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SATURN S-IVB-506N STAGE
CCEPTANCE FIRING REPORT

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

[redacted]

SEPTEMBER 1968

MCDONNELL DOUGLAS
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SATURN S-IVB-506N STAGE
ACCEPTANCE FIRING REPORT

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COORDINATED BY: W. L. BROWNING
PROJECT OFFICE - TEST
H. B. DEVELOPMENT ENGINEERING -
SATURN/APOLLO

PREPARED BY:
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
SATURN S-IVB TEST PLANNING
AND EVALUATION COMMITTEE

[redacted]

PREPARED FOR:
NATIONAL AERONAUTICS AND
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UNDER NASA CONTRACT NAS7-101

[redacted]

H.B Mitchell for
APPROVED BY: A. P. O'NEAL, DIRECTOR
HUNTINGTON BEACH DEVELOPMENT/ENGINEERING-
SATURN/APOLLO

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
WESTERN DIVISION
5301 Bolsa Avenue, Huntington Beach, CA 92647 (714) 897-0311

ABSTRACT

This report presents an evaluation of the Saturn S-IVB-506N stage acceptance firing that was conducted at the Sacramento Test Center on 17 July 1968. Included in this report are stage and ground support equipment deviations associated with the acceptance firing configuration.

The acceptance firing test program was conducted under National Aeronautics and Space Administration Contract NAS7-101, and established the acceptance criteria for buyoff of the stage.

DESCRIPTORS

Saturn S-IVB-506N Stage

Saturn S-IVB-506N Stage Test Evaluation

J-2 Engine

Complex Beta

Countdown Operations

Saturn S-IVB-506N Stage Acceptance Firing

Saturn S-IVB-506N Stage Test Configuration

Sacramento Test Center

Sequence of Events

O_2-H_2 Burner

PREFACE

This report documents the evaluation of the Saturn S-IVB-506N stage acceptance firing as performed by MDAC-WD personnel at the Sacramento Test Center.

The report was prepared under National Aeronautics and Space Administration Contract NAS7-101 and is issued in accordance with line item 129 of the MSFC Data Requirements List 021, dated 15 September 1966.

This report evaluates stage test objectives, instrumentation, and configuration deviations of the stage, test facility, and ground support equipment.

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■ SECTION 1

INTRODUCTION

1. INTRODUCTION

1.1 General

This report was prepared at the McDonnell Douglas Astronautics Company - Western Division (MDAC-WD) Huntington Beach, by the Saturn S-IVB Test Planning and Evaluation (TP&E) Committee for the National Aeronautics and Space Administration under Contract NAS7-101.

Activities connected with the Saturn S-IVB-506N stage included a pre-firing checkout and the acceptance firing. Checkout started at the subsystem level and progressed to completion with the integrated systems test and the simulated acceptance firing. The information contained in the following sections documents and evaluates all events and test results of the acceptance firing which was completed on 17 July 1968. The tests were performed at Complex Beta, test stand III, Sacramento Test Center (STC).

1.2 Background

The S-IVB-506N stage was assembled at MDAC-WD. A checkout was performed in the vertical checkout laboratory (VCL) prior to shipping the stage to STC. The stage was delivered to STC on 23 January 1968 and installed on test stand III on 26 January 1968. The stage was ready for acceptance firing on 9 July 1968.

The APS modules were shipped to Santa Monica checkout laboratory for production acceptance tests. The modules were then shipped to STC for stage interface checks. No confidence firings of these modules were scheduled.

Table 1-1 lists the milestones of the Saturn S-IVB-506N stage events and dates of completion.

1.3 Objectives

All test objectives outlined in Douglas Drawing No. 1B71775B, Test Plan Acceptance Firing, S-IVB/SV-STC, dated 4 April 1968 were successfully completed.

TABLE 1-1
MILESTONES, SATURN S-IVB-506N STAGE

Event	Completion Date
Tank assembly	14 April 1967
Proof test leak and dye	2 May 1967
Insulation and bonding	26 June 1967
Stage checkout and join J-2 engine	6 Sept. 1967
Systems checkout	3 Nov. 1967
Ship to STC	23 Jan. 1968
Stage installed on test stand	26 Jan. 1968
Ready for acceptance firing	9 July 1968
Acceptance firing	17 July 1968
Abbreviated postfire checkout on stand	24 July 1968
Ready for storage	25 July 1968

SECTION 2

SUMMARY

2. SUMMARY

The S-IVB-506N stage was acceptance fired on 17 July 1968 at Complex Beta, test stand III, Sacramento Test Center. The countdown was designated as CD 614109. The mainstage firing duration was 448.092 sec; engine cutoff was initiated through the PU processor when LOX was depleted below the 1 percent level.

2.1 Countdown Operations

Countdown 61409 was initiated on 16 July and proceeded to a successful acceptance firing on 17 July 1968. The following anomalies were experienced during this countdown:

a. The control helium regulator discharge pressure (D0581) exceeded the upper redline limit causing the countdown to be stopped and recycled. The regulator was stabilized in the normal operating range and operated within limits for the remainder of the countdown.

b. During the first test stand inspection, a cold helium leak at the umbilical tee for the helium supply swing arm pressure transducer (D0873) was noted; therefore, in order to conserve helium, cold sphere pressurization was delayed until start of terminal count and the supply pressure was set to the lower side of the tolerance (2,800 psia). A bad seal at the tee (D0873) was replaced after the countdown.

2.2 J-2 Engine System

The S-IVB-506N stage utilized an uprated (230,000 lbf thrust) J-2 engine, (S/N J2101). All systems operated satisfactorily and the performance predictions were well within the allowable deviations. No performance shifts occurred, as they did during several previous firings, and all hardware functioned normally.

2.3 Oxidizer System

The oxidizer system functioned adequately supplying LOX to the engine pump inlet within the specified limits. The new LOX tank pressurization sequence eliminated the LOX ullage pressure dip during the first part of engine burn and satisfactorily maintained pressure in the LOX tank throughout the firing.

2.4 Fuel System

The fuel system performed as designed and supplied LH2 to the engine within the limits defined in the engine specification. The LH2 tank pressurization system adequately controlled LH2 tank ullage pressure throughout the firing and during the repressurization periods. As part of an effort to avoid overstressing the LH2 tank structure, the tank operating pressure levels were reduced.

2.5 Pneumatic Control and Purge System

The pneumatic control and purge system performed adequately during the acceptance firing except during the critical components test prior to O_2-H_2 burner testing and J-2 engine firing, and again during the terminal countdown. The pneumatic control helium regulator did not regulate the control helium sphere pressure down to the specified maximum; however, performance was not affected. All other components functioned normally.

2.6 Oxygen-Hydrogen Burner System

The high chamber pressure O_2-H_2 burner was started twice prior to J-2 engine firing--the first time to repressurize the LH2 and LOX tanks and the second time to demonstrate burner restart capability for ullaging purposes. The burner functioned satisfactorily during both operations which lasted 456 sec and 130 sec, respectively.

2.7 Propellant Utilization System

The PU system performed satisfactorily and accomplished all the design objectives.

2.8 Data Acquisition System

The data acquisition system performed satisfactorily throughout the O_2-H_2 burner and mainstage firing. Two hundred and eighteen measurements were active of which one failed resulting in a measurement efficiency of 99.5 percent.

2.9 Electrical Power and Control Systems

The electrical power and control systems performed satisfactorily throughout the acceptance firing. All firing objectives were satisfied and all system variables operated within design limits.

2.10 Hydraulic System

The hydraulic system operated properly supplying pressurized fluid to the servo-actuators. All specified test objectives were achieved and all system variables operated within design limits.

2.11 Flight Control System

The dynamic response of the hydraulic servo-thrust vector control system was measured while the J-2 engine was gimbaled during the acceptance firing. The performance of the pitch and yaw hydraulic servo control systems was satisfactory.

2.12 Structural Systems

Structural integrity of the stage was maintained for the vibration, temperature, and thrust load conditions of the acceptance firing with the exception of cracking and peeling of Korotherm ablative coating on certain areas of the forward and aft skirt. The damaged coating is to be replaced when the stage is erected in the vertical checkout laboratory.

2.13 Thermoconditioning and Purge System

The thermoconditioning and purge system functioned properly supplying purge and environmental conditioning to the stage within design limits.

2.14 Effectiveness Engineering and Human Engineering

All malfunctions of Flight Critical Items were investigated and documented as follows:

Total number of malfunctions	10
Number of items reworked in place and accepted by engineering	1

Number of items replaced	6
Number of items determined to be acceptable by engineering	1
Number of items requiring final disposition	1
Number of items to be replaced postfiring	1

A Human Engineering evaluation was conducted in support of the acceptance firing.

[redacted]

SECTION 3

TEST CONFIGURATION

3. TEST CONFIGURATION

This section describes the stage and ground support equipment (GSE) deviations and modifications from the flight configuration affecting the acceptance firing. Additional details of specific system modifications are discussed in appropriate sections of this report. Details of the S-IVB-506N stage configurations are presented in Douglas drawing No. 1B66684, S-IVB/V Stage End-Item Test Plan.

Figure 3-1 is a schematic of the S-IVB-506N stage propulsion system and shows the telemetry instrumentation transducer locations from which the test data were obtained. The functional components are listed in table 3-1. Hardwire measurements are noted in the appropriate subsystem schematics included in this report. The propulsion system orifice characteristics and pressure switch settings are presented in tables 3-2 and 3-3. J-2 engine S/N 2101 was installed.

The propulsion GSE (figure 3-2) consisted of pneumatic consoles "A" and "B", two propellant fill and replenishing control sleds, a vacuum system console, and a gas heat exchanger.

3.1 Configuration Deviations

Configuration deviations required for the acceptance firing are discussed in Douglas drawing 1B71775B, Test Plan, Acceptance Firing, S-IVB/SV-STC. Significant configuration changes to the stage and GSE for the acceptance firing are discussed in the following paragraphs.

3.1.1 Propulsion System

a. Stage propellant vent and bleed systems were connected to the facility vent system. The nozzles were removed from the LH2 tank continuous vent system and the LOX and LH2 nonpropulsive vent systems.

b. The stage portions of the propellant and pneumatic quick-disconnects were replaced with hardlines.

c. A converging water-cooled diffuser was installed in the engine thrust chamber exit to reduce the possibility of sideloads induced by jet stream separation.

d. A GN2 ejector system was used to provide low pressure environment at the O_2-H_2 burner nozzle exit.

e. A heated GN2 purge was used for the LOX dome to prevent injector icing during the simulated orbital coast.

3.1.2 Propellant Utilization System

a. The propellant loading fast-fill sensors installed on the instrumentation probes were used in the indicating mode only.

3.1.3 Electrical Power System

a. Model DSV-4B-170 battery simulators were used to supply stage internal power.

b. Model DSV-4B-727 primary battery simulators were used in place of primary flight batteries

3.1.4 Electrical Control System

a. The instrument unit and S-IVB/V stage electrical interfaces were simulated by GSE.

b. Two Model DSV-4B-188B APS simulators were used to provide APS module electrical loads to the stage control signals.

c. The electrical umbilicals remained connected throughout the acceptance firing.

3.1.5 Data Acquisition System

a. The MSFC Basic Static Firing Measurement Program hardwire transducers were installed.

b. All instrumentation parameters without transducers, and those disconnected for hardwire usage, were left as open channels.

3.1.6 Forward Skirt Environmental Control System

a. Coolant for the forward skirt thermoconditioning system was supplied by Model DSV-4B-359 Servicer.

3.1.7 Secure Range Safety Command System

a. The engine cutoff command output from Range Safety Systems 1 and 2 was disconnected and stowed.

b. Pulse sensors were attached to the output of the exploding bridgewire (EBW) firing units.

3.1.8 Structural Systems

a. The main and auxiliary tunnel covers were not installed.

b. The stage was mounted on the Model DSV-4B-540 Dummy Interstage.

3.1.9 GSE and Facilities

a. Resistance wire fire detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

b. GH2 leak detection system was installed for monitoring critical areas of the stage, GSE, and facilities.

c. Blast detectors were installed in the test area for monitoring ranges of 0 to 25 psi overpressure.

d. Model 742 static firing hazardous gas shield, thrust cone water spray Firex, cryogenic spill pan, forward skirt support ring, and vent port covers were installed.

e. Model 601 flame resistant protective firing cover was installed to enclose the forward skirt area.

f. An auxiliary propellant tank pressurization system was installed using a GSE ambient helium source.

g. Model DSV-4B-618 Engine Unlatch Restrainer Links were installed to restrain the J-2 engine during start transient sideloads.

h. Two O_2 content analyzer sense lines were installed in the thrust structure.

TABLE 3-1 (Sheet 1 of 4)
S-IVB-506N STAGE HARDWARE LIST

FIND NO.*	PART NO.	SERIAL NO.	NAME
1	7851861-1	30	Disconnect, LH2 tank prepressurization
2	10414087	N/A	Valve, hand, LOX vent and relief valve purge
3	1B65673-1	7	Valve, check, LH2 tank prepressurization line
4	1A57350-507	0233	Module, control helium fill
--	1B66868-501	--	Sphere, control helium, 4.5 cubic feet (seven installed)
6	1A58345-523	107	Module, pneumatic power control
7	7851823-503	1092	Disconnect, ambient helium fill
9	1A48857-503	51	Plenum, control helium, 100 cubic inches
10	1A48848-511	N/A	Disconnect, LH2 ground vent
11	10414087	N/A	Valve, hand, LH2 chilldown valve, vent and relief valve, continuous vent, nonpropulsive vent, and fill valves purge
--	1B67598-501	--	Valve, check (eight installed)
15	1B66692-501-004	94	Module, actuation control, continuous vent bypas
18	1B67193-507	014	Module, continuous vent
22	1B66692-501-004	90	Module, actuation control, LH2 fill and drain
24	1B66932-501	N/A	Disconnect, LH2 fill and drain
25	1A48240-505-007	0121	Valve, LH2 fill and drain
26	1B41065-1	N/A	Disconnect, common bulkhead vacuum system
27	1B66932-501	58	Disconnect, LOX fill and drain
30	1A48240-505-007	114	Valve, LOX fill and drain
31	1B66692-501-004	92	Module, actuation control LOX fill and drain val
32	1B57781-507	0040	Module, cold helium dump
33	1B40824-507	115	Valve, check, cold helium fill

*Indicates location in figures 3-1 and 3-2.   N/A = Not available

TABLE 3-1 (Sheet 2 of 4)
S-IVB-506N STAGE HARDWARE LIST

FIND NO.*	PART NO.	SERIAL NO.	NAME
34	1B42290-507	0037	Module, LOX tank pressurization control
35	7851844-501	36	Disconnect, cold helium fill and LOX tank prepressurization
36	1B40384-507	114	Valve, check, cold helium fill
37	1A49991-1	A	Plenum, LOX tank pressurization
41	1A49958-517	N/A	Disconnect, ground checkout, cold helium, ambient helium, and engine purge
42	1A49958-517	N/A	Disconnect, mainstage OK pressure switch checkout
42A	1A49958-519	N/A	Disconnect, thrust chamber jacket purge and chilldown
43	1B66230-505	1054	Module, control, LH2 tank pressurization
51	1A49988-501R	0028	Valve, directional, LH2 tank vent
54	1A49591-533-016	165	Valve, relief, LH2 tank, crack 38 psia max, reseat 35 psia min
55	1A48257-511-006	0054	Valve, LH2 tank vent and relief, crack 37 psia max, reseat 34 psia min
--	1A48858-1	--	Sphere, cold helium, 3.5 cubic feet (nine installed)
57	1B58100-503	N/A	Probe, LH2 tank instrumentation
57A	1A48430-503	N/A	Probe, LOX mass sensor
58	1B65812-1	N/A	Diffuser, LH2 tank pressurization
59	1A48431-501	N/A	Probe, LH2 mass sensor
59A	1A69275	N/A	Probe, LOX instrumentation
60	1A49421-507-010	158	Pump, LH2 chilldown
64	1A49423-509	--	Valve, relief, LOX chilldown pump purge, crack and reseat 65 to 85 psia (part of pump assembly)
65	1A67913-1	--	Valve, dump, LOX chilldown pump purge
66	1A49423-509	1865	Module, pump, LOX chilldown

*Indicates location in figures 3-1 and 3-2. N/A = Not available

TABLE 3-1 (Sheet 3 of 4)
S-IVB-506N STAGE HARDWARE LIST

FIND NO.*	PART NO.	SERIAL NO.	NAME
67	1A49964-501	280	Valve, check, LOX chilldown return line
68	1A49965-529-013A	601	Valve, LOX chilldown shutoff
69	1A89104-507	56999	Flowmeter, LOX chilldown
70	1B53920-503	056	Valve, check, LOX chilldown pump discharge
71	1B52985-501	N/A	Filter, LOX chilldown pump purge
72	1A49968-509-010	108	Prevalve, LOX
74	1B53920-501	045	Valve, check, GH2 tapoff pressurization line
75	1B69550-1	0023	Module, LH2 repressurization control
77	1A49990-505	N/A	Sphere, LH2 repressurization, 4.5 cubic feet
78	1B66692-501-004	93	Module, actuation control, directional vent
79	1B66692-501-004	96	Module, actuation control, LH2 tank vent and relief valve
80	1B66692-501-004	83	Module, actuation control, O_2-H_2 burner LOX supply valve
83	1B66639-515	0042	Actuator assembly, valve, O_2-H_2 burner LOX shutdown
84	1B59008-501	N/A	Filter, O_2-H_2 burner LOX supply
87	1B67723-1	--	Injector, No. 2, O_2-H_2 burner
88	1B67723-1	--	Injector, No. 1; O_2-H_2 burner
89	1B62600-527-0090	013	Burner assembly, O_2-H_2
92	1B59010-503-010	0114	Valve, O_2-H_2 burner LH2 supply
93	1B66692-501-004	93	Module, actuation control, O_2-H_2 burner LH2 supply and LOX shutdown valves
94	1B59008-501	N/A	Filter, O_2-H_2 burner LH2 supply
97	1B40824-507	113	Valve, check, O_2-H_2 burner LH2 tank pressurization coil inl
100	1B40824-507	118	Valve, check, O_2-H_2 burner LOX tank pressurization coil inlet

*Indicates location in figures 3-1 and 3-2. N/A = Not available

TABLE 3-1 (Sheet 4 of 4)
S-IVB-506N STAGE HARDWARE LIST

FIND NO.*	PART NO.	SERIAL NO.	NAME
101	1B69030-1	0005	Valve, relief, LOX tank, crack 45 psia max, reseat 41 psia min
102	1B43659-501	N/A	Filter, O_2-H_2 burner LOX tank pressurization coil inlet
104	1A48312-505-008	0036	Valve, vent and relief, LOX tank, crack 44 psia max, reseat 41 psia min
105	1B62778-503	0032	Module, plenum and valve, O_2-H_2 burner LH2 tank pressurization coil inlet, 250 cubic inches
106	1B62778-503	0034	Module, plenum and valve, O_2-H_2 burner LOX tank pressurization coil inlet, 250 cubic inches
107	1B66692-501-004	82	Module, actuation control, LOX tank vent and relief valve
110	1A49968-507-010	119	Prevalve, LH2
111	1B52985-501	N/A	Filter, LH2 chilldown pump discharge
112	1B53920-503	053	Valve, check, LH2 chilldown pump discharge
113	1A89104-509	31611	Flowmeter, LH2 chilldown pump discharge
114	1A49965-523-012	0517	Valve, shutoff, LH2 chilldown line
115	1B66692-501-004	74	Module, actuation control, chilldown valves and prevalves
116	1A49964-501	283	Valve, check, LH2 chilldown return
117	1B69550-1	0029	Module, control, LOX tank repressurization
118	1A49990-505	N/A	Sphere, LOX tank repressurization, 4.5 cubic feet
120	1A58347-513	0002	Module, engine purge control
122	1A49958-521	N/A	Disconnect, engine start sphere vent and relief valve drain
123	1A49958-515	N/A	Disconnect, engine control helium sphere fill
124	1A49958-523	N/A	Disconnect, engine start sphere fill
125	1A49958-517	N/A	Disconnect, LH2 turbine seal drain

*Indicates location in figures 3-1 and 3-2.   N/A = Not available

TABLE 3-2 (Sheet 1 of 4)
S-IVB-506N STAGE AND GSE ACCEPTANCE FIRING ORIFICES

FIND NO.*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
	Stage			
15C	Continuous vent bypass valve actuation control module inlet	0.017 in. dia	--	
16	Continuous vent bypass valve bellows purge	300 scim with 3,200 psid	--	Sintered
17	Continuous vent bypass valve switch cavity purge	15 scim with 3,200 psid	--	Sintered
19	Continuous vent No. 1	1.090 in. dia	--	
20	Continuous vent No. 2	1.090 in. dia	--	
21	Continuous vent purge	1 scfm with 3,200 psid	--	Sintered
23	LH2 fill and drain valve purge	15 scim with 3,200 psid	--	Sintered
29	LOX fill and drain valve purge	15 scim with 3,200 psid	--	Sintered
35A	LH2 childown valve purge	66 scfm with 1,600 psid	--	Sintered
39	LOX tank pressurization module, heat exchanger primary	0.2189 in. dia	0.87	0.03201
40	LOX tank pressurization module, heat exchanger bypass	0.185 in. dia	0.87	0.0222
43	LH2 tank pressurization--step mode (all three orifices used for acceptance firing only)	--	--	0.12734***
44	LH2 tank pressurization module (overcontrol-second burn)	0.201 in. dia	**	0.09987***

*Indicates location in figures 3-1 and 3-2.

**Not recorded during calibration.

***Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

TABLE 3-2 (Sheet 2 of 4)
S-IVB-506N STAGE AND GSE ACCEPTANCE FIRING ORIFICES

FIND NO.*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
45	LH2 tank pressurization module normal (undercontrol)	0.299 in. dia	**	0.07241
46	LH2 tank pressurization module control (overcontrol-first burn)	0.201 in. dia	**	0.09987***
47	LH2 tank repressurization module outlet	0.3128 in. dia	0.88	0.063
47A	O_2-H_2 burner LH2 supply valve purge	15 scim with 3,200 psid	--	Sintered
48	LH2 tank nonpropulsive vent purge	1 scfm with 3,200 psid	--	Sintered
49	LH2 tank nonpropulsive vent No. 1	2.180 in. dia	--	
50	LH2 tank nonpropulsive vent No. 2	2.180 in. dia	--	
61	LOX chilldown pump purge	37 scim with 475 psid	--	Sintered
73A	LOX sensing line purge	1 scfm with 3,200 psid	--	Sintered
85	O_2-H_2 burner GH2 balance, injector No. 1	0.525 in. dia	--	--
86	O_2-H_2 burner GH2 balance, injector No. 2	0.525 in. dia	--	--
90	O_2-H_2 burner LH2 tank pressurization coil outlet	0.221 in. dia	--	0.0342

*Indicates location in figures 3-1 and 3-2.

**Not recorded during calibration.

***Discharge coefficient and effective area are calculated for overcontrol and step orifices in combination with the undercontrol orifice.

TABLE 3-2 (Sheet 3 of 4)

S-IVB-506N STAGE AND GSE ACCEPTANCE FIRING ORIFICES

FIND NO.*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
91	LOX tank vent and relief valve purge	65 scfm with 3,200 psid	--	Sintered
95	O_2-H_2 burner LH2 tank pressurization coil helium inlet balance	0.120 in. dia	0.88	0.00993
96	O_2-H_2 burner LOX tank pressurization coil outlet	0.089 in. dia	0.895	0.00565
119	LOX tank ambient repressurization module outlet	0.1114 in. dia	--	0.00855
120	Engine purge control module	6 scfm	--	0.00028
	Console A			
--	All console A stage bleeds	Variable	--	--
A9515	Pressure actuated valve and mainstage pressure switch supply	1.2 scfm	--	Sintered
A9526	J-box inerting supply	0.013 in. dia	--	--
A9533	LH2 system checkout supply	1.2 scfm	--	Sintered
A9534	LOX system checkout supply	2.0 scfm	--	Sintered
A9535	LH2 tank and umbilical purge supply	0.260 in. dia	0.87	0.0466
A9536	Pressure switch checkout--Low pressure	1.2 scfm	--	Sintered
A9537	Pressure switch checkout--High pressure	0.044 in. dia	0.88	0.00134

*Indicates location in figures 3-1 and 3-2.

TABLE 3-2 (Sheet 4 of 4)

S-IVB-506N STAGE AND GSE ACCEPTANCE FIRING ORIFICES

FIND NO.*	DESCRIPTION	ORIFICE SIZE OR NOMINAL FLOWRATE	COEFFICIENT OF DISCHARGE	EFFECTIVE AREA (in.^{2})
A9538	LH2 tank repressurization supply	Union	--	--
A9539	Console GN2 inerting supply	0.013 in. dia	--	--
	Console B			
--	All console B stage bleeds	Variable	--	--
--	LOX tank repressurization supply	0.114 in. dia	0.88	0.00898
--	Turbine start sphere supply	Union	--	--
--	LOX tank prepressurization supply	0.096 in. dia	0.94	0.00680
A9348	Console GN2 inerting supply	Variable	--	--
A9525	Engine control helium sphere supply	0.125 in. dia	0.82	0.0101
A9527	LH2 tank prepressurization supply	0.161 in. dia	0.95	0.01879
A9528	Thrust chamber jacket purge and chilldown supply	0.072 in. dia	0.88	0.00355
A9529	LOX tank and umbilical purge supply	0.305 in. dia	0.88	0.0642
A9540	J-box inerting supply	0.013 in. dia	--	
A9552	Turbine start sphere supply vent	0.081 in. dia	0.83	0.00479
OR396	LOX tank auxiliary pressure	0.251 in. dia	0.82	0.0406
OR396	LH2 tank auxiliary pressure	0.343 in. dia	0.88	0.0820

*Indicates location in figures 3-1 and 3-2.

TABLE 3-3
S-IVB-506N STAGE PRESSURE SWITCHES

FIND NO.	NAME	PART NO. AND SERIAL NO.	SPECIFICATIONS (psia)		PREFIRING (psia)	
			PICKUP	DROPOUT	PICKUP*	DROPOUT*
	LH2 TANK					
52	First burn flight control	1B52624-511 S/N 26	31 max	28 min	30.66	28.30
53	Second burn, ground fill and prepressurization	1B52624-511 S/N 27	31 max	28 min	30.49	28.25
	LOX TANK					
73	LOX flight control and ground fill	1B52624-515 S/N 48	41 max	38 min	40.43	39.05
	LOX PRESSURIZATION SYSTEM					
38	Cold helium regulator backup	1B52624-519 S/N 49	465^{+20}_{-15}	350^{+40}_{-15}	473.40	382.76
	PNEUMATIC POWER SYSTEM					
**	Control helium regulator backup	1B52624-517 S/N 25	600 ±15	490 ±25	605.23	488.17
121	Engine pump purge	1B52623-515 S/N 21	130 max	105 min	119.27	109.25
	J-2 ENGINE SYSTEM					
**	Mainstage OK No. 1	308390 S/N 25541A	515 ±30	Deadband is 62.5 ±42.5	505.33	434.42
**	Mainstage OK No. 2	308390 S/N 25510A	515 ±30	Deadband is 62.5 ±42.5	515.10	440.51
	O_2-H_2 BURNER					
103	LOX tank repressurization	1B52624-519 S/N 53	465^{+20}_{-15}	350^{+40}_{-15}	471.34	372.40
99	LH2 tank repressurization	1B52624-519 S/N 57	465^{+20}_{-15}	350^{+40}_{-15}	466.67	377.05

*The values listed are the average of three actuations

**Part of module

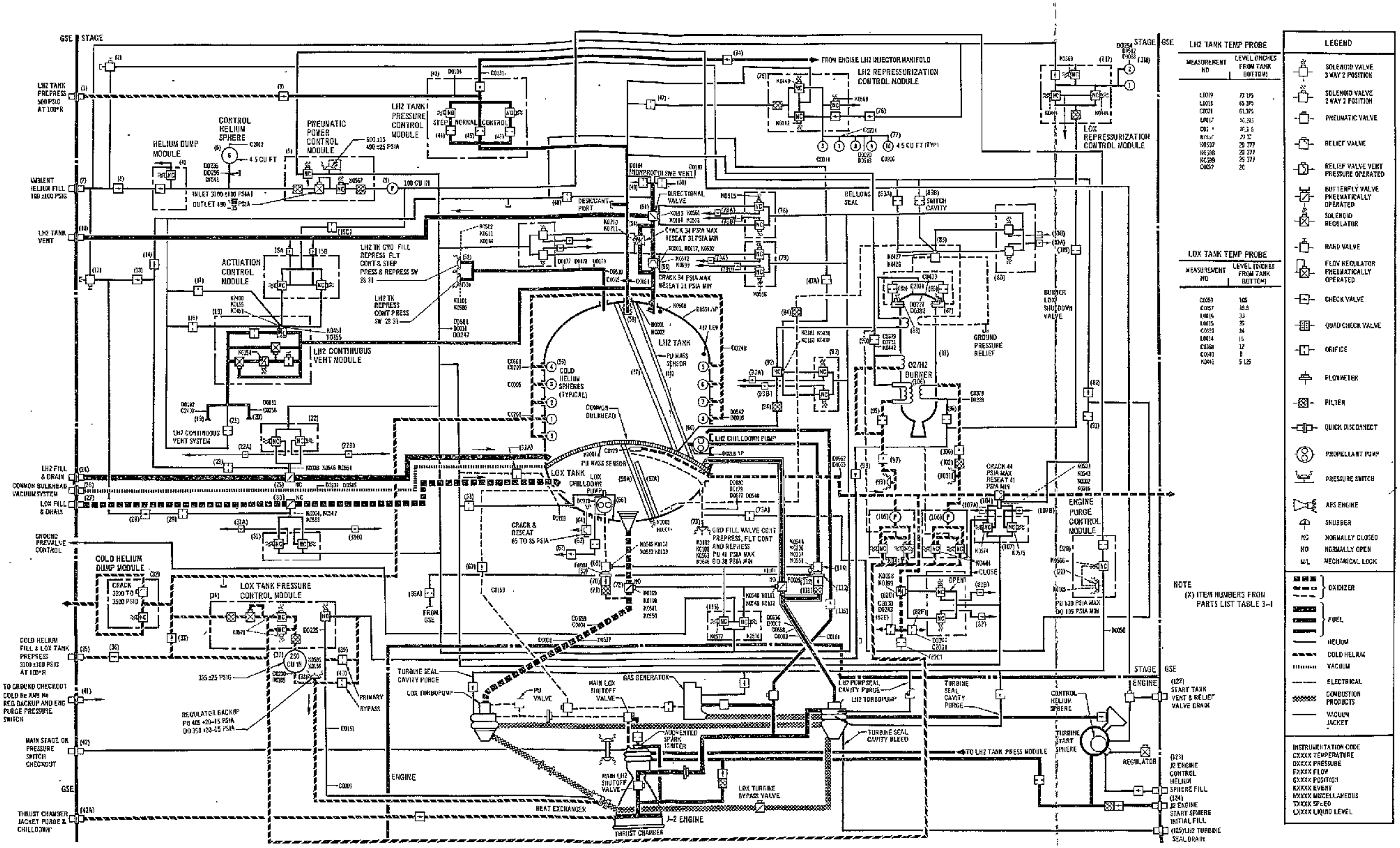

Figure 3-1. Propulsion System and Instrumentation

FOLDOUT FRAME

FOLDOUT FRAME 2

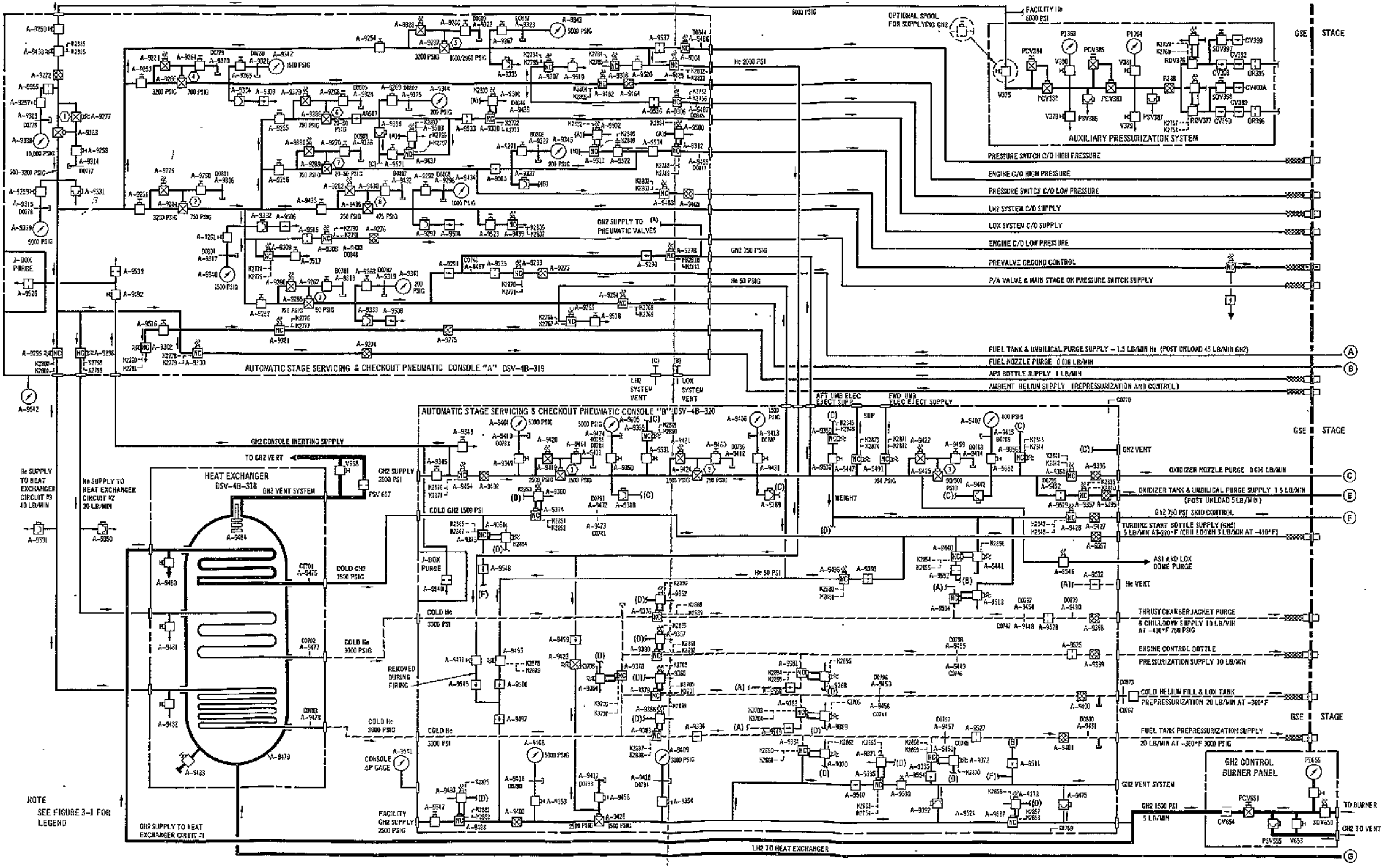

Figure 3-2. Facility Propellant and Pneumatic Loading Systems (Sheet 1 of 2)

FOLDOUT FRAME /

FOLDOUT FRAME 2

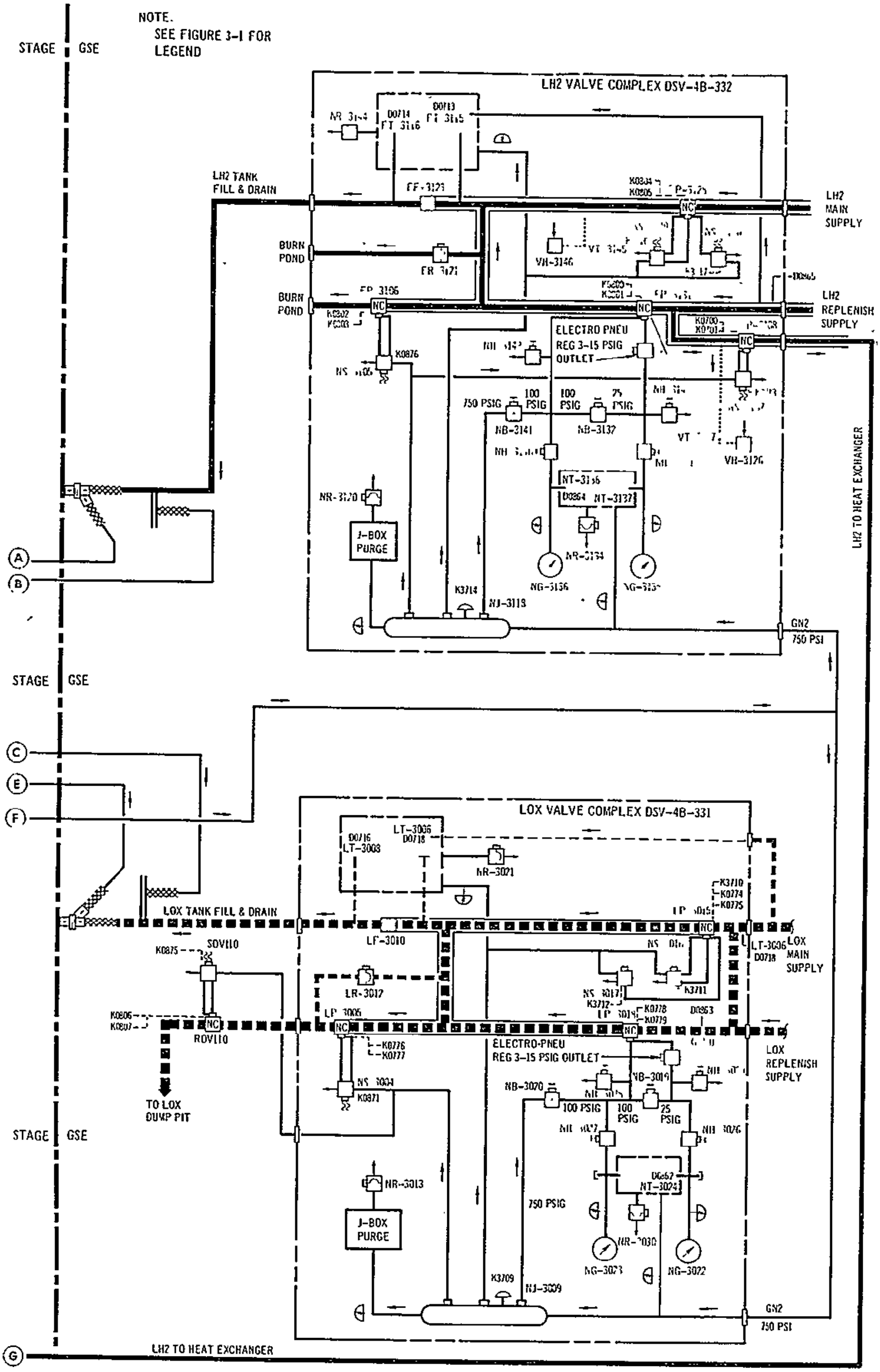

Figure 3-2. Facility Propellant and Pneumatic Loading Systems (Sheet 2 of 2)

SECTION 4

COUNTDOWN OPERATIONS

4. COUNTDOWN OPERATIONS

The S-IVB-506N stage was the sixth of the basic S-IVB/V series to be successfully acceptance fired and the third with an operational telemetry system. The acceptance firing was preceded by two O_2-H_2 burner firings and an ambient repressurization test. Details of the countdown and checkout (precountdown) activities are presented in the following paragraphs.

4.1 Countdown 614108

A propellant loading test was conducted on 11 July 1968 in accordance with drawing 1B71775, Test Plan, Acceptance Firing, S-IVB/V-STC, S.E.O. 004, and Test Request 1316. The test was performed to provide crew training and to demonstrate that the stage and facility can safely load and unload propellants.

Detailed discussions of the propellant loading test are presented in Douglas report No. DAC-61229, S-IVB-506N Stage Acceptance Firing 15-Day Report Sacramento Test Center.

4.2 Countdown 614109

Countdown 614109 was a full duration J-2 engine firing initiated on 16 July and terminated on 17 July 1968. The countdown proceeded normally with only two problems encountered - one during propellant loading and the other during O_2-H_2 burner firing preparations.

Except for the deviations necessitated by a single J-2 engine burn and performance of the O_2-H_2 burner firings and the ambient repressurization test, the countdown conformed to the sequence intended for use at Kennedy Space Center. Significant events during these operations are presented in tables 4-1, 4-2, and 4-3. The propulsion operations were performed in the following sequence:

a. Propellants were loaded to the 68 percent level

b. A cold helium system leak test was performed

c. LOX and LH2 tanks were pressurized to relief settings

d. Continuous vent valve was functionally tested.

e. Two O_2-H_2 burner firings were performed.

f. The ambient repressurization system was functionally tested.

g. The LOX and LH2 tanks were reloaded to the 100 percent level.

h. The terminal countdown and J-2 firing were performed.

i. Cold helium system leak test was performed.

The tank vent relief tests were accomplished during the propellant loading test and were not repeated during the acceptance firing countdown. The pressures at which the vent and relief valves vented were as follows:

Valve	Pressure (psia)		
LOX	43.1	43.0	43.0
LH2	32.4	32.9	32.8

The first firing of the restartable O_2-H_2 burner started at 1431 PDT and proceeded normally through burner shutdown. The planned quick turnaround into a second burner firing was delayed by the slow cooling of the burner interior; however, this was determined to be normal for the configuration used during this test. The burner dome purge reduced the temperature, the countdown was recycled, and the second burner firing proceeded as programmed.

4.2.1 Cryogenic Loading

Setups for LOX loading began on 17 July, and both tanks were loaded to the 68 percent level. The on-stand inspection revealed no problems except a leak in the facility cold helium system at the swing arm helium supply pressure transducer port (D0873). The leak was not immediately repairable, and the countdown was continued.

After the burner and ambient repressurization tests were accomplished, the tanks were reloaded to the 100.5 percent levels. The propellant utilization probe immersion test was accomplished during the propellant loading test and was deleted from the acceptance firing requirements.

4.2.2 Terminal Countdown

The terminal countdown was initiated at 1754 PDT (T -20:30 min). The count proceeded smoothly through the J-2 engine firing of 448.092 sec; cutoff was initiated by the PU processor due to LOX depletion. The PU ratio valve cutback occurred at ESC +179 sec.

4.3 Checkout

After the S-IVB-506N stage was assembled at the McDonnell Douglas Astronautics Company in Huntington Beach, it was subjected to a complete production checkout. It was shipped to the Sacramento Test Center (STC) on 23 January 1968 and was installed on the Complex Beta Test Stand III on 26 January 1968. An extensive modification program was begun in February and completed in May. Two of the more significant modifications were the installation of the LOX nonpropulsive vent and the O_2-H_2 restartable burner systems.

Stage power turn-on and prefire checkout were started in March and completed 22 June. The "ready to acceptance fire" milestone was met on 9 July. A propellant loading test was conducted on 11 July to prove the operational compatibility of the stage mated to the rebuilt Beta III test stand and to provide training for countdown personnel. The handling and checkout procedures that were used for the prefiring and postfiring checkouts are described in report DAC-56622: Narrative End Item Report - Saturn S-IVB-506N, dated February 1968.

4.4 Countdown Problems

Two problems occurred during the countdown and a suspected leak was investigated:

a. The O_2-H_2 burner preparations proceeded smoothly until the control helium regulator discharge pressure (measurement D0581), exceeded the upper redline limit, causing the countdown to be stopped and recycled. The regulator was stabilized in the normal operating range and operated within limits for the remainder of the countdown.

b. The on-stand inspection during the propellant loading operations revealed a leak in the facility cold helium system at the swing arm helium supply pressure transducer port D0873. The leak was not immediately repairable, and the countdown was continued.

c. An additional on-stand inspection was performed in order to locate a suspected GH2 leak that had been indicated in the area of the LH2 low pressure feed during chilldown pump operation. The leak could not be found, and the countdown proceeded.

4.5 Atmospheric Conditions

The following atmospheric conditions prevailed during the countdown:

Time (PDT)	1200	1400	1600	1800
Wind speed (knots)	4	5	6	6
Wind direction (deg)	340	310	310	300
Barometric pressure (in. Hg)	29.900	29.987	29.983	29.981
Ambient temperature (deg F)	85	90	94	95
Dew point (deg F)	53	54	49	44

TABLE 4-1 (Sheet 1 of 2)
O_2-H_2 BURNER SEQUENCE

TIME (sec)	MEAS	EVENT
-8.483	K0532	LH2 tank vent valve closed
0		Start first burner operation ignition sequence (14:33:07 PDT)
0.429	K0431	O_2-H_2 LH2 propellant valve open
1.207	K0427	O_2-H_2 LOX propellant valve open
1.366	K0699	LH2 tank vent relief overboard valve closed
1.400	K2400	LH2 tank vent orifice bypass valve closed
3.411	K0452	LH2 tank vent orifice and relief reset
4.576	K0437	O_2-H_2 burner system relay reset
7.156	K0438	O_2-H_2 voting circuit enabled
7.272	K0443	LH2 tank repressurization valve energized
7.486	K0444	LOX tank repressurization valve energized
7.894	K0429	APS 70 lbf ullage engine relay reset
154.643	K0443	LH2 tank repressurization valve closed
154.644	K0616	LH2 tank overpressurization pressure switch energized
178.845	K0445	Hydraulic pump coast relay reset
178.845	K0513	Hydraulic auxiliary pump on energized
208.105	K0444	LOX tank repressurization valve closed
208.306	K0519	LOX chilldown pump/inverter energized
213.364	K0512	LH2 chilldown pump/inverter energized
218.557	K0576	LH2 and LOX prevalve closed - energized
233.139	K5814	LOX tank vent boiloff closed
340.8 387.1	K0532	LH2 tank vent feathering
409.135	K0524	LH2 tank flight pressure valve energized
409.135	K0523	LH2 tank step pressurization valve energized
455.956	K0432	LH2 propellant valve closed
456.098	K0441	LH2 and LOX repressurization system reset

TABLE 4-1 (Sheet 2 of 2)
O_2-H_2 BURNER SEQUENCE

TIME (sec)	MEAS	EVENT
456.101	K0438	O_2-H_2 voting circuit disabled
456.341	K0452	LH2 tank vent orifice and relief reset off
456.757	K0440	LH2 and LOX repressurization mode - ambient
460.572	K0428	O_2-H_2 LOX propellant valve closed
463.608	K0437	O_2-H_2 burner system relay reset
519.387	K0544	LH2 childown shutoff valve open
520.752	K0540	LH2 prevalve open
521.139	K0541	LOX prevalve open
528.569	K0641	LH2 chilldown pump relay reset
528.779	K0644	LOX chilldown pump relay reset
530.136	K0621	Hydraulic auxiliary pump flight relay reset
1483.450*	K0532	LH2 tank vent valve closed
1491.000	--	Start second burner operation ignition sequence
1491.468	K0431	LH2 propellant valve open
1492.209	K0427	LOX propellant valve open
1498.198	K0438	O_2-H_2 voting circuit enabled
1622.083	K0432	LH2 propellant valve closed
1626.616	K0438	LOX propellant valve closed

*Start of second burner operation sequence

TABLE 4-2
AMBIENT REPRESSURIZATION SEQUENCE

TIME (sec)	MEAS	EVENT
-121.189	K0543	LOX tank vent valve closed
0	K0444	LOX tank repressurization valve open (Start of ambient repressurization--1502:24 PDT)
4.543	K0699	LH2 tank vent relief overboard valve closed
4.576	K2400	LH2 tank vent orifice bypass closed
20.000	K0443	LH2 tank repressurization valve open
60.600	K0443	LH2 tank repressurization valve closed
60.600	K0523	LH2 tank step pressurization valve open
60.601	K0616	LH2 tank over-pressure pressure switch energized
118.59	K0444	LOX tank repressurization valve closed
118.60	K0563	LOX tank over-pressure pressure switch energized
158.660	K0516	LH2 tank vent valve open
162.527	K0523	LH2 tank step pressurization valve closed
177.935	K2424	LOX tank vent and NPV latch reset
180.108	K0466	LOX tank NPV valve open

TABLE 4-3 (Sheet 1 of 4)
ACCEPTANCE FIRING SEQUENCE

TIME (sec)	MEAS	EVENT
-874.254	K2881	Engine start tank purge supply
-870.657	K2853	Start engine start tank fill
-408.537	K2888	Start engine thrust chamber purge
-326.600	K2852	End engine start tank fill
-326.480	K2855	Engine start tank vent open
-299.690	K2892	Start engine control bottle fill
-299.439	K0512	LH2 chilldown pump on
-289.411	K0519	LOX chilldown pump on
-284.343	K0576	LOX and LH2 prevalve closed command
-284.222	K0540	LH2 prevalve open position drop-out
-284.201	K0541	LOX prevalve open position drop-out
-283.933	K0549	LH2 prevalve closed position pick-up
-283.857	K0550	LOX prevalve closed position pick-up
-208.850	K2424	LOX NPV latched
-165.989	K0533	LOX vent valve closed
-164.378	K0571	Start LOX tank prepress
-153.912	K0571	End LOX tank prepress
-146.112	K0571	Start LOX tank prepress
-145.276	K0571	End LOX tank prepress
-96.083	K0532	LH2 tank vent valve closed
-94.659	K2897	Start LH2 tank prepress
-44.186	K2897	End LH2 tank prepress
-8.535	K3705	Cold helium supply vent opened
-8.477	K2870	LH2 tank prepressurization supply vent open
0		Simulated Liftoff (18.14:40.000 PST)
12.696	K5815	LOX tank boiloff vent valve open
20.046	K5814	LOX tank boiloff vent valve closed
23.335	K5815	LOX tank boiloff vent valve opened
37.152	K5814	LOX tank boiloff vent valve closed
68.402	K0532	LH2 tank vent valve opened
68.403	K0532	LH2 tank vent valve closed

TABLE 4-3 (Sheet 2 of 4)
ACCEPTANCE FIRING SEQUENCE

TIME (sec)	MEAS	EVENT
68.404	K0532	LH2 tank vent valve open
68.419	K0532	LH2 tank vent valve closed
68.420	K0532	LH2 tank vent valve open
70.696	K0532	LH2 tank vent valve closed
212.765	K0563	LOX tank minimum pressure indicated
212.772	K0571	Cold helium shutoff valves opened
213.789	K0563	LOX tank maximum pressure indicated
213.795	K0571	Cold helium shutoff valves closed
216.582	K5815	LOX tank boiloff vent valve opened
220.674	K5814	LOX tank boiloff vent valve closed
346.411	K0563	LOX tank minimum pressure indicated
346.418	K0571	Cold helium shutoff valves opened
347.463	K0563	LOX tank maximum pressure indicated
347.469	K0571	Cold helium shutoff valves closed
376.934	K5815	LOX tank boiloff vent valve opened
377.964	K5814	LOX tank boiloff vent valve closed
488.474	K2889	Engine thrust chamber chilldown terminated
507.378	K0576	LH2 and LOX prevalve open command
508.077	K0549	LH2 prevalve closed position drop-out
508.583	K0550	LOX prevalve closed position drop-out
508.997	K0571	Open cold helium shutoff valves
509.659	K0540	LH2 prevalve open pick-up
510.160	K0541	LOX prevalve open pick-up
510.653	K0519	LOX chilldown pump off
510.741	K0512	LH2 chilldown pump off
511.229	K0533	LOX tank vent valve opened
511.378	K0556	Engine start command
511.380	K0531	Engine control helium valve opened
511.419	K0627	LOX ASI valve opened
511.434	K0557	LH2 bleed valve closed
511.435	K0632	Main LH2 valve start to open

TABLE 4-3 (Sheet 3 of 4)
ACCEPTANCE FIRING SEQUENCE

TIME (sec)	MEAS	EVENT
511.448	K0558	LOX bleed valve closed
511.480	K0458	Main LH2 valve opened
512.469	K0536	Start tank discharge valve open command
512.631	K0695	Start tank discharge valve starts to open
512.687	K0460	Start tank discharge valve open
512.923	K0536	Start tank discharge valve close command
513.012	K0633	MOV starts to open
513.015	K0631	GG valve starts to open
513.063	K0460	Start tank valve starts to close
513.134	K0457	GG valve open
513.256	K0695	Start tank valve closed
514.860	K0524	LH2 tank flight pressure valve closed command
514.361	K0523	LH2 tank step press valve close command
514.580 515.055	K0533	LOX vent valve relieving
515.059	K0459	MOV open
515.068 515.103	K0533	LOX vent valve relieving
515.169	K0532	LH2 tank vent valve closed position drop-out
526.275	K0532	LH2 tank vent valve closed position pick-up
526.280 531.342	K0532	LH2 5ank vent valve relieving
532.383	K2432	J-2 heat exchanger bypass valve open disabled
538.438	K0563	J-2 heat exchanger bypass valve opened
551.052	K0563	Heat exchanger bypass valve closed
557.111	K0563	Heat exchanger bypass valve opened
567.486	K0563	Heat exchanger bypass valve closed
576.721	K0563	Heat exchanger bypass valve opened
586.335	K0563	Heat exchanger bypass valve closed
599.205	K0563	Heat exchanger bypass valve opened
609.326	K0563	Heat exchanger bypass valve closed

TABLE 4-3 (Sheet 4 of 4)
ACCEPTANCE FIRING SEQUENCE

TIME (sec)	MEAS	EVENT
627.218	K0563	Heat exchanger bypass valve opened
638.131	K0563	Heat exchanger bypass valve closed
663.146	K0563	Heat exchanger bypass valve opened
675.691	K0563	Heat exchanger bypass valve closed
708.614	K0563	Heat exchanger bypass valve opened
711.543	K0524	LH2 tank flight pressurization valve opened
711.543	K0523	LH2 tank step pressurization valve opened
711.636	K0524	LH2 tank flight pressurization valve closed
711.636	K0523	LH2 tank step pressurization valve closed
722.813	K0563	Heat exchanger bypass valve closed
921.526	K0524	LH2 tank flight pressurization valve opened
921.526	K0523	LH2 tank step pressurization valve opened
921.627	K0577	LH2 and LOX chilldown shutoff valve closed command
921.786	K0544	LH2 chilldown shutoff valve open drop-out
921.849	K0551	LH2 chilldown shutoff valve closed pick-up
921.852	K0545	LOX chilldown shutoff valve open drop-out
921.947	K0552	LOX chilldown shutoff valve closed pick-up
927.473	K0532	LH2 tank vent valve open position drop-out
959.470	K4796	Engine cutoff command

[redacted] SECTION 5 [redacted]

SEQUENCE OF EVENTS

5. SEQUENCE OF EVENTS

The S-IVB-506N acceptance firing sequence of events is presented in table 5-1. The two time bases used in this table are as follows:

First O_2-H_2 Burner Ignition Sequence	1433:07 hr PDT
Simulated Liftoff	1814:40 hr PDT

The data sources were the Digital Events Recorder (DER/CAT 57) and the PCM/FM Sequencer (CAT 42). Accuracies of the listed events are as follows:

Data Source	Accuracies
Digital Events Recorder (DER/CAT 57)	+0, -1 ms
PCM/FM Discrete Bi-Level (CAT 42)	+0, -9 ms

TABLE 5-1 (Sheet 1 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57) MEAS. NO.	DIGITAL EVENT RECORDER (CAT 57) TIME (sec)	PCM/FM SEQUENCE (CAT 42) MEAS. NO.	PCM/FM SEQUENCE (CAT 42) TIME (sec)
Launch Automatic Sequence Start (J-2 Eng. Firing Phase)					
Engine Cutoff On	12	K3890	-478.479		
Aux. Hyd. Pump Flt. Mode On	28	K3890	-477.518		
Aux. Hyd. Pump Flt. Rel. Reset - Off		K0621	-477.514		
Aux. Hyd. Pump Power On		K0513	-477.419		
Aux. Hyd. Pump Coast Mode Off	31	K3890	-477.408		
Aux. Hyd. Pump Coast Relay Reset - On		K0445	-477.403		
Eng. St. Tk. Dump Close		K3885	-330.566		
LH_2 Chilldown Pump On	58	K3890	-299.448		
LH_2 C/D Pump Rel. Reset - Off		K0641	-299.441		
LH_2 C/D Pump Inverter On		K0512	-299.439		
LOX C/D Pump Inverter On		K0519	-289.411		
LOX C/D Pump Rel. Reset - Off		K0644	-289.412		
LOX Chilldown Pump On	22	K3890	-289.418		
LOX & LH_2 Prevalve Close Command - On		K0576	-284.343		
LH_2 Prevalve Open Indication - Off		K0540	-284.222	K0111	-284.154

TABLE 5-1 (Sheet 2 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Prevalve Open Indication - Off		K0541	-284.201	K0109	-284.154
LH_2 Prevalve Closed Indication - On		K0549	-283.933	K0112	-283.904
LOX Prevalve Closed Indication - On		K0550	-283.857	K0110	-283.737
LOX Tk Heat Exchanger Bypass Valve Disable	51	K3890	-209.018		
LOX Tk Heat Exchanger Bypass Disable		K2432	-209.009		
LOX Tk NPV Open Latch Off	45	K3890	-208.859		
LOX Tk Vent & NPV Latch Rst On		K2424	-208.850		
LOX Tank Vent Valve Open Command - Off		K0575	-166.437	——	
LOX Tank Vent Valve Closed Indication - On		K0533	-165.989	K0002	-165.967
Cold He Shutoff Valve Open Command		K3802	-164.383		
Cold He Shutoff Valve Open Indication		K0571	-164.376		
LOX Tk Overpres P/S Ener		K0563	-153.918		
He Cold Sol Vlv Opn De-Ener		K0571	-153.912		
LOX Tk Overpres P/S De-Ener		K0563	-146.119		
He Cold Sol Vlv Opn Ener		K0571	-146.112		

TABLE 5-1 (Sheet 3 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Tk Overpres P/S Ener		K0563	-145.282		
He Cold Sol Vlv Opn De-Ener		K0571	-145.276		
LH_2 Tank Vent Valve Close Command - On		K0516	-96.803		
LH_2 Tank Vent Valve Closed Indication - On		K0532	-96.083	K0001	-96.047
LOX Tank Fill & Drain Bst Close - On		K3845	-84.965		
LOX Tank Fill & Drain Open - Off		K0547	-84.391		
LOX Tank Fill & Drain Closed Indication - On		K0553	-83.903	K0004	-83.878
LOX Tank Fill & Drain Bst Close - Off		K3845	-82.908		
LH_2 Tank Fill & Drain Bst Close - On		K3831	-82.871		
LH_2 Tank Fill & Drain Open - Off		K0546	-82.177		
LH_2 Tank Fill & Drain Closed Indication - On		K0554	-81.461	K0003	-81.461
LH_2 Tank Fill & Drain Bst Close - Off		K3831	-80.775		
Aft Bus 1 Transfer Internal Indication		K0622	-49.881		
Aft Bus 2 Transfer Internal Indication		K0623	-49.618		

TABLE 5-1 (Sheet 4 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Fwd Bus Transfer Internal		K0639	-49.369		
LH_2 Tank Vent Dir. Gnd. Position Off		K0561	-26.312	K0113	-26.276
LH_2 Tank Vent Dir. Flight Position On		K0562	-26.152	K0114	-26.110
R/S 1 PD Cmd Inhibit Off Indication		K0662	-8.448		
R/S 2 PD Cmd Inhibit Off Indication		K0661	-8.416		
Simulated Liftoff (T_0)*			000.000		
T/M Cal Relays On	62	K3890	116.668		
T/M Cal Relays Off	63	K3890	117.783		
Eng Pump Prg Cont Valve Enable - On	24	K3890	330.508		
Eng Pump Prg Sol Valve Energized		K0566	330.522		
Eng Cutoff Arm - Observer		K5811	333.538		
Eng Pump Prg Cont Valve Enable - Off	25	K3890	450.635		
Eng Pump Prg Sol Valve De-energized		K0566	450.648		
T/M Cal Relays On	62	K3890	451.802		
T/M Cal Relays Off	63	K3890	452.916		
Charge Ullage Ingition On	54	K3890	507.212		

