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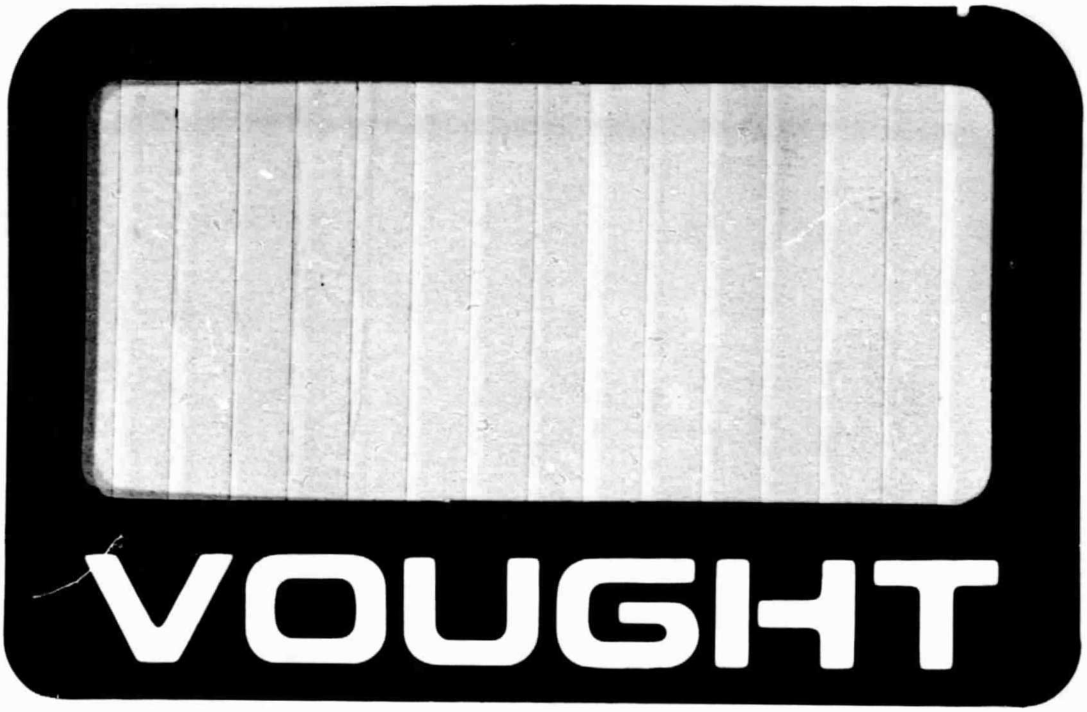

FINAL REPORT

SPACE SHUTTLE L-TUBE RADIATOR TESTING
AT
JOHNSON SPACE CENTER

REPORT NO. T169-67

DECEMBER 23, 1976

PREPARED UNDER CONTRACT NAS9-10534

for

NASA JOHNSON SPACE CENTER

CREW SYSTEMS DIVISION

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1.0 SUMMARY

A series of tests has been conducted at JSC to directly support development of the Orbiter Heat Rejection System (OHRS). The test series is a Shuttle in-line program task which provides data essential in establishing the final design of the baseline Orbiter radiators. These in-line Shuttle tests are being jointly conducted by NASA-JSC and Rockwell International in the NASA-JSC Space Environmental Simulation Laboratory (SESL) Chamber "A".

The test program definitized the details of the May 1974 baseline radiator by designing, fabricating, and testing representative hardware. The testing was conducted in a simulated thermal environment incorporating realistic vehicle interfaces. The forward Shuttle radiator panel "view factors" to deep space, the radiation interchange between the payload bay door and panel and the total solar absorption of the panels including reflections were determined in the SESL Chamber "B" in a prior test conducted during the Spring of 1975 (Reference 4). The testing reported herein, performed in Chamber "A", used an IR source to simulate total solar and infra-red environmental loads on the flowing Shuttle radiator panels. Results of the Chamber "B" tests were used where applicable for environmental simulation, and in particular, for panel cavity assessment. The end product of this effort established the thermal and mechanical performance of "L" tube space radiators (forward and aft panels), including their thermal coating.

The Vought Systems Division of Vought Corporation designed and developed the test hardware under Contract (NAS 9-10534) to the Crew Systems Division.

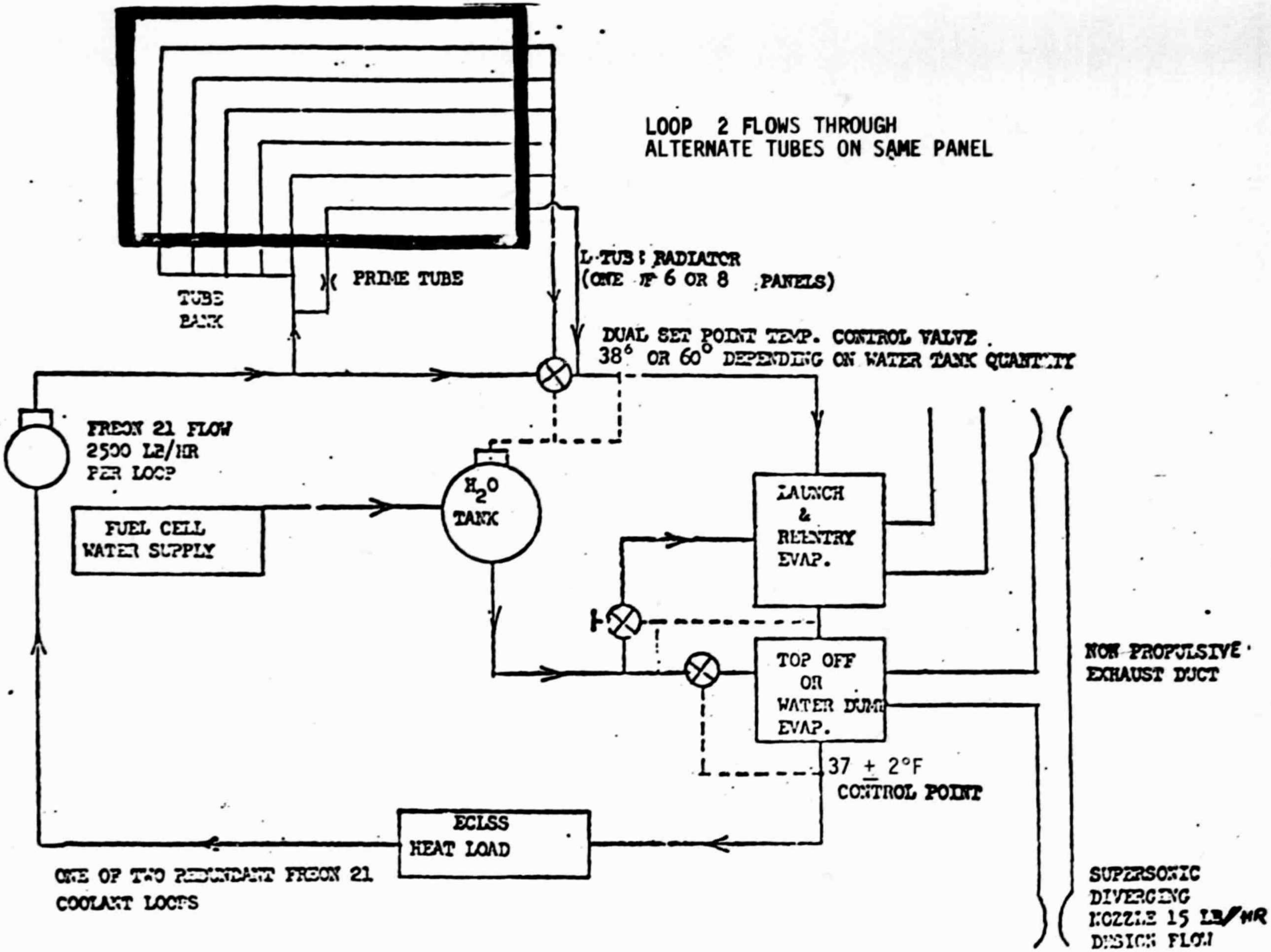
2.0 INTRODUCTION

2.1 Background

The OHRS consists of three devices to reject the spacecraft heat: space radiators, flash evaporators and an ammonia boiler. Supplemental heat rejection capacity will be provided on the ground by a Ground Support Equipment (GSE) heat exchanger. The flash evaporator system (FES) provides the primary means of cooling for the Orbiter above an altitude of 140,000 feet during ascent and above 100,000 feet during reentry. Below 100,000 feet the ammonia boiler is activated to provide cooling during reentry and through the post landing phase. On-orbit heat rejection is accomplished primarily by the space radiators supplemented by water evaporation through the FES (Figure 2-1). The baseline on-orbit OHRS system is designed using 6 or 8 panels which are mounted to the payload bay doors as shown in Figure 2-2. The two forward panels on each side are to be deployed away from the doors to increase the heat rejection capacity.

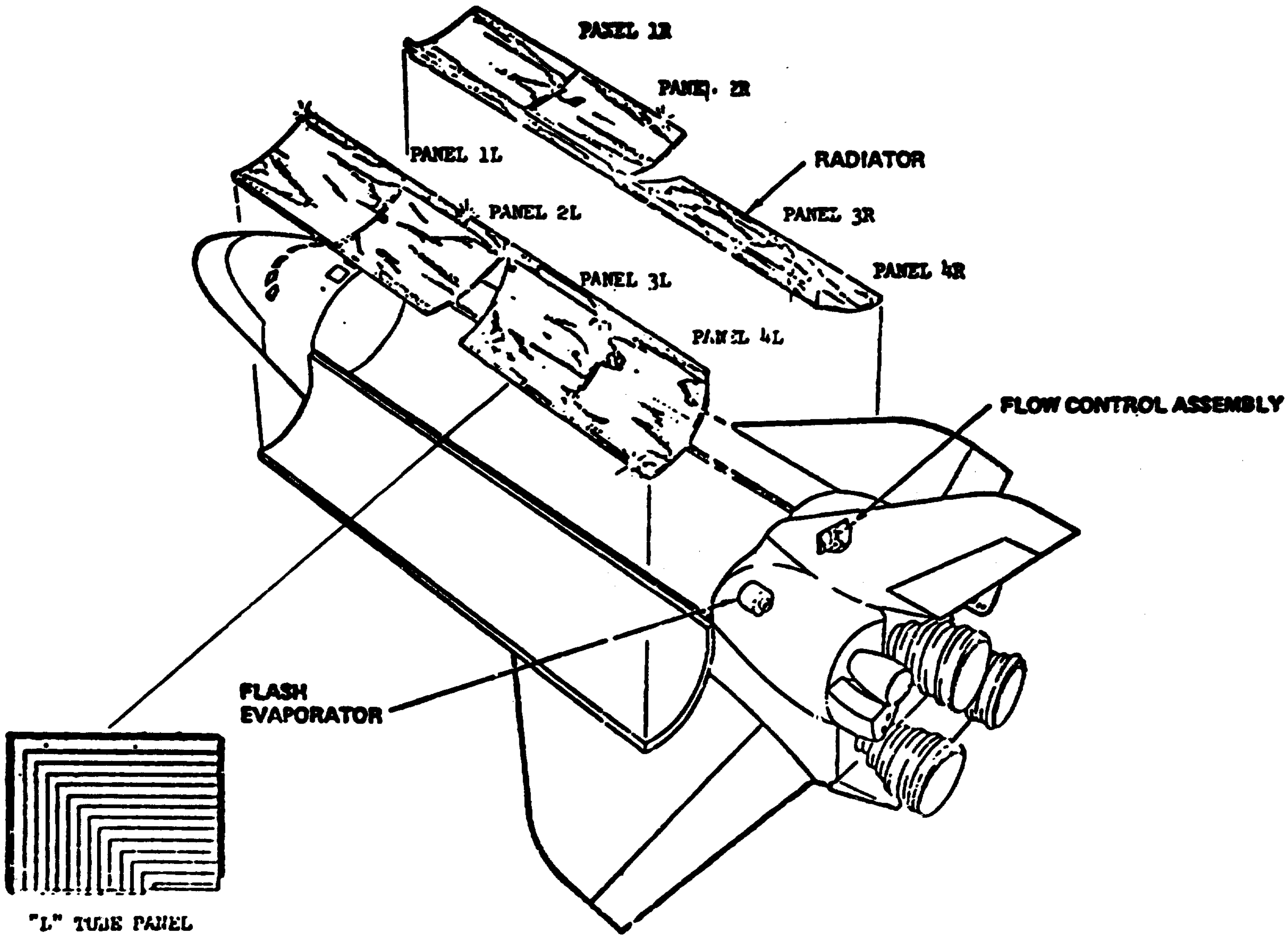
The radiator panels have a unique heat load control technique (Figure 2-1) which allows a wide range of heat loads to be rejected. A panel contains a bank of L-shaped tubes (manifolded together) and a single prime tube, which is the innermost L-shaped tube on the panel. The wide heat load range capability is obtained by varying the flow between the radiator tubes and a bypass line. At low heat loads, the radiator tubes receive less flow, causing the flow in the bank of tubes to successively stagnate by freezing (from the longest to the shortest tube) and thus progressively reduce the overall radiator effectiveness.

The prime tube and bypass valve are sized such that the prime tube never stagnates and will always receive significant flow, even when the main bank of tubes is effectively bypassed. If the radiator is exposed to the worst cold environment the freon in over half of the bank of tubes can freeze. The continuous flow provided to the prime tube is sufficient to insure that the stagnant radiator tubes can be thawed as the heat load increases.



ORBITER HEAT REJECTION SYSTEM

FIGURE 2-1



SPACE SHUTTLE ORBITER RADIATOR CONFIGURATION

Figure 2-2

Flow to the radiator tube banks on all of the panels is regulated by a downstream temperature control valve. The valve will bypass a portion of the flow to regulate the radiator outlet temperature to either of two temperature set points (38°F and 60°F). The set point temperature will depend upon the quantity of water in the fuel cell water storage tank. As excessive water accumulates in the holding tank the set point in increased to 60°F thereby reducing heat rejection of the radiators, and the flash evaporator top-off system is activated. This lowers the freon temperature to 37±2°F until the holding tank level decreases, at which time the control valve is reset to 38°F.

Under worst case high ECLSS heat loads and radiator environmental loads the limited radiator area will not maintain the 38°F outlet temperature. Under these conditions, the flash evaporator will activate as necessary to control the freon supplied to the vehicle at 37°F. During all on-orbit FES operations, the water from the flash evaporator is rejected from the spacecraft through a set of non-propulsive, diverging, supersonic nozzles to minimize the particle and gas contamination of the environment exterior to the spacecraft.

A silver-Teflon coating on the radiators is required to minimize radiator absorption of solar radiation, and thus, maximize radiator heat rejection under conditions where the radiator directly views the sun.

2.2 Objectives

The purpose of the radiator test was to provide the technology required to definitize the orbiter radiator system and the analytical performance predicting math models. The principal objectives of this test program can be summarized as follows:

a. Determine radiator panel performance/fin effectiveness.
b. Evaluate low load recovery techniques.
c. Determine coating adhesive suitability.
d. Determine thermal distortion of panels.
e. Verify analytical model.
f. Evaluate Flow Control Valve.

2.2.1 Determine Radiator Panel Performance/Fin Effectiveness

The radiator panels were tested over a wide range of anticipated ECLSS heat loads and environmental orientations. Steady state performance and transient response was determined for "on-orbit" dual loop operation. Fin effectiveness was determined by mapping the temperature profile across the panel. The heat rejection capability of the radiator panel is optimized when the surface temperature is maximized. This is a direct function of the flow distribution in each tube and the number and spacing of the flow tubes. To properly evaluate the performance of the panel and determine the success of the design, the surface temperature profile is necessary.

2.2.2 Evaluate Low Load Recovery Techniques

The capability of the prime tube to thaw the radiator from freeze conditions was evaluated. Also, alternate methods of recovery utilizing electrical heaters and natural environment recovery was tested.

2.2.3 Evaluation of Coating Adhesive

During the course of the radiator test, the flowing radiator panels and a separate test article with test panels were stressed with high and low temperatures to simulate anticipated environmental transients. Evaluation of the adhesive performance to endure this stressing will determine the adhesive cure-cycle acceptability. The evaluation of the coating adhesive is documented in Reference 1.

2.2.4 Determine Thermal Distortion of Panel

Due to the large size of the radiator panel and potential thermal gradients resulting from skewed environments, radiator distortion could impact forward panel latching requirements and/or present potential payload envelope interference problems. Quantification of this distortion was determined during the thermal/structural testing for the predicted worst-case distortion conditions. Reference 2 documents the structural aspects of the test.

2.2.5 Analytical Model Verification

Pretest predictions were performed to determine radiator performance. The test data was used to verify these analytical computer models. This effort included evaluating the analytical capability to predict radiator performance with diffuse/specular reflections.

2.2.6 Control Valve Operation

The capability of the control valve to maintain the desired set point temperature was evaluated.

3.0 TEST DESCRIPTION

3.1 Overview and Approach

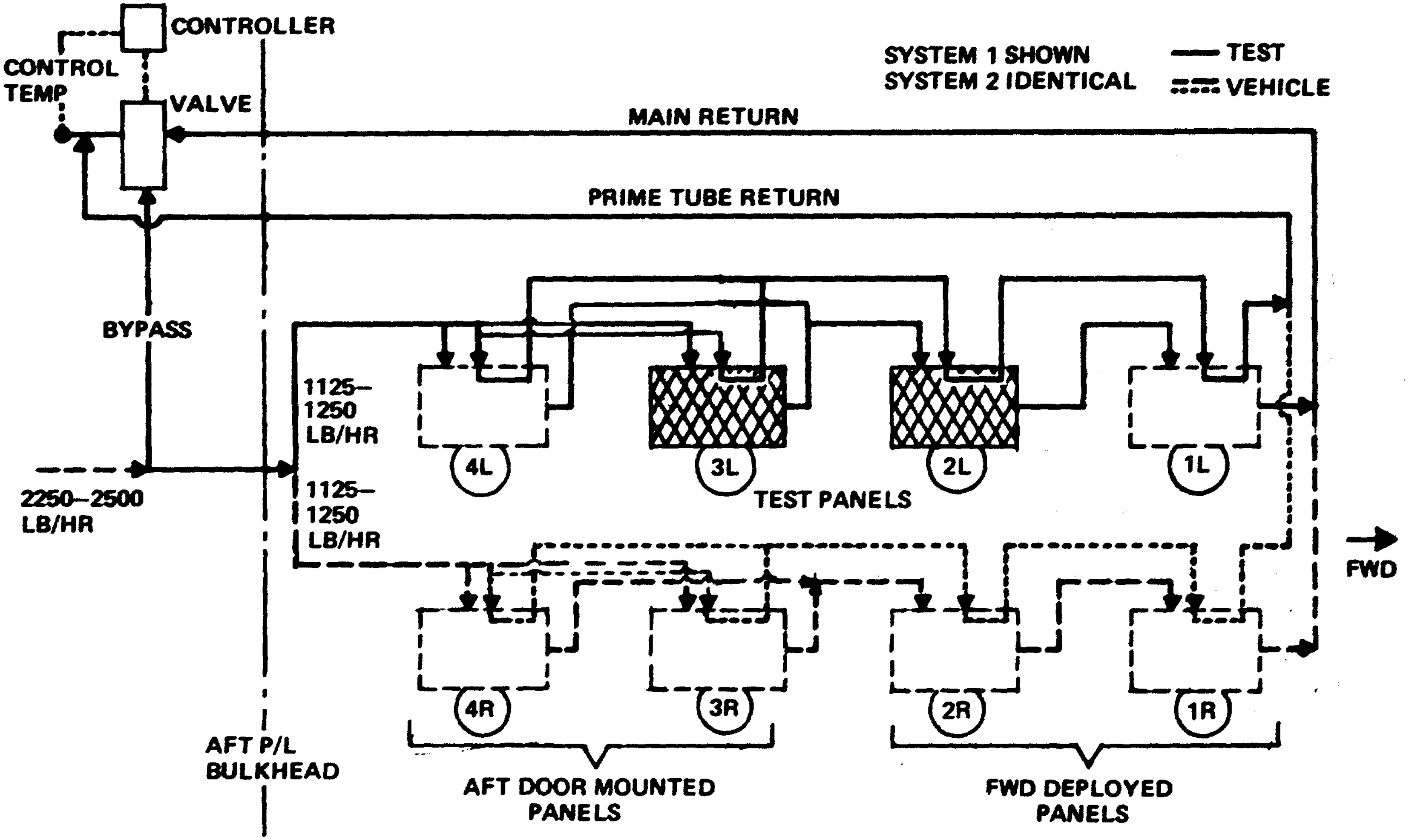
The test subjected two Shuttle representative panels to a thermal-vacuum environment and the operating conditions expected during earth orbital flight. One panel was representative of the aft one-sided configuration that remains attached to the payload bay door. The other panel represents the forward two-sided configuration that is deployed away from the payload bay door. Figure 3-1 shows the radiator system schematic and a typical arrangement of the two test panels. Other arrangements allow the panels to be tested in the number 1 and number 4 positions and, of course, either right or left hand door positions can be tested.

A payload bay door simulator was included with the forward panel to provide simulation of the cavity formed by the panel and door. A flow bench and two flight representative flow control valves and controllers provided the desired flow rates and inlet temperature to the panels. The flow system is designed for two independent flow loops with simultaneous or individual loop operation.

The test sequence was designed to obtain performance maps of the two panels under steady-state environments representative of the two sides of the vehicle in the design orbit. These performance maps provide data for thermal math model correlation and can be used to determine system performance of the 6 panel or 8 panel system under a variety of flow rates and inlet temperatures. Low load performance maps were also determined and transients between high and low loads (cold soak/recovery) have been compared for the prime tube and inherent stagnation low load control techniques.

FIGURE 3-1

RADIATOR SYSTEM FLOW SCHEMATIC



3.2 Test Article Definition

Vought was responsible for providing the radiator panels, flow control valves, electronic controllers, flow bench, PBD simulator, test hardware mounting structure and flow, temperature, strain and pressure instrumentation. NASA SESL was responsible for panel distortion instrumentation, chamber operation, thermal environment simulation and all data recording. Vought and SESL jointly installed the test equipment in Chamber "A" as shown in Figure 3-2 and performed checkout of the equipment including proof-pressure checks, leak checks, instrumentation calibration, environment simulator checkout and calibration, etc.

3.2.1 Test Panels

3.2.1.1 Flowing Radiator Panels - The test panels are structurally and thermally representative of the anticipated flight hardware. The panels are constructed of an aluminum honeycomb core bonded between aluminum facesheets with a contour approximating the shape of panel number 2 (mid forward) flight hardware. Round tubes are bonded to the inside surface of the facesheets, immersed in the honeycomb core to provide a smooth external surface for applying the silver-Teflon coating. The tubes are attached to both facesheets on the forward panel and to the concave facesheet on the aft panel. Figure 3-3 summarizes the panel design. The tube pattern is "L" shaped for both the forward and aft panels.

Simulated non-operational hinges and deployment booms are used on the forward panel. Two of the anticipated three latch points, used to stow the radiator panels for launch and re-entry, are included on the forward panel. These two attach points were used to suspend the panel from a counter balance system to simulate a zero "G" environment allowing the panel to thermally deflect without weight constraints. The aft panel was attached to the simulated PBD at the 4 attach points and 4 hinges baselined for the flight vehicle panel number 3 (mid aft). The attach point and hinge designs are structurally similar to the anticipated flight vehicle to allow for thermal distortion. Local area buildup at the attach area is required to distribute the thermal stress loads into the panel.

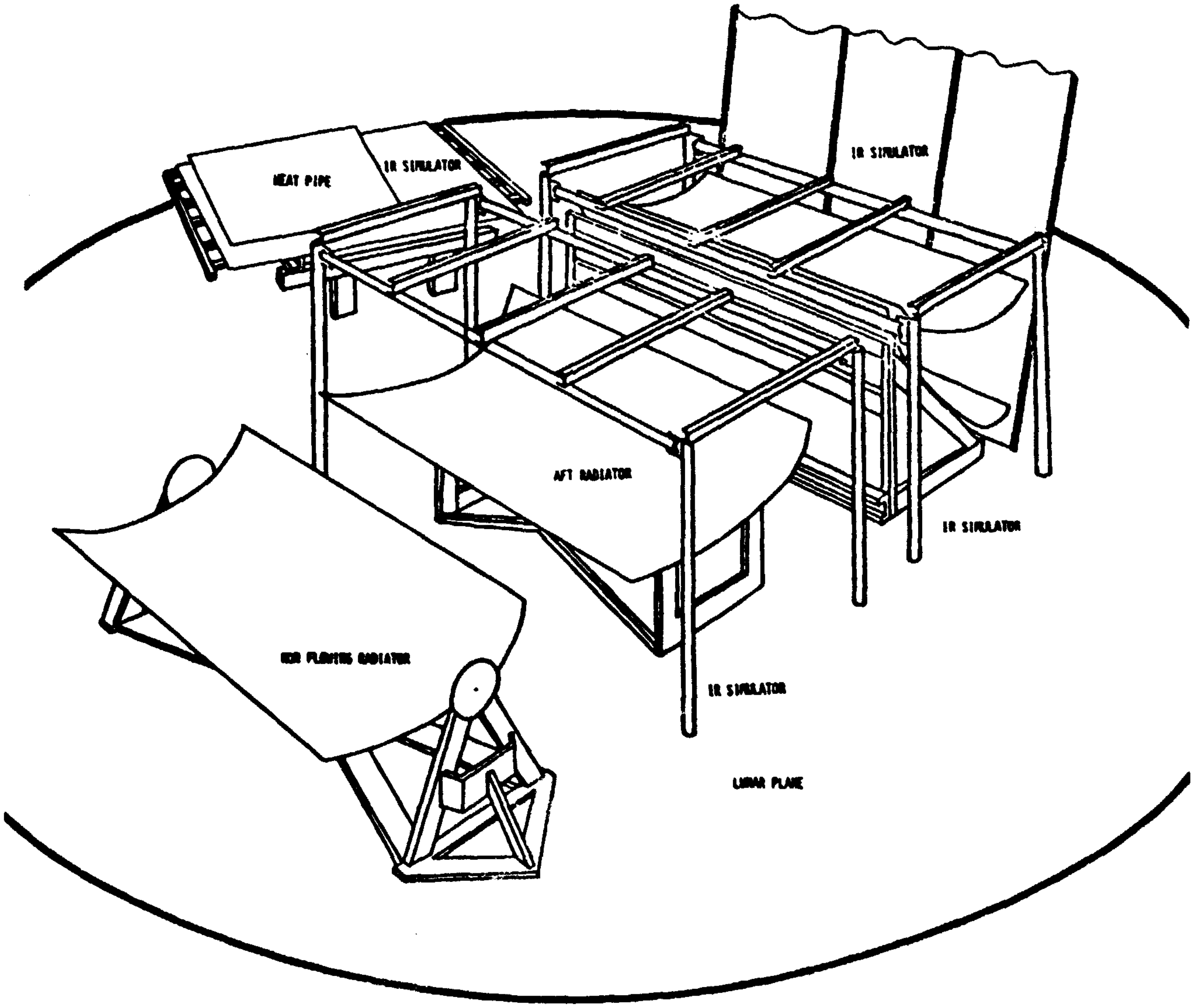


FIGURE 3-2
CHAMBER AND TEST ARTICLE CONFIGURATION

FIGURE 3-3

REPRESENTATIVE PANEL DESIGN

- "L" TUBE PATTERN, REVISED VALVE STAGNATION
- HONEYCOMB PANEL

  0.012 IN. 2024 T81 ALUM FACE SHEETS
  5056-H39, 3.1 LB/FT^3 ALUM H/C CORE

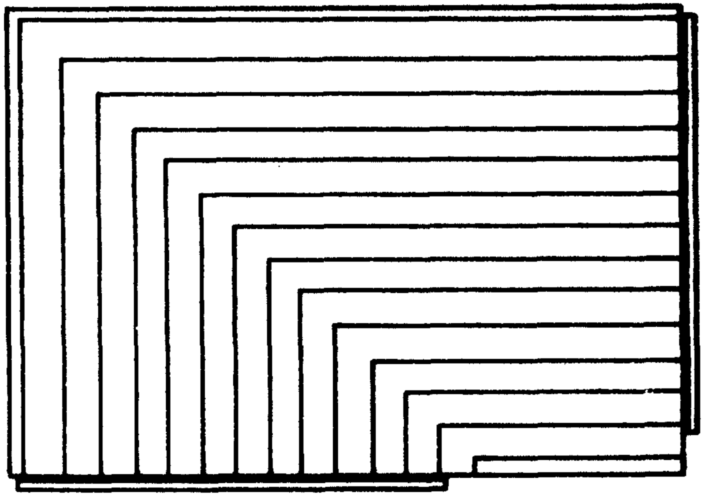
- FORWARD PANEL

  68 TUBES ATTACHED TO ALTERNATE FACE SHEETS
  3.8 IN. TUBE SPACING, TUBE I.D. = .135 IN.
  0.90 IN. H/C THICKNESS

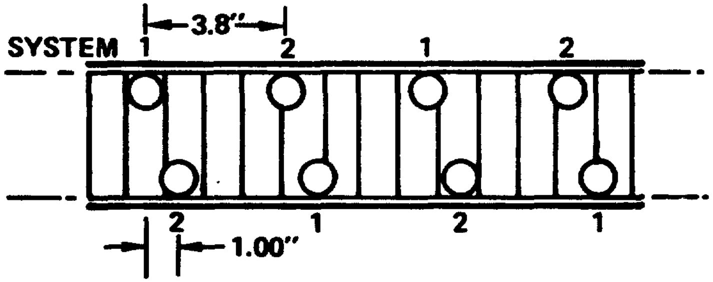
- AFT PANEL

  26 TUBES ATTACHED TO EXPOSED FACE SHEET
  4.96 IN. TUBE SPACING, TUBE I.D. = .18 IN.
  0.50 IN. H/C THICKNESS

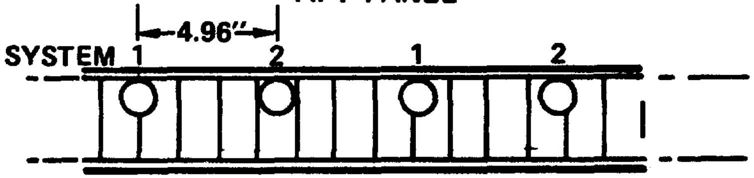
- TUBES BONDED TO FACE SHEET



"L" TUBE PANEL



FWD PANEL



AFT PANEL

3.2.2 PBD Simulator

The aft PBD simulator is support structure only to mount the aft panel. Thermal simulation of the panel/PBD interface is not required. Thermal analyses conducted to date indicate that the on-orbit radiator performance is not significantly influenced by the PBD. Verification of this analysis is desirable; however accurate thermal simulation would require the use of an actual door to obtain correct local door temperatures at the attach points and correct transient response.

The forward PBD simulator simulated the thermal radiation characteristics only. No structural simulation of the forward door is required. The simulator provides a smooth surface for application of the silver-Teflon coating. The forward PBD is made up of 18 different electrical heater panels to provide for localized environmental heating. The back-side of the PBD is insulated to prevent heat loss and insure that all input heat will be "seen" by the panel.

3.2.3 Control Valve

Two development valves supplied by Carleton Controls are used to control the outlet of each flow loop of the two panel test system to 38 ±2°F or 60 ±2°F. Table 3-1 summarizes the valve design specifications. The test valves are functionally identical to the anticipated flight valves; however, certain items have been changed to minimize cost. The valves are machined out of aluminum and have a bolted assembly with static o-ring seals instead of the anticipated welded stainless steel construction of the flight valve, which results in the test valve configuration not being of flight weight or exterior shape. The metal bellows and the internal parts, poppets, and flow passages are anticipated to be representative of the planned flight valve. Only one stepper motor was used in the test valve, whereas redundant motors are planned for the flight configuration.

TABLE 3-1
RADIATOR CONTROL VALVE SPECIFICATIONS

MEDIA: FREON 21 REFRIGERANT

TEMPERATURE CONTROL: MIXES HOT AND COLD FLUID TO 38/60 ±2°F
MAX HOT TEMP. 185°F
MIN COLD TEMP. -180°F
THE VALVE HAS APPROXIMATELY 35,000 POSITIONS. SELECTIBLE BY APPLYING PULSES TO A STEPPING MOTOR.

FLOW RATE: 2500 POUNDS PER HOUR

PRESSURE DROP: 2.0 PSID (FULL OPEN)

VALVE PORTS: (3/4) INCH O.D. LINE

INTERNAL LEAKAGE: .5 POUNDS PER HOUR (0.000734 GPM) AT A PRESSURE DROP OF 20 PSID (FULL CLOSED)

EXTERNAL LEAKAGE: 0.01 CC/HR AT THE OPERATING PRESSURE

OPERATING LIFE: 40,000 HOURS

ELECTRICAL POWER SOURCE: 28VDC

STEPPER MOTORS: IMC MAGNETICS CORPORATION 008-002 W 8:1 GEARHEADS

POSITION INDICATION: BY OUTPUT SIGNAL OR INTERNAL LVDT WITH 24VDC EXCITATION AND 0-5 VDC OUTPUT FOR FULL SCALE VALVE TRAVEL

PRESSURES:

OPERATING:	330 PSIA MAX
PROOF:	495 PSIA
BURST:	660 PSIA MIN.

WEIGHT: 2.8 LBS CALC.

3.2.4 Electronic Controller

Two electronic controllers supplied by Vought are used to provide electrical impulses to the valves. The controller monitors the resistance of the temperature sensor in the radiator outlet flow and generates a temperature error signal which is proportional to the temperature error. An error amplifier generates control signals to drive the valve motor in a direction to reduce the temperature error. The valve motor is driven at a rate proportional to temperature sensed error. The two different control temperatures (38 or 60°F) require switching to the proper sensor bridge resistors. This is accomplished either by a manual switch located on the controller case or by a 0-5 VDC signal from an external source simulating a water tank quantity sensor. The control temperature is set to 60°F (water-dump mode) when a 4.0 volt signal is received, simulating a water tank capacity of 80%, and is set back to 38°F when a 2 volt signal is received, simulating a 40% water tank capacity.

Selectable manual or automatic control modes are provided. In the manual control mode two selectable control step rates are used, a coarse rate of approximately 64 pulses per second and a fine rate of about 8 pulses per second. A single pulse switch is also provided. Displays are built into the controller case to indicate the mixed outlet temperature, the temperature error from the set point and the valve position. Figure 3-4 is a top view of the controller and Figure 3-5 shows the controller with the cover removed.

3.2.5 Flow Control Console

The Freon 21 Fluid Flow System is a modular component design that contains a flow control console, a thermal conditioning system, a dual pump station, and a radiator flow bypass/temperature control system.

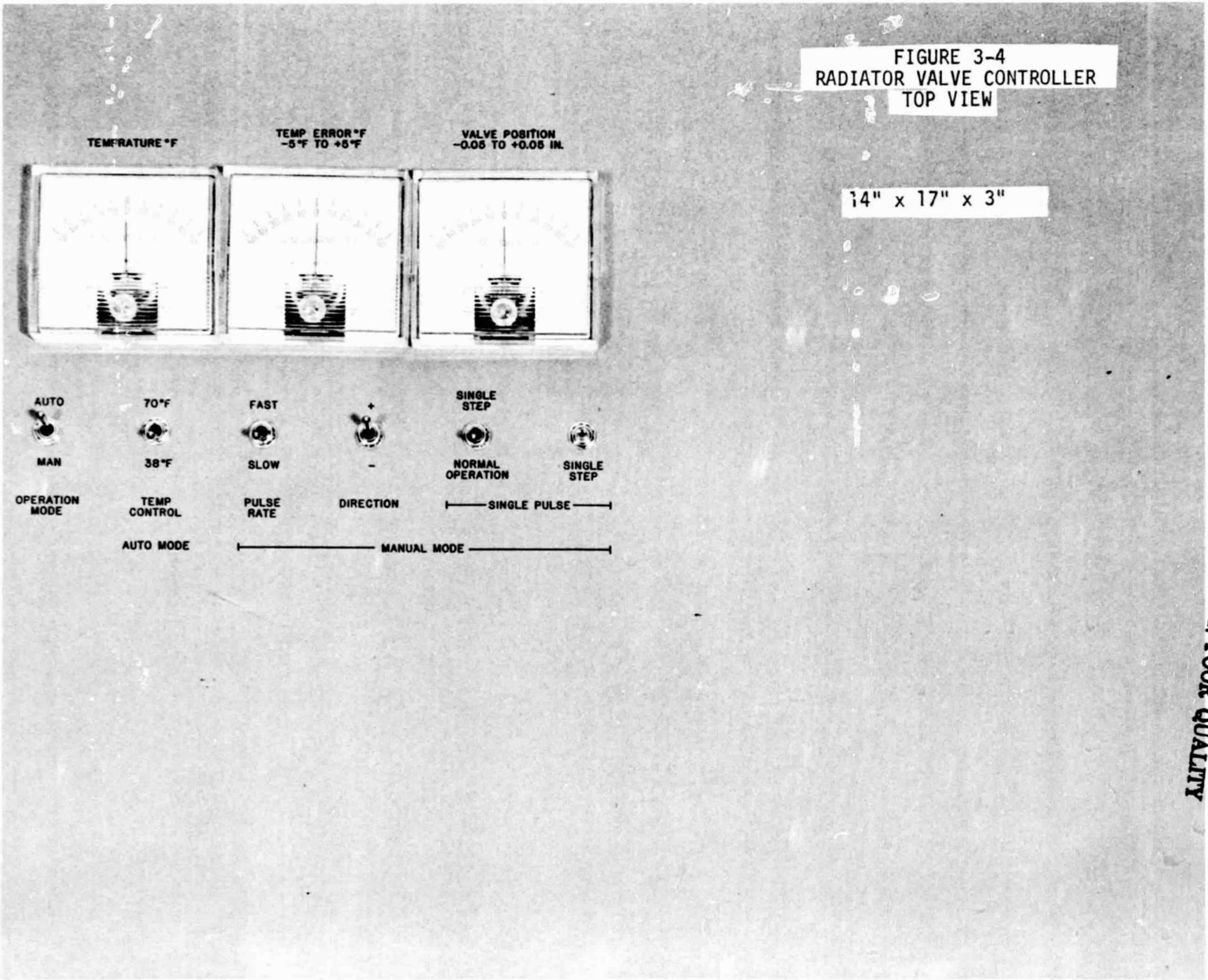


FIGURE 3-4
RADIATOR VALVE CONTROLLER
TOP VIEW

14" x 17" x 3"

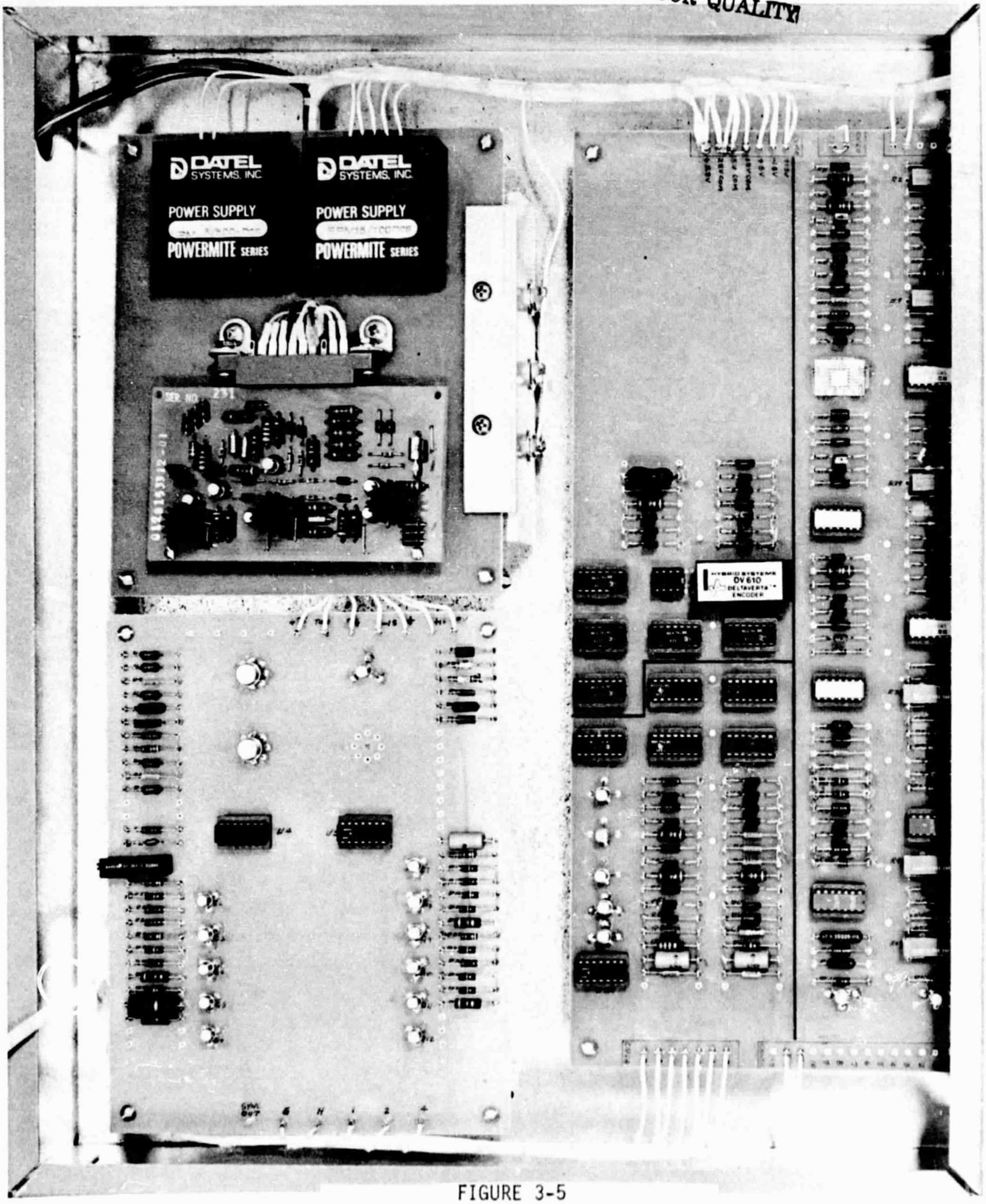


FIGURE 3-5

VALVE CONTROLLER WITH COVER REMOVED

The flow control console contains two independent flow loops to provide fluid flow control for the #1 and #2 loops of the radiator panels and has the capability of maintaining flow to both loops simultaneously or individually. Freon flow rate is controlled and monitored by a flow meter network with range capability of 3 to 3000 lb/hr per system.

The freon thermal conditioning system contains a LN_2 finned-tube heat exchanger, finned Calrod heaters with thermal control feedback power supplies, and a trichlorethylene refrigerated cold pack unit. The system has the capability of providing a heat load per radiator of .5 to 7 KW by controlling radiator fluid inlet temperatures from -150°F to +140°F with a temperature transient of ±60°F per hour.

The pump system consists of two 10 hp varidrive units that drive gear pumps fitted with special seals compatible with freon fluids. The pump system is designed in such a manner that each pump train can provide the required flow rate to either radiator flow loop simultaneously or individually.

The installation of the above system is shown schematically on NASA/JSC Drawing SK20054 Fluid Schematic (Revision 7-3-75).

3.2.6 Environment Simulator

Flux on the radiator panels was simulated by an array of quartz lamps calibrated to provide a known flux at a given power setting. Additional flux to the cavity was provided by the PBD heater elements. The cavity opening was covered by LN_2 panels to provide a cold radiation sink temperature. This arrangement is shown in Figure 3-6.

TEST PANEL INSTALLATION IN CHAMBER

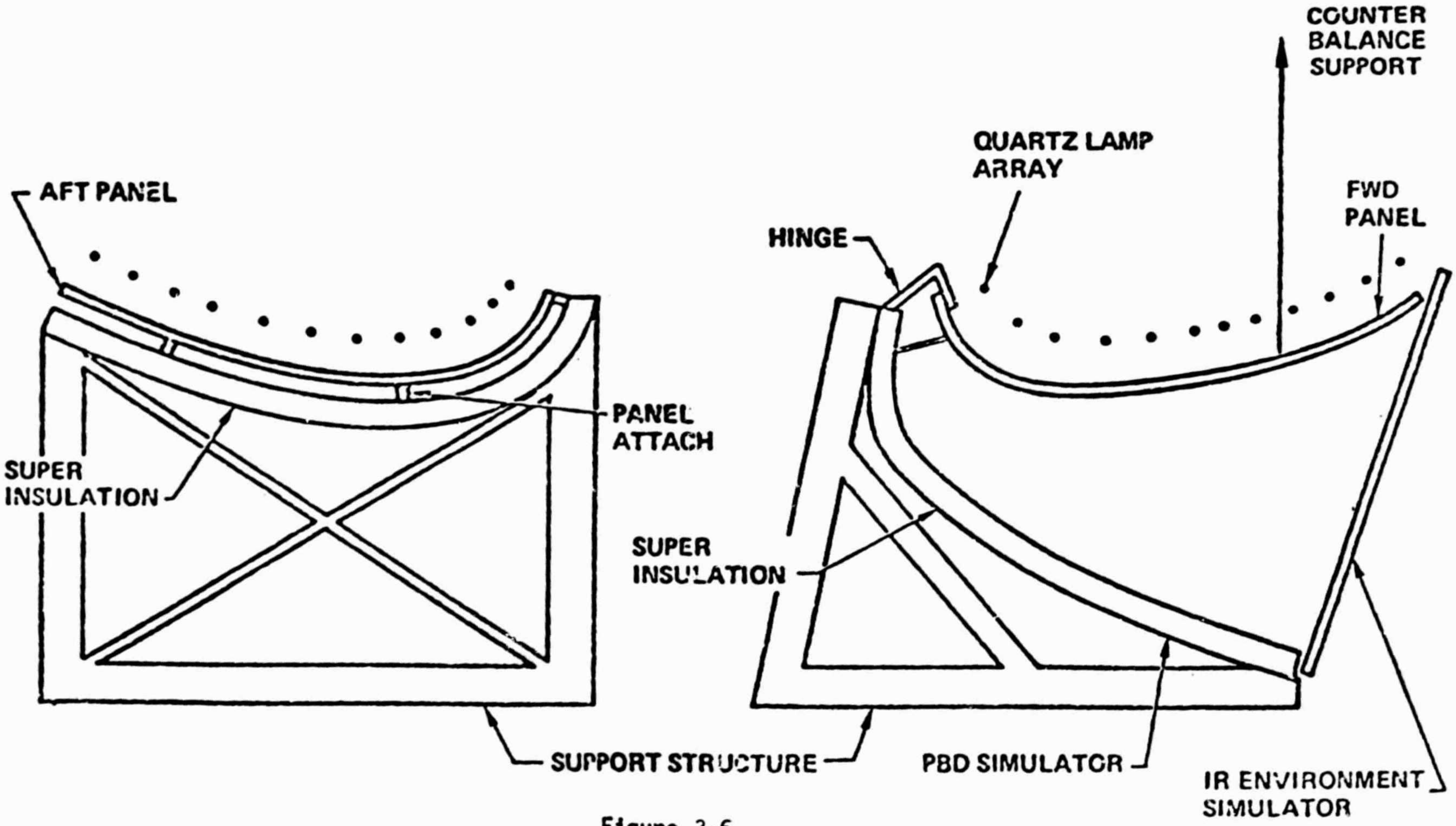


Figure 3-6

3.2.7 Instrumentation

The test article was instrumented with the thermocouples on the exterior of the radiator panels, payload bay door simulator, IR simulator, and some of the support structure (i.e., aft panel studs, forward panel hinges and deployment booms). Thermocouple locations for 70 aft panel locations and 192 locations on the forward panels are shown in Figures 3-7, 3-8 and 3-9. Eighteen payload bay door simulator thermocouple locations are shown in Figure 3-10. The Freon-21 supply and return lines to each panel were fitted with redundant immersion thermocouples. A temperature reading at each immersion thermocouple location allowed calculation of panel performance. Pressure drop across each of the radiator panels from inlet manifold to outlet manifold was recorded and displayed on the CRT real time.

Redundant flow metering devices were used to determine flow rates to the radiator panels. A temperature correction factor was used to convert the flow meter output (GPM) at the measured temperature in lb/hr.

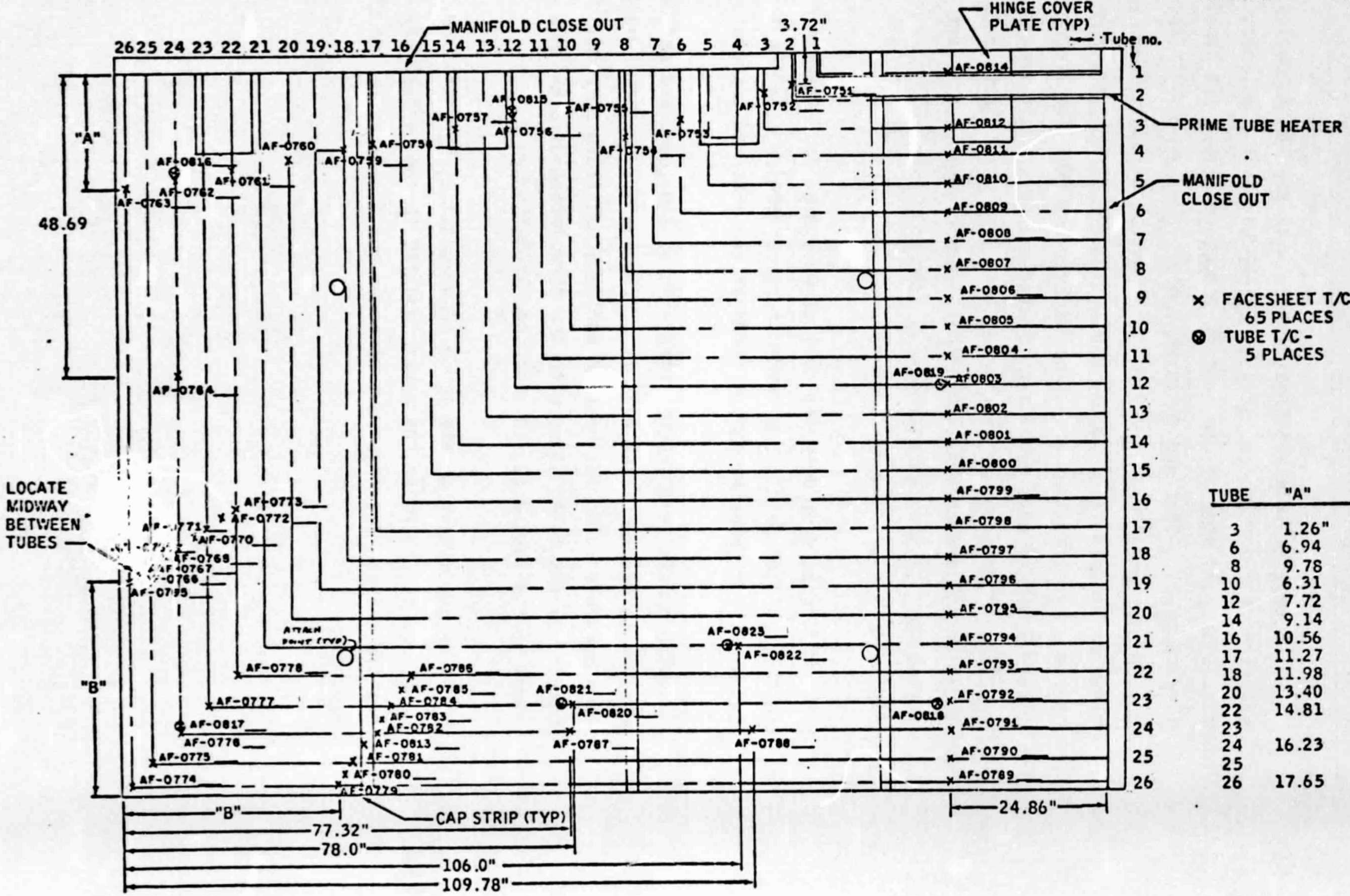
The panels were instrumented with strain gages and deflection sensors to determine the effects of the thermal gradients which exist from uneven environment heating and internal fluid changes. This portion of the test, along with the correlation of a NASTRAN analytical model to the test data, is discussed in Reference 2.

The amp meters on the 12050 power modules, furnished by SESL, were used to determine the power supplied to the payload bay door heaters. These readings were recorded and displayed on the CRT real time.

