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Jim
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Summary of ALSEP Subpackage No. 2
Thermal Control Design

This ATM presents the thermal design, analyses, and testing of the ALSEP Engineering and Prototype Subpackage 2 pallet and the RTG models and includes a summary of Flight transient and steady state temperatures for the Subpackage 2 equipment during ALSEP lunar deployment and operation.

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1.0 Introduction

This report summarizes the thermal analyses and design of the ALSEP Subpackage No. 2. Results of this ATM are based on the analysis, design, and testing of the Thermal/Mechanical Simulator (D-1A model), the analysis and design of the Prototype A and Flight 1 models, and the thermal testing of the Prototype A model. The thermal analysis of the Engineering D-1A model in the lunar environment, including deployment, is presented as well as the results from the D-1A tests (July 1967) and the Prototype A Thermal Vacuum Tests (December 1967). The thermal analysis of the Flight 1 design, including Subpackage No. 2 equipment, astronaut tools and cable reel, is presented and compared with the D-1A analysis. A thermal analysis of astronaut glove inner surface temperatures is also presented for the time span corresponding to the astronaut traverse to deployment site.

This summary is primarily concerned with the transient phases of the ALSEP deployment during lunar surface operations. The deployment phases include the SNAP-27 fuel capsule transfer, the astronaut traverse to deployment site, and the subsequent removal of the subpackage equipment at the deployment site (see Figure 1). The temperature responses of the deployed ALSEP Pallet 2/SNAP-27 RTG as illustrated in Figure 2 also are given.

2.0 Subpackage No. 2 Description

Subpackage No. 2 components and equipment identification along with thermal coatings are listed in Table 1.

Subpackage No. 2 is shown in Figure 3 in the stowed configuration and consists of the SNAP-27 Generator Assembly, Pallet Assembly No. 2, the Apollo Lunar Handling Tool Carrier, the Suprathermal Ion Detector Experiment (SIDE) plus additional equipment boxes and astronaut handling tools. The deployed configuration consists of only the RTG mounted on Pallet No. 2. Figure 4 illustrates the deployed configuration plus the position of the subpallet and the ALHT Carrier on the pallet. These latter assemblies are removed prior to completion of deployment with the removal point in the sequence of deployment varying with the deployment mode. The one man deployment concept calls for the removal of these items at the deployment site, while the two man deployment concept calls for the removal prior to fueling the Generator Assembly. The D-1A model utilizes the one may deployment concept, while both concepts have been considered for the Flight and the Proto A models.

Reference to the subpallet assembly in this ATM is defined as the assembly consisting of the SIDE, Antenna Gimbal Box, UHT and the subpallet.

The pallet becomes a base for the deployed Generator Assembly and provides a conductive thermal radiation surface between the Generator Assembly and the lunar surface. The pallet also acts as a thermal shield between the fueled Generator Assembly and the astronaut during the transposition of

LUNAR SURFACE PHASE

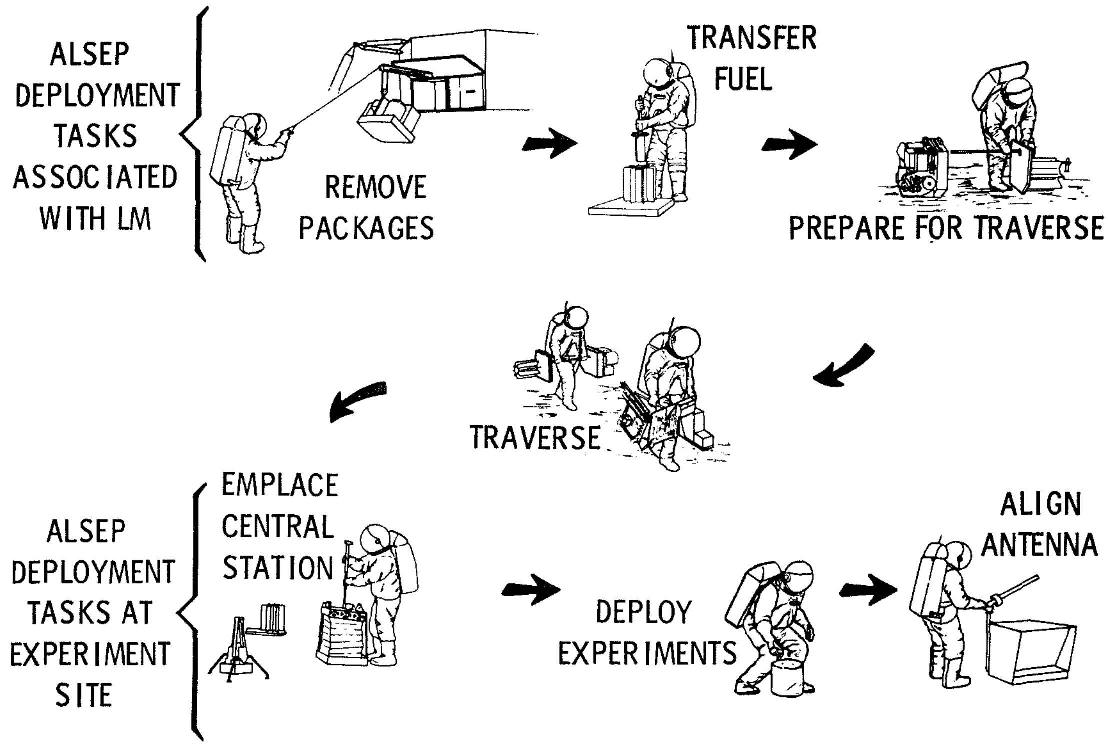


FIGURE 1

DEPLOYMENT FOR ALSEP 1

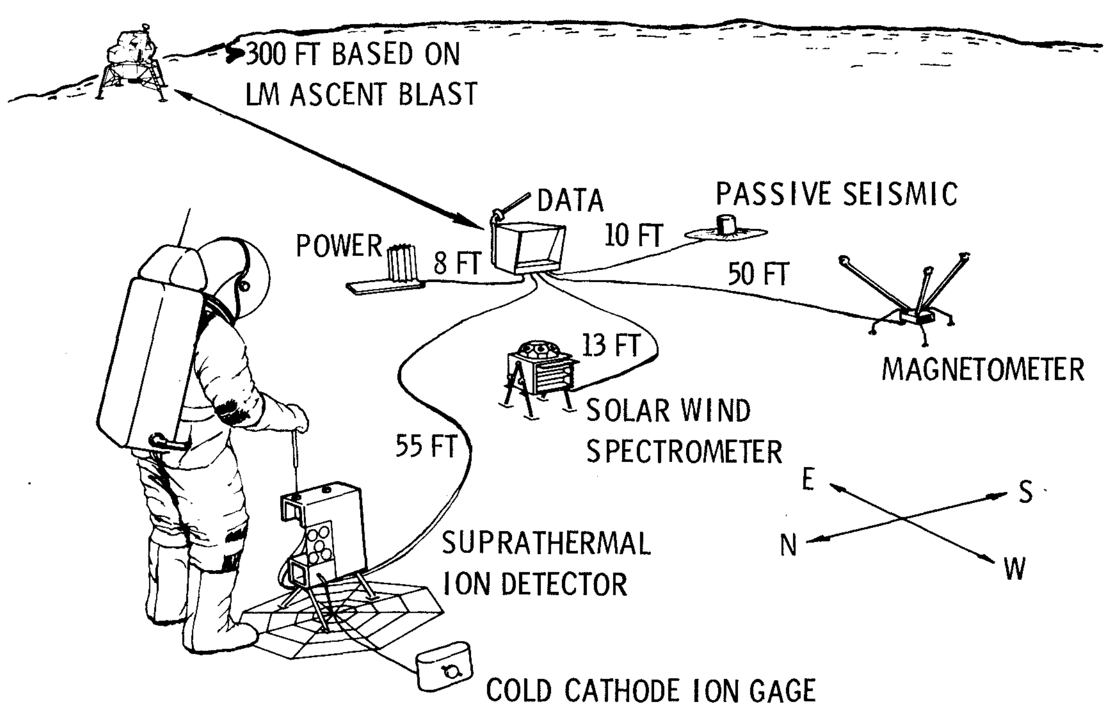


FIGURE 2

TABLE 1

Summary of Radiative Properties of Surfaces On
Subpackage No. 2 Thermal Models

	Surface Description	α	ε	Comments
1.	Pallet Assembly No. 2 (top/bottom)	.2	.9	Z-93 White Paint
2.	Apollo Lunar Hand Tool (ALHT)	.25	.85	Sulfuric Anodized
3.	Antenna Gimbal Box	.25	.85	3M401 White Paint
4.	Fuel Cask Handling Tool (FHT)	.25	.85	3M401 White Paint
5.	Cask Dome Removal Tool (CDRT)	.25	.85	3M401 White Paint
6.	Carry Bars	.25	.85	3M401 White Paint
7.	RTG Cable Reel	.25	.85	3M401 White Paint
8.	Universal Handling Tool (UHT)	.25	.85	3M401 White Paint
9.	RTG Surfaces	.85	.85	Iron Titinate
10.	Subpallet	.2	.9	3M401 White Paint
11.	Suprathermal Ion Detector Experiment (SIDE)	.25	.85	S-13G White Paint

STOWED CONFIGURATION

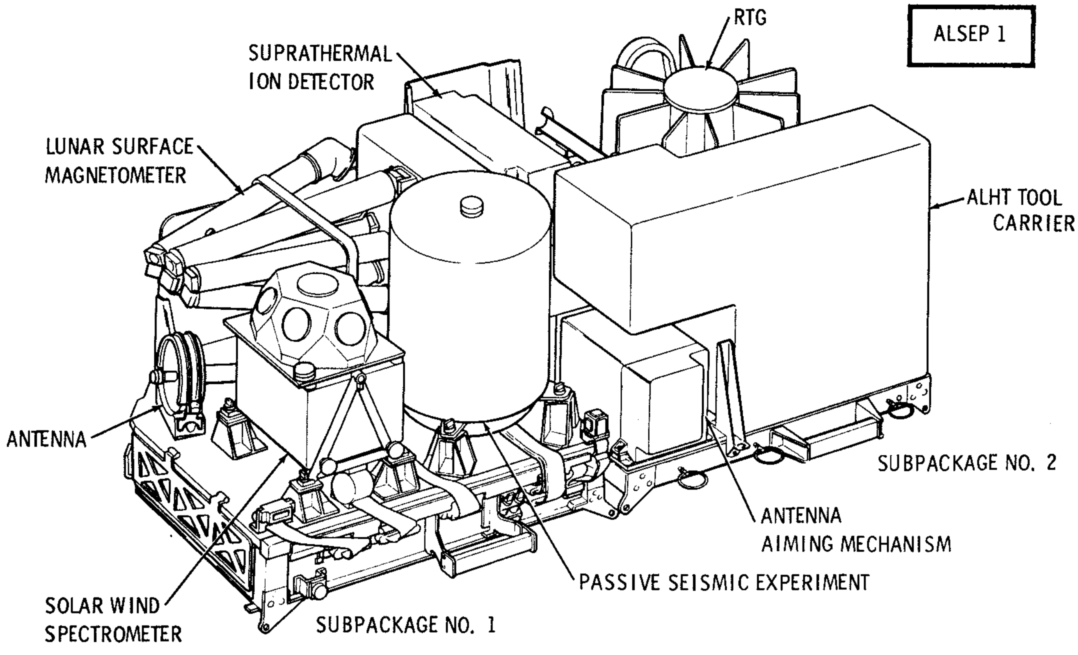


FIGURE 3

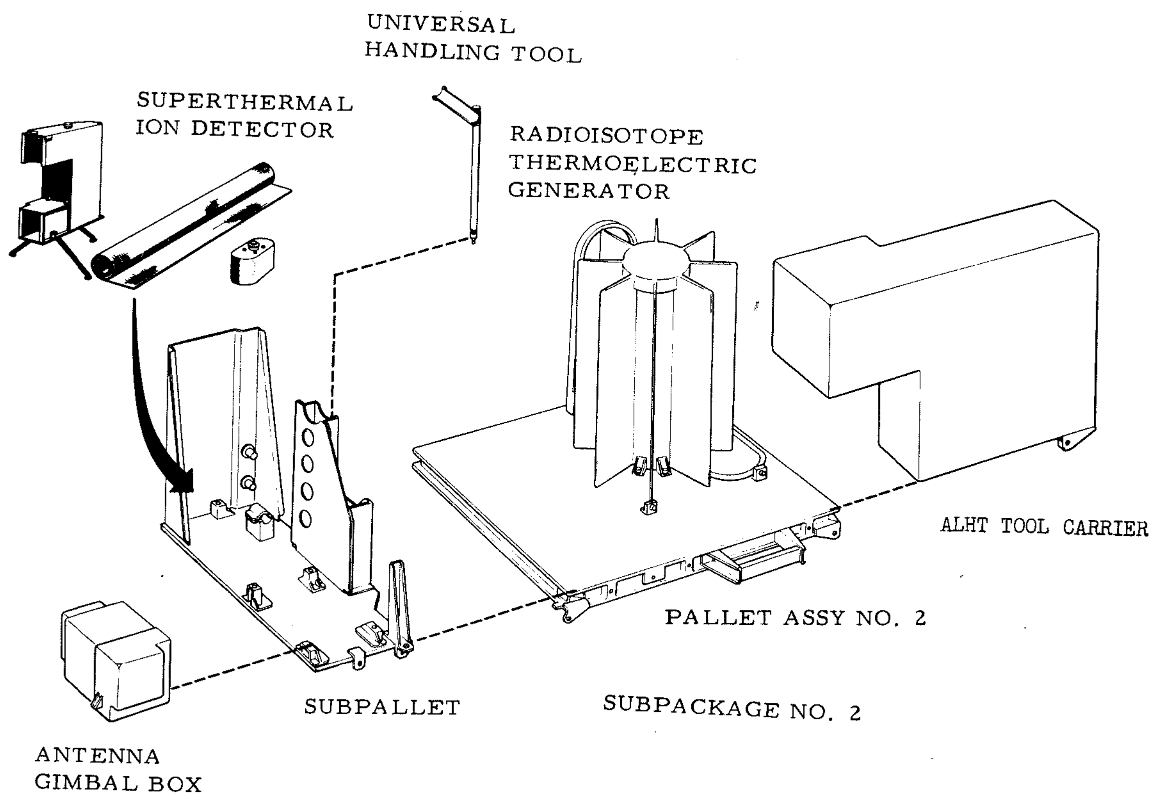


FIGURE 4

TABLE 2

Thermal Model Nodes

Node Number	Node Description	Total Thermal Capacitance (BTU/°F)
1	Fuel	0.555
2	Capsule	0.350
3	Hot Frame	0.631
4	Thermopile and Insulation	0.411
5	Cold Frame	3.003
6-7	Outer Shell (symmetric about GA axis)	1.086
8-9	Fins (4 fins/node)	1.550
10	Capsule End Plate	0.151
11	RTG Bottom Plate (hermetic seal, lower)	0.030
12-13	RTG/Pallet Interface (mounting lug and inserts)	0.042
14-21	Pallet (4 top and 4 bottom)	0.658
22	Lunar Surface	∞
23	Space	∞

ALSEP to the deployment site. The RTG is blocked by the other assemblies during this latter phase for the one man deployment concept. No blockage occurs with the two man deployment concept. These are illustrated in Figures 5 and 6.

The fueled SNAP-27 Generator Assembly consists of the fuel capsule assembly, the hot frame, thermopile and insulation, cold frame, outher shell and fins, and the hermetic seal and mounting feet. Basically, the Generator Assembly is a series of concentric cylinders with insulated ends, the inner cylinder being the hot frame. The outer cylinder is the cold frame and outer shell, hereafter referred to simply as the cold frame. Eight radial heat rejection fins are attached to the cold frame. The capsule is the innermost cylinder of the RTG, facing the hot frame. The thermopile (Thermoelectric couple assembly) and insulation occupy the space between the hot frame and the cold frame. The annulus at each end is a hermetic seal, the lower one forming the bottom of the Generator Assembly. The capsule end plate forms the top of the Generator Assembly. The hot frame receives radiant energy directly from the capsule and conducts most of this to the thermopile and insulation. The thermopile converts a portion of this thermal energy into electrical energy. The remaining thermal energy is conducted from the thermopile and insulation layers to the cold frame. The cold frame rejects this heat, plus solar heating, primarily by conduction to the fins and then by radiation to space and the lunar surface.

