MASTER
NTO-R-0110

ETS-1

TEST SUMMARY REPORT

FEP TEST SERIES

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

NERVA TEST OPERATIONS

Jackass Flats, Nevada

TECHNICAL DOCUMENT CENTER
Nuclear Rocket Operations

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DOC. NO. X-10825

AGCS 0120-48

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Nuclear Rocket Development Station

P. O. BOX 2027, JACKSON FLATS, NEVADA-89028

MASTER

June 27, 1967

NTO-M-16809

Dr. W. O. Wetmore, Manager - NRO
Aerodiet-General Corporation
Post Office Box 15847
Sacramento, California 95813

Attention: C. M. Rice/P. W. Rowe

Subject: Transmittal of NTO Test Report for ETS-1 FEP Test Series.

Dear Dr. Wetmore:

Attached is the final test summary report for the ETS-1 FEP test series.

Very truly yours,

N. E. Erickson, Manager
NERVA Test Operations

DCR:NEE:cs

Enclosure

[illegible]

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ETS-1
TEST SUMMARY REPORT
FEP TEST SERIES

June 26, 1967

Prepared by:

ETS-1 Test Operations

Approved by:
S. N. Kemp, Manager
ETS-1 Test Operations

Approved by:
W. D. Wayne
Manager, ETS-1

ETS-1 TEST SUMMARY REPORT FEP TEST SERIES

TABLE OF CONTENTS

	<u>PAGE</u>
LIST OF FIGURES	iii
LIST OF TABLES	vii
1.0 INTRODUCTION.	.1
2.0 SUMMARY	.1
2.1 Low Pressure GN ₂ System	3
2.2 LN ₂ System.	.4
2.3 HP GHe Cooldown System.	.6
2.4 HP GH ₂ /GN ₂ Cooldown System.	.8
2.5 HP LH ₂ Cooldown System.	.9
2.6 LP LH ₂ Propellant, Storage and Transfer Systems	12
3.0 TECHNICAL DISCUSSION.	14
3.1 LP GN ₂ System	14
3.2 LN ₂ System.	22
3.3 HP GHe System	42
3.4 HP GH ₂ System	63
3.5 HP GN ₂ System	83
3.6 HP LH ₂ System	89
3.7 HP LH ₂ Storage and Transfer System.	123
3.8 LP LH ₂ Propellant System.	134
3.9 Engine Flow Simulator	160
3.10 Test Stand Heating	167
3.11 Cooldown and Propellant System(s) Contaminant Evaluation. . .	171
4.0 REFERENCES.	175
5.0 APPENDIX.	176

LIST OF FIGURES

	<u>PAGE</u>
3.1.1 LP GN ₂ SYSTEM STEADY-STATE PRESSURE DISTRIBUTION WITH FE-X	16
3.1.2 FE-X FLOW RATE VS FE-50 INLET PRESSURE	17
3.1.3 GN ₂ FLOW RATE VS FCV-50 PERCENT OPEN	19
3.1.4 FE-50 CALCULATED FLOW RATE VS FE-X FLOW RATE	20
3.1.5 FREQUENCY RESPONSE OF GN ₂ LINE AT ETS-1 OBTAINED FROM THE RESPONSE OF PT-774 TO A STEP CHANGE IN FCV-50.	21
3.2.1 V-3601 PRESSURE VS TIME	25
3.2.2 CHILLDOWN CHARACTERISTICS OF LN ₂ LINE FROM V-3601 TO PCV-517	27
3.2.3 CHILLDOWN CHARACTERISTICS PCV-517 TO RSV-545 INLET VENTING THROUGH RSV-717	29
3.2.4 PRESSURE DIFFERENTIAL VS LN ₂ FLOW RATE	30
3.2.5 PCV-517 C _v VS PCV-517 POSITION	32
3.2.6 W/ $\sqrt{\Delta P_s}$ VERSUS PCV-517 POSITION	33
3.2.7 DEWAR PRESSURE VERSUS LN ₂ FLOW RATE	35
3.2.8 FT-52 LN ₂ FLOW RATE VS FE-X FLOW RATE	36
3.2.9 VALVE POSITIONS, PRESSURES, TEMPERATURES, AND FLOW RATE VS TIME FOR LN ₂ SYSTEM TRANSIENT PERFORMANCE, FEP-I	37
3.2.10 VALVE POSITIONS, PRESSURES, TEMPERATURES AND FLOW RATES VS CONTROL ROOM TIME DURING GHe TO LN ₂ SWITCHING TEST, FEP-IV	39
3.2.11 FE-X AND PCV-750 INLET PRESSURE VS TEMPERATURE	41
3.3.1 PRESSURE VS GHe FLOW RATE	45
3.3.2 DIFFERENTIAL PRESSURE VS GHe FLOW RATE	46
3.3.3 DIFFERENTIAL PRESSURE VS GHe FLOW RATE	47
3.3.4 DIFFERENTIAL PRESSURE VS GHe FLOW RATE	48
3.3.5 DIFFERENTIAL PRESSURE VS GHe FLOW RATE	50
3.3.6 DIFFERENTIAL PRESSURE VS GHe FLOW RATE	51
3.3.7 FE-X FLOW RATE VERSUS FE-415 FLOW RATE FOR FEP-IIB	52
3.3.8 FE-415 CALCULATED VERSUS MEASURED FLOW RATES FOR FEP-IIB	54
3.3.9 C _v [*] VS VALVE POSITION FOR PCV-471	55
3.3.10 T [*] VERSUS P [*] FOR THREE VESSEL BLOWDOWN	57
3.3.11 VALVE POSITIONS, PRESSURES, TEMPERATURES, AND FLOW RATES VS TIME DURING LH ₂ TO GHe SWITCHING TEST, FEP-IV	58

LIST OF FIGURES (Cont'd)

	<u>PAGE</u>
3.3.12 VALVE POSITION, TEMPERATURE AND PRESSURE VS TIME DURING LH ₂ TO GHe SWITCHING TEST	60
3.3.13 TEMPERATURE AND FLOW RATE VS TIME FOR LH ₂ TO GHe SWITCHING TEST	61
3.4.1 PRESSURE VS GH ₂ FLOW RATE	66
3.4.2 DIFFERENTIAL PRESSURE VS GH ₂ FLOW RATE	67
3.4.3 DIFFERENTIAL PRESSURE VS GH ₂ FLOW RATE	68
3.4.4 DIFFERENTIAL PRESSURE VS GH ₂ FLOW RATE	69
3.4.5 DIFFERENTIAL PRESSURE VS GH ₂ FLOW RATE	71
3.4.6 DIFFERENTIAL PRESSURE VS GH ₂ FLOW RATE, FEP-IV	72
3.4.7 FE-X GH ₂ FLOW RATE VERSUS FT-15 FLOW RATE FOR FEP-IIB	74
3.4.8 C _v * VS % OPEN FOR PCV-251	75
3.4.9 T* VERSUS P* FOR GH ₂ FLOW OUT OF V-3207 AND V-3208	76
3.4.10 T* VERSUS P* FOR GH ₂ FLOW OUT OF V-3207	77
3.4.11 GH ₂ FLOW INITIATION TRANSIENTS	79
3.4.12 GH ₂ TRANSIENT DURING GH ₂ INITIATION WITH LH ₂ DOWNSTREAM, FEP-IV	81
3.4.13 TRANSIENT BEHAVIOR DURING CHANGE IN SIMULATED ENGINE IMPEDANCE	82
3.5.1 PRESSURE VS GN ₂ FLOW RATE	85
3.5.2 DIFFERENTIAL PRESSURE VS GN ₂ FLOW RATE	86
3.5.3 COMPARISON OF FE-15 AND FE-X FLOW RATES	87
3.5.4 COMPARISON OF FE-15 CALCULATED AND MEASURED FLOW RATES	88
3.5.5 GN ₂ TEMPERATURE VS PRESSURE	90
3.6.1 V-5002 PRESSURE AND PRESSURE DEMAND VERSUS TIME	94
3.6.2 V-5002 PRESSURIZATION RATE VS ULLAGE VOLUME	96
3.6.3 RSV-109 AND RSV-110 PERFORMANCE DURING V-5002 VENTING	97
3.6.4 PCV-250 COMMAND, POSITION, PRESSURE DEMAND AND DEWAR PRESSURE VS TIME FOR VENTING TEST	98
3.6.5 INITIAL CHILLDOWN OF COOLDOWN LINE AND SIMULATION	100
3.6.6 INITIAL LH ₂ LINE BLOWDOWN TRANSIENTS	103
3.6.7 PRESSURE AND FLOW RATE VS TIME DURING LH ₂ FLOW INITIATION	104
3.6.8 PRESSURE RATIO VS GAS ULLAGE VOLUME RATIO DURING LH ₂ FLOW INITIATION	105

LIST OF FIGURES (Cont'd)

	<u>PAGE</u>
3.6.9	DEWAR PRESSURE RATIO VS DEWAR ULLAGE VOLUME RATIO 107
3.6.10	PRESSURE, TEMPERATURE, VALVE POSITION AND FLOW RATE VS TIME 109
3.6.11	PRESSURE, TEMPERATURE, FLOW RATE AND VALVE POSITION VS TIME 110
3.6.12	LH ₂ SYSTEM TRANSIENTS DURING FLOW CONTROL CLOSURE OF PCV-472 112
3.6.13	LH ₂ FE-12 FLOW RATE VS FE-X FLOW RATE 114
3.6.14	LH ₂ FE-12 FLOW RATE VS FT-12 FLOW RATE 115
3.6.15	DIFFERENTIAL PRESSURE VS LH ₂ FLOW RATE 116
3.6.16	DIFFERENTIAL PRESSURE VS LH ₂ FLOW RATE 117
3.6.17	PCV-472 C _v VS PCV-472 PERCENT OPEN 119
3.6.18	V-5002 ULLAGE VOLUME VS LT-009 PROBE HEIGHT 121
3.6.19	PERCENT PROBE HEIGHT IN V-5002 VERSUS POUNDS OF LH ₂ IN DEWAR 122
3.7.1	V-3801 PRESSURE, TEMPERATURE AND PCV-248 POSITION VERSUS TIME DURING INITIAL PRESSURIZATION 127
3.7.2	V-3801 PRESSURE, TEMPERATURE AND PCV-248 POSITION VERSUS TIME DURING PRESSURIZATION 128
3.7.3	TRANSFER LINE TEMPERATURE (TT-44) DURING LONG CHILL MAINTENANCE PERIOD 131
3.7.4	TOPPING FLOW RATE VS DIFFERENTIAL PRESSURE BETWEEN V-3801 AND V-5001 132
3.7.5	LT-2 CALIBRATION LT-2 % PROBE HEIGHTS VS POINT RESISTANCE PROBE INCHES ABOVE BOTTOM 135
3.7.6	LT-2 % HEIGHT VS LBS VOLUME 136
3.8.1	PRESSURE AND VALVE POSITION VS TIME DURING V-5001 PRESSURIZATION 139
3.8.2	V-5001 PRESSURIZATION DURING LH ₂ OUTFLOW WITH AND WITHOUT TOPPING 140
3.8.3	V-5001 PRESSURE AND LEVEL DURING INITIAL FILL AND CHILLDOWN 144
3.8.4	V-5001 TEMPERATURE DURING INITIAL FILL AND CHILLDOWN 145
3.8.5	PRESSURE AND PCV-576 POSITION VERSUS TIME DURING INITIAL CHILLDOWN OF THE PROPELLANT SUPPLY LINE 147

LIST OF FIGURES (Cont'd)

	<u>PAGE</u>
3.8.6	LINE TEMPERATURE VERSUS TIME DURING INITIAL CHILLDOWN OF THE PROPELLANT SUPPLY LINE 148
3.8.7	FT-14 LH ₂ FLOW RATE VS FT-425 LH ₂ FLOW RATE 149
3.8.8	DIFFERENTIAL PRESSURE VERSUS FT-14 LH ₂ FLOW RATE 151
3.8.9	TEMPERATURE RISE VS FT-14 LH ₂ FLOW RATE 152
3.8.10	V-5001 PRESSURE VS LH ₂ FLOW OUT OF PCV-579 154
3.8.11	CALIBRATION OF LT-453 BASED ON INTEGRAL V-5001 OUTFLOW 156
3.9.1	$\frac{Q}{W(\Delta P \ell)^{\frac{1}{2}}}$ VS PCV-750 PERCENT OPEN 162
3.9.2	PT-774 PRESSURE VS FLOW RATE 163
3.9.3	PT-775 PRESSURE VS FLOW RATE 164
3.9.4	FT-14 LH ₂ FLOW RATE VS PRESSURE 166

LIST OF TABLES

		<u>PAGE</u>
3.7.1	SUMMARY TABLE OF V-3801 PRESSURIZATION	125
3.7.2	V-3801 LH ₂ LEVEL INSTRUMENTATION DATA	133
3.8.1	SUMMARY TABLE OF V-5001 PRESSURIZATION	142
3.8.2	V-5001 LH ₂ LEVEL INSTRUMENTATION DATA	155
3.8.3	V-5001 INSTRUMENTATION PERFORMANCE	157
3.10.1	ENERGY RELEASE	169
3.10.2	MEASURED HEAT FLUX	170
3.11.1	DISTRIBUTION OF CONTAMINANTS DURING FEP-IV	172

1.0

INTRODUCTION

This document is a summary report of the FEP test series, i.e., FEP-I through IV, conducted on Engine Test Stand No. 1 (ETS-1) at NRDS, Nevada between 26 September 1966 and 24 March 1967.

The information summarized in this report has been based primarily on information reported previously in data evaluation memorandum issued following each FEP by the ETS-1 Facility Data Evaluation Team (FDET).

Detailed description of the tests performed during the FEP test series and the detailed test objectives established for each FEP have been reported previously in the FDET memorandum, and therefore are not contained within this report. This report does however summarize the tests performed and their test dates; the system deficiencies identified and corrected; current system status relative to its capability to support engine testing; and the significant system performance data applicable to the current systems.

2.0

SUMMARY

The purpose of the FEP test series was to check out the functional performance of certain ETS-1 systems; and to provide system performance data required to evaluate the capability of the system(s) to support engine testing, and to develop accurate facility prediction models. The FEP test series also provided an important means for training of operator personnel and development of operating procedures.

The FEP test series consisted primarily of operation and testing of the ETS-1 low pressure (LP) GN_2 purge, LN_2 cooldown, high pressure (HP) GHe cooldown, high pressure GH_2/GN_2 cooldown, high pressure LH_2 cooldown, low pressure LH_2 storage and transfer, and low pressure LH_2 propellant systems. The tests performed consisted of independent operation of each of the above systems, and investigating the interaction between some of these systems.

SUMMARY (Cont'd)

The interaction between the HP GN₂ and LN₂ cooldown systems (FEP-IC); between the HP LH₂ and HP GHe/GH₂ cooldown systems (FEP-IV); between the HP GHe and LN₂ cooldown systems (FEP-IV); and between the LP LH₂ storage and transfer, and LP LH₂ propellant systems (FEP-III-2) were investigated.

The test dates and systems checked out during the tests performed for each Facility Experimental Plan are summarized below:

<u>Test</u>	<u>Date</u>	<u>Systems</u>
FEP-I	28 September 1966	LP GN ₂ Purge and LN ₂ Cooldown Systems
FEP-IA	4 October 1966	LN ₂ Cooldown System
FEP-II	20 October 1966	HP GHe and HP GN ₂ Cooldown Systems
FEP-IB	26 October 1966	LN ₂ Cooldown Systems
FEP-IIA	26 October 1966	HP GHe and HP GH ₂ Cooldown Systems
FEP-IC	9 November 1966	HP GN ₂ and LN ₂ Cooldown Systems
FEP-IIB	9 November 1966	HP GHe and HP GH ₂ Cooldown System
LN ₂ Checkout of V-5002	29 November 1966	HP LH ₂ Cooldown System
LN ₂ Checkout of V-5002	10 January 1967	HP LH ₂ Cooldown System
FEP-III-I	14 January 1967	HP LH ₂ Cooldown and LP LH ₂ Storage and Transfer Systems
FEP-III-IA	17 January 1967	HP LH ₂ Cooldown and LP LH ₂ Storage and Transfer Systems
FEP-IV	24 February 1967	HP LH ₂ , HP GHe, HP GH ₂ , and LN ₂ Cooldown Systems
LN ₂ Checkout of V-5001/LN ₂	21 March 1967	HP LH ₂ and LN ₂ Cooldown System
FEP-III-2	24 March 1967	LP LH ₂ Propellant and LP Storage and Transfer Systems

During the tests conducted during the FEP test series, a number of system deficiencies, or potential problem areas were identified. Some of these were corrected and the system re-tested, while others remain to be resolved. The significant changes made to the ETS-1

2.0 SUMMARY (Cont'd)

systems tested during the FEP test series, the significant performance characteristics of the current system, and the status of each system in regard to its capability to support engine testing are summarized in the following sections:

2.1 Low Pressure GN_2 System

2.1.1 System Changes

2.1.1.1 The on-line computer for FT-50 was modified to include the measured upstream pressure instead of a constant 500 psig after FEP-I. This change was necessary because PRV-107 was unable to maintain downstream pressure at its dome loading of 500 psig above 3 lbs/sec GN_2 .

2.1.2 System Performance

2.1.2.1 PRV-107 is unable to maintain downstream pressure at its dome loading of 500 psig above 3 lbs/sec GN_2 . A maximum of 18 lbs/sec GN_2 at a PRV-107 downstream supply pressure of 250 psig can be provided by this system with PRV-107 dome loaded to 500 psig.

2.1.2.2 FE-50 post test calculated and FT-50 on-line computed GN_2 flow rates give good correlation with FE-X calculated flow rates.

2.1.2.3 The system fails to control properly in the AUTO (flow rate) control mode.

2.1.3 System Status

2.1.3.1 System acceptable for MANUAL (position) GN_2 purge operations.

- 2.1.3.2 Recommend deletion of AUTO (flow rate) control mode for this system.
- 2.2 LN₂ System
- 2.2.1 System Changes
- 2.2.1.1 The original pneumatic actuated (50 in.²) PCV-517 (C_v = 220, linear) valve was replaced with the pneumatic actuated (100 in.²) FCV-52 valve with modified plug (C_v = 110, equal percentage) between FEP-IA and FEP-IB. This change was required since the original PCV-517 stem packing leaked, and the actuator was undersized to maintain stable operating conditions. The new PCV-517 (old FCV-52) was reversed after FEP-IV, so that flow is under the plug in order to achieve a fail safe (open) condition.
- 2.2.1.2 The 1-inch pressurization line between PRV-108 and V-3601 was replaced with a 2-inch line, RSV-325 was replaced with a 2-inch valve and the original APCO regulator was replaced with a Grove regulator between FEP-IA and FEP-IB. This change was required since with the original V-3601 pressurization line 15/39 minutes were required to initially pressurize V-3601 with PRV-108 dome-loaded to 250/400 psig; and original line could not maintain dewar pressure at LN₂ outflow above 30 pps.
- 2.2.1.3 CHV-1885 was modified by increasing the spring pre-load from 40 lbs to 65 lbs with the installation of a spacer on 29 November, i.e., after FEP-IC. This change was required to prevent back leakage during gas to LN₂ switching operations.
- 2.2.1.4 V-3601 discharge shutoff valve RSV-526 opening time was increased and the 2-LN-4 line was strapped down in order to reduce pressure hammer effects when RSV-526 was opened with a pressurized dewar and a depressurized line. These changes resulted in reduced but still excessive line movements for this mode of operation.

2.2.2 System Performance

2.2.2.1 The system is capable of supplying up to 85 lbs/sec LN_2 with V-3601 maintained at 250 psig and with maximum engine impedance. This flow capability was evidenced prior to the modification expressed in Section 2.2.1.3. The actual maximum flow capability of the system will depend on the final CHV-1885 impedance characteristics (refer to Section 2.2.3.4).

2.2.2.2 V-3601 pressurization system is capable of maintaining dewar pressure at 250 psig for LN_2 outflows up to the maximum achievable rates. With PRV-108 dome loaded to 400 psig, V-3601 can be pressurized to 250 psig within 7 minutes with a dewar ullage of 20-22%.

2.2.2.3 System (PCV-517) fails to control properly in the AUTO (flow rate) control mode.

2.2.2.4 FT-52 on-line computed LN_2 flow rates give good correlation with FE-X calculated flow rates.

2.2.2.5 Natural oscillation frequency of LN_2 system is 1 cps which is excited by closure/opening of RSV-545.

2.2.2.6 Initial chilldown of LN_2 system between PCV-517 and RSV-545 requires 5 minutes with V-3601 pressurized up to 250 psig. System warmup rate is $0.8^\circ\text{R}/\text{min}$ with no flow and $0.45^\circ\text{R}/\text{min}$ with continuous flow rate of 1 pps through PCV-754 set at 4%.

Pulse chill maintenance requires changes over of line inventory (2600 lbs LN_2) between V-3601 and RSV-545 before appreciable temperature reduction is achieved.

