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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1902-05 THROUGH J4-1902-07)

W. W. Muse and C. H. Kunz

ARO, Inc.

October 1969

This document has been approved for public release

Per AF Letter dtd 12 July 74 signed William O. Cole

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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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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EP-J), under Program Area 921E.

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; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted between March 6 and 20, 1969, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1902. The manuscript was submitted for publication on July 30, 1969.

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

Seven idle-mode firings of the J-2S rocket engine (S/N J-112-1) were conducted during test periods J4-1902-05 through J4-1902-07 between March 6 and 20, 1969, in Test Cell J-4 of the Large Rocket Facility. The objectives of these firings were to determine the effect of restricting fuel bypass and thrust chamber film coolant flows on fuel density at the injector and idle-mode performance. Reduction of fuel bypass flow from 2 lb_m/sec to zero resulted in a 20-percent reduction in calculated fuel density at the injector; reduction of film coolant flow from 1 lb_m/sec to zero apparently had no effect on calculated density at the injector. Essentially no performance differences were noted in engine steady-state, idle-mode performance because of reduction of these flows. No significant engine damage was sustained on any of the firings. Total accumulated engine idle-mode firing duration was 656.5 sec.

Per AF letter dtd. 17 July 74 signed William D. Cole.

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I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
CCP	Customer connect panel
EBW	Exploding bridge wire
FM	Frequency modulation
MFV	Main fuel valve
MOV	Main oxidizer valve
O/F	Propellant mixture ratio, oxidizer to fuel, by weight
SPTS	Solid-propellant turbine starter
T/C	Thrust chamber
t_0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, defined as engine vibration in excess of 0 to 50 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-2S rocket engine using an S-IVB battleship stage has been in progress since December, 1968, at AEDC. The seven firings reported herein were idle-mode tests conducted with R & D engine J-112-1 during test periods J4-1902-05 through -07 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). Pressure altitudes at engine start ranged from 73,500 to 100,500 ft (geometric pressure altitude, Z, Ref. 1).

These firings were accomplished primarily to evaluate the effect of restricting fuel bypass and film coolant flows on fuel density at the injector and on idle-mode performance. These engine modifications were tested as a possible solution to the idle-mode performance and operation deficiencies encountered with R & D engine J-111-A on test periods J4-1902-01 through -04 (Ref. 2). The deficiencies were attributed to the much higher fuel density at the injector at altitude than for sea-level conditions and resulted in severe thrust chamber damage on firing 04A. Data collected for evaluating engine idle-mode performance and operation are presented herein.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lb_f and mixture ratio of 2.5 or at main stage at any precalibrated thrust level between 230,000 and 265,000 lb_f at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II).

All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5 and 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 with a throat diameter of 12.192 in., a characteristic length (L*) of 35.4, and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 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 and by film cooling inside the combustion chamber.

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 19.2 and 5.9 in.^{2}, respectively. The oxidizer portion is compartmentalized, the outer compartment supplying oxidizer during main-stage operation only. The porous material, forming the injector face, allows approximately 3.5 percent of main-stage 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 fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lb_f-thrust rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump - The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally

produces, at the 265,000-lb_f-thrust rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve - The motor-driven propellant utilization valve is a sleeve-type valve which 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.

7. 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 injector. The first-stage actuator positions the main oxidizer valve at the 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to the main-stage operating level.

8. 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.

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

10. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package - The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank - The helium tank has a volume of 4000 $in.^3$ and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve - The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve - The idle-mode valve is a pneumatically operated ball-type valve which supplies liquid oxygen to

the idle-mode compartment of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve - The hot gas tapoff valve is a pneumatically operated butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter - The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum usable propellant capacity of 43, 000 lb of liquid hydrogen and 194, 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 engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. 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 flight were routed to the respective facility venting systems.

2.2 TEST CELL

Propulsion Engine Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1. 5-million-lb_f-thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid-oxygen and gaseous-helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100, 000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2S 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.

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 engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-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 thrust chamber bypass flow was measured by a turbine-type flowmeter which was installed in a specially fabricated bypass duct. Vibrations were measured by accelerometers mounted on the oxidizer injector dome, the thrust, the chamber throat, and 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 the capacitance-type pressure transducer.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 50 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-2S 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 start and shutdown is presented in Figs. 7a and b.

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 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. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Table V presents the engine purges during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

Firing J4-1902-04 with R & D engine J-111-A sustained major engine damage to the combustion chamber caused by high combustion pressure perturbations. Analysis of test data indicates that these pressure perturbations were caused by detonations of unburned oxidizer-fuel mixtures on the internal chamber wall. These unburned mixtures were believed to have been caused by lower than expected fuel injection temperatures resulting from the higher than expected fuel density at the injector and increased total fuel flow rate. These conditions are attributed to the reduction in external heat transfer to the hydrogen flowing through the thrust chamber tubes at altitude conditions. The objectives of these firings were to determine the effect of restricting fuel bypass and thrust chamber film coolant flows on fuel density at the injector. Restricting fuel bypass and film coolant flows at simulated altitude conditions was proposed to force a larger percentage of the fuel flow through the thrust chamber tubes where heat addition to the flow would cause a reduction in fuel density at the injector and a reduction in total fuel flow. The tests reported herein were accomplished with restricted fuel bypass and film coolant flows to determine if such modifications were solutions to the idle-mode operational deficiencies at altitude conditions.

4.2 TEST SUMMARY

Seven firings of the Rocketdyne J-2S rocket engine (S/N J-112-1) were conducted between March 6 and 20, 1969, during test periods J4-1902-05 through J4-1902-07. Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Engine idle-mode performance for these firings is presented in Table VIII. Figure 8 shows engine start conditions for propellant pump inlets and the helium tank. Engine ambient and combustion chamber pressures, fuel system chilldown data, and propellant system performance are presented in Figs. 9 through 29, respectively. Accumulated idle-mode firing duration for these three test periods was 656.5 sec. Data presented herein are from the digital data acquisition system except where indicated otherwise. Specific test objectives and a brief summary of results obtained for each firing are presented in the following sections. Primary test variables and results are summarized in the following table.

Firing	Duration, sec	Pump Inlet Pressures: Oxidizer, psia	Pump Inlet Pressures: Fuel, psia	Flow Rates, lb_m/sec: Fuel Total	Flow Rates: T/C Fuel Bypass	Flow Rates: T/C Fuel Film Coolant	Flow Rates: Fuel Injector	Flow Rates: Oxidizer Total	Engine Mixture Ratio, O/F	Fuel Injection Density, lb_m/ft^3	Characteristic Velocity, ft/sec	Time to Steady-State Main Chamber Pressure, sec
05A	69.6	36.4 (Nominal)	32.2 (Nominal)	8.6	2.0	1.0	8.6	13.6	1.79	0.37	2350	35
05B	89.5	44.5 (Maximum)	23.1 (Low)	7.5	2.1	0.8	6.7	16.1	2.20	0.22	3010	50
06A	100.2	39.0 (Nominal)	33.0 (Nominal)	10.3	2.0	0.1	10.2	15.0	1.47	0.43	2780	45
06B	100.2	38.7 (Nominal)	33.4 (Nominal)	9.2	2.3	0.1	9.1	14.7	1.56	0.41	2800	35
07A	100.1	39.1 (Nominal)	32.9 (Nominal)	8.7	0	0	8.7	14.9	1.71	0.31	2880	60
07B	101.8	44.8 (Maximum)	27.1 (Minimum)	5.4	0	0	5.4	18.9	3.53	0.15	2040	Not Attained
07C	59.2	20.7 (Minimum)	33.2 (Nominal)	8.9	0	0	8.9	9.6	1.10	0.34	3640	52

4.2.1 Firing J4-1902-05A

The objective of this firing was to determine the effect of reduced fuel bypass and thrust chamber film coolant flow rates on fuel density at the injector and idle-mode performance with nominal pump inlet pressures (39-psia oxidizer and 33-psia fuel).

The bypass flow was reduced from an estimated 70 percent of total fuel flow experienced on previous firings with engine S/N J-111-A to approximately 22 percent (2 lb_m/sec for this firing). Film coolant flow was reduced from an estimated 15 percent of total fuel flow to 10 percent (0.9 lb_m/sec for this firing). This reduction in film coolant and thrust chamber fuel bypass flow resulted in an average calculated steady-state fuel density of 0.37 lb_m/ft^3 at the injector. This was only approximately 5 percent lower than for firing J4-1902-03B (Ref. 2) which had similar pump inlet pressures. No significant increase in idle-mode performance was experienced.

4.2.2 Firing J4-1902-05B

The objectives of this firing were to determine the effect of low fuel pump inlet pressure (30 psia) and maximum oxidizer pump inlet pressure (45 psia) on fuel density at the injector and on idle-mode performance.

These pump inlet conditions resulted in calculated fuel density at the injector of approximately 0.22 lb_m/ft^3 (40-percent reduction as compared to firing 05A) and no significant change in idle-mode performance.

4.2.3 Firing J4-1902-06A

The objective of this firing was to determine the effect of further reduced thrust chamber film coolant flow on fuel density at the injector and idle-mode performance with nominal pump inlet conditions.

Film coolant flow was reduced to approximately 0.1 lb_m/sec. However, this reduction did not have a significant effect on fuel density at the injector or on idle-mode performance.

4.2.4 Firing J4-1092-06B

The objective of this firing was to determine the effect of zero bypass flow on fuel density at the injector and idle-mode performance.

Although the thrust chamber fuel bypass valve was fully closed for this firing, leakage through the valve produced approximately the same flow rate as on firing 06A. No significant change in fuel density at the injector or in idle-mode performance was noted for this firing.

4.2.5 Firing J4-1902-07A

The objective of this firing was to determine the effect of zero fuel bypass and thrust chamber film coolant flow on fuel density at the injector and idle-mode performance with nominal pump inlet pressures.

Fuel density at the injector was 0.31 lb_m/sec (16-percent reduction when compared to firing 05A). No significant change in engine idle-mode performance was noted with these test conditions.

4.2.6 Firing J4-1902-07B

The objective of this firing was to determine the effect of zero fuel bypass and thrust chamber film coolant flow on fuel density at the injector and idle-mode performance with high oxidizer pump inlet pressure (45 psia) and low fuel pump inlet pressure (27 psia).

Fuel density at the injector calculated during steady-state operation averaged 0.16 lb_m/ft^3. This was within the range of fuel density at the injector experienced on sea-level, idle-mode firings conducted by the engine manufacturer. This was a 48-percent reduction as compared to firing 07A. No significant change in engine idle-mode performance was noted with these test conditions.

4.2.7 Firing J4-1902-07C

The objective of this firing was to determine the effect of zero fuel bypass and thrust chamber film coolant flow on fuel density at the injector and idle-mode performance with reduced oxidizer pump inlet pressure (30 psia) and nominal fuel pump inlet pressure (33 psia).

Fuel density at the injector was approximately 0.34 lb_m/ft^3 (10-percent increase as compared to firing 07A). Characteristic velocity was 3640 ft/sec (24 percent higher than on firing 07A).

4.3 FUEL DENSITY AT THE INJECTOR

Fuel density at the injector, estimated by the method of calculation presented in Appendix IV, ranged from 0.16 to 0.43 lb_m/ft^3 during idle mode, steady state. These densities represent a range in hydrogen quality from 70 to 24 percent (quality is defined as the ratio of the mass of vapor to the total mass). Figure 30 shows fuel density at the injector as a function of fuel injector flow rate. Although fuel density is directly proportional to flow squared, this relation may be approximated as directly proportional to flow (0.055 lb_m/ft^3 per lb_m/sec) in the 5- to 10-lb_m/sec flow regime. For the same flow regime, Fig. 31 indicates that fuel injector flow rate can be approximated as directly proportional to fuel pump inlet pressure (0.69 lb_m/sec per psia) for a given fuel system flow configuration. Combining these data indicates a 0.038 lb_m/ft^3 density reduction with a 1-psia fuel pump inlet pressure reduction in the 5- to 10-lb_m/sec fuel flow regime.

The primary objective of this test series was to evaluate the effect of restricting fuel bypass and film coolant flows on idle-mode fuel density at the injector. Orificing of these flows (summarized for each test period in Table II) yielded the following nominal flow rates:

Test	Bypass, lb_m/sec	Film Coolant, lb_m/sec
05	2	1
06	2	0.1
07	0	0

The effects of restricting these fuel flows on fuel injector flow rate are also presented in Fig. 31. (Fuel injector flow is the sum of thrust chamber and bypass flow minus film coolant flow). The limited number of data points presented in Fig. 31 indicates that a reduction in bypass flow from 2 lb_m/sec to zero results in approximately a 13-percent reduction in fuel injector flow. From Fig. 30 it can be seen that a 13-percent reduction in fuel injector flow results in approximately a 20-percent reduction in fuel density at the injector. Film coolant flow reduction from 1 lb_m/sec to zero apparently had a negligible effect on fuel density at the injector.

The effect of oxidizer flow rate on fuel density at the injector can be seen by comparison of firings 07A and 07C. Test conditions for 07C were the same as for 07A, except for reduced oxidizer pump inlet pressure. The results are summarized as follows:

	07A	07C
Oxidizer flow, lb_m/sec	14.9	9.7
Fuel flow, lb_m/sec	8.7	8.9
Chamber pressure, psia	18.1	17.9
Fuel density, lb_m/sec	0.31	0.34

These data show that the reduction in oxidizer flow on 07C did not have a significant effect on fuel density at the injector. The decrease in oxidizer flow apparently did not change the combustion heat release because no significant change in chamber pressure occurred. Also, because of the injector design, approximately 90 percent of the total fuel enters the combustion chamber outside of the idle-mode compartment, most of which serves as film coolant. Variations in oxidizer flow rate with pump inlet pressure are shown in Fig. 32.

Minimum fuel density at the injector of 0.16 lb_m/ft^3 on firing 07B was realized with zero bypass and film coolant flows and minimum fuel pump inlet pressure. This density value was within the 0.12- to 0.18-lb_m/sec range encountered during sea-level tests and targeted for this test series. However, the desired injection density was not attainable for any other engine idle-mode model specifications (Ref. 5) starting conditions tested. Furthermore, engine modifications would be required to permit transition to mainstage from idle-mode operation with zero bypass and film coolant flows.

4.4 IDLE-MODE OPERATION

4.4.1 Transient Performance

Transient idle-mode operation was observed to exist until engine components attained near thermal equilibrium (Figs. 9 through 29). During this transient period, main chamber pressure oscillations were observed until fuel at the injector reached saturated conditions. These oscillations were of larger amplitude on firings with reduced steady-state fuel flow (reduced steady-state fuel density at the injector, see Section 4.3). These firings with reduced fuel flow also required longer run durations to attain saturated conditions at the fuel injector (see Fig. 33; note that data points from firings 06A and 07A have been omitted from this figure because of abnormal chilldown rates resulting from abnormal test cell conditions).

4.4.2 Steady-State Performance

Engine steady-state, idle-mode performance, calculated by the methods presented in Appendix III, is summarized in Table VIII. These data are averaged for ±0.5 sec at the indicated times. A time-history of selected parameters from this table, grouped by similar pump inlet pressures, is presented in Fig. 34 to show the effects of restricting bypass and film coolant flow on engine performance. These data indicate a lower thrust, but higher specific impulse and characteristic velocity, with reduced bypass and film coolant flows at the beginning of the steady-state period, diminishing to essentially no performance differences by engine cutoff.

The effect of pump inlet pressures on idle-mode, steady-state performance can be seen by comparison of data from Table VIII (Fig. 34). For the four firings with nominal pump inlet pressures of 39-psia oxidizer and 33-psia fuel (firings 05A, 06A, 06B, and 07A), characteristic velocity averaged 2,850 ± 100 ft/sec and engine oxidizer-to-fuel mixture ratio averaged 1.6 ± 0.1. For the two firings which were conducted with high oxidizer pump inlet pressure of 43 psia and low fuel pump inlet pressures of 27 to 29 psia (firings 05B and 07B), characteristic velocity averaged 2,975 ± 35 ft/sec (less than 5-percent increase as compared to nominal pump inlet conditions), and engine oxidizer-to-fuel mixture ratio averaged 2.6 ± 0.3. For the one firing with low oxidizer pump inlet pressure of 30 psia and nominal fuel pump inlet pressure of 33 psia (firing 07C), characteristic velocity was 3,640 ft/sec with a mixture ratio of 1.1. This was the only firing that showed a significant increase in performance with a change in pump inlet pressures (characteristic velocity was 28 percent higher than the average for firings with nominal pump inlet pressures).

4.5 ENGINE-GENERATED SIDE LOADS

Engine-generated side loads were measured for all firings, and these data are presented in Fig. 35. The indicated levels before engine start resulted from tare loads caused by engine propellant supply line pressures and temperatures. These data indicate no significant side load forces were experienced during idle-mode operation. These loads were less than 1,000 lb_f above the prefire tare level for all firings.

SECTION V
SUMMARY OF RESULTS

The results of the seven idle-mode firings of the J-2S rocket engine S/N J-112-1 during test periods J4-1902-05 through J4-1902-07 between March 6 and 20, 1969, are summarized as follows:

1. The desired fuel density at the injector (0.12 to 0.18 lb_m/ft^3) was not obtained for all engine operating conditions tested. Steady-state idle-mode fuel density at the injector for these firings was calculated to range from 0.16 to 0.43 lb_m/ft^3. The minimum density was obtained with zero thrust chamber film coolant and fuel bypass flows and with minimum fuel pump inlet pressure (27 psia).

2. Fuel density at the injector was approximately directly proportional to fuel injector flow rates, and fuel injector flow rate was approximately directly proportional to fuel pump inlet pressure in the 5- to 10-lb_m/sec flow regime tested.

3. Reduction of fuel bypass flow from 2 lb_m/sec to zero produced approximately a 20-percent reduction of fuel density at the injector. Reduction of film coolant flow from 1 lb_m/sec to zero apparently had a negligible effect on fuel density at the injector.

4. Main chamber pressure oscillations measured during transient idle-mode operation were of larger amplitude and longer duration on firings with reduced fuel injector flow rates.

5. No significant side load forces were experienced during idle-mode operation (less than 1000 lb_f).

6. Restriction of fuel bypass and film coolant flows had no significant effect on engine steady-state, idle-mode performance. The only firing which showed any significant increase in performance (firing 07C) utilized low oxidizer and nominal fuel pump inlet pressures.

7. No significant engine damage was sustained on any of these firings.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS

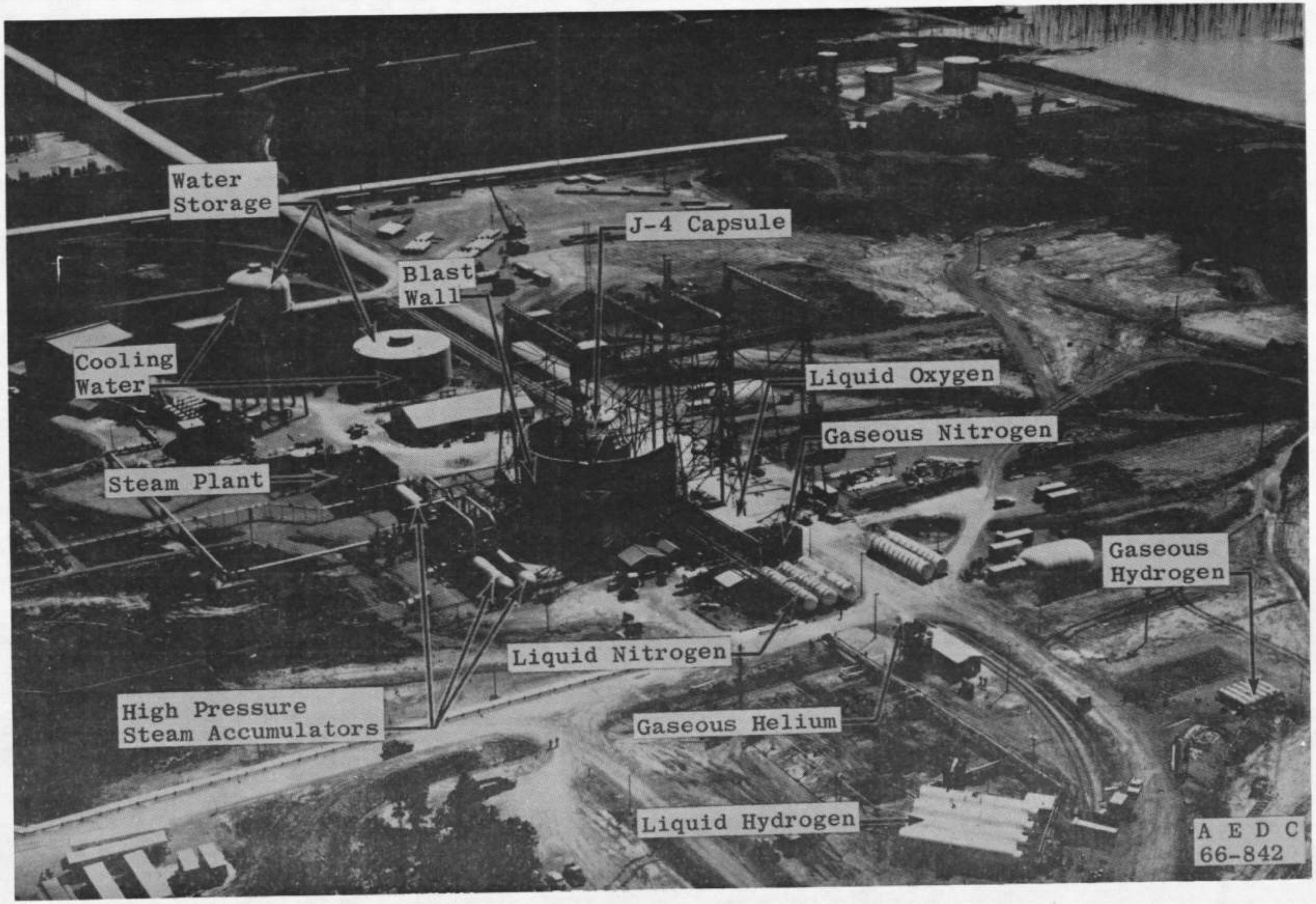


Fig. 1 Test Cell J-4 Complex

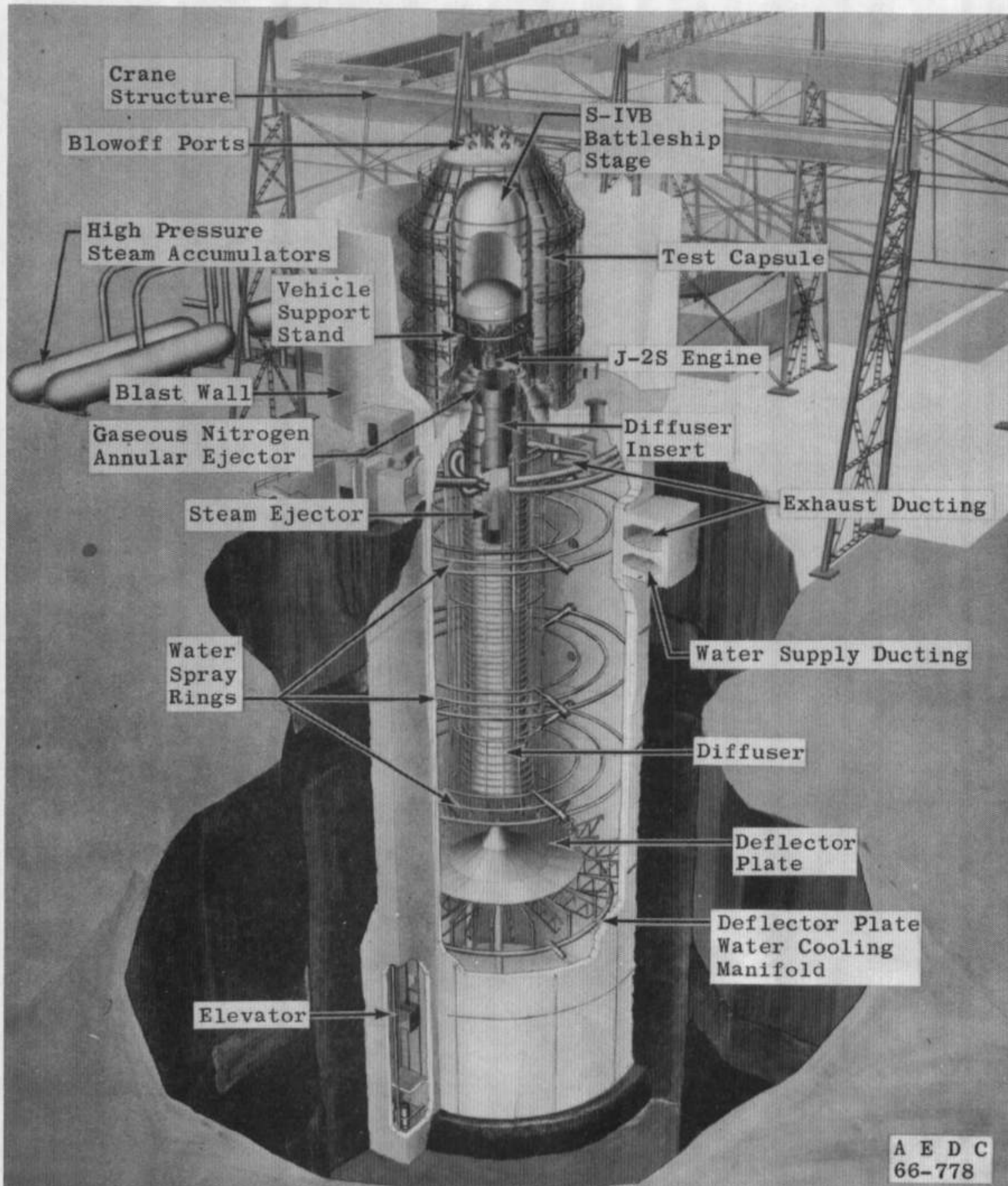


Fig. 2 Test Cell J-4, Artist's Conception

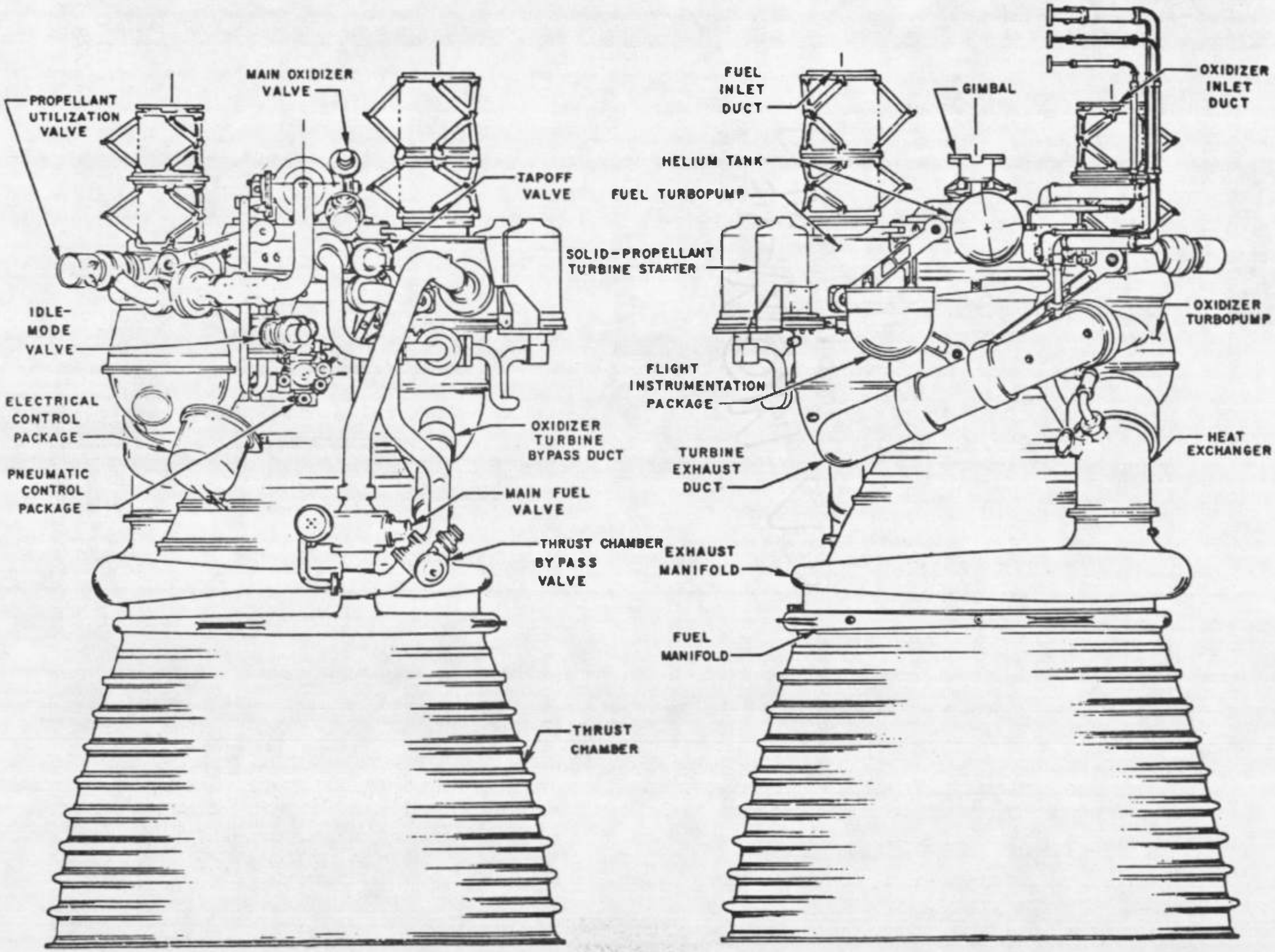


Fig. 3 J-2S Engine General Arrangement

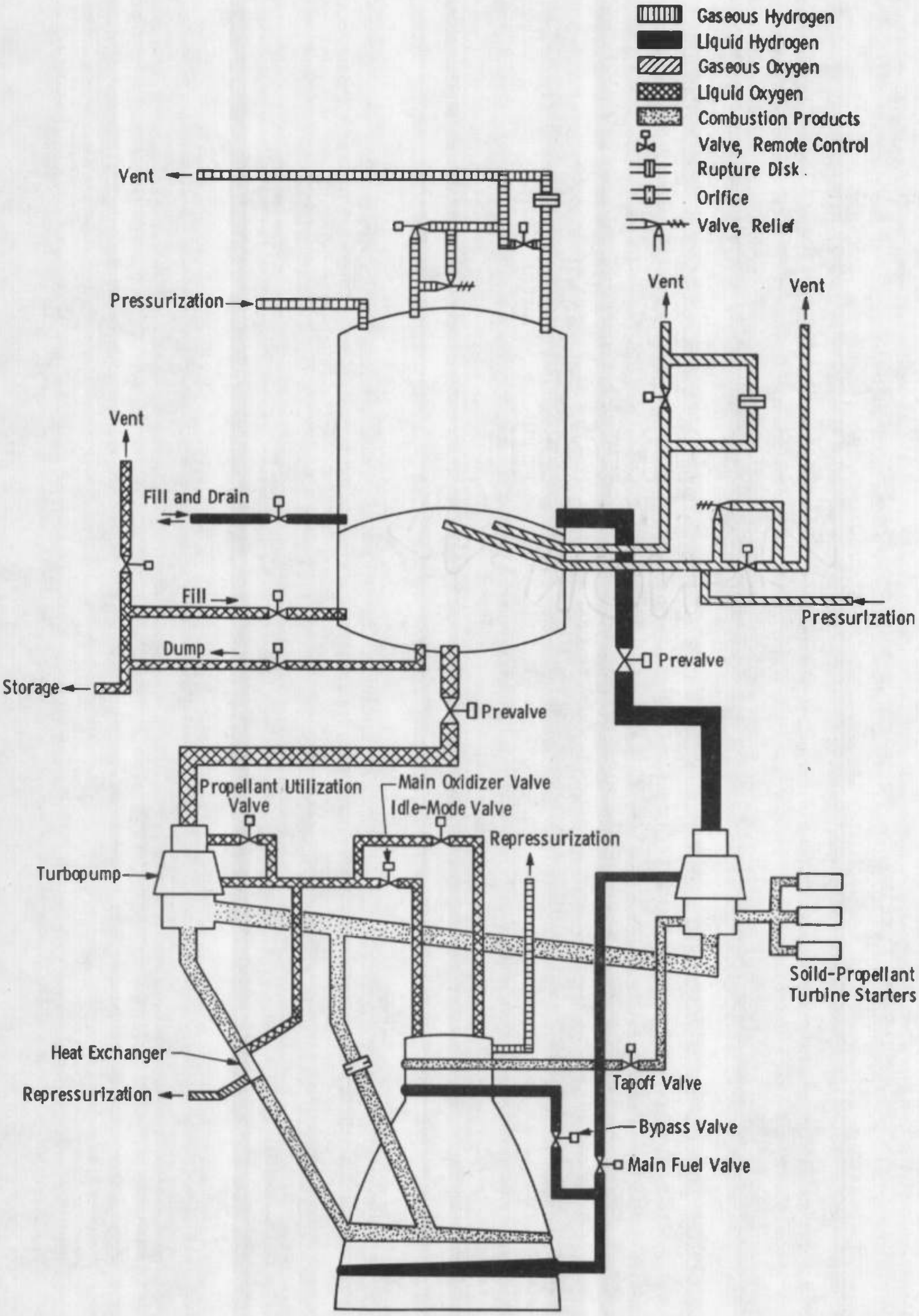
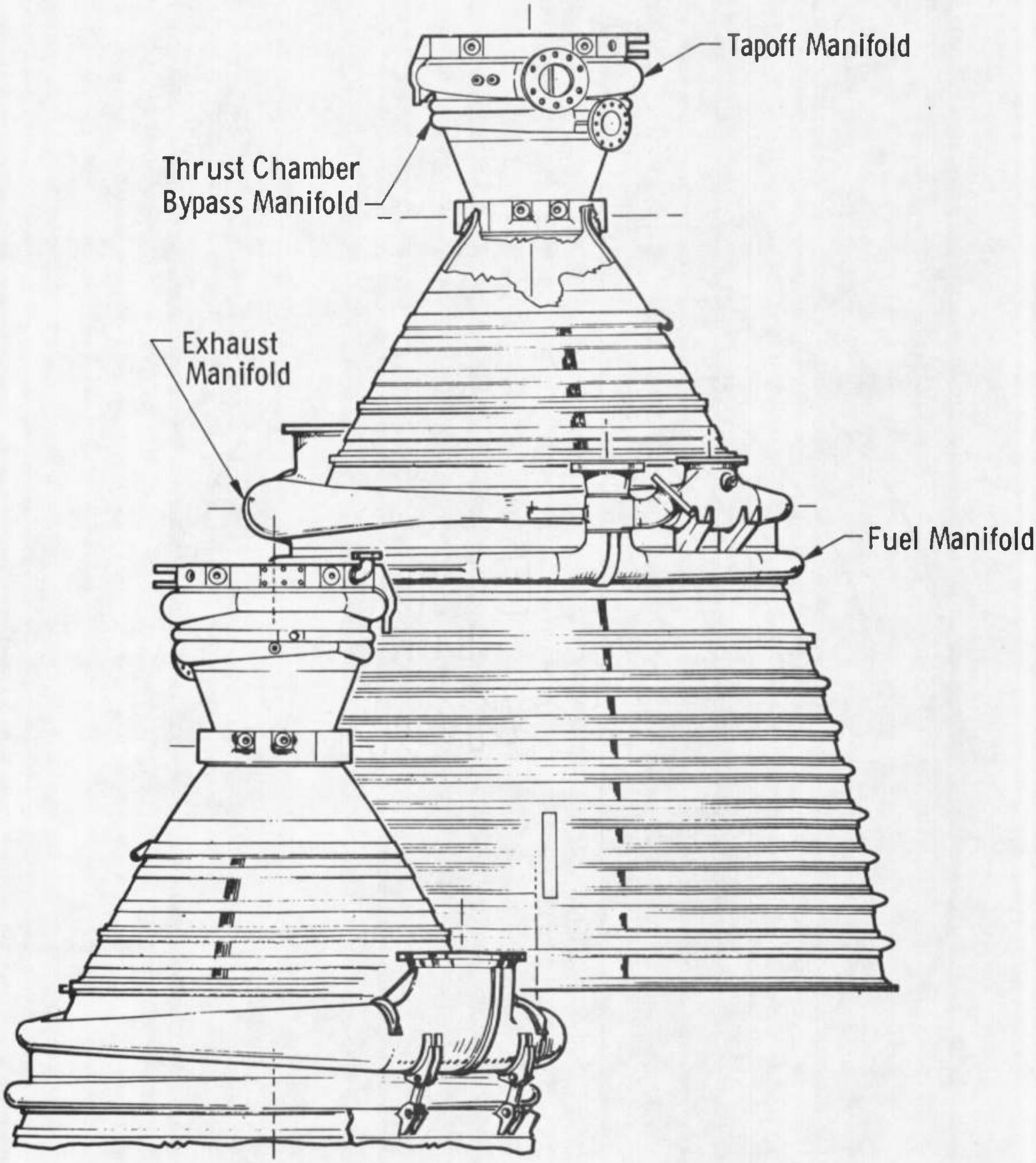
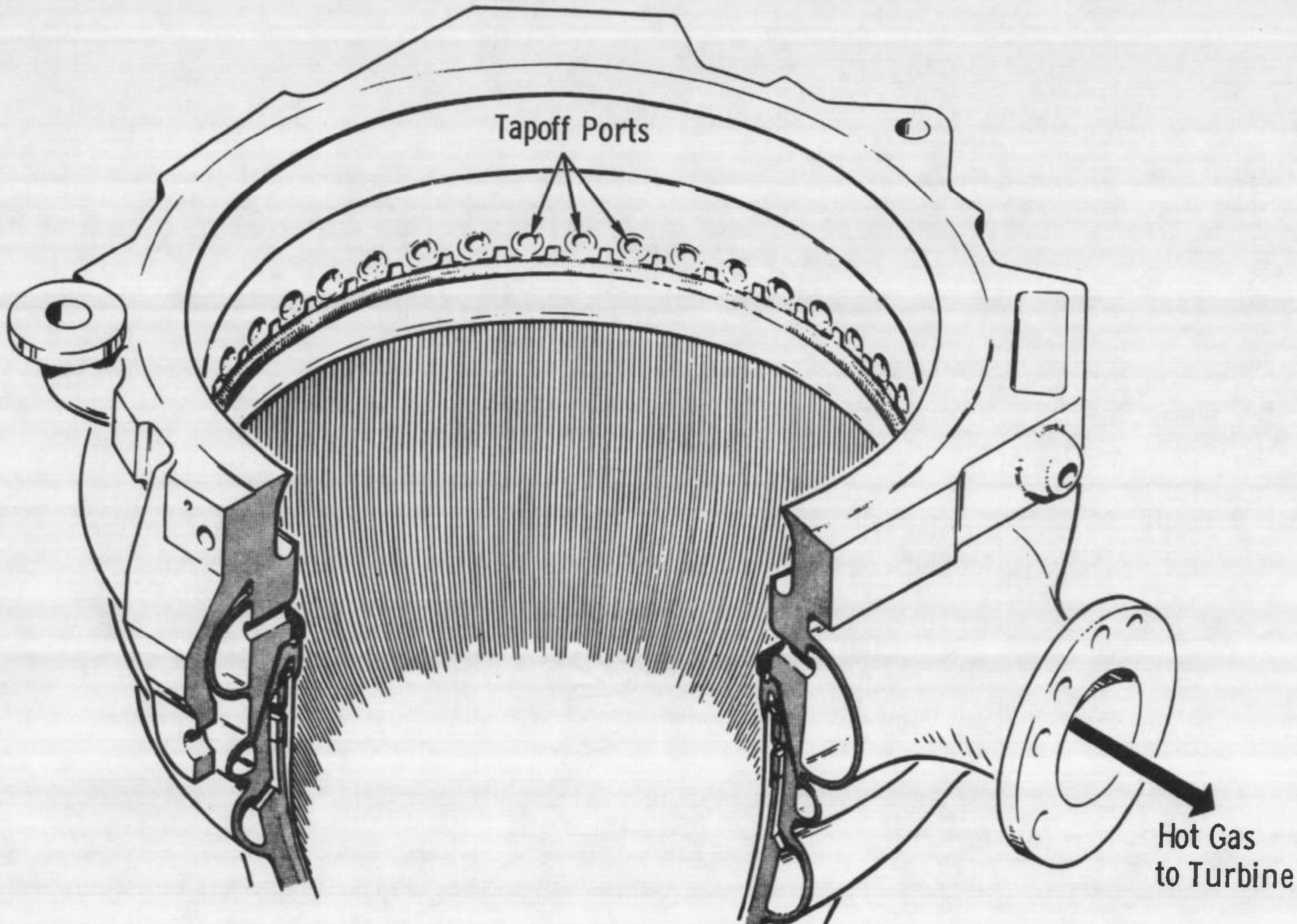


Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic

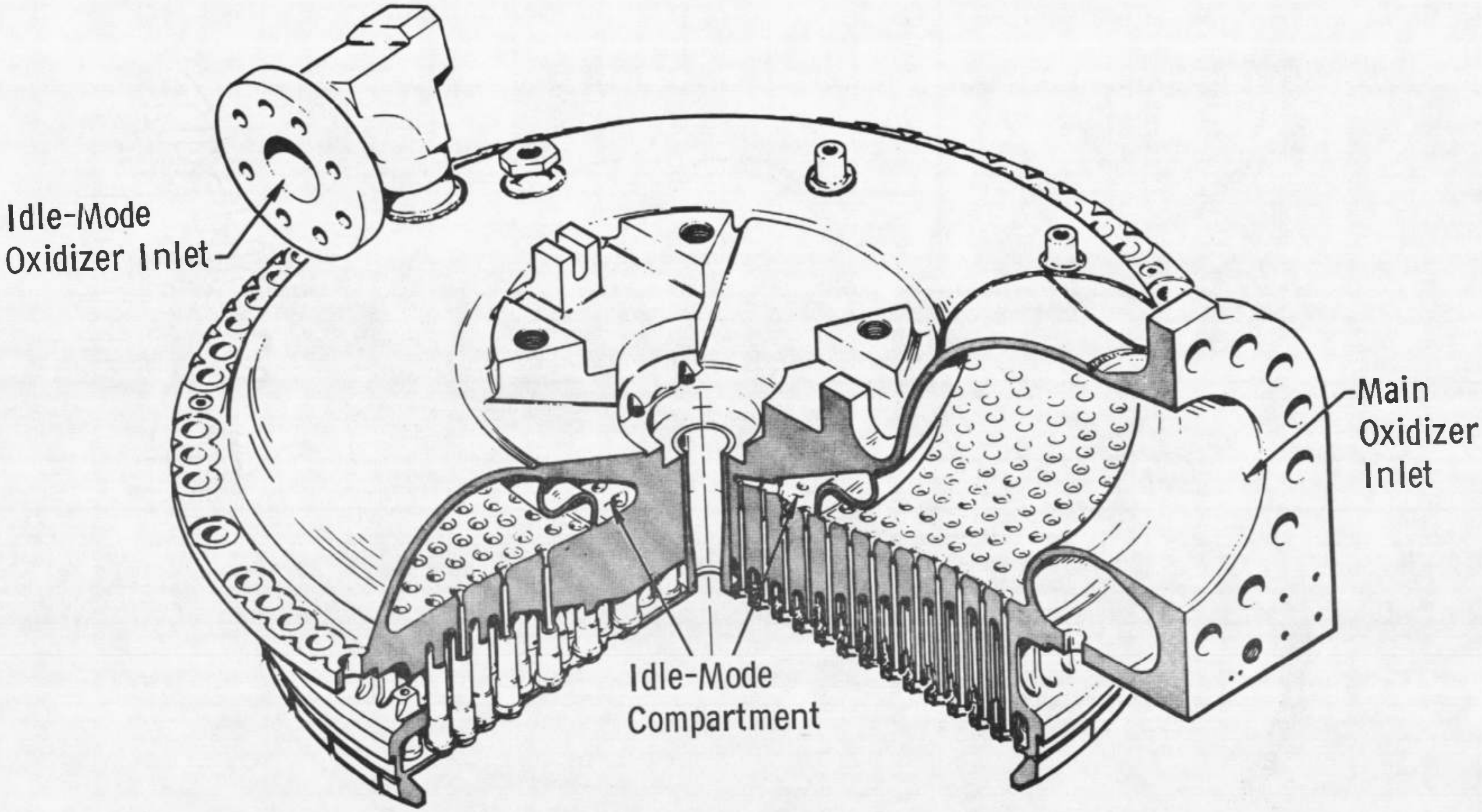


a. Thrust Chamber
Fig. 5 Engine Details

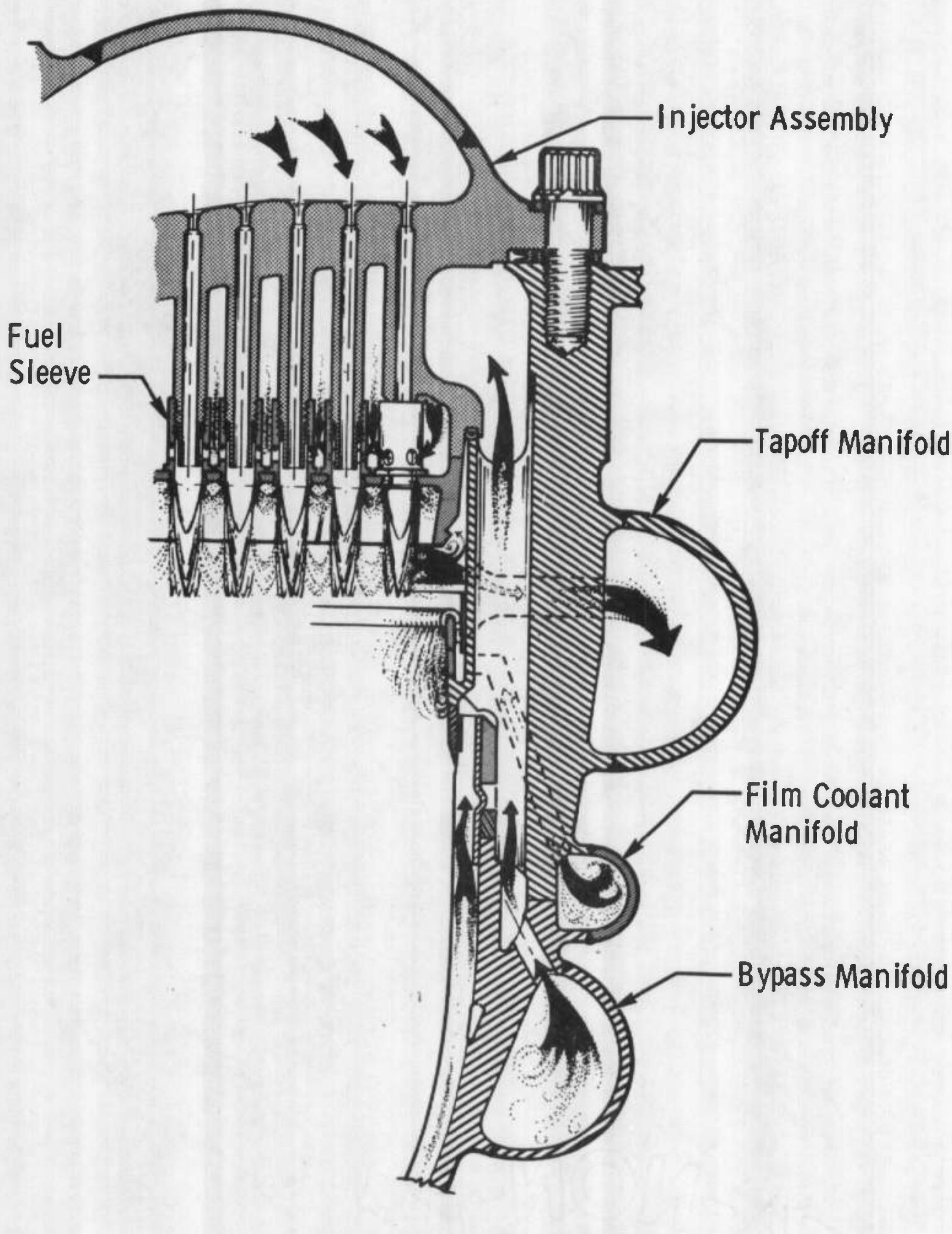


b. Combustion Chamber

Fig. 5 Continued



c. Injector
Fig. 5 Continued



d. Injector to Chamber
Fig. 5 Concluded

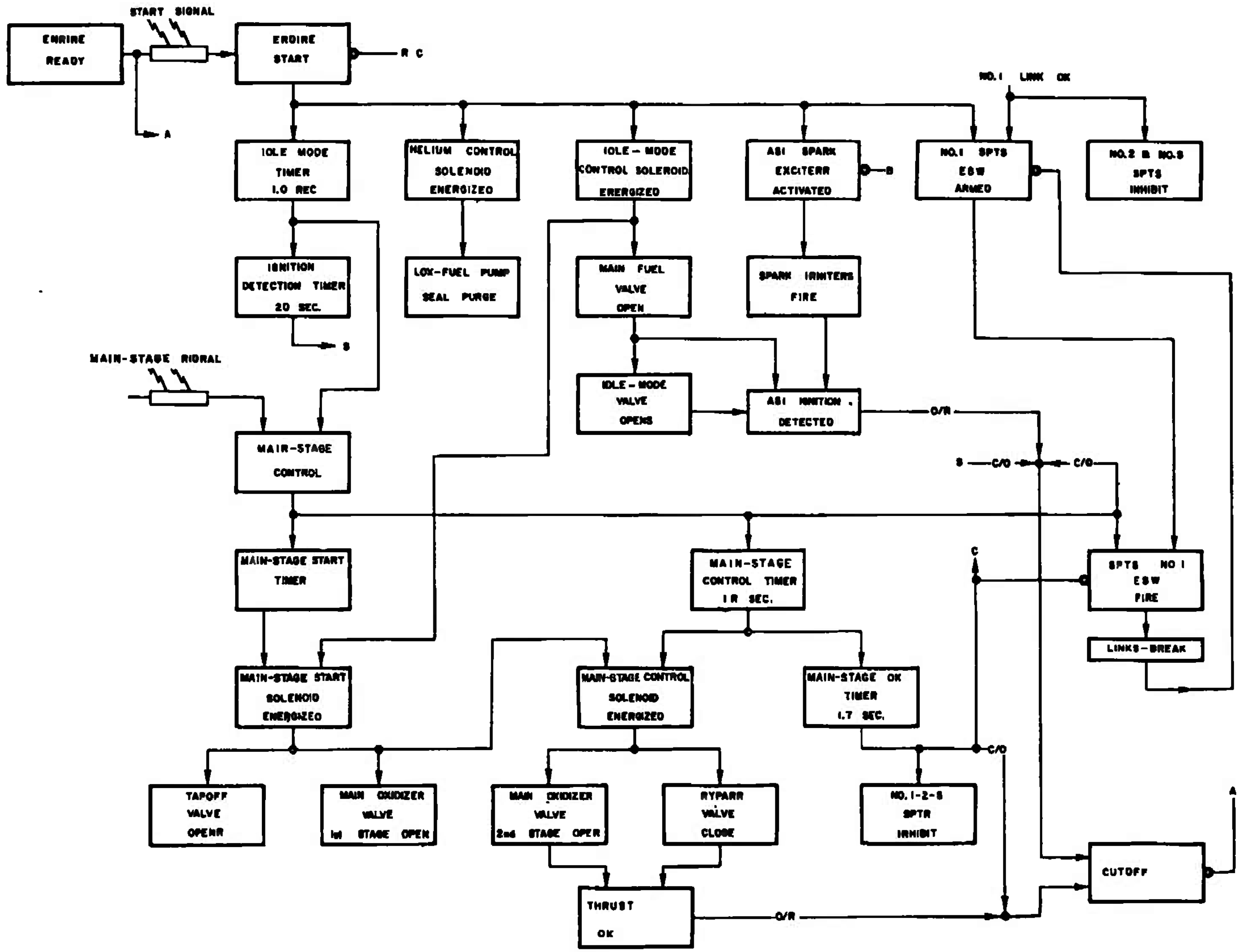
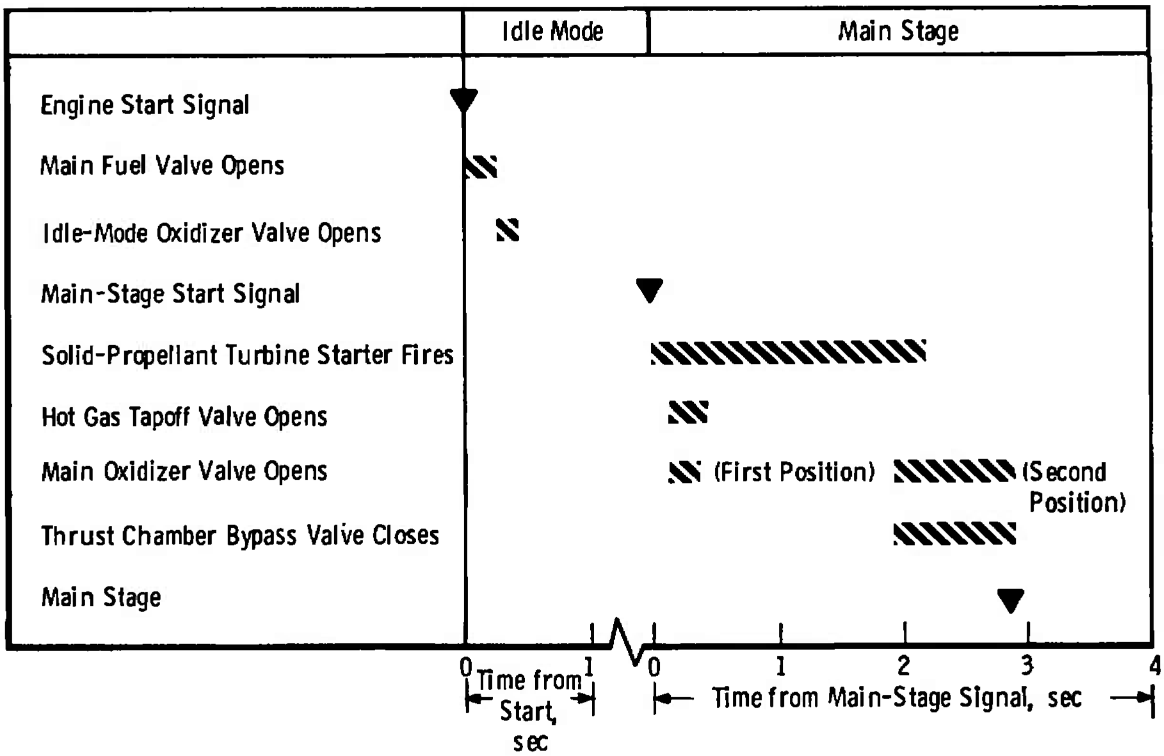
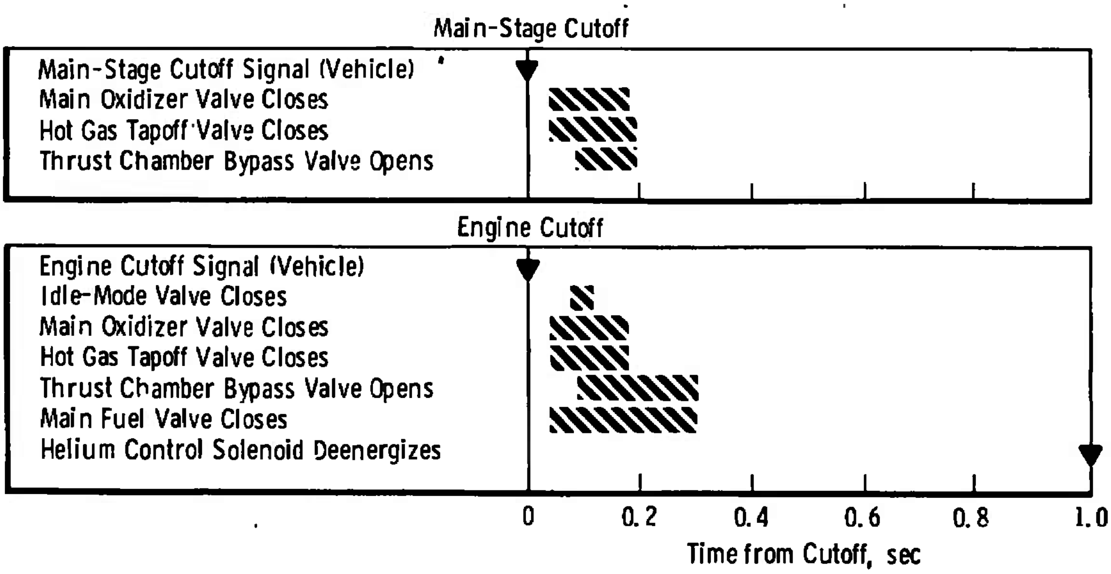


Fig. 6 Engine Start Logic Schematic

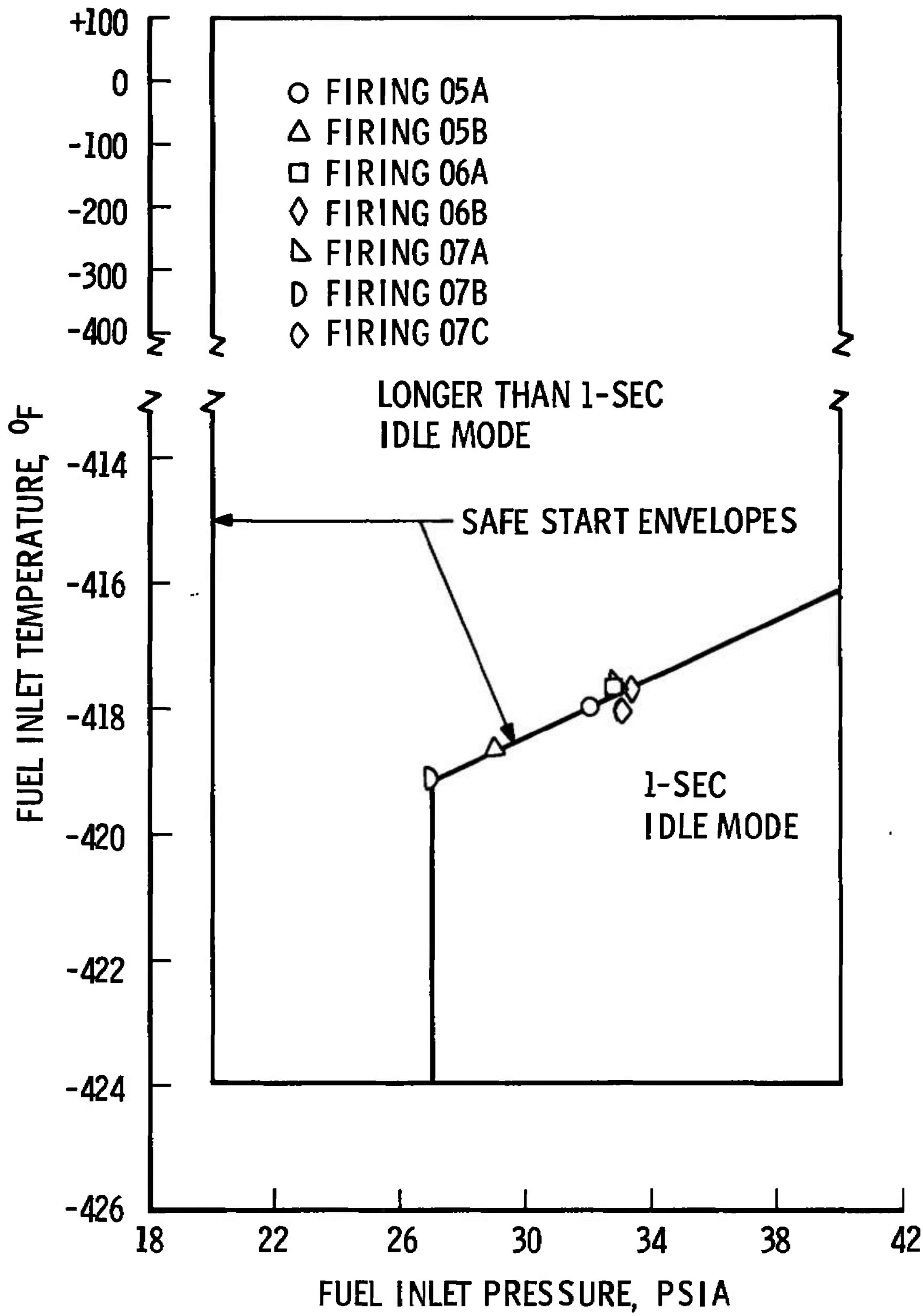


a. Start Sequence



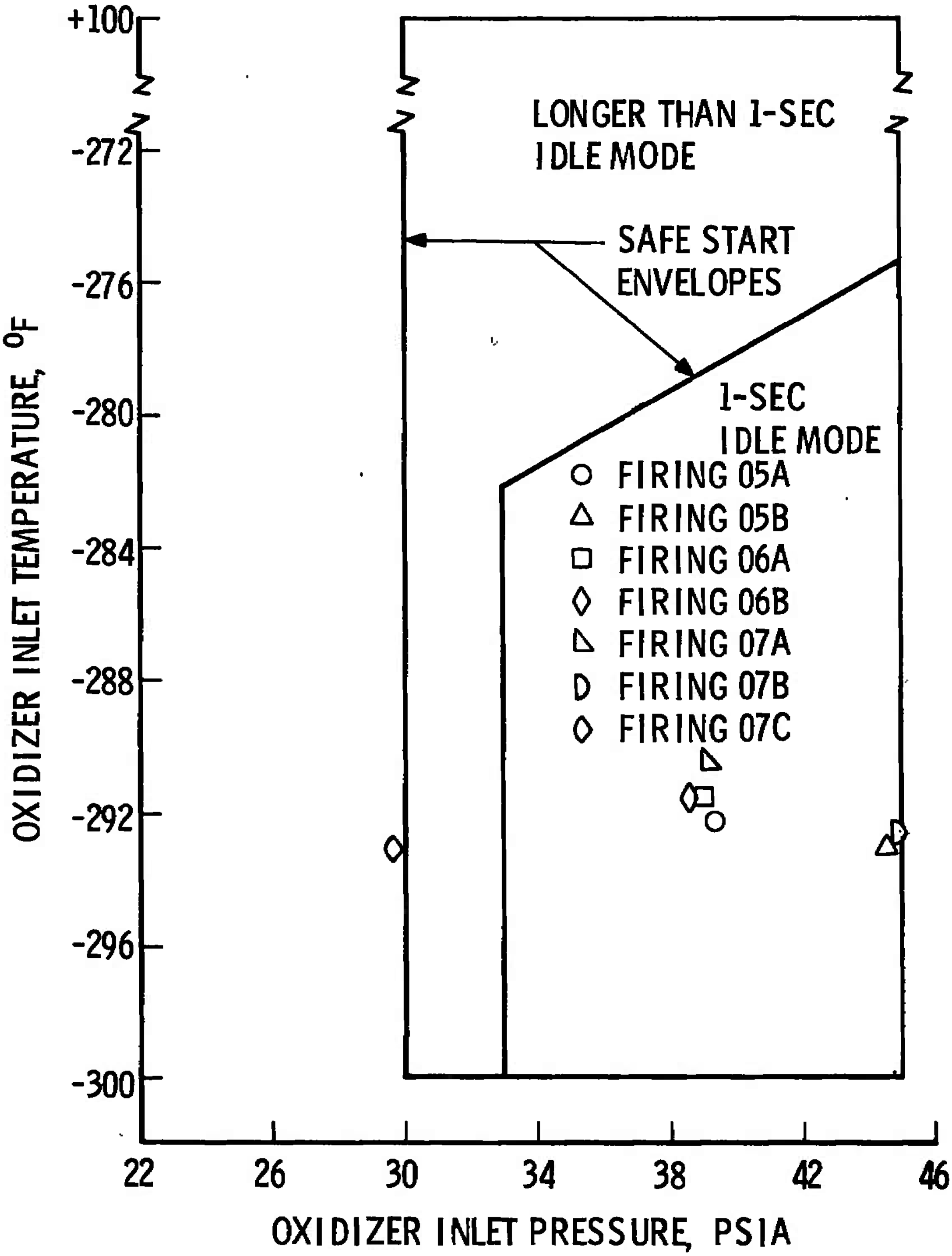
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

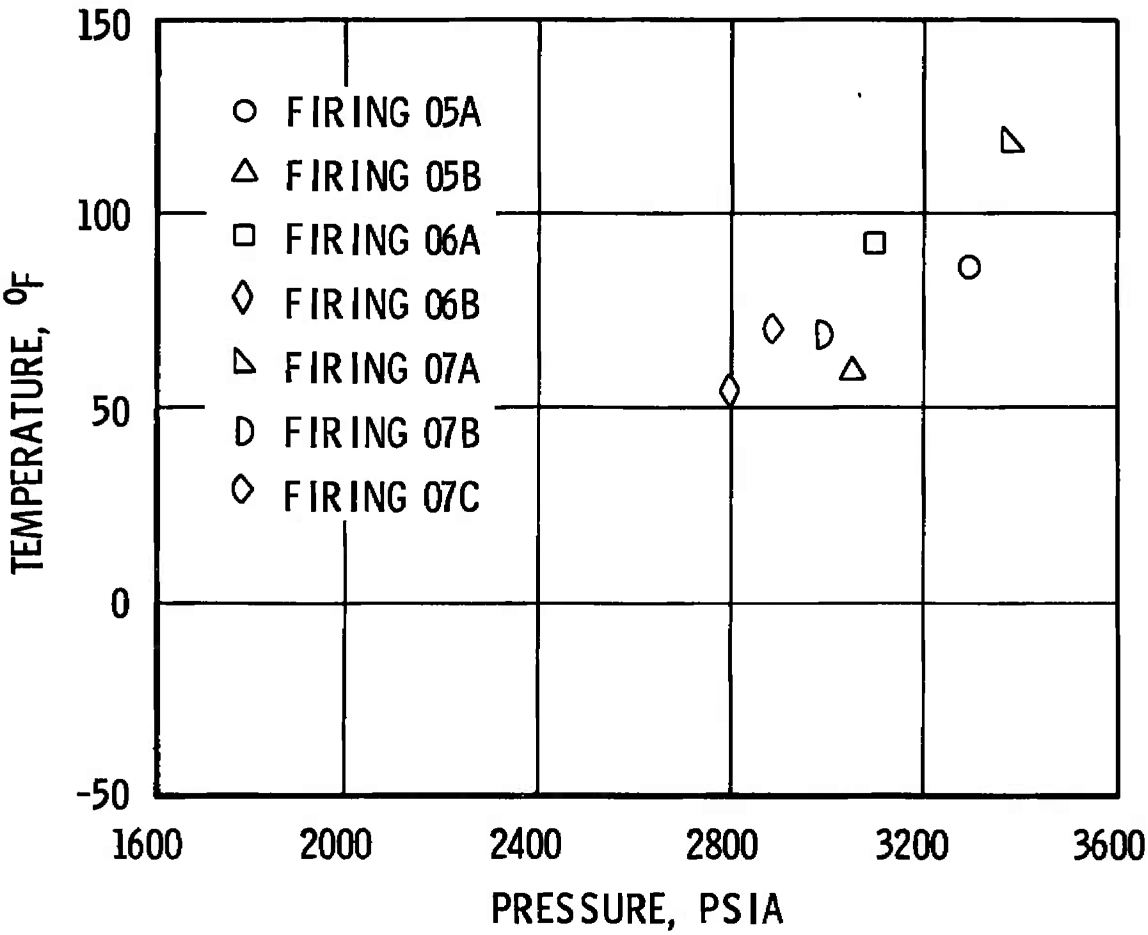


a. Fuel Pump

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



b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank

Fig. 8 Concluded

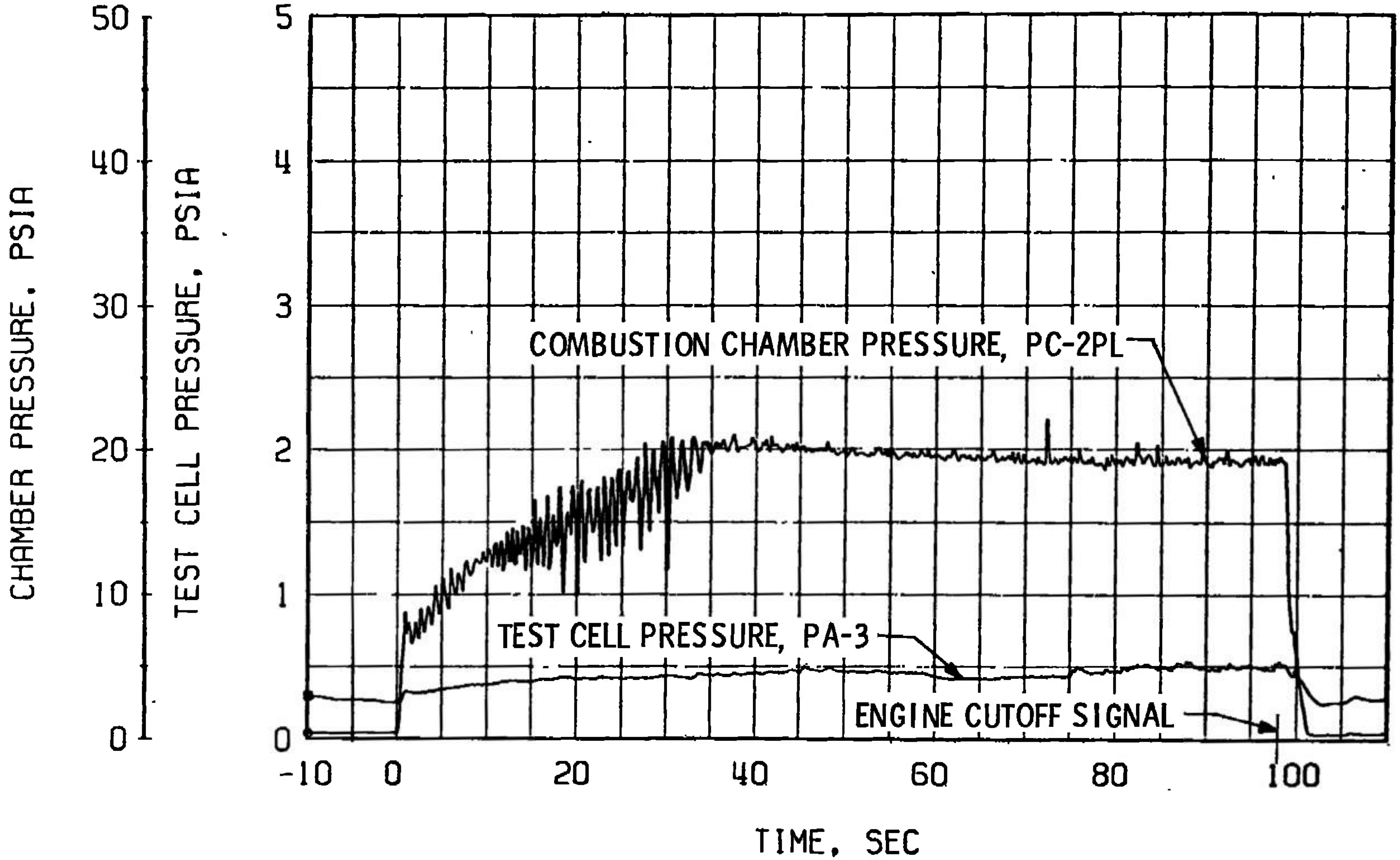
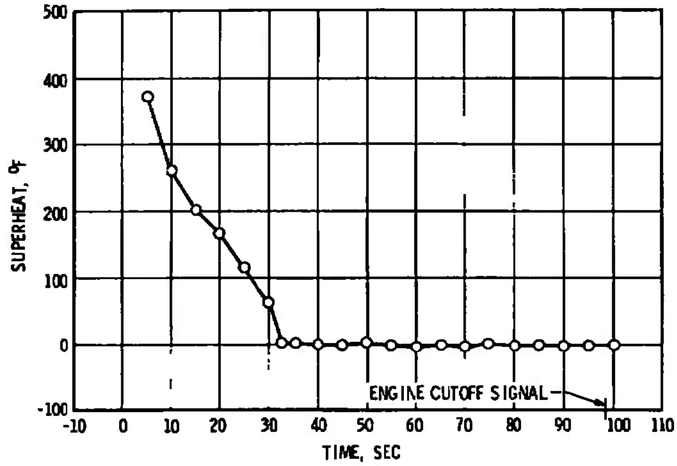
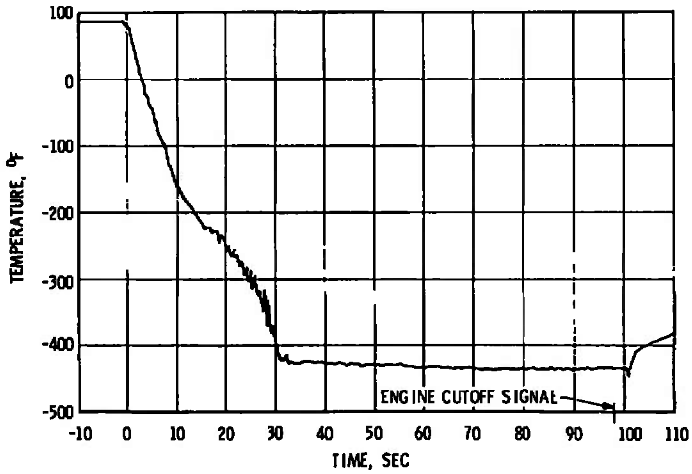


