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Simplified Liquid Oxygen Propellant Conditioning Concepts

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Simplified Liquid Oxygen Propellant Conditioning Concepts

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March 1995

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INTRODUCTION

Simplified propellant conditioning concepts were studied in a Joint Independent Research and Development (JIRAD) program between General Dynamics Space Systems (GDSS) Division and Marshall Space Flight Center (MSFC). Currently, the shuttle liquid oxygen (lox) feed system uses a high overboard bleed to condition the turbopumps. This results in propellant being wasted. Also, a bleed system hardware failure could result in a scrubbed launch attempt.

As alternatives to the high-bleed, four-propellant conditioning concepts were studied. These included: (1) passive recirculation, (2) low bleed through the engine, (3) recirculation lines, and (4) helium bubbling. Passive recirculation was emphasized in this study due to its simplicity. The conditioning concepts studied would increase launch probability, minimize propellant waste, or reduce operations and hardware costs. During this program, testing was performed using liquid nitrogen (LN_2) in place of lox for safety and economic reasons; LN_2 is less hazardous and cheaper to handle, yet its properties are comparable to lox.

The test configurations for the JIRAD program were based on the feed system design shown in figure 1. For this design, the main recirculation loop was insulated on the downcomer and uninsulated on the upcomer. This configuration produces a natural recirculation flow. The objective of the JIRAD program was to measure the feedline temperature profile from the main recirculation loop to the engine inlet. The effects of several different parameters on feedline temperature profiles were studied in this program. These parameters included: flow configuration, feedline slope, bottom/side heat flux, main recirculation loop velocity, pressure, bleed rate, helium bubbling, and recirculation lines.

From the feed system design shown in figure 1, there were three possible main recirculation loop configurations. The three configurations and the direction of the main flow loop for each are shown in figure 2. The sustainer and booster 1 configurations were chosen for study in this program.

TEST ARTICLE DESCRIPTION

Two test articles were used in this program. The first was a full scale 25° slope test article. The test article was a 12-in inside diameter (I.D.), 0.375-in wall thickness, 6061-T6 aluminum feedline. Figure 3 shows this feedline in sustainer and booster configurations. A pump simulator was attached to the bottom of the feedline to simulate the surface area of a typical turbopump. Centerline length of this test article was approximately 187 in (sustainer configuration). Kapton™ strip heaters were attached to the feedline to simulate prevalve and gimbal flexible joint heat loads. Kapton™ heaters were also attached to the pump simulator to simulate heat from an engine turbopump. Silicon diode temperature sensors were placed at 20 locations along the test article to provide an accurate temperature profile. The test article was coated with approximately 2 in of polyurethane insulation, and a vapor barrier was applied to keep moisture away from the insulation.

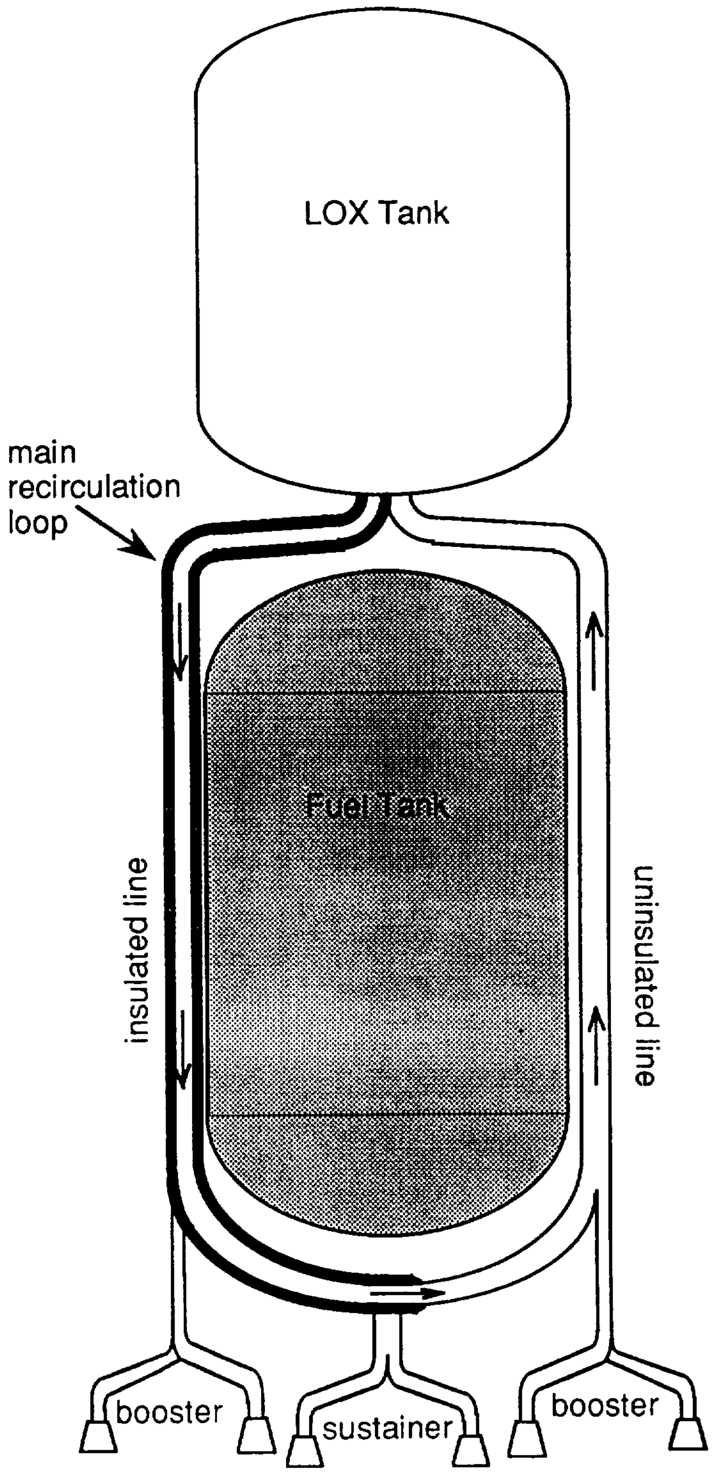

Figure 1. Feed system design.

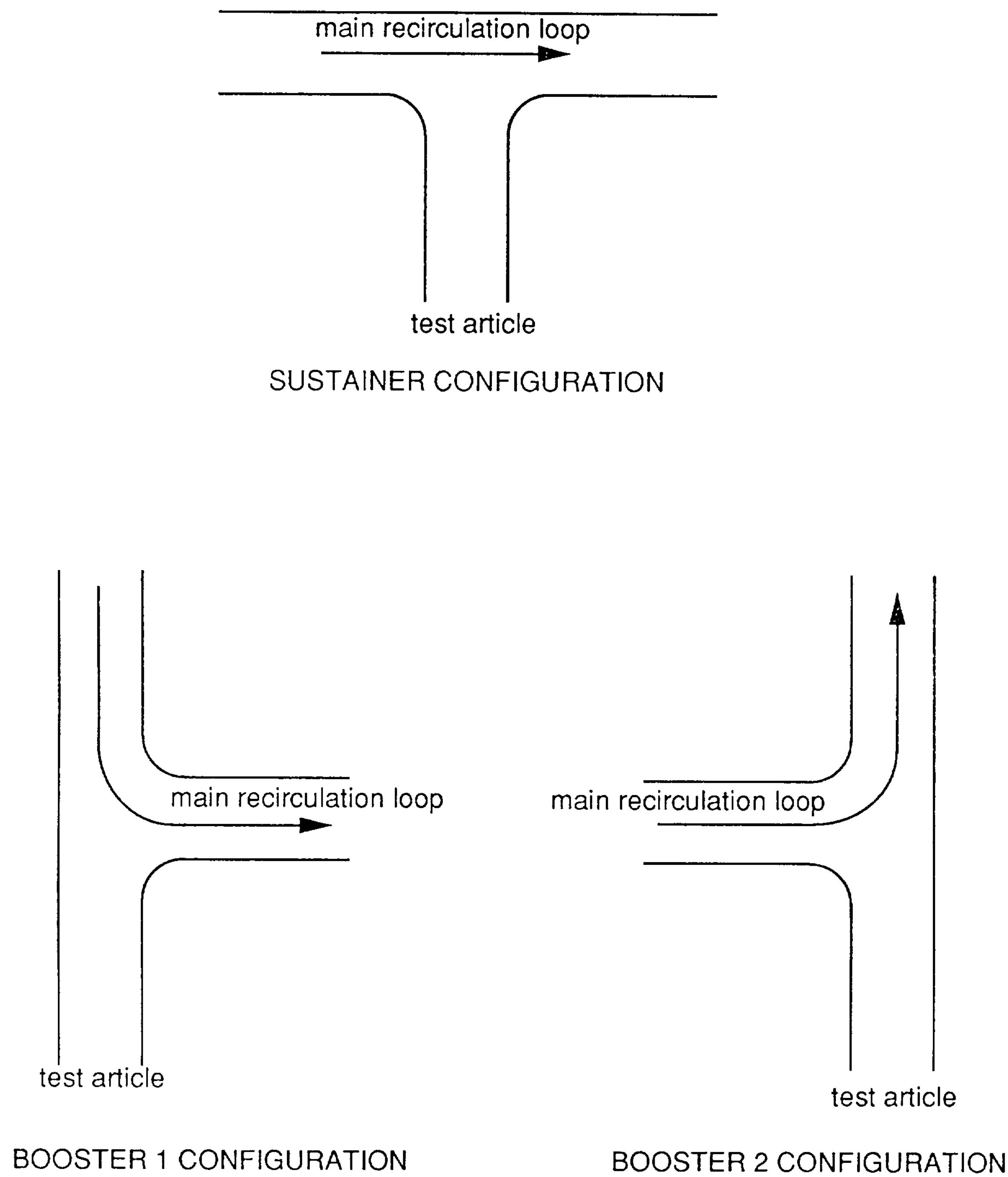

Figure 2. Main recirculation loop configurations.

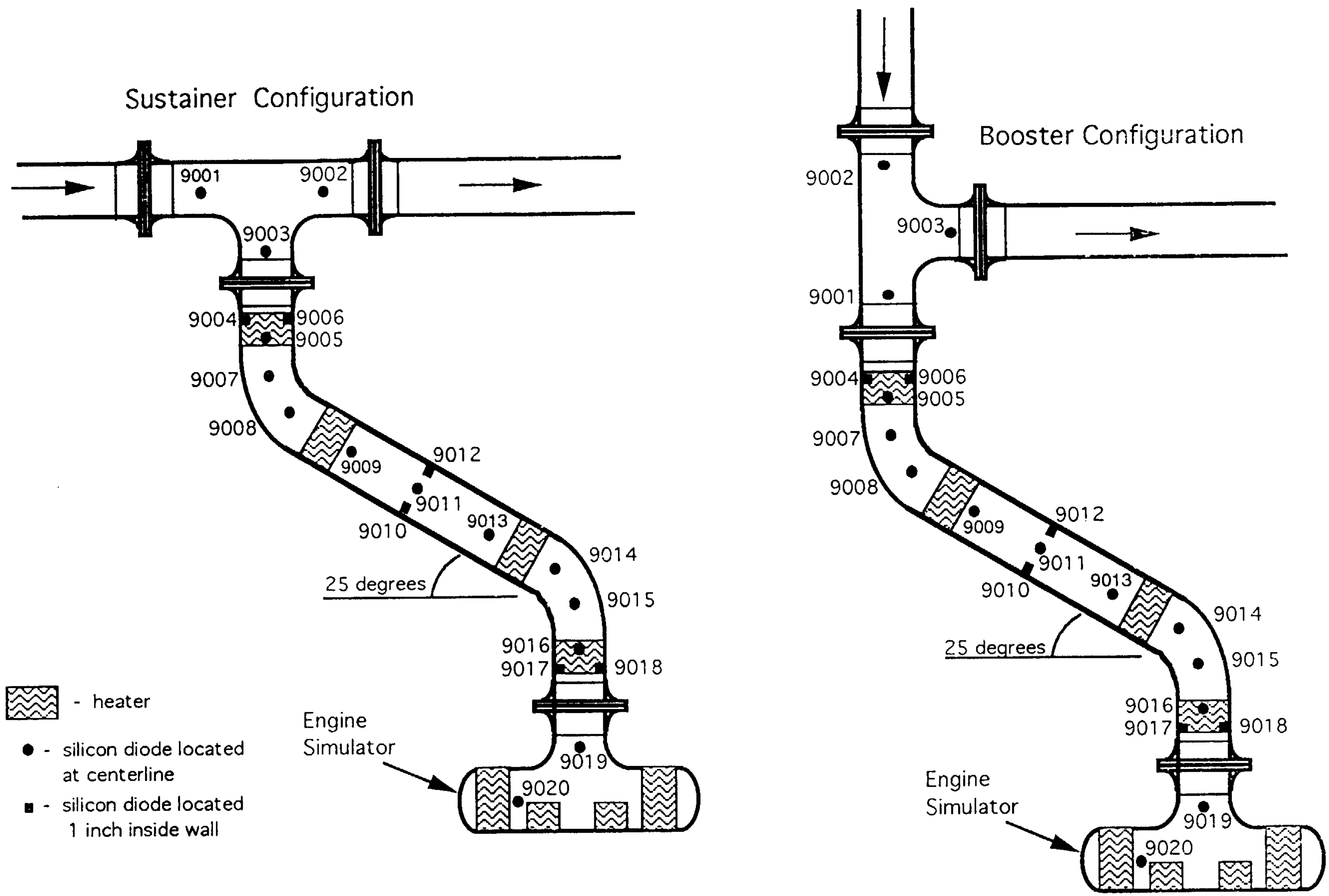

Figure 3. 25° test article.

A second feedline, with 15° slope, was also fabricated and tested in the facility. Instrumentation on this feedline was similar to that of the 25° feedline, and the same pump simulator was used for both feedline slopes. The centerline length of the 15° test article was 184 in.

TEST FACILITY DESCRIPTION

LN_2 testing for this program was performed at the Cold Flow Facility in the West Test Area of MSFC. Figure 4 shows a schematic of the LN_2 test facility. The recirculation loop ran from the 10,000-gal LN_2 tank to a circulation pump. This pump was used to reach the target flowrates and pressures at the top of the test article. The recirculation loop continued from the pump, across the test article, and returned to the tank. The loop was insulated from the tank to about 4 ft beyond the test article. The return line to the tank was uninsulated. A bypass line was also used to control the flowrate across the top of the test article.

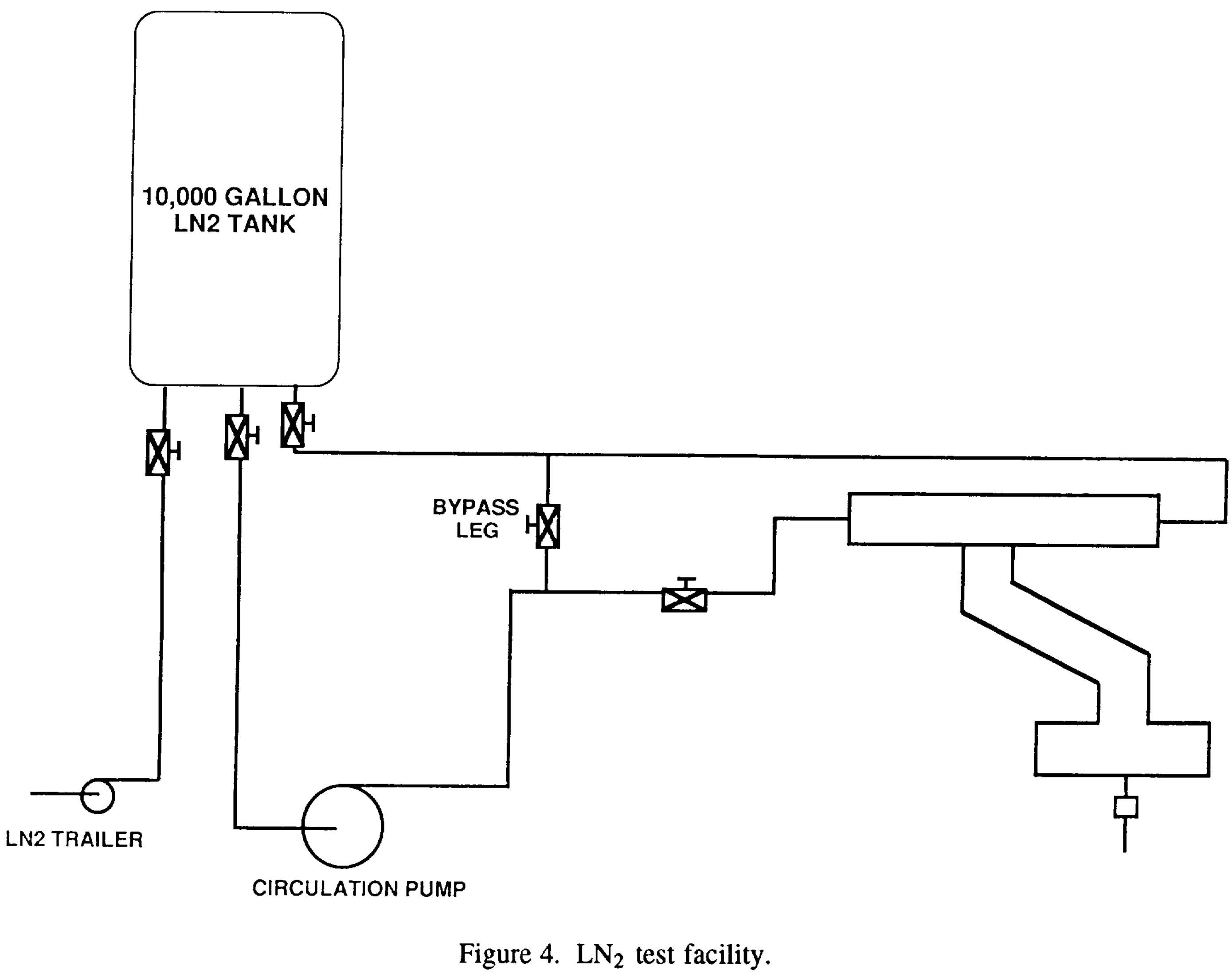

Figure 4. LN_2 test facility.

PROPELLANT CONDITIONING TESTS

Test Matrix

A test matrix was developed for the propellant conditioning program to study the effects of several different parameters on feedline temperature profiles. The parameters studied included: flow configuration, feedline slope, pump simulator/feedline heat flux, main recirculation loop velocity, pressure, bleed rate, helium bubbling, and recirculation lines. The parameter variations are shown in figure 5. The baseline configuration was chosen as 25° sustainer, 3,000/2,500 Btu/h pump simulator/feedline heating, 530 gal/min flowrate in the main loop, 100 lb/in^2 absolute at the top of the test article, no bleed, with no recirculation line, and no helium bubbling. The parametric test data acquired from this matrix will be useful in validating analytical models and creating a data base for future design guidelines. Calibration tests were also performed during this test program to determine the heat leaks into each portion of the test article. A complete test matrix is shown in appendix A.

Control parameters	Parameter variations
1. Flow configuration	- **Sustainer,** booster
2. Slope	- **25 deg,** 15 deg
3. Side heating	- **2500 Btu/hr,** 4500 Btu/hr, 11200 Btu/hr
4. Bottom heating	- **3000 Btu/hr,** 5500 Btu/hr, 6600 Btu/hr
5. Velocity	- **530 gpm,** 350 gpm (**1.5 ft/sec**, 1 ft/sec)
6. Pressure	- **85 psig,** 45 psig (**100 psia**, 60 psia)
7. Bleed rates	- **0.0,** 0.96, 2.87, 4.78, 9.57 gpm (**0.0**, 0.1, 0.3, 0.5, 1.0 lb/sec)
8. Helium bubbling	- **0.0,** 2.5, 4.2, 8.4 acfm (**0.0,** 0.003, 0.005, 0.010 lb/sec)
9. Recirculation configurations	- Before pump (A-1-1) - After pump (A-1-2) - Before pump-alternate (A-1-3)
Note: Bold indicates baseline configuration	

Figure 5. Test matrix.

Testing

The propellant conditioning test series for the 25° test article began in June 1993. Each test day began with filling the uninsulated 10,000-gal tank with LN_2. The LN_2 was loaded from a trailer into the tank, with three trailers (~4,000 gal each) typically being used for each day of conditioning tests. During pretest, the test article and main recirculation loop were filled with LN_2, and the circulation pump was turned on. The bypass valve was set to acquire the correct loop velocity and pressure at the top of the test article. The test parameters were set up for the first test and the process of data collection began. The LN_2 was allowed to reach a steady state, which usually took around 30 min. The total test duration of approximately 1 h allowed ample steady-state data to be recorded. If any problems arose during a test day which required a test to be stopped, the test was repeated when the problem was corrected. A test day usually consisted of a pretest, five or six propellant conditioning tests, and a drain test. The drain tests, run at the end of each test day, were used to determine a correction factor for each silicon diode on that day. For this test, LN_2 was drained from all facility piping and remained only in the test article. The liquid was allowed to reach saturation temperature, then a bleed valve was opened to allow the slow drain of liquid from the bottom of the test article.

Several problems were encountered during the propellant conditioning test series. Some were major and interfered with the test schedule, while others where minor and testing continued, as scheduled, while repairs were made. One problem occurred during an unrelated test program when damage was done to the Kapton™ heaters on the pump simulator. The insulation and heaters were removed from this portion of the test article. MSFC and GDSS decided that it would be beneficial to run a set of conditioning tests with the pump simulator uninsulated. During these tests, a helium barrier bag was placed around the pump simulator to prevent the buildup of frost. Meanwhile, replacement heaters, adhesive, and insulation were ordered for the simulator.