2.2.3 System Status

2.2.3.1 System is acceptable for engine cooldown operations in MANUAL (position) control mode.

- 2.2.3.2 Recommend deletion of AUTO (flow rate) control mode for this system.
- 2.2.3.3 Due to excessive pressure hammer effects, RSV-326 should not normally be used to initiate LN₂ flow with V-3601 pressurized.
- 2.2.3.4 Due to the modification discussed in Section 2.2.1.3, the plug travel of CHV-1885 was severely limited (1/8 inch) resulting in a maximum LN₂ flow capability of 65 lbs/sec. Therefore, it is planned to remove the spacer previously installed and replace the old spring with one which will provide sufficient pre-load to prevent back leakage.
- 2.3 HP GHe Cooldown System
 - 2.3.1 System Changes
 - 2.3.1.1 PCV-471 pneumatic actuator (113 in², 150 psi) was replaced with hydraulic actuator (3.14 in², 2700 psi) between FEP-IIB and FEP-IV. This change was made since the valve response of 50%/sec with 1 sec opening delay would not satisfy engine cooldown requirements.
 - 2.3.1.2 PCV-471 AUTO (pressure) controller was modified in conjunction with the change in PCV-471 actuation.
 - 2.3.1.3 CHV-685 was modified by increasing the spring pre-load from 40 lbs to 65 lbs on 30 November 1966, i.e., after the LN₂ checkout of V-5002. This change was required to prevent check back leakage.
 - 2.3.1.4 CHV-1721 was modified by increasing the spring pre-load from 40 lbs to 65 lbs on 30 November, i.e., after the LN₂ checkout of V-5002. This change was required to prevent checkback leakage during LN₂ flow.

2.3.2 System Performance

- 2.3.2.1 The system is capable of supplying up to 63 pps GHe with storage vessel V-3206 at 2500 psig with expected engine impedance.
- 2.3.2.2 A maximum valve slew rate of approximately 600%/sec with nominal opening delay of 10 milliseconds is achievable with PCV-471 in AUTO (pressure) control.
- 2.3.2.3 Pressure demand overshoots of 25% are obtained in AUTO (pressure) control with initial pressure near demand, and overshoots of 70% with initial pressure much less than demand.
- 2.3.2.4 CHV-1721 exhibited inconsistent flow pressure characteristics during testing of FEP-IV. The maximum pressure drop experienced was 80 psi at 10 GHe lbs/sec.
- 2.3.2.5 Both FT-415 on-line computed, and FE-415 calculated flow rates give good correlation with FE-X calculated flow rates when proper FT-415 computer zero offset is accomplished after initial header pressurization.

2.3.3 System Status

- 2.3.3.1 System in AUTO (pressure) control is basically adequate for engine cooldown with PCV-472 closed when gas between CHV-1721 and CHV-681/685 is available at near pump discharge pressure.
- 2.3.3.2 Pressure controller compensations adjustment may be required due to marginal stability and pressure overshoot.
- 2.3.3.3 CHV-1721 is to be replaced with a new plug type CHV to eliminate the inconsistent behavior of the old CHV-1721. Bypass piping, with shutoff capability, is also being supplied around CHV-1721, CHV-681, and CHV-685 to provide pressure at near engine pump discharge pressure back to the gas control valves.

- 2.3.3.4 Further testing of GHe system in its final configuration is required to insure that engine cooldown requirements can be met.
- 2.4 HP GH₂/GN₂ Cooldown System
- 2.4.1 System Changes
- 2.4.1.1 PCV-251 pneumatic actuator (400 in², 200 psi) was replaced with hydraulic actuator (19.6 in², 2700 psi) between FEP-IIB and FEP-IV. This change was made since the low valve response (18 seconds was required for the valve to travel to 65% with step demand in MANUAL control) would not satisfy engine cooldown requirements.
- 2.4.1.2 PCV-251 AUTO (pressure) controller was modified in conjunction with the change in PCV-251 actuation.
- 2.4.1.3 CHV-1721 was modified as described in Section 2.3.1.4.
- 2.4.2 System Performance
- 2.4.2.1 The system is capable of supplying up to 48 lbs/sec GH₂ with storage vessel V-3207 at 2500 psig with expected engine impedance. The system is capable of supplying up to 170 lbs/sec GN₂ with storage vessels V-3201, V-3202 and V-3203 at 2500 psig with expected engine impedance.
- 2.4.2.2 A maximum valve slew rate of 400%/second with nominal opening delay of 10 milliseconds is achievable with PCV-251 in AUTO (pressure) control.
- 2.4.2.3 Pressure demand overshoots of 40-50% were obtained in AUTO (pressure) control.
- 2.4.2.4 CHV-681 exhibited inconsistent flow pressure characteristics

2.4.2.4 (Cont'd)

during FEP-IV. The maximum pressure drop experienced was 210 psi at 8 lbs/sec.

2.4.2.5 Both FT-15 on-line computed and FE-15 calculated flow rates give good correlation with FE-X calculated flow rates when FT-15 computer offset is adjusted after initial header pressurization.

2.4.3 System Status

2.4.3.1 System in AUTO (pressure) control is basically adequate for engine cooldown with gas between CHV-1721 and CHV-681/685 at near pump discharge pressure.

2.4.3.2 Pressure controller compensations adjustment may be required due to marginal stability and pressure overshoot.

2.4.3.3 Replacement of CHV-1721 is as discussed in Section 2.3.3.3.

2.4.3.4 Further testing of the GH_2 system in its final configuration is required to insure that engine cooldown requirements can be met.

2.4.3.5 CHV-681 has been equipped with bronze guides to eliminate its inconsistent behavior.

2.5 HP LH_2 Cooldown System

2.5.1 System Changes

2.5.1.1 PCV-472 pneumatic actuator (200 in², 40 psi) was replaced with a hydraulic actuator (12.56 in², 2700 psi) on 9 December 1966. This change was required since the original pneumatic actuator was not adequate to maintain stable operating conditions; and to significantly improve valve response for engine cooldown application.

- 2.5.1.2 The original RSV-458 was modified to CHV-458 on 27 December 1966. This change was made to provide isolation capability between HP LH₂ and gas cooldown systems during LH₂ to gas cooling transient with PCV-472 and PCV-471 or 251 open.
- 2.5.2 System Performance
- 2.5.2.1 Flow pressure characteristics of the HP LH₂ system, except for CHV-458, are consistent and predictable. The pressure drop across CHV-458 at 3 pps LH₂ did not exceed 80 psid. for tests conducted to date.
- 2.5.2.2 The maximum valve slew rate obtained in MANUAL (position), AUTO (flow), and AUTO (pressure) control were 600%/sec, 130%/sec, and 30%/sec, respectively.
- 2.5.2.3 Stable operation of the HP LH₂ system was obtained in position, flow rates, and pressure feedback control modes.
- 2.5.2.4 Initial chilldown of the 4-LH-6 cooldown line between V-5002 and the facility/simulator interface can be achieved within approximately 10 minutes with LH₂ from V-3801 at 95 psig. Cooldown line warmup rate is 36°R/min with no chill maintenance flow rate. With V-5002 LH₂ temperature of 38.5°R, a LH₂ temperature of 50°R can be maintained at TT-495 (CHV-458 inlet) and TT-474 (4-LH-6 gas line interface) at continuous LH₂ flow rates of 0.3 lbs/sec LH₂ and 0.7 lbs/sec LH₂, respectively.
- 2.5.2.5 Pressurization rates up to 285 psi/sec at LH₂ levels of 100% and header pressures of 2500 psi; and venting rates up to -500 psi/sec (RSV-110) for LH₂ levels above 80% are achievable. The low slew rate of PCV-250 pneumatically actuated valve of 6.3%/sec results in up to 4 sec lag between demand/actual pressures.

- 2.5.2.6 The FT-12 on-line computed and FE-12 calculated flow rates gave good correlation with FE-X calculated flow rates, except during final tests, FEP-IV.
- 2.5.2.7 The GF-17 filter element collapsed during both FEP-III and FEP-IV pressurization tests.
- 2.5.2.8 CHV-1721 leaks with LH₂ downstream resulting in pressure build-up between CHV-681/685 and CHV-1721.
- 2.5.3 System Status
- 2.5.3.1 Modification of CHV-1721, to obtain reliable isolation capability between the gas and HP LH₂ cooldown system is as described in Section 2.3.3.3 to prevent injection of gas bubbles into the LH₂ cooldown fluid during HP LH₂ flow initiations.
- 2.5.3.2 CHV-458 has been equipped with bronze guides to eliminate its inconsistent behavior.
- 2.5.3.3 CHV-2302 internals have been removed to permit LH₂ backflow during engine operation.
- 2.5.3.4 The LH₂ system appears to have adequate response capability in MANUAL (position) control required to initiate HP LH₂ cooldown flow with PCV-472 initially closed, and the HP LH₂ system cooldown line downstream PCV-472/CHV-458 appears to have adequate LH₂ storage capability required for initial nozzle cooling.
- 2.5.3.5 V-5002 pressurization and venting valves do not have sufficient response capability in order to maintain the HP LH₂ dewar at pressures close to the engine nozzle torus inlet pressures that would be required if the HP LH₂ system were to be used for engine cooldown with PCV-472 initially open.

- 2.5.3.6 The current PCV-472 pressure controller response is not adequate to control LH₂ flow for engine cooldown following LH₂ flow initiation with PCV-472 initially full open with high dewar pressures.
- 2.5.3.7 GF-17 has been equipped with a sufficiently high pressure drop rated element to prevent element collapse.
- 2.5.3.8 Resolution of FE-12 flow measurement errors observed during FEP-IV tests are required.
- 2.6 LP LH₂ Propellant, Storage and Transfer Systems
- 2.6.1 System Changes
- None
- 2.6.2 System Performance
- 2.6.2.1 LH₂ topping flow rates up to 75 pps can be achieved for V-3801/V-5001 differential pressures up to 80 psid with a temperature rise of about 1°R.
- 2.6.2.2 A NPSP at the F/E interface of as high as 15 psi without topping, and as low as 2 psi with topping would be obtained for V-5001 pressure of 35 psia at 80 pps LH₂. These NPSP valves do not include the LH₂ head effects at F/E interface.
- 2.6.2.3 The pressure drop and temperature rise between V-5001 and F/E interface at 80 pps LH₂ was 6.3 psid and .5°R, respectively.
- 2.6.2.4 The FE-14 measured LH₂ flow rates gave good correlation with that calculated based on V-5001 level changes. FE-425 stuck at very low flow rates and at flow rates around 40 lbs/sec.

2.6.2.5 The V-5001 level instrumentation, except for the continuous capacitance Simmonds probe (LT-10) and the point capacitance indicators functioned properly. The temperature probes functioned correctly and can be used as level instrumentation under the conditions stated in Section 3.8.3.3.

2.6.3 System Status

2.6.3.1 The V-3801/V-5001 systems are basically adequate to support engine testing.

2.6.3.2 Modification of V-3801 vent line check valve is recommended in order to improve the NPSP at the F/E interface during subsequent V-5001 topping operations. A maximum NPSP gain of 8 psi is possible. FE-425 has been removed from the system which will increase the NPSP by about 1 psi.

2.6.3.3 Repair of the V-5001 continuous capacitance level gage and the point capacitance indicators are required.

2.6.3.4 Adjustment of the PCV-165/180 pressure controller is required to minimize dewar pressure oscillation during pressure changes.

3.0 TECHNICAL DISCUSSION

3.1 LP GN₂ SYSTEM

3.1.1 Description

The LP GN₂ system and associated instrumentation is shown in Figure 5.1. The LP GN₂ system consists of the three gas storage vessels V-3201, V-3202 and V-3203 and the LP GN₂ purge supply system.

3.1.1.1 GN₂ Storage Vessels

The GN₂ storage vessels V-3201, V-3202 and V-3203 each have a 1763 cubic foot water volume and a maximum rated operating pressure of 2500 psig.

3.1.1.2 LP GN₂ Purge Supply System

The LP GN₂ purge supply system is as shown in the aforementioned Figure. The significant components of the system tested through the cooldown line during FEP-I, are the pressure regulating valve (PRV-107), the orifice plate flowmeter (FE-50), the flow control valve (FCV-50), CHV-496, and CHV-1721.

The pressure regulating valve, PRV-107, is a 4-inch dome loaded Vacco valve with a vendor quoted Cv of 125. It has an inlet pressure range of 600 to 3000 psig and an outlet range of 0-500 psig.

Flowmeter, FE-50, is a 1/8" thick, stainless steel, square edged orifice plate with an orifice diameter of 3.804 inches.

The FE-50 GN₂ flow rate is calculated from the equation;

$$\dot{W} = .351 (P_1 \Delta P)^{\frac{1}{2}} F(T)/F(P),$$
 where P_1 is the inlet pressure (PT-191) in psia, ΔP is the differential pressure (PT-584) in psid, $F(T)$ is the temperature correction factor $(F(T) = (\frac{530}{TT-54})^{\frac{1}{2}})$, and $F(P)$ is the compressibility correction factor $(F(P) = Z^{\frac{1}{2}})$.

The on-line computed flow rate, FT-50, was originally calculated from the equation; $\dot{W} = 7.99 (\Delta P)^{\frac{1}{2}}$ where a constant inlet pressure and temperature of 500 psig and 530°R was assumed. However, after FEP-1, the on-line computed flow equation was changed to

3.1.1.2 LP GN₂ Purge Supply System (Cont'd)

$W = .352 (P_1 \Delta P)^{\frac{1}{2}}$ because of the inability of PRV-107 to maintain the downstream pressure at 500 psig.

The flow control valve, FCV-50, is a 4-inch Annin valve with a vendor quoted Cv of 110.

CHV-496 and CHV-1721 are 6-inch security "Y" pattern, lift-type check valves with a vendor quoted Cv of 580. The modifications made to CHV-1721 are discussed in Section 3.4.1.2.

3.1.2 Performance Objectives

The low pressure GN₂ system performance objectives accomplished during the FEP test series were to:

- 1.0 Determine the steady-state flow and pressure characteristics of the low pressure GN₂ system.
- 2.0 Determine the frequency response characteristics of the low pressure GN₂ system.
- 3.0 To evaluate the adequacy of the low pressure GN₂ flow control in both position (MANUAL) and flow rate (AUTOMATIC) control modes.

3.1.3 Test Results

3.1.3.1 System Steady State Characteristics

The performance of the LP GN₂ purge supply line system has been evaluated for steady state characteristics. Figure 3.1.1 shows selected system pressures downstream of PRV-107 as a function of GN₂ flow rate based on FE-X venturi parameters.

Figure 3.1.2 shows the GN₂ flow rate as a function of required and available FE-50 inlet pressure (PT-191) for PRV-107 dome set at 500 psig and a nominal GN₂ header pressure of 1700 psig. It is to be noted that PRV-107 was unable to maintain a downstream pressure of 500 psig for GN₂ flow rates greater than

FIGURE 3.1.1

○ - FEP-I Data

FE-X FLOW RATE ~ lbs/sec

FIGURE 3.1.2

⊙ - FEP-I Data

FE-X Flow Rate Vs FE-50 Inlet Pressure

3.1.3.1 System Steady State Characteristics (Cont'd)

3 lbs/sec. The intersection of the required and available FE-50 inlet pressure indicates that a maximum flow rate of 18.6 lbs/sec GN_2 is attainable at a FE-50 inlet pressure of 255 psig.

Figure 3.1.3 shows the GN_2 flow rate as a function of FCV-50 position for PRV-107 dome pressure set at 500 psig. This indicates that GN_2 flow rate is linear with FCV-50 position. The GN_2 flow rate to FCV-50 position ratio is approximately 0.18 lbs/sec GN_2 per percent opening.

Figure 3.1.4 compares the GN_2 flow rate calculated from the measured FE-X venturi parameters with that calculated from measured FE-50 orifice parameters. The equations used for FE-X and FE-50 flow rate calculations are given in Section 3.9.1 and 3.1.1.2, respectively. As shown in Figure 3.1.4, good correlation was obtained between the post-test calculated FE-50 and FE-X GN_2 flow rates at the highest flow rate achieved, but deviates at the lower flow rate. It should be noted, however, that at the lower flow rate, i.e., 9 pps GN_2 , FE-X was not sonic and the FE-50 differential pressure was only 2% of the transducer range. Since a constant FE-50 inlet pressure of 500 psig was used for the on-line computed flow, FT-50 did not provide correct flow rates when the FE-50 inlet pressure deviated from 500 psig. It was determined, however, that the FT-50 on-line computer would have given good correlation with post-test calculated FE-50 flow rates if the change in FE-50 inlet pressure had been incorporated in the flow computer. As discussed in Section 3.1.1.2, this change to FT-50 has been made.

3.1.3.2 Frequency Response Characteristics

Figure 3.1.5 shows the transfer function between FCV-50 position and PCV-750 inlet pressure based on step response data obtained during FEP-I in MANUAL control and processed by the WANL digital step response code.

GN₂ FLOW RATE ~ lbs/sec

20

10

0 10 20 30 40 50 60 70 80 90 100

FCV-50 PERCENT OPEN

PRV-107 DOME PRESSURE = 500 PSIG

FIGURE 3.1.3

GN₂ Flow Rate Vs FCV-50 Percent Open

⊙ - FEP-I Data

FE-50 CALCULATED FLOW RATE ~ lbs/sec

FE-X FLOW RATE ~ lbs/sec

Figure 3.1.4

○ - FEP-I Data

FE-50 Calculated Flow Rate
Vs FE-X Flow Rate

3.1.3.3 Auto (Flow Rate) Control

Although adequate GN₂ flow control was obtained in MANUAL (position) control, attempts to operate in AUTO control during FEP-I showed that the AUTOMATIC control loop as designed was not adequate.

Since AUTOMATIC control of the low pressure GN₂ purge system was not deemed required following FEP-I, no further efforts have been expended on correcting this mode of control.

3.2 LN₂ SYSTEM

3.2.1 Description

The LN₂ system and associated instrumentation is shown in Figure 5.1. The LN₂ system consists of the LN₂ storage dewar (V-3601), the LN₂ dewar pressurization system, and the LN₂ coolant supply line system.

3.2.1.1 LN₂ Storage Dewar

The LN₂ storage dewar has a 250 psig maximum working pressure and a capacity of 28,000 gallons of LN₂ with a 10% ullage.

3.2.1.2 LN₂ Storage Dewar Pressurization System

The LN₂ storage dewar pressurization system is as shown in the aforementioned Figure. The original pressurization system from PRV-108 to V-3601 was replaced between FEP-IA and FEP-IB because the GN₂ flow through the original system was not adequate to keep the dewar pressurized at high LN₂ flow rates. A 2-inch line has replaced the 1-inch line and the original 1-inch block valve, RSV-325 has been replaced by a 2-inch valve. The original Apco regulator has also been replaced by a Grove regulator because the Grove regulator is considered more reliable.

3.2.1.2 LN₂ Storage Dewar Pressurization System (Cont'd)

The pressure reducing valve, PRV-108, is the main component of this system. It is a 1-inch Grove servo-dome type valve having an inlet pressure range of 0-3500 psig and a vendor quoted Cv of 12.

3.2.1.3 LN₂ Coolant Supply Line

The LN₂ coolant supply line system is as shown in the aforementioned Figure. The significant components in the system are the turbine flowmeter, (FE-52) the pressure control valve (PCV-517), and CHV-1885.

Flowmeter, FE-52, is a three-inch turbine meter, manufactured by Potter Aeronautical Co., having a flow range from 30 to 650 gpm. Water calibration data from the vendor indicates that the K factor is 47.78 cycles/gal. At a LN₂ density of 48.75 lb/ft³, the K factor is 7.33 cycles/lb which is used for the on-line computed flow rates.

The stem of pressure control valve, PCV-517; which was a 3-inch, 50 in² pneumatically actuated, Security "Y" pattern valve (C_v = 220), froze during the operation of FEP-I and IB due to incorrect packing clearance. It was not possible to properly seal off leakage from the valve making it necessary to replace the original PCV-517 with modified FCV-52 which was originally intended for use at the mixing station. This valve is a 3-inch Annin "S" pattern valve with a vendor quoted Cv of 110 and a 100 in² actuator. It has an equal percentage plug and was initially installed with flow over the plug. However, prior to the LN₂ checkout of V-5001 (FEP-III-2 LN₂ checkout), the valve body was re-installed such that flow would be under the plug in a fail safe (open) condition.

CHV-1885 is a 4-inch Security "Y" pattern lift-type check valve with a vendor quoted Cv of 260. This check valve is located in the 225 LN 4 line downstream RSV-545. Due to its demonstrated

3.2.1.3 LN₂ Coolant Supply Line (Cont'd)

inability to properly check back pressure, it was disassembled and modified on 29 November 1966 following FEP-IC. The modification performed on that date consisted of machining the I. D. of the guide out by 0.010" and installing a spring spacer to increase the pre-load.

3.2.2 Performance Objectives

The LN₂ system performance objectives accomplished during the FEP test series were:

- 1.0 Determine the initial chilldown and chill maintenance characteristics of the LN₂ coolant supply line system.
- 2.0 Determine the steady-state flow, pressure, and temperature characteristics of the LN₂ system.
- 3.0 Determine the LN₂ system transient response characteristics during LN₂ flow initiation.
- 4.0 Determine the pressurization characteristics of the LN₂ dewar.

3.2.3 Test Results

3.2.3.1 LN₂ Dewar Pressurization System

The performance of the LN₂ dewar (V-3601) pressurization system was evaluated for the following conditions: (a) initial pressurization and (b) pressurization during LN₂ outflow.

3.2.3.1.1 Initial Pressurization

Figure 3.2.1 shows the PRV-108 dome pressure (PT-585), the pressure immediately downstream of PRV-108 (PT-197), and the V-3601 pressure (PT-181) as a function of time for a typical V-3601 initial pressurization. The time required to pressurize the V-3601 dewar to 237 psig with an ullage of 20-22% and a

Figure 3.2.1

3.2.3.1.1 Initial Pressurization (Cont'd)

PRV-108 dome pressure of 400 psig was approximately 6.6 minutes. The calculated collapse factor for the initial pressurization was about 2.5.

A PRV-108 dome pressure of 304 psig is sufficient to maintain a constant dewar pressure of 239 psig during LN₂ outflow as discussed in Section 3.2.3.1.2. The initial pressurization could therefore be made with a dome pressure of 300 psig but would require a longer pressurization time.