FIGURE 3-7

AFT PANEL THERMOCOUPLE LOCATIONS

TUBE WELD JOINT
AF-0813 AF-0821
AF-0820 AF-0822



× FACESHEET T/C - 65 PLACES

⊗ TUBE T/C - 5 PLACES

TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

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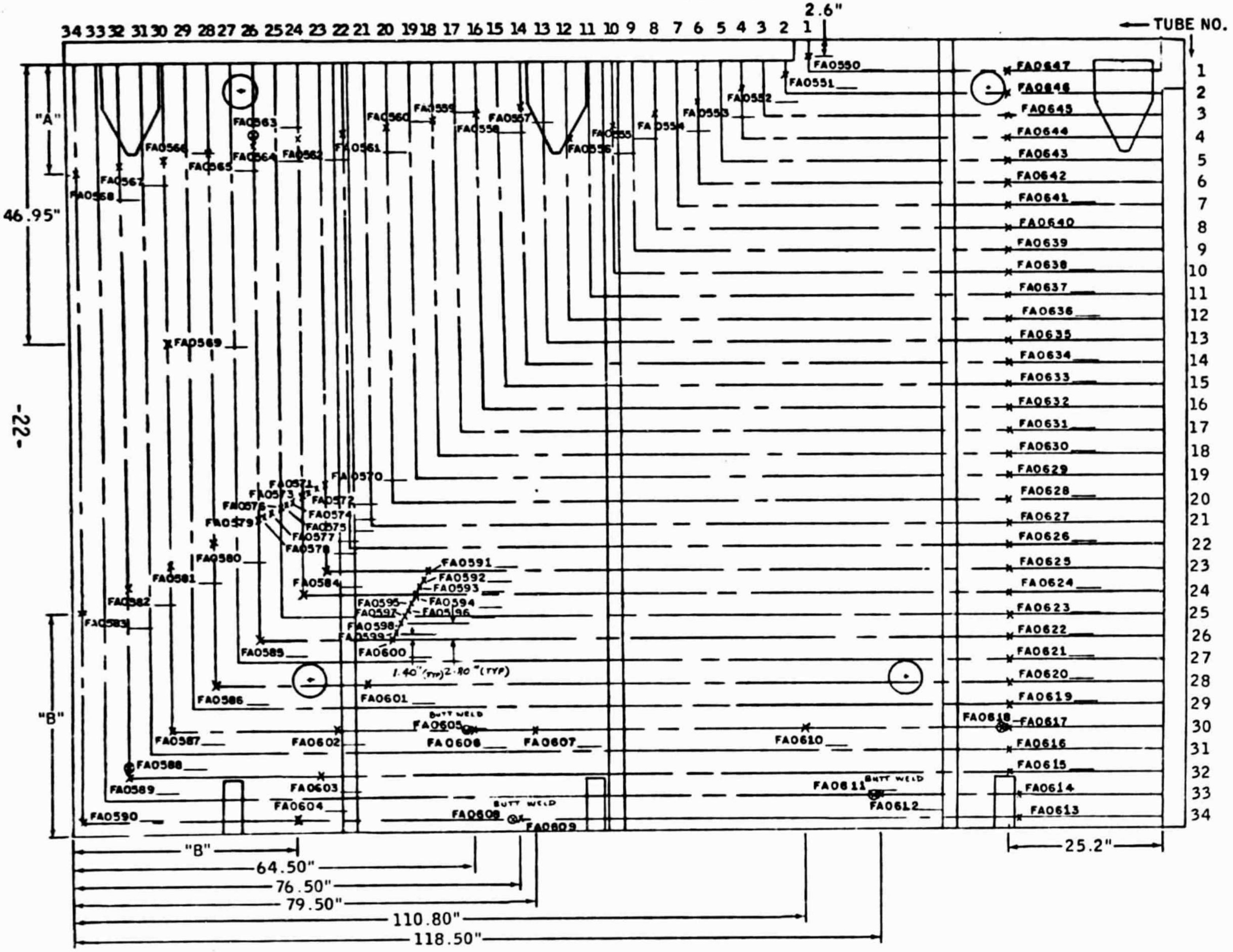
FIGURE 3-8

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



× FACE SHEET T/C - 93 PLACES

⊗ TUBE T/C - 6 PLACES

TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58 90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

NASA-JSC

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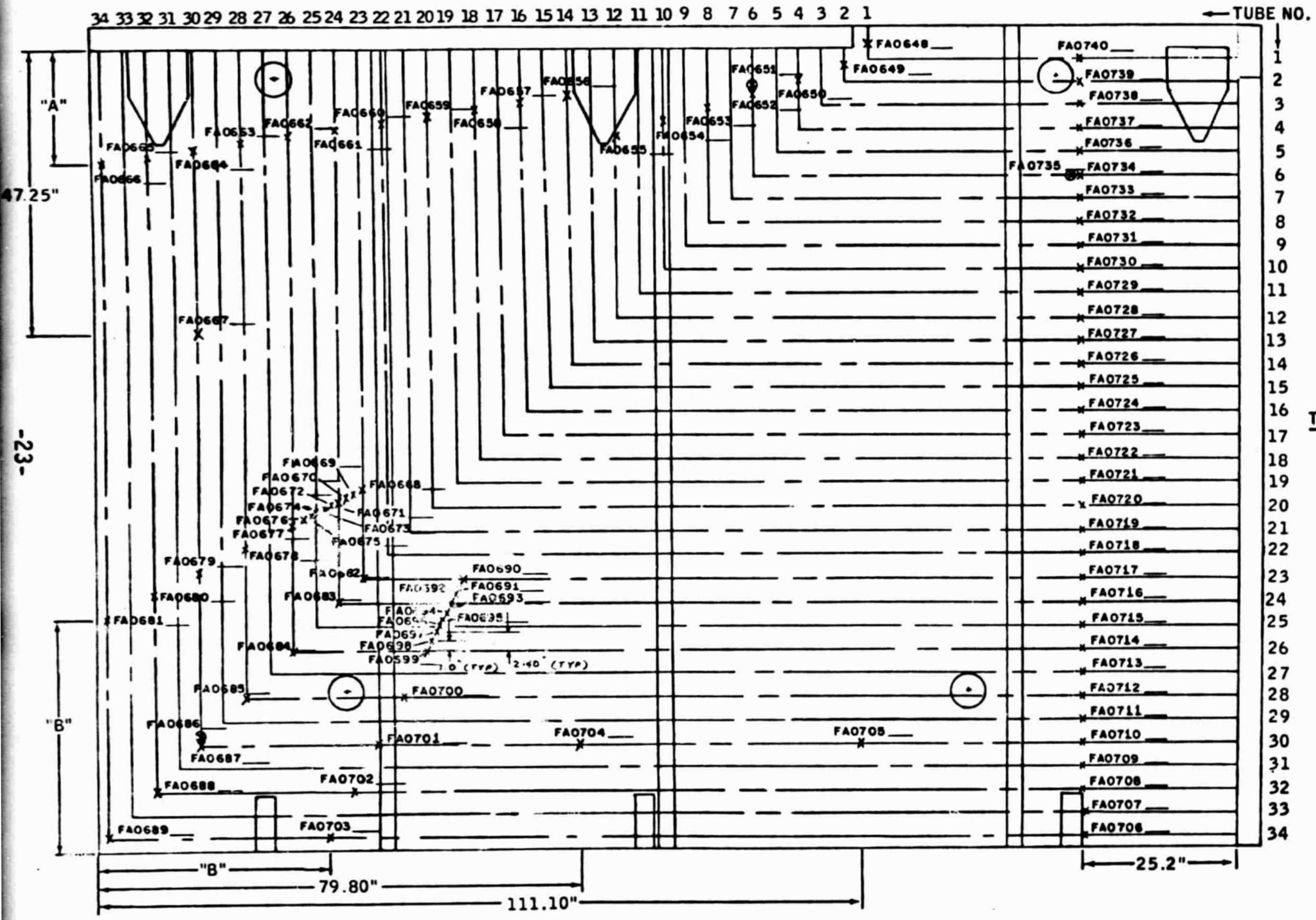
FIGURE 3-9

"BOTTOM" FORWARD PANEL THERMOCOUPLE LOCATIONS



× FACE SHEET T/C - 90 PLACES

⊗ TUBE T/C - 3 PLACES

TUBE	"A"	"B"
2	2.75"	
4	3.70	
6	5.70	
8	7.85	
10	10.00	
12	12.10	
14	7.10	
16	8.10	
18	9.20	
20	10.25	
22	11.30	
23		67.10"
24	12.35	64.60
25		62.60
26	13.40	59.20
28	14.50	53.80
30	15.55	48.50
32	16.55	43.30
34	17.65	38.30

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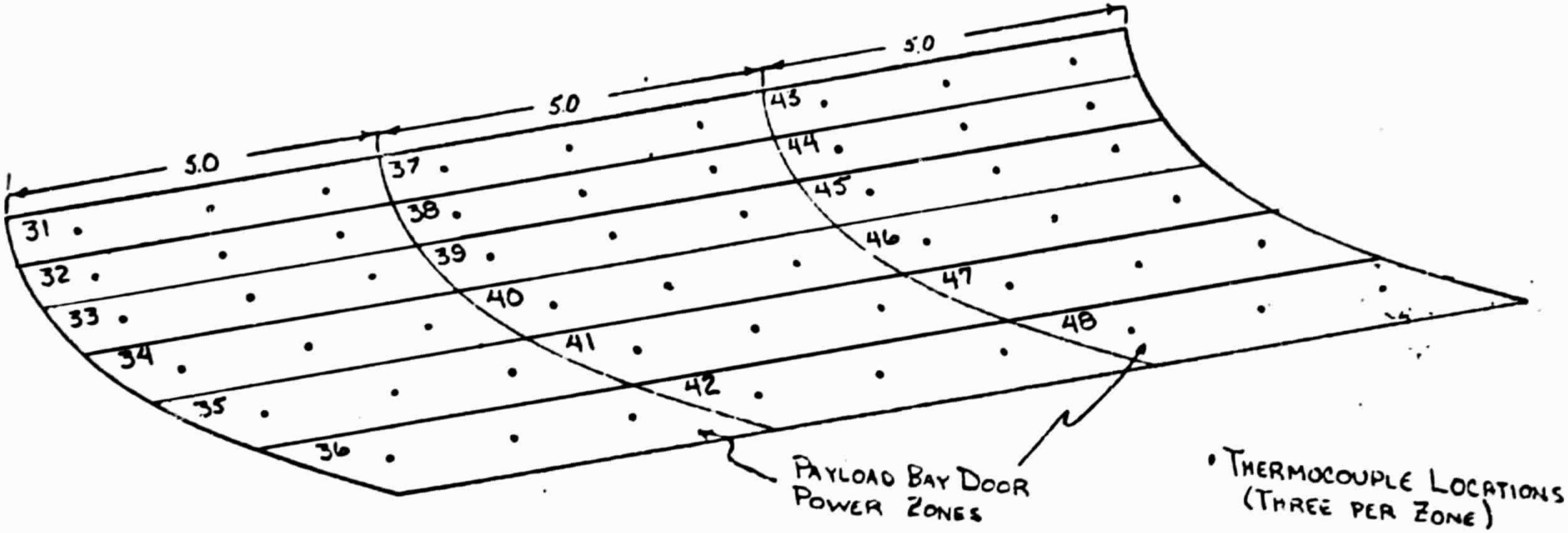

FIGURE 3-10

PAYLOAD BAY DOOR SIMULATOR POWER ZONES

4.0 TEST DESCRIPTION

4.1 Summary

A total of 124 test points were run during the five weeks of testing encompassing approximately 460 hours of thermal vacuum testing. All test objectives were satisfactorily achieved during the test and no retest requirements have been identified.

Tables 4-1 thru 4-5 summarize the test points accomplished during the five weeks.

4.2 Test Narrative/Facility Summary

The testing was accomplished through the joint efforts of Crew Systems Division/Rockwell/Vought as planners and analysts; and Space Environment Test Division/Vought Laboratories with test facility and hardware responsibility. The primary facility functions of high vacuum, deep space simulation, environment simulation, and instrumentation and display were accomplished with a few anomalies.

The first week of three weeks testing the baseline cavity deployment angle of 38 degrees began on August 18 (Day 230). Visual inspection was made of the radiator panels prior to chamber closeout. The forward panel top surface was in good condition, with only minor evidence of peeling. The forward panel bottom surface coating had numerous places where the edges of the silver-Teflon strips had begun to curl up. Vought repaired most of the peeled areas with Eastman 910 adhesive. In general, however, the surface appeared in satisfactory condition for testing. The coating on the payload bay door simulator was in acceptable condition. The aft panel surface coating was in good condition, except for three places where edges had curled up for a distance of several inches. It was not possible to repair the aft panel coating due to inaccessibility.

TABLE 4-1
WEEK 1 TEST SUMMARY
38° CAVITY

TEST POINT	COMPLETION TIME DAY:HR:MIN	INLET TEMP[1] MAIN SYS (°F)	TOTAL FLOW[2] LBS/HR	ENVIRONMENT BTU/HR-FT^2		REMARKS
				FWD	AFT	
1	230:17:35	131.6(130.3)	2844.5	0	0	High load performance
2	230:19:05	131.6(130.3)	2445.4	0	0	
3	230:20:50	113.9(114.4)	2439.	0	0	
4	230:23:20	100.7(102.2)	2448.7	0	0	
5	231:01:52	100.7(100.7)	1241.8	0	0	
6	231:05:55	101.7(100.3)	1216.5	40	30	
7	231:08:40	100.7(99.3)	2456.9	40	30	
8	231:10:57	114.9(115.4)	2451.5	40	30	
9	231:13:05	130.7(130.3)	2457.1	40	30	
10	231:14:20	130.7(130.3)	2788.8	40	30	
11	231:18:40	130.7(132.1)	2738.9	80	60	
12	231:19:50	131.6(132.1)	2356.2	80	60	
13	231:22:30	131.6(130.3)	1232.	80	60	
14	232:02:20	115.4(115.4)	1222.2	80	60	
15	232:04:35	114.9(114.4)	1950.3	80	60	
16	232:05:55	116.8(116.3)	2430.2	80	60	
17	232:07:10	114.9(114.4)	2794.1	80	60	
17A	232:10:28	129.8(130.3)	2783.5	80	60	
18	232:13:00	99.8(100.7)	2831.2	80	60	
19	232:14:20	101.2(100.7)	2446.9	80	60	
20	232:16:45	100.7(100.3)	1249.5	80	60	High load performance
26	232:20:00	116.3(N/A)	635.4	80	60	Single loop
25	232:22:00	115.4(N/A)	1403.9	80	60	
24	233:00:35	130.3(N/A)	1316.5	80	60	
23	233:04:05	130.3(N/A)	1410.8	40	30	
22	233:07:05	100.3(N/A)	1430.7	40	30	
21	233:11:18	101.2(N/A)	635.7	40	30	Single loop
28	233:14:30	109.7(90.6)	1247.6	40	30	Delta on inlet temp
27	233:18:15	124.8(105.)	2479.4	40	30	Delta on inlet temp
29	233:19:15	75.0(75.0)	2449.	40	30	Valve check
30	233:20:00	74.0(74.0)	2087.5	0	0	Valve check
40	234:05:35	114.9(115.4)	2451.8	Skew	Skew	Solar simulation
41	234:10:48	114.9(114.4)	2449.7	Skew	Skew	Solar simulation

[1] XXX - Loop 1, (XXX) Loop 2

[2] Total Flow Both Loops, Prime & Main

TABLE 4-2
WEEK 2 TEST SUMMARY
38° CAVITY

TEST POINT	COMPLETION TIME DAY:HR:MIN	INLET TEMP[1] MAIN SYS (°F)	TOTAL FLOW[2] LBS/HR	ENVIRONMENT BTU/HR-FT^2		REMARKS
				FWD	AFT	
37	237:12:30	65.1(65.1)	775.2	0	0	Valve check
38	237:15:17	72.0(72.0)	57.0	0	0	Valve check
39	237:18:50	71.5(74.0)	956.8	0	0	Valve check
5A	237:23:30	130.7(130.7)	1279.6	0	0	High load performance
5B	238:02:20	99.3(100.3)	2882.3	0	0	High load performance
42	238:06:30	115.8(115.8)	2434.3	Skew	Skew	Solar simulation
43	238:12:30	115.8(115.8)	2440.8	Skew	Skew	Solar simulation
12A	238:14:30	131.2(131.2)	2405.4	80	60	High load performance
13B	238:16:35	130.3(130.3)	1245.2	80	60	High load performance
29	238:17:20	75.5(75.0)	2446.1	40	30	Valve check
30	238:18:05	75.5(75.0)	1573.9	0	0	↑
31	238:18:50	75.5(75.0)	2425.3	40	30	
32	238:19:35	75.5(75.0)	1419.1	0	0	
33	238:20:20	76.5(76.0)	421.2	0	0	
34	238:21:05	75.5(77.0)	447.1	40	30	
35	238:21:50	49.5(49.0)	70.6	0	0	
36	238:22:35	49.5(49.0)	73.5	40	30	
36A	238:23:20	45.4(46.9)	75.7	0	0	
37A	239:00:20	75.0(75.0)	928.8	0	0	
38A	239:01:02	75.5(75.0)	730.8	0	0	↓
39A	239:02:12	75.0(75.5)	1049.6	0	0	Valve check
5C	239:03:50	115.8(116.3)	1287.6	0	0	High load performance
37AA	239:05:08	74.5(75.0)	1131.0	0	0	Valve check
38AA	239:06:08	74.0(74.5)	73.1	0	0	↑
39AA	239:07:08	74.5(75.0)	897.4	0	0	↓
33AA	239:07:35	74.5(75.0)	67.6	0	0	Valve check
42A	239:15:15	115.8(115.4)	2423.4	Skew	Skew	Solar simulation
15A	239:18:15	100.3(100.3)	1953.	80	60	High load performance
15B	239:21:30	130.3(130.3)	1953.2	80	60	High load performance
10A	240:01:00	99.3(100.3)	2835.6	40	30	High load performance
22A	240:03:20	100.2(N/A)	1430.6	40	30	Single loop
6A	240:05:55	129.8(129.8)	1252.7	40	30	High load performance
41H	240:10:45	114.9(115.4)	2469.	Skew	Skew	PBD Heater
44A	240:19:40	102.6(99.3)	1996.	40	30	Valve Check

[1] XXX - Loop 1, (XXX) - Loop 2

[2] Total Flow Both Loops, Prime & Main

TABLE 4-3
WEEK 3 TEST SUMMARY
38° CAVITY

TEST POINT	COMPLETION TIME DAY:HR:MIN	INLET TEMP[1] MAIN SYS (°F)	TOTAL FLOW[2] LBS/HR	ENVIRONMENT BTU/HR-FT^2 FWD	AFT	REMARKS
46	245:24:00	- 99.4(- 99.4)	151.7	0	0	Low load performance
46A	246:08:10	-100.2(-101.1)	183.6	0	0	Low load performance
44	246:21:34	- 65.6(- 70.2)	45.1	0	0	Freeze
47	247:02:24	101.1(101.7)	2420.	0	0	Prime Tube Thaw
50	247:19:04	-101.9(-104.3)	32.3	0	0	Freeze
51	247:23:15	99.9(100.5)	2501.6	0	0	Ramp Thaw
52	248:12:54	-129.3(N/A)	10.5	0	0	Freeze
53	248:13:40	- 94.6(-101.1)	247.4	40	30	Envr Thaw
45	248:18:15	-107.6(-107.6)	160.8	0	0	Low load
4A	248:20:00	99.3(100.5)	2505.9	0	0	Repeat T.P. 4

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[1] XXX - Loop 1, (XXX) Loop 2

[2] Total Flow Both Loops, Prime & Main

TABLE 4-4
WEEK 4 TEST SUMMARY
50° CAVITY

TEST POINT	COMPLETION TIME DAY:HR:MIN	INLET TEMP[1] MAIN SYS (°F)	FLOW RATE[2] LBS/HR	ENVIRONMENTS BTU/HR-FT^2 FWD	AFT	REMARKS
5001	293:15:05	104.6(104.6)	2836.2	0	0	High load performance
5002	293:16:50	101.4(101.4)	2420.9	0	0	↑
5003	293:18:47	89.5(88.7)	2398.4	0	0	
5004	293:20:35	75.2(76.0)	2449.8	0	0	↓
5005	293:23:35	76.0(76.0)	2906.3	0	0	High load performance
5006	294:04:05	87.9(88.7)	2483.3	Skew	Skew	PBD Heaters
5007	294:07:40	110.2(110.2)	2815.4	40	30	High load performance
5008	294:09:41	106.2(106.2)	2437.4	40	30	↑
5009	294:12:08	93.5(93.5)	2505.5	40	30	
5010	294:14:08	82.3(82.3)	2460.2	40	30	
5011	294:16:05	84.7(83.9)	2821.1	40	30	
5012	294:20:05	117.1(117.1)	2809.7	80	60	
5013	294:21:05	114. (114.)	2401.1	80	60	
5014	295:00:05	101.4(101.4)	2442.6	80	60	
5015	295:02:05	87.1(87.9)	2440.1	80	60	↓
5016	295:03:36	88.7(90.3)	2841.7	80	60	High load performance
5018	295:09:55	100.6(100.6)	2438.4	Skew	Skew	Solar simulation
5017	295:14:50	103. (104.6)	2421.4	Skew	Skew	↑
5019	295:19:20	101.4(101.4)	2432.9	Skew	Skew	↓
5020	295:23:05	99.9(99.9)	2458.8	Skew	Skew	Solar simulation
5021	296:09:50	- 21.4(- 20.5)	113.2	0	0	Low load
5022	296:16:05	- 70.6(- 70.6)	109.1	0	0	↑
5023	296:22:50	-112.2(-112.2)	114.9	0	0	↓
5024	297:05:04	-105.7(-106.8)	33.5	0	0	Low load
5025	297:06:30	100.6(101.4)	2511.1	0	0	Ramp thaw
5001A	297:10:05	105.4(105.4)	2830.8	0	0	Repeat T.P. 5001

[1] XXX - Loop 1, (XXX) - Loop 2

[2] Total Flow Both Loops, Prime & Main

TABLE 4-5
WEEK 5 TEST SUMMARY
70° CAVITY

TEST POINT	COMPLETION TIME DAY:HR:MIN	INLET TEMP[1] MAIN SYS (°F)	FLOWRATE [2] LBS/HR	ENVIRONMENT BTU/HR-FT^2 FWD	AFT	REMARKS
7001	308:14:50	104.6(104.6)	2870.3	0	0	High load performance
7002	308:17:05	101.4(101.4)	2434.2	0	0	↑
7003	308:20:05	88.7(88.7)	2483.5	0	0	
7004	308:22:45	76.8(76.0)	2444.4	0	0	↓
7005	309:00:20	77.6(77.6)	2869.8	0	0	High load performance
7006	309:05:20	87.1(87.1)	2497.6	Skew	Skew	PBD Heaters
7007	309:09:05	109.4(109.4)	2783.	40	30	High load performance
7008	309:11:05	107.8(107.8)	2451.1	40	30	↑
7009	309:13:19	93.5(95.1)	2453.7	40	30	
7010	309:15:05	82.3(82.3)	2454.8	40	30	
7011	309:16:20	83.9(83.9)	2847.1	40	30	
7012	309:19:50	115.5(116.3)	2805.8	80	60	
7013	309:21:20	114.0(114.0)	2425.4	80	60	
7014	309:23:20	101.4(101.4)	2467.2	80	60	
7015	310:01:48	88.7(88.7)	2470.	80	60	↓
7016	310:03:05	88.7(88.7)	2849.5	80	60	High load performance
7021	310:14:50	- 20.5(- 20.5)	116.8	0	0	Low load
7022	310:20:05	- 70.6(- 70.6)	114.9	0	0	Low load
7023	311:00:45	-112.2(-112.2)	117.4	0	0	Low load
7018	311:06:00	100.6(99.9)	2467.4	Skew	Skew	Solar simulation
7020	311:11:00	99.9(100.6)	2458.3	Skew	Skew	Solar simulation

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[1] XXX - Loop 1, (XXX) Loop 2

[2] Total Flow Both Loops, Prime & Main

Chamber pumpdown was initiated at 4 a.m. and chamber pressure was reduced to test conditions ($<$10-5 torr) at 1248 at which time test point 1 was initiated. The first test sequence was to determine high load performance with both Freon 21 loops flowing at various flowrates and inlet temperatures. Environments were varied from 0 BTU/Hr-Ft^2 (T.P.1-5) to a uniform environment of 30 BTU/Hr-Ft^2 on the aft and 40 BTU/Hr-Ft^2 on the forward (TP6-10). Then the environment was increased to a uniform 60 BTU/Hr-Ft^2 on the aft and the forward had 80 BTU/Hr-Ft^2 for the last test points in this sequence (TP 7-17). On August 19 (Day 231), after the completion of test point 13, it was discovered that some of IR lamp modules on both panels had been off. This caused test points 11-13 to have some undetermined low flux. Upon completion of test point 17 a test point (17A) was added to duplicate test point 11 with correct flux.

The second test sequence was to evaluate radiator performance with only one Freon 21 loop flowing. Environments were varied for the aft from 30 to 60 BTU/Hr-Ft^2 and for the forward from 40 to 80 BTU/Hr-Ft^2. These points (21-26) were completed on August 21 (Day 233) at 1118.

The next sequence of two test points (27-28) were run to determine the effect of varying inlet temperatures by 20°F between the two Freon 21 loops. The environment was a uniform 30 BTU/Hr-Ft^2 on the aft and 40 BTU/Hr-Ft^2 on the forward.

Sequence four and five of the test were to check out the transient response of the valves and control valve operation between set point temperatures of 38°F and 60°F respectively. The first test point (29) was completed at 1915 on August 21 (Day 233). At this point one of the valves malfunctioned and would not control to the desired set point temperature. Various fixes were attempted real time, but no solution could be found. Vought sent to Dallas for an electrical engineer to repair the valve.

The week was ended with two test points (40-41) which had been scheduled for the second week. These points were attempts of simulating on-orbit solar environments with the IR lamps and payload bay heaters. The first week of testing was terminated at 1330 on August 22 (Day 234).

At the conclusion of the week 1 test, visual inspection of the radiator panels was made immediately after the chamber door was opened. Water had collected in three areas on the concave portion of the forward panel. A cloth was used to wipe the accessible areas of the panel, while other areas were left to dry over the weekend. An inspection of the coating indicated no observable change on the forward panel including those areas repaired prior to the test with the Eastman 910 adhesive. The three areas of tape curling on the aft panel appeared to have increased, but could not be repaired due to inaccessibility.

The second week of testing began on August 25 (Day 237) with a visual inspection of the chamber which indicated the general acceptability of the test articles for testing. The forward panel coating appeared spotted in the areas where the water was observed during the week 1 post-test inspection, but the panels were dry.

The chamber door was closed at 0200 and the chamber pumpdown was initiated. Test conditions were reached at 0830 and the first series of test points (37-39) to test the valve operation during set point changes (38/60°F) were begun. Once again one of the valves did not operate correctly, but was controlled manually to complete the test series. While Vought engineers worked on the valve problem, two additional high load performance points (5a and 5b) were completed at 0220 on August 25 (Day 237).

Following this, the other two solar simulation environment points (42, 43) were completed. However, it was determined that test point 42 had T.P. 42 flux on the panel, but T.P. 43 flux on the payload bay door simulator. These points were completed on August 26 (Day 238) at 1230.

At this time, two more high load performance points (12a, 13b) were added to the test timeline. These points had 60 BTU/Hr-Ft^2 on the aft and 80 BTU/Hr-Ft^2 on the forward and added to the parametric data for that environment.

At 1635 on August 26 (Day 238), the valve test series was again attempted. Test points 29 to 36 were completed with an oscillation in one of the valves noticed in T.P. 33-36. Then test point (36A), which had a higher flowrate, operated successfully. After making some design changes to the electronic controller, another series of test points (37A-39A) were attempted to determine valve performance during set points (38/60°F), but these also indicated unstable valve operation. An intensive investigation of the electronic controller indicated that the electronic stepping motor drive PC board had bad characteristics. While electronic circuit changes were made to both controllers, another high load performance point (5A) was completed without the IR lamps and payload bay door heaters. At 0708 on August 27 (Day 239) test points 37AA-39AA, which were reruns of the original test points 37-39, were successfully completed with the repaired controllers. A test series (33A-39A) was again attempted to evaluate transient response with a low flow in each loop thru the panels. On T.P. 33A both valves had problems controlling, and it was determined that the valves would not handle this condition, which appeared to be an unrealistically lower flow rate to control to 38°F. For this reason, this test series was aborted.

The rest of the week was used to complete additional high load performance mappings. The first of these was test point 42A which was completed on August 27 (Day 239) at 1515. T.P. 42A was a skewed environment solar simulation point repeating T.P. 42, but with the correct flux on the payload bay door. At this point several high load uniform environment points (15A, 15B, 10A, 22A, 6A) were added to determine the linearity of outlet temperature for a given flow rate. Test point 41H was run identical to T.P. 41 without IR lamps to obtain data for correlation with a future point with a larger cavity opening.

The last test point (44A) of the week was a checkout for the valve with a very cold inlet temperature followed by a ramp temperature increase. Chamber repressurization was begun a day early, August 28 (Day 240) at 2250, to allow for strain gage installation for measurements to be made during the low load testing.

Visual inspection of both radiator panels was made upon opening of the chamber at the end of week 2 testing. An excessive amount of frost had formed in the chamber during repressurization and covered all the test articles, instrumentation, and equipment. Upon chamber opening it was found that this had caused a large puddle of water to accumulate on the west end of the forward panel extending approximately to the center of the panel. There were also droplets of water scattered over the rest of the forward panel and on the aft panel. There was some curling of the edges of Teflon strips in the puddled area of the forward panel. There were also several curled spots in the center of the aft panel. The large puddle of water was blown off of the forward panel west end by using a compressed air hose. This caused a significant part of the water to fall onto the west end of the PBD simulator. All portions of both panels and the PBD simulator that could be reached were wiped with clean white cloths to remove as much of the moisture as possible. The cloths used on the two radiator panels were quite dirty after use.

The third and last week of testing the baseline 38 degree cavity deployment angle began with chamber door closed on September 2 (Day 245) at 0220. The entire week was devoted to radiator low load performance with several freeze/than cycles being made. In setting up for the first test point the LN_2 heat exchanger froze up. While a fix was being worked to allow very cold inlet temp (<-100°F) and low flow (<70 lbs/hr) rates, two low load performance points (46, 46A) were completed. A bypass was added to allow high flow through the LN_2 heat exchanger to keep it from freezing and a low flow to the radiators to allow them to freeze.

At 1129 on September 3 (Day 246), setup began for test point 44 to freeze the panels. The prime tube flow was turned off until the panel reached steady state 10 hours later; at which time T.P. 44 was completed and the prime tube recovery point (47) began with flow going through the prime tubes and the bypass temperature increasing from 53°F to 108°F and the radiator inlet temperature increasing from -100°F to 100°F over a 2.75 hour period.

Test point 50 was the second frozen panel point beginning at 0224 on September 4 (Day 247) and lasting approximately 18 hours at which time test point 51 was initiated. This thaw, like the first, simulated a system heat load change from minimum to maximum by increasing inlet temperature but without prime tube flow. Test point 51 was completed at 2315 on September 4 (Day 247).

During the third freeze (T.P. 52), the chamber pressure was increased to approximately 1 torr to speed up the cold soak. The tubes did not stagnate in the proper order during this test point, but, after the environment recovery (T.P. 53), the flow skew appeared normal. Just prior to the environment thaw, the prime tube heater was used to thaw the forward panel after a complete freeze up of one loop. Approximately 38 minutes of prime tube heater operation was required to re-initiate flow.

Another low load performance point (T.P. 45) was initiated at 1340 on September 5 (Day 248). The forward panel again froze and at the completion of this point a fourth thaw (T.P. 4A) was initiated at 1815 on September 5 (Day 248). This last thaw was accomplished by increasing the panel flow rate and inlet temperature as rapidly as the flow bench would allow to obtain a severe thermal shock. Test point 4A was also intended to be an exact duplication of test point 4 from week 1 to show that the three weeks of testing had not degraded the radiator performance. However, it was later discovered that the prime flow had not been activated, so the point was not completely accurate. The third week of testing was concluded at 2002 on September 5 (Day 248).

Visual inspection of the radiator panels was made when the chamber doors were opened at the conclusion of the third week of testing. As in the prior week, water had collected on the panels and the cloths used to wipe the panel were soiled. An inspection of the coating indicated curling and several areas repaired prior to the first week of testing with the Eastman 910 adhesive had peeled up. A tap test on the accessible areas of the forward panel indicated no structural unbonding of the face sheets and honeycomb core.

Six weeks elapsed between the third and fourth weeks of testing and test setup was slightly altered. The next two weeks of testing were "piggybacked" to the self-contained Heat Rejection Module (SHRM) test. The forward panel was the only one tested and the cavity deployment angle was increased to 50 degrees.

The forward panel was inspected prior to chamber closeout at 0454 October 20 (Day 293). The coating on both the upper and lower surfaces of the radiator panel, and on the payload bay door simulator appeared to be in satisfactory condition for testing.

Efforts were made to verify the accuracy of the cavity angle which was preset during test buildup to simulate a 50 degree deployment angle. The chord length, measured from the lower, outer tip of the radiator panel to the upper, outer tip of the payload bay door simulator, was 108.1 inches.

Test conditions were reached at 1210 on October 20 (Day 293) with a chamber pressure of approximately 1×10^{-5} torr. The first sequence of test points (5001-5016) were run to compare wide cavity high load performance with results obtained during the baseline cavity angle testing. This test sequence varied inlet temperature and flowrate for the three uniform environments previously established (0, 40, 80 BTU/Hr-Ft^2). The last of the sixteen points was completed on October 22 (Day 295) at 0336.

The second test sequence (T.P. 5017-5020) involved duplicating the mission simulation points from the baseline deployment angle using the Quartz lamp array and payload bay heaters. These points tested the panel operation under conditions approximating those expected during flight and were completed on October 22 (Day 295) at 2305.

Four low load performance test points (T.P. 5021-5024) and one high load thaw point (T.P. 5025) concluded the last sequence of testing. This sequence was intended to determine the influence of the deployment angle on low load performance. The last of these points was completed at 0630 October 24 (Day 297), at which time another high load performance point (T.P. 5001A) was made to duplicate the first point (T.P. 5001) of the week. This point was to show that no degradation in panel performance had occurred during the week.

One week elapsed between weeks four and five of testing. Week five had a larger deployment angle (70°) to get performance data for another cavity deployment angle and for direct comparison to the two angles previously tested.

The visual observation of test article prior to chamber closeout indicated no significant changes in the condition of the radiator or payload bay door simulator. However, the edges of the silver-Teflon coating were curled slightly at several locations on the panel.

The fifth and final week of testing began with chamber pumpdown occurring at 2345 on November 3 (Day 307) after a one day delay to permit replacement of a SHRM compressor assembly. Again the first test sequence was for high load performance data over a wide range of inlet temperatures flow rates and the three uniform environments (0, 40, 80 BTU/Hr-Ft^2). These sixteen points (T.P. 7001-7016) were completed on November 6 (Day 310) at 0305. The next series of three test points (T.P. 7021-7023) involved determining the low load performance. These were completed at 0045 November 7 (Day 311). Due to the time factor only two on-orbit environment simulation points (T.P. 7018, 7020) could be made. These points were finished at 1100 and the five weeks of testing was concluded.

5.0 TEST RESULTS

A discussion of the test results as they relate to the stated test objectives, is given in the following paragraphs. The weekly status reports for each week of testing are presented in Appendix A. However, complete test data, including time plots of all recorded data and panel temperature maps for each steady state point are too volumous for publication. This data is available for examination by interested parties from the Crew Systems Division of NASA/JSC.

5.1 Radiator Panel Performance

One of the primary objectives of the test was to provide performance data for the L-tube radiator configuration. Tables 5-1 thru 5-3 summarize the aft and forward panel performance data for each steady state point during the five weeks of testing. (Flow rate was adjusted for density and temperature variation)

5.1.1 Baseline Panel Performance (38° Cavity Development)

The high load phase of testing provided steady-state performance data for dual and single loop operation. In addition, performance data was gathered for inlet temperature gradients between loops, and for several solar simulation "on-orbit" environments. Also provided was performance data for low load operations, with and without prime tube flow.

The first sequence of testing provided aft and forward panel performance data for three different environments over a range of inlet temperatures and flow rates. This data which is representative of high load Shuttle operations is summarized in Figures 5-1 thru 5-6. The 1250 lbs/hr data is representative of a candidate 8 panel flow configuration which has two aft panels on each door flowed in parallel. Since the test panels are flowed in series, data for the 1250 lbs/hr case was also obtained on the forward panel. Although this data is not representative of the forward panel operating conditions, it is included for reference data. Flow rate appears to have a negligible effect on heat rejection, indicating that flowing the aft panels in parallel is acceptable from a heat rejection standpoint.

TABLE 5-1 AFT PANEL STEADY STATE PERFORMANCE DATA FOR 38° CAVITY

T/P No.	T_{IN} MAIN		T_{OUT} MAIN		T_{IN} PRIME		T_{OUT} PRIME		FLOW MAIN		FLOW PRIME		Q_{REJ}
	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	
1	131.6	130.3	104.7	104.3	128.8	127.5	106.4	106.5	1388.2	1377.3	39.4	39.6	19951.3
2	131.6	130.3	101.3	100.4	128.8	127.5	102.6	103.0	1193.7	1185.7	33.3	32.7	19478.5
3	113.9	114.4	87.1	86.2	111.6	111.6	87.9	88.8	1195.3	1177.7	33.1	32.9	17383.1
4	100.7	102.2	76.4	75.0	99.3	99.3	76.4	77.3	1196.7	1186.5	32.9	32.6	15957.1
4A	99.3	100.5	75.2	75.2	-26.8	-25.4	-53.5	-18.6	1248.3	1257.6	0.0	0.0	15864.9
5	100.7	100.7	55.6	54.7	97.9	96.5	56.1	57.1	598.3	609.5	17.1	16.4	14287.0
5A	130.7	130.7	78.6	77.7	125.7	125.7	75.0	78.2	6127	634.0	16.6	16.3	17553.3
5B	99.3	100.3	77.7	77.7	96.4	97.4	76.4	78.2	1404.4	1405.0	36.1	36.8	16249.6
5C	115.8	116.3	67.2	66.7	111.1	111.6	63.5	66.3	617.1	638.1	16.3	16.1	16155.4
6	101.7	100.3	67.6	66.7	98.8	96.5	67.2	69.0	576.2	606.8	17.0	16.5	10448.3
6A	129.8	129.8	88.8	87.5	125.7	124.8	86.2	89.7	599.7	620.8	16.0	16.2	13680.4
7	100.7	99.3	81.2	80.3	98.3	97.4	81.7	82.6	1198.3	1198.8	33.1	32.7	12104.9
8	114.9	115.4	94.2	93.7	113.0	113.5	94.2	95.1	1197.8	1188.3	32.8	32.6	13528.4
9	130.7	130.3	107.3	106.4	128.8	128.4	108.2	108.2	1205.2	1186.4	33.0	32.5	15434.1
10	130.7	130.3	109.5	108.6	128.4	127.5	109.9	110.8	1370.8	1341.7	37.7	38.6	15891.3
10A	99.3	100.3	88.5	83.0	96.9	97.4	82.6	84.4	1387.1	1376.9	35.4	36.2	12017.1
11	130.7	132.1	111.6	110.3	129.8	129.3	115.5	115.9	1331.6	1332.2	37.5	37.6	14854.1
12	131.6	132.1	109.1	108.6	129.8	129.3	114.2	115.1	1160.2	1131.7	32.2	32.1	14840.1
12A	131.2	131.2	113.8	112.5	129.8	128.4	114.2	115.1	1175.7	1167.7	30.7	31.3	11226.5
13	131.6	130.3	92.4	91.0	127.9	126.6	99.9	101.3	588.8	614.5	17.3	16.4	12649.2
13B	130.3	130.3	100.4	99.4	127.0	126.6	100.8	103.0	606.5	606.5	16.1	16.1	9998.6
14	115.4	115.4	89.7	89.2	113.0	111.6	91.9	93.3	599.2	539.7	17.1	16.2	8000.8
15	114.9	114.4	98.1	97.7	113.9	113.5	99.9	101.3	959.7	938.6	26.1	25.9	8499.7
15A	100.3	100.3	86.2	84.8	98.8	97.4	86.6	88.0	956.5	947.2	24.4	24.9	7382.6
15B	130.3	130.3	109.9	108.6	127.9	127.5	110.3	111.6	950.9	952.3	24.9	25.1	10907.8
16	116.8	116.3	102.2	100.8	114.9	113.5	103.0	103.9	1187.6	1177.8	32.4	32.4	9529.6
17	114.9	114.4	102.6	101.7	113.9	112.6	103.8	103.9	1364.4	1353.4	38.2	33.1	9098.5
17A	129.8	130.3	115.5	114.6	129.3	128.4	116.3	116.8	1367.1	1340.4	38.3	37.7	11115.3
18	99.8	100.7	89.2	88.8	98.8	99.3	90.1	91.5	1396.5	1358.3	38.1	38.3	8157.8
19	101.2	100.7	88.4	88.0	99.8	98.4	89.2	90.6	1200.7	1180.8	32.7	32.7	8022.1
20	100.7	100.3	79.5	78.2	98.8	96.5	81.2	82.6	602.3	613.5	17.0	16.7	6901.9
21	50.0	101.2	44.9	50.1	54.6	97.4	37.9	51.5	9.8	619.1	11.3	16.6	8236.6
22	53.0	100.3	67.2	73.2	55.6	98.4	48.2	73.7	0.0	1392.6	0.0	33.1	9894.0
22A	100.2	63.1	73.7	69.0	98.3	61.1	78.6	63.5	1394.9	0.0	35.7	0.0	9656.6
23	57.1	130.3	89.7	98.1	59.6	128.4	63.0	97.7	0.0	1372.8	0.0	38.0	12001.1
24	64.1	130.3	99.5	104.7	63.6	128.4	80.3	105.6	0.0	1281.2	0.0	35.3	8943.3
25	57.1	115.4	89.7	94.6	59.6	113.5	73.7	96.0	0.0	1365.9	0.0	38.0	7589.1
26	55.1	116.3	73.6	76.8	57.6	111.6	64.9	79.9	0.0	618.7	0.0	16.7	6455.2
27	124.8	105.0	96.9	91.5	123.3	108.1	100.4	92.4	1216.3	1198.4	32.6	32.1	13430.6
28	109.7	90.6	68.1	65.8	106.4	86.7	69.0	68.1	586.7	627.4	17.0	16.5	10434.1
40	114.9	115.4	103.0	102.2	114.4	114.4	103.4	104.7	1196.9	1189.8	32.3	32.8	8053.0
41	114.9	114.4	99.5	99.0	113.5	112.6	96.0	98.6	1196.9	1188.7	31.5	32.6	9885.0
41H	114.9	115.4	88.0	87.5	112.1	112.6	87.1	88.0	1207.8	1198.8	30.8	31.6	17558.7
42	115.8	115.8	100.4	99.5	114.4	113.5	96.3	98.6	1185.9	1186.4	30.3	31.7	10169.9
42A	115.8	115.4	99.5	98.1	113.9	113.5	96.4	97.7	1184.7	1176.6	30.5	31.6	10679.6
43	115.8	115.8	98.1	97.3	113.9	113.5	97.7	99.5	1189.2	1189.8	30.6	31.2	11552.4
44	-65.6	-70.2	-182.4	-183.6	-71.8	-77.3	-150.6	-153.0	23.7	21.4	0.0	0.0	1210.6
45	-107.6	-107.6	-143.6	-144.7	-142.3	-137.8	-172.3	-172.3	80.0	80.8	0.0	0.0	1368.8

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OF POOR QUALITY

TABLE 5-1 CONT'D

I/P NO.	T_{IN} MAIN		T_{OUT} MAIN		T_{IN} PRIME		T_{OUT} PRIME		FLOW MAIN		FLOW PRIME		Q_{REJ}
	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	
46	-99.4	-99.4	-143.6	-143.6	-102.7	-102.7	-128.4	-127.8	76.6	75.1	0.0	0.0	1559.9
46A	-100.2	-101.1	-138.9	-140.0	-108.4	-104.3	-124.1	-123.0	94.5	89.1	0.0	0.0	1657.8
47	101.1	101.7	76.0	75.2	98.7	99.3	72.0	76.0	1183.3	1180.6	26.4	29.7	15989.4
50	-101.9	-104.3	-203.1	-203.1	-138.7	-137.8	-181.1	-177.4	16.6	15.7	0.0	0.0	758.1
51	99.8	100.5	75.2	75.2	-5.0	-3.0	-27.0	-0.6	1255.9	1245.7	0.0	0.0	16013.8
52	-129.3	-155.8	-217.0	-217.0	-177.3	-170.7	-208.7	-211.5	10.5	0.0	0.0	0.0	215.2
53	-94.6	-101.1	-120.8	-123.0	-154.0	-152.2	-203.1	-203.1	118.6	128.8	0.0	0.0	1380.1

TABLE 5-2 FWD PANEL STEADY STATE PERFORMANCE DATA FOR 38° CAVITY

T/C No.	T_{IN} MAIN		T_{OUT} MAIN		T_{IN} PRIME		T_{OUT} PRIME		FLOW MAIN		FLOW PRIME		Q_{EES}
	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	
1	104.7	104.3	66.7	67.2	103.0	103.0	89.7	90.6	1388.4	1377.3	39.4	39.6	26779.7
2	101.3	100.8	59.3	59.3	98.6	99.0	83.9	83.9	1193.7	1185.7	33.3	32.7	25459.9
3	86.6	86.6	48.2	48.7	84.4	85.3	70.9	71.8	1195.3	1177.7	33.1	32.9	22909.3
4	75.9	75.9	39.3	39.3	73.7	74.6	60.2	61.7	1196.7	1186.5	32.9	32.6	21864.3
4A	74.4	75.2	36.9	38.6	-71.6	-53.5	-147.1	-131.8	1248.3	1257.6	0.0	0.0	22997.2
5	55.6	55.2	2.2	2.2	49.7	51.5	30.4	31.3	598.8	609.5	17.1	16.4	15756.2
5A	78.6	78.2	15.9	16.9	68.1	71.8	45.9	48.2	612.7	634.0	16.6	16.3	19204.7
5B	77.7	77.7	45.4	45.9	73.7	76.4	62.6	64.4	1404.4	1405.0	36.1	36.8	22660.8
5C	66.7	67.2	8.1	8.6	55.2	58.0	34.6	36.9	617.1	638.1	16.3	16.1	18125.3
6	68.1	67.6	29.4	29.9	61.7	63.5	51.0	51.5	576.2	606.8	17.0	16.5	11212.1
6A	88.8	88.4	42.6	42.6	79.5	82.6	66.7	68.1	599.7	620.8	16.0	16.2	14149.1
7	81.7	81.2	55.6	56.1	79.1	79.9	71.8	71.8	1198.3	1198.8	33.1	32.7	15506.1
8	94.2	94.6	65.8	65.8	91.5	92.4	83.0	83.5	1197.8	1188.3	32.8	32.6	17455.2
9	107.3	107.3	75.0	75.0	104.7	104.7	94.2	95.1	1205.2	1186.4	33.0	32.5	20002.7
10	109.9	109.5	80.3	80.3	106.9	107.3	98.6	98.6	1370.8	1341.7	37.7	38.6	20736.5
10A	83.5	83.9	60.2	60.7	80.8	82.6	74.6	75.5	1387.1	1376.9	35.4	36.2	16279.4
11	112.5	112.0	86.6	87.1	113.4	114.2	106.5	106.5	1331.6	1332.9	37.5	37.6	17727.0
12	109.9	109.5	81.7	81.7	110.8	111.6	103.4	103.4	1160.2	1131.7	32.2	32.1	16724.4
12A	114.2	114.6	91.0	91.0	111.6	112.5	106.9	107.3	1175.7	1167.7	30.7	31.3	14369.3
13	93.3	92.8	55.2	54.7	94.2	94.6	82.6	82.6	583.8	614.3	17.3	16.4	11615.2
13B	101.3	100.8	69.5	69.0	96.0	97.7	91.0	91.5	606.5	606.5	16.1	16.1	9895.2
14	90.6	90.6	63.5	63.5	88.4	89.3	84.4	84.4	599.2	589.7	17.1	16.2	8190.7
15	99.0	99.0	76.8	77.3	97.7	98.6	94.2	94.2	959.7	938.6	26.1	25.9	10740.8
15A	86.6	86.6	68.1	68.1	84.4	86.2	83.0	82.6	956.5	946.8	24.4	24.9	8967.7
15B	110.3	110.3	84.8	84.4	107.3	108.2	102.6	103.0	949.6	952.3	24.9	25.1	12754.2
16	102.6	102.6	82.6	82.6	100.8	101.7	98.1	97.7	1187.6	1178.3	32.4	32.4	12244.0
17	103.4	103.0	85.3	85.3	102.2	103.0	99.0	99.5	1364.4	1353.4	38.2	38.1	12657.6
17A	115.9	116.3	94.6	95.1	114.2	115.0	110.3	110.8	1367.1	1340.4	38.3	37.7	15143.0
18	90.1	91.0	75.5	75.9	89.2	90.6	87.5	88.0	1396.5	1358.3	38.1	38.3	10478.1
19	89.2	89.2	73.2	73.2	88.0	89.2	86.6	86.2	1200.7	1180.8	32.7	32.7	9752.7
20	79.9	79.5	57.1	57.0	78.2	79.0	75.9	75.5	602.3	613.2	17.0	16.7	6920.6
21	33.7	51.0	11.0	5.2	30.9	46.8	27.5	32.7	9.8	619.1	11.3	16.6	7000.2
22	51.9	74.1	42.6	40.7	42.1	72.7	51.5	60.7	0.0	1392.6	0.0	38.1	11656.6
22A	74.6	58.4	38.8	40.7	76.4	54.7	64.4	55.6	1394.9	0.0	35.7	0.0	12473.8
23	70.0	99.0	59.3	56.6	55.2	95.1	69.5	80.8	0.0	1372.2	0.0	38.0	14890.5
24	83.9	106.5	79.9	76.4	75.0	103.8	90.6	96.9	0.0	1281.2	0.0	35.3	9982.9
25	75.9	96.4	73.7	70.9	68.1	94.2	83.0	88.0	0.0	1365.2	0.0	38.0	8951.3
26	63.9	76.4	54.3	46.8	60.7	76.4	68.5	71.8	0.0	618.5	0.0	16.7	6171.9
27	96.7	92.8	65.8	65.3	96.0	89.2	84.8	83.0	1216.3	1197.8	32.6	32.1	18051.5
28	68.1	66.7	29.4	29.4	62.6	61.6	51.0	51.5	586.7	627.2	17.0	16.5	11431.9
40	103.4	103.4	81.2	81.7	100.4	102.1	94.6	95.1	1196.9	1189.8	32.3	32.8	13615.0
41	101.8	100.8	82.1	82.1	95.1	97.7	99.9	101.3	1196.7	1189.2	31.5	32.6	11547.9
41H	81.5	87.5	55.6	55.6	83.0	85.3	74.6	76.8	1207.8	1198.8	30.8	31.6	19448.4
42	100.8	100.8	84.4	84.4	95.5	96.8	92.8	93.3	1185.9	1186.4	30.8	31.7	10101.7
42A	100.4	100.0	83.9	83.5	94.6	95.5	93.8	94.2	1184.7	1177.2	30.5	31.6	10029.9
43	98.6	98.6	81.2	80.8	95.1	96.8	88.0	89.7	1189.2	1189.8	30.6	31.2	10846.7
44	-167.2	-174.8	-193.8	-193.8	-129.5	-126.2	-177.4	-177.4	23.7	21.4	0.0	0.0	241.6
45	-143.6	-143.6	-177.4	-177.4	-162.4	-151.8	-195.1	-192.5	80.0	80.8	0.0	0.0	1265.3

TABLE 5-2 CONT'D

T/P NO.	T_{IN} MAIN		T_{OUT} MAIN		T_{IN} PRIME		T_{OUT} PRIME		FLOW MAIN		FLOW PRIME		Q_{REJ}
	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	
46	-142.4	-148.6	-172.3	-172.3	-120.8	-116.5	-143.6	-143.6	76.6	75.1	0.0	0.0	1035.2
46A	-138.9	-138.9	-171.0	-169.8	-118.7	-113.2	-138.9	-138.9	94.5	89.1	0.0	0.0	1348.2
47	74.4	75.2	35.2	36.1	63.0	67.1	49.5	52.9	1199.2	1180.6	26.4	29.7	23251.9
50	-200.4	-203.1	-208.7	-205.9	-174.8	-168.5	-183.6	-181.1	16.6	15.7	0.0	0.0	42.3
51	74.4	75.2	38.6	38.6	-69.5	-44.1	-113.2	-97.0	1255.9	1275.7	0.0	0.0	22453.6
52	-208.7	-195.1	-208.7	-199.0	-195.1	-183.6	-208.7	-208.7	10.5	0.0	0.0	0.0	4.8
53	-125.2	-125.2	-163.5	-162.4	-187.5	-179.9	-208.1	-200.4	118.6	128.8	0.0	0.0	2174.2

TABLE 5-3 FWD PANEL STEADY STATE PERFORMANCE DATA

FOR 50° AND 70° CAVITY

T/P NO.	T_{IN} MAIN		T_{OUT} MAIN		T_{IN} PRIME		T_{OUT} PRIME		FLOW MAIN		FLOW PRIME		Q_{REJ}
50° CAVITY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	PRIMARY	SECONDARY	
5001 A	105.4	105.4	66.3	66.3	105.5	107.0	90.3	91.9	1379.6	1371.8	40.0	39.4	27801.2
5001	104.6	104.6	66.3	66.3	104.6	107.0	90.3	91.9	1388.4	1369.5	39.0	39.3	27277.1
5002	101.4	101.4	57.9	57.9	101.4	102.2	83.9	85.5	1186.8	1167.7	33.3	33.1	26281.7
5003	89.5	88.7	48.6	49.5	88.7	91.1	73.6	75.2	1176.8	1156.6	32.6	32.4	23696.6
5004	75.2	76.0	38.6	39.4	76.0	78.3	63.0	63.0	1187.5	1196.7	32.9	32.7	21882.9
5005	76.0	76.0	43.6	44.5	76.0	78.3	63.0	64.6	1416.9	1416.9	36.0	36.5	22746.8
5006	87.9	88.7	52.0	52.9	87.9	89.5	74.4	76.0	1213.4	1204.3	32.7	32.9	21988.3
5007	110.2	110.2	78.3	79.1	109.4	110.2	98.3	99.9	1391.6	1346.5	38.3	38.5	22467.6
5008	106.2	106.2	72.8	72.8	106.2	108.6	93.5	95.1	1190.4	1181.5	32.6	32.9	20553.1
5009	93.5	93.5	63.0	63.0	93.5	94.3	82.3	83.9	1219.0	1219.0	33.8	33.7	19026.6
5010	82.3	82.3	54.6	54.6	82.3	83 :	72.8	72.8	1202.4	1192.3	32.7	32.8	16799.2
5011	84.7	83.9	59.6	59.6	83.9	86.3	76.0	76.0	1389.6	1360.5	35.5	35.5	17262.6
5012	117.1	117.1	91.9	91.9	115.5	117.0	109.4	110.2	1382.7	1347.1	40.1	39.8	18122.2
5013	114.0	114.0	87.1	87.1	114.0	115.5	106.2	106.2	1173.0	1166.2	31.3	30.6	16507.8
5014	101.4	101.4	79.1	79.1	101.4	102.2	95.1	95.9	1193.6	1184.7	32.1	32.2	13726.8
5015	87.1	87.9	68.0	68.8	87.9	89.5	83.9	83.1	1197.2	1177.3	32.9	32.7	11573.8
5016	88.7	90.3	72.8	72.8	88.7	91.1	85.5	85.5	1399.5	1365.1	38.7	38.4	11814.4
5017	103.0	104.6	79.1	79.9	103.0	103.8	96.7	97.5	1183.7	1173.9	32.1	31.7	14842.7
5018	100.6	100.6	80.7	80.7	99.9	102.2	95.1	95.1	1199.6	1173.9	31.0	33.9	12268.9
5019	101.4	101.4	82.3	82.3	101.4	103.0	98.3	98.3	1188.8	1180.9	31.5	31.7	11711.4
5020	99.9	99.9	78.3	78.3	99.9	100.6	90.3	91.1	1192.6	1203.4	31.0	31.8	13399.7
5021	-21.4	-20.5	-125.2	-124.1	-46.9	-28.9	-102.4	-99.2	56.1	57.1	0.0	0.0	2738.8
5022	-70.6	-70.6	-148.3	-147.1	-86.7	-75.6	-129.5	-125.2	54.6	54.5	0.0	0.0	1959.5
5023	-112.2	-112.2	-167.2	-164.7	-127.3	-115.4	-153.0	-145.9	56.5	58.4	0.0	0.0	1437.3
5024	-105.7	-106.8	-174.8	-171.0	-125.2	-111.1	-167.2	-160.0	16.4	17.1	0.0	0.0	521.6
5025	100.6	101.4	57.0	57.0	47.0	89.5	-88.7	-76.6	1264.1	1247.0	0.0	0.0	27999.4
70° CAVITY													
7001	104.1	104.6	65.4	65.4	104.6	107.0	90.3	91.9	1399.6	1390.7	39.7	40.3	28191.9
7002	101.4	101.4	56.2	56.2	101.4	102.2	88.9	85.5	1188.7	1178.6	33.3	33.6	27421.2
7003	88.7	88.7	47.8	47.8	88.7	91.1	72.8	74.4	1218.2	1197.9	33.8	33.6	25055.1
7004	76.8	76.0	36.9	37.8	76.0	76.8	61.3	63.0	1189.1	1189.1	33.2	33.0	23255.2
7005	77.6	77.6	43.6	44.5	77.6	79.9	64.6	66.3	1397.6	1399.7	36.2	36.3	23586.5
7006	87.1	87.1	49.5	49.5	87.1	89.5	72.8	74.4	1225.4	1206.2	33.1	32.9	23170.6
7007	109.4	109.4	76.0	76.0	109.4	111.0	96.7	98.3	1366.3	1338.8	38.9	39.0	23532.3
7008	107.8	107.8	71.2	71.2	107.8	110.2	95.1	95.1	1190.4	1193.3	34.0	33.4	22631.9
7009	93.5	95.1	61.3	61.3	95.1	95.9	82.3	83.1	1204.0	1184.9	32.3	32.5	20172.0
7010	82.3	82.3	52.0	52.9	82.3	83.1	71.2	72.8	1204.3	1184.1	33.2	33.2	18026.4
7011	83.9	83.9	56.2	57.0	83.9	84.7	74.4	74.4	1401.9	1372.7	36.4	36.1	19197.7
7012	115.5	116.3	88.7	88.7	115.5	117.8	107.8	108.6	1377.7	1349.5	39.2	39.4	19511.9
7013	114.0	114.0	84.7	84.7	114.0	115.5	104.6	105.4	1186.8	1177.0	30.8	30.8	18147.0
7014	101.4	101.4	76.0	76.0	101.4	102.2	94.3	94.3	1205.4	1196.5	32.4	32.9	15767.8
7015	88.7	88.7	66.3	67.1	88.7	89.5	83.1	83.1	1206.2	1198.2	32.7	32.9	13479.9
7016	38.7	88.7	69.6	69.6	88.7	90.2	83.9	83.9	1405.0	1367.2	38.8	38.5	13538.6
7018	100.6	99.9	71.2	71.2	99.9	101.4	88.7	90.3	1211.2	1192.3	31.2	32.7	18040.9
7020	99.9	100.6	14.4	74.4	99.9	102.2	90.3	91.9	1198.4	1198.4	30.3	31.2	16032.9
7021	-20.5	-20.5	-118.7	-115.4	-45.9	-28.0	-107.9	-103.5	58.0	58.8	0.0	0.0	2634.0
7022	-70.6	-76.6	-150.6	-148.3	-88.7	-75.6	-131.8	-125.2	58.0	56.9	0.0	0.0	2109.4
7023	-112.2	-112.2	-167.2	-165.9	-125.2	-116.4	-150.6	-143.6	58.7	58.7	0.0	0.0	1486.8

