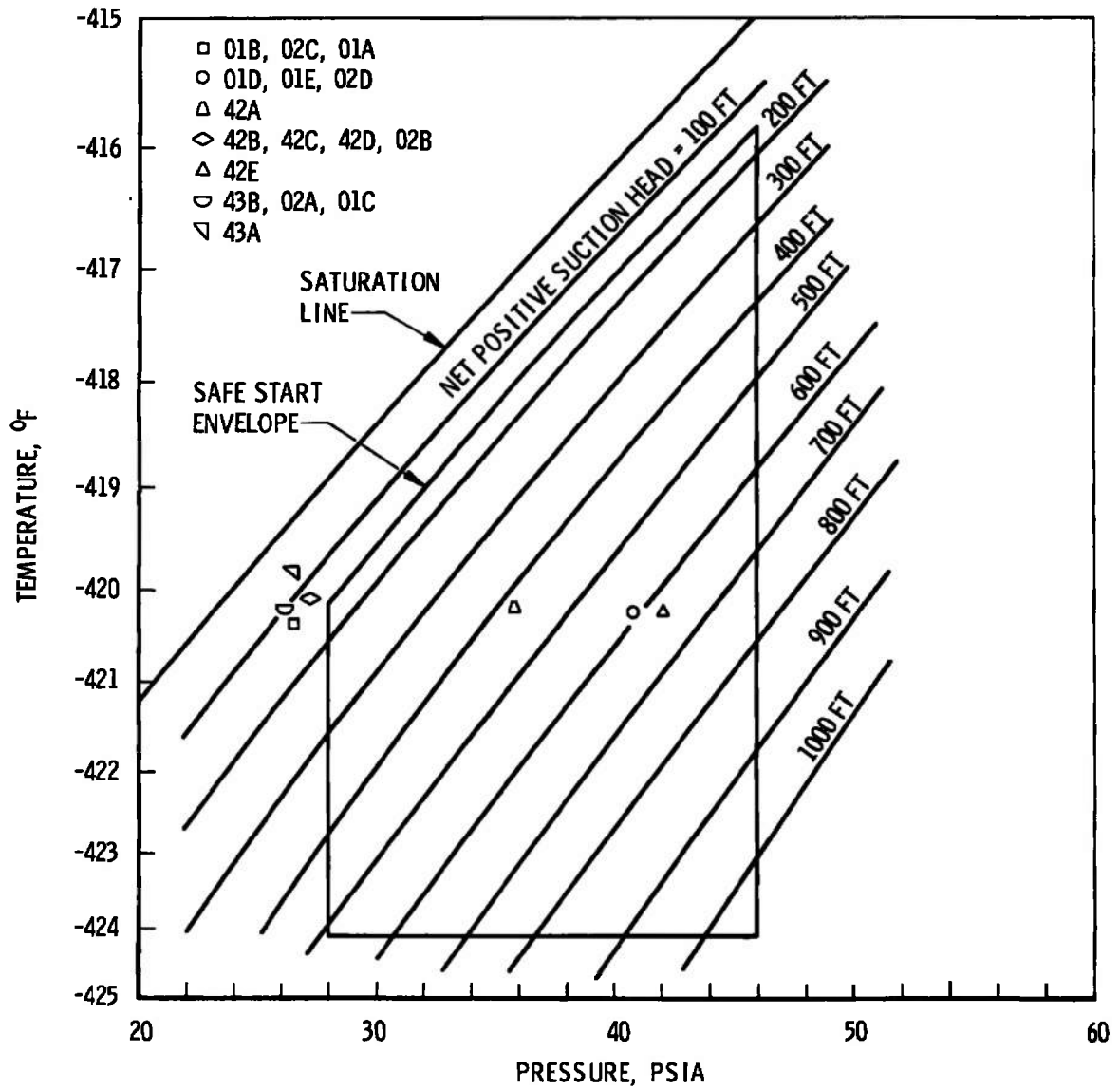
c. Normal Logic Start Sequence



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

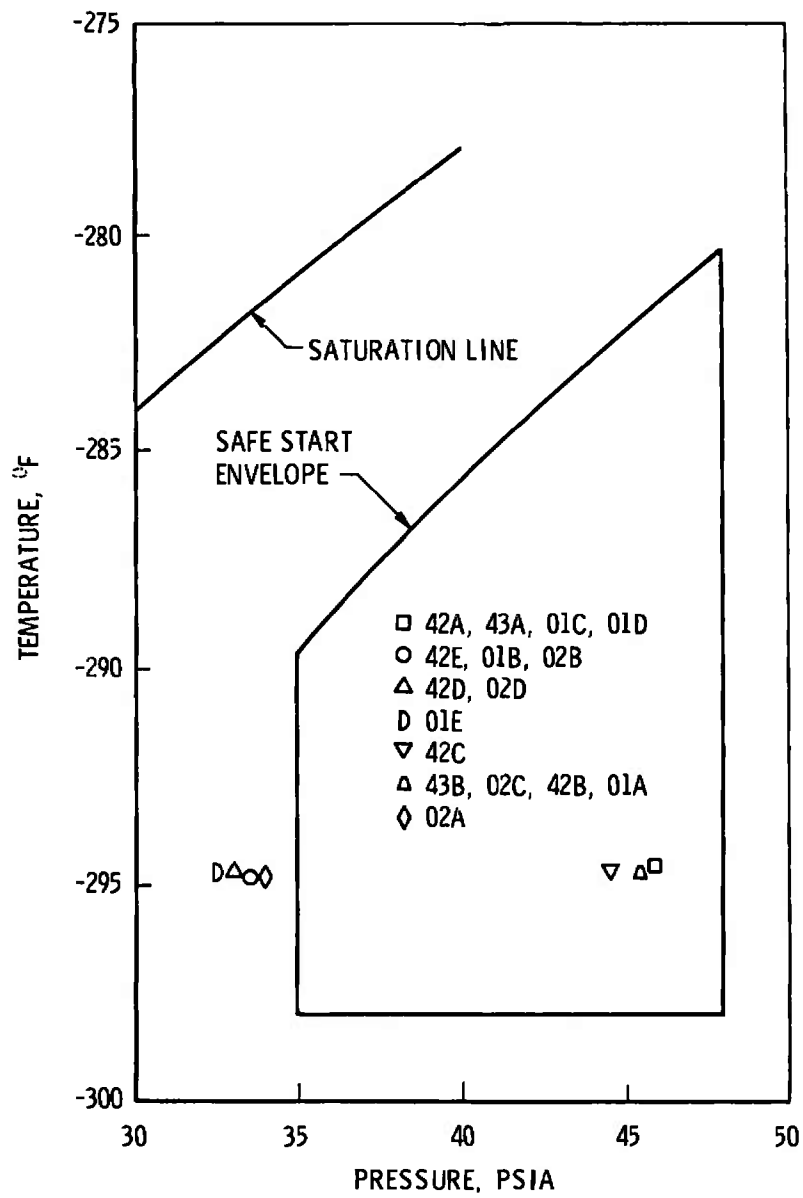
d. Auxiliary Logic Start Sequence

Fig. 8 Concluded



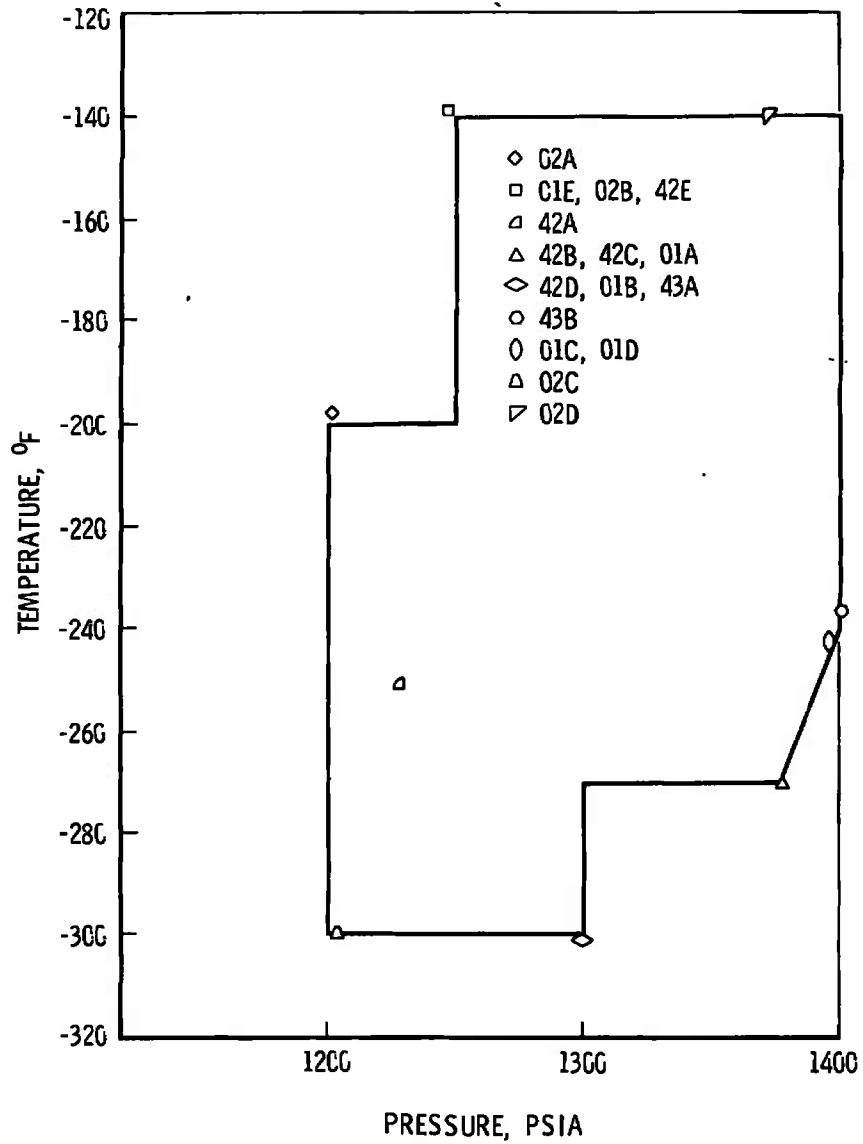
a. Fuel Pump Inlet Start Conditions

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



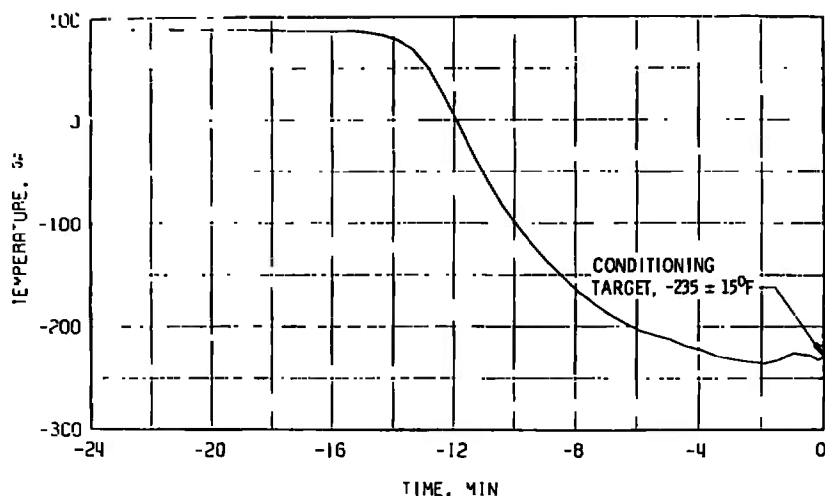
b. Oxidizer Pump Inlet Start Conditions

Fig. 9 Continued

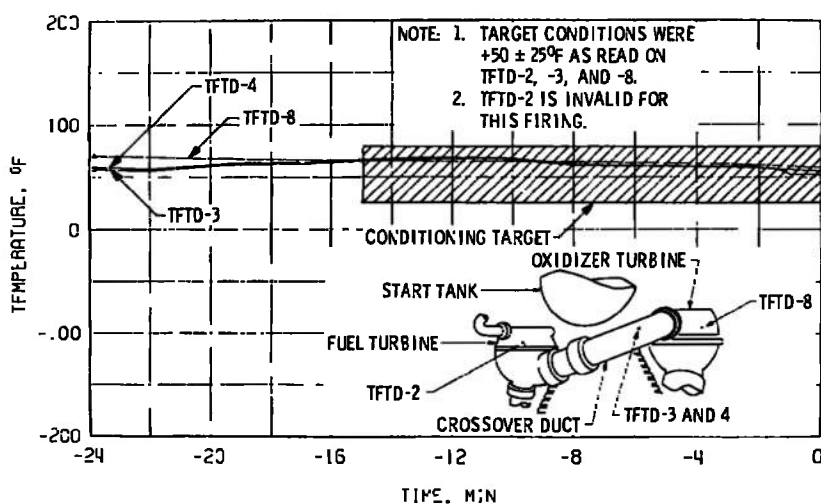


c. Start Tank Start Conditions

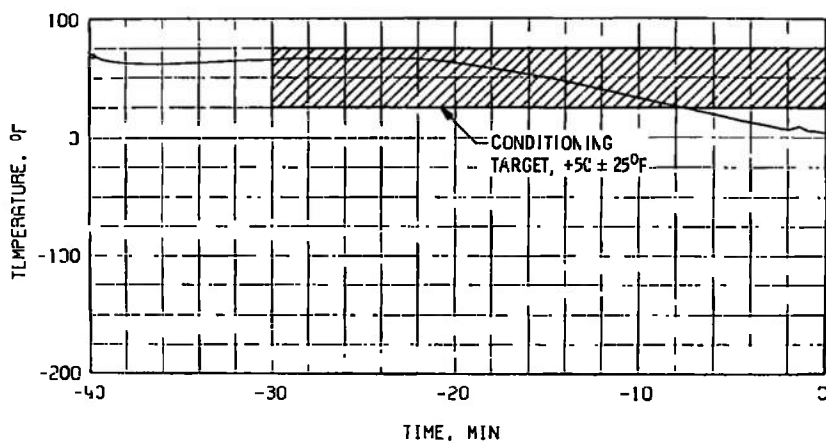
Fig. 9 Concluded



a. Thrust Chamber, TTC-1P

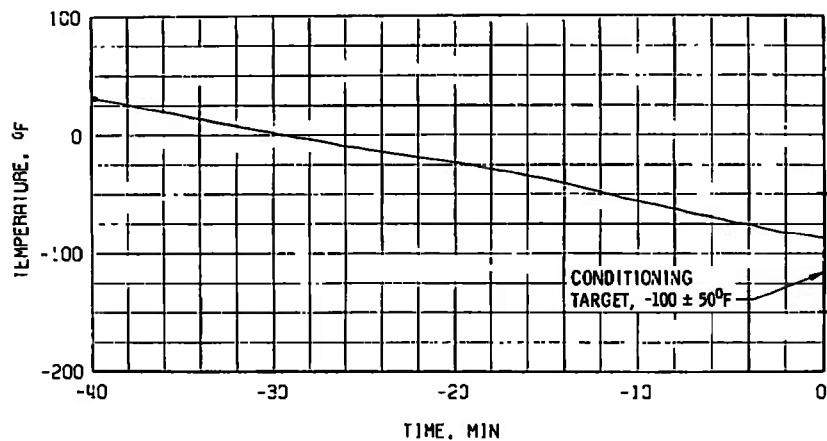


b. Crossover Duct, TTFD

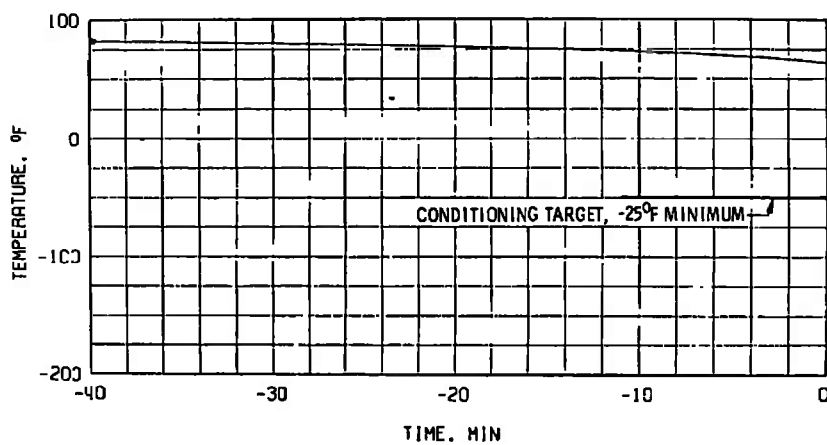


c. Start Tank Discharge Valve, TSTDVOC

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

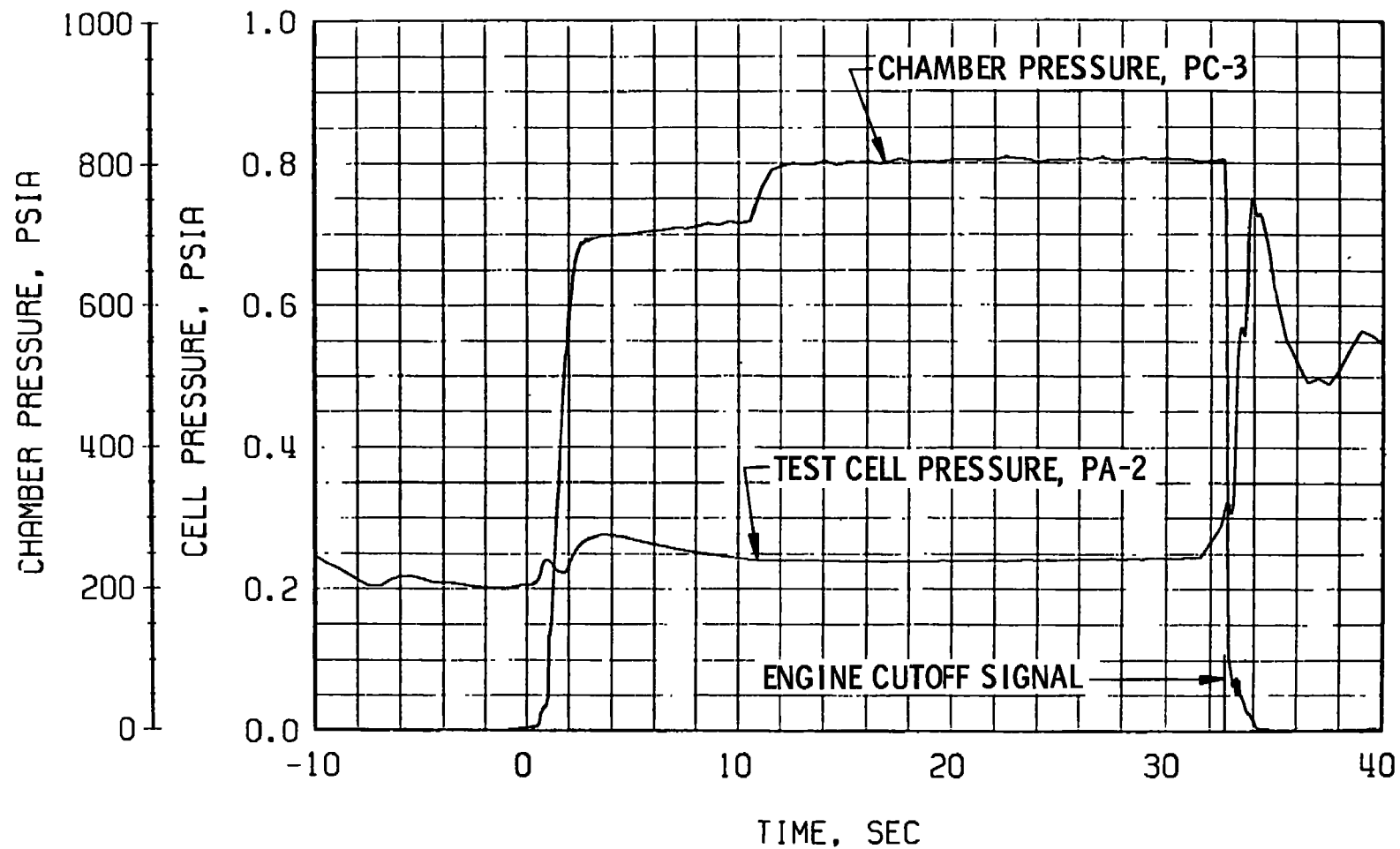
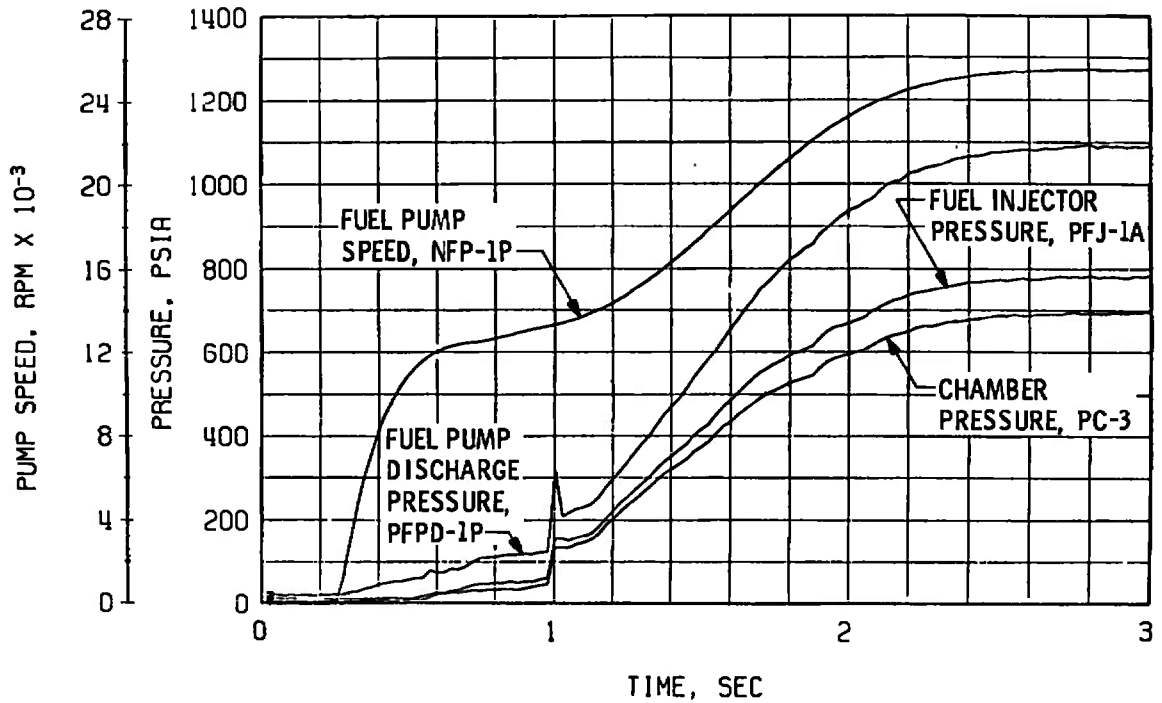
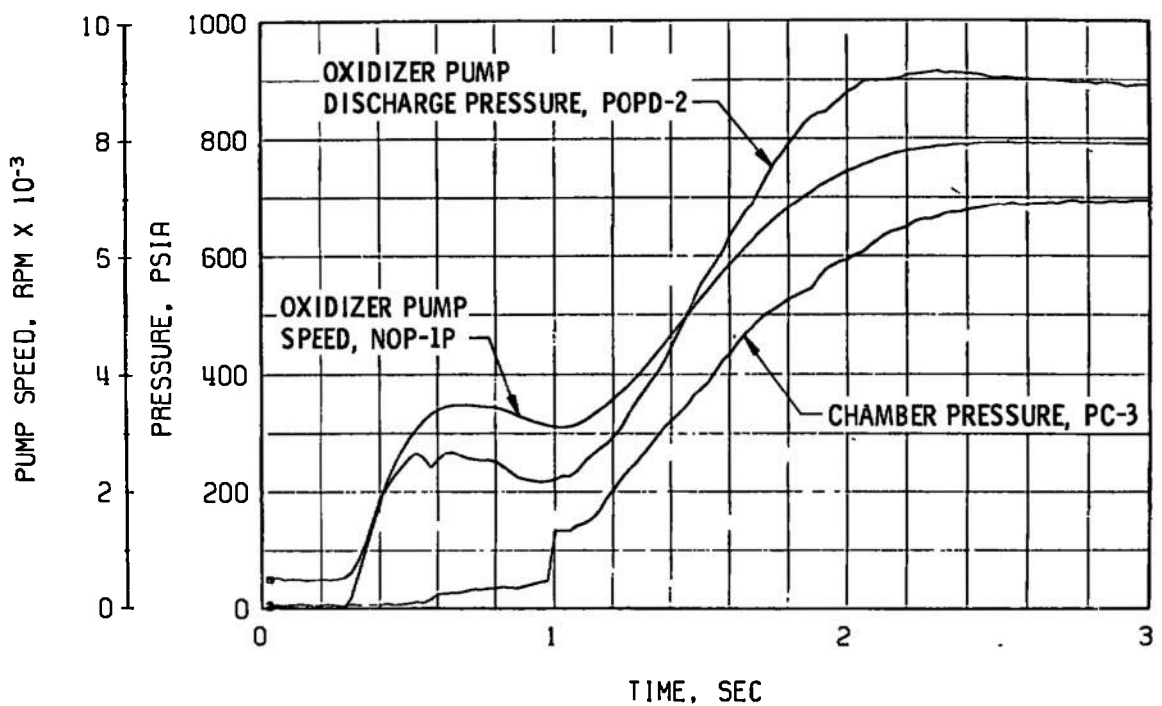
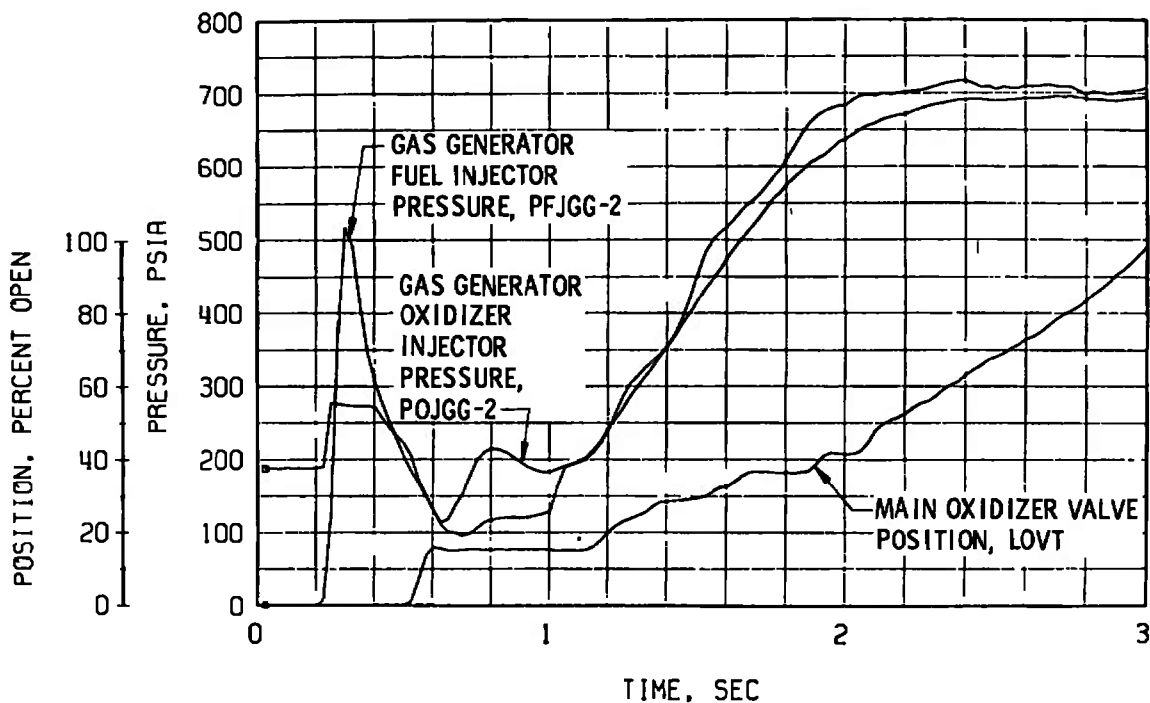


Fig. 11 Engine Ambient and Combustion Chamber Pressures, Firing 42A

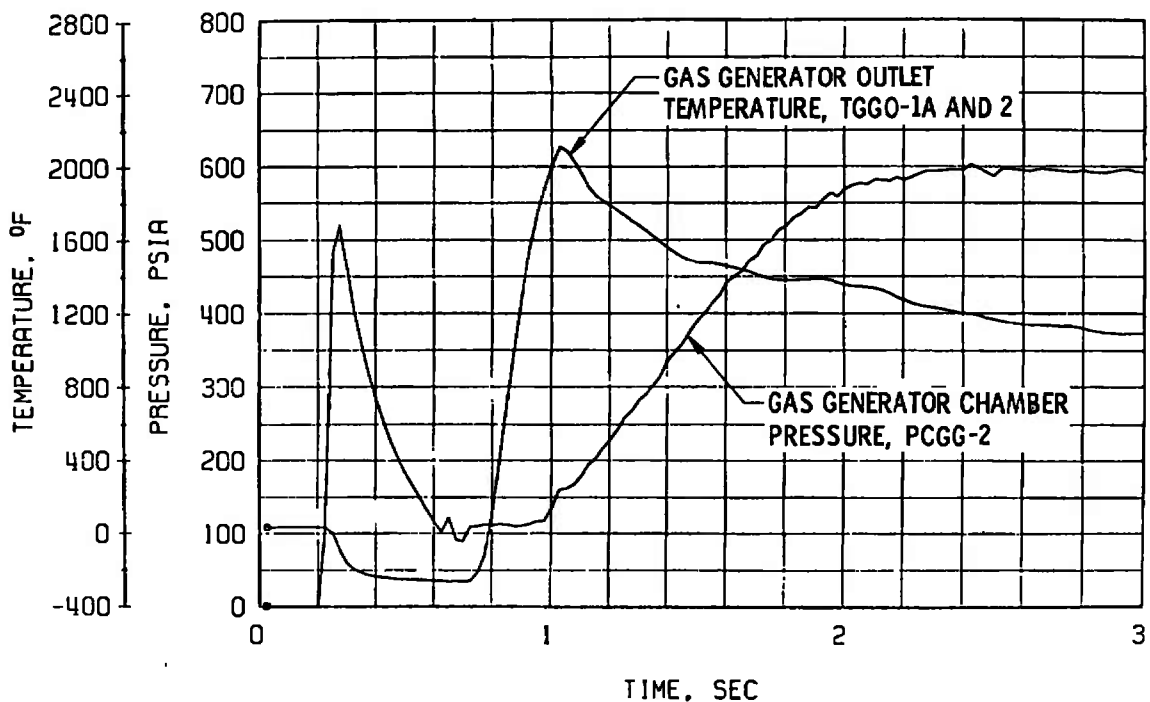


a. Thrust Chamber Fuel System, Start

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

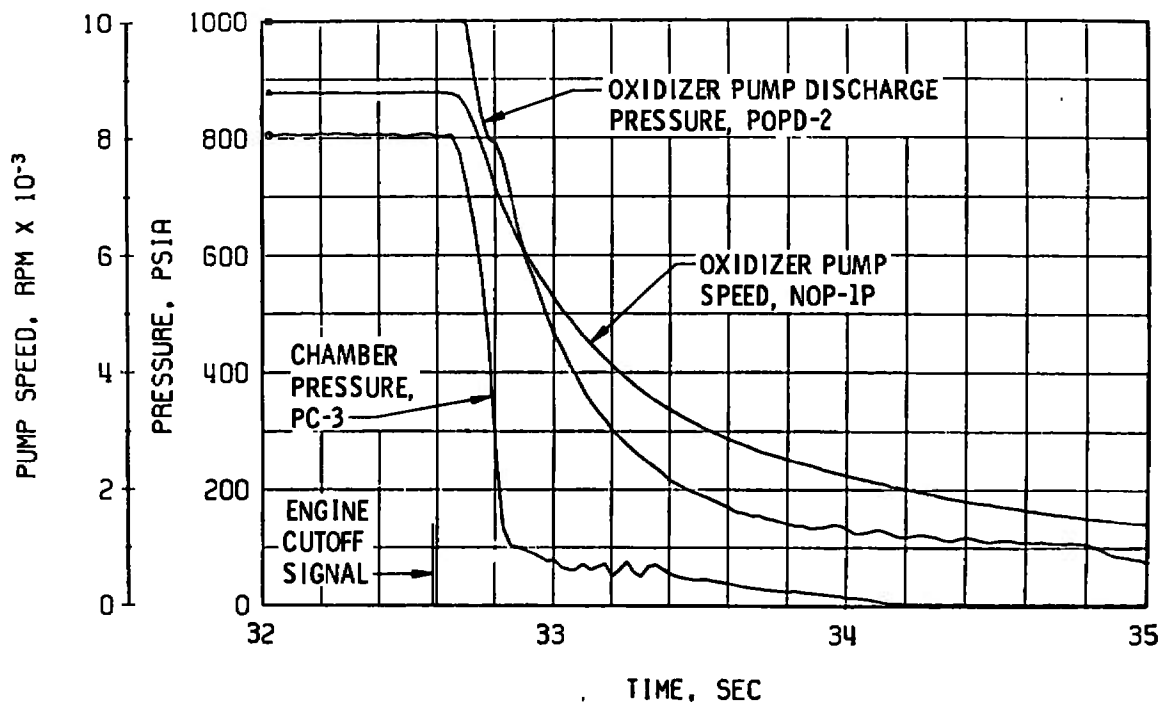
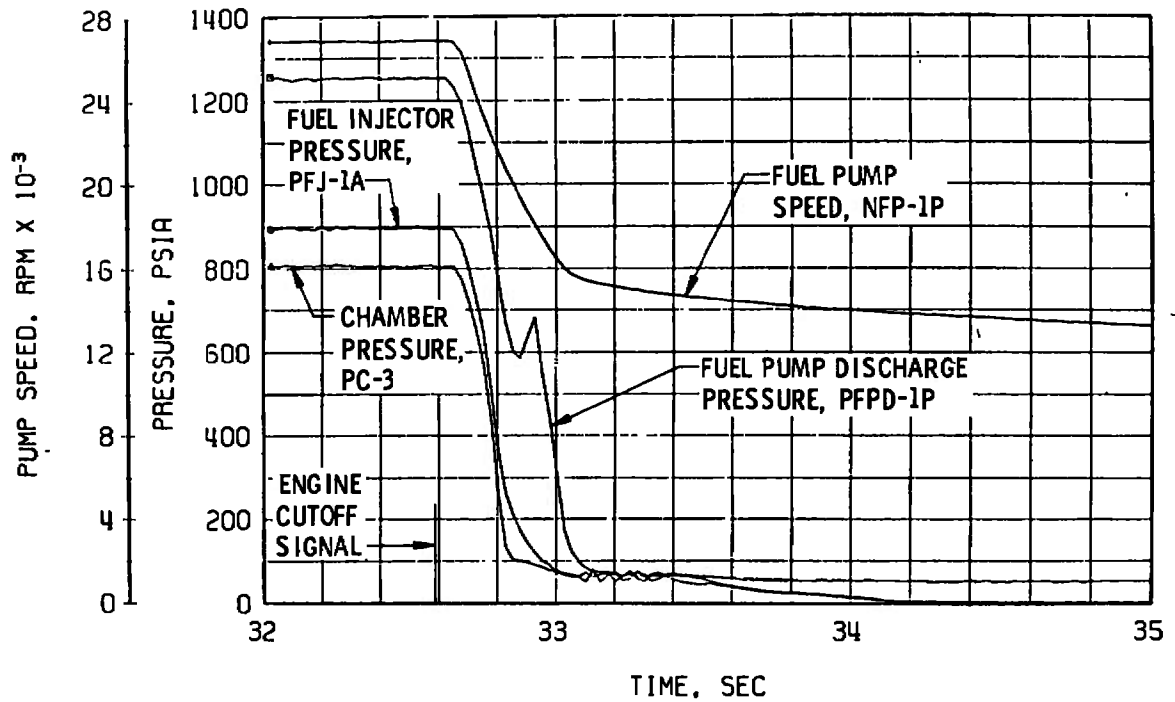


Fig. 12 Continued

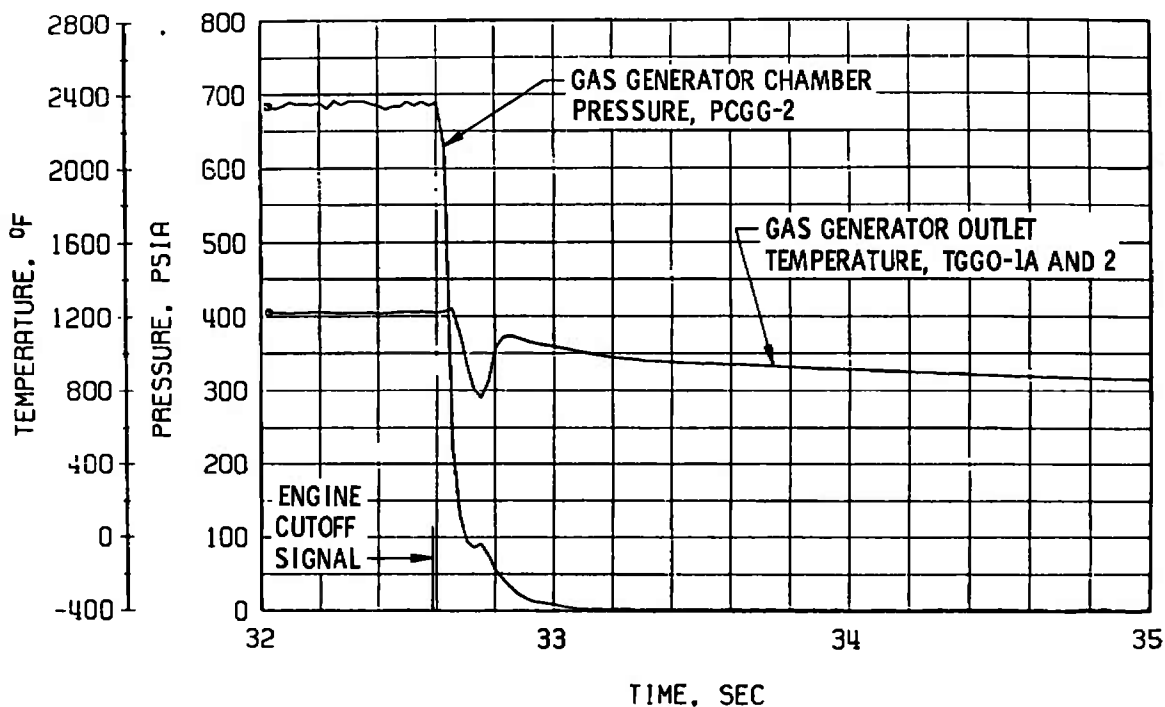
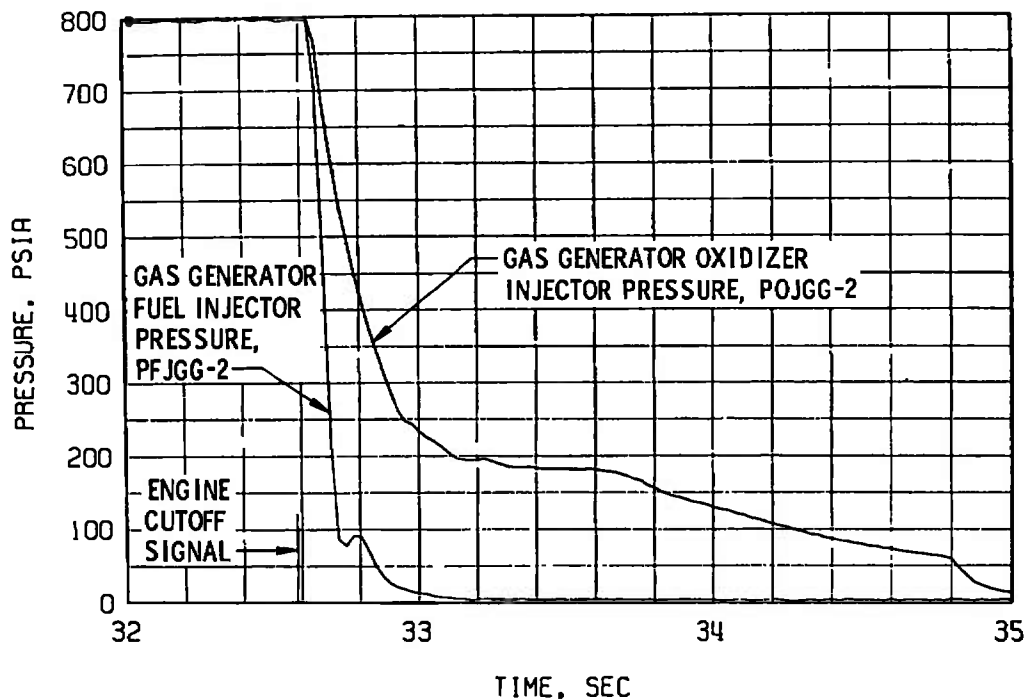


Fig. 12 Concluded

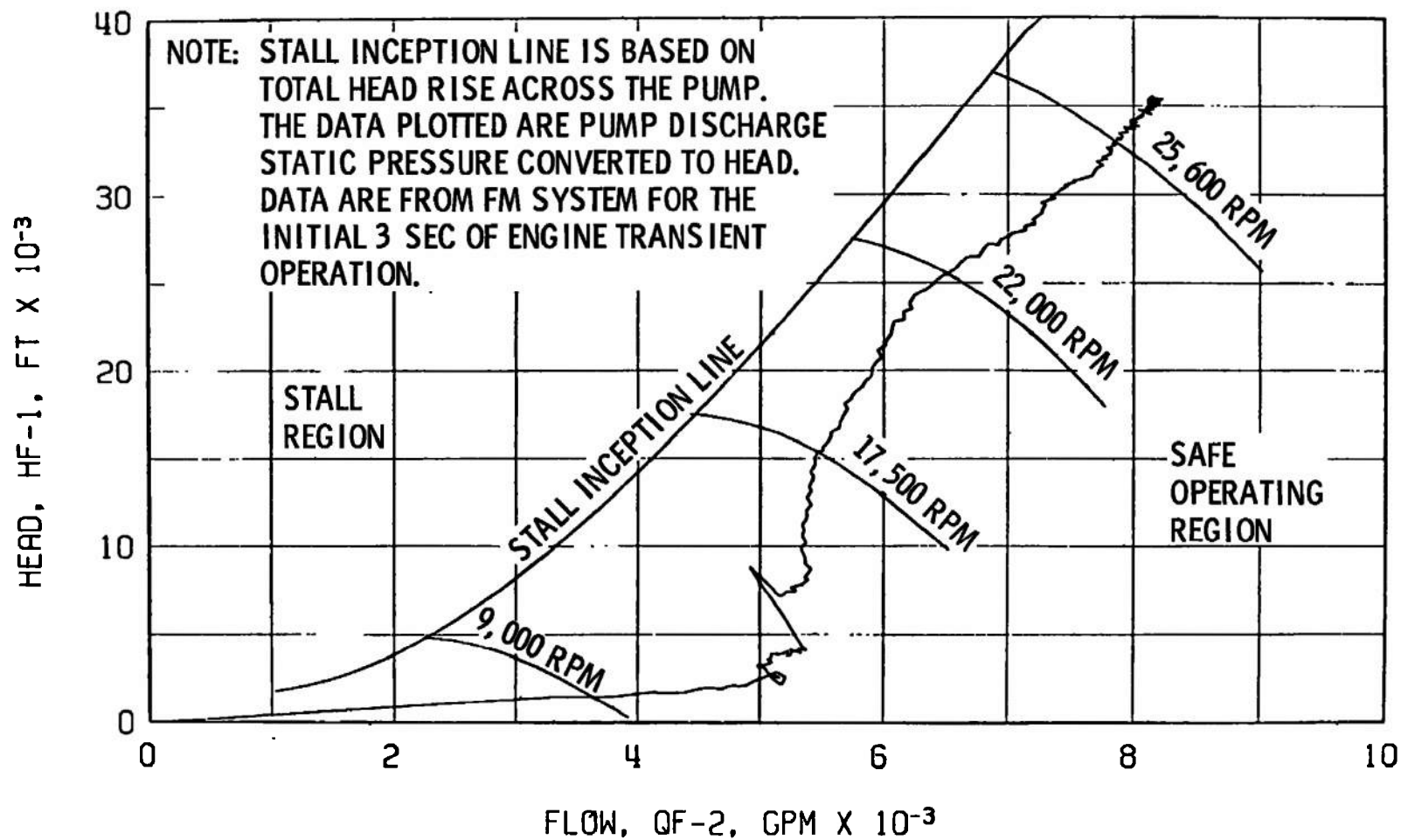
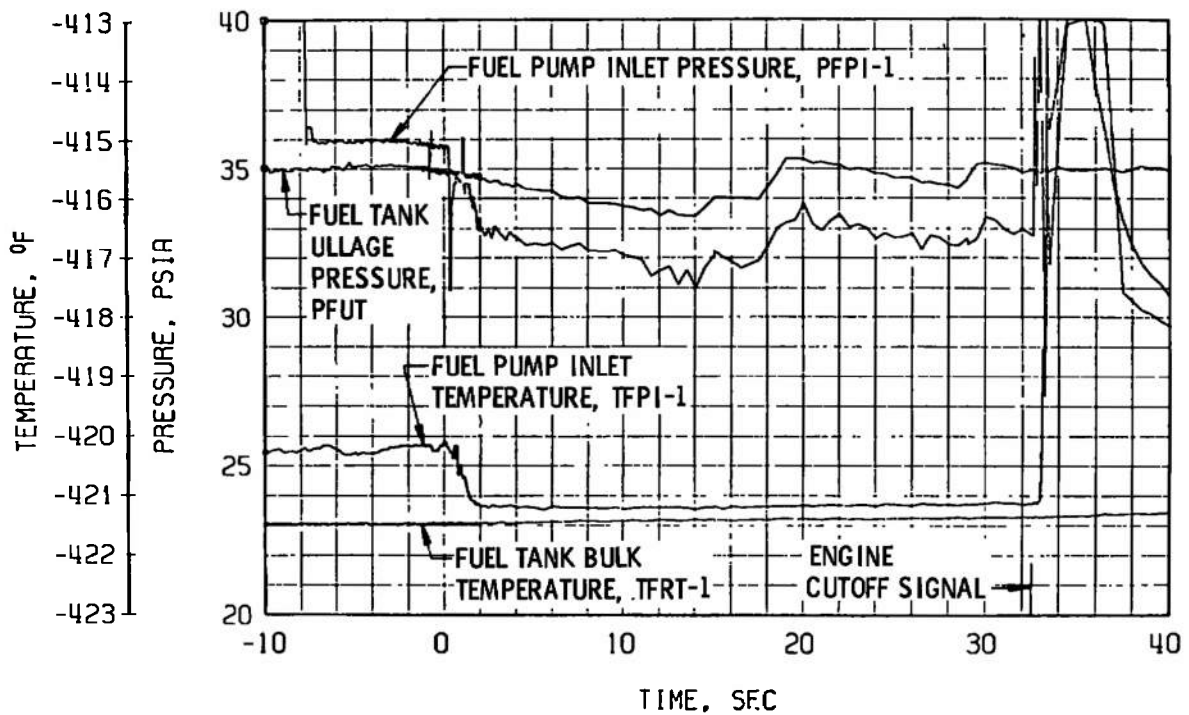
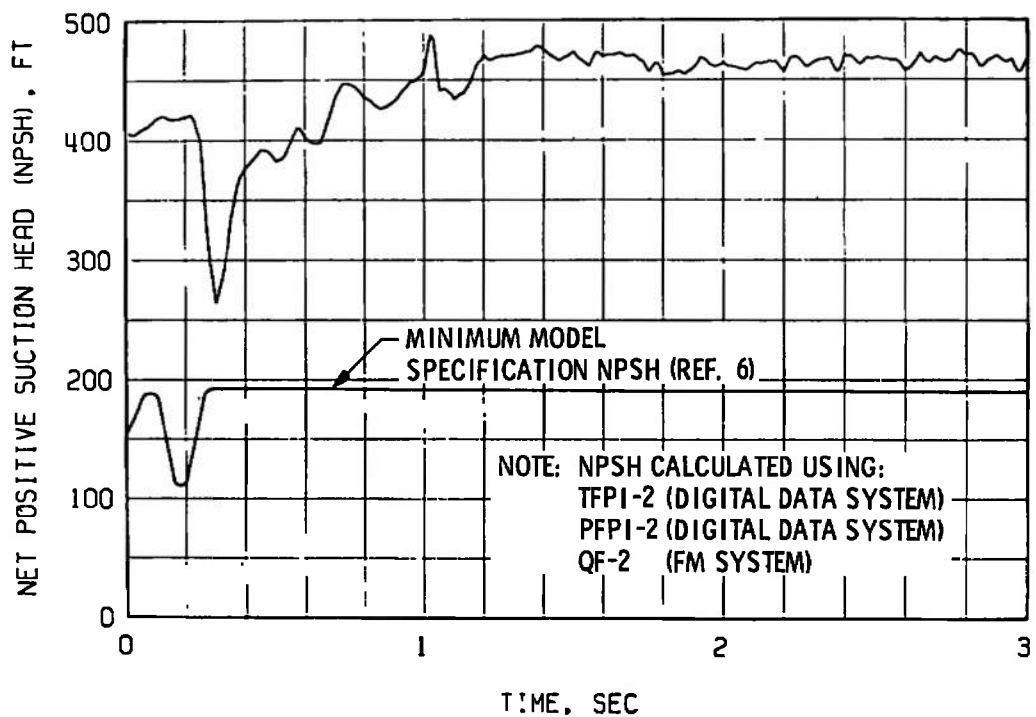


Fig. 13 Fuel Pump Start Transient Performance, Firing 42A

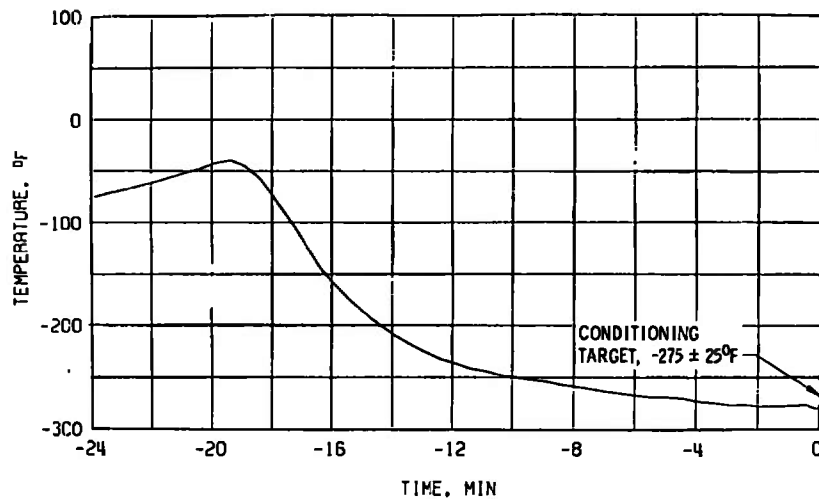


a. Duct Pressure and Temperature Transients

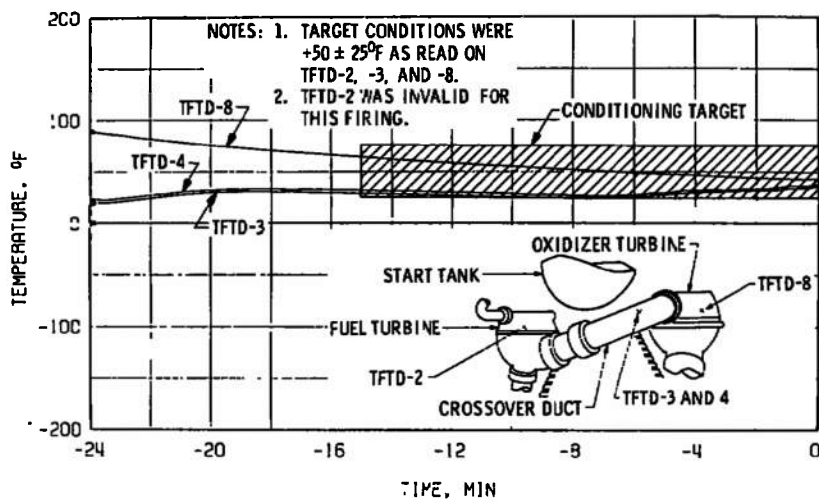


b. Fuel Pump NPSH during Start Transient, Firing 42A

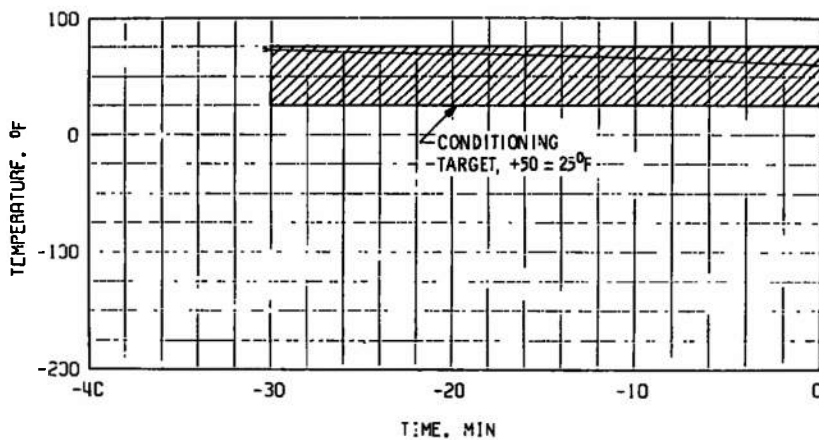
Fig. 14 Fuel Low Pressure Duct Performance, Firing 42A



a. Thrust Chamber, TTC-1P

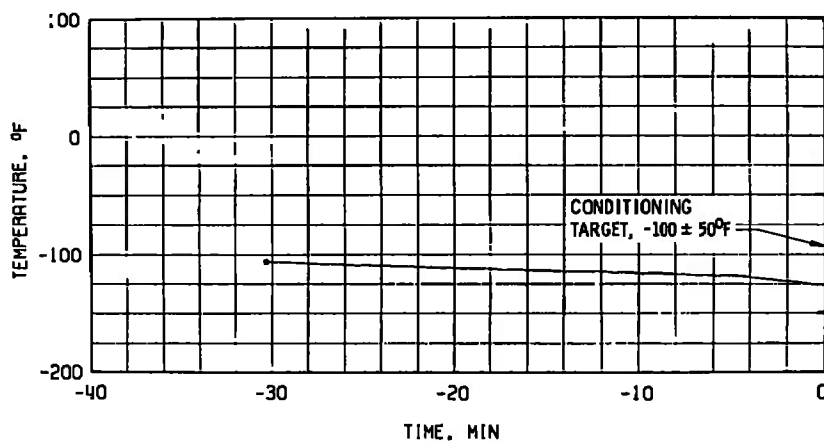


b. Crossover Duct, TTFD

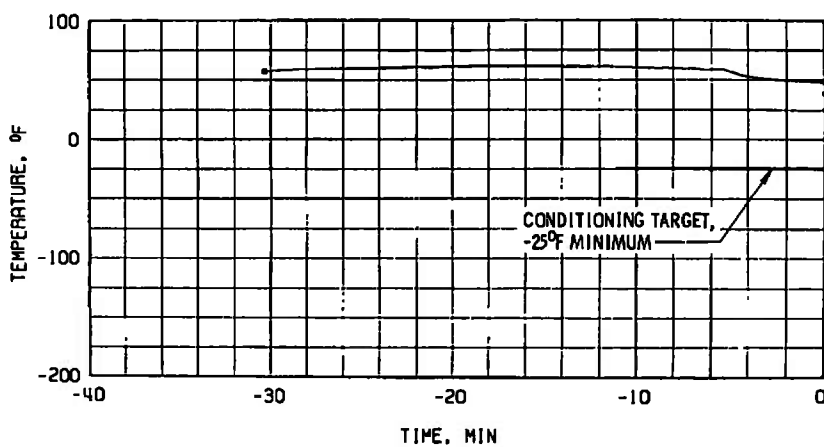


c. Start Tank Discharge Valve, TSTDVOC

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

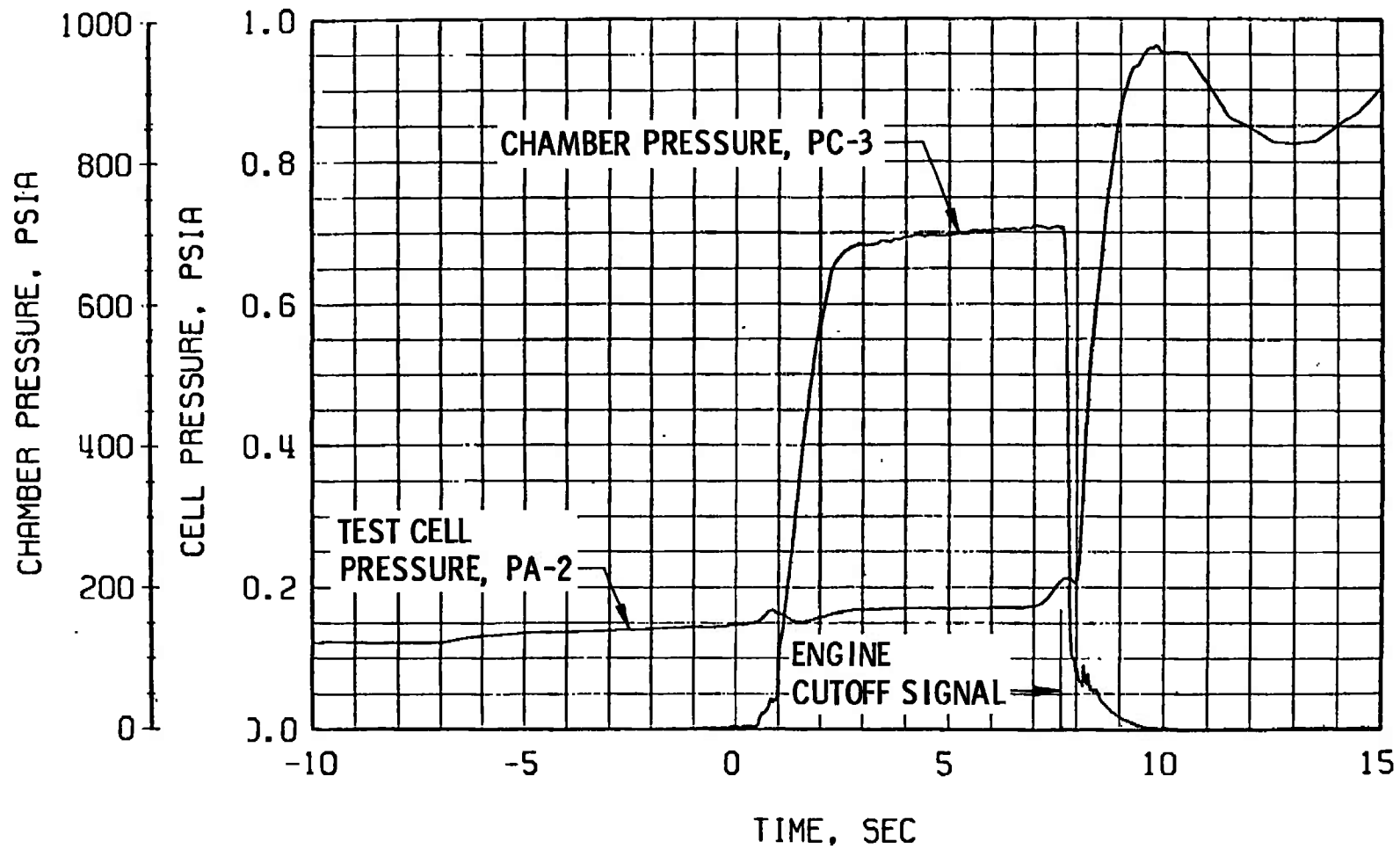
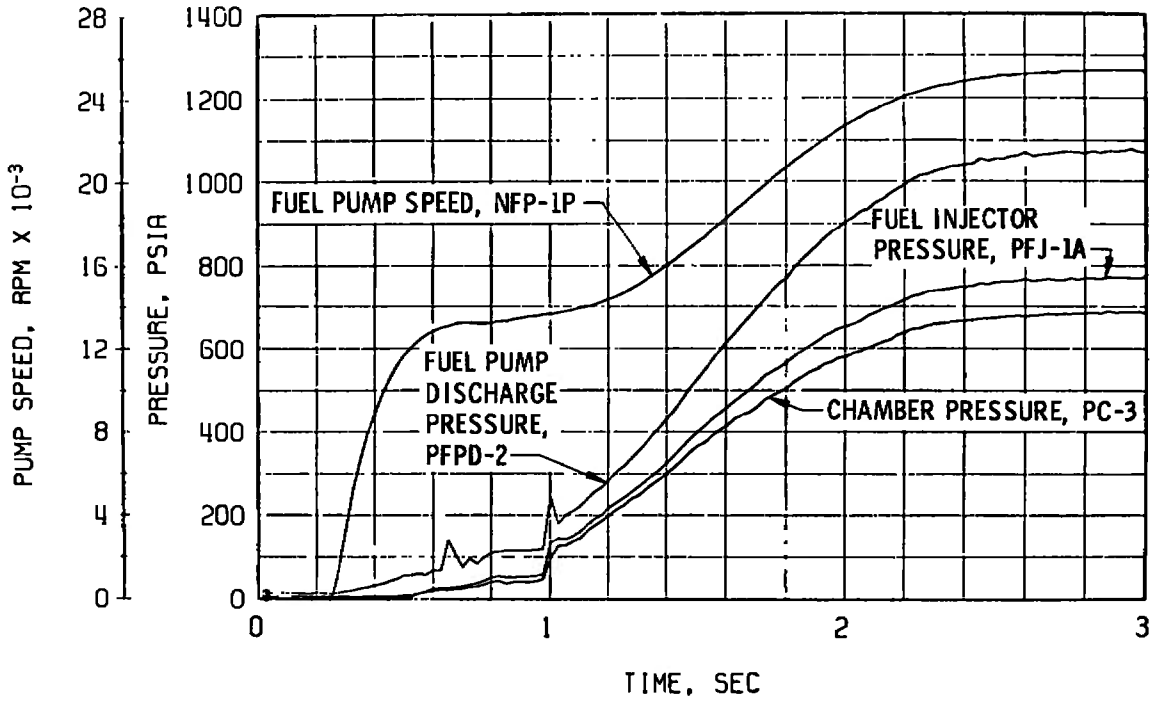
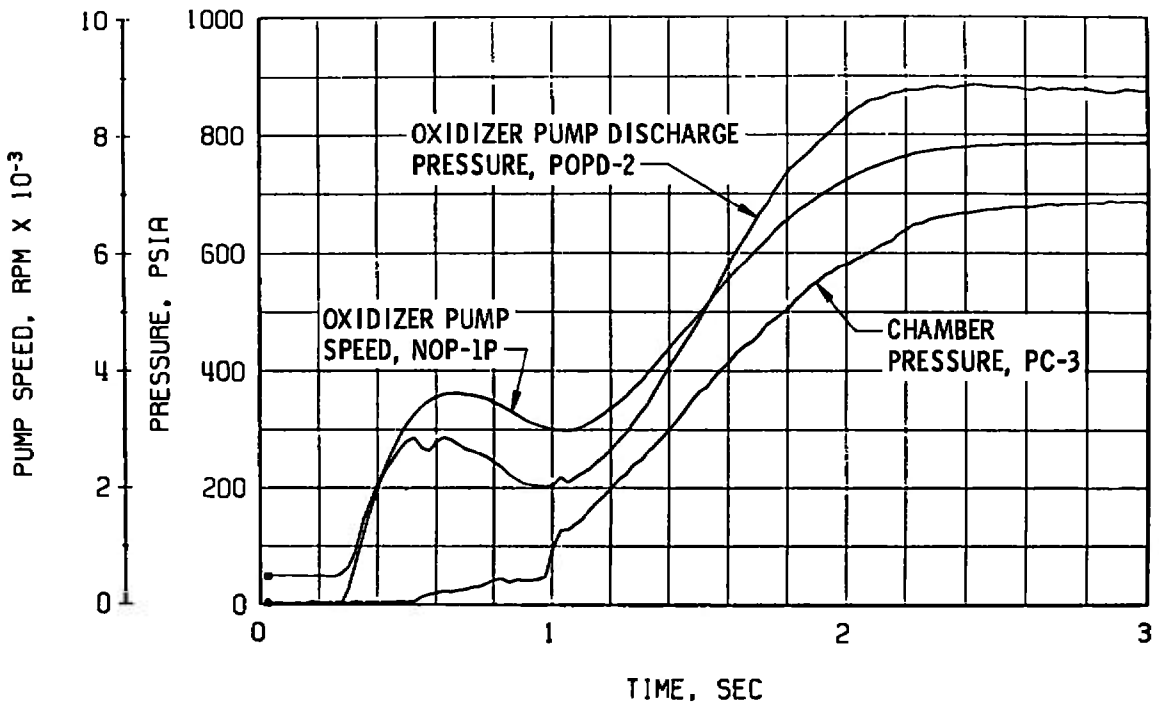


Fig. 16 Engine Ambient and Combustion Chamber Pressures, Firing 42B

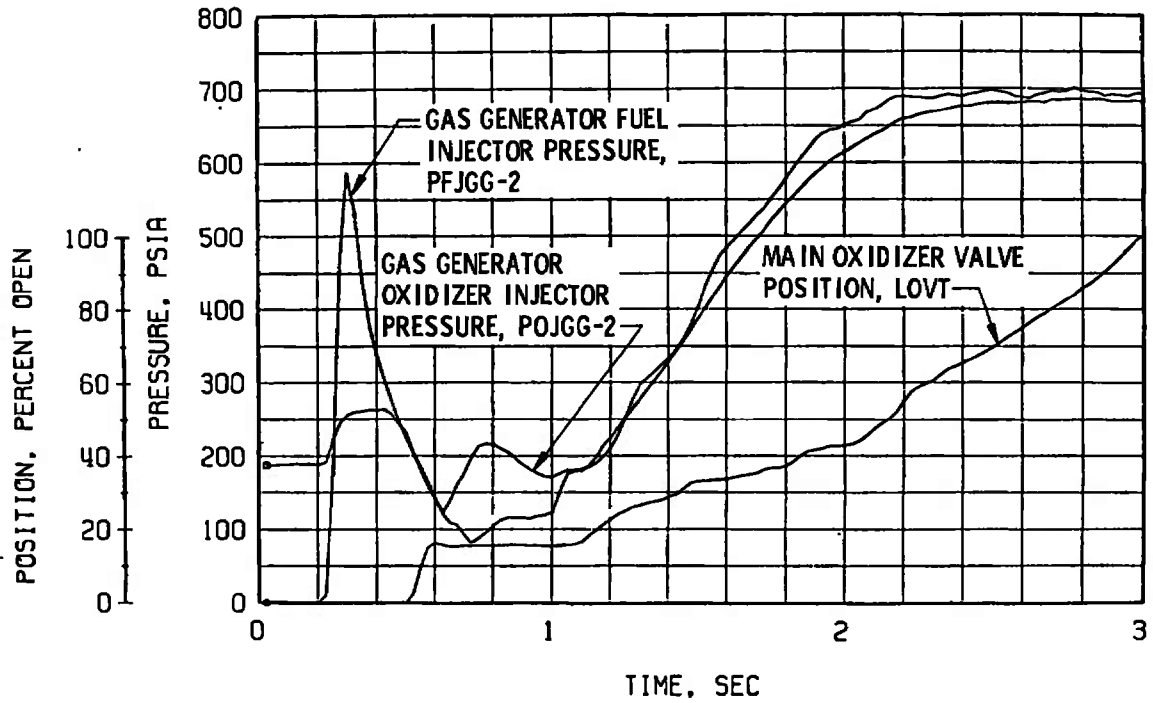


a. Thrust Chamber Fuel System, Start

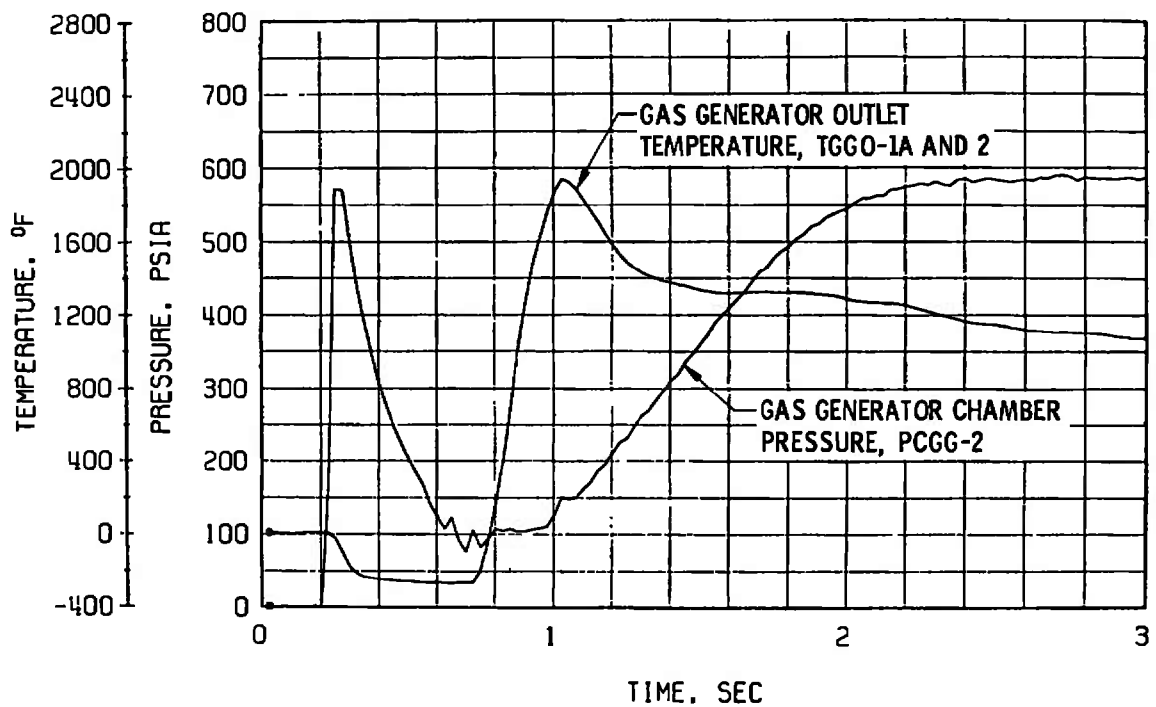


b. Thrust Chamber Oxidizer System, Start

Fig. 17 Engine Transient Operation, Firing 42B

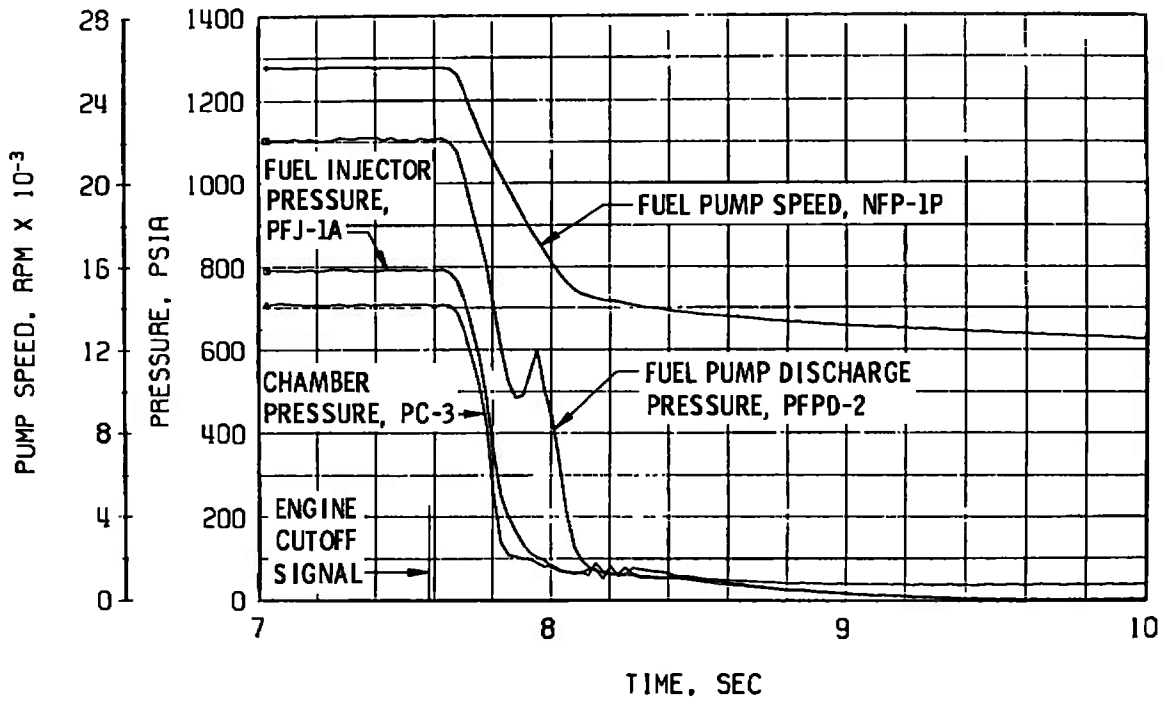


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

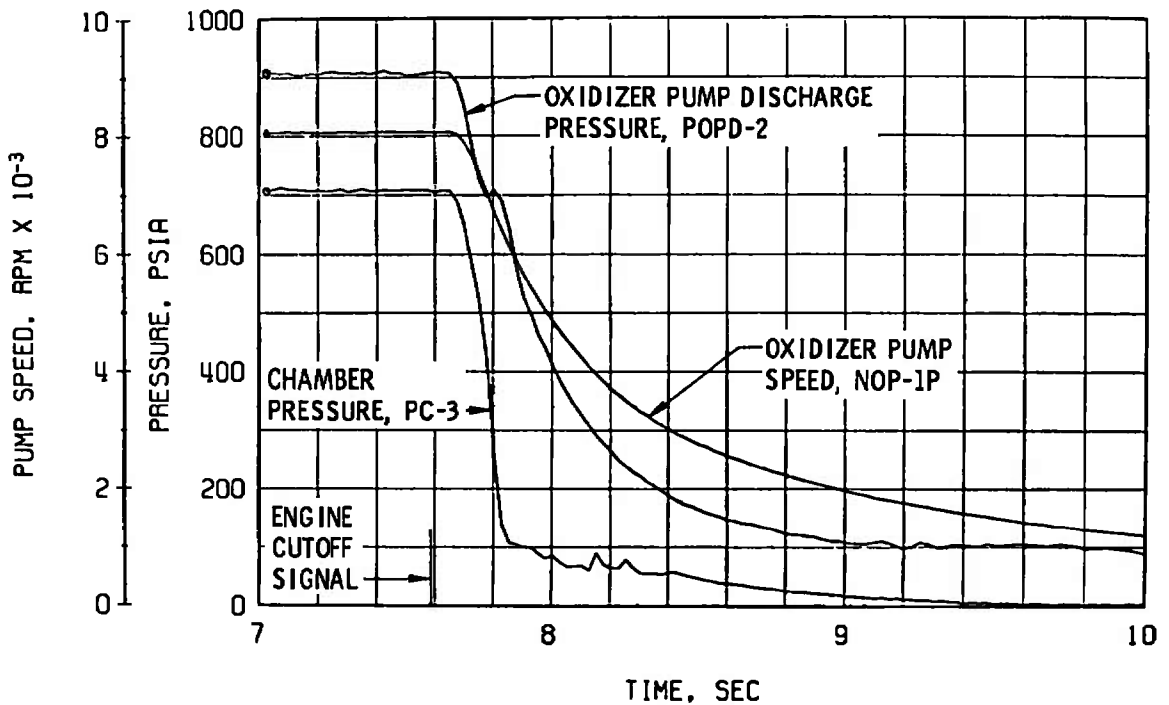


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 17 Continued

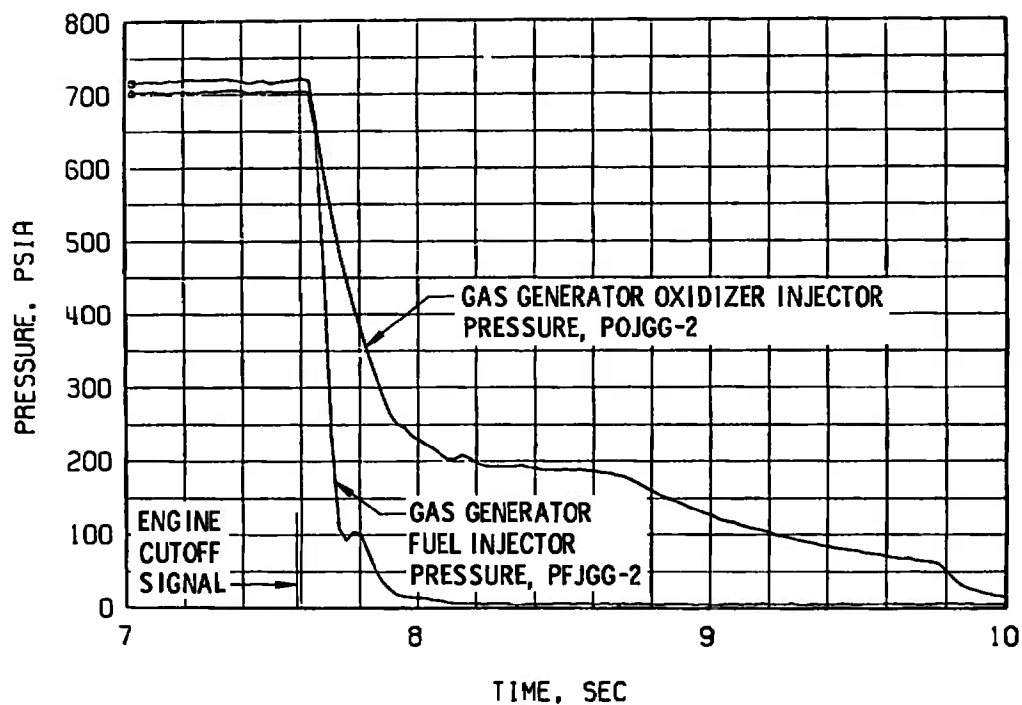


e. Thrust Chamber Fuel System, Shutdown

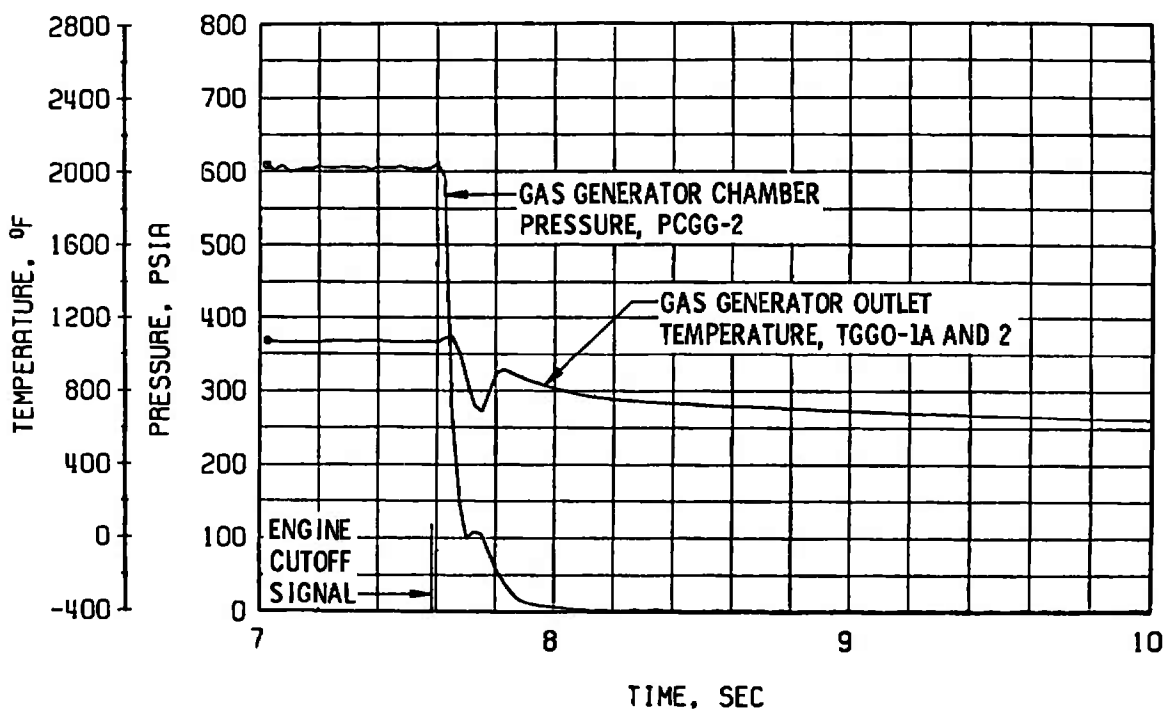


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 17 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 17 Concluded

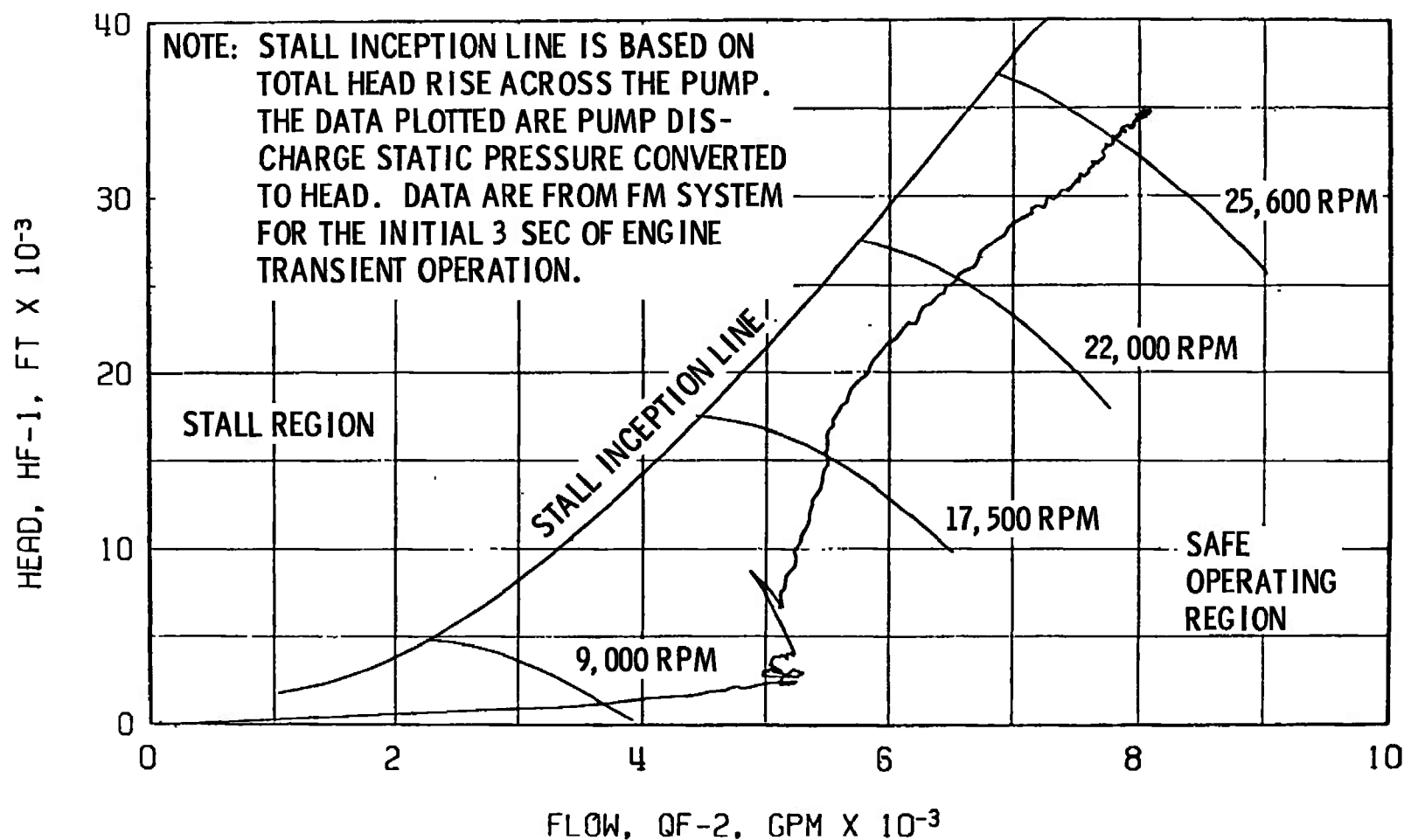
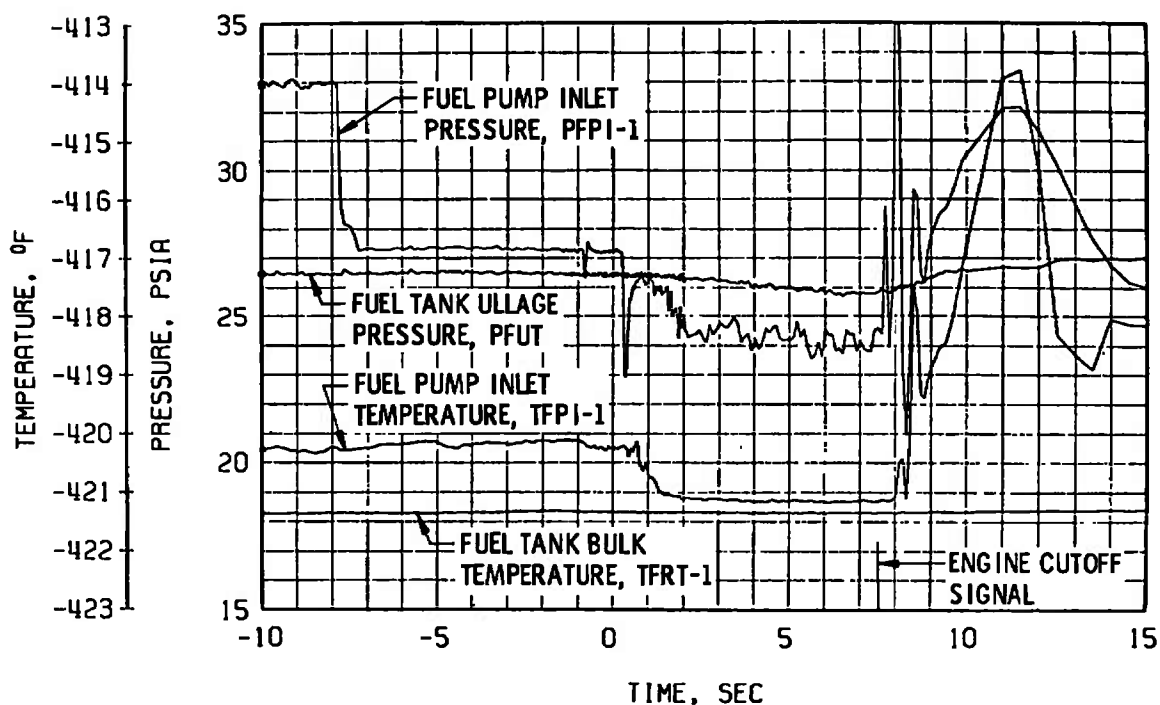
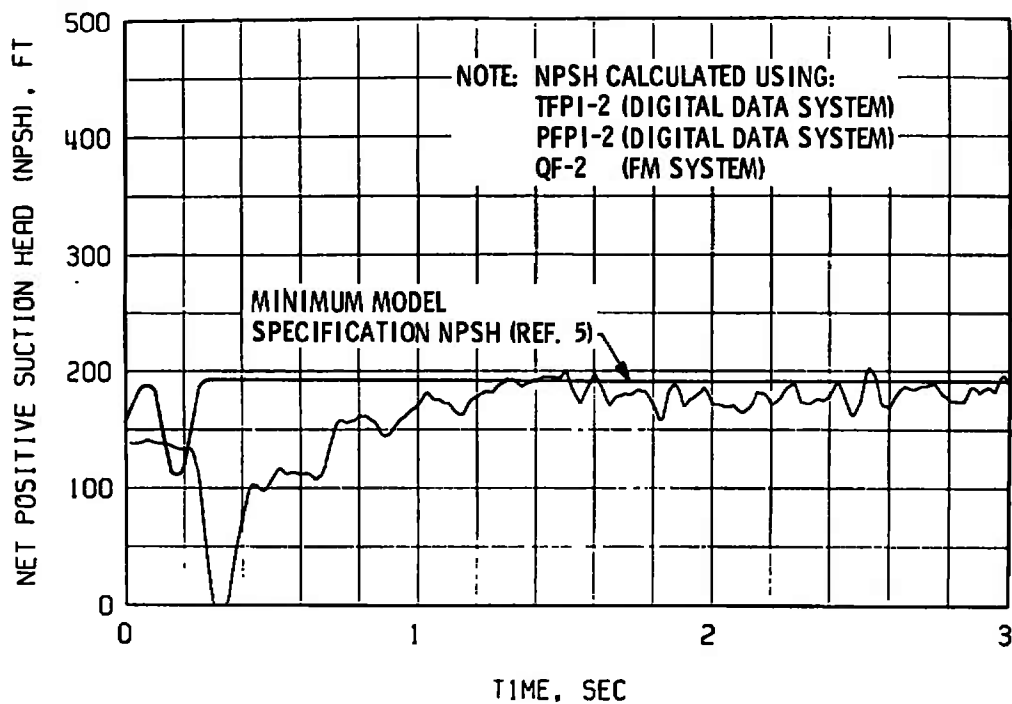


