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PASSIVE RECIRCULATION IN THE NATIONAL LAUNCH SYSTEM'S FUEL FEEDLINES

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This report contains the passive recirculation tests on the fuel feedline of the National Launch System (NLS). The majority of testing was performed in February 1992, at the National Institute of Standards and Technology in Boulder, CO. The primary objective was to characterize passive recirculation in the NLS fuel feedline. The objective was met by observing the passive recirculation in a one-fifth scale model of the feedline with clear glass sections. The testing was recorded on video tape and with photographs. A description of the testing apparatus and support equipment is included. The experiment indicates that passive recirculation was occurring; higher angles from the horizontal transfer more heat.

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INTRODUCTION

Problem Definition

The National Launch System (NLS) is currently being defined at Marshall Space Flight Center. The goal is to design a rocket to deliver 150 klb to low-Earth orbit, satisfying the launch need of NASA and the Air Force. An all-liquid propulsion system is under investigation. Six liquid oxygen/liquid hydrogen engines, each producing 580 klb of thrust, are proposed to achieve the payload goals. Before launch, the fuel feedlines must be at liquid hydrogen temperature to prevent vapor from entering the turbopump when starting the engines. Traditionally, a bleed valve has been employed to maintain a cool feedline before starting the engines. Passive recirculation has been proposed, eliminating the need for a bleed system. Passive recirculation was successfully performed in the liquid oxygen feedlines of the Saturn V rocket main stage. The Saturn V burned kerosene for fuel; hence, fuel feedline preconditioning was not needed. Data on passive recirculation for liquid hydrogen feedlines has not been found.

Objectives and Approach

The primary objectives are to determine the characteristics of passive recirculation during steady-state and prepressurization simulations. The test objectives will be met experimentally by observing passive recirculation in a one-fifth scale model for the NLS fuel feedline.

EXPERIMENTAL APPARATUS

Test Section[1]

The apparatus built to test passive recirculation was approximately one-fifth geometric scale of the proposed fuel feedline (fig. 1). Clear sections were placed in the upper and lower legs for viewing. A 2.5-kg brass plug with a band resistance heater was attached to the free end of the lower leg for simulating the heat flux from a space transportation main engine (STME) fuel turbopump. A 25-L dewar was used to simulate the liquid hydrogen tank on the NLS. The test section had flexible joints for observing passive recirculation characteristics at 0°, 10°, and 20° to the horizontal in the upper leg.

The glass tube sections (2.4-in inside diameter) in the upper and lower legs were 29.2-cm (11.5-in) long. The glass tube sections were aligned approximately with the outer duct containing the vacuum. Tubular aluminum sections spanning the gap between the glass-to-metal seal are slit to optimize viewing. The slits are 6.4-cm wide and are on opposite sides of the cylinder for observing the

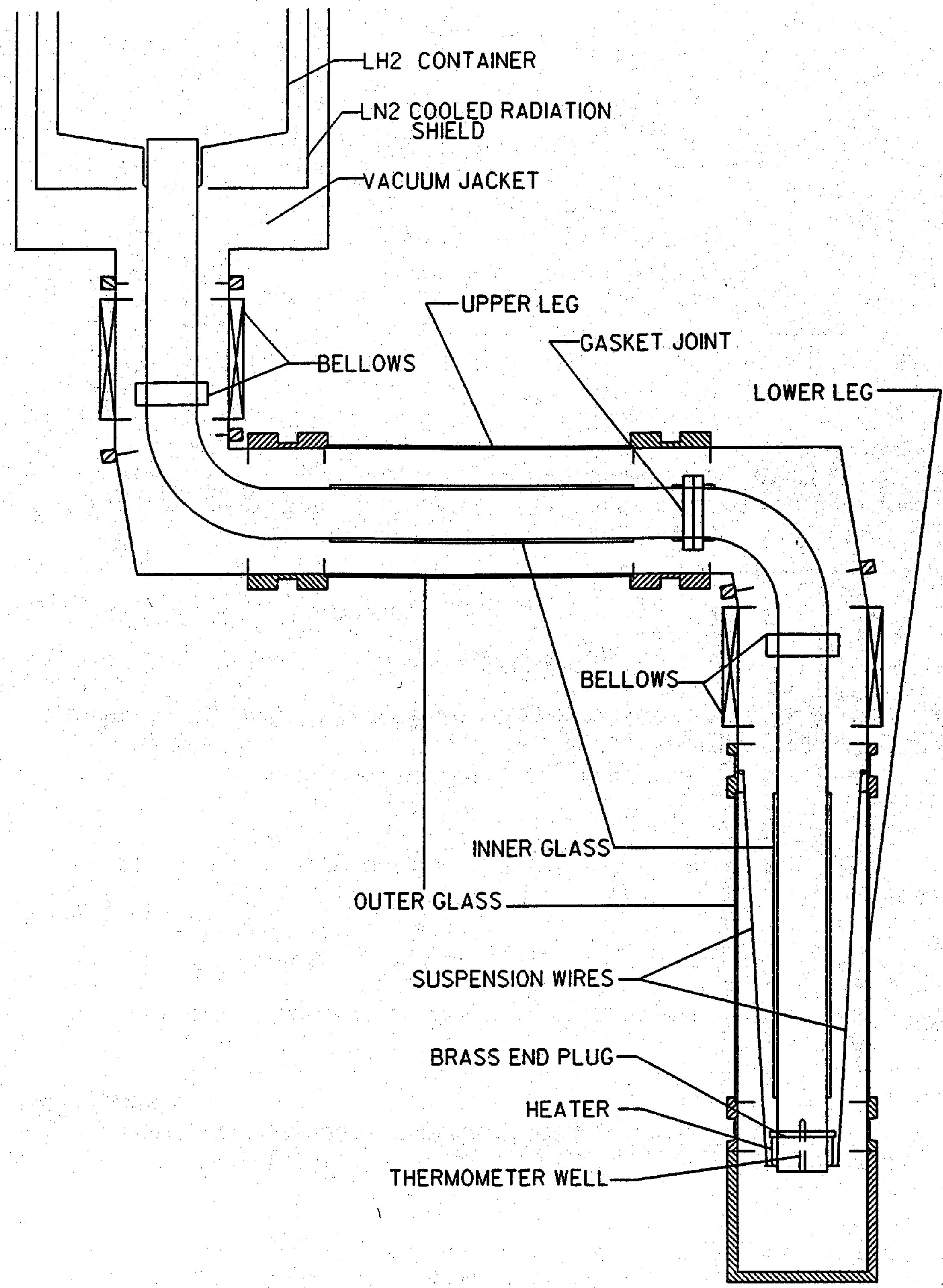

Figure 1. Test apparatus.

interior glass section. The aluminum sections reduce the radiant heat flux incident on the inner glass duct. They are also load carrying so the glass sections are unstressed by forces applied to the outer duct. More is written about the glass-to-metal seals in the chronology of events.

