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STS-1 Environmental Control and Life Support System

Consumables and Thermal Analysis

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SHUTTLE PROGRAM

STS-1 Environmental Control and Life Support System Consumables and Thermal Analysis

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Houston, Texas

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ACRONYMS AND SYMBOLS

ARS	atmospheric revitalization system
ATCS	active thermal control system
CO_2	carbon dioxide
ECLSS	environmental control and life support system
EVA	extravehicular activity
FEAR	Fortran environmental analysis routines
GSE	ground support equipment
H_2O	water
IMU	inertial measurement unit
LiOH	lithium hydroxide
MET	mission elapsed time
MR	metabolic rate
NH_3	ammonia
O_2	oxygen
PLB	payload bay
psia	pounds per square inch, absolute
PTC	passive thermal conditioning
SECURE	Shuttle environmental consumables usage requirements evaluation
STS	Space Transportation System

1.0 SUMMARY

The ECLSS/thermal systems analysis for the Space Transportation System (STS-1) mission was performed using the Shuttle environmental consumables usage requirements evaluation (SECURE) computer program. This program employs a nodal technique utilizing the Fortran environmental analysis routines (FEAR). The output parameters evaluated were consumable quantities, fluid temperatures, heat transfer and rejection, and cabin atmospheric pressure. Analysis of these parameters indicated that adequate margins exist for the nonpropulsive consumables and related thermal environment for the nominal STS-1 mission profile.

2.0 INTRODUCTION

This document presents the results of a detailed transient analysis of the environmental control and life support system (ECLSS)/thermal systems usage for the STS-1 mission.

3.0 GUIDELINES AND ASSUMPTIONS

The ECLSS/thermal output parameters evaluated in this analysis are as follows:

a. Consumable quantities for supply water (H_2O), waste H_2O, gaseous oxygen (O_2), cryogenic O_2 (ECLSS usage only), nitrogen, lithium hydroxide (LiOH) and ammonia (NH_3)

b. Fluid temperatures for air, water, and freon

c. Heat transfer/rejection rates

d. Atmospheric pressures for O_2, nitrogen (N_2), carbon dioxide (CO_2), and H_2O

The analyzed system configuration is illustrated in figure 1. The configuration is based on data obtained from references 1 through 6.

Additional guidelines and assumptions used in this analysis were obtained from references 7 and 8.

The contingency reserves were obtained from reference 9.

3.1 STS-1 UNIQUE GUIDELINES AND ASSUMPTIONS

Guidelines and assumptions for the STS-1 are as follows:

a. The Orbiter heat load timeline is as defined by the electrical power system consumables analysis on tape X10827.

b. Incident heat flux on the radiators is calculated as a function of Orbiter attitude and position in space, based on the following:

(1) A 150-n. mi. circular orbit at a beta angle between -17^{o} and -27^{o}.

(2) A constant -ZLV attitude (payload bay (PLB) to the Earth) for most of the mission, with a period (4.5 to 9.67 hours mission elapsed time (MET)) at 0.2 deg/sec passive thermal conditioning (PTC).

(3) A 40.3^{o} inclination.

c. The mission timeline is defined in references 6 and 7.

d. A standard environmental heat load during entry, obtained from reference 6, is imposed on the Orbiter cabin.

e. A two-man crew is assumed, working on a single shift basis.

f. All members of the crew are assumed to be functioning continuously at a nominal metabolic rate of 450 Btu/hr.

3.2 ACTIVE THERMAL CONTROL SUBSYSTEM

Parameters of the active thermal control subsystem are as follows:

a. Individual component performance parameters are as defined in references 1 through 9.

b. The flow split between the fuel cell heat exchanger and the mid cold plates at node 1 (fig. 1) is 87.1 and 12.9 percent, respectively.

c. The freon flow split to the aft cold plates at node 99 (fig. 1) is 10.45 percent in the interchanger mode and 8.0 percent in the payload mode.

d. The freon flow split to the payload HX at node 28 (fig. 1) is 10.5 percent in the interchanger mode and 43.1 percent in the payload mode.

e. The freon flow rate is based on a 71-pound per square inch, absolute (psia) pump at 2540 lb/hr and varies between 2650 and 2927 lb/hr/loop as a function of flow through the radiators and through the payload HX.

f. Heat rejection is provided as follows:

(1) By the GSE HX from power-up until lift-off (zero hour).

(2) By no heat from lift-off to 140 000 feet (0.036 hour).

(3) By hi-load and topping flash evaporator from 140 000 feet to radiator deploy (2.35 hours).

(4) By the radiators during onorbit periods except for the deorbit rehearsal; supplemental cooling is provided by the topping flash evaporator as required.

(5) By hi-load and topping flash evaporator during deorbit rehearsal (27.0 to 29.7 hours).

(6) By hi-load and topping flash evaporators from radiator retract (51.02 hours) to 120 000 feet (54.36 hours) and as required, until 85 000 feet (54.40 hours) during descent.

(7) By the NH_3 boiler from 120 000 feet through landing to ground support equipment (GSE) hookup (54.762 hours).

g. An eight-panel radiator is utilized with a bypass flow rate controlled to provide a discharge temperature of 38° F at nodes 18 and 19 (fig. 1).

h. The flash evaporators utilize water with a heat dissipation capacity of 1010 Btu/lb. The water flow is controlled to provide a freon discharge temperature of 39° F at node 99 (fig. 1). This accounts for an evaporator effectiveness of 99 percent.

i. The ammonia boiler utilizes NH_3 with a heat dissipation capability of 520 Btu/lb. The NH_3 flow is controlled to provide a freon discharge temperature of 35° F at node 24 (fig. 1).

j. Six tanks, each with a usable capacity of 165 pounds, are assigned to potable water storage. The mission is initiated with five tanks loaded full and one loaded to 65 percent at lift-off. Potable water is maintained between 975 and 675 pounds onorbit. The excess water is dumped overboard through the dump valves when necessary.

3.3 ATMOSPHERIC REVITALIZATION SUBSYSTEM

Parameters of the atmospheric revitalization subsystem are as follows:

a. Water flow rate through the interchanger is set at 950 lb/hr/loop for one loop throughout the missions. Periodic cycling of the second water loop is not considered.

b. Cabin temperature is controlled to 70° F.

c. Cabin pressure is controlled as follows:

(1) Total pressure is 14.5 ± 0.2 psia.

(2) Oxygen partial pressure is 3.2 ± 0.5 psia.

(3) Cabin relief pressure is 15.5 psia.

d. Atmospheric leakage from the pressurized cabin is 8.2 lb/day.

e. Metabolic requirements and production as a function of metabolic rate (MR) are as follows:

(1) O_2 requirement is 0.0739 lb/man-hour at 450 Btu/hr.

(2) CO_2 production is 0.0882 lb/man-hour at 450 Btu/hr.

(3) H_2O production is The larger value for QL.

$$QL = (MR - 430 + (10 + 0.001MR)\ (T-60))/1050 \quad lb/man\text{-}hr$$

or

$$QL = (0.22\ MR + 2.6(T-60))/1050 \quad lb/man\text{-}hr$$
$$(MR = 450\ Btu/hr)$$

(4) Urine production is 0.138 lb/man-hr.

(5) Crew water consumption is 0.344 lb/hr.

f. Canisters of LiOH that are used to remove atmospheric CO_2 perform as follows:

(1) Water of reaction is 0.409 lb/lb of CO_2 absorbed

(2) Heat of reaction is 876 Btu/lb of CO_2 absorbed

The canisters are not installed until 5.5 hours MET, with one being replaced at 12.25 hours, and the other at 36.42 hours. Both are removed prior to deorbit at 49.28 hours MET.