Fig. 18 Fuel Pump Start Transient Performance, Firing 42B

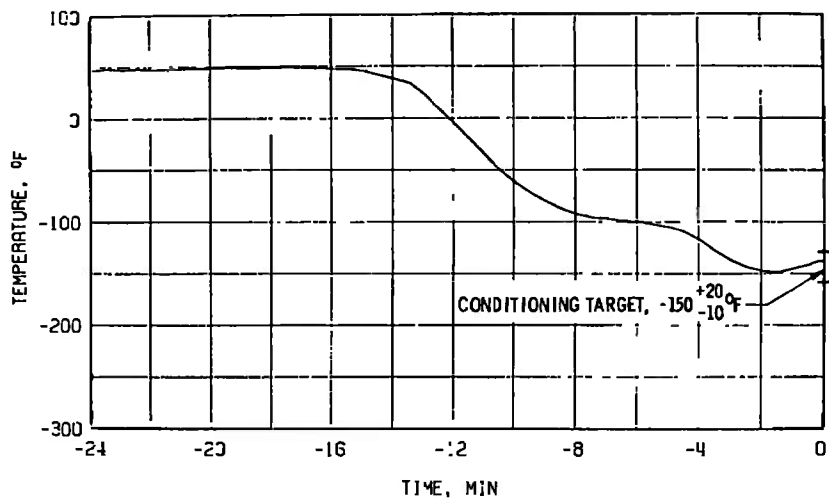


a. Duct Pressure and Temperature Transients

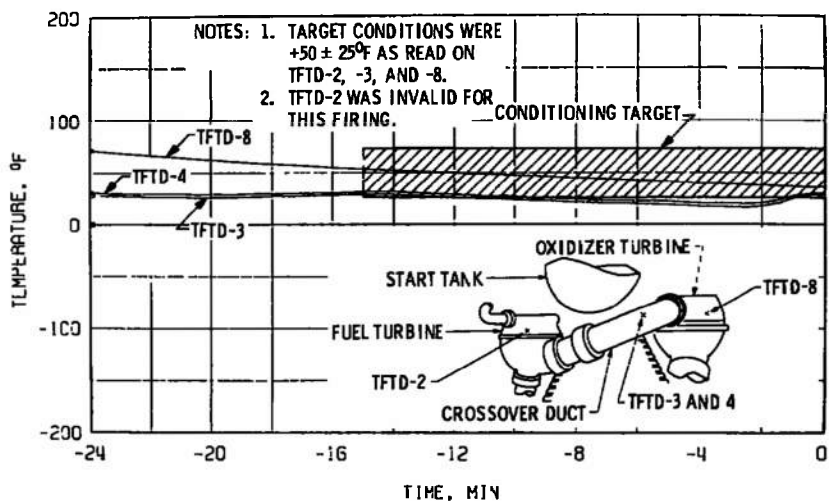


b. Fuel Pump NPSH during Start Transient, Firing 42B

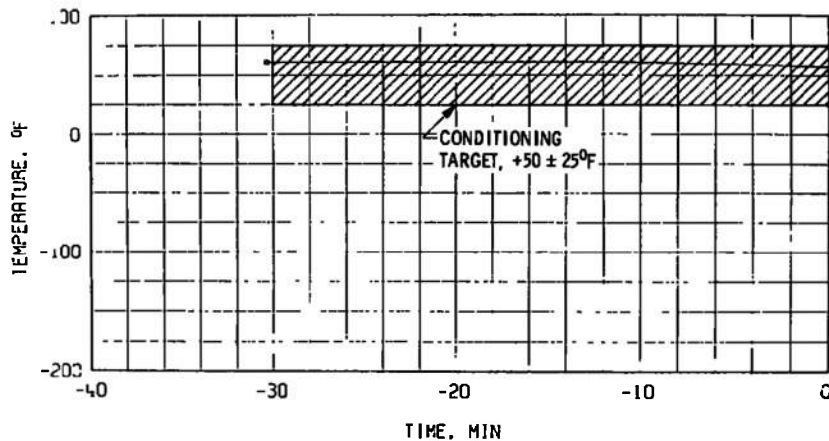
Fig. 19 Fuel Low Pressure Duct Performance, Firing 42B



a. Thrust Chamber, TTC-1P

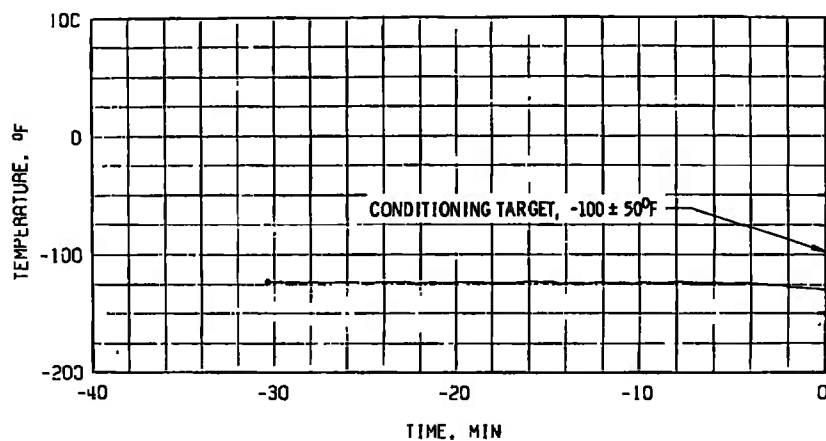


b. Crossover Duct, TFTD

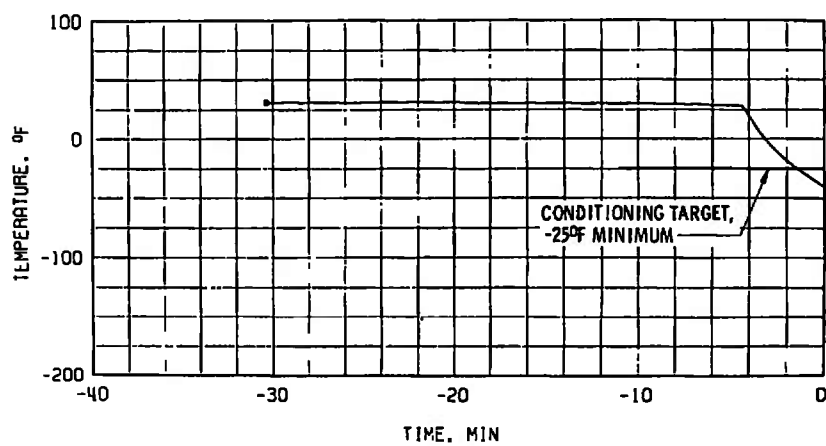


c. Start Tank Discharge Valve, TSTDVOC

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

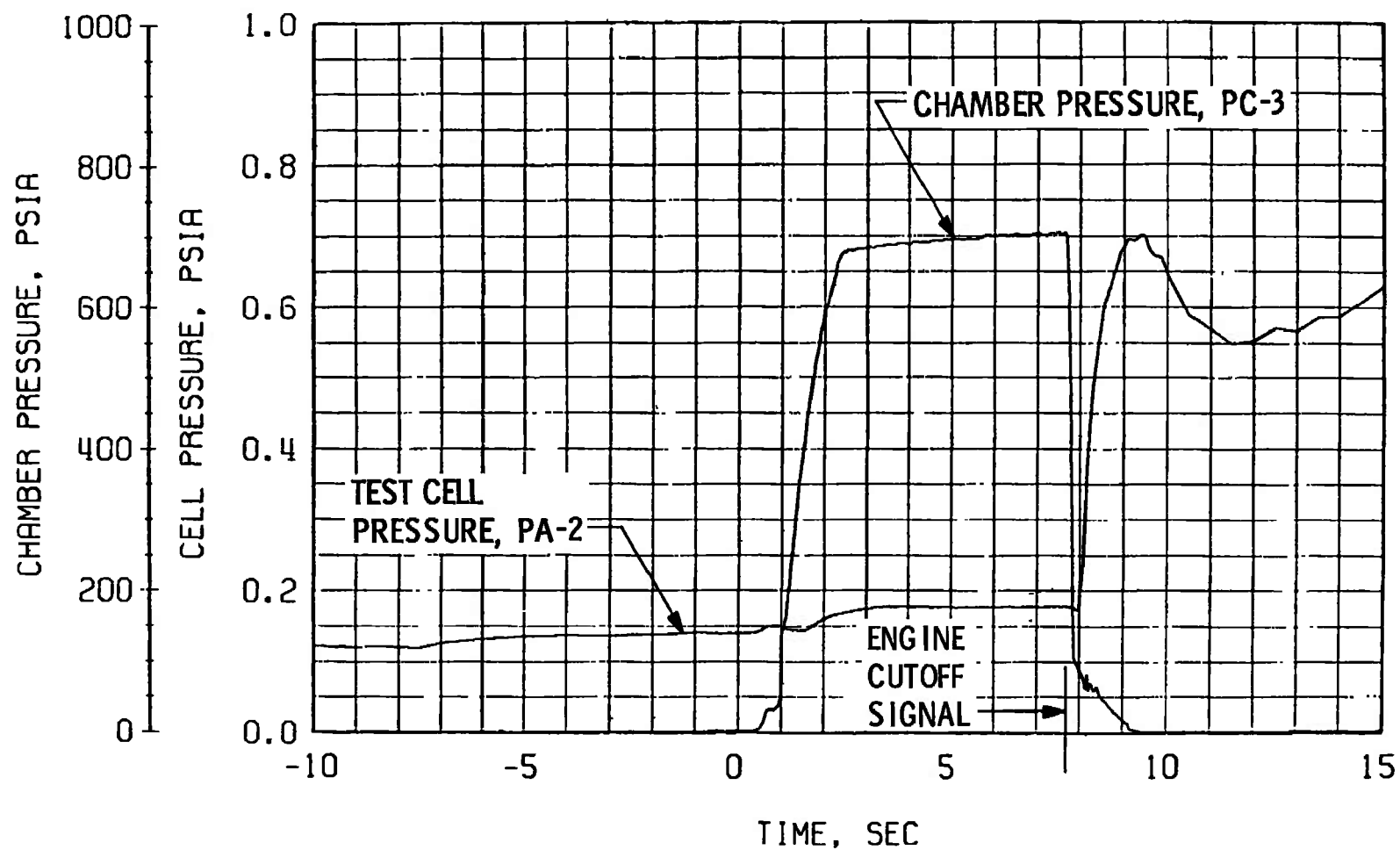
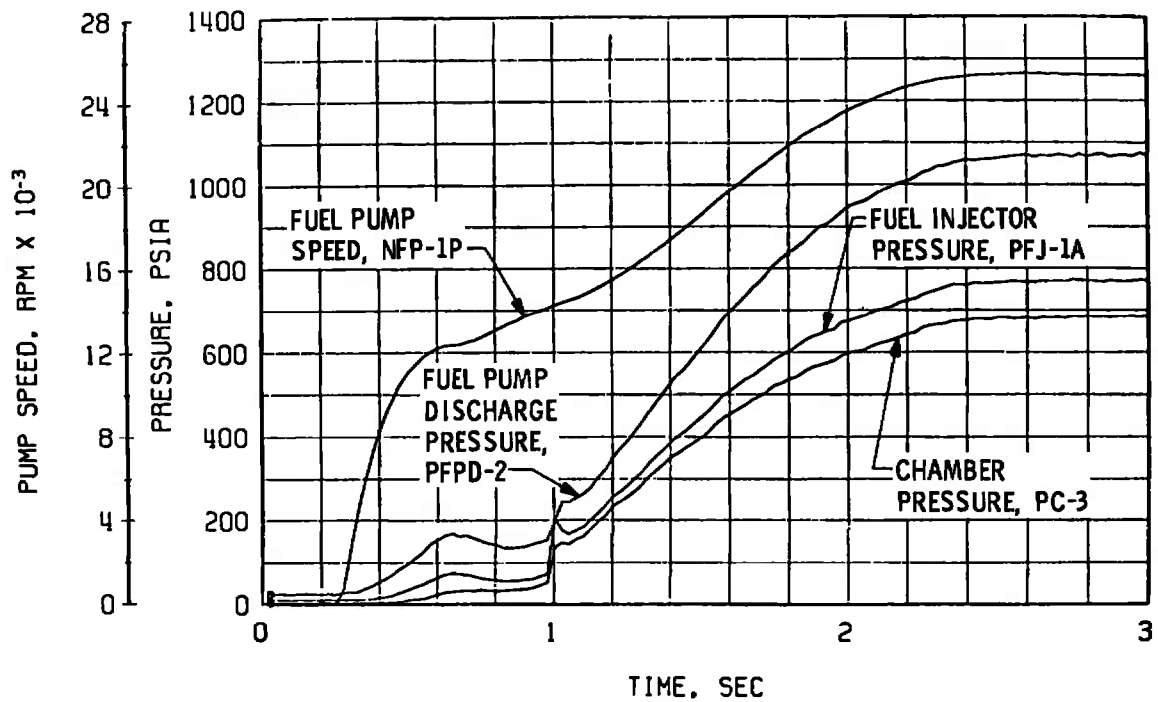
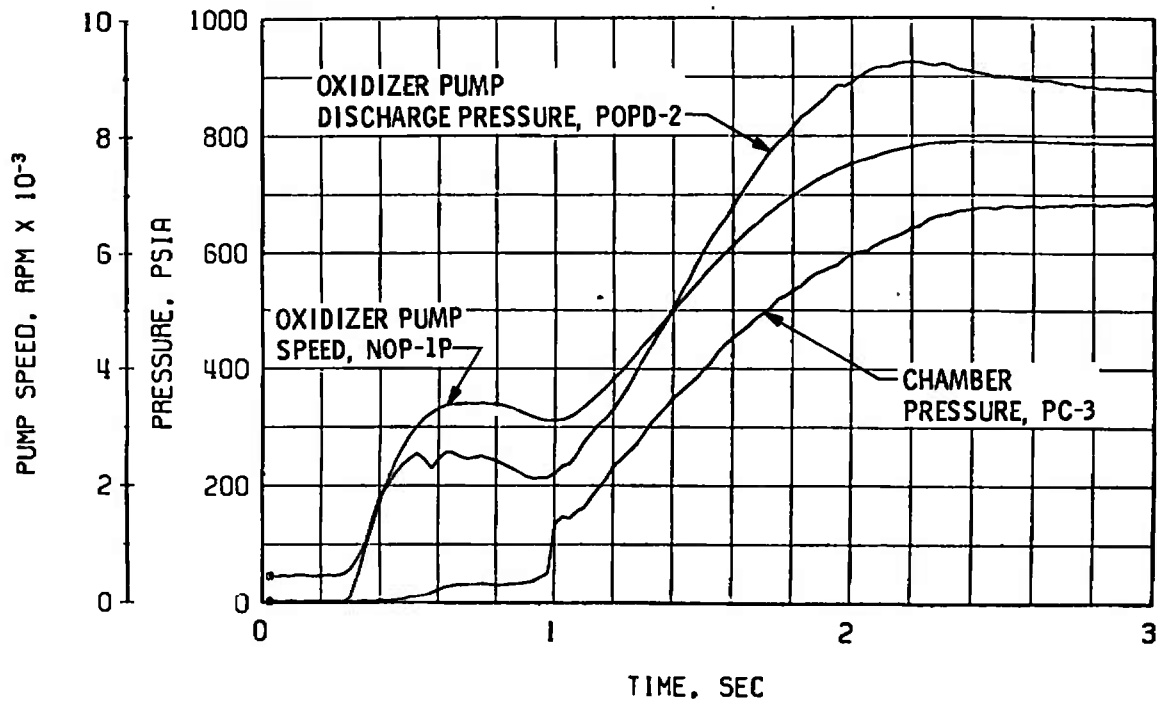


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 42C

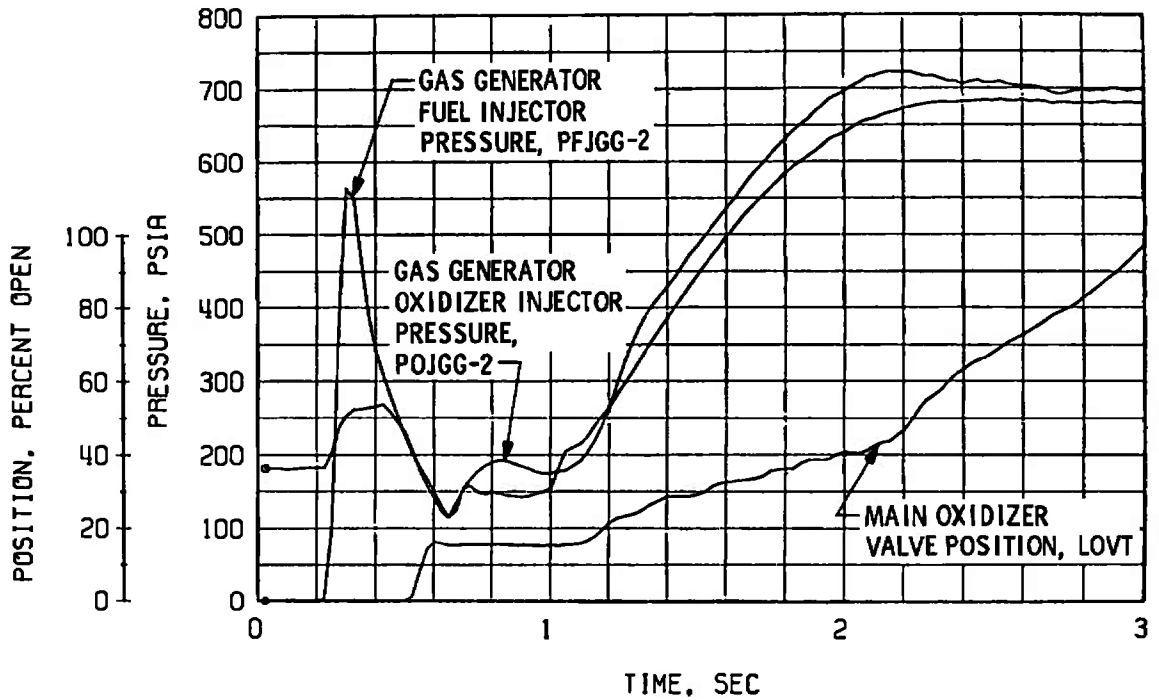


a. Thrust Chamber Fuel System, Start

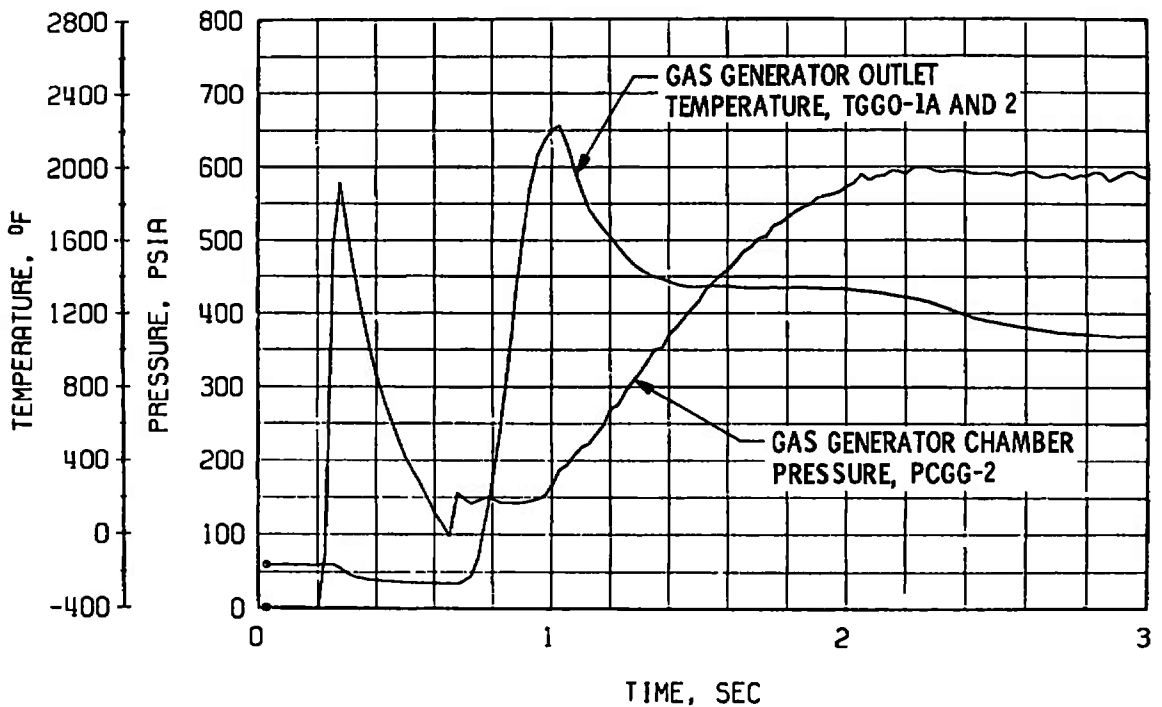


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 42C

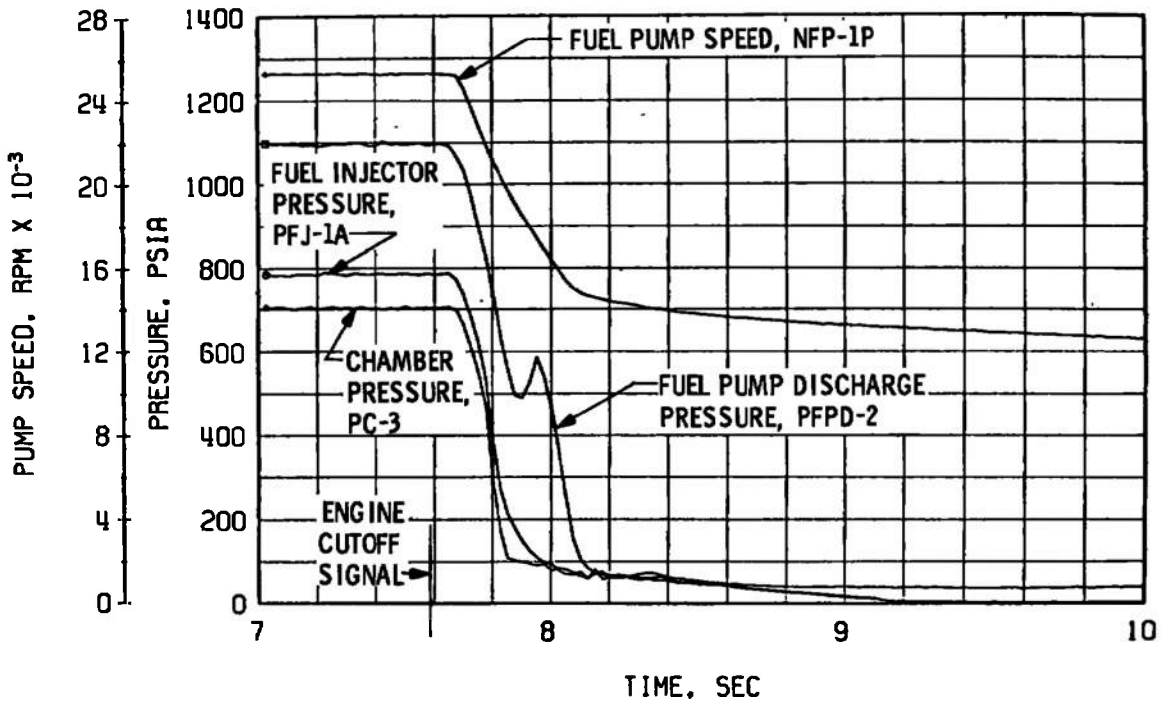


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

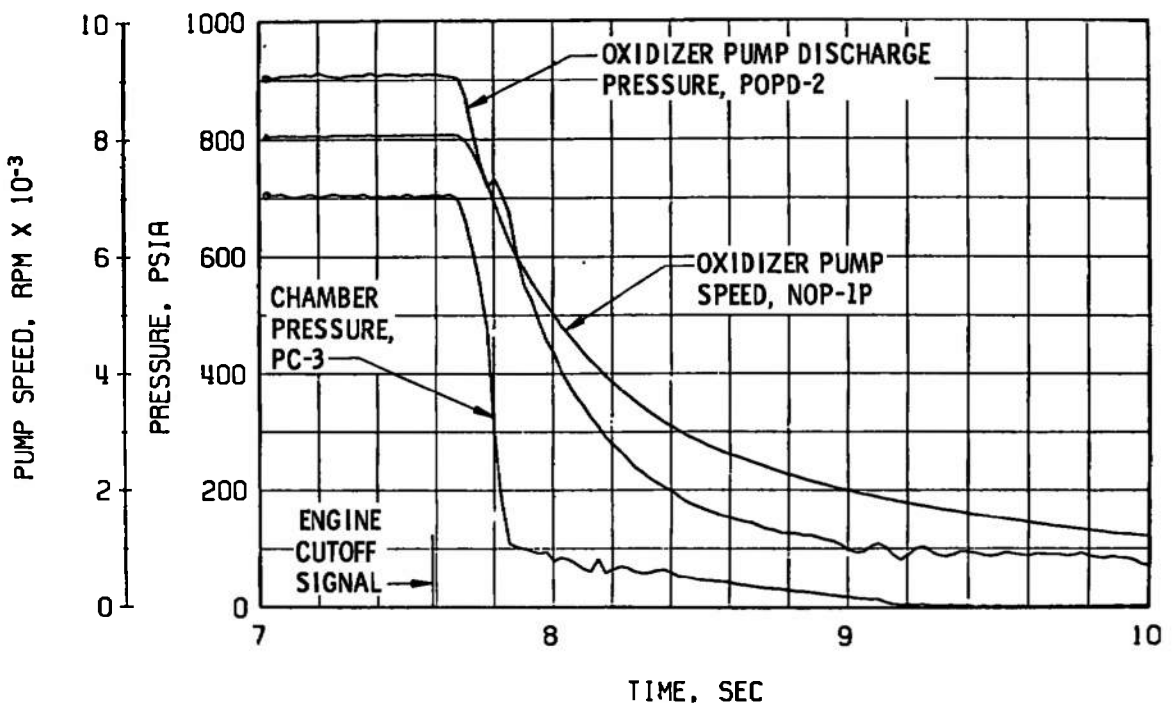


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued

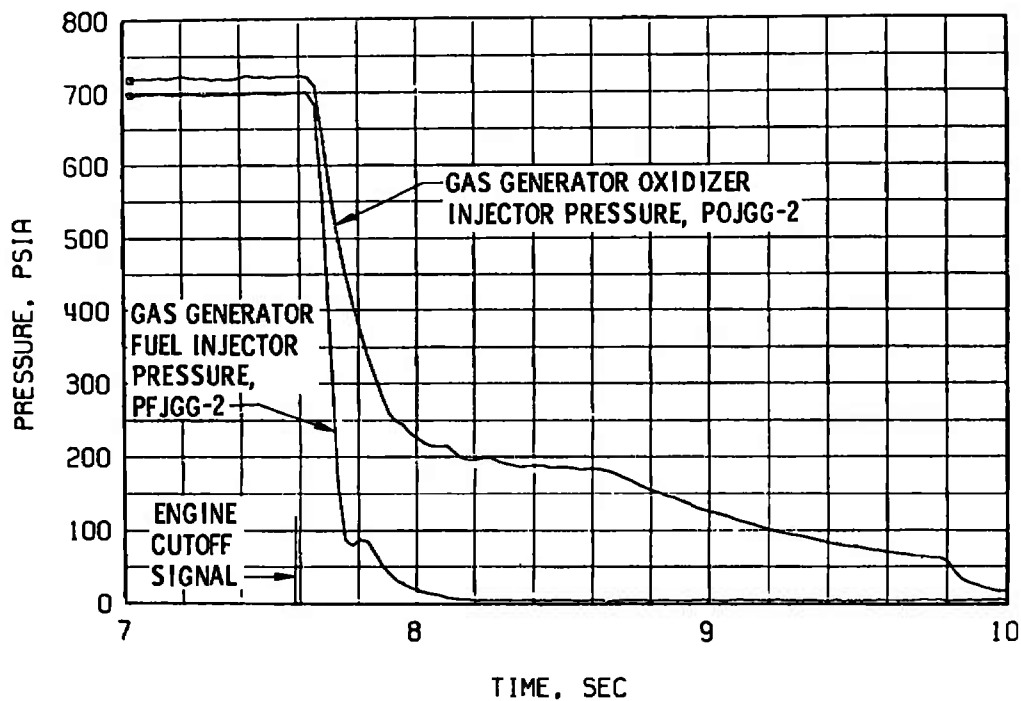


e. Thrust Chamber Fuel System, Shutdown

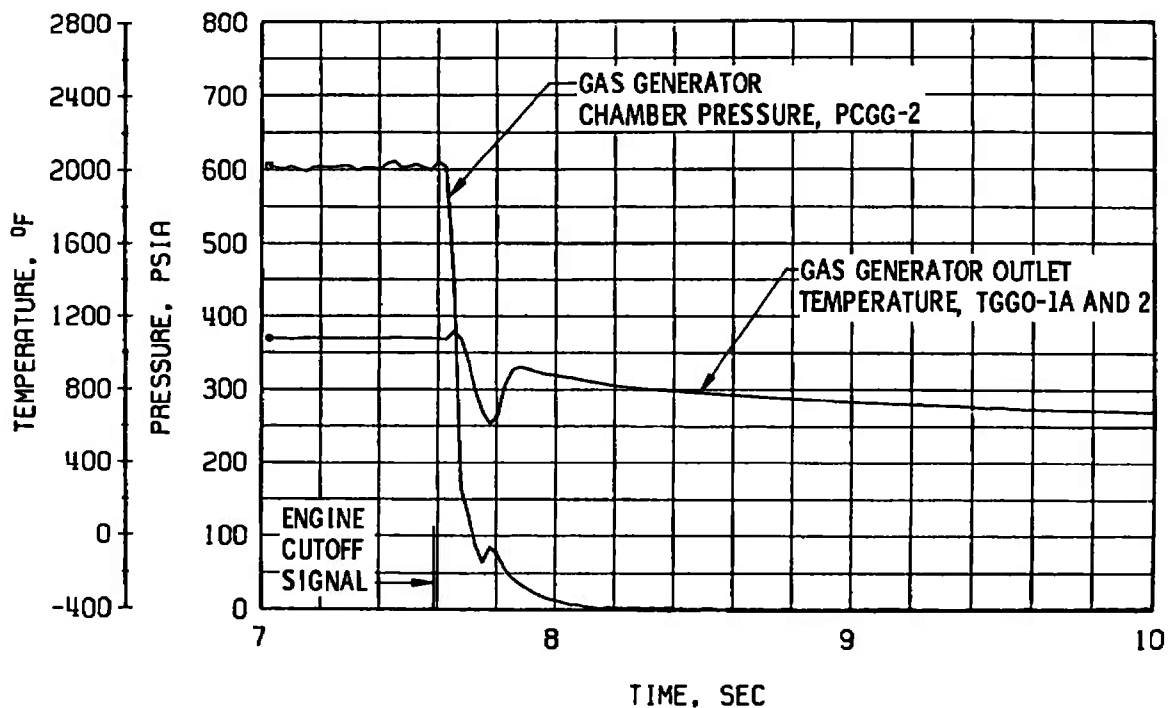


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

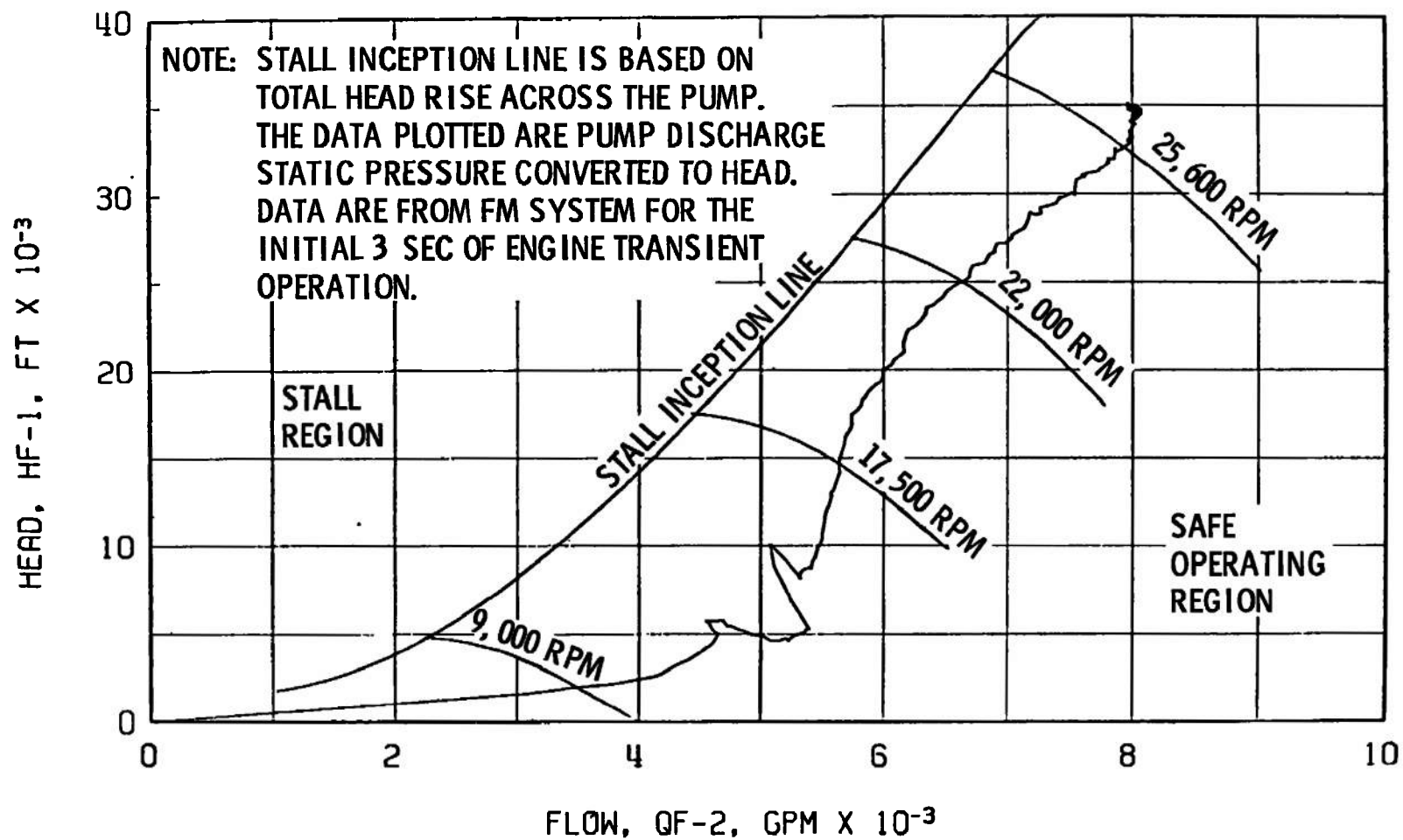
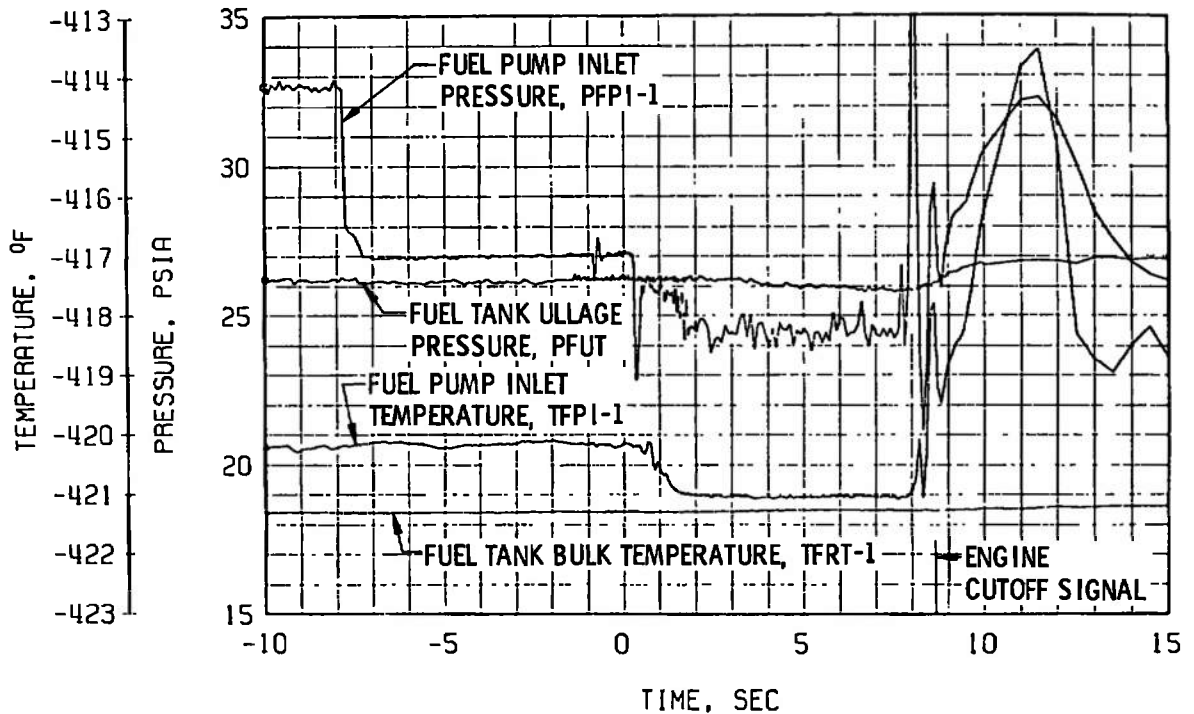
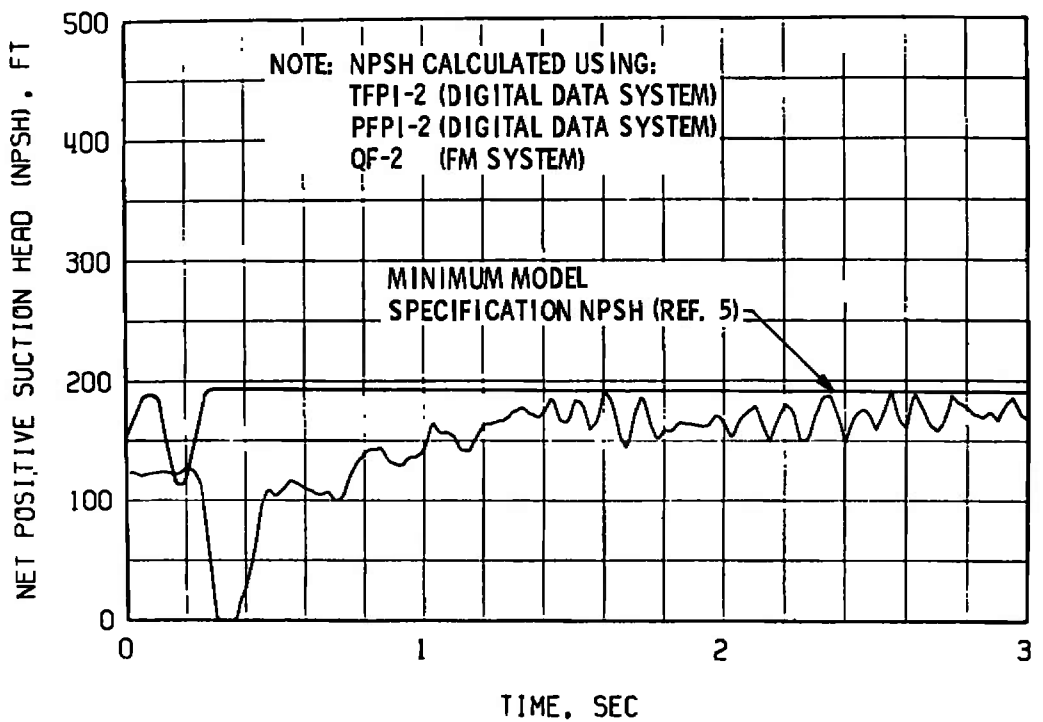


Fig. 23 Fuel Pump Start Transient Performance, Firing 42C

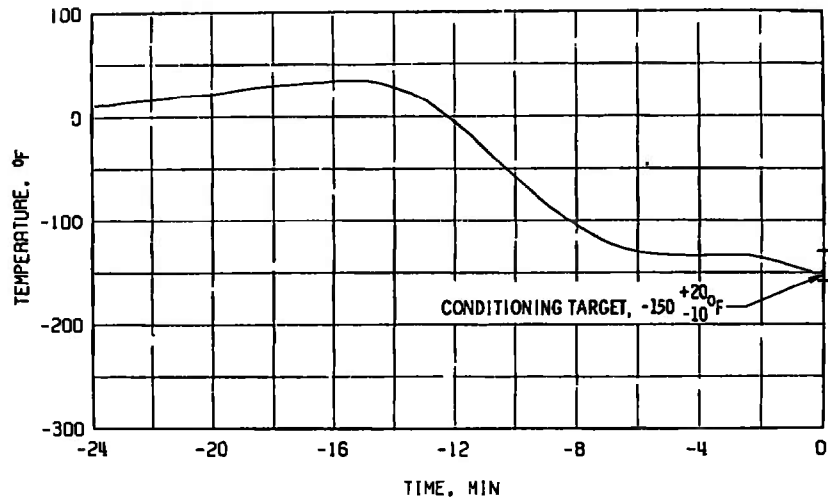


a. Duct Pressure and Temperature Transients

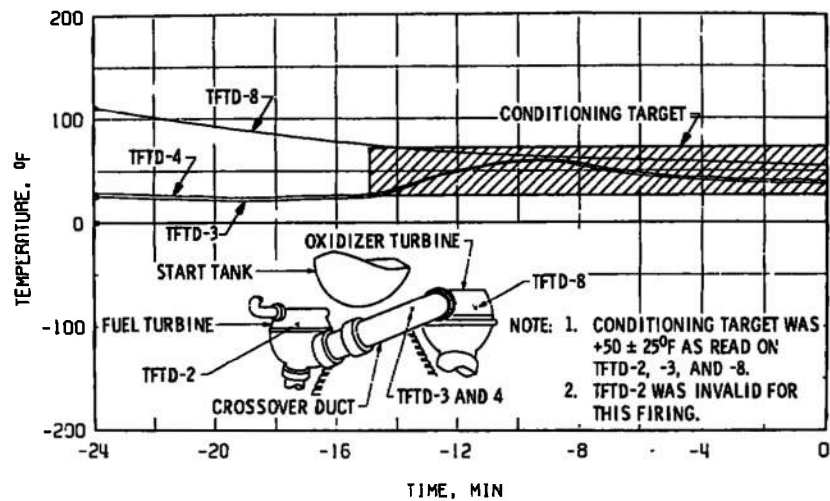


b. Fuel Pump NPSH during Start Transient, Firing 42C

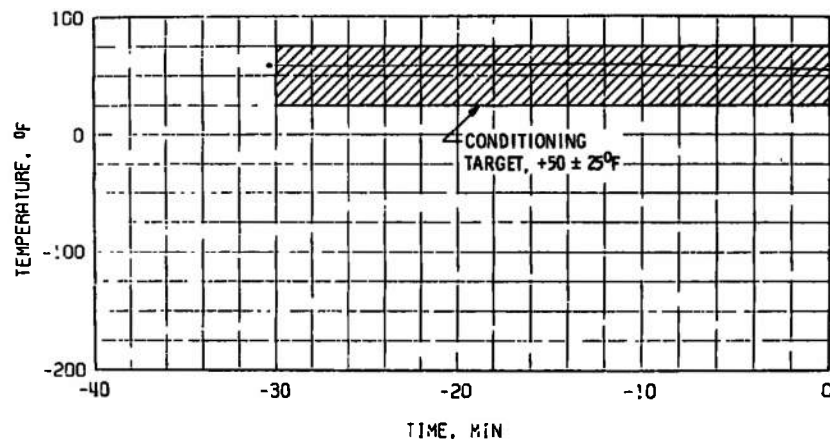
Fig. 24 Fuel Low Pressure Duct Performance, Firing 42C



a. Thrust Chamber, TTC-1P

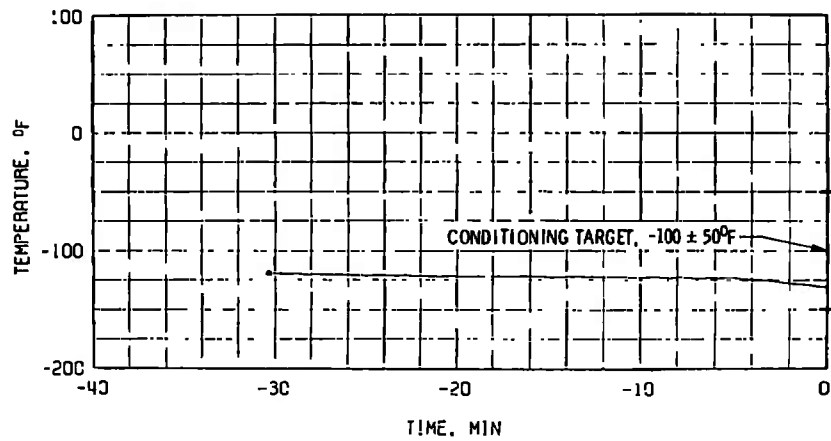


b. Crossover Duct, TFTD

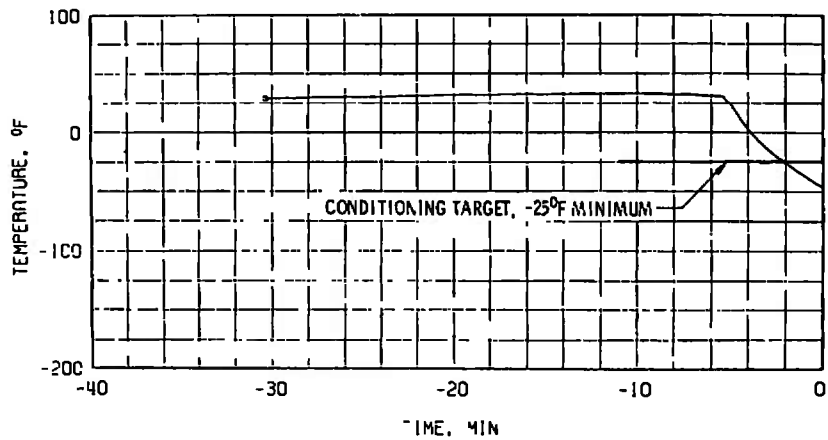


c. Start Tank Discharge Valve, TSTDVOC

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

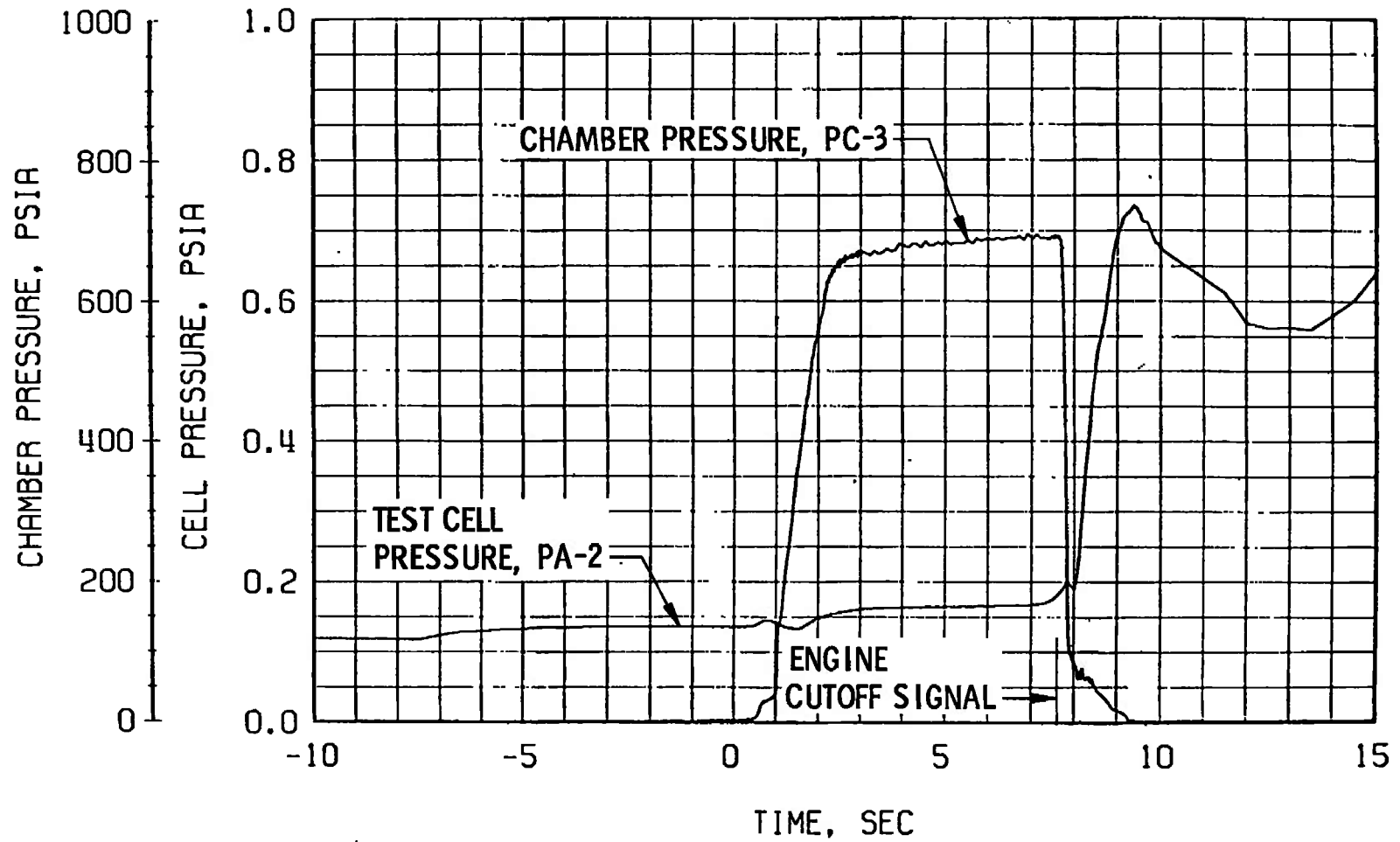
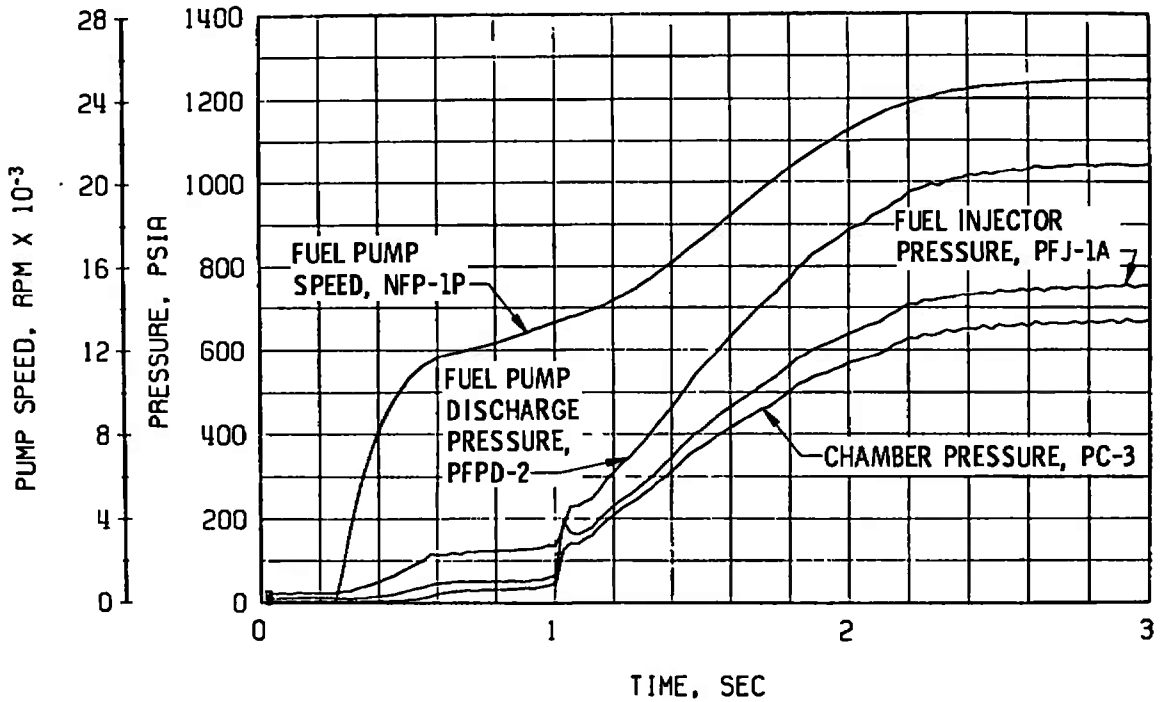
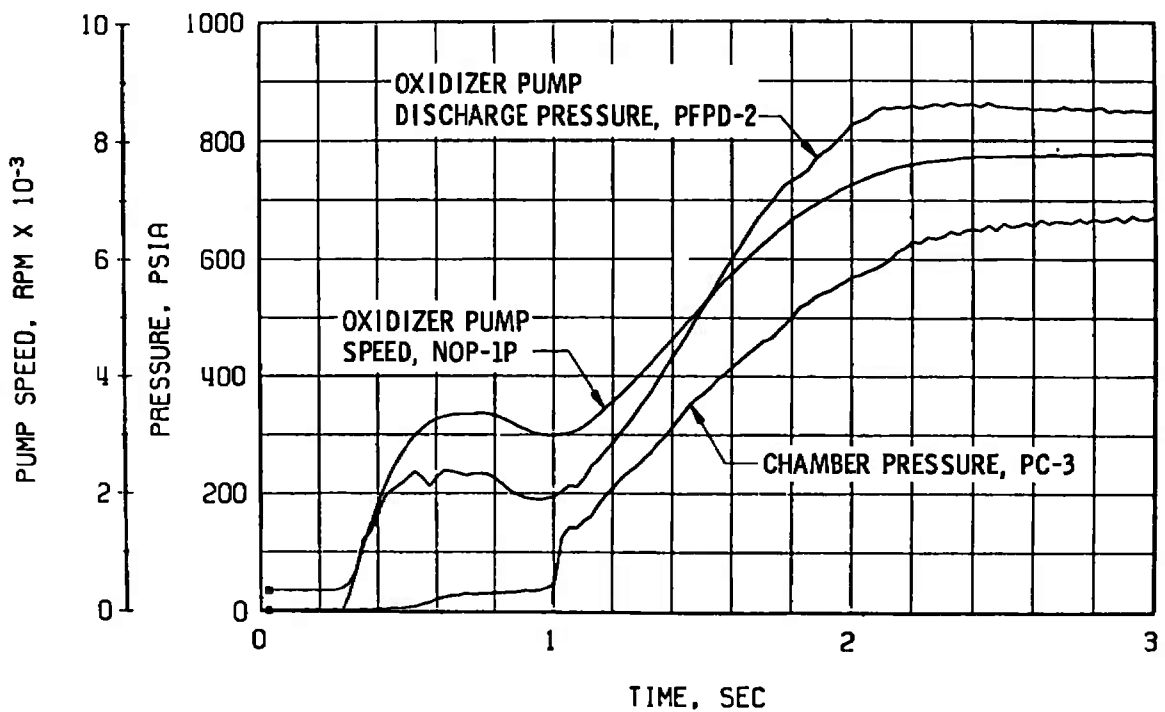


Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 42D

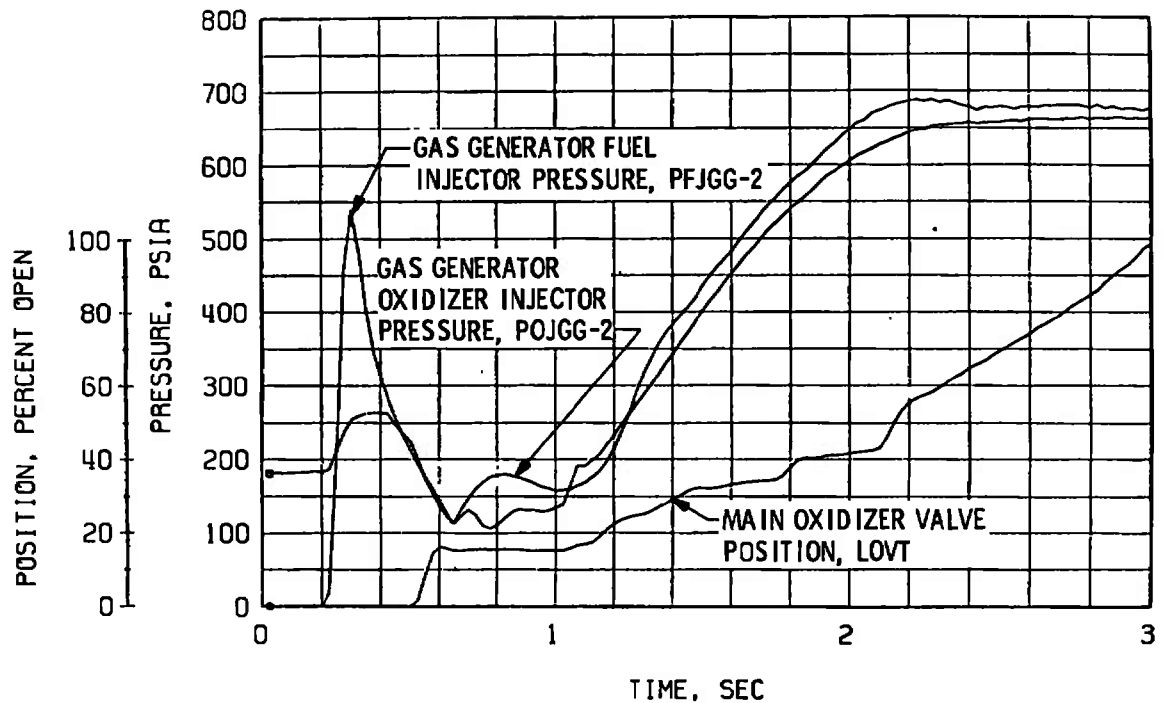


a. Thrust Chamber Fuel System, Start

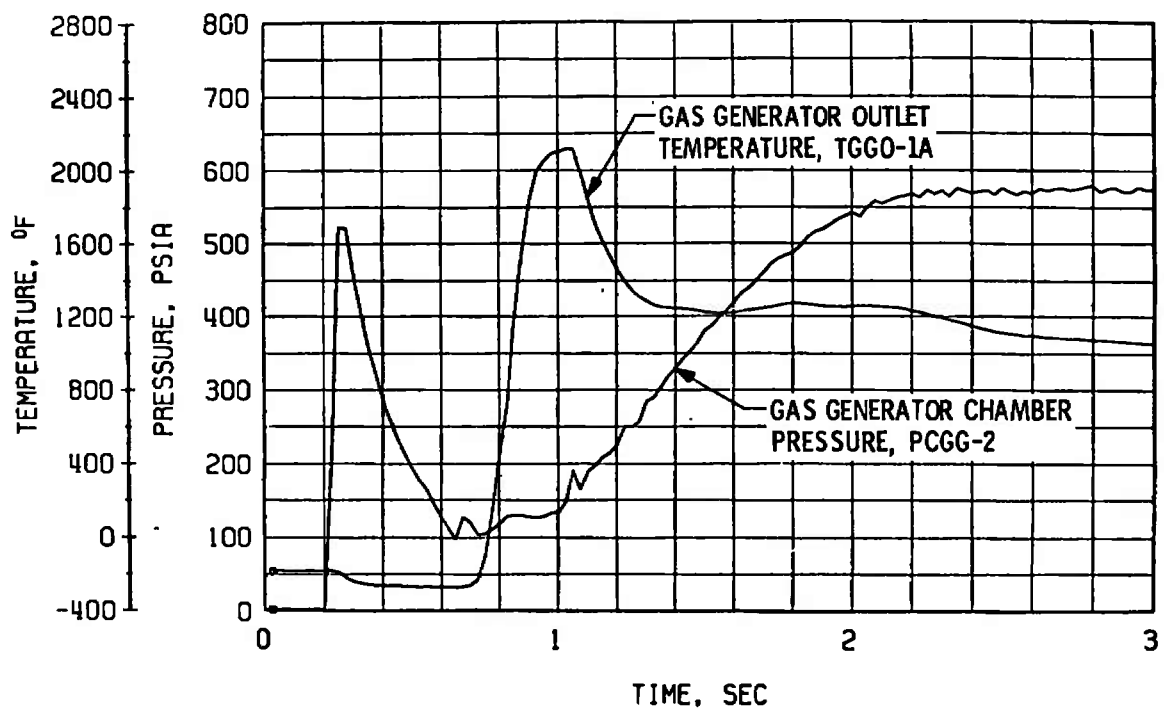


b. Thrust Chamber Oxidizer System, Start

Fig. 27 Engine Transient Operation, Firing 42D

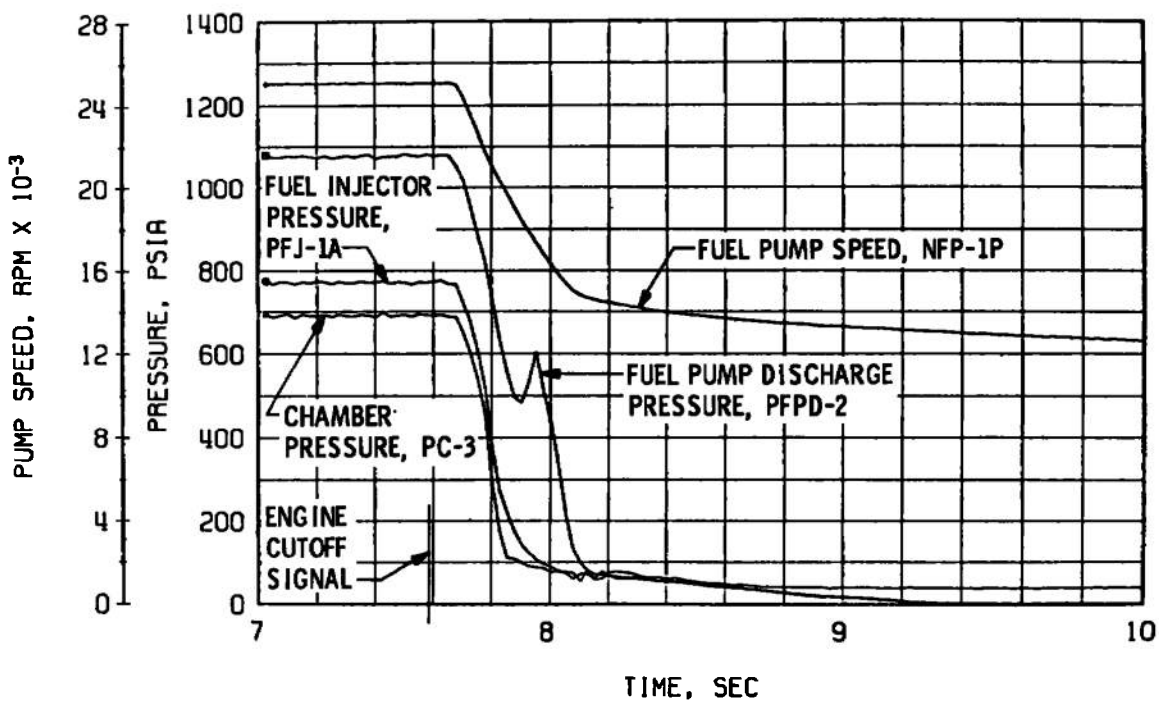


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

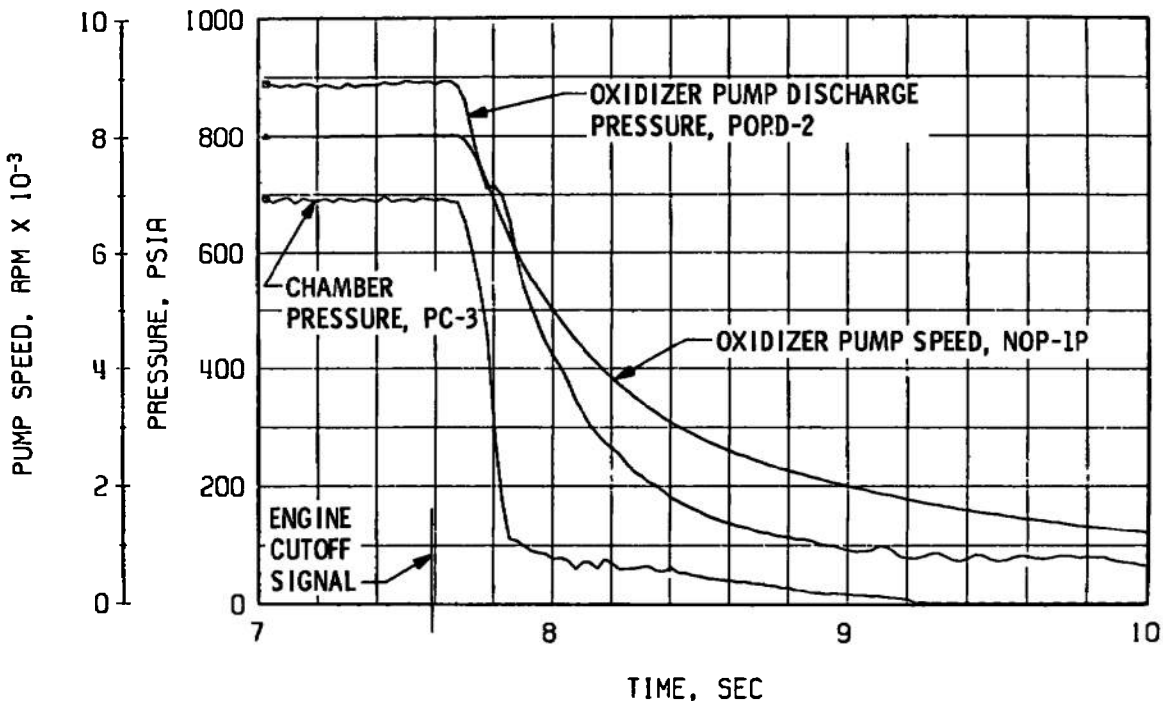


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 27 Continued

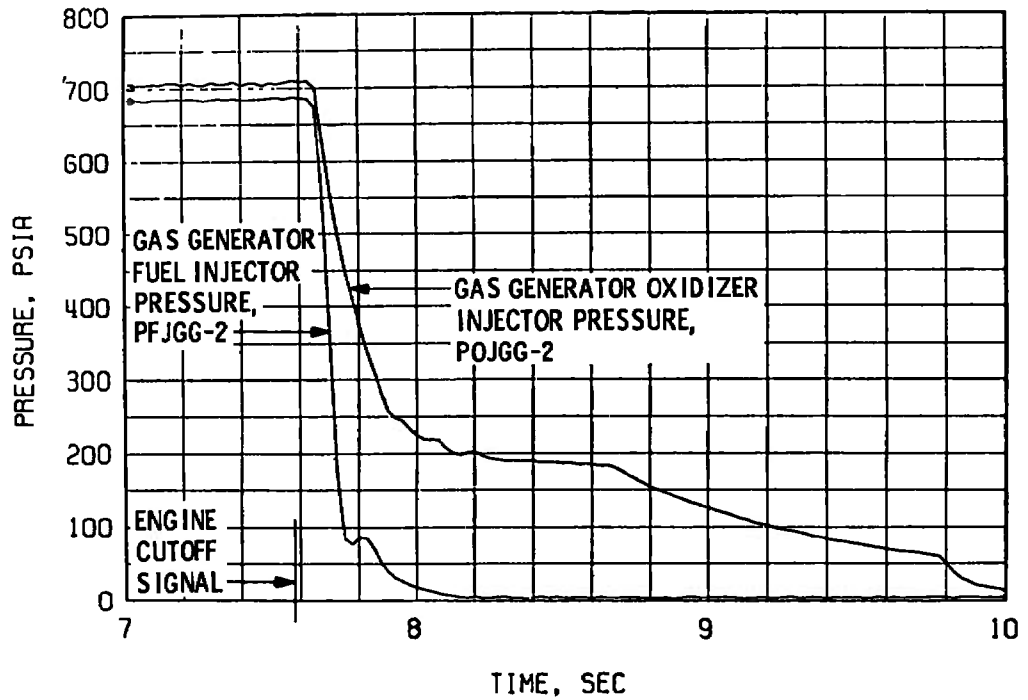


e. Thrust Chamber Fuel System, Shutdown

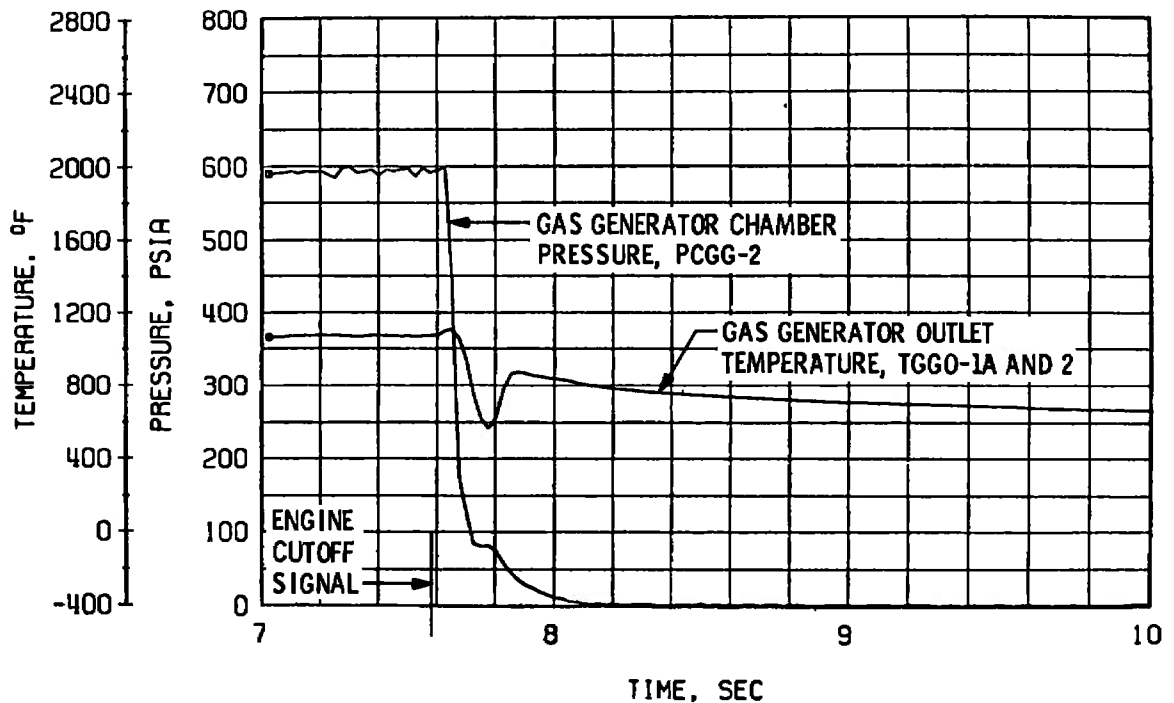


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 27 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 27 Concluded

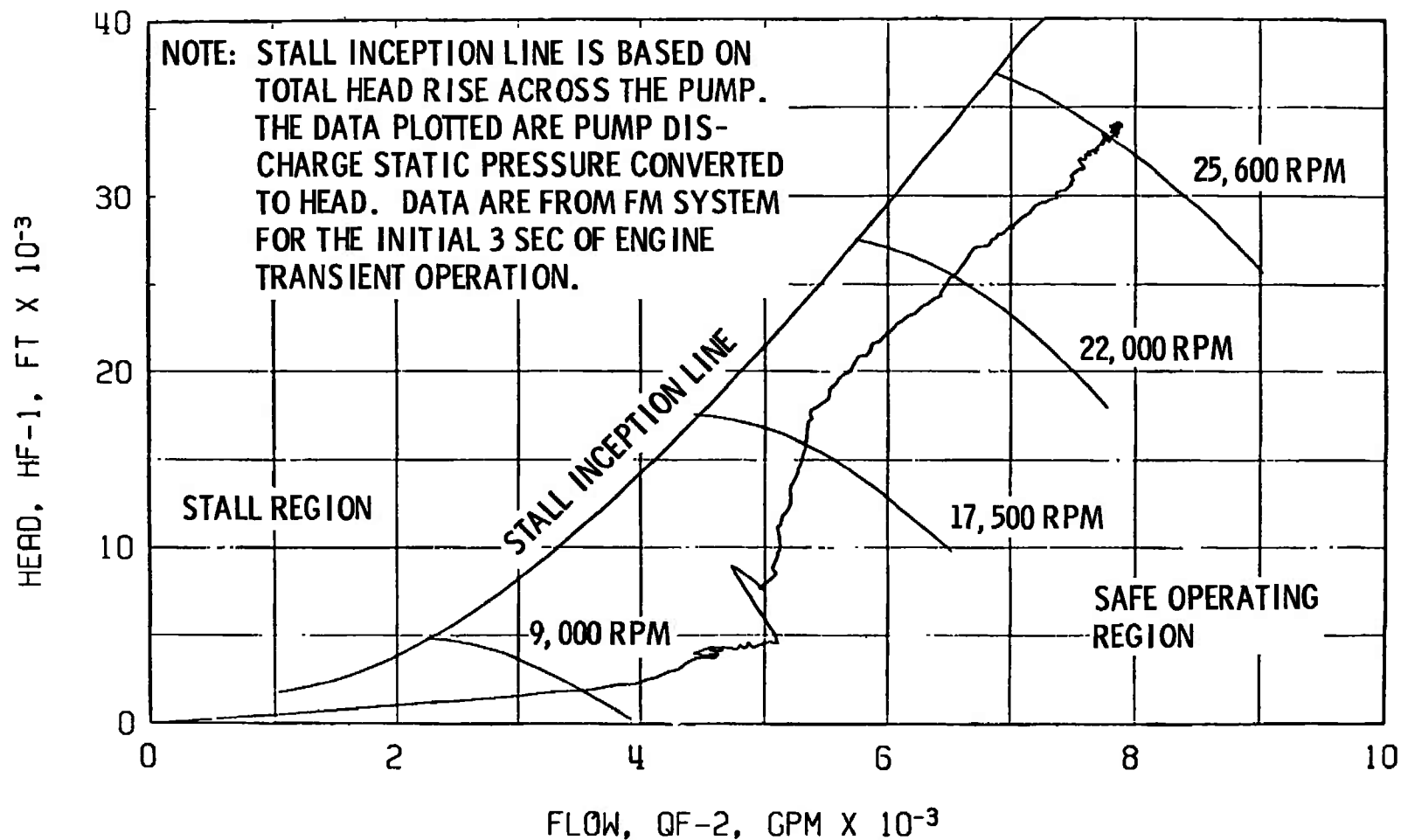
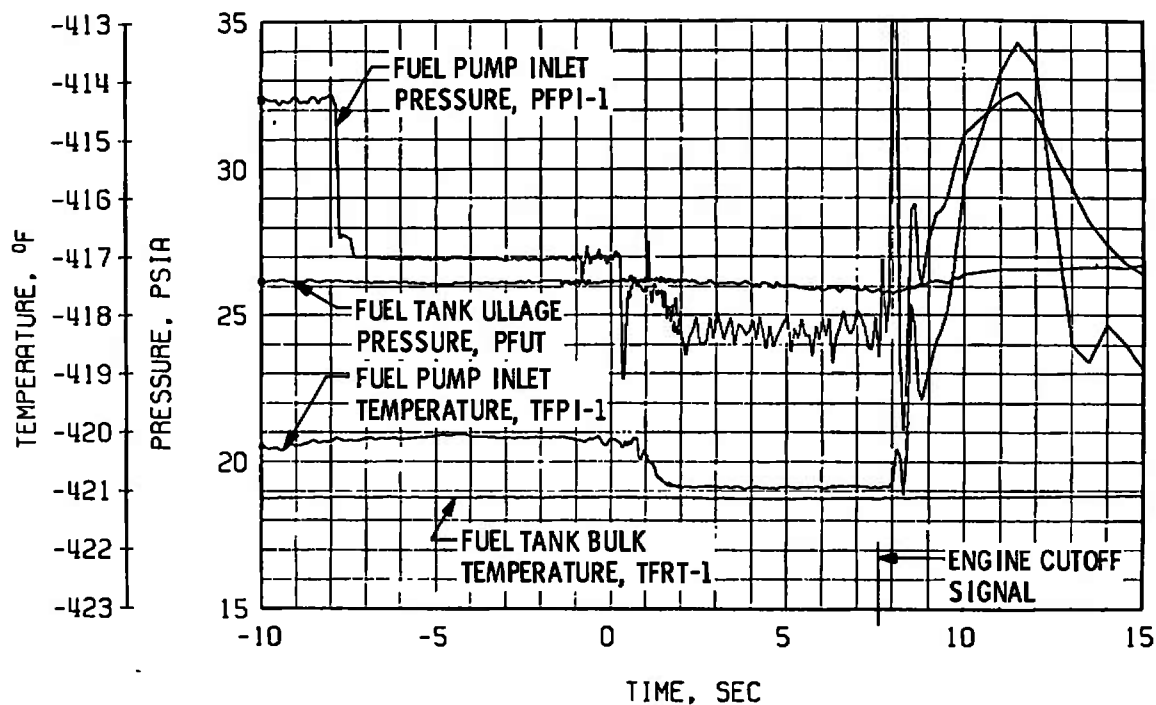
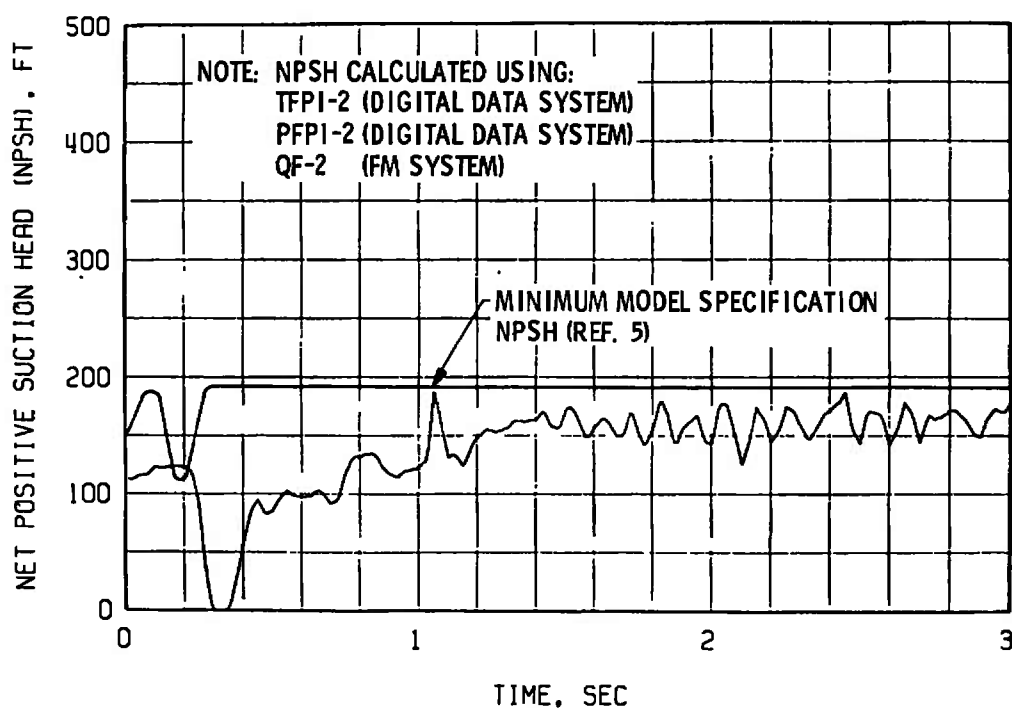


Fig. 28 Fuel Pump Start Transient Performance, Firing 42D

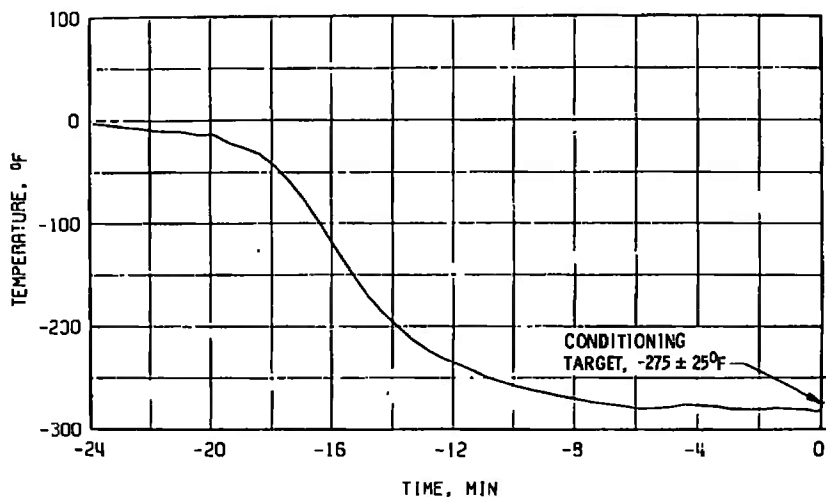


a. Duct Pressure and Temperature Transients

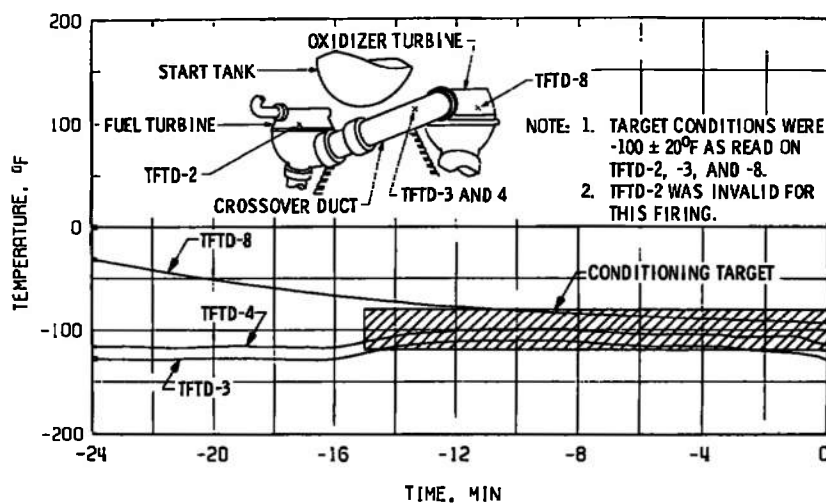


b. Fuel Pump NPSH during Start Transient, Firing 42D

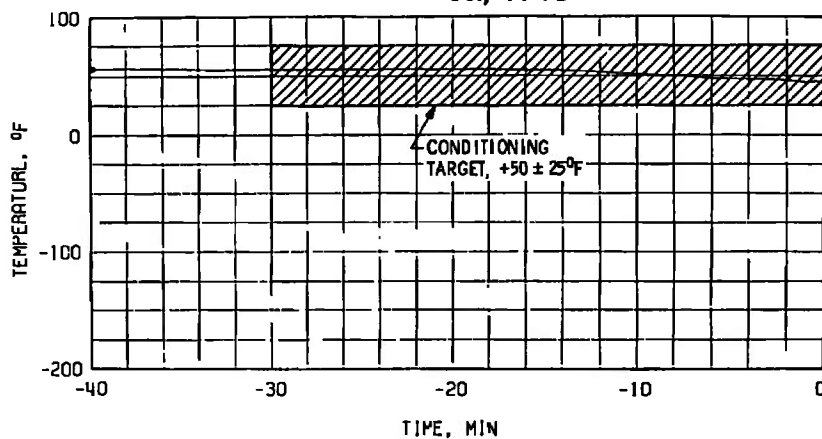
Fig. 29 Fuel Low Pressure Duct Performance, Firing 42D



a. Thrust Chamber, TTC-1P

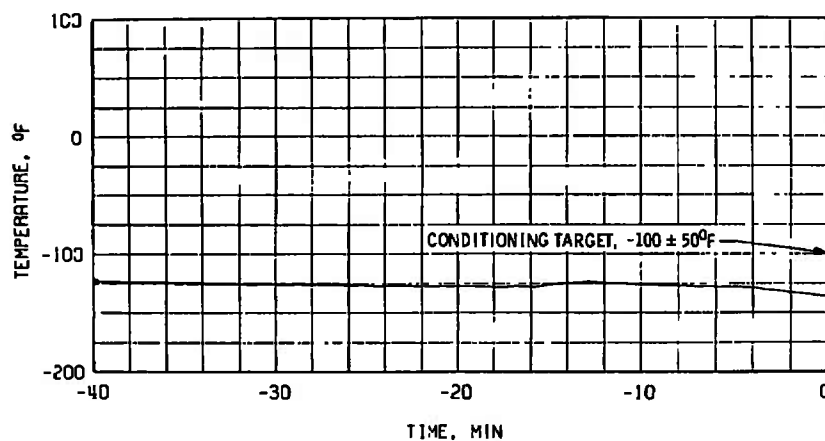


b. Crossover Duct, TTFD

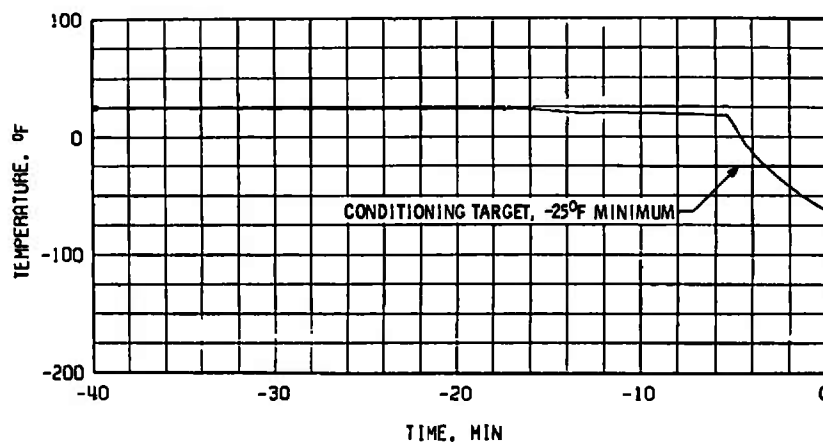


c. Start Tank Discharge Valve, TSTDVOC

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

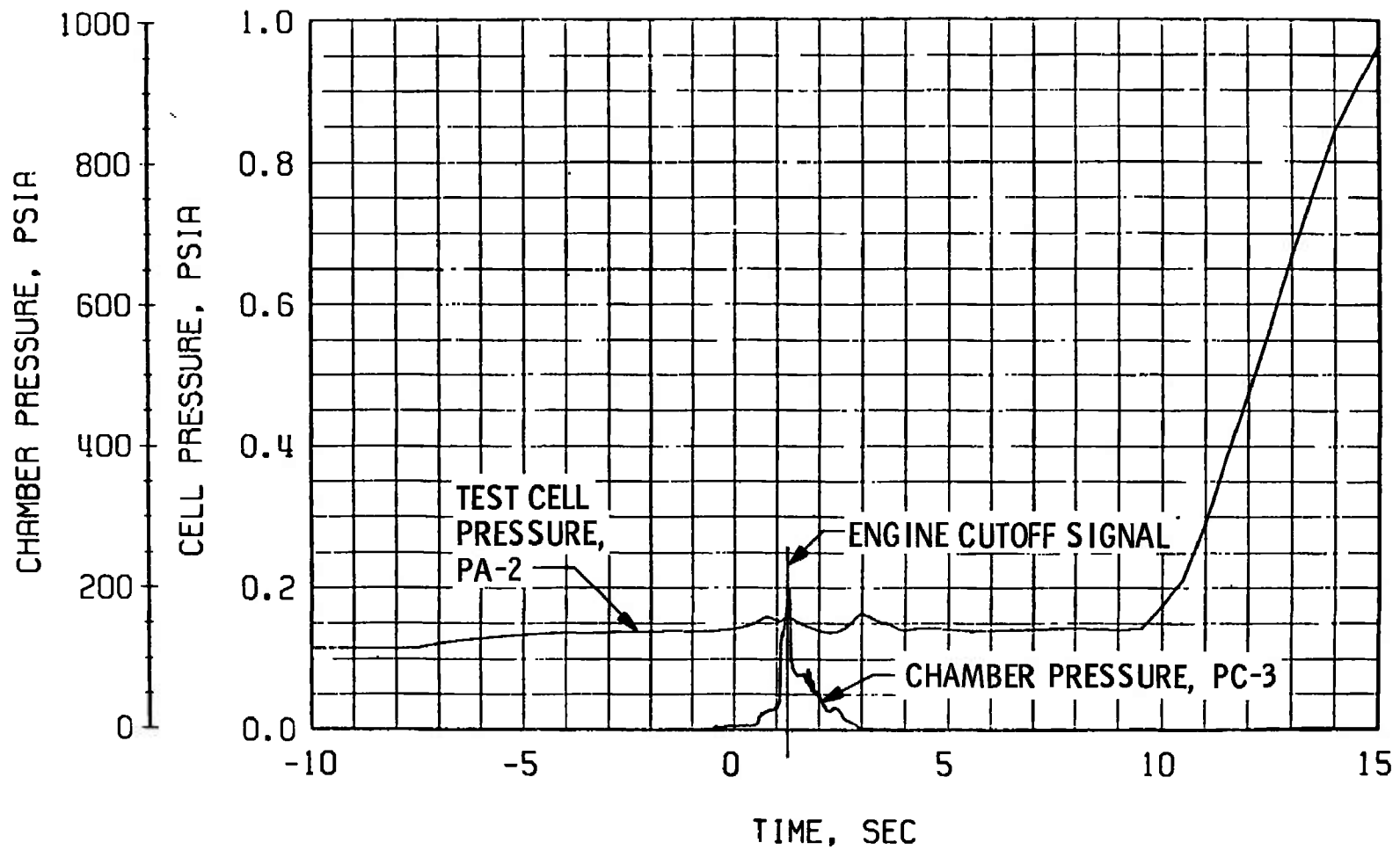
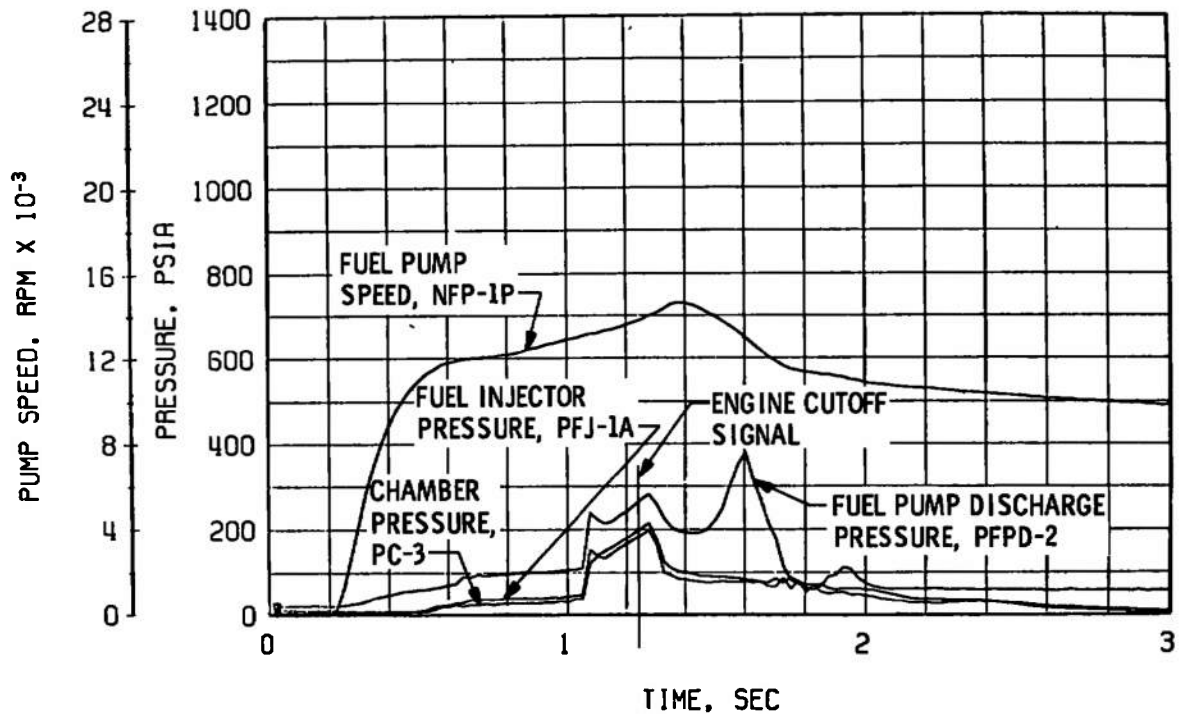
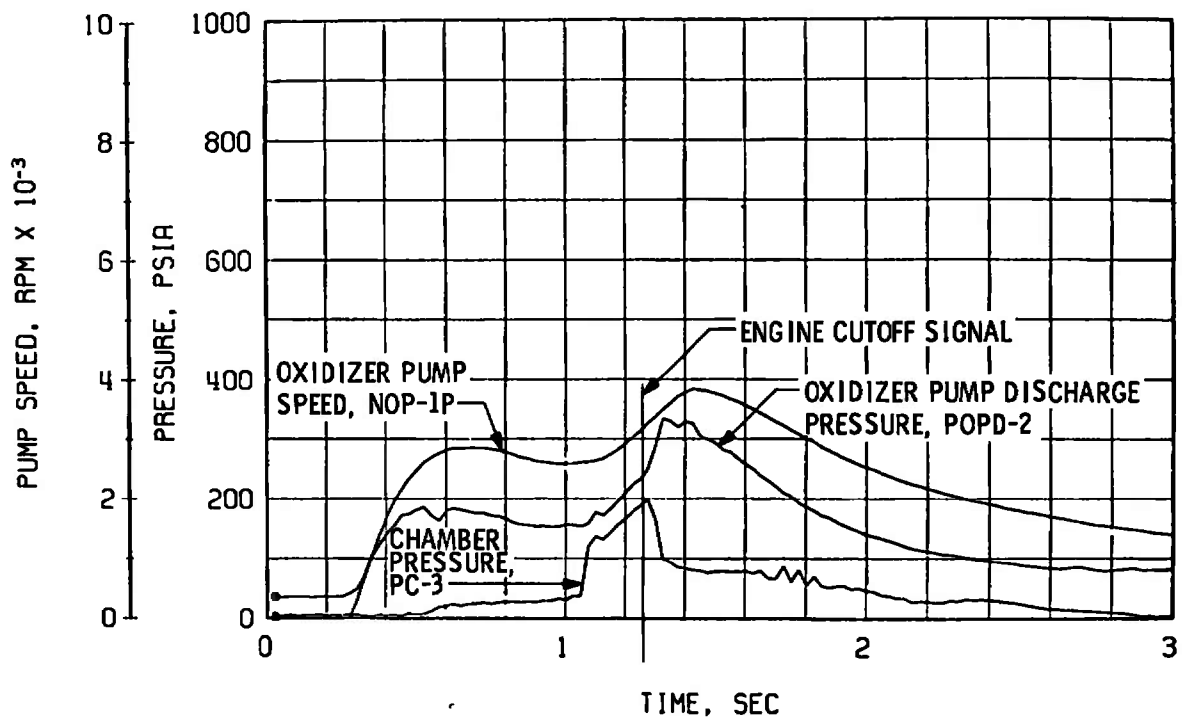


Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 42E

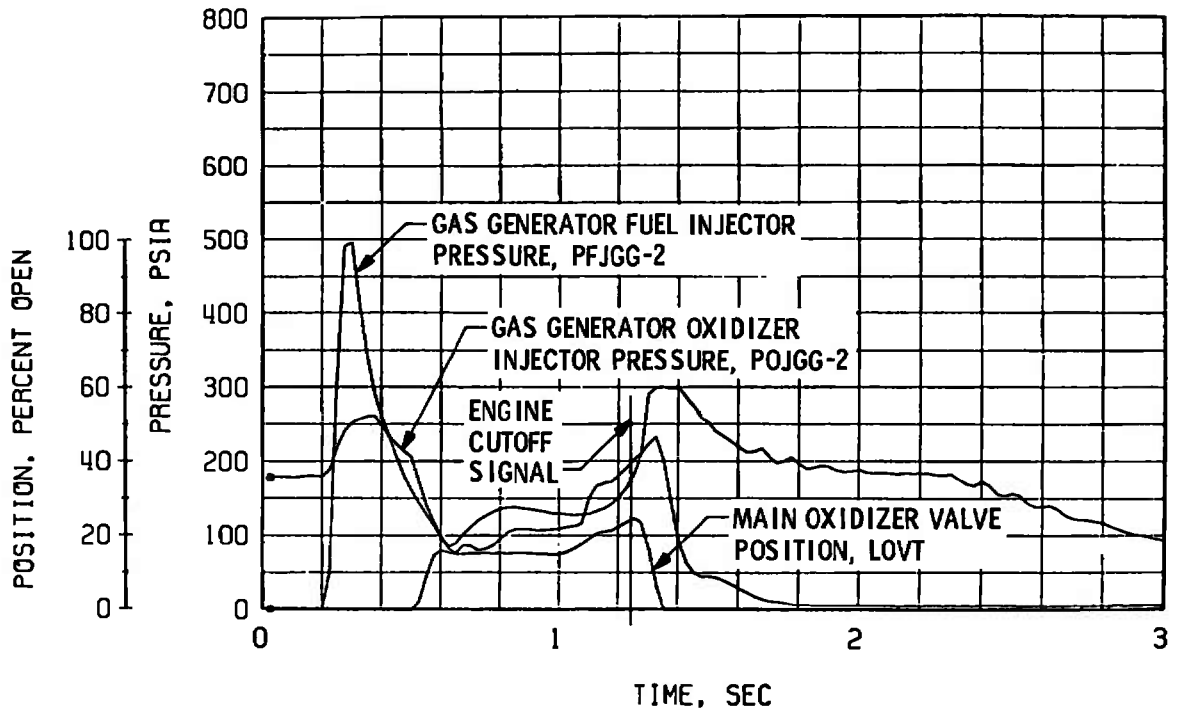


a. Thrust Chamber Fuel System, Start and Shutdown

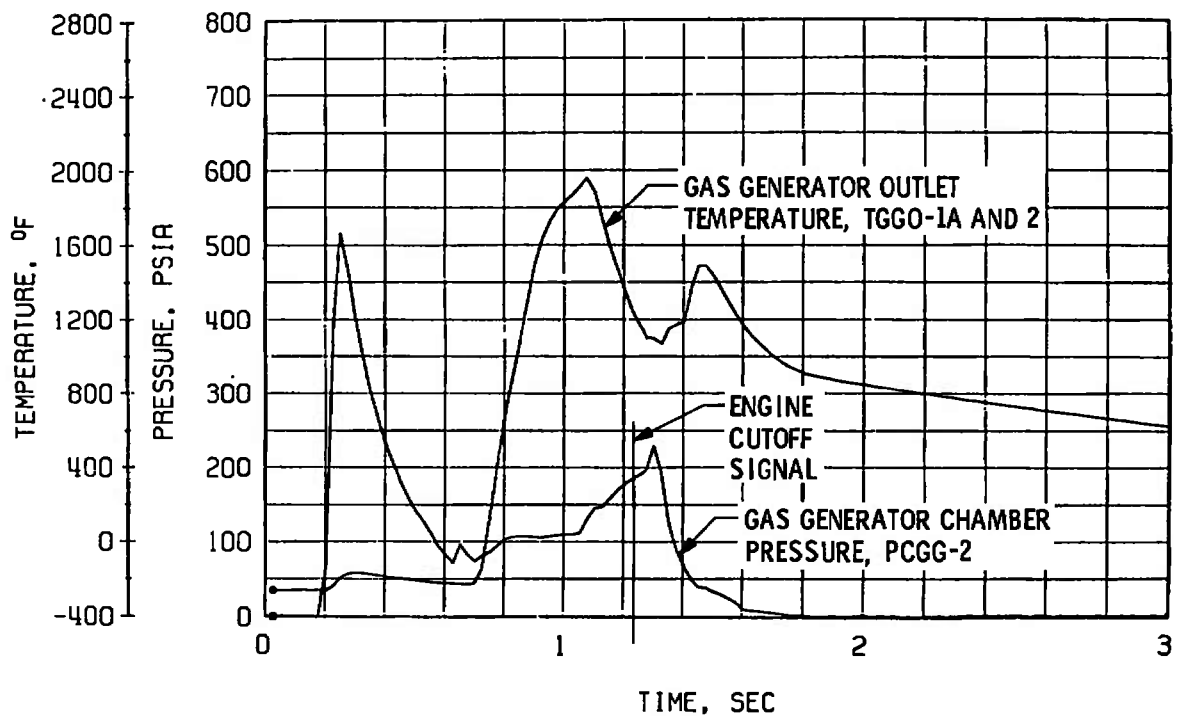


b. Thrust Chamber Oxidizer System, Start and Shutdown

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

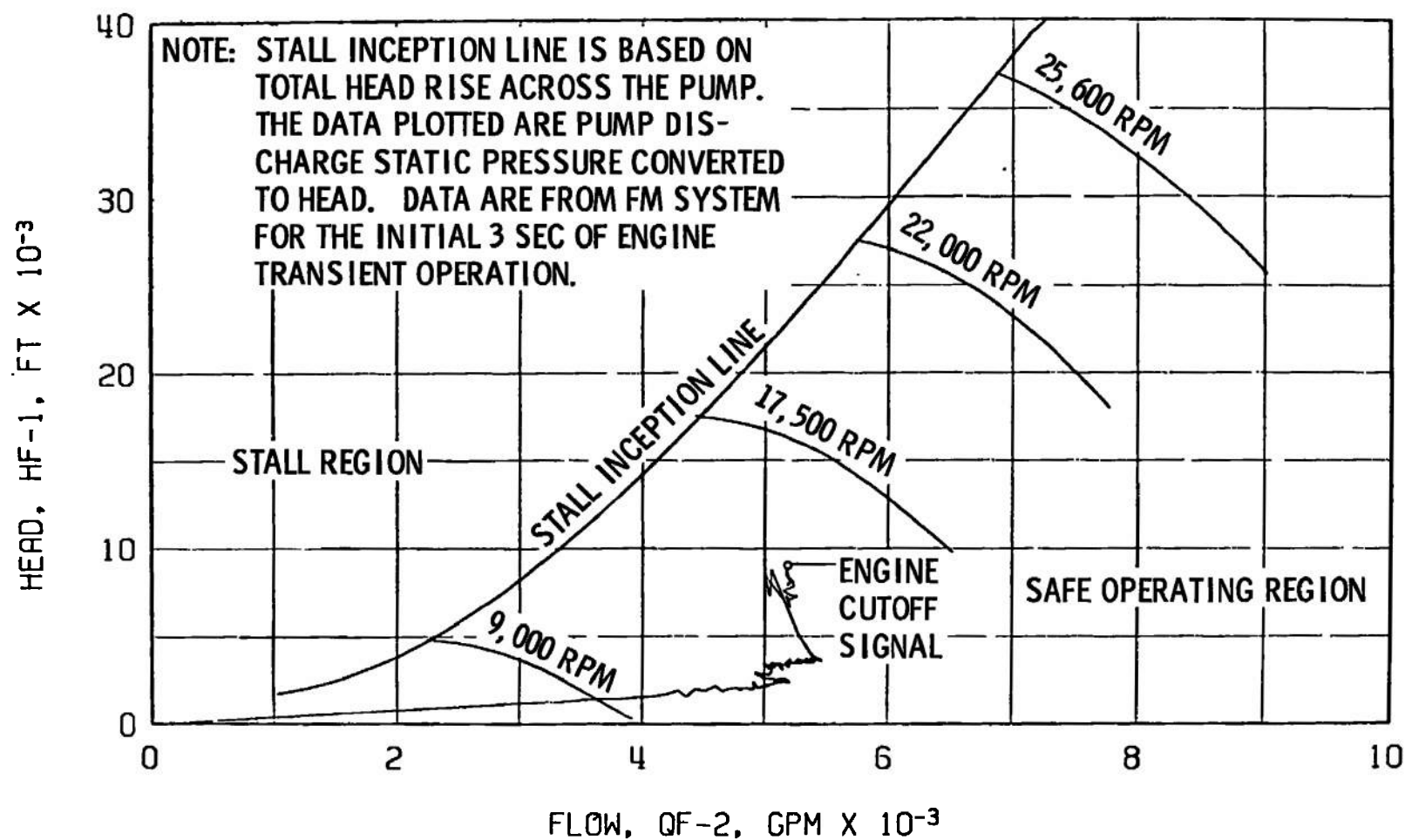
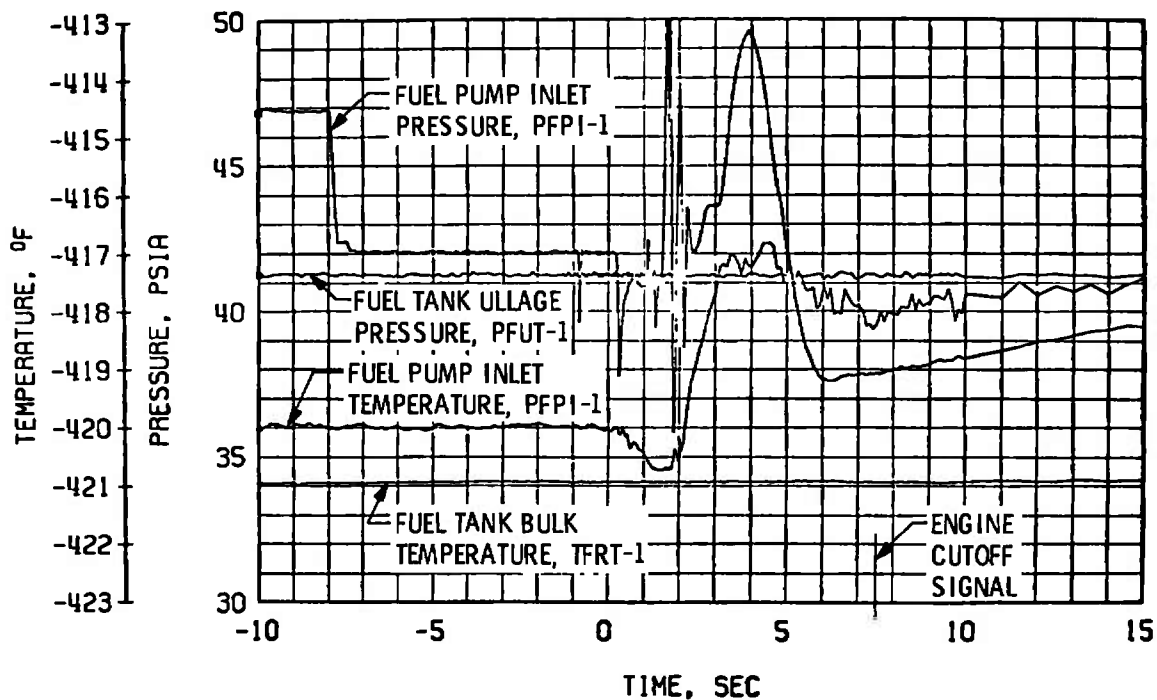
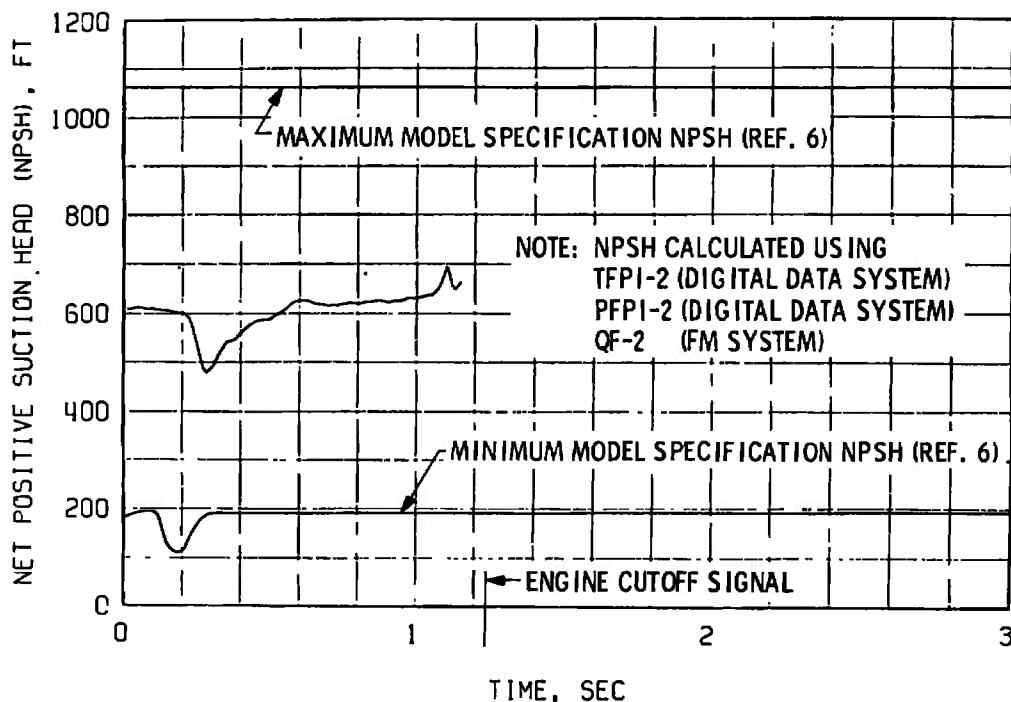


Fig. 33 Fuel Pump Start Transient Performance, Firing 42E

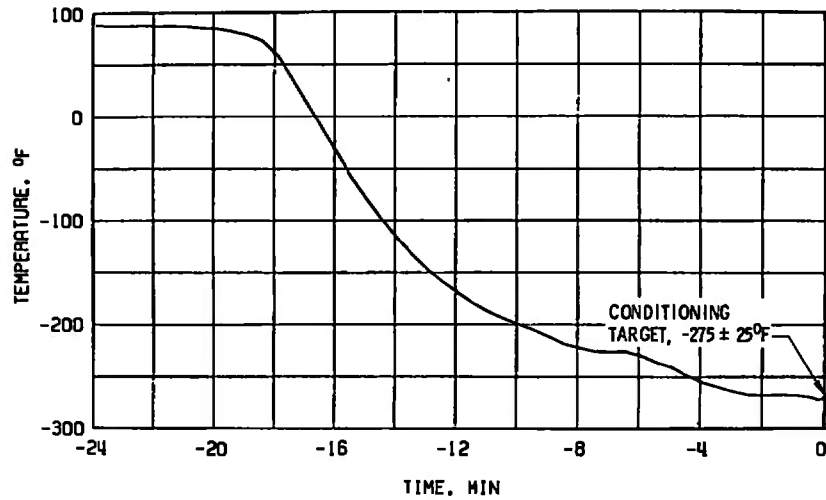


a. Duct Pressure and Temperature Transients

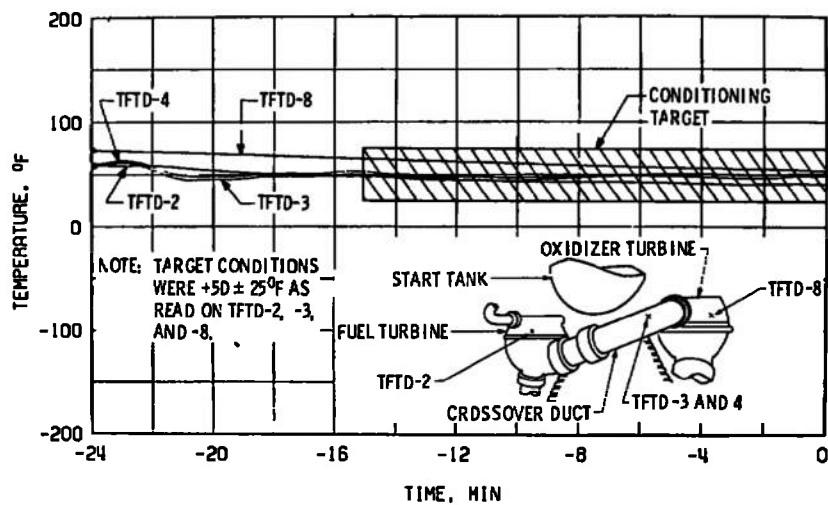


b. Fuel Pump NPSH during Start Transient, Firing 42E

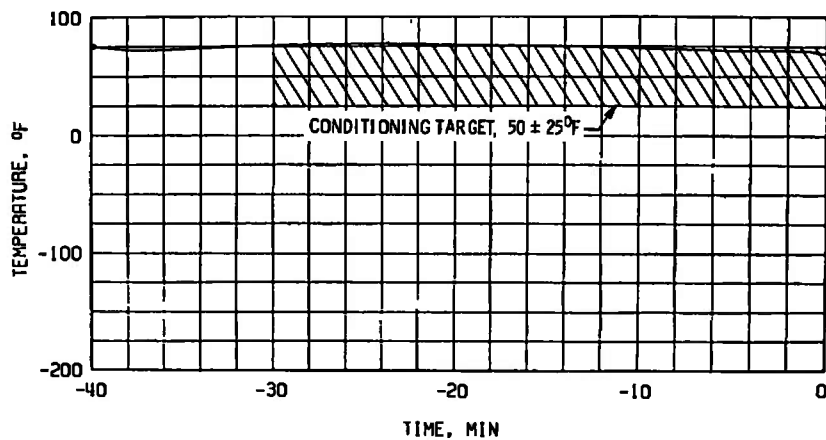
Fig. 34 Fuel Low Pressure Duct Performance, Firing 42E



a. Thrust Chamber, TTC-1P

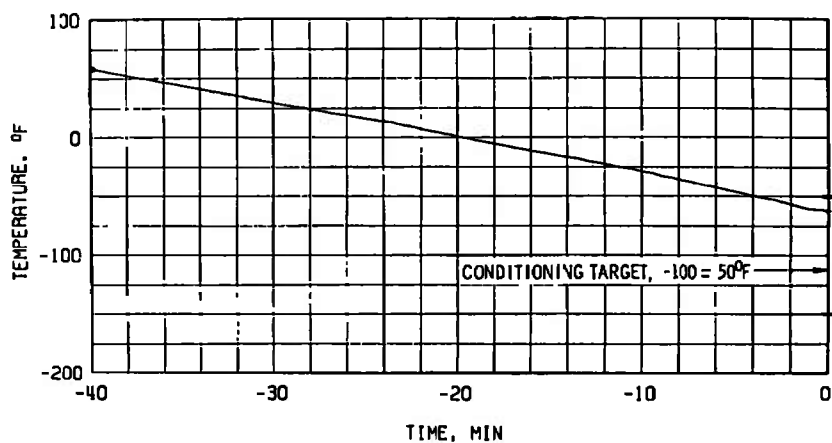


b. Crossover Duct, TTFD

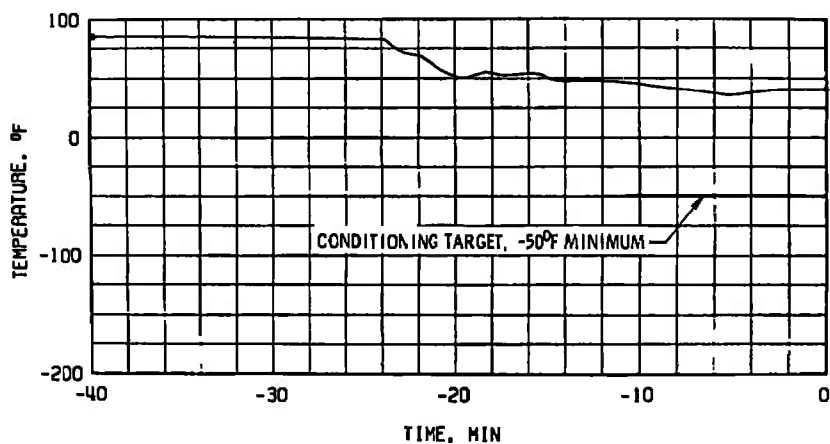


c. Start Tank Discharge Valve, TSTDVOC

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

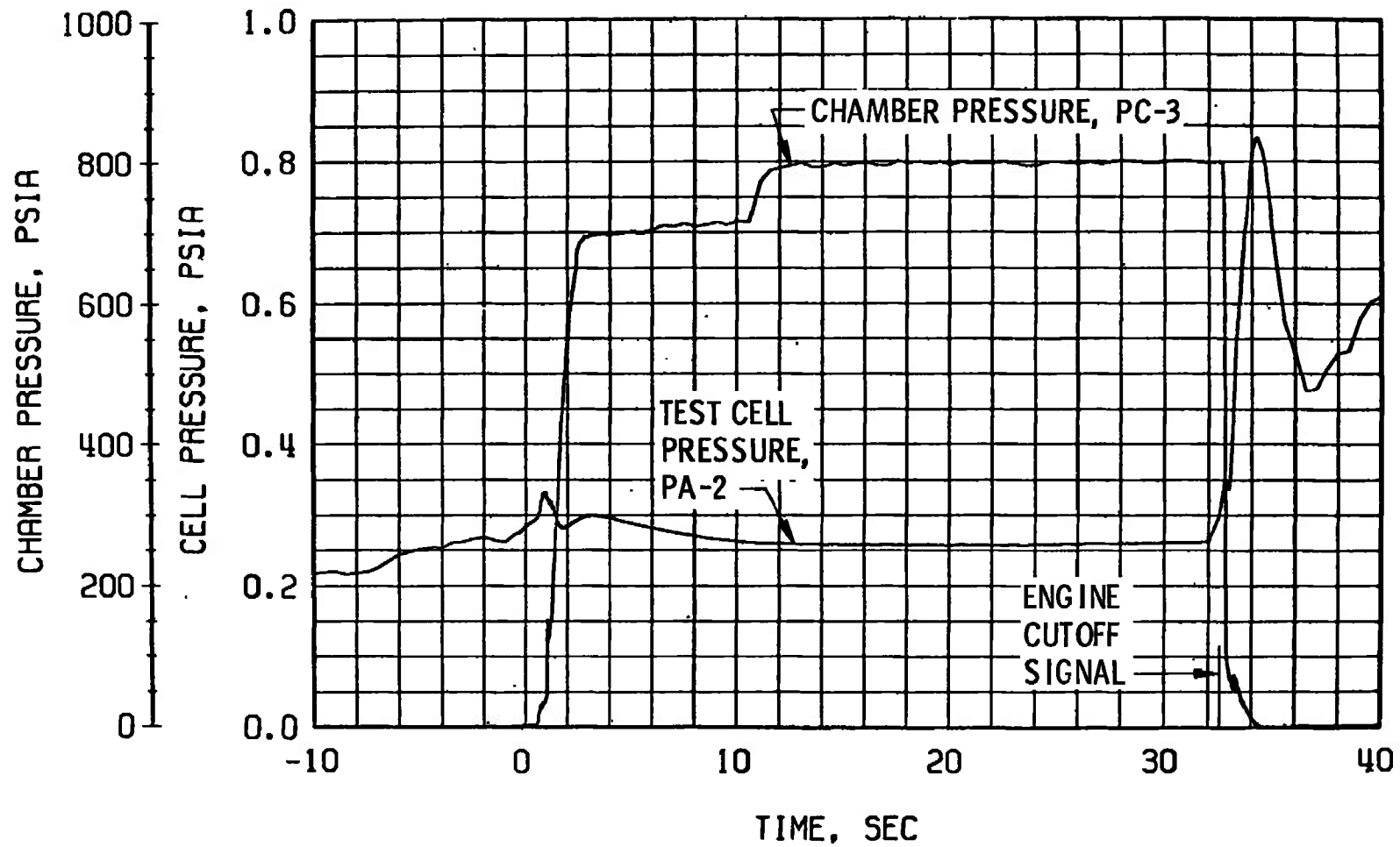
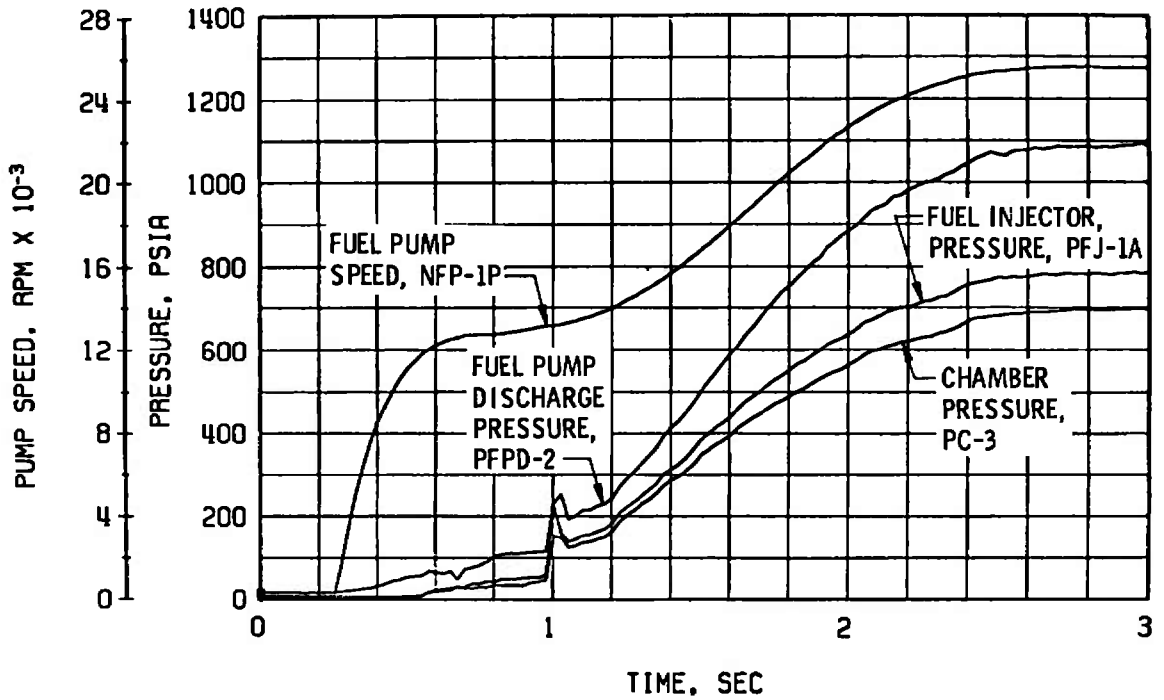
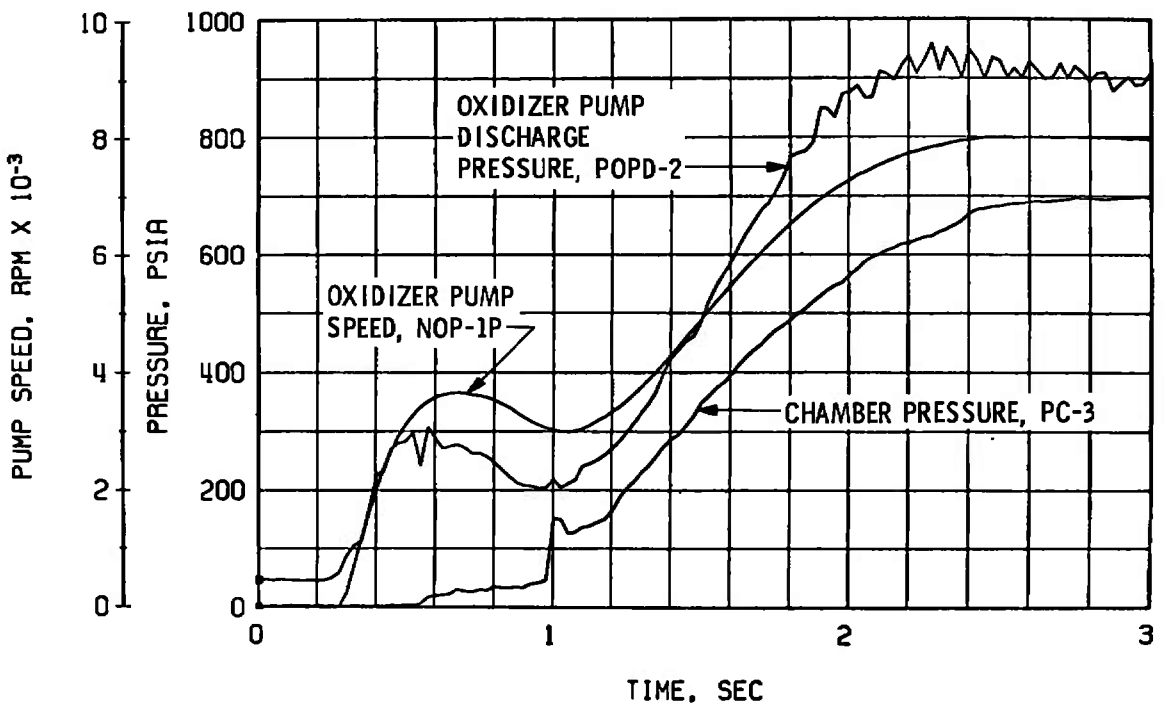


Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 43A

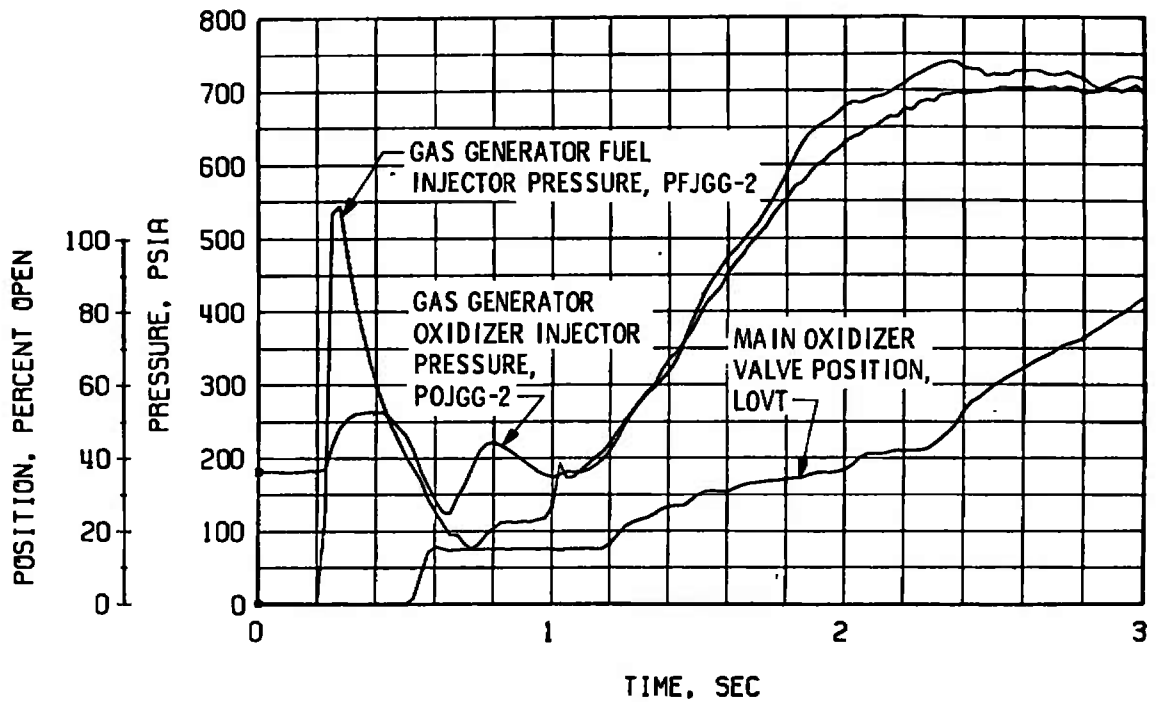


a. Thrust Chamber Fuel System, Start

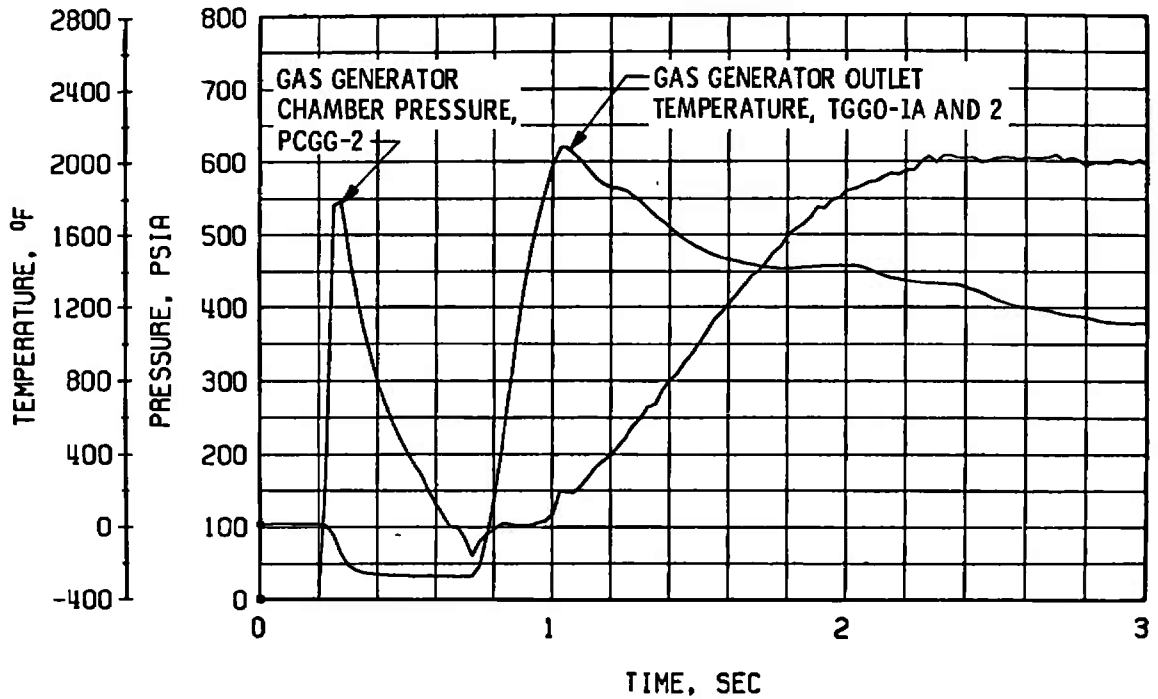


b. Thrust Chamber Oxidizer System, Start

Fig. 37 Engine Transient Operation, Firing 43A

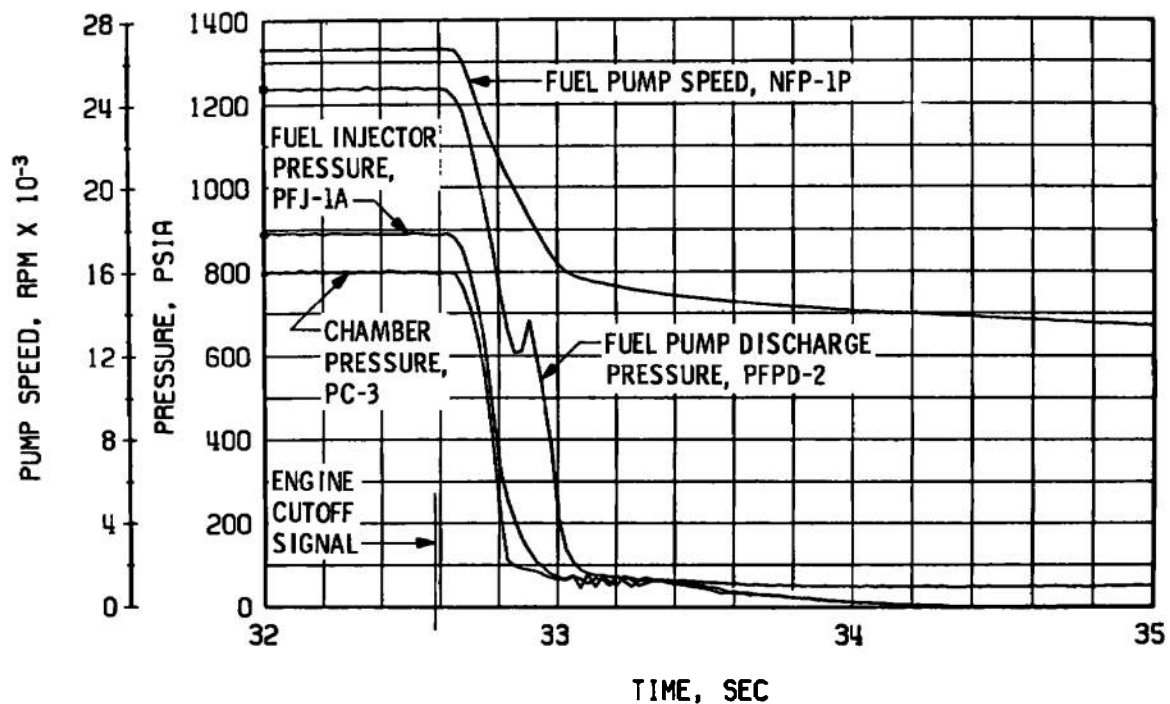


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

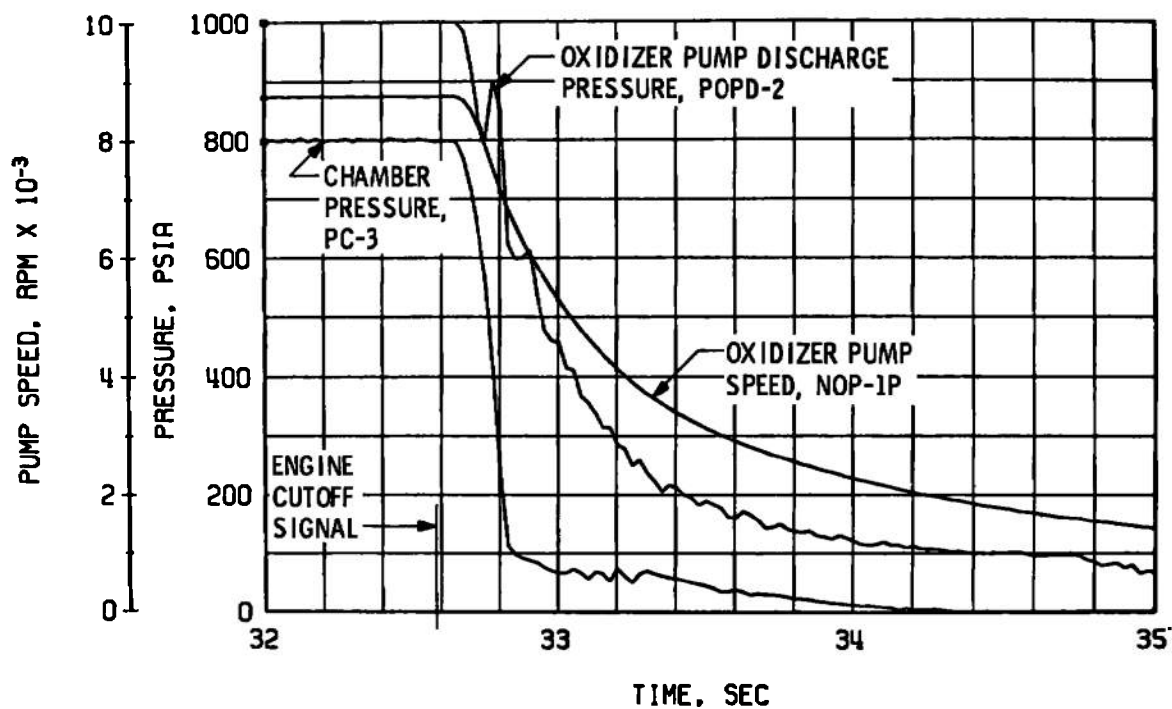


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 37 Continued

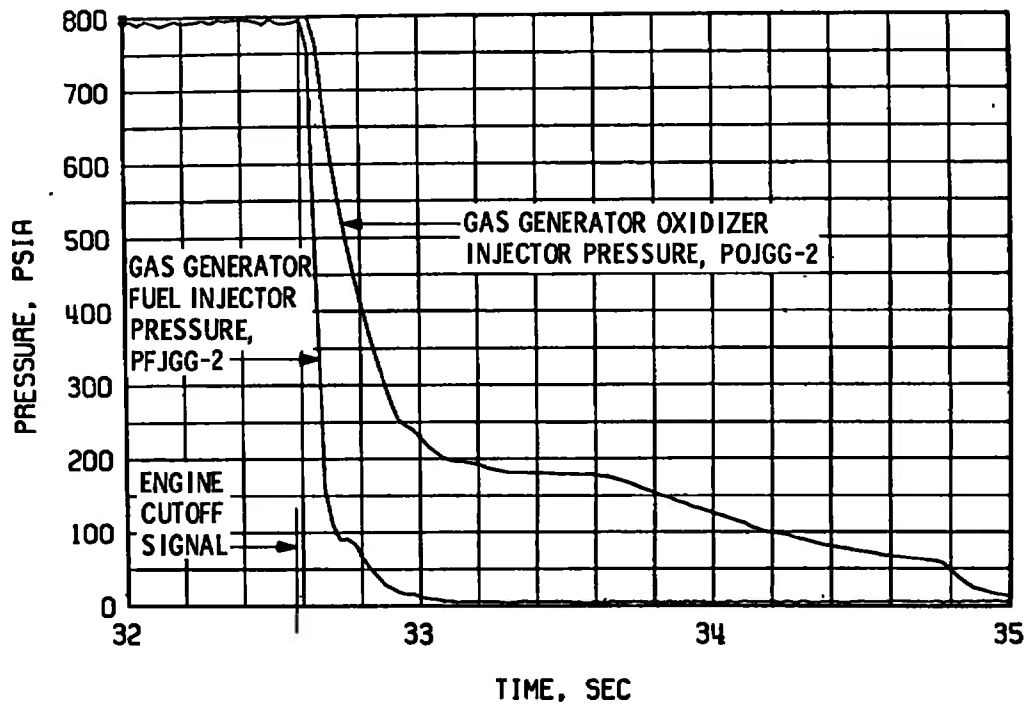


e. Thrust Chamber Fuel System, Shutdown

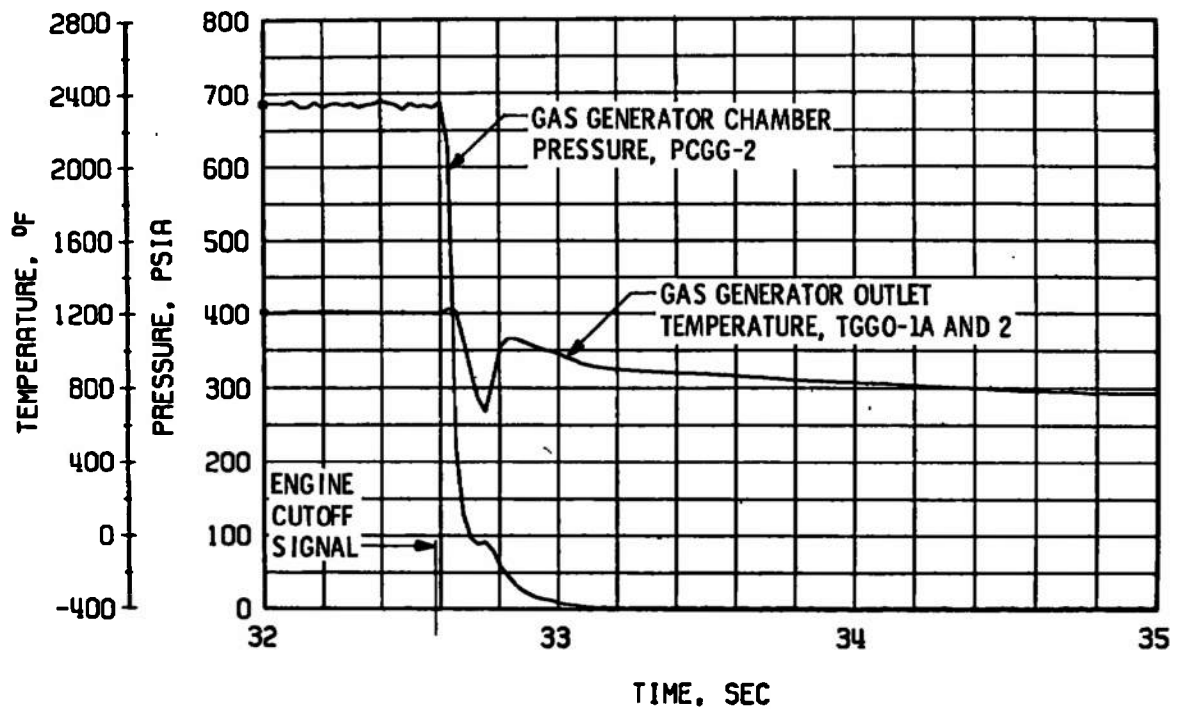


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 37 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 37 Concluded

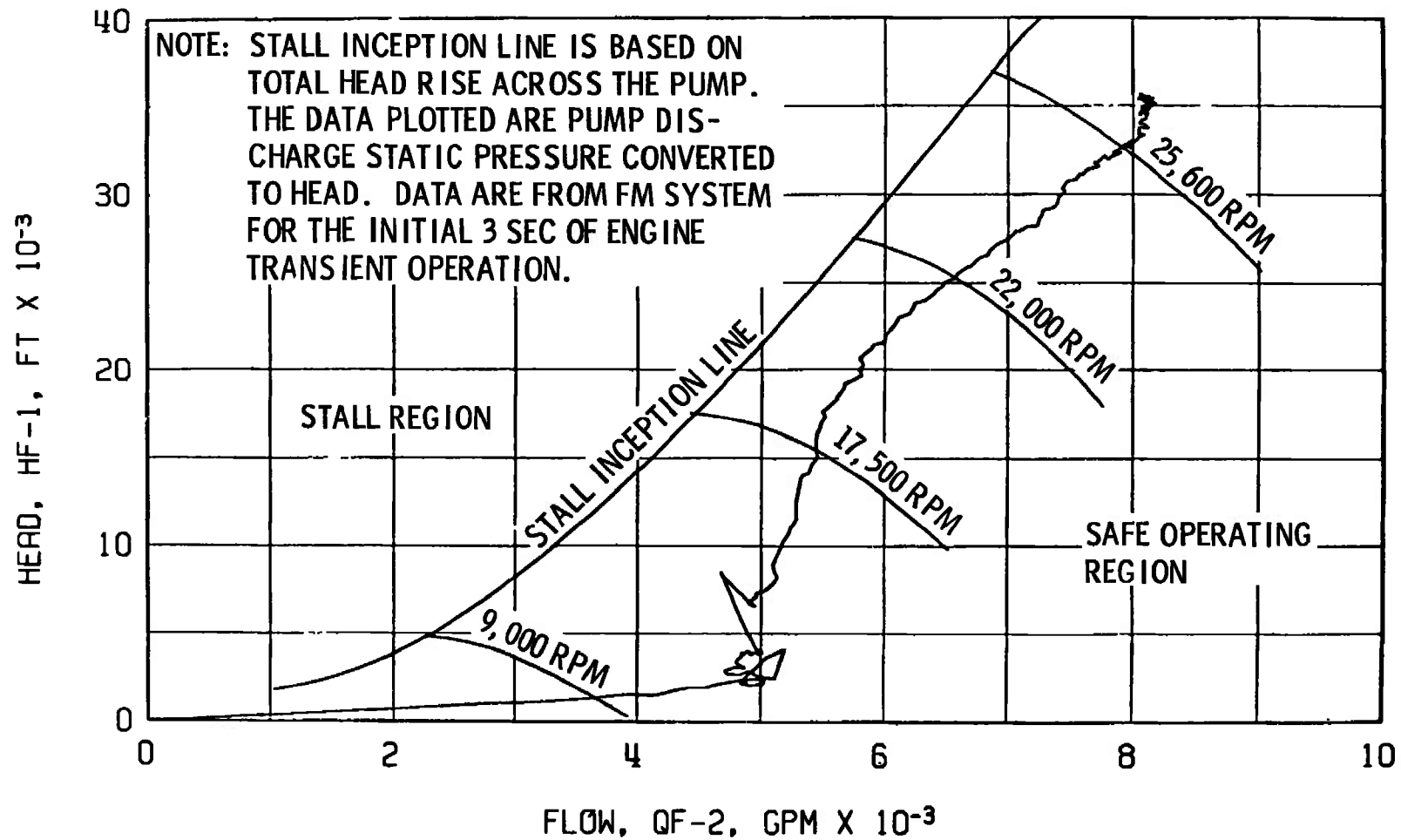
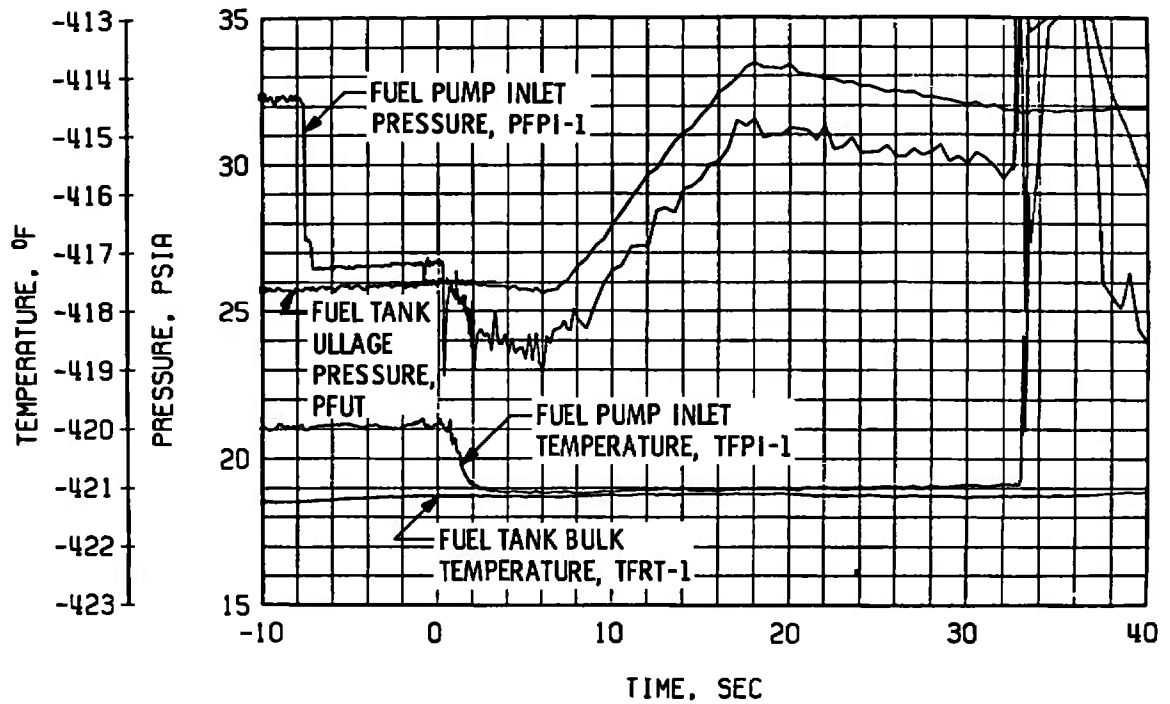
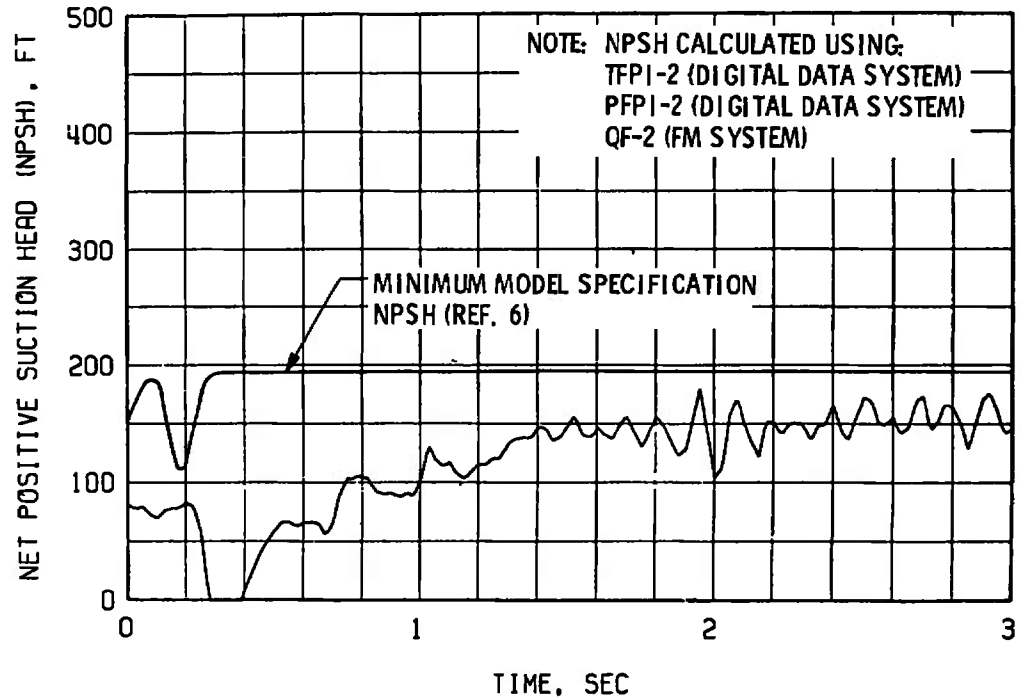


Fig. 38 Fuel Pump Start Transient Performance, Firing 43A

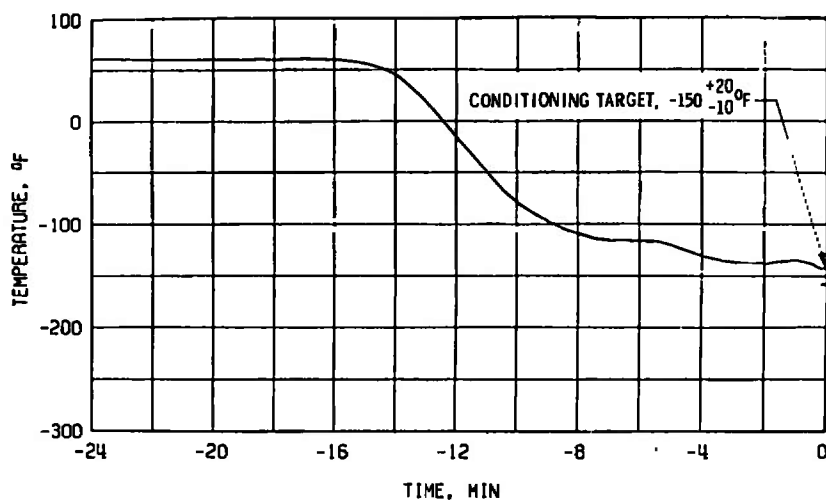


a. Duct Pressure and Temperature Transients

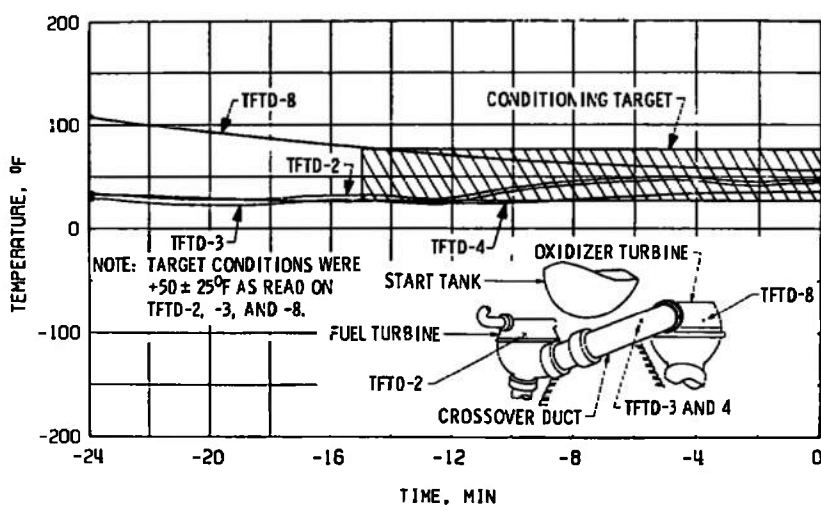


b. Fuel Pump NPSH during Start Transient, Firing 43A

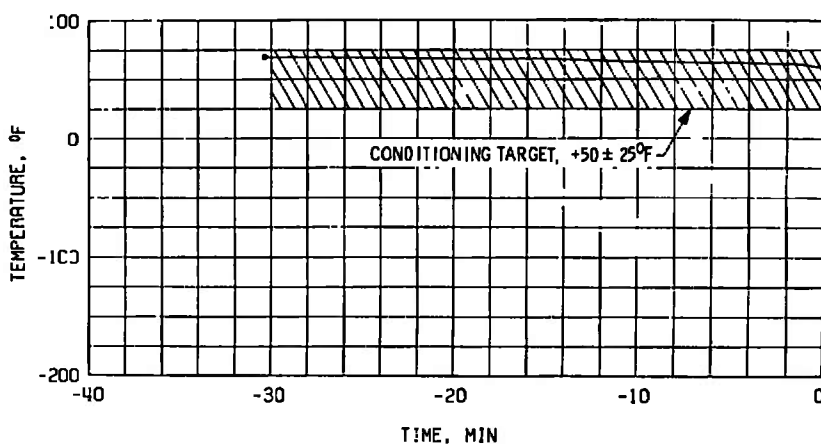
Fig. 39 Fuel Low Pressure Duct Performance, Firing 43A



a. Thrust Chamber, TTC-1P

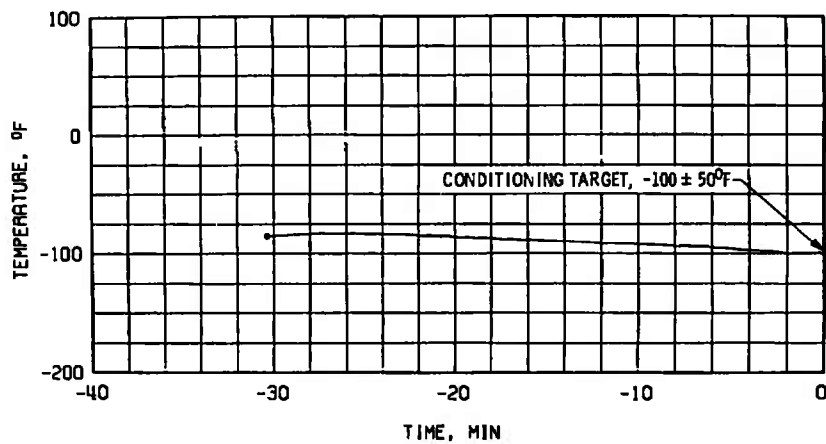


b. Crossover Duct, TFTD

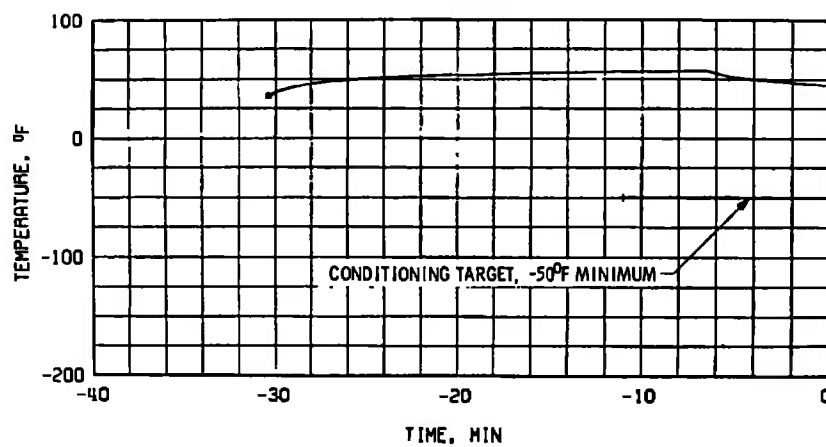


c. Start Tank Discharge Valve, TSTDVOC

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

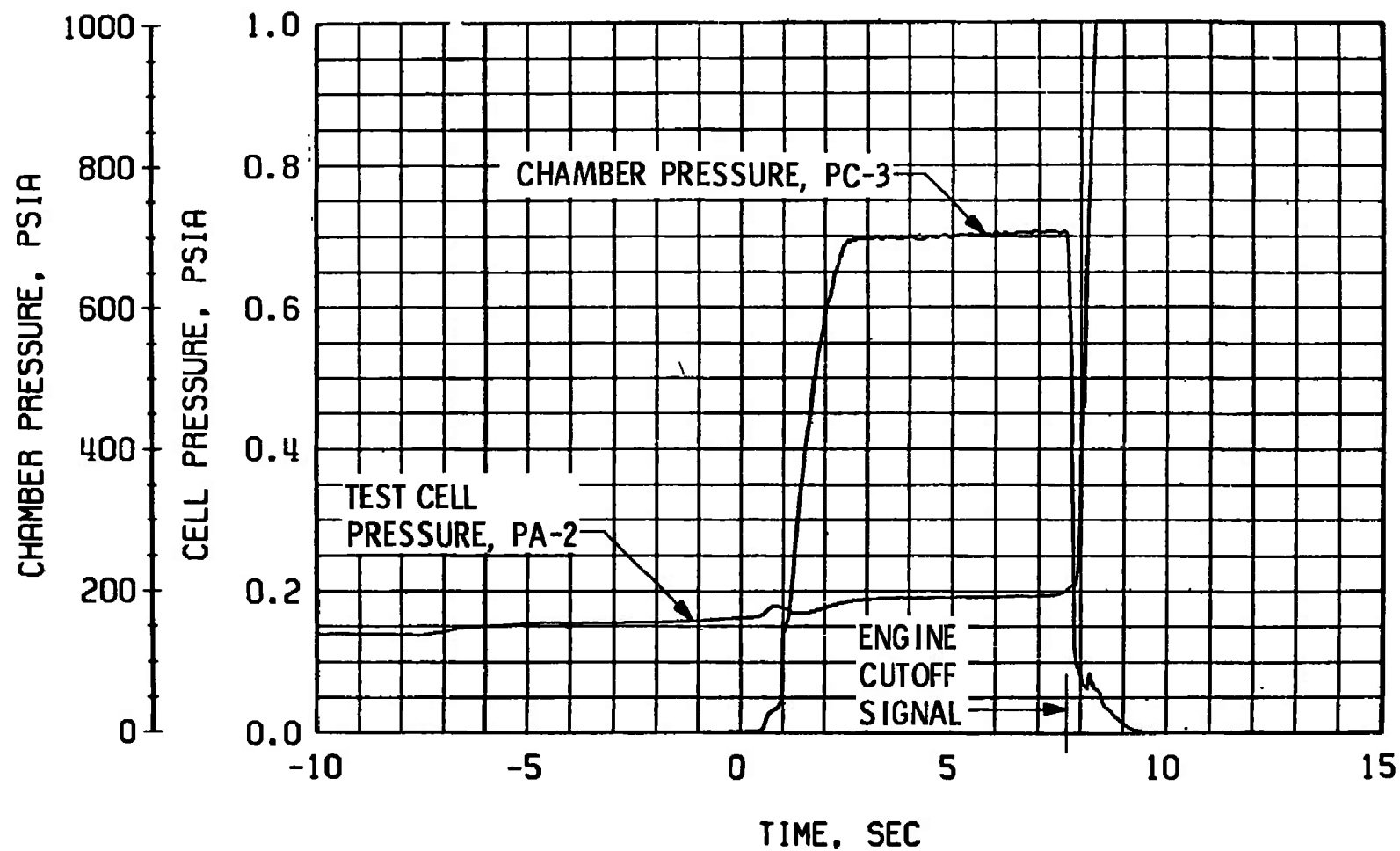
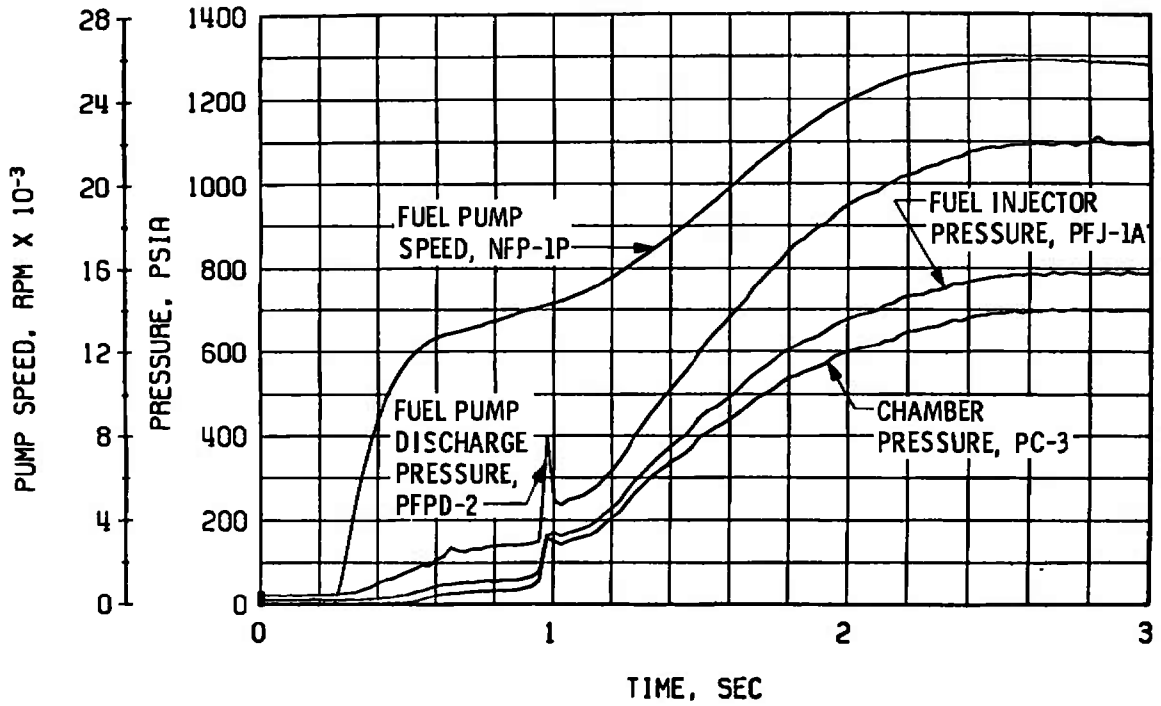
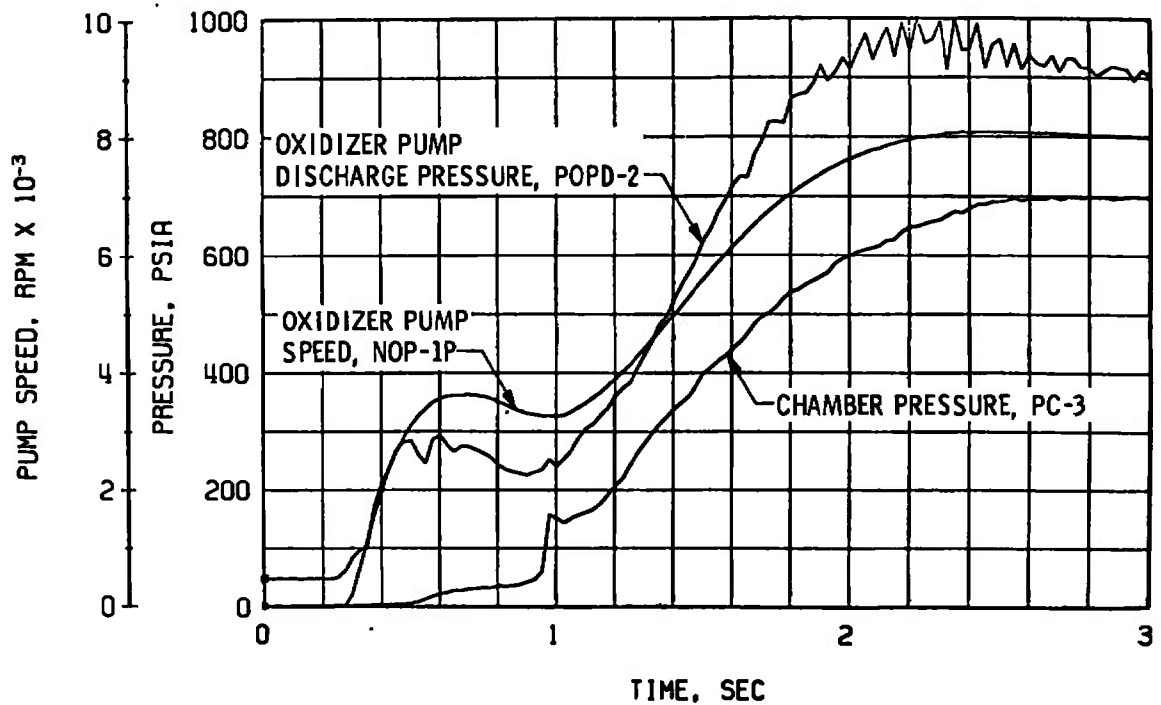


Fig. 41 Engine Ambient and Combustion Chamber Pressures, Firing 43B

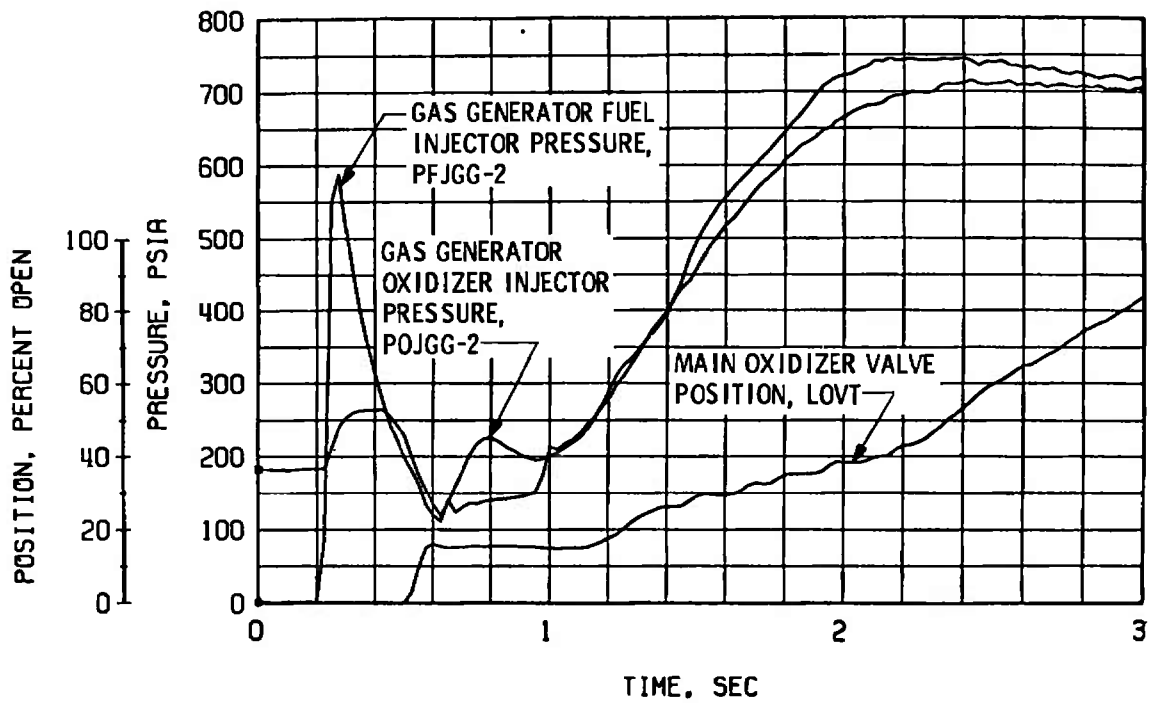


a. Thrust Chamber Fuel System, Start

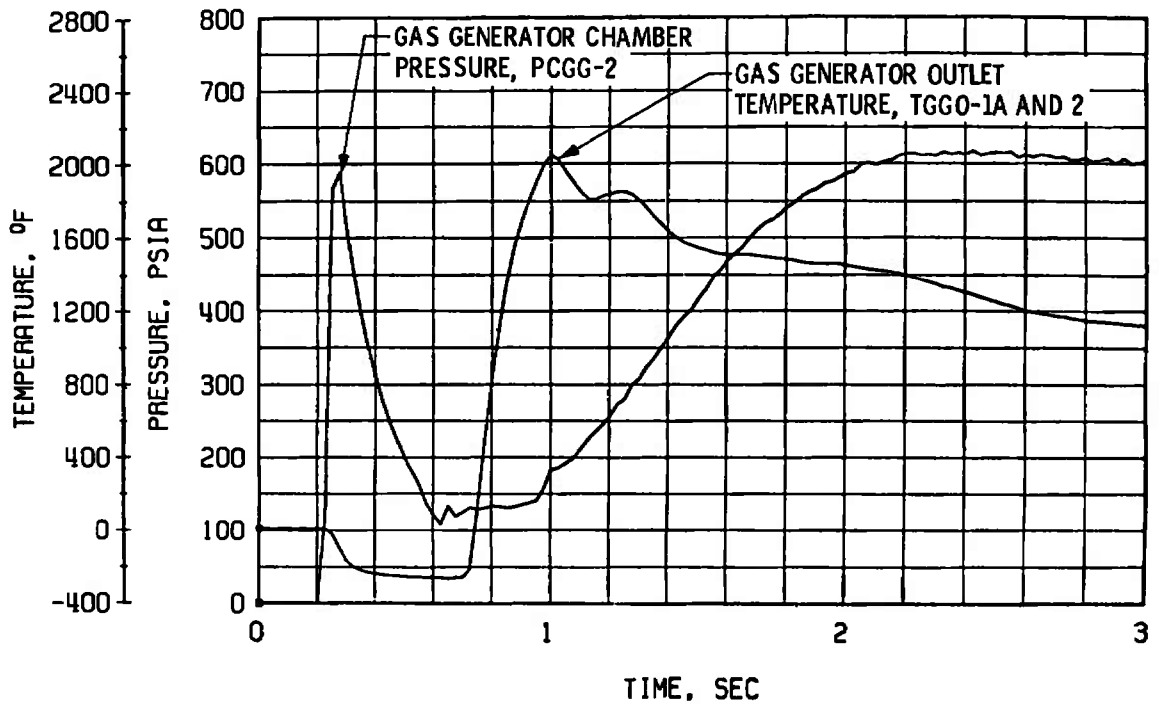


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 43B

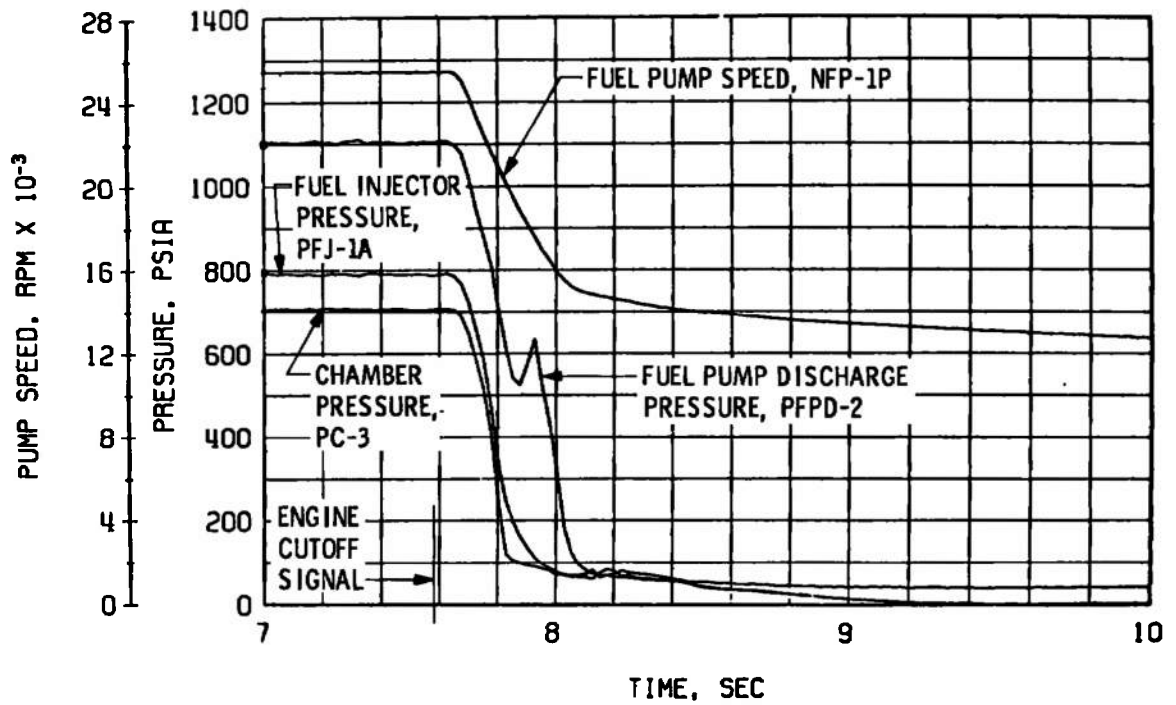


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

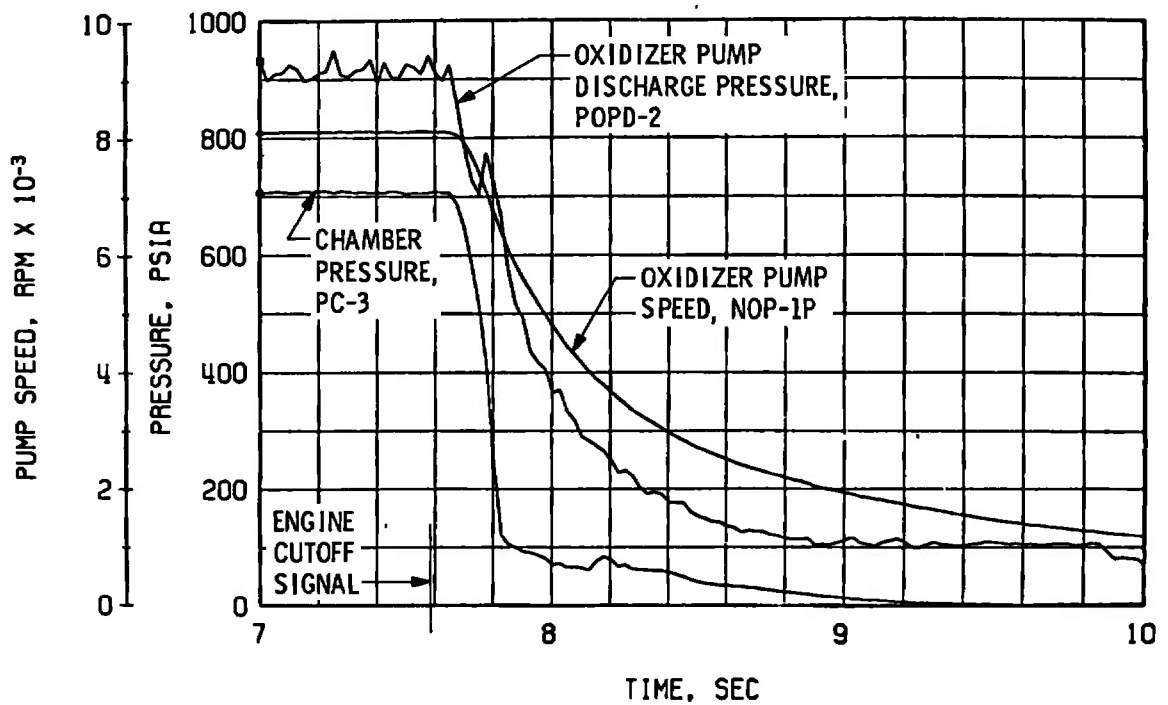


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued



e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued

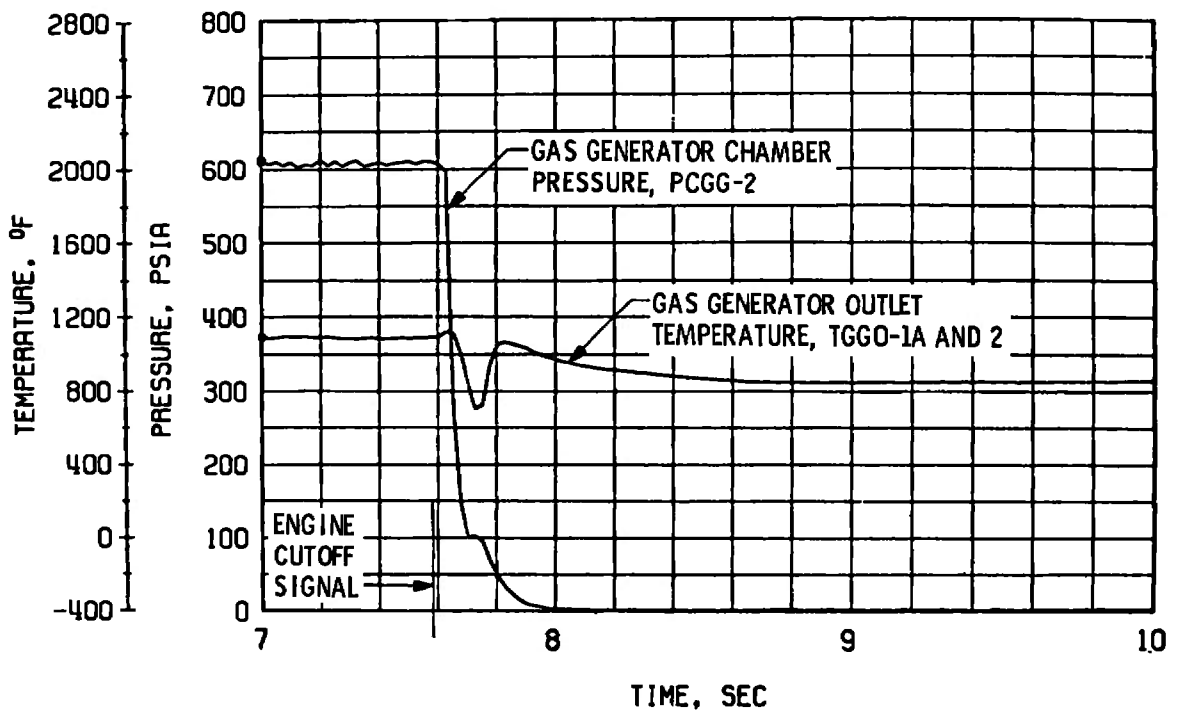
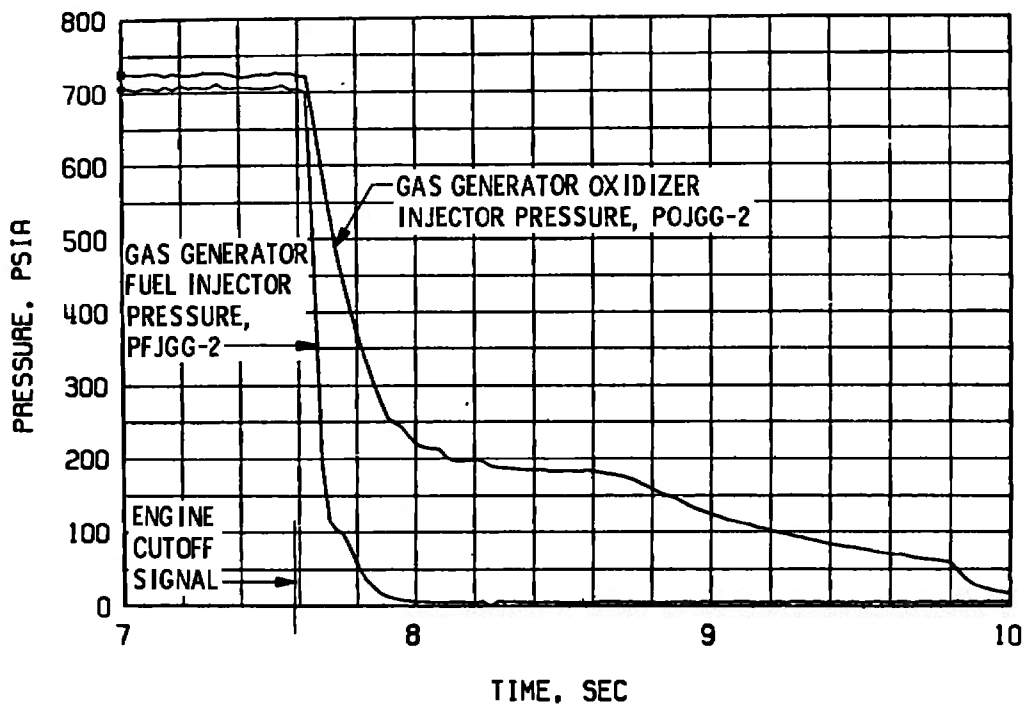


Fig. 42 Concluded

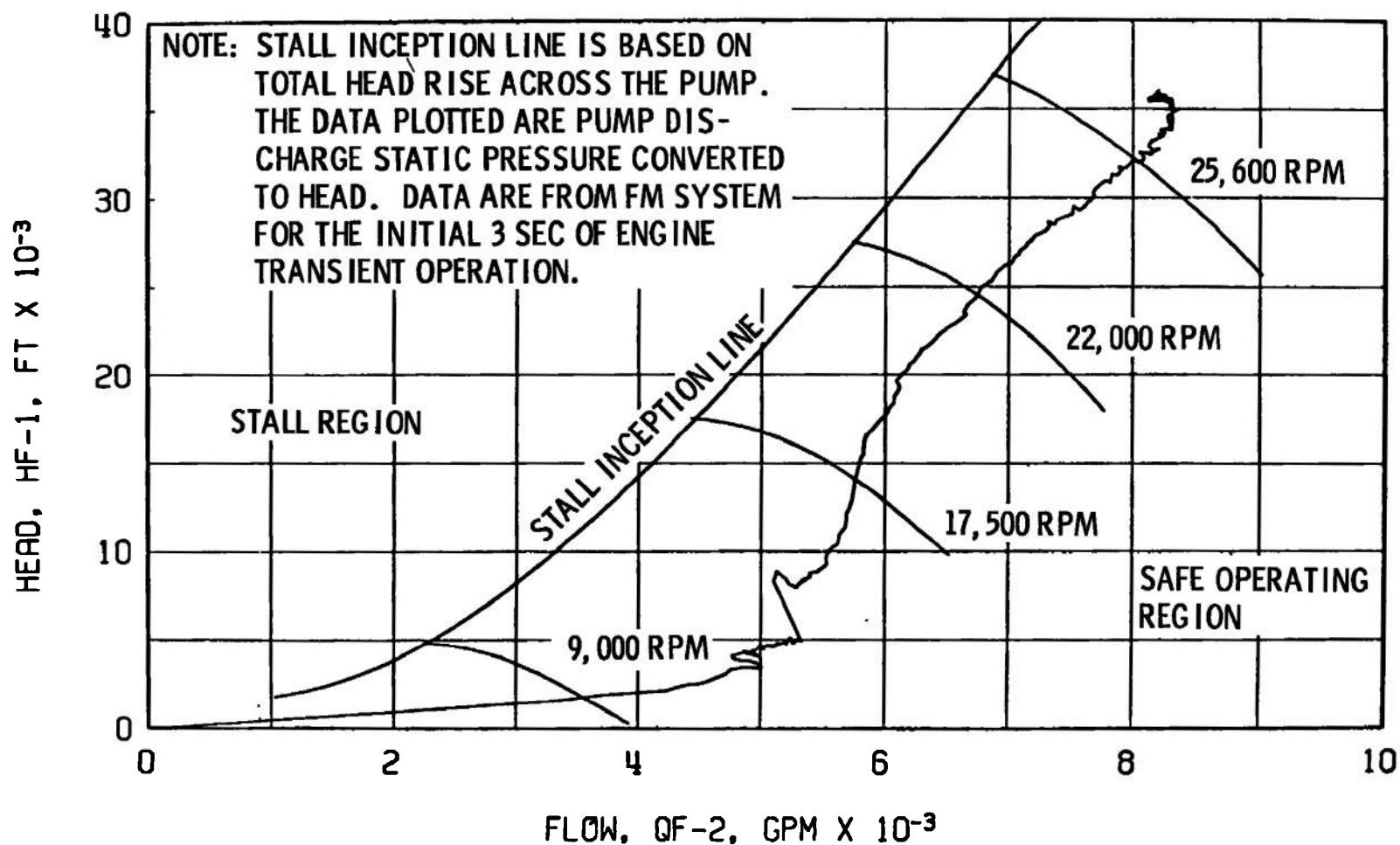
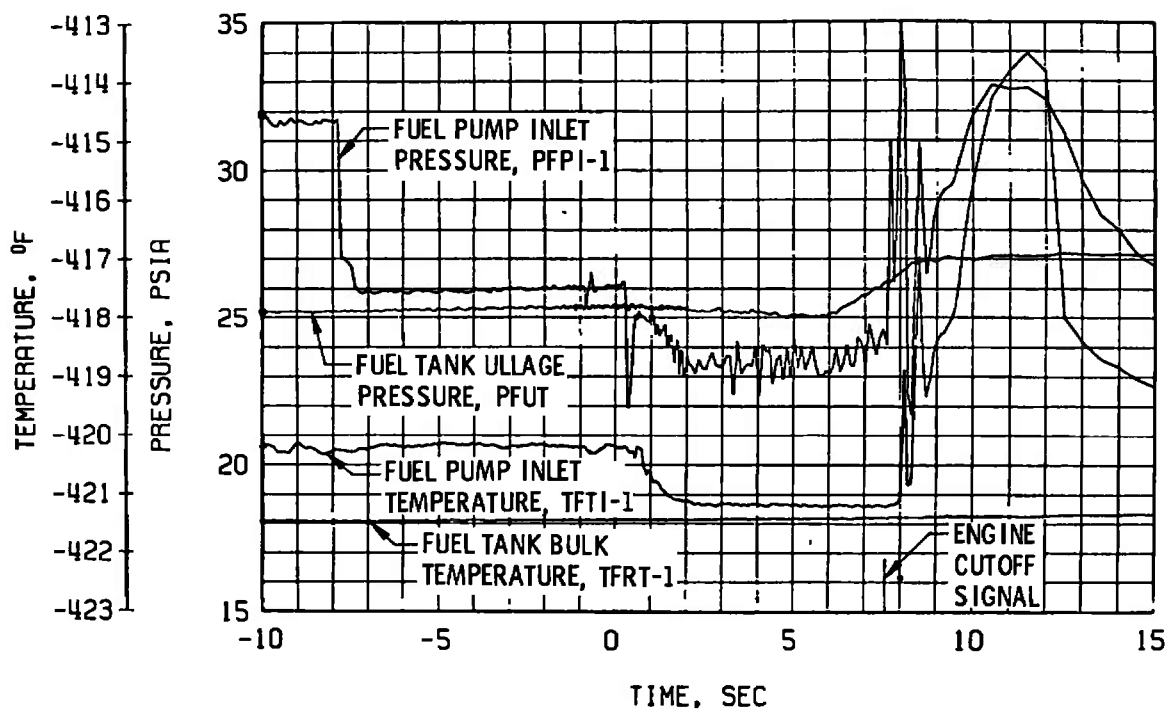
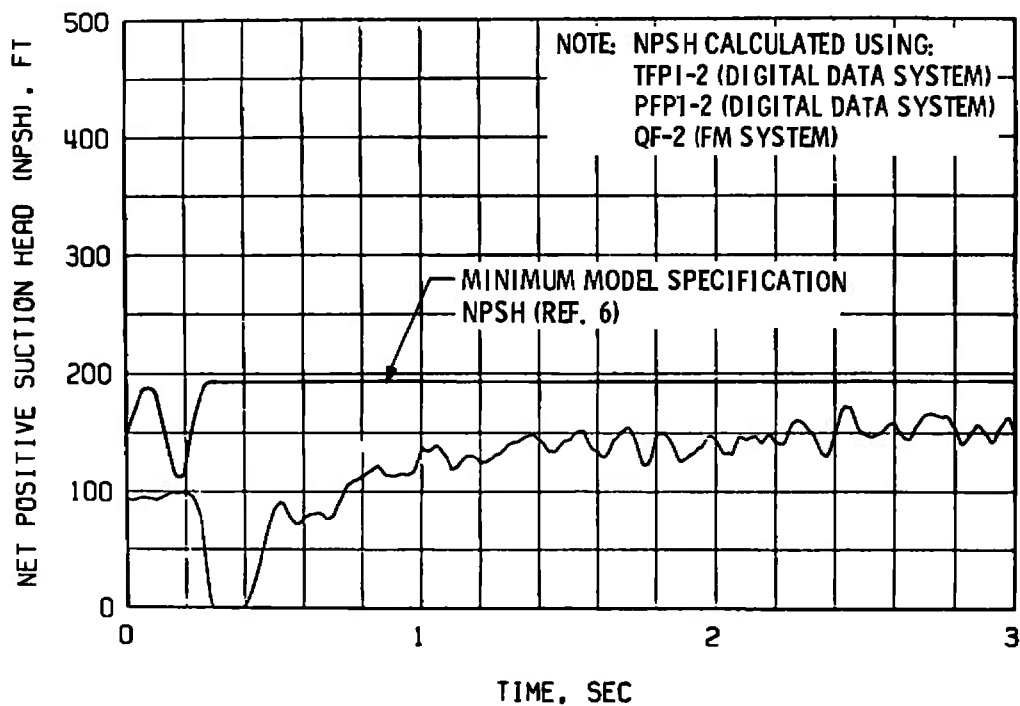