*T_0 = 1814:40.000 PDT

TABLE 5-1 (Sheet 5 of 18)
SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Ullage Rkt. Pilot Relays Rst Off		K0673	507.219		
LH_2 & LOX Prevalve Open Command - On		K0576	507.378		
LH_2 Prevalve Closed Indication - Off		K0549	508.077	K0112	508.146
LOX Prevalve Closed Indication - Off		K0550	508.583	K0110	508.646
LOX Flt Press. On	103	K3890	508.984		
LH_2 Prevalve Open Indication - On		K0540	509.659	K0111	509.730
LOX Prevalve Open Indication - On		K0541	510.160	K0109	510.230
LOX Chilldown Pump Off	23	K3890	510.646		
LOX C/D Pump Inverter Off Indication		K0519	510.653		
LOX C/D Pump Rel. Reset Indication		K0644	510.654		
LH_2 C/D Pump Off	59	K3890	510.735		
LH_2 C/D Pump Inverter Off Indication		K0512	510.741		
LH_2 C/D Pump Rel. Reset Indication		K0641	510.743		
Engine Cutoff Off	13	K3890	510.891		
Engine Cutoff Ind - Sw. Sel. Reset		K0418	510.897	K0140	510.956
Engine Cutoff Indicator - De-energized		K0522	510.901		

TABLE 5-1 (Sheet 6 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Fire Ullage Ign. On	56	K3890	511.039		
Ullage Rkt. Ign. P.S. 1 Indication				K0176	511.080
Ullage Rkt. Ign. P.S. 2 Indication				K0177	511.080
Engine Start On	9	K3890	511.375		
Engine Start Comm. Rel. Rst.		K0634	511.378		
Engine Start Comm. On		K0556	511.378	K0021	511.379
Eng. Ign. Ph. Cont. Sol. Ener.		K0535	511.380	K0006	511.387
Eng. Cont. He. Sol. Valve Ener.		K0531	511.380	K0007	511.387
Eng. Spark T/C Sys. On		K0454	511.381	K0010	511.387
Eng. Spark GG Sys. On		K0455	511.381	K0011	511.387
Eng. Ready Sig. Off		K0530	511.384	K0012	511.405
Eng. ASI LOX Valve Open		K0627	511.419		
Eng. LH_2 Bld Valve Cls - On		K0557	511.434		
Eng. Main LH_2 Vlv Cls - Off		K0632	511.435		
Eng. LOX Bld Vlv Cls - On		K0558	511.448		
Eng. Main LH_2 Vlv Open - On		K0458	511.480	K0118	511.489
Eng. Ign. Detected		K0537	511.558	K0008	511.562

TABLE 5-1 (Sheet 7 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Fuel Inj. Temp. OK Bypass On	11	K3890	512.460		
Fuel Inj. Temp. OK Bypass Reset		K0446	512.467		
Engine Start Tk. Disch. Sol. Ener.		K0536	512.469	K0096	512.470
Engine Start Off	27	K3890	512.668		
Engine Start Comm. Rel. Rst		K0634	512.672		
Engine Start Comm Off		K0556	512.673	K0021	511.737
Eng. St. Tk. Disch. Vlv. Cls - On		K0460	512.687	K0122	512.739
Eng. St. Tk. Disch. Sol. Ener - Off		K0536	512.923	K0096	512.929
Eng. M/S Cont. Sol. Ener. - On		K0538	512.923	K0005	512.920
Engine Ign Detected		K0537	512.952		
Eng. Main LOX Vlv. Cls - Off		K0633	513.012		
Eng. GG Vlv. Cls. - Off		K0631	513.015		
Eng. St. Tk Disch. Vlv. Opn - Off		K0460	513.063	K0122	513.072
Eng. GG Vlv Opn - On		K0457	513.134	K0117	513.155
Eng. LOX Turb Byp Vlv Open - Off		K0461	513.172	K0124	513.247
Eng. St. Tk. Disch. Vlv Cls - On		K0695	513.256		

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TABLE 5-1 (Sheet 8 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng. LOX Turb Byp Vlv Closed - On		K0463	513.367	K0125	513.414
First Burn Relay On	68	K3890	514.352		
First Burn Press Cont Vlv Sol. Ener.		K0524	514.360		
First Burn Step Press Cont Vlv Ener.		K0523	514.361		
Eng. M/S OK Press Sw		K0610	514.444		
Eng. M/S OK P/S-2 Pressurized		K0573	514.444	K0159	514.514
Eng. M/S OK P/S-2 Pressurized				K0157	514.514
Eng. M/S OK Press Sw. Pick-up (No)		K0685	514.446		
Eng. M/S OK Press Sw. Pick-up (No)		K0412	514.446		
Eng. M/S OK P/S-1 Pressurized		K0572	514.470	K0158	514.514
Eng. M/S OK P/S-1 Pressurized				K0014	514.472
Eng. Main LOX Vlv Open		K0459	515.059	K0120	515.072
Eng. Spark T/C Sys - Off		K0454	516.216	K0010	516.221
Eng. Spark GG Sys - Off		K0455	516.216	K0011	516.221
PU Activate On	5	K3890	517.523		
PU Activated		K0507	517.527		

TABLE 5-1 (Sheet 9 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Chg Ullage Jett. On	55	K3890	518.969		
Fire Ullage Jett. On	57	K3890	521.510		
EBW Fire 1 P.S.				K0149	521.590
EBW Fire 2 P.S.				K0150	521.590
Fuel Inj Temp OK Bypass - Off	16	K3890	522.723		
Engine LH_2 Inj Temp Byp Rst		K0446	522.730		
Ullage Chg Reset	88	K3890	524.868		
Ullage Fire Reset	73	K3890	525.079		
U.R. Pilot Relays Rst		K0673	525.087		
LOX Tnk Ht Exch Bypass - Enable	50	K3890	532.376		
R/S Tone 2 EBW Arm & ECO		K5758	535.829		
R/S 2 Arm & ECO Comm Rcvd		K0659	535.935		
R/S 2 PD EBW F.U. Pwr On		K0651	535.937		
R/S 1 Arm & ECO Comm Rcvd		K0660	535.939		
R/S 2 EBW Arm & ECO On		K0692	535.940		
R/S 1 PD EBW F.U. Pwr On		K0650	535.942		
R/S 1 EBW Arm & ECO On		K0693	535.947		
R/S 1 Arm & ECO Cmd Rcvd Off		K0660	535.965		
R/S 2 Arm & ECO Cmd Rcvd off		K0659	535.967		

TABLE 5-1 (Sheet 10 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
R/S Tone 2 EBW Arm & ECO Off		K5758	536.076		
R/S Tone 1 PD Cmd On		K5757	539.187		
R/S 2 PD Cmd Rcvd On		K2405	539.294	K0142	539.334
R/S 1 PD Cmd Rcvd On		K2404	539.299	K0141	539.334
R/S 1 PD Cmd Rcvd Off		K2404	539.324		
R/S 2 PD Cmd Rcvd Off		K2405	539.326		
R/S Tone 1 PD Cmd Off		K5757	539.443		
R/S Tone 6 Sys Off Cmd - On		K5759	542.529		
R/S 2 Sys Off Cmd Rcvd - On		K0679	542.637		
R/S 2 Sys Off Cmd Rcvd - Off		K0679	542.638		
R/S 2 PD EBW FU Pwr Off		K0651	542.638		
R/S 2 Rcvr Pwr Off		K0678	542.638		
R/S 1 Sys Off Cmd Rcvd - On		K0681	542.641		
R/S 1 Sys Off Cmd Rcvd Off		K0681	542.643		
R/S 1 PD EBW F.U. Pwr Off		K0650	542.643		
R/S 1 Rcvr Pwr Off		K0680	542.643		
R/S Tone 6 Sys Off Cmd - Off		K5759	542.777		

TABLE 5-1 (Sheet 11 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aux Hyd Pmp Flt Mode Off	29	K3890	655.986		
Aux Hyd Pmp Flt Rel Rst - Off		K0621	655.990		
Aux Hyd Pmp On Ener - Off		K0513	656.240		
Aux Hyd Pmp Flt Mode On	28	K3890	705.927		
Aux Hyd Pmp Flt Rel. Reset - Off		K0621	705.930		
Aux Hyd Pmp Power On		K0513	706.028		
First Burn Relay Off	69	K3890	711.537		
Fuel Tank Step Press Cont. Vlv. Sol. De-ener.		K0523	711.543		
Fuel Tank Press Cont Vlv. Sol. De-ener.		K0524	711.543		
Second Burn Relay On	32	K3890	711.627		
Fuel Tk Press Cont. Vlv. Sol. Ener.		K0524	711.636		
LH_2 Tk Step Pres Vlv Ener		K0523	711.636		
Second Burn Relay Off	33	K3890	921.520		
Fuel Tk. Press Cont. Vlv. Sol. De-ener.		K0524	921.526		
LH_2 Tk Step Pres Vlv Ener		K0523	921.526		
LH_2 & LOX C/D Shutoff Close Ener - On		K0577	921.627		
LH_2 C/D Shutoff Valve Open - Off		K0544	921.786	K0137	921.849

TABLE 5-1 (Sheet 12 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 C/D Shutoff Valve Closed - On		K0551	921.849	K0136	921.849
LOX C/D Shutoff Valve Open - Off		K0545	921.852	K0138	921.858
LOX C/D Shutoff Valve Closed - On		K0552	921.947	K0139	922.025
Point Level Sensor Arm On	97	K3890	950.235		
Eng Pump Purge Cont Vlv Enable On	24	K3890	950.336		
Eng Pump Prg Sol Vlv Ener - On		K0566	950.350	K0105	951.638
Eng Cutoff Lock-in Ind - On		K0539	959.471		
Eng. Ign Ph. Cont. Sol. Ener - Off		K0535	959.472	K0006	959.479
Eng Cutoff Ind - Veh Ener - On		K0522	959.474		
Eng. M/S Cont Sol Ener - Off		K0538	959.475	K0005	959.479
Eng. Cutoff Ind - Non Prog - On		K0419	959.475		
Engine Cutoff Signal				K0013	959.480
O_2H_2 Burner Sys Rel Rst		K0437	959.479		
Eng GG Vlv Open - Off		K0457	959.508	K0117	959.564
Eng Main LOX Vlv Open - Off		K0459	959.565	K0120	959.647

TABLE 5-1 (Sheet 13 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng GG Vlv Cls - On		K0631	959.578		
Eng Main LH_2 Vlv Open - Off		K0458	959.608	K0118	959.647
Eng M/S OK P/S-2 Depressurized		K0573	959.658	K0159	959.672
Eng M/S OK P/S-1 Depressurized		K0572	959.659	K0158	959.672
Eng M/S OK Press Sw. No. 1 - Off		K0610	959.661		
Eng Thrust OK 2		K0412	959.662		
Eng Thrust OK 1		K0685	959.663		
Eng Main LOX Vlv Cls - On		K0633	959.674		
Eng Pmp Prg Cont Vlv Enable - On	24	K3890	959.699		
Eng LOX Turb Byp Vlv Cls - Off		K0463	959.739	K0125	959.822
Eng Main LH_2 Vlv Cls - On		K0632	959.801		
Fwd Bus Transfer External Indication		K0639	959.805		
Aft Bus 1 Transfer External Indication		K0622	959.951		
Aft Bus 2 Transfer External Indication		K0623	960.130		
Eng LOX Turb Byp Vlv Opn		K0461	960.149		
Eng Cont He Sol Vlv Ener - Off		K0531	960.463	K0007	960.462

TABLE 5-1 (Sheet 14 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Cutoff Lock-in Ind - Off		K0539	960.464		
Eng Ready Sig On		K0530	960.468		
LH_2 & LOX Repress Vlvs Enab		K0439	960.756		
LH_2 & LOX Prevalve Closed Command - On		K0576	960.778		
LH_2 Prevlv Open Indication - Off		K0540	960.900	K0111	960.972
LOX Prevlv Open Indication - Off		K0541	960.924	K0109	960.972
LH_2 Prevlv Cls - On		K0549	961.209	K0112	961.222
LOX Prevalve Close - On		K0550	961.284	K0110	961.389
Engine Start Off	27	K3890	961:413		
He Cold Sov Cls - On		K3802	961.485		
He Cold Sov Opn - Ener - Off		K0571	961.490		
Engine Cutoff On	12	K3890	961.537		
Engine Cutoff Ind - Sw Sel		K0418	961.541		
Coast Period On	79	K3890	961.640		
First Burn Relay Off	69	K3890	961.730		
Second Burn Relay Off	33	K3890	961.831		
LOX Tank Flight Press System - Off	104	K3890	961.921		

TABLE 5-1 (Sheet 15 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Chilldown Pmp Off	23	K3890	962.081		
LH_2 Chilldown Pmp Off	59	K3890	962.171		
Point Level Sensor Disarm	98	K3890	963.508		
Fuel Inj Temp OK Bypass Reset	16	K3890	964.750		
Chg Ullage Reset	88	K3890	965.174		
Fire Ullage Reset	73	K3890	965.280		
T/M Cal Relays Off	63	K3890	965.401		
LOX Tk Heat Exchanger Bypass Enab	50	K3890	965.666		
Eng Cont Btl Dmp Opn - On		K3817	965.746		
Eng Cutoff Arm - Observer - Off		K5811	965.827		
Eng Cutoff Cmd - Observer - Off		K2741	965.828		
PU Fuel Boiloff Bias Cutoff Off	34	K3890	965.943		
PU Boiloff Bias On		K0417	965.947		
LOX Tk Ht Exc Byp Dsbl	51	K3890	981.270		
PU Activate Off	6	K3890	981.403		
PU System Off		K0507	981.405		
Aux Hyd Pmp Flt Mode Off	29	K3890	981.525		
Aux Hyd Pmp Flt Rel Rst		K0621	981.529		

TABLE 5-1 (Sheet 16 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aux Hyd Pump Coast Mode On	30	K3890	981.642		
Aux Hyd Pmp Cst Rel Rst		K0445	981.645		
Aux Hyd Pmp On Ener		K0513	981.781		
LH_2 Tk Vnt Vlv Cls - On		K0532	999.010	K0001	999.554
LOX Tk Nonprop Vent Open - Off	106	K3890	1072.849		
LOX Tk Nonprop Vent Open - Off	106	K3890	1141.861		
PU Valve Hardover Position On	17	K3890	1178.742		
PU Valve Hardover Position Off	18	K3890	1180.867		
Eng Cutoff Cmd - C/T Pwr		K4796	1180.996		
Eng Cutoff Cmd - GSE Pwr		K4797	1181.022		
Eng Cutoff Off	13	K3890	1213.143	K0140	1213.157
Eng Cutoff Ind - Sw Sel - Off		K0418	1213.149		
Eng Cutoff Ind - Veh Ener - Off		K0522	1213.152		
LH_2 & LOX Prevalve Open Command On		K0576	1213.279		
LH_2 & LOX C/D Sov Clsd Ener - Off		K0577	1213.306		

TABLE 5-1 (Sheet 17 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Prevlv Cls - Off		K0549	1213.994	K0112	1214.015
LOX Prevlv Cls - Off		K0550	1214.372	K0110	1214.432
LH_2 C/D Sov Cls - Off		K0551	1214.529	K0136	1214.648
LOX C/D Sov Cls - Off		K0552	1214.664	K0139	1214.740
LOX C/D Sov Opn - On		K0545	1215.352	K0138	1215.490
LH_2 C/D Sov Opn - On		K0544	1215.433	K0137	
LH_2 Prevlv Opn Indication - On		K0540	1215.627	K0111	1215.682
LOX Prevlv Opn Indication - On		K0541	1215.903	K0109	1216.015
Coast Period Off	80	K3890	1226.661		
LH_2 Tk Vnt Dir Flt Pos - Off		K0562	1227.041		
LH_2 Tk Vnt Dir Gnd Pos - On		K0561	1227.106		
T/M Prelnch C/O Grp On Command		K0406	1291.417		
T/M Prelnch C/O Grp On Indication		K0408	1291.465		
T/M Prelnch C/O Grp On Comm - Off		K0406	1291.686		
He Htr LH_2 Prop Vlv Close	60	K3890	1295.597		
T/M Cal Relays Off	63	K3890	1296.711		
RACS Cal (Beginning)			1296.766		
RACS Cal (End)			1321.590		

TABLE 5-1 (Sheet 18 of 18)

SEQUENCE OF EVENTS (J-2 ENGINE)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57) MEAS. NO.	DIGITAL EVENT RECORDER (CAT 57) TIME (sec)	PCM/FM SEQUENCE (CAT 42) MEAS. NO.	PCM/FM SEQUENCE (CAT 42) TIME (sec)
T/M Cal Relays On	62	K3890	1372.031		
T/M Cal Relays Off	63	K3890	1373.162		
RACS Calibration (Beginning)		K4804	1373.233		
RACS Calibration (End)		K4802	1398.021		
PCM RF Assy Pwr Off	65	K3890	1461.529		
Eng M/S OK P/S-1 Depress				K0158	1455.089
Eng M/S OK P/S-2 Depress				K0159	1455.089
PU Inv. & Elect. Pwr Off	8	K3890	5167.048		

TABLE 5-2 (Sheet 1 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
O_2H_2 Burner Start (T_2)*					
T/M Cal Rel On	62	K3890	-558.171		
T/M Cal Rel Off	63	K3890	-557.058		
RACS Cal (End)		K4802	-532.221		
T/M Prelnch C/O Grp Off Command		K0403	-527.473		
T/M Prelnch C/O Grp On Ind - Off		K0408	-527.439		
T/M Prelnch C/O Grp Off Command - Reset		K0403	-523.553		
Aft Bus 1 Transfer Internal Indication		K0622	-523.513		
Aft Bus 2 Transfer Internal Indication		K0623	-523.258		
Fwd Bus Transfer Internal Indication		K0639	-523.008		
Stage Repress Sys Mode Sel. Off	37	K3890	-488.309		
O_2H_2 Burner Fuel Vlv & LOX Shutdown Vlv. Clsd Off	61	K3890	-488.211		
O_2H_2 Burner Voting Cir Enable On	85	K3890	-484.153		
Stage Repress Sys Mod Sel Off	37	K3890	-478.658	K0195	-478.588

*T_2 = 1433:07.00 PDT

TABLE 5-2 (Sheet 2 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
70 Lb Ullage Eng. No. 1 Off	43	K3890	-478.499		
70 Lb Ullage Eng. No. 2 Off	102	K3890	-478.407		
O_2H_2 Bnr Voting Cir Enab Off	86	K3890	-478.317		
O_2H_2 Bnr Fuel Vlv & LOX Shutdown Vlv Clsd Off	61	K3890	-478.159		
He Htr Prop Vlv Cls Off	75	K3890	-478.069		
Envrn Cont Grp On	44	K3890	-465.988		
70 Lb Ullage Eng No. 1 On	42	K3890	-69.459		
70 Lb Ullage Eng Rel Rst		K0429	-69.452		
70 Lb Ullage Eng No. 2 On	101	K3890	-69.360		
O_2H_2 Burner Fuel Vlv. & LOX Shutdown Valve Open - On	26	K3890	0.369		
O_2H_2 Burner System Rel Rst - Off		K0437	0.376		
O_2H_2 Burner LOX Shutdown Vlv Cls - Off		K0428	1.201		
O_2H_2 Burner LH_2 Prop. Vlv. Cls - Off		K0432	0.429	K0180	0.496

TABLE 5-2 (Sheet 3 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
O_2H_2 Burner LH_2 Prop Vlv Opn - On		K0431	0.456	K0181	0.496
O_2H_2 Burner Spark Exciters On	70	K3890	0.677		
O_2H_2 Burner LOX Prop Valve Open On	89	K3890	1.132		
O_2H_2 Burner LOX Shutdown Vlv Cls - Off		K0428	1.201		
O_2H_2 Burner LOX Shutdown Vlv Opn - On		K0427	1.207		
LH_2 Tank Continuous Vent Valve Closed On	84	K3890	1.344		
LH_2 Tank Continuous Vent Valve Relays Reset - Off		K0452	1.349		
LH_2 Tank Continuous Vent Relief Overrd Vlv Clsd - On		K0699	1.366	K0154	1.405
LH_2 Tank Continuous Vent Orf. Byp. Vlv. Open - Off		K0451	1.390		
LH_2 Tank Continuous Vent Orf. Byp. Vlv. Closed - On		K2400	1.400	K0155	1.421
O_2H_2 Burner Fuel Vlv. & LOX Shutdown Valve Open - Off	72	K3890	1.956		
O_2H_2 Burner LOX Prop Valve Open Off	90	K3890	2.674		
LH_2 Tank Continuous Vent Valve Close Off	87	K3890	3.402		

TABLE 5-2 (Sheet 4 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 Tank Continuous Vent Valve Relays Reset - On		K0452	3.411		
O_2H_2 Burner Spark Exciters Off	71	K3890	4.567		
O_2H_2 Burner Sys Rel Rst - On		K0437	4.576		
O_2H_2 Burner Voting Ckt Enable On	85	K3890	7.152		
LH_2 & LOX Repress Sys. Rst - Off		K0441	7.155		
He Htr Voting Ckt Enable On		K0438	7.156		
LH_2 Repress Valve On	39	K3890	7.264		
LH_2 Repress Valve Ener - On		K0443	7.272		
LOX Repress Cont Valve On	3	K3890	7.473		
LOX Tk Repress Valve Ener On		K0444	7.486		
70 Lb Ullage Eng No. 1 Off	43	K3890	7.788		
70 Lb Ullage Eng No. 2 Off	102	K3890	7.886		
APS 70 Lb. Ull Eng Rel Rst - Off		K0429	7.894		
LH_2 Tk Repress. Vlv. Ener - Off		K0443	154.643		

TABLE 5-2 (Sheet 5 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Repress Cont Vlv On	3	K3890	154.808		
Aux Hyd Pump Flt Mode On	28	K3890	178.750		
Aux Hyd Pump Flt Rel Rst		K0621	178.753		
Aux Hyd Pump Coast Mode Off	31	K3890	178.840		
Aux Hyd Pump Cst Rel Rst		K0445	178.845		
Aux Hyd Pump On - Ener		K0513	178.845		
LOX Repress Cont Vlv Off	4	K3890	208.093		
LOX Tk Repress Vlv Ener - Off		K0444	208.105		
LOX Chilldown Pump On	22	K3890	208.299		
LOX Chilldown Pump Rel Rst - Off		K0644	208.305		
LOX Chilldown Pump Inv On		K0519	208.306		
LH_2 Chilldown Pump On	58	K3890	213.356		
LH_2 Chilldown Pump Rel Rst - Off		K0641	213.362		
LH_2 Chilldown Pump Inv On		K0512	213.364		

TABLE 5-2 (Sheet 6 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LH_2 & LOX Prevlv Close Command - On		K0576	218.557		
LH_2 Prevlv Open Indication - Off		K0540	218.679	K0111	218.718
LOX Prevlv Open Indication - Off		K0541	218.703	K0109	218.718
LH_2 Prevlv Closed Indication - On		K0549	219.001	K0112	219.051
LOX Prevlv Closed Indication - On		K0550	219.086	K0110	219.134
Second Burn On	32	K3890	409.126		
LH_2 Tk Flt Press Vlv Ener		K0524	409.135	—	
LH_2 Tk Step Presvlv Ener		K0523	409.135		
PU Hardover Command On	17	K3890	409.224		
70 Lb Ull Eng No. 1 On	42	K3890	455.338		
70 Lb Ull Eng Rel Rst		K0429	455.345		
70 Lb Ull Eng No. 2 On	101	K3890	455.448		
LOX Repress Cont Valve Off	4	K3890	455.585		
LH_2 Repress Cont Valve Off	81	K3890	455.731		
O_2H_2 Burner Fuel Vlv. & LOX Shutdown Vlv Clsd On	60	K3890	455.874		

TABLE 5-2 (Sheet 7 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
O_2H_2 Burner Voting Ckt Enab Off	86	K3890	456.094		
LH_2 + LOX Repress Sys Rst		K0441	456.098		
O_2H_2 Voting Ckt Enab		K0438	456.101		
LH_2 Cont Vent Close On	84	K3890	456.336		
Amb Repress Sys Mode Sel On	36	K3890	456.753		
LH_2 + LOX Repress Sys Rst		K0441	456.757		
LH_2 + LOX Repress Mode Amb		K0440	456.757		
O_2H_2 Burner Fuel Vlv & LOX Shutdown Vlv Clsd Off	61	K3890	456.962		
LH_2 Cont Vent Close Off	87	K3890	458.348		
LH_2 Tk Vent Orf + Rlf Rst		K0452	458.357		
O_2H_2 Burner Sys Rel Rst - On		K0437	458.971		
He Htr LOX Prop Vlv Close On	74	K3890	460.505		
LH_2 Cont Vent Close - Off	87	K3890	460.642		

TABLE 5-2 (Sheet 8 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
He Htr Prop Vlv Close Off	75	K3890	463.598		
O_2H_2 Burner Sys Rel Rst		K0437	463.608		
LH_2 + LOX Prevlv Close Ener		K0576	518.492		
LH_2 Prevalves Open - On		K0540	520.752	K0111	520.770
LOX Prevalves Open - On		K0541	521.139	K0109	521.270
LH_2 Childown Pump Off	59	K3890	528.562		
LH_2 C/D Pmp Inv. Off - Indication		K0512	528.567		
LH_2 C/D Pmp Relay Rst Indication		K0641	528.569		
LOX Chilldown Pump Off	23	K3890	528.771		
LOX C/D Pmp Inv. Off Indication		K0519	528.778		
LOX C/D Pmp Relay Rst Indication		K0644	528.779		
Aux Hyd Pump Coast Mode On	30	K3890	530.041		
Aux Hyd Pump Coast Rel Rst On		K0445	530.045		
Aux Hyd Pmp Flt Mode Off	29	K3890	530.131		

TABLE 5-2 (Sheet 9 of 11)
SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Aux Hyd Pump Flt Rel Rst - Off		K0621	530.136		
70 Lb Ull Eng No. 1 Off	43	K3890	530.311		
70 Lb Ull Eng No. 2 Off	102	K3890	530.400		
70 Lb Ull Eng Rel Rst		K0429	530.408		
PU Hardover Cmd Off	18	K3890	530.539		
He Htr LH_2 Prop Vlv Opn On	26	K3890	1491.380		
O_2H_2 Burner Sys Rel Rst		K0437	1491.386		
O_2H_2 LH_2 Prop Vlv Cls Off		K0432	1491.440		
O_2H_2 LH_2 Prop Vlv Opn On		K0431	1491.468		
He Htr Spark Exc On	70	K3890	1491.682		
He Htr LOX Prop Vlvs Opn On	89	K3890	1492.133		
O_2H_2 LOX Prop Vlv Cls Off		K0428	1492.203		
O_2H_2 LOX Prop Vlv Opn On		K0427	1492.209		
He Htr LH_2 Prop Vlv Opn Off	72	K3890	1492.952		
He Htr LOX Prop Vlvs Open Off	90	K3890	1493.683		

TABLE 5-2 (Sheet 10 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
Eng Ign Detected On		K0537	1495.246		
Eng Ign Detected Off		K0537	1495.247		
He Htr Spark Exc Off	71	K3890	1495.587		
O_2H_2 Burner Sys Rel Rst		K0437	1495.596		
O_2H_2 Burner Voting Cir Enab On	85	K3890	1498.194		
He Htr Prop Vlv Close On	60	K3890	1622.001		
O_2H_2 Burner Sys Rel Rst		K0437	1622.009		
O_2H_2 Burner Voting Cir Enab Off Cmd	86	K3890	1622.224		
O_2H_2 Burner Voting Cir Enab Off		K0438	1622.230		
He Htr LH_2 Prop Vlv Cls Off	61	K3890	1625.030		
O_2H_2 Burner Sys Rel Rst		K0437	1625.038		
He Htr LOX Prop Vlv Cls On	74	K3890	1626.551		
He Htr Prop Vlv Cls Off	75	K3890	1629.522		
O_2H_2 Burner Sys Rel Rst		K0437	1629.531		

TABLE 5-2 (Sheet 11 of 11)

SEQUENCE OF EVENTS (O_2-H_2 BURNER)

EVENT/RESULT OF COMMAND	SWITCH SELECTOR CHANNEL	DIGITAL EVENT RECORDER (CAT 57)		PCM/FM SEQUENCE (CAT 42)	
		MEAS. NO.	TIME (sec)	MEAS. NO.	TIME (sec)
LOX Repress Cont Vlv On	3	K3890	1757.228		
LOX Tk Repress Vlv Ener		K0444	1757.241		
LH_2 Cont Vent Close On	84	K3890	1761.761		
LH_2 Tk Vent Orf + Rlf Rst		K0452	1761.767		
LH_2 Tk Vent Rlf Ovrd Cls		K0699	1761.784		
LH_2 Tk Vent Orf Byp Opn		K0451	1761.807		
LH_2 Cont Vent Close Off	87	K3890	1763.876		
LH_2 Tk Vent Orf + Rlf Rst		K0452	1763.885		
Heat Exc Byp Vlv Disable	51	K3890	1777.732		
LH_2 Tk Repress Vlv Ener		K0443	1777.741		
LH_2 Tk Repress Vlv De-ener		K0443	1818.341		
LH_2 Tk Step Preslvlv Ener		K0523	1818.341		

[redacted]

SECTION 6

ENGINE SYSTEM

6. ENGINE SYSTEM

The S-IVB-506N stage acceptance firing was performed with an uprated (230,000 lbf thrust) Rocketdyne engine S/N 2101 (figure 6-1) mounted on the stage. The engine was manufactured in the configuration baseline designated for J-2 engine S/N 2088 and subs and is described in the Rocketdyne configuration report (R-5788). The necessary performance demonstration was achieved in the mainstage firing which had a duration of 448.092 sec. The engine performance "tag values" were established as follows:

Thrust (F)	229,780 lbf
Engine mixture ratio (EMR)	5.552
Specific impulse (I_{sp})	426.6 sec

The tag values were established with a LOX flowmeter constant of 5.5336 cpg and an LH2 flowmeter constant of 1.8521 cpg. The gas generator feed system contained orifices with diameters of 0.276 in. for LOX and 0.486 in. for LH2. The engine was equipped with a 1-sec start tank discharge valve timer in the engine control circuit and a rotated propellant utilization (PU) valve baffle to reduce steady-state performance shifts. None of the other modifications produced any significant performance effects.

6.1 Engine Chilldown and Conditioning

6.1.1 Turbopump Chilldown

Chilldown of the engine LOX and LH2 turbopumps was adequate to provide the conditions required for proper engine start. An analysis of the chilldown operation is presented in paragraphs 7.4 and 8.3. The LOX pump discharge was 21.2 deg subcooled compared to the recommended minimum of 3 deg.

6.1.2 Thrust Chamber Chilldown

The thrust chamber skin temperature (figure 6-2) was 237 deg R at Engine Start Command, well within the engine start requirements of 235 ±75. A comparison of three acceptance firings is presented in table 6-1. The LH2 pump demonstrated satisfactory start transient buildup characteristics as shown in figure 6-3.

6.1.3 Engine Start Sphere Chilldown and Loading

Chilldown and loading of the engine GH2 start sphere (figure 6-4) met the requirements for engine start (figure 6-5). The maximum sphere warmup rate was 3.5 deg R/min for 2.0 min after sphere pressurization and average 2.09 deg R/min from sphere pressurization to Engine Start Command. Significant data from three S-IVB stages are compared in table 6-2.

6.1.4 Start Tank Refill Performance

Figure 6-6 shows the refill performance of the J-2 start tank during the S-IVB-506N stage acceptance firing. Immediately prior to start tank discharge, the start tank conditions (1,329 psia and 287 deg R) were within the safe start envelope. When the start tank discharge valve (STDV) opened, the GH2 discharged through the turbines along the adiabatic line as shown in figure 6-6. The discharge was completed and the refill initiated when the temperature and pressure were 194 deg R and 132 psia, respectively, at ESC +1.79 sec. The tank was topped with lower temperature hydrogen from the LH2 pump discharge starting at ESC +9.8 sec. The topping was terminated when the pressure differential across the topping check valve was lower than the minimum required for flow. At this time (ESC +41.500 sec) the tank pressure and temperature were 1,162 psia and 215.9 deg R, respectively. Heat input to the start tank caused the pressure and temperature to increase along an isochoric line.

Figure 6-7 shows the restart capability of the engine based on a Rocketdyne-determined criterion. The start tank pressure at STDV +60 sec (ESC +61.09 sec) was 1,194.0 psia as compared to a minimum allowable of 950 psia. At ESC +69.5 sec, the start tank condition was within the safe start envelope; at Engine Cutoff Command, the pressure and temperature were 1,324.5 psia and 246.7 deg R. The pressure did not reach the relief valve setting (1,485 psia) during the firing.

6.1.5 Engine Control Sphere Chilldown and Loading

The engine control sphere conditioning was adequate (figure 6-4), and all objectives were satisfactorily accomplished. The engine start requirement (2,625 ±825 psia) was met. Significant engine control sphere performance data from three S-IVB stages are compared in table 6-3.

6.2 J-2 Engine Performance Analysis Methods and Instrumentation

Engine performance for the acceptance firing was calculated by use of computer programs PA53, AA89, G105-3, and G307. The average of the results of AA89 and G105-3, which is considered to be the best current estimate of engine performance, was calculated by computer program PA49. (Program G307 could not be used in PA49 due to problems with the PA49 logic.) Computer program PA53, utilizing revised techniques and the latest Rocketdyne correlations, was used to compute start and cutoff transient performance. A description of the operation and a comparison of the results of AA89 and G105-3 is presented in table 6-4. Data inputs to the computer programs, with the applicable biases, are shown in table 6-5.

6.3 J-2 Engine Performance

The engine performance was satisfactory. Plots of selected data showing engine characteristics are presented in figures 6-8 through 6-13. The engine propellant inlet conditions are discussed in sections 7 and 8. The engine altitude performance level (tag values) at ESC +60 sec as determined by computer program G307 (Past-641 deck) was as follows:

Parameter	DAC Acceptance	Rocketdyne Acceptance	Difference	3σ Run to Run
Thrust (lbf)	229,780	229,452	+328	±2,901
Mixture Ratio	5.55	5.52	+0.03	±0.09
Specific Impulse (sec)	426.6	426.3	+0.3	±2.7

These values are comparable, within the run-to-run deviations, to the J-2 engine acceptance firing results. The composite values for steady-state performance are shown in table 6-6.

Flow integral mass analysis indicated that 191,017 lbm of LOX and 36,705 lbm of LH2 were consumed between Engine Start Command and Engine Cutoff Command. The overall engine average performance from the 90 percent performance level (ESC +3.59 sec) to Engine Cutoff Command (ESC +448.092 sec) is presented in table 6-6. The variation of specific impulse with mixture ratio is shown in figure 6-13.

Total impulse generated from Engine Start Command to Engine Cutoff Command was 97.16 x 10^6 lbf-sec. Extrapolation of the propellant residual as indicated by the point level sensors (1,557 lbm of LOX, 1,419 lbm of LH2) indicates that a LOX depletion cutoff would have occurred at ECC +3.15 sec. In that time an additional 654,000 lbf-sec impulse would have been generated, making the total stage potential impulse from Engine Start Command to depletion cutoff 97.81 x 10^6 lbf-sec as compared to the predicted value of 98.00 x 10^6 lbf-sec. The 0.19 percent deviation is within the prediction accuracy of approximately 1 percent. The 1.735 sec difference between the actual (ESC +451.242 sec and predicted (ESC +452.977 sec) depletion times is also within the prediction accuracy.

6.3.1 Start Transient

The J-2 engine start transient was satisfactory. A summary of engine performance is presented in the following table:

Parameter	Acceptance Firing	Log Book
Time to 90 percent performance level (sec)	ESC +3.59	ESC +3.5
Time of start tank discharge command (sec)	ESC +1.091	ESC +1.0
Total impulse (lbf-sec)	187,404	173,834*

*Based on stabilized thrust at null PU and standard altitude conditions.

Thrust buildup to the 90 percent performance level (STDV +2.5 sec) was within the maximum and minimum thrust bands as shown in figure 6-14. The acceptance firing start transient total impulse was in good agreement with the value computed from the log book. The start of thrust buildup occurred slightly later than normal because the start tank discharge command occurred slightly late as it did in the S-IVB-505N acceptance firing. Figure 6-14 shows the thrust chamber pressure, the thrust buildup, and total impulse during the start transient of the acceptance firing.

6.3.2 Steady-State Performance

Satisfactory performance was exhibited by the J-2 engine during the steady-state portion of engine burn.

Average performance values for the acceptance firing steady-state operation are presented in figure 6-15 and compared with predicted performance values in table 6-6. During closed PU valve operation, the deviation was less than 0.3 percent. Overall performance deviations were a result of the difference in predicted and actual cutback time (refer to section 11). There were no noticeable performance shifts during the S-IVB-506N acceptance firing.

Engine thrust variations during the acceptance firing are presented in table 6-7. They are compared to the predicted acceptance firing thrust history and to Contract End Item (CEI) thrust variation limits for flight. These limits do not apply to acceptance firing performance and are presented for reference only. The thrust variations will be modified by flight effects on stage operation. Thrust variations during three phases of engine operation are presented in figure 6-16 and discussed in the following paragraphs:

a. The thrust variations during hardover, or maximum, engine mixture ratio operation (EMR = 5.5) were within the CEI limits for normal engine operation. Normal operating thrust variations during this period of engine burn are caused by stabilization of the engine and by stage perturbations, including the effects of variations in propellant supply environmental conditions.

b. Thrust variations during the transient period from PU valve cutback +75 sec to ECC -70 sec were within the CEI limits for normal engine operation. The thrust variations during this period were caused by stabilization of the engine after cutback and can be directly linked to movements of the PU valve. Data derived from the acceptance firing will aid in the flight calibration of the PU system in order to more accurately predict the thrust variation during the cutback transient.

c. Thrust variations during the final 70 sec of engine operation were not within the present CEI limits for normal engine operation. The out-of-spec thrust variation was due to the step character of the tank pressurization system. Because the present CEI limits were formulated without consideration for step pressurization, they are presently being revised to reflect this.

6.3.3 Cutoff Transient

The time lapse between engine cutoff, as received at the J-2 engine, and thrust decrease to 11,500 lbf was within the maximum allowable time of 800 ms for the acceptance firing as shown in the following table:

Parameter	Acceptance Firing	Log Book
Time of thrust decrease to 11,500 lbf (ms)	477	319
Measured total impulse (lbf-sec)	40,311*	
Total impulse corrected to null (-2.0 deg) PU valve position (lbf-sec)	38,910	33,422
Total impulse corrected to 0 deg F oxidizer valve skin temperature (lbf-sec)	**	33,462

*PU valve at -1.2 deg
**Valve skin temperature data not available

The thrust decay time for the acceptance firing was greater than the log book value, and the cutoff total impulse was correspondingly higher than the log book value. For this firing, the total impulse was corrected to null PU valve position using a method given by Rocketdyne so that a direct comparison could be made to the log book value. It was not possible to accurately correct to 0 deg F LOX valve skin temperature since that measurement was not available; however, this correction would be approximately -4,500 lb-sec for an acceptance firing since the MOV temperature should be about 355 deg R. The corrected total impulse would then be within 1,100 lb-sec of the log book value. Figure 6-17 presents the data for the thrust chamber pressure cutoff transient, the accumulated cutoff impulse, and the cutoff thrust to the 11,500 lbf level.

6.4 Engine Sequencing

As in the past, the engine start sequence event times (figure 6-18 and table 6-8) differ in many respects from the values quoted in the log book. In most instances, these differences are inconsequential and may be ascribed to sampling rate errors or to the presence of liquids in the valves. The only significant differences from the specified event times are the start tank discharge control solenoid energize which was slightly late and the gas generator valve opening time which was somewhat long.

6.5 Component Operation

6.5.1 Main LOX Valve

The main LOX valve opened satisfactorily during the acceptance firing. The main LOX valve opening time data were as follows:

Item	Specification (Ambient Conditions)	Acceptance Firing
First stage travel (ms)	50 ±25	63
First plateau (ms)	510 ±70	505
Second stage travel (ms)	1,825 ±75	1,816
Total time (ms)	2,385 ±170	2,384

The valve opening times for the acceptance firing were well within specification, indicating nominal main LOX valve performance during the opening phase of operation. The valve closing time was 181 ms (relative to valve open dropout) which was approximately 61 ms longer than the maximum specified value for ambient conditions; however, this did not contribute to any significant reduction in cutoff transient performance.

The longer than specified closing time was similar to that exhibited during the S-IVB-505N acceptance firing and is probably due to the colder valve environment.

6.5.2 Main Fuel Valve

The main fuel valve position data (G0506) indicated a position slightly away from full open during two periods (ESC +15 sec to ESC +70 sec, and ESC +227 sec to ESC +286 sec). This deviation was slight, reaching a maximum of 3 percent. The microswitch talkback data indicated that the main fuel valve remained fully open during these periods. Also, engine data associated with the main fuel valve did not show any changes during these times that could be attributed to a slightly closed fuel valve. Due to the lack of any supporting anomalies, it was concluded that the deviation from full open was due to noise in the data and that the main fuel valve performed satisfactorily throughout the firing.

6.5.3 LH2 Pump

LH2 pump performance was satisfactory. LH2 pump speed and discharge pressure and temperature responded satisfactorily to PU system cutback and engine inlet conditions. The pump developed head and the temperature rise across the pump were satisfactory. Figure 6-3 shows the pump developed head as a function of flowrate during the critical stall period. It shows that the performance was well within the stall inception line during the start transient.

6.5.4 LOX Pump

LOX pump performance was satisfactory. LOX pump speed and discharge pressure and temperature responded to PU system cutback and perturbations and also to engine inlet conditions. The pressure and temperature rise across the pump were satisfactory. Performance profiles indicative of the pump operation are shown in figure 6-10.

6.5.5 Turbines

Performance of both LH2 and LOX turbines was satisfactory. Temperatures and pressures for both turbines responded as expected to PU system cutback and perturbations. Pressure and temperature drops across the turbines were nominal. Performance profiles are presented in figure 6-11.

6.5.6 PU Valve

At Engine Start Command, the PU valve was at -2 deg (null) which was within the -2 ±2 deg limit. PU valve response was satisfactory (see section 11). PU activation occurred at ESC +6.149 sec. (The required activation time is presently 5 ±0.5 sec from STDV.) The PU valve went to the high EMR position where it remained until PU cutback at ESC +179.1 sec as shown in figure 6-13. PU cutback occurred at a slightly different time than predicted because of system errors as discussed in section 11.

6.5.7 Gas Generator

The gas generator (GG) performance was adequate. The GG chamber pressure and LH2 turbine inlet temperature indicated nominal values before and after EMR cutback. The performance shifts present during previous firings were not present during this firing. Plots of GG performance are shown in figure 6-19.

6.5.8 Engine-Driven Hydraulic Pump

The engine-driven hydraulic pump performed satisfactorily during the acceptance firing. The required horsepower at 60 sec after engine start was approximately 5.00.

TABLE 6-1
THRUST CHAMBER CHILLDOWN DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N	S-IVB-503N
Thrust chamber chilldown initiated (sec from simulated liftoff)	-408.537	-405.356	-405.619	-404.562
Thrust chamber chilldown terminated (sec from simulated liftoff)	488.474	488.288	519.96	488.984
Thrust Chamber Temperature				
Required at Engine Start Command (deg R)	235 ±75	260 ±50	260 ±50	260 ±50
At Engine Start Command (deg R)	237	247	225	229
At end of chilldown (deg R)	228	244	217	220

TABLE 6-2
ENGINE START SPHERE PERFORMANCE DATA

PARAMETER	TEMPERATURE (°R)			PRESSURE (PSIA)			MASS (LBM)		
	506N	505N	504N	506N	505N	504N	506N	505N	504N
Engine start requirement*									
Engine Start Command*							3.42	3.40	3.45
After start sphere blowdown	194	196	198	132	138	151	0.54	0.56	0.70
Engine cutoff	247	256	245	1,325	1,321	1,342	3.97	3.82	4.10
Total GH2 usage during start	-	-	-	-	-	-	2.88	2.84	2.75

*See start region (figure 6-5).

TABLE 6-3
ENGINE CONTROL SPHERE PERFORMANCE DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N	S-IVB-503N
Temperature				
Required* at Engine Start Command (deg R)	287 ±20	291 ±20	291 ±20	281 ±20
At Engine Start Command (deg R)	298	297	295	285
At Engine Cutoff Command (deg R)	252	262	254	252
Pressure				
Required at Engine Start Command (psia)	1,800 to 3,450	2,975 ±475	2,975 ±475	2,975 ±475
At Engine Start Command (psia)	2,933**	3,082	3,081	3,045
At Engine Cutoff Command (psia)	1,987**	2,161	2,094	2,094
Mass				
At Engine Start Command (lbm)	1.81	1.89	1.90	1.94
After Engine Cutoff Command (lbm)	1.43	1.54	1.53	1.53
Total helium usage (lbm)	0.38	0.35	0.37	0.41

*Actual requirement is GH2 start sphere temperature ±20 deg R.

**Pressures are lower than usual because of low GSE regulator setting.

TABLE 6-4
COMPARISON OF COMPUTER PROGRAM RESULTS

PROGRAM	INPUT	METHOD	RESULTS
AA89	LOX and LH2 pump inlet pressures and temperatures, PU valve position, and engine tag values.	Influence equations relate nominal inlet conditions to nominal performance. Using actual inlet conditions, PU valve position and engine tag values, the actual performance is simulated.	$F = 218{,}368$ lbf $\dot{W}_T = 511.1$ lbm/sec $I_{sp} = 427.4$ sec $MR = 5.23$
G0105 Mode 3	LOS and LH2 flowmeters, pump discharge pressures and temperatures, chamber pressures, chamber thrust area.	Flowrates are computed from flowmeter data and propellant densities. The C_F is determined from equation $C_F = f(P_c, MR)$ and thrust is calculated from equation $F = C_F A_t P_c$.	$F = 217{,}612$ lbf $\dot{W}_T = 509.8$ lbm/sec $I_{sp} = 426.9$ sec $MR = 5.26$

NOTE: See appendix 1 for abbreviations.

TABLE 6-5 (Sheet 1 of 2)
DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
Chamber Pressure	G105-3	D0001(T/M)	H/W appeared to have voltage shift	-16.5 psi	P_c meas -15 = P_c act Rocketdyne estimation of P_c Purge Effect), and reading too high at ESC (+1.5 psi)
	PA53	D0001(T/M)	Best transient data	-1.5 psi	Reading too high at ESC (1.5 psi)
LH2 Pump Discharge Pressure	G105-3	D0008(T/M)	Close agreement between (H/W) and T/M. Used (T/M).	0	
LH2 Pump Discharge Temperature	G105-3	C0134(T/M)	Close agreement between (H/W) and T/M. Used (T/M).	0	
LOX Pump Discharge Pressure	G105-3	D0009(T/M)	Close agreement between (H/W) and (T/M). Used (T/M).	0	
LOX Pump Discharge Temperature	G105-3	C0648(H/W)	Close agreement between (H/W) and (T/M). Used (H/W).	0	
LH2 Flowrate	G105-3	F0001(T/M)	(H/W) data very noisy.	-91.88 gpm	Agree with actual pip count.
LOX Flowrate	G105-3	F0002(T/M)	(H/W) data very noisy.	-44.56 gpm	Agree with actual pip count.
LH2 Pump Inlet Pressure	AA89	D0002(T/M)	Close agreement between (H/W) and (T/M). Used (T/M).	+1.375	Charge static pressure to total pressure.

TABLE 6-5 (Sheet 2 of 2)
DATA INPUTS TO COMPUTER PROGRAMS

PARAMETER	PROGRAM	SELECTION	REASON	BIAS	REASON
LH2 Pump Inlet Temperature	AA89	C0658(H/W)	Very close agreement between (H/W) and (T/M). Used (T/M).	0	
LOX Pump Inlet Pressure	AA89	D0003(T/M)	Very close agreement between (H/W) and (T/M). Used (T/M).	+2.625	Change static pressure to total pressure.
LOX Pump Inlet Temperature	AA89	C0659(H/W)	Very close agreement between (H/W) and (T/M). Used (T/M).	0	
PU Valve Position	AA89	G0010(T/M)	Very close agreement between (H/W) and (T/M) Used (T/M).	0	

TABLE 6-6
ENGINE PERFORMANCE

PARAMETER	CLOSED PU VALVE OPERATION			REFERENCE MIXTURE RATIO OPERATION			OVERALL PERFORMANCE 90% TO ECC		
	ACTUAL	PREDICTED	DEV. (%)	ACTUAL	PREDICTED	DEV. (%)	ACTUAL	PREDICTED	DEV. (%)
Thrust (lbf)	230,999	230,924	+0.03	206,136	206,347	-0.10	217,990	218,367	-0.17
Total flowrate (lbm/sec)	541.61	542.05	-0.08	482.12	481.41	+0.15	510.41	511.09	-0.13
LOX flowrate (lbm/sec)	458.63	458.85	-0.05	401.70	400.99	+0.18	428.73	426.03	+0.63
LH2 flowrate (lbm/sec)	82.98	83.20	-0.26	80.42	80.42	0.0	81.63	81.80	-0.15
Engine mixture ratio	5.527	5.515	+0.22	4.995	4.986	+0.18	5.244	5.243	+0.02
Specific impulse	426.50	426.02	+0.11	427.56	428.63	-0.25	427.18	427.34	-0.04

TABLE 6-7
ENGINE THRUST VARIATIONS

PARAMETER/TIME PERIOD	LIMITS	HARDOVER OPERATION	TRANSIENT FROM PU VALVE (CUTBACK +75 SEC TO ECC -70 SEC)	FINAL 70 SEC OF S-IVB BURN
Variation in mean thrust level (lbf) or thrust band centerline variation at ECC -70 sec (lbf)	Allowable	±4,000	±8,000	+6,000, -5,000
	Actual	+175	+815	-2,400
	Predicted	--	--	--
Oscillations about mean thrust level (lbf) or thrust variation band (lbf)	Allowable	±2,500	±7,500	±3,000
	Actual	±1,110	±1,440	±995
	Predicted	±600	±2,500	±2,600
Rate of change of thrust (lbf/sec)	Allowable	±500	±500	+435, -385
	Actual	+414	-221	-1,250
	Predicted	±100	±100	±100
Thrust acceleration (lbf/sec/sec)	Allowable	±125	±500	±500
	Actual	±67.3	±78	±453
	Predicted	--	--	--
Thrust band slope (lbf/sec)	Allowable	--	--	+100, -85
	Actual	--	--	+7.2
	Predicted	--	--	-20.7
Variation of thrust band slope about nominal (lbf/sec)	Allowable	--	--	+35, -50
	Actual	--	--	-27.9
	Predicted	--	--	--

TABLE 6-8 (Sheet 1 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0021 (K0021)	*Engine Start Command P/U			0	0	
		K0007 (K0531)	Helium Control Solenoid Enrg P/U	Within 10 ms of K0021	002	002
		K0010 (K0454)	Thrust Chamber Spark on P/U	Within 10 ms of K0021	003	003
		K0011 (K0455)	Gas Generator Spark on P/U	Within 10 ms of K0021	003	003
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg P/U	Within 20 ms of K0021	002	002
		K0012 (K0530)	Engine Ready D/O	Within 20 ms of K0006	006	004

(KOXXX) Actual number from acceptance firing event recorder.

*Engine ready and stage separation signals (or simulation) are required before this command will be executed. This command also actuates a 1,000 ±30 ms timer which controls energizing of the start tank discharge solenoid valve (K0096).

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 2 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0126 (K0558)	LOX Bleed Valve Closed P/U	Within 110 ms of K0007	068	066
		K0127 (K0557)	LH2 Bleed Valve Closed P/U	Within 110 ms of K0007	054	052
		K0020 (K0627)	ASI LOX Valve Open P/U	Within 80 ms of K0006	041	039
		K0119 (G0506)	Main Fuel Valve Closed D/O	60 ±30 ms from K0006	046	044
		K0118 (G0506)	Main Fuel Valve Open P/U	80 ±50 ms from K0119	142	096
K0008 (K0537)	Ignition Detected			Within 250 ms of K0021 P/U	180	180
K0021 (K0021)	Engine Start D/O			Approx 200 ms from K0021 P/U	358	358

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 3 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0096 (K0536)	*Start Tank Disc Control Solenoid Enrg			1,000 ±40 ms from K0021 P/U	1091	1091
		K0123 (G0508)	Start Tank Disc Valve Closed D/O	100 ±20 ms from K0096	1201	110
		K0122 (G0508)	Start Tank Disc Valve Open P/U	105 ±20 ms from K0123	1355	154
K0005 (K0538)	Mainstage Control Solenoid Enrg			450 ±30 ms from K0096	1545	454
		K0096 (K0536)	Start Tank Disc Control Solenoid Enrg D/O	450 ±30 ms from K0096	1545	454
		K0121 (G0507)	Main LOX Valve Closed D/O	50 ±20 ms from K0005	1592	047

*An indication of fuel injection temperature of -150 ±40 deg F (or simulation) is required before this command will be executed. This command also actuates a 450 ±30 ms timer which controls the start of mainstage.

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 4 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
K0013 (K0522)	Engine Cutoff P/U (New time reference)			0	0	
		K0005 (K0538)	Mainstage Control Solenoid Enrg D/O	Within 10 ms of K0013	005	005
		K0006 (K0535)	Ignition Phase Control Solenoid Enrg D/O	Within 10 ms of K0013	002	002
		K0020 (K0622)	ASI LOX Valve Closed P/U	Fully closed 100 ms after K0013 P/U	023	023
		K0120 (G0507)	Main Oxidizer Valve Open D/O	60 ±15 ms from K0005	077	072
		K0117 (G0509)	Gas Generator Valve Open D/O	75^{+25}_{-35} ms from K0006	028	026
		K0118 (G0506)	Main Fuel Valve Open D/O	90 ±25 ms from K0006	101	099
		K0121 (G0507)	Main Oxidizer Valve Closed P/U	120 ±15 ms from K0120	258	181

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 5 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
		K0125 (G0510)	Oxidizer Turbine Bypass Valve Closed D/O		216	
		K0124 (G0510)	Oxidizer Turbine Bypass Valve Open P/U	10,000 max ms from K0013	805	800
		K0126 (K0558)	LOX Bleed Valve Closed D/O	30,000 max ms from K0013	6581	6576
		K0127 (K0557)	LH2 Bleed Valve Closed D/O	30,000 max ms from K0013	8912	8907
		K0116 (G0509)	Gas Generator Valve Closed P/U	Within 500 ms from K0006	274	272
		K0119 (G0506)	Main Fuel Valve Closed P/U	225 ±25 ms from K0118	392	291

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 6 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ECC	FROM SPECIFIED REFERENCE
		K0116 (G0509)	Gas Generator Valve Closed P/U	Within 500 ms from K0006	274	272
		K0119 (G0506)	Main Fuel Valve Closed P/U	225 ±25 ms from K0118	392	291
K0158 (K0572)	*Mainstage Press Sw A Depress P/U				189	
K0159 (K0573)	Mainstage Press Sw B Depress P/U				188	
K0191 (K0610)	Mainstage OK D/O				191	
K0007 (K0531)	Helium Control Solenoid Enrg D/O			1,000 ±110 ms from K0013	993	993
K0158 (K0572)	Mainstage Press Sw No. 1 Depress D/O				3092	
K0159	Mainstage Press Sw No. 2 Depress D/O				3066	

*Signal drops out when pressure reaches 425 ±25 psig

P/U - Pickup

D/O - Dropout

TABLE 6-8 (Sheet 7 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
K0191 (K0610)	*Mainstage OK				3066	
		K0120 (G0507)	Main LOX Valve Open P/U	2,435 ±145 ms from K0005	3976	2431
		K0010 (K0454)	Thrust Chamber Spark On D/O	3,300 ±200 ms from K0005 P/U	4838	3293
		K0011 (K0455)	Gas Generator Spark On D/O	3,300 ±200 ms from K0005 P/U	4838	3293
K0507 CSS-22	PU Activate Sw P/U				6149	
		K0116 (G0509)	Gas Generator Valve Closed D/O	140 ±10 ms from K0005	1637	092
		K0122 (G0508)	Start Tank Disc Valve Open D/O	130 ±20 ms from K0096	1663	118
		K0117 (G0509)	Gas Generator Valve Open P/U	50 ±30 ms from K0116	1756	119

*One of these signals must be received within 4,750 ±260 ms from K0021 P/U, or cutoff will be initiated. Signal occurs when LOX injection pressure is 500 ±30 psig.