3.2.3.1.2 Pressurization During LN₂ Outflow

During a LN₂ flow rate of 73 to 77 lbs/sec out of V-3601, the pressurization system maintained the dewar pressure (PT-181) at an essentially constant pressure of 239 psig with the PRV-108 dome pressure set at a constant 304 psig and an initial dewar ullage of 40%. Therefore, the pressurization system is adequate to maintain the desired dewar pressure during LN₂ outflow with no further adjustment of the dome pressure.

3.2.3.2 LN₂ Cooldown Supply Line System

The performance of the LN₂ cooldown supply line system was evaluated under the following conditions: (a) initial system chilldown and chillholding, (b) flow initiation transient, and (c) steady-state during LN₂ outflow.

3.2.3.2.1 Initial Chilldown and Chillholding Characteristics

The line 2-LN-4 from V-3601 to 50-PCV-517 was chilled down during the pressurization of V-3601 to eliminate the water hammer effects produced when RSV-326 is opened with high V-3601 pressures. The line chilldown time is approximately 200 seconds longer than the pressurization time of V-3601. Figure 3.2.2 shows the line temperature (TT-55) and V-3601 pressure (PT-181) as a function of time during initial chilldown.

RANGE TIME (SECONDS)
TIME ZERO = 80787.9

Chiltdown Characteristics
of LN₂ Line From V-3601 to
PCV-517

FIGURE 3.2.2

3.2.3.2.1 Initial Chillover and Chillover Characteristics (Cont'd)

The initial chillover of the 225-LN-4 line from PCV-517 to RSV-545 as a function of time is shown in Figure 3.2.3. The line requires approximately 260 seconds to chill down to the saturated vapor point with V-3601 dewar at 245 psig. An additional 80 seconds is required to obtain saturated liquid at RSV-545 inlet.

Chillover tests were conducted after the LN₂ temperature at TT-510 stabilized at approximately 158°R. Under no flow conditions, TT-55 and TT-510 increased at 1.1°R/min and 3.1°R/min, respectively, over a period of 300 seconds. The system was then hard chilled to 142°R and 144°R at TT-55 and TT-510, respectively, by flowing approximately 4100 lbs of LN₂ at about 8 lbs/sec. The LN₂ flow was then reduced to 1 lb/sec for about 400 seconds and TT-55 and TT-510 increased by 0.17°R/min and 0.45°R/min, respectively. When TT-510 indicated 147°R the LN₂ flow was increased to 8.5 lbs/sec for 250 seconds, i.e., 2125 lbs of LN₂ which decreased TT-55 and TT-510 by 2°R.

A second no-flow chillover test was then conducted for a period of 700 seconds. TT-55 and TT-510 increased 0.66°R/min and 0.83°R/min, respectively, which is considerably less than the first test indicating that the line was not adequately chilled during the first no-flow test. RSV-717 was then opened for 250 seconds allowing 1900 lbs of LN₂ to flow which reduced TT-55 and TT-510 by 8°R and 11°R, respectively, to their minimum temperatures.

Therefore, at a nominal flow rate of 1 lb/sec, TT-510 will increase by approximately 9°R over a period of 18 minutes and require approximately 1100 lbs of LN₂. While under no-flow conditions, TT-510 increases 15°R (i.e., 145°R to 160°R) in 18 minutes and requires approximately 2600 lbs of LN₂ to reduce TT-510 to 145°R. Since the line storage between V-3601 and RSV-545 is also 2600 lbs, it is necessary to change out this volume before an appreciable temperature drop will occur.

10X10 TO THE CM 35314
AFIPRI 08730W M. SING A

FIGURE 3.2.3

FIGURE 3.2.4

Pressure Differential Vs LN₂ Flow Rate

3.2.3.2.2 Steady-State Characteristics

The LN₂ cooldown system steady-state characteristics were determined from data obtained from steady-state LN₂ flow tests performed during the FEP test series.

Figure 3.2.4 shows the pressure drop between V-3801 (PT-181) and FE-52 flowmeter inlet (PT-194), RSV-545 inlet (PT-580) and FE-X inlet (PT-770), and between FE-X inlet (PT-770) and PCV-750 inlet (PT-774) as a function of LN₂ flow rate. Except for the LN₂ cooldown line between RSV-545 and FE-X, the line pressure drop characteristics based on FEP-I and FEP-III-2 test data are consistent. Figure 3.2.4 shows that the pressure drop between RSV-545 and FE-X was significantly different between FEP-I, IV, and III-2. This difference was due primarily to the modification performed on CHV-1885 after FEP-IC as discussed in Section 3.2.1.3. CHV-1885 was disassembled and inspected on 5 May 1967 (after FEP-III-2). This inspection indicated that the 7/8" spacer installed in the valve reduced the full travel of the plug from 7/8" to 1/8". It is presently planned to reassemble CHV-1885 without the 7/8" spacer and to install a new spring with sufficient pre-load to eliminate the back leakage experienced during FEP-I.

Figure 3.2.5 shows the Cv of PCV-517 as a function of PCV-517 position for both flow over (FEP-IC) and flow under the plug (FEP-III-2 LN₂ checkout). The Cv values given in Figure 3.2.5 are based on the equation: $W = 0.0176 C_v \sqrt{\Delta P_v \rho}$ where the valve pressure drop (ΔP_v) has been corrected for the line pressure drop between transducers PT-194 and PT-580. The Cv of PCV-517 at 100% open is approximately 145. The test data indicates that the PCV-517 pressure drop characteristics were not significantly affected by reversing the valve.

Figure 3.2.6 shows the LN₂ system (V-3601 to FE-X inlet) impedance factor ($K = \frac{W}{\sqrt{\Delta P_s}}$) as a function of PCV-517 position. The difference in system impedance between FEP-IC and FEP-III-2 above PCV-517 positions of 60% is due to the performance of CHV-1885 as

PCV-517 C_v Vs PCV-517 Position

FIGURE 3.2.5

- △-△- FEP-IC
- LN₂ Checkout of V-5001
- FEP-III-2

$\frac{W}{\sqrt{\Delta P_s}}$
 $W = \text{FT-52}$
 $\Delta P_s = \text{PT-181} - \text{PT-770}$
 corrected for elevation head

PCV-517 Position

$\frac{W}{\sqrt{\Delta P_s}}$ Versus PCV-517 Position

—▲— FEP-IC
 —●— LN Checkout of V-5001 FEP-III-2

FIGURE 3.2.6

3.2.3.2.2 Steady-State Characteristics (Cont'd)

discussed previously. It is to be noted that PCV-517 does not have a significant effect on system impedance above 80%.

Figure 3.2.7 shows the facility tee pressure and the required V-3601 dewar pressure (PT-181) for PCV-517 full open as a function of LN_2 flow rate. The pressure at the facility tee is that given in Reference A for an engine chamber temperature of 1200°R . The pressure drop between V-3601 and the facility tee is based on both FEP-IC and FEP-III-2 data shown in Figure 3.2.6. It is to be noted that the maximum steady-state LN_2 flow obtainable from the LN_2 flow system with an engine chamber temperature of 1200°R is 85 pps based on FEP-IC test data.

Figure 3.2.8 shows the on-line computed LN_2 flow rate (FT-52) versus the LN_2 flow rate based on measured FE-X parameters. The excellent agreement between FT-52 and FE-X flow rates shown in Figure 3.2.8 indicates that FT-52 can be used with confidence to determine LN_2 flow rates during engine cooldown operations.

3.2.3.2.3 Transient Characteristics

LN_2 system transient characteristics following LN_2 flow initiation were determined during the FEP test series with different initial conditions. LN_2 flow initiation tests were performed with the pressure downstream CHV-1885 both initially greater and less than the LN_2 supply line pressure. The V-3601 dewar was pressurized to a nominal 250 psig and a hard chill established in the LN_2 supply line downstream to RSV-545 prior to all tests.

Figure 3.2.9 shows the transient behavior of selected LN_2 cooldown system and engine flow simulator valve positions, pressures, flow, and temperatures after the opening of RSV-545. This test, performed during FEP-IC after replacement of PCV-517 but before modification of CHV-1885, is typical of the three LN_2 flow initiation tests performed. Prior to the opening of RSV-545; the pressure downstream of CHV-1885 was atmospheric, PCV-750 was pre-set at 89%

Dewar Pressure Versus LN_2 Flow Rate

FIGURE 3.2.7

FIGURE 3.2.8

Valve Positions, Pressures, Temperatures, and Flow Rate Vs Time
For LH₂ System Transient Performance, FEP-I

3.2.3.2.3 Transient Characteristics (Cont'd)

in order to simulate engine gas impedance, and PCV-517 was pre-set at 75% in MANUAL control in order to limit the initial LN₂ flow to less than full scale on FT-52 (i.e., 100 pps). PCV-750 was closed from the engine gas impedance setting of 89% to 60% when the inlet temperature reached 150°R in order to simulate the engine liquid nitrogen impedance for a chamber temperature of 1200°R. During this period PCV-517 was being opened in MANUAL control in a manner to maintain FT-52 on scale. After LN₂ conditions were obtained at PCV-750 the LN₂ flow rate stabilized at 77 pps with PCV-517 at 91% and V-3601 at 245 psig.

Figure 3.2.9 shows that gas flow conditions (i.e., above 200°R) existed at the inlet to PCV-750 for approximately four (4) seconds after RSV-545 opened. Since PCV-750 simulated the expected engine impedance throughout this time, it is believed that the transient characteristics during this interval are typical of that expected with the actual engine. As shown in Figure 3.2.9, the LN₂ flow rate peaked at 98 pps approximately one second after RSV-545 opened which resulted in a rapid increase in the LN₂ supply line pressure drop (PT-181 to PT-580) from 0 to 210 psid. The momentary decrease in LN₂ flow from 98 pps to 85 pps is attributed to the momentary closure of PCV-517 from 75 to 72%. This response of PCV-517 to a rapid change in pressure loading is typical of pneumatic actuated valves with flow over the plug. Since PCV-517 is currently installed with flow under the plug, it is expected that PCV-517 will open slightly under similar LN₂ flow initiation conditions.

During this test, CHV-2302 leaked resulting in the rise in PT-103 pressure as shown in Figure 3.2.9, and a decrease in CHV-2302 upstream temperature to 185°R. Due to this leakage, a bubble of warm fluid appeared at FE-X and PCV-750 during reduction in LN₂ flow.

Figure 3.2.10 shows the transient behavior of selected LN₂ cool-down system and engine flow simulator valve positions, pressures, flows and temperatures during the switch from GHe to LN₂ performed during FEP-IV. This test was performed after modification of CHV-1885 which increased its impedances as discussed in Section

FIGURE 3.2.10 Valve Positions, Pressures, Temperatures and Flow Rates Vs Control Room Time
During GHe to LM₂ Switching Test, FEP-IV

3.2.3.2.3 Transient Characteristics (Cont'd)

3.2.3.2.2. Prior the opening of RSV-545, the pressure downstream of CHV-1885 was greater than the LN_2 supply line pressure, PCV-750 was set at 61.5% in order to simulate the engine liquid nitrogen impedance, and PCV-517 was set essentially full open at 89%. As shown in Figure 3.2.10, damped oscillations having a frequency of 0.8 cps occurred in the LN_2 system pressures when RSV-545 was opened against closed CHV-1885. CHV-1885 opened resulting in initiation of LN_2 flow to the engine simulator line when the CHV-1885 downstream pressure (PT-770) was reduced to 200 psig during the closure of the GHe supply valve, PCV-471. The oscillations in the LN_2 supply line pressures stopped when CHV-1885 opened, and did not affect the conditions downstream of CHV-1885. CHV-1885 prevented back flow into the LN_2 system during this test following opening of RSV-545 as shown by the behavior of FT-52 and TT-511. The modification performed on CHV-1885 between FEP-I and FEP-IV as discussed in Section 3.2.1.3 was therefore adequate to prevent reverse LN_2 flow conditions. Back leakage through CHV-1885 occurred during a similar test performed during FEP-I, resulting in reverse LN_2 flow.

Figure 3.2.10 also shows that the CHV-2302 upstream temperature TT-474 decreased from 400°R during GHe flow to 100°R after closure of PCV-471 indicating boiloff of the LN_2 remaining in the 4-LH-6 line between PCV-472 and the gas line interface.

During this test, the LN_2 flow, FT-52, increased following the closure of PCV-471 and stabilized at 72 pps with PCV-517 set at 89%. The initial LN_2 flow over-shoot observed during the FEP-I Test (Figure 3.2.9) was not observed during the FEP-IV Test (Figure 3.2.10). This difference is due to the higher impedance characteristics of CHV-1885 and the lower initial setting of PCV-750.

Figure 3.2.11 shows a cross plot of temperature versus pressure at the inlet to FE-X and PCV-750 for both the FEP-I and FEP-IV Tests. The time after initiation of LN_2 flow when saturated

FIGURE 3.2.11

FEP-X And PCV-750 Inlet
Pressure Vs Temperature

NOTES:

- 1) ○ FEP-IV - Run 8
- FEP-I - Run 3

3.2.3.2.3 Transient Characteristics (Cont'd)

vapor and liquid conditions were achieved at FE-X and PCV-750 are shown. The integral FT-52 flow required to achieve LN₂ conditions at FE-X and PCV-750 for both FEP-I and FEP-IV indicates that for both tests approximately 300 lbs and 1200 lbs LN₂ are required to achieve LN₂ conditions at FE-X and PCV-750, respectively.

3.3 HP GHe SYSTEM

3.3.1 Description

The HP GHe system and associated instrumentation is shown in Figure 5.1. The HP GHe system consists of the three gas storage vessels V-3204, V-3205, and V-3206 and the HP GHe cooldown supply line system.

3.3.1.1 GHe Storage Vessels

Each of the GHe storage vessels V-3204, V-3205, and V-3206 has an average water volume of 1766 cubic feet and a maximum rated operating pressure of 2500 psig.

3.3.1.2 HP GHe Cooldown Supply Line System

The HP GHe cooldown supply line system is shown in the aforementioned Figure. The significant components of the system are the flow tube flowmeter (FE-415), the pressure control valve (PCV-471), CHV-685, and CHV-1721.

Flowmeter, FE-415, is a 6-inch, Hammel-Dahl impact-type headmeter flow tube. The FE-415 GHe flow rate is calculated from the equation:

$$\overset{0}{W} = 0.271 (P_1 \Delta P)^{\frac{1}{2}} F(T)/F(P)$$

where P_1 is the inlet pressure (PT-586) in psia, ΔP is the differential pressure (PT-777) in psid, $F(T)$ is the temperature correction factor $(F(T) = (\frac{530}{TT-528})^{\frac{1}{2}})$, and $F(P)$ is the compressibility correction factor $(F(P) = Z^{\frac{1}{2}})$. The on-line computed GHe

3.3.1.2 HP GHe Cooldown Supply Line System (Cont'd)

flow rate, FT-415, is calculated from the equation:

$$\dot{W} = .259 (P_1 \Delta P)^{\frac{1}{2}}$$

which assumes an inlet temperature of 530°R and a GHe compressibility factor (Z) at 2500 psig.

The pressure control valve, PCV-471, is a 6-inch, 113 in², 150 psi pneumatically actuated, Y-type balanced Flowmatics globe valve with a vendor quoted C_v of 290. The valve response during FEP-II was 50%/sec with a 1 second opening delay which would not satisfy engine cooldown requirements. Therefore, before FEP-IV, the pneumatic actuator was replaced with a 3.14 in², 2700 psi hydraulic actuator. The AUTO (pressure) controller was also modified in conjunction with the change in PCV-471 actuation.

CHV-685 and CHV-1721 are 6-inch Security "Y" pattern, lift-type check valves with a vendor quoted C_v of 580. Due to observations of back leakage during FEP-II, CHV-685 was disassembled on 24 October 1966. Upon disassembly, it was found that the shaft was galled approximately 1 1/2". The shaft, seat, and seals were replaced. Due to observation of back leakage during FEP-III, CHV-685 was disassembled on 30 November 1966. The stainless steel guides were replaced with glass impregnated teflon, and a spring spacer installed to increase the pre-load. CHV-1721 has been modified as described in Section 3.4.1.2.

3.3.2 Performance Objectives

The HP GHe cooldown system performance objectives accomplished during the FEP test series were:

- 1.0 Determine the steady-state flow and pressure characteristics of the HP GHe cooldown system.
- 2.0 Determine the blowdown characteristics of the GHe storage vessels.

3.3.2 Performance Objectives (Cont'd)

- 3.0 Determine the transient response characteristics of the HP GHe cooldown system in AUTO (pressure) control during switching between LH₂ and GHe flow.
- 4.0 Evaluate the adequacy of the HP GHe cooldown flow control in both MANUAL (position) and AUTO (pressure) control.

3.3.3 Test Results

3.3.3.1 System Steady-State Characteristics

Figure 3.3.1 shows selected steady-state system pressures as a function of GHe flow rate based on FE-X venturi parameters and with flow out of storage vessel V-3206. All system pressures have been normalized to a reference gas temperature of 530°R. The storage vessel outlet (PT-016), header (PT-005), and FE-415 inlet (PT-586) pressures are given for PCV-471 at essentially 100% open position. It should be noted that due to the FE-X venturi installed in the flow simulator, the pressure expected at the facility tee, located downstream of LF-7, with the engine installed is lower than that obtained during the FEP test series. Figure 3.3.1 shows the facility tee pressure as a function of GHe flow rate expected with the engine installed (Reference A). As shown, the pressure at the inlet to the FE-X venturi (PT-770) was 5% higher than that expected with the actual engine installed.

Figures 3.3.2, 3.3.3 and 3.3.4 show, respectively, the differential pressure; between the header (PT-005) and FE-415 inlet (PT-586), between the GHe storage vessel outlet and the header (PT-005) for the single storage vessels (V-3205 or V-3206) and all three storage vessels (V-3204, 5, 6) on-line, and between the GHe storage vessel outlet and FE-415 inlet (PT-586) for the single storage vessels (V-3204 or V-3206) and all three storage vessels (V-3204, 5, and 6) on-line as a function of GHe flow rate. These pressure drops have been normalized to a reference vessel pressure of 1500 psig and fluid temperature of 530°R. It is to be noted that the pressure drop between the storage vessel and the header (PT-005) at a given

FIGURE 3.3.1

Pressure Vs GHe Flow Rate

FIGURE 3.3.3

Differential Pressure Vs GHe Flow Rate

Differential Pressure Vs GHe Flow Rate

Differential Pressure, ΔP , psid

- Δ - ΔP , PT-016 to PT-586
Vessel 3206, FEP-II
- $\odot$ - ΔP , PT-10 to PT-586
Vessel 3204, FEP-IV
- $\square$ - ΔP , Vessel Discharge
to PT-586, 3 Vessels
FEP-IV

FIGURE 3.3.4

NOTES:

- 1) All Data Temperature
Corrected ($T_c = 530^\circ R$)
- 2) All Data Vessel Pressure
Corrected ($P_c = 1500$ psig)

GHe Flow Rate, Lbs/Sec

3.3.3.1 System Steady-State Characteristics (Cont'd)

total GHe flow from three storage vessels is 0.306 of that for storage vessel V-3206 alone.

Figures 3.3.5 and 3.3.6 compare the system pressure drops downstream of PCV-471 based on FEP-II and FEP-IV test data. The pressure drop data shown in Figures 3.3.5 and 3.3.6 have been normalized to a fluid temperature of 530°R. It is to be noted that the pressure transducer PT-814 was not installed for FEP-II. Although good agreement is obtained for the pressure drop between PT-103 and PT-770 (Curve No. 2, Figure 3.3.5) the characteristic pressure drop between PT-473 and PT-103 (Curve No. 1, Figure 3.3.5) is significantly different. The major components between PT-473 and PT-103 are CHV-685, RSV-78, RSV-454/460 and CHV-1721. The pressure drop characteristic between PT-814 and PT-103 (Curve No. 2), and between PT-473 and PT-814 (Curve No. 1) based on FEP-IV test data are shown in Figure 3.3.6. The pressure drop characteristic across CHV-1721, i.e., PT-814 to PT-103 appears to be in agreement with what is expected; however, it is felt that the valve is not functioning correctly (refer to Sec. 3.4.3.1). The pressure drop characteristic across CHV-685, i.e., PT-473 to PT-814 is in accordance with what is generally expected.

As discussed in Section 3.4.1.2, CHV-1721 was modified between FEP-II and FEP-IV. It is believed that the difference between FEP-II and FEP-IV test data between PT-475 and PT-103 is due to the performance of CHV-1721 after modification.

Figure 3.3.7 compares the GHe flow rate calculated from the measured FE-X venturi parameters with that calculated from the measured FE-415 Dahl tube parameters. The calculated GHe flow rates were based on the equation for FE-415 and FE-X given in Section 3.3.1.2 and 3.9.1, respectively. The good correlation between the post-test calculated FE-415 and FE-X GHe flow rates shown in Figure 3.3.7 indicates that FE-415 can be used with confidence to determine GHe flow rates during engine testing.

Differential Pressure Vs GHe Flow Rate

FIGURE 3.3.5

FIGURE 3.3.6

Differential Pressure Vs GHe Flow Rate

FE-X GHe FLOW RATE - lbs/sec

FE-415 GHe CALCULATED FLOW RATE - lbs/sec

FE-X FLOW RATE VERSUS FE-415 FLOW RATE FOR FEP-IIB

FIGURE 3.3.7

3.3.3.1 System Steady-State Characteristics (Cont'd)

Figure 3.3.8 compares the GHe flow rate calculated from measured FE-415 Dahl tube parameters with that determined by the on-line FT-415 flow rate computer. It is to be noted that good correlation exists at the higher flow rates (40 lbs/sec); but deviates at low flow rates such that FT-415 would indicate -2.5 lbs/sec GHe at zero flow based on FE-415, which, as shown previously, agrees with FE-X. The difference between FE-415 and FT-415 flow rates is attributed to an incorrect zeroing of the FT-415. A 0.38 psid adjustment error in FT-415 would account for the flow rate difference shown in Figure 3.3.8.