3.0 Thermal Models and Analyses

3.1 Steady State Model - Nodes

The steady state model for Subpackage 2 consisted of 23 nodes. The nodal arrangement was divided into eight (8) nodes for the pallet, nine (9) nodes for the Generator Assembly, two (2) nodes for the RTG/Pallet interface, and two (2) nodes for the environment. Table 2 lists the number of nodes, node description, and thermal capacitance. Nodes were also assigned for the fuel element and the capsule.

Figures 7 and 8 show the locations of the RTG nodes and the pallet nodes respectively, while Figure 9 illustrates the deployed state.

The steady state analysis assumptions were as follows:

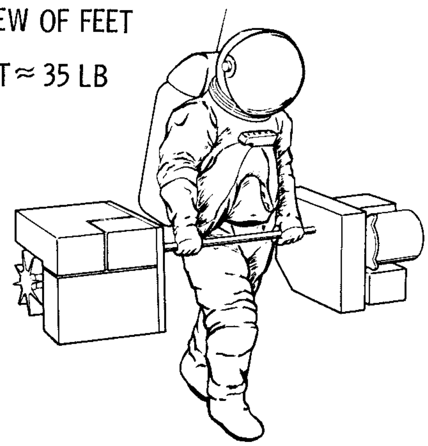
1. RTG surface emittance = 0.85

2. Pallet surfaces coated with thermal control paint having an α/ϵ of .20/.85

3. No conductive coupling between the pallet and the lunar surface

BARBELL CARRY

- ALLOWS ALL EQUIPMENT TO BE CARRIED BY ONE MAN IN ONE TRAVERSE
- SUITCASE HANDLES FOR TWO-MAN OR BACKUP CARRY MODE
- GIVES GOOD BALANCE & VIEW OF FEET
- EQUIVALENT EARTH WEIGHT ≈ 35 LB



- MAY BE SET DOWN TO REST
- CARRY BAR LATER USED AS ANTENNA MAST

FIGURE 5

TRAVERSE

- COMMANDER CARRIES INSTRUMENT SUBPALLET & TOOL CARRIER
- COMMANDER LEADS & PICKS ROUTE
- LM PILOT CARRIES ALSEP BARBELL
- REST, AS NECESSARY

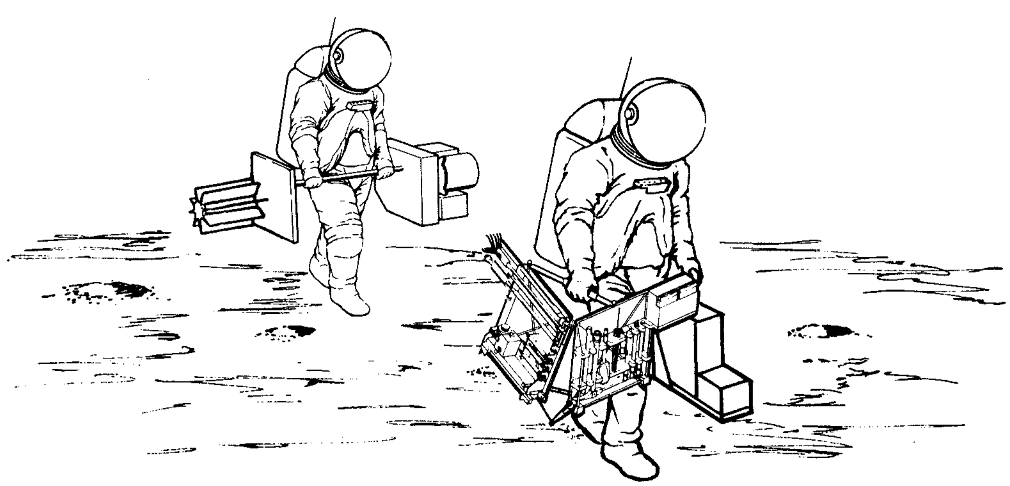
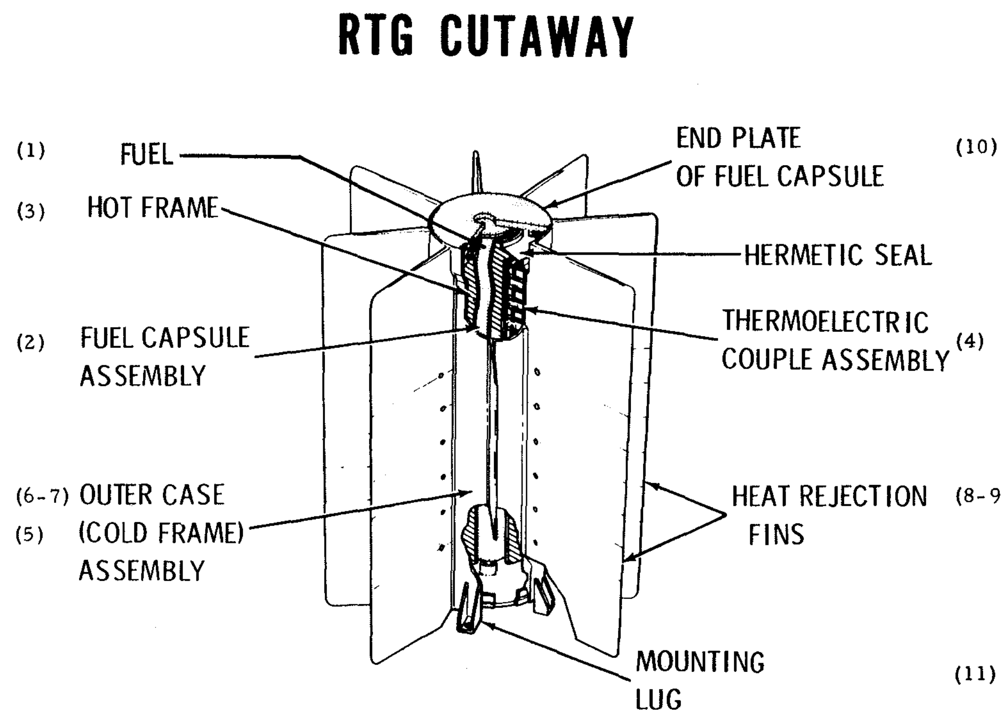


FIGURE 6

Figure 7. Nodal Breakdown of RTG



NOTE: Node numbers in parenthesis

A --- Nodes 12 and 13 on Pallet under RTG

B --- Nodes 14 and 15 near RTG cable reel

C --- Nodes 16 and 17 near crew tools

D --- Nodes 18 and 19 beneath ALHT carrier

E --- Nodes 19 and 21 under SP/2 subpallet

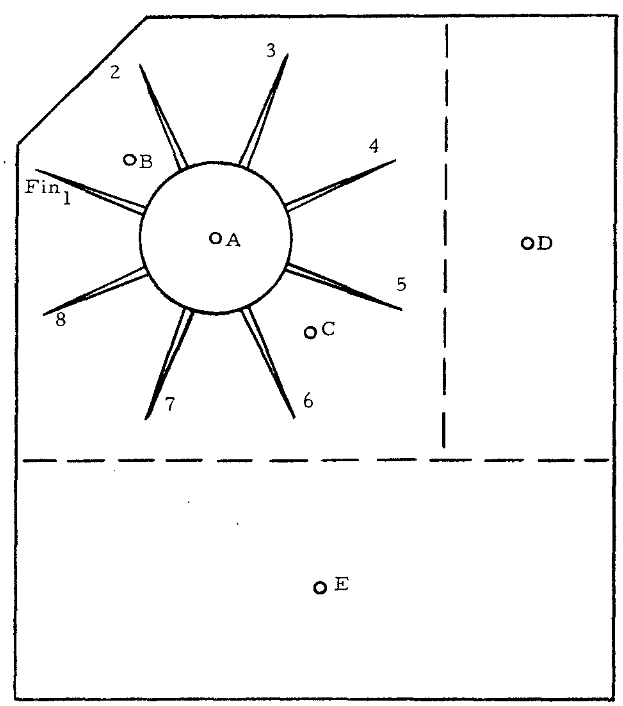


Figure 8. Nodal Breakdown of Subpackage 2 Pallet.

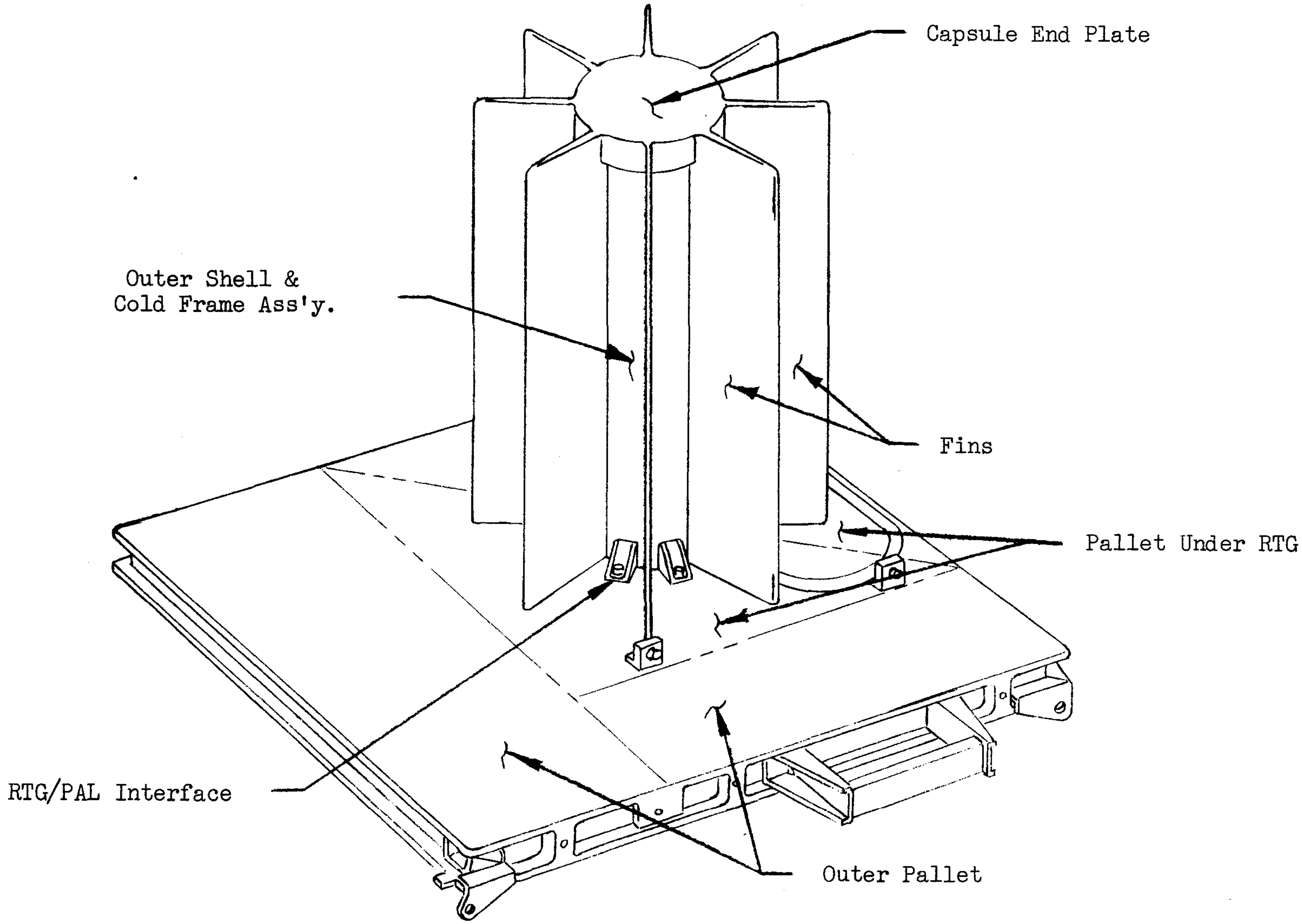


Figure 9. Pallet 2 Deployed

4. All boxes and equipment, except RTG, removed.

5. RTG axis perpendicular to the lunar surface.

3.2 Transient Thermal Models - Nodes

The transient thermal models of D-1A and the Flight (one man), with Subpallet Assembly and the Apollo Lunar Hand Tool (ALHT) Carrier mounted, consisted of the steady state nodes plus 6 nodes for each equipment box and/or experiment. The 6 nodes correspond to the 6 sides of each box or experiment. The Flight (two man) transient model was the same configuration as the steady state model. Figure 5 shows the one man deployment concept and Figure 6 illustrates the two man deployment.

All transient analyses assumed the following:

1. Surface emissivities and solar absorptivities per the steady state model.

2. No conductive coupling between the pallet and the lunar surface.

3. Surface of boxes facing RTG, $\epsilon = 0.1$ for D-1A, and $\epsilon = 0.85$ for Flight model (one man).

4. Box/equipment surfaces not facing RTG coated with a white thermal coating with an $\alpha/\epsilon = .25/.85$.

5. RTG axis parallel to lunar surface.

6. Corner of pallet closest to RTG oriented closest to lunar surface.

7. Bottom of the Subpackage No. 2 pallet radiating to a lunar surface temperature of $100^{o}F$.

8. Initial SP2 temperature at $160^{o}F$, except capsule assembly.

9. Capsule assembly at lunar landing temperatures.

Conduction resistors were calculated from configuration geometry and the material thermal conductivities. Thermal capacitances were calculated from material properties and nodal weights. Radiation resistors were derived from a Gebhart Absorption analysis wherein perfectly diffuse surfaces were assumed. Configuration factors for the Absorption program were derived with the BxA Confac II program. Surface areas were obtained from the configuration geometry, and emissivities were obtained from the particular surface properties. Solar heating was calculated for each surface, taking into account solar absorptivity, solar angle, shadowing and reflection from

TABLE 3

Pallet 2 Steady State Thermal Model Resistors

Conduction Resistors

Node to Node	R, hr-F/Btu	Comments
1 - 2	0.564	Outer shell facing experiments to connecting nodes.
1 - 3	0.077	↓
1 - 9	23.64	↓
1 - 17	0.0018	↓
1 - 22	1.47	↓
2 - 4	0.077	Outer shell away from experiments to connecting nodes.
2 - 9	23.64	↓
2 - 17	0.0018	↓
2 - 23	1.47	↓
5 - 6	1.52	Pallet under RTG facing experiments to connecting nodes.
5 - 20	0.0266	↓
5 - 22	0.865	↓
5 - 7	3.16	↓
5 - 8	2.70	↓
6 - 21	0.0266	Pallet under RTG away from experiments to connecting nodes.
6 - 23	0.830	
7 - 8	10.24	Outer pallet under SIDE to connecting nodes.
7 - 18	0.0196	
8 - 19	0.0233	Outer Pallet under ALHT to Bottom
18 - 19	10.24	Pallet bottom to connecting nodes.
18 - 20	3.16	↓
19 - 20	2.67	↓
21 - 20	1.52	↓
9 - 13	114.0	RTG bottom to Hot Frame.
1 - 12	3.0	Outer shell to capsule and plate.
2 - 12	3.0	↓
12 - 14	3.96	Capsule end plate to capsule.
9 - 16	28.15	RTG bottom to Thermopile and insulation.
13 - 16	0.0614	Hot frame to Thermopile and insulation.
14 - 15	0.067	Capsule to Fuel.
16 - 17	0.0614	Thermopile and insulation to Cold Frame.