Fig. 43 Fuel Pump Start Transient Performance, Firing 43B

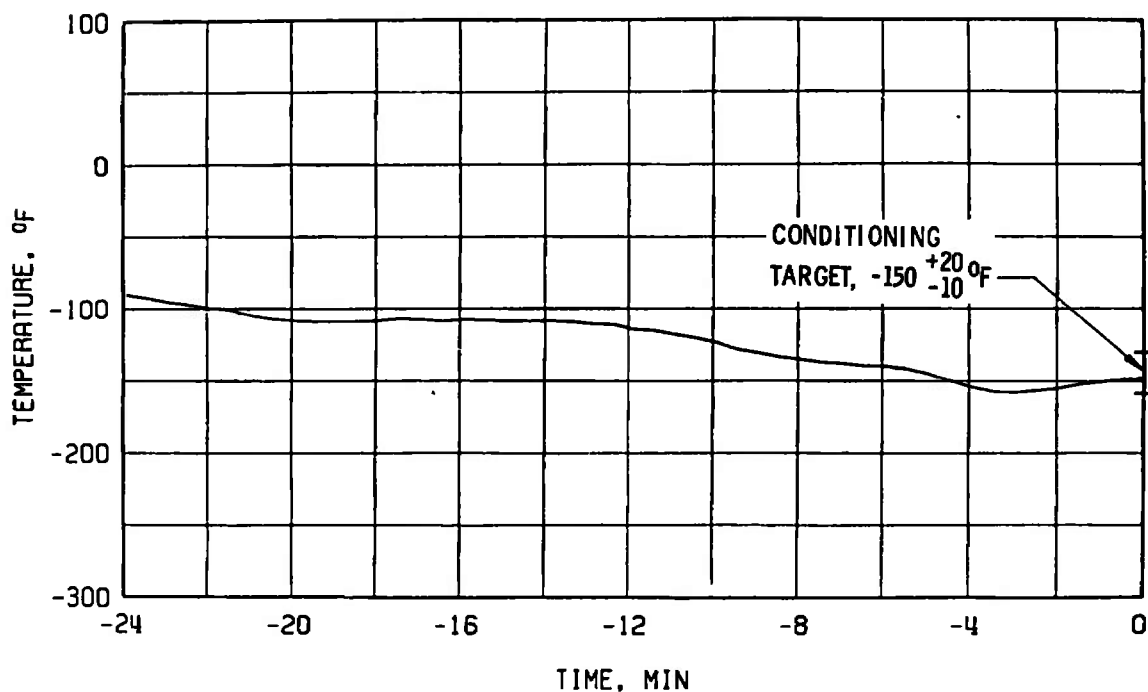


a. Duct Pressure and Temperature Transients

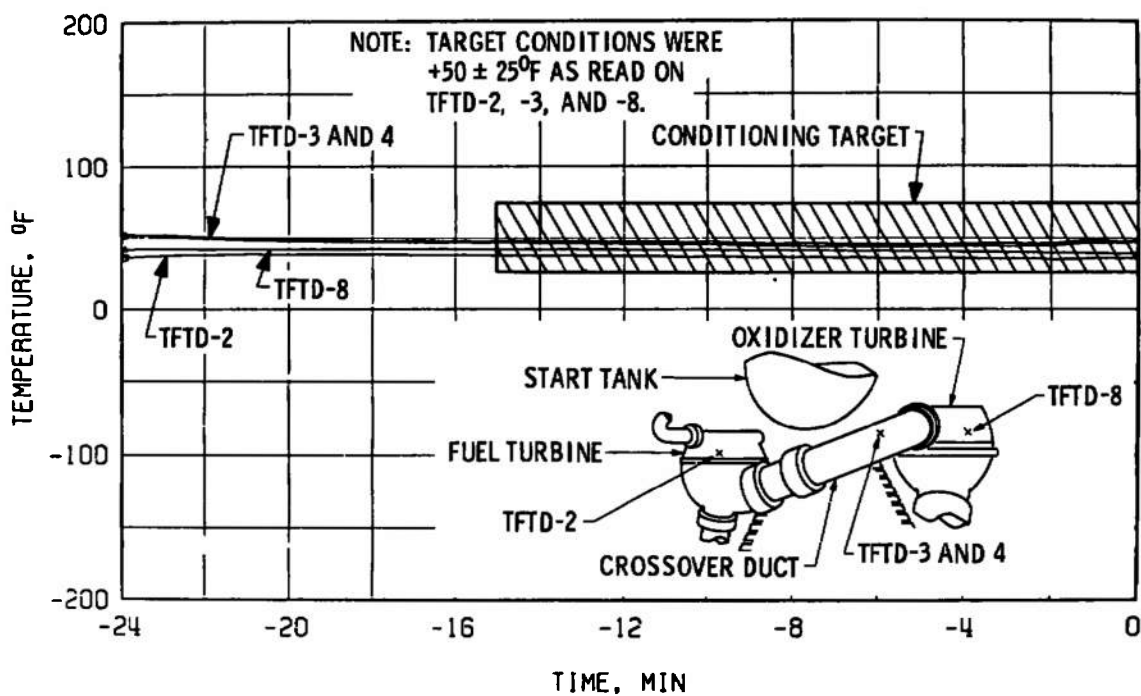


b. Fuel Pump NPSH during Start Transient, Firing 43B

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

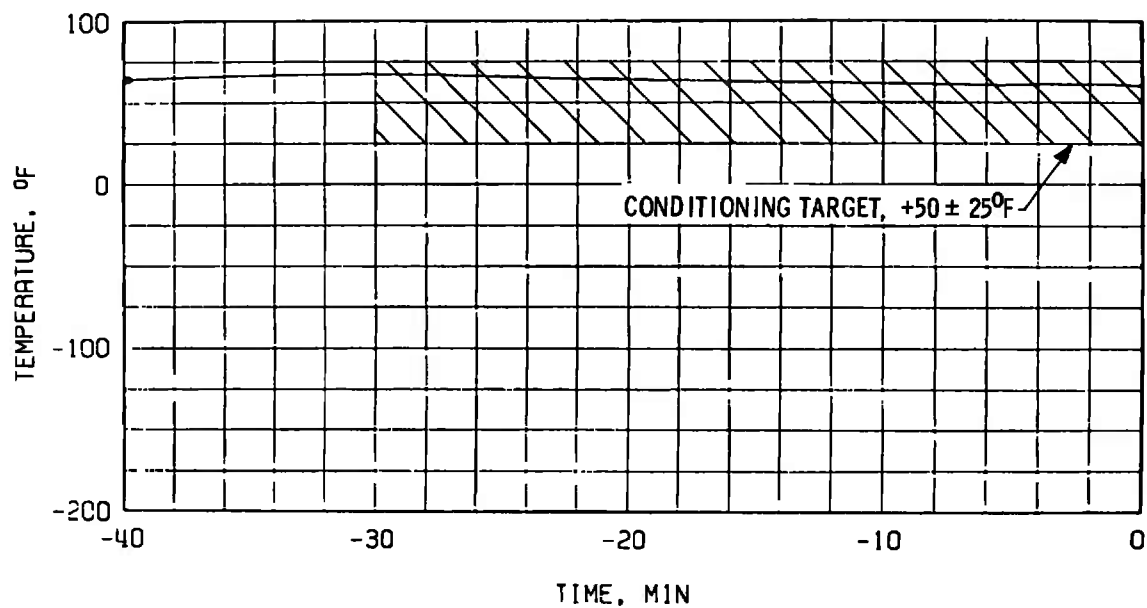


a. Thrust Chamber, TTC-1P

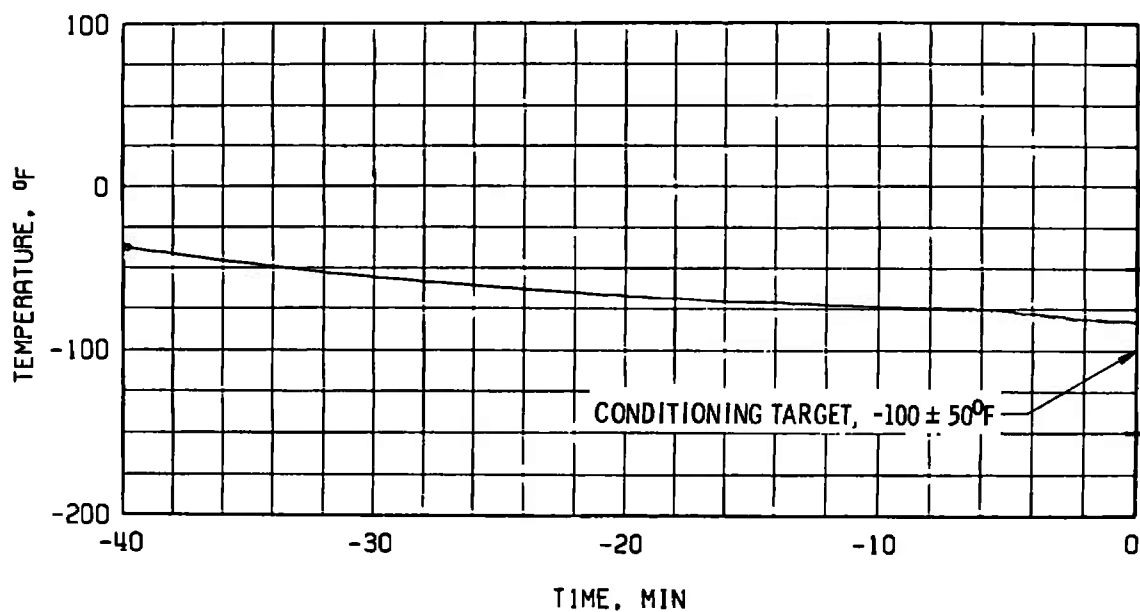


b. Crossover Duct, TTFD

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

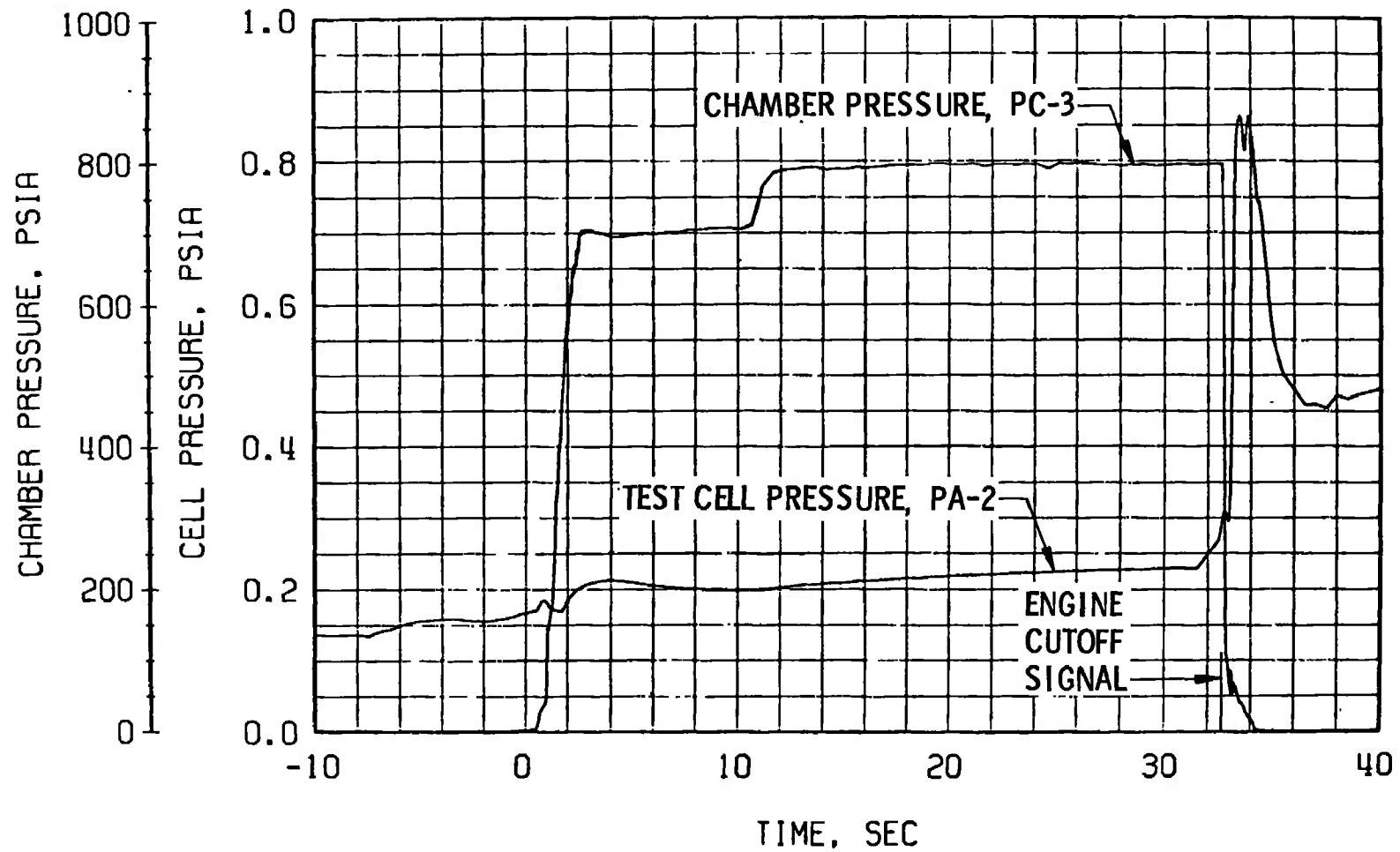
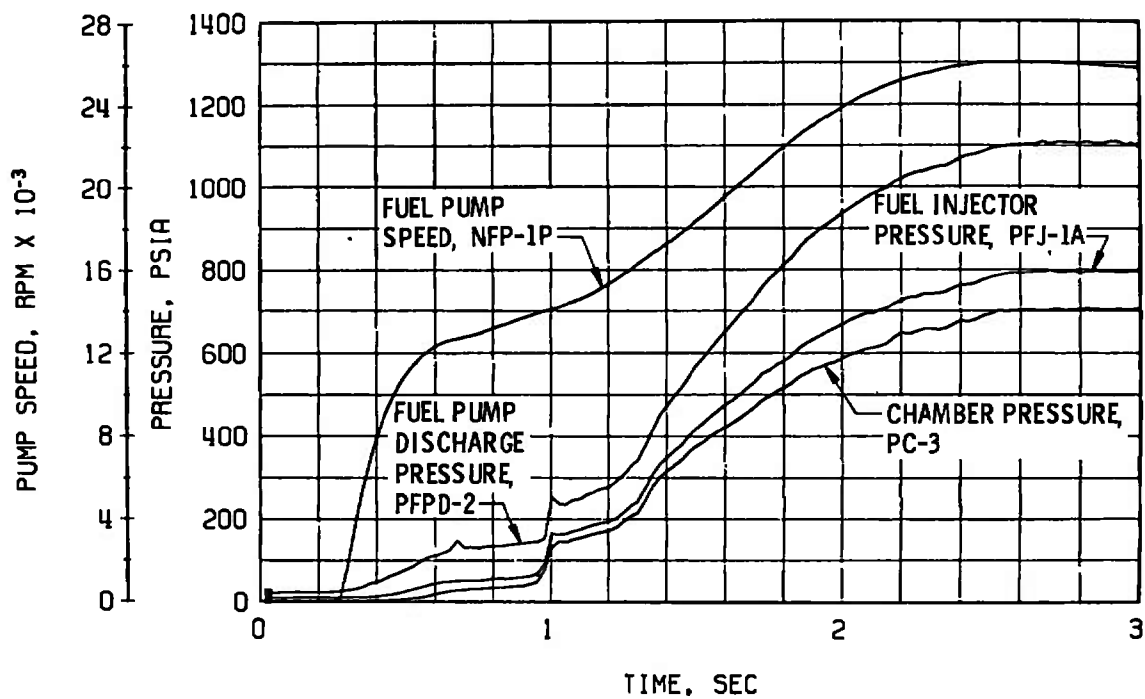
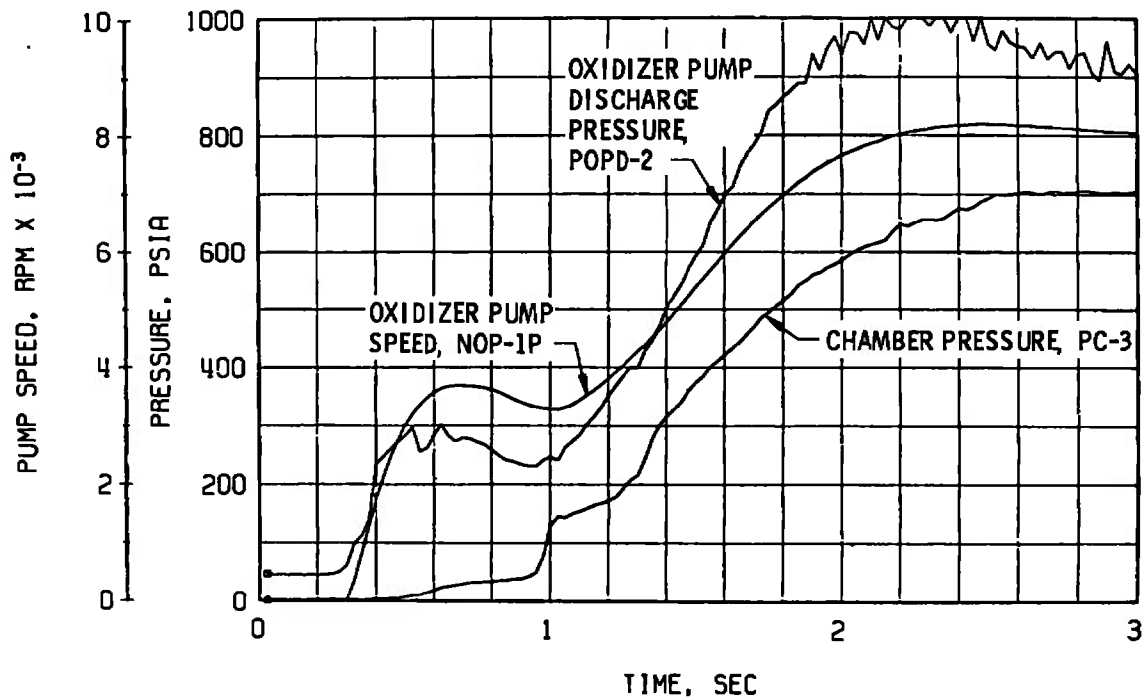


Fig. 46 Engine Ambient and Combustion Chamber Pressures, Firing 01A

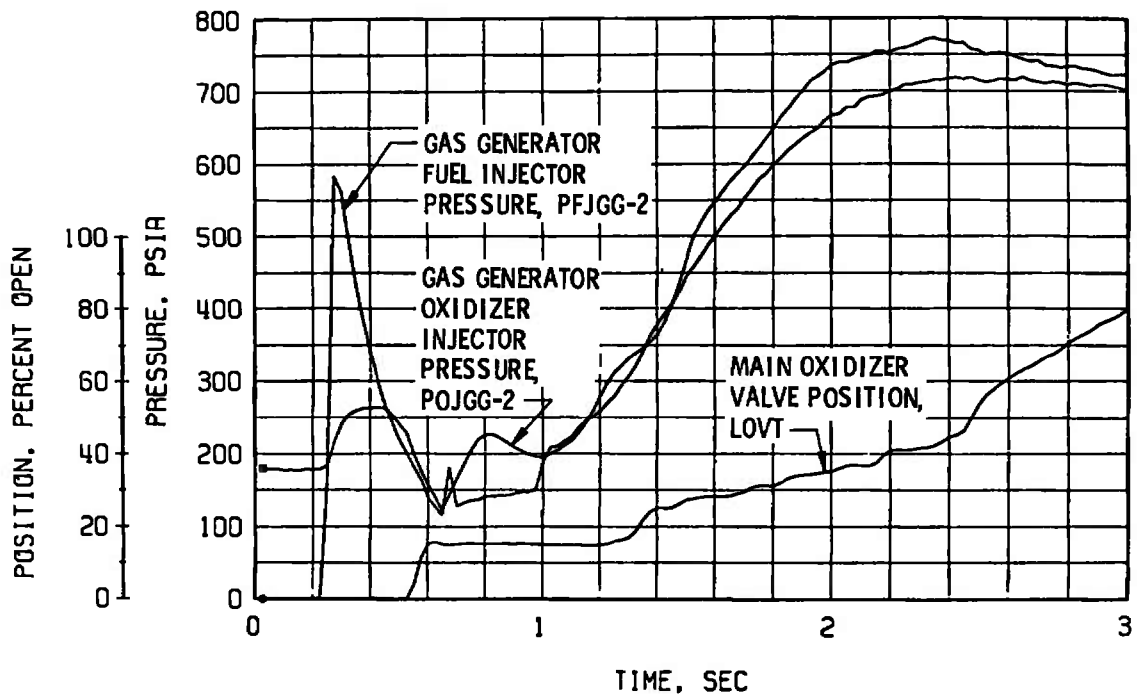


a. Thrust Chamber Fuel System, Start

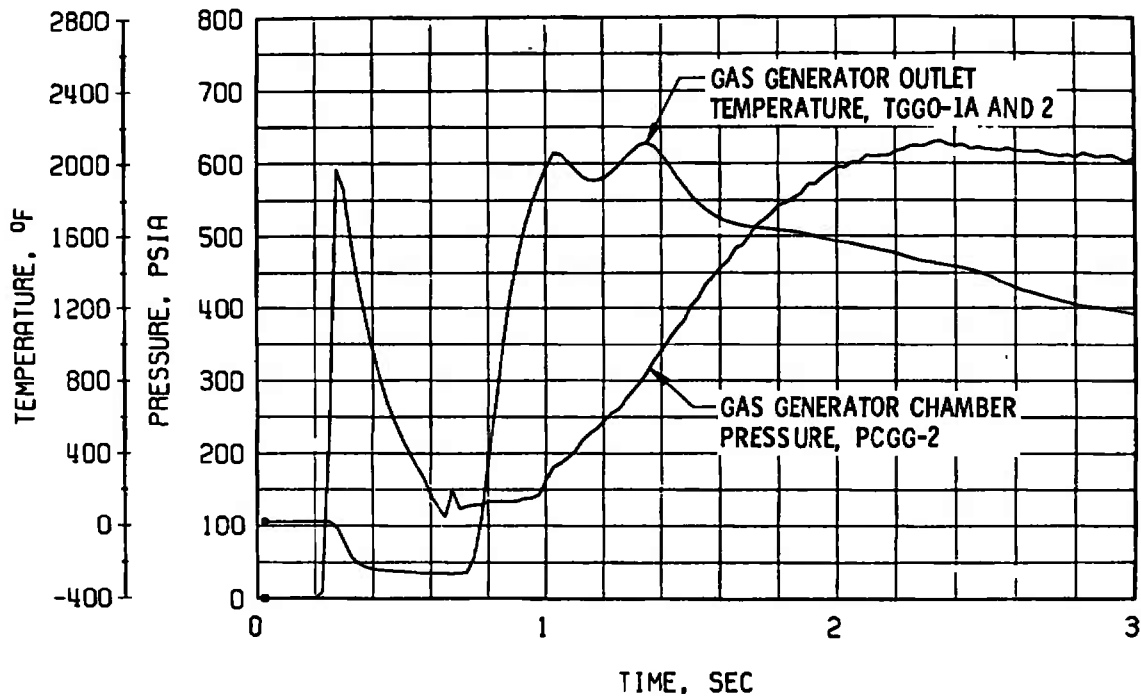


b. Thrust Chamber Oxidizer System, Start

Fig. 47 Engine Transient Operation, Firing 01A

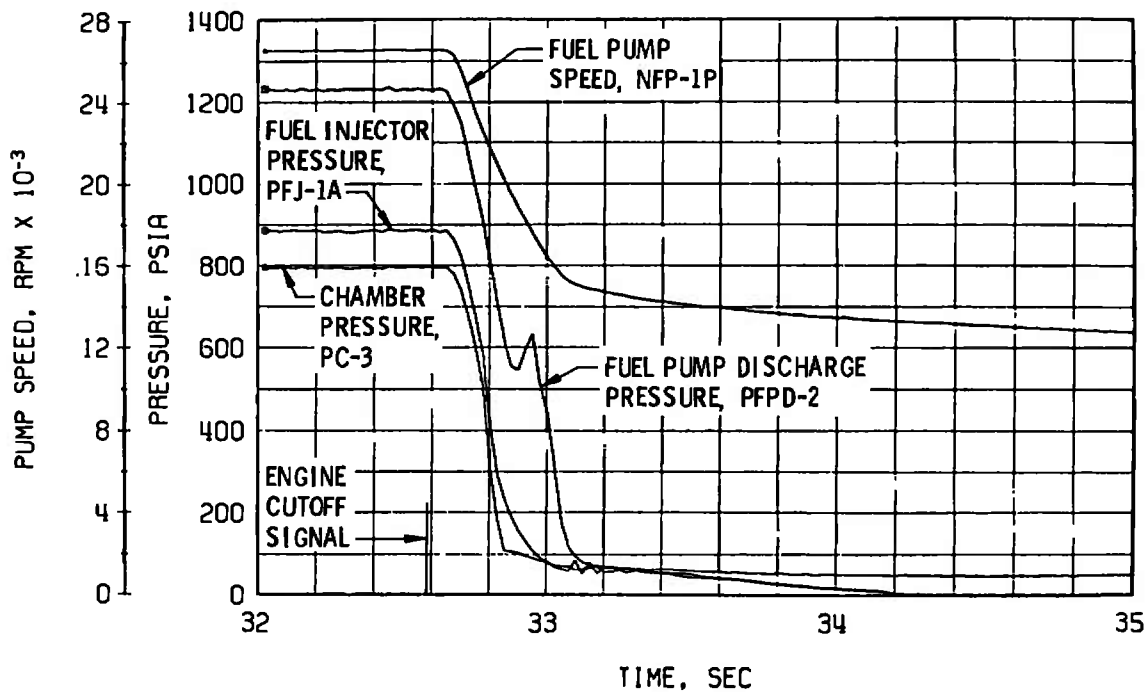


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

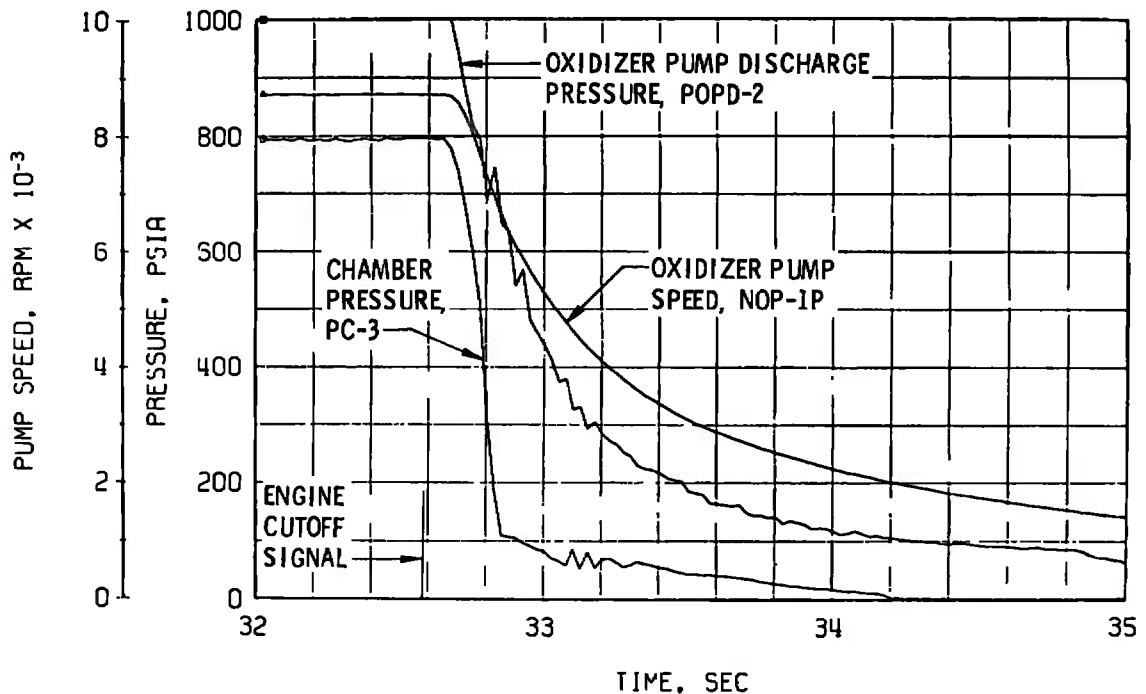


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 47 Continued



e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 47 Continued

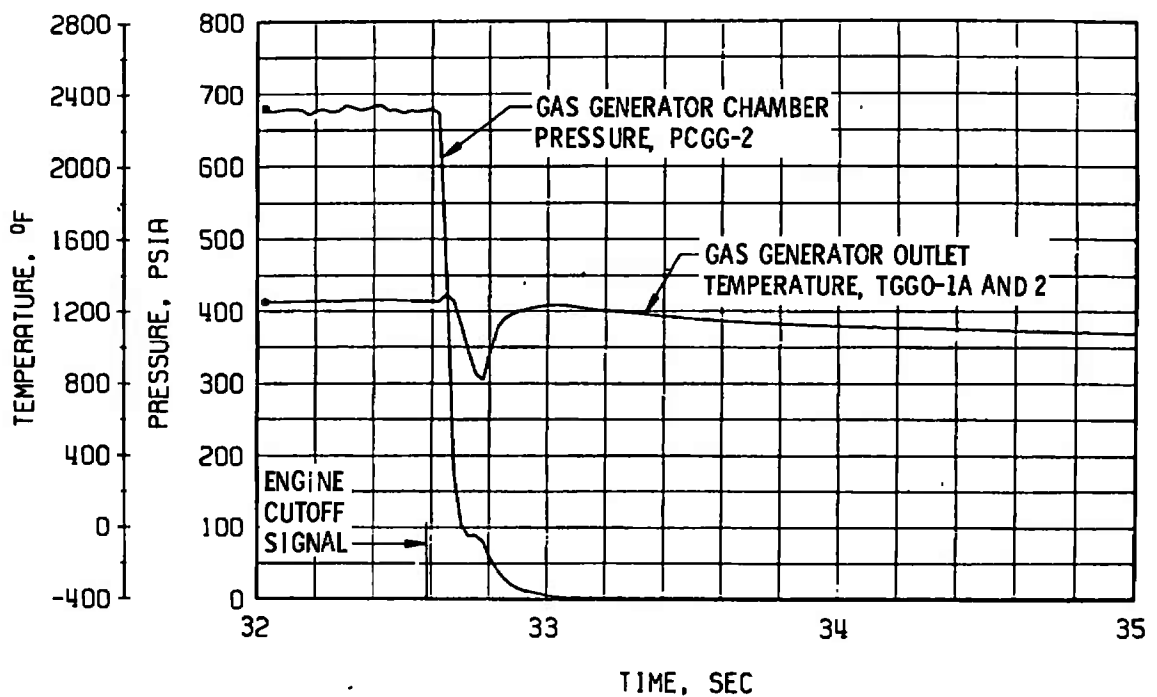
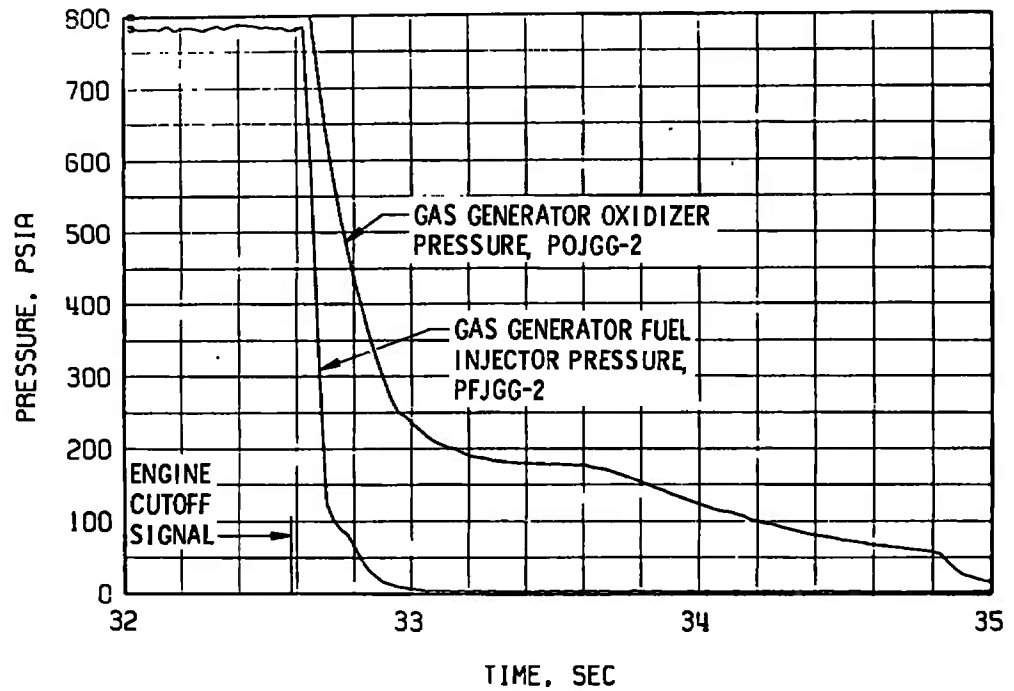


Fig. 47 Concluded

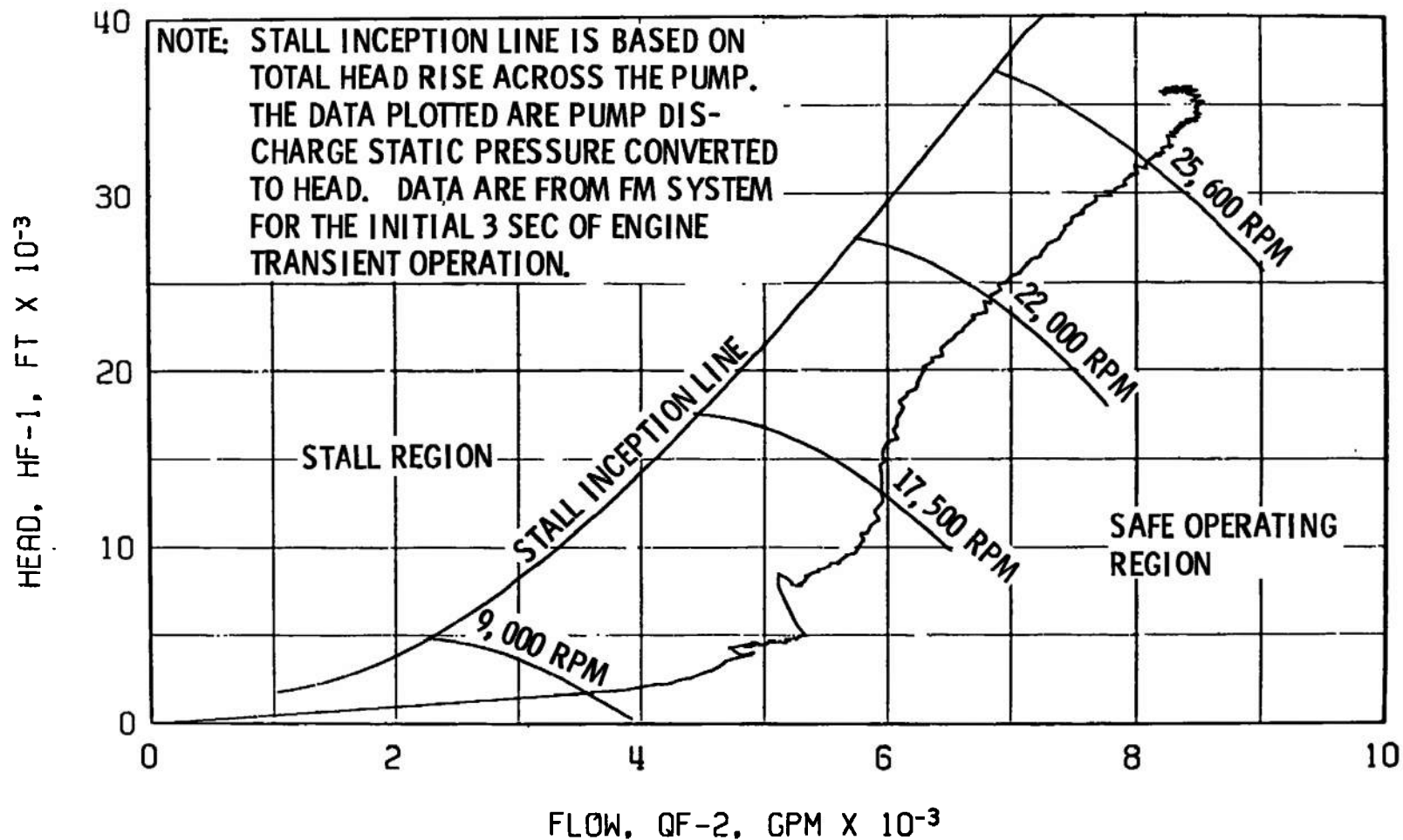
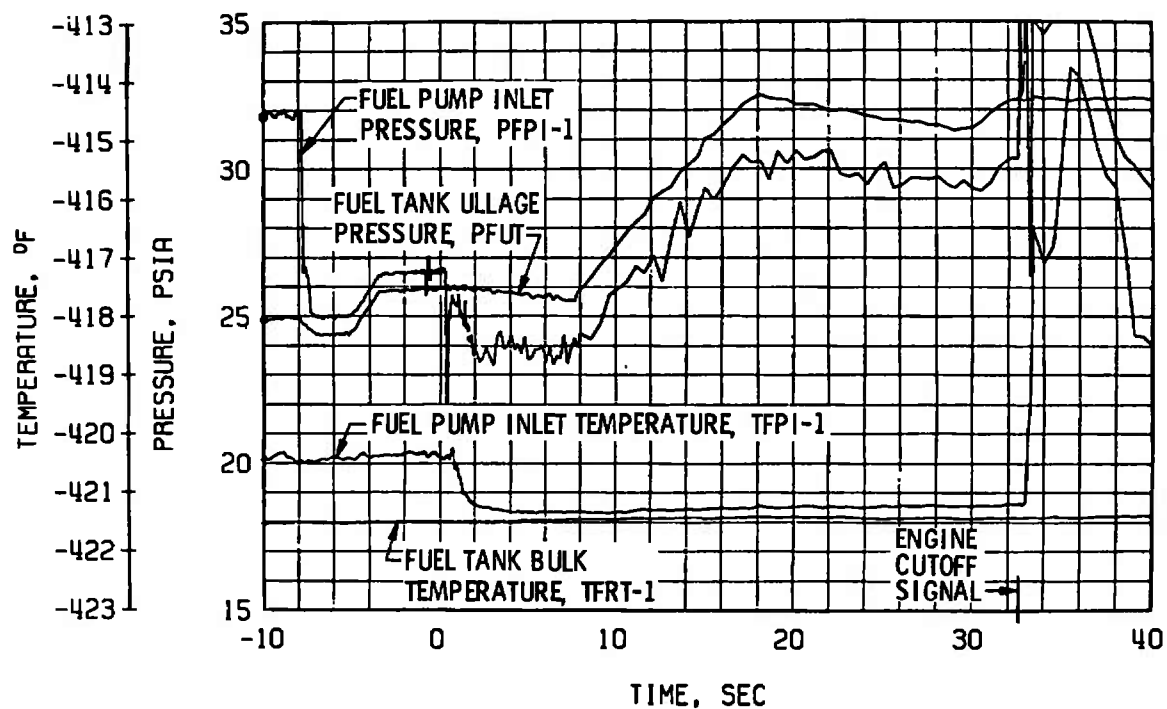
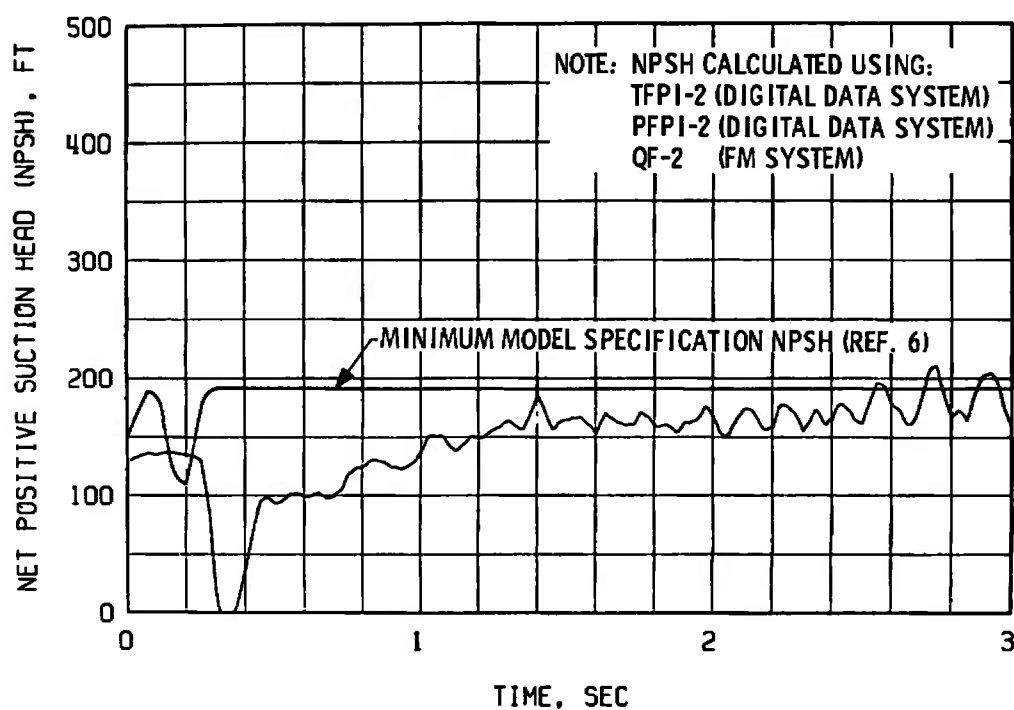


Fig. 48 Fuel Pump Start Transient Performance, Firing 01A

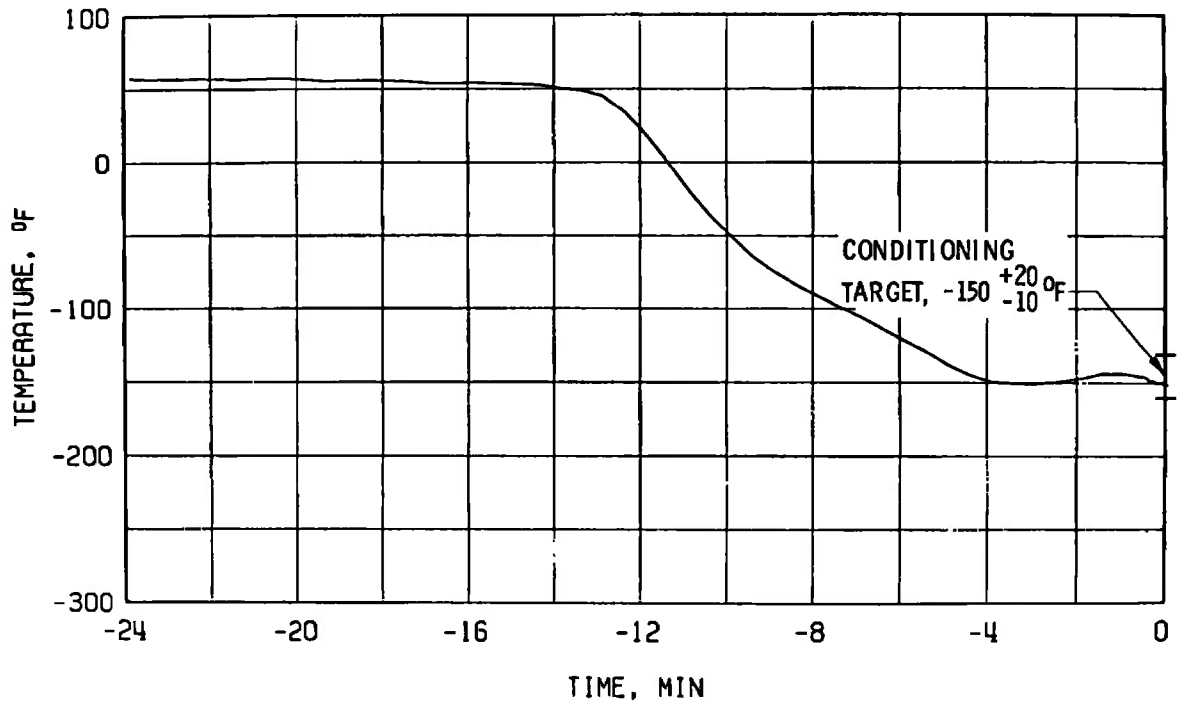


a. Duct Pressure and Temperature Transients

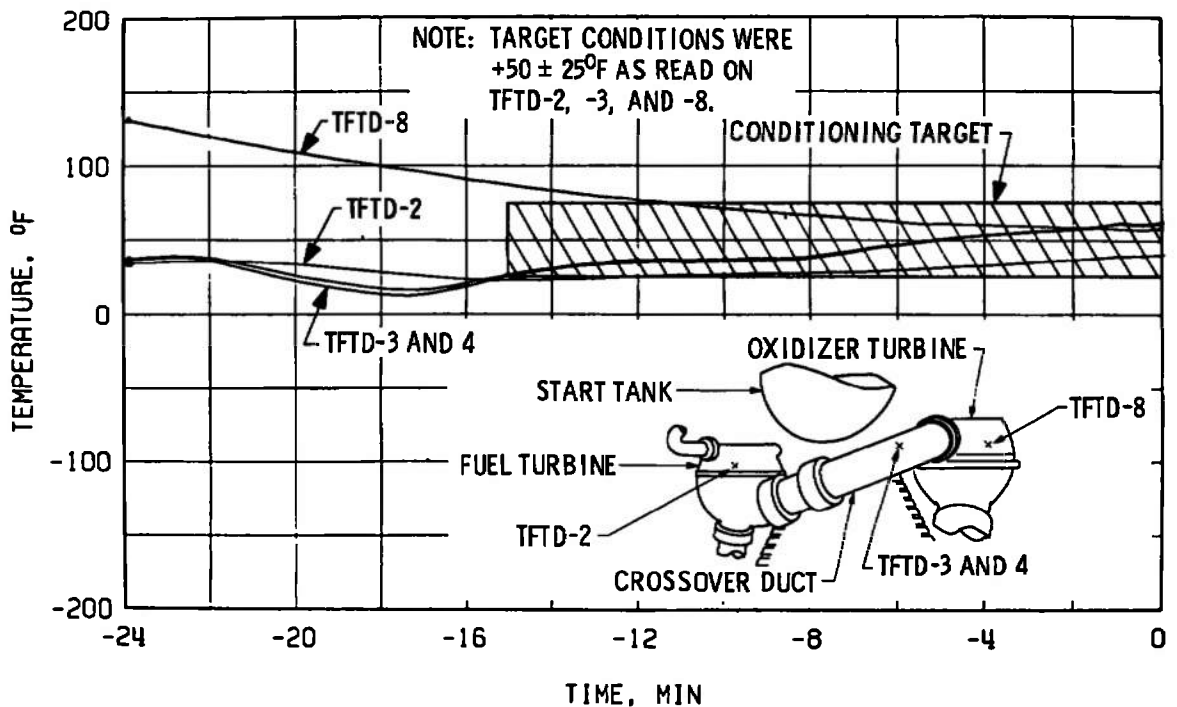


b. Fuel Pump NPSH during Start Transient, Firing 01A

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

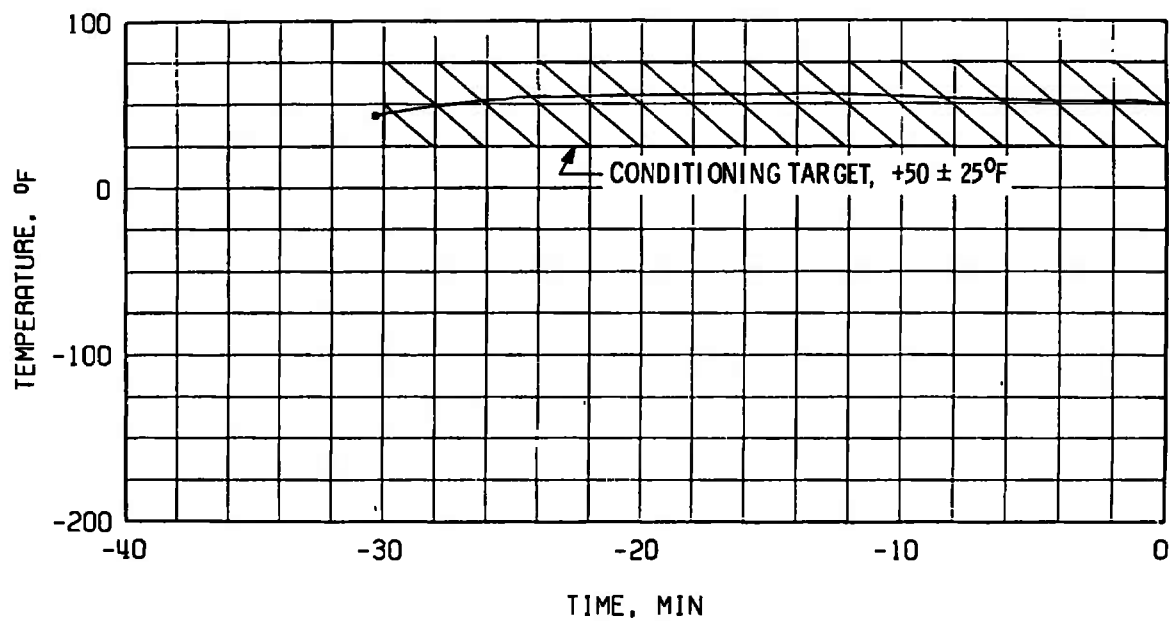


a. Thrust Chamber, TTC-1P

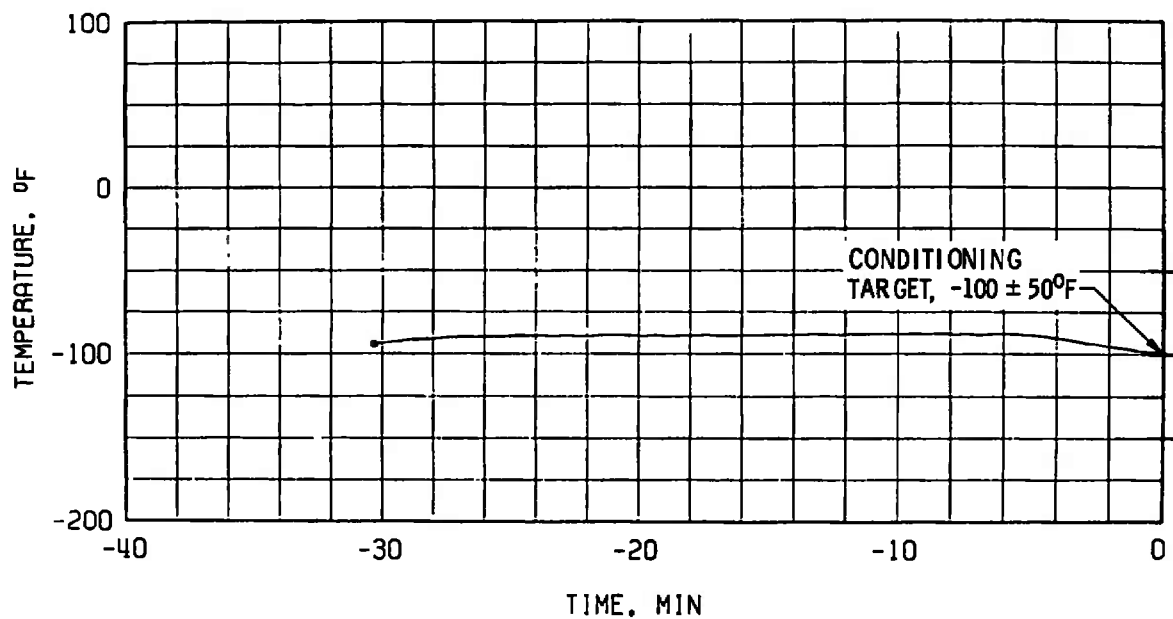


b. Crossover Duct, TFTD

Fig. 50 Thermol 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

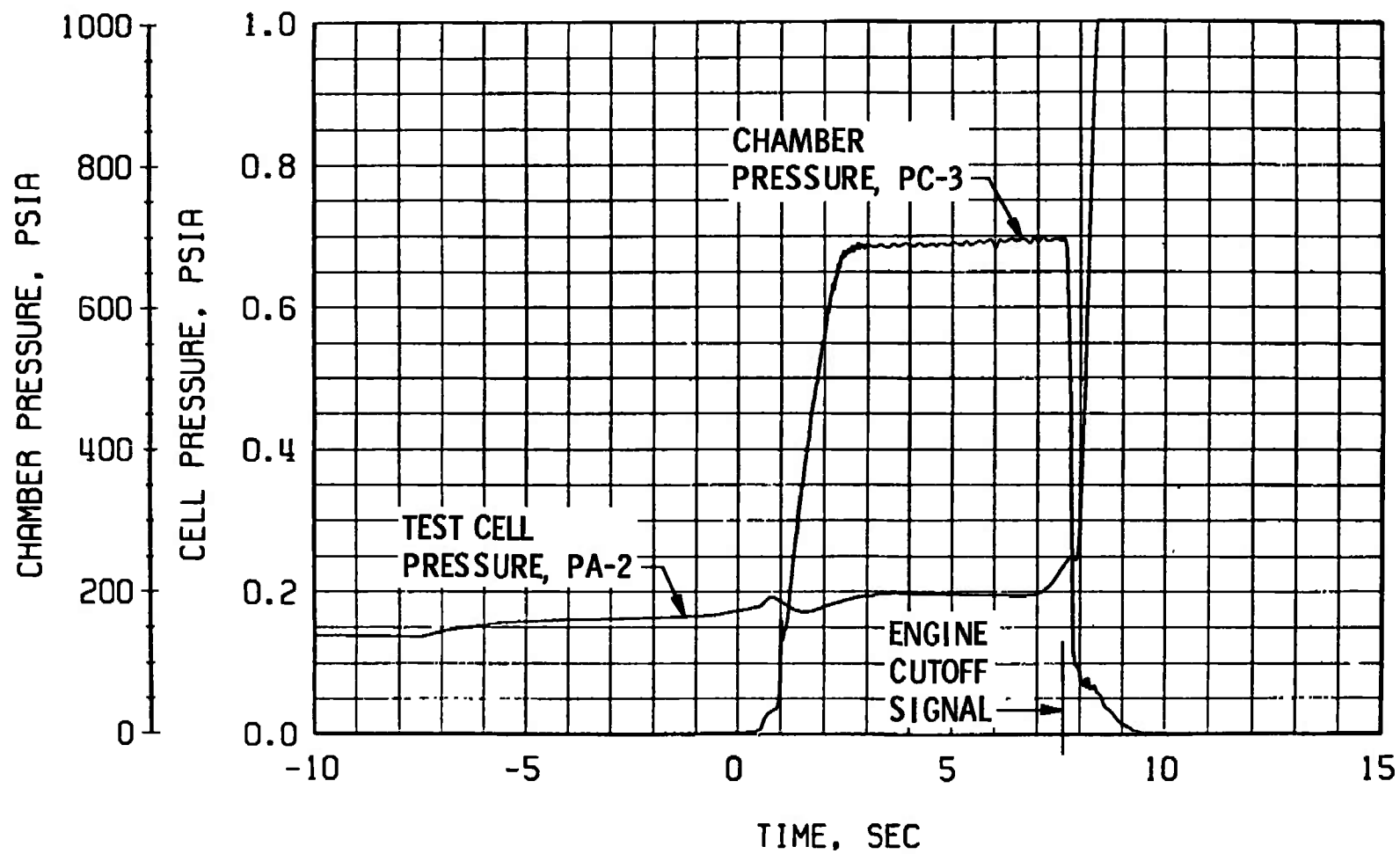
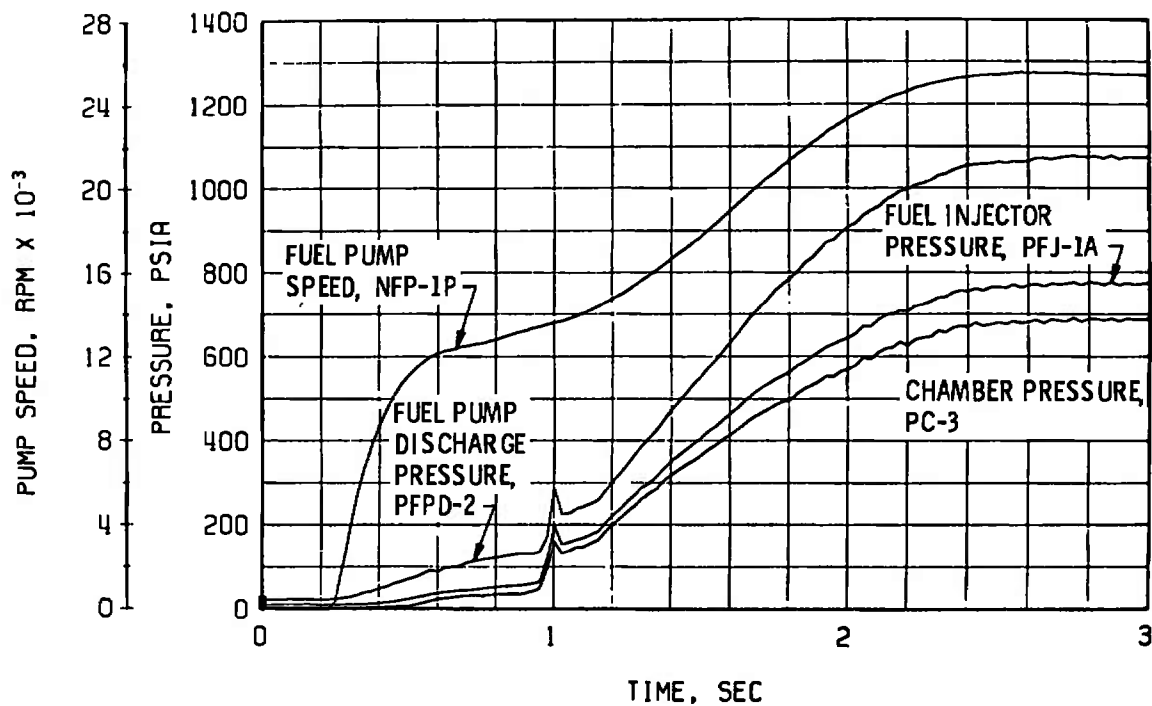
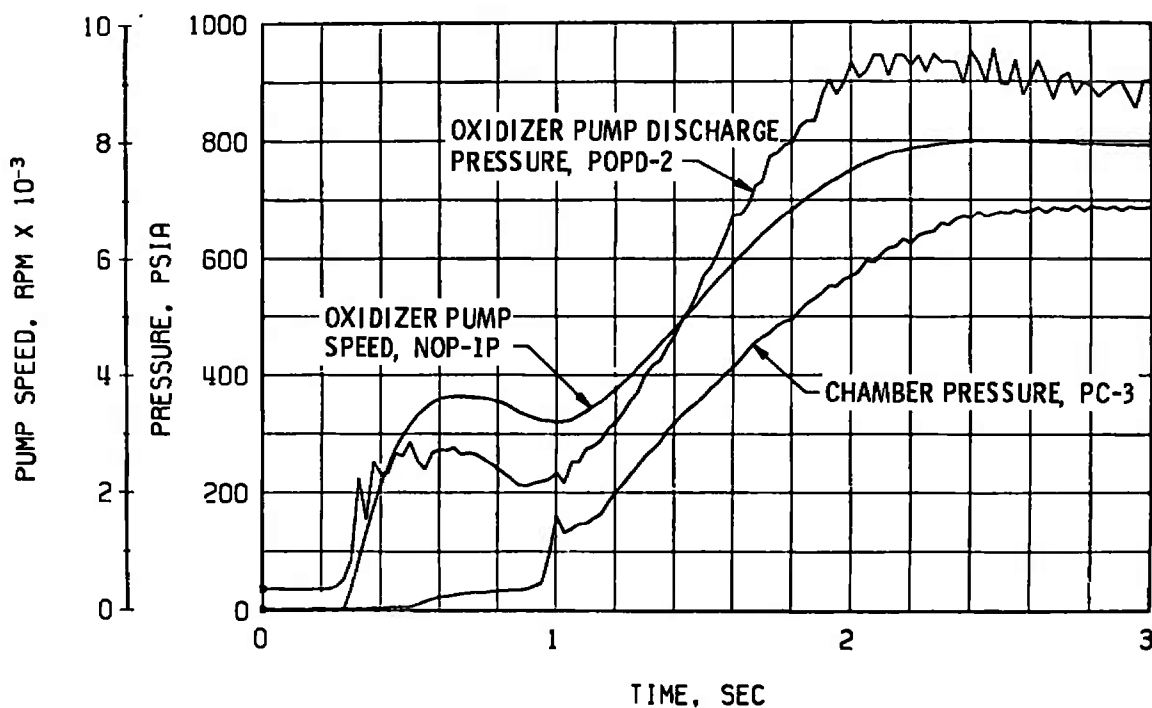


Fig. 51 Engine Ambient and Combustion Chamber Pressures, Firing 01B

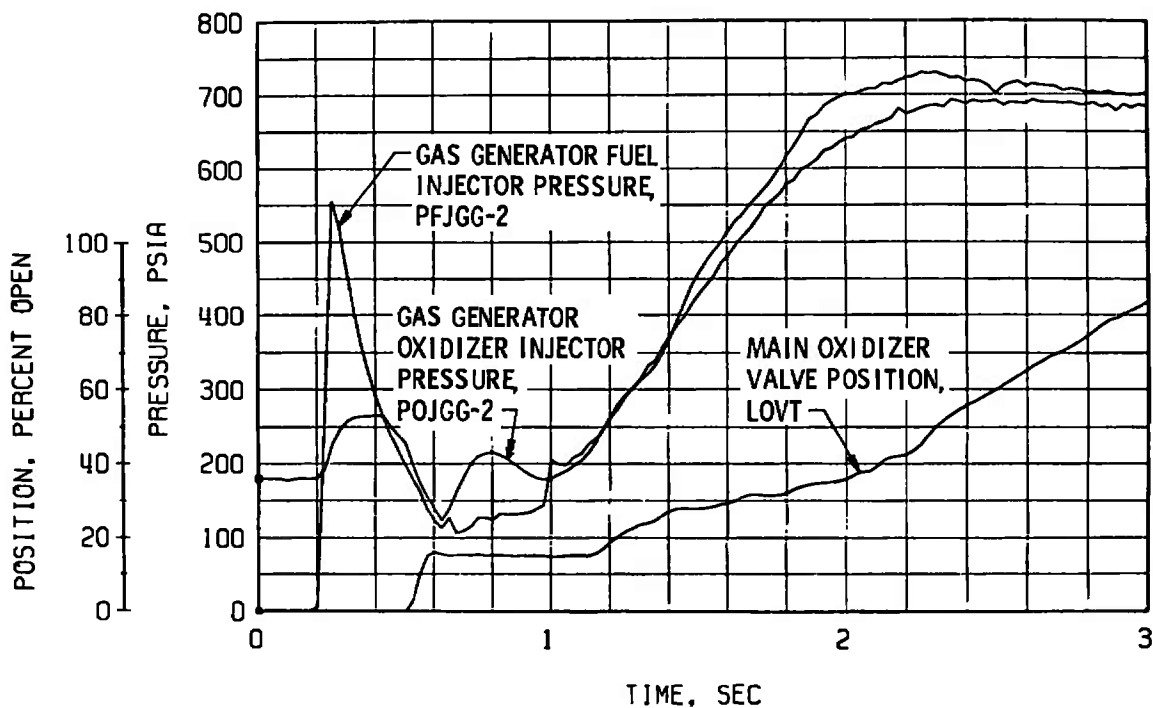


a. Thrust Chamber Fuel System, Start

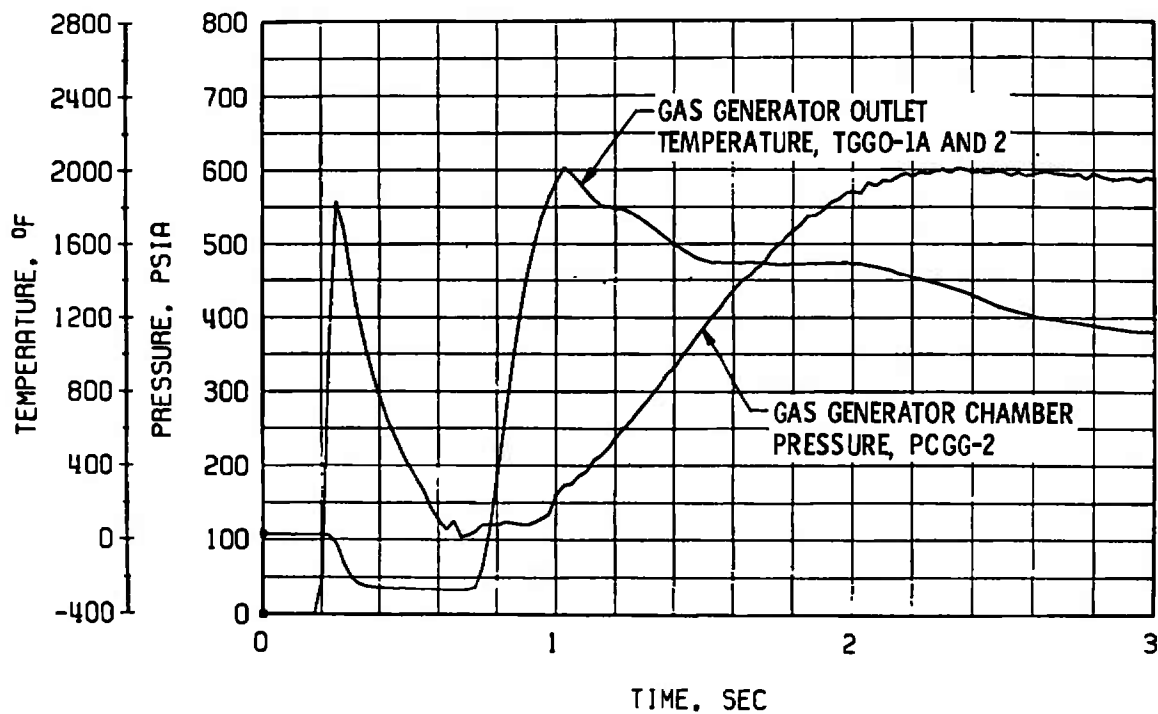


b. Thrust Chamber Oxidizer System, Start

Fig. 52 Engine Transient Operation, Firing 01B

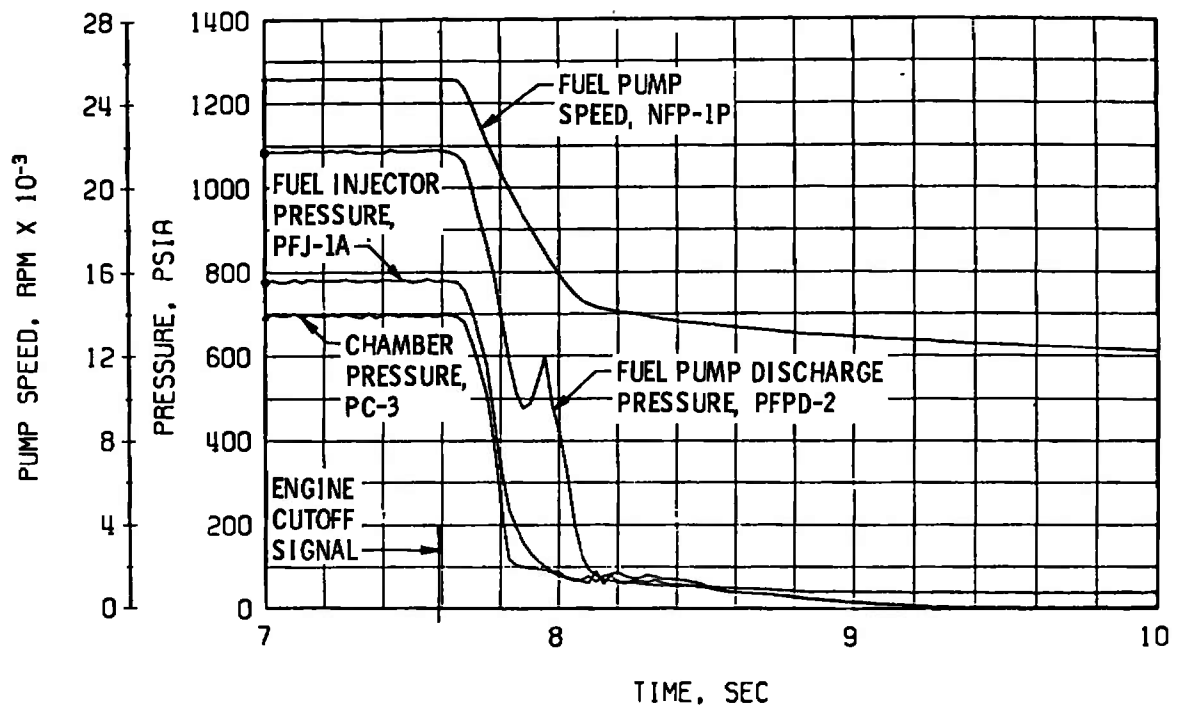


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

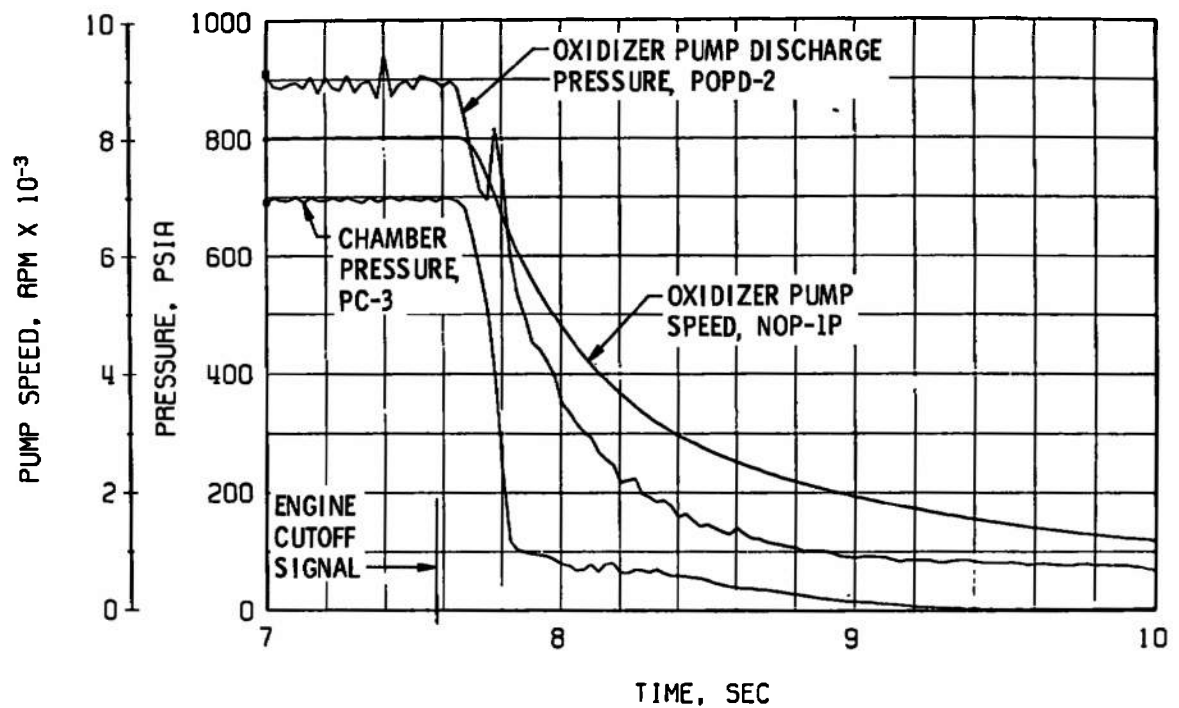


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 52 Continued

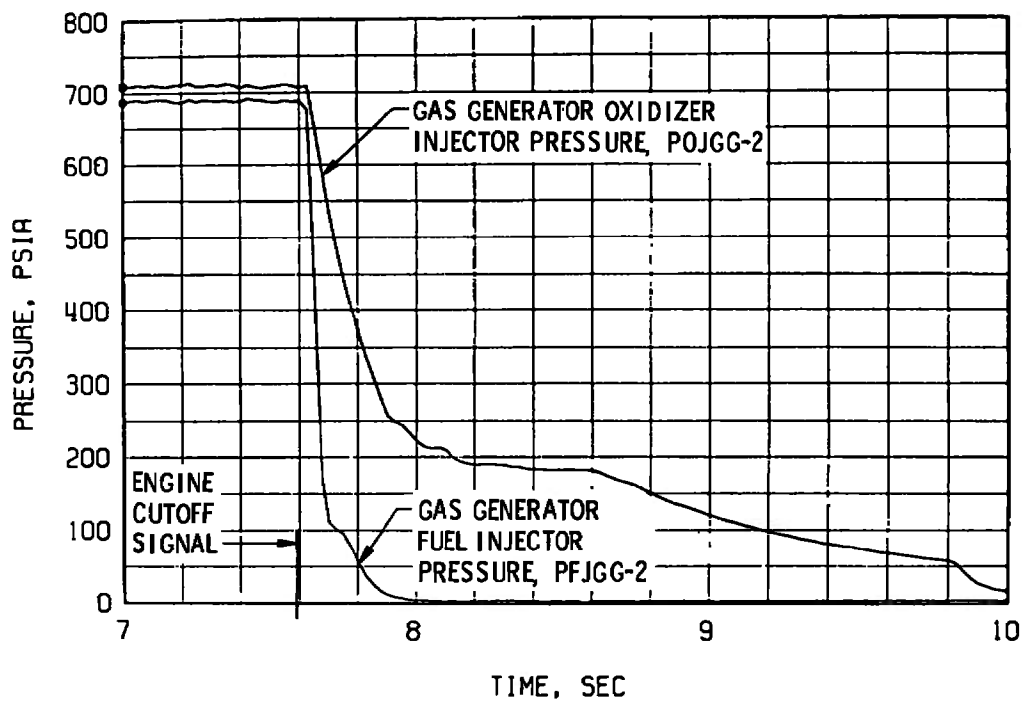


e. Thrust Chamber Fuel System, Shutdown

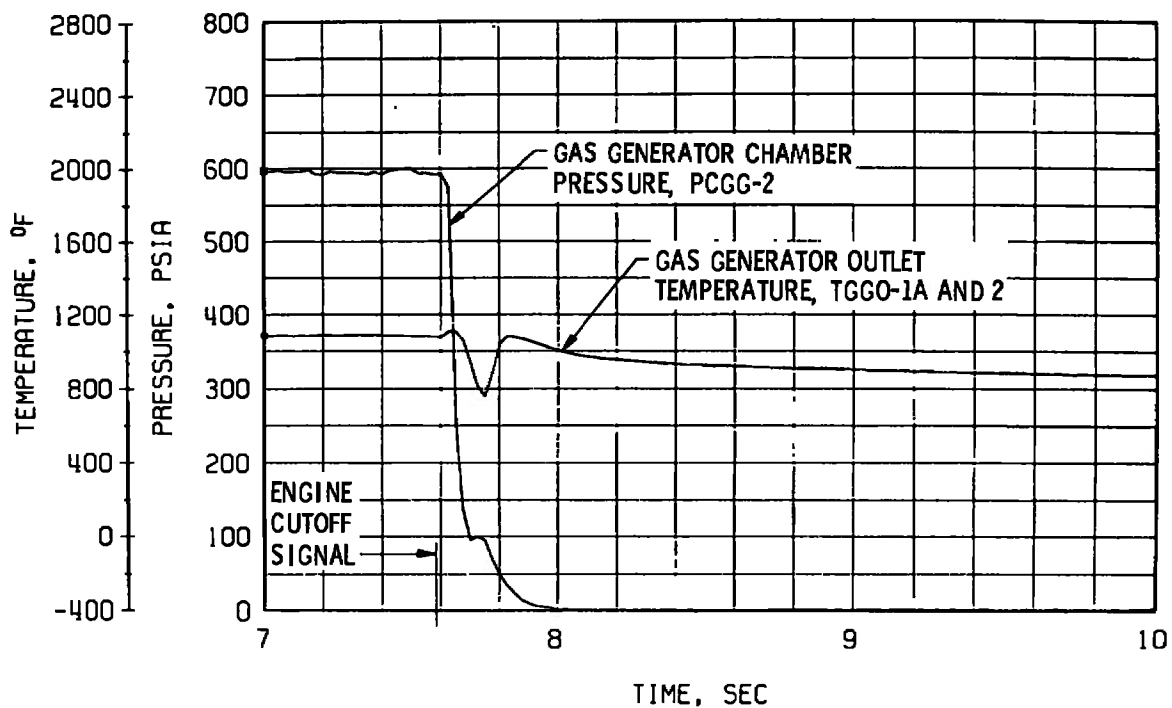


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 52 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 52 Concluded

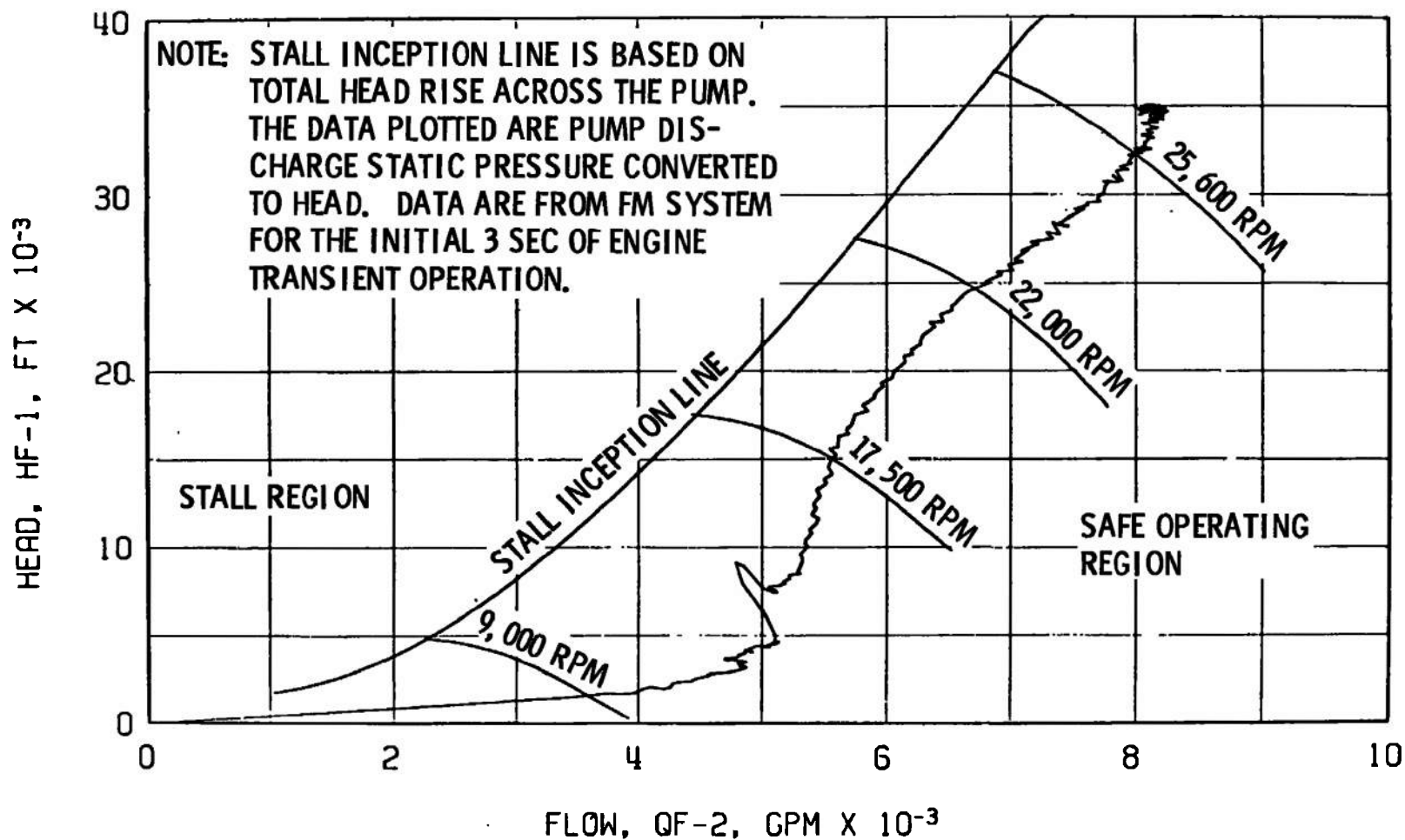
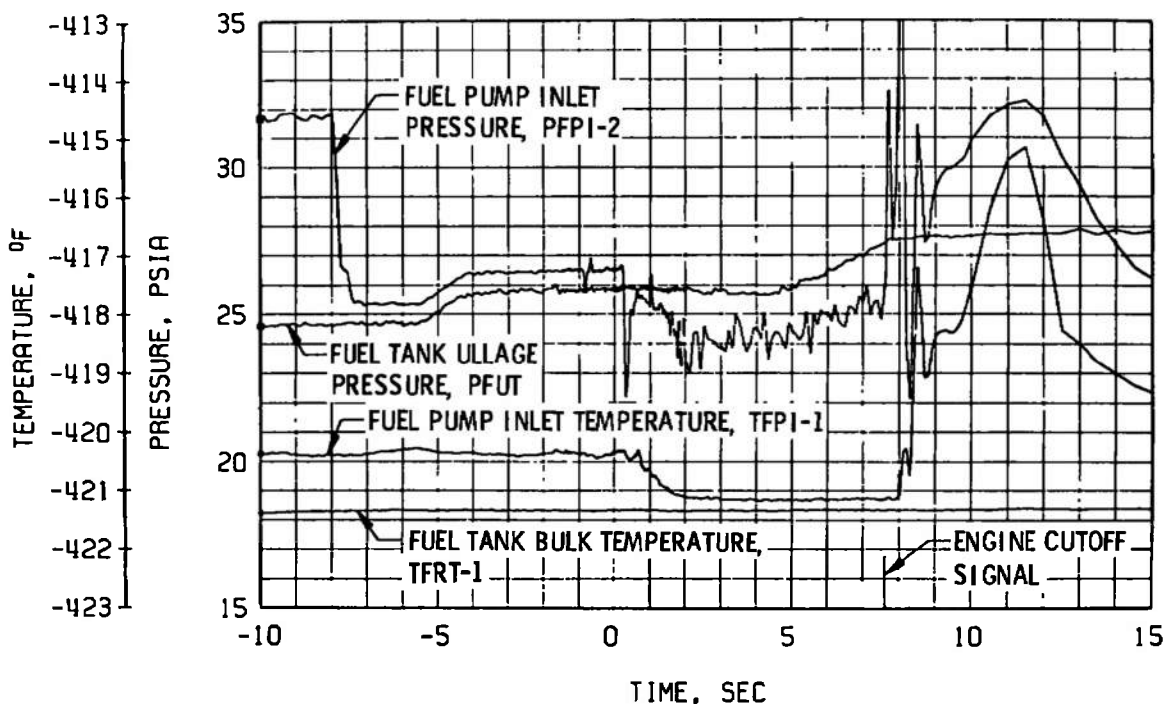
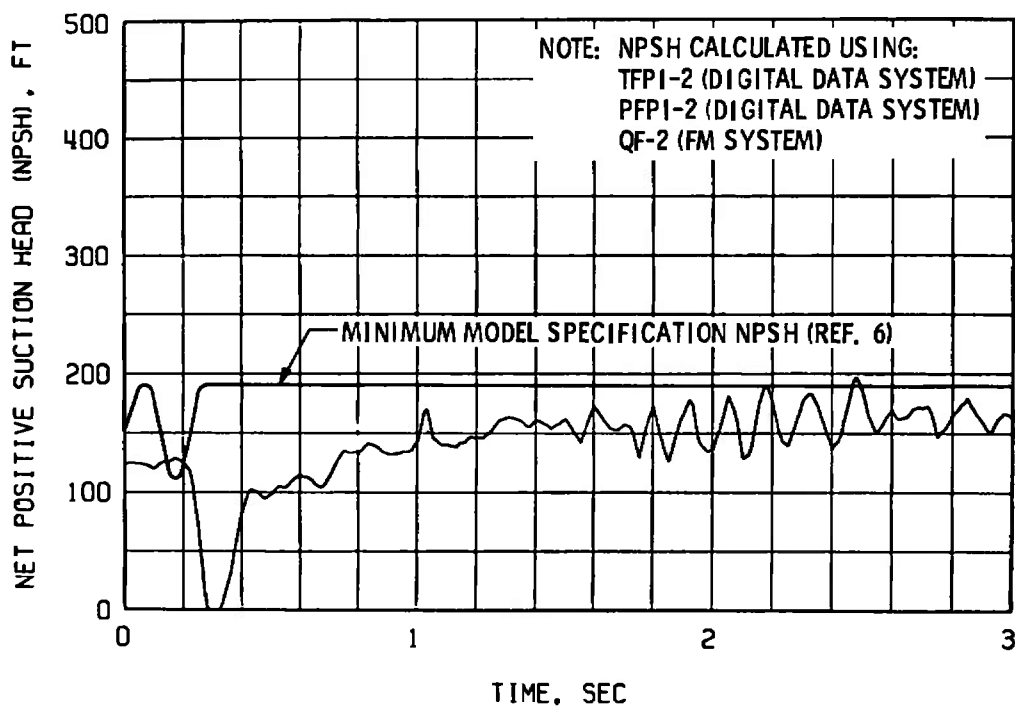