Figure 3.3.9 shows the C_v^* versus stem position characteristic. The valve C_v^* of PCV-471 at any given valve position was based on the following equation:

$$C_v^* = \frac{\overset{\circ}{W}}{0.0176 \sqrt{\rho_2 (P_1 - P_2)}} \quad P_2 > 0.5P_1$$

or

$$C_v^* = \frac{\overset{\circ}{W}}{0.0088 \sqrt{\rho_1 P_1}} \quad P_2 \leq 0.5P_1$$

Where: P_1 = PCV-471 upstream pressure, psia
 P_2 = PCV-472 downstream pressure, psia
 ρ_1 = Upstream GHe density, lb/ft³
 ρ_2 = Downstream GHe density, lb/ft³
 $\overset{\circ}{W}$ = GHe flow rate; lb/sec

The PCV-471 upstream and downstream pressures have not been corrected for the theoretical line pressure drop between PT-586 and PCV-471 inlet; and between PCV-471 outlet and PT-473.

As shown in Figure 3.3.9, the valve exhibits a linear characteristic between 10 and 100% open and has a maximum C_v^* of 240.

FE-415 GHe CALCULATED FLOW RATE - lbs/sec

FT-415 GHe MEASURED FLOW RATE - lbs/sec

FE-415 CALCULATED VERSUS MEASURED FLOW RATES
FOR FEP-IIB

FIGURE 3.3.8

C_v^* Vs Valve Position for PCV-471

FIGURE 3.3.9

3.3.3.2 Vessel Blowdown Characteristics

Figure 3.3.10 shows the storage vessel fluid temperature ratio, i.e., $T(t)/T(0)$, versus storage vessel fluid pressure ratio, i.e., $P(t)/P(0)$, during blowdown of the three GHe storage vessels V-3204, 5, and 6. The theoretical adiabatic (isentropic) expansion characteristic is also shown for comparison. Although a lag in fluid temperature decrease appears to exist, the blowdown process is in close agreement with an ideal isentropic expansion down to a pressure ratio of 0.85.

3.3.3.3 Transient Characteristics During GHe Flow Initiation

Figure 3.3.11 shows the transient response of PCV-750, PCV-471, and selected system pressures for one second following initiation of GHe flow with PCV-471 in AUTO (pressure) control and LH₂ locked up at 835 psig between PCV-472, CHV-1721, and PCV-750. It is to be noted that CHV-1721 leaked prior to the initiation of GHe flow, so that the 4.55 ft³ volume between CHV-1721 and CHV-681/685 (PT-814) was at the LH₂ line pressure. The test was initiated, PCV-750 was stepped to 62%, and PCV-471 simultaneously switched to AUTO (pressure) control with a 965 psig demand. It is to be noted that PCV-750 inlet pressure (PT-774), which was used as the PCV-471 pressure feedback signal, dropped to 615 psig in 160 milliseconds, reached its demand of 965 psig in 200 milliseconds, overshoot its demand to 1185 psig in 250 milliseconds, and returned to its demand in 360 milliseconds following the switch of PCV-471 to AUTO. The initial pressure undershoot, therefore, was 0.74 times the initial pressure; and overshoot was 1.22 times the demand. The time required to pressurize the gas line segment between PCV-471 and CHV-681/685 (PT-473) to 700 psi was 160 milliseconds with an initial header pressure of 1950 psig. Approximately 3 times as long would have been required if CHV-1721 had not leaked, however.

PCV-472 opened to 70% at a maximum rate of 585%/sec, and an average rate of 390%/sec. The valve delay was about 10 milliseconds. The valve closed at a maximum rate of 630%/sec.

T* VERSUS P* FOR THREE VESSEL BLOWDOWN

FIGURE 3.3.10

Valve Positions, Pressures, Temperatures, and Flow Rates
Vs Time During LH₂ To GHe Switching Test, FEP-IV

FIGURE 3.3.11

3.3.3.3 Transient Characteristics During GHe Flow Initiation (Cont'd)

It should be noted that LH_2 was being expelled through PCV-750 over the time interval shown in Figure 3.3.11. The LH_2/GHe interface reached FE-X and PCV-750 in about 0.3 seconds and 1.3 seconds after PCV-471 was switched to AUTO.

Figure 3.3.12 shows the transient behavior of PCV-750, PCV-471, and selected system pressures following initiation of GHe flow with PCV-471 in AUTO (pressure) control with LH_2 downstream CHV-1721. A HP LH_2 flow of 12 pps was established with PCV-472 in pressure control at 40 psig with a V-5002 dewar pressure of 105 psig. No pressure existed at PT-473 but CHV-1721 leakage allowed P-814 to reach the initial cooldown line pressure of 40 psig. For this test PCV-471 was switched to AUTO (pressure) control with a nominal 400 psig demand. It is to be noted for this test that PCV-750 inlet pressure overshoot its demand to 720 psig in about 200 milliseconds after PCV-471 was switched to AUTO. The initial pressure overshoot, therefore, was 1.72 times the demand. The maximum opening rate of PCV-471 during this test was 500%/sec.

As shown in Figure 3.3.12, PCV-750 was stepped to the engine gas impedance position of 89% approximately 200 milliseconds before the LH_2/GHe interface reached PCV-750. It is to be noted that PT-774 dropped from 400 psig to 340 psig in 50 milliseconds, and returned to 375 psig in 30 milliseconds. There was no significant effect when the LH_2/GHe interface reached PCV-750.

3.3.3.4 Cooldown Line Warmup Characteristics

Figure 3.3.13 shows the behavior of fluid temperatures in the cooldown line downstream CHV-1721 during expulsion of LH_2 and warmup of the cooldown line with gaseous helium through PCV-471. The cooldown line between CHV-1712, PCV-472, and PCV-750 was chilled down and filled with LH_2 prior to the initiation of GHe flow. During the complete GHe flow interval, the initial LH_2 between

Valve Position, Temperature and Pressure Vs Time
During LH₂ to GHe Switching Test

FIGURE 3.3.12

FIGURE 3.3.13
Temperature And Flow Rate Vs. Time For LH₂
To GHe Switching Test

3.3.3.4 Cooldown Line Warmup Characteristics (Cont'd)

PCV-472 and the LH_2 /gas cooldown line interface downstream CHV-1721 was not purged out through RSV-456/457. This residual LH_2 had a significant affect on the cooldown line fluid temperature during the initial portion of the GHe warmup phase.

As shown in Figure 3.3.13, the trapped LH_2 boiled off into the GHe flow stream resulting in maintaining the cooldown line temperatures below 250°R for the first 10 seconds. The behavior of TT-474 (immediately downstream of the LH_2 /gas cooldown line interface) during this interval indicates the pulsing of LH_2 into GHe. The approximately 180 lbs of GHe used during the first 9.5 seconds, resulted in increasing the cooldown line temperature to less than 200°R . An additional 110 lbs of GHe was required to raise TT-474, TT-760, and TT-762 to 440°R , 400°R , and 300°R , respectively. An attempt was made to determine the response of the pipe wall temperature near FE-X during the GHe warmup phase. The metal wall temperature increased from 107°R to 169°R when the fluid temperature was increased from 62°R to 400°R . As shown in Figure 3.3.13, the fluid temperature at TT-474 dropped from 440°R to 100°R 3.5 seconds after GHe flow was shut off. The decrease in TT-760 and TT-762 following shutoff of GHe flow was due to the initiation of LN_2 flow through CHV-1885. The TT-474 persisted below LN_2 freezing temperature of 130°R for approximately 4 seconds.

Although the effect of the trapped LH_2 would be to increase the effectiveness of GHe for engine cooling, it decreases the effectiveness of line warmup prior to the switch to LN_2 and could result in freezing of LN_2 . It is recommended that the LH_2 between PCV-472 and CHV-1721 be purged out through RSV-456/457 immediately after the initiation of GHe flow during future testing.

3.4 HP GH₂ System

3.4.1 Description

The HP GH₂ system and associated instrumentation is shown in Figure 5.1 . The HP GH₂ system consists of the three gas storage vessels V-3207, V-3208, and V-3209 and the HP GH₂ cooldown line supply system.

3.4.1.1 GH₂ Storage Vessels

Each of the GH₂ storage vessels V-3207, V-3208, and V-3209 has an average water volume of 2372 cubic feet and a maximum rated operating pressure of 2500 psig.

3.4.1.2 HP GH₂ Cooldown Line Supply System

The HP GH₂ cooldown line supply system is shown in the aforementioned Figure. The significant components of the system are the orifice plate flowmeter (FE-15), the pressure control valve (PCV-251), CHV-681, and CHV-1721.

Flowmeter, FE-15, is a 3/8" thick, stainless steel, square-edged orifice plate with an orifice diameter of 3.68 inches. GH₂ flow rate is calculated from the equation:

$$\dot{W} = .0928 (P_1 \Delta P)^{\frac{1}{2}} F(T)/F(P),$$

where: P_1 is the inlet pressure (PT-587) in psia,

ΔP is the differential pressure (PT-778) in psid,

$F(T)$ is the temperature correction factor equal to $\left(\frac{530}{PT-527}\right)^{\frac{1}{2}}$

and $F(P)$ is the compressibility correction factor equal to $Z^{\frac{1}{2}}$.

The on-line computed GH₂ flow rate, FT-15, was calculated from the equation; $\dot{W} = .0882 (P_1 \Delta P)^{\frac{1}{2}}$ which assumes an inlet temperature of 530°R and a GH₂ compressibility factor (Z) at 2500 psig.

3.4.1.2 HP GH₂ Cooldown Line Supply System (Cont'd)

The pressure control valve, PCV-251; which was a 6-inch, 400 in², 200 psi pneumatically actuated, Annin valve ($C_v = 195$), exhibited unsatisfactory valve response during FEP-IIB. Therefore, before FEP-IV, the pneumatic actuator was replaced with a 19.6 in², 2700 psi hydraulic actuator. The AUTO (pressure) controller was also modified in conjunction with the change in actuation system.

CHV-681 and CHV-1721 are 6-inch Security "Y" pattern, lift-type check valves with a vendor quoted C_v of 580. CHV-1721 is located immediately upstream of the gas/liquid hydrogen line(s) interface. Due to back leakage observed during the FEP-III LN₂ flow tests, this valve was disassembled on 30 November 1966. Both the shaft and sleeve were found to be galled. The stainless steel sleeves were replaced with glass impregnated teflon and a 9/16" spring spacer installed to increase the pre-load. Although CHV-1721 did not back leak during FEP-III-1, the bonnet was modified due to leakage at the upper bonnet flange on 9 February 1967. Back leakage through CHV-1721 was observed during FEP-IV tests performed on 24 February 1967.

3.4.2 Performance Objectives

The HP GH₂ cooldown system performance objectives accomplished during the FEP test series were:

- 1.0 Determine the steady-state flow and pressure characteristics of the HP GH₂ cooldown system.
- 2.0 Determine the blowdown characteristics of the GH₂ storage vessels.
- 3.0 Determine the transient response characteristics of the HP GH₂ cooldown system in AUTO (pressure) control during switching between LH₂ and GH₂ flow.
- 4.0 Evaluate the adequacy of HP GH₂ cooldown flow control in both MANUAL (position) and AUTO (pressure) control.

3.4.3 Test Results

3.4.3.1 System Steady-State Characteristics

Figure 3.4.1 shows selected steady-state system pressures as a function of GH_2 flow rate based on FE-X venturi parameters and with flow out of storage vessel V-3207. All system pressures have been normalized to a reference gas temperature of 530°R . The storage vessel outlet (PT-441), header (PT-003), and FE-15 inlet (PT-587) pressures are given for PCV-251 full open (100%). Figure 3.4.1 shows that the pressure at the inlet to the FE-X venturi (PT-770) was about 8% higher than expected at the same location with the engine installed.

Figure 3.4.2 shows the differential pressure between the header (PT-003) and FE-15 inlet (PT-587) as a function of GH_2 flow rate. The deviation of the data points from the square function fit of the data below 10 lbs/sec is due to the characteristics of CHV-117 at low flow rates.

Figure 3.4.3 shows the differential pressure between the storage vessel V-3207 outlet (PT-441) and the header (PT-003) pressure; and the differential pressure between the storage vessels V-3207 and V-3208 outlet pressures (PT-441 and PT-442) and the header (PT-003) as a function of GH_2 flow.

Figure 3.4.4 shows the differential pressure between the storage vessel V-3207 outlet (PT-441) and FE-15 inlet (PT-587) as a function of GH_2 flow. The deviation of the data below 10 lbs/sec due to CHV-117 is again evident as it was on Figure 3.4.2.

The pressure differentials shown in Figures 3.4.2, 3.4.3, and 3.4.4 have been normalized to a reference vessel pressure of 1500 psig, and a fluid temperature of 530°R . It is to be noted that the pressure drop between the storage vessel(s) and the header at a given total GH_2 flow rate from two storage vessels is 0.6 of that for storage vessel V-3207 alone.

FIGURE 3.4.1

Differential Pressure ΔP^* ~ psid
PT-003 to PT-587

110
100
90
80
70
60
50
40
30
20
10
0

0

5

10

15

20

NOTES:

1. All Data Temperature Corrected
($T_c = 530^\circ R$)
2. All Data Vessel Pressure Corrected
($P_c = 1500$ psig)

GH_2 Flow Rate ~ Lbs/Sec

FIGURE 3.4.2

○ - FEP-IV Data

□ - FEP-II Data

Differential Pressure Vs GH_2 Flow Rate

NOTES:

1. All Data Temperature Corrected
($T_c = 530^{\circ}R$)
2. All Data Vessel Pressure Corrected
($P_c = 1000$ psig)

FIGURE 3.1.1.

○ - " P-I Data
 □ - P-II Data

Differential Pressure Vs. GH₂ Flow Rate

FIGURE 3.4.4

○ - FEP-IV Data

□ - FEP-II Data

Differential Pressure Vs. GH₂ Flow Rate

3.4.3.1 System Steady-State Characteristics (Cont'd)

Figure 3.4.5 and 3.4.6 compare the system pressure drops downstream of PCV-251 based on FEP-II and FEP-IV test data. The pressure drop data shown in these Figures have been normalized to a fluid temperature of 530°R. It is to be noted that the pressure transducer PT-814 was not installed for FEP-II. Although good agreement is obtained for the pressure drop between PT-103 and PT-770 (Curve No. 2, Figure 3.4.5), the characteristic pressure drop between PT-475 and PT-103 (Curve No. 1, Figure 3.4.5) is significantly different. The major components between PT-475 and PT-103 are CHV-681, RSV-454, RSV-460, and CHV-1721. The pressure drop characteristics between PT-814 and PT-103 (Curve No. 2), and between PT-475 and PT-814 (Curve No. 1) based on FEP-IV test data are shown in Figure 3.4.6. The pressure drop characteristic of CHV-1721, i.e., PT-814 to PT-103, is in agreement with what is normally expected; however, it is inconsistent between runs.

CHV-1721 was disassembled on 16 March 1967 to determine the cause of this discrepancy and it was found that the plug seat did not match with the hard seat and that the separator tube and spring were damaged. Therefore, 1/16" was machined off the contours of the plug seat, a stem guide of bronze installed and a new separator tube installed. However, the damaged spring was not replaced since no replacement was available at the time. After these modifications, it was determined that only 50% of the plug seat contacts the Kel-F seat. The check valve was then reassembled without further modification.

The pressure drop characteristic of CHV-681 and RSV-454/460, i.e., PT-475 to PT-814, for FEP-IV is also inconsistent. CHV-681 was disassembled on 12 May 1967 to resolve this discrepancy. It was found that the clearance between the glass impregnated teflon guide and the plug stem was not sufficient, which created variable pressures in the upper cavity resisting plug moment. Therefore, the

Differential Pressure, ΔP , Psid

FIGURE 3.4.5

Differential Pressure Vs GH₂ Flow Rate

Differential Pressure ΔP , Psid

FIGURE 3.4.6

Differential Pressure
Vs. CH₂ Flow Rate, FEP-IV

3.4.3.1 System Steady-State Characteristics (Cont'd)

force required to open the valve would vary as the initial cavity pressure varied. Bronze guides have been installed with an additional clearance of .010" from the original Security dimensions to eliminate this problem.

Figure 3.4.7 compares the GH_2 flow rate calculated from the measured FE-X venturi parameters with that determined from the on-line FT-15 flow computer. It is to be noted that good correlation exists at the higher flow rates (20 pps), but deviates at the low flow rates such that FT-15 would indicate about - 2.5 lbs/sec. GH_2 at zero flow based on FE-X. The difference between FT-15 and FE-X flow rates is attributed to an incorrect zeroing of FT-15. A 1.5 psid adjustment error in FT-15 would account for the flow rate differences shown in Figure 3.4.7. As discussed in Section 3.5.3.1, good correlation was obtained between FE-X and FE-15 calculated flow rates during the HP GN_2 flow testing.

Figure 3.4.8 shows the C_v^* versus stem position characteristics of PCV-251 based on both HP GN_2 and GH_2 flow data. The equations used to compute the C_v^* values given in Figure 3.4.8 are the same as those given in Section 3.3.3.1 for PCV-471. The PCV-251 upstream and downstream pressures have not been corrected for the theoretical line pressure drop between PT-587 and PCV-251 inlet; and between PCV-251 outlet and PT-475. As shown in Figure 3.4.8, PCV-251 exhibits an equal percentage characteristic with a maximum C_v^* of about 180.

3.4.3.2 Vessel Blowdown Characteristics

Figures 3.4.9 and 3.4.10 show the storage vessel fluid temperature ratio, $T(t)/T(0)$ versus pressure ratio, $P(t)/P(0)$, during blowdown of two vessels (V-3207 and V-3208), and one vessel (3207), respectively. It is to be noted that in both cases the blowdown process is in close agreement with theoretical isentropic expansion down to pressure ratios of 0.5.

FE-X GH_2 FLOW RATE - lbs/sec

20

15

10

5

0

FT-15 GH_2 MEASURED FLOW RATE - lbs/sec

FE-X GH_2 FLOW RATE VERSUS FT-15 FLOW RATE FOR FEP-IIB

FIGURE 3.4.7

FIGURE 3.4.8

C_v^* Vs % Open for PCV-251

T^* VERSUS P^* FOR GH_2 FLOW OUT OF V-3207 AND V-3208

FIGURE 3.4.9

T*

T* VERSUS P* FOR GH₂ FLOW OUT OF V-3207

FIGURE 3.4. 10

3.4.3.3 Transient Characteristics During GH_2 Flow Initiation

Figure 3.4.11 shows the transient response of PCV-750, PCV-251, and selected system pressures for approximately 1.1 seconds following initiation of GH_2 flow with PCV-251 in AUTO (pressure) control, and LH_2 locked up at 935 psig between PCV-472, CHV-1721, and PCV-750. It is to be noted that CHV-1721 leaked prior to the initiation of this test, so that the 4.55 ft^3 volume between CHV-1721 and CHV-681/685 (PT-814) was at the initial LH_2 line pressure of 935 psig. The cause of this leakage is discussed in Section 3.4.3.1. For the test run shown in Figure 3.4.11, the gas line volume (2.07 ft^3) between PCV-251 and CHV-681 was initially at zero pressure. The test was initiated by simultaneously stepping PCV-750 position demand to 58% and switching PCV-251 to AUTO (pressure) control. The pressure demand to PCV-251 was planned to be as follows:

$$P_d = 647 + (P_i - 647)e^{-t/0.5}$$

The initial pressure demand (P_i) was to be that PT-774 pressure existing at the time PCV-251 switched to AUTO, i.e., 935 psig. It is to be noted that PCV-251 was not commanded open until 150 milliseconds following the switch of PCV-251 to AUTO since for some unexplained reason, the pressure decay demand was faster than planned.

It is to be noted that PCV-750 inlet pressure PT-774 dropped to 515 psig in 250 milliseconds and overshoot its demand to 990 psig in 360 milliseconds following the switch of PCV-251 to AUTO. The initial pressure overshoot, therefore, was about 1.53 times the final demand of 647 psig. This corresponds to 1.06 times the initial line pressure. If it were necessary to charge the entire gas line (6.62 ft^3) between PCV-251 and CHV-1721, the overshoot would have been greater. The time required to pressurize the gas line between PCV-251 and CHV-681 from zero to 700 psig was 300 milliseconds. Assuming that PCV-251 opened without pausing twice as shown for this run, 160 milliseconds would have been required for the same initial header pressure of 1560 psig. It

GH₂ Flow Initiation Transients

FIGURE 3.4.11

3.4.3.3 Transient Characteristics During GH_2 Flow Initiation (Cont'd)

appears that it would have taken 3.2 (i.e., $6.62/2.07$) times as long, or 500 milliseconds, to pressurize the gas line between PCV-251 and CHV-1721 if CHV-1721 had not leaked.

The initial opening rate of PCV-251, which was the maximum measured, was 400%/sec between valve positions of 3% and 8%.

It should be noted that LH_2 was being expelled through PCV-750 over the time interval shown in Figure 3.4.11. The LH_2/GH_2 interface reached FE-X and PCV-750 in about 0.35 seconds and 1.5 seconds, respectively, after PCV-251 started to open.