P/U - Pickup

D/O - Dropout

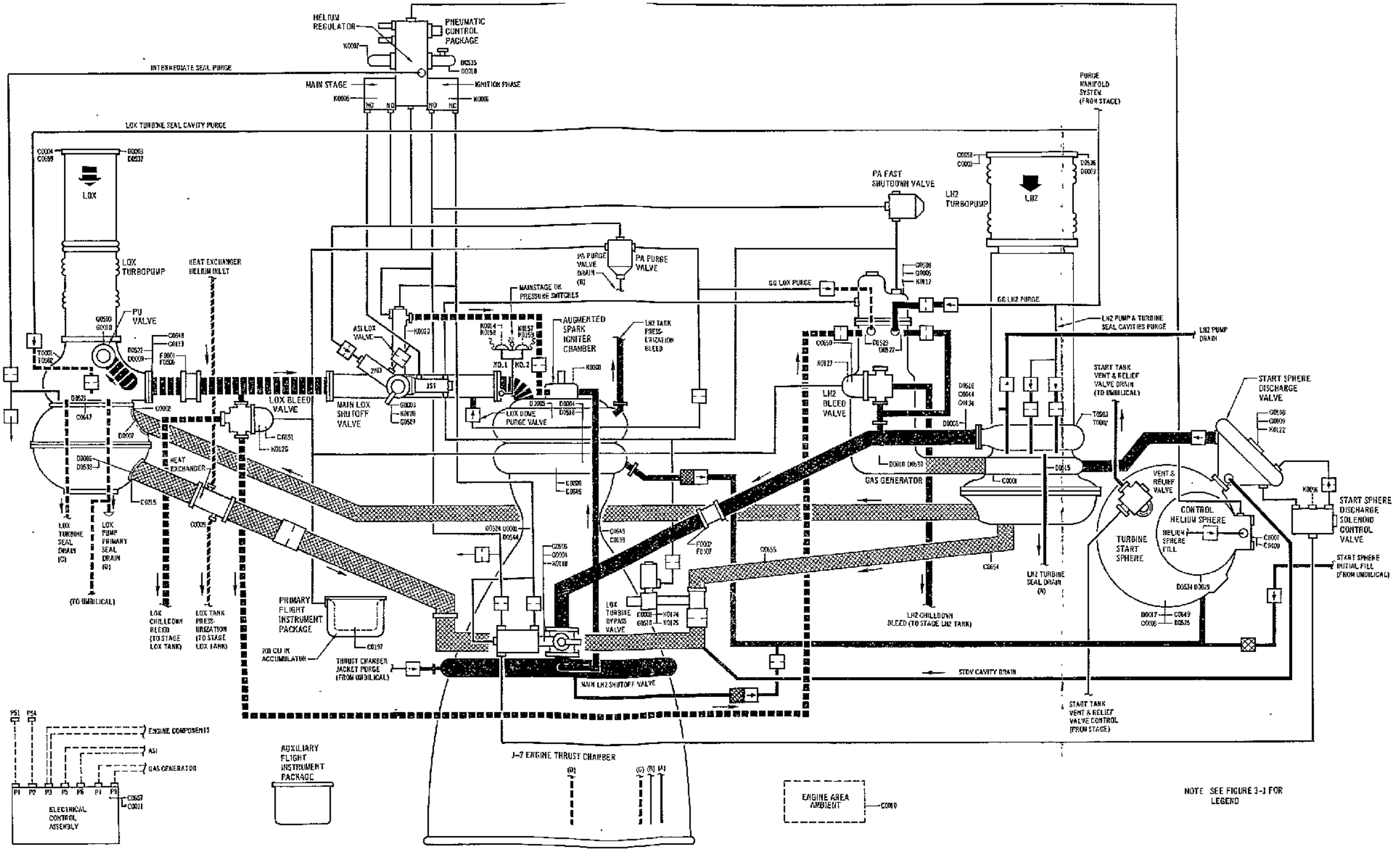
TABLE 6-8 (Sheet 8 of 8)
ENGINE SEQUENCE

CONTROL EVENTS		CONTINGENT EVENTS		NOMINAL TIME FROM SPECIFIED REFERENCE	ACTUAL TIME (MS)	
MEAS NO.	EVENT AND COMMENT	MEAS NO.	EVENT AND COMMENT		FROM ESC	FROM SPECIFIED REFERENCE
		K0124 (G0510)	LOX Turbine Bypass Valve Open D/O	N/A	1725	N/A
			LOX Turbine Bypass Valve 80% Closed	400 $^{+500}_{-50}$ ms from K0122	1977	314
		K0123 (G0508)	Start Tank Disc Valve Closed P/U	215 ±40 ms from K0122	1908	245
		K0125 (G0510)	*LOX Turbine Bypass Valve Closed P/U		2033	

*Within 5,000 ms of K0005 (Normally = 500 ms)

P/U - Pickup

D/O - Dropout



NOTE SEE FIGURE 3-1 FOR LEGEND

Figure 6-1. J-2 Engine System and Instrumentation

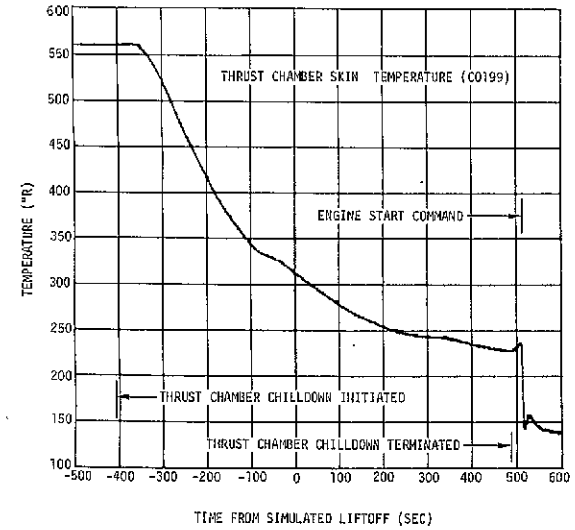


Figure 6-2. Thrust Chamber Chilldown

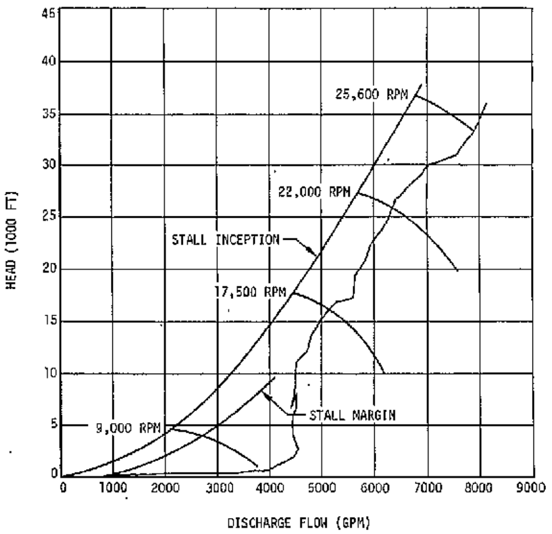


Figure 6-3. LH2 Pump Performance During Engine Start

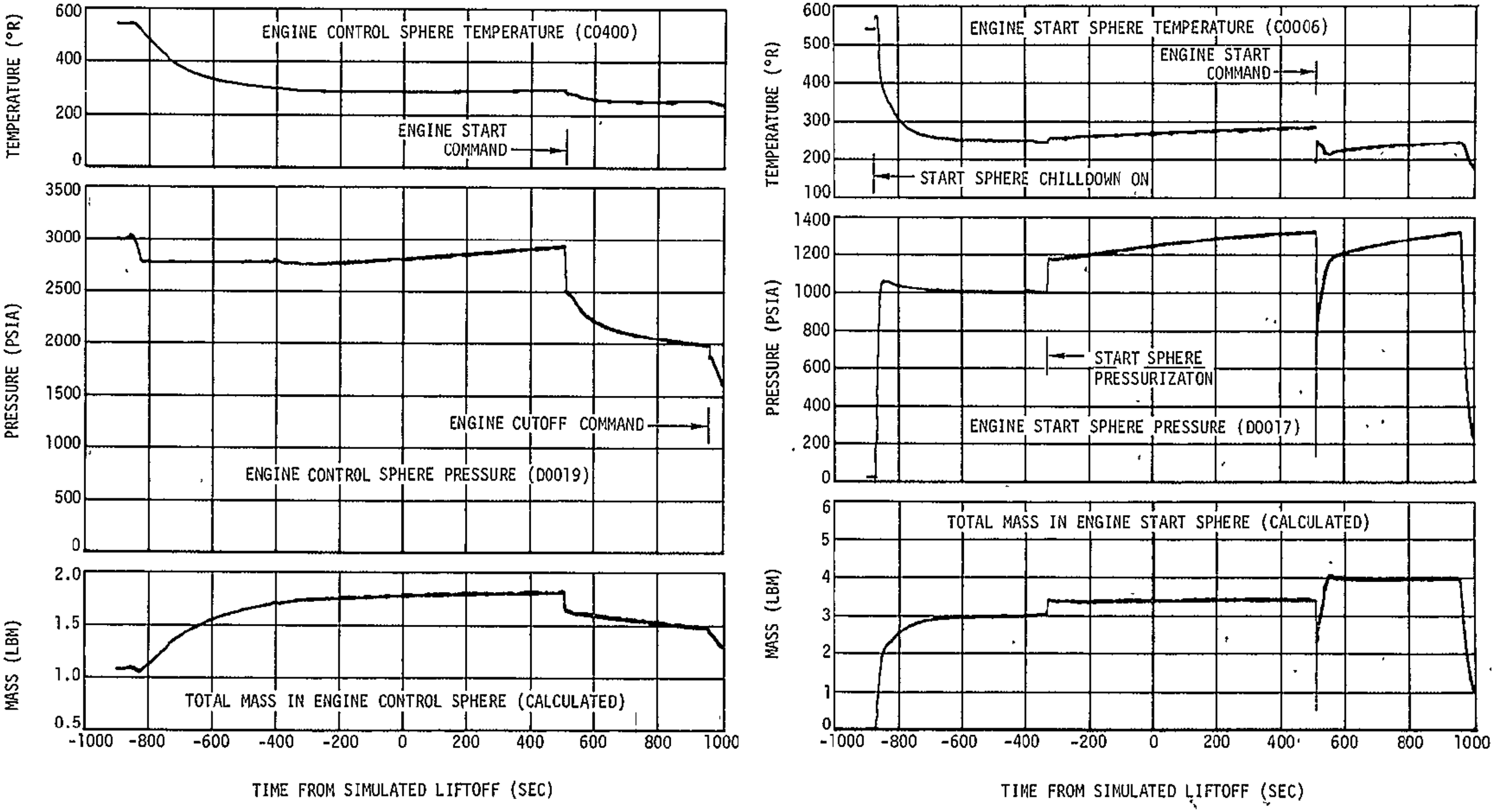


Figure 6-4. Engine Start and Control Sphere Performance

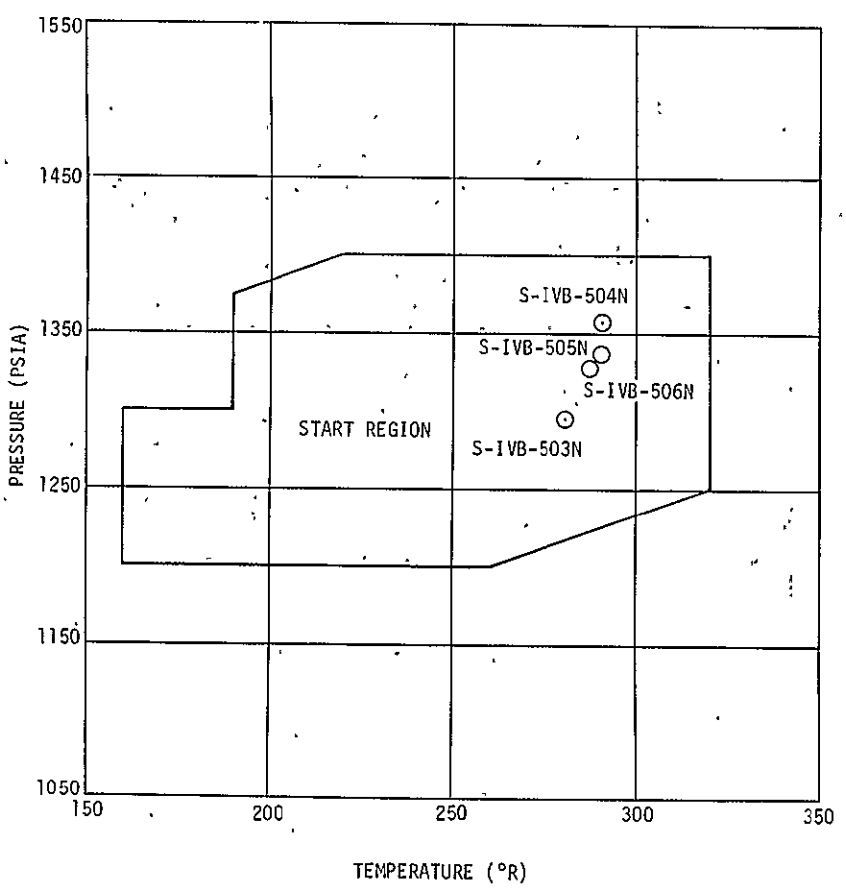


Figure 6-5. Engine Start Sphere Performance

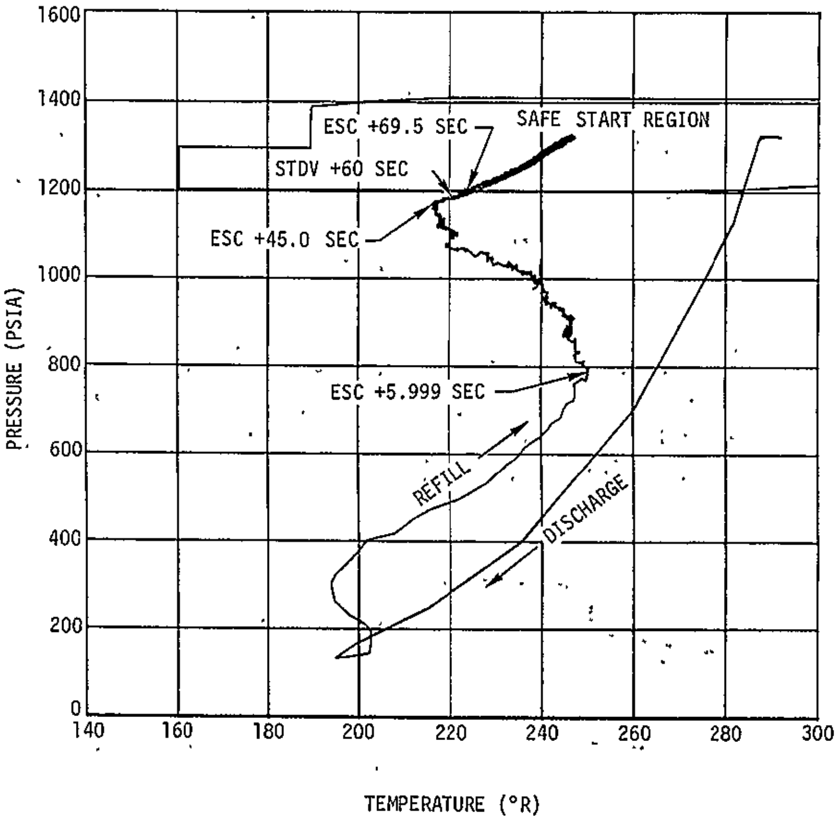


Figure 6-6. Start Tank Refill Performance

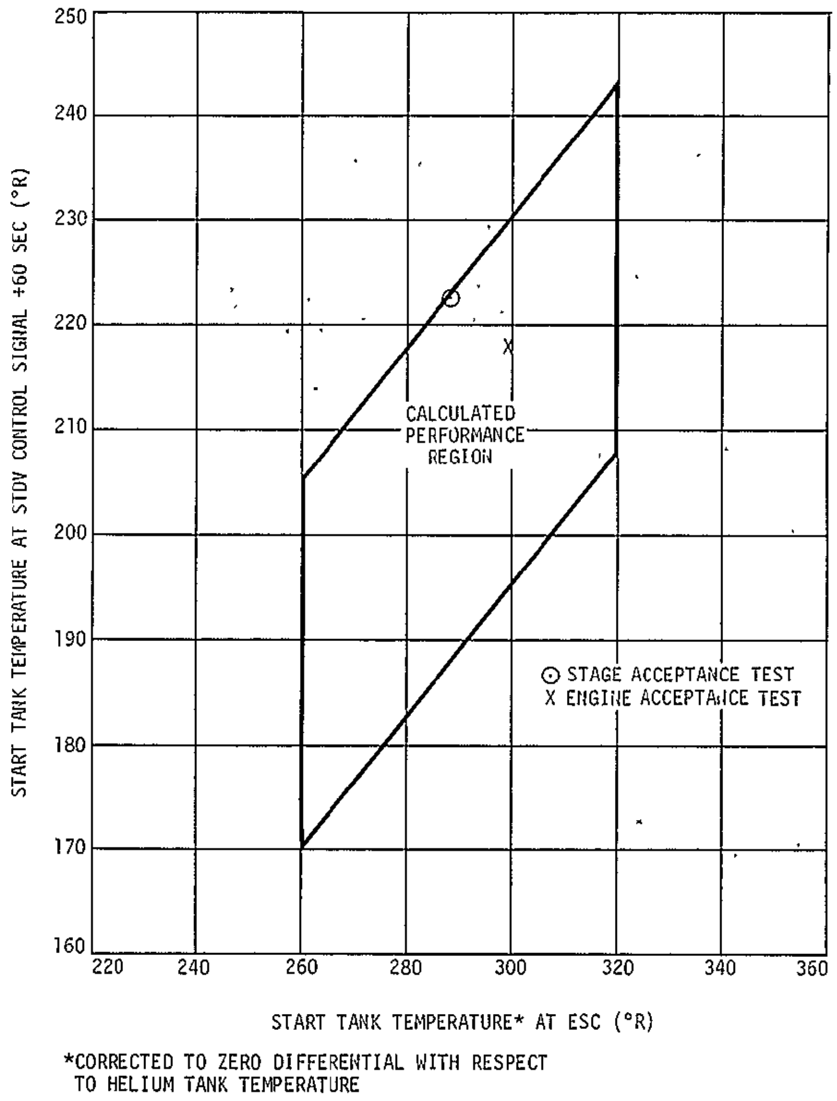


Figure 6-7. J-2 Engine Restart Capability

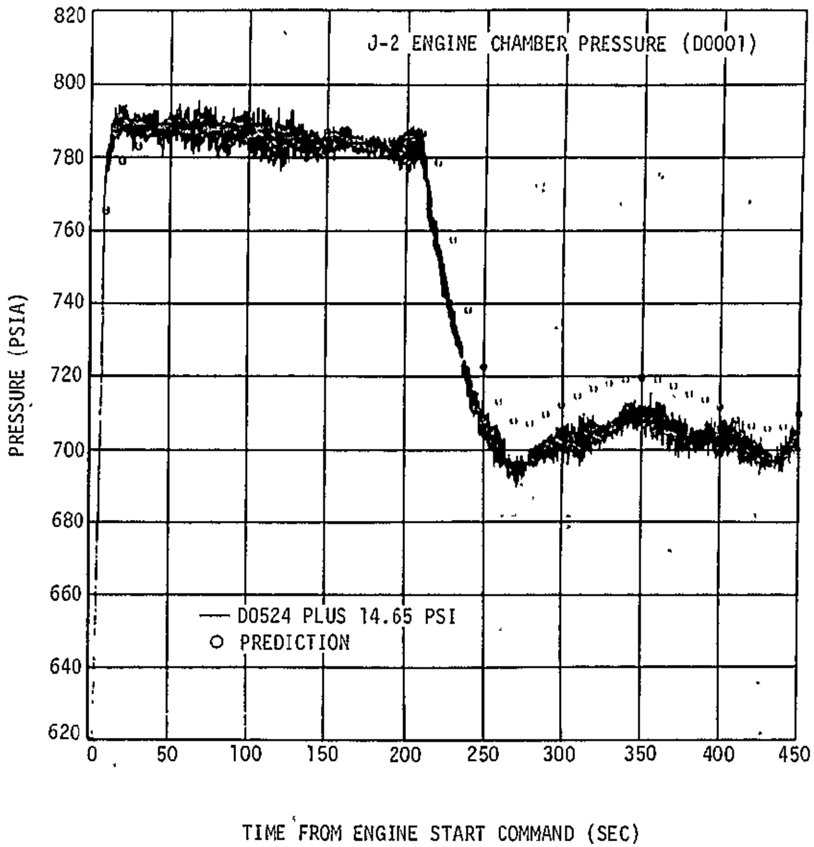


Figure 6-8. J-2 Engine Chamber Pressure

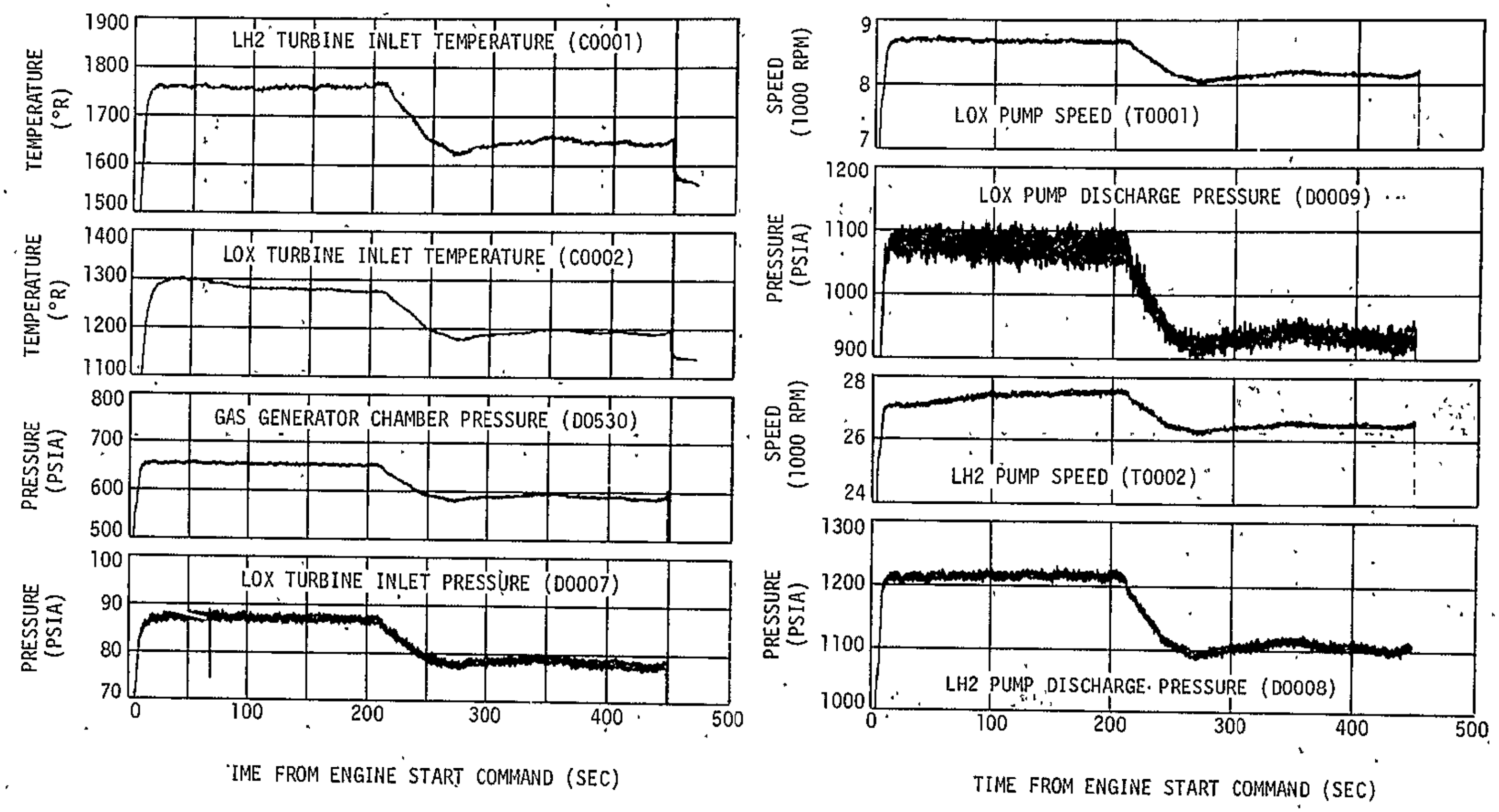


Figure 6-9. Turbopump Operating Characteristics

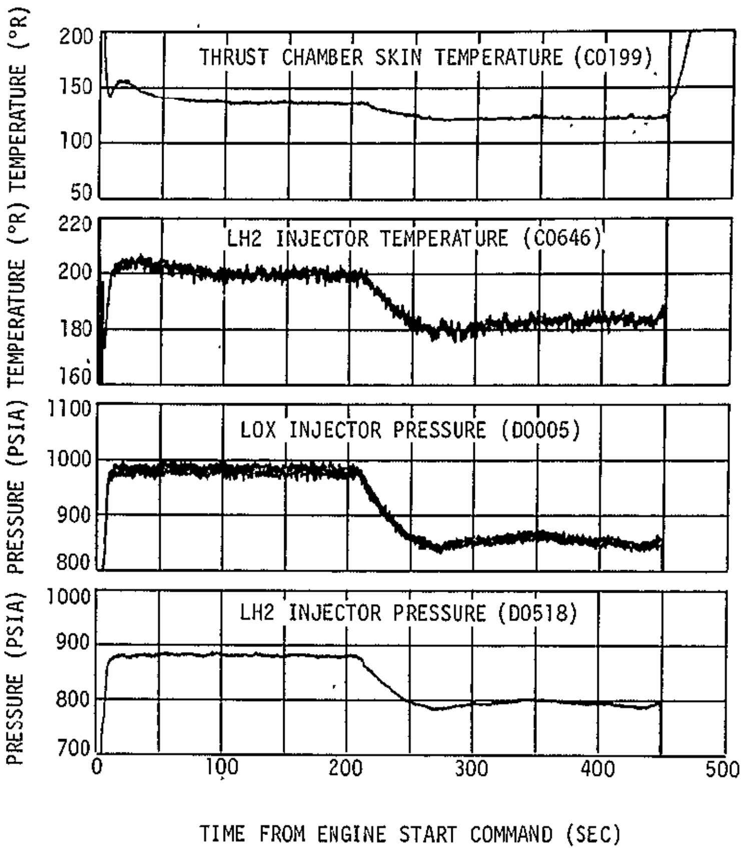


Figure 6-10. J-2 Engine Injector Supply Conditions

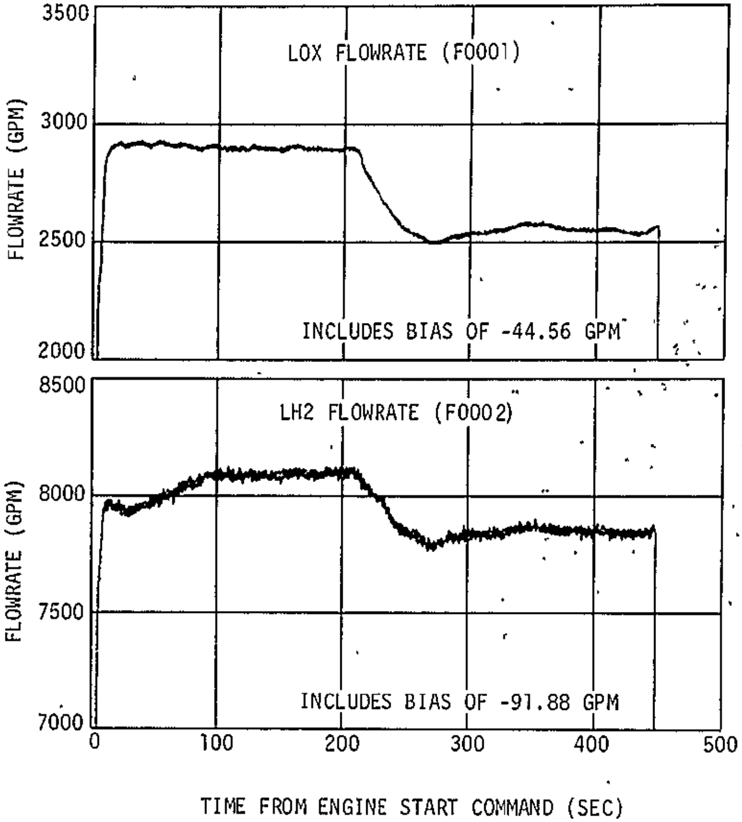


Figure 6-11. LOX and LH2 Flowrate

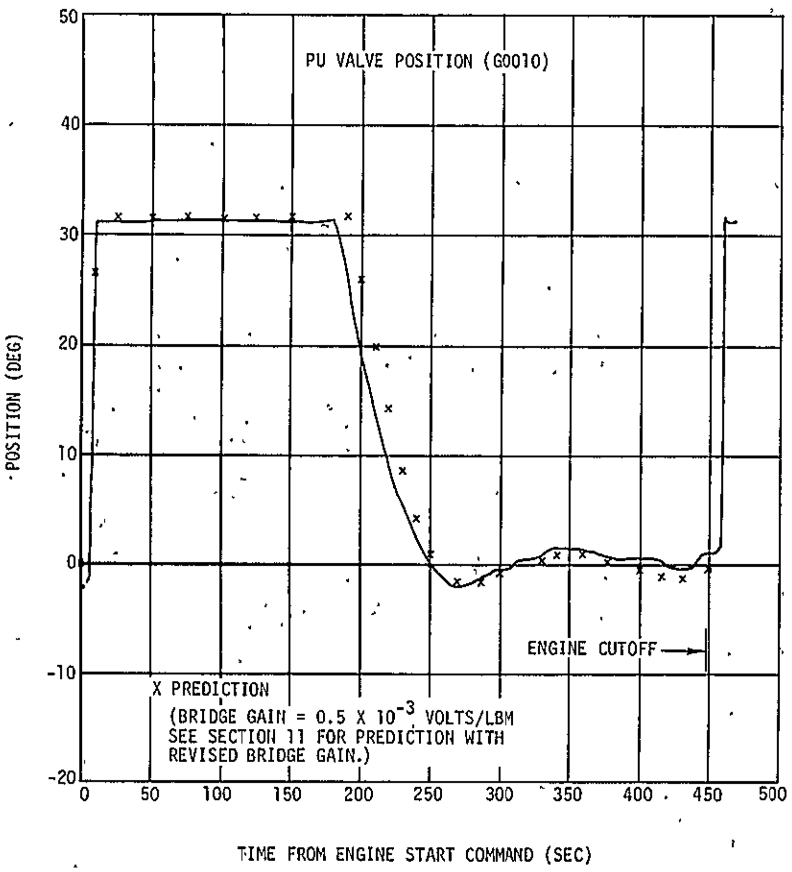


Figure 6-12. PU Valve Position

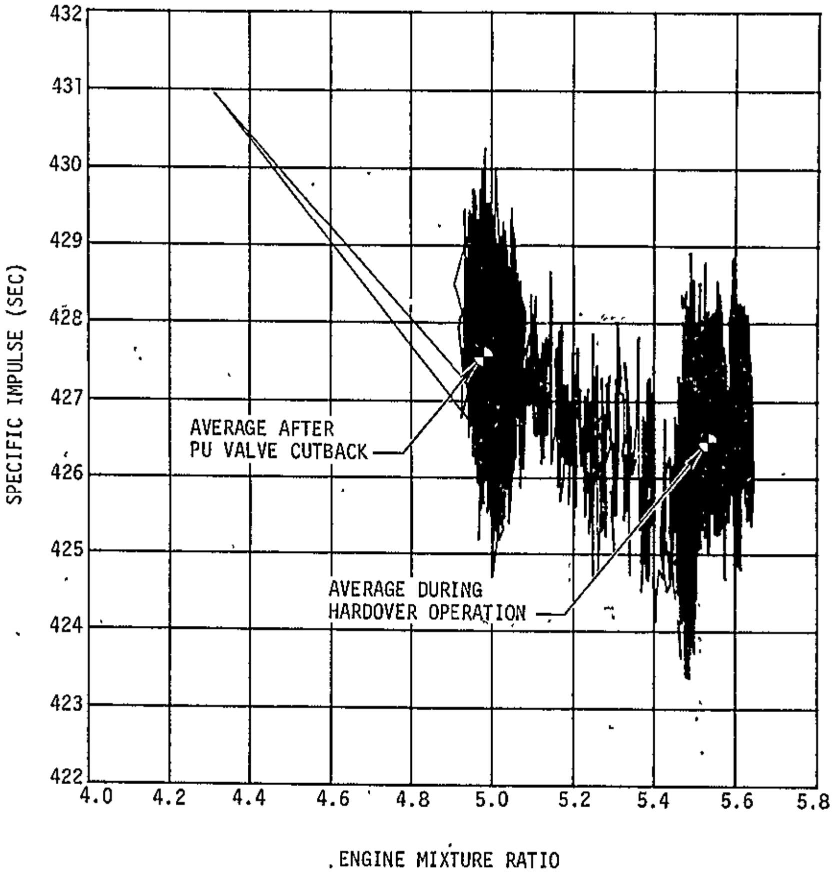


Figure 6-13. Engine Mixture Ratio Comparison to Specific Impulse

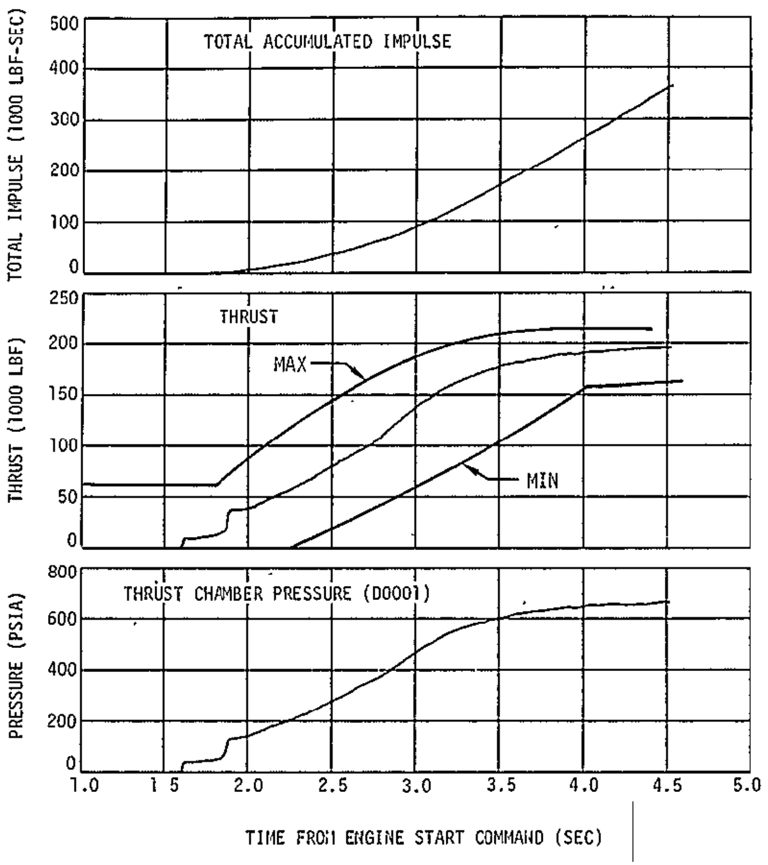


Figure 6-14. Engine Start Transient Characteristics

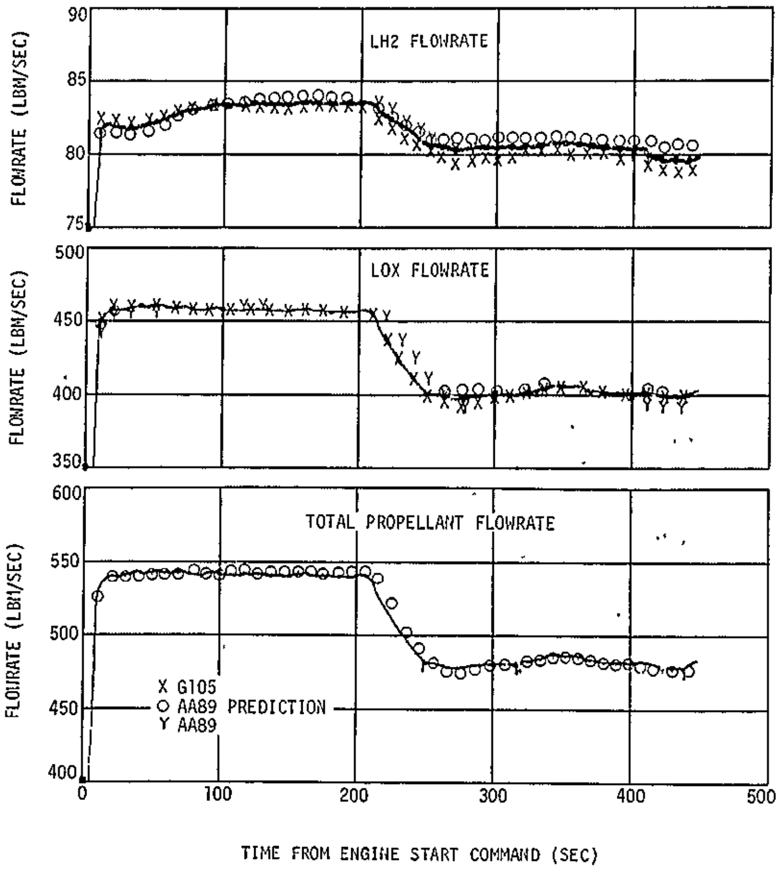


Figure 6-15. Engine Steady-State Performance (Sheet 1 of 2)

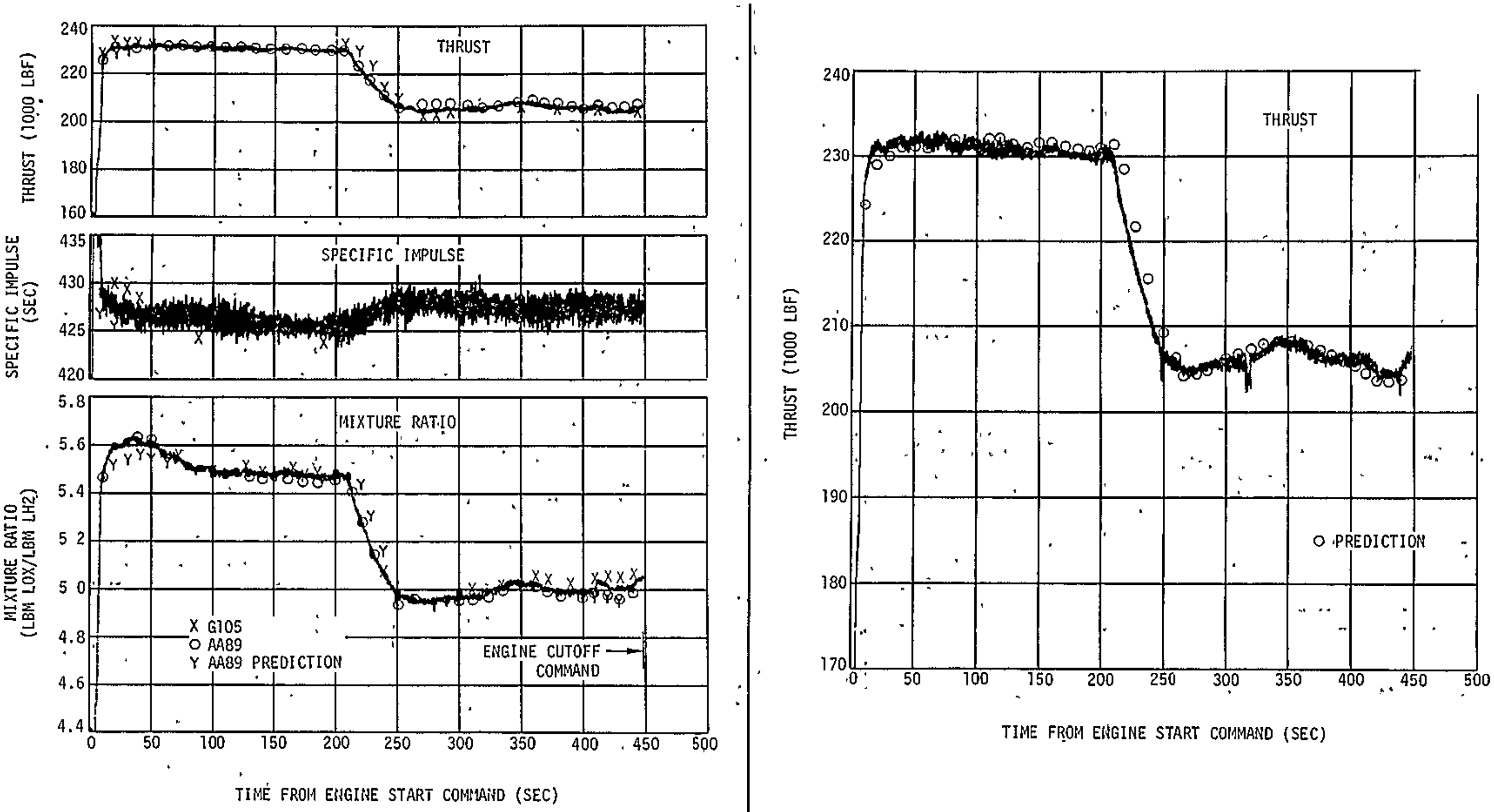


Figure 6-15. Engine Steady State Performance (Sheet 2 of 2)

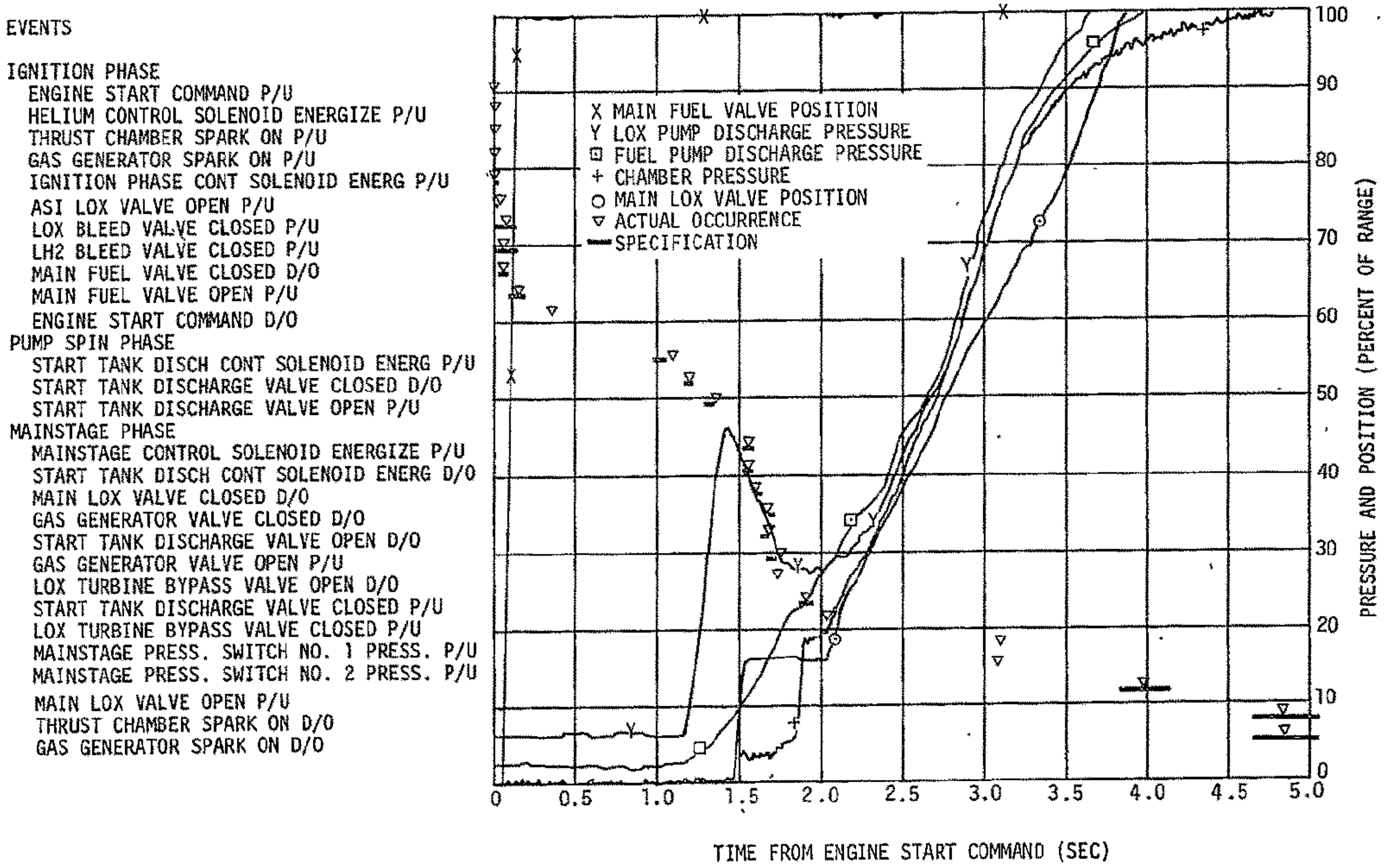


Figure 6-18. Engine Start Sequence

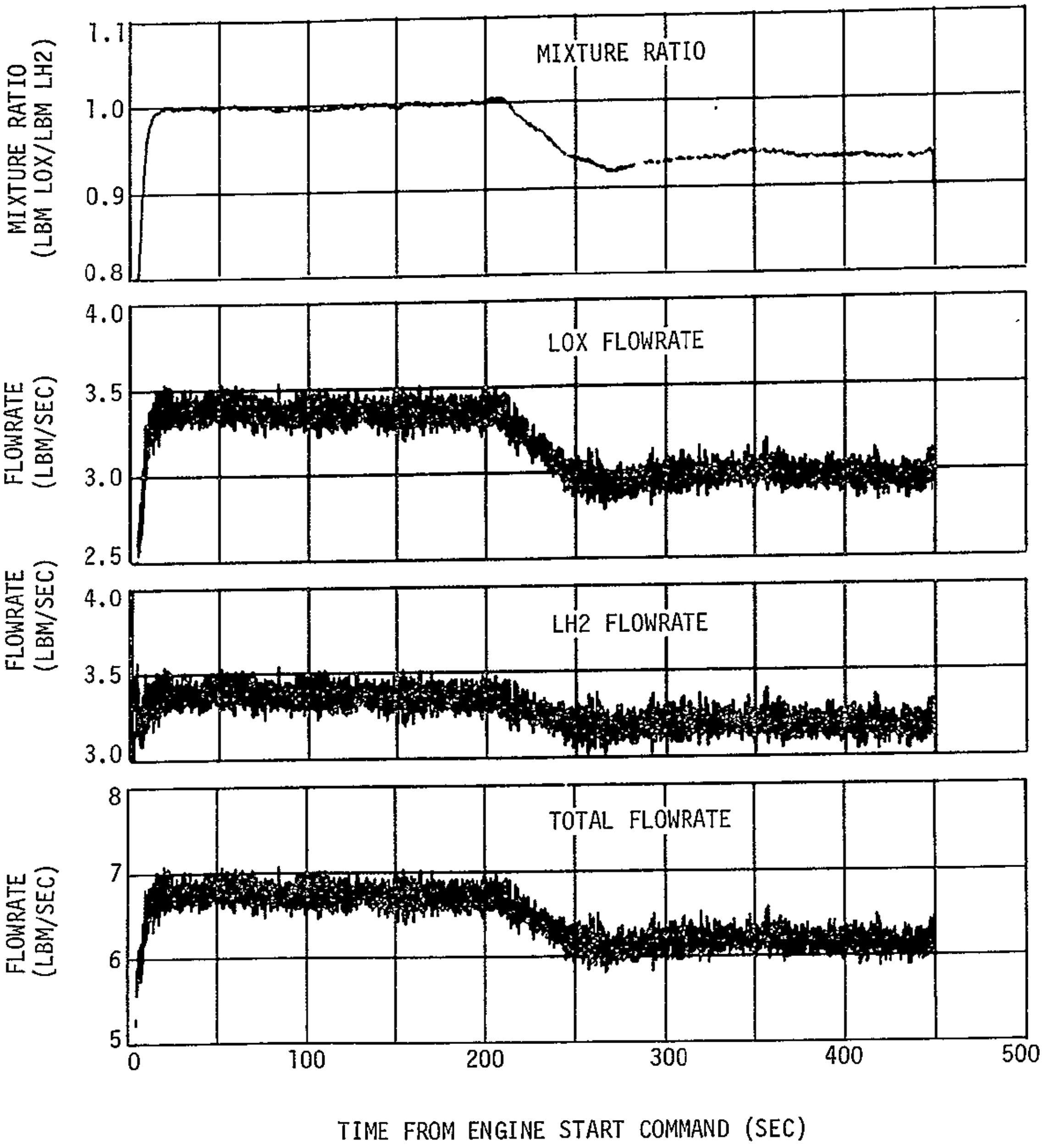


Figure 6-19. Gas Generator Performance

[redacted]

SECTION 7

OXIDIZER SYSTEM

7. OXIDIZER SYSTEM

The oxidizer system functioned adequately, supplying LOX to the engine pump inlet within the specified limits. The net positive suction pressure (NPSP) available at the LOX pump inlet exceeded the engine manufacturer's minimum requirement at all times.

7.1 Pressurization Control

The LOX tank pressurization system (figure 7-1) satisfactorily maintained pressure in the LOX tank throughout the acceptance firing. All portions of the system performed within the design requirements except for the LOX tank pressurization control module which, like the S-IVB-503N, 504N, and 505N modules, operated outside of specification during the overcontrol mode.

7.1.1 Prepressurization

LOX tank prepressurization and the pressure makeup cycle before simulated liftoff were accomplished from ground support equipment (GSE) console B cold helium supply (figure 7-2). The LOX tank pressure increased from 39.0 psia to 41.6 psia due to an ullage volume decrease (caused by the common bulkhead depression that occurs during LH2 tank prepressurization) and to the helium purges of the vent valve and the LOX tank ullage pressure sensing line.

In the course of simulated boost, the ullage pressure twice decayed to 38.6 psia, thus initiating two cold helium sphere supplied helium cycles which increased the ullage pressure to the upper switch setting of 40.5 psia. Since a low ullage pressure prior to Engine Start Command was desired (paragraph 7.1.2), the makeup cycles were immediately followed by manual venting through the boiloff valve to allow the ullage pressure to decay to 39.6 psia. Neither relief venting nor vent valve leakage were indicated during the periods following the boiloff valve vents. Therefore, the protracted pressure decays following the boiloff valve vents were probably caused by ullage gas cooling resulting from heat transfer with the cold common bulkhead. (Ullage gas cooling during prepressurization would have been increased by gas circulation induced by the makeup cycles and vents.)

Significant LOX tank prepressurization data are compared with that from two previous acceptance firings in table 7-1.

7.1.2 Pressurization

The LOX tank pressurization system performance was satisfactory during engine operation (figure 7-3) and compared reasonably well with that from previous stages. The ullage pressure was 43.1 psia at Engine Start Command. Secondary flow was required eight times, instead of the expected six times, to maintain the ullage pressure within the range of 38.6 to 40.5 psia during the firing. The actual pressurant flowrate was somewhat lower than predicted.

The S-IVB-506N stage LOX tank pressurization system data are compared with that from the S-IVB-504N and 505N acceptance firings in table 7-2.

A modified LOX tank pressurization sequence was utilized for the first time during the 506N acceptance firing. To provide the most demanding test conditions, the LOX ullage pressure was maintained at a low level prior to the initiation of pressurization. The cold helium shutoff valves were opened at ESC -2.4 sec, increasing the ullage pressure from 39.4 to 43.1 psia by Engine Start Command. During this 2.4-sec period, 0.45 lbm of helium was added to the LOX tank ullage. During prior flights and acceptance firings, the shutoff valves were not opened until Start Tank Discharge Valve Command (STDV) minus 0.2 sec. The heat exchanger control valve was programmed to the open position during cold helium lead and during the first 21 sec of engine burn. The resulting high initial flowrate completely eliminated the usual LOX tank ullage pressure dip. During previous flights and acceptance firings, the control valve was maintained (by the pressure switch) in the closed position until the ullage pressure had dropped below the lower switch setting. This modified pressurization sequence is planned for all future flights and acceptance firings.

During the start transient, the first overcontrol cycle, and the initial part of the second overcontrol cycle, the LOX pressurization module outlet pressure (D0105) was below the specified limits of 368 to 428 psia because of warm gases upstream of the regulator and because of warm pressurization system components between the regulator and the system control orifices. Although this start transient effect is normal during LOX tank pressurization, the duration of the transient was shorter and the module outlet pressure was higher than usual because the regulator was quickly chilled by the cold helium lead high (overcontrol) flowrate. After the warm gases had been removed and the components had been further chilled, the pressure stabilized above the specification lower limit.

7.1.3 O_2-H_2 Burner Repressurization

LOX tank repressurization was performed during a special test utilizing the O_2-H_2 burner and pressurant helium from the cold helium spheres. The tank was filled to a nominal second start level and prepressurized to 34.7 psia to simulate the burner inlet conditions expected during burner start and subsequent repressurization. The tank conditions are shown in figure 7-4; significant data are compared to that from previous firings in table 7-3.

Burner start was followed by a 7.057 sec lag before the initiation of LOX tank repressurization in order to provide higher burner chamber pressure (and improved combustion stability) during the start transient. The tank was pressurized from 34.7 to 38.6 psia during the approximately 201 sec of repressurization for an average tank pressure rise rate of 1.16 psi/min, which is very close to the theoretical prediction of 1.17 psi/min.

7.1.4 Ambient Repressurization

After burner repressurization, the ambient repressurization test was performed. The LOX tank was loaded to approximately 68 percent to simulate the load expected during orbital restart. The test data are presented in figure 7-5.

The S-IVB-506N ambient repressurization system performance for the acceptance firing is compared with the performances for the 504N and 505N acceptance firings in table 7-3. The 506N ullage pressure was higher initially than that of the 504N and 505N tests; consequently a shorter repressurization period and less repressurant helium were required to pressurize the LOX tank to the pressure switch pickup setting. Since the helium flowrate decays with time, the average helium flowrate and, therefore, the average ullage pressure rise rate were higher than usual during this shorter repressurization period.

With the appropriate corrections for boundary conditions, the actual ullage pressure increase was in close agreement with the theoretical value predicted for a 118-sec repressurization.

7.2 Cold Helium Supply

The cold helium spheres were the source of the pressurant utilized for both propellant tanks during O_2-H_2 burner operation and for the LOX tank during engine operation.

The system performance during the O_2-H_2 burner firing is discussed in paragraph 10.4.

During J-2 engine operation, demands on the cold helium system were normal and were adequately met. Procedural changes necessitated by a GSE helium leak resulted in a lower than normal sphere pressure and a slightly higher than normal sphere temperature at Engine Start Command. The sphere pressure (2,664 psia) at Engine Start Command was well within the start requirement of 2,600 ±600 psia; however, due to the failure of the primary cold helium pressure measurement, the backup measurement was used for system evaluation. The 506N system performance is shown in figure 7-6. System conditions at significant times are compared in table 7-4 for S-IVB-506N, -505N, and -504N.

7.3 J-2 Heat Exchanger

The J-2 heat exchanger functioned satisfactorily (figure 7-7). The heat exchanger pressures and temperatures, heat exchanger helium flowrates and heat input rate, the LOX vent inlet temperature and pressure, and the theoretical mixture temperature compared reasonably well with previous test data. Table 7-5 compares significant 506N acceptance firing data with that from two previous acceptance firings.

7.4 LOX Pump Chilldown

The LOX pump chilldown system performance was adequate. At Engine Start Command, the NPSP at the LOX pump inlet was above the minimum 11.6 psi required at that time. The results of the chilldown performance calculations are presented in figures 7-8 and 7-9; significant chilldown system data are compared with 505N and 504N data in table 7-6.

The chilldown pump was started at T_0 -289 sec in order to closely simulate conditions during flight. The chilldown shutoff valve was left open until ESC +410 sec. This change is due to the sequence change of the LH2 Step Pressurization ON Command which is concurrent with chilldown shutoff valve close command.

For the calculation of heat input to the LOX chilldown system, the normal reference temperature for section 1 (tank to engine pump inlet) is the chilldown pump discharge temperature (C0163). This assumes no heat input from the tank to the chilldown pump outlet. Since C0163 was not installed on 506N, the LOX bulk temperature (C0040) was used as a basis for constructing the chilldown pump discharge temperature.

7.5 Engine LOX Supply

The LOX supply system (figure 7-10) delivered the necessary quantity of LOX to the engine pump inlet throughout the engine firing and maintained the pressure and temperature conditions within a range that provided a LOX pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 7-11 and compared with that from two previous acceptance firings in table 7-7.

During engine operation, the LOX pump inlet pressure and temperature were very near the predicted values. The LOX pump inlet temperature and pressure were plotted in the engine LOX pump operating region (figure 7-12) and showed that the LOX pump inlet conditions were satisfactory throughout engine operation.

In figure 7-13, the LOX pump inlet temperature is plotted against the mass remaining in the tank during engine operation and compared to the 504N and 505N acceptance firing data. The data used for comparison have been biased to the LOX pump inlet temperature observed at Engine Start Command of the S-IVB-506N acceptance firing to correct for instrumentation error, different heating during pressurization, and other test-to-test variations.

TABLE 7-1
LOX TANK PREPRESSURIZATION DATA

PARAMETER	S-IVB-506N	S-IVB-504N	S-IVB-505N
Prepressurization duration (sec)	12.9	14.0	18.5
Number of makeup cycles	3*	2	2
Prepressurization helium			
Flowrate (lbm/sec)	0.36	0.32	0.25
Mass added to LOX tank during prepressurization (lbm)	4.58	4.5	4.25
Mass added to LOX tank during makeup cycles (lbm)	2.20*	1.4	1.32
Ullage pressure			
At prepressurization initiation (psia)	14.9	15	15.3
At prepressurization termination (psia)	41.0	40.6	41.2
At Engine Start Command (psia)	43.1	37.5	39.1
Events (sec from T_0)			
Prepressurization initiation	-164.38	-159.24	-159.01
Prepressurization termination	-153.91	-145.263	-142.17
Engine Start Command	511.378	543.463	511.789

*1.61 lbm of helium were added to the tank during the GSE-supplied makeup cycle; two cold-helium-sphere-supplied makeup cycles during simulated boost added 0.59 lbm more to the tank.

TABLE 7-2
LOX TANK PRESSURIZATION DATA

PARAMETER	S-IVB-506N	S-IVB-504N	S-IVB-505N
Number of secondary flow intervals	8	8	6
Pressure control band			
Minimum (psia)	38.6	38.7	38.4
Maximum (psia)	40.5	40.2	40.1
Ullage Pressure			
At Engine Start Command (psia)	43.1*	39.1	37.5
Minimum during start transient (psia)	42.5	38.7	35.6
At Engine Cutoff Command (psia)	39.6	39.3	39.2
Total pressurant flowrate			
Overcontrol (lbm/sec)	0.32 to 0.43	0.30 to 0.45	0.38 to 0.43
Predicted (lbm/sec)	0.37 to 0.45	0.30 to 0.43	0.39 to 0.43
Undercontrol (lbm/sec)	0.24 to 0.32	0.20 to 0.325	0.28 to 0.32
Predicted (lbm/sec)	0.28 to 0.34	0.280 to 0.315	0.29 to 0.33
Maximum LOX tank vent inlet temperature (deg R)	**	478	510

*At the initiation of the pre-burn cold helium blowdown (ESC -2.4 sec) the ullage pressure was 39.3 psia.

**Instrumentation not available.

TABLE 7-3
LOX TANK REPRESSURIZATION DATA

PARAMETER	S-IVB-506N		S-IVB-505N		S-IVB-504N	
	AMBIENT	BURNER	AMBIENT	BURNER	AMBIENT	BURNER
Repressurization duration (sec)	118	201	205	181	228	192
Number of makeup cycles	0	0	0	0	0	0
Repressurization helium						
Usage (lbm)	11.5	5.5*	14.7	5.2*	13.4	5.3*
Average flowrate (lbm/sec)	0.0974	0.025	0.0717	0.027	0.0587	0.025
Orifice effective area (in^2)	0.00858	0.00565	0.00875	0.00563	0.00881	0.00554
Ullage pressure						
At repressurization initiation (psia)	31.5	34.7	25.9	34.4	24.5	34.4
At repressurization termination (psia)	40.3	38.6	36.6	38.0	34.7	38.2
Rise rate (psi/min)	4.47	1.16	3.14	1.19	2.68	1.18

*These values include the flow through the pilot bleed port on the burner helium shutoff valves. See paragraph 10.5 for further information.

TABLE 7-4
COLD HELIUM SUPPLY DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Pressure			
Simulated liftoff (psia)	2,806	3,070	3,011
Engine Start Command (psia)	2,664*	2,425***	2,927
Engine Cutoff Command (psia)	1,021	815	1,119
Average Temperature			
Simulated liftoff (deg R)	41.6	40.3	40.3
Engine Start Command (deg R)	40.8*	36.8**	39.7
Engine Cutoff Command (deg R)	43.8	44.9	44.5
Helium Mass			
Engine Start Command (lbm)	360*	337	378
Engine Cutoff Command (lbm)	211	168	216
Helium Consumption			
Calculated from sphere conditions (lbm)	149**	169	162
Calculated from flowrate integration (lbm)	145**	148	146

*At ESC -2.4 sec, when LOX pressurization was initiated

**Includes 2.4 sec of flow prior to Engine Start Command

***Low because of cold helium leak

TABLE 7-5

J-2 HEAT EXCHANGER DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Flowrate through heat exchanger			
During overcontrol (lbm/sec)	0.20	0.20	0.20
During undercontrol (lbm/sec)	0.085	0.080	0.085
Heat exchanger inlet temperature			
During overcontrol (deg R)	70	62	73
During undercontrol (deg R)	80	70	90
Minimum (deg R)	60	59	63
Heat exchanger outlet temperature			
At end of 50-sec transient (deg R)	960	960	955
During overcontrol (deg R)	980	975	980
During undercontrol (deg R)	1,000	995	1,000
At Engine Cutoff Command (deg R)	962	941	964
Heat exchanger outlet pressure			
During overcontrol (psia)	350	330	325
During undercontrol (psia)	400	375	385
Average LOX vent inlet pressure			
During overcontrol (psia)	62	70	71
During undercontrol (psia)	48	50	51
Maximum LOX vent inlet temperature (deg R)	*	478	510

*Instrumentation not available.

TABLE 7-6
LOX CHILLDOWN SYSTEM PERFORMANCE DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
NPSP			
At Engine Start Command (psi)	34.6	30.3	28.6
Minimum required at start (psi)	11.6	16.5	16.5
At opening of prevalve (psi)	39.7	38.7	37.0
Pump inlet conditions			
Pressure at engine start (psia)	51.3	47.0	45.9
Temperature at engine start (deg R)	164.5	164.7	165.4
Average flow coefficient ($sec^2/in^2 ft^3$)	16.9	15.7	16.5
Heat absorption rate (Btu/hr)			
Section 1 (tank to pump inlet)	3,200	3,500	5,500
Section 2 (pump inlet to bleed valve)	14,500	16,000	9,000
Section 3 (bleed valve to tank)	1,800	1,500	0*
Total	19,500	21,000	14,500
Childown flowrate			
Unpressurized (gpm)	39.4	40.8	40.5
Pressurized (gpm)	42.5	43.0	43.0
Chilldown system pressure differential			
Unpressurized (gpm)	9.8	9.0	9.5
Pressurized (gpm)	10.7	10.9	10.8
Events (sec from T_0)			
Chilldown initiated	-289.4	-298.2	-298.5
Prepressurization	-164.4	-159.0	-159.6
Prevalve open command	507.4	507.5	539.1
Prevalve closed signal dropout	508.6	508.8	540.0
Prevalve open signal pickup	510.2	510.9	541.8
Delay between prevalve open command and pickup of open signal	2.78	3.45	2.66
Engine Start Command	511.4	511.8	543.6
Chilldown shutoff valve closed	921.9	862.2	893.9

*Section 3 heat absorption rate could not be calculated because of data inaccuracy.

