This ATM summarizes the analytical and test results of the CPLEE thermal control system which was originally developed for use at the nominal ALSEP deployment about the lunar equator. The analytical results summarized include (1) the pertinent engineering tradeoffs, (2) the design changes to improve performance and to satisfy off-equator experiment requirements and (3) the thermal performance at the equator and at off-equator deployment sites up to 60° latitude. The off-equator modification and performance analysis have been performed per work authorized under Bendix direction of CCPs 216 and 229.

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1.0 Introduction

The charged-particle lunar environment experiment (CPLEE) is a subsystem of the Apollo Lunar Surface Experiments Package (ALSEP). The CPLEE is used to detect both positive and negative particles near the lunar surface. It will monitor ambient solar wind particles, thermalized solar wind particles, particles in the magnetospheric tail of the earth, and low energy solar cosmic rays. The experiment consists of two separate sensor assemblies, common power conditioning and common output electronics, housed in a single package.

Exhibit B ALSEP Technical Specification paragraph 3.2.2.7.4 states the CPLEE shall provide its own thermal control subsystem.

From a thermal design standpoint CPLEE consists of electronics with a maximum operating temperature range of -50 to 155 degrees Fahrenheit. These electronics are housed in a thermally insulated case topped by a horizontal radiator plate which absorbs a minimum of solar irradiation and rejects from 3 to 5 watts of heat dissipated in the electronics. The radiator plate consists of a thermally coated flat plate with two analyzer openings. One analyzer opening, the vertical analyzer, provides directional flux information in the east-west vertical plane. The other opening, the angular sensor cavity, provides directional flux information in the north-south vertical plane.

The thermal analysis and design effort consisted of the:

(1) Determination of heat leak or gain through

  (a) Cables
  (b) Experiment Case
  (c) Legs
  (d) Physical Analyzer Slits

(2) Determination of the thermal performance in a lunar environment.

(3) Recommendation of thermal coatings

(4) Design of thermal simulator model

(5) Fabrication of thermal simulator model

(6) Correlation of analytical performance with test results

(7) Utilization of data obtained from the performance of the thermal simulator model to design the DVT, Qual and Flight models.

(8) Utilization of data from the CPLEE DVT and ALSEP systems qualification thermal-vacuum tests to verify the performance of the actual hardware.

The three basic testing programs designed to qualify the CPLEE were, the Design Verification Test (DVT) which verifies the CPLEE thermal design under various simulated lunar conditions, the Qual SB test which qualifies the CPLEE in the ALSEP system to qual level experimental conditions, and finally the Flight Acceptance Tests which qualify CPLEE flight hardware with the ALSEP flight hardware to nominal qualification conditions.

The original lunar deployment location was per Exhibit B Specification paragraph 3.1.1.4.5 at $\pm$ 5° from the equator and $\pm$ 45° from the prime meridian on the earth side. Possible Apollo 14 landing sites such as Frau Mauro, 4° south latitude, and Littrow Rille at 22° north latitude prompted the off-equator deployment studies of 0 to 60 degrees latitude. Studies were thus, required to determine CPLEE performance at off-equator deployment.

Exhibit B ALSEP Technical Specification paragraph 3.1.1.9 states "The effects of dust accretion shall not be included in the thermal design of those particle experiments in which the sensor has a low tolerance to dust." This paragraph implies that dust protection should be provided to those experiments which dust accretion would impair sensor function. The CPLEE falls in this category, consequently, the nominal thermal control system did not incorporate features to account for dust accretion. The sensors have been provided with a dust cover for protection from the debris anticipated upon LM ascent. This cover provides protection for the sensors, the gold stripe on the centerline of the radiator plate and a portion of the radiator plate coated with the Z-93 thermal control coating. The dust cover is ejected by command subsequent to LM ascent. The unprotected section of the radiator plate may accumulate debris upon LM ascent. In addition, data from Apollo flights 11 and 12 indicate; (1) dust is raised by the deployment process, (2) a gradual accretion of particulate matter with time will soil and degrade exposed surfaces. To eliminate the dust degradation prior to and during the deployment process, an additional dust cover is recommended as presented in reference 15. Additional analytical studies were performed, indicating the effects of dust coverage, to account for the gradual accretion of dust particles.

2.0 SUMMARY

Included in this report is a discussion of the thermal model of CPLEE, changes required for off-equator deployment, the results of a study on the effective solar absorptance of the angular sensor cavity, the effect of heat leaks through the fiberglass case and a summary of results of surface radiative property measurements on flight hardware radiator plates.

The CPLEE design concept is discussed including the radiator plate trade-off studies. The final coating selection includes a Z-93 coated plate with 8.8 square inches of polished gold forming a center strip. These coating combinations, coupled with heaters supplying heat during lunar night, maintain CPLEE's operating temperature range within the acceptable specification limits of -50 to 150°F for the radiator plate and -50 to 155°F for the electronics. The Design Verification Test prompted the redesign of the CPLEE support legs and test cable and squib wire leads when test data indicated these to be heat leak sources.

Studies were made of the CPLEE operating temperatures when deployed off the equator and with various dust coverages. At lunar noon without any dust coverage the CPLEE will operate within the specified operating temperature limits except at latitudes between 34 and 60 degrees latitude. At these latitudes the electronics will exceed the 155°F specification operating temperature limit. Dust coverage of 50 and 100 percent will cause the CPLEE to exceed the maximum operating temperature limit at any deployment latitude. At 50 and 100 percent dust coverages the CPLEE radiator plate temperatures will peak at 199.5 and 230.1°F respectively. The maximum dust coverage possible with the CPLEE deployed at the equator is 13 percent. Beyond 13 percent dust coverage the maximum electronics operating temperature is exceeded and at 17 percent the maximum survival temperature is exceeded. The CPLEE requires 1.66 watts of heater power to maintain the -50°F lunar night minimum operating temperature in addition to the 3.0 watts dissipated in the electronics. In order to maintain the minimum survival temperature limit of -60°F, 4.3 watts of power must be dissipated in the CPLEE heaters.

The CPLEE testing program consisted of the Design Verification Test (DVT), the ALSEP qualification test Qual-SB, and the Flight Acceptance Tests Flight 3 and Flight 4 and Flight 4 retest. The DVT which took place at MSC in Houston, Texas was a comprehensive test verifying the original CPLEE design.

The DVT consisted of seven separate test conditions designed to verify the CPLEE thermal control. The Qual-SB Test integrated CPLEE with the ALSEP system for the qual level environment conditions. This test was performed in the Bendix Aerospace System Division Thermal/Vacuum Test Chamber. The Flight 3 and Flight 4 Acceptance Tests again integrated CPLEE with the array of ALSEP experiments for each flight at the nominal expected lunar conditions. These tests were conducted at the Bendix Thermal/Vacuum Test Chamber and have also shown the integrity of the thermal design. The predicted radiator plate and electronics temperatures at the proposed Apollo 14 landing site of Frau Mauro are +120 and +135.5°F at lunar noon and -19.0 and +6.0°F at lunar night respectively.

3.0 DESIGN SPECIFICATION REQUIREMENTS

3.1 Temperature Requirement

References 2 and 3 state both the survival limits and the maximum permissible operating range for both the CPLEE radiator plate and electronics temperatures (See Table 3-1).

3.2 Power Requirement

Paragraph 3.2.3.1 of Reference 7 states that CPLEE shall require no more than 3.0 watts of electrical power, exclusive of up to 3.5 watts for thermal control, to perform all functions except those intermittent and transient functions. The electrical power consumed when the stand by (survival) power line is energized shall be 0 or 4.5 watts, depending on the thermal environment.

TABLE 3.1

CPLEE Required Temperature Ranges

	Survival Limits	Maximum Permissible Operating Range
Radiator Plate	-60 to 160°F	-50 to 150°F
Electronics	-60 to 160°F	-50 to 155°F
Sensors	-60 to 160°F	-50 to 150°F

(Ref. No. 3)

4.0 ANALYTICAL THERMAL MODEL

4.1 Node Description

The thermal model of CPLEE (Figure 4.1) was developed utilizing the Bendix Thermal Analyzer Computer Program. The model consists of 18 nodes representing the various components of CPLEE as well as the lunar surface and space. These nodes and their physical significances are listed in Table 4.1.

4.2 Resistors - Equator and Off-Equator Studies

For off-equator deployment of CPLEE, the radiator plate is oriented directly towards the sun at lunar noon. This is due to the scientific requirement that the sensors mounted on the radiator plate be oriented in the lunar ecliptic plane and perpendicular to the solar vector at lunar noon. This requirement results in some CPLEE components having varying exposures to space and the lunar surface. Dust degradation studies also result in thermal resistor changes. All thermal resistors used in the CPLEE thermal model are tabulated in Table 4.2. Those which vary with dust coverage and deployment latitudes are tabulated in Table 4.3.

4.3 Solar Heating

The solar flux absorptance of the thermal plate at lunar noon varies with dust coverage only for all latitudes, since the plate always remains in the lunar ecliptic plane. Only the radiator plate and tool socket receive solar irradiation. Effective radiator plate absorptances and radiator plate individual absorptances are listed in Table 4.4. Absorbed solar radiation of the plate and tool socket is tabulated in Table 4.5.

4.4 Lunar Surface Temperature

Variation of the lunar surface temperature as a function of deployment latitude was considered in the analysis. Temperatures of the surface as a function of latitude angle are shown in Figure 4.2. During lunar night the lunar surface temperature was -300°F.

4.5 Electronics Power

The power input to CPLEE consists of operational electronics power, operational heater power, and standby (survival) heater power. These three inputs are handled through one node in the thermal model.

The input power data obtained from CPLEE qualification tests and flight hardware tests per Bendix Preintegrated Test Procedure 2333067 is tabulated in Table 4.6. This data was used in calculating lunar surface performance of CPLEE. (Ref. 11)

4.6 Angular Sensor Cavity Effective Absorptance (Ref. 5)

The angular sensor cavity located near the center of the CPLEE radiator plate consists of a trough shaped hole 1.5 x 2.4 x 1.2 inches. Its surfaces are coated with Z-93 thermal coating and the cavity has an unpolished gold plated baffle. The cavity surface constitutes 9.5 percent of the radiator plate surface. Since this cavity significantly influences the effective radiator plate absorptance, a calculation utilizing a radiosity technique was used to account for all incident radiation absorbed and reflected by surfaces internal to the angular cavity. The cavity consists of eleven absorbing and reflecting surfaces. The resulting radiosity equations lend themselves to a convenient solution on the Bendix thermal analyser computer program. The values obtained vary between 0.54 and 0.59 depending upon the value assumed for the unpolished gold baffle. (See Figure 4.4.) A sketch of the model used in the analysis is given in Figure 4.3.

4.7 Heat Transfer Study of Fiberglass Case

An extensive analysis of the effect of the fiberglass case radiation to the lunar surface on the radiator plate heat leak was made. The case is directly mounted to the radiator plate which provides a major source of heat leak from the plate.

The fiberglass case with its large surface area presents a large view factor to the lunar surface and space; however, the thermal conductivity of fiberglass makes almost the entire surface of the case ineffective as a heat radiator. A small band of the case, about two inches below the radiator plate, absorbs and rejects the entire heat leakage from the radiator plate.

Figure 4.6 indicates the nodal pattern used for the study. Figure 4.8 and 4.9 give the resulting heat leaks in watts for various plate temperatures at lunar noon and night. Figure 4.7 presents a temperature profile of the side of the case for the lunar night condition. This figure indicates the narrow effective band of high temperature gradient resulting in heat leak to space and lunar surface.

The case - radiator plate interface required a two-dimensional nodal pattern because the case doesn't have direct contact around the entire top edge of the case. The areas of no contact are indicated in Figure 4.6.

4.8 CPLEE Radiator Plate Thermal Coating Optical Properties

In September, 1968, BxA conducted measurements of the optical properties of the thermal plate serial numbers 3, 4, 6 and 7. Absorptance was measured using a Gier Dunkel MS 251 Mobile Solar Reflectometer per T.P. 2338614, and emittance was measured using a Gier Dunkel DB 100 Infrared Reflectometer per T.P. 2338615. Coating thicknesses were measured using a Twin City Testing Corp. Permascope per TP 2338613. A summary of these properties is listed in Table 4.7. These properties were used as the optical properties of coatings in CPLEE analytical models.