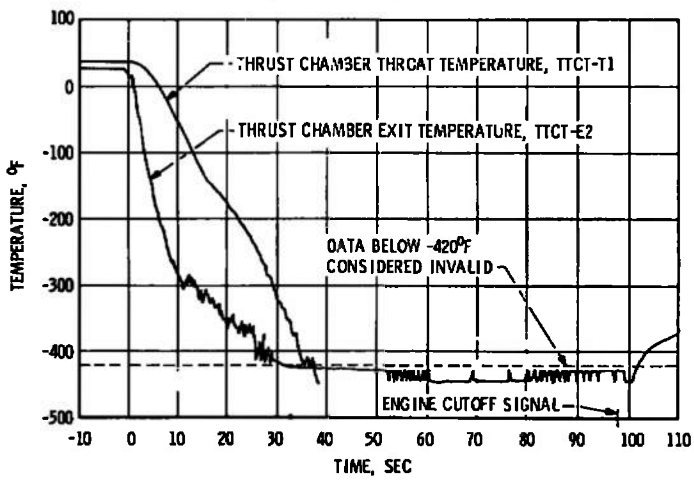
Fig. 9 Engine Ambient and Combustion Chamber Pressure, Firing 05A



a. Fuel Conditions at Injector, °F (Superheat)

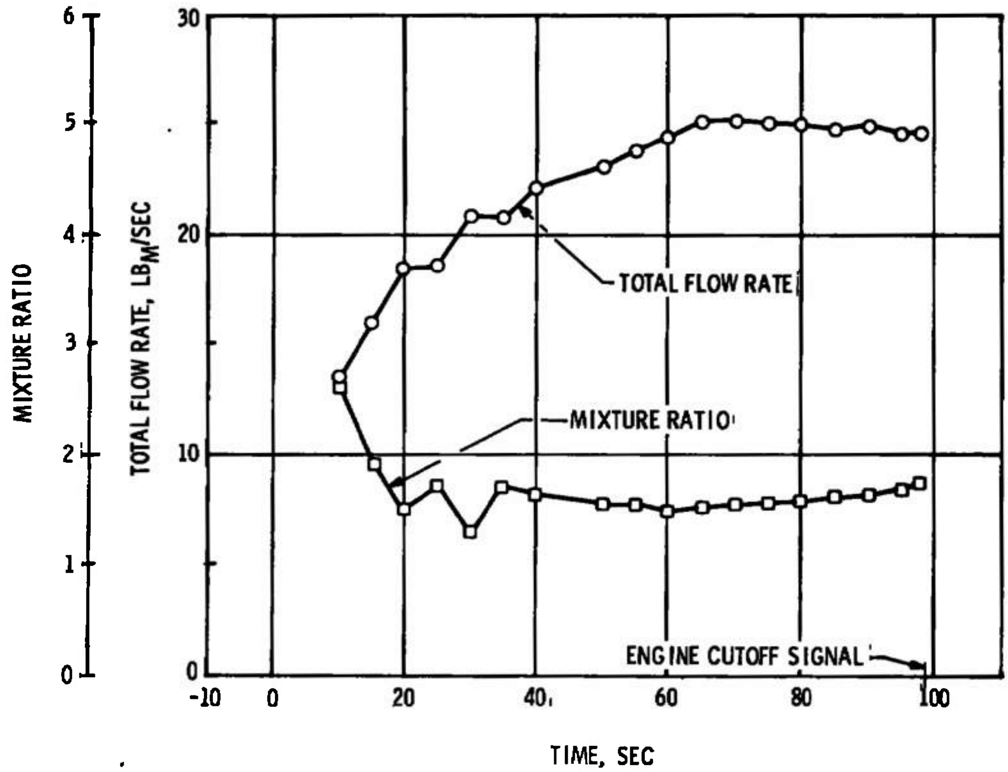


b. Fuel Injector Temperature, TFJ-2P

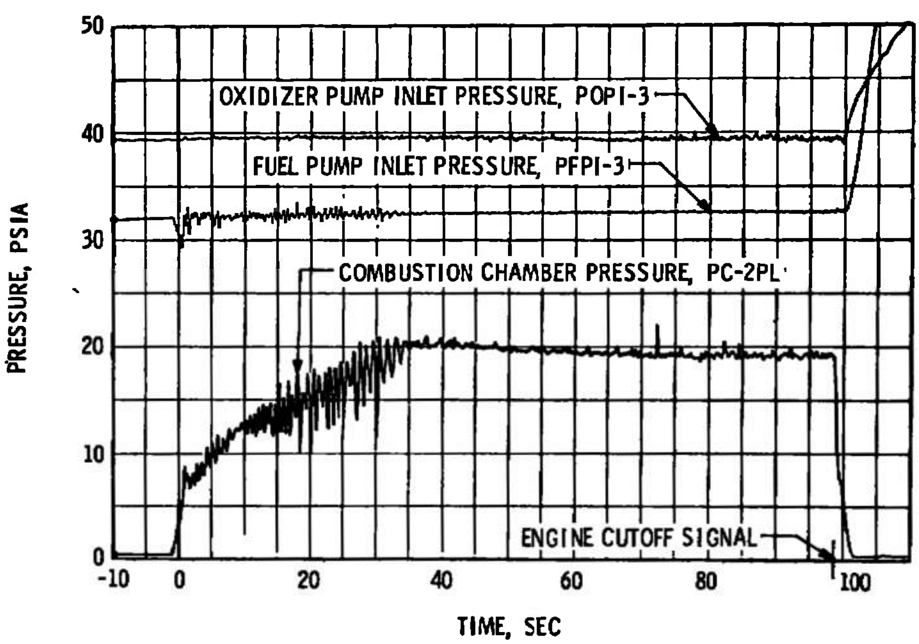


c. Thrust Chamber Childown

Fig. 10 Fuel System Chilldown, Firing 05A



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 11 Propellant System Performance, Firing 05A

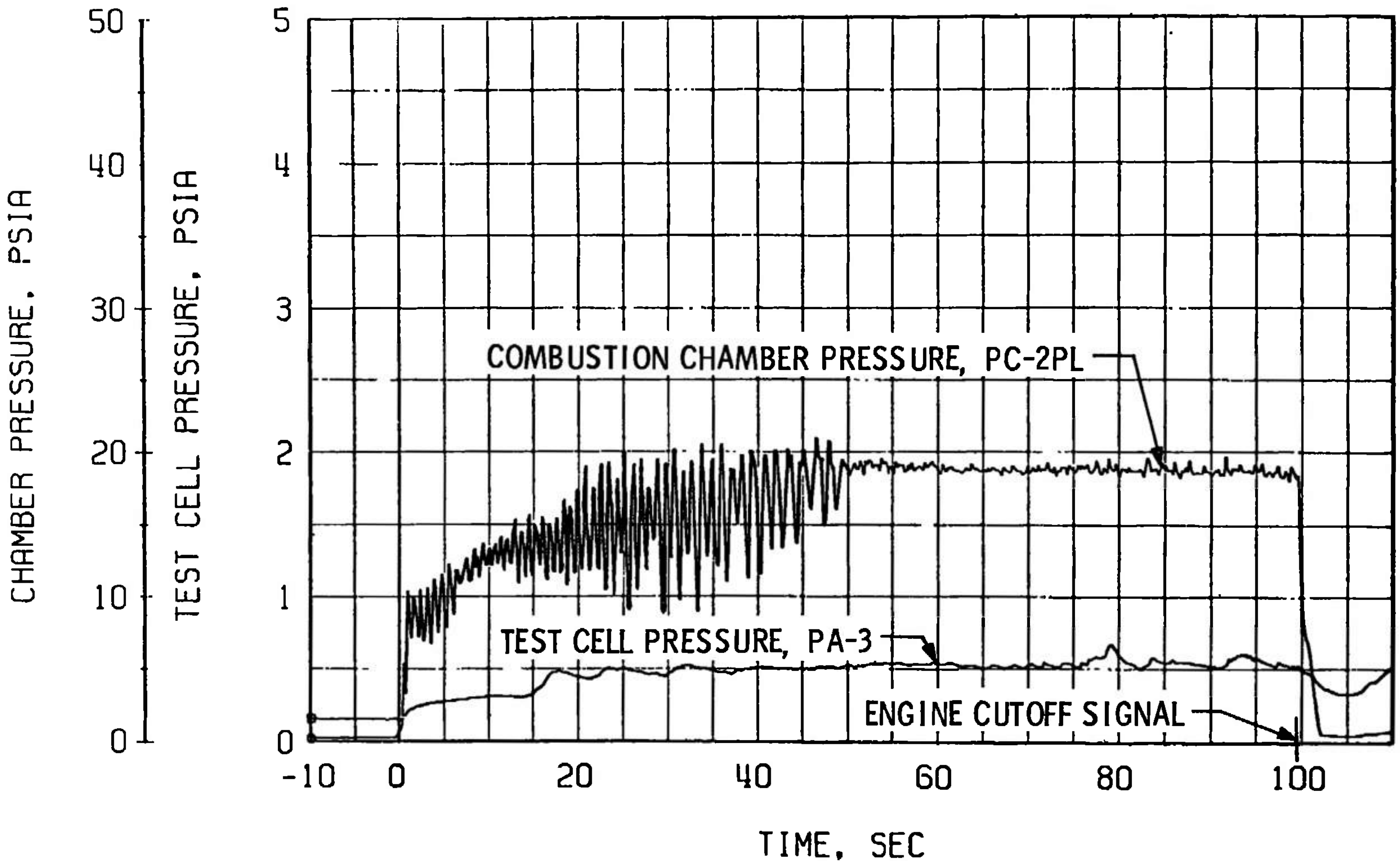
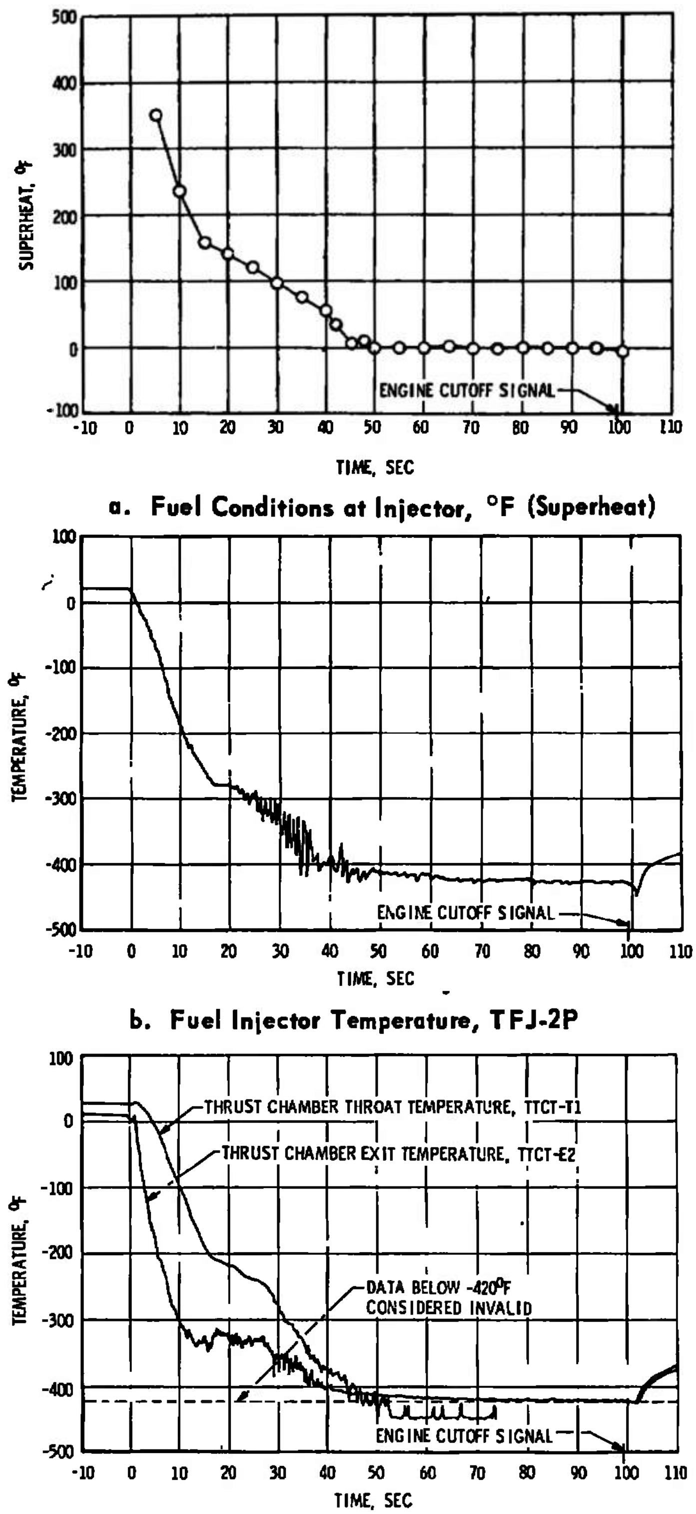


Fig. 12 Engine Ambient and Combustion Chamber Pressure, Firing 05B

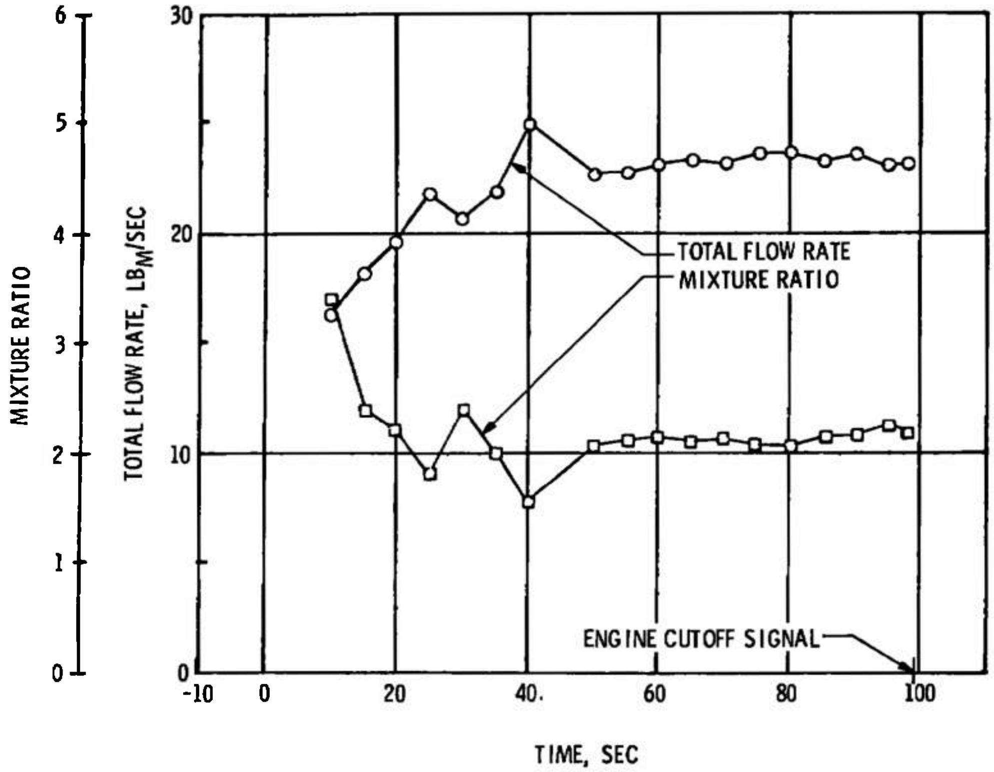


a. Fuel Conditions at Injector, °F (Superheat)

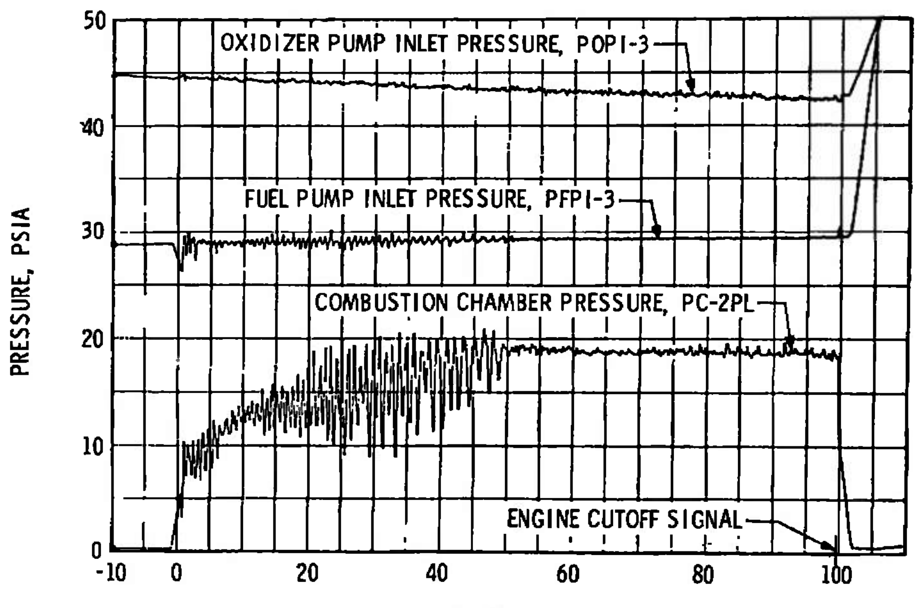
b. Fuel Injector Temperature, TFJ-2P

c. Thrust Chamber Childown

Fig. 13 Fuel System Childown, Firing 05B



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 14 Propellant System Performance, Firing 05B

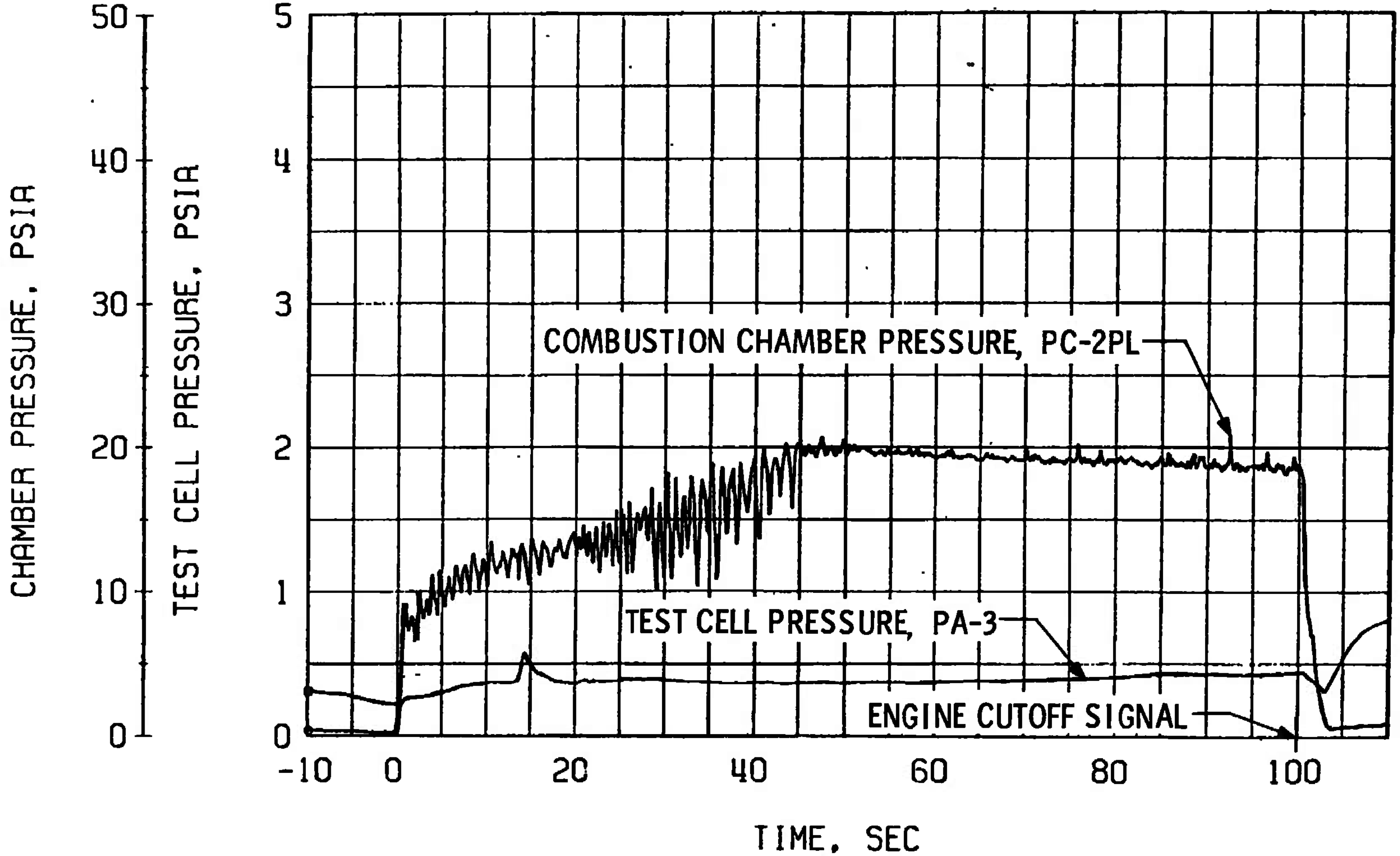
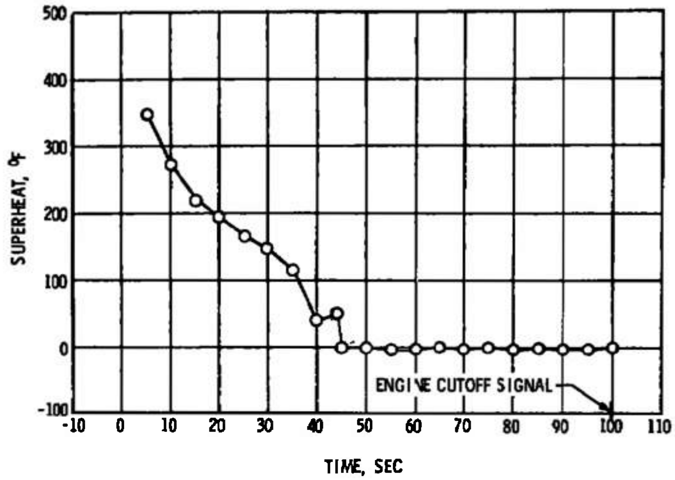
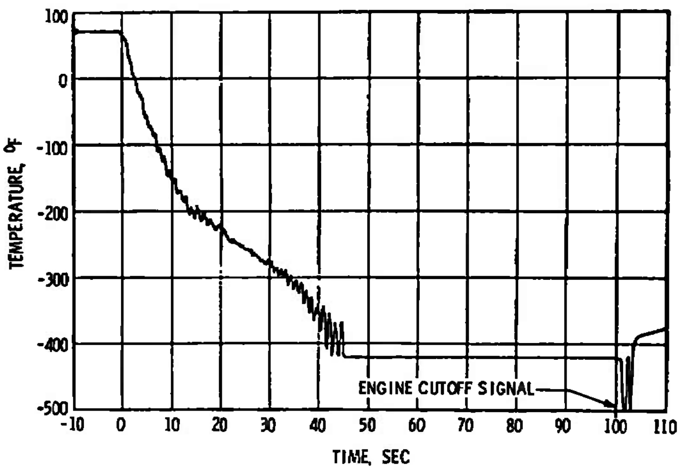


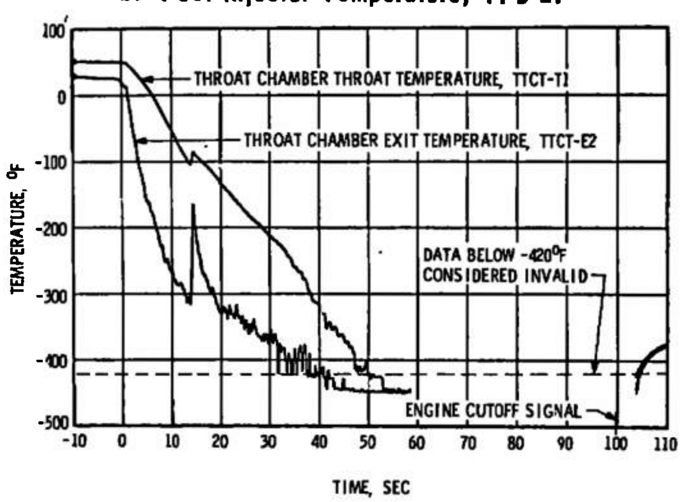
Fig. 15 Engine Ambient and Combustion Chamber Pressure, Firing 06A



a. Fuel Conditions at Injector, °F (Superheat)

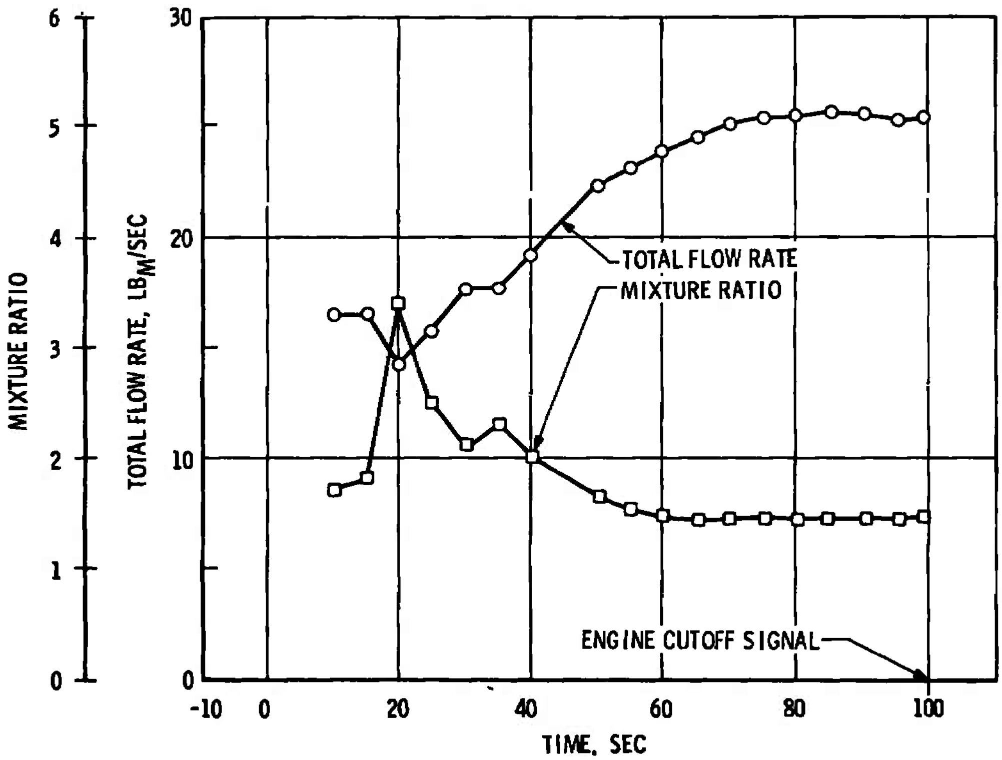


b. Fuel Injector Temperature, TFJ-2P

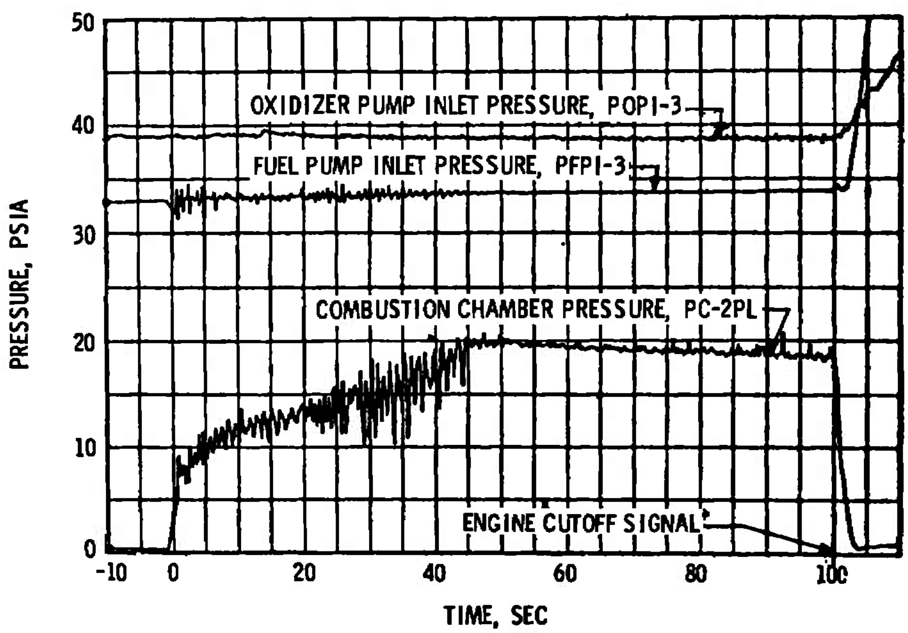


c. Thrust Chamber Chilldown

Fig. 16 Fuel System Chilldown, Firing 06A



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 17 Propellant System Performance, Firing 06A

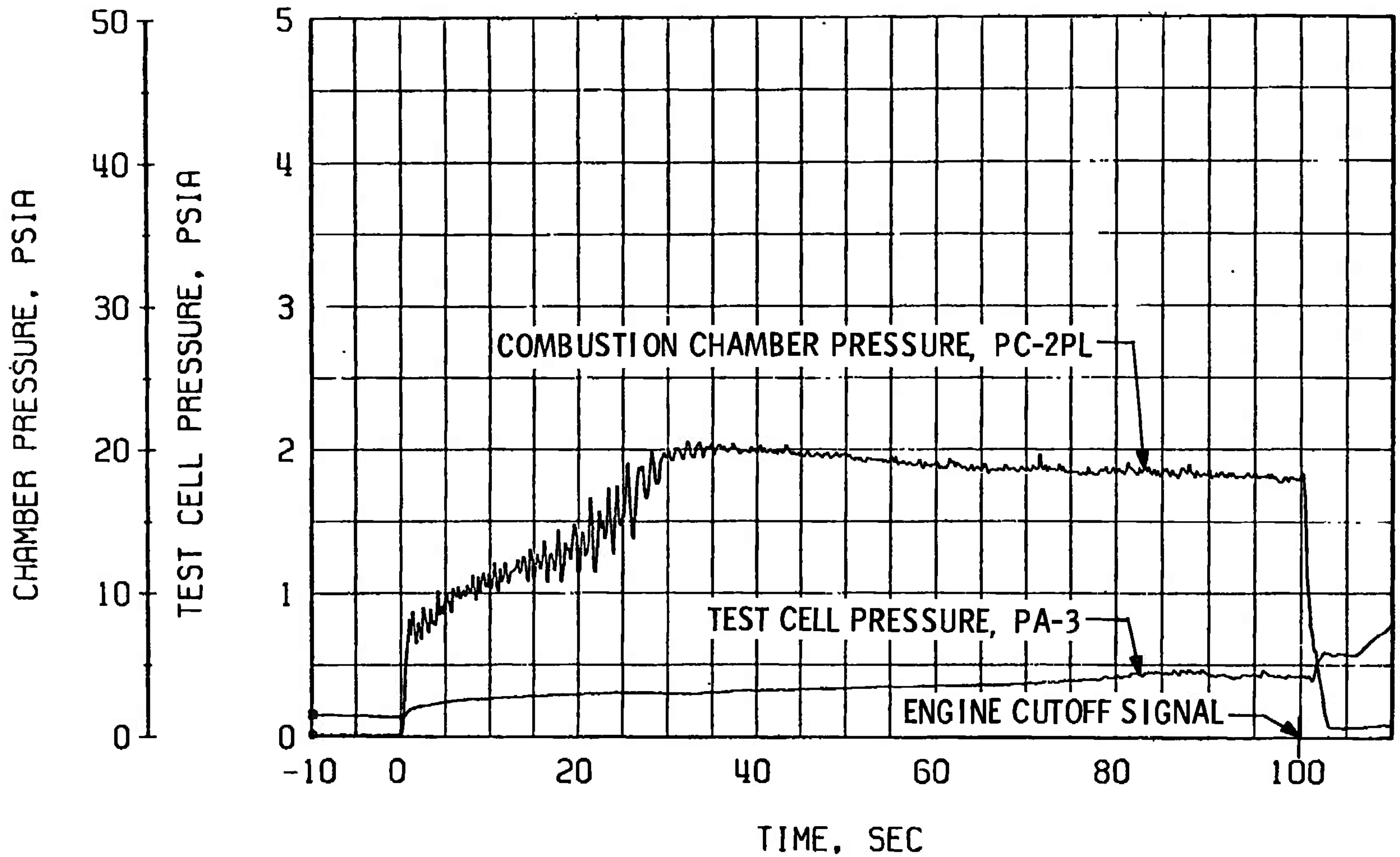
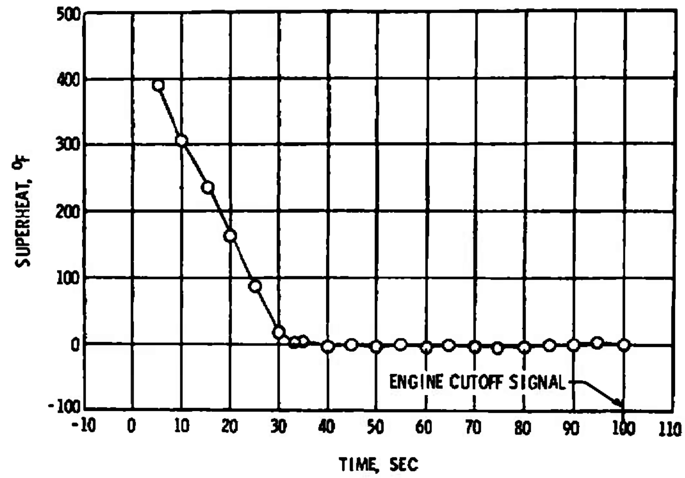
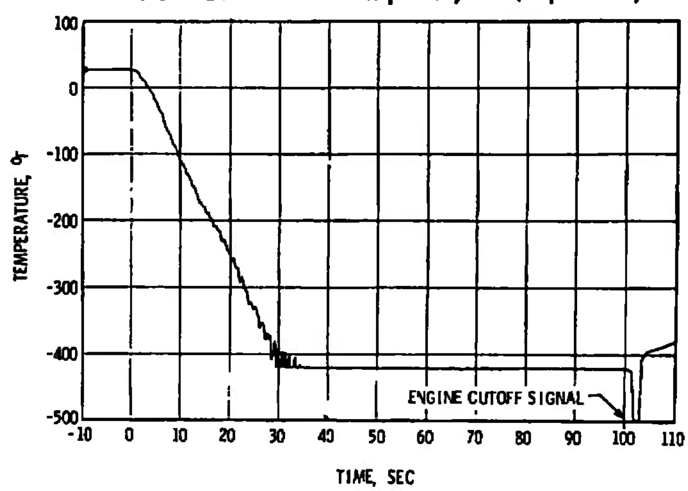