TABLE 7-7
LOX PUMP INLET CONDITION DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Pump inlet conditions			
Static pressure at engine start (psia)	51.3	46.8	45.9
Temperature at engine start (deg R)	164.5	164.8	165.4
Temperature at engine cutoff (deg R)	166.3	166.4	167.7
NPSP requirements at pump interface			
Minimum at engine start (psi)	11.6	16.3	16.3
At high EMR (psi)	19.8	20.8	20.8
After EMR cutback (psi)	14.7	15.6	15.7
NPSP available at pump interface			
At engine start (psi)	34.6	30.0	28.6
Maximum during firing (psi)	34.6	34.4	28.5
Time of maximum (sec from ESC)	0	5	85
Minimum during firing (psi)	22.4	22.1	21.6
Time of minimum (sec from ESC)	448	450	440
At Engine Cutoff Command (psi)	22.4	22.1	21.6
LOX feed duct			
At high EMR			
Pressure drop (psi)	2.0	2.5	1.4
Flowrate (lbm/sec)	460	463	460
After EMR cutback			
Pressure drop (psi)	1.2	1.5	0.8
Flowrate (lbm/sec)	400	397	405

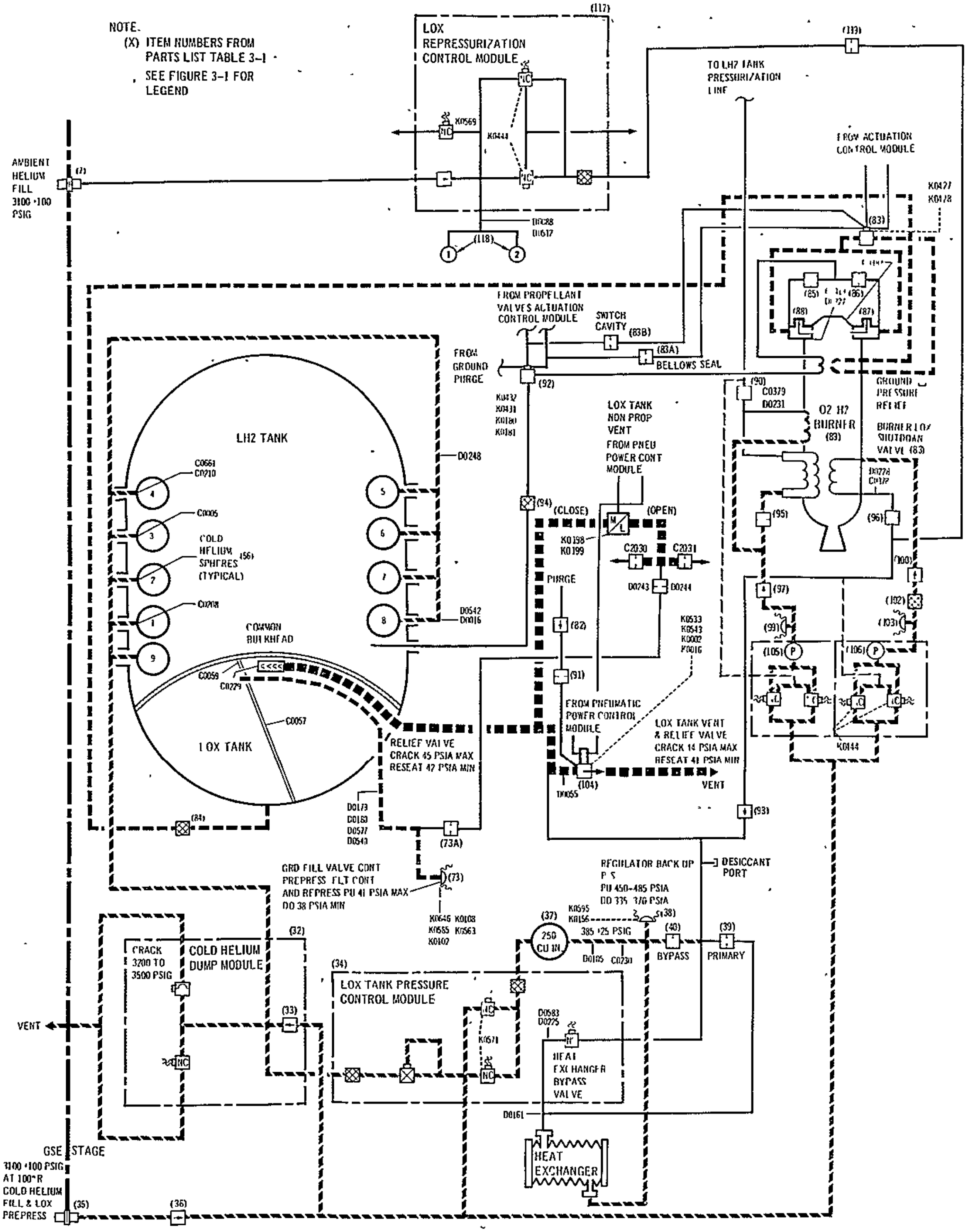


Figure 7-1. LOX Tank Pressurization System

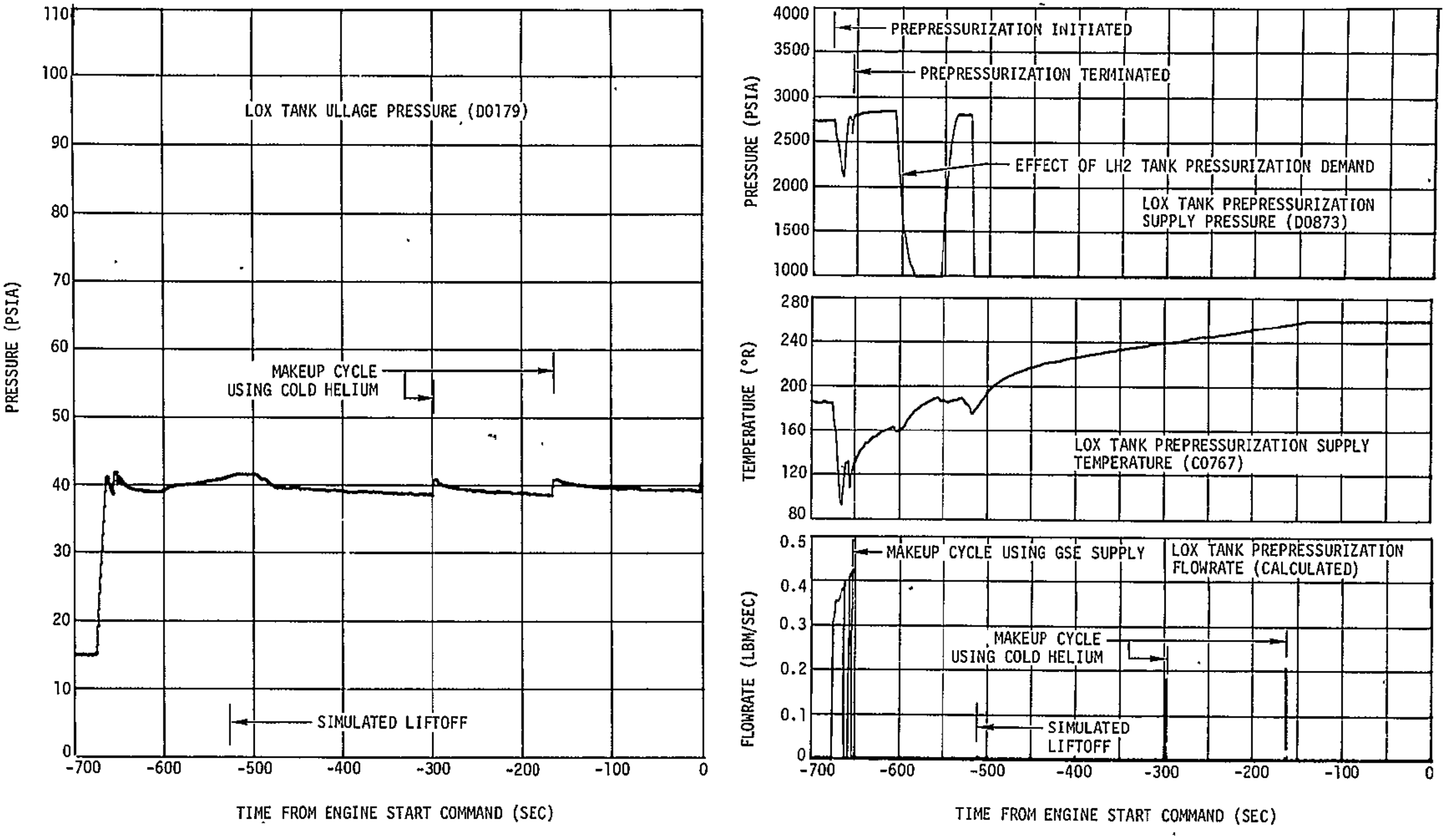


Figure 7-2. LOX Tank Prepressurization System Performance

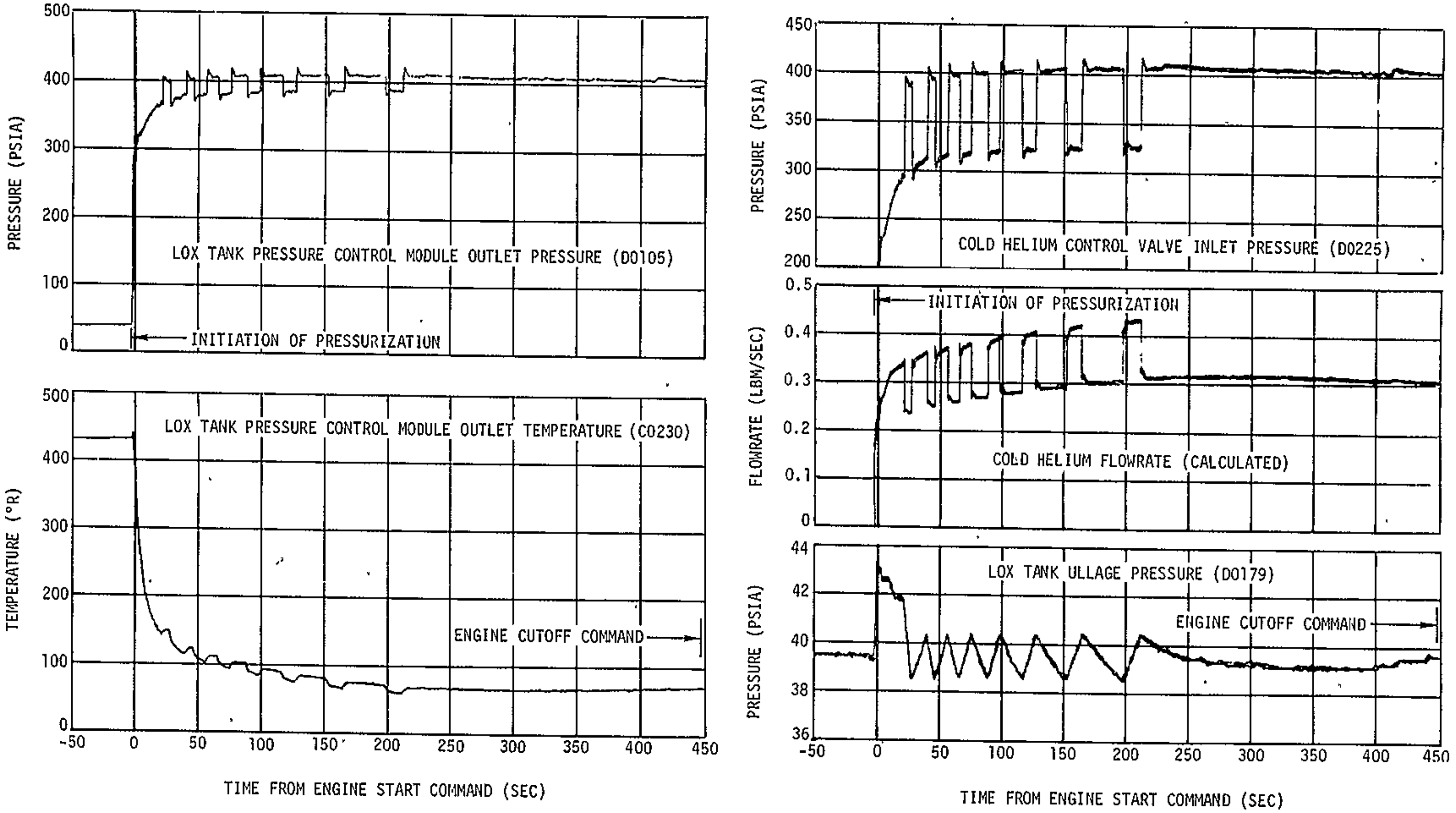


Figure 7-3. LOX Tank Pressurization System Performance

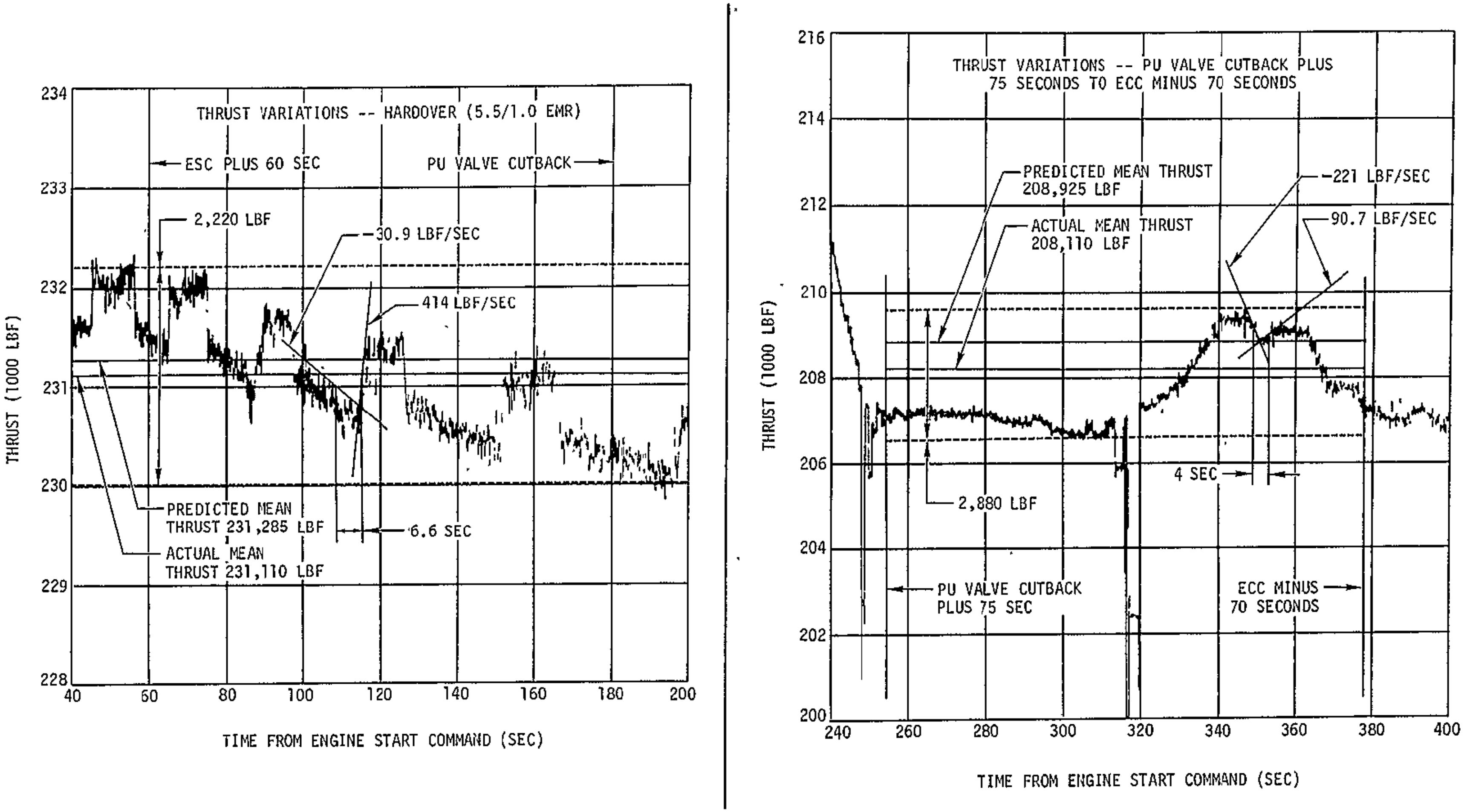


Figure 6-16. Thrust Variation (Sheet 1 of 2)

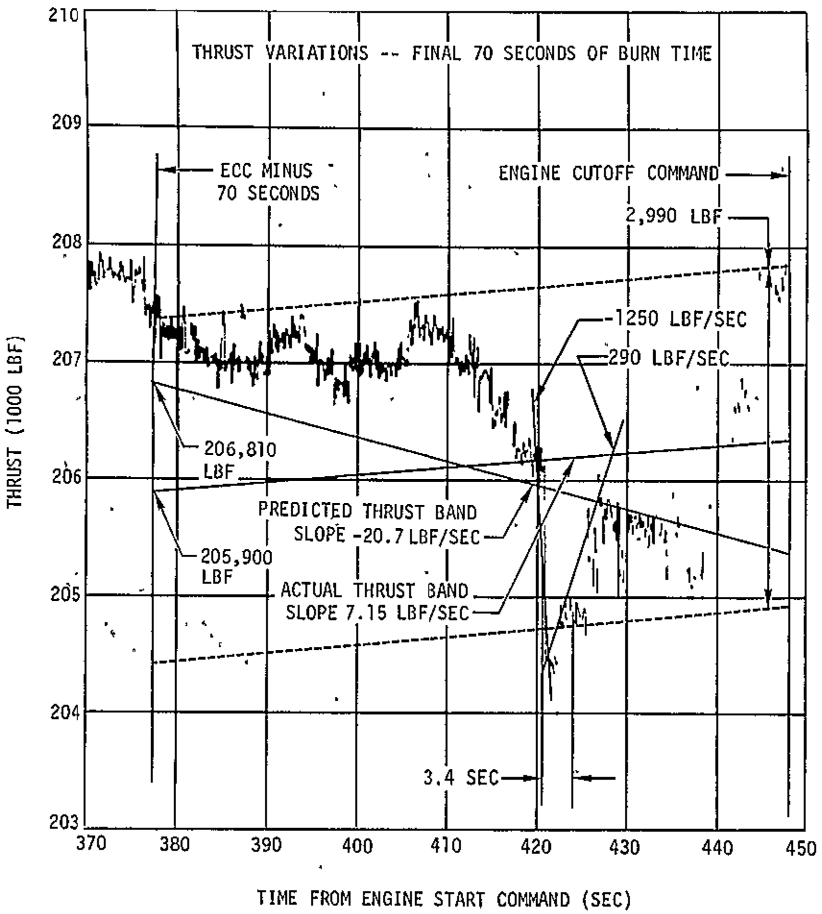


Figure 6-16. Thrust Variation (Sheet 2 of 2)

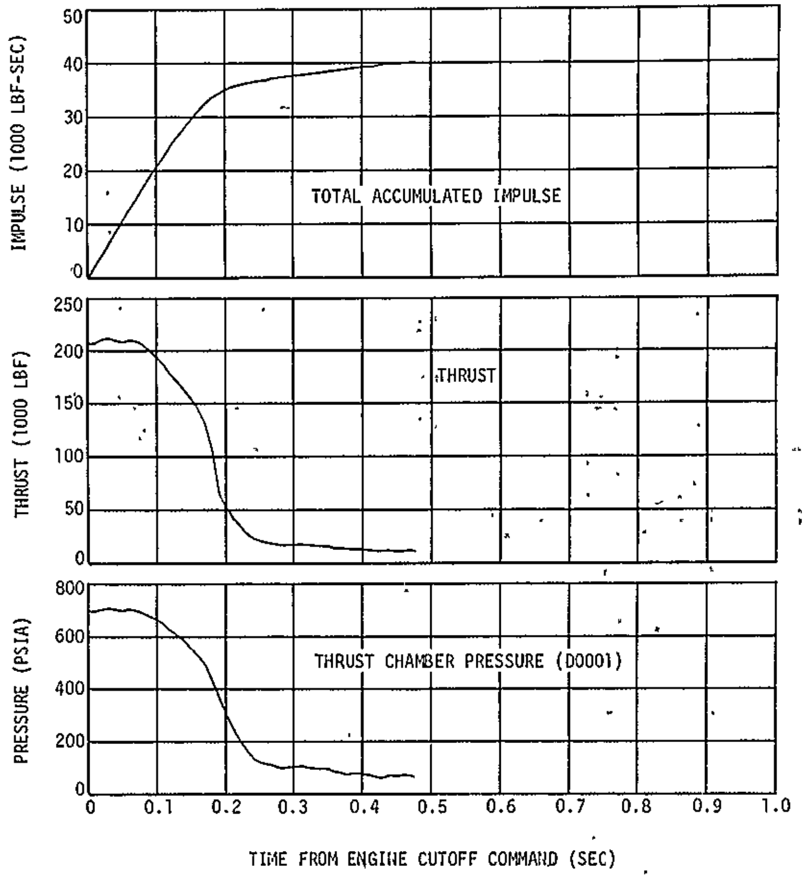


Figure 6-17. Engine Cutoff Transient Characteristics

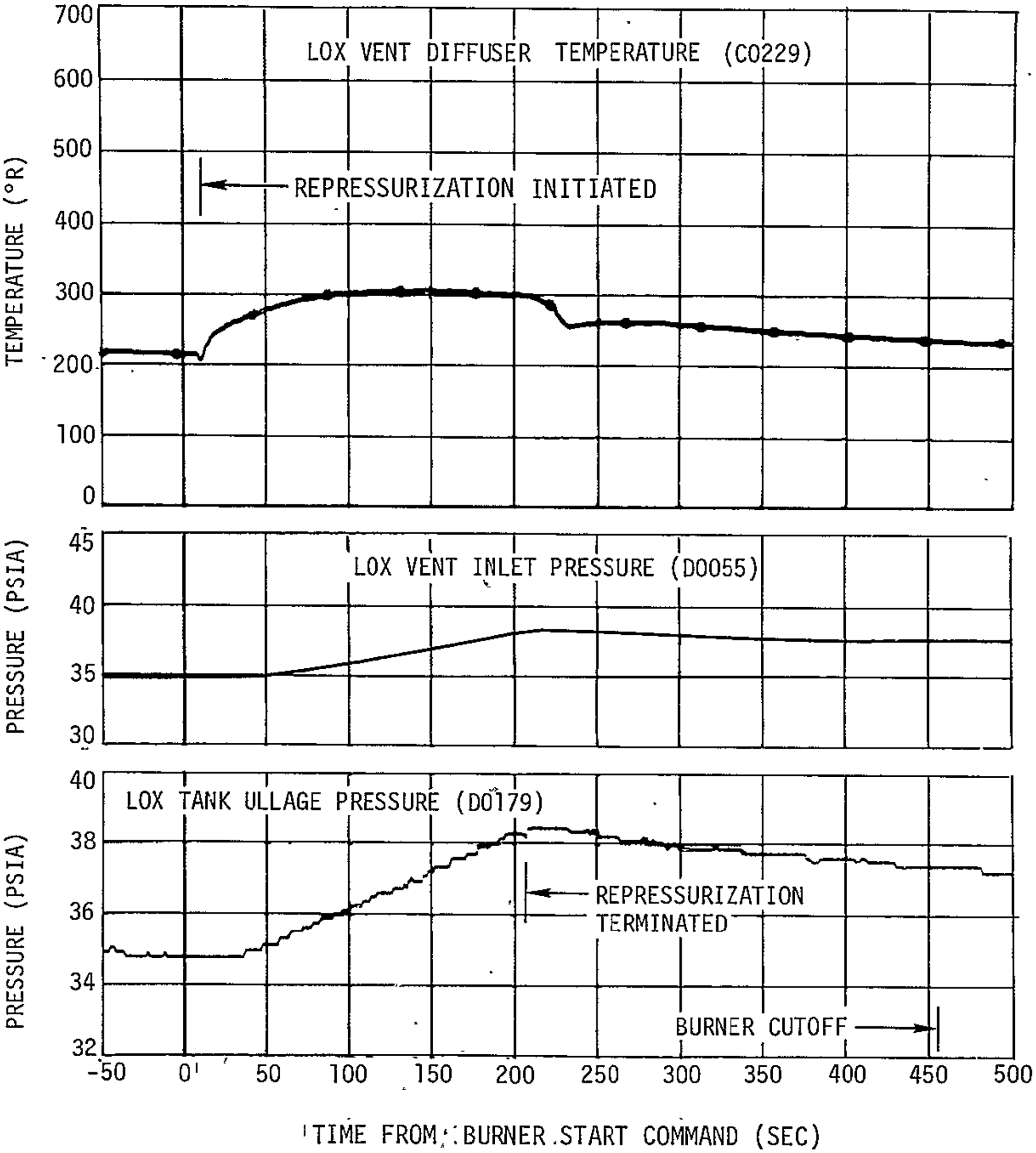


Figure 7-4. LOX Tank Repressurization with O_2-H_2 Burner

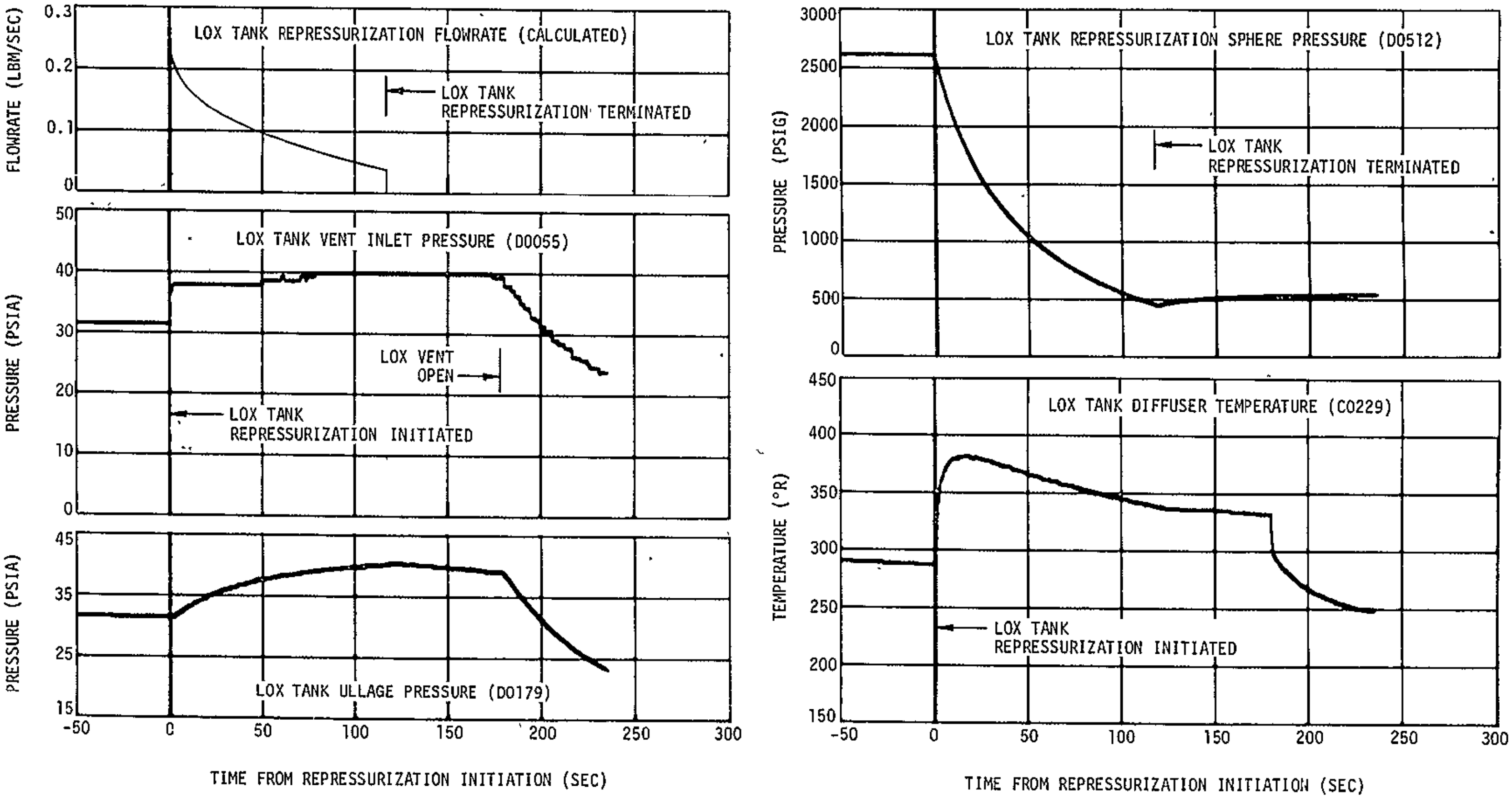


Figure 7-5. LOX Tank Ambient Helium Repressurization

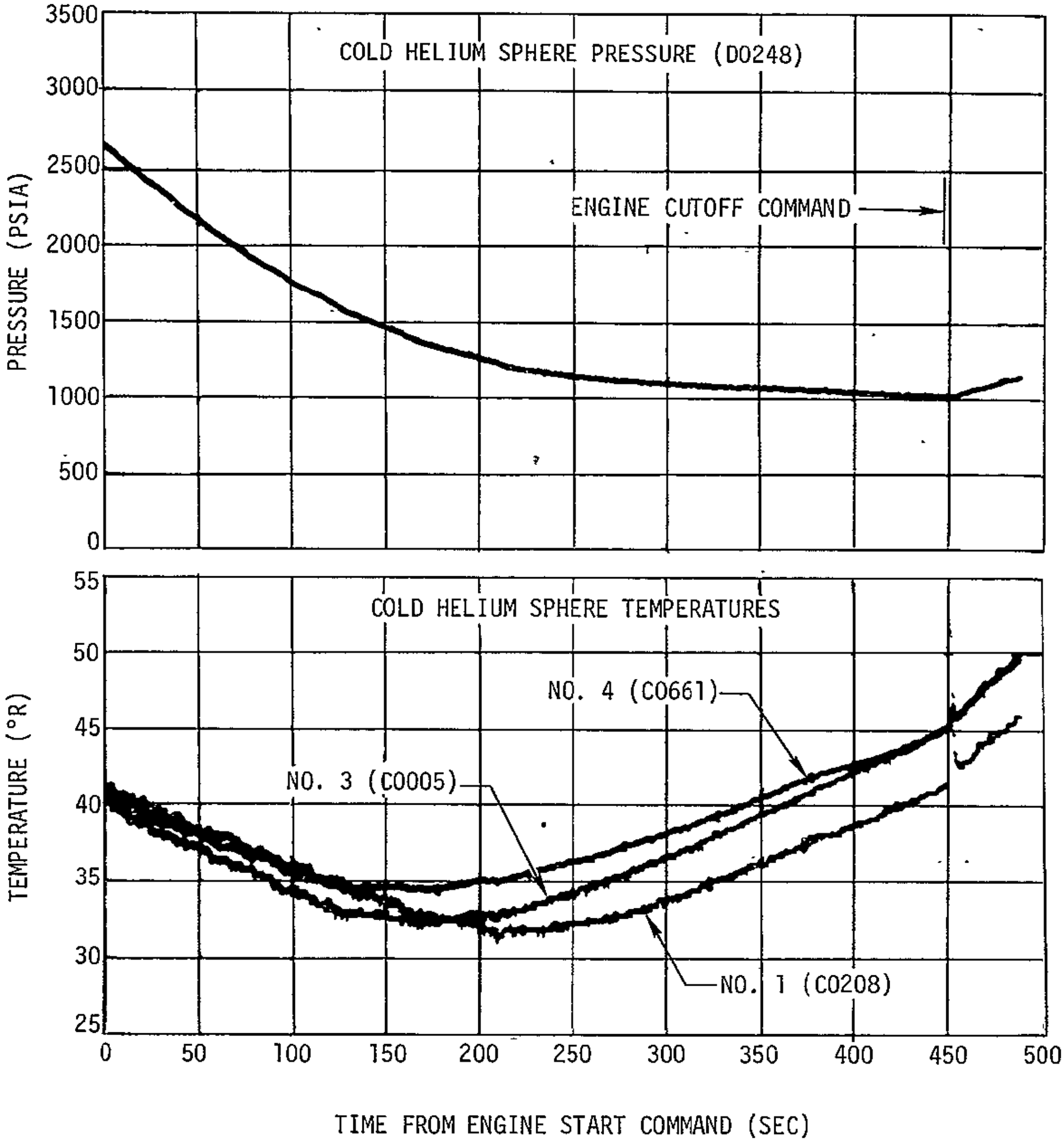


Figure 7-6. Cold Helium Supply

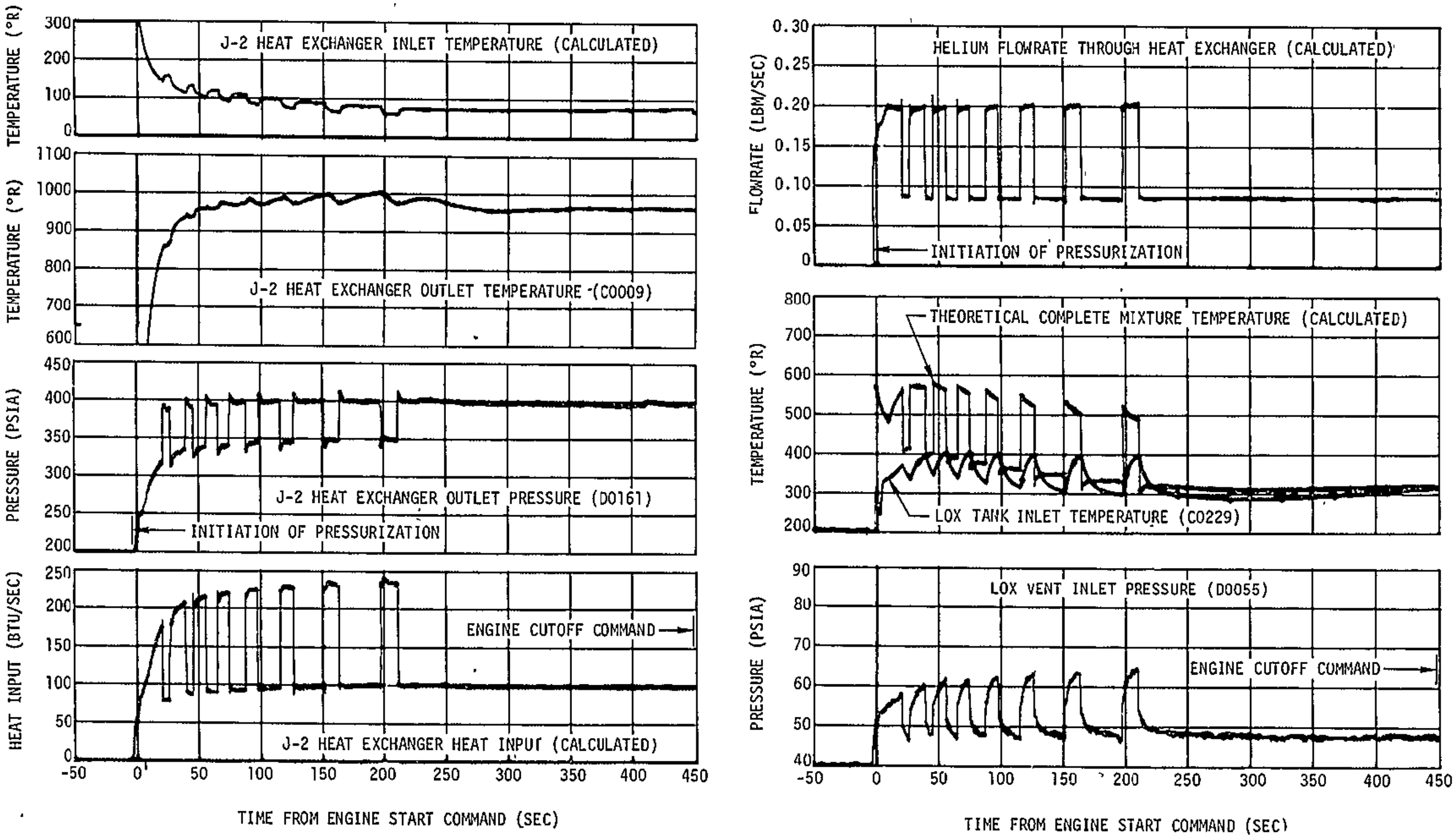


Figure 7-7. J-2 Heat Exchanger Performance

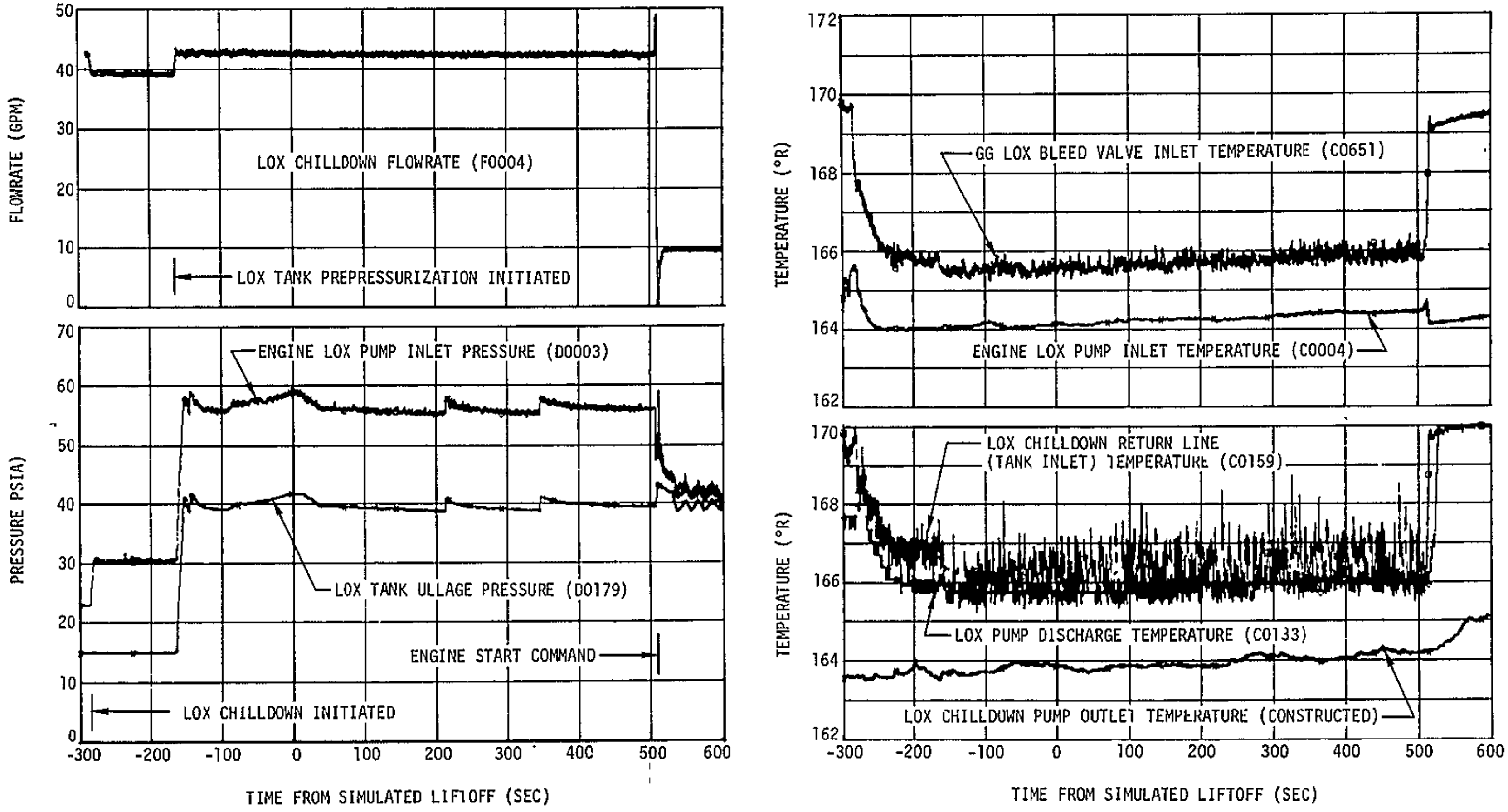


Figure 7-8. LOX Pump Childown System Operation

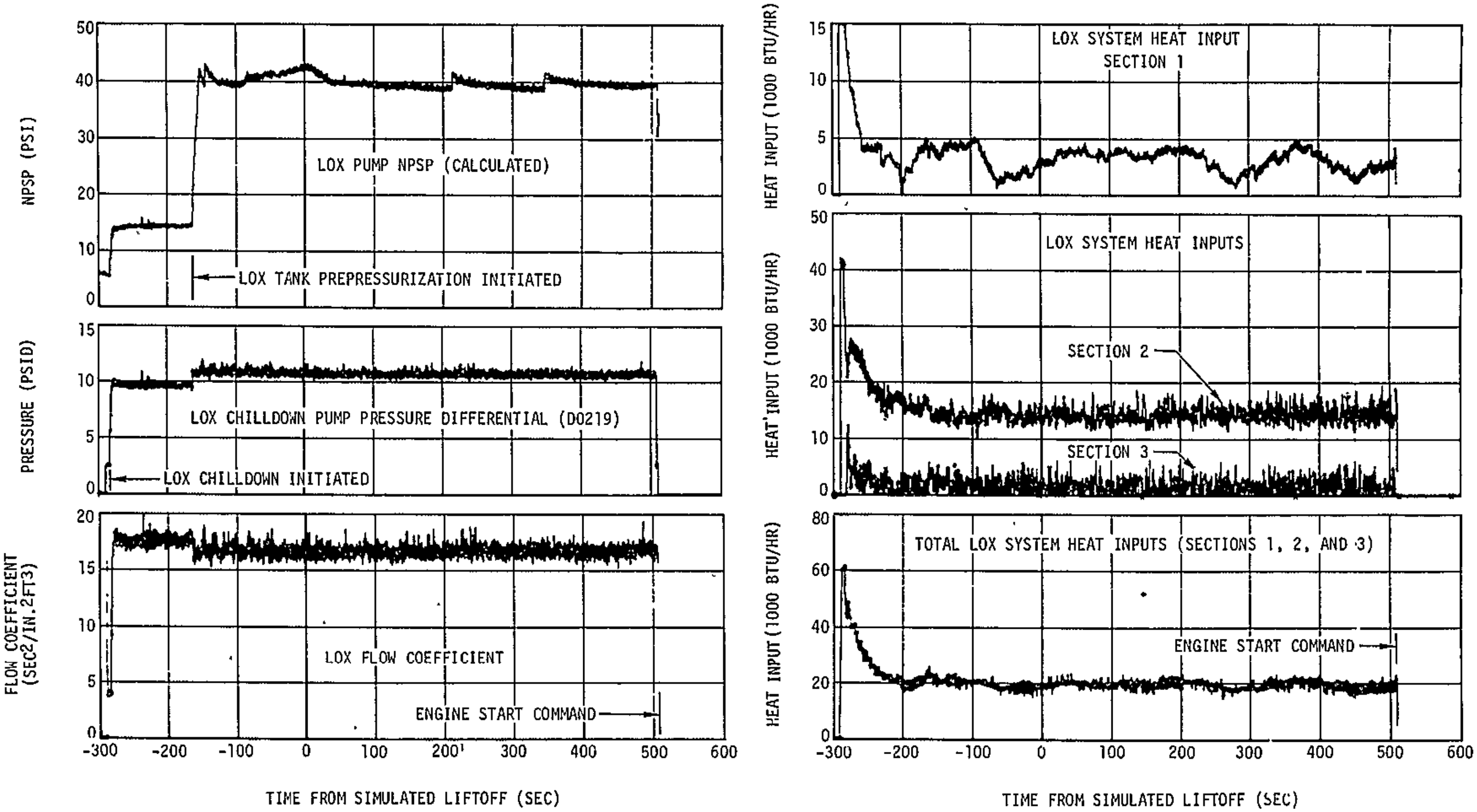
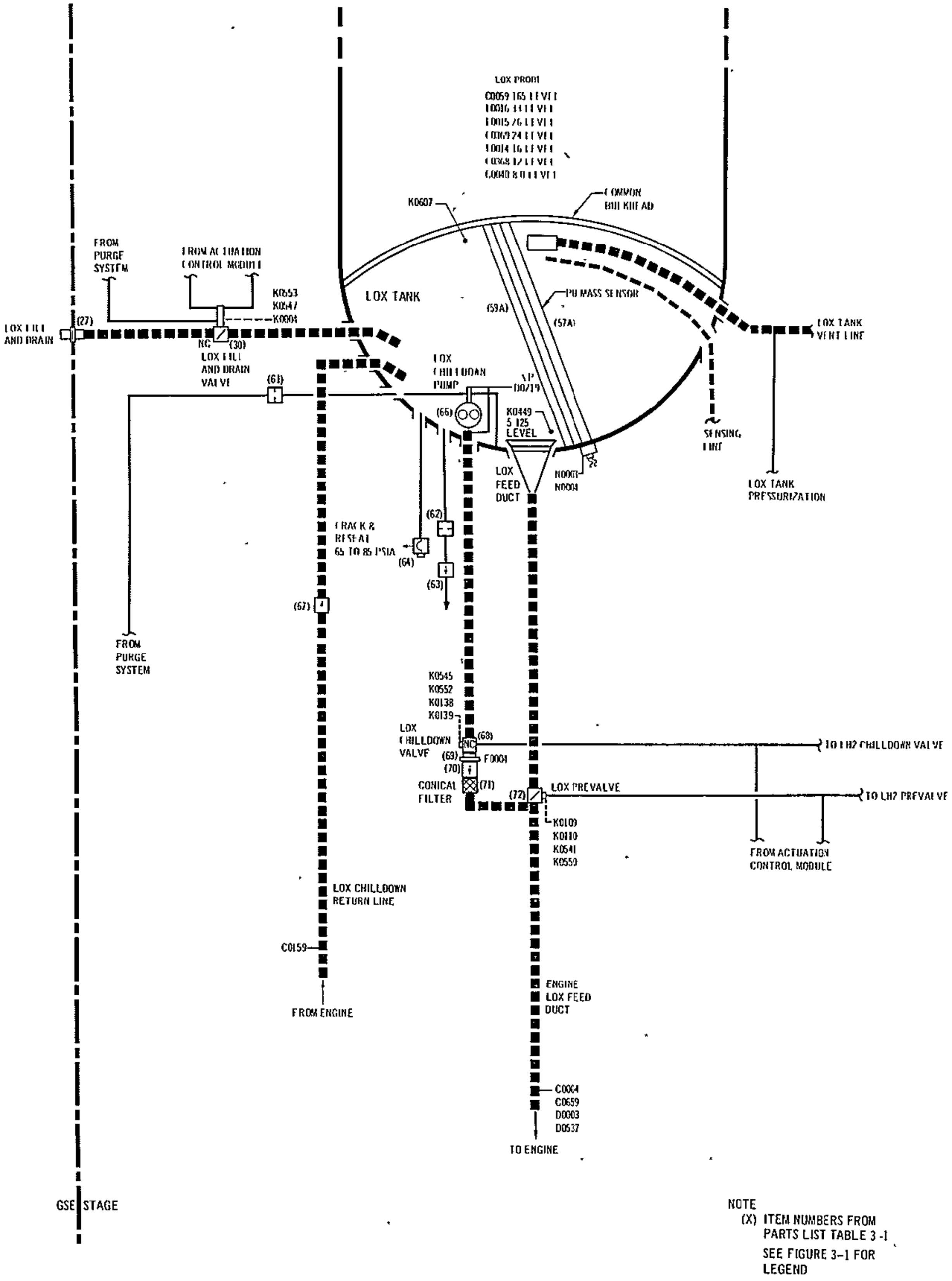


Figure 7-9. LOX Pump Chilldown System Performance



NOTE
(X) ITEM NUMBERS FROM
PARTS LIST TABLE 3-1
SEE FIGURE 3-1 FOR
LEGEND

Figure 7-10. LOX Supply System

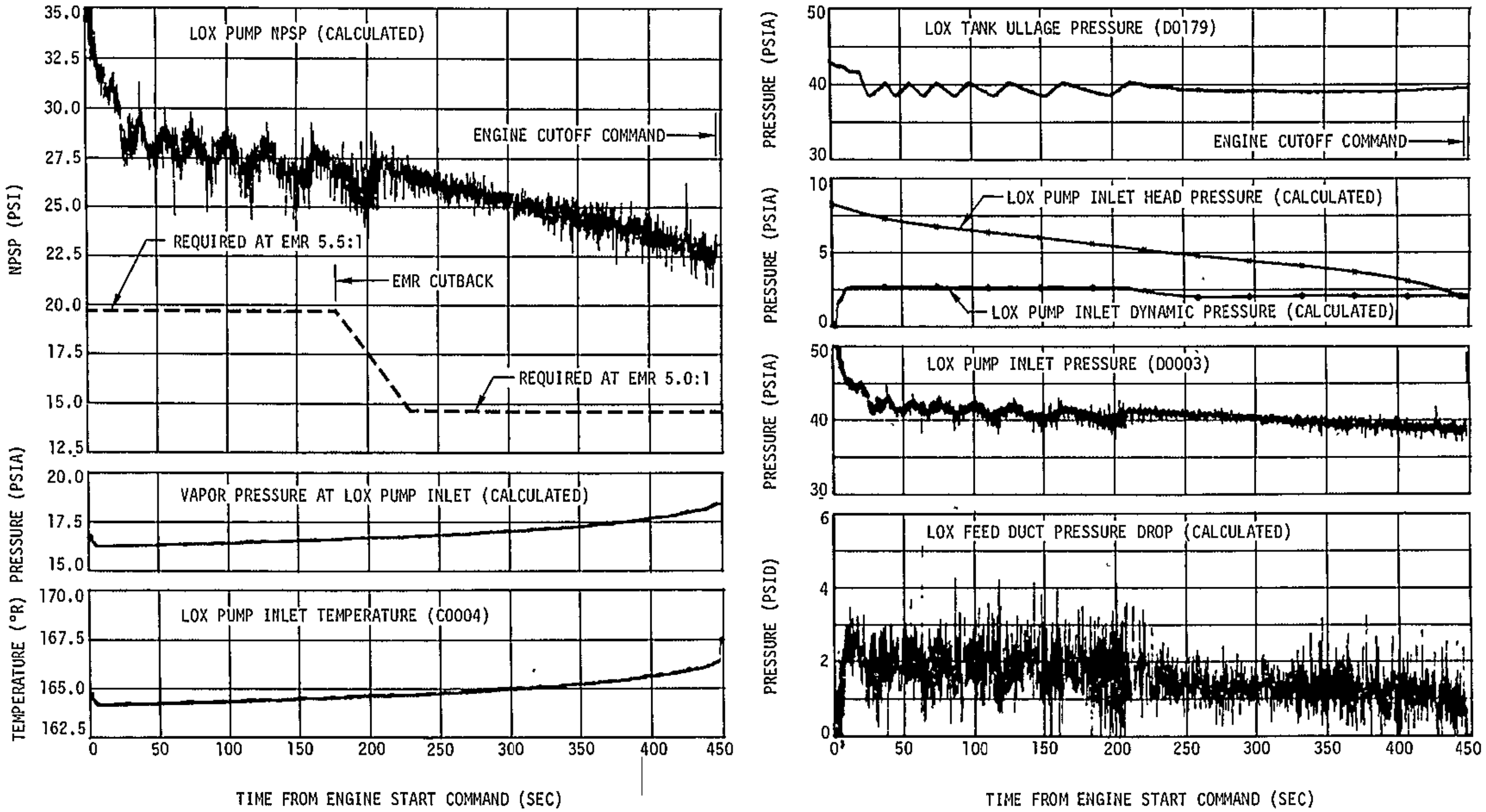


Figure 7-11. LOX Pump Inlet Conditions

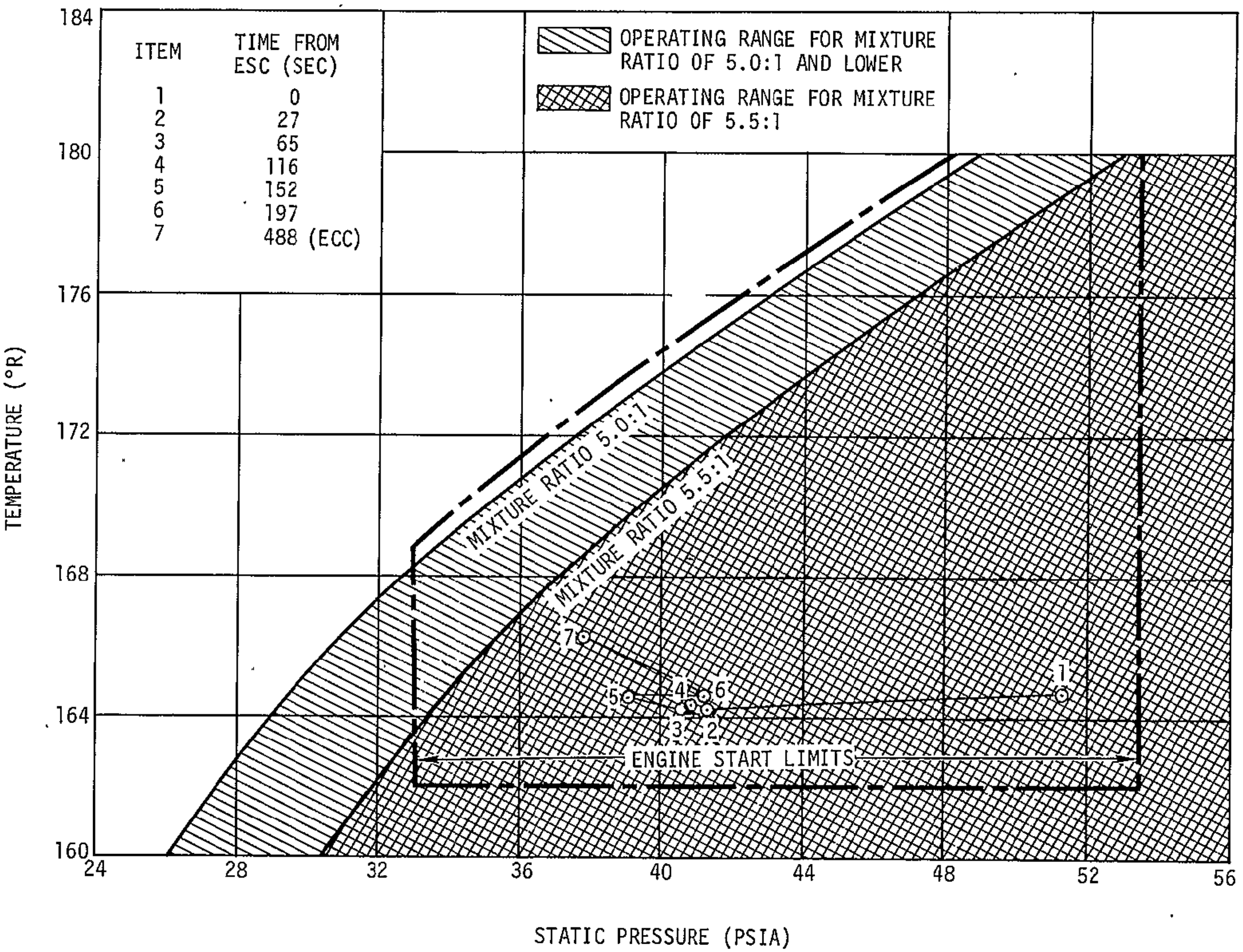


Figure 7-12. LOX Pump Inlet Conditions During Firing

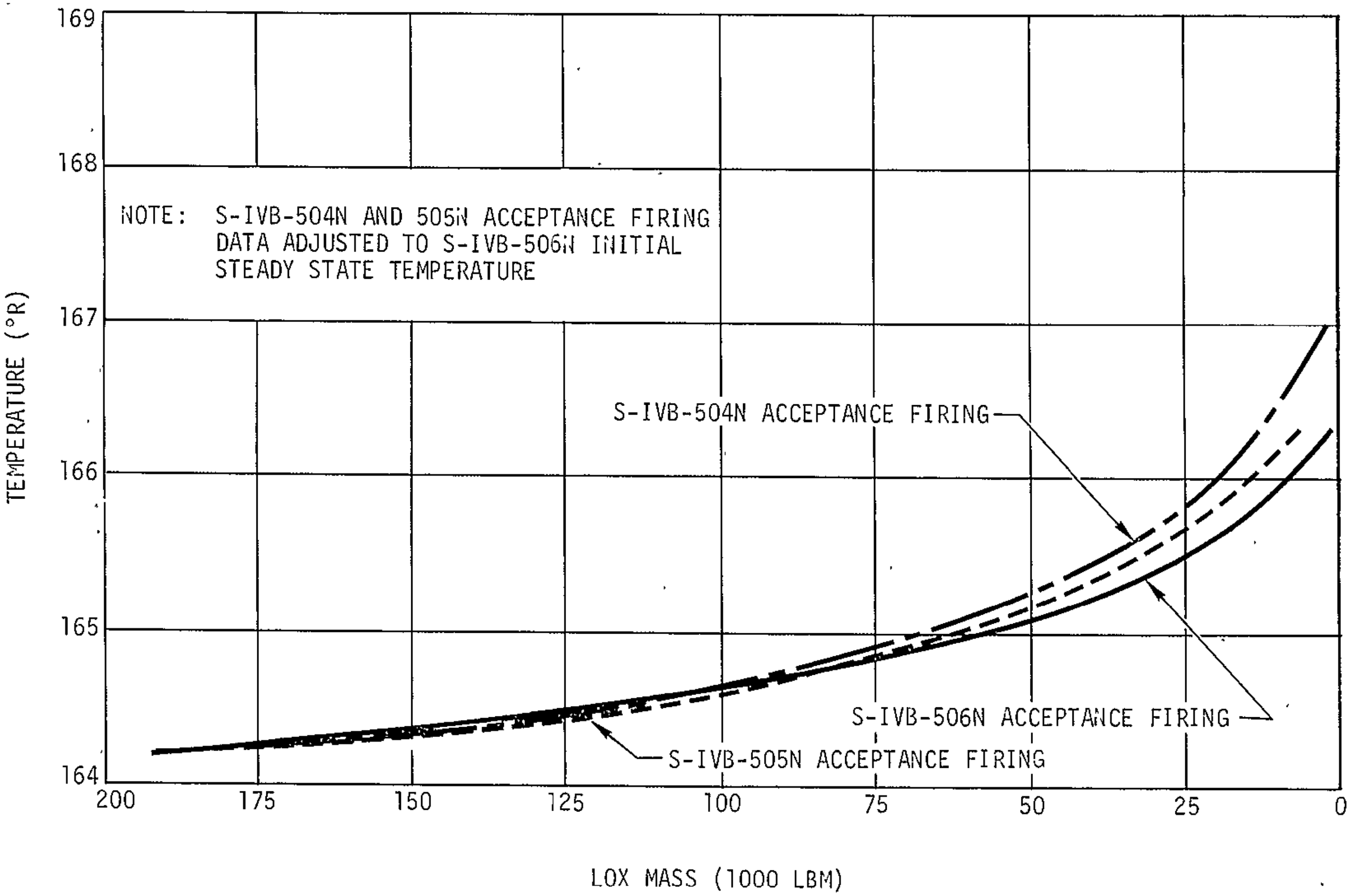


Figure 7-13. Effect of LOX Mass Level on LOX Pump Inlet Temperature

SECTION 8

FUEL SYSTEM

8. FUEL SYSTEM

The fuel system performed as designed and supplied LH2 to the engine within the limits defined in the engine specification.

8.1 Pressurization Control

The LH2 tank pressurization system (figure 8-1) adequately controlled LH2 tank ullage pressure throughout the firing and during repressurization periods. As part of an effort to avoid overstressing the LH2 tank structure, the LH2 tank operating pressure levels were reduced on this and subsequent stages. The pressurization system operating range during the second burn phase was reduced to 28 - 31 psia from the previous 31 - 34 psia. The vent/relief valve relief band was also lowered from 34 - 37 psia to 31 - 34 psia.

8.1.1 Prepressurization

The LH2 tank was satisfactorily prepressurized with helium from ground support equipment console B. Figure 8-2 presents the prepressurization data; table 8-1 compares the S-IVB-506N data with 504N and 505N data. The smaller quantity of helium used for 506N was the result of the lower ullage pressure switch setting. Prepressurization was terminated by actuation of the control pressure switch at T_0 -44 sec. After prepressurization, the ullage pressure increased because of ambient heat input until it reached the relief setting of 32.1 psia at T_0 +68.4 sec.