FIGURE 5-1 AFT PANEL OUTLET TEMPERATURE FOR BASELINE CAVITY
(QLA OFF)

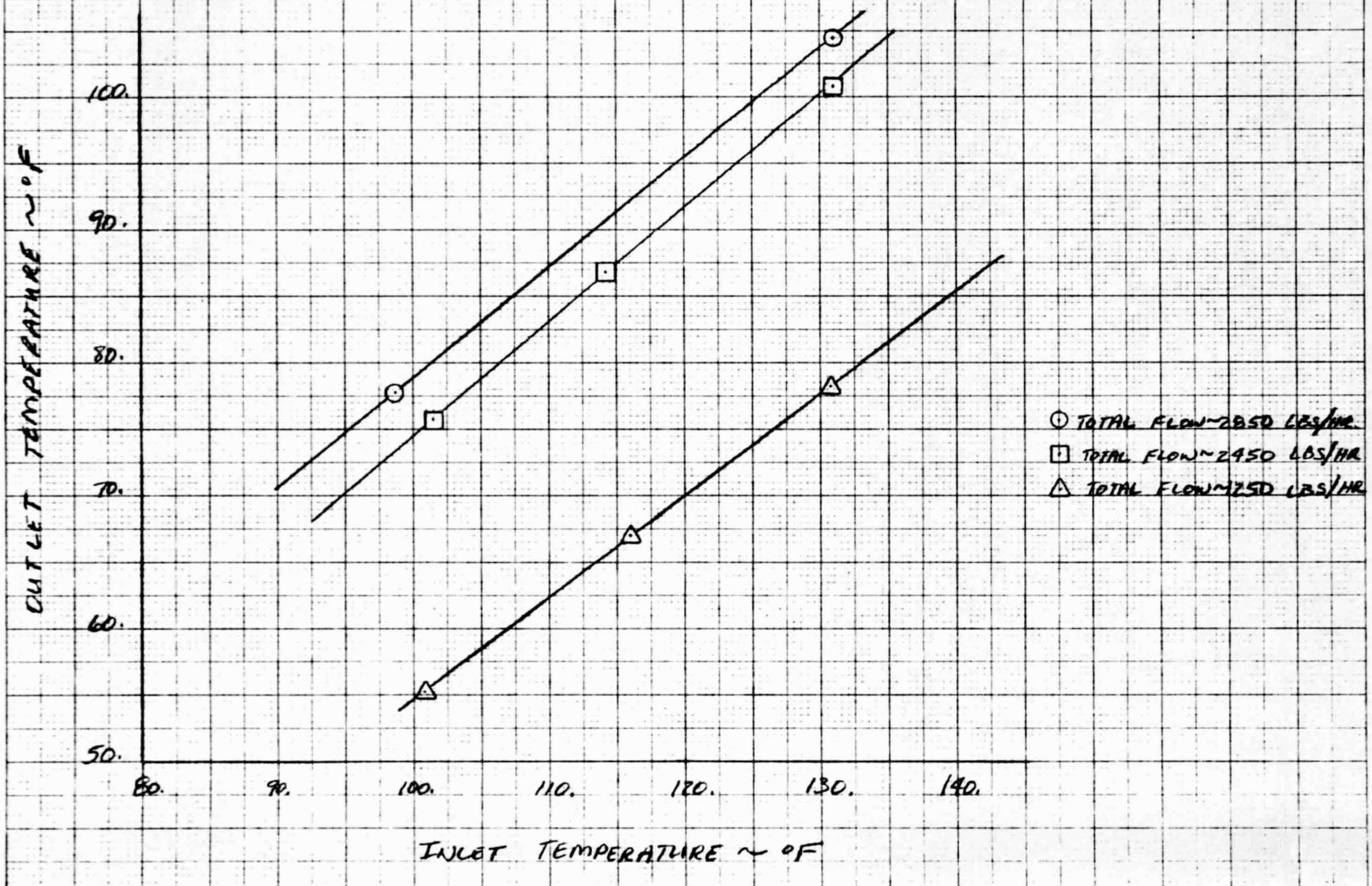


FIGURE 5-2 AFT PANEL OUTLET TEMPERATURE FOR 38° CAVITY
(30 BTU/HR-FT²)

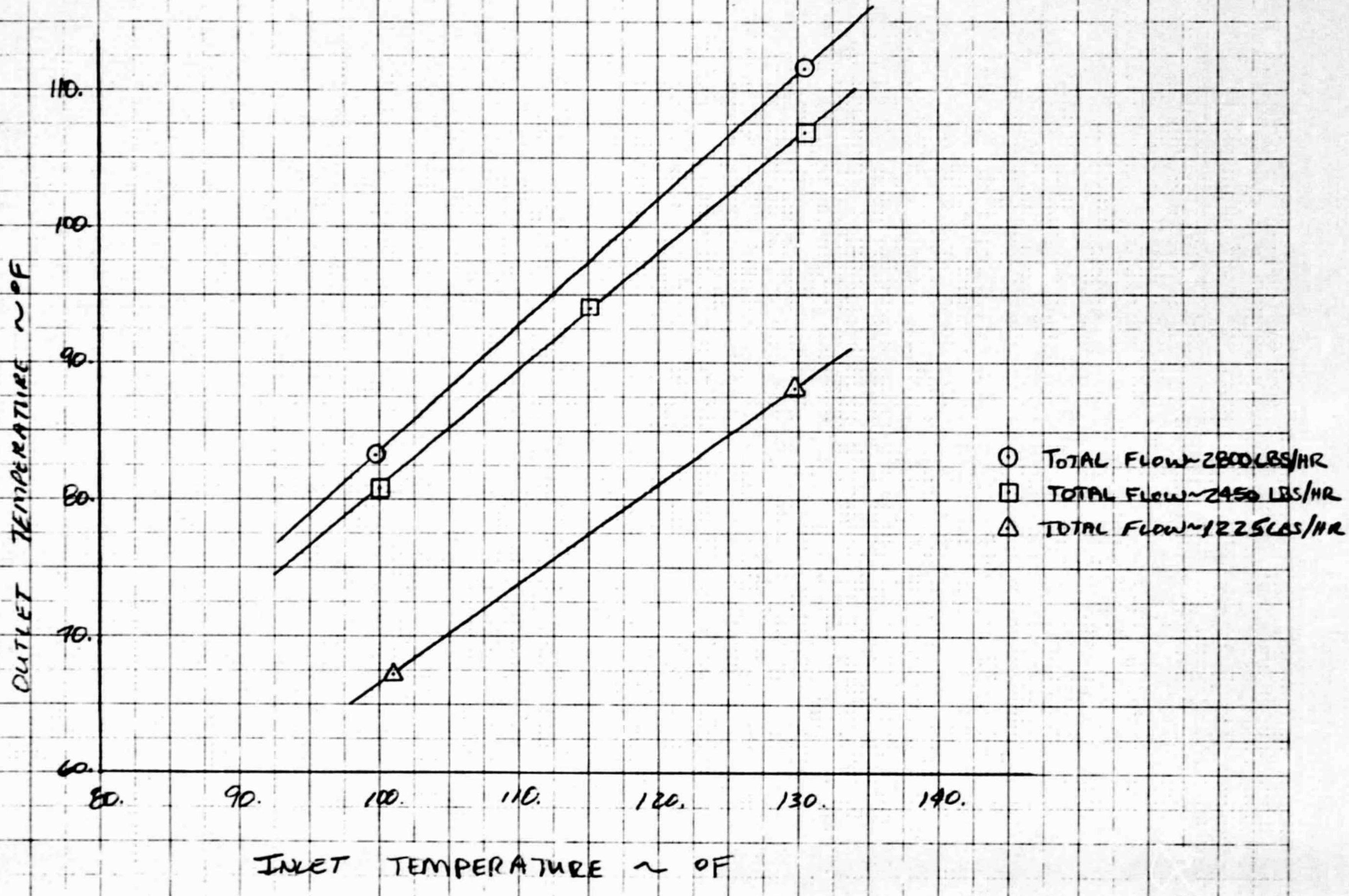


FIGURE 5-3 AFT PANEL OUTLET TEMPERATURE FOR 38° CAVITY
(60 BTU/HR-FT^2)

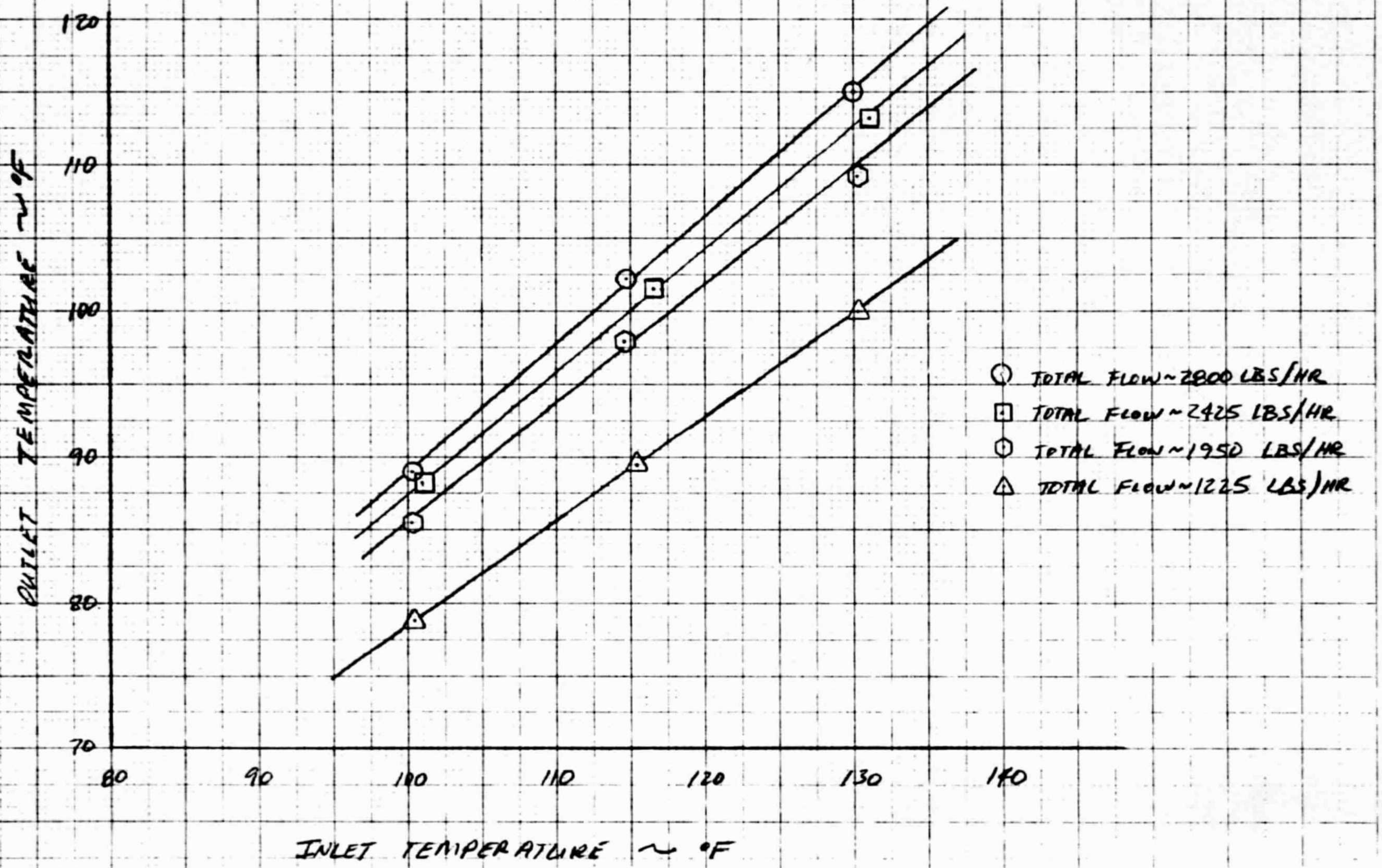


FIGURE 5-4

FWD PANEL OUTLET TEMPERATURE FOR 38° CAVITY

(QLA OFF)

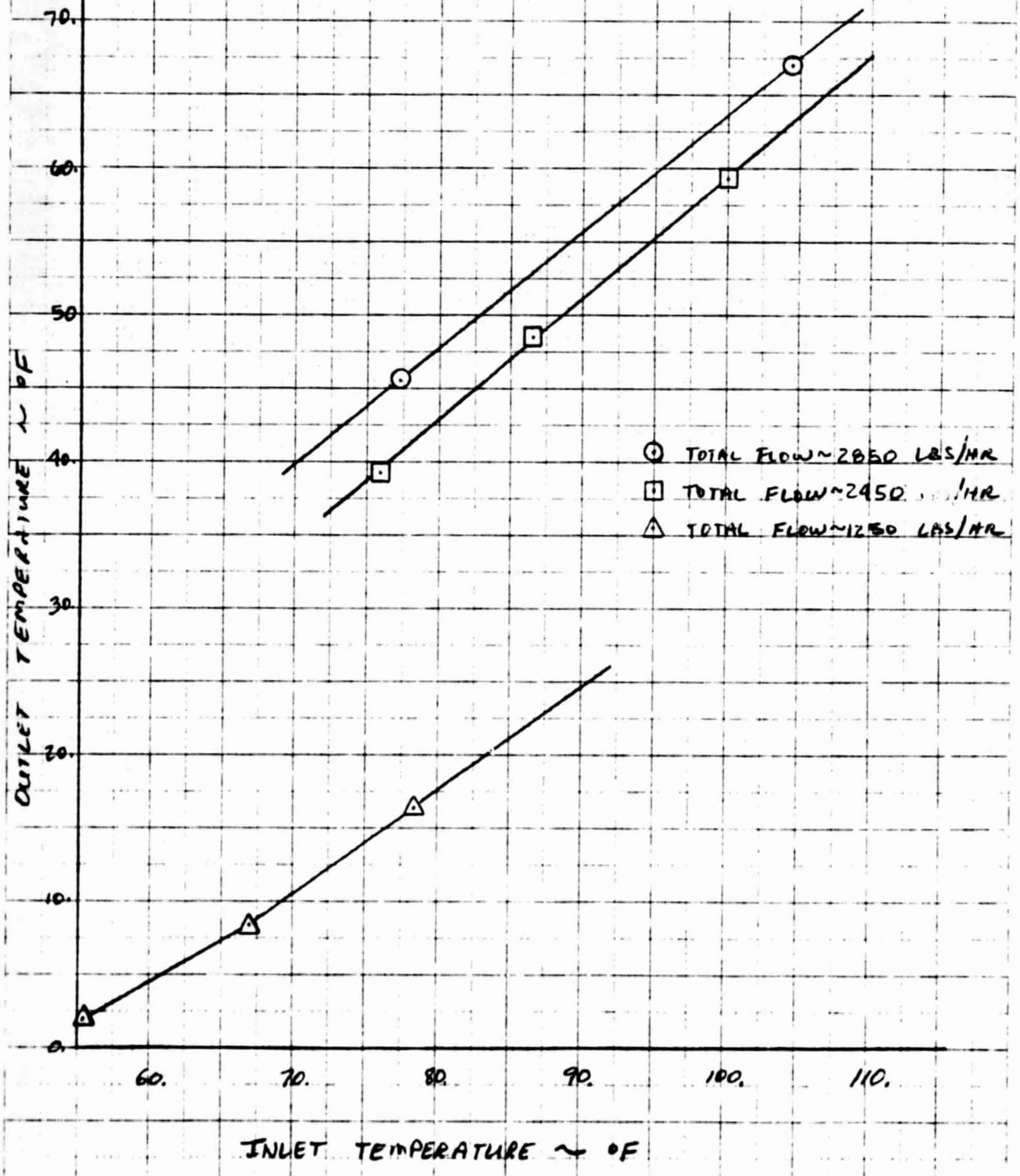


FIGURE 5-5

FWD PANEL OUTLET TEMPERATURES

FOR 38° CAVITY (40 BTU/HR-FT^2)

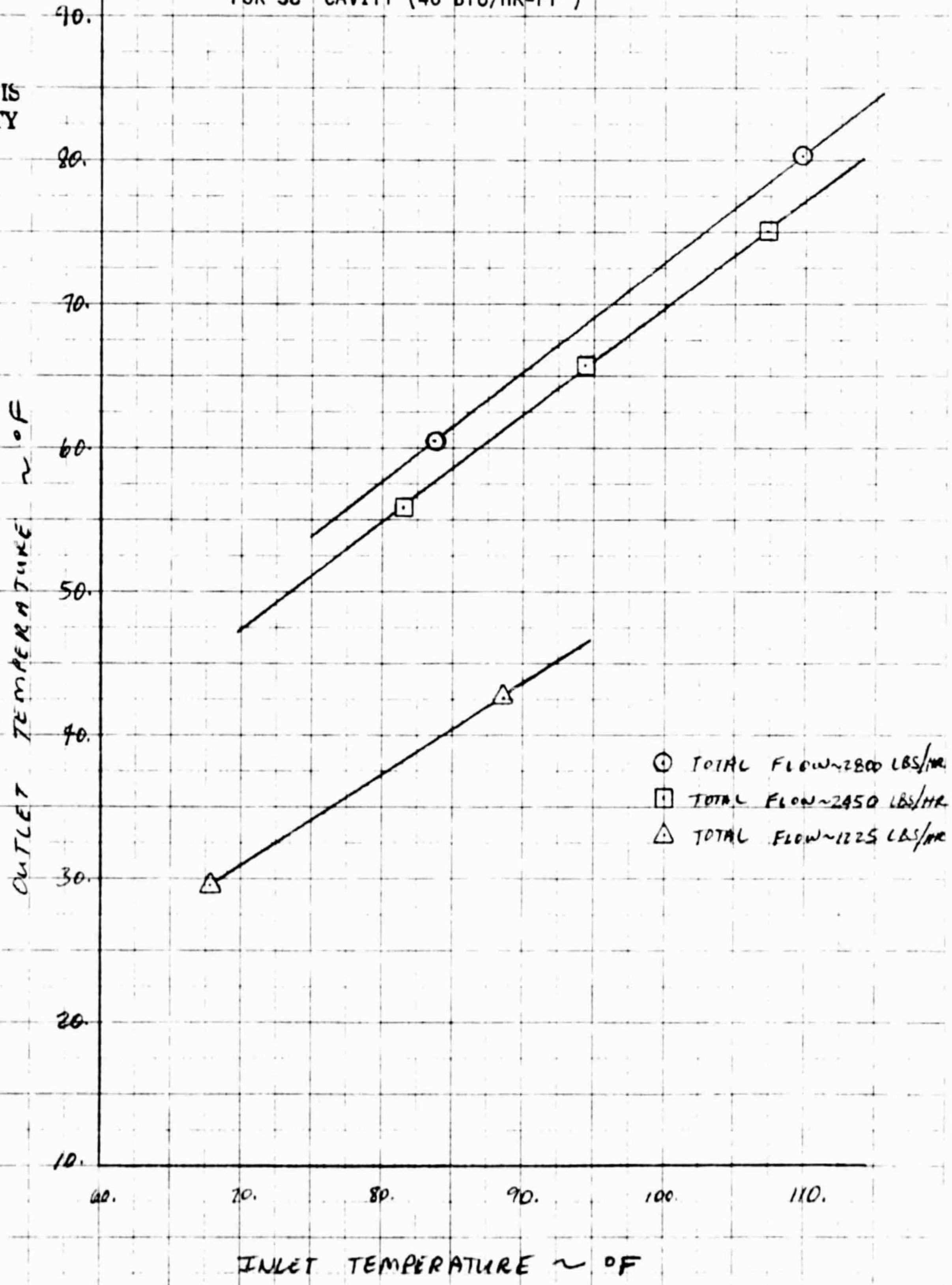
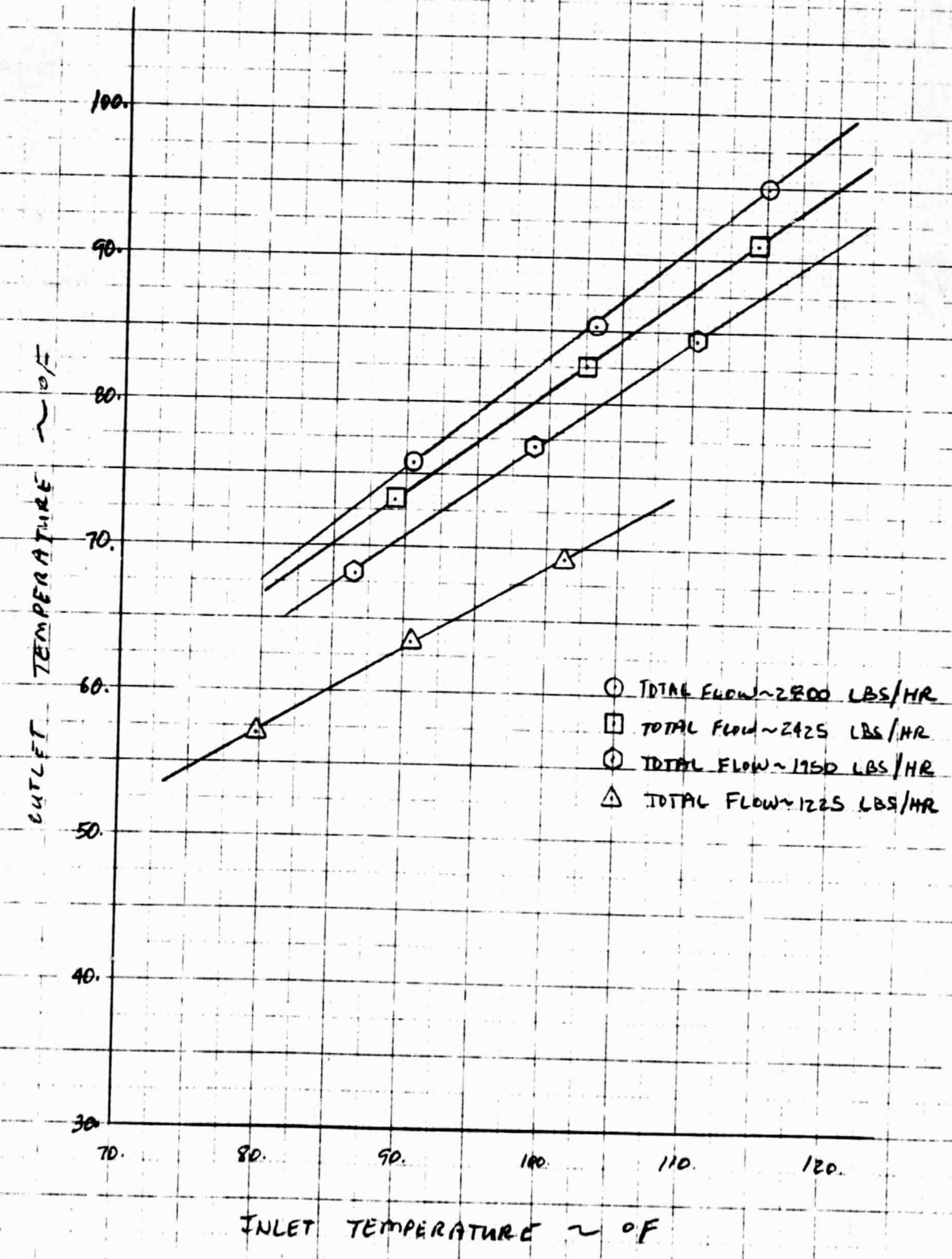


FIGURE 5-6

FWD PANEL OUTLET TEMPERATURE

FOR 38° CAVITY (80 BTU/HR-FT^2)



Figures 5-7 thru 5-9 show panel temperature maps for typical high load operating conditions. This data indicates that the panel heat rejection could possibly be improved with better flow distribution among the radiator tubes. The longest tube outlet temperature on the aft panel is approximately 20°F cooler than the shortest tube and the forward panel is about 50°F cooler. By routing more flow to the longest tube the tube outlet temperatures can be made more uniform and panel heat rejection improved. Panel design studies prior to the test indicated that the selected tube size offered the best compromise between panel pressure drop and flow distribution based on the use of "off-the-shelf" tubes. Production hardware could be made with specified tube sizes and/or variable tube sizes to improve panel performance.

The next sequence of testing provided data for the radiators when only one of the Freon-21 loops is flowing. Table 5-4 compares the single loop performance data with dual loop data. For cases with the same inlet temperature and flow rate, the single loop rejects between 17% and 24% less heat. However, the actual Shuttle operation will have a higher inlet temperature for single loop operation and therefore reject some additional heat.

Two test points were run to determine the effects of varying the inlet temperature between the two loops. From Table 5-1, a comparison of aft panel test point 27 (inlet temperatures of 124.8°F and 105°F and flow rate of 1216.3 lbs/hr). with test point 8 (inlet temperature 115.2 and flow rate of 1197.8 lbs/hr) indicates no noticable difference in the overall panel performance. (Similarly Test Point 28 compared to Test Point 6). Therefore, it appears that a twenty degree difference between loops doesn't effect panel heat rejection.

Panel operations were tested under conditions approximating those expected during flight. Using the quartz lamp array and heaters on the payload bay door simulator, four different sun angles were simulated. Tables 5-5 and 5-6 summarize the performance and environment data for each sun angle.

Another sequence of testing provided low load performance data. Figures 5-10 thru 5-12 show panel temperature maps for a low load operating condition. Figures 5-13 thru 5-15 show the panel temperature maps for the lowest load tested. The heat rejected on the aft panel was 215.2 BTU/hr and 4.8 BTU/hr on the forward panel with only the primary loop flow meter registering flow. For this test point, in which 88% of the forward panel is frozen, the chamber

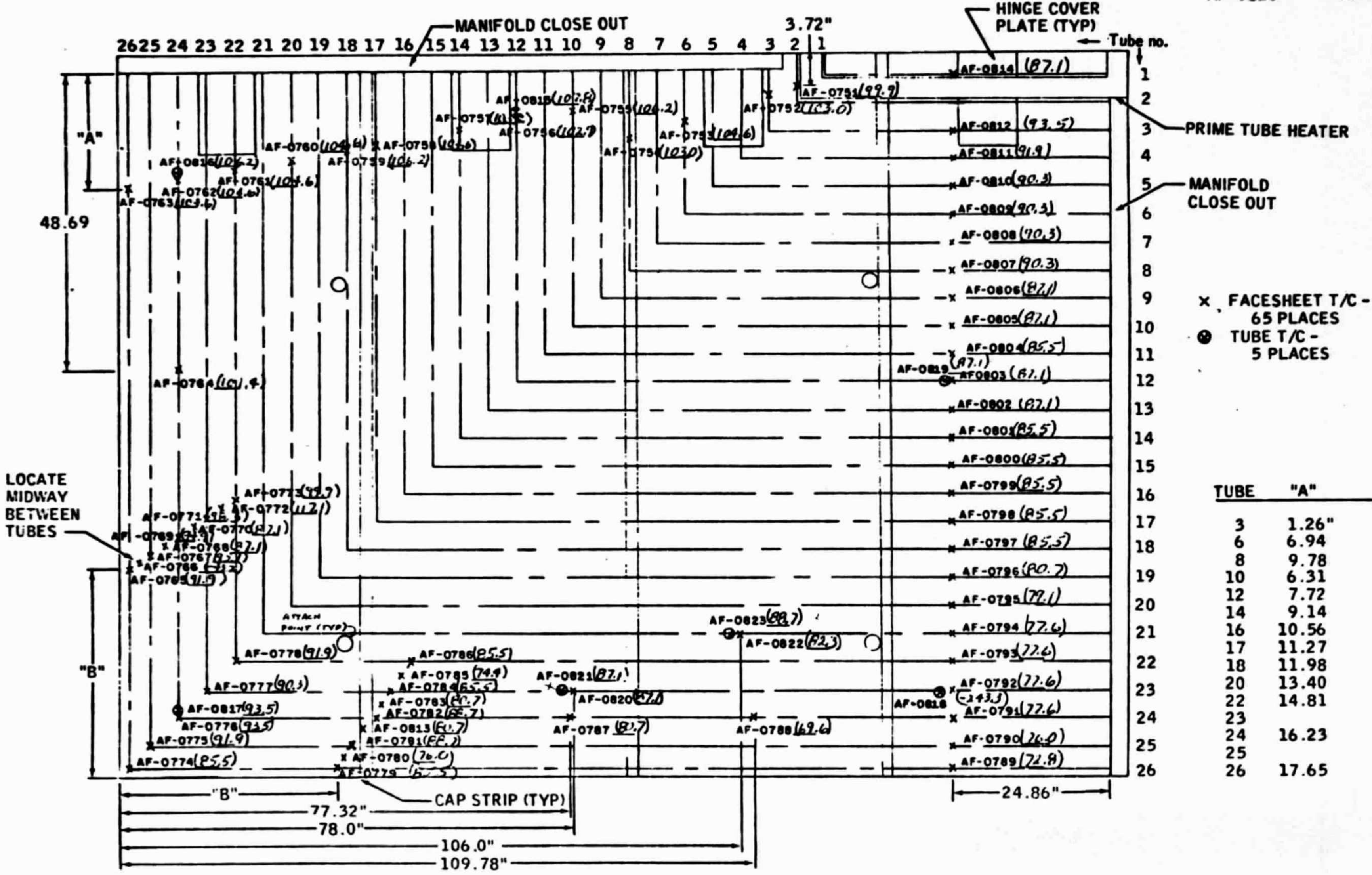
FIGURE 5-7 AFT PANEL TEMPERATURE MAP

TIN = 114. °F
ẇ = 2439. LBS/HR

TEST POINT 3
AFT PANEL THERMOCOUPLE LOCATIONS

TUBE WELD JOINT

AF-0813	AF-0821
AF-0820	AF-0822



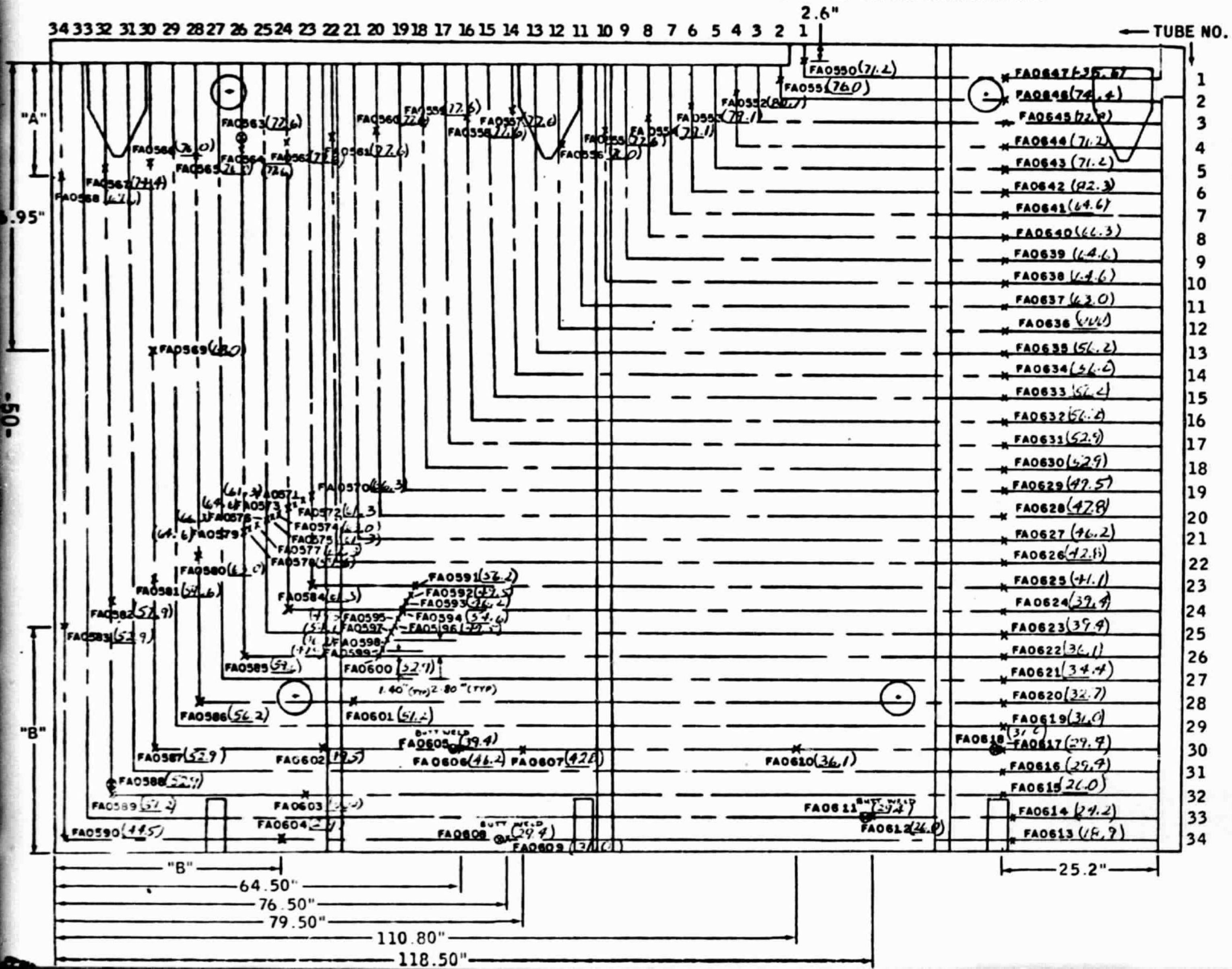
× FACESHEET T/C - 65 PLACES
⊗ TUBE T/C - 5 PLACES

TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

FIGURE 5-8 FWD TOP PANEL TEMPERATURE MAP

TEST POINT 3

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



TIN = 86.6 °F
TOUT = 48.5 °F
ẇ = 2439. LBS/HR

× FACE SHEET T/C - 93 PLACES
⊗ TUBE T/C - 6 PLACES

TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58 90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

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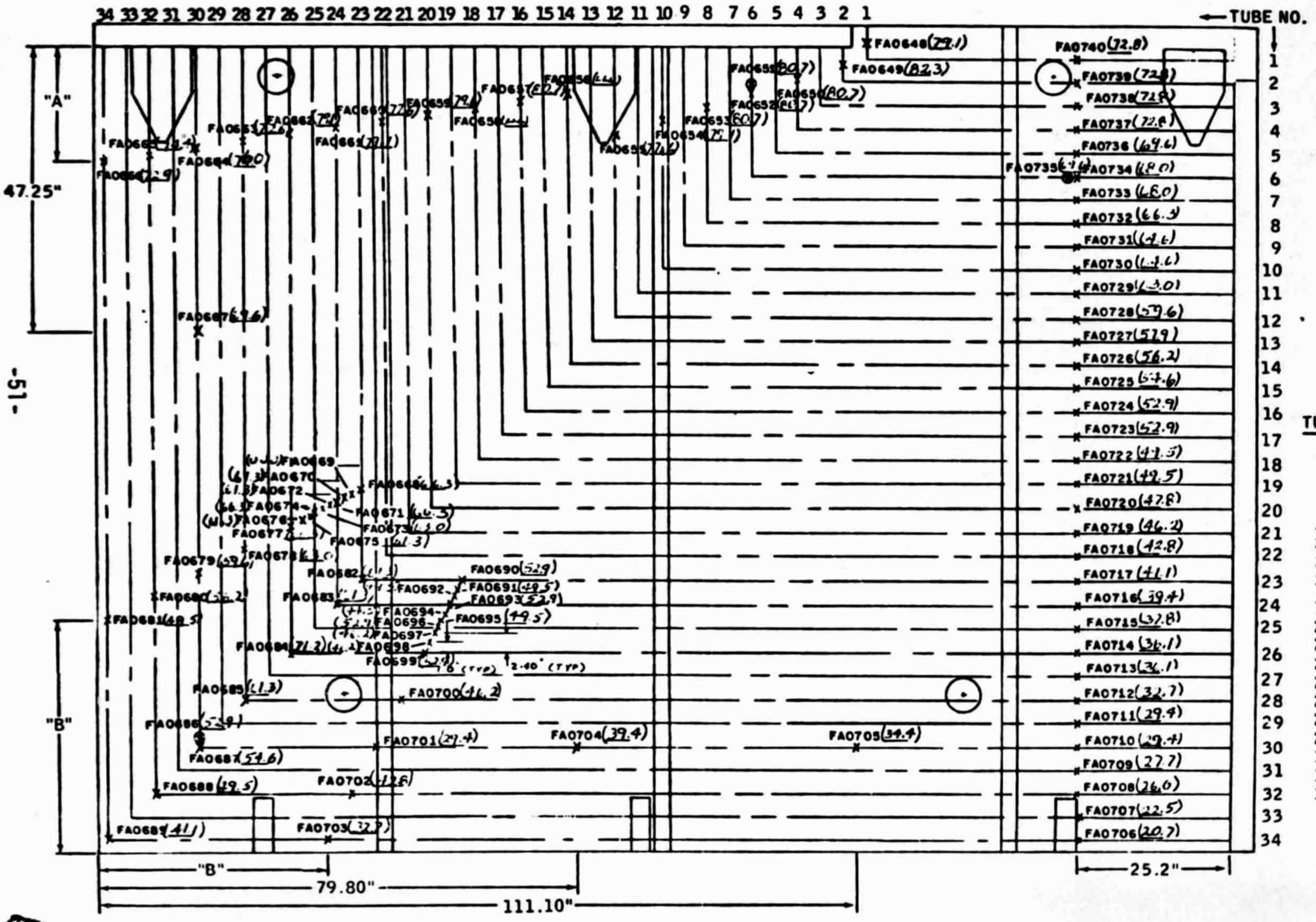
FIGURE 5-9 FWD BTM PANEL TEMPERATURE MAP

TEST POINT 3

"BOTTOM" FORWARD PANEL THERMOCOUPLE LOCATIONS



TIN = 86.6°F

TOUT = 48.5°F

ẇ = 2439 LBS/HR

× FACE SHEET T/C - 90 PLACES

● TUBE T/C - 3 PLACES

TUBE	"A"	"B"
2	2.75"	
4	3.70	
6	5.70	
8	7.85	
10	10.00	
12	12.10	
14	7.10	
16	8.10	
18	9.20	
20	10.25	
22	11.30	
23		67.10"
24	12.35	64.60
25		62.60
26	13.40	59.20
28	14.50	53.80
30	15.55	48.50
32	16.55	43.30
34	17.65	38.30

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TABLE 5-4
SINGLE LOOP VS. DUAL LOOP OPERATION

	INLET TEMP (°F)	OUTLET TEMP (°F)	FLOW LBS/HR	Q REJ BTU/HR	ENVR BTU/HR-FT^2	% CHANGE
AFT:	101.2 (101.)	50.1 (62.2)	635. (1216.)	8236. (10448.)	30	21
	100.3 (99.8)	73.2 (83.3)	1430. (2836.)	9894. (12017.)	30	12
	130.3 (130.5)	98.1(109.1)	1410. (2788.)	12001. (15891.)	30	24
	130.3 (130.)	104.7(115.)	1316. (2783.)	8943. (11115.)	60	20
	115.4 (114.7)	94.6(102.2)	1403. (2794.)	7589. (9098.)	60	17
	116.3 (115.4)	76.8 (89.5)	635. (1222.)	6455. (8001.)	60	19

(xxx) Dual Loop

xxx Single Loop

TABLE 5-5

SUMMARY OF "ON-ORBIT" OPERATIONS

TEST POINT	SIMULATED SUN ANGLE	INLET TEMP (°F)	OUTLET TEMP (°F)	FLOW LBS/HR	QREJ BTU/HR
40	46	115.2 (103.4)	102.6 (81.5)	2452.	8053. (13615.)
41	77	114.7 (101.6)	99.3 (82.1)	2450.	9885. (11547.)
42A	103	115.6 (100.2)	98.8 (83.8)	2423.	10680. (10030.)
43	131	115.8 (98.6)	97.7 (81.)	2441.	11552. (10847.)

xxx AFT PANEL

(xxx) FWD PANEL

TABLE 5-6
ENVIRONMENT FOR "ON-ORBIT" SIMULATION
(BTU/HR)

ENVIRONMENT REQUIREMENTS FOR TEST POINTS 40, 41, 42, 43
(BTU/hr)

	TEST POINT	40		41		42		43	
	SIMULATED SUN ANGLE	46		77		103		131	
	STRIP #	FWD	AFT	FWD	AFT	FWD	AFT	FWD	AFT
RADIATOR PANEL	1	1303	1237	3003	774	1731	838	1318	993
	2	903	840	1548	964	1399	836	1223	914
	3	2287	1656	1678	1367	2189	1550	2448	1450
	4	3568	2515	2645	2189	4150	2400	4277	2010
	5	3735	3355	3636	3129	5106	2960	5353	2290
PAYLOAD BAY DOOR	6	45		994		513		91	
	7	13		983		937		88	
	8	74		654		1177		423	
	9	183		1907		1677		1068	
	10	1155		2255		1637		1750	
	11	2197		2551		3031		3023	

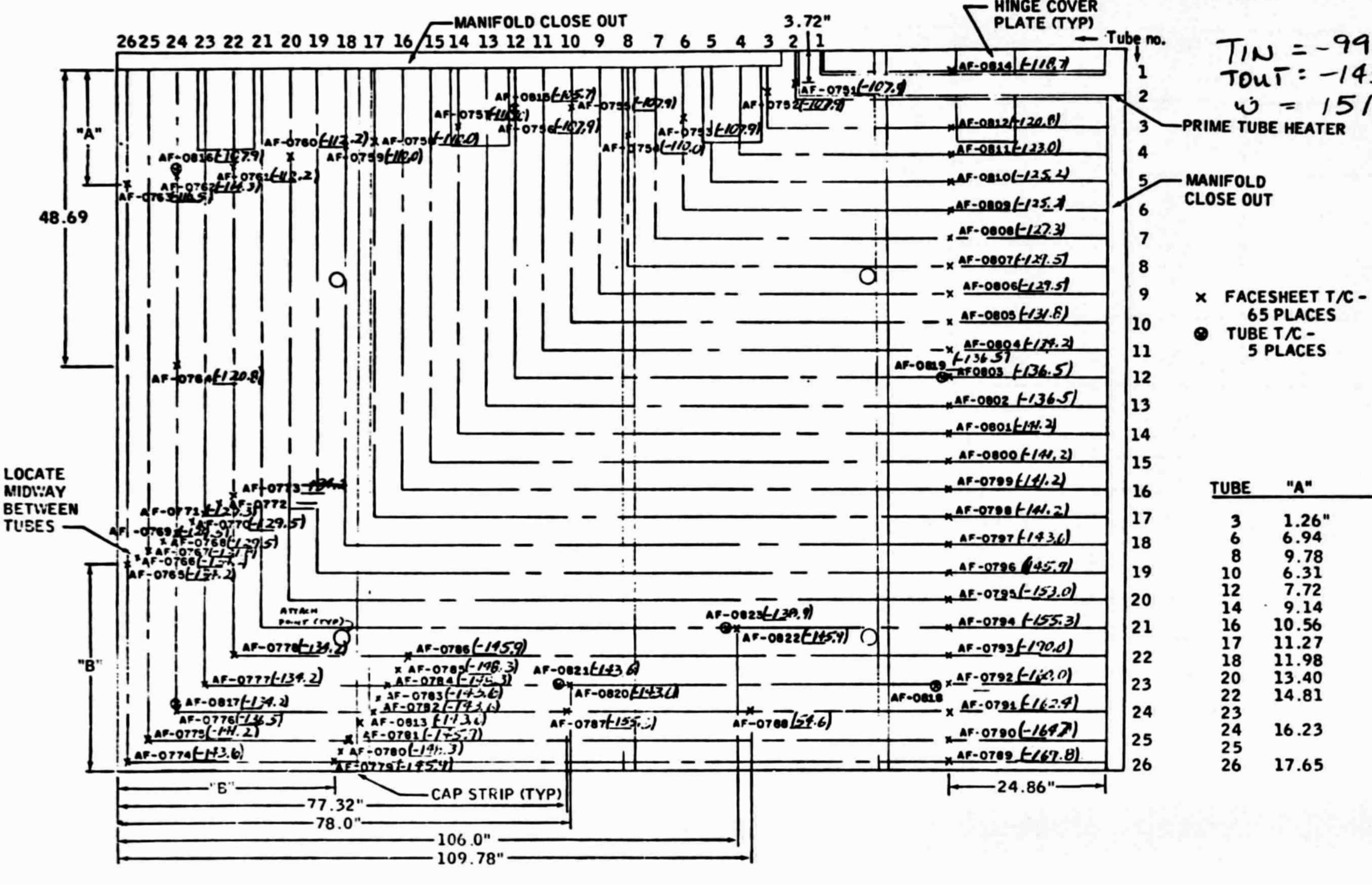
FIGURE 5-10 AFT PANEL LOW LOAD TEMPERATURE MAP

TEST POINT 46

AFT PANEL THERMOCOUPLE LOCATIONS

TUBE WELD JOINT
AF-0813 AF-0821
AF-0820 AF-0822

$T_{IN} = -99.4$ °F
$T_{OUT} = -143.6$ °F
$\dot{w} = 151.7$ LBS/HR



TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

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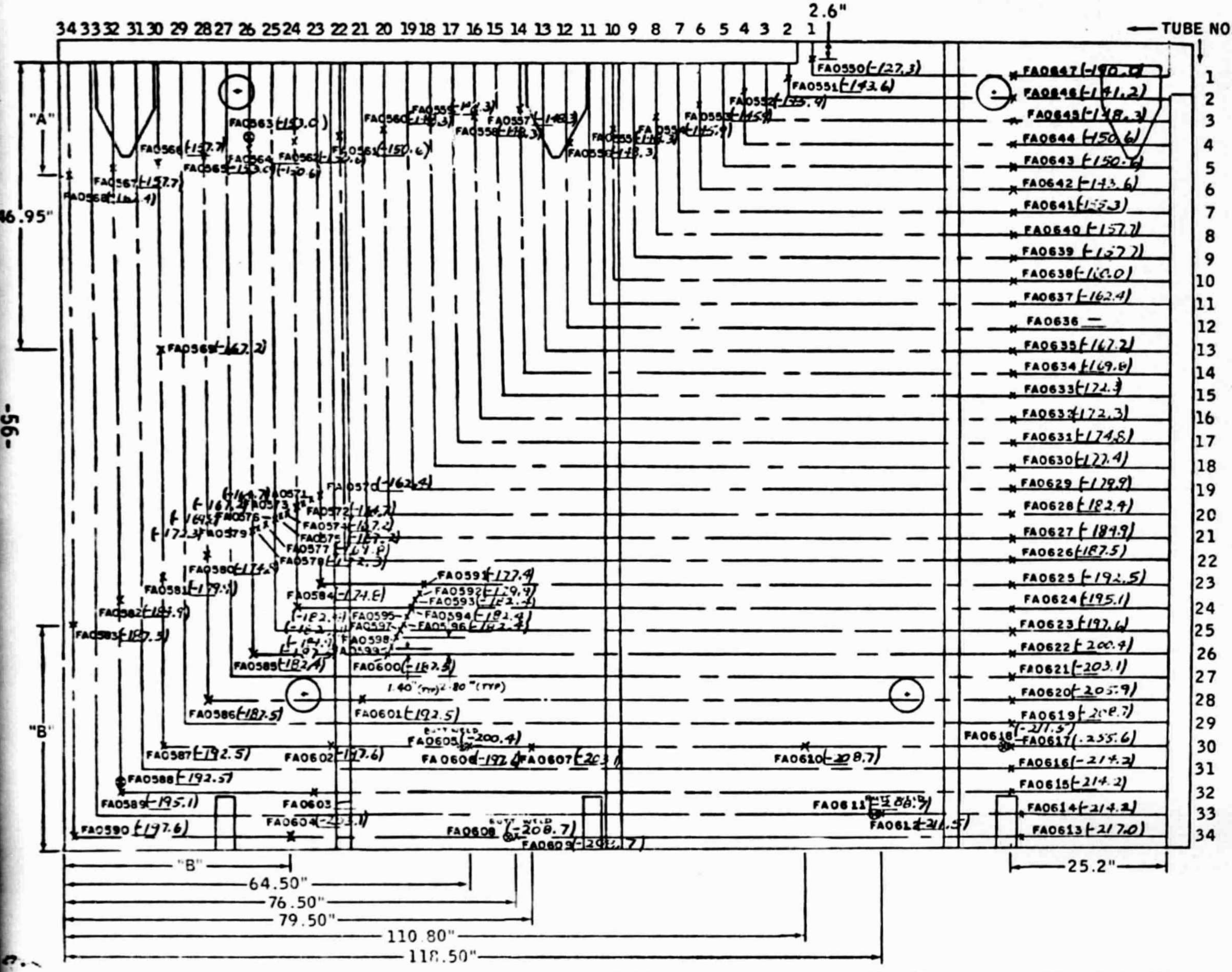
FIGURE 5-11 "TOP" FWD PANEL LOW LOAD TEMPERATURE MAP

TEST POINT 46

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



TIN = -193. °F
TOUT = -172.3 °F
ω = 151.7 LBS/HR

× FACE SHEET T/C - 93 PLACES
⊗ TUBE T/C - 6 PLACES

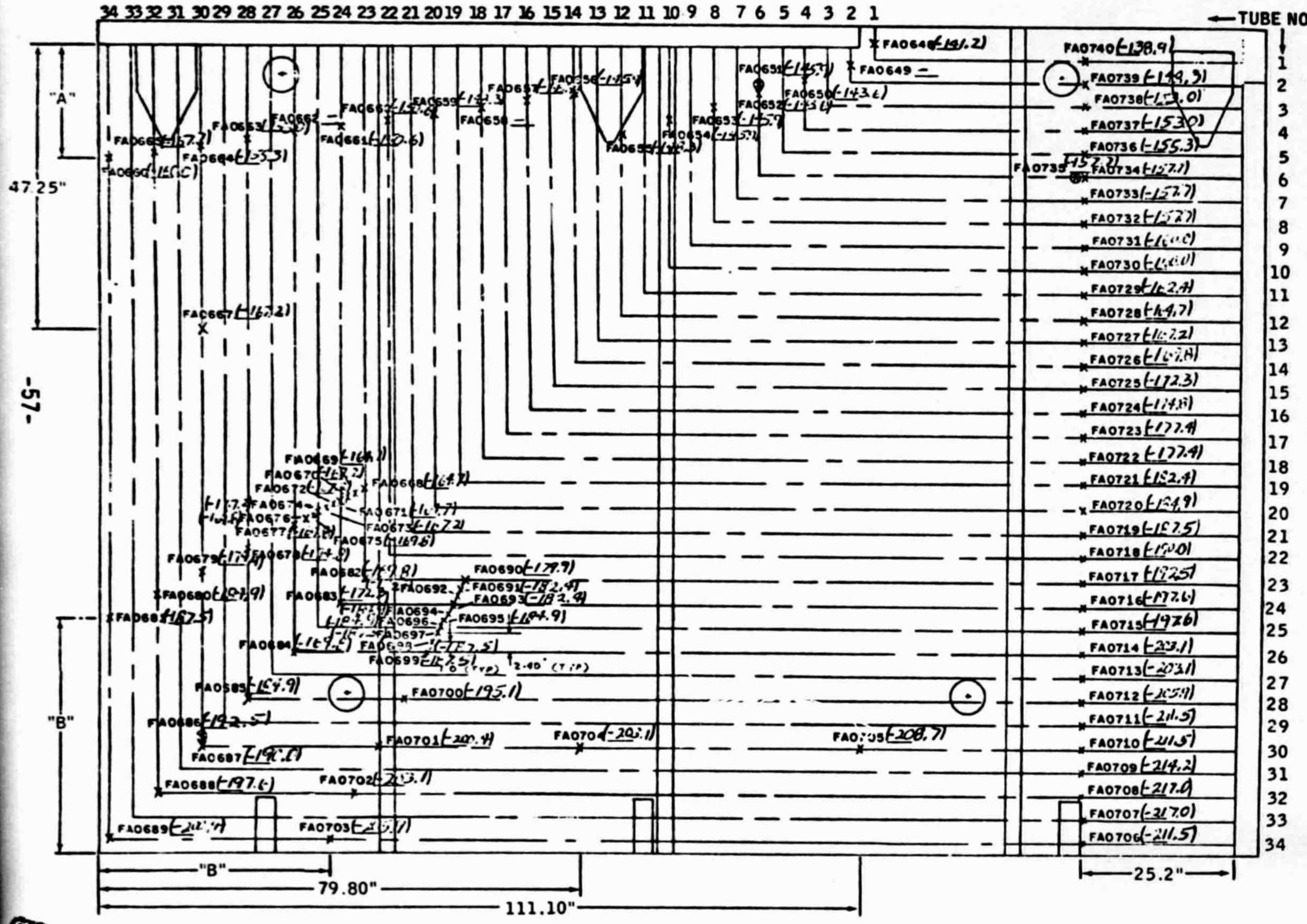
TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58 90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

FIGURE 5-12 "BTM" FWD PANEL LOW LOAD TEMPERATURE MAP

TEST POINT 46

"BOTTOM" FORWARD PANEL THERMOCOUPLE LOCATIONS

TIN = -143.°F
TOUT = -172.3 °F
ẇ = 151.7 LBS/HR



× FACE SHEET T/C - 90 PLACES
⊕ TUBE T/C - 3 PLACES

TUBE	"A"	"B"
2	2.75"	
4	3.70	
6	5.70	
8	7.85	
10	10.00	
12	12.10	
14	7.10	
16	8.10	
18	9.20	
20	10.25	
22	11.30	
23		67.10"
24	12.35	64.60
25		62.60
26	13.40	59.20
28	14.50	53.80
30	15.55	48.50
32	16.55	43.30
34	17.65	38.30