Radiation Resistors

Node to Node	$\sigma \mathcal{F} A$ Btu/hr $^{o}R^{4}$	Comments
1 - 3	0.3242×10^{-9}	Outer shell facing experiments to fins, pallet RTG, lunar surface and space.*
1 - 4	0.3529×10^{-11}	↓
1 - 5	0.2837×10^{-9}	↓
1 - 7	0.2393×10^{-10}	↓

TABLE 3 (Cont'd)

Pallet 2 Steady State Thermal Model Resistors

Radiation Resistors

Node to Node	$\sigma \mathcal{F} A$ Btu/hr $^{\circ}R^4$	Comments
1 - 8	0.1483×10^{-10}	Outer shell facing experiments to
1 - 9	0.4077×10^{-11}	fins, pallet RTG, lunar surface
1 - 10	0.2731×10^{-9}	and space.*
1 - 11	0.6539×10^{-9}	
2 - 3	0.3525×10^{-11}	Outer shell away from experiments
2 - 4	0.3238×10^{-9}	to fins, pallet, RTG lunar surface,
2 - 6	0.2837×10^{-9}	and space.*
2 - 9	0.4077×10^{-11}	
2 - 10	0.2956×10^{-9}	
2 - 11	0.6705×10^{-9}	
3 - 4	0.4430×10^{-9}	Fins facing experiments to fins,
3 - 5	0.3268×10^{-9}	pallet, RTG, lunar surface,
3 - 6	0.3899×10^{-11}	and space.*
3 - 7	0.8169×10^{-10}	
3 - 8	0.1143×10^{-9}	
3 - 9	0.4748×10^{-11}	
3 - 10	0.1594×10^{-8}	
3 - 11	0.2459×10^{-8}	
4 - 5	0.3899×10^{-11}	Fins from experiments to fins,
4 - 6	0.3268×10^{-9}	pallet, RTG, lunar surface,
4 - 7	0.8863×10^{-12}	and space.
4 - 8	0.1240×10^{-11}	
4 - 9	0.4747×10^{-11}	
4 - 10	0.1765×10^{-8}	
4 - 11	0.2594×10^{-8}	
5 - 6	0.8572×10^{-11}	Pallet under RTG facing experiments
5 - 7	0.1359×10^{-11}	to pallet, RTG, lunar surface,
5 - 8	0.1335×10^{-11}	and space.*
5 - 9	0.1134×10^{-9}	
5 - 10	0.2064×10^{-10}	
5 - 11	0.6069×10^{-9}	
6 - 9	0.1134×10^{-9}	Pallet under RTG away from experiments
6 - 10	0.2264×10^{-10}	to RTG, lunar surface, and space.*
6 - 11	0.6084×10^{-9}	
7 - 10	0.1739×10^{-11}	Outer pallet under SIDE to lunar
7 - 11	0.2094×10^{-8}	surface and space.*
8 - 10	0.1888×10^{-11}	Outer pallet under ALHT to lunar
8 - 11	0.1082×10^{-8}	surface and space.*
9 - 11	0.1739×10^{-10}	RTG bottom to space.*
12 - 11	0.2940×10^{-9}	Capsule end plate to space.*

*Evaluated using Gebhart absorption factor technique other surfaces. Contact conductance was estimated as 50.0 Btu/hr ft^2 F for high contact interfaces, 5.0 Btu/hr ft^2 F for medium contact interfaces, and 1.0 Btu/hr ft^2 F for loose contact interfaces. Nodes were connected with the applicable resistors, listed in Table 3, and assigned thermal capacitance values, initial temperatures and heat loads corresponding to each case under study. The Bendix Thermal Analyzer Program was utilized on the IBM 360 Computer to solve for both transient and steady state temperatures.

3.3 Sub-Pallet, Cable Reel and ALHT Carrier

The sub-pallet and ALHT Carrier were analyzed concurrently with the Pallet Assembly No. 2. Emissivity of the sub-pallet was assumed to be 0.85 for all surfaces, while the ALHT Carrier was analyzed for both 0.1 and 0.85 emissivities for the surface facing the RTG. The remaining surfaces of the ALHT Carrier were assumed to have an emissivity of 0.85.

The cable reel was analyzed as two nodes, the spool and the mounting struts. Emissivity was assumed to be 0.85 for all surfaces. No conduction to the pallet, cable, or between the mounting struts and the spool was assumed.

Figure 10 illustrates areas where the Universal Handling Tool (UHT) will be used. This tool will have approximately the same transient response as the cable reel if the sub-pallet is mounted on the Subpackage 2 during traverse.

3.4 Fuel Transfer Tool

The FTT was analyzed as 4 nodes with a constant temperature source node. The four nodes were:

1. Disc facing source

2. Fingers contacting source

3. Handle attach adapter for 1 and 2 above

4. Handle (center of node at handle C.G.)

Heat transfer is by radiation from the source to the disc, conduction from the source to the fingers, conduction from the disc and fingers to the attach adapter, and conduction from the adapter to the handle. Radiation to the environment and solar heating were not considered for this analysis in order to study worst case conditions. See Figures 11 and 12 for a summary of the fuel transfer task.

Figure 13 presents the results of a transient analysis on the Fuel Transfer Tool. The heat source was the Capsule End Plate at a constant

EXPERIMENT MOUNTING PROVISIONS

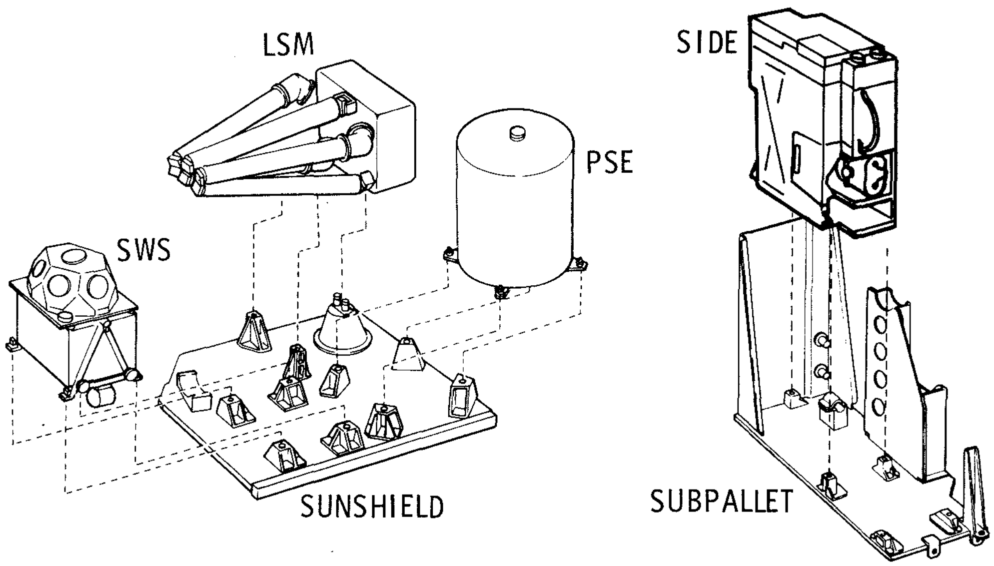


FIGURE 10

TRANSFER FUEL

- PREPARE CASK

  RETRIEVE LOCK-PIN LANYARD, PULL PIN, RETRIEVE CASK-TILT LANYARD, ROTATE CASK TO DESIRED ANGLE, REMOVE DOME

- PREPARE SUBPACKAGE 2

  RETRIEVE MAST SECTIONS & TOOLS, PLACE IN NEW LOCATIONS, ROTATE SUBPACKAGE TO TRANSFER POSITION, PREPARE FUEL TRANSFER ASSEMBLY TOOL

- FUEL RTG

  ENGAGE TOOL WITH CAPSULE, LOCK TOOL / CAPSULE TO RELEASE FROM CASK, WITHDRAW CAPSULE, CARRY TO RTG, RELEASE TOOL / CAPSULE TO LOCK IN RTG

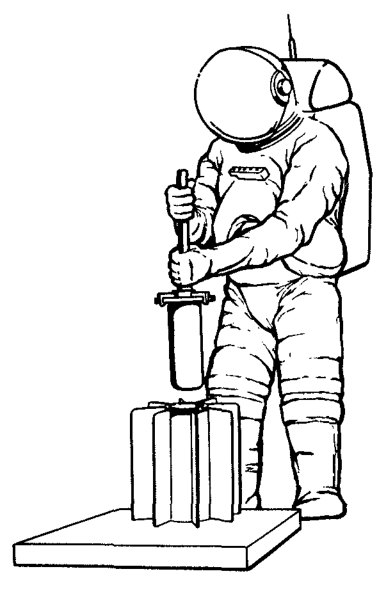


FIGURE 11

RTG FUEL TRANSFER

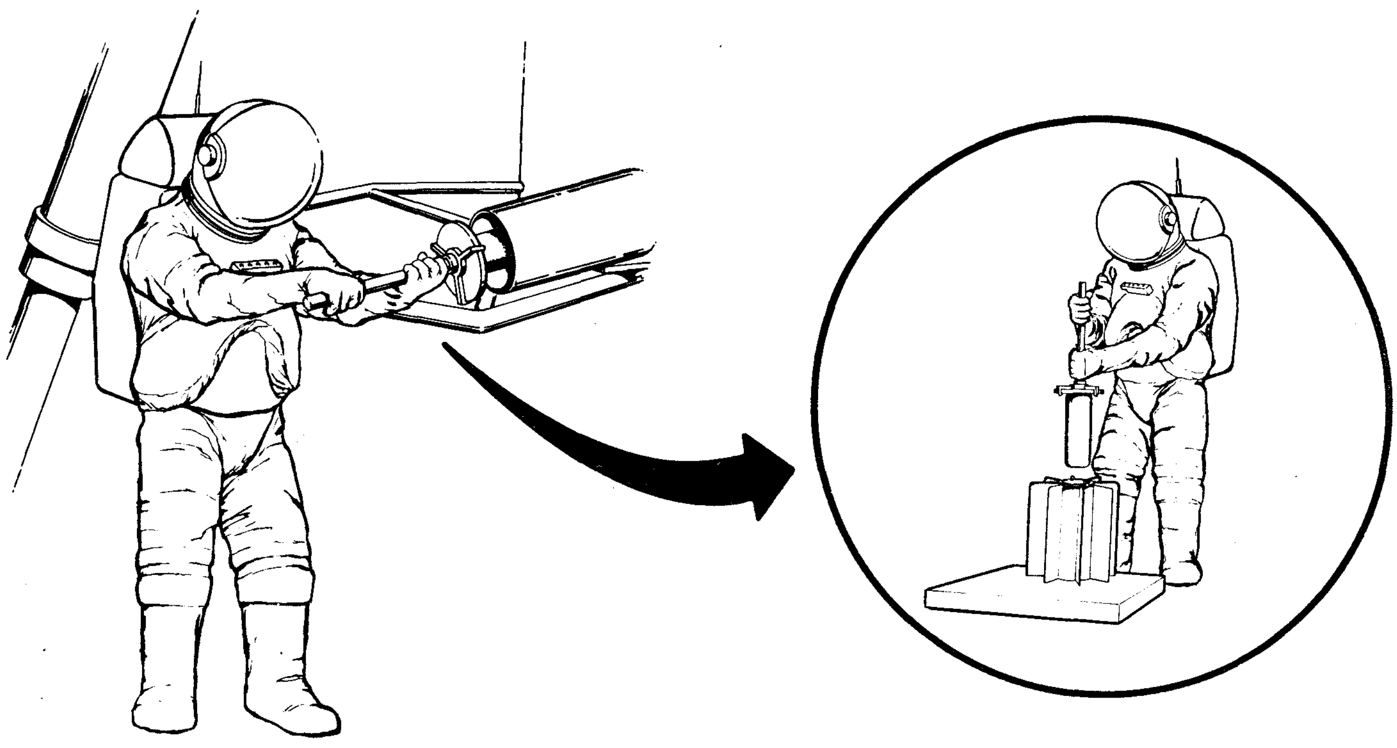


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FIGURE 12

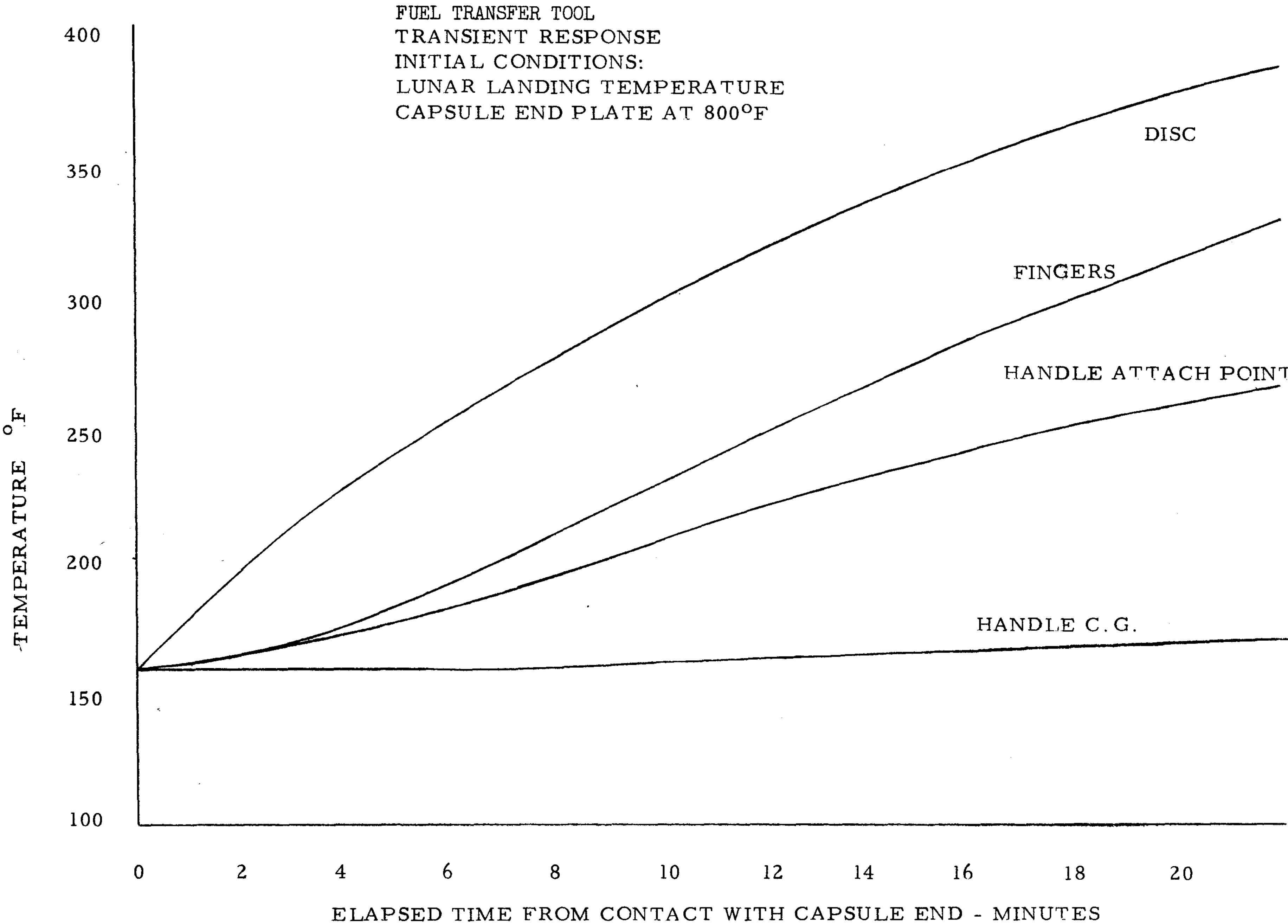

FUEL TRANSFER TOOL
TRANSIENT RESPONSE
INITIAL CONDITIONS:
LUNAR LANDING TEMPERATURE
CAPSULE END PLATE AT 800°F
DISC
FINGERS
HANDLE ATTACH POINT
HANDLE C.G.
TEMPERATURE °F
400
350
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
ELAPSED TIME FROM CONTACT WITH CAPSULE END - MINUTES

FIGURE 13

temperature of 800° F. Surface emissivity of the disc was assumed to be 0.25. Radiation to other surfaces of the FTT was assumed negligible. The disc exceeded 250° F within 2 minutes after contact of FTT with the Capsule End Plate. The remainder of that end of the FTT exceeded 250° F within 9 minutes. Temperature rise at the handle C.G. was approximately 2° F during the first 10 minutes.

Figure 14 shows the temperature decay of the capsule and end plate between removal from the GLFC and RTG insertion. The decay is very high for the first few minutes after removal. Thus the temperatures, beyond the first 2 minutes, shown in Figure 13, are conservative.