A comparison between the transient response of PCV-251 and PCV-750 inlet pressure PT-774 with and without initial pressure between PCV-251 and CHV-681 is given in Figure 3.4.12 following initiation of GH_2 flow with PCV-251 in AUTO (pressure) control. The line segment between PCV-251 and CHV-681 was pre-charged to 715 psig for Run 6B only. It is to be noted that no significant overshoot in either PCV-251 position or PT-774 occurred when the line segment between PCV-251 and CHV-1721 was at or near the initial LH_2 line pressure.

Figure 3.4.13 shows the transient behavior of PCV-750, PCV-251, and selected system pressures and temperatures when PCV-750 was stepped to simulate change in engine impedance for LH_2 to GH_2 conditions, i.e., 58 to 89%. As shown in Figure 3.4.13, PCV-750 reached 89% about 0.8 seconds after LH_2/GH_2 interface had reached PCV-750. It is to be noted that although PT-774 dropped from 647 psig to 500 psig in about 140 milliseconds, the GH_2 flow rate at PCV-750 did not decrease below its final value of 22 pps since the PCV-750 inlet temperature at the time of minimum PT-774 pressure was 220°R . There was no significant effect on PT-774 pressure when the LH_2/GH_2 interface reached PCV-750.

GH₂ Transient
During GH₂ Initiation
with LH₂ Downstream, FEP-IV

FIGURE 3.4.12

Transient Behavior
During Change in Simulated Engine Impedance

FIGURE 3.4.13

3.5 HP GN₂ SYSTEM

3.5.1 Description

The HP GN₂ system and associated instrumentation is shown in Figure 5.1. The HP GN₂ system consists of the three gas storage vessels V-3201, V-3202, and V-3203 and the HP GN₂ cooldown system.

3.5.1.1 GN₂ Storage Vessels

The storage vessels for the HP GN₂ system are the same as those for the LP GN₂ system described in Section 3.1.1.1.

3.5.1.2 HP GN₂ Cooldown System

The HP GN₂ cooldown system is shown in the aforementioned Figure. The significant components of the system are the same as those of the HP GH₂ cooldown system which are described in Section 3.4.1.2. However, it should be noted that the on-line computed flow rate, FT-15 (GH₂ flow rate), must be corrected by the ratio of the gas densities to obtain the on-line computed GN₂ flow rate. The FE-15 GN₂ flow rate can be calculated from the measured orifice parameters using the equation;

$$\dot{W} = .3455 (P_1 \Delta P)^{\frac{1}{2}} F(T)/F(P)$$

where the parameters are the same as discussed in Section 3.4.1.2

3.5.2 Performance Objectives

The HP GN₂ cooldown system performance objectives accomplished during the FEP test series were:

- 1.0 Determine the steady-state flow and pressure characteristics of the HP GN₂ cooldown gas system.
- 2.0 Determine the blowdown characteristics of the GN₂ storage vessels.

3.5.3 Test Results

3.5.3.1 System Steady-State Characteristics

Figure 3.5.1 shows selected steady-state system pressures as a function of GN_2 flow rate based on FE-X venturi parameters with storage vessels V-3201, V-3202, and V-3203 on-line. The V-3201 storage vessel outlet pressure (PT-001) has been corrected by about 30 psig since it consistently read less than the other vessels under no-flow conditions. The storage vessels outlet (PT-001, PT-004, PT-007), header (PT-002), and FE-15 inlet (PT-587) pressures are given for PCV-251 full open (100%). All system pressures have been normalized to a reference gas temperature of 530°R . Figure 3.5.1 shows that pressure at the inlet to the FE-X venturi (PT-770) was 8% higher than what is expected at the same location with the engine installed. Figure 3.5.2 shows the measured differential pressure between the header (PT-002) and FE-15 inlet (PT-587); between V-3201 (PT-001), V-3202 (PT-004), and V-3203 (PT-007) and the header (PT-002); and between V-3201 (PT-001), V-3202 (PT-007), and V-3203 (PT-007) and FE-15 inlet (PT-587) as a function of GN_2 flow rate out of the three storage vessels (V-3201, V-3202, and V-3203). These pressure drops have been normalized to a reference vessel pressure of 1500 psig, and GN_2 temperature of 530°R .

Figure 3.5.3 compares the GN_2 flow rate calculated from the measured FE-X venturi parameters with that calculated from the measured FE-15 orifice parameters. The good correlation between the post-test calculated FE-15 and FE-X GN_2 flow rates shown in Figure 3.5.3 indicates that FE-15 can be used with confidence to determine GN_2/GH_2 flow rates during engine testing.

Figure 3.5.4 compares the GN_2 flow rate calculated from the measured FE-15 parameters with the on-line GN_2 computed flow rate, FT-15 (corrected by the ratio of the gas densities). It is seen that there is good correlation between the post-test calculated FE-15 and the on-line computed flow.

FIGURE 3.5.1

Differential Pressure, ΔP , Psid

○ - ΔP , PT-001, 4,7 to PT-587

□ - ΔP , PT-002 to PT-587

△ - ΔP , PT-001, 4,7 to PT-002

FEP-II Data

3 Vessel Outflow

FIGURE 3.5.2

Differential Pressure

Vs

GN₂ Flow Rate

FIGURE 3.5.3

FIGURE 3.5.4

3.5.3.1 System Steady-State Characteristics (Cont'd)

The PCV-251 impedance characteristics as a function of stem position based on GN_2 flow test data is discussed in Section 3.2.3.2.3.

3.5.3.2 Vessel Blowdown Characteristics

Figure 3.5.5 shows the V-3203 storage vessel GN_2 temperature versus pressure during blowdown of the three GN_2 storage vessels (V-3201, 3202, and 3203). It is to be noted that during the period when the total GN_2 flow was 100 lbs/sec, the contained GN_2 expanded isentropically. However, during the later part of the test when the total GN_2 flow rate was 20 lbs/sec, the GN_2 expansion approached an isothermal process.

3.6 HP LH_2 System

3.6.1 Description

The HP LH_2 system and associated instrumentation is shown in Figure 5.1. The HP LH_2 system consists of the HP LH_2 dewar (V-5002), the HP LH_2 dewar pressurization and vent system, and the HP LH_2 cooldown supply line system.

3.6.1.1 HP LH_2 Dewar

The HP LH_2 dewar has a maximum working pressure of 1500 psig and a LH_2 capacity of 4,400 gallons.

3.6.1.2 HP LH_2 Dewar Pressurization and Vent System

The HP LH_2 dewar pressurization and vent system is shown in the aforementioned Figure. The significant component of the pressurization system is the pressure control valve PCV-750, which is a 2-inch, pneumatically actuated, Annin valve with a percentage plug and a vendor quoted C_v of 35. The significant components of the vent system are RSV-109 and RSV-110. RSV-109

FIGURE 3.5.5

GN₂ Temperature Vs Pressure

3.6.1.2 HP LH₂ Dewar Pressurization and Vent System (Cont'd)

is a 2-inch pneumatically actuated, Security valve with a vendor quoted C_v of 70. RSV-110 is a 4-inch pneumatically actuated, Security valve with a vendor quoted C_v of 260.

3.6.1.3 HP LH₂ Cooldown Supply Line System

The HP LH₂ cooldown supply line system is shown in the aforementioned Figure. The significant components of the system are the flow tube flowmeter (FE-12), the pressure control valve (PCV-472), CHV-458, CHV-2302, and the liquid filter (LF-7).

Flowmeter FE-12 is a 6-inch, Hammel-Dahl flow tube. The FE-12 LH₂ flow rate is calculated from the vendor supplied equation; $\dot{W} = 4.42 (\rho \Delta P)^{\frac{1}{2}}$ where ρ is the LH₂ density in lbs/ft³ and ΔP is the differential pressure (PT-601) in psid. The on-line computed LH₂ flow rate, FT-12, is calculated from the equation; $\dot{W} = 9.26 \Delta P^{\frac{1}{2}}$ which assumes a LH₂ density of 4.4 lbs/ft³.

The pressure control valve, PCV-472, is a 4-inch, 200 in², 40 psi pneumatically actuated, Y-type Security valve with a vendor quoted C_v of 260. However, the original pneumatic actuator was not adequate to maintain stable operating conditions or to provide adequate valve response for engine cooldown application. Therefore, the pneumatic actuator was replaced by a 12.56 in², 2700 psi hydraulic actuator on 9 December 1966.

CHV-458 is a 6-inch Security "Y" pattern lift-type check valve with a vendor quoted C_v of 580. This check valve is located in the 4-LH-6 line downstream of PCV-472 and was the original RSV-458 converted to CHV-458 on 27 December 1966. This modification was made to provide isolation capability between the HP LH₂ and the gas cooldown systems during LH₂ to gas cooling transitions with PCV-472 and PCV-471 or

3.6.1.3 HP LH₂ Cooldown Supply Line System (Cont'd)

PCV-251 open. At that time, the stainless steel guides were replaced with glass impregnated teflon and a spring spacer was installed to increase the pre-load.

Tests performed on 10 January 1967, following the conversion of RSV-458 to CHV-458, indicated that the pressure drop at 30 lbs/sec LH₂ was 20 to 30 psi. At a LH₂ flow rate of 30 lbs/sec LH₂, the pressure drop across RSV-458 blocked open was 7 psid based on tests performed on 29 November 1966. FEP-III-1A tests performed on 9 February 1967 showed that the check valve was apparently sticking at various positions. The pressure drop at 30 lbs/sec LH₂ varied between 30 to 70 psi depending on the initial flow rate. CHV-458 was disassembled on 9 February 1967, and it was determined that the spring spacer was cocked due to it being installed incorrectly on the bottom of the spring. The spacer was relocated to the top of the spring.

CHV-2302 is a 6-inch, swing-type, Pacific valve with a vendor quoted C_v of 580.

Liquid filter, LF-7, is a Capitol Westward filter with an element rating of 72 microns (nominal) and a vendor quoted k valve for LH₂ of 6.6.

3.6.2 Performance Objectives

The high pressure LH₂ cooldown system performance objectives accomplished during the FEP test series were to:

- 1.0 Determine the initial chilldown and chillholding characteristics of the HP LH₂ cooldown system.
- 2.0 Determine the steady-state flow, pressure, and temperature characteristics of the HP LH₂ cooldown system.
- 3.0 Determine the frequency response characteristics of the HP LH₂ cooldown line supply system.

3.6.2 Performance Objectives (Cont'd)

- 4.0 Determine the transient characteristics of the HP LH₂ cooldown system following LH₂ flow initiation in MANUAL (position), AUTO (flow), and AUTO (pressure) control.
- 5.0 Determine the transient characteristics of the HP LH₂ dewar pressurization and vent systems in MANUAL (position) and AUTO (pressure) control.
- 6.0 Evaluate the adequacy of the HP LH₂ dewar LH₂ level instrumentation during LH₂ filling and outflow operations.

3.6.3 Test Results

3.6.3.1 HP LH₂ Dewar Pressurization and Vent System

The performance of the HP LH₂ dewar (V-5002) pressurization and vent system has been evaluated for pressurization and venting without LH₂ outflow to determine the systems capability to follow the turbopump discharge pressure during engine operations.

3.6.3.1.1 Pressurization Without LH₂ Outflow

Pressurization tests without LH₂ outflow conducted during the FEP test series consisted of AUTO (pressure) step demands to 840 psig, 900 psig, and 910 psig and AUTO (pressure) demand ramp rates of 8 psi/sec, 18 psi/sec, 75 psi/sec, and 113 psi/sec.

Figure 3.6.1 shows the V-5002 pressure (PT-97) and demand as a function of time during a typical pressurization from about 70 psig to 900 psig with an ullage of 17.7% and a header pressure of 1950 psig. Also shown is the PCV-250 demand and position. It should be noted that the PCV-250 command varies from 0 to 120% because of a -20% bias incorporated in the control circuit. The pressure demand ramp-up was +113 psi/sec. It is noted that there is a lag time of approximately 3.2 seconds between the time when PCV-750 demand exceeds 20% and when the valve begins to open. The demanded pressure ramp rate is not satisfied until after PCV-750 position exceeds 42%. Figure 3.6.1 also shows a lag time of .8 seconds between the demand and position during

FIGURE 3.6.1

3.6.3.1.1 Pressurization Without LH₂ Outflow (Cont'd)

closure of the valve which results in a pressure overshoot of less than 4%.

Figure 3.6.2 shows the reciprocal of the maximum pressurization rates with PCV-250 greater than 40% open as a function of ullage volume based on the corrected LT-009 reading (refer to Section 3.6.3.3). The data has also been corrected to a header pressure of 2500 psig. It is seen that for a dewar liquid level of 100% that the maximum pressurization rate of 285 psi/sec is attainable at a tank pressure of 2500 psig.

3.6.3.1.2 Venting Without LH₂ Outflow

Venting tests without LH₂ outflow were conducted using RSV-109 and RSV-110 in manual control and using RSV-109 with programmed venting rates of -6 psi/sec, -16 psi/sec, -74 psi/sec and -85 psi/sec.

The manual venting characteristics of RSV-109 and RSV-110 are shown in Figure 3.6.3 which shows the log of the dewar pressure (PT-97) as a function of t/V_u where t is the time after the vent valve opens in seconds and V_u is the ullage volume in cubic feet. The pressure in the dewar at any time during venting is represented by the equations:

$$P(t) = P_o e^{-31 t/V_u} \text{ for venting through RSV-109,}$$

and

$$P(t) = P_o e^{-110.5 t/V_u} \text{ for venting through RSV-110.}$$

It appears that venting rates up to -500 psi/sec are attainable through RSV-110 for indicated LH₂ levels (LT-009) above 80%. The test data was normalized to an initial pressure of 900 psig.

Figure 3.6.4 shows the programmed venting operations, using RSV-109, for venting rates of -74 psi/sec between 900 to 500 psi

Inverse Pressurization Rate, Normalized
To a Header Pressure of 2500 psig
 $\frac{dt}{dp} \frac{P_H}{2500}, (\text{psi/sec})^{-1}$
Highest Pressurization
Rate →

.015

.010

.005

0

NOTES:

- 1) FEP-IV Data
- 2) PCV-250 Position
> 40% Open

<u>Data Point</u>	<u>Header Pressure</u>
1	1168 psig
2	1950 psig
3	2087 psig
4	1172 psig
5	2132 psig
6	2132 psig
7	2176 psig
8	1648 psig
9	1600 psig

Ullage Volume, Cubic Feet

0

50

100

150

200

100%

90%

80%

70%

LT-009 Corrected Reading

V-5002 Pressurization Rate Vs. Ullage Volume

FIGURE 3.6.2

FIGURE 3.6.3

FIGURE 3.6.4

PCV-250 Command, Position, Pressure Demand and Dewar Pressure Vs Time For Venting Test

3.6.3.1.2 Venting Without LH₂ Outflow (Cont'd)

and -16 psi/sec between 500 to 0 psig. This figure shows that the system maintains the pressure within +80 psig of the demanded pressure.

3.6.3.2 HP LH₂ Cooldown System

The performance of HP LH₂ cooldown system has been evaluated under the following conditions: (a) initial dewar and system fill, chilldown, and chillholding, (b) line blowdown, (c) dewar blowdown, (d) flow initiation transient and (e) steady-state LH₂ outflow.

3.6.3.2.1 Initial Dewar and System Fill, Chilldown and Chillholding Characteristics

It has been determined from data obtained during the FEP test series that V-5002 can be initially filled in about 400 seconds, 100 seconds of which is required to chill the transfer line and 300 seconds to initially fill V-5002. 3600 pounds of LH₂ were required for this operation. Some difficulty was experienced during the FEP series in determining when the dewar was 100% full; i.e., LT-009 was not calibrated correctly, but this problem has been corrected. An additional time of about 35 minutes is required to chill V-5002 and refill to 85%.

The initial chilldown of the cooldown (4-LH-6) and simulator lines is shown in Figure 3.6.5. LH₂ at 39.2°R from V-3801 pressurized to 95 psig, was used with PCV-750 set at 39% to approximately simulate the impedance of the engine cooldown vent valve, i.e., CVV. It is seen that saturation temperatures are reached at FE-X and PCV-750 in about 8.2 and 10 minutes, respectively, after opening RSV-107. Final chilldown of the 4-LH-6 line was accomplished by allowing LH₂ downstream of RSV-107 to boiloff followed by rechilling of the line. The no-flow temperature rise at TT-495 after the first boiloff cycle was approximately 36°R/minute, but was not significantly improved during later boiloff cycles.

3.6.3.2.1 Initial Dewar and System Fill, Chillydown and Chillyholding Characteristics (Cont'd)

Chilly maintenance of the 4-LH-6 line was accomplished by flow out of PCV-750. Temperature rises above V-5002 LH₂ temperature (38.5°R) of 4°R and 8°R were maintained at TT-495 (CHV-458 inlet) and TT-474 (4-LH-6 gas line interface) for approximately 5 minutes at an average flow rate of 1 lb/sec from V-5002. To maintain 50°R at TT-495 and TT-474 with a V-5002 temperature of 38.5°R, continuous LH₂ flow rates of 0.3 lbs/sec and 0.7 lbs/sec, respectively, are required. RSV-457/456 are orificed to provide LH₂ flow rates of 1 and 0.5 lb/sec, respectively, for a line pressure of 100 psig. Temperatures of 45°R to 50°R are maintained at TT-495 by periodically opening and closing RSV-457/456 for approximately 5 minutes, with LH₂ at 40°R obtained from V-5002. The average LH₂ flow rate to maintain this chilly was 0.4 lbs/sec.

Based on chilly maintenance test data, 180 lbs of LH₂ is required to maintain the 4-LH-6 line down to CHV-458 at 50°R for 10 minutes with a V-5002 supply temperature of 40°R. 240 pounds of LH₂ is required for the same time interval if a pulsing technique is used to maintain CHV-458 inlet temperature between 45°R to 50°R.

3.6.3.2.2 Line Blowdown Characteristics

Line blowdown tests were conducted during the FEP test series to determine if any portion of the 4-LH-6 line had sufficient accumulation at pump discharge pressure to provide adequate nozzle tube flow after a turbopump shutdown with low V-5002 pressures. Tests were evaluated for line blowdowns of LH₂ downstream of CHV-2302, PCV-472, RSV-107, and for a dewar and line blowdown. However, during a portion of these tests CHV-1721 leaked resulting in GH₂ pressure upstream of this CHV. For the tests with GH₂ pressure upstream of CHV-1721, the LH₂ expansion was augmented by the gas expansion. Thus, the HP LH₂ cooldown line (4-LH-6) blowdown characteristics have been evaluated for blowdown

3.6.3.2.2 Line Blowdown Characteristics

with and without pressure upstream of CHV-1721. Figure 3.6.6 shows the PCV-750 position, PCV-750 inlet pressure (PT-774), FE-X inlet temperature (TT-760), FE-X inlet pressure (PT-770) and the FE-X calculated flow rate for the initial phase of each line blowdown.

Run 9 was a blowdown of the LH_2 downstream of CHV-2302 at an initial pressure of 775 psig and the LH_2 in the line upstream of the valve at 280 psig. Run 2D was a blowdown of the LH_2 downstream of RSV-107 at an initial pressure of 797 psig. It is noted from Figure 3.6.6 that the initial flow capability after a turbopump shutdown during Run 2D is greater than that of Run 9 due to the increased LH_2 volume in the line. Neither of these blowdown methods appear to be adequate, however, since the minimum 31 lbs/sec LH_2 required nozzle tube flow after a turbopump shutdown from full power is not obtained.

Run 3B was a blowdown of the LH_2 downstream of PCV-472 at an initial pressure of 766 psig and a GH_2 pressure upstream of CHV-1721 of 789 psig. It is seen that the initial flow rate for this run appears to be adequate to maintain nozzle tube flow after a turbopump shutdown.

Run 6A was a blowdown of the LH_2 downstream of PCV-472 at an initial pressure of 917 psig and a GH_2 pressure of 920 psig upstream of CHV-1721. Run 7A was a LH_2 blowdown with an initial pressure of 875 psig in the 4-LH-6 line and in V-5002. Also there was an initial GH_2 pressure of 875 psig upstream of CHV-1721. The flow rates for these runs appear to be adequate to maintain nozzle tube flow.

Figures 3.6.7 and 3.6.8 are shown to evaluate the effects of pressure upstream of CHV-1721 on the pressure and flow behavior at FE-X during the line blowdown with PCV-472 closed, and to determine the thermodynamic behavior of the fluid upstream of CHV-1721.

FIGURE 3.6.6

Initial LK₂ Line Blowdown Transients

Pressure & Flow Rate Vs Time
During LH₂ Flow Initiation

FIGURE 3.6.7

Pressure Ratio Vs Gas Ullage Volume Ratio

During LN_2 Flow Initiation

FIGURE 3.6.8

3.6.3.2.2 Line Blowdown Characteristics (Cont'd)

Figure 3.6.7 shows the CHV-1721 upstream pressure (PT-814), FE-X inlet pressure (PT-770), and FE-X calculated LH₂ flow rate as a function of time after the start of PCV-750 step open for Runs 6A and 3B. The time interval chosen for Run 6A was prior to the time that CHV-681 opened. The final position of PCV-750 for Runs 3B and 6A were 47.7% and 57.8%, respectively.

Figure 3.6.8 shows the pressure ratio $P(t)/P(0)$ versus gas volume ratio $V(0)/V(t)$ for both Runs 3B and 6A. The volume ratio is based on an initial calculated volume between CHV-1721 and CHV-681/685 of 4.55 ft³, and the assumption that the change in gas volume is proportional to the integral of the LH₂ flow rate at FE-X, i.e.,

$$\Delta V(t) = \frac{1}{\rho} \int_0^t W_{FE-X}(t) dt.$$

As shown in Figure 3.6.8, the change in CHV-1721 upstream pressure with change in gas volume (based on LH₂ flow rate) can be correlated using an apparent expansion coefficient of $k = 1.0$, i.e., isothermal expansion.