Some minor problems seemed to be recurrent throughout the test program. For instance, there were many occasions when silicon diodes failed to function properly, and would register temperatures inconsistent with those surrounding it (this is why some points may be missing from the data). These were replaced with spare silicon diodes at the first opportunity. Also, problems with liquid and gas flowmeters freezing up occurred intermittently during testing, due to moisture in the system. There were also problems with the bearings in the liquid and gas flowmeters. The flowmeters were replaced when the bearings went out, and a purge was put on the test article while not in test mode to keep moisture out of the system. One recurrent problem arose only when we tried to perform high bleed rate tests on the 15° test article. Each time this test was attempted, the filter in the test article would become clogged. The 15° test article was not cleaned thoroughly before testing, thus leaving sediment in the test article. The high bleed rate caused this debris to clog the filter. Even though obstacles were encountered, all scheduled tests were completed with the exception of one high bleed test.

DATA ANALYSIS

For each conditioning test, a steady-state time frame was found by looking at the pressure, temperature, and flowrates and determining when they were steady. Typically, steady state was reached after about 30 min of testing. A complete set of raw data from the baseline configuration is shown for reference in appendix B. An average for each measurement was taken over the steady-state time frame and input to a spreadsheet. Also input to the spreadsheets were the correction factors for the silicon diodes as determined from each day's drain test data. To find these corrections, the time, pressure, and temperature at which each sensor was no longer exposed to saturated LN_2 was determined. From the pressure, the corresponding saturation temperature was found from National Bureau of Standards (NBS) nitrogen tables, and compared to the measured temperature to find the delta for each silicon diode. This delta was then applied to the averaged data. For example, if a silicon diode went dry at 45 lb/in^2 absolute and 158R, and the NBS tables listed saturation temperature for 45 lb/in^2 absolute as 158.9R, then the delta applied to that sensor was 0.9R. A sample spreadsheet that corresponds to the raw data in appendix B is shown in appendix C for reference. Also input to the spreadsheets were the centerline heights of the silicon diodes, with the origin being at the center of the pump simulator (silicon diode 9020). From the spreadsheets, a temperature profile for the feedline was plotted and the effects of each parameter variation were compared. On all parameter charts, the temperature data are plotted against the centerline height of the silicon diodes. A sample chart is shown in figure 6. On this chart, some of the data points appear at the same centerline height. This occurs because the silicon diodes were grouped; two wall sensors and one centerline sensor were present. For example, in figure 6, silicon diodes 9010, 9011, and 9012 are all located at the same centerline height, yet they are at different temperatures. This is because 9011 takes a measurement in the center of the feed duct while 9012 and 9010 take measurements 1 in inside the top and bottom walls of the feed duct, respectively. Also on the parameter charts, some data points may be missing. This is because the silicon diodes sometimes stopped functioning properly, therefore the incorrect data was omitted from the temperature profile.

Parameter Charts

The most significant changes in the temperature profile were seen with variation in heat flux, bleed rate, and recirculation line configurations. However, temperatures in the feedline remained subcooled during all propellant conditioning tests. Figure 7 shows parameter variations and the increase in temperature produced down the feedline. On this chart, temperatures are taken at the top (9001) and bottom (9020) of the test article, and the difference between these two temperatures is shown for each variable. Even though heat flux, bleed rate, and recirculation line parameters produced the largest change in temperature gradients, their effects on temperatures through the feedline were not profound, as shown in figure 7.

Figure 8 shows the effect of change in the flow configuration. Both sustainer and booster configurations are shown. The only physical difference between the sustainer and booster configurations is at the inlet. The tee which connects the test article with the main flow loop for the sustainer configuration is turned to provide the correct flow angle for the booster configuration (see fig. 3 for reference). Thus, silicon diodes 9001, 9002, 9003 are in different positions for the two configurations. This produces a difference in temperature of at most 0.5R, thus the change in configuration does not have a major effect on the temperature profile.

Figure 9 shows the effect of changing the slope of the feedline. One test was performed on a 25° sustainer while the other was performed on a 15° sustainer. Again, the temperature profiles in the feedline are very similar with at most 1R difference between the two cases.

Figure 10 shows the effects of changing the heat flux into the test article. The different heat fluxes are shown in the legend. Bottom/feedline represents the heat input into the pump simulator and feedline, respectively. Ambient heat flux is the total amount of atmospheric heat into the test article when the heaters are not on. This number is 1,337/1,358 Btu/h as derived from the calibration tests performed on the 25° test article. Even though changes in heat flux have the most significant effects on the temperature profile, the variations still do not produce a large change in feedline temperatures. From figure 10, one can see that an increase of approximately 8,000 Btu/h in heat flux (from 5,500/4,500 to 66,00/11,200 Btu/h) produces a mere 2R increase in temperature throughout

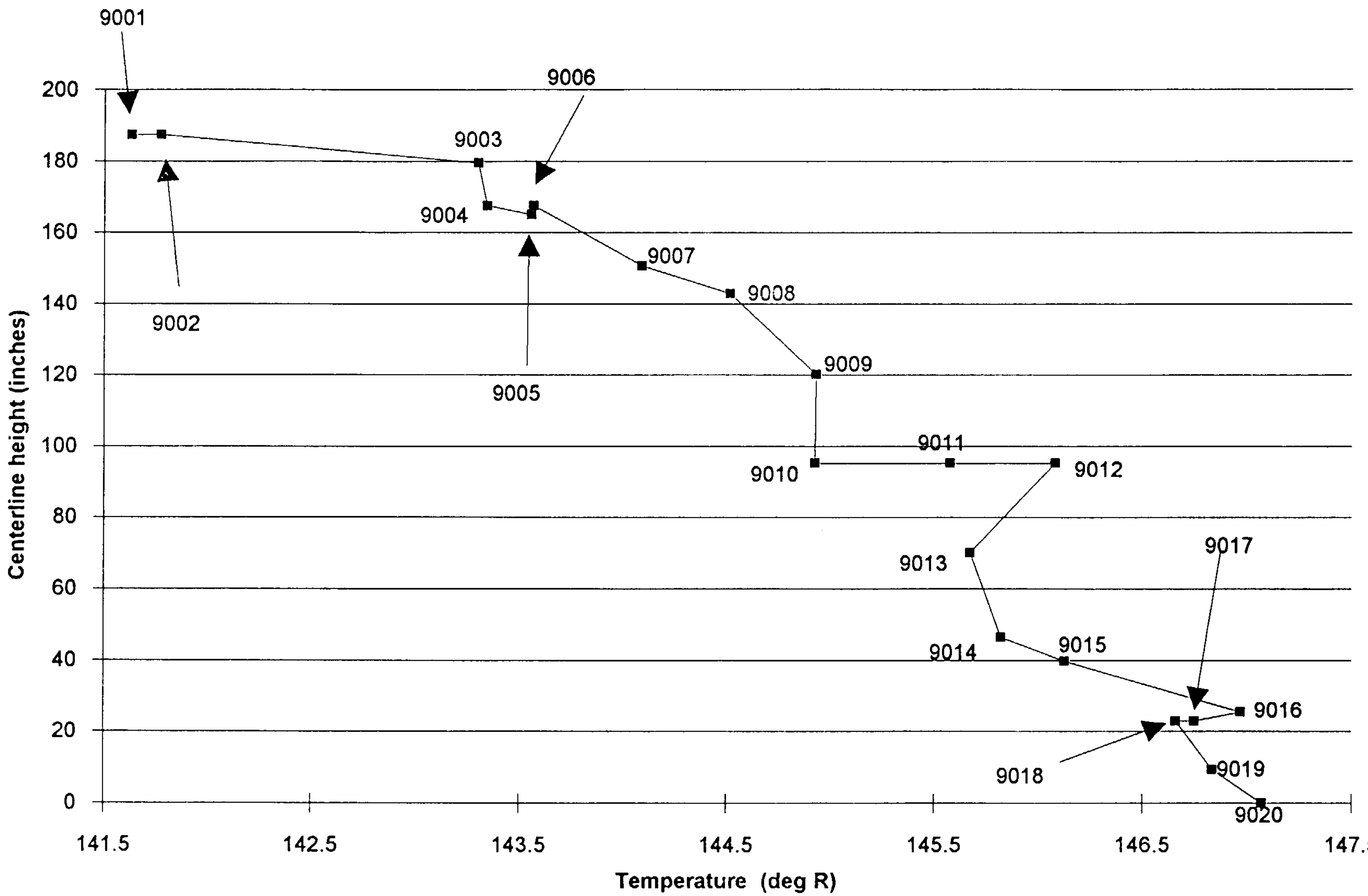

Figure 6. Baseline configuration test data.

Control parameters	Parameter variations	Delta T (9001 to 9020)
1. Flow configuration	- **Sustainer,** booster	**5.44,** 4.71 deg
2. Slope	- **25 deg,** 15 deg	**5.44,** 6.17 deg
3. Bottom/side heating	- **3000/2500 Btu/hr** 6600/11200 Btu/hr	**5.44 deg** 9.96 deg
4. Flowrate **(15 degree sustainer)**	- **530 gpm,** 350 gpm	**6.17,** 4.98 deg
5. Pressure	- **85 psig,** 45 psig	**5.44,** 5.17 deg
6. Bleed rates	- **0.0,** 4.78 gpm	**5.44,** 3.27 deg
7. Helium bubbling **(15 degree sustainer)**	- **0.0,** 8.4 acfm	**6.17,** 5.58 deg
8. Recirculation configurations	**-No recirculation line** After pump (A-1-2)	**5.44 deg** 3.56 deg
Note: Bold indicates baseline configuration (25 deg sustainer, 3000/2500 btu/hr, 530 gpm, 85 psig, no bleed) unless otherwise noted		

Figure 7. Delta T due to parameter variations.

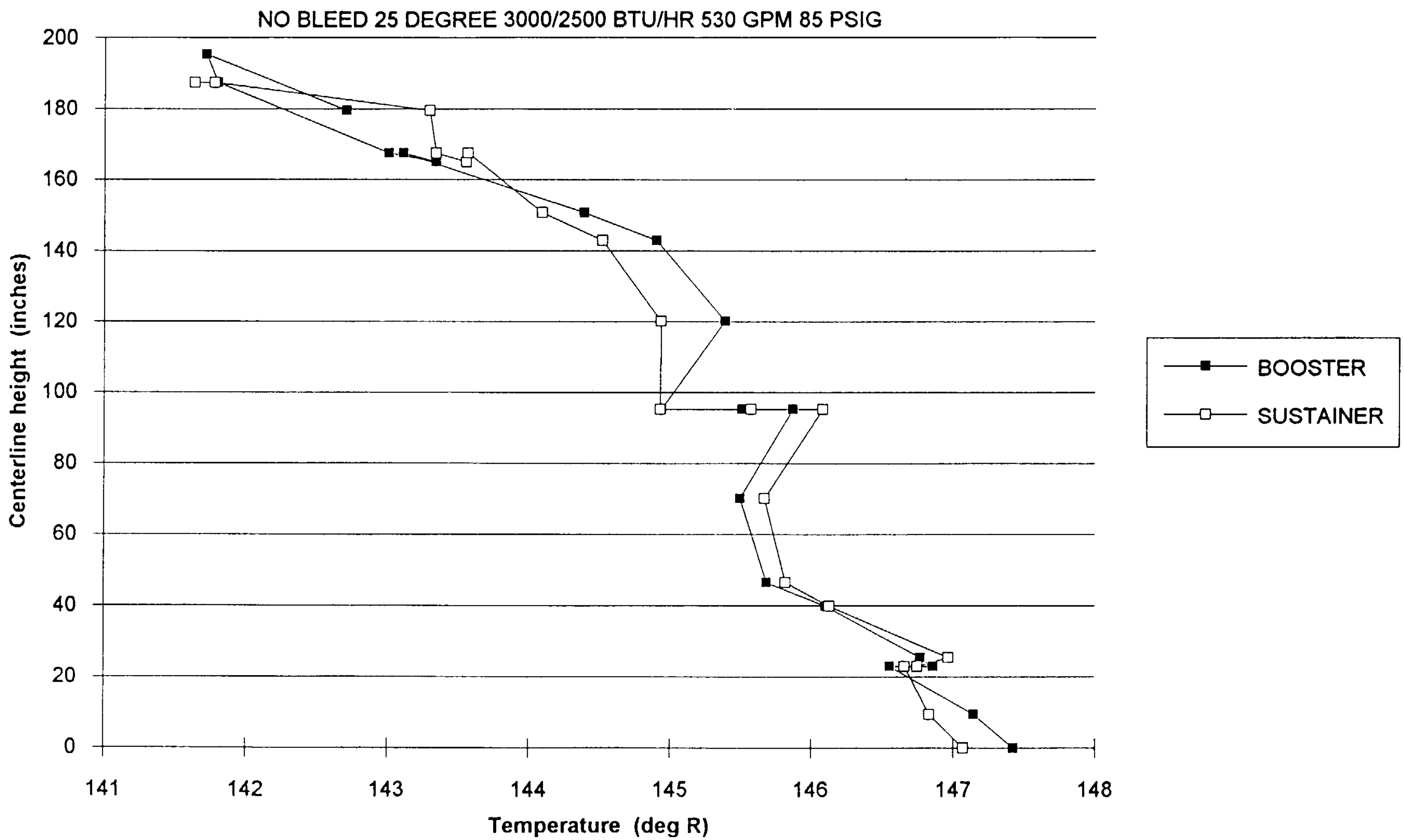

Figure 8. Effect of change in flow configurations.

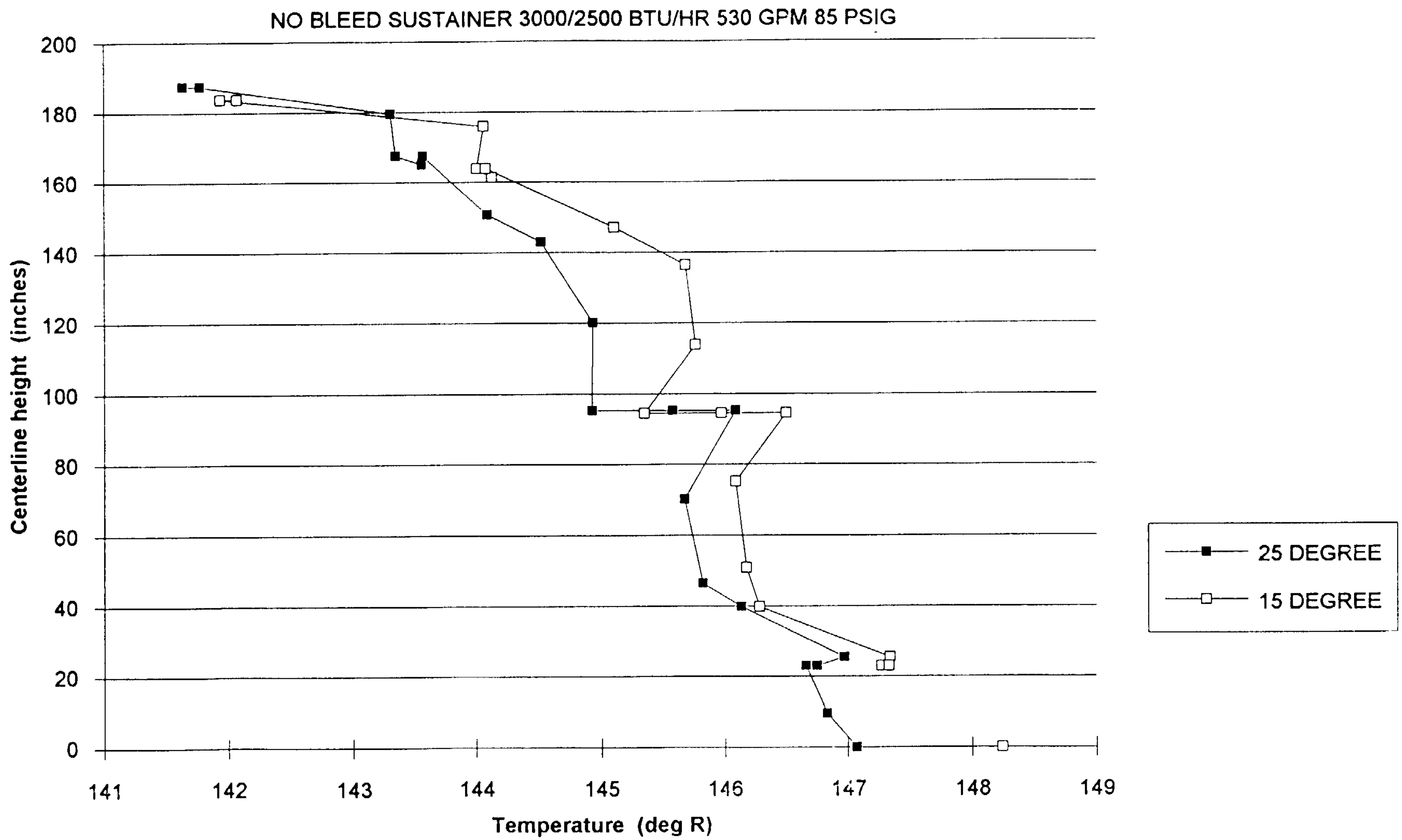

Figure 9. Effect of change in slope.

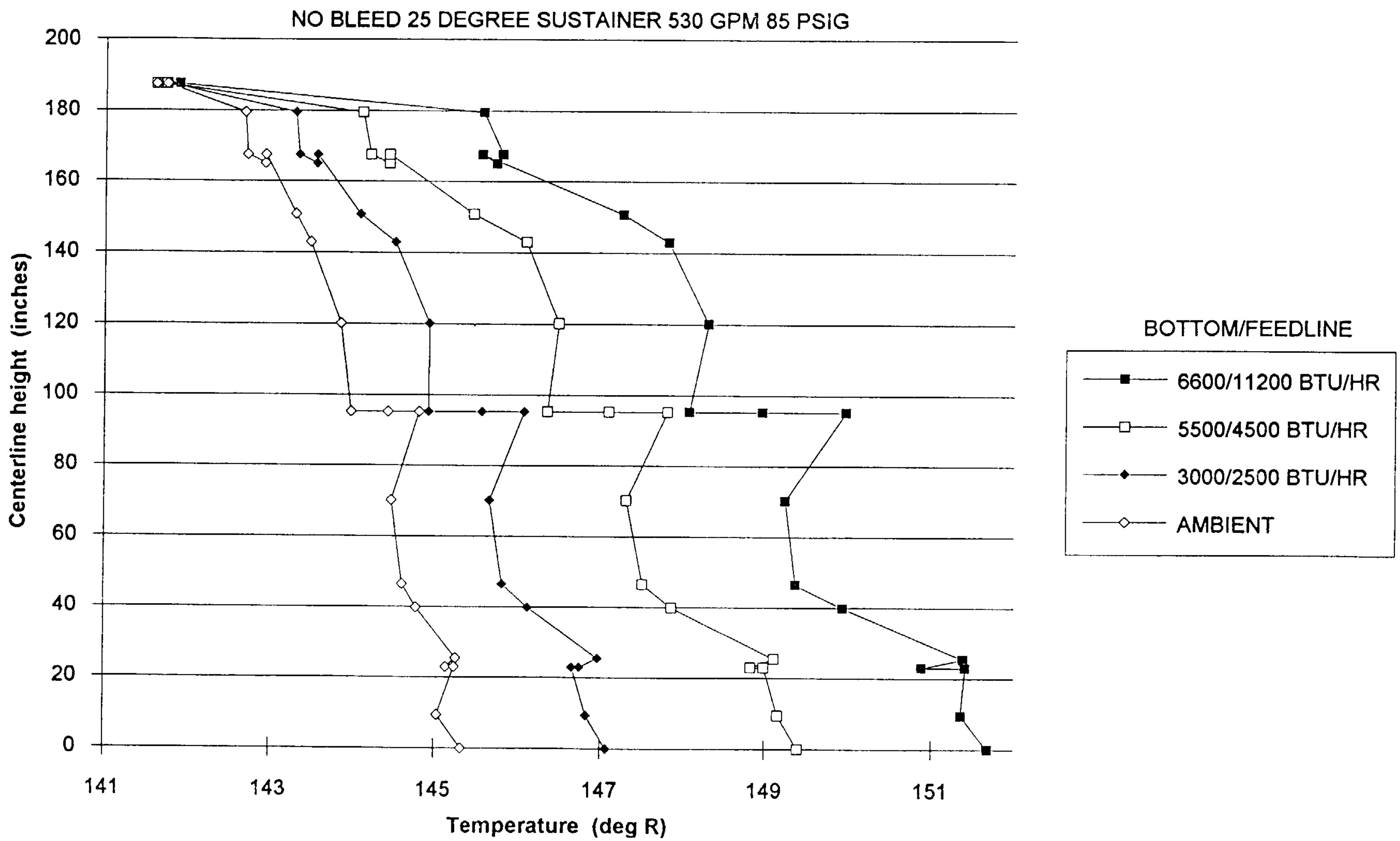

Figure 10. Effect of change in heat flux.

the feedline. Also, temperatures in the test article are subcooled, even with the highest heat input attainable using current instrumentation.

Figure 11 shows the 15° test article baseline of 3,000/2,500 Btu/h along with the uninsulated pump simulator test with heat flux of 14,960/2,500 Btu/h. The difference in temperature is around 6.5 R, however, both fluids are subcooled.