Eight and six tenths percent of the airflow is routed through each LiOH canister.

g. One tank, with a usable capacity of 165 pounds, is assigned to waste-water storage. The waste-water tank is loaded to 97 percent (160 pounds) with purified H_2O prior to lift-off for use in the flash evaporator in the event of a failure of the radiators to deploy properly. The tank will be dumped to 80 percent (132 pounds) at 4.5 hours MET, and again at 33.65 hours MET.

h. The cabin volume is 2325 cubic feet.

i. The cabin fan provides a constant volume airflow of 307 ft^3/hr (1380 lb/hr at 14.7 psia and 70° F).

j. An airflow rate of 156 lb/hr (at 14.7 psia) is directed through the inertial measurement units (IMU's).

k. An airflow rate of 1140 lb/hr at 14.7 psia (node 212) is directed through the cabin avionics, with 240 lb/hr through the waste management compartment.

l. Maximum airflow bypass around the cabin HX is 71.4 percent.

m. The water pump flow rate is computed as a function of bypass valve position and the number of pumps operating, and varies between 1280 and 1641 lb/hr per loop.

n. The flow split at node 113 (fig. 1) to avionics bays 1, 2, 3, and 3A is 24.2 percent, 24.0 percent, 47.3 percent, and 4.5 percent, respectively.

4.0 CONCLUDING REMARKS

This analysis indicates adequate margins for the nonpropulsive consumables and related thermal environment for the nominal STS-1 mission profile. The nonpropulsive budgets are presented in tables I through V. The related thermal performance is presented in figures 2 through 12. A summary of subsystem maximum temperatures from the analysis versus the specifications for the subsystems is given in table VI.

It is noteworthy that the radiators are incapable of maintaining a 38° F outlet temperature continually during the onorbit period. It is necessary for the topping flash evaporator to provide supplemental cooling of up to 18 000 Btu/hr for approximately 45 minutes of each orbit (fig. 3). As a consequence of this required water usage, the maximum water quantity achieved was 940 pounds, and it was not necessary to dump the supply water tanks.

5.0 REFERENCES

1. Operational Data Branch: Shuttle Operational Data Book, Vol. 1 - Shuttle Systems Performance and Constraints Data. JSC-08934, Rev. B, Feb. 1980.

2. Operational Data Branch: Shuttle Operational Data Book, Vol. II - Mission Mass Properties. JSC-08934, Sept. 1975.

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4. Rockwell International: Requirements/Definition Document, Environmental Control and Life Support; Book 6; Food, Water & Waste Systems, Vol. 6-2. Rockwell International SD72-SH-0106-2, June 1976.

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6. Systems Engineering Branch: Space Shuttle ECLS System Data. Memo EC2-78-044, Rev. A, Mar. 31, 1979.

7. Mission Planning and Analysis Division: STS-1 Operational Flight Profile, Cycle 3, Onorbit. JSC IN 78-FM-51, Rev. 1, Vol. III, Dec. 1979.

8. Crew Training and Procedures Division: STS-1 Crew Activity Plan, JSC-12799, Rev. D, Preliminary, Nov. 1979.

9. Mission Planning and Analysis Division: STS-1 Operational Flight Profile, Cycle 3, Nonpropulsive Consumables Analyses. JSC IN 78-FM-51, Rev. 1, Vol. VIII, Feb. 1980.

TABLE I.- ECLSS ATMOSPHERIC GAS BUDGET

Item	Cryogenic oxygen, lb	Auxiliary oxygen, lb	High-pressure nitrogen, lb
Total loaded	112.0[a]	66.0	262.2
Prelaunch requirement	0	0	-
Launch load	112.0	66.0	262.2
Unusables: residual	N/A[a]	11.0	26.0
Available for mission planning	112.0	55.0	236.2
Reserves			
Measurement error	N/A[a]	5.0	16.2
Dispersion allowance (10 percent)	0.7	0	1.4
Contingency			
a. 1-day mission extension	8.6 ± 0.4	0	8.4 ±. 4
b. Cabin puncture	26.9 ± 1.3	29.0 ± 1.4	97.1 ± 1.1
c. Single-cabin repress to 14.7 psia	0	41.8 ± 2.1	131.6 ± 6.6
d. Single-cabin repress to 8 psia	0	28.7 ± 1.4	66.4 ± 3.3
e. Single-cabin repress 8 to 14.7 psia	0	13.1 ± 0.7	65.2 ± 3.3
f. One EVA	6.3 ± 0.3	0	8.2 ± 0.4
Total reserves[b]	28.9	48.9	155.8
Available for nominal mission	83.1	6.1	80.4
Flight requirement	13.3	0	14.1
Margin	69.8	6.1	66.3

[a]Two cryogenic tank sets contain 1574 lb cryogenic O_2 to provide for fuel cell requirements, plus 112.0 lb for ECLSS requirements, plus residual and measurement error.
[b]Includes worst single contingency.

TABLE II.- ECLSS AMMONIA BUDGET

Item		Ammonia, lb
Total loaded		97.6
Prelaunch requirement	0	
Launch load		97.6
Unusables, residual	2.0	
Available for mission planning		95.6
Reserves		
Measurement error	5.4	
Dispersion allowance (10 percent)	7.5	
Contingency: none identified	0	
Total reserves	12.9	
Available for nominal mission		82.7
Flight requirement	75.4	
Margin		7.3

TABLE III.- ECLSS LITHIUM HYDROXIDE BUDGET

Item		LiOH canisters
Total loaded		6
Prelaunch requirement	0	
Launch load		6
Unusables	0	
Available for mission planning		6
Reserves:		
Measurement error	0	
Dispersion allowance	0	
Contingency	1	
Total reserves	1	
Available for nominal mission		5
Flight requirement	4	
Margin		1

TABLE IV.- ECLSS WASTE WATER BUDGET

Item		Orbiter waste water, lb
Total capacity		168.3
Prelaunch requirement	-1.0	
Off-load	9.3	
Launch load (95 percent)		160.0
Unusables, residual	3.3	
Available for mission planning		156.7
Reserves		
Measurement error	8.4	
Dispersion/flight planning uncertainty[a]	0	
Total reserves	8.4	
Available for nominal mission		148.3
Flight requirement:		
Water generated	31.6	
Water dumped	48.2	
Net use	16.6	
Available for cooling at EOM		131.7
Usable fill margin[b] ((168.3 - 3.3 - 8.4) - 131.7)		24.9

[a]Since the waste-water tank is periodically dumped to 80 percent (132 lb), the analysis dispersion is limited to the 8.4-lb measurement uncertainty.

[b]The unusable capacity (residual and allowance for measurement error) must be deducted from the fill margin (total capacity - available for cooling) to give the usable fill margin.

TABLE V.- ECLSS POTABLE/SUPPLY WATER BUDGET

Item	Supply water, lb			
	Nominal mission		Contingency at PLBD opening	
Total capacity (6 tanks)		1009.8		1009.8
Prelaunch requirement[a]	31.3		31.3	
Off-load	116.1		116.1	
Launch load		925.0		925.0
Unusables, residual	19.8		19.8	
Available for mission planning		905.2		905.2
Reserves				
Measurement uncertainty	50.4		50.4	
Dispersion/flight planning uncertainty (10 percent)	193.3		98.3	
Contingency				
Loss of one tank at PLDB close	156.8		--	
Miss deorbit opportunity[b] (1 orbit wait)	123.8 ± 6.2		waste tank required	
PLBD fail to open[c]	--		247.6 ± 12.4	
Total reserves[d]	530.5		408.7	

[a]Water generated by fuel cells prior to launch.
[b]Contingency occurs at the end of nominal mission. Both contingencies are included in margin and reserves.
[c]Contingency includes a maximum of 3 hours of normal onorbit operation prior to deorbit preparation.
[d]Includes all contingencies.

TABLE V.- Concluded

Item	Supply water, lb: Nominal mission		Supply water, lb: Contingency at PLBD opening	
Available for flight management		374.7		496.5
Flight requirement:				
Crew use	38.4		5.6	
Ascent requirement	265.4		265.4	
Onorbit requirement[a]	469.7		See contingency	
Descent requirement	335.9		335.9	
Water dumped	0		0	
Less water generated	824.9		129.0	
Net water used	284.5		477.9	
Margin		90.2		18.6

[a]Includes deorbit rehearsal.