The test dewar consisted of a 25.4-cm (10-in) inside diameter open-topped inner vessel. Two radiation shields reduce heat flux from the O-ring sealed top plate. A liquid nitrogen-cooled copper radiation shield surrounded the inner dewar vessel. The vacuum jacket of the dewar and test section were commonly connected to a 300-L/s oil diffusion pump. The liquid hydrogen level was monitored by a capacitance level gauge. The gauge read in percent of 72-in; 28-percent scale indicated a full dewar.

A 2.5-kg cylindrical brass plug, simulating the thermal capacitance of an STME fuel turbopump, was placed in the bottom of the lower leg. A band resistance heater capable of producing 150 W was clamped to the brass plug. A silicon diode for temperature measurement was inserted into a port in the bottom center of the brass plug. The calibration of the silicon diode is included in appendix C.

The 80° elbows of the test section had a 12.7-cm (5-in) centerline radius. The 80° elbows in the outer shell were 15.2-cm (6-in) outside diameter. When the upper leg was at 10° below the horizontal, the bellows were straight. The bellow sections were required to bend a maximum of 10° to achieve the 0° and 20° settings for the upper leg. The angle was changed by moving the free end of the test section.

Support Equipment[1]

The support equipment includes a 450-L liquid hydrogen supply dewar, transfer line, pressurization system, diffusion pump, gas heater, and vent system (fig. 2).

The test system was designed to operate at 52 lb/in^2 absolute. Later, the 450-L supply dewar was found to have a 10-lb/in^2 gauge pressure relief valve. The transfer line from the supply dewar was removed, and helium gas from a cylinder was used to create 41.3 lb/in^2 absolute in the ullage of the test dewar.

A 4.5-kW resistance coil heated the boiloff gas before passing through a backpressure regulator and vent system to prevent condensation. The diffusion pump for the vacuum jacket is shown in figure 2.

TESTING RESULTS

Chronology of Events[1]

The subscale passive recirculation of the NLS fuel feedlines contract was awarded in August 1991. The test apparatus was then fabricated, and the first nitrogen cold shock tests were performed on January 3 and 14, 1992. The glass sections cracked during the second cold shock test. It is suspected there was damage during the first cold shock that was undetected. The cracking started from the epoxied Pyrex to Invar joints and then propagated through the glass section. The cracking may have been prevented by purging with cold gaseous nitrogen before transferring liquid nitrogen. Cracking first occurred in the joint nearest the elbow below the dewar as liquid nitrogen was introduced.

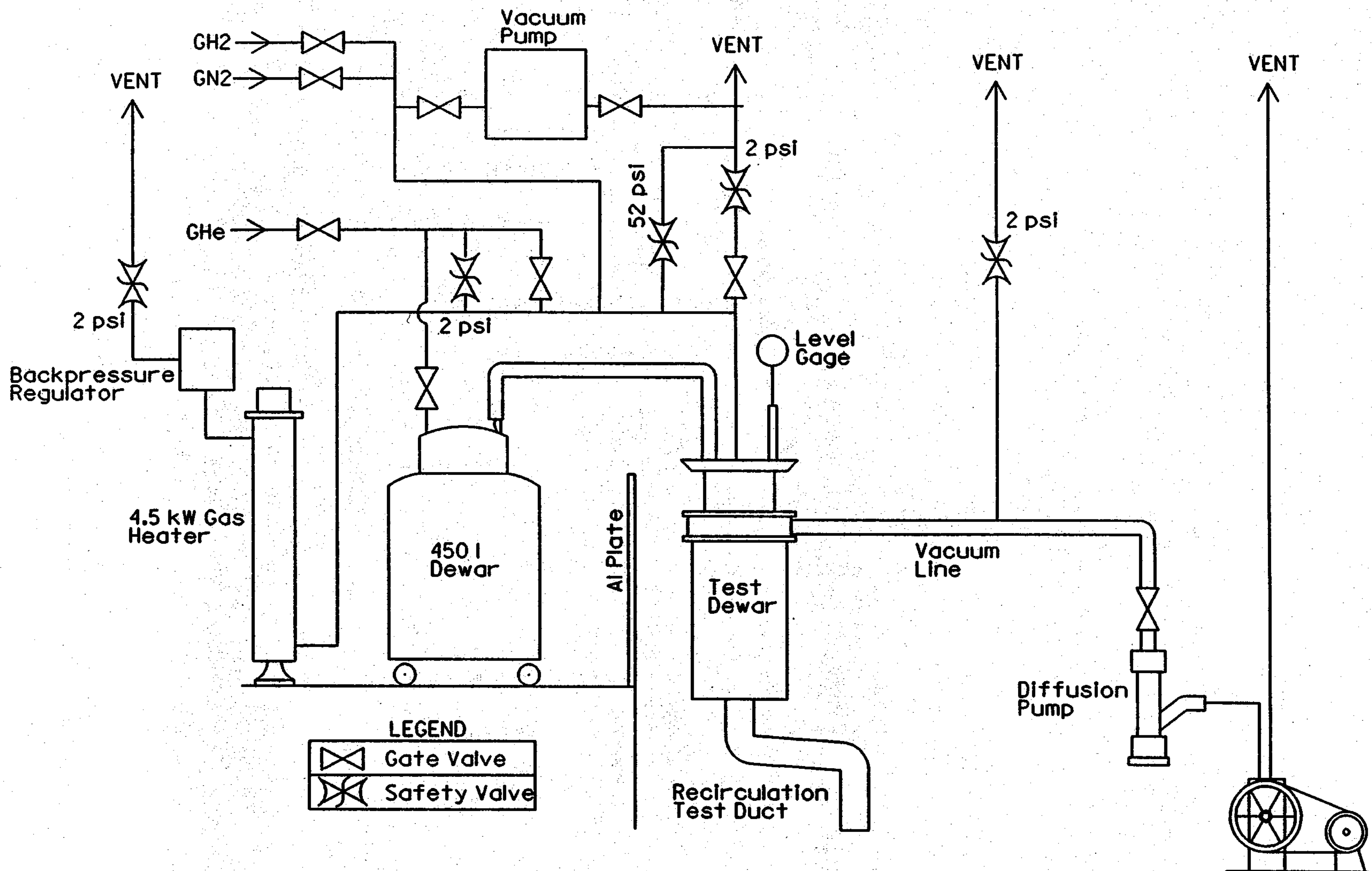

Figure 2. Support equipment.

In the following weeks, several glass-to-metal joints were cold shocked because of the cracking problem. The Kovar to 7052 glass joint showed the most promise. The test section was reassembled with the Kovar to 7052 glass joint and showed no cracking during the cold shock test on February 6, 1992.

Liquid hydrogen was introduced to the test section on February 11, 1992. With concerns of cracking, it was decided to limit the ullage pressure to 1-atm the first day to insure that data were obtained. The parasitic heat flux of 200 W was much higher than the maximum applied heat flux of 90 W, and there was no visible distinction in flow characteristic with different applied heating fluxes. The hydrogen was essentially stratified at the 0° setting, and the amount of eddying of gas into the liquid increased with angle. The boiling rate seemed larger than anticipated. It was not clear that the boiloff was excessive, considering a large portion of the test section was glass without any radiation absorber. As the afternoon temperature decreased, the glass sections frosted.