TABLE 4.1

THERMAL MODEL NODES

Node Number	Description
1	Thermal Plate
2	Long side of case - exterior
3	Narrow side of case - exterior
4	Narrow side of case - exterior
5	Long side of case - exterior
6	Bottom of case - exterior
7	Bracket handling tool socket
8	Receptacle assembly
12	Long side of thermal bag - interior
13	Narrow side of thermal bag - interior
14	Narrow side of thermal bag - interior
15	Long side of thermal bag - interior
16	Bottom of thermal bag - interior
17	Electronics
50	Lunar Surface
51	Space
100	Cable Potential
101	Case Potential

TABLE 4-2

RESISTORS AND EXCHANGE FACTORS
FOR NON-EQUATORIAL STUDY

Res. No.	Connecting Nodes	Heat Transfer Mode	Physical Significance	Resistance HR-°F/BTU	Area (ft^2)	Exchange Factor
6	6-15	Conduction	Case bottom to lunar surface	587.9		
7	12-14		Side of thermal bag to end of thermal bag	1609.0		
8	12-13		Side of thermal bag to end of thermal bag	1609.0		
9	15-13		Side of thermal bag to end of thermal bag	1609.0		
10	15-14		Side of thermal bag to end of thermal bag	1609.0		
11	16-14		Bottom of thermal bag to end of thermal bag	4016.0		
12	16-13		Bottom of thermal bag to end of thermal bag	4016.0		
13	16-12		Bottom of thermal bag to side of thermal bag	1595.0		
14	16-15		Bottom of thermal bag to side of thermal bag	1595.0		
15	2-3		Side of case to end of case	1100.0		
16	2-4		Side of case to end of case	1100.0		
17	5-3		Side of case to end of case	1100.0		
18	5-4		Side of case to end of case	1100.0		
19	4-6		End of case to bottom of case	2493.0		
20	3-6		End of case to bottom of case	2493.0		
21	2-6		Side of case to bottom of case	1060.0		
22	5-6		Side of case to bottom of case	1060.0		
23	17-1		Electronics to plate	1.43		
24	1-100		Case potential to plate	53.8		
25	1-7		Tool socket bracket to plate	1018.0		
26	1-101		Cable to plate	366.0		
32	3-50	Radiation	Case side to lunar surface		0.2358	0.45
33	4-50		Case side to lunar surface		0.2358	0.45
34	6-50		Case bottom to lunar surface		0.2422	0.90
37	3-51		End of case to space		0.2358	0.45
38	4-51		End of case to space		0.2358	0.45
39	12-17		Side of thermal bag to electronics		0.3642	0.04167
40	15-17		Side of thermal bag to electronics		0.3642	0.04167
41	13-17		End of thermal bag to electronics		0.1862	0.04167
42	14-17		End of thermal bag to electronics		0.1862	0.04167
43	16-17		Bottom of thermal bag to electronics		0.182	0.04167
50	1-4		Bottom of plate to end of case		*	*
51	1-50		Bottom of plate to lunar surface		*	*
52	1-4		Leg plate to end of case		*	*
53	1-50		Leg plate to lunar surface		*	*
54	1-3		Leg plate to end of case		*	*
55	1-50		Leg plate to lunar surface		*	*
56	1-50		Sides of plate (gold) to lunar surface		*	*
57	1-51		Sides of plate (gold) to space		*	*
58	1-50		Sides of plate (holes) to lunar surface		*	*
59	1-50		Sides of plate (holes) to space		*	*
60	1-50		Right end of plate to lunar surface		*	*
61	1-51		Right end of plate to space		*	*
62	1-50		Left end of plate to lunar surface		*	*
63	1-51		Left end of plate to space		*	*
64	1-50		Left end plate holes to lunar surface		0.000822	0.72
65	1-51		Left end plate holes to space		0.000822	0.135
66	1-50		Left end plate cutout to lunar surface		*	*
67	1-51		Left end plate cutout to space		*	*
68	1-50		Level bottom to lunar surface		*	*
69	1-51		Level bottom to space		*	*
72	7-8		Tool socket bracket to receptacle assembly		0.004595	0.07672
73	7-51		Tool socket bracket to space		*	*
74	7-50		Tool socket bracket to lunar surface		*	*
81	1-4		Plate bottom holes to case left side		0.0003409	0.180
82	1-50		Plate bottom holes to lunar surface left side		0.0003409	0.270
83	1-3		Plate bottom holes to case right side		0.0006818	0.180
84	1-50		Plate bottom holes to case right side		0.0006818	0.270
100	1-50		Physical analyzer holes to lunar surface		*	*
101	1-51		Physical analyzer holes to space		*	*
102	1-50		Bubble level to lunar surface		*	*
103	1-51		Bubble level to space		*	*
104	1-50		Stainless steel screws to lunar surface		*	*
105	1-51		Stainless steel screws to space		*	*
106	1-50		Polished gold stripe to lunar surface		*	*
107	1-51		Polished gold stripe to space		*	*
108	1-50		Z-93 coating to lunar surface		*	*
109	1-51		Z-93 coating to space		*	*
110	1-50		Fastener holes to lunar surface		*	*
111	1-51		Fastener holes to space		*	*
112	2-50		Case sides to lunar surface		*	*
113	2-51		Case sides to space		*	*
116	5-51		Case sides to space		*	*
117	5-50		Case sides to lunar surface		*	*
124	8-50		Receptacle to lunar surface		*	*
125	8-51		Receptacle to space		*	*
151	1-51		Thermal plate bottom to space		*	*
153	1-51		Leg plate left side to space		*	*
155	1-51		Leg plate right side to space		*	*
301	3-13	Conduction	Case end to thermal bag end	1485.0		
302	4-14		Case end to thermal bag end	1485.0		
303	2-12		Case side to thermal bag side	795.0		
304	5-15		Case side to thermal bag side	795.0		
305	6-16		Case bottom to thermal bag bottom	1480.0		

*See TABLE 4-3 for these values

TABLE 4.3

EXCHANGE FACTOR VALUES WHICH CHANGE WITH DEPLOYMENT ANGLE AND DUST COVERAGE

Exchange Factors With No Dust Coverage

No.	Exchange Factor Value
50	0.009
52	0.015
54	0.009
56	0.0125
57	0.0125
58	0.50
59	0.50
60	0.01125
61	0.0087
62	0.0144
63	0.00562
66	0.0125
67	0.0125
68	0.233
69	0.0675
73	0.15
74	0.15
112	0.45
113	0.45
116	0.45
117	0.45
120	0.01
121	0.01
122	0.50
123	0.50
124	0.25
125	0.25

TABLE 4. 3

EXCHANGE FACTORS WITH NO DUST COVERAGE - VARYING WITH LATITUDE CHANGE

No.	0°	15°	30°	45°	60°
51	.012	.0118	.0112	.01025	.0084
151	0	.0002	.0008	.00175	.0030
53	.012	.0118	.0112	.01025	.0084
153	0	.0002	.0008	.00175	.0030
55	.012	.0118	.0112	.01025	.0084
155	0	.0002	.0008	.00175	.0030
100	0	.01615	.06357	.13899	.23729
101	.95	.9340	.88643	.71702	.71271
102	0	.0172	.0620	.1390	.2380
103	.9500	.9330	.8630	.7150	.7130
104	0	.0051	.0200	.04389	.07493
105	.3000	.2949	.2799	.2261	.2251
106	0	.00034	.00134	.00293	.0050
107	.020	.0196	.0187	.0151	.0150
108	0	.0168	.0620	.1350	.2310
109	.926	.910	.885	.695	.695
110	0	.00085	.03346	.07315	.12489
111	.50	.4915	.4665	.3768	.3751

TABLE 4.3

EXCHANGE FACTORS FOR 50% DUST COVERAGE

No.	Exchange Factor Value
50	.1665
52	.1665
54	.1665
56	.231
57	.231
58	.500
59	.500
60	.260
61	.202
62	.332
63	.130
66	.230
67	.230
68	.465
69	.135
73	.300
74	.300
112	.450
113	.450
116	.450
117	.450
120	.235
121	.235
122	.500
123	.500
124	.350
125	.350

TABLE 4. 3

EXCHANGE FACTOR WITH 50% DUST COVERAGE - VARYING WITH LATITUDE CHANGE

No.	0°	15°	30°	45°	60°
51	.277	.272	.258	.236	.208
151	0	.0047	.0185	.0405	.0692
53	.277	.272	.258	.236	.208
153	0	.0047	.0185	.0405	.0692
55	.277	.272	.258	.236	.208
155	0	.0047	.0185	.0405	.0692
100	0	.01615	.0635	.139	.237
101	.95	.935	.885	.810	.712
102	0	.01615	.0635	.139	.237
103	.95	.934	.885	.810	.712
104	0	.0102	.0401	.0875	.1495
105	.6	.59	.56	.512	.45
106	0	.0078	.0308	.0672	.1145
107	.46	.452	.430	.399	.345
108	0	.01575	.0620	.1350	.2310
109	.926	.910	.865	.790	.675
110	0	.0119	.0468	.1020	.1745
111	.700	.688	.653	.597	.525

TABLE 4.3

EXCHANGE FACTORS WITH 100% DUST COVERAGE

No.	Exchange Factor Value
50	.324
52	.324
54	.324
56	.450
57	.450
58	.500
59	.500
60	.505
61	.393
62	.647
63	.253
66	.450
67	.450
68	.697
69	.203
73	.450
74	.450
112	.450
113	.450
116	.450
117	.450
120	.450
121	.450
122	.500
123	.500
124	.450
125	.450

TABLE 4. 3

EXCHANGE FACTORS WITH 100% DUST COVERAGE - VARYING WITH LATITUDE CHANGE

No.	0°	15°	30°	45°	60°
51	.54	.54	.504	.46	.405
151	0	.0092	.036	.079	.1345
53	.54	.53	.504	.46	.405
153	0	.0092	.036	.079	.1345
55	.54	.53	.504	.46	.405
155	0	.0092	.036	.079	.1345
100	0	.0162	.0635	.1385	.236
101	.95	.933	.885	.810	.712
102	0	.0162	.0635	.1385	.236
103	.95	.933	.885	.810	.712
104	0	.0153	.0603	.1315	.225
105	.90	.885	.840	.768	.675
106	0	.0153	.063	.1315	.225
107	.90	.885	.840	.768	.675
108	0	.0153	.063	.1315	.2250
109	.90	.885	.840	.768	.675
110	0	.0153	.063	.1315	.2250
111	.90	.885	.840	.768	.675

TABLE 4.4

RADIATOR PLATE SOLAR ABSORPTANCE

Component	(Area (in^2)	Absorptance		
		Nominal	50% Dust Coverage	100% Dust Coverage
Vertical Analyser	.326	.950	.950	.950
Angular Sensor	3.600	.570	.735	.900
Screws	.743	.500	.700	.900
Level	.518	.500	.700	.900
Polished Gold	8.776	.250	.575	.900
Z-93 Coating	28.160	.156	.528	.900
Effective Total Absorptance		.229	.568	.905

TABLE 4.5

ABSORBED SOLAR RADIATION -
BTU/HR ON CPLEE RADIATOR PLATE AND TOOL SOCKET

Node	Description	% Dust Coverage		
		0	50	100
1	Radiator Plate	29.5	73.2	116.5
8	Tool Socket	1.36	1.66	1.95

TABLE 4.6

CPLEE POWER DISSIPATION

Ref. (Bendix Aerospace Systems Division Preintegrated Test Procedure 2333067)

S/N	Flight	Voltage (volts)	Current (ma)		Power (watts)	
			Heater	No Heater	Heater	No Heater
2	Qual SB	29.08	170	100	4.95	2.91
6	3	29.11	196	103	5.70	3.00
5	4	29.07	200	98	5.82	2.85
3	Flight Spare	29.07	198	103	5.77	3.00

TABLE 4.7

SURFACE PROPERTY MEASUREMENTS ON CPLEE RADIATOR PLATES

Thermal Plate Serial Number	Absorptance Z-93	Emittance Z-93	Thickness Z-93 (mils)	Absorptance Gold	Emittance Gold
3	.167	.929	4.7/9.5	.246	.020
4	.160	.928	5.5/10.5	.246	.021
6	.147	.923	4.0/8.0	.248	.018
7	.150	.924	4.7/19.7	.261	.023

