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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-01)

Per AF letter dtd 12 July 74
Signed ... O. Cole.

W. W. Muse and C. E. Pillow
ARO, Inc.

December 1967

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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W. W. Muse and C. E. Pillow
ARO, Inc.

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (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 AF40(600)-1200. Program direction was provided by NASA/MSFC; technical and engineering liaison were provided by North American Aviation, Inc., Rocketdyne Division, Manufacturer of the J-2 rocket engine; and engineering liaison was provided by Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on July 6 and 7, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on August 11, 1967.

This technical report has been reviewed and is approved.

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ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-01 at pressure altitudes ranging from 97,000 to 108,000 ft at engine start to evaluate S-V/S-II gas generator ignition characteristics for J-2 engine J-2052. Engine components were temperature conditioned to the predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 45.3 sec.

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NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g in a 960- to 9000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine (S/N J-2052) using a 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 four firings reported herein were conducted during test period J4-1801-01 on July 6 and 7, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-V/S-II gas generator ignition characteristics. These firings were accomplished at pressure altitudes ranging from 97,000 to 108,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start and with predicted S-II interstage/engine temperature conditions as the targets for conditioning engine components.

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. A S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

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

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

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

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

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

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

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel

turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

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

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

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

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

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

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

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

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

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

2.1.2 S-IVB Battleship Stage

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

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

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100, 000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

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

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, pneumatic regulator, and main oxidizer valve closing control line and second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the pneumatic regulator and main oxidizer valve closing control line and second-stage actuator.

2.3 INSTRUMENTATION

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

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

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

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

2.4 CONTROLS

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

SECTION III
PROCEDURE

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

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

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Four firings of the J-2 rocket engine were conducted on July 6 and 7, 1967, during test period J4-1801-01 to investigate the J-2 engine S-II/S-V gas generator ignition characteristics. These firings completed the first series of S-II start transient investigation testing at AEDC (Ref. 2). Testing was accomplished at pressure altitudes ranging from 97,000 to 108,000 ft at engine start and with predicted S-II interstage/engine temperature conditions as the targets for conditioning engine components. Each engine firing was preceded by a 1-sec fuel lead.

User test requirements requesting temperature conditioning of the turbine crossover duct, pneumatic regulator, main oxidizer valve second-stage actuator, and main oxidizer valve closing control line within specified limits for 30 min before the engine firing were not completely attained because of inadequate control of the conditioning systems. Table VI presents the conditioning targets for the engine components and the measured test conditions at engine start.

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

Firing	Test Objectives	Results
01A	To investigate gas generator ignition characteristics for S-II worst-case gas generator second peak temperature conditions and to verify nominal engine performance	Main oxidizer valve component temperatures were colder than the conditioning targets. A gas generator second peak temperature did not occur; an initial peak temperature of 2170°F was recorded. Calculated engine thrust was 2.62 percent higher than rated thrust.
01B	To determine the effect of thrust chamber temperature on S-II gas generator ignition characteristics by comparing the test results with firing 01A	Engine conditioning compared closely with that for firing 01A, except for a 90°F colder thrust chamber. The initial peak temperature was 1950°F. Inadequate fuel quantity to sustain gas generator combustion appeared to exist for 93 msec immediately after ignition.

Firing	Test Objectives	Results
01C	To determine the effect of crossover duct temperature on S-II gas generator ignition characteristics by comparing the test results with firing 01B	Engine conditioning compared closely with that for firing 01B, except for a 60°F colder crossover duct. The initial peak temperature was 2000°F. Inadequate fuel quantity to sustain gas generator combustion appeared to exist for 87 msec immediately after ignition.
01D	To investigate gas generator ignition characteristics for S-II worst-case gas generator second peak temperature conditions	Engine conditioning compared closely with the target temperatures, except main oxidizer valve second-stage actuator, which was 13°F warm. A gas generator second peak temperature of 1550°F was recorded; the initial peak temperature was 1990°F.

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

4.2 TEST RESULTS

4.2.1 Firing J4-1801-01A

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are shown in Fig. 8. Table VII presents selected engine valve operating times for start and shutdown. Engine ambient pressure altitude at engine start was 97,000 ft. Figure 9 presents engine ambient pressure and combustion chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion at about t_0 + 10 sec, which changed the engine mixture ratio from 5.0 to 5.5. The increase in cell pressure during the firing to 0.412 psia (80,000 ft) resulted from excessive secondary flow, caused by a leaking facility gaseous nitrogen annular ejector supply valve.

Thermal conditioning history of selected engine components is shown in Fig. 10. The rapid chilling of the main oxidizer valve closing control line and the second-stage actuator, beginning at about t_0 - 60 sec, resulted from additional chilled helium, which was diverted from the terminated thrust chamber chill. The main oxidizer valve component temperatures colder than the specified conditioning limits would tend normally to produce a higher gas generator second peak temperature. For all subsequent engine firings, all thermal conditioning systems were terminated at approximately t_0 - 60 sec.

The gas generator ignition characteristics for S-II worst-case gas generator second peak temperature conditions are shown in Fig. 11. Ignition occurred at t_0 + 0.656 sec, beginning engine bootstrap operation, and was characterized with the absence of gas generator fuel system backflow, which was prevalent during previous S-II testing at AEDC. A gas generator second peak temperature was not experienced because the main oxidizer valve movement from the plateau position, beginning at t_0 + 0.988 sec, occurred before engine conditions could be developed which would produce the second peak temperature. The gas generator initial peak temperature was 2170°F. Thrust chamber ignition, which produces the engine conditions for terminating the temperature peak, occurred at t_0 + 0.965 sec.

An abnormally high gas generator peak temperature of 2100°F occurred during shutdown (Fig. 12). The closing of the gas generator propellant control valve appeared nominal. The high temperature peak was attributed to a leaking gas generator oxidizer purge check valve. The valve apparently leaked oxidizer into the purge system during the firing and expelled it into the chamber immediately after shutdown during the normal purging operations.

The fuel pump start transient performance is presented in Fig. 13. Transient fuel pump head/flow data compared conservatively with the pump stall inception data.

Vibration, in excess of 150 g in the 960- to 6000-Hz frequency range, was encountered for 120 msec beginning at t_0 + 0.969.

Engine steady-state performance data are presented in Table VIII. The data presented were for a 1-sec data average from 29 to 30 sec and were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV. Engine performance for this test was higher than nominal. Calculated engine thrust, corrected for vacuum conditions, was 230,900 lb_f, which is 2.62 percent higher than rated thrust. Normalized performance data revealed that the gas generator fuel supply orifice was slightly oversize and that the orifice in the oxidizer turbine bypass nozzle was slightly undersize.

4.2.2 Firing J4-1801-01B

The engine firing was successfully accomplished for the programmed 5-sec duration. Test conditions at engine start are presented in Table VI. Figure 14 presents the engine start and shutdown transients. Selected engine valve operating times for start and shutdown are presented in Table VII. Engine ambient pressure altitude at engine start was 106,000 ft with an average pressure altitude of 97,000 ft during engine main-stage operation. Engine ambient pressure and combustion chamber pressure for the firing duration are presented in Fig. 15.

Thermal conditioning history of selected engine components is shown in Fig. 16. Engine component conditioning for this firing compared sufficiently close to the firing 01A conditioning to permit determination of the influence of the variable, thrust chamber temperature. Thrust chamber throat temperature for firing 01B was -257°F as compared to -163°F for firing 01A.

The gas generator ignition characteristics are presented in Fig. 17. Ignition occurred at t_0 + 0.644 sec. Fuel for ignition was gaseous hydrogen from the start tank discharge, since gas generator fuel injector pressure (reflecting start tank discharge) was approximately 40 psia higher than fuel pump discharge pressure (Fig. 18). As a result, reverse flow from the gas generator into the fuel system occurred throughout the time period from fuel poppet valve opening until after ignition. Immediately after ignition, the flame was apparently extinguished for approximately 93 msec because of inadequate fuel quantity to sustain combustion. This is evident by the decay of gas generator fuel injector pressure and chamber pressure.

Comparison of gas generator ignition for firings 01A and 01B (Fig. 17) reveals that the gas generator ignition anomaly on firing 01B displaced the gas generator transient temperature by about 50 msec. The initial temperature peak recorded for firing 01B was 1950°F, as compared with 2170°F for firing 01A. A second peak temperature was not experienced on either firing because the main oxidizer valve movement from the plateau position, beginning at t_0 + 1 sec (Table VI), occurred before engine conditions could be developed which would produce the second peak temperature.

The effect of the colder thrust chamber for firing 01B was a lower gas generator energy during the bootstrap transient period. This condition, along with the gas generator ignition anomaly, resulted in firing 01B having a lower spin speed of the turbines and lower propellant pump discharge pressures than did firing 01A. Therefore, a longer time was required for thrust chamber ignition (defined as the time that combustion chamber pressure attains 100 psia) and for combustion chamber pressure to attain main-stage operation (indicated in Table VI by the time required for combustion chamber pressure to attain 550 psia). The effect of thrust chamber temperature on the gas generator initial peak temperature cannot be meaningfully established by comparing firings 01A and 01B because of the gas generator ignition anomaly on firing 01B.

The gas generator shutdown for firing 01B was nominal, as shown in Fig. 19. A fuel-rich environment at shutdown caused the momentary drop in temperature; probe and hardware cooling is reflected thereafter.

Transient fuel pump head/flow data, as compared to the pump stall inception data, are presented in Fig. 20. Firing 01B data more nearly approached a high level stall than did firing 01A, although a conservative stall margin existed for both firings.

Vibration, in excess of 150 g in the 960- to 6000-Hz frequency range, was experienced for 13 msec beginning at t_0 + 0.999 sec.

4.2.3 Firing J4-1801-01C

The programmed 5-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Figure 21 shows the engine start and shutdown transients. Table VII presents selected engine valve operating times for start and shutdown. Engine ambient pressure altitude at engine start was 108,000 ft with an average pressure altitude at 99,000 ft during engine main-stage operation. Engine ambient pressure and combustion chamber pressure for the firing duration are presented in Fig. 22.

Thermal conditioning history of selected engine components is shown in Fig. 23. Engine component conditioning for this firing compared sufficiently close to that of firing 01B to permit determination of the influence of the variable, crossover duct temperature. The crossover duct temperature was approximately 60°F colder along the length of the duct for firing 01C than for firing 01B.

The gas generator ignition characteristics are presented in Fig. 24. Ignition occurred at t_0 + 0.659 sec. Fuel for ignition was gaseous hydrogen from the start tank discharge since the gas generator fuel injector pressure (reflecting start tank discharge) was approximately 45 psia higher than the fuel pump discharge pressure (Fig. 18). As a result, reverse flow from the gas generator into the fuel system occurred throughout the time period from fuel poppet valve opening until after ignition. Analog data indicated that the oxidizer poppet valve was allowed to travel in a closing direction during ignition. Immediately after ignition the flame was apparently extinguished for approximately 87 msec because of inadequate fuel quantity to sustain combustion. This is evident by the decay of gas generator fuel injector pressure and chamber pressure.

The gas generator initial peak temperature recorded was 2010°F; again no second peak temperature was experienced because the main oxidizer valve movement from the plateau position, beginning at t_0 + 1.007 sec, occurred before engine conditions could be developed which would produce the second peak temperature.

Figure 24 shows a comparison of the gas generator ignition characteristics for firings 01B and 01C. The effect of crossover duct temperature on the gas generator initial peak temperature cannot meaningfully be established by comparing these firings because of the occurrence of an ignition anomaly on both firings. However, from the data collected, no appreciable effect was observed.

The gas generator shutdown on firing 01C is shown in Fig. 25. The fuel-rich environment at shutdown caused the momentary drop in temperature; probe and hardware cooling is reflected thereafter.

Transient fuel pump head/flow data comparison with the pump stall inception data is presented in Fig. 26. A conservative pump stall margin was maintained throughout the engine start transient.

Engine vibration in excess of 150 g in the 960- to 6000-Hz frequency range was recorded for 149 msec.

4.2.4 Test J4-1801-01D

This was a successful engine firing for a 5.072-sec duration. The pressure altitude at engine start was 108,000 ft with an average altitude of 102,000 ft during engine main-stage operation. Ambient engine pressure and combustion chamber pressure during the firing are shown in Fig. 27. The engine start and shutdown transients are shown in Fig. 28. Selected engine valve operating times for start and shutdown are presented in Table VII.

Before engine start, engine components were thermally conditioned. Temperature histories of these components are shown in Fig. 29. Test conditions at engine start are presented in Table VI. Comparing component temperature conditions at engine start for firings 01A and 01D, thrust chamber temperature averaged approximately 40°F colder for firing 01D, and the main oxidizer valve components averaged approximately 50°F colder for firing 01D.

The gas generator start transient characteristics are shown in Fig. 30. Ignition occurred at t_0 + 0.642 sec. Fuel for ignition was gaseous hydrogen from the start tank discharge, since the gas generator fuel injector pressure was approximately 10 psia higher than the fuel pump discharge pressure at ignition (Fig. 18). Analog data during gas generator ignition show that the oxidizer poppet valve was momentarily allowed to travel in a closing direction. Gas generator ignition was followed immediately by an apparent low energy combustion from t_0 + 0.674 sec to t_0 + 0.697 sec. The gas generator initial peak temperature was 1990°F; a second peak temperature of 1547°F was recorded. The main oxidizer valve moved from its 14-deg position at t_0 + 0.984 sec but did not continue to ramp open until t_0 + 1.29 sec. This, coupled with a lower buildup rate of the fuel pump discharge pressure as a result of a colder thrust chamber for firing 01D than for firing 01A, resulted in an increase in the gas generator mixture ratio and subsequently the second peak temperature on firing 01D. Gas generator shutdown for firing 01D was nominal, as shown in Fig. 31.

Transient fuel pump head/flow data compared with the pump stall inception data are presented in Fig. 32. The head/flow data for this firing more nearly approached a low level pump stall than did firings 01A, 01B, and 01C; however, a conservative stall margin was maintained.

Engine vibration in excess of 150 g in the frequency range from 960 to 9000 Hz was experienced for 168 msec beginning at t_0 + 0.946 sec.

4.3 POST-TEST INSPECTION

The post-test visual inspection of the J-2 engine showed that the gas generator temperature probe was eroded. In addition, engine leak checks revealed that the gas generator oxidizer purge check valve was leaking. Replacement components were subsequently installed. No other engine irregularities were observed.

SECTION V
SUMMARY OF RESULTS

The results of the four firings of the Rocketdyne J-2 rocket engine conducted on July 6 and 7, 1967, in Test Cell J-4 are summarized as follows:

1. Adequate engine component conditioning was realized for all engine firings to permit an evaluation of the influence that the engine conditions under consideration had on gas generator ignition characteristics.
2. The specified engine component conditioning targets for firings 01A and 01D were for a worst-case gas generator second peak temperature. No significant gas generator second peak temperature was recorded on these firings, indicating that a second peak temperature problem does not exist for the J-2 engine/S-II stage application.
3. At the coldest thrust chamber temperature predicted for the J-2 engine/S-II stage application (-260°F), the gas generator start transient was characterized by apparent inadequate fuel quantity to sustain gas generator combustion for approximately 90 msec immediately after ignition. However, no adverse effect was observed on the engine start transient.
4. The initial gas generator peak temperature ranged from 1950 to 2170°F.
5. An abnormally high gas generator temperature of 2100°F occurred during shutdown on firing 01A as a result of leaking oxidizer purge check valve.
6. Calculated engine thrust was 2.62 percent higher than engine rated thrust.
7. Vibration in excess of 150 g in the 960- to 9000-Hz frequency range occurred on all firings with durations ranging from 13 to 168 msec.
8. Comparison of the transient fuel pump head/flow data with the pump stall inception data indicated that a conservative stall margin was maintained for all firings.
9. Engine ambient pressure altitude at engine start ranged from 97,000 to 108,000 ft.

REFERENCES

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

2. Vetter, N. R., Franklin, D. E., and Muse, W. W. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-27 through J4-1801-01)." AEDC-TR-67-180, November 1967.