TABLE VI.- SUBSYSTEM MAXIMUM TEMPERATURE LIMITS ANALYSIS VERSUS SPECIFICATION

Parameter	Node[a]	Maximum specified limit, °F	Analysis maximum temperature, °F
Cabin	205	77[b]	79.6
Cabin dew point	205	61[c]	50.0
Cabin avionics out	214	130	95.5
IMU air in[d]	207	95	79.6
IMU air out	208	130	108.2
Avionics bay 1 air in	122	95	90.3
air out	143	130	111.1
C/P in	119	120	94.0
C/P out	126	130	99.4
Avionics bay 2 air in	123	95	90.3
air out	145	130	111.0
C/P in	120	120	94.0
C/P out	127	130	98.5
Avionics bay 3 air in	124	95	82.3
air out	147	130	92.9
3A C/P in	121	120	82.2
3B C/P in	125	120	79.7

[a]Refer to figure 1.
[b]84° F for 165 minutes.
[c]90° F during entry.
[d]The SODB limit for IMU air inlet is 95° F; a reevaluated, but presently unofficial limit is 89° F, with the discharge limit being eliminated.

TABLE VI.- Concluded

Parameter	Node[a]	Maximum specified limit, °F	Analysis maximum temperature, °F
3A C/P out	138	130	83.0
3B C/P out	137	130	74.0
Fuel cell coolant in	37	140	94.5
Mid body C/P in	2, 7	120	92.2
AFT C/P in	31	120	71.0

[a]Refer to figure 1.

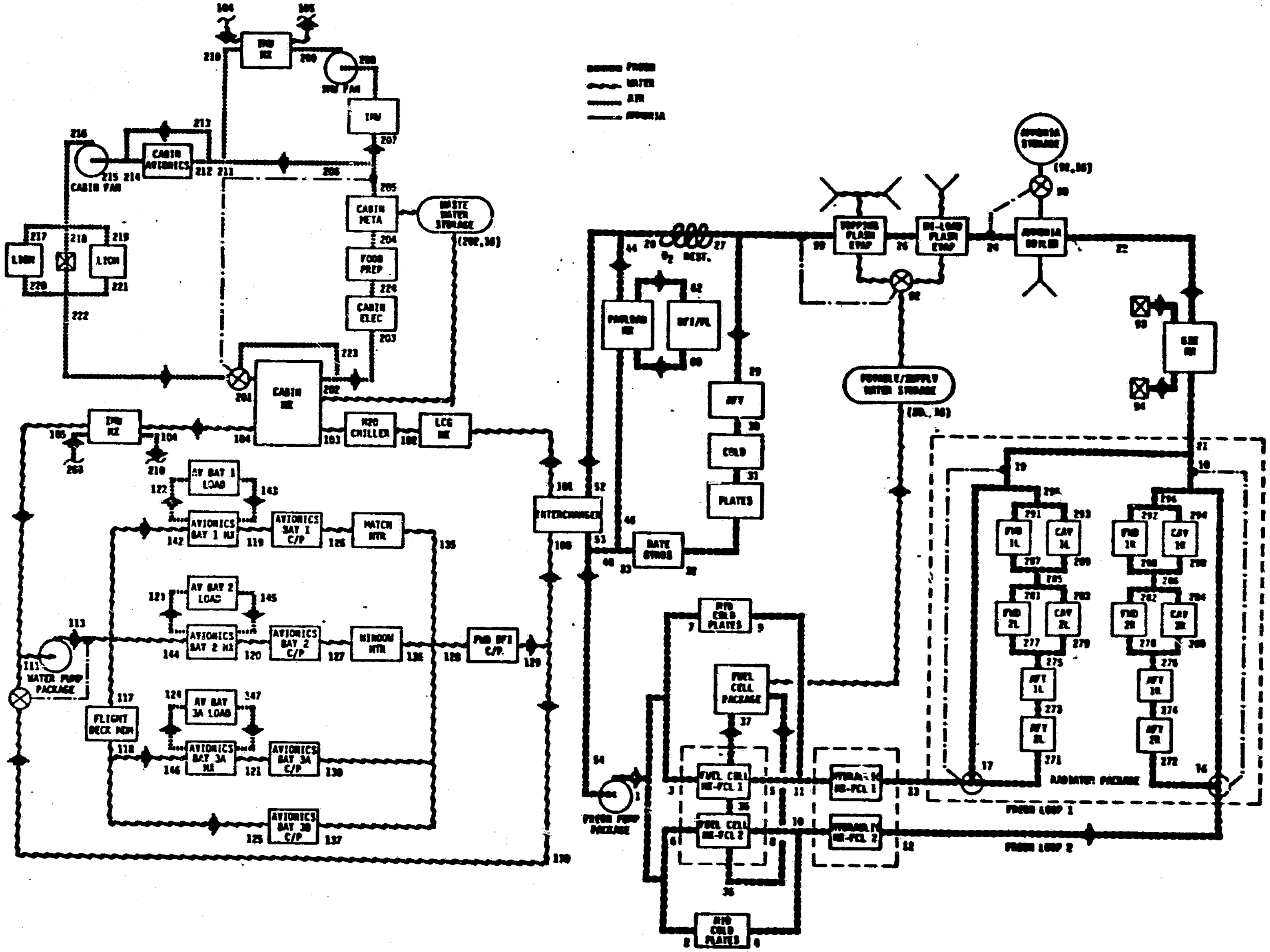

Figure 1.- ECLSS thermal model schematic.

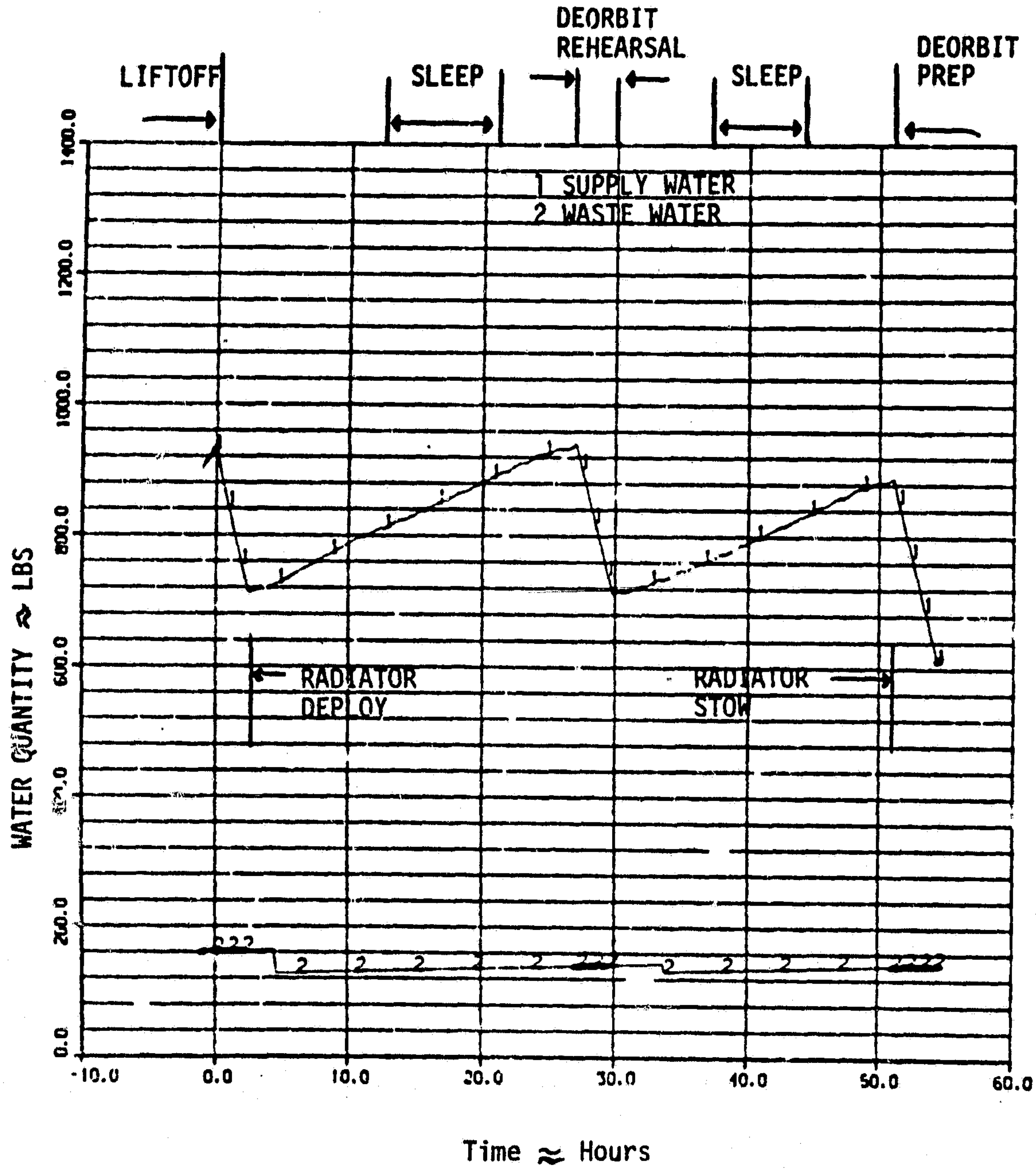

Figure 2.- Orbiter water levels.