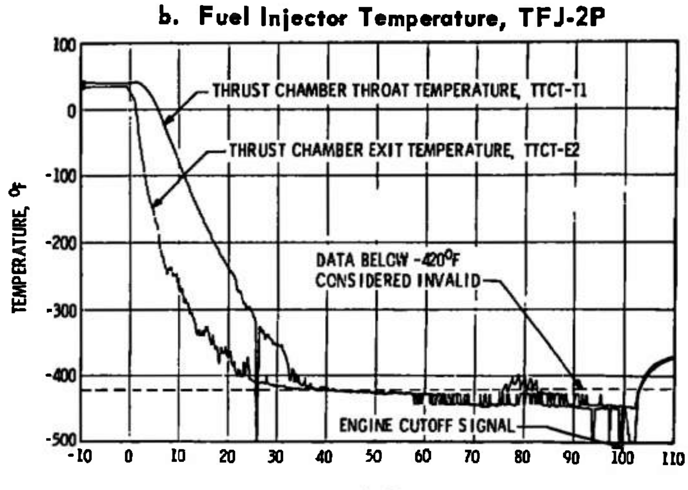
Fig. 18 Engine Ambient and Combustion Chamber Pressure, Firing 06B



a. Fuel Conditions at Injector, °F (Superheat)

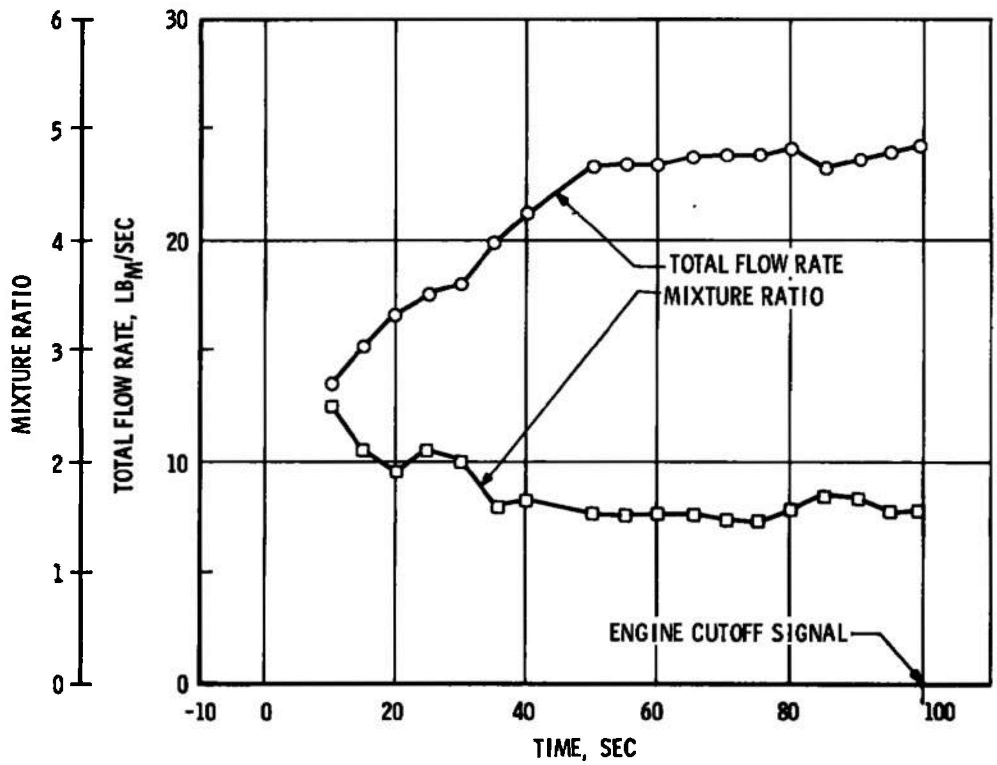


b. Fuel Injector Temperature, TFJ-2P

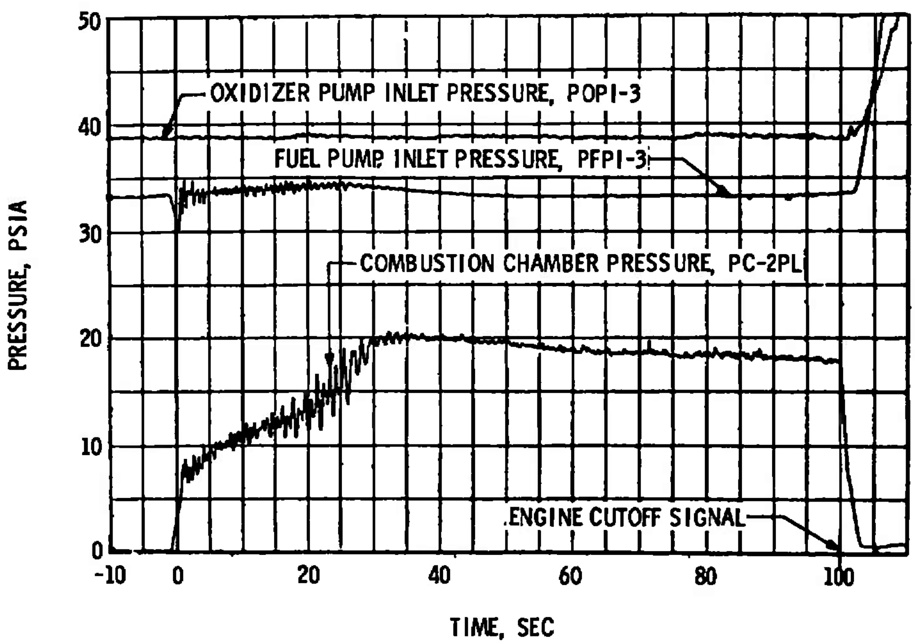


c. Thrust Chamber Chilldown

Fig. 19 Fuel System Chilldown, Firing 06B



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 20 Propellant System Performance, Firing 06B

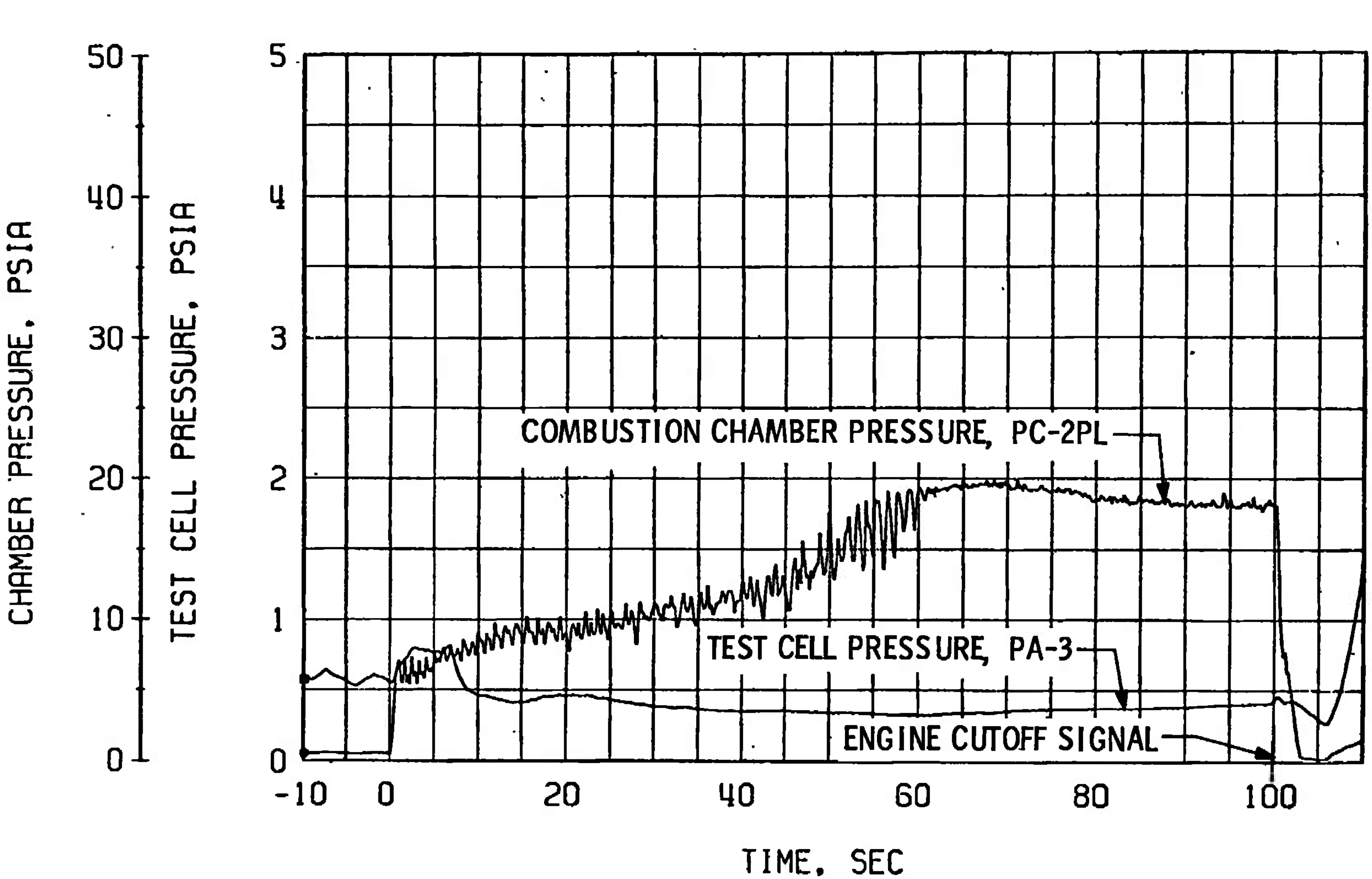
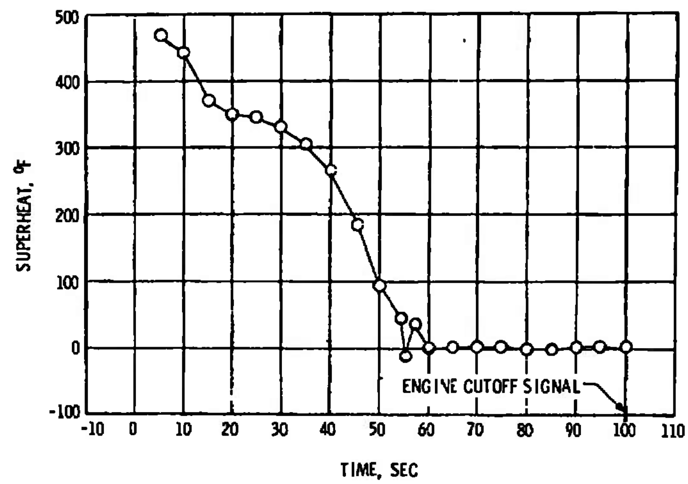
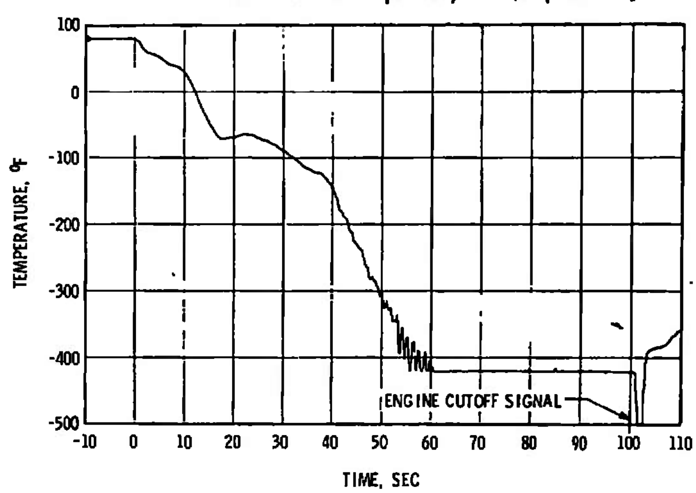


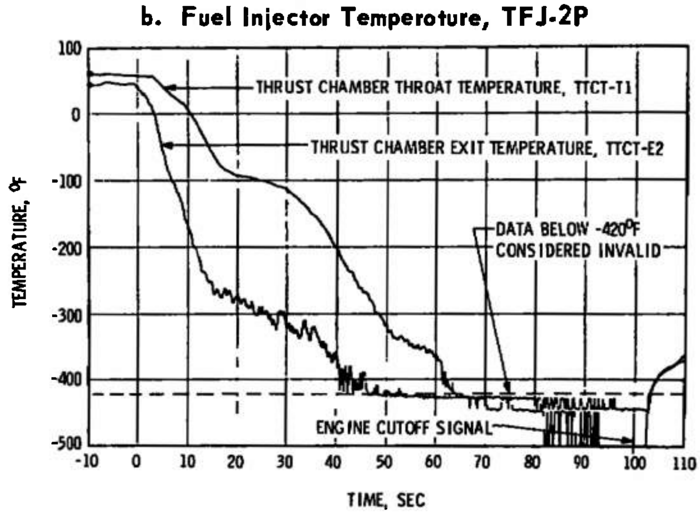
Fig. 21 Engine Ambient and Combustion Chamber Pressure, Firing 07A



a. Fuel Conditions at Injector, °F (Superheat)

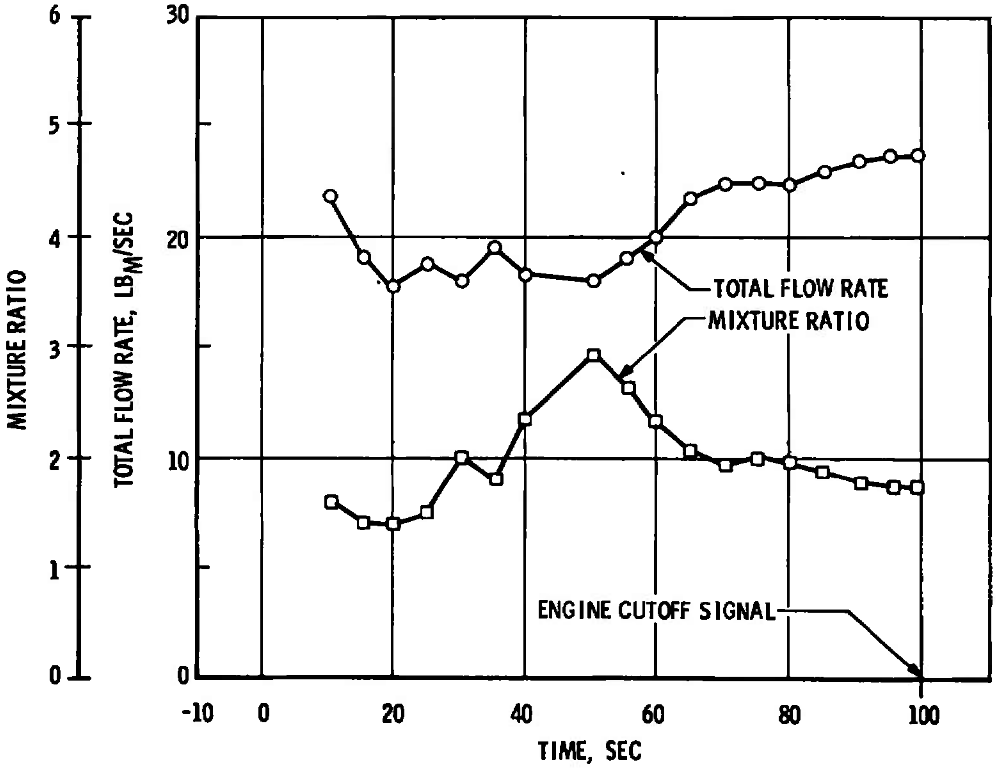


b. Fuel Injector Temperature, TFJ-2P

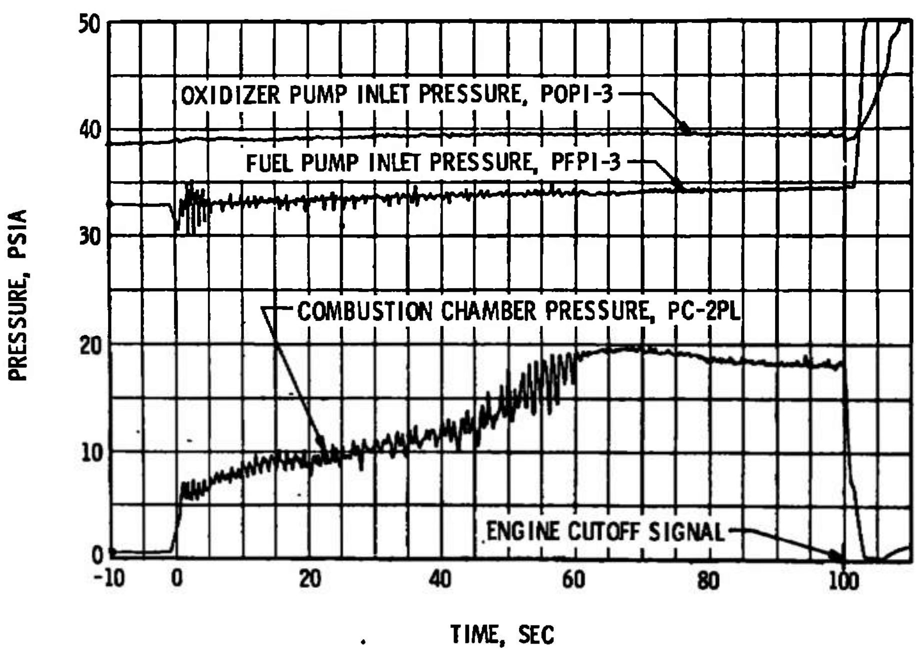


c. Thrust Chamber Childown

Fig. 22 Fuel System Childown, Firing 07A



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 23 Propellant System Performance, Firing 07A

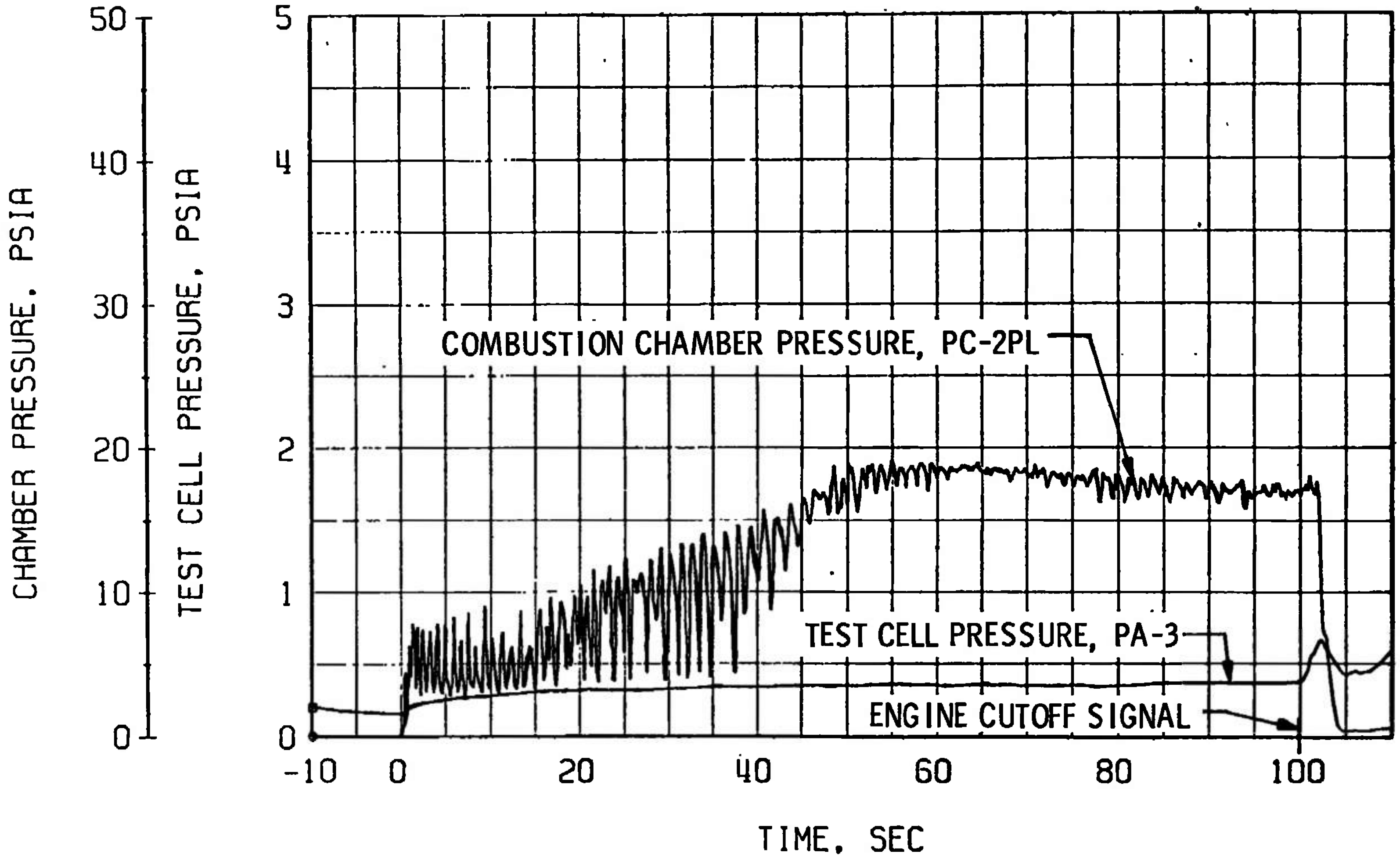
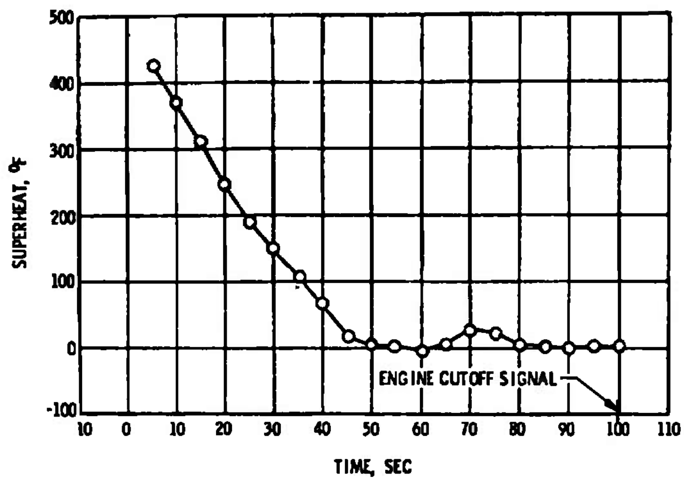
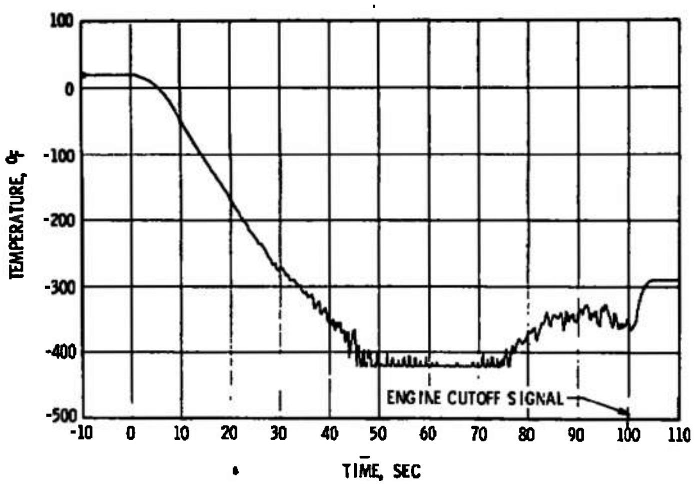


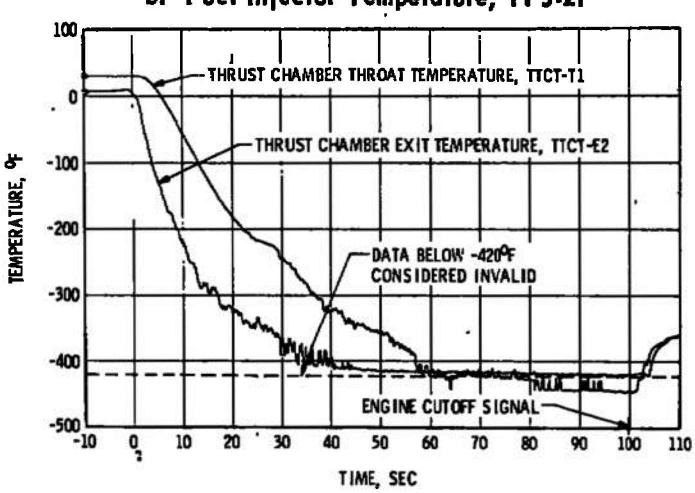
Fig. 24 Engine Ambient and Combustion Chamber Pressure, Firing 07B



a. Fuel Conditions at Injector, °F (Superheat)

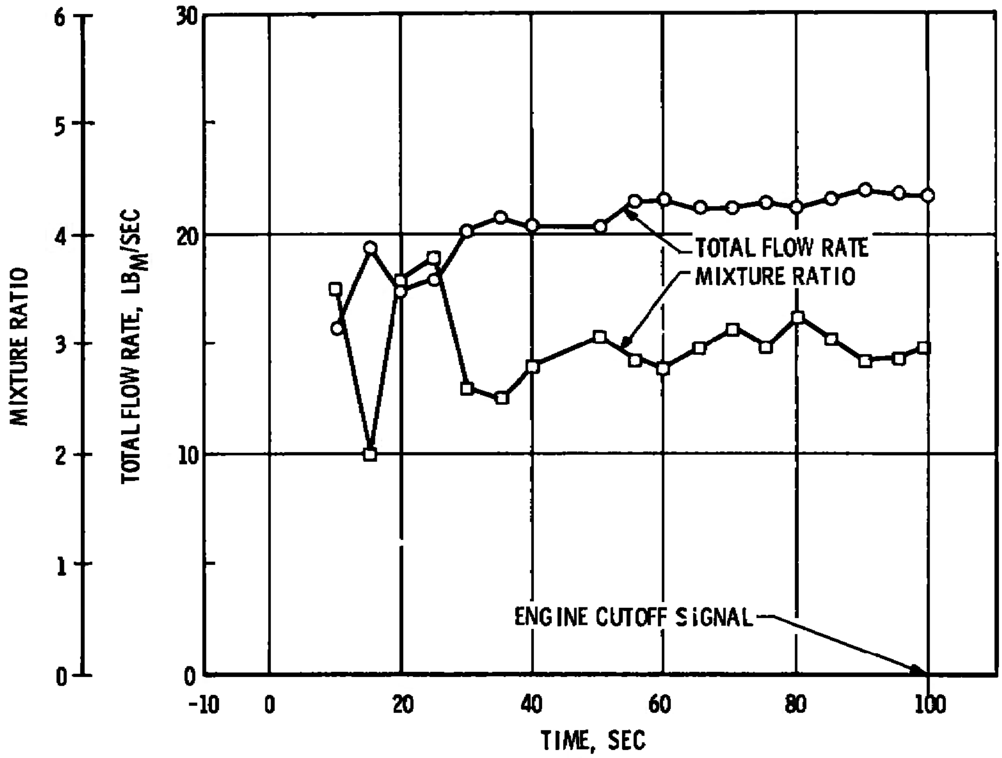


b. Fuel Injector Temperature, TFJ-2P

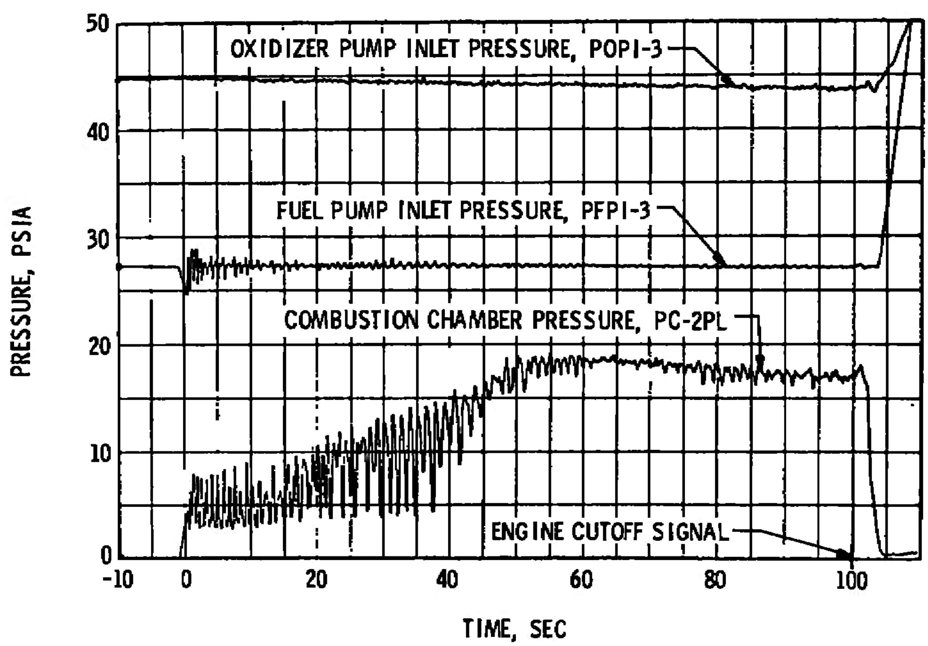


c. Thrust Chamber Childown

Fig. 25 Fuel System Chilldown, Firing 07B



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 26 Propellant System Performance, Firing 07B

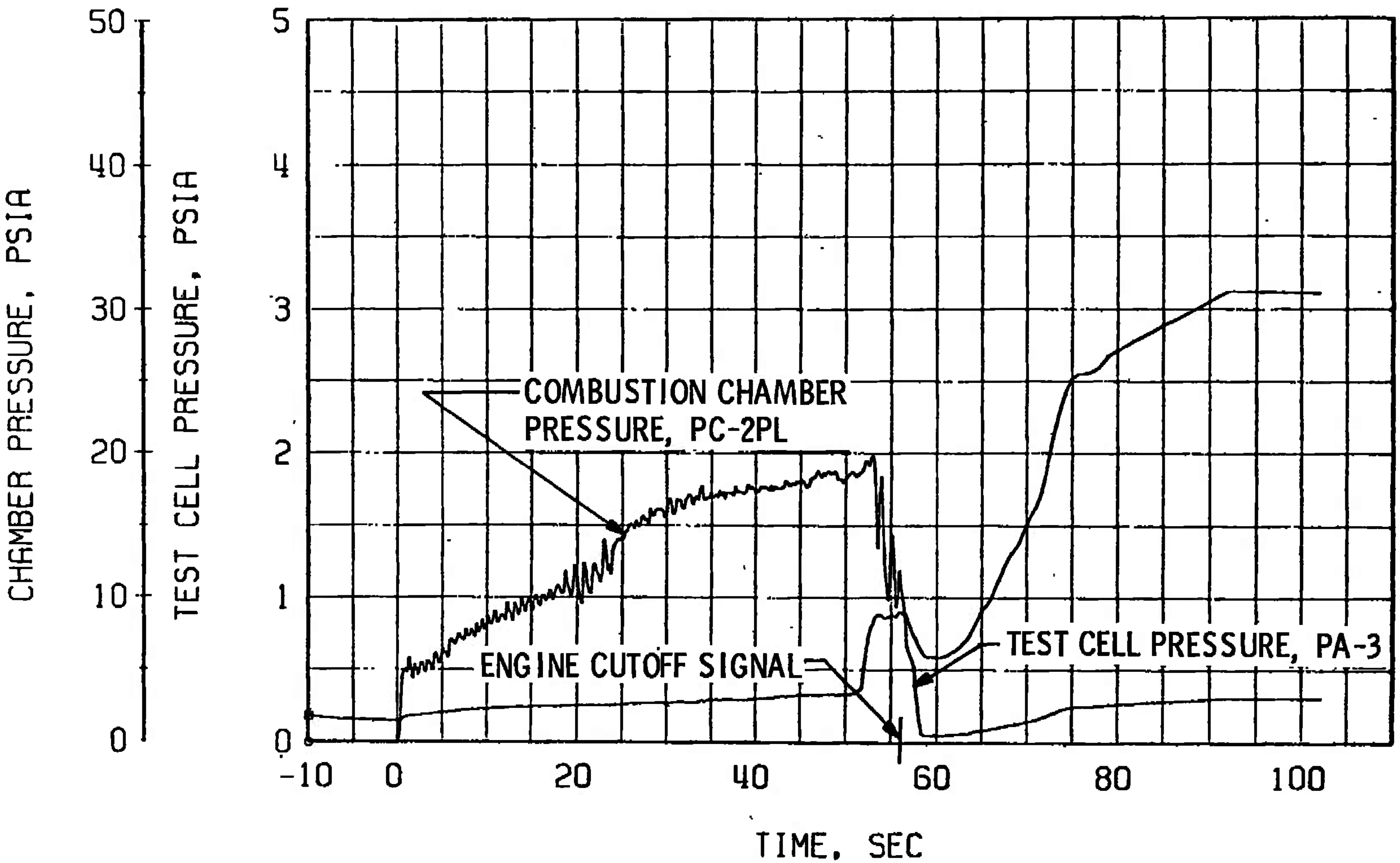
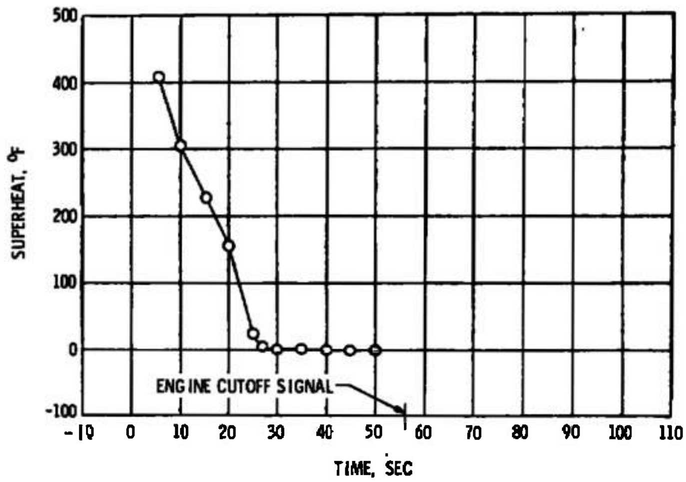
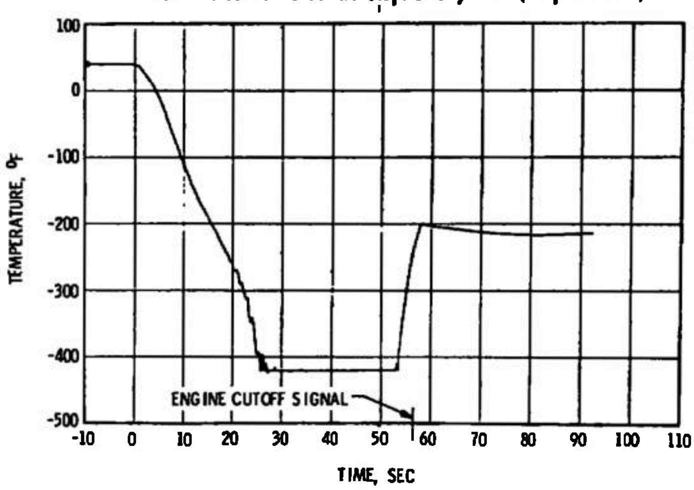


