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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J4-1001-08 THROUGH -10 AND J4-1001-12 THROUGH -14)

C. H. Kunz and J. F. Saunders

ARO, Inc.

June 1970

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ENGINE TEST FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

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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 Element 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc., (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; 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 September 2 and October 15, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF) under ARO Project No. RN1001. The manuscript was submitted for publication on April 29, 1970.

This technical report has been reviewed and is approved.

Walter C. Knapp
Lt Colonel, USAF
AF Representative, ETF
Directorate of Test

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

ABSTRACT

Ten idle-mode firings of the J-2S rocket engine S/N J-112 were conducted during test periods J4-1001-08 through J4-1001-10, and J4-1001-12 through J4-1001-14 between September 2 and October 15, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility. The primary objectives of these firings were to determine engine idle-mode operating characteristics at various engine mixture ratios utilizing a new noncompartmented injector. Engine performance, as indicated by characteristic velocity, was 120 percent higher than experienced with previous compartmented injector designs at nominal pump inlet conditions. Total accumulated engine idle-mode operation was 1408.2 sec.

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NOMENCLATURE

A	Area, sq in.
ASI	Augmented spark igniter
*C	Characteristic velocity, ft/sec
CCP	Customer connect panel
C_D	Discharge coefficient
EBW	Exploding bridgewire

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 vibrations in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress since December 1968 at AEDC. The ten firings reported herein were idle-mode tests conducted with research and development engine S/N J-112 during test periods J4-1001-08 through -10, and J4-1001-12 through -14.

The firings were accomplished in Rocket Development Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Engine Test Facility (ETF). The firings were accomplished at pressure altitudes ranging from 91,000 to 111,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Data collected for evaluating engine idle-mode performance and operating characteristics 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 lbf and mixture ratio of 2.5, or at main stage at any precalibrated thrust level between 230,000 and 265,000 lbf 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, Ref. 2) 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 sq in., respectively. The oxidizer enters the injector during idle-mode operation by way of a manifold which provides even distribution of oxidizer over the entire injector. 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-lbf 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-lbf 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 fully 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 cu in. 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 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 lbm of liquid hydrogen and 194,000 lbm 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

Rocket Development 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), 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. 3.

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. Vibrations were measured by accelerometers mounted on the oxidizer injector dome, thrust chamber throat, and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

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

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.

Low thrust idle mode was accomplished by sequencing the engine for operation with the main fuel valve, idle-mode oxidizer valve, and thrust chamber bypass valve in the open positions and the main oxidizer and hot gas tapoff valves in the closed positions.

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 used during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

Test data from idle-mode firings J4-1902-01 through -04 (Ref. 4) revealed that idle-mode performance at simulated altitude conditions was much lower than expected. During idle-mode firing J4-1902-04, major damage to the combustion chamber and injector was experienced. Idle-mode firings during test periods J4-1902-05 through -07 (Ref. 5) revealed that restricting thrust chamber fuel bypass and film coolant flows did not result in a significant change in engine performance. Idle-mode firings J4-1902-09 and -10 (Ref. 6) with a redesigned injector (oxidizer routed through the tenth row of injector posts rather than through the inner four) did not show any significant change in engine performance. Test periods J4-1902-16 and -17 (Ref. 7) and J4-1001-05 (Ref. 8) simulated a noncompartmented (full face oxidizer flow) injector by opening the main oxidizer valve to the first-stage position and flowing oxidizer through all of the oxidizer posts during idle-mode operation. Data from these firings indicated that a significant increase in idle-mode performance could be gained with the noncompartmented injector design.

The first noncompartmented injector was fabricated and installed on engine S/N J-112 before test period J4-1001-06. The firings reported herein were conducted to determine engine idle-mode operating characteristics and performance at simulated altitude conditions with this new injector design. Operation of the engine before test period J4-1001-08 had produced damage to the thrust chamber tubes in the combustion zone. Although the significant damage was repaired by in-place welding, small fuel leaks existed between the tubes and the combustion zone. Some tube blockage and surface irregularities also existed as a result of the weld repairs.

4.2 TEST SUMMARY

Ten low thrust idle-mode firings of the J-2S rocket engine S/N J-111 were conducted between September 2 and October 15, 1969, between test periods J4-1001-08 through -10 and J4-1001-12 through -14. 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, propellant system chilldown data, propellant system performance, and selected engine performance parameters are presented in Figs. 9 through 38, respectively.

Accumulated idle-mode firing duration for these ten firings was 1408.2 sec. Data presented herein are from the digital data acquisition system except where indicated otherwise. Methods of calculations are shown in Appendix IV. 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 table on the following page.

4.3 TEST RESULTS

4.3.1 Firing J4-1001-08A

The objective of this firing was to determine long-duration engine idle-mode operating characteristics and performance at five mixture ratios.

Test objectives were not completely satisfied because of difficulty in controlling oxidizer pump inlet pressures. This difficulty was attributed to operator/monitor coordination problems and was corrected for subsequent tests. Oxidizer pump inlet pressures decreased 20 psi from the required pressure 18 sec after engine start (Fig. 10b). After a duration of 13 sec, the oxidizer inlet pressure returned to its original level. This pressure drop may have resulted from partial closure of the oxidizer recirculation valve; however, since the open talkback from this valve was inoperative, this could not be verified. Fuel pump impeller speed reached a peak of 1800 rpm, 100 sec after engine start with a corresponding pressure rise across the fuel pump of 2.0 psi at that time (Fig. 39).

Both oxidizer and fuel appeared to be subcooled at the oxidizer and fuel pump discharge ducts 100 sec after engine start. Engine performance calculations were based on flow data obtained from the recirculation system flowmeters. The firing was terminated 223 sec after engine start upon depletion of the steam supply to the facility main steam ejector.

4.3.2 Firing J4-1001-09A

The objective of this firing was to determine long-duration engine idle-mode operating characteristics and performance at five mixture ratios.

Test data indicated tapoff valve leakage sufficient to result in a gradual increase in fuel pump impeller speed to 2200 rpm resulting in equal pump inlet and discharge pressures at engine cutoff. The high impeller speed and low head rise indicated pump cavitation attributable to poor fuel quality.

Firing J4-1001-	Time from t-0, sec	Propellants on Engine Valves, min	Oxidizer Idle-Mode Orifice Diameter, in.	Pump Inlet Pressure Oxidizer, psia	Pump Inlet Pressure Fuel, psia	Pump Discharge Pressure Oxidizer, psia	Pump Discharge Pressure Fuel, psia	Total Flow Rate, lbm/sec	Oxidizer-to-Fuel Mixture Ratio, O/F	Combustion Chamber Pressure, psia	Vacuum-Corrected Calculated Axial Thrust, lbf	C* Efficiency, percent	Vacuum-Corrected Specific Impulse, sec
08A	100	0	0.977	40.7	33.7	42.9	38.1	15.3	1.08	24.7	5010	86.0	328
	140			37.8	39.8	39.8	40.5	16.6	1.51	28.7	5860	86.5	354
	180			35.0	39.4	36.7	40.2	15.5	1.33	28.0	5700	91.9	367
09A	80	0		42.4	27.3	43.1	25.0	-	-	19.7	-	-	-
	120			32.5	27.3	33.1	25.0	-	-	18.8	-	-	-
	160			32.4	19.8	33.0	19.8	-	-	15.8	-	-	-
	200			38.5	20.4	39.1	20.5	-	-	17.9	-	-	-
	260			45.8	20.0	45.9	20.2	-	-	18.8	-	-	-
10A	40	60		32.3	39.8	34.7	40.7	16.3	1.08	27.8	5630	90.3	345
	80			38.8	40.1	41.3	39.8	19.1	1.32	32.6	6630	87.0	347
	120			39.8	32.8	40.3	33.6	11.5	1.82	29.8	6110	83.0	351
	180			46.0	33.5	46.5	35.5	19.3	1.97	32.0	8590	79.7	340
	200			46.4	39.9	46.2	40.0	20.8	1.52	33.9	6920	81.8	335
	260			46.3	27.2	46.6	32.5	16.2	4.83	30.3	6760	91.8	417
12A	180	0	1.033	33.3	40.3	33.9	36.2	24.2	1.77	22.9	4890	46.1	194
13A	90	12		33.0	34.3	33.3	34.0	18.2	1.34	28.2	5740	79.0	316
B	19	90		44.0	20.4	44.0	21.5	-	-	19.6	-	-	-
C	25	60		44.9	27.3	45.3	29.9	-	-	28.9	-	-	-
14A	140	0	0.977	34.3	33.5	35.1	30.9	-	-	20.6	-	-	-
B	40	70		43.0	27.8	43.5	30.8	15.1	4.93	27.9	6250	91.5	414
C	90	120		34.1	33.3	34.8	30.3	18.0	1.81	25.7	5290	78.8	331

Thrust chamber throat external temperature, presented in Fig. 14e, attained 375°F. Oxidizer and fuel did not become subcooled at their respective pump discharge ducts and flowmeters; thus, valid performance calculations could not be made. Posttest inspection revealed some engine thrust chamber tube damage (see Section 4.7).

4.3.3 Firing J4-1001-10A

The objective of this firing was to determine long-duration engine idle-mode operating characteristics and performance at various mixture ratios.

Thrust chamber throat external temperature attained 190°F before engine cutoff (Fig. 17c). Fuel pump impeller speed reached a peak of 1450 rpm at engine cutoff and was greater than 1000 rpm 20 sec after engine start until engine cutoff. Maximum fuel pump pressure rise was 5 psi at engine cutoff. Large, low-frequency combustion chamber pressure oscillations occurred during this firing (Section 4.6); however, no apparent engine damage occurred.

4.3.4 Firing J4-1001-12A

The objective of firing 12A was to determine low thrust idle-mode firing duration required to obtain subcooled oxidizer at the pump discharge. Oxidizer and fuel pump inlets were to be 34 and 40 psia, respectively.

Test data indicated that the oxidizer remained saturated at the oxidizer pump discharge until approximately 185 sec after engine start; at this time, the oxidizer appeared to become subcooled. Fuel became subcooled at the engine fuel pump discharge 80 sec after engine start and remained liquid until engine cutoff. Fuel pump impeller speed decreased steadily during the firing from 860 rpm, 20 sec after engine start to 520 rpm at engine cutoff. A leak in the oxidizer pump primary seal was discovered after the firing (Section 4.7).

4.3.5 Firing J4-1001-13A

The objective of firing 13A was to determine low thrust idle-mode firing duration required to obtain subcooled oxidizer at the pump discharge. Low oxidizer (33 psia) and nominal fuel (34 psia) pump inlet pressures were to be used.

Firing 13A was aborted twice before engine start. As a result of the aborts, the engine prevalves were opened before the successful firing, chilling the engine propellant system to the thrust chamber valves. Although the primary objective was not met, engine operating characteristics and performance were investigated. Oxidizer remained subcooled at the engine oxidizer pump discharge during the entire firing. Fuel became subcooled 20 sec after engine start and remained subcooled at the fuel pump discharge until engine cutoff.

4.3.6 Firing J4-1001-13B

The objective of firing 13B was to determine thrust chamber heatup rate using high oxidizer pump (45 psia) and low fuel pump (20 psia) inlet pressures.

The firing was prematurely terminated 20 sec after engine start because the thrust chamber throat external temperature exceeded the red-line limit of 300°F, Fig. 26e. Oxidizer remained subcooled at the engine oxidizer pump discharge throughout the firing; fuel was not subcooled at the fuel pump discharge at any time.

4.3.7 Firing J4-1001-13C

The objective of firing 13C was to determine thrust chamber heatup rate using high oxidizer pump (45 psia) and low fuel pump (27 psia) inlet pressures.

The firing was prematurely terminated 28 sec after engine start attributable to thrust chamber throat external temperatures exceeding the redline limit of 300°F (Fig. 29e). Oxidizer became subcooled at the engine oxidizer pump discharge 10 sec after engine start and remained liquid until engine cutoff. Because of the short duration, performance calculations were not made. Posttest inspection revealed engine damage, Section 4.7.

4.3.8 Firing J4-1001-14A

The objective of firing 14A was to determine firing time required to obtain good quality oxidizer at the injector (prechilled to -200 ± 50°F). Low oxidizer (34 psia) and nominal fuel (33 psia) pump inlet pressures were to be used.

Oxidizer became saturated at the injector 5 sec after engine start and remained saturated throughout the firing. Oxidizer did not appear to become saturated at the oxidizer pump discharge until 110 sec after engine start, and was not subcooled at any time. Fuel became saturated at the fuel pump discharge 30 sec after engine start. Fuel pump impeller speed increased gradually throughout the firing to a maximum of 880 rpm before engine cutoff.

4.3.9 Firing J4-1001-14B

The objective of this firing was to determine thrust chamber heatup rate using high oxidizer pump (44 psia) and low fuel pump (27 psia) inlet pressures.

Firing 14B was prematurely terminated 45.9 sec after engine start when thrust chamber throat external temperature exceeded redline limits of 250°F (Fig. 35e). Engine prevalves remained open from the previous firing. Therefore, oxidizer was subcooled during the firing at the oxidizer pump discharge and fuel became subcooled at the fuel pump discharge 10 sec after engine start.

4.3.10 Firing J4-1001-14C

The objective of this firing was to determine idle-mode performance with the injector prechilled to -200 ± 50°F. Low oxidizer (34 psia) and nominal fuel (33 psia) pump inlet pressures were to be used.

Engine prevalves were opened before engine start; therefore, both oxidizer and fuel were subcooled during the firing (Fig. 38). Performance calculations indicated a characterstic velocity of 7100 ft/sec at an O/F of 2.2.

4.4 FUEL PUMP ROTATION DURING IDLE-MODE OPERATION

Pump discharge pressures were observed to exceed pump inlet pressures on many of the idle-mode firings. To further evaluate this, fuel pump rotational speed was manually reduced during idle-mode operation on the firings reported herein. Although windmilling of the pump during idle mode might be expected, rotation sufficient to produce a fuel pressure increase across the pump (5 psi, firing J4-1001-10A) is indicative of power being supplied to the fuel turbine. The source of this power input must be tapoff valve leakage flow.

The small pressure rise being produced during idle mode, closely correlated with the square of pump speed, Fig. 39, for those firings (such as firing J4-1001-08) with subcooled fuel at the pump discharge. Firings with saturated or superheated fuel at the fuel pump yielded excessively high pump speed for low pump pressure rise, probably indicative of pump cavitation.

The effect of the pressure rise across the fuel pump is to increase injector pressure by the amount of the pump pressure rise, in addition to the normal pressure loss across the fuel pump which would have occurred without pump rotation. Thus, a pumping increase of 5.0 psi is equivalent to approximately an 8.0-psi increase at the injector for a nominal idle-mode fuel flow rate. Since pump inlet pressures have been used to adjust engine idle-mode mixture ratio, fluctuating pumping pressures make idle-mode mixture ratio difficult to set or to predict.

4.5 FLOWMETER MEASUREMENT DIFFICULTIES—IDLE-MODE OPERATION

The J-2S engine incorporates integral propellant flowmeters (nominally 4-in. diameter) within the pump discharge piping on the engine. The S-IVB battleship stage which is the propellant supply tankage for the engine has no normal provisions for installing flowmeters in the engine supply ducts, and no special flowmeters were installed for J-2S idle-mode testing. The engine flowmeters are calibrated by the engine manufacturer (using a secondary standard flowmeter in series with each of the engine meters during main-stage sea-level acceptance tests on each engine); the engine is shipped and installed in J-4 Test Cell, and no further calibration of the meters is accomplished for the duration of the tests at AEDC on the particular engine.

The uncertainties involved in the measurement of propellant flow rates with the engine operating in idle mode are magnified by several factors. These are (1) low quality (unknown density) propellants at the engine flowmeters; (2) use of engine flowmeters at approximately 2 to 5 percent of their main-stage capacity; (3) unsteady idle-mode flow rates; (4) inability to calibrate flowmeters at AEDC and thereby evaluate bias and repeatability changes as flowmeter wears over many engine firings.

To reduce the uncertainty in idle-mode flow measurement attributable to low propellant quality, flow rates are reduced and presented herein from flowmeter output only when propellants are subcooled at the flowmeters. When propellants are not subcooled, this method precludes the reduction of meaningful performance on the initial portion of all idle-mode firings.

To add confidence in the engine oxidizer flowmeter output, the 2-in. oxidizer recirculation system meter was calibrated at AEDC-ESF and utilized in series with the engine oxidizer flowmeter on a limited number of idle-mode firings. However, only one firing (J4-1001-10A) was obtained with subcooled propellant at both flowmeters. Unexplained and unacceptable recirculation system pressure drop occurred on more than one firing, causing this flow verification method to be abandoned. On the one firing on which both meters operated satisfactorily in series, the recirculation system flowmeter read 1.5 percent lower than the engine flowmeter at an engine-indicated oxidizer flow of 13 lbm/sec.

Typical flowmeter cyclic output for an idle-mode firing is shown in Fig. 40. Since the output is irregular and unsteady, manual cycle counting is required to make any reasonable determination of flow rate as opposed to the highly accurate computerized reduction of normal, steady flowmeter output. Flowmeter cycles for typical idle-mode firings are being manually counted to within an estimated uncertainty band of approximately ±2 percent. However, the low-frequency and irregular nature of the flowmeter output, even if counted precisely, causes additional uncertainty in using the single specified flow constant to reduce the output cycles to volumetric flow rate.

4.6 IDLE-MODE PERFORMANCE

Engine idle-mode performance, calculated by the methods presented in Appendix III, is summarized in Table VIII. These data are averaged for ±1.0 sec at the indicated times. A time history of calculated thrust, specific impulse, and characteristic velocity (C*) from this table for each firing is included within Fig. 41. Performance data for four firings (09A, 13B, 13C, and 14A) are not included because the fuel and/or oxidizer did not subcool at the engine flowmeter.

Figure 42 shows the variation of characteristic velocity with engine mixture ratio. These data show that significant increases in performance were gained with the full-face oxidizer flow (noncompartmented) injector design. Nominal characteristic velocity (C*) values during idle-mode operation for both the inner four row and row ten oxidizer flow injector designs was about 3000 ft/sec at mixture ratios between 1.8 and 2.0 (Refs. 5 and 6). The full-face flow injector design, utilized on the tests reported herein, produced characteristic velocities of about 6500 ft/sec at the same mixture ratios.

Film coolant flow for these firings with subcooled fuel was 1 lbm/sec on the average through the 0.581-in. film coolant orifice. Combustion chamber pressure reached its highest steady-state value (30 psia) on test J4-1001-10A. This firing had the best propellant qualities and the highest theoretical calculated thrust of all firings reported herein.

4.7 OPERATING CHARACTERISTICS

4.7.1 Operation Instability

Anomalous combustion chamber pressure oscillations occurred during firings J4-1001-10A, -13A and -14C (Figs. 15b, 21, and 36). These oscillations occurred at high average combustion chamber pressures for idle-mode operation (25 to 33 psia), and low mixture ratios (1.5 to 3.0). The maximum amplitude of the pressure oscillations was 50 percent of the mean pressure level (15 psi peak to peak during firings J4-1001-10A and -13A). The frequency of these oscillations was 0.6 to 0.9 Hz with superimposed pressure oscillations (5-psi peak-to-peak maximum amplitude) at a frequency of 30 to 60 Hz.

Firing J4-1001-10A produced large oscillations from 165 sec after engine start to 200 sec, at which time the oscillations damped out. At the same time that the oscillations were reduced, mixture ratio increased from 3.0 to 4.5 attributable to a programmed reduction of fuel pump inlet pressure from 40 to 27 psia. No significant mixture ratio change occurred during firings J4-1001-13A and -14C, and the oscillations, once started, continued until engine cutoff.

4.7.2 Thrust Chamber Throat External Temperature Transients

Three firings were conducted to determine thrust chamber heat up rates with high oxidizer and low fuel pump inlet pressures. Oxidizer idle-mode line orifice diameters were 1.033 and 0.977 in. for tests J4-1001-13 and -14, respectively. Propellants were on the engine valves 90, 60, and 70 min before firings J4-1001-13B, -13C, and -14B, respectively. All three firings were manually terminated because combustion chamber throat external temperature exceeded the established maximum temperature limit. Mixture ratio on firing J4-1001-14B was 4.5, 35 sec after engine start. This was the only firing of the three for which valid mixture ratio data could be reduced. The effect of pump inlet pressures on combustion chamber throat external temperature (TTCT-T1) is shown in the following table.

Firing J4-1001-	Oxidizer Pump Inlet Pressure, psia	Fuel Pump Inlet Pressure, psia	TTCT-T1 at 250°F, Time after t-0, sec
13B	44.0	20.4	17
13C	44.9	27.3	21
14B	43.0*	27.8	46

*Note idle-mode orifice change.

Firing J4-1001-13B had the highest heatup rate (22°F/sec) with combustion chamber throat external temperature increasing from 34°F at engine start to 310°F at engine cutoff (Fig. 26e). Firing J4-1001-13C had a thrust chamber throat external temperature increase from 80°F at engine start to 300°F at cutoff. Firing J4-1001-14B had a thrust chamber throat external temperature increase from -200°F at engine start to 250°F at cutoff. Maximum heatup rates were 15 and 17°F/sec for firings J4-1001-13C and 14B, respectively.

4.7.3 Propellant System Temperature Transients

Firings J4-1001-08A, -09A, and -12A had ambient temperature propellant ducts and injector; firing J4-1001-14A had a prechilled injector. Propellant system temperature transients are shown for these firings in Figs. 11, 14, 20, and 32. Tabulated below are the propellant phases with the corresponding times at which these phases appeared.

Firing J4-1001-	Time after t-0, sec	Oxidizer Phase at Pump Discharge	Fuel Phase at Pump Discharge
08A	100	Subcooled	Subcooled
09A	180	Subcooled	Saturated
12A	180	Subcooled	Subcooled
14A	110	Saturated	Saturated

Firing J4-1001-14A had saturated oxidizer at the injector 5 sec after engine start which remained saturated until the end of the firing.

4.8 ENGINE DAMAGE OR MALFUNCTIONS

Engine damage was sustained on several tests in this series attributable to excessive idle-mode combustion temperatures. Although damage was limited to thrust chamber tubes in the combustion zone and throat area, fluctuating temperatures may have adversely influenced tapoff valve leak rates. Low oxidizer turbine temperatures and ice evidently caused a temporary leak in the oxidizer pump primary seal on firing J4-1001-12A.

Heat discoloration of the injector face and thrust chamber tubes near the thrust chamber exit was observed during posttest J4-1001-09 inspection. During this inspection, erosion of some of the tapoff ports in the tapoff ring was noted, and elongation of previous thrust chamber tube cracks was also observed. Repair of the damage was completed after test J4-1001-10A. Extensive damage of 100 thrust chamber tubes was found during the inspection following test J4-1001-13. This damage was repaired before test J4-1001-14, but these repairs did not return the engine to an as-designed configuration. Small tube leaks and internal/external surface irregularities existed which may have altered specific tube flow and heat-transfer rates.

Checks conducted immediately after J4-1001-12A on the oxidizer pump primary seal indicated seal leakage in excess of 10,000 scim; however, the leakage rate was approximately 22 scim (within allowable limits) several hours after the test period, and after the pump was manually rotated. This malfunction might have been caused by water vapor collecting and freezing in the oxidizer turbine during idle mode.

SECTION V
SUMMARY OF RESULTS

The results of the low thrust idle-mode firings of the J-2S rocket engine (S/N J-112) during tests J4-1001-08 through -10 and J4-1001-12 through -14, between September 2 and October 15, 1969, are summarized as follow:

1. Significant increase in engine idle-mode performance (120 percent over inner four rows and row ten injector designs) was observed with the full-face oxidizer flow design at nominal pump inlet conditions.

2. Anomalous increases in pressure across the fuel pump (5.0-psi maximum) occurred on idle-mode firings with subcooled fuel and high combustion chamber pressure. This appeared to be caused by tapoff valve leakage.

3. Anomalous combustion chamber pressure oscillations of 15-psi peak-to-peak maximum amplitude and 0.6- to 0.9-Hz frequency appeared during three firings.

4. Thrust chamber tube erosion in the throat region resulted from excessive combustion temperatures and reduced thrust chamber fuel flow. Chamber repair was required posttest J4-1001-10 and -13.

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APPENDIXES

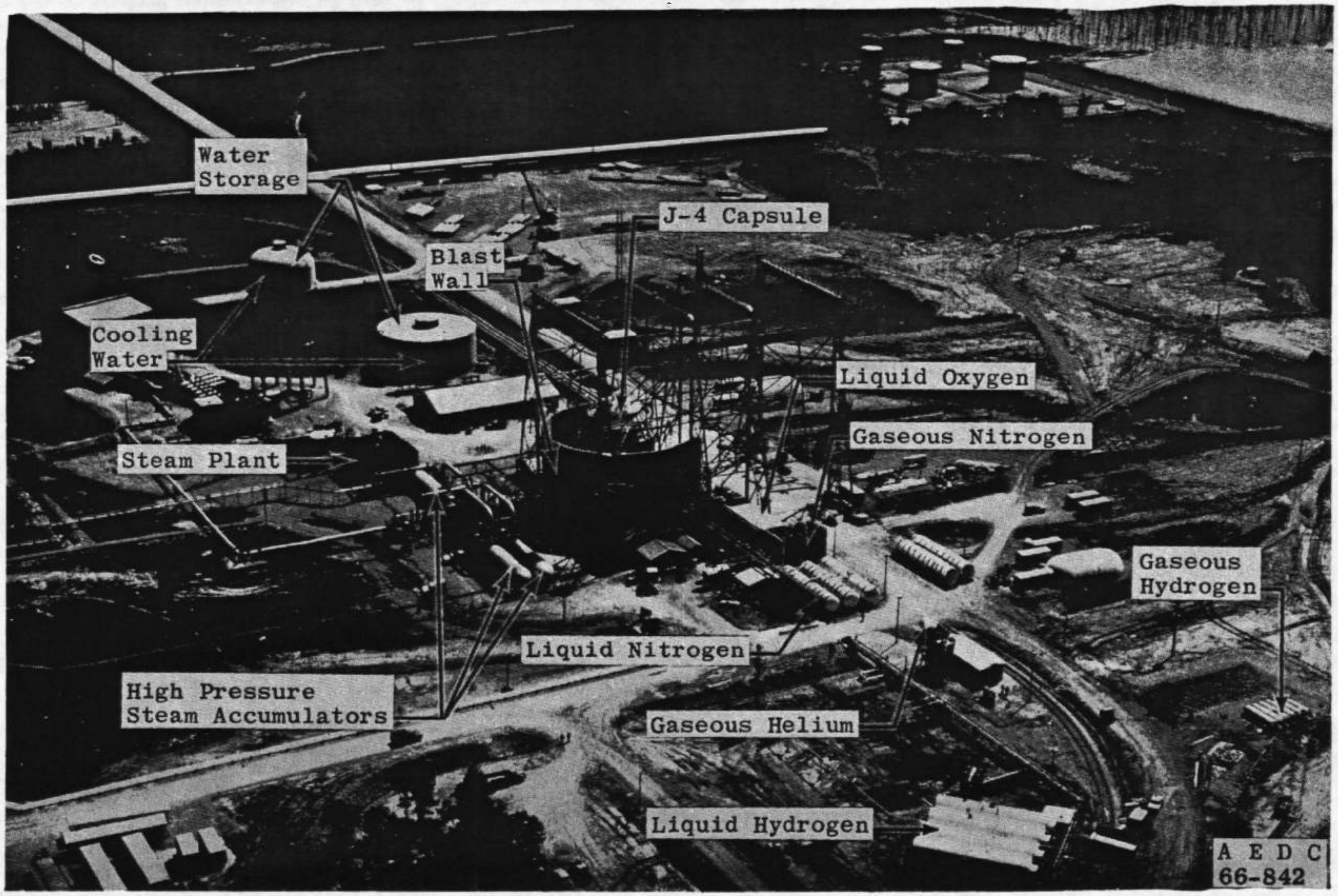


Fig. 1 Test Cell J-4 Complex

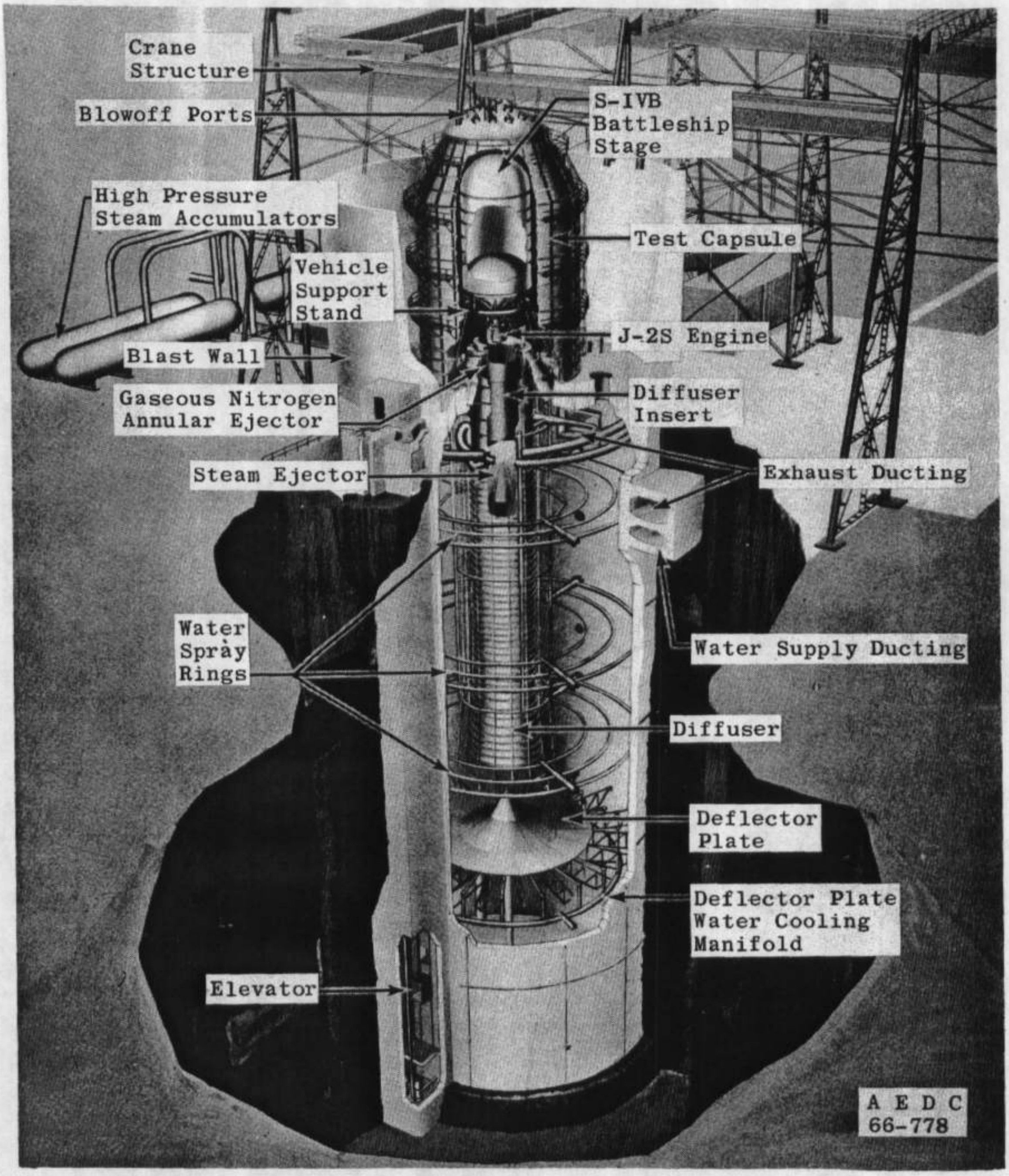


Fig. 2 Test Cell J-4, Artist's Conception

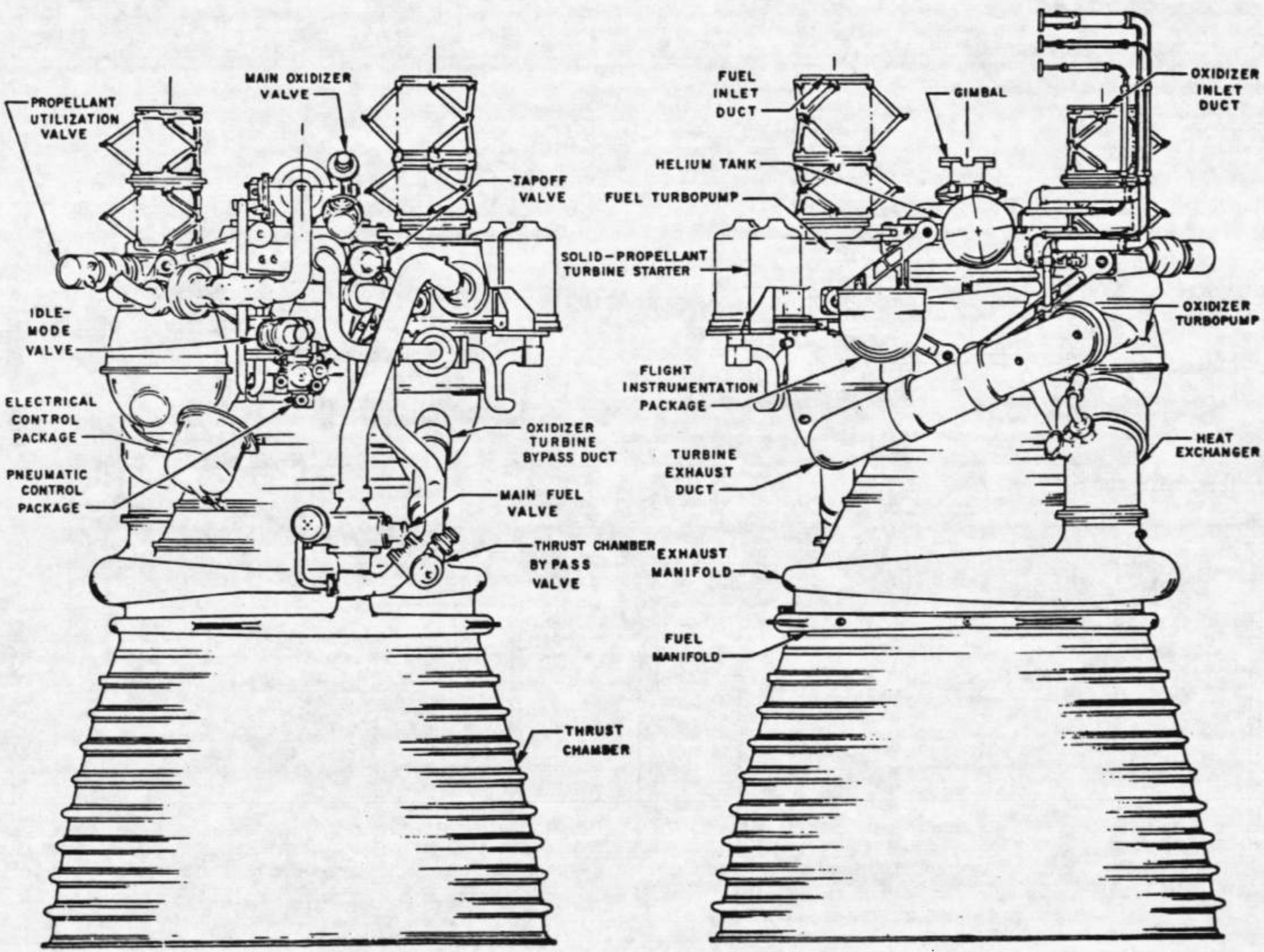


Fig. 3 J-2S Engine General Arrangement

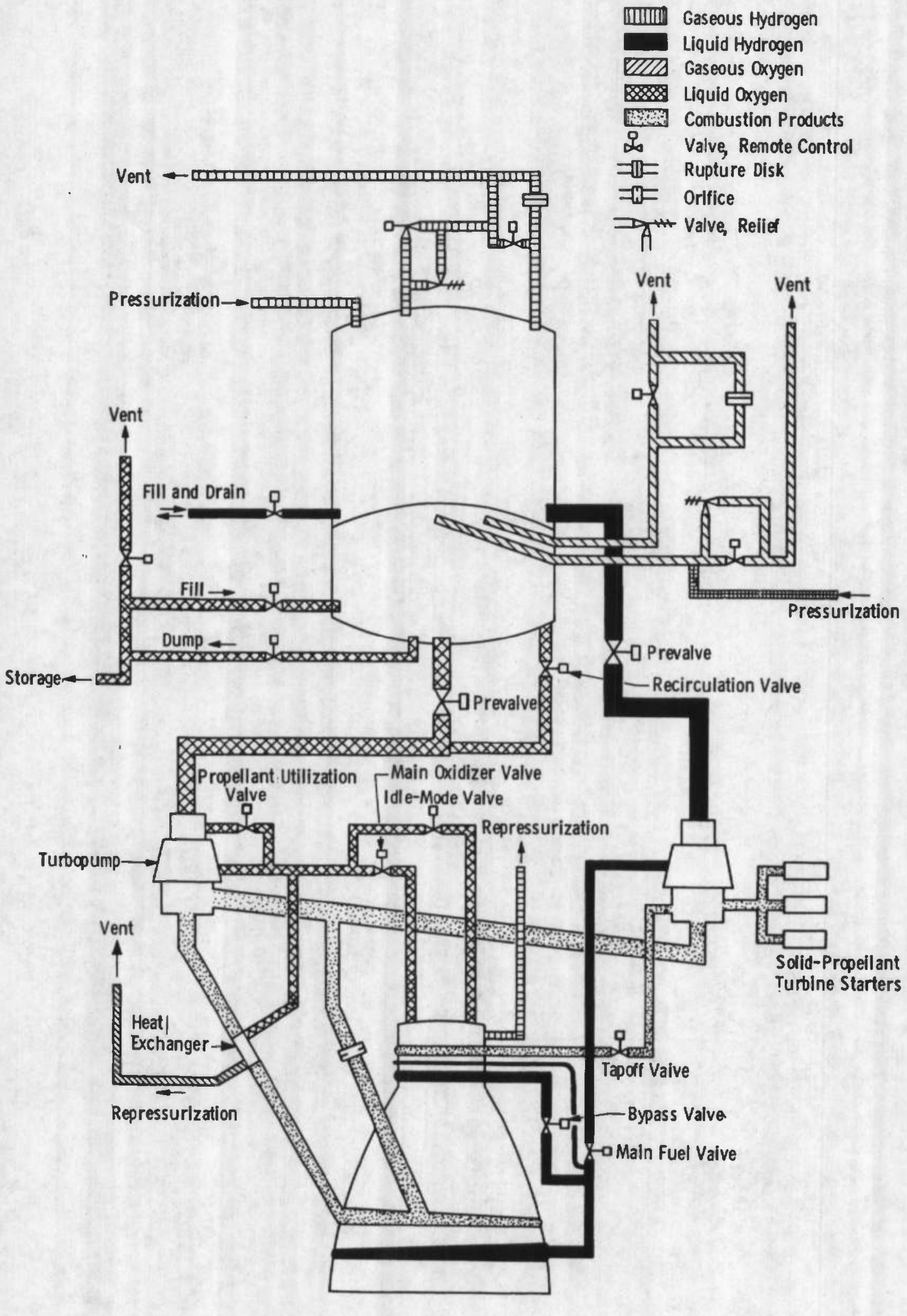
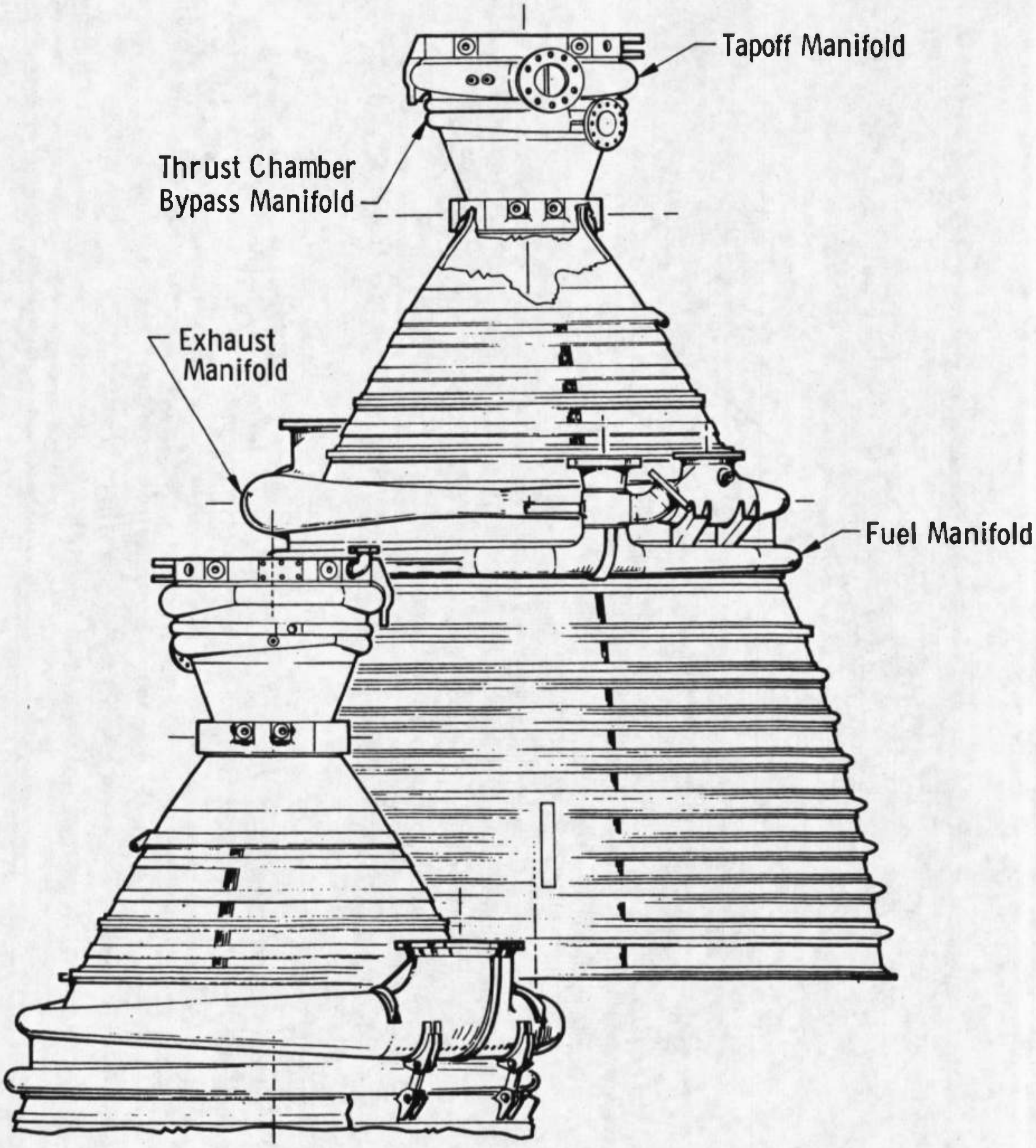
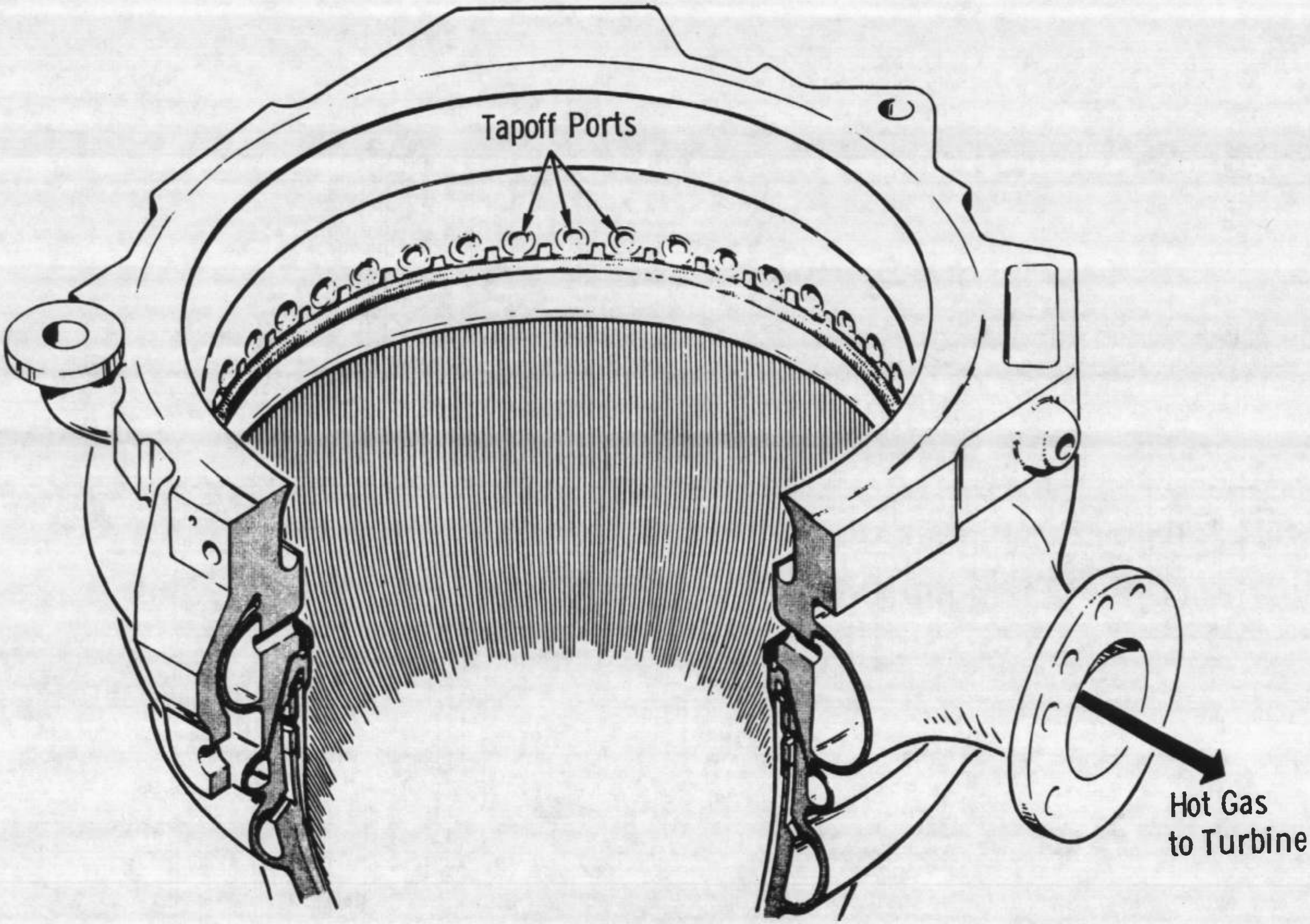