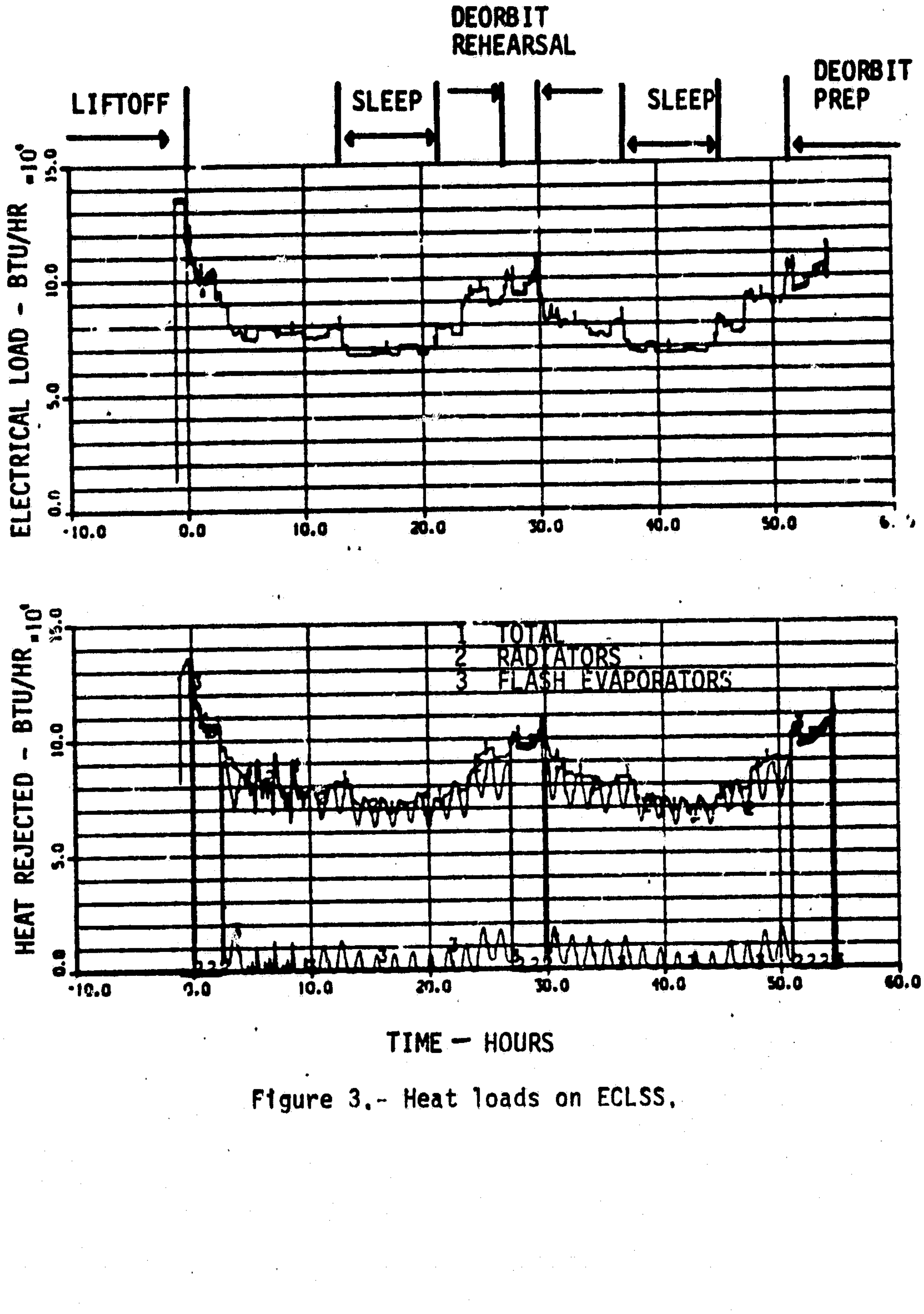

Figure 3.- Heat loads on ECLSS.

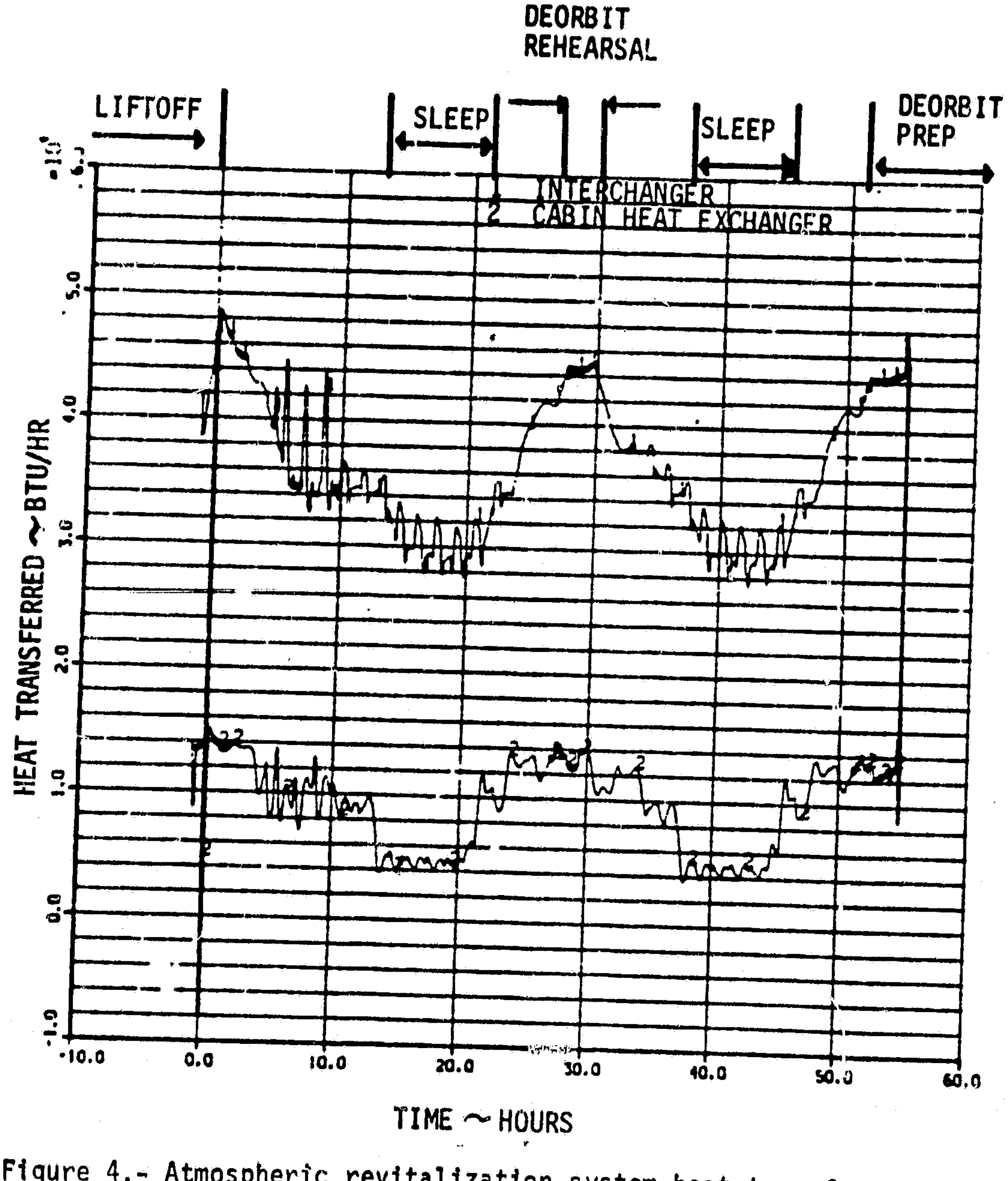

Figure 4.- Atmospheric revitalization system heat transfer rates.