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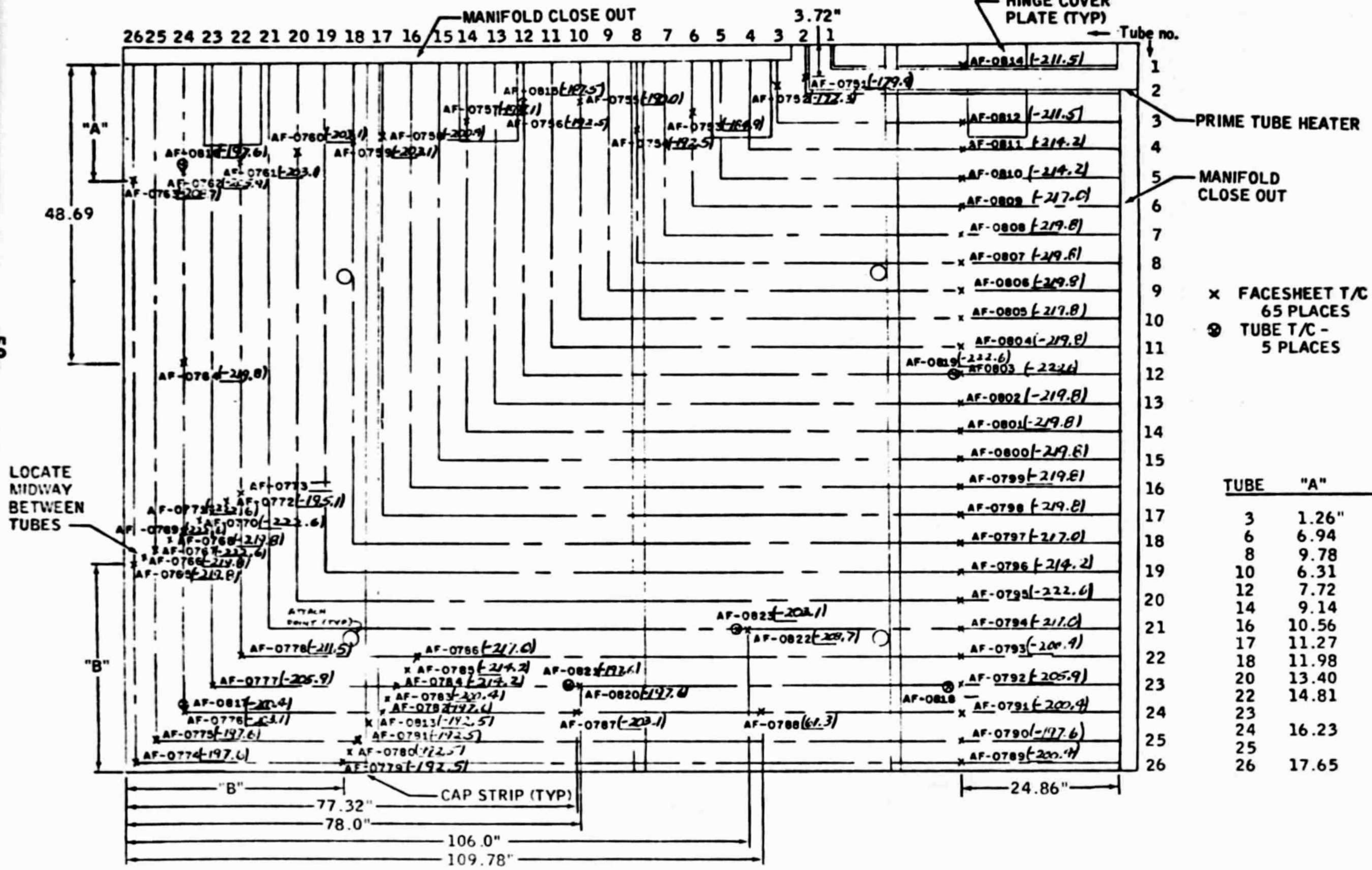
FIGURE 5-13 AFT PANEL LOWEST LOAD TEMPERATURE MAP

TEST POINT 52

AFT PANEL THERMOCOUPLE LOCATIONS



TUBE WELD JOINT

AF-0813 AF-0821
AF-0820 AF-0822

× FACESHEET T/C - 65 PLACES

⊗ TUBE T/C - 5 PLACES

TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

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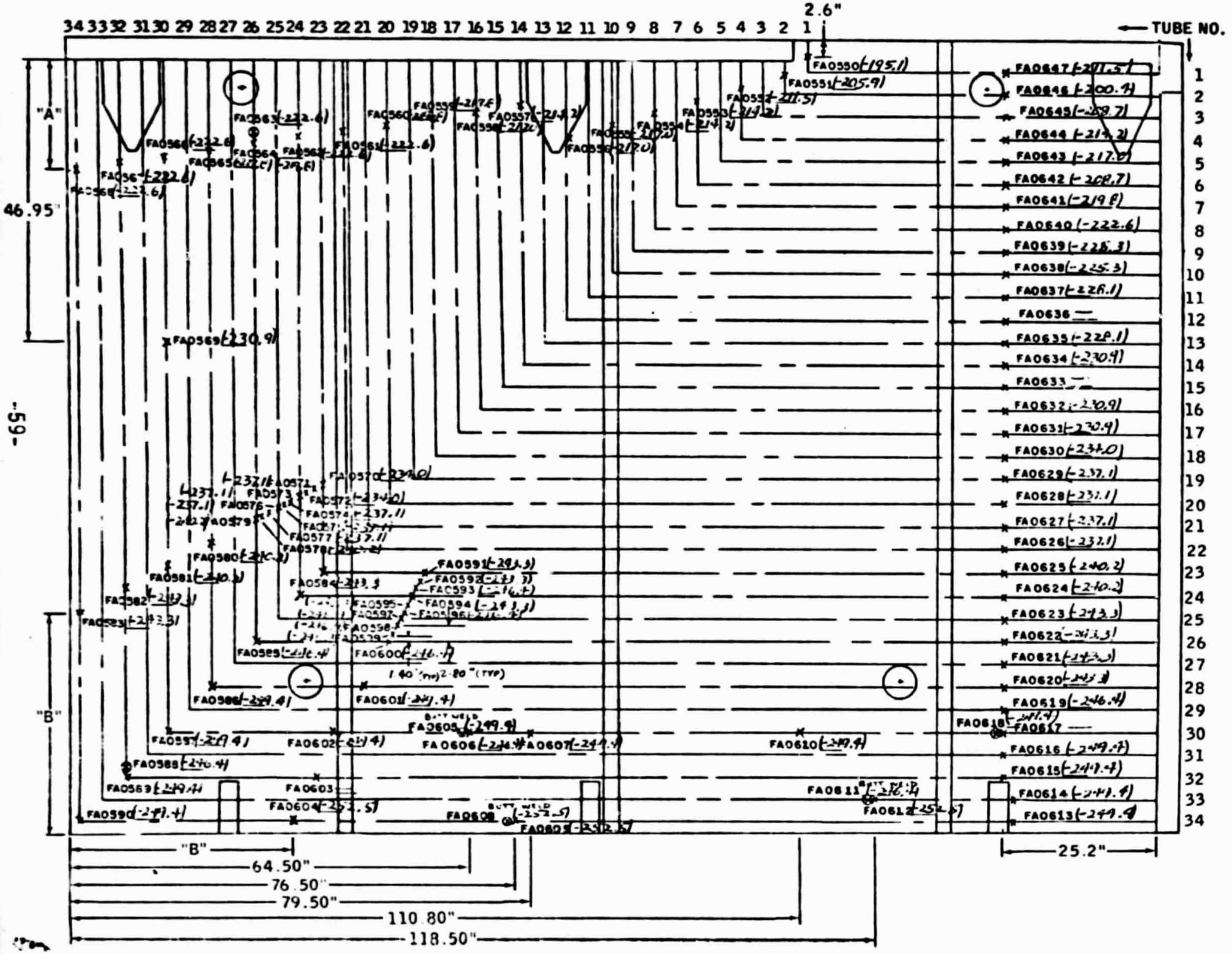
FIGURE 5-14 "TOP" FWD PANEL LOWEST LOAD TEMPERATURE MAP

TEST POINT 52

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



× FACE SHEET T/C - 93 PLACES

⊗ TUBE T/C - 6 PLACES

TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58 90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

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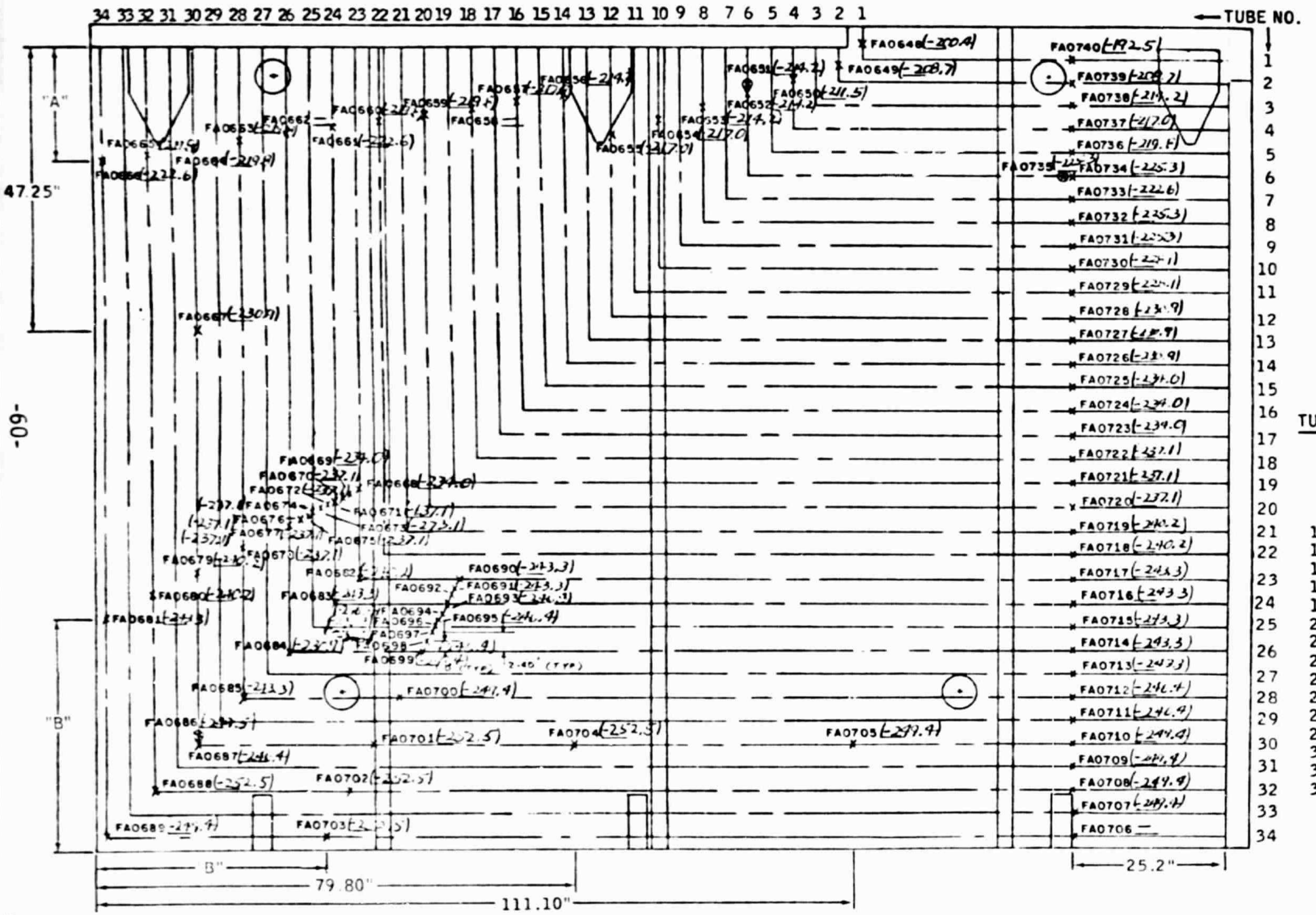
OF POOR QUALITY

FIGURE 5-15 "BTM" FWD PANEL LOWEST LOAD TEMPERATURE MAP

TEST POINT 52

"BOTTOM" FORWARD PANEL THERMOCOUPLE LOCATIONS



× FACE SHEET T/C - 90 PLACES

⊗ TUBE T/C - 3 PLACES

TUBE	"A"	"B"
2	2.75"	
4	3.70	
6	5.70	
8	7.85	
10	10.00	
12	12.10	
14	7.10	
16	8.10	
18	9.20	
20	10.25	
22	11.30	
23		67.10"
24	12.35	64.60
25		62.60
26	13.40	59.20
28	14.50	53.80
30	15.55	48.50
32	16.55	43.30
34	17.65	38.30

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pressure was increased to speed up freezing. The convection cooling of the panels caused irregular freezing patterns. The aft panel inlet is colder than the outlet and the forward panel was observed to freeze at the tube bend (corner of the "L") first. Other low load test points with "natural" (radiation only) cooling froze at the outlet first with a uniform temperature decrease from inlet to outlet. Table 5-7 summarizes the low load performance and indicates the number of tubes which all or part were frozen.

Figures 5-16 thru 5-21 show the measured fin temperature profiles of the aft and forward panels at various locations of a typical test point. The fin base to mid-point temperature ratio:

$$T^* = \frac{Tl - Ts}{Tb - Ts}$$

where Tl is fin mid-point temp.
Tb is fin base temp.
Ts is sink temp.

is used to determine the equivalent length parameter and fin effectiveness (Reference 3). Table 5-8 summarizes the steady state temperature ratios and fin effectiveness for selected test points. An average value of .966 for the aft panel and .955 for the forward panel results from the test data. This indicates the thermal adequacy of the honeycomb panel design and verifies the selected tube spacing.

Table 5-9 summarizes the measured tube to face sheet ΔT's for selected steady state test points. The temperature recording resolution is 1.6°F with an accuracy of ±3°F. Therefore, absolute temperature differences cannot be determined from this data nor was that the intent. Rather this data was intended to show trends and serve to isolate causes of poor panel performance if necessary. However, overall panel performance was good, indicating a good tube to face sheet bond and the ΔT data generally confirms this. It is also observed that the ΔT's appeared to vary throughout the test but did not appear to degrade with test time. The ΔT is a function of panel heat rejection and should increase at high heat loads although the test data did not always confirm this.

Table 5-10 shows the recorded panel pressure drops at each steady state test point. The full flow pressure drops indicate that the aft panel pressure drop is somewhat higher than would be allowed (a design goal of 1.5 psi was established) to meet total system pressure drop requirements. The previous discussion on different tube sizes and flow distribution also applies to panel pressure drop. The panel pressure drop data generally confirms the manifold and flow restrictor design.

TABLE 5-7

LOW LOAD PERFORMANCE

TEST POINT	INLET TEMP (°F)	OUTLET TEMP (°F)	FLOW LBS/HR	Q REJ BTU/HR	# OF FROZEN TUBES
44	- 67.9 (-171.)	-183. (-193.8)	45.1	1210.6 (241.6)	7 (51)
45	-107.6 (-143.6)	-144.2(-177.4)	160.8	1368.8 (1265.3)	0 (15)
46	- 99.4 (-143.)	-143.6(-172.3)	151.7	1559.9 (1035.2)	0 (8)
46A	-100.7 (-138.9)	-139.5(-170.4)	183.6	1657.8 (1348.2)	0 (10)
50	-103.1 (-201.8)	-203.1(-207.3)	32.3	753.1 (42.3)	10 (52)
52	-142.6 (-201.9)	-217. (-203.9)	10.5*	215.2 (4.8)	18 (63)

*One Loop

xxx Aft Panel

(xxx)Fwd Panel

FIGURE 5-16

TEST POINT 1

AFT PANEL FIN TEMP PROFILE (UPSTREAM)

1

$\frac{T_\ell - T_s}{T_o - T_s} = \frac{563-160}{574-160} = .973$

$\frac{T_s}{T_o} = \frac{160}{574} = 0.28$

L = .20

$\boxed{\eta = .953}$

2

$\frac{561-160}{575.4-160} = .970$

$\frac{160}{575.4} = 0.28$

L = .22

$\boxed{\eta = .946}$

3

$\frac{561.5-160}{575.4-160} = .967$

$\frac{160}{575.4} = 0.28$

L = .23

$\boxed{\eta = .942}$

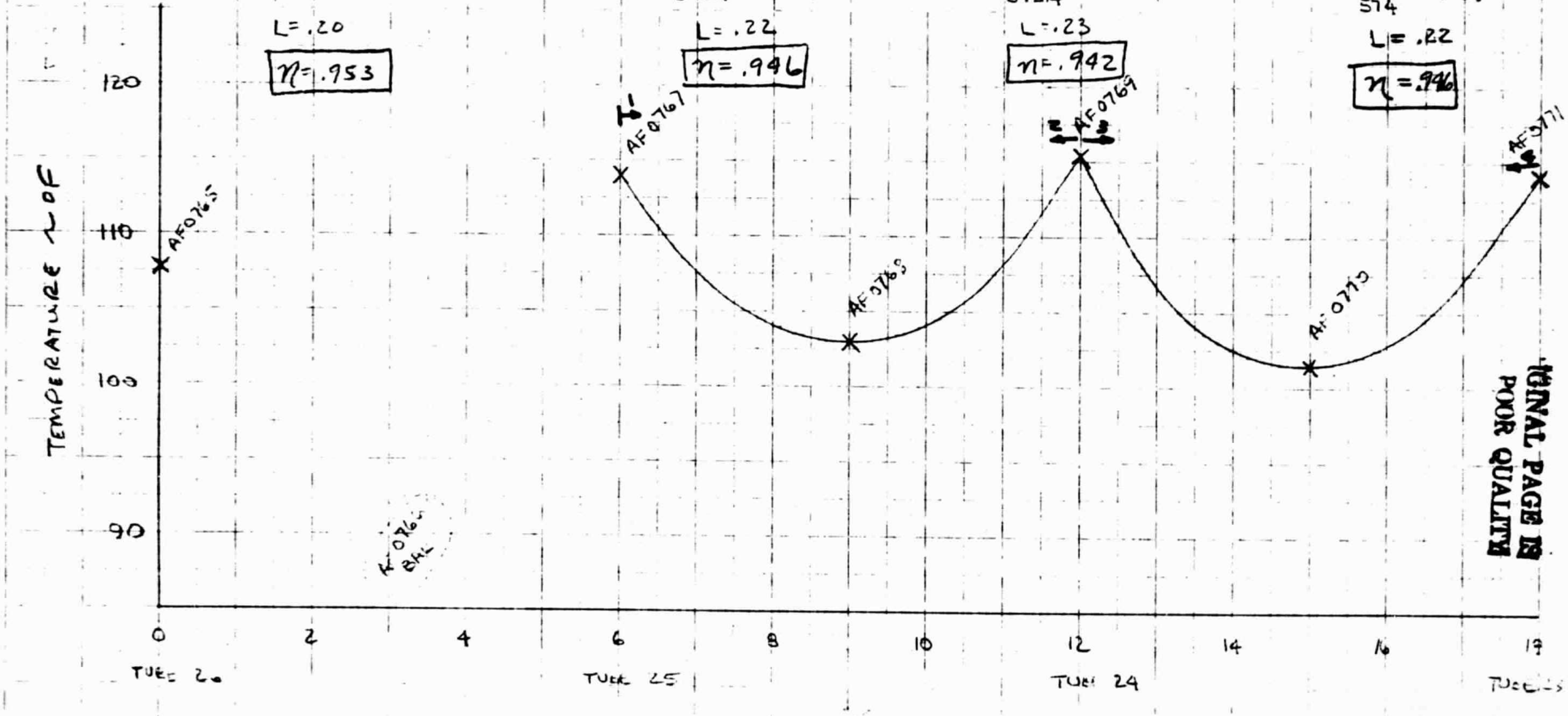
4

$\frac{561.5-160}{574-160} = .970$

$\frac{160}{574} = 0.28$

L = .22

$\boxed{\eta = .946}$

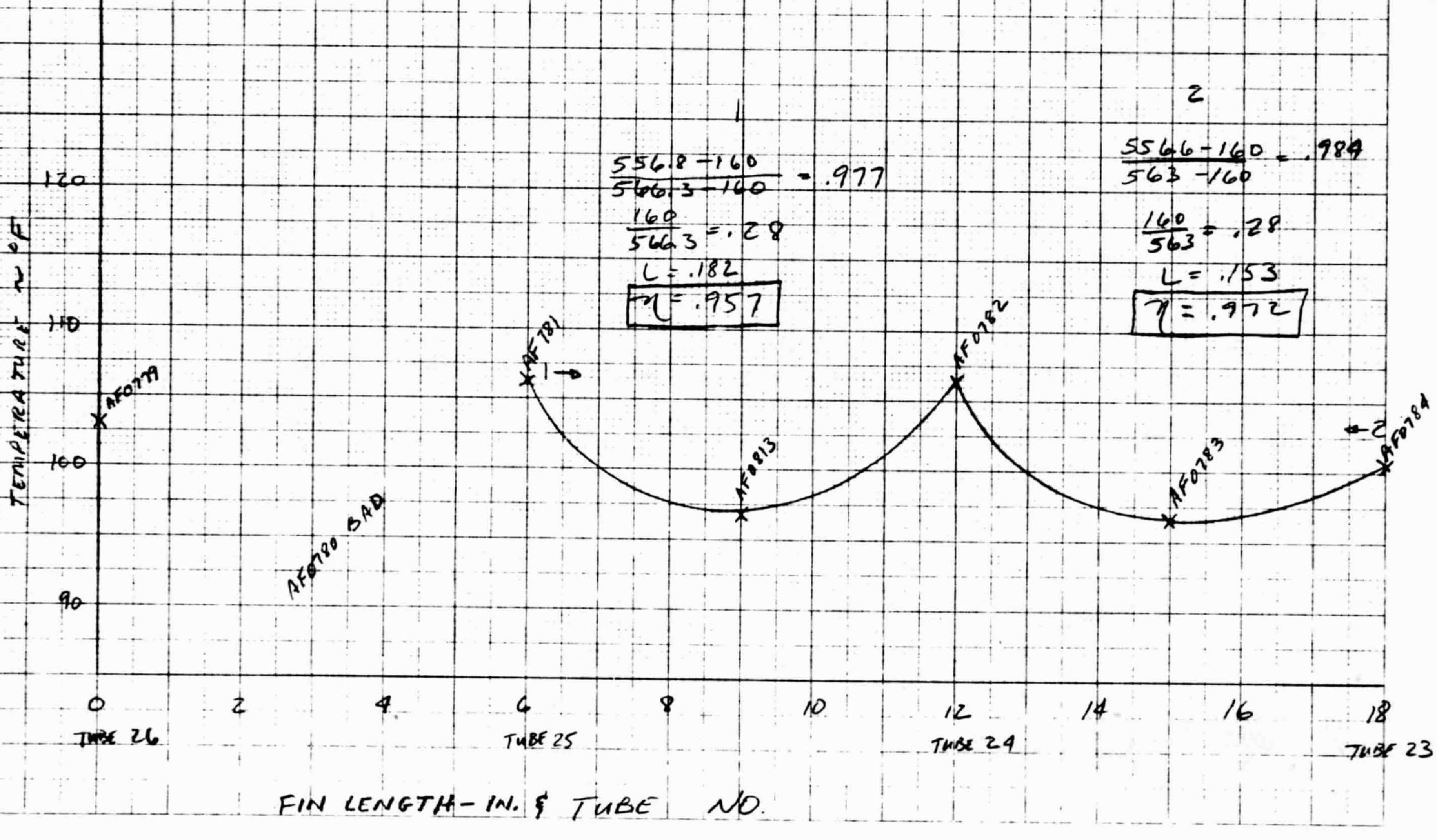


FIN LENGTH - IN. & TUBE NO.

FIGURE 5-17

TEST POINT 1

AFT PANEL FIN TEMP PROFILE (DOWNSTREAM)



1

$$\frac{556.8-160}{566.3-160} = .977$$

$$\frac{160}{566.3} = .28$$

L = .182

$$\boxed{\eta = .957}$$

2

$$\frac{556.6-160}{563-160} = .984$$

$$\frac{160}{563} = .28$$

L = .153

$$\boxed{\eta = .972}$$

FIGURE 5-18

TEST POINT 1

TOP FWD PANEL FIN TEMP PROFILE (UPSTREAM)

$$\frac{T_\ell - T_s}{T_o - T_s} = \frac{536.8-160}{543.8-160} = .982 \qquad \frac{T_\ell - T_s}{T_o - T_s} = \frac{538.5-160}{542.3-160} = .990$$

$$\frac{T_s}{T_o} = \frac{160}{543.9} = .29 \qquad \frac{T_s}{T_o} = \frac{160}{542.3} = .30$$

$L = .16$ $\qquad$ $L = .12$

$\boxed{\eta = .965}$ $\qquad$ $\boxed{\eta = .982}$

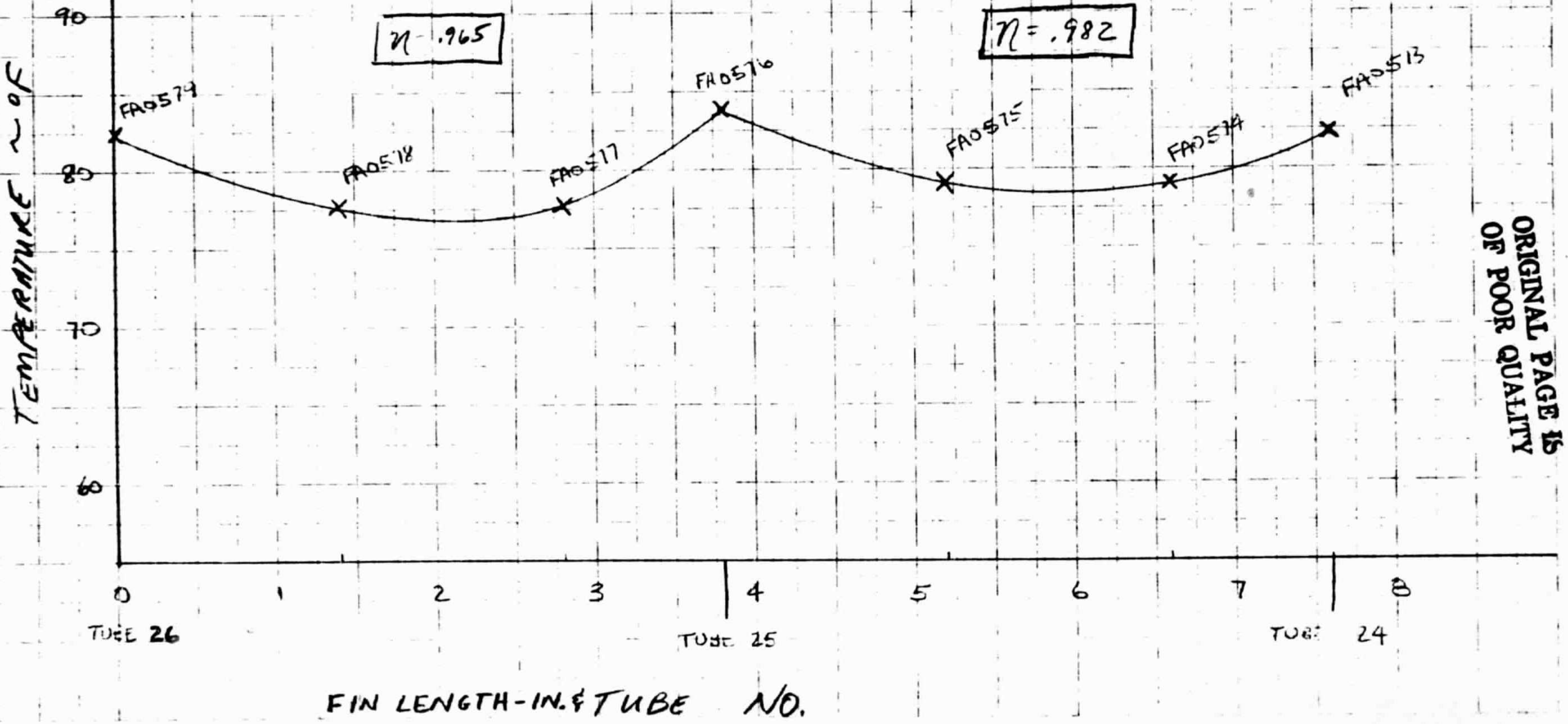


FIGURE 5-19

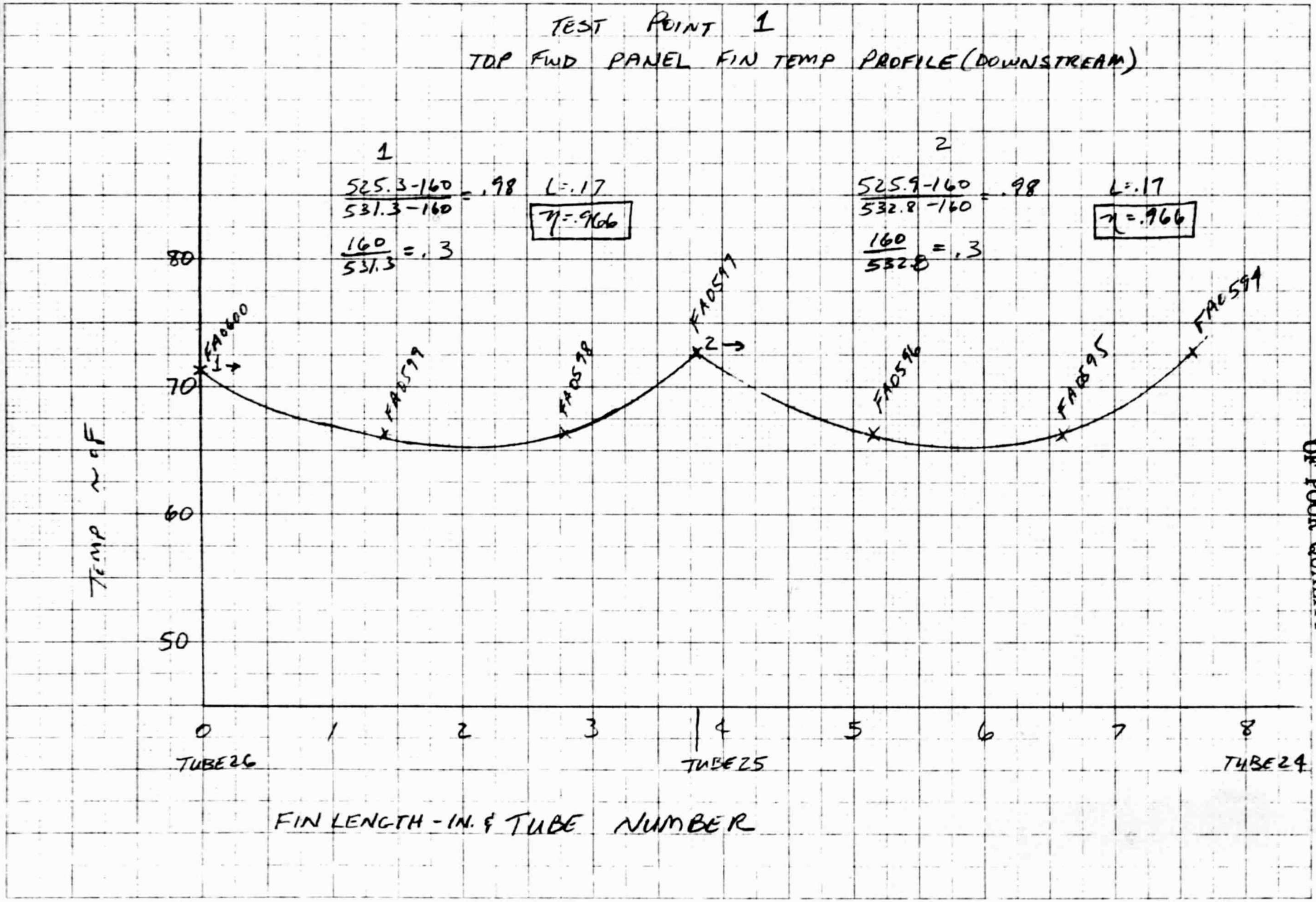
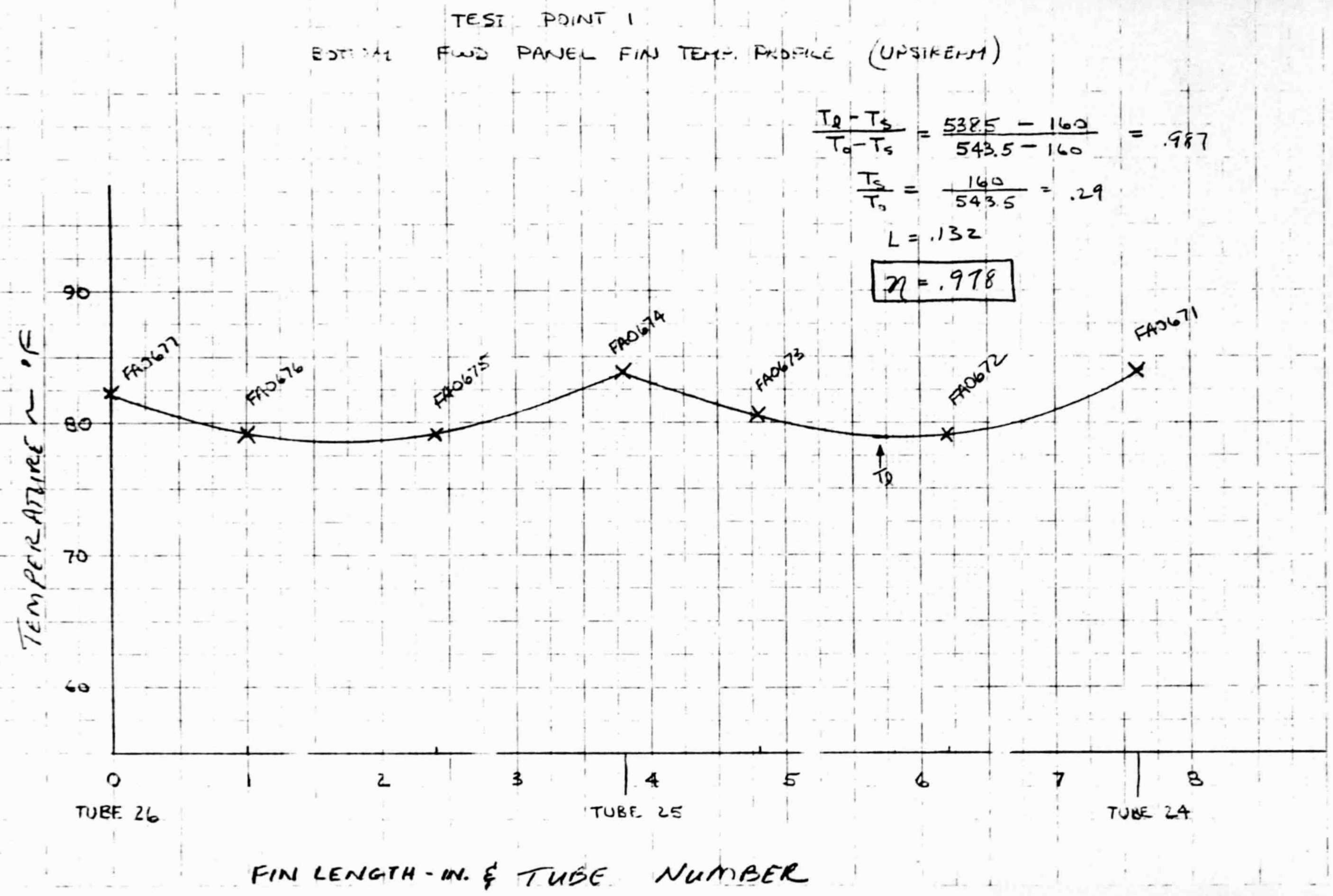

TEST POINT 1
TOP FWD PANEL FIN TEMP PROFILE (DOWNSTREAM)
1
$\frac{525.3-160}{531.3-160} = .98$
L = .17
$\boxed{\eta = .966}$
$\frac{160}{531.3} = .3$
2
$\frac{525.9-160}{532.8-160} = .98$
L = .17
$\boxed{\eta = .966}$
$\frac{160}{532.8} = .3$
FA0600
1 →
FA0599
FA0598
FA0597
2 →
FA0596
FA0595
FA0594
80
70
60
50
TEMP ~ °F
0
1
2
3
4
5
6
7
8
TUBE 26
TUBE 25
TUBE 24
FIN LENGTH - IN. & TUBE NUMBER

FIGURE 5-20



TEST POINT 1

ESTIMATED FWD PANEL FIN TEMP. PROFILE (UPSTREAM)

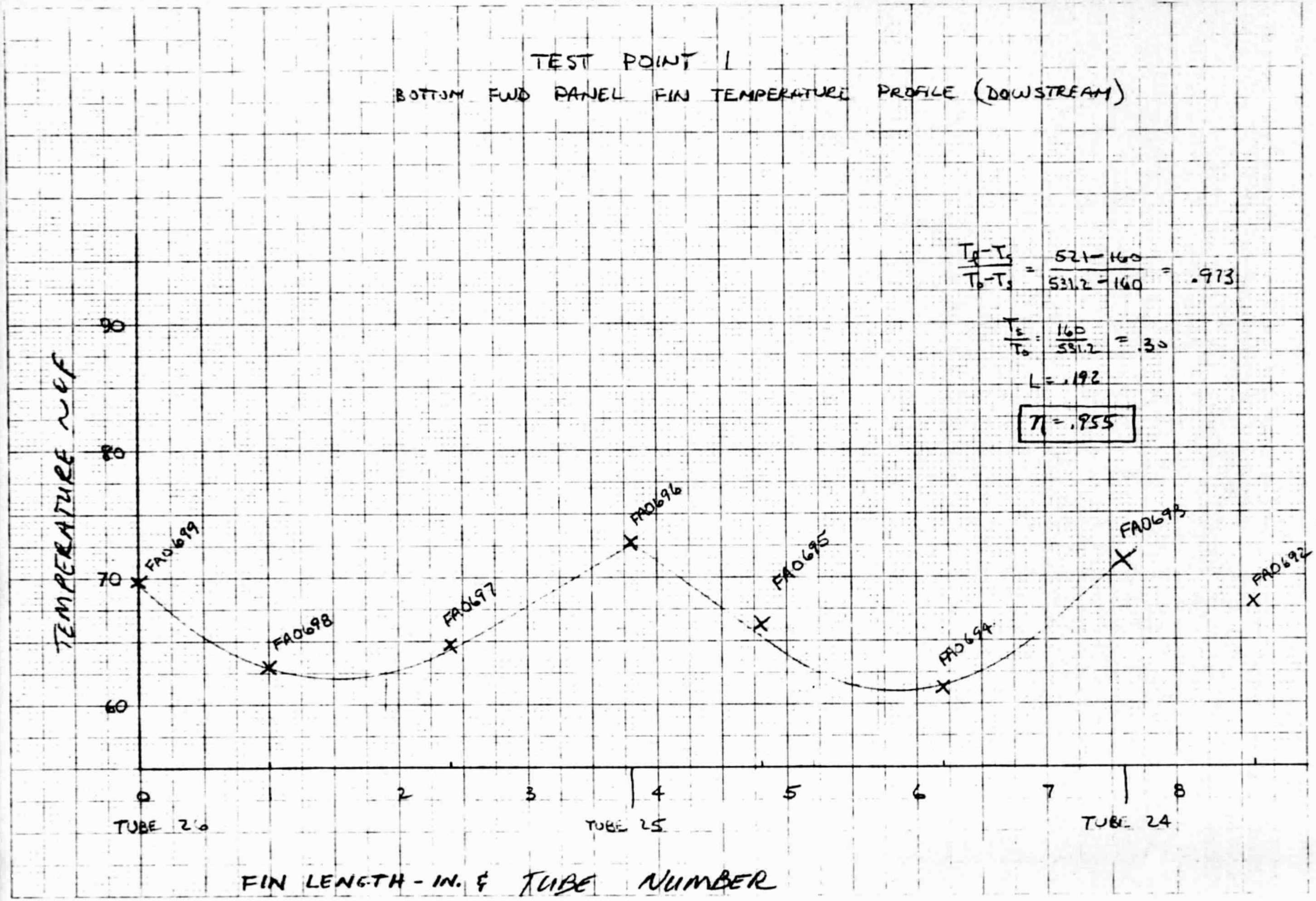
$$\frac{T_\ell - T_s}{T_o - T_s} = \frac{538.5 - 160}{543.5 - 160} = .987$$

$$\frac{T_s}{T_o} = \frac{160}{543.5} = .29$$

$$L = .132$$

$$\boxed{\eta = .978}$$

FIGURE 5-21



$$\frac{T_f - T_s}{T_b - T_s} = \frac{521 - 160}{531.2 - 160} = .973$$

$$\frac{T_s}{T_b} = \frac{160}{531.2} = .30$$

$L = .192$

$$\boxed{\eta = .955}$$

Table 5-8
Panel Fin Effectiveness

Test Point	Aft Panel T_{Avg} - °F	Aft η	Fwd Panel T_{Avg} - °F	Fwd η
1	117.7	.949	85.7	.967
2	115.9	.957	80.2	.974
3	100.4	.958	67.5	.973
4	88.6	.957	57.6	.980
4A	87.6	.951	56.3	.975
5	77.9	.961	28.8	.975
5A	104.4	.956	47.4	.976
5B	88.8	.955	61.7	.975
5001	---	---	85.5	.975
5001A	---	---	85.9	.976
5002	---	---	79.7	.971
5003	---	---	69.1	.972
5004	---	---	57.3	.976
7001	---	---	85.0	.971
7002	---	---	78.8	.977
7003	---	---	68.3	.974
7004	---	---	56.9	.977
7005	---	---	60.8	.977

TABLE 5-9

TUBE TO FACE SHEET ΔT - °F

FORWARD PANEL ZT01OX

TEST POINT	Q KBTU/HR	1	2	3	4	5*	6*	7	8	9
1	26.33	0	-5.1	0	3.2	3.3	0	1.6	1.6	3.2
2	25.03	0	-5.0	0	3.3	5.0	0	1.6	3.2	1.7
3	22.37	0	-5.1	1.6	3.4	3.4	-1.6	0	1.6	-1.7
4	21.47	0	-5.1	1.8	3.4	3.6	0	1.6	1.7	1.7
5	15.10	0	-3.5	1.9	3.5	1.9	0	0	1.7	0
6	10.66	0	-1.7	0	3.4	1.8	-1.8	0	0	0
7	14.96	0	-3.3	0	5.1	3.4	0	0	0	1.7
8	17.19	0	-3.3	1.7	1.6	3.4	0	0	1.6	-1.7
9	19.85	0	-3.2	1.7	3.1	3.4	0	1.6	1.6	4.7
10	20.94	0	-3.1	1.7	3.2	3.3	-1.7	1.6	1.6	1.6
11	17.41	0	0	0	4.8	3.2	0	1.6	0	0
12	16.72	0	0	0	4.8	1.6	1.6	0	0	1.6
13	11.42	0	1.7	-1.7	5.1	3.3	1.7	0	1.6	-1.7
14	8.20	0	0	-1.7	5.0	1.7	0	1.6	0	0

*Butt-weld

TABLE 5-9 Cont'd

FWD PANEL ZT010X

TEST POINT	Q KBTU/HR	1	2	3	4	5	6	7	8	9
15	10.56	-1.6	0	0	3.2	3.3	1.6	1.6	0	0
16	12.22	0	0	0	4.8	3.2	0	0	0	1.6
17	12.47	0	0	0	3.2	3.1	1.6	1.5	0	1.6
17A	15.85	0	0	0	6.3	3.2	1.6	1.5	0	3.2
18	10.44	0	0	-1.6	3.1	3.2	1.6	0	0	0
19	9.53	0	0	-1.7	3.2	1.7	1.6	0	-1.6	0
20	6.88	-1.5	0	0	3.4	1.7	1.7	0	0	-1.6
40	13.72	-1.6	0	0	3.2	3.3	0	0	0	-1.6
41	11.62	-1.6	-1.5	0	3.2	3.4	0	-3.2	0	0
43	10.92	0	0	0	3.2	3.4	0	0	0	1.6
5A	18.45	0	-3.5	1.8	3.5	3.5	-1.8	1.7	0	1.7
5B	22.21	0	-5.0	1.6	3.4	3.4	0	1.6	1.7	3.4
5C	17.22	0	-5.3	1.9	1.7	3.8	-1.8	1.6	1.7	-1.8

Table 5-9 Cont'd

TUBE TO FACE SHEET T - °F

AFT PANEL ZT01XX

TEST POINT	Q KBTU/HR	10	11	12*	13	14	15	16
1	19.66	3.0	0	7.9	0	-	1.5	0
2	18.95	3.0	0	7.9	0	-	1.5	1.6
3	16.79	1.6	0	6.4	0	-	3.2	0
4	15.74	1.6	0	8.0	0	-	0	0
5	13.48	3.2	1.7	5.0	1.7	-	1.6	0
6	10.25	1.6	0	4.9	0	-	1.6	0
7	11.70	0	0	4.7	1.6	-	1.6	0
8	13.66	1.6	0	4.8	1.6	-	3.2	1.6
9	15.46	3.0	0	6.4	1.6	-	1.5	1.5
10	15.97	3.0	0	6.4	1.6	-	1.5	0
11	15.54	1.5	0	6.2	0	3.2	1.6	1.6
12	14.75	1.5	0	7.9	1.6	6.3	3.1	1.5
13	12.44	1.5	1.6	6.4	0	4.8	3.0	1.6
14	8.29	1.5	-1.6	6.4	3.2	3.2	3.1	1.6

*Butt-weld

TABLE 5-9 Cont'd

AFT PANEL ZT01XX

TEST POINT	Q KBTU/HR	10	11	12	13	14	15	16
15	8.69	1.5	0	6.3	0	4.8	3.0	1.6
16	9.49	0	1.6	6.3	1.6	6.4	3.0	1.6
17	9.55	0	0	6.3	1.6	6.3	3.0	1.6
17A	11.18	1.6	0	6.1	1.5	4.7	3.1	1.5
18	8.79	1.6	0	6.4	1.6	4.8	3.2	0
19	8.08	1.6	0	8.0	1.6	4.8	3.2	0
20	6.96	0	-1.6	4.7	1.6	4.8	4.8	1.6
40	8.03	1.5	0	6.4	3.2	4.7	3.0	1.6
41	9.76	1.5	0	6.3	0	6.4	1.5	1.6
43	11.43	0	0	6.4	0	-	1.5	0
5A	16.49	3.0	1.6	6.3	0	-	1.6	0
5B	16.01	1.6	0	6.3	1.6	-8.3	1.6	1.6
5C	15.39	1.6	0	8.2	0	-	3.2	0

TABLE 5-10
PANEL PRESSURE DROP

TEST POINT	AFT PANEL ΔP - PSID	FWD PANEL ΔP - PSID	TEST POINT	AFT PANEL ΔP - PSID	FWD PANEL ΔP - PSID
1	5.4	3.2	18		
2	4.1	2.4	19	4.0	2.1
3	4.0	2.4	20	1.2	0.8
4	4.0	2.4	21	1.2	0.8
4A	4.5	2.7	22	5.7	3.0
5	1.0	0.8	22A	4.7	3.0
5A	1.3	0.8	23	5.7	3.3
5B	5.3	3.2	24	5.1	2.8
5C	1.0	0.8	25	5.3	2.8
6	1.0	0.7	26	1.2	0.8
6A	1.0	0.8	27	4.2	2.4
7	4.0	2.4	28	1.0	0.8
8	4.2	2.4	40	3.9	2.5
9	4.1	2.5	41	4.1	2.4
10	5.1	3.1	41H	4.1	2.3
10A	5.2	2.9	42	3.8	2.4
11	5.0	2.8	42A	3.9	2.3
12	3.6	2.2	43	4.1	2.2
12A	3.9	2.3	44	<0.1	0.1
13	1.0	0.7	45	<0.1	<0.1
13B	0.9	0.8	46	0.1	<0.1
14	1.1	0.8	46A	0.1	<0.1
15	2.8	1.6	47	4.0	2.5
15A	2.6	1.5	50	<0.1	0.1
15B	2.8	1.5	51	4.6	2.9
16	3.8	2.3	52	<0.1	1.2
17	4.8	2.9	53	<0.1	0.7
17A	5.1	2.8			

5.1.2 Wide Cavity Performance (50° and 70° Cavity Deployment)

The primary objective of this sequence of testing was to determine thermal performance of the two-sided (forward) radiator panel at deployment angles greater than the baseline configuration. So, the forward panel was tested over a selected range of heat loads and external environmental conditions for cavity deployment angles of 50° and 70°.

The first sequence of testing provided steady state performance data for the dual loop operation and the same three uniform environments used in the baseline radiator performance testing. Figures 5-22 thru 5-27 summarize the radiator performance data for the two additional cavity angles. The mission simulation and low load performance sequence of testing is summarized in Table 5-11.

Table 5-12 compares the baseline cavity performance data to the 50° and 70° data. This comparison is for the same IR lamp and PBD heater settings. Since the cavity opening angles also influence the total flux on the panel and the amount of PBD flux which is absorbed by the panels is reduced for wider cavities, Table 5-12 does not reflect the actual heat rejection improvement which would result in orbit. Furthermore, a test configuration change and anomalous chamber cold wall operation makes comparison with the 38° cavity data invalid. Comparison of 50° and 70° cavity data is valid, although the exact environment is not known. This test anomaly is discussed further in paragraph 5.3.

5.2 Low Load Recovery Techniques

The primary objective of this phase of testing was to evaluate the capability to thaw frozen tubes on the radiator which occur during a long cold soak. Figures 5-28 thru 5-30 show the typical freeze pattern of the panels as a function of time. Each line represents fifteen minutes. During the third freeze, the chamber pressure was increased to approximately 1 torr to speed up the cold soak. The tubes did not stagnate in proper order (see figures 5-31 and 5-32), but, after recovery, the flow skew seemed normal.