Figure 12 shows the change in temperatures through the feedline with changing flowrates. These flowrates are for the main flow loop, through the tee at the top of the test article. When the flowrate is varied from 350 to 530 gal/min, there is almost no detectable change in temperature, as shown.

Figure 13 shows deviation from the baseline pressure of 85 lb/in^2 gauge (100 lb/in^2 absolute) and its effect on the temperature profile in the test article. This chart shows that varying the pressure from 45 to 85 lb/in^2 gauge produces a temperature difference of less than 0.5R throughout the feedline. However, the saturation temperature at 85 lb/in^2 gauge is 176.8R whereas the saturation temperature at 45 lb/in^2 gauge is 164.8R. Thus, the temperatures are similar for both cases, but the higher pressure produces more subcooling.

Figure 14 shows the effects of changing the bleed rate on the 25° sustainer test article. The rates were varied from 0.0 to 9.57 gal/min. These bleed rates are attained by adjusting a valve which controls the flow of liquid out of the pump simulator. As the bleed rates increase, the temperatures in the test article decrease. Varying the bleed rate produces one of the largest changes in the temperature profile; however, these are not profound changes. Varying the bleed rate from 0.0 to 9.57 gal/min produces a maximum temperature change of 4R at each sensor.

Helium Bubbling and Recirculation Line Configurations

Figure 15 shows the different configurations used for helium bubbling and recirculation tests. The helium inlet is near silicon diodes 9015 and 9016. The recirculation line has three connection configurations. In configuration A-1-1, the recirculation line is connected to the helium inlet and the top of the feedline. For A-1-2, the line is connected to the bottom of the pump simulator and to the main flow loop downstream of the test article. For A-1-3, the line is connected to the helium inlet and the main flow loop upstream of the test article.

Figure 16 shows the effects of different rates of helium bubbling and the temperatures that were produced in the feedline. By altering the rate of helium bubbling from 0.0 to 2.5 acfm, the temperatures throughout the test article were cooled by approximately 1/2 to 2 1/2 R. The higher rates of helium injection did not produce a significant amount of additional cooling.

The temperature profiles produced by each recirculation line connection are shown in figure 17. Configurations A-1-2 and A-1-3 yield lower temperatures in the feedline than the baseline configuration (A-1-0). Configuration A-1-1, however, produces *warmer* temperatures in the feedline. This result may be due to the location of the recirculation line connections. This configuration may be causing warm liquid from the bottom of the feedline to be deposited back at the top of the feedline. From there, part of the liquid flows down through the feedline and is further heated, whereas in the other two configurations, liquid flows out into the main flow loop where it is carried back to the LN_2 tank.

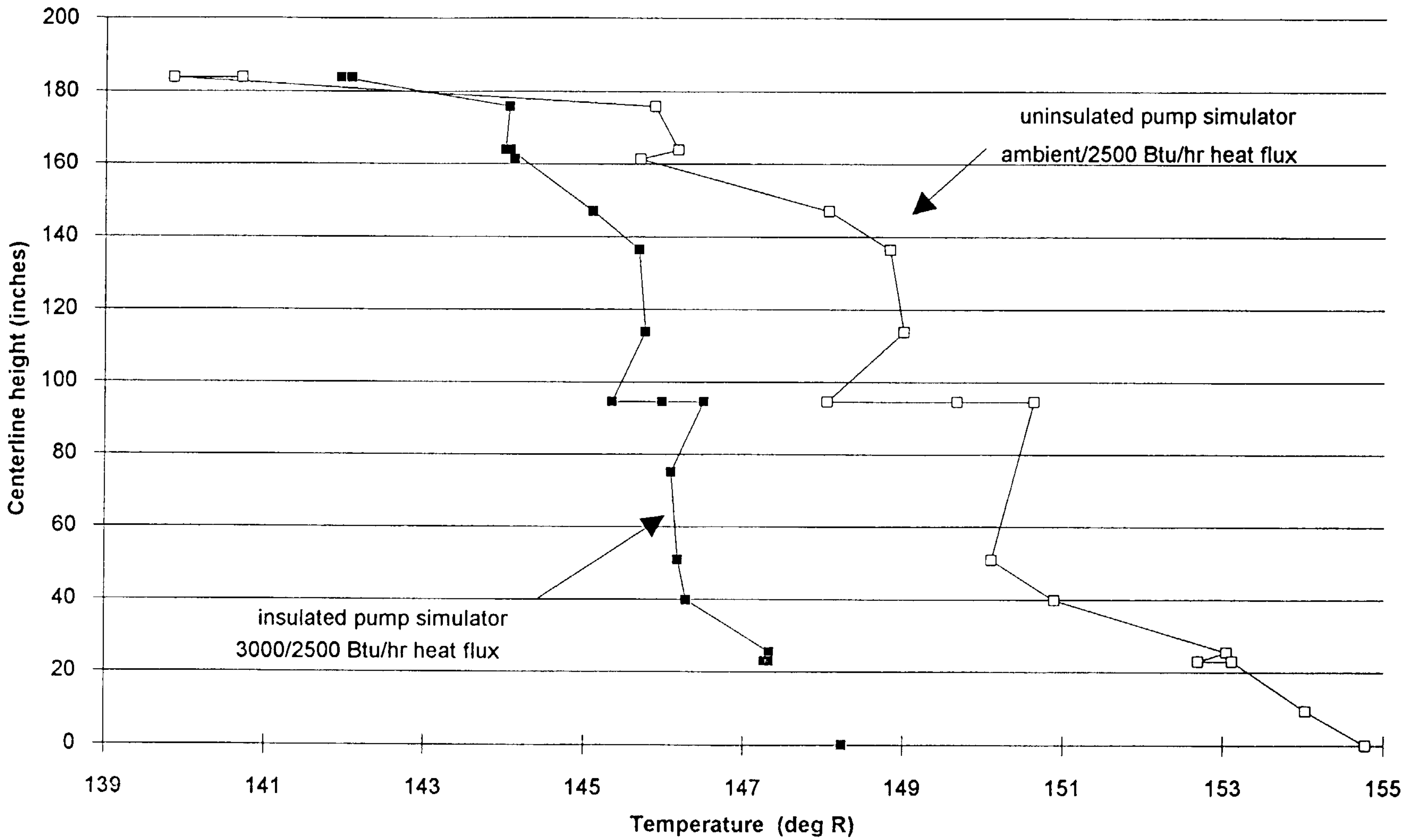

Figure 11. 15° baseline.

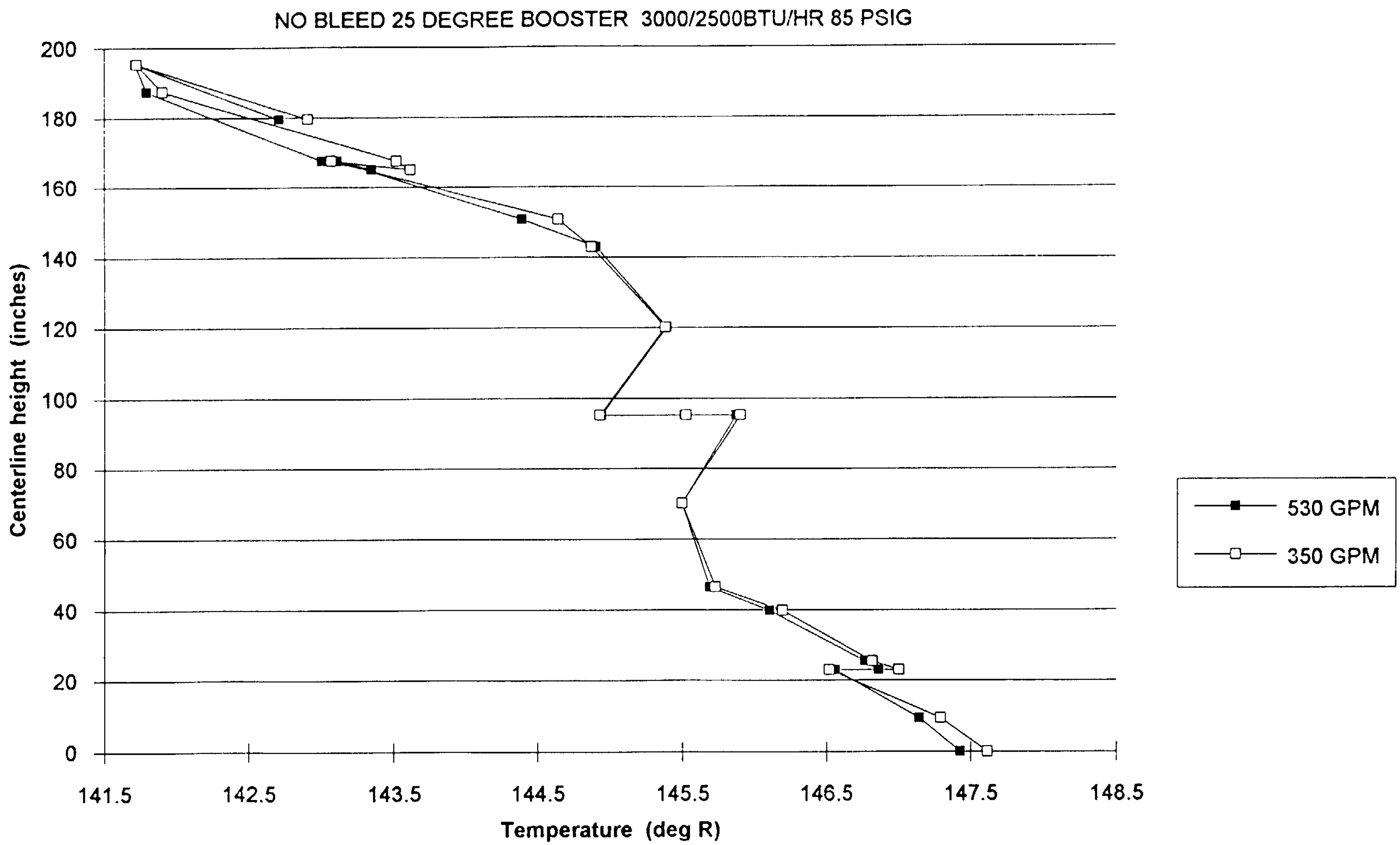

Figure 12. Effect of change in flowrate.

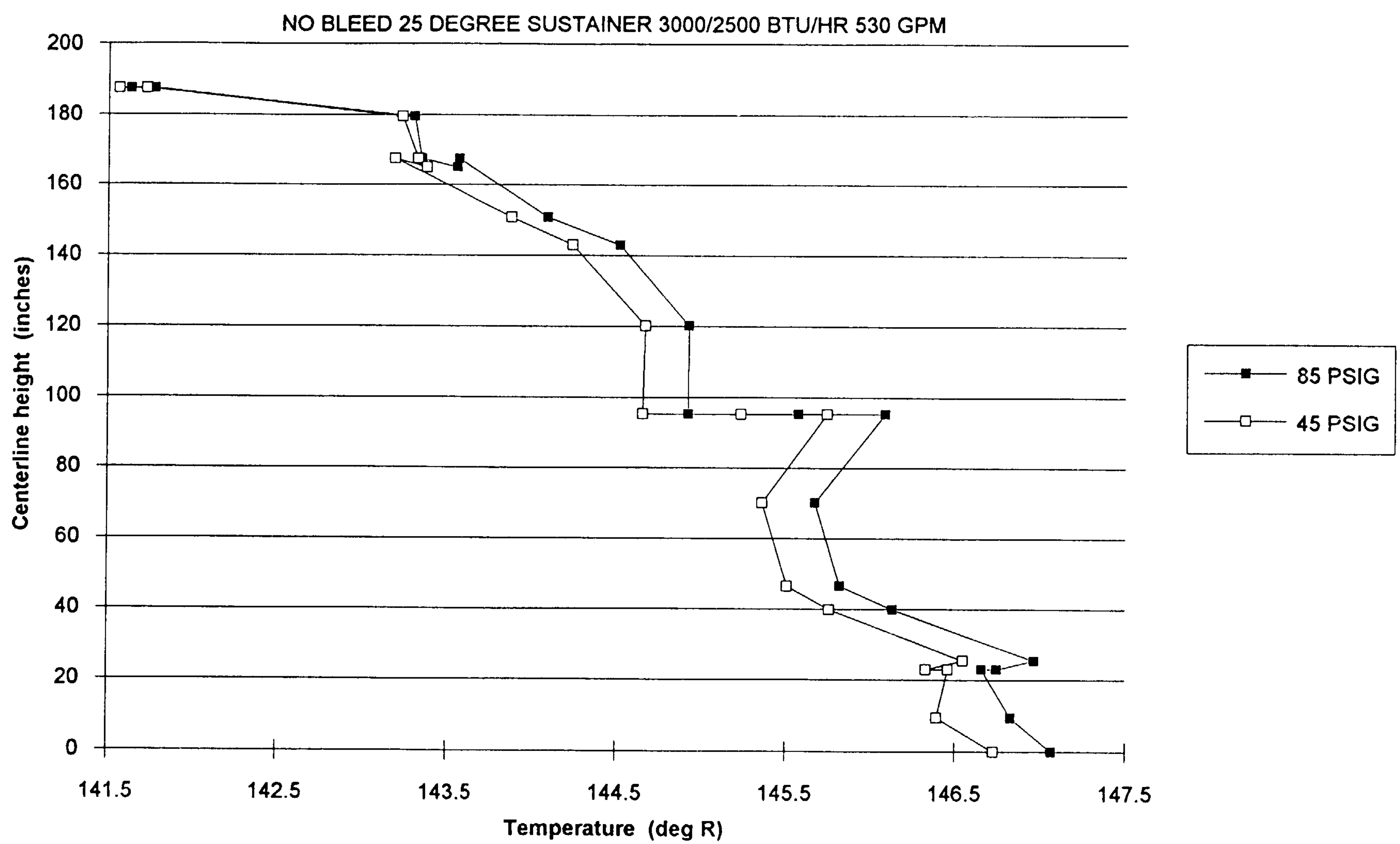

Figure 13. Effect of change in pressure.

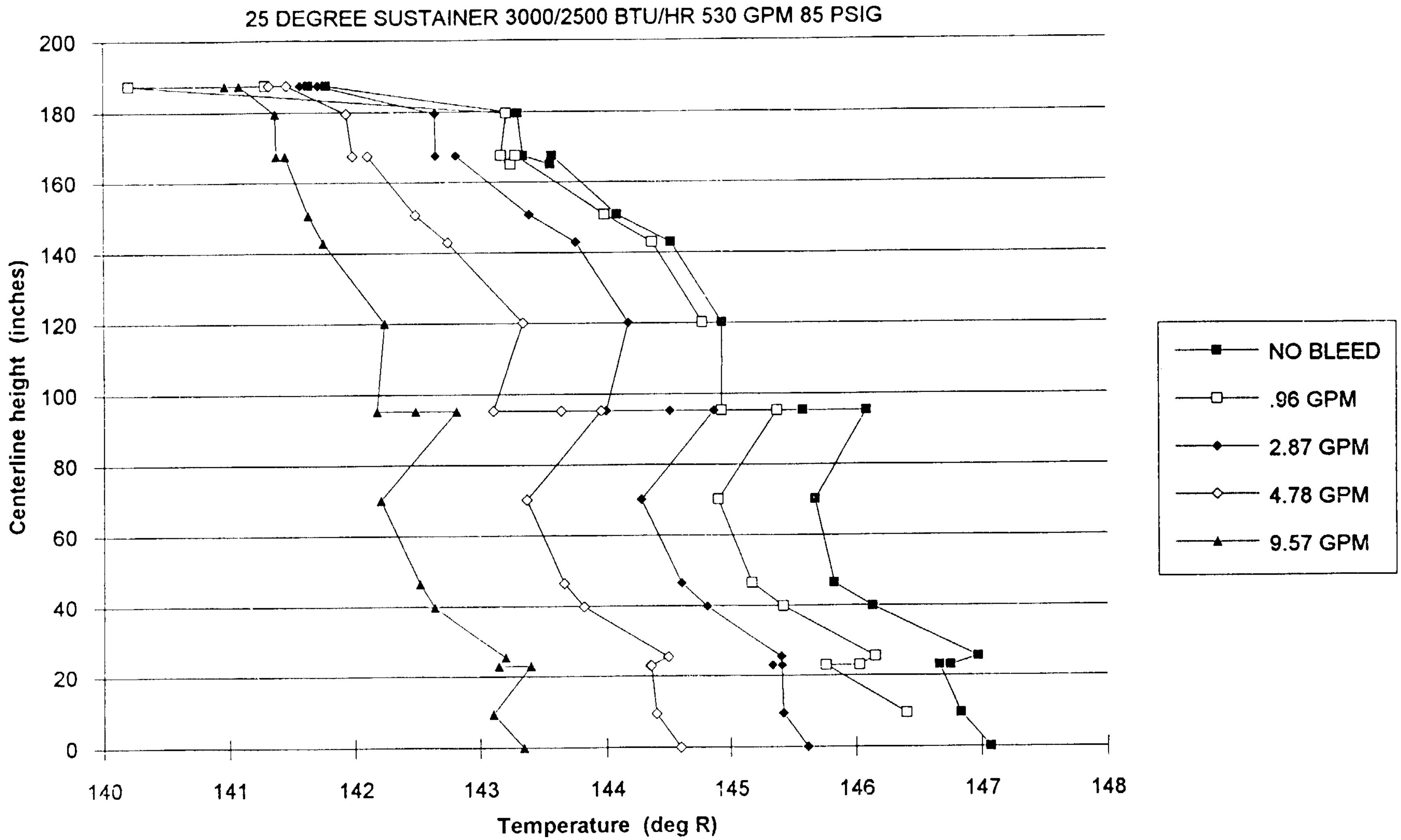

Figure 14. Effect of change in bleed rate.

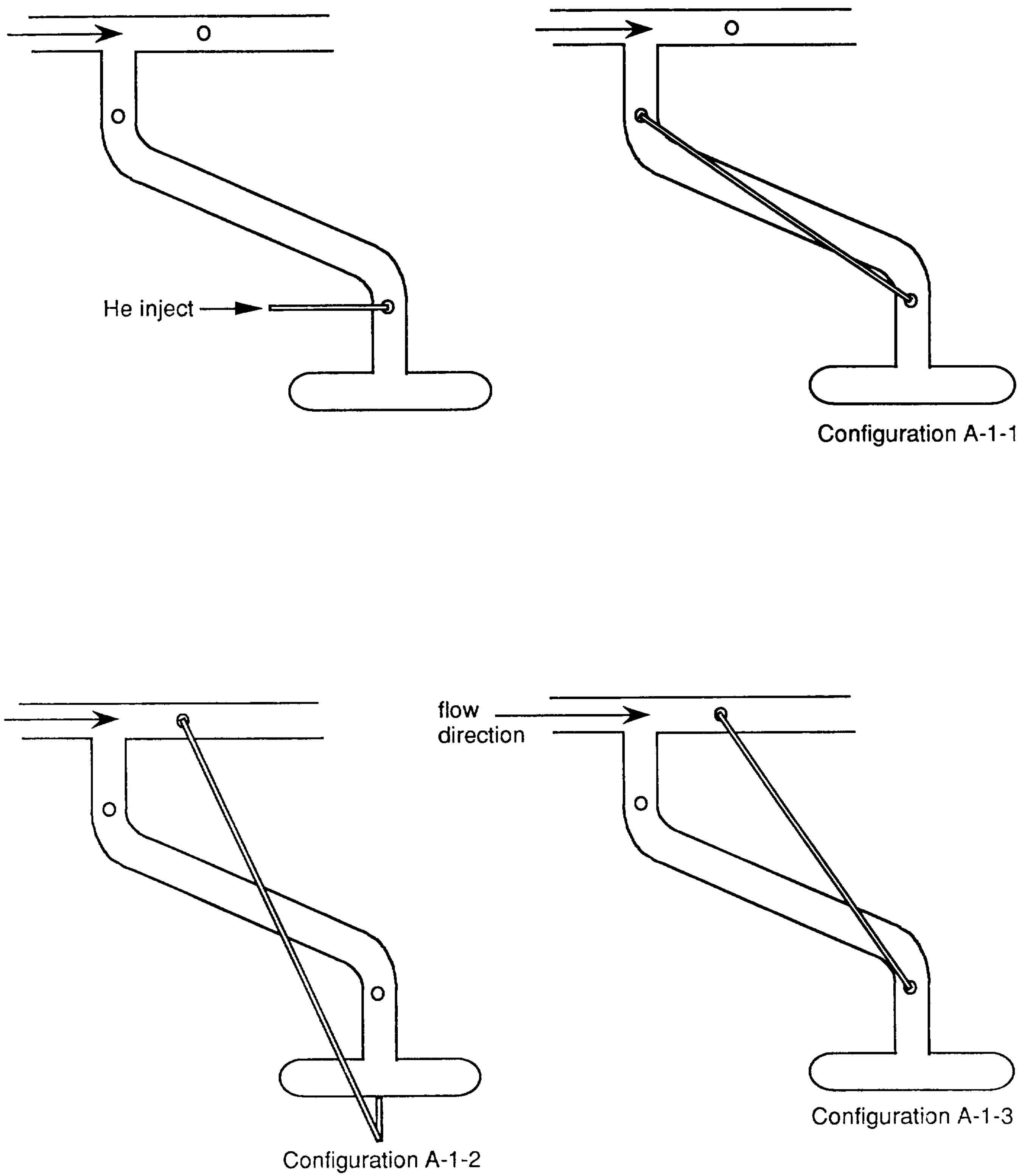

Figure 15. Helium bubbling and recirculation line configurations.