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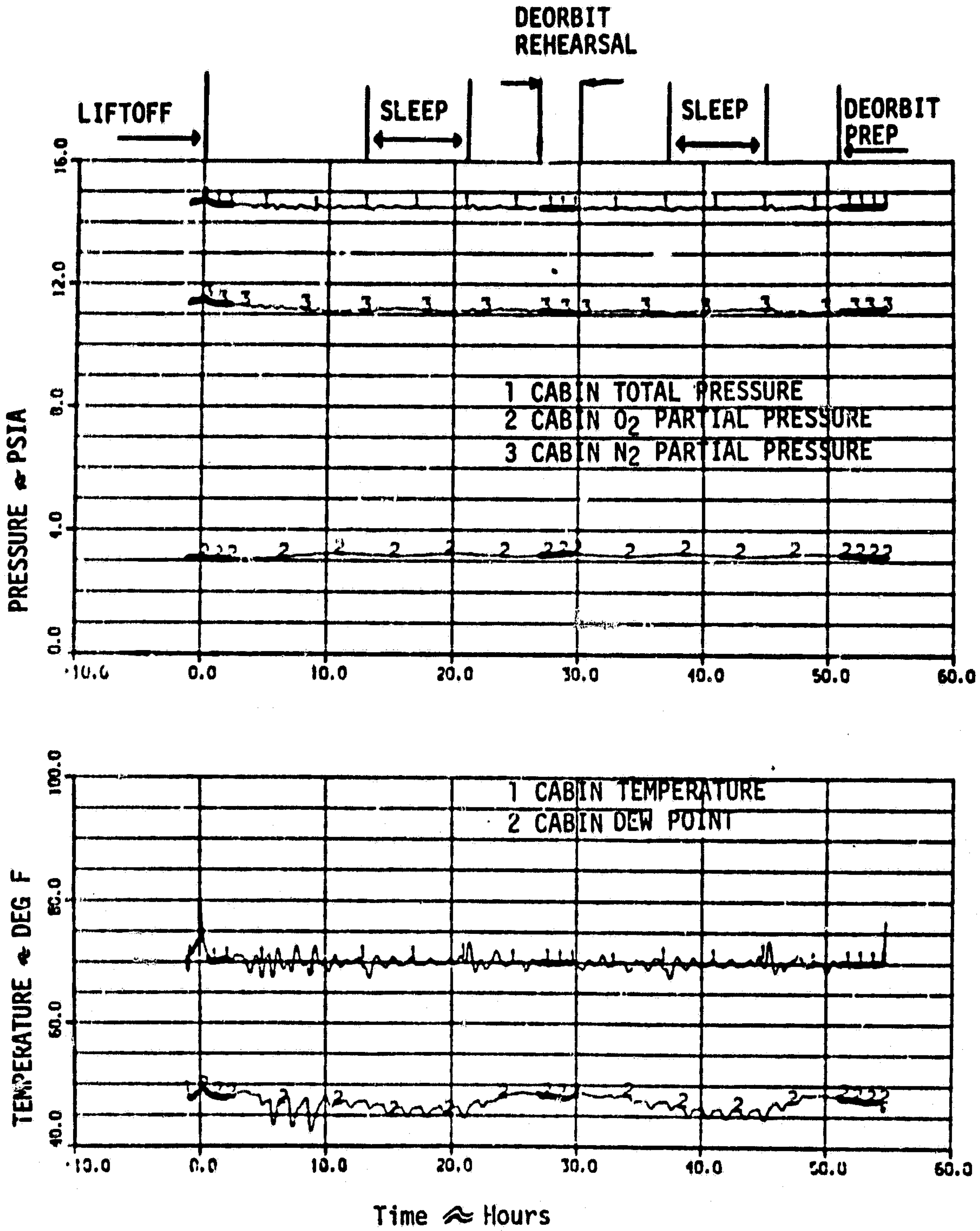

Figure 5.- Cabin pressure and temperatures.

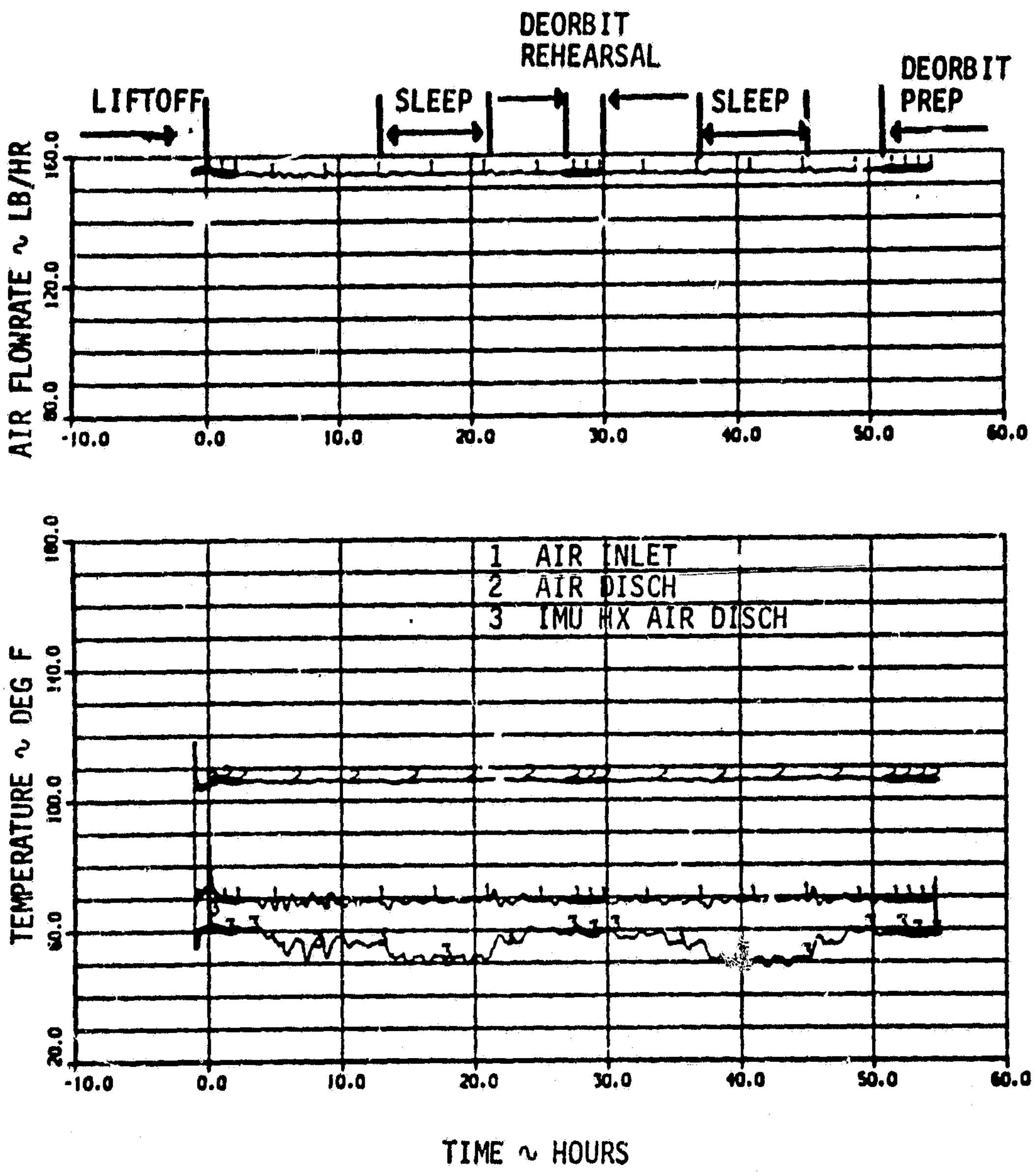

Figure 6.- IMU thermal conditions.