8.1.2 Pressurization

During engine operation, the LH2 tank pressurization was satisfactorily accomplished by GH2 bleed from the J-2 engine (figures 6-1 and 8-1). The data are presented in figure 8-3 and compared with data from two previous acceptance firings in table 8-2.

As a result of the changes noted in paragraph 8.1, the LH2 tank ullage pressure was lower at each reference point than during the previous acceptance firings, as shown in table 8-2. In order to exercise all system components in both burn modes, control was transferred from the first burn pressurization mode to the second burn pressurization mode at ESC +200 sec. Since the pressure switch range is the same for both modes (28 to 31 psia), no change in system performance resulted. During both burn phases, the system operated in the undercontrol mode. To preclude the possibility of loss of NPSP near the end of the firing because of bulk heating, step pressure was initiated at ESC +410 sec.

Throughout most of the burn the tank ullage pressure was above the 31 psia pressure switch pickup level and at the vent and relief valve relief setting. At propellant utilization (PU) cutback, the ullage pressure decreased 0.4 psi and remained at this new level until step pressurization, at which time the pressure increased causing venting until after Engine Cutoff Command. The relative stability of the ullage pressure prior to PU cutback suggests the tank was relieving. The vent and relief valve microswitch talkback indicates tank relieving did occur during two periods: from Engine Start Command to ESC +20 sec and from ECC -22 sec to Engine Cutoff Command. Analysis of the tank data (figure 8-3) indicated the tank was relieving until approximately ESC +225 sec, as shown by the collapse factor. The high level of the ullage pressure resulted from an increase in the primary orifice size in the GH2 pressurization module causing an increased pressurant flow.

The collapse factor shown in figure 8-3 is higher than normal and would indicate excessive pressurant flow or low pressurization efficiency. However, with the vent/relief valve relieving pressure continuously during the first burn phase, the system would not be closed and a high collapse factor would result.

8.1.3 Repressurization with O_2-H_2 Burner

The O_2-H_2 burner was utilized for LH2 tank repressurization during a test for which the tank was filled to a nominal second start level. Burner start command was followed by a 6.84-sec lag before the initiation of repressurization in order to provide higher burner chamber pressure (and improved combustion stability) during the start transient. The LH2 tank conditions are shown in figure 8-4; significant data are compared to previous stage data in table 8-3.

The LH2 tank ullage pressure rise rate was 39 percent higher than the theoretical rate of 3.10 psi/min that was based on a constant-Q burner, constant helium flowrate, and assumed constant burner helium inlet temperature of 40 deg R (the same reference conditions used for the S-IVB-503N, 504N, and 505N acceptance firing evaluations). During the 506N burner operation, the actual total energy in the helium at the burner outlet to the LH2 tank was 34 percent higher than the theoretical total energy calculated by assuming the temperature of the helium at the burner inlet to be 40 deg R. The 34 percent increase was due to the ambient heating that occurred between the cold helium spheres and the O_2-H_2 burner inlet.

Under ideal conditions any heating above the reference should be reflected by a corresponding percentage increase of the pressurization rate above theoretical. The actual and theoretical values do not agree because the boundary conditions vary slightly and because LH2 boiloff does not actually terminate when pressurization is initiated.

8.1.4 Ambient Helium Repressurization

Although the S-IVB-506N stage was equipped with an O_2-H_2 burner, the ambient helium repressurization system was retained as a redundant system and was tested prior to the 506N acceptance firing.

The LH2 tank was satisfactorily repressurized from the five ambient helium spheres. Repressurization time was considerably less than for 504N and 505N due to a higher initial ullage pressure and a lower required final pressure. Data and performance levels are presented in figure 8-5 and compared to S-IVB-504N and 505N data in table 8-3.

8.2 LH2 Tank Vent and Relief Operations

LH2 tank ullage pressure was maintained at an acceptable level throughout the acceptance firing.

8.2.1 LH2 Tank Vent and Relief Valve Performance

Performance of the LH2 tank vent and relief valve was satisfactory. The valve cracked after prepressurization, then apparently feathered at 32.1 psia until shortly after engine mixture ratio cutback. Near the end of J-2 engine operation, step pressurization was initiated, and the pressurant flowrate increased accordingly. This caused the ullage pressure to increase and force the vent and relief valve partially open, as indicated by the loss of the closed talkback. Neither the open nor the closed talkback was picked up until after Engine Cutoff Command, which indicates that the valve remained partially open until after engine cutoff.

8.2.2 Vent Operations during Simulated Coast

The continuous vent system (CVS) was operated for approximately 26 min prior to O_2-H_2 burner repressurization. Both the CVS nozzles and the nonpropulsive vent (NPV) orifices were removed and a manifold system conducted the vented GH2 to the facility burn pond. At the LH2 tank ullage pressures maintained during the period, the flow of GH2 through the manifold (to atmospheric back pressure) was unchoked; however, choked flow at the vent exits will occur during actual orbital coast conditions. Due to the manifold system, both CVS and NPV pressure data reflected venting through either system (figure 8-6).

Continuous venting was initiated by opening the relief override valve and allowing the continuous vent regulator (CVR) to open. After CVS initiation the ullage pressure dropped from 31.8 to 29.5 psia in 28 sec, yielding a pressure decay rate of 4.9 psi/min. This is consistent with the decay rates of 5.2 and 4.5 psi/min noted on the 504N and 505N stages, respectively. At 28 sec after CVS initiation the CVR was closed. The CVS bypass orifice was opened at CVS initiation plus 35.5 sec, and the CVR was reopened at CVS initiation plus 88 sec. The ullage pressure then decreased and stabilized at 20.6 psia, indicating that the CVR was functioning properly. At first CVS initiation plus 362 sec, the LH2

NPV valve was opened for 5 sec in order to drop the ullage pressure below the regulation band of the CVR and thus allow the main poppet of the regulator to reseat. The tank was then allowed to self-pressurize. At 20.6 psia the CVR cracked; regulation at 20.6 psia continued for 465 sec. During this time the regulator was able to flow the existent boiloff, indicating that the subcooled LH2 bulk was absorbing most of the heat input. At first CVS activation plus 912 sec, however, the ullage pressure began to increase gradually, reaching 20.8 psia by the beginning of burner start preparations. This indicated that the LH2 bulk had become saturated, resulting in more boiloff than the regulator could flow.

During the period prior to burner operation, the LH2 NPV valve was cycled in order to maintain the ullage pressure within the burner start limits.

8.3 LH2 Pump Chilldown

The LH2 pump chilldown system performed adequately. At engine start command the net positive suction pressure (NPSP) at the LH2 pump inlet was above the 4.5 psi required. The chilldown system data are presented in figures 8-7 and 8-8. The 506N acceptance test data are compared in table 8-4 with data from two previous acceptance firings.

At Engine Start Command, the NPSP at the LH2 pump inlet was 6 psi lower than previous acceptance tests; however, this reduction in NPSP is not indicative of anomalous performance. The limits of the pressure sensing switches that control the ullage pressure range were dropped 3 psi from 31-34 psia to 28-31 psia. There was also a 3 psi reduction in the NPSP due to the one degree higher pump inlet temperature (C0003). These considerations therefore account for the 6 psi loss of NPSP.

The chilldown system operation was initiated at T_0 -299.4 sec. System performance levels were in good agreement with those of previous S-IVB/V acceptance firings. During unpressurized chilldown, the liquid in the system was subcooled to a point between the engine pump inlet and the chill system return line; the system became entirely subcooled during prepressurization. In accordance with the 506N revised flight sequence, the chilldown shutoff valve was left open until shortly before engine cutoff (ECC -38 sec).

For the calculation of heat input to the LH2 chilldown system, the normal reference temperature for section 1 (tank to pump inlet) is the chilldown pump discharge temperature (C0157). Since this measurement was not installed on S-IVB-506N, the LH2 bulk temperature (C0052) plus 1.0 deg R was substituded for it. This bias was established from previous acceptance firing data.

8.4 Engine LH2 Supply

The LH2 supply system (figure 8-9) delivered the necessary quantity of LH2 to the engine LH2 pump inlet throughout the engine firing and maintained the pressure and temperature conditions within a range that provided an LH2 pump NPSP above the minimum requirements. The data and the calculated performance are presented in figure 8-10. Table 8-5 compares the S-IVB-506N stage data and calculated performance with that from previous acceptance firings.

During engine operation, the LH2 pump inlet temperature and pressure were very near the predicted values. The LH2 pump inlet temperature and pressure at selected times during engine operation were plotted in the engine LH2 pump operating region (figure 8-11) and showed the engine inlet conditions were met satisfactorily throughout engine operation.

Figure 8-12 is a plot of the pump inlet temperature as a function of the propellant mass remaining in the LH2 tank and includes S-IVB-505N and S-IVB-504N data for comparison. The data used for comparison have been biased to the LH2 pump inlet temperature observed at S-IVB-506N Engine Start Command to correct for instrument error, different heating during pressurization, and other test-to-test variations.

TABLE 8-1
LH2 TANK PREPRESSURIZATION DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Prepressurization duration (sec)	50.5	51.8	46.0
Helium mass added (lbm)	20.2	30.5	28.0
Ullage pressure			
At prepressurization initiation (psia)	15.4	15.1	15.3
At prepressurization termination (psia)	30.2	33.7	33.7
At simulated liftoff (psia)	31.0	34.3	34.6
At Engine Start Command (psia)	32.0	35.8	36.1
Rate of increase after prepressurization (psi/min)	1.0	1.0	1.1
Events (sec from To)			
Prepressurization initiation	-94.7	-93.5	-93.5
Prepressurization termination	-44.2	-41.7	-48.0
Engine Start Command	511.4	511.8	543.6

TABLE 8-2
LH2 TANK PRESSURIZATION DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Pressure switch setting			
First burn			
Lower (psia)	28.3	28.0	28.0
Upper (psia)	30.7	30.7	30.3
Second burn			
Lower (psia)	28.3	31.1	31.6
Upper (psia)	30.5	33.6	33.7
Ullage pressure			
At Engine Start Command (psia)	32.0	35.8	36.1
At step pressurization (psia)	31.9	33.0	33.5
At Engine Cutoff Command (psia)	32.7	35.8	36.0
GH2 pressurant flowrate			
Overcontrol - high EMR (lbm/sec)	--	--	--
Overcontrol - low EMR (lbm/sec)	--	0.70	0.73
Undercontrol - high EMR (lbm/sec)	0.63	0.51	0.54
Undercontrol - low EMR (lbm/sec)	0.60	--	--
Step	1.03	0.90	0.93
Total GH2 added (lbm)	290	294	302
Events (sec from T_o)			
Vent and relief valve open	927.5	927.3	960.6
Engine Cutoff Command	959.5	963.3	984.2

TABLE 8-3
LH2 TANK REPRESSURIZATION DATA

PARAMETER	S-IVB-506N		S-IVB-505N		S-IVB-504N	
	AMBIENT HELIUM	BURNER	AMBIENT HELIUM	BURNER	AMBIENT HELIUM	BURNER
Repressurization duration (sec)	40	147*	157	181**	226	192**
Ullage volume (ft^3)	4,720	4,880	4,820	4,750	5,660	5,010
Ullage pressure						
At repressurization initiation (psia)	21.0	19.6	17.2	20.2	16.9	20.4
At repressurization termination (psia)	30.0	30.2	33.4	33.5	33.5	34.2
Rise rate (psi/min)	13.5	4.30	6.18	4.41	4.40	4.31
Repressurization helium usage (lbm)	26.1	16.5	39.0	22.6	37.2	22.8

*Does not include the 6.84 sec lag in repressurization initiation following Burner Start Command.
**Does not include the 11 sec lag in repressurization initiation following Burner Start Command.

TABLE 8-4 (Sheet 1 of 2)
LH2 RECIRCULATION CHILLDOWN DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
NPSP			
At Engine Start Command (psi)	8.8	14.8	14.2
Min required at start (psi)	4.5	6.3	6.3
Max during childown (psi)	19.2	23.4	22.5
Average flow coefficient ($sec^2/in.^2/ft^3$)	18.1	18.2	18.0
Fuel quality in sections* 2 and 3 (lb gas/lb mixture)			
Max - unpressurized childown	0.027	0.034	0.044
At prepressurization initiation	0.023	0.020	0.026
Fuel pump inlet conditions			
Static pressure at start (psia)	33.6	36.8	37.4
Temperature at start (deg R)	39.9	38.9	39.4
Amount of subcooling at start (deg R)	2.3	3.6	3.6
Heat absorption rate			
Unpressurized chilldown			
Section* 1 (Btu/hr)	20,000	18,200	18,000
Sections* 2 and 3 (Btu/hr)	17,500	16,900	21,000
Total (Btu/hr)	37,500	35,100	39,000
Pressurized chilldown			
Section* 1 (Btu/hr)	18,000	16,200	26,000
Section* 2 (Btu/hr)	8,500	13,900	18,000
Section* 3 (Btu/hr)	18,000	13,600	6,000
Total (Btu/hr)	44,500	43,700	50,000

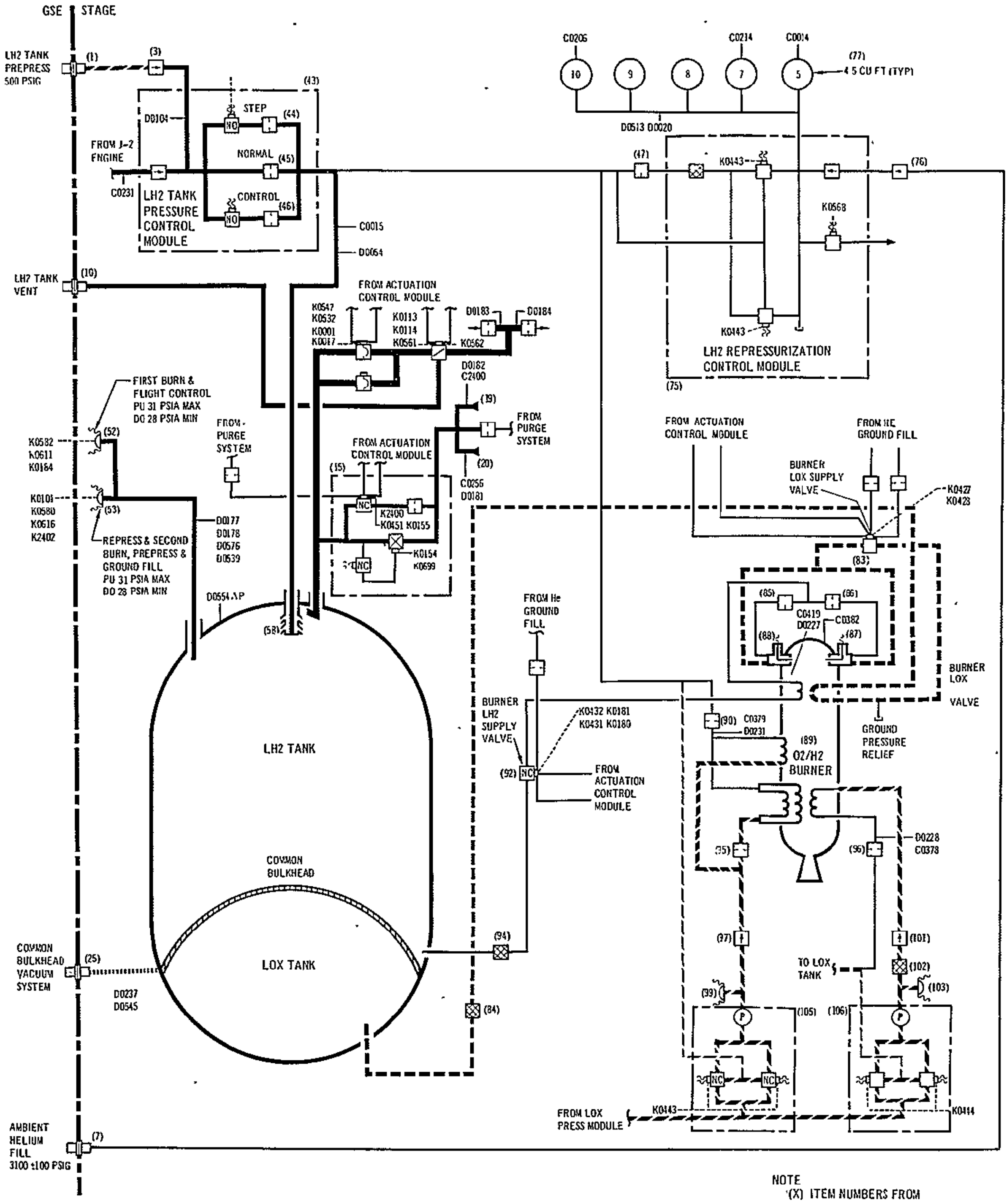
*Section 1 is tank to pump inlet; section 2 is pump inlet to bleed valve; section 3 is bleed valve to tank.

TABLE 8-4 (Sheet 2 of 2)
LH2 RECIRCULATION CHILLDOWN DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Chilldown flowrate			
Unpressurized (gpm)	108	108	104
Pressurized (gpm)	137	138	137
Chilldown pump pressure differential			
Unpressurized (psi)	9.4	8.8	9.0
Pressurized (psi)	7.75	7.6	7.5
Events (sec from SLO)			
Chilldown initiated	-299.4	-295.1	-295.4
Prevalve closed	-283.9	-291.4	-291.7
Prepressurization	-94.7	-93.5	-93.9
Prevalve opened	509.7	508.4	539.1
Chilldown pump Off	510.7	510.8	542.6
Engine Start Command	511.378	511.8	543.6
Chilldown shutoff valve closed	921.8	862.2	893.9

TABLE 8-5
LH2 PUMP INLET CONDITION DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Pump inlet conditions			
Static pressure at engine start (psia)	33.6	36.8	37.4
Static pressure at engine cutoff (psia)	31.1	34.5	36.4
Temperature at engine start (deg R)	39.9	38.9	39.4
Temperature at engine cutoff (deg R)	39.6	39.5	39.5
NPSP requirements at pump interface			
Minimum at engine start (psi)	4.5	6.0	6.3
At high EMR (psi)	5.3	6.5	6.5
After EMR cutback (psi)	4.9	5.8	5.8
NPSP available at pump interface			
At engine start (psi)	8.8	14.8	14.2
Maximum (psi)	15.1	21.5	19.0
Minimum (psi)	9.5	10.3	11.5
At engine cutoff (psi)	10.0	12.2	13.3
LH2 suction duct			
At high EMR			
Pressure drop (psi)	0.5	0.9	0.6
Flowrate (lbm/sec)	83	81	84.8
After EMR cutback			
Pressure drop (psi)	0.4	0.8	0.5
Flowrate (lbm/sec)	80	77	81.5



NOTE
(X) ITEM NUMBERS FROM PARTS LIST TABLE 3-1
SEE FIGURE 3-1 FOR LEGEND

Figure 8-1. LH2 Tank Pressurization System

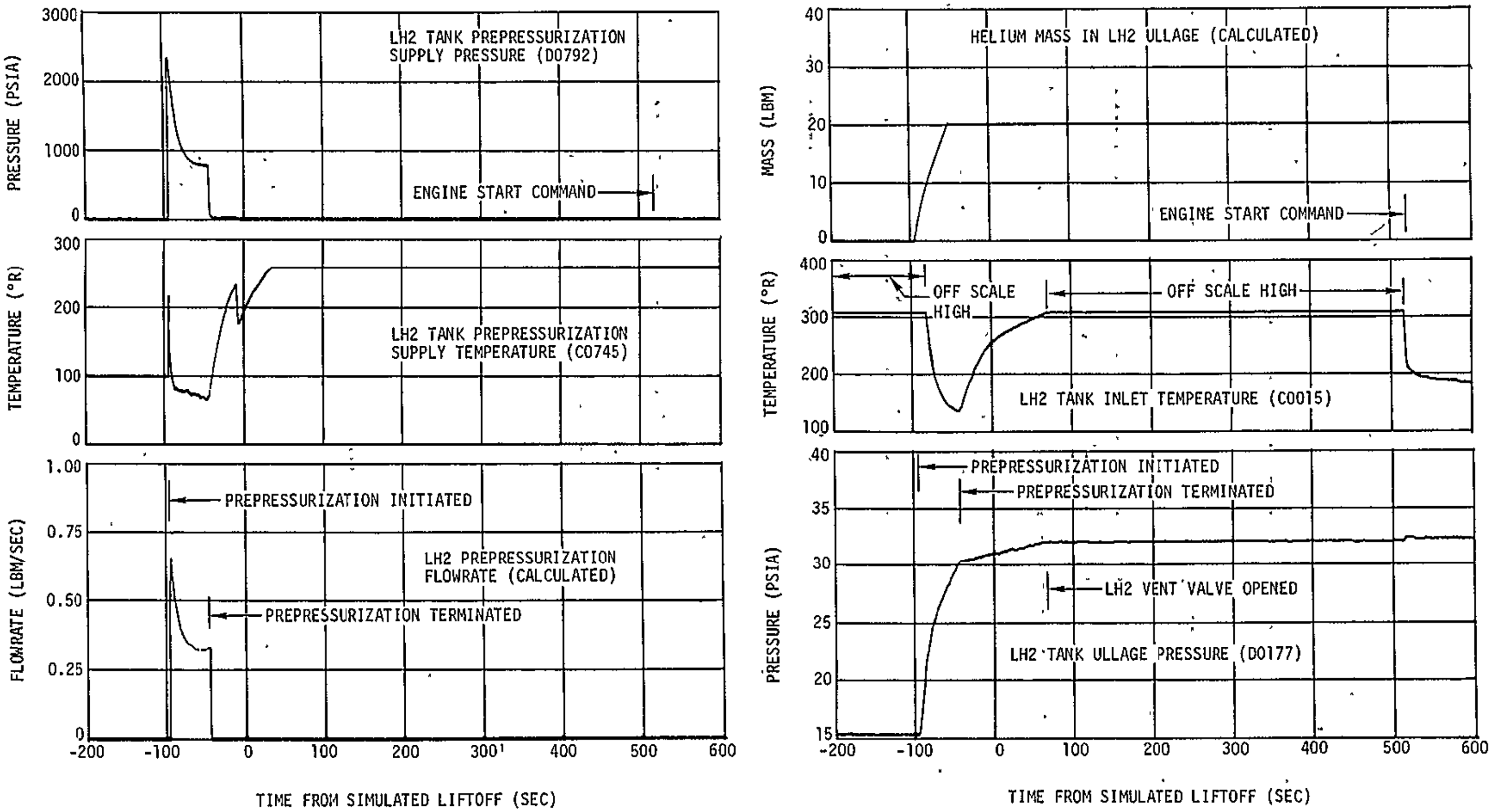


Figure 8-2. LH2 Tank Prepressurization System Performance

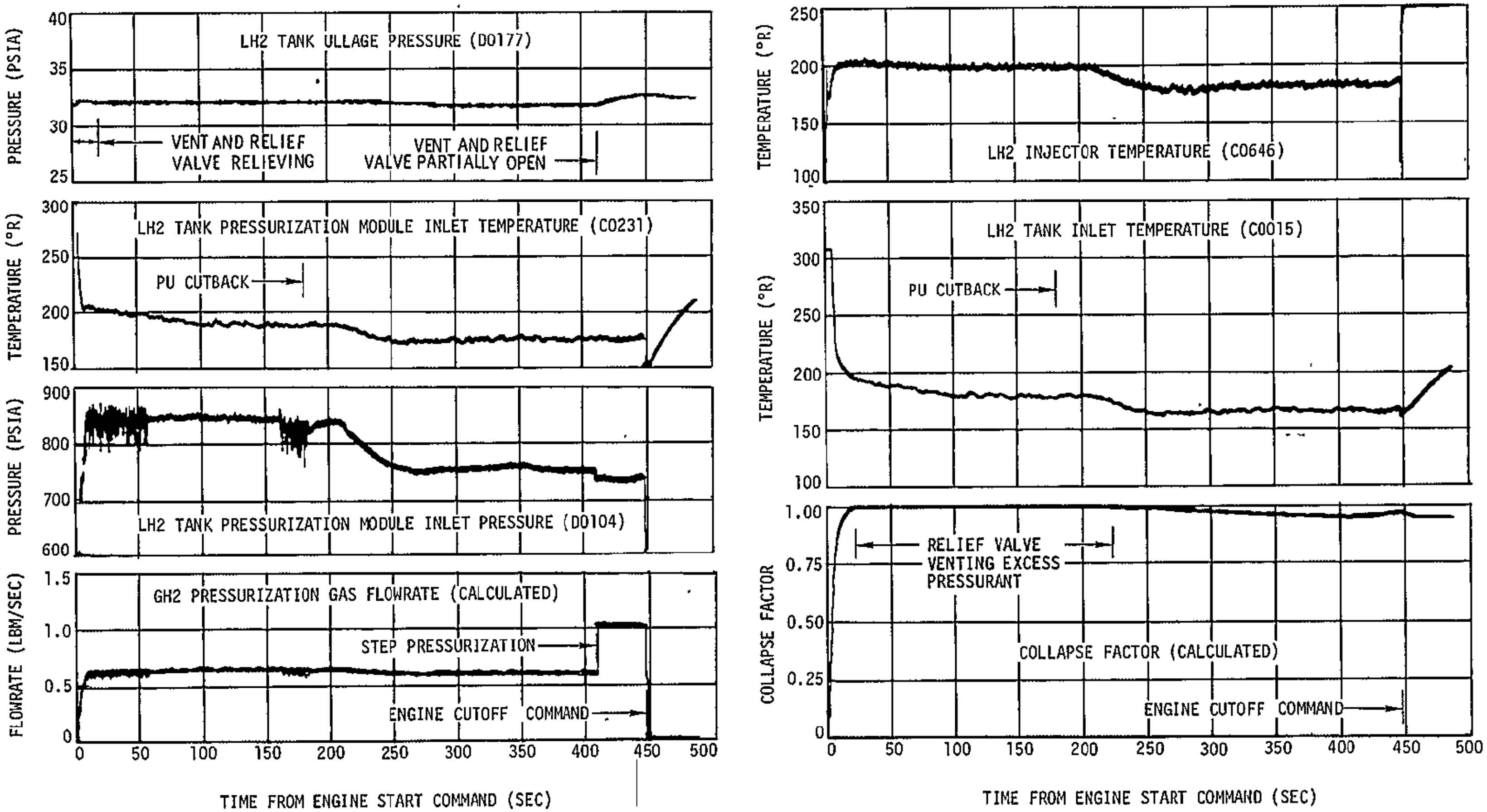


Figure 8-3. LH2 Tank Pressurization System Performance

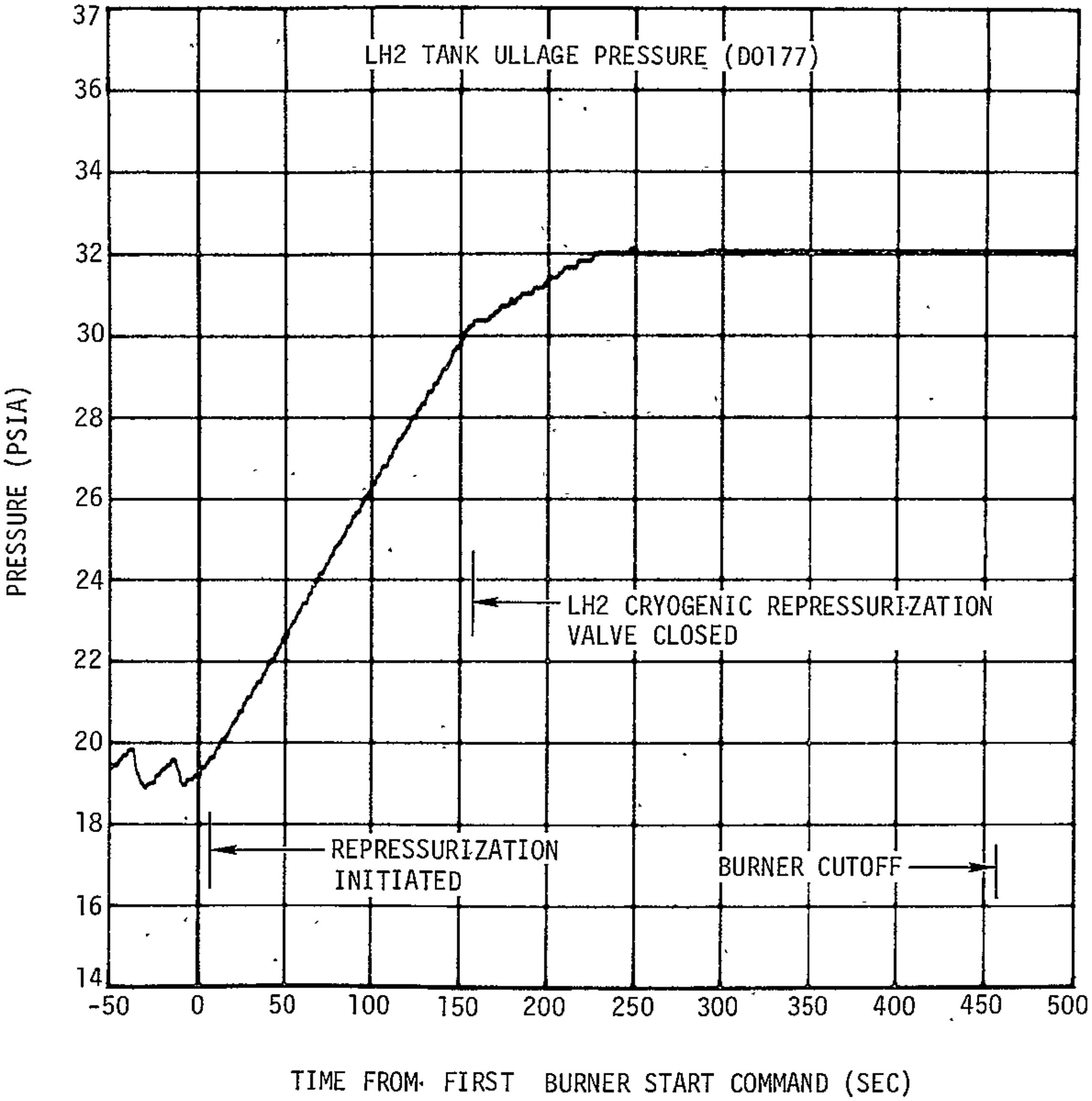


Figure 8-4. LH2 Tank Ullage Pressure During Repressurization with O_2-H_2 Burner

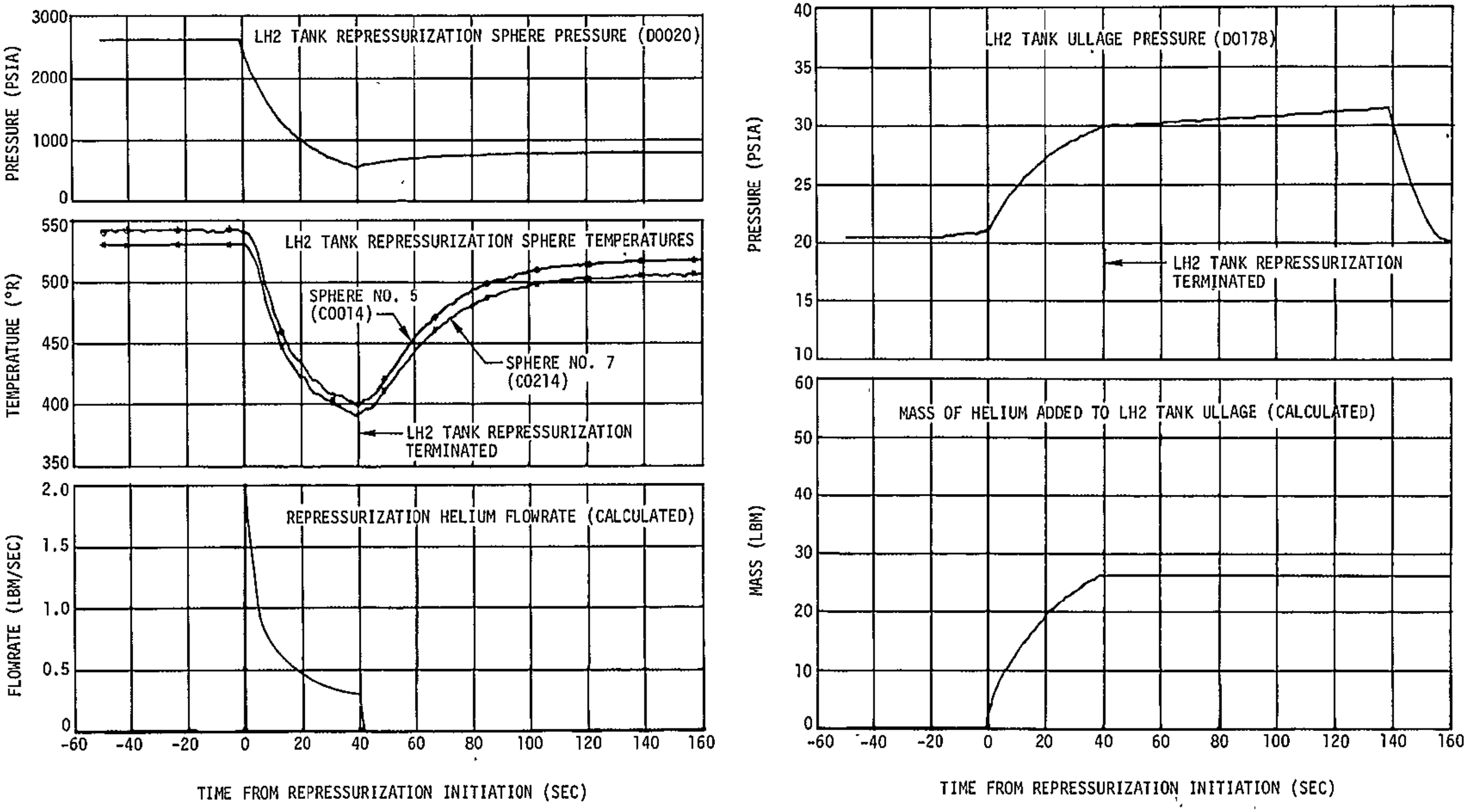


Figure 8-5. Ambient Helium Repressurization System Performance

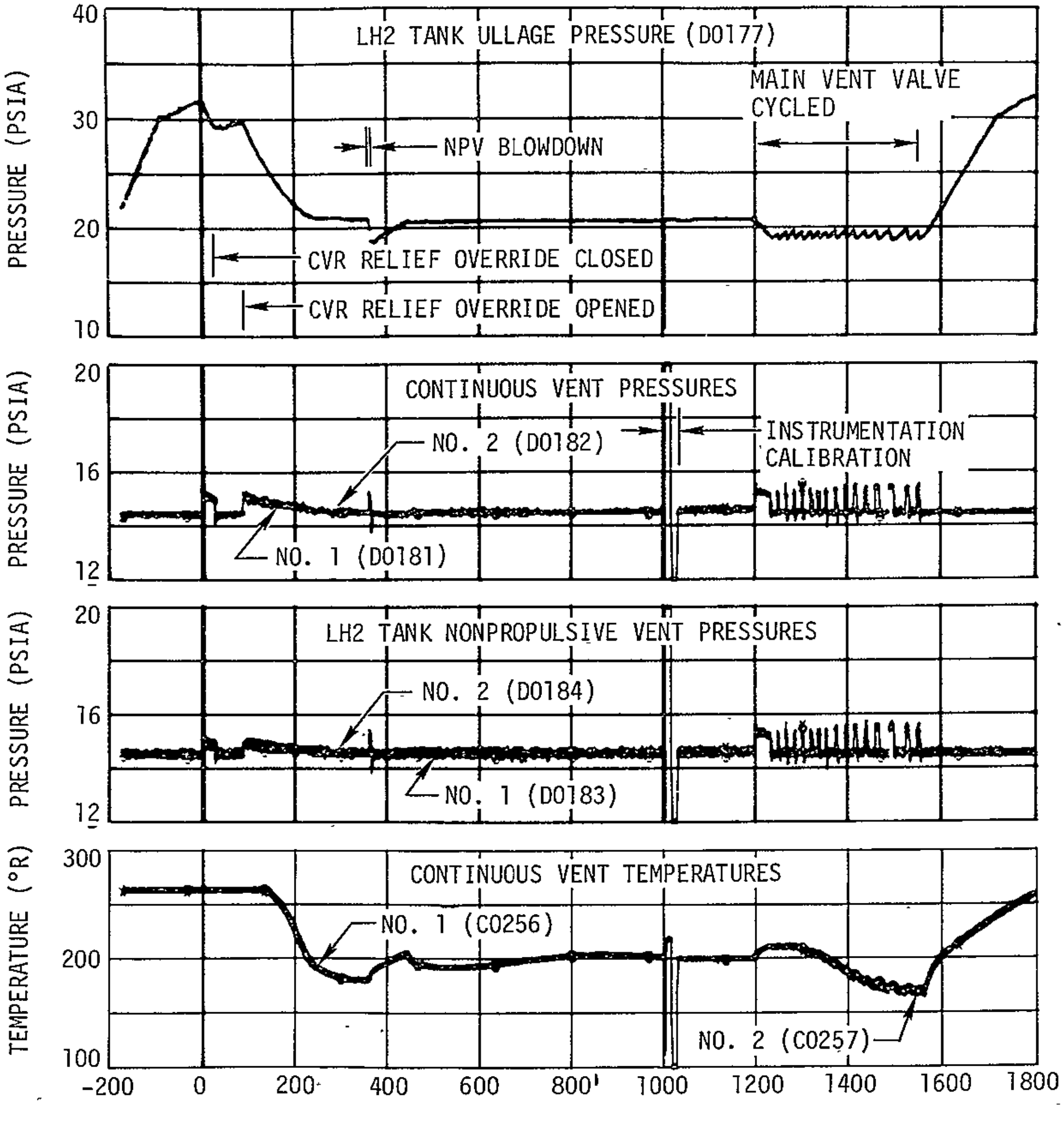


Figure 8-6. LH2 Tank Venting System Operation

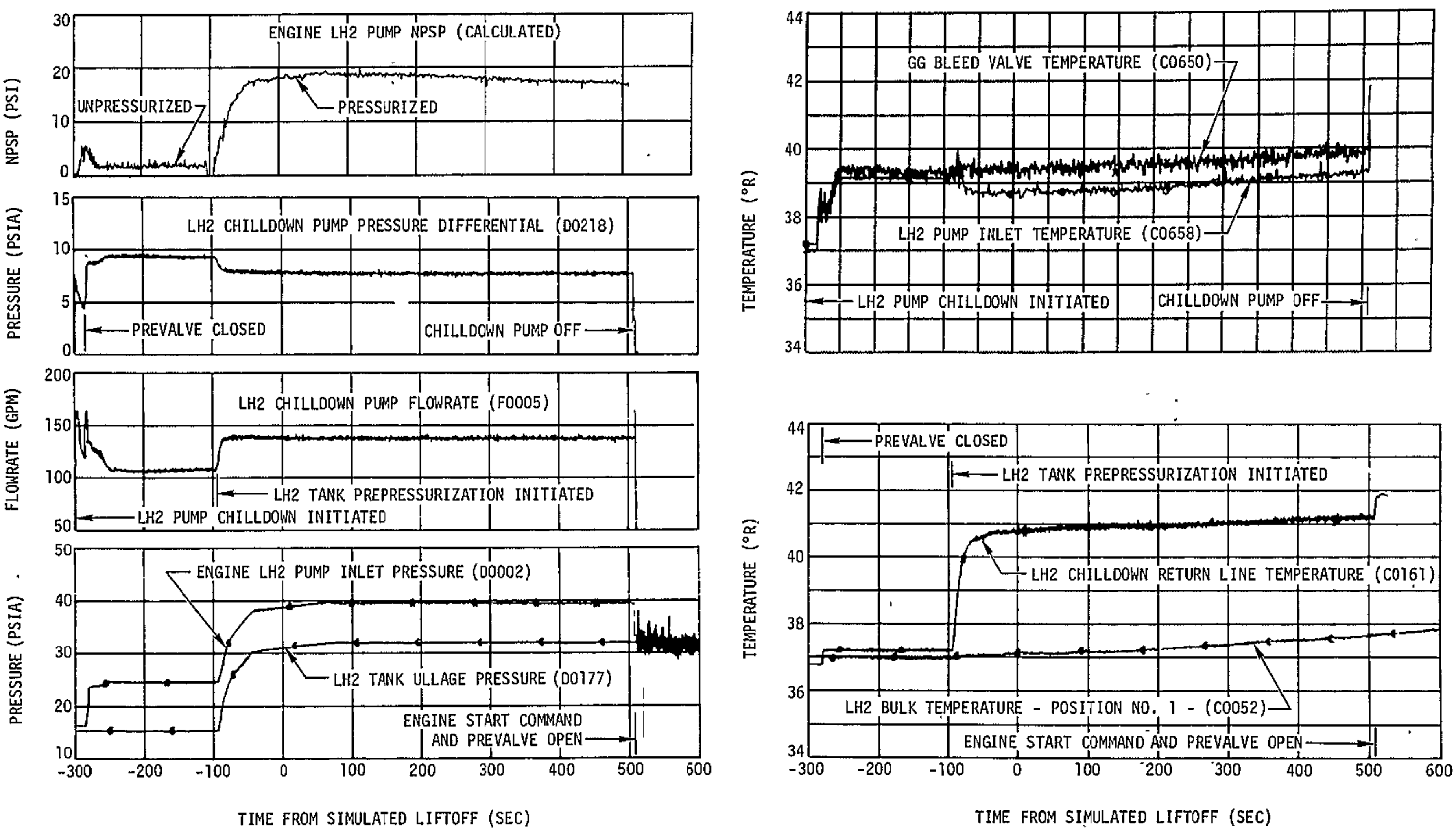


Figure 8-7. LH2 Pump Chilldown

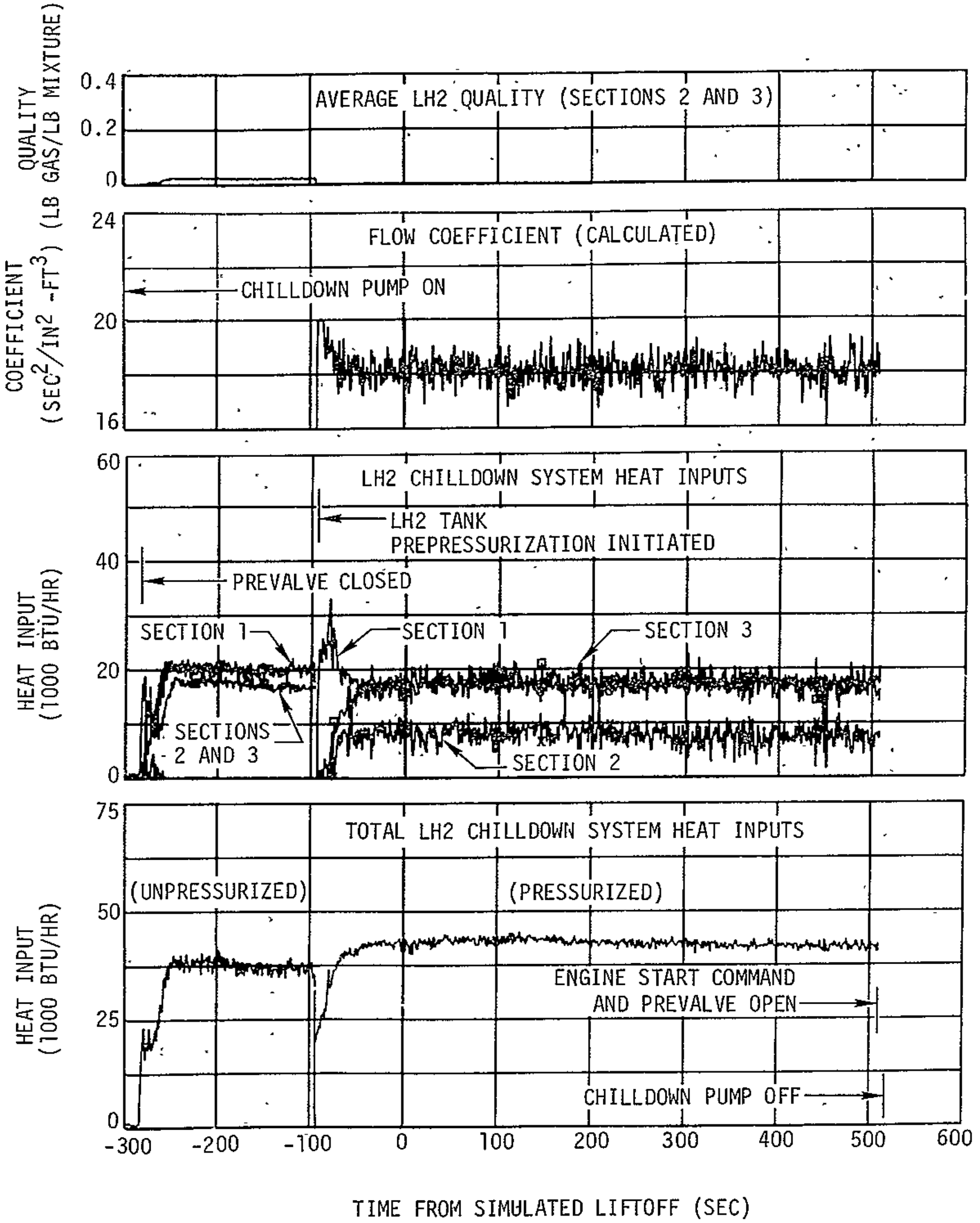
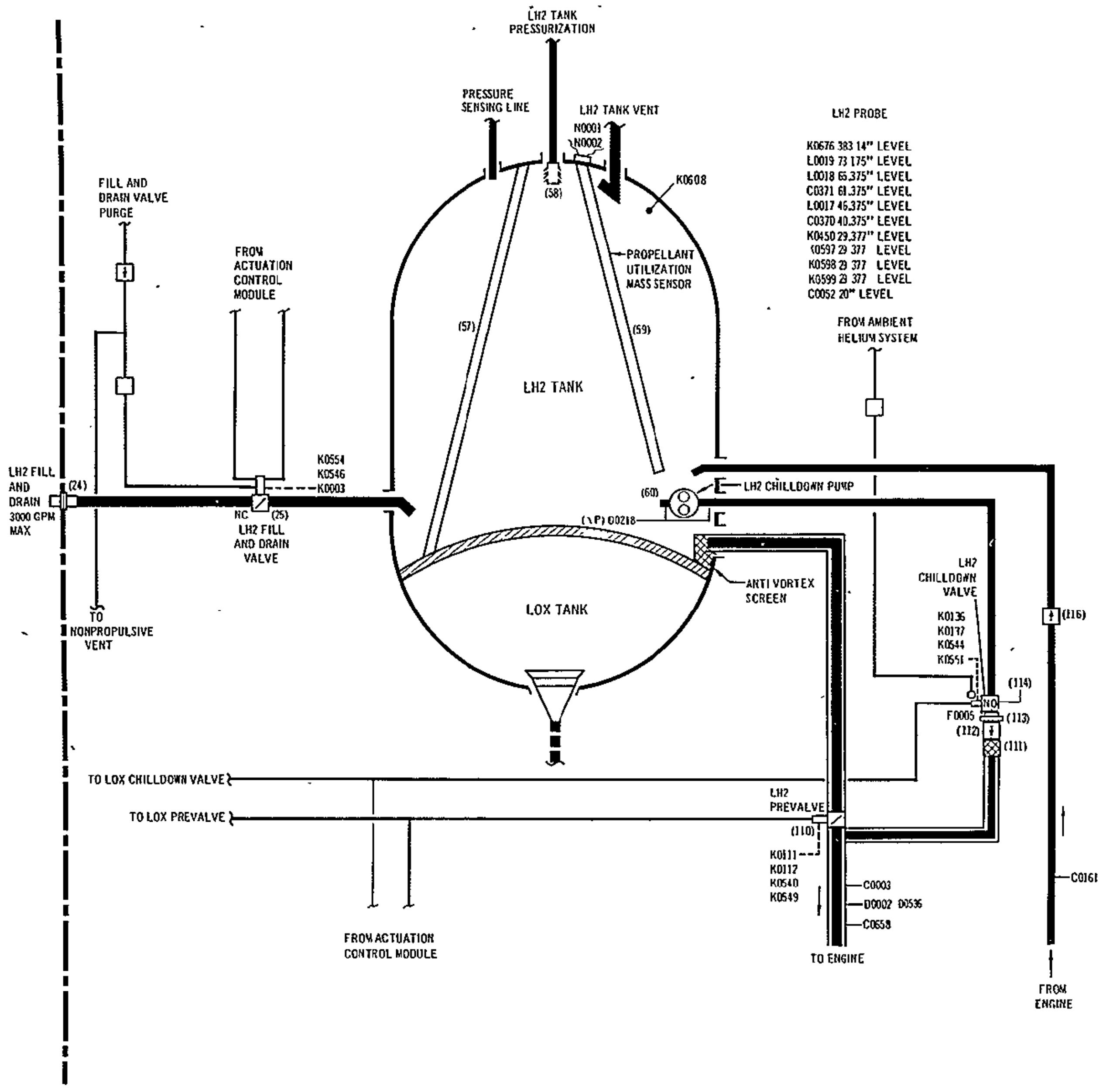


Figure 8-8. LH2 Pump Chilldown Characteristics



NOTE.
(X) ITEM NUMBERS FROM PARTS LIST TABLE 3-1
SEE FIGURE 3-1 FOR LEGEND

Figure 8-9. LH2 Supply System

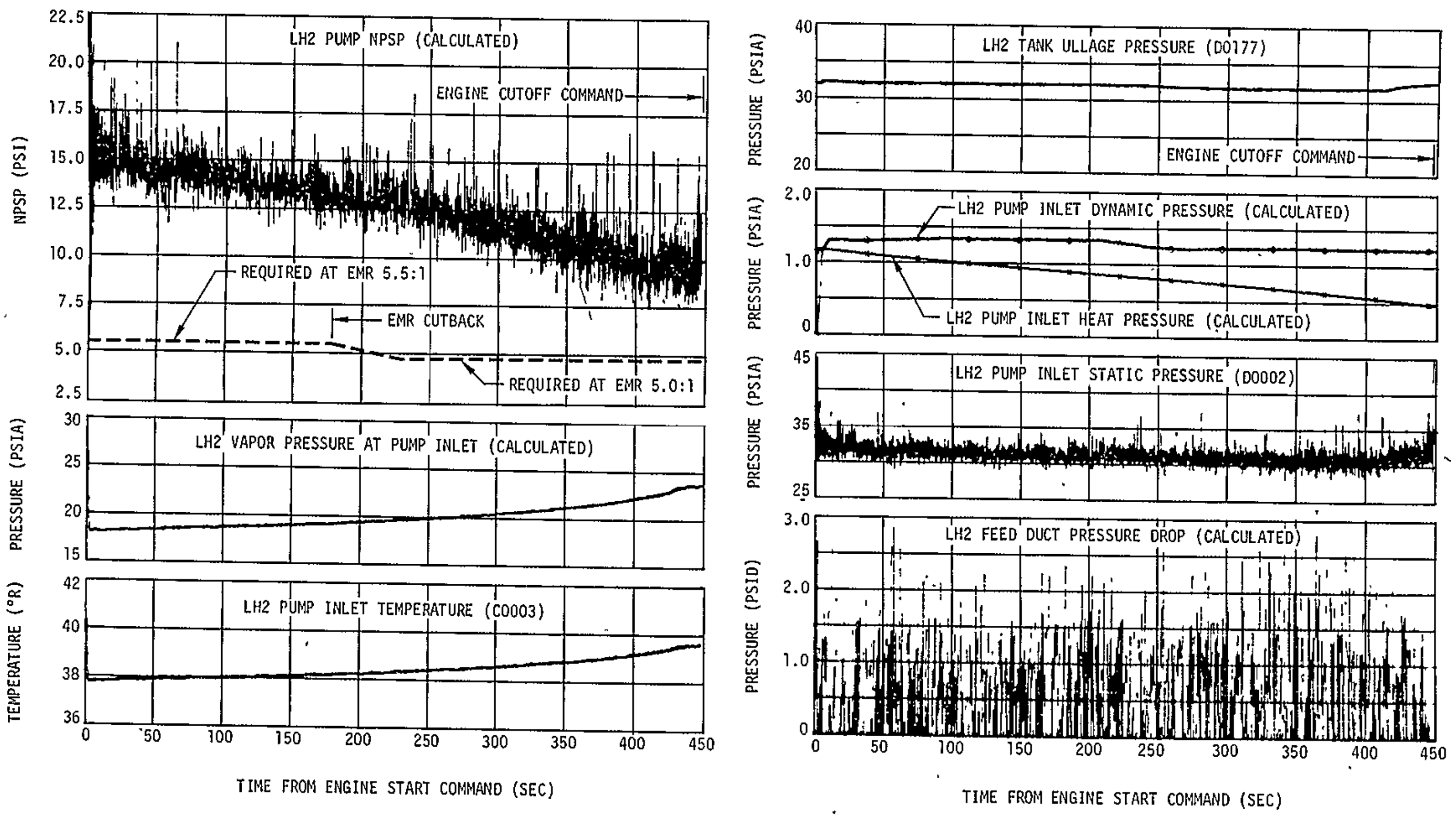


Figure 8-10. LH2 Pump Inlet Conditions

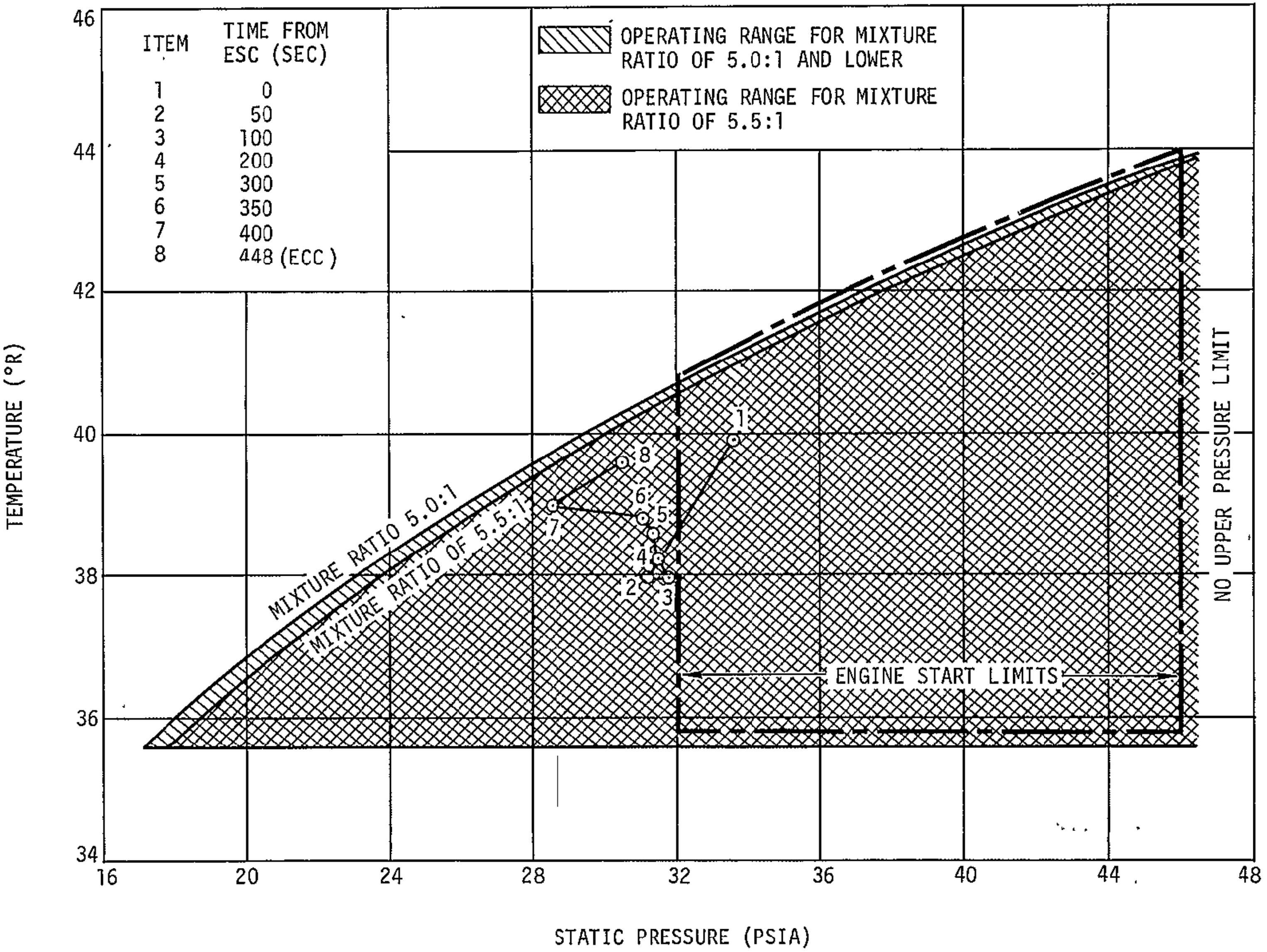


Figure 8-11. LH2 Pump Inlet Conditions During Firing

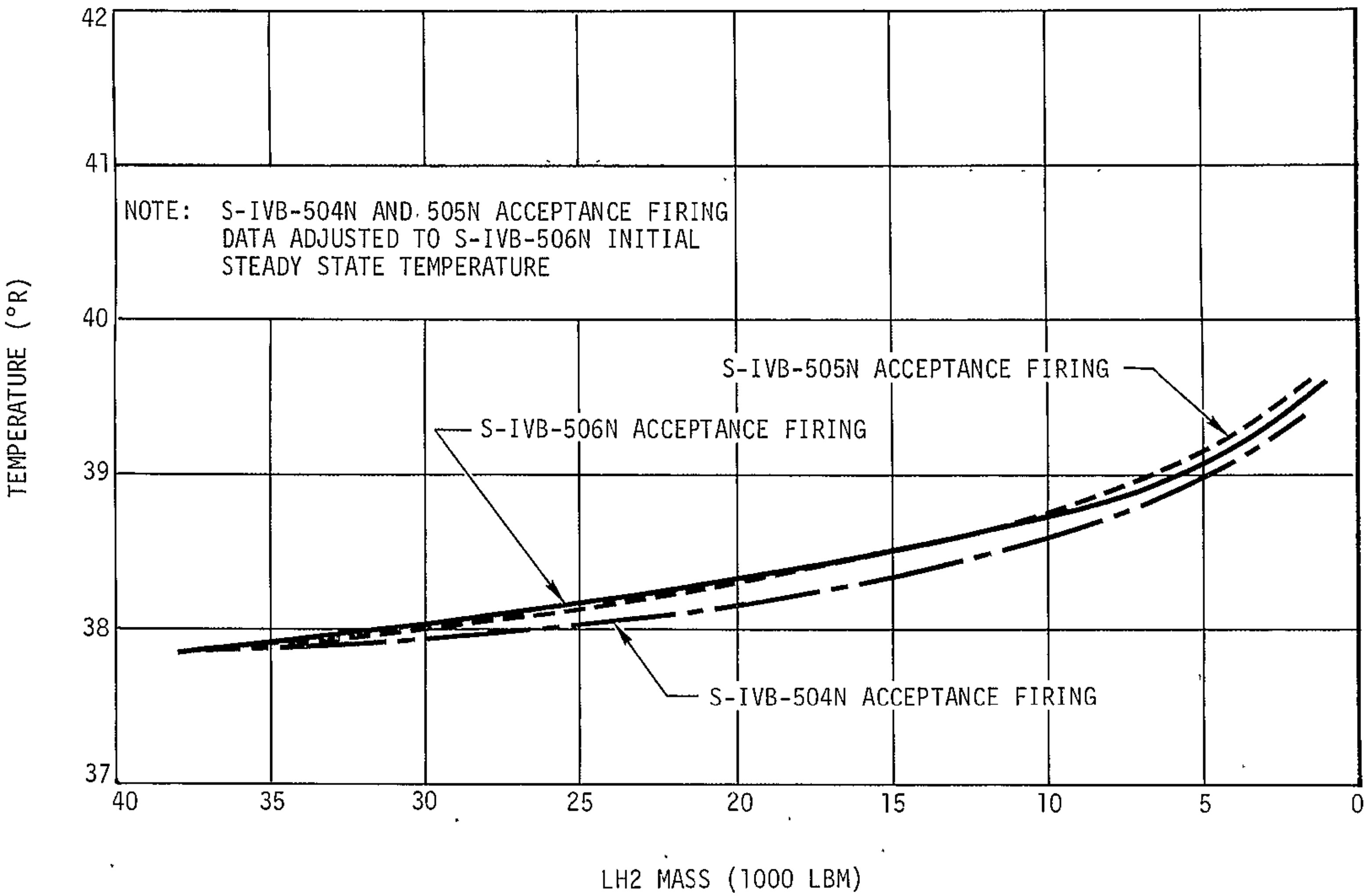


Figure 8-12. Effect of LH2 Tank Mass Level on LH2 Pump Inlet Temperature

SECTION 9

PNEUMATIC CONTROL AND PURGE SYSTEM

9. PNEUMATIC CONTROL AND PURGE SYSTEM

The pneumatic control and purge system (figure 9-1) performed adequately during the acceptance firing with two exceptions. During one period of the critical components test prior to O_2-H_2 burner testing and J-2 engine firing, and again during terminal countdown, the pneumatic control helium regulator did not regulate the control helium sphere pressure down to the specified blueline maximum of 550 psia. All other components functioned normally. The test results are summarized and compared with previous acceptance firing data in table 9-1.