The surface of the disc may have a high emissivity, in which case FTT temperatures will be considerably higher. However, present FTT contact time with the capsule end is approximately one minute. An analysis of the FTT, with $\epsilon = 0.9$ for the disc, resulted in a disc temperature of 250° F with the remainder of the FTT below 200° F for one minute contact time.

4.0 Analysis and Test Results

4.1 Subpackage No. 2 Transient Analyses

Figures 15 through 17 present time-temperature predictions for Subpackage 2 during traverse to the deployment site. Figure 15 is the transient analysis for the Flight (two man) model. The others are models with boxes and/or equipment mounted during traverse. RTG temperatures are approximately the same for all three cases. Pallet surfaces under the RTG are considerably cooler for the Flight (two man) model than for the other two cases. Cold frame temperatures exceed 250° F within 12 minutes from time of fueling, and all external RTG temperatures exceed 250° F within 25 minutes. Maximum pallet temperatures exceed 250° F in 40 to 50 minutes from fueling, depending on the model.

Test results indicate thermocouple location temperatures, while analytical temperatures are average nodal temperatures. Thus analytical results indicate approximately the average temperatures under the RTG and for the remainder of the pallet.

4.2 Cable Reel and Equipment

Figure 18 presents the results of a transient analysis on the Cable Reel during traverse. The mounting struts exceed 250° F in approximately 30 minutes after RTG fueling while the cable spool exceeds 250° F in approximately 50 minutes. Temperatures in the deployed mode will be less than for the traverse, but the time to reach 250° F during the deployment mode will be no more than 5 minutes greater than for traverse.

TEMPERATURE DECAY OF FUEL CAPSULE
GLFC REMOVAL TO RTG INSERTION

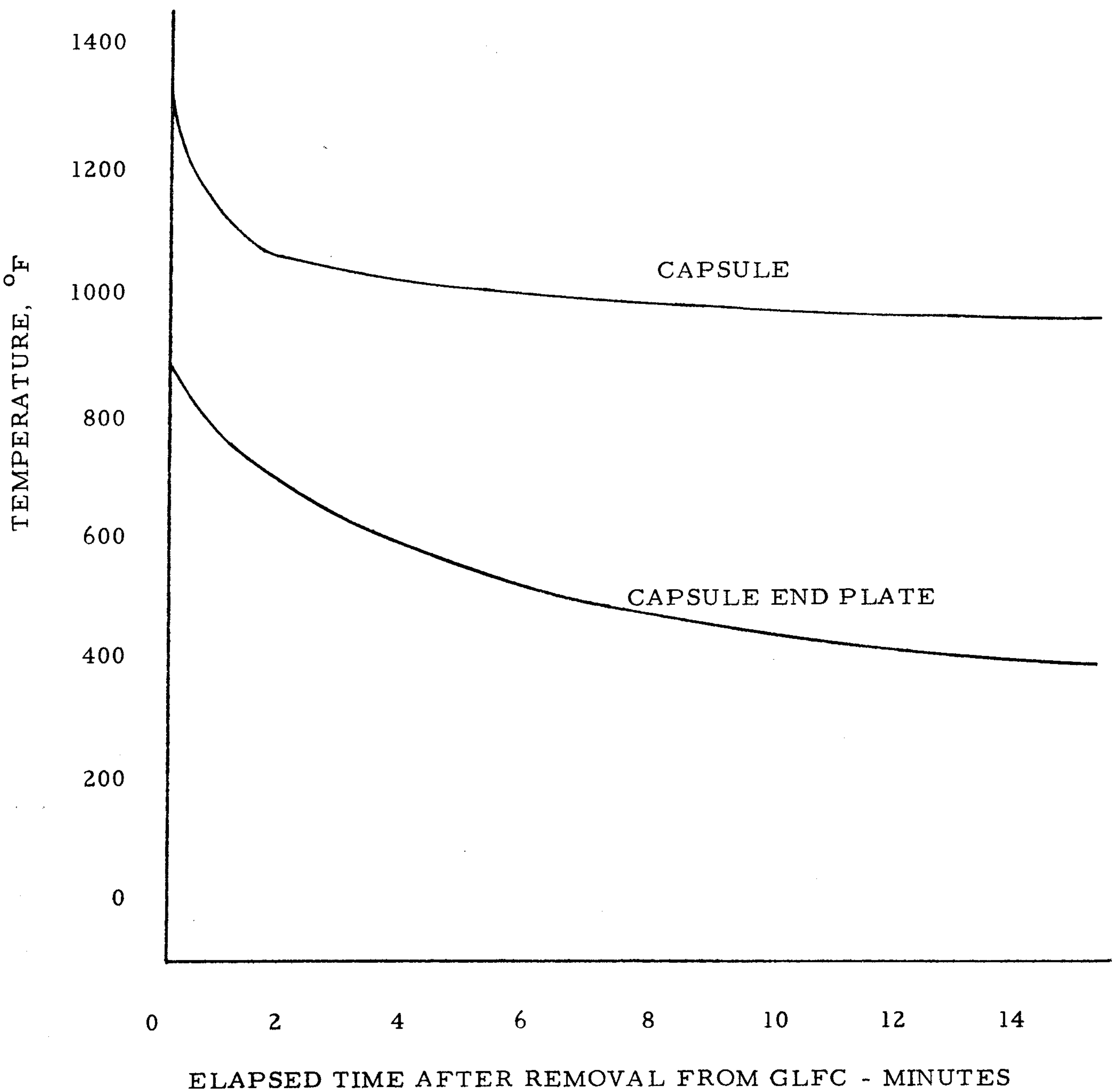


FIGURE 14

FLIG MODEL

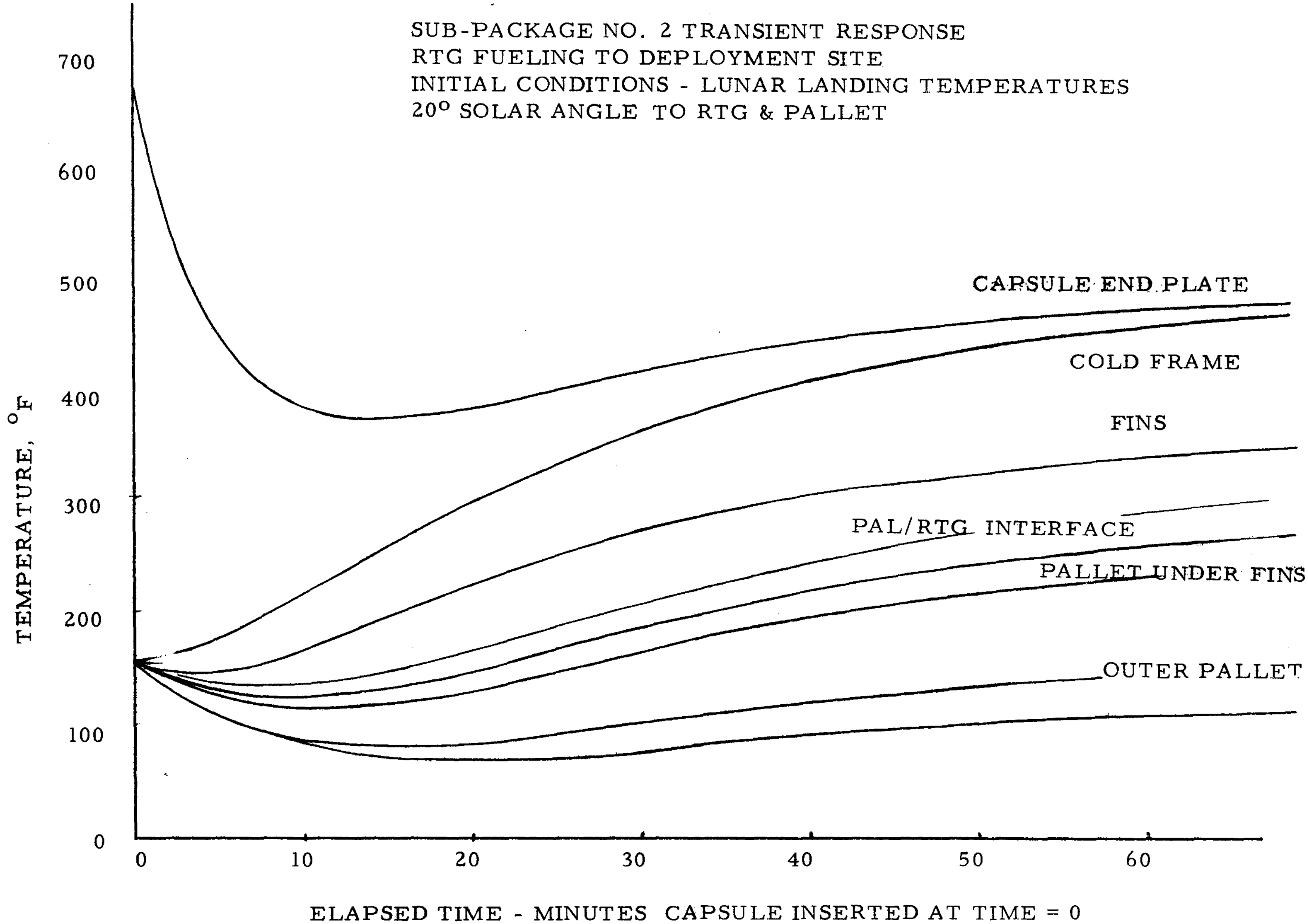


FIGURE 15

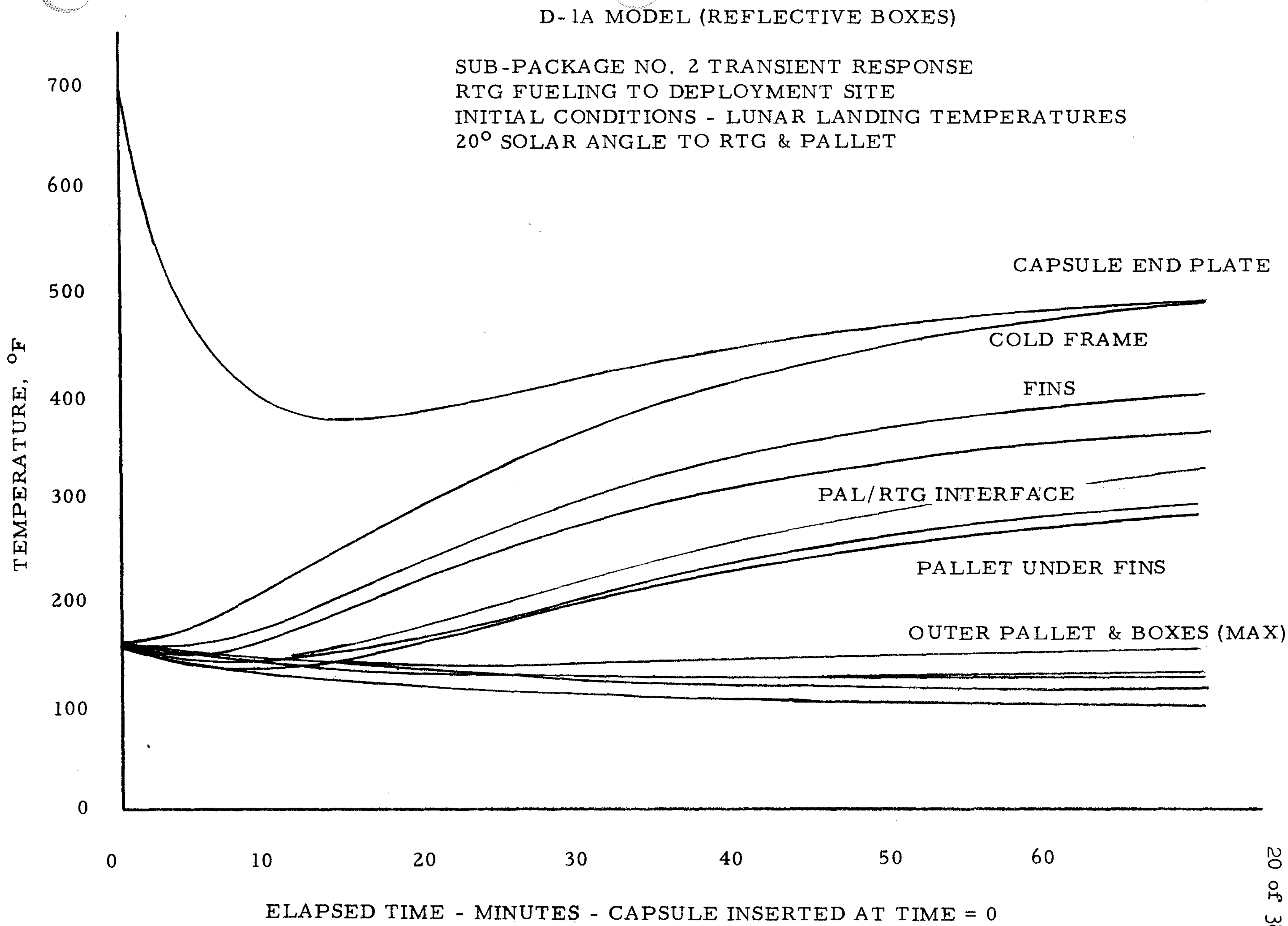
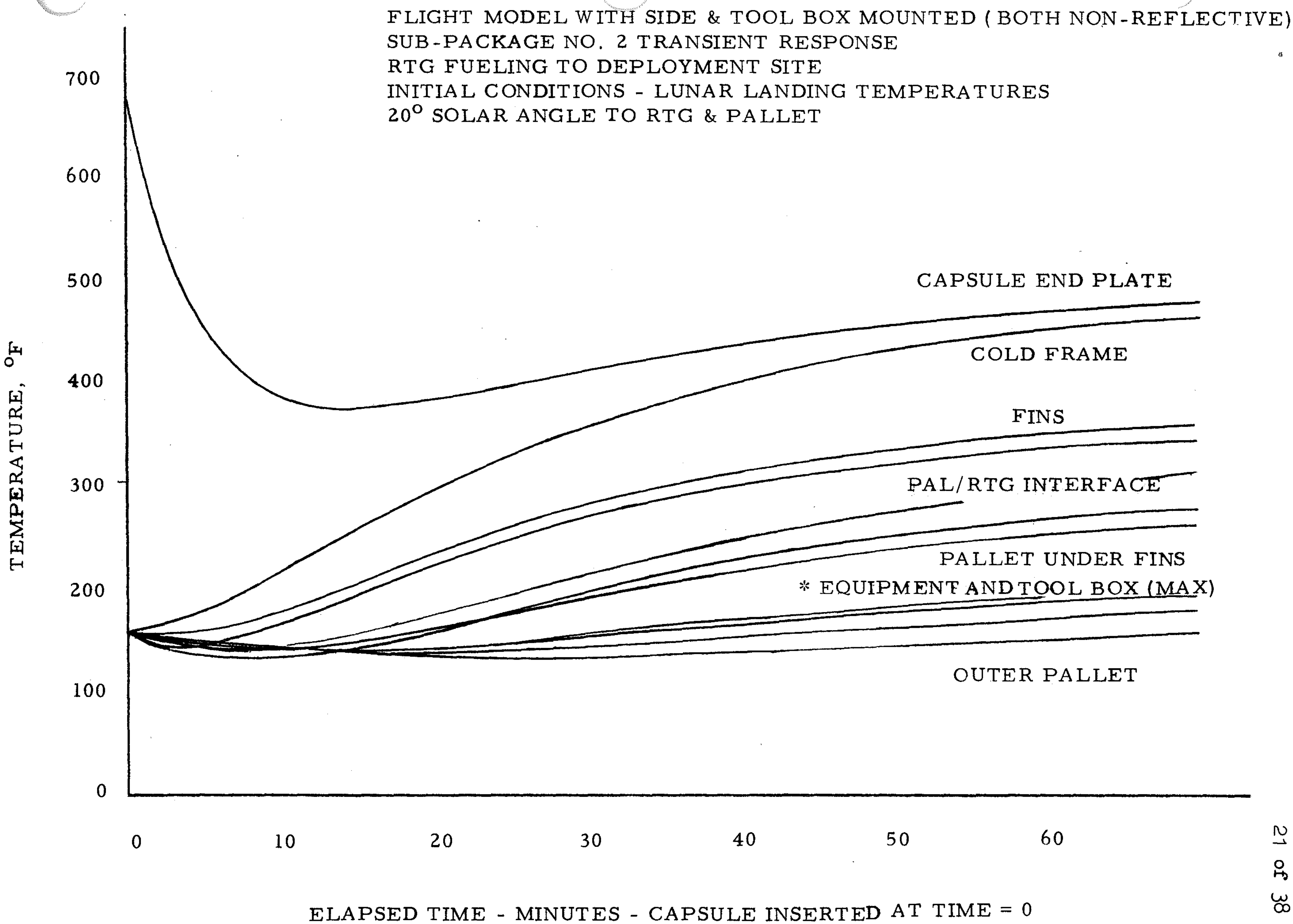