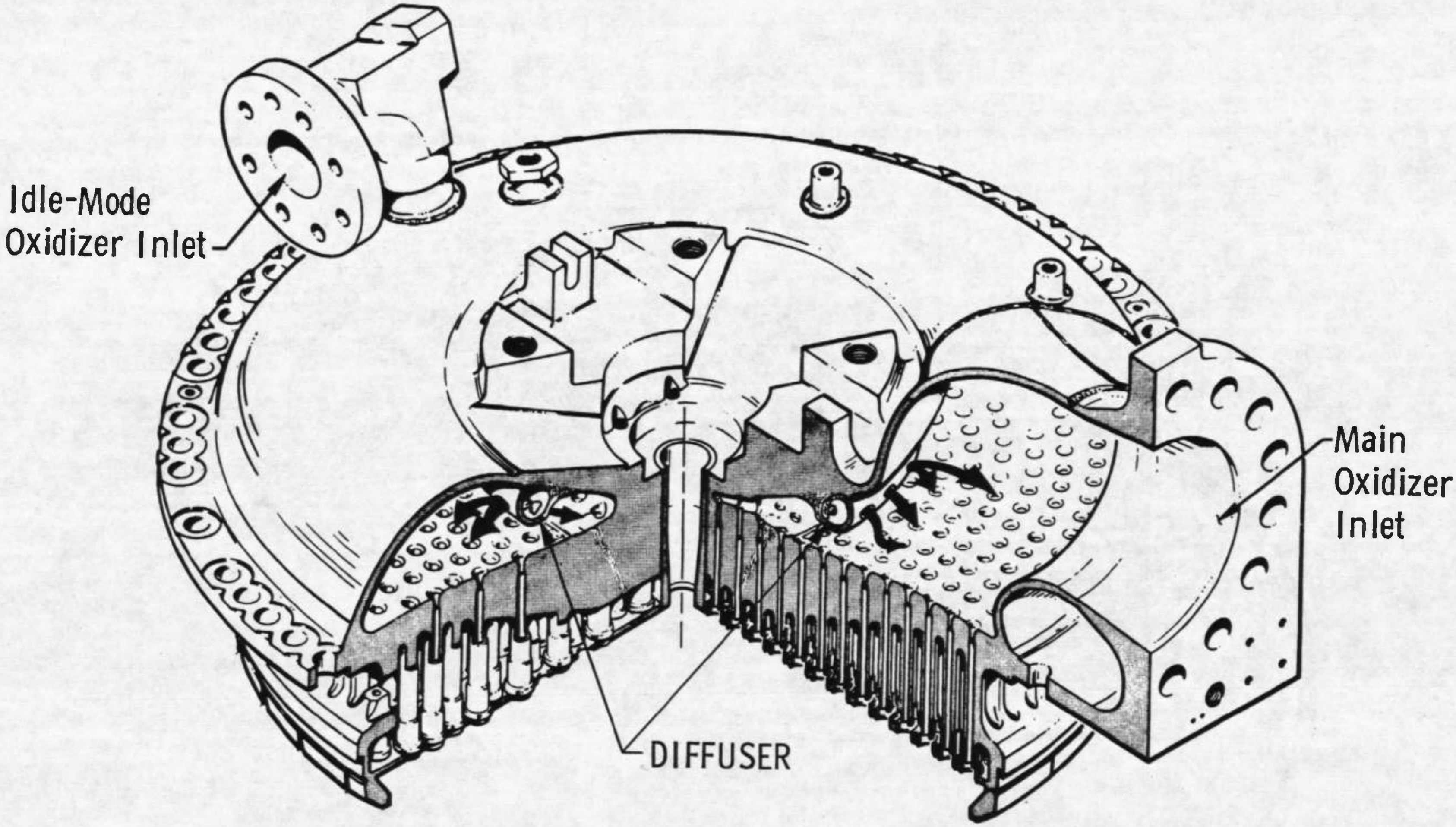
Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



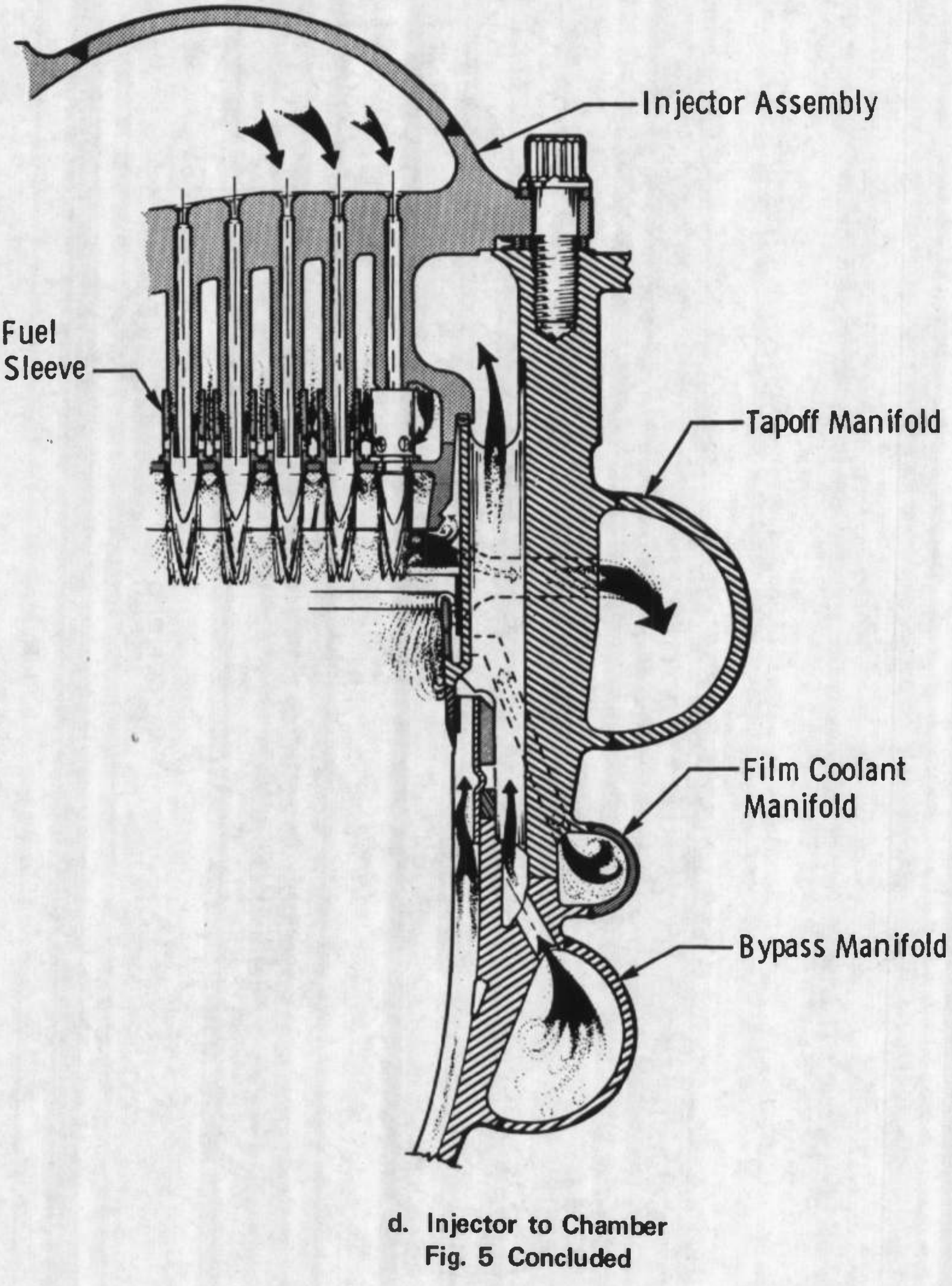
a. Thrust Chamber
Fig. 5 Engine Details



b. Combustion Chamber
Fig. 5 Continued



c. Injector
Fig. 5 Continued



d. Injector to Chamber
Fig. 5 Concluded

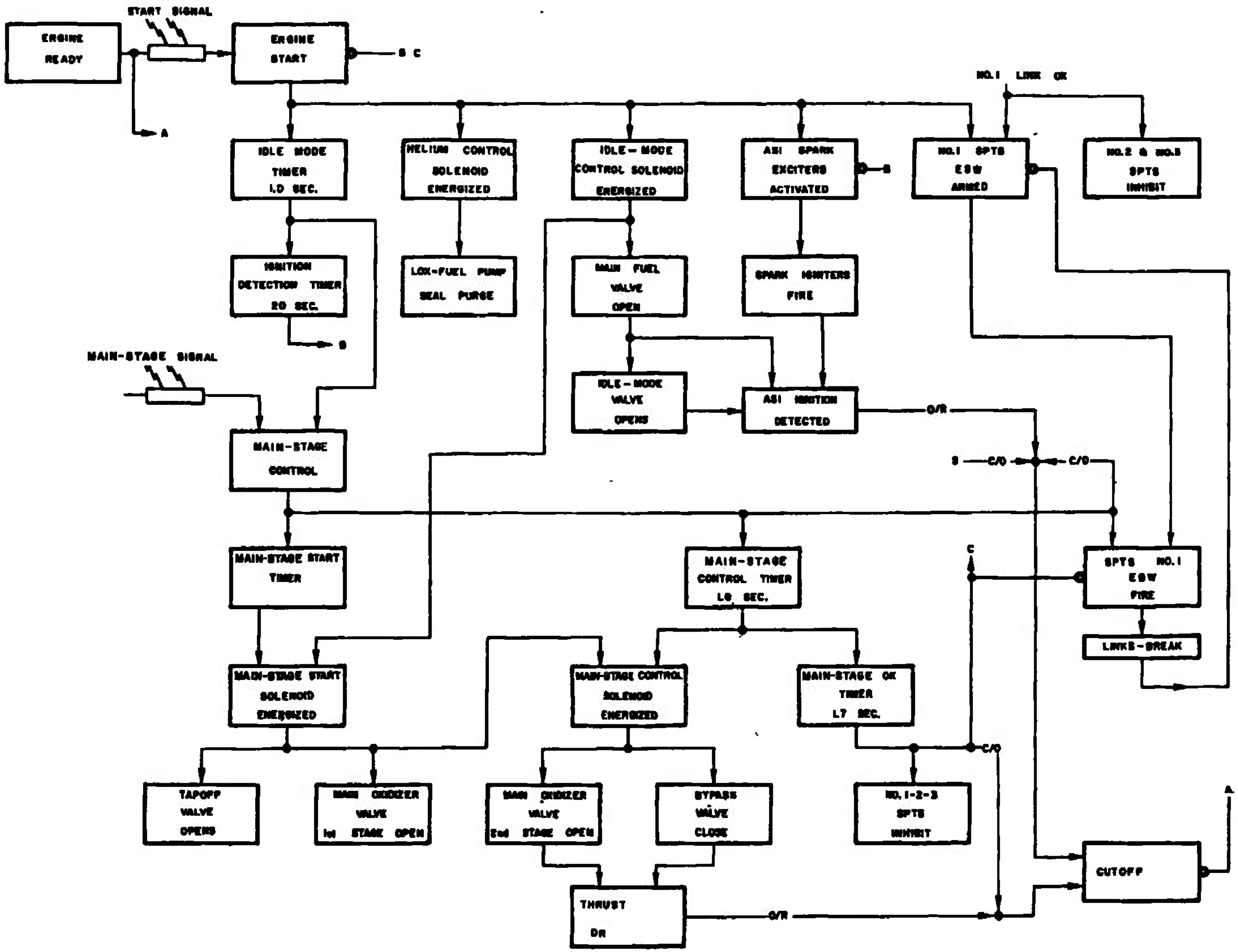
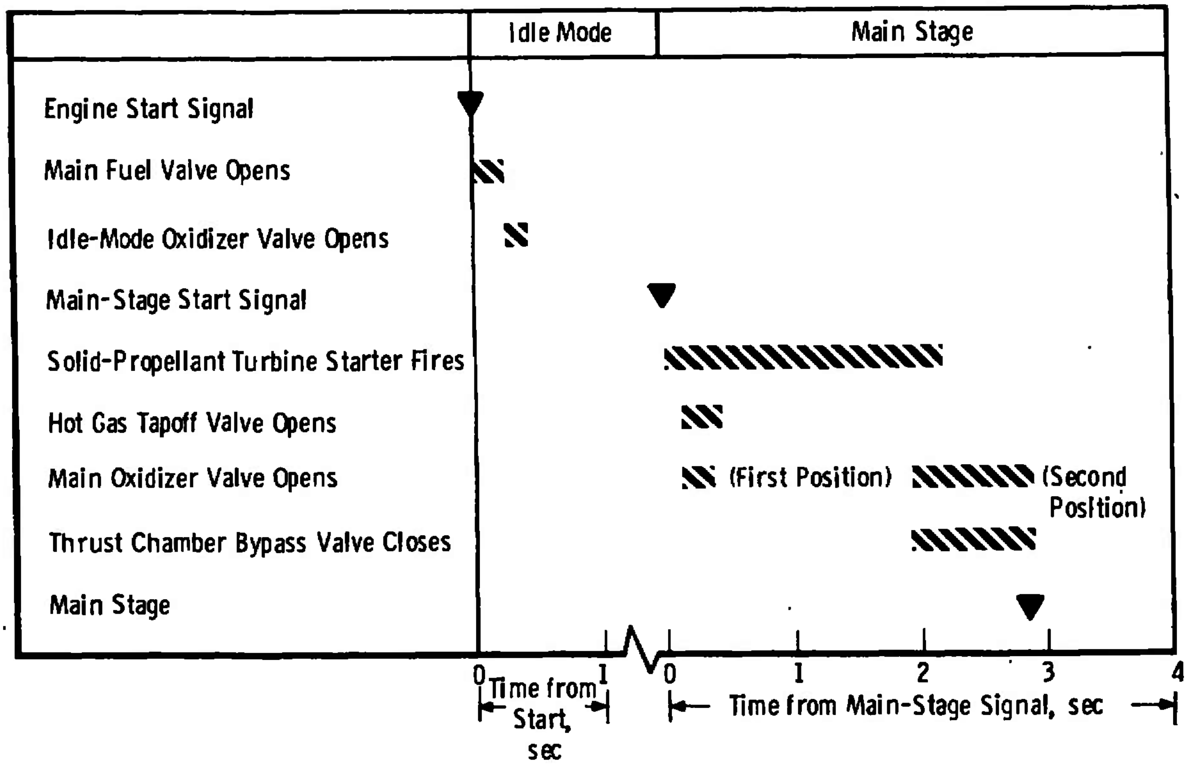
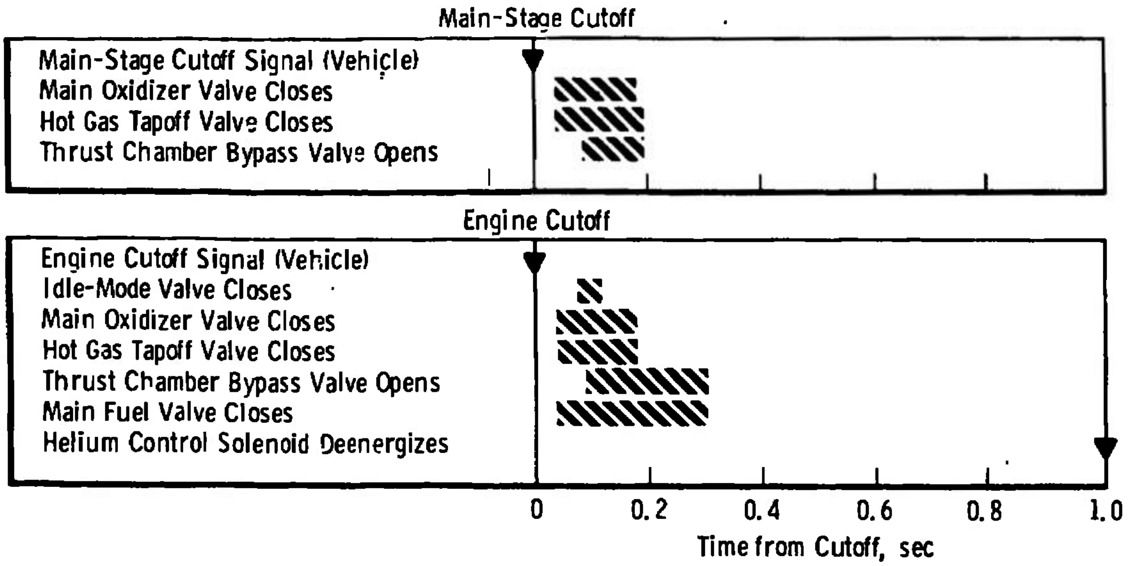


Fig. 6 Engine Start Logic Schematic

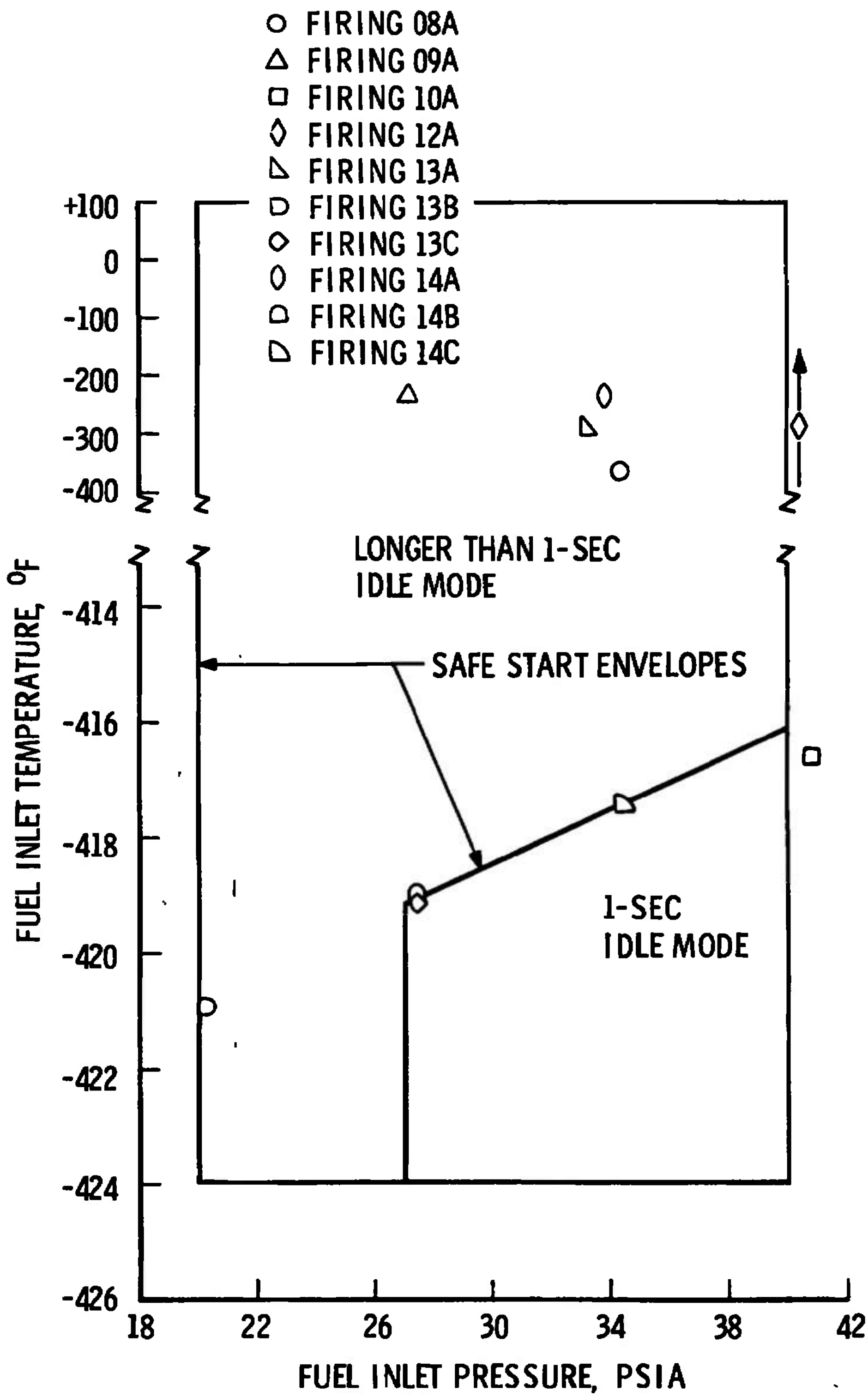


a. Start Sequence



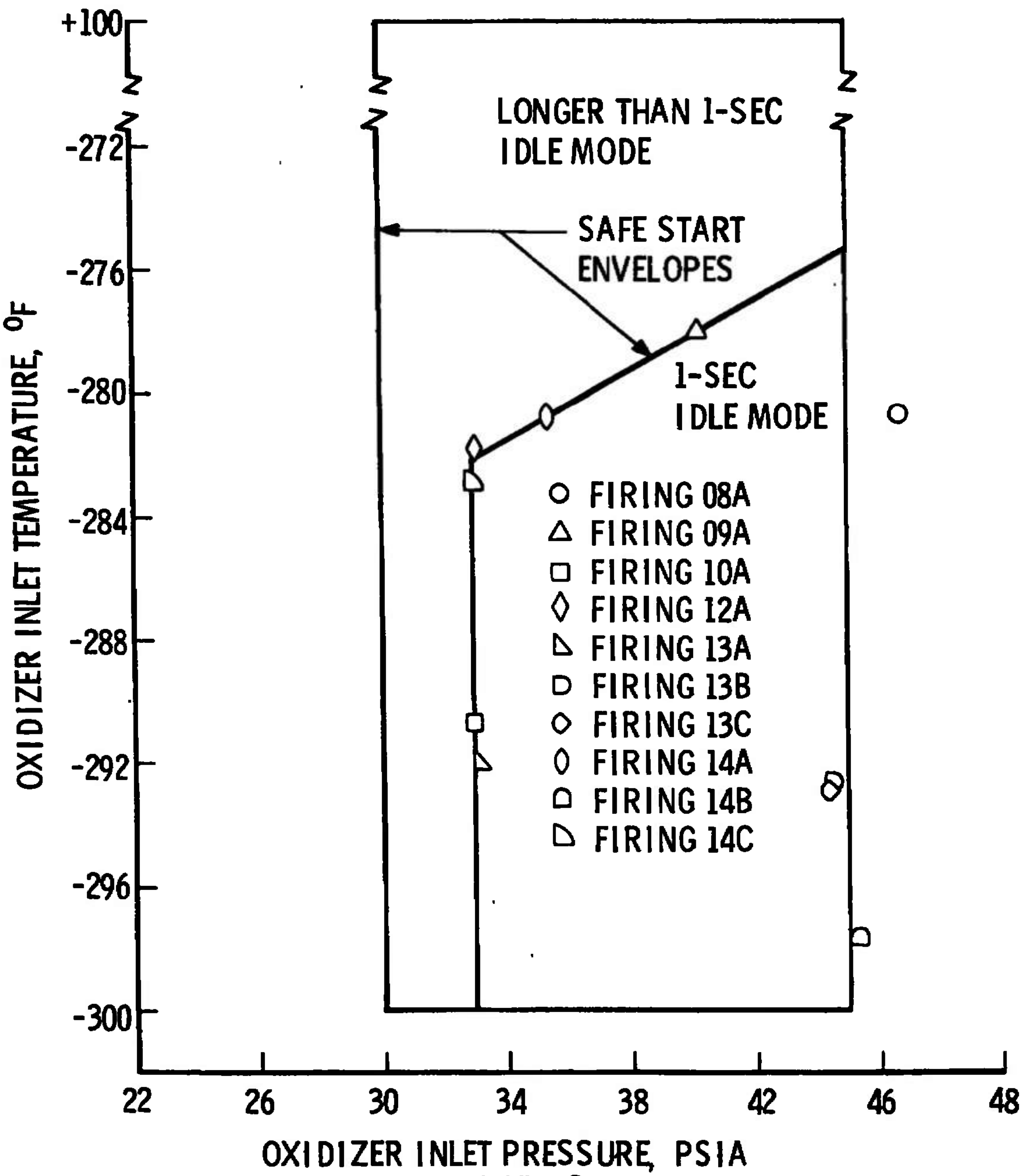
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



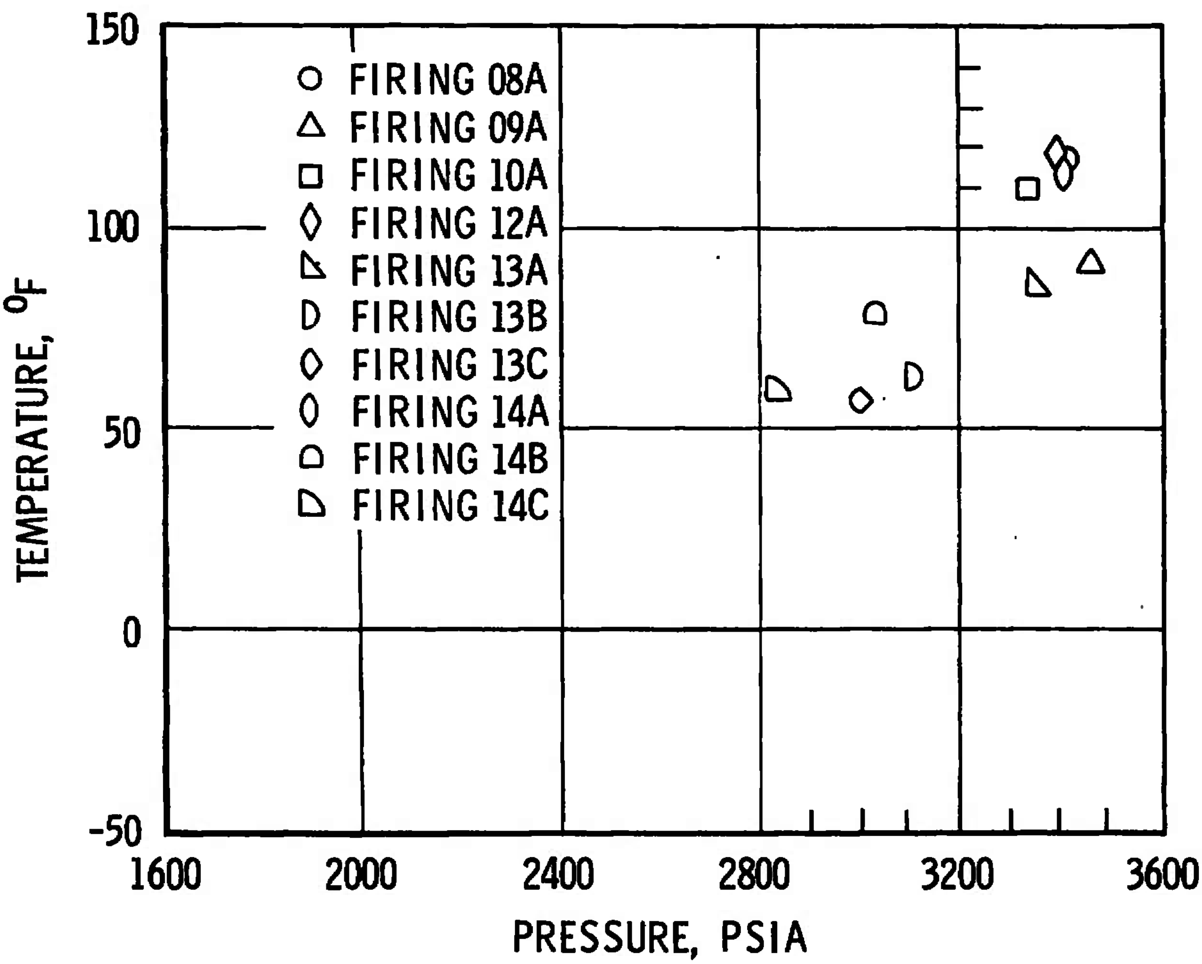
a. Fuel Pump

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



b. Oxidizer Pump

Fig. 8 Continued



c. Helium Tank
Fig. 8 Concluded

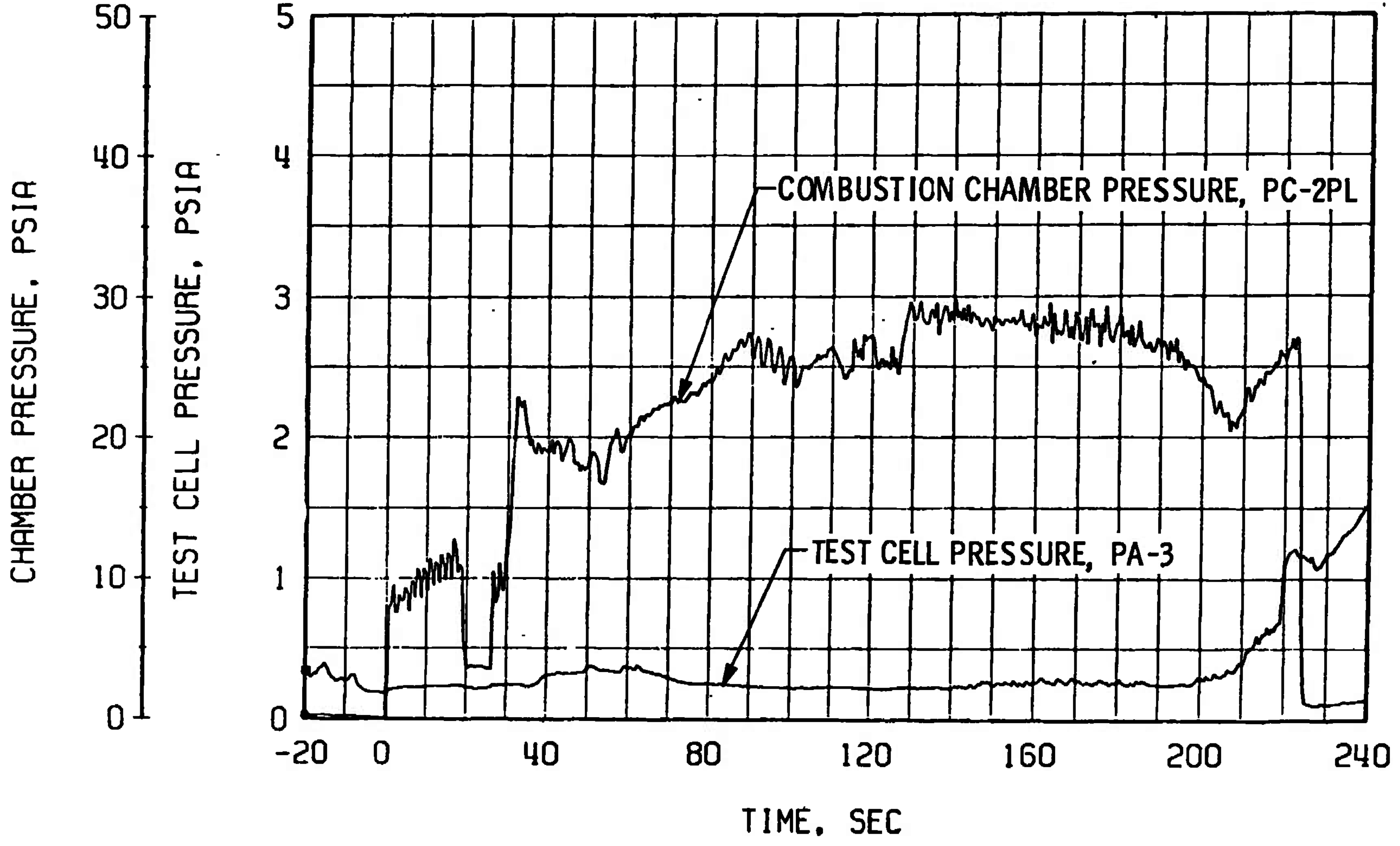
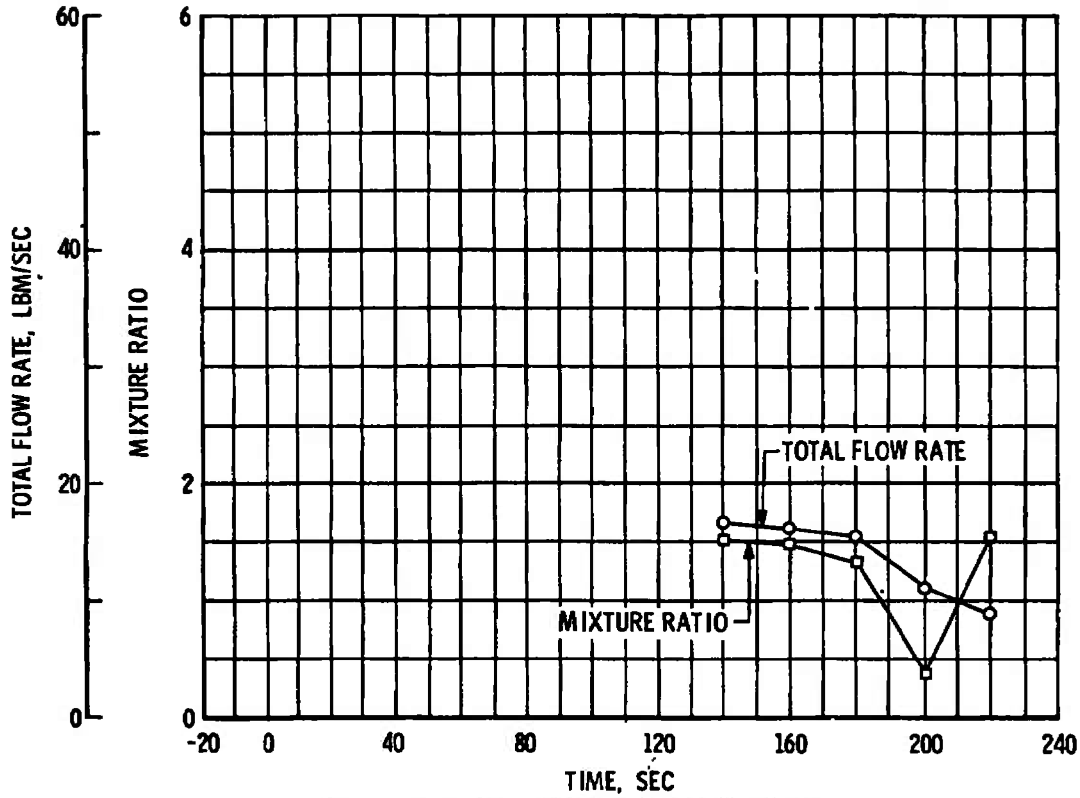
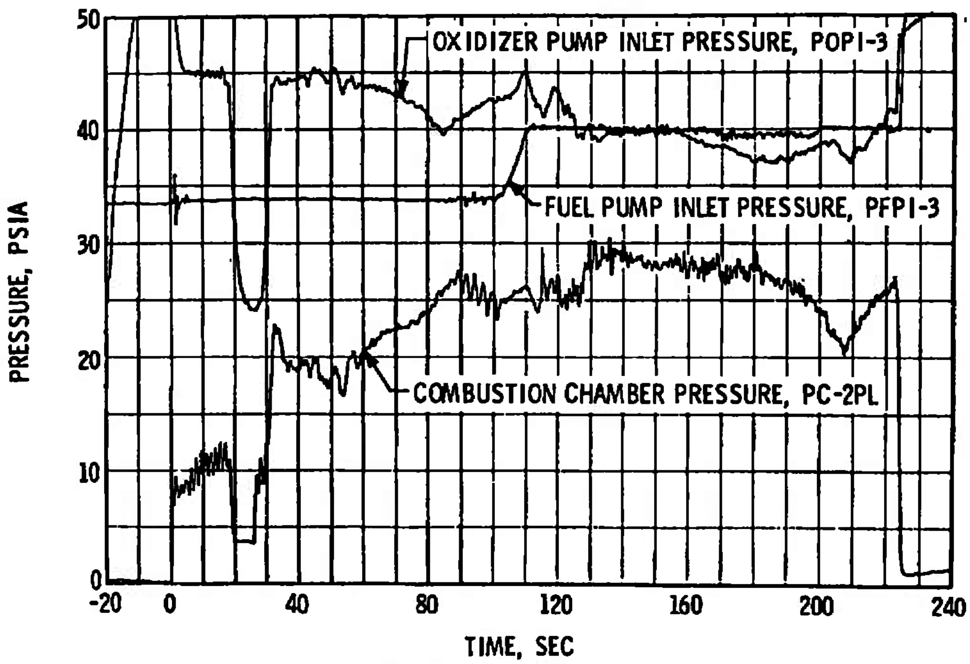