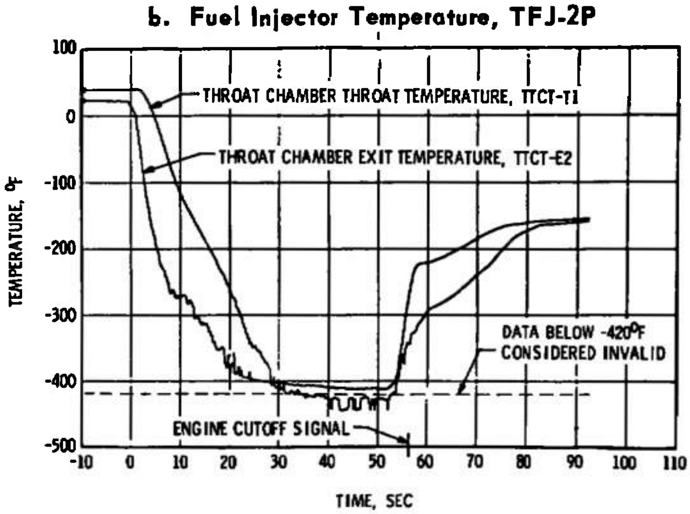
Fig. 27 Engine Ambient and Combustion Chamber Pressure, Firing 07C



a. Fuel Conditions at Injector, °F (Superheat)

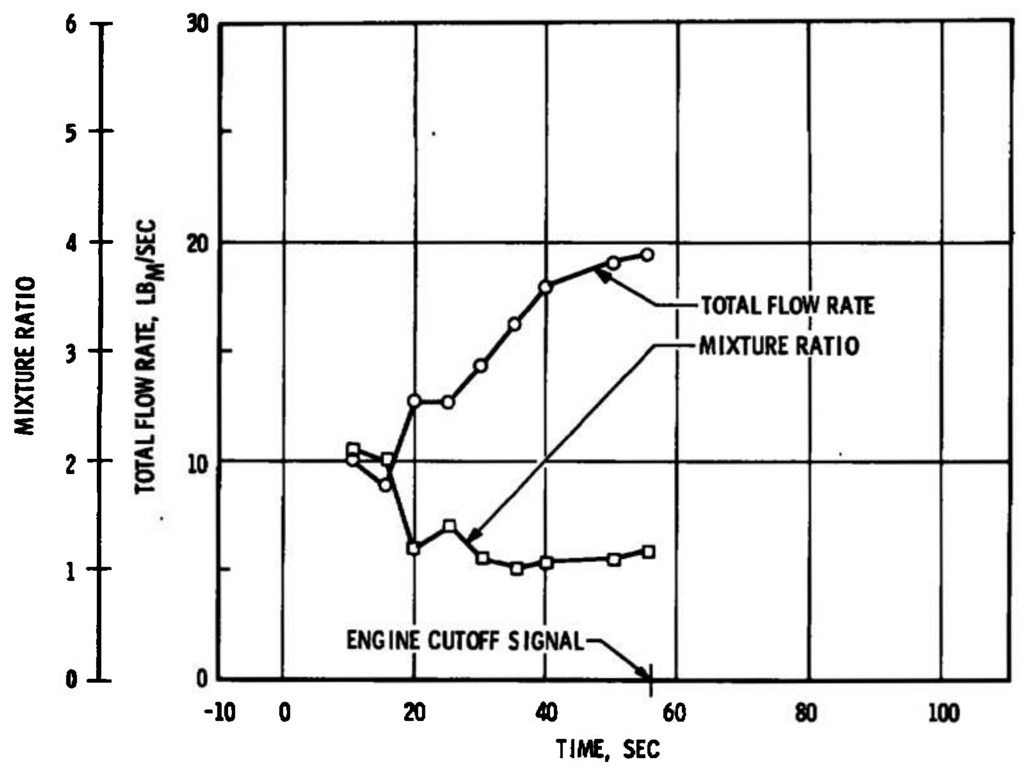


b. Fuel Injector Temperature, TFJ-2P

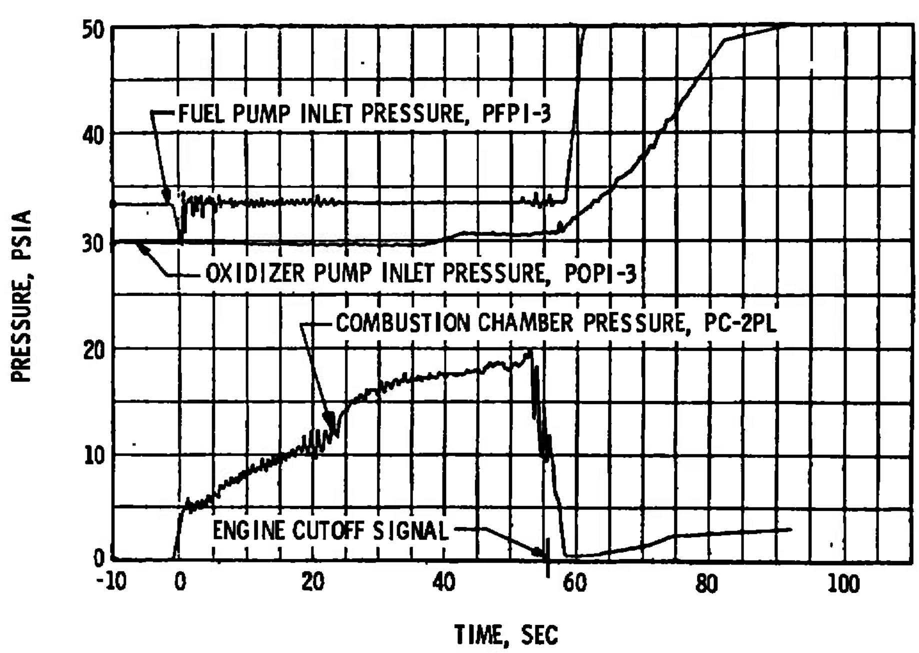


c. Thrust Chamber Childown

Fig. 28 Fuel System Chilldown, Firing 07C



a. Total Flow Rate and Mixture Ratio



b. Pump Inlet and Combustion Chamber Pressures

Fig. 29 Propellant System Performance, Firing 07C

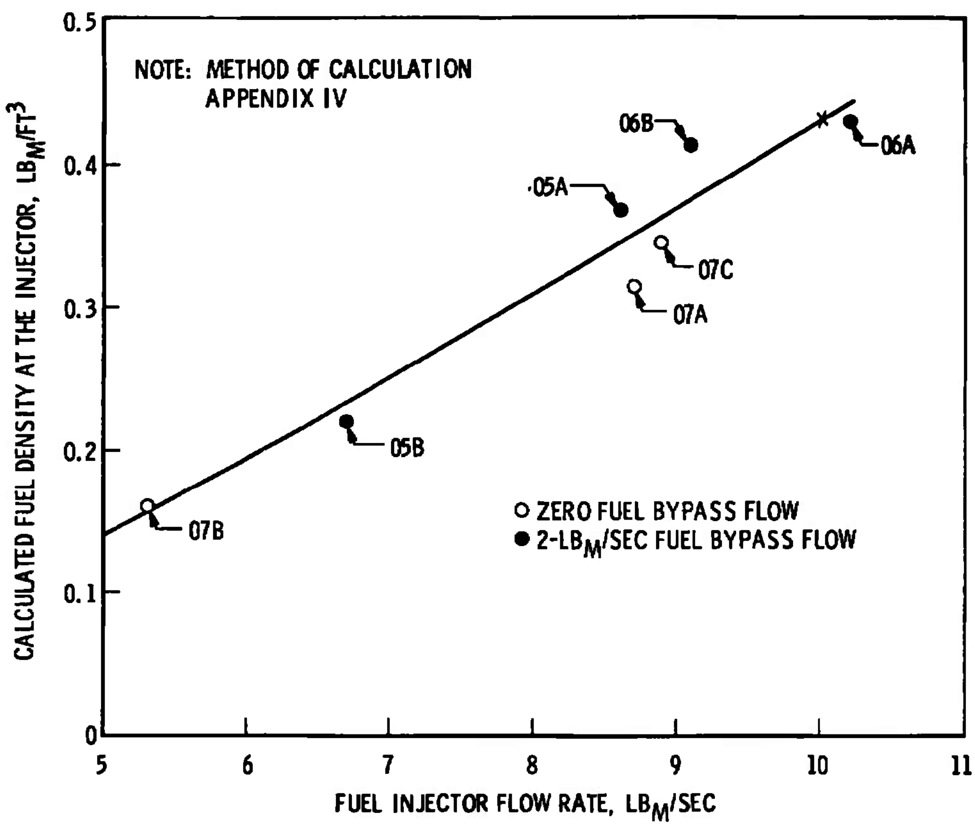


Fig. 30 Effect of Fuel Injector Flow Rate on Fuel Density at the Injector

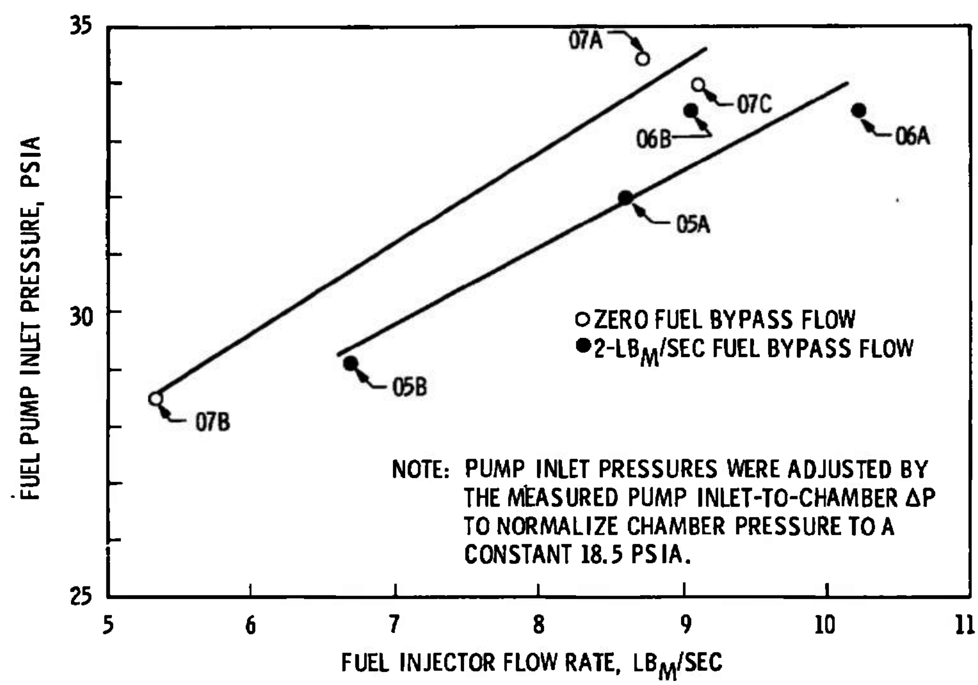


Fig. 31 Effect of Fuel Pump Inlet Pressure on Fuel Injector Flow Rate

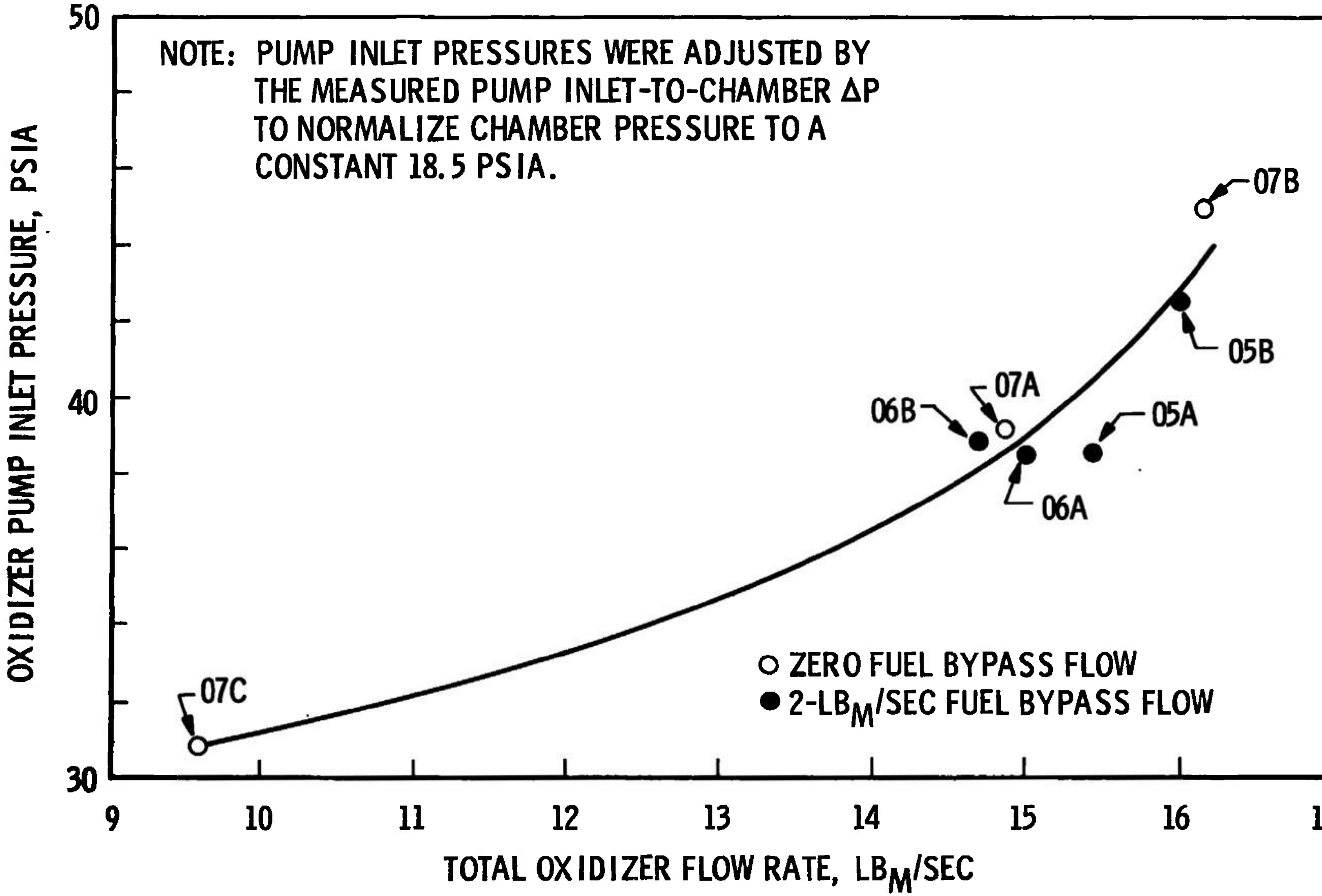


Fig. 32 Effect of Oxidizer Pump Inlet Pressure on Oxidizer Flow Rate

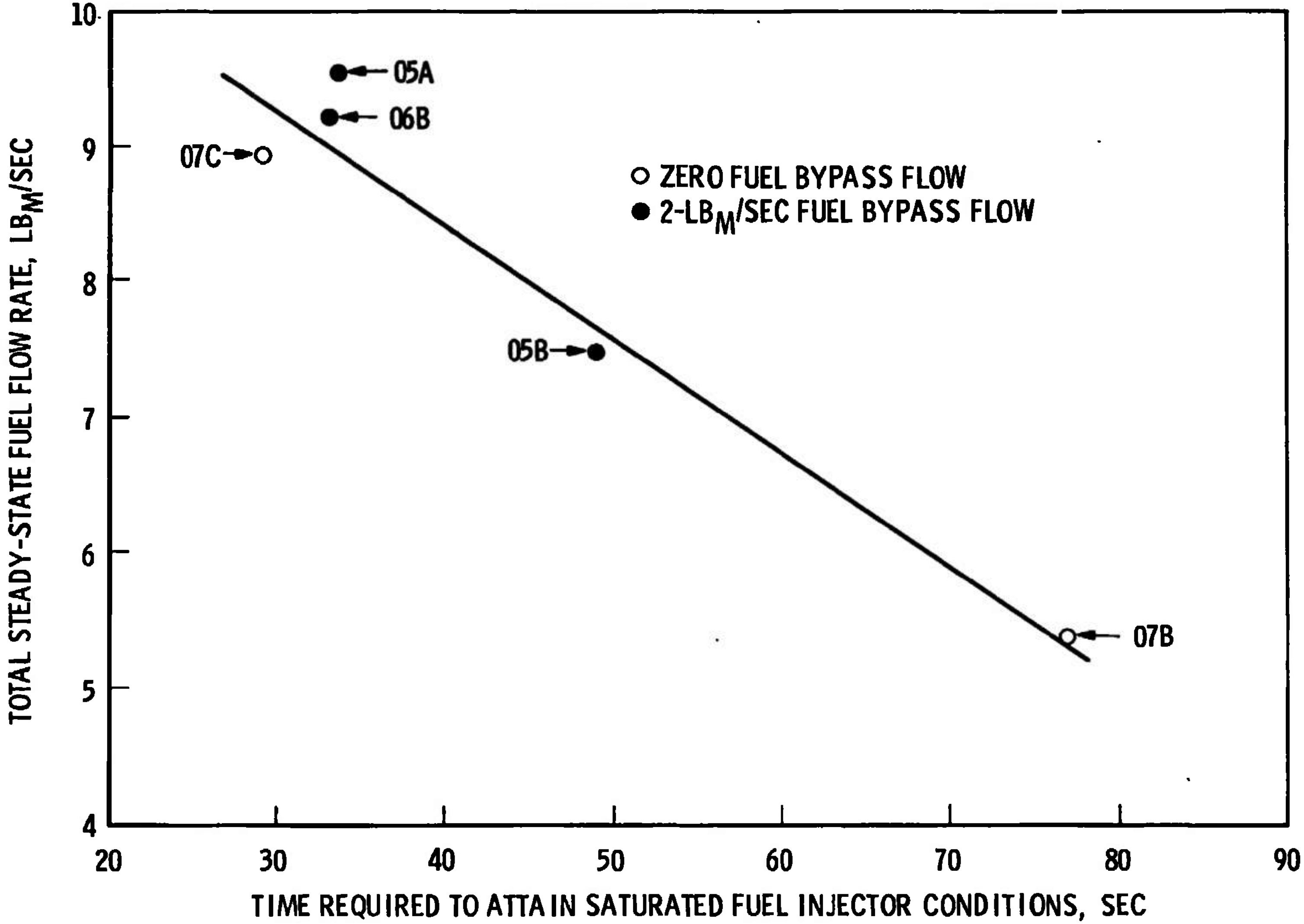
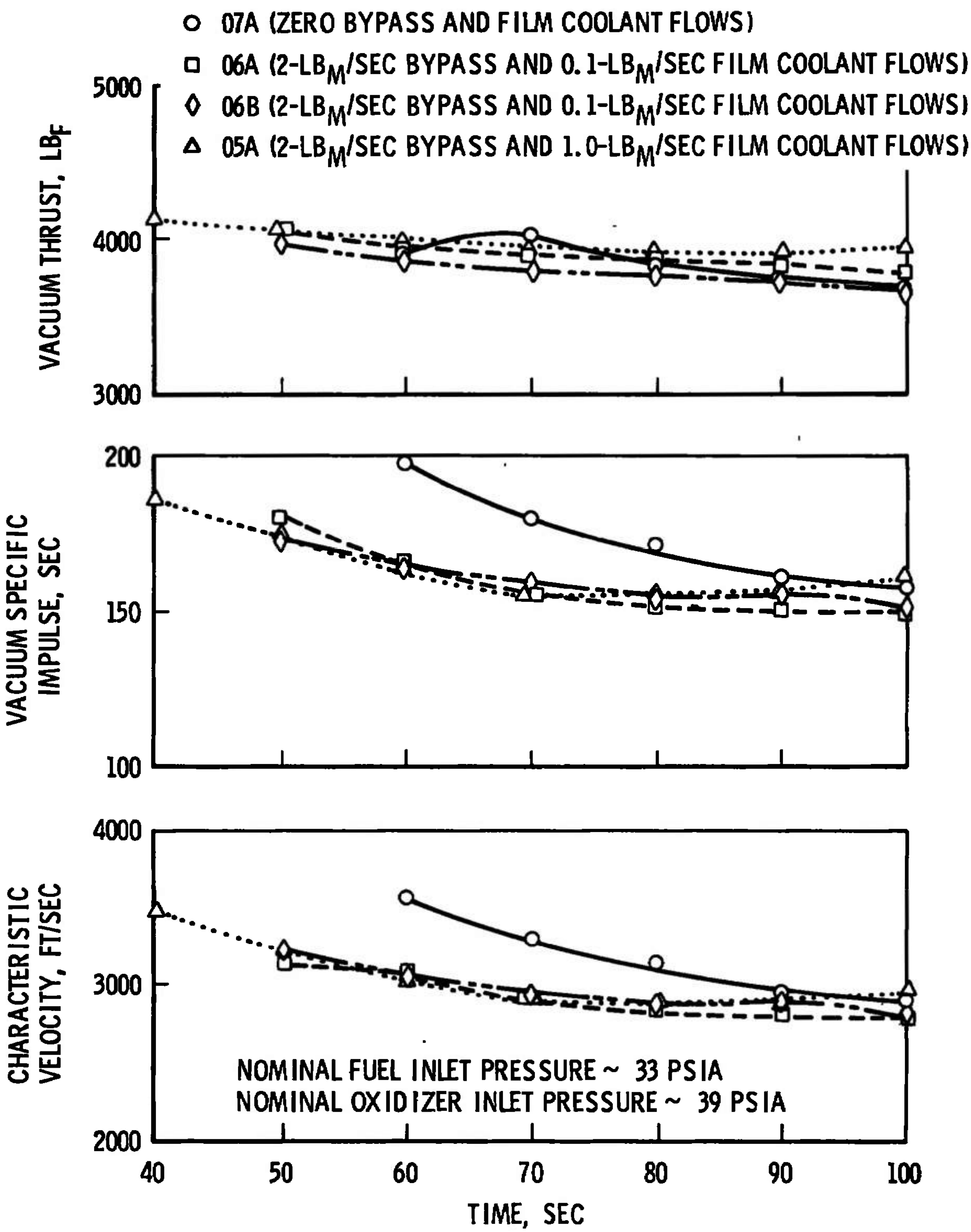
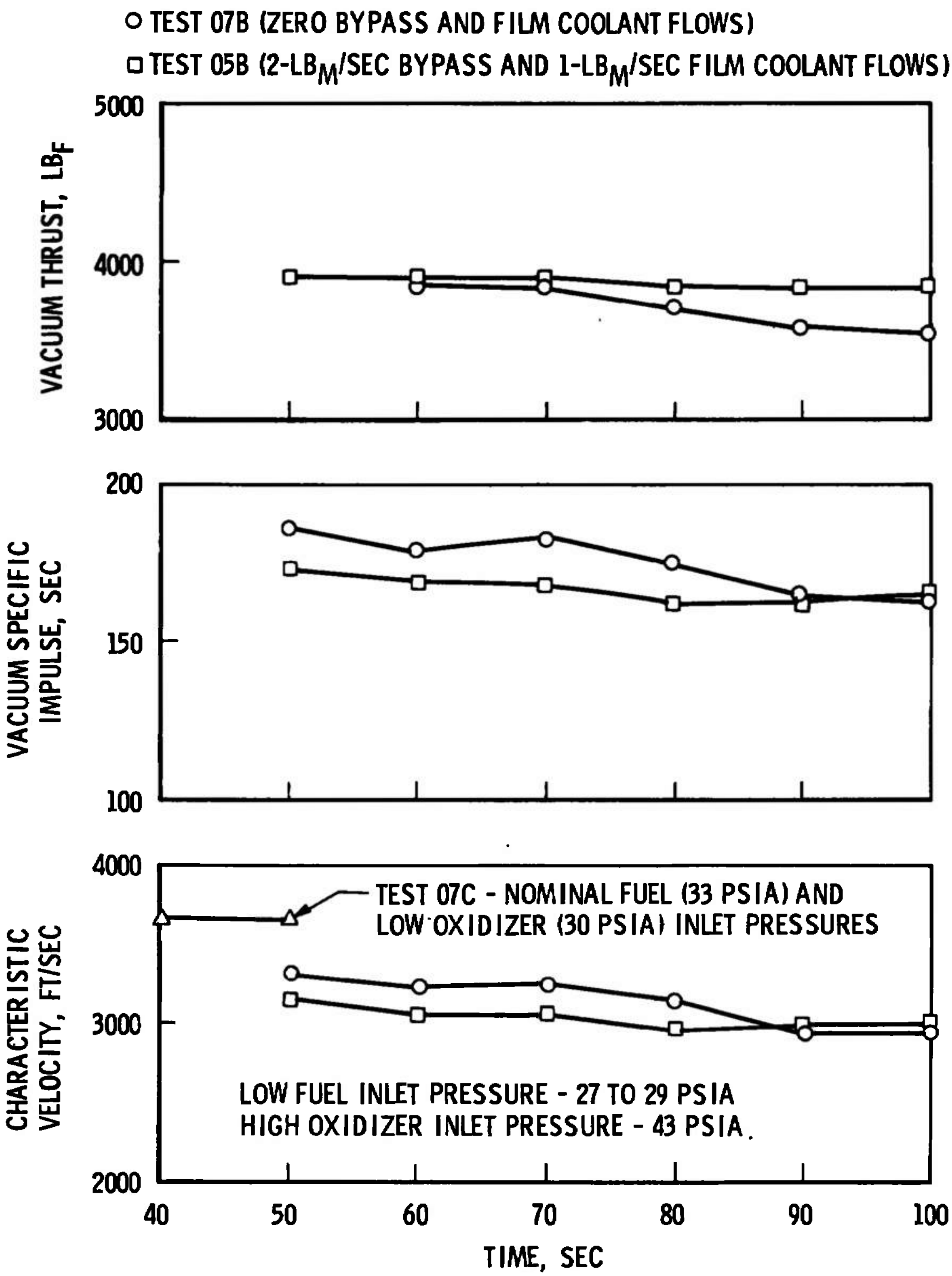


Fig. 33 Effect of Fuel Flow on Time Required to Attain Steady-State, Idle-Mode Operation



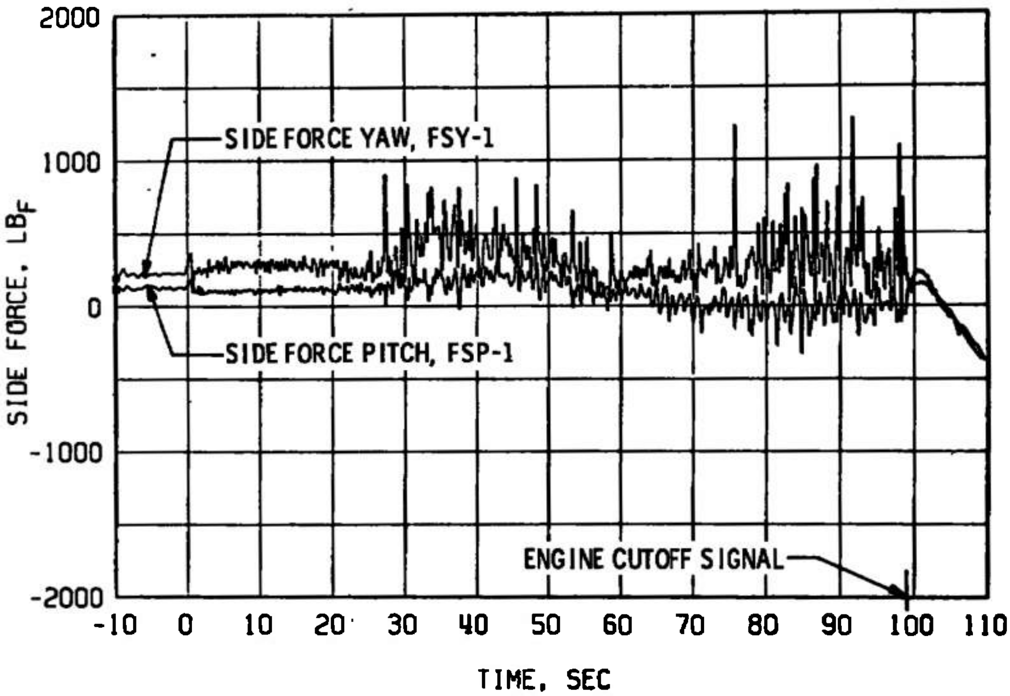
a. Nominal Fuel and Oxidizer Inlet Pressures