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

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

APPENDIXES

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

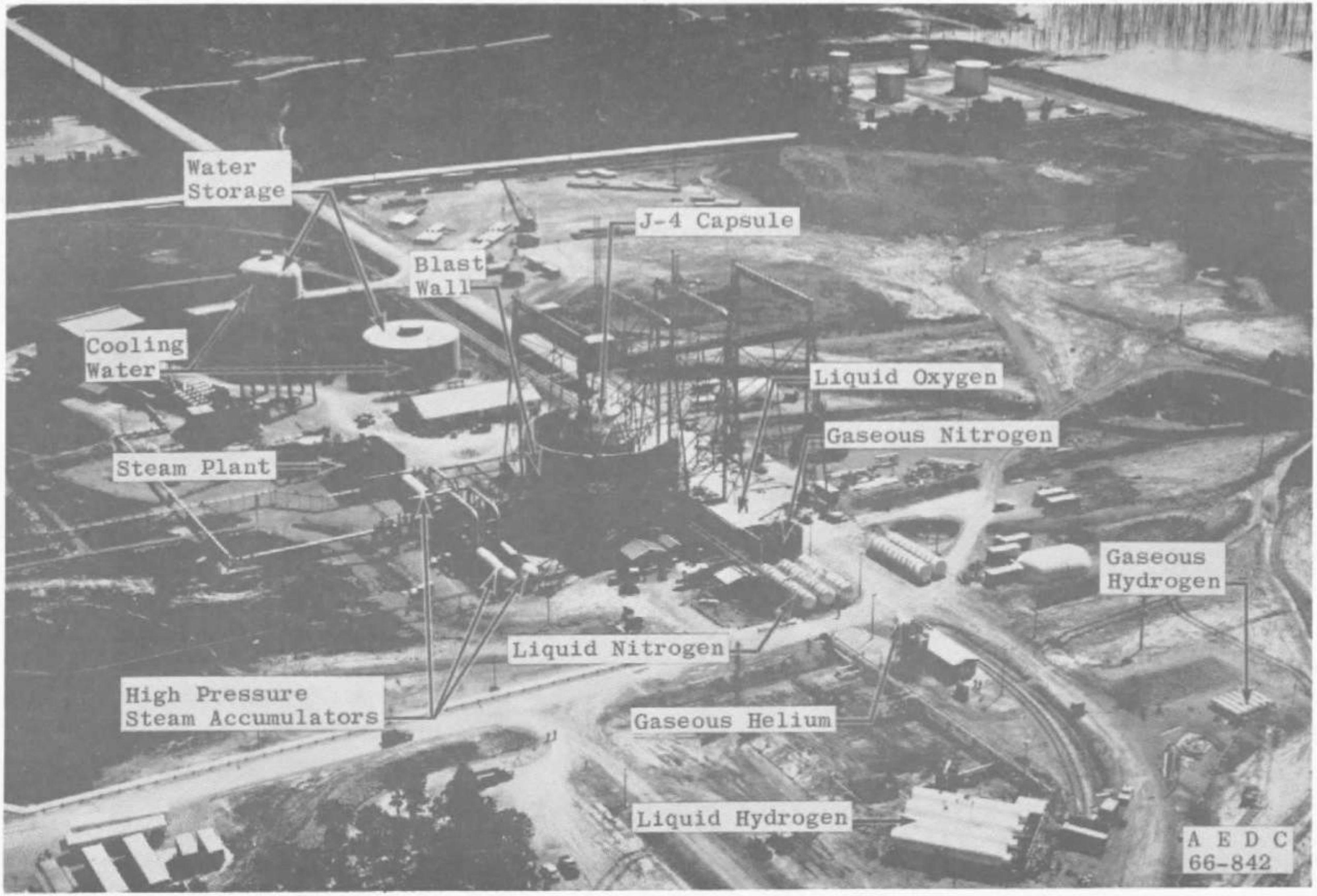


Fig. 1 Test Cell J-4 Complex

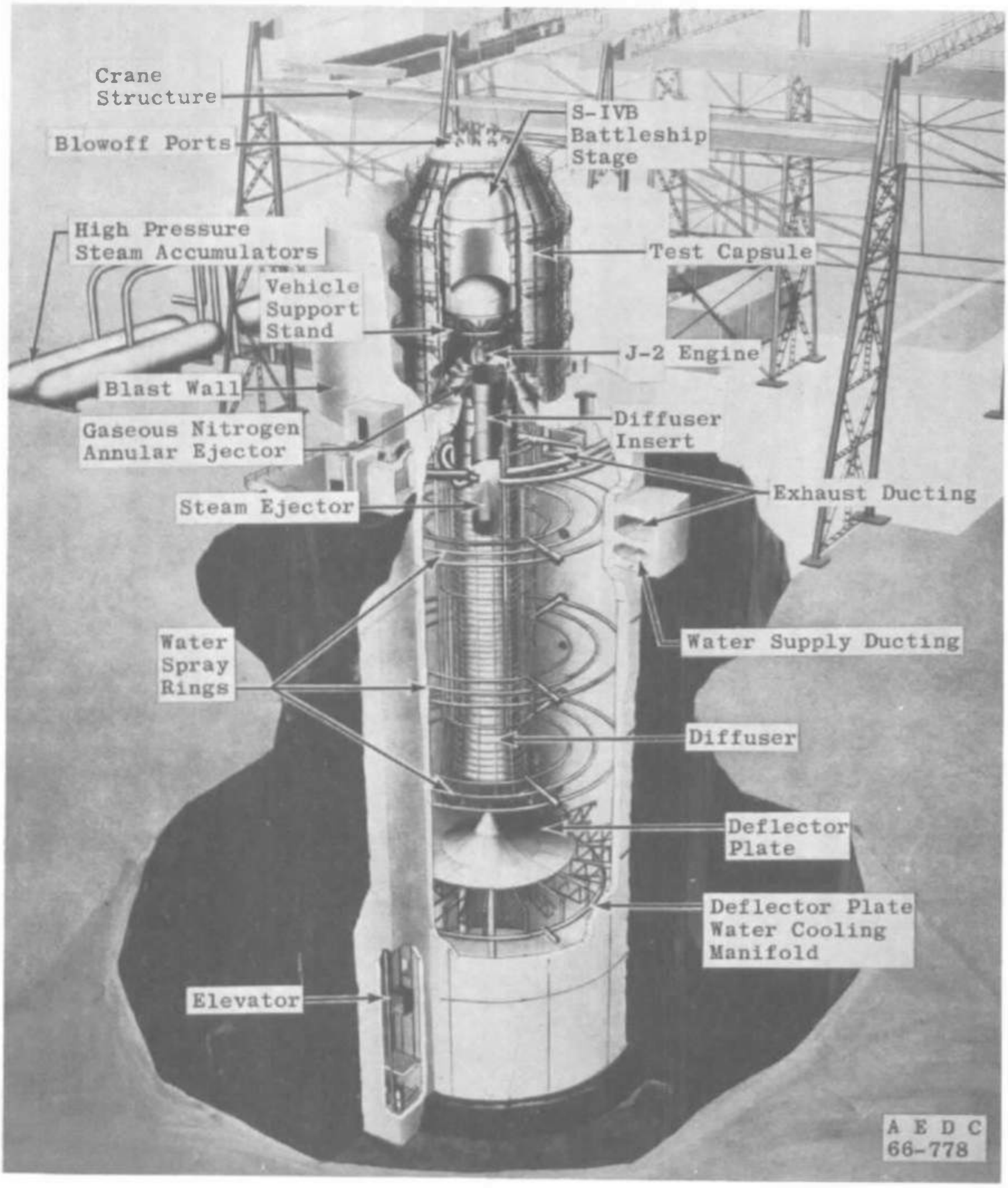


Fig. 2 Test Cell J-4, Artist's Conception

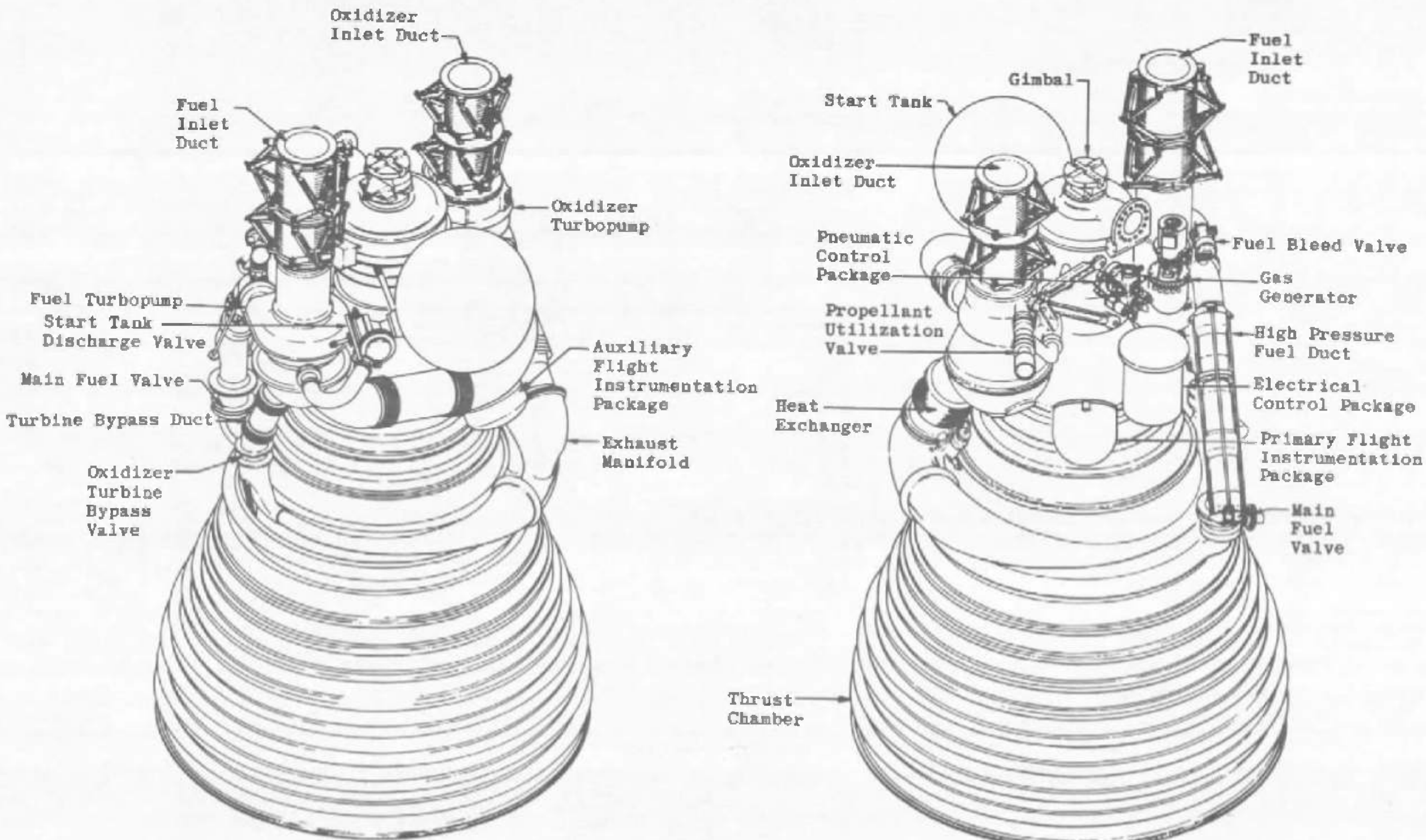


Fig. 3 Engine Details

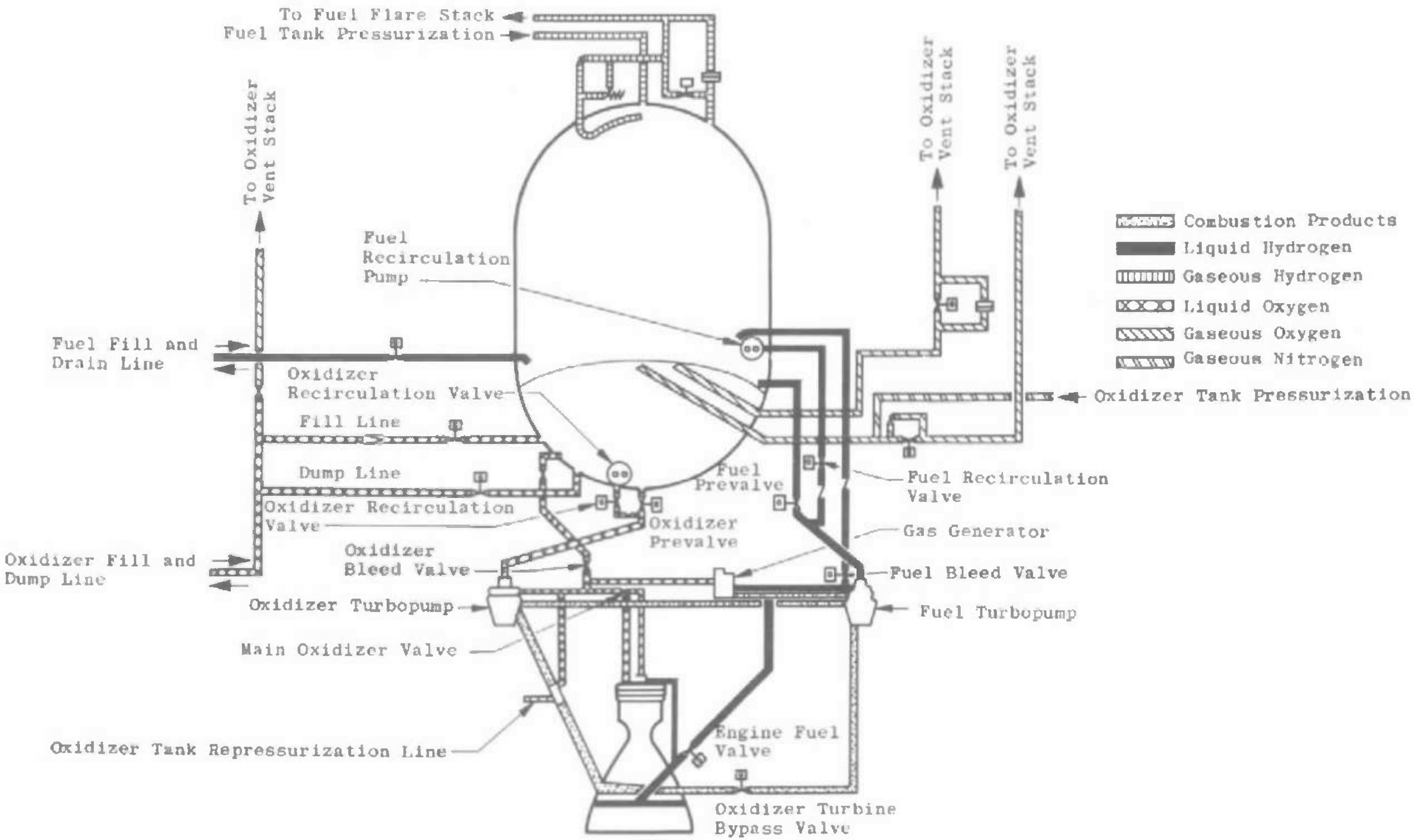


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

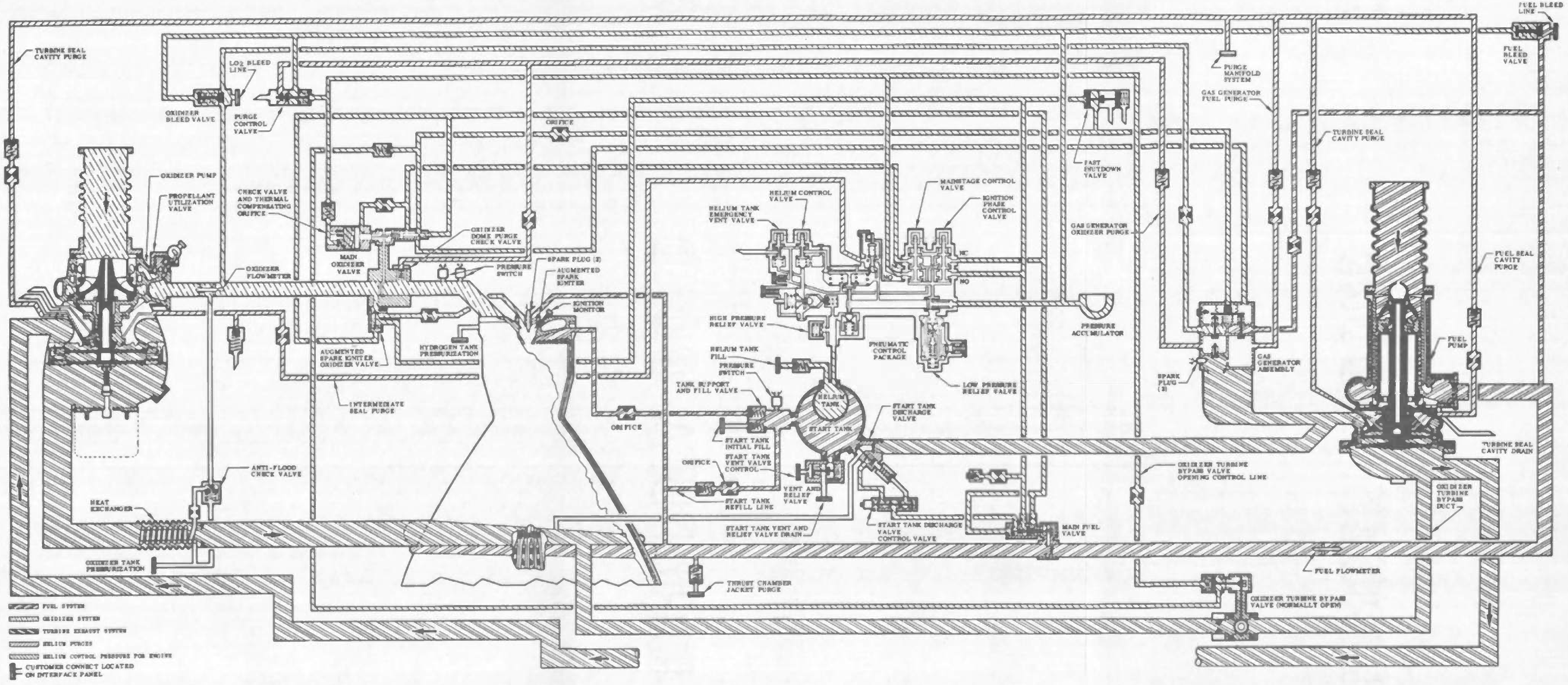


Fig. 5 Engine Schematic

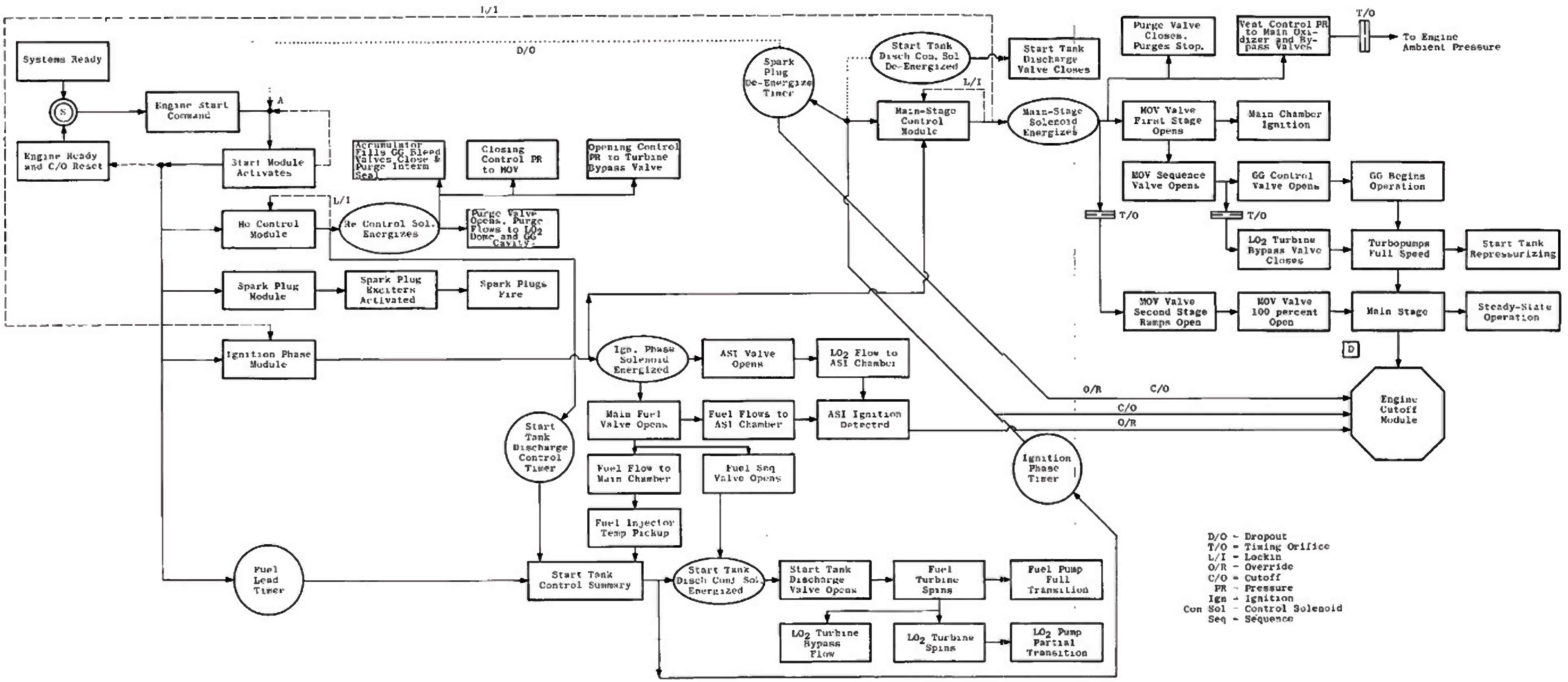
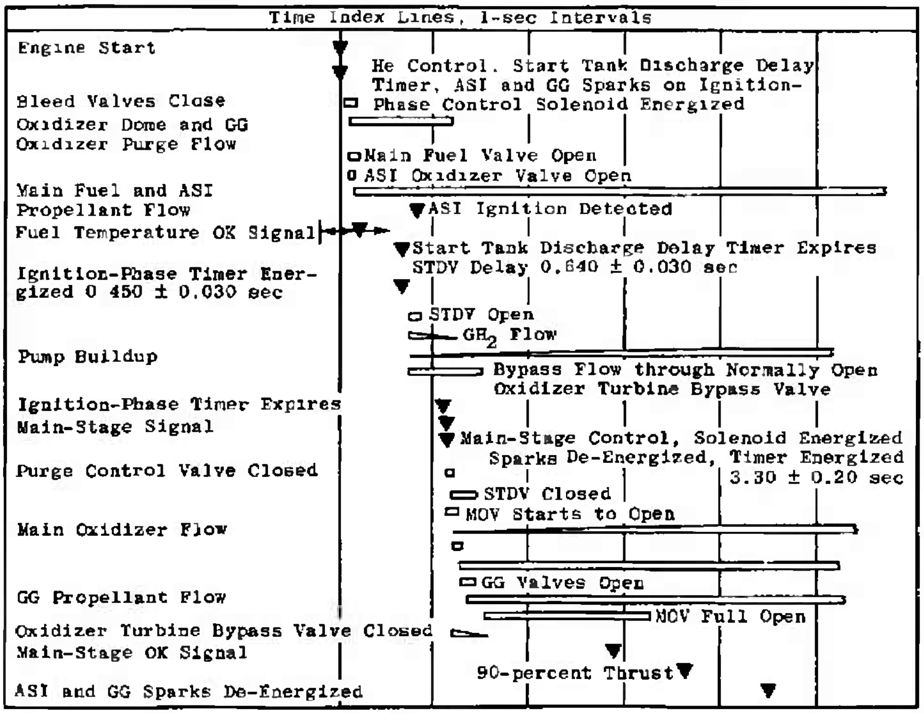
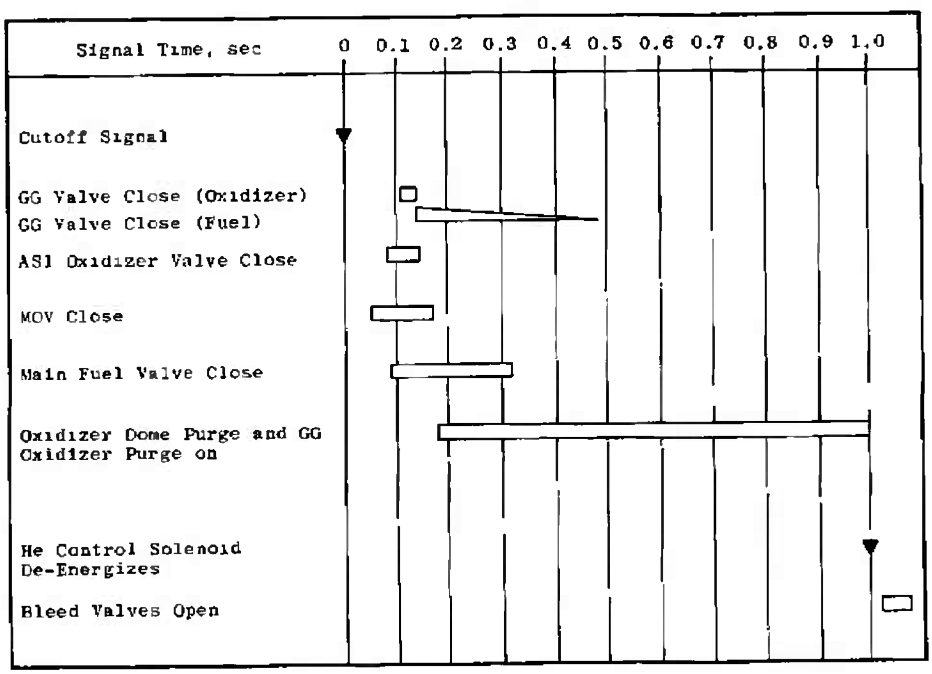


Fig. 6 Engine Start Logic Schematic

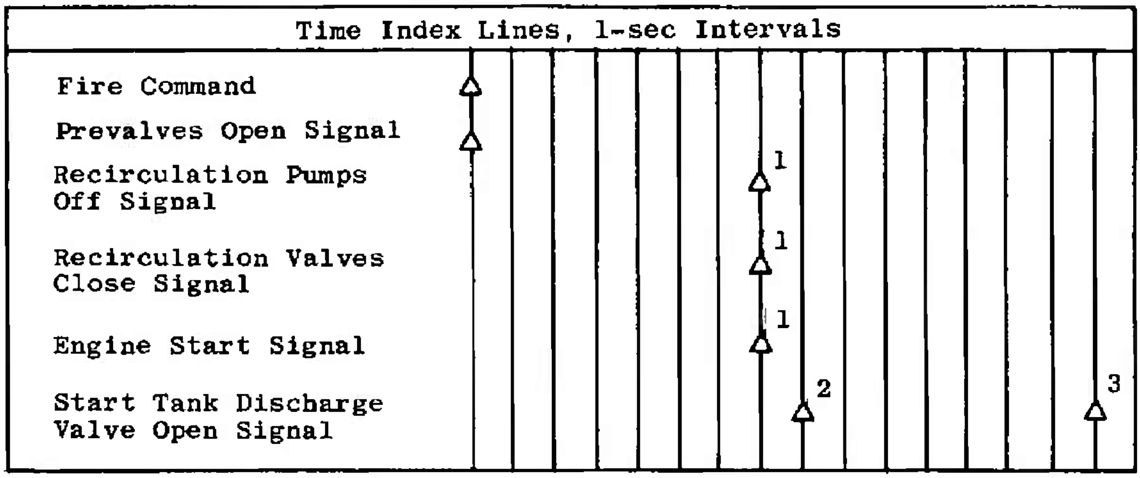


a. Start Sequence



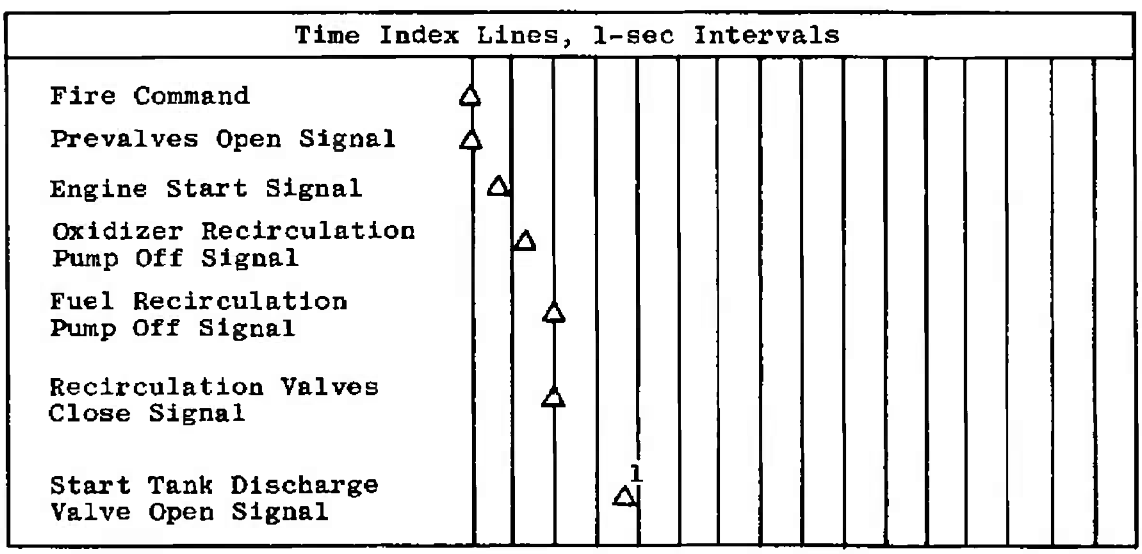
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



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

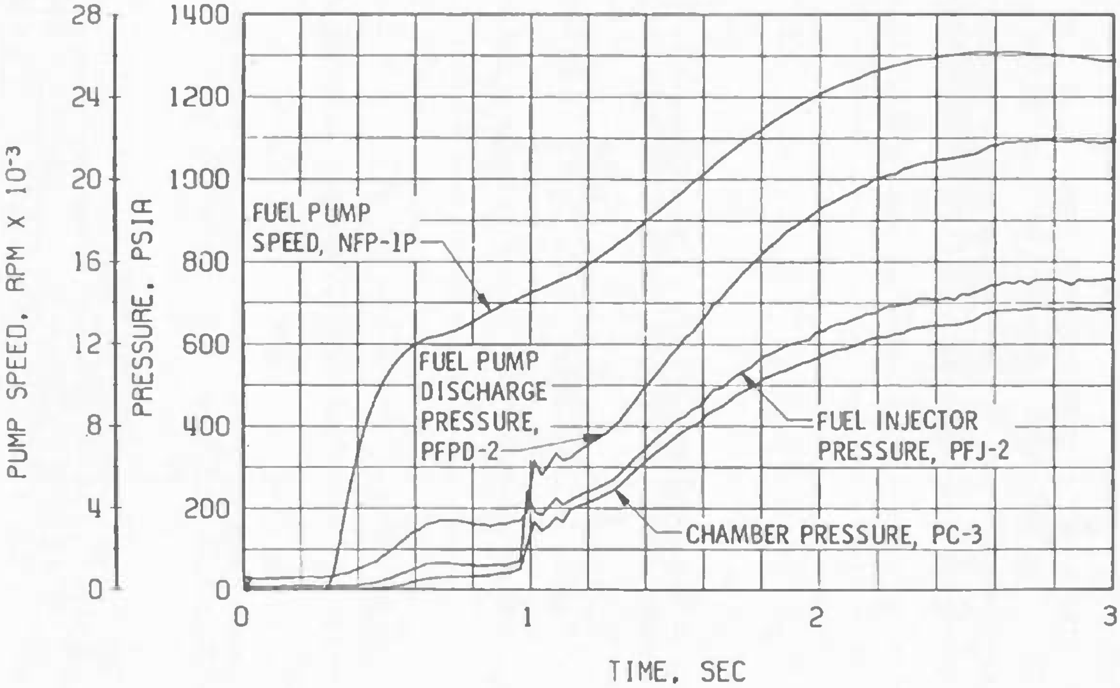
c. "Normal" Start Sequence



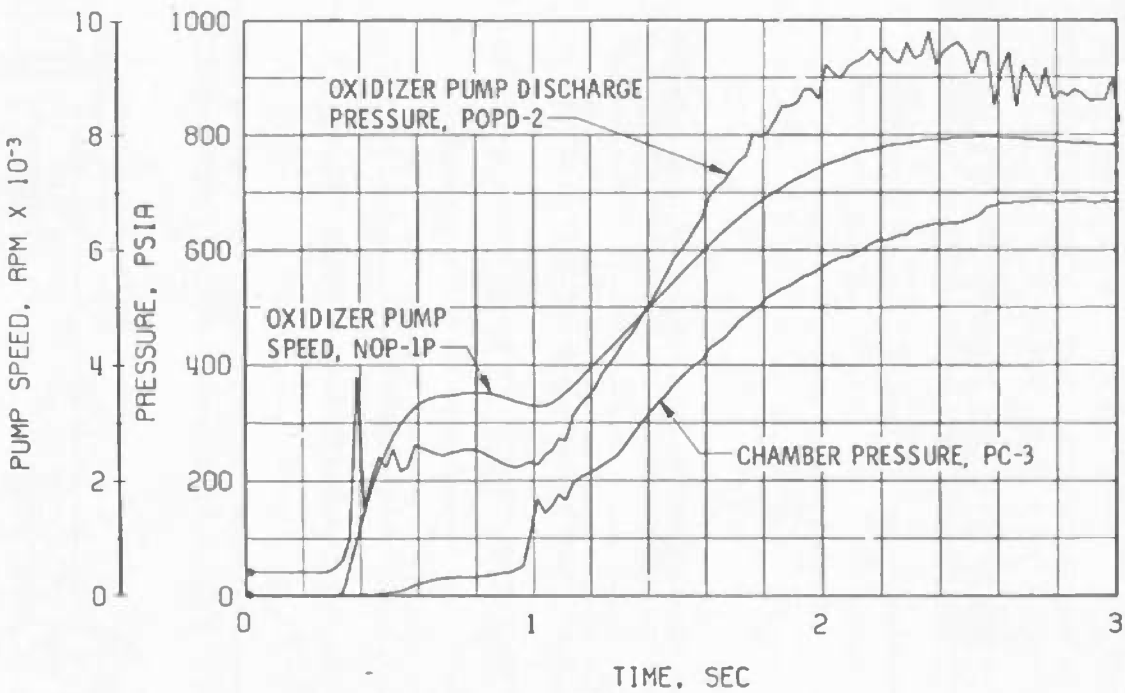
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded

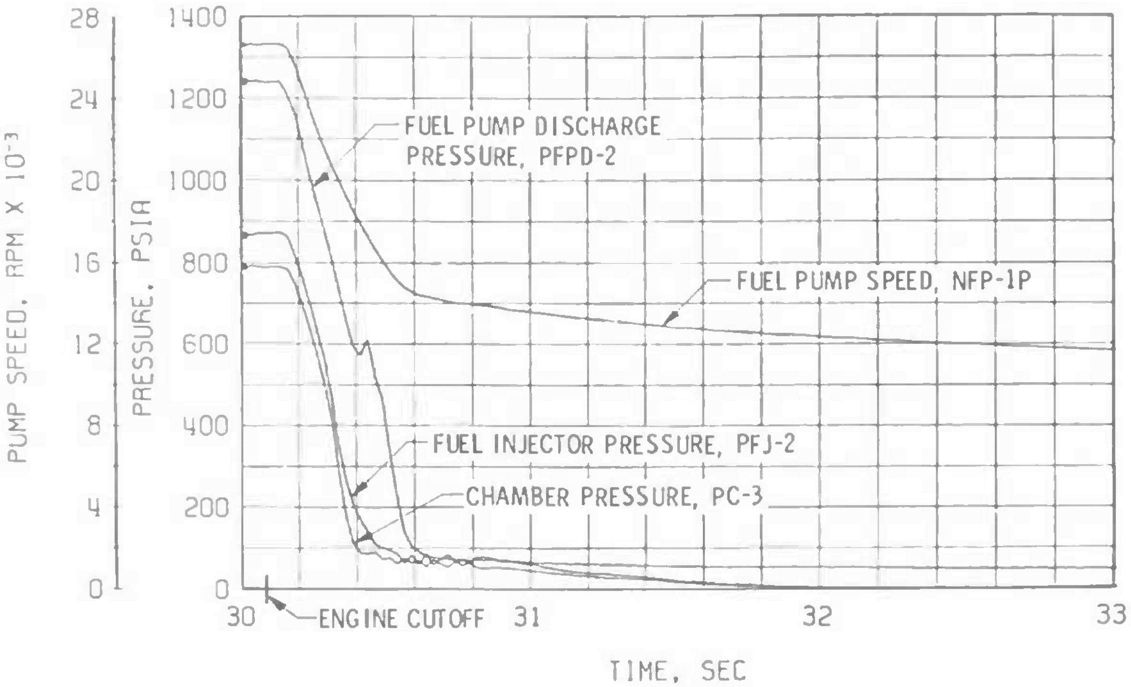


a. Thrust Chamber Fuel System, Start

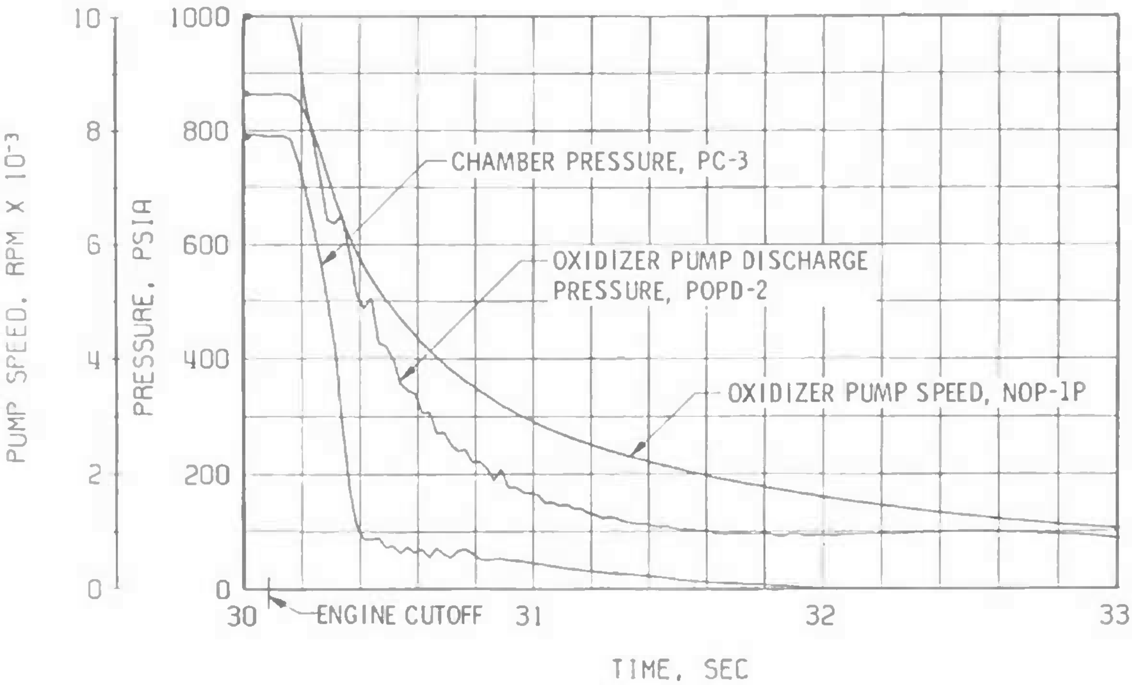


b. Thrust Chamber Oxidizer System, Start

Fig. 8 Engine Transient Operation, Firing 01A



c. Thrust Chamber Fuel System, Shutdown



d. Thrust Chamber Oxidizer System, Shutdown

Fig. B Concluded

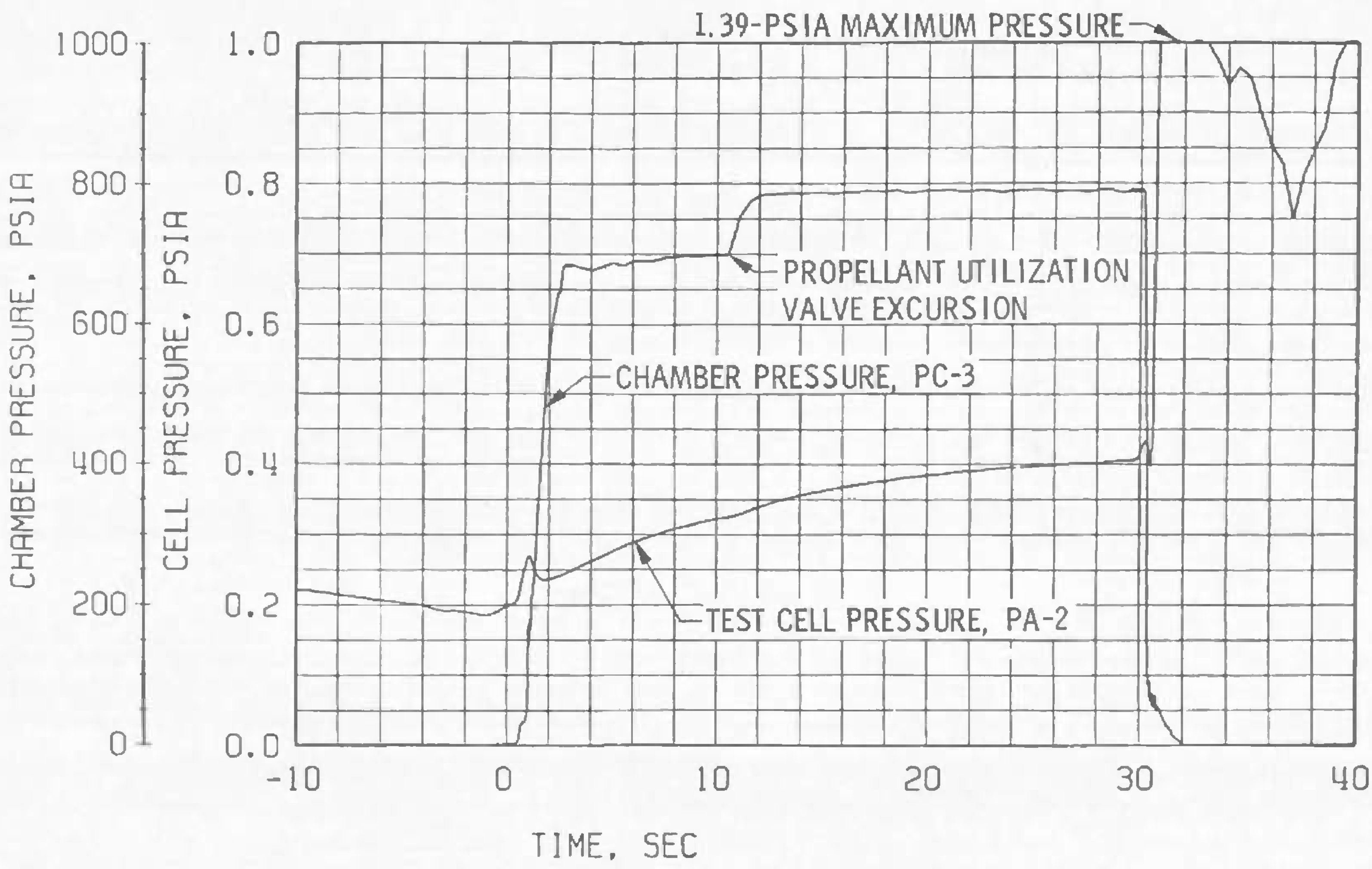
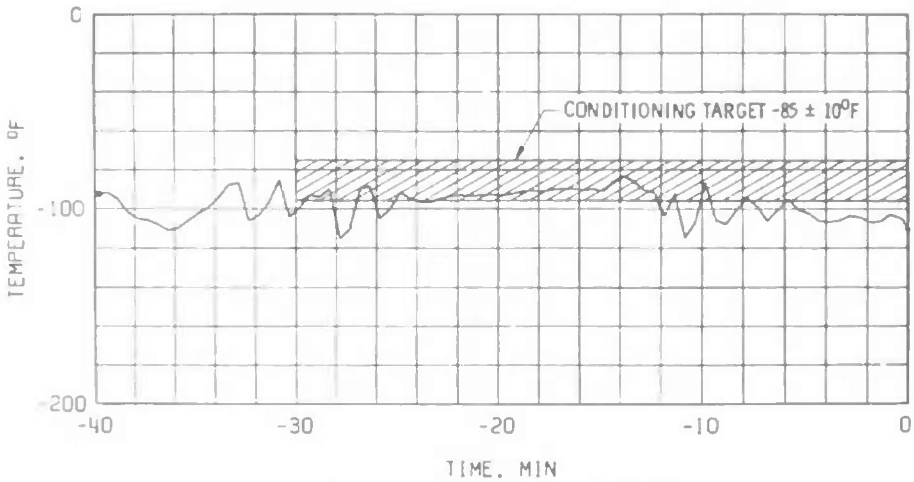
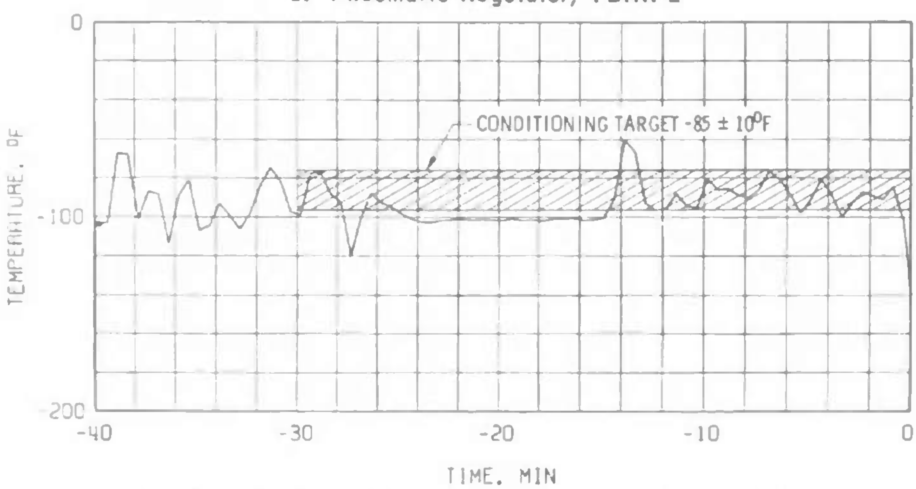


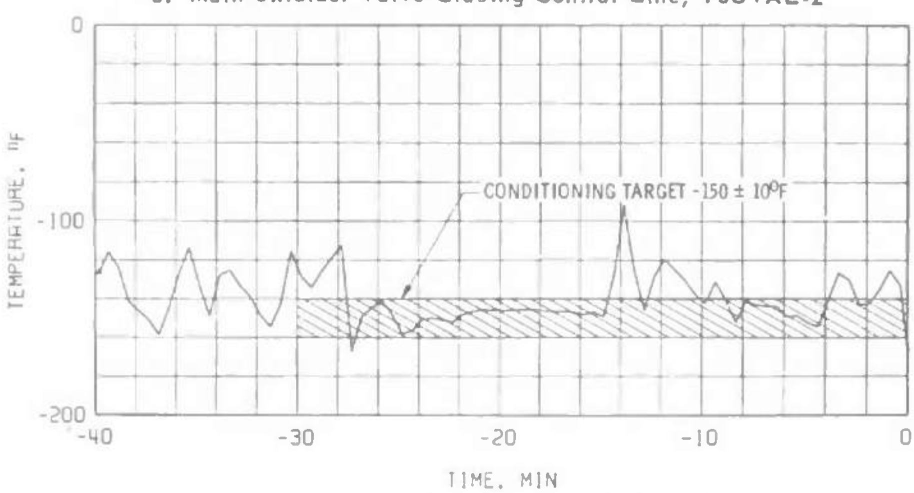
Fig. 9 Engine Ambient and Combustion Chamber Pressures, Firing 01A



a. Pneumatic Regulator, TBHR-2

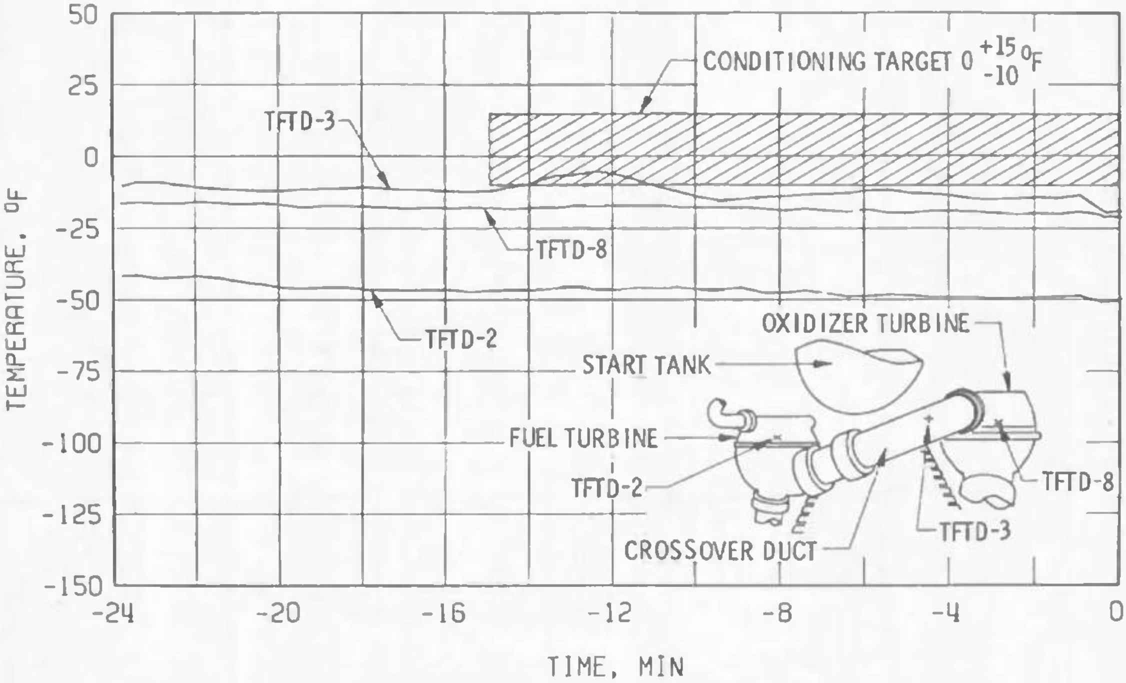


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

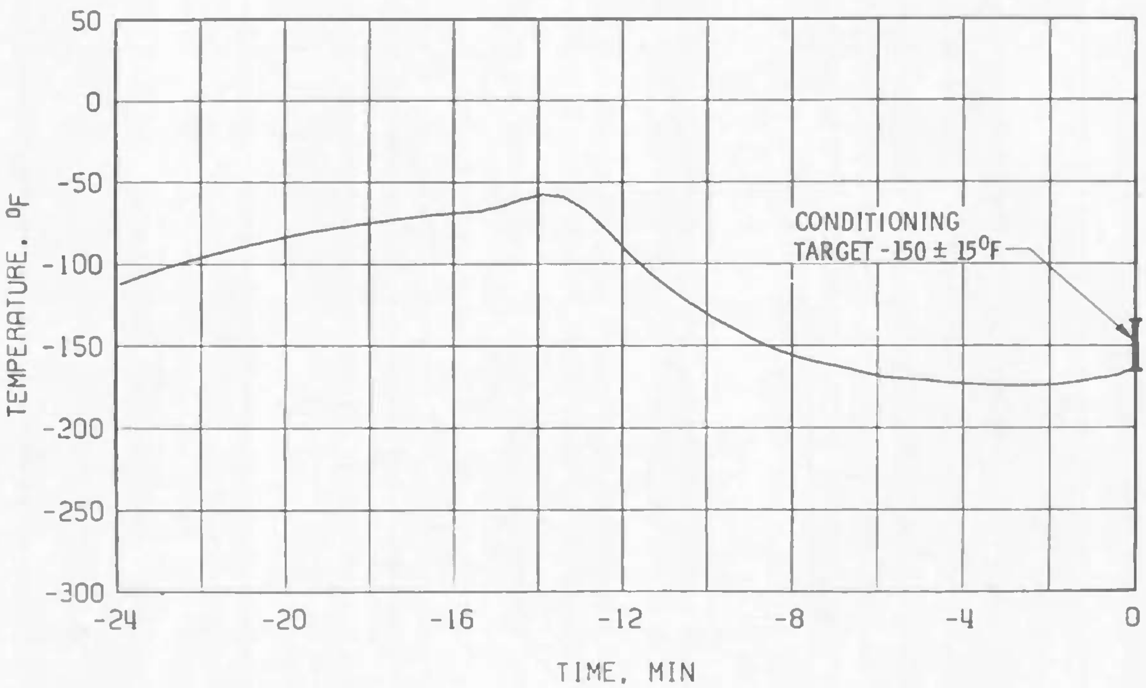


c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 10 Thermal Conditioning History of Engine Components, Firing 01A



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 10 Concluded

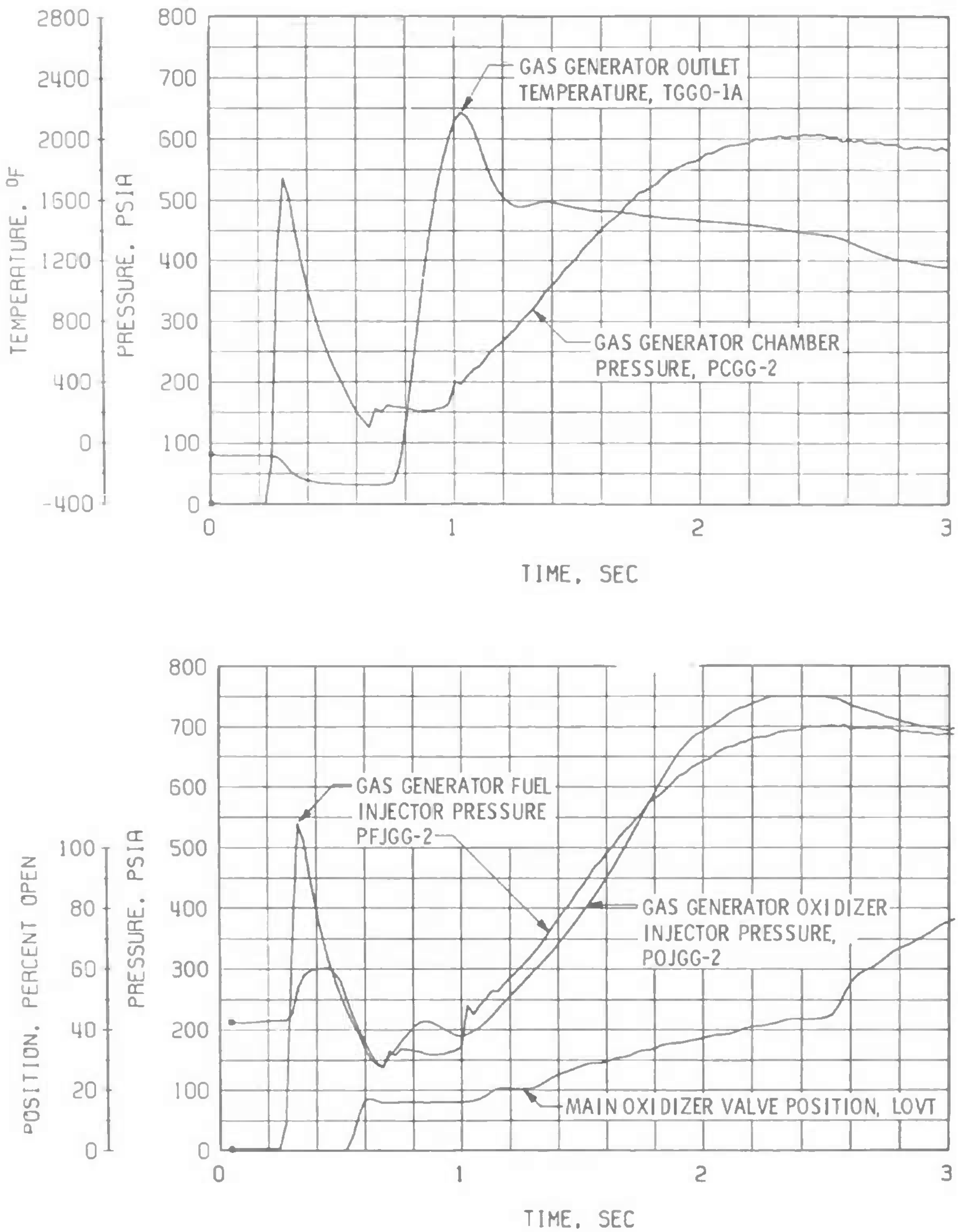
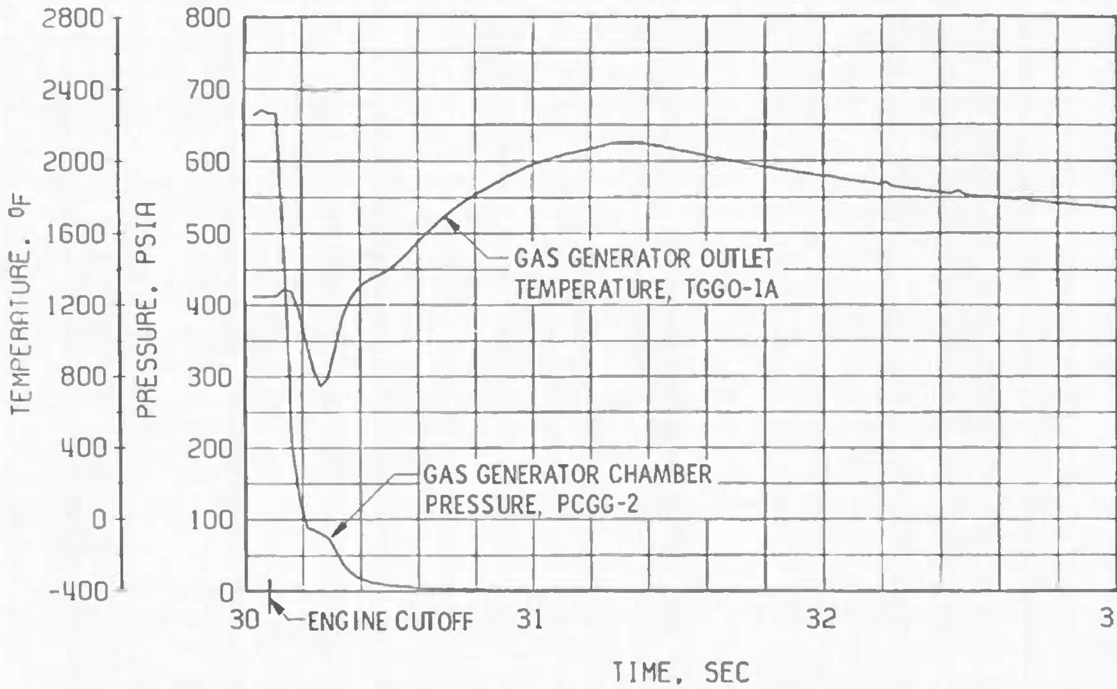


Fig. 11 Gas Generator Start Transient, Firing 01A



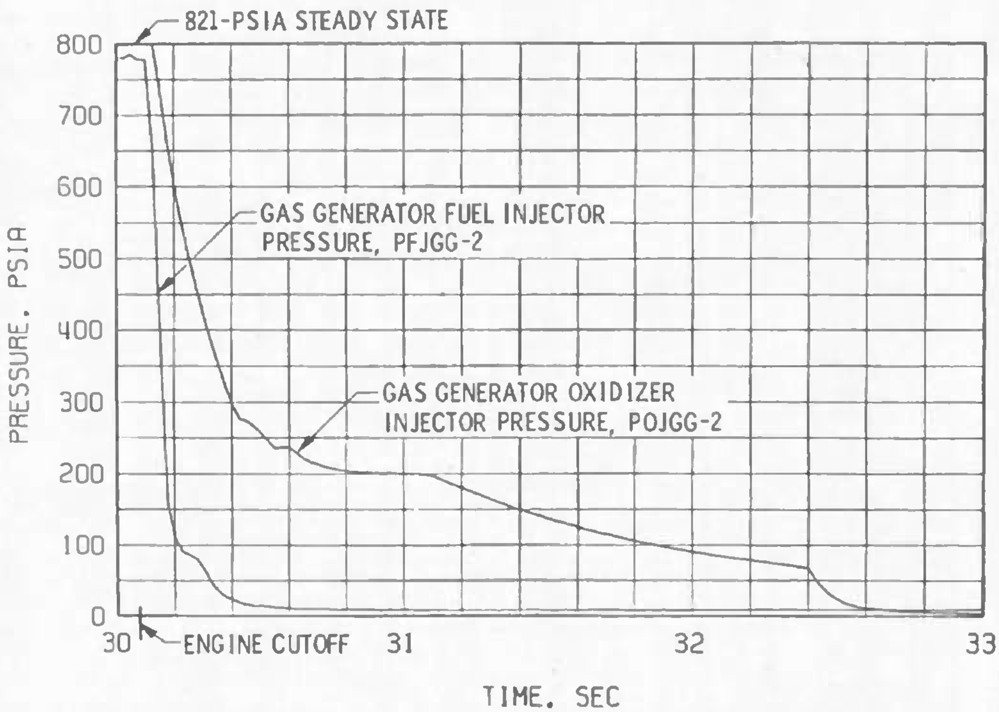


Fig. 12 Gas Generator Shutdown Transient, Firing 01A

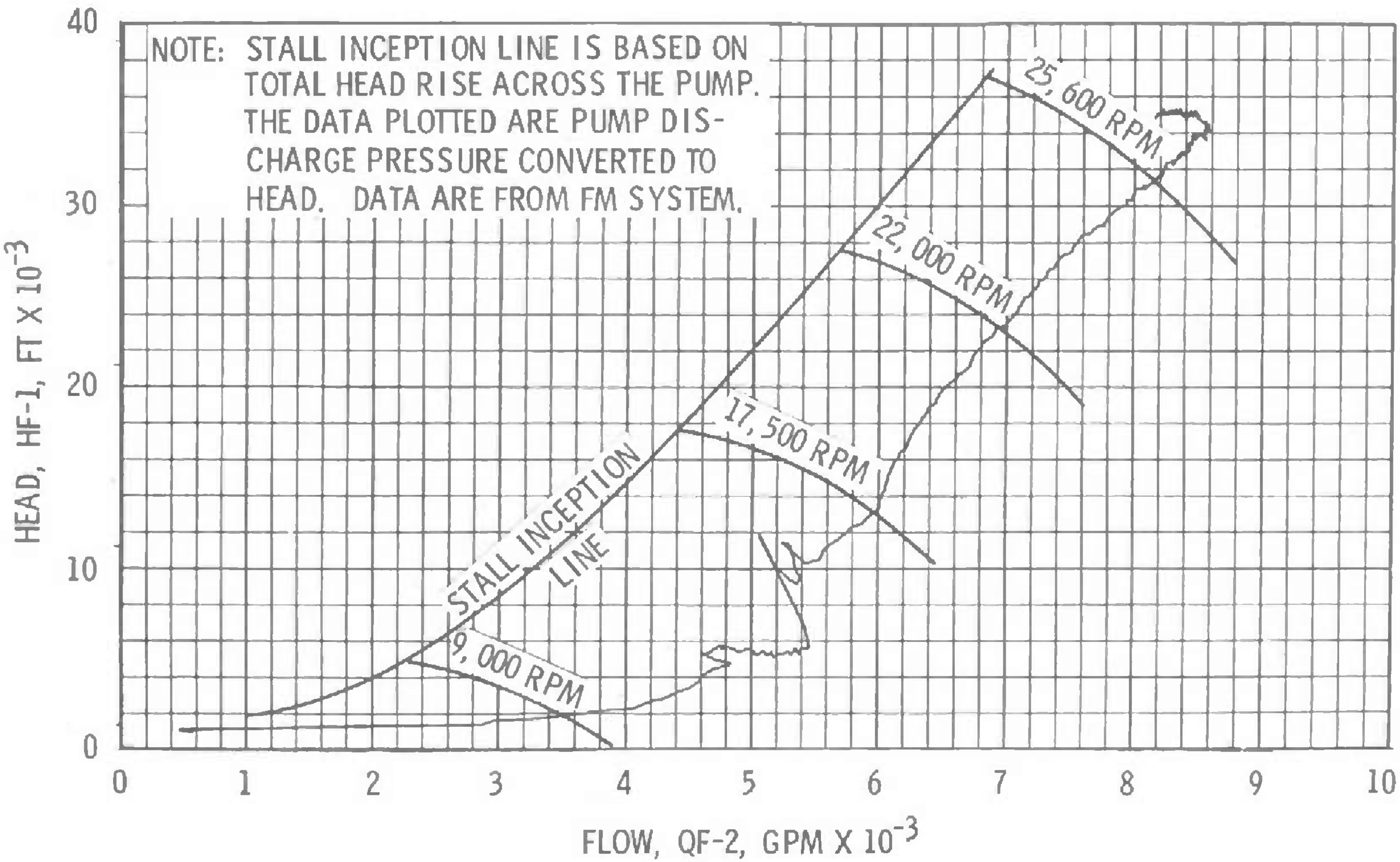
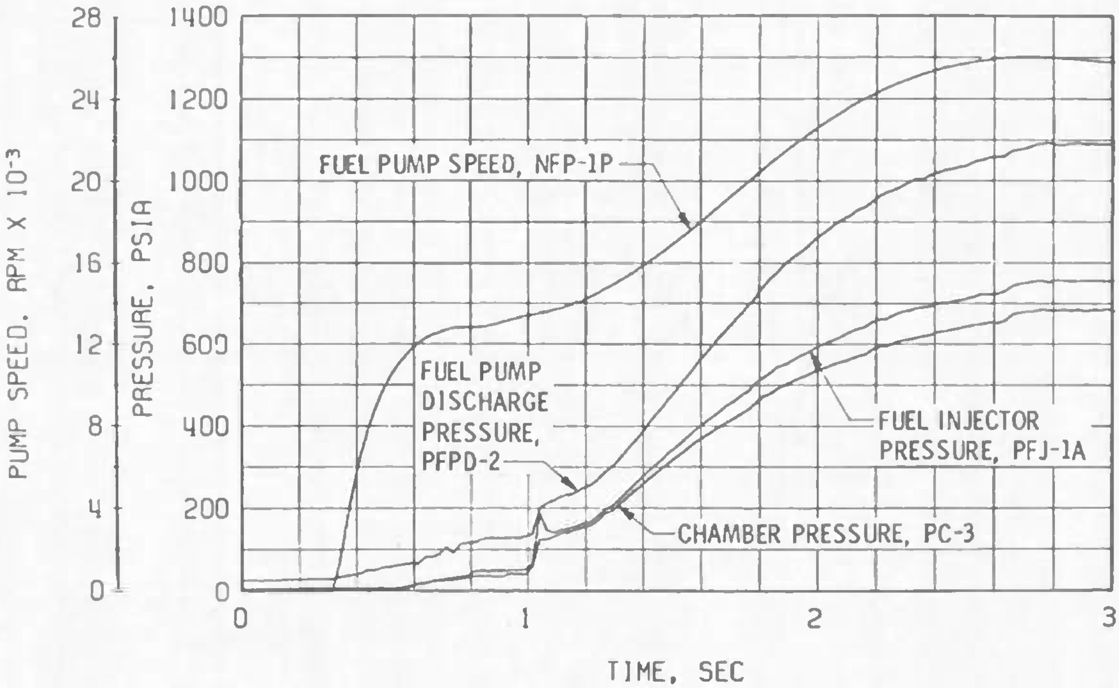
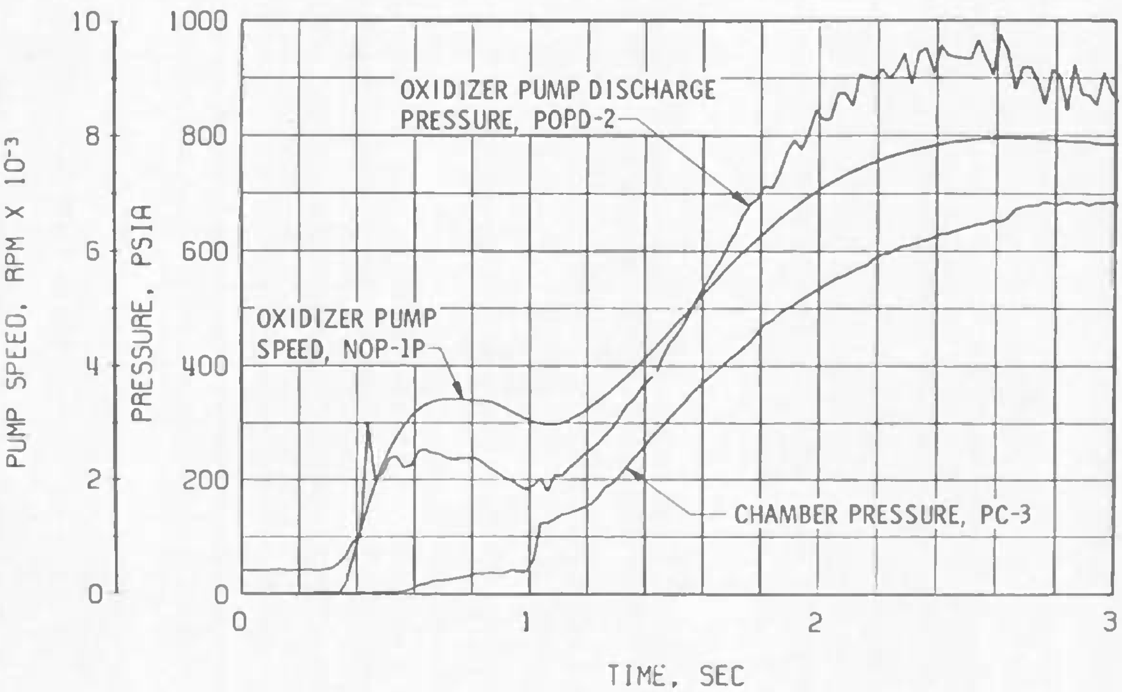