3.6.3.2.3 Dewar Blowdown Characteristics

The V-5002 dewar blowdown characteristics are shown in Figure 3.6.9. The dewar pressure ratio, $P(t)/P(0)$, is shown as a function of the dewar ullage volume ratio, $V(0)/V(t)$ for all blowdown tests. The dewar ullage volume is based on LT-009 indications, and the initial dewar pressure and ullage volumes are those immediately prior to initiation of each run. The data has been corrected for a time lag of approximately two seconds which existed between LT-009 and the dewar pressure, PT-097, readings. As shown in Figure 3.6.9, the change in dewar pressure with change in ullage volume can be correlated using an apparent expansion coefficient of $k = 1.9$ where $P(t) \times V(t)^k$ equals a constant.

NOTES:

1) FEP-III-1A Data

<u>Run</u>	<u>Dewar Pressure (PT-097)</u>		<u>Dewar Level LT-009</u>	
	<u>Initial</u>	<u>Final</u>	<u>Initial</u>	<u>Final</u>
○ 4A	226	53	60.6	22.1
□ 4B	263	97	71.5	51.7
▽ 4B'	248	95	76.4	61.9
◇ 5A	399	121	69.9	42.4
◊ 5B	394	99	74.8	47.9
● 6	853	317	68.3	43.1

Dewar Pressure Ratio Vs Dewar Ullage Volume Ratio

FIGURE 3.6.9

3.6.3.2.3 Dewar Blowdown Characteristics (Cont'd)

A correlation of the calculated ullage volume as a function of LT-009 percent indication and the ullage volume based on the integral of FT-12 flow assuming the initial ullage volume based on LT-009 to be correct was made based on this blowdown data and is discussed in Section 3.6.3.3.

3.6.3.2.4 Flow Initiation Transient Characteristics

The flow initiation transient characteristics of the HP LH₂ cooldown system has been evaluated for under the following conditions:

- 1.0 Step closure of PCV-472 from 72% to 2%.
- 2.0 Pressure control closure of PCV-472 with a step demand.
- 3.0 Pressure control opening of PCV-472 with a varying demand.
- 4.0 Flow control closure of PCV-472 with a step demand.

Figure 3.6.10 shows the system parameters during the step closure of PCV-472 to determine its maximum closing response. The maximum closing response of the valve is seen to be 600%/sec with an overshoot of the demanded position of less than 1%. CHV-1721 leaked during this test which resulted in the appearance of low density fluid at FE-X inlet six seconds after PCV-750 was stepped open.

Figure 3.6.11 shows the system transient characteristics during flow initiation with a pressure of 875 psig in the dewar and line and with PCV-472 in pressure control with a step demand of 300 psig. It is seen that CHV-1721 also leaked during this run resulting in the appearance of a low density fluid spike at FE-X .6 seconds after PCV-750 was stepped open. It is also seen that PCV-472 required 11 seconds to reduce the PT-774 pressure to the demanded 300 psig.

During the flow initiation with PCV-472 initially closed and in pressure control, the LH₂ in the line downstream of the PCV-472

Pressure, Temperature, Flow Rate and Valve Position Vs Time

3.6.3.2.4 Flow Initiation Transient Characteristics (Cont'd)

was at 766 psig. The pressure demand of the valve was to consist of an exponential decay from 790 psig to 247 psig with a .8 second time constant. However, PCV-472 was not commanded open until 2.1 seconds after PCV-750 was stepped open. This delay in opening might have been caused by a delay in switching PCV-472 to auto or by the incorrect operation of the exponential pressure demand. Considering these factors the controller delay was between 1.2 and 1.7 seconds. When the valve did open, it opened at a rate of 8%/sec. Because of this slow opening rate and the delay in opening, the LH₂ flow was interrupted 2.4 seconds into the run, for 1.6 seconds. CHV-1721 leaked during this run resulting in the appearance of low density liquid at FE-X .7 seconds after PCV-750 was stepped open. It is felt that flow initiation by opening PCV-472 in pressure demand holds no practical application as a cooldown method, but that the use of this method with PCV-472 in Manual (maximum response of 600%/sec) control may be applicable.

Figure 3.6.12 shows the system transients during a flow control closure of PCV-472 with a step demand of 25 lbs/sec. It is seen that PCV-472 controls to the demanded flow rate in about 1.5 seconds after PCV-750 is stepped open. Both FE-X and FE-12 flow rates do not exceed the maximum allowable flow rates to prevent excessive rates of reactor component cooldown after a scram.

3.6.3.2.5 Steady-State Characteristics During LH₂ Outflow

The HP LH₂ cooldown system steady-state characteristics have been evaluated for; 1) flowmeter correlation, 2) system pressure drops as a function of flow rate, and 3) PCV-472 C_v as a function of valve position. The data has not been corrected for elevation head which is negligible (less than 1 psi) in the system.

LH₂ System Transients
During Flow Control Closure of PCV-472

Time, Sec.
FIGURE 3.6.12

3.6.3.2.5 Steady-State Characteristics During LH_2 Outflow (Cont'd)

Figure 3.6.13 compares the LH_2 flow rate calculated from the measured FE-X venturi parameters with that calculated from the measured FE-12 flow tube parameters. The good correlation between the post-test calculated FE-12 and FE-X flow rates shown in Figure 3.6.13 indicates that FE-12 can be used with confidence to determine LH_2 flow rates during engine testing.

Figure 3.6.14 compares the LH_2 flow rates calculated from the measured FE-12 parameters with the on-line LH_2 computed flow rates, FT-12. It is seen that there is good correlation between the post-test calculated FE-12 and the on-line computed flow.

It should be noted, however, that during FEP-IV the post-test calculated, FE-12, and the on-line computed, FT-12, flow rates indicated about 30% lower than the FE-X calculated flows. The fittings and the associated tubing for PT-601 have been leak tested to determine if a leak might have existed during the test. However, no leakage was found and the cause of this discrepancy is unresolved at the present time.

Figure 3.6.15 shows the differential pressure from PT-97 to PT-101, PT-103 to PT-770, and PT-770 to PT-774 as a function of LH_2 flow rates. Curve No. 1 is the differential pressure from the HP LH_2 dewar to the inlet of FE-12, i.e., PT-97 to PT-101. Curve No. 2 is the differential pressure from the outlet of CHV-458 to the inlet of FE-X, i.e., PT-103 to PT-770. Curve No. 3 is the differential pressure from the inlet of FE-X to the inlet of PCV-750, i.e., PT-770 to PT-774. It is to be noted that the fluctuations in the test data given in Figure 3.6.15 are within 1% of the accuracy of the pressure transducers involved.

Figure 3.6.16 compares the system pressure drops downstream of PCV-472 based on FEP-III, FEP-IV, and the LN_2 checkout of V-5002

LH₂ FE-12 Flow Rate Vs FE-X Flow Rate

FIGURE 3.6.13

LH₂ FE-12 Flow Rate Vs FT-12 Flow Rate

FIGURE 3.6.14

Differential Pressure Vs LH_2 Flow Rate

FIGURE 3.6.15

Differential Pressure, ΔP , psid

ΔP , PT-484 to 103

ΔP , PT-484 to PT-770

NOTES:

1) $\square$ FEP-III Data

$\circ$ FEP-IV Data

$\triangle$ LN_2 Checkout of V-5002

Differential Pressure Vs LH_2 Flow Rate

FIGURE 3.6.16

3.6.3.2.5 Steady-State Characteristics During LH_2 Outflow (Cont'd)

(29 November 1966) test data. Curve No. 2 is the differential pressure from PCV-472 outlet to FE-X inlet, i.e., PT-484 to PT-770. The major components between PT-484 and PT-770 are CHV-458, CHV-2302, and LF-7. It is seen that before any modifications were made to RSV-458 that at an LH_2 flow rate of 30 lbs/sec the differential pressure was 8 psi. Also shown in Curve No. 2 is test data from two runs during FEP-III. These curves agree with what is generally expected, i.e., a square function fit, but is inconsistent between runs. The differential pressure at 30 lbs/sec varies from 30 to 72 psi during FEP-III. CHV-458 was modified prior to FEP-IV as discussed in Section 3.6.1.3.

Curve No. 1 of Figure 3.6.16 shows the differential pressure across CHV-458, i.e., PT-484 to PT-103, during FEP-IV. The pressure drop characteristics of CHV-458 is in agreement with a square function fit but it is inconsistent between runs. The differential pressure at a LH_2 flow rate of 20 lbs/sec varies from 8 to 73 psi which indicates that there was no improvement in performance from that observed during FEP-III.

The valve was disassembled on 23 May 1967 and although no obvious reason for the valves behavior was found, the glass impregnated teflon guides were replaced with bronze guides.

Figure 3.6.17 shows the C_v versus stem position characteristics of PCV-472 based on FEP-III and FEP-IV test data. The equation to compute the C_v values given in Figure 3.6.17 is the same as that given for the subsonic case in Section 3.3.3.1 for PCV-471. The PCV-472 upstream and downstream pressures have been corrected for the theoretical line pressure drop between PT-101 and PCV-472 inlet; and between PCV-472 outlet and PT-484. As shown in Figure 3.6.17, PCV-472 exhibits a linear plug characteristic with a maximum C_v of 220.

3.6.3.3 High Pressure LH_2 Dewar Instrumentation

The performance of the high pressure LH_2 dewar (V-5002) level

PCV-472 C_v Vs. PCV-472 Percent Open

FIGURE 3.6.17

3.6.3.3 High Pressure LH_2 Dewar Instrumentation (Cont'd)

instrumentation has been evaluated based on data obtained during the LN_2 checkout of V-5002 on 29 November 1967 and during FEP-III. The instrumentation evaluated was the continuous capacitance probe, the point capacitance indicators, the point resistance indicators, and the temperature probes.

Figure 3.6.18 shows the calculated ullage volume as a function of the continuous capacitance probe LT-009 percent indication. The ullage volume based on the integral of FT-12 flow rates and assuming the initial ullage volume based on LT-009 indication to be correct are also shown. It is noted that the ullage volume change based on LT-009 reading agrees with the change based on FT-12 flow measurements. The LN_2 checkout data also substantiates the agreement between the changes in LT-009 indicating and the integral FT-12 flow measurements. It should be noted that the data, except for Run 4A, has not been corrected for LT-009 lag times of approximately 1.5 seconds. The data, also, has not been corrected for an incorrect calibration of LT-009; i.e., 92.6% LT-009 indications are actually 100%. This calibration error has been corrected and it is felt that LT-009 can provide dewar level information during fill and flow operations within about 5%.

Figure 3.6.19 shows the LT-009 percent probe height as a function of the pounds of LH_2 in the dewar. This figure is based on a LH_2 density of 4.37 lb/ft³.

Except for the 25% point, the point capacitance indicators appeared to indicate level correctly. However, work has been done to correct the 25% capacitor point. Both capacitance gages may be affected by radiation while the reactor is at high power levels rendering their indications questionable.

The point resistance indicators did not indicate level correctly at high pressure. This is because the point resistor indication is based on the difference in thermal conductivity of LH_2 and GH_2

FIGURE 3.6.18

V-5002 Ullage Volume Vs LT-009 Probe Height

3.6.3.3 High Pressure LH₂ Dewar Instrumentation (Cont'd)

and at high ullage pressures the thermal conductivity of the low and high density fluid are nearly the same.

The RTT temperature probes do appear to read temperature accurately and appear to be useful as liquid level instrumentation under some conditions within about 5%. The RTT probes indicate liquid level changes for varying and constant dewar pressures above the critical point. They also indicate level changes for constant dewar pressures below the critical point. However, they do not indicate liquid level changes reliably during fill operations and during varying dewar pressures below the critical point.

3.7 LP LH₂ Storage and Transfer System

3.7.1 Description

The LP LH₂ storage and transfer system and associated instrumentation is shown in Figure 5.1. The LP LH₂ storage and transfer system consists of the LH₂ storage dewar (V-3801), the LH₂ storage dewar pressurization system, and the LH₂ transfer (V-3801/V-5001) system.

3.7.1.1 LH₂ Storage Dewar

The LH₂ storage dewar has a maximum working pressure of 100 psig and a LH₂ capacity of 250,000 gallons.

3.7.1.2 LH₂ Storage Dewar Pressurization and Vent System

The LH₂ storage dewar pressurization and vent system is shown in the aforementioned Figure. The significant component of the pressurization system is the pressure control valve, PCV-248, which is a 2-inch pneumatically actuated, Annin valve with a percentage type plug and a vendor quoted C_v of 13. The significant component of the vent system is the pressure control valve, PCV-179, which is a 12-inch

3.7.1.2 LH_2 Storage Dewar Pressurization and Vent System (Cont'd)
pneumatically actuated, Annin valve with a percentage type plug and a vendor quoted C_v of 1500.

3.7.1.3 LH_2 Transfer (V-3801/V-5001) System

The LH_2 transfer (V-3801/V-5001) system is shown in the aforementioned Figure. The significant components of the system are RSV-128 and RSV-129. RSV-128 and 129 are, respectively, 2 and 4-inch, pneumatically actuated, Security valves with a vendor quoted C_v of 92 and 800.

3.7.2 Performance Objectives

The LP LH_2 storage and transfer system performance objectives accomplished during the FEP test series were to:

- 1.0 Determine the initial chilldown and chill maintenance characteristics of the LP LH_2 transfer systems.
- 2.0 Determine the steady-state flow, pressure, and temperature characteristics of the LP LH_2 transfer system.
- 3.0 Evaluate the adequacy of the V-3801 LH_2 level instrumentation systems.
- 4.0 Evaluate the adequacy of the V-3801 pressurization and vent system(s).
- 5.0 Determine the V-3801 gas utilization for facility operations.

3.7.3 Test Results

3.7.3.1 LH_2 Storage Dewar Pressurization and Vent System

The LH_2 storage dewar pressurization and vent system has been evaluated based on data obtained during the FEP test series for; 1) initial pressurization, 2) minimum LH_2 temperature obtainable with present vent, 3) pressurization during V-5001/3-LH-6 initial fill and chilldown, 4) pressurization during V-5001 topping, and 5) pressurization during V-5002/4-LH-6 initial fill and chilldown. The important parameter data for each of these pressurizations are given in Table 3.7.1.

Summary Table of V-3801 Pressurization

Operation	FEP	Time Interval Considered For Utilization Sec.	V-3801 Press. PT-068 Psig	V-3801 Liquid Level LT-002	V-5001 Press. PT-099 Psig	V-5001 Level % LT-453	V-5002 Press. PT-097 Psig	V-5002 Level % LT-009	Lbs. GH ₂ Used	Apparent Collapse Factor	Polytropic Exponent n	Lbs. LH ₂ Used	Specific Ratio #GH ₂ /#LH ₂
V-3801 Press. (9.76 to 94.56 psi)	IV	35590.8 35637.8 35758.8 35788.8	9.76 11.18 94.78 94.56	88.62 88.58 88.12 88.21	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- ----- 133 139	----- ----- 2.0 2.05	----- ----- 1.28 -----	----- ----- ----- -----	----- ----- ----- -----
V-3801 Press. (1.5 to 50.25 psi)	III-II	34680.7 34745.4 34780.7 34830.1	1.50 48.0 50.02 50.25	84.73 84.68 84.32 84.34	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- 59 66.7 72.20	----- 1.12 1.21 1.31	----- 1.2 ----- -----	----- ----- ----- -----	----- ----- ----- -----
V-3801 Press. (50 - 97 psi)	III-II	45600.2 45905.2 46798.2 46830.0	15.11 96.49 97.07 97.27	57.49 57.54 57.37 57.42	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- ----- ----- -----	----- 301 375 385	----- ----- ----- 1.70	----- 1.2 ----- -----	----- ----- ----- -----	----- ----- ----- -----
V-3801 Press. During Transf. to V-5001 Until Initial Fill	III-II	34834.1 36021.1 36175.1 36201.1	50.12 46.7 46.56 47.76	84.34 65.86 61.72 61.55	.17 1.15 .67 .43	0 100 90 80	----- ----- ----- -----	----- ----- ----- -----	----- 416 510 517	----- 2.8 2.7 2.7	----- 1.17 ----- -----	----- 27800 35000 35100	----- .0151 .0147 .0148
Usage During Chill-down & Final Fill of V-5001 & 3-LH-6	III-II	36201.1 36235.1 36404.1 37394.0	47.76 47.9 49.4 50.4	61.55 61.49 61.11 58.01	.43 .70 .31 .32	80 5 100 100	----- ----- ----- -----	----- ----- ----- -----	----- ----- 521 700	----- ----- ----- -----	----- ----- ----- -----	35100 35300 36000 41400	----- ----- ----- .017
V-3801 Press. Usage During LH ₂ Transf. to V-5002 Until Initial Fill	IV	35788.0 36188.8	94.6 94.4	88.21 84.61	----- -----	----- -----	----- -----	.4 85	----- 141	----- -----	----- -----	0 3800	----- .035
Initial Fill & Chill at 4-LH-6 Line (V-5002)	IV	38000.8 38557.8 38557.8 39700.1 39950.1 40150.1	94.2 94.3 94.31 94.53 94.65 95.06	82.2 80.25 80.25 78.33 78.38 77.54	----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- -----	----- ----- 58.4 88.5 84.1 5.4	72.1 88.9 88.9 70.5 27 83.5	----- 93 ----- 237 ----- 272	----- ----- ----- ----- ----- -----	----- 1.14 ----- ----- ----- 1.07	0 2500 ----- 5200 ----- 6300	----- .037 ----- .046 ----- ----- .043
V-5002 Fill & Chill 4-LH-6 Chill & Fill	III-IA	36630.3 37070.3 37070.3 38471.3	94.9 92.5 92.5 92.3	43.1 41.1 41.1 39.9	----- ----- ----- -----	----- ----- ----- -----	0 0.7 0.7 1.0	0 78.6 78.6 90.4	0 107 107 244	----- ----- ----- -----	----- ----- ----- -----	0 ----- ----- 6700	----- ----- ----- -----
V-3801/V-5001 Utilization During Topping	III-II	47290.0 47350.0 50840 50900 51410.0 51570.0	96.19 92.88 93.7 91.7 93.96 90.00	53.68 51.56 32.4 29.9 23.73 15.89	28.27 29.80 30 31.3 44.72 44.9	76 74 15 15 20 15	----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- -----	----- ----- ----- 69.6 67.5 ----- 168	----- ----- ----- ----- ----- -----	----- ----- ----- ----- ----- 1.14	----- ----- ----- ----- 4860 @ 80 pps 4670 @ 77 pps 13125 @ 82 pps	----- ----- ----- ----- .0143 .0145 .0128

3.7.3.1 LH₂ Storage Dewar Pressurization and Vent System (Cont'd)

Figure 3.7.1 shows the pressure, temperature, and valve characteristics during the initial pressure of V-3801 from 1.5 to 50.3 psig at an initial V-3801 level of 85%. Thermal equilibrium of the ullage gas temperature was achieved about 2.5 minutes after pressurization was initiated. The quantity of GH₂ utilized was 72.2 lbs with an apparent collapse factor of 1.3. The pressurization time was about 65 seconds. The dewar level decreases by about .5% and the temperature of the liquid increases by about .3°R during this pressurization.

V-3801 was vented prior to each applicable FEP performed to obtain a minimum LH₂ temperature. The minimum temperature obtained at the 10% level temperature probe (TT-402) was 38.25°R. This corresponds to the saturation temperature at a pressure of 6 psig which is close to what the facility personnel report to be the back pressure maintained in V-3801 by the check valves in the vent system. It therefore appears that it may not be possible to obtain an initial temperature lower than 38.2°R with the existing vent system.

The GH₂ utilized to maintain V-3801 pressurized at 50 psig during the initial fill and chilldown of V-5001 and 3-LH-6 transfer line was 700 lbs with an initial V-3801 level of 84%. This operation was accomplished in about 23 minutes with expulsion of 41,000 lbs of LH₂ from V-3801. The specific ratio of lbs of GH₂ to lbs of LH₂ was .017.

Figure 3.7.2 shows the same parameters as Figure 3.7.1 except for the elimination of TT-402 for the pressurization of V-3801 from 50 to 97 psig with an initial V-3801 level of 57%. Thermal equilibrium of the ullage gas temperature was achieved 20.5 minutes after pressurization was initiated. The GH₂ utilized was 385 lbs with an apparent collapse factor of 1.7. The liquid temperature (TT-402) increased .3°R to 39°R during this pressurization. The difference in collapse factors between this pressurization and the initial pressurization is probably due

V-3801 Pressure, Temperature and PCV-248 Position versus Time During Initial Pressurization

FIGURE 3.7.2

3.7.3.1 LH₂ Storage Dewar Pressurization and Vent System (Cont'd)

to the difference in ullage volumes and to the fact that the ullage gas in the initial pressurization had not reached thermal equilibrium.

The GH₂ utilized to maintain V-3801 pressurized at 50 psig and V-5001 during topping of V-5001 was evaluated. At the maximum topping flow rate of 82 lbs/sec for 160 seconds, 168 lbs of GH₂ was utilized for a corresponding LH₂ outflow of 13,120 lbs resulting in a specific ratio of lbs of GH₂ to lbs of LH₂ of .0128. The V-3801 pressure decreased about 4 psi during this topping period which is not surprising since the V-3801 liquid level was 23.7% and the GH₂ bank pressure was less than 600 psig. Utilization data based on other topping tests are given in Table 3.7.1.