51

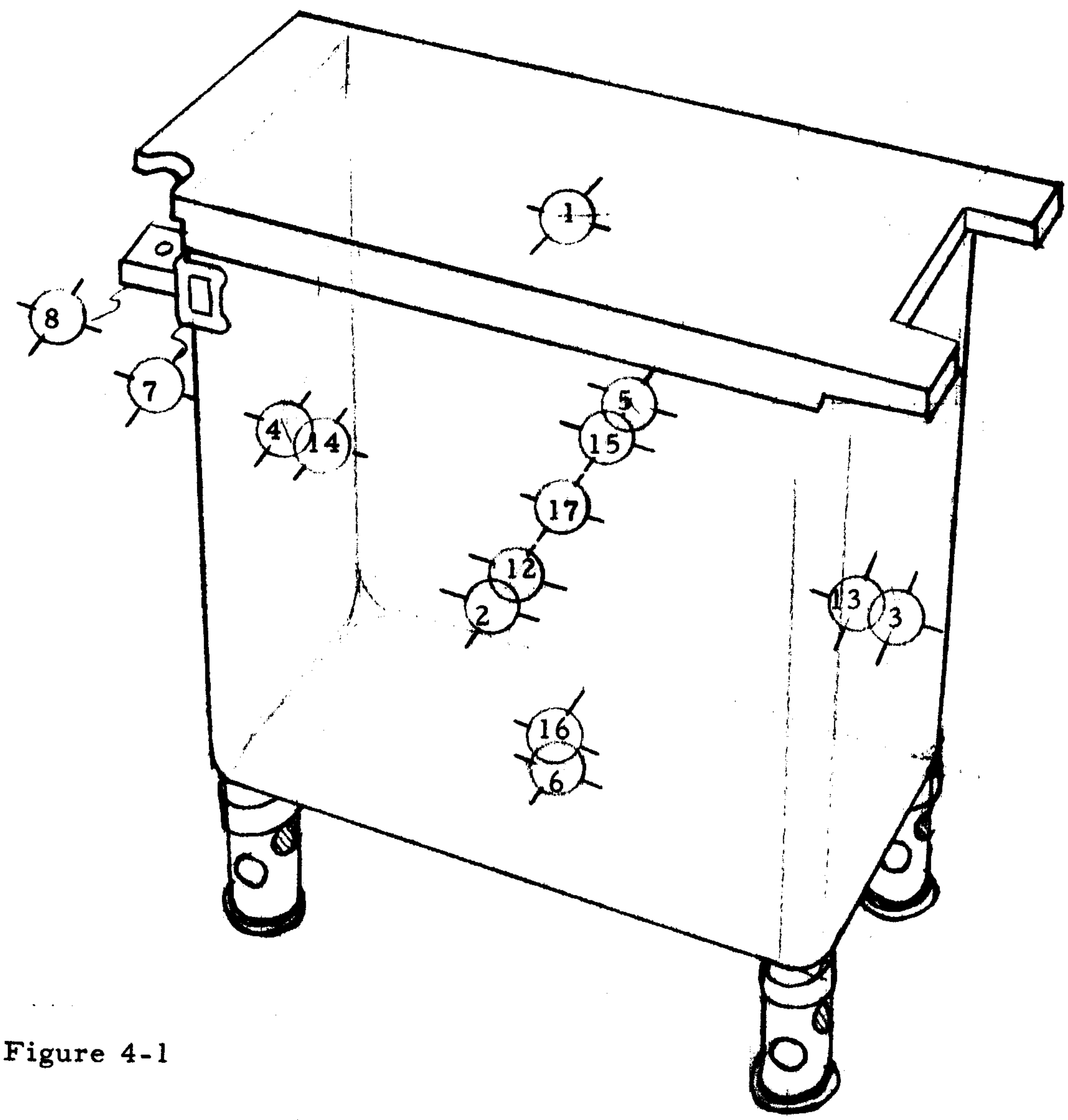


Figure 4-1

CPLEE Node Locations

Lunar Surface

50

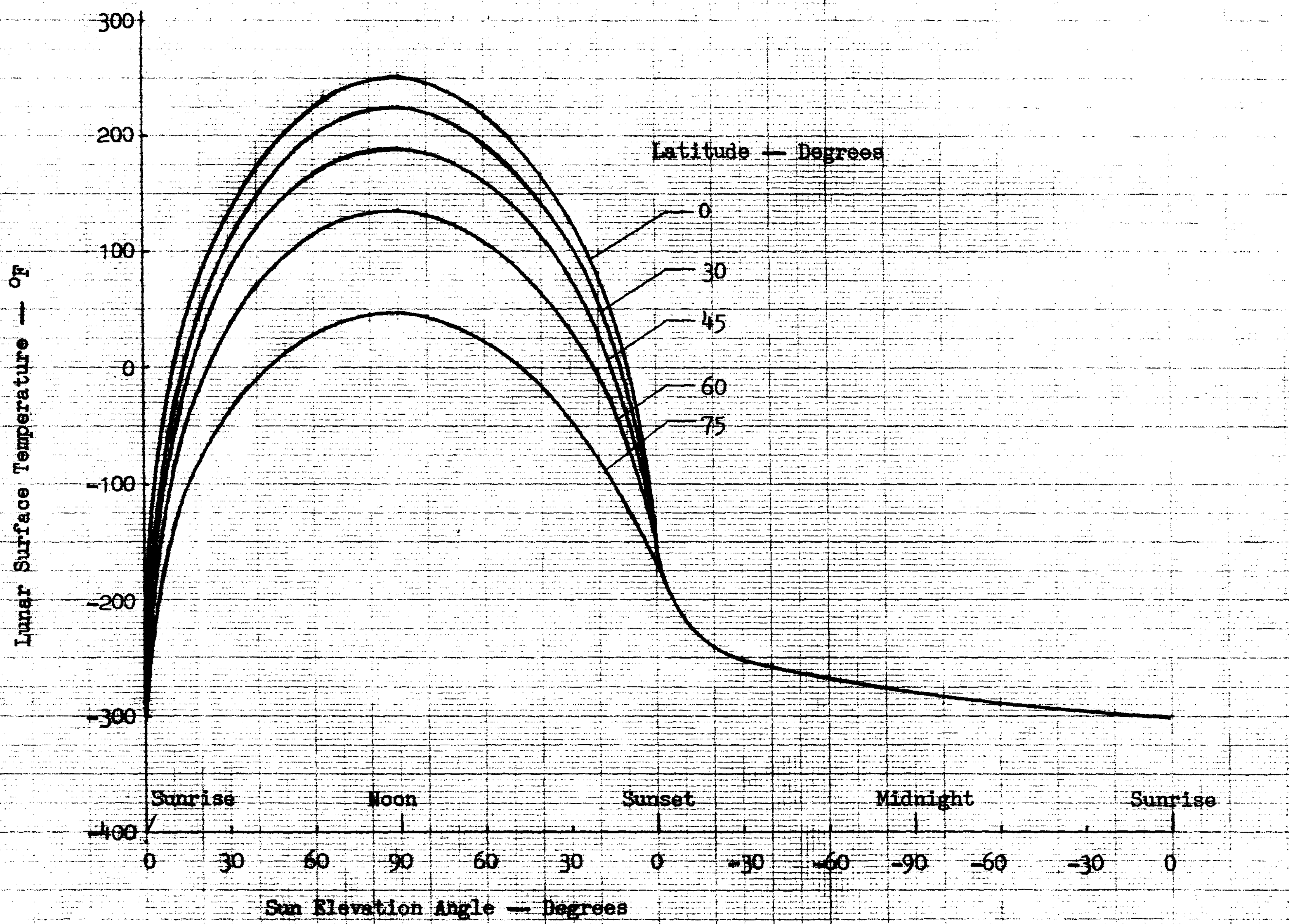
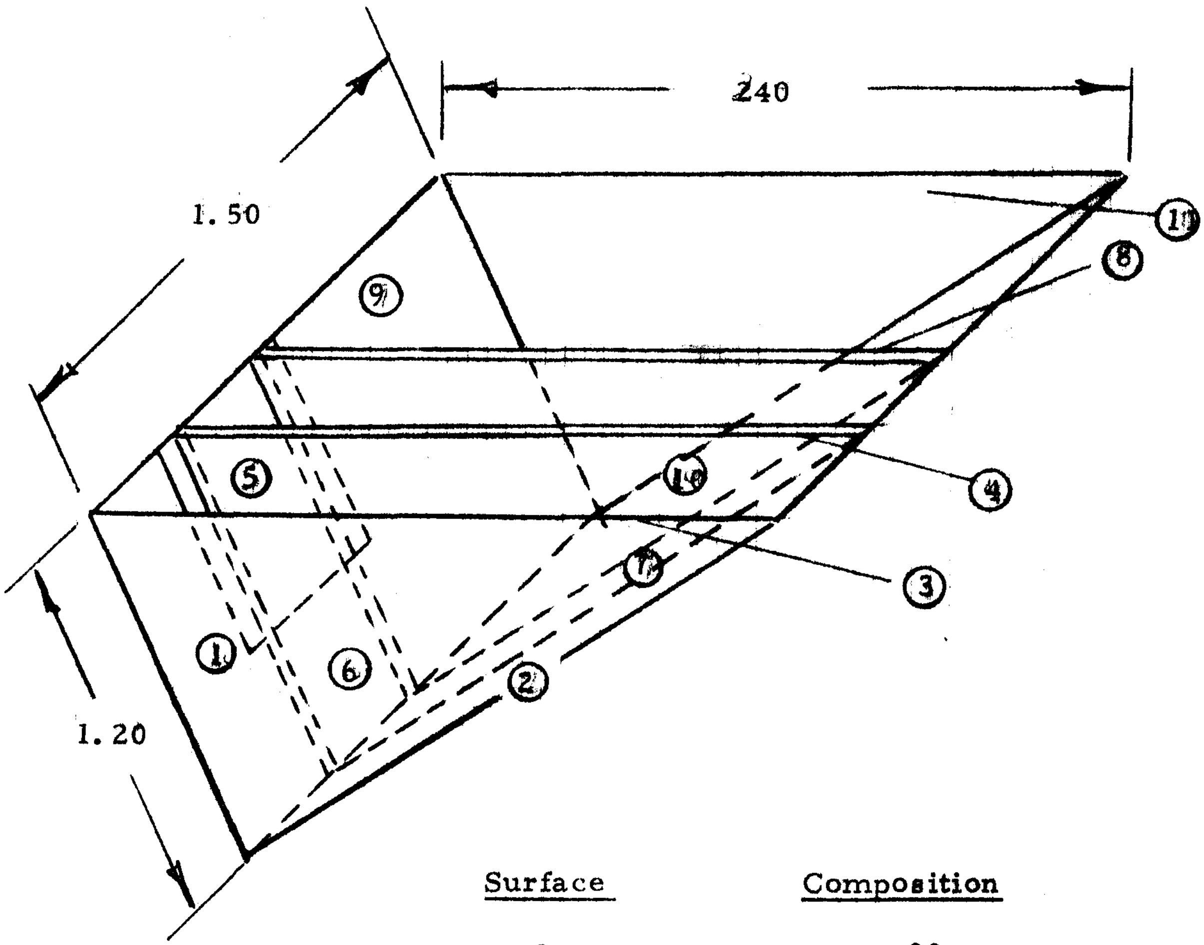