Fig. 34 Steady-State, Idle-Mode Performance

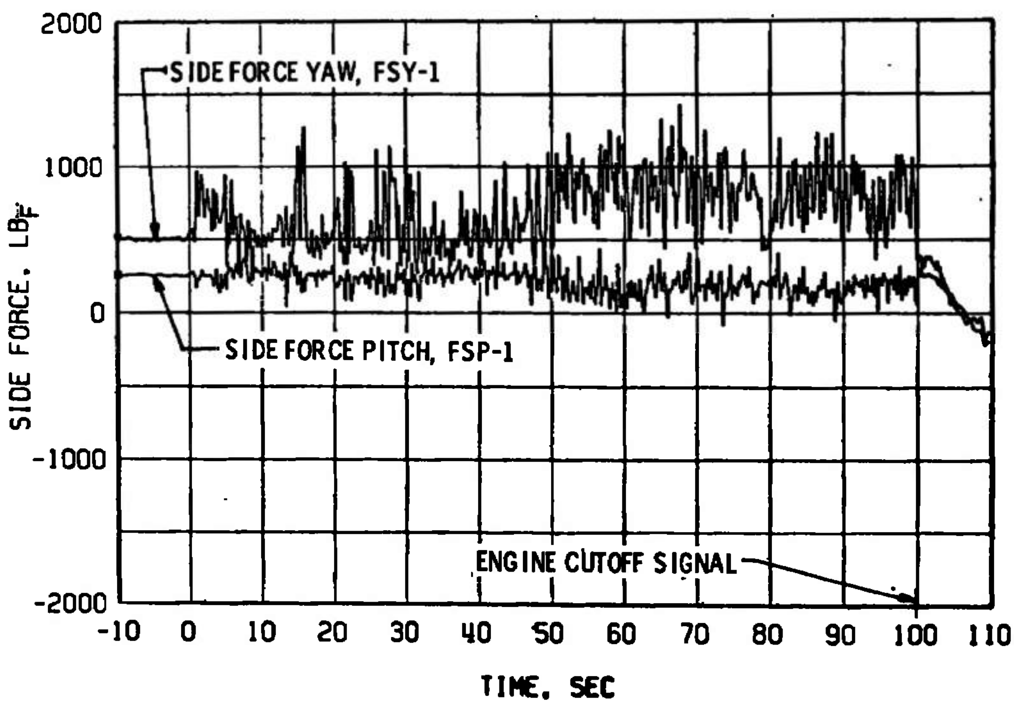


b. Low Fuel-High Oxidizer Pump Inlet Pressures

Fig. 34 Concluded

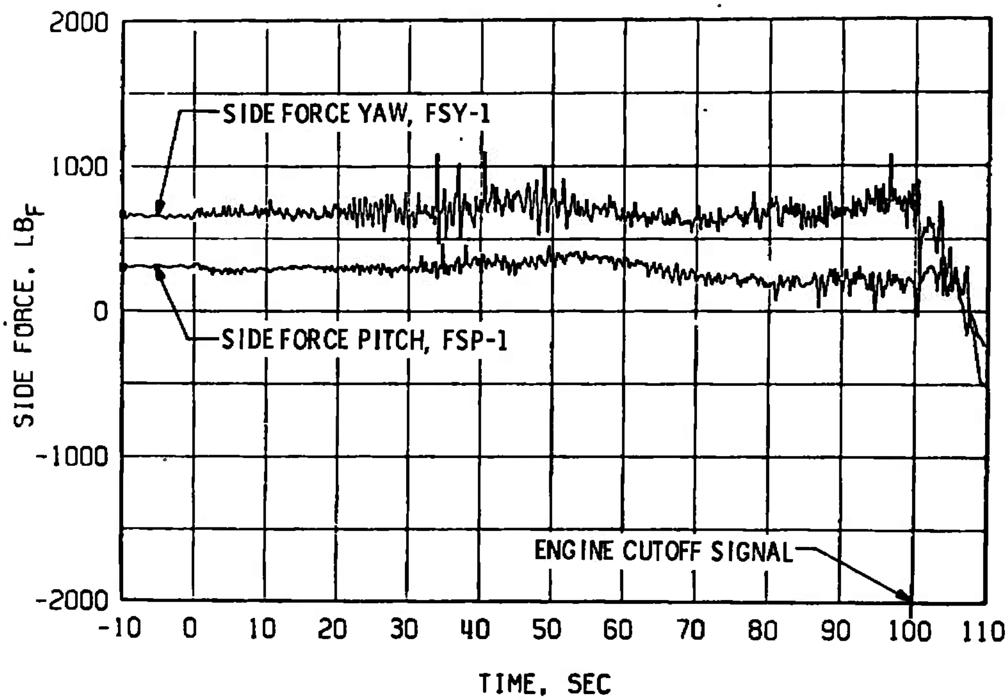


a. Firing 05A

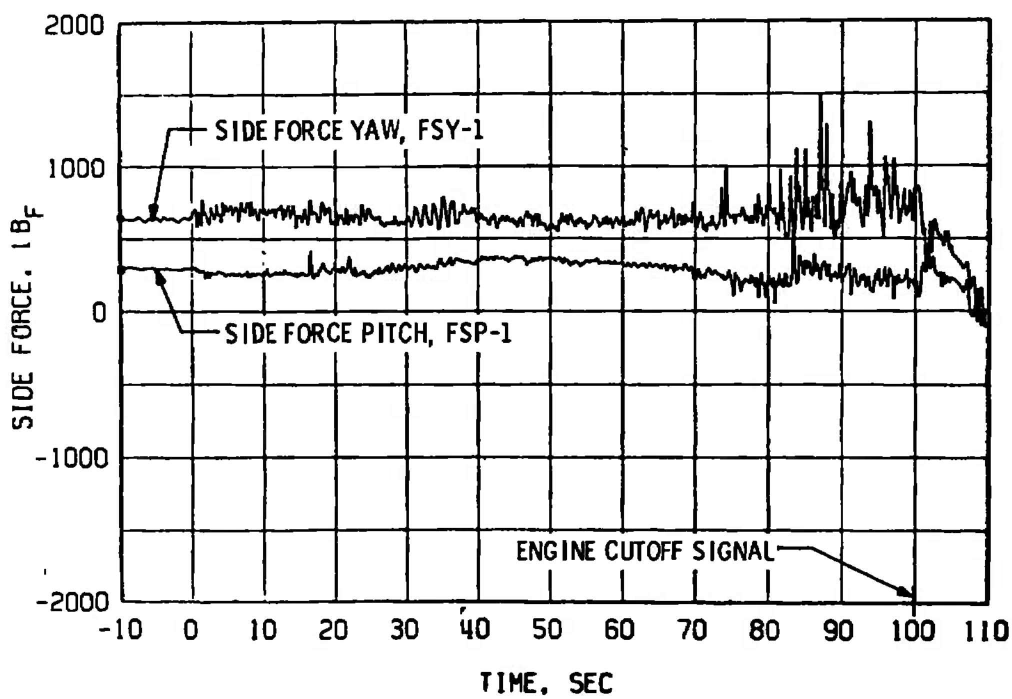


b. Firing 05B

Fig. 35 Engine-Generated Side Forces

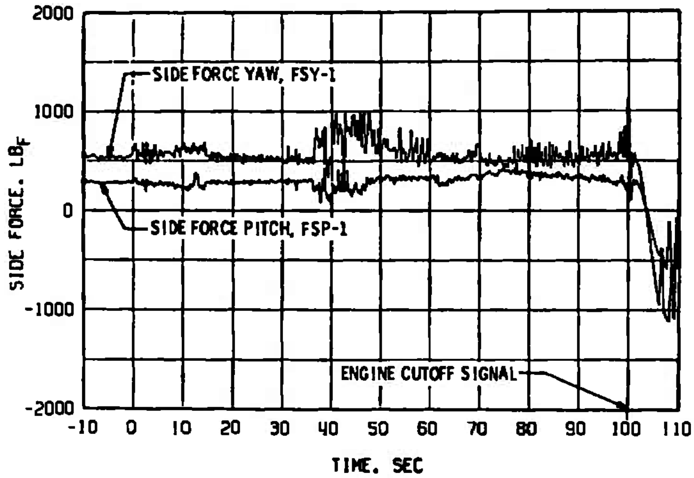


c. Firing 06A

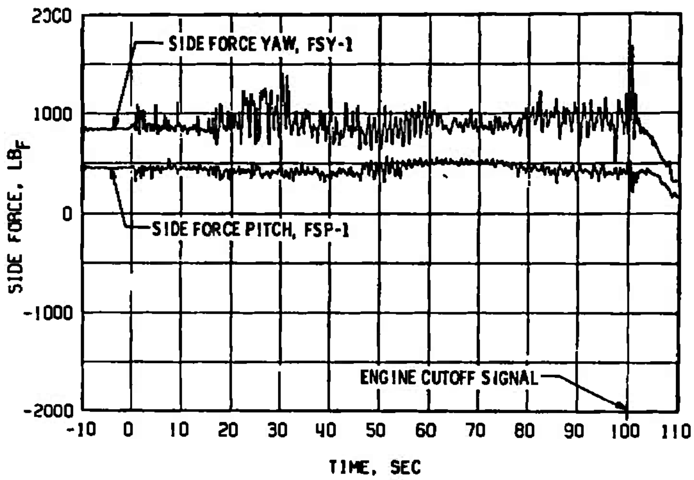


d. Firing 06B

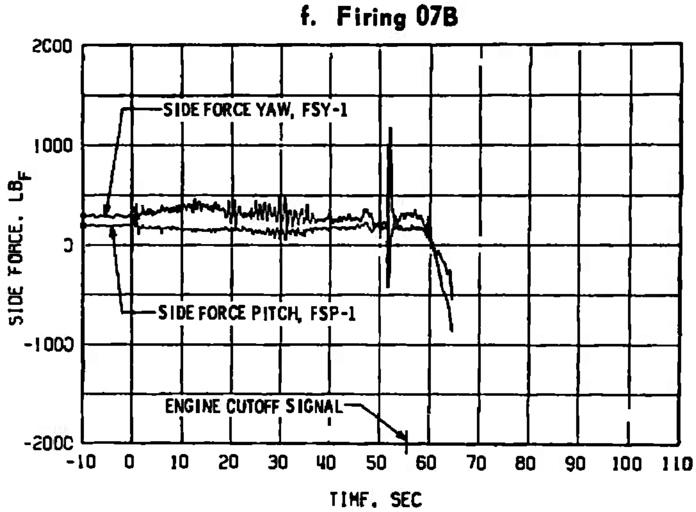
Fig. 35 Continued



e. Firing 07A



f. Firing 07B



g. Firing 07C

Fig. 35 Concluded

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1902-05)

Part Name	P/N	S/N
Thrust Chamber Body Assembly	99-210620	4094439
Thrust Chamber Injector Assembly	99-210610-71	4087381
Augmented Spark Igniter Assembly	EWR-113811-21	4901310
Ignition Detector Probe 1	3243-2	041
Ignition Detector Probe 2	3243-1	003X
Fuel Turbopump Assembly	99-461500-31	R004-1A
Oxidizer Turbopump Assembly	99-460430-21	S003-0A
Main Fuel Valve	99-411320X3	8900881
Main Oxidizer Valve	99-411225X4	8900929
Idle-Mode Valve	99-411385	8900867
Thrust Chamber Bypass Valve	99-411180	8900806
Hot Gas Tapoff Valve	99-557824-X2	8900847
Propellant Utilization Valve	99-251455X5	8900911
Electrical Control Package	99-503680	4097867
Engine Instrumentation Package	99-704641	4097437
Pneumatic Control Package	99-558330	8900817
Restart Control Assembly	99-503680	4097867
Helium Tank Assembly	NA5-260212-1	0002
Oxidizer Flowmeter	251216	4096874
Fuel Flowmeter	251225	4096875
Fuel Inlet Duct Assembly	409900-11	6631788
Oxidizer Inlet Duct Assembly	409899	4052289
Fuel Pump Discharge Duct	99-411082-7	439
Oxidizer Pump Discharge Duct	99-411082-5	439
Thrust Chamber Bypass Duct	99-411079	417
Fuel Turbine Exhaust Bypass Duct	307879-11	2143580
Hot Gas Tapoff Duct	99-411080-51	7239768
Solid-Propellant Turbine Starters Manifold	99-210921-11	7216433
Heat Exchanger and Oxidizer Turbine Exhaust Duct	307887	2142922
Crossover Duct	307879-11	2143580

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Test Effective	Comments
Augmented Spark Igniter Fuel Supply Line	---	Open	J4-1902-05	---
Augmented Spark Igniter-Oxidizer Supply Line	99-652050	0.0999	J4-1902-05	---
Film Coolant Flow	99-411094	0.581	J4-1902-05	---
	---	0.198	J4-1902-06	EWR-1138 EWR-121086
	---	Blank	J4-1902-07	EWR-113825-5 EWR-121851
Fuel Bypass Line	---	1.000	J4-1902-05	EWR-113813 EWR-121064
Oxidizer Turbine Bypass Nozzle	99-210924	1.996	J4-1902-05	---
Propellant Utilization Valve Inlet	XEOR-934826	1.250	J4-1902-05	---
Film Coolant Venturi	---	1.027 Inlet 0.744 Throat	J4-1902-05	$C_D = 0.97$

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1902-04 AND J4-1902-07)

Modification Number	Completion Date	Description of Modification
	Test J4-1902-04, 1/10/69	
EWR 121064	2/25/69	Installation of New Fuel Bypass Line Orifice (1.000-in. Diam)
EWR 121076	3/4/69	Insulation of Augmented Spark Igniter Fuel Line
EWR 121058	3/5/69	Installation of Fuel Bypass Valve Remote Control System
	Test J4-1902-05, 3/6/69	
EWR 121086	3/7/69	Installation of New Film Coolant Orifice (0.198-in. Diam)
	Test J4-1902-06, 3/13/69	
EWR 121851	3/18/69	Installation of Blank Film Coolant Orifice
	Test J4-1902-07, 3/20/69	

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1902-04 AND J4-1902-07)

Replacement	Completion Date	Component Replaced
	Test J4-1902-04, 1/10/69	
Ignition Detect Probe 1 P/N 3243-2 S/N 041	2/25/69	P/N 500750 S/N 7232994
	Test J4-1902-05, 3/6/69	
	None	
	Test J4-1902-06, 3/13/69	
Ignition Detect Probe 1 P/N 3243-1 S/N 002	3/14/69	P/N 3243-2 S/N 041
Fuel Bypass Valve P/N 00-411180-X1 S/N 8900934	3/17/69	P/N 00-411180 S/N 8900806
	Test J4-1902-07, 3/20/69	

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Purge	Requirement	Solid-Propellant Turbine Starter Installed	Air-On	Propellant Drop	Engine Start	Cutoff / Coast Period	Propellant Drop	Restart	Cutoff (Last Firing)
Oxidizer Dome and Idle-Mode Compartment	Nitrogen, 600 ± 25 psia, 100 to 200°F at CCP 150 scfm								15 min
Thrust Chamber Jacket, Film Coolant and Turbopump Purges	Helium, 150 ± 25 psia, 100 to 150°F at CCP (125 scfm)		(b) (c)		(a)	15 min (b) (c)		(a)	15 min

[(a)]Engine-Supplied Oxidizer Turbopump Intermediate Seal Cavity Purge

[(b)]Any Time Facility Water On

[(c)]30 min before Propellant Drop

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number		J4-1902-05A		J4-1902 05B		J4-1902-06A		J4-1902-06B		J4-1902 07A		J4 1902 07B		J4-1902-07C	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day		--- / ---	3-6-60 / 1455 hr	--- /	1-8-60 / 1516 hr	/ ---	3-13-69 / 1014 hr	--- / ---	3-13-69 / 1208 hr	--- / ---	3-20-69 / 1206 hr	--- / ---	3-20-69 / 1335 hr	--- / ·	3 20-69 / 1534 hr
Pressure Altitude at t_0, ft (Ref 1)		100,000	90,000	100,000	100,500	100,000	04,000	100,000	102,000	100,000	71,500	100,000	100,000	100,000	100,000
Idle-Mode Duration Pre-Main Stage, sec*		100	08.549	100	00 468	100	100.215	100	100 169	100	100 120	100	101 816	---	56 157
Fuel Pump Inlet Pressure at t_0, psia		33 0 1 1 0	32 2	30 0 ± 1 0	29 1	33 0 1 1 0	33.0	33 0 ± 1 0	33 4	33.0 ± 1.0	32.9	97.0 ± 1.0	27 1	33.0 ± 1 0	33 2
Fuel Pump Inlet Temperature at t_0, °F		---	-417 9	---	-418 6		-417.6	---	-417.8	---	-417 6	---	419 0	---	-418 0
Fuel Tank Bulk Temperature at t_0, °F		-422 4 ± 0 4	-422.8	-422 4 + 0.4	-422 7	422.4 ± 0 4	-422 5	-422 4 ± 0.4	-422.5	422 4 ± 0 4	-422.6	-422 4 ± 0 4	-422 8	-422 4 ± 0.4	-421.7
Oxidizer Pump Inlet Pressure at t_0, psia		39.0 ± 1 0	38 4	45 0 ± 1.0	44.5	39 0 ± 1 0	39.0	39 0 ± 1 0	36 7	39.0 ± 1.0	39 1	45.0 ± 1.0	44.8	30.0 ± 1 0	20.7
Oxidizer Pump Inlet Temperature at t_0, °F		---	-292 1	-	-292 6	---	-291.3		-291 3	---	-290 3	---	292.4	---	-293 1
Oxidizer Tank Bulk Temperature at t_0, °F		-295 0 ± 0.4	-295 4	-295 0 ± 0.4	-295 8	-295 0 1 0 4	-294 6	295 0 ± 0 4	-294 7	-295 0 ± 0 4	-295 1	-295 0 ± 0.4	-294 6	-295 0 1 0 4	-295 0
Helium Tank Conditions at t_0	Pressure, psia	3450^{+10}_{-200}	3293	Remains from A	3047	3160^{+10}_{-300}	3067	Remains from A	2783	3450^{+10}_{-900}	3375	Remains from A	3090	Remains from A	2889
	Temperature, °F	---	87	--	80	---	91	---	56	---	116	---	70	-	71
Main Fuel Valve Temperature at t_0, °F		---	71	---	36	---	68	---	83	---	68	---	58	---	47
Augmented Spark Igniter - Ignition Detected, sec (Ref t_0)*		---	0 472	---	0 463	--	0 482	---	0.481	---	0 403	---	0 406	---	0 446
Propellant Utilization Valve Position at t_0		Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Fuel Flow, lb_m/sec	Total	---	0 6		7.5	---	10 3	---	0 2	---	8 7	---	5.4	---	8.0
	Bypass	---	2 0	---	2 1	---	2 0	---	2 3	---	0	---	0	---	0
	Injector	---	6 6	---	6 7	---	10 2	-	9 1	---	6 7	---	5 4		8.9
	Film Coolant	---	1 0	---	0 8	--	0 1	--	0.1	---	0	---	0	- -	0
	Thrust Chamber	---	6 6	-	4 6	---	8 2	---	6 8	---	8.7	---	5.4	---	8.9
Oxidizer Flow, lb_m/sec	Total	---	15 6	-	16 1	---	15 0		14 7	---	14 0	---	16.9	---	0 8

*Data Reduced from Oscillogram

TABLE VII
ENGINE VALVE TIMINGS

Test J4-1902-	Firing	Start						Shutdown					
		Main Fuel Valve			Idle-Mode Oxidizer Valve			Main Fuel Valve			Idle-Mode Oxidizer 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 Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
05	A	0.0	0.050	0.058	0.0	0.117	0.045	98.549	0.069	0.260	98.549	0.065	0.151
	B	0.0	0.051	0.060	0.0	0.125	0.046	99.468	0.071	0.262	99.468	0.065	0.158
	Final Sequence	0.0	0.049	0.072	0.0	0.122	0.043	9.944	0.069	0.259	9.944	0.062	0.144
06	A	0.0	0.051	0.055	0.0	0.117	0.045	100.215	0.068	0.261	100.215	0.065	0.150
	B	0.0	0.050	0.062	0.0	0.125	0.045	100.182	0.072	0.260	100.182	0.065	0.155
	Final Sequence	0.0	0.050	0.070	0.0	0.121	0.048	10.740	0.069	0.260	10.740	0.061	0.115
07	A	0.0	0.048	0.055	0.0	0.112	0.065	100.120	0.068	0.260	100.120	0.066	0.145
	B	0.0	0.050	0.060	0.0	0.120	0.065	101.818	0.070	0.265	101.818	0.068	0.152
	C	0.0	0.050	0.063	0.0	0.122	0.060	56.157	0.071	0.264	56.157	0.067	0.155
	Final Sequence	0.0	0.047	0.068	0.0	0.117	0.045	12.457	0.070	0.257	12.457	0.060	0.110

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 are reduced from oscillogram.

TABLE VIII
ENGINE IDLE-MODE PERFORMANCE

Test Number, J4-1902-	05A							05B							06A						
Time Slice, sec*	40	50	60	70	80	90	90	40	50	60	70	80	90	88	40	50	60	70	80	90	89
Fuel Pump Inlet Pressure, psia	32.8	32.6	32.6	32.6	32.7	32.7	32.7	29.4	28.5	29.5	29.6	28.6	28.6	28.7	33.5	33.6	33.6	33.6	33.6	33.6	33.7
Oxidizer Pump Inlet Pressure, psia	39.5	39.5	39.4	38.4	39.3	38.3	39.2	43.6	43.4	43.1	43.0	42.7	42.6	42.4	38.9	38.9	38.8	38.8	38.7	30.7	30.7
Chamber Pressure, P_c, psia	20.2	18.8	19.5	19.3	19.1	19.1	19.3	15.1	10.8	18.0	18.8	18.6	18.6	18.6	16.6	18.7	18.4	18.2	18.0	18.8	18.5
Propellant Mixture Ratio, O/F, dimensionless	1.61	1.56	1.49	1.54	1.57	1.62	1.73	1.55	2.07	2.14	2.12	2.07	2.17	2.20	2.01	1.64	1.48	1.43	1.43	1.46	1.48
Characteristic Velocity, C^*, ft/sec	3440	3220	3010	2000	2880	2880	2950	2280	3130	3050	3040	2980	2900	3010	3250	3120	3050	2880	2820	2770	2780
Characteristic Velocity Efficiency, C^*_{eff}, percent	45.0	42.5	40.0	38.0	37.8	37.0	38.4	30.1	38.9	38.8	38.6	37.7	37.8	30.2	41.5	43.4	40.6	38.4	37.6	36.9	36.8
Vacuum-Corrected Thrust, F_{vac}, lb_f	4130	4060	3980	3940	3910	3920	3880	3080	3800	3880	3880	3850	3860	3850	3420	4040	3880	3810	3870	3830	3780
Vacuum Corrected Coefficient of Thrust, CF_{vac}, dimensionless	1.75	1.75	1.74	1.74	1.74	1.75	1.75	1.74	1.76	1.77	1.77	1.76	1.77	1.77	1.76	1.75	1.74	1.74	1.74	1.74	1.74
Vacuum-Corrected Specific Impulse, $I_{sp_{vac}}$, lb_f-sec/lb_m	187	175	103	156	158	157	161	124	172	168	167	162	183	188	178	180	165	136	152	150	148
Total Oxidizer Flow Rate, $\dot{W}_o$, lb_m/sec	13.7	14.1	14.8	15.3	15.3	15.5	15.6	15.1	15.3	15.8	15.0	16.0	16.2	16.0	12.8	13.8	14.3	14.8	14.9	15.1	15.1
Total Fuel Flow Rate, $\dot{W}_f$, lb_m/sec	8.30	9.05	9.78	9.82	8.75	8.57	8.04	8.78	7.41	7.40	7.46	7.71	7.46	7.28	8.38	8.48	9.85	10.4	10.5	10.3	10.2
Idle-Mode Fuel Flow Rate, $(\dot{W}_f)_{imc}$, lb_m/sec	0.980	1.06	1.14	1.16	1.14	1.12	1.08	1.14	0.087	0.888	0.873	0.802	0.873	0.851	0.748	0.992	1.13	1.22	1.23	1.21	1.19
Idle-Mode Mixture Ratio, $(O/F)_{im}$, dimensionless	14.0	13.3	12.8	13.2	13.4	13.0	14.7	13.2	17.6	18.2	18.1	17.7	18.0	18.8	17.2	14.0	12.7	12.1	12.1	12.5	12.7
Fuel Injection Density, $P_{f_{inj}}$, lb_m/ft^3	0.31	0.24	0.31	0.35	0.42	0.39	0.32	0.33	0.10	0.18	0.20	0.22	0.23	0.20	0.13	0.24	0.34	0.41	0.43	0.43	0.43

*Data averaged for +0.5 sec at the indicated times.

TABLE VIII (Concluded)

Test Number, J4-1902-	08B							07A							07B							07C	
Time Slice, sec*	40	50	60	70	80	90	99	40	50	80	70	80	90	99	40	50	60	70	80	90	99	40	50
Fuel Pump Inlet Pressure, psia	33.6	33.3	33.2	33.2	33.2	33.3	33.4	33.6	33.8	33.9	34.0	34.1	34.2	34.2	27.2	27.2	27.1	27.1	27.0	27.0	26.9	33.3	33.3
Oxidizer Pump Inlet Pressure, psia	38.8	38.8	38.7	38.5	38.0	38.6	38.5	39.7	39.9	39.9	39.9	39.8	39.7	39.6	44.3	44 2	44.1	44.0	43.8	43.6	43.5	29.9	30.4
Chamber Pressure, P_c, psia	19.9	19 5	18.9	18.6	18.4	18.2	10.0	12.0	14.8	18.8	19 5	18.5	18.3	18.1	12.3	17.9	18.3	18.2	17.6	17.1	16.0	17.5	18.3
Propellant Mixture Ratio, O/F, dimensionless	1.84	1.52	1.52	1.49	1.56	1.66	1.56	2.34	2.92	2.31	1.93	1.96	1.78	1.71	2.79	3.06	2.78	3.12	3.24	2.81	2.93	1.07	1.10
Characteristic Velocity, C^*, ft/sec	3540	3220	3050	2940	2870	2900	2800	2460	3100	3560	3280	3130	2950	2080	2280	3310	3210	3240	3130	2940	2940	3870	3640
Characteristic Velocity Efficiency, C^*_{eff}, percent	46.3	42.6	40.3	39.0	37.8	37.8	36.8	31.1	38.8	45.0	42.1	40.2	30.3	37.5	28.5	41.5	40.3	40.6	39.2	36.8	36.8	51.9	51.2
Vacuum-Corrected Thrust, F_{vac}, lb_f	4080	3980	3860	3790	3770	3720	3670	2490	3110	3900	4010	3820	3750	3710	2580	3770	3840	3040	3720	3590	3560	---	--
Vacuum Corrected Coefficient of Thrust, CF_{vac}, dimensionless	1.75	1.74	1.74	1.74	1.74	1.75	1.74	1.77	1.80	1.77	1.76	1.76	1.75	1.75	1.79	1.80	1.79	1.01	1.81	1.79	1.80	---	---
Vacuum-Corrected Specific Impulse, $I_{sp_{vac}}$, lb_f-sec/lb_m	192	174	165	159	155	157	152	136	1.73	198	179	171	161	157	127	186	179	102	176	164	164	---	---
Total Oxidizer Flow Rate, $\dot{W}_o$, lb_m/sec	13.2	13.7	14.1	14.3	14.0	14.8	14.8	12.9	13.4	13.9	14.8	14 8	14.9	14.9	15.0	15.3	15.8	16.0	16.2	16.2	18.2	9.25	9.05
Total Fuel Flow Rate, $\dot{W}_f$, lb_m/sec	8.03	9.06	9.29	9.55	9.46	8.87	9.45	5.48	4.58	6.01	7.65	7.55	8.40	8.73	5.37	5.00	5.60	5.13	4.98	5.74	5.51	8.67	9.05
Idle-Mode Fuel Flow Rate, $(\dot{W}_f)_{imc}$, lb_m/sec	0.939	1.06	1.09	1.12	1.11	1.04	1.10	0.641	0.536	0 703	0.895	0.833	0.083	1.02	0.828	0.585	0.666	0.800	0.583	0.671	0.645	1.01	1.06
Idle-Mode Mixture Ratio, $(O/F)_{imc}$, dimensionless	14.1	12.9	12.9	12.8	13.3	14.2	13.5	20.1	25.0	19.8	18.5	17.8	15.2	14.6	23.9	26.2	23.7	26.7	27 8	24.1	25.1	9.16	9.39
Fuel Injection Density, $P_{f_{inj}}$, lb_m/ft^3	0.23	0.33	0.34	0.41	0.42	0.36	0.42	0.08	0.06	0.12	0.25	0.24	0.30	0.31	0.12	0 12	0.17	0.14	0.13	0.17	0.18	0.32	0.37

*Data averaged for ±0.5 sec at the indicated times

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1902-05 through J4-1902-07 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST FOR IDLE-MODE OPERATION

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Current		**amp**						
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter Spark 1		On/Off					x	
EASIS-2	Augmented Spark Igniter Spark 2								
EECL	Engine Cutoff Lockin			x		x			
EECO	Engine Cutoff Signal			x		x			
EER	Engine Ready Signal								
EES	Engine Start Command			x		x			
EESCO	Programmed Duration Cutoff								
EFBVO	Fuel Bleed Valve Open Limit								
EFPVC	Fuel Prevalve Closed Limit			x					
EFPVO	Fuel Prevalve Open Limit			x					
EHCS	Helium Control Solenoid Energized			x	x	x			
EID	Ignition Detected			x		x			
EIDA-1	Ignition Detect Amplifier 1								
EIDA-2	Ignition Detect Amplifier 2								
EIMCS	Idle-Mode Control Solenoid Energized			x		x			
EIMVC	Idle-Mode Valve Closed Limit								
EIMVO	Idle-Mode Valve Open Limit								
EMFVC	Main Fuel Valve Closed Limit								
EMFVO	Main Fuel Valve Open Limit								
EOBVO	Oxidizer Bleed Valve Open Limit								
EOCO	Observer Cutoff Signal								
EOPVC	Oxidizer Prevalve Closed Limit			x					
EOPVO	Oxidizer Prevalve Open Limit			x					
ERASIS-1	Augmented Spark Igniter Spark Rate 1					x			
ERASIS-2	Augmented Spark Igniter Spark Rate 2					x			
ESTCO	Start (OK) Timer Cutoff Signal							x	
ETCBC	Thrust Chamber Bypass Valve Closed							x	
ETCBO	Thrust Chamber Bypass Valve Open							x	
EVSC-1	Vibration Safety Counts 1					x			
EVSC-2	Vibration Safety Counts 2					x			
EVSC-3	Vibration Safety Counts 3					x			
	Flows		**gpm**						
QF-1	Engine Fuel	PFF	0 to 11,000	x					
QF-2	Engine Fuel	PFFa	0 to 11,000	x	x	x			
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QFBD	Fuel Bypass Duct		0 to 500	x	x	x			
QO-1	Engine Oxidizer	POF	0 to 3600	x					
QO-2	Engine Oxidizer	POFa	0 to 3600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3600			x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Forces		**lb_f**						
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000						
	Position		**Percent Open**						
LFBT	Thrust Chamber Bypass Valve		0 to 100						
LFVT	Main Fuel Valve		0 to 100						
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100						
LOVT	Main Oxidizer Valve		0 to 100						
LPUTOP	Propellant Utilization Valve		5 v				x		
LTVT	Hot Gas Tapoff Valve		0 to 100						
	Pressure		**psia**						
PA-1	Test Cell		0 to 0.5						
PA-2	Test Cell		0 to 1.0						
PA-3	Test Cell		0 to 5.0			x	x		
PC-1P	Thrust Chamber	CG1	0 to 1500						
PC-2P	Thrust Chamber	CG1a-2	0 to 1500			x			
PC-2PL	Thrust Chamber	CG1a-1	0 to 50			x	x		
PCASI-L	Augmented Spark Igniter Chamber	IG1	0 to 50			x			
PCW-1	Thrust Chamber Wall		0 to 1						
PCW-2	Thrust Chamber Wall		0 to 1						
PCW-3	Thrust Chamber Wall		0 to 1						
PCW-4	Thrust Chamber Wall		0 to 1						
PCW-5	Thrust Chamber Wall		0 to 1						
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500						
*PFCO-L	Film Coolant Orifice	CF4	0 to 50						
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000						
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50						
PFCVT	Film Coolant Venturi Throat	CF6	0 to 2000						
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50						
PFJ-1	Fuel Injection	CF2	0 to 1500			x			
PFJ-1L	Fuel Injection	CF2	0 to 50						
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000						
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50						
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000						
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000						
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50						
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500						
PFPD-2	Fuel Pump Discharge	PF2	0 to 3000		x	x			
PFPI-1	Fuel Pump Inlet	PF1	0 to 100						x
PFPI-2	Fuel Pump Inlet		0 to 100						x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100		x	x			
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000						
PFPS	Fuel Pump Interstage	PF8	0 to 1000			x			
PFPSI	Fuel Pump Shroud Inlet		0 to 2500						
PFTI-1P	Fuel Turbine Inlet	TG1	0 to 1000						
PFTO	Fuel Turbine Outlet	TG2	0 to 200						

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure		**psia**						
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500	x					
PFUT	Fuel Ullage Tank		0 to 100						
PHEA	Helium Accumulator	NN3	0 to 750						
PHES	Helium Supply		0 to 5000						
PHET-1P	Helium Tank	NN1-1	0 to 5000						x
PHET-2P	Helium Tank	NN1-3	0 to 5000						
PHRO-1P	Helium Regulator Outlet	NN2	0 to 750						
PNODP	Oxidizer Dome Purge at Customer Connect Panel		0 to 750						
POASIJ	Augmented Spark Igniter Oxidizer Injection	I03	0 to 1500			x			
POASIJ-L	Augmented Spark Igniter Oxidizer Injection	I03	0 to 50						
POIML	Oxidizer Idle-Mode Line	P010	0 to 2000						
POIML-L	Oxidizer Idle-Mode Line	P010	0 to 50						
POJ-1	Oxidizer Injection	C03	0 to 1500						
POJ-2	Oxidizer Injection	C03a	0 to 2000			x			
POPBC	Oxidizer Pump Bearing Coolant	P07	0 to 500						
POPD-1L	Oxidizer Pump Discharge	P03	0 to 50						
POPD-1P	Oxidizer Pump Discharge	P03	0 to 2500						
POPD-2	Oxidizer Pump Discharge	P02	0 to 3000		x	x			
POPI-1	Oxidizer Pump Inlet	P01	0 to 100						x
POPI-2	Oxidizer Pump Inlet		0 to 100						x
POPI-3	Oxidizer Pump Inlet	P01a	0 to 100		x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	P06	0 to 50						
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200						
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100						
POUT	Oxidizer Ullage Tank		0 to 100						
PPTD	Photocon Cooling Water (Downstream)		0 to 100						
PPTU	Photocon Cooling Water (Upstream)		0 to 100						
PPUVI	Propellant Utilization Valve Inlet	P08	0 to 2000						
PPUVO	Propellant Utilization Valve Outlet	P09	0 to 1000						
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200						
PTEM	Turbine Exhaust Manifold	TG5	0 to 50						
PTM	Tapoff Manifold	GG2b	0 to 1500						
PTM-3	Tapoff Manifold	GG2a	0 to 500		x	x			
PTM-L	Tapoff Manifold	GG2b	0 to 200			x			
	Speeds		**rpm**						
NFP-1	Fuel Pump	PFV	0 to 33,000		x				
NFP-2	Fuel Pump	PFV	0 to 33,000	x		x			
NFP-3	Fuel Pump	PFV	0 to 33,000			x			
NOP-1	Oxidizer Pump	POV	0 to 12,000		x				
NOP-2	Oxidizer Pump	POV	0 to 12,000	x		x			
NOP-3	Oxidizer Pump	POV	0 to 12,000			x			

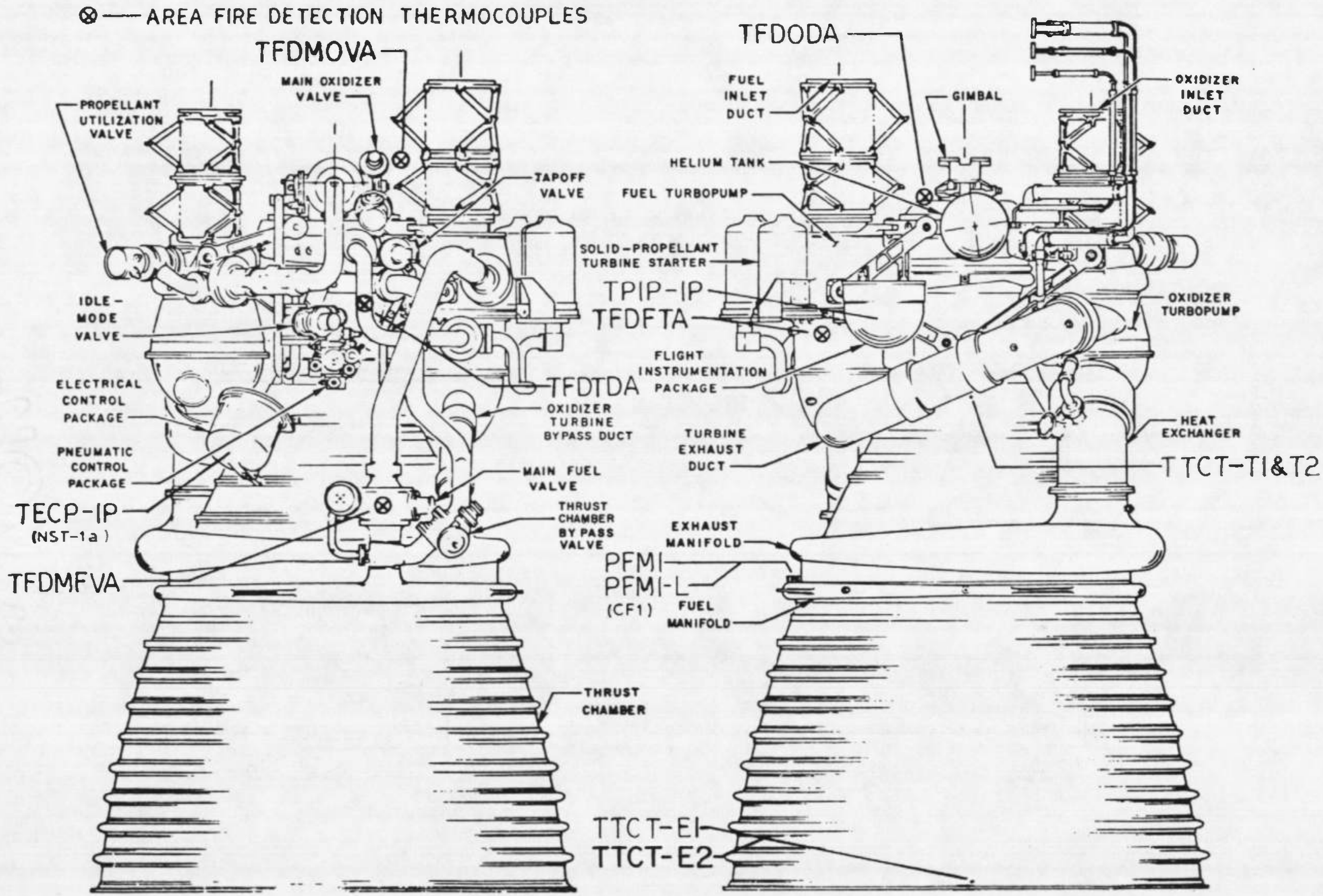
TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures		°F						
TA-1	Test Cell North		-50 to 800	x					
TA-2	Test Cell East		-50 to 800						
TA-3	Test Cell South		-50 to 800						
TA-4	Test Cell West		-50 to 800						
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200						
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT2	-425 to 100						
TFBM	Fuel Bypass Manifold		-425 to 100						
TFCO	Film Coolant Orifice	IFT1	-425 to -375						
TFD-Avg	Fire Detection Average		0 to 1000			x			
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500						
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500						
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500						
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500						
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500						
TFJ-1P	Fuel Injection	CFT2	-425 to -390						x
TFJ-2P	Fuel Injection	CFT2a	-425 to 100			x	x		
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to -375						
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -390		x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100						
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400						x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100						x
TFPRS-1	Fuel Pump Rear Support		-400 to 1800						
TFPRS-2	Fuel Pump Rear Support		-400 to 1800						
TFPRS-3	Fuel Pump Rear Support		-400 to 1800						
TFRT-1	Fuel Run Tank		-425 to -400						
TFRT-3	Fuel Run Tank		-425 to -400						
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400				x		
TFTI-4	Fuel Turbine Inlet	GGT2 and GG2	-300 to 2000						
THESL	Helium Tank Supply Line		0 to 150						
THET-1P	Helium Tank	NNT1	-200 to 150						x
THETS-1	Helium Tank Surface		0 to 500						
THETS-2	Helium Tank Surface		0 to 500						
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100				x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100				x		
TNODP	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200						
TOIML	Oxidizer Idle-Mode Line	POT5	-300 to 100						
TOJ	Oxidizer Injection	COT1	-300 to 1200			x			
TOBSC	Oxidizer Pump Bearing Coolant	POT4	-300 to -250						
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250						
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100						
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250						x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100						x
TORT-1	Oxidizer Run Tank		-300 to -285						
TORT-5	Oxidizer Run Tank		-300 to -285						
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200						