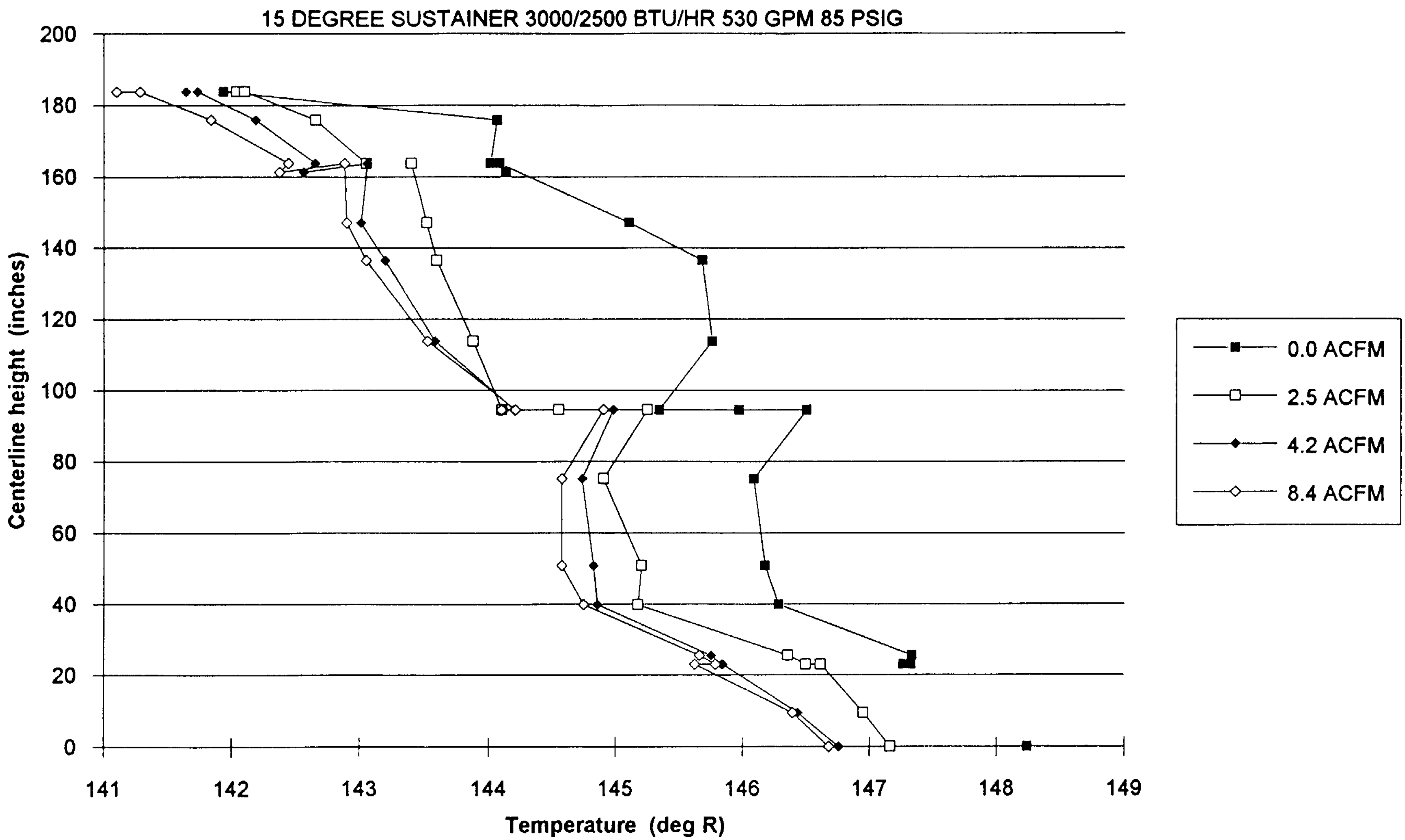

Figure 16. Effect of helium bubbling.

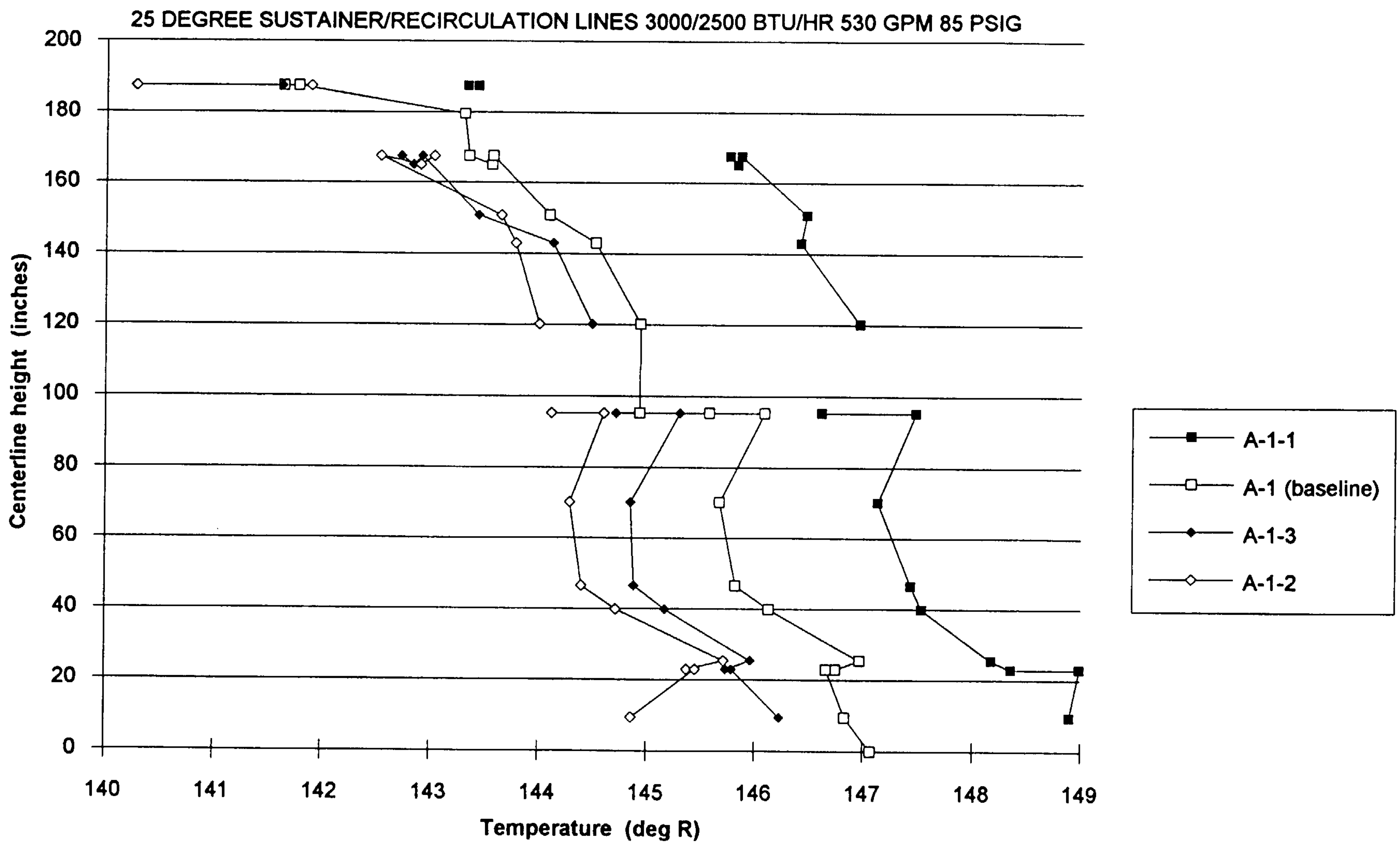

Figure 17. Effect of recirculation line.

FURTHER TESTING

Due to the success of this series of conditioning tests, other test configurations are being considered. Some alternatives for future testing include: fabricating and testing a 0° slope (horizontal) test article, testing the booster 2 configuration, attaching the feedline directly to the lox tank (therefore having no main recirculation loop), testing with constrictions in the feedline, and possibly testing with lox.

CALIBRATION TESTING

Calibration tests were necessary to determine the heat leaks into each portion of the test article. Calibration tests were first performed on the pump simulator. A schematic of this calibration test set up is shown in figure 18. A superconducting liquid level sensor was placed at the inlet to the simulator to measure the change in liquid level due to boiloff. However, during testing, the liquid level sensor did not properly register the amount of liquid in the pump simulator. As a secondary measurement, 1/2- and 1-in flowmeters were placed upstream of the test article to measure boiloff rates. The 1/2- and 1-in flowmeters were used to measure the rates of 0 to 10 and 10 to 50 actual ft^3/min (acfm), respectively. During filling of the pump simulator, the bypass line was open. When filling was completed, all lines were closed except for one of the boiloff lines, which measured the boiloff rate in the pump simulator.

During this set of calibration tests, pressures ranged from 0 to 35 lb/in^2 gauge, while heater settings ranged from 0 to 6,000 Btu/h. Several tests were run within these ranges to determine sensitivity of the system to different pressures and heater settings.

The heat leak for the pump simulator was found using the pressure, temperature, and flowrate measured at the flowmeter along with the pressure measured in the test article. The vapor temperature (measured with a thermocouple) and pressure, measured at the flowmeter, were used to find the density of the boiloff. The pressure in the test article was used to find the heat of vaporization (h_{fg}) of the LN_2. Then, the heat flux was calculated using the following equation: $\dot{Q} = \rho \times h_{fg} \times \dot{V}$, where $\dot{Q}$ is heat flux into the test article, ρ is the density of the boiloff, h_{fg} is the heat of vaporization, and $\dot{V}$ is the volumetric flowrate. A sample calculation follows:

Heater setting: 0.0 Btu/h
Test article pressure: 0.18 lb/in^2 gauge
$\approx$ 14.88 lb/in^2 absolute
h_{fg}: 85.396 Btu/lbm
ρ: 0.07313 lbm/ft^3

Vapor temperature: 527.45R
Vapor pressure: 0.07 lb/in^2 gauge
$\approx$ 14.77 lb/in^2 absolute
Vapor flowrate: 3.625 acfm

$$\dot{Q} = 0.07313 \frac{\text{lbm}}{\text{ft}^3} \times 85.396 \frac{\text{Btu}}{\text{lbm}} \times 3.625 \frac{\text{ft}^3}{\text{min}} \times 60 \frac{\text{min}}{\text{h}} \approx 1{,}358 \frac{\text{Btu}}{\text{h}} \ .$$

Initial calculations showed a 10-percent loss in the heater flux into the test article. For example, if the ambient heat flux was calculated to be 1,358 Btu/h without heaters, and then the heaters were set at 2,000 Btu/h, the expected total heat flux would be 3,358 Btu/h. However, the initial calculations indicated that heat flux was ambient plus 0.9 times the heater input

(1,358+0.9×2,000) or 3,158 Btu/h. A thermal model of the pump simulator was initiated to explore this 10-percent loss in heat flux.

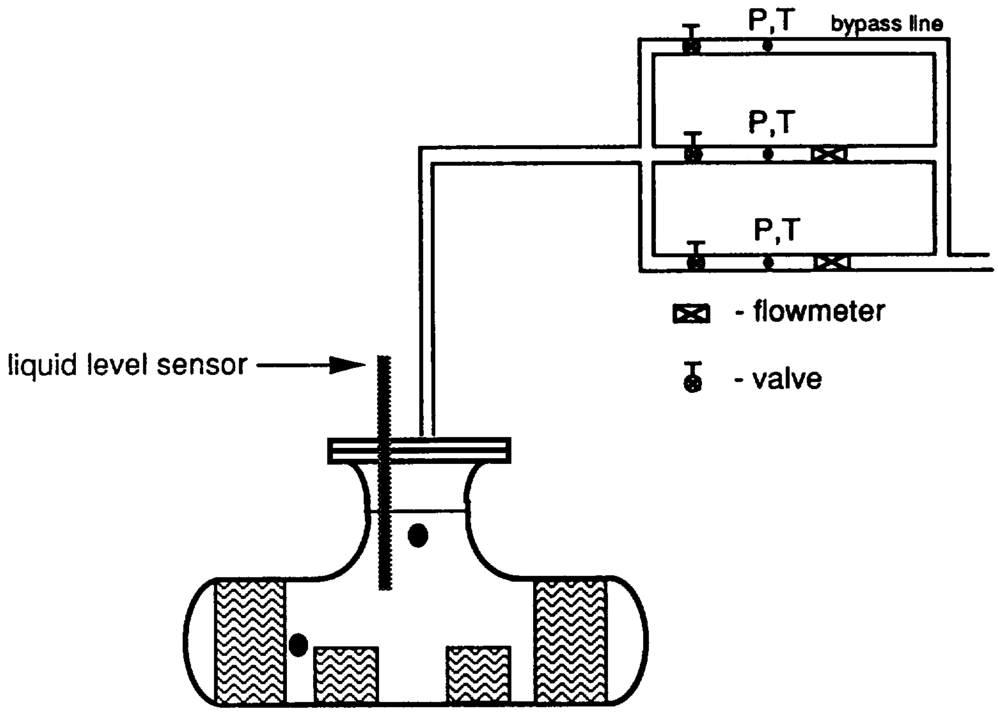

Figure 18. Calibration setup (pump simulator).

The second set of calibration tests were performed on the 25° feedline with the pump simulator attached. This setup is shown in figure 19. Pressure and heater inputs were again varied to determine sensitivity. For this particular set of tests, the target pressures (measured at the top of the test article) were 0 and 30 lb/in^2 gauge, while the target heat inputs were varied from 0 to 6,000 Btu/h for the feedline and from 0 to 5,500 Btu/h for the pump simulator. Problems arose during this testing due to a leak in the flanges which attach the pump simulator to the feedline. The insulation had to be stripped from around the flanges so the leak could be stopped. During this down time, two thermocouples were attached to measure skin temperatures near silicon diode 9019. These were intended for use with the thermal modeling in an attempt to explain the 10-percent loss of heat flux from the pump simulator heat leak calculations. After the leak was fixed, calibration tests resumed.

During testing, the readings from the two skin temperatures (9101, 9102) were approximately 50R warmer than the readings from silicon diode 9019, which prompted examination of other thermocouple readings. When liquid was flowing through the bypass line (referenced in fig. 19), the temperature reading was approximately 40R above the saturation temperature corresponding to the pressure in the line. This led to the conclusion that there was a problem with the temperature reference junction for the thermocouples. The reference junction was replaced, and more calibration tests were performed on the entire test article. During this testing, the differences in readings for 9019 and the skin temperatures were about 2R. The heat flux was recalculated using the new thermocouple readings, and a 10-percent deficit was no longer seen. For this set of heat leak tests, the target pressures were 0, 30 lb/in^2 gauge and the target heater settings were 0, 2,500, 4,500 Btu/h for the feedline heating, with 0, 3,000, 5,500 Btu/h for the pump simulator heating.

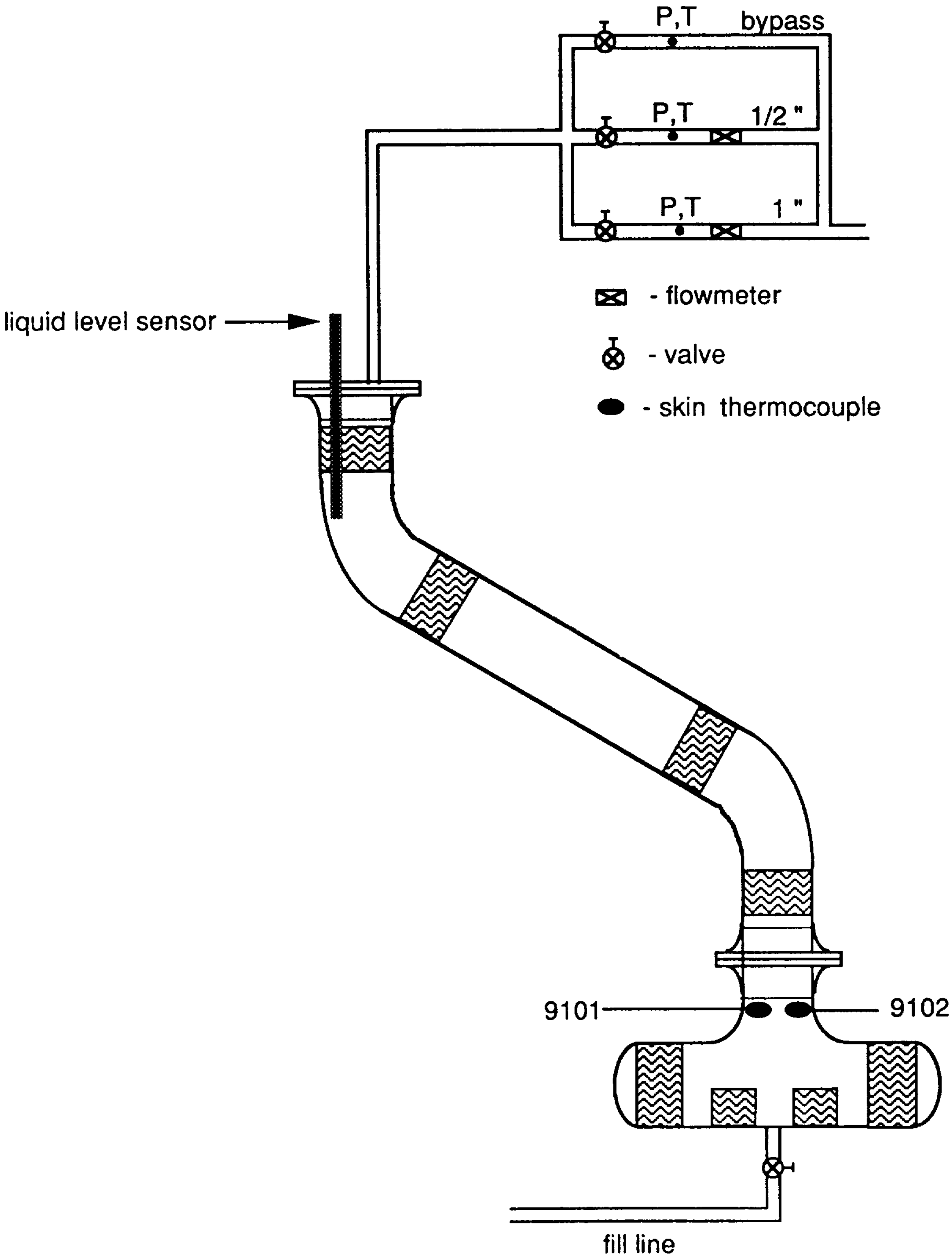

Figure 19. Calibration setup (pump simulator/25° feedline).

During all calibration testing, problems were seen when trying to perform tests at 30 lb/in^2 gauge. The pressure tended to fluctuate, thus causing the saturation temperature to increase or decrease (see fig. 20). An increase in pressure causes an increase in the effective heat capacity of the system. A decrease in pressure causes heat release from the system as the heat capacity decreases. A correction for the heat flux was calculated based on the change in pressure with respect to time. For example: at time t_1 the pressure was x and the saturated enthalpy was h_x. At time t_2, the pressure had increased to x+1 and the saturated enthalpy changed to h_{x+1}. The change in heat flux ($\Delta\dot{Q}$) due to the change in pressure could be described by the following equation: $\Delta\dot{Q} = (h_{x+1}-h_x)\times(m/(t_2-t_1))$, where m is the mass of liquid in the test article. This correction accounted for the fluctuations in boiloff due to pressure changes.

Problems encountered during an unrelated test program caused damage to the insulation and Kapton™ heaters on the pump simulator. This damage led to the opportunity to perform conditioning tests on the 15° feedline with the uninsulated pump simulator attached. Calibration tests were then necessary to find the heat leak for the uninsulated simulator. Two heat leak tests were performed on the uninsulated pump simulator; one at ambient pressure and one at 30 lb/in^2 gauge, both with no heater input. During testing, a barrier bag was placed around the pump simulator and purged with helium to prevent the formation of frost on the uninsulated pump simulator. When replacement heaters were received, they were attached to the pump simulator and it was refoamed. Heat leak tests were then performed on the insulated pump simulator because the new foam would change the ambient heat leak. The parameter variations for these tests included changes in pressure (0, 30 lb/in^2 gauge) and pump simulator heat flux (0, 3,000, 5,500 Btu/h). After these tests were performed, the pump simulator was reattached to the 15° feedline and a heat leak was performed on the entire insulated test article. The same pressure and bottom heat flux variations, along with side heat flux variations (0, 2,500, 4,500 Btu/h) were tested. After completion of these heat leak tests, the ambient heat leaks (shown below) were calculated for each portion of the test article.

Description	Ambient Heat Leak
Insulated engine simulator	1,358 Btu/h
Uninsulated engine simulator	14,960 Btu/h
15° feedline	1,277 Btu/h
25° feedline	1,337 Btu/h

CONCLUSIONS

Data Analysis

These data will be used to try to validate a two-dimensional flow and heat transfer computer code being written at MSFC. Also, two-dimensional and three-dimensional computational fluid dynamics analysis is underway. Once the LN_2 temperature profile is matched, lox properties will be substituted into the models. This will allow feedline temperature profiles to be predicted for new vehicle configurations.