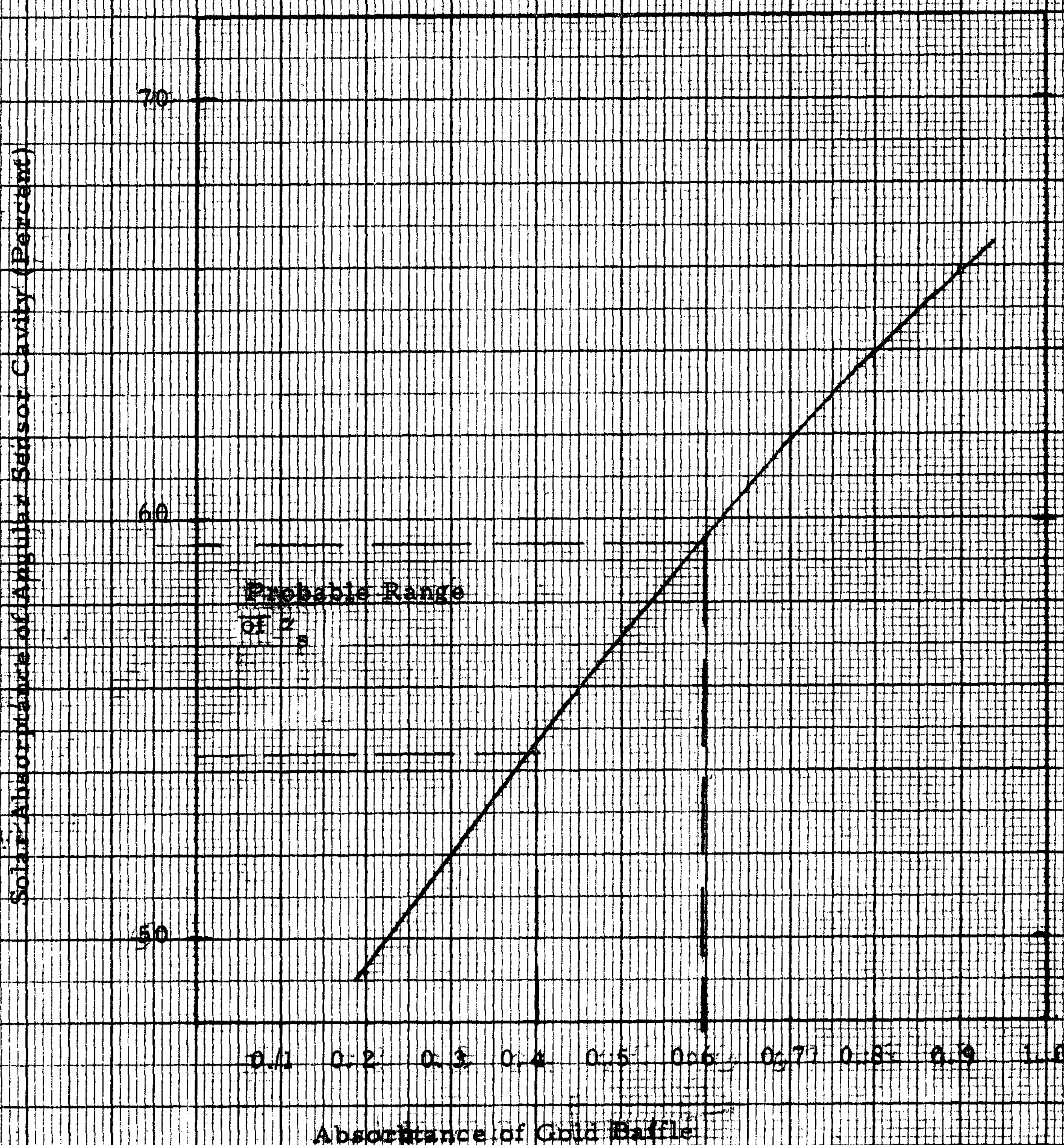
Figure 4-2. Lunar Surface Temperature vs Sun Angle and Latitude

Nodal Model of Angular Sensor Cavity



Surface	Composition
1	z-93
2	z-93
3	z-93
4	Unpolished Gold
5	Analyzer Opening
6	z-93
7	Unpolished Gold
8	Unpolished Gold
9	z-93
10	z-93
11	z-93

Figure 4-3



Equivalent Solar Absorptance of Angular Sensor Cavity vs.
Solar Absorptance of Gold Plated Baffle (Lunar Noon)