Four different freeze/thaw cycles were performed on the panels. One of the cycles used a recovery with the prime tubes flowing and the other three cycles were run with the prime tubes valved off (inherent stagnation). The first two thaws simulated a system heat load change from minimum to maximum

FIGURE 5-22

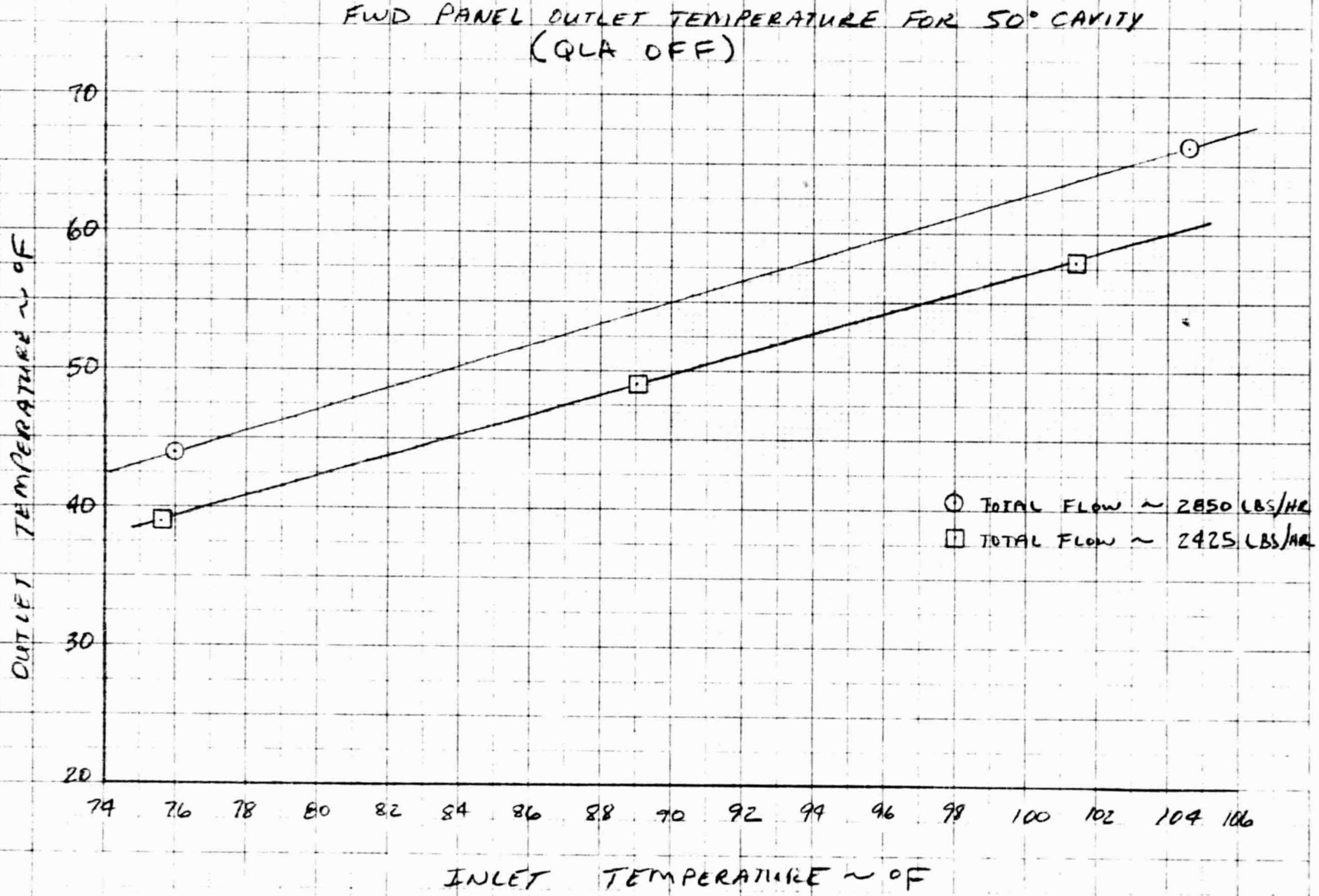

FWD PANEL OUTLET TEMPERATURE FOR 50° CAVITY
(QLA OFF)
70
60
50
40
30
20
OUTLET TEMPERATURE ~ °F
74
76
78
80
82
84
86
88
90
92
94
96
98
100
102
104
106
INLET TEMPERATURE ~ °F
○ TOTAL FLOW ~ 2850 LBS/HR
☐ TOTAL FLOW ~ 2425 LBS/HR

FIGURE 5-23

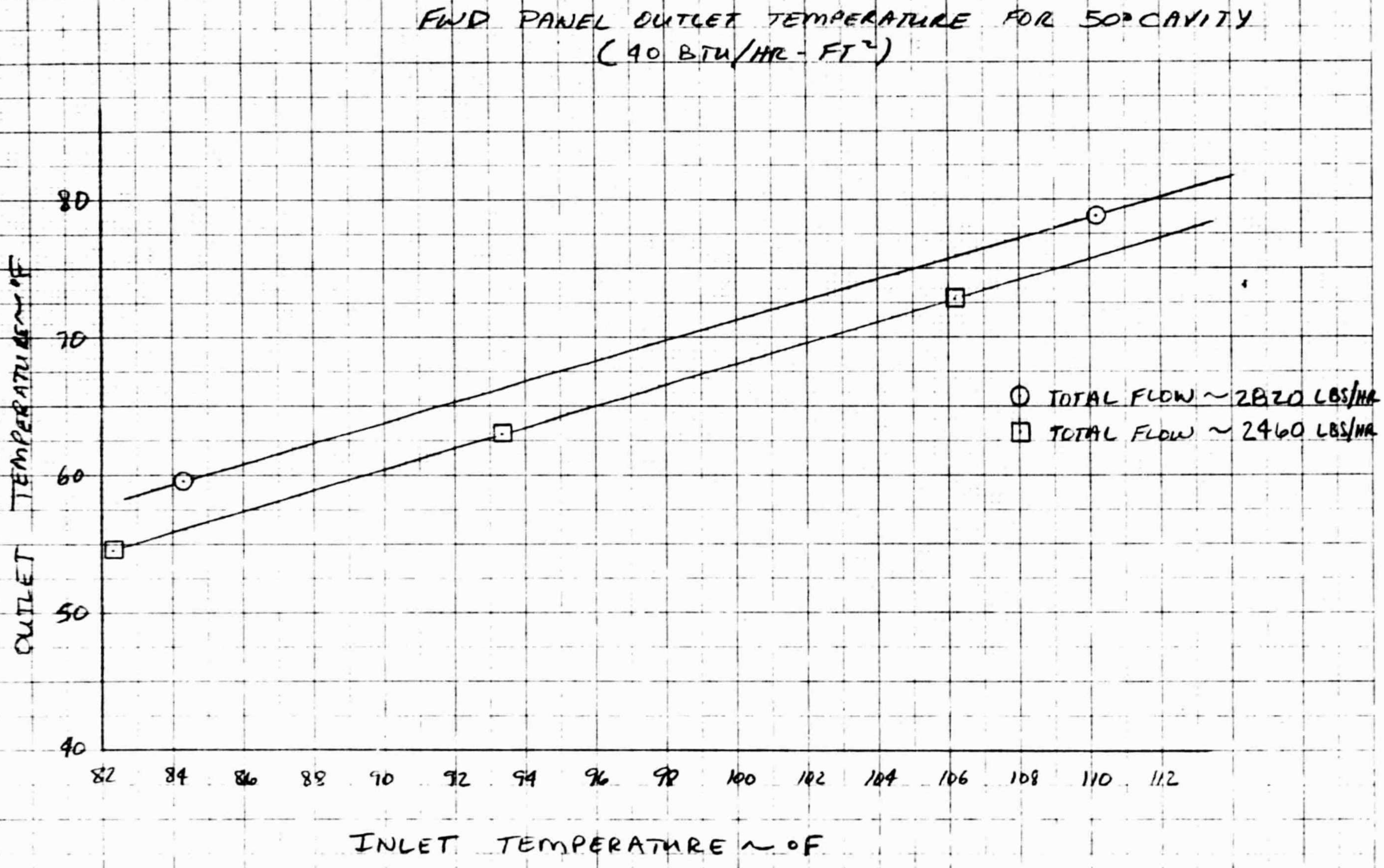

FWD PANEL OUTLET TEMPERATURE FOR 50° CAVITY
(40 BTU/HR - FT²)
OUTLET TEMPERATURE ~ °F
80
70
60
50
40
82
84
86
88
90
92
94
96
98
100
102
104
106
108
110
112
INLET TEMPERATURE ~ °F
○ TOTAL FLOW ~ 2820 LBS/HR
□ TOTAL FLOW ~ 2460 LBS/HR

FIGURE 5-24

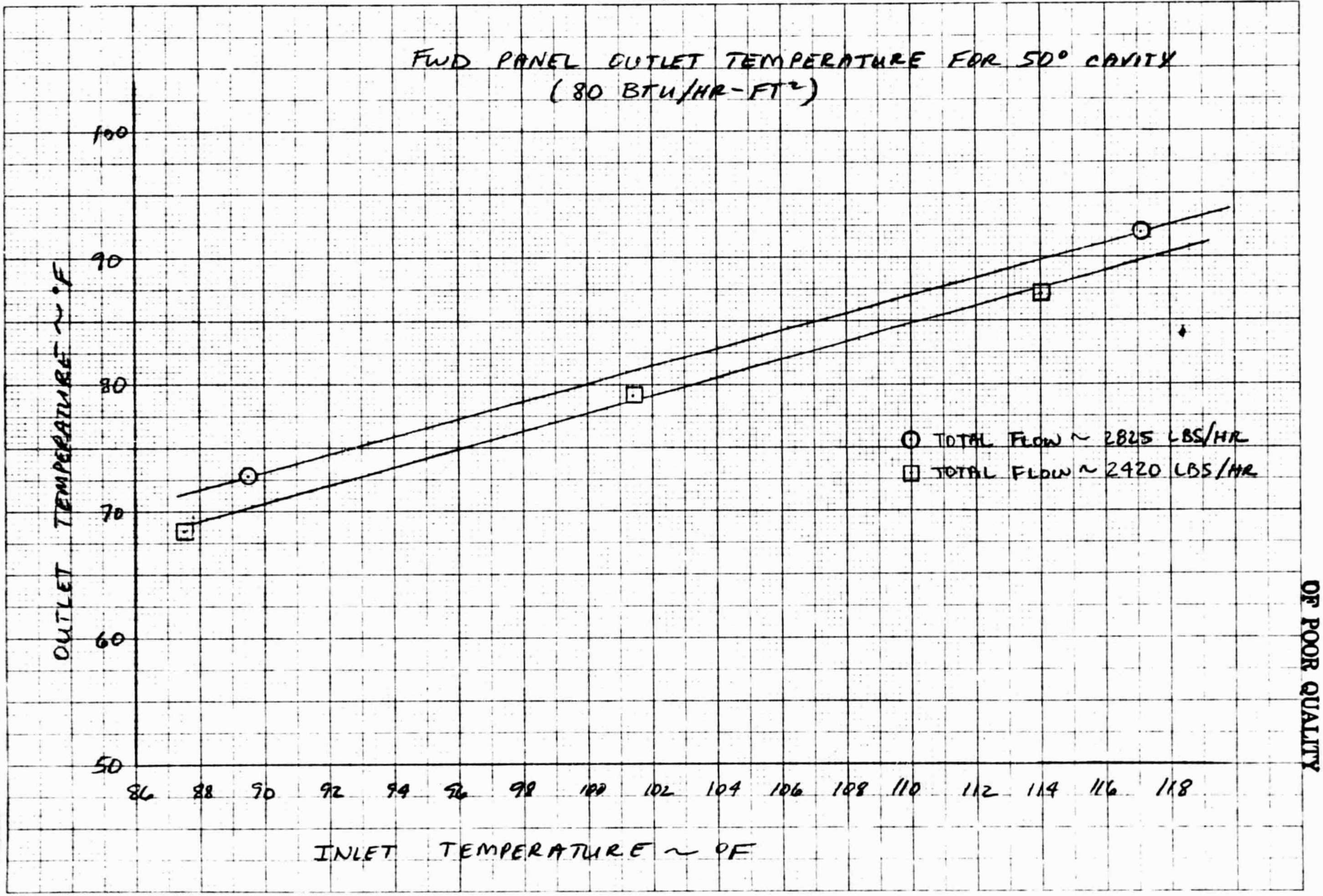

FWD PANEL OUTLET TEMPERATURE FOR 50° CAVITY
(80 BTU/HR-FT²)
OUTLET TEMPERATURE ~ °F
100
90
80
70
60
50
86
88
90
92
94
96
98
100
102
104
106
108
110
112
114
116
118
INLET TEMPERATURE ~ °F
○ TOTAL FLOW ~ 2825 LBS/HR
□ TOTAL FLOW ~ 2420 LBS/HR

FIGURE 5-25

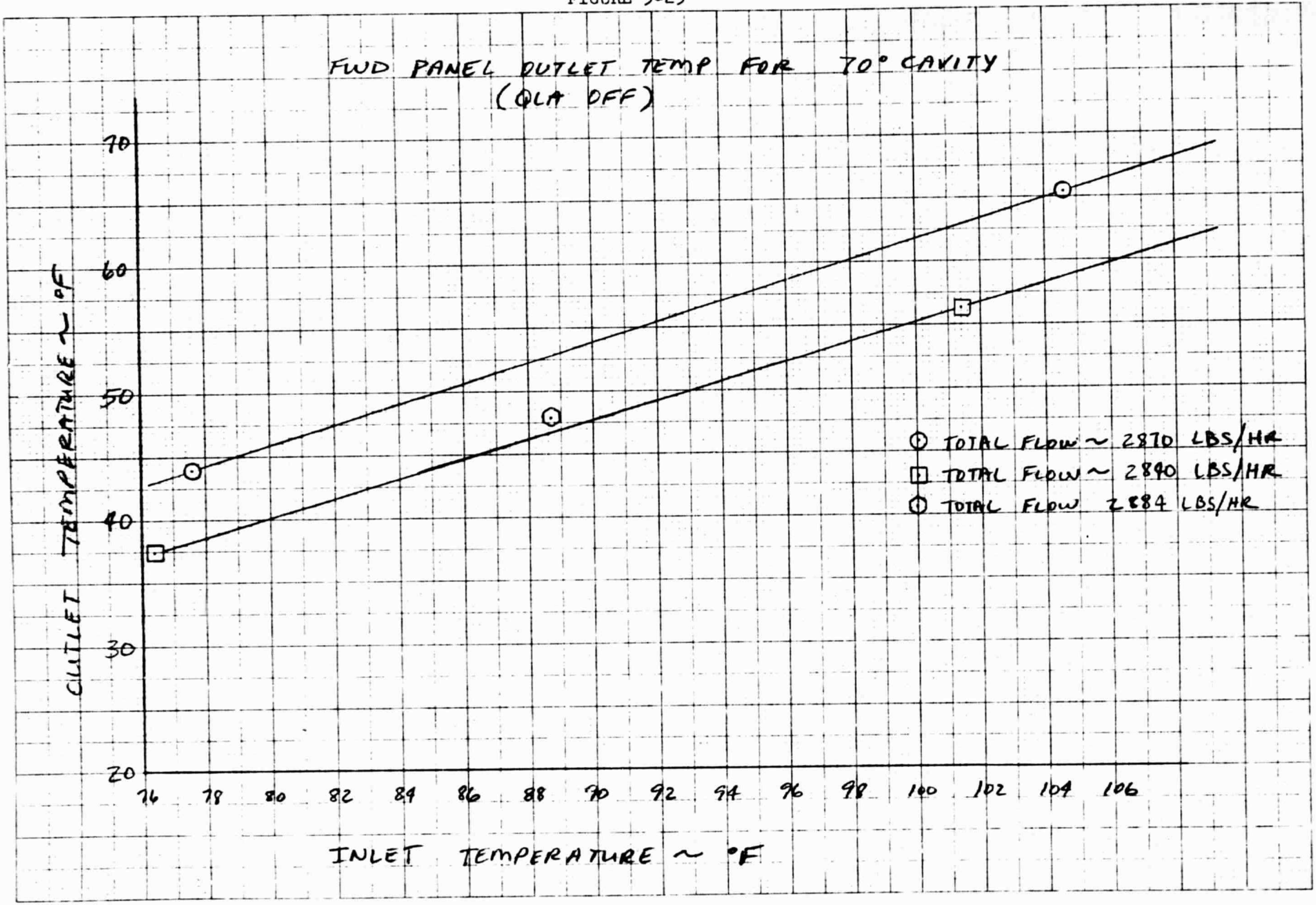

FWD PANEL OUTLET TEMP FOR 70° CAVITY
(QLA OFF)
OUTLET TEMPERATURE ~ °F
70
60
50
40
30
20
76
78
80
82
84
86
88
90
92
94
96
98
100
102
104
106
INLET TEMPERATURE ~ °F
⊙ TOTAL FLOW ~ 2870 LBS/HR
⊡ TOTAL FLOW ~ 2890 LBS/HR
⬡ TOTAL FLOW 2884 LBS/HR

FIGURE 5-26

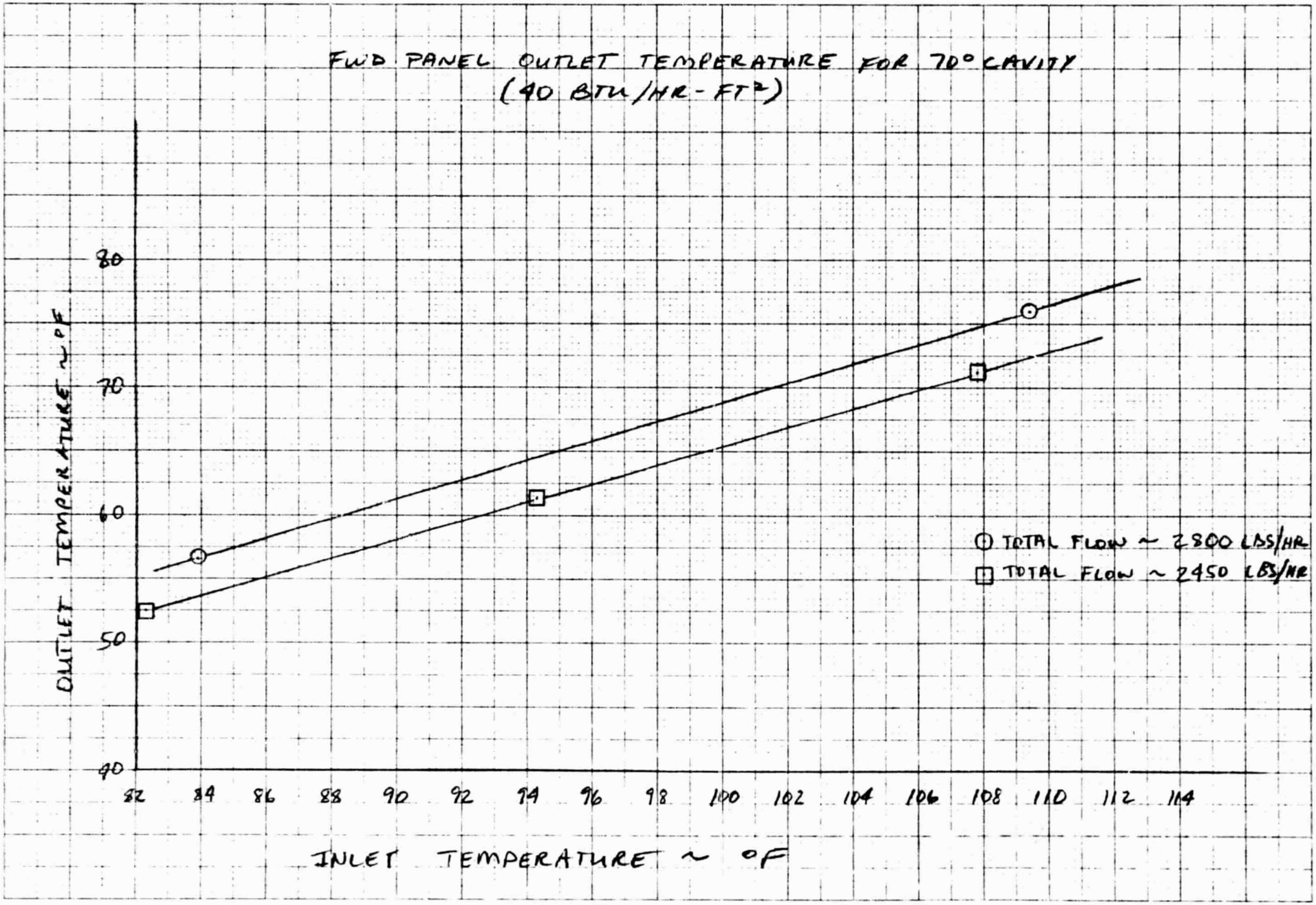

FWD PANEL OUTLET TEMPERATURE FOR 70° CAVITY
(40 BTU/HR-FT²)
OUTLET TEMPERATURE ~ °F
80
70
60
50
40
82
84
86
88
90
92
94
96
98
100
102
104
106
108
110
112
114
INLET TEMPERATURE ~ °F
○ TOTAL FLOW ~ 2800 LBS/HR
□ TOTAL FLOW ~ 2450 LBS/HR

FIGURE 5-27

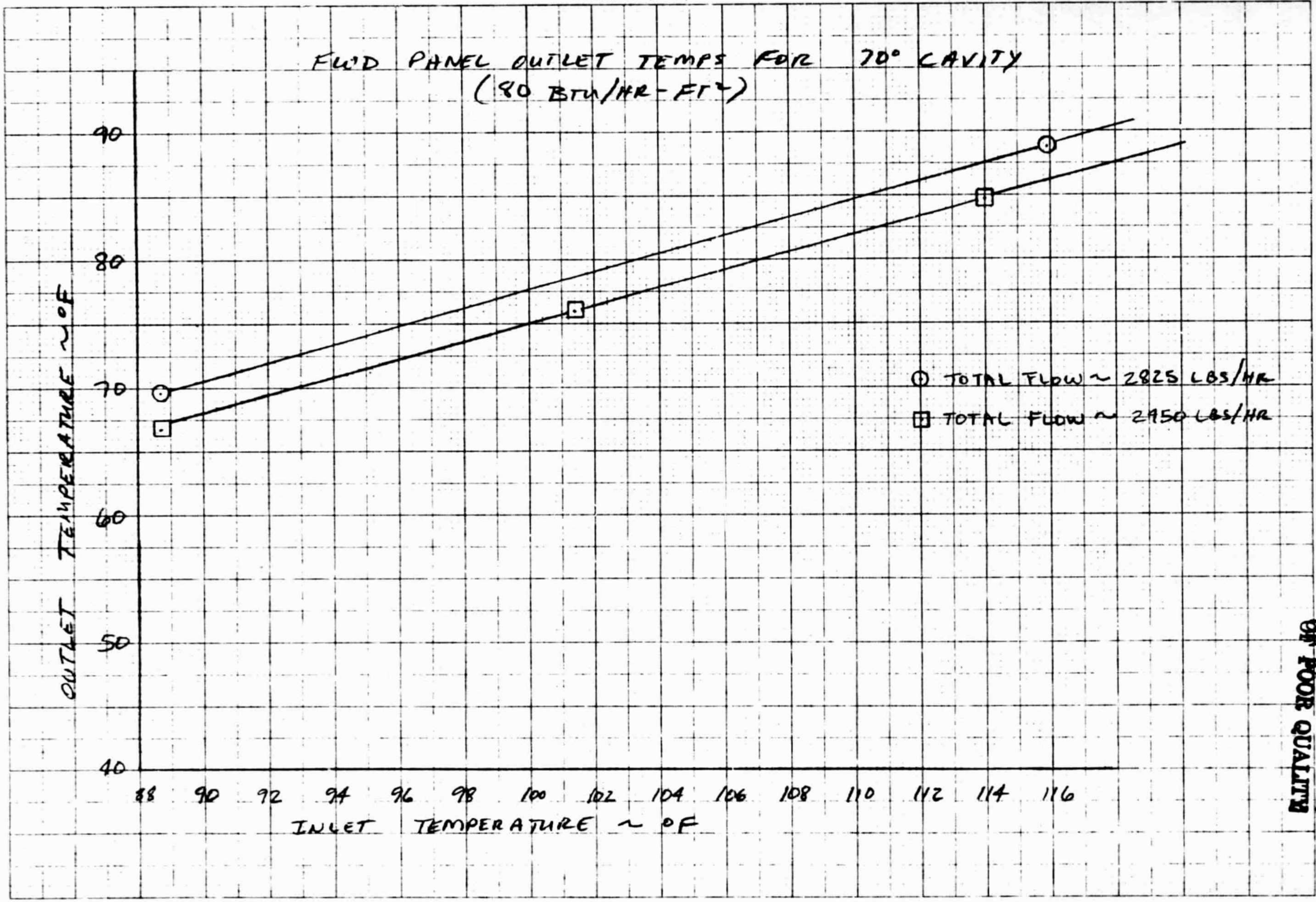

FWD PANEL OUTLET TEMPS FOR 70° CAVITY
(80 BTU/HR-FT²)
OUTLET TEMPERATURE ~ °F
90
80
70
60
50
40
INLET TEMPERATURE ~ °F
88
90
92
94
96
98
100
102
104
106
108
110
112
114
116
⊙ TOTAL FLOW ~ 2825 LBS/HR
⊡ TOTAL FLOW ~ 2950 LBS/HR

TABLE 5-11

WIDE CAVITY MISSION SIMULATION AND LOW LOAD PERFORMANCE

TEST POINT	SUN SIMULATION ANGLE	TIN °F	TOUT °F	FLOW LBS/HR	QREJ BTU/HR	CAVITY ANGLE
5017	46	103.8	79.5	2421	14843.	50
5018	77	100.6	80.7	2438.	12269.	50
5019	103	101.4	82.3	2433.	11711.	50
5020	131	99.9	78.3	2458.	13400.	50
5021	N/A	-21.0	-124.7	113.	2739.	50
5022	N/A	-70.6	-147.7	109.	1960.	50
5023	N/A	-112.2	-166.0	115.	1437.	50
5024	N/A	-106.3	-172.9	34.	522.	50
7018	77	100.3	71.2	2467.	10841.	70
7020	131	100.3	74.4	2458.	16033.	70
7021	N/A	-20.5	-117.1	117.	2634.	70
7022	N/A	-70.6	-149.5	115.	2109.	70
7023	N/A	-112.2	-166.6	117.	1487.	70

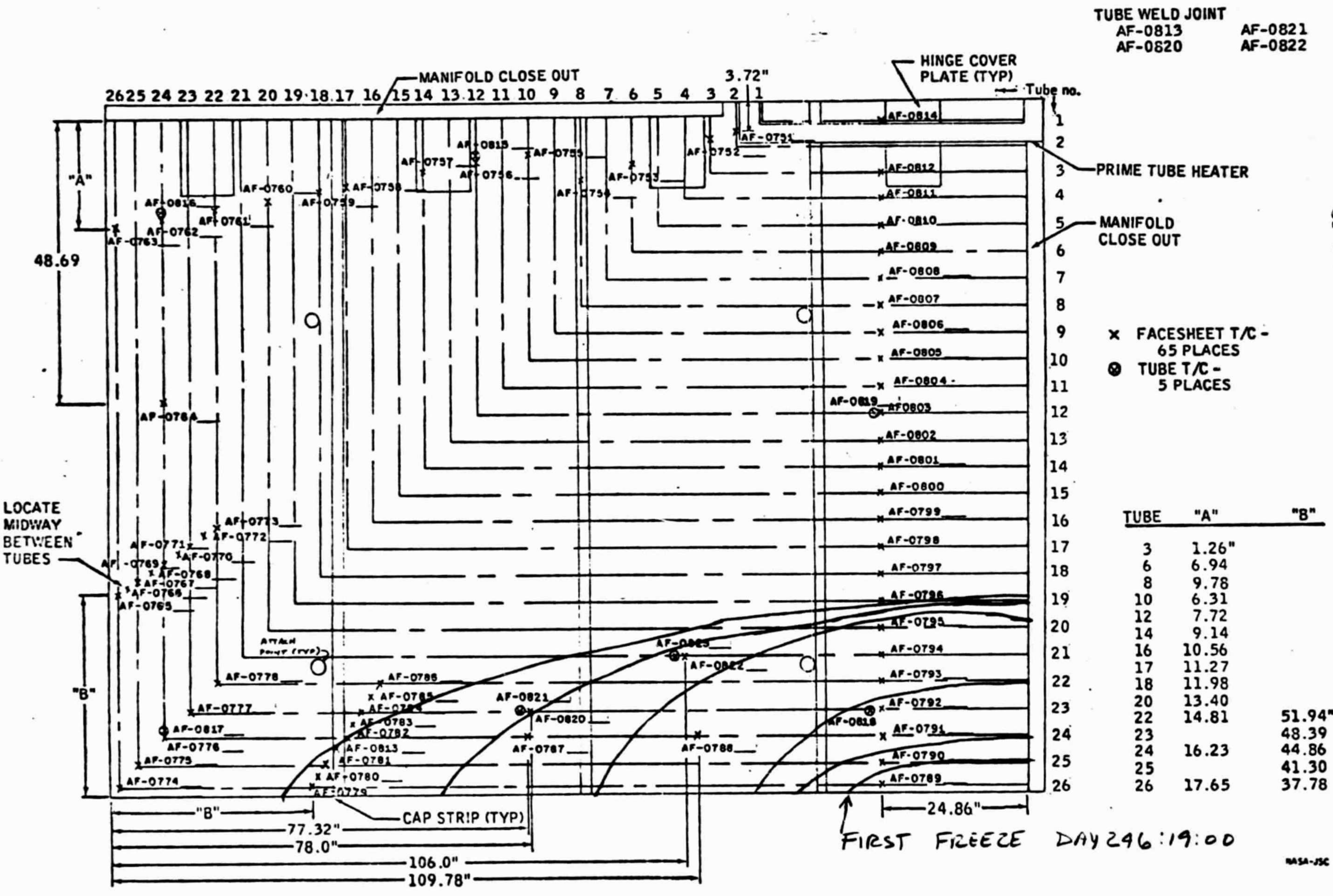
TABLE 5 - 12

WIDE CAVITY HEAT REJECTION IMPROVEMENT

38° CAVITY		50° CAVITY			70° CAVITY			
TEST POINT	QREJ BTU/HR	TEST POINT	QREJ BTU/HR	% > 38°	TEST POINT	QREJ BTU/HR	% > 38°	ENVR BTU/HR FT^2
1	26780.	5001	27277.	1.9%	7001	28192.	5.3%	0
2	25460.	5002	26282.	3.2%	7002	27421.	7.7%	0
3	22909.	5003	23697	3.4%	7003	25055.	9.4%	0
4	21864.	5004	21883.	0.1%	7004	23255.	6.4%	0
5B	22661.	5005	22747	0.4%	7005	23587.	4.1%	0
7	15506.	5010	16799.	8.3%	7010	18026.	16.3%	40
8	17455.	5009	19027.	9.0%	7009	20172.	15.6%	40
9	20003.	5008	20553.	2.7%	7008	22632.	13.1%	40
10	20737.	5007	22468.	8.3%	7007	23533	13.5%	40
10A	16279.	5011	17263.	6.0%	7011	19198.	17.9%	40
12A	14369.	5013	16508.	14.9%	7013	18147.	26.3%	80
16	12244.	5014	13727.	12.9%	7014	15768.	28.8%	80
17A	15143.	5012	18122.	19.7%	7012	19512.	28.9%	80
18	10478.	5016	11814.	12.8%	7016	13539.	29.2%	80
19	9753.	5015	11574.	18.7%	7015	13480.	38.2%	80
40	13615.	5017	14843.	9.0%	N/A	N/A	N/A	SKEW
41	11548.	5018	12269.	6.2%	7018	18041.	56.2%	SKEW
41H	19448.	5006	21988.	13.1%	7006	23171.	19.1%	PBD HTRS
42A	10030.	5019	11711.	16.8%	N/A	N/A	N/A	SKEW
43	10847.	5020	13400.	25.5%	7020	16033.	47.8%	SKEW

FIGURE 5-28

TEST POINT 44 AFT PANEL FREEZE PATTERN

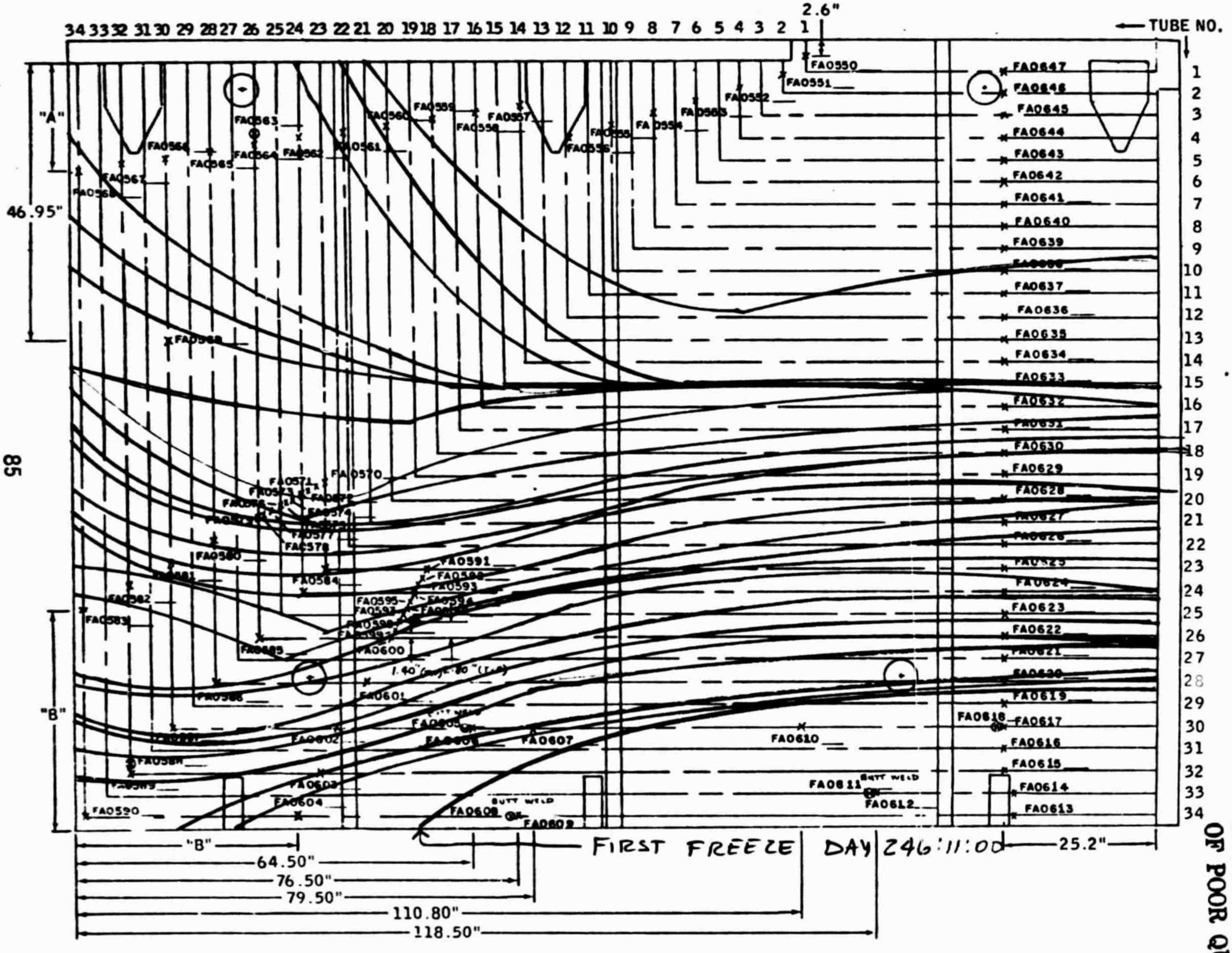


TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

FIGURE 5-29

TEST POINT 44 TOP FWD PANEL FREEZE PATTERN

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



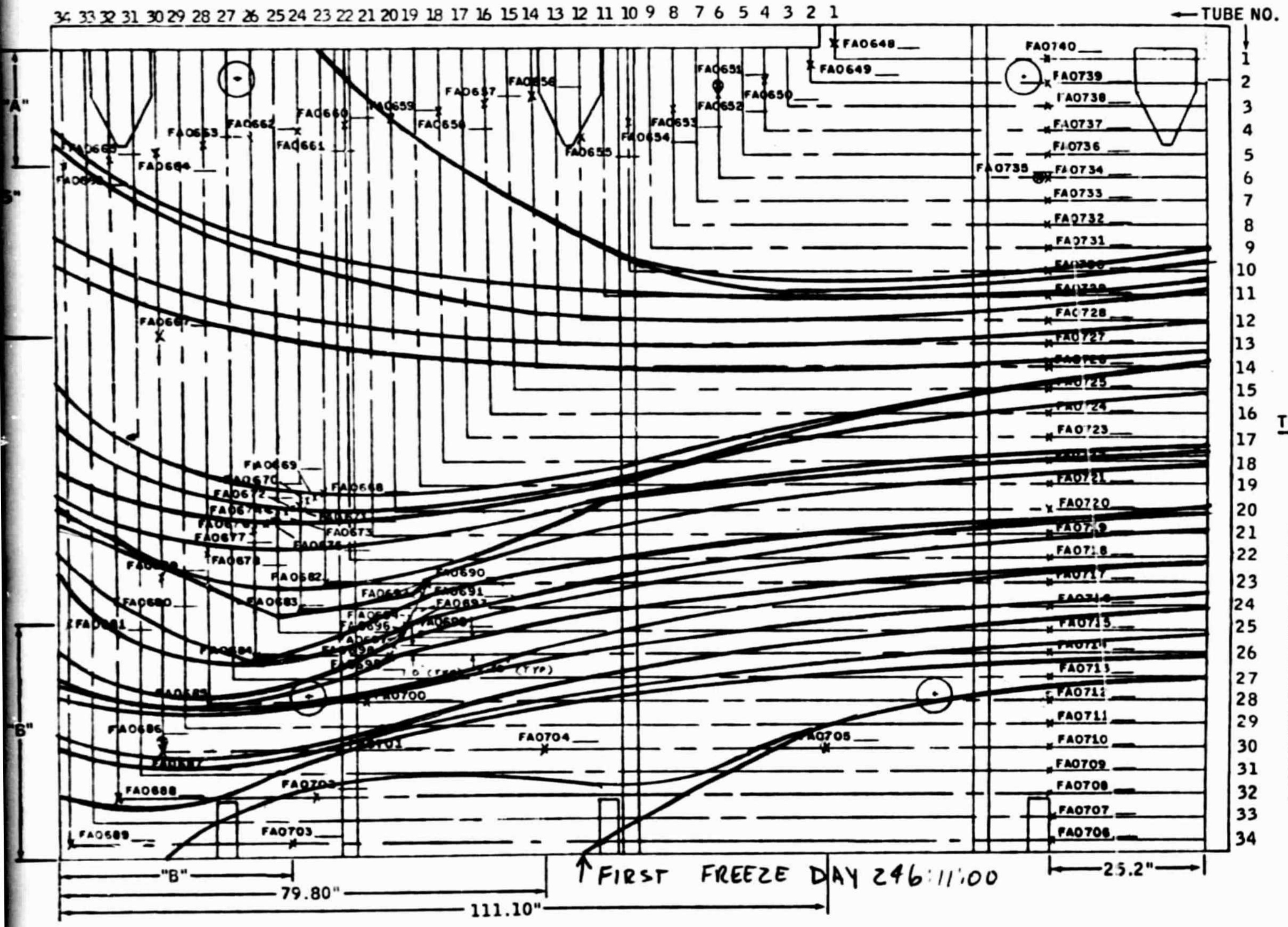
× FACE SHEET T/C - 93 PLACES

⊗ TUBE T/C - 6 PLACES

TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58.90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

FIGURE 5-30 TEST POINT 44 BTM FWD PANEL FREEZE PATTERN

"BOTTOM" FORWARD PANEL THERMOCOUPLE LOCATIONS



↑FIRST FREEZE DAY 246:11:00

× FACE SHEET T/C - 90 PLACES

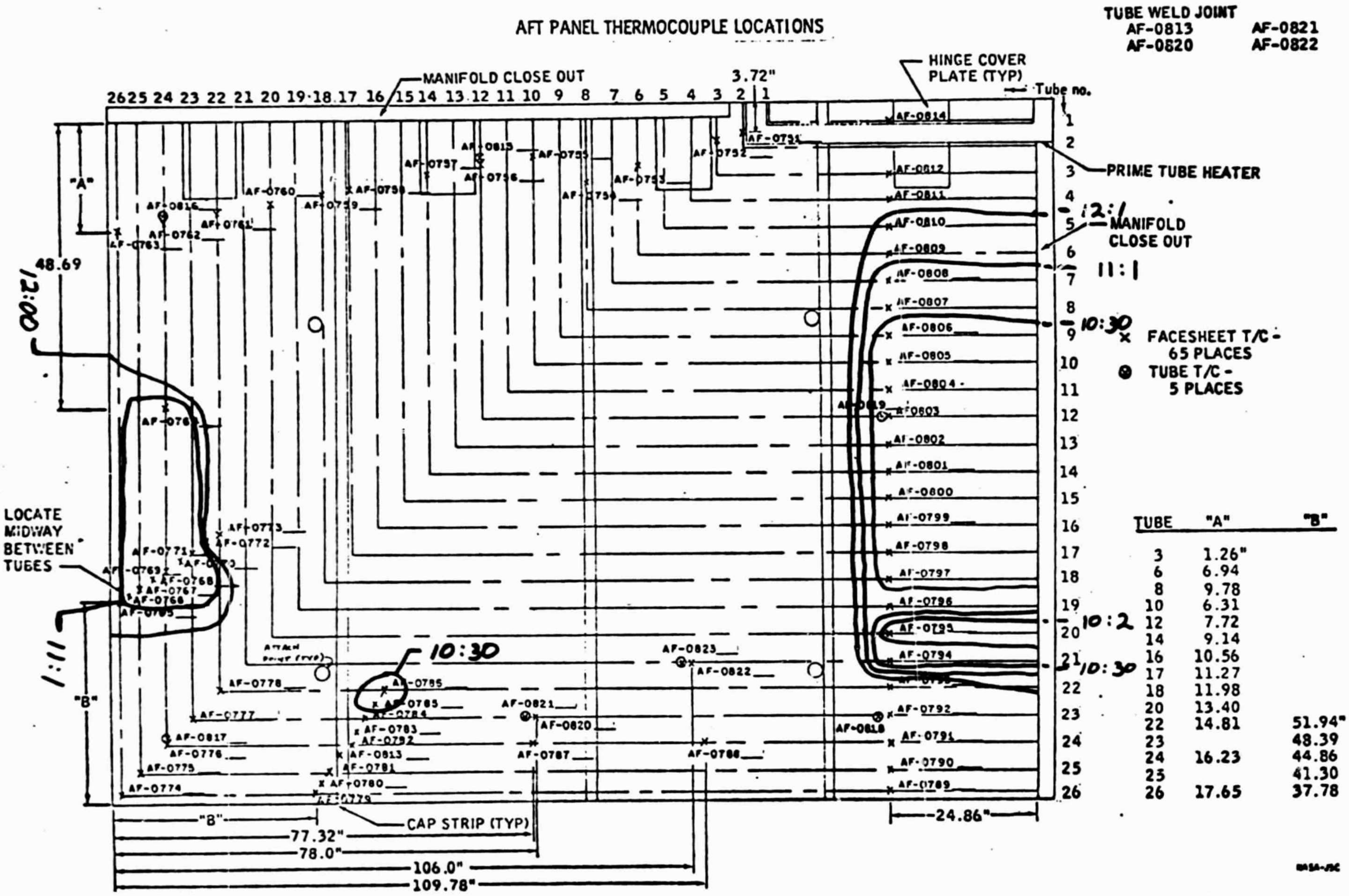
● TUBE T/C - 3 PLACES

TUBE	"A"	"B"
2	2.75"	
4	3.70	
6	5.70	
8	7.85	
10	10.00	
12	12.10	
14	7.10	
16	8.10	
18	9.20	
20	10.25	
22	11.30	
23		67.10"
24	12.35	64.60
25		62.60
26	13.40	59.20
28	14.50	53.80
30	15.55	48.50
32	16.55	43.30
34	17.65	38.30

NASA-JSC

FIGURE 5-31
TEST POINT 52 AFT PANEL FREEZE PATTERN

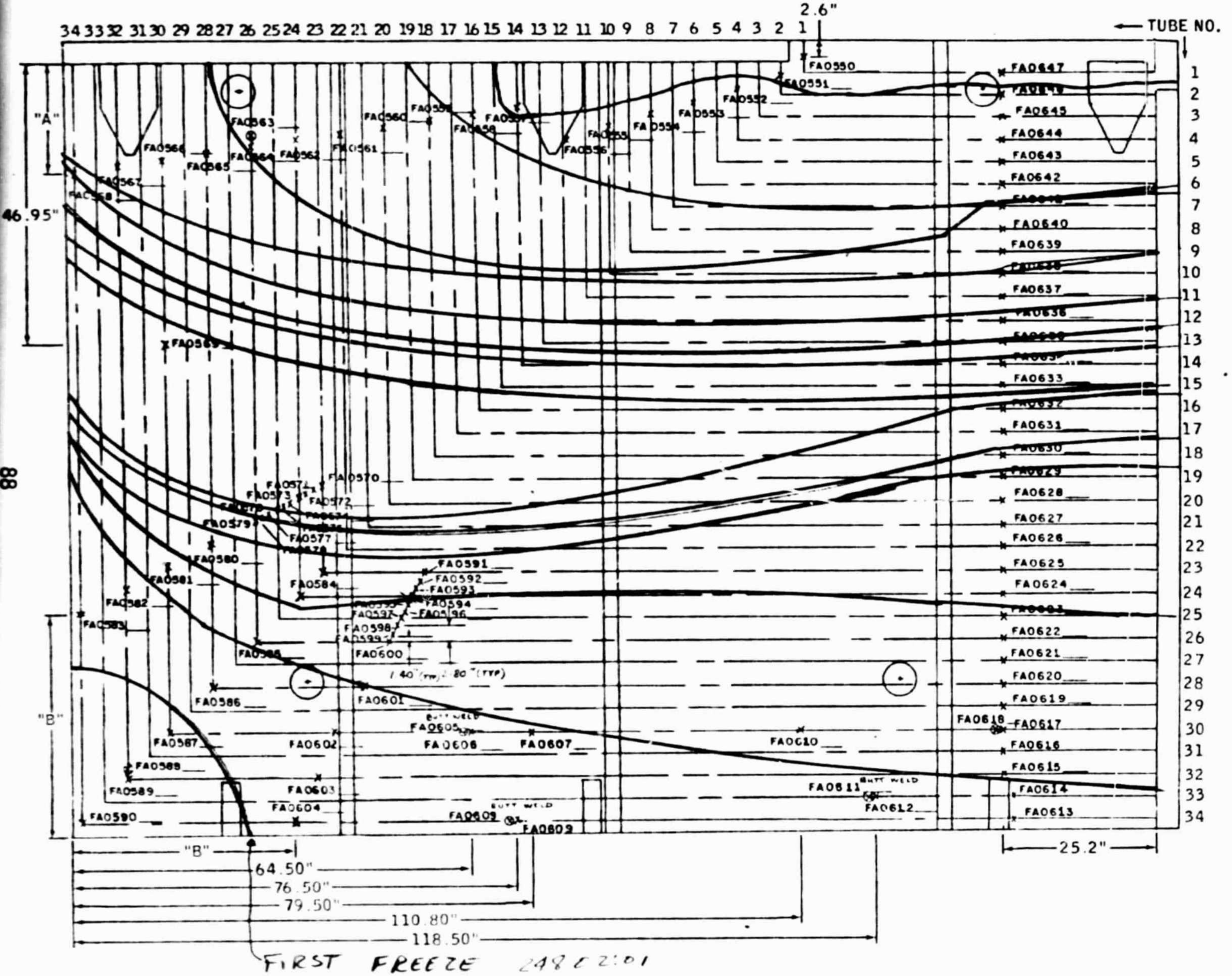
ALL TIMES ARE DAY 248



TUBE	"A"	"B"
3	1.26"	
6	6.94	
8	9.78	
10	6.31	
12	7.72	
14	9.14	
16	10.56	
17	11.27	
18	11.98	
20	13.40	
22	14.81	51.94"
23		48.39
24	16.23	44.86
25		41.30
26	17.65	37.78

FIGURE 5-32 TEST POINT 53 TOP FWD PANEL FREEZE PATTERN

"TOP" FORWARD PANEL CONCAVE SIDE THERMOCOUPLE LOCATIONS



FIRST FREEZE 248 C 2:01

× FACE SHEET T/C - 93 PLACES

⊗ TUBE T/C - 6 PLACES

TUBE	"A"	"B"
2	3.25	
4	3.90	
6	6.00	
8	8.20	
10	10.30	
12	12.40	
14	7.25	
16	8.30	
18	9.35	
20	10.40	
22	11.50	
23		66.80
24	12.50	64.30
25		62.30
26	13.60	58.90
28	14.70	53.50
30	15.70	48.20
32	16.75	43.00
34	17.80	38.00

NASA-JSC

by increasing the bypass temperature from 53°F to 108°F and the radiator inlet temperature from -100°F to 100°F over a 2.75 hour period. The third thaw showed the capability of the panel to recover using environment on the panels and no change in bypass or inlet temperature. Just prior to the environment thaw, the prime tube heater was used to thaw the forward panel after a complete freeze up of one loop. Approximately 38 minutes of prime tube heater operation was required to re-initiate flow. The fourth thaw was accomplished by increasing the panel flow rate and inlet temperature as rapidly as the flow bench would allow to obtain a severe thermal shock. The flow control valve was used to maintain the bypass and radiator outlet temperature to 38°F during all these thaws. In all cases the panel thaw rates were sufficient to meet the 38°F control temperature.

5.3 Analytical Model Correlation

Detailed analytical models of the aft and forward panels using the SINDA computer routine were used to make radiator performance predictions. These models have 26 tubes on the aft(one sided) panel and 34 tubes per side on the forward (two sided) panel. The tubes are divided into two systems with half of the tubes in each system. The aft panel has a total of 1451 nodes (262 fluid, 262 tube, 927 structure), while the forward panel has 3142 nodes (540 fluid, 540 tube, 2062 structure). The structural buildup which includes the facesheet doublers higher density honeycomb core and hinges are not modeled on either panel. Also, the aft panel attachment studs and forward panel deployment booms are not modeled. Test data was then used to verify modeling techniques. Table 5-13 and 5-14 present test data compared to analytical model results for selected testpoints of the aft and forward panels.

Pretest predictions for the aft panel analytical model predicted the mixed outlet temperature for most high load cases within 3°F during the test. The tube to facesheet temperature delta in the test was in the range of 1°F to 2°F, while the model was much higher. The model was corrected

TABLE 5-13

AFT PANEL TEST VS MODEL

Test Point	Test Main Tout °F	Model Main Tout °F	Delta °F	Flow/Sys Lbs/Hr	Test Prime Tout °F	Model Prime Tout °F	Delta °F	Flow/Sys Lbs/Hr	ENVR BTU/Hr-Ft^2
1	104.5	103.9	0.6	1383.	106.5	107.9	1.4	39.5	0
3	86.7	85.7	1.0	1187.	88.4	90.3	1.9	33.0	0
4	75.7	74.8	0.9	1192.	76.9	79.2	2.3	32.3	0
5	55.2	53.4	1.8	604.	56.6	68.9	12.3	16.8	0
6	67.2	64.1	3.1	592.	68.1	76.2	8.1	16.8	30
7	80.8	79.7	1.1	1199.	82.2	82.5	0.3	32.9	30
8	94.0	92.6	1.4	1193.	94.7	96.1	1.4	32.7	30
10	109.	108.2	0.8	1356.	110.4	111.1	0.7	38.2	30
16	101.5	99.6	1.9	1183.	103.5	102.1	1.4	32.4	60
17A	115.1	113.	2.1	1354.	116.6	116.2	0.4	38.0	60
19	88.2	86.5	1.7	1191.	89.9	89.1	0.8	32.7	60
20	78.9	75.7	3.2	608.	81.9	84.2	2.3	16.9	60

TABLE 5-14

FWD PANEL TEST VS MODEL

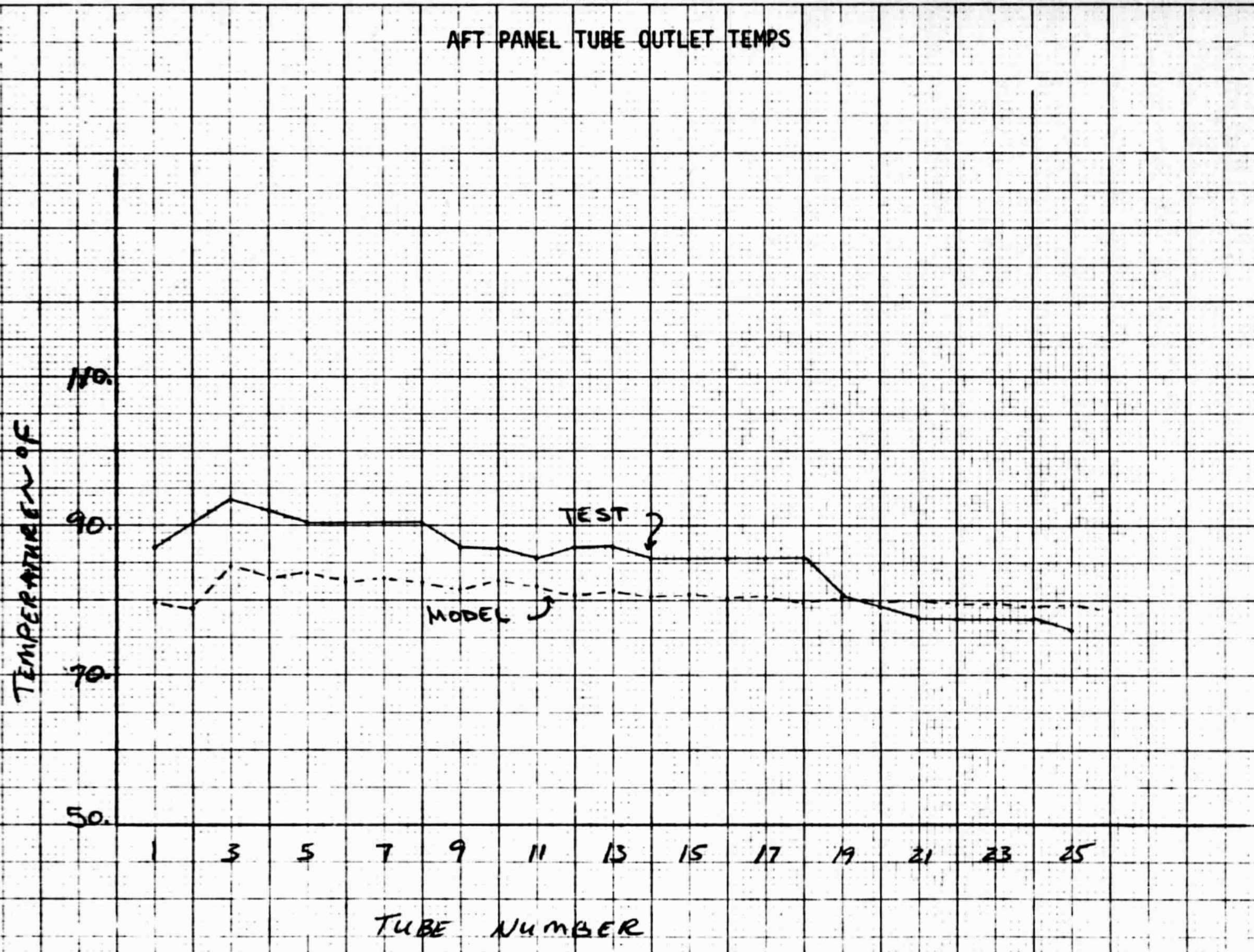
Test Point	Test Main Tout °F	Model Main Tout °F	Delta °F	Flow/Sys Lbs/Hr	Test Prime Tout °F	Model Prime Tout °F	Delta °F	Flow/Sys Lbs/Hr	ENVR BTU/Hr-Ft^2
1	67.0	65.2	1.8	1383.	90.2	87.8	2.4	39.5	0
3	48.5	46.3	2.2	1187.	71.4	68.7	2.7	33.0	0
4	39.3	38.3	1.0	1192.	61.0	58.8	2.2	32.3	0
5	2.2	0.8	1.4	604.	30.9	31.1	0.2	16.8	0
6	29.7	25.7	4.0	592.	51.3	48.6	2.7	16.8	40
7	55.9	52.8	3.1	1199.	71.8	69.2	2.6	32.9	40
8	65.8	62.4	3.4	1193.	83.3	80.3	3.0	32.7	40
10	80.3	77.6	2.7	1356.	98.6	95.7	2.9	38.2	40
16	82.6	77.1	5.5	1183.	97.9	93.3	4.6	32.4	80
17A	94.9	90.0	4.9	1354.	110.6	106.1	4.5	38.0	80
19	73.2	67.4	5.8	1191.	86.4	81.8	4.6	32.7	80
20	57.1	48.0	9.1	608.	75.7	69.1	6.6	16.9	80

and after measured test data was input for flow rate and inlet temperature, the analytical model showed less than 2°F difference from measured test values for most of the selected test points compared. This is within the resolution of the test measuring devices. The only questionable area is test point 5 and 6, where the prime tube outlet in the test measured 12.3°F and 8.1°F, respectively, less than the analytical model. However, during the test it was noted that the flow meter registering low flow had intermittent output for flows around 10 lbs/hr and questionable accuracy. The prime tube flow is in the suspect range for both of these test points. Therefore, it appears the difference in temperature is attributed to a larger flow used in the analytical model than actually existed in the test.

Correlation of the forward panel was not as straight-forward as the aft panel. First, the payload bay door simulator was modified in the analytical model from 15 to 18 zones to correspond to the test article and the view factors between the door and panel were changed. The LN_2 panel which covered the cavity opening was also added to the model. Again, the tube to facesheet temperature delta had to be corrected. These changes allowed the mixed outlet temperature of the model to match the test data for test points when the quartz lamp array and payload bay heaters were not being used. However, as flux was applied to the forward panel the temperature difference between the model and test increased. (See Table 5-14). The analytical model is consistently lower than test data, indicating more flux is needed to correlate the model. However, the aft panel required no additional flux, indicating the chamber background was negligible. Therefore, the problem exists with the cavity portion of the forward panel. The model assumes diffuse properties for the silver-teflon when in actuality it is specular. This specularity reduces radiant interchange with the payload bay door and IR panel which causes a reduced heat rejection. It appears that the diffuse IR panel and specular forward panel and PBD with heat addition to the PBD cannot be precisely modeled using a diffuse cavity.

During the test, it was noted that the face sheet thermocouples on the test panel did not agree with the analytical model even though the mixed outlet temperature agreed. Figure 5-33 shows a plot of

FIGURE 5-33



AFT PANEL TUBE OUTLET TEMPS

individual tube outlets for the aft panel measured test data versus the model prediction. The tube outlets on the outboard edge agree fairly well. However, the temperature difference increases as it approaches the hingeline. If the predicted tube outlets are made to agree with the test data by adding flux to the tubes on the hingeline, the mixed outlet temperature will increase and no longer agree with the test. Therefore, it appears that the thermocouples were in error.

Table 5-15 presents the data used to correlate the models for low load. The aft panel required an additional flux of 5 BTU/HR-FT^2 to match the model to test predictions. This could be due to the facesheet doublers, higher density honeycomb core, hinges and attachment studs which were not modeled, but did exist on the test panel. This structure would not be as significant at the the high load operations, but would be at the low load.

The forward panel model matches the low load test data fairly well as shown in Table 5-15. However, the forward panel model does not have the deployment booms or the other structural buildup modeled which was on the test panel. Also, the frozen tubes in the test which cause flow to stop, also cause a different flow skew across the panel and SINDA does not have the capability to have tubes with no flow. Therefore, low load cannot be accurately modeled for these conditions and the model correlation is questionable.