Fig. 9 Engine Ambient and Combustion Chamber Pressures, Firing 08A

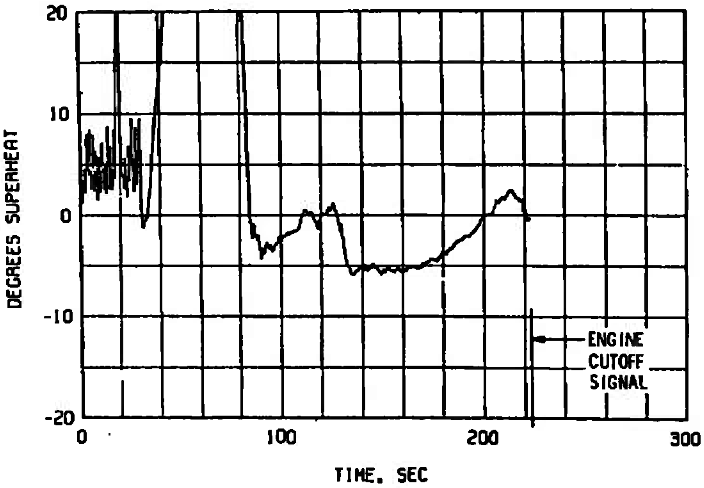


a. Total Flow Rate and Mixture Ratio

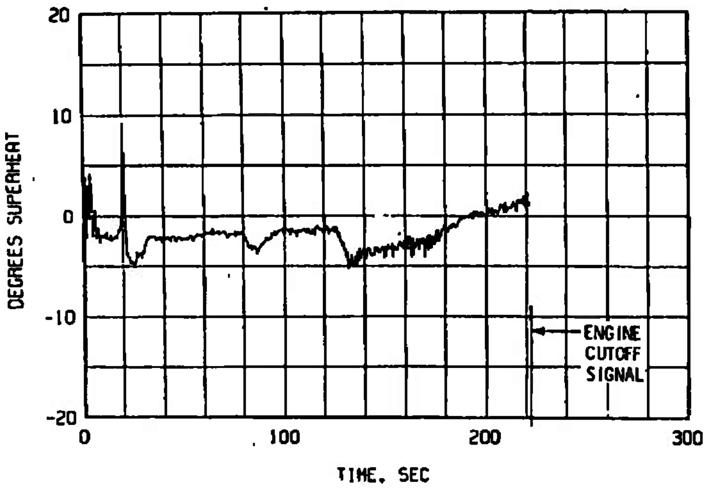


b. Pump Inlet and Combustion Chamber Pressures

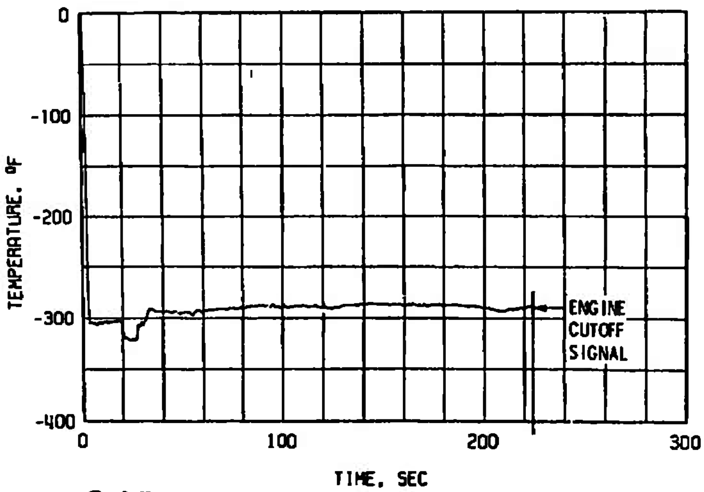
Fig. 10 Propellant System Performance, Firing 08A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

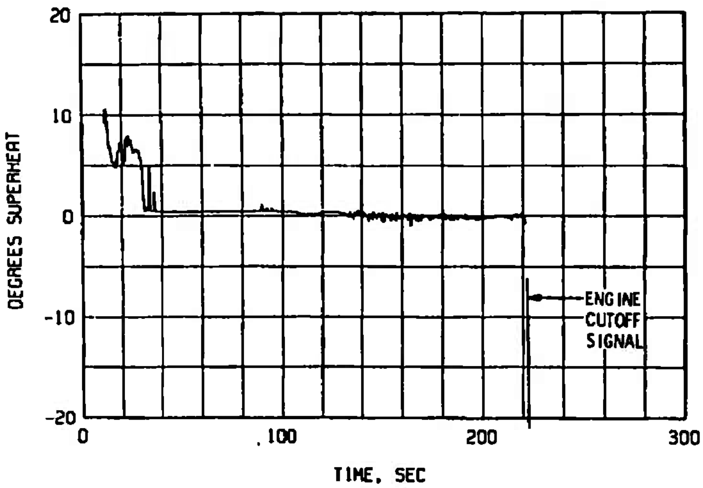


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

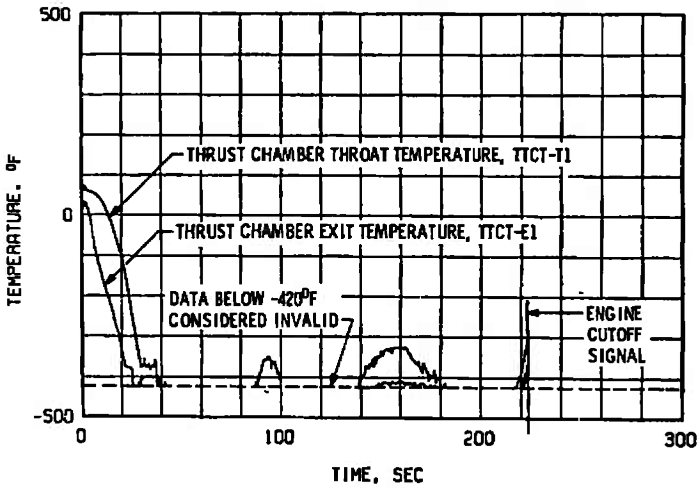


c. Oxidizer Temperature at Injector (TOJ), °F

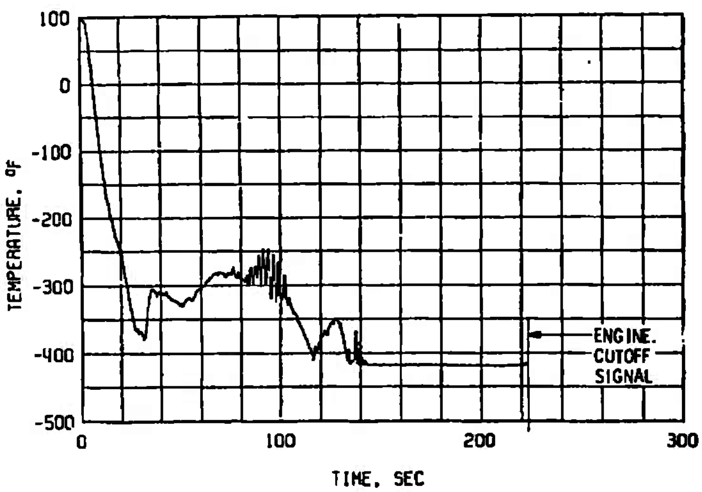
Fig. 11 Propellant System Temperature Transients, Firing 08A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperatures, °F



f. Fuel Temperature at injector (TFJ-2P), °F

Fig. 11 Concluded

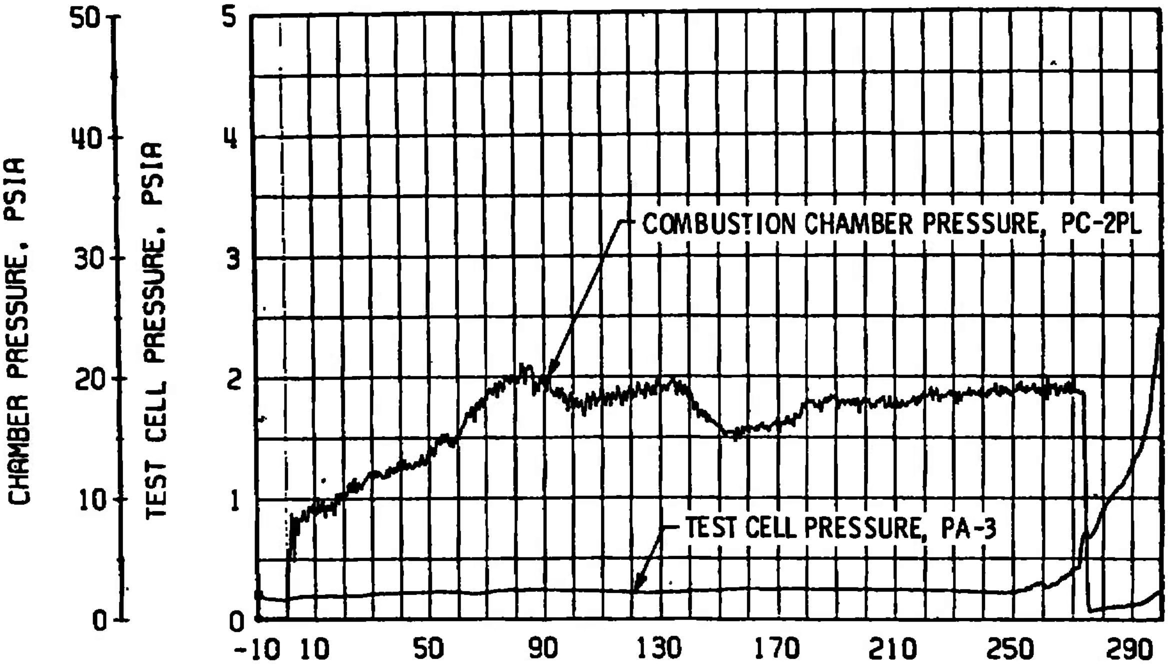


Fig. 12 Engine Ambient and Combustion Chamber Pressures, Firing 09A

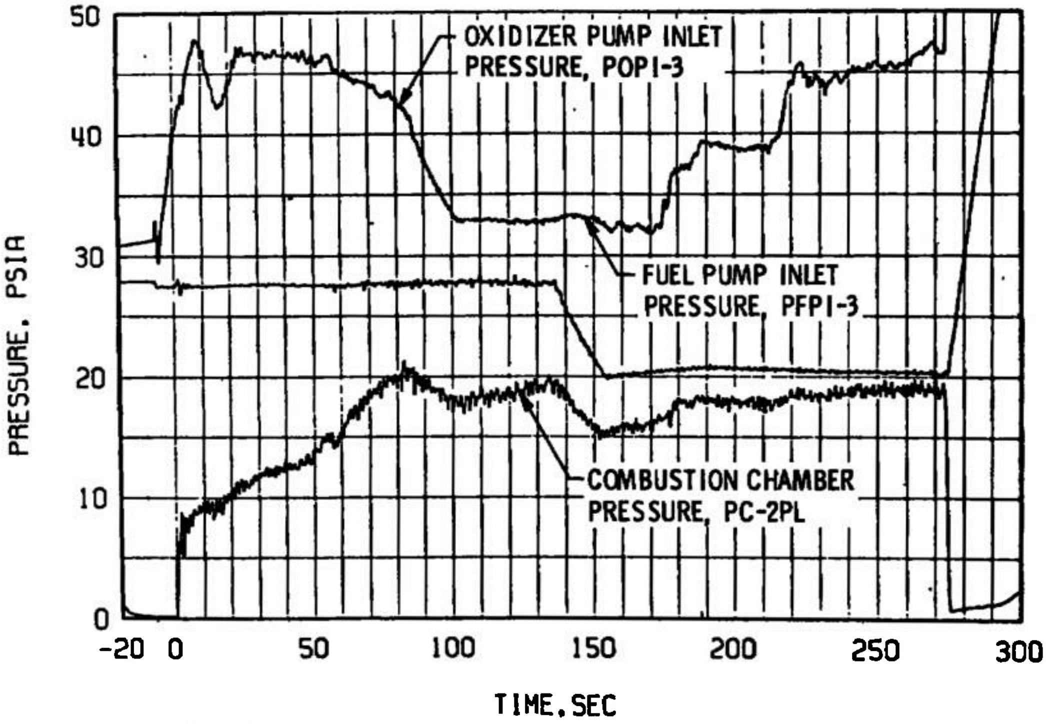
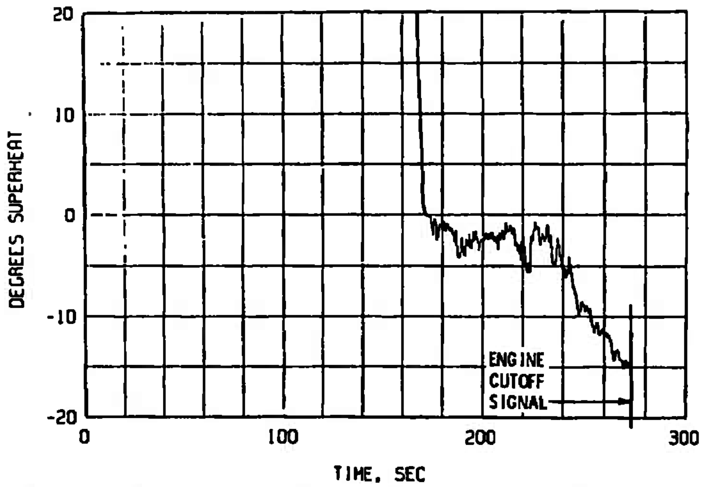
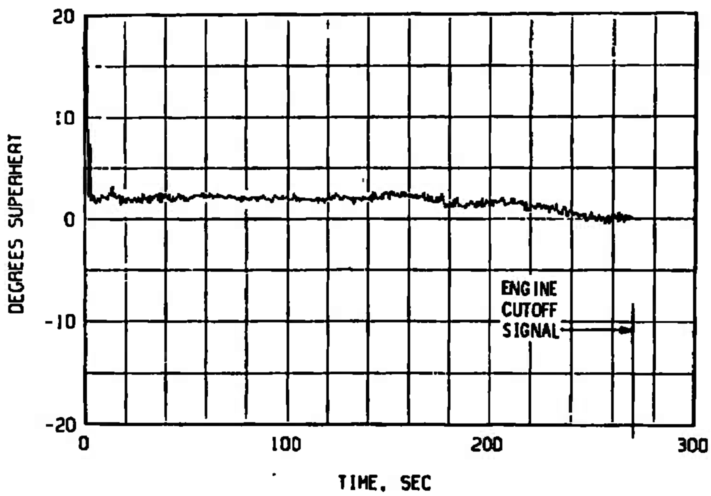


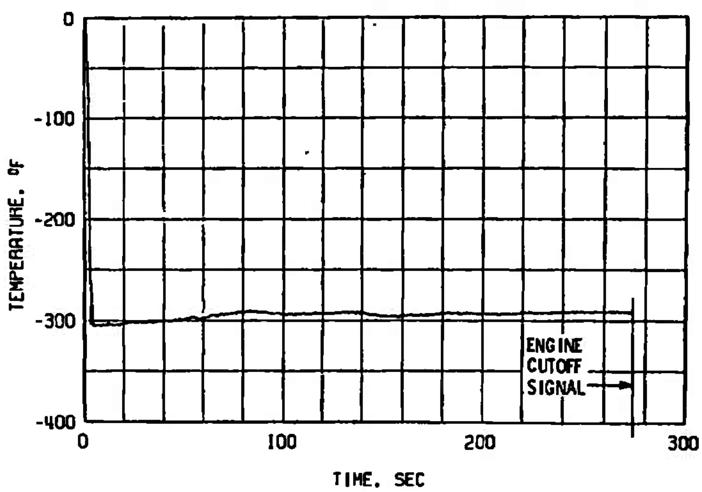
Fig. 13 Propellant System Performance, Firing 09A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

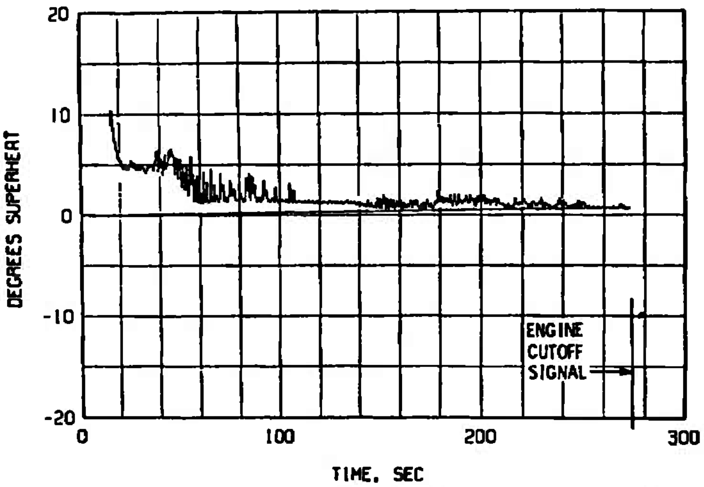


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

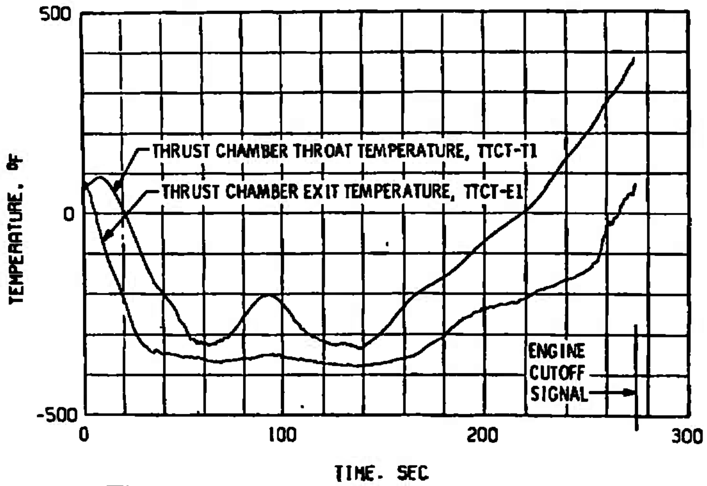


c. Oxidizer Temperature at Injector (TOJ), °F

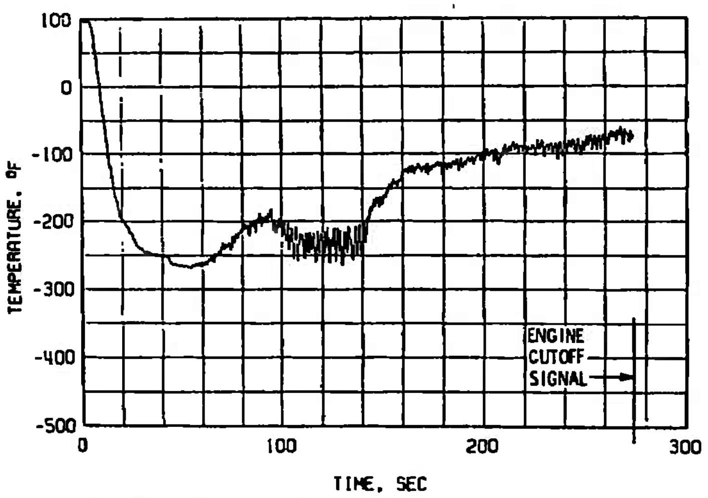
Fig. 14 Propellant System Temperature Transients, Firing 09A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Injector Temperature (TJF-2P), °F

Fig. 14 Concluded

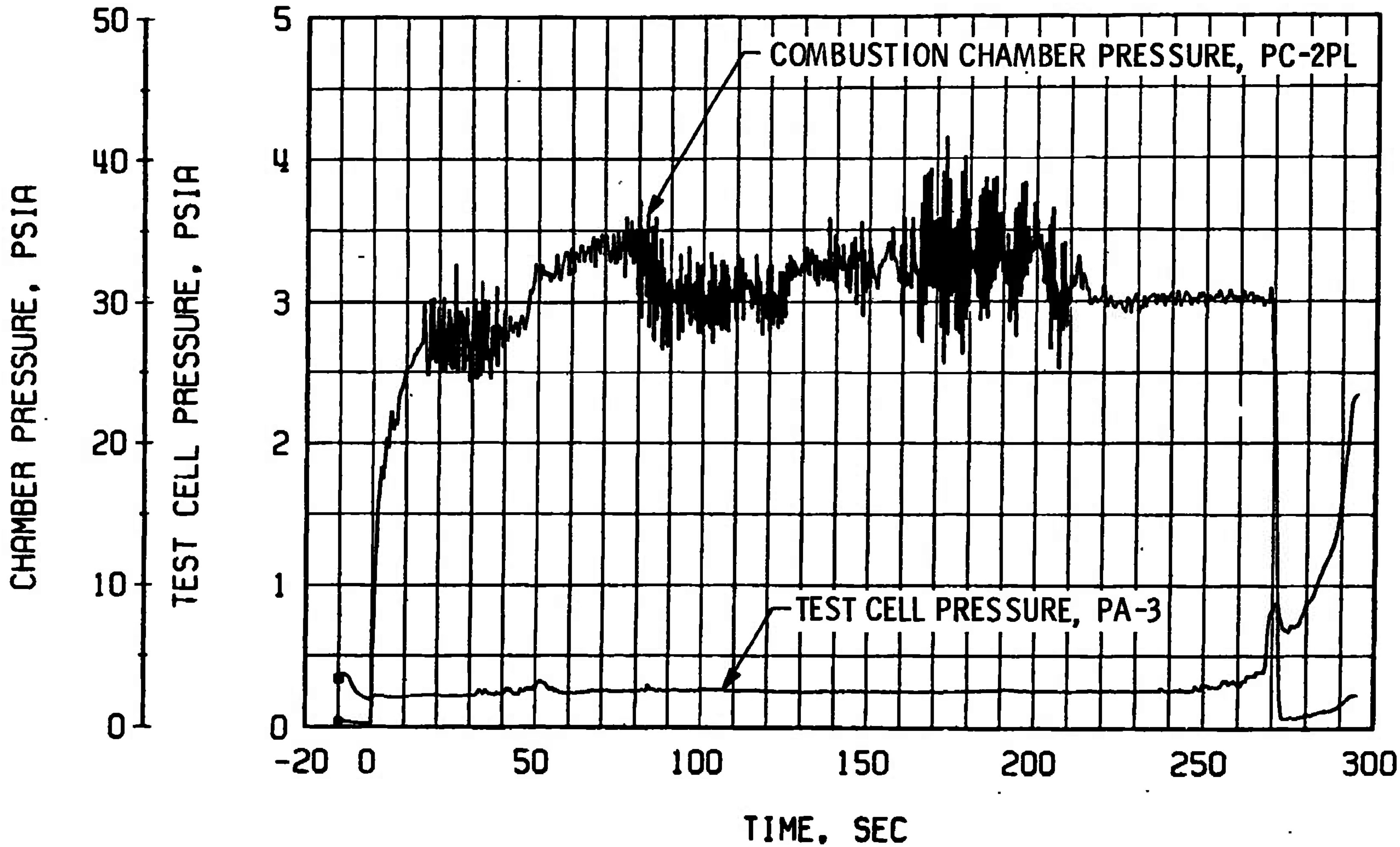
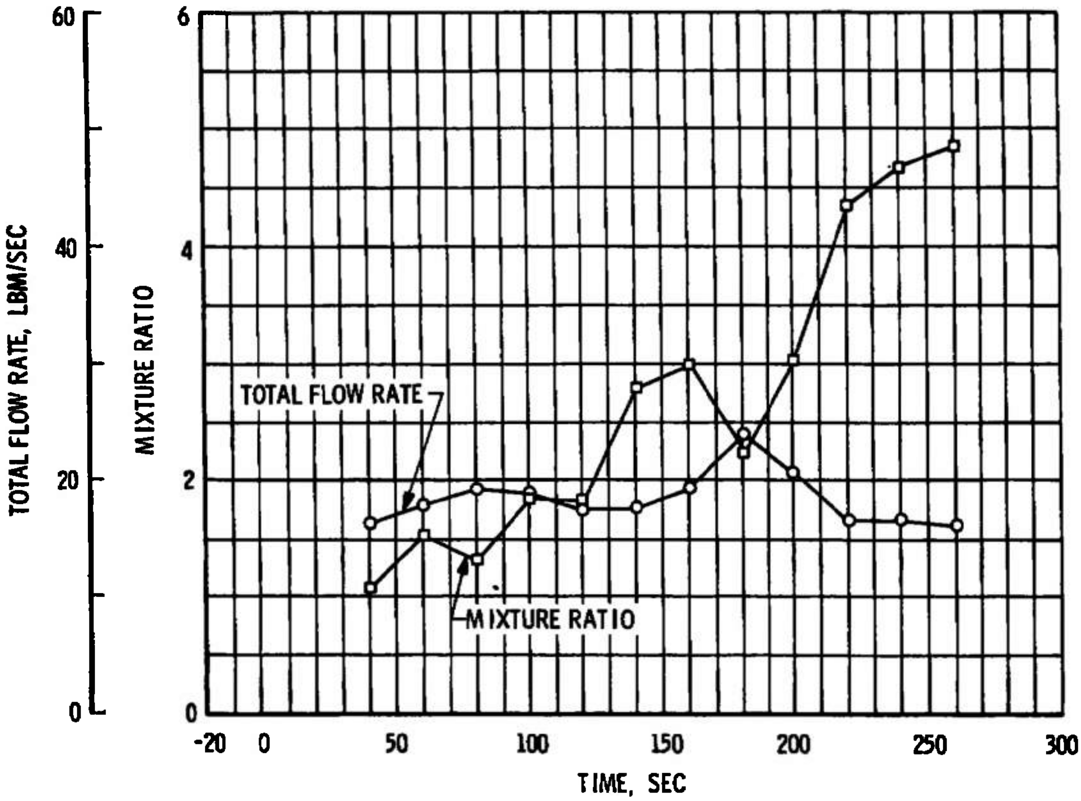
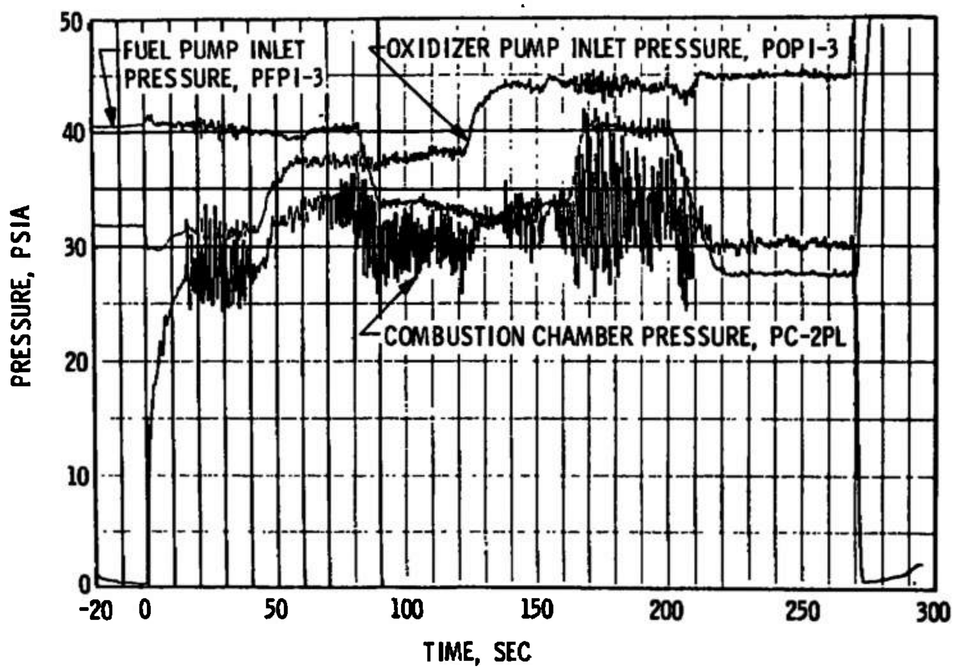


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 10A

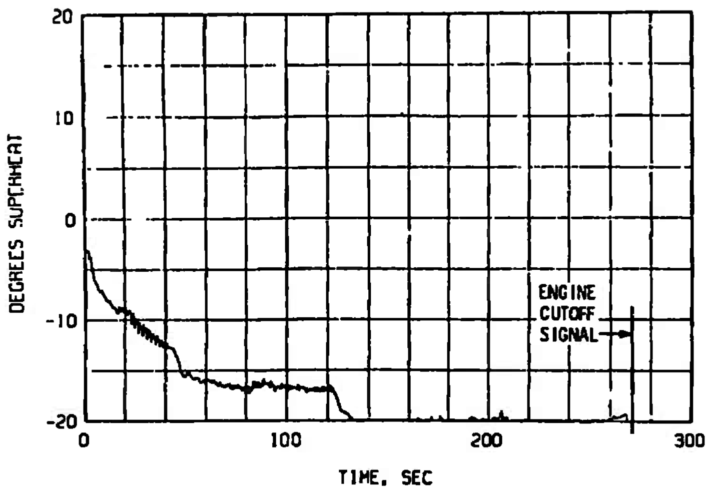


a. Total Flow Rate and Mixture Ratio

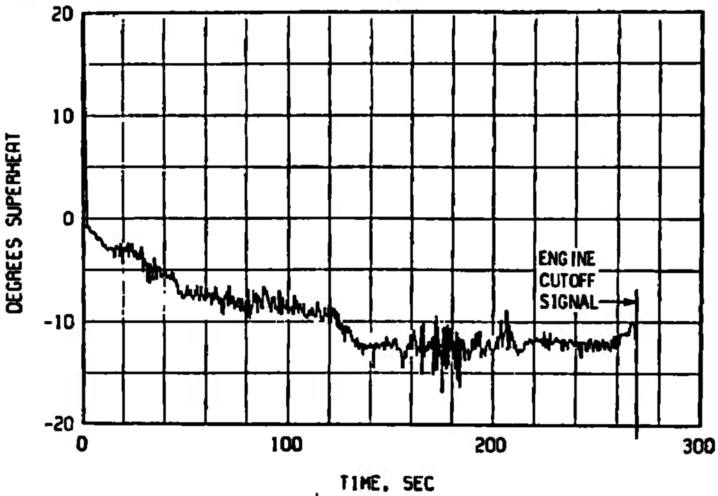


b. Pump Inlet and Combustion Chamber Pressures

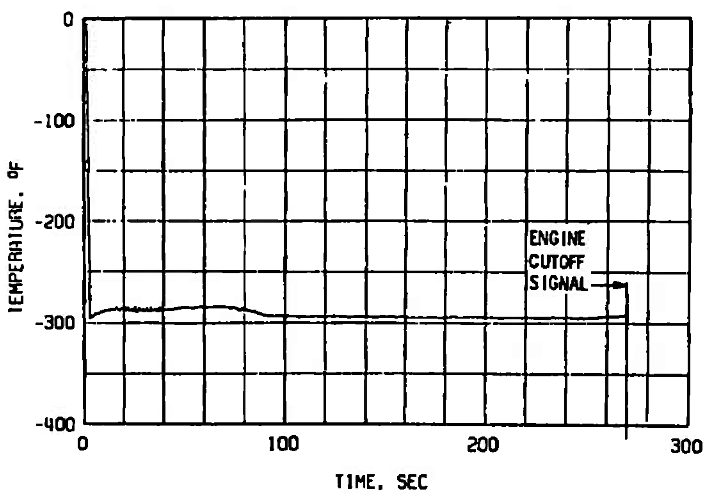
Fig. 16 Propellant System Performance, Firing 10A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

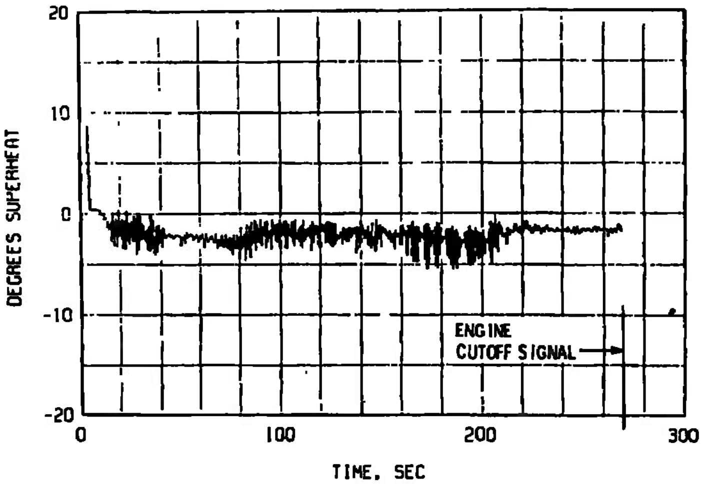


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

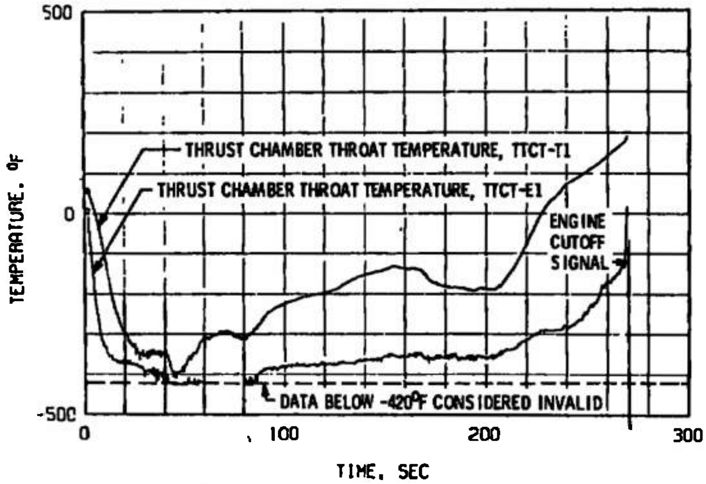


c. Oxidizer Temperature at Injector (TOJ), °F

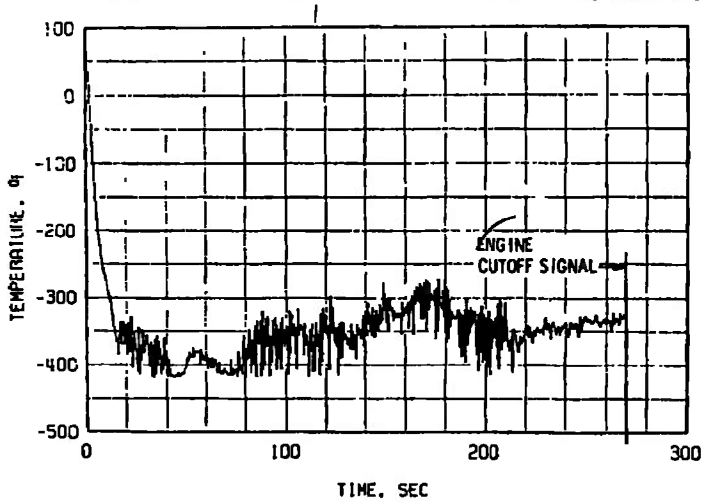
Fig. 17 Propellant System Temperature Transients, Firing 12A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 17 Concluded

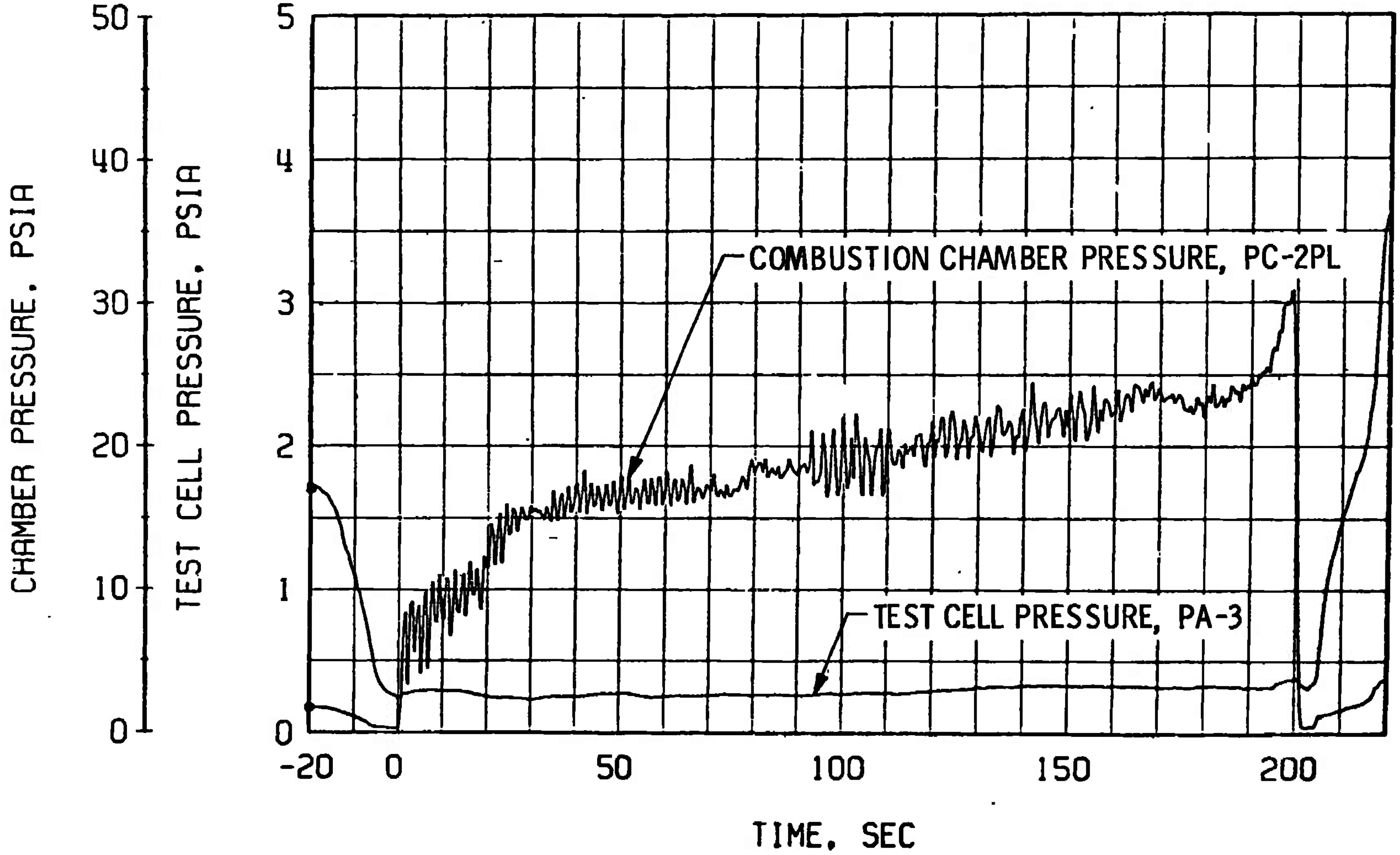
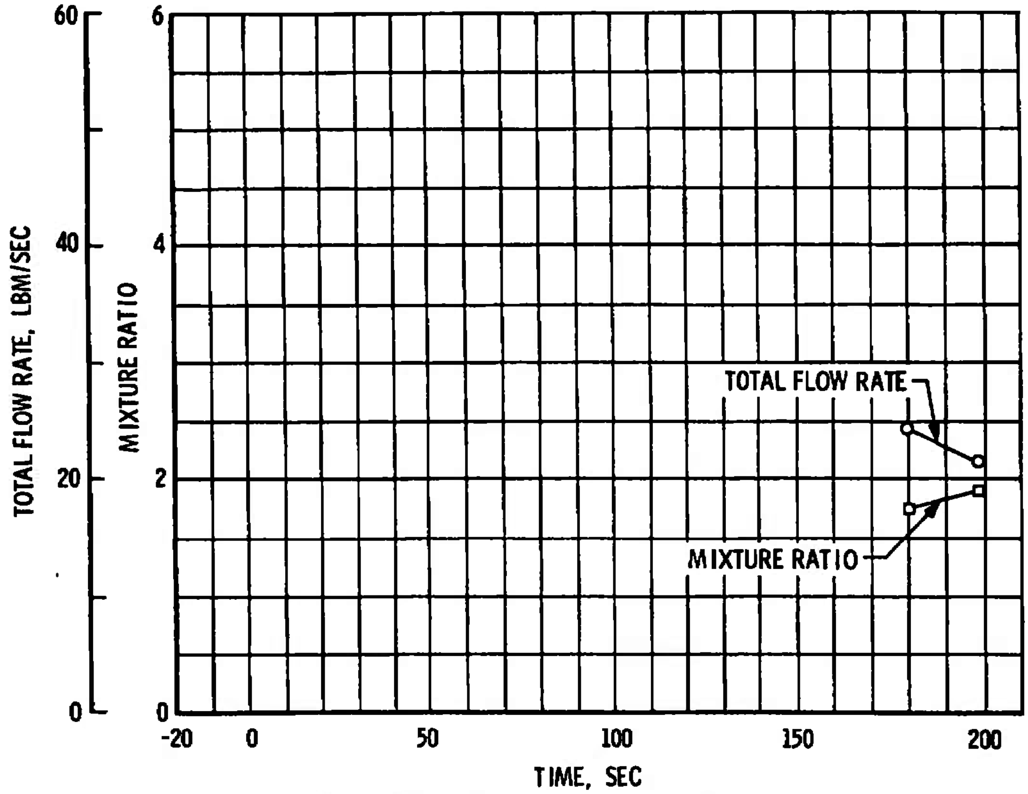
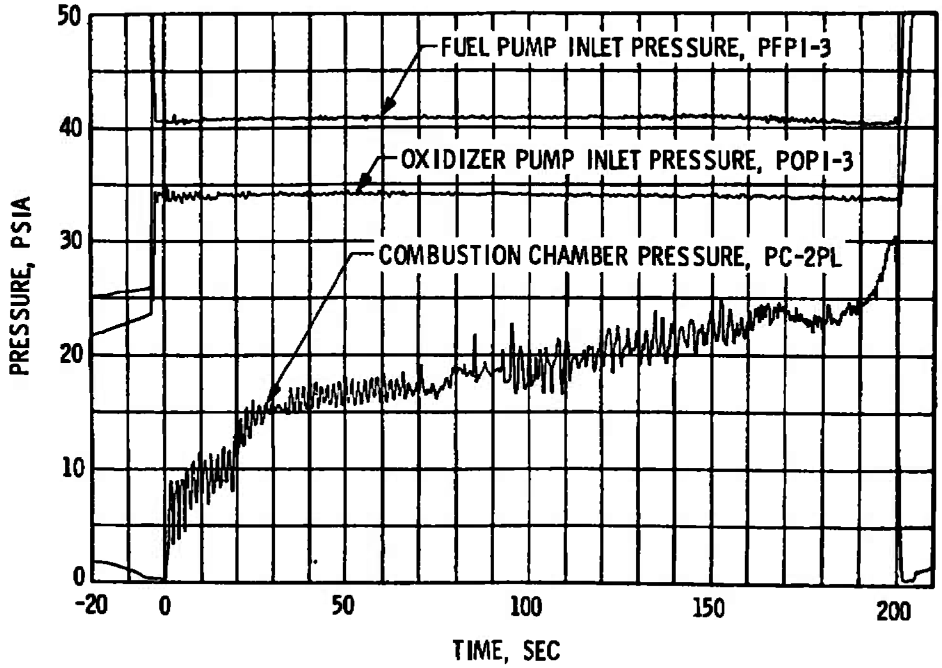