Figure 4-4

Sketch of Section of Fiberglass Case

Which was Nodalized for Radiator Plate

to Case Heat Leak Analysis

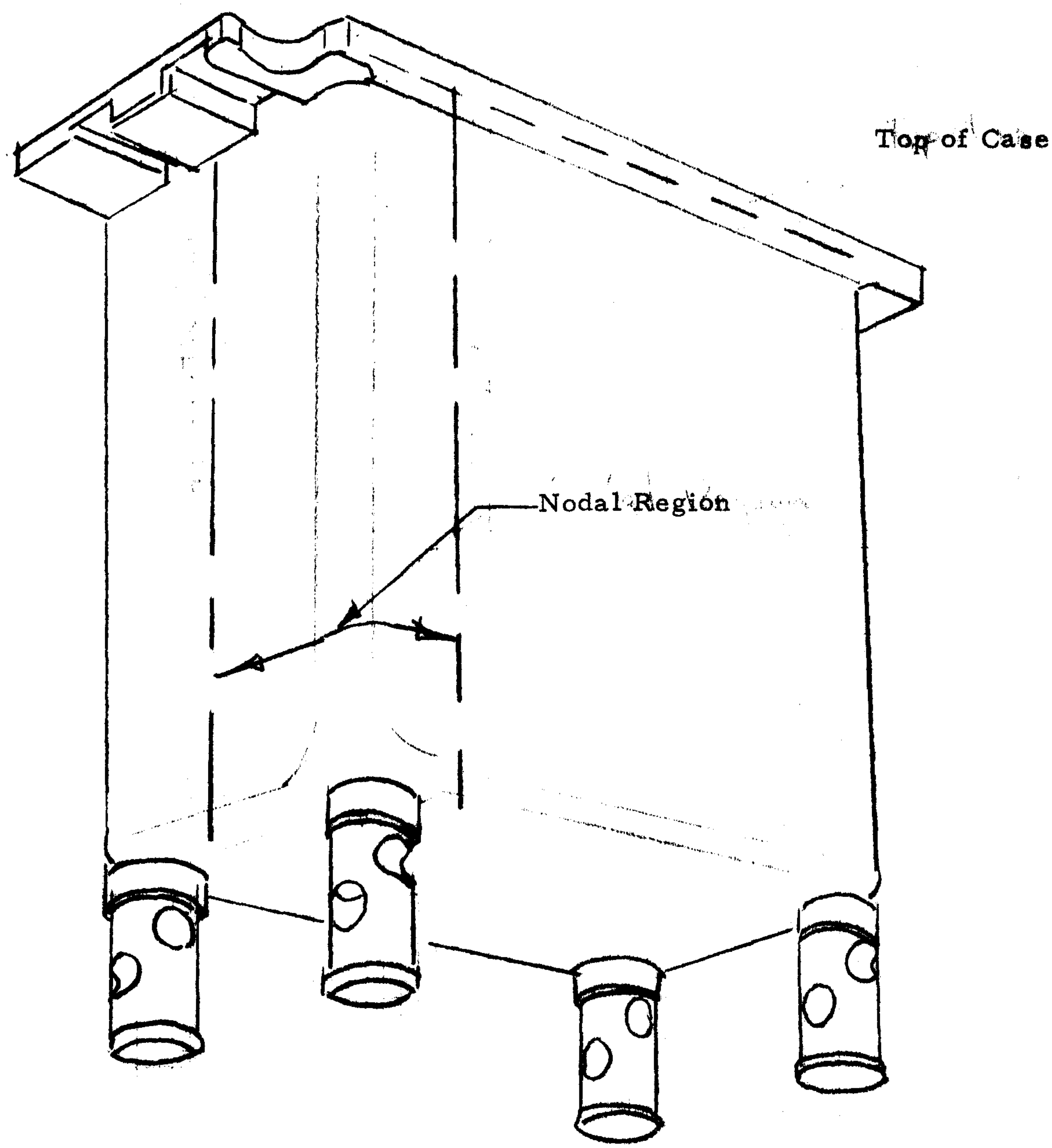


Figure 4-5

Nodal Model of Fiberglass Case Heat Leak Study

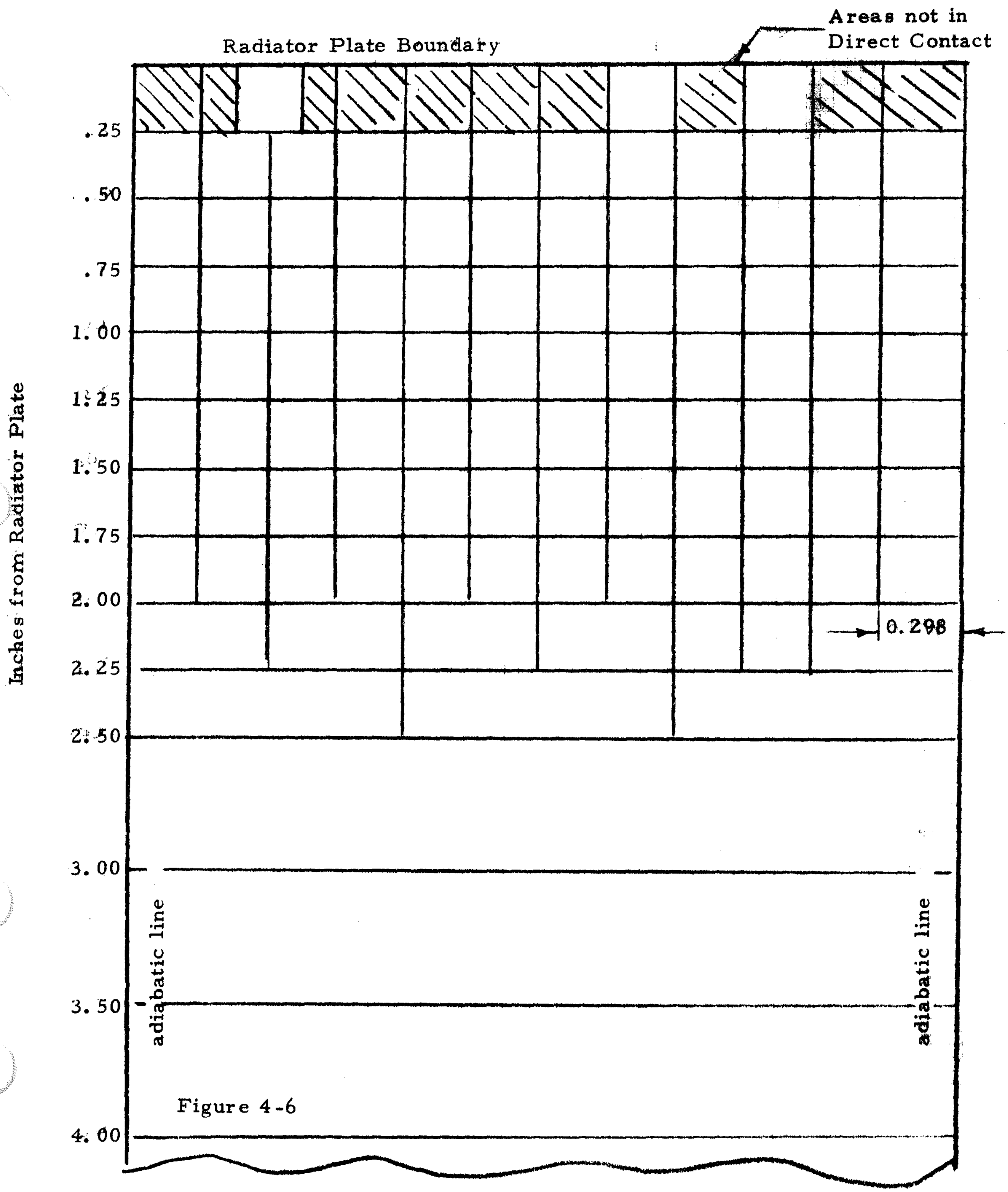
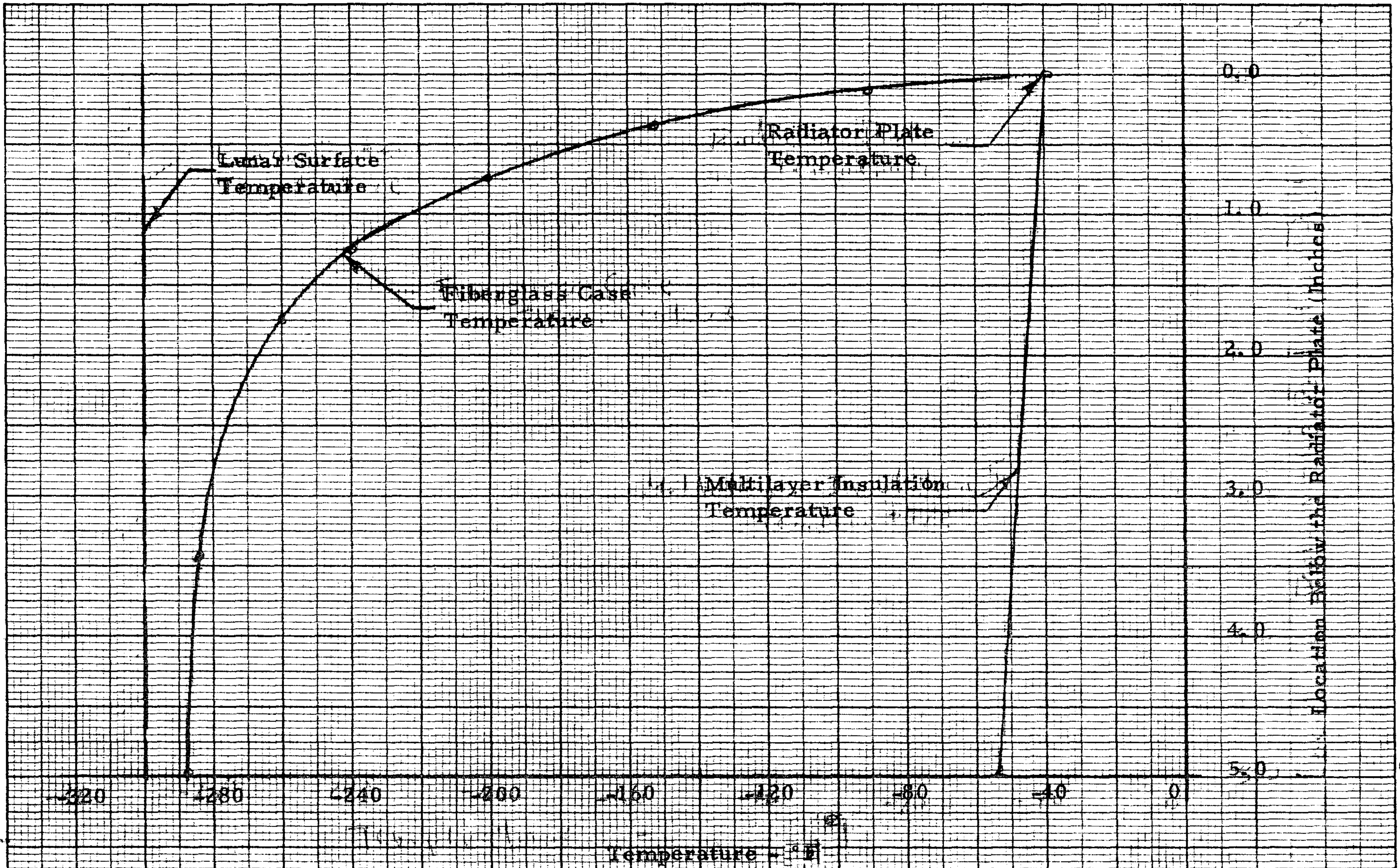
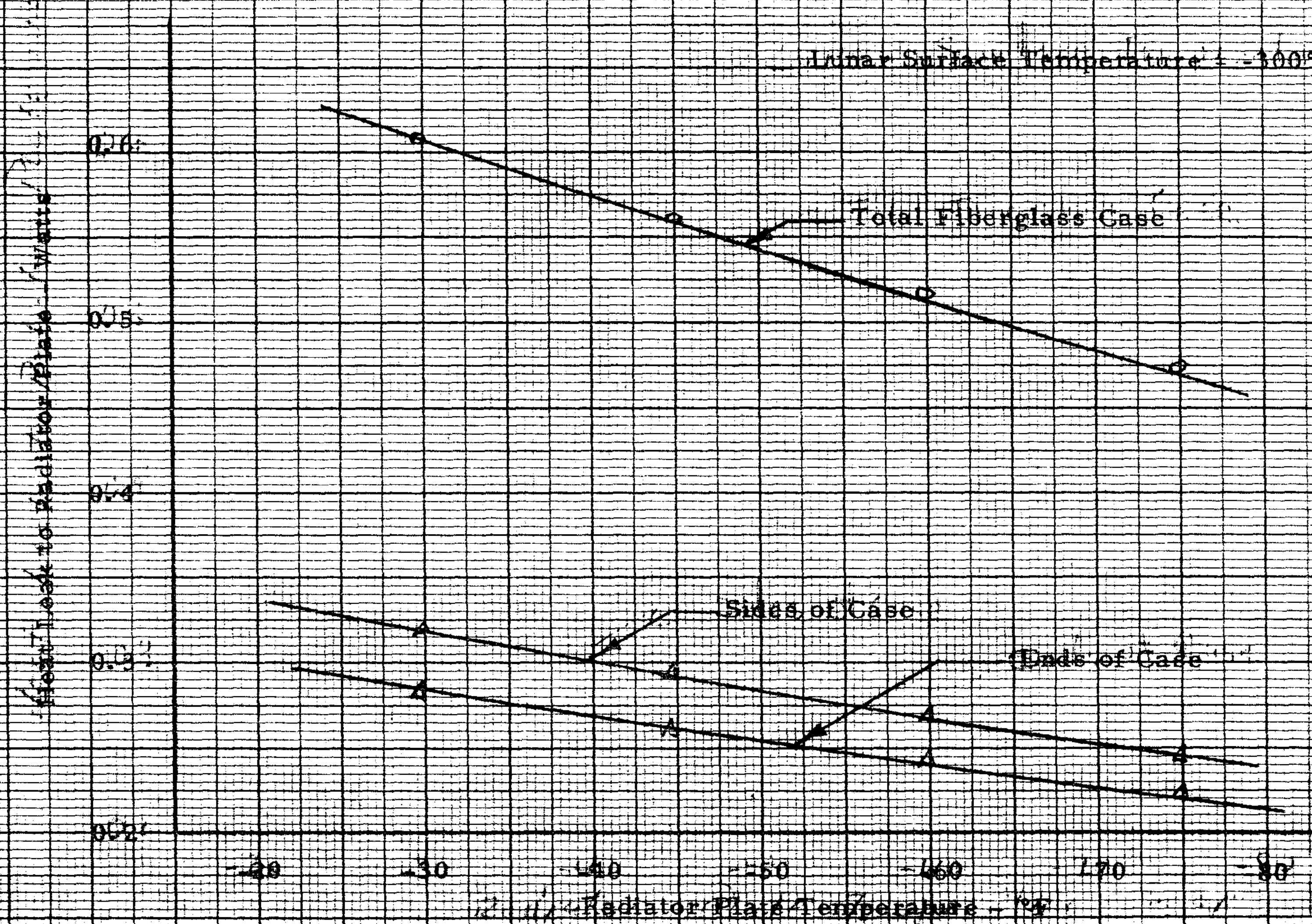


Figure 4-6



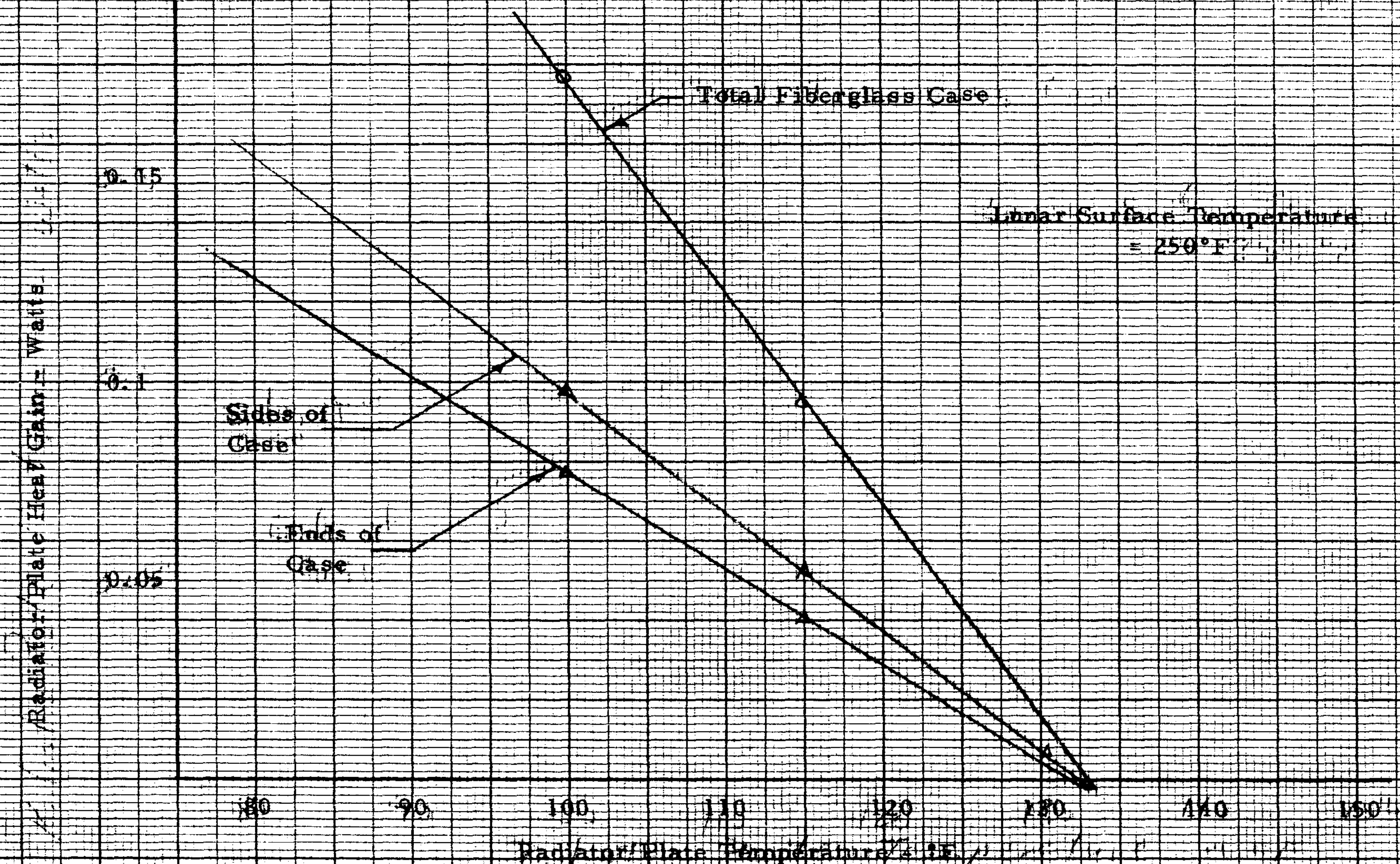
Temperature of Fiberglass Case and Multilayer Insulation at Points Below the Radiator Plate

Figure 4-7



The Effect of Radiator Plate Temperature On Heat Leak Through the Fiberglass Case at Lunar Night

Figure 4-8



The Effect of Radiator Plate Temperature On
Heat Gain Through the Fiberglass Case at Lunar Noon

Figure 4-9

5.0 DESIGN CONSIDERATIONS

5.1 CPLEE Design Concept

The purpose of the CPLEE thermal control system is to protect the electronic components of the CPLEE from the severe lunar environment and includes the lunar surface which varies from 250°F at lunar noon to -300°F at lunar night and deep space temperature of -459.0°F.

The design concept is to encase the entire electronics in a thermally insulated bag of multilayer insulation to protect the electronics from the direct effects of the lunar surface temperature variations of 250°F to -300°F then dissipate the power of the electronics through a thermally coated radiator plate which is highly reflective to solar energy and posses a high infrared emittance to dissipate the internal power of the electronics. Electric heaters are used to maintain the electronics temperature above the lower operating temperature limit during lunar night operation.

5.2 Radiator Plate Design

The critical design criteria from the standpoint of thermal design was the requirement that the radiator plate temperature conform to the specification maximum operating temperature range (-50°F to 150°F).

Z-93 thermal coating was chosen as the radiator plate coating because of its low solar absorptance ($\alpha = 0.156$). The low absorptance would tend to limit the maximum lunar noon operating temperature.

Because Z-93 has a high infrared emittance ($\alpha = 0.926$), coating the entire plate would result in lunar night temperatures which would exceed the lower operating temperature limit. To limit the lower operating temperature a composite plate consisting of Z-93 thermal coating and a coating of good insulating properties was considered. Multilayer insulation and polished gold were candidates. The results of these design studies are plotted in Figures 5.1, 5.2, 5.3.

Multilayer insulation from a thermal standpoint was the better method of reducing the solar absorptance (See Figure 5.1); however, there were certain mechanical design problems involved which ruled out its use. The requirement that CPLEE be mounted with the radiator plate face down on the ALSEP pallet required that the radiator plate - pallet interface be interference free. Multilayer being a flexible sheet might have caused complication with the interface. The required insulating stripe is only 1 1/2 inches in width. Multilayer insulation in narrow strips presents problems with edge conditions. Finally, a view of the sensors to the charged particles requires a clean and flat radiator plate surface. The multilayer insulation may have presented a problem with this requirement also.