The next day, February 12, 1992, the prepressurization tests were run. Pressures of approximately 2 and 3 atm were tested. Between test 20 and 21, the parasitic heat flux drastically decreased. This event has not been explained. One theory suggests that a foreign particle in the liquid hydrogen plugged a leak in the test apparatus. The computer simulation, in a later section, concentrates on tests 20 and 21. Both were a prepressurization test to about 3 atm. Tests 20 and 21 showed a quiescent period of about 80 and 120 s, respectively. After the parasitic heat leak decreased, the test apparatus was cycled through the angles again.

Summarized in appendix A are the video times for 0°, 10°, and 20° angles and applied heat fluxes of 0, 30 ,60 and 90 W. Copies of the video are available through Kelly Moder (Audio Visual Information Processor, 205-544-6155) from the Boeing Computer Support Services communications video library. In addition to the videos, slides were taken of each case and are on file at the NASA photographic lab (contact Linda Marsh, Librarian, 205-544-4586). The slides are categorized in appendix B.

Parasitic Heat Flux[1]

The parasitic heat flux was the most difficult to determine. The heat into the test apparatus was measured from boiloff. The slopes of the curves in figure 3 were based on boiloff in the dewar.

The measurement on February 11 yielded a heat flux of 200 W. The pressure in the vacuum jacket was not monitored because the gauge may be an ignition source if the interior test section failed and spilled liquid hydrogen into the vacuum jacket. The heat flux was 300 W on the morning of February 12. The pressure sensor was operated for brief periods on the second day after it was felt that the test section would not break. At the start of transferring liquid hydrogen on February 12, the vacuum jacket was at 10E-6 torr and at 0.01 torr when the test section was full. Although this event cannot be explained, the vacuum jacket pressure decreased to 3×10E-4 at about 4:15 p.m.. The heat flux at this time was calculated to be 62 W. One more rate of liquid level fall in the dewar was recorded about 6:00 p.m. and yielded 40 W.

The heat flux from the boiloff in the lower leg was measured to be 10.7 W on February 11 and 5.5 W on February 12. A void fraction correction was not applied to the measurements. A plot of the data is shown in figure 4.

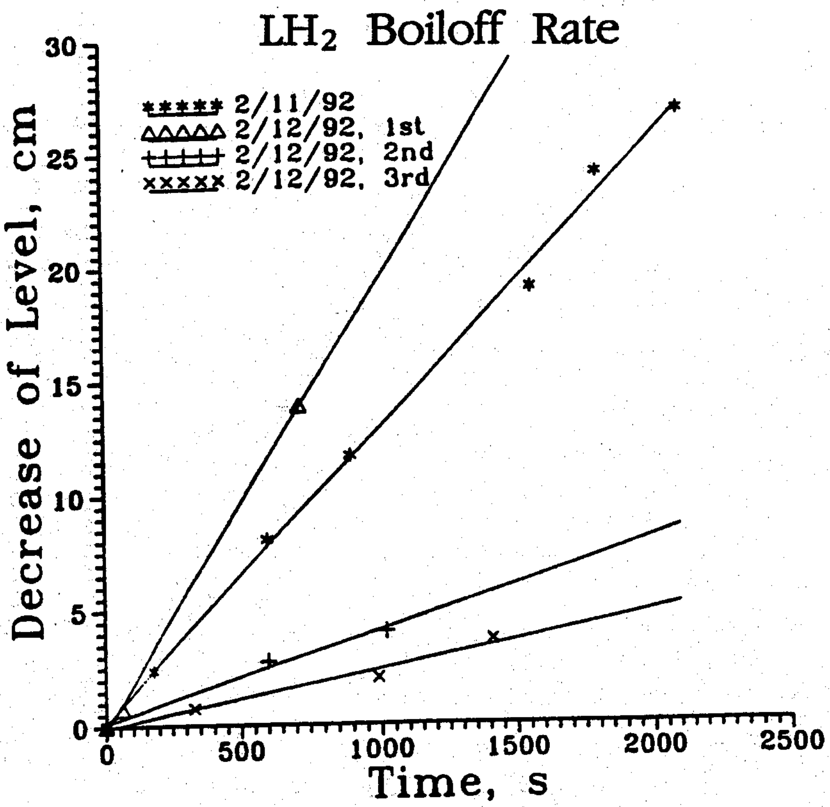

Figure 3. Heat input measured by rate of level change of the level of liquid hydrogen in the test dewar. Slopes: 2/11 test—0.0127 cm/s; 2/12 test—first, 0.0196 cm/s, second, 0.00398 cm/s, and third, 0.00249 cm/s.[1]

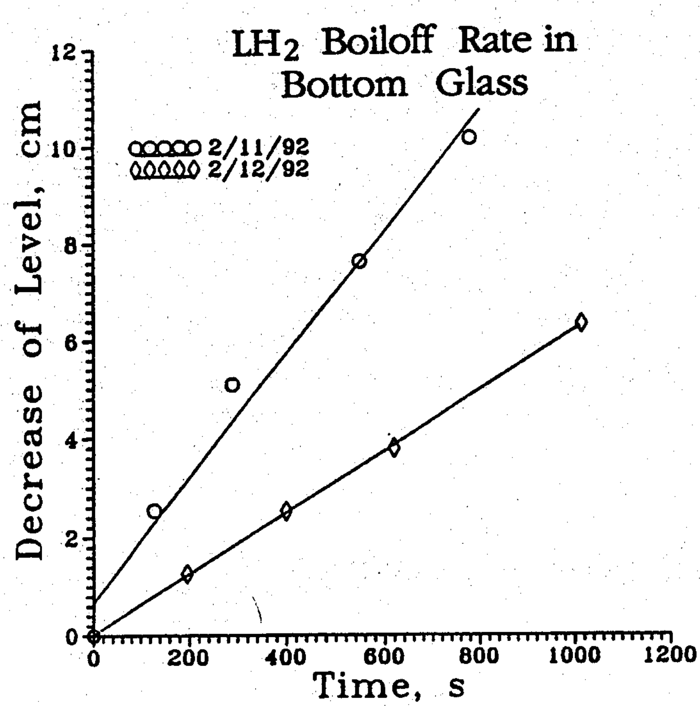

Figure 4. Heat input from boiloff rate when the level of liquid hydrogen was in the lower glass section. Slope: 2/11—0.0126 cm/s; 2/12—0.0644 cm/s.[1]

The heat flux into the liquid hydrogen in the test section alone cannot be separated with reliability from the total heat flux to the test dewar and section. The heat flux is transmitted by radiation, conduction through the support structure, and convection through the gas in the vacuum jacket. The radiative and conductive components are fairly constant, but the convective component will vary as a function of vacuum jacket pressure. The convective component of the parasitic heat flux decreases dramatically when the vacuum drops below 10E–3 torr. Also, the dewar is surrounded by a liquid nitrogen jacket, while the test section is not.