TABLE III-1 (Concluded)

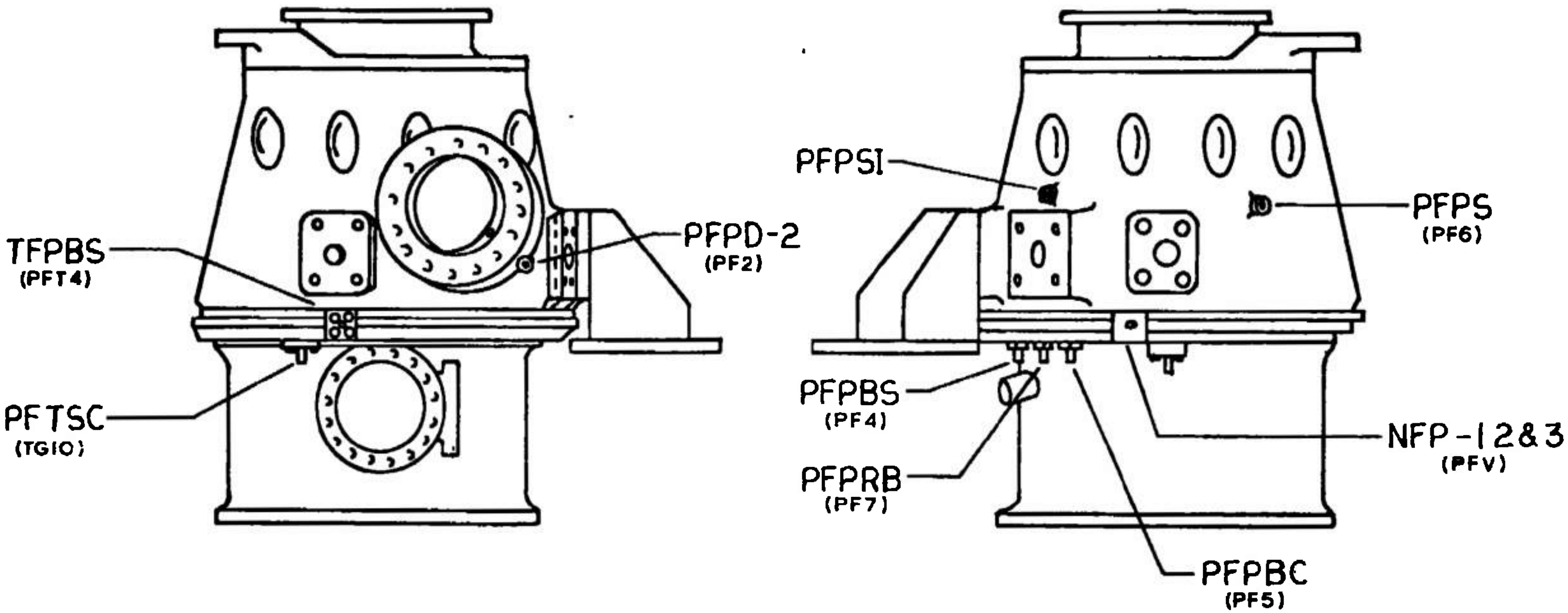
AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures		°F						
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000						
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000						
TPTU	Photocon Cooling Water (Upstream)		0 to 300						
TTCIS-1	Thrust Chamber Internal Skin		-425 to 100						
TTCIS-2	Thrust Chamber Internal Skin		-425 to 100						
TTCIS-3	Thrust Chamber Internal Skin		-425 to 100						
TTCP	Thrust Chamber Purge		-250 to 200						
TTCT-E1	Thrust Chamber Tube (Exit)		-425 to 500						
TTCT-E2	Thrust Chamber Tube (Exit)		-425 to 500						
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500				x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500						
	Vibrations		g's, peak						
UFPR	Fuel Pump Radial	PZA-1	450		x				
UFTR	Fuel Turbine Radial	V123-2	450						
UOPR	Oxidizer Pump Radial	PZA-2	300						
UTCD-1	Thrust Chamber Dome	FZA-1a	100			x			
UTCD-2	Thrust Chamber Dome	FZA-2	100			x			
UTCD-3	Thrust Chamber Dome	FZA-3	100			x			
UTCT-1	Thrust Chamber Throat		300						
UTCT-2	Thrust Chamber Throat		300						
	Voltage		v						
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36						
VIDA-1	Ignition Detect Amplifier		9 to 16						
VIDA-2	Ignition Detect Amplifier		9 to 16						
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5						

*Effective J4-1902-06

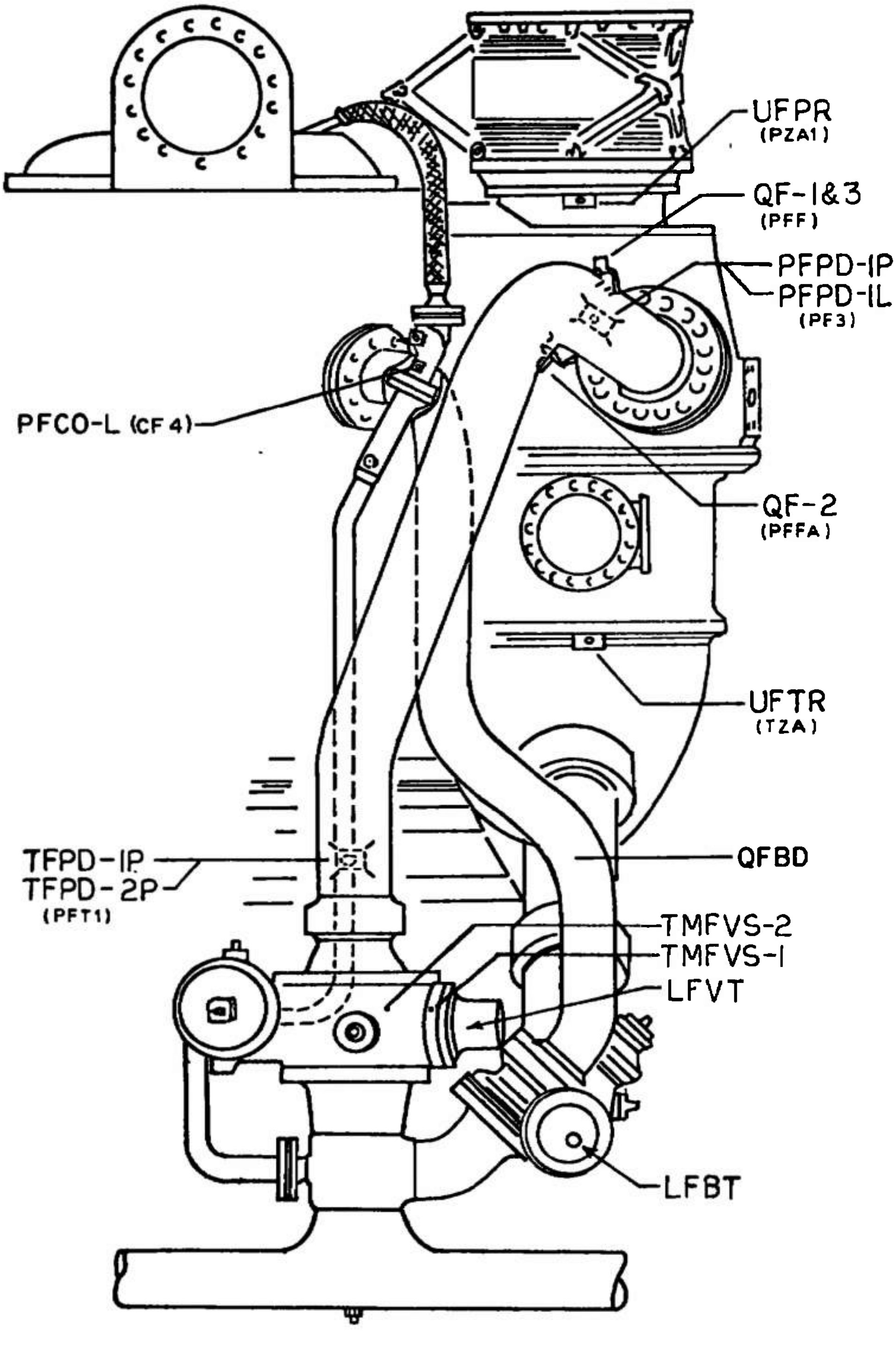


a. General Arrangement

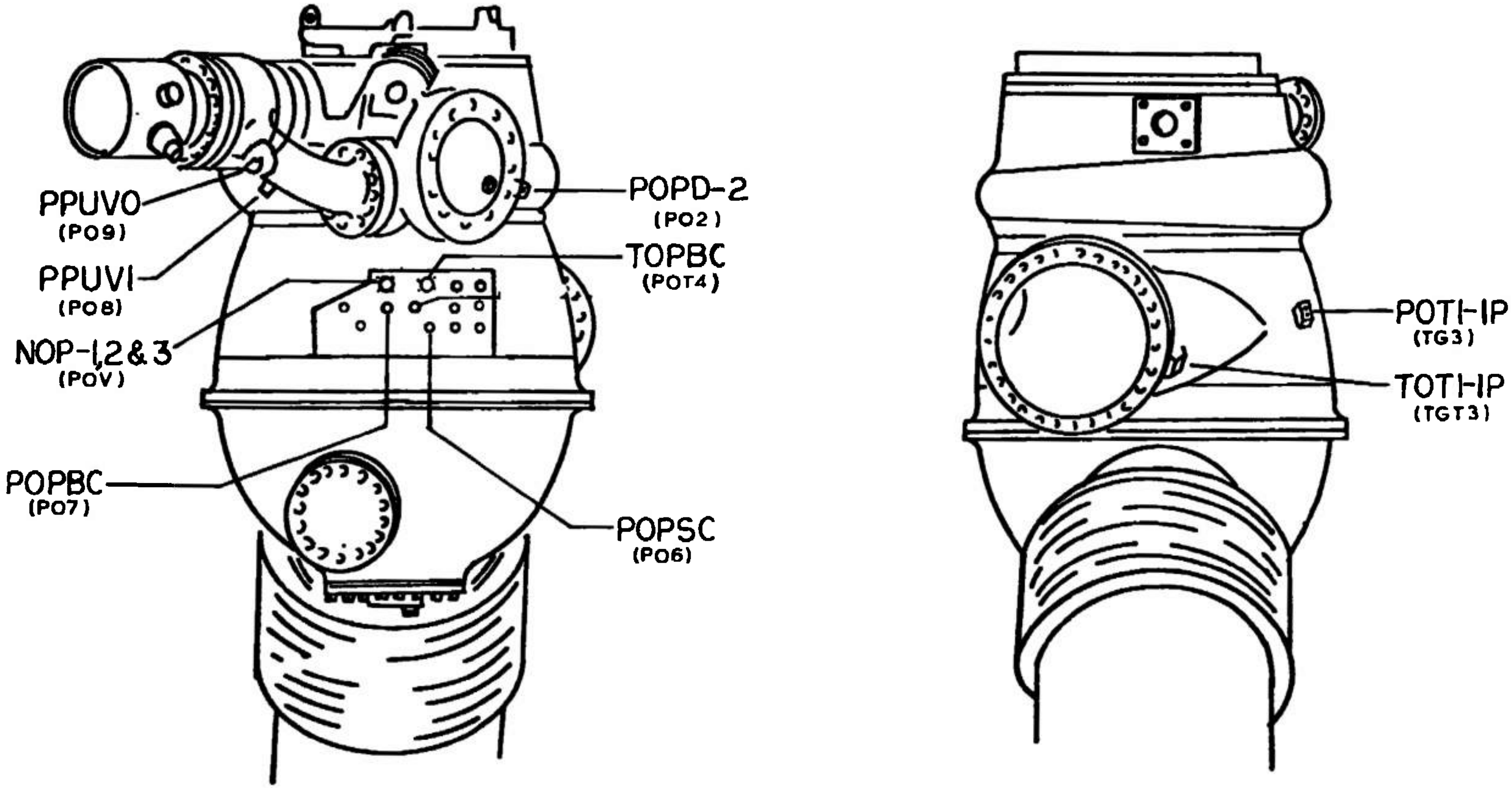
Fig. III-1 Selected Sensor Locations



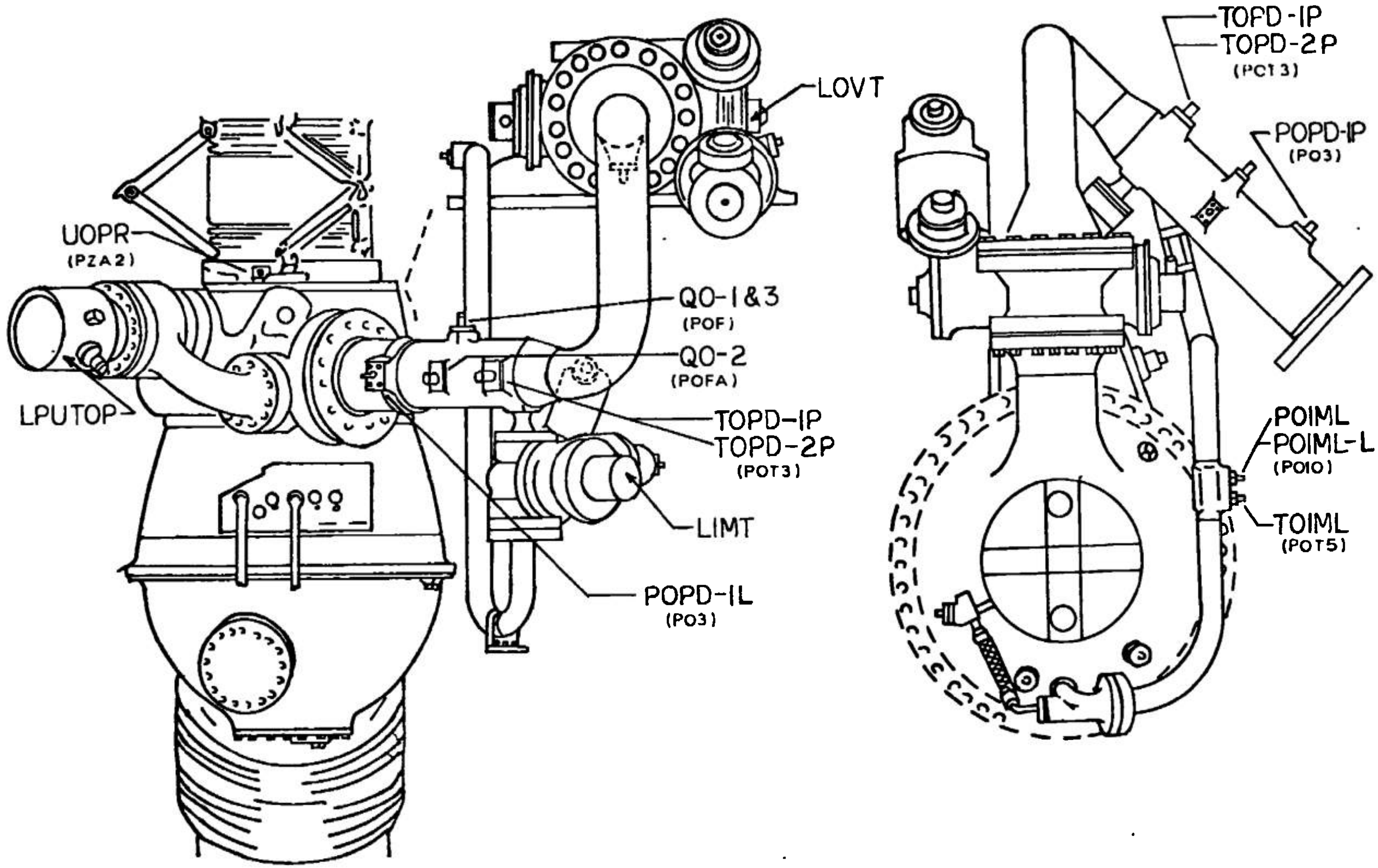
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



c. Fuel System Sensor Locations
Fig. III-1 Continued

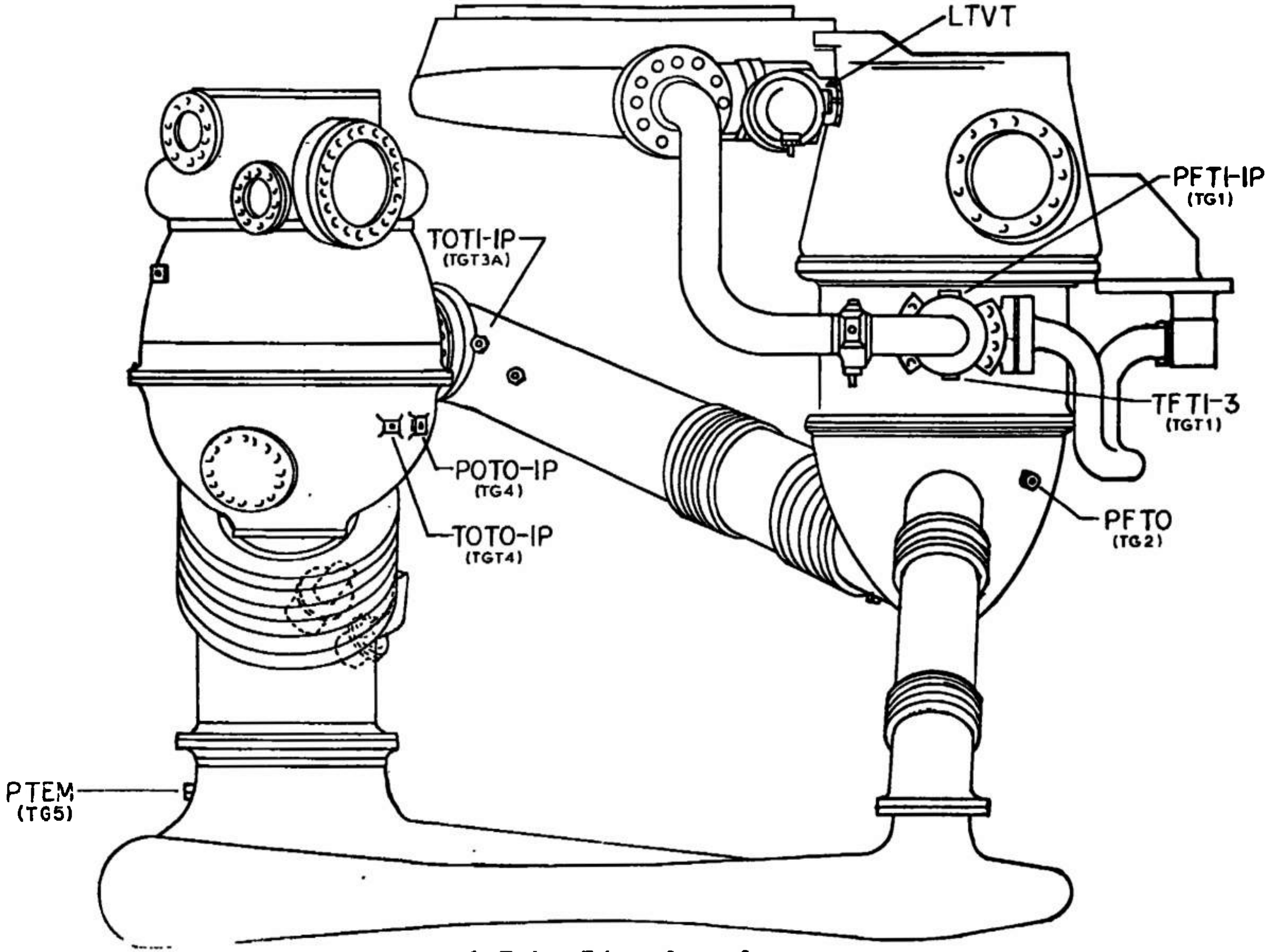


d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued



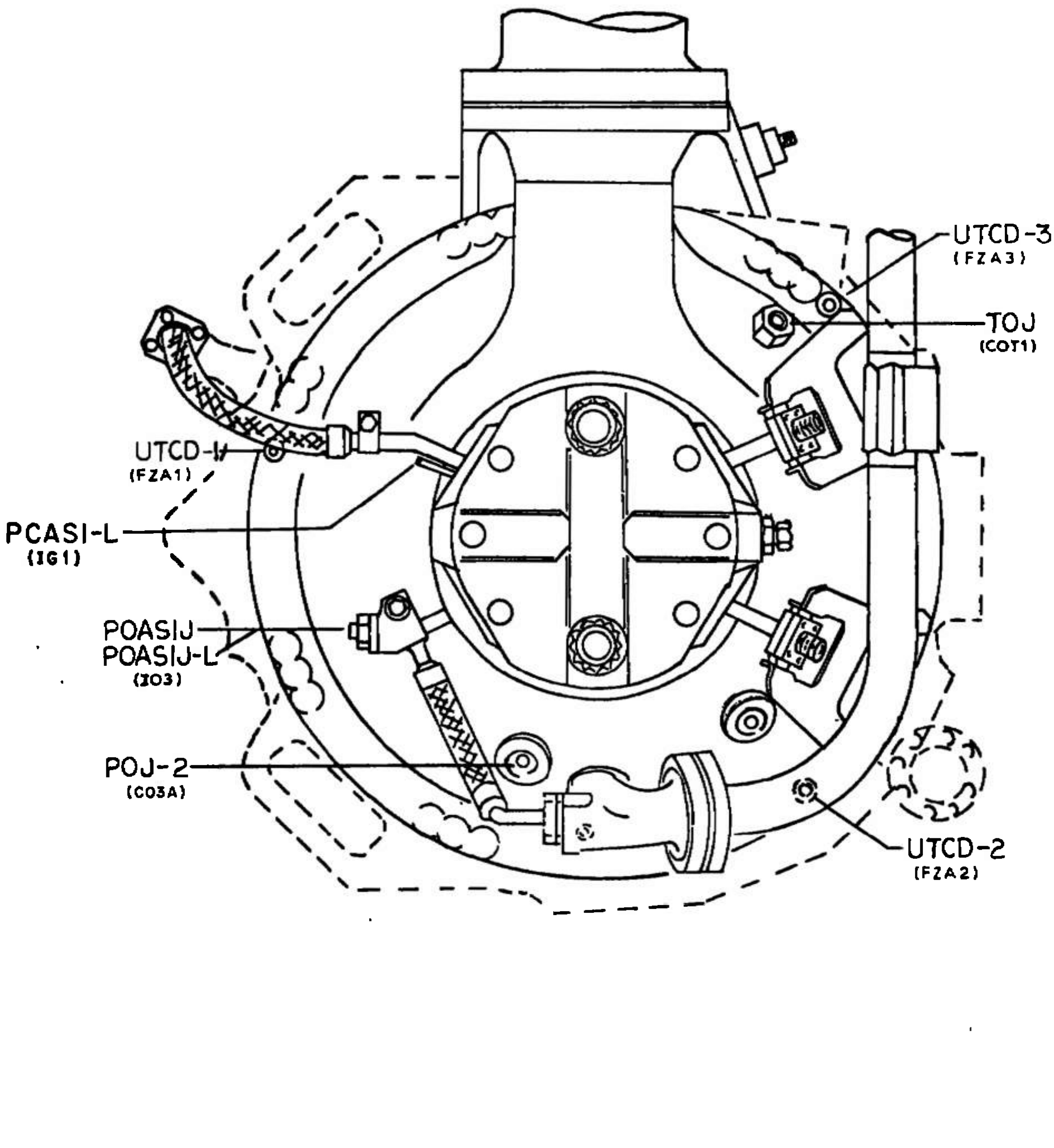
e. Oxidizer System Sensor Locations

Fig. III-1 Continued



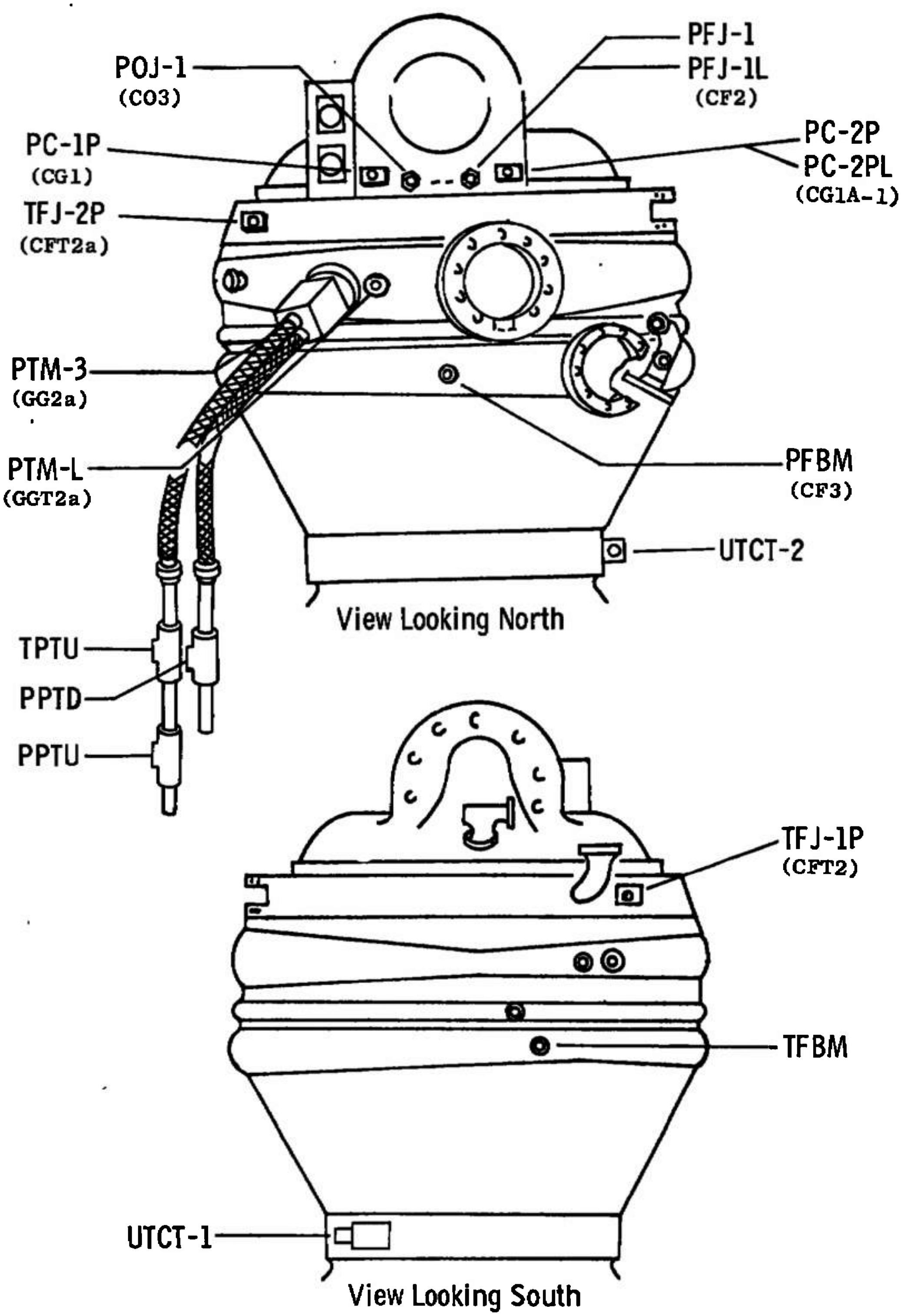
f. Turbine Exhaust System Sensor

Fig. III-1 Continued



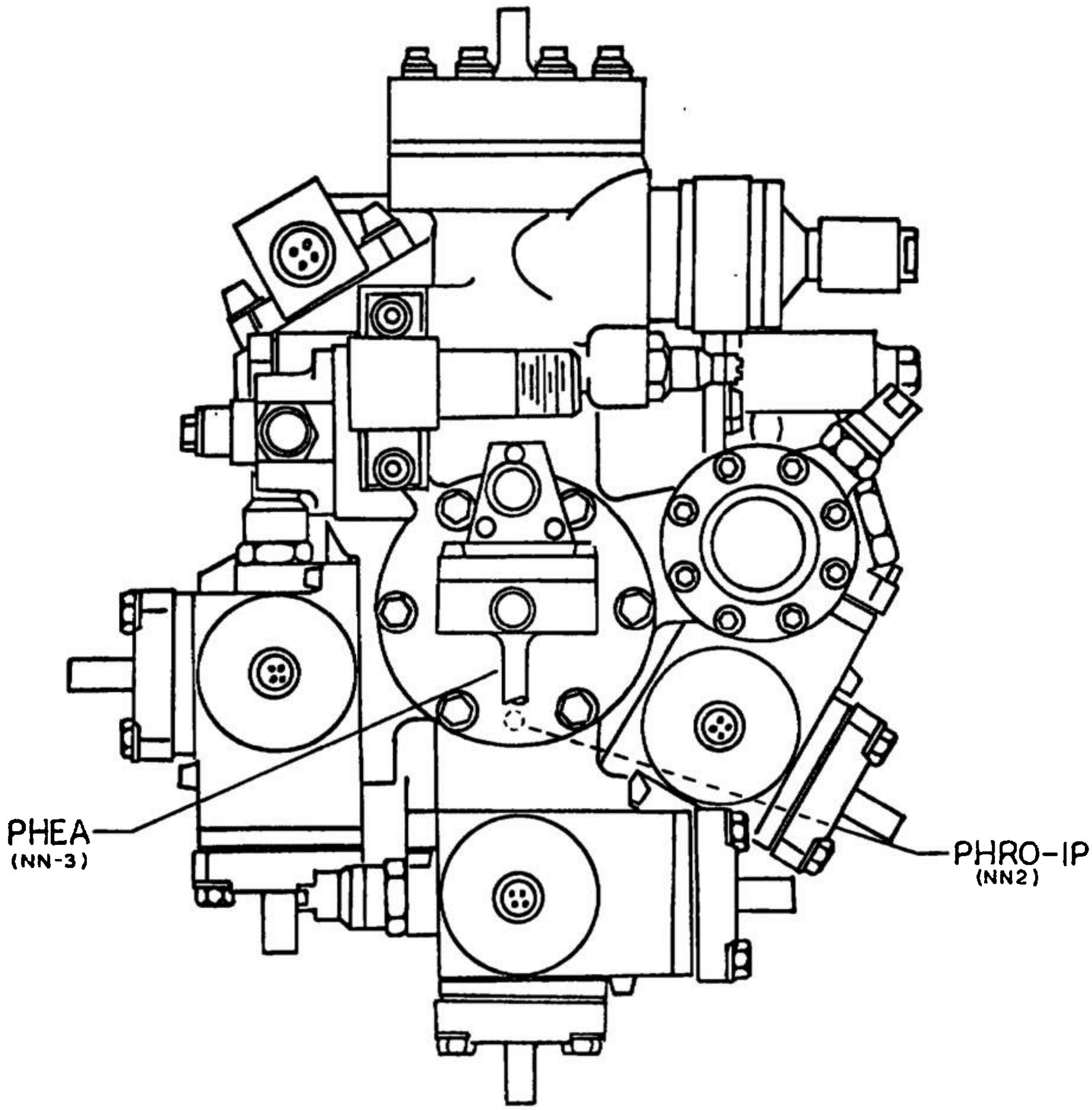
g. Thrust Chamber Injector Sensor Locations