Gold appeared to be the best choice. An area of 8.8 square inches resulted in an operating range of -47°F to 139°F with DVT power input conditions and these were in the operating limit range. (See Figures 5.2 and 5.3).

5.3 Support Leg Redesign

Prior to the Design Verification Test (DVT), CPLEE was supported on three adjustable legs which were attached directly to the radiator plate. Measurements of temperature differences across the leg socket assemblies indicated these legs to be a prime source of heat leakage.

The fiberglass legs and metal leg socket assemblies provided a radiation view from both the lunar surface and the sun. The legs themselves provided little of the heat input because of the low conductivity of fiberglass; however, tested temperature differences across the highly conductive leg sockets warranted removal of the leg in subsequent models of the CPLEE.

This problem was solved by moving the supporting legs to the bottom of the fiberglass case to increase the conduction path and then reduce the heat losses.

5.4 Test Cable and Squib Wire Heat Leak

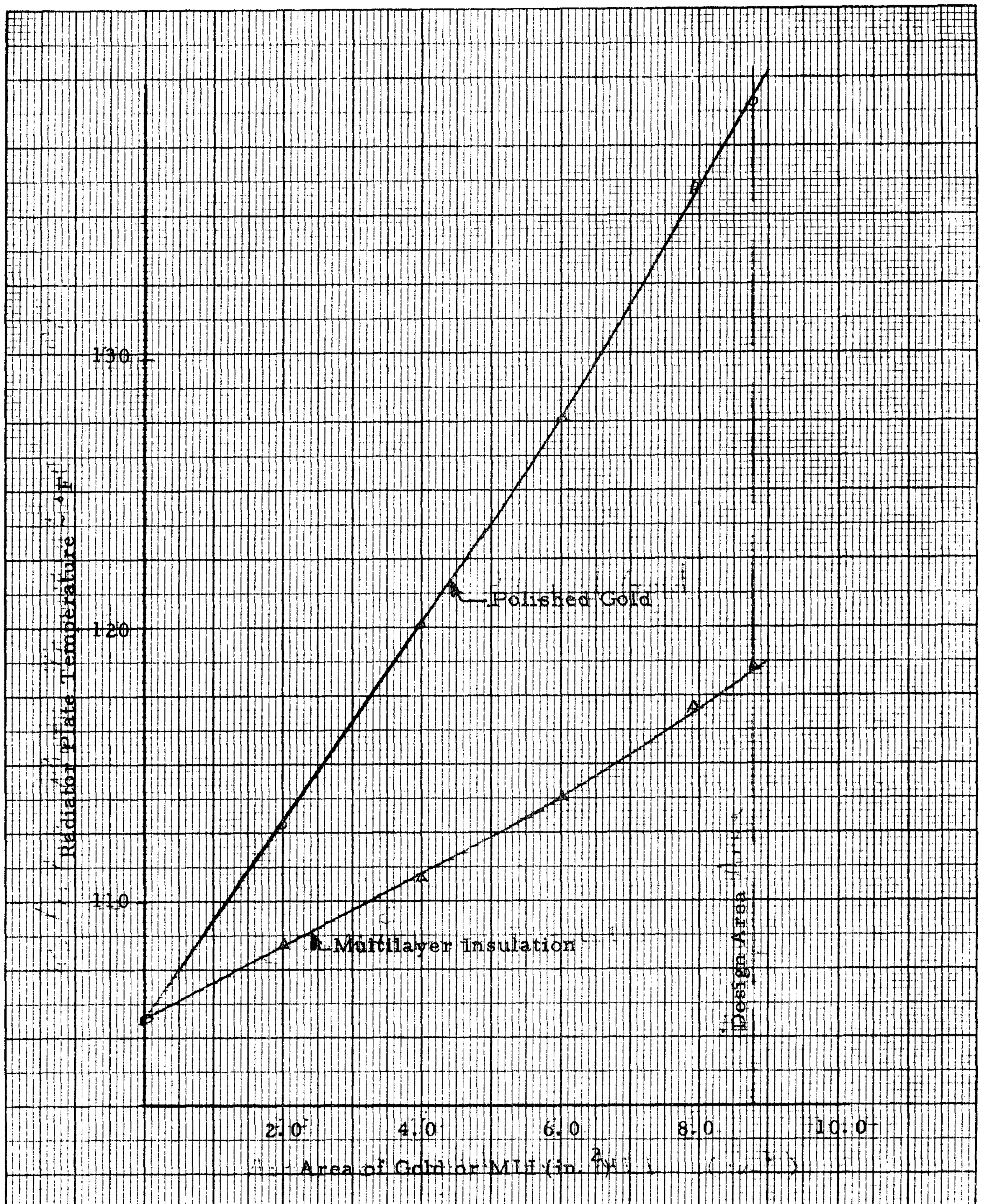
In the process of investigating for major sources of heat leak which occurred during the DVT test, an investigation of the heat leakage to the thermal plate through the test cables and squib wire was undertaken. The results of the study are tabulated in Table 5.1.

The heat leak from the wire leads to the plate originates from two sources. Conduction directly from the wire lead mounting bracket, and radiation from space and the lunar surface to the wires and conduction to the plate. Calculation determined a 3.9°F contribution to the plate temperature for both modes of heat transfer. The recommendation was to add a manganin insert to the wires and wrap the wires in reflective tape.

TABLE 5-1

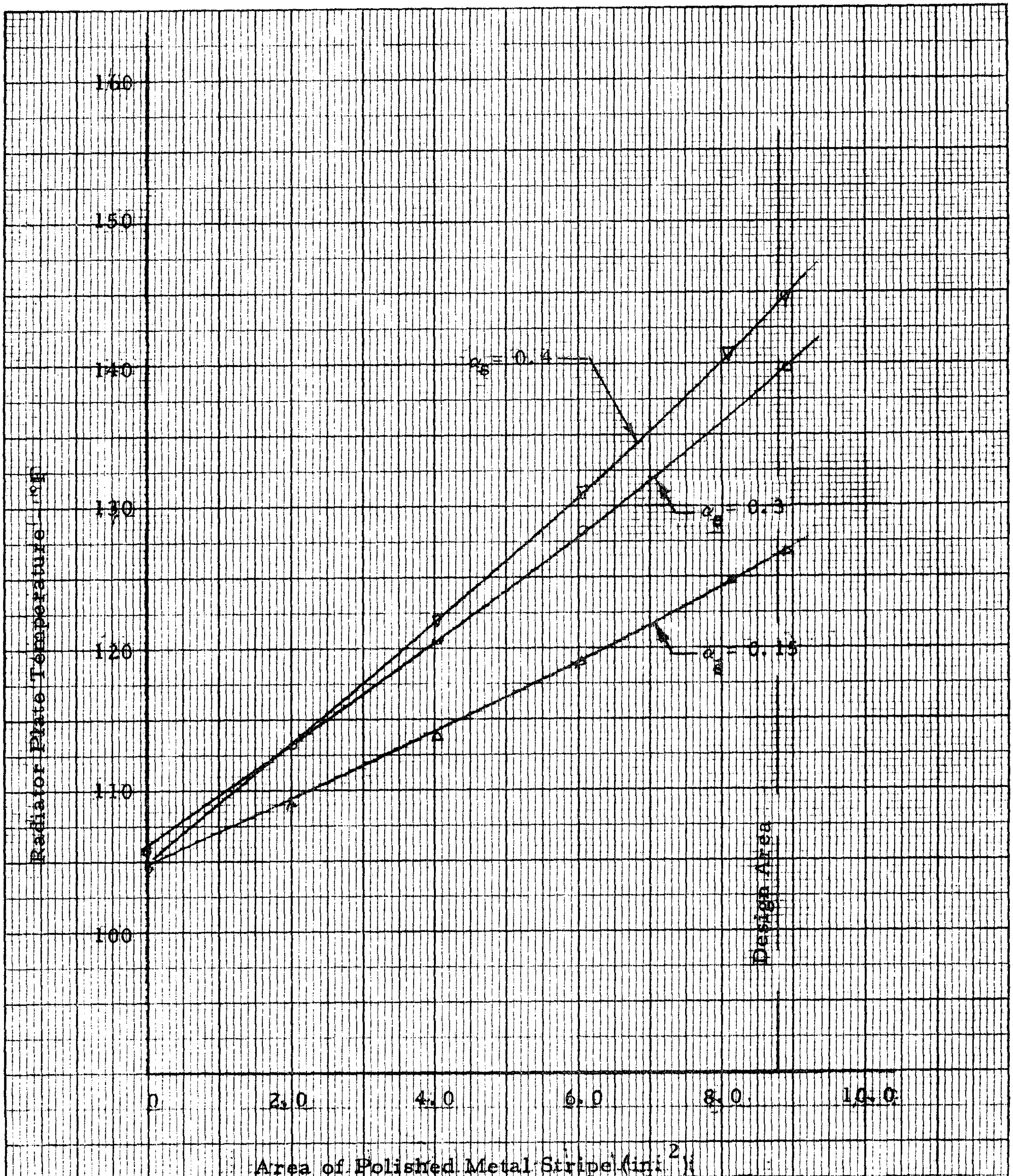
EFFECTS OF TEST CABLE WIRES AND SQUIB WIRES ON THERMAL PLATE TEMPERATURE DURING LUNAR NIGHT OPERATION

	Thermal Plate Temperature (°F)	Total Heat Loss Through Wires (watts)
Heat Leak Through Wires Minimized by use of Manganin wires	-34.1	0
Heat Leak Through Wires is by Pure Conduction to Mounting Bracket Assembly; Radiation from Wires Neglected	-37.9	0.16
Heat Leak Through Wires is by Pure Radiation from Wires; Conduction to Mounting Bracket Neglected	-38.0	0.16
Heat Leak Through Wires is by Both Radiation and Conduction	-41.8	0.31
Wires Wrapped with Reflective Tape (ϵ , = 0.1); Heat Transfer is by Pure Radiation Only	-35.3	0.04



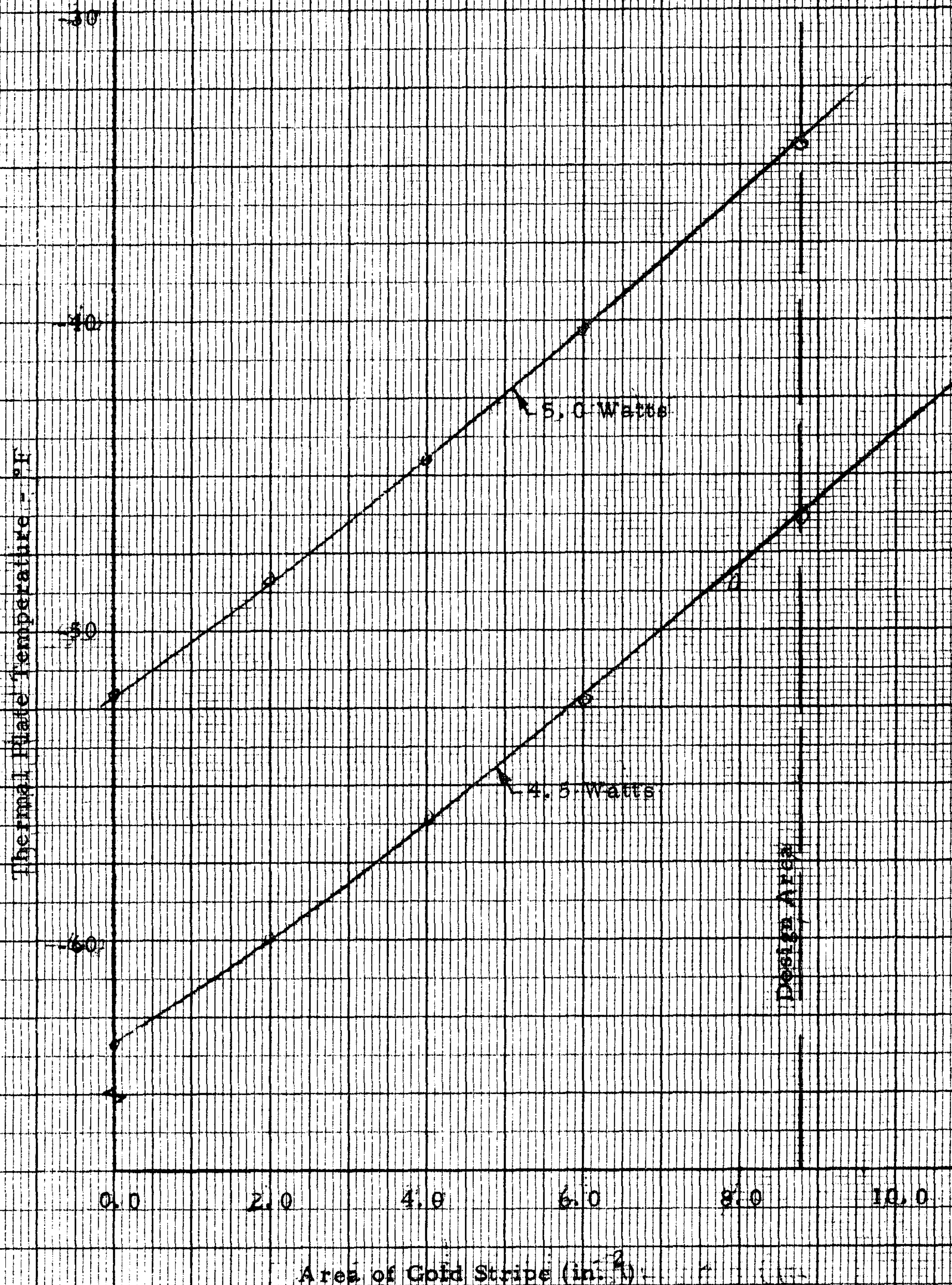
Effect of Varying the Surface Area of a Gold Stripe or a Multilayer Stripe on the Radiator Plate Temperature