In Reference 5, an attempt was made to correlate the 50° cavity radiator test data using a simplified system model. Figure 5-34 presents test data for the baseline and wide cavity (50°) forward radiator heat rejection versus total panel absorbed flux for inlet temperatures of 80°F and 110F. The test data indicated that the 50°cavity performance was worse than the baseline except for very high values of absorbed flux. This result cannot be valid for a system in which every variable except the deployment angle has been held constant. This indicates that the test conditions were not the same for the wide cavity test as they were for the baseline test. In the wide cavity test the LN$_2$ panel which had covered the cavity for the baseline test was not installed. Further investigation revealed the probability that the chamber wall adjacent to the cavity was much warmer than the -300°F that was expected. It was beyond the scope of this task to determine the flux contributed due to the warmer chamber wall. Therefore, an attempt to correlate the wide cavity detailed panel model was not attempted.

TABLE 5-15

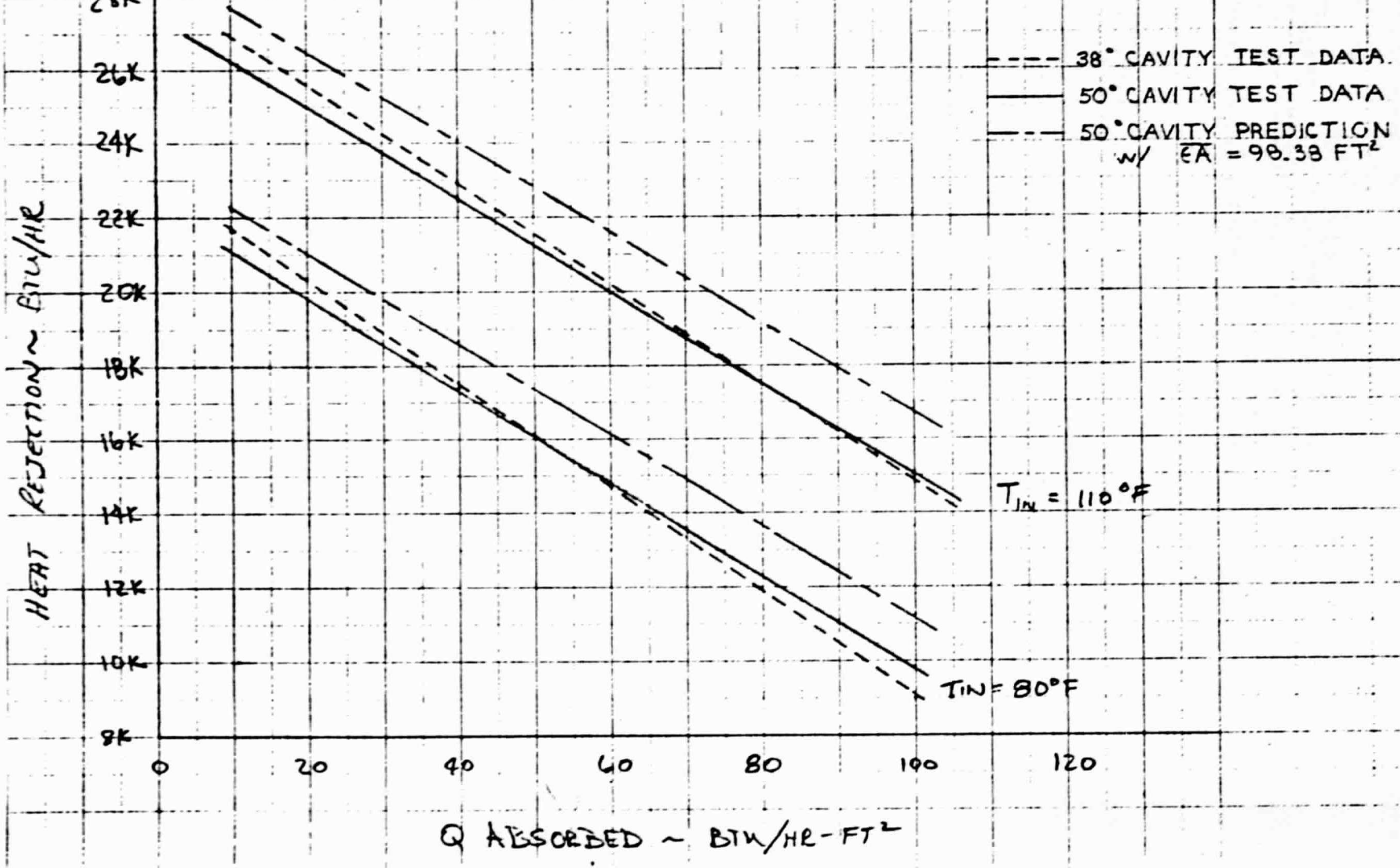
LOW LOAD CORRELATION

Panel	Test Point	T_{IN} °F	Tout °F	Flow Lbs/Hr	QREJ BTU/Hr	Remarks
Aft	45	-107.6	-144.2(-156.9)	160.8	1369.(1844.)	
Aft	45	-107.6	-144.2(-142.8)	160.8	1369.(1316.)	5 BTU/Hr-Ft^2 Added to Model
Aft	46A	-100.7	-139.5(-148.7)	91.8	1658.(2051.)	
Aft	46A	-100.7	-1395.(-137.1)	91.8	1658.(1555.)	5 BTU/Hr-Ft^2 Added to Model
Fwd	45	-143.6	-177.4(-173.8)	160.8	1265.(1130.)	
Fwd	46A	-138.9	-170.4(-171.9)	91.8	1348.(1412.)	

XXX	Test Data
(XXX)	Model Prediction

FIGURE 5-34

BASELINE AND WIDE CAVITY RADIATOR PERFORMANCE COMPARISON



5.4 Control Valve Evaluation

A total of 22 test points were conducted to evaluate the control valve and electronic controller design functions. The initial test results indicated unstable valve operation and controller operating discrepancies. Subsequent to modifications to the controller electronics, made real-time during the test, the test results demonstrated that the controller and valve could provide a stable controlled temperature over a wide range of operating conditions and could provide a smooth transition between a 38°F control temperature and a 60°F control temperature. The valve is unique in that two cold streams (the main outlet and the prime outlet) and one hot stream (bypass from radiator inlet) are mixed to provide a controlled outlet. The valve had three ports (hot, cold and mixed) and the prime outlet was joined with the valve mixed outlet just downstream of the valve. Figure 5-35 shows a schematic representation of the test system. The fluid conditioning equipment and flow meters contained in the radiator supply line and the bypass line resulted in a higher system pressure drop than expected for the flight valve. The test pressure drop is estimated to be approximately 50 psi, whereas the flight conditions will be less than 30 psi.

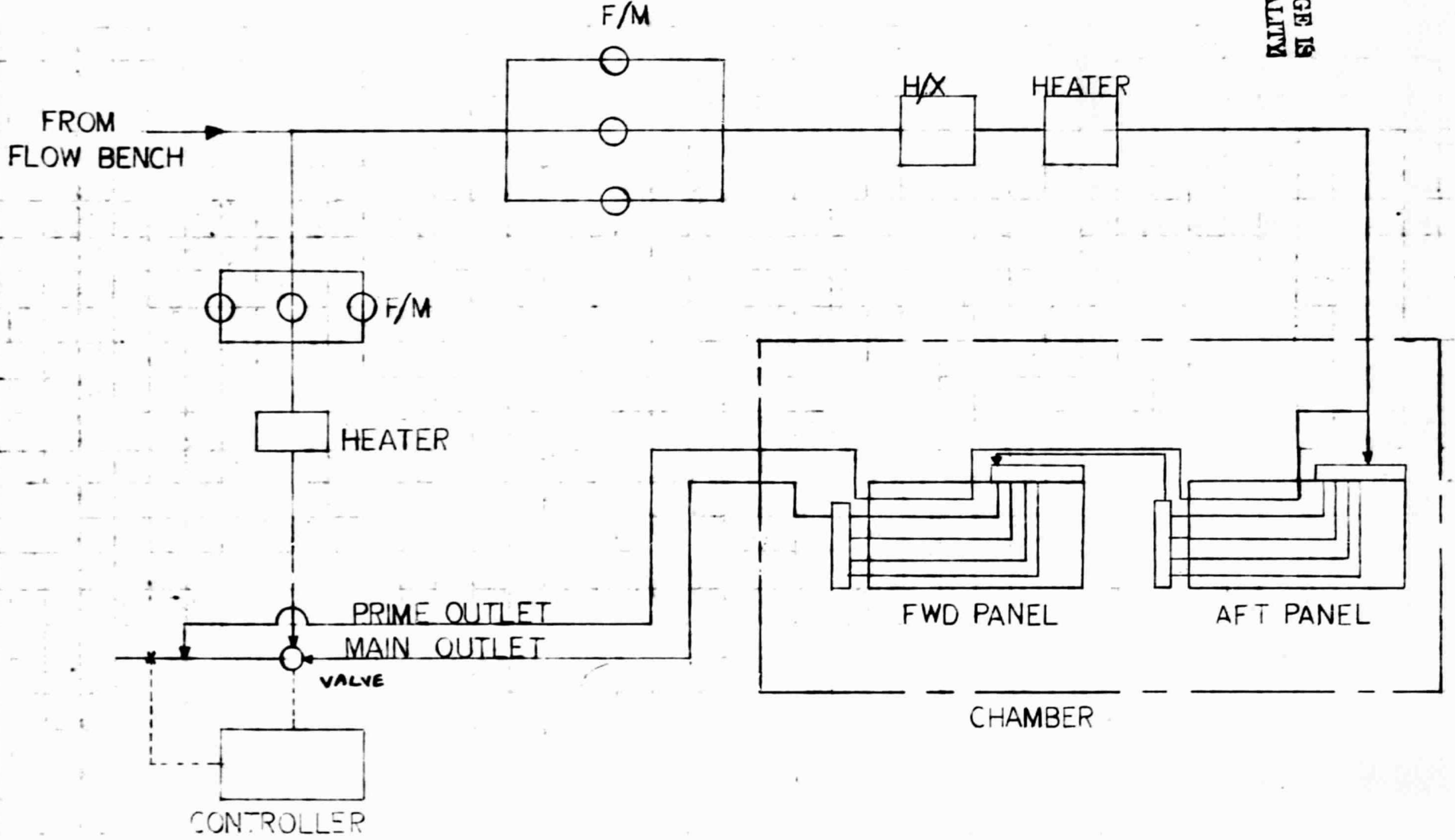
The testing was designed to evaluate the control valve under 3 operating conditions:

1. Constant inlet temperature - variable outlet temperature due to orbital environment fluctuations, TP 29-36.
2. Set point changes 38°F to 60°F to 38°F with constant inlet temperature and transient outlet temp. TP 37-39.
3. Cold soak and rapid transient to high load condition - 20°F/hr increase in inlet temp. TP 44A.

During the latter part of week one testing (Day 233) test points 29 and 30 were initiated. Valve no. 2 did not control the mixed outlet to 38°F when the radiator outlet went below the control point. Further valve testing was delayed and the test proceeded with other test points. The valve and controller were checked out over the weekend between week one and week two testing. Controller no. 2 appeared to be operating satisfactorily during the checkout procedures. Some moisture (condensation) was found in the thermistor

FIGURE 5-35

TEST FLUID FLOW SCHEMATIC



probe assembly which changed the measured resistance characteristics. It was speculated that this prevented proper signals to the controller. The thermistor probe assembly was reconfigured to alleviate the moisture problem.

TP 37-39, valve setpoint changes, were run during the first part of week two (Day 237). Again, the valve did not provide adequate control and the test points were completed with manual control of the valve. The controller was still not providing the proper signals to the valve. The valve was isolated from the system and an investigation into the problem was made as other test points continued without loss of test time. The investigation of the electronic controller indicated that the electronic stepping motor driver PC board purchased from IMC had bad characteristics. When improper trigger pulses were applied to the driver board, the board would lock up and apply current to all three windings of the stepping motor continuously. The application of proper trigger pulses would not unlock the driver board.

Electronic circuit changes were made to the controllers to provide better noise immunity and reduce the chance of improper trigger pulses being applied to the stepping motor driver board.

TP 29-36 were run (Day 238) with the repaired controllers. Figures 5-36 and 5-37 present the results of these tests. The control function is observed to operate satisfactorily with a total flow of 1250 lbs/hr (TP 29-31) expect for short periods, e.g., between 18:13 to 18:18 hrs and 18:42 to 18:53 hrs for loop one (Figure 5-36) and between 18:55 and 19:03 hrs for loop two (Figure 5-37) where the 38°F ±2°F tolerance is exceeded. With a total flow of 625 lb/hr the valve began to oscillate when the outlet temperature reached approximately -30°F for loop two and -35°F for loop one. Loop two also began to oscillate at -65°F outlet temperature with 1250 lb/hr flow although loop one remained stable. Test point 36 was rerun with 1450 lb/hr as TP 36A to determine the effect of flow rate on flow stability. The following table illustrates the valve sensitivity to total flow rate.

FIGURE 5-36

LOOP 1 VALVE TEST

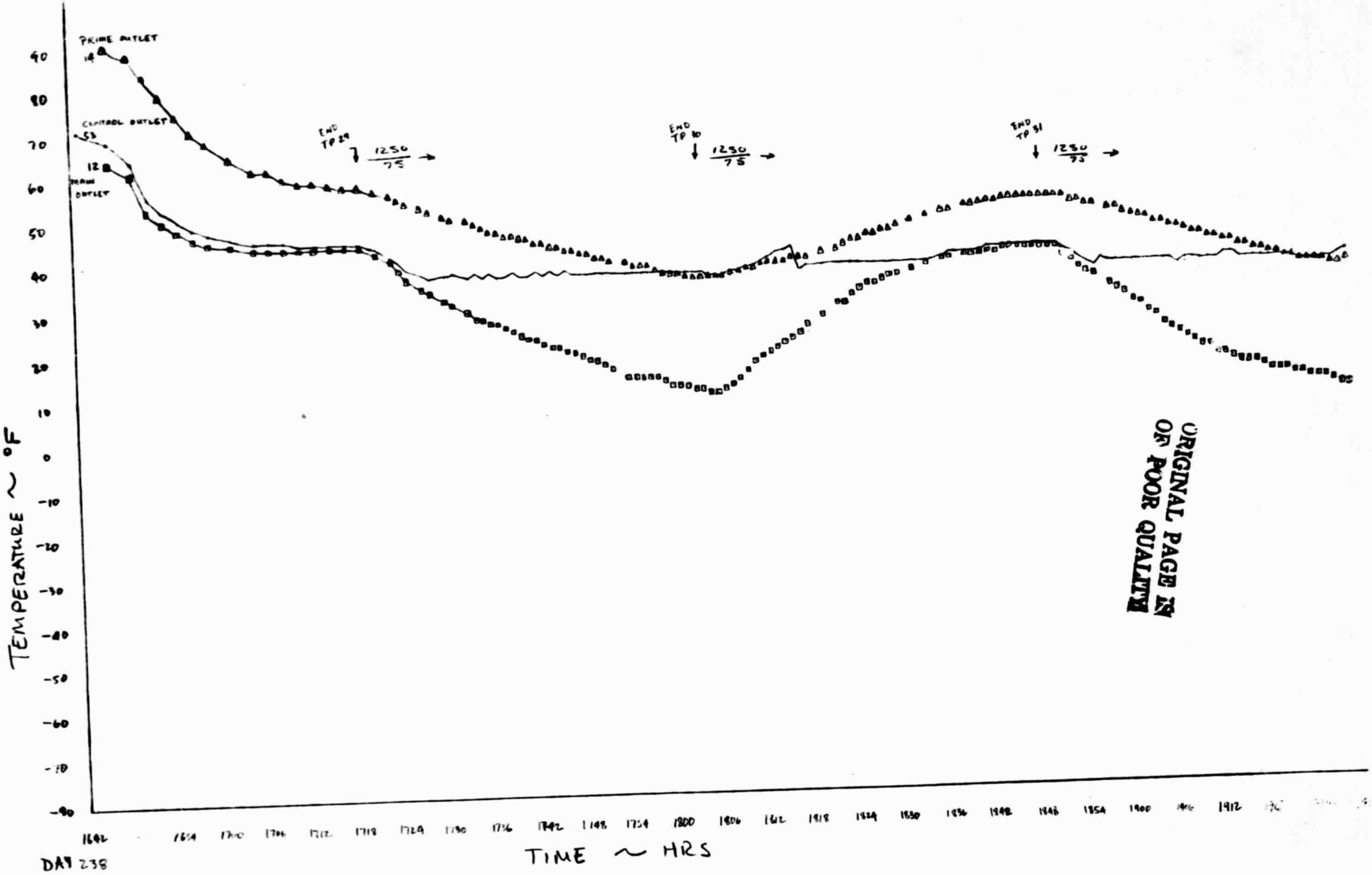


FIGURE 5-36 - (Cont)

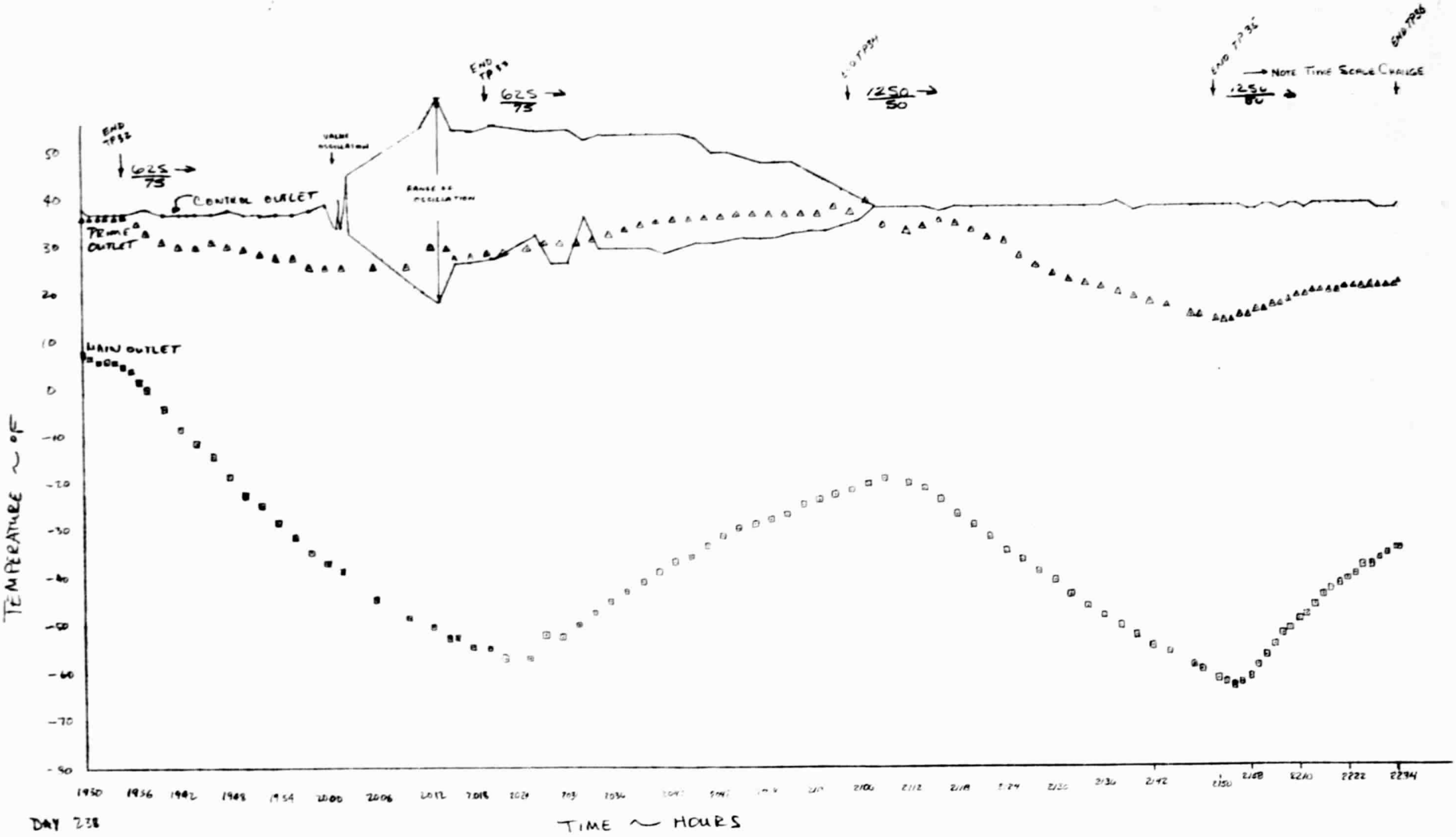


FIGURE 5-36 (cont)

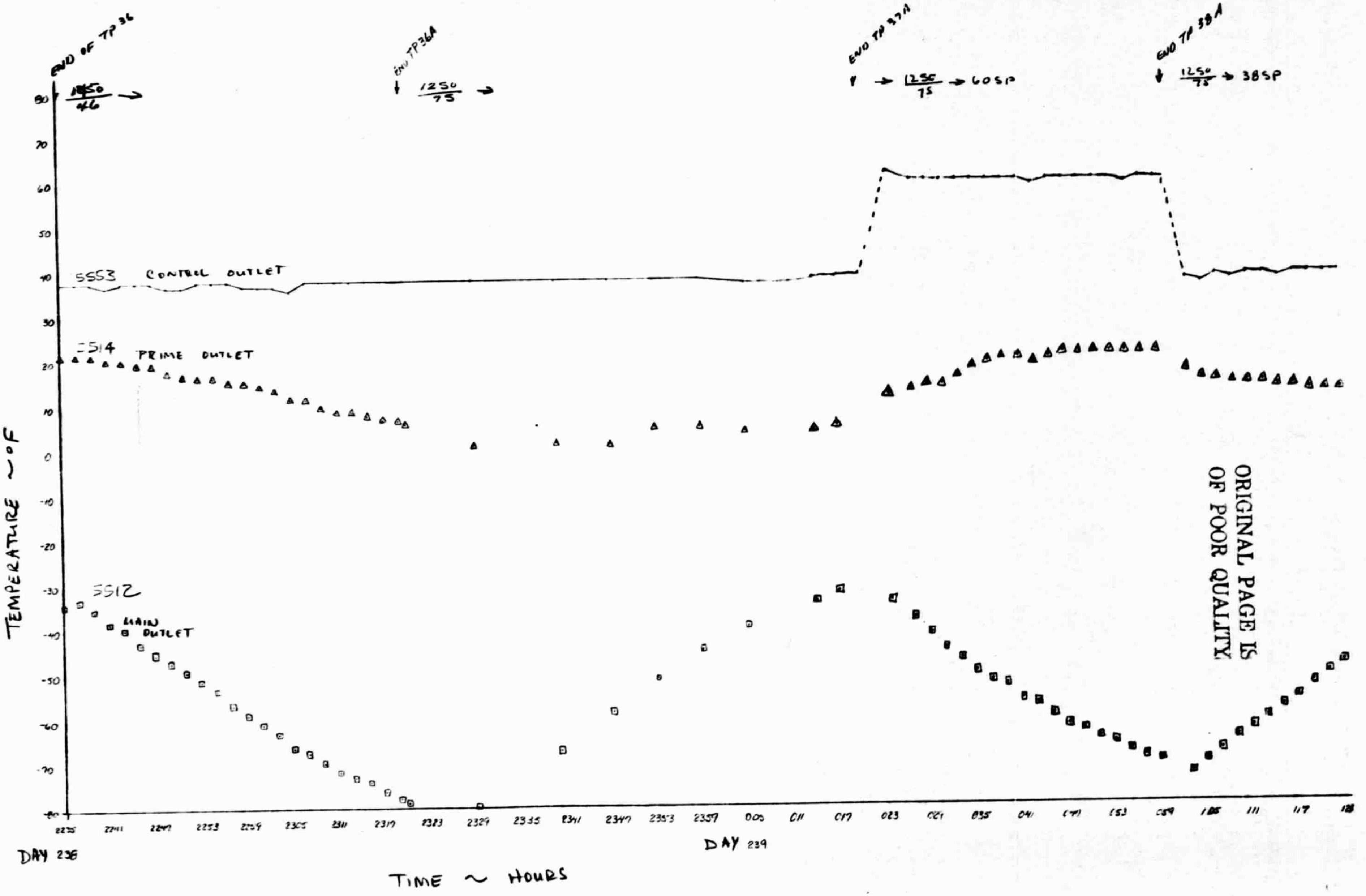


FIGURE 5-36 (CONT)

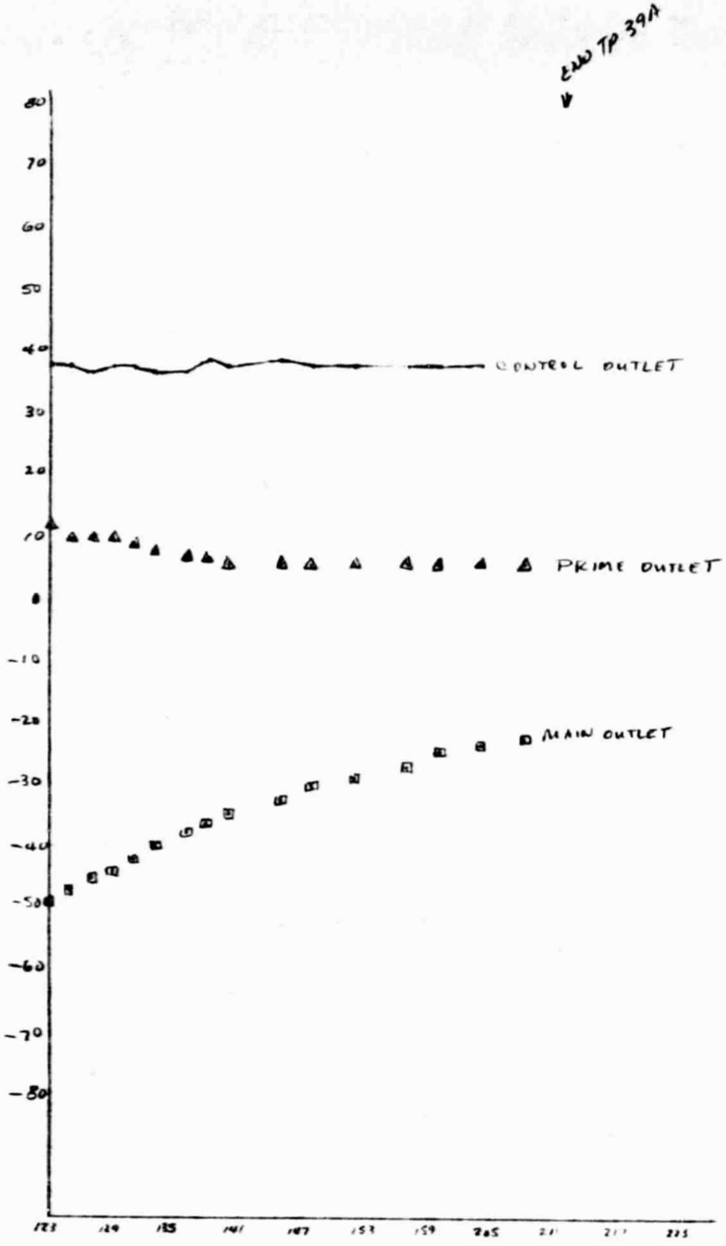
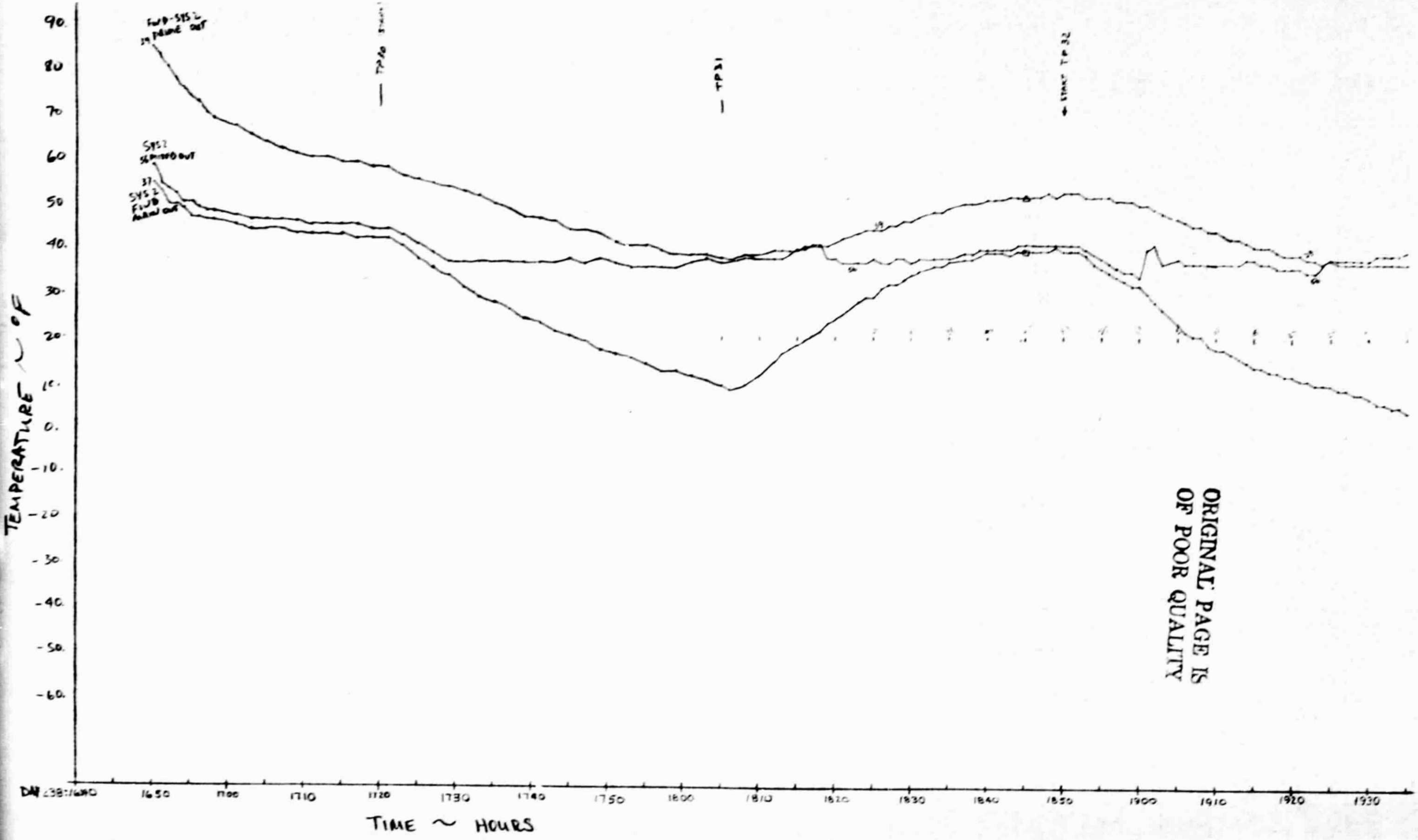
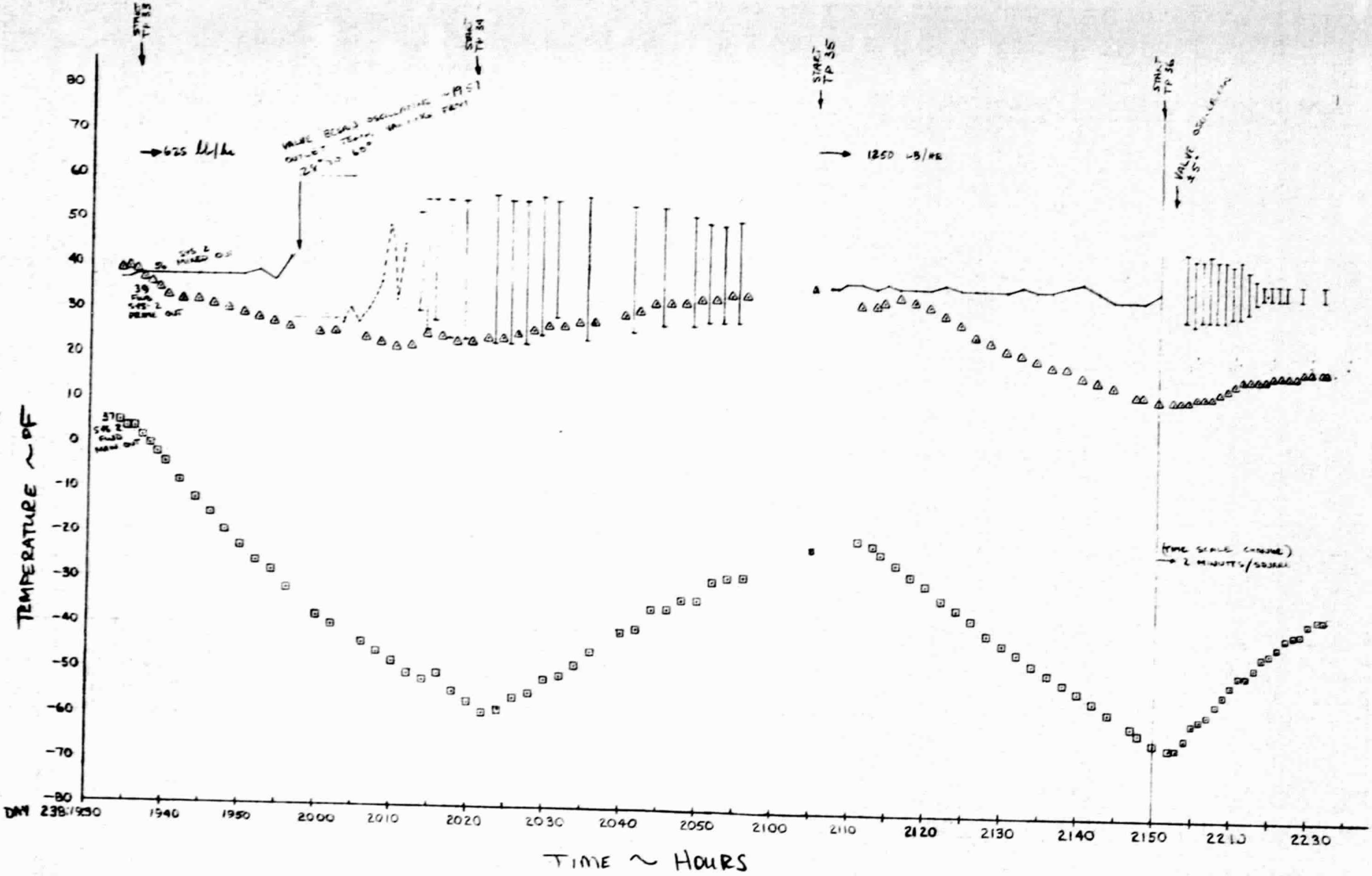


FIGURE 5-37
LOOP 2 VALVE TEST



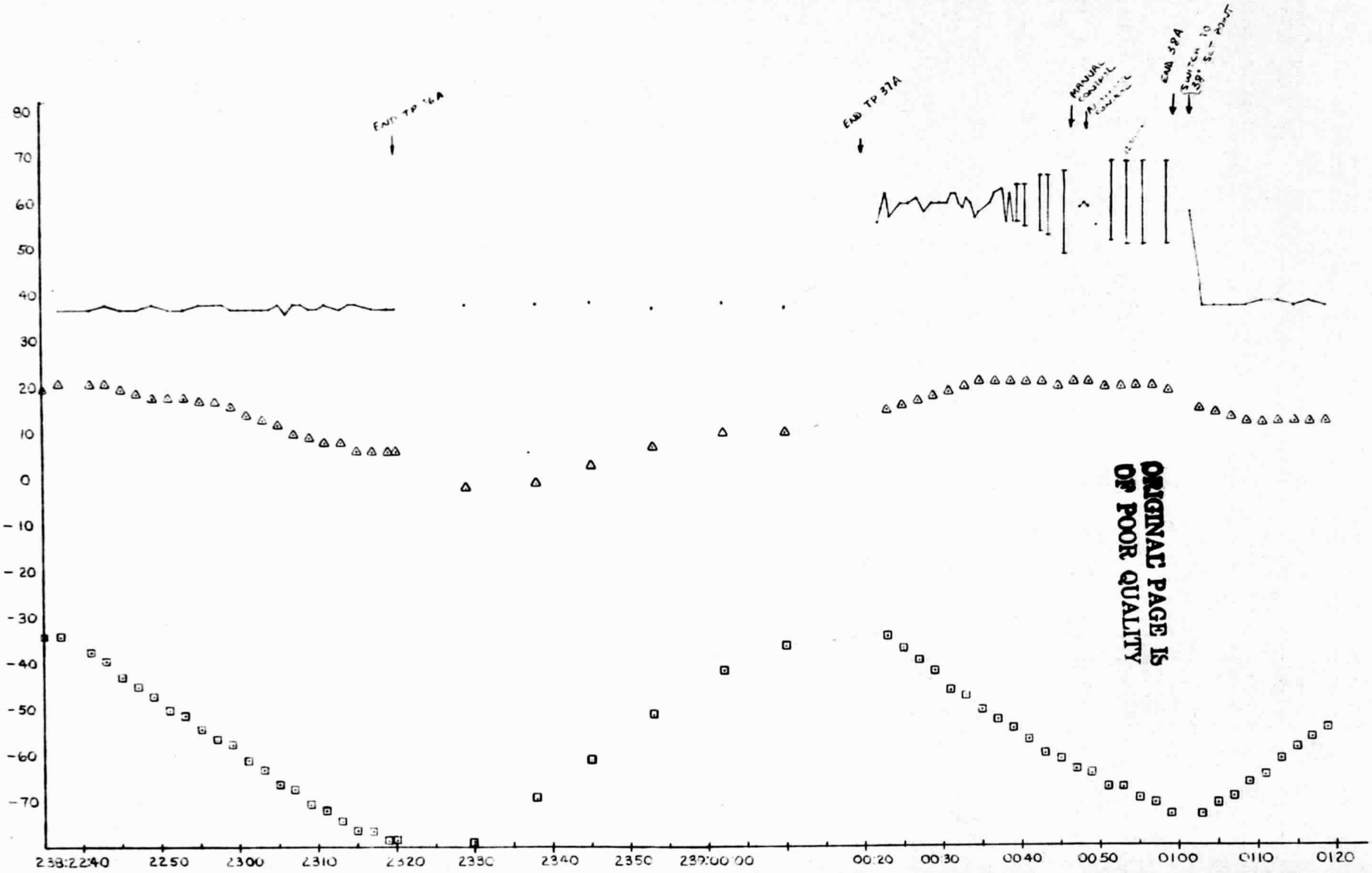
MAP/JGR

FIGURE 5-37 (CONT)



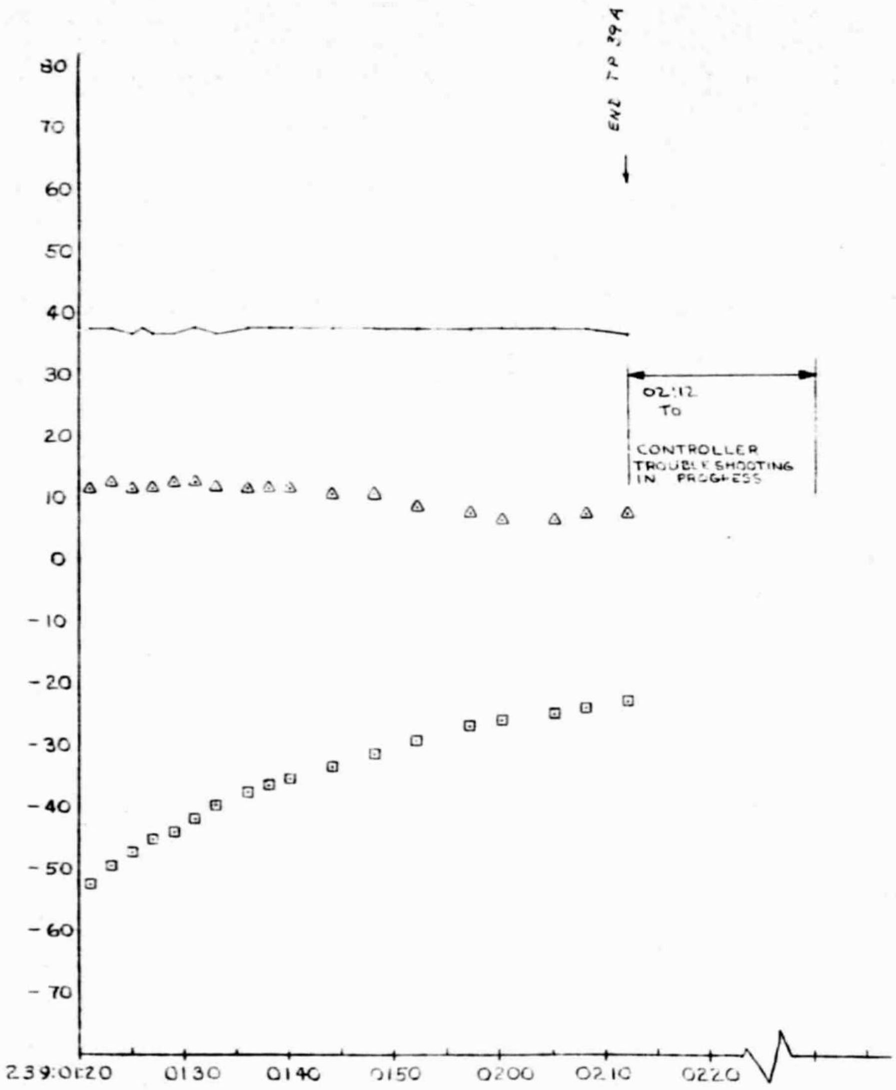
JGR

FIGURE 5-37 (CONT)



JGR

FIGURE 5-37



JGP.

Test Point	Total flow-lb/hr	Coldest Temperature - °F	Valve Stable
33-34	625	-30	No
35-36	1250	-65	No
36A	1450	-75	Yes

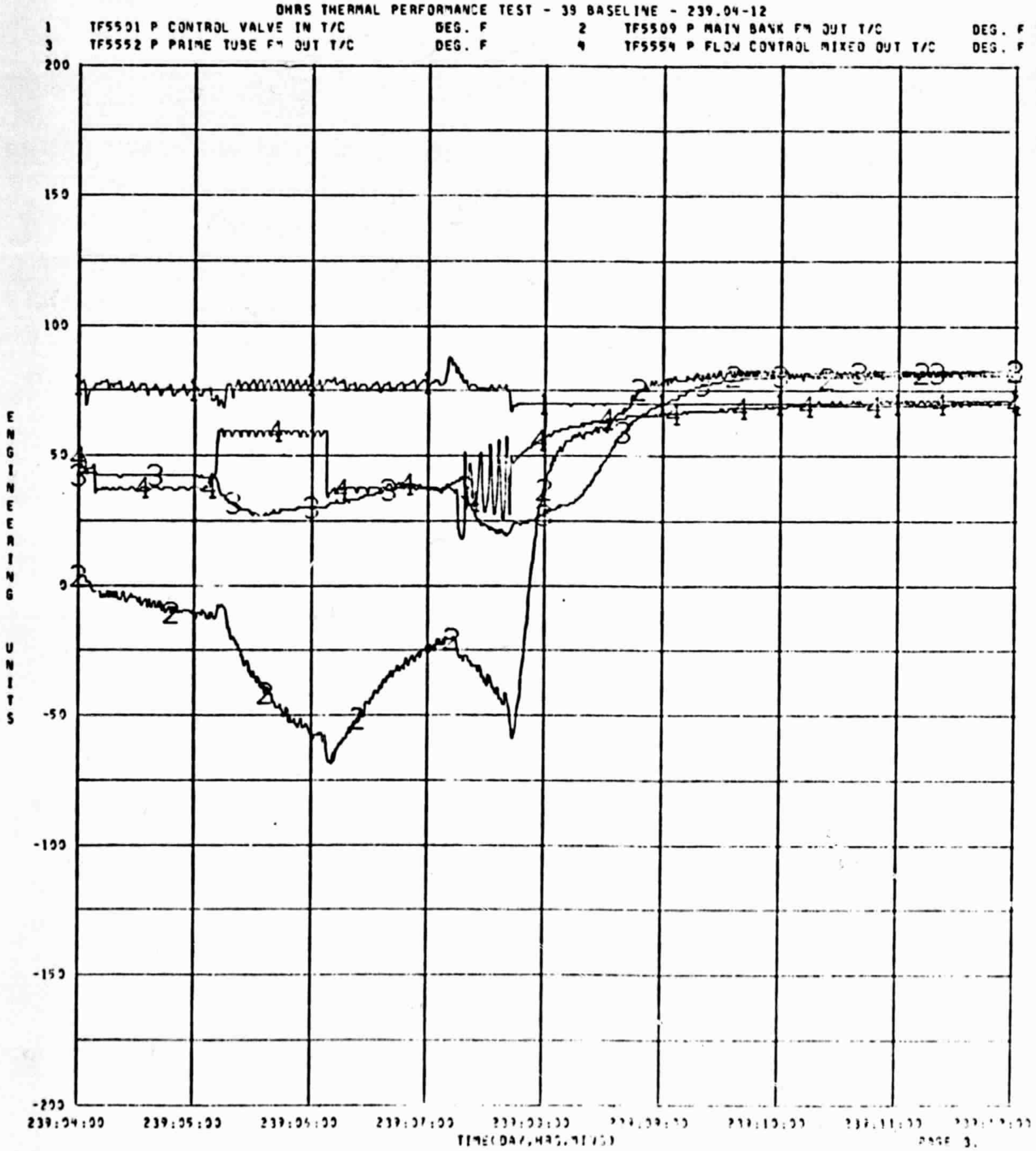
The test configuration represents only one of the parallel radiator legs (see Figure 3-1). Thus, the test flow rates through the valve are only 1/2 the flight configuration flows. The 625 lb/hr flow was run only to provide colder radiator outlet temperatures and is much less of a realistic condition than the 1250 or 1450 lb/hr flows. TP 37-39A were run to evaluate the control function during the transition between 38°F and 60°F set point temperatures. As indicated by Figure 5- 37, approximately 239:00:20, loop 2 became unstable when the set point was changed from 38°F to 60°F.

An examination of the test data indicated that a slower initial valve speed would improve the stability. Accordingly, the pulse rate from the stepping motor driver board was reduced to 2 pulses per second from the original 12 pulses per second for sensed temperature errors of ±0.5°F. Above ±0.5°F error the pulse rate is changed to 12 pulses per second.

Subsequent to this design change the valve set point change test points were rerun as TP 37AA-39AA. These results are shown on Figures 5-38 and 5-39. As indicated the control system provided a smooth transition between set points. A minimum temperature of 34°F was observed during the change from 60°F to 38°F set point. Test point 33 was also rerun with the design changes as TP 33AA with a flow rate of 625 lb/hr. The control function was still not able to maintain stable conditions as shown on Figures 5-38 and 5-39 at approximately 239:07:15. However, as previously discussed this is an unrealistic condition for the valve and should not be considered a design discrepancy.

Test point 44A was run to evaluate the valve performance during a cold soak and subsequent transient (20°F/hr increase in inlet temperature) to a high load condition. Figures 5-40 and 5-41 show the results of this test. The control function demonstrated stable operations throughout including

FIGURE 5.38



|← T.P. 37AA - 39 AA →| TP 33AA

625 LB/HR

TOTAL FLOW

FIGURE 5-39

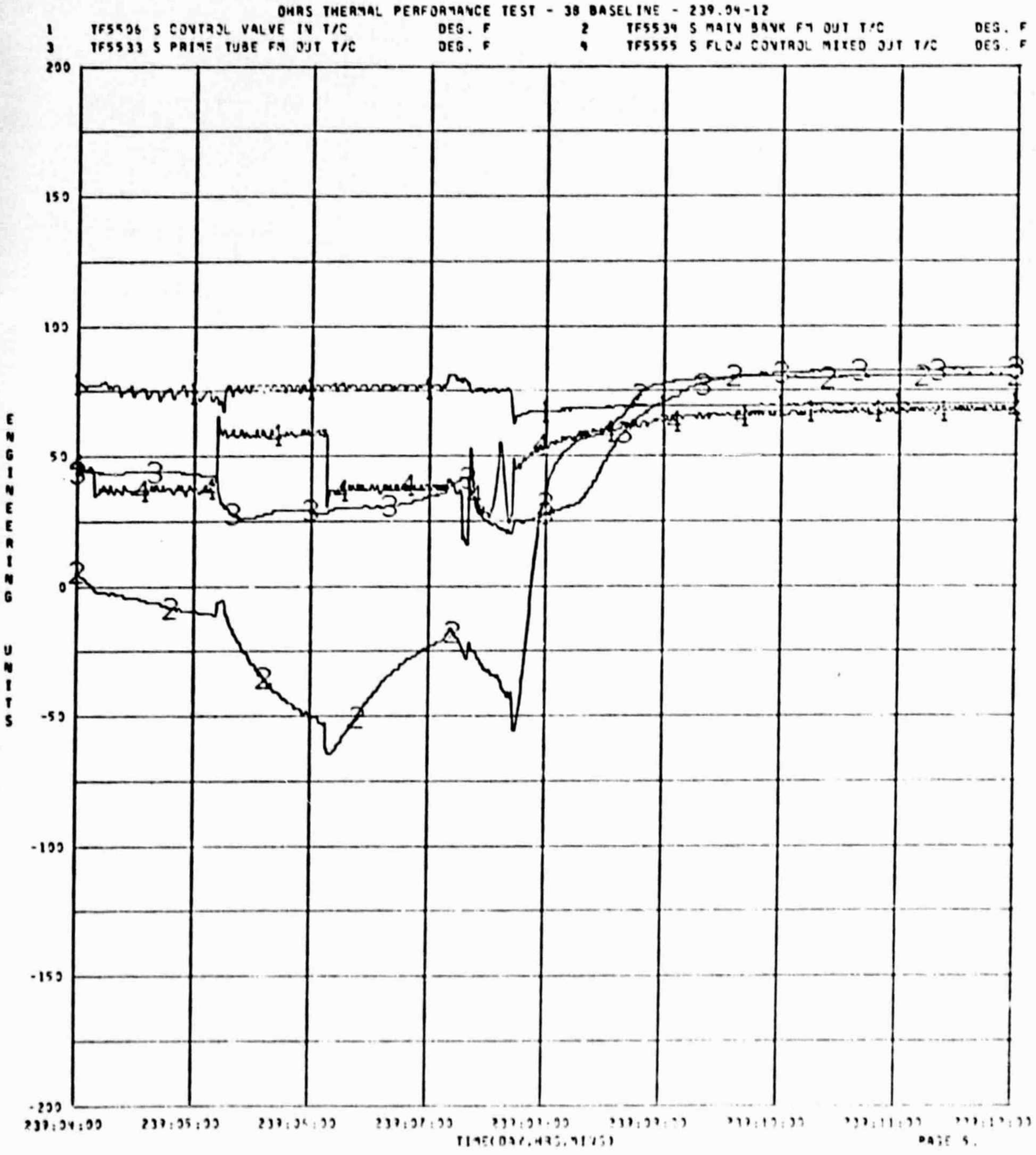

OHRS THERMAL PERFORMANCE TEST - 38 BASELINE - 239.04-12
1 TF5506 S CONTROL VALVE IN T/C DEG. F
2 TF5534 S MAIN BANK FM OUT T/C DEG. F
3 TF5533 S PRIME TUBE FM OUT T/C DEG. F
4 TF5555 S FLOW CONTROL MIXED OUT T/C DEG. F
200
150
100
50
0
-50
-100
-150
-200
ENGINEERING UNITS
239:04:00
239:05:00
239:06:00
239:07:00
239:08:00
239:09:00
239:10:00
239:11:00
239:12:00
TIME(DAY,HRS,MINS)
PAGE 5.