Analysis shows that all concepts studied could be used in future launch vehicles. Each option studied was capable of providing subcooled liquid to the engine interface. The particular options chosen for a launch vehicle would depend upon the requirements placed on the lox propulsion system. However, from the data gathered, passive recirculation is the simplest option.

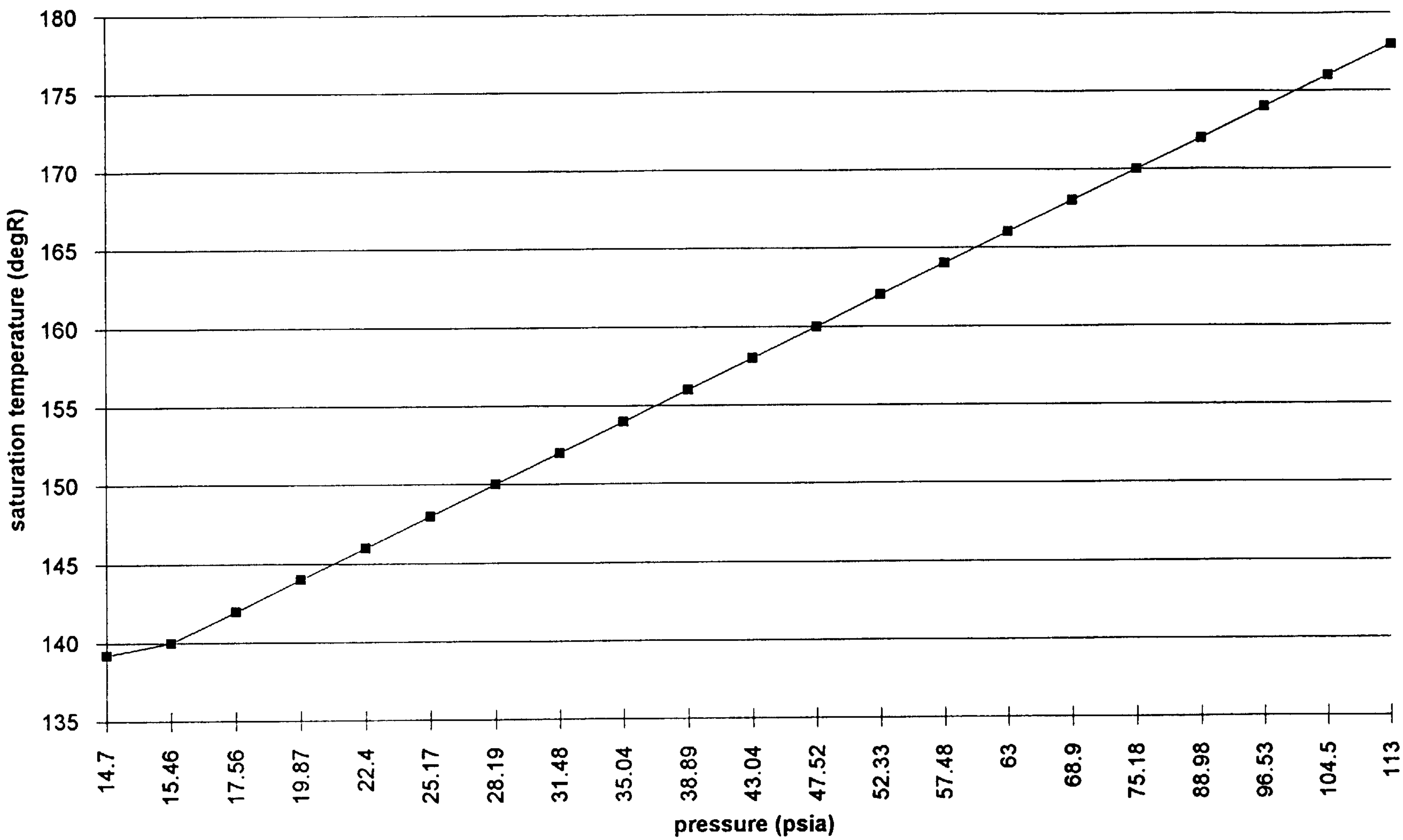

Figure 20. LN_2 saturation curve.

APPENDIX A

25 degree sustainer test schedule

filename	test	start time	stop time	date	configuration	heat leak (btu/hr) pump / side	bleed rate (gpm)	recirc flowrate (gpm)
lo2ta701	pt	11:09:17	15:05:45	6/8/93	A-1			
lo2ta702	22	15:06:09	15:13:24	6/8/93	A-1			
lo2ta703	3	15:13:45	16:54:40	6/8/93	A-1	3000 / 2500	11	530
lo2ta801	4a	8:31:03	10:20:24	6/9/93	A-1	3000 / 2500	0.96	530
lo2ta802	3r	10:20:55	11:16:23	6/9/93	A-1	3000 / 2500	0	530
lo2ta803	22	11:16:47	12:44:06	6/9/93	A-1	5500 / 4500	0	530
lo2ta804	2.4	12:44:40	14:27:26	6/9/93	A-1			
lo2ta805	2.1	14:27:48	14:48:50	6/9/93	A-1			
lo2ta806	2.2	14:49:10	17:28:35	6/9/93	A-1		10	
lo2ta901	pt	8:30:45	10:04:18	6/10/93	A-1			
lo2ta902	5a	10:04:38	12:28:13	6/10/93	A-1	3000 / 2500	0	530
lo2ta903	5b	12:28:31	13:28:37	6/10/93	A-1	3000 / 2500	0	530
lo2ta904	6a	13:28:56	14:12:55	6/10/93	A-1	5500 / 4500	0	530
lo2ta905	6b	14:13:13	15:09:45	6/10/93	A-1	5500 / 4500	0	530
lo2ta906	20	15:10:35	16:07:11	6/10/93	A-1	3000 / 4500	0	530
lo2ta907	24	16:07:45	17:00:30	6/10/93	A-1	5500 / 2500	0	530
lo2ta908	2.5	17:01:15	18:35:20	6/10/93	A-1			
lo2ta10a	pt	9:00:30	12:25:15	6/15/93	A-1			
lo2ta10b	5c	12:25:16	12:54:24	6/15/93	A-1	3000 / 2500	0	530
lo2ta10c	15	12:55:10	13:44:40	6/15/93	A-1	3000 / 2500	0	530
lo2ta10d	5c	13:45:15	14:20:04	6/15/93	A-1	3000 / 2500	0	530
lo2ta10e	6c	14:20:20	15:04:59	6/15/93	A-1	5500 / 4500	0	530
lo2ta10f	17	15:05:15	16:18:20	6/15/93	A-1	3000 / 2500	0	530
lo2ta10g	1111	16:18:48	16:45:00	6/15/93	A-1			
lo2ta11a	pt	8:18:13	9:47:53	6/16/93	A-1			
lo2ta11b	4d	9:48:22	9:55:29	6/16/93	A-1	3000 / 2500	9.57	530
lo2ta11c	18d	9:55:55	10:25:30	6/16/93	A-1	3000 / 2500	9.57	530

25 degree sustainer test schedule		
filename	recirc pressure	comments
	(psig)	UPPER HEATERS DISCONNECTED FOR
		ALL TESTS THROUGH LO2TA10G.
lo2ta701		
lo2ta702		
lo2ta703	85	
lo2ta801	85	
lo2ta802	85	
lo2ta803	85	loop temp-thermocouples not calibrated
lo2ta804		heat leak
lo2ta805		He check
lo2ta806		drain-high drain rate
lo2ta901		can't verify He/recirc flow/ flowmeters off line
lo2ta902	85	He acfm:lbm/sec:scfm 2.5:.003
lo2ta903	85	4.2:.005
lo2ta904	85	2.5:.003
lo2ta905	85	4.2:.005
lo2ta906	85	
lo2ta907	85	
lo2ta908		drain/ high drain rate/ He system check
lo2ta10a		
lo2ta10b	85	He: 8.4:.010:58
lo2ta10c	85	
lo2ta10d	85	8.4:.01:58
lo2ta10e	85	8.4:.01
lo2ta10f	45	test bleed
lo2ta10g		
lo2ta11a		
lo2ta11b	85	
lo2ta11c	45	

lo2ta11d	18e	10:26:02	10:45:15	6/16/93	A-1	5500 / 4500	9.57	530
lo2ta11e	18f	10:45:38	11:07:46	6/16/93	A-1	100v / 100v	9.57	530
lo2ta11f	26	11:08:03	11:50:19	6/16/93	A-1	no heaters	0	
lo2ta11g	26b	11:50:38	12:19:41	6/16/93	A-1	3000 / 2500	0	
lo2ta11h	26c	12:19:59	12:57:45	6/16/93	A-1	5500 / 4500	0	
lo2ta11i	2.4	12:58:02	13:52:11	6/16/93	A-1			
lo2ta11j	2.5	13:52:27	14:44:29	6/16/93	A-1			
lo2ta11k	2.3	14:44:47	17:13:22	6/16/93	A-1			
lo2ta12a	pt	8:04:01	9:14:47	6/18/93	A-1			
lo2ta12b	tim 1	9:16:29	9:31:20	6/18/93	A-1			
lo2ta12c	4b	9:31:39	10:33:09	6/18/93	A-1	3000 / 2500	2.87	530
lo2ta12d	4b	10:33:17	11:15:23	6/18/93	A-1	3000 / 2500	2.87	530
lo2ta12e	4b	11:15:49	11:59:08	6/18/93	A-1	3000 / 2500	2.87	530
lo2ta12f	4a	11:59:25	12:09:46	6/18/93	A-1	3000 / 2500	0.98	530
lo2ta12g	4c	12:10:06	12:51:18	6/18/93	A-1	3000 / 2500	4.78	530
lo2ta12h	4d	12:51:37	14:02:05	6/18/93	A-1	3000 / 2500	9.57	530
lo2ta12i	2.5	14:02:27	15:45:14	6/18/93	A-1			
lo2ta13a	pt	8:36:28	11:15:20	6/22/93	A-1			
lo2ta13b	2.5	11:15:36	14:05:54	6/22/93	A-1			
lo2ta13c	8a	14:10:46	15:18:00	6/22/93	A-1	100v / 100v	0	530
lo2ta13d	22r	15:18:33	16:02:22	6/22/93	A-1	5500 / 4500	0	530
lo2ta13e	3rr	16:02:54	16:44:49	6/22/93	A-1	3000 / 2500	0	530
lo2ta13f	27	16:45:03	17:27:18	6/22/93	A-1	no heaters	0	530
lo2ta13g	17r	17:27:38	18:01:56	6/22/93	A-1	3000 / 2500	0	530
lo2ta14a	pt	8:18:37	10:17:22	6/23/93	A-1			
lo2ta14b	4a	10:18:14	11:17:28	6/23/93	A-1	3000 / 2500	0.96	530
lo2ta14c	4a	11:17:30	11:57:38	6/23/93	A-1	3000 / 2500	0.96	530
lo2ta14d	21a	11:57:53	12:56:12	6/23/93	A-1	5500 / 4500	0.96	530
lo2ta14e	28b	12:57:14	13:57:59	6/23/93	A-1	100v / 100v	0.96	530
lo2ta14f	19a	13:58:23	15:07:20	6/23/93	A-1	3000 / 4500	0.96	530
lo2ta14g	2.5	15:07:40	17:08:35	6/23/93	A-1			
lo2ta15a	pt	8:10:36	8:58:01	6/24/93	A-1			

lo2ta11d	45	
lo2ta11e	45	
lo2ta11f		Pump off--natural convection
lo2ta11g		Pump off--natural convection
lo2ta11h		Pump off--natural convection
lo2ta11i		heat leak { remove top 2 heaters from zone 1 to prepare for drain &heat leak testing}
lo2ta11j		drain
lo2ta11k		heat leak
lo2ta12a		
lo2ta12b		
lo2ta12c	85	upper heaters disconnected
lo2ta12d	85	heaters off
lo2ta12e	85	heaters back on
lo2ta12f	85	flow unsteady w/current configuration
lo2ta12g	85	
lo2ta12h	85	
lo2ta12i		Drain rate about 2.5 gpm
lo2ta13a		
lo2ta13b		drain test
lo2ta13c	85	
lo2ta13d	85	
lo2ta13e	85	
lo2ta13f	85	
lo2ta13g	45	
lo2ta14a		
lo2ta14b	85	ROV 340 failed open--shut down test
lo2ta14c	85	
lo2ta14d	85	
lo2ta14e	85	unsteady bleed flowmeter reading
lo2ta14f	85	
lo2ta14g		drain--ROV 396 failed closed
lo2ta15a		ROV 350 open during all tests except drain test

lo2ta15b	23a	8:58:32	10:01:40	6/24/93	A-1	5500 / 4500	0.96	530
lo2ta15c	16a	10:02:08	10:58:55	6/24/93	A-1	3000 / 2500	0.96	530
lo2ta15d	18a	10:59:18	11:54:23	6/24/93	A-1	3000 / 2500	0.96	530
lo2ta15e	18b	11:54:43	12:39:02	6/24/93	A-1	3000 / 2500	2.87	530
lo2ta15f	18c	12:39:22	13:04:56	6/24/93	A-1	3000 / 2500	4.78	530
lo2ta15g	21b	13:05:15	13:20:03	6/24/93	A-1	5500 / 4500	2.87	530
lo2ta15h	21c	13:20:20	13:25:18	6/24/93	A-1	5500 / 4500	4.78	530
lo2ta15i	21d	13:25:36	14:17:17	6/24/93	A-1	5500 / 4500	9.57	530
lo2ta15j	21c	14:17:23	15:09:59	6/24/93	A-1	5500 / 4500	4.78	530
lo2ta15k	2.5	15:10:25	17:14:36	6/24/93	A-1			
lo2ta16a	pt	8:49:06	9:54:52	6/25/93	A-1			
lo2ta16b	23a	10:00:11	10:57:44	6/25/93	A-1	5500 / 2500	0.96	530
lo2ta16c	4ar	10:58:10	11:37:58	6/25/93	A-1	3000 / 2500	0.96	530
lo2ta16d	21ar	11:38:18	12:23:08	6/25/93	A-1	5500 / 4500	0.96	530
lo2ta16e	21b	12:23:27	13:10:11	6/25/93	A-1	5500 / 4500	2.87	530
lo2ta16f	21c	13:10:33	13:58:15	6/25/93	A-1	5500 / 4500	4.78	530
lo2ta16g	21d	13:58:30	14:41:44	6/25/93	A-1	5500 / 4500	9.57	530
lo2ta16h	28d	14:42:05	16:12:53	6/25/93	A-1	100v / 100v	4.78	530
lo2ta16i	2.5	16:13:20	17:40:39	6/25/93	A-1			
lo2ta17a	pt	9:10:07	9:31:41	6/28/93	A-1			
lo2ta17b	28b	9:32:03	10:39:23	6/28/93	A-1	100v / 100v	0.96	530
lo2ta17c	16a	10:39:44	11:26:57	6/28/93	A-1	3000 / 2500	0.96	530
lo2ta17d	18a	11:27:34	12:35:34	6/28/93	A-1	3000 / 2500	0.96	530
lo2ta17e	18c	12:35:51	13:12:14	6/28/93	A-1	3000 / 2500	4.78	530
lo2ta17f	18b	13:12:36	13:53:01	6/28/93	A-1	3000 / 2500	2.87	530
lo2ta17g	2.3	13:53:19	15:34:51	6/28/93	A-1			
lo2ta17h	2.5	15:35:11	16:39:37	6/28/93	A-1			
lo2ta17i	2.6	16:39:58	17:36:16	6/28/93	A-1			
lo2ta18a.	pt	7:49:20	8:56:38	6/30/93	A-1-3			
lo2ta18b	10	8:56:58	10:59:30	6/30/93	A-1-3	3000 / 2500	0	530
lo2ta18c	13	10:59:16	11:43:40	6/30/93	A-1-3	5500 / 4500	0	530
lo2ta18d	11	11:43:53	12:29:54	6/30/93	A-1-3	100v / 100v	0	530
lo2ta18e	2.3	12:30:19	13:46:14	6/30/93	A-1-3			

lo2ta15b	85	
lo2ta15c	85	
lo2ta15d	45	
lo2ta15e	45	
lo2ta15f	45	
lo2ta15g	85	
lo2ta15h	85	
lo2ta15i	85	
lo2ta15j	85	
lo2ta15k		drain test
lo2ta16a		
lo2ta16b	85	
lo2ta16c	85	
lo2ta16d	85	
lo2ta16e	85	
lo2ta16f	85	
lo2ta16g	85	
lo2ta16h	85	
lo2ta16i		drain
lo2ta17a		
lo2ta17b	85	
lo2ta17c	85	
lo2ta17d	45	
lo2ta17e	45	
lo2ta17f	45	
lo2ta17g		heat leak
lo2ta17h		drain
lo2ta17i		bottom heat leak
lo2ta18a.		recirc line connected to He inlet, piping to right of test article tee.
lo2ta18b	85	flowmeter not working
lo2ta18c	85	flowmeter on line at 3.5 gpm
lo2ta18d	85	
lo2ta18e		heat leak

lo2ta18f	2.5	13:46:40	15:40:05	6/30/93	A-1-3			
lo2ta19a	pt	6:42:28	8:02:48	7/1/93	A-1-1			
lo2ta19b	7	8:03:08	8:25:25	7/1/93	A-1-1	3000 / 2500	0	530
lo2ta19c	7	8:25:38	9:26:01	7/1/93	A-1-1	3000 / 2500	0	530
lo2ta19d	8	9:26:16	10:07:10	7/1/93	A-1-1	5500 / 4500	0	530
lo2ta19e	14	10:07:24	10:48:34	7/1/93	A-1-1	100v / 100v	0	530
lo2ta19f	2.5	10:48:51	12:44:09	7/1/93	A-1-1			
lo2ta20a	pt	7:19:33	8:07:40	7/2/93	A-1-2			
lo2ta20b	9	8:08:00	9:04:20	7/2/93	A-1-2	3000 / 2500	0	530
lo2ta20d	29	9:07:57	9:52:51	7/2/93	A-1-2	100v / 100v	0	530
lo2ta20f	'10-2'	9:55:50	10:39:48	7/2/93	A-1-2	5500 / 4500	0	530
lo2ta20g	2.3	10:40:05	11:10:15	7/2/93	A-1-2			
lo2ta20h	2.3	11:10:23	12:52:45	7/2/93	A-1-2			
lo2ta20i	2.5	12:53:07	13:52:45	7/2/93	A-1-2			

lo2ta18f		drain & bottom heat leak
lo2ta19a		recirc line connected to He inlet, recirc connection in top of test article
lo2ta19b	85	liquid level too low for steady pump operation
lo2ta19c	85	pump ok
lo2ta19d	85	
lo2ta19e	85	
lo2ta19f		drain/ pressure fluctuations: tried to maintain pressure
lo2ta20a		recirc line connected to drain line,piping to right of test article tee.
lo2ta20b	85	
lo2ta20d	85	
lo2ta20f	85	
lo2ta20g		heat leak /turned off lower heaters to see if they were affecting 9020 temps.
lo2ta20h		heat leak
lo2ta20i		drain

25 degree booster test schedule								
filename	test	start time	stop time	date	configuration	heat leak (btu/hr) pump / side	bleed rate (gpm)	recirc flowrate (gpm)
lo2ta21a	pt	8:50:16	9:33:06	7/13/93	A-2			
lo2ta21b	30	9:33:21	10:31:05	7/13/93	A-2	3000 / 2500	0	530
lo2ta21c	30r	10:31:32	10:55:20	7/13/93	A-2	3000 / 2500	0	530
lo2ta21d	31a	10:55:45	12:06:30	7/13/93	A-2	3000 / 2500	0.96	530
lo2ta21e	31b	12:06:49	12:56:33	7/13/93	A-2	3000 / 2500	2.87	530
lo2ta21f	31c	12:57:15	13:02:26	7/13/93	A-2	3000 / 2500	4.78	530
lo2ta21g	32	13:02:53	14:07:52	7/13/93	A-2	5500 / 4500	0	530
lo2ta21h	31c	14:08:16	15:06:50	7/13/93	A-2	3000 / 2500	4.78	530
lo2ta21i	2.2	15:07:16	16:47:54	7/13/93	A-2			
lo2ta22a	pt	7:40:37	8:38:27	7/14/93	A-2			
lo2ta22b	31d	8:38:53	8:50:25	7/14/93	A-2	3000 / 2500	9.57	530
lo2ta22c	35	8:50:42	10:05:56	7/14/93	A-2	3000 / 2500	0	350
lo2ta22d	31d	10:06:28	10:34:12	7/14/93	A-2	3000 / 2500	9.57	530
lo2ta22e	33a	10:34:37	11:43:02	7/14/93	A-2	5500 / 4500	0.96	530
lo2ta22f	33b	11:43:19	12:28:28	7/14/93	A-2	5500 / 4500	4.78	530
lo2ta22g	37	12:28:54	13:26:00	7/14/93	A-2	100v / 100v	0	530
lo2ta22h	38a	13:26:25	14:30:11	7/14/93	A-2	100v / 100v	0.96	530
lo2ta22i	38b	14:30:37	15:56:21	7/14/93	A-2	100v / 100v	4.78	530
lo2ta22j	2.2	15:56:43	17:57:28	7/14/93	A-2			
lo2ta23a	pt	8:02:22	8:58:18	7/15/93	A-2			
lo2ta23b	34a	8:58:47	9:42	7/15/93	A-2	3000 / 2500	0	530
lo2ta23c	34ar	9:53:45	10:23:17	7/15/93	A-2	3000 / 2500	0	530
lo2ta23d	34b	10:23:40	11:16:31	7/15/93	A-2	3000 / 2500	0	530
lo2ta23e	34c	11:16:54	12:07:40	7/15/93	A-2	3000 / 2500	0	530
lo2ta23f	39	12:07:58	13:13:13	7/15/93	A-2	5500 / 2500	0	530
lo2ta23g	40a	13:13:34	14:26:05	7/15/93	A-2	5500 / 2500	0.96	530
lo2ta23h	40b	14:26:27	15:22:35	7/15/93	A-2	5500 / 2500	4.78	530
lo2ta23i	36b	15:23:00	16:09:48	7/15/93	A-2	3000 / 2500	4.78	350
lo2ta23j	36a	16:10:07	17:02:24	7/15/93	A-2	3000 / 2500	0.96	350