The parasitic heat flux changed dramatically because of varying vacuum jacket pressure and the liquid hydrogen level in the test dewar. The heat flux to the test section cannot be specified with certainty. Without accurate measurements, applying half the boiloff rate to the test section is probably a good assumption.

COMPUTER SIMULATION

Input Parameters

A computer code was written by Federick D. Bachtel[2] to analyze feedline passive recirculation for the NLS design. The computer code assumes one-dimensional flow and is capable of handling one-phase or two-phase flow. The code can run steady-state conditions, transient wall temperatures with steady flow, or transient wall temperatures and flow. Real fluid properties are used in the analysis.

The test apparatus is shown in figure 1. In the analysis, the inner duct is divided into 19 cells. The configuration of the cells is defined in an input file. These parameters specify cell geometry, frictional and component losses, thermal conductivity, capacitance, and temperatures. Feedline inlet conditions are initialized to the fluid properties in the dewar. The computer code uses the energy equation to calculate successive cell gas generation and fluid flowrates. The fluid flowrates are based on the parasitic heat leak and the conditions at the preceding cell. Cell pressure, liquid and vapor mass, liquid temperature, subcooled temperature, and vapor fraction are available for output.

Several of the input variables were assumed or approximated from known data. The dewar bulk temperature was assumed to be 32 °R. A case with a bulk liquid temperature of 36 °R was run; the temperature profile of the upper and lower leg were unaffected. The test apparatus heat flux was calculated from the boiloff. Half of this heat flux was assumed to be from the feedline and half from the dewar. The parasitic heat flux was distributed along the surface of the feedline.

Results of Simulation

Tests 20 and 21 were analyzed and compared with the video. There are three variables approximated from the video. The first is the unpressurized steady-state vapor fraction in the upper leg. The second is the quiescent period between the vapor collapse and reappearance. The third is the pressurized steady-state vapor fraction. Because the fluid is stratifying in the upper leg, the vapor fraction is approximated by measuring it from the video. Unfortunately, the vapor fraction in the lower leg cannot be measured with any confidence. Therefore, all comparisons are made to the upper leg. A plot of the actual pressurizations as a function of time is shown in figure 5.

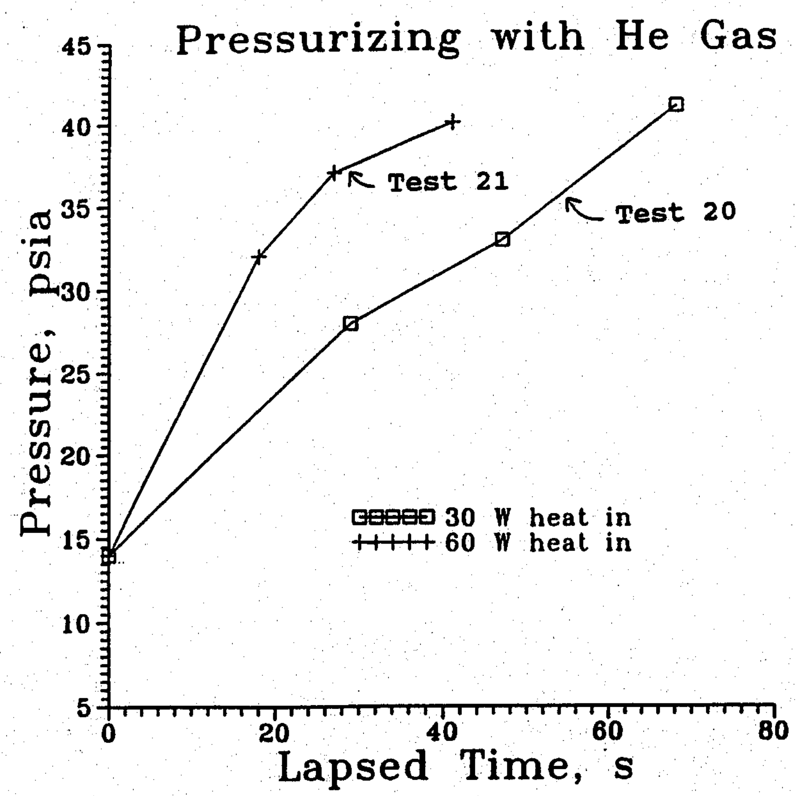

Figure 5. Dewar pressure as a function of time.[1]

In test 20, the unpressurized tank ullage was 14.5 lb/in^2 absolute. The plug applied heat was set at 30 W, and the feedline parasitic heat flux was 150 W (300 W total parasitic heat flux for the feedline and the dewar). The vapor fraction was measured to be about 16 percent. The dewar was then pressurized to 41.3 lb/in^2 as shown in figure 5. There was approximately an 80-s quiescent period. Occasionally, small bubbles pass along the top of the duct during this period. After pressurization, the steady-state vapor fraction was about 10 percent.

Figure 6 shows the predicted vapor fraction at the upper and lower legs and at the heater for test 20. The first 100 s are run steady-state at a pressure of 14.5 lb/in^2 absolute. The steady-state vapor fraction in the upper leg is approximately 21 percent by volume. The model then pressurizes the dewar to 41.3 lb/in^2 absolute over 68 s, simulating the transient. This pressure is held while the feedline approaches steady-state conditions. The steady-state vapor fraction is about 13.5 percent. The model shows that the vapor did not completely collapse in the upper leg. However, for a period, the vapor decreases as it travels up the feedline. Therefore, the quiescent period is defined as the time when the vapor fraction in the upper leg is less than the vapor fraction at the heater. In figure 6, the calculated quiescent period is approximately 60 s.

The model predicts temperatures in the feedline. Figure 7 shows the amount the liquid is subcooled at the heater and the upper and lower legs. The bulk liquid temperature is below saturation for about 115 s. After pressurization is complete (at 168 s), the liquid is subcooled about 2 °R. Within 45 s, the liquid temperature increased to saturation. Figure 8 shows the temperature profile along the feedline from the dewar to the heater. This shows the temperature profile unpressurized, pressurized, and then at intervals of 20 s.