Fig. 18 Engine Ambient and Combustion Chamber Pressures, Firing 12A

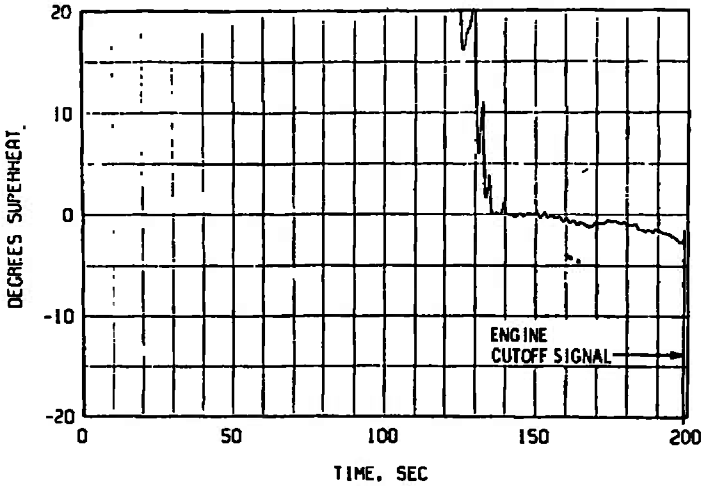


a. Total Flow Rate and Mixture Ratio

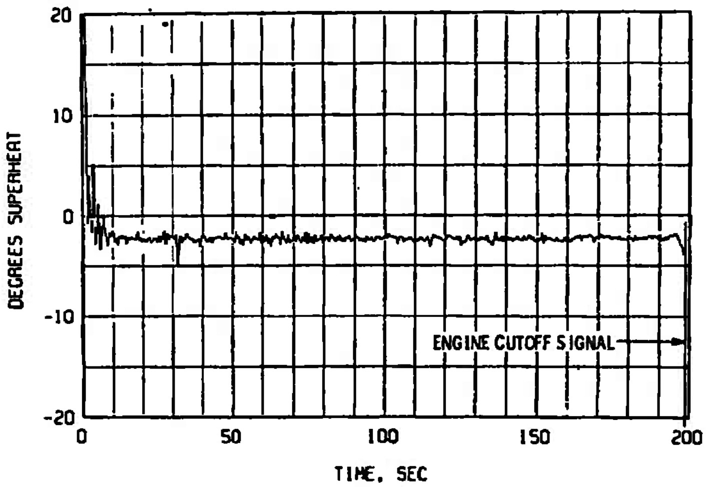


b. Pump Inlet and Combustion Chamber Pressures

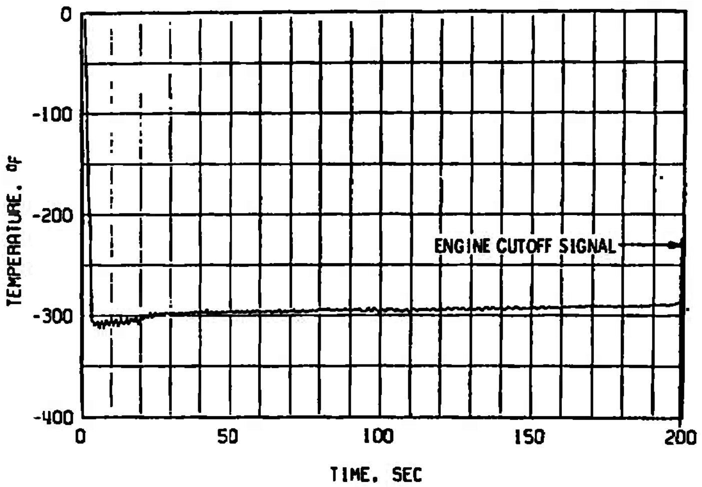
Fig. 19 Propellant System Performance, Firing 12A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

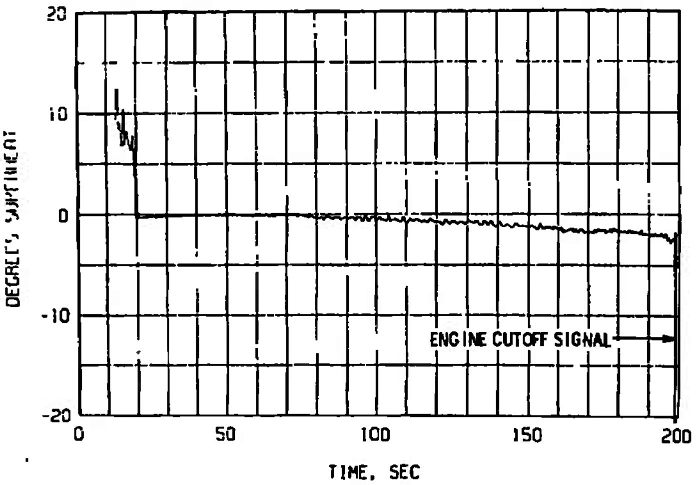


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

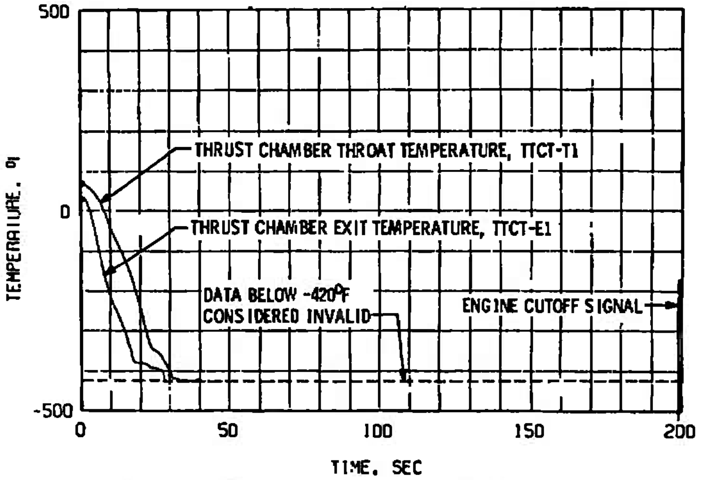


c. Oxidizer Temperature at Injector (TOJ), °F

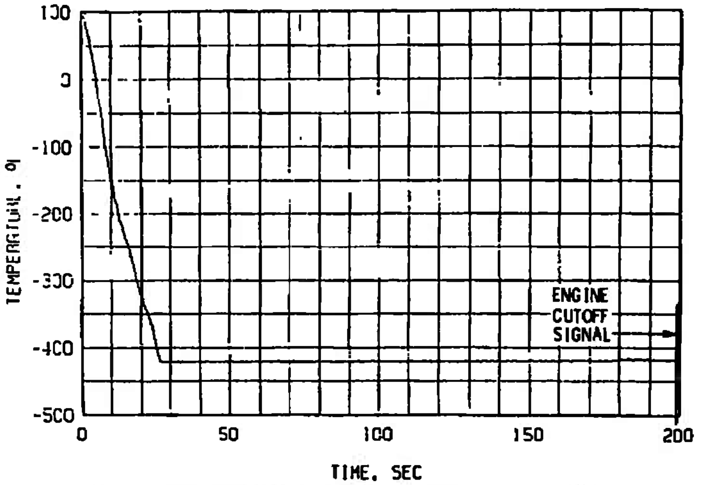
Fig. 20 Propellant System Temperature Transients, Firing 12A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 20 Concluded

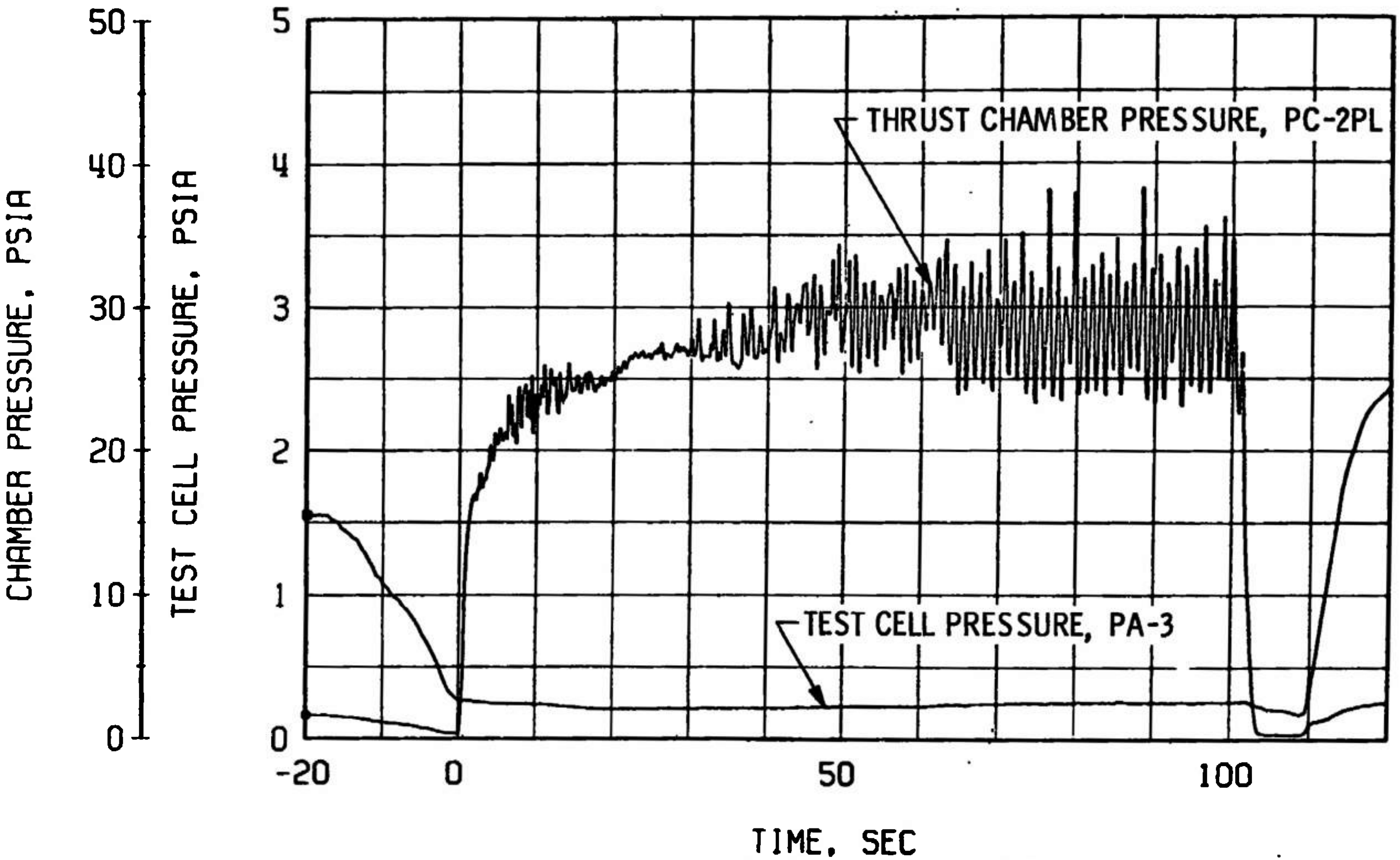
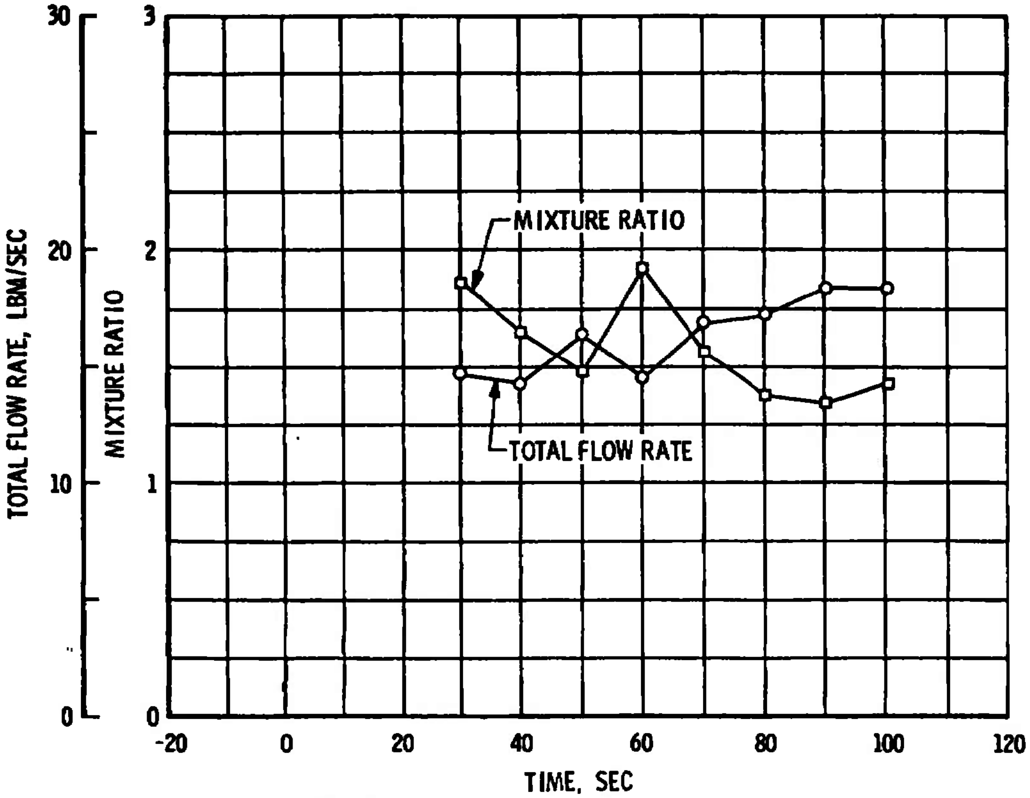
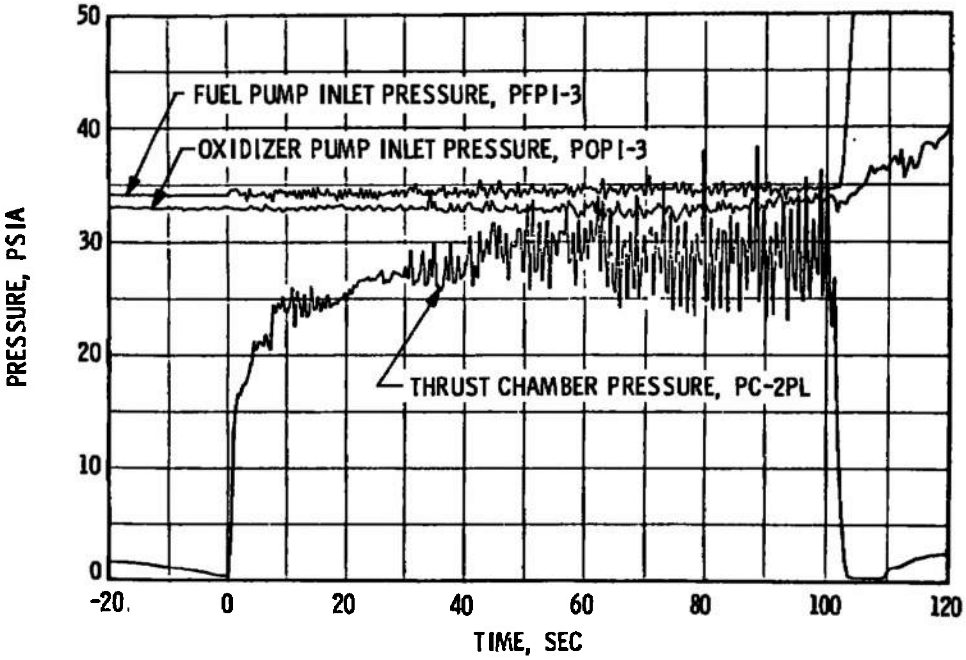


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 13A

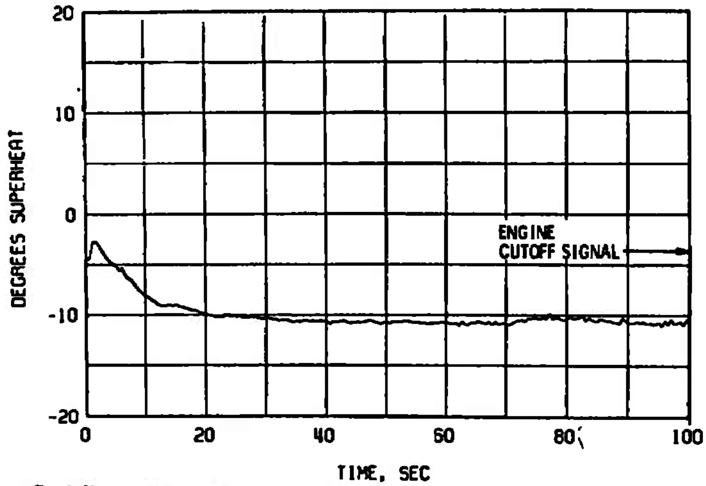


a. Total Flow Rate and Mixture Ratio

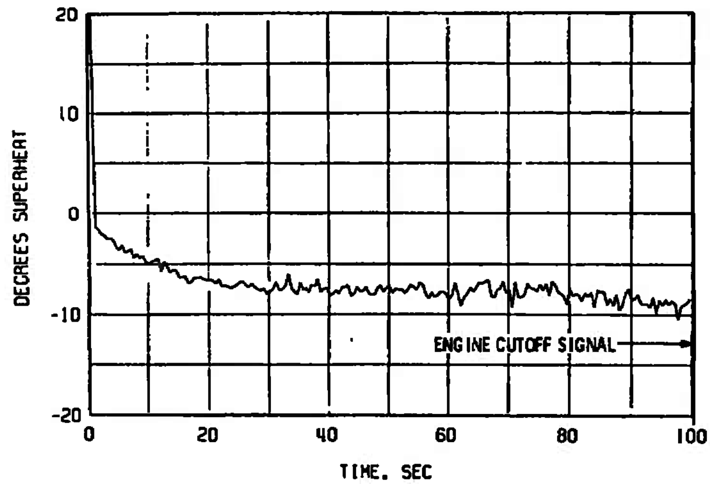


b. Pump Inlet and Combustion Chamber Pressures

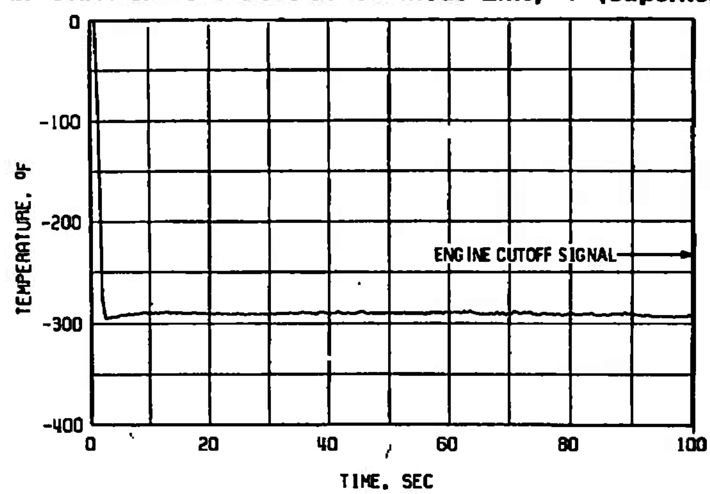
Fig. 22 Propellant System Performance, Firing 13A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

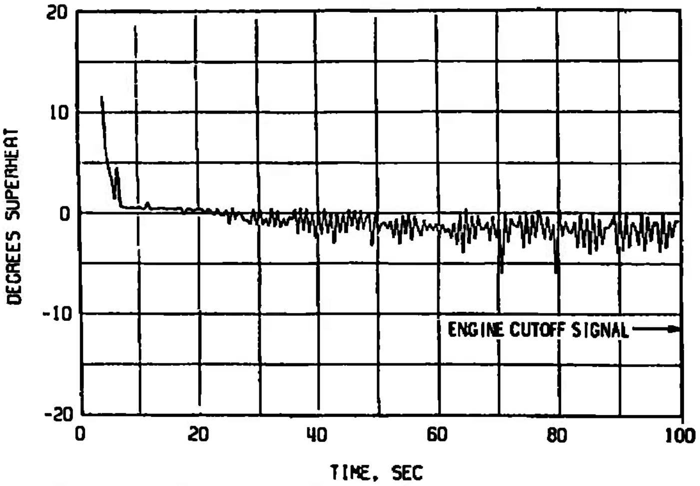


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

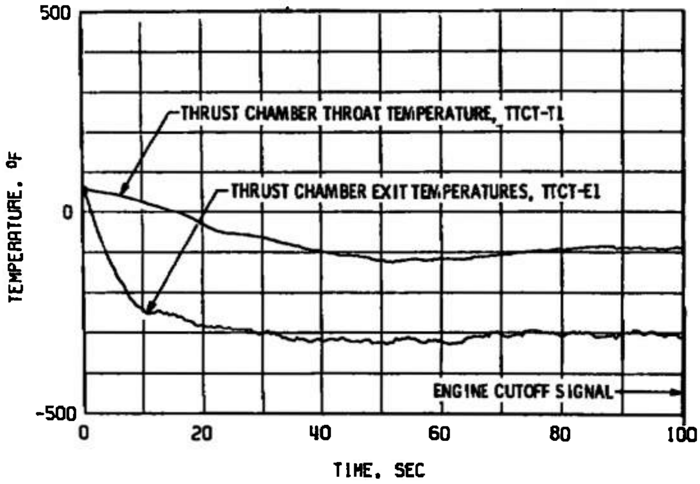


c. Oxidizer Temperature at Injector (TOJ), °F

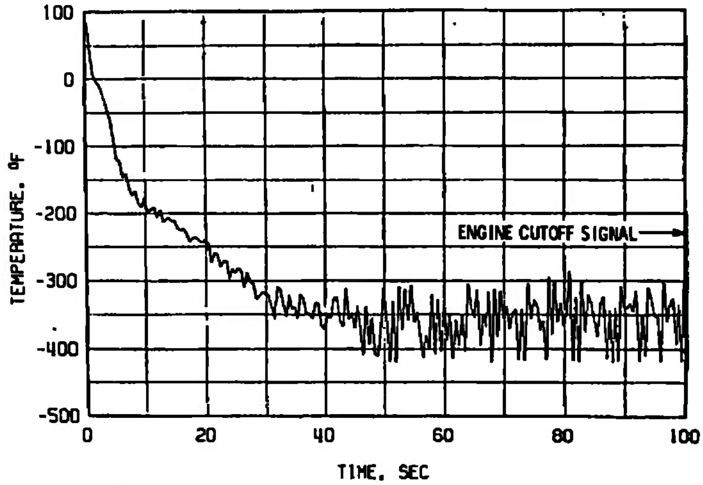
Fig. 23 Propellant System Temperature Transients, Firing 13A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 23 Concluded

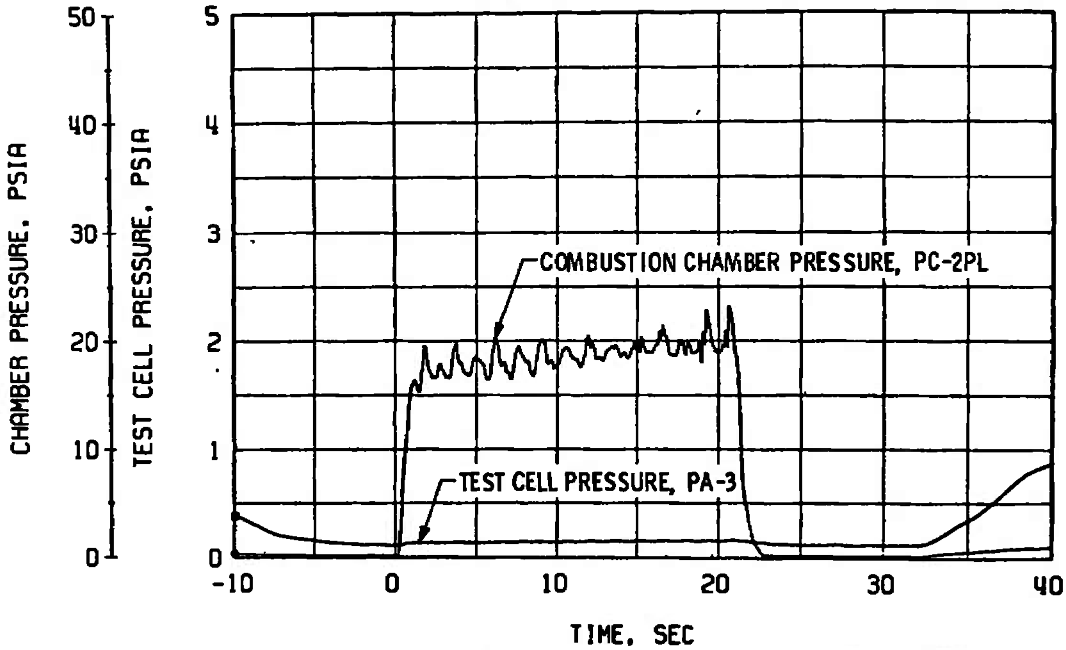


Fig. 24 Engine Ambient and Combustion Chamber Pressures, Firing 13B

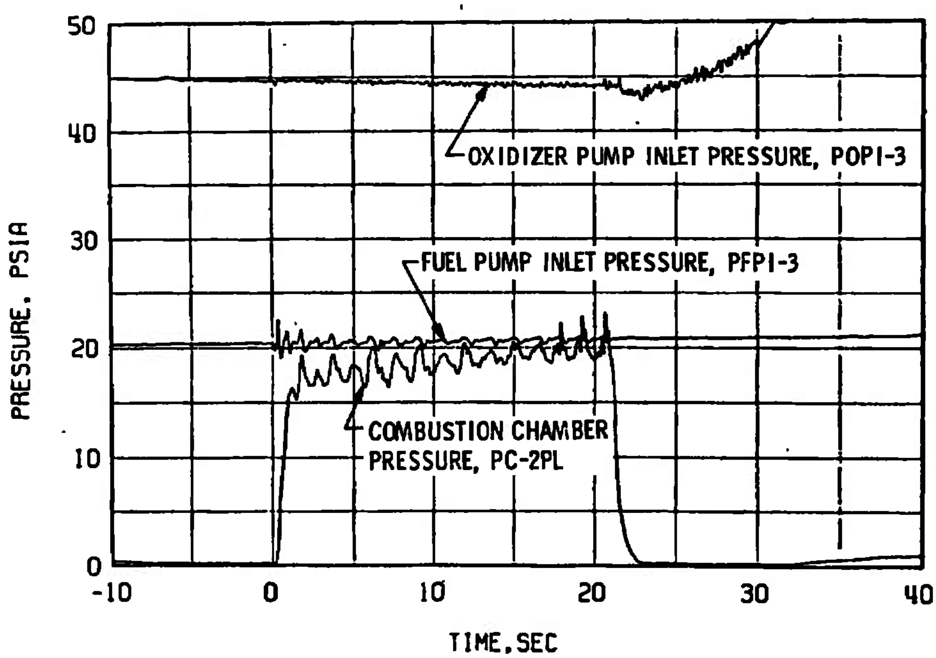
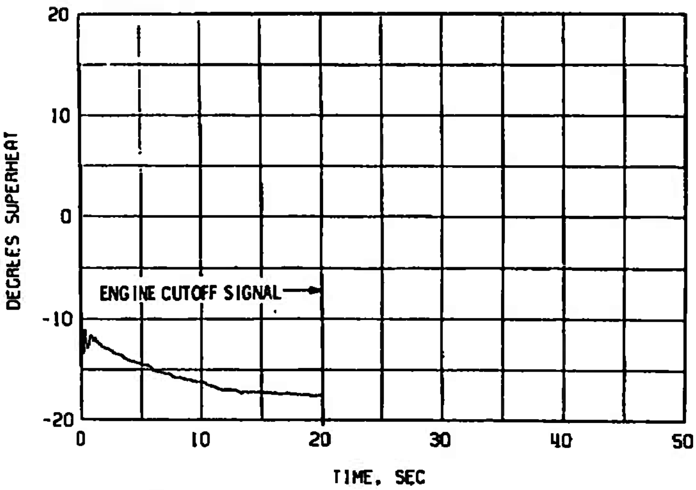
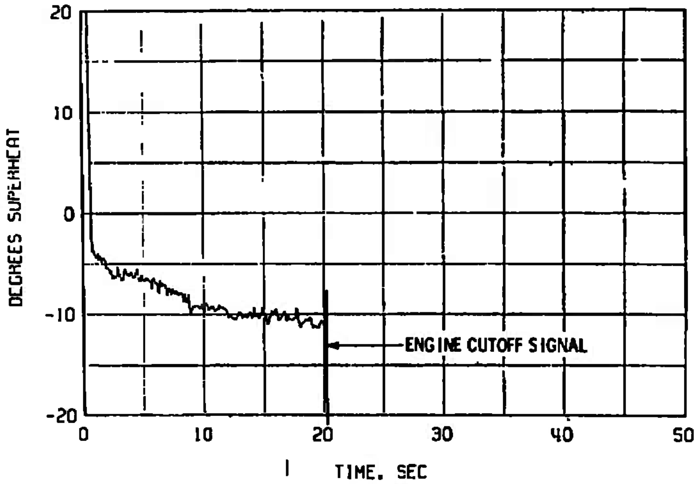


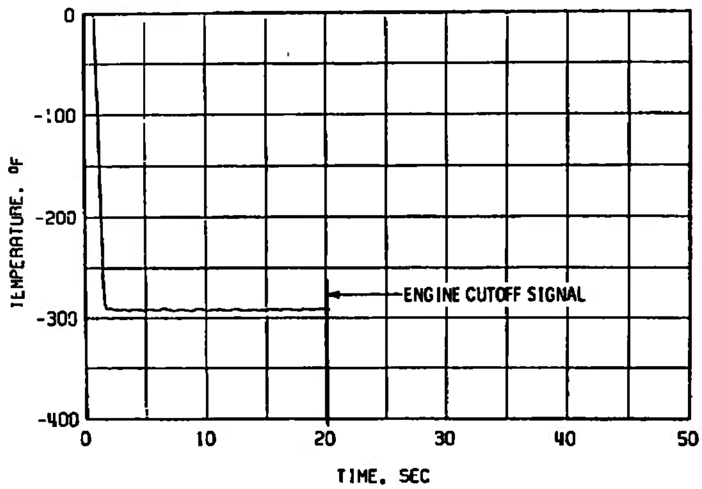
Fig. 25 Propellant System Performance, Firing 13B



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

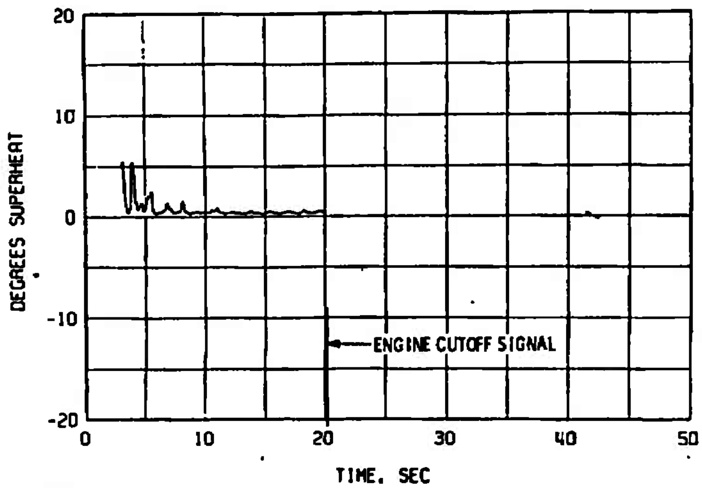


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

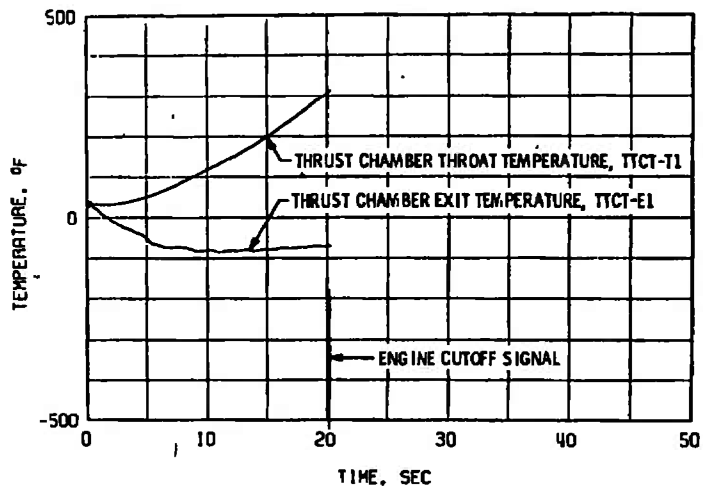


c. Oxidizer Conditions at Injector (TOJ), °F

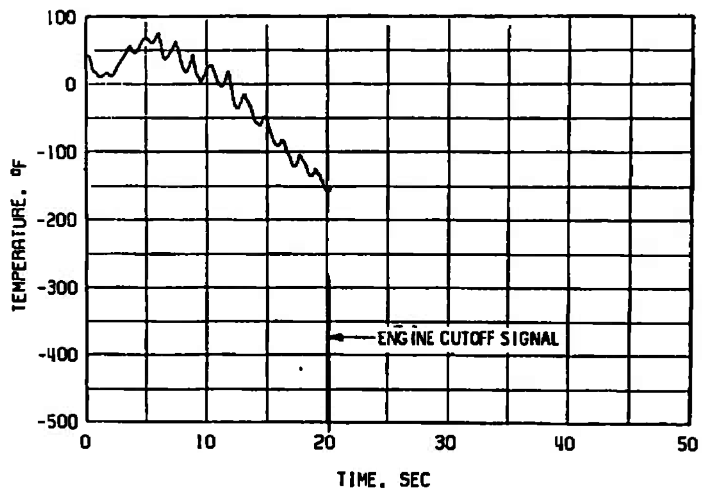
Fig. 26 Propellant System Temperature Transients, Firing 13B



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 26 Concluded

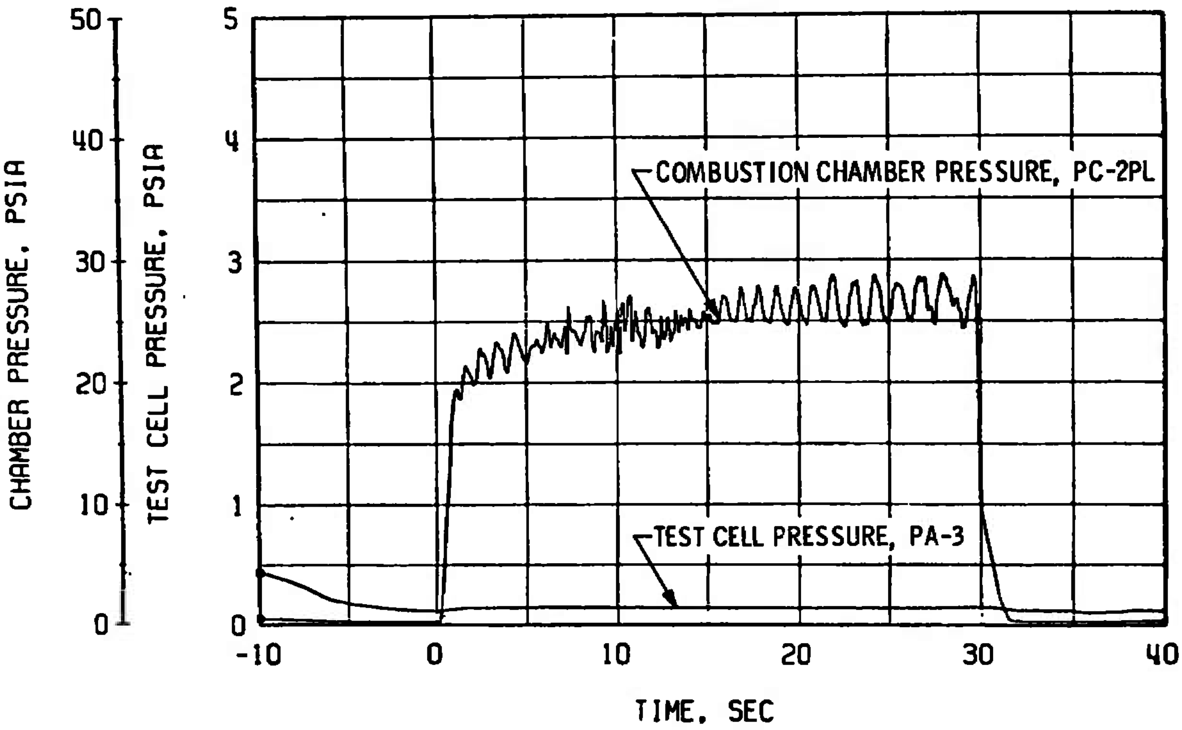


Fig. 27 Engine Ambient and Combustion Chamber Pressure, Firing 13C

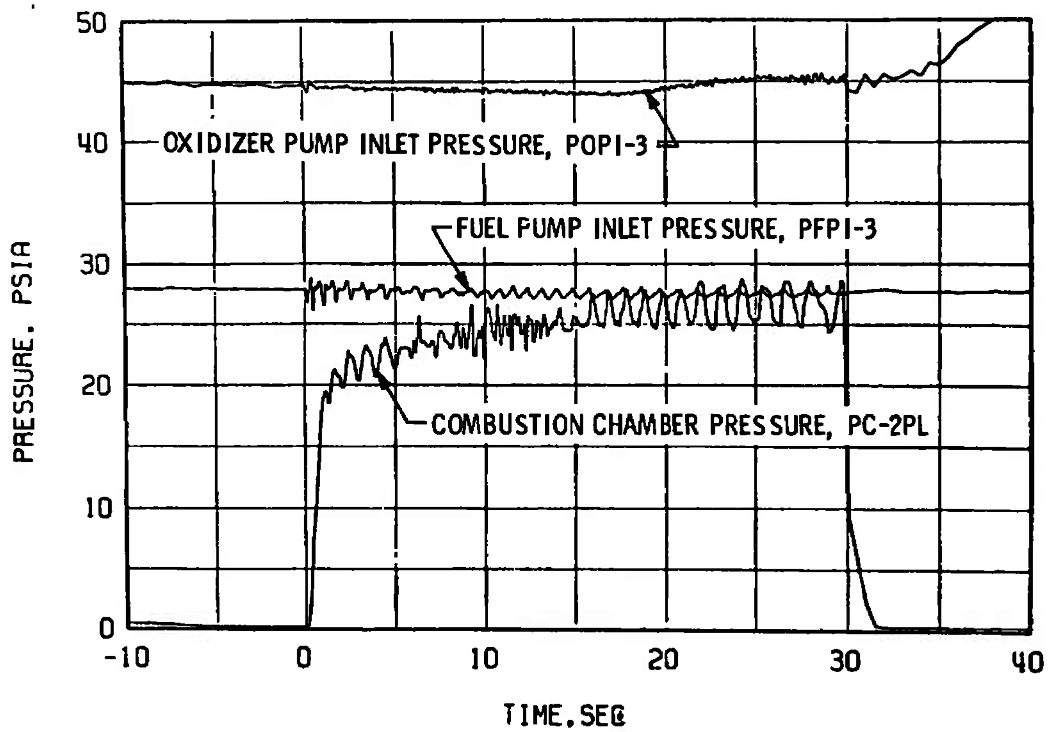
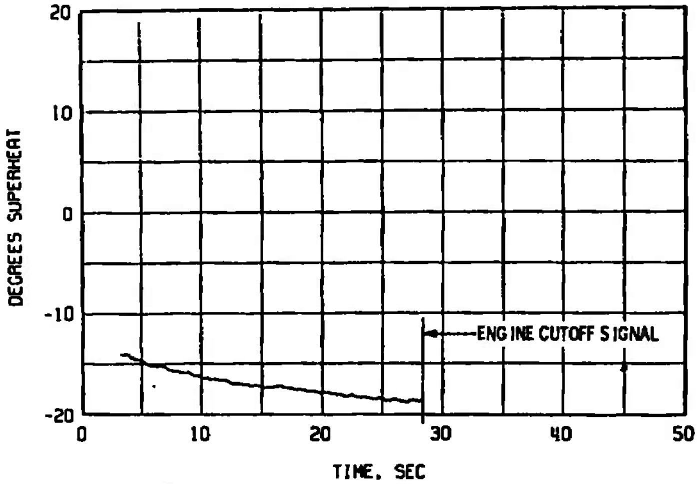
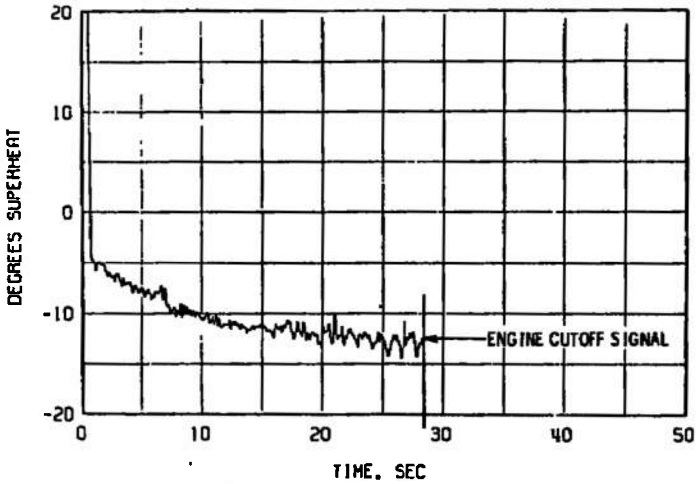