Figure 5-1



The Effect of the Polished Metal Stripe Area
On Radiator Plate Temperatures for Various
Solar Absorptances

Figure 5-2



The Effect of Increasing the Gold Stripe Area
On the Radiator Plate Temperature

Figure 5-3

10 X 10 TO 1/2 INCH 46 1323
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

6.0 CPLEE LUNAR SURFACE PREDICTION

6.1 Analytical Results

6.1.1 Off Equator Deployment with no Dust Coverage Lunar Noon - (Figures 6.1 and 6.2)

The radiator plate and electronics temperatures were calculated for the maximum and minimum electronics input power experienced in flight hardware acceptance tests (See Table 6.1).

With 3.0 watts electronic power dissipation, the electronics temperature at the equator is 135.7°F. The electronics exceed the operation maximum temperature limit between 34 degrees and 60 degrees latitude. The maximum survival temperature limit is exceeded between 37 and 57 degrees latitude. The maximum electronics temperature is attained when CPLEE is deployed at 45 degrees latitude. The temperature at this point is 168.8°F.

The radiator plate temperature at the equator with 3.0 watts power dissipation is 119.9°F. The plate exceeds the operation maximum temperature limit between 38 and 55 degrees latitude. The plate never exceeds the survival limit temperature. The maximum radiator plate temperature occurs at 45 degrees latitude deployment. This temperature is 154.5°F.

CPLEE will operate within the specification operating temperature limit from zero to 34 degrees latitude and beyond 60 degrees latitude. Any operation between 34 and 60 degrees latitude would result in the CPLEE electronics exceeding the 155°F specification operating temperature limit.

6.1.2 Dust Effects of Off Latitude and Equator Deployment - Lunar Noon - (Figures 6.1 and 6.2)

Studies were made of 50 and 100 percent dust coverage at various latitudes. Figures 6.1 and 6.2 indicate relatively flat temperature profiles over the entire deployment latitude range.

CPLEE with a 50 percent dust coverage maintains a maximum radiator plate temperature of 199.5°F at 45 degrees deployment and an electronics maximum temperature of 212.4°F at 45 degrees deployment latitude.

A CPLEE with 100 percent dust coverage has a maximum radiator plate temperature of 232.0°F at 30 degrees latitude deployment and an electronics maximum temperature of 245.0°F at 30 degrees deployment.

The effect of dust coverage at an equatorial deployment was considered for dust coverage of 0 to 100 percent coverage (See Figure 6.3). CPLEE electronics reach their maximum operating temperature limit at 13 percent dust coverage and their maximum survival temperature limit at 15 percent dust coverage for an equatorial deployment. The radiator plate reaches the operating maximum temperature limit at 17 percent coverage and the survival temperature limit at 23 percent dust coverage.

These dust studies would seem to indicate any dust coverage greater than 13 percent would exceed the maximum operating temperature of the CPLEE electronics regardless of the deployment latitude.

6.1.3 CPLEE Lunar Night Prediction - (Figure 6.4)

CPLEE has available 3.5 watts of operation mode heater power and 4.5 watts of standby mode heater power.

Studies were made of CPLEE electronics and radiator plate temperatures as a function of total electronics and heat input power. Standby mode will require 4.3 watts of heater power to maintain the -60°F minimum survival specification temperature. Since CPLEE electronics dissipates 3.0 watts of power an additional 1.66 watts of operational heater power is required to meet the minimum specification operating temperature of -50°F.

The total power input of CPLEE flight models is approximately 5.75 watts (See Table 4.6). At this power input the CPLEE radiator plate will operate at -25°F and the electronics will operate at 0°F.

6.2 Discussion of Off-Latitude Curve Trends at Lunar Noon

There are three factors which influence the curve trends in Figures 6.3 and 6.2

1. The effect of increasing radiator plate view to lunar surface and decreasing the radiator plate view to space with increasing deployment latitude.

2. The effect of decreasing lunar surface temperature with increasing deployment latitude.

3. The effect of increase in solar heat absorbed as a result of increase in surface emittance and absorptance from increased dust coverage.

All the curves in Figures 6.1 and 6.2 exhibit the same general trend. The curves increase from zero to 45 degrees deployment latitude and then decrease. This trend results for two reasons. First, the Z-93 coating and the gold stripe surfaces are absorbing increasing amounts of heat radiating from the lunar surface. Second, components and surfaces not affected by orienting the radiator toward the sun are absorbing heat from the lunar surface which is considerably warmer than the plate for small latitude angles. (See Figure 4.2.) At 45 degrees latitude the curve reaches a maximum and decreases rapidly. This results when the lunar surface temperature has decreased to the point where components not affected by increasing view to the lunar surface began to lose more heat to the cool lunar surface than the thermal plate is gaining by its increasing view of the lunar surface.

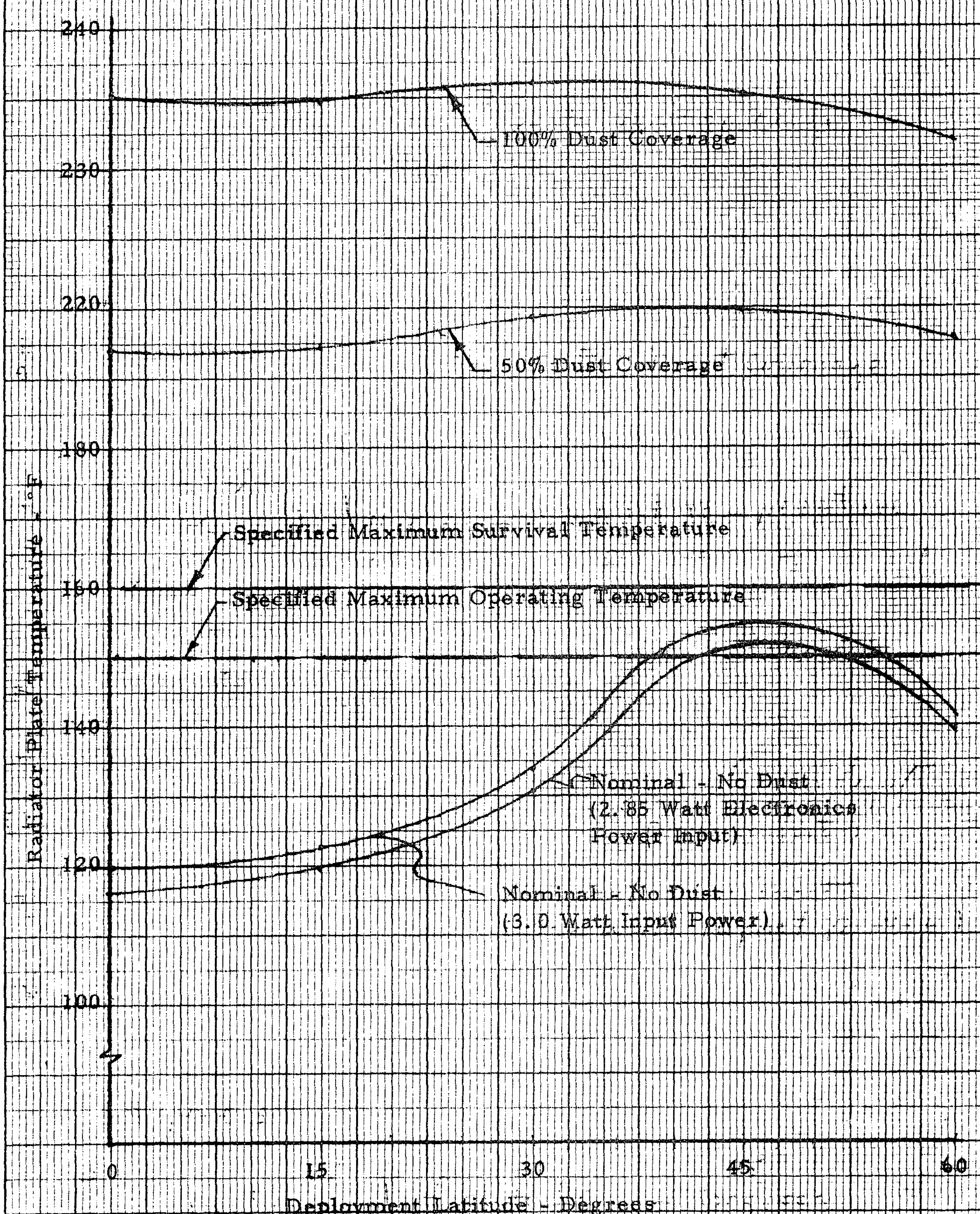
As the dust coverage increases the plate temperature increases. The solar absorptance of dust is 0.9. As more area of CPLEE is covered by the highly absorbing dust, the resulting temperature of the radiator plate increases.

The temperature versus latitude deployment curve exhibits a less pronounced maximum as the dust coverage increases. The cause of this maximum at low dust coverage is the result of the variation in radiation exchange between the lunar surface and the CPLEE with deployment latitude change. This is the only factor since the CPLEE radiator plate always faces the sun and absorbs a constant solar flux with deployment latitude change. As the dust coverage becomes greater, the heat absorbed directly from the sun becomes considerably more significant than the heat absorbed from the lunar surface, and the curve approaches a constant value.