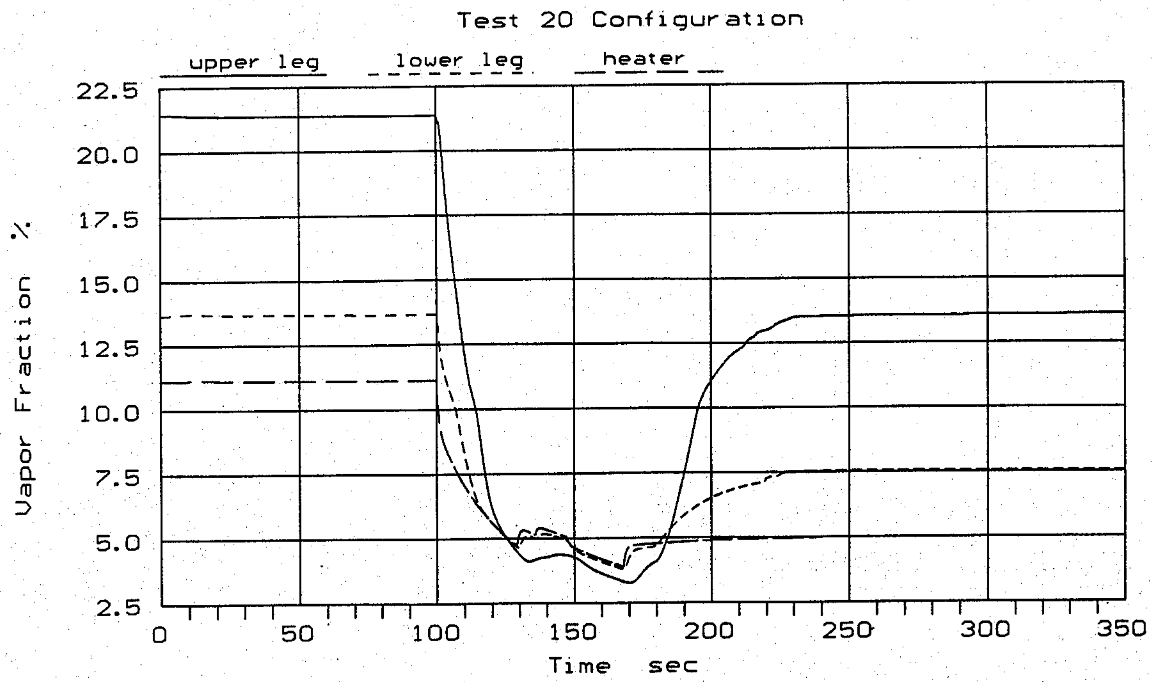

Figure 6. Vapor fraction versus time for test 20.

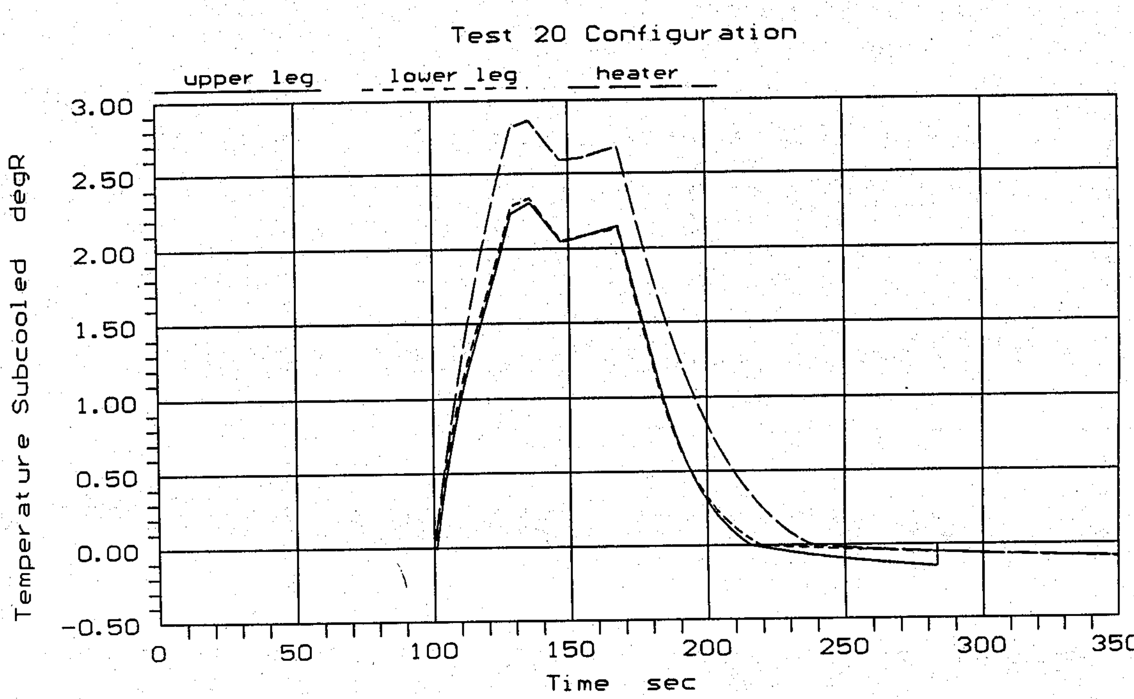

Figure 7. Subcooled temperature versus time for test 20.

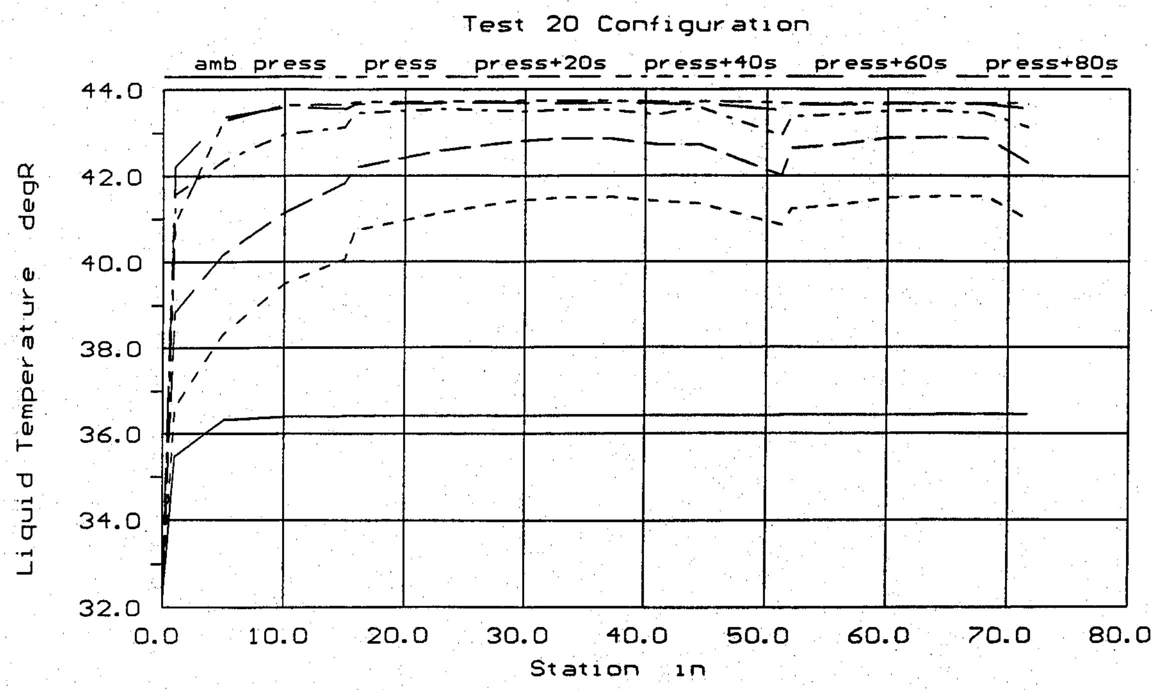

Figure 8. Liquid temperature versus centerline station for test 20.