The GH₂ utilized to maintain V-3801 pressurized at 95 psig during initial fill of V-5002 was 141 lbs with an initial V-3801 level of 88%. 3800 lbs of LH₂ were used resulting in a specific ratio of lbs of gas to lbs of LH₂ of .035. The initial fill and chillover of the 4-LH-6 line was then accomplished in about 10 minutes with an expulsion of 6300 lbs of LH₂ from V-3801. The GH₂ utilization to maintain pressurization during this time was 272 lbs. This results in a specific ratio of lbs of GH₂ to lbs of LH₂ of .043.

3.7.3.2 V-3801/V-5001 Transfer System

The V-3801/V-5001 transfer system (3-LH-6 line) has been evaluated based on data obtained during the FEP test series for; 1) initial fill, chillover and chillholding characteristics, and 2) steady-state characteristics during V-5001 topping operations.

The initial fill and chillover of the 3-LH-6 transfer line and V-5001 was accomplished in one operation by opening RSV-83 with 50 psig in V-3801 and flowing through RSV-128

3.7.3.2 V-3801/V-5001 Transfer System (Cont'd)

into V-5001 while venting out PCV-180 and RSV-390. The liquid interface reached RSV-128 in 170 seconds after opening RSV-83. The measured amount of LH_2 to fill and chill the transfer line was about 500 lbs.

Figure 3.7.3 exhibits the chillholding characteristics of the 3-LH-6 line. Figure 3.7.3 shows TT-44, the temperature in the transfer line upstream of RSV-128/129, during the V-5001 dewar drain from 70% to 15%. It is seen that while the line was locked up for over 400 seconds, a temperature rise was not observable at TT-44. When the line was vented through RSV-130, slugs of warm fluid pass TT-44, but after about 55 seconds a liquid temperature of 39.9°R is re-established at TT-44. Thus after hold periods it is necessary before the initiation of topping to flush the transfer line (460 lbs of LH_2) through RSV-130 for about 50 seconds until TT-44 reaches stable conditions.

Figure 3.7.4 shows the pressure differential between V-3801 (PT-68) and V-5001 (PT-99) versus the topping flow rate. The topping flow rates were determined by both the change in V-3801 level and by the change in V-5001 level and integral FT-14 flow. There is good agreement between the methods of topping flow rate determination and generally good agreement with what is expected.

The LH_2 warm-up in the line between the 10% level of V-3801 (TT-402) and TT-44 during chillholding flow rates of 14 lbs/sec is approximately $.7^\circ\text{R}$. During the topping flow tests with flow rates of about 80 lbs/sec, the temperature rise was 1.0°R .

3.7.3.3 LH_2 Storage Dewar Instrumentation

Table 3.7.2 is a summary of V-3801 level instrumentation. The location given for each transducer is height above the bottom of the dewar in inches (the rake starts 11.5 inches above the bottom of the dewar).

FIGURE 3.7.3

TRANSFER LINE TEMPERATURE (TT-44)

V-3801 Temperature = 38.5°R
during this time.

Topping Flow Rate Vs Differential Pressure
Between V-3801 and V-5001

FIGURE 3.7.4

TABLE 3.7.2

V-3801 LH₂ Level Instrumentation Data

Instrument Number	Sensor Type	Location Above Bottom	Volume (based on 69,534 gal = 100%)		
			%	Gallons	Lbs (at 4.35 $\frac{\text{lb}}{\text{ft}^3}$)
LT-492	Resistor	438.8	100	244,830	142,000
491		399.7	95	232,609	134,910
490		374.4	90	220,389	127,820
489		352.9	85	208,169	120,740
488		333.6	80	195,949	113,650
487		314.7	75	183,728	106,560
486		298.7	70	171,508	99,470
485		282.3	65	159,288	92,390
484		266.4	60	147,067	85,300
483		252.6	55	134,847	78,210
482		235.1	50	122,627	71,120
481		219.3	45	110,407	64,040
480		203.6	40	98,116	56,930
479		187.5	35	85,966	49,860
478		170.8	30	73,746	42,770
477		153.5	25	61,526	35,680
476		135.0	20	49,305	28,600
475		114.9	15	32,085	21,510
474		92.1	10	24,865	14,420
473		63.5	5	12,645	7,330
472		11.5	0	425	246
LT-493	11 Resistors	11.5 to 434.8	0-100%	425-244,830	246-142,000
LT-2	Continuous Capacitance	11.5 to 434.8	0-100%	425-244,830	246-142,000
LT-405	Capacitor	436.1	100 H	244,990	142,100
404		329.6	75 H	193,473	112,210
403		226.0	50 H	113,146	65,620
402		116.5	25 H	37,977	22,030
401		52.0	10 H	8,800	5,090
TT-508	RTT	434.8	100 H	244,990	142,000
35		52.0	10 H	8,800	5,090
401		52.0	10 H	8,800	5,090
402		52.0	10 H	8,800	5,090

NOTE: 1. The point capacitance probe locations are based on percentage of probe height. This is converted to volume in the gallons and lbs columns.

3.7.3.3 LH₂ Storage Dewar Instrumentation (Cont'd)

Figure 3.7.5 shows the comparison of the level indications obtained from the continuous capacitance Simmonds probe (LT-002) and the point resistance probe. The 0% and 100% intercepts establish the location of LT-002 and show an apparent height of 422 inches which is in good agreement with the height of 421.19 inches as shown on the Simmond's drawing. Figure 3.7.5 indicates that the bottom of LT-002 is 32.5 inches above the bottom of the dewar while the drawing indicates it as 17 inches. This discrepancy has not been resolved; however, better agreement with other instrumentation (LT-453, integral of FT-14, and V-3801 point resistors) is obtained by using 32.5 inches. The relation of LT-002 indication in percent of probe height to lbs of LH₂ assuming a density of 4.35 lbs/ft³ is shown in Figure 3.7.6. This curve is based on the apparent height of 32.5 inches. As discussed in Section 3.8.3.3, LT-002 indications correlated well with LT-453 and the integral outflow measured by FT-14.

The resistance ladder, LT-493, which is composed of eleven carbon resistors was not set up during the test analyzed. As discussed previously, all the point resistors for which data was available worked properly. Of the point capacitors, only the 25% point capacitor worked. TT-32 was the only one of the 10% RTT's which was set up during the tests analyzed and it functioned properly. Also the 100% (ullage) temperature appeared to work correctly.

3.8 LP LH₂ Propellant System

3.8.1 Description

The LP LH propellant system and associated instrumentation is shown in Figure 5.1. The LP LH₂ propellant system consists of the LP LH₂ dewar (V-5001), the LP LH₂ dewar pressurization and vent system, and the LP LH₂ propellant system.

FIGURE 3.7.5

LT-2 Calibration

LT-2 % Probe Heights Vs. Point Resistance

Probe Inches Above Bottom

3.8.1.1 LP LH₂ Dewar

The LP LH₂ dewar has a maximum working pressure of 50 psig and a LH₂ capacity of 77,000 gallons.

3.8.1.2 LP LH₂ Dewar Pressurization and Vent System

The LP LH₂ dewar pressurization and vent system is shown in the aforementioned Figure. The significant components of the system are the pressure regulation valve, PRV-426, and the pressure control valves, PCV-165/180. PRV-426 is a 2-inch, pneumatically actuated, Grove valve with a vendor quoted C_v of 20 which is used to maintain a constant pressure upstream of PCV-165. PCV-165 is a 2-inch, pneumatically actuated, Annin pressurization control valve with a percentage plug and a vendor quoted C_v of 13. PCV-180 is a 6-inch, pneumatically actuated, Annin vent control valve with a percentage plug and a vendor quoted C_v of 400. PCV-165/180 control the dewar pressure simultaneously when in the automatic control mode.

3.8.1.3 LP LH₂ Propellant System

The LP LH₂ propellant system is shown in the aforementioned Figure. The significant components of the system are the remote shutoff valves RSV-455 and RSV-132 and the turbine flowmeters FE-425 and FE-14. RSV-455 and RSV-132 are, respectively, 2 and 8-inch, pneumatically actuated Hadley butterfly valves with a vendor quoted C_v of 114 and 3473. Flowmeters, FE-425 and FE-14, are 8-inch Potter turbine meters. Based on water flow calibration from the vendor and a LH₂ density of 4.4 lbs/ft³, a k factor of 4.55 cycles/lb was used for both meters.

3.8.2 Performance Objectives

The LP LH₂ propellant system performance objectives accomplished during the FEP test series were to:

3.8.2 Performance Objectives (Cont'd)

- 1.0 Determine the initial chilldown and chillholding characteristics of the LP LH_2 dewar (V-5001) and propellant supply line.
- 2.0 Determine the steady-state flow, pressure, and temperature characteristics of the LP LH_2 propellant system with and without topping.
- 3.0 Evaluate the adequacy of the V-5001 LH_2 level instrumentation systems.
- 4.0 Evaluate the adequacy of the V-5001 pressurization and vent systems.

3.8.3 Test Results

3.8.3.1 LP LH_2 Dewar Pressurization and Vent System

The LP LH_2 dewar pressurization and vent system has been evaluated based on data obtained during the FEP test series for initial pressurization and for pressurization during LH_2 outflow without and with topping.

Figure 3.8.1 shows the V-5001 dewar pressure (PT-099) and PCV-165 position during the initial manual pressurization from 2 psig to 45 psig. The pressurization time was 1.3 minutes and utilized 37.9 lbs of GH_2 . The apparent collapse factor was 1.1. It is noted that the 10% liquid level temperature increased $.2^\circ\text{R}$ during the pressurization.

Figure 3.8.2 shows the dewar pressurization characteristics during LH_2 outflow without and with topping. The parameters shown are PCV-165 position, PCV-180 position, PCV-750 position, V-5001 demand pressure, V-5001 actual pressure (PT-099), PCV-165 inlet pressure (PT-598), FT-14 flow rate, and liquid level (LT-453). It is seen that the pressurization system is

FIGURE 3.8.1

Pressure and Valve Position Vs Time
During V-5001 Pressurization

Figure 3.8.2

V-5001 Pressurization During LH₂ Outflow With and Without Topping

3.8.3.1 LP LH₂ Dewar Pressurization and Vent System (Cont'd)

capable of maintaining the demanded pressure with 1 psi even under flow initiation transients up to 100 lbs/sec. The oscillations in PCV-165 position are due to the gain of the pressure control system. As the liquid level decreases these oscillations decrease. The GH₂ utilized during the expulsion of 3550 lbs of LH₂ at 82 lbs/sec was 39.2 lbs. which gives a specific ratio of lbs of GH₂ to lbs of LH₂ of .011. Table 3.8.1 presents the pressurization data for various pressurizations during LH₂ outflow without topping. Figure 3.8.2 shows that after topping is initiated, the pressurization system is capable of maintaining the demanded pressure. The GH₂ utilization in V-3801/V-5001 during topping is discussed in Section 3.7.3.1. It is to be noted that GH₂ utilization is decreased during topping operations.

It was noted during the FEP-III-2 test that with PCV-165/180 in AUTO control, increasing the demanded dewar pressure at low ullage conditions resulted in swings in V-5001 pressure of approximately 7 psi. The valves, PCV-165/180, behaved as though they were in binary control, i.e., the valves alternately went from closed to fully open and then closed again at their maximum slew rates. The swings on dewar pressure during reduction in demanded dewar pressure were not so severe. To eliminate this condition PCV-180 is being removed from the AUTO control mode.

3.8.3.2 LP LH₂ Propellant System

The LP LH₂ propellant system has been evaluated based on data obtained during the FEP test series for 1) initial chilldown and chillholding of the LP LH₂ dewar, 2) initial chilldown of the propellant supply line, and 3) steady-state characteristics during LH₂ outflow.

3.8.3.2.1 Initial Chilldown and Chillholding of the LP LH₂ Dewar

The initial fill and chill of the 3-LH-6 transfer line and

TABLE 3.8.1
Summary Table of V-5001 Pressurization

Operation	FEP	Time Interval Considered For Utilization Sec.	V-3801 Press. PT-086 Psig	V-3801 Liquid Level LT-002	V-5001 Press. PT-009 Psig	V-5001 Level % LT-453	V-5002 Press. PT-097 Psig	V-5002 Level % LT-009	Lbs. GH ₂ Used	Apparent Collapse Factor	Polytropic Exponent n	Lbs. LH ₂ Used	Specific Ratio #GH ₂ /#LH ₂
V-5001 Utilization During Outflow With No Topping	III-II	47010.0	96.32	56.8	8.7	80	----	----	----	----	----	----	----
		47090.0	97.16	56.4	10.3	78	----	----	41	----	----	3950@ 52 pps	.0104
		47245.0	95.7	53.6	28.5	80	----	----	----	----	----	----	----
		47285.0	96.1	53.6	27.4	78	----	----	31	----	----	3110@ 80 pps	0.010
		49760.0	96.1	41.6	44.6	80	----	----	----	----	----	----	----
		49803.0	96.7	41.5	44.9	78	----	----	39.2	----	----	3550@ 82 pps	.011
		50560.3	96.4	39.24	10.1	15	----	----	----	----	----	----	----
		50595.0	95.7	39.07	9.99	15	----	----	15.7	----	----	1420@ 40 pps	.011
		51400	93.9	23.8	44.8	40	----	----	----	----	----	----	----
		51410	94.0	23.73	44.72	20	----	----	10.9	----	----	807@ 82 pps	.0135
		51890.2	94.23	14.6	44.4	8	----	----	----	----	----	----	----
		519300	94.3	14.6	44.6	4	----	----	33	----	----	2540@ 66 pps	.013

3.8.3.2.1 Initial Chillydown and Chillyholding of the LP LH₂ Dewar (Cont'd)

V-5001 was accomplished in one operation by opening RSV-83 and flowing through RSV-128 into V-5001 while venting out PCV-180 and RSV-390. The 6-inch fill valve, RSV-129, was opened when LH₂ was detected in V-5001.

Figures 3.8.3 and 3.8.4 show the V-3801 and V-5001 level, temperature and pressure during the fill and initial chillydown operation. The transfer line temperature, TT-44, is also shown. It is seen that liquid reached RSV-128 170 seconds after RSV-83 was opened. During the next 400 seconds, all of the LH₂ flowing into V-5001 flashed immediately and no LH₂ was accumulated in the dewar. Although the 10% point resistance probe indicated liquid, this was not confirmed by the RTT probes (TT-32 and TT-512). The amount of LH₂ transferred during this time was 1700 lbs. The RTT temperature indication in V-5001 decreases rapidly from ambient as soon as liquid began arriving, stabilizing finally at 35.5°R. When RSV-129 was opened, the fill rate increased from 4 lbs/sec to 40 lbs/sec as indicated by the V-3801 level change. V-5001 was filled for another 775 seconds. Then after waiting 275 seconds for boil-off, the run tank was topped off. The total time required to fill, stabilize, and refill V-5001 was about 30 minutes with V-3801 pressurized to about 95 psig.

The total LH₂ required to fill and chill the transfer line and V-5001 was 41,000 lbs as measured by V-3801 level change. 700 lbs of GH₂ was utilized during this operation which results in a specific ratio of lbs of GH₂ to lbs of LH₂ of .017. The LH₂ utilized, however, is felt to be low since the pipe and dewar volume is 42,000 lbs.

After venting, the extent of the chillydown was evaluated by closing the vent valves and observing the pressure and temperature rise for a period of five minutes. During this hold, the pressure rose rapidly to the saturation pressure of the

FIGURE 3.8.3

V-5001 Pressure and Level
During Initial Fill and Chillovn

N.T.O.-ETS-1
TEST ED1-3 DATE MAR24.67

1	--	PT-068	--	PSIG
2	--	PT-098	--	PSIG
3		LT-2		% FULL
4		LT-453		% FULL
5		TT-32		OR
6		TT-402		OR
7		TT-44		OR

FIGURE 3.8.4

V-5001 Temperature During Initial Fill and Chilledown

N.T.O.-ETS-1
TEST EDI-4 DATE MAR 24.67

3.8.3.2.1 Initial Chillover and Chillover of the LP LH_2 Dewar (Cont'd)
surface fluid (about 7.5 psig) and from there held steady. Throughout this time, the temperature measured at the 10% liquid level held steady at 35.5°R . The dewar thus appeared to be fairly well chilled.

3.8.3.2.2 Initial Chillover of the Propellant Supply Line

Figures 3.8.5 and 3.8.6 show temperature, pressure, and vent valve action during the propellant supply line (PSL) initial chillover. The PSL was pressurized with GHe using PRV-439 prior to LH_2 operations. It was seen that with 65 psig at PCV-439 outlet (PT-547) GHe was flowed through the PSL with a flowmeter indication of 86 lbs of LH_2 /sec and with no line pressure rise. Therefore, GHe can be flowed through the PSL without overspeeding the flowmeter and with no line pressure rise provided the pressure at PCV-439 outlet (PT-547) is maintained below 75 psig.

For the first 200 seconds, the line temperature did not show much change, but when V-5001 pressure was raised to 5 psi, TT-31 indication came down rapidly and the vent temperature more slowly so that in 450 seconds, liquid conditions were achieved at the vent. No measurement of the amount of fluid used could be made, because the level probe LT-453 read in only 10% or 4,000 lbs steps in this region and only a maximum of 600 lbs was predicted as necessary to chill and fill the PSL.

3.8.3.2.3 Steady-State Characteristics During LH_2 Outflow

The V-5001 propellant system flow, pressure, and temperature characteristics have been evaluated during the FEP test series. Tests were conducted with and without topping for various V-5001 dewar pressures.

Figure 3.8.7 shows the correlation of the flowmeters FT-014 and FT-425. Analysis of the test data indicated that FT-425

FIGURE 3.6.6

N.T.O.4-ETS-I
TEST EDP-1 DATE MAR 24 .67

Line Temperatures Versus Time
During In Hel Chill down of the Propellant Supply Line

1	-#- TT031	-#- RANKINE
2	-#- TT032	-#- RANKINE
3	-#- TT475	-#- RANKINE
4	-#- TT533	-#- RANKINE
5	-#- TT763	-#- RANKINE

FT-14 LH₂ Flow Rate Vs FT-425 LH₂ Flow Rate

FIGURE 3.8.7

3.8.3.2.3 Steady-State Characteristics During LH_2 Outflow (Cont'd)

had a tendency to stick at very low flow rates and at flow rates around 40 lbs/sec. FT-014 integrated flow agreed with the decrease in dewar level and appears to be adequate for engine testing.

Flowmeter FT-425 has been removed to decrease the pressure drop in the propellant feed system.

Figure 3.8.8 shows the propellant system pressure drops as a function of FT-014 LH_2 flow rate. The system pressure drops shown are; 1) between the dewar, PT-99, and the flowmeter inlet, PT-100, 2) between PT-100 and the F/E interface pressure, PT-485, and 3) between PT-99 and PT-485.

The pressure drop data shown in Figure 3.8.8 has been corrected for elevation head. It is seen that the pressure drop between PT-99 and PT-100 at 80 lbs/sec is 3.6 psi. The pressure drop between PT-100 and PT-485 is 2.6 psi at 80 lbs/sec. It should be noted, however, that this pressure should decrease by about 1 psid after FT-425 is removed. The total system pressure drop between PT-99 and PT-485 of 6.3 psi at 80 lbs/sec will also be decreased by about 1 psid with the removal of FT-425. Thus, at a run tank pressure of 35 psia the F/E interface pressure will be 28.7 psia excluding elevation head effects. The saturation temperature at 28.7 psia is 42°R.

Figure 3.8.9 shows the increase in LH_2 temperature between the V-5001 dewar (TT-32) and the F/E interface (TT-475) as a function of LH_2 flow rate for three ramp ups to 80 lbs/sec. It is anticipated that there will be an increase in LH_2 temperature of .5°R at a flow rate of 80 lbs/sec. This increase in LH_2 temperature appears to be independent of the initial LH_2 temperature in the dewar. Thus, during topping operations with warmer LH_2 , the dewar and F/E interface temperatures will maintain the same differential temperature but increase as the warmer fluid is evidenced in the system.

Differential Pressure, ΔP , psid

PT-99 to PT-100

PT-100 to PT-485

PT-99 to PT-485

FIGURE 3.8.8

Differential Pressure Versus FT-14 LH₂ Flow Rate

Temperature Rise Vs FT-14 LH_2 Flow Rate

FIGURE 3.8.9

3.8.3.2.3 Steady-State Characteristics During LH₂ Outflow (Cont'd)

Figure 3.8.10 shows the LH₂ flow rates obtainable through PCV-579 essentially 100% open for various V-5001 dewar pressures. It is seen that for a dewar pressure of 35 psia that the LH₂ flow rate is 5.2 lbs/sec. At this flow rate through PCV-579, it is expected that the temperature rise between the dewar and the F/E interface will be about 2°R.

3.8.3.3 Low Pressure LH₂ Dewar Instrumentation

The performance of the low pressure LH₂ dewar (V-5001) level instrumentation has been evaluated based on data obtained during FEP-III-2. The instrumentation evaluated were the continuous capacitance probe, the point capacitance indicators, the point resistance indicators, and the temperature probes.

Table 3.8.2 is a summary of V-5001 level instrumentation, including locations and the percent volume at these locations.

Figure 3.8.11 is a comparison of the level changes based on the integral FT-14 flow and on the carbon resistance level probe (LT-453). Figure 3.8.11 is based on data obtained when the dewar was emptied from 15% to 1% and from 60% to 20%. There was no topping during these periods. It is seen that there is agreement between the integral FT-14 flow and LT-453. The only point resistor that failed to indicate was the 30% one. The cause of this failure has been investigated, but no reason for this anomaly has been found.