9.1 Ambient Helium Supply

In order to simulate actual flight conditions (stage isolation), the ground support equipment (GSE) helium supply valve was closed 225 sec prior to simulated coast and remained closed during the continuous venting period and burner and ambient repressurization operations. The valve was also closed at T_0 -8 sec and remained closed through J-2 engine operation.

9.2 Pneumatic Control

All engine and stage pneumatic control valves responded properly throughout the countdown, simulated coast, O_2-H_2 burner operation, ambient repressurization, and engine operation.

During the critical components tests the pneumatic control helium regulator outlet pressure increased to 568 psia when the LH2 and LOX tank fill and drain valves were closed. It increased again, to 592 psia, following the closing of the LOX tank vent valve. At this point the helium control shutoff valve was closed thus allowing the plenum pressure to decay below normal regulation level. Regulation returned to normal after the helium control shutoff valve was reopened. During terminal countdown the regulator outlet pressure increased to 560 psia when the engine start tank vent was opened. Opening of the LOX and LH2 tank vent valves brought the pressure back down to 550 psia. Following the acceptance firing this module was removed from the stage for examination and testing, and contamination was found in the tubing upstream of the module. After the module testing had been completed, contamination was found within the regulator; however, it was not possible to determine whether the contamination occurred during the acceptance firing or during the module testing.

During the S-IVB-506N countdown demonstration test a similar regulation problem occurred; contamination was also found within that module after it was removed and examined. Since the contamination in both modules had passed through the inlet filter, the installation of an improved filter upstream of the module is being considered as a means of improving regulation.

The normal system pressure drops that result from regulator operation during J-2 engine and O_2-H_2 burner operation are shown in figures 9-2 and 9-3, respectively.

9.3 Ambient Helium Purges

During the acceptance firing all stage purge functions that utilize stage pneumatics were satisfactorily accomplished. The pneumatic system was isolated from the GSE during the periods of simulated coast and engine firing, thus discontinuing those purges that were facility supplied. Table 3-2 lists the flowrates of the various purge orifices.

This stage incorporated a new LOX chillpump purge system which consists of a sintered orifice to control the inflow, and a sharp edged orifice to control the outflow of helium from the chillpump motor case. An acceptable range of helium flowrates and pressure levels can be maintained to purge the motor case by the appropriate selection of the inlet and outlet orifices. The LOX chillpump motor container pressure was generally maintained within the limits predicted for this new configuration. The pressure decreased from 60 to 56 psia during engine operation.

TABLE 9-1 (Sheet 1 of 2)
PNEUMATIC CONTROL AND PURGE SYSTEM DATA

PARAMETER	S-IVB-506N		S-IVB-505N		S-IVB-504N	
	ENGINE OPERATION	BURNER OPERATION	ENGINE OPERATION	BURNER OPERATION	ENGINE OPERATION	BURNER OPERATION
Sphere volume (cu ft)	4.5	4.5	4.5	4.5	4.5	4.5
Sphere pressure						
At simulated liftoff (psia)	2,817	--	2,945	--	3,045	--
At Engine Start Command (psia)	2,709	2,159 1,965*	2,844	2,728	2,886	2,626
At Engine Cutoff Command (psia)	2,713	2,099 1,950*	2,842	2,725	2,878	2,611
Sphere temperature						
At simulated liftoff (deg R)	549	-	537	--	538	--
At Engine Start Command (deg R)	541	537 536*	540	536	532	534
At Engine Cutoff Command (deg R)	541	537 536*	541	537	533	534
Helium mass usage rate						
Pre-burn engine pump purge (lbm/min)	0.080	--	0.076	--	0.095	--
Post-burn engine pump purge (lbm/min)	0.125	--	0.100	--	0.095	--
Simulated coast with no engine pump purge	0.0033	--	0.0037	--	0.0022	--

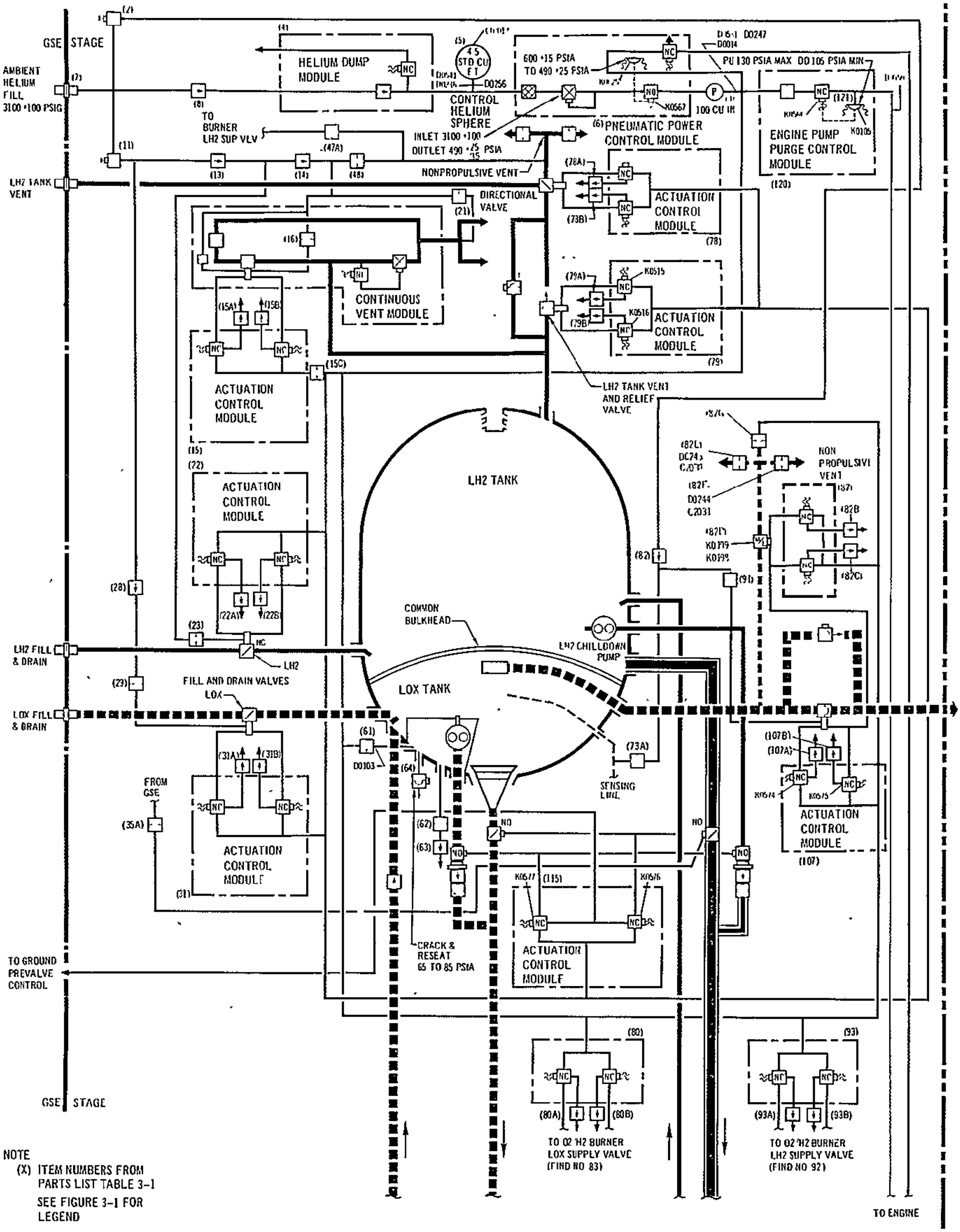
*Value obtained from second burner operation.

TABLE 9-1 (Sheet 2 of 2)
PNEUMATIC CONTROL AND PURGE SYSTEM DATA

PARAMETER	S-IVB-506N		S-IVB-505N		S-IVB-504N	
	ENGINE OPERATION	BURNER OPERATION	ENGINE OPERATION	BURNER OPERATION	ENGINE OPERATION	BURNER OPERATION
Burn duration (sec)	448.1	456 130*	451.5	190	440.5	203
Helium mass						
At simulated liftoff (lbm)	7.89	--	8.39	--	8.64	--
At Engine Start Command (lbm)	7.71	6.29 5.78*	8.12	7.78	8.31	7.58
At Engine Cutoff Command (lbm)	7.71	6.13 5.74*	8.10	7.76	8.28	7.54
Usage during engine or burner operation (lbm)	0.00	0.16 0.04*	0.02	0.02	0.03	0.04
Usage during 10-min post-burn engine pump purge** (lbm)	1.25	--	1.00	--	0.095	--
Maintained regulator outlet pressure band						
Low (psia)	513	510 510*	520	520	509	531
High (psia)	556	543 540*	550	540	540	540
System minimum during start and cutoff transient (psia)	423	--	434	--	425	--
Average LOX chilldown motor container purge pressure (psia)	57	57 56*	72	63	54	65

*Value obtained from second burner operation.

**Estimated on basis of purge flowrate.



NOTE
(X) ITEM NUMBERS FROM PARTS LIST TABLE 3-1
SEE FIGURE 3-1 FOR LEGEND

Figure 9-1. Pneumatic Control and Purge System

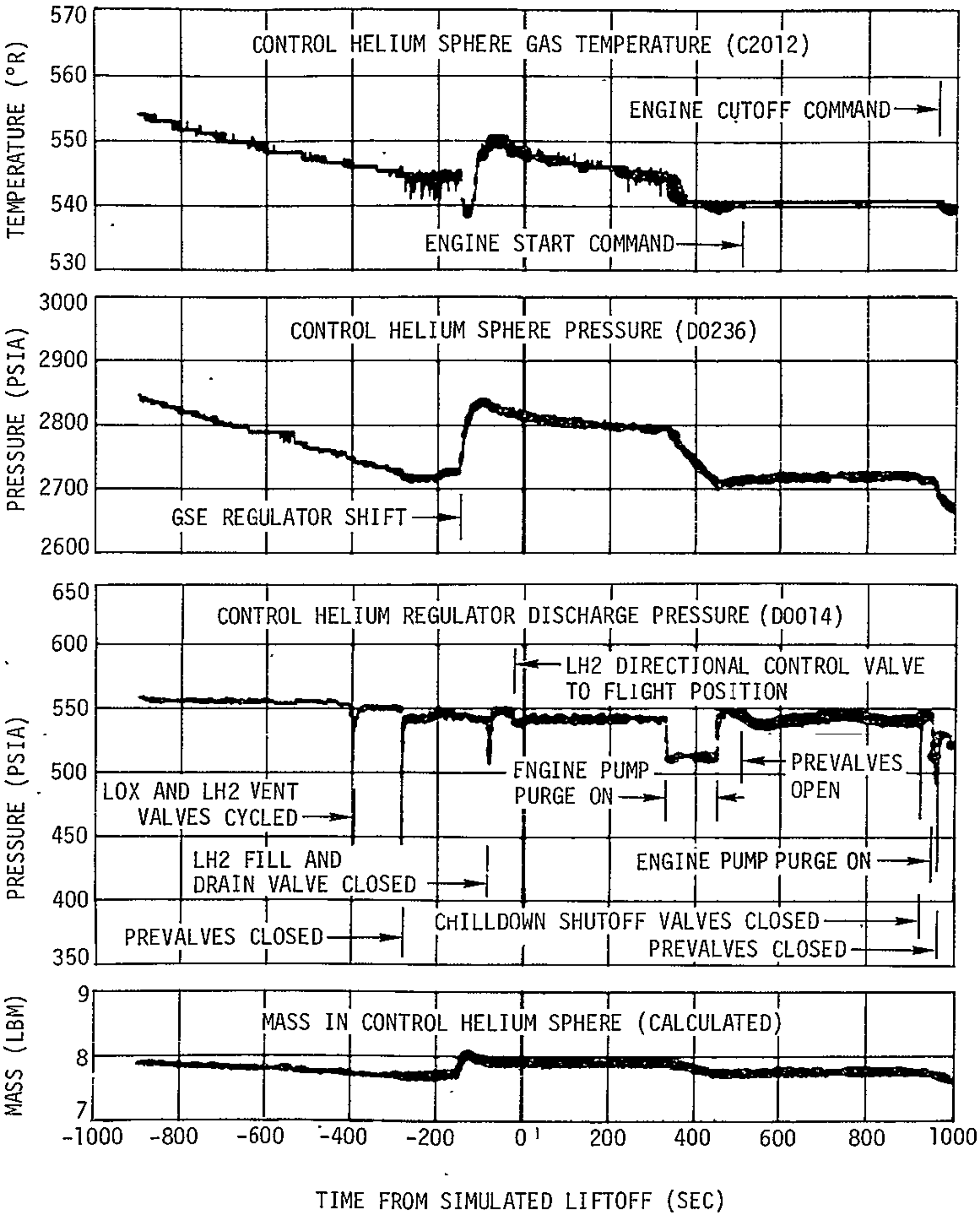


Figure 9-2. Pneumatic Control and Purge System Performance

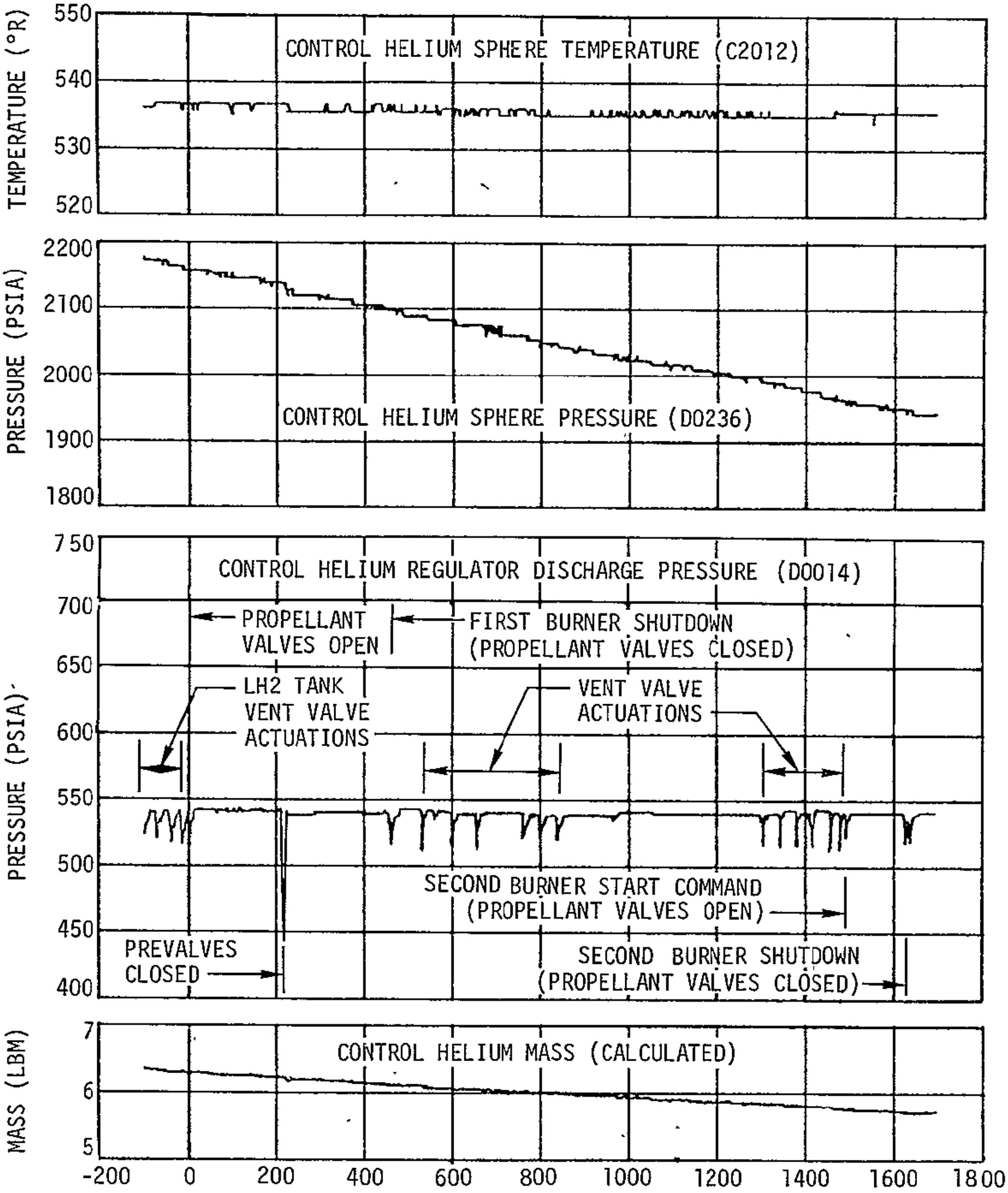


Figure 9-3. Pneumatic Control System Conditions during O_2-H_2 Burner Operation

[redacted] SECTION 10

OXYGEN-HYDROGEN BURNER SYSTEM

10. OXYGEN-HYDROGEN BURNER SYSTEM

The O_2-H_2 burner (figure 10-1) was acceptance tested prior to the S-IVB-506N acceptance firing. It was of the same design (high chamber pressure) that was tested on the 504N and 505N stages but differed from the low chamber pressure design that was installed on the 503N stage in that it exhibited a greater stability during the start transient and a more predictable range for chamber pressure and thrust.

The 506N burner acceptance tests differed from previous acceptance tests in two ways. The 503N, 504N, and 505N burner operations were terminated by pickup of the LH2 flight control pressure switch, whereas the 506N burner operation was not. In addition, the burner was operated twice during the 506N acceptance test - the first time to repressurize the LH2 and LOX tanks, and the second to show the burner restart capability.

10.1 O_2-H_2 Burner Performance

10.1.1 First Burner Operation

The burner performed satisfactorily during the first operation which lasted 456 sec. The LH2 tank was repressurized 154 sec after burner start command and the LOX tank 208 sec after burner start command. Performance data presented in figures 10-2 to 10-5 compare the LH2 tank and LOX tank burner repressurization performance during S-IVB-505N and 506N burner acceptance tests.

10.1.2 Second Burner Operation

The burner functioned normally during the second operation which was 130 sec long. The fuel supply pressure increased from 20 to 21.5 psia and the LOX supply pressure decreased from 40 to 39 psia as shown in figure 10-6. The maximum combustion chamber temperature and thrust were 2,150 deg R and 15.5 lbf, respectively. The comparatively steady supply pressures (because of no repressurization during second burner operation) produced the stable burner operation following the 50-sec start transient.

10.2 LH2 Tank Repressurization

LH2 tank pressurant started flowing 6.84 sec after burner start command and the LH2 tank was repressurized from 19.64 to 30.21 psia in 147 sec - an average rate of 4.30 psi/min. Actual burner LH2 supply pressure range was from 20.51 psia to 31.08 psia due to a 0.87 psi head.

The 4.30 psi/min repressurization rate was 1.20 psi/min higher than the theoretical rate based on an adiabatic repressurization process. The higher than theoretical pressurization rate was the result of the unstabilized temperatures of the cold helium spheres (paragraph 10.4).

The average total LH2 tank repressurization heat flux (the heating of the LH2 tank pressurant from the 40 deg R reference base to the burner LH2 repressurization outlet temperature) was 234,000 Btu/hr. Ambient heating (the heating of the LH2 tank pressurant from the 40 deg R reference base to the burner inlet temperature) contributed approximately 66,500 Btu/hr to the total LH2 tank repressurization heat flux. The ambient heating was greater for 506N (compared to previous acceptance tests) due to the higher initial temperatures of the cold helium spheres.

The LH2 tank repressurization burner heat input rate (the total minus the ambient heating rate), helium flowrate, and repressurization coil outlet temperature are shown in figure 10-3 and further discussed in paragraph 8.1.3. A comparison of O_2-H_2 burner performance during three burner acceptance tests is presented in table 10-1.

10.3 LOX Tank Repressurization

LOX tank pressurant started flowing 7.057 sec after burner start command and the LOX tank was repressurized from 34.7 to 38.6 psia in approximately 201 sec - an average rate of 1.16 psi/min, which is very close to the theoretical prediction of 1.17 psi/min. To compensate for the 4.6 psia head due to the LOX load during ground testing, the ullage pressure was kept low enough to provide a burner supply pressure range of 39.3 to 43.2 psia.

The total average LOX tank repressurization heat flux (the heating of the LOX tank pressurant from the 40 deg R reference base to the burner LOX repressurization outlet temperature) was 48,800 Btu/hr. Ambient heating (the heating of the LOX tank pressurant from the 40 deg R reference base to the burner inlet temperature) contributed approximately 10,980 Btu/hr to the total LOX tank repressurization heat flux. As a result of unusually high cold helium sphere temperatures, the ambient heating and LOX repressurization heat flux were higher than they were on previous acceptance tests. Approximately 5.5 lbm of helium were required for LOX tank repressurization.

The LOX tank repressurization burner heat input rate (the total minus the ambient heating rate), helium flowrate, and repressurization coil outlet temperature are shown in figure 10-4 and are further discussed in paragraph 7.1.3. A comparison of O_2-H_2 burner performance during three burner acceptance tests is presented in table 10-1.

10.4 Cold Helium Supply

The cold helium spheres were pressurized later than usual due to a GSE helium leak. This resulted in a shorter cooldown period and, consequently, higher than usual sphere temperatures. One transducer was off scale high at burner start command. This, plus the reduced number of sphere temperature transducers, made calculations for the mass in the spheres difficult. The usage calculated from sphere conditions (approximately 22 lbm) agreed reasonably well with the usage calculated by integration of flowrates (22.9 lbm). The temperature and pressure profiles were as expected and are shown in figure 10-5. The 506N acceptance firing cold helium supply system performance is compared with the S-IVB-504N and 505N performances in table 10-1.

10.5 Pilot Bleed Flowrate

The burner helium shutoff valves utilize a pilot bleed system which diverts approximately 0.006 lbm/sec of the total cold helium flow passing through each module and dumps it downstream of the burner exit orifices. Previously, the small amount of helium flow through the pilot bleed ports had been neglected; however, to add greater accuracy to helium usage evaluations, this pilot bleed flow has now been included (table 10-1).

TABLE 10-1 (Sheet 1 of 2)
O_2-H_2 BURNER PERFORMANCE DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
Duration of burner operation (sec)			
First firing	456	192	203
Second firing	130.6	None	None
Lag in pressurant flow after burner start (sec)	6.84	11	11
Cold helium supply			
Initial pressure (psia)	1,819	1,509	1,750
Initial average temperature (deg R)	60.3*	57.8	65.5
Initial mass (lbm)	252	214	214
Consumption during burner operation (lbm)	22.9	26.6**	26.9**
Burner propellant supply during repressurization period			
LH2 supply pressure range (psia)	20.5 - 31.1	21.1 - 34.4	21.3 - 35.1
LOX supply pressure range (psia)	39.3 - 43.2	38.9 - 42.5	38.9 - 42.7
LH2 tank pressurization			
Ullage volume (cu ft)	4,880	4,750	5,010
Initial pressure (psia)	19.6	20.2	20.4
Final pressure (psia)	30.2	33.5	34.2
Average pressurization rate (psi/min)	4.30	4.41	4.31
Total average heat flux rate*** from burner (Btu/hr)	234,000	223,000	228,000
Ambient heating rate*** of pressurant gas (Btu/hr)	66,536	40,000	42,000
Pressurant helium through burner (lbm)	16.5	22.6	22.8
Pressurant helium through valve pilot bleed (lbm)	0.9	1.06	1.13
Total helium required (lbm)	17.4	23.66	23.93

*Weight average

**Bleed flowrates not included

***Measured from 40 deg R reference base

TABLE 10-1 (Sheet 2 of 2)
O_2-H_2 BURNER PERFORMANCE DATA

PARAMETER	S-IVB-506N	S-IVB-505N	S-IVB-504N
LOX tank pressurization			
Ullage volume (cu ft)	999	1,056	968
Initial pressure (psia)	34.7	34.4	34.4
Final pressure (psia)	38.6	38.0	38.2
Average pressurization rate (psi/min)	1.16	1.19	1.18
Total average heat flux rate* from burner (Btu/hr)	48,880	46,400	45,500
Ambient heating rate* of pressurant gas (Btu/hr)	10,980	7,900	7,500
Pressurant helium through burner (lbm)	4.3	4.0	4.1
Pressurant helium through valve pilot bleed (lbm)	1.2	1.1	1.1
Total helium required (lbm)	5.5	5.1	5.2

*Measured from 40 deg R reference base

NOTE
(X) ITEM NUMBERS FROM PARTS LIST TABLE 3-I
SEE FIGURE 3-I FOR LEGEND

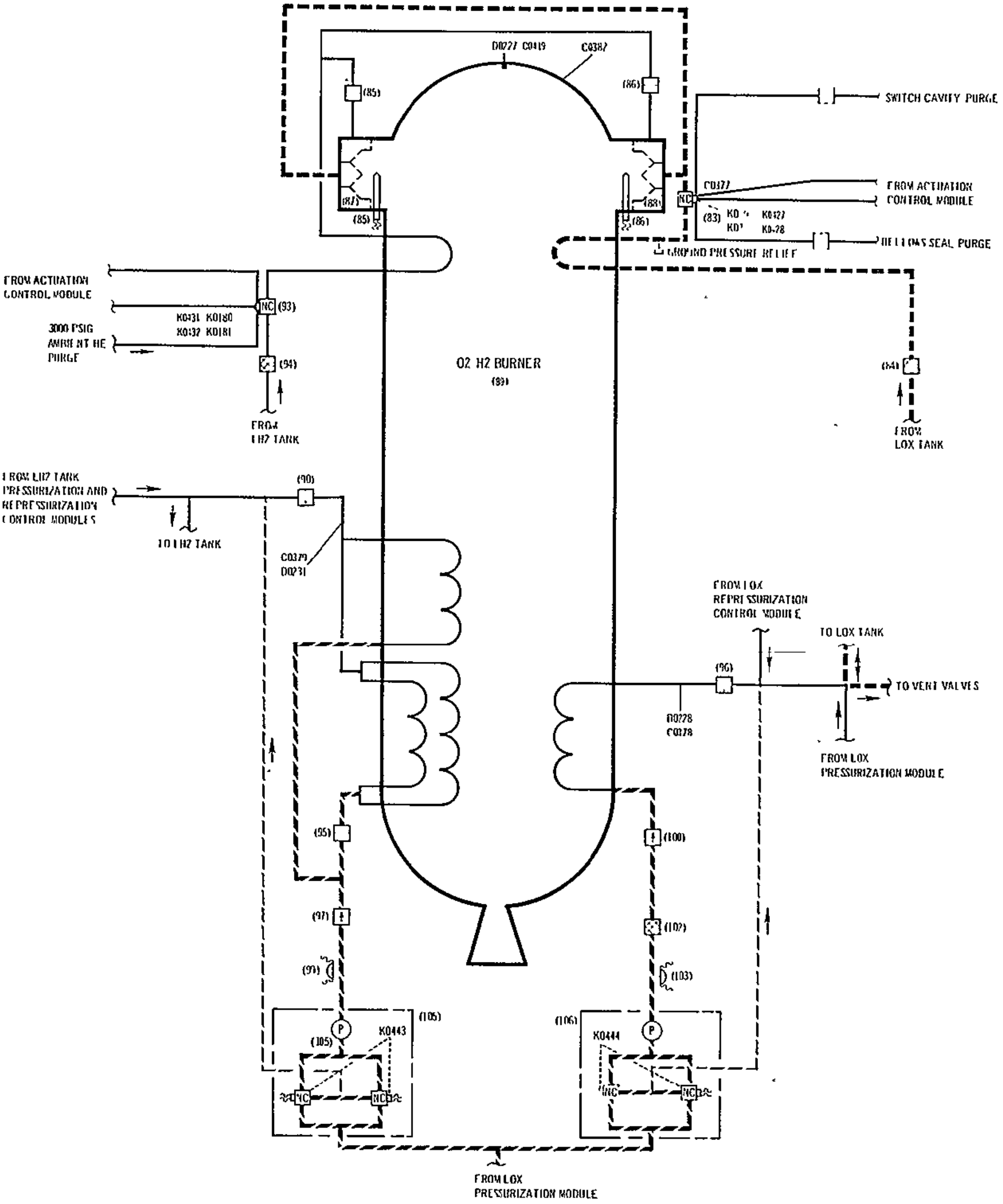


Figure 10-1. O_2-H_2 Burner Configuration and Instrumentation

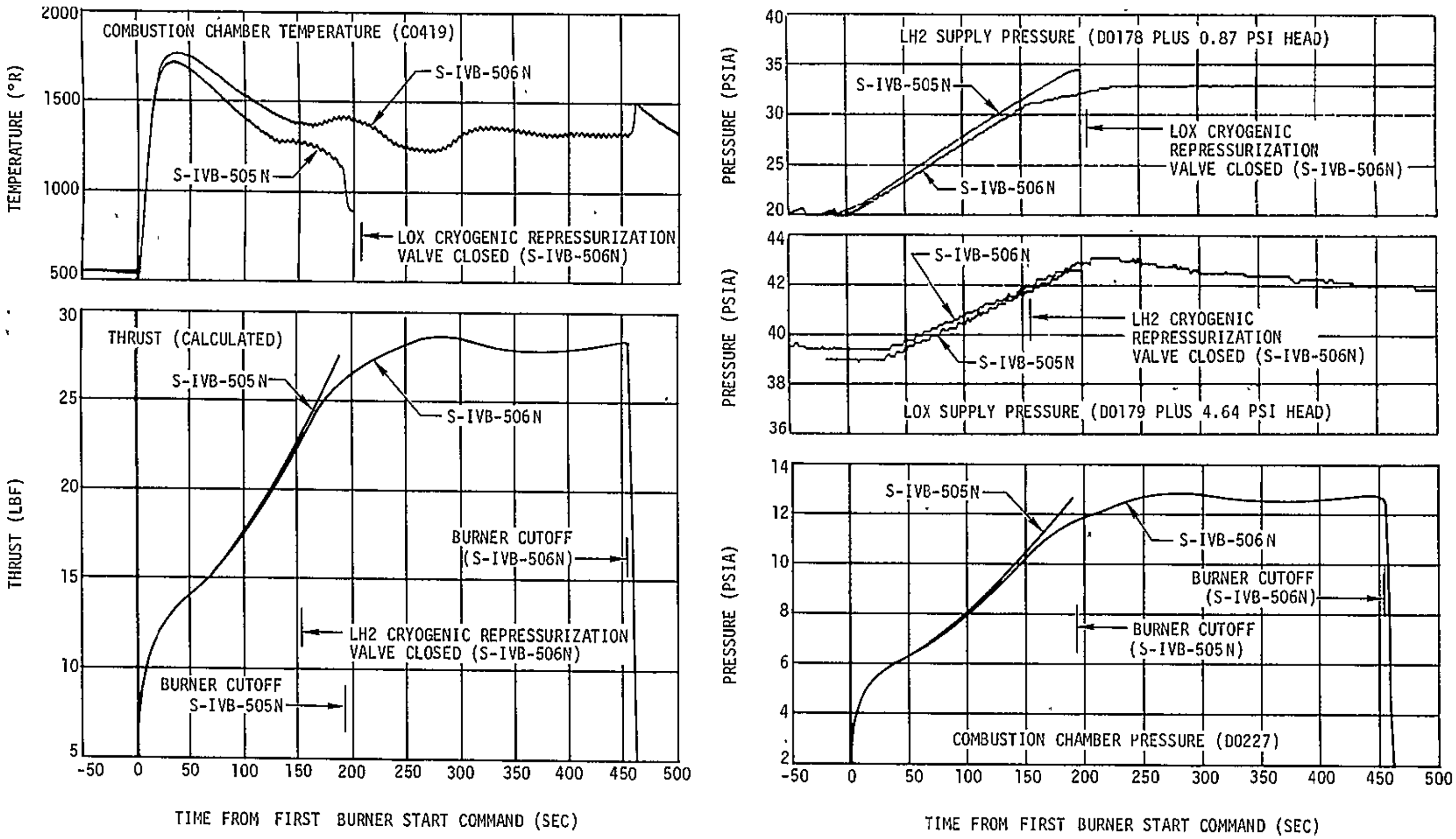


Figure 10-2. First Burner Firing

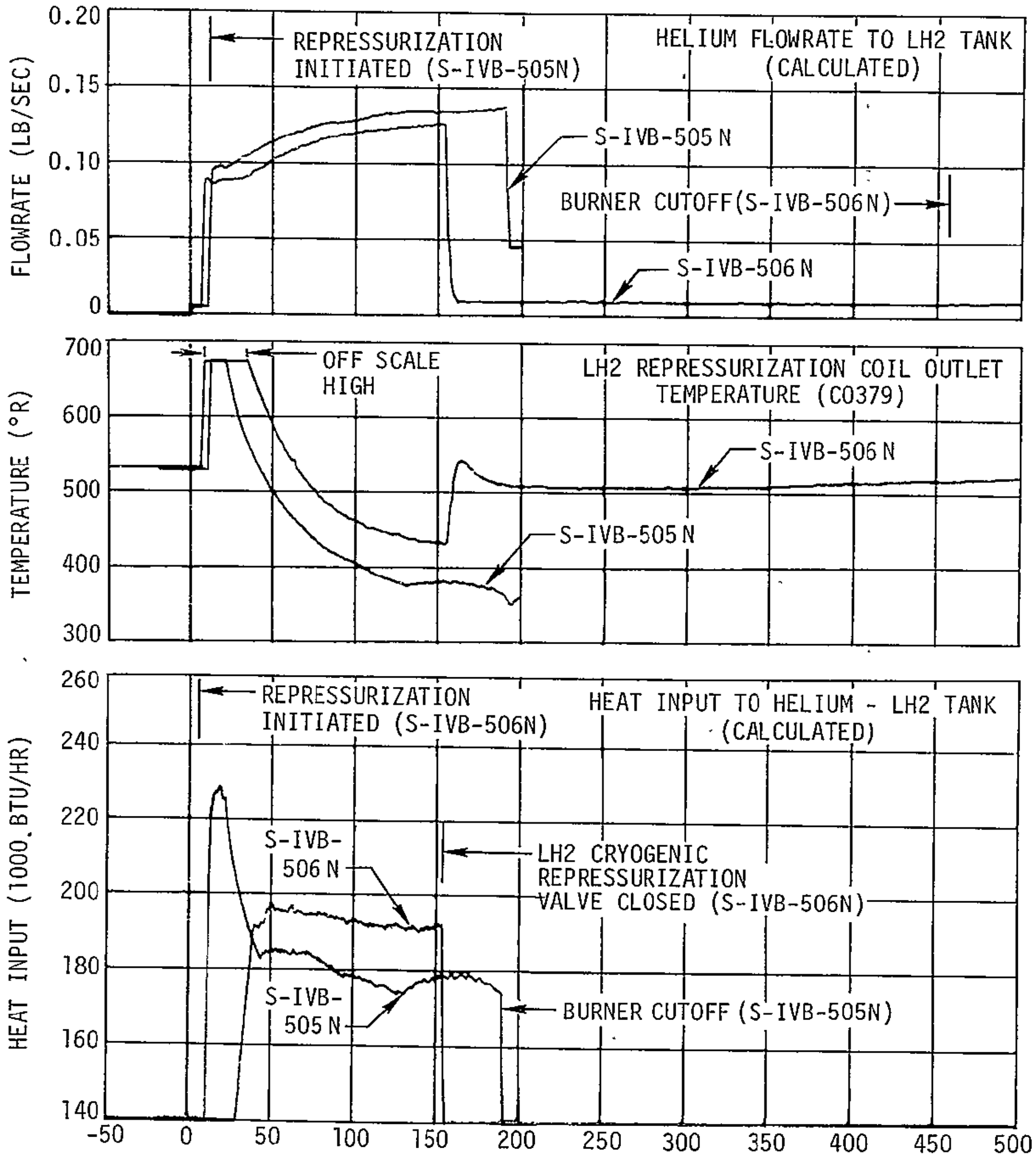


Figure 10-3. LH2 Tank Repressurization

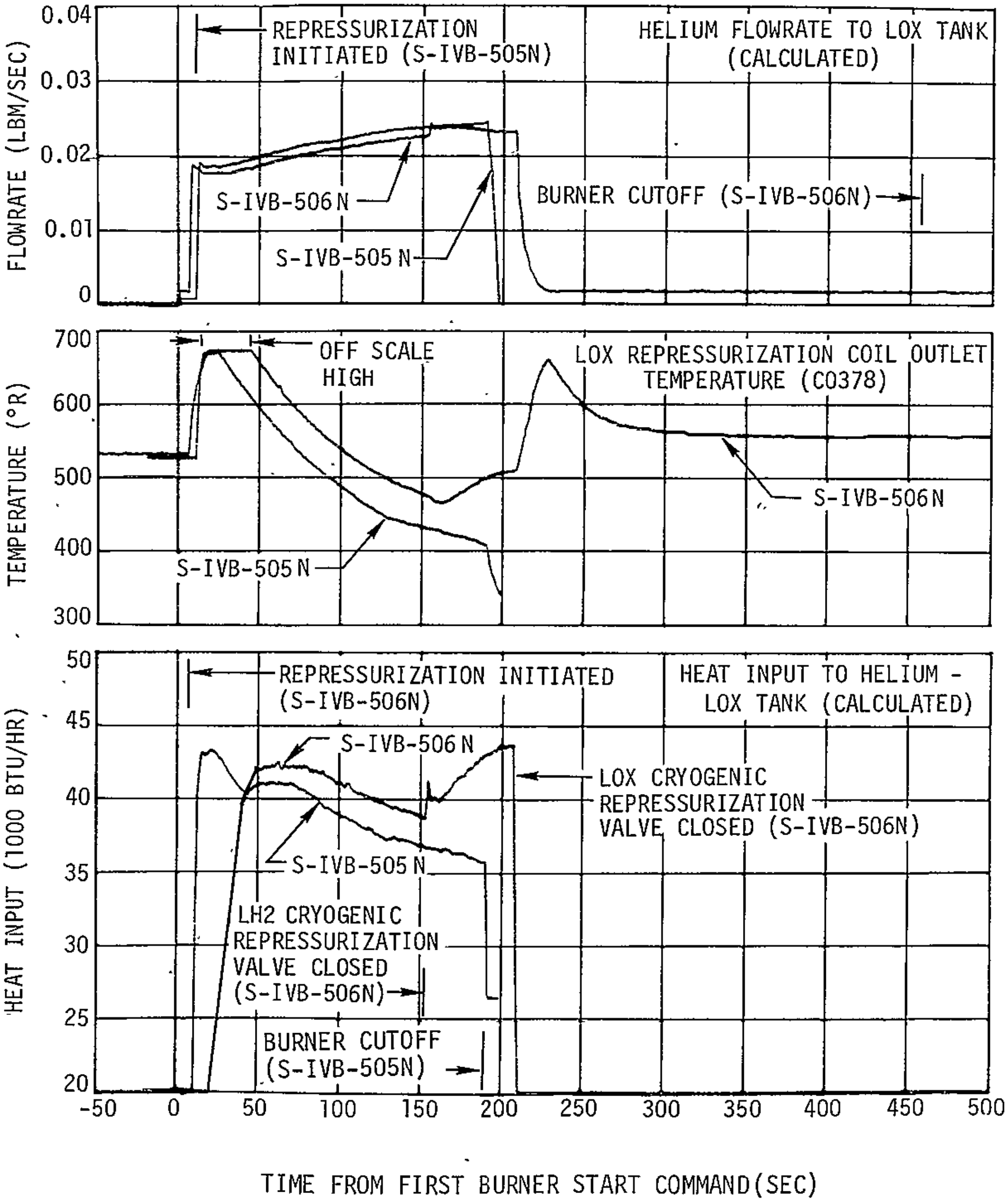


Figure 10-4. LOX Tank Repressurization

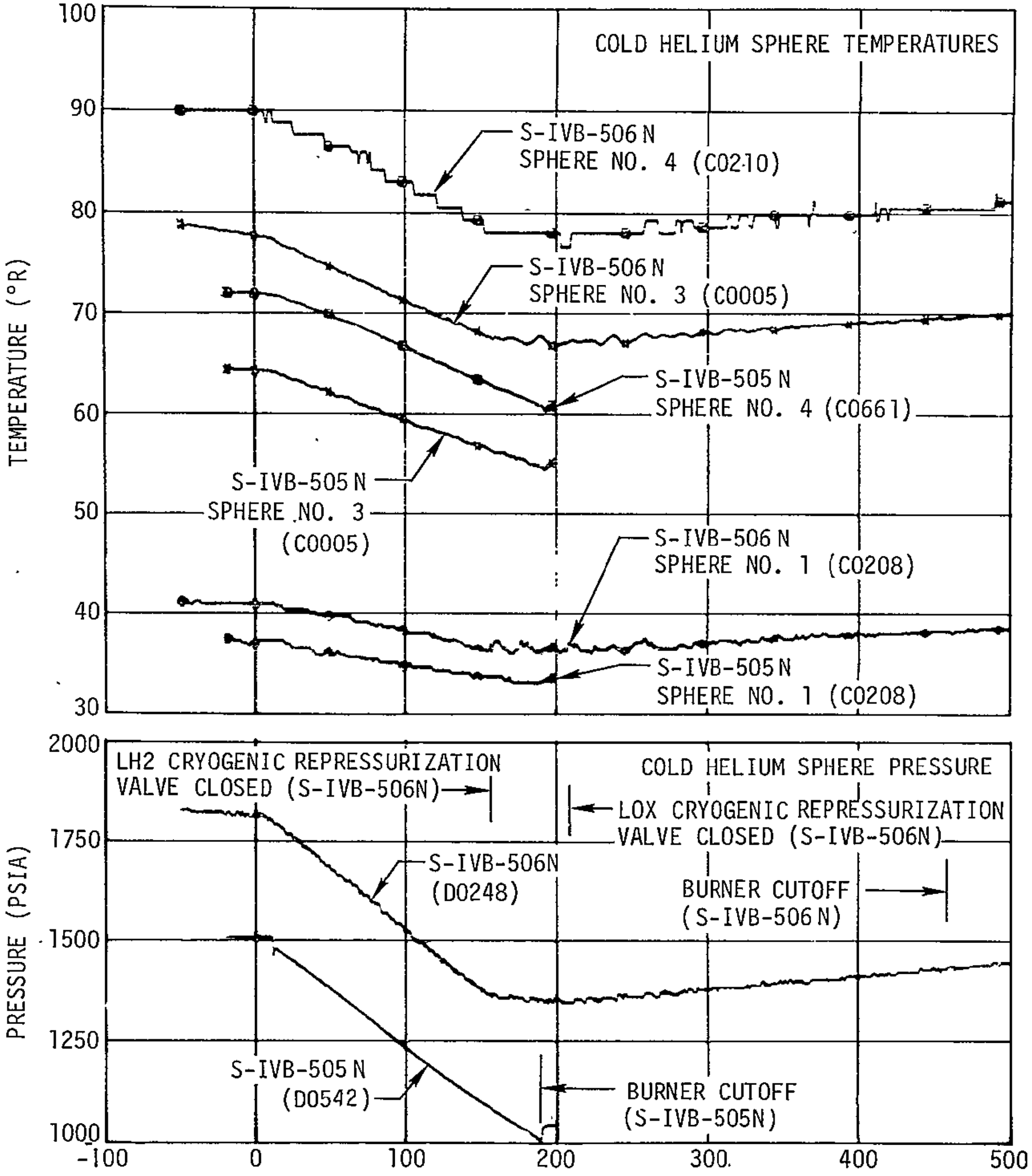


Figure 10-5. Cold Helium Sphere Conditions

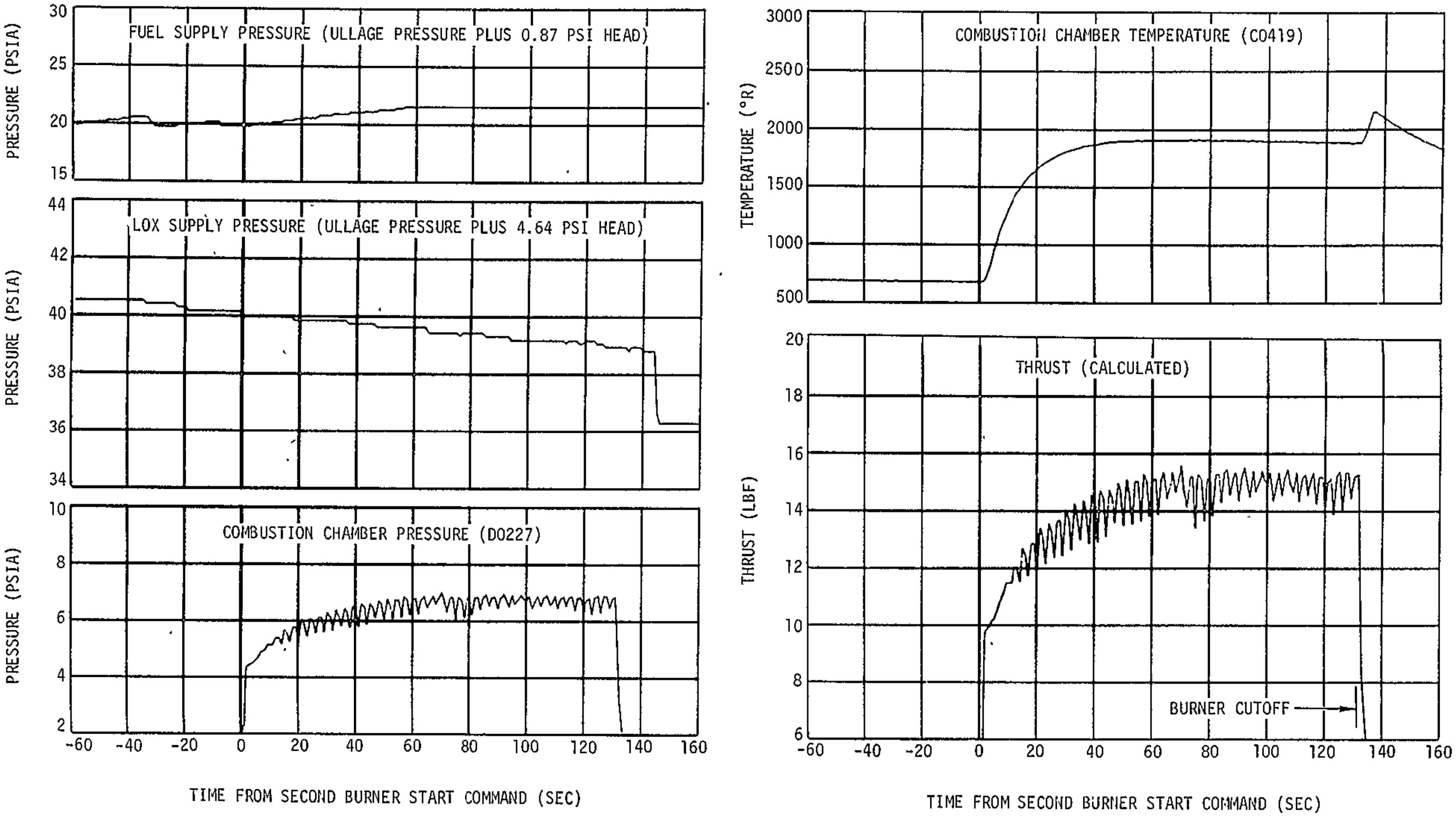


Figure 10-6. Second Burner Firing

[redacted]

SECTION II

PROPELLANT UTILIZATION SYSTEM

11. PROPELLANT UTILIZATION SYSTEM

The propellant utilization (PU) system performed satisfactorily during the acceptance firing. Propellant loading was successfully accomplished based upon a desired common propellant load of 193,273 lbm LOX and 38,000 lbm LH2. The PU indicated LOX and LH2 masses were 193,199 lbm and 38,077 lbm respectively. The actual LOX and LH2 masses obtained by the flow integral method were 192,806 lbm and 37,861 lbm respectively. The PU indicated LOX and LH2 masses were 0.20 percent and 0.57 percent higher than the flow integral masses. These deviations are within the allowable 3 percent tolerance of PU indicated and flow integral derived masses.

The PU indicated LOX mass was 0.04 percent lower than the desired LOX loading and the PU indicated LH2 mass was 0.20 percent higher than the desired LH2 load. The LOX and LH2 full load masses, as determined by the volumetric method, were respectively 0.14 percent and 0.18 percent higher than the flow integral method derived mass. Actual load as determined by the flow integral method was within 0.24 percent and -0.37 percent of desired for LOX and LH2 respectively.

The PU system operated in the closed-loop mode with a reference mixture ratio of 5.0:1 throughout the single-burn full duration firing. PU valve cutback occurred at Engine Start Command (ESC) +179.1 sec. The predicted valve cutback time was ESC +191 sec. The steady-state valve position following the cutback transient was approximately 1.8 deg lower than predicted.

Based upon extrapolation from the conditions at cutoff, LOX depletion would have occurred with 144 lbm of usable LH2 onboard as compared to a guaranteed maximum flight residual of 575 lbm.

Engine thrust variations were well within the flight thrust variation limits derived for the Contract End Item (CEI) specification. Use of both reshaped LOX and LH2 sensors significantly reduced sensor induced thrust variations.

11.1 PU System Calibration

The nominal S-IVB-506N pre-acceptance mass sensor calibration data was determined from previous acceptance firing results.

The propellant mass at the upper and lower calibration point was determined from calculated unique tank volume data and predicted propellant densities. The capacitance at the lower end was determined from the vendor's sensor air capacitance and average fast drain data from previous acceptance firings.

The LOX sensor capacitance at the full immersion point was determined from the vendor's air capacitance and the mean data accumulated from LOX sensor full immersion tests conducted on S-IVB-207, 208, 209, 503N, and 504N. The LH2 sensor capacitance at the upper calibration point was determined from the S-IVB-209, 504N, and 505N immersion test results and vendor's air capacitance.

The LOX and LH2 PU calibration data are presented in the following table:

PU MASS SENSOR	MASS (lbm)	CAPACITANCE (pf)	LOCATION
LOX	196,757	413.29	Top of Inner Element
	1,374	281.36	Bottom of Inner Element
LH2*	44,678	1188.28	Top of Inner Element
	204	973.90	Bottom of Inner Element

*These values are revised from the pre-acceptance firing calibration values. They represent an acceptable deviation from the former values and were necessitated by an LH2 mass probe retrofit.

11.2 PU Mass History

The flow integral and volumetric methods were used to evaluate the acceptance firing propellant full load and mass history; however, only the flow integral method will be used to recalibrate the PU system for flight.

The flow integral method consists of determining the mass flowrate of LOX and LH2 and integrating as a function of time to obtain total consumed mass during firing. Flow integral mass values are based on the analysis of engine flowmeter data, thrust chamber pressure, engine influence equations, engine tag values.

The initial full load mass, using the flow integral method is determined by adding the propellant residuals at engine cutoff, the fuel pressurant added to the ullage, and the propellants lost to boiloff, to the total mass consumed.

The PU volumetric masses were derived from raw PU probe output data computed according to volumetric calibration slopes and volumetric nonlinearities. The calibration slopes (pounds per picofarad [lbm/pf]) were computed from capacitance propellant mass relationships at the upper and lower probe active element extremities. The propellant mass at these extremities was calculated from unique tank volume determined from tank measurements and propellant density.

Table 11-1 presents the propellant mass history for salient times during the acceptance firing.

11.2.1 Propellant Loading

Propellant loading was accomplished automatically by the loading computer. Desired, indicated, and actual full propellant loads at ESC are presented in table 11-1.

Table 11-1 shows the close agreement between the desired load and actual load as determined by the flow integral method. The LOX and LH2 were loaded within -0.24 percent and -0.37 percent of desired values.

11.2.2 Propellant Residuals

Propellant residuals were computed at Engine Cutoff Command using both the PU mass sensors and the residual point level sensors. Three level sensors in each tank (L0017, L0018, and L0019 in the LH2 tank and L0014, L0015 and L0016 in the LOX tank) were activated during the firing and were used for residual analysis.

Level sensor residuals were computed using the engine consumption data (G105 program) to extrapolate from level sensor activation to engine cutoff. A statistical average residual was computed for the point level sensors for each propellant tank. The final residual masses at engine cutoff were the weighted average residuals generated by a weighted averaging of the point level sensor and PU mass sensor residuals data.

Table 11-2 contains a tabulation of PU indicated, level sensor, and weighted average data. The residuals as determined from the weighted average data was 1,789 and 1,156 lbm for LOX and LH2 respectively.

11.2.3 PU Efficiency

The closed-loop PU efficiency is determined by expressing the usable residual propellant at depletion cutoff as a percentage of the total propellant load. LOX depletion cutoff would have occurred 3.15 sec after the actual Engine Cutoff Command. Total stage propellant consumption rates (determined by engine and stage flowrate evaluations) at ECC were 403.83 lbm/sec for LOX and 79.88 lbm/sec for LH2. Extrapolating these flowrates to the theoretical LOX depletion cutoff, results in a usable LH2 residual of 144 lbm and a PU efficiency of 99.94 percent.

11.3 PU System Response

PU system valve cutback occurred at ESC +179.1 sec, which was 11.9 sec earlier than the predicted cutback time of 191 sec. The PU system response during the cutback transient had a more gradual slope than predicted, thus indicating a PU electronic assembly bridge gain reduction. The actual valve history settled at a steady-state valve position which was approximately 1.8 deg lower than predicted.

The reconstruction of the actual PU valve history was made using the actual engine environment, tank-to-sensor mismatches derived from the flow integral mass histories, and other known system operating conditions. The reconstruction includes the effect of the new PU flow baffle on the engine, thrust, EMR, and ISP characteristics.

The following table summarizes the deviations between the actual and predicted PU valve position histories and their sources, based on the flow integral results.

DESCRIPTION	CUTBACK TIME DEVIATION (sec)	VALVE POSITION SHIFT (deg)
Loading Computer Deviations	-10.7	0
Flow Integral Mass/Capacitance Calibration Deviation	+5.0	+1.1
Deviations in Engine Environment and Engine Tag Values from Predicted	-6.0	0
Difference Between Predicted and Actual Flow Integral Tank-to-Sensor Mismatch Nonlinear	+9.0	0
Revised Engine Characteristics due to PU Baffle Effect	0	-2.9
PU System Gain Change	-9.0	0
Total	-11.7	-1.8

The summation of deviations listed in the table would decrease the predicted cutback time by 11.7 sec and lower the mean value of valve position by 1.8 deg. This provides a close comparison between the actual cutback time and steady-state valve position, and the postfiring reconstruction shown in figure 11-1.

11.3.1 PU Cutback Deviations

11.3.1.1 Loading Computer Deviation

Loading computer deviations are the difference between the PU system indicated loads at ESC and the desired PU system indicated loads at ESC. The loading deviations were -74 lbm LOX (-0.038 percent) and +77 lbm LH2 (0.20 percent). These deviations are within acceptable loading errors of ±0.5 percent. The combined effect of these loading computer deviations decreased cutback time by 10.7 sec. The mean level of the valve position after cutback was not affected by these loading computer deviations.

11.3.1.2 Flow Integral Mass/Capacitance Calibration Deviation

Calibration deviations are the difference between indicated loads and actual loads during burn. Calibration deviations at ESC were -0.20 percent LOX and -0.57 percent LH2, thus causing the initial masses to be underloaded by the above amounts. Calibration deviations at ECC were -0.02 percent LOX and -0.06 percent LH2. The slope deviations between ESC and ECC were -0.18 percent LOX and -0.51 percent LH2.

The desired reference mixture ratio (RMR) for the 506N acceptance firing was 5.0:1.0. The bridge gain ratio (BGR) was also calibrated at 5.0:1.0. Since PU sensor calibration deviations also effect the BGR, the actual ratio was 5.02:1.0. The calibration deviations increased cutback time by 5 sec and shifted the mean value of valve position by +1.1 deg.

11.3.1.3 Deviations in Engine Environment from Predicted

The effect of the differences between the predicted and actual pump inlet conditions, pressurization rates, boiloff rates, and engine tag values for the 506N acceptance firing was to decrease cutback time by 6 sec. The mean level of the valve position was not altered significantly.

11.3.1.4 Difference Between Predicted and Actual Tank-To-Sensor Mismatch

The effect of the differences between the average of previous acceptance firing flow integral tank-to-sensor mismatch results used for the S-IVB-506N prediction and the actual S-IVB-506N flow integral tank-to-sensor mismatch, increased cutback time by 9 sec and had very little effect on the mean level of valve position. Figures 11-2 and 11-3 show the observed flow integral and volumetric LOX and LH2 non-linearities normalized to the actual loaded masses with the sensor manufacturing non-linearities included.

11.3.1.5 Revised Engine Characteristics Due to PU Baffle Effect

The revised engine tag values, reflecting the effects of the PU valve flow baffle, were incorporated into the postfiring reconstruction. The baffle effects did not alter the cutback time, but they did lower the mean level of the valve position during the RMR operation by 2.9 deg.

11.3.1.6 PU System Gain Difference

The postfiring reconstruction indicated that the slope deviation, following cutback, between the actual and predicted 506N valve profiles can be attributed to a reduced bridge gain in the actual PU Electronics Assembly. Reconstruction of the 506N acceptance firing valve history revealed that a reduction of approximately 1.1 db in the simulation model bridge gain is required to match the actual observed valve slope during cutback. This is an acceptable gain deviation and will be incorporated in the flight simulation model to improve the 506N flight test predictions. Figure 11-4 compares the postfiring reconstruction with and without the gain shift deviation.

11.3.2 Thrust Variation

The complete thrust profile is presented in figure 6-15 and the guidance critical period prior to cutoff is shown in figure 6-16.

The rate-of-change of thrust following cutback was in agreement with the prediction. Thrust excursions between ESC +280 sec and ESC +420 sec were caused by the 506N LH2 mass sensor (D4/C2) manufacturing nonlinearities. The mean thrust slope during the last 70 sec of burn was +7 lbf/sec and the thrust variation band was ±1,495 lbf. The thrust variations were within the CEI thrust limits and are provided in table 6-7.