In test 21, the ullage pressure in the dewar was initialized at 14.5 lb/in^2 absolute, and the applied plug heat was 60 W. The feedline parasitic heat flux was 31 W (62 W total for the feedline and dewar). The steady-state vapor fraction in the upper leg is approximately 10 percent. The dewar was pressurized to 40.3 lb/in^2 absolute according to figure 5, and the quiescent period was about 123 s. The vapor fraction in the upper leg was then 7 percent.

The predicted vapor fraction is shown in figure 9 for the heater and upper and lower legs. The model ullage pressure was 14.5 lb/in^2 absolute for the first 100 s. The steady-state vapor fraction is about 17 percent. The model then ran the transient. The dewar was pressurized to 40.3 lb/in^2 absolute and held while the flow returned to steady-state. The steady-state vapor fraction for the upper leg is then about 11 percent. As previously defined, the calculated quiescent period is approximately 205 s.

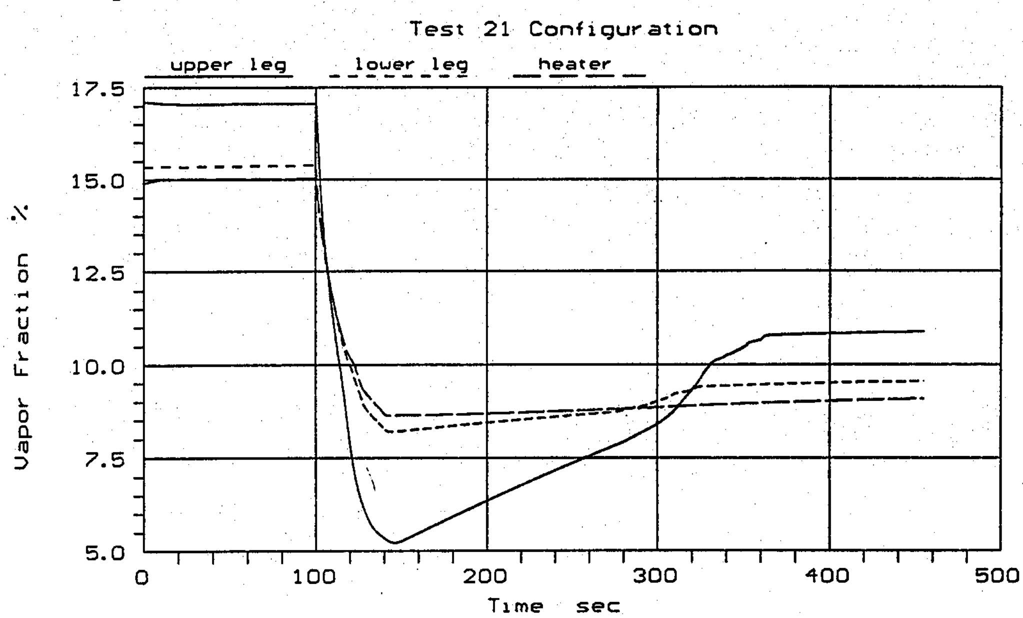

Figure 9. Vapor fraction versus time for test 21.

The temperatures for test 21 are shown in figures 10 and 11. This shows that the fluid at the heater remains saturated. The fluid in the upper leg is subcooled about 5° after pressurization is complete. After 240 s, the fluid temperature increases to saturation. Figure 11 shows the feedline temperature profile from the dewar to the heater. The temperature profile is shown unpressurized, after pressurization, and then at intervals of 50 s. The data from the model are summarized in table 1.

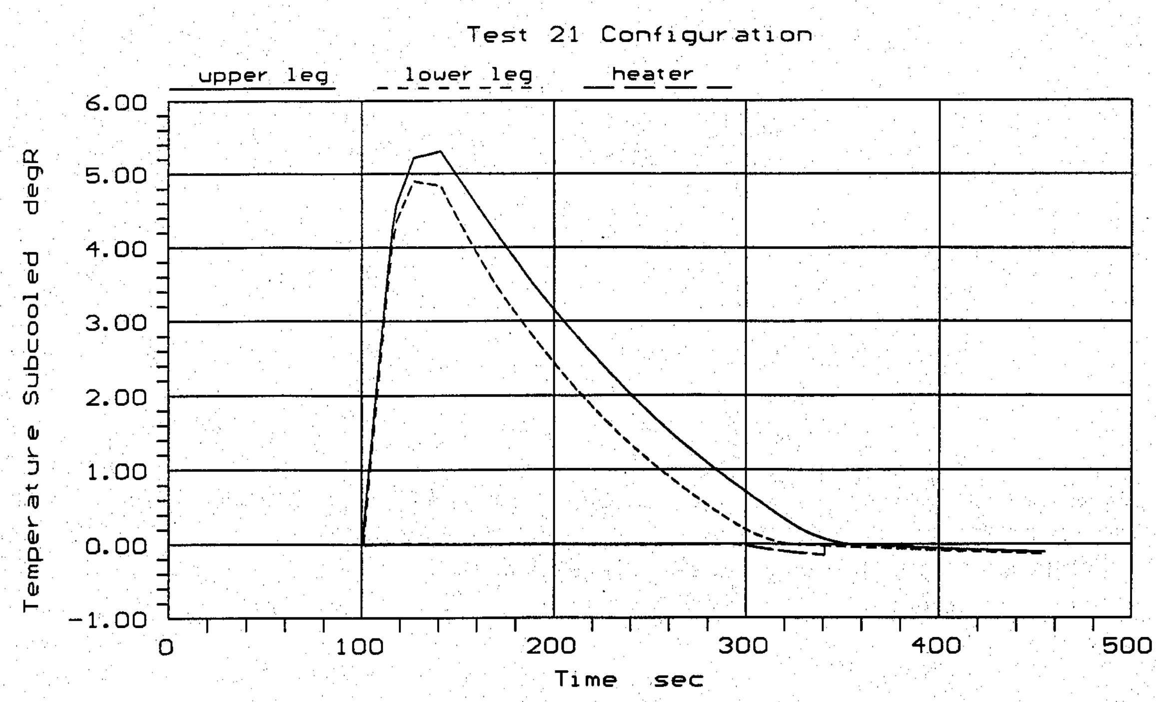

Figure 10. Subcooled temperature versus time for test 21.