The continuous capacitance Simmonds probe (LT-10) did not function properly; however, during the test, LT-453 successfully backed it up. The point capacitance indicators also did not function.

Table 3.8.3 is a comparison of LT-453, the point resistors, and the temperature probes. Point resistor data above 20% was not recorded. This table shows that LT-453 is indicating

V-5001 Pressure Vs LH₂ Flow Out of PCV-579

FIGURE 3.8.10

TABLE 3.8.2

V-5001 LH₂ Level Instrumentation Data

Instrument Number	Sensor Type	Location Above Empty Mark, Inches	Volume (based on 69,534 gal = 100%)		
			%	Gallons	Lbs (at 4.4 $\frac{\text{lb}}{\text{ft}^3}$)
LT-458	Resistor	360.68	100	69,534	40,900
451		329.12	90	62,500	36,800
450		297.82	80	55,500	32,600
449		291.56	78	54,200	31,800
448		285.30	76	52,800	31,000
447		279.05	74	51,400	30,200
446		272.79	72	50,000	29,400
445		266.53	70	48,600	28,600
444		235.23	60	41,700	24,500
443		203.83	50	34,700	20,400
442		172.63	40	27,800	16,400
441		141.34	30	20,800	12,200
440		110.04	20	13,900	9,700
439		90.38	15	10,400	7,200
438		77.60	10	7,000	4,100
437		69.54	8	5,600	3,400
436		60.08	6	4,200	2,500
435		48.37	4	2,800	1,600
434		32.28	2	1,400	800
433		20.46	1	700	400
432		0	0	0	0
453	ALL Above Resistors	0-360.68	0-100	0-69,534	0-40,900
LT-010	Continuous Capacitance	0-360.68	0-100	0-69,534	0-40,900
LT-425	Capacitor	360.68	100 H	69,534	40,900
424		282.17	75 H	52,100	30,500
423		203.83	50 H	34,700	20,400
422		125.69	25 H	17,400	10,200
421		77.60	10 H	1,400	1,000
TT-518	RTT	360.68	100	69,534	40,900
517		297.82	80	55,500	32,600
516		235.23	60	41,700	24,500
515		172.63	40	27,800	16,400
514		110.04	20	13,900	9,700
513		77.60	10	7,000	4,100
512		53.59	5	3,500	2,100
032		77.60	10 H	1,400	1,000
421					
420					

LT-453 Level Indication
Pounds of $\text{LH}_2 \times 10^{-3}$

FIGURE 3.8.11

Calibration of LT-453

Based on Integral V-5001 Outflow

TABLE 3.8.3
V-5001 INSTRUMENTATION
PERFORMANCE

Resistance Probe LT-453		Individual Resistors		RTT			REMARKS
Level	Time	LT Numbers	Time	RTT	Lag	Temp.	
80-78	47075		Not Recorded	517	No Response	--	Dewar Press. at 10 psig
78-70	47105		Not Recorded	517	No Response	--	TT-518 100% Indicated 58°R
-----	47230		-----	---	-----	--	Dewar Press. Increased
80-78	47278		Not Recorded	517	8 Sec.	45°R	Dewar Press. at 25-28 psig
78-80	47385		Not Recorded	517	0 Sec.	45°R	Dewar Press. at 30-32 psig
80-78-76	47592		Not Recorded	517	0 Sec.	45°R	Dewar Press. at 45 psig
78-80	48510		Not Recorded	517	0 Sec.	45°R	Dewar Press. at 19.5 psig
80-78	49800		Not Recorded	517	0 Sec. 10 Sec.	40°R 45°R	Dewar Press. at 45 psig
-----	49870						Dewar Press. Decreased from 40 psig. T-517 (80%) Dropped to 39.5°R at 49915 Sec.
60-50	49990		Not Recorded	516	No Change	39°R	Dewar Press. = 10 psig TT-517 (80%) Read 34°R
40-20	50400		Not Recorded	515	No Change	39°R	Dewar Press. 10 psig TT-516 (60%) Reads 39°R
20-15	50550	440	50550	514	No Change	40°R	Dewar Press. = 10 psig TT-515 (40%) Reads 40°R

TABLE 3.8.3 (Cont'd)

V-5001 INSTRUMENTATION
PERFORMANCE

Resistance Probe LT-453		Individual Resistors		RTT			REMARKS
Level	Time	LT Numbers	Time	RTT	Lag	Temp.	
15-20	50650	440	50657	514	No Change	40°R	Dewar Press. = 10 psig
-----	50765						Dewar Press. Rises from 10 psig
	50815						Dewar Press. at 30 psig
20-15	50820	440	50823	514	0-5 Sec Late	38-40°R	Dewar Press. = 31 psig
					45 Sec Late	45°R	
15-20	50925	440	50920 ⁺ 10	514	0 Sec Late	45°R	" " " " "
20-15	51565	440	51565	514	-20-0 Sec. Early	40-42°R	" " " 45 psig
					25 Sec.	45°R	
	51630			514	Not Related	40°R	Temp. Falls to Sat. Point when Press. Falls to 25 psig
	51720			514	Not Related	40°R	Temp. Rises Above Sat. when Press. Rises Above 25 psig
15-10	51800		Not Recorded				
10-8	51888	438	Data Lost	513	10 Sec. Late	45°R	Dewar Press. = 45 psig
8-6	51900	437	Data Lost				
6-4	51914	436	Data Lost				
(5)				512	10 Sec. Late	45°R	Dewar Press. = 45 psig
4-2	51929	435	Not Recorded				
2-1	52000	434	52003				

3.8.3.3 Low Pressure LH₂ Dewar Instrumentation (Cont'd)

a change in level at the time that the point resistor is switching. Thus the point resistors are capable of being used as a backup in the event that a point resistor fails and causes LT-453 indication to fall below the actual liquid level.

The temperature probes indicated a change in LH₂ levels consistent with LT-453 under constant dewar pressure conditions. However, the temperature probes failed to respond to level changes during those periods when the dewar pressure decreased. When the dewar pressure drops, boiloff results, which creates a layer of saturated vapor which extends above the liquid surface. As the liquid level falls below a RTT probe, no discernible change in temperature occurs until the passage of the saturated vapor layer. As soon as the dewar is again pressurized, the layer of saturated vapor condenses and the temperature probes accurately indicate the passing of the liquid-gas interface.

The point resistors are not affected by the ullage being at saturated temperature; they indicate gas as soon as the heat removal rate seen by them becomes less than that in liquid. Therefore, the RTT temperature probe rake and the point resistor readout can provide reliable and independent backups to LT-453, provided that the dewar pressure is held relatively constant during LH₂ propellant flow operations.

3.9 ENGINE FLOW SIMULATOR

3.9.1 Description

The engine flow simulator is a temporary system of piping used to permit checkout of the facility cooldown and propellant systems during the FEP test series. The engine flow simulator and associated instrumentation is shown in Figure 5.1. It consists of two lines; a cooldown simulator line which tees into the facility cooldown line downstream of LF-7, and a propellant simulator line which ties into the propellant feed line at the facility/engine interface. These two lines join with spectacle blind flanges at the inlet to PCV-750 which was adjusted to either simulate engine impedance for various cooldown fluids, or to permit varying tank pressures for propellant flow testing. The cooldown or propellant fluids were then discharged to atmosphere through a 24-inch by 150-foot temporary flare stack.

During checkout of the cooldown systems performed during FEP-I, II, III-1 and IV, the propellant simulator line was blanked off near PCV-750. Conversely, during FEP-III-2, when flowing through the propellant simulator line, the cooldown line was blanked off. An 8-inch bypass line was installed around PCV-750 prior to FEP-III. This bypass line contained a blank for cooldown system testing and a 4-inch diameter restricting orifice for propellant system testing.

The significant components of the simulator are the venturi meter, FEX and pressure control valve, PCV-750. The venturi meter ($\beta = .5$) was installed to provide a cross check of the calibration of the various facility flowmeters. The following equations were developed to express mass flow rate through FE-X as a function of inlet conditions based on water flow calibration data. The gas equations are for choked FE-X conditions.

$$\overset{\circ}{W}_{\text{liquid}} = 3.04 \sqrt{\Delta P \rho}$$

$$\overset{\circ}{W}_{\text{GH}_2} = 0.0272 P$$

3.9.1 Description (Cont'd)

$$\begin{aligned} \overset{\circ}{W}_{\text{GHe}} &= 0.0415 P \\ \overset{\circ}{W}_{\text{GN}_2} &= 0.1015 P \end{aligned}$$

Where P is the inlet pressure, ΔP is the inlet to throat static differential pressure, and ρ is the fluid density at inlet conditions in lbs/ft^3 . The gas equations are normalized to an inlet temperature of 530°R and a compressibility factor (Z) of 1.0.

The engine back pressure simulation is provided by PCV-750 installed with flow under the plug. This is a 5-inch, equal percentage plug, maximum C_v of 265, Annin cryogenic valve.

3.9.2 Test Results

The engine flow simulator characteristics have been evaluated based on data obtained from the FEP test series.

Figure 3.9.1 shows the PCV-750 valve liquid impedance characteristics without the 4-inch bypass orifice installed. $W/(\Delta P \rho)^{\frac{1}{2}}$ is shown as a function of PCV-750 percent open. The ΔP in this relationship is the differential pressure across PCV-750 (PT-774 to PT-775). The differential pressure between FE-X inlet (PT-770) and PCV-750 inlet (PT-774) as a function of LH_2 and LN_2 flow is presented in Section 3.6.3.

Figures 3.9.2 and 3.9.3 show, respectively, the PCV-750 inlet (PT-774) and outlet (PT-775) pressure characteristics for GH_2 , GHe and GN_2 with PCV-750 set approximately 89% open. The PCV-750 setting required to simulate the nozzle torus pressure for gas flow was determined to be 89%. At this setting both PCV-750 and FE-X are sonic, while significantly below this setting FE-X venturi was not sonic. The FE-X inlet pressure as a function of GH_2 , GHe and GN_2 flows are presented, respectively, in Sections 3.4.3, 3.3.3 and 3.5.3.

FIGURE 3.9.1

PT-774 Pressure Vs Flow Rate

FIGURE 3.9.2

PT-775 Pressure Vs. Flow Rate

FIGURE 3.9.3

3.9.2 Test Results (Cont'd)

Figure 3.9.4 shows the facility/engine interface pressure (PT-485) and the PCV-750 inlet (PT-774) and outlet (PT-775) pressure as a function of FT-14 flow rate with the 4-inch bypass orifice around PCV-750 installed. The curves of PT-485 and PT-774 are for PCV-750 0% and 100% open. The curve of PT-775 is independent of the PCV-750 position.

FT-14 LH₂ Flow Rate Vs. Pressure

FIGURE 3.9.4

3.10 TEST STAND HEATING

3.10.1 Purpose

A study of the effects of the plume thermal radiation resulting from LH_2 discharge from the temporary exhaust header during FEP-III-2 has been made. This study was performed to 1) evaluate methods for obtaining plume heat flux data, 2) evaluate the effects of plume heating on test stand equipment, and 3) evaluate the effects of wind conditions on the behavior of the temporary exhaust plume. The experience and general information gained from this study will be used in the NEP plume thermal radiation study.

3.10.2 Instrumentation

The location of the five types of data collecting devices used to obtain test stand thermal radiation data during FEP-III-2 are shown in Figure 3.10.1. One 12-frame/sec (20-min duration) IR camera was located 250 feet northwest of the plume and one 12-frame/sec (20-min duration) color camera viewed the Tempilaq painted on the southwest side of the TV Bunker shield. The backside of the TV Bunker shield was stripped with 200°F, 400°F, 600°F, 800°F, 900°F and 950°F Tempilaq paint to obtain temperature limits on a large area close to the plume. Thermocouples (TE-769 through TE-775) were installed on critical areas of the test stand and the side shield to be monitored during the test to prevent major damage. Two 60 BTU/Sec-ft² radiometers (TI-777 and 778) were located on the projected flare stack centerline in an attempt to ascertain near plume heat flux. A 15 BTU/sec-ft² radiometer (TE-776) was mounted on the shadow wall adjacent to the test stand to gather test stand incident heat flux. An Anemometer, located approximately 30 feet above the CP, was used to measure the wind velocity and direction.

3.10.3 Test Results

The flow and heat release rates for three of the runs during

FIGURE 3.10.1

3.10.3 Test Results (Cont'd)

during FEP-III-2 are given in Table 3.10.1. The plume radiant heat flux is then the heat release times its emissivity divided by the plume surface area. A summary of the measured heat flux during Runs A, B and C are shown in Table 3.10.2. The maximum measured temperature of 756°R was recorded by TE-775 during Run B (range time 50905).

TABLE 3.10.1

ENERGY RELEASE

RUN	Range Time	Δ Sec.	Total H ₂ Used (lb)	Average Flow Rate Lb/sec	Total Heat Release BTU x 10 ⁻⁸	Average Heat Release Rate(BTU/sec)
A	46822 to 47105	283	8,450	30	4.39	1.5 x 10 ⁶
B	49750 to 51045	1,295	54,000	41.5	28	2.15 x 10 ⁶
C	51385 to 51596	211	16,000	80	8.72	4.15 x 10 ⁶

The damage to the area near the temporary exhaust header exit consisted of; 1) destruction of the insulation on the portion of the cables for TI-777 and TI-778 that was behind the outboard shield track near the spalled concrete, 2) spalling of the concrete at the end of the NE shield park pad, 3) smoldering of the steam generator tarp and of the paint on the storage bin, 4) burning of the west light pole, 5) maximum displacement of the EIV track of 24 inches with a maximum permanent deformation of 7 inches, and 6) software damage to the exposed portion of the steam generator.

TABLE 3.10.2

MEASURED HEAT FLUX

RUN	RANGE TIME	W Lb/sec FT-014	TE-776 BTU/Ft ² sec	TI-777 BTU/Ft ² sec	TT-778 BTU/Ft ² sec
A	46894	12.7	.48	1.09	.42
	46895	13.7	.45	.59	.23
	46904	18.4	.51	1.29	.50
	47006	45.0	.49	3.5	1.76
	47060	47.5	.64	3.87	1.83
	47100	40.0	.69	3.15	1.11
	47104	0	.68	3.57	.28
	47118	0	.62	1.21	Lost Signal
	47128	0	.45	Lost Signal	-
B	50778 to 50790	43.0 to 67.0	.73	----	----
	50803 to 50808	79.0	.77 to .81	----	----
	50210 to 50909	28.0 to 79.0	.6	----	----
	51387	20.0	.52	----	----
	51388	100 Spike	.59	----	----
	51452	82.0	.66	----	----
C	51385 to 51596	81.0 (Avg.)	.6 (Avg.)	----	----

3.10.3 Test Results (Cont'd)

This test has demonstrated that plume flow rates as high as 83 lbs/sec and exit velocities of near mach 1 are guided by a wind velocity as low as 4 to 10 mph. The steam generator area, the shield trailer, and the steam generator tarp configuration are an excellent example of how equipment, when properly protected, can sustain high radiant heat flux. The northwest and northeast sides and top of the shield trailer were covered with aluminum foil and its paint and rubber tires were not damaged while unprotected equipment on either side was damaged.

From the present data, it appears that the facility damage encountered during FEP-III-2 was caused by a high flow rate plume directed by 4 to 20 mph winds which made 360° changes in direction, 4 cycles during the first 30 minutes of testing and another 360° cycle during the next 40 minutes. When the wind direction stabilized on a west 20° north direction, it probably sweeps up the duct trench, run-off ditch, across the flare stack exit, and down the EIV track ditch sweeping the plume with it.

This capricious wind made it impossible to make a quantitative plume radiant heat flux analysis. However, it did illustrate that the NES duct plume, which will have a lower exit mach number, could cause major damage with adverse wind conditions.

3.11 COOLDOWN AND PROPELLANT SYSTEM(S) CONTAMINANT EVALUATION

3.11.1 Purpose

The cooldown and propellant system(s) contaminant evaluation has been made to verify compliance with the proposed Standards for XE Cleanliness Levels for NRDS Operations, Specification AGC-STD-9007.

3.11.2 Test Results

The contaminant evaluation of the engine cooldown systems was made during FEP-IV. During the test series an equivalent of

3.11.2

Test Results (Cont'd)

approximately 100,000 gallons of fluid was passed through LF-7, the permanently installed terminal filter, located upstream of the XE cooldown inlet line.

The residue collected in that filter and the distribution of contaminants throughout the total amount of flushing fluids used during FEP-IV is shown in Table 3.11.1.

TABLE 3.11.1

<u>Particle Size in Microns</u>	<u>Particle Count of 500 ml Sample of Filter Flushing Fluid</u>	<u>Calculated Particle Count Per 1000 ml of Flushing Fluid Through Filter</u>
150 - 300	Too Numerous To Count	Undetermined
301 - 600	1200 Approx.	0.12 Average
601 - 3000	40 Approx.	0.004 Average
3001 - ∞	3 Approx.	0.0003 Average

It is surmised that the number of particles in the 150 to 300 micron size, although too numerous to count in the concentrated sample, fall into the order of magnitude of the established number of the larger particles.

The low level of contamination of the system can be explained by the fact that the ETS-1 cooldown system, after final installation, had been flushed with copious amounts of fluids during FEP-I, II, III-1 and III-2, as well as the cryo-shock tests preceding FEP-III.

It should be further understood that the system cleanliness thus established covers the system upstream of the terminal filter, LF-7. Any amount of remaining contamination will be further reduced by filtration prior to entering the engine.

The contamination evaluation of V-5001 and the propellant system was made during FEP-III-2 and three (3) GN₂ blowdown tests

3.11.2 Test Results (Cont'd)

conducted on 23-24 May 1967. During FEP-III-2, a system consisting of an impact collection tube, a remotely operated valve, and a 10 micron filter were installed at the lower end of the test pipe. During the latter portion of the flow test, approximately two gallons of LH_2 were shunted through the sample system. The residue collected in the sample filter and the distribution of contaminants through the fluid sampled indicated that the particle count in the 150 to 300 micron size exceeded the allowable amount by 50%. However, there was some doubt as to the validity of this sample because it might have been possible to trap contaminants in the impact tube prior to the sampling.

The doubt of the systems cleanliness lead to the three GN_2 blowdown and wipe tests of the system. The first blowdown and wipe test was conducted on 23 May 1967. The target plate, which was located 6 inches from the discharge flange, was 14 inches square and covered with blueing. The target plate showed particulate impact and was sent to PAA valve shop laboratory for analysis to determine the largest particle size. Their results show the size to be 580 microns. All blowdown tests were conducted with 25 psig GN_2 exhausting to atmosphere by locking up 25 psig in V-5001 and opening RSV-132 to discharge against the target. The flowmeters were removed and replaced with existing spool pieces as per cleanliness procedures to prevent over-spinning.

Following the first blowdown test, three wipe samples were taken from a one-square-foot area inside the propellant discharge line above the target area. The results of the wipe tests indicated that two were Level IV and the other was Level III clean.

Since the target plate showed impact of small particles, two more blowdowns were conducted on 24 May 1967. No wipe tests were performed after blowdown number two. The target plate from number two blowdown showed very little particle impact and blowdown number three was instigated.

3.11.2 Test Results (Cont'd)

The third blowdown test was conducted using target number one with one-half of the plate blanked out to show the contrast in impact between blowdowns one and three on one target. No noticeable particulate impact occurred on test number three. At the conclusion of blowdown test number three, another series of three satisfactory wipe tests were performed.

Based on these tests, it is concluded that the fluid supply systems meet the Level III cleanliness requirement for XE testing provided the systems are kept intact.

REFERENCES

A. Test Prediction Reports

NTO-R-0092 dated 26 September 1966, ETS-1 Test Prediction Summary Report for Facility Experimental Plans ETS-1.

NTO-M-10173 dated 7 October 1966, Subj: ETS-1 Test Prediction Summary Report, Addendum Number 1 Facility Experimental Plans.

NTO-M-11269 dated 6 January 1967, Same Subject, Addendum Number 2 Facility Experimental Plans.

NTO-M-11283 dated 23 February 1967, Same Subject, Addendum Number 3 Facility Experimental Plans.

NTO-M-11289 dated 21 March 1967, Same Subject, Addendum Number 4 Facility Experimental Plans.

B. FDET Memorandum

NTO-M-11237 dated 5 October 1966, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-I; Memo Numbers 1 through 7.

NTO-M-11239 dated 12 October 1966, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-IA; Memo Numbers 8 through 13.

NTO-M-11251 dated 7 November 1966, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-IIA and IB; Memo Numbers 14 through 24.

NTO-M-11255 dated 22 November 1966, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-IIB and IC; Memo Numbers 25 through 37.

NTO-M-11261 dated 13 December 1966, Subj: Transmittal of FDET Memoranda for ETS-1 LN₂ Checkout of V-5002; Memo Numbers 38 through 40.

4.0

REFERENCES (Cont'd)

B. FDET Memorandum

NTO-M-11276 dated 30 January 1967, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-III, Phase I and IA; Memo Numbers 41 through 51.

NTO-M-11284 dated 14 March 1967, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-IV; Memo Numbers 52 through 59.

NTO-M-11290 dated 3 April 1967, Subj: Transmittal of FDET Memoranda for ETS-1 FEP-III-2; Memo Numbers 60 through 68.

C. Internal Memorandum

NTO-M-15226 dated 31 March 1967, B. A. Bernstein to W. D. Wayne, Subj: Verification of Cleanliness Conditions of the ETS-1 Engine Supply Systems.

NTO-M-15259 dated 6 June 1967, B. A. Bernstein to W. D. Wayne, Subj: Interim Report on V-5001 GN₂ Blowdown/Cleanliness Check.

5.0

APPENDIX

The facility schematic is shown in Figure 5.1