Fig. 13 Fuel Pump Start Transient Performance, Firing 01A

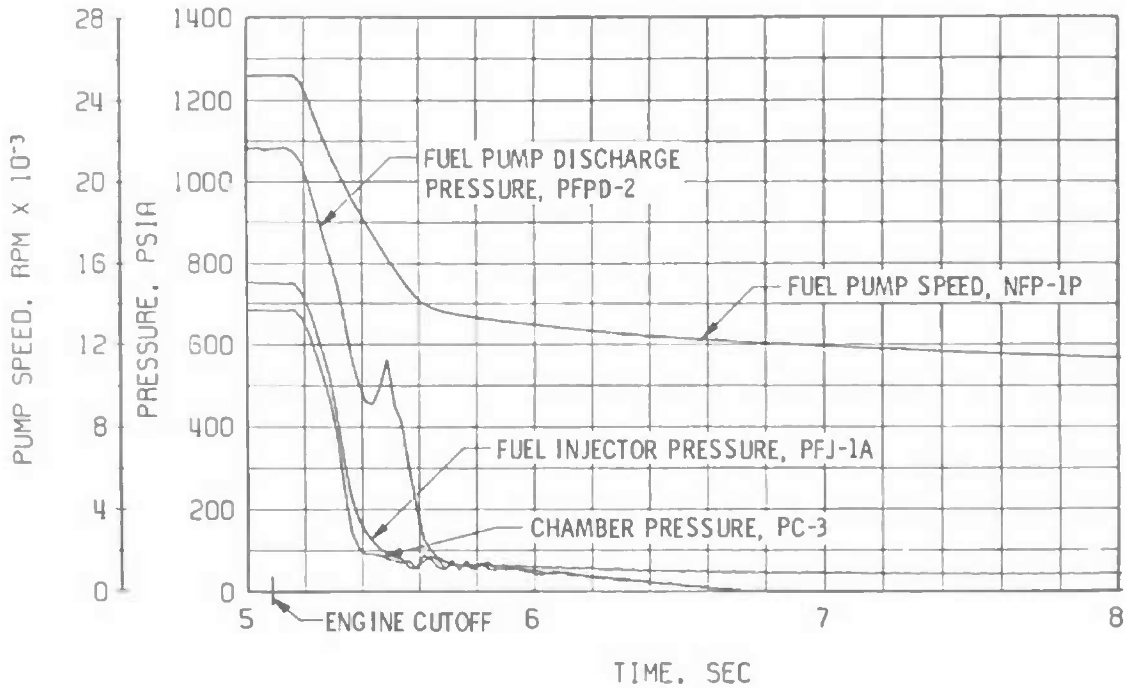


a. Thrust Chamber Fuel System, Start

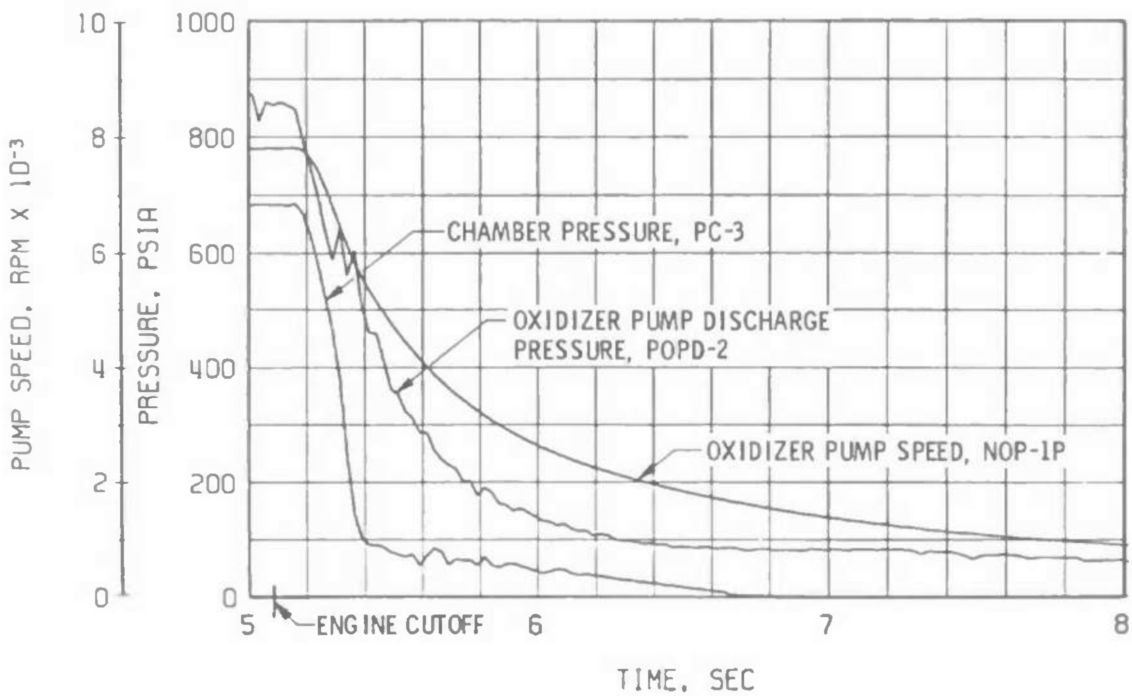


b. Thrust Chamber Oxidizer System, Start

Fig. 14 Engine Transient Operation, Firing 01B



c. Thrust Chomber Fuel System, Shutdown



d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Concluded

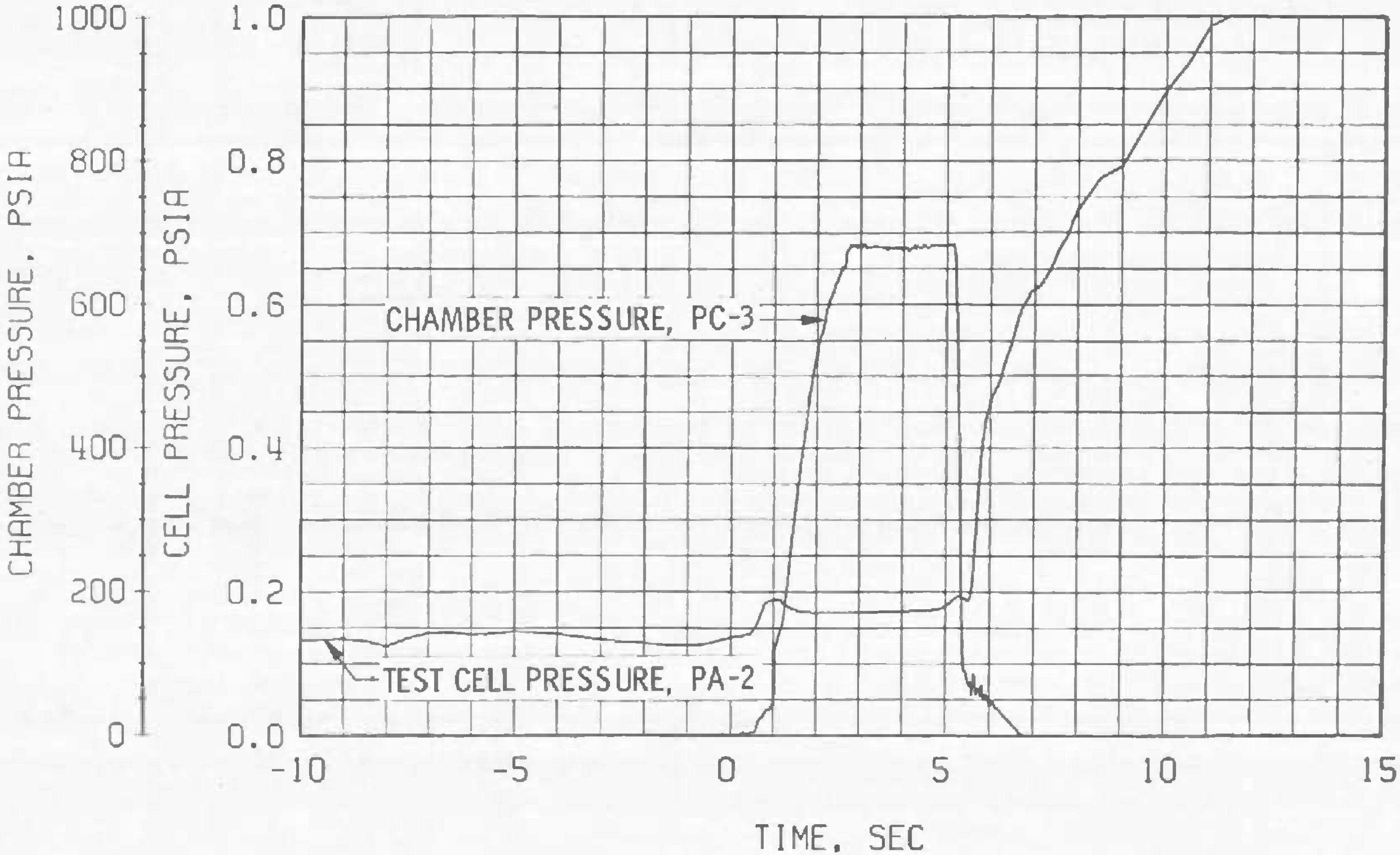
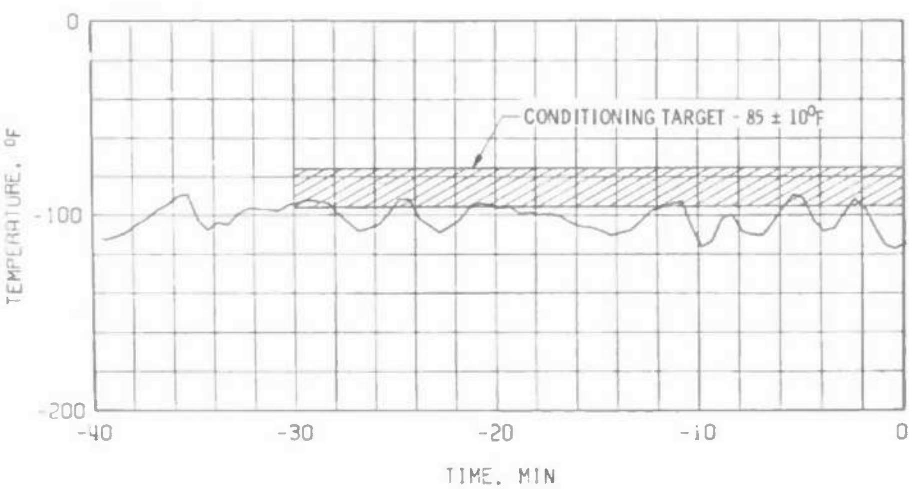
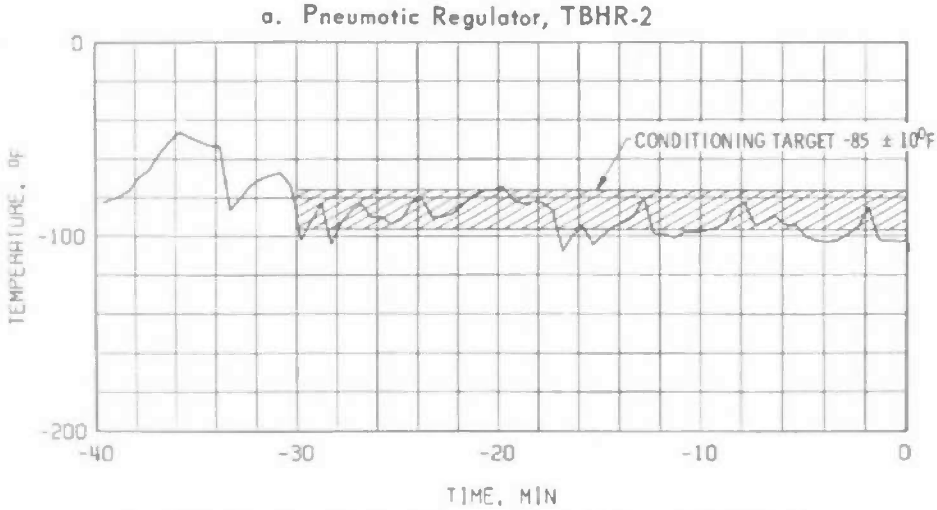


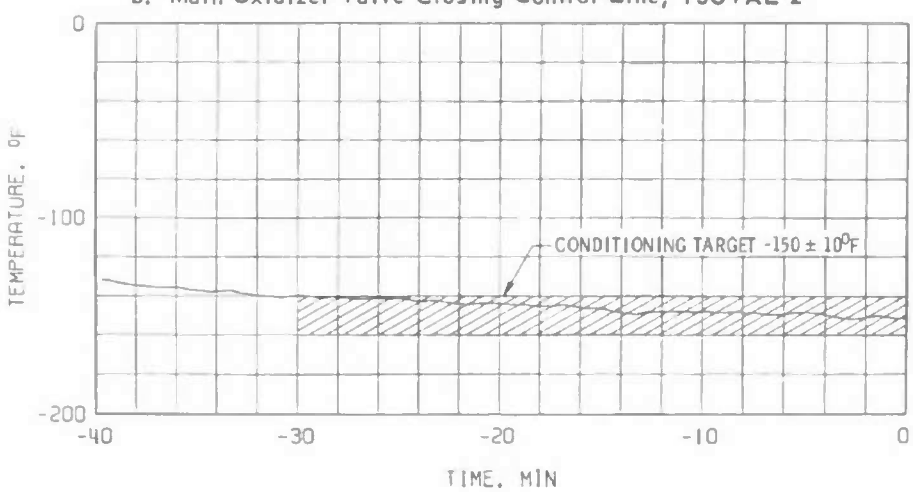
Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 01B



a. Pneumotic Regulator, TBHR-2

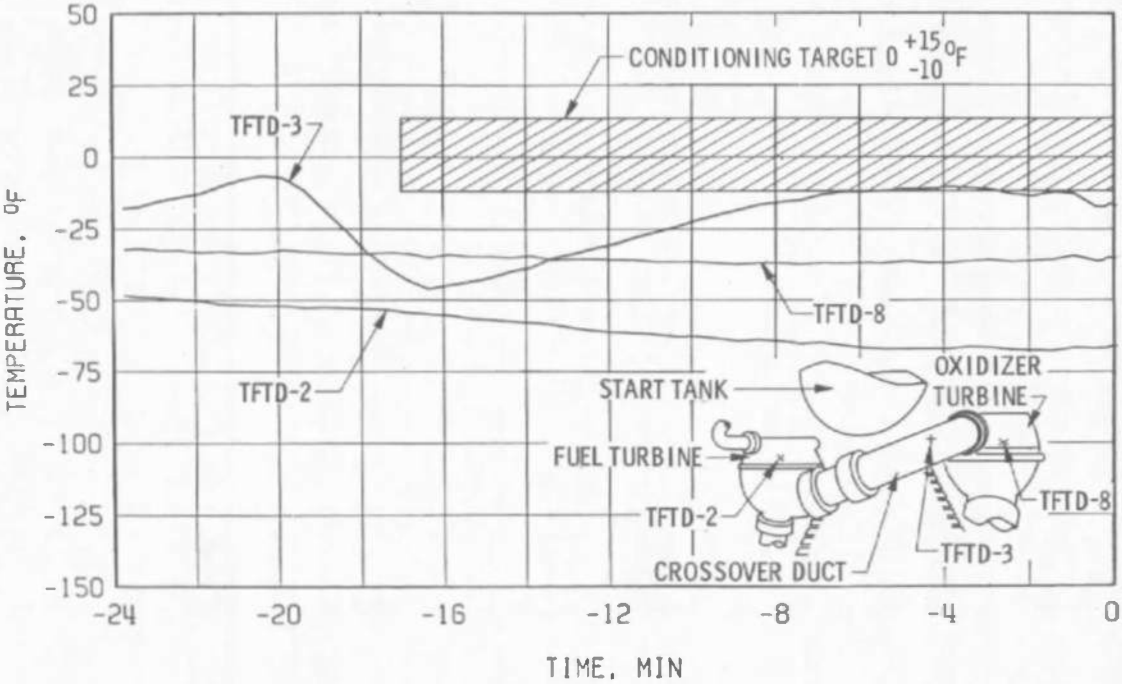


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

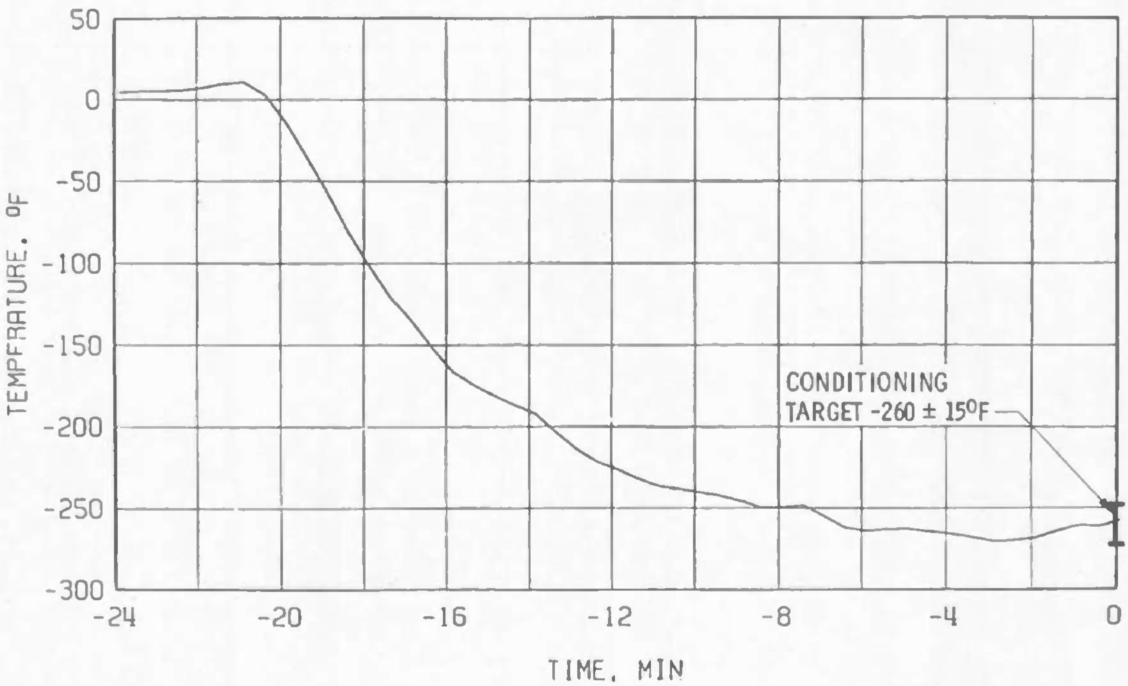


c. Main Oxidizer Volve Second-Stoge Actuator, TSOVC-2

Fig. 16 Thermal Conditioning History of Engine Components, Firing 01B



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 16 Concluded

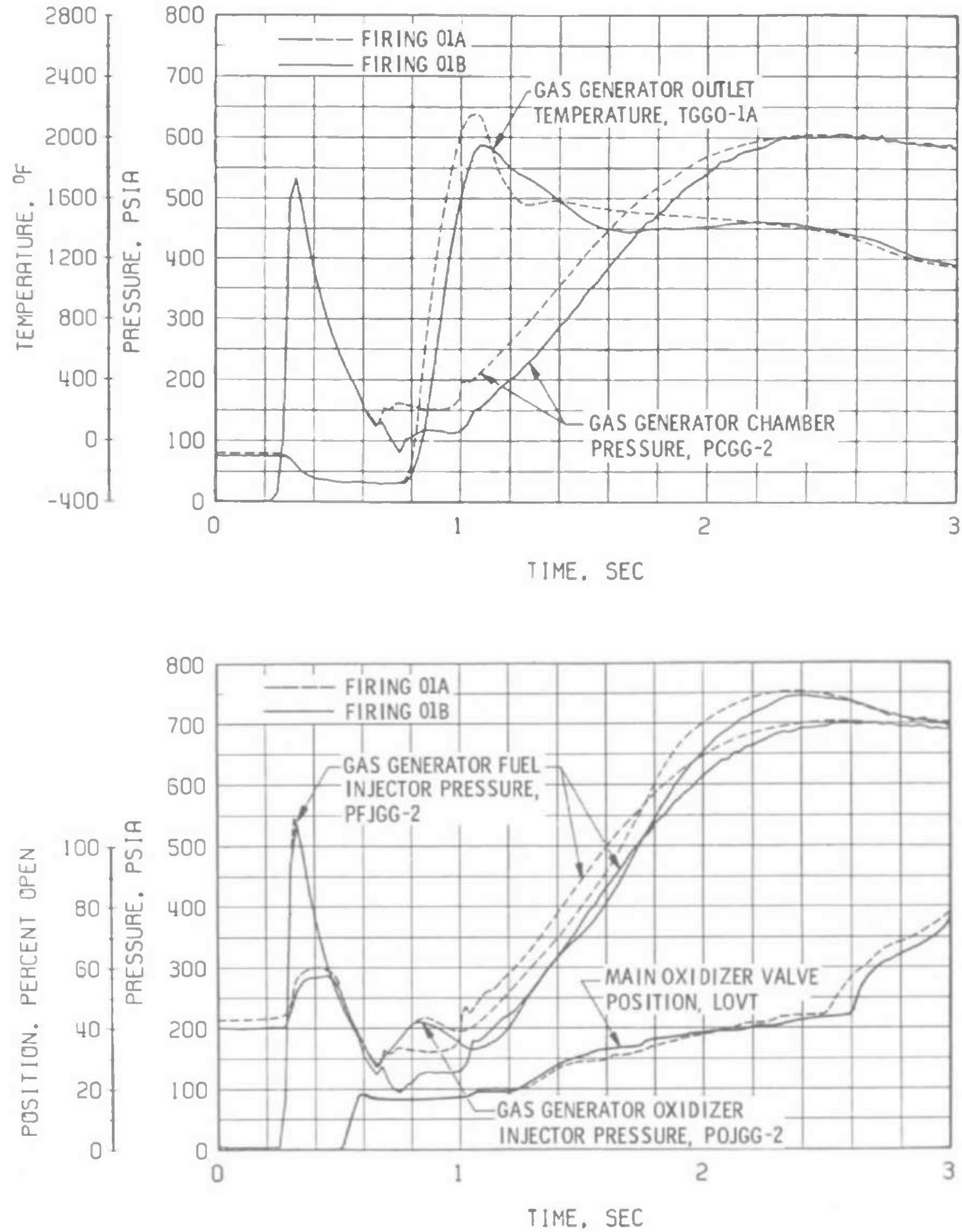


Fig. 17 Gas Generator Start Transient, Comparison of Firings 01A and 01B

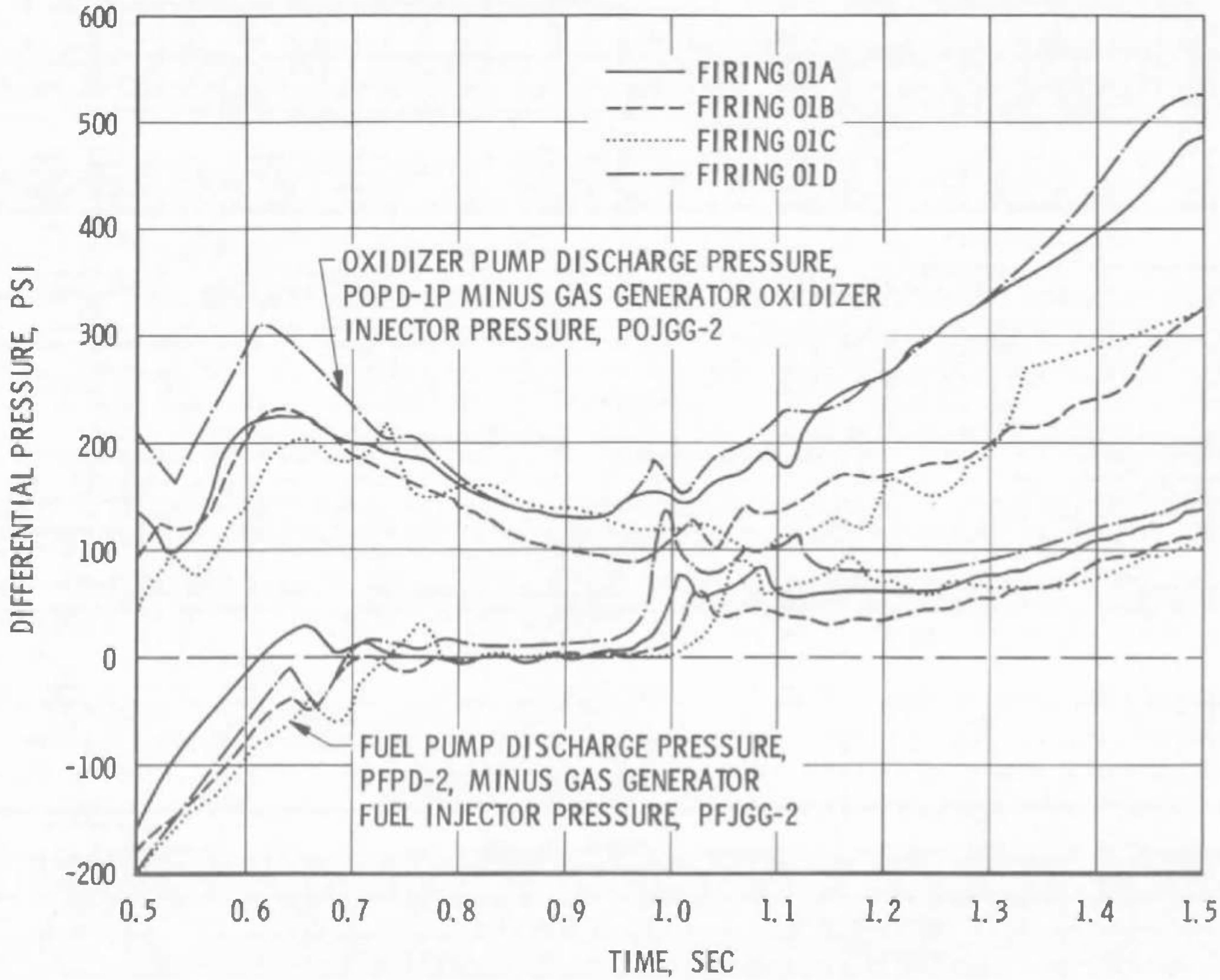
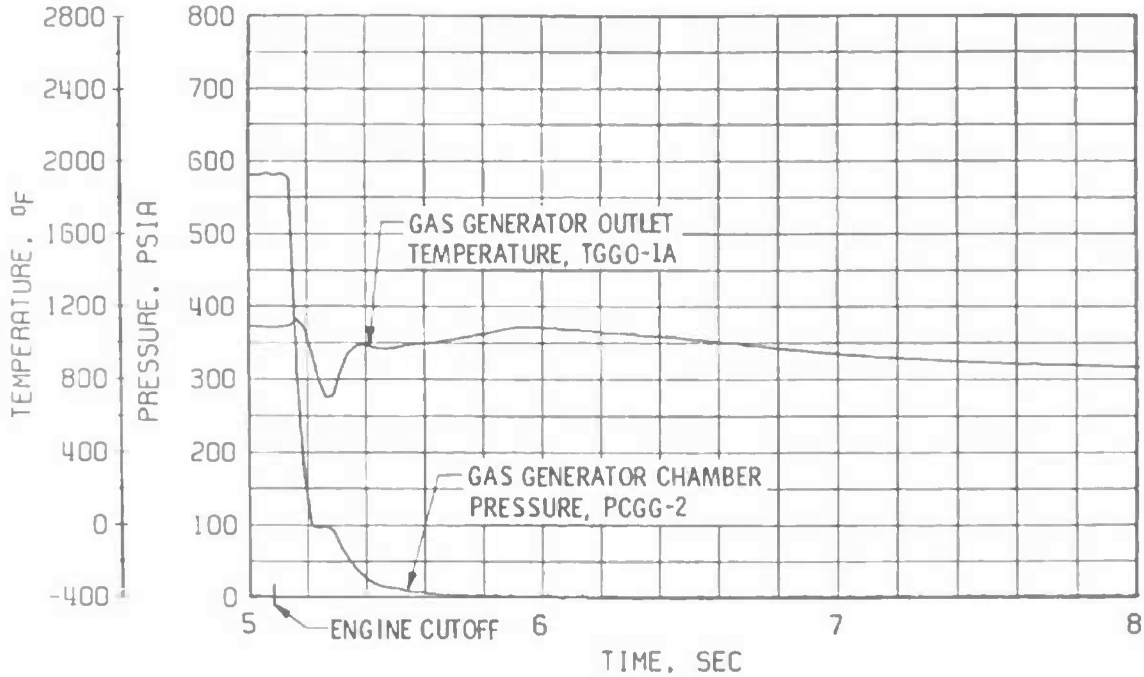