25 degree booster test schedule		
filename	recirc pressure (psig)	comments
lo2ta21a		leak through liquid level probe
lo2ta21b	85	
lo2ta21c	85	
lo2ta21d	85	
lo2ta21e	85	
lo2ta21f	85	
lo2ta21g	85	
lo2ta21h	85	changed one of 1/2" bleed valves w/a 1".
lo2ta21i		
lo2ta22a		
lo2ta22b	85	No data/can't get required gpm/go to no-bleed tests
lo2ta22c	85	Filter in drain line was clogged / filter replaced
lo2ta22d	85	
lo2ta22e	85	
lo2ta22f	85	
lo2ta22g	85	
lo2ta22h	85	
lo2ta22i	85	
lo2ta22j		drain/ 1" bleed valve closed
lo2ta23a		
lo2ta23b	85	He:2.5/.003/17 lower Si-diodes seem warm/DSU stopped
lo2ta23c	85	DSU back on line He:2.5/.003/17
lo2ta23d	85	4.2/.005/29
lo2ta23e	85	8.4/.01/58 large fluctuations in 9035
lo2ta23f	85	
lo2ta23g	85	
lo2ta23h	85	
lo2ta23i	85	
lo2ta23j	85	large fluctuations in bleed gpm--aborted because of sun

lo2ta24a	pt	7:48:26	8:59:03	7/16/93	A-2			
lo2ta24b	36ar	8:59:26	10:29:11	7/16/93	A-2	3000 / 2500	0.96	350
lo2ta24d	2.3	10:42:09	12:01:28	7/16/93	A-2			
lo2ta24e	2.2	12:01:48	12:39:02	7/16/93	A-2			
lo2ta24f	2.3t	12:40:02	12:59	7/16/93	A-2			
lo2ta24g	2.2f	12:59:57	13:12:18	7/16/93	A-2			

lo2ta24a		
lo2ta24b	85	disconnect top 2 heaters. Cut off circ pump. Set up for heat leak
lo2ta24d		heat leak
lo2ta24e		drain
lo2ta24f		tank heat leak
lo2ta24g		final drain

15 degree test schedule								
file name	test	start time	finish time	date	configuration	heat leak (btu/hr)	bleed rate	recirc flow rate
						pump / side	gpm	gpm
lo2ta25a	pt	7:47:59	8:11:44	8/9/89	A-3			
lo2ta25b	47	8:12:01	9:07:08	8/9/89	A-3	3000 / 2500	0	530
lo2ta25c	58	9:07:23	10:43:32	8/9/89	A-3	3000 / 2500	0	nat
lo2ta25d	058b	10:43:49	11:45:50	8/9/89	A-3	5500 / 4500	0	nat
lo2ta25e	058a	11:46:11	12:47:09	8/9/89	A-3	0 / 0	0	nat
lo2ta25f	2.3	12:47:23	14:47:20	8/9/89	A-3	3000 / 2500	0	none
lo2ta25g	2.2	14:47:37	15:24:39	8/9/89	A-3	0 / 0	2.5	none
lo2ta26a	pt	7:43:29		8/11/89	A-3			
lo2ta26b	47	8:19:02	9:46:13	8/11/89	A-3	3000 / 2500	0	530
lo2ta26c	048a	9:46:37	10:53:41	8/11/89	A-3	3000 / 2500	0.96	530
lo2ta26d	048b	10:53:56	11:52:48	8/11/89	A-3	3000 / 2500	2.87	530
lo2ta26e	048c	11:53:06	11:58:17	8/11/89	A-3	3000 / 2500	4.78	530
lo2ta26f	49	11:58:31	13:10:16	8/11/89	A-3	5500 / 4500	0	530
lo2ta26g	54	13:10:29	14:08:36	8/11/89	A-3	3000 / 4500	0	530
lo2ta26h	56	14:08:54	15:08:59	8/11/89	A-3	5500 / 2500	0	530
lo2ta26i	2.2	15:09:20	17:10:53	8/11/89	A-3			
lo2ta27a	pt	7:46:22	8:48:30	8/12/89	A-3			
lo2ta27b	61	8:48:47	9:59:20	8/12/89	A-3	100V / 100V	0	530
lo2ta27c	062b	9:59:47	10:16:32	8/12/89	A-3	3000 / 2500	4.78	530
lo2ta27d	062b	10:42:12	11:40:37	8/12/89	A-3	3000 / 2500	4.78	530
lo2ta27e	050b	11:41:03	12:45:58	8/12/89	A-3	5500 / 4500	4.78	530
lo2ta27f	055b	12:46:15	13:40:00	8/12/89	A-3	3000 / 4500	4.78	530
lo2ta27g	2.2	13:40:21	15:10:36	8/12/89	A-3			
lo2ta28a	pt	11:37:49	12:16:04	8/15/89	A-3			
lo2ta28b	048c	12:16:18	12:25:12	8/15/89	A-3	3000 / 2500	4.78	530
lo2ta28c	59	12:25:39	13:26:54	8/15/89	A-3	3000 / 2500	0	350
lo2ta28d	051a	13:27:16	14:34:12	8/15/89	A-3	3000 / 2500	0	530
lo2ta28e	051b	14:34:33	15:24:01	8/15/89	A-3	3000 / 2500	0	530
lo2ta28f	051c	15:24:16	16:28:43	8/15/89	A-3	3000 / 2500	0	530
lo2ta28g	2.2	16:29:06	17:58:32	8/15/89	A-3			

15 degree test schedule		
file name	recirc press	comments
	psig	
lo2ta25a		9010 is reading bad
lo2ta25b	85	pump blew at about 8:45am
lo2ta25c	nat	
lo2ta25d	nat	9002 si diode died
lo2ta25e	nat	
lo2ta25f	30	heat leak 1/2" flowmeter bad; 1"flowmeter gave 2 distinct flowrates??
lo2ta25g	30	drain test 3:01pm
lo2ta26a		Howard replaced 9019, 9010, 9009, 9002 & pump motor was replaced
lo2ta26b	85	top heater not connected; reconnected them at 8:45
lo2ta26c	85	
lo2ta26d	85	drain flowmeter fluctuating
lo2ta26e	85	drain flowmeter fluctuating so much that we killed the test
lo2ta26f	85	run bleed up to cool the test article then shut bleed off; filter clogged
lo2ta26g	85	
lo2ta26h	85	
lo2ta26i		9030 and 9030a drain flowmeters bad
lo2ta27a		bad thunderstorm
lo2ta27b	85	draining thru 350 to work on flowmeter during a no bleed test
lo2ta27c	85	
lo2ta27d	85	
lo2ta27e	85	
lo2ta27f	85	
lo2ta27g		drain test
lo2ta28a		replaced 9002 & 9019
lo2ta28b	85	filter clogged (check 9077&9026)
lo2ta28c	85	Heater 1 is being set manually
lo2ta28d	85	he acfm:lbm/sec:scfm 2.5:0.003:17
lo2ta28e	85	he acfm:lbm/sec:scfm 4.2:0.005:29
lo2ta28f	85	he acfm:lbm/sec:scfm 8.4:0.010:58 (go by scfm not acfm)
lo2ta28g		drain test

lo2ta29a	pt	7:47:15	8:26:58	8/16/89	A-3			
lo2ta29b	048c	8:27:19	9:14:17	8/16/89	A-3	3000 / 2500	4.78	530
lo2ta29c	057b	9:14:37	10:06:27	8/16/89	A-3	5500 / 2500	4.78	530
lo2ta29d	060b	10:06:51	10:58:11	8/16/89	A-3	3000 / 2500	4.78	350
lo2ta29e	060a	10:58:30	12:05:02	8/16/89	A-3	3000 / 2500	0.96	350
lo2ta29f	057a	12:05:20	13:07:43	8/16/89	A-3	5500 / 2500	0.96	530
lo2ta29g	055a	13:08:03	14:00:54	8/16/89	A-3	3000 / 4500	0.96	530
lo2ta29h	062a	14:01:16	14:15:35	8/16/89	A-3	100V / 100V	0.96	530
lo2ta29i	2.2	14:15:53	16:21:10	8/16/89	A-3			
lo2ta30a	pt	7:51:44	8:46:12	8/17/89	A-3			
lo2ta30b	58c	8:46:34	9:53:21	8/17/89	A-3	3000 / 2500	0	¯30
lo2ta30c	50a	9:53:43	11:21:10	8/17/89	A-3	5500 / 4500	0.96	530
lo2ta30d	62a	11:21:37	12:06:48	8/17/89	A-3	100V / 100V	0.96	530
lo2ta30e	48d	12:07:17	12:16:21	8/17/89	A-3	3000 / 2500	9.57	530
lo2ta30f	2.3	12:16:40	13:58:28	8/17/89	A-3			
lo2ta30g	2.2	13:58:50	14:50:16	8/17/89	A-3			
lo2ta30h	48d	14:50:35	15:12:28	8/17/89	A-3	3000 / 2500	9.57	530
lo2ta31a	pt			9/21/89	A-4			
lo2ta31b	65	about 10:30		9/21/89	A-4			
lo2ta32a	pt	7:49:53	8:49:40	10/25/89	A-4			
lo2ta32b	65	8:49:57	10:22:59	10/25/89	A-4	0 / 2500	0	530
lo2ta32c	66a	10:23:20	11:27:08	10/25/89	A-4	0 / 2500	0.96	530
lo2ta32d	66b	11:27:29	12:32:43	10/25/89	A-4	0 / 2500	4.78	530
lo2ta32e	67	12:33:01	13:50:07	10/25/89	A-4	0 / 4500	0	530
lo2ta32f	2.2	13:50:26	14:59:05	10/25/89	A-4			

lo2ta29a		
lo2ta29b	85	
lo2ta29c	85	
lo2ta29d	85	
lo2ta29e	85	
lo2ta29f	85	
lo2ta29g	85	
lo2ta29h	85	drain flowmeter fluctuating so we killed the test (check 9077 &9026)
lo2ta29i		
lo2ta30a		
lo2ta30b		
lo2ta30c	85	
lo2ta30d	85	
lo2ta30e	85	high bleed rate
lo2ta30f		
lo2ta30g		
lo2ta30h	85	high bleed rate
lo2ta31a		Engine simulator uninsulated/He enclosure around engine simulator/ROV350 open to work on FF9030
lo2ta31b		loading 3rd trailer/pump making loud noise/pump off/pump bearings seized @ 11:20
lo2ta32a		9068 not working/Howard repaired it
lo2ta32b	85	9013 not reading properly/valve 366 screaming due to increased flow through the pump
lo2ta32c	85	began set-up for bleed test at 9:56/vpv365 leaking around valve stem/ 9024 decreasing
lo2ta32d	85	9024 still decreasing at 12:17
lo2ta32e	85	9024 fluctuating/stabilized at 12:55
lo2ta32f		drain test/9006 has stopped functioning properly

APPENDIX B

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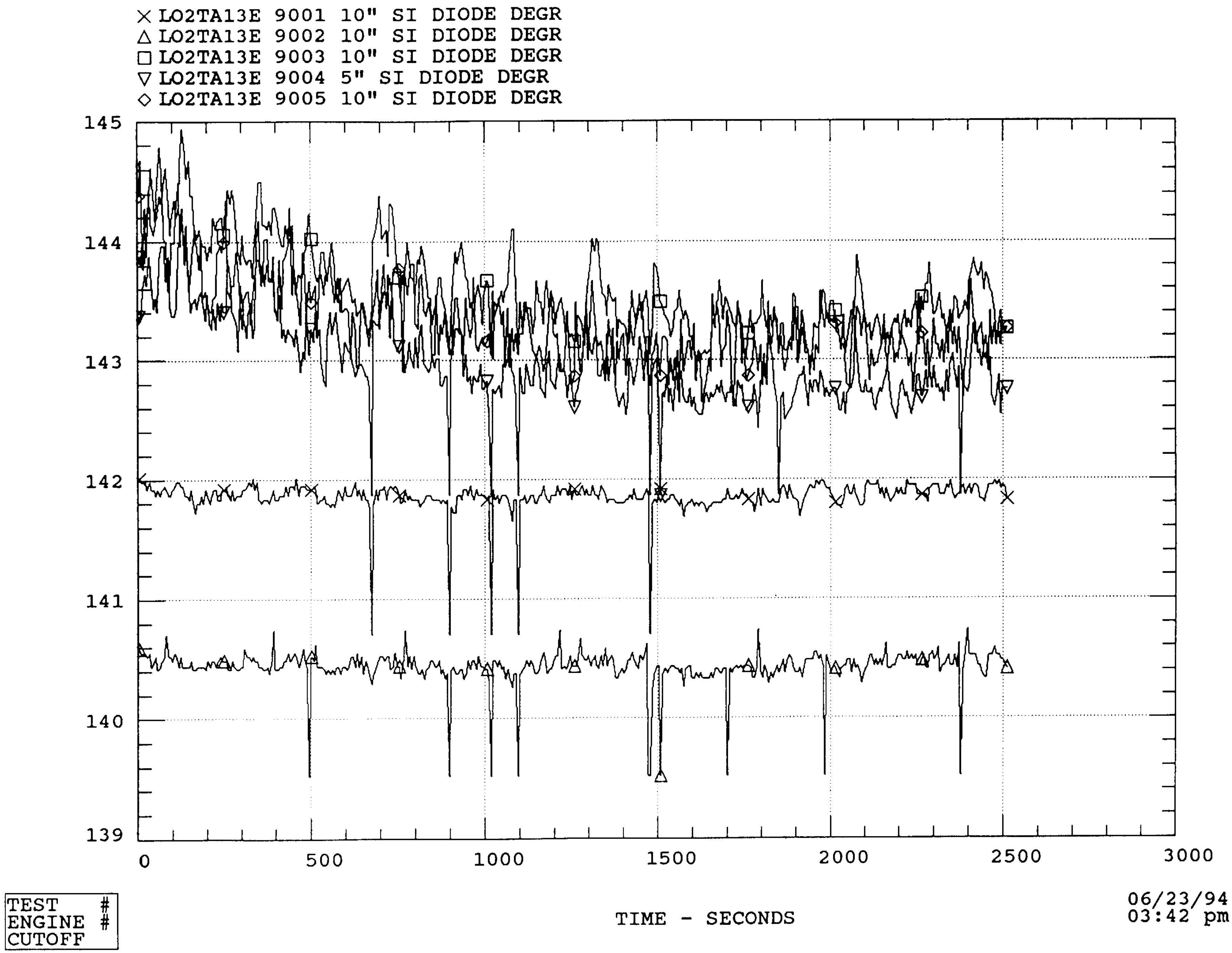
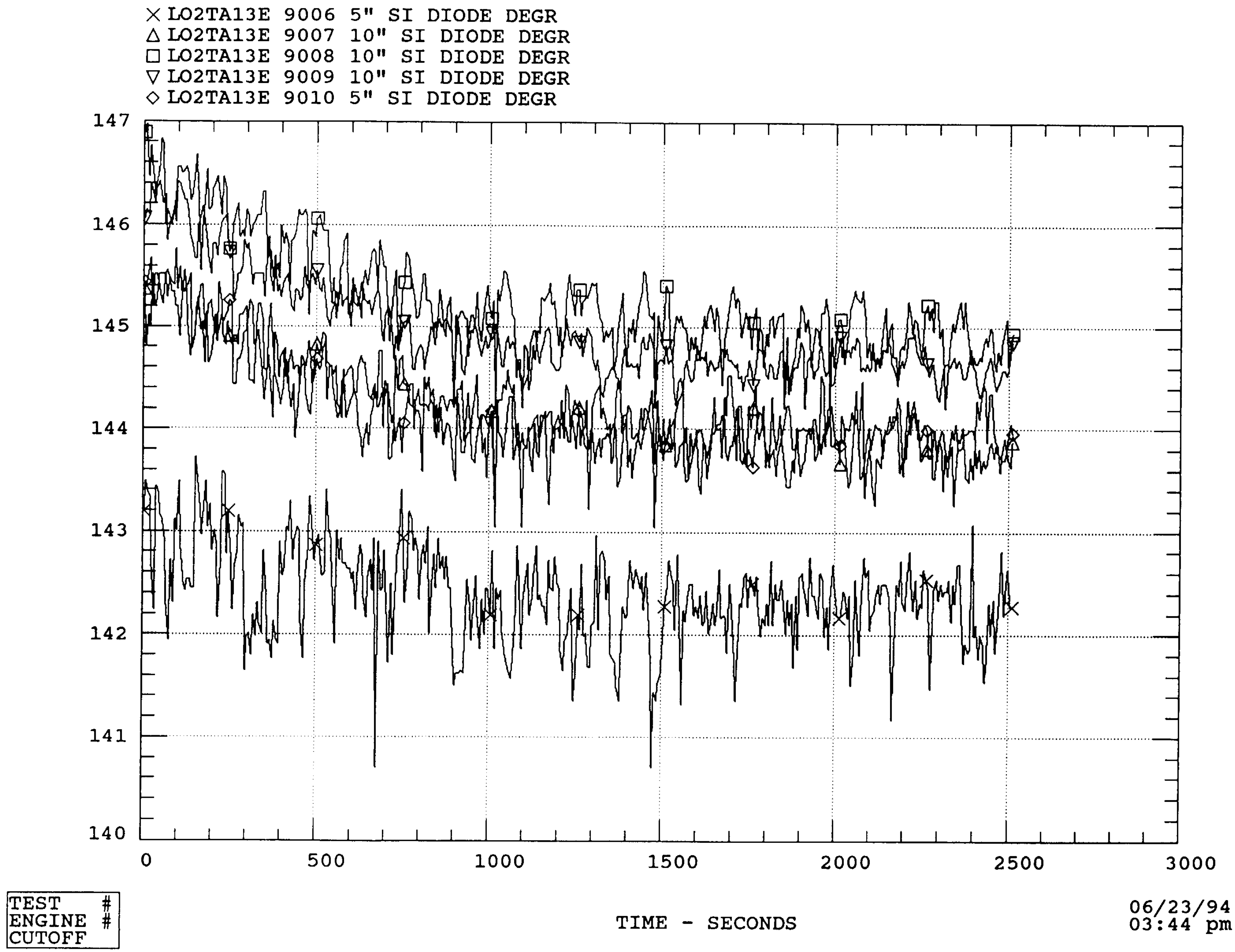
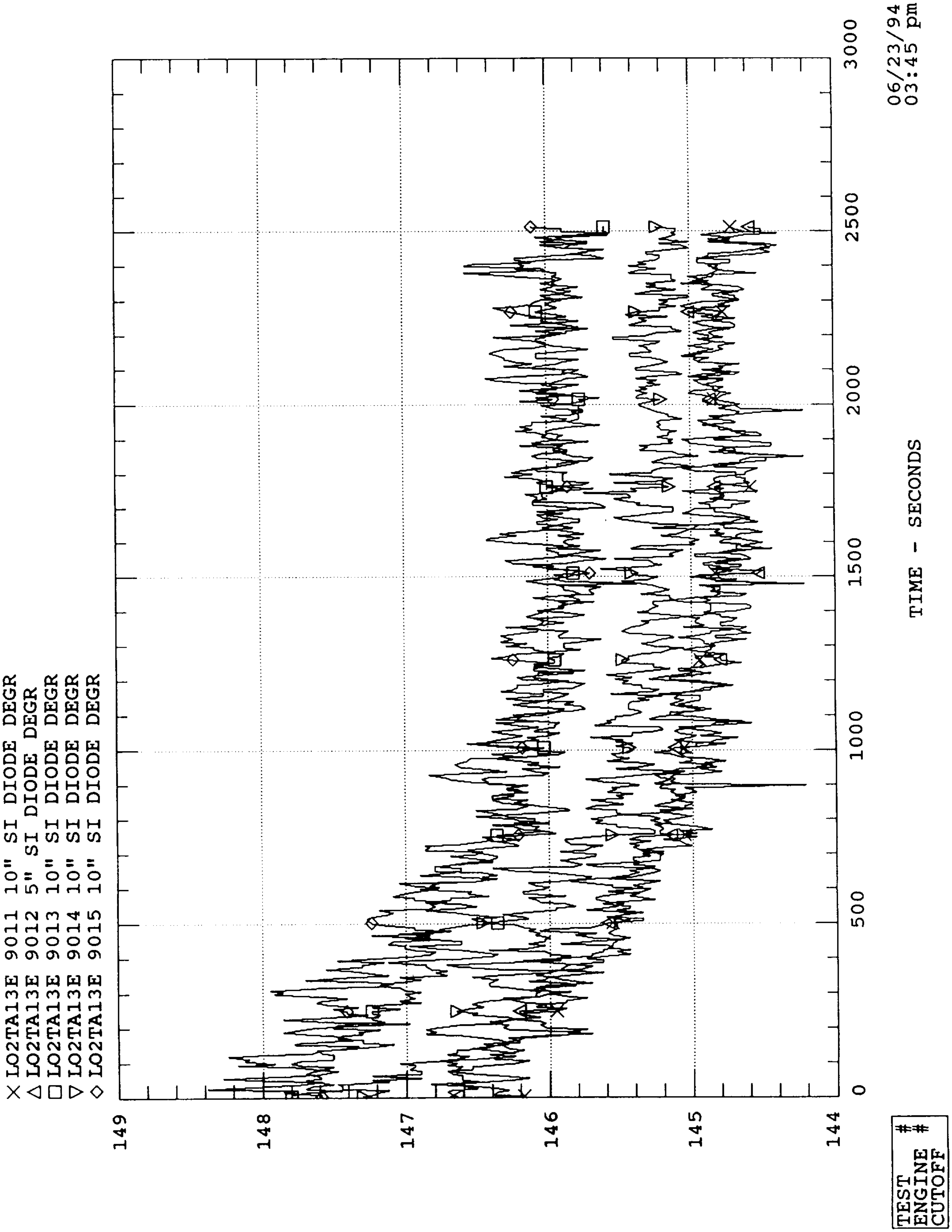