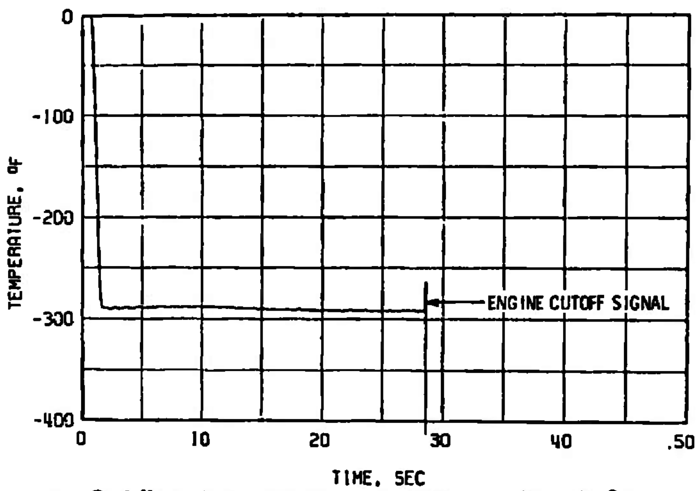
Fig. 28 Propellant System Performance, Firing 13C



a. Oxidizer Conditions at Engine Flowmeter, °F

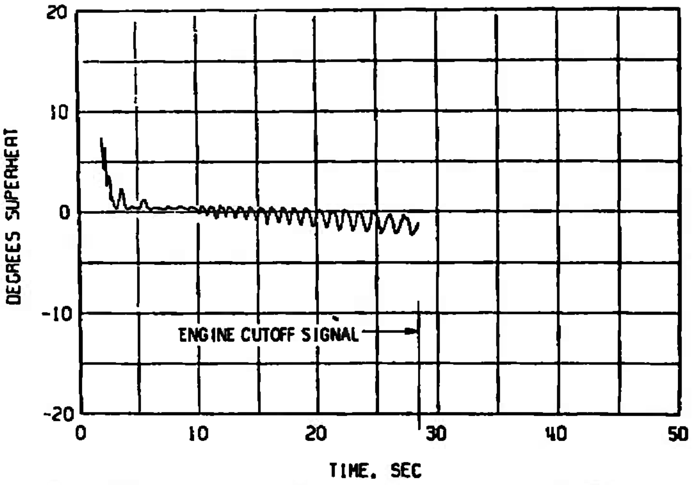


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

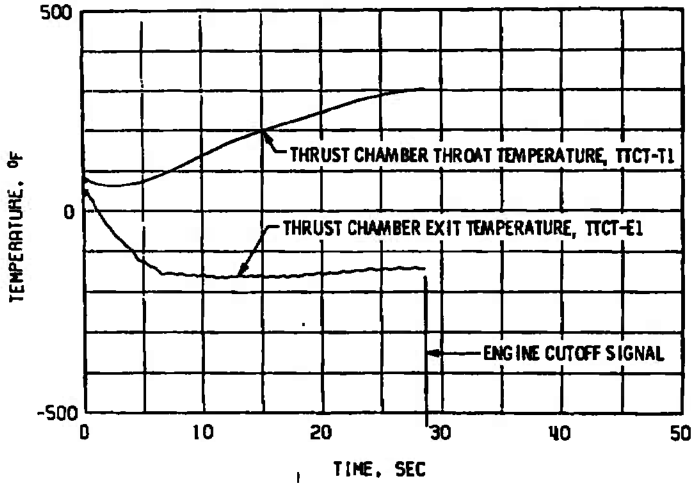


c. Oxidizer Temperature at Injector (TOJ), °F

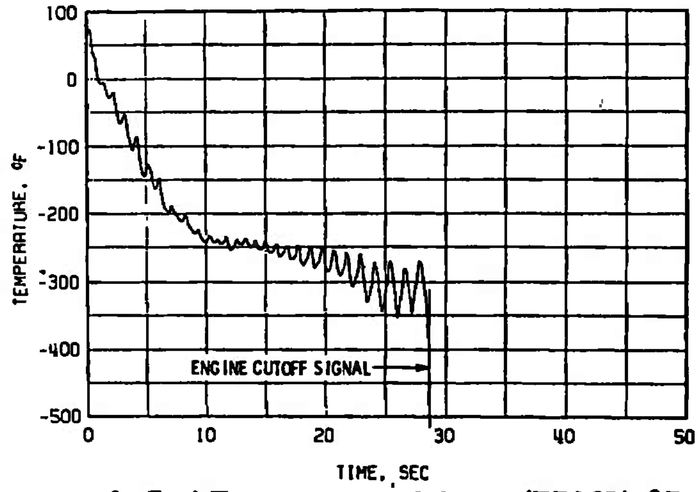
Fig. 29 Propellant System Transients, Firing 13C



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 29 Concluded

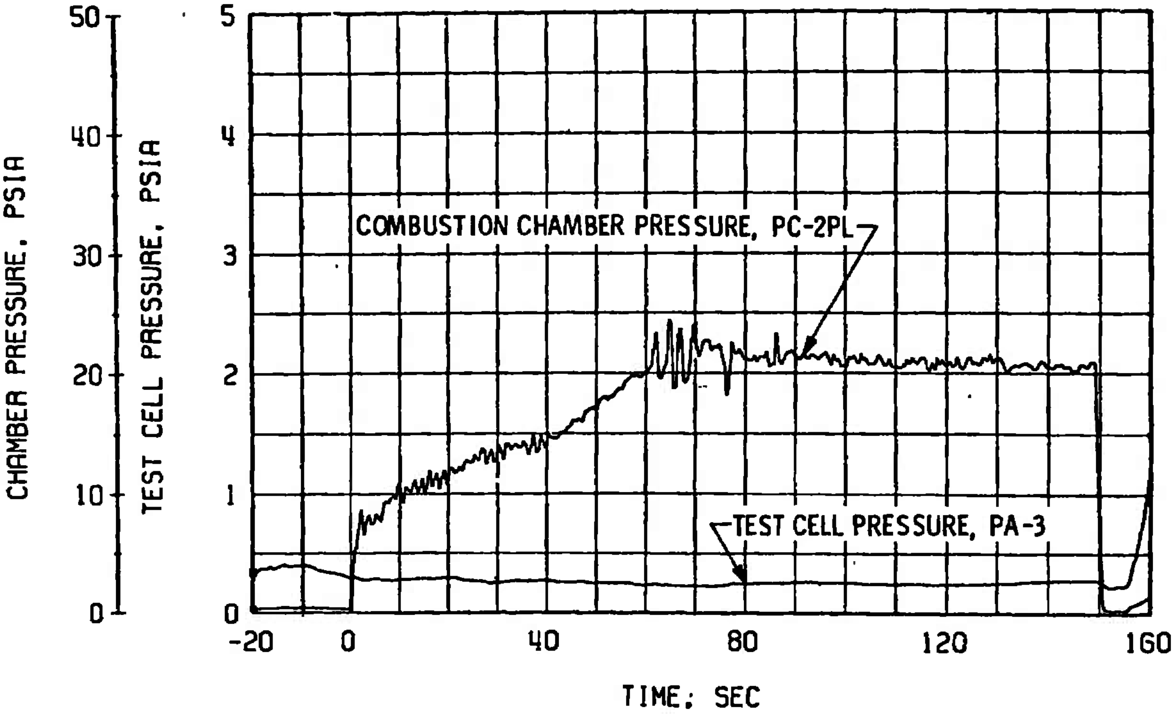


Fig. 30 Engine Ambient and Combustion Chamber Pressures, Firing 14A

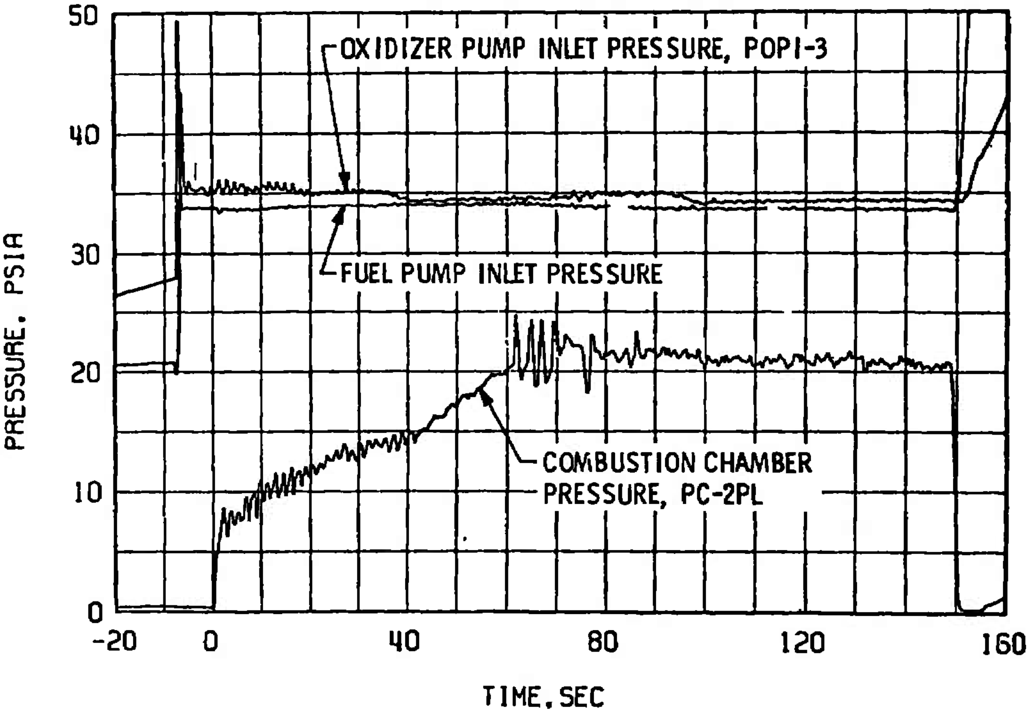
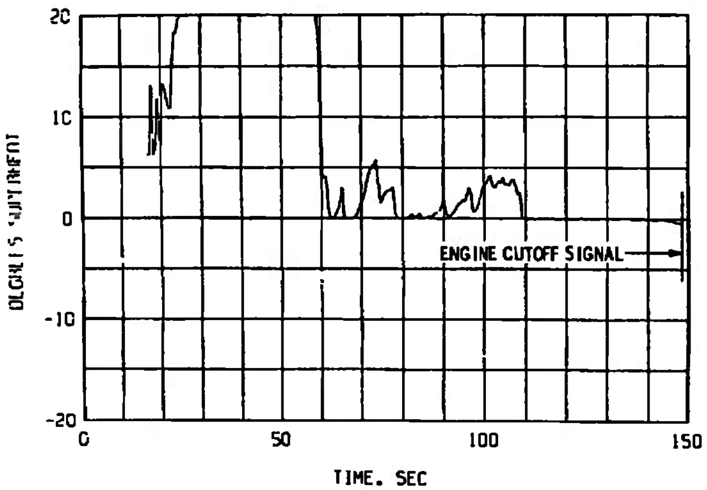
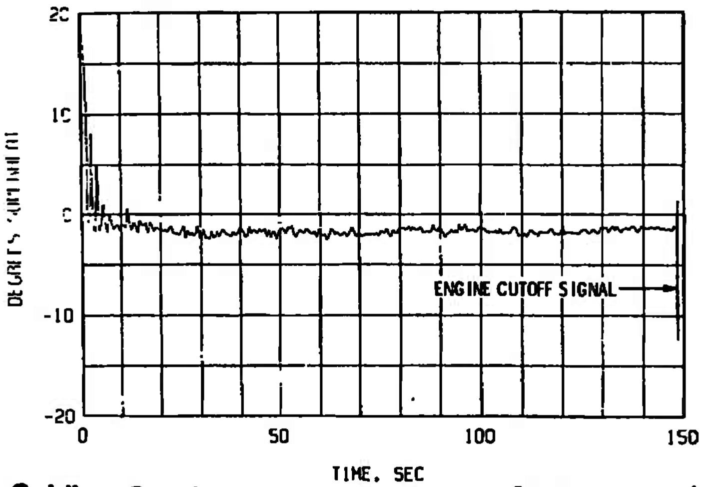


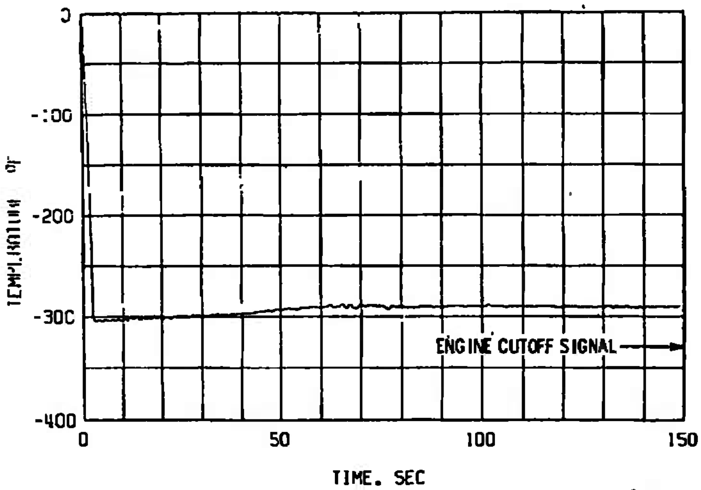
Fig. 31 Propellant System Performance, Firing 14A



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

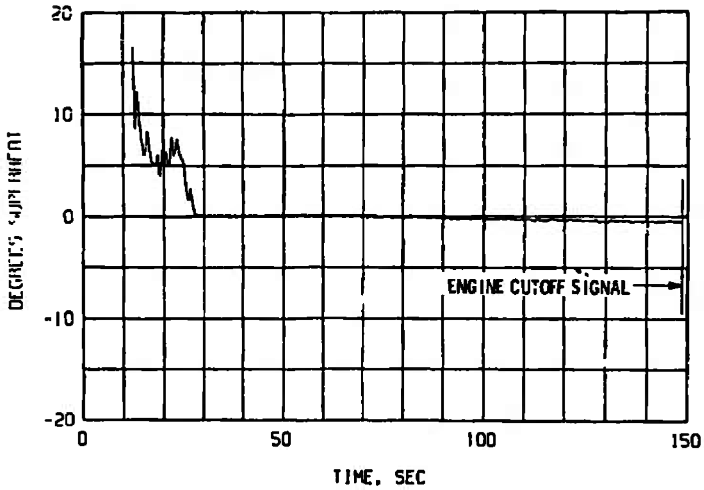


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

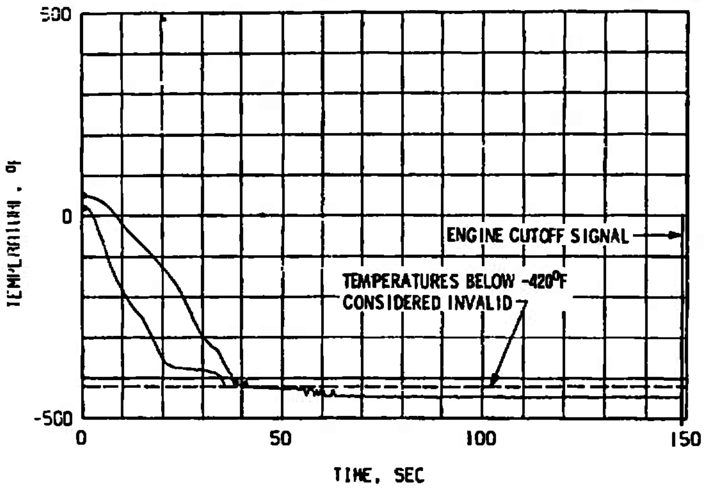


c. Oxidizer Temperature at Injector (TOJ), °F

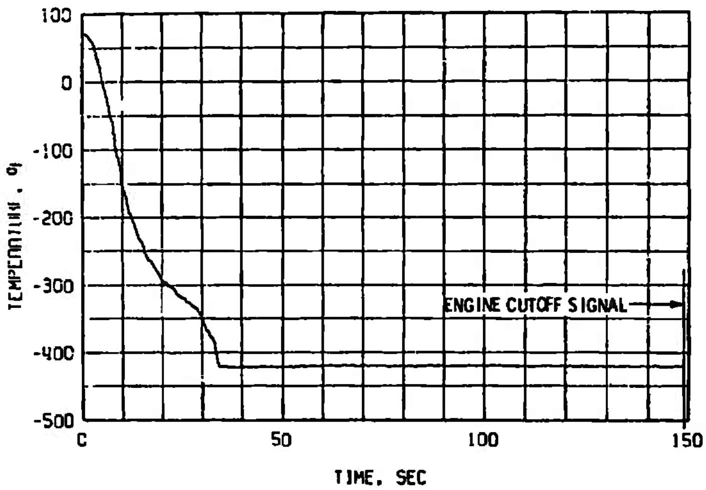
Fig. 32 Propellant System Temperature Transients, Firing 14A



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperature, °F



f. Fuel Injector Temperature (TFJ-2P), °F

Fig. 32 Concluded

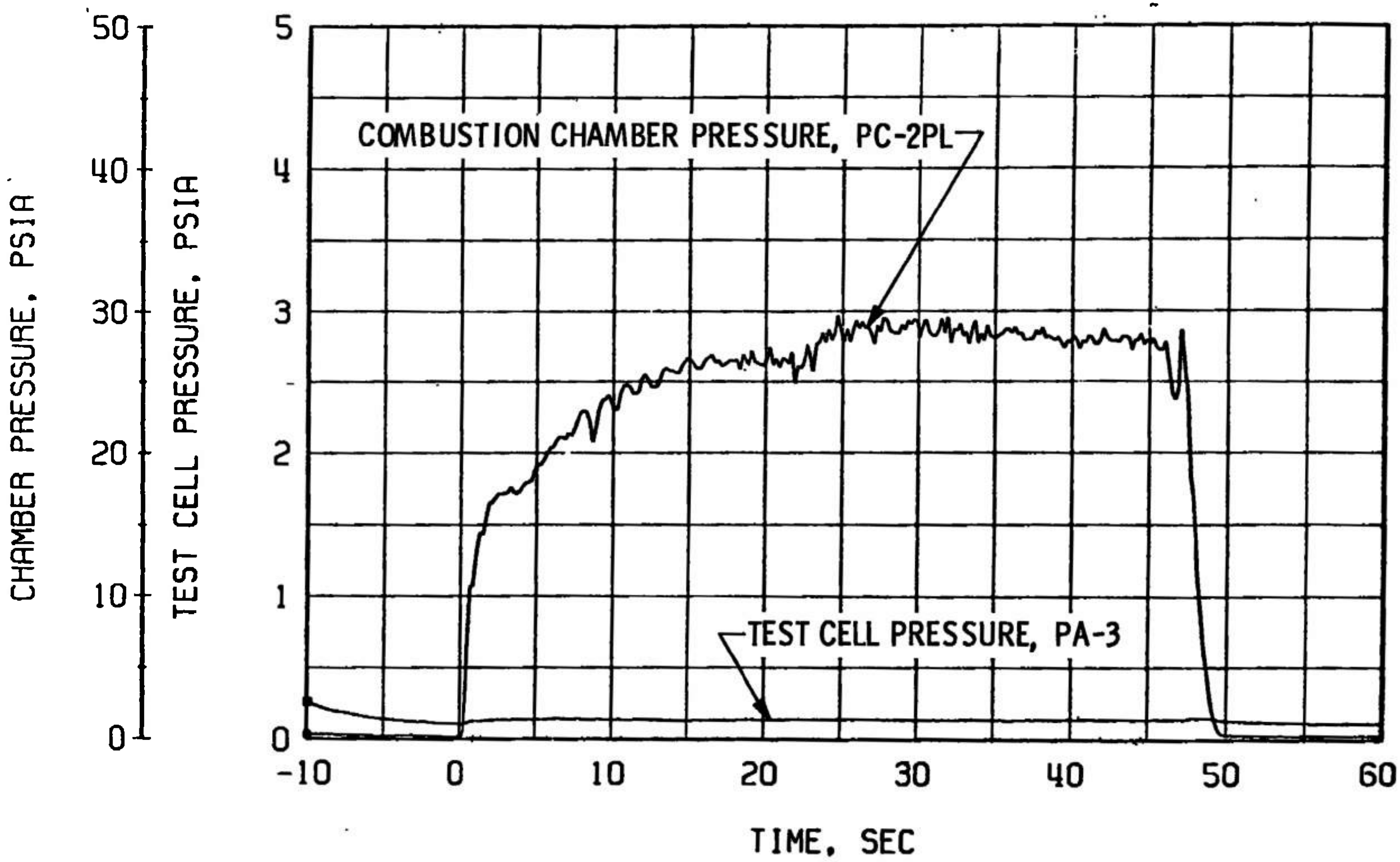
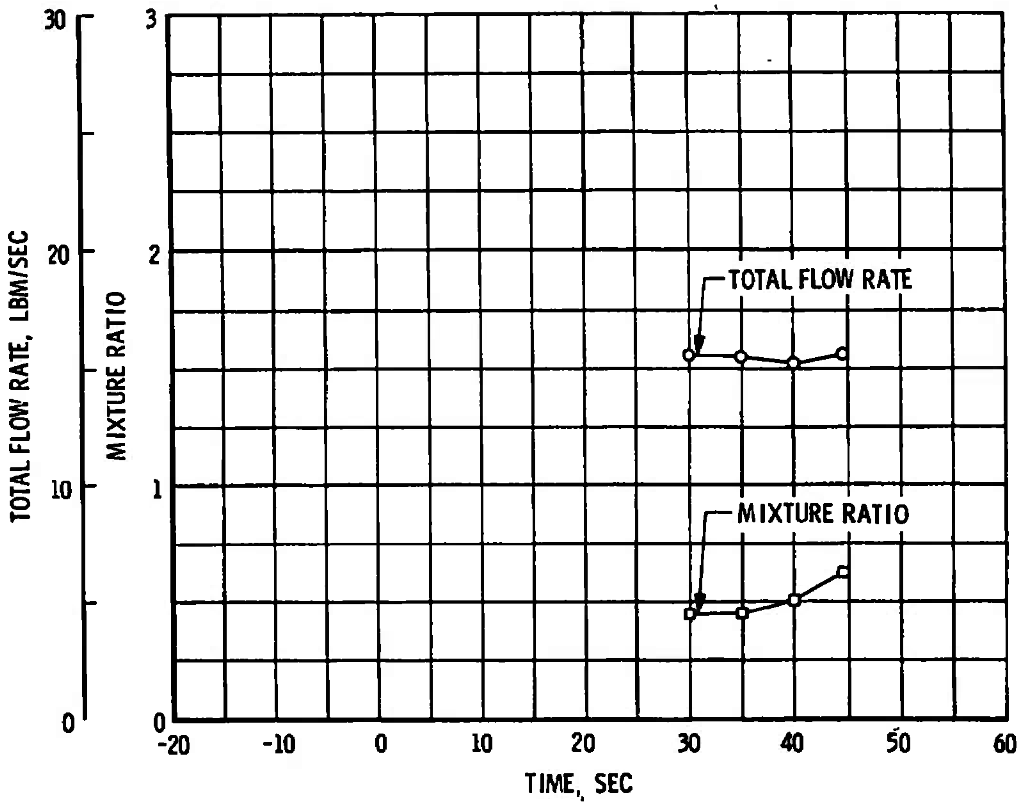
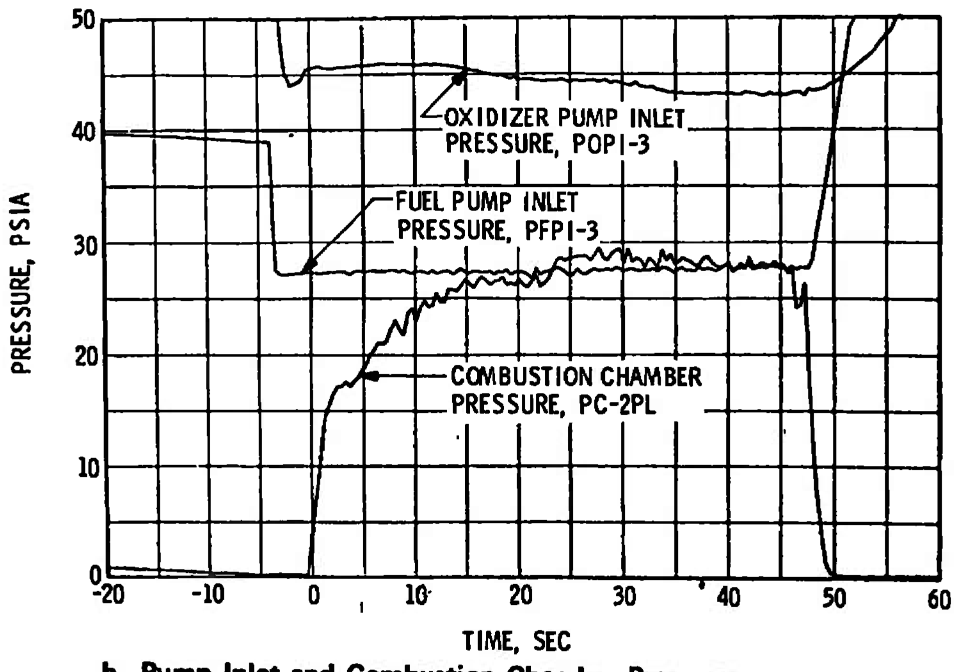


Fig. 33 Engine Ambient and Combustion Chamber Pressures, Firing 14B

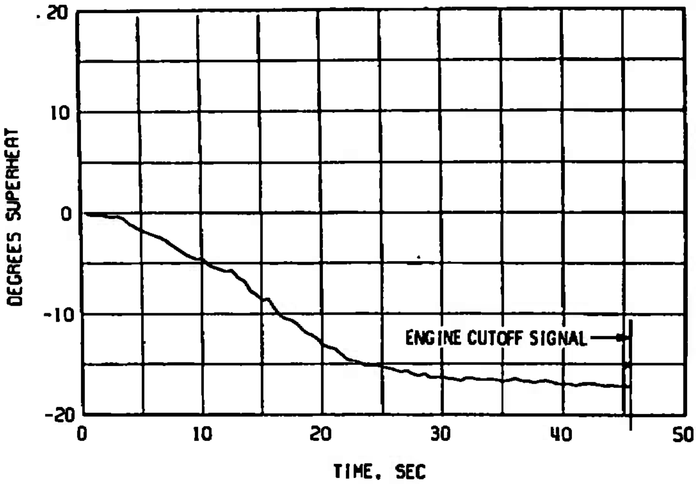


a. Total Flow Rate and Mixture Ratio

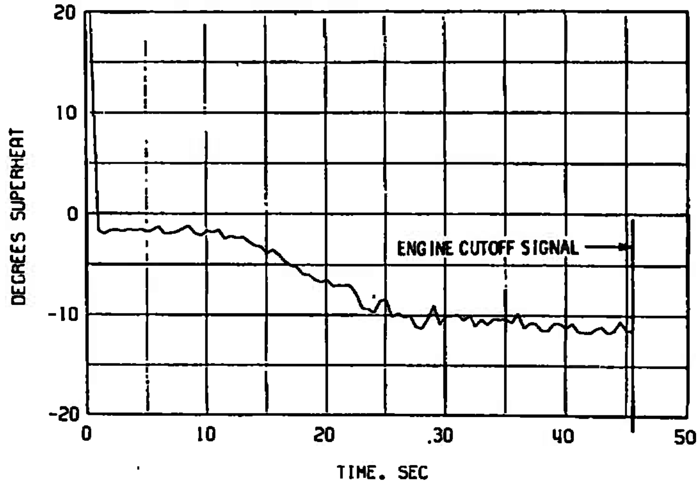


b. Pump Inlet and Combustion Chamber Pressures

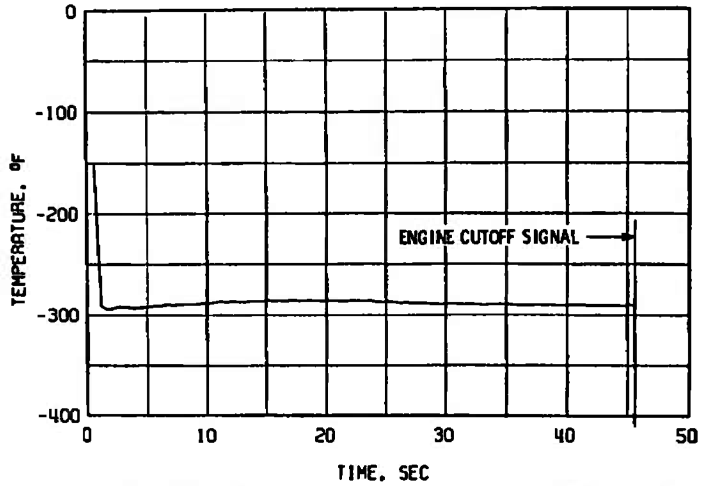
Fig. 34 Propellant System Performance, Firing 14B



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

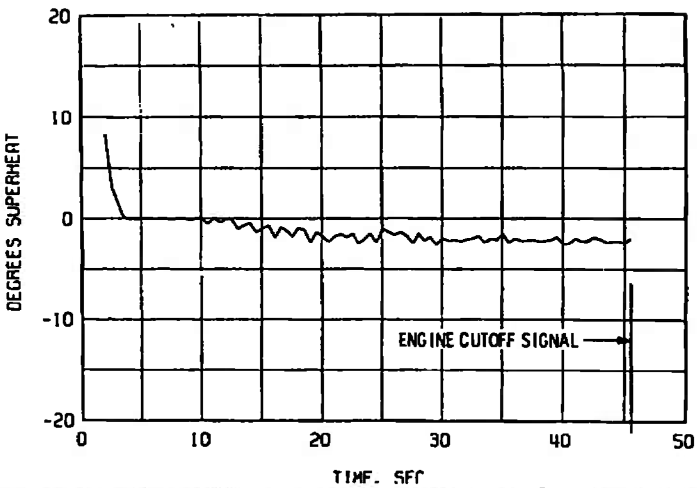


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

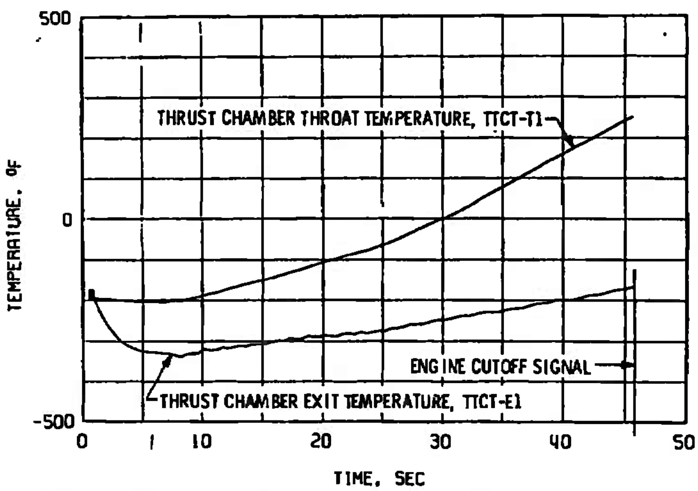


c. Oxidizer Temperature at Injector (TOJ), °F

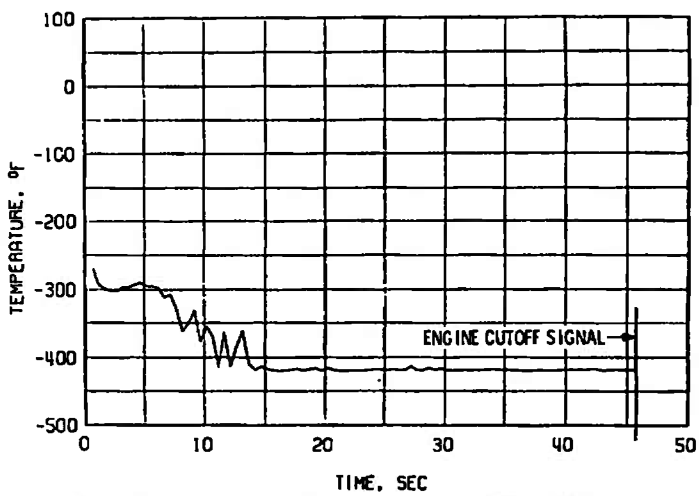
Fig. 35 Propellant System Temperature Transients, Firing 14B



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)



e. Thrust Chamber External Surface Temperatures, °F



f. Fuel Temperature at Injector (TFJ-2P), °F

Fig. 35 Concluded

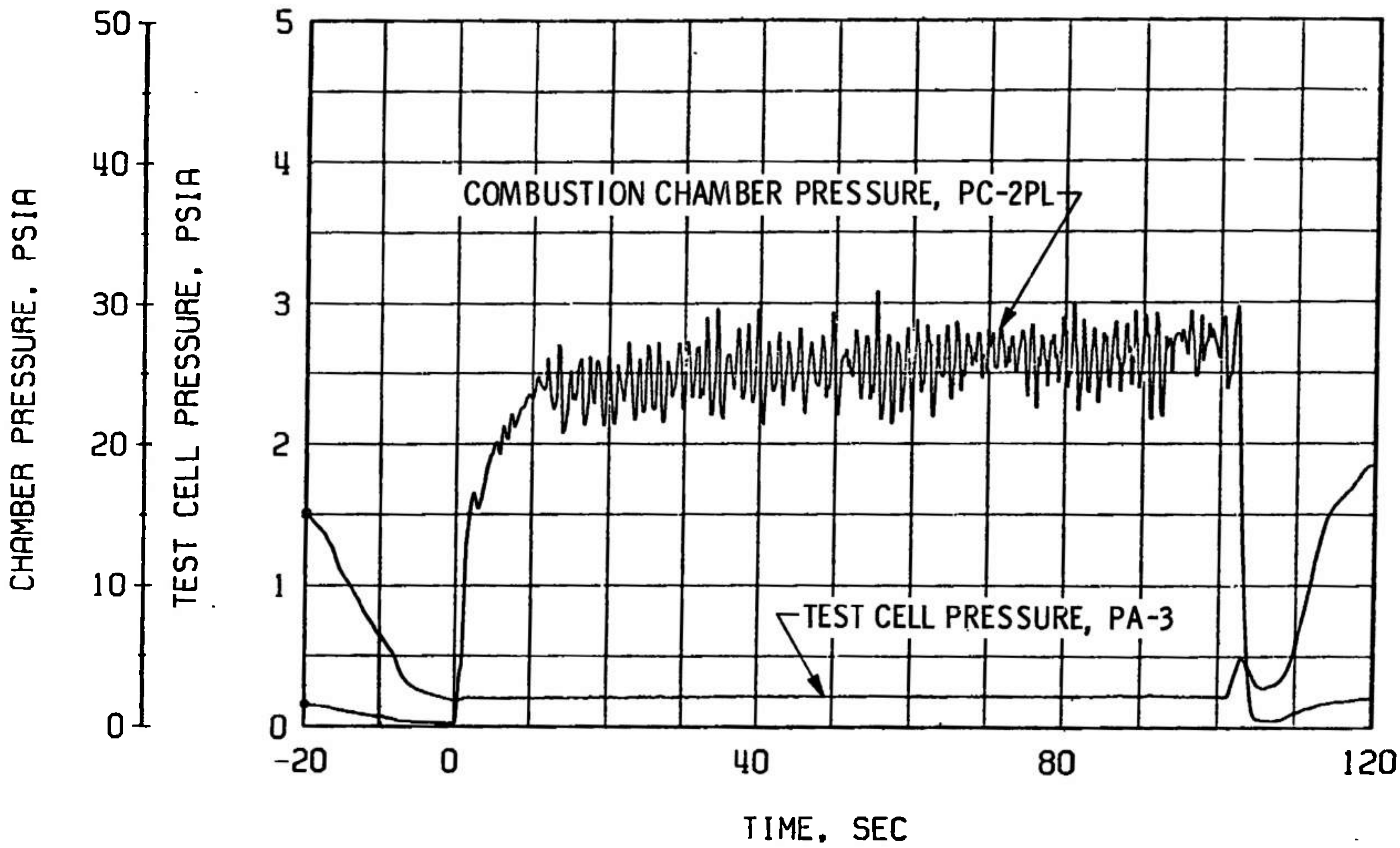
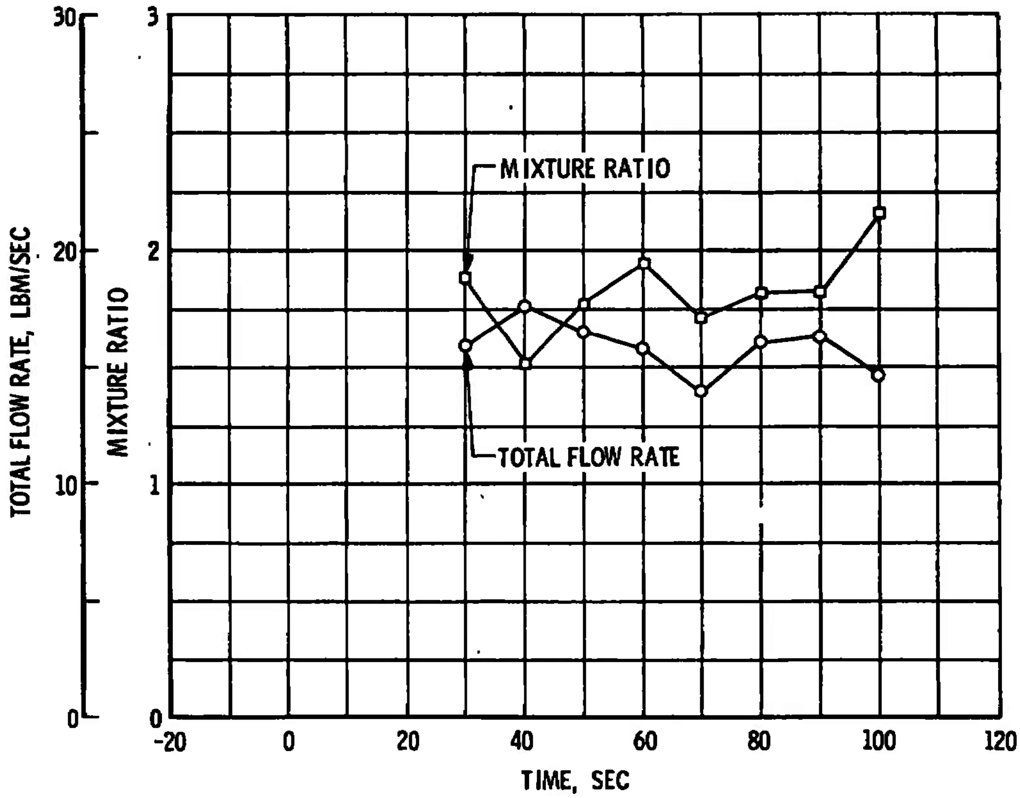
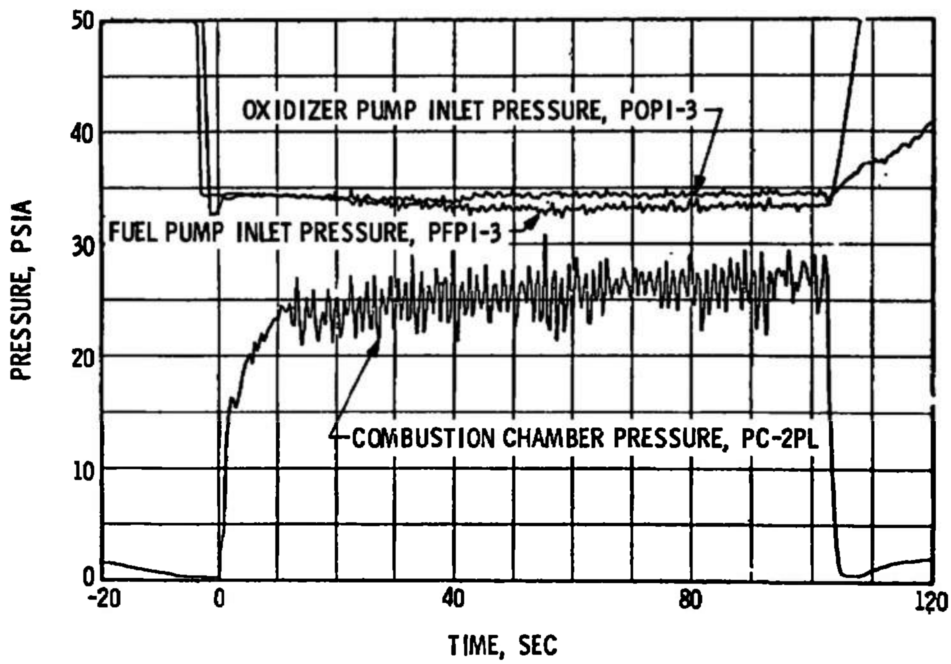


Fig. 36 Engine Ambient and Combustion Chamber Pressures, Firing 14C

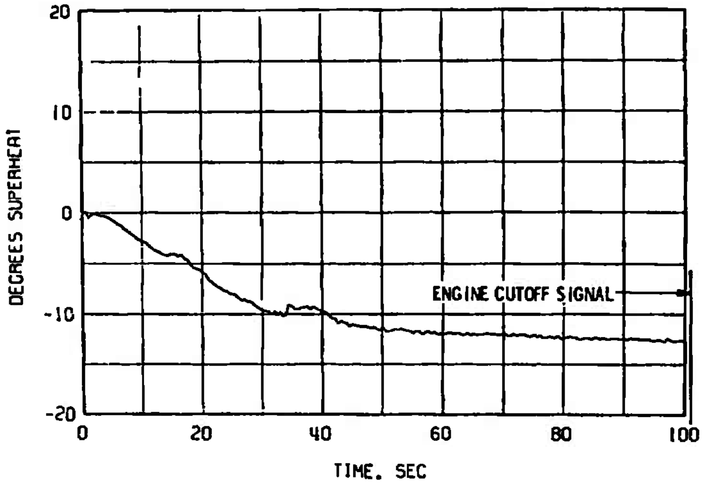


a. Total Flow Rate and Mixture Ratio

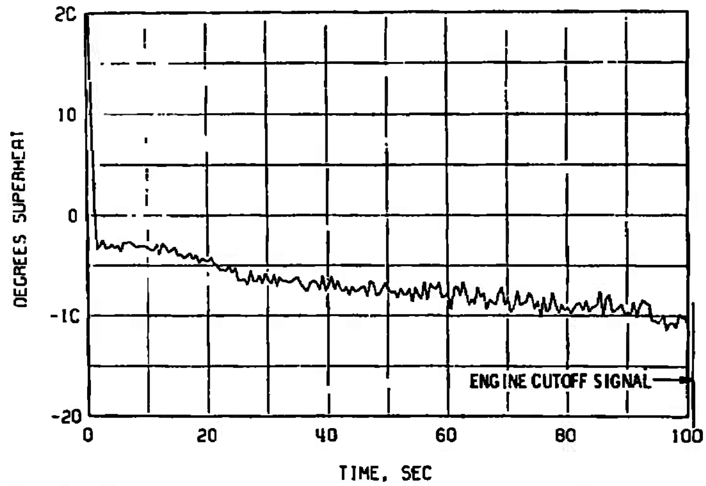


b. Pump Inlet and Combustion Chamber Pressures

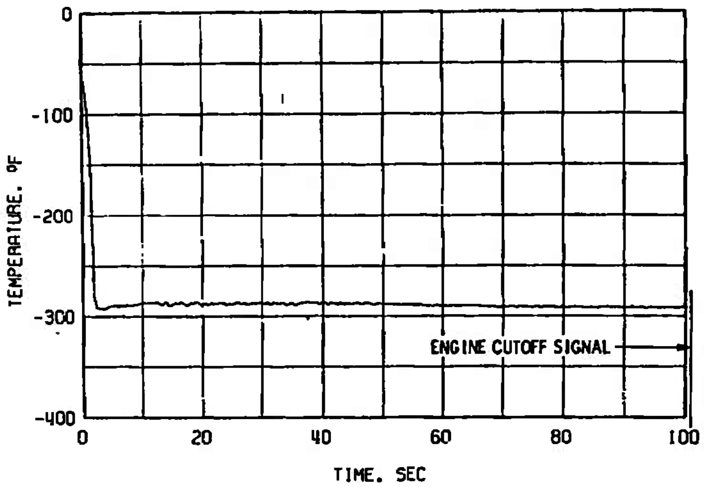
Fig. 37 Propellant System Performance, Firing 14C



a. Oxidizer Conditions at Engine Flowmeter, °F (Superheat)