D-1A MODEL (REFLECTIVE BOXES)
SUB-PACKAGE NO. 2 TRANSIENT RESPONSE
RTG FUELING TO DEPLOYMENT SITE
INITIAL CONDITIONS - LUNAR LANDING TEMPERATURES
20° SOLAR ANGLE TO RTG & PALLET
CAPSULE END PLATE
COLD FRAME
FINS
PAL/RTG INTERFACE
PALLET UNDER FINS
OUTER PALLET & BOXES (MAX)
TEMPERATURE, °F
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
ELAPSED TIME - MINUTES - CAPSULE INSERTED AT TIME = 0

FIGURE 16



* Equipment consists of SIDE, PSE Mount, Antenna Gimbal and Experiment Handling Tool

FIGURE 17

FLIGHT MODEL

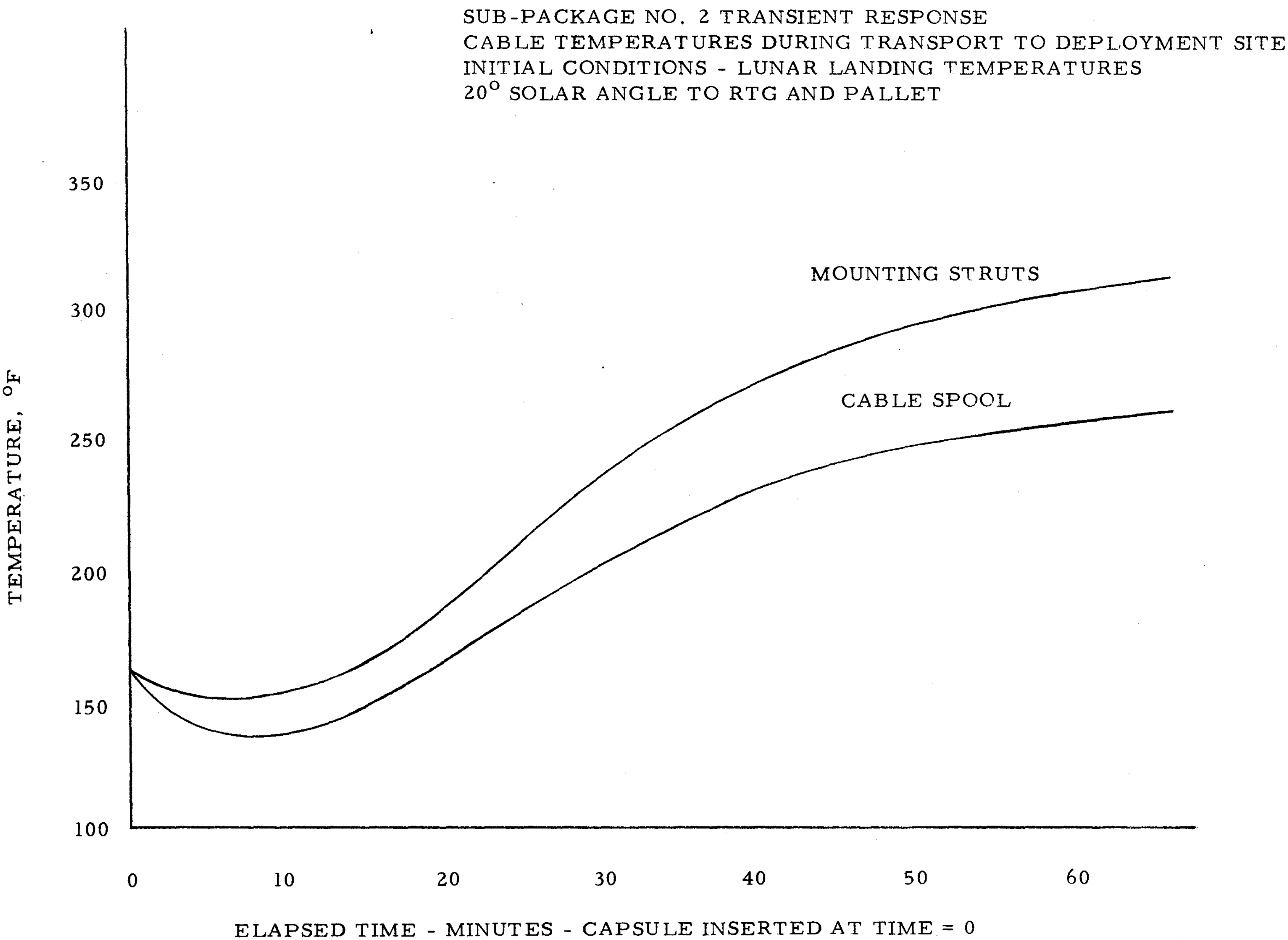


FIGURE 18

Maximum traverse temperatures of the SIDE, Antenna Gimbal, UHT, and the non-reflective ALHT Carrier mounted to the Pallet Assembly No. 2 are shown in Figure 17. Traverse temperatures for reflective boxes mounted to Pallet Assembly No. 2 are shown in Figure 16. None of the temperatures exceed 200° F within 45 minutes after RTG fueling. UHT temperatures for the one man deployment may be taken from Figure 18.

The above parts are coated with thermal paint having a low α/ϵ ratio (.20/.85). Therefore, the temperatures will not exceed 250° F when the parts are removed from the fueled Subpackage No. 2. The equilibrium temperature for an α/ϵ = .20/.85 vertical surface with a solar angle of 40° is 140° F.

4.3 Subpackage No. 2 — Deployed

Figures 19 through 28 present the Subpackage No. 2 temperature profiles during Lunation. Figure 19 temperatures represent the analytical model, and others show D-1A and Proto Thermal Vacuum Test Results. The only mode of heat transfer assumed to exist between the bottom surface of the pallet and the lunar surface was radiation for all three cases. Analysis and test results showed that the RTG temperature changes are primarily a function of solar heating, being only slightly affected by pallet temperature changes. Analysis has shown a RTG temperature drop of 5° F for lunar noon and a drop of 14° F for lunar night resulting from the addition of high coupling between the bottom surface of the pallet and the lunar surface. The pallet temperatures follow the lunar surface temperature more closely for the latter case than for the analytical case shown.

Pallet and RTG maximum temperatures are:

Component	Lunar Noon, °F	Lunar Night, °F
Capsule	1380	1350
Hot Frame	1100	1050
Cold Frame	480	440
Pallet under RTG	425	250

The pallet is nearly isothermal from the top surface to the bottom surface, and isothermal planes are approximately concentric with the longitudinal axis of the RTG.

SUB-PACKAGE NO. 2 ANALYTICAL MODEL
DEPLOYED STEADY STATE TEMPERATURES
ONE LUNATION PERIOD

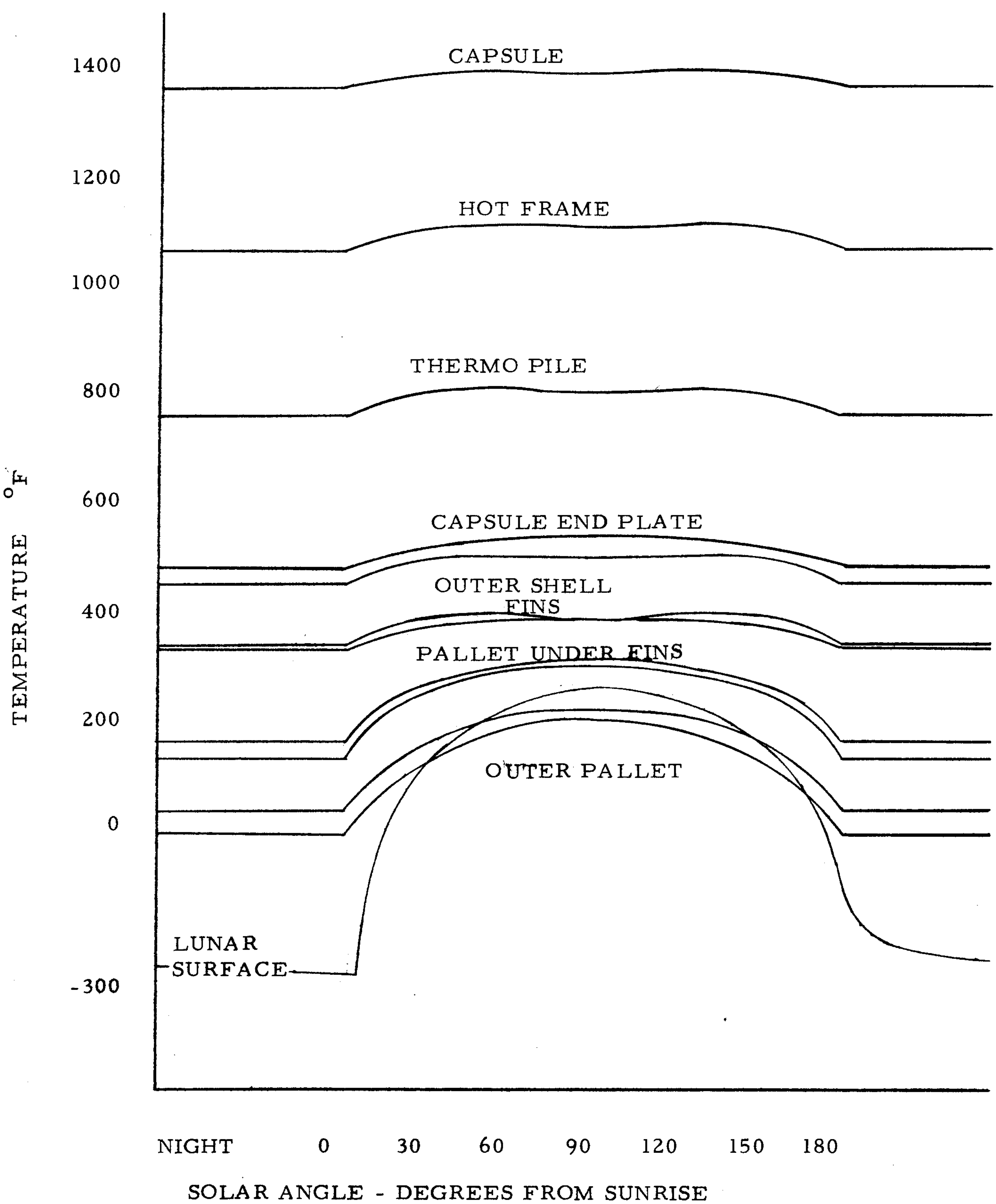


FIGURE 19

SUB-PACKAGE NO. 2 - D-1A TEST RESULTS
DEPLOYED STEADY STATE TEMPERATURES

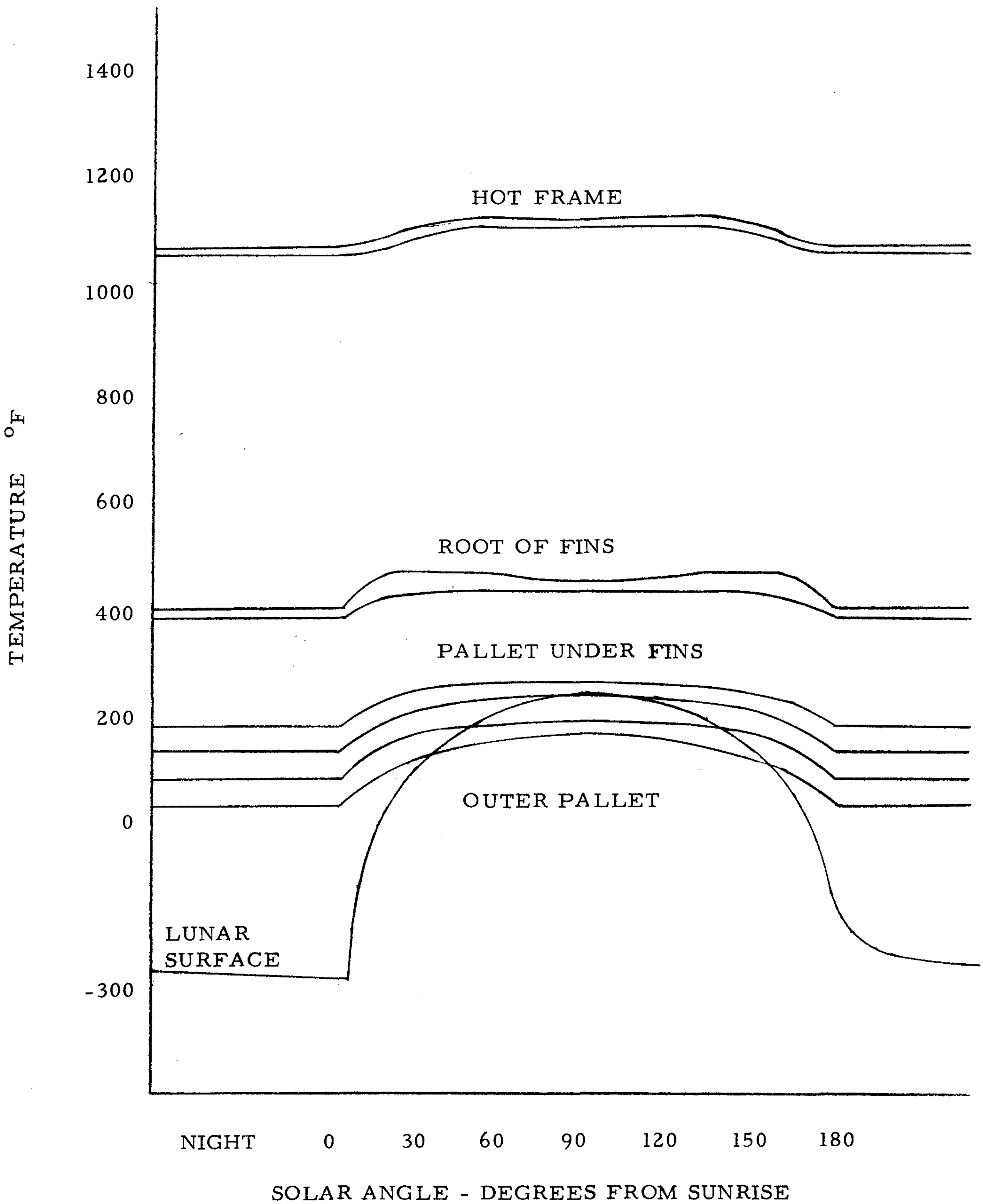
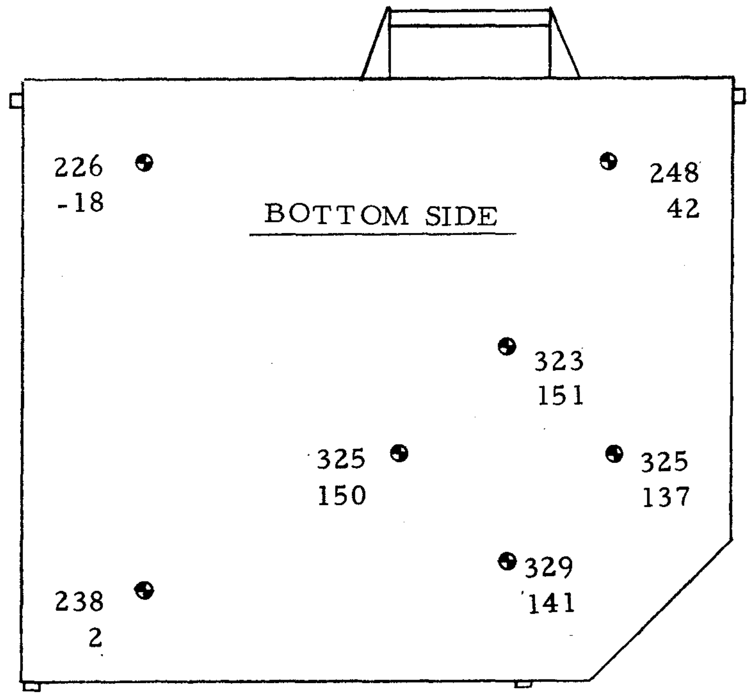