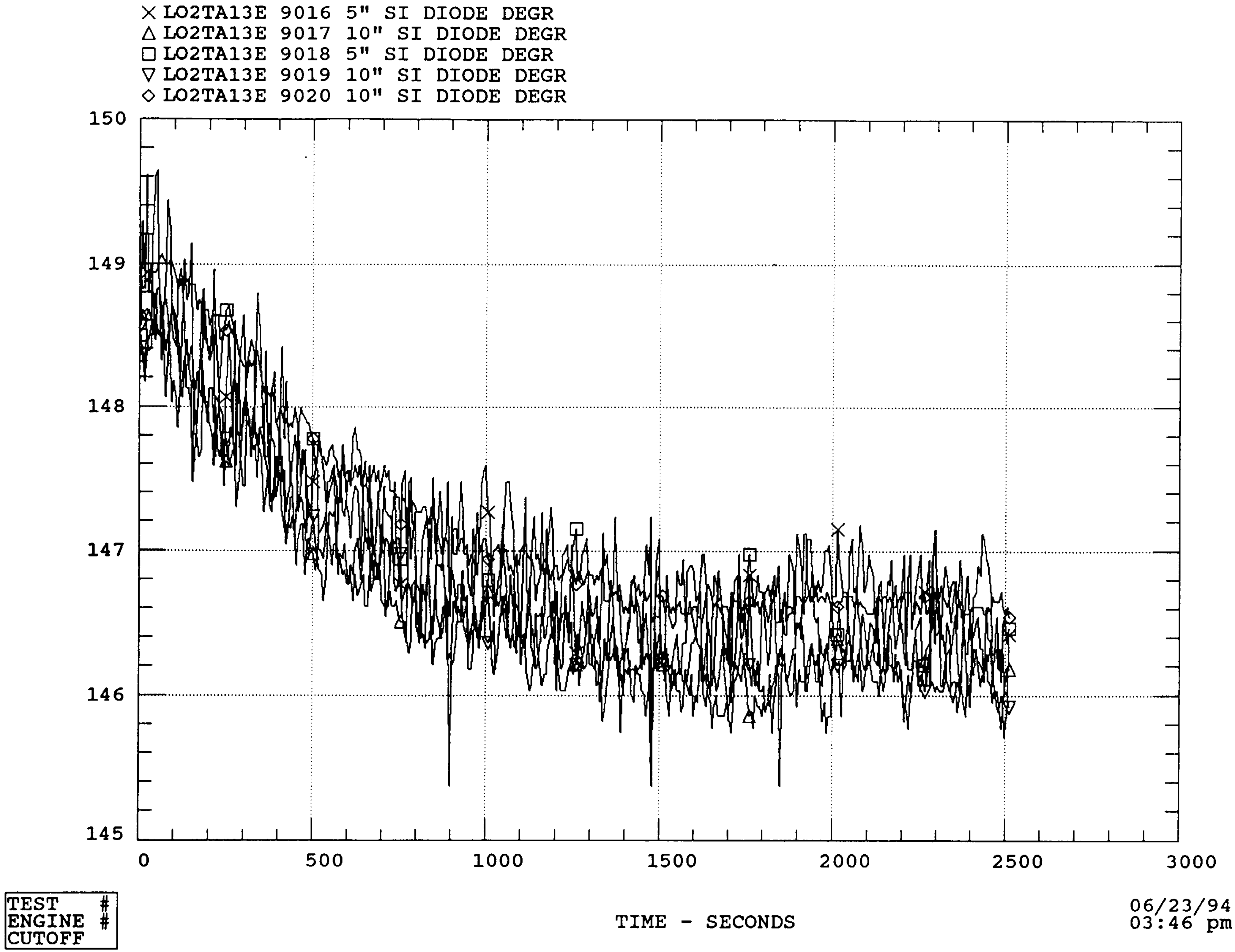
× LO2TA13E 9001 10" SI DIODE DEGR
△ LO2TA13E 9002 10" SI DIODE DEGR
□ LO2TA13E 9003 10" SI DIODE DEGR
▽ LO2TA13E 9004 5" SI DIODE DEGR
◇ LO2TA13E 9005 10" SI DIODE DEGR
145
144
143
142
141
140
139
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
03:42 pm

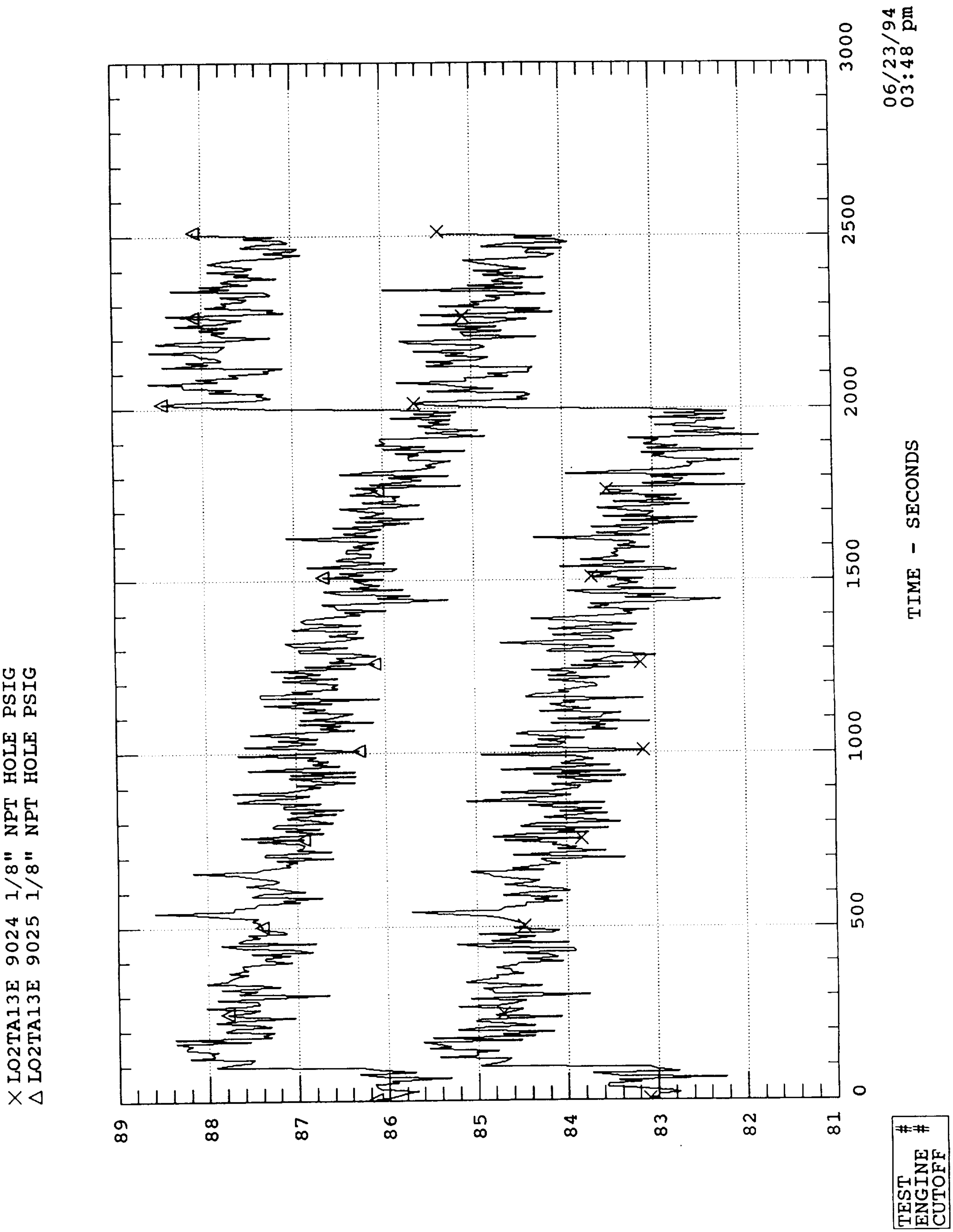


× LO2TA13E 9006 5" SI DIODE DEGR
△ LO2TA13E 9007 10" SI DIODE DEGR
□ LO2TA13E 9008 10" SI DIODE DEGR
▽ LO2TA13E 9009 10" SI DIODE DEGR
◇ LO2TA13E 9010 5" SI DIODE DEGR
147
146
145
144
143
142
141
140
0
500
1000
1500
2000
2500
3000
TEST #
ENGINE #
CUTOFF
TIME - SECONDS
06/23/94
03:44 pm

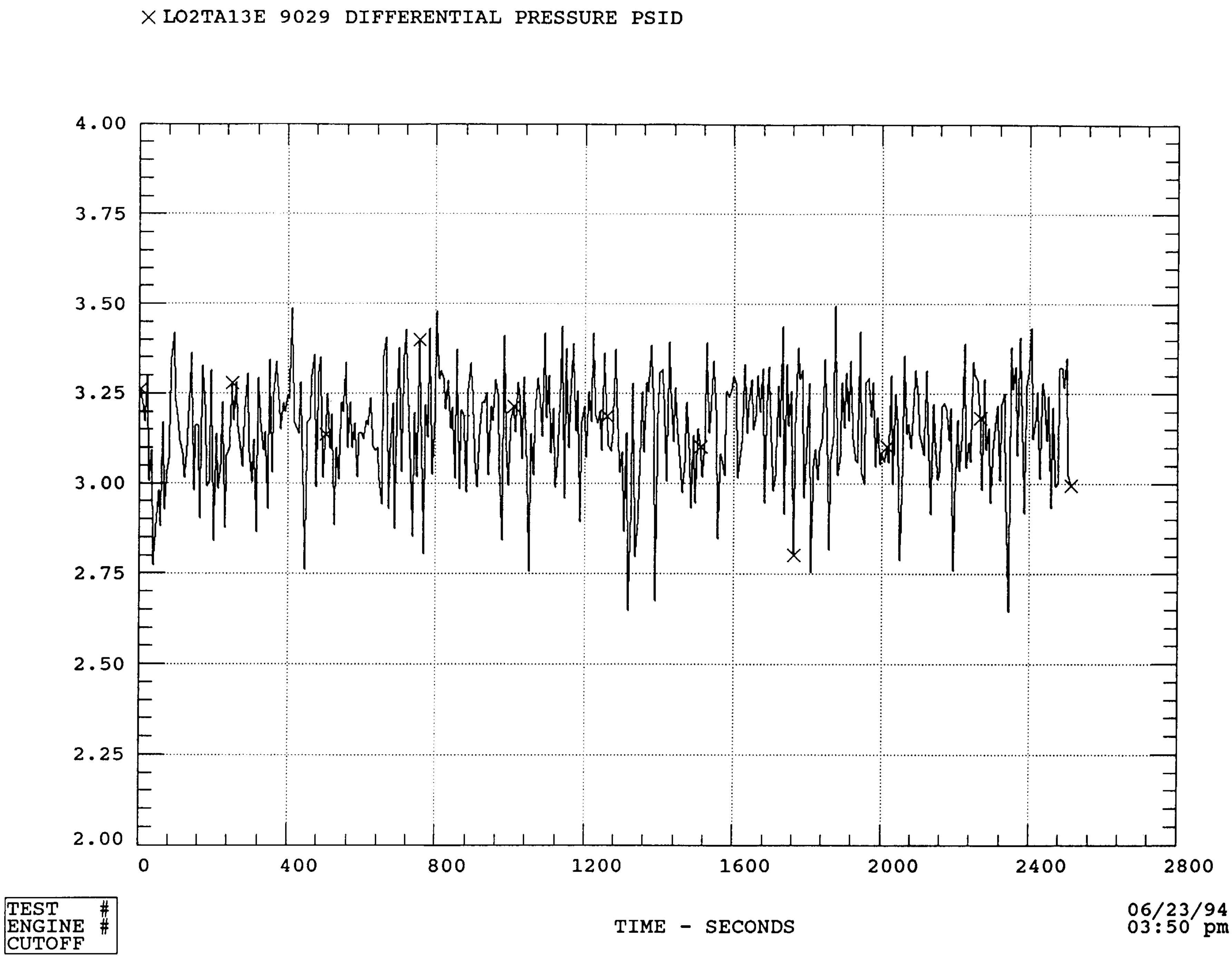


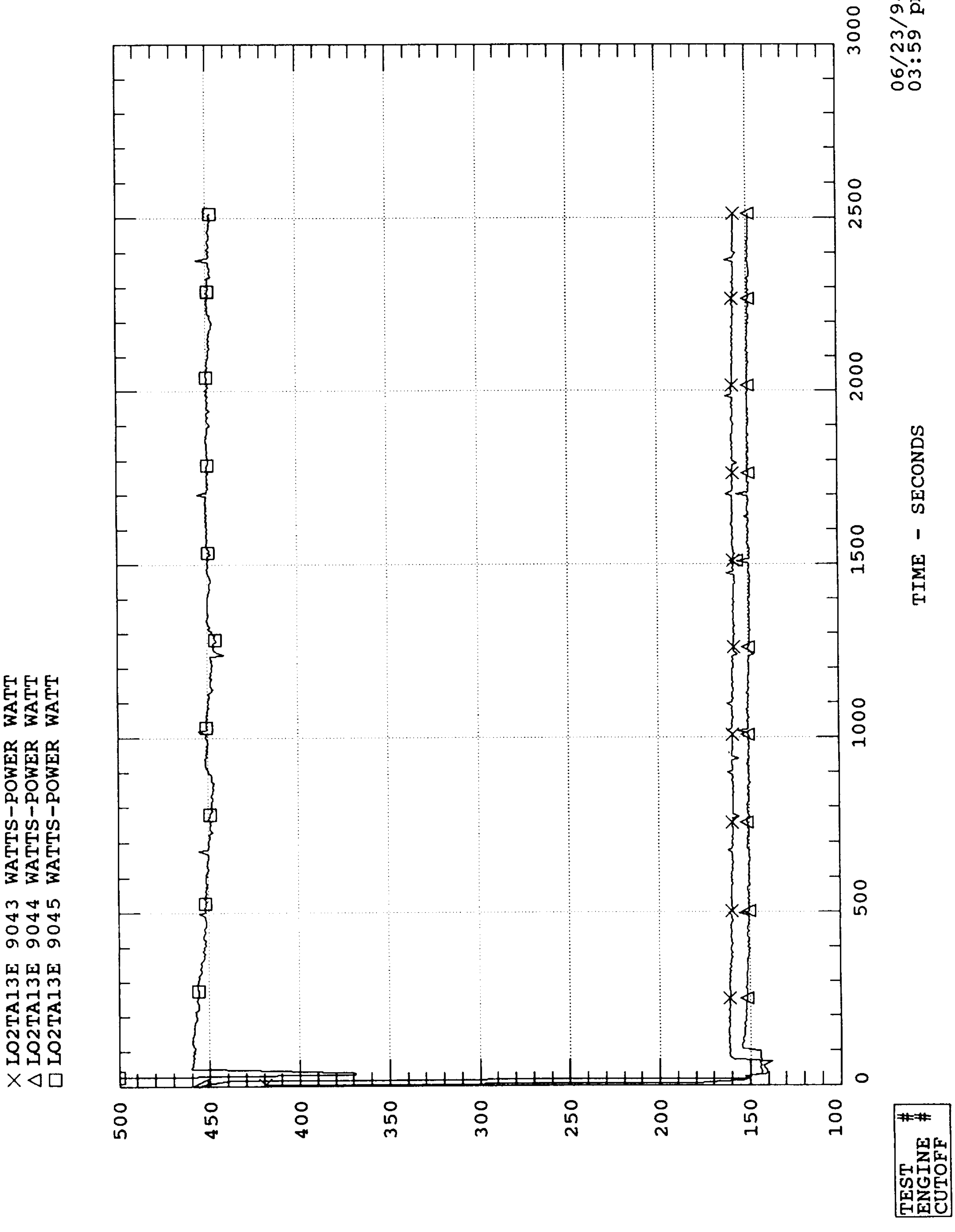
LO2TA13E 9011 10" SI DIODE DEGR
LO2TA13E 9012 5" SI DIODE DEGR
LO2TA13E 9013 10" SI DIODE DEGR
LO2TA13E 9014 10" SI DIODE DEGR
LO2TA13E 9015 10" SI DIODE DEGR
149
148
147
146
145
144
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
06/23/94
03:45 pm
TEST #
ENGINE #
CUTOFF


LO2TA13E 9016 5" SI DIODE DEGR
LO2TA13E 9017 10" SI DIODE DEGR
LO2TA13E 9018 5" SI DIODE DEGR
LO2TA13E 9019 10" SI DIODE DEGR
LO2TA13E 9020 10" SI DIODE DEGR
150
149
148
147
146
145
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
03:46 pm

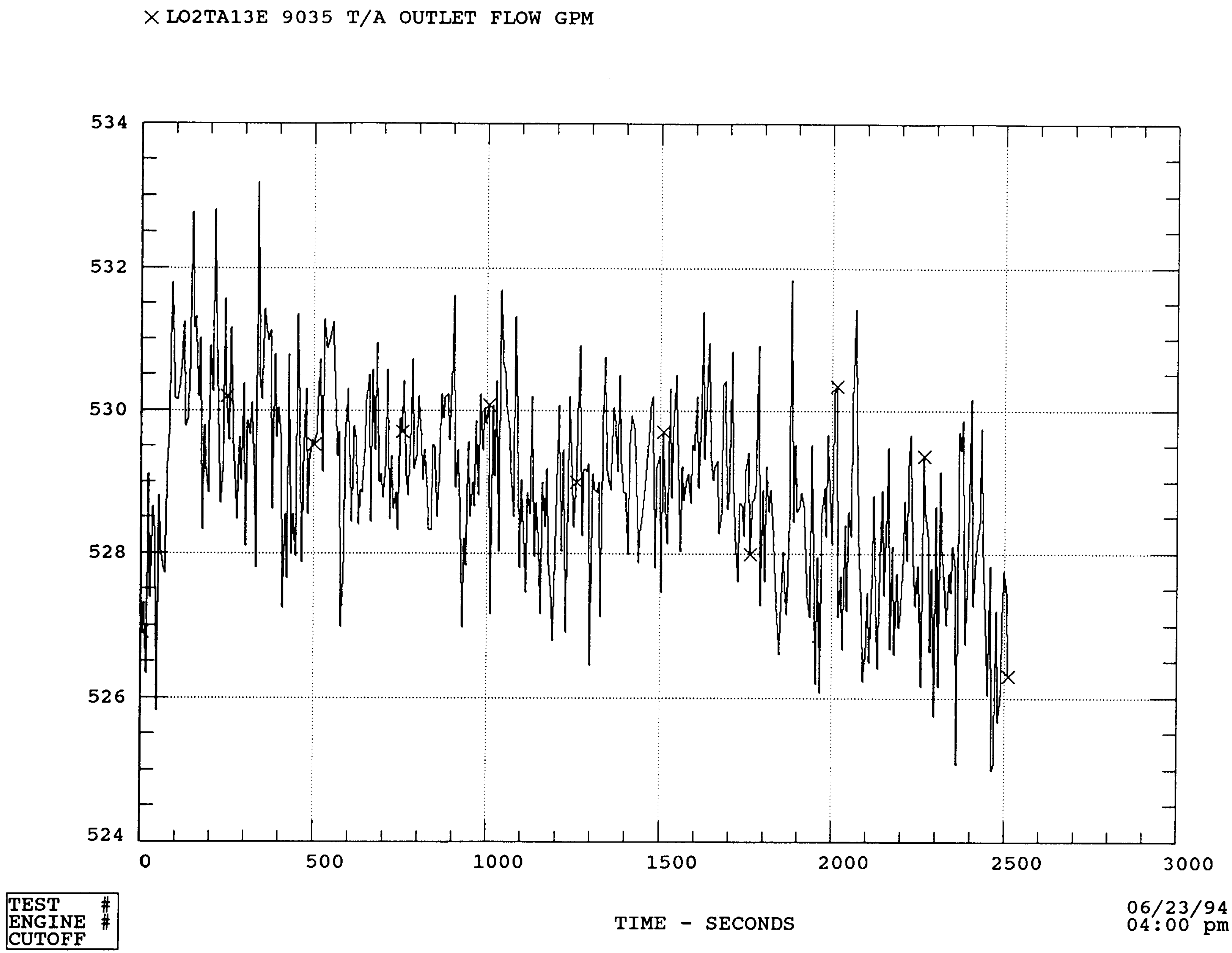


× LO2TA13E 9024 1/8" NPT HOLE PSIG
Δ LO2TA13E 9025 1/8" NPT HOLE PSIG
89
88
87
86
85
84
83
82
81
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
06/23/94
03:48 pm
TEST #
ENGINE #
CUTOFF