FIGURE 5-40

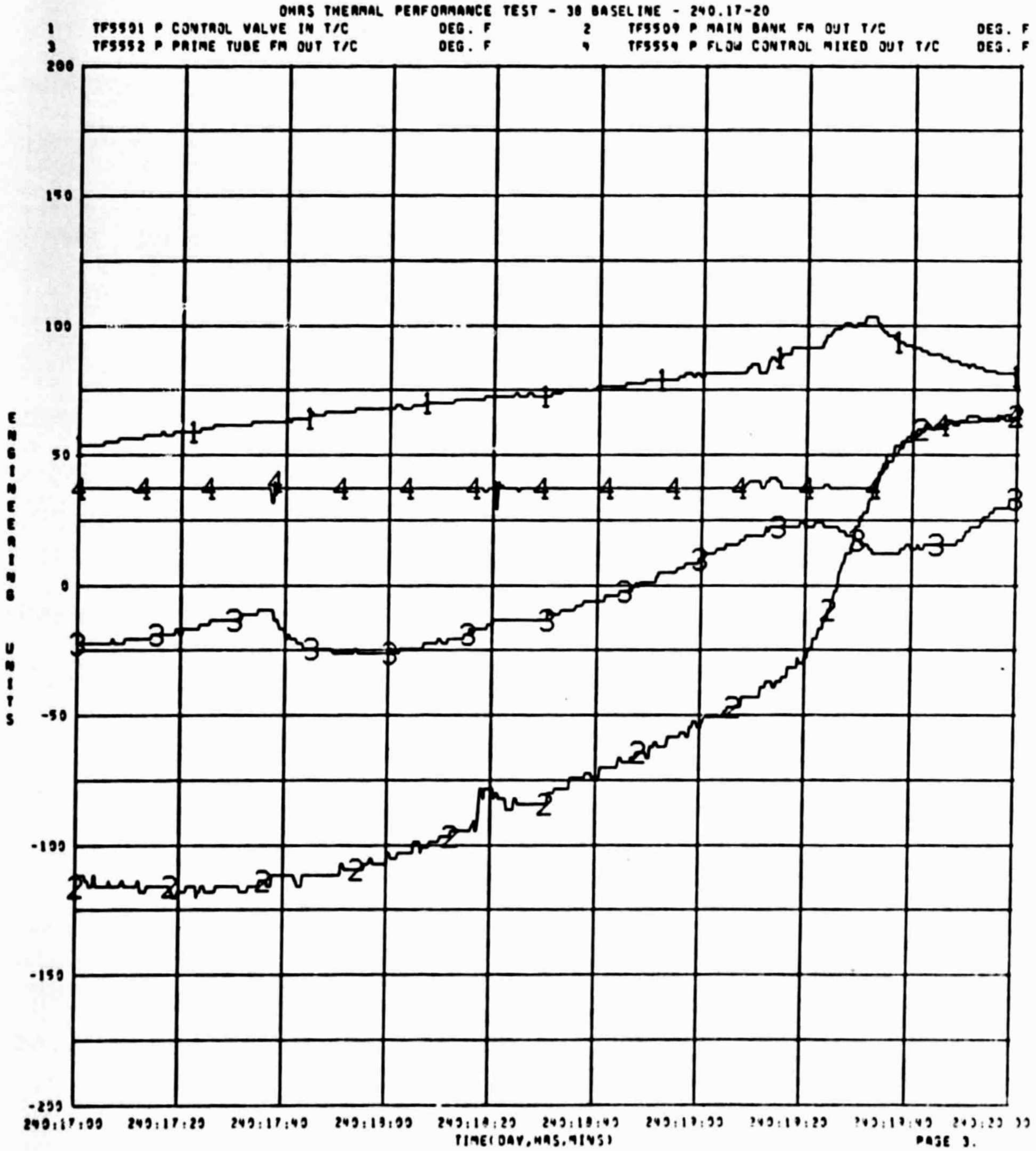
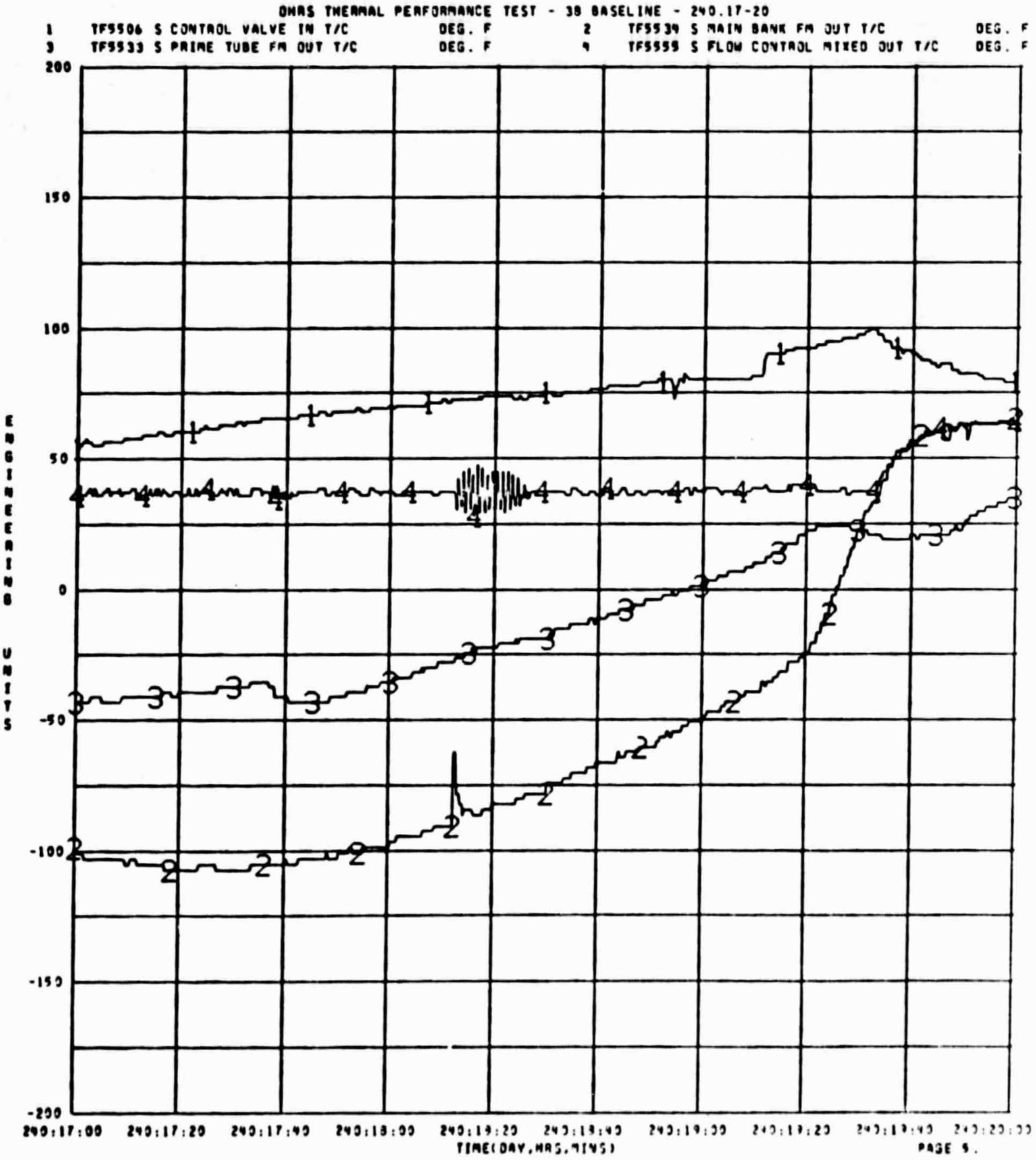

OHRS THERMAL PERFORMANCE TEST - 38 BASELINE - 240.17-20
1 TF5501 P CONTROL VALVE IN T/C DEG. F
2 TF5509 P MAIN BANK FM OUT T/C DEG. F
3 TF5552 P PRIME TUBE FM OUT T/C DEG. F
4 TF5554 P FLOW CONTROL MIXED OUT T/C DEG. F
ENGINEERING UNITS
200
150
100
50
0
-50
-100
-150
-200
240:17:00
240:17:20
240:17:40
240:18:00
240:18:20
240:18:40
240:19:00
240:19:20
240:19:40
240:20:00
TIME(DAY,HRS,MINS)
PAGE 3.

FIGURE 5 -41



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OF POOR QUALITY

a radiator outlet temperature of -120°F. The control temperature oscillation which occurred between 240:18:10 and 240:18:30 was caused by a sudden change in the radiator supply line pressure drop when a higher range flow meter was brought on line. The flow meter arrangement (Figure 5-35) had three parallel legs with a different range meter in each leg. Normally only one leg was flowed - the other two legs are valved off. As flow is increased through the radiator and reduced through the bypass line the flow meters are manually valved in or out to insure continuous recording from maximum to minimum flow. The manual procedure involves momentarily opening a parallel leg then shutting off the out of range flow meter leg. This technique caused sudden changes in pressure drop and flow rates which the valve could not compensate for. Manual control of the valve was required to reestablish stable conditions.

6.0 CONCLUSIONS/RECOMMENDATIONS

The L-tube radiator panels were tested over a wide range of heat loads, environmental conditions and cavity deployment angles during a five week period for a total of 460 hours of thermal vacuum testing. The high load phase of testing provided steady-state performance data for dual and single loop operation. In addition, performance data was gathered for inlet temperature gradients between loops and for several solar simulation "on-orbit" environments. Also provided was performance data for low load operations with and without prime tube flow.

The high load performance data included environmental fluxes from 0 to 80 BTU/hr ft^2 and inlet temperatures of 130°F for the aft panel and 115°F for the forward panels. Both panels exhibited good heat rejection characteristics with high fin effectiveness and tube to face sheet conductance. An average fin effectiveness of 0.966 for the aft panel and 0.955 for the forward panel was measured. Tube to face sheet temperature differences of 2 - 3°F are indicated by the data although precise measurements were not possible due to the wide thermocouple resolution and accuracy. The data also indicated that heat rejection could be improved by optimization of the tube sizes to improve panel flow distribution. Only standard tubes were used in the test hardware.

The advantage of flowing two redundant loops in the same panel was demonstrated by the test data which indicated only a 12 to 24% loss in heat rejection capability with the loss of one loop. Dual loop operation with different inlet temperatures indicated no performance degradation or anomalous operation. Results of testing with skewed, fluxes representative of on orbit solar focusing by the forward radiator panel and door cavity indicated no change in performance from the uniform flux results.

Low load stagnation/destagnation operation was demonstrated with both the prime tube and inherent stagnation methods. The inherent stagnation design eliminates the requirement for additional panel supply and return lines, thus providing design simplification and weight savings. The inherent stagnation/destagnation test demonstrated that at least 52 of the 68 forward panel tubes could successfully be stagnated and thawed. Total panel heat rejection was reduced to only 42.3 BTU/hr during this low load test. Recovery of a frozen panel was also demonstrated by the use of electrical surface heaters in the prime tube area.

Analytical thermal models of the aft and forward panels using the SINDA computer routine were used to make pretest radiator performance predictions. After analyzing the test data, model adjustments were made which allowed a better correlation between the test data and the analytical model for panel heat rejection (radiator outlet temperature). However, the radiator panel temperatures from the analytical model did not always match the test data. It was concluded the error must have been due to bad thermocouple readings. The aft panel model predictions and test data show good agreement. The forward panel model does not provide adequate predictions of panel performance under the high panel fluxes (80 BTU/hr ft^2) and payload bay door fluxes. Comparisons of predictions and test data for the 0 - 40 BTU/hr ft^2 flux conditions indicate a fair agreement. Apparently, the complex specular radiant interchange between the panel and door (even more complicated in the test set-up by a diffuse LN_2 panel over the cavity opening) is not adequately modeled or there is an unknown reflected flux in the test that is not accounted for in the analysis. The prediction error steadily increases with increased environment.

Several test points were conducted to evaluate the control valve and electronic controller design functions. The initial test results indicated unstable valve operations and controller operating discrepancies. Subsequent to modifications to the controller electronics, made real-time during the test, the test results demonstrated that the controller and valve could provide a stable controlled temperature over a wide range of operating conditions and could provide a smooth transition between a 38°F control temperature and a 60°F control temperature.

All the principal objectives of the test program were achieved which allowed the L-tube test program to be considered a complete success.

APPENDIX A

WEEKLY STATUS REPORTS

OHRS RADIATOR TESTING

1ST WEEK

STATUS REPORT

AUGUST 22, 1975

1.0 TEST ARTICLE

Visual inspection was made of the radiator panels prior to chamber closeout. The forward panel top surface coating was in good condition, with only minor evidence of peeling. The forward panel bottom surface coating had numerous places where the edges of the silver teflon strips had begun to curl up. The more pronounced peel areas had been repaired by LTV. In general, however, the surface appeared in satisfactory condition for testing. The coating on the PBD was in acceptable condition. The aft panel surface coating was in good condition, except that there were at least three places where the edges were curled up for distances of several inches. It was not possible to repair the aft panel coating due to inaccessibility.

2.0 INSTRUMENTATION ASSESSMENT

The test dry run performed in the week preceding pumpdown identified test article and facility instrumentation that required checkout and repair.

After chamber closeout, and during the pumpdown operation, the following radiator test instrumentation was found to be off-scale or an erroneous display.

FM 5656 Loop 2 Prime Flowmeter - Error (Factor of 10)
FM 5660 Total Flowmeter - Error (Factor of 10)
CC 1252 PBD Simulator Zone 48 T/C - Off Scale Low
FA 0603 Fwd Radiator Panel T/C - Off Scale High
FA 0636 Fwd Radiator Panel T/C - Off Scale High
FA 0658 Fwd Radiator Panel T/C - Reading Low
FA 0647 Fwd Radiator Panel T/C - Reading Low
AF 0766 Aft Radiator Panel T/C - Reading Low
AF 0818 Aft Radiator Panel T/C - Reading High

Instrumentation at beginning of test was adequate to accomplish radiator test objectives. A complete listing of faulty measurements at conclusion of the first week of testing will be contained in the NASA Discrepancy Report (DR) prepared by the Quality Assurance Inspector.

3.0 TIMELINE

Table 1 summarizes the timeline as run. In general, the planned timeline was followed up to the bypass valve problem at TP 30 (further discussed in section 5.0). Test sequence 2 and 3 were

TABLE 1

TEST POINT	COMPLETION TIME DAY HR MIN	TEST POINT	COMPLETION TIME DAY HR MIN
1	230 17 35	18	232 13 00
2	19 05	19	14 20
3	20 50	20	16 45
4	23 20	26	20 00
5	231 01 52	25	22 00
6	05 55	24	233 00 35
7	08 40	23	04 05
8	10 57	22	07 05
9	13 05	21	11 18
10	14 20	28	14 30
11*	18 40	27	18 15
12*	19 50	29**	19 15
13*	22 30	30**	20 00
14	232 02 20		
15	04 35	40	234 05 35
16	05 55	41	10 48
17	07 10	43	Aborted****
17A***	10 28		

* Test Point not valid due to low flux setting

** Test Point not valid due to bypass valve problem

*** 17A is a repeat of Test Point 11

**** Test Point lost due to ACE system failure run in reverse order to reduce overall test time and TP 11 was repeated (identified as TP 17A). Upon observing the valve problem, test sequences 4 and 5 were deferred to second test week (they require an operating bypass valve), and test sequence 6 was initiated (it does not require bypass valve operation). Test sequence 6 was planned for the second week of testing, but was run, in part, the first week in place of sequences 4 and 5.

The following times to reach steady state were observed during the test and are provided for planning purposes.

		Hours
(1)	Change fluxes	4
(2)	Change flow 1450/1250	1
	1250/625	2.5
(3)	Change inlet temperature 15°	2

4.0 PERFORMANCE

Sequence 1 - Two Loop High Load Performance (Test Points 1-20)
The test results indicated that the heat rejection from both the forward and aft panels agreed with the thermal math model predictions. Figure 1 shows the comparison of the test results and predicted values. A more detailed study of the test data will be required to define the indicated fin effectiveness and overall thermal model adequacy.

Sequence 2 - Single Loop Performance (Test Points 21-26)
The scheduled 6 points were completed and the results appeared satisfactory as shown in figure 2. Both forward and aft panel outlet temperatures were about 3°F higher than predicted for the one point where predictions were available. Single loop forward panel outlet temperatures were about 20°F below the two loop values, as expected.

Sequence 3 - Effect of Temperature Difference (Test Points 27-28)
Figure 3 shows the predicted and test results for a 20°F difference in loop supply temperatures. At high flow, the outlets differ by 1°F, but at low flow the outlets are equal.

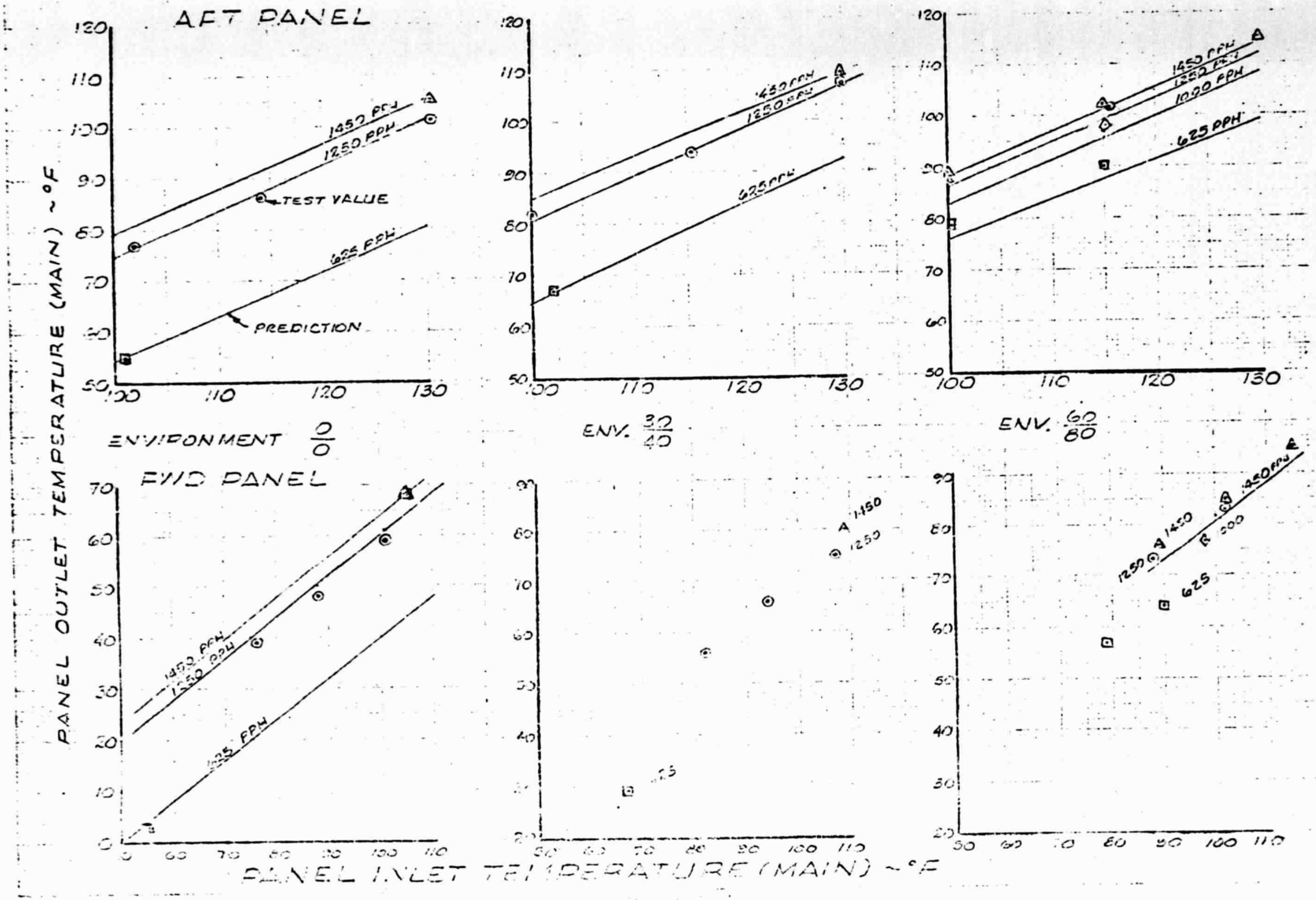
Sequence 4 - Not run due to valve problem (see anomalies)

Sequence 5 - Not run due to valve problem (see anomalies)

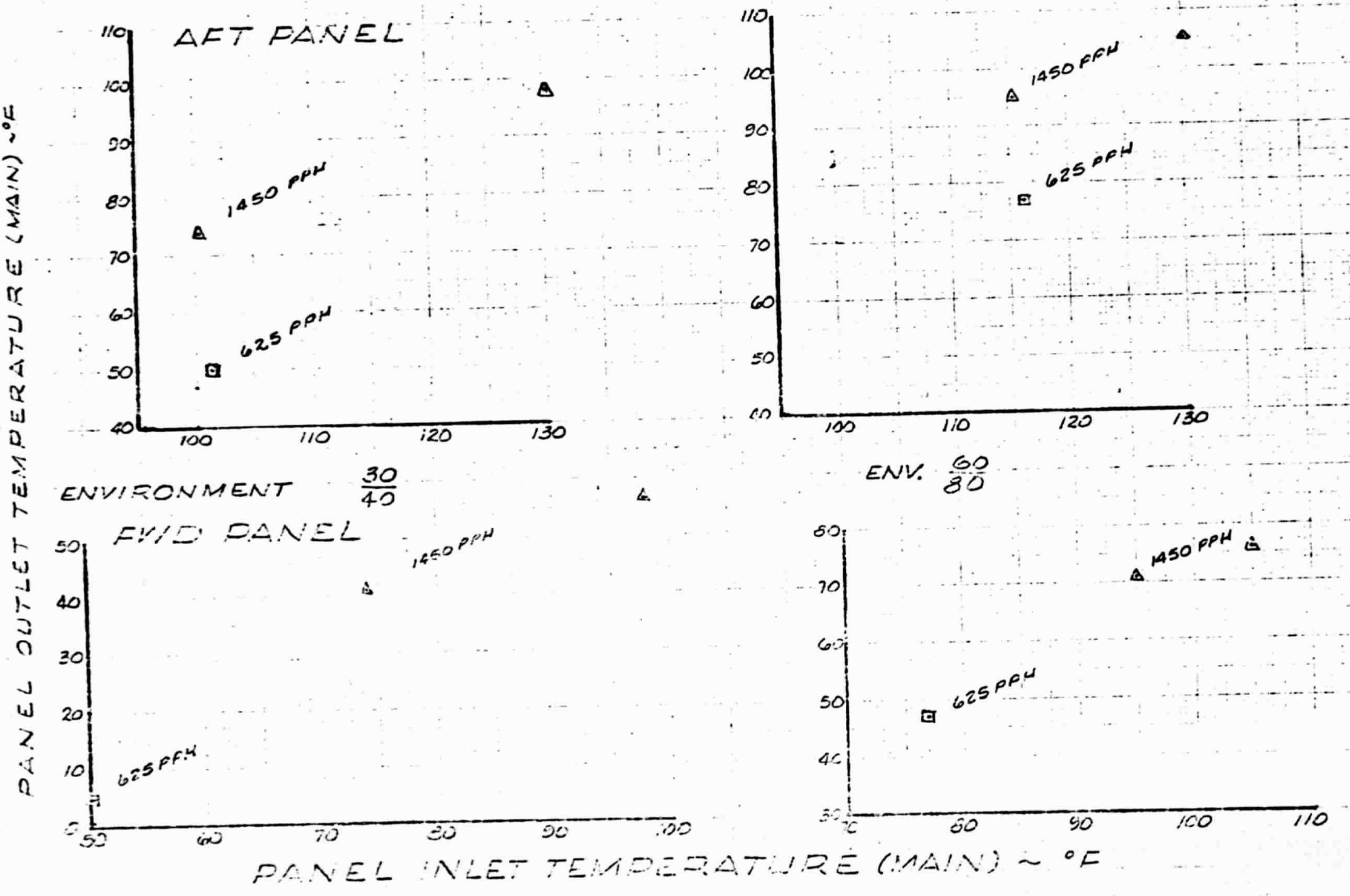
Forward Panel Deflection

The forward panel deflection data was taken throughout the week. There is some indication of anomalous readings, but the data is still being evaluated. Measurement 7210 hook pulled off the panel and measurement 7200 wire was broken. These were the only two obvious defects noticed after repressurization.

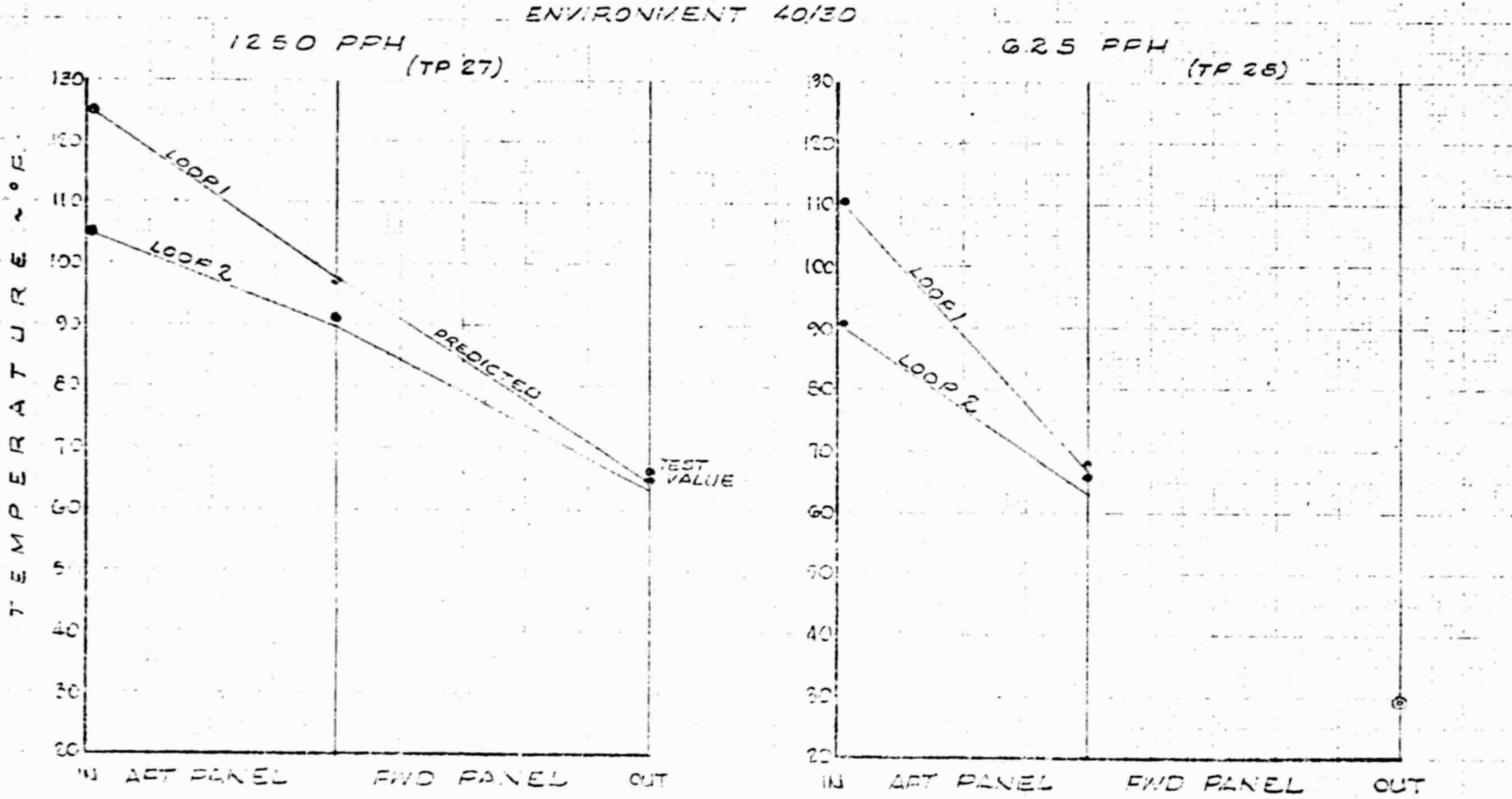
2 LOOP HIGH LOAD PERFORMANCE (TEST POINTS 1-20)



SINGLE LOOP PERFORMANCE (TEST POINTS 21-26)



EFFECT OF TEMPERATURE DIFFERENCE



5.0 ANOMALIES

a. Portions of the software calculations logic were inadvertently connected with the automatic heater control function, which resulted in override of the manual control inputs prior to resolution during the third day of testing.

b. Radiometer calibration proved to be inadequate for indicating and displaying the absorbed flux. The radiometers were installed on the forward and aft radiator panels to monitor the quartz lamps. Indicated flux levels will need to be determined post test from the raw data.

c. During setup for test point 11, an unnoticed change occurred in the quartz lamp array flux output that extended through test points 11, 12, and 13. The problem was resolved prior to setup for test point 14. Subsequently, test point 11 was rerun at the preplanned flux settings.

d. During the testing for transient response performance, the flow controller was ineffective in controlling the control valve. As a result, sequences 4 and 5 of the test timeline were not accomplished in the first week of testing.

6.0 RECOMMENDATIONS FOR SECOND WEEK TIMELINE

It is recommended that a conservative approach be exercised for the second week of testing by prioritizing test point accomplishments per the timeline listed below (which assumes that the control valve problem has been rectified).

a. Transient Response Performance (Test Points 29 through 36) - 6 hours estimated.

b. Control Valve Operation (Test Points 37, 38 and 39) - 9 hours estimated.

c. Low Load Performance (Test Points 45, 46, 48, 49, 54, 55 and 44) - 32 hours estimated.

d. Freeze/Thaw Techniques (Test Points 47, 50, 51, 52, 53, 56 and 57) - 43 hours estimated.

The total test time required for this sequence is 90 hours, however, the time periods required for some test points are not well defined and may take longer than anticipated. Therefore, the freeze/thaw techniques should be performed in the following order (1) prime tube recovery, (2) inherent recovery, (3) prime tube heater recovery, and (4) environmental recovery.

In addition, it is recommended that valid strain gage data be mandatory for the freeze/thaw portion of the second week of testing.

OHRS RADIATOR TESTING

2nd WEEK

STATUS REPORT

AUGUST 29, 1975

1.0 TEST ARTICLE

Visual inspection of the radiator panels was made immediately after the chamber door was opened at the conclusion of the week 1 test. Water had collected in three areas on the concave portion of the forward panel. A cloth was used to wipe the area on the east end of the panel. The wiping caused water to be splashed on the PBD simulator. The two other areas were not easily accessible and were left to dry over the weekend.

An inspection of the coating indicated no observable change on the forward panel. Those areas repaired prior to the test with the Eastman 910 adhesive still appeared good. There were three areas on the aft panel where the tape curling appeared to have increased. These areas cannot easily be reached for repair.

Pretest inspection just prior to pumpdown indicated the general acceptability of the test article for testing. The forward panel coating appeared spotted in the areas where the water was observed during the week 1 post-test inspection, but the panels were dry. The coatings appeared the same as the week 1 post-test inspection.

Visual inspection of both radiator panels was made upon opening of the chamber at the end of week 2 testing. An excessive amount of frost had formed in the chamber during repressurization and covered all the test articles, instrumentation, and equipment. Upon chamber opening it was found that this had caused a large puddle of water to accumulate on the west end of the forward panel extending approximately to the center of the panel. There were also droplets of water scattered over the rest of the forward panel and on the aft panel. There was some curling of the edges of Teflon strips in the puddled area of the forward panel. There were also several curled spots in the center of the aft panel. The large puddle of water was blown off of the forward panel west end by using a compressed air hose. This caused a significant part of the water to fall onto the west end of the PBD simulator. All portions of both panels and the PBD simulator that could be reached were wiped with clean white cloths to remove as much of the moisture as possible. The cloths used on the two radiator panels were quite dirty after use. It was also noted that an instrumentation hook on the outer corner of the west end of the forward panel had detached from the panel, causing the loss of the two deflection measurement wires attached to it.

2.0 INSTRUMENTATION ASSESSMENT

The following radiator test instrumentation was found to be reading incorrectly:

TF5544 reads high
TF5549 reads high
TF5534 reads high
FA0603 off scale
FA0636 off scale
FA0658 reads low
FA0647 reads low
FA0743 off scale
FA075A off scale
FA0758 off scale
FA0762 off scale
AF0766 reads low
AF0818 reads low

These erroneous readings will not jeopardize the accomplishment of the test objectives, but their repair is desirable for the third week of testing.

A review of the week 1 deflection measurements indicated the possibility of the counter-balance system exerting an upward force on the forward panel. TV coverage of the counter-balance weight movement was added for the second week of testing and the safety wires used to prevent excessive weight movement were removed. TV monitoring during the second week indicated the counter-balance weight moved upward over 2.0 inches. Since the weight movement was restricted during the week 1 test, it is probable that this was the cause of the upward pull on the panel. The week 2 measurements indicated only small deflections as expected and no upward pull on the panel.

3.0 TIMELINE

Table 1 presents a summary of the timeline for week 2 and Table 2 shows the parameters of the deviation test points. In general, test points were run to checkout the control valve and obtain additional high load performance maps. Nine test points of the sequence 1 type of week 1 were run and are shown in Table 2. Sequence 2 test point 22 with single loop operation was rerun (identified as 22A) with the opposite loop (#1) flowing. The two remaining points (42, 43) of sequence 6 were run. Sequence 4 with an inlet temperature change to 75°F was run and test points 35 and 36 were run at a flow of 1250 lbs/hr due to valve oscillation at the 625 lbs/hr flow. Sequence 5 was repeated three times with electronic controller design changes incorporated between each series. Test point 41H was identical to 41 without IR lamps to obtain data for correlation with a future possible test with a larger cavity opening. Test point 44A was a checkout for the valve with a very cold inlet temperature followed by a ramp temperature increase.

Table 1

Test Point	Completion Time		
	Day	Hr	Min
37	237	12	30
38		15	17
39		18	50
5A		23	30
5B	238	02	20
42*		06	30
43		12	30
12A		14	30
13B		16	35
29		17	20
30		18	05
31		18	50
32		19	35
33		20	20
34		21	05
35		21	50
36		22	35
36A		23	20
37A	239	00	20
38A		01	02
39A		02	12
5C		03	50
37AA		5	08
38AA		6	08
39AA	239	07	08
33AA		07	35
42A		15	15
15A		18	15
15B		21	30
10A	240	01	00
22A		03	20
6A		05	55
41H		10	45
44A		19	40

*Test point not valid due to wrong PBD flux

Table 2

Test Point	Inlet Temp °F	Flow Rate lbs/hr-per system	Environment BTU/hr-ft^2 FWD	Environment BTU/hr-ft^2 AFT	Remarks
5A	130	625	0	0	
5B	100	1450	0	0	
5C	115	625	0	0	
6A	130	625	40	30	
10A	100	1450	40	30	
12A	130	1250	80	60	
13B	130	625	80	60	
15A	100	1000	80	60	
15B	130	1000	80	60	
22A	100	1450	40	30	Single loop #1 only
33AA	100	1250	0	0	Rerun of 33
36A	46	1450	0	0	
37A 37AA 38A 38AA 39A 39AA	75	1250	0	0	Rerun sequence 5 w/valve fix
41H	115	1250	0	0	Environment on P/L bay door from TP41
44A	-60	varying	0	0	Perform valve check-out w/cold inlet temp and ramp.

4.0 PERFORMANCE

Sequence 1 - The nine additional high load two loop performance points obtained during week 2 are shown on Figure 1. All data agrees well with predictions and the week 1 data. These points were run primarily to fill in time while waiting for the strain gauge instrumentation.

Sequence 2 - One additional single loop performance point was run to determine the effect of having loop 1 rather than loop 2 off. This point is shown on Figure 2.

Sequences 4 and 5 - The initial test points run in these sequences indicated that the control valve/electronic controller would not provide adequate control of the radiator return temperature when the radiator outlet was cold (approximately -50°F) or the total flow through the valve was low (625 lb/hr). The 625 lb/hr flow was planned only to provide colder temperatures to the valve. This is an unrealistic condition since the flight valves will have a total flow of 2200-2900 lb/hr. The following table illustrates the valve sensitivity to total flow:

Test Point	Total flow-lb/hr	Coldest temperature - °F	Valve Stable
33-34	625	-30	No
35-36	1250	-65	No
36A	1450	-75	Yes

These test points were run prior to design changes made to the electronic controller. The initial test points (37A-39A) to determine valve performance during changes in set points (38/60°F) also indicated unstable valve operation. An examination of data from test points 33, 34, 35, 36, 36A, 37A, 38A and 39A indicated that when the temperature error from the set point (38°F or 60°F) was sufficient to start applying pulses to the stepping motor driver board the pulse rate was too fast (approximately 12 pulses per second). This corresponds to 12 steps per second for the stepping motor.

The pulse rate was reduced to approximately 2 pulses per second for temperature errors of ± 0.5°F. Above ± 0.5°F error the pulse rate is the same as it was before the fix was incorporated. Subsequent to this design change the valve operated satisfactorily down to -120°F radiator outlet temperature with a flow rate of 1250 lb/hr. Unstable operation still occurred with a total flow of 625 lb/hr, but this is not considered a valve design problem since this is not a realistic condition. Figure 3 shows the controlled outlet temperature as the valve set point is changed from 38 to 60 and back to 38°F. Figure 4 shows the controlled outlet temperature when the radiator outlet is approximately -120°F and the bypass and radiator inlet temperature are increased.

Sequence 6 - Panel performance with skewed environments simulating different sun angles in the cavity is summarized in Table 3.

TP41 simulated the 77° sun angle which has the worst cavity focusing effect and resulted in the highest PBD temperature (160°F) at the hinge line. However, as expected, forward panel performance is not degraded due to high fluxes near the hinge line due to the L tube design. Table 3 also shows T016 for comparison with the uniform flux performance.

General

Tables 4 and 5 summarize the tube to face sheet Delta T measurements recorded during the week 1 and 2 tests. No excessive Delta T's were obtained except for a butt weld area on the aft panel (ZT 1012). Most of the data is within the ± 1.6°F error band of the thermocouple reading.

Figures 5 and 6 show typical measured fin temperature profiles and radiation fin effectiveness for the aft and forward panels. This data verifies the panel design objectives of a high fin effectiveness.

2 LOOP HIGH LOAD PERFORMANCE (TEST POINTS 1 - 20)

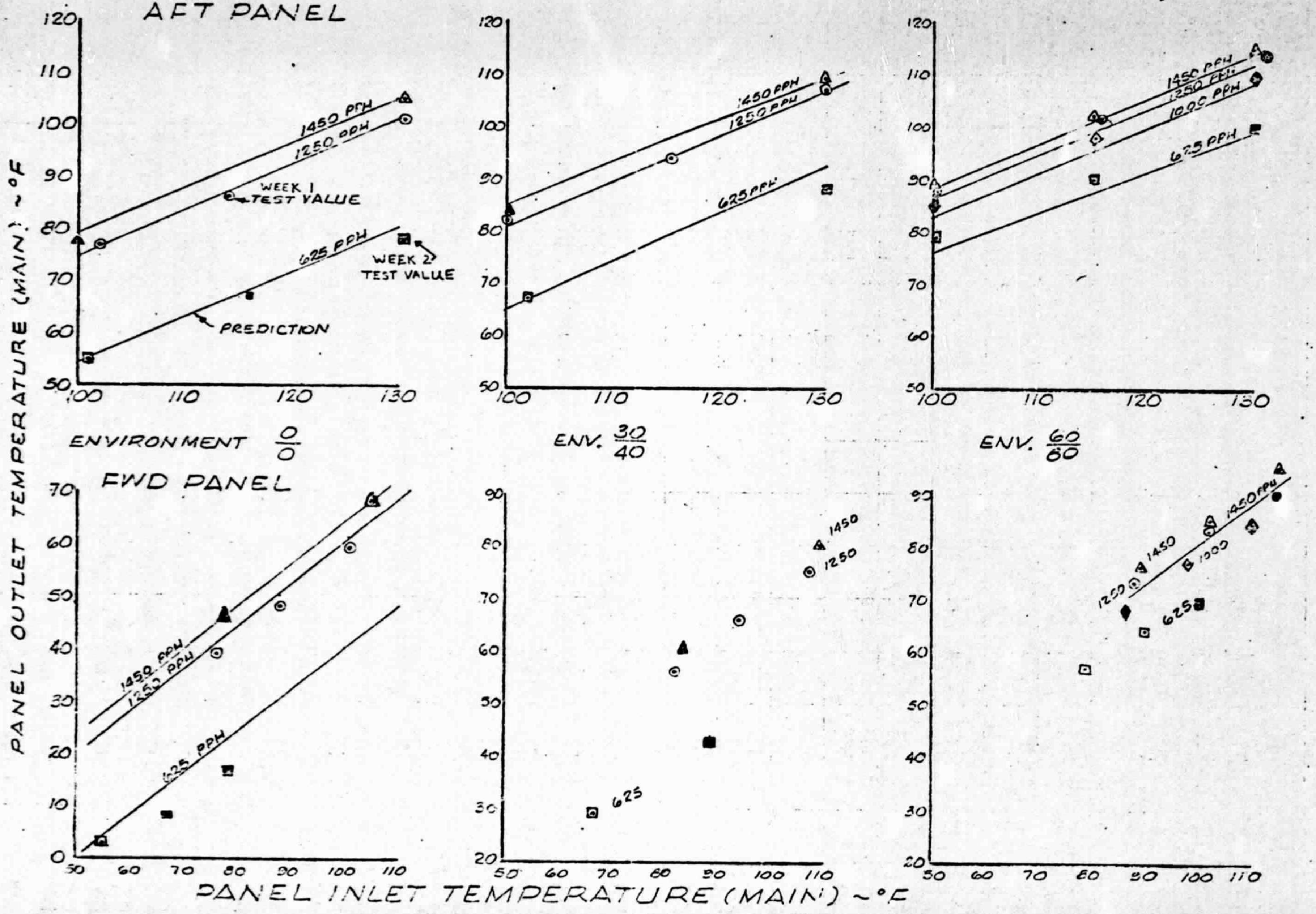


FIGURE 1

SINGLE LOOP PERFORMANCE (TEST POINTS 21-26)

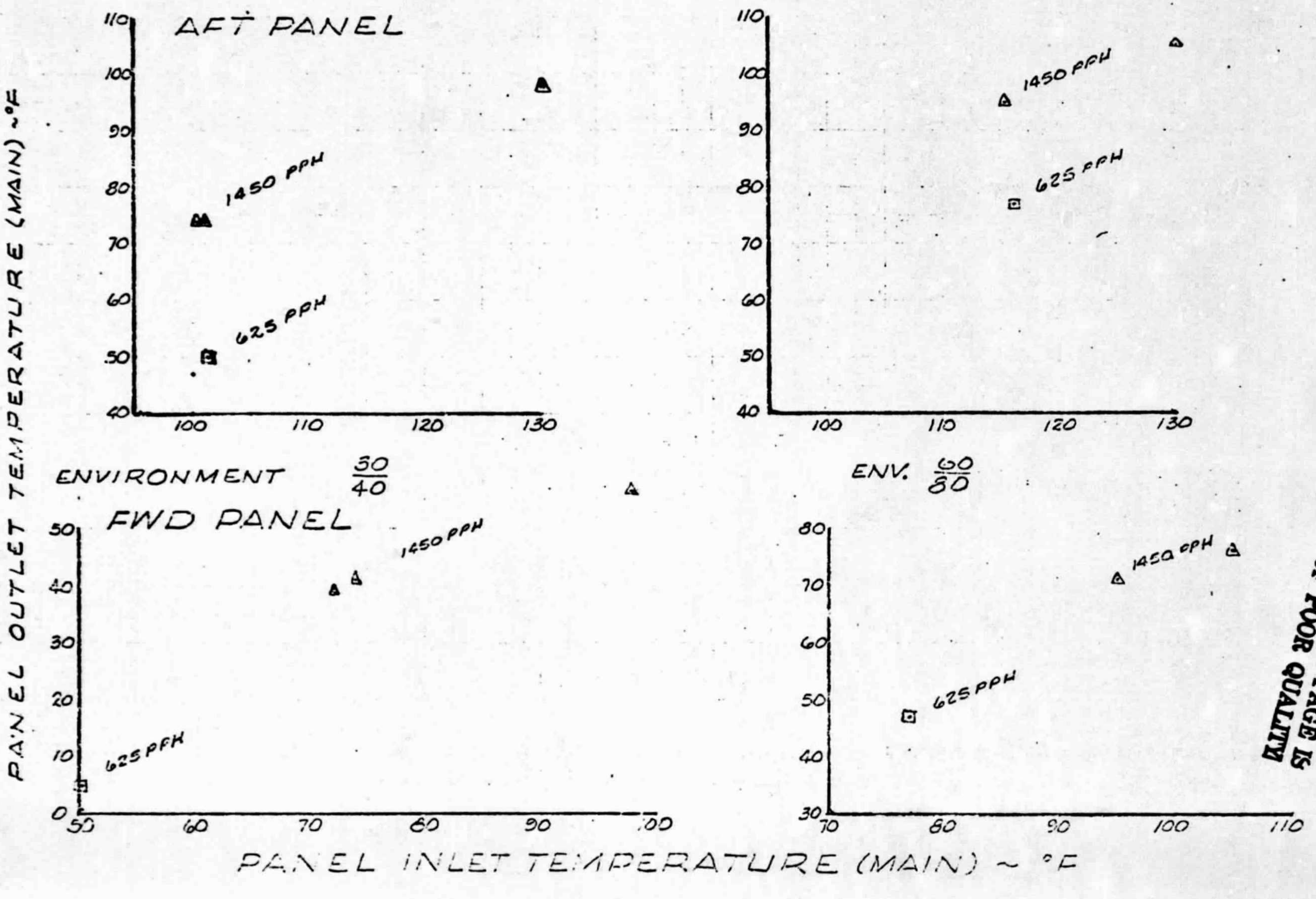


FIGURE 2

FIGURE 3
SEQUENCE 5
CONTROL VALVE OPERATION

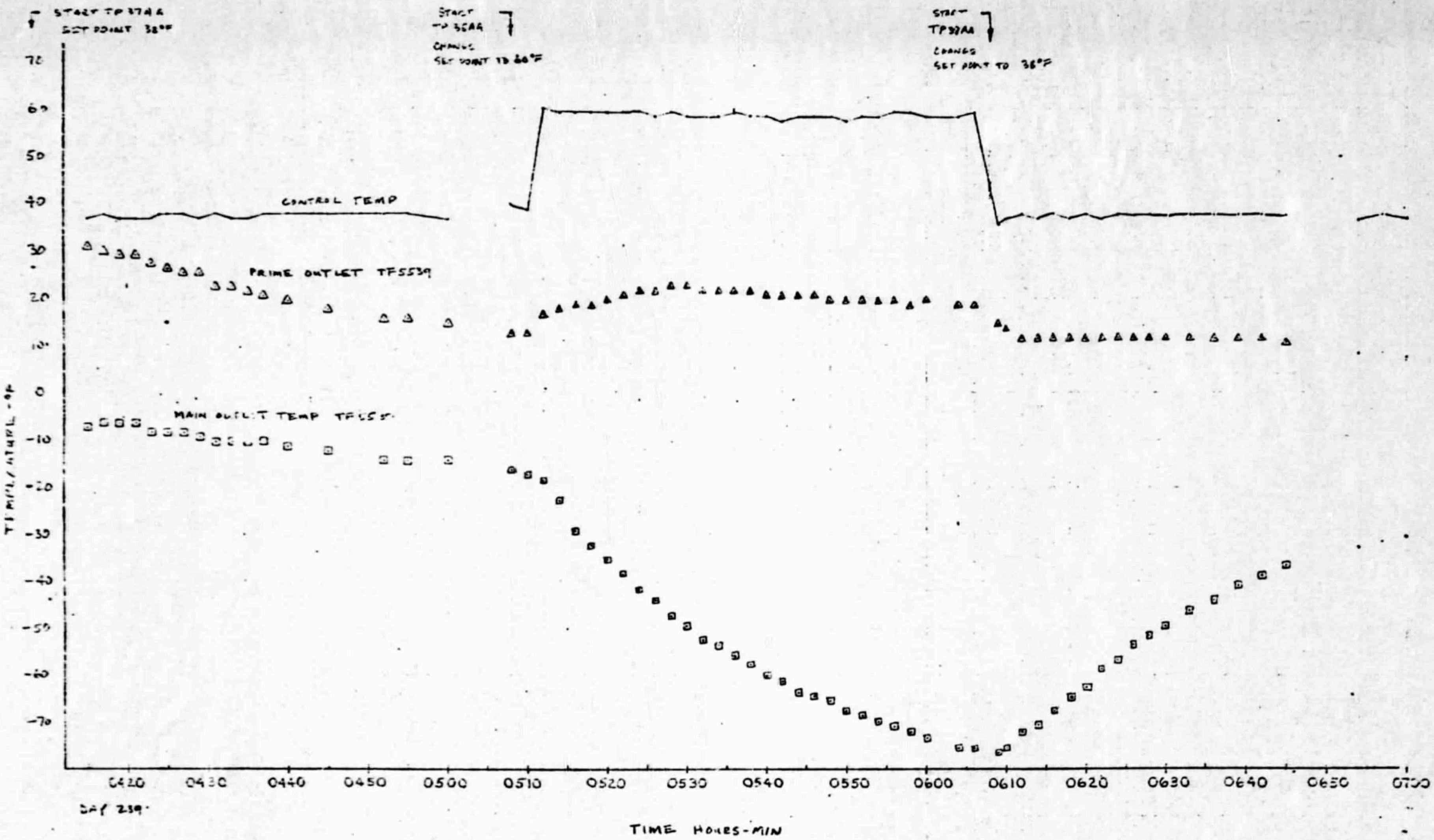


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FIGURE 4
LOOP 1 VALVE CHECKOUT
TP 44A

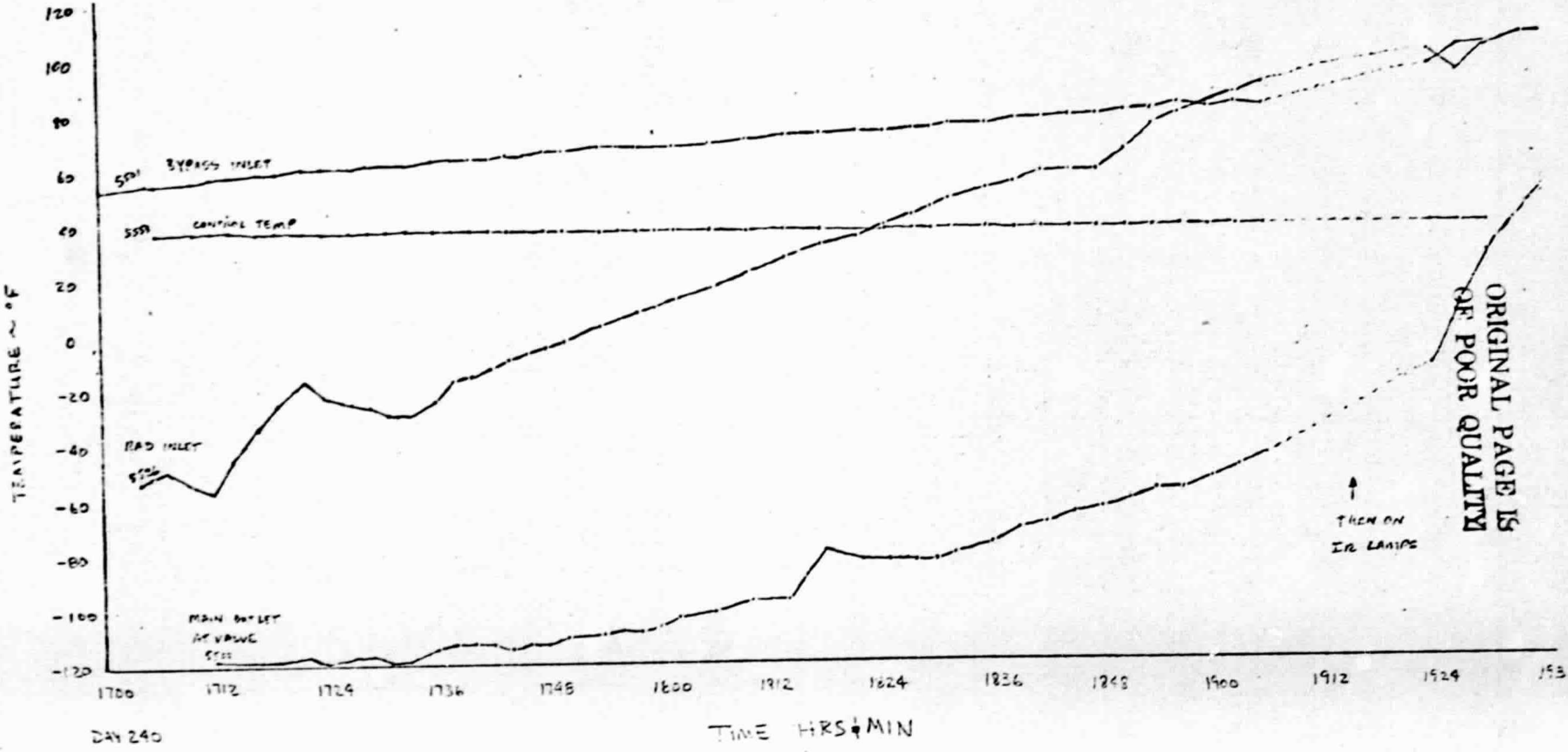
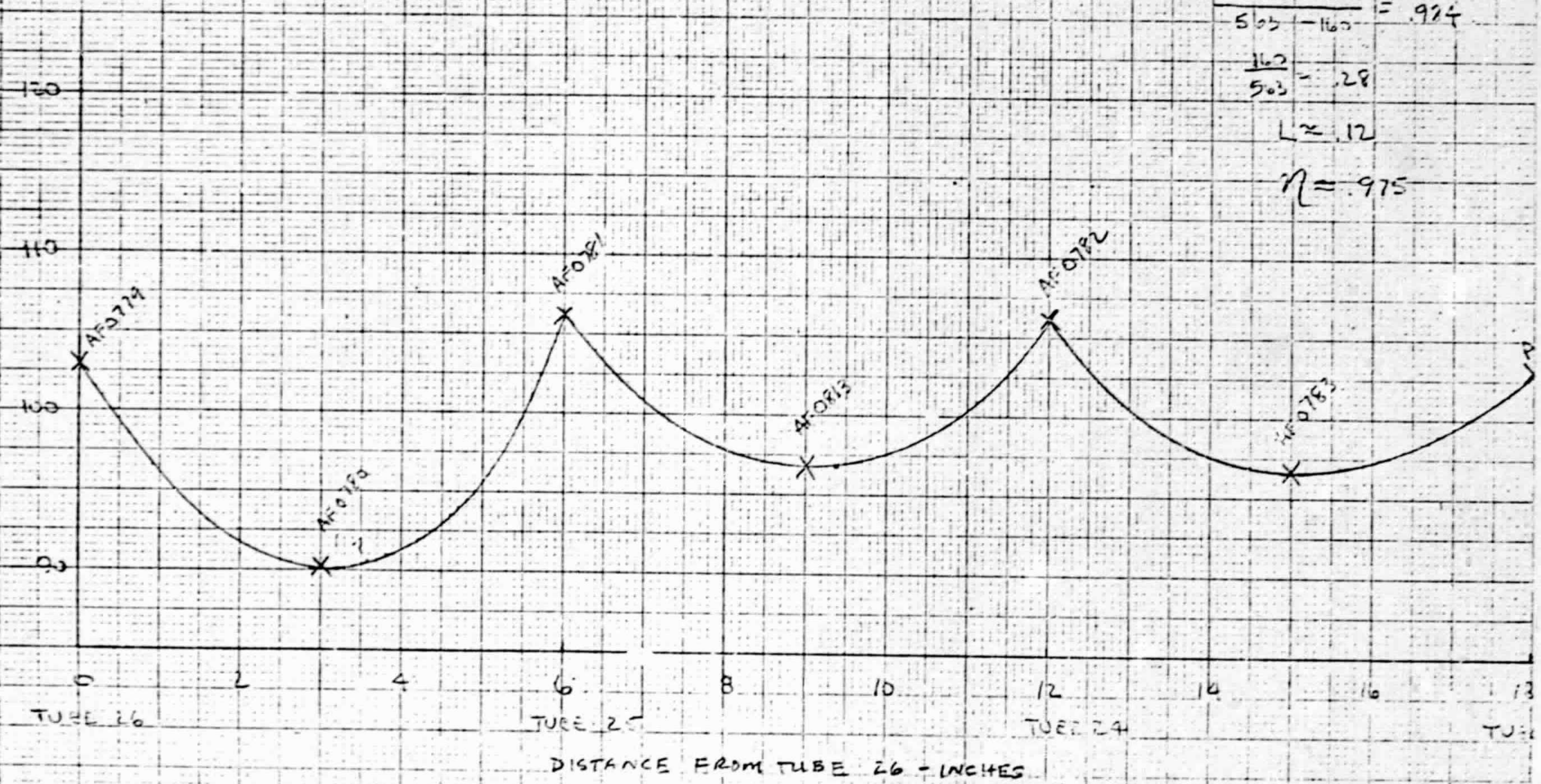