FIGURE 20

PALLET ASSEMBLY NO. 2 - PROTO TEST RESULTS
DEPLOYED STEADY STATE TEMPERATURES, °F
UPPER TEMPERATURE AT EACH POINT IS LUNAR NOON
LOWER TEMPERATURE IS LUNAR NIGHT



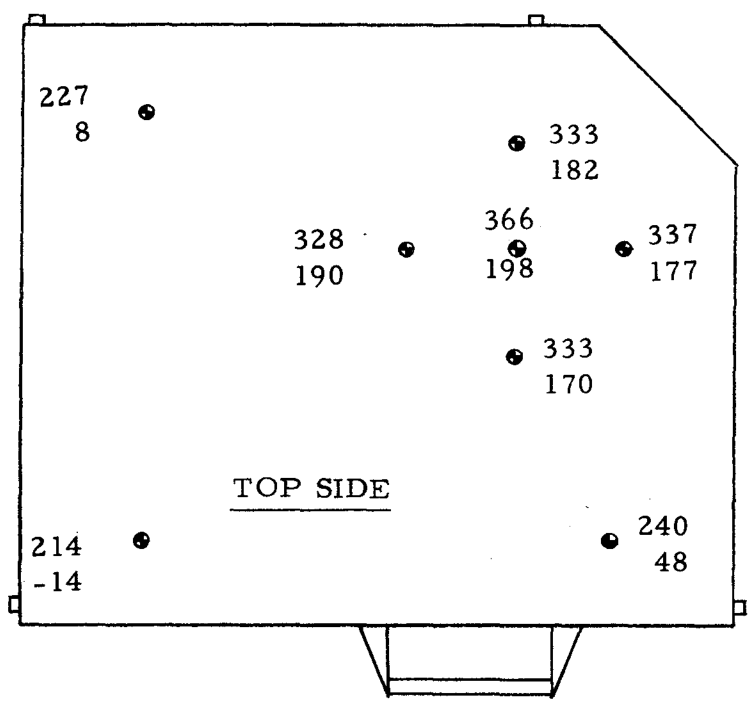


FIGURE 21

FIGURE 22

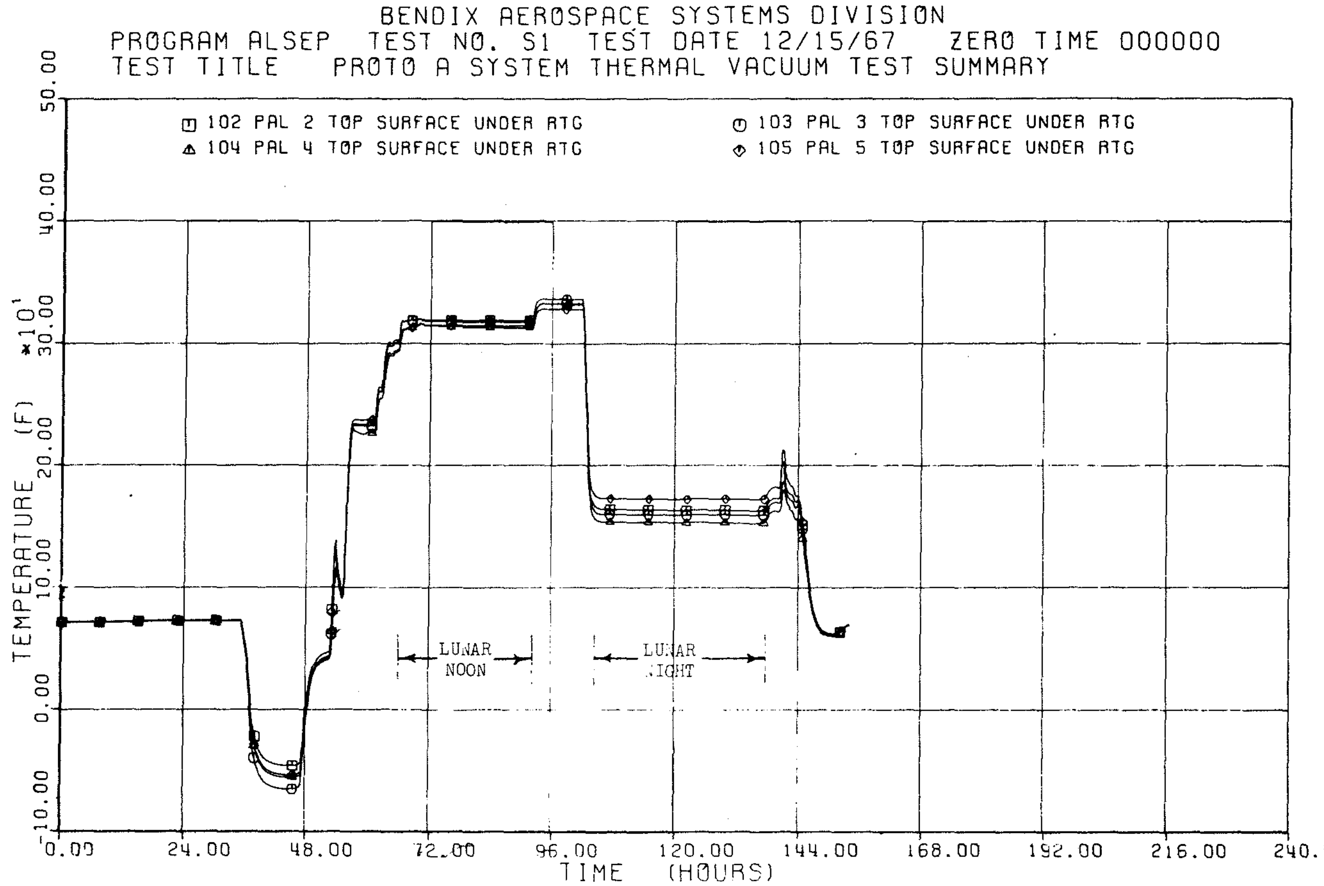


FIGURE 23

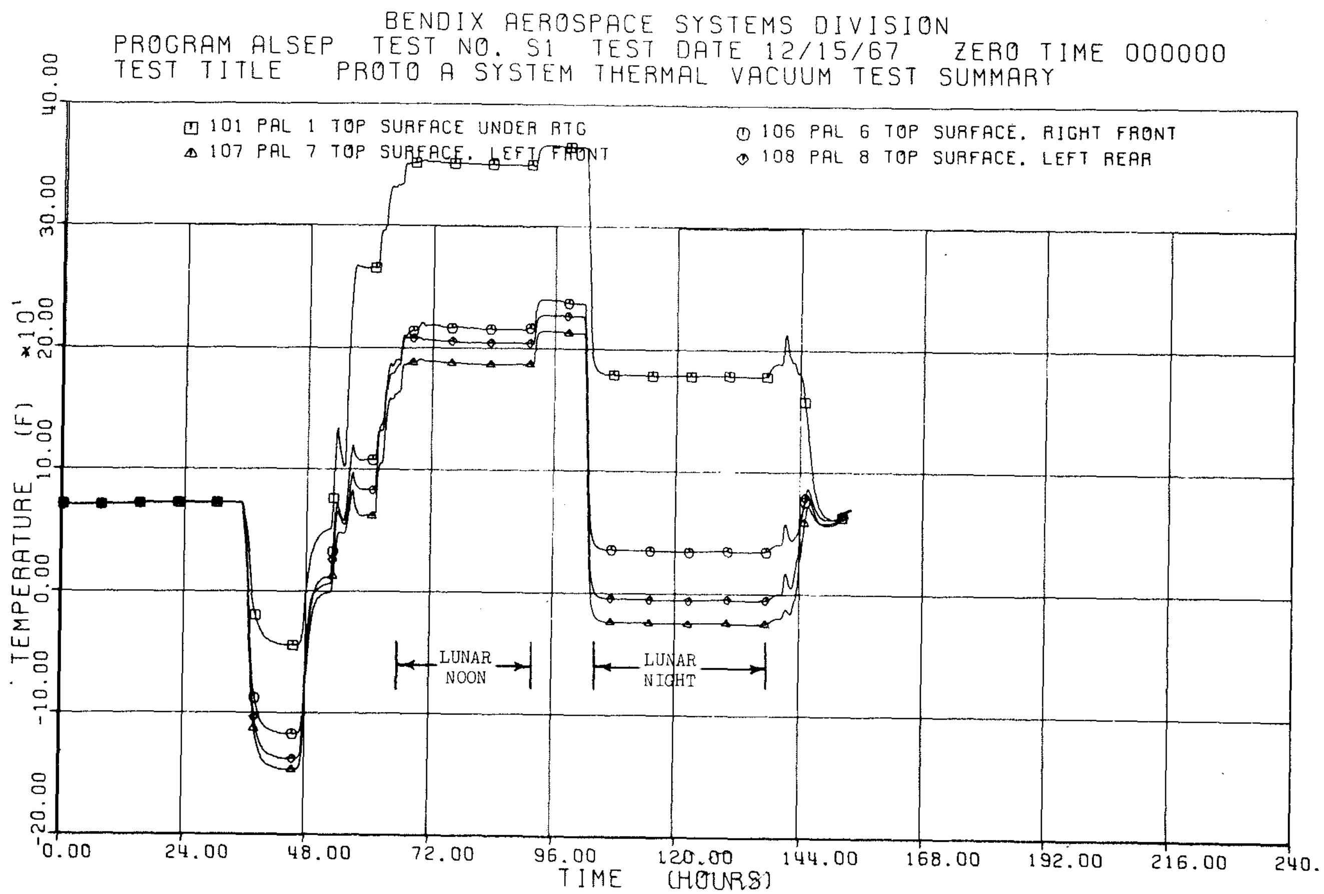


FIGURE 24

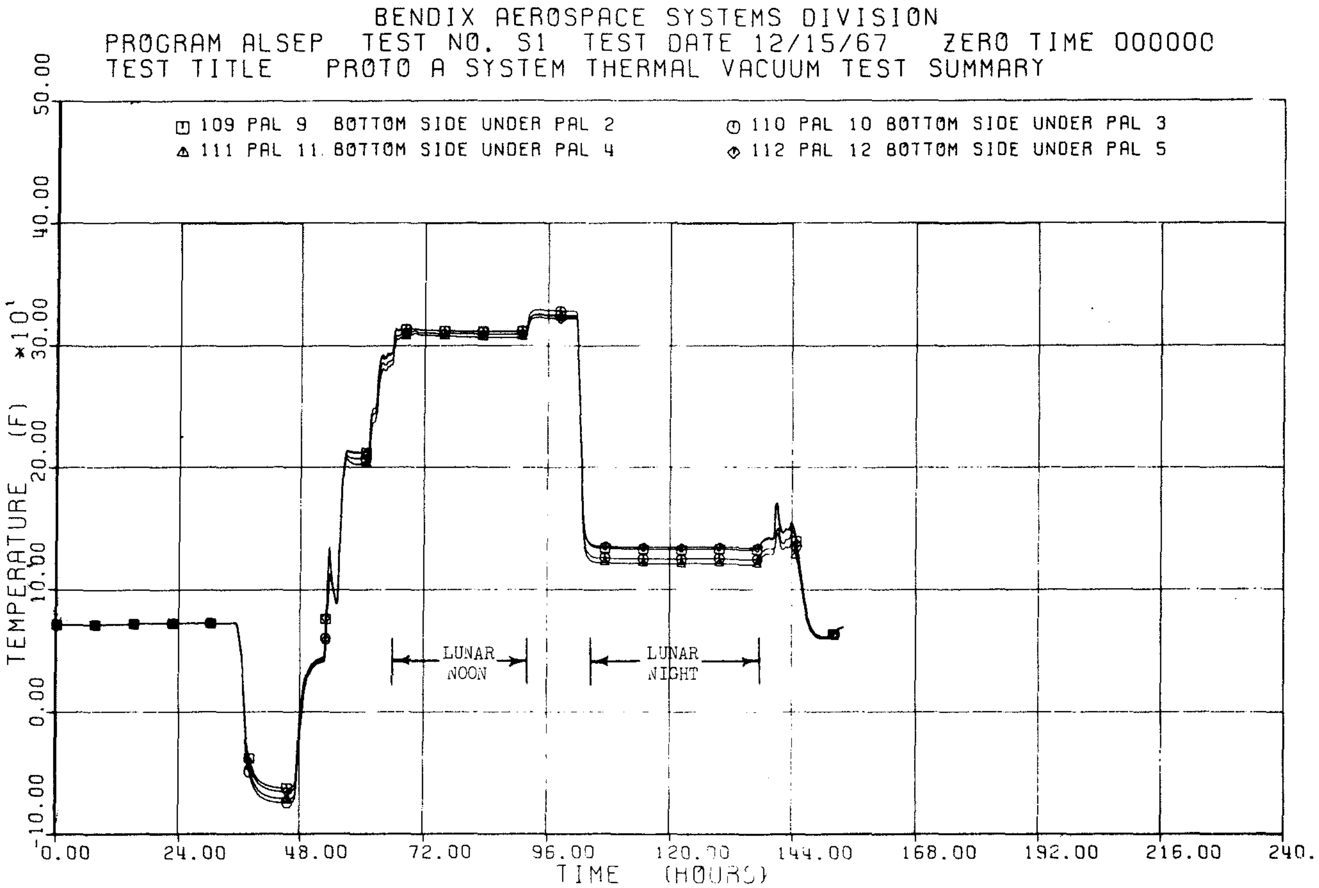


FIGURE 25

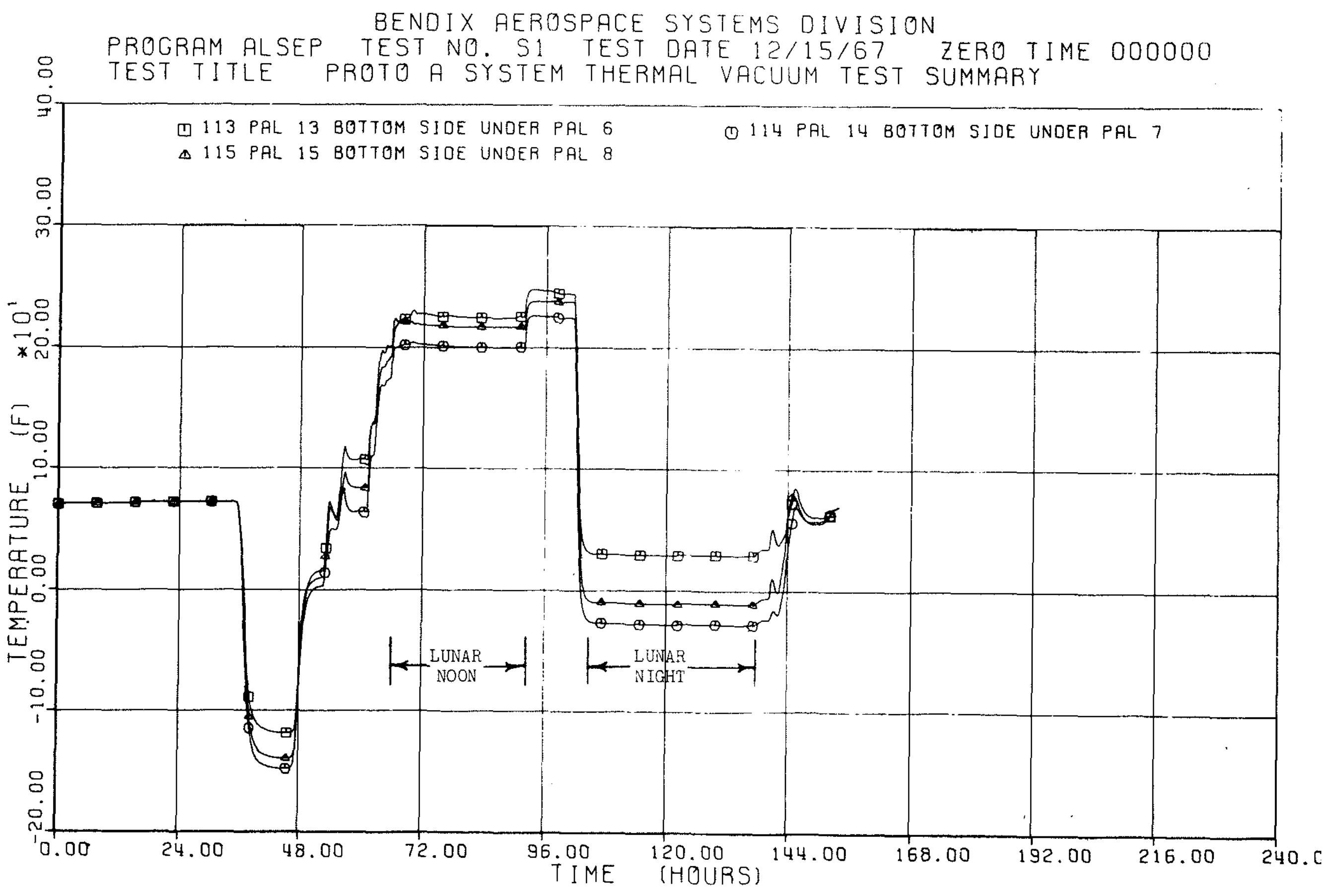


FIGURE 26

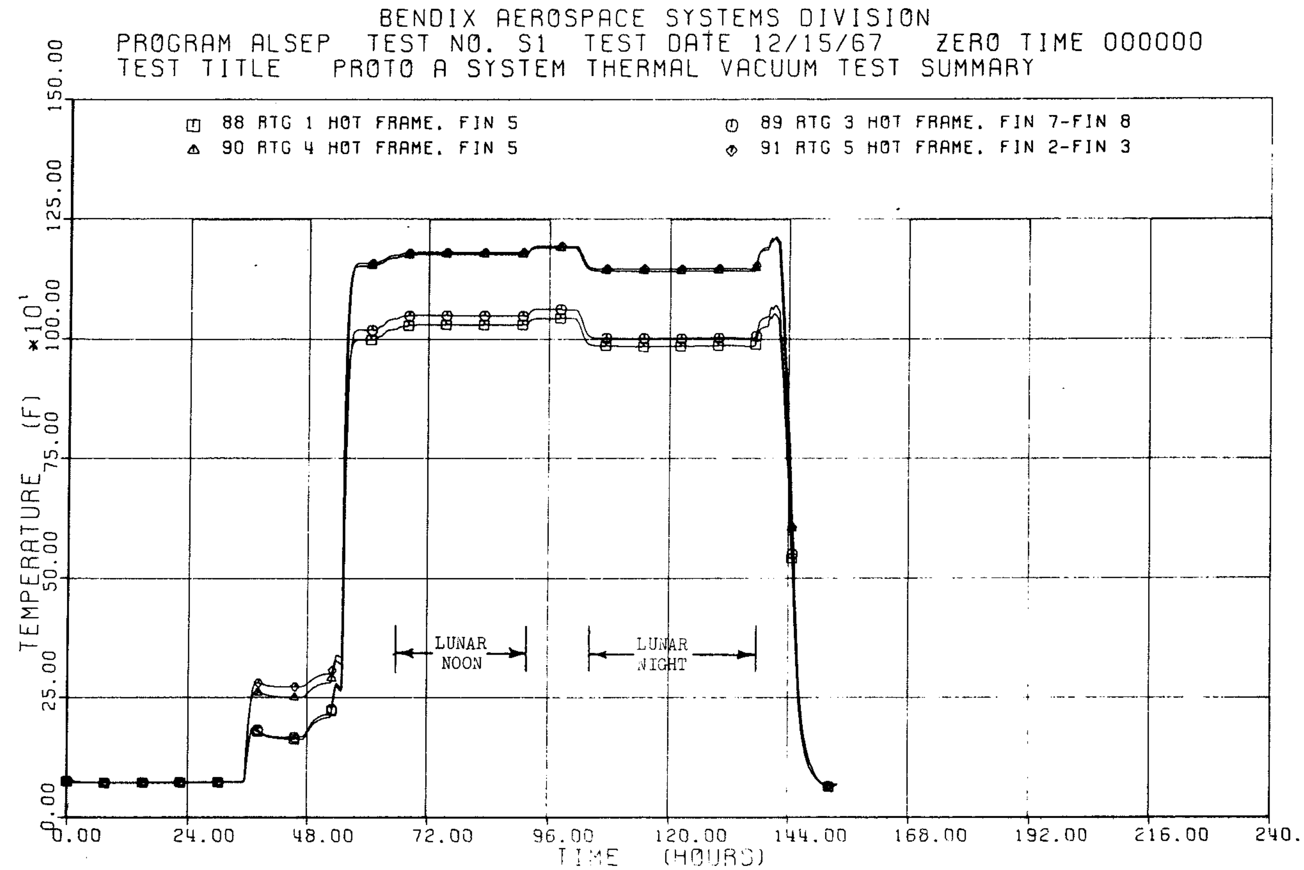


FIGURE 27

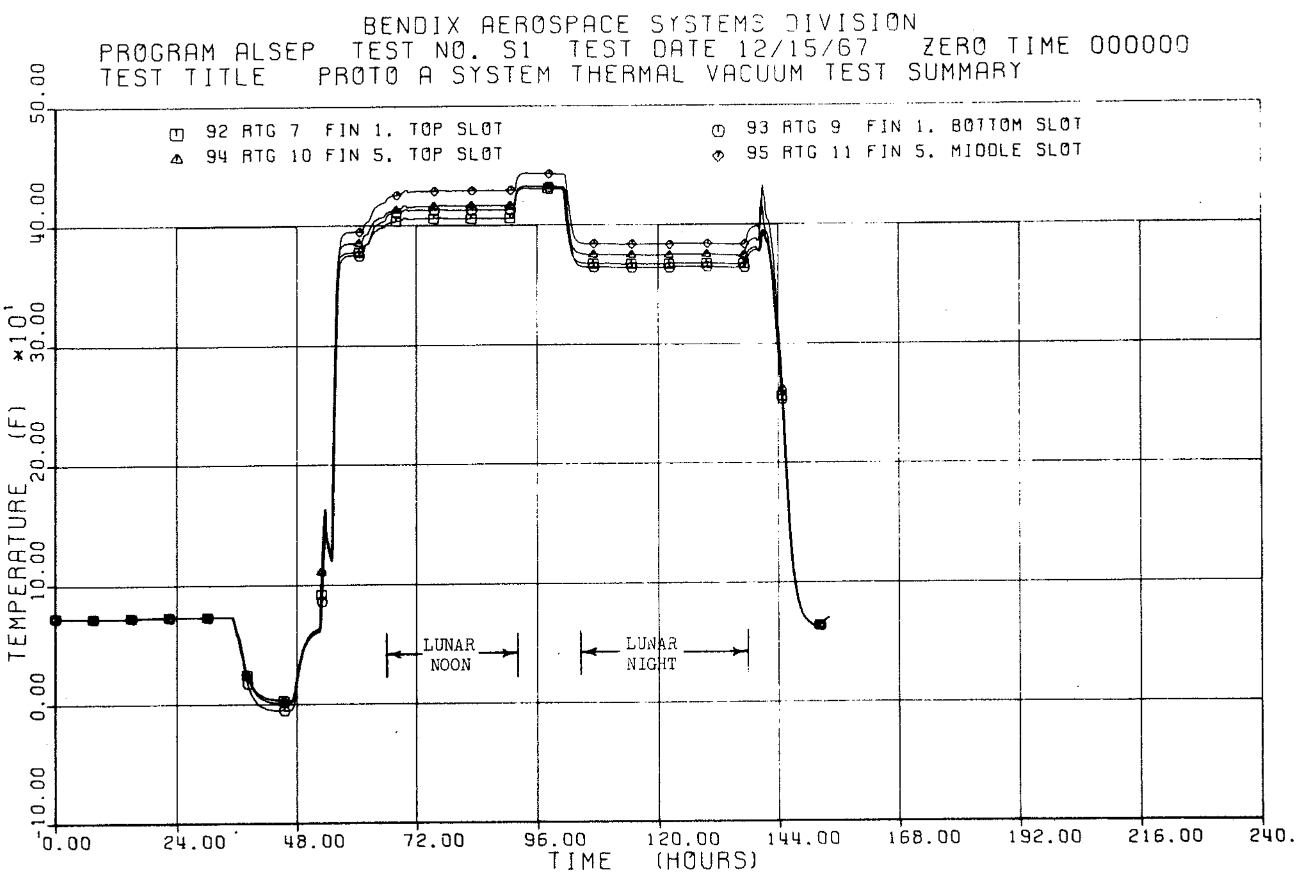
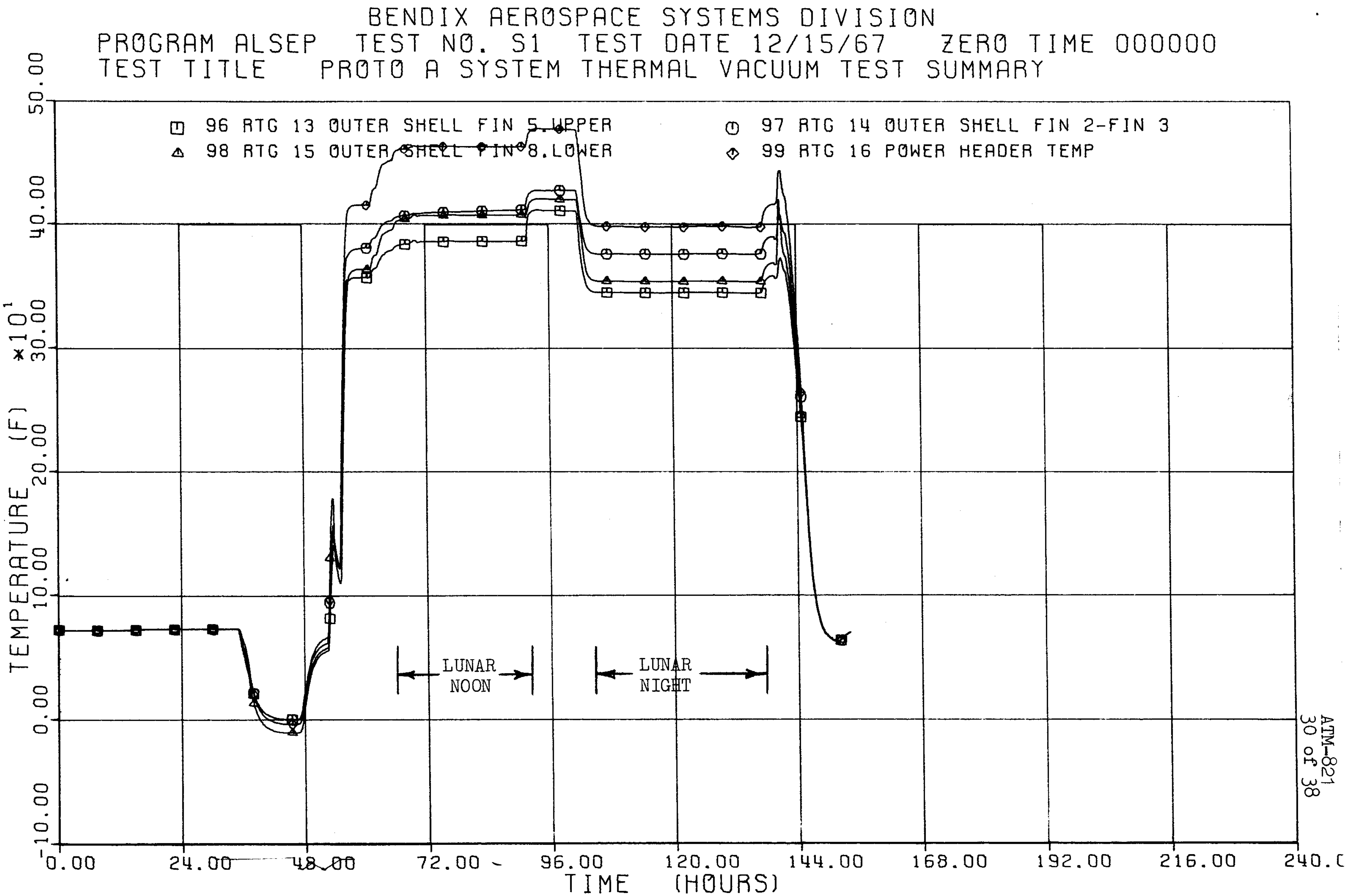


FIGURE 28


BENDIX AEROSPACE SYSTEMS DIVISION
PROGRAM ALSEP TEST NO. S1 TEST DATE 12/15/67 ZERO TIME 000000
TEST TITLE PROTO A SYSTEM THERMAL VACUUM TEST SUMMARY
96 RTG 13 OUTER SHELL FIN 5 UPPER
97 RTG 14 OUTER SHELL FIN 2-FIN 3
98 RTG 15 OUTER SHELL FIN 8 LOWER
99 RTG 16 POWER HEADER TEMP
TEMPERATURE (F) *10^1
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
LUNAR NOON
LUNAR NIGHT
0.00
24.00
48.00
72.00
96.00
120.00
144.00
168.00
192.00
216.00
240.0
TIME (HOURS)

The temperature results of the Proto A Thermal Vacuum Test for the integrated SNAP-27 RTG/Pallet 2 configuration were near nominal. Generator steady state hot and cold frame maximum temperatures were 1190° F and 440° F for lunar day operation and 1145° F and 380° F for lunar night at an electric fuel capsule setting of 1400 watts. Pallet 2 equilibrium surface temperatures ranged from 225 to 375° F during lunar noon to -35 to 180° F for lunar night.

Figures 21 through 28 illustrate the temperature distribution on Subpackage No. 2 for Proto A. The temperature of the Pallet 2 surface below the RTG ranged from a maximum of 375° F during lunar noon to 177° F during lunar night compared to predicted temperature limits of 394° F and 187° F, respectively. Lunar morning, noon, and night are indicated in Figure 22. The differences between pretest predictions and the Prototype test results are attributed to the lower RTG power setting of 1400 watts instead of the 1500 watt RTG dissipation used in the analysis.