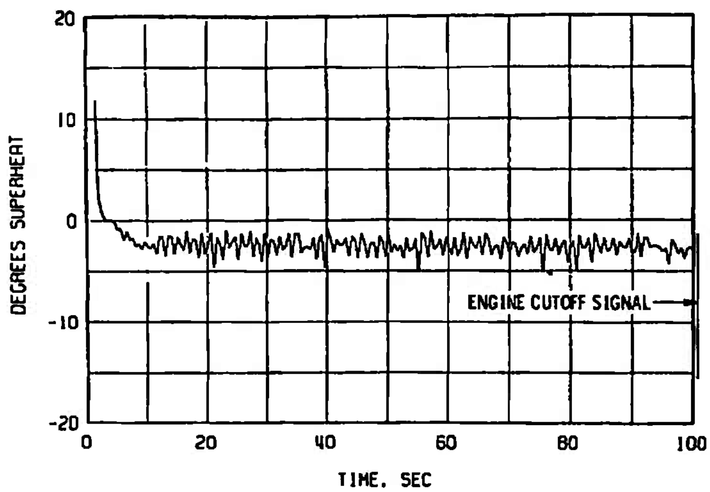


b. Oxidizer Conditions at Idle-Mode Line, °F (Superheat)

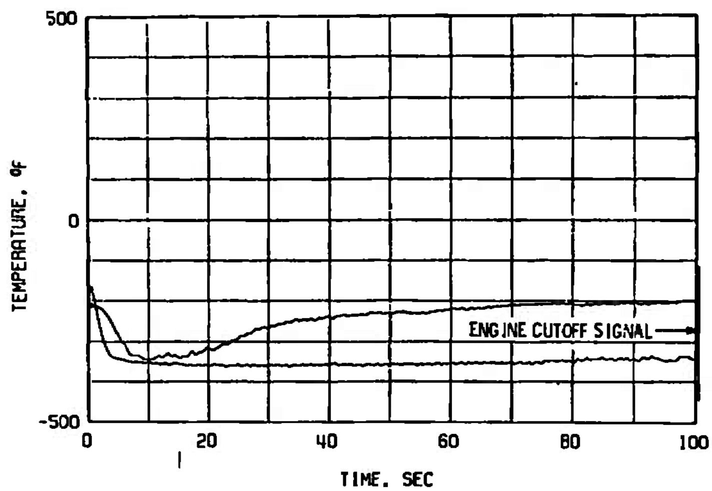


c. Oxidizer Temperature at Injector (TOJ), °F

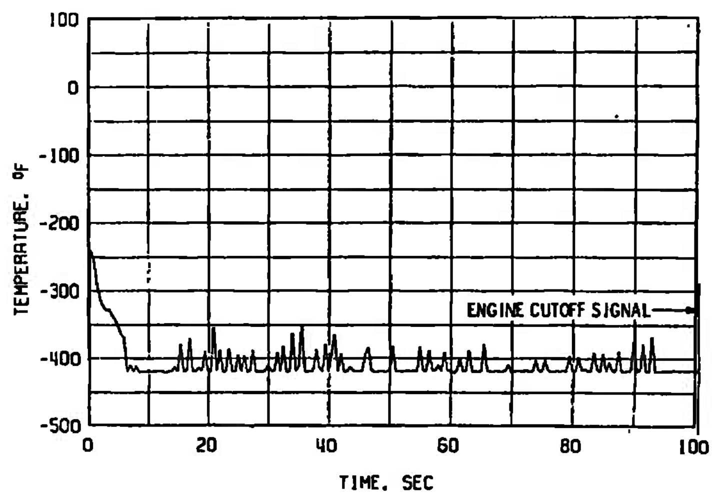
Fig. 38 Propellant System Temperature Transients, Firing 14C



d. Fuel Conditions at Engine Flowmeter, °F (Superheat)

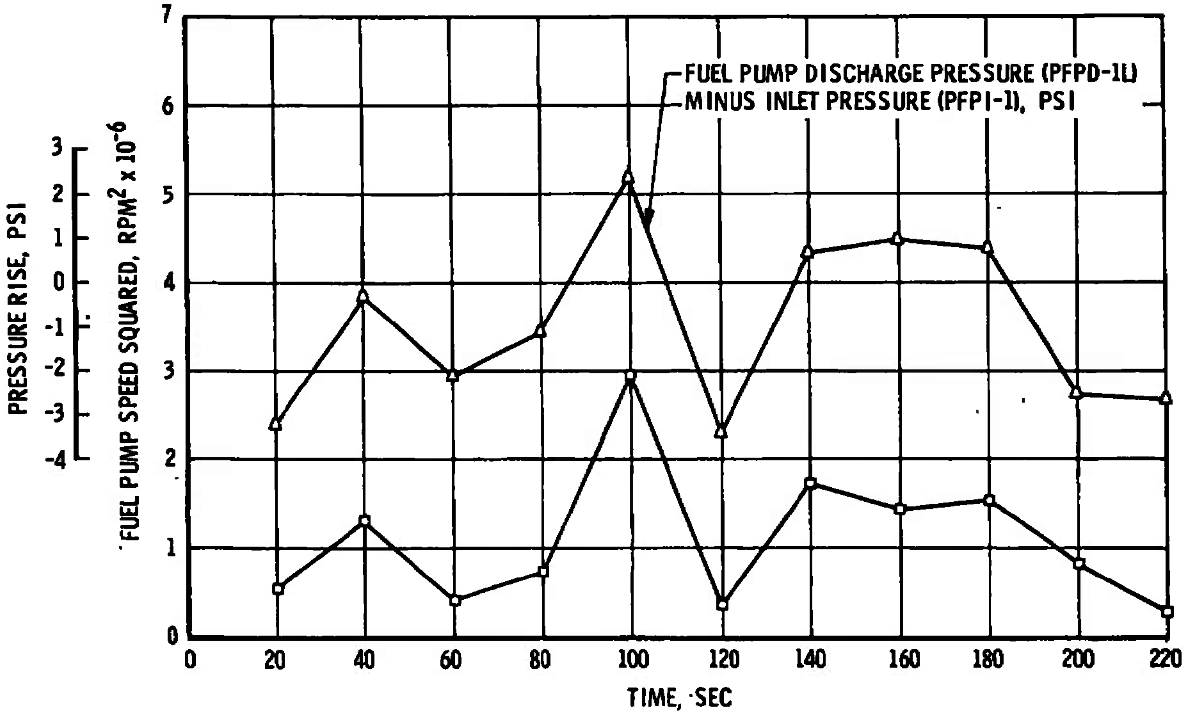


e. Thrust Chamber External Surface Temperature, °F

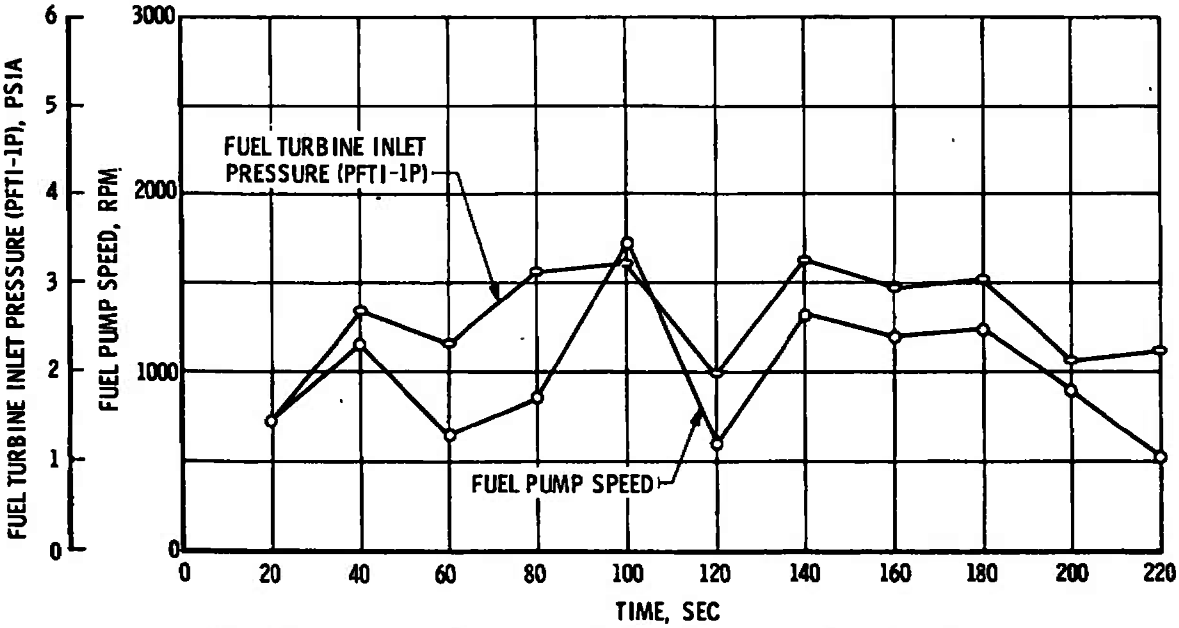


f. Fuel Injector Temperature (TFJ-2P), °F

Fig. 38 Concluded



a. Fuel Pump Pressure Rise and Fuel Pump Impeller Speed Squared



b. Fuel Turbine Inlet Pressure and Fuel Pump Impeller Speed

Fig. 39 Fuel Pump Performance, Firing 08A

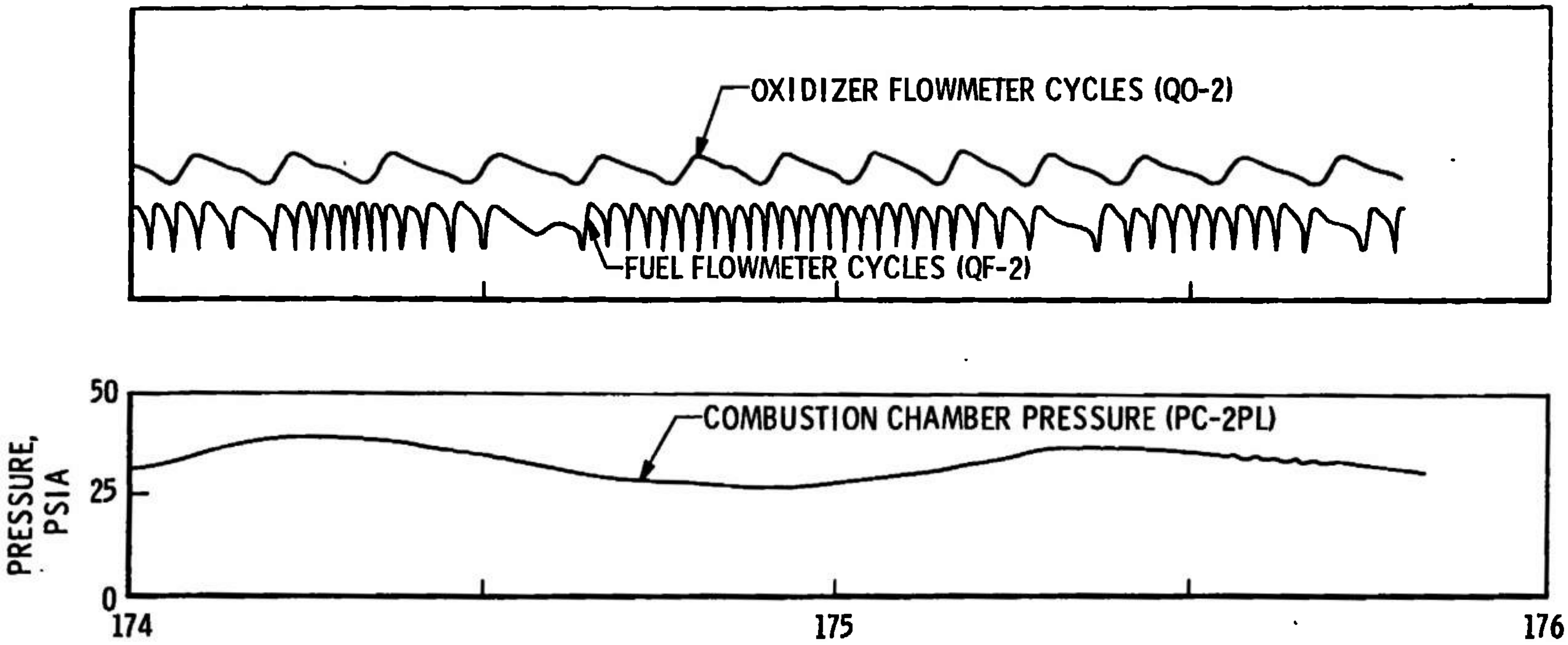
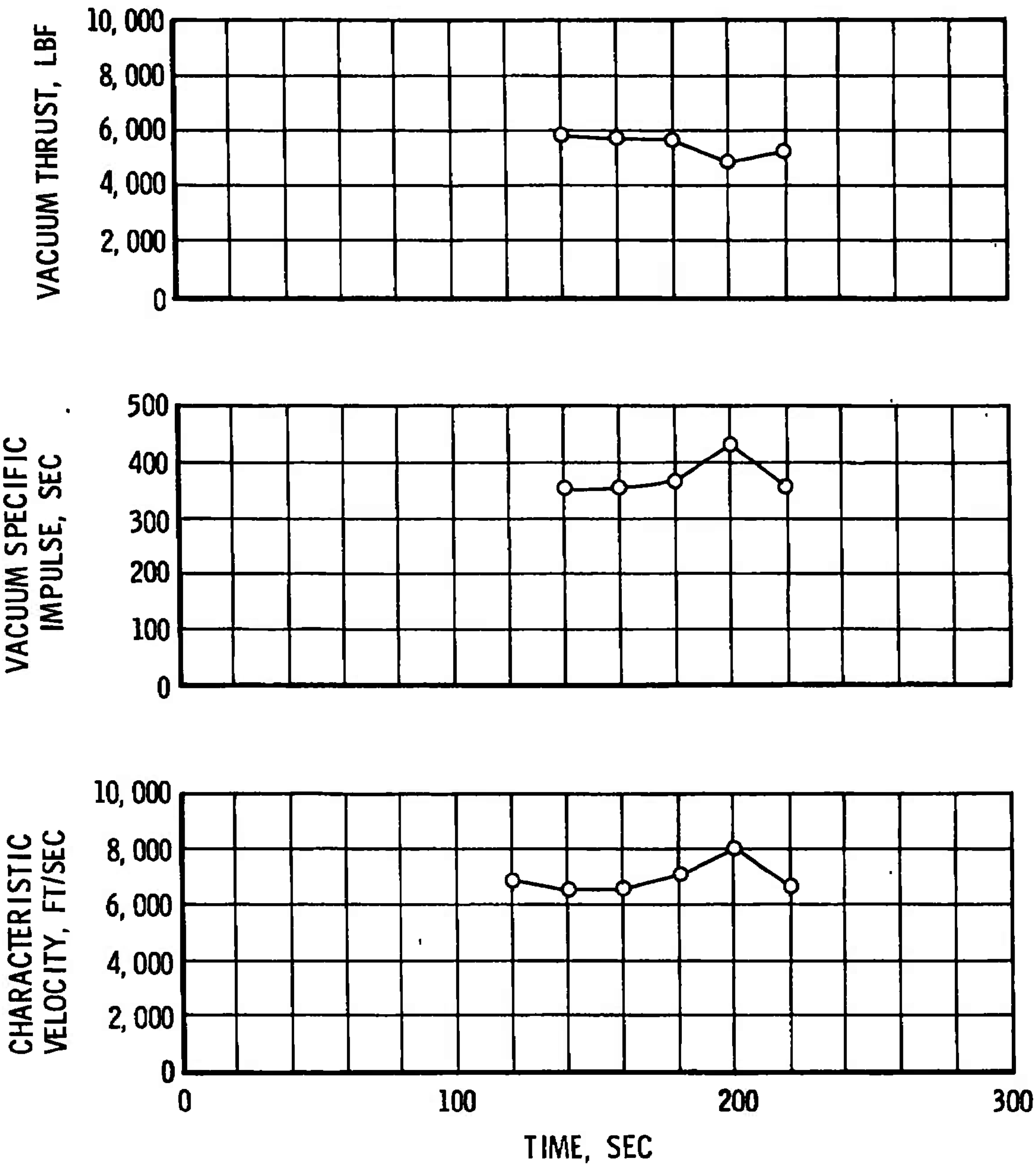
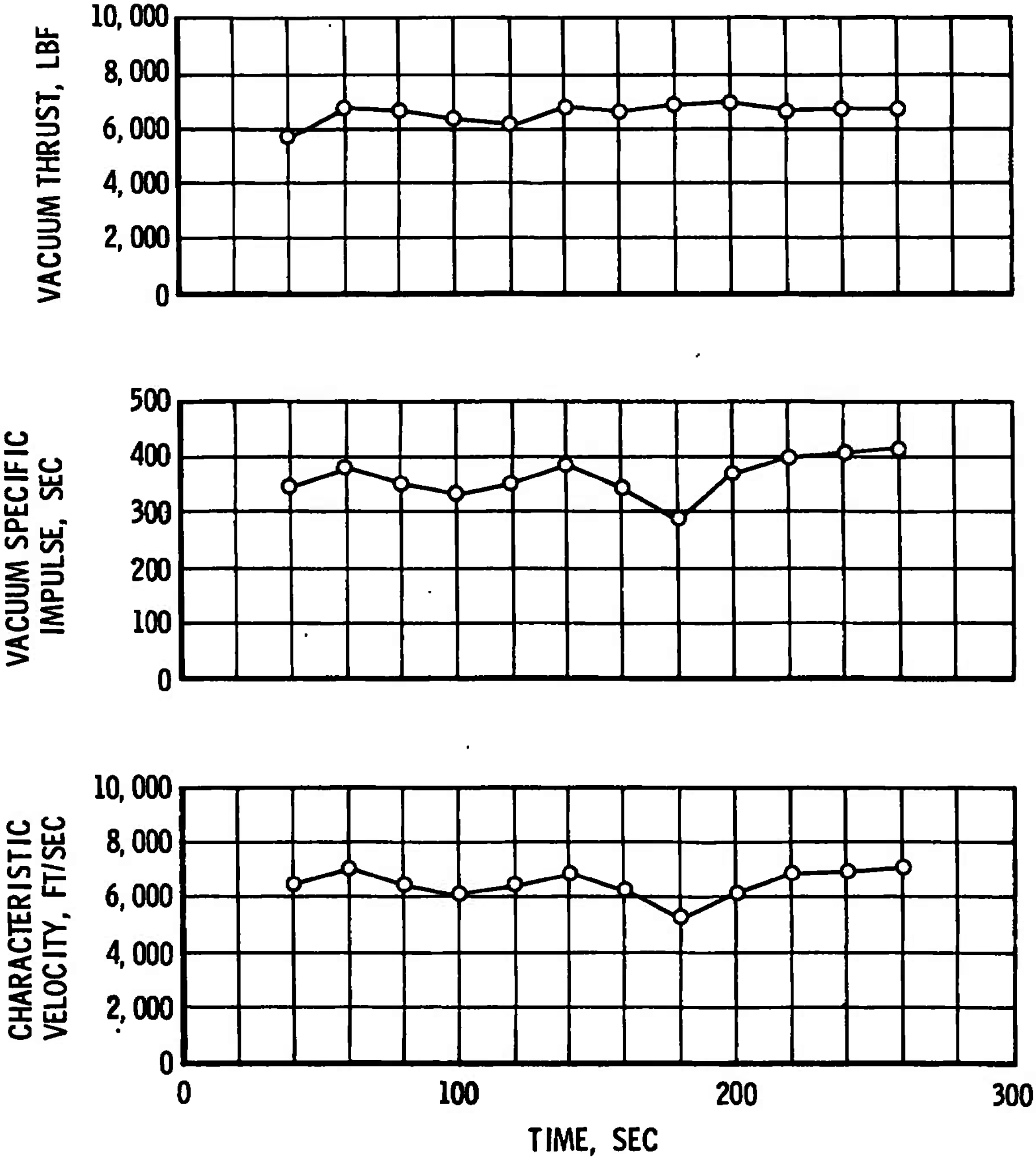


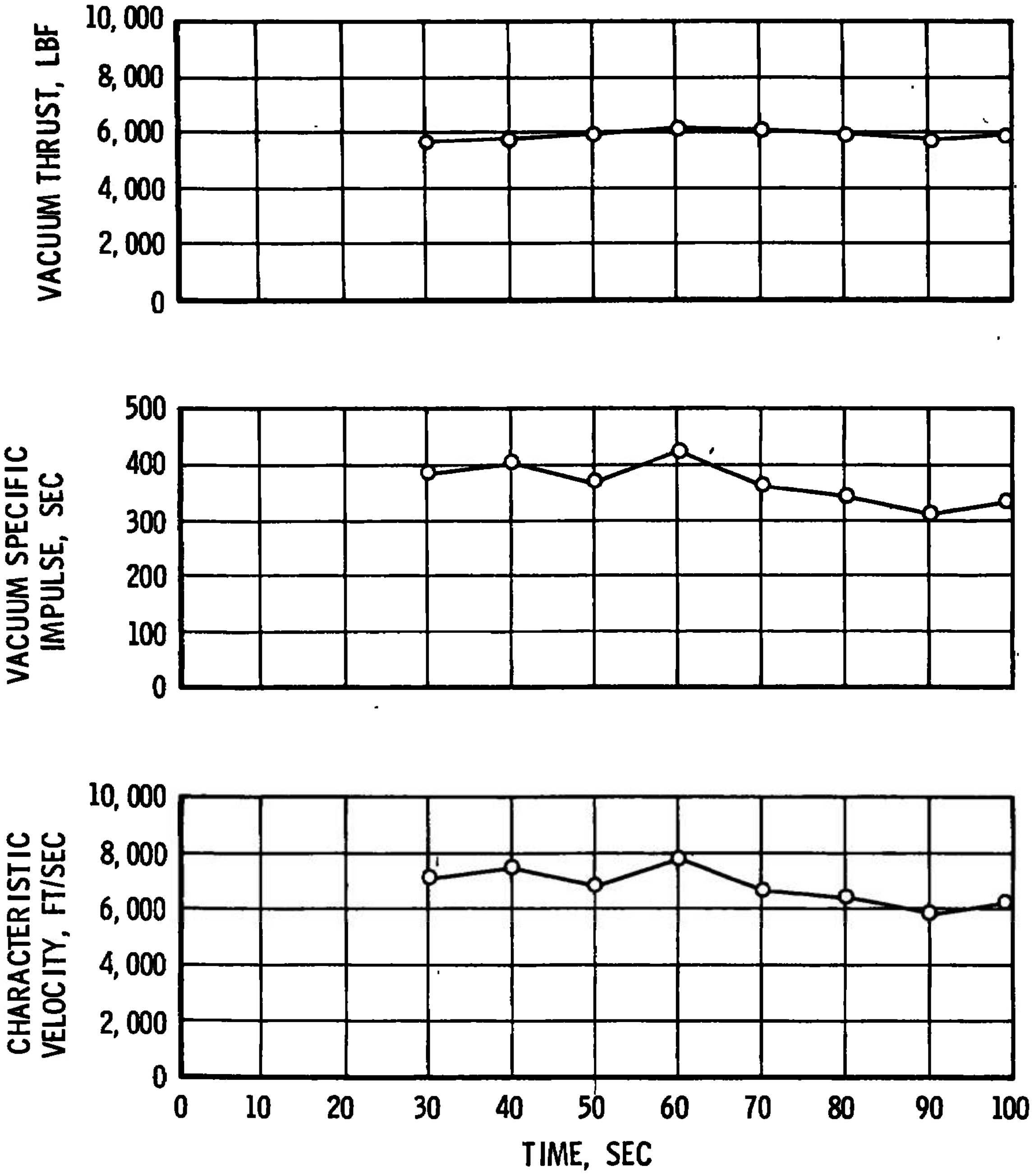
Fig. 40 Oscillogram Time History of Flowmeter Cycles and Combustion Chamber Pressure, Firing 10A



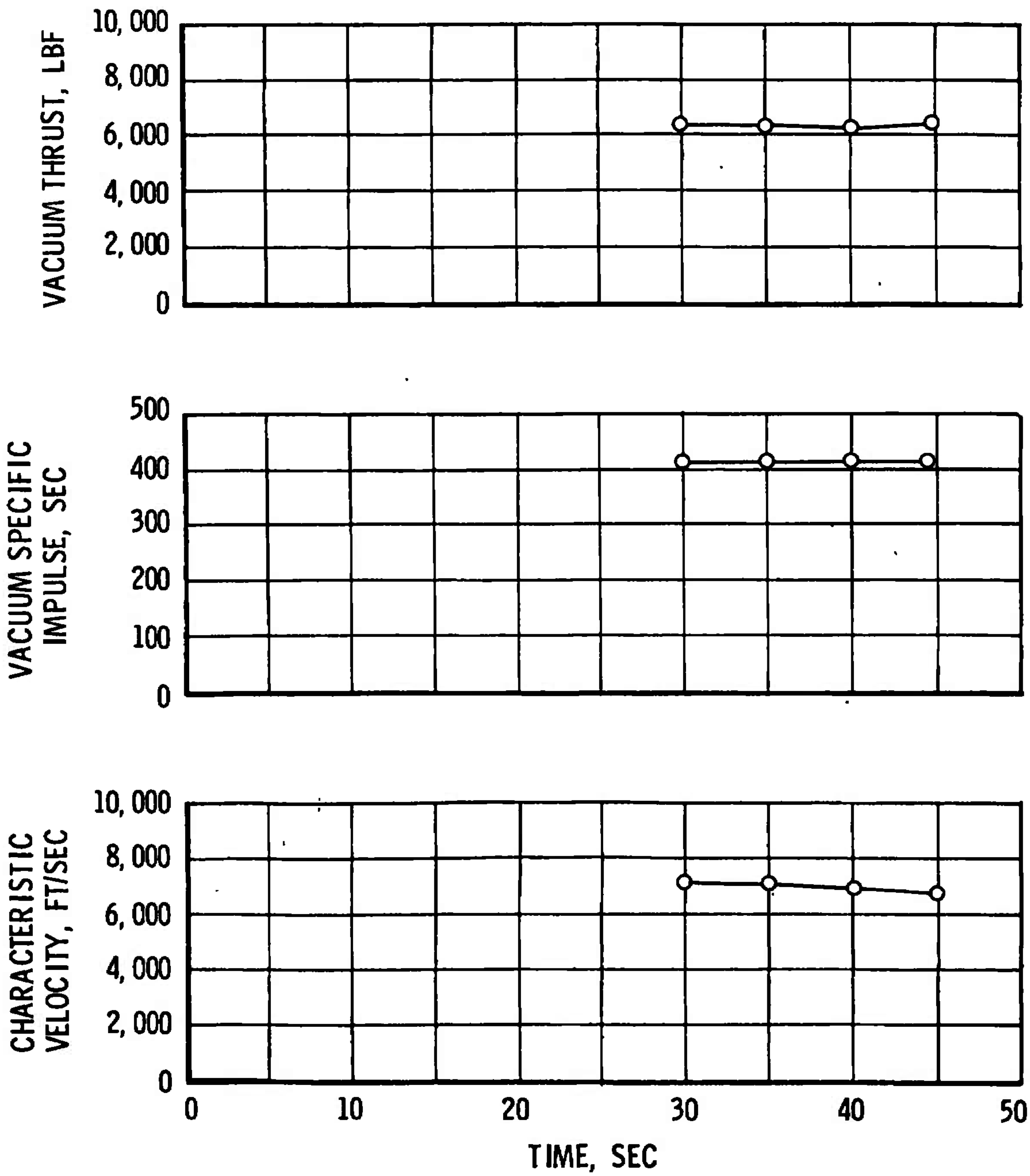
a. Engine Idle-Mode Performance, Firing 08A
Fig. 41 Engine Idle-Mode Performance History



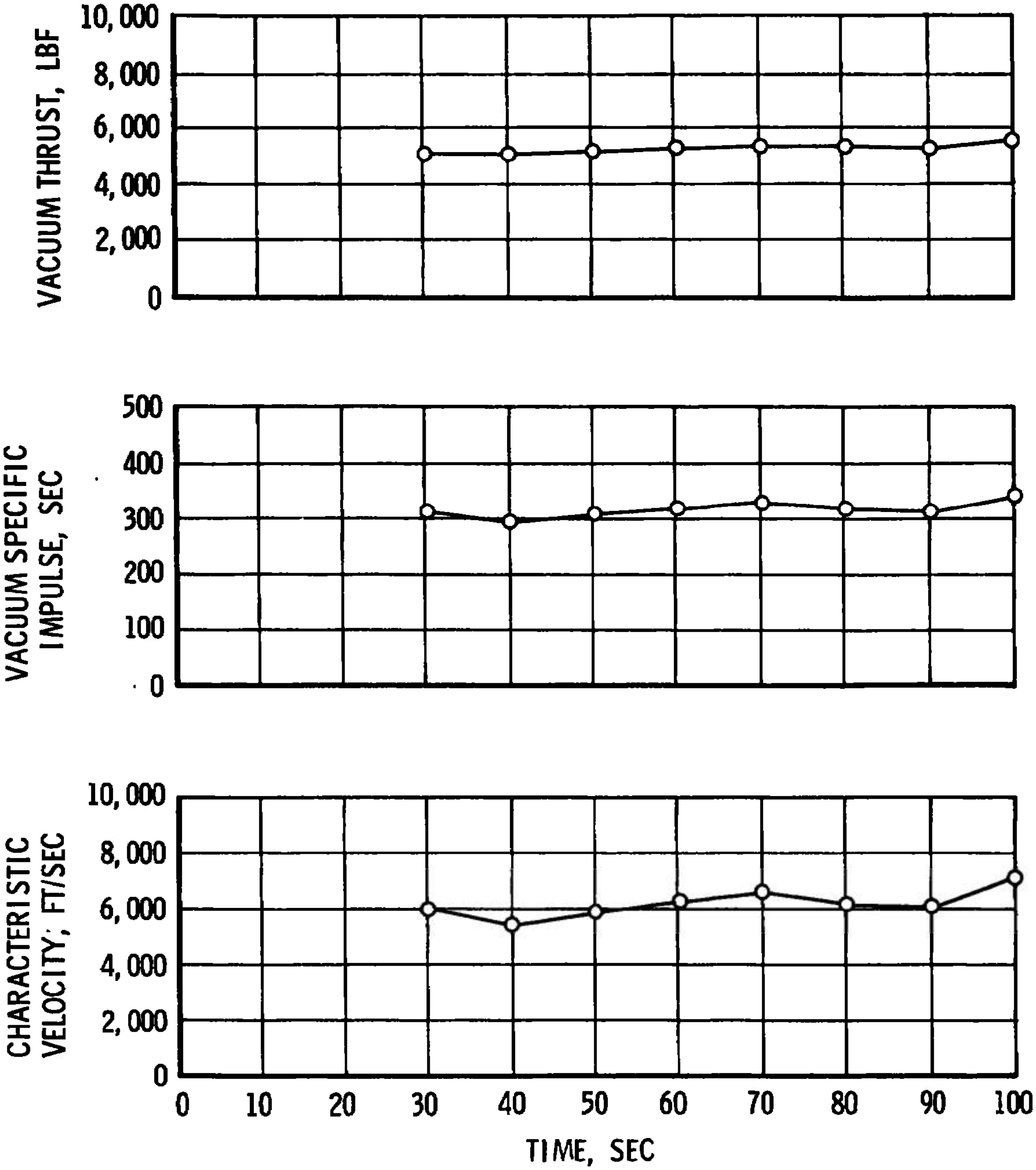
b. Engine Idle-Mode Performance, Firing 10A
Fig. 41 Continued



c. Engine Idle-Mode Performance, Firing 13A
Fig. 41 Continued



d. Engine Idle-Mode Performance, Firing 14B
Fig. 41 Continued



e. Engine Idle-Mode Performance, Firing 14C
Fig. 41 Concluded

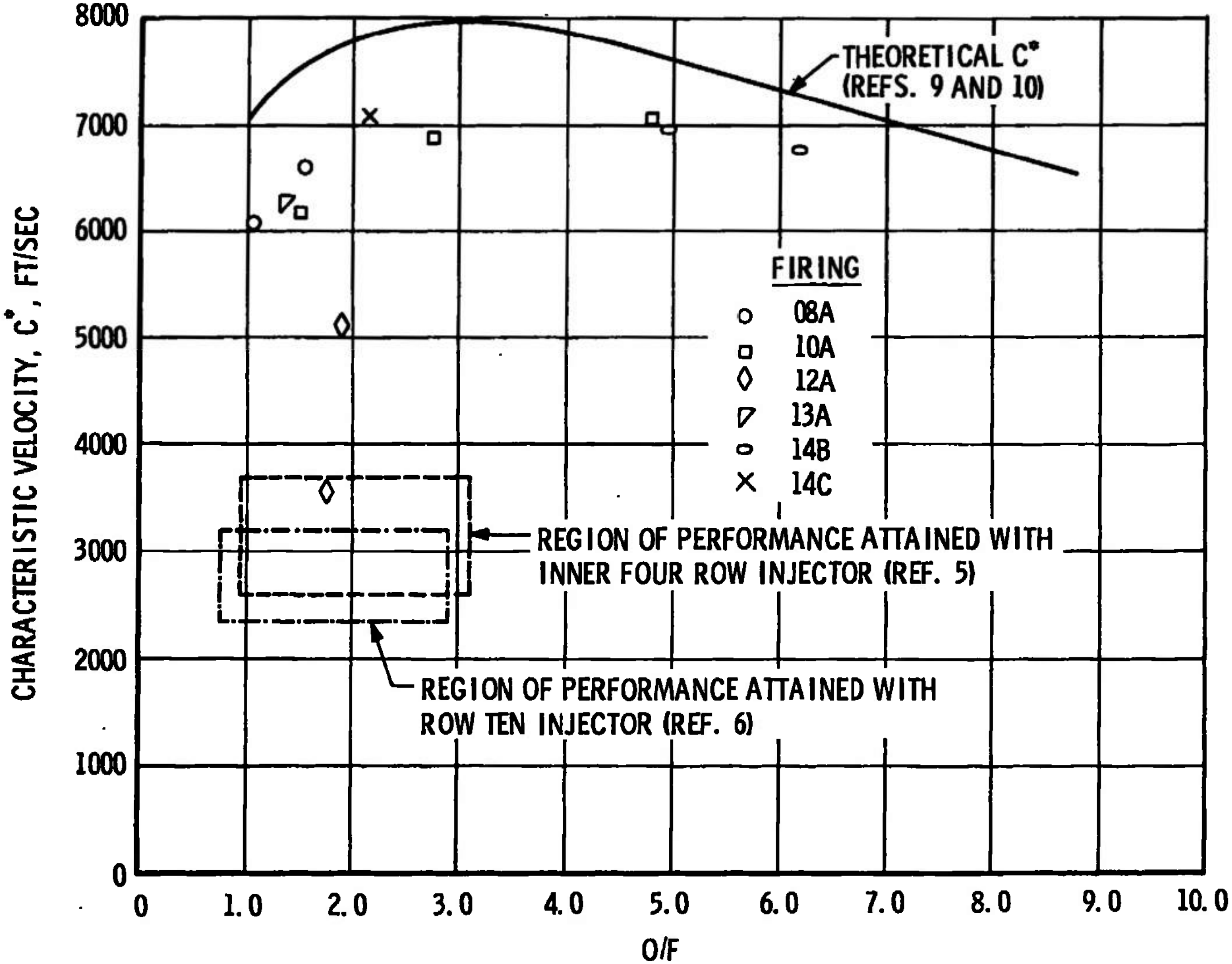


Fig. 42 Effect of Engine Oxidizer-to-Fuel Ratio on Characteristic Velocity

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1001-08)

Part Name	P/N	S/N
Thrust Chamber Body Assembly	99-210620	4094439
Thrust Chamber Injector Assembly	XEOR-937173 210610-81	4087380 4087387*
Augmented Spark Igniter Assembly	EWR113811-21	4901310
Ignition Detector Probe 1	3243-2	016
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-X1	8900806
Hot Gas Tapoff Valve	99-557324-X2	8900847
Propellant Utilization Valve	99-251455X5	8900911
Electrical Control Package	99-503670	4098176
Engine Instrumentation Package	99-704641	4097437
Pneumatic Control Package	99-558330	8900817
Restart Control Assembly	99-503680	4087867
Helium Tank Assembly	NA5-260212-1	0002
Oxidizer Flowmeter	251216	4096874
Fuel Flowmeter	251225	4096875
Fuel Inlet Duct Assembly	409900-11	6632788
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	439
Fuel Turbine Exhaust Bypass Duct	307879-11	2143580
Hot Gas Tapoff Duct	99-411808-51	7239768
Solid-Propellant Turbine Starters Manifold	99-210921-11	7216433
Heat Exchanger and Oxidizer Turbine Exhaust Duct	307887	2142822
Crossover Duct	307879	2143592

*Effective J4-1001-14

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	J4-1902-08	---
Fuel bypass line	99-406384	1.500	J4-1001-08	EWR 121320
Oxidizer turbine bypass nozzle	99-210924	1.695	J4-1902-07	EWR 121319
Propellant utilization valve inlet	XEOR-934826	1.250	J4-1902-05	---
Film coolant venturi	---	1.027 Inlet 0.744 Throat	J4-1902-05	$C_D = 0.97$
Oxidizer idle-mode line	99-411092 99-411092 99-411092	0.997 1.033 0.977	J4-1001-07 J4-1001-12 J4-1001-14	EWR 121315 EWR 121322 EWR 121331

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1001-08 AND J4-1001-14)

Modification Number	Completion Date	Description of Modification
	Test J4-1001-07 8/28/69	
	None	
	Test J4-1001-10 9/8/69	
121362	9/12/69	Repair of thrust chamber combustion zone tube damage
	Test J4-1001-11 9/17/69	
	None	
	Test J4-1001-12 9/24/69	
121326	9/29/69	Installed oxidizer pump seal drain shutoff valve
	Test J4-1001-13 10/1/69	
121329	10/7/69	Returned augmented spark igniter fuel line to original configuration (removed bypass line)
	Test J4-1001-14 10/15/69	

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1001-08 AND J4-1001-14)

Replacement	Completion Date	Component Replaced
Test J4-1001-07 8/28/69		
	None	
Test J4-1001-13 10/1/69		
P/N XEOR 937173 S/N 4087380 Unit 602	9/10/69	Dome and injector assembly P/N 210610-81 S/N 4087387 Unit 607
P/N 309065	10/3/69	Hot gas check valve P/N 309065-31 S/N 2203033
Test J4-1001-14 10/15/69		

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Purge	Requirement	SPTS 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 customer connect panel (150 scfm)§								15 min
Thrust chamber jacket, film coolant, and turbopump purges	Helium, 150 ± 25 psia 50 to 150°F at customer con-nect panel (125 scfm)		(**) (†)		(*)	15 min (**) (†)		(*)	30 min
SPTS conditioning	Nitrogen, -50 to 140°F	1, 2, and 3				Remaining SPTS			
Main fuel valve conditioning	Helium, -300°F to ambient			§					

*Engine-supplied liquid-oxygen pump intermediate seal cavity purge
**Anytime facility water is on
†30 min before propellant drop
††Initiate MFV conditioning 30 min before engine start for those firings with temperature requirements
§100 to 150°F for firing 04A

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number	J4-1001-08A		J4-1001-09A		J4-1001-10A		J4-1001-12A		J4-1001-13A	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day	— / —	9/3/69 / 1001 hr	— / —	9/5/69 / 1440 hr	— / —	9/8/69 / 1112 hr	— / —	9/8/69 / 1117 hr	— / —	10/1/69 / 1423 hr
Pressure Altitude at t-0, ft (Ref. 1)	100,000	97,000	100,000	99,500	100,000	96,000	100,000	91,000	100,000	90,000
Low Thrust Idle-Mode Duration, sec	300	223.710	300	273.169	300	300.000	200	196.00	100	100.183
High Thrust Idle-Mode Duration, sec	—	—	—	—	—	—	—	—	—	—
Main-Stage Duration, sec	—	—	—	—	—	—	—	—	—	—
Post-Main-Stage Idle-Mode Duration, sec	—	—	—	—	—	—	—	—	—	—
Fuel Pump Inlet Pressure at t-0, psia	33.0 ± 1.0	34.4	37.0 ± 1.0	37.1	40.0 ± 1.0	40.0	40.0 ± 1.0	40.3	34.0 ± 1.0	33.0
Fuel Pump Inlet Temperature at t-0, °F	—	-380.2	—	-338.0	—	-416.3	—	—	—	-417.0
Fuel Tank Bulk Temperature at t-0, °F	-422.0 ± 0.4	-421.4	-423.0 ± 0.4	-423.8	-418.0 ± 0.4	-400.8	-420.0 ± 0.4	-422.4	-422.0 ± 0.4	-422.8
Oxidizer Pump Inlet Pressure at t-0, psia	30.0 ± 1.0	31.0	46.0 ± 1.0	46.4	32.0 ± 1.0	30.0	33.0 ± 1.0	33.0	33.0 ± 1.0	37.0
Oxidizer Pump Inlet Temperature at t-0, °F	—	-287.7	—	-278.0	—	-281.3	—	-281.0	—	-292.1
Oxidizer Tank Bulk Temperature at t-0, °F	-294.0 ± 0.4	-280.1	-294.0 ± 0.4	-294.0	-295.0 ± 0.4	-289.4	-293.0 ± 0.4	-280.3	-290.0 ± 4.4	-290.4
Helium Tank Pressure at t-0, psia	3400^{+0}_{-200}	3300	3450^{+0}_{-200}	3400	3450^{+0}_{-200}	3330	3450^{+0}_{-200}	3299	3450^{+0}_{-200}	3270
Helium Tank Temperature at t-0, °F	—	110	—	81	—	111	—	101	—	80.0
Main Fuel Valve Temperature at t-0, °F	—	—	—	110	—	90	—	100	—	85.0
Augmented Spark Igniter Ignition Detection, sec (Ref. t-0)	—	0.330	—	0.297	—	0.449	—	0.429	—	0.007
Propellant Utilization Valve Position at t-0	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null

Firing Number	J4-1001-13B		J4-1001-13C		J4-1001-14A		J4-1001-14B		J4-1001-14C	
	Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Firing Date/Time of Day	— / —	10/1/69 / 1550 hr	— / —	10/1/69 / 1838 hr	— / —	10/13/69 / 0958 hr	— / —	10/13/69 / 1110 hr	— / —	10/13/69 / 1311 hr
Pressure Altitude at t-0, ft (Ref. 1)	100,000	111,000	100,000	111,000	100,000	88,000	100,000	100,000	100,000	88,000
Low Thrust Idle-Mode Duration, sec	100	30.130	100	80.400	150	146.7	100	40.0	100	100.0
High Thrust Idle-Mode Duration, sec	—	—	—	—	—	—	—	—	—	—
Main-Stage Duration, sec	—	—	—	—	—	—	—	—	—	—
Post-Main-Stage Idle-Mode Duration, sec	—	—	—	—	—	—	—	—	—	—
Fuel Pump Inlet Pressure at t-0, psia	30.0 ± 1.0	30.0	37.0 ± 1.0	31.0	31.0 ± 1.0	32.0	37.0 ± 1.0	37.4	33.0 ± 1.0	34.0
Fuel Pump Inlet Temperature at t-0, °F	—	-401.0	—	-410.0	—	-424.4	—	-410.1	—	-417.0
Fuel Tank Bulk Temperature at t-0, °F	-422.0 ± 0.4	-400.0	-422.0 ± 0.4	-422.7	-427.0 ± 0.4	-422.7	-420.0 ± 0.4	-400.0	-420.0 ± 0.4	-400.0
Oxidizer Pump Inlet Pressure at t-0, psia	40.0 ± 1.0	44.0	46.0 ± 1.0	44.4	34.0 ± 1.0	33.2	44.0 ± 1.0	43.2	34.0 ± 1.0	33.0
Oxidizer Pump Inlet Temperature at t-0, °F	—	-293.0	—	-282.0	—	-280.0	—	-297.0	—	-280.0
Oxidizer Tank Bulk Temperature at t-0, °F	-295.0 ± 0.4	-281.4	-294.0 ± 0.4	-299.0	-293.0 ± 0.4	-289.2	-290.0 ± 0.4	-290.2	-290.0 ± 0.4	-295.0
Helium Tank Pressure at t-0, psia	Remains from "A"	3128	Remains from "B"	3086	3450^{+0}_{-300}	3405	Remains from "A"	3401	Remains from "B"	3030
Helium Tank Temperature at t-0, °F	—	81.1	—	80.0	—	110	—	78	—	90
Main Fuel Valve Temperature at t-0, °F	—	80.0	—	22.3	—	90.0	—	-232.0	—	-240.4
Augmented Spark Igniter Ignition Detection, sec (Ref. t-0)	—	0.390	—	0.000	—	0.301	—	0.428	—	0.003
Propellant Utilization Valve Position at t-0	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null

TABLE VII
ENGINE VALVE TIMINGS

Test J4-1001-	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
08	Final Sequence	0	0.044	0.055	0	0.114	0.047	16.96	0.070	0.259	16.96	0.066	0.112
	A	0	0.050	0.045	0	0.105	0.040	222.71	0.068	0.260	222.71	0.058	0.108
09	Final Sequence	0	0.045	0.065	0	0.113	0.043	7.36	0.068	0.253	7.36	0.066	0.110
	A	0	0.050	0.055	0	0.106	0.045	273.16	0.070	0.263	273.16	0.059	0.111
10	Final Sequence	0	0.045	0.063	0	0.114	0.048	19.11	0.065	0.255	19.11	0.063	0.111
	A	0	0.050	0.043	0	0.112	0.040	269.09	0.067	0.270	269.09	0.065	0.144
12	Final Sequence	0	0.046	0.060	0	0.115	0.040	12.08	0.070	0.260	12.08	0.068	0.111
	A	0	0.050	0.052	0	0.110	0.042	198.89	0.075	0.260	198.89	0.064	0.106
13	Final Sequence	0	0.050	0.060	0	0.120	0.040	10.64	0.068	0.255	10.64	0.062	0.110
	A	0	0.048	0.050	0	0.108	0.042	100.19	0.069	0.260	100.19	0.067	0.150
	B	0	0.050	0.052	0	0.121	0.040	20.34	0.072	0.268	20.34	0.071	0.160
	C	0	0.050	0.050	0	0.121	0.040	28.57	0.071	0.267	28.57	0.070	0.161
14	Final Sequence	0	0.050	0.050	0	0.108	0.040	7.73	0.080	0.260	7.73	0.079	0.110
	A	0	0.050	0.050	0	0.121	0.040	148.70	0.072	0.260	149.70	0.066	0.106
	B	0	0.067	0.082	0	0.165	0.039	45.89	0.037	0.320	45.89	0.078	0.151
	C	0	0.069	0.090	0	0.171	0.037	100.95	0.075	0.370	100.95	0.080	0.145

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.
5. Main oxidizer valve first stage only.