FIGURE 5

TEST POINT 1

AFT PANEL FIN TEMP PROFILE (DOWNSTREAM)



$$\frac{556.6-160}{503-160} = .974$$

$$\frac{160}{503} = .28$$

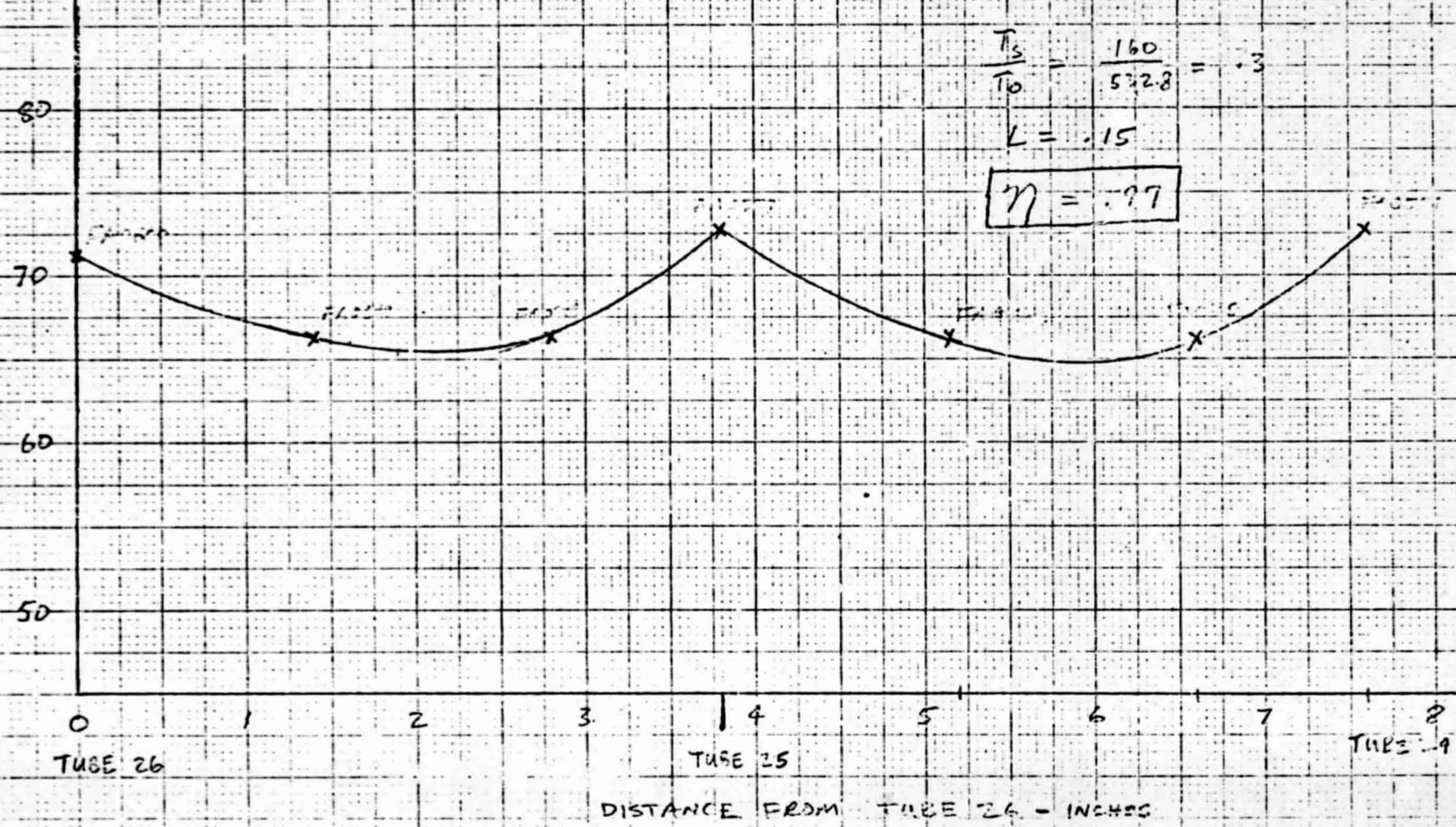
$$L \approx .12$$

$$\eta = .975$$

FIGURE 6

TEST POINT 1

TOP FWD PANEL FIN TEMP PROFILE (DOWNSTREAM)



$$\frac{T_e - T_s}{T_o - T_s} = \frac{525.9 - 160}{532.2 - 160} = .98149$$

$$\frac{T_s}{T_o} = \frac{160}{532.8} = .3$$

$$L = .15$$

$$\boxed{\eta = .77}$$

Table 3

CAVITY ENVIRONMENT SIMULATION

TIN = 115°F, Flow = 1250 lb/hr

TEST POINT	SUN ANGLE DEGREES	AFT OUTLET °F	FWD OUTLET °F
40	46	102.6	81
41	77	100	82
42	103	99.5	84
43	131	98	81
16*	-	102	83

*Uniform flux of 60 BTU/hr ft^2 on aft panel and 80 BTU/hr ft^2 on forward panel

Table 4

TUBE TO FACE SHEET ΔT - °F

FORWARD PANEL ZT010X

TEST POINT	Q KBTU/HR	1	2	3	4	5*	6*	7	8	9
1	26.33	0	-5.1	0	3.2	3.3	0	1.6	1.6	3.2
2	25.03	0	-5.0	0	3.3	5.0	0	1.6	3.2	1.7
3	22.37	0	-5.1	1.6	3.4	3.4	-1.6	0	1.6	-1.7
4	21.47	0	-5.1	1.8	3.4	3.6	0	1.6	1.7	1.7
5	15.10	0	-3.5	1.9	3.5	1.9	0	0	1.7	0
6	10.66	0	-1.7	0	3.4	1.8	-1.8	0	0	0
7	14.96	0	-3.3	0	5.1	3.4	0	0	0	1.7
8	17.19	0	-3.3	1.7	1.6	3.4	0	0	1.6	-1.7
9	19.85	0	-3.2	1.7	3.1	3.4	0	1.6	1.6	4.7
10	20.94	0	-3.1	1.7	3.2	3.3	-1.7	1.6	1.6	1.6
11	17.41	0	0	0	4.8	3.2	0	1.6	0	0
12	16.72	0	0	0	4.8	1.6	1.6	0	0	1.6
13	11.42	0	1.7	-1.7	5.1	3.3	1.7	0	1.6	-1.7
14	8.20	0	0	-1.7	5.0	1.7	0	1.6	0	0

*Butt-weld

Table 4 Cont'd

FWD PANEL ZTO1OX

TEST POINT	Q KBTU/HR	1	2	3	4	5	6	7	8	9
15	10.56	-1.6	0	0	3.2	3.3	1.6	1.6	0	0
16	12.22	0	0	0	4.8	3.2	0	0	0	1.6
17	12.47	0	0	0	3.2	3.1	1.6	1.5	0	1.6
17A	15.85	0	0	0	6.3	3.2	1.6	1.5	0	3.2
18	10.44	0	0	-1.6	3.1	3.2	1.6	0	0	0
19	9.53	0	0	-1.7	3.2	1.7	1.6	0	-1.6	0
20	6.88	-1.5	0	0	3.4	1.7	1.7	0	0	-1.6
40	13.72	-1.6	0	0	3.2	3.3	0	0	0	-1.6
41	11.62	-1.6	-1.5	0	3.2	3.4	0	-3.2	0	0
43	10.92	0	0	0	3.2	3.4	0	0	0	1.6
5A	18.45	0	-3.5	1.8	3.5	3.5	-1.8	1.7	0	1.7
5B	22.21	0	-5.0	1.6	3.4	3.4	0	1.6	1.7	3.4
5C	17.22	0	-5.3	1.9	1.7	3.8	-1.8	1.6	1.7	-1.8

Table 5

TUBE TO FACE SHEET T - ^{o}F

AFT PANEL ZT01XX

TEST POINT	Q KBTU/HR	10	11	12*	13	14	15	16
1	19.66	3.0	0	7.9	0	-	1.5	0
2	18.95	3.0	0	7.9	0	-	1.5	1.6
3	16.79	1.6	0	6.4	0	-	3.2	0
4	15.74	1.6	0	8.0	0	-	0	0
5	13.48	3.2	1.7	5.0	1.7	-	1.6	0
6	10.25	1.6	0	4.9	0	-	1.6	0
7	11.70	0	0	4.7	1.6	-	1.6	0
8	13.66	1.6	0	4.8	1.6	-	3.2	1.6
9	15.46	3.0	0	6.4	1.6	-	1.5	1.5
10	15.97	3.0	0	6.4	1.6	-	1.5	0
11	15.54	1.5	0	6.2	0	3.2	1.6	1.6
12	14.75	1.5	0	7.9	1.6	6.3	3.1	1.5
13	12.44	1.5	1.6	6.4	0	4.8	3.0	1.6
14	8.29	1.5	-1.6	6.4	3.2	3.2	3.1	1.6

*Butt-weld

Table 5 Cont'd

AFT PANEL ZT01XX

TEST POINT	Q KBTU/HR	10	11	12	13	14	15	16
15	8.69	1.5	0	6.3	0	4.8	3.0	1.6
16	9.49	0	1.6	6.3	1.6	6.4	3.0	1.6
17	9.55	0	0	6.3	1.6	6.3	3.0	1.6
17A	11.18	1.6	0	6.1	1.5	4.7	3.1	1.5
18	8.79	1.6	0	6.4	1.6	4.8	3.2	0
19	8.08	1.6	0	8.0	1.6	4.8	3.2	0
20	6.96	0	-1.6	4.7	1.6	4.8	4.8	1.6
40	8.03	1.5	0	6.4	3.2	4.7	3.0	1.6
41	9.76	1.5	0	6.3	0	6.4	1.5	1.6
43	11.43	0	0	6.4	0	-	1.5	0
5A	16.49	3.0	1.6	6.3	0	-	1.6	0
5B	16.01	1.6	0	6.3	1.6	-8.3	1.6	1.6
5C	15.39	1.6	0	8.2	0	-	3.2	0

5.0 ANOMALIES

The electronic controller/valve did not operate properly during test points 37-39 (set point changes). The test points were completed with manual control of loop 2 valve. An intensive investigation of the electronic controller indicated that the electronic stepping motor driver PC board purchased from IMC has bad characteristics. When improper trigger pulses are applied to the driver board, the board will lockup and apply current to all three windings of the stepping motor continuously. The application of proper trigger pulses will not unlock the driver board.

Electronic circuit changes were made to controllers #1 and #2 to provide better noise immunity and reduce the chance of improper trigger pulses being applied to the stepping motor driver board. Test points 37-39 were rerun with the repaired controllers as TP 37A-39A.

The PBD heater power settings for TP42 were in error. Test point 42 was rerun with the correct PBD power settings as TP42A.

6.0 RECOMMENDATIONS FOR SECOND WEEK TIMELINE

It is recommended that sequence 7, low load performance and freeze/thaw be tested in the order defined in the Detailed Test Plan. If stain gauge data is not available, it is recommended to proceed with the test without it, to avoid any further delay.

OHRS RADIATOR TESTING

3RD WEEK

STATUS REPORT

SEPTEMBER 8, 1975

1.0 TEST ARTICLE

Visual inspection of the radiator panels was made at the conclusion of the third week of testing. As in the prior week, water had collected on the panels and cloths used to wipe the panel were soiled.

An inspection of the coating indicated increased curling and several of the areas repaired prior to the test with the Eastman 910 adhesive had peeled up. In general, however, the panels appeared in good condition. A tap test on accessible areas of the forward panel indicated no structural unbonding of the face sheets and honeycomb core.

2.0 INSTRUMENTATION ASSESSMENT

During the third week, the following instrumentation was found to be reading incorrectly:

FA0550
FA0603
FA0617
FA0633
FA0636
FA0647
FA0658
FA0662
FA0706
FA0773
AF0793
AF0818
TF5544
TF5549
TF5534

These erroneous readings did not affect the accomplishment of the test objectives.

The apparent strain curve used in the reduction of the strain guage data appears to be in error. Element tests will be required to obtain correct apparent strain curves for both the forward and aft panels, hinges and support struts. These new curves then will have to be applied to the raw strain data recorded during this week to obtain the required strain data.

3.0 TIMELINE

Table 1 presents a summary of the timeline for the third week of testing. The largest portion of the week was dedicated to the freeze/thaw cycles which were test points 44 and 47, 50 and 51, 52 and 53. Low load performance test points 45 and 46 were run and test point 46A was added with an inlet temperature of $-100^{\circ}F$ and flow rate of 100 LBS/HR. One high load performance point (4A) which was a duplicate of test point 4 from week 1 ended the test.

The radiators were videotaped from 247:19:25 to 247:19:42 and 247:22:47 to 247:23:08.

TABLE 1

TEST POINT	COMPLETION TIME
46	245:24:00
46A	246:08:10
44	246:21:34
47	247:02:24
50	247:19:04
51	247:23:15
52	248:12:54
53	248:13:40
45	248:18:15
4A	248:20:00

4.0 PERFORMANCE

Sequence 7 - Freeze/Thaw Low Load Performance

Four different freeze/thaw cycles were performed on the panels. One of the cycles used the prime tube concept and the other three cycles were run with the prime tube valved off (inherent stagnation). The first two thaws simulated a system heat load change from minimum to maximum by increasing the bypass temperature from 53°F to 108°F and the radiator inlet temperature from -100°F to 100°F over a 2.75 hour period. The third thaw was accomplished with environment on the panels and no change in bypass or inlet temperature. The flow control valve was used to maintain the bypass and radiator outlet temperature to 38°F during these thaws. In all cases the panel thaw rates were sufficient to meet the 38°F control temperature. The fourth thaw was accomplished by increasing the panel flow rate and inlet temperature as rapidly as the flow bench would allow to obtain a severe thermal shock.

Just prior to the environment thaw, the prime tube heater was used to thaw the forward panel after a complete freeze up of one loop. Approximately 38 minutes of prime tube heater operation was required to re-initiate flow.

During the third freeze, the chamber pressure was increased to approximately 1 tor to speed up the cold soak. The tubes apparently did not stagnate in the proper order during this test point but, after recovery, the flow skew appeared normal.

On at least the last two freeze/thaw cycles, the tube corners were the first to freeze and the last to thaw. There is some question as to whether this occured on the other cycles. The tube outlets were apparently the first to freeze on the first freeze but the corners were the last to thaw. A more complete data analysis will be required to determine the panel freezes and thaw patterns, but there does appear to be some discrepancy between the four cycles run.

The flow control valves operated satisfactorily during these test sequences but appeared to be very sensitive to system pressure changes. When the radiator side pressure drop was lowered by opening a parallel flow meter leg to activate a higher range flow meter, the valve would lose control momentarily. The test procedure involved manually controlling the flow rate to the panels during the freeze cycle then activating the valve for the thaw cycles. The valve was not able to stabilize on one occasion after activation and was manually controlled until stable control temperatures were obtained.

The test was concluded with a high load performance point which duplicated test point 4 of week 1. The results were the same, which proves the radiator performance was not degraded during the three weeks of testing.

5.0 ANOMALIES

a. In the first attempt to reach test conditions for test point 45 (inlet temperature of -100°F and flowrate of 70 LBS/HR), the LN_2 heat exchanger froze up. A bypass was added from downstream of the LN_2 heat exchanger in the main supply line to the prime/main radiator return line. This arrangement allowed a high flow through the LN_2 heat exchanger and low flow to the radiator panels.

b. During test point 50, there was a period of time in which the flow meters for the main bank of tubes (FM 5652 and FM 5659) were reading approximately 1/10 of the actual flow. No reason for the problem was discovered.

OHRS RADIATOR TESTING

4TH WEEK

STATUS REPORT

OCTOBER 8, 1975

A-34a

1.0 TEST ARTICLE

The OHRS Wide Cavity test article was inspected prior to chamber close-out at 0454 hours Monday, 20 October (293:04:54). The coating on both the upper and lower surfaces of the radiator panel, and on the PBD, appeared to be in satisfactory condition for testing. The coating was last inspected at the conclusion of the third week of baseline configuration performance testing on 5 September, at which time it appeared to be in generally good condition. No significant changes could be identified.

Efforts were made to verify the accuracy of the cavity angle which was preset during test buildup to simulate a 50-degree deployment angle. The chord length, measured from the lower, outer tip of the radiator panel to the upper, outer tip of the PBD, determined by LTV was 108.1 inches. Measurements between the above points were approximately 110 inches at the panel west end and approximately 111 inches at the east end. Two small steel plates were removed from the counterbalance weight to permit the panel to return to the proper position. Measurements taken subsequent to counterbalance correction were approximately 108 inches.

2.0 INSTRUMENTATION ASSESSMENT

During the first week of testing, the following thermocouple instrumentation was found to be reading incorrectly.

CC1241
FA0562
FA0582
FA0617
FA0632
FA0633
FA0634
FA0636
FA0647
FA0658
FA0715
FA0717
TF5529
TF5540

These erroneous readings will not jeopardize the accomplishments of the test objectives, but their repair is desirable for the second week of testing.

3.0 TIMELINE

Table 1 presents a summary of the timeline as run. The sixteen high load performance cases, four mission simulation cases and five low load performance cases as described on Figure 18 (Test Schedule - Week 1) of the Detailed Test Procedure (Test No. 55-A-75) were completed. One high load performance point (5001A) which was a duplicate of the first test point ended the forth week of testing.

4.0 PERFORMANCE

The results of the forth week of testing are summarized in Table 2. A comparison of the heat rejection for cavity angles of 38° and 50° are shown in Table 3. In general, the heat rejection increase was the most when the highest flux was applied to the panel and the payload bay door. The week was concluded with a high load performance point which duplicates test point 5001. The results were the same, indicating the radiator performance was not degraded during the first week of testing.

Figures 1, 2, and 3 are test nomographs depicting the additional performance of the 50° interface angle. This nomograph is read by placing a straight edge between the desired flowrate and inlet temperature and then the outlet temperature for the 38° and 50° configurations can be read.

5.0 APPARENT STRAIN DATA

Real time and post-test evaluation of the strain data acquired during the 38-degree baseline test was inconclusive because of inadequacy of the apparent strain curves applied to the test data. Efforts were made during the first week of wide cavity testing to obtain an accurate temperature induced strain relationship of the radiator test article. Three test samples consisting of 1) a 1-inch thick honeycomb panel, 2) a ½-inch thick honeycomb panel, and 3) the test article struct. were instrumented in an attempt to provide the necessary data. A cursory inspection of the data shows the expected trend. Figure 4 depicts raw data from one of the instrumented locations on the 1-inch panel as compared to the data generated by LTV and used in the previous tests. No efforts have yet been made to analyze the adequacy of these results; however, initial results indicates the previous LTV data was adequate.

6.0 RECOMMENDATIONS FOR SECOND WEEK TIMELINE

It is recommended that the test points which were deleted for the week 5 test be added back, so that week 5 duplicates week 4 except for cavity angle of 70°.

Table 1

TEST POINT	COMPLETION TIME DAY	HR	MIN
5001	293	15	05
5002		16	50
5003		18	47
5004		20	35
5005		23	35
5006	294	04	05
5007		07	40
5008		09	41
5009		12	08
5010		14	08
5011		16	05
5012		20	05
5013		21	05
5014	295	00	05
5015		02	05
5016		03	36
5018		09	55
5017		14	50
5019		19	20
5020		23	05
5021	296	09	50
5022		16	05
5023		22	50
5024	297	05	04
5025		6	30
5001A		10	05

TABLE 2

	°F		°F		°F		°F		lb/hr	
Test	Tin Loop 1		Tin Loop 2		Tout Loop 1		Tout Loop 2			
Point	TF5518	TF5519	TF5542	TF5543	TF5512	TF5513	TF5536	TF5537	Flow 1	Flow 2
5001	104.6	104.6	104.6	104.6	66.3	66.3	66.3	66.3	1433.8	1415.2
5002	101.4	101.4	101.4	101.4	57.9	57.9	57.9	57.9	1215.8	1196.6
5003	90.3	88.7	88.7	88.7	49.5	47.8	49.5	49.5	1195.8	1175.6
5004	76.	74.4	76.	76.	39.4	37.8	39.4	39.4	1194.8	1204.6
5005	76.	76.	76.	76.	44.5	42.8	44.5	44.5	1429.9	1430.9
5006	88.7	87.1	88.7	52.9	51.2	52.9	52.9	52.9	1233.8	1225.1
5007	111.	109.4	111.	109.4	79.1	77.6	79.1	79.1	1442.8	1404.5
5008	106.2	106.2	106.2	106.2	72.8	72.8	72.8	72.8	1234.3	1225.6
5009	93.5	93.5	93.5	93.5	63.	63.	63.	63.	1254.2	1254.1
5010	82.3	82.3	82.3	82.3	54.6	54.6	54.6	54.6	1224.8	1214.9
5011	85.5	83.9	83.9	83.9	59.6	59.6	59.6	59.6	1419.7	1390.8
5012	117.1	117.1	117.1	117.1	91.9	91.9	91.9	91.9	1464.5	1425.2
5013	114.	114.	114.	114.	87.1	87.1	87.1	87.1	1233.2	1223.5
5014	101.4	101.4	101.4	101.4	79.1	79.1	79.1	79.1	1243.8	1233.9
5015	87.1	87.1	88.7	87.1	68.	68.	68.	69.6	1234.3	1205.1
5016	88.7	88.7	90.3	90.3	72.8	72.8	72.8	72.8	1452.3	1414.0
5017	103.	103.	104.6	104.6	79.1	79.1	79.1	80.7	1233.8	1224.4
5018	101.4	99.9	101.4	99.9	80.7	80.7	80.7	80.7	1251.7	1226.6
5019	101.4	101.4	101.4	101.4	82.3	82.3	82.3	82.3	1243.2	1233.4
5020	99.9	99.9	99.9	99.9	79.1	77.6	77.6	79.1	1242.5	1252.4
5021	- 20.5	- 20.5	- 20.5	- 20.5	-125.2	-125.2	-123.	-123.	49.1	49.1
5022	- 70.6	- 70.6	- 70.6	- 70.6	-148.3	-148.3	-148.3	-145.9	48.1	48.1
5023	-112.2	-112.2	-112.2	-112.2	-167.2	-167.2	-164.7	-164.7	49.1	50.9
5024	-105.7	-105.7	-105.7	-107.9	-174.8	-174.8	-172.3	-169.8	15.7	16.
5025	101.4	99.9	101.4	101.4	57.9	56.2	57.9	56.2	1259.	1240.

TABLE 3

TEST POINT	QREJ BTU/HR	TEST POINT*	QREJ BTU/HR	ENV BTU/HR FT^2	%INCREASE
5001	27430	1	26330	0	4%
5002	26320	2	25030	0	5%
5003	23570	3	22370	0	5.4%
5004	21390	4	21470	0	-0.4%
5005	22130	5B	22210	0	-0.4%
5006	22290	41H	19290	**	15.6%
5007	22940	10	20940	40	9.6%
5008	20660	9	19850	40	4.1%
5009	19060	8	17190	40	10.8%
5010	16670	7	14570	40	14.4%
5011	17620	10A	15940	40	10.5%
5012	18010	17A	15850	80	13.6%
5013	16880	12A	14640	80	15.3%
5014	13930	16	12220	80	14. %
5015	11620	19	9530	80	21.9%
5016	13070	18	10440	80	25.2%
5017	14820	40	13720	S	8 %
5018	12940	41	11620	K	11.4%
5019	11910	42A	10250	W	16.2%
5020	13140	43	10920	E	20.3%
5021	2350	N/A	-	0	-
5022	1700	N/A	-	0	-
5023	1210	N/A	-	0	-
5024	480	N/A	-	0	-
5025	27650	N/A	-	0	-
5001A	27430	1	26330		

* THESE TEST POINT ARE FOR A 38° CAVITY

** PAYLOAD BAY DOOR HTRS ONLY

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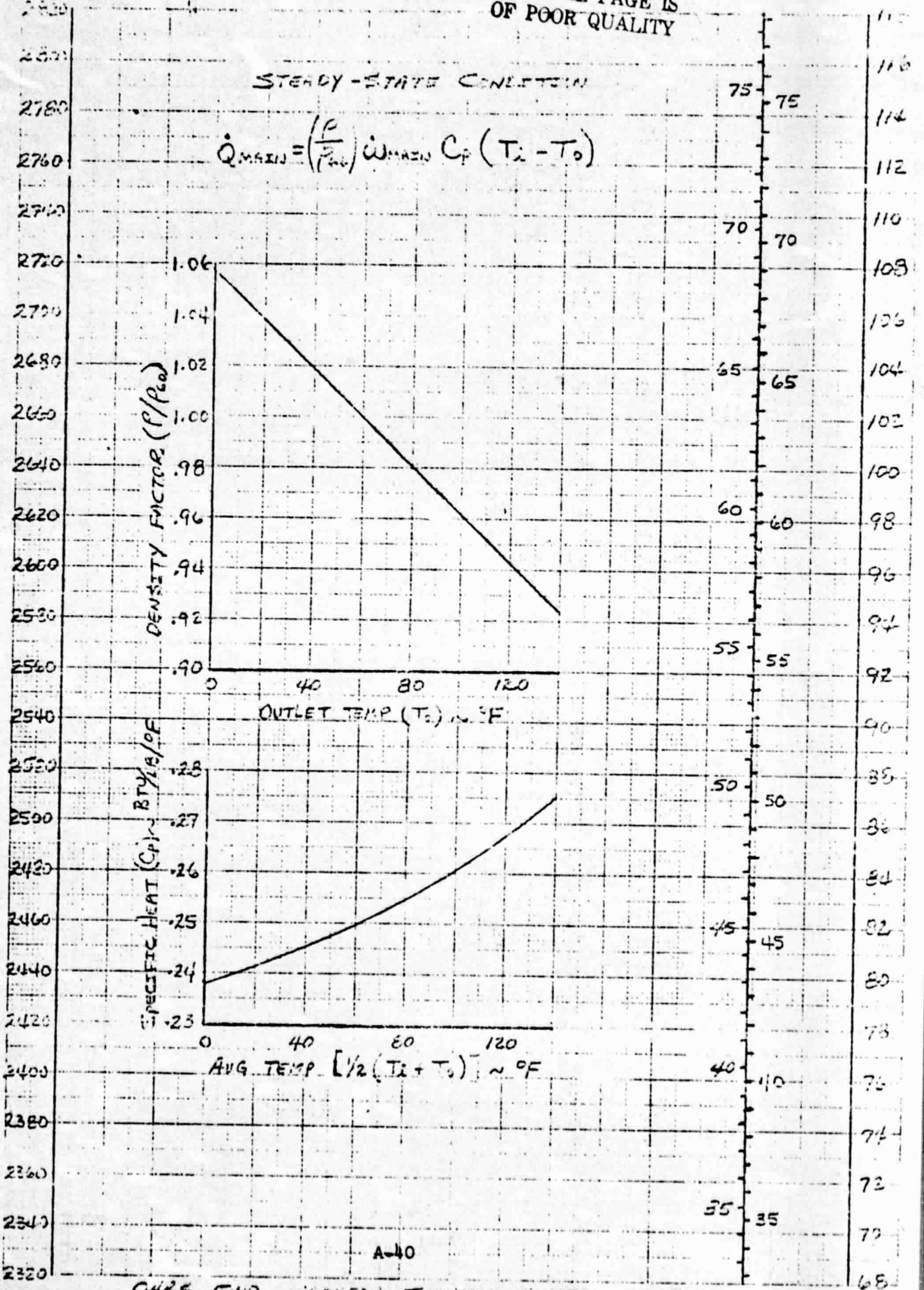
STEADY-STATE CONDITION

$$\dot{Q}_{MAIN} = \left(\frac{\rho}{\rho_{60}}\right) \dot{\omega}_{MAIN}\, C_P \left(T_i - T_o\right)$$



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OHRS FWD RADIATOR THERMAL PERFORMANCE

FIG. 1 (33° VS. 50° [illegible] COMPARISON)

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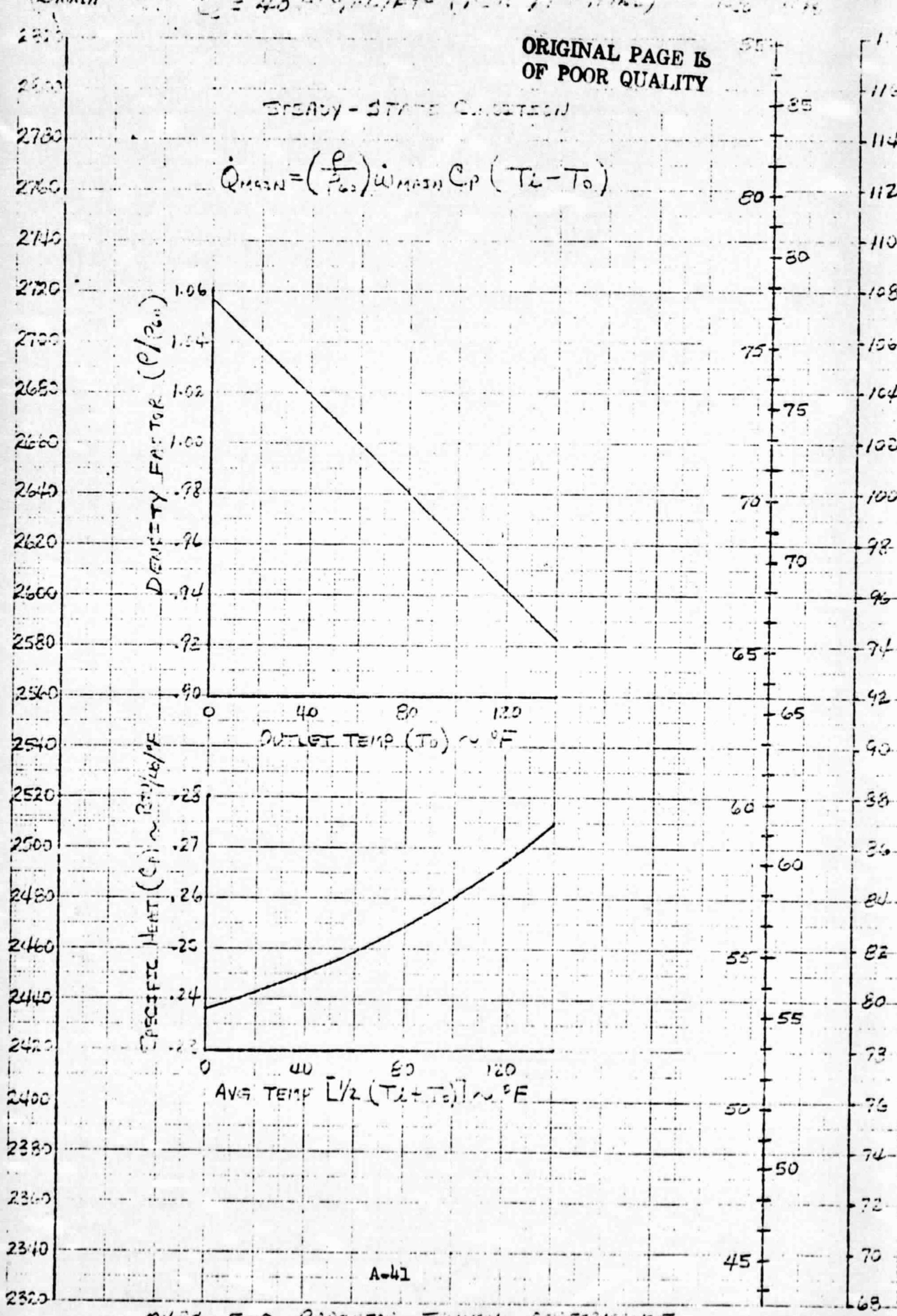

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FIG. 2 OHRS FWD RADIATOR THERMAL PERFORMANCE (38° VS 50° CAVITY COMPARISON) 10/27/75

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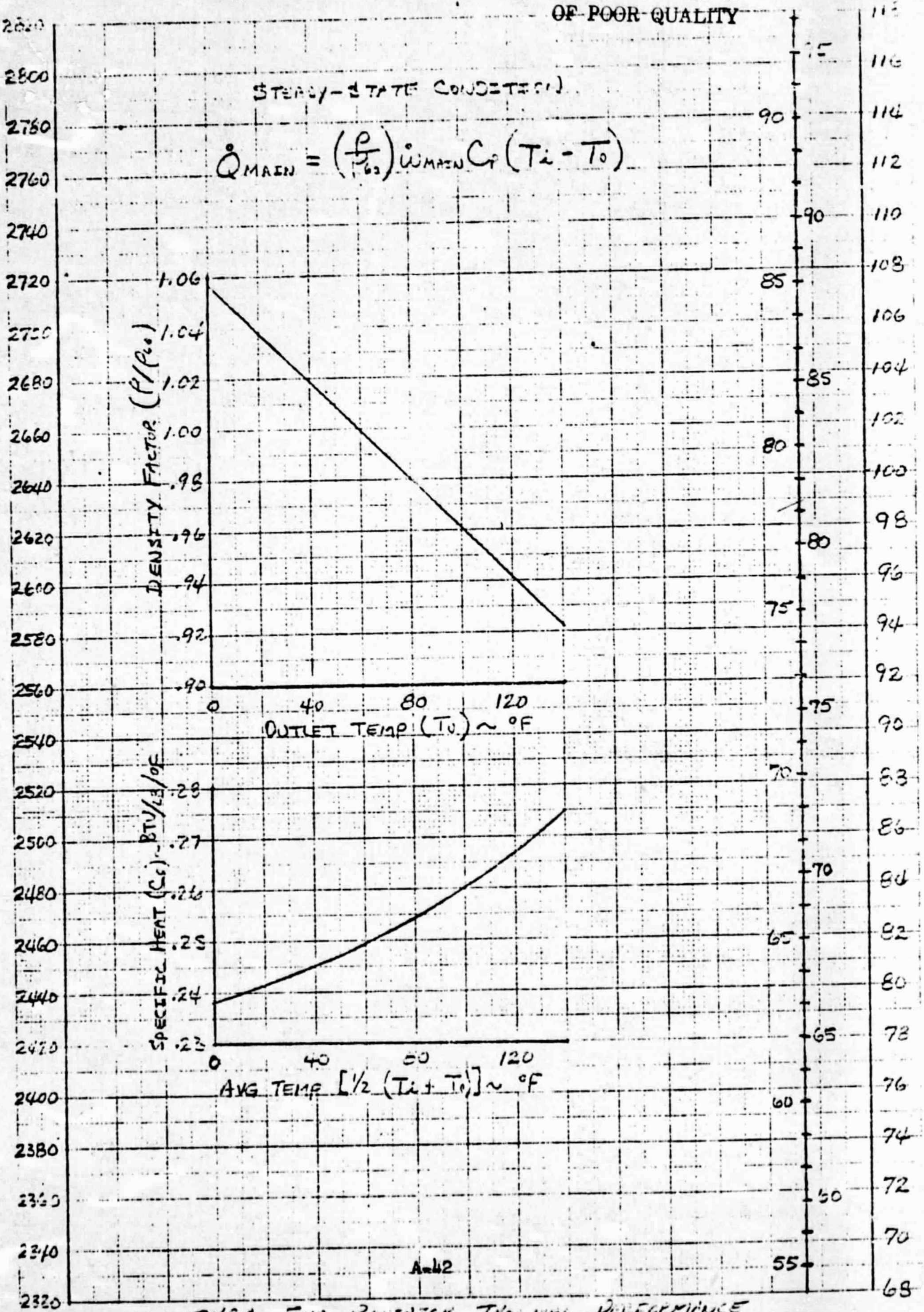


STEADY-STATE CONDITION

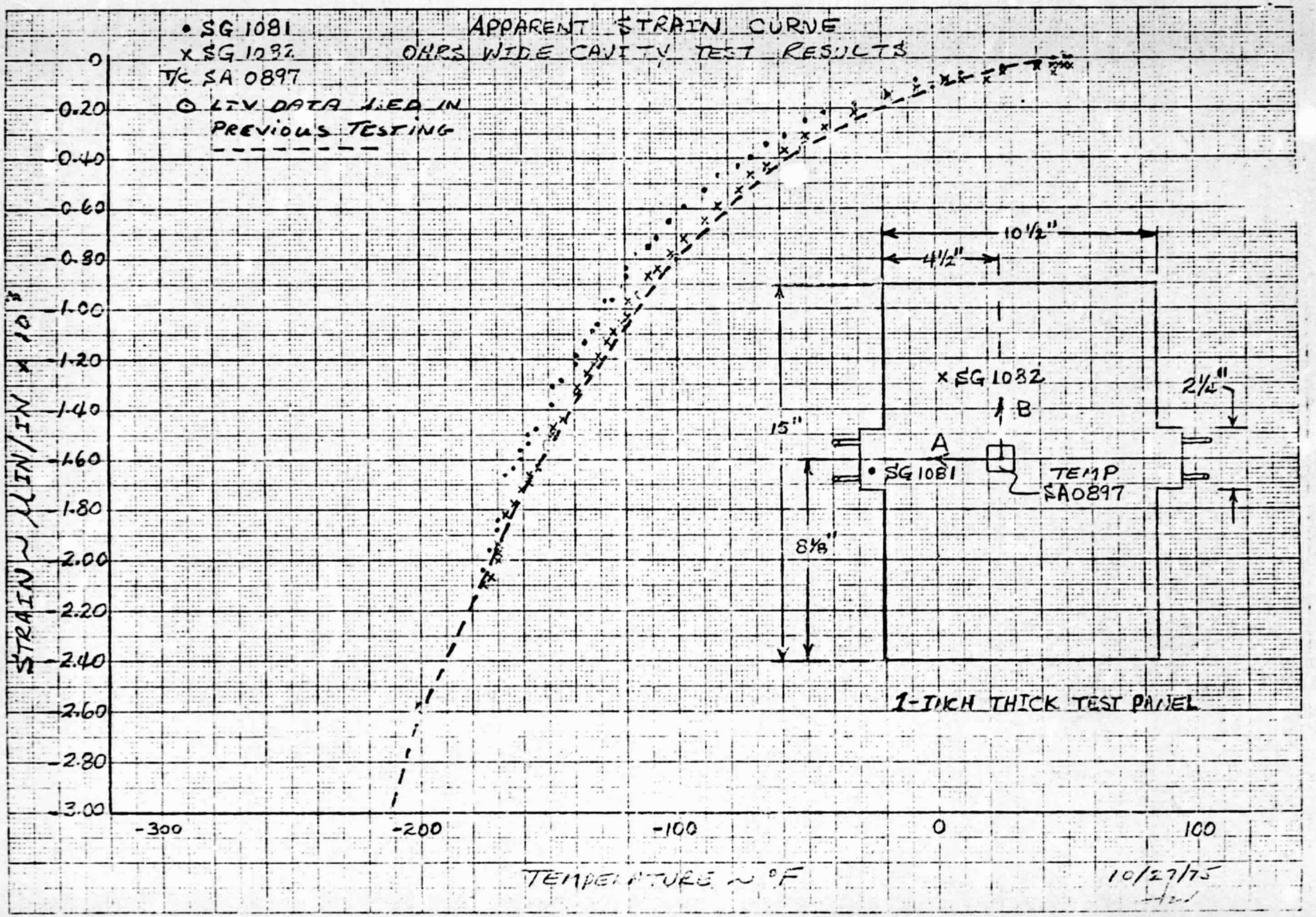
$$\dot{Q}_{MAIN} = \left(\frac{\rho}{\rho_{62}}\right) \dot{w}_{MAIN} C_P (T_i - T_o)$$

OHRS FWD RADIATOR THERMAL PERFORMANCE
(38° VS. 50° CAVITY COMPARISON)

FIG. 3

10/27/75

FIGURE 4



10/27/75

OHRS RADIATOR TESTING

5TH WEEK

STATUS REPORT

NOVEMBER 18, 1975

1. TEST ARTICLE

The OHRS test article was visually inspected after completion of the 70° cavity angle testing. No significant changes in the condition of the silver Teflon coating were noted; however, the edges of the coating were curled slightly at several locations.

2. INSTRUMENTATION ASSESSMENT

Instrumentation checkout prior to pumpdown indicated data would be sufficient to accomplish test objectives. Incorrect and questionable instrumentation are listed below:

Incorrect

FA0582
FA0617
FA0632
FA0633
FA0634
FA0636
CC1207
CC1222
CC1227
CC1241
TF5529

Questionable

FA0562
FA0647
FA0658
FA0715
FA0717
TF5540

3. TIMELINE

Table 1 presents a summary of the test point sequence accomplished during the fifth week of testing. All test points originally planned for four days of testing were accomplished. A four day schedule was necessary due to a delay in chamber pumpdown to permit replacement of a SHRM compressor assembly. Pumpdown began at 2345 hours on Monday, November 3 (307:23:45).

4. PERFORMANCE

The results of the fifth week of testing are summarized in Table 2. The first sixteen test points (7001-7016) were performed to determine high load performance. Test points 7018 and 7020 represent the effect of skewed environments, and the last three test points (7021-7023) were performed to determine low load performance.

As expected, the 70° cavity resulted in a general improvement in panel heat rejection capacity when compared to both the 38° and 50° cavity results. Radiator outlet temperatures were approximately 6°F lower, at representative operational flowrates and high environmental heat loads, than the Shuttle baseline performance. The 6°F lower outlet temperature represents about 3000 to 4000 BTU/hr (depending upon flowrates and inlet conditions) improvement in heat rejection capacity. Detailed analysis will be required to correlate the relationship between performance of the test article and actual radiator system performance during on-orbit conditions.

The high load performance testing duplicated test points conducted during both the 38° and 50° cavity tests. Three environmental conditions were impressed on the test article as follows:

Test Condition	Panel Top Flux (BTU/hr/ft^2)	PBD Absorbed Flux (BTU/hr
1	0	0
2	40	2400
3	80	4800

Test results for each of the above conditions are shown in Figures 1, 2, and 3, respectively. These figures are nomographs constructed from the raw data included in Table 2 with similar data from the 38° cavity test. Caution should be exercised in the interpretation of these figures since they do not represent a detailed evaluation of the test results, and are intended only for quick look assessment.

5. APPARENT STRAIN DATA

Efforts were continued during the fifth week of testing to monitor the temperature induced strain relationship of the radiator test article A cursory inspection of the data from the three test samples showed no significant deviations from the results obtained during the fourth week.

TABLE 1

OHRS WIDE CAVITY (70°) TEST POINTS

TEST POINT NUMBER	COMPLETION TIME DAY	HR	MIN
7001	308	14	50
7002		17	05
7003		20	05
7004		22	45
7005	309	00	20
7006		05	20
7007		09	05
7008		11	05
7009		13	19
7010		15	05
7011		16	20
7012		19	50
7013		21	20
7014		23	20
7015	310	01	48
7016		03	05
7021		14	50
7022		20	05
7023	311	00	45
7018		06	00
7020		11	00

TABLE 2

OHRS WIDE CAVITY (70°) TEST POINT RESULTS

	PRIME TIN (°F)		PRIME TOUT (°F)		MAIN TIN (°F)		MAIN TOUT (°F)		PRIME	MAIN
	Loop 1	Loop 2	Loop 1	Loop 2	Loop 1	Loop 2	Loop 1	Loop 2	(LB/HR)	(LB/HR)
TEST	TF5516	TF5540	TF5514	TF5538	TF5518	TF5542	TF5512	TF5536	FM5655	FM5654
POINT	TF5517	TF5541	TF5515	TF5539	TF5519	TF5543	TF5513	TF5537	FM5656	FM5657
7001	104.6	107.0	90.3	91.9	104.6	104.6	65.4	65.4	81.7	2798
7002	101.4	102.2	83.9	85.5	101.4	101.4	56.2	56.2	67.9	2354
7003	88.7	91.1	72.8	74.4	88.7	88.7	47.8	47.8	67.8	2383
7004	76.0	76.8	61.3	63.0	76.8	76.0	36.9	37.8	66.0	2326
7005	77.6	79.9	64.6	66.3	77.6	77.6	43.6	44.5	72.4	2750
7006	87.1	89.5	72.8	74.4	87.1	87.1	49.5	49.5	66.4	2403
7707	109.4	111.0	96.7	98.3	109.4	109.4	76.0	76.0	79.8	2739
7008	107.8	110.2	95.1	95.1	107.8	107.8	71.2	71.2	68.8	2421
7009	95.1	95.9	82.3	83.1	93.5	95.1	61.3	61.3	65.5	2383
7010	82.3	83.1	71.2	72.8	82.3	82.3	52.0	52.9	66.6	2364
7011	83.9	84.7	74.4	74.4	83.9	83.9	56.2	57.0	72.9	2759
7012	115.5	117.9	107.8	108.6	115.5	116.3	88.7	88.7	81.2	2797
7013	114.0	115.5	104.6	105.4	114.0	114.0	84.7	84.7	63.4	2413
7014	101.4	102.2	94.3	94.3	100.7	101.4	76.0	76.0	66.7	2431
7015	88.7	89.5	83.1	83.1	88.7	88.7	66.3	67.1	66.4	2413
7016	88.7	90.3	83.9	83.9	88.7	88.7	69.6	69.6	78.3	2788
7018	99.9	101.5	88.7	90.3	100.7	99.9	71.2	71.2	65.0	2421
7020	99.9	102.2	90.3	91.9	99.9	100.7	74.4	74.4	62.5	2422
7021	N/A	N/A	N/A	N/A	- 20.5	- 20.5	-118.7	-115.4	-0-	104.4
7022	N/A	N/A	N/A	N/A	- 70.6	- 70.6	-150.6	-148.3	-0-	100.9
7023	N/A	N/A	N/A	N/A	-112.2	-112.2	-167.2	-166.0	-0-	101.8

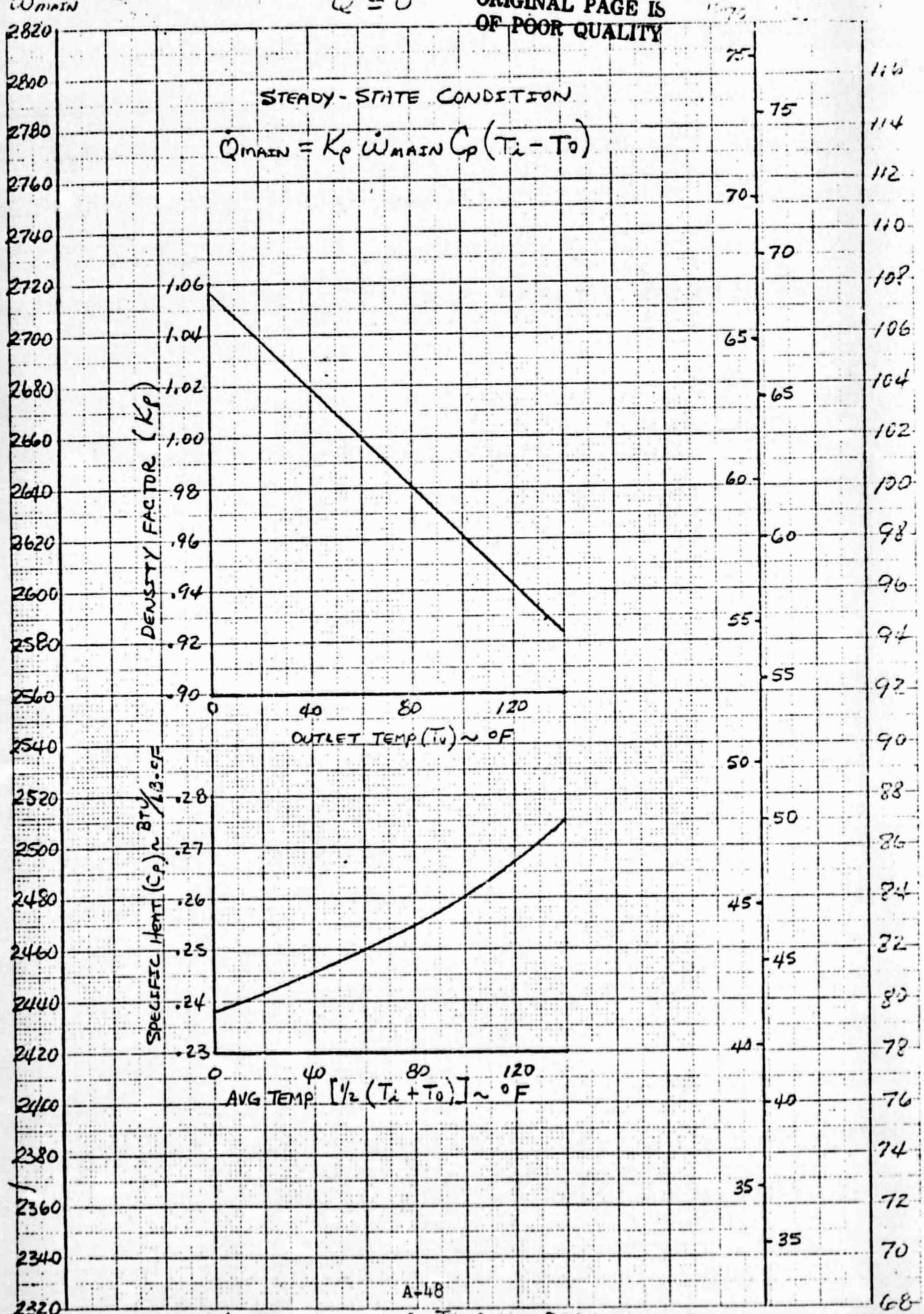
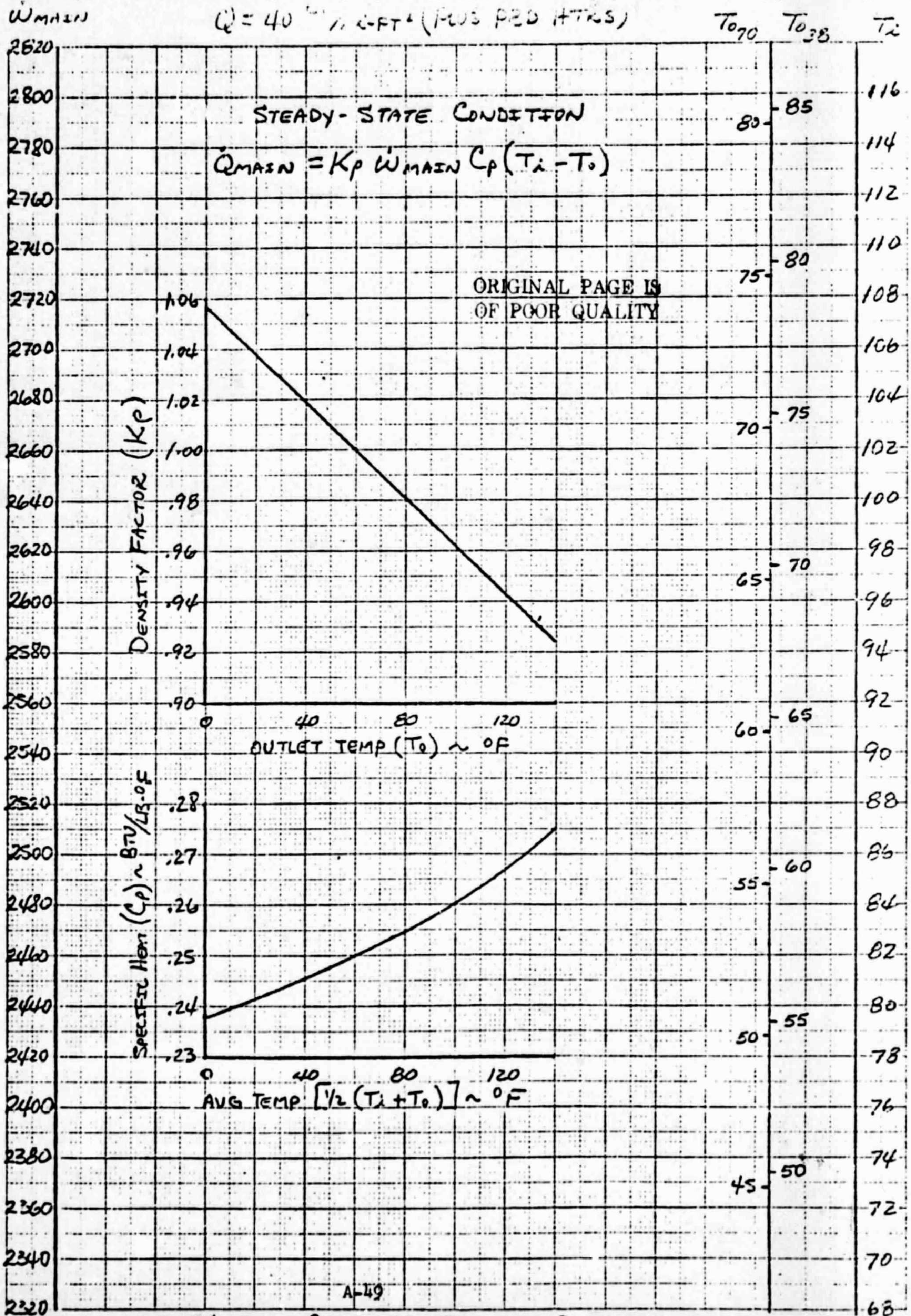


FIG. 1 OHRS FWD RADIATOR THERMAL PERFORMANCE
(38° VS. 70° CAVITY COMPARISON)

11/12/75



OHRS FWD RADIATOR THERMAL PERFORMANCE

11/12/75

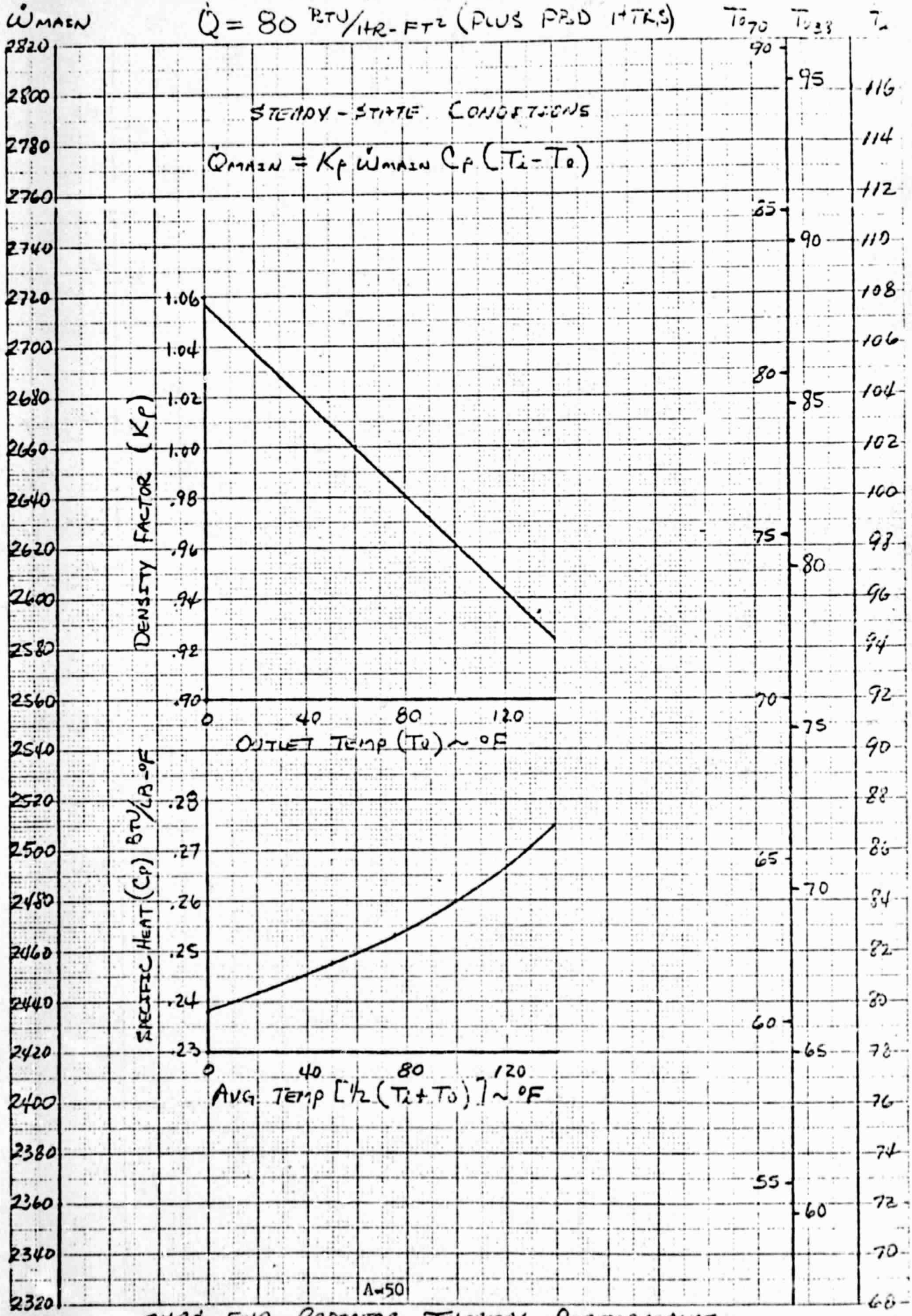


FIG. 3 OHRS FWD RADIATOR THERMAL PERFORMANCE (38° VS. 70° CAVITY COMPARISON) 11/12/75