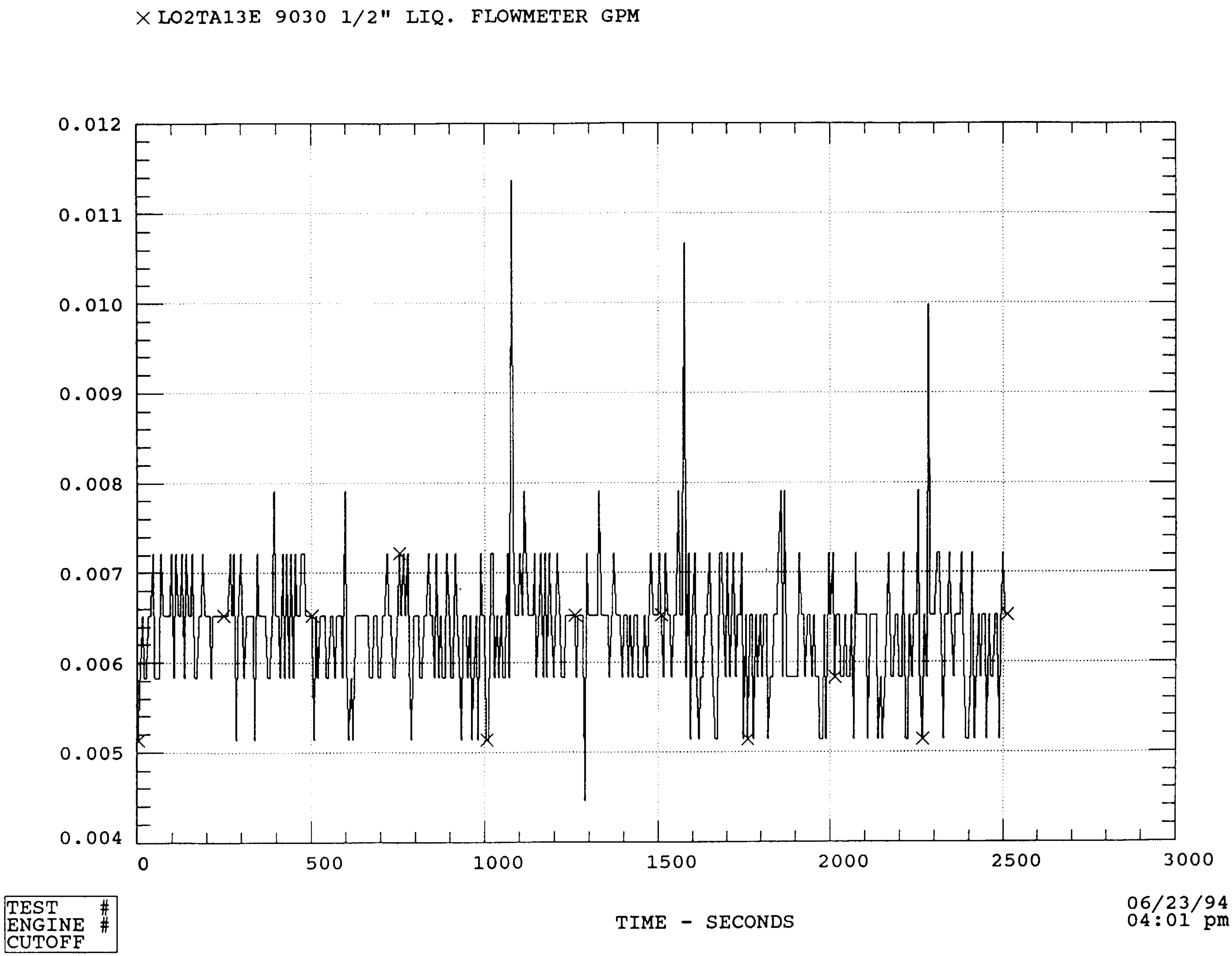

× LO2TA13E 9029 DIFFERENTIAL PRESSURE PSID
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
0
400
800
1200
1600
2000
2400
2800
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
03:50 pm



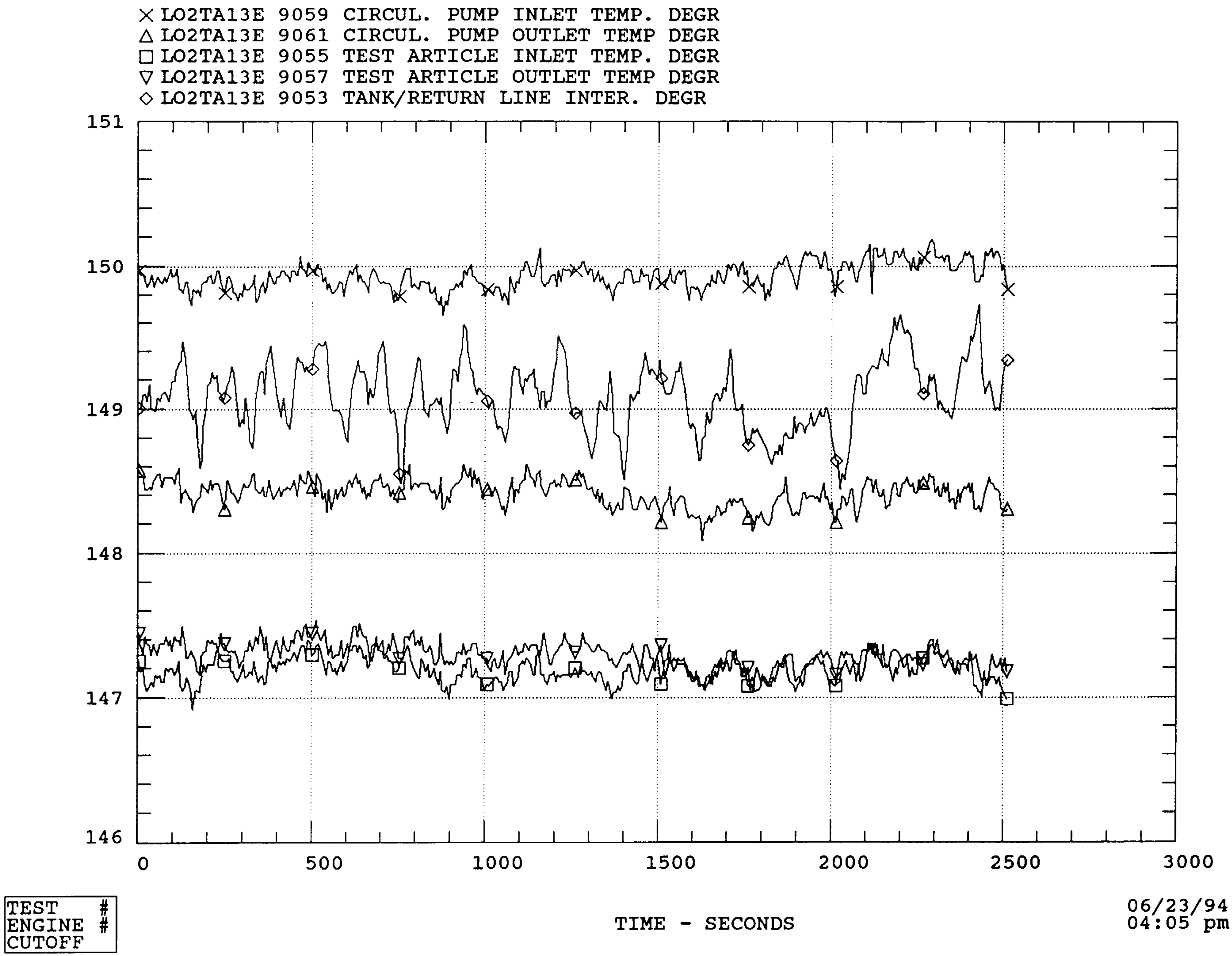
× LO2TA13E 9043 WATTS-POWER WATT
△ LO2TA13E 9044 WATTS-POWER WATT
□ LO2TA13E 9045 WATTS-POWER WATT
500
450
400
350
300
250
200
150
100
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
06/23/94
03:59 pm
TEST #
ENGINE #
CUTOFF



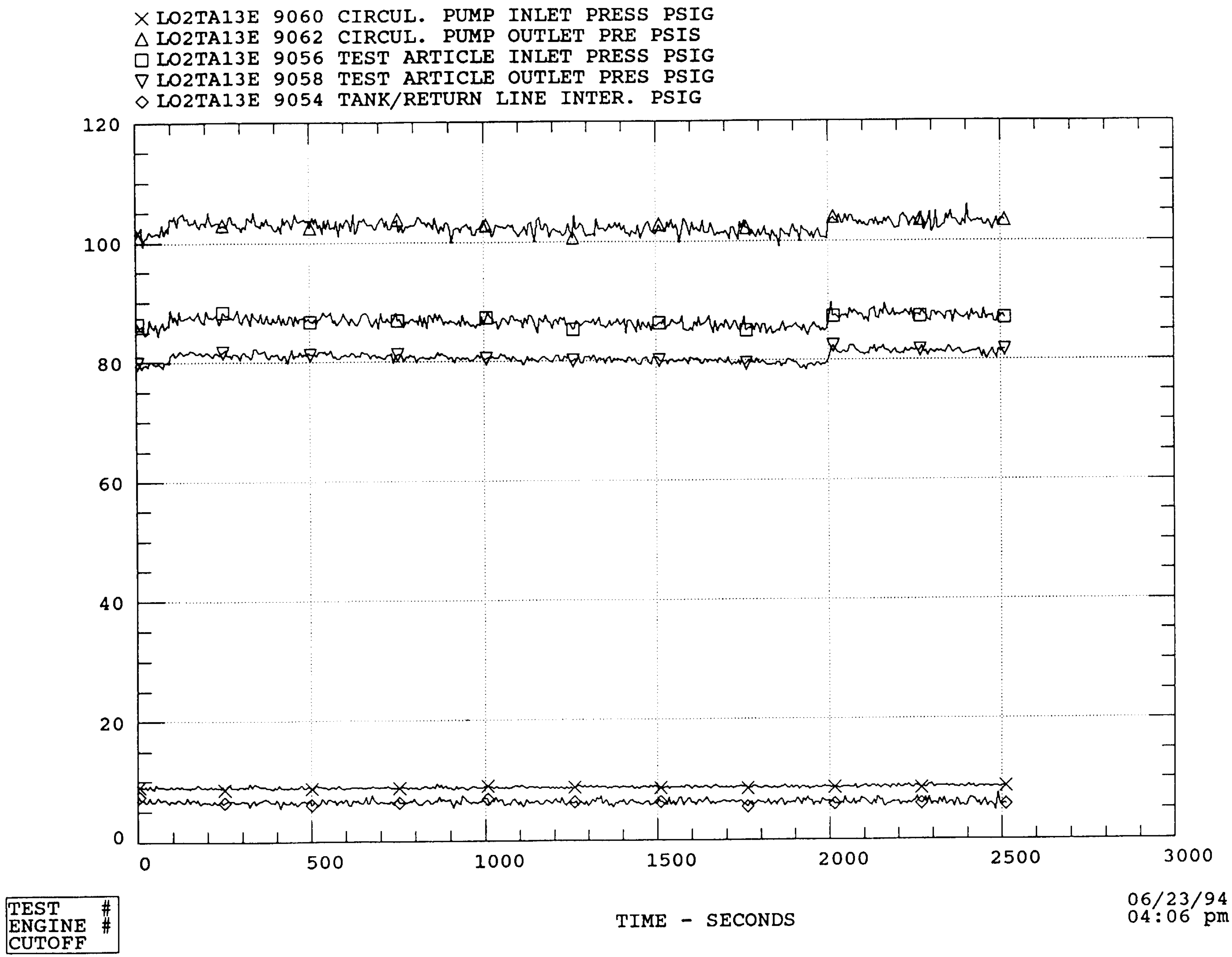
× LO2TA13E 9035 T/A OUTLET FLOW GPM
534
532
530
528
526
524
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
04:00 pm

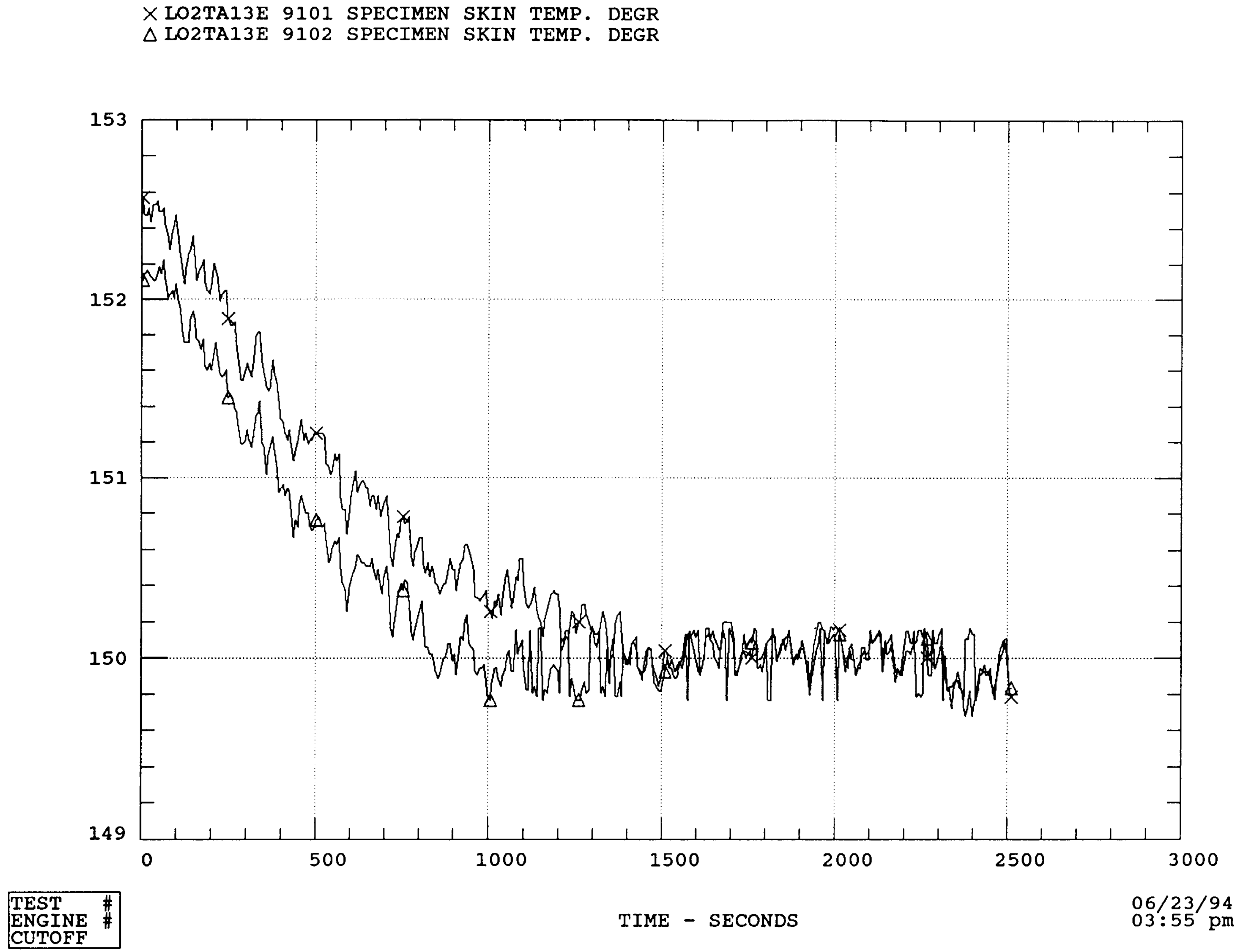


× LO2TA13E 9030 1/2" LIQ. FLOWMETER GPM
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
04:01 pm



× LO2TA13E 9059 CIRCUL. PUMP INLET TEMP. DEGR
△ LO2TA13E 9061 CIRCUL. PUMP OUTLET TEMP DEGR
□ LO2TA13E 9055 TEST ARTICLE INLET TEMP. DEGR
▽ LO2TA13E 9057 TEST ARTICLE OUTLET TEMP DEGR
◇ LO2TA13E 9053 TANK/RETURN LINE INTER. DEGR
151
150
149
148
147
146
0
500
1000
1500
2000
2500
3000
TEST #
ENGINE #
CUTOFF
TIME - SECONDS
06/23/94
04:05 pm


× LO2TA13E 9060 CIRCUL. PUMP INLET PRESS PSIG
△ LO2TA13E 9062 CIRCUL. PUMP OUTLET PRE PSIS
□ LO2TA13E 9056 TEST ARTICLE INLET PRESS PSIG
▽ LO2TA13E 9058 TEST ARTICLE OUTLET PRES PSIG
◇ LO2TA13E 9054 TANK/RETURN LINE INTER. PSIG
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
04:06 pm


× LO2TA13E 9101 SPECIMEN SKIN TEMP. DEGR
△ LO2TA13E 9102 SPECIMEN SKIN TEMP. DEGR
153
152
151
150
149
0
500
1000
1500
2000
2500
3000
TIME - SECONDS
TEST #
ENGINE #
CUTOFF
06/23/94
03:55 pm

APPENDIX C

Baseline configuration spreadsheet

lo2ta13e		description	pid #	avg value			
time avg	2000-2500	loop flowrate gpm	9035	527.82			
date of test	6/22/93						
		test article top P psig	9024	84.83	99.53	psia	
		test article bottom P psig	9025	87.72	102.42	psia	
		test article delta P psid	9029	3.15			
		bleed flowrate gpm	9030	0			
		bleed fluid T degR	9021	0			
		bleed fluid P psig	9026	0			
		zone 1 heater setting W	9043	157.63	538.14882	btu/hr	
		zone 2 heater setting W	9044	149.27	509.60778	btu/hr	
		zone 3 heater setting W	9045	449.38	1534.18332	btu/hr	
		pump inlet T degR	9059	150.04			
		pump exit T degR	9061	148.41			
		test article inlet T degR	9055	147.24			
		test article exit T degR	9057	147.24			
		tank inlet T degR	9053	149.14			
		pump inlet P psig	9060	8.84	23.54	psia	
		pump exit P psig	9062	103.3	118	psia	
		test article inlet P psig	9056	87.62	102.32	psia	
		test article exit P psig	9058	81.5	96.2	psia	
		tank inlet P psig	9054	6.21	20.91	psia	

Baseline configuration spreadsheet

description	silicon diode pid #'s	Temperature degR	delta T	T corrected	Height (inches)
center	9001	141.9	-0.2669643	141.633036	187.42
center	9002	140.47	1.304241985	141.774242	187.42
center	9003	143.41	-0.10673209	143.303268	179.42
wall	9004	142.79	0.557238534	143.347239	167.42
center	9005	143.15	0.409317135	143.559317	164.92
wall	9006	142.27	1.299562631	143.569563	167.42
center	9007	143.87	0.221444596	144.091445	150.61
center	9008	144.93	-0.41106677	144.518933	142.92
center	9009	144.65	0.281511355	144.931511	120.05
wall bottom	9010	143.9	1.027926069	144.927926	95.2
center	9011	144.8	0.775113755	145.575114	95.2
wall top	9012	144.82	1.263415293	146.083415	95.2
center	9013	145.92	-0.24891637	145.671084	70.12
center	9014	145.25	0.570922069	145.820922	46.41
center	9015	146.05	0.079459038	146.129459	39.76
center	9016	146.63	0.338355625	146.968356	25.4
wall	9017	146.18	0.567172554	146.747173	22.9
wall	9018	146.43	0.229666249	146.659666	22.9
center	9019	146.19	0.64281919	146.832819	9.4
center	9020	146.65	0.41919737	147.069197	0

APPROVAL

SIMPLIFIED LIQUID OXYGEN PROPELLANT CONDITIONING CONCEPTS

By N.L. Cleary, K.A. Holt, and R.H. Flachbart

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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13. ABSTRACT *(Maximum 200 words)*

Current liquid oxygen feed systems waste propellant and use hardware, unnecessary during flight, to condition the propellant at the engine turbopumps prior to launch. Simplified liquid oxygen propellant conditioning concepts are being sought for future launch vehicles. During a joint program, four alternative propellant conditioning options were studied: 1) passive recirculation, 2) low bleed through the engine, 3) recirculation lines, and 4) helium bubbling. The test configuration for this program was based on a vehicle design which used a main recirculation loop that was insulated on the downcomer and uninsulated on the upcomer. This produces a natural convection recirculation flow. The test article for this program simulated a feedline which ran from the main recirculation loop to the turbopump. The objective was to measure the temperature profile of this test article. Several parameters were varied from the baseline case to determine their effects on the temperature profile. These parameters included: flow configuration, feedline slope, heat flux, main recirculation loop velocity, pressure, bleed rate, helium bubbling, and recirculation lines. The heat flux, bleed rate, and recirculation line configurations produced the greatest changes from the baseline temperature profile. However, the temperatures in the feedline remained subcooled. Any of the options studied could be used in future vehicles.

14. SUBJECT TERMS
propellant conditioning, liquid oxygen, liquid nitrogen, main propulsion system, passive recirculation, helium bubbling, recirculation lines, overboard bleed, feedlines, feed system

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