Fig. 18 Gas Generator System Differential Pressures



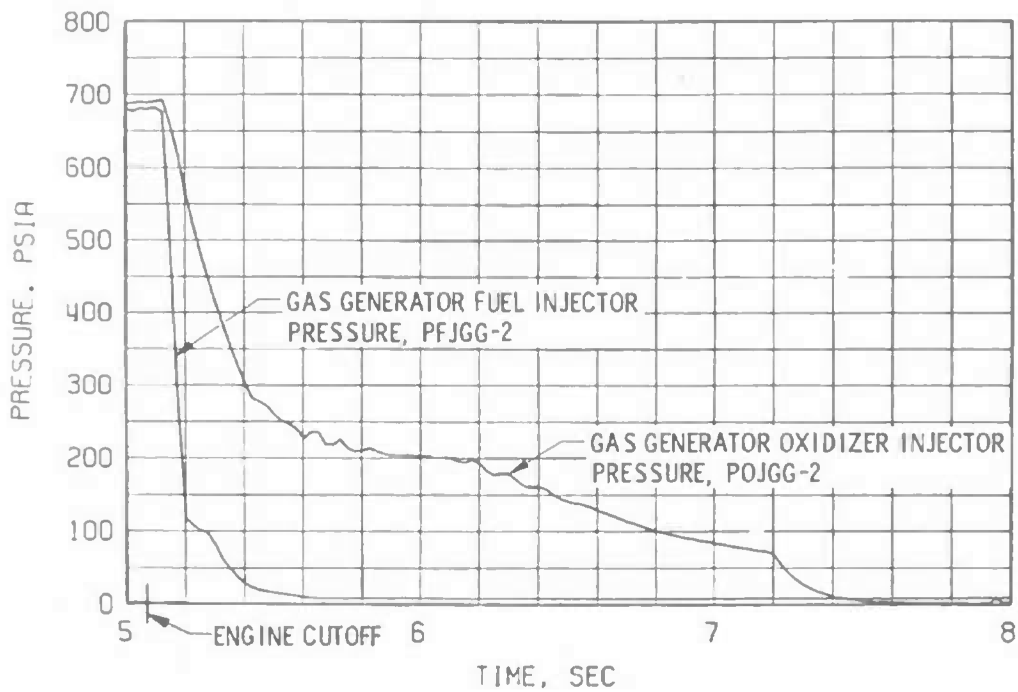


Fig. 19 Gas Generator Shutdown Transient, Firing 01B

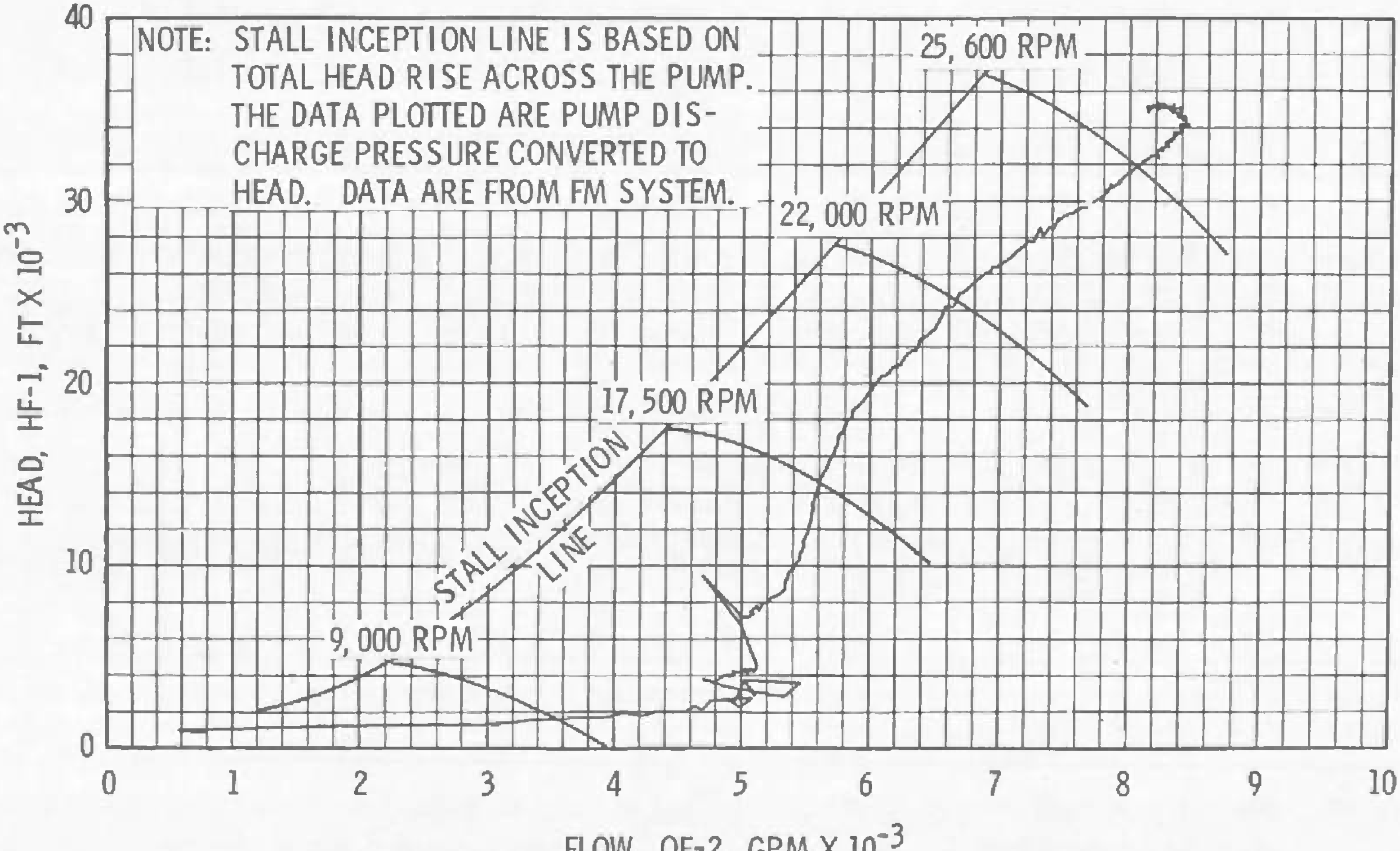
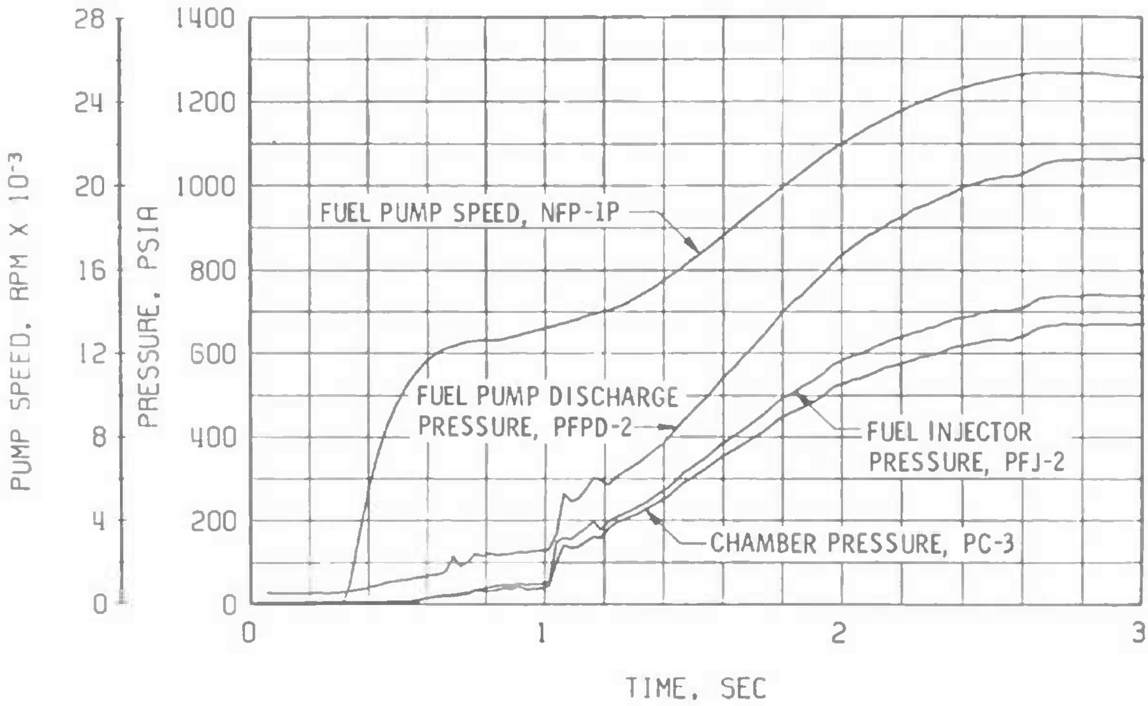
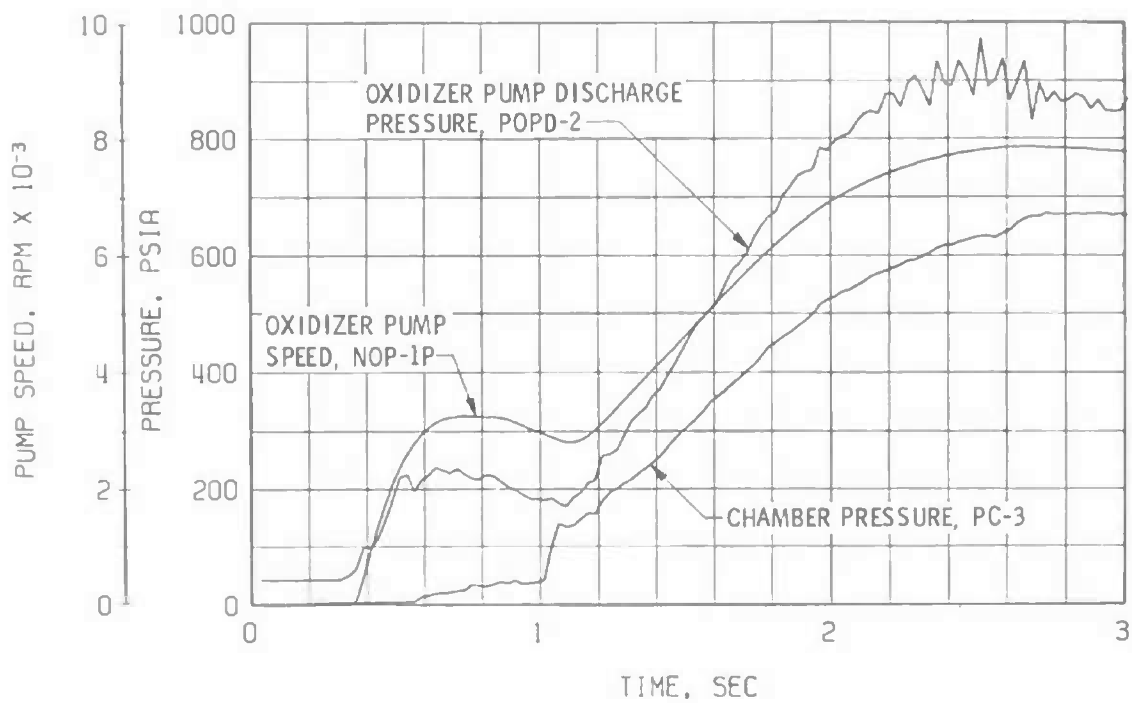


Fig. 20 Fuel Pump Start Transient Performance, Firing 01B

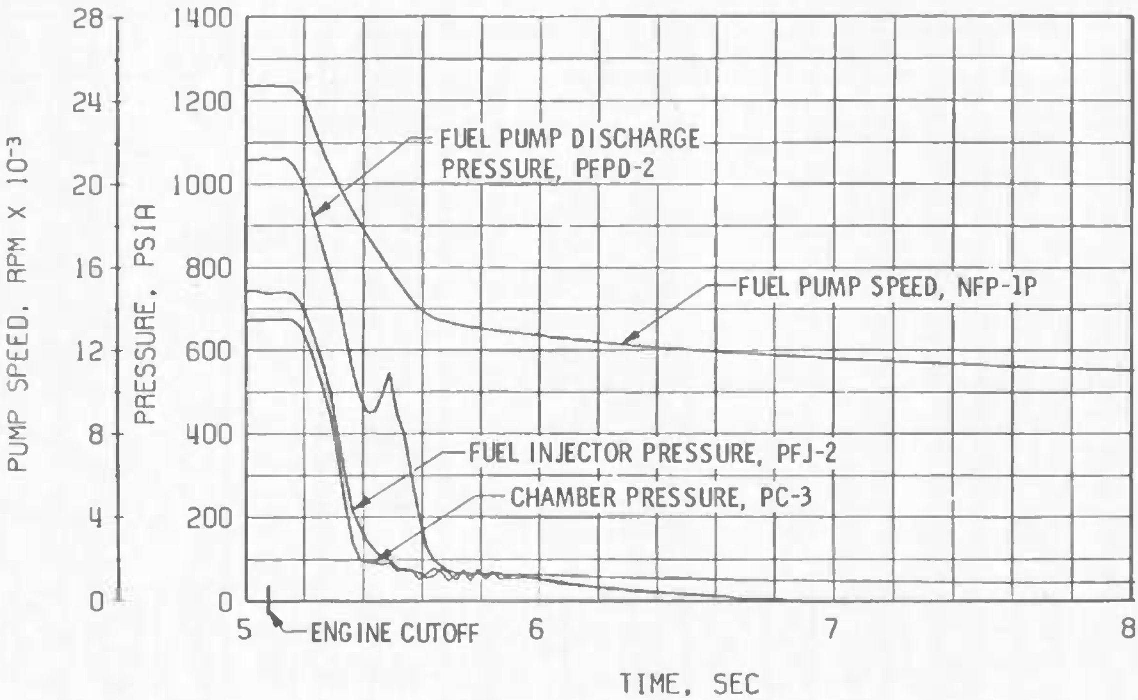


a. Thrust Chamber Fuel System, Start

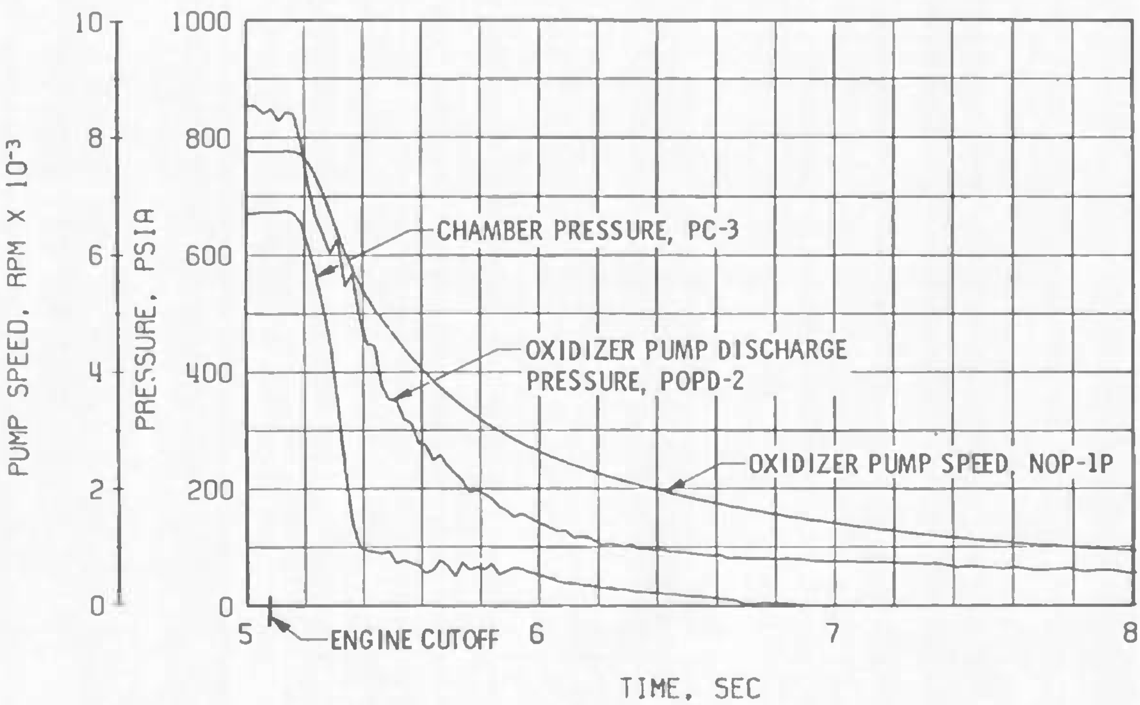


b. Thrust Chamber Oxidizer System, Start

Fig. 21 Engine Transient Operation, Firing 01C



c. Thrust Chamber Fuel System, Shutdown



d. Thrust Chamber Oxidizer System, Shutdown

Fig. 21 Concluded

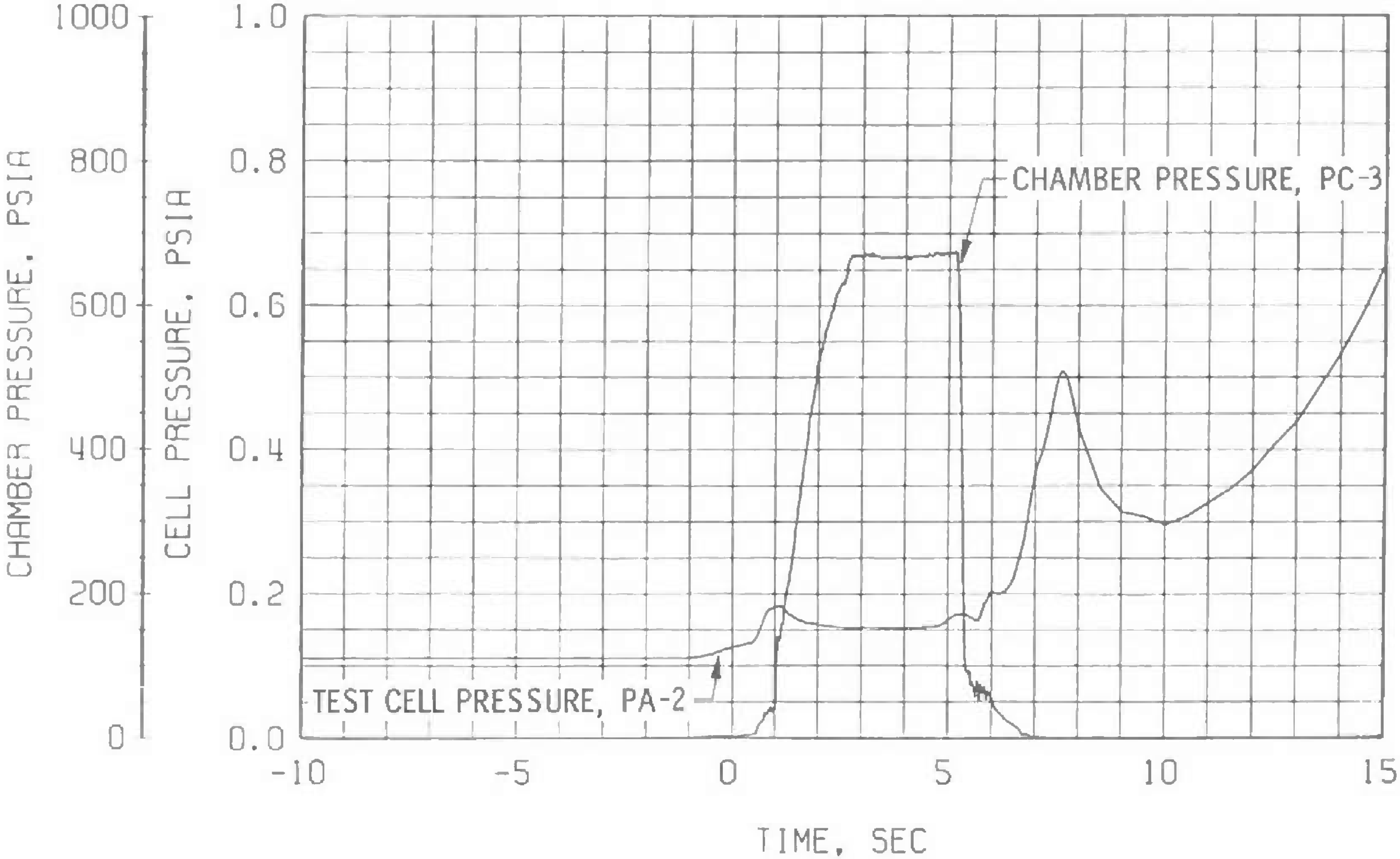
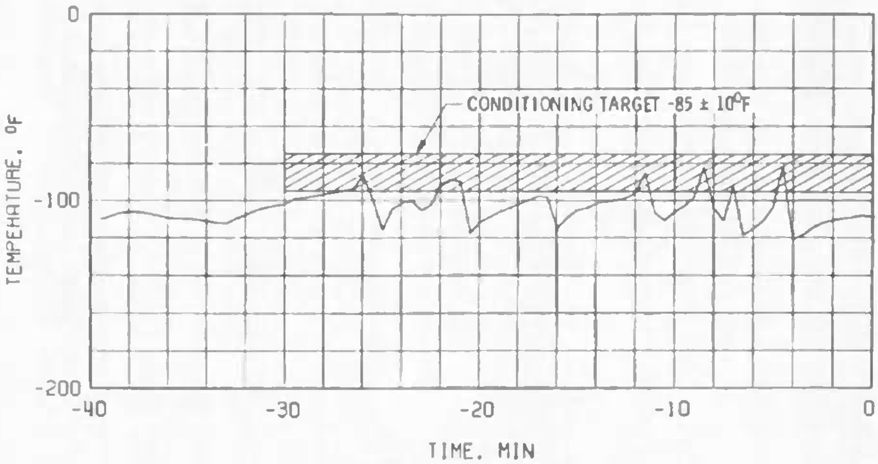
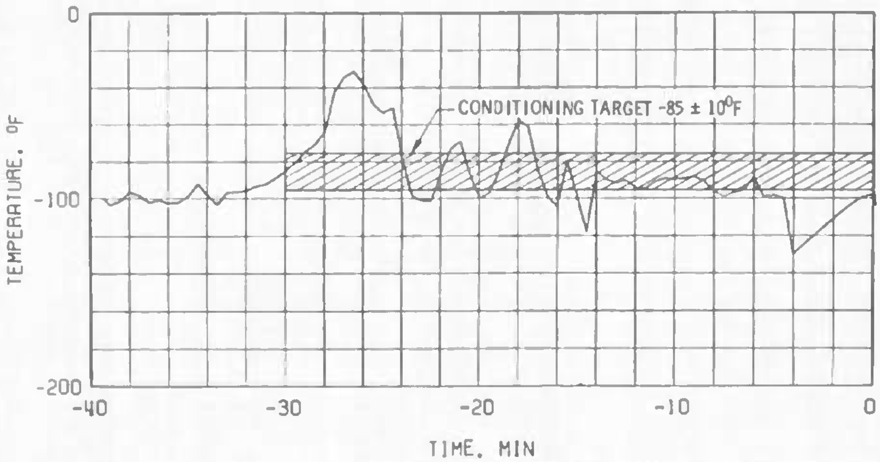


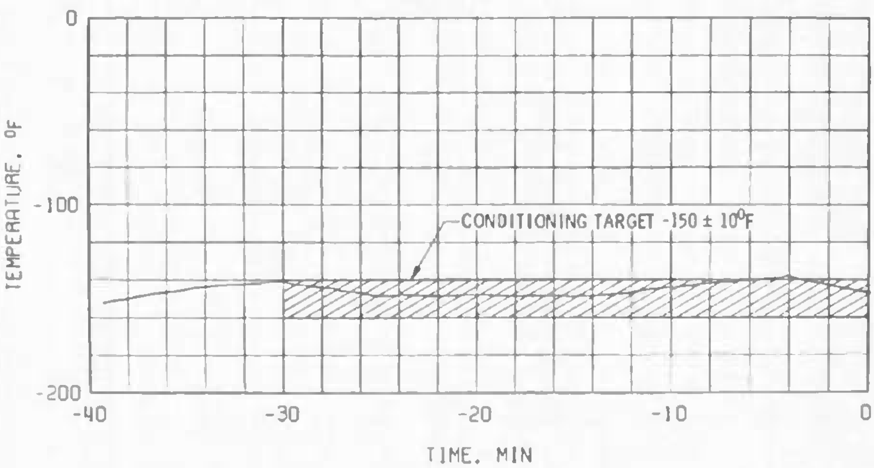
Fig. 22 Engine Ambient and Combustion Chamber Pressures, Firing 01C



a. Pneumatic Regulator, TBHR-2

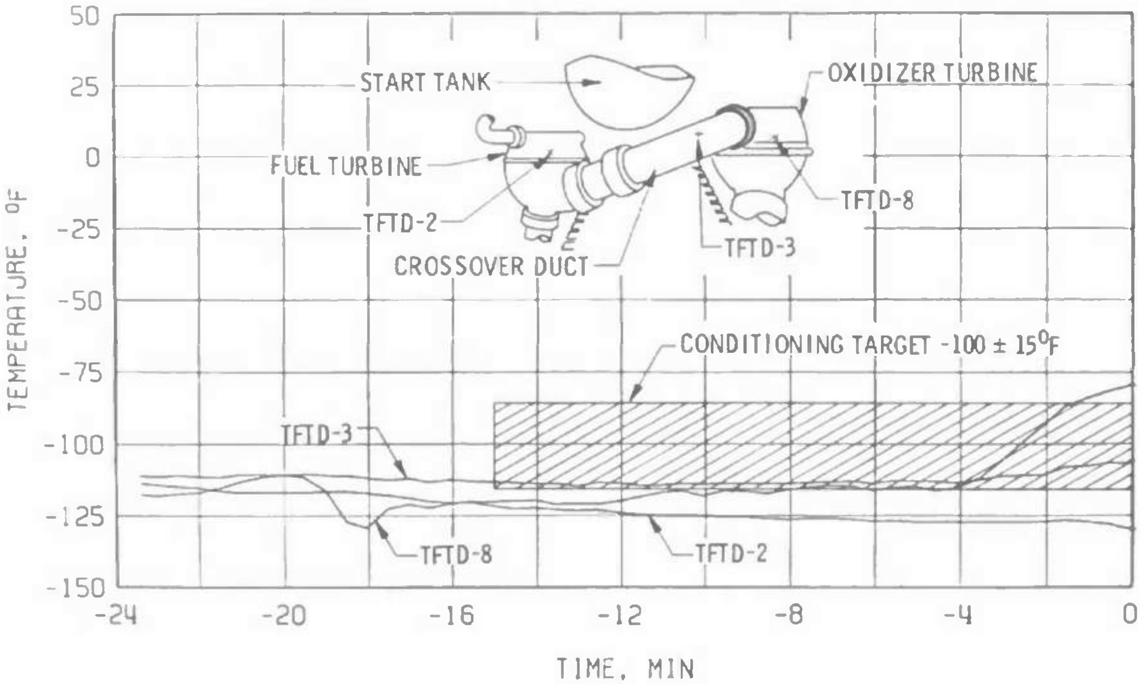


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

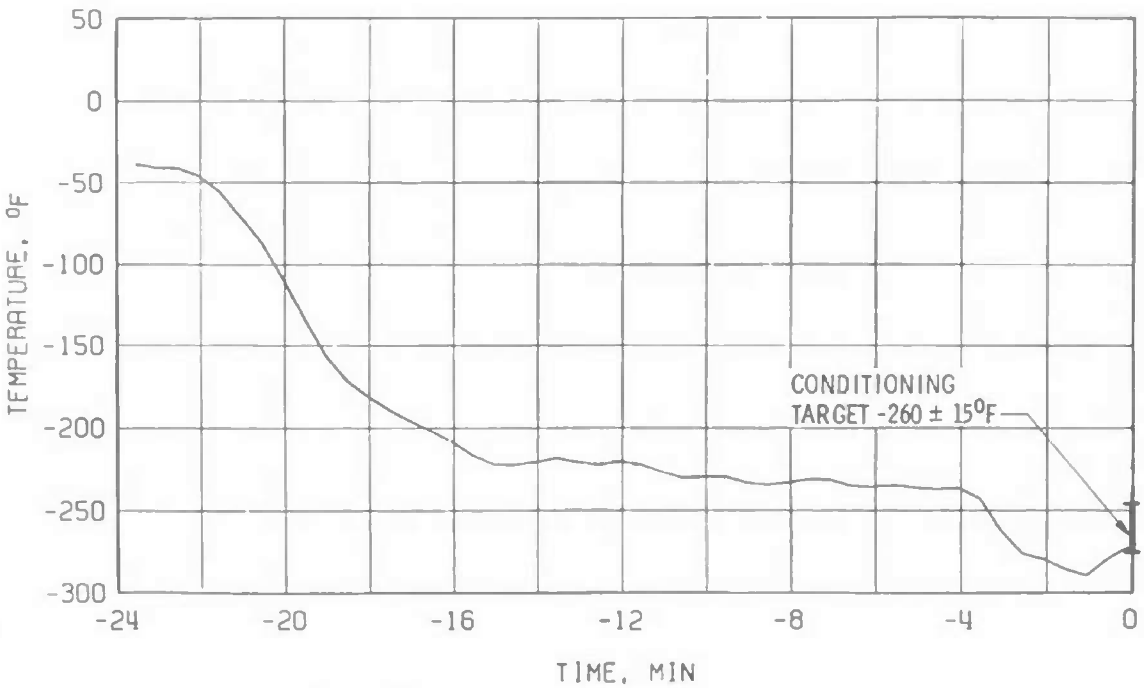


c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 23 Thermal Conditioning History of Engine Components, Firing 01C