Fig. III-1 Continued

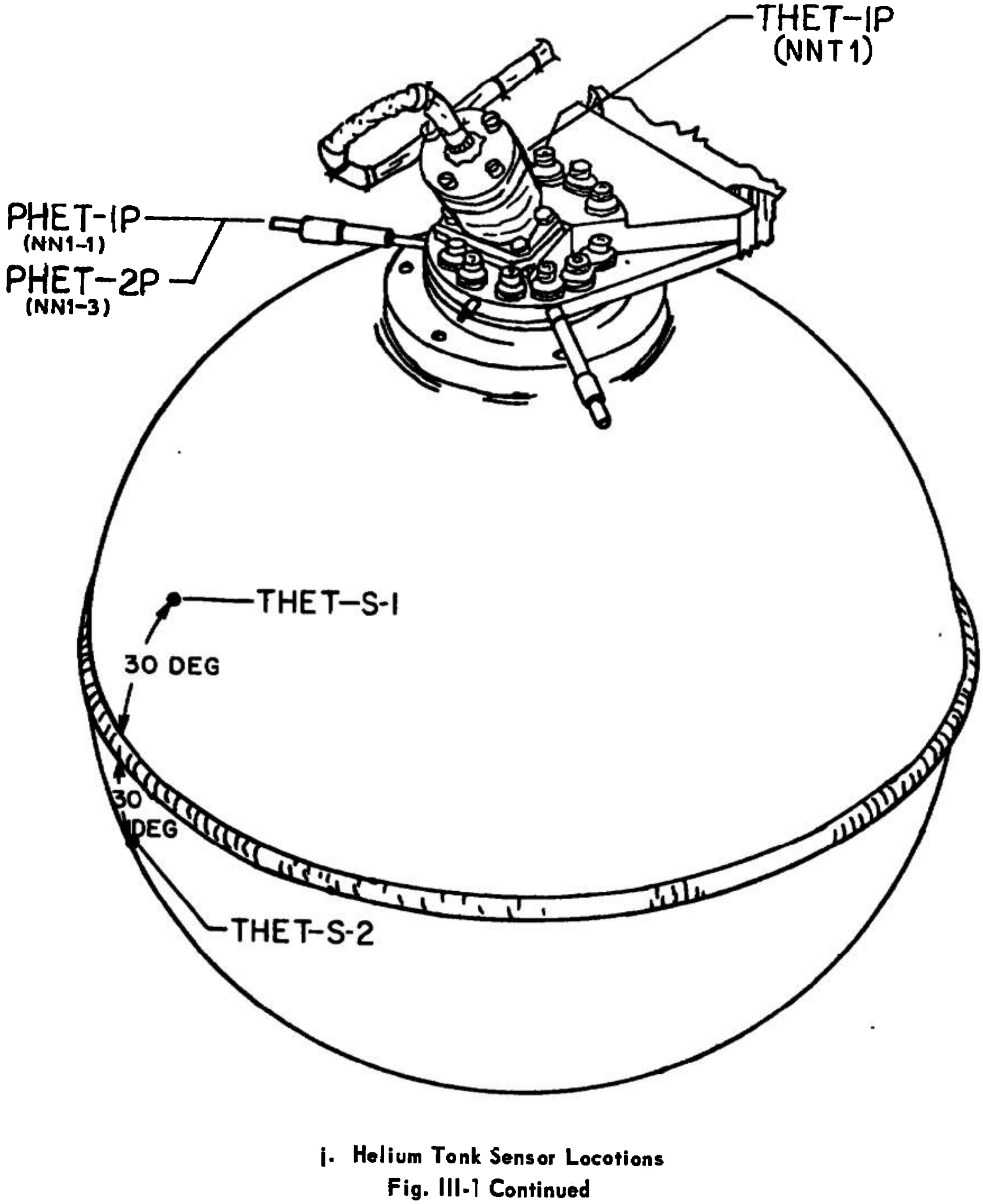


h. Thrust Chamber Sensor Locations

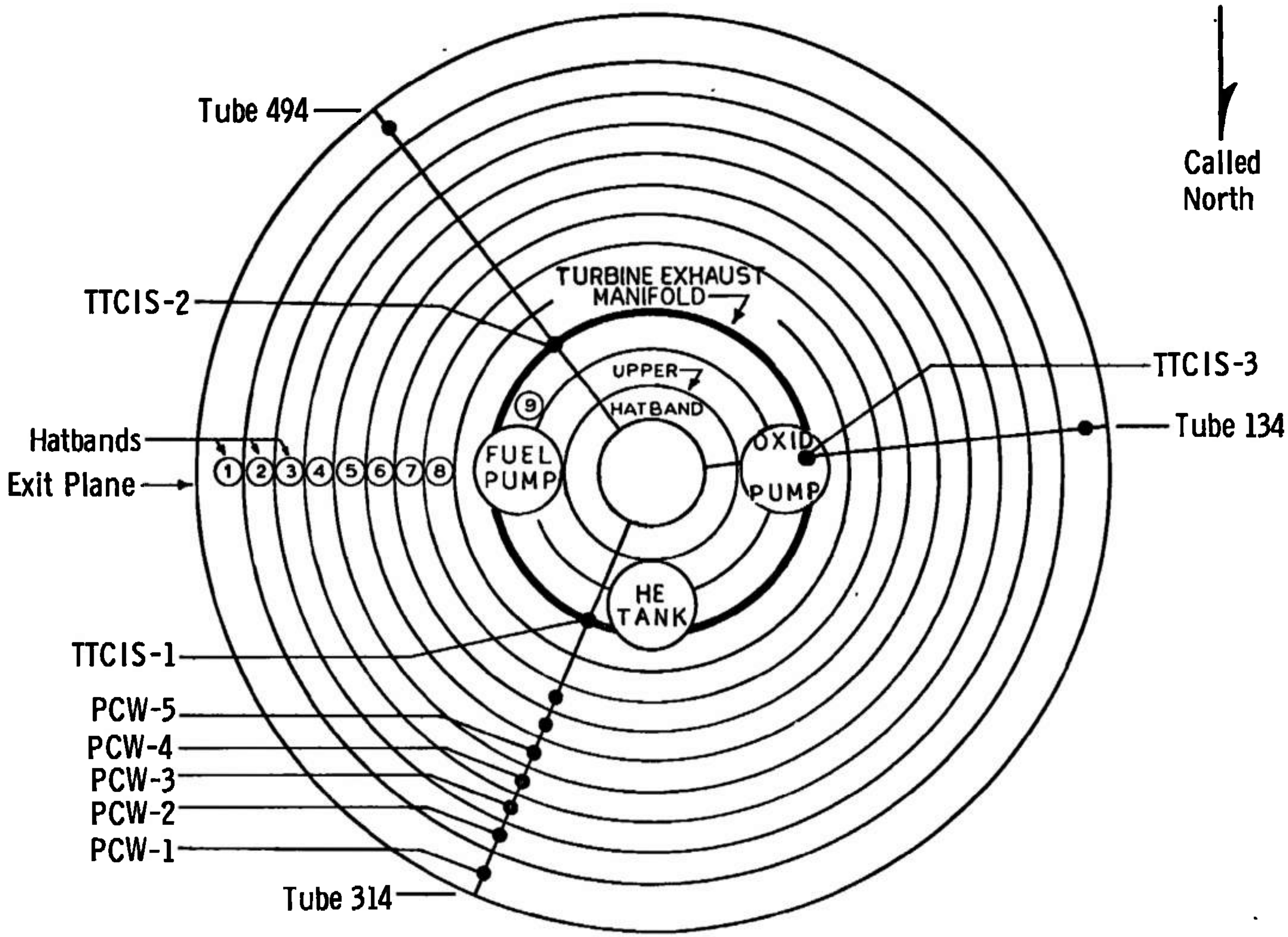
Fig. III-1 Continued



i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued

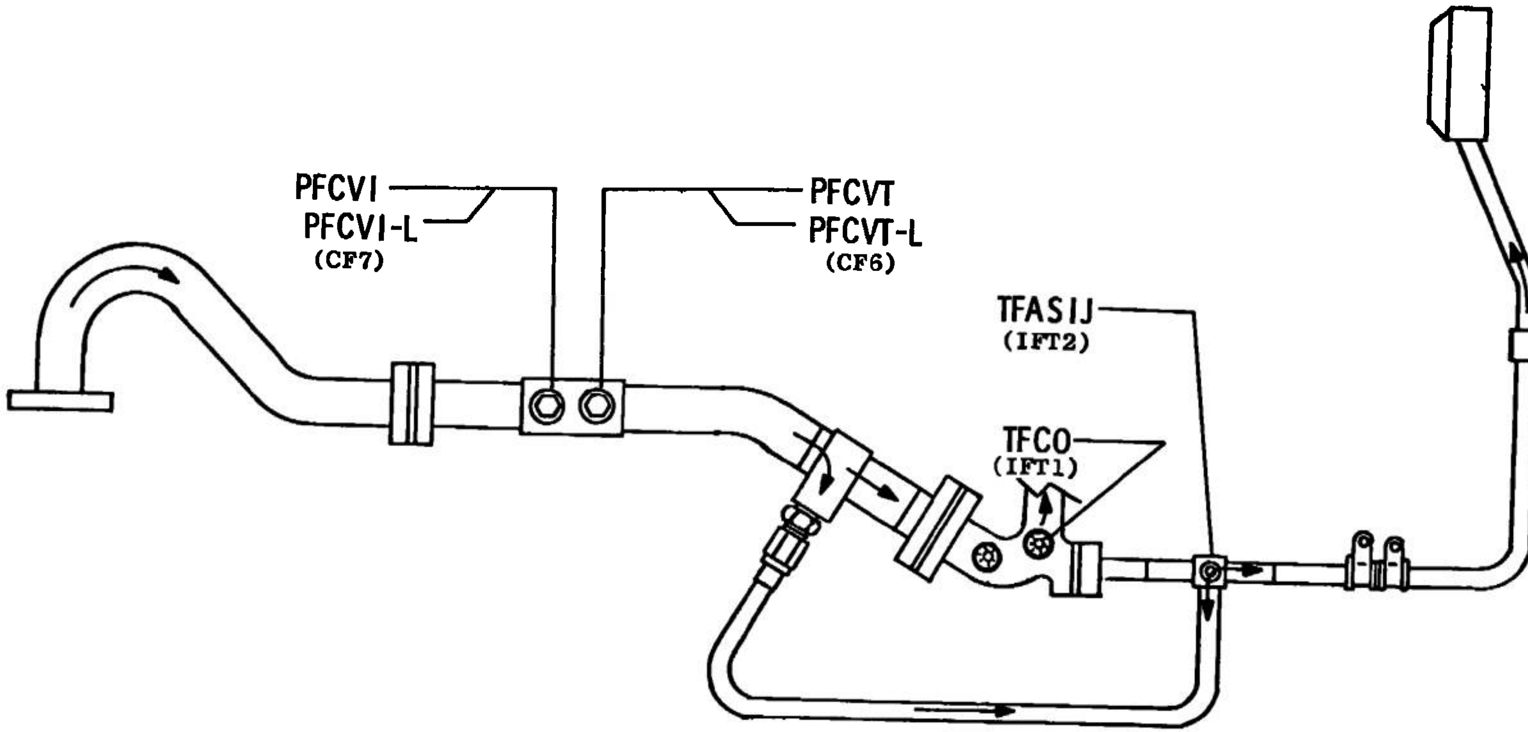


j. Helium Tank Sensor Locations
Fig. III-1 Continued

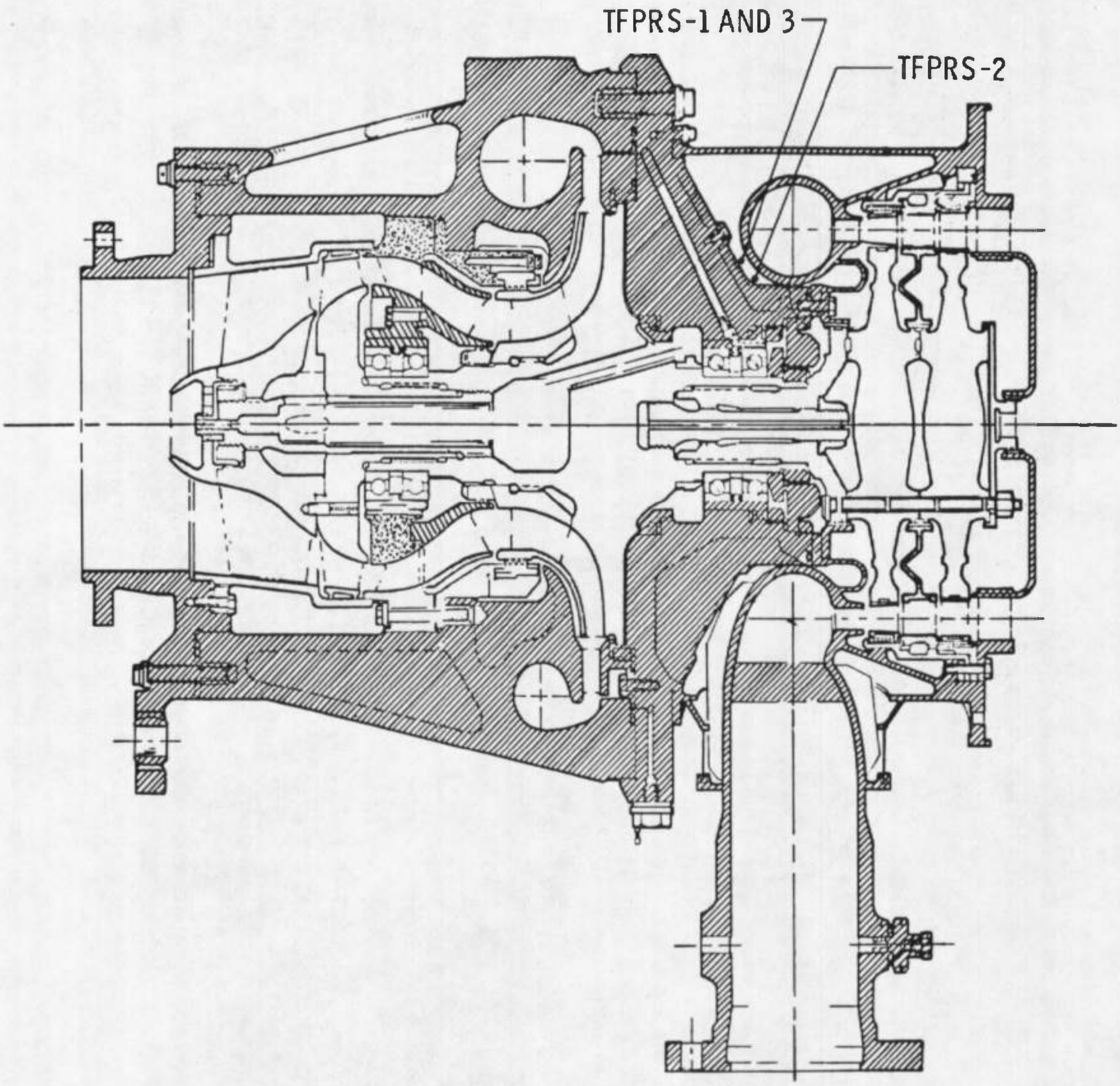


View Looking Aft

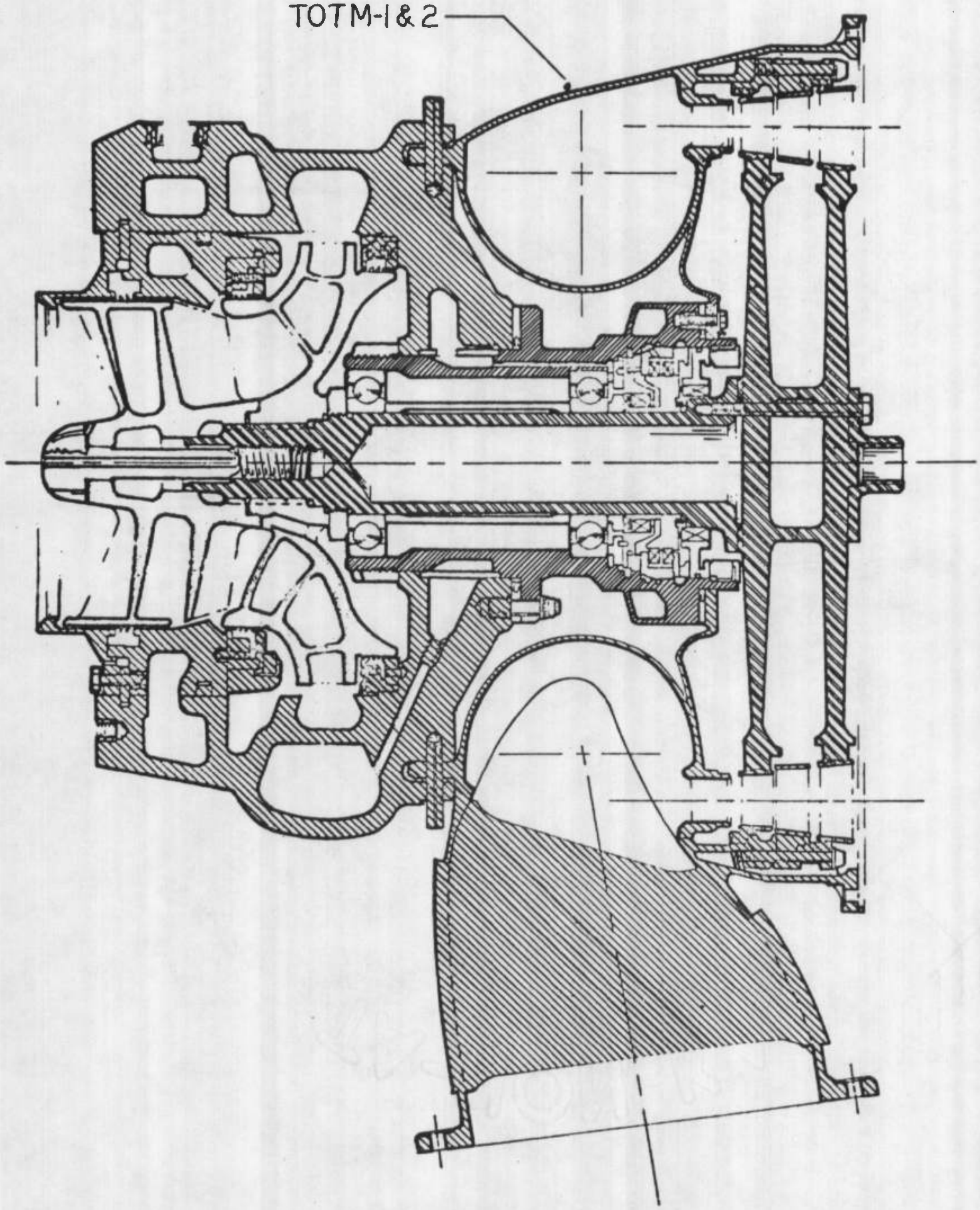
k. Thrust Chamber Instrumentation
Fig. III-1 Continued



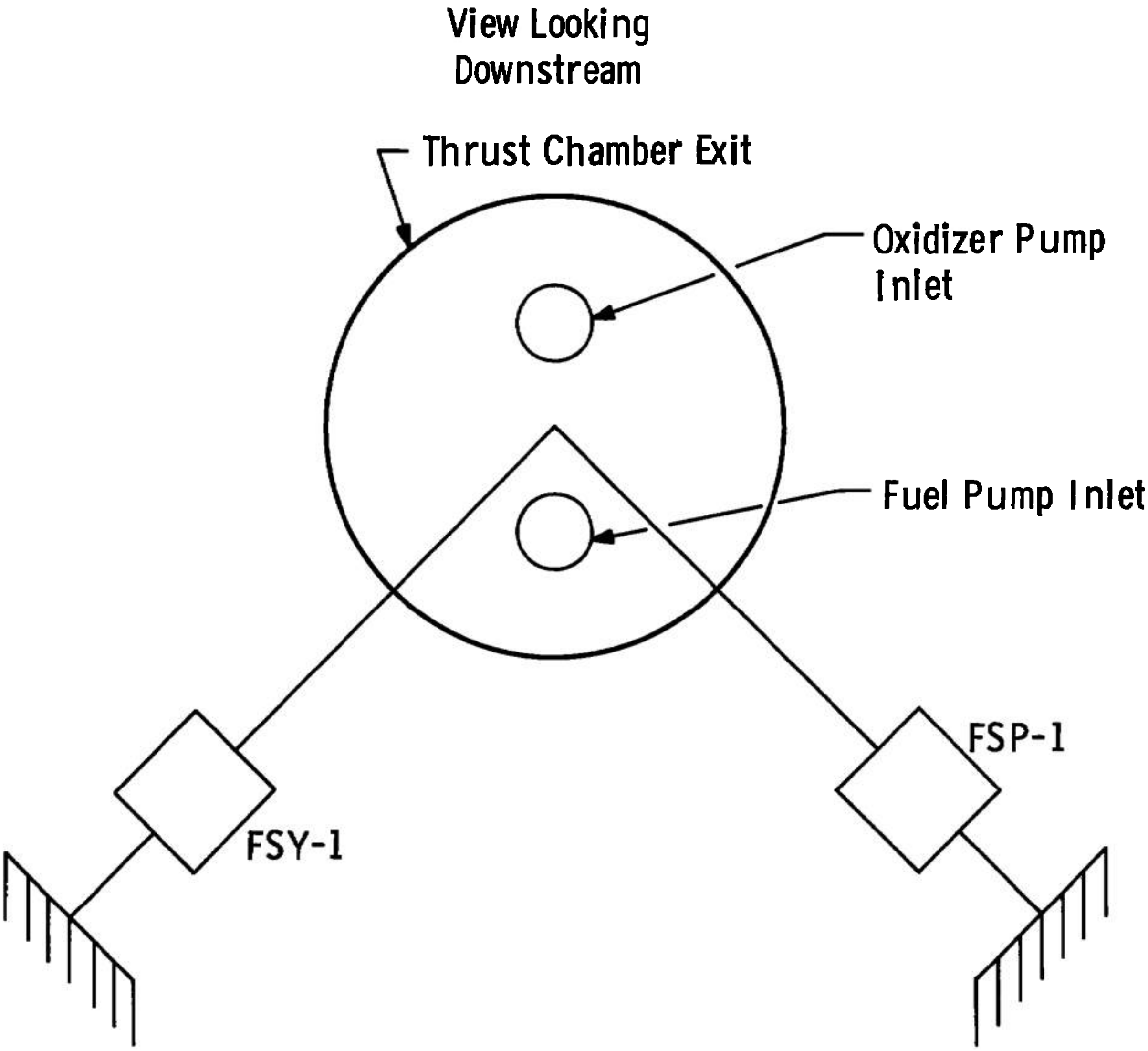
I. Augmented Spark Igniter/Film Coolant Fuel Line Assembly Instrumentation
Fig. III-1 Continued



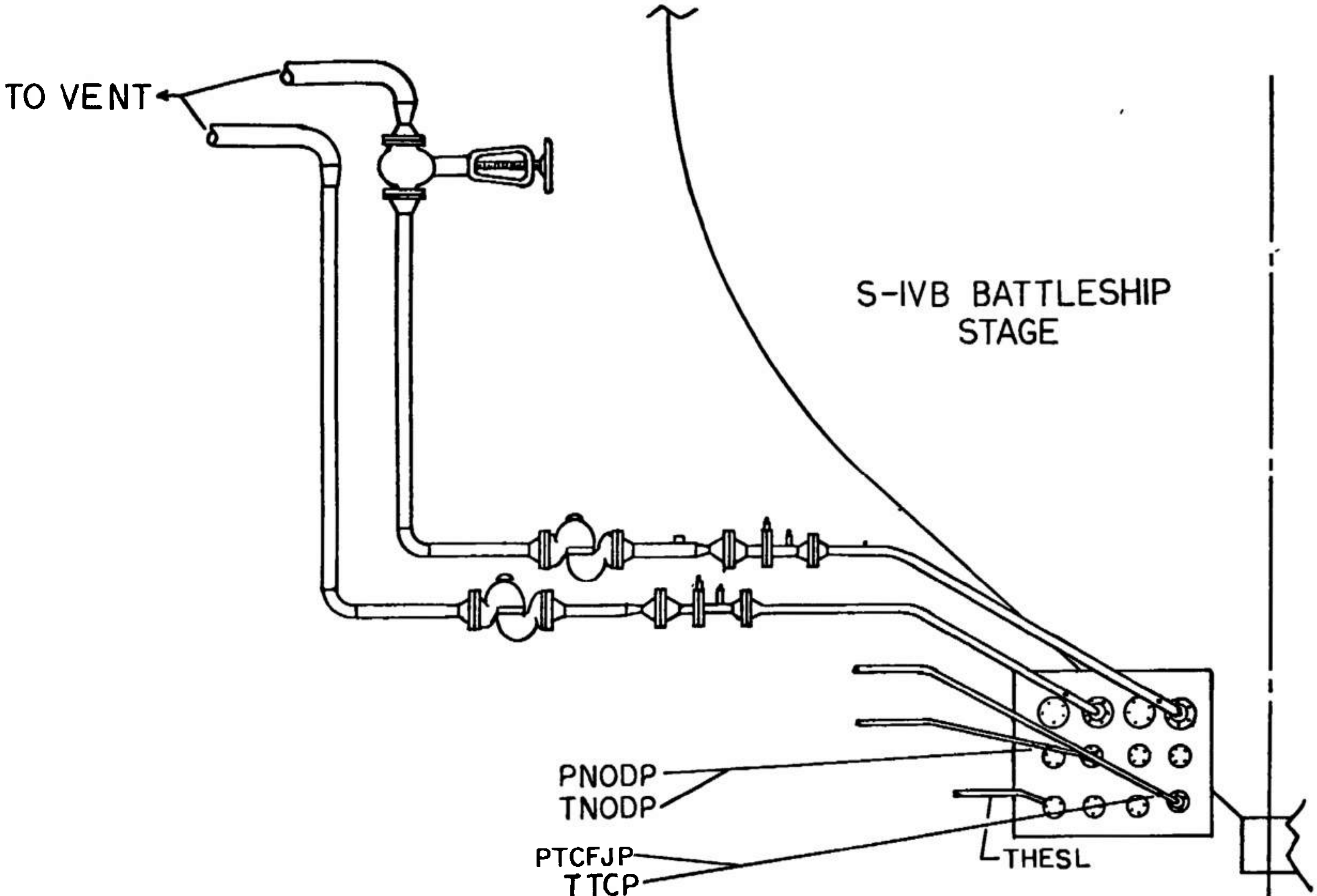
m. Fuel Turbine Sensor Locations
Fig. III-1 Continued



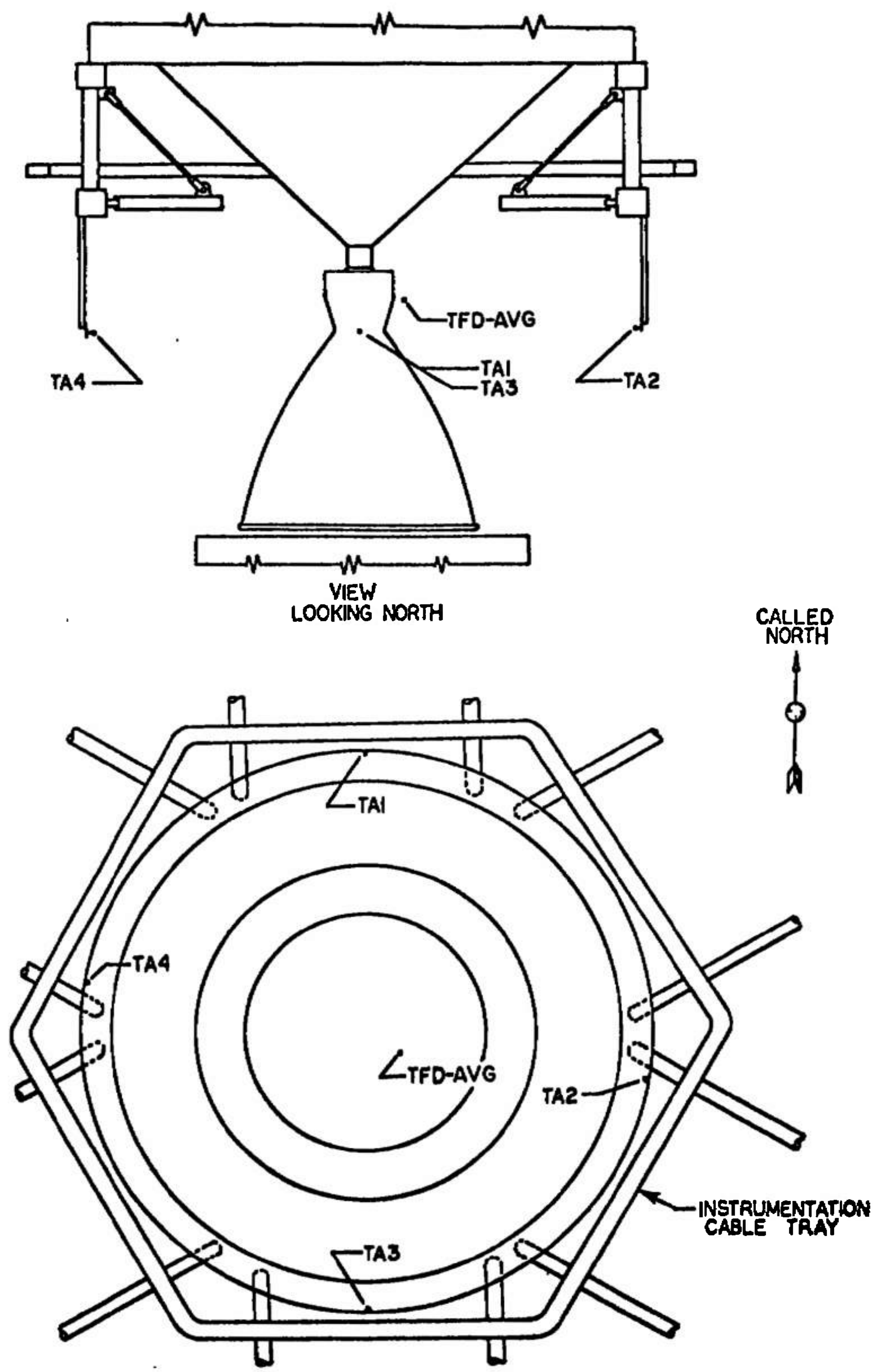
n. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



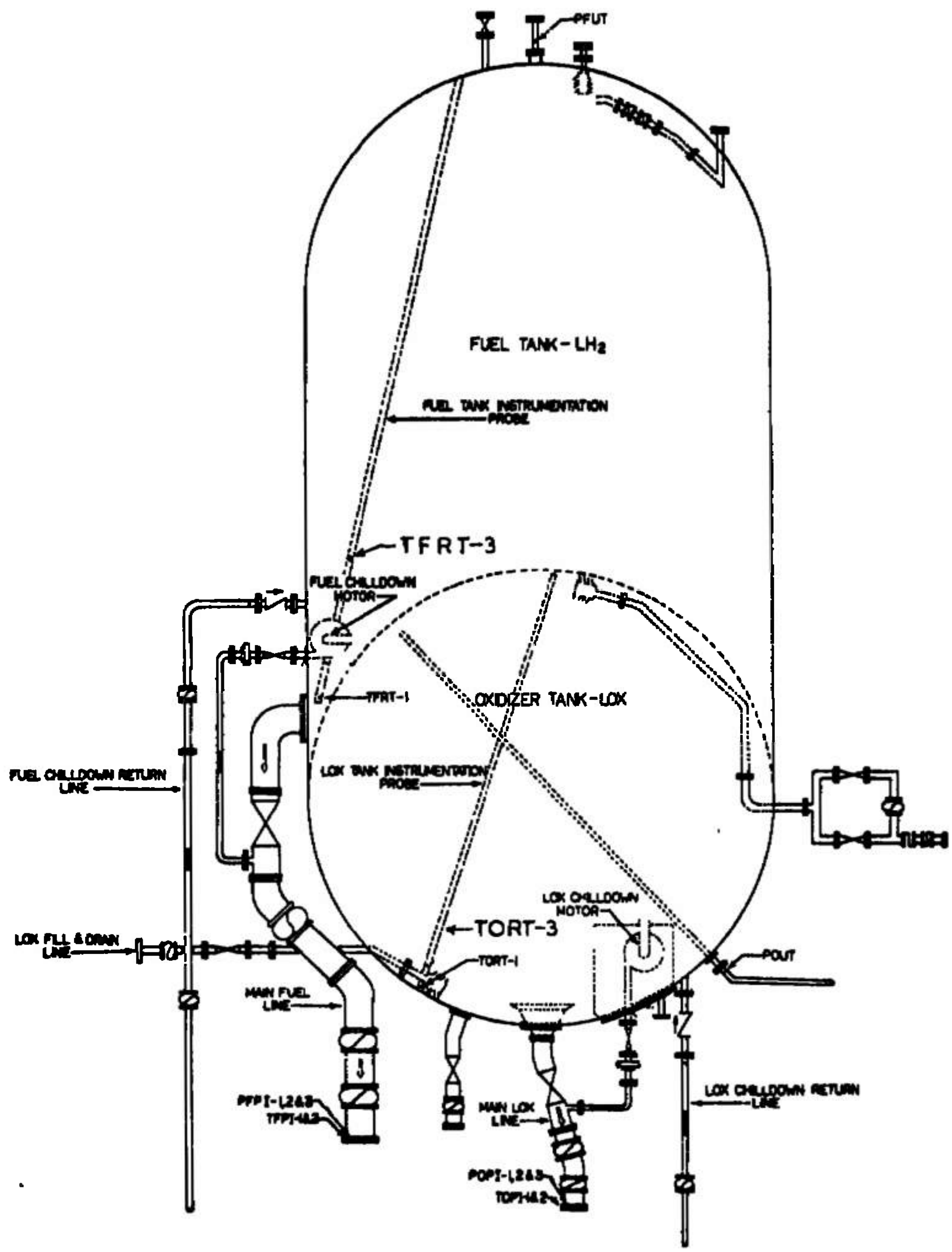
o. Side Load Forces Sensor Locations
Fig. III-1 Continued



p. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



q. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



r. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS

NOMENCLATURE

A	Area, in.^{2}
CF	Coefficient of thrust
C*	Characteristic velocity, ft/sec
F	Thrust, lb_f
I	Impulse, sec
O	Oxidizer
P	Pressure, psia
W	Flow rate, lb_m/sec
ρ	Density, lb_m/ft^3

SUBSCRIPTS

a	Ambient
c	Chamber
e	Exit
eff	Efficiency
f	Fuel
fc	Film coolant
imc	Idle-mode compartment
inj	Injector
ns	Nozzle static
o	Oxidizer
sp	Specific
t	Total
vac	Vacuum

SUPERSCRIPTS

*	Throat

CALCULATIONS

I. IDLE-MODE PERFORMANCE

A. THEORETICAL (IDEAL)

Calculations of theoretical rocket performance for chemical composition during an isentropic expansion were made by iterative computations using the method of calculations presented in Refs. 6 and 7. Computations were based on an enthalpy-entropy analysis, and program inputs were (1) reactants, (2) enthalpy of reactants, (3) stagnation pressure, (4) stagnation-to-static pressure ratio, and (5) nozzle exit area ratio. Enthalpy of reactants was obtained from Refs. 8 and 9 for hydrogen and oxygen, respectively.

B. ACTUAL

Flow Rates

1. Total Propellant Flow Rate

$$W_t = W_f + W_o$$

2. Injector Flow Rate

$$W_{inj} = W_f - W_{fc}$$

3. Idle-Mode Compartment Fuel Flow Rate

$$(W_f)_{imc} = \frac{(A_f)_{imc}}{(A_f)_{inj}} W_f$$

Mixture Ratio

1. Total Propellant Mixture Ratio

$$O/F = \frac{W_o}{W_f}$$

2. Idle-Mode Compartment Mixture Ratio

$$O/F_{imc} = \frac{W_o}{(W_f)_{imc}}$$

Thrust

1. Thrust at $P_{ns} = P_a$

$$F_{vac} = P_c A^* (CF)_{ideal}$$

2. Vacuum Thrust

$$F_{vac} = P_c A^* (CF_{vac})_{ideal}$$

where

$$(CF_{vac})_{ideal} = (CF)_{ideal} + \frac{A_e}{A^*}\frac{P_e}{P_c}$$

and

$$(CF)_{ideal} = F\left(\frac{O}{F}, P_c, \frac{A_e}{A^*}\right) \text{ (from Refs. 5 and 6)}$$

Vacuum Specific Impulse

$$(I_{sp})_{vac} = \frac{F_{vac}}{W_t}$$

Characteristic Velocity

$$C^* = \frac{P_c A^* g}{W_t}$$

Characteristic Velocity Efficiency

$$C^*_{eff} = \frac{C^*}{C^*_{ideal}}$$

II. PROPELLANT FLOW RATES

Propellant flow rates are based on engine flowmeter constants supplied by the engine manufacturer: 5.50 and 2.00 Hz per gal for the oxidizer and fuel flowmeters, respectively. Propellant properties for conversion of volumetric to weight flow was obtained from Refs. 8 and 9 for hydrogen and oxygen, respectively.

III. FUEL INJECTION DENSITY

Fuel injection density was estimated using the following equation supplied by the engine manufacturer:

$$\rho = \frac{K[(W_f)_{inj}]^2}{(P_{inj} - P_c)}$$

where

$$K = 0.01106$$

IV. FUEL FILM COOLANT FLOW

Fuel film coolant flow was estimated by using the standard Venturi flow equation

$$\dot{W} = C_D A\sqrt{2g(144)\,\Delta P\rho}$$

and

$$\left.\begin{aligned} C_D &= 0.97 \\ A &= 5.75 \times 10^{-3}\ \text{ft}^2 \end{aligned}\right\}\ \text{supplied by engine manufacturer}$$

thus,

$$\dot{W} = 0.311\sqrt{\rho\Delta P}\ \ \text{lb}_m/\text{sec}$$

where

$$\Delta P = \text{PFCVI} - \text{PFCVT}$$

$$\rho = \rho\,(\text{PFJ, TFJ})$$

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

March 6 through 20, 1969 - Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*

W. W. Muse and C. H. Kunz, ARO, Inc.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

Seven idle-mode firings of the J-2S rocket engine (S/N J-112-1) were conducted during test periods J4-1902-05 through J4-1902-07 between March 6 and 20, 1969, in Test Cell J-4 of the Large Rocket Facility. The objectives of these firings were to determine the effect of restricting fuel bypass and thrust chamber film coolant flows on fuel density at the injector and idle-model performance. Reduction of fuel bypass flow from 2 lb_m/sec to zero resulted in a 20-percent reduction in calculated fuel density at the injector; reduction of film coolant flow from 1 lb_m/sec to zero apparently had no effect on calculated density at the injector. Essentially no performance differences were noted in engine steady-state, idle-mode performance because of reduction of these flows. No significant engine damage was sustained on any of the firings. Total accumulated engine idle-mode firing duration was 656.5 sec.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
rocket engines						
liquid propellants						
altitude simulation						
performance evaluation						

1. Rocket motors -- Performance

" -- J-2S

2 "

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