TABLE 11-1
PROPELLANT MASS HISTORY

EVENT	PREDICTED MASS (lbm)	PU INDICATED MASS (lbm)	PU VOLUMETRIC MASS (lbm)	FLOW INTEGRAL MASS (lbm)	DEVIATION FROM FLOW INTEGRAL MASS		
					PREDICTED	PU INDICATED	VOLUMETRIC
Simulated Liftoff (To) and Engine Start Command	LOX 193,273	193,199	193,089	192,806	-467 (0.24%)	-393 (0.20%)	-283 (0.14%)
	LH2 38,000	38,077	37,930	37,861	-139 (0.37%)	-216 (0.57%)	-69 (0.18%)
	Total 231,273	231,276	231,019	230,667			
PU Valve Cutback (ESC +179.1 sec)	LOX NA	112,841	112,461	112,532	NA	-309 (0.27%)	71 (0.06%)
	LH2 NA	23,144	23,063	23,125	NA	-19 (0.08%)	62 (0.27%)
	Total NA	135,985	135,524	135,657	NA		
Engine Cutoff Command	LOX 1,934	1,770	1,760	1,789	-145 (0.08%)	19 (0.01%)	+29 (0.02%)
	LH2 759	1,091	1,091	1,156	397 (1.05%)	65 (0.17%)	65 (0.17%)
	Total 2,693	2,861	2,851	2,945			

TABLE 11-2
PROPELLANT RESIDUAL SUMMARY

	LEVEL SENSOR (ACTIVATION TIME)							
	LOX TANK				LH2 TANK			
	L0016 T_0 + (922.008)	L0015 T_0 + (936.926)	L0014 T_0 + (953.429)	ECC T_0 + (959.470)	L0019 T_0 + (931.675)	L0018 T_0 + (939.844)	L0017 T_0 + (956.847)	ECC T_0 + (959.470)
PU Mass Sensor Indicated Value	16,855	10,823	4,227	1,760 (±492)	3,385	2,746	1,380	1,091 (±130)
Level Sensor Indicated Value	16,652	10,643	4,316		3,390	2,742	1,365	
Level Sensor Extrapolated Residual	1,680	1,639	1,892	1,791* (±139)	1,159	1,168	1,154	1,159* (±29)
Weighted Average Residual				1,789** (±134)				1,156** (±29)

*Statistical average of level sensor residuals

**Statistical average of level sensor and PU system residuals

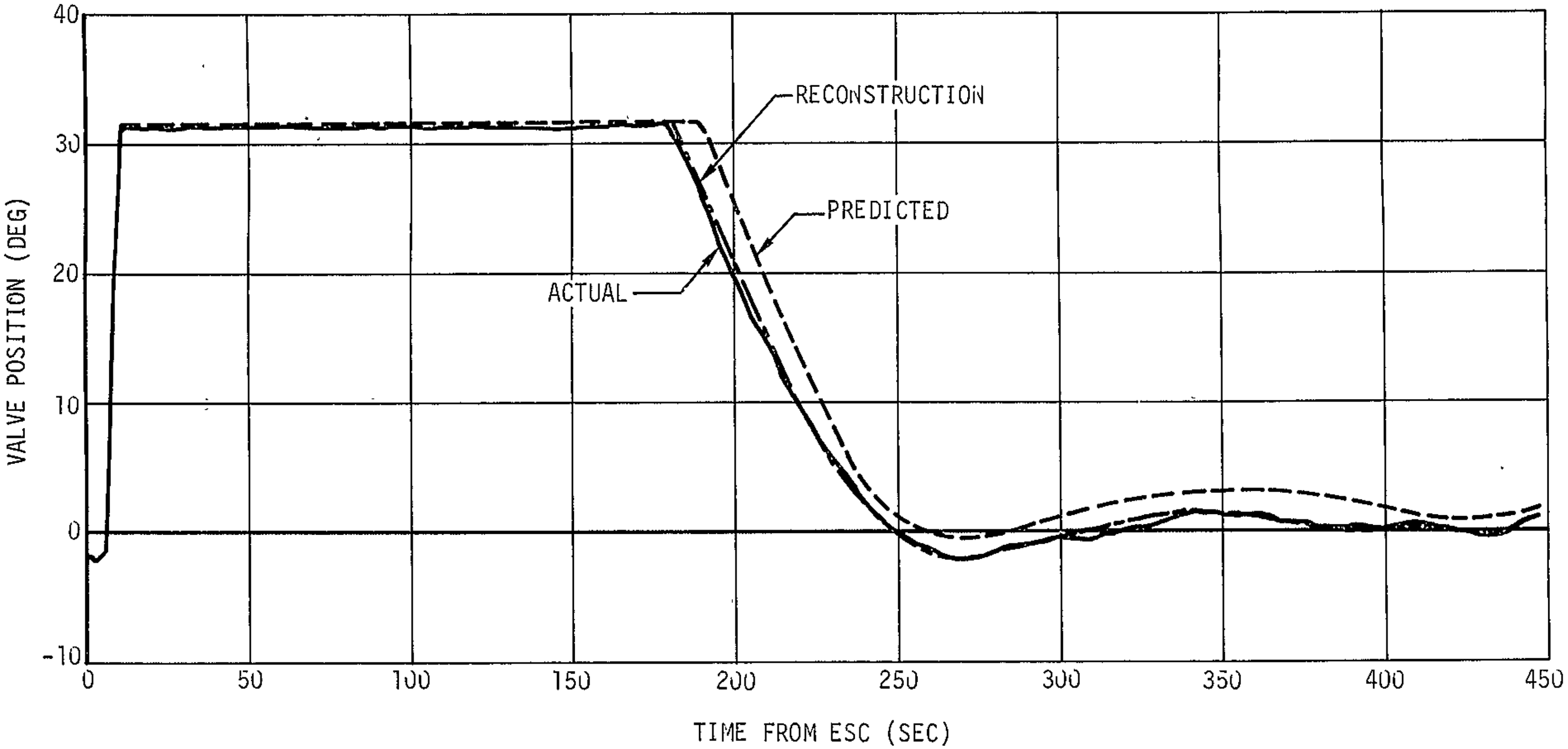


Figure 11-1. PU Valve Response - Actual, Reconstruction, and Predicted

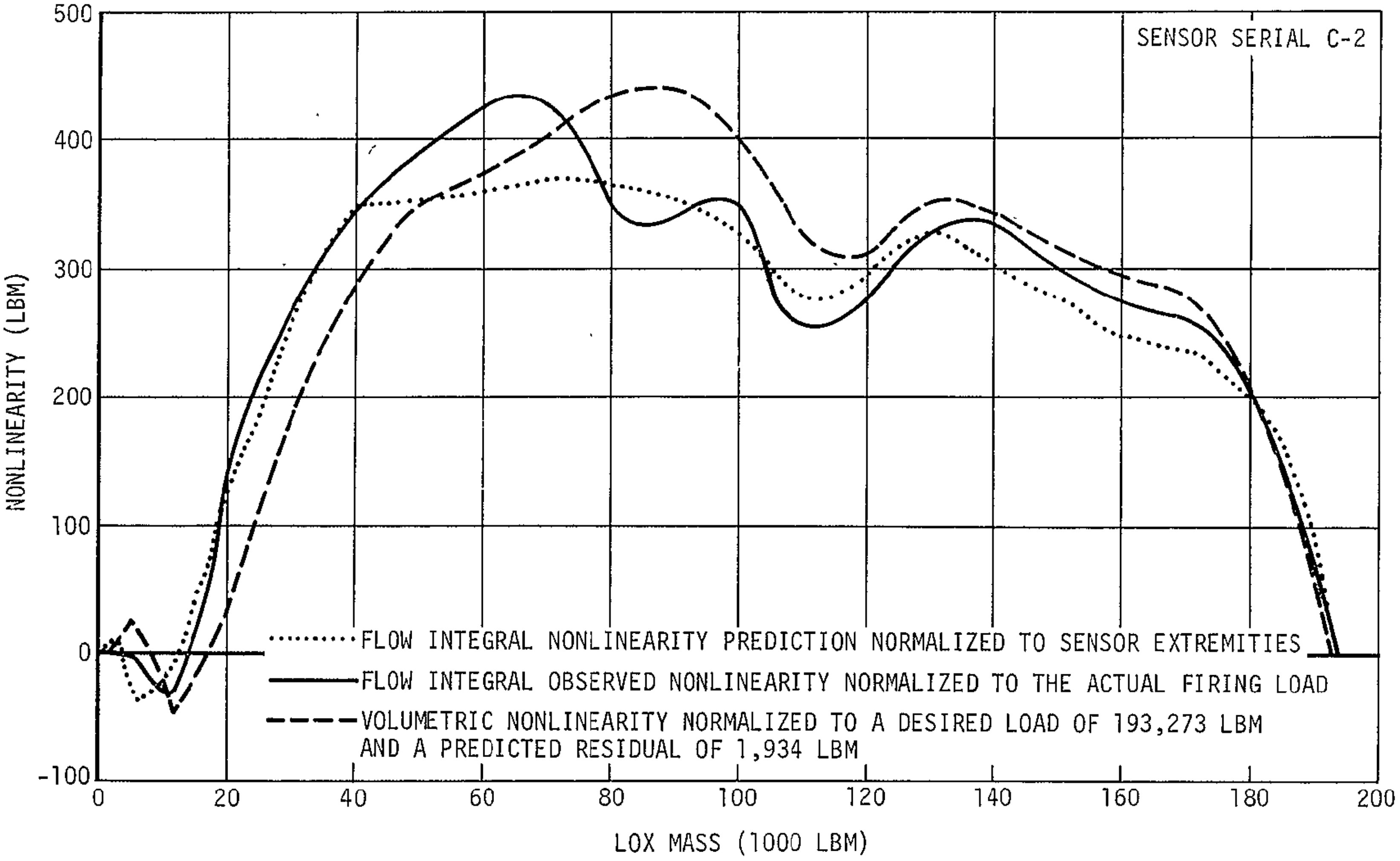


Figure 11-2. LOX Mass Sensor Non-linearity

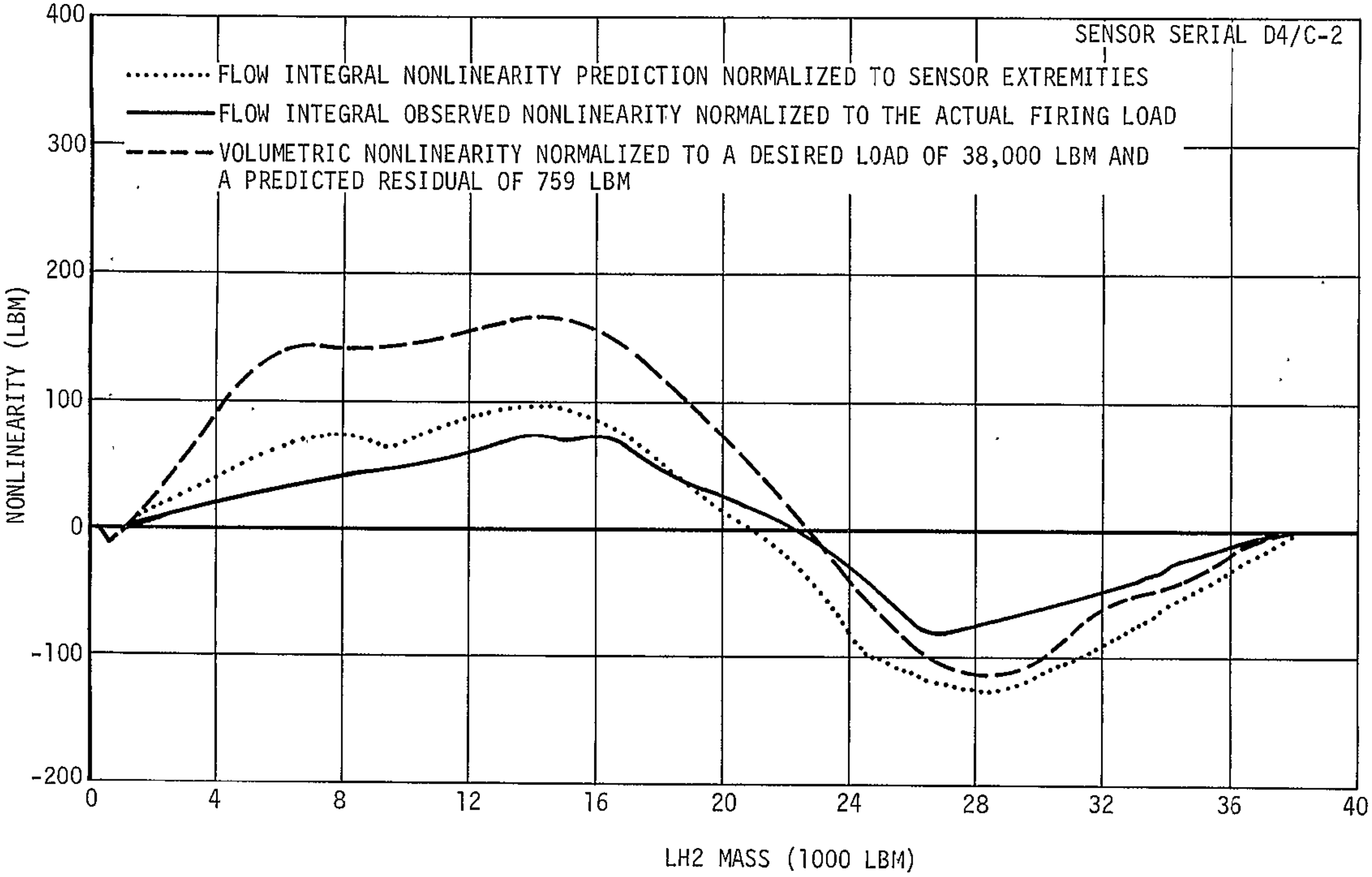


Figure 11-3. LH2 Mass Sensor Nonlinearity

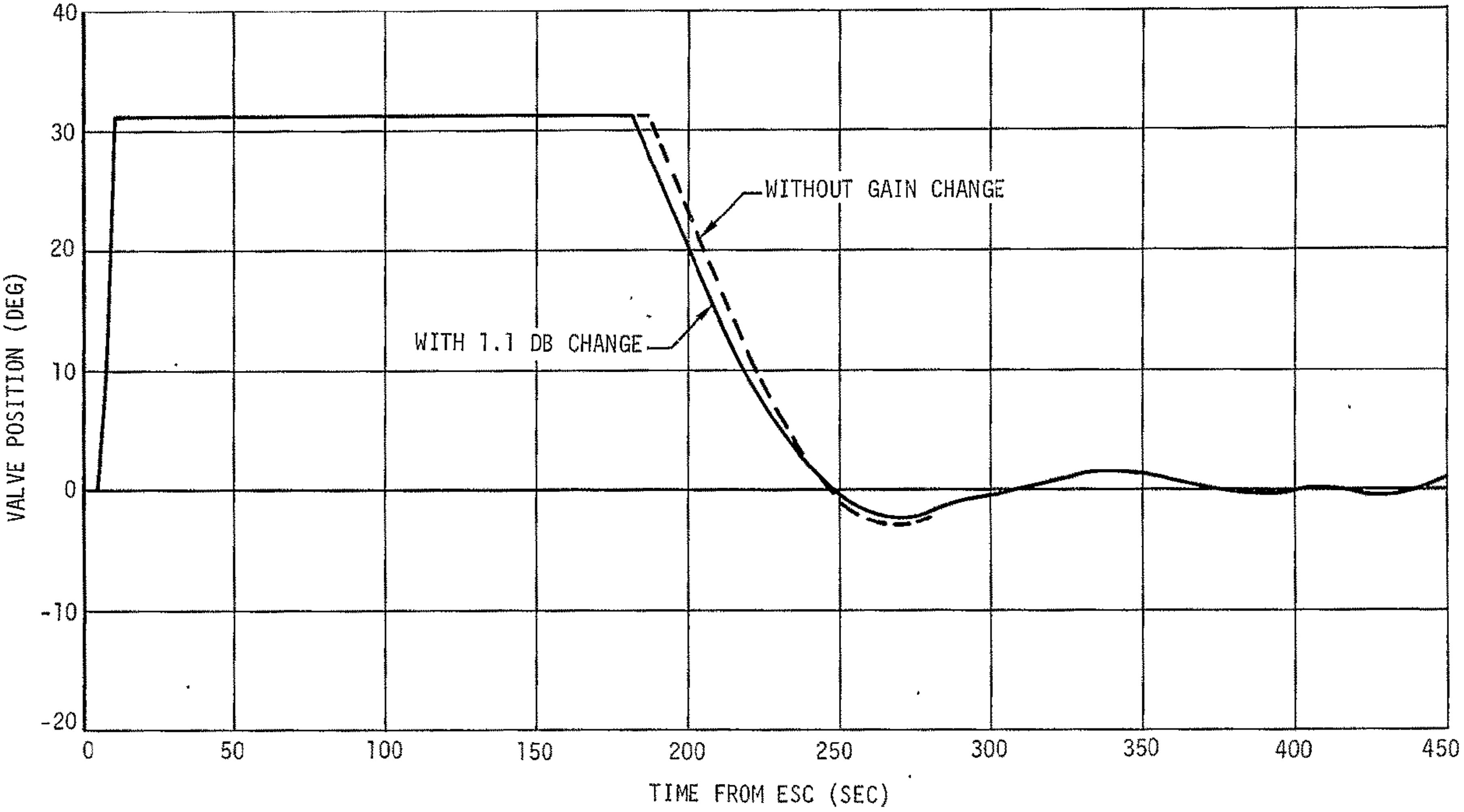


Figure 11-4. PU Valve Response

[redacted]

SECTION 12

DATA ACQUISITION SYSTEM

12. DATA ACQUISITION SYSTEM

The data acquisition system demonstrated competency in acquiring stage information, conditioning the data signals, translating these signals into proper telemetry format, and transmitting the telemetry information to a ground station. The measurements which comprise this system are specified in Douglas Drawing No. 1B67860 Change G, AEO H, J, K, and L, Instrumentation Program and Components List (IP&CL); although, not all measurements specified in the IP&CL were in operation during this test. The system demonstrated that it was free of radio frequency interference and was electromagnetically compatible with other stage systems.

The performance of the data acquisition system was satisfactory throughout the O_2-H_2 burner and mainstage firing phases of the acceptance firing. The reduced data from all channels were acceptable with the exception of the discrepancies described in tables 12-1 and 12-2.

The following is a summary of the data measurement system performance during acceptance firing:

Total number of measurements assigned	274
Total number of measurements deleted	56
Total number of active measurements	218
Measurement failures	1
Total acceptable measurements	217
Measurement efficiency	99.5 percent
Measurement discrepancies	4

12.1 Instrumentation System Performance

The instrumentation system performed satisfactorily during all phases of the acceptance firing. One measurement failure was observed and four measurements exhibited data problems. Table 12-1 lists these measurements and table 12-2 elaborates their malfunction characteristics. Table 12-3 lists the measurements that were inactive.

One measurement exhibited invalid data. Measurement D0016 (Press - Cold He Sphere) was invalid throughout the firing phase.

Four measurements indicated data problems. Measurement D0055 (Press - LOX Tank Inlet) indicated data dropout. Measurement D0249 (Press - LH2 Tank He Btl Repress, Bkup) displayed RACS level problem. Measurements M0060 (Volt-PU Valve Contr) and N0055 (T/M RF System Refl Pwr) exhibited excessive RFI response.

The measurements listed below were susceptible to the high RF field experienced on the Complex Beta test stand. The RFI condition was exhibited as noise or data shift, or both, when comparing open and closed loop RF data. RFI responses have been observed during previous firings; this problem does not exist when the stage is in the launch vehicle configuration. No action is being contemplated to remedy the problem.

M0060	Volt - PU Valve Contr
N0018	Misc - PCM/FM Xmtr Output Pwr
N0055	Misc - T/M RF Syst Refl Pwr

The measurements listed below indicated noise during auxiliary hydraulic pump and/or chilldown inverter operation. All measurements were below EMR criterion.

C0378	Temp - Burner LOX Press Coil
D0001	Press - Thrust Chamber
D0002	Press - LH2 Pump
D0005	Press - Main LOX Injector
D0007	Press - LOX Turbine Inlet
D0010	Press - Gas Gen Chamber
D0014	Press - Contr He Reg Discharge
D0228	Press - Burner LOX Press Coil
M0012	Freq - Static Inv/Conv
M0069	Volt - Aft T/M Full Scale Ref

RACS calibrations were evaluated for proper levels at T_0 -2,759 sec (1728:41 hr). Closed RF loop RACS calibration at T_0 +1,373 sec

(1837:33 hr) was used to verify RACS levels under RFI free environment. Listed below are measurements that exceeded 2 percent from nominal RACS level. Measurement D0249 exceeded the 3 percent tolerance specified by system requirements.

MEASUREMENT	RACS LEVEL	DIGITAL COUNTS	PERCENT FROM NOMINAL	CLOSED LOOP DIGITAL COUNTS	OP/CL LOOP DIFF
D0249 Press-LH2 Tnk He Btl Repress	High Low	844 219	+4.1 0.0	810 215	-34 -4
N0055 Misc-T/M RF Sys Refl Pwr	High Low	804 247	0.0 +2.9	800 213	-4 -34

Comparison of the T/M and GIS hardware data was conducted during the Sacramento test facility evaluation. Satisfactory comparisons were accomplished except for measurement D0016 which failed during the firing. T/M measurement discrepancies are described in table 12-2.

12.2 Telemetry System Performance

The telemetry system performed satisfactorily. There was no loss of system synchronization and good data were received from all channels. DDAS hardwire (600KC) to T/M (open loop RF) comparison did not reveal any vehicle data discrepancies.

Inflight T/M calibrations were evaluated from the mainstage firing phase. T/M calibrations were evaluated at T_0 +452 and at T_0 +1,295 sec. The multiplexers indicated data point dispersions of +4, -8 and +2, -5 bit counts, respectively; a bit is approximately 5 mv and dispersions are evaluated from a nominal of 999 bits at the 100 percent calibration level. The higher dispersion of T_0 +452 sec was the result of the operation of the auxiliary hydraulic pump and the chilldown inverters.

12.3 RF System Performance

No difficulties were encountered in the performance of the RF system. The RF power output for closed-loop operation was 22.4 W with the VSWR calculated to be 1.15:1. The RF power measurements were susceptible to the RF field during open-loop operation; therefore, proper assessment of the RF system could not be accomplished. For worst case, using the closed-loop power output and the open-loop reflected power, the VSWR was 1.41:1.

RF SUBSYSTEM DATA		
SYSTEM	OPEN LOOP VALUE*	CLOSED LOOP VALUE
PCM/FM Transmitter Output Power (minimum acceptable is 15 W)	22.8 W	22.4 W
VSWR (maximum acceptable is 1.8:1)	1.41:1	1.15:1

*RF measurements were susceptible to RFI

12.4 Electromagnetic Compatibility

The data acquisition system did not interfere with other stage systems in the areas of electromagnetic compatibility. However, measurements did exhibit data shift and noise caused by the susceptibility to the high RF field experienced on the Complex Beta test stand. Also, measurements indicated noise during the auxiliary hydraulic pump and chilldown inverters operation. See paragraph 12.1 for the complete listing.

12.5 Emergency Detection System Measurements

Measurements D0177 (Press - LH2 Tank Ullage, EDS No. 1), D0178 (Press - LH2 Tank Ullage, EDS No. 2), D0179 (Press - LOX Tank Ullage EDS No. 1), and D0180 (Press - LOX Tank Ullage, EDS No. 2) all performed satisfactorily.

12.6 Hardwire Data Acquisition System Performance

The ground instrumentation system (GIS) provides a backup and data comparison for certain stage telemetry system parameters in addition to recording measurements from the ground support and facility equipment.

The GIS also provides strip charts for redline and cutoff parameter monitoring. The GIS performance during acceptance firing was satisfactory.

The following table presents the type of recording equipment and the number of channels used.

GROUND RECORDER	CHANNELS ASSIGNED
Beckman 210 Digital Data System	179
Constant Bandwidth FM	64
Wideband FM	11
Strip Charts	36
TOTAL	290

Table 12-5 presents a list of the various types of measurement data recorded and the performance of the system.

12.6.1 Hardwire Measurement Discrepancies

There were four measurement failures, yielding an overall hardwire measurement efficiency of 99.5 percent. Measurement discrepancies that occurred during the acceptance firing are listed in table 12-6.

TABLE 12-1
INSTRUMENTATION SYSTEM PERFORMANCE SUMMARY

FUNCTION	NUMBER ASSIGNED PER IP&CL	INACTIVE	NET ACTIVE	DISCREPANCIES	FAILURES	PERFORMANCE* (percent)
Acceleration (A)	0	-	-	-	-	-
Acoustic (B)	0	-	-	-	-	-
Temperature (C)	60	17	43	0	0	100.0
Pressure (D)	76	24	52	2	1	98.0
Vibration (E)	0	-	-	-	-	-
Flow (F)	4	0	4	0	0	100.0
Position (G)	8	5	3	0	0	100.0
Events (K)	70	7	63	0	0	100.0
Liquid Level (L)	7	1	6	0	0	100.0
Volt/Current/Freq (M)	38	2	36	1	0	100.0
Miscellaneous (N)	9	0	9	1	0	100.0
Strain (S)	0	-	-	-	-	-
Speed (T)	2	0	2	0	0	100.0
TOTAL	274	56	218	4	1	99.5 percent

*Performance (percent) = $\frac{\text{Net Active - Failures}}{\text{Net Active}}$ X 100

TABLE 12-2 (Sheet 1 of 2)
T/M MEASUREMENT DISCREPANCIES

MEASUREMENT NO.	PARAMETER	REMARKS
D0016-425	Press - Cold Helium Sphere	The measurement was invalid throughout the engine firing period. The data indicated gross pressure trend with a 3 percent peak-to-peak varying low frequency noise. The malfunction first occurred after an RACS calibration period; however, all RACS levels were properly cycled whenever commanded. Once the pressure abruptly indicated good data but subsequently malfunctioned after an RACS period. Definite determination of the malfunction has not been made; however, a transducer RACS calibration relay is suspected of "sticking." The noise problem appears associated with the relay problem. Analysis of the cause is still under investigation. After the firing, the malfunction could not be duplicated; however, the transducer will be replaced.
D0055-424	Press - LOX Tank Inlet	The data indicated a measurement information dropout at T_0 +312 sec for 4 sec. The nominal data level at the time dropout occurred was 16.6 percent. This transducer is a potentiometer type thus wiper lift or contamination on the winding could cause a signal interruption. Upon investigation during a postfiring test, the malfunction could not be duplicated. It has been concluded that the problem was of a random nature thus corrective action was not contemplated. The transducer will be observed in future tests to determine if the malfunction recurs.
D0249-403	Press - LH2 He Bottle Repress Backup	The prefiring high RACS level was 4.1 percent higher than nominal. It appeared that the prefiring RACS level for this measurement did not represent the normal characteristics as the other RACS periods. The postfiring

TABLE 12-2 (Sheet 2 of 2)
T/M MEASUREMENT DISCREPANCIES

MEASUREMENT NO.	PARAMETER	REMARKS
D0249-403 (Continued)	Press - LH2 He Bottle Repress Backup	RACS level appears within system requirement. A postfiring test could not duplicate the problem; therefore, it was concluded that the prefiring RACS level was erroneous and did not represent the normal levels. The prefire level was initially 4.1 percent high then slowly decreased to 2 percent high prior to switching to the low RACS level. No action will be taken unless the problem recurs.
M0060-411	Volt - PU Valve Control	The data indicated a data shift of 2.2 percent when switched from open to closed RF loop operation. This data shift did not appear to affect the PU system. This measurement, from previous test, was known to be RFI susceptible to the high RF field experienced on the Beta test stand. This problem does not exist when the stage is erected at FTC.
N0055-411	Misc - T/M RF Syst Refl Pwr	The measurement indicated susceptibility to the T/M RF field on the Beta test stand. There were data variations of 2 percent throughout the firing phase. During mainstage firing, the noise frequency and amplitude increased. This condition was noted during previous firings. Since this problem does not exist at FTC when the stage is erected for launch, no action will be taken to remedy the problem on this stage.

TABLE 12-3 (Sheet 1 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
C0007-401	Temp - Engine Control Helium	Open, H/W requirement
C0021-415	Temp - Fuel, Mod 2, APS	Simulated, APS not installed
C0022-415	Temp - Oxid, Mod 2, APS	Simulated, APS not installed
C0023-414	Temp - He Press Tank, Mod 1, APS	Simulated, APS not installed
C0050-401	Temp - Hyd Pump Inlet Oil	Open, H/W requirement
C0102-411	Temp - Fwd Battery No. 1	Simulated, primary battery not used
C0103-411	Temp - Fwd Battery No. 2	Simulated, primary battery not used
C0104-404	Temp - Aft Battery No. 1	Simulated, primary battery not used
C0105-404	Temp - Aft Battery No. 2	Simulated, primary battery not used
C0131-404	Temp - Aft Battery No. 1 Unit 2	Simulated, primary battery not used
C0132-414	Temp - Oxid, Mod 1, APS	Simulated, APS not installed
C0136-414	Temp - Fuel, Mod 1, APS	Simulated, APS not installed
C0187-415	Temp - He Press Tank, Mod 2, APS	Simulated, APS not installed
C0200-401	Temp - LH2 Injection	Open, H/W requirement
C0211-411	Temp - Fwd Battery No. 1 Unit 2	Simulated, primary battery not used
C0212-411	Temp - Fwd Battery No. 2 Unit 2	Simulated, primary battery not used
C0382-403	Temp - Chamber Dome, O_2-H_2 Burner	Open, H/W requirement
D0027-414	Press - Att Contr Chamber 1-1	Simulated, APS not installed
C0028-414	Press - Att Contr Chamber 1-2	Simulated, APS not installed
D0029-414	Press - Att Contr Chamber 1-3	Simulated, APS not installed
D0030-415	Press - Att Contr Chamber 2-1	Simulated, APS not installed
D0031-415	Press - Att Contr Chamber 2-2	Simulated, APS not installed
D0032-415	Press - Att Contr Chamber 2-3	Simulated, APS not installed

TABLE 12-3 (Sheet 2 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
D0035-414	Press - He Press Tank, Mod 1, APS	Simulated, APS not installed
D0036-415	Press - He Press Tank, Mod 2, APS	Simulated, APS not installed
D0037-414	Press - He Reg Outlet, Mod 1, APS	Simulated, APS not installed
D0038-415	Press - He Reg Outlet, Mod 2, APS	Simulated, APS not installed
D0041-403	Press - Hydraulic System	Open, H/W requirement
D0042-403	Press - Reservoir Oil	Open, H/W requirement
D0070-414	Press - Fuel Supply Manf, Mod 1, APS	Simulated, APS not installed
D0071-414	Press - Oxid Supply Manf, Mod 1, APS	Simulated, APS not installed
D0072-415	Press - Fuel Supply Manf, Mod 2, APS	Simulated, APS not installed
D0073-415	Press - Oxid Supply Manf, Mod 2, APS	Simulated, APS not installed
D0097-414	Press - Ullage, Fuel Tank, Mod 1, APS	Simulated, APS not installed
D0098-414	Press - Ullage, Oxid Tank, Mod 1, APS	Simulated, APS not installed
D0099-415	Press - Ullage, Oxid Tank, Mod 2, APS	Simulated, APS not installed
D0100-415	Press - Ullage, Fuel Tank, Mod 2, APS	Simulated, APS not installed
D0220-414	Press - Ull Contr Chamber 1-4	Simulated, APS not installed
D0221-415	Press - Ull Contr Chamber 2-4	Simulated, APS not installed
D0250-414	Press - He Press, Tank 1, APS	Simulated, APS not installed
D0251-415	Press - He Press, Tank 2, APS	Simulated, APS not installed
G0003-401	Posit - Main LOX Valve	Simulated, H/W requirement
G0004-401	Posit - Main LH2 Valve	Simulated, H/W requirement
G0005-401	Posit - Gas Generator Valve	Simulated, H/W requirement
G0008-401	Posit - LOX Turbine Bypass Valve	Simulated, H/W requirement
G0009-401	Posit - GH2 Start Tank Valve	Simulated, H/W requirement

TABLE 12-3 (Sheet 3 of 3)
INACTIVE MEASUREMENTS

MEASUREMENT NO.	PARAMETER	REMARKS
K0020-401	Event - ASI LOX Valves, Open	Open, computer requirement
K0126-401	Event - LOX Bleed Valve, Closed	Open, computer requirement
K0127-401	Event - LH2 Bleed Valve, Closed	Open, computer requirement
K0128-404	Event - Switch Selector Output	Open, computer requirement
K0152-404	Event - Rate Gyro Whl Spd, OK	Open, rate gyro not installed
K0210-410	Event - LH2 Latch Rlf Vlv - Closed	Open, instl on post-test rework
K0211-410	Event - LH2 Latch Rlf Vlv - Open	Open, instl on post-test rework
L0007-404	Level - Reservoir Oil	Simulated, H/W requirement
M0073-404	Volt - Spark Exciter 2, O_2-H_2 Burner	Open, computer requirement
M0074-404	Volt - Spark Exciter 1, O_2-H_2 Burner	Open, computer requirement

TABLE 12-4 (Sheet 1 of 2)
TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +574 sec)

PARAMETER	UNITS	TELEMETRY		HARDWIRE		
		MEAS NO.	PCM	MEAS NO.	GIS	F/M
Temp - LH2 Pump Inlet	deg R	C0003	37.6	C0658	37.7	37.7
Temp - LOX Pump Inlet	deg R	C0004	164.1	C0659	164.2	164.1
Temp - GH2 Start Bottle	deg R	C0006	223.0	C0649	229.0	--
Temp - Electrical Control Assy	deg R	C0011	549.0	C0657	549.0	--
Temp - LOX Pump Discharge	deg R	C0133	170.0	C0648	169.8	169.7
Temp - LH2 Pump Discharge	deg R	C0134	52.1	C0644	52.0	52.0
Temp - Thrust Chamber Jacket	deg R	C0199	140.0	C0645	144.0	--
Temp - Cold He Sphere - No. 4	deg R	C0210	36.0	C0661	37.1	--
Press - Thrust Chamber	psia	D0001	802.0	D0524	808.0	805.0
Press - LH2 Pump Inlet	psia	D0002	31.0	D0536	31.7	31.0
Press - LOX Pump Inlet	psia	D0003	41.5	D0537	41.7	42.0
Press - Main LH2 Injector	psia	D0004	872.0	D0518	883.0	875.0
Press - LH2 Pump Discharge	psia	D0008	1,211.0	D0516	1,243.0	1,235.0
Press - LOX Pump Discharge	psia	D0009	1,059.0	D0522	1,076.0	1,073.0
Press - Gas Generator Chamber	psia	D0010	663.0	D0530	655.0	665.0
Press - Cont He Reg Discharge	psia	D0014	537.0	D0581	535.0	540.0
Press - Cold He Sphere	psia	D0016	2,034.0	D0542	2,036.0	--
Press - GH2 Start Bottle	psia	D0017	1,197.0	D0525	1,189.0	1,185.0
Press - Engine Reg Outlet	psia	D0018	419.0	D0535	408.0	--
Press - Engine Cont He Sphere	psia	D0019	2,287.0	D0534	2,177.0	--
Press - LH2 Tank Repress Sphere	psia	D0020	2,865.0	D0513	2,865.0	--
Press - LOX Turbine Outlet	psia	D0086	34.0	D0533	34.7	--
Press - LOX Tank Repress Sphere	psia	D0088	2,875.0	D0512	2,887.0	--
Press - LH2 Tank Ullage	psia	D0177	32.2	D0539	32.1	--
Press - LH2 Tank Ullage	psia	D0178	31.9	D0539	32.1	--
Press - LOX Tank Ullage	psia	D0179	39.0	D0540	39.3	--
Press - LOX Tank Ullage	psia	D0180	39.0	D0540	39.3	--
Press - Ambient He Pneu Sphere	psia	D0236	2,721.0	D0541	2,736.0	--
Press - Common Bulkhead Internal	psia	D0237	0.1	D0545	0.0	--
Flowrate - LOX	gpm	F0001	2,952.0	F0506	2,214.0	2,961.8

TABLE 12-4 (Sheet 2 of 2)
TELEMETRY TO HARDWIRE DATA COMPARISON (T_0 +574 sec)

PARAMETER	UNITS	TELEMETRY		HARDWIRE		
		MEAS NO.	PCM	MEAS NO.	GIS	F/M
Flowrate - LH2	gpm	F0002	8,113.0	F0507	9,211.0	8,013.0
Position - Pitch Actuator	deg	G0001	-0.1	G0504	-0.0	-0.5
Position - Yaw Actuator	deg	G0002	0.0	G0505	0.1	0.1
Position - PU Valve	deg	G0010	31.3	G0503	31.3	31.2
Voltage - Engine Cont Bus	vdc	M0006	28.7	M0514	28.6	28.0
Voltage - Engine Ign Bus	vdc	M0007	28.8	M0515	28.8	28.9
Voltage - Aft Battery 1	vdc	M0014	28.2	M0541	28.9	28.9
Voltage - Aft Battery 2	vdc	M0015	8.5	M0540	58.2	58.5
Voltage - Fwd Battery 1	vdc	M0016	28.6	M0543	28.3	28.0
Voltage - Fwd Battery 2	vdc	M0018	27.4	M0542	27.6	27.8
Current - Fwd Battery 1	amp	M0019	11.0	M0731	12.5	12.0
Current - Fwd Battery 2	amp	M0020	4.7	M0732	4.6	4.6
Current - Aft Battery 1	amp	M0021	12.0	M0733	13.0	14.0
Current - Aft Battery 2	amp	M0022	29.0	M0734	29.0	29.0
Speed - LOX Pump	rpm	T0001	8,889.0	T0502	8,775.0	8,751.5
Speed - LH2 Pump	rpm	T0002	27,196.0	T0503	27,142.0	27,105.0

NOTES:

1. The primary hardwire measurement D0524 data were qualified as "Data Invalid after T_0 +521 sec." The FM data were acquired from an equivalent measurement D0544.

2. The primary flight measurement D0016 data were qualified as "Invalid Data." The data were obtained from the flight backup measurement D0248.

3. The hardwire measurement D0534 data were qualified "Trend- 3 percent low at approximately 3,000 psia."

4. The hardwire digital data for F0506 and F0507 were qualified as "Invalid-Use raw FM ac PIP data for evaluation."

TABLE 12-5
HARDWIRE DATA ACQUISITION SYSTEM

MEASUREMENT TYPE	RECORDED	FAILED	SUCCESSFUL (percent)
Pressure	103	2	98.8
Temperature	41	0	100.0
Flow	2	2	-
Position	10	0	100.0
Voltage/Current	31	0	100.0
Events	633	0	100.0
Speed	2	0	100.0
Level	1	0	100.0
Vibration	7*	0	100.0
Miscellaneous	4	0	100.0
TOTAL	834	4	99.0 percent

*Vibration measurements E0555 and E0556 appeared active during the acceptance firing; however, after postfire analysis (refer to section 18) they were found to be invalid.

TABLE 12-6
HARDWIRE MEASUREMENT DISCREPANCIES

MEASUREMENT NO.	PARAMETER	REMARKS
D0524	Press - Thrust Chamber J-2 Engine	The primary hardwire measure measurement D0524 data were qualified as "Data Invalid after T_0 +521 sec." The FM datum was acquired from an equivalent measurement D0544.
D0534	Press - Control Helium Supply J-2 Engine	The hardwire measurement D0534 data were qualified "Trend - 3 percent low at approximately 3,000 psia."
F0506	Flow - Engine LOX, AC Outlet	The hardwire digital data for F0506 was qualified as "Invalid - use raw FM ac PIP data for evaluation.
F0507	Flow - Engine LH2, AC Outlet	The hardwire digital data for F0507 was qualified as "Invalid - use raw FM ac PIP data for evaluation."

SECTION 13

ELECTRICAL POWER AND CONTROL SYSTEMS

13. ELECTRICAL POWER AND CONTROL SYSTEMS

13.1 Electrical Control System

The operational integrity of the electrical control system is verified in the sequence of events (section 5). All incremental response times to switch selector commands were within design tolerances.

13.1.1 J-2 Engine Control System

All measurements verified that the engine control system responded properly to the Engine Start and Cutoff Commands. The sequence of events (section 5) lists the engine firing events and response times.

13.1.2 Secure Range Safety Command System

The secure range safety command system was tested during the engine burn phase to verify the capability of engine cutoff and propellant dispersion. Evaluation of the data showed that the Arm and Engine Cutoff (ECO) and Propellant Dispersion (P/D) commands were received, and that the EBW Firing Units (F/U) discharged into their respective pulse sensors. The following measurements were evaluated for system performance:

K0141	R/S 1 EBW Pulse Sensor Indication
K0142	R/S 2 EBW Pulse Sensor Indication
K0650*	R/S 1 P/D EBW F/U Power On
K0651*	R/S 2 P/D EBW F/U Power On
K0659*	R/S 2 Arm and ECO Command Received
K0660*	R/S 1 Arm and ECO Command Received
K0678*	R/S 2 Receiver Power On
K0679*	R/S 2 System Off Command Received
K0680*	R/S 1 Receiver Power On
K0681*	R/S 1 System Off Command Received
K0692*	R/S 2 EBW Arm and ECO On
K0693*	R/S 1 EBW Arm and ECO On
M0030	R/S 1 EBW Firing Unit (Volts)
M0031	R/S 2 EBW Firing Unit (Volts)

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*Hardwire Measurement

N0057	R/S 1 Low Level Signal Strength
N0062	R/S 2 Low Level Signal Strength
K5757*	R/S Tone 1/Propellant Dispersion Command
K5758*	R/S Tone 2/EBW Arm and ECO Command
K5759*	R/S Tone 6/System Off Command

13.1.3 Control Pressure Switches

A review of the event and pressure measurements associated with the control pressure switches verified that each switch functioned properly. A description of their performance is presented in the following paragraphs.

The LH2 ground fill valve control, prepress, flight control, and step pressure switch operated within the range of 28 to 31 psia of LH2 tank ullage pressure. Its function is to maintain the LH2 tank ullage pressure within this range during the times that the first and second burn relays are on. For first burn, it closes or opens the first burn bypass control valve as the pressure switch actuates or deactuates, respectively. During the time that the second burn relay is on, the pressure switch actuates or deactuates to close or open, respectively, the step pressure control valve. The following event and pressure measurements verified that the pressure switch operated properly during all phases of the acceptance firing:

K0101	LH2 Repress Control Switch - De-energized
K0184	LH2 Flight Control Pressure Switch - Energized
K0523*	LH2 Tank Step Pressure Valve - Energized
K0524*	LH2 Tank Flight Pressure Valve - Energized
K0616*	LH2 Tank Overpressurization Pressure Switch - Energized
D0177	LH2 Tank Ullage EDS 1
D0178	LH2 Tank Ullage EDS 2

The LH2 tank repress pressure switch also operates within the range of 28 to 31 psia of tank ullage pressure. During the time that the LH2 Tank Repress Control Valves Enable-On Command is energized, this pressure

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*Hardwire Measurement

switch can close the repress control valves in the LH2 repress modules (cryogenic or ambient) as the tank ullage pressure reaches the actuation level of the pressure switch. The following measurements verified that the pressure switch functioned properly during the repress phase of the acceptance firing:

K0101	LH2 Repress Control Switch - De-energized
K0184	LH2 Flight Control Pressure Switch - Energized
D0177	Fuel Tank Ullage EDS 1
D0178	Fuel Tank Ullage EDS 2

The LOX tank ground fill valve control, prepress, flight control, and repress pressure switch regulates the cold helium supply shutoff valves during the "Off" portion of the LOX Tank Flight Pressure System Command, and it regulates the heat exchanger bypass valve during the "On" portion of this command. Actuation and deactuation of the pressure switch should occur within the range of 41 to 38 psia of LOX tank ullage pressure. This pressure switch also controls the LOX tank repress control valves after the LOX Tank Repress Control Valve Open-On Command is given. Data from the following measurements verified that the switch responded properly to ullage pressure changes throughout the acceptance firing:

K0102	LOX Prepress Flight Switch - Energized
K0108	LOX Prepress Flight Switch - De-energized
D0179	LOX Tank Ullage EDS 1
K0180	LOX Tank Ullage EDS 2

The engine pump purge control module pressure switch regulates the pressure of the helium gas in the pump purge line to stay between 105 and 130 psia when the Engine Pump Purge Control Valve Enable-On Command is given. The following measurements furnished data verifying that the pressure switch operated properly:

K0105	Pump Purge Regulator Backup - De-energize
D0050	Engine Pump Purge Regulator Pressure

The LOX chilldown pump purge pressure switch operates within the range of 38 to 41 psia in the pump purge line. It controls the LOX chilldown pump purge control valve when the LOX Chilldown Pump Purge Enable-On Command is given. Data showed that the purge line pressure was above the actuation level of the switch during all phases of the acceptance firing.

D0103	He Pressure to LOX Motor Control

The operation of the LOX tank regulator backup pressure switch is redundant to that of the cold helium pressure regulator in the LOX tank pressure control module. During ambient repressurization mode, if the regulator fails, the pressure switch can actuate and close the cold helium supply shutoff valves and thereby regulate the cold helium supply line pressure. The operating range of this pressure switch is from 335 to 485 psia in the cold helium supply line. Since the data indicated that the regulator functioned properly, the line pressure was below the actuation level of the pressure switch therefore it did not actuate during the acceptance firing.

K0156	LOX Tank Regulator Backup Pressure Switch - Energized
K0571*	Cold Helium Shutoff Valves - Energized
D0105	LOX Tank Pressurization Module He Gas
K0225	Cold Helium Control Valve Inlet

The LOX tank repress regulator backup pressure switch provides a backup means of regulating the pressure in the cold helium supply line to the LOX press coils in the O_2-H_2 burner. Normally, the cold helium pressure regulator in the LOX tank pressure control module maintains the line pressure at a safe level. If the regulator fails, the pressure switch would prevent an overpressurization condition in the coils by closing the repress control valves in the LOX tank cryogenic repress control module. The pressure switch operates within the range of 335 to 485 psia in the cold helium supply line. Data from the following measurements indicated that the line pressure remained below the actuation level of the pressure switch:

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*Hardwire Measurement

K0444*	LOX Tank Repress Valve - Energized
D0228	GOX/GH2 Burner LOX Press Coil

The LH2 tank repress regulator backup pressure switch would prevent an overpressurization condition in the LH2 press coils of the O_2-H_2 burner if the cold helium pressure regulator should fail.

In the event of a regulator failure, this pressure switch would actuate and close the repress control valves in the LH2 tank cryogenic repress control module. The operating range of this switch is 335 to 485 psia in the cold helium supply line. The following measurements showed that the line pressure remained below the actuation level of the pressure switch:

K0443*	LH2 Tank Repress Valve - Energized
K0231	GOX/GH2 Burner LH2 Press Coil

The control (ambient) helium regulator backup pressure switch is employed in the pneumatic power control module as a redundant control of the ambient helium line pressure should the module regulator fail. The switch operating range is 465 to 615 psia in the ambient helium line. Pressure measurement D0014 showed that the regulator kept the line pressure below the actuation level of the pressure switch.

D0014	Control Helium Regulator, Discharge

13.1.4 Vent Valves

The LOX and LH2 tank vent valves and the LH2 tank directional vent valve are commanded open or close by GSE. Data evaluation showed that these valves responded to the commands. Several times during the acceptance firing excessive feathering of both vent valves was observed. The problem has been attributed to the microswitches that furnish the valve talkback. They are to be replaced by a new configuration. The event measurements for the commands and the corresponding talkbacks are listed below:

K0516* (Cmd)	Fuel Tank Vent Valve Open - Energized
K0001; K0532*	Fuel Tank Vent Valve - Closed
K0017; K0542*	Fuel Tank Vent Valve 1 - Opened

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*Hardwire Measurement

K0575* (Cmd)	Oxid Tank Vent Valve Open - Energized
K0002; K0533*	Oxid Tank Vent Valve - Closed
K0016; K0543*	Oxid Tank Vent Valve 1 - Opened
K0561* (Cmd)	LH2 Tank Directional Vent Valve - Ground (Preflight) Position
K0562* (Cmd)	LH2 Tank Directional Vent Valve - Inflight Position
K0113	LH2 Tank Directional Vent Valve C - Closed
K0114	LH2 Tank Directional Vent Valve D - Closed

13.1.5 Chilldown Shutoff Valves

The following measurements indicated that the LOX and LH2 chilldown shutoff valves responded to commands:

K0136; K0551*	LH2 Chilldown Shutoff Valve Closed
K0137; K0554*	LH2 Chilldown Shutoff Valve Open
K0139; K0552*	LOX Chilldown Shutoff Valve Closed
K0138; K0545*	LOX Chilldown Shutoff Valve Open
K0577*	LH2 and LOX Chilldown Shutoff Valve Closed - Energized

13.1.6 Fill and Drain Valves (Fuel and LOX)

The LOX and LH2 fill and drain valves are commanded open and close by GSE commands. A review of the following command and talkback events showed that these valves operated according to the commands issued. During the C1 phase (first LH2 loading), it was noted that the hardwire event measurement K0546 indicated valve flutter in the open position. This indication could not be verified on T/M since no T/M measurement monitors the valve open position. The problem has been attributed to a faulty microswitch which is being replaced by a new configuration.

K3831* (Cmd)	LH2 Tank Fill and Drain Boost Close
K3832* (Cmd)	LH2 Tank Fill and Drain Valve Open
K0003; K0554*	LH2 Tank Fill and Drain Valve - Closed
K0546	LH2 Tank Fill and Drain Valve - Opened

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*Hardwire Measurement

K3845* (Cmd)	LOX Tank Fill and Drain Boost Close
K3846* (Cmd)	LOX Tank Fill and Drain Valve Open
K0004; K0553*	LOX Tank Fill and Drain Valve - Closed
K0547*	LOX Tank Fill and Drain Valve - Opened

13.1.7 Depletion Sensors

A review of the following measurements showed that the LOX and LH2 depletion sensors performed satisfactorily, and no anomalies were observed during the test:

K0601*	LOX Depletion Sensor No. 1 - Wet
K0602*	LOX Depletion Sensor No. 2 - Wet
K0603*	LOX Depletion Sensor No. 3 - Wet
K0604*	LOX Depletion Sensor No. 4 - Wet
K0597*	LH2 Depletion Sensor No. 1 - Wet
K0598*	LH2 Depletion Sensor No. 2 - Wet
K0599*	LH2 Depletion Sensor No. 3 - Wet
K0576*	LH2 Depletion Sensor No. 4 - Wet

13.2 Auxiliary Propulsion System (APS) Electrical Control System

The APS simulators, Model DSV-4B-188B, are used during the acceptance firing to verify the APS-stage interface control functions. An evaluation of the performance of the APS engine feed valves in the simulator verified that the stage electrical control system operated within its prescribed limitations during the test. The measurements that were evaluated and the results are listed below:

		Specified Min Value (vdc)	Value (vdc)
K0132	APS Eng. 1-1/1-3 Feed Valves Open	3.2	3.79
K0133	APS Eng. 1-2 Feed Valves Open	3.2	3.83
K0134	APS Eng. 2-1/2-3 Feed Valves Open	3.2	3.75
K0135	APS Eng. 2-2 Feed Valves Open	3.2	3.73

The specified minimum value of 3.2 vdc indicates that all of the feed valves are operating according to commands.

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*Hardwire Measurement

13.3 Electrical Power System

The electrical power system performed satisfactorily throughout the acceptance firing. It supplied power to other stage systems, as required, and the external/internal and motor-driven switches functioned properly.

13.3.1 Battery Simulators

The voltage and current levels on the battery simulators were maintained within their required limits. Figures 13-1 through 13-6 are plots showing the voltage and current levels on these battery simulators during selected phases of the acceptance firing.

13.3.2 Static Inverter-Converter

This device is a power converter that furnished the regulated AC and DC voltages required to operate the PU electronics assembly. The static inverter-converter operated within its required limits during the firing. Its voltage and frequency values are given below.

Measurements and Characteristics	Nominal	Acceptable Limits
M0001 Voltage (VRMS)	114.85	115.0 ±3.45
M0004 Voltage (vdc)	5.02	$5.00^{+0.10}_{-0.55}$
M0023 Voltage (vdc)	21.7	$21.0^{+1.5}_{-1.0}$
M0012 Frequency (Hz)	403.3	400.0 ±6.0

13.3.3 Chilldown Inverters

The LOX and LH2 chilldown pump motors operate from a three-phase power supply. The LOX and LH2 chilldown inverters convert 56 vdc into three-phase square wave ac power for the pump motors. The inverters performed satisfactorily during the firing and the O_2-H_2 burner repressurization test. The phase voltages and frequencies are listed in the following table:

Measurements and Characteristics	Nominal	Acceptable Limits
M0027 Phase A-B, LOX C/D Inv (VAC)	56.0	56 ±4 VAC
M0040 Phase A-C, LOX C/D Inv (VAC)	56.1	56 ±4 VAC
M0029 Frequency LOX C/D Inv (Hz)	400.8	400 ±10 Hz
M0026 Phase A-B, LH2 C/D Inv (VAC)	56.7	56 ±4 VAC
M0041 Phase A-C, LH2 C/D Inv (VAC)	56.5	56 ±4 VAC
M0028 Frequency LH2 C/D Inv (Hz)	400.9	400 ±10 Hz

13.3.4 5-Volt Excitation Modules

These modules convert 28 vdc to +5 vdc and -20 vdc for use as operating voltages for potentiometer type transducers and temperature bridges; the +5 vdc is also used as a reference voltage for the multiplexers. The three modules performed properly during the firing and during the repressurization test. The actual values are shown below:

Measurements and Characteristics	Nominal	Acceptable Limits
M0025 Aft Voltage (vdc)	4.99	5.0 ±0.03
M0024 Forward 1 Voltage (vdc)	5.01	5.0 ±0.03
M0068 Forward 2 Voltage (vdc)	5.00	5.0 ±0.03

13.4 Separation Exploding Bridgewire (Ullage Rocket EBW) System

Since live ordnance is not installed, EBW pulse sensors are used during the acceptance firing to verify the operational integrity of the stage electrical control system in providing the commands necessary to charge, fire, and jettison the ullage rockets. The measurements given below furnished the data used to verify this integrity:

K0149	Ullage Rocket Jettison EBW P/S 1 Indication
K0150	Ullage Rocket Jettison EBW P/S 2 Indication
K0176	Ullage Rocket Ignition EBW P/S 1 Indication
K0177	Ullage Rocket Ignition EBW P/S 2 Indication
K0673*	Ullage Rocket Pilot Relays Reset

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*Hardwire Measurement

M0064	Ullage Rocket Ignition, EBW F/U 1 (Volts)
M0064	Ullage Rocket Ignition, EBW F/U 2 (Volts)
M0067	Ullage Rocket Jettison, EBW F/U 1 (Volts)
M0068	Ullage Rocket Jettison, EBW F/U 2 (Volts)

13.5 O_2-H_2 Burner

The operation of the O_2-H_2 burner, with respect to the operational integrity of the electrical control system, was normal and no problems were encountered. The sequence of events (section 5) verifies that burner control commands were sent and received, and that instrumentation response and talkback signals occurred as predicted. The voltage and current profiles of the battery simulators during the burner firings are presented in figures 13-2, 13-3, 13-5 and 13-6.