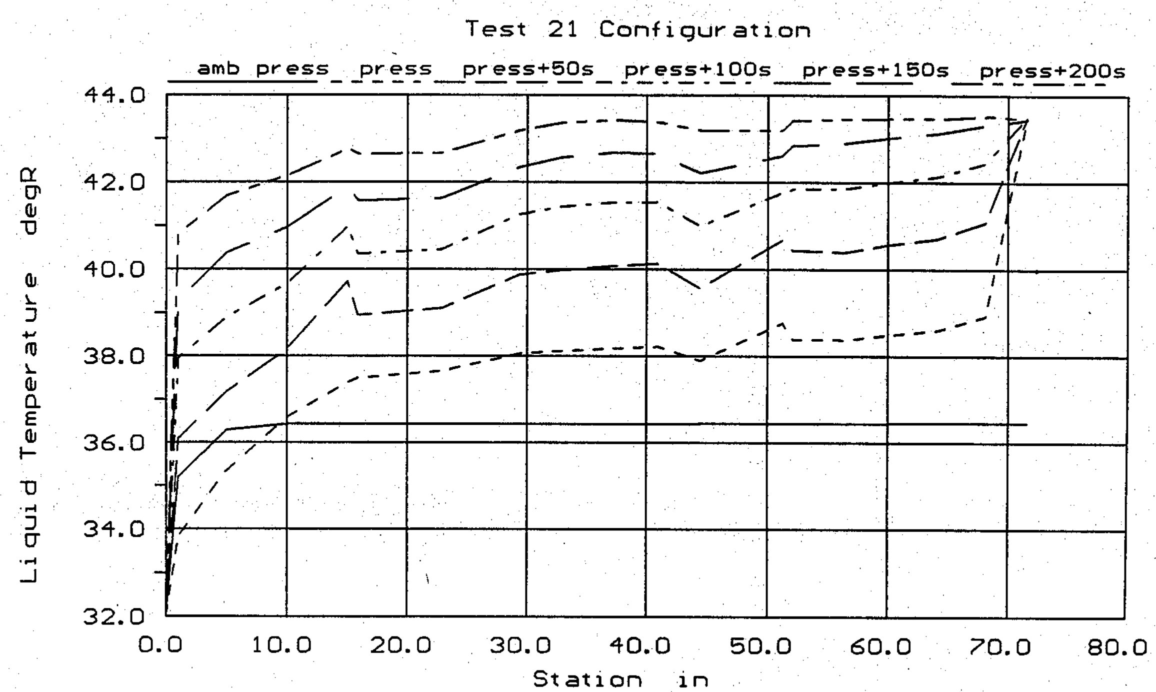

Figure 11. Liquid temperature versus centerline station for test 21.

Table 1. Summary of model output and video observation

	Configuration 20		Configuration 21	
	Model	Test	Model	Test
Vapor Fraction, unpressurized	21%	16%	17%	10%
Vapor Fraction, pressurized	13.5%	10%	11%	7%
Quiescent Period	60 s	80 s	205 s	120 s

CONCLUSIONS

The primary objective of determining the characteristics of passive recirculation was achieved. The parasitic and applied heat fluxes did not hinder the test section from filling with liquid hydrogen. The prepressurization test concluded that a quiescent period of 120 s can be created by pressurizing to 3 atm.

The computer simulation corresponds well to what is seen on the video tapes. However, there is still room for improvements to the code. For instance, the video tapes showed the vapor completely collapsing after pressurization. The code needs to be able to predict this collapse in the vapor. Also, temperature and pressure data in the feedline would help benchmark the code.

The objective of the experiment was to characterize passive recirculation in a fuel feedline. The experiment clearly shows that higher angles transfer more heat. Also, the experiment demonstrates what can be expected at the lower angles and will be key in determining minimum slope requirements for fuel feedlines if passive recirculation is implemented.

REFERENCES

1. Siegwarth, J.D., Lewis, M.A., Wilson, W.R., and Mehta, G.: "Recirculation Cooling Test of a Model Liquid Hydrogen Turbopump Feed Duct." National Institute of Standards and Technology, February 1992.

2. Bachtel, F.D., Chief, Performance Analysis Branch, Propulsion Laboratory, Marshall Space Flight Center.

App A

SUMMARY OF TESTING (HORIZONTAL SECTION)

Test #	Press. (PSIA)	Angle Deg	Applied Heat(W)	Paracit Heat(W)	Video Start Time	Video End Time
****Tuesday 2/11/92****						
1	14.5	10	0	200	13:11:15	13:13:15
2	14.5	0	0	200	13:56:06	13:58:06
3	14.5	20	0	200	14:09:35	14:11:35
4	14.5	20	30	200	14:17:00	14:19:00
5	14.5	10	30	200	14:27:00	14:29:00
6	14.5	0	30	200	14:32:50	14:34:50
7	14.5	0	60	200	14:42:40	14:44:40
8	14.5	10	60	200	14:47:50	14:49:50
9	14.5	20	60	200	14:53:46	14:55:46
10	14.5	20	90	200	15:02:00	15:04:00
11	14.5	20	0	200	15:06:58	15:08:38
	Low Head Boiloff					
12	NO VIDEO					
13	NO VIDEO					
14	NO VIDEO					
****Wednesday 2/12/92****						
15	NO VIDEO					
16	14.5	10	0	300	11:34:35	11:36:35
17	14.5-25.8	10	0	300	11:50:40	11:52:40
	Fill line attached to dewar; very slow pressurization					
18	14.5-39.8	10	0	300	14:31:45	14:34:10
	Prepress with He gas					
19	14.5-27.8	10	0	300	15:52:15	15:54:16
	17 sec Prepress with He, about 23 sec quiescence					
20	14.5-41.3	10	30	300	16:04:15	16:07:00
	LH2 level at 18% scale, about 80 sec quiescence					

(HORIZONTAL CONTINUED)

Test #	Press. (PSIA)	Angle Deg	Applied Heat(W)	Paracit Heat(W)	Video Start Time	Video End Time
21	14.5-40.3	10	60	62	16:26:20	16:30:50
	LH2 level at 32% scale, about 123 sec quiescence					
22	35.0	10	0	62	16:41:30	16:45:00
	Constant pressure					
23	35.0	0	0	62	16:58:45	17:00:45
	Constant pressure					
24	35.0	10	0	62	17:06:40	17:08:40
	Constant pressure					
25	35.0-14.5	20	0	62	17:15:15	17:17:15
	Pressure released					
26	14.5	10	0	40	17:23:50	17:25:50
	Recheck point because of lower heat leak					
27	14.5	0	0	40	17:31:35	17:33:45
	Recheck point because of lower heat leak					

SUMMARY OF TESTING (VERTICAL SECTION)

Test #	Press. (PSIA)	Angle Deg	Applied Heat (W)	Paracit Heat (W)	Video Start Time	Video End Time
			****Tuesday 2/11/92****			
1	14.5	10	0	200	13:11:15	13:13:15
2	14.5	0	0	200	13:56:06	13:58:06
3	14.5	20	0	200	14:09:19	14:11:19
4	14.5	20	30	200	14:17:00	14:19:00
5	14.5	10	30	200	14:27:00	14:29:00
6	14.5	0	30	200	14:32:50	14:34:50
7		NO VIDEO				
8		NO VIDEO				
9		NO VIDEO				
10		NO VIDEO				
11		NO VIDEO				
12	14.5	20	0	200	15:13:04	15:15:04
	Low head boiloff					
13	14.5	20	0	200	15:25:56	15:26:12
	Low head boiloff					
14	14.5	20	0	200	15:39:54	15:41:40
	Low head boiloff					
			****Wednesday 2/12/92****			
15	14.5	20	0	300	10:38:20	10:41:37
	Filling test section					
16	14.5	10	0	300	11:37:52	11:39:52
17	14.5-25.8	10	0	300	11:50:40	11:52:40
	Fill line attached to dewar; very slow presserization					
18	14.5-39.8	10	0	300	14:31:45	14:33:55
	Prepress with He gas					
19	14.5-27.8	10	0	300	15:52:15	15:54:00
	17 sec Prepress with He gas, about 23 sec quiescence					