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 23 Concluded

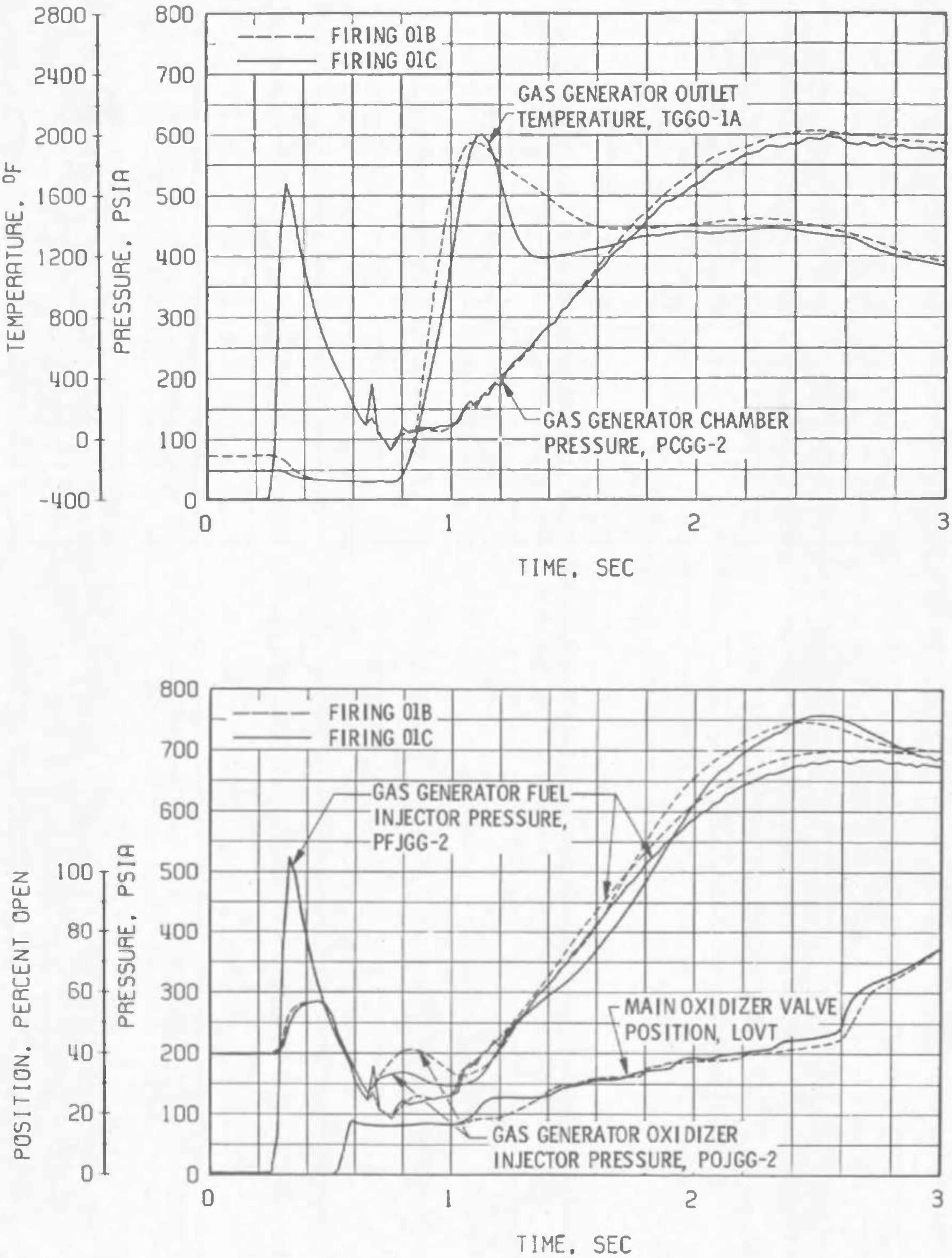


Fig. 24 Gas Generator Start Transient, Comparison of Firings 01B and 01C

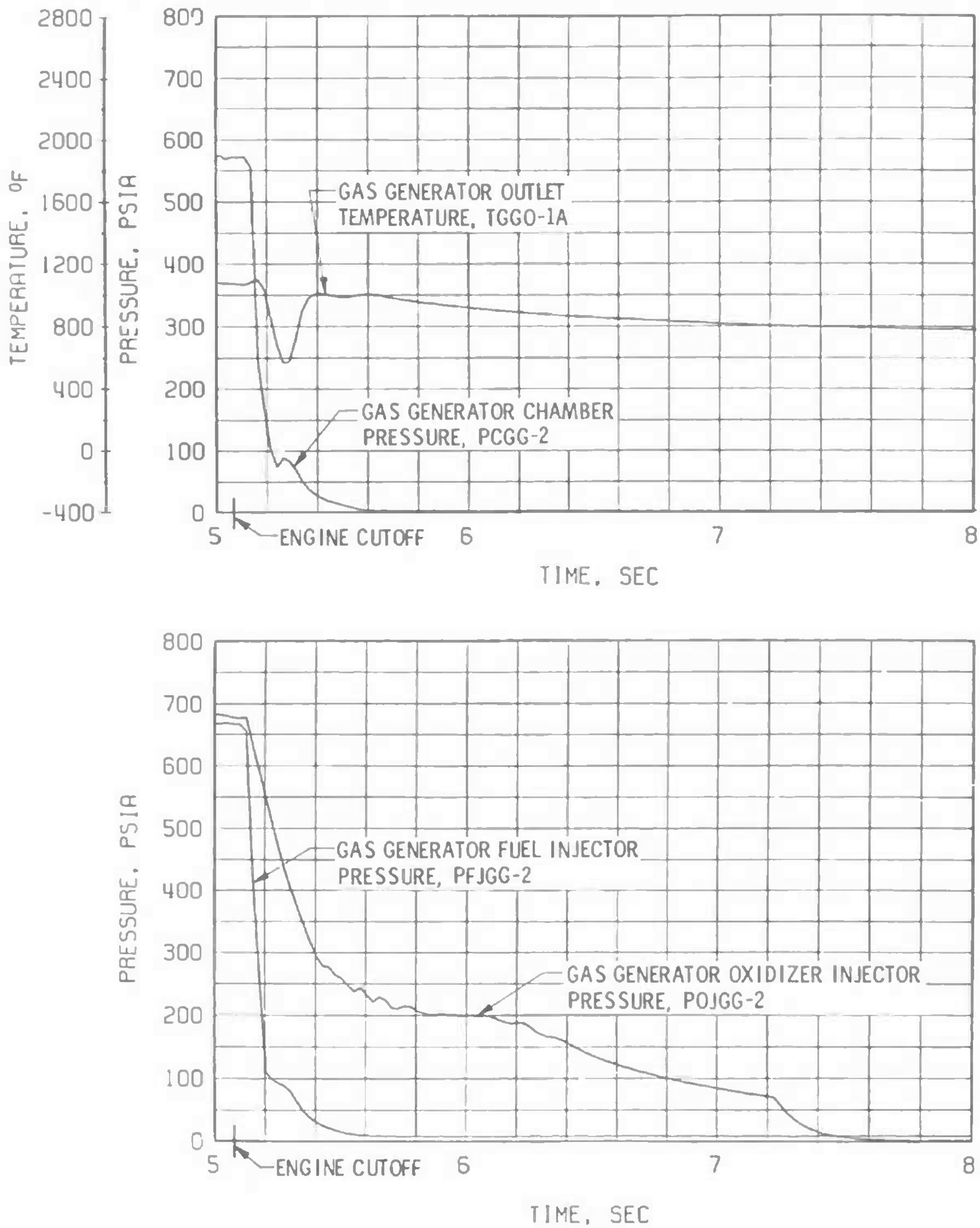


Fig. 25 Gas Generator Shutdown Transient, Firing 01C

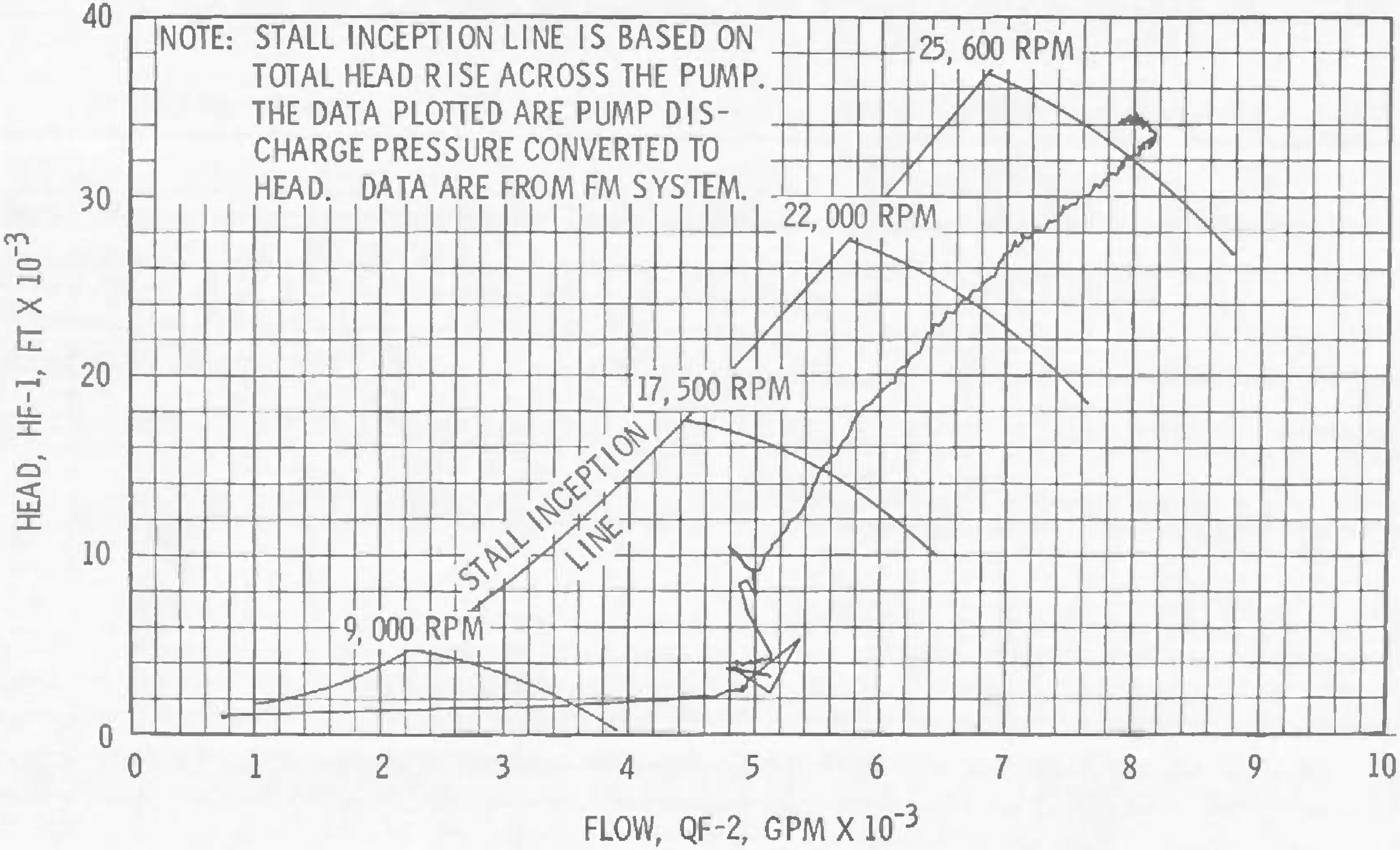


Fig. 26 Fuel Pump Start Transient Performance, Firing 01C

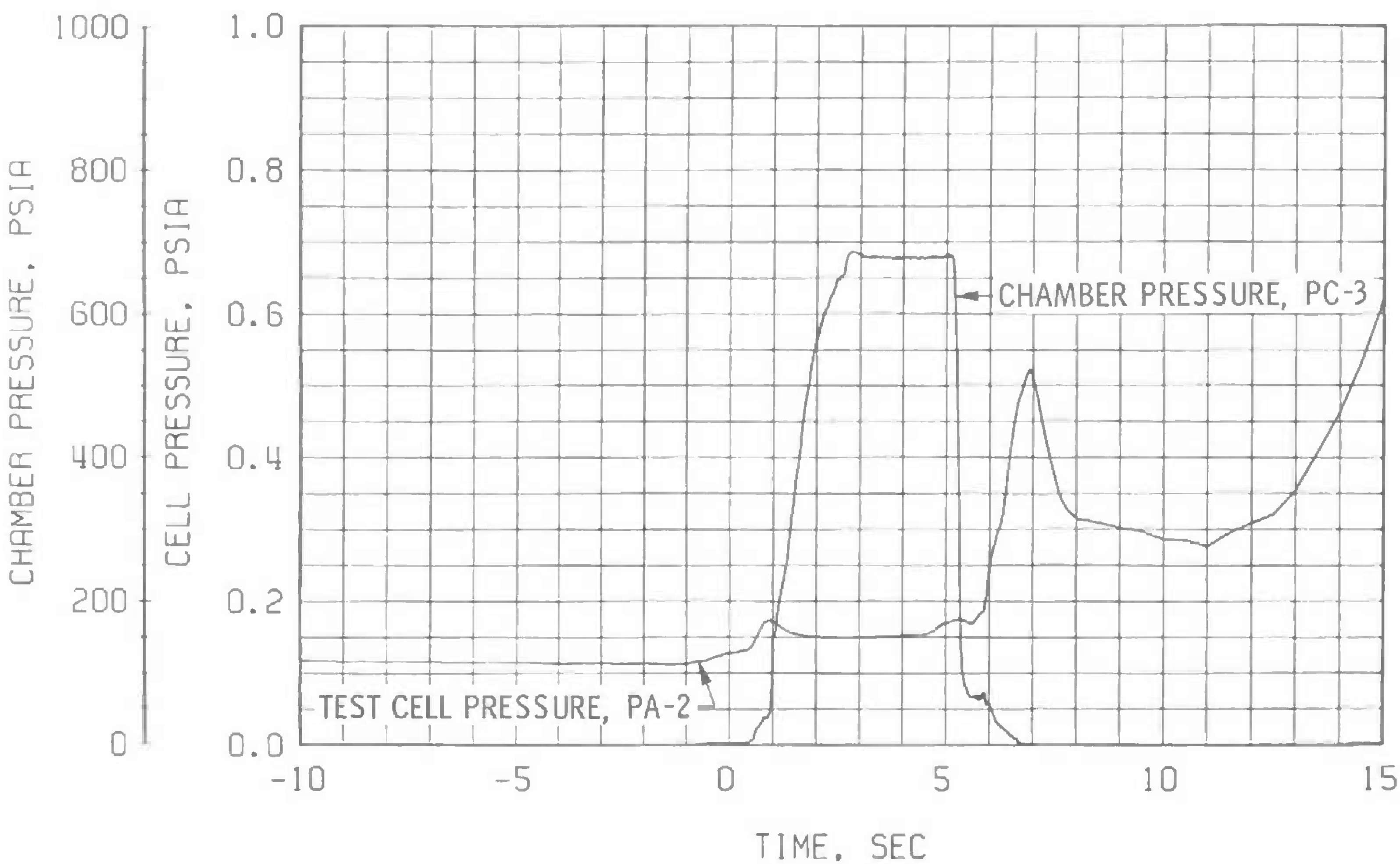
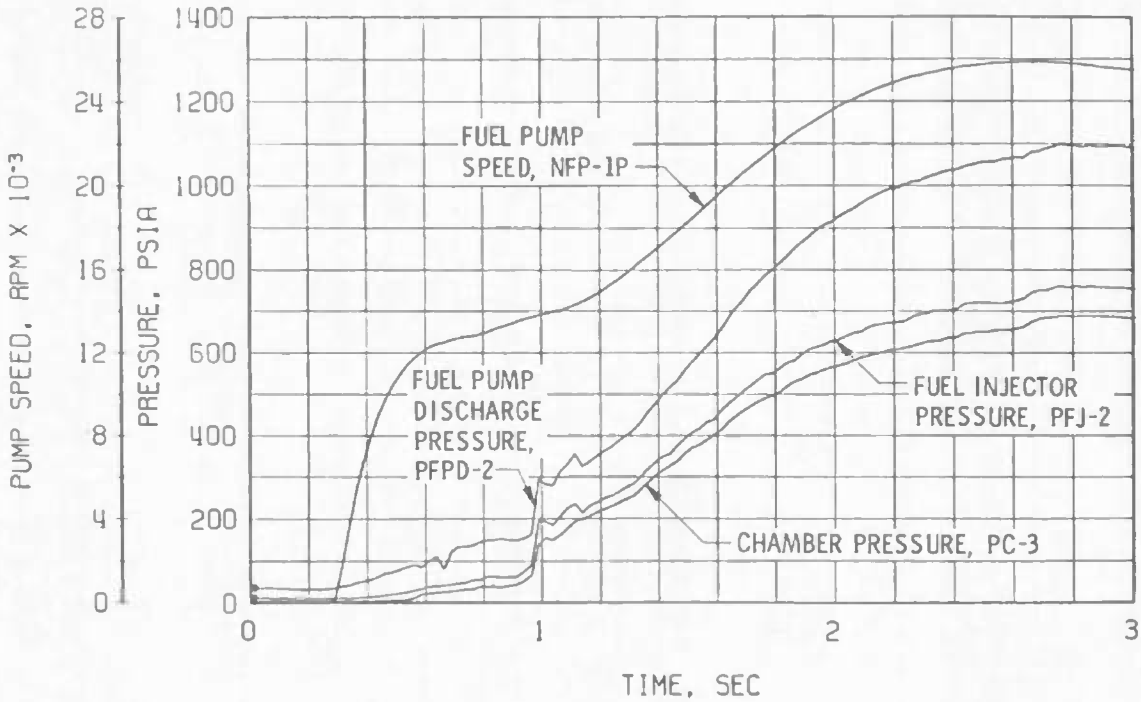
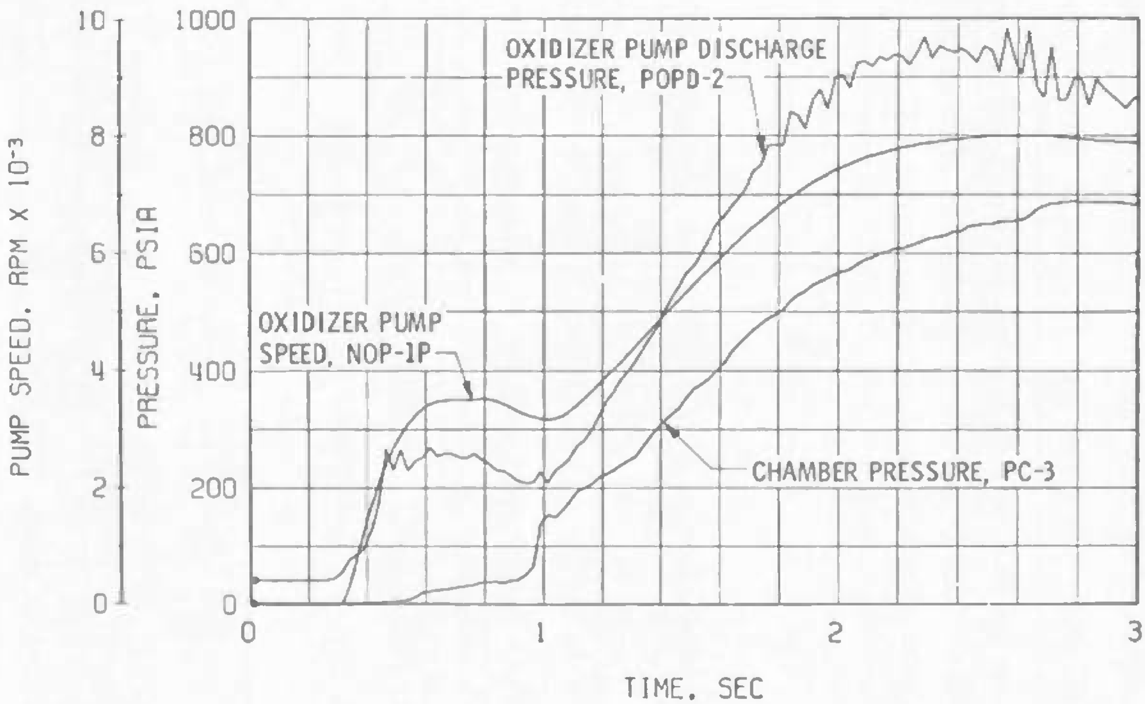