Fig. 53 Fuel Pump Start Transient Performance, Firing 01B

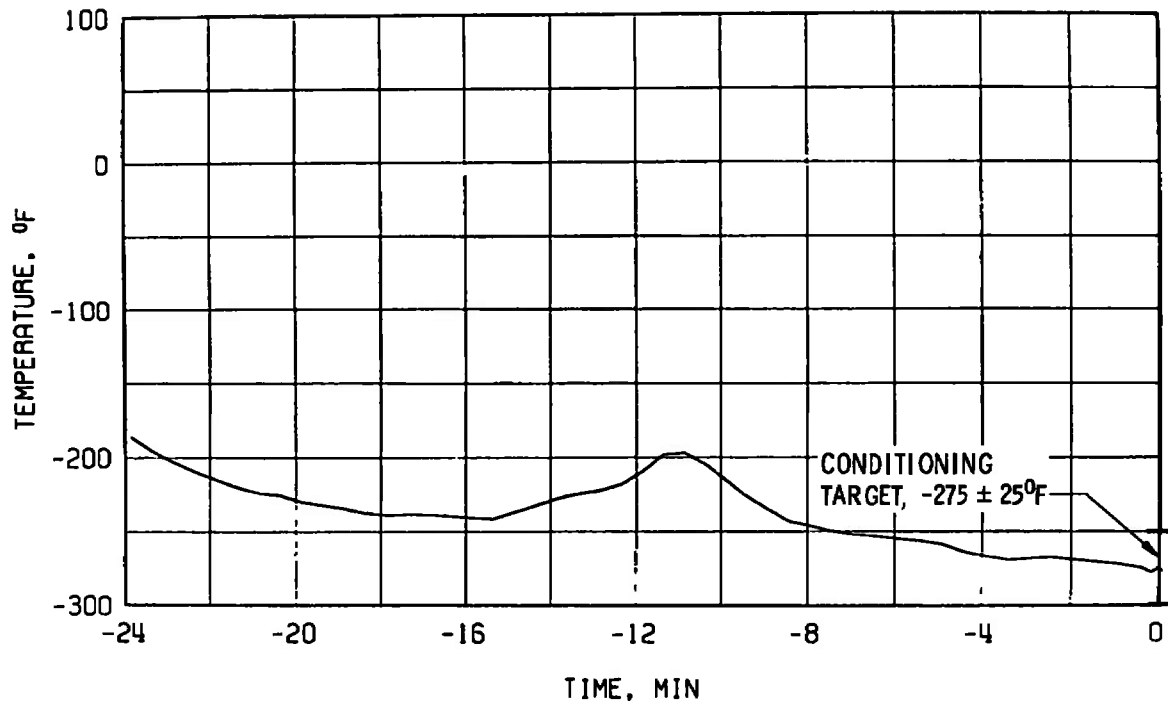


a. Duct Pressure and Temperature Transients

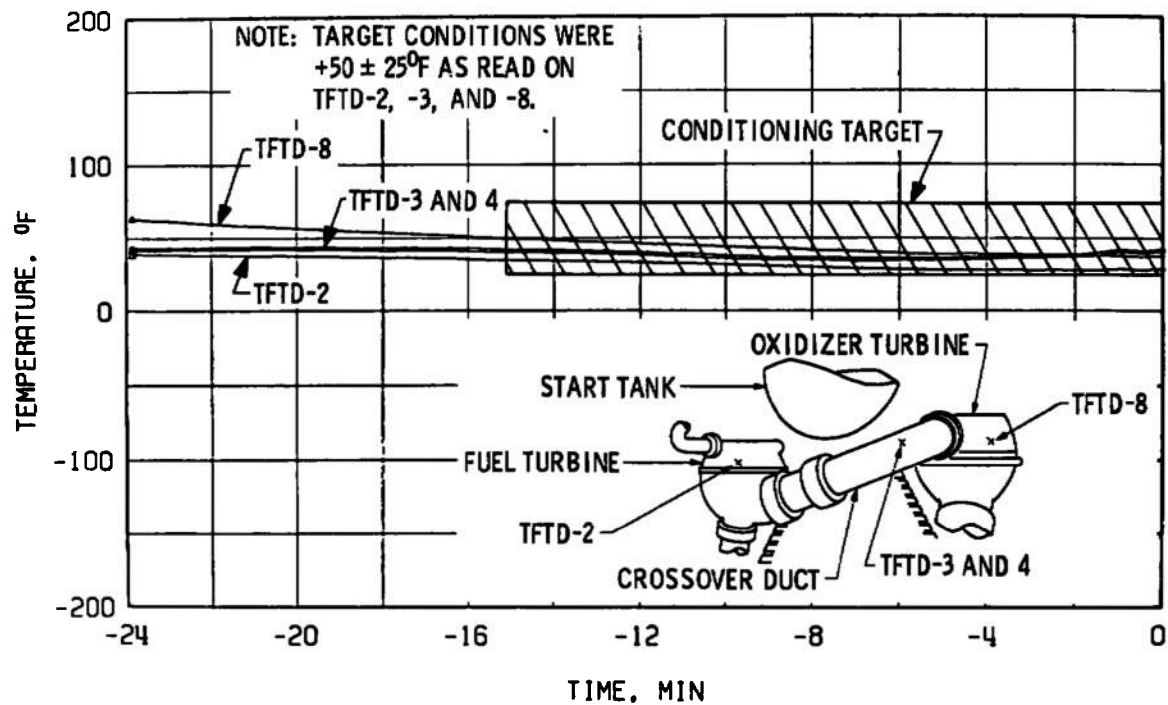


b. Fuel Pump NPSH during Start Transient, Firing 01B

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

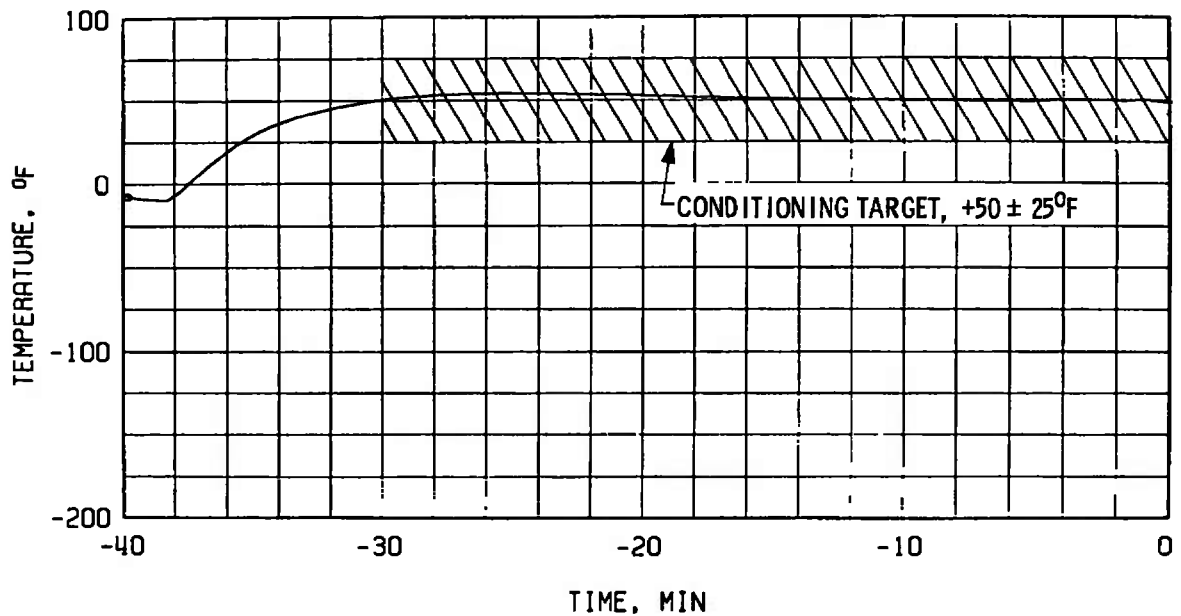


a. Thrust Chamber, TTC-1P

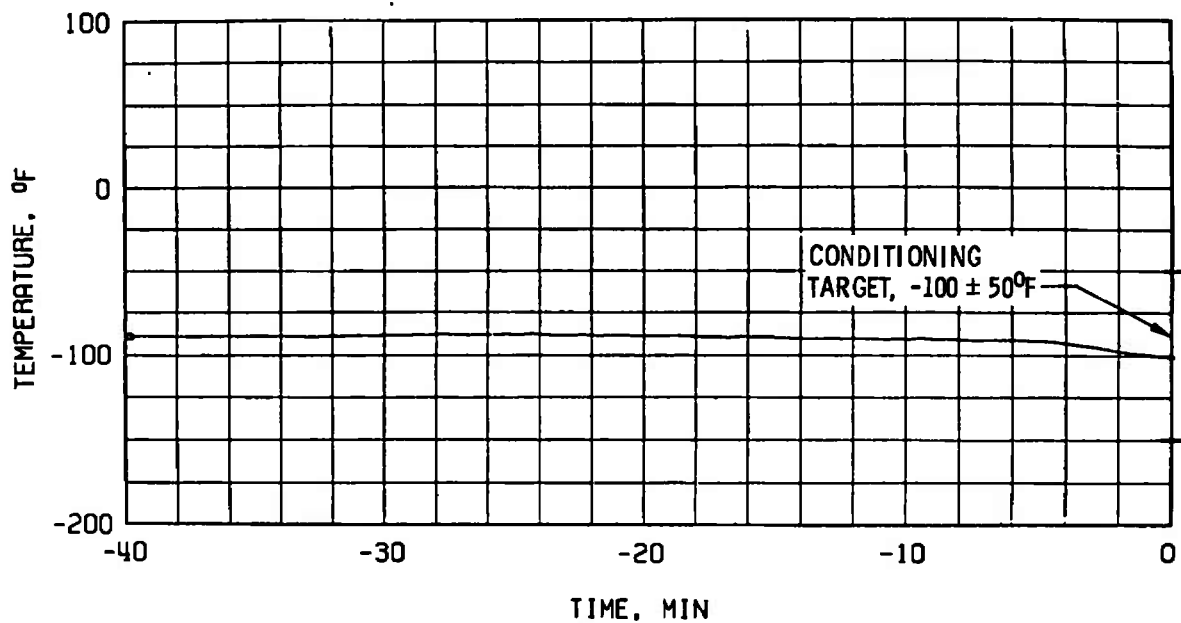


b. Crossover Duct, TFTD

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

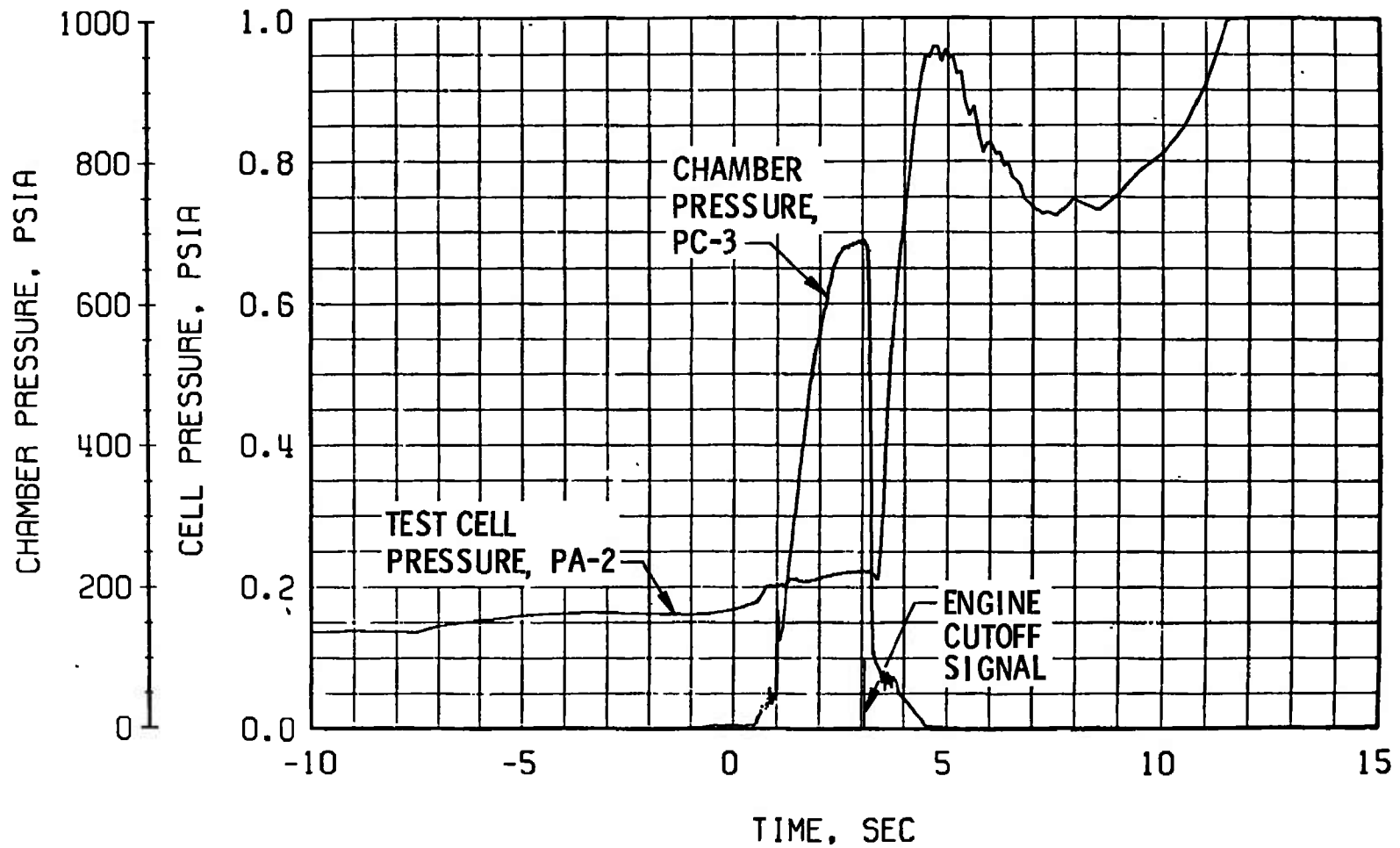
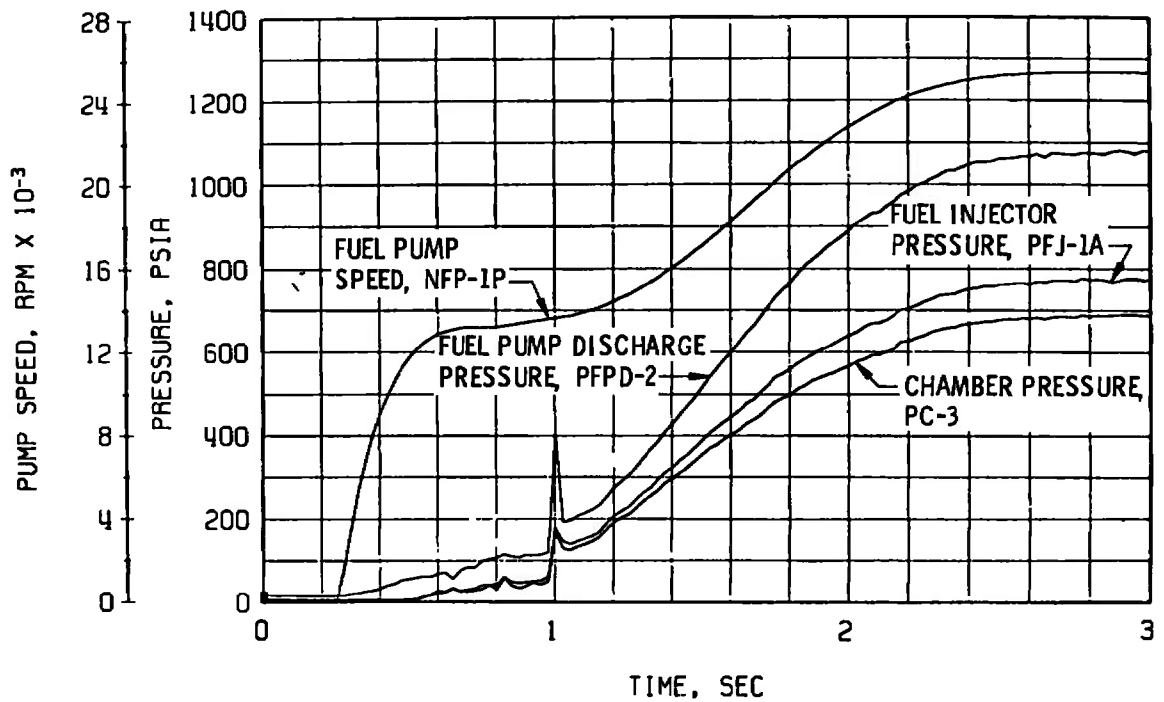
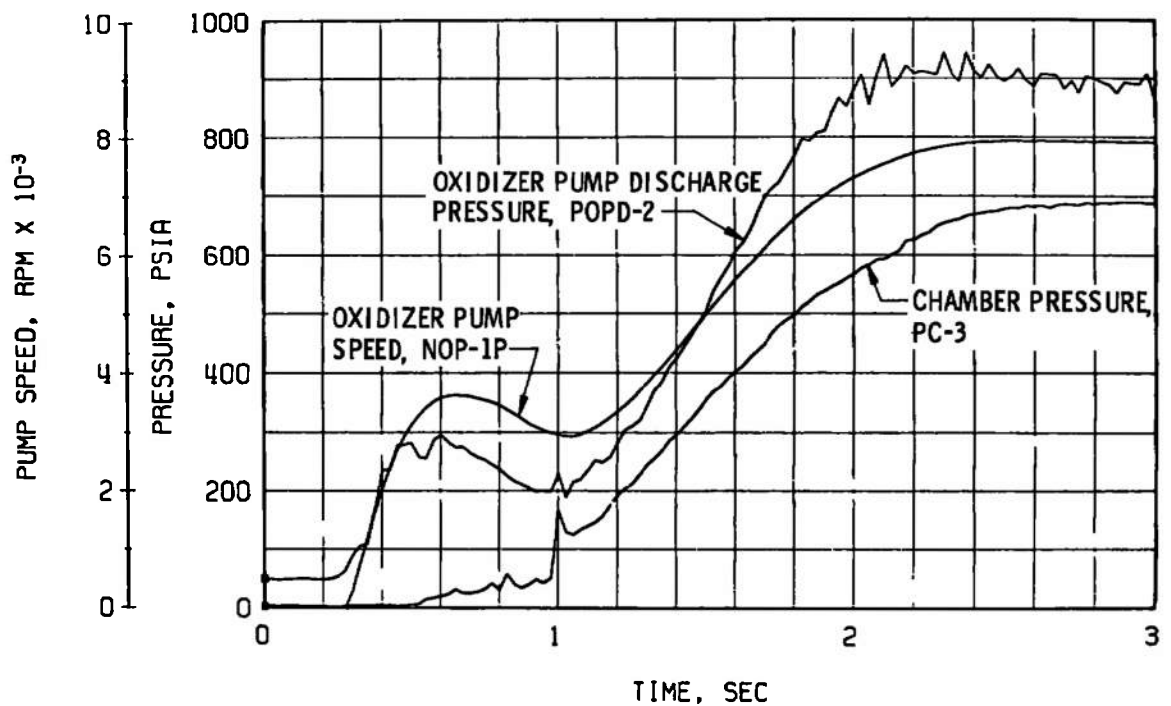


Fig. 56 Engine Ambient and Combustion Chamber Pressures, Firing 01C

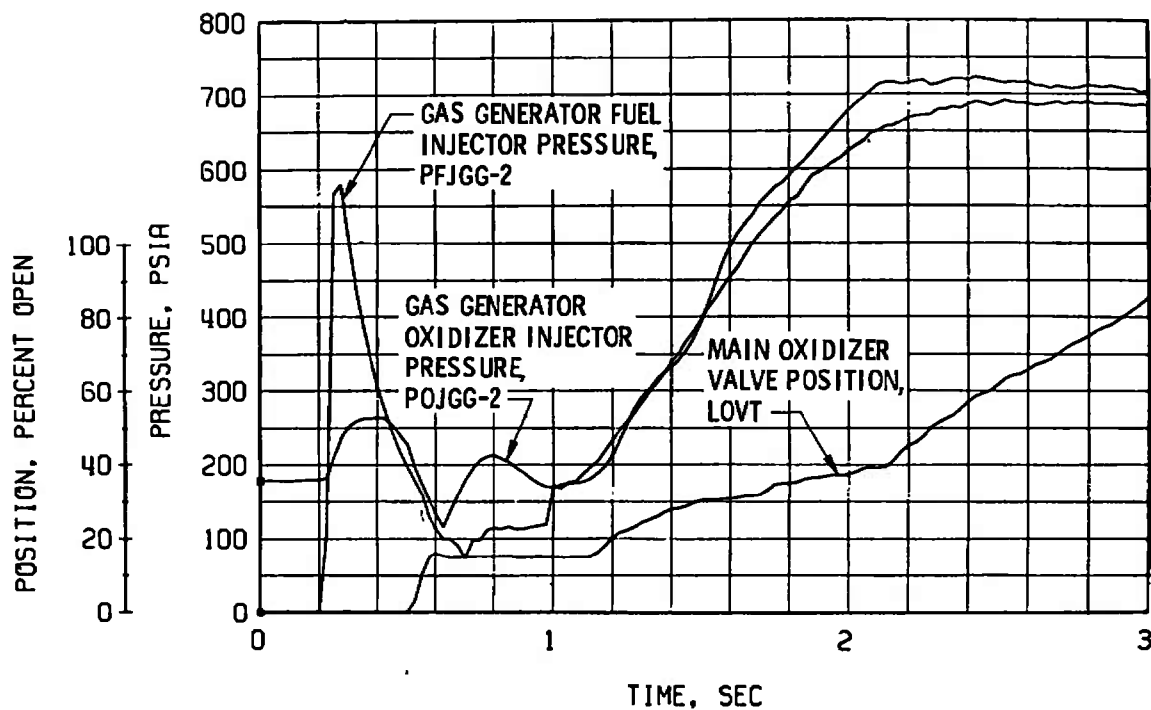


a. Thrust Chamber Fuel System, Start

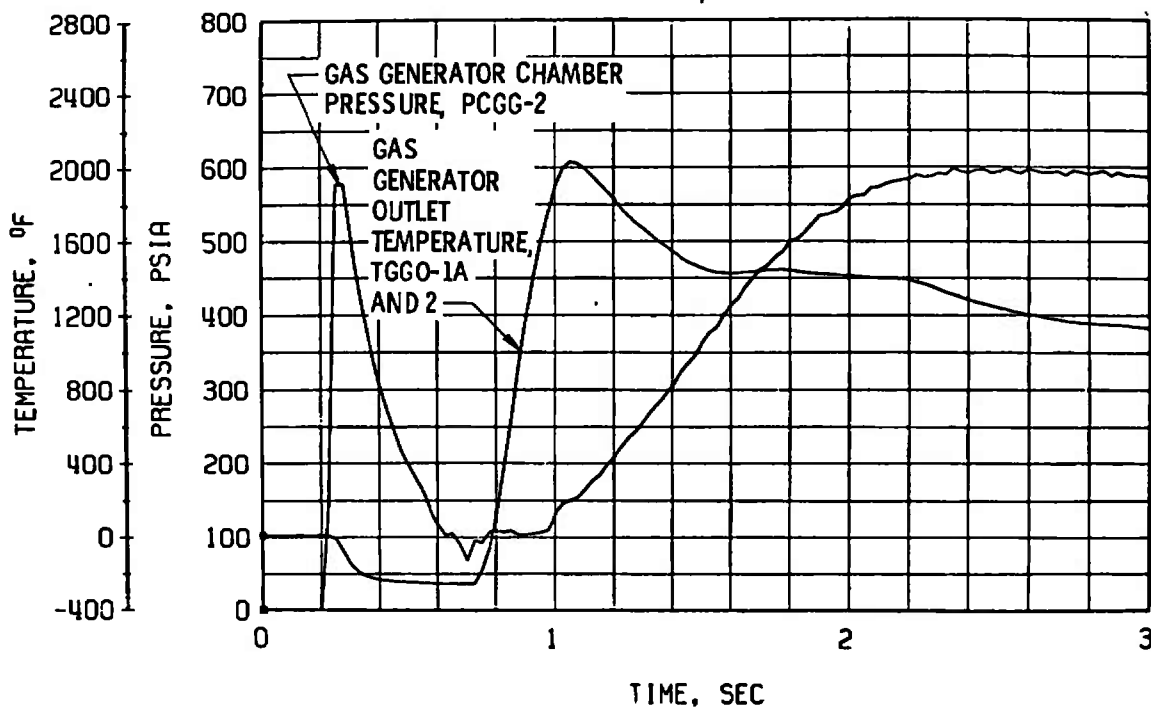


b. Thrust Chamber Oxidizer System, Start

Fig. 57 Engine Transient Operation, Firing 01C

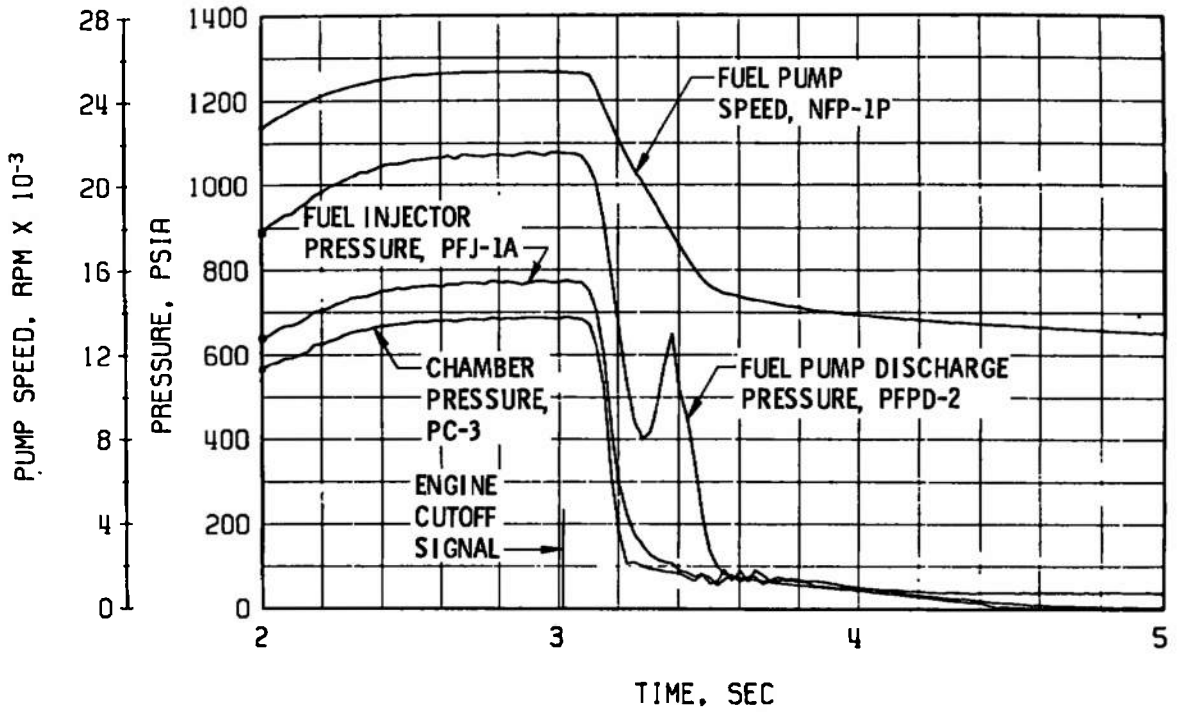


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

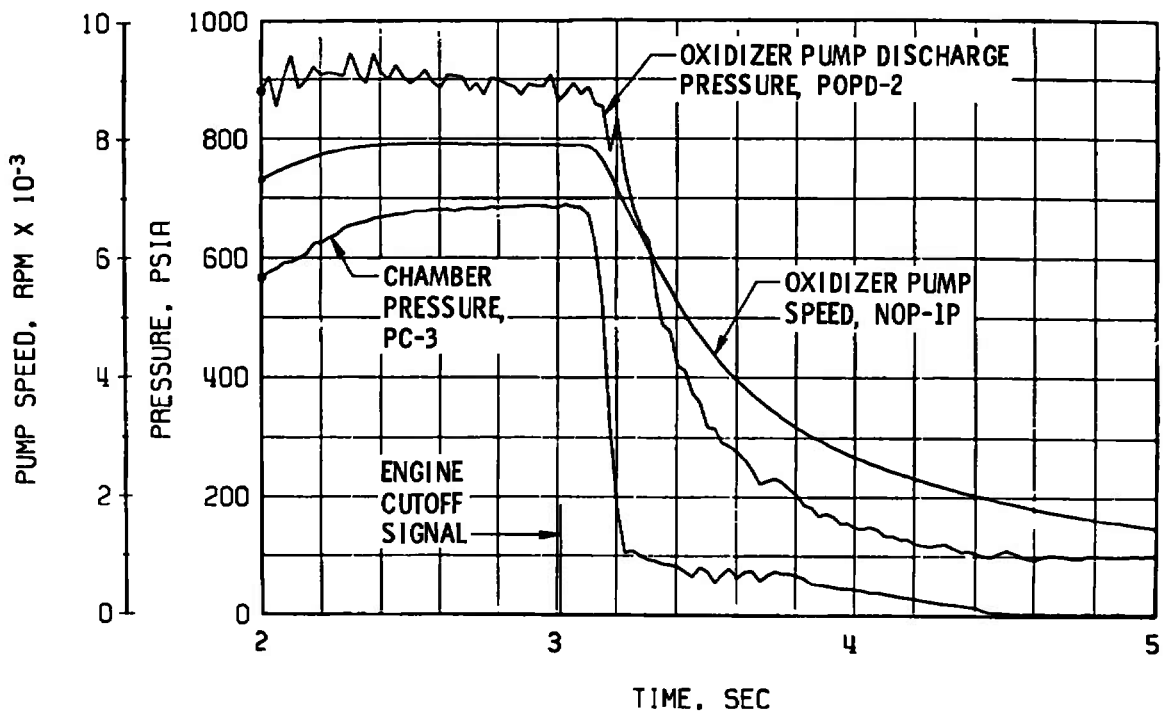


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 57 Continued

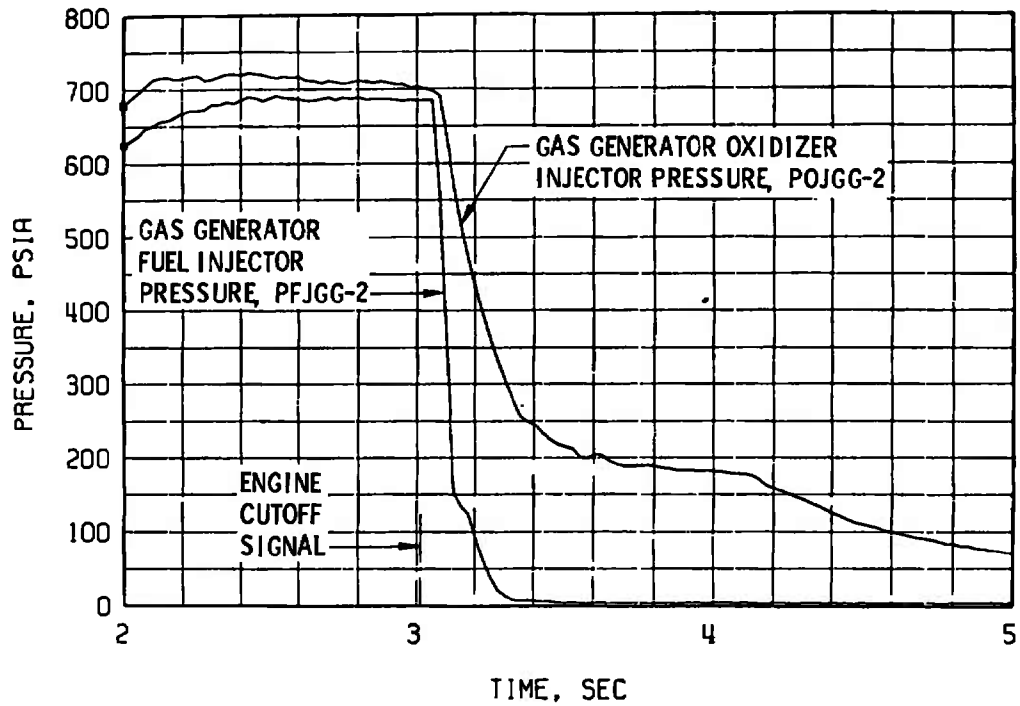


e. Thrust Chamber Fuel System, Shutdown

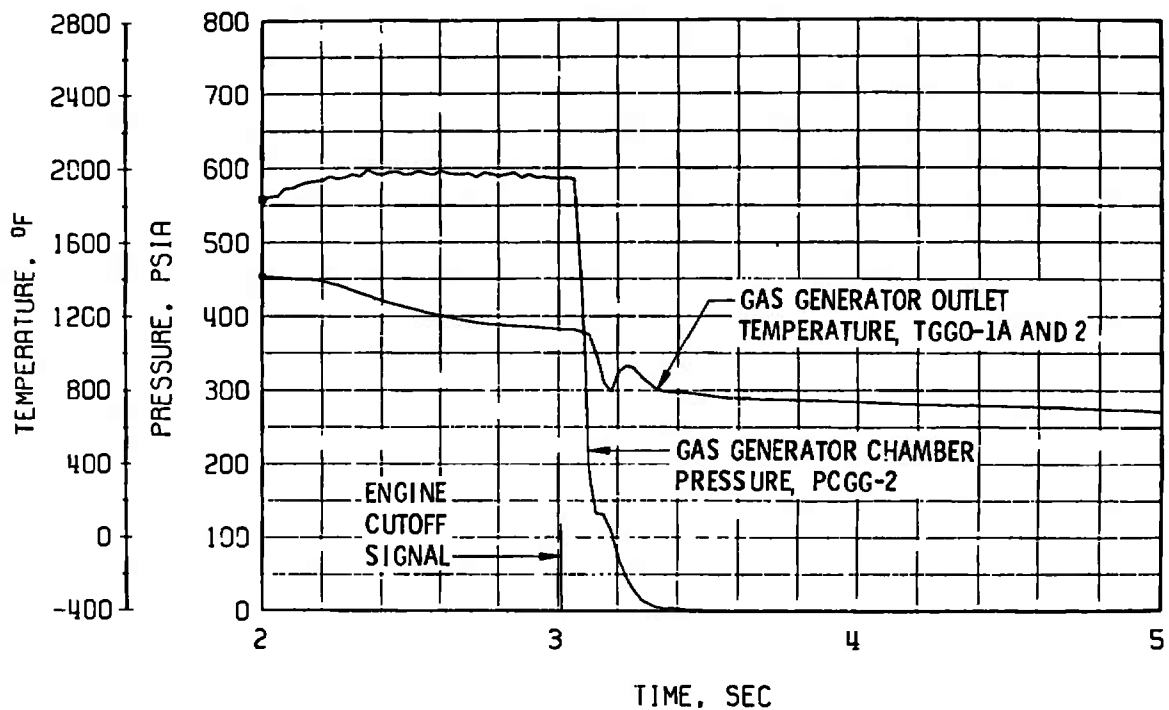


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 57 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 57 Concluded

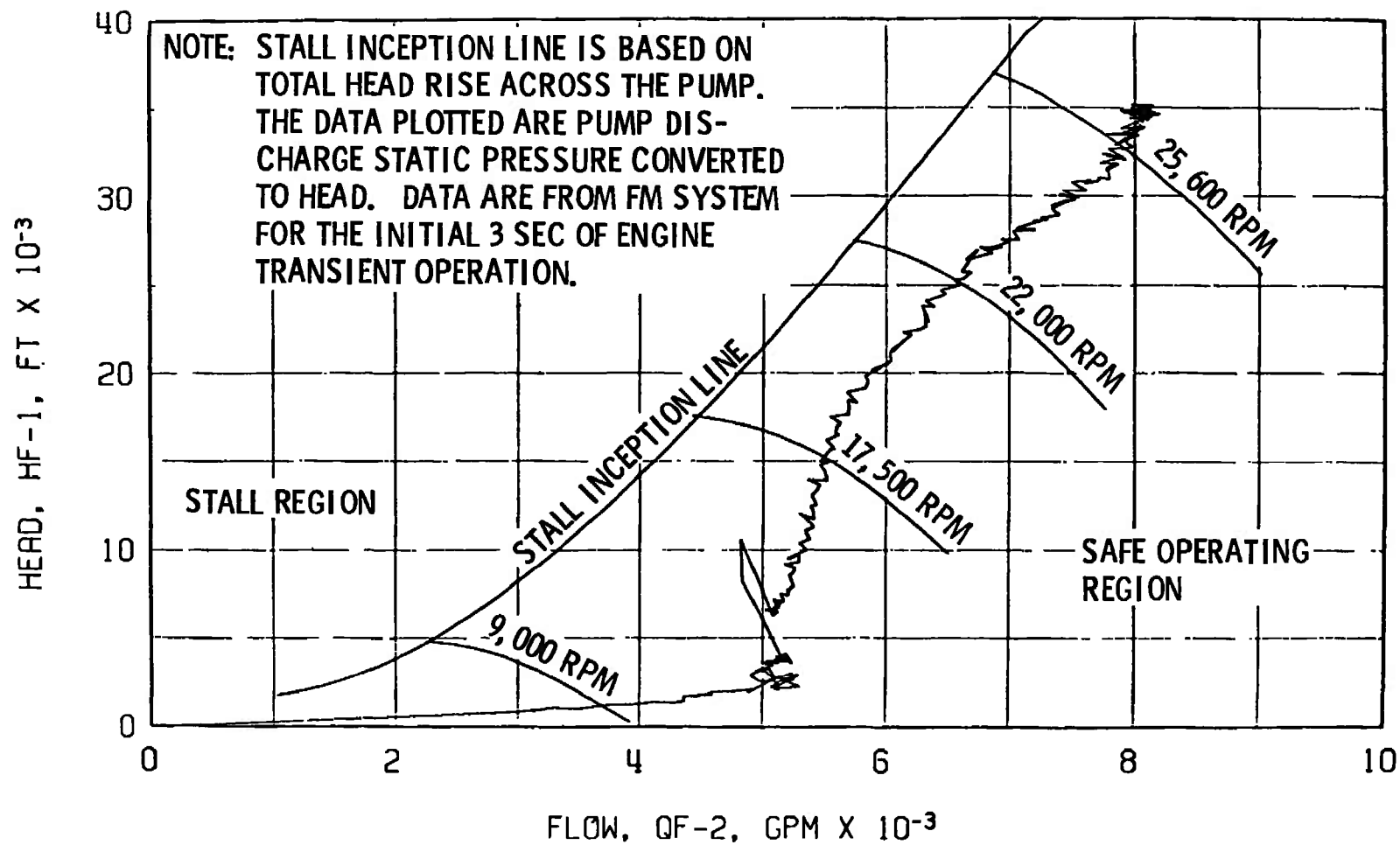
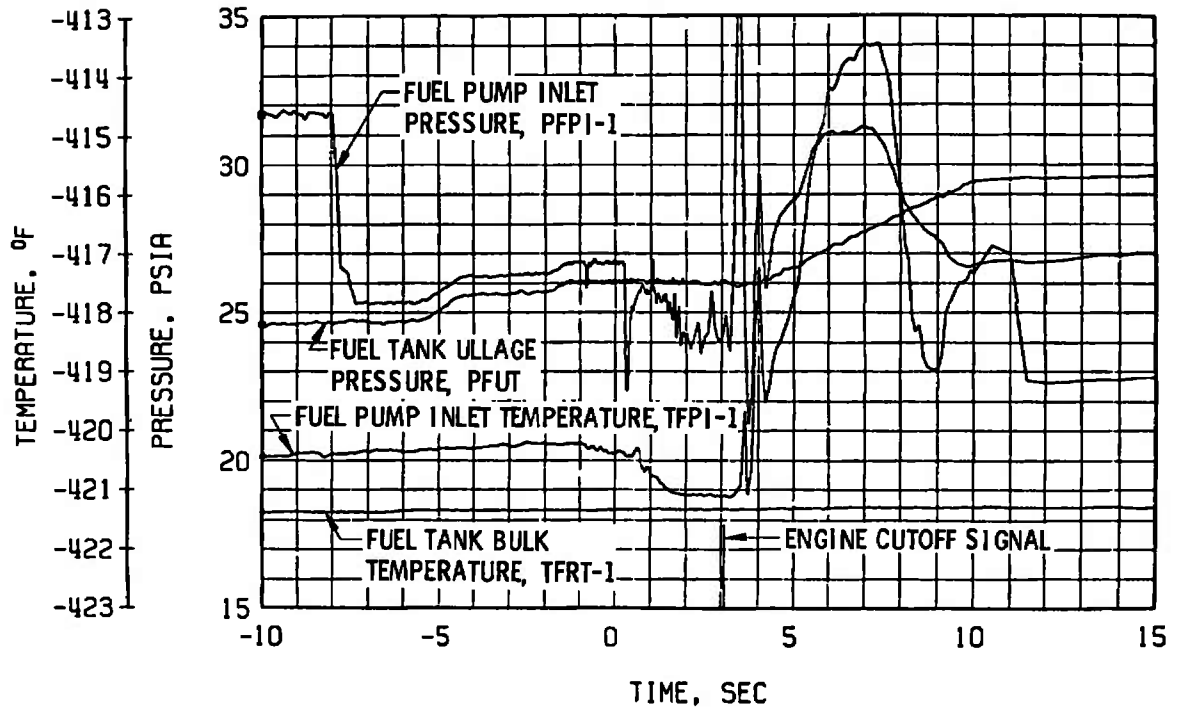
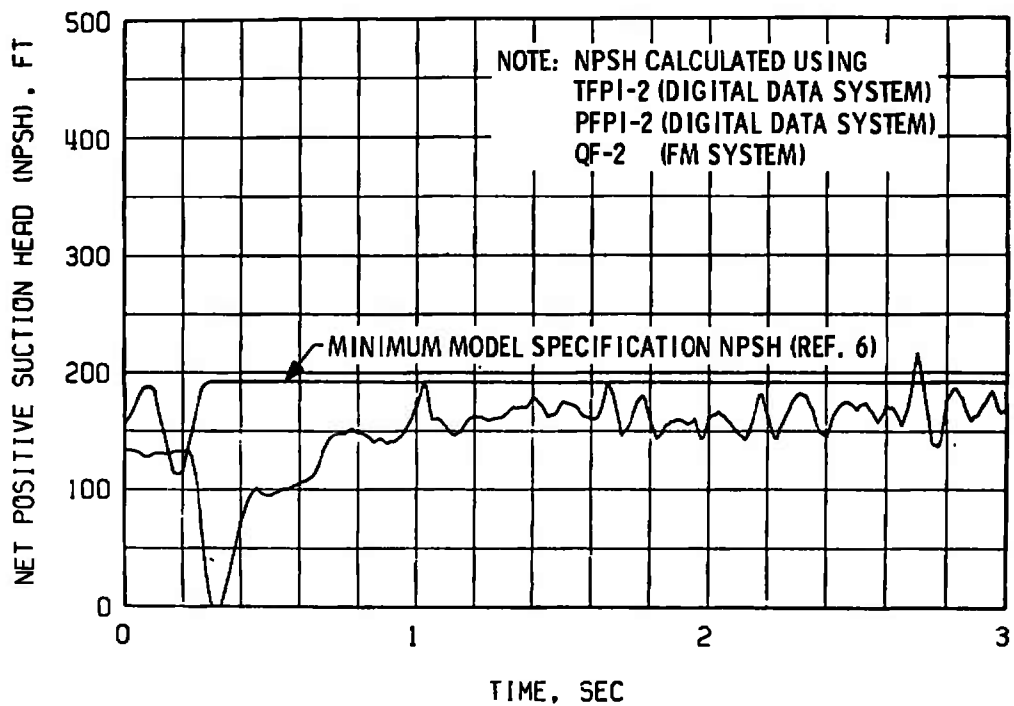


Fig. 58 Fuel Pump Start Transient Performance, Firing 01C

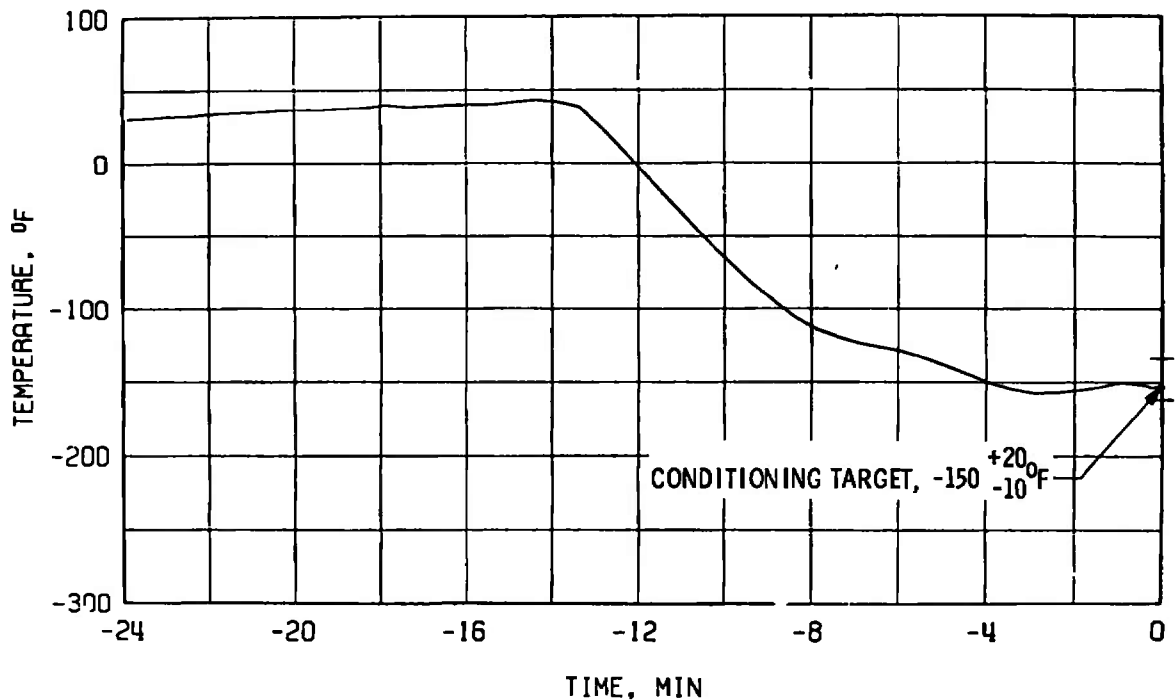


a. Duct Pressure and Temperature Transients

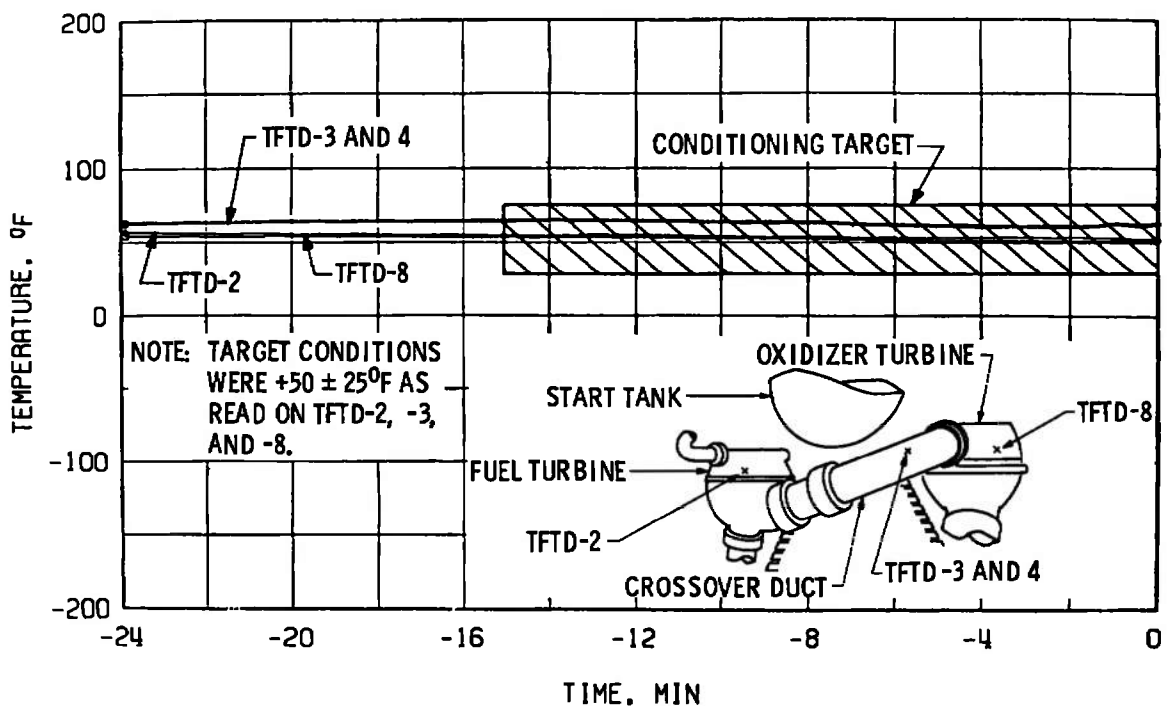


b. Fuel Pump NPSH during Start Transient, Firing 01C

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

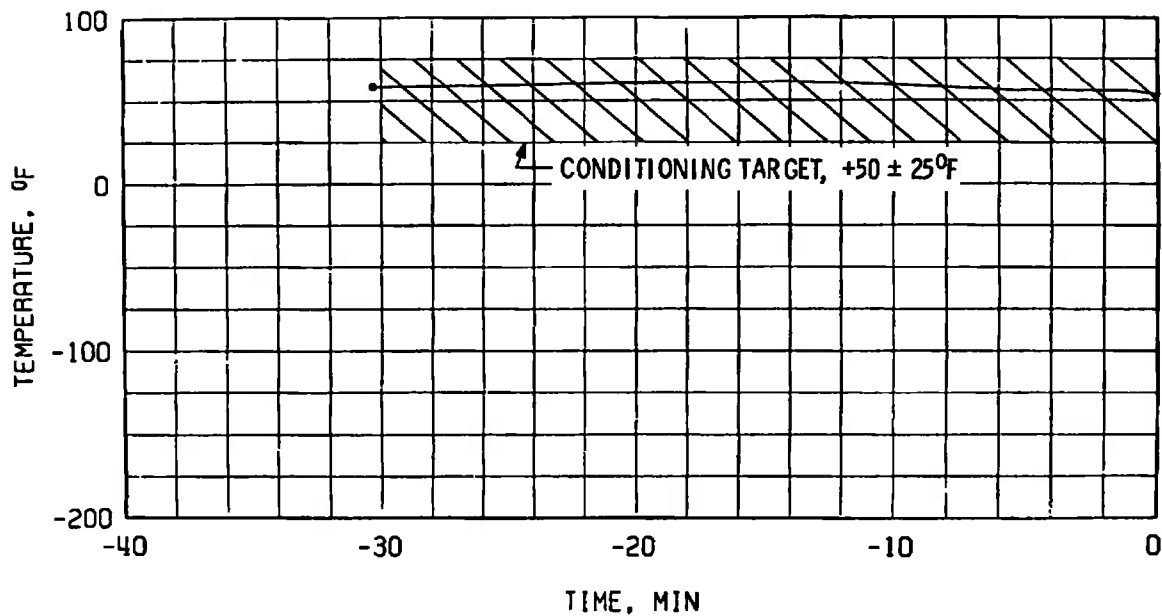


a. Thrust Chamber, TTC-1P

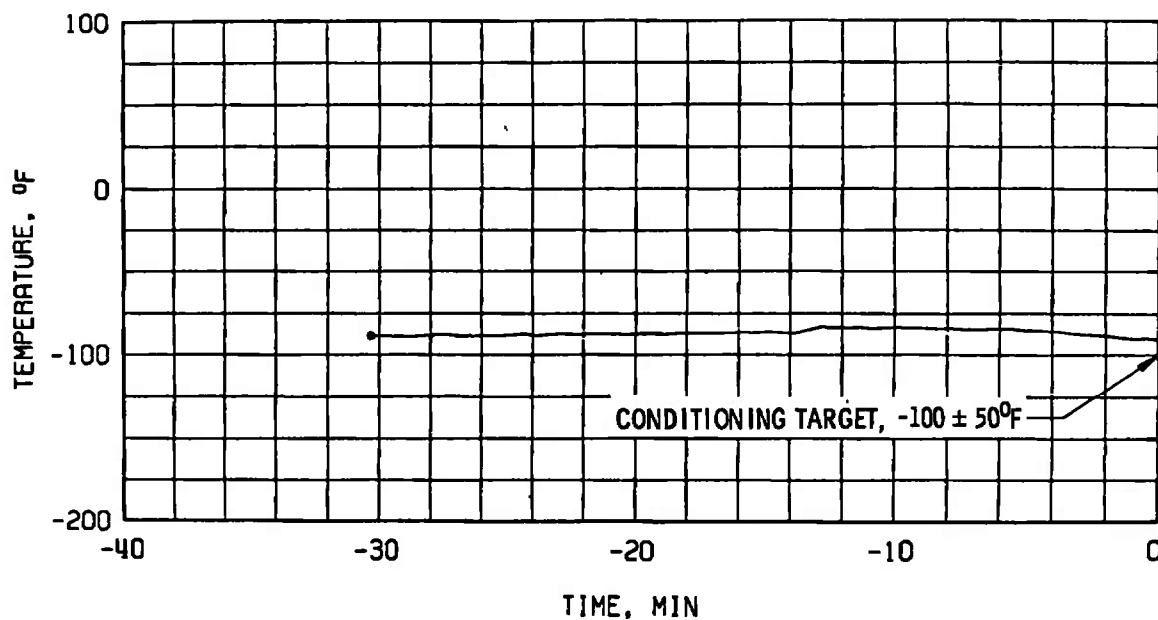


b. Crossover Duct, TFTD

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

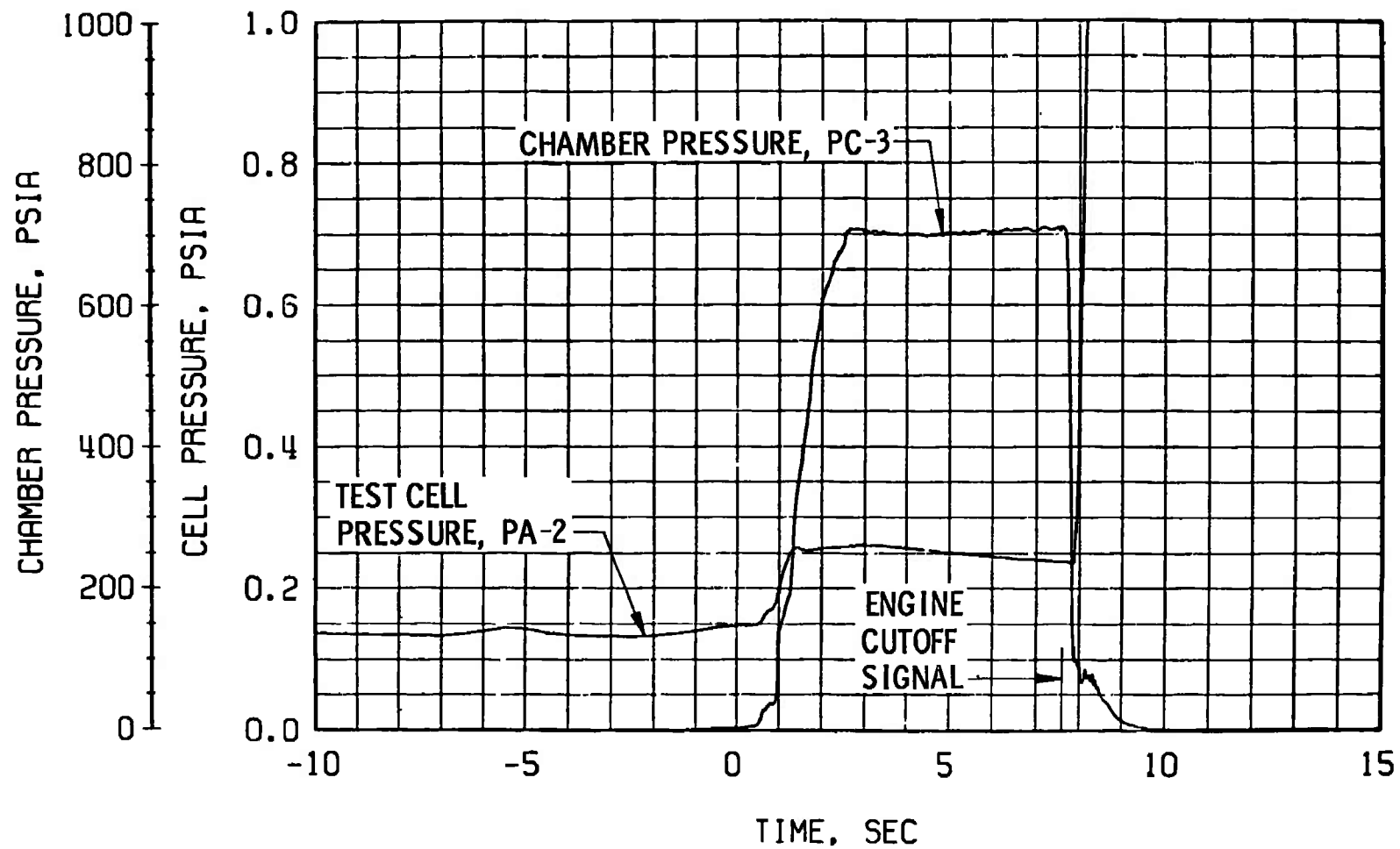
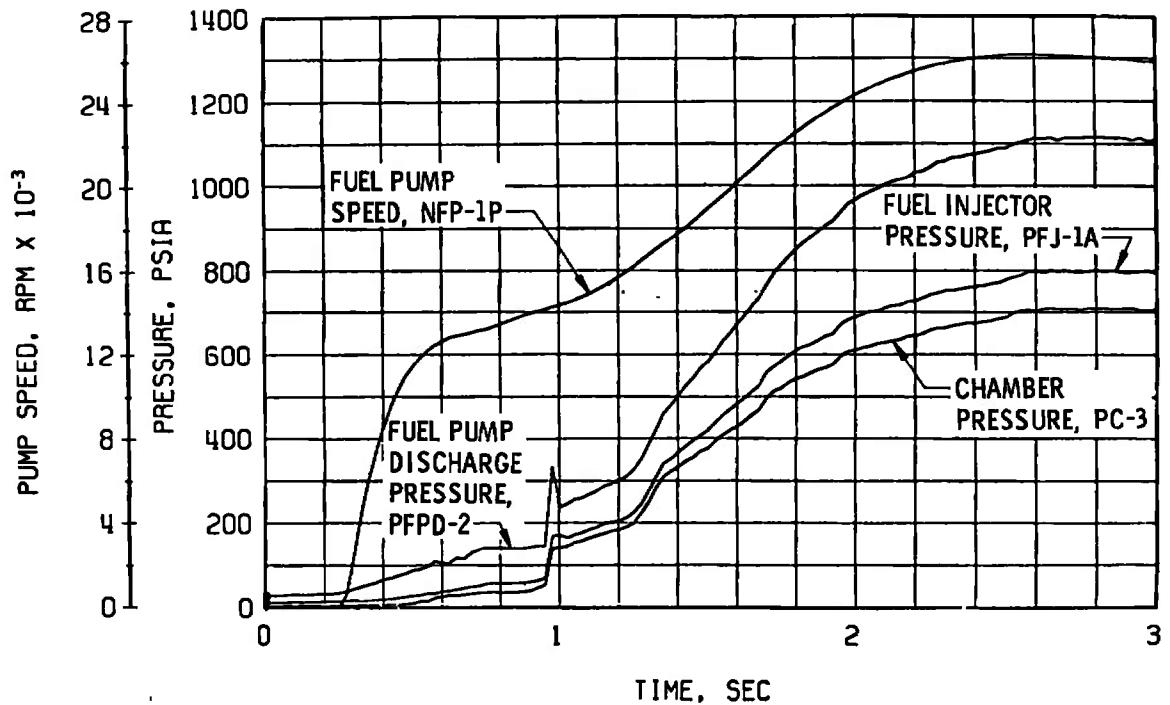
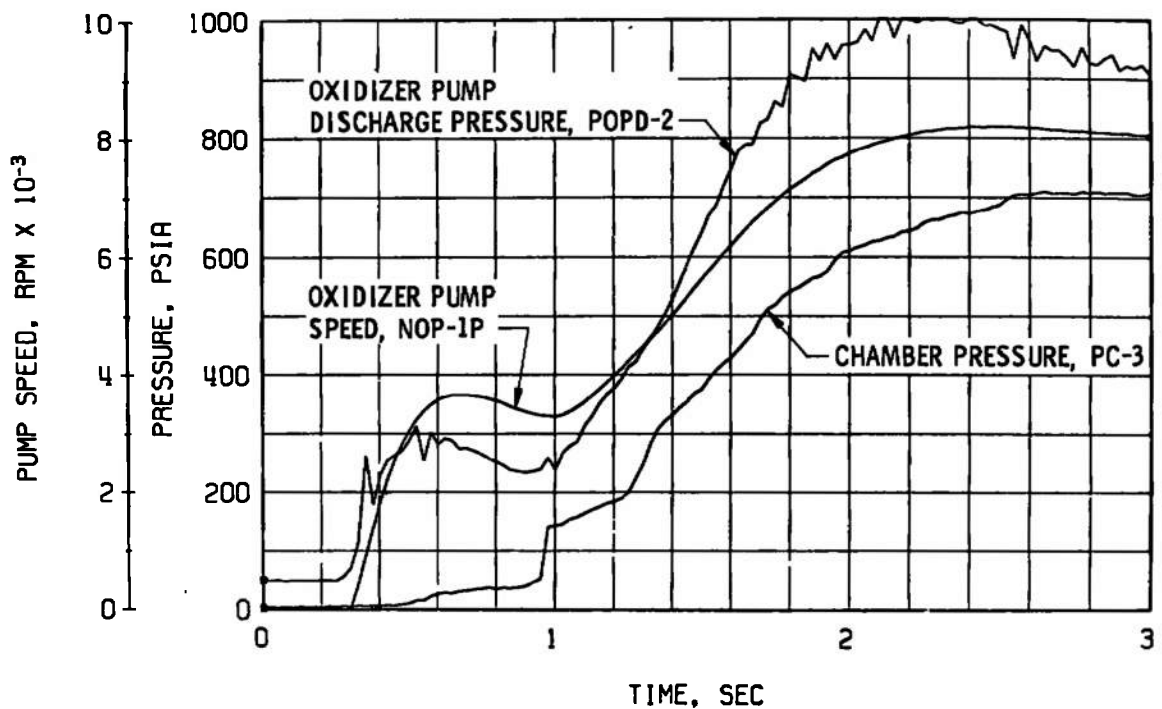


Fig. 61 Engine Ambient and Combustion Chamber Pressures, Firing 01D

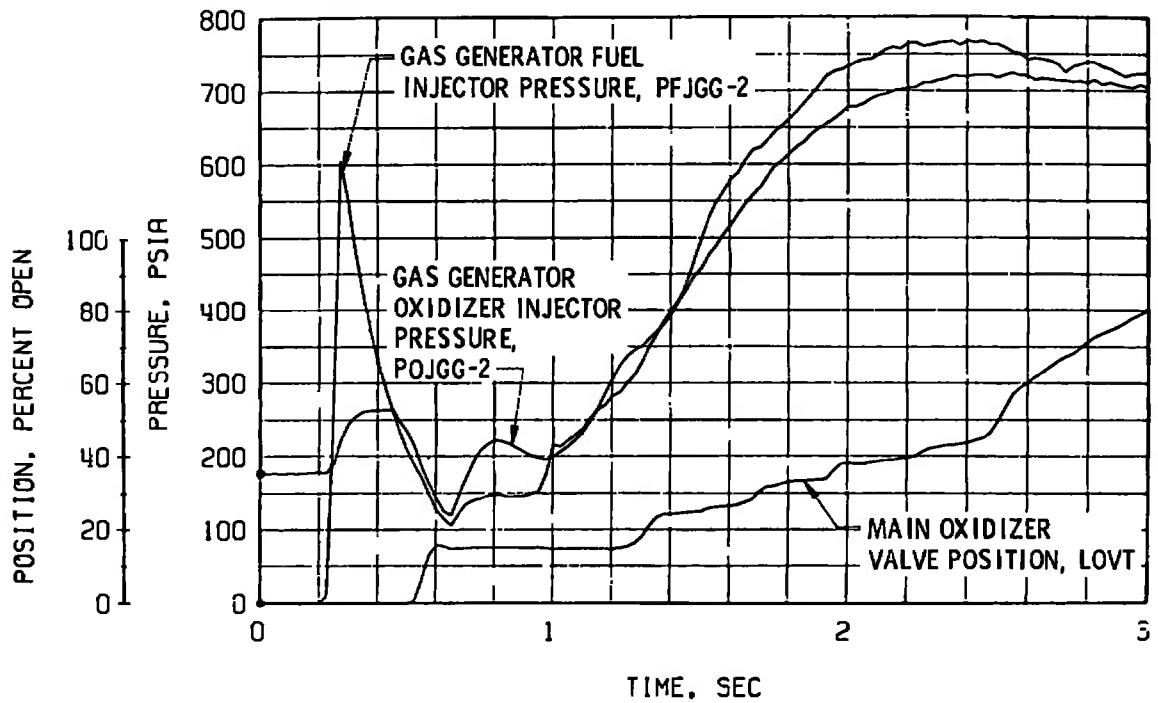


a. Thrust Chamber Fuel System, Start

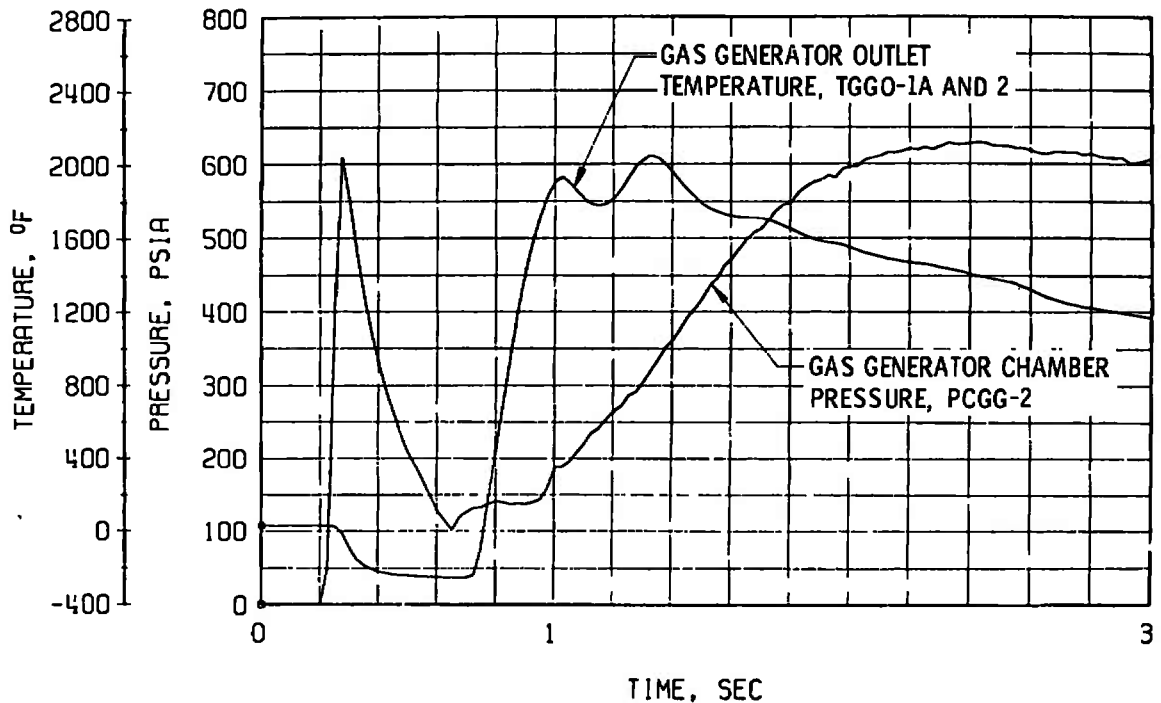


b. Thrust Chamber Oxidizer System, Start

Fig. 62 Engine Transient Operation, Firing 01D

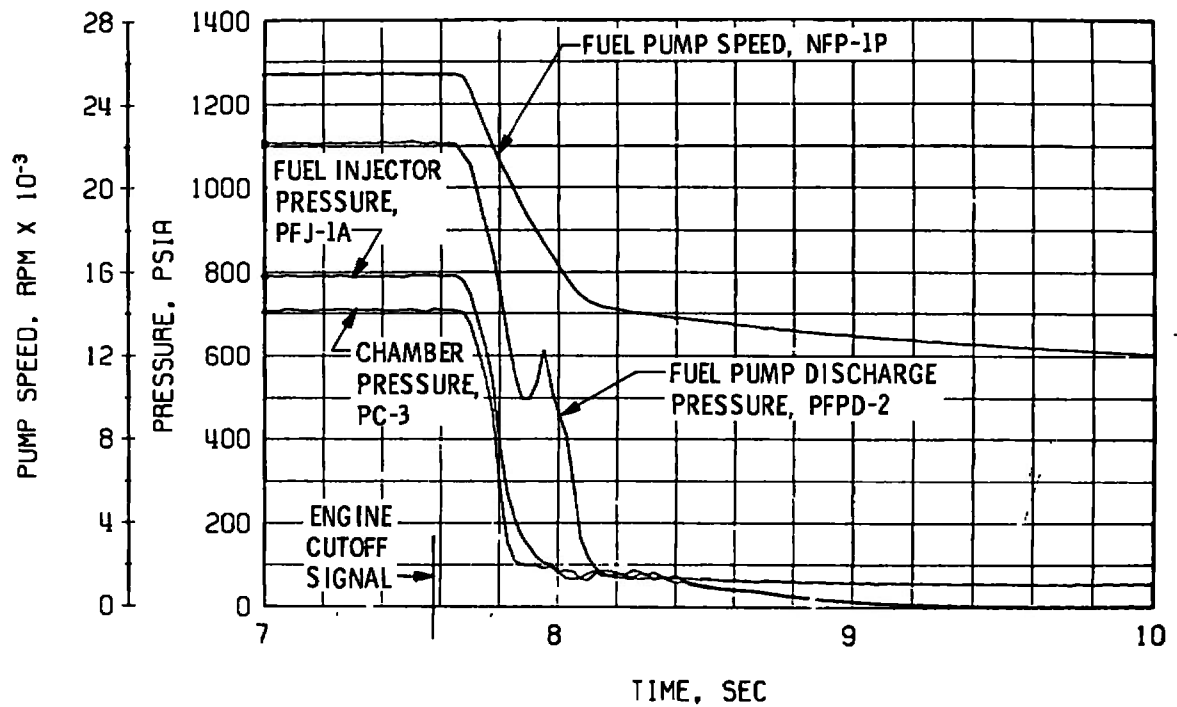


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

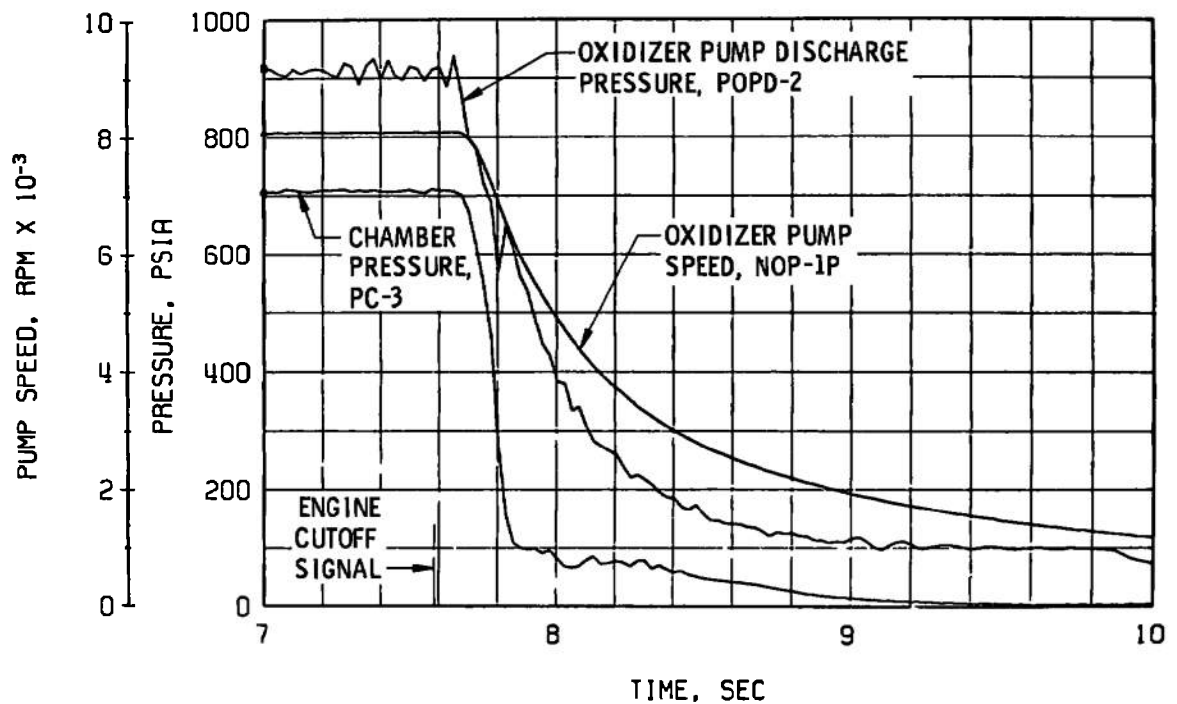


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 62 Continued

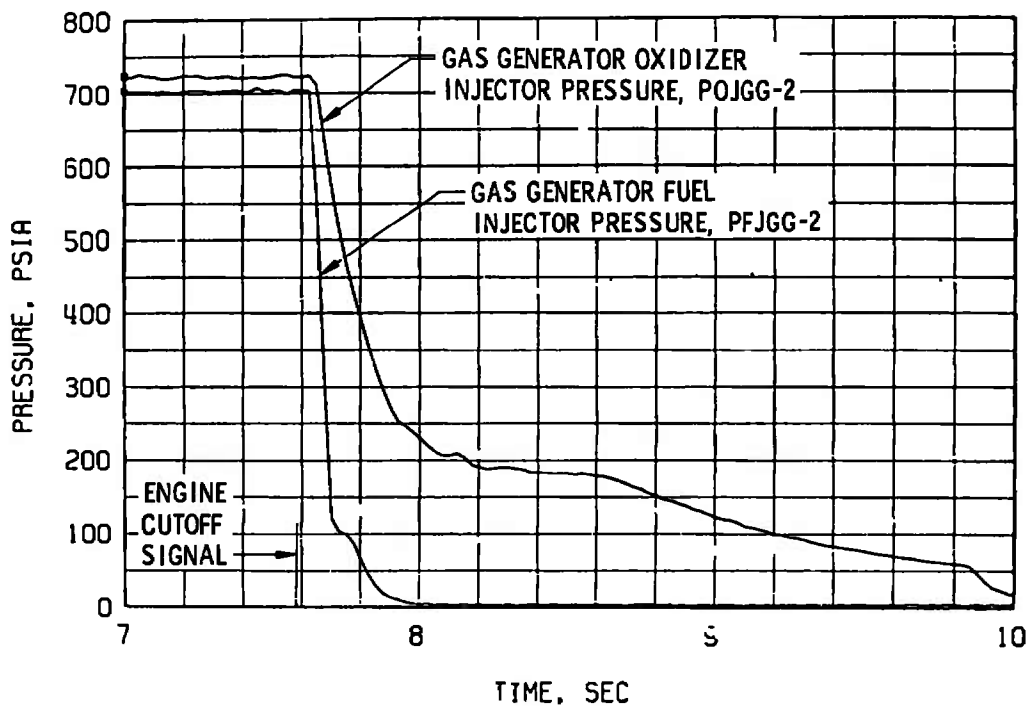


e. Thrust Chamber Fuel System, Shutdown

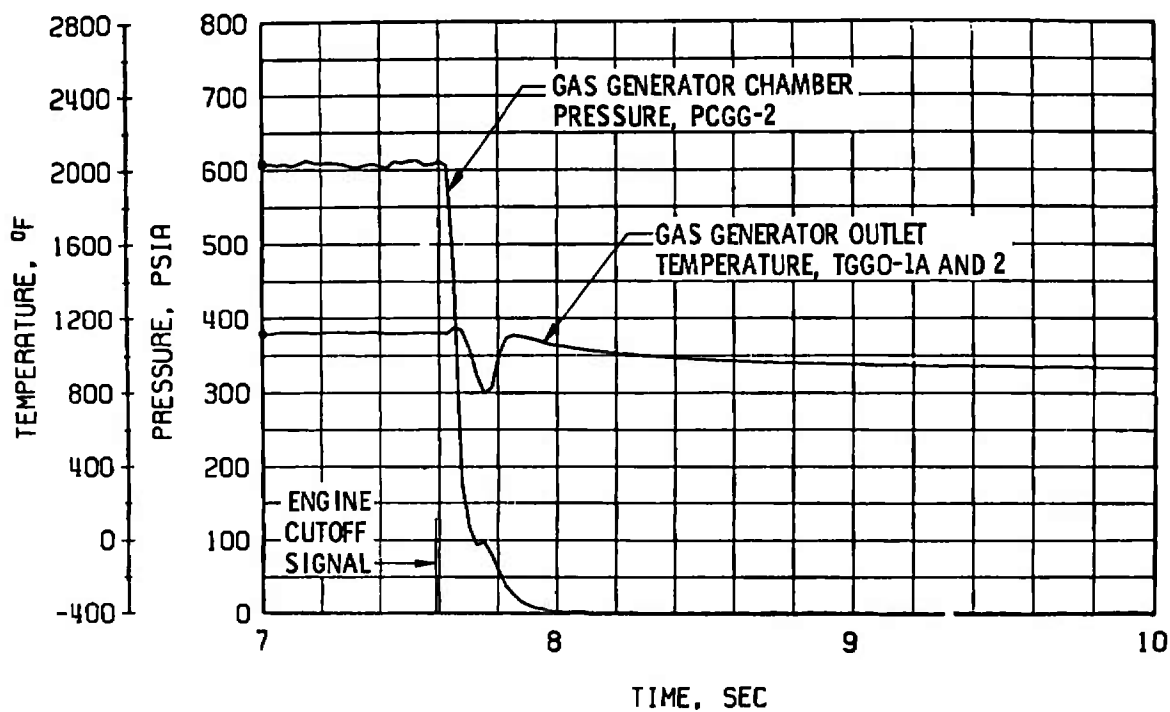


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 62 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 62 Concluded

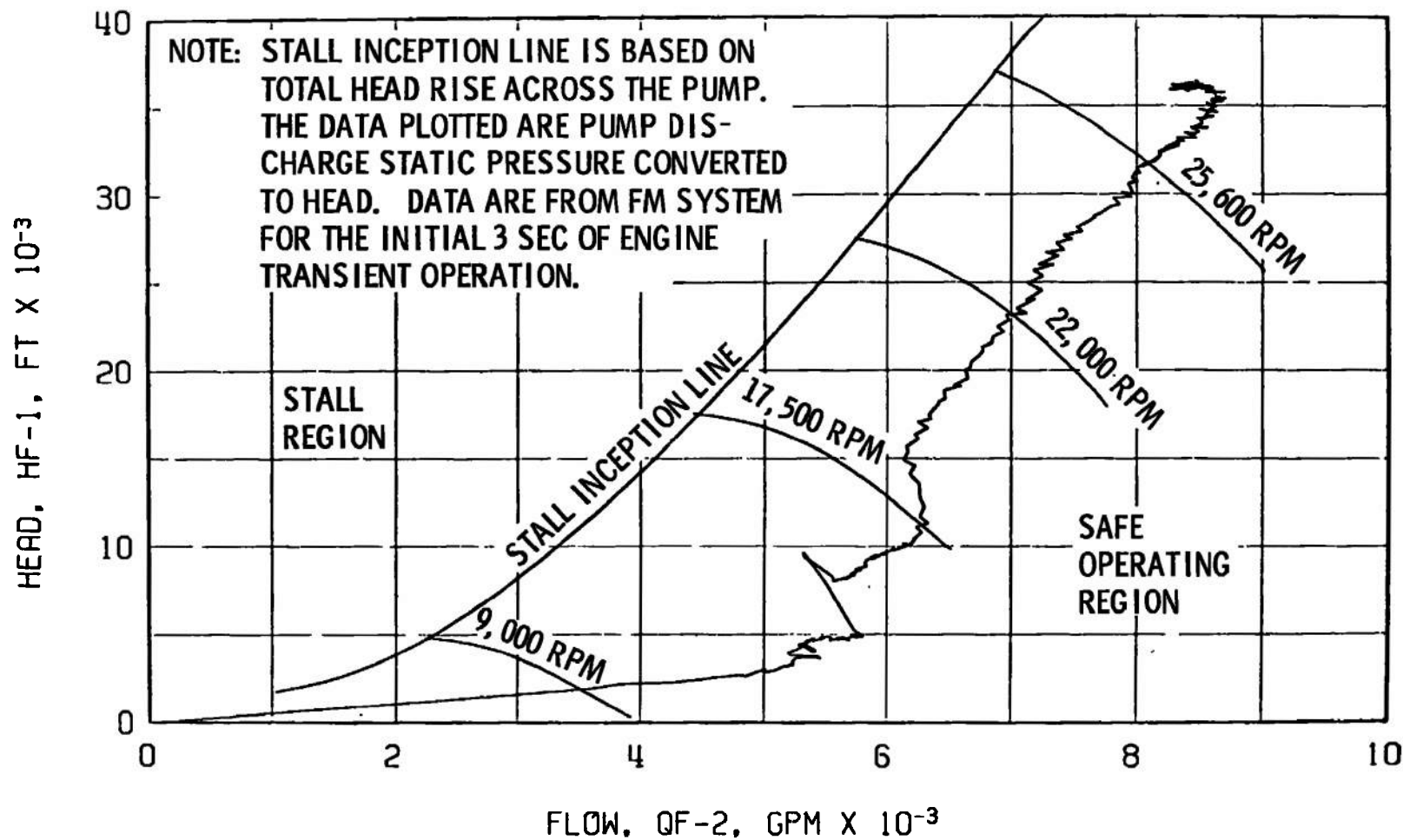
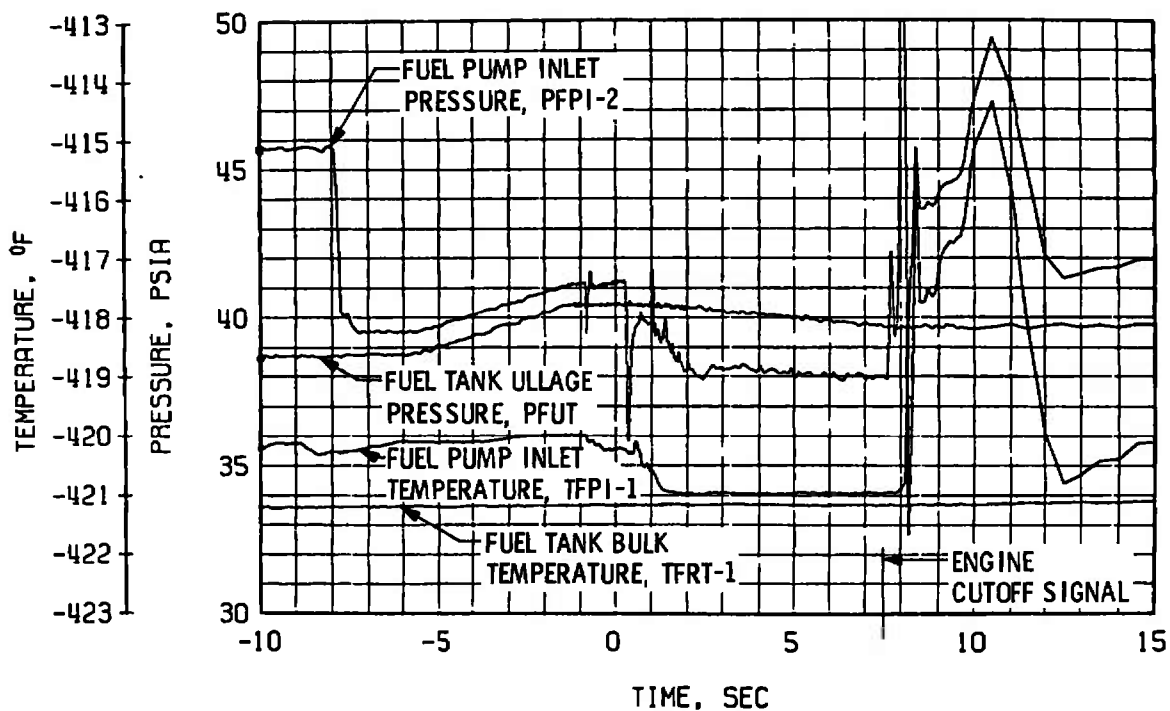
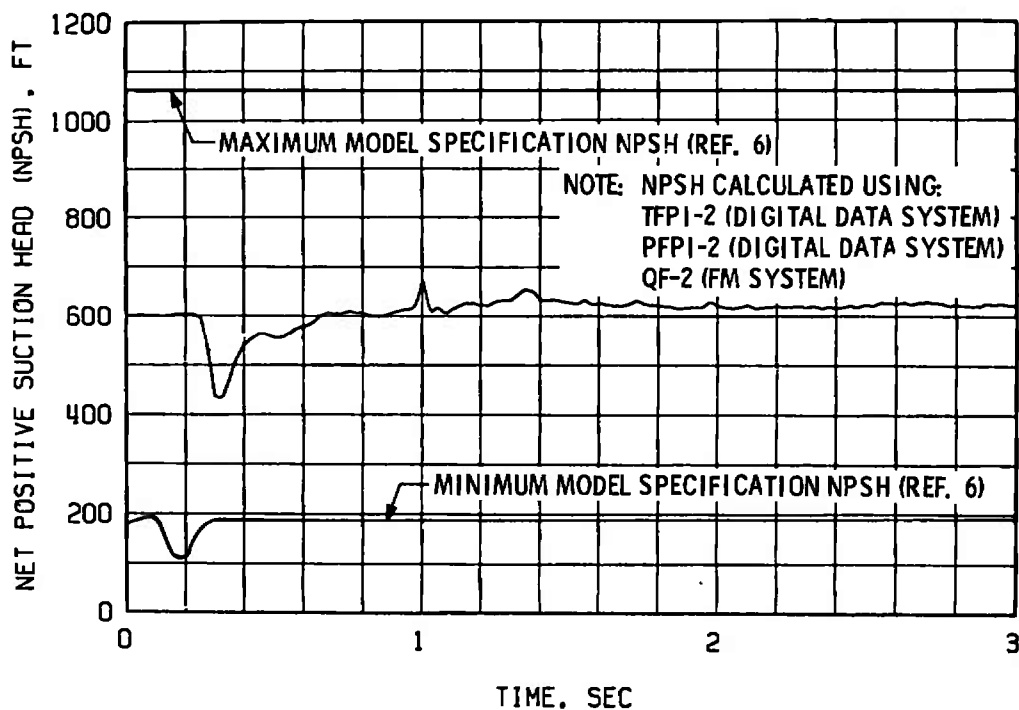