(VERTICAL CONTINUED)

Test #	Press. (PSIA)	Angle Deg	Applied Heat(W)	Paracit Heat(W)	Video Start Time	Video End Time
20	14.5-41.3	10	30	300	16:04:15	16:07:00
	LH2 level at 18% scale, about 80 sec quiescence					
21	14.5-40.3	10	60	62	16:26:20	16:29:30
	LH2 level at 32% scale, about 123 sec quiescence					
22	35.0	10	0	62	16:36:40	16:38:40
	Constant pressure					
23	35.0	0	0	62	16:58:45	17:00:45
	Constant pressure					
24	35.0	10	0	62	17:06:50	17:08:50
	Constant pressure					
25	35.0-14.5	20	0	62	17:15:15	17:17:15
	Pressure released					
26	14.5	10	0	40	17:23:50	17:25:50
	Recheck point because of lower heat leak					
27	14.5	0	0	40	17:31:35	17:33:45
	Recheck point because of lower heat leak					

App B

SUMMARY OF SLIDES

Set#	Slide#	Angle Deg	Applied Heat (W)	Description
				*****Nitrogen cold shock 1/3/92*****
1	1	10	0	LN2 vertical section
1	3	10	0	LN2 horizontal section
1	5	10	0	LN2 horizontal section
1	6	10	0	LN2 horizontal section
1	11	10	0	LN2 vertical section
1	12	10	0	LN2 vertical section
1	14	10	0	LN2 vertical section
1	16	10	0	LN2 horizontal section
1	17	10	0	LN2 horizontal section
1	19	n/a	n/a	Dewar and test section
1	20	10	0	LN2 vertical section
1	23	10	30	LN2 vertical section
1	24	10	60	LN2 vertical section
1	25	10	?	LN2 horizontal section
				****Hydrogen testing 2/11/92****
2	1	10	0	LH2 vertical section filling
2	2	10	0	LH2 vertical section filling
2	3	10	0	LH2 vertical section filling
2	4	10	0	LH2 horiz section filling
2	5	10	0	LH2 vertical section filling
2	6	10	0	dewar and test sections
2	7	0	0	LH2 horizontal section
2	8	0	0	LH2 vertical section
2	9	0	0	LH2 vertical section
2	10	20	0	LH2 horizontal section
2	11	20	0	LH2 horizontal section
2	12	20	0	LH2 horizontal section
2	13	20	0	LH2 vertical section
2	14	20	0	LH2 vertical section
2	15	20	0	LH2 vertical section
2	16	20	30	LH2 horizontal section
2	17	20	30	LH2 horizontal section
2	18	20	30	LH2 vertical section
2	19	20	30	LH2 vertical section
2	20	10	30	LH2 vertical section
2	21	10	30	LH2 horizontal section
2	22	10	30	LH2 horizontal section
2	23	10	30	vertical and horizontal
2	24	0	30	LH2 horizontal section
2	25	0	30	LH2 horizontal section
2	26	0	30	LH2 horizontal section
3	1	0	30	LH2 vertical section
3	2	0	30	LH2 horizontal section
3	3	0	60	LH2 vertical section

SUMMARY OF SLIDES (continued)

Set#	Slide#	Angle Deg	Applied Heat(W)	Description
3	4	0	60	LH2 horizontal section
3	5	10	60	LH2 horizontal section
3	6	10	60	LH2 vertical section
3	7	20	60	LH2 horizontal section
3	8	20	60	LH2 vertical section
3	9	n/a	n/a	Gopal Mehta, Walter Wilson
3	10	n/a	n/a	Jim Siegwarth (NIST)
3	11	20	90	LH2 horizontal section
3	12	20	90	LH2 horizontal section
3	13	20	90	LH2 vertical section
3	14	20	90	LH2 vertical section
3	15	20	0	LH2 vertical boiloff
3	16	20	0	LH2 vertical boiloff
3	17	20	0	Lh2 horizontal boiloff
3	18	20	0	LH2 vertical boiloff
				****Hydrogen testing 2/12/92****
3	19	10	0	LH2 horizontal, 2 atm
3	20	10	0	LH2 vertical, 2 atm
3	21	10	60	LH2 horiz, 2 Atm, quiesent
3	22	10	60	LH2 vert, 3 atm
3	23	10	60	LH2 vert, 3 atm
3	24	10	60	LH2 horiz, 3 atm
3	25	10	60	LH2 horiz, 3 atm, blurry
3	26	10	60	LH2 horiz, 3 atm
4	1	0	0	LH2 horiz
4	2	0	0	LH2 vert
4	3	0	0	LH2 vert, blurry
4	4	20	0	LH2 horiz
4	5	20	0	LH2 horiz
4	5A	?	0	LH2 vert
4	6	?	0	LH2 horiz
4	7	?	0	LH2 horiz
4	8	?	0	LH2 vert
4	9	?	0	LH2 vert
4	10	?	0	LH2 vert
4	11-25	n/a	n/a	testing apparatus

*Set number is designated by number of lines on the boarder edge of the slide.

App. C

LakeShore
Measurement and Control Technologies

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Fax: (614) 891-1392
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INTERPOLATION TABLE

Calibration Report No.: 181712
Sensor Type: Silicon Diode
Calibration Current: 10 μA

Sensor Serial no.: D91874
Model: DT-470-SD-13
Temp. Range: 4 to 325 K

Temp. (K)	Voltage	dV/dT (mV/K)
18.50	1.23840	-17.41
19.00	1.22972	-17.35
19.50	1.22103	-17.40
20.00	1.21230	-17.54
21.00	1.19438	-18.50
22.00	1.17475	-21.06
23.00	1.15260	-22.18
24.00	1.13401	-14.10
25.00	1.12399	-6.867
26.00	1.11866	-4.261
27.00	1.11491	-3.337
28.00	1.11186	-2.839
29.00	1.10916	-2.571
30.00	1.10670	-2.367
31.00	1.10441	-2.218
32.00	1.10225	-2.104
33.00	1.10019	-2.015
34.00	1.09821	-1.944
35.00	1.09630	-1.892
36.00	1.09443	-1.851
37.00	1.09259	-1.817
38.00	1.09079	-1.791
39.00	1.08901	-1.771
40.00	1.08725	-1.756
42.00	1.08375	-1.739
44.00	1.08028	-1.736
46.00	1.07680	-1.743
48.00	1.07331	-1.754
50.00	1.06979	-1.766
52.00	1.06624	-1.779
54.00	1.06267	-1.791
56.00	1.05908	-1.803
58.00	1.05546	-1.813
60.00	1.05183	-1.823
65.00	1.04264	-1.851

APPROVAL

PASSIVE RECIRCULATION IN THE NATIONAL LAUNCH SYSTEM'S FUEL FEEDLINES

By W.R. Wilson and K.A. Holt

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

J.P. McCARTY
Director, Propulsion Laboratory

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