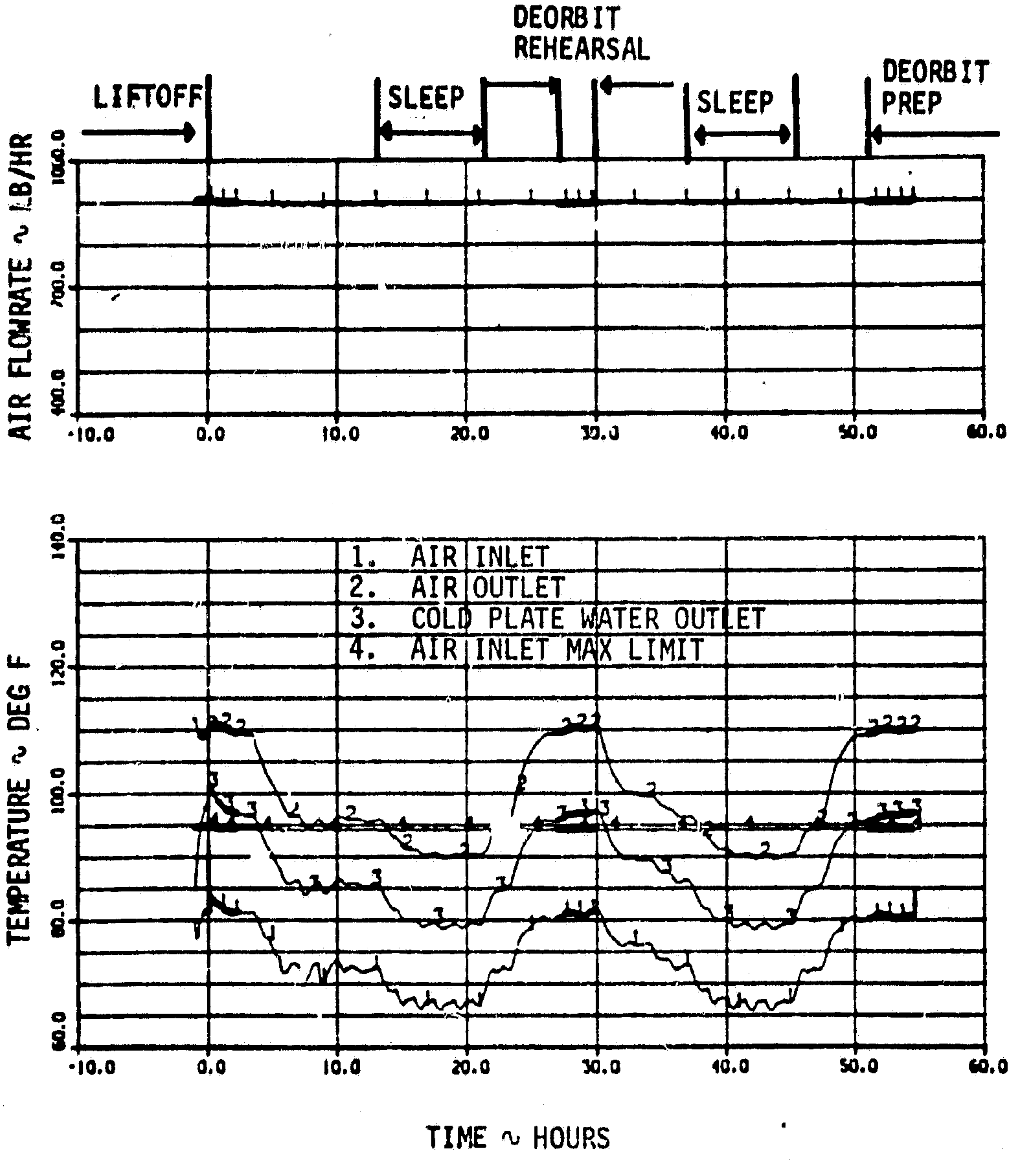

Figure 7.- Avionics bay 1 thermal conditions,

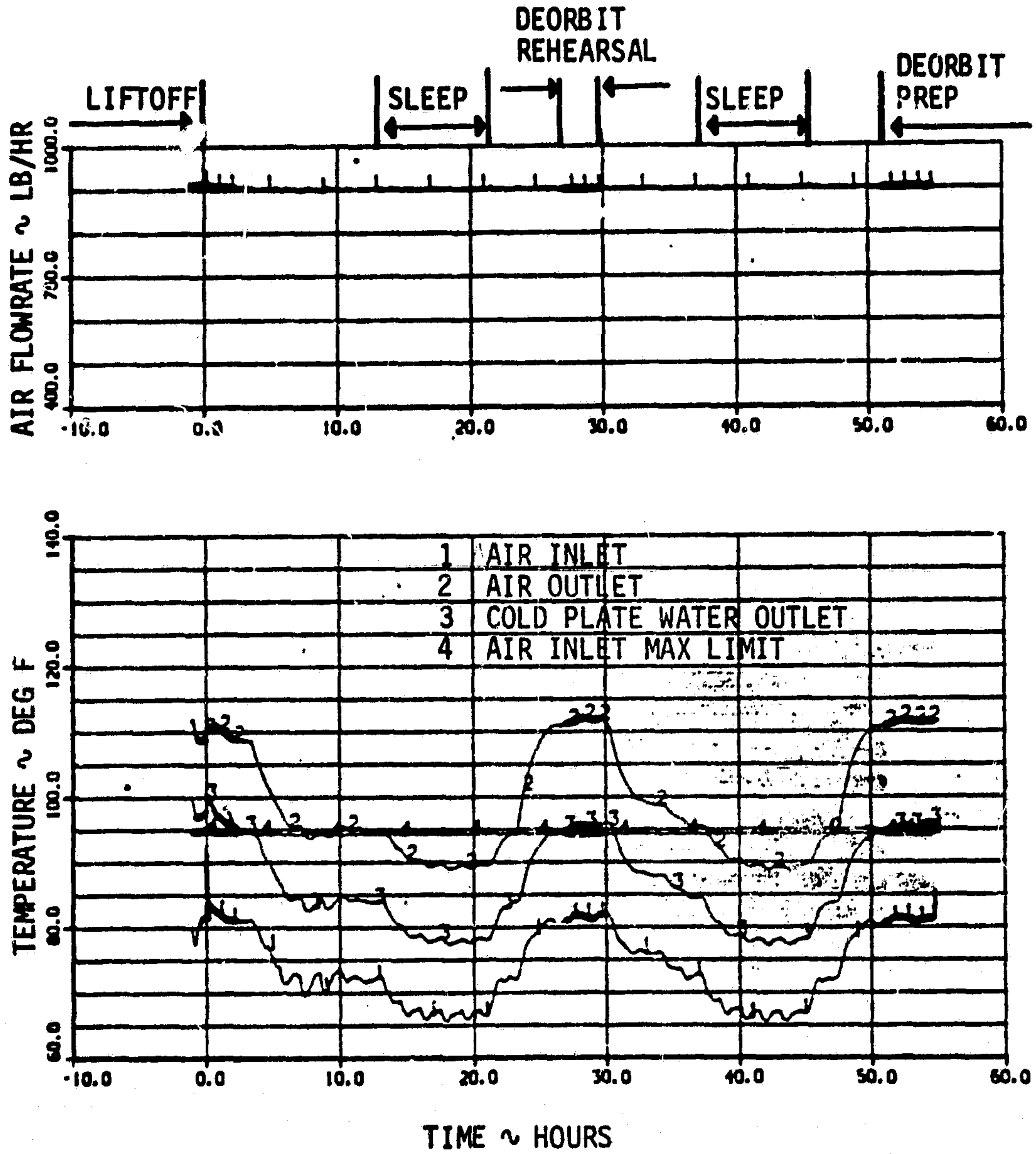

Figure 8.- Avionics bay 2 thermal conditions.