Fig. 63 Fuel Pump Start Transient Performance, Firing 01D

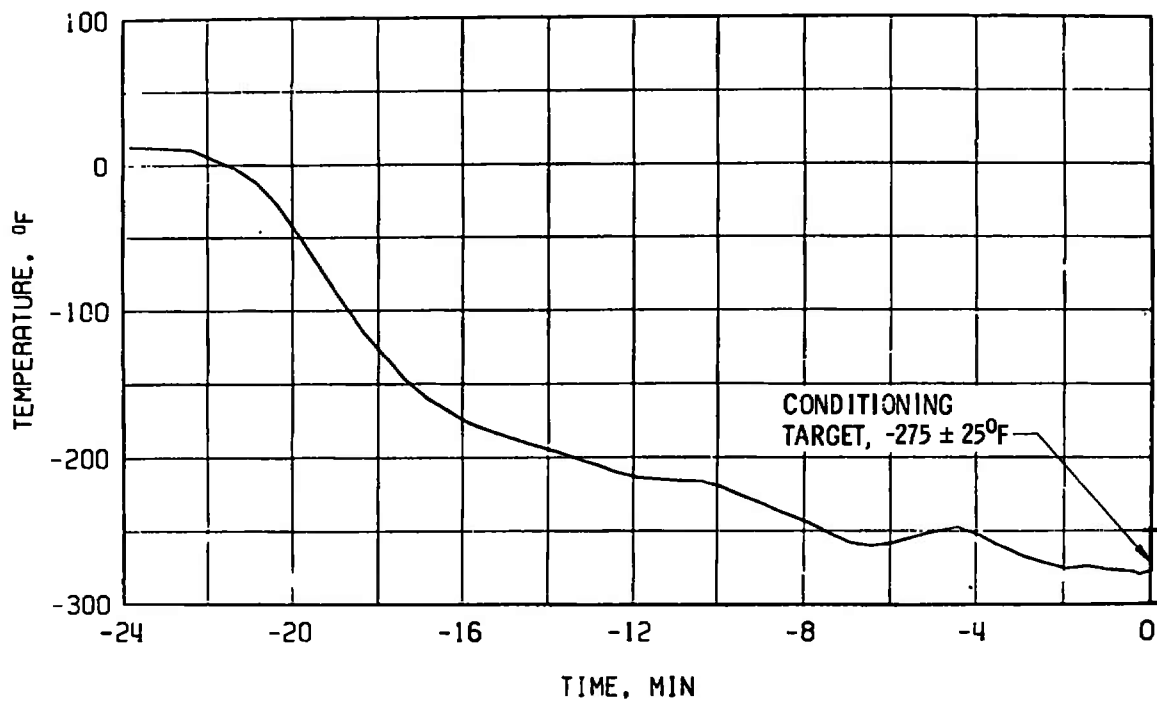


a. Duct Pressure and Temperature Transients

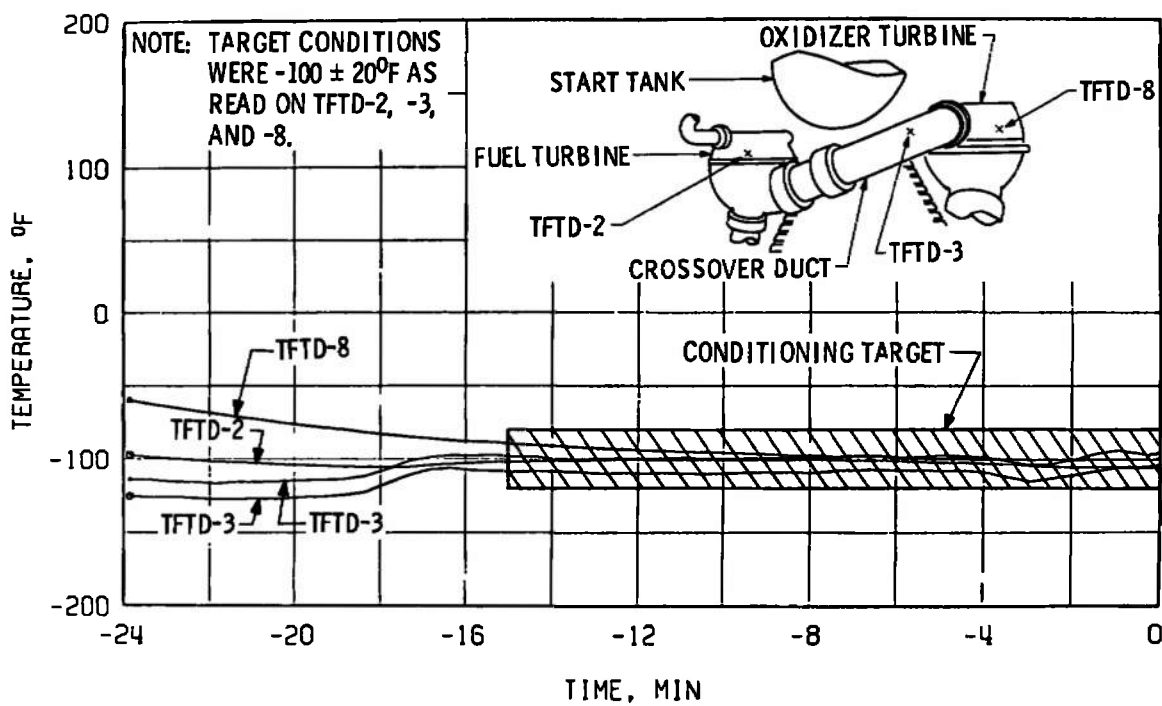


b. Fuel Pump NPSH during Start Transient, Firing 01D

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

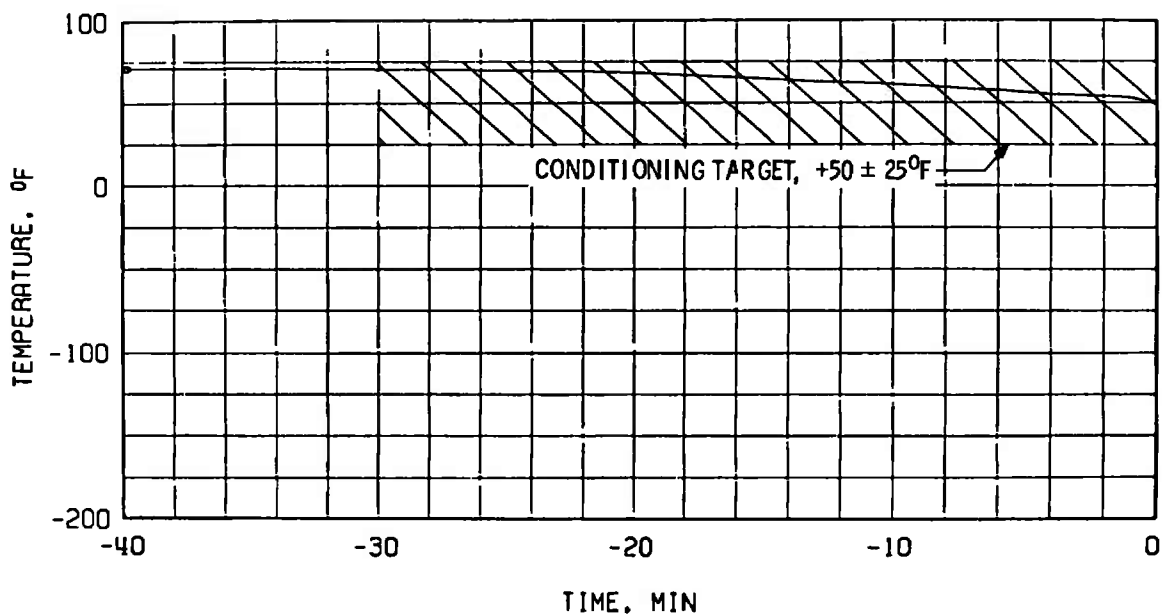


a. Thrust Chamber Throat, TTC-1P

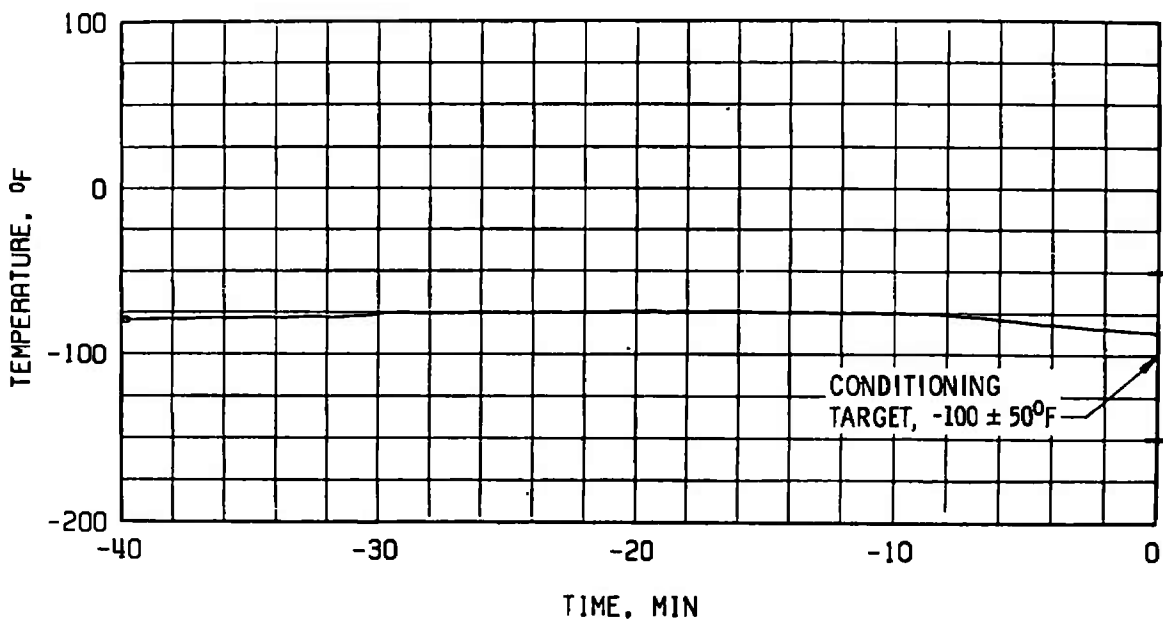


b. Crossover Duct, TFTD

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

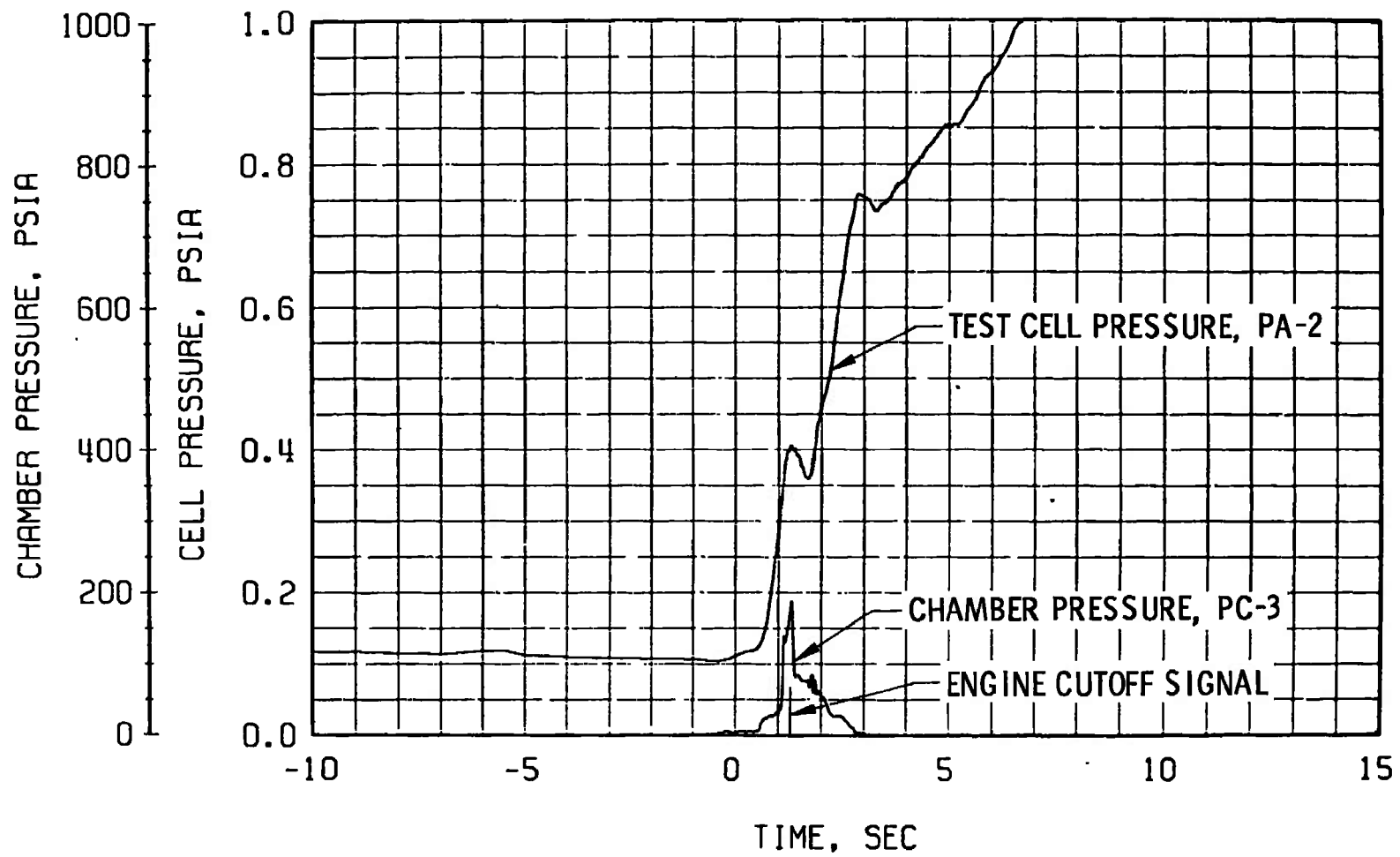
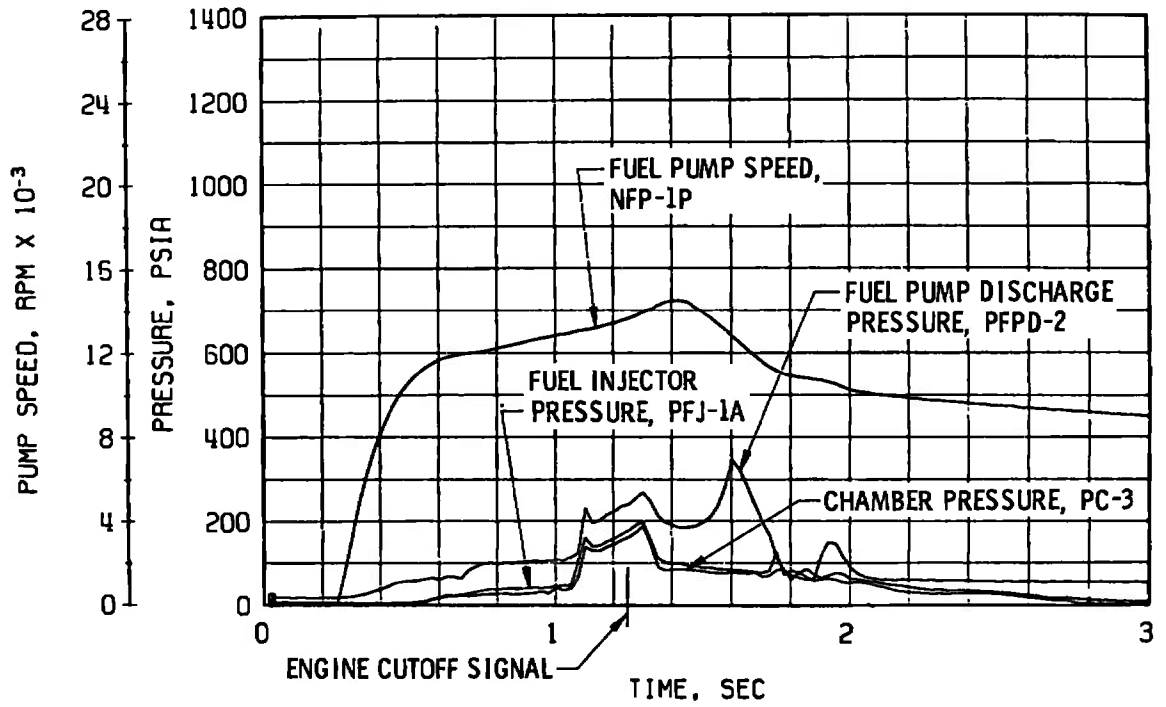
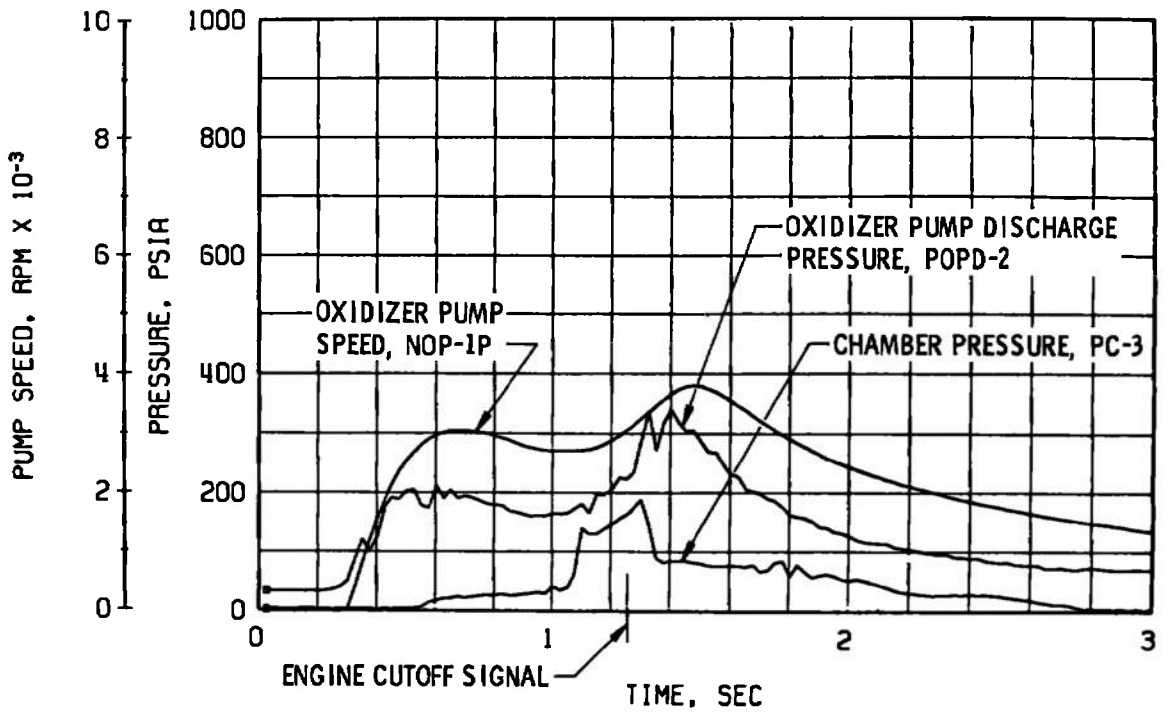


Fig. 66 Engine Ambient and Combustion Chamber Pressures, Firing 01E

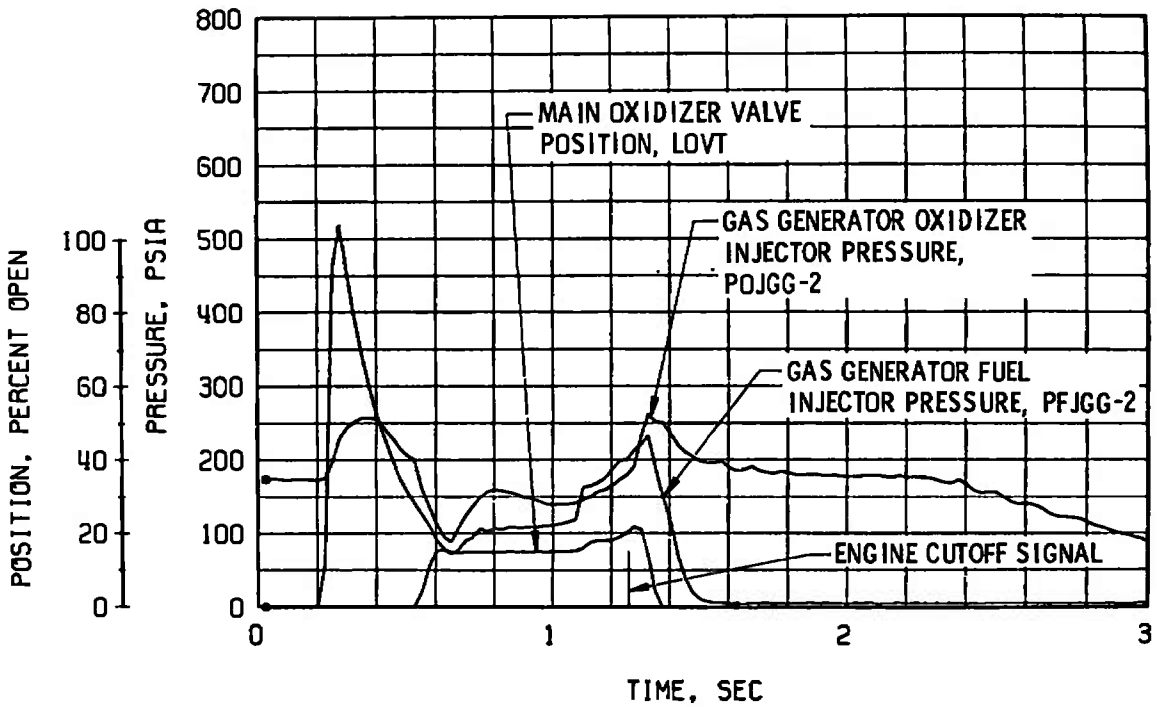


a. Thrust Chamber Fuel System, Start and Shutdown

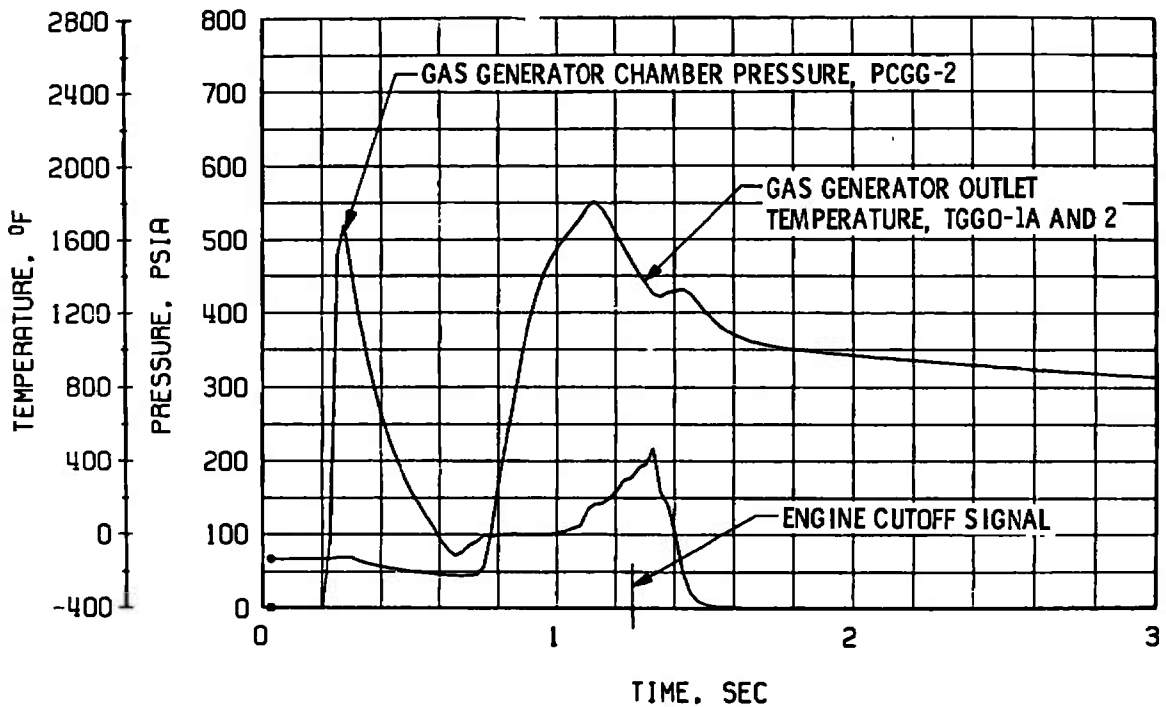


b. Thrust Chamber Oxidizer System, Start and Shutdown

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

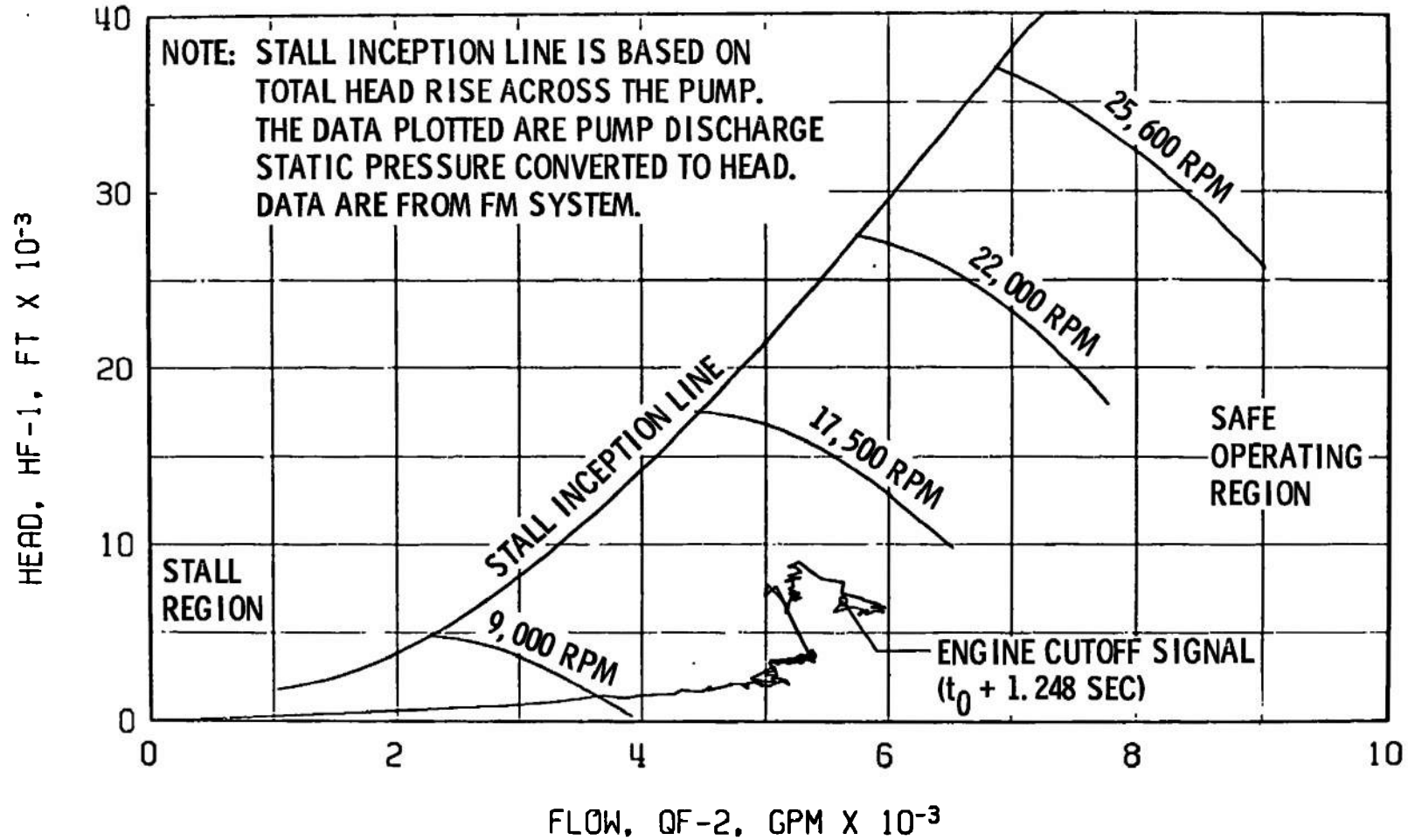
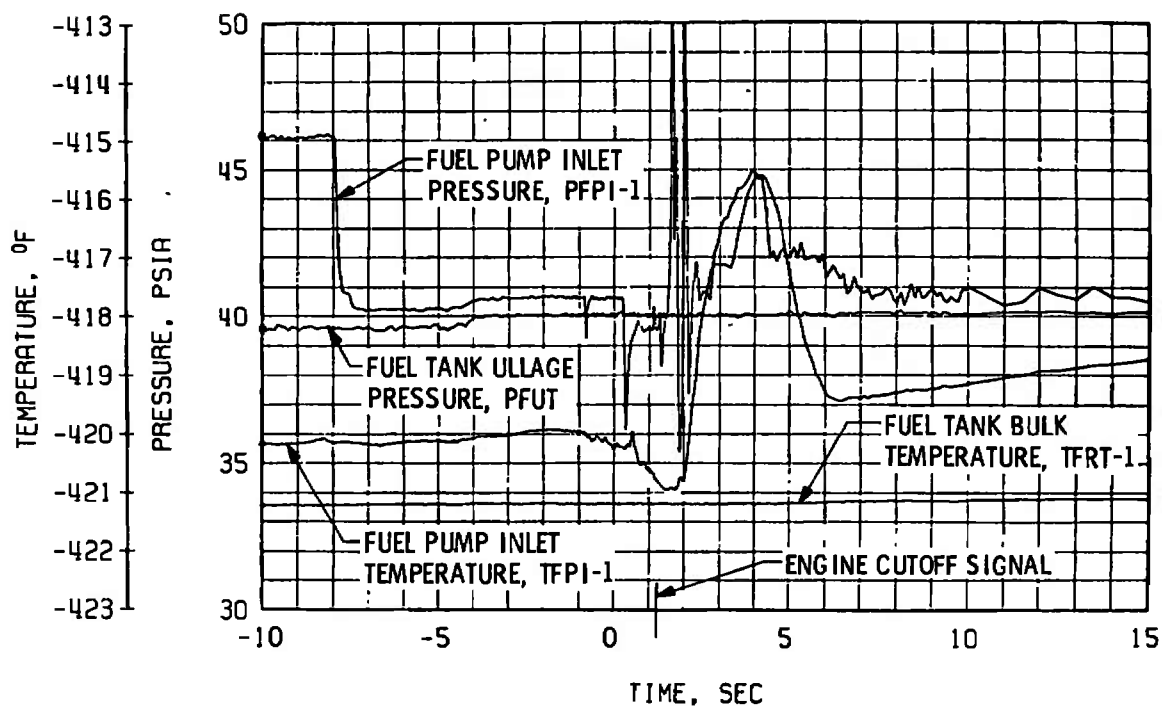
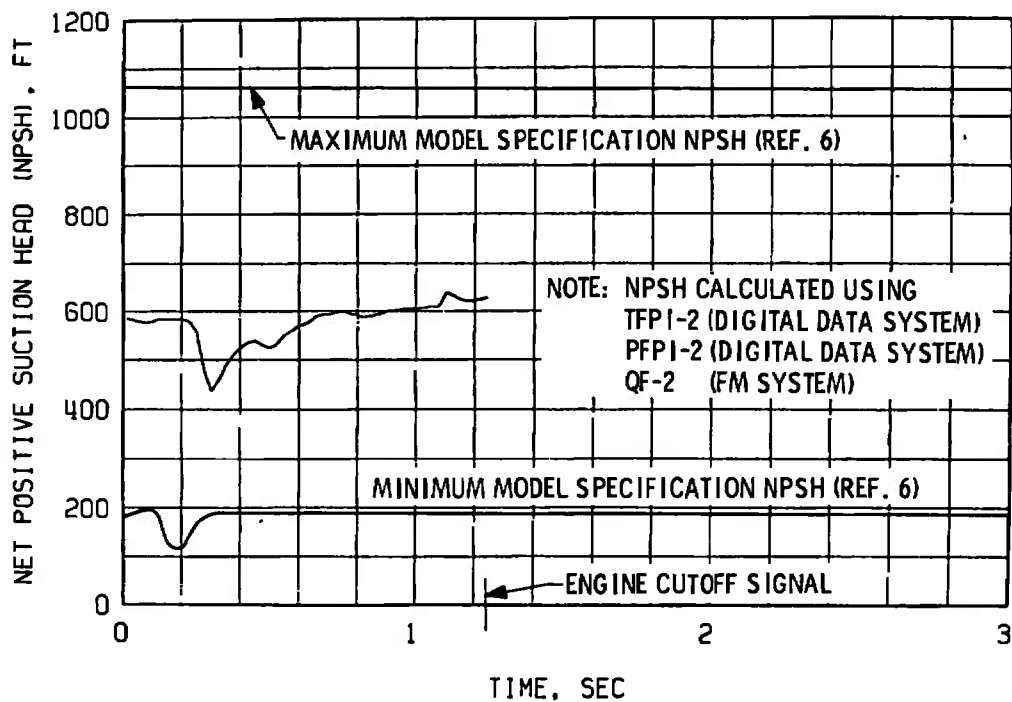


Fig. 68 Fuel Pump Start Transient Performance, Firing 01E

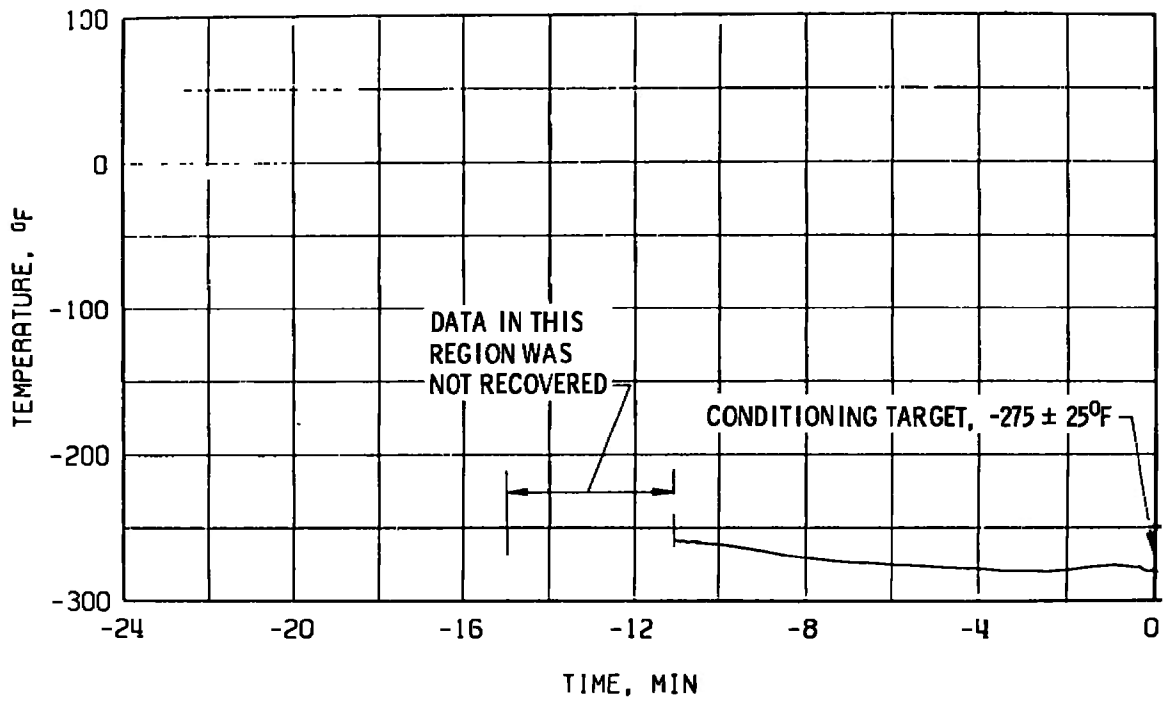


a. Duct Pressure and Temperature Transients

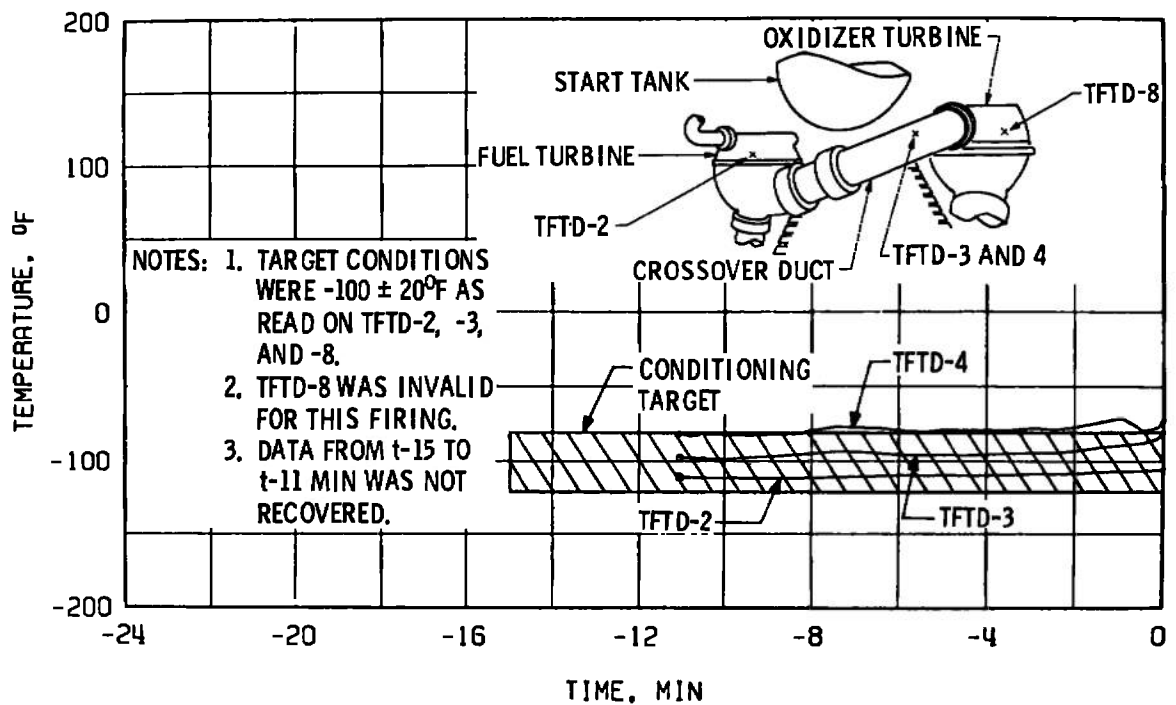


b. Fuel Pump NPSH during Start Transient, Firing 01E

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

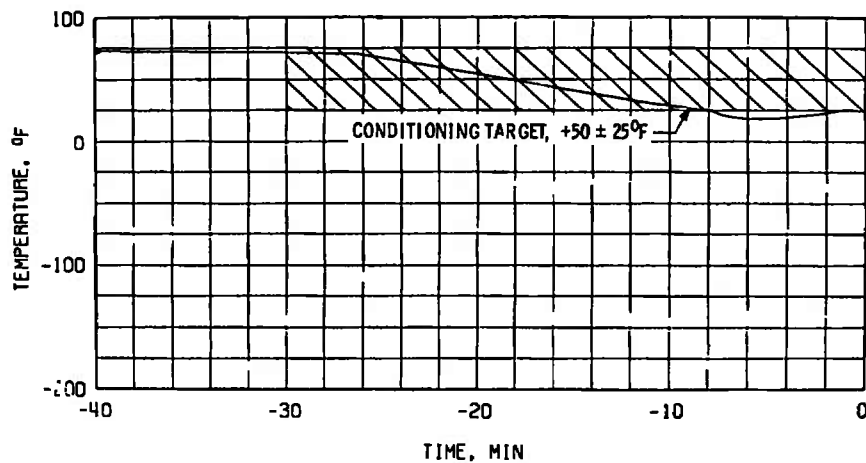


a. Thrust Chamber, TTC-1P

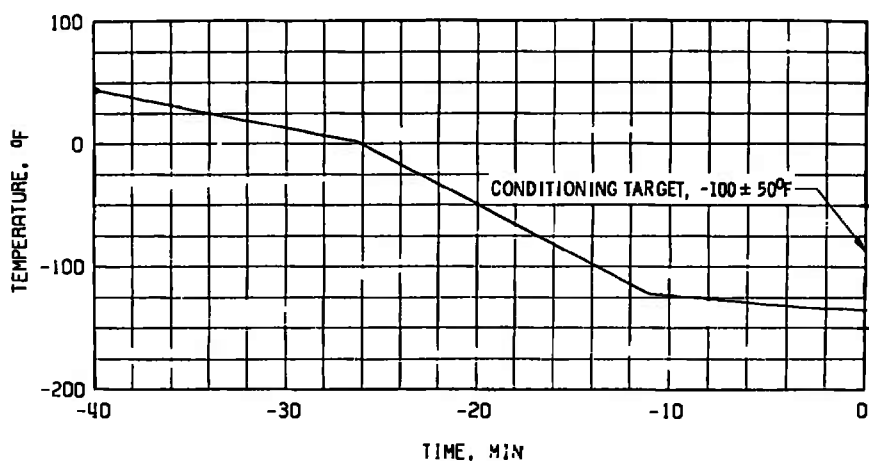


b. Crossover Duct, TFTD

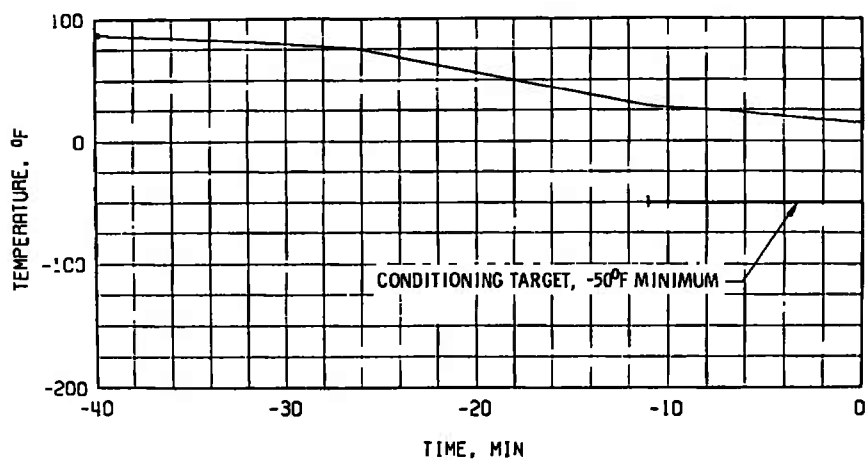
Fig. 70 Thermal Conditioning History of Engine Components, Firing 02A



c. Start Tank Discharge Valve, TSTDVOC



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



e. Gas Generator Control Valve, TGGVRS

Fig. 70 Concluded

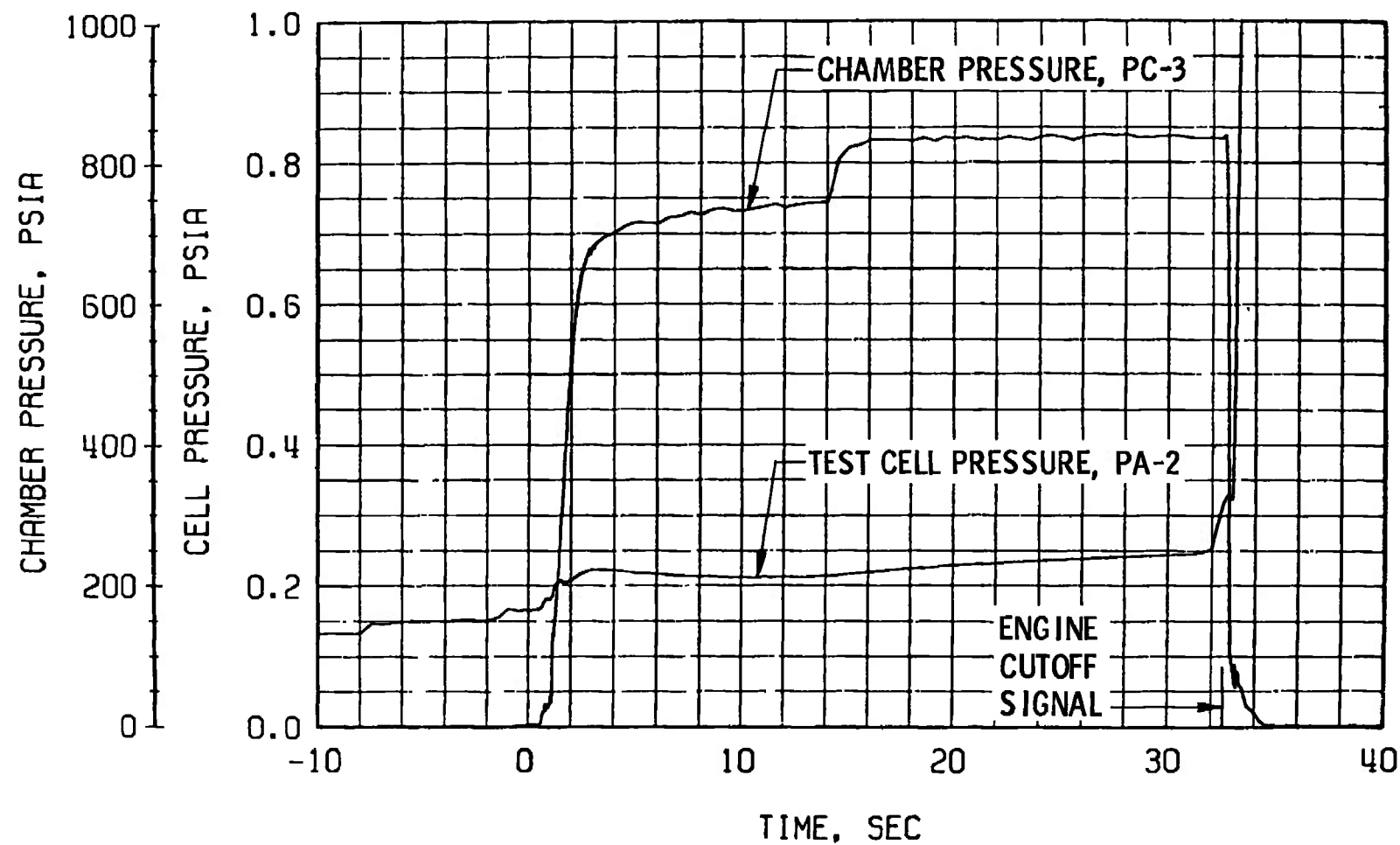
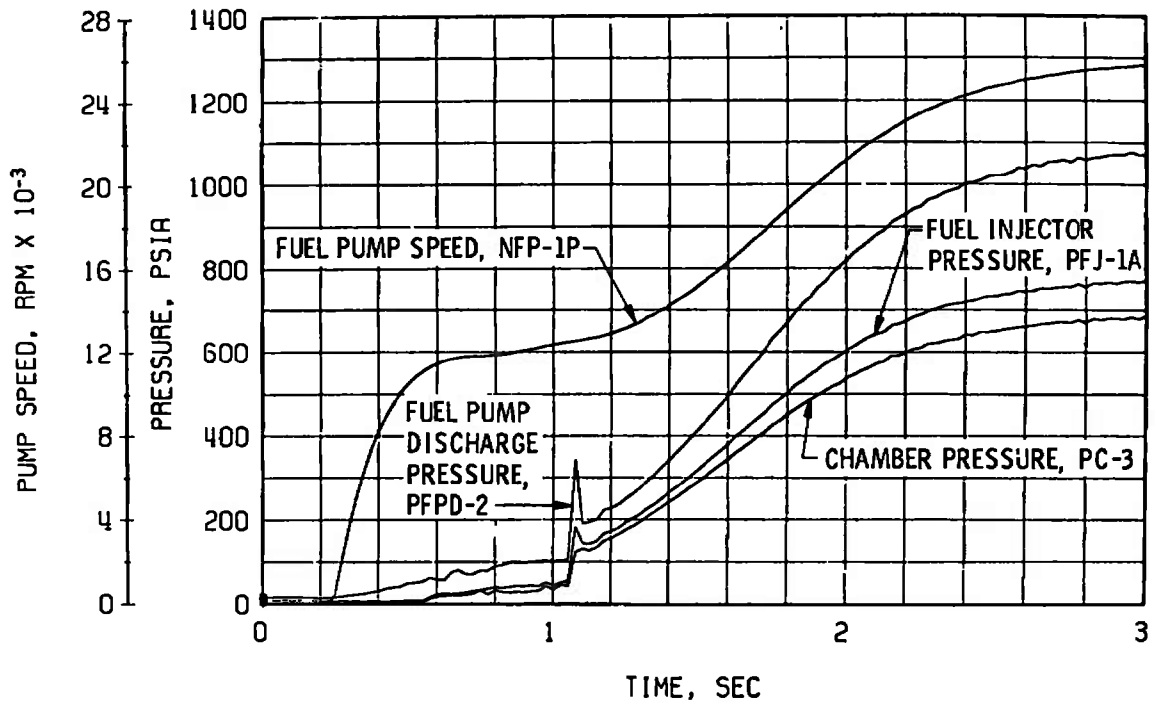
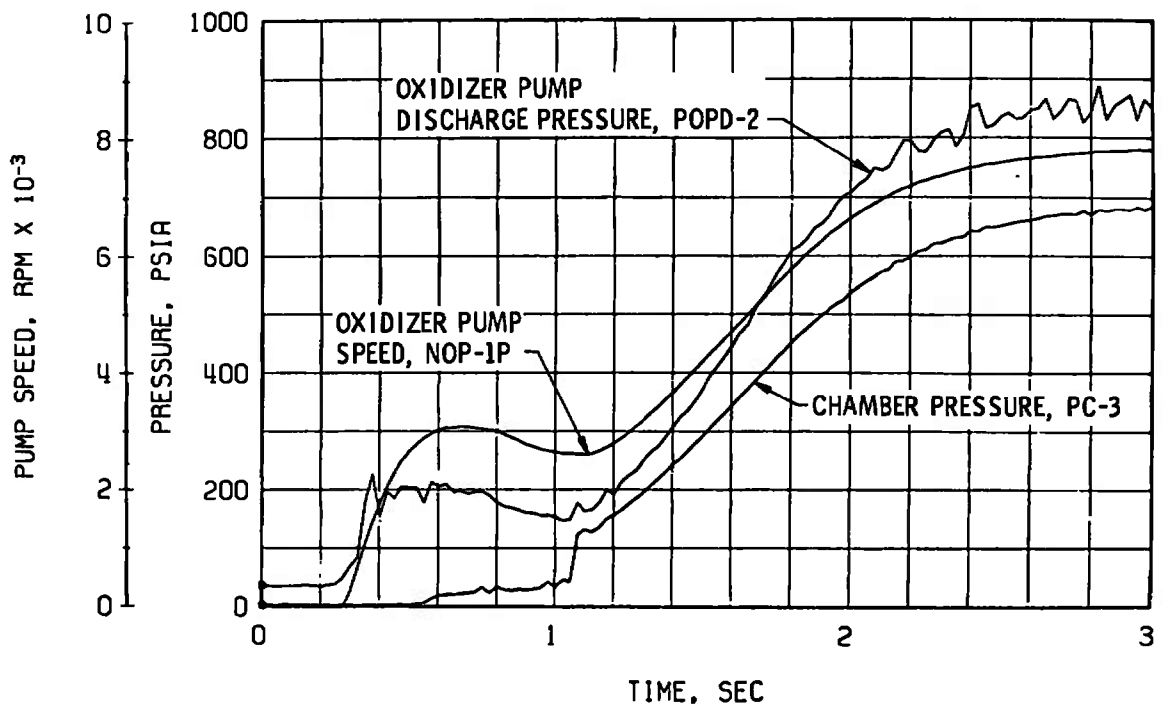


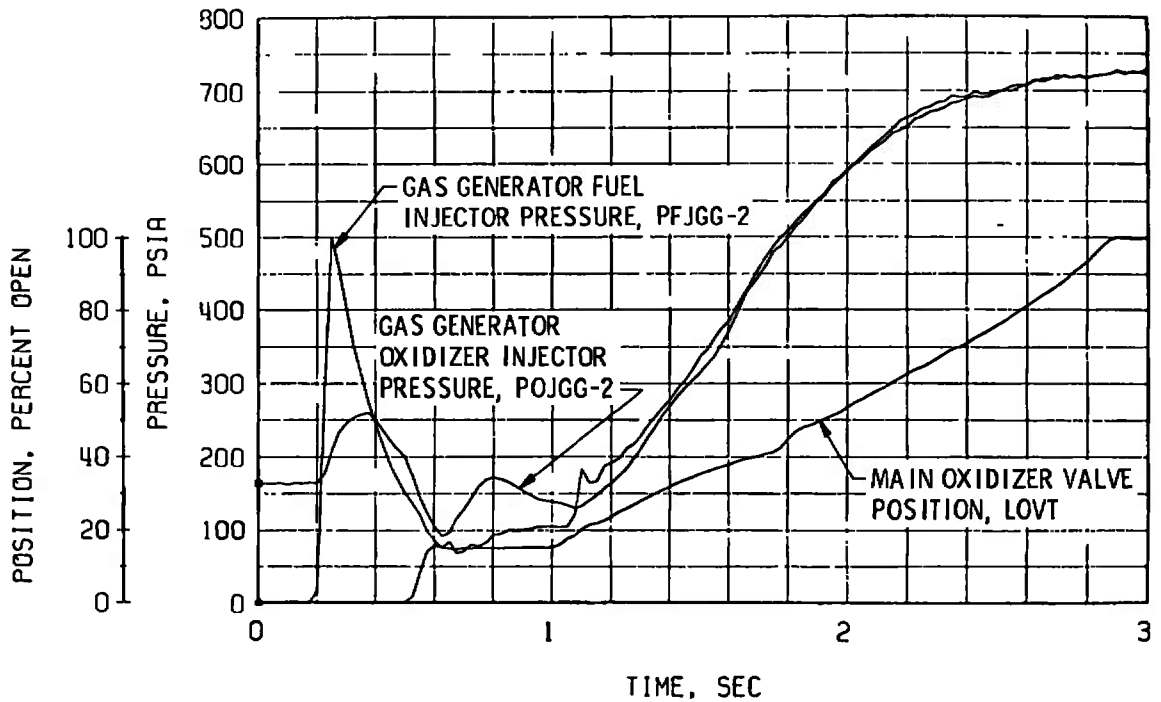
Fig. 71 Engine Ambient and Combustion Chamber Pressures, Firing 02A



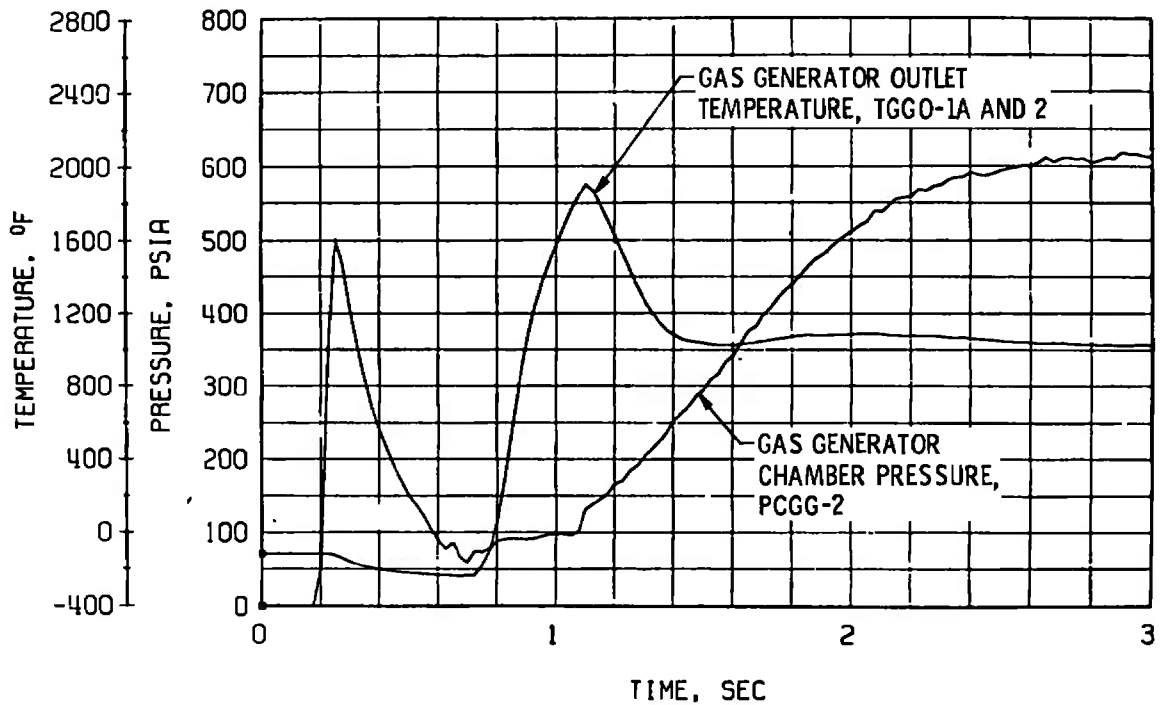
a. Thrust Chamber Fuel System, Start



b. Thrust Chamber Oxidizer System, Start
 Fig. 72 Engine Transient Operation, Firing 02A

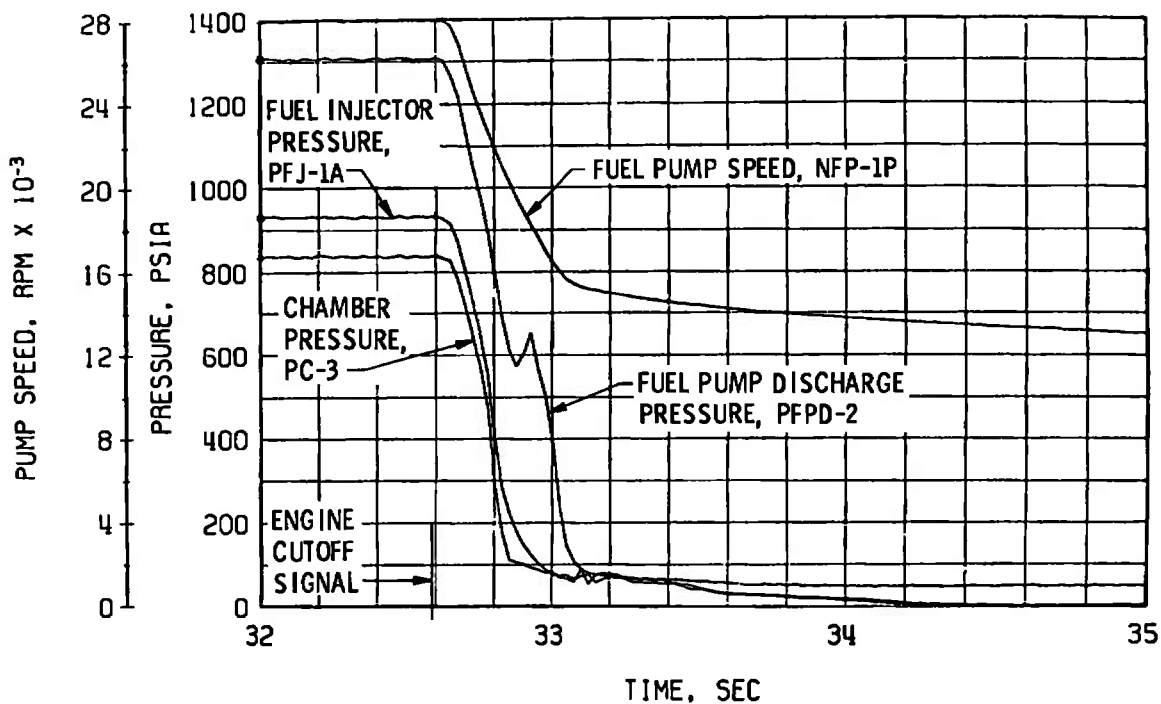


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

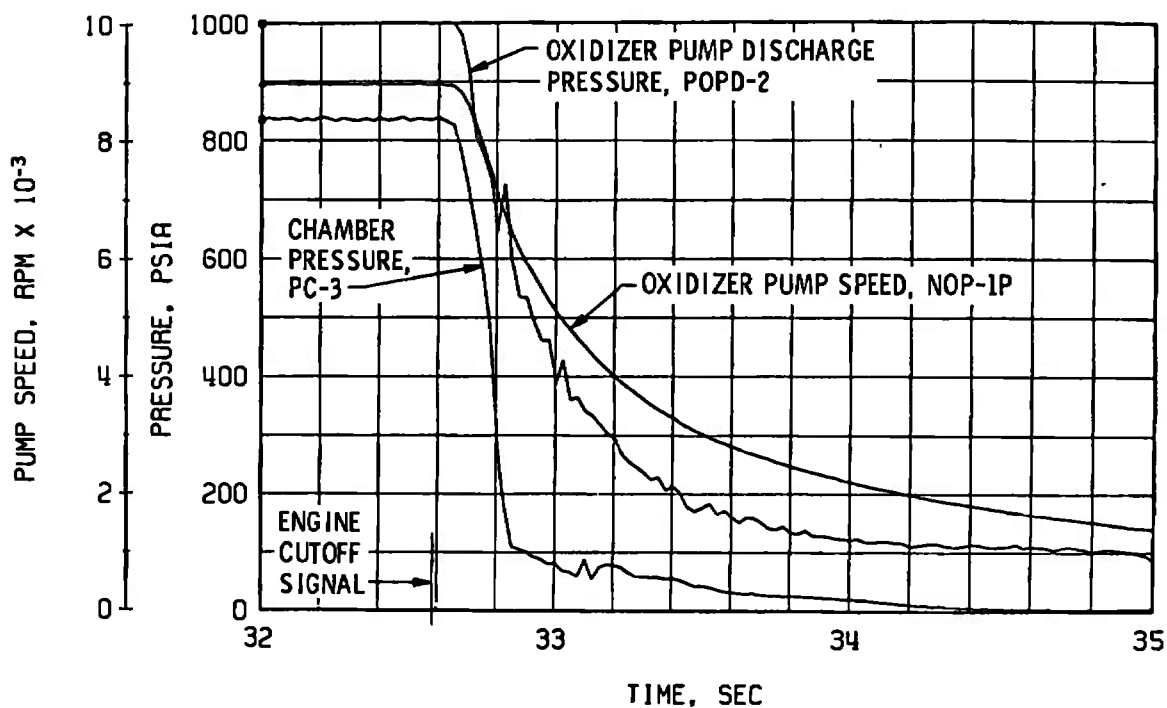


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 72 Continued

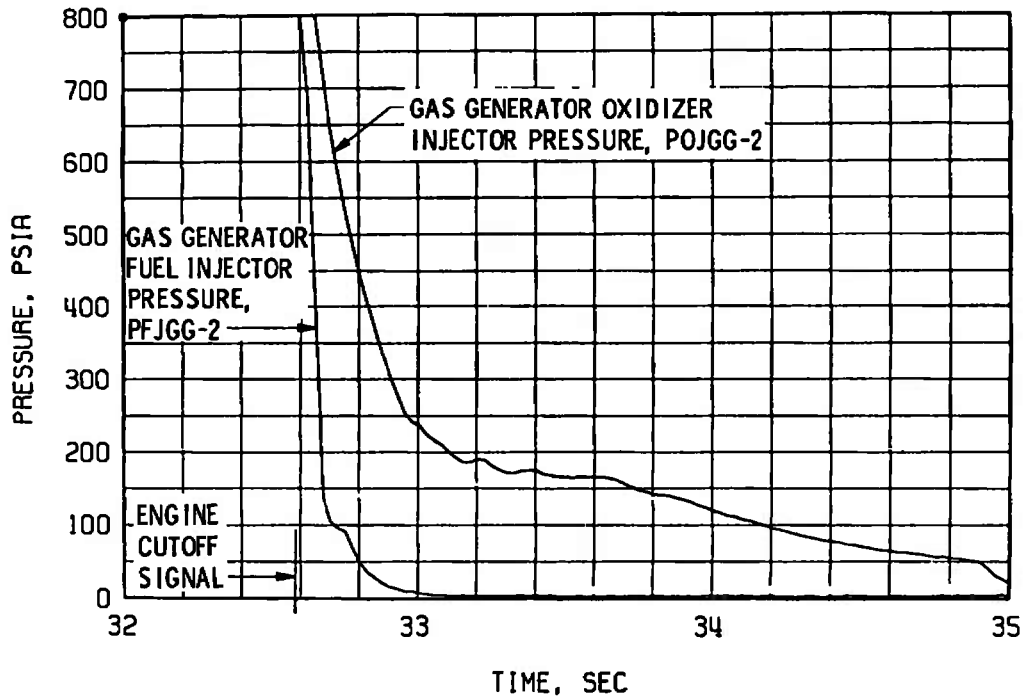


e. Thrust Chamber Fuel System, Shutdown

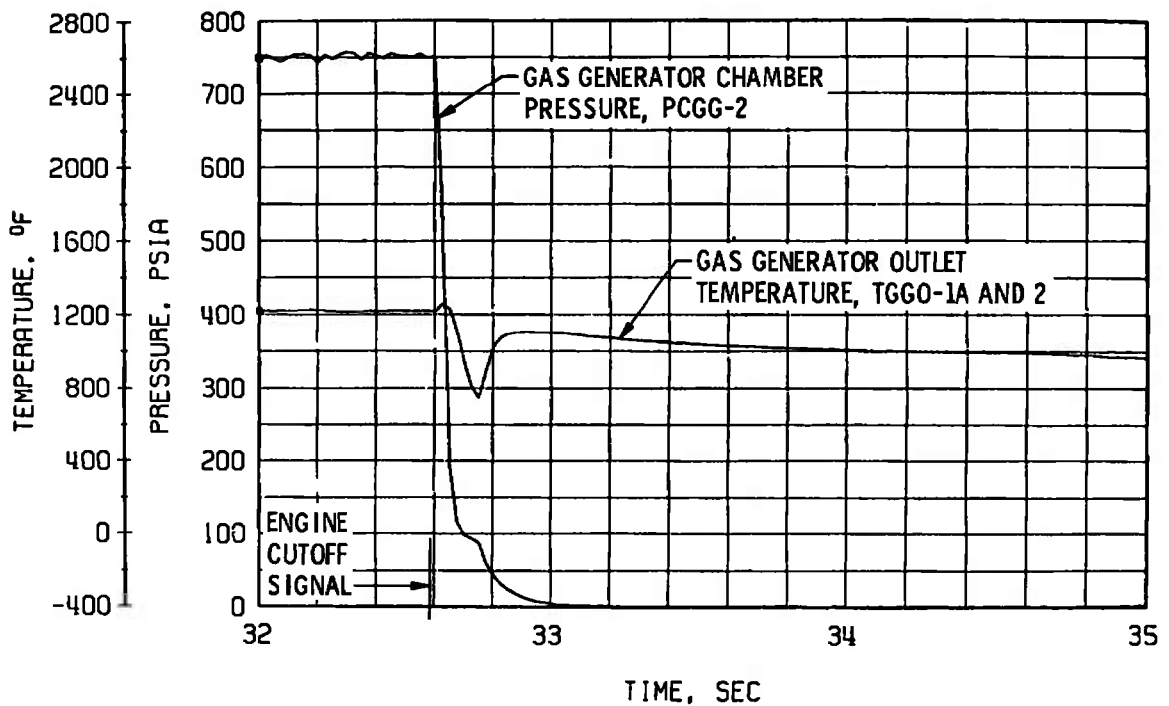


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 72 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 72 Concluded

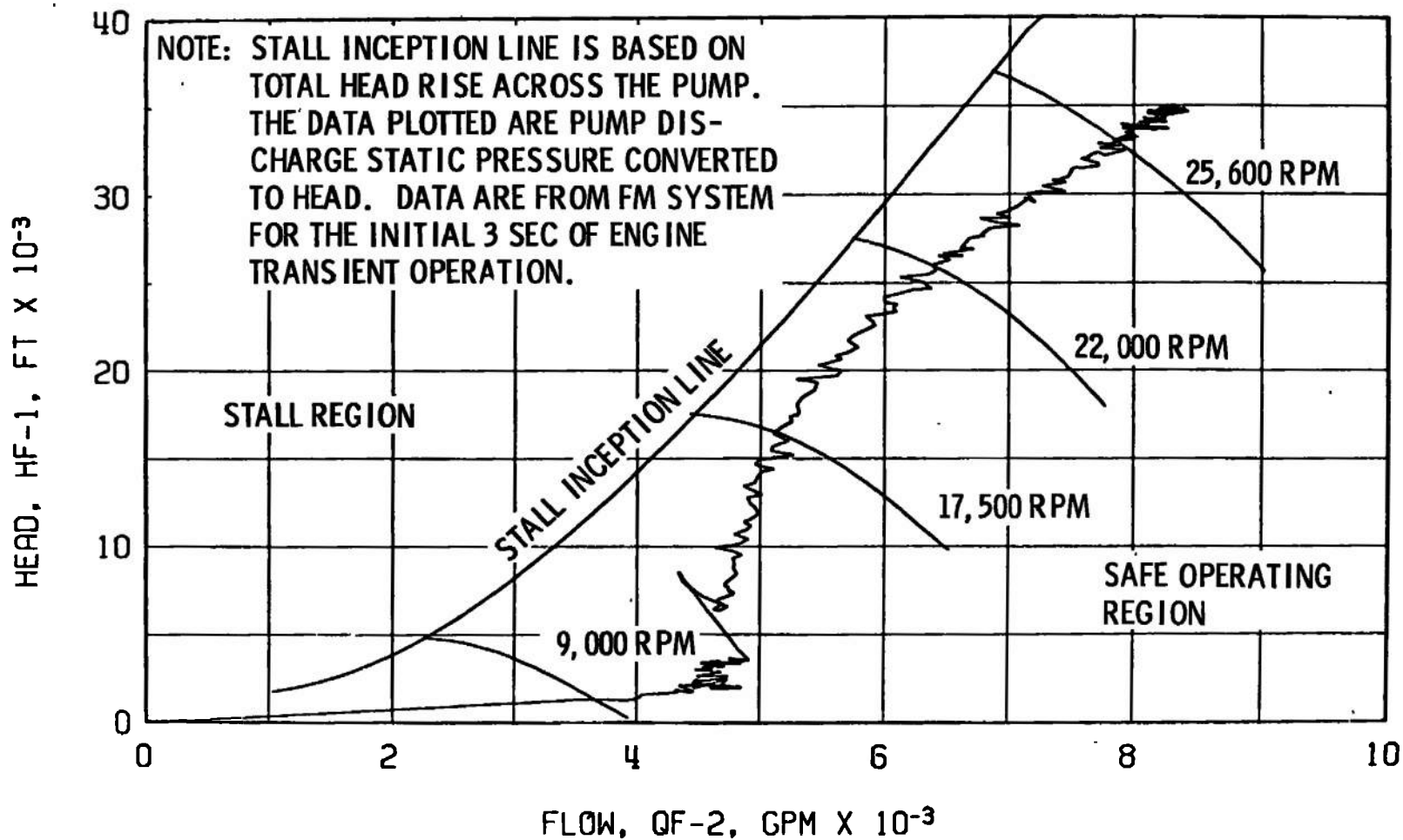
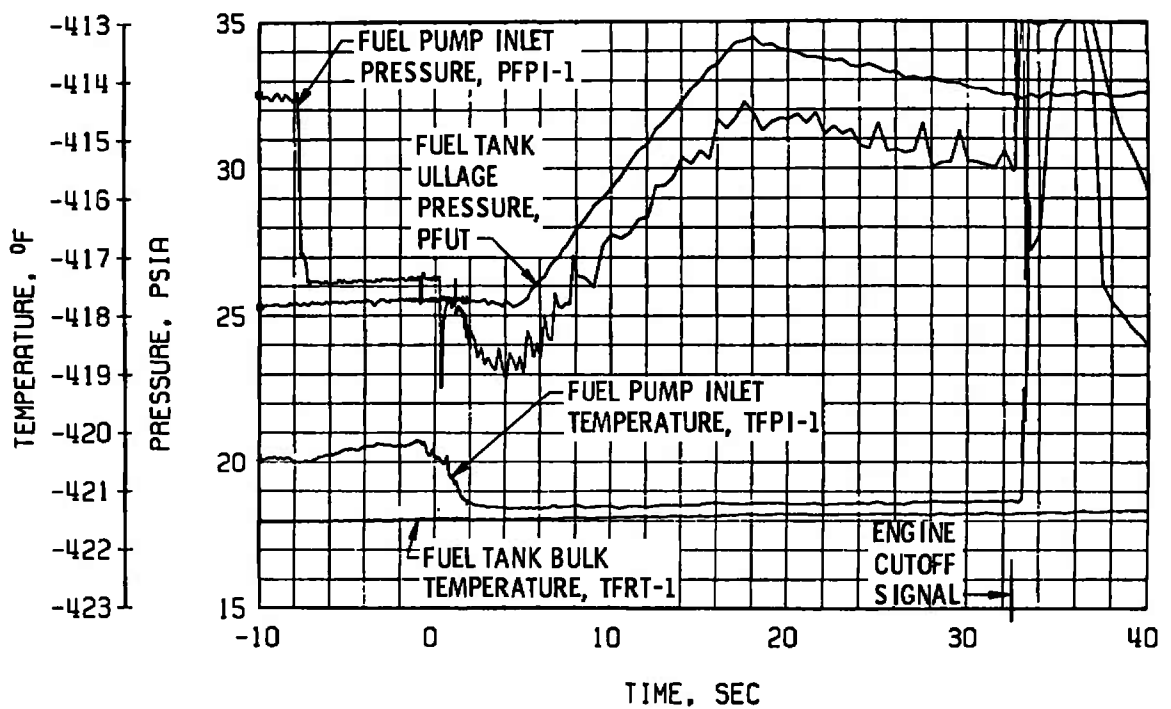
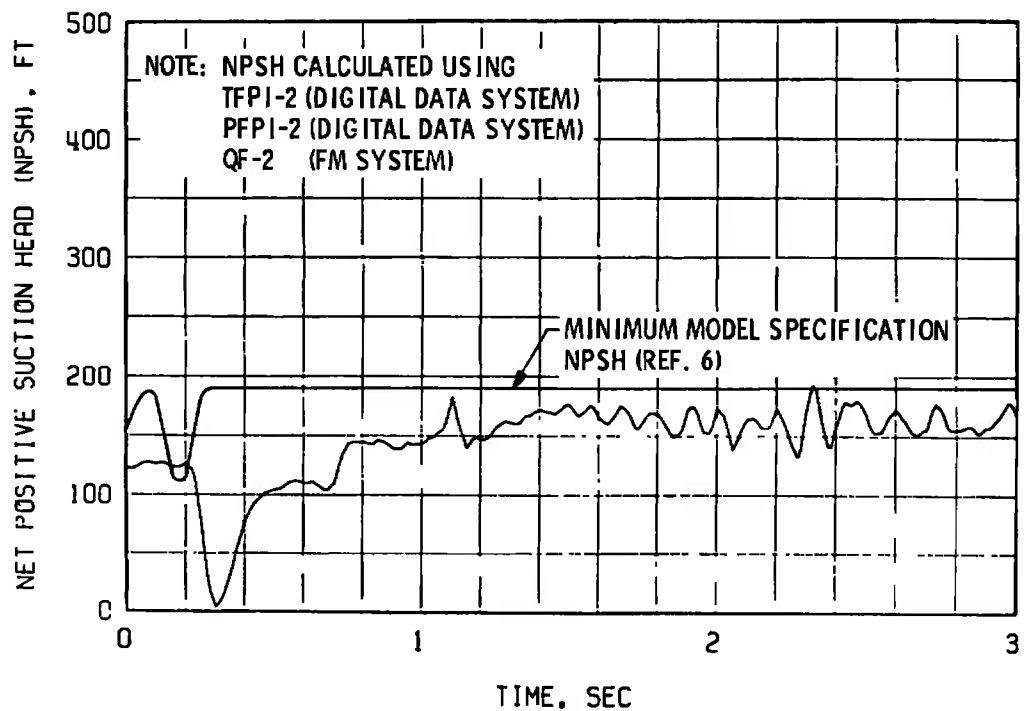


Fig. 73 Fuel Pump Start Transient Performance, Firing 02A

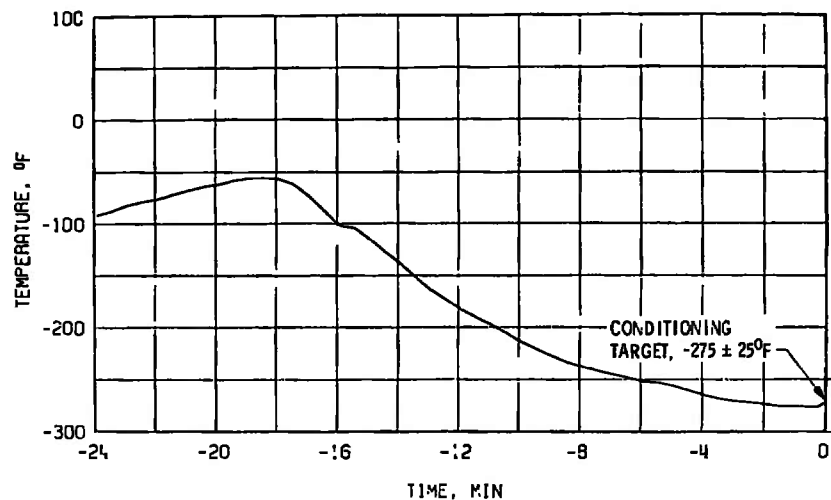


a. Duct Pressure and Temperature Transients

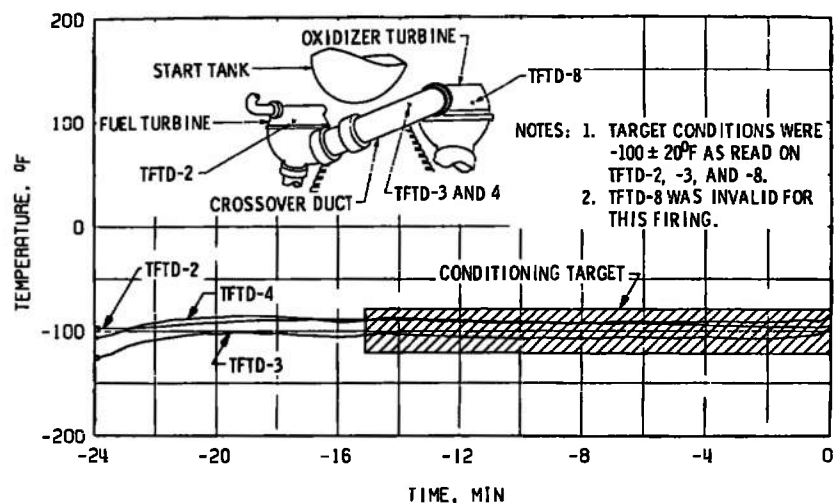


b. Fuel Pump NPSH during Start Transient, Firing 02A

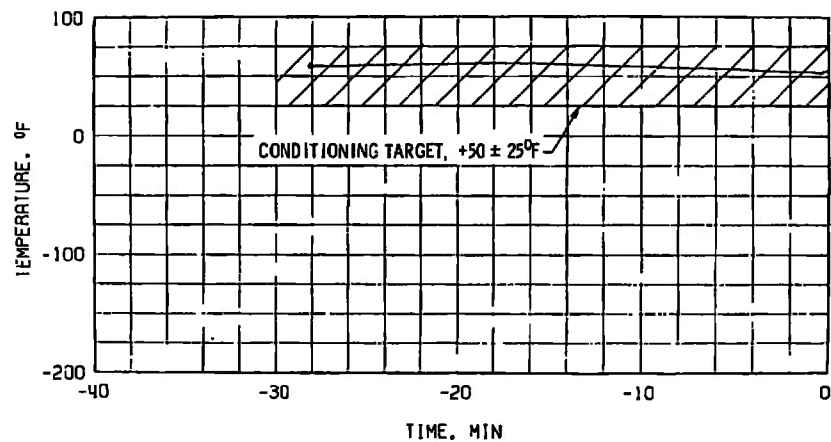
Fig. 74 Fuel Low Pressure Duct Performance, Firing 02A



a. Thrust Chamber, TTC-1P

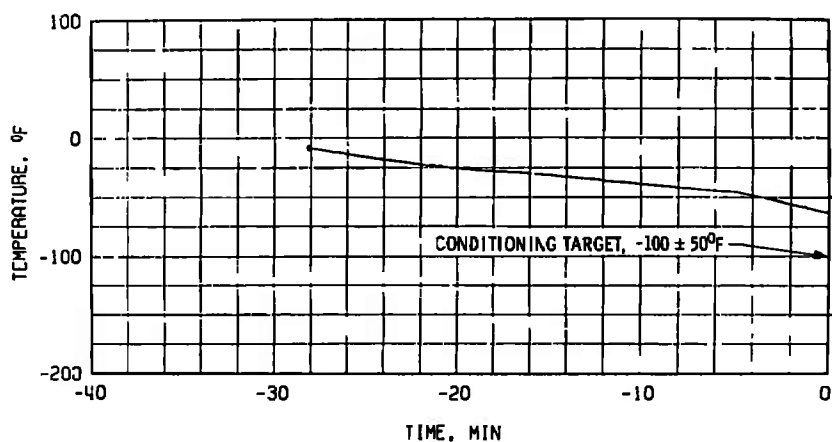


b. Crossover Duct, TFTD

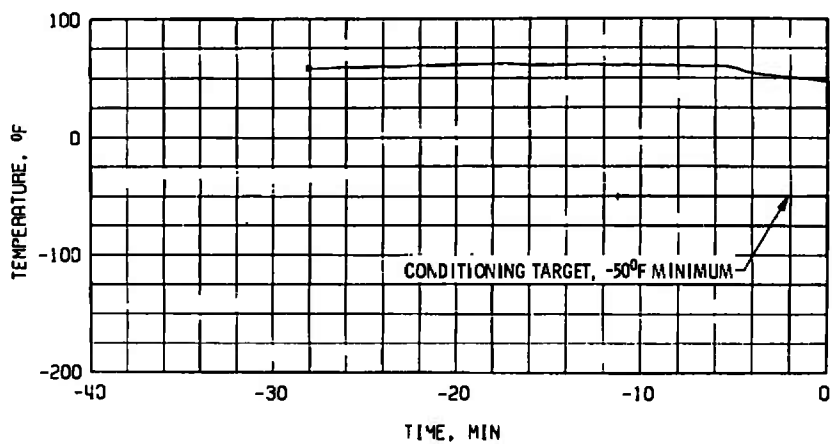


c. Start Tank Discharge Valve, TSTDVOC

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

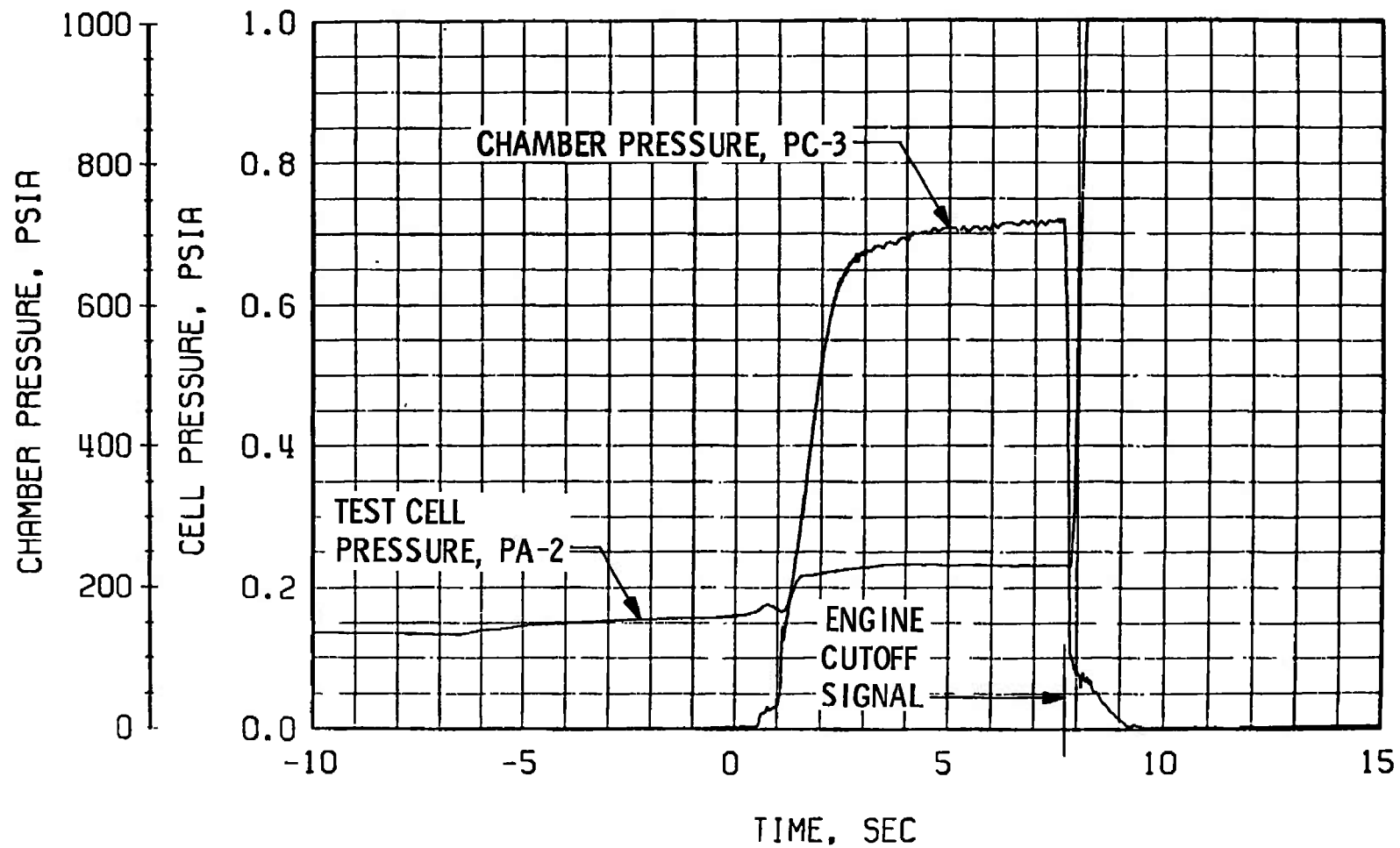
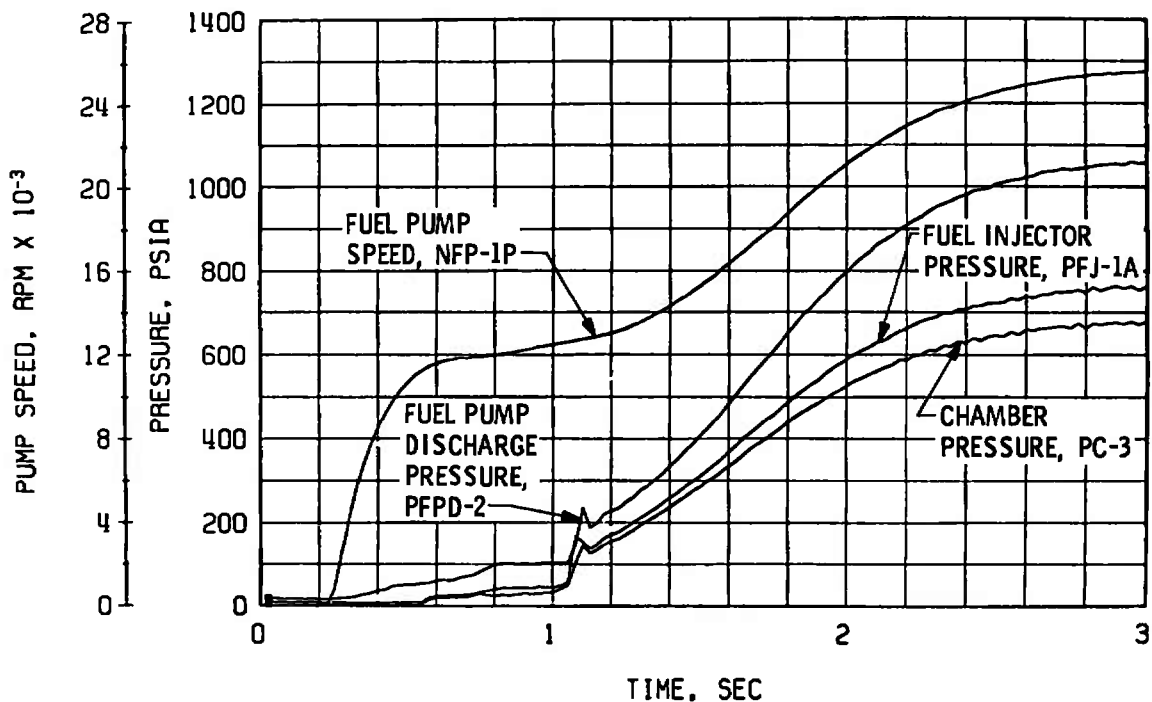
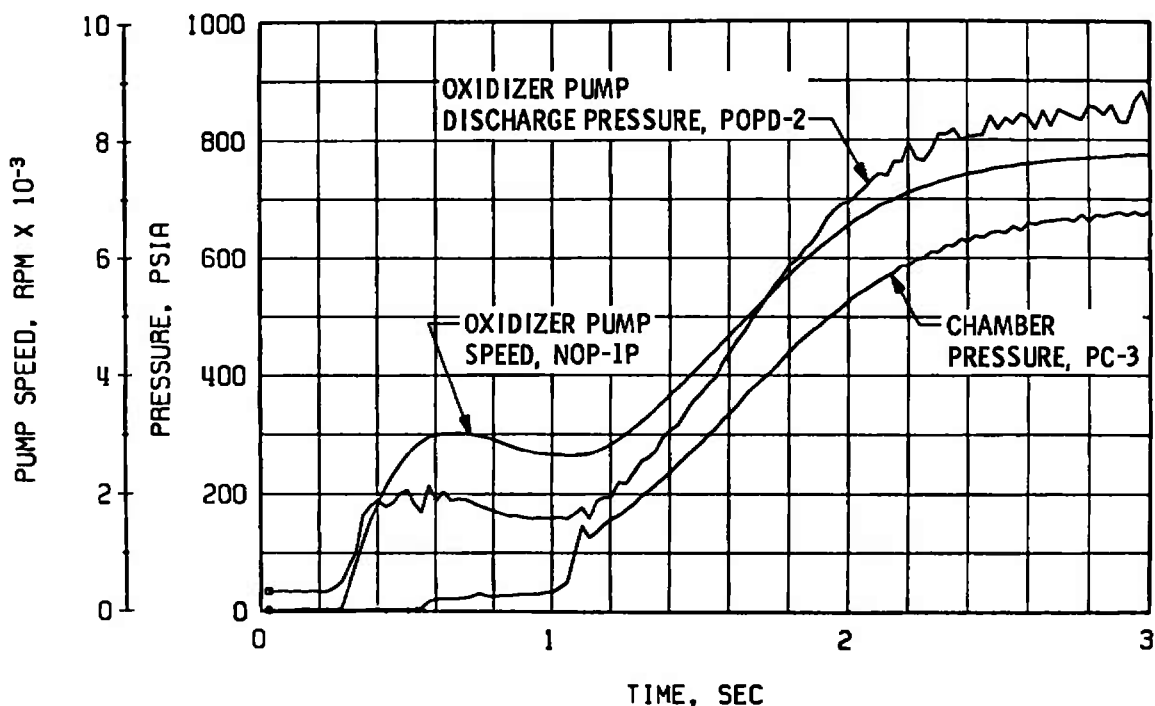