TABLE VIII
ENGINE IDLE-MODE PERFORMANCE

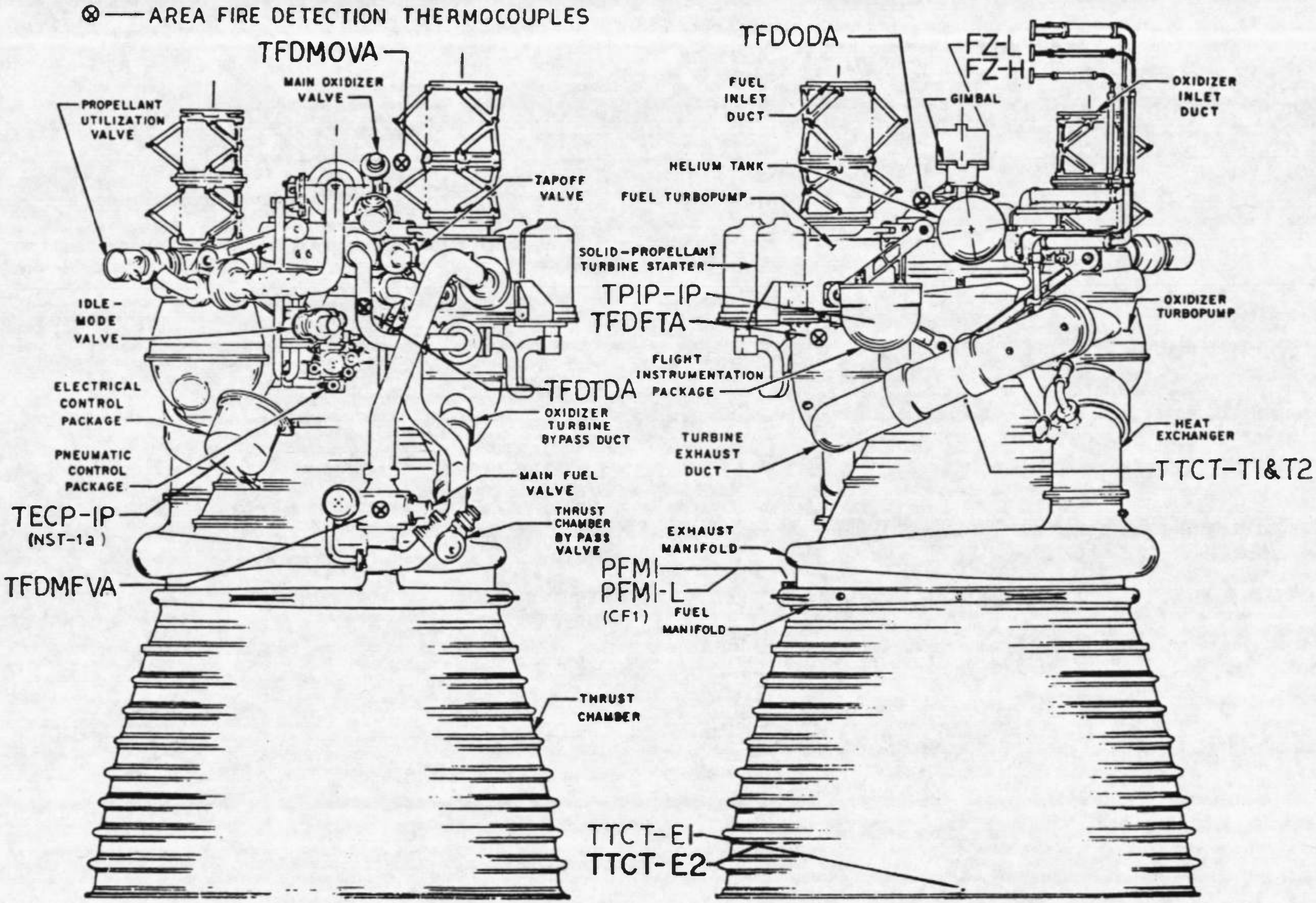
Test Number J4-1001-	06A				10A												12A	
Time Slice, sec	140	180	180	220	40	80	60	100	120	140	160	180	200	220	240	260	180	197.5
Fuel Pump Discharge Pressure, psia	40.5	40.6	40.2	37.2	40.7	40.9	39.6	35.2	33.6	35.7	35.5	39.0	40.0	32.1	32.5	32.5	36.2	42.1
Oxidizer Pump Discharge Pressure, psia	39.8	38.6	36.7	39.6	34.7	40.7	41.3	40.2	40.3	48.4	46.5	46.2	46.2	48.6	46.9	46.6	33.9	34.0
Chamber Pressure, PC-2PL, psia	28.7	28.1	28.0	25.9	27.8	33.2	32.6	30.4	29.8	32.2	32.0	33.0	33.9	30.1	30.3	30.3	22.9	29.5
Total Oxidizer Flow Rate, $\dot{W}_o$, lbm/sec	9.96	9.56	8.66	8.96	6.47	10.8	10.9	12.2	11.3	12.9	12.6	13.1	12.4	13.4	13.5	13.4	15.5	14.2
Total Fuel Flow Rate, $\dot{W}_f$, lbm/sec	6.59	6.48	6.65	5.81	7.82	7.05	8.24	6.61	6.17	4.67	8.52	10.7	8.20	3.10	2.91	2.78	8.74	7.50
Total Propellant Flow Rate, WT, lbm/sec	16.6	16.1	15.5	14.6	16.3	17.8	19.1	18.7	17.4	17.6	19.4	23.9	20.6	16.5	16.6	16.2	24.2	21.7
Propellant Mixture Ratio, O/F, dimensionless	1.51	1.46	1.33	1.54	1.06	1.53	1.32	1.64	1.82	2.77	1.97	1.23	1.52	4.33	4.65	4.83	1.77	1.90
Characteristic Velocity, C*, ft/sec	6537	6569	6609	6605	6429	7022	6424	6094	8431	6691	8220	5214	6190	6664	6943	7035	3555	5110
Characteristic Velocity Efficiency, C^*_{eff}, percent	86.5	87.5	91.9	67.1	90.3	92.6	87.0	76.6	63.0	88.2	79.7	71.5	81.8	88.0	90.0	91.6	46.1	85.7
Vacuum-Corrected Thrust, F_{vac}, lbf	5659	5722	5698	5284	5625	6774	6625	6236	6113	6757	6586	6611	6918	6621	6731	6755	4691	6069
Vacuum-Corrected Coefficient of Thrust, CF_{vac}, dimensionless	1.74	1.74	1.74	1.74	1.73	1.74	1.74	1.75	1.75	1.79	1.76	1.76	1.74	1.86	1.90	1.91	1.75	1.76
Vacuum-Corrected Specific Impulse, $I_{sp_{vac}}$, lbf-sec/lbm	354	357	387	358	345	360	347	332	351	384	340	285	335	400	409	417	194	279

TABLE VIII (Concluded)

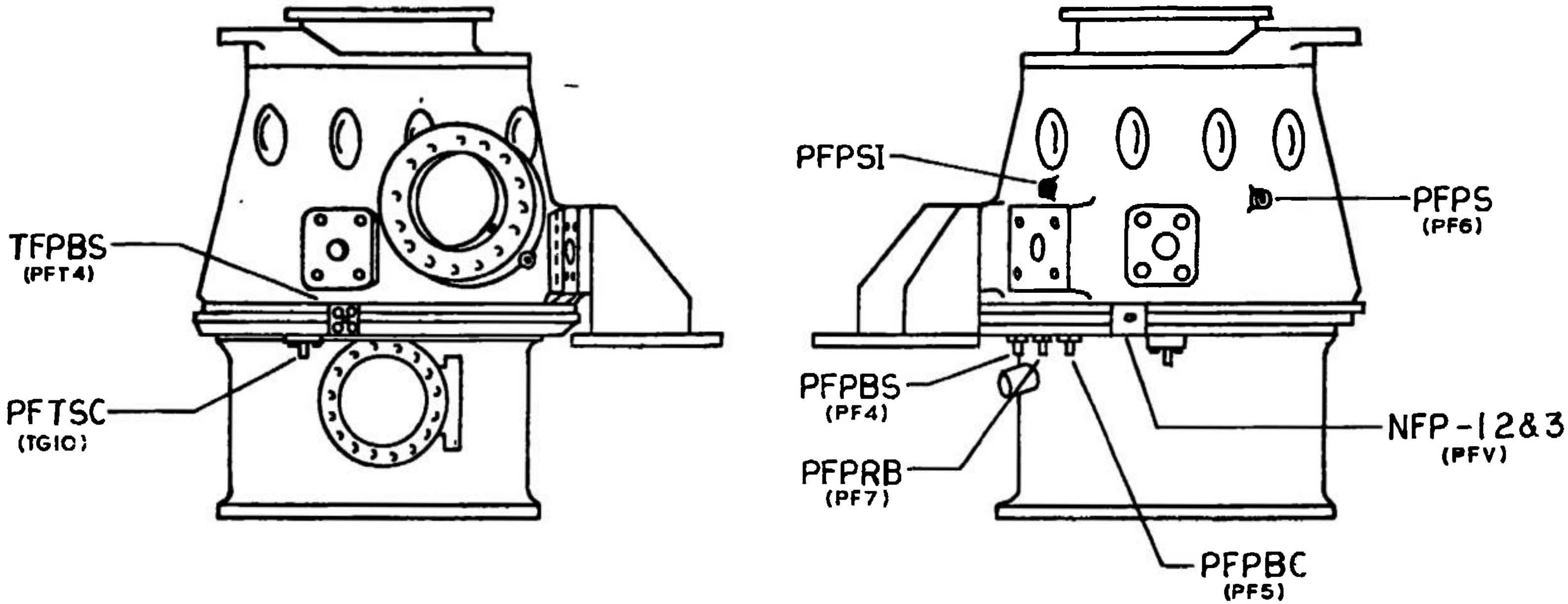
Test Number 14-1001-	13A								14B				14C							
Time Slice, sec	30	40	50	60	70	80	80	98	30	35	40	44.5	30	40	50	80	70	60	90	100
Fuel Pump Discharge Pressure, psia	37.1	36.9	34.8	35.5	35.5	35.1	34.0	34.4	31.9	31.5	30.8	30.8	31.2	30.8	31.5	31.3	30.9	32.0	30.3	31.5
Oxidizer Pump Discharge Pressure, psia	33.8	33.7	33.6	33.4	33.1	33.0	33.3	34.1	44.5	43.7	43.5	43.5	34.7	34.4	34.8	34.8	34.8	34.6	34.8	34.8
Chamber Pressure, PC-2PL, psia	27.3	28.1	29.3	29.8	29.6	29.1	28.2	28.9	28.9	28.5	27.9	27.8	25.0	24.0	25.3	26.0	26.3	26.3	25.7	27.1
Total Oxidizer Flow Rate, $\dot{w}_o$, lbm/sec	9.34	6.75	9.61	9.36	10.1	9.78	10.4	10.0	12.6	12.5	12.6	13.4	10.2	10.4	10.4	10.4	9.93	10.2	10.3	9.78
Total Fuel Flow Rate, $\dot{w}_f$, lbm/sec	5.07	5.31	6.49	5.01	6.58	7.23	7.77	7.33	2.62	2.77	2.54	2.15	5.58	7.05	5.91	5.28	5.10	5.82	5.66	4.57
Total Propellant Flow Rate, $\dot{w}_T$, lbm/sec	14.4	14.1	16.1	14.4	16.6	17.0	16.2	17.4	15.4	15.3	15.1	15.5	15.8	17.4	16.3	15.6	15.0	16.0	16.0	14.4
Propellant Mixture Ratio, O/F, dimensionless	1.84	1.65	1.48	1.87	1.53	1.35	1.34	1.37	4.45	4.51	4.96	8.22	1.63	1.47	1.75	1.96	1.95	1.75	1.82	2.14
Characteristic Velocity, C*, ft/sec	7134	7519	6647	7815	6695	6438	5835	6278	7080	7044	6950	6756	5965	5377	5872	6256	6585	6180	6080	7111
Characteristic Velocity Efficiency, C^*_{eff}, percent	92.0	98.2	90.9	100.7	88.5	86.7	79.0	84.4	91.1	90.9	91.1	93.2	77.0	71.5	76.1	80.1	84.4	60.1	78.5	90.4
Vacuum-Corrected Thrust, F_{vac}, lbf	5606	5736	5989	6128	8035	5807	5737	5889	6372	6307	6258	8439	5133	5077	5189	5349	5414	5383	5285	5603
Vacuum-Corrected Coefficient of Thrust, CF_{vac}, dimensionless	1.75	1.75	1.74	1.78	1.74	1.74	1.74	1.74	1.88	1.89	1.91	1.98	1.75	1.74	1.75	1.78	1.76	1.76	1.75	1.77
Vacuum-Corrected Specific Impulse, $I_{sp_{vac}}$, lbf-sec/lbm	389	408	371	427	363	347	316	339	414	413	414	415	325	291	319	342	360	336	331	391

APPENDIX III
INSTRUMENTATION

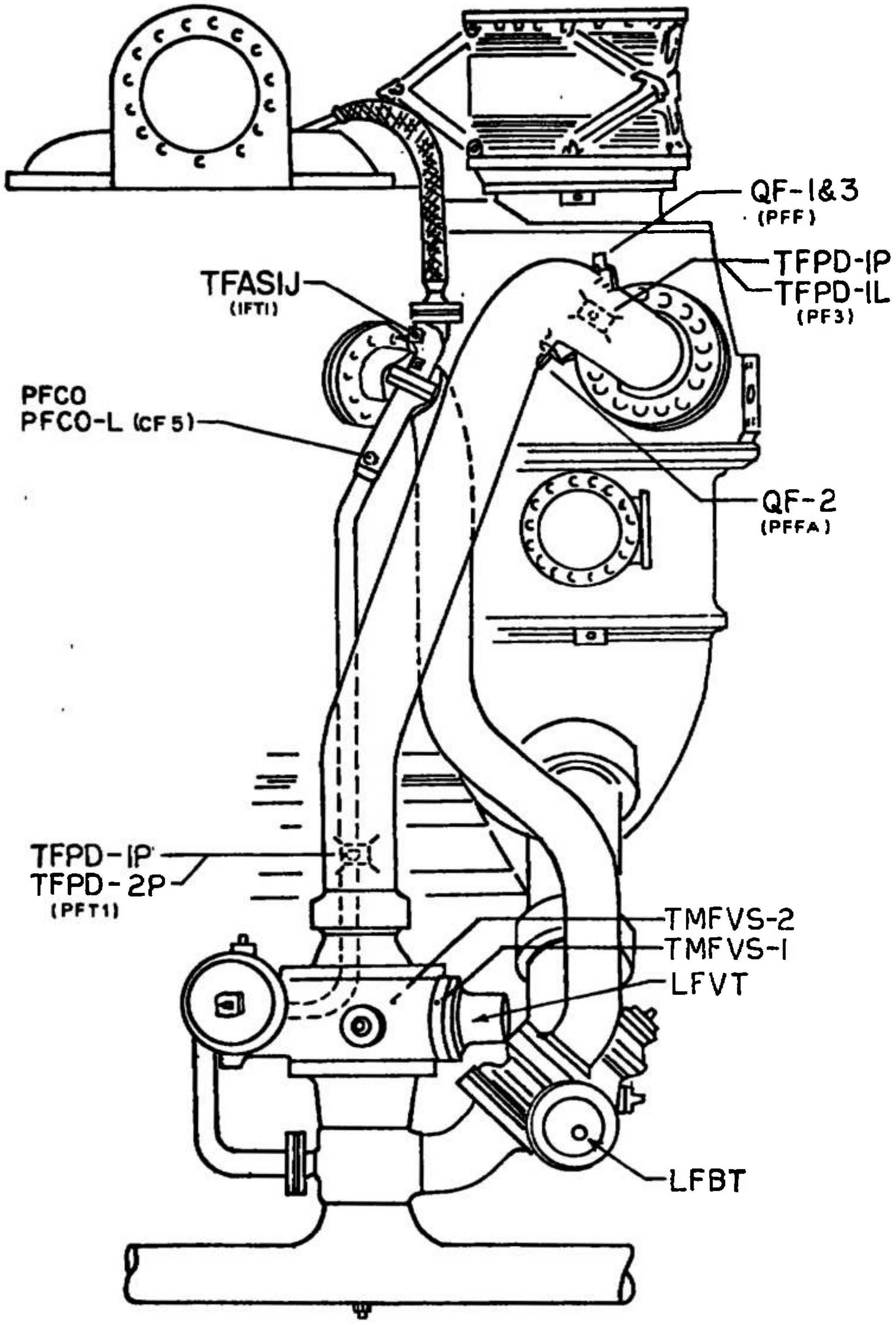
The instrumentation for AEDC tests J4-1001-08 through -10 and J4-1001-12 through -14 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.



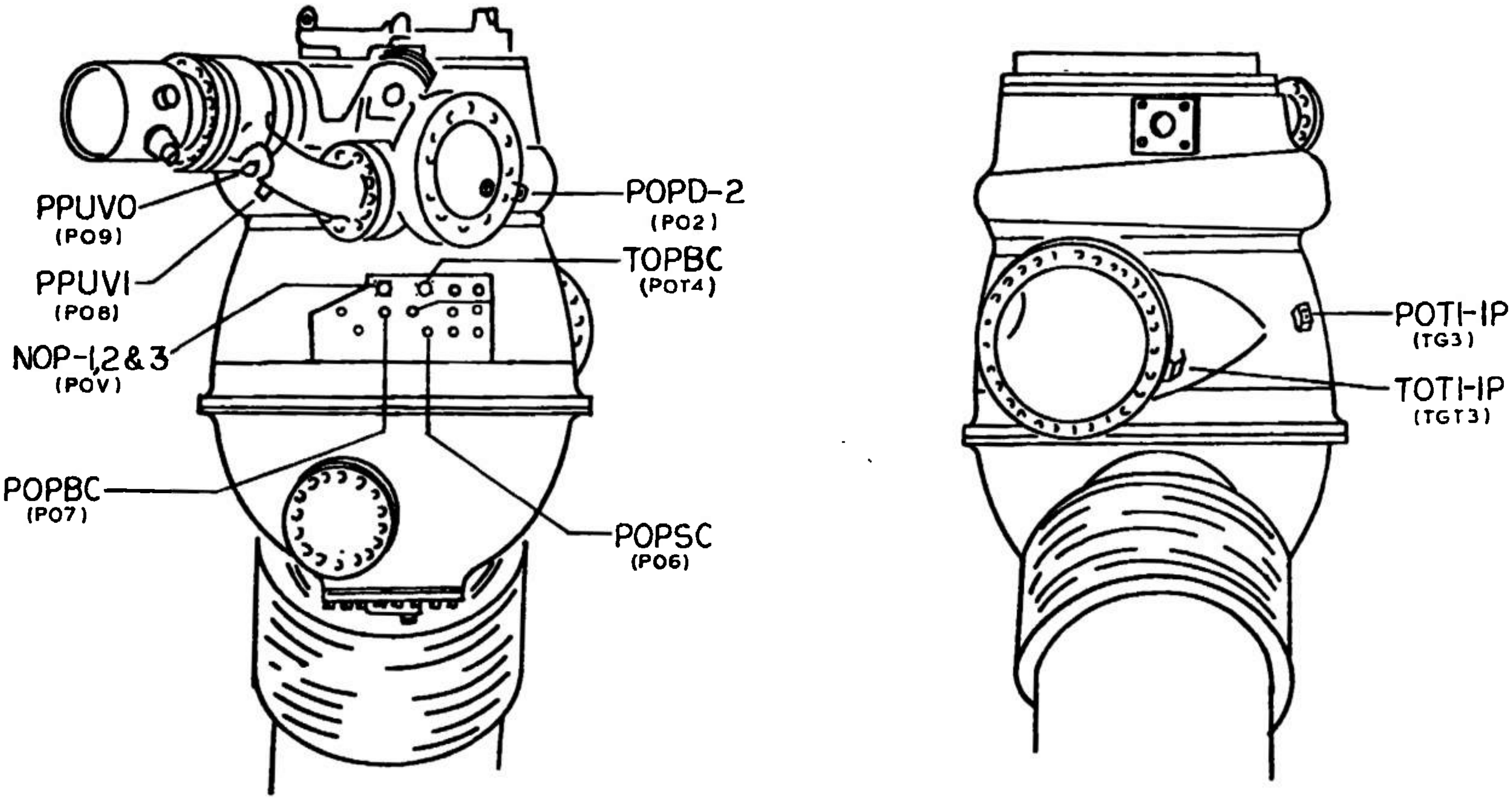
a. General Arrangement
Fig. III-1 Selected Sensor Locations



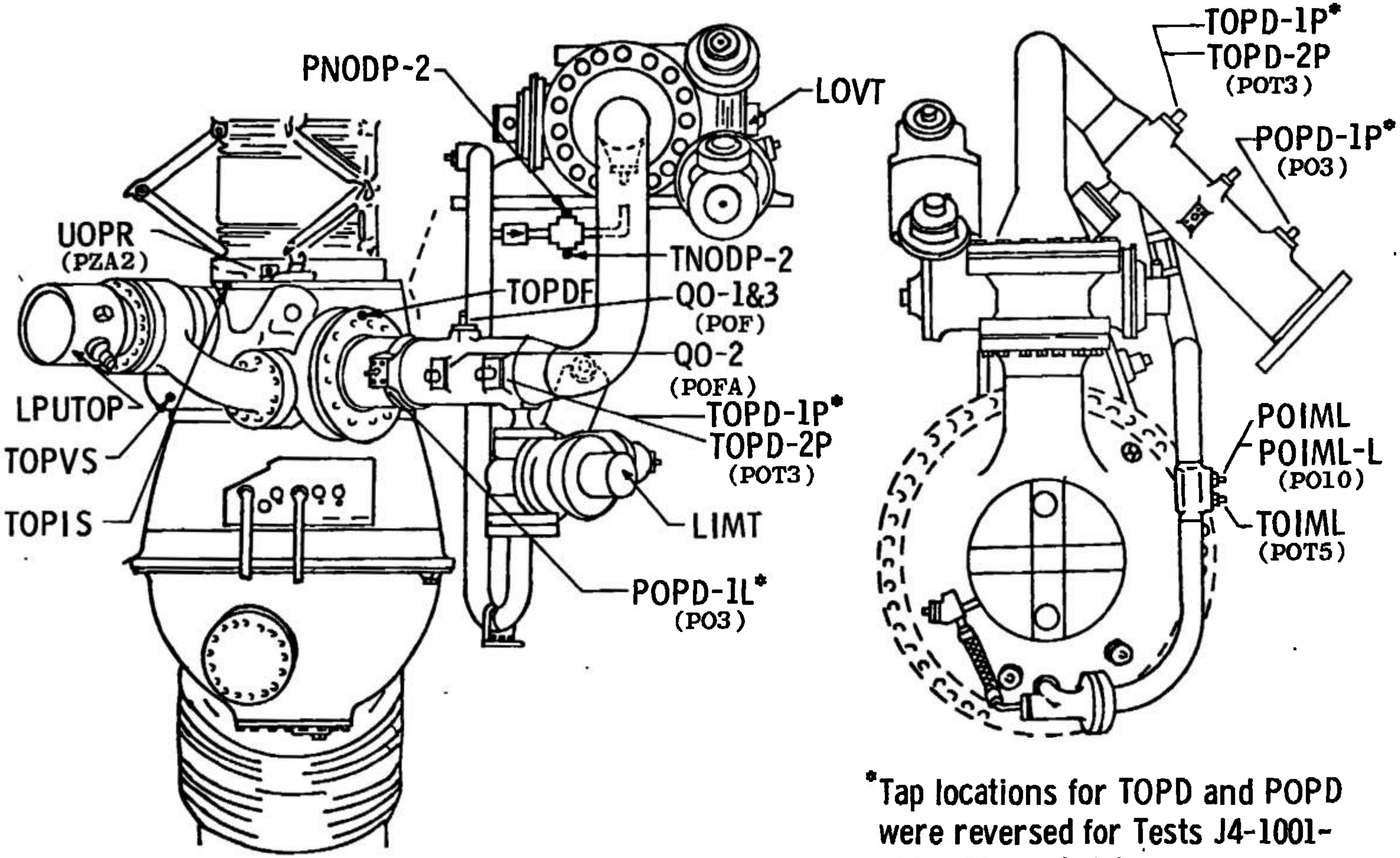
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



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

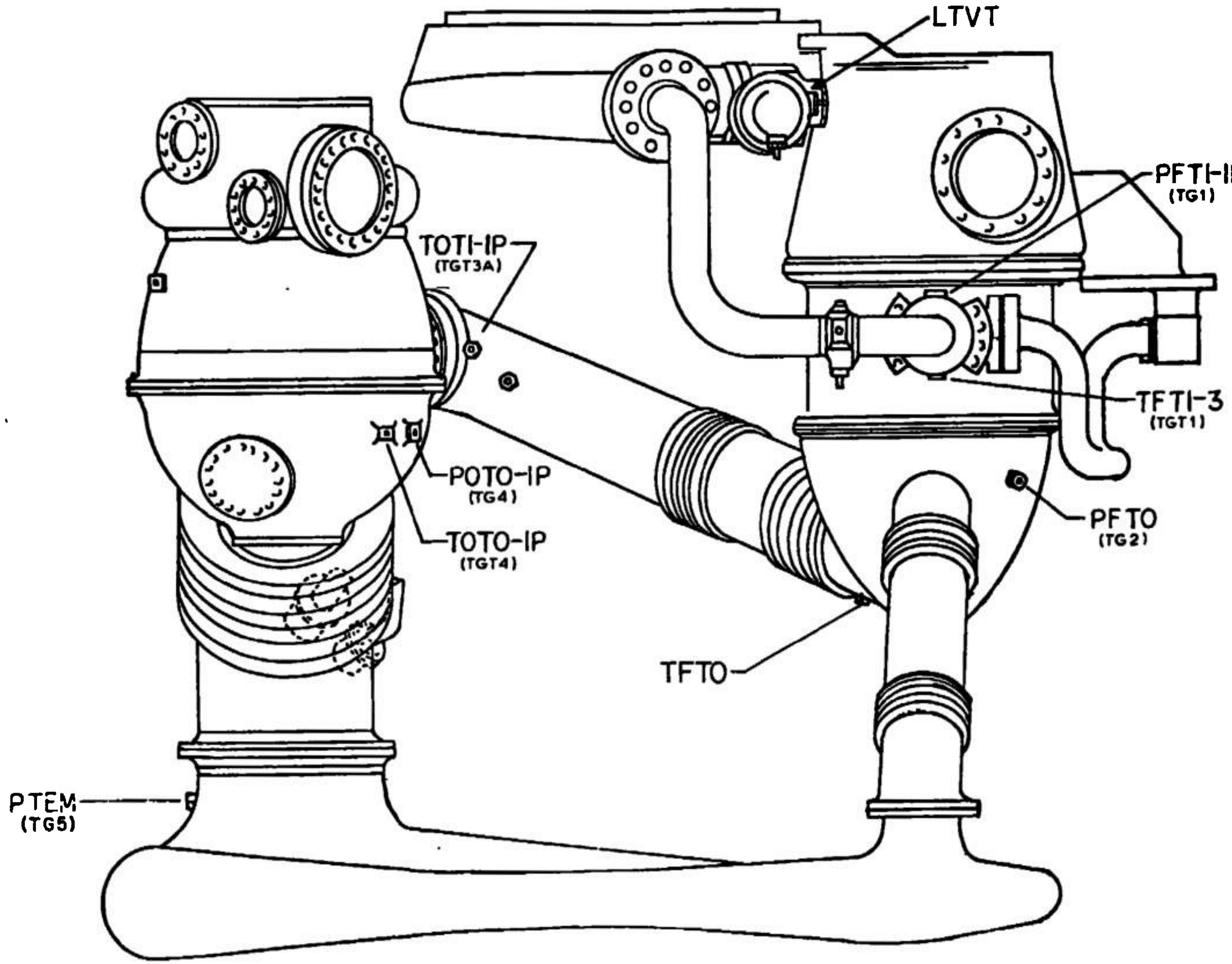


d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued

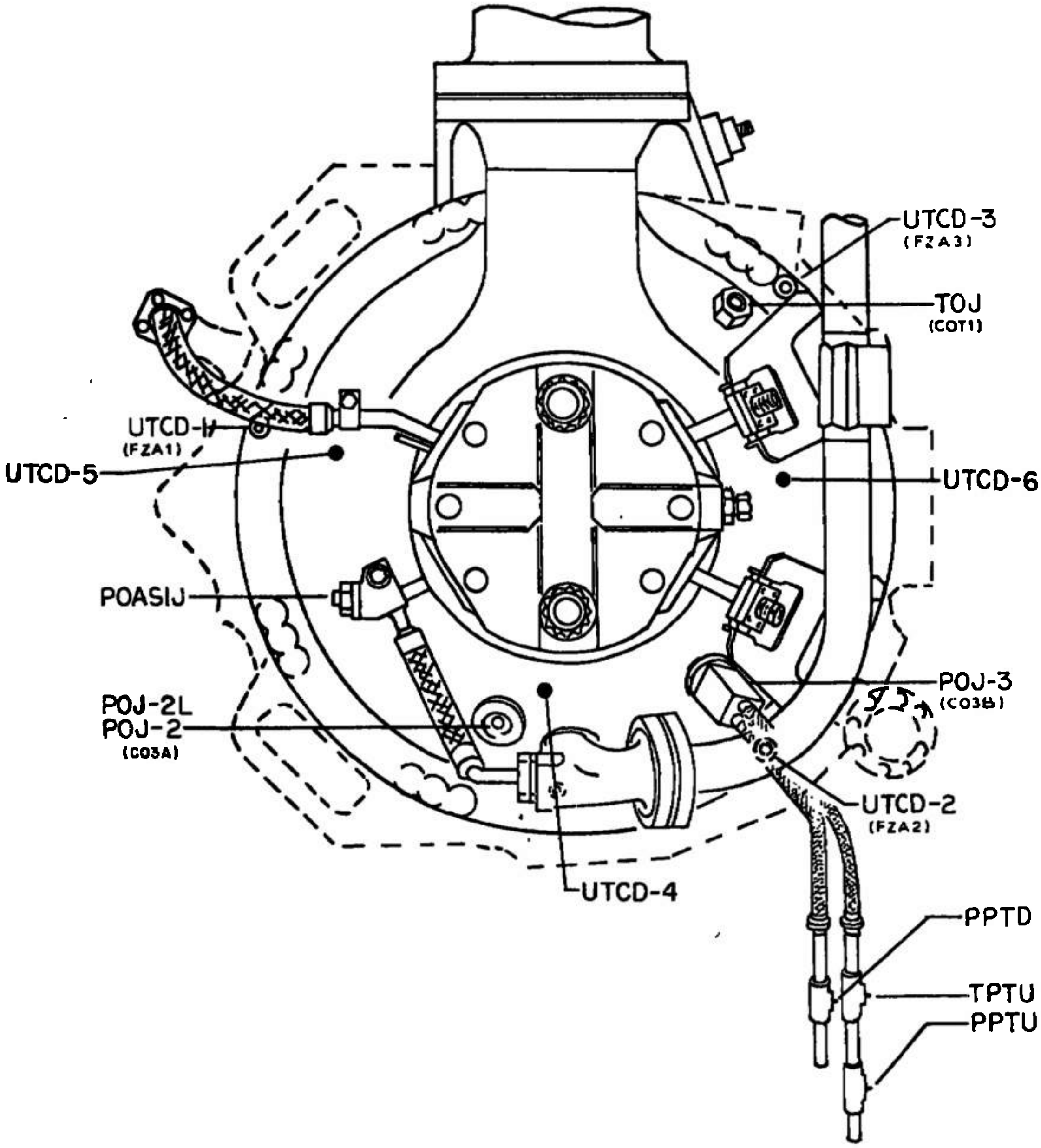


*Tap locations for TOPD and POPD were reversed for Tests J4-1001-12, -13, and -14.