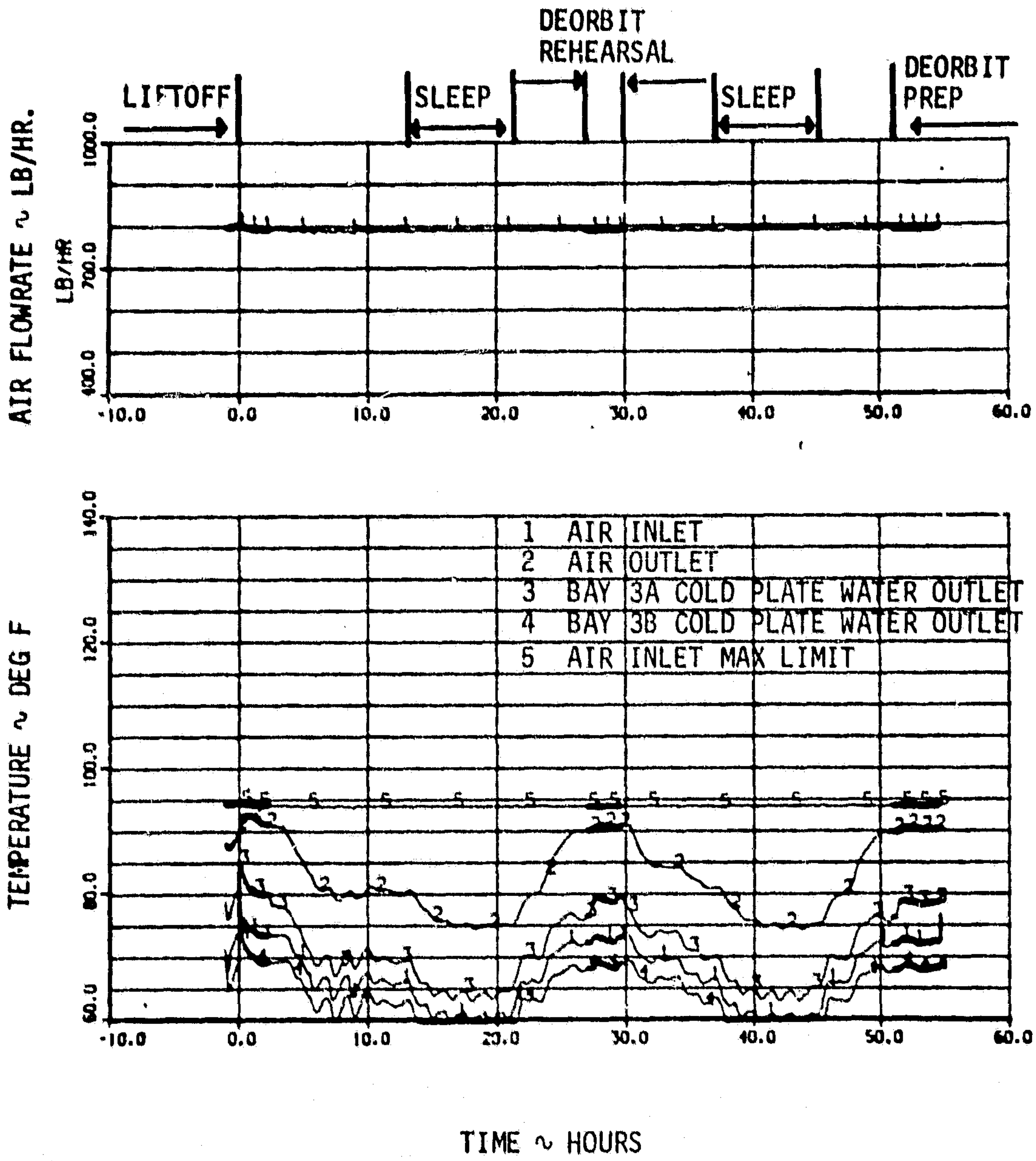

Figure 9.- Avionics bay 3 thermal conditions.

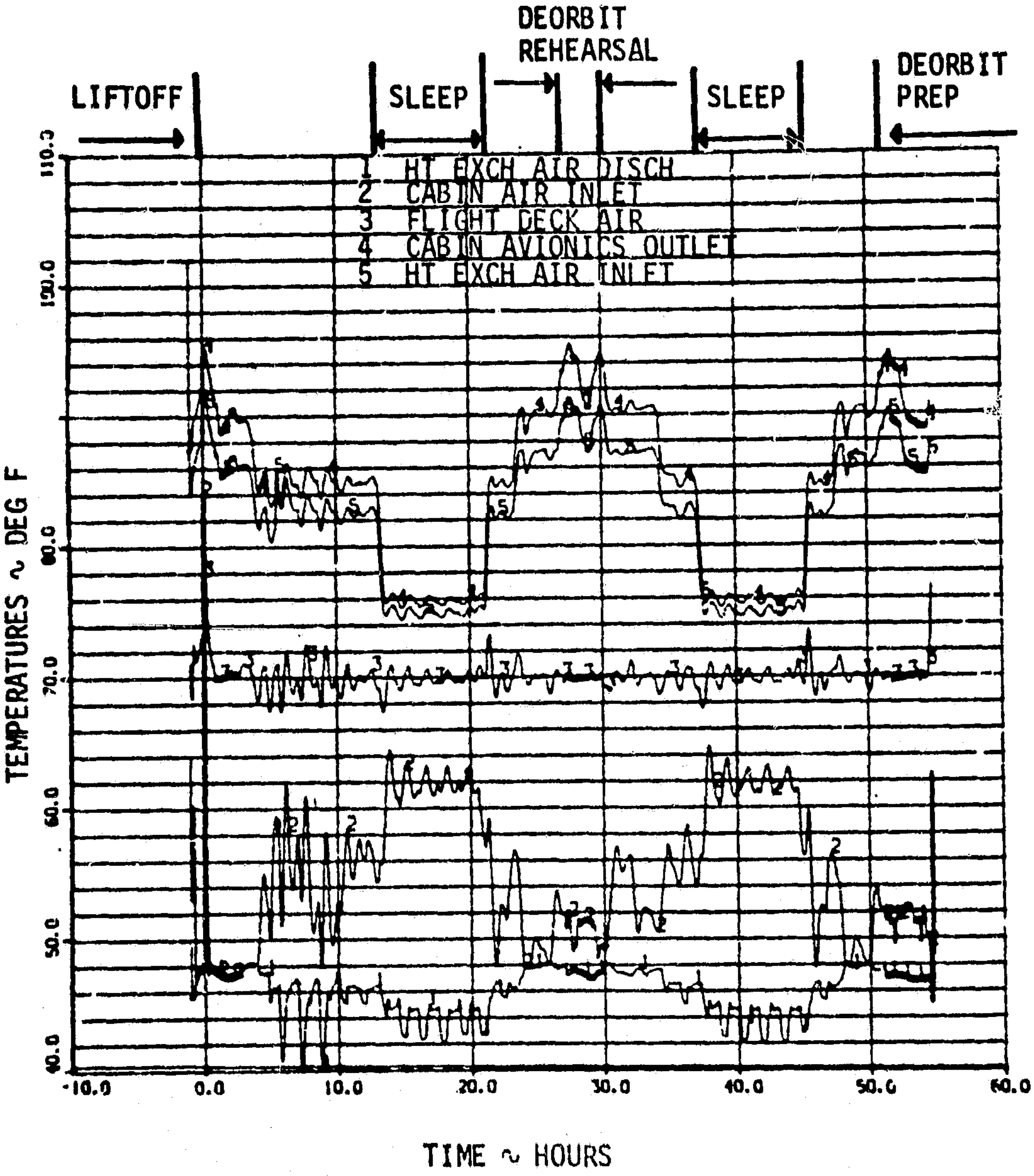

Figure 10.- Cabin air loop thermal profile.