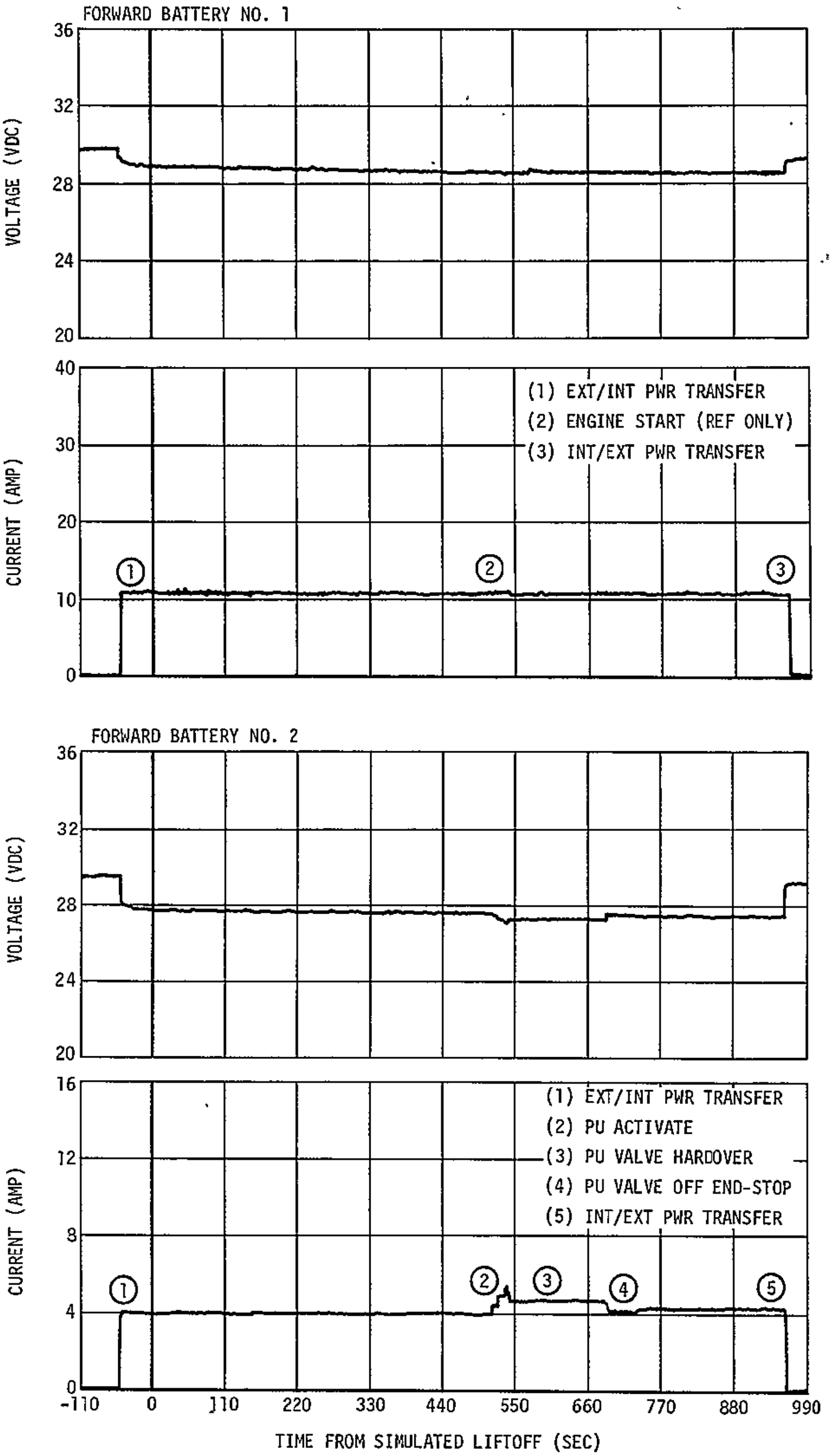


Figure 13-1. Forward Battery Voltage and Current Profiles (Mainstage Firing)

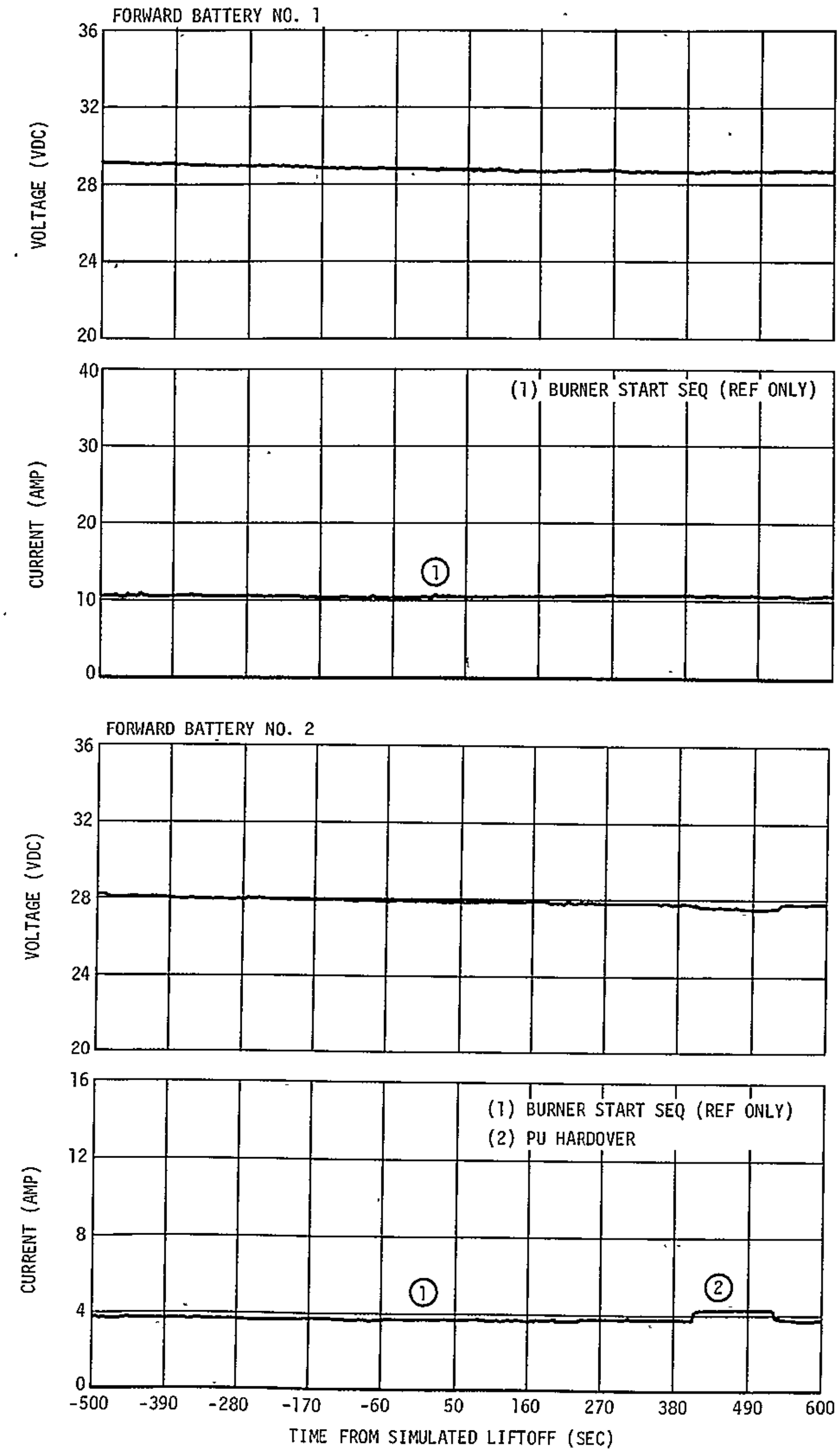


Figure 13-2. Forward Battery Voltage and Current Profiles (First Burner Firing)

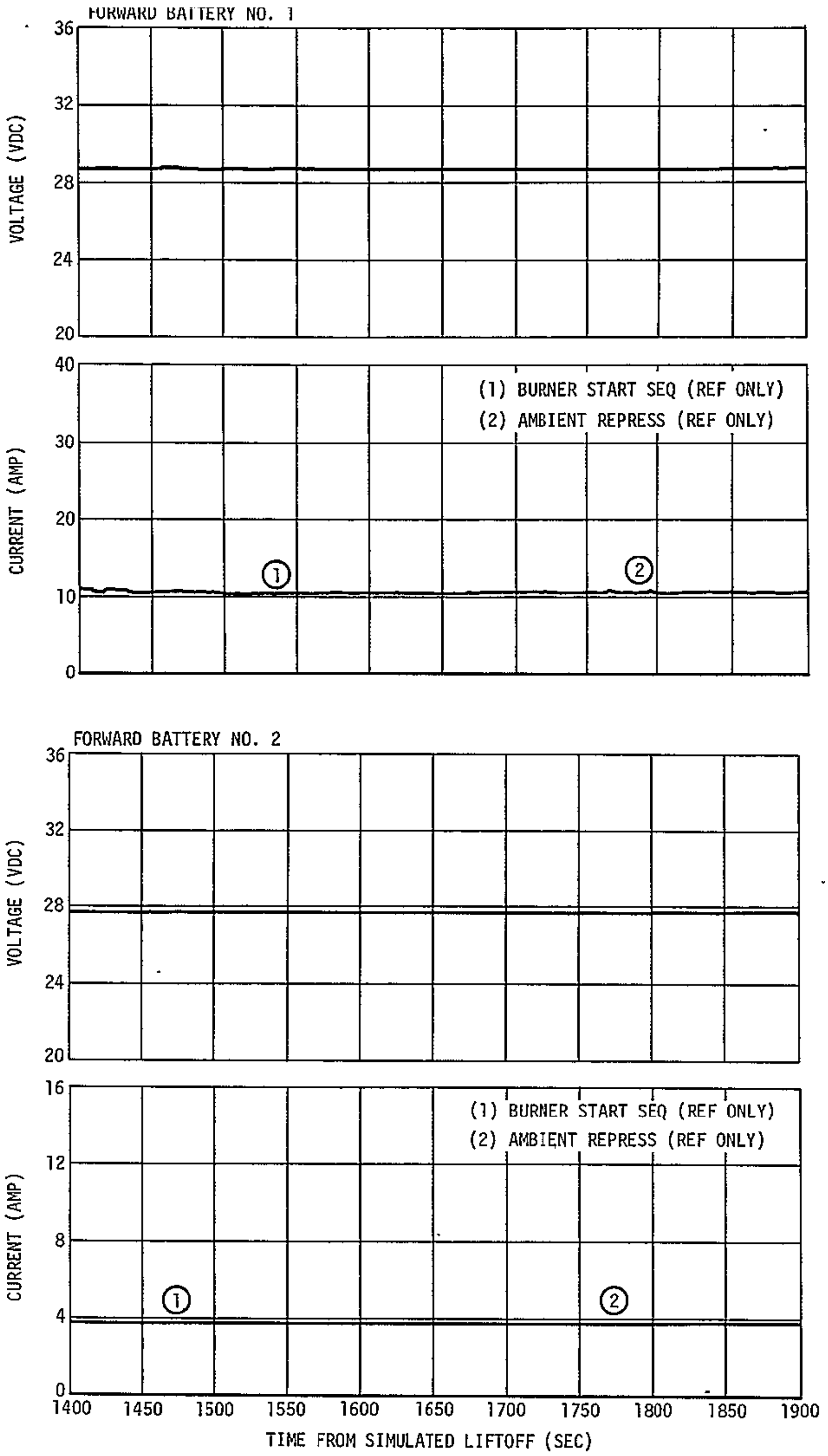


Figure 13-3. Forward Battery Voltage and Current Profiles (Second Burner Firing and Ambient Repress Phase)

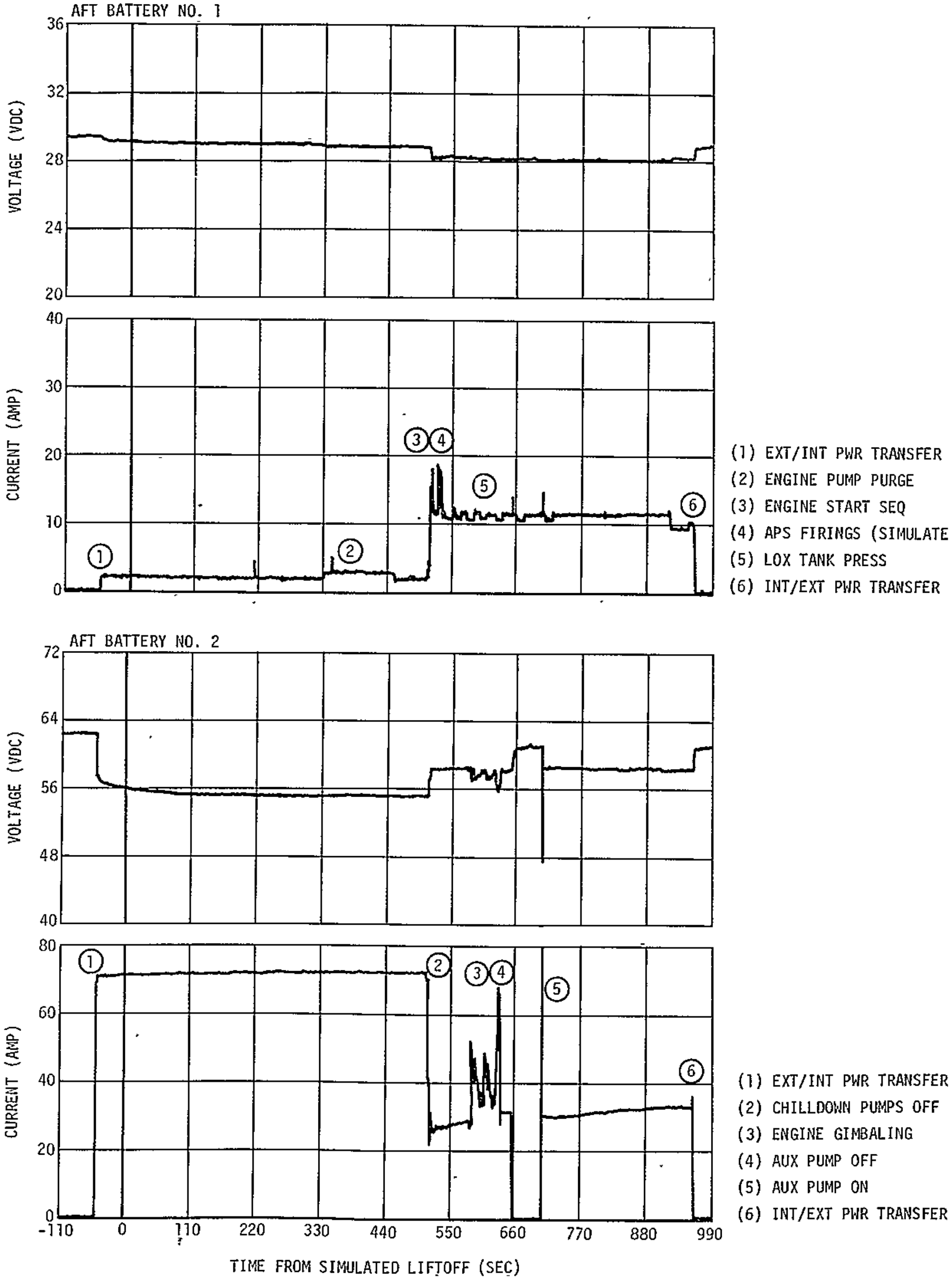


Figure 13-4. Aft Battery Voltage and Current Profiles (Mainstage Firing)

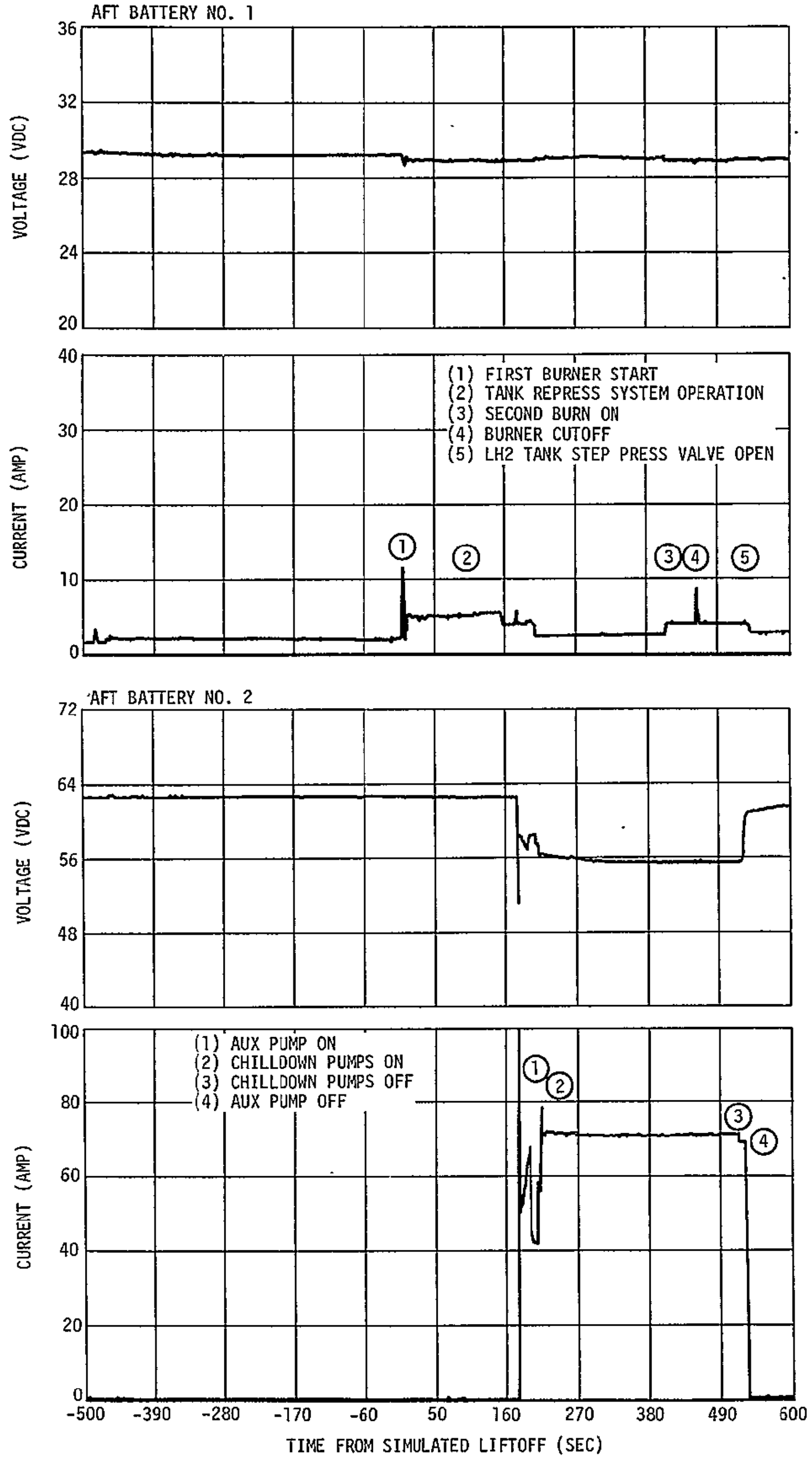


Figure 13-5. Aft Battery Voltage and Current Profiles (First Burner Firing)

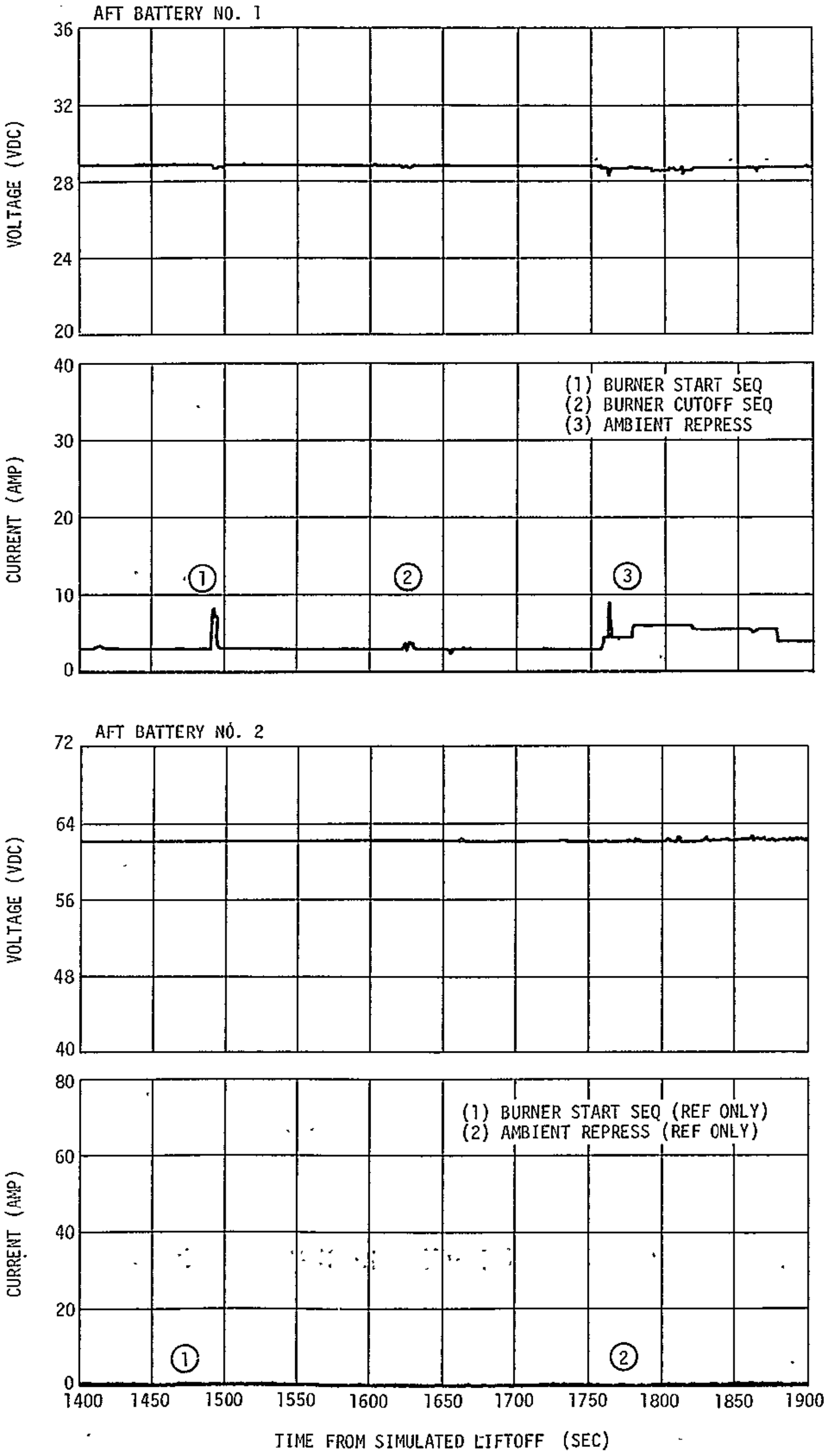


Figure 13-6. Aft Battery Voltage and Current Profiles (Second Burner Firing and Ambient Repress Phase)

[redacted]

SECTION 14

HYDRAULIC SYSTEM

14. HYDRAULIC SYSTEM

14.1 Hydraulic System Operation

The hydraulic system test program was conducted during CD 614109, during which the engine was successfully positioned and gimbaled. System running time for this test, from auxiliary pump ON prior to simulated liftoff to auxiliary pump OFF following cutoff, was 1,459 sec. The gimbal program was initiated after the engine start side loads subsided and the support links dropped. The auxiliary pump was turned OFF after the gimbaling program for 50 sec to verify satisfactory engine-driven pump operation.

Significant event times are presented in the following table:

Event	Approximate Time (sec)
Auxiliary Pump ON	T_0 -477
(Simulated Liftoff)	(T_0 +0)
Engine Ignition (Engine-Driven Pump Start)	T_0 +511 (1823:11.378)
Support Links Dropped	T_0 +556
Gimbal Program Start	T_0 +580
Gimbal Program Stop	T_0 +636
Auxiliary Pump OFF	T_0 +656
Auxiliary Pump ON	T_0 +706
Engine Cutoff (Engine-Driven Pump Stop)	T_0 +961
Auxiliary Pump OFF	T_0 +982

14.2 System Pressure at Salient Times

The GN2 accumulator precharge pressure was monitored at 2,245 psia at 48 deg F during prefire checkout and was found to be approximately 2,260 psia at 62 deg F following the test program. After correcting these gas pressures to 70 deg F temperature, the values were found to be within the 2,350 ±50 psia allowable limits.

Test data indicated that the auxiliary pump discharge pressure increased to 3,600 psia in 18 sec after energizing the pump motor. Acceptable pump pressure was maintained from T_0 -477 sec through T_0 -0. The simulated launch requirements were met.

During the brief period of auxiliary pump cutoff (50 sec), the engine-driven pump pressure was observed to be 3,620 psia. It supplied the system leakage flow throughout the firing. The auxiliary pump shared some of the gimbal flow requirement as seen from fluctuation of the motor current draw. The engine-driven pump compensator setting was sufficiently higher than that of the auxiliary pump to prevent the latter from furnishing any system leakage flow while the engine-driven pump was operating steady-state. The auxiliary pump was turned off 21 sec after engine cutoff; 55 sec were required to bleed down the accumulator oil volume after pump shutdown.

GN2 pressure was similar to hydraulic system pressure with the pump(s) operating. The significant system pressures are presented in the following table:

Time (sec)	System Pressure (psia)	Reservoir Pressure (psia)
T_0 -390 (aux pump on)	3,600	170
T_0 +0 (simulated launch)	3,610	179
T_0 +520 (after ignition)	3,620	179
580 to 636 (gimbal)	3,680 max 3,510 min	180 max 169 min
T_0 +950 (prior to aux pump off)	3,620	180

14.3 Reservoir Level at Salient Times

Reservoir level prior to system operation was 91 percent at an oil temperature of 60 deg F. Minimum level during operation was 31 percent which occurred 100 sec after auxiliary pump start.

14.4 Hydraulic Fluid Temperature History

Time	Engine-Driven Pump Inlet (°F).	Reservoir (°F)	Accumulator GN2 (°F)
T_0 -390 (aux on)	75	60	60
T_0 +0	100	80	60
T_0 +520	115	100	60
T_0 +950	132	110	60

14.5 Engine Side Loads

Peak loads in the support links during engine start transients are as follows:

Item	Load, (lbf)
Pitch Link	+9,500, -15,500
Yaw Link	+9,000, -14,500

14.6 Hydraulic Fluid Flowrates

Approximations from reservoir fill and emptying rates are as follows:

Item	Flow (gpm)	Allowable (gpm)
System Internal Leakage	0.68	0.4 to 0.8
Auxiliary Pump Max Flowrate	1.81	150 min

14.7 Auxiliary Pump Motor Voltage and Current

Auxiliary pump motor electrical data were read only after the stage power source had switched to internal power (battery) and after the childown pumps had shut down. The design requirements are as follows:

Voltage	51-61 vdc
Max Starting Current	300 amp
Max Operating Current	85 amp

The following table shows the values observed during the firing:

Time	Aft Bus No. 2 Voltage Supply (M0540) (V)	Aft Battery No. 2 Current Load (M0022) (amp)
T_0 +0	56	72
T_0 +530 (after ignition C/D pumps off)	58	28
T_0 +580 to 636 (gimbal)	58 max 55.2 min	70 max 26 min
T_0 +706 (turn aux pump on after brief shutdown)	51 min	190 pk
T_0 +950 (prior to engine C/O)	57.8	32

[redacted] SECTION 15

FLIGHT CONTROL SYSTEM

15. FLIGHT CONTROL SYSTEM

The dynamic response of the hydraulic servo thrust vector control system was measured while the J-2 engine was gimbaling during the acceptance firing. The performance of the pitch and yaw hydraulic servo control system was acceptable.

15.1 Actuator Dynamics

The frequency response test of the pitch and yaw hydraulic servo control system for a ±1/2-deg sinusoidal signal between 0.6 and 9 cps, and for a ±1/4-deg sinusoidal signal between 0.6 and 2 cps verified the acceptability of the actuator responses. The acceptable limits and the gain and phase plots within these limits are presented in figures 15-1 and 15-2.

15.2 Engine Slew Rates

A nominal two-deg step command was applied to the pitch and yaw actuators from which the engine slew rates were determined. The minimum acceptable engine slew rate is 8 deg/sec, which corresponds to an actuator piston travel rate of 1.66 ips. A nominal slew rate for a two-deg step without the effects of gimbal friction is 13.6 deg/sec. The measured values were found to be acceptable and are presented in the following table:

Actuator	Condition	Engine Travel (deg)	Engine Slew Rate (deg/sec)
Pitch	Retract	0.0 to +2.0	11.7
	Extend	+2.0 to 0.0	11.9
	Extend	0.0 to -2.0	12.5
	Retract	-2.0 to 0.0	12.4
Yaw	Extend	0.0 to +2.0	11.9
	Retract	+2.0 to 0.0	11.7
	Retract	0.0 to -2.0	12.1
	Extend	-2.0 to 0.0	12.9

The minimum engine slew rate obtained is 11.7 deg/sec. This corresponds to an actuator piston travel of 2.42 ips when using a conversion of 4.83 deg of engine movement per inch of actuator travel. Thus, in all cases, each actuator exceeded the minimum acceptable piston travel rate of 1.66 ips, or corresponding engine travel rate of 8 deg/sec.

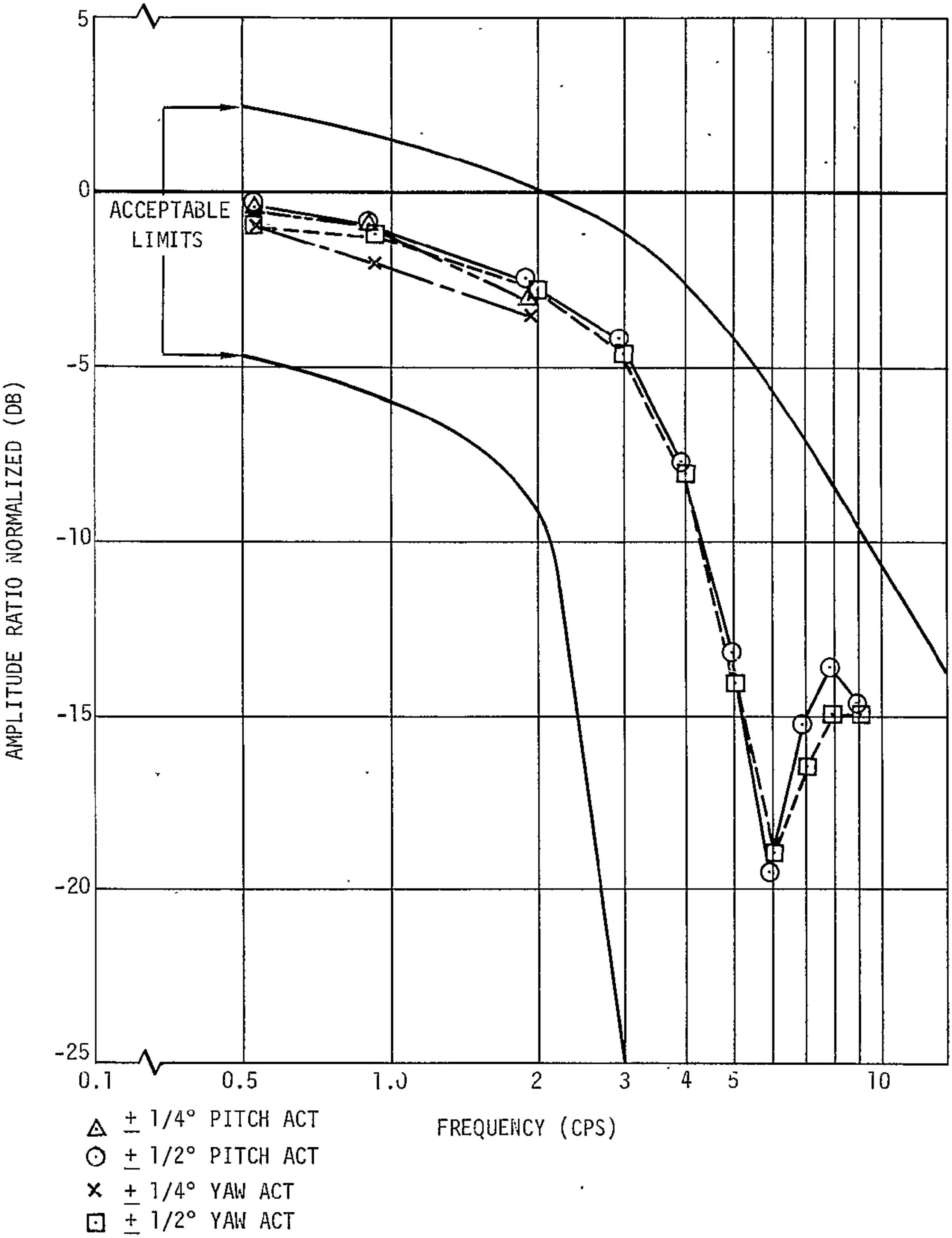


Figure 15-1. Actuator Response (Gain)

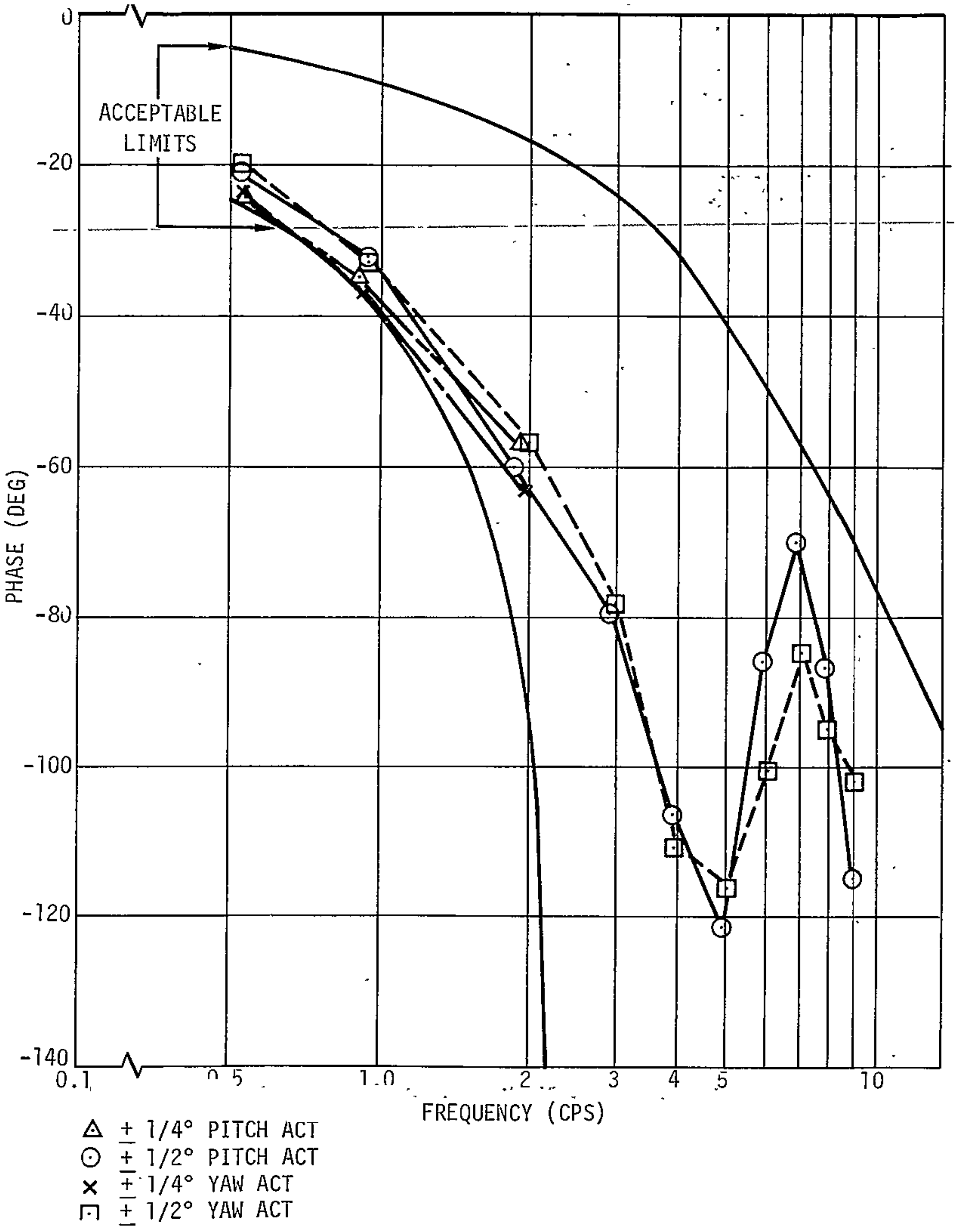


Figure 15-2. Actuator Response (Phase Lag)

[redacted] SECTION 16

STRUCTURAL SYSTEMS

16. STRUCTURAL SYSTEMS

Structural integrity of the S-IVB-506N stage was maintained for the vibration, temperature, pressure, and thrust load conditions of the acceptance firing and the special propellant loading test at Sacramento Test Center. With the exception of cracking and peeling of Korotherm ablative coating on certain areas of the forward skirt and aft skirt, no structural irregularities were encountered as a result of cryogenic loading, static firing, and the O_2-H_2 burner firing. The damaged Korotherm coating is to be removed and replaced. Corrective action is being taken to eliminate the cracking and peeling of Korotherm coating during future stage testing at Sacramento.

16.1 Common Bulkhead

The results of the gas sample surveys, combined with satisfactory common bulkhead decay checks, indicate the bulkhead is sound and leak tight. During the actual acceptance firing, the bulkhead internal pressure readings were less than 1 psia. Gas sample analyses consistently indicated negligible quantities of hydrogen and helium gases within the common bulkhead. The bulkhead pressure decay history and gas sample analyses recorded during pre-fire pumpdown, static firing, and post-firing activities are presented in Report DAC-61229, S-IVB-506N Stage Acceptance Firing 15 Day Report, dated August, 1968.

16.2 Exterior Structure

A visual inspection of the thrust structure, LOX tank aft dome, aft skirt, LH2 tank cylindrical section, LH2 tank forward dome, forward skirt, and O_2-H_2 burner revealed no structural damage after the full duration acceptance firing. The inspection revealed no debonding of standoffs, tunnel clips, or the aft skirt membrane. The stage and O_2-H_2 burner mechanical interface was compatible under burner operating conditions.

16.3 Forward Skirt Ablative Coating

Six days prior to the acceptance firing, a special 10-hr propellant loading test was conducted to provide crew training and to demonstrate safe propellant loading procedures. This loading test duplicated the procedures and ullage pressurization cycles used in an acceptance firing.

Inspection following the propellant loading test revealed no damage to Korotherm ablative coating on the S-IVB-506N stage, with the exception of skin panel areas adjacent to the auxiliary tunnel of the forward skirt. The Korotherm coating had cracked and severely peeled in the two adjacent panels on each side of the auxiliary tunnel. The damage extended forward approximately 3 ft from the aft flange. This was a recurring problem and motion pictures were taken of these areas during the loading test. The motion pictures indicated that cracks in the coating began to appear approximately one hr after initiation of LH2 loading, which was also one-half hr after temporary stabilization of LH2 loading at 68 percent fill. The corresponding LH2 ullage pressure was approximately 1 psig. The temperature of the affected panels at this time had decreased to approximately -50 to -100 deg F by comparison to monitored results from the subsequent acceptance firing.

The first major cracking and peeling of Korotherm coating adjacent to the auxiliary tunnel occurred when the LH2 ullage pressure was increased to 32 psia. This was 4 hr after initiation of LH2 loading. Up to that time the temperatures of the affected panels had remained stabilized at approximately -50 to -100 deg F. Additional cracking and peeling at the affected areas was also observed in the motion pictures at times of subsequent repressurizations.

During the full seventh hour of the 10-hr propellant loading test, the affected panels adjacent to the auxiliary tunnel experienced markedly reduced temperatures. This occurrrd immediately following LH2 loading to 100 percent fill and was during the time of continuous LH2 topping and venting. By comparison to the subsequent monitored acceptance firing, the panel temperatures decreased to approximately -200 to

-250 deg F. The corresponding LH2 ullage pressure was stabilized at 0 psig. During this seventh hour of reduced temperatures, the motion pictures did not reveal additional cracking and peeling. However, at a subsequent LH2 repressurization, additional cracking and peeling of the Korotherm coating was observed.

In contrast to the -50 to -100 deg F temperatures generally indicated at the forward skirt panels adjacent to the auxiliary tunnel during the propellant loading test, the corresponding temperatures of panels adjacent to the forward skirt main tunnel were generally 0 to 30 deg F. This temperature data, which were obtained during cryogenic loading for the subsequent acceptance firing, indicated that the forward skirt structure in the vicinity of the auxiliary tunnel had been subjected to exceptionally low temperatures not experienced in the main tunnel areas. This local condition at the auxiliary tunnel appears to have resulted from the adjacent locations of a large cryogenic heat-sink. The components of the heat-sink included the LH2 tank vent and relief valve, the directional control valve, the continuous vent regulator module, and associated ducting. The heat-sink appears to have chilled and condensed nitrogen purge gas which was introduced at a rate only one seventh of the flowrate at Florida Test Center. The chilled nitrogen liquid apparently dripped from the heat-sink components onto the nylon cloth debris shroud. The liquid appears to have seeped through the shroud and down the inside of the forward skirt adjacent to the auxiliary tunnel. The first Korotherm crack noted in the motion picture study appeared at the debris shroud location.

The damaged Korotherm coating adjacent to the auxiliary tunnel was not replaced prior to the acceptance firing. This damaged coating was scheduled to be removed and replaced when the S-IVB-506N stage is erected in the vertical checkout laboratory.

After the acceptance firing, hairline cracks were found in the Korotherm coating on the forward skirt adjacent to the main tunnel. The cracks, located on the tank aft flange and the skirt panel adjacent to the flange, were not detected until several days after the firing. These cracks were similar to hairline cracks found in the same areas on the S-IVB-505N stage several days after a special cold flow test. The cracks apparently opened up and became visible as a function of time.

The cracking and peeling of Korotherm coating was apparently due to the combined effects of low temperatures and structural strains. The Korotherm becomes brittle at low temperatures. The strains in the forward skirt resulted partially from differential thermal structural contractions and expansions, and partially from pressurization of the LH2 tank. The thermal effects were especially severe at either side of the auxiliary tunnel probably due to the leakage of condensed nitrogen as discussed before. The most evident times of cracking and peeling were during pressurization of the LH2 tank. A contributing factor in causing Korotherm coating cracking may have been the differential rates of thermal contraction between the coating and aluminum panels.

The corrective action being taken to eliminate the cracking and peeling of Korotherm coating at panels adjacent to the auxiliary tunnel is to modify the N2 purge system to redistribute a larger portion of the available purge gases into the areas above and adjacent to the auxiliary tunnel. The effect will be to reduce or eliminate condensation of N2 at the heat-sink components. This redistribution of purge gases will be accomplished by rework of the existing purge duct and ports system.

The corrective modification being incorporated to prevent cracking of Korotherm coating near the main tunnel is to modify the N2 purge system to direct more of the available purge gases in a direction to improve the thermal insulation of the affected areas.

The modifications to the nitrogen purge system are being incorporated on the S-IVB-507 stage. To evaluate the effectiveness of the modifications, that stage will be provided with four temperature sensors on skin panels in the affected areas, and five temperature sensors spaced within the forward skirt to record purge gas temperatures at significant locations. In addition, during cryogenic loading and acceptance firing of the S-IVB-507 stage, camera coverage of the critical Korotherm areas will be provided.

16.4 Aft Skirt Ablative Coating

Inspection following the propellant loading test revealed no damage to Korotherm ablative coating on the aft skirt. However, inspection following the acceptance firing revealed cracked and peeled Korotherm coating on the panel and frame sector immediately below and adjacent to the LH2 fill and drain port. Similar damage was reported on the S-IVB-505N stage following a special cold flow test, but otherwise damage in these areas has not occurred previously.

The cause of the Korotherm cracking and peeling near the LH2 fill and drain port has been tentatively attributed to differential thermal contraction combined with low local temperatures. However, current evaluations are inconclusive. This anomaly is being investigated further.

SECTION 17

THERMOCONDITIONING AND PURGE SYSTEMS

17. THERMOCONDITIONING AND PURGE SYSTEMS

17.1 Aft Skirt Thermoconditioning and Purge System

The aft skirt environmental purge system thermally conditioned the aft skirt area with air and GN2. The air purge was initiated prior to LOX loading and was switched to GN2 prior to LH2 loading. Following LH2 loading, the air purge was reinitiated for test stand inspection and then was switched back to GN2 for the relief test, O_2-H_2 burner sequence, and static firing. The purge flowrate was maintained between 3,580 and 3,970 scfm, and the aft skirt environmental temperature was maintained at a constant 554 deg R.

The oxygen (O_2) concentrations measured at the thrust structure locations 1A and 2A (measurements N0510 and N0511) remained below the flammability limit (for hydrogen - oxygen mixtures) of 4 percent O_2 by volume during the GN2 purge concurrent to LH2 loading and during the GN2 purge which started after test stand inspection and which continued through the completion of tank purges. Typical O_2 concentration values during the static firing were 0.5 to 1.5 percent (by volume) for both measurements N0510 and N0511.

17.2 Forward Skirt Environmental Control and Thermoconditioning Systems

17.2.1 Forward Skirt Purge

The forward environmental purge system supplied the forward skirt with thermally conditioned GN2. The GN2 purge of the forward skirt was initiated prior to LOX loading and continued throughout the test until the completion of the tank purges. A flowrate of 500 scfm was maintained. The forward skirt GN2 supply temperature (measurement C0768) was maintained between 515 and 548 deg R.

17.2.2 Forward Skirt Thermoconditioning System

The forward skirt thermoconditioning system was supplied with coolant throughout the acceptance firing by the Model DSV-4B-359 Servicer. The coolant supply temperature (measurement C0753) was maintained between 517 and 526 deg R.

SECTION 18

VIBRATION ENVIRONMENT

18. VIBRATION ENVIRONMENT

Seven vibration measurements were monitored during the acceptance firing. A list of these measurements, including calibration ranges and composite levels (10 Hz to 3,000 Hz) is presented in table 18-1.

Measurements E0555-401 and E0556-401 were located on the LOX and LH2 turbopumps respectively, oriented radially to the pump centerlines. The signal from E0555-401 had uni-directional noise spikes superimposed on its data and the signal from E0556-401 lacked symmetry. The lack of symmetry is attributed to an extremely large number of noise spikes; therefore, these two measurements are considered invalid.

Measurements E0706-B03, E0707-B03 and E0708-B03 were located on the thrust chamber dome of the J-2 engine, oriented in the thrust direction. The data from E0706 and E0708 were contaminated with noise for approximately 5 sec after S-IVB ignition, but the data from the rest of the firing were valid and sufficient to define the environment. The data from all 3 measurements (figure 18-1) are in good agreement with previous data.

Measurements E0631-403 and E0632-403 monitored the response of, and the input to, the hydraulic accumulator located on the thrust structure. These measurements were used in conjunction with the supplementary failure analysis of the hydraulic accumulator requalification test to demonstrate design adequacy of the accumulator vent tube. Both measurements (figure 18-2) produced valid data.

TABLE 18-1
VIBRATION MEASUREMENTS

MEASUREMENT NO.	TITLE	COMPOSITE LEVEL (G_{rms})		CALIBRATION (G 0-peak)
E0555-401	LOX Turbopump - Radial	Data Invalid		±300
E0556-401	LH2 Turbopump - Radial	Data Invalid		±600
E0631-403	Accumulator Response - Normal	2.93g at T +3.5	2.14g at T +447	±100
E0632-403	Accumulator Input - Normal	7.6g at T +3.5	6.3g at T +447	±100
E0706-B03	Vib Safety Cutoff 2 - Thrust	8.1g at T +5.5	7.3g at T +447	±212
E0707-B03	Vib Safety Cutoff 1 - Thrust	6.9g at T +5.5	6.9g at T +447	±212
E0708-B03	Vib Safety Cutoff 3 - Thrust	8.0g at T +5.5	7.2g at T +447	±212

T = S-IVB ignition

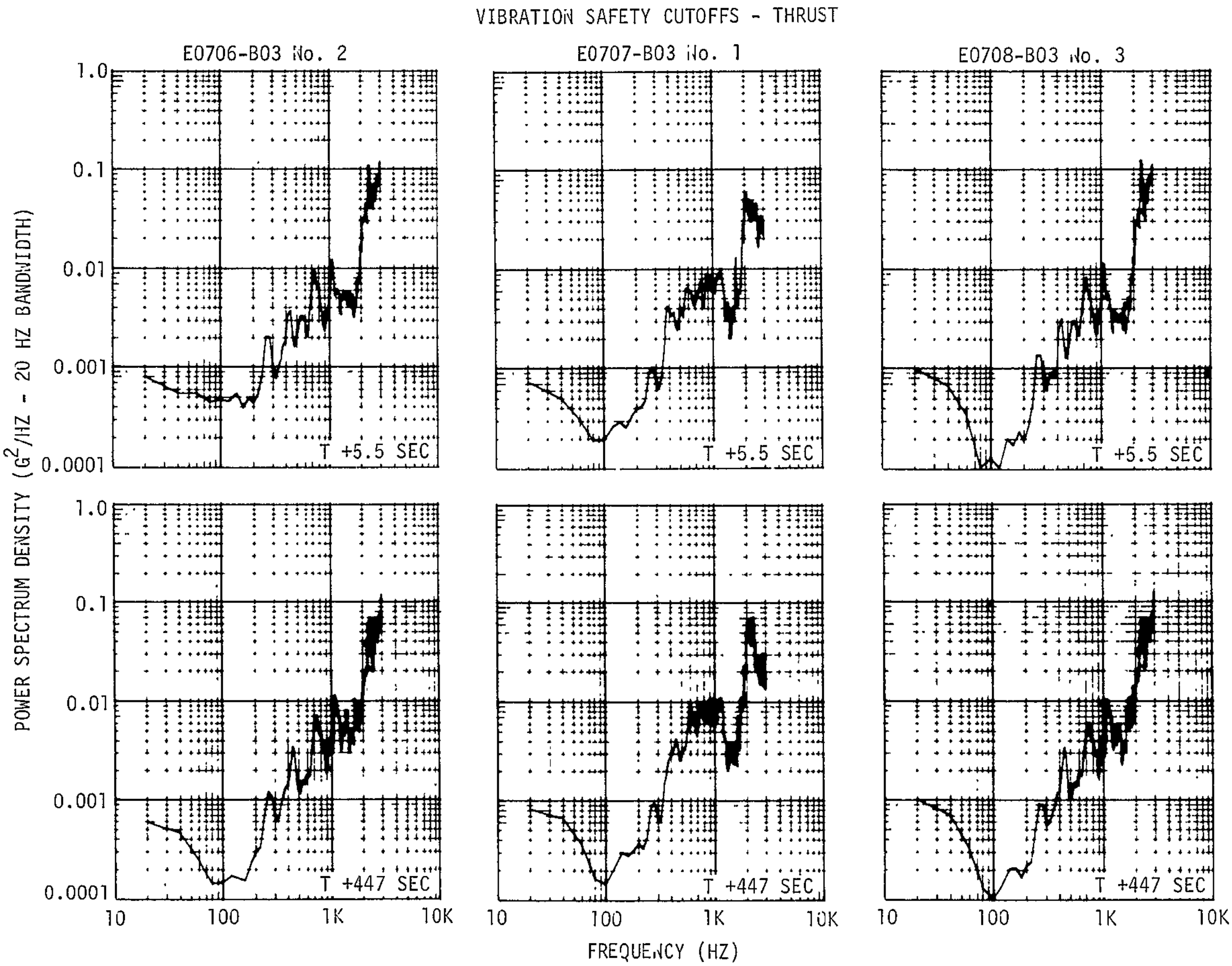
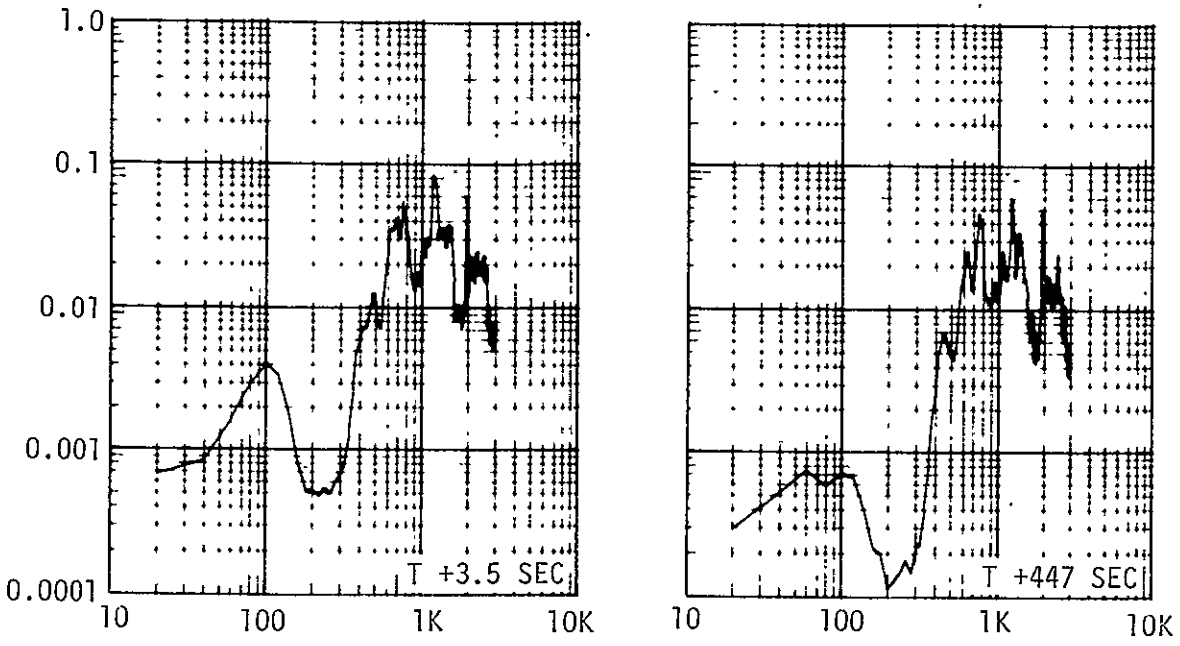


Figure 18-1. J-2 Engine Vibration Levels - Thrust Chamber Dome

E0632-403 - INPUT TO FORWARD END
NORMAL TO THRUST STRUCTURE



E0631-403 - RESPONSE - AFT END OF
RESERVOIR - NORMAL TO THRUST STRUCTURE

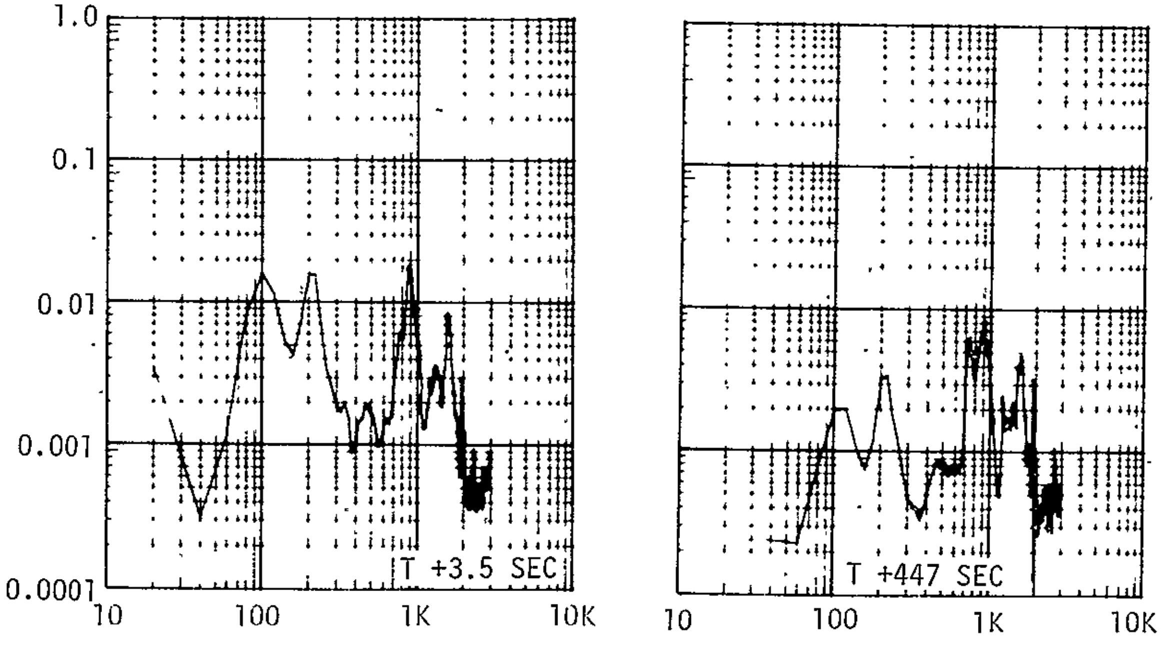


Figure 18-2. Vibration Levels - Hydraulic Accumulator

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SECTION 19

EFFECTIVENESS ENGINEERING AND HUMAN ENGINEERING

19. EFFECTIVENESS ENGINEERING AND HUMAN ENGINEERING

19.1 Effectiveness Engineering

All functional failures of flight critical items (FCI) and ground support equipment/special attention items were investigated by Effectiveness Engineering. Significant malfunctions of FCI's documented are noted in table 19-1.

19.2 Human Engineering

A Human Engineering evaluation was made in support of the S-IVB-506N stage acceptance firing.

No significant man-machine problems were identified.

TABLE 19-1 (Sheet 1 of 4)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE	CAUSE	ACTION TAKEN
1A66248-507 S/N 74	Actuator Assy, Hydraulic	A leakage on the hydraulic actuator (pitch) was discovered while performing handling and checkout procedure (H&CO) 1B41005. Hydraulic fluid was noted on the side of the pitch actuator under the cylinder bypass valve. The area was cleaned with Freon. A drop of hydraulic fluid was noted on the bypass valve plunger during a 15-min pressurized check. The plunger area was cleaned and rechecked again and the discrepancy was again noted. No leakage is allowable per H&CO 1B41005, Sheet 10.0, Para. 3.8.1, "Allowable Leakage Points."	To be determined. Suspected O-ring failure in hydraulic actuator bypass valve assembly. The possibility of contamination of the hydraulic fluid in the system was eliminated by the fluid sampling verification prior to and after acutator testing.	Discrepant actuator assembly sent to A-MRCC-Location for further disposition and evaluation and with a recommendation for a Supplemental Failure Analysis (SFA). The actuator was replaced with a line configuration actuator, S/N 84.
1A48240-505 -007 S/N 0009	Valve, Fill and Drain	During the Propulsion Leak and Functional Check, Prefire Procedure 1B71877, the valve exhibited a leakage rate of 400 scim at the actuation control module vent port (L-2). The maximum allowable leakage is 2 scim. The retest in the A45 LOX Laboratory verified the failure.	To be determined.	Discrepant valve was shipped to A-MRCC-Location for further investigation and replaced with a like configuration valve, S/N 0114.

TABLE 19-1 (Sheet 2 of 4)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE	CAUSE	ACTION TAKEN
1A58345-523 S/N 1047	Module, Pneumatic Power Control	During propellant loading test per CD614108, TR1316, a high lockup pressure of 565 psia was noted which gradually increased to 590 psia. A purge was used to control the pressure. Termination of the purge resulted in the pressure increasing to pressure switch pickup.	Preliminary failure analysis revealed valve seat damage. Damage was suspected to be caused by contamination.	The module was sent to A3 Location and then shipped to the vendor where a failure analysis was performed. The results of the failure analysis will be evaluated upon receipt from the vendor. The discrepant module was replaced with a like configuration module, S/N 1071.
1A58345-523 S/N 1071	Module, Pneumatic Power Control	During acceptance firing per CD614109, TR 1316, the lockup pressure increased to 590 psia exceeding the maximum allowable pressure of 540 psia.	To be determined. Samples from the module and a 12-in section of the inlet line adjacent to the module revealed some contamination.	The significance of the contamination is being evaluated. A replacement module has not been installed.
1B42290-507 S/N 0024	Module, Control, LO2 Tank Pressurization	During Critical Components Check of the propellant loading test per CD614108, TR1316, the pressure from the module spiked to 310 psia, dropped to 230 psia and then increased to 320 psia. The failure of the module was verified at Alpha I Site I Location.	To be determined.	The discrepant module was sent to A-Location for further investigation. The module was replaced with a like configuration module, S/N 0037.

TABLE 19-1 (Sheet 3 of 4)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE	CAUSE	ACTION TAKEN
1B51361-501 S/N 413	Valve, Check-Hydrogen Vent Purge.	During pretest propulsion leak checks, the check valve exhibited reverse leakage of 51 scim at a pressure of 1,450 psig. The allowable leakage is 10 scim maximum.	To be determined.	The valve to be reworked and identified as a test part and "Not For Production Use." The discrepant 1B51361-501 valve was replaced with 1B67598-503 valve per WRO 3992.
1B66639-501 S/N 011	Actuator Assy, Pneumatic Latching	During Critical Components Check of the acceptance firing test per CD614109 TR1316, the actuation time for vent valve to open when commanded open, was 0.069 sec. Prior to first burn of the O_2-H_2 burner, the actuation time for the vent valve was 2.234 sec. This latter actuation time was considered excessive in relation to the actuation time during critical components check.	To be determined.	The discrepant valve will be replaced.
103826 S/N J2101	J-2 Engine	Engine leak checks revealed a small fuzz leak at LOX dome purge inlet boss. The leak was located on the inside edge of the weld.	To be determined.	The Thrust Chamber Injector Assembly P/N 208021-11, S/N 4081787 was repaired at R/NAR and reinstalled on the stage.

TABLE 19-1 (Sheet 4 of 4)
FLIGHT CRITICAL COMPONENTS MALFUNCTIONS

P/N and S/N	PART NAME	TROUBLE	CAUSE	ACTION TAKEN
1A59358-529 S/N 031	Electronic Assy, PU	During PU sub-system calibration per Procedure 1B64368, the linearity checks were found to be out of tolerance. LH2 full ratio during data acquisition was .82360 during linearity checks was .82908. LOX full ratio was .82308 during data acquisition and .82757 during linearity checks. Also, the oven temperature stability monitor voltage drifted from 4.395 vdc to 3.728 vdc in 6 hr.	Oven, Component PU P/N 1A59564-501, S/N 043 was found to contain a faulty thermister.	The Electronic Assy, PU, S/N 031, was removed and sent to A-Location for verification of the failure. Troubleshooting at A-Location confirmed a defective oven component PU P/N 1A59564-501, S/N 043, which was removed from the Electronic Assy, PU S/N 031 and subsequently rejected on FARR 500-436-166. The defective oven S/N 043 was returned to the vendor for a Supplemental Failure Analysis. The oven was replaced with a like configuration oven, S/N 069.
1A59358-529 S/N 031	Electronic Assy, PU	During PU Auto Procedure 1B55823, the boiloff bias signal M10 was out of tolerance.	Extraneous noise in the PU System	This condition was evaluated and the part was determined to be acceptable to engineering for use.

APPENDIX 1

ABBREVIATIONS

TABLE AP 1-1 (Sheet 1 of 2)
ABBREVIATIONS

ITEM	TERM
ac	Alternating current
Act	Actuator
APS	Auxiliary Propulsion System
ASI	Augmented Spark Igniter
attch	Attach
A_t	Throat area
Aux	Auxiliary
Btu	British thermal unit
Bgr	Bridge gain ratio
c_f	Thrust Coefficient
Cfm	Cubic feet per minute
Contr	Control
cpg	Cycles per gallon
cps	Cycles per second
db	Decibel
dc	Direct current
DDAS	Digital Data Acquisition System
deg	Degree
DER	Digital Events Recorder
Disch	Discharge
DNA	Data not available
D/O	Dropout
DPF	Differential Pressure Feedback
EBW	Exploding bridgewire
ECC	Engine Cutoff Command
ECO	Engine Cutoff
EDS	Emergency Detection System
E/I	External/Internal
EMI	Electromagnetic Interference
EMR	Engine Mixture Ratio
ESC	Engine Start Command
F	Fahrenheit
F	Thrust
FCI	Flight Critical Items
Flt	Flight
ft	Feet
FM	Frequency modulation
FTC	Florida Test Center
Fwd	Forward
GG	Gas generator
GH2	Gaseous hydrogen
GIS	Ground Instrumentation System
GN2	Gaseous nitrogen
gpm	Gallons per minute
GSE	Ground support equipment
He	Helium
Hg	Mercury
H_2O	Water
hr	Hour
hp	Horsepower
Hyd	Hydraulic
Hz	Hertz
in.	Inch
IPS	Inches per second
IP&CL	Instrumentation Program and Components List
I_{sp}	Specific impulse
IU	Instrument Unit
K	Kilo - 1,000 or 10^3
Kc	Kilocycle
KSC	Kennedy Space Center
lbf	Pounds force
lbm	Pounds mass

TABLE AP 1-1 (Sheet 2 of 2) ABBREVIATIONS

ITEM	TERM
LH2	Liquid hydrogen
Loc	Location
LOX	Liquid oxygen
M&A	Manufacturing and Assembly
MR	Mixture ratio
ms	Millisecond
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
N/A	Not applicable
NPSP	Net positive suction pressure
P_c	Chamber pressure
PCM	Pulse code modulation
PDT	Pacific Daylight Time
pf	Picofarad
Posit	Position
pps	Pulses per second
Press	Pressure
psi	Pounds per square inch
psia	Pounds per square inch, absolute
psid	Pounds per square inch, differential
psig	Pounds per square inch, gauge
PST	Pacific Standard Time
Pt	Point
P/U	Pickup
PU	Propellant Utilization
Pwr	Power
R	Rankine
RACS	Remote Analog Checkout System
RAD	Radial
Refl	Reflected
Reg	Regulator
RF	Radio Frequency
RMR	Reference Mixture Ratio
RPM	Revolutions per minute
RSS	Root sum square
SAI	Special Attention Items
SCC	Standard cubic Centimeter
SCI	Standard cubic inch
scim	Standard cubic inch per minute
scfm	Standard cubic foot per minute
sec	Second
sps	Samples per second
SSC	Space Systems Center
STC	Sacramento Test Center
sw	Switch
Syst	System
T_0	Simulated liftoff
TAN	Tangential
Temp	Temperature
T/M	Telemetry
TP&E	Test Planning and Evaluation
vac	Volts alternating current (100 vac)
V	Volts
VCL	Vehicle Checkout Laboratory
vdc	Volts direct current
Vib	Vibration
vswr	Voltage standing wave ratio
$\dot{W}_T$	Total mass flowrate

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5301 Bolsa Avenue, Huntington Beach, CA 92647