Fig. 76 Engine Ambient and Combustion Chamber Pressures, Firing 02B

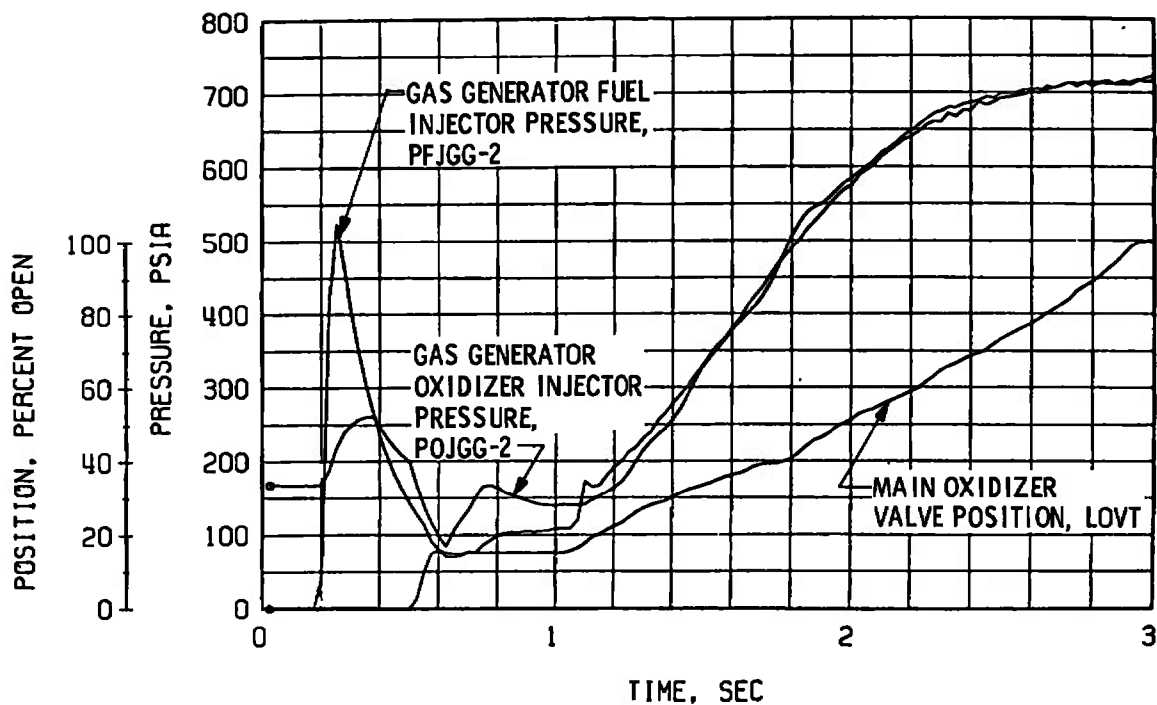


a. Thrust Chamber Fuel System, Start

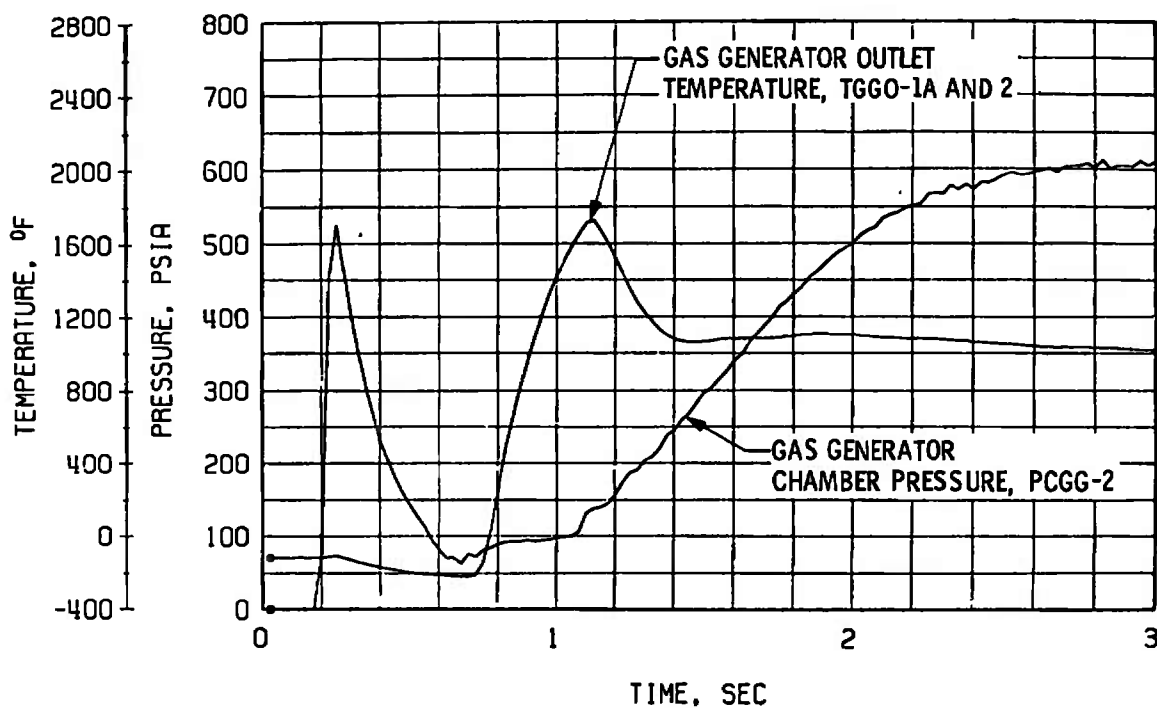


b. Thrust Chamber Oxidizer System, Start

Fig. 77 Engine Transient Operation, Firing 02B

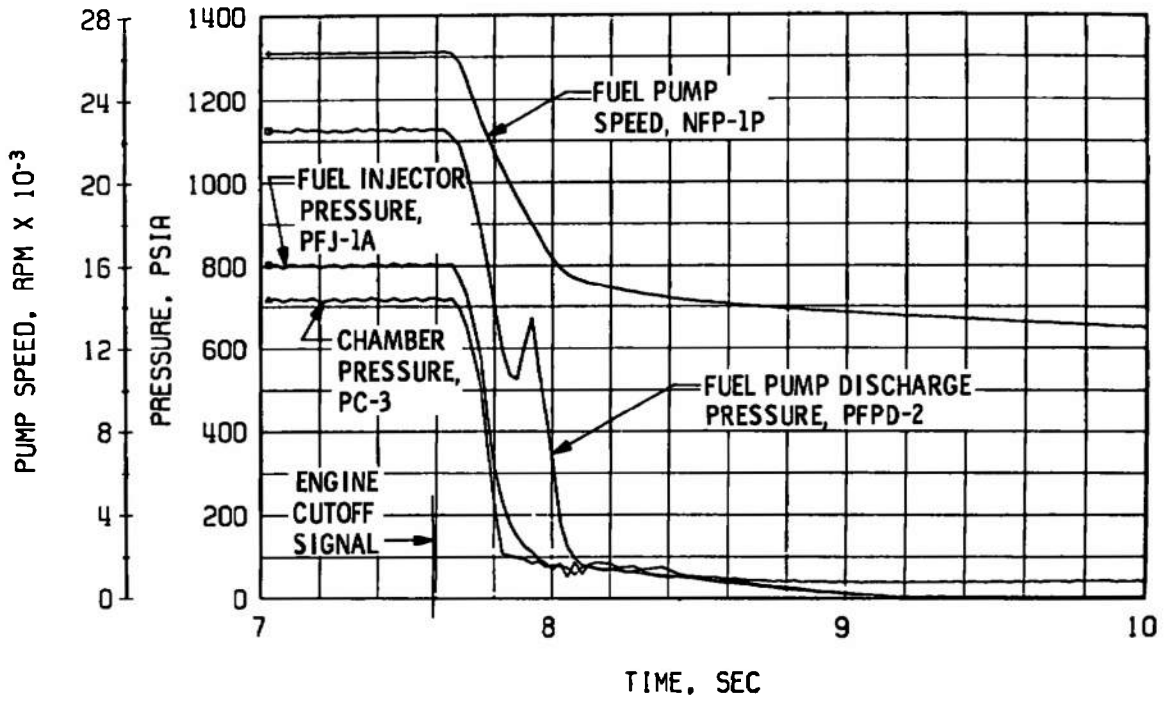


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

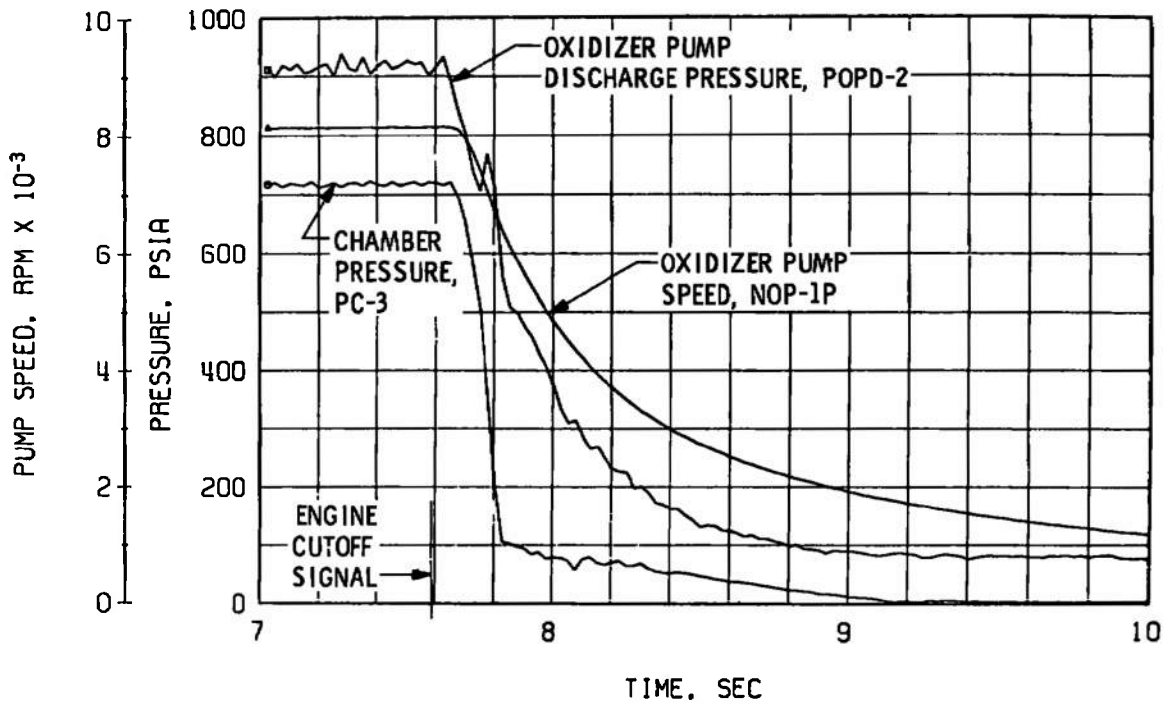


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 77 Continued



e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 77 Continued

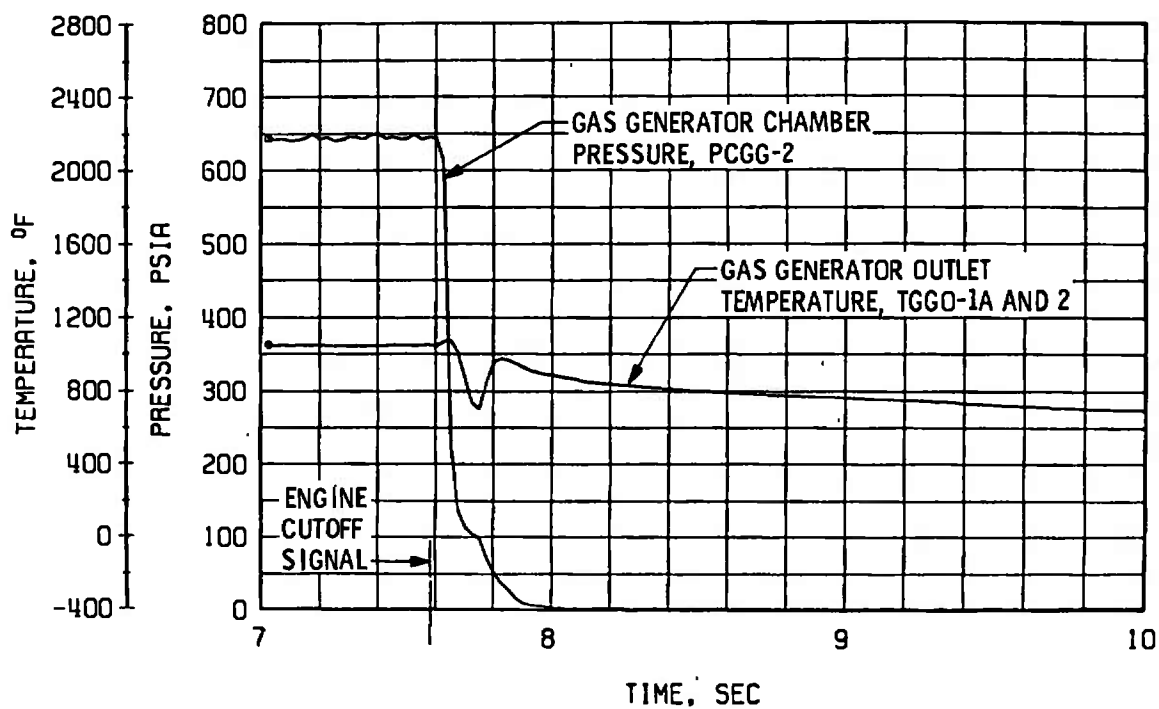
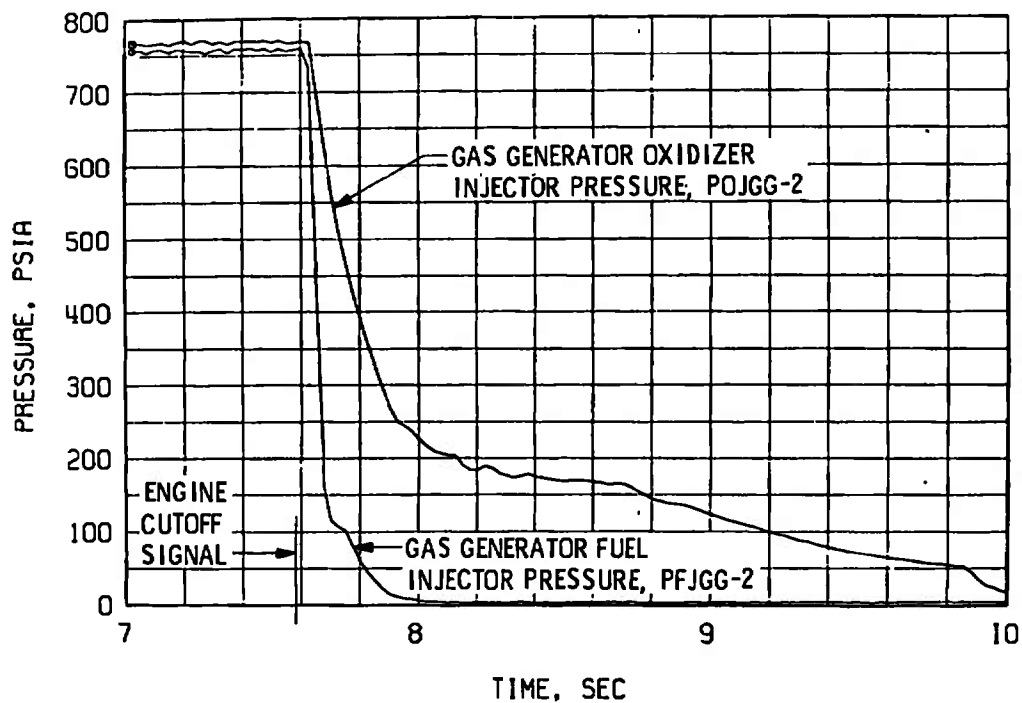


Fig. 77 Concluded

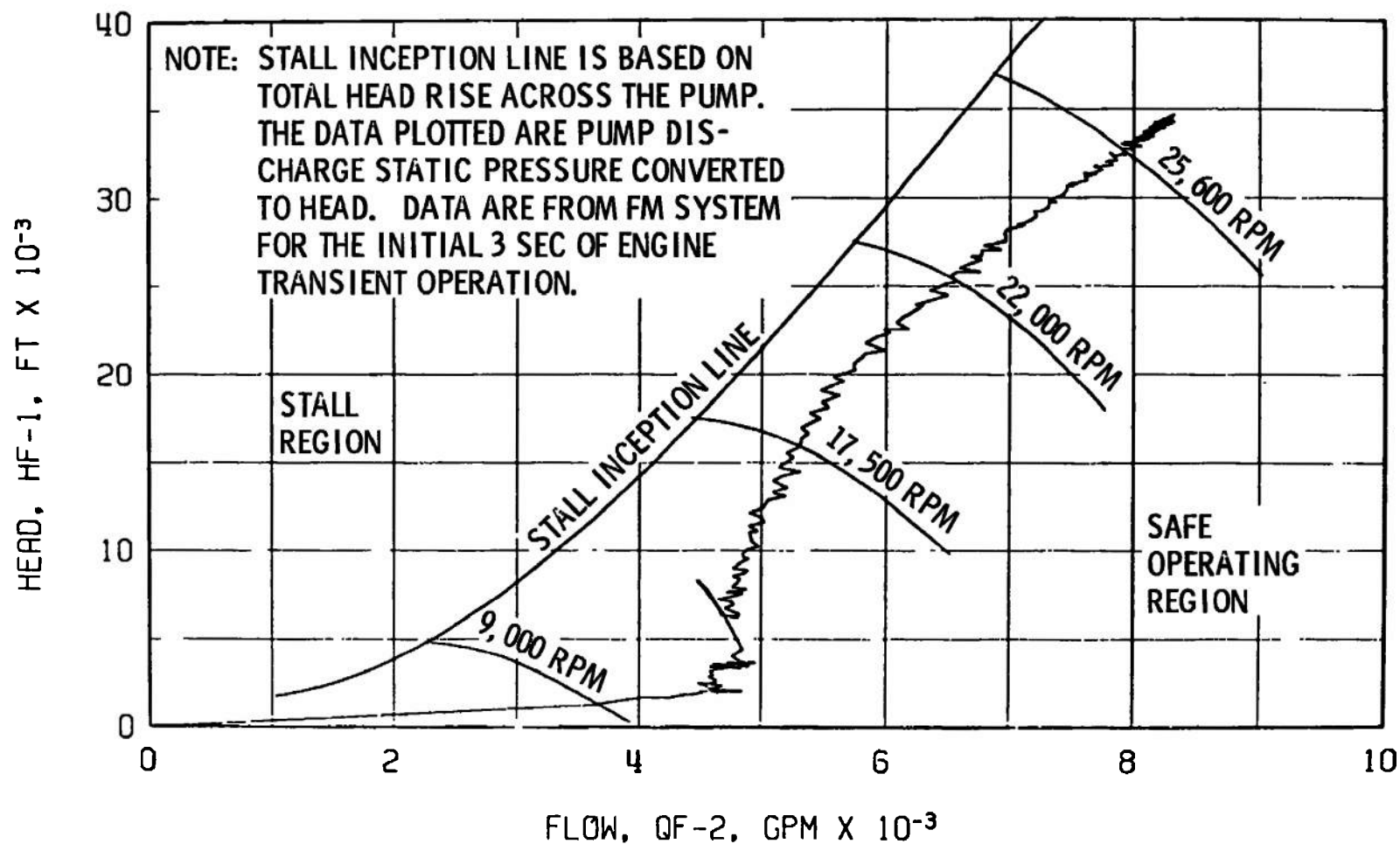
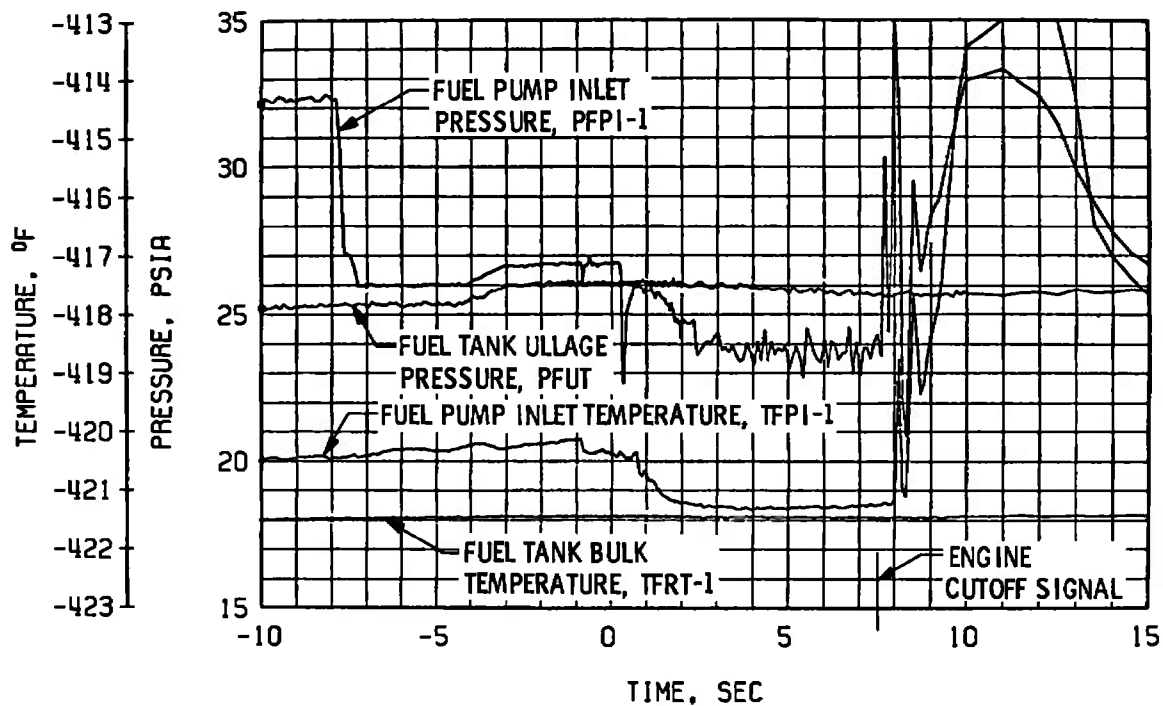
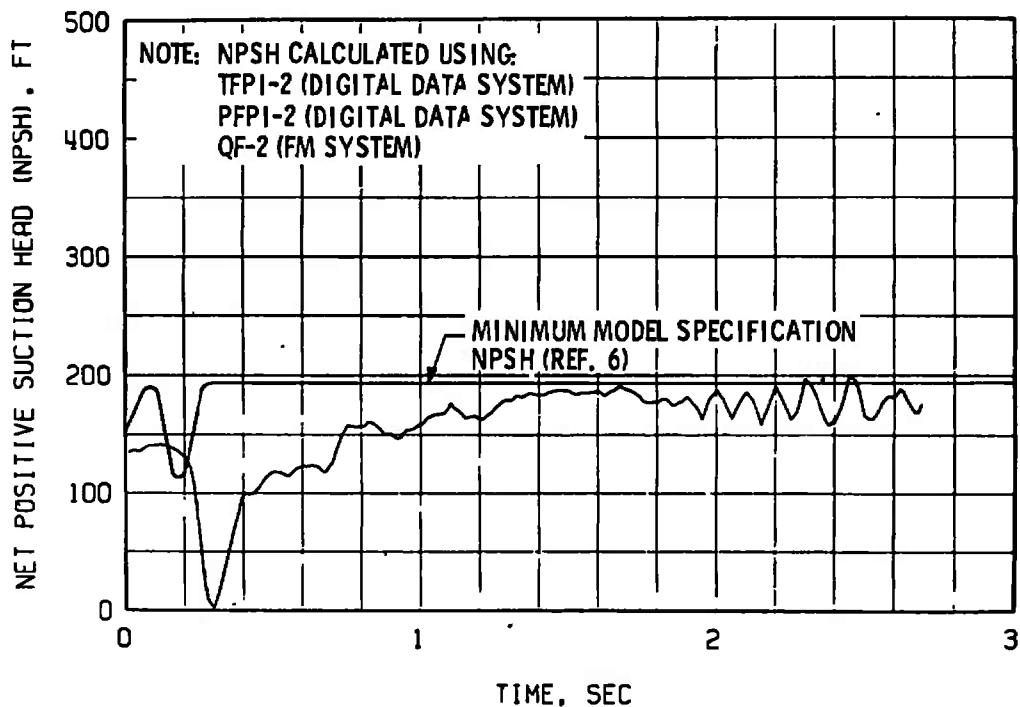


Fig. 78 Fuel Pump Start Transient Performance, Firing 02B

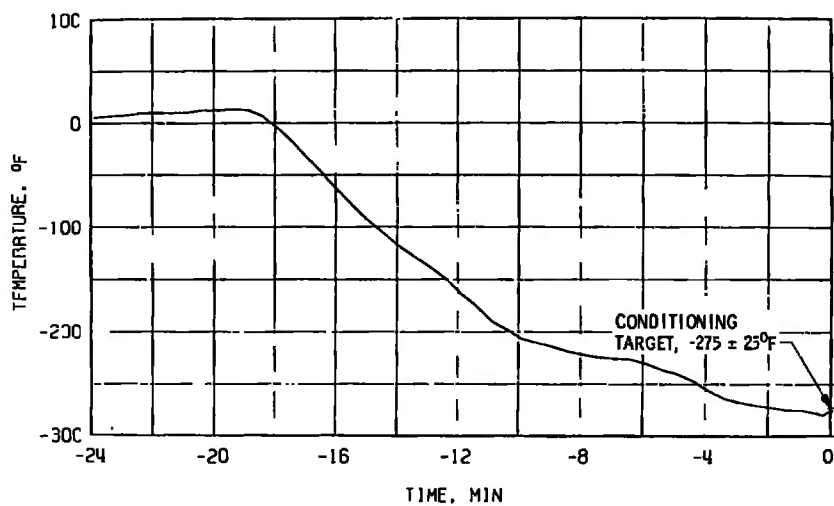


a. Duct Pressure and Temperature Transients

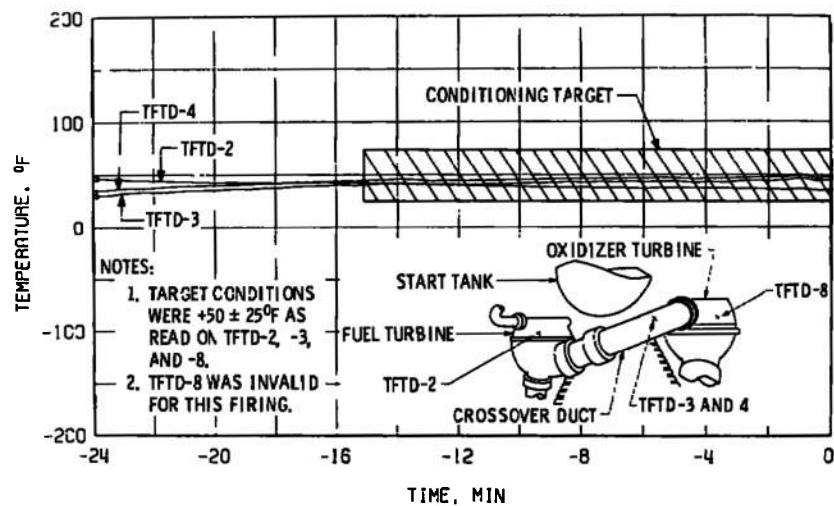


b. Fuel Pump NPSH during Start Transient, Firing 02B

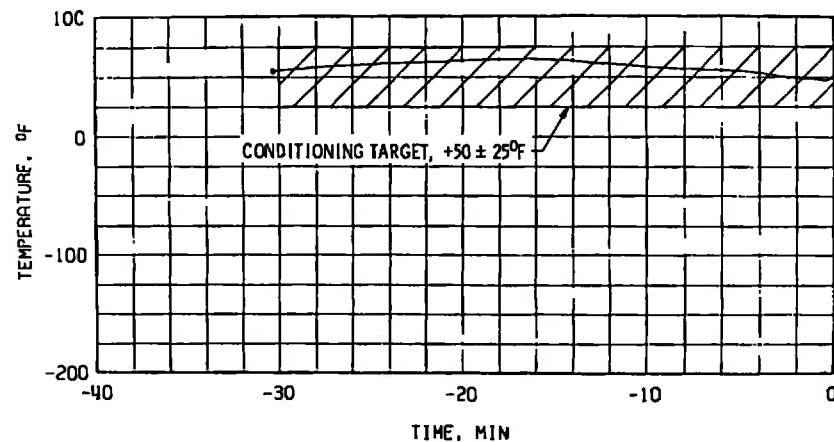
Fig. 79 Fuel Low Pressure Duct Performance, Firing 02B



a. Thrust Chamber, TTC-1P

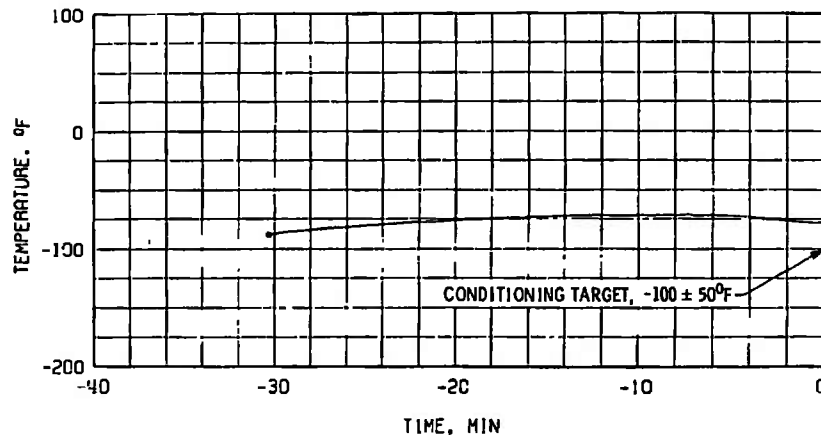


b. Crossover Duct, TTFD

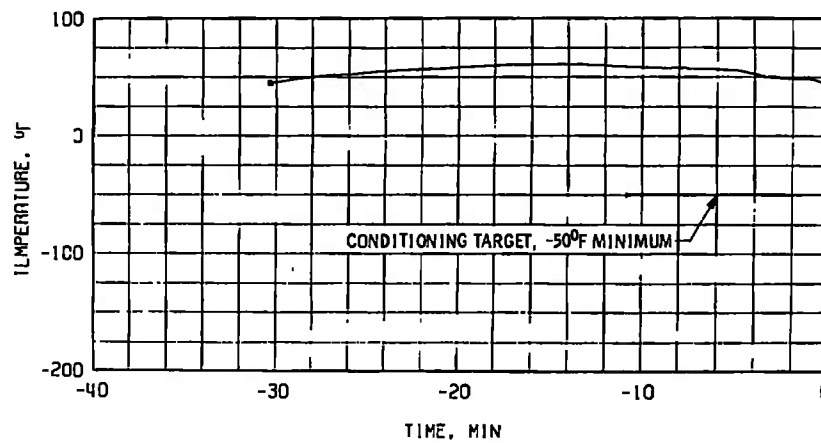


c. Start Tank Discharge Valve, TSTDVOC

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

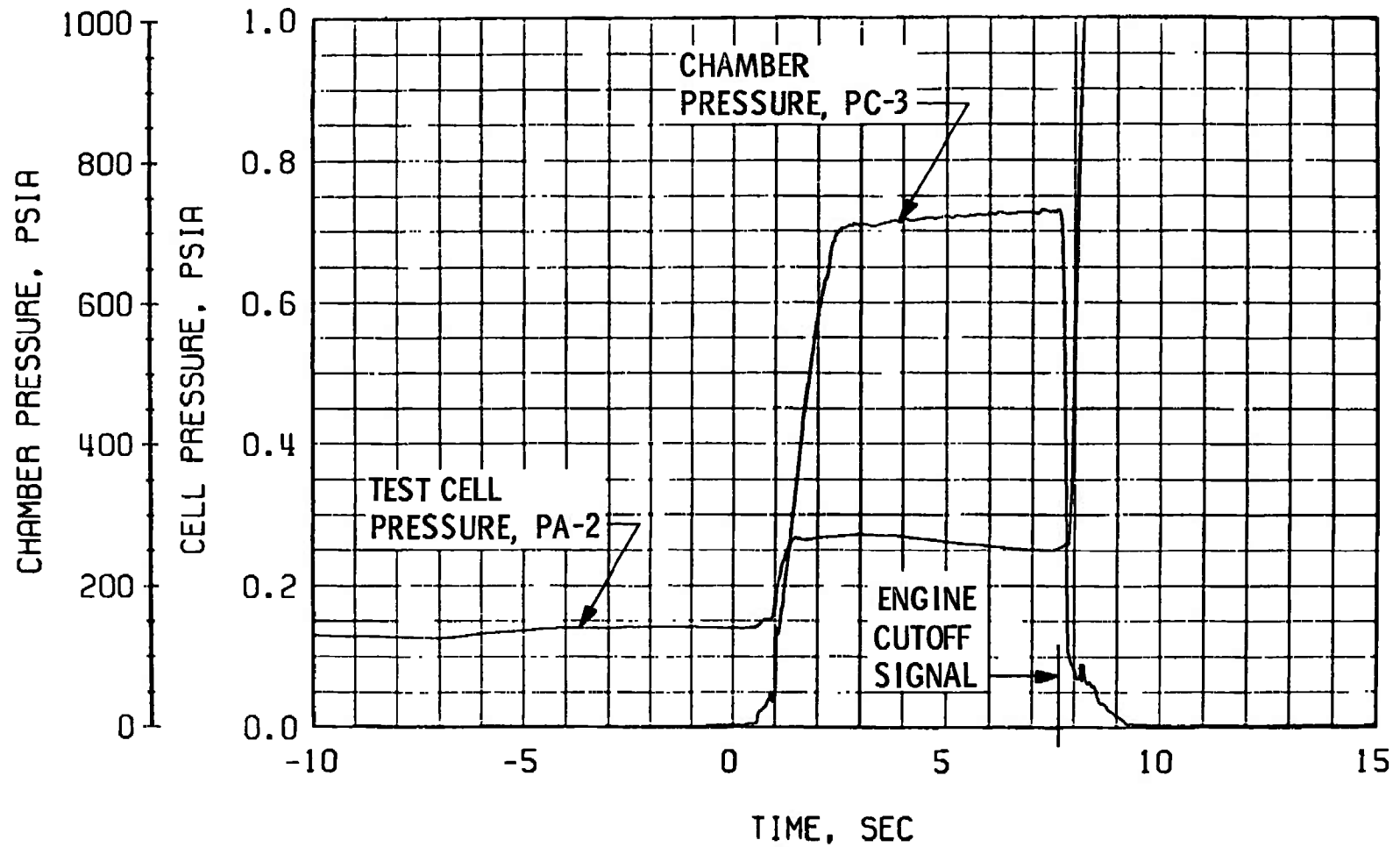
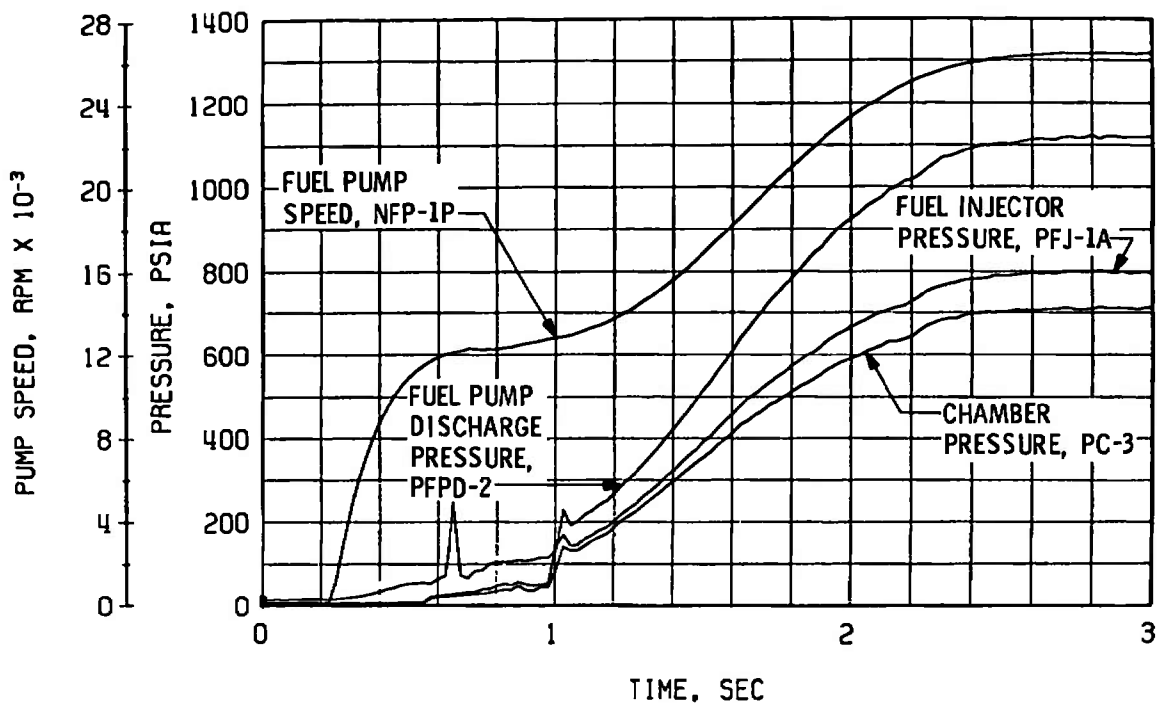
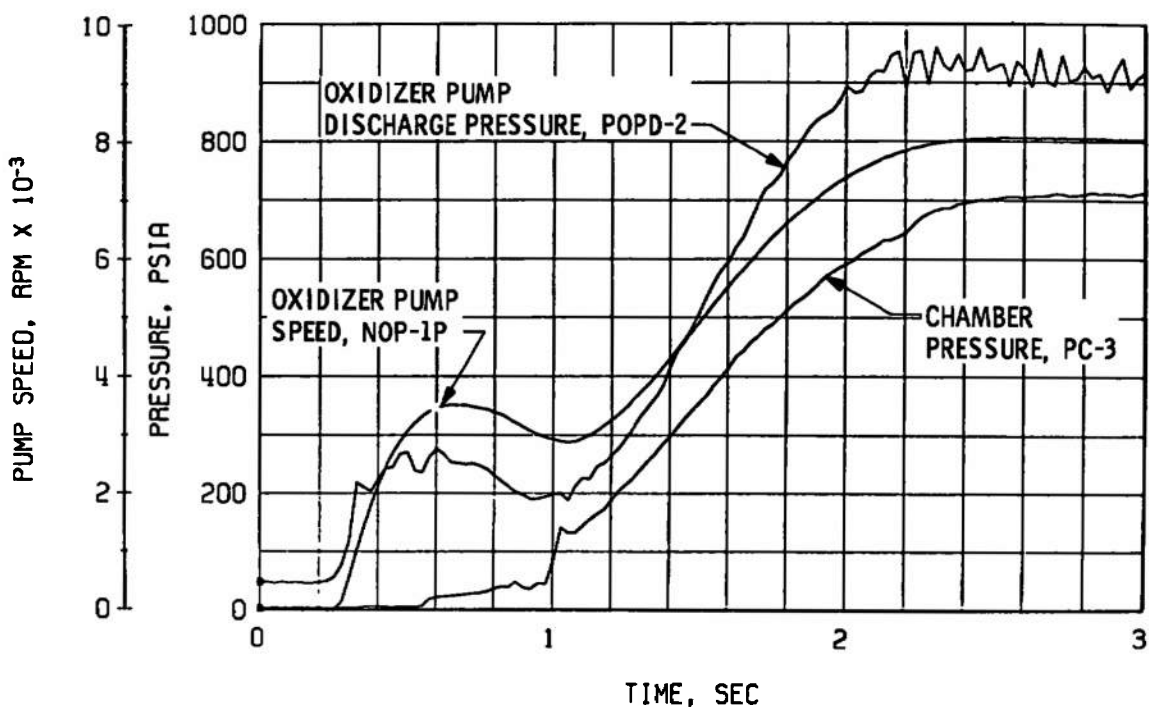


Fig. 81 Engine Ambient and Combustion Chamber Pressures, Firing 02C

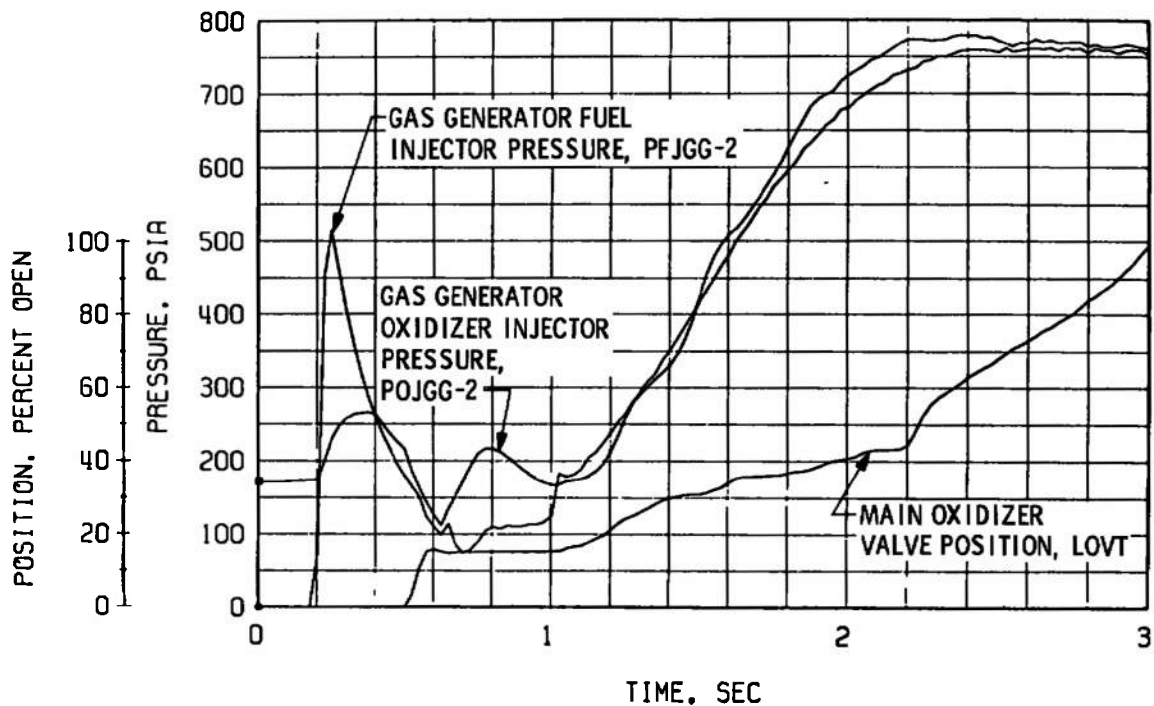


a. Thrust Chamber Fuel System, Start

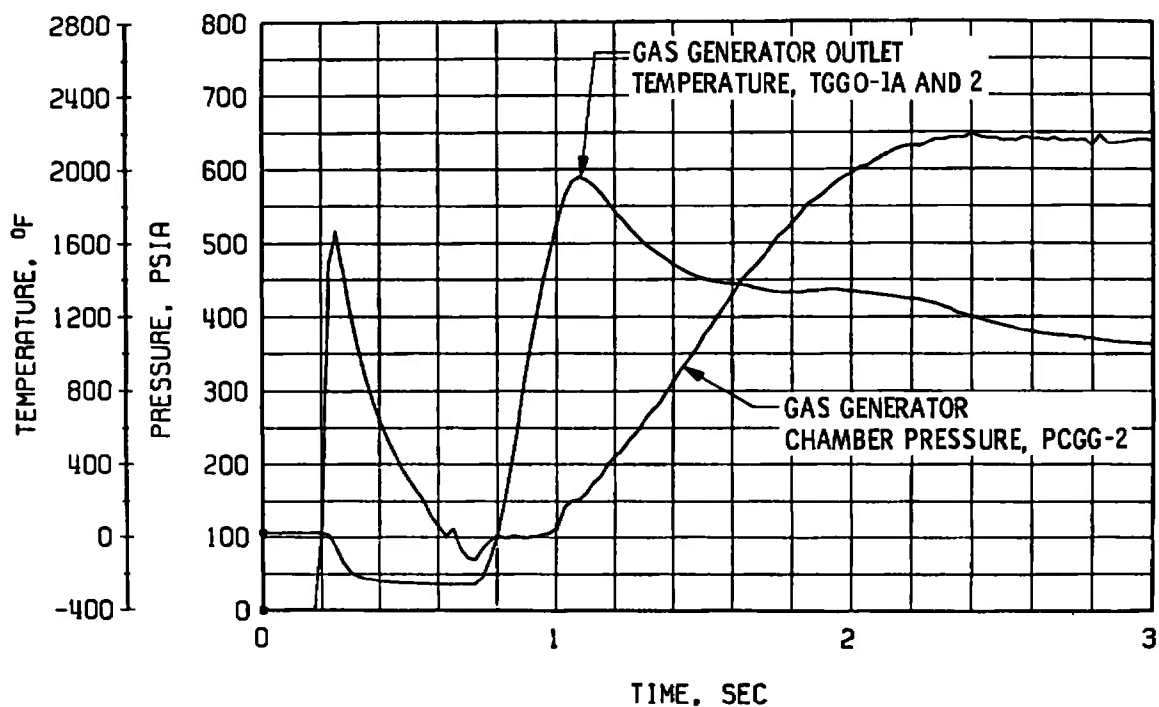


b. Thrust Chamber Oxidizer System, Start

Fig. 82 Engine Transient Operation, Firing 02C

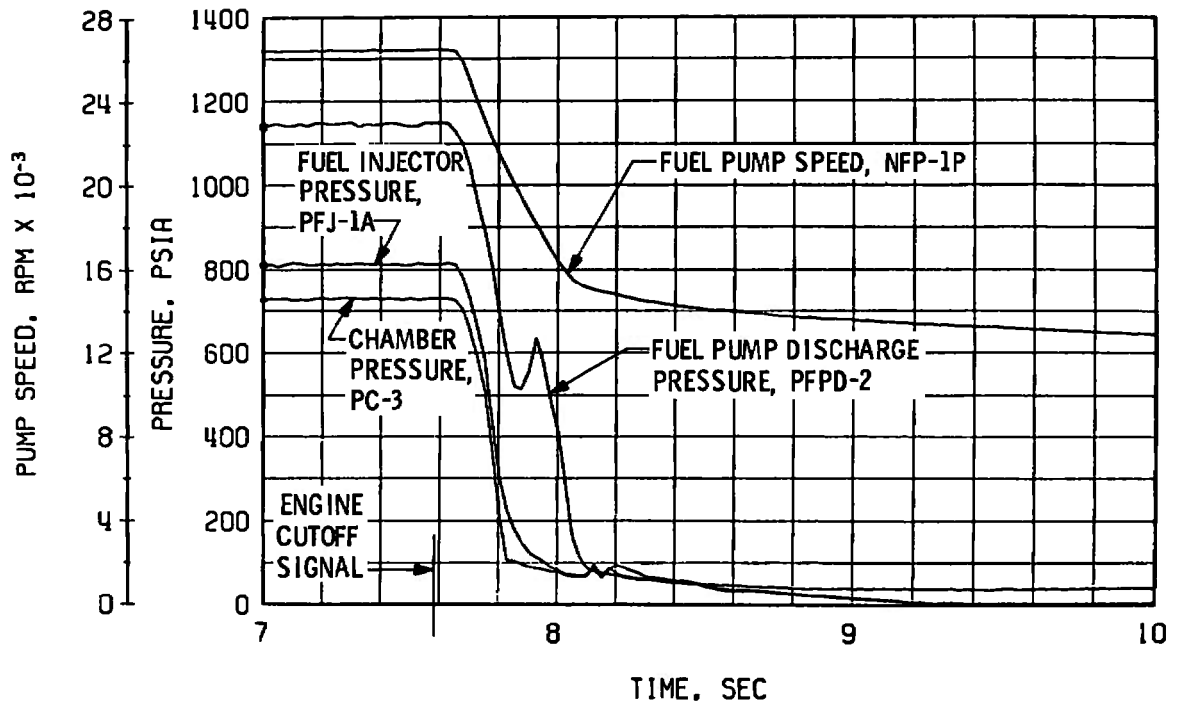


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

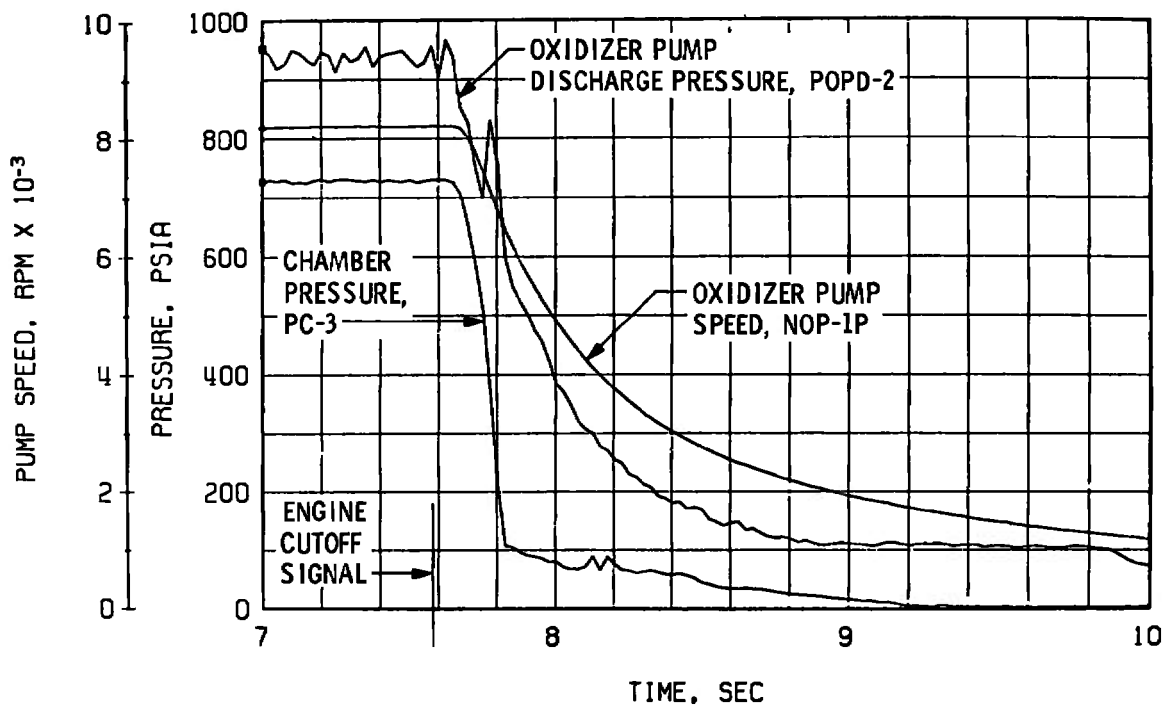


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 82 Continued

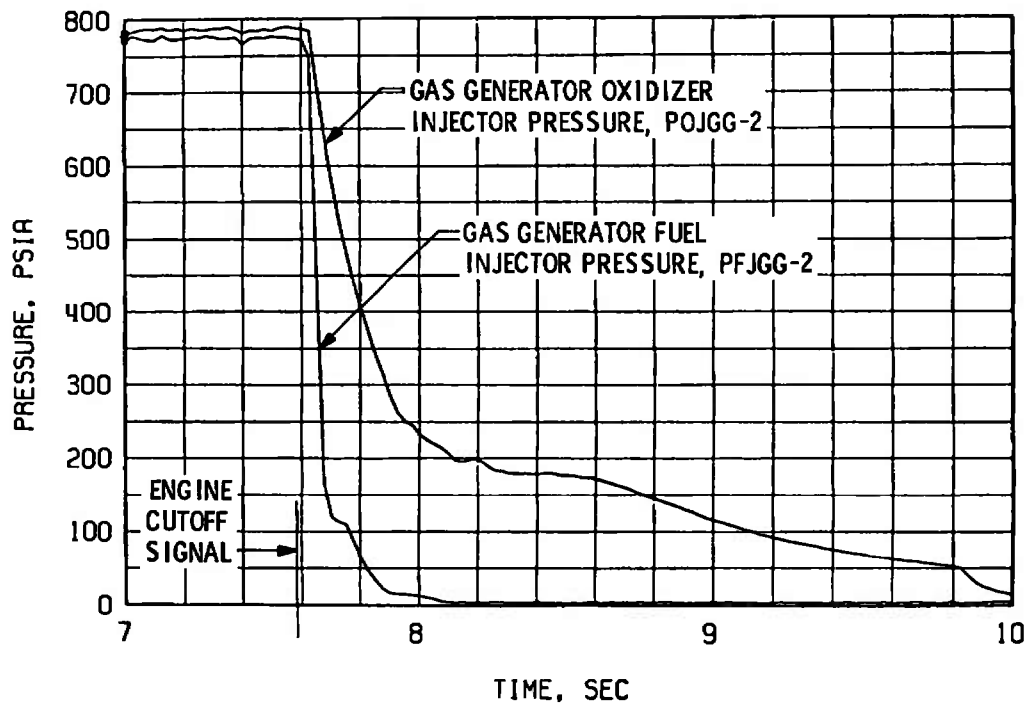


e. Thrust Chamber Fuel System, Shutdown

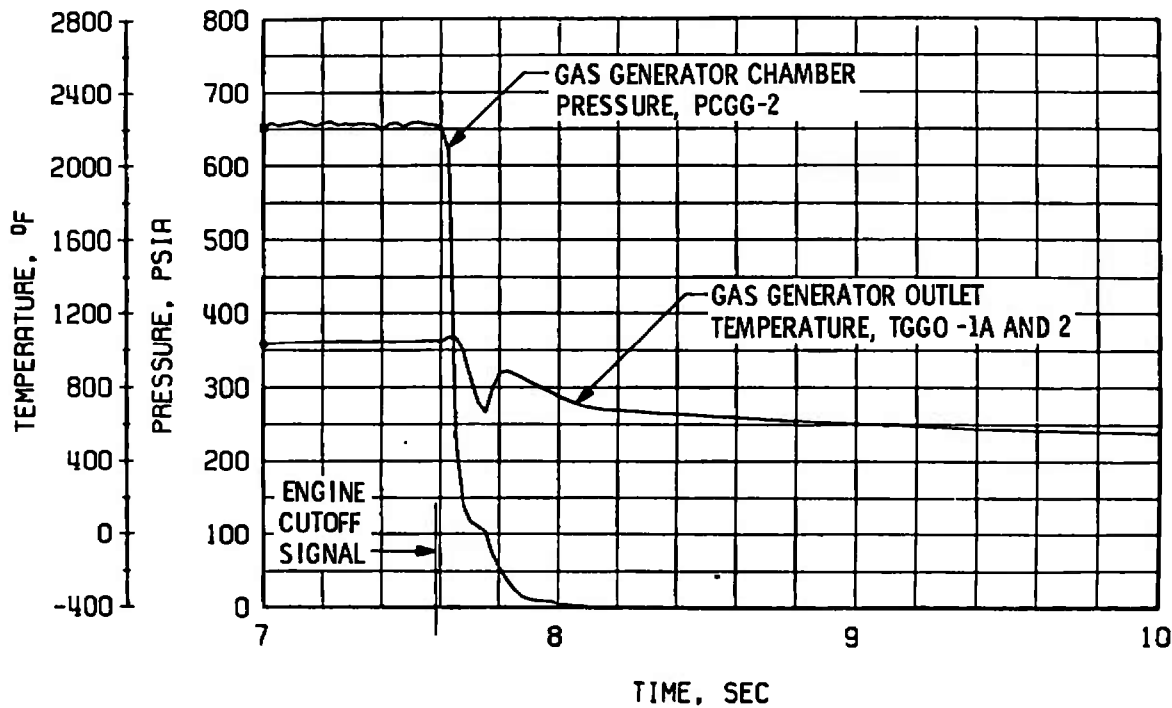


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 82 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 82 Concluded

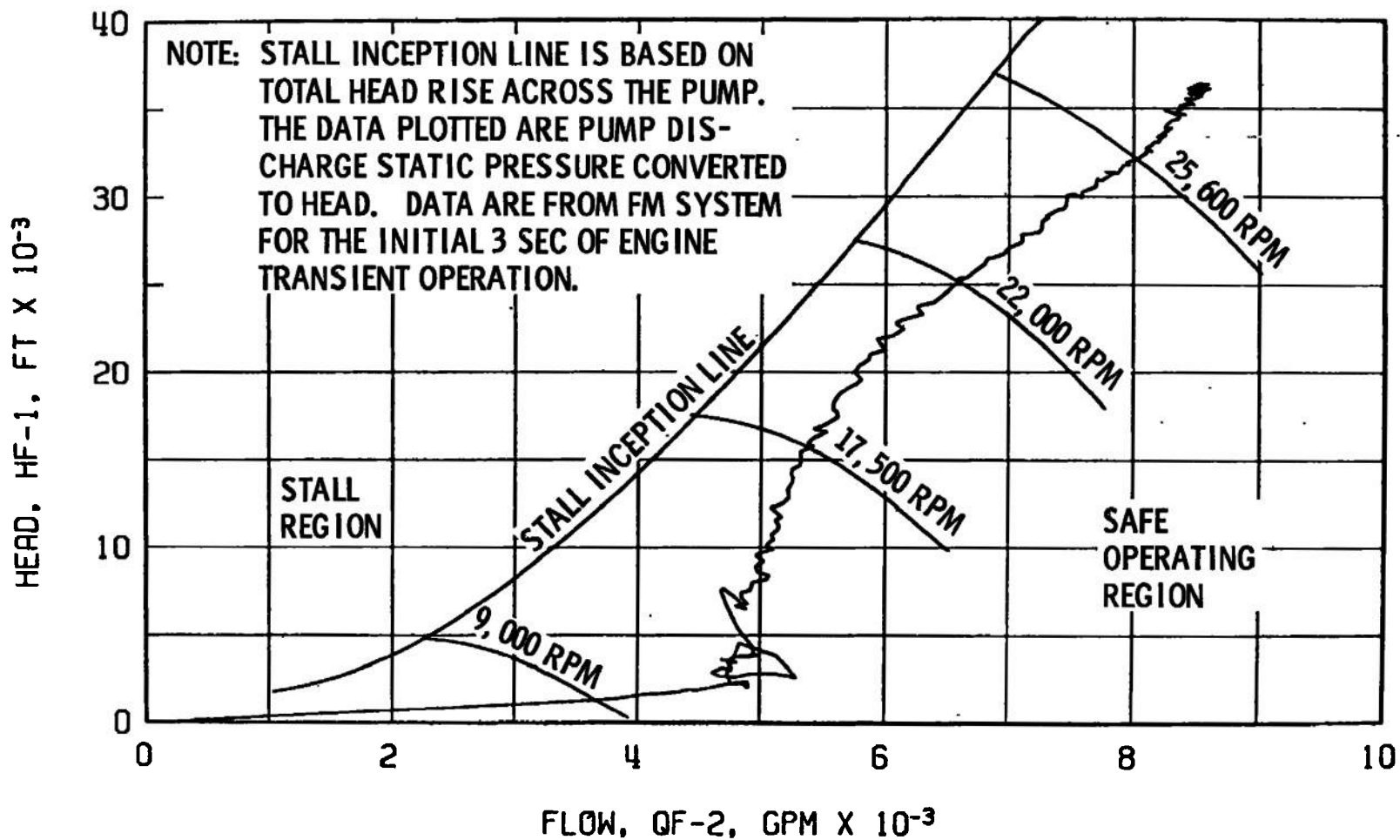
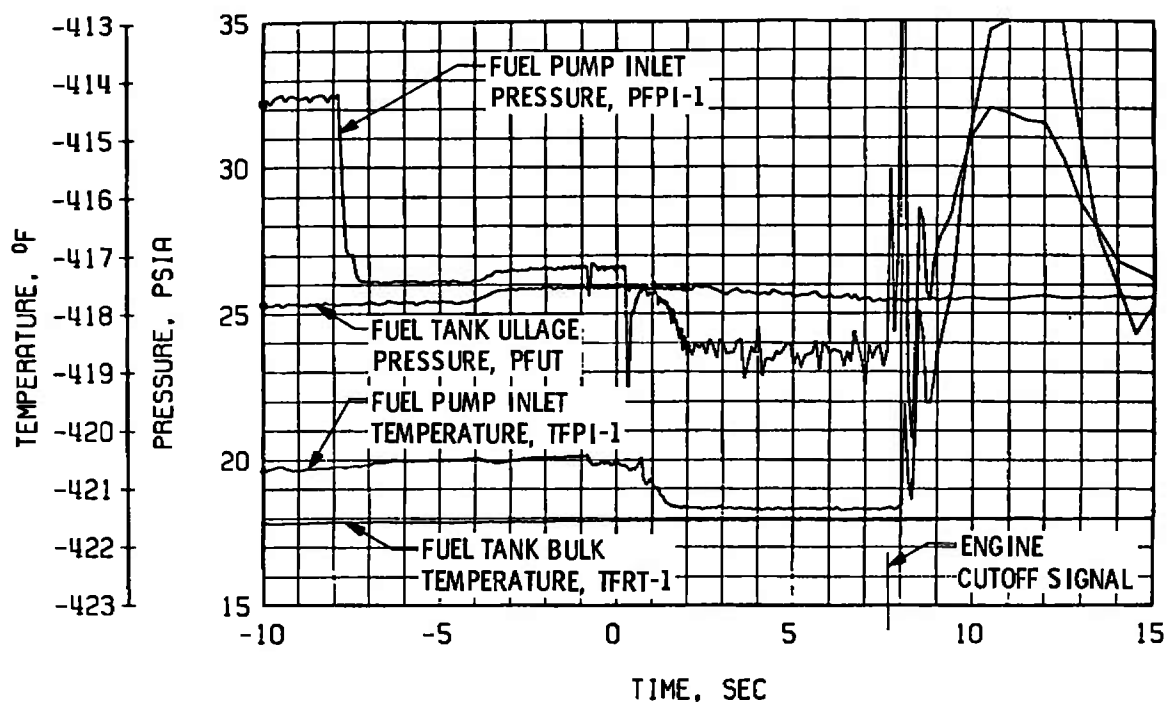
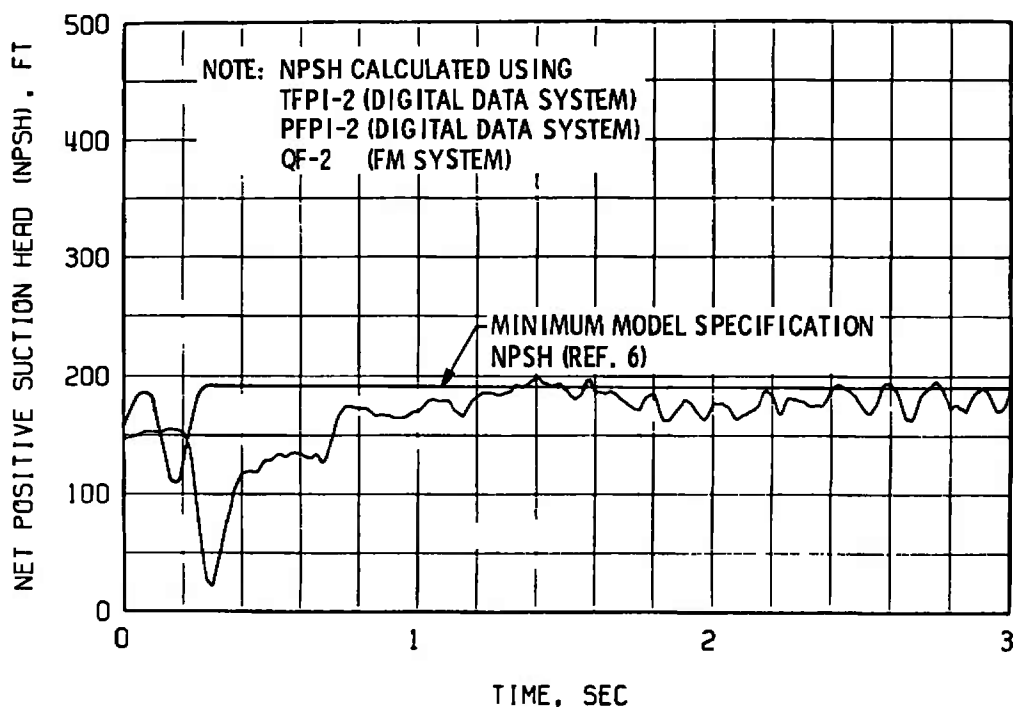


Fig. 83 Fuel Pump Start Transient Performance, Firing 02C

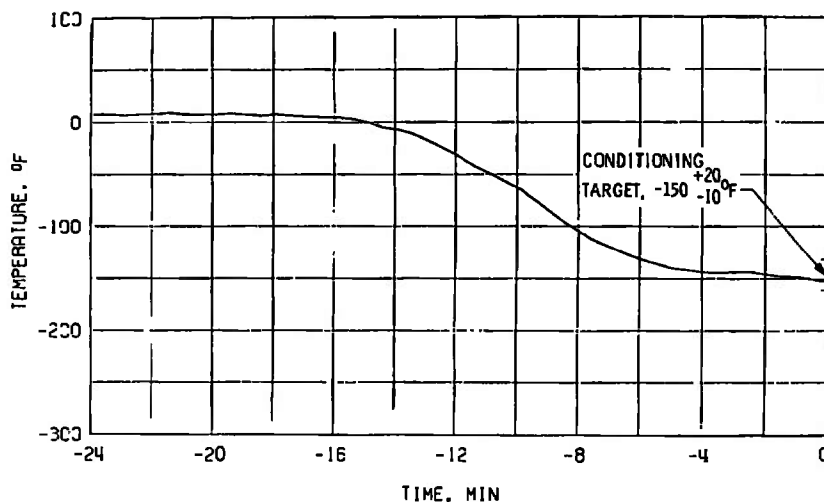


a. Duct Pressure and Temperature Transients

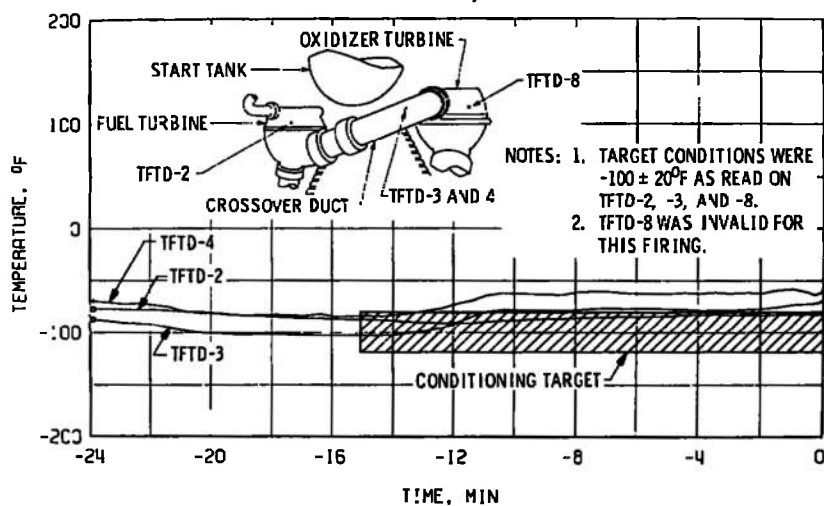


b. Fuel Pump NPSH during Start Transient, Firing 02C

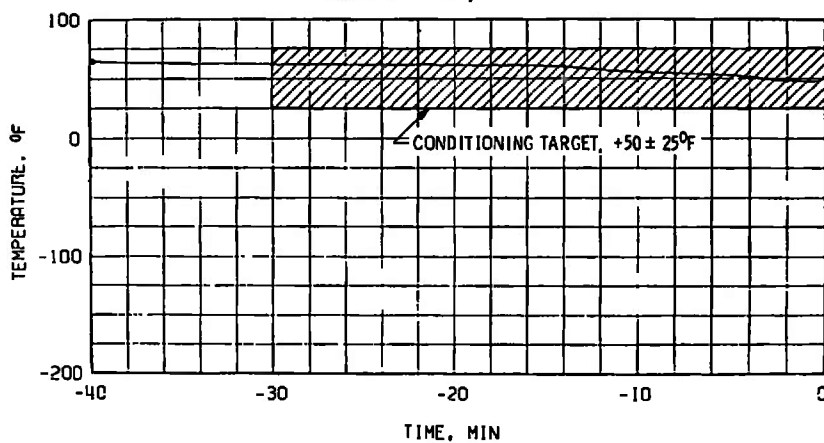
Fig. 84 Fuel Low Pressure Duct Performance, Firing 02C



a. Thrust Chamber, TTC-1P

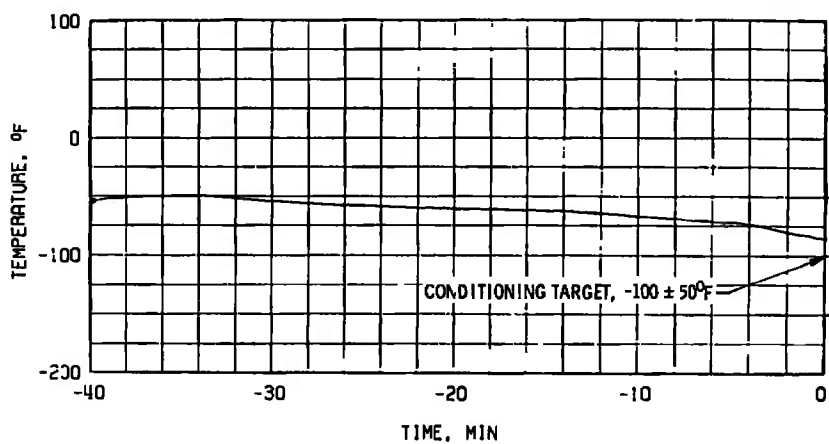


b. Crossover Duct, TFD

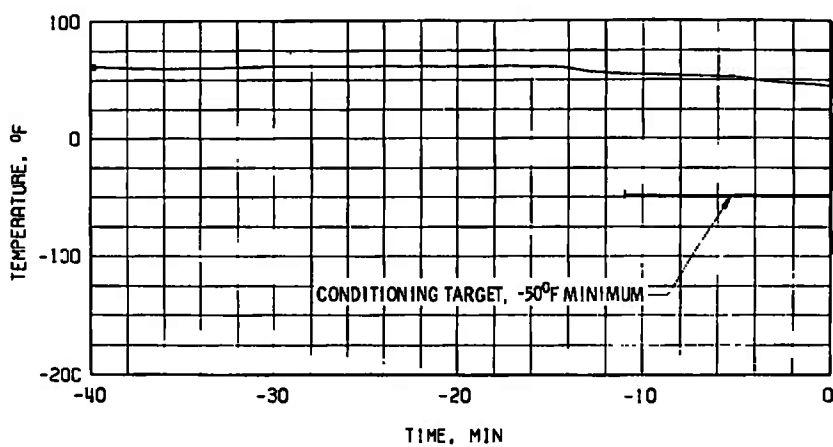


c. Start Tank Discharge Valve, TSTDVOC

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

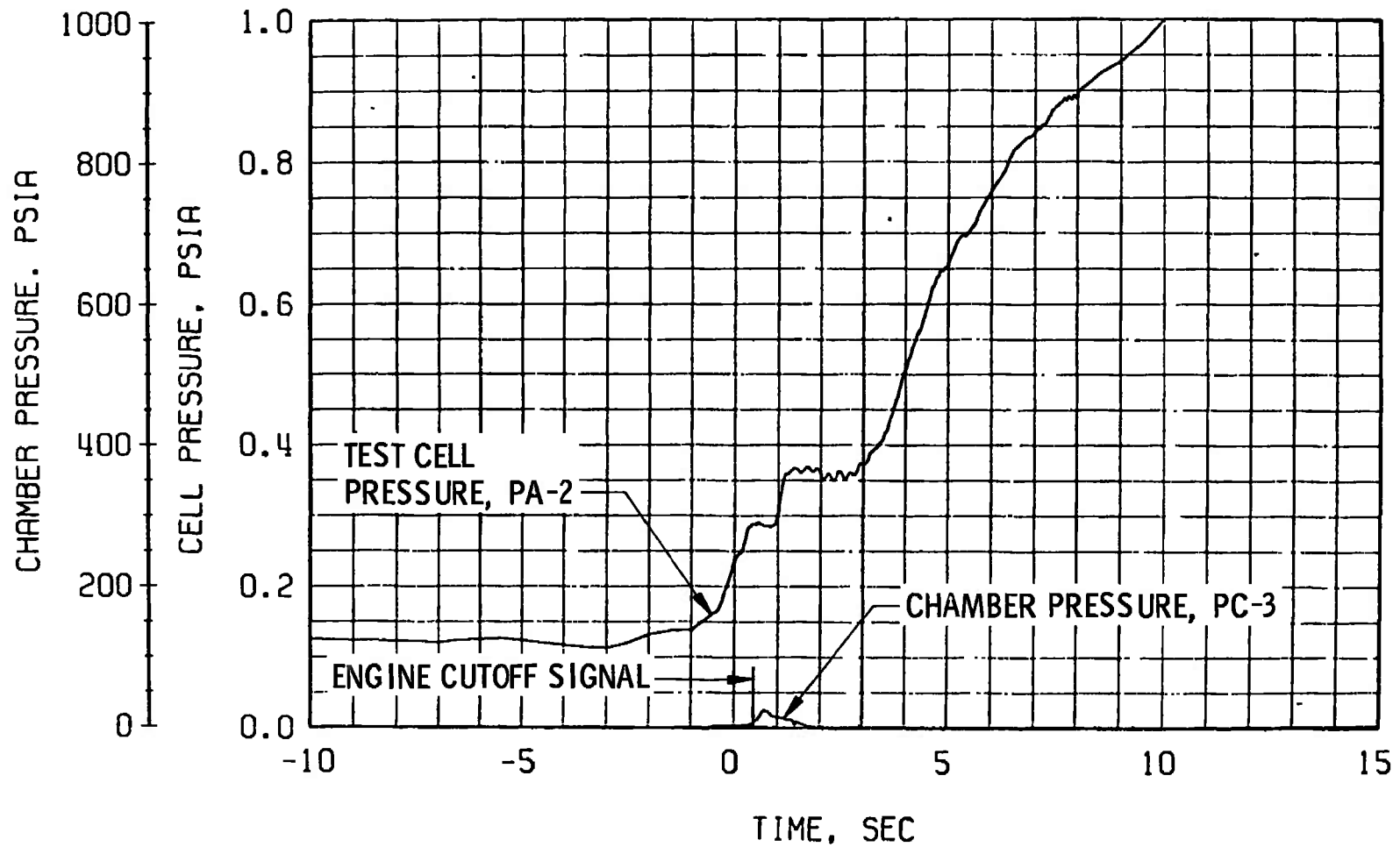
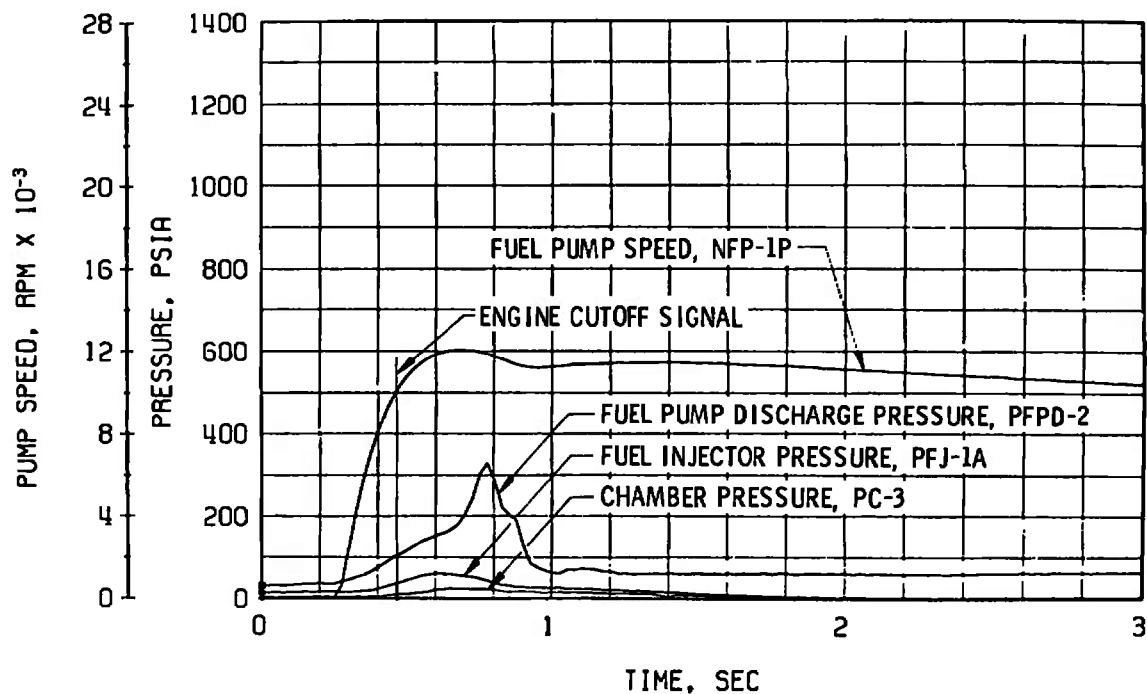
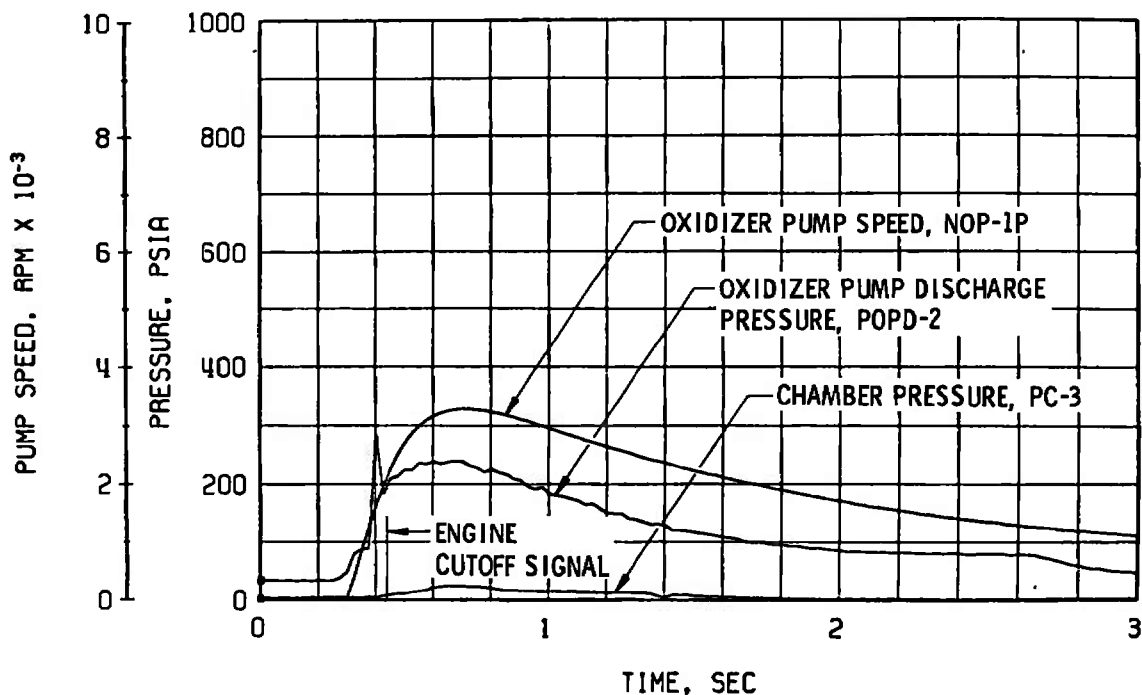


Fig. 86 Engine Ambient and Combustion Chamber Pressures, Firing 02D

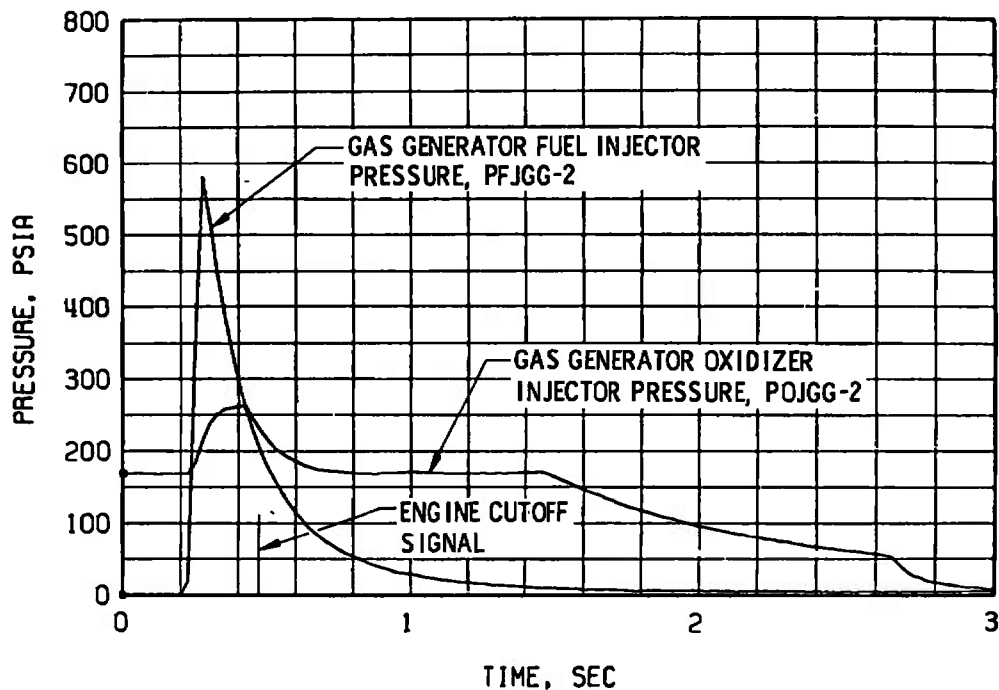


a. Thrust Chamber Fuel System, Start and Shutdown

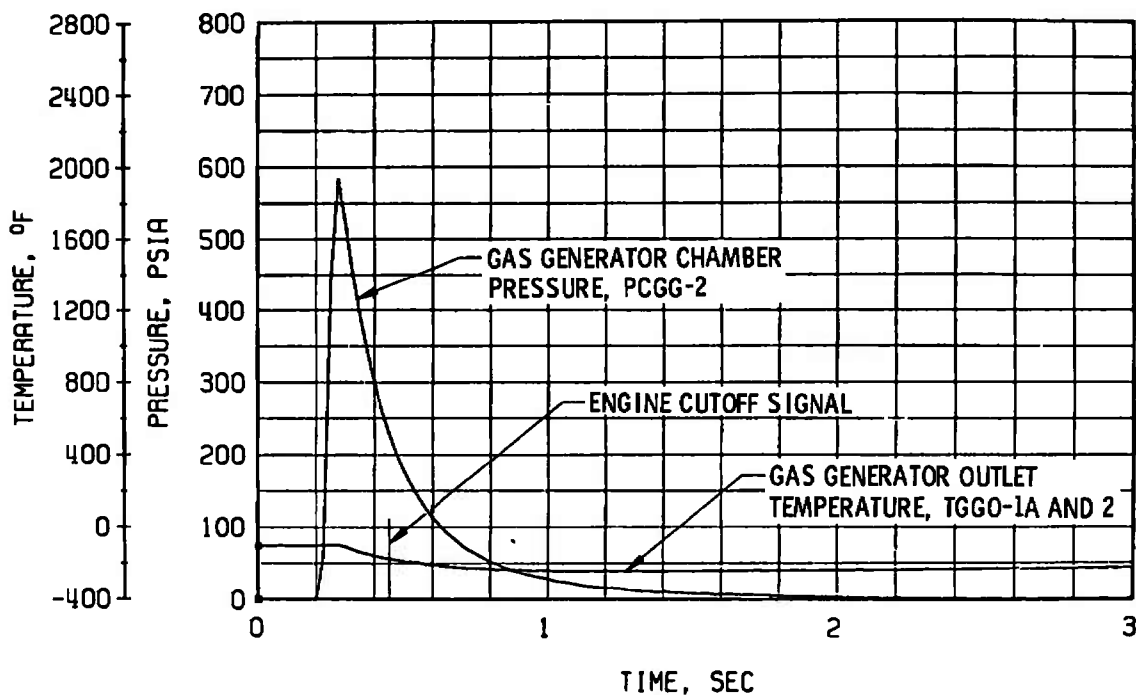


b. Thrust Chamber Oxidizer System, Start and Shutdown

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

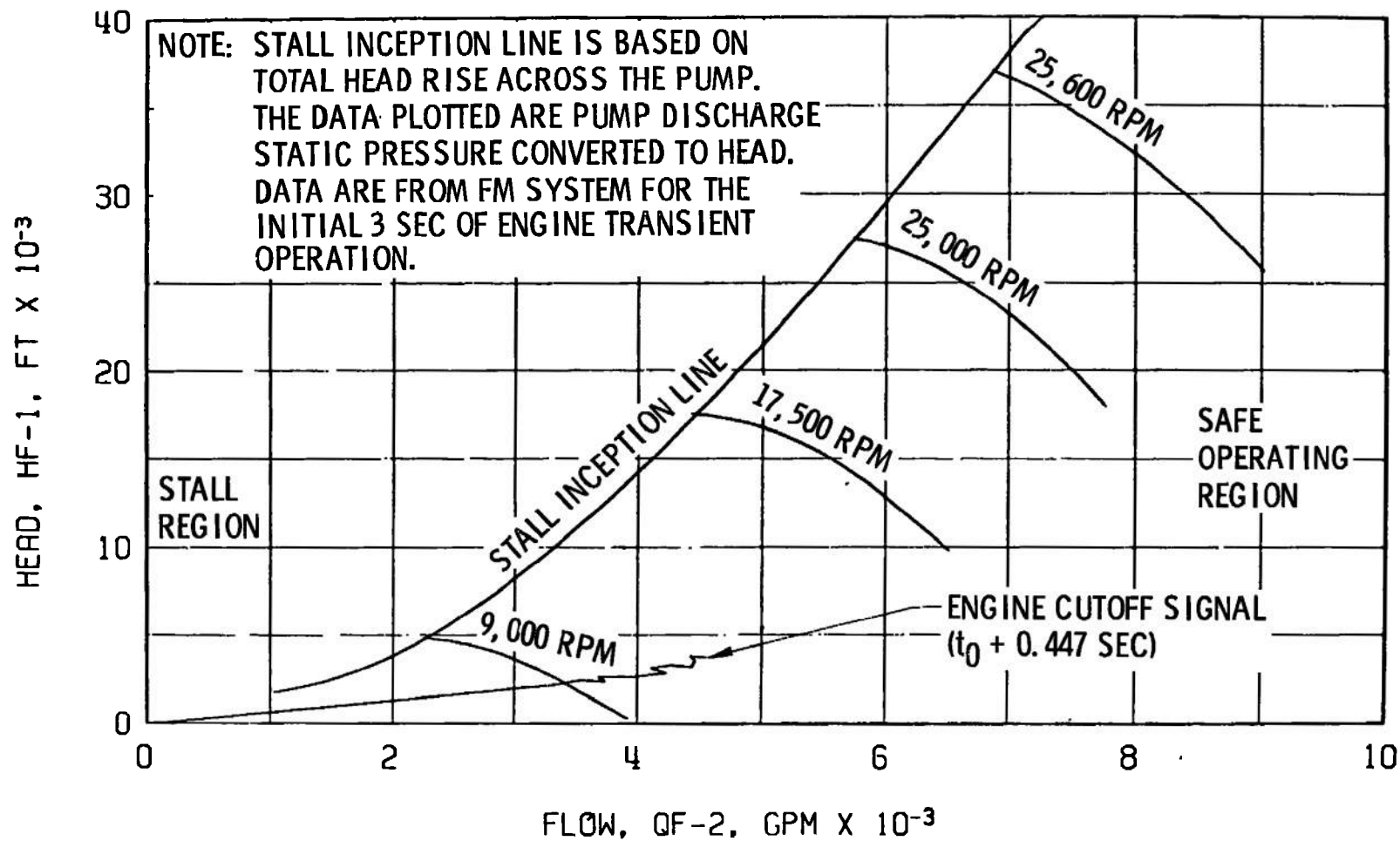
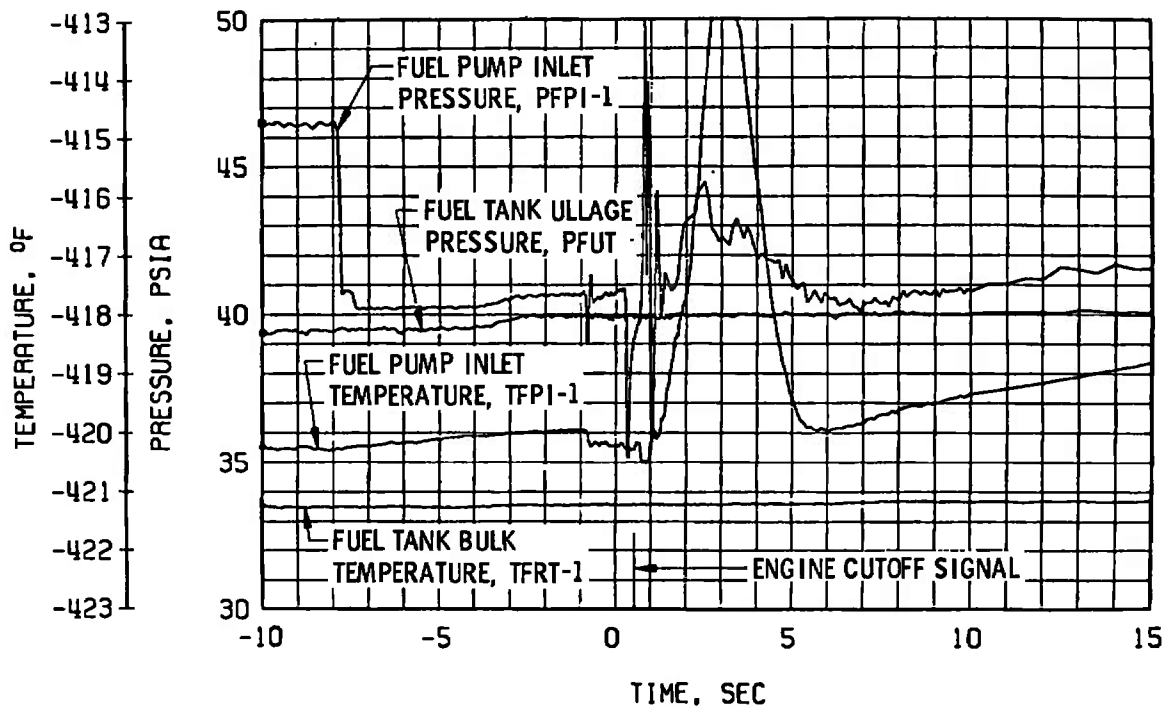
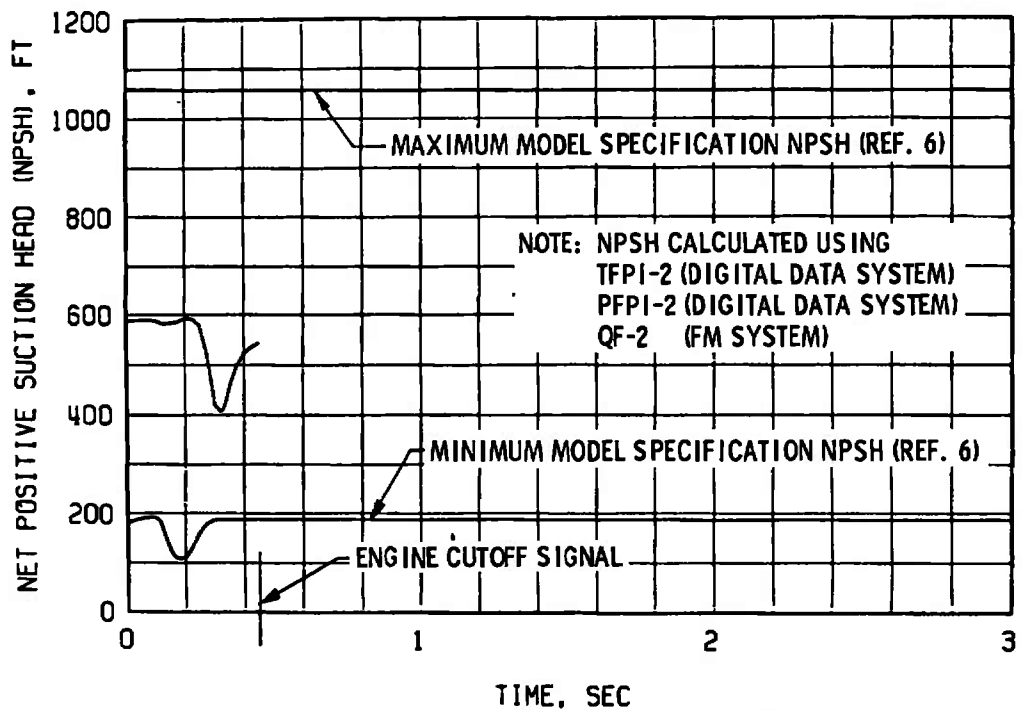


Fig. 88 Fuel Pump Start Transient Performance, Firing 02D



a. Duct Pressure and Temperature Transients



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

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

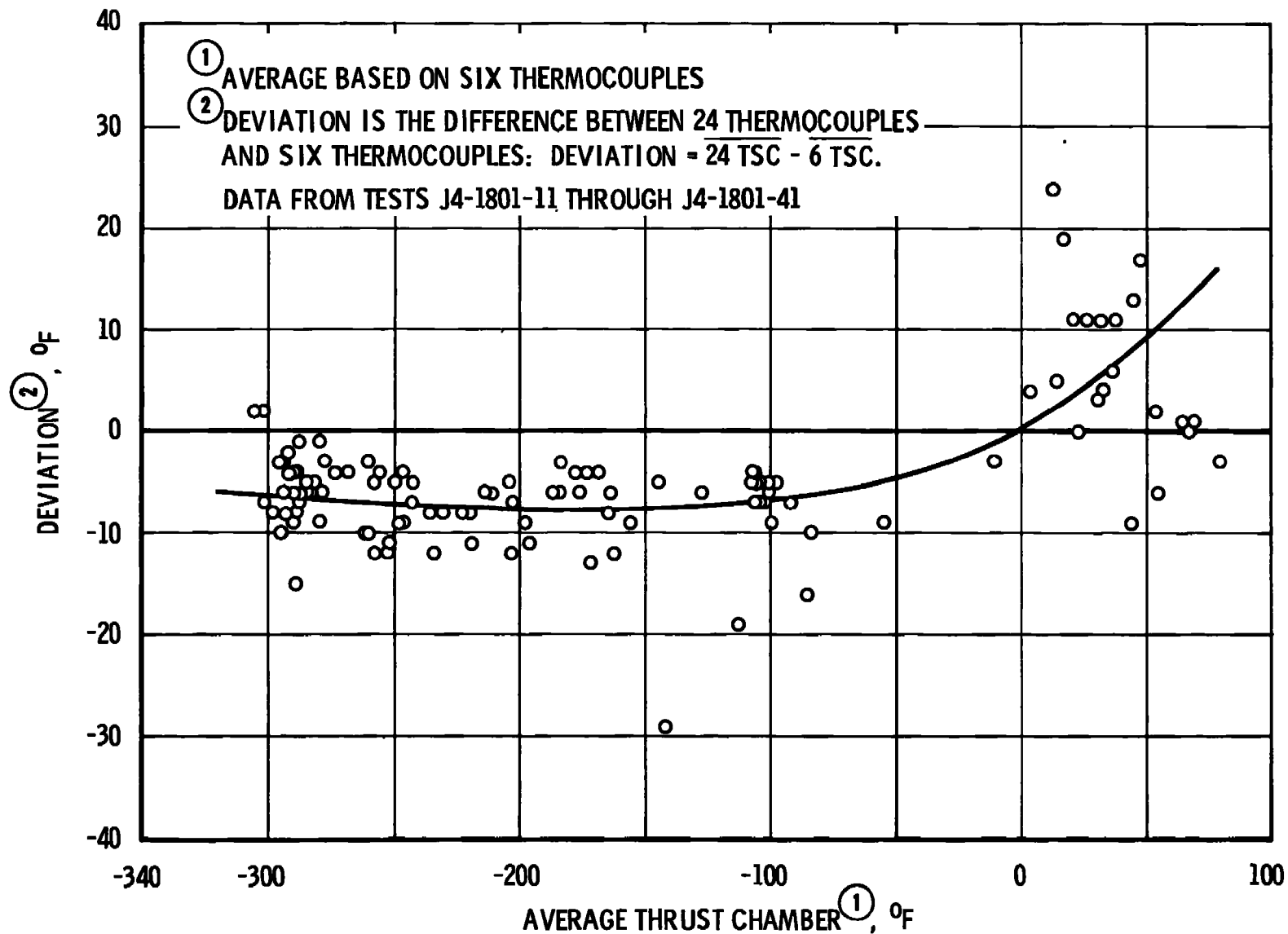
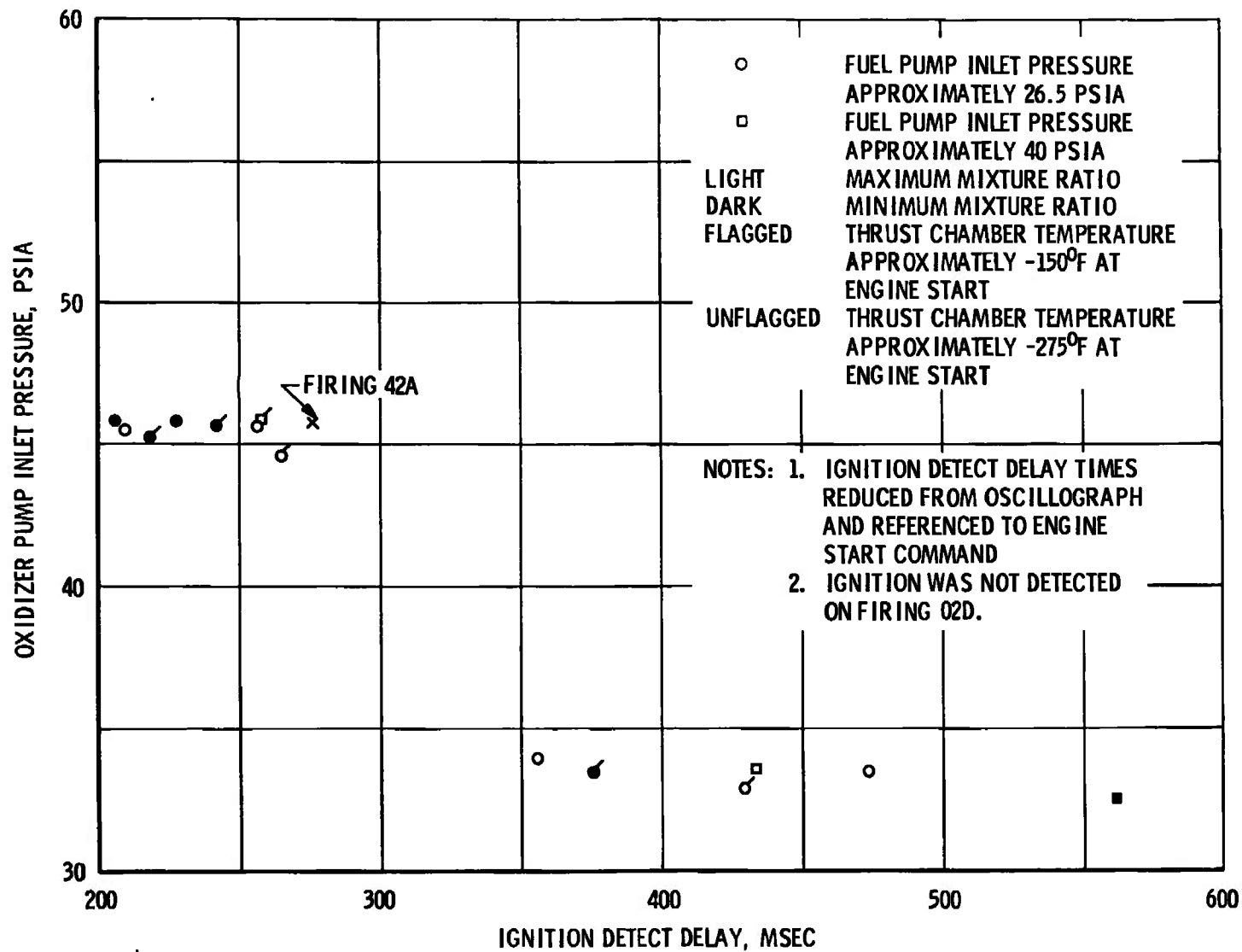