Fig. 27 Engine Ambient and Combustion Chamber Pressures, Firing 01D

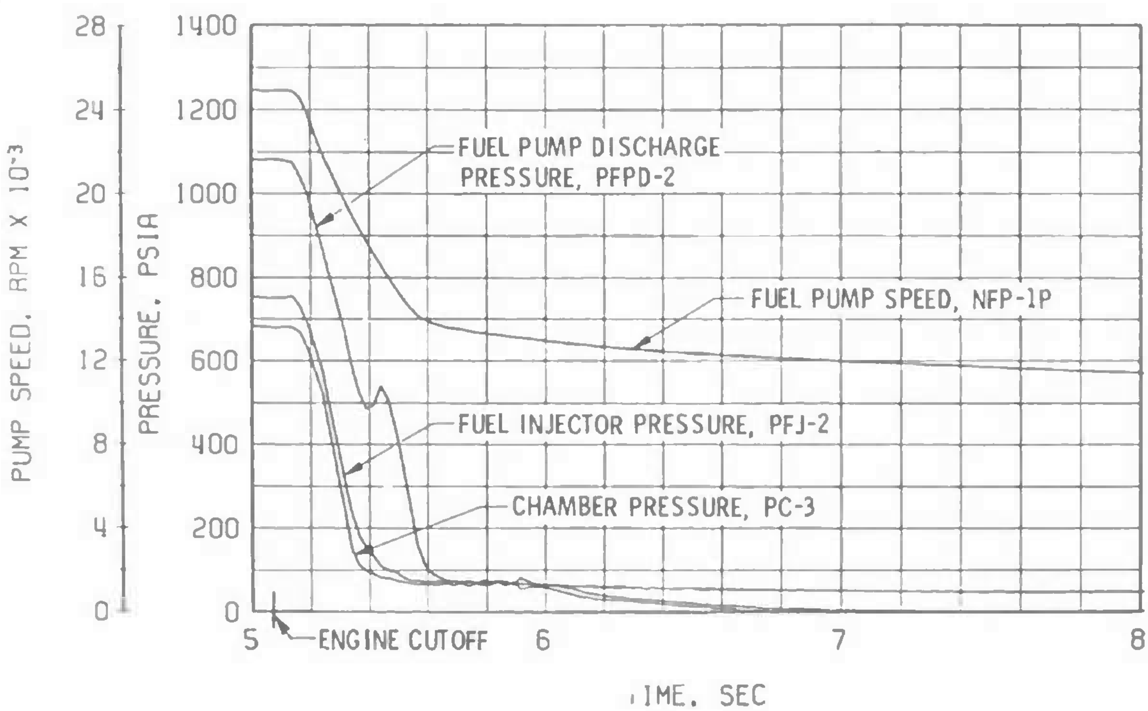


a. Thrust Chamber Fuel System, Start

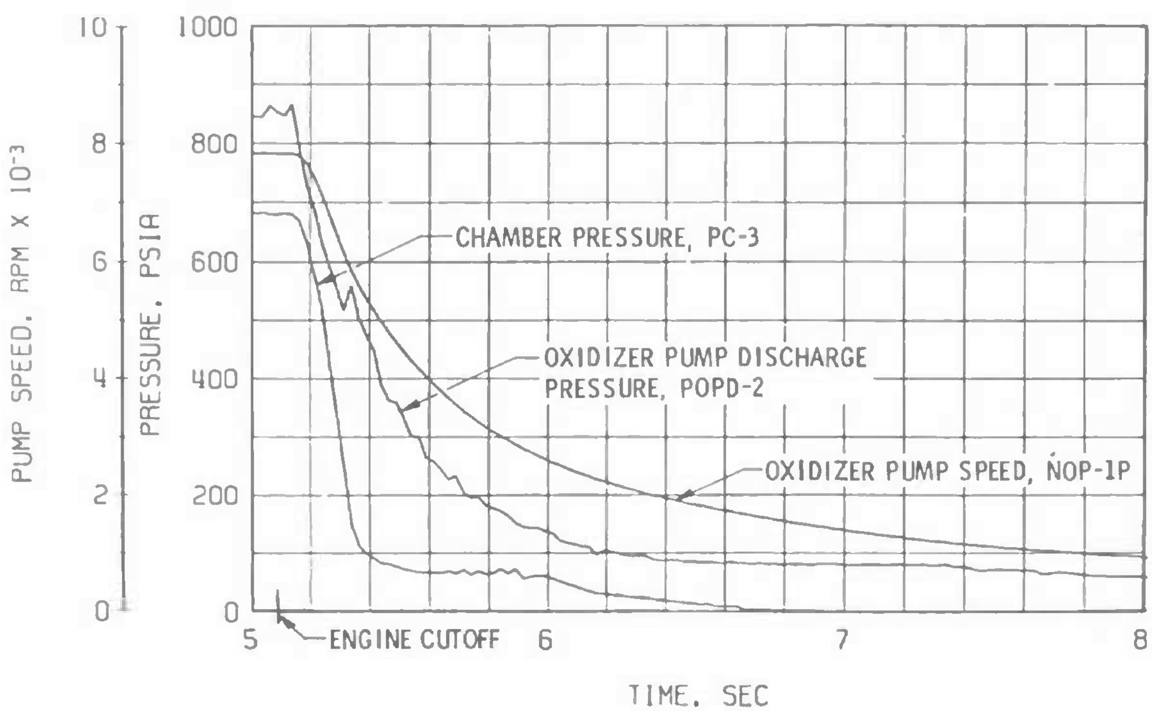


b. Thrust Chamber Oxidizer System, Start

Fig. 28 Engine Transient Operation, Firing 01D

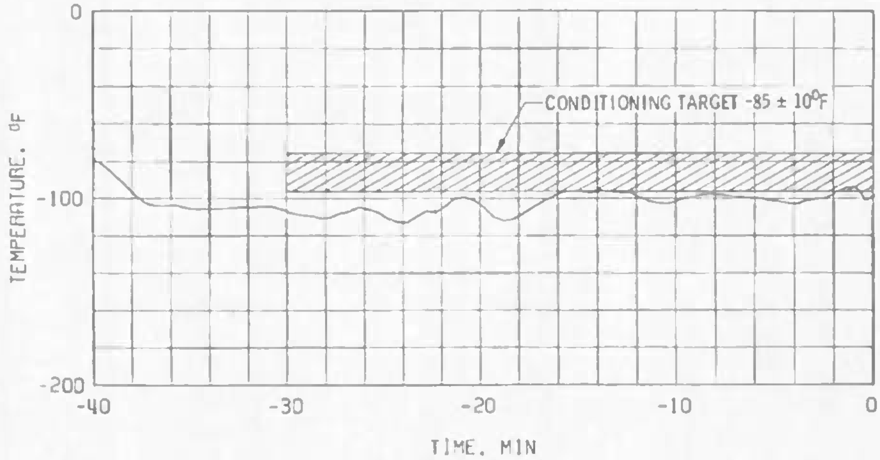


c. Thrust Chomber Fuel System, Shutdown

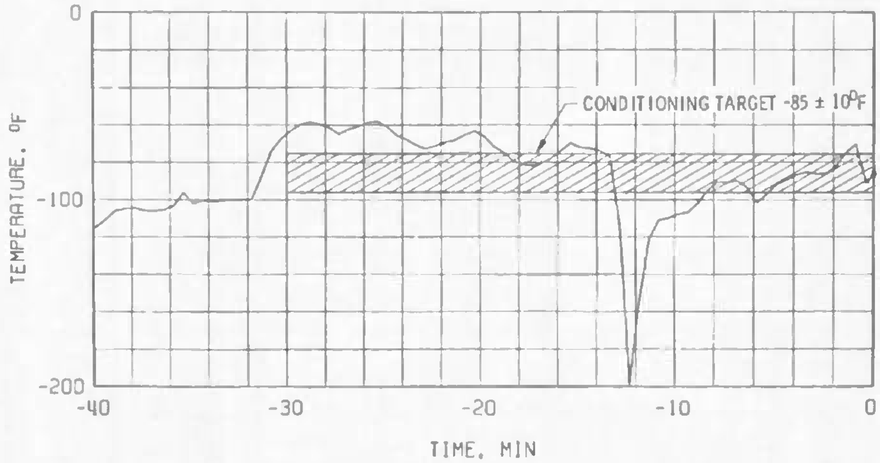


d. Thrust Chamber Oxidizer System, Shutdown

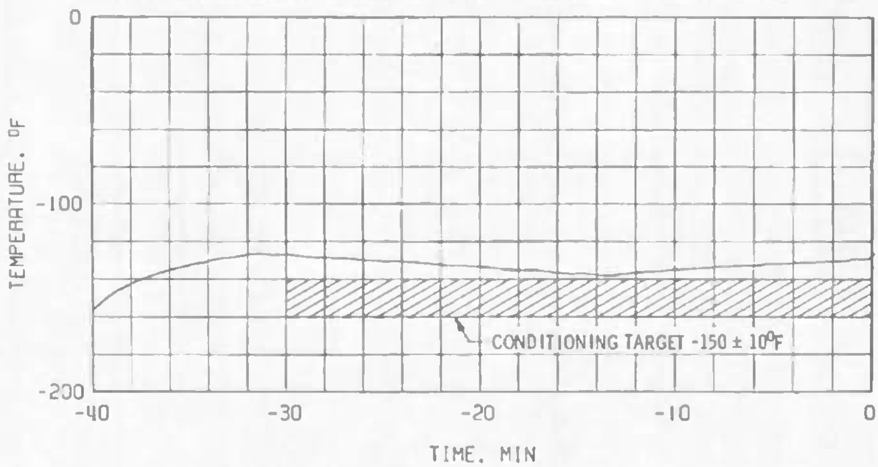
Fig 28 Concluded



a. Pneumatic Regulator, TBHR-2

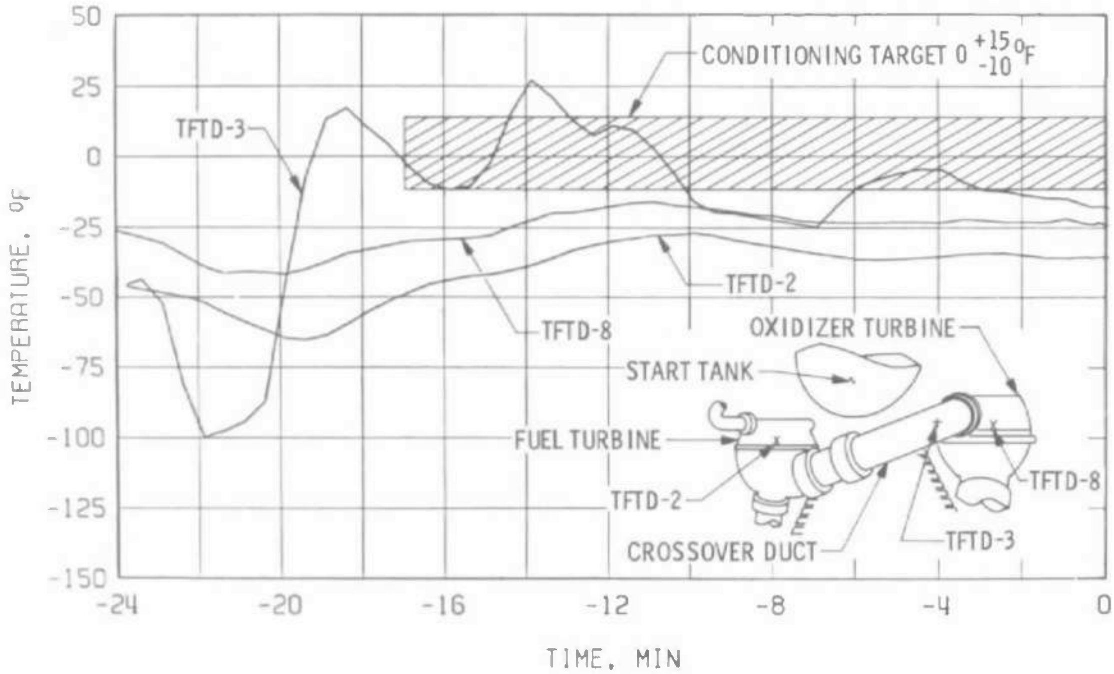


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

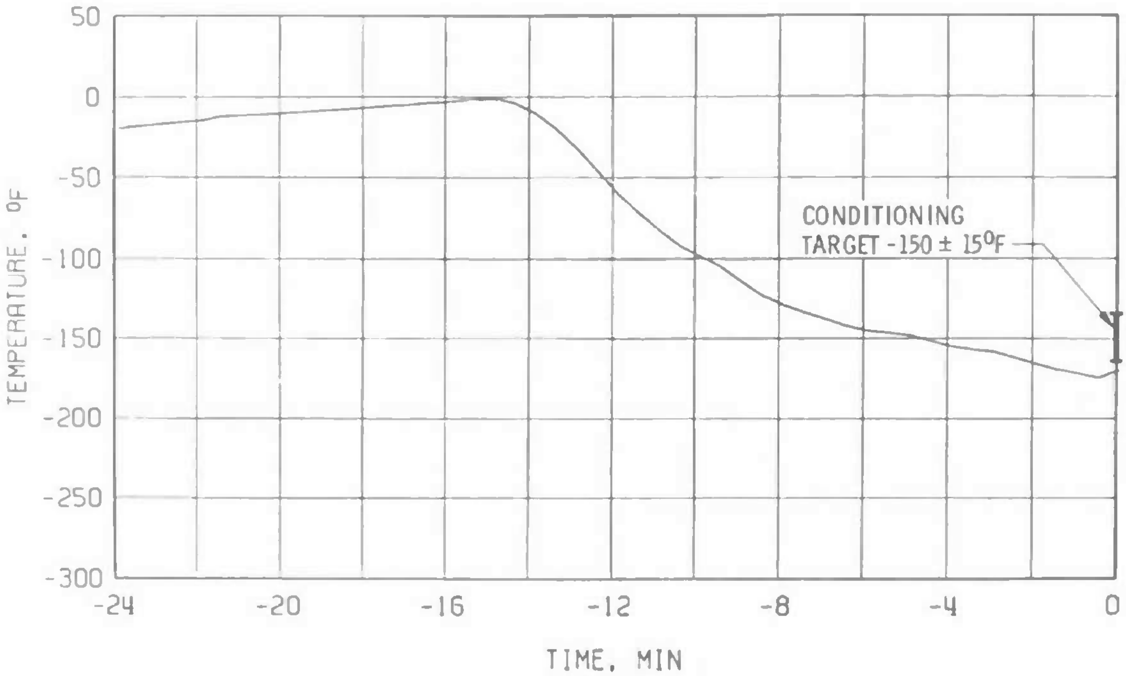


c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 29 Thermal Conditioning History of Engine Components, Firing 01D



d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

Fig. 29 Concluded

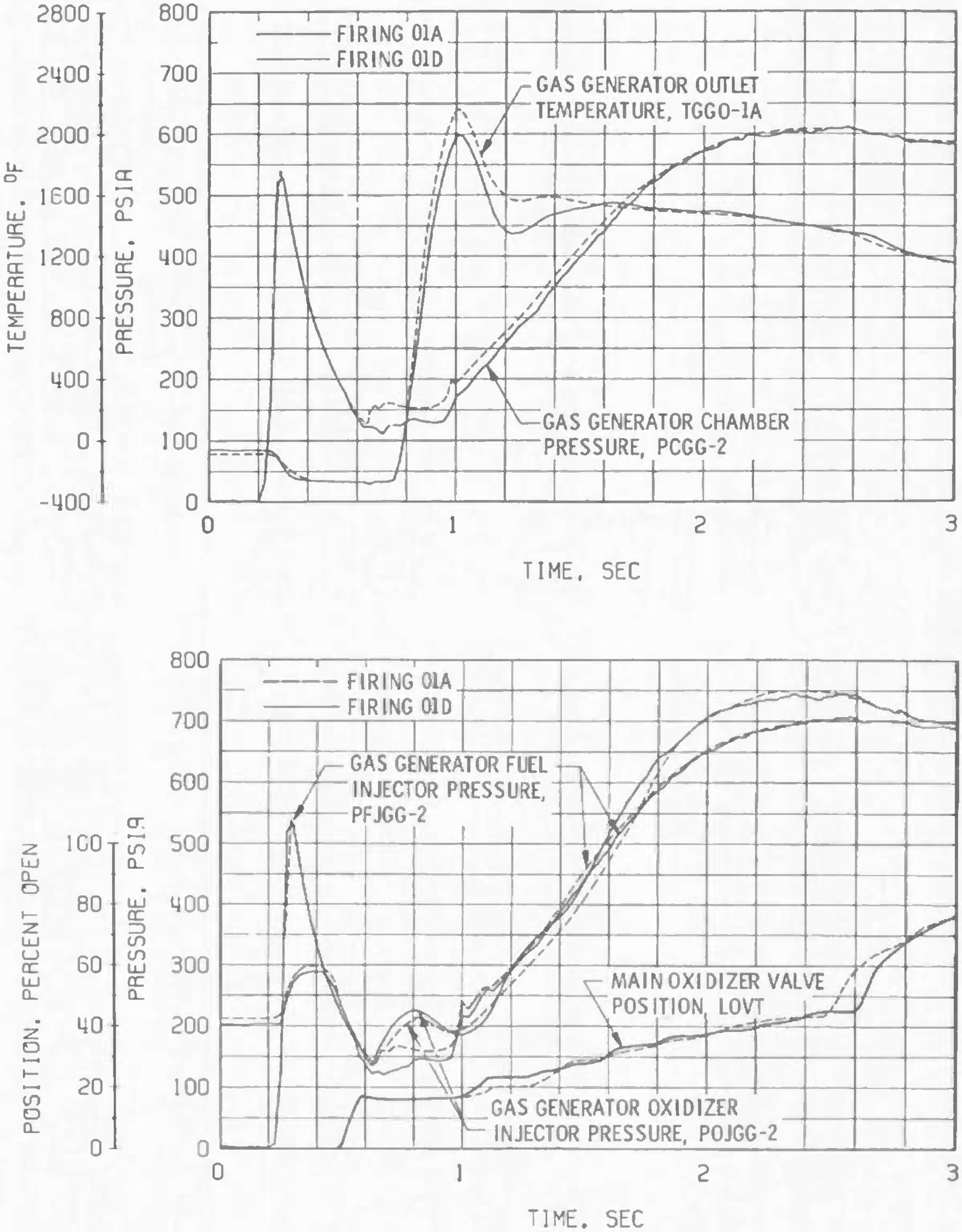
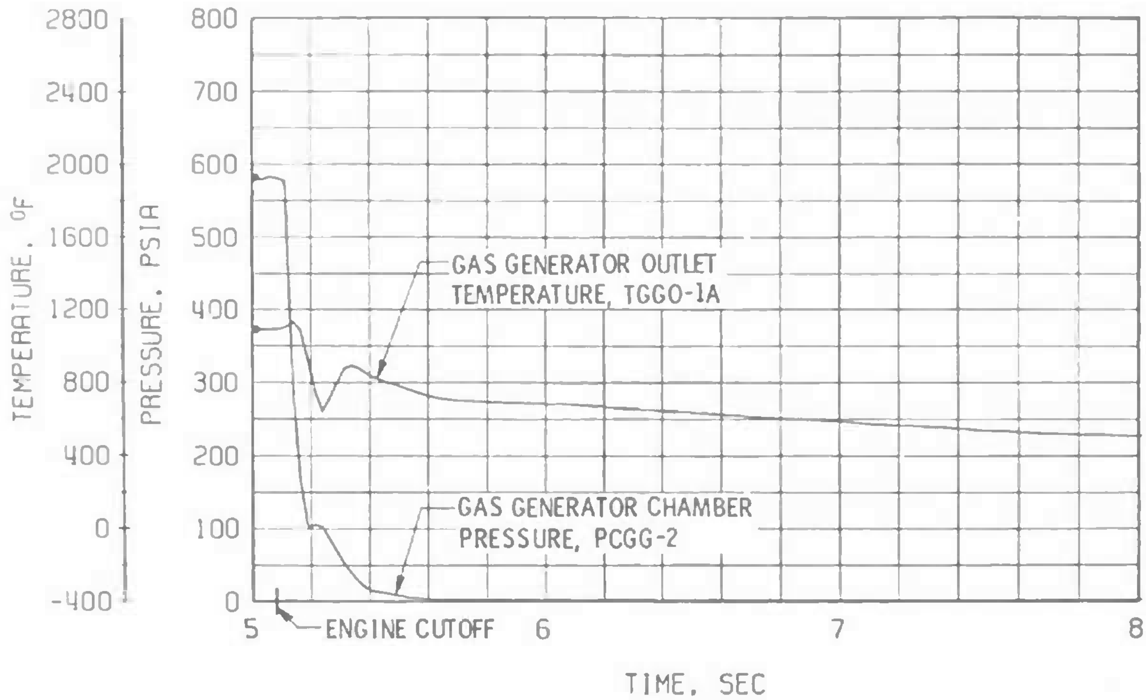


Fig. 30 Gas Generator Start Transient, Comparison of Firings 01A and 01D



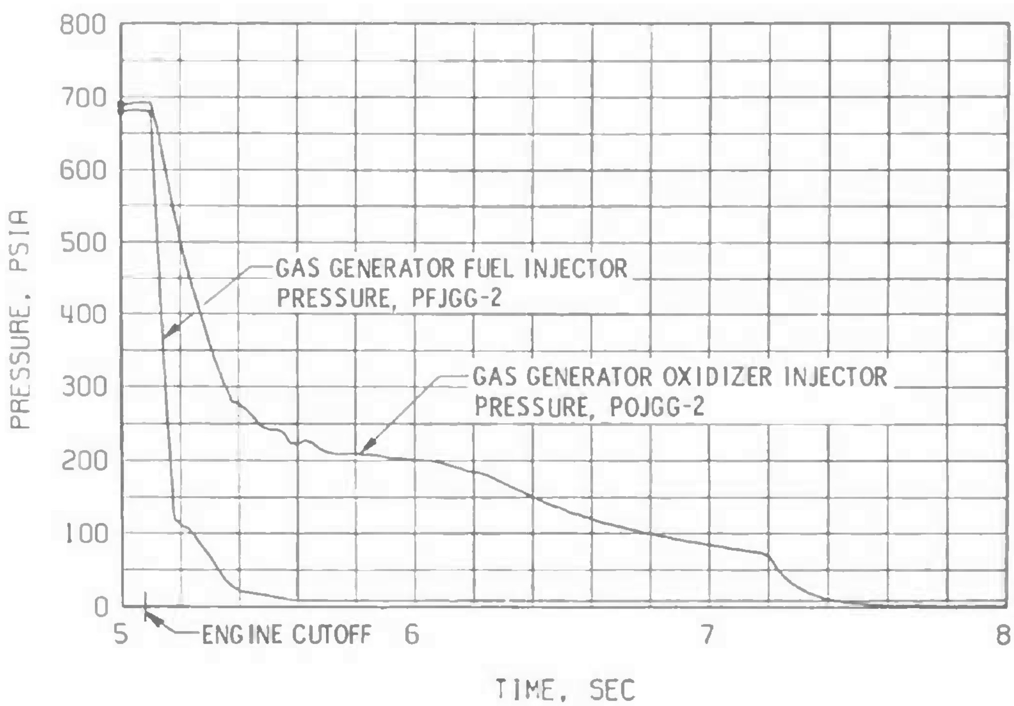


Fig. 31 Gas Generator Shutdown Transient, Firing 01D

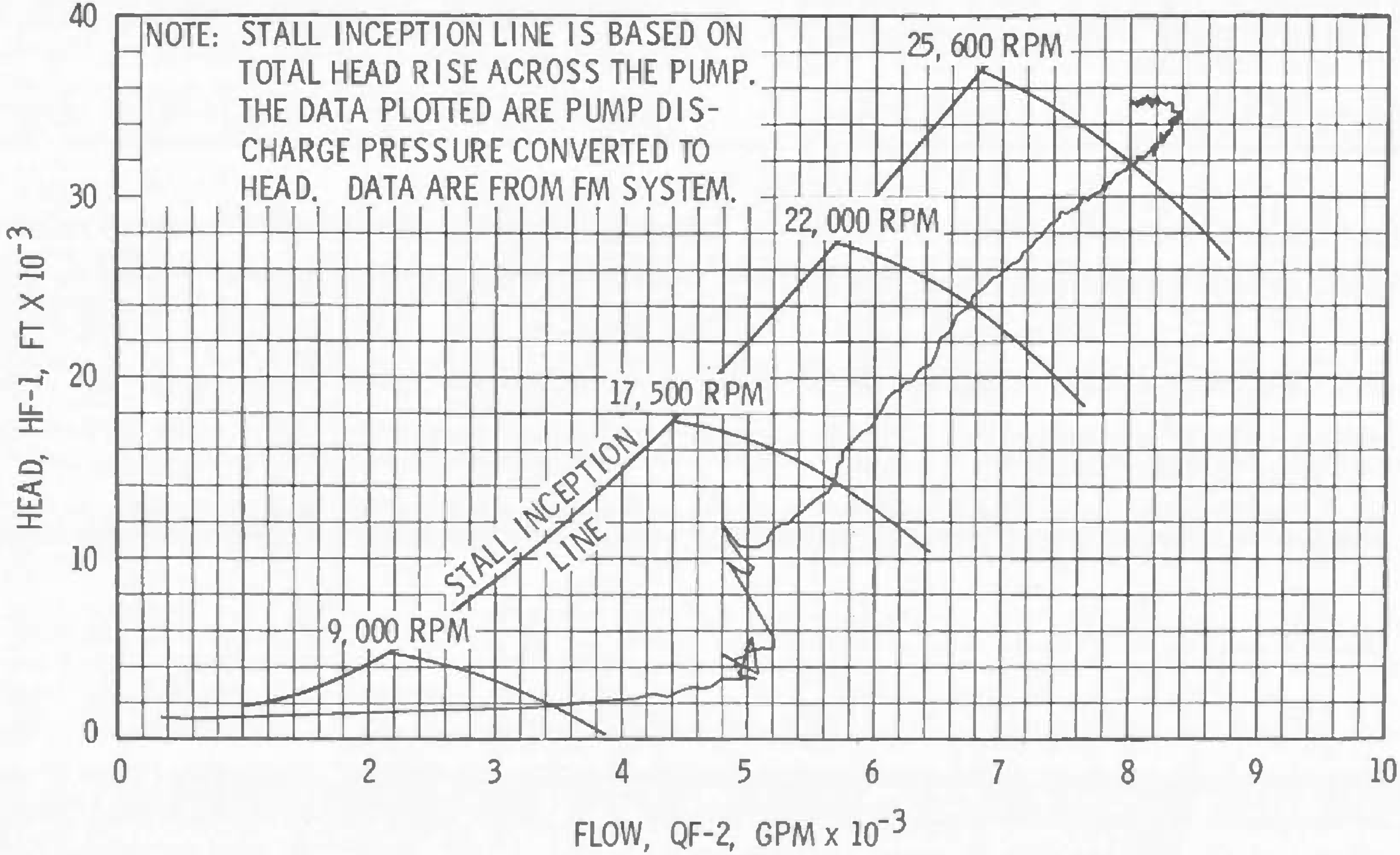


Fig. 32 Fuel Pump Start Transient Performance, Firing 01D

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-161	4062324
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Pneumatic Control Assembly	556947	4079720
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	409969	4072594
Gas Generator Control Valve	309040	4078714
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Phase Control Valve	558069	8275775
Helium Control Valve	106012000	342270
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XEOR915389	211

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel Supply Line	RD273-4107	0.472	May 15, 1967	Accomplished to raise engine performance to model specifications
Gas Generator Oxidizer Supply Line	RD251-4106	0.276	April 28, 1967	Necessitated by fuel turbopump replacement
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.300	May 17, 1967	Accomplished to raise engine performance to model specifications
Oxidizer Turbine Exhaust Manifold	RD251-9004	9.99	January 18, 1966	Installed on engine before shipment to AEDC
Main Oxidizer Valve Closing Control Line	410437	0.26	May 22, 1967	Accomplished to change main oxidizer valve second-stage opening time from 1350^{+10}_{-20} to 1430^{+20}_{-10}
Augmented Spark Igniter Oxidizer Supply Line	406361	0.150	April 7, 1967	Sized per S-II specifications

TABLE III
ENGINE MODIFICATIONS (BETWEEN TESTS J4-1554-30 AND J4-1801-01)

Modification Number	Completion Date	Description of Modification
RFD*-44-67	June 1, 1967	Addition of Oxidizer Bootstrap Line Thermocouples
RFD-45-67	June 16, 1967	Removed Thermocouples Installed per ECP's J2-495 and J2-564 on Engine
RFD-39-67	June 16, 1967	Installation of Thrust Chamber Thermocouples
RFD-46-67	June 20, 1967	Start Tank Discharge Valve Opening and Closing Control Port Thermocouples Installed
RFD-47-67	June 23, 1967	Addition of Engine Conditioning System Screen Manifolds

*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1554-30 AND J4-1801-01)

Replacement	Completion Date	Component Replaced
UCR*-007948	May 25, 1967	Fuel Turbopump Assembly
UCR-007939	May 25, 1967	Gas Generator Control Valve
UCR-007939	May 25, 1967	Gas Generator Outlet Temperature Transducer
UCR-007948	May 25, 1967	Fuel Turbine Inlet Temperature Transducer

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Time, min: t - 80 | t - 70 | t - 60 | t - 50 | t - 40 | t - 30 | t - 20 | t - 10 | t - 0 | t + 10

		Time, min
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min; Propellant Drop; 2-min Minimum Following Recirculation; 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min; 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min; On at Engine Cutoff; 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2800 - 7000 scfm	15 min; Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to; 15 min; On at Engine Cutoff
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min
Pump Inlet Pressure and Temperatore Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	1
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient	1
Main Oxidizer Valve Closing Control Line (Conditioning)	Helium; -300°F to Ambient	1
Pneumatic Regulator Temperature Conditioning	Helium; -300°F to Ambient	1

[1]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1601		01A Target	01A Actual	01B Target	01B Actual	01C Target	01C Actual	01D Target	01D Actual
Time of Day, hr/Firing Date		1226/July 5, 1967		1443/July 6, 1967		1405/July 6, 1967		0107/July 7, 1967	
Pressure Altitude at Engine Start, ft (Ref. 1)		---	97,000	---	100,000	---	108,000	---	108,000
Firing Duration, sec (1)		30.0	30.075	5.0	5.073	5.0	5.073	5.0	5.073
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28^{+1}_{-0}	29.0	28^{+1}_{-0}	28.1	28.0^{-1}_{-0}	28.5	28.0^{+1}_{-0}	29.0
	Temperature, °F	-421.4 ± 0.4	-420.8	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.6	-421.4 ± 0.4	-421.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	41^{+0}_{-1}	40.4	41^{+0}_{-1}	40.4	41^{+0}_{-1}	40.3	41^{+0}_{-1}	40.6
	Temperature, °F	-295.2 ± 0.4	-295.6	-295.2 ± 0.4	-294.7	-295.2 ± 0.4	-295.8	-295.2 ± 0.4	-295.7
Start Tank Conditions at Engine Start	Pressure, psia	1300 ± 10	1307	1300 ± 10	1293	1300 ± 10	1298	1300 ± 10	1269
	Temperature, °F	-300 ± 10	-304	-300 ± 10	-306	-300 ± 10	-308	-300 ± 10	-301
Helium Tank Conditions at Engine Start	Pressure, psia	---	2407	---	2158	---	2198	---	2539
	Temperature, °F	---	-304	---	-305	---	-307	---	-301
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-150 ± 15	-163	-250 ± 15	-257	-260 ± 15	-273	-150 ± 15	-170
	Average	---	-152	---	-235	---	-228	---	-204
Crossover Duct Temperature at Engine Start, °F (2)	TFTD-2	0^{+15}_{-10}	-50	0^{+15}_{-10}	-67	-100 ± 15	-130	0^{+15}_{-10}	-36
	TFTD-3	0^{+15}_{-10}	-19	0^{+15}_{-10}	-17	-100 ± 15	-60	$0^{\pm 15}_{-10}$	-18
	TFTD-8	0^{+15}_{-10}	-22	0^{+15}_{-10}	-35	-100 ± 15	-106	0^{+15}_{-10}	-24
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F (1)		-65 ± 10	-139	-65 ± 10	-102	-65 ± 10	-98	-65 ± 10	-61
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F (3)		-150 ± 10	-167	-150 ± 10	-152	-150 ± 10	-146	-150 ± 10	-127
Pneumatic Control Package Temperature at Engine Start, °F (1)		-85 ± 10	-110	-55 ± 10	-115	-85 ± 10	-109	-85 ± 10	-69
Fuel Lead Time, sec (1)		1.0 ± 0.05	1.010	1.0 ± 0.05	1.014	1.0 ± 0.05	1.011	1.0 ± 0.05	1.014
Propellant in Engine Time, min		60	60	60	---	60	73	60	112
Propellant Recirculation Time, min		10	10	10	10	10	16	10	10
Start Sequence Logic		"Normal"	"Normal"	"Normal"	"Normal"	"Normal"	"Normal"	"Normal"	"Normal"
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	---	-75.0	---	-44.0	---	-66.5	---	-14.4
	TOBS-2	---	-76.7	---	-74.7	---	-162.0	---	-68.3
	TOBS-3	---	-256.7	---	-249.6	---	-257.1	---	-251.0
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	-123.9	---	-105.2	---	-132.5	---	-80.6
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 (1)		--- / ---	120 / 0.860	--- / ---	13 / 0.999	--- / ---	149 / 1.002	--- / ---	158 / 0.945
Gas Generator Outlet Temperature, °F	Initial Peak	---	2170	---	1950	---	2000	---	1990
	Second Peak	---	---	---	---	---	---	---	1550
Thrust Chamber Ignition Time, sec (Ref. t_0) (PC-3 = 100 psia) (1)		---	0.865	---	0.999	---	1.004	---	0.962
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) (1)		---	0.988	---	1.002	---	1.007	---	0.984
Main-Stage Pressure No. 2, sec (Ref. t_0) (1)		---	1.633	---	1.744	---	1.799	---	1.667
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	1.913	---	2.042	---	2.086	---	1.922
Propellant Utilization Valve Position at Engine Start, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes: (1) Data reduced from oscillogram.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Component conditioning to be maintained within limits for last 30 min before engine start.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																							
	Start Tank Discharge Valve			Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve			Start Tank Discharge Valve		
	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 Opening Signal	Valve Delay Time, sec	Valve Opening 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
01A	0	0.166	0.148	-1.010	0.053	0.050	0.442	0.051	0.054	0.442	0.548	2.383	0.442	0.095	0.056	0.442	0.197	0.078	0.442	[illegible]	0.300	0.442	0.105	0.293
01B	0	0.159	0.152	-1.014	0.060	0.048	0.441	0.052	0.060	0.441	0.560	2.452	0.441	0.096	0.052	0.441	0.192	0.060	0.441	0.258	0.568	0.441	0.102	0.282
01C	0	0.166	0.165	-1.011	0.058	0.052	0.442	0.054	0.056	0.442	0.561	2.417	0.442	0.097	0.054	0.442	0.196	0.058	0.442	0.265	0.577	0.442	0.107	0.292
01D	0	0.156	0.150	-1.013	0.059	0.046	0.440	0.058	0.050	0.440	0.549	2.420	0.440	0.093	0.050	0.440	0.186	0.060	0.440	0.260	0.206	0.440	0.100	0.277
Pre-Fire Final Sequence	0	0.098	0.110	-1.011	0.045	0.076	0.446	0.048	0.050	0.446	0.507	1.480	0.446	0.076	0.046	0.446	0.140	0.060	0.446	0.217	0.235	0.446	0.005	0.250

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
01A	30.076	0.115	0.323	30.076	0.098	0.199	30.076	0.070	0.020	30.076	0.018	0.029	30.076	0.282	0.803
01B	5.073	0.122	0.355	5.073	0.070	0.203	5.073	0.072	0.022	5.073	0.018	0.027	5.073	0.259	0.702
01C	5.073	0.124	0.354	5.073	0.070	0.206	5.073	0.076	0.020	5.073	0.018	0.032	5.073	0.268	0.721
01D	5.072	0.118	0.341	5.072	0.070	0.205	5.072	0.072	0.020	5.072	0.018	0.030	5.072	0.261	0.684
Pre-Fire Final Sequence	---	0.080	0.247	---	0.070	0.129	---	0.087	0.028	---	0.005	0.019	---	0.230	0.695