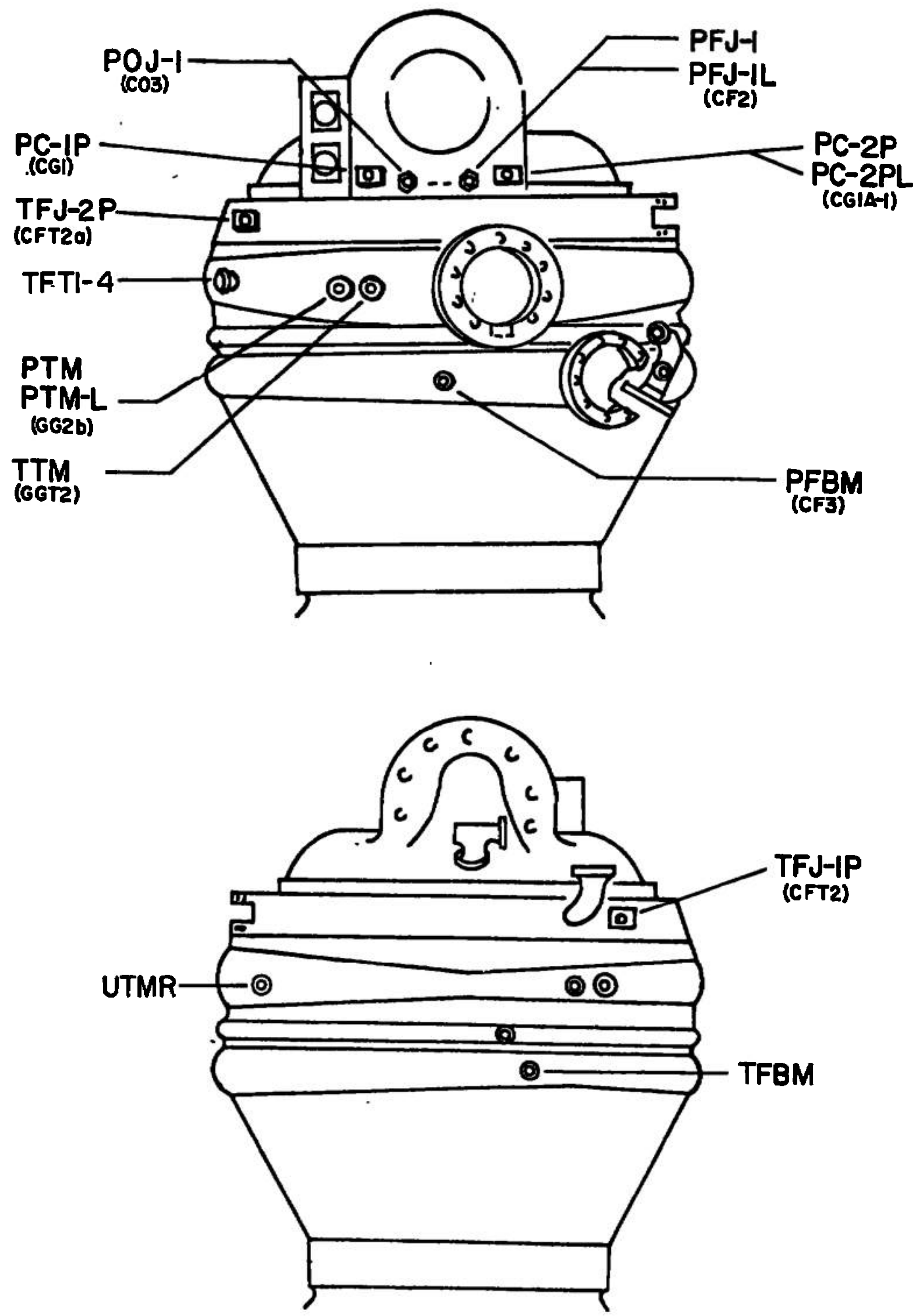
e. Oxidizer System Sensor Locations
Fig. III-1 Continued



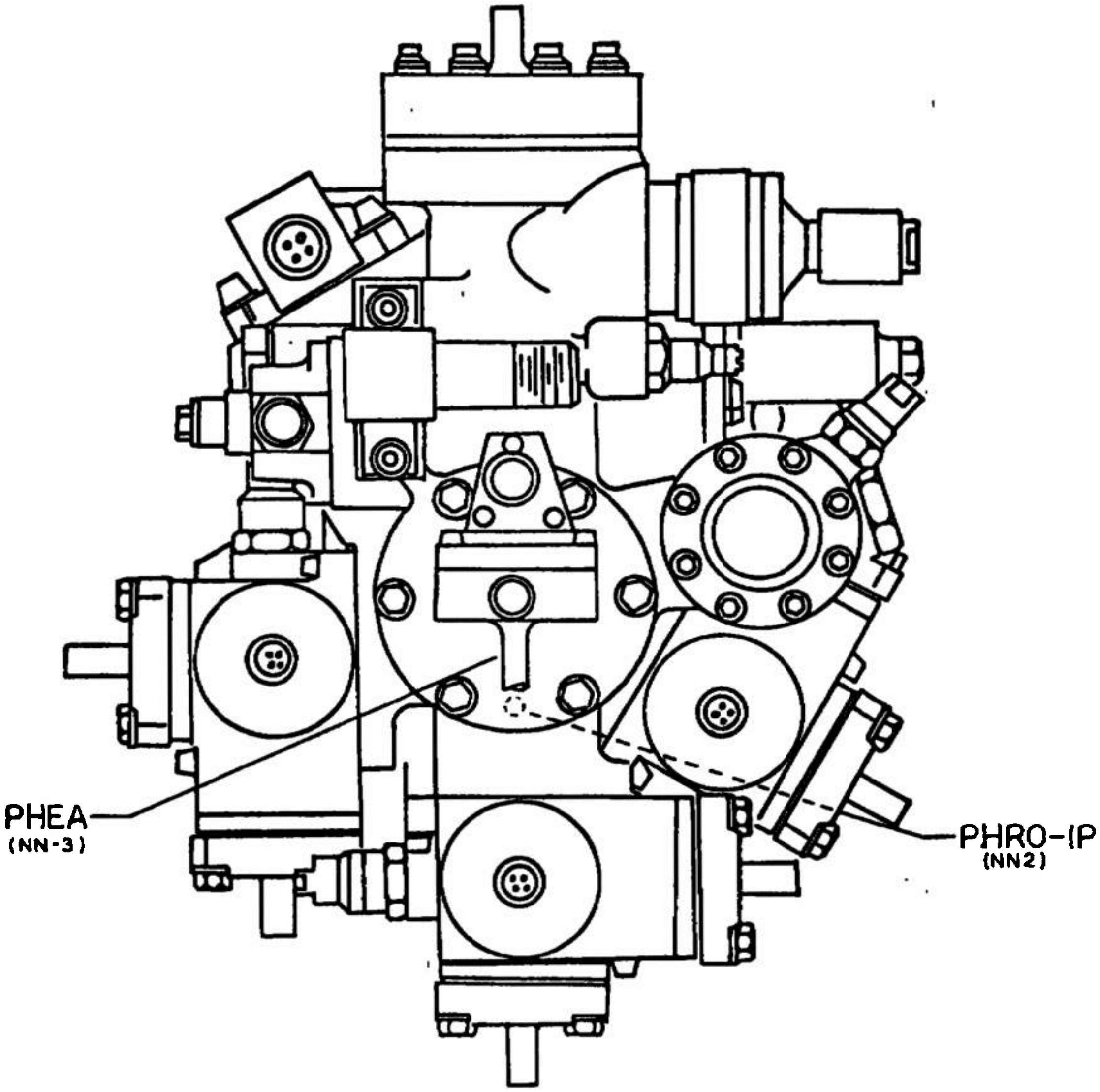
f. Turbine Exhaust System Sensor
Fig. III-1 Continued



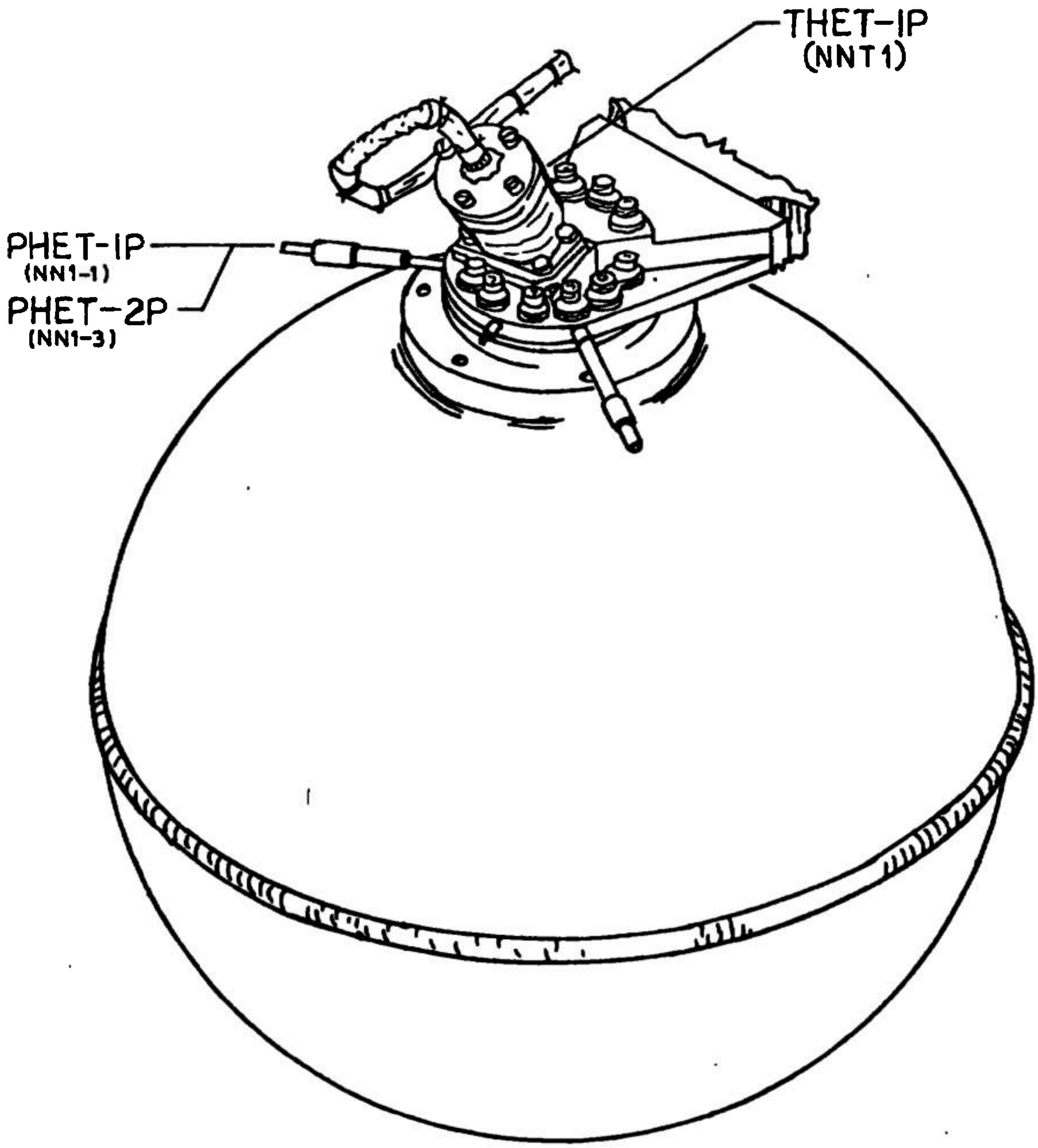
g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



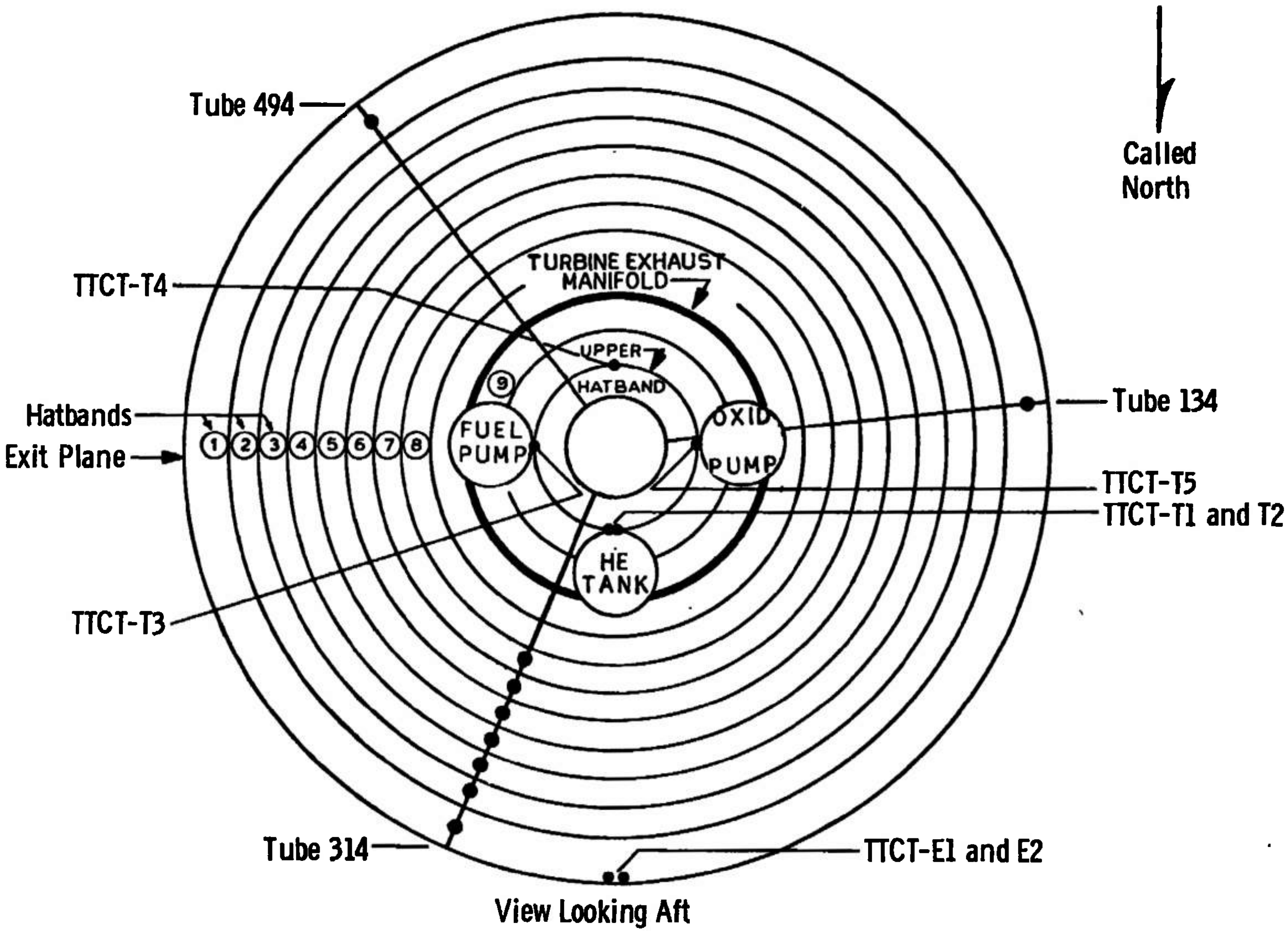
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



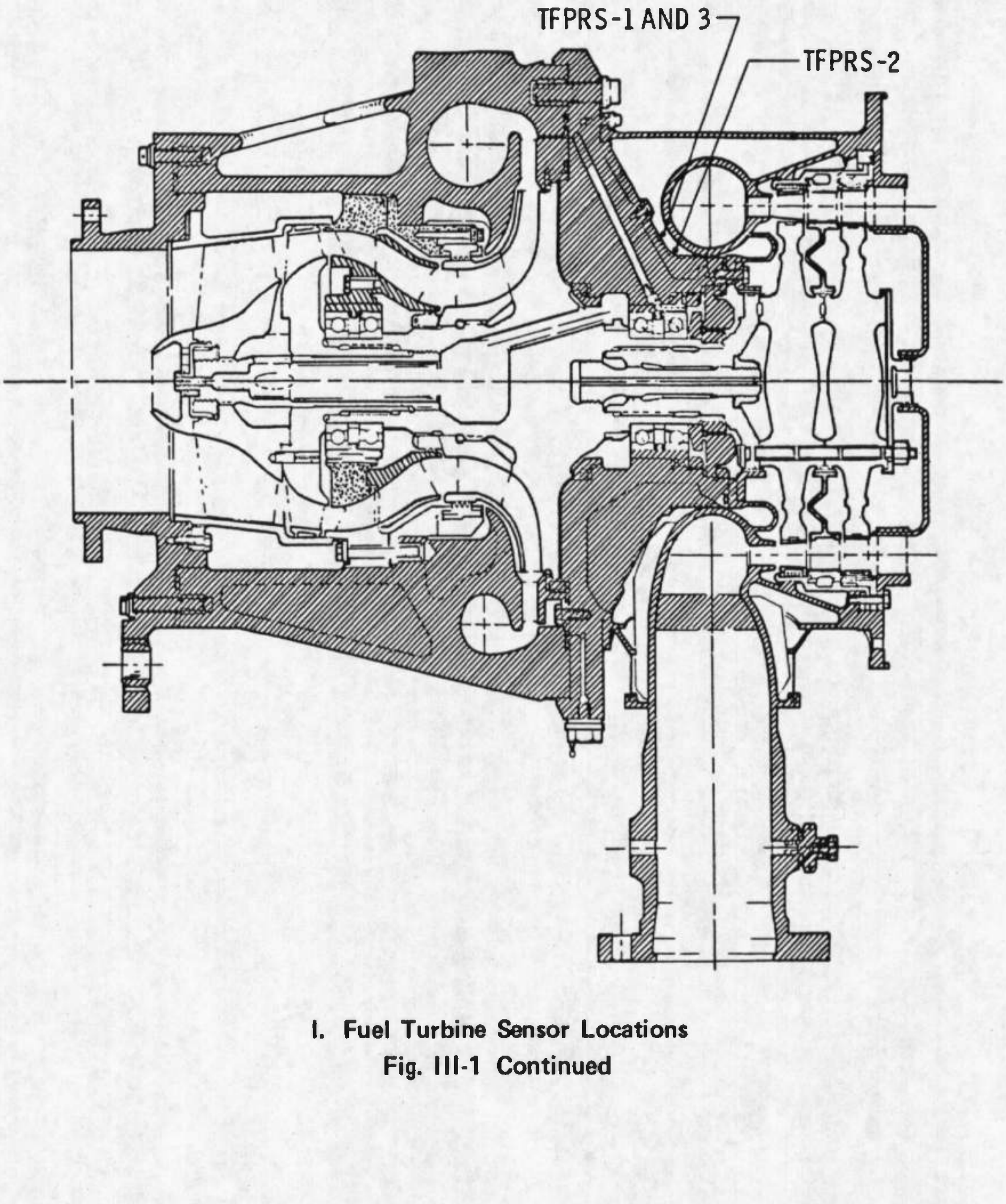
i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



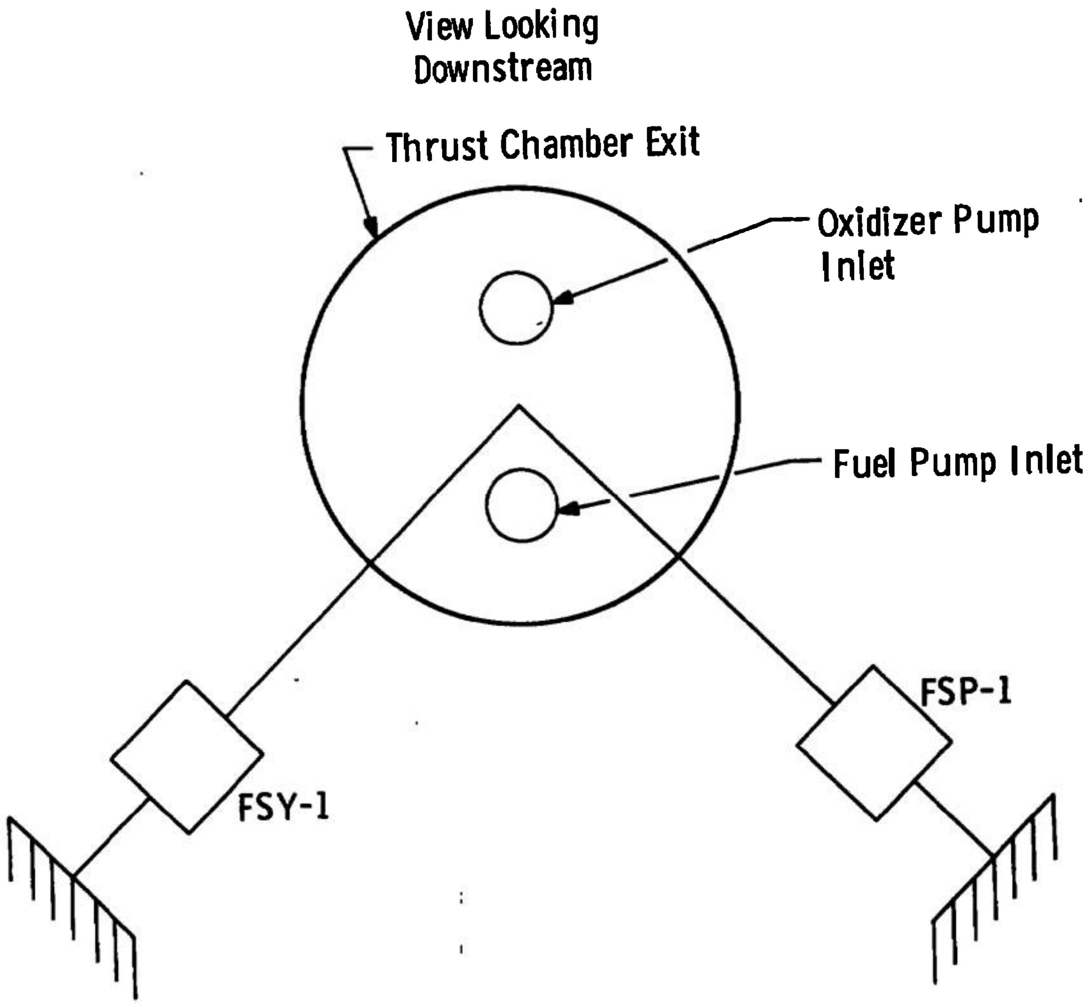
j. Helium Tank Sensor Locations
Fig. III-1 Continued



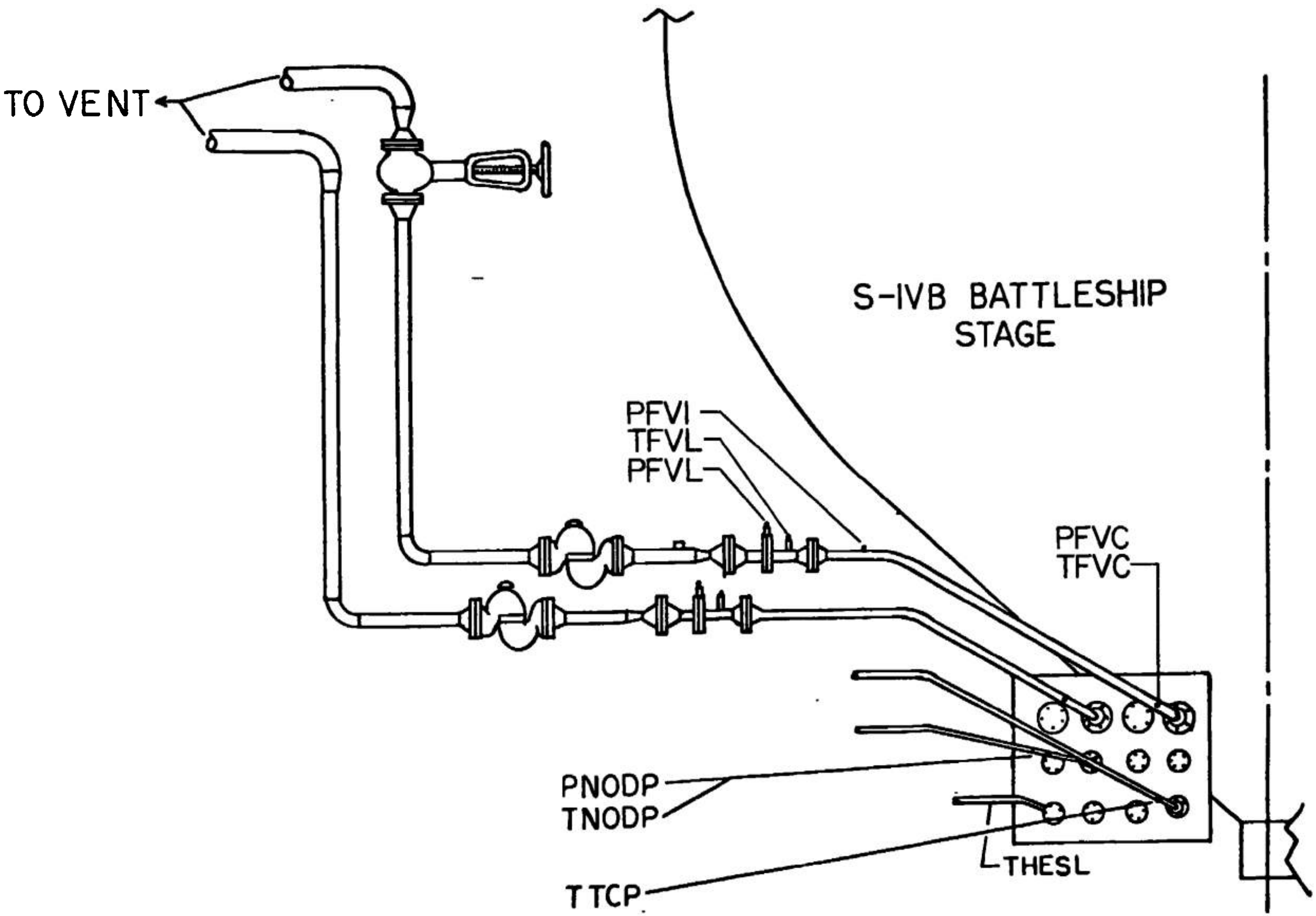
k. Thrust Chamber Instrumentation
Fig. III-1 Continued



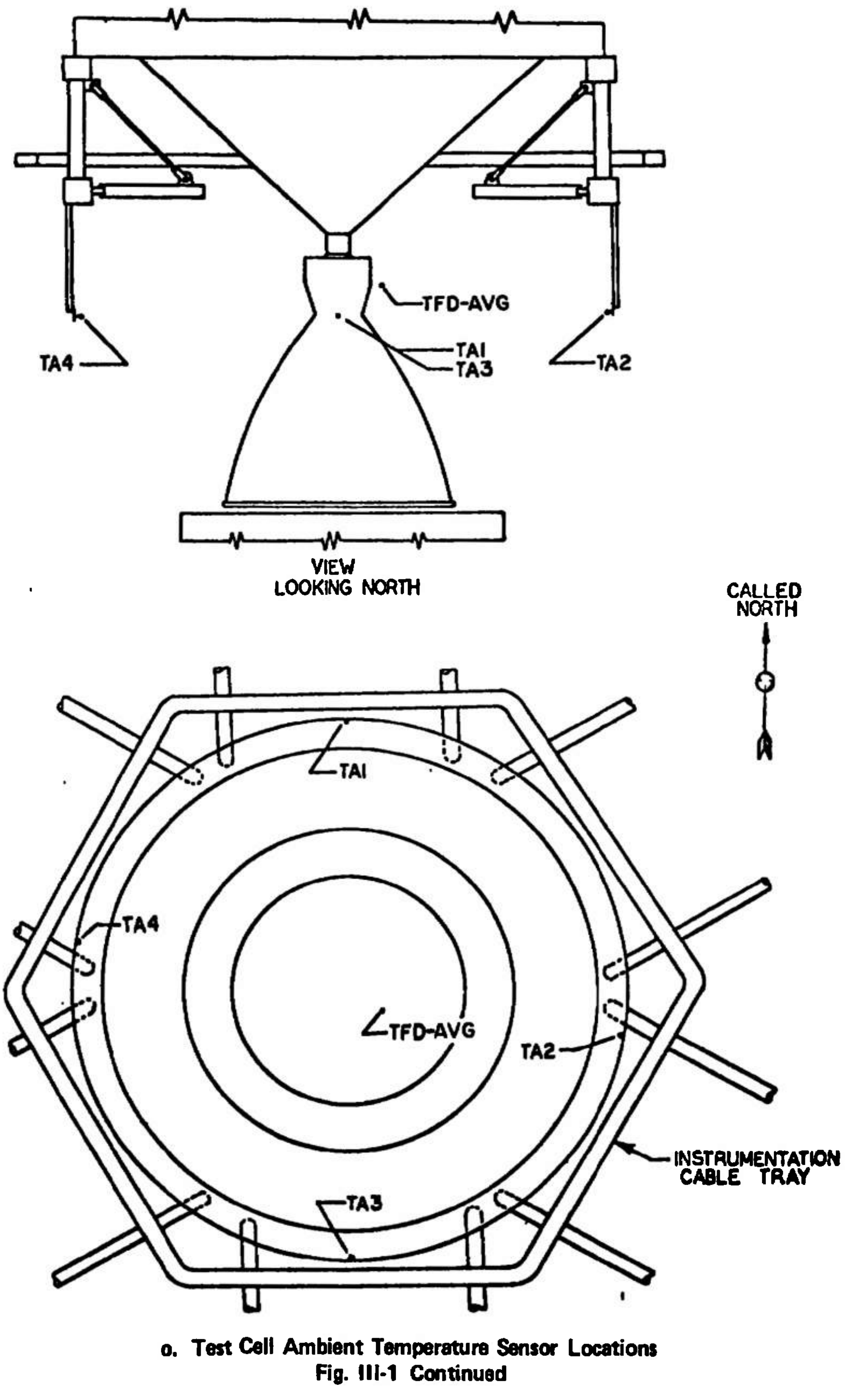
I. Fuel Turbine Sensor Locations
Fig. III-1 Continued



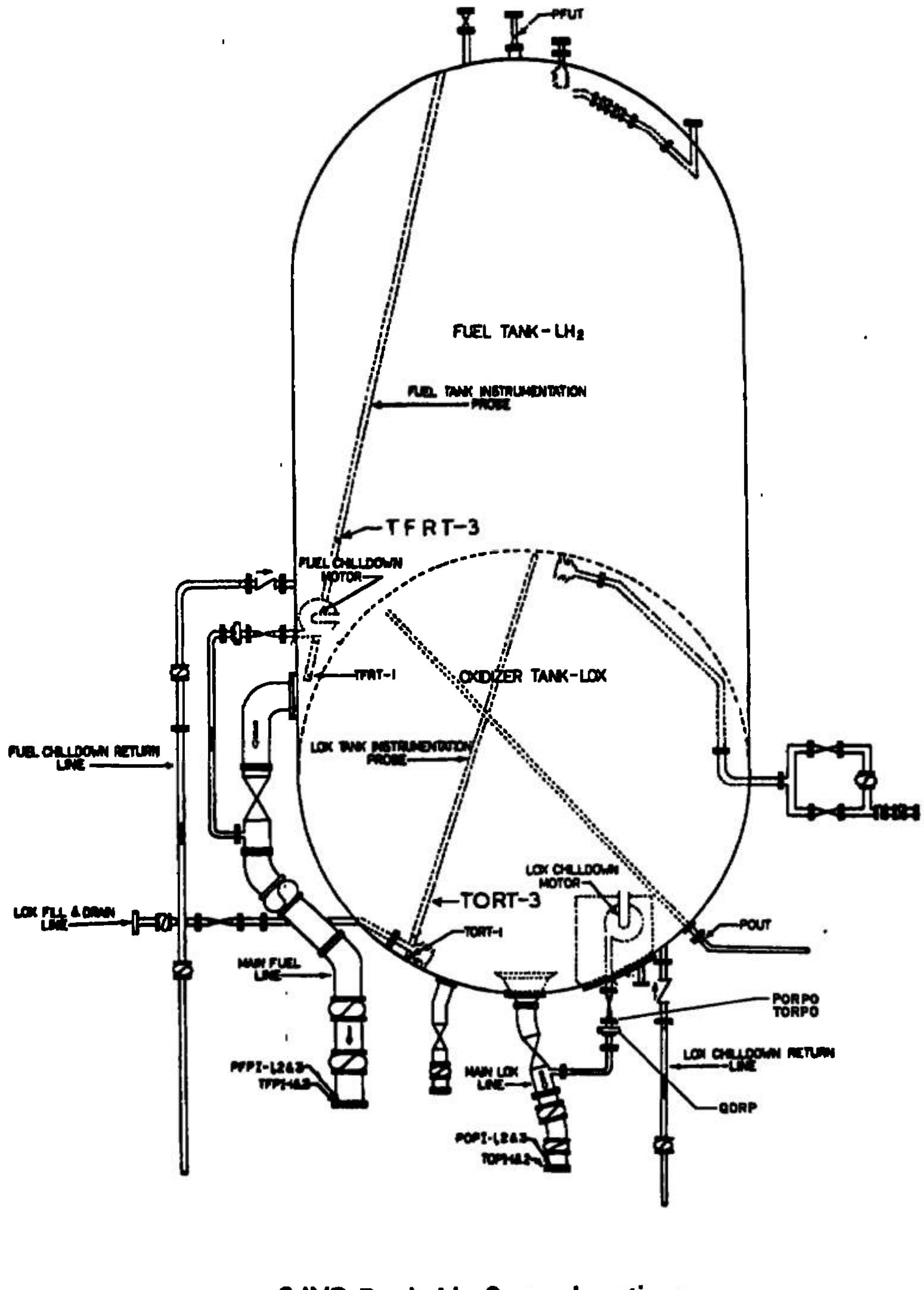
m. Side Load Forces Sensor Locations
Fig. III-1 Continued



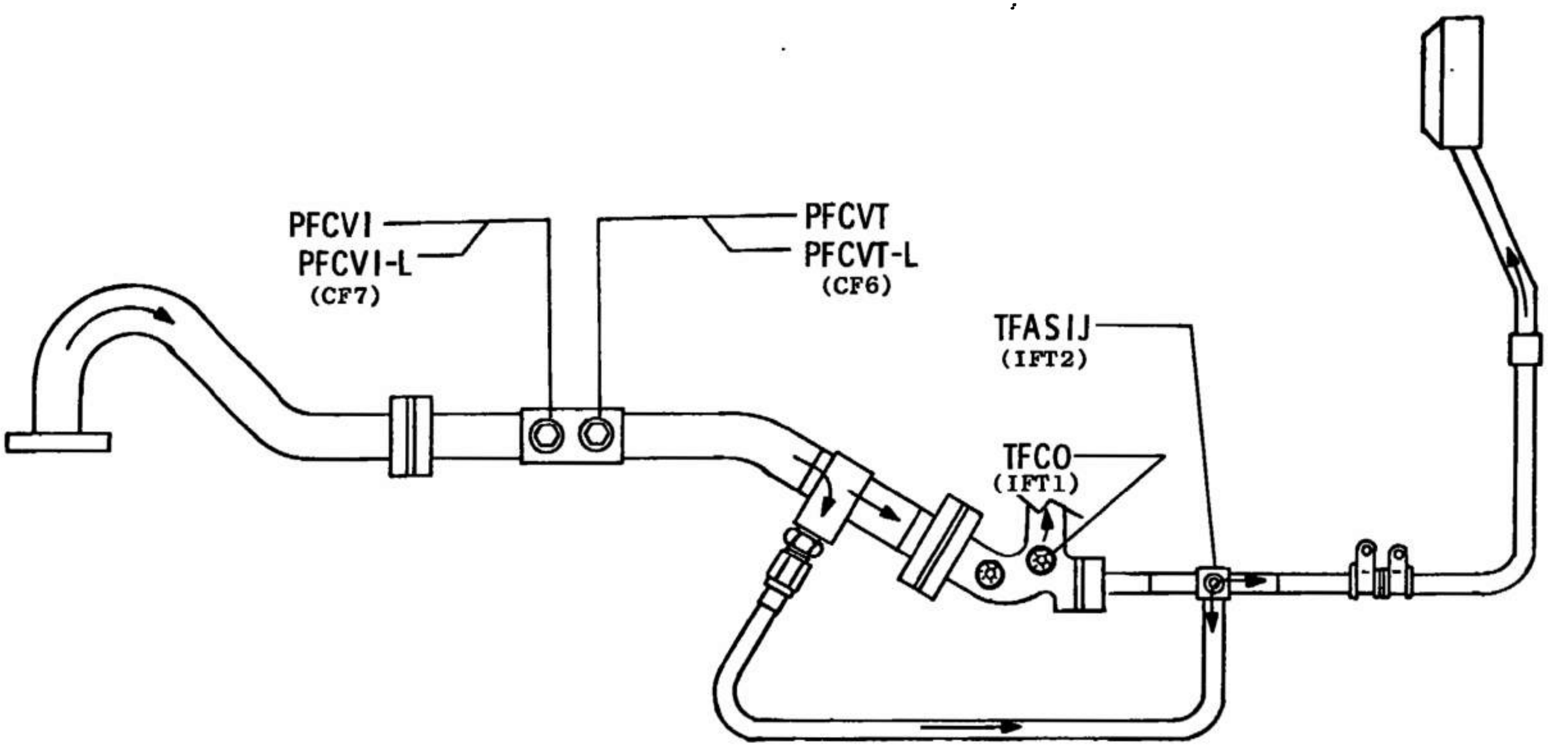
n. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



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



p. S-IVB Battleship Sensor Locations
Fig. III-1 Continued



q. Augmented Spark Igniter/Film Coolant Fuel Line Assembly Instrumentation
Fig. III-1 Concluded

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	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		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EESCO	Programmed Duration Cutoff		On/Off					x	
EFBVO	Fuel Bleed Valve Open Limit		On/Off					x	
EFPCO	Fuel Pump Overspeed Cutoff		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EFUA	Exploding Bridgewire Firing Units Armed		On/Off					x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EIO	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier -1		On/Off					x	
EIDA-2	Ignition Detect Amplifier -2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off	x		x		x	
EMCO	Main-Stage Cutoff Signal		On/Off	x		x			
EMCS	Main-Stage Control Solenoid		On/Off	x		x		x	
EMD-1	Main Stage "OK" Depressurized -1		On/Off	x		x		x	
EMD-2	Main Stage "OK" Depressurized -2		On/Off	x		x		x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed Limit		On/Off					x	
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	Main Stage "OK" Pressurized -1		On/Off	x		x		x	
EMP-2	Main Stage "OK" Pressurized -2		On/Off	x				x	
EMSS	Main-Stage Start Solenoid Energized		On/Off	x	x	x		x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EOBVO	Oxidizer Bleed Valve Open Limit		On/Off					x	
EOCO	Observer Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
ERASIS-1	Augmented Spark Igniter Spark Rate -1		On/Off			x			
ERASIS-2	Augmented Spark Ignitor Spark Rate -2		On/Off			x			
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts -1		On/Off			x			
EVSC-2	Vibration Safety Counts -2		On/Off			x			
EVSC-3	Vibration Safety Counts -3		On/Off			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			x
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QO-1	Engine Oxidizer	POF	0 to 3,600	x					
QO-2	Engine Oxidizer	POFa	0 to 3,600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3,600			x			
QORP*	Oxidizer Recirculation System		0 to 10	x	x	x			
	Forces, lbf								
FSP-1	Side Load (Pitch)		20,000	x		x			
FSY-1	Side Load (Yaw)		20,000	x		x			
FZ-H	Axial Thrust		0 to 300,000	x	x	x			
FZ-L	Axial Thrust		10,000	x	x				
	Position, Percent Open								
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LOVT	Main Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 volts	x		x	x		
LTVT	Hot Gas Tapoff Valve		0 to 100	x		x			
	Pressure, psia								
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x			
PC-1P	Thrust Chamber	CG1	0 to 1500	x					
PC-2P	Thrust Chamber	CG1a-2	0 to 1500	x		x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x		x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500	x					
PFCO	Film Coolant Orifice	CF4	0 to 2000	x					
PFCO-L	Film Coolant Orifice	CF4	0 to 50	x					
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000	x					
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50	x					
PFCVT	Film Coolant Venturi Throat	CF6	0 to 2000	x					
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50	x					
PFJ-1	Fuel Injection	CF2	0 to 1500	x		x			
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50						
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000	x		x	x		
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000	x		x	x		
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500	x			x		
PFPI-1	Fuel Pump Inlet	PF1	0 to 100	x			x		x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			x
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000	x			x		
PFPS	Fuel Pump Interstage	PF6	0 to 1000	x		x	x		
PFPSI	Fuel Pump Shroud Inlet		0 to 2500	x			x		
PFTI-1P	Fuel Turbine Inlet	TG1	0 to 1000	x		x			
PFTO	Fuel Turbine Outlet	TG2	0 to 200	x					
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500	x					
PFUT	Fuel Ullage Tank		0 to 100	x					
PFVC	Fuel Repressurization at Customer Connect Panel		0 to 2000	x					
PFVI	Fuel Repressurization Nozzle Inlet	KHF1	0 to 2000	x					
PFVL	Fuel Repressurization Nozzle Throat	KHF2	0 to 1000	x					
PHEA	Helium Accumulator	HH3	0 to 750	x					
PHES	Helium Supply		0 to 5000	x					
PHET-1P	Helium Tank	HH1-1	0 to 5000	x					x
PHET-2P	Helium Tank	HH1-3	0 to 5000	x					
PHRO-1P	Helium Regulator Outlet	HH2	0 to 750	x					
PNODP-1	Oxidizer Dome Purge at Customer Connect Panel		0 to 750	x					
PNODP-2	Oxidizer Dome Purge at Customer Connect Panel		0 to 1500	x					
POASIJ	Augmented Spark Igniter Oxidizer Injection	IO3	0 to 1500	x		x			
POIML	Oxidizer Idle Mode Line	PO10	0 to 2000	x					
POIML-L	Oxidizer Idle Mode	PO10	0 to 50	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
POJ-1	Oxidizer Injection	CO3	0 to 1500	x					
POJ-2	Oxidizer Injection	CO3a	0 to 2000	x		x			
POJ-2L	Oxidizer Injection	CO3a	0 to 50	x		x			
POJ-3	Oxidizer Injection Manifold	CO3b	0 to 5000		x				
POPBC	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x					
*POPD-1L	Oxidizer Pump Discharge	PO3	0 to 50	x					
*POPD-1P	Oxidizer Pump Discharge	PO3	0 to 2500	x					
POPD-2	Oxidizer Pump Discharge	PO2	0 to 3000		x				
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1a	0 to 100	x	x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x					
PORPO*	Oxidizer Recirculation Pump Outlet		0 to 100	x		x	x		
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200	x					
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100	x					
POUT	Oxidizer Ullage Tank		0 to 100	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					
PPUVI	Propellant Utilization Valve Inlet	PO8	0 to 2000	x					
PPUVO	Propellant Utilization Valve Outlet	PO9	0 to 1000	x					
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTEM	Turbine Exhaust Manifold	TG5	0 to 50	x					
PTM	Tapoff Manifold	GG2b	0 to 1500	x					
PTM-L	Tapoff Manifold	GG2b	0 to 50	x		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			
	Temperatures, °F								
TA-1	Test Cell, North		-50 to 800	x					
TA-2	Test Cell, East		-50 to 800	x					
TA-3	Test Cell, South		-50 to 800	x					
TA-4	Test Cell, West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200	x					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to 100	x		x			
TFBM†	Thrust Chamber Bypass Manifold		-425 to 100	x					
TFCO	Film Coolant Orifice	IFT1	-425 to -375	x					
TFD	Fire Detection		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, °F								
TFOODA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTOA	Fire Detect Tapoff Duct Area		0 to 500	x					
TFJ-1P	Fuel Injection	CFT2	-425 to -300	x					
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x			
TFPBS	Fuel Pump Balance Piston Sump	FFT4	-425 to -375	x			x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -300	x	x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPD-3	Fuel Pump Discharge	PF3	-425 to -350	x					
TFPD-4	Fuel Pump Discharge	PF3	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFPRS-1	Fuel Pump Rear Support		-400 to 1800	x					
TFPRS-2	Fuel Pump Rear Support		-400 to 1800	x					
TFPRS-3	Fuel Pump Rear Support		-400 to 1800	x					
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400	x			x		
TFTI-4	Fuel Turbine Inlet	GGT2 and GG2	-300 to 2000	x		x	x		
TFTO	Fuel Turbine Outlet		-100 to 1200	x					
TFVC	Fuel Repressurization at Customer Connect Panel		-300 to -100	x					
TFVL	Fuel Repressurization Nozzle Inlet	KHFT1	-300 to -100	x					
THET-1P	Helium Tank	HHT1	-200 to 150	x					x
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100	x			x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x			x		
TNODP-1	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
TNODP-2	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
TOIML	Oxidizer Idle-Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x					
**TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
**TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					
TOPDF	Oxidizer Pump Discharge Flange		-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TOPIS††	Oxidizer Pump Inlet Seal		-310 to 100	x					
TOPVS	Oxidizer Pump Volute Skin		-300 to 100	x					
TORPO	Oxidizer Pump Recirculation Outlet		-300 to 100	x					
TORT-1	Oxidizer Run Tank		-300 to -285	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x					
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					
TPTU	Photocon Cooling Water (Upstream)		0 to 300	x					

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, °F								
TTCT-E1	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-E2	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	x			x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
	Peak Vibrations, g								
UFPR	Fuel Pump	PSA-1	450		x				
UFTR	Fuel Turbine	V123-2	450		x				
UOPR	Oxidizer Pump Radial	PSA-2	300		x				
UTCD-1	Thrust Chamber Dome	FZA-1a	1400		x	x			
UTCD-2	Thrust Chamber Dome	FZA-2	1400		x	x			
UTCD-3	Thrust Chamber Dome	FZA-3	300		x	x			
UTCT-1	Thrust Chamber Throat		300		x				
UTCT-2	Thrust Chamber Throat		300		x				
UTCD-4	Thrust Chamber Dome		1400		x				
UTCD-5	Thrust Chamber Dome		1400		x				
UTCD-6	Thrust Chamber Dome		1400		x				
UTMR	Tapoff Manifold Radial		300		x				
	Voltage, v								
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	x					
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5	x					

* For J4-1001-08, 09 and 10, only

** Tap locations for TOPD and POPD were reversed for tests J4-1001-12, -13, and -14

† For J4-1001-08 and 09, only

†† Not required for J4-1001-12 and 13

APPENDIX IV
METHODS OF CALCULATIONS

NOMENCLATURE

A	Area, sq in.
C*	Characteristic velocity, ft/sec
CF	Coefficient of thrust
F	Thrust, lbf
I	Impulse, sec
O	Oxidizer
P	Pressure, psia
W	Flow rate, lbm/sec
ρ	Density, lbm/cu ft

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

SUPERCRIPT

*	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. 9 and 10. 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. 11 and 12 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 $P_{ns} = P_a$

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

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

$$(CF)_{ideal} = f\left(\frac{O}{F}, P_c, \frac{A_e}{A^*}\right) \quad \text{from Refs. 9 and 10}$$

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 were obtained from Refs. 11 and 12 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

$$C_D = 0.97$$
$$A = 5.75 \times 10^{-3}\ ft^2$$

} supplied by engine manufacturer

thus

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

where

$$\Delta P = PFCVI - PFCVT$$
$$\rho = \rho\,(PFJ, TFJ)$$

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13. ABSTRACT

Ten idle-mode firings of the J-2S rocket engine S/N J-112 were conducted during test periods J4-1001-08 through J4-1001-10, and J4-1001-12 through J4-1001-14 between September 2 and October 15, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility. The primary objectives of these firings were to determine engine idle-mode operating characteristics at various engine mixture ratios utilizing a new noncompartmented injector. Engine performance, as indicated by characteristic velocity, was 120 percent higher than experienced with previous compartmented injector designs at nominal pump inlet conditions. Total accumulated engine idle-mode operation was 1408.2 sec.

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