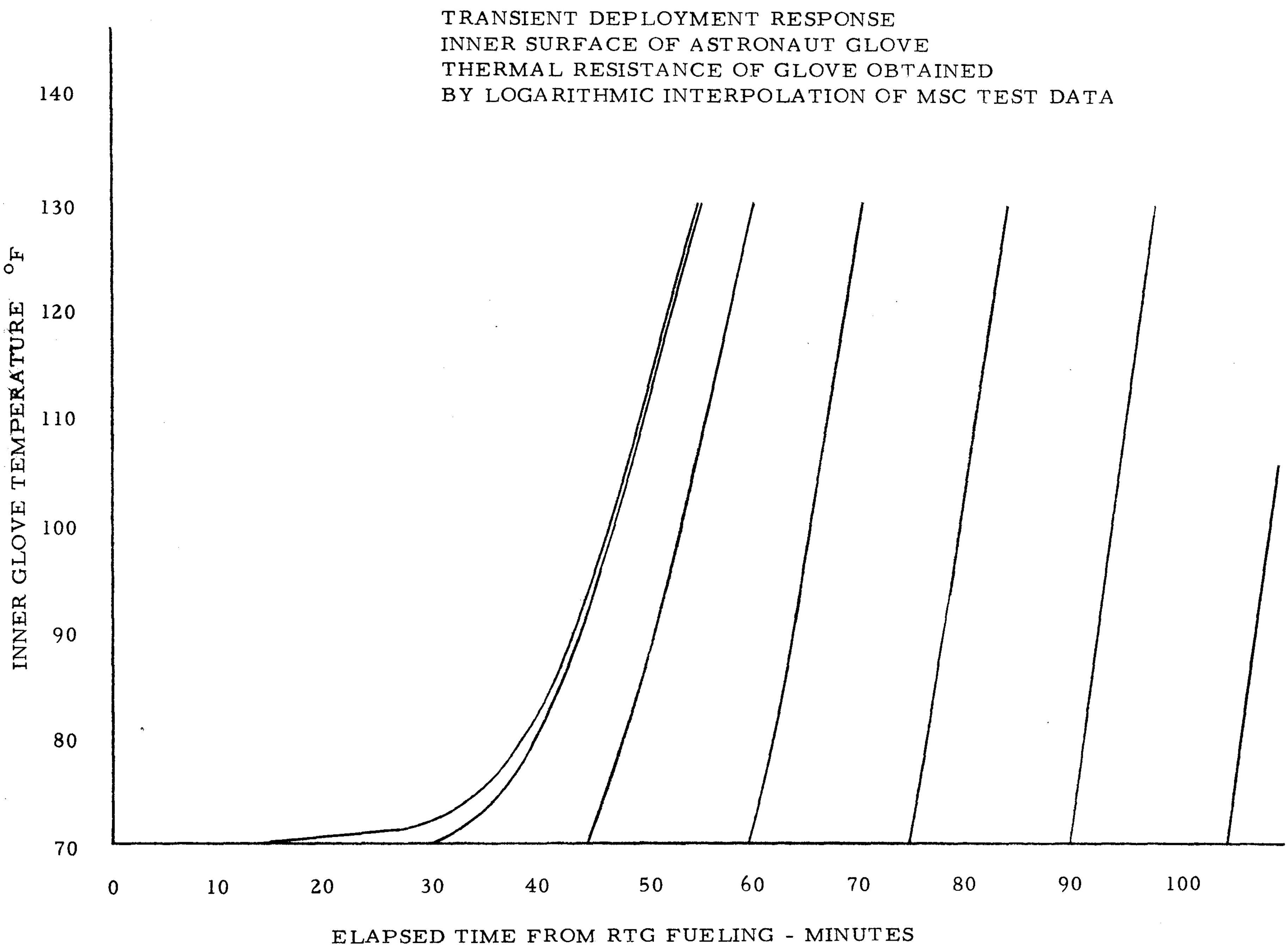
Near the end of the lunar night, the RTG power was increased to 1500 watts. The average hot and cold frame temperatures reached 1109° F and 392° F, respectively. This increase in power caused an increase in temperature across Subpackage 2 and is shown in the temperature plots at the end of lunar night.

4.4 Astronaut Glove Temperature During Traverse

Figures 29 and 30 present analytical temperature responses for the inner surface of the astronaut glove during traverse. The thermal properties of the glove were derived by interpolation of test data presented in the reference. This reference is an MSC report on tests to determine the temperature rise of the inner surfaces of the astronaut suit and glove. Tests were conducted with the outer glove surface in contact with various constant temperature sources.

No data were presented for source temperatures below 250° F. The data were presented in the form of inner surface temperature vs. time, for constant source temperatures. The slopes of these curves are then temperature rise per unit time.

The slope of the time temperature curve was assumed zero at 70° F. The temperatures shown in Figure 29 are the result of logarithmic interpolation of the slopes from test data. Figure 30 presents the glove inner surface temperatures with linear interpolation of the slopes from the test data. The source temperatures used for both cases were the transient temperatures of the pallet surface under the RTG for Flight (two man) configuration. The source temperature will be somewhat lower due to the thermal resistance between the pallet and the astronaut contact area on the carry bar (see Figure 31). Since linear interpolation of the slopes is worst case this will be assumed pending information as to the thermal properties of the glove at temperatures other than those presented in the reference.



TRANSIENT DEPLOYMENT RESPONSE
INNER SURFACE OF ASTRONAUT GLOVE
THERMAL RESISTANCE OF GLOVE OBTAINED
BY LOGARITHMIC INTERPOLATION OF MSC TEST DATA
INNER GLOVE TEMPERATURE °F
140
130
120
110
100
90
80
70
0
10
20
30
40
50
60
70
80
90
100
ELAPSED TIME FROM RTG FUELING - MINUTES

FIGURE 29

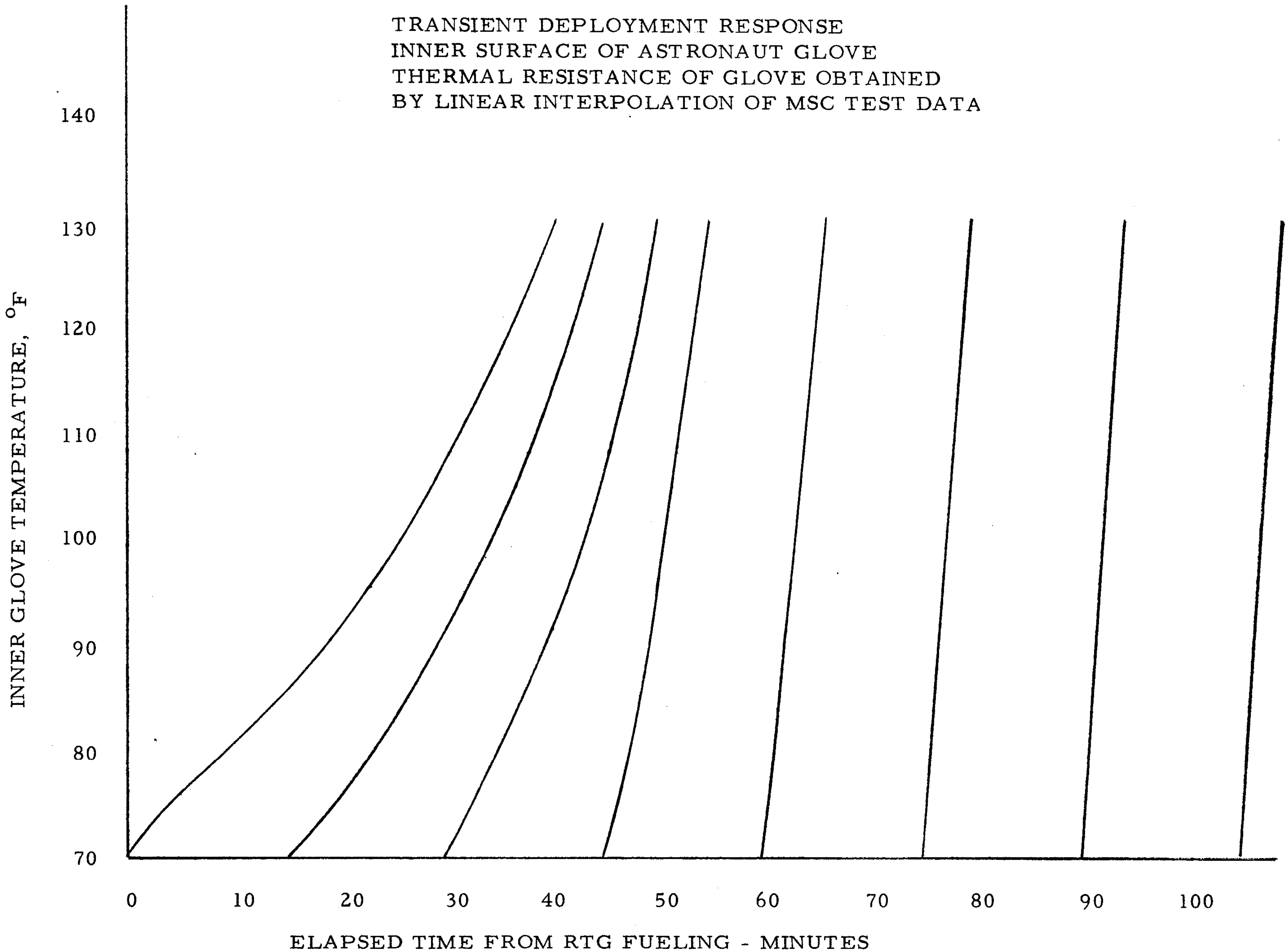

TRANSIENT DEPLOYMENT RESPONSE
INNER SURFACE OF ASTRONAUT GLOVE
THERMAL RESISTANCE OF GLOVE OBTAINED
BY LINEAR INTERPOLATION OF MSC TEST DATA
INNER GLOVE TEMPERATURE, °F
140
130
120
110
100
90
80
70
0
10
20
30
40
50
60
70
80
90
100
ELAPSED TIME FROM RTG FUELING - MINUTES

FIGURE 30

MAST/CARRY BAR

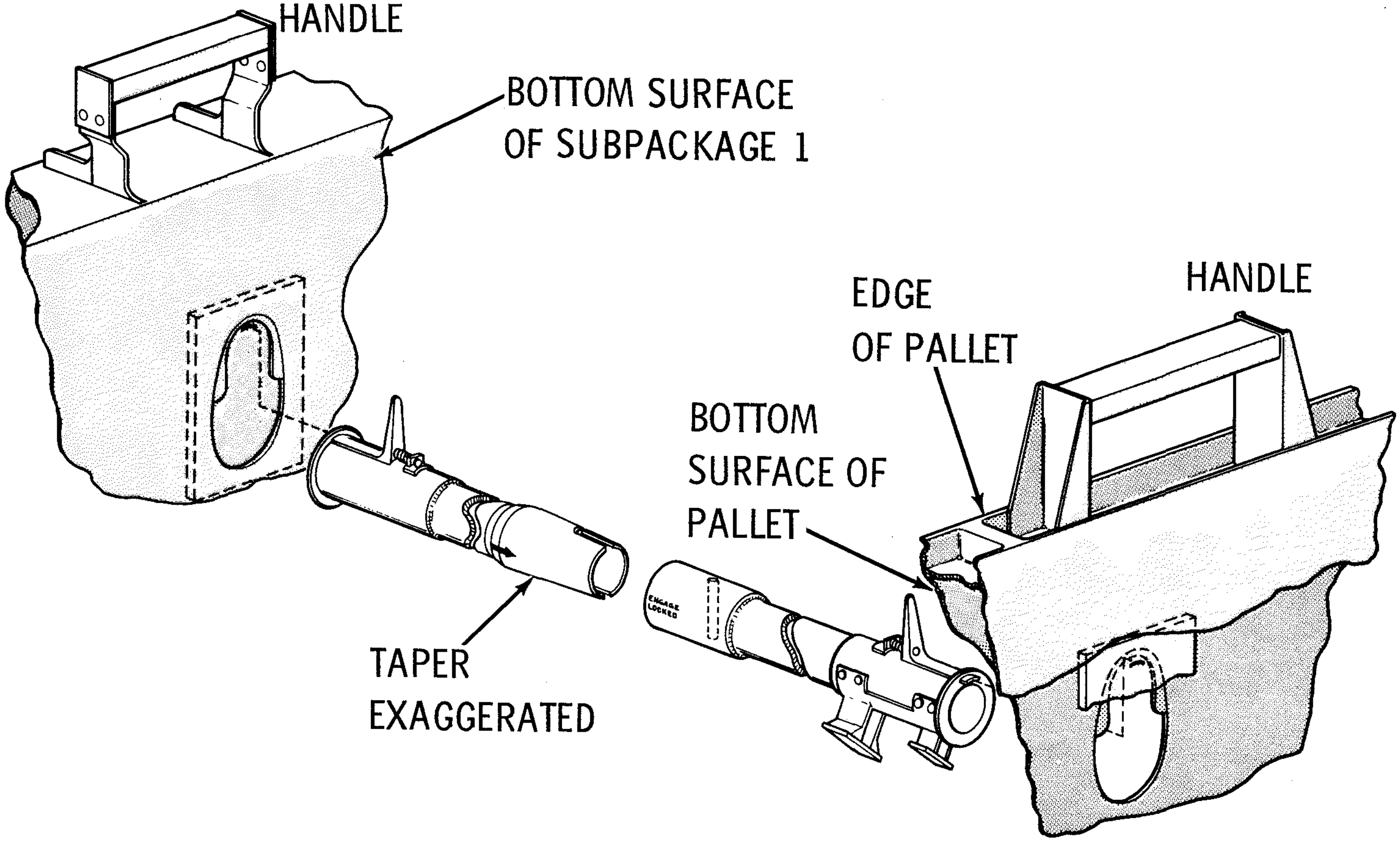


FIGURE 31

The reference defines "pain" as an inner glove temperature of 115°F. Therefore, maximum contact time is defined herein as the time required for the inner surface to reach a temperature of 115° F when initially at 70° F.

Table 4 presents predicted safe contact times for various contact temperatures.

Inner glove data is from the reference report.

5.0 Summary and Conclusions

Steady state deployed temperatures for Subpackage No. 2 do not exceed maximum RTG performance temperatures. Outer shell temperature range is 430 - 490° F with no conductive coupling to the lunar surface and 415 - 485° F with conductive coupling. Conductive heat leak into the pallet from the RTG was 60 to 80 watts. Pallet temperature changes have little effect on RTG temperatures.

An elapsed time of 30 minutes from RTG fueling to the last contact with Subpackage No. 2, or parts mounted on Subpackage No. 2 during traverse, appears to be the safe deployment period at this time. This number contains many safety factors, and could possibly be lengthened after further analysis and testing. However, it is approximately double the present deployment period, including a four minute rest during traverse. Therefore, this number and the present state of analysis is considered sufficient for the present.

The maximum contact times for the FTT are a minimum of 5 times the anticipated FTT contact time (approximately one minute). All tools and equipment (except UHT and cable reel assembly) mounted on Subpackage No. 2 during traverse will be below 200° F at 30 minutes after RTG fueling. All tool contact times are less than one minute, as is the removal time for the sub-pallet and deployment of the cable. Therefore, no thermal hazard is seen during the use of any tools or removal of equipment.

Astronaut glove maximum contact times are summarized in Tables 4 and 5. Contact of the astronaut's glove with surfaces at or under 250° F appears safe for 18 minutes maximum, but the maximum contact time drops sharply for surfaces above 250° F. The maximum contact time for a 400° F source is less than 2 minutes and is under one minute for sources above 600° F. Contact with a 300° F source is safe for approximately 4 minutes. These times could be used for the present, but more data on the glove is needed if a more exact analysis is desired.

In conclusion, the thermal control design of Subpackage No. 2 and astronaut tools is more than adequate to ensure against thermal hazards to the astronaut during RTG fueling and deployment. This, of course, assumes no contact with the capsule, GLFC, or RTG and is based on existing Task Sequence times.

TABLE 4

Maximum Astronaut Contact Times

Pallet Assembly No. 2

Initial Contact in Minutes from RTG fueling	0	15	30	45	60	75
Maximum Contact Time — Minutes	34	26	17	8	5	4

Cable Reel Assembly and UHT

Initial Contact in Minutes from RTG fueling	15	30	45	60
Maximum Contact Time for Spool	43	25	19	13
Maximum Contact Time for Mounting Struts	39	20	7	4

Fuel Transfer Tool

Initial Contact with FTT when FTT Contacts Fuel Capsule End Plate

Surface FTT	Maximum Contact Times — Minutes
Disc (ϵ_H = 0.25)	10
Fingers	15
Handle End	20

TABLE 5

Inner Glove Safe Contact Time

Source Temperature, °F	Maximum Contact Time Seconds	Maximum Contact Time Minutes	Slope, °F/Min
250	1080	18	2.5
400	105	1.75	25.7
600	75	1.25	36
700	49	.82	55
1100	35	.58	77.5
1255	20	.33	135

Linear interpolation of above slopes (zero slope at 70° F) resulted in the following:

Source Temperature, °F	Slope, °F/Min	Maximum Contact Time Minutes	Maximum Contact Time Seconds
150	1.11	40.60	2240
200	1.81	24.90	1494
250	2.50	18.00	1080
300	10.23	4.40	264
350	18.00	2.50	150
400	25.70	1.75	105
450	28.52	1.58	95
500	31.35	1.44	86
550	34.17	1.32	79
600	36.00	1.25	75
650	45.00	.99	59
700	55.00	.82	49

REFERENCE

T. J. Ballentine, MSC Crew Systems Division, "Heat Transfer Measurement on Extravehicular Mobility Unit Composites at Various Temperature Levels," 28 November 1967.