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

TABLE VIII
ENGINE PERFORMANCE SUMMARY

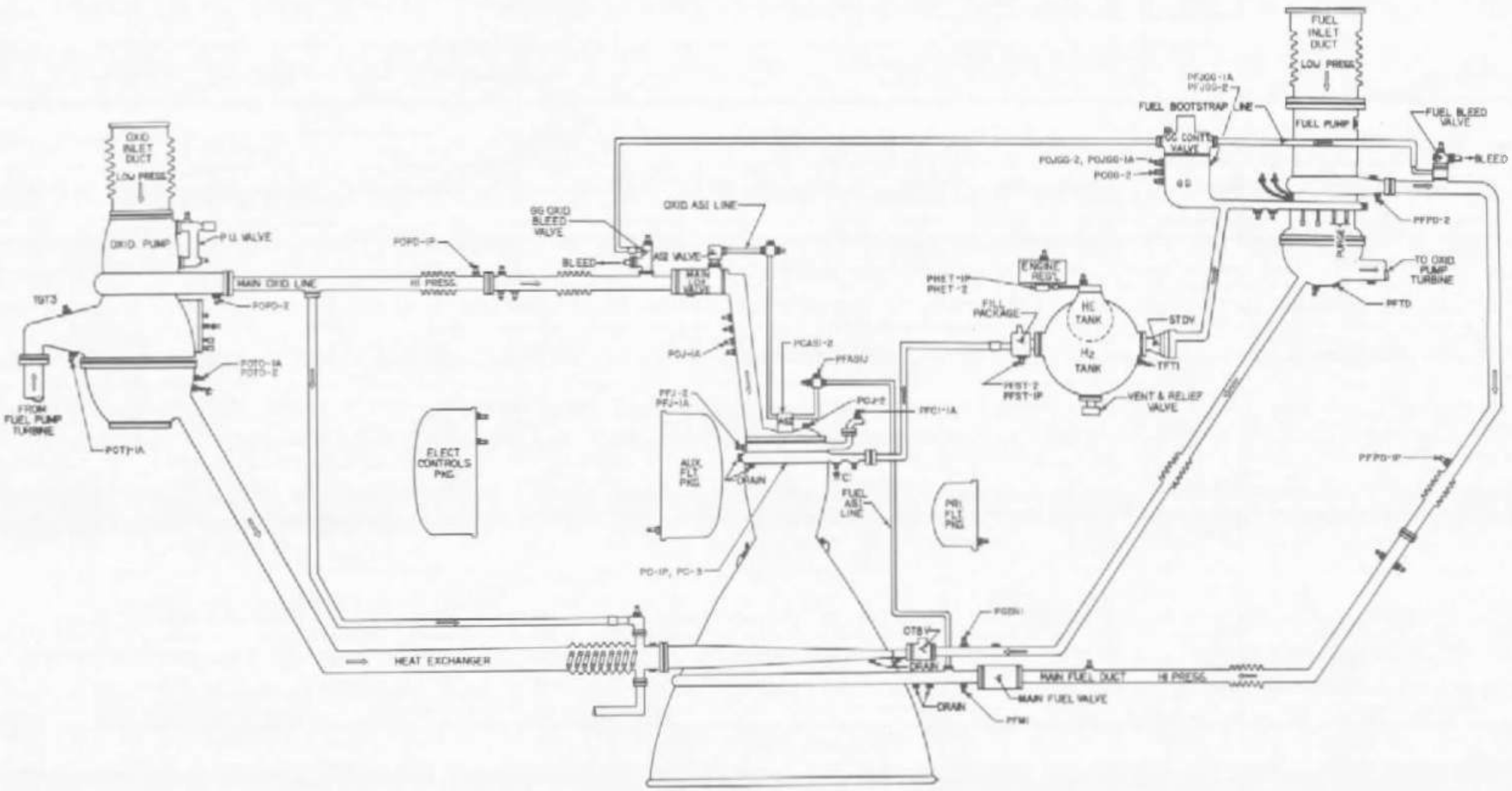
Firing Number J4-1801-01A		Site	Normalized
Time, sec		29.5	29.5
Overall Engine Performance	Thrust, lb_f	229,000	228,200
	Chamber Pressure, psia	775.5	766.4
	Mixture Ratio	5.569	5.568
	Fuel Weight Flow, lb_m/sec	82.60	81.66
	Oxidizer Weight Flow, lb_m/sec	458.4	453.1
	Total Weight Flow, lb_m/sec	540.7	534.5
Thrust Chamber Performance	Mixture Ratio	5.778	5.779
	Total Weight Flow, lb_m/sec	533.7	527.5
	Characteristic Velocity, ft/sec	7965	7963
Fuel Turbopump Performance	Pump Efficiency, percent	73.1	73.1
	Pump Speed, rpm	26,640	26,490
	Turbine Efficiency, percent	59.6	59.5
	Turbine Pressure Ratio	7.22	7.22
	Turbine Inlet Temperature, °F	1251	1236
	Turbine Weight Flow, lb_m/sec	7.02	6.97
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.3	80.3
	Pump Speed, rpm	8639	8584
	Turbine Efficiency, percent	45.5	45.4
	Turbine Pressure Ratio	2.68	2.68
	Turbine Inlet Temperature, °F	813.9	802.4
	Turbine Weight Flow, lb_m/sec	6.38	6.34
Gas Generator Performance	Mixture Ratio	0.970	0.961
	Chamber Pressure, psia	660.0	653.7

Site - Test Data

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

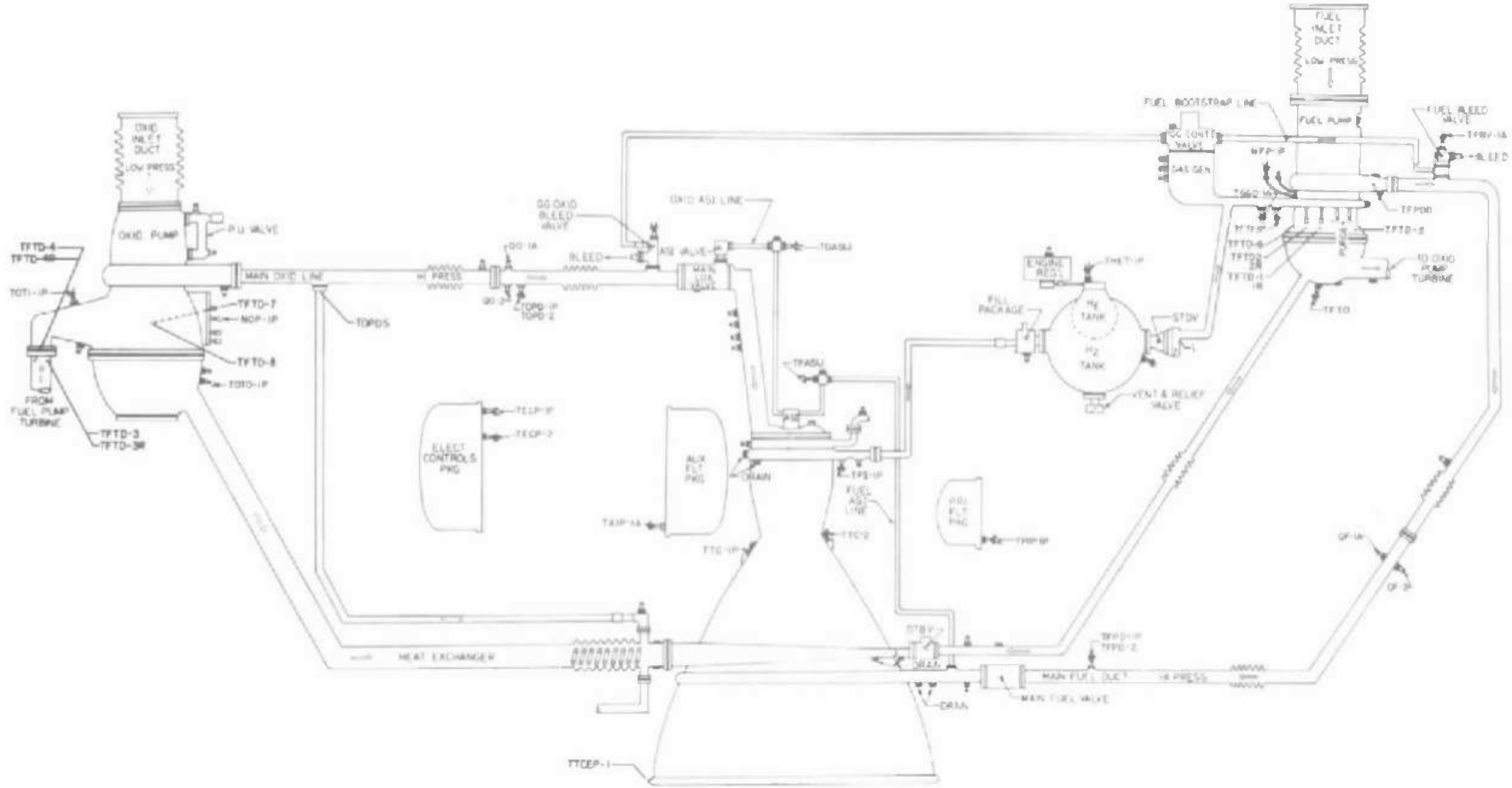
APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-01 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.



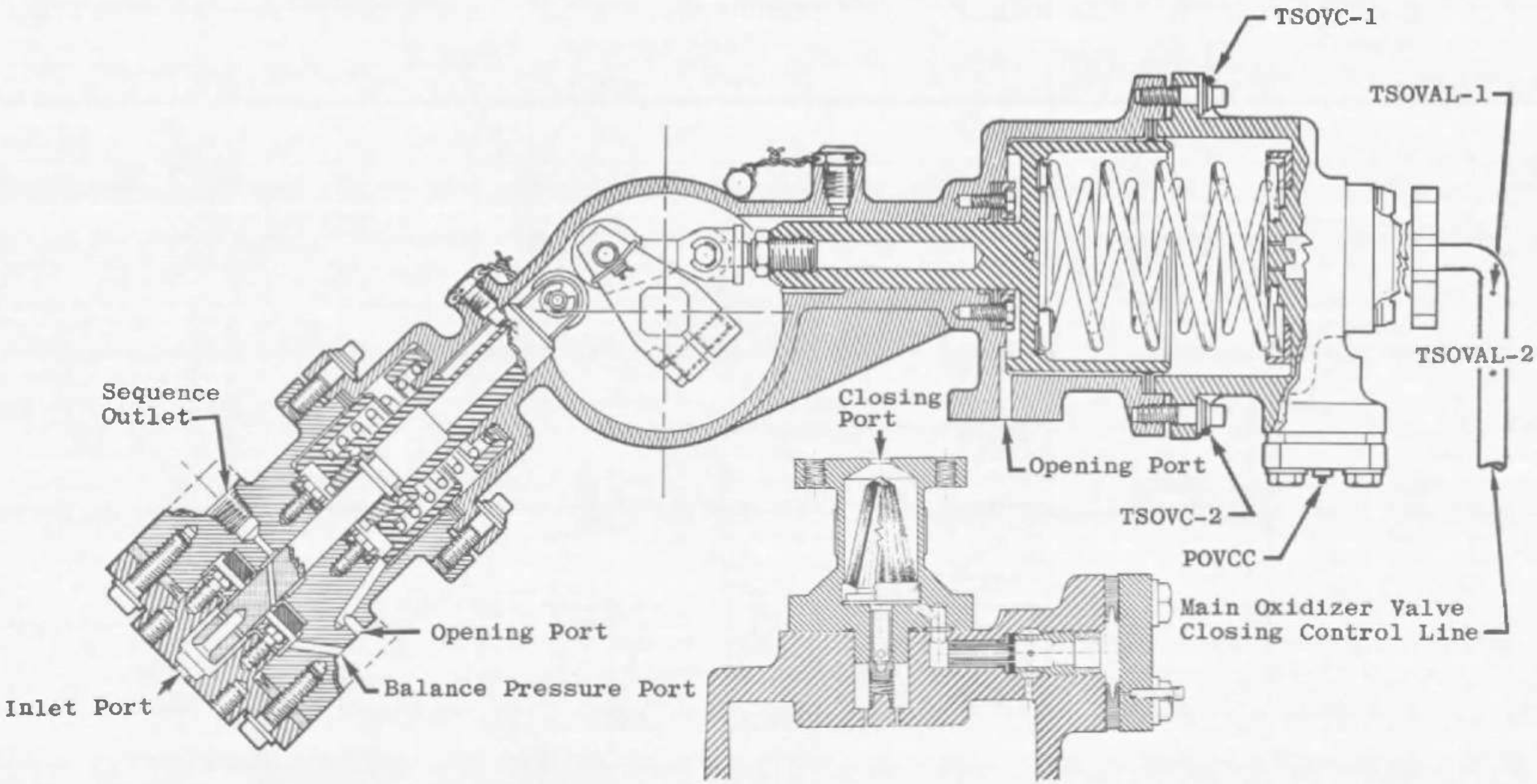
a. Engine Pressure Tap Locations

Fig. III-1 Instrumentation Locations



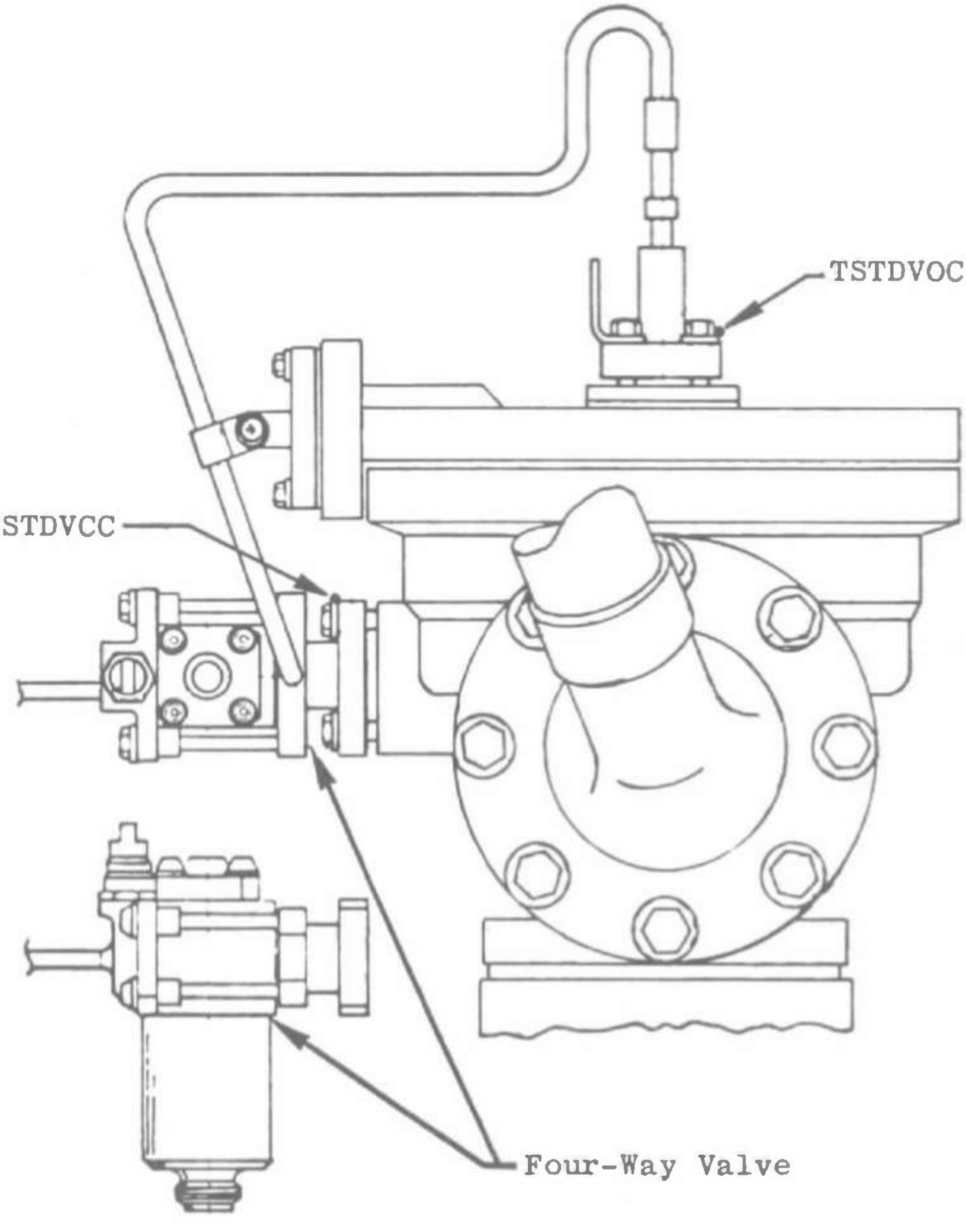
b. Engine Temperature, Flow, and Speed Instrumentation Locations

Fig. III-1 Continued



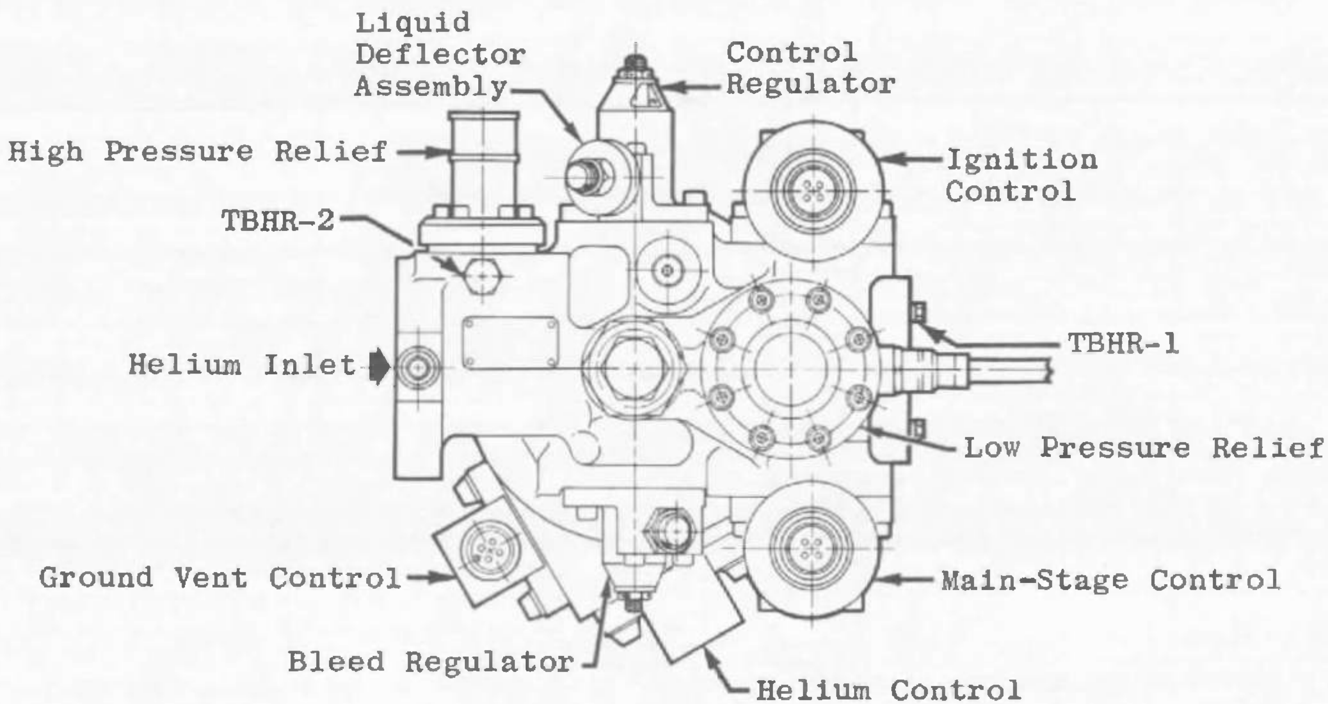
c. Main Oxidizer Valve

Fig. III-1 Continued



d. Start Tank Discharge Valve

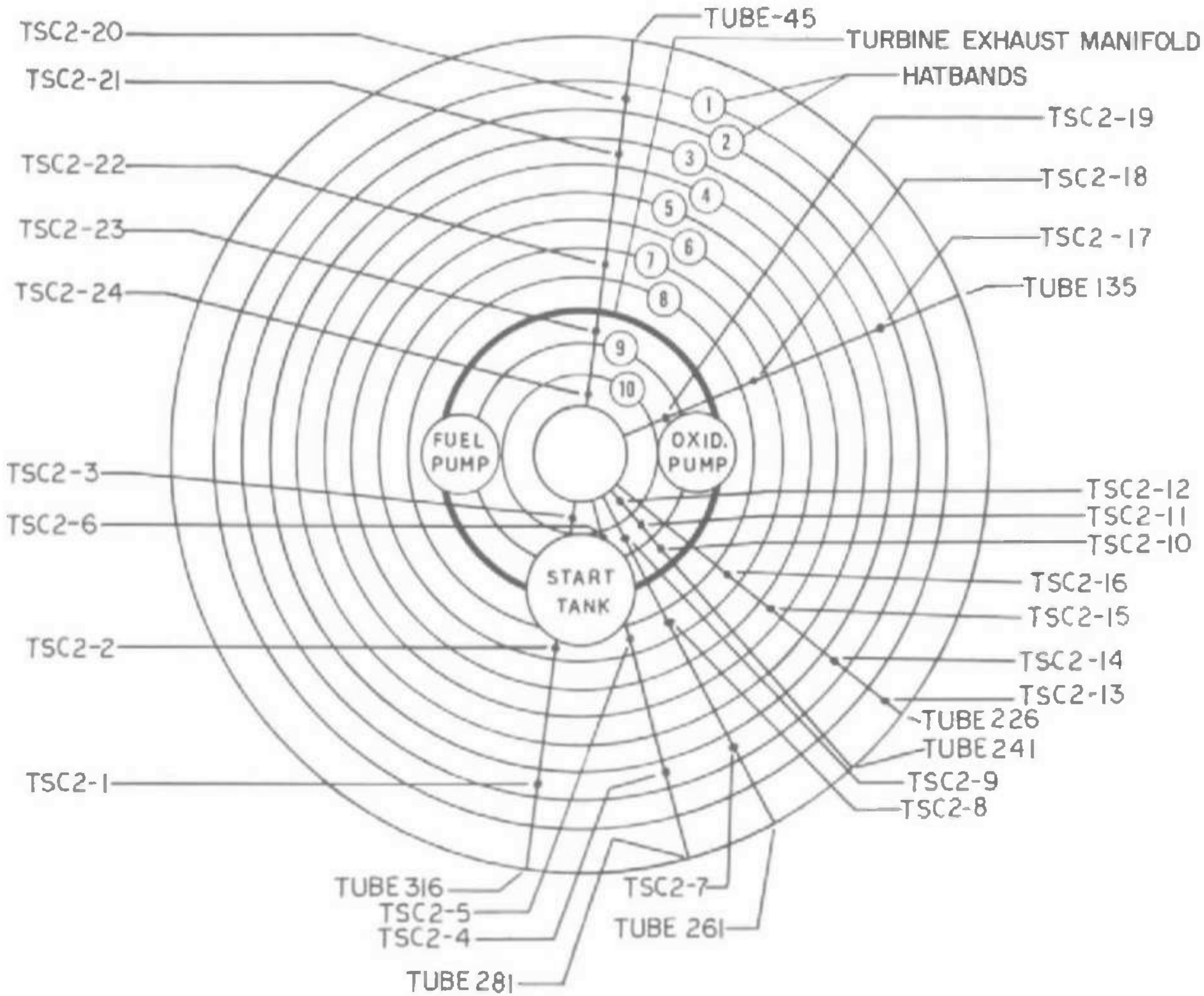
Fig. III-1 Continued



Top View

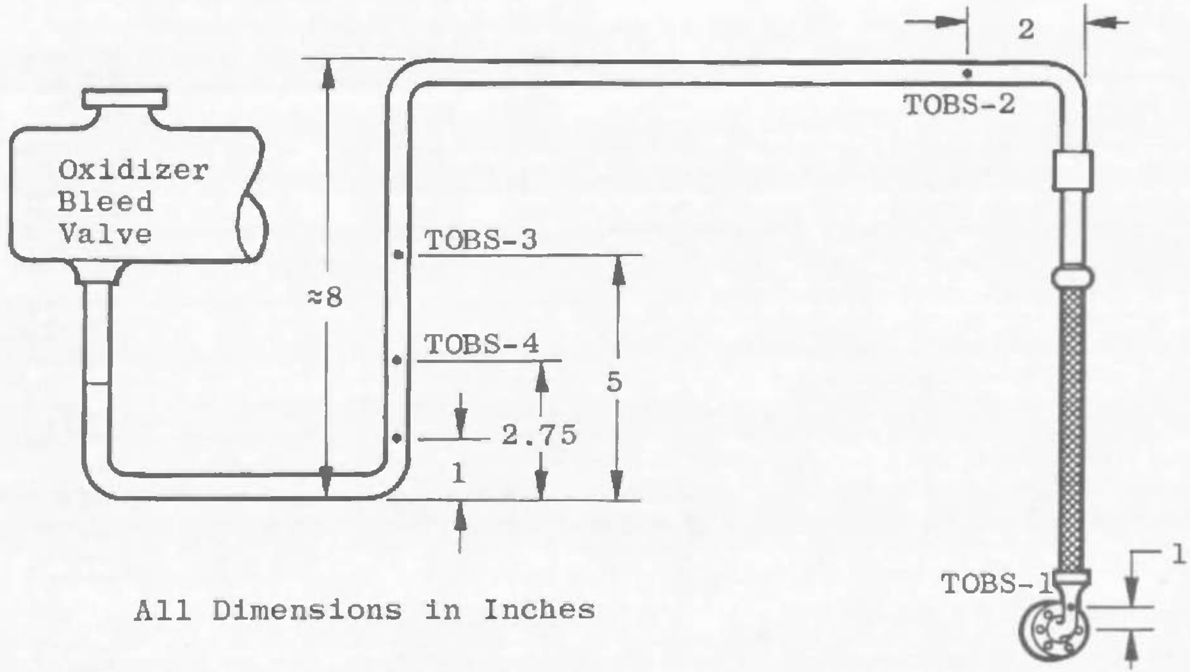
e. Helium Regulator

Fig. III-1 Continued



f. Thrust Chamber

Fig. III-1 Continued



g. Oxidizer Bootstrap Line

Fig. III-1 Concluded

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2					x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Forces		lbf					
FSP-1	Side Load (Pitch)		±20, 000	x		x		
FSY-1	Side Load (Yaw)		±20, 000	x		x		
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-2	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCASI-2	Augmented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PGBNI	Bypass Nozzle Inlet	TG8	0 to 200	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHECP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure							
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to -50	x			x	
TBSC	Oxidizer Bootstrap Conditioning		-350 to -150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to -100	x		x		
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-5	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPH-1A	Oxidizer Pump Heating Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				

TABLE III-1 (Concluded)

AFDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVCC	Start Tank Discharge Valve Closing Control Port		-350 to +100	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

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

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

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

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

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

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{\dot{W}_{EO}}{\dot{W}_{EF}}$$

$$\dot{W}_{EO} = \dot{W}_{OM} - \dot{W}_{XO}$$

$$\dot{W}_{EF} = \dot{W}_{FM} - \dot{W}_{XF}$$

$$\dot{W}_{E} = \dot{W}_{EO} - \dot{W}_{EF}$$

Thrust Chamber

$$r_C = \frac{\dot{W}_{CO}}{\dot{W}_{CF}}$$

$$\dot{W}_{CO} = \dot{W}_{OM} - \dot{W}_{XO} - \dot{W}_{GO}$$

$$\dot{W}_{CF} = \dot{W}_{FM} - \dot{W}_{XF} - \dot{W}_{GF}$$

$$\dot{W}_{XO} = 0.8 \text{ lb/sec}$$

$$\dot{W}_{XF} = 1.8 \text{ lb/sec}$$

$$\dot{W}_{GO} = \dot{W}_{T} - \dot{W}_{GF}$$

$$\dot{W}_{GF} = \frac{\dot{W}_{T}}{1 + r_G}$$

$$\dot{W}_{T} = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

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

CHARACTERISTIC VELOCITY

Thrust Chamber

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

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

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

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

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

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

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

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

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

$$K_4 = 144$$

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

Fuel

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

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

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

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

PUMP EFFICIENCIES

Fuel, Isentropic

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

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

Oxidizer, Isentropic

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

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

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

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

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

$$K_5 = 0.001818$$

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

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

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

$$A = -1597$$

$$B = 2.3828$$

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

$$\ln R = A_3 + B_3 \, (\theta_{PUVO}) + C \, (\theta_{PUVO})^3 + D_3 \, (e)^{\frac{\theta_{PUVO}}{7}}$$

$$- E_3 \, (\theta_{PUVO}) \, (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

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

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

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

$$D_3 = 1.2343$$

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

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

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

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

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

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

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

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

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

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

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

$$K_{56} = -15$$

Fuel, Developed Horsepower

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

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

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

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

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

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

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

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

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

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

$$K_{13} = 0.7854$$

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

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

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

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

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

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

$$A_1 = 0.2575$$

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

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

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

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

Flows

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

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

$$B_2 = 3.2267$$

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

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

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

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{H1R} = T_{TIF}$$

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

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11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
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13 ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished during test period J4-1801-01 at pressure altitudes ranging from 97,000 to 108,000 ft at engine start to evaluate S-V/S-II gas generator ignition characteristics for J-2 engine J-2052. Engine components were temperature conditioned to the predicted values for the S-II interstage/engine environment. Satisfactory engine operation was obtained. The accumulated firing duration was 45.3 sec.

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UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J-2 rocket engines						
altitude testing						
gas generator ignition characteristics						
performance						

1. Rocket motors -- J-2
2. " " -- Ignition
3. " " -- Performance

16 - 3.