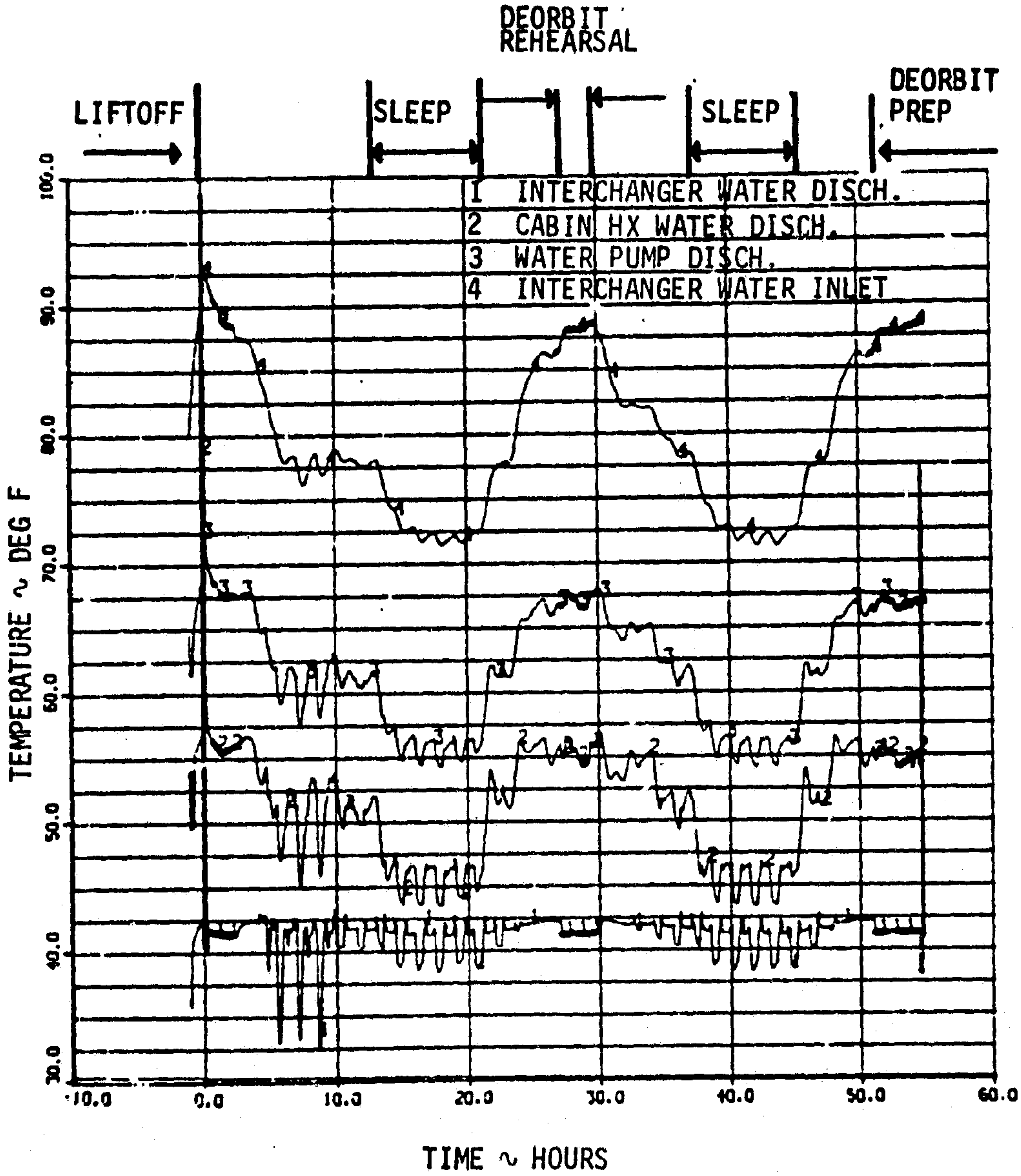

Figure 11.- ARS water loop thermal profile.

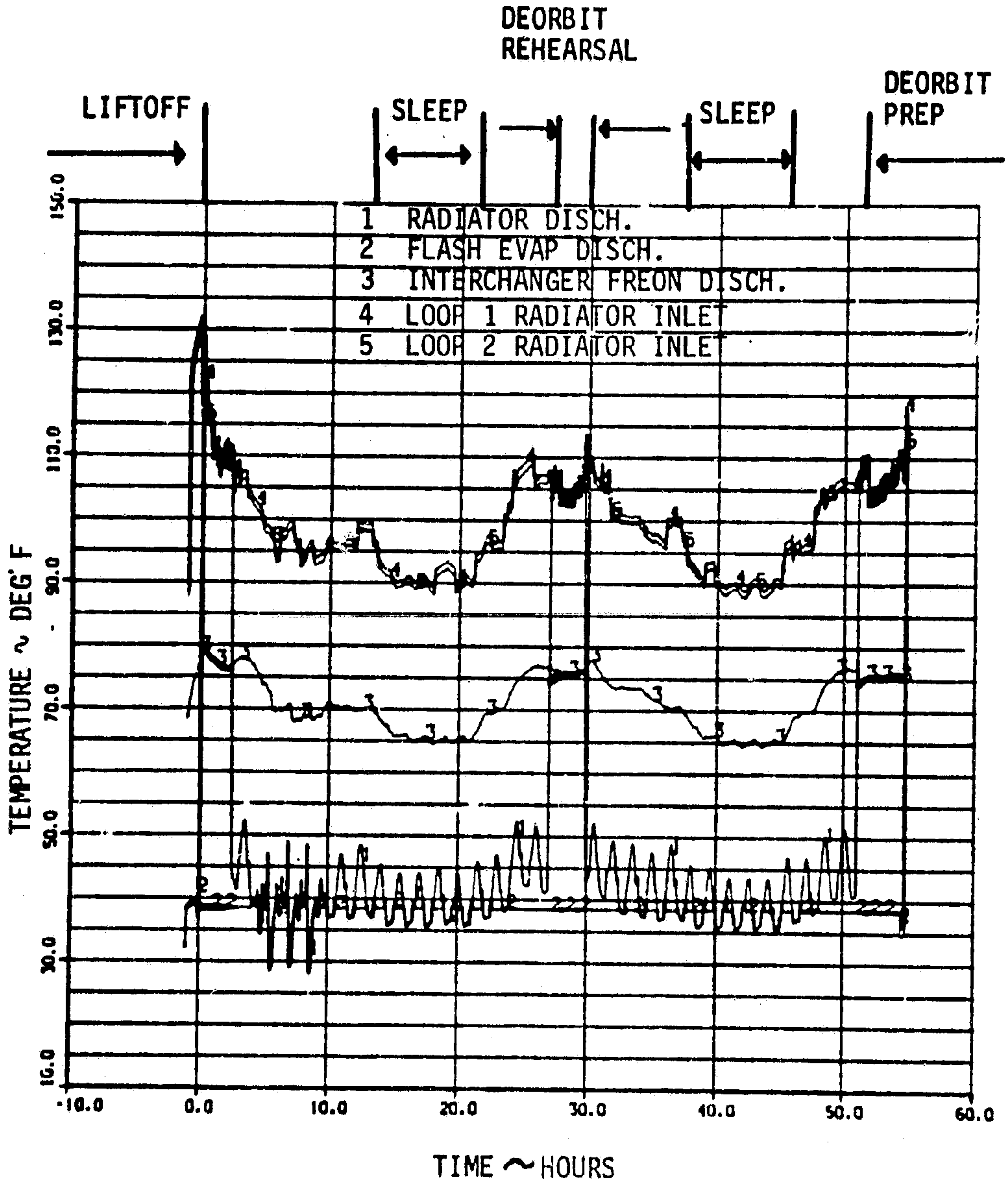

Figure 12.- ATCS freon loop thermal profile.

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