Fig. 90 Expected Deviation in Comparing Thrust Chamber Average Temperature Utilizing 6- and 24-Thermocouple Averages



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

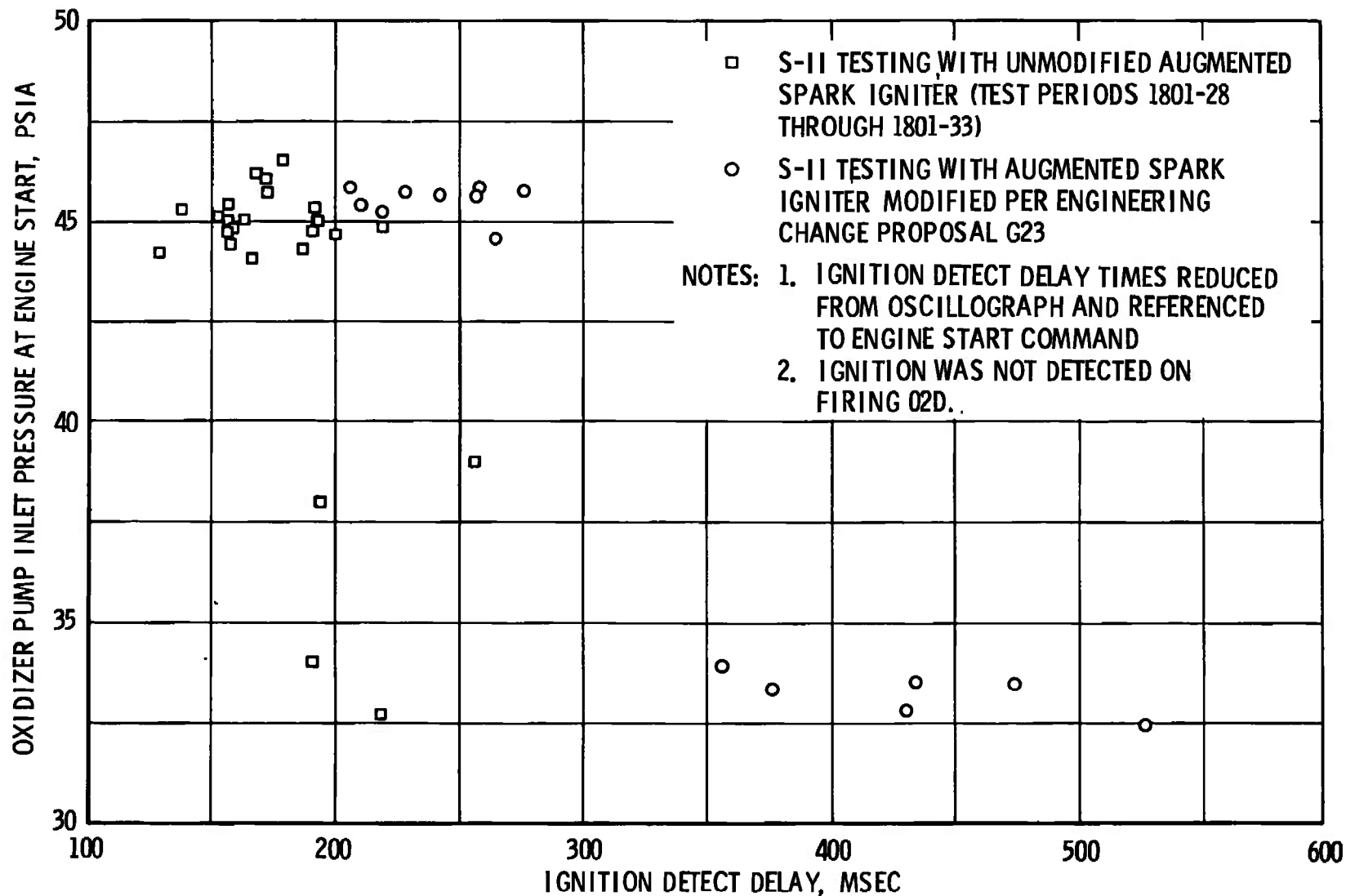


Fig. 92 Comparison of Augmented Spark Igniter Ignition Detect Delay for Test Periods J4-1801-42 through J4-1901-02 and J4-1801-28 through J4-1801-33

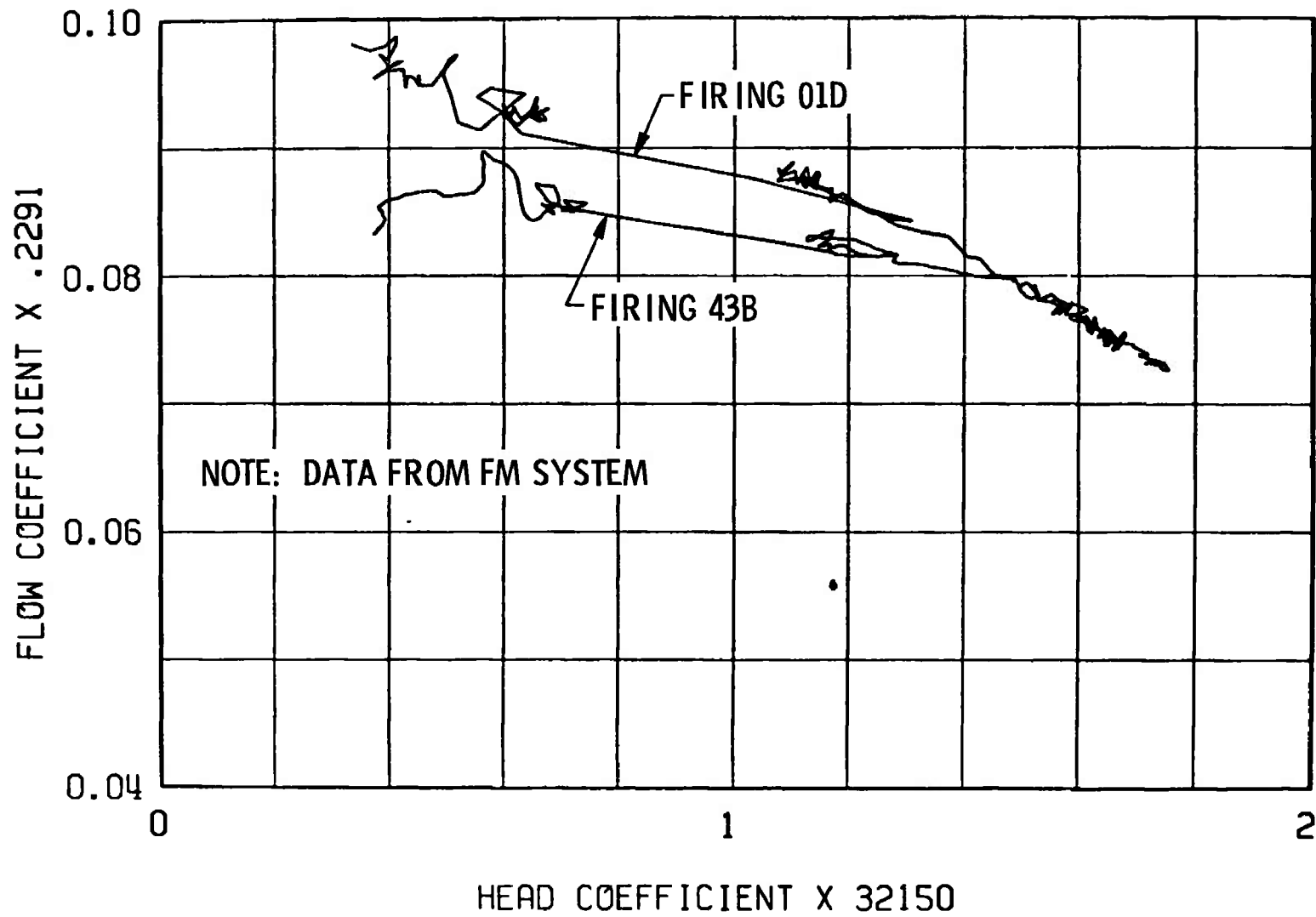


Fig. 93 Fuel Pump Operating Characteristics, Firings 43B and 01D

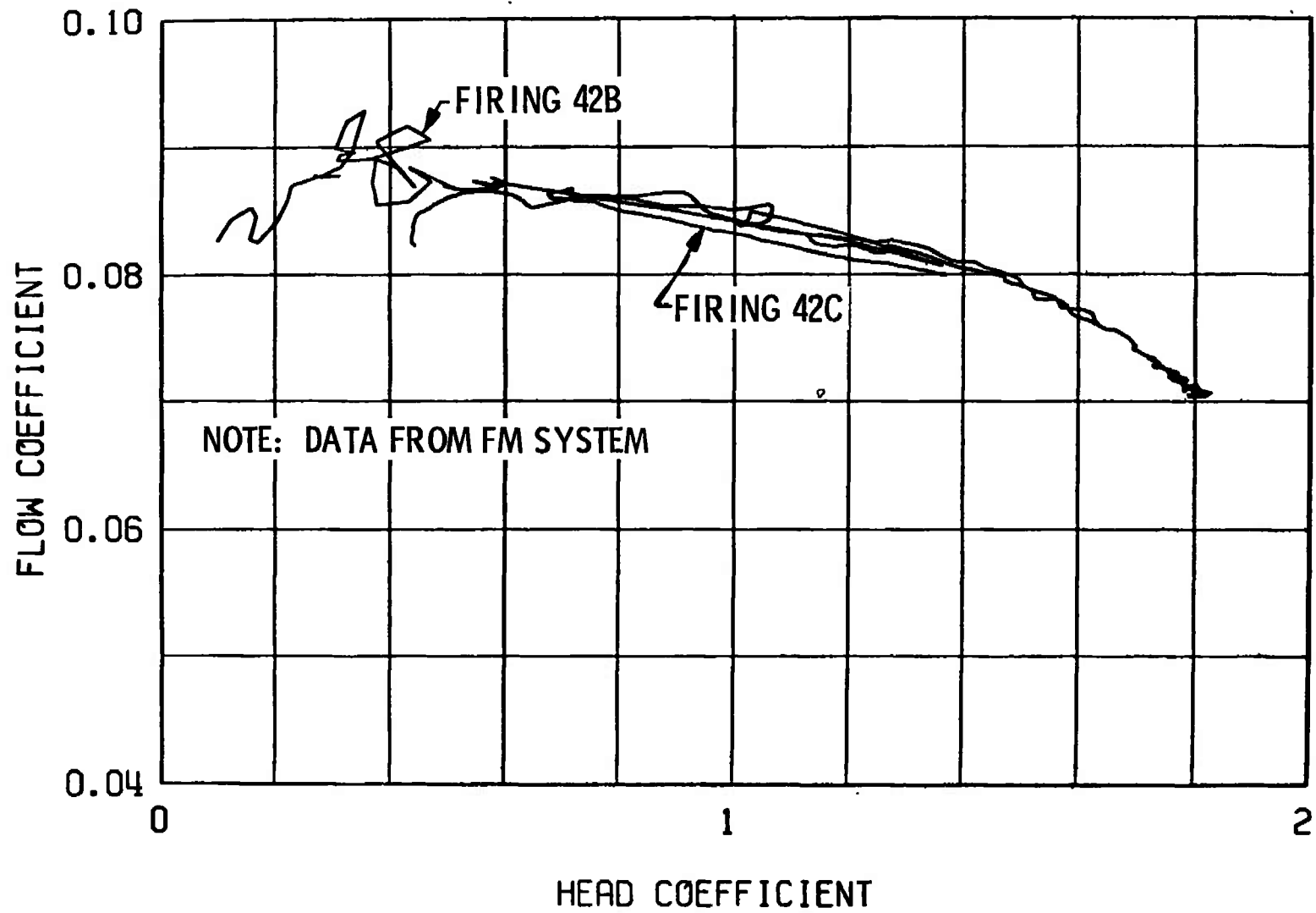


Fig. 94 Fuel Pump Operating Characteristics, Firings 43B and 42C

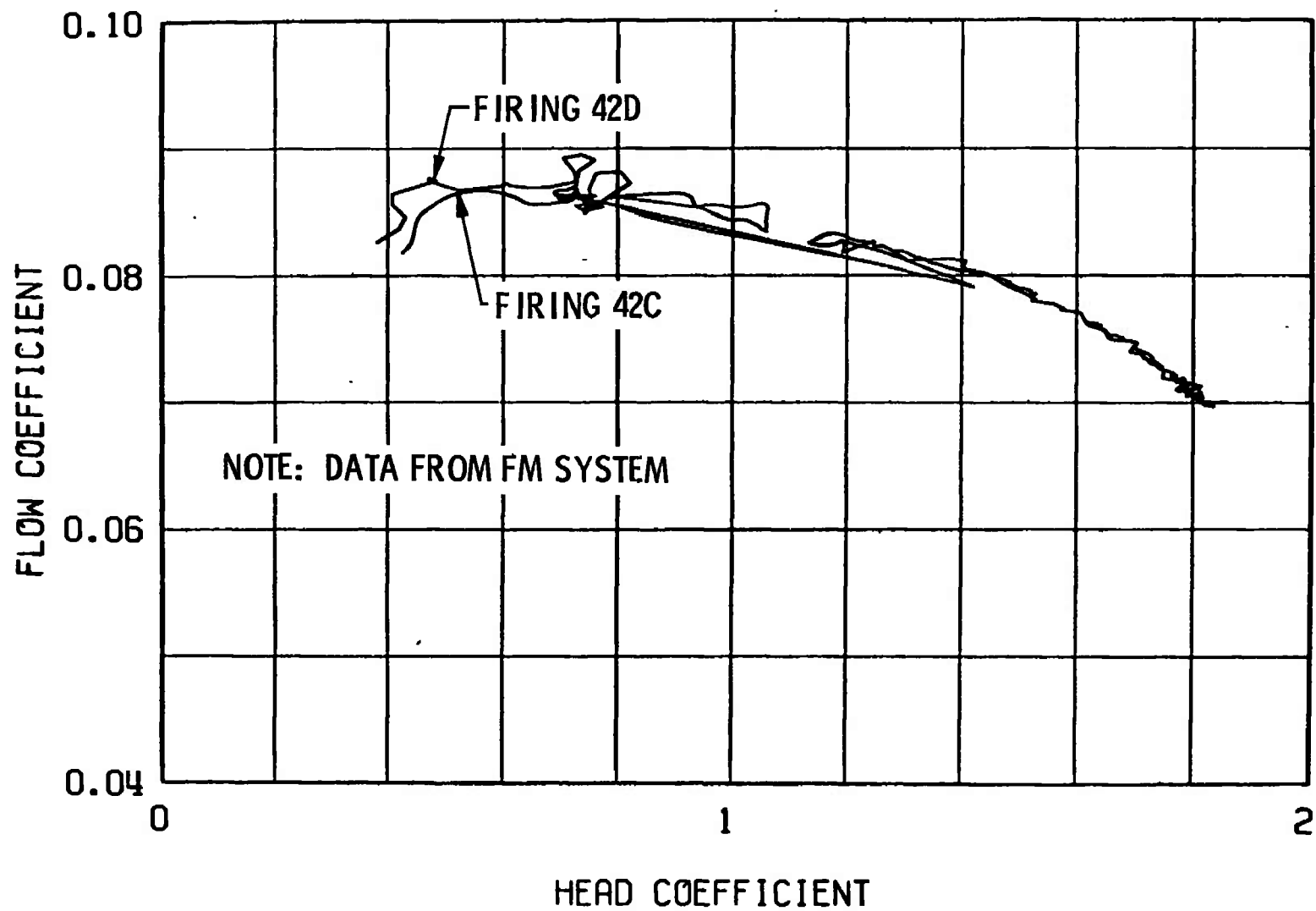


Fig. 95 Fuel Pump Operating Characteristics, Firings 42D and 42C

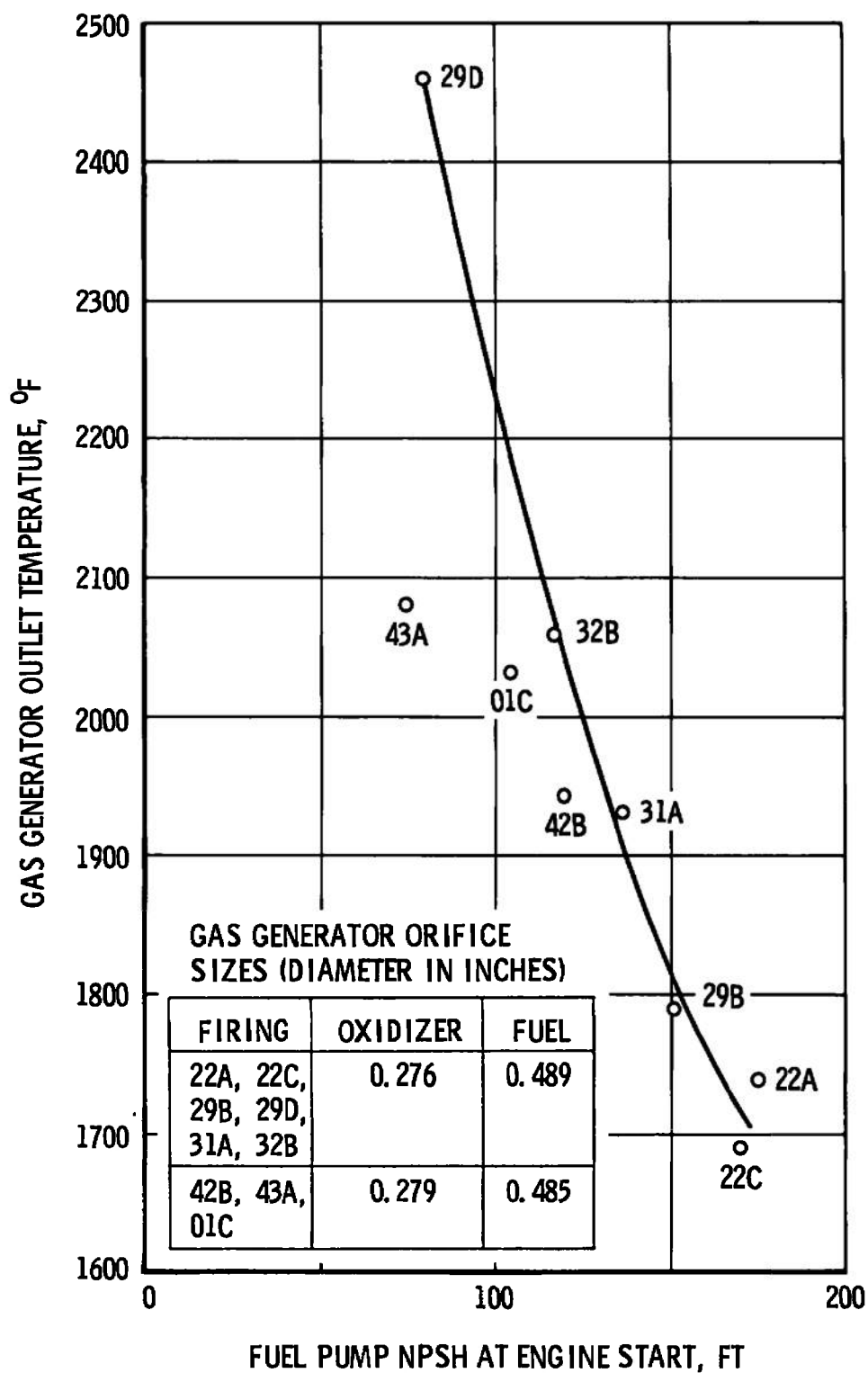


Fig. 96 Fuel Pump NPSH Influence on Gas Generator Initial Peak Temperature

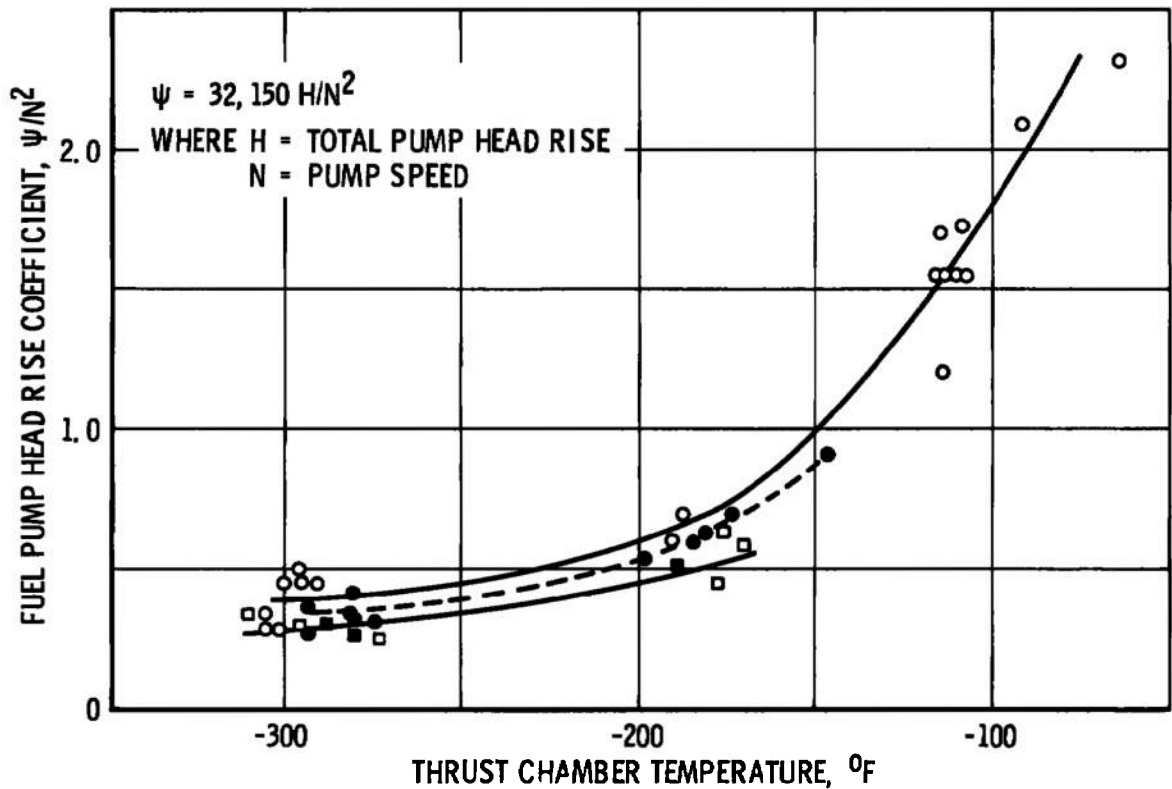
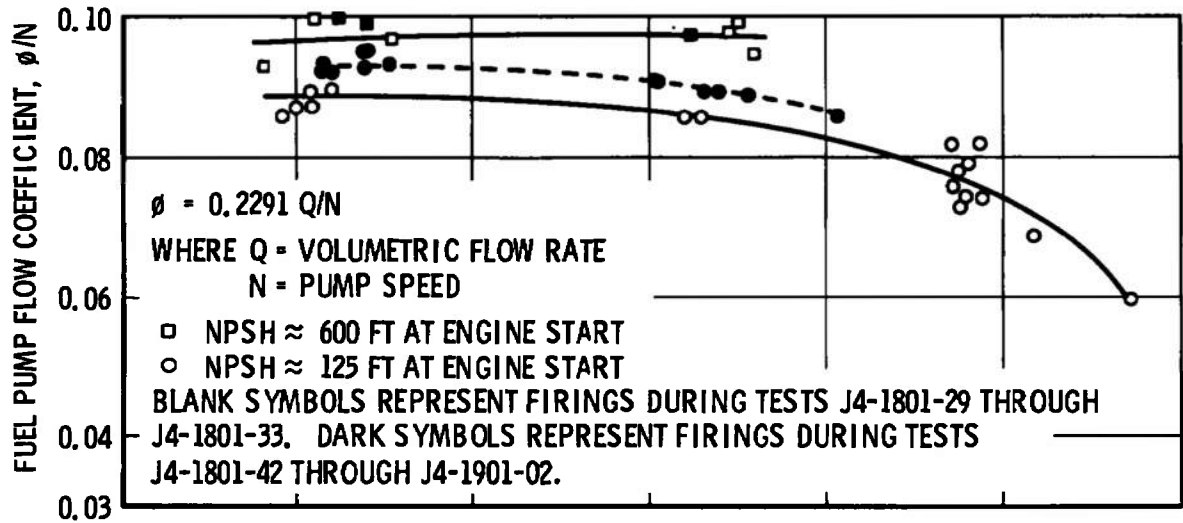


Fig. 97 Fuel Pump NPSH Influence on Fuel Pump Stall Margin during Start Tank Discharge

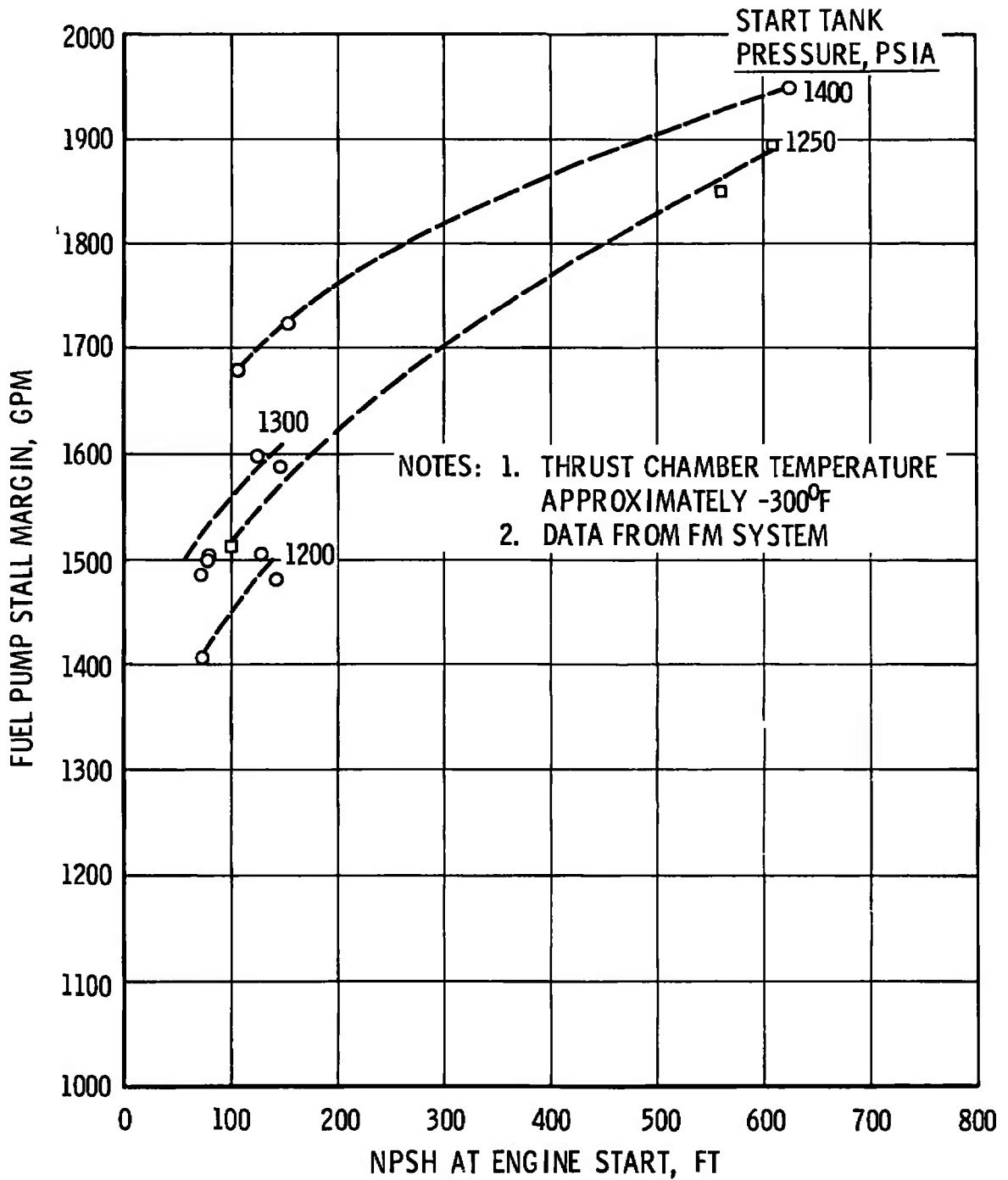


Fig. 98 Fuel Pump NPSH and Thrust Chamber Temperature Effect on Fuel Pump Flow and Head Rise Coefficients

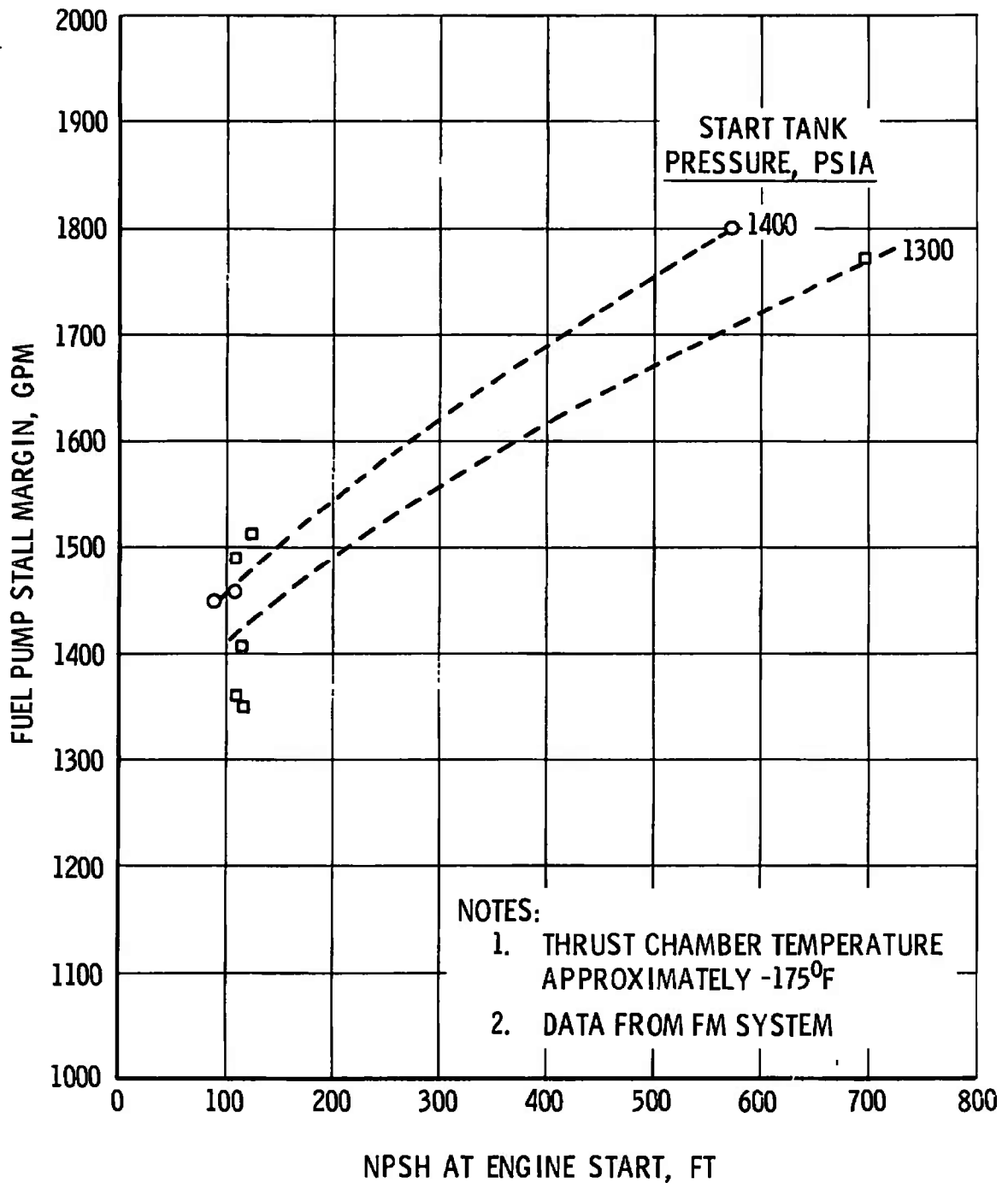
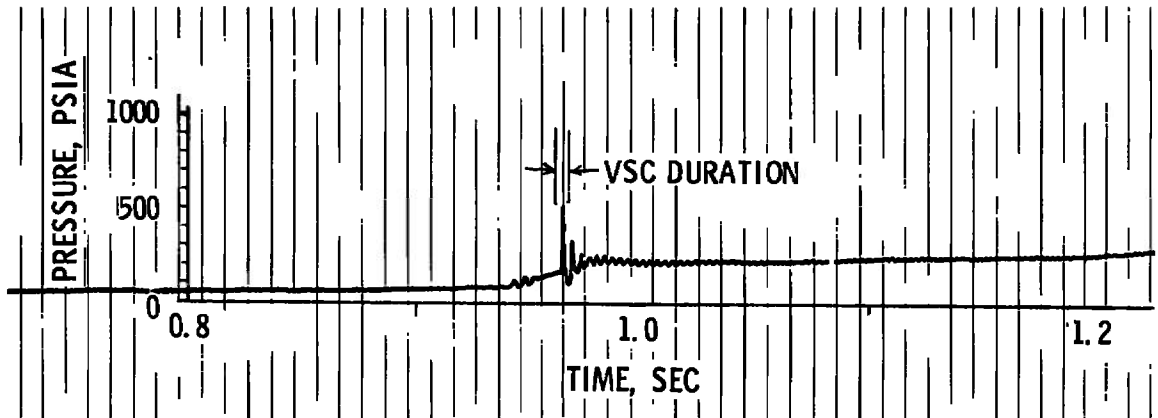
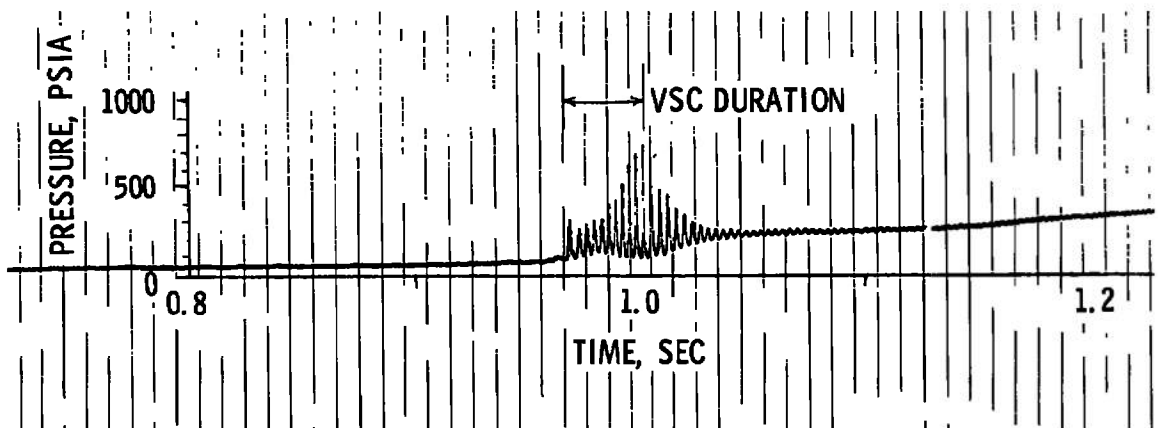


Fig. 98 Concluded



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 RD251-4107	0.485 0.524	July 5, 1968 ^①	---
Gas Generator Oxidizer Supply Line	RD251-4132 RD251-4132	0.279 0.304	July 5, 1968 ^①	---
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002 RD273-8002	1.424 1.600	July 5, 1968 ^①	---
Main Oxidizer Closing Control Line	410437-082 410437-0760 710437-083	8.20 scfm 7.60 scfm 8.30 scfm	June 21, 1968 ^① 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	---

^①As 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 $1900 \pm \begin{smallmatrix} 20 \\ 10 \end{smallmatrix}$ 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

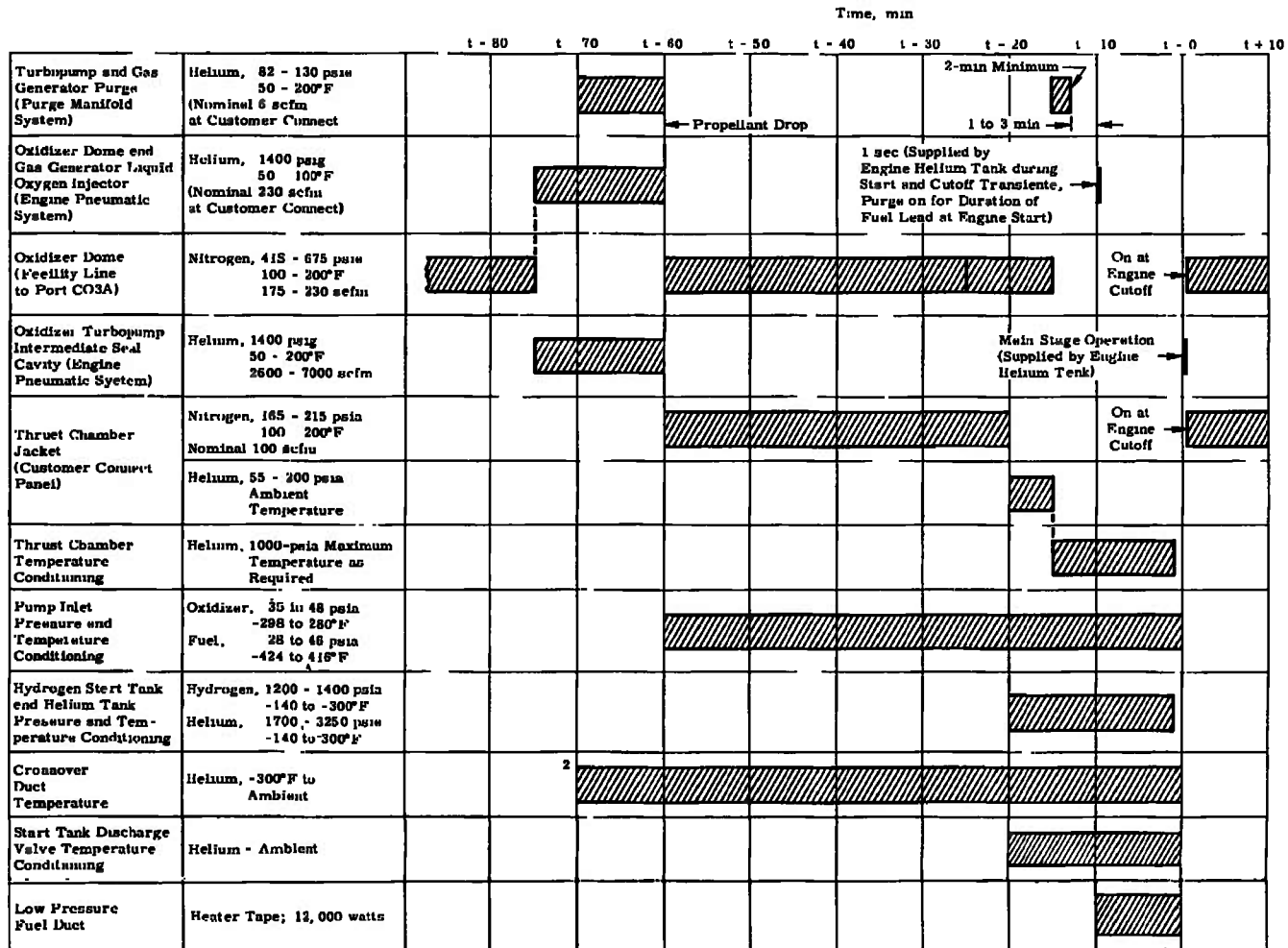
¹RFD - Rocketdyne Field Directive

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

¹UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE



¹Required on Tests 31 and 32 only

²Conditioning 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 ^{①②}		J4-1801-42B ^{①②}		J4-1801-42C ^{①②}		J4-1801-42D ^{①②}		J4-1801-42E ^{①②}	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1252	8/19/68	1424	8/19/68	1531	8/19/68	1620	8/19/68	1710	8/19/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	85,000	100,000	103,000	100,000	105,000	100,000	104,000	100,000	104,000
Firing Duration, sec ^③		32,500	32,572	7,500	7,585	7,500	7,585	7,500	7,588	1,250	1,243
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	35.0 \pm 1	35.6	26.5 \pm 1	27.2	26.5 \pm 1	27.0	26.5 \pm 1	27.1	41 \pm 1	42.1
	Temperature, °F	-420.4 \pm 0.4	-420.2	-420.4 \pm 0.4	-420.1	-420.4 \pm 0.4	-420.1	-420.4 \pm 0.4	-420.1	-420.4 \pm 0.4	-420.0
	NPSH, ft	410	415	128	120	125	115	125	115	810	810
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	48.0 \pm 1	45.7	45.0 \pm 1	45.4	48.0 \pm 1	44.5	33.0 \pm 1	32.8	33 \pm 1	33.5
	Temperature, °F	-294.5 \pm 0.4	-294.4	-294.5 \pm 0.4	-294.5	-294.5 \pm 0.4	-294.5	-294.5 \pm 0.4	-294.4	-294.5 \pm 0.4	-294.4
Start Tank Conditions at Engine Start	Pressure, psia	1225 \pm 10	1229	1380 \pm 10	1378	1380 \pm 10	1380	1300 \pm 10	1300	1250 \pm 10	1248
	Temperature, °F	-250 \pm 10	-260	-270 \pm 10	-270	-270 \pm 10	-288	-300 \pm 10	-303	-140 \pm 10	-138
Helium Tank Conditions at Engine Start	Pressure, psia	---	2118	---	2077	---	2120	---	2140	---	2494
	Temperature, °F	---	-245	---	-264	---	-264	---	-297	---	-138
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-235 \pm 15	-229	-275 \pm 25	-278	-150 \pm 20	-137	-150 \pm 20	-150	-275 \pm 25	-281
	Average	---	-245	---	-260	---	-148	---	-173	---	-280
Crossover Duct Temperature at Engine Start, °F ^④	TFTD-2	+50 \pm 28	---	+50 \pm 25	---	+50 \pm 25	---	+50 \pm 25	---	-100 \pm 20	---
	TFTD-3	---	66	---	36	---	28	---	37	---	-129
	TFTD-4	---	58	---	43	---	36	---	55	---	-94
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-100 \pm 50	-88	-100 \pm 50	-128	-100 \pm 50	-130	-100 \pm 50	-131	-100 \pm 50	-137
Fuel Lead Time, sec ^⑤		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		②	87	②	47	②	68	②	42	②	82
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	---	58	---	80	---	58	---	57	---	54
Start Tank Discharge Valve Body Temperature at Engine Start, °F		50 \pm 25	3	50 \pm 25	58	50 \pm 25	57	50 \pm 25	55	50 \pm 25	45
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t ₀		---	21 0.977	---	29 0.963	---	14 0.965	---	14 1.013	---	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 ^⑥		---	278	---	210	---	285	---	430	---	434
Thrust Chamber Ignition (P _C = 100 psia) Time, sec (Ref. t ₀) ^⑦		---	0.978	---	0.987	---	0.988	---	1.015	---	1.057
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t ₀) ^⑧		---	1.110	---	1.007	---	1.000	---	1.024	---	0.968
Main-Stage Pressure No. 2, asc (Ref. t ₀) ^⑨		---	1.610	---	1.873	---	1.580	---	1.854	---	---
Thrust Chamber Pressure Attains 550 psia, asc (Ref. t ₀) ^⑩		---	1.885	---	1.903	---	1.645	---	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	-46	-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-to-engine time in dependent on main oxidizer valve conditioning requirements; minimum time in 30 min.

④ Shell approach monitor activated.

⑤ Turbine overspeed trip activated.

TABLE VI (Continued)

Firing Number	J4-1901-43A		J4-1901-43B ^①		J4-1901-01A ^{①②}		J4-1901-01B ^{①③}		J4-1901-01C ^{①④}	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date	1056	6/29/68	1215	8/28/68	1135	7/3/68	1248	7/3/68	1358	7/3/68
Pressure Altitude at Engine Start, ft (Ref. 1)	100,000	99,000	100,000	101,000	100,000	101,000	100,000	100,000	100,000	101,000
Firing Duration, sec ^⑤	32,500	32,57	7,500	7,59	32,500	32,675	7,500	7,588	7,500	3,925
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.5 ± 0.5	26.6	26.5 ± 0.5	26.0	26.5 ± 0.5	20.5	26.5 ± 0.5	20.5	20.5 ± 0.5
	Temperature, °F	-420.4 ± 0.4	-410.6	-420.4 ± 0.4	-420.2	-420.4 ± 0.4	-420.3	-420.4 ± 0.4	-420.4	-420.4 ± 0.4
	NPSH, ft	126	75	125	80	125	110	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
	Temperature, °F	-204.5 ± 0.4	-204.4	-204.5 ± 0.4	-204.8	-204.5 ± 0.4	-204.3	-204.5 ± 0.4	-204.5	-204.5 ± 0.4
Start Tank Conditions at Engine Start	Pressure, psia	1300 ± 10	1304	1400 ± 10	1400	1380 ± 10	1302	1380 ± 10	1302	1400 ± 10
	Temperature, °F	-300 ± 10	-300	-240 ± 10	-236	-270 ± 10	-271	-300 ± 10	-304	-240 ± 10
Helium Tank Conditions at Engine Start	Pressure, psia	---	2116	---	2145	---	2134	---	2118	---
	Temperature, °F	---	-300	---	-238	---	-270	---	-205	---
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-275 ± 25	-269	-150 ± 20	-142	-150 ± 20	-140	-150 ± 20	-150	-275 ± 25
	Average	---	-201	---	-164	---	-160	---	-107	---
Crossover Duct Temperature at Engine Start, °F ^⑥	TFTD-2	50 ± 25	41	50 ± 25	34	50 ± 25	36	50 ± 25	40	50 ± 25
	TFTD-3	---	49	---	45	---	47	---	31	---
	TFTD-6	---	54	---	56	---	59	---	50	---
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
Fuel Lead Time, sec ^⑦	---	1,000	0,000	1,000	0,008	1,000	1,001	1,000	1,001	1,000
Propellant in Engine Time, min	---	0	61	0	37	0	96	0	72	0
Propellant Recirculation Time, min	---	10	10	10	11	10	11	10	10	10
Start Sequence Logic	---	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	---
	TOBS-2	---	36	---	27	---	25	---	20	---
	TOBS-3B	---	50	---	46	---	41	---	44	---
Start Tank Discharge Valve Body Temperature at Engine Start, °F	---	50 ± 25	00	50 ± 25	61	50 ± 25	60	50 ± 25	50	50 ± 25
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
Gas Generator Outlet Temperature, °F	Initial Peak	---	2060	---	2051	---	2059	---	2014	---
	Second Peak	---	---	---	1840	---	2115	---	---	---
Fuel Pump Stall Margin during Start Tank Discharge, gpm	---	---	1460	---	1490	---	1490	---	1510	---
Augmented Spark Ignition Detect Delay Time from Engine Start, msec ^⑧	---	---	228	---	242	---	219	---	378	---
Thrust Chamber Ignition (P _c = 100 psia) Time, sec (Ref. t ₀) ^⑨	---	---	0.962	---	0.064	---	0.086	---	0.967	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t ₀) ^⑩	---	---	1,156	---	1,120	---	1,182	---	1,125	---
Main-Stage Pressure No. 2, sec (Ref. t ₀) ^⑪	---	---	1,001	---	1,616	---	1,032	---	1,693	---
Thrust Chamber Pressure Attains 550 psia, sec (Ref. t ₀) ^⑫	---	---	1,072	---	1,720	---	1,078	---	1,923	---
Propellant Utilization Valve Position, Engine Start/t ₀ + 10 sec	Null	Closed	Null	Closed	Null	Closed	Null	Closed	Null	Closed
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 ^①		J4-1901-01E ^②		J4-1901-02A ^③		J4-1901-02B ^④		J4-1901-02C ^⑤		J4-1901-02D ^⑥	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date	1508	7/5/68	1603	7/5/68	1138	7/11/68	1333	7/11/68	1425	7/11/68	1616	7/11/68
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 ^⑦	7,500	7,590	1,250	1,248	32,800	32,873	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	40.8	26.5 ± 0.5	26.3	26.5 ± 0.5	26.7	26.5 ± 0.5	26.8	41.0 ± 1.0
	Temperature, °F	-420.4 ± 0.4	-420.0	-420.4 ± 0.4	-420.0	-420.4 ± 0.4	-420.3	-420.4 ± 0.4	-420.1	-420.4 ± 0.4	-420.4	-420.4
	NPSH, ft	810	575	410	580	125	95	125	100	125	130	610
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45.0 ⁺¹ ₋₀	45.6	33.0 ⁺¹ ₋₀	33.4	33.0 ⁺¹ ₋₀	33.9	33.0 ⁺¹ ₋₀	33.4	45.0 ⁺¹ ₋₀	45.5	33.0 ⁺¹ ₋₀
	Temperature, °F	-294.5 ± 0.4	-294.3	-294.5 ± 0.4	-294.8	-294.5 ± 0.4	-294.6	-294.5 ± 0.4	-294.6	-294.5 ± 0.4	-294.6	-294.5 ± 0.4
	NPSH, ft	810	575	410	580	125	95	125	100	125	130	610
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
	Temperature, °F	-240 ± 10	-240	-140 ± 10	-135	-200 ± 10	-198	-140 ± 10	-137	-300 ± 10	-300	-140 ± 10
	NPSH, ft	810	575	410	580	125	95	125	100	125	130	610
Helium Tank Conditions at Engine Start	Pressure, psia	---	2265	---	2655	---	2527	---	2217	---	2189	---
	Temperature, °F	---	-239	---	-137	---	-198	---	-129	---	-302	---
	NPSH, ft	810	575	410	580	125	95	125	100	125	130	610
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-150 ⁺²⁰ ₋₁₀	-162	-275 ± 25	-278	-275 ± 25	-260	-275 ± 25	-272	-275 ± 25	-275	-150 ⁺²⁰ ₋₁₀
	Average	---	-168	---	-266	---	-260	---	-274	---	-293	---
	NPSH, ft	810	575	410	580	125	95	125	100	125	130	610
Crossover Duct Temperature at Engine Start, °F ^⑧	TFTD-2	50 ± 25	51	-100 ± 20	-106	-100 ± 20	-108	-100 ± 20	-95	+50 ± 25	+35	-100 ± 20
	TFTD-3	---	62	---	-103	---	-61	---	-95	---	+46	---
	TFTD-5	---	53	---	-100	---	-92	---	---	---	---	---
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F	---	-100 ± 50	-92	-100 ± 50	-87	-100 ± 50	-135	-100 ± 50	-63	-100 ± 50	-76	-100 ± 50
Fuel Lead Time, sec ^⑨	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	⑩	64	⑪	63	⑫	96	⑬	114	⑭	51	⑮	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	---
	TOBS-2	---	17	---	13	---	15	---	35	---	52	---
	TOBS-2B	---	44	---	42	---	50	---	55	---	53	---
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	---	32	---	29	---	38	---	31	---	---
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 ^⑯	---	258	---	362	---	356	---	474	---	257	---	---
Thrust Chamber Ignition (P _c = 100 psia) Time, sec (Ref. t ₀) ^⑰	---	0,933	---	1,055	---	1,063	---	1,071	---	0,996	---	---
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t ₀) ^⑱	---	1,200	---	1,036	---	0,887	---	1,023	---	1,011	---	---
Main-Stage Pressure No. 2, sec (Ref. t ₀) ^⑲	---	1,621	---	---	---	1,766	---	1,613	---	1,647	---	---
Thrust Chamber Pressure Attains 350 psia, sec (Ref. t ₀) ^⑳	---	1,635	---	---	---	2,040	---	2,059	---	1,666	---	---
Propellant Utilization Valve Position, Engine Start/t ₀ + 10 sec	Null	Null	Null	Null	Null	Closed	Null	Closed	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 Valve, Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
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	0.089	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

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 propellant 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	32.574	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	0.075	0.010	32.573	0.030	0.013	32.573	0.268	0.580
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	7.590	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	4.664	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	824	815	799	789
	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	81.6	81.1	81.5	80.9	86.6	86.1	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	5.826	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/aec	8001.2	7999.3	7971.8	7973.7	7952.0	7953.0	8007.4	8010.6	8026	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
Oxidizer Turbopump Performance	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
	Pump Efficiency, percent	80.4	80.3	80.4	80.3	80.4	80.3	80.5	80.4	80.3	80.2
	Pump Speed, rpm	8773	8723	8742	8695	8713	8663	8984	8910	8797	8749
	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
Gas Generator Performance	Turbine Inlet Temperature, °F	804	789	798	781	820	804	770	752	789	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	879.5	879.5	875.6	876.0	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 Con- ditions 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 Tempera- ture at Engine Start, °F	---	1201	---
Fuel Lead Time, sec	---	8	1
Propellant Utili- zation 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

<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro-sadic</u>	<u>Magnetic Tape</u>	<u>Oscillograph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
	<u>Current</u>		<u>amp</u>					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	<u>Event</u>							
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 Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x				
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	<u>Flows</u>		<u>gpm</u>					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-1SAM	Fuel Flow Stal. Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 150	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	<u>Position</u>		<u>Percent Open</u>					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x		x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	<u>Pressure</u>		<u>psia</u>					
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)

<u>AEDC</u> <u>Code</u>	<u>Parameter</u>	<u>Tap</u> <u>No.</u>	<u>Range</u>	<u>Micro-</u> <u>static</u>	<u>Magnetic</u> <u>Tape</u>	<u>Oscillo-</u> <u>graph</u>	<u>Strip</u> <u>Chart</u>	<u>X-Y</u> <u>Plotter</u>
	<u>Pressure</u>		<u>psia</u>					
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 F.L.C. 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			
PFPSPD-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				
PHECNO	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-sadc	Magnetic Tape	Osculograph	Strip Chart	X-Y Plotter
	<u>Pressure</u>		<u>psia</u>					
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				
	<u>Speeds</u>		<u>rpm</u>					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	<u>Strain</u>		<u>μin./in.</u>					
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			
	<u>Temperatures</u>		<u>°F</u>					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TCDP	Crossover Duct Purge		-150 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	

TABLE III-1 (Continued)

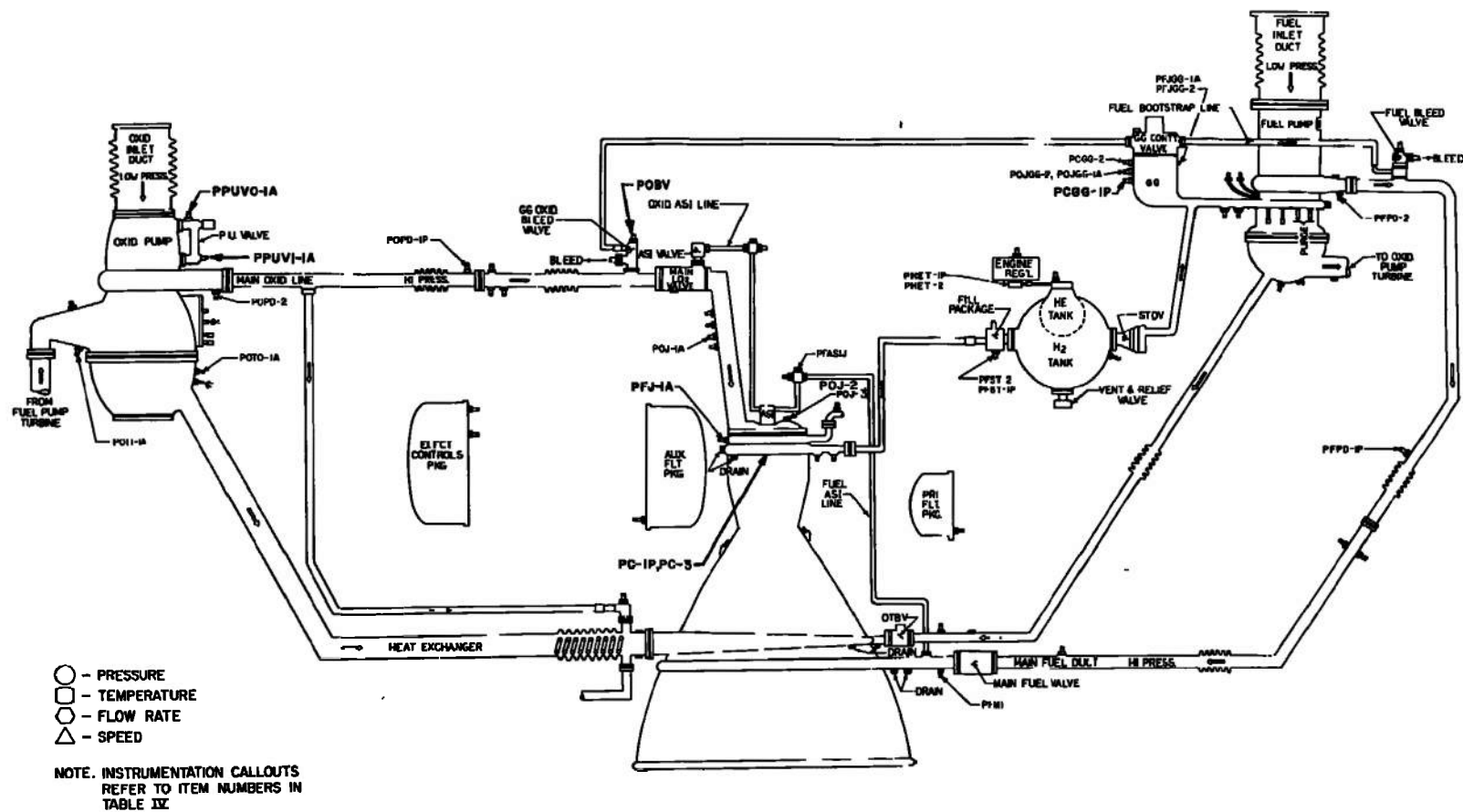
<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro- sadic</u>	<u>Magnetic Tape</u>	<u>Oscillo- graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
	<u>Temperatures</u>		<u>°F</u>					
TFASIL-4	Augmented Spark Igniter Line		-425 to +500	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	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)

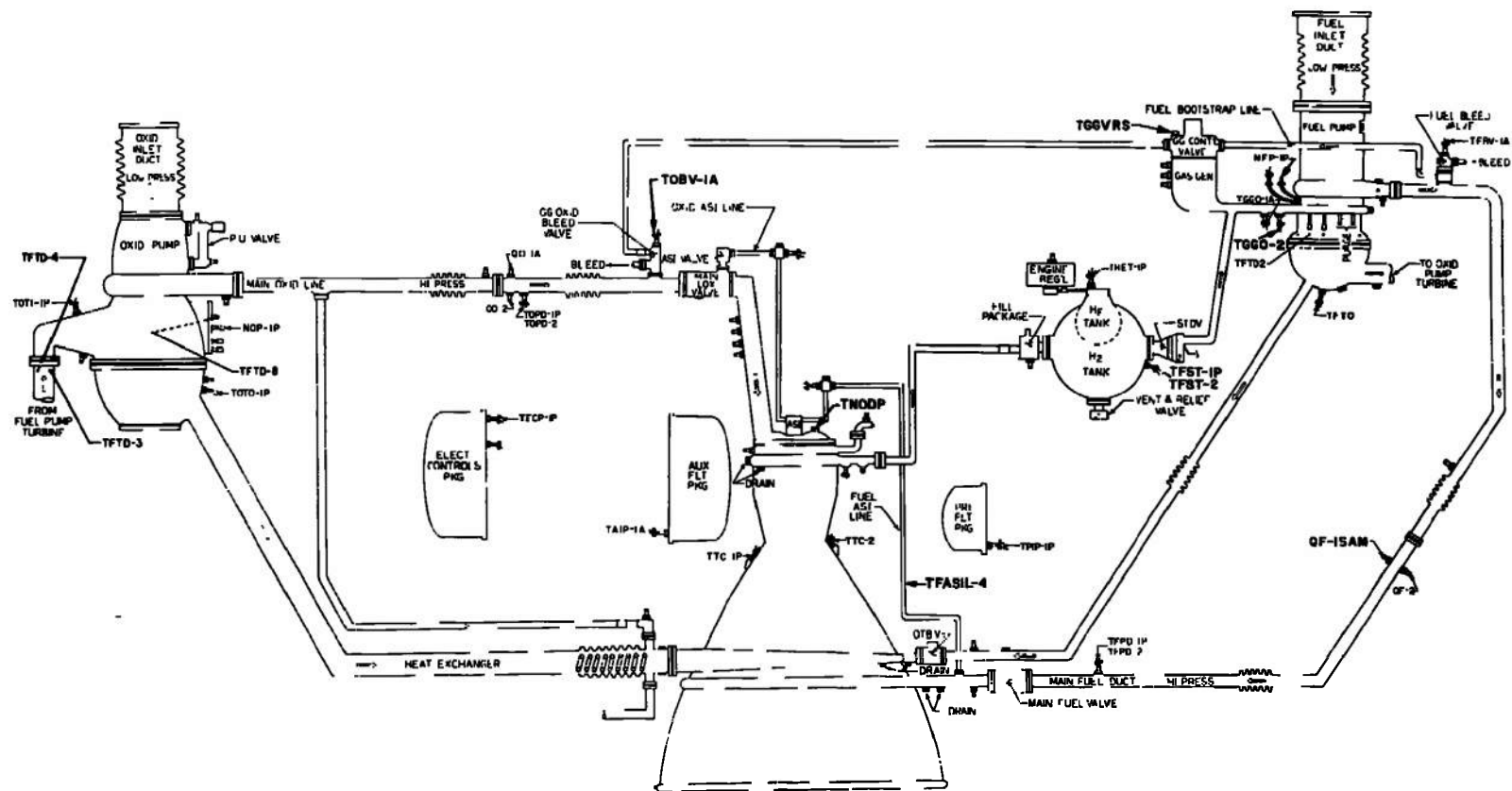
<u>AEDC Code</u>	<u>Parameter</u>	<u>Tap No.</u>	<u>Range</u>	<u>Micro-sadie</u>	<u>Magnetic Tape</u>	<u>Oscillo-graph</u>	<u>Strip Chart</u>	<u>X-Y Plotter</u>
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	-300 to 1200	x			x	
TOTO-1P	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				
<u>Vibrations</u>			<u>g's</u>					
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			
UFRP	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		
<u>Voltage</u>			<u>volts</u>					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		8 to 16	x		x		
VPUTEF	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.

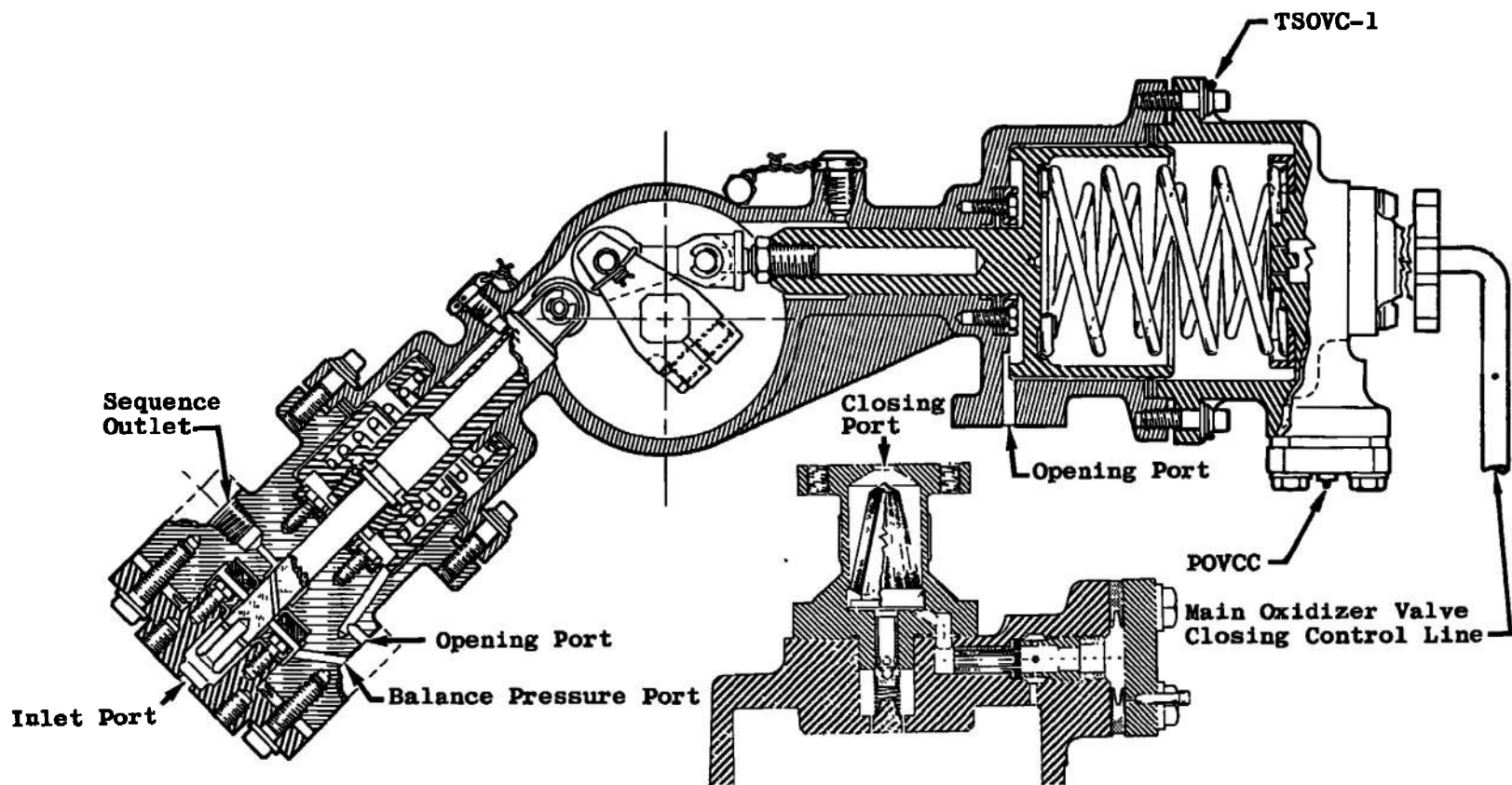
4. Deleted after firing 43.
 5. Added beginning with firing 02.



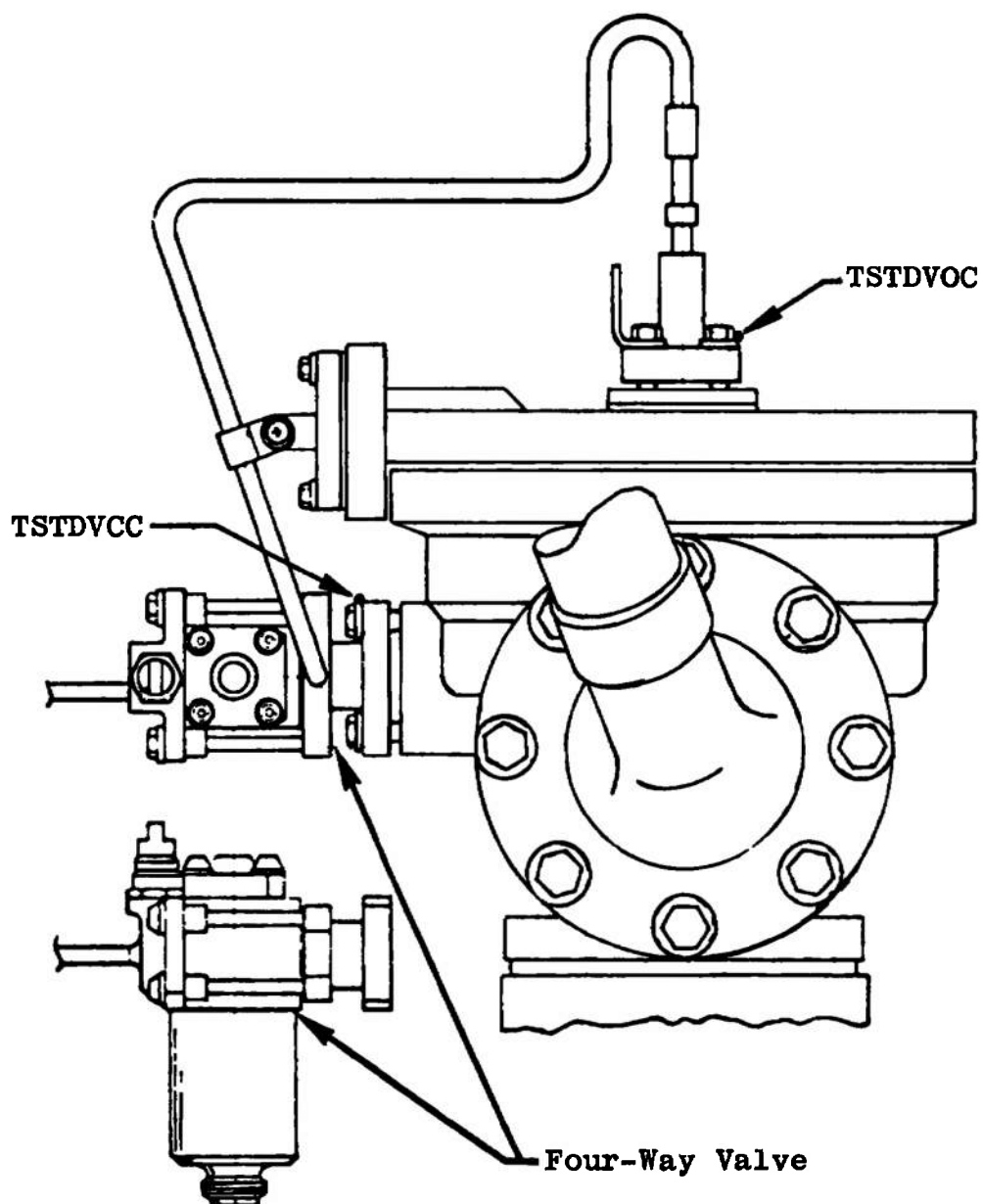
a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations



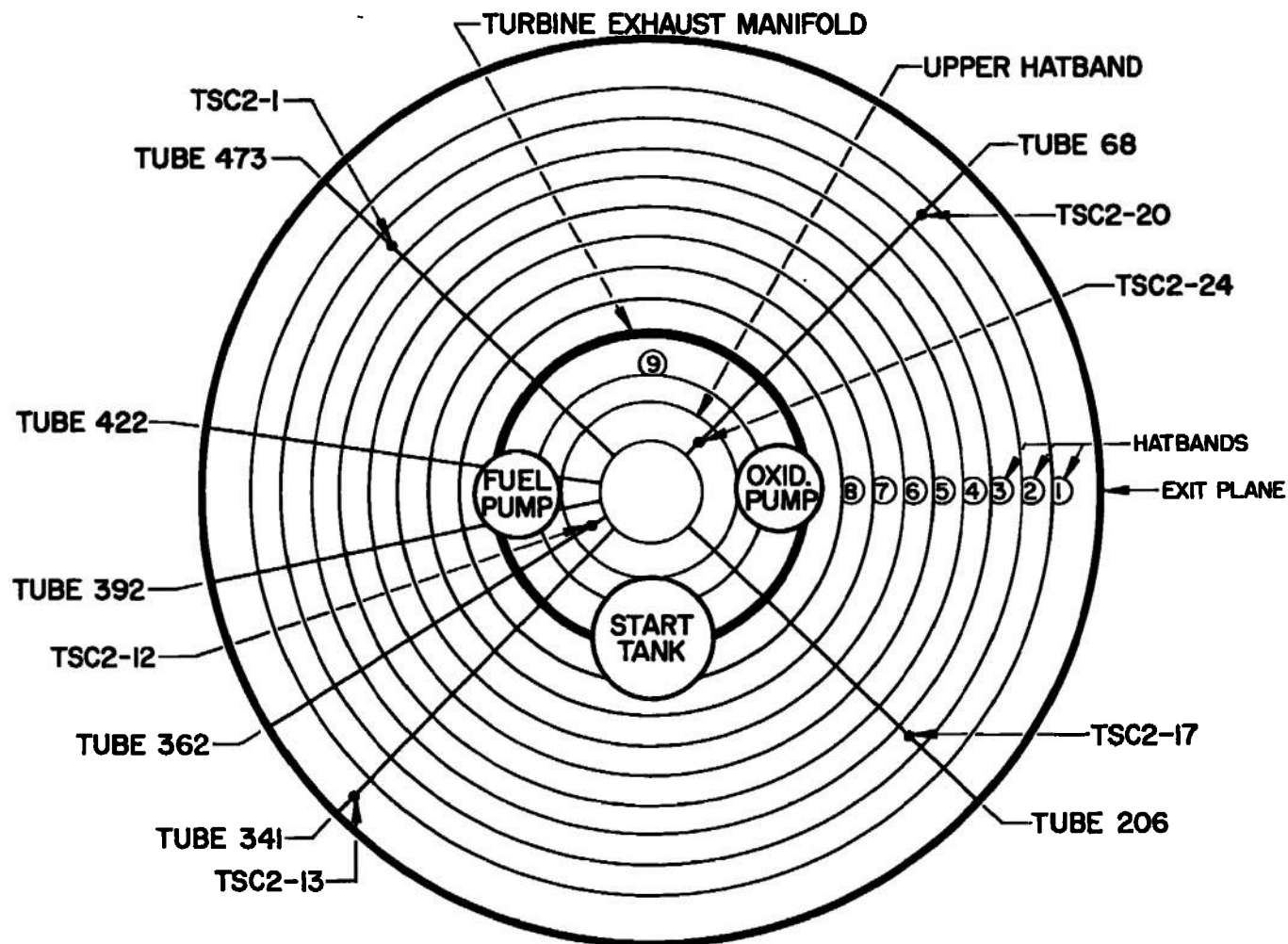
b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

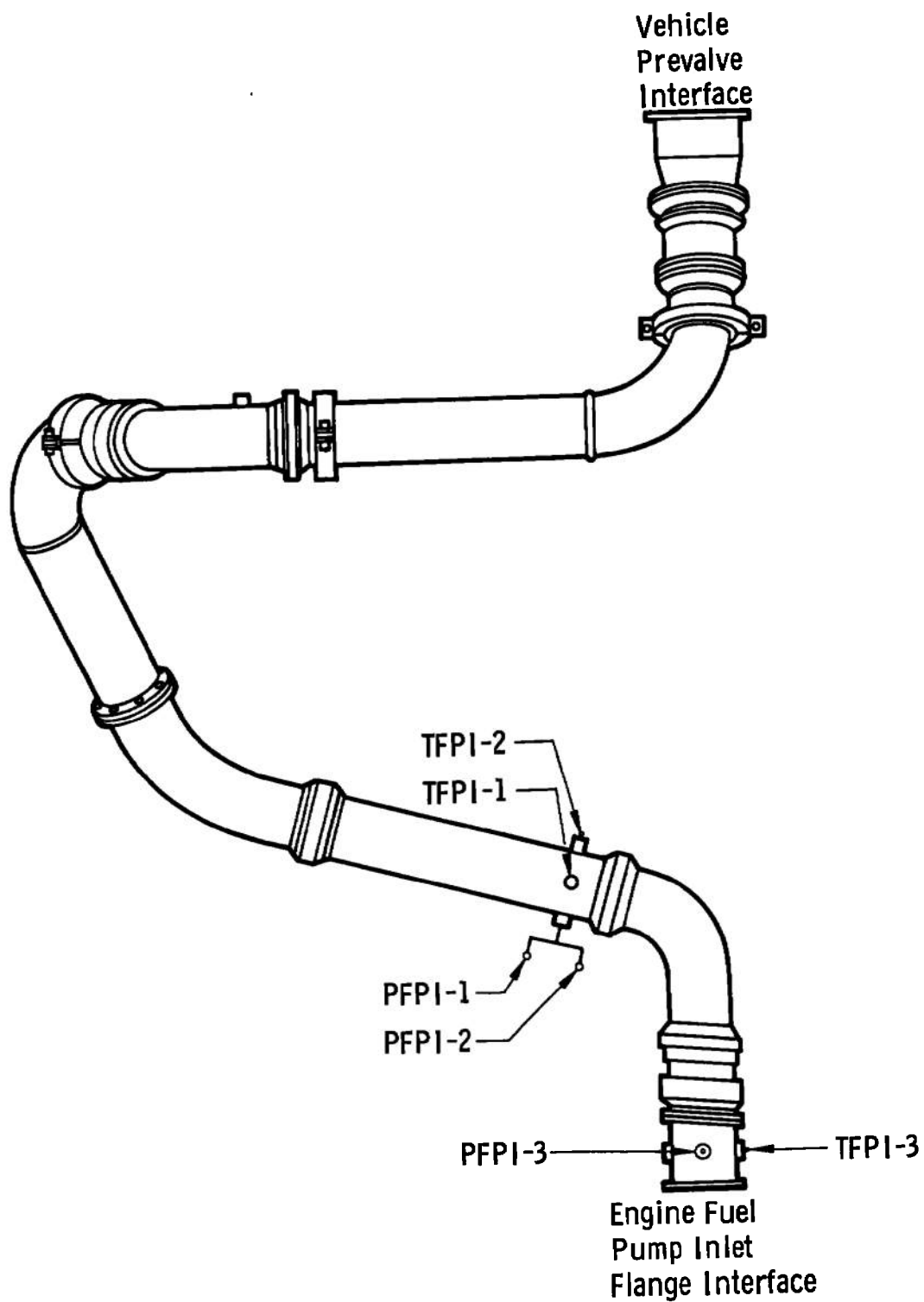


d. Start Tank Discharge Valve
Fig. III-1 Continued



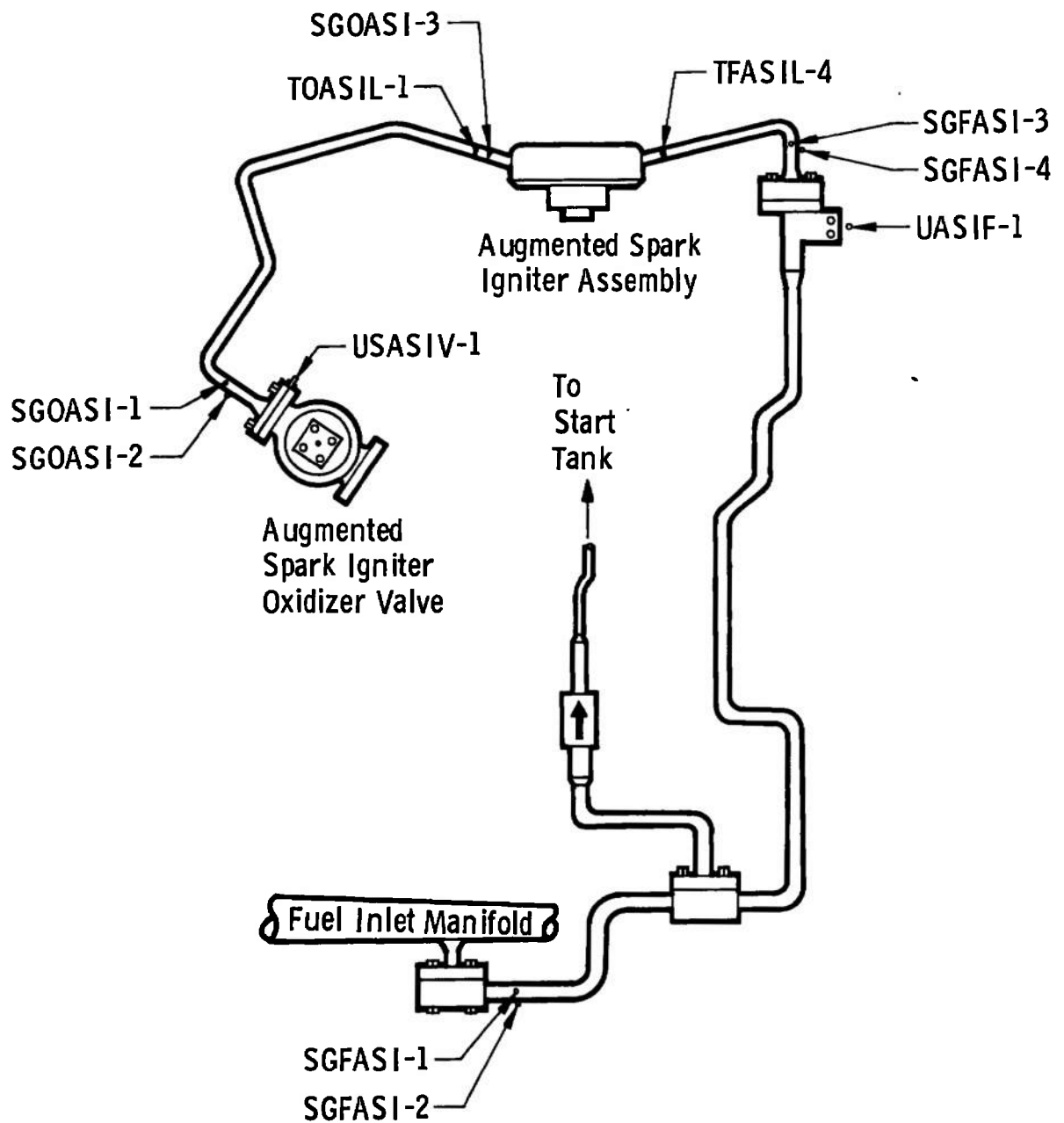
VIEW LOOKING AFT

e. Thrust Chamber
Fig. III-1 Continued



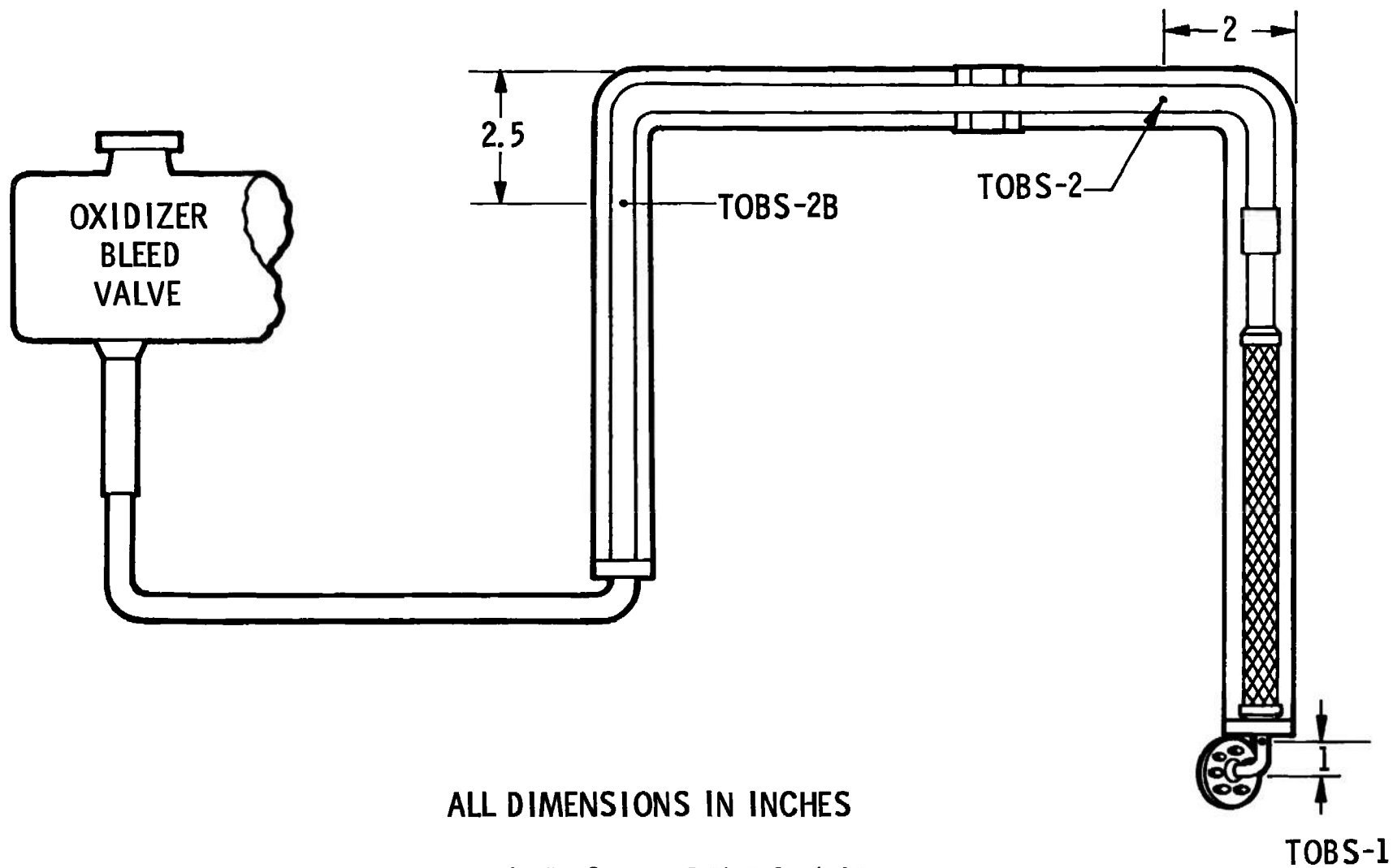
f. Low Pressure Fuel Duct

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, lbf
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
β	Ratio
γ	Ratio of specific heats
η	Efficiencies
θ	Degrees
ρ	Density, lb/ft ³

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

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

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

PERFORMANCE PROGRAM EQUATIONS

THRUST

Thrust Chamber, Vacuum

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

Empirical Determination from Curve Fit of Thrust
versus P_C

Thrust Chamber

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

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

$$P_{AA} = \text{Measured Cell Pressure}$$

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

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

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

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

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

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

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

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

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

$$K_7 = 32.174$$

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

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

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

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

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

$$T_{IO} \text{ STD} = -295.2^\circ\text{F}$$

$$T_{IF} \text{ STD} = 422.5^\circ\text{F}$$

SPECIFIC IMPULSE

Engine

$$I_{SE} = \frac{F_E}{W_E}$$

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

Engine, Vacuum

$$I_{SEV} = \frac{F_{EV}}{W_{EV}}$$

$W_{EV} = W_E$ Normalized using standard inlet pressures, temperatures, and densities

Chamber

$$I_{SC} = \frac{F_C}{W_C}$$

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

Chamber, Vacuum

$$I_{SCV} = \frac{F_{CV}}{W_{CV}}$$

$W_{CV} = W_C$ Normalized using standard inlet pressures, temperatures, and densities

CHARACTERISTIC VELOCITY

Thrust Chamber

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

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

$$C^*_V = \frac{K_7 P_{CV} A_t}{W_{CV}}$$

$$K_7 = 32.174$$

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

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

$$K_4 = 144$$

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

Fuel

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

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

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

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

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

$$\eta_0 = \eta_{OC} \gamma_0$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_0} \right)^2 + K_{50} \left(\frac{Q_{PO}}{N_0} \right) + K_{60}$$

$$\gamma_0 = 1.000$$

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

TURBINES

Oxidizer, Efficiency

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

$$B_{TO} = K_5 \frac{W_{PO} H_0}{\eta_0}$$

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

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

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

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

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

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

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

$$D = 1.234$$

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

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

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

$$B_{TO} \approx B_{PO}$$

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

$$K_5 = 0.001818$$

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

$$W_{TF} = W_T$$

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

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

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

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

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

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

$$K_{13} = 0.7854$$

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

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

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

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

$$K_8 = 38.90$$

GAS GENERATOR

Mixture Ratio

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

$$A_1 = 0.2575$$

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

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

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

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

Flows

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

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

$$B_2 = 3.2267$$

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

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

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

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

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

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

APPENDIX V

METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)

FLOW COEFFICIENT, ϕ

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

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

$$V_f = \frac{Q}{(448.9) A} \quad \begin{array}{l} Q = \text{Flow rate, gpm} \\ A = \text{Inducer annulus area, ft}^2 \text{ (specified as 0.2856 ft}^2 \text{ by Rocketdyne)} \end{array}$$

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

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

$$V_T = \left(\frac{\pi}{60}\right) (D_T) (N) \quad \begin{array}{l} N = \text{Pump speed, rpm} \\ D_T = \text{Inducer rotor tip diameter, ft (specified as 0.653 ft by Rocketdyne)} \end{array}$$

Therefore,

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

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

HEAD RISE COEFFICIENT

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

where H = Total pump head rise, ft

$$g = 32.174 \text{ ft/sec}^2$$

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

$$V_{T^1} = \left(\frac{\pi}{60}\right) (D_{T^1}) (N) \quad \begin{array}{l} N = \text{Pump speed, rpm} \\ D_{T^1} = \text{Pump rotor tip diameter, ft (specified as 0.6043 ft by Rocketdyne)} \end{array}$$

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

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 <p>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.</p> <p>This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812.</p> <p>This document has been approved for public release its distribution is unlimited. <i>Per A 5 letter 10/1/68 signed [signature]</i></p>			

14.

KEY WORDS

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2. Missiles -- Saturn
3. Rocket motors -- Performance.
4. " " -- Ignition
5. Spark ignition
6. Igniters

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