TABLE 6.1

CPLEE Thermal Plate and Electronics Temperatures
With Increasing Latitude Deployment and Dust Coverage in Degrees F

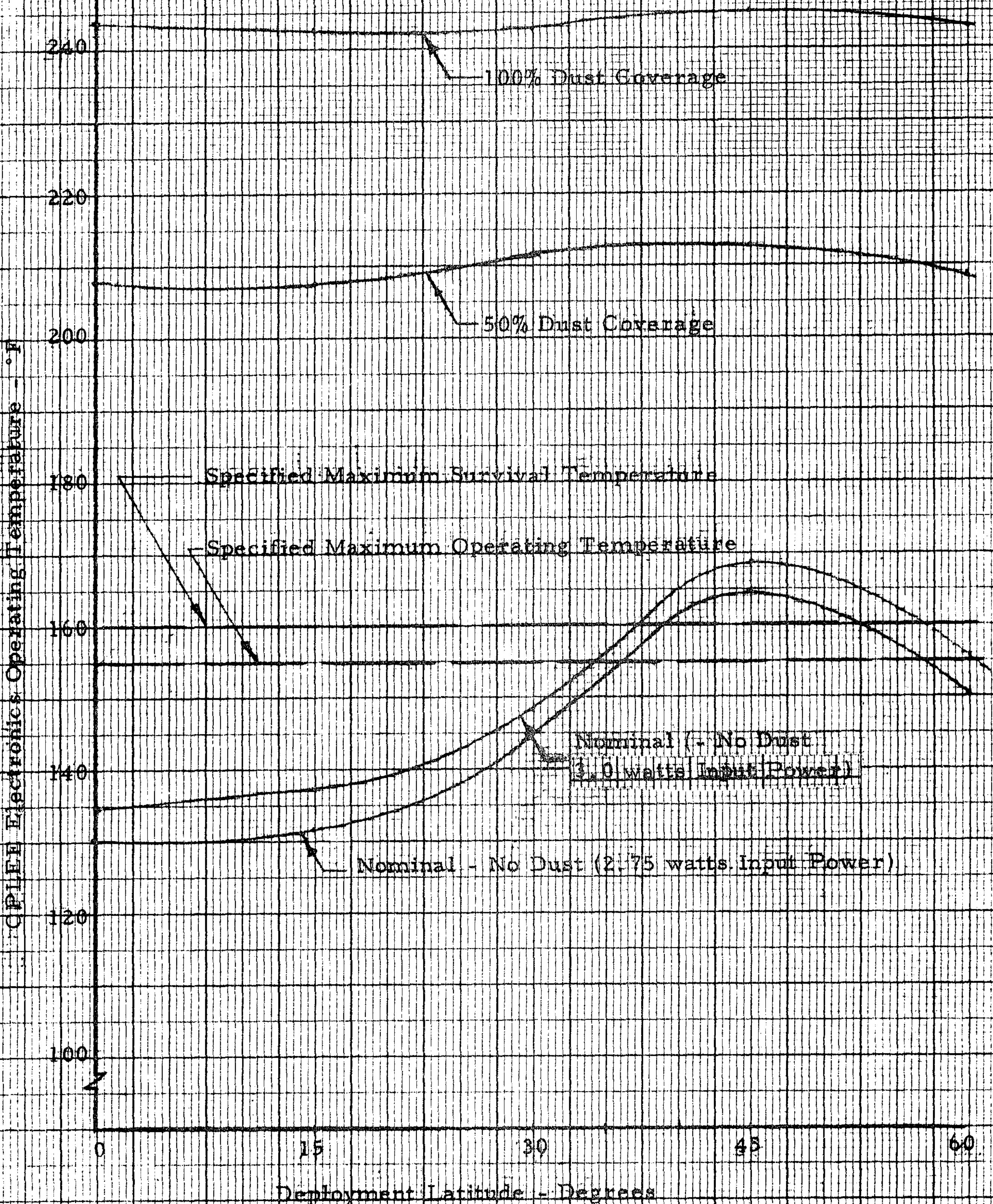
Condition	% Dust Coverage	Landing Site Latitude Degrees				
		0	15	30	45	60
Radiator Plate (3.00 Watts)	0	119.9	122.9	133.7	154.5	141.8
Electronics (3.00 Watts)	0	134.7	137.6	148.3	168.8	155.8
Radiator Plate (2.85 Watts)	0	116.9	119.9	130.9	151.8	139.3
Electronics (2.85 Watts)	0	130.2	133.2	144.0	164.7	152.0
Radiator Plate	50	194.1	194.1	198.3	199.5	195.5
Electronics	50	207.4	207.4	211.5	212.4	208.2
Radiator Plate	100	230.5	229.3	232.0	230.1	223.8
Electronics	100	243.6	242.4	245.0	242.9	236.3



CPLEE Radiator Plate Temperature as a Function of Deployment Latitude and Dust Coverage at Lunar Noon

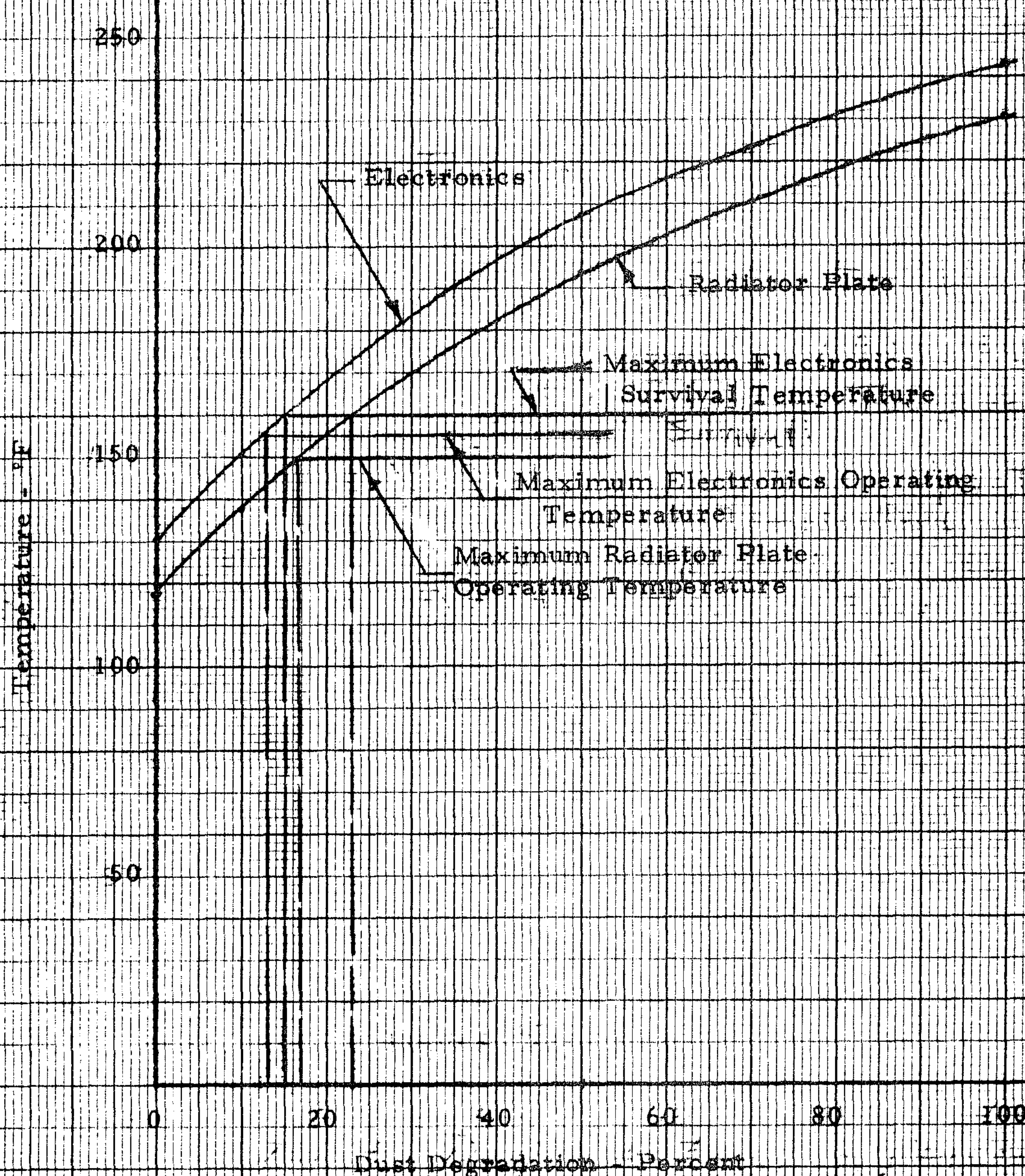
Figure 6-1

10 X 10 TO ½ INCH 46 1323
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



CPLEE Electronics Temperature as a Function of Deployment Latitude and Dust Coverage at Lunar Noon

Figure 6-2



Radiator Plate and Electronics Temperature as a Function of Dust Degradation for Zero Degrees Latitude Deployment

Figure 6-5

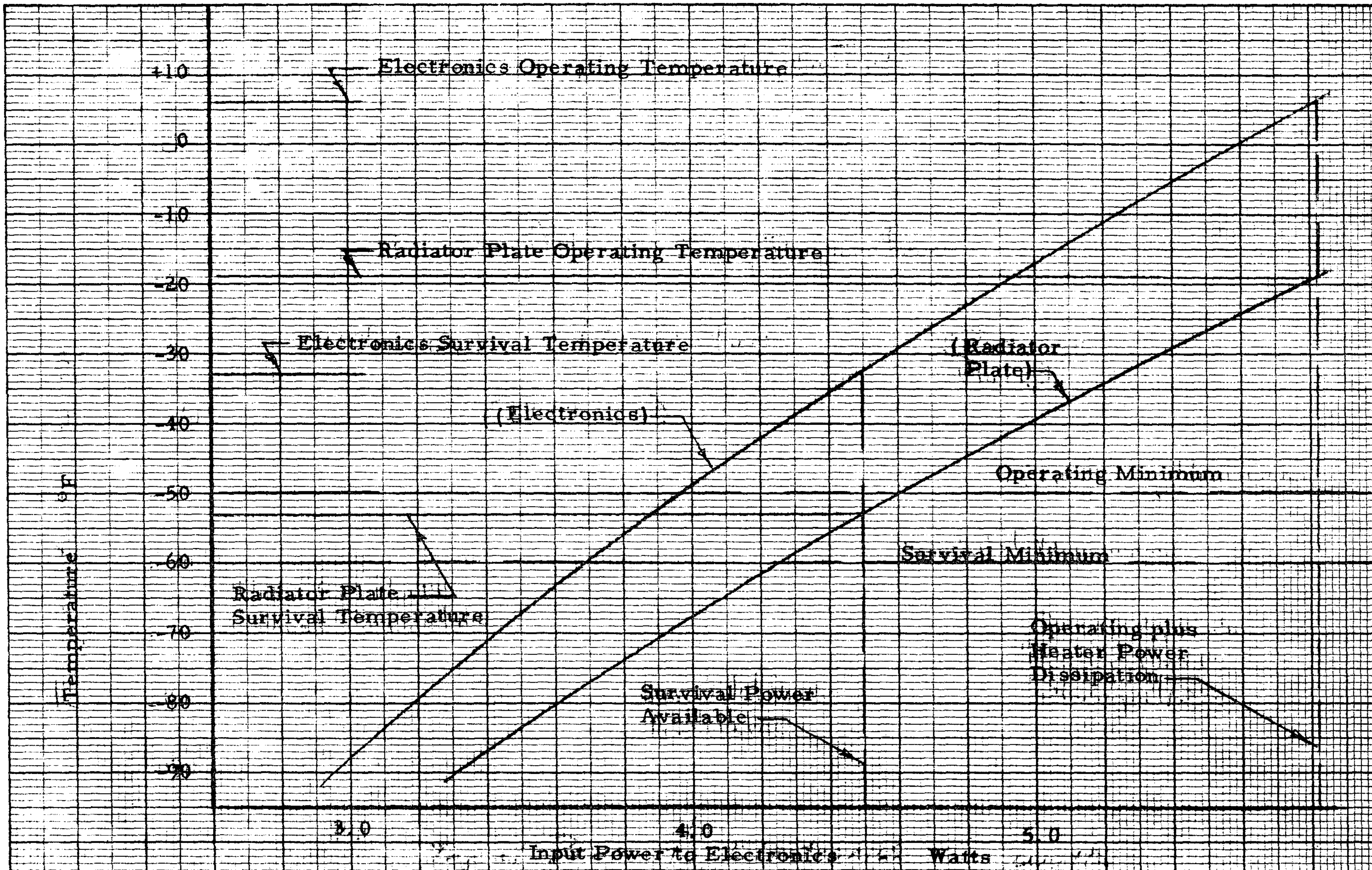


Figure 6-4 Effect of Input Power to CPLEE Electronics on the Radiator Plate and Electronics Temperatures at Lunar Night

7.0 CPLEE TESTING PROGRAM

The thermal performance of CPLEE has been tested in three basic tests.

1. DVT (Design Verification Test) is carried out to verify that the CPLEE thermal control design performs as predicted.

2. Qual SB integrated CPLEE with the entire array of ALSEP experiments. This test verified the CPLEE system at qualification test levels within the ALSEP system.

3. Flight Acceptance Test integrates CPLEE with flight hardware at nominal acceptance test level for each flight system.

7.1 Design Verification Test

7.1.1 Model Configuration

The CPLEE model used for the DVT had two major differences from final CPLEE Acceptance configurations. First, the original CPLEE was supported on three expandable legs which were mounted directly to the CPLEE radiator plate via ball and socket joints. Second, aluminized Mylar tape was applied to the top of the thermal plate to simulate the polished gold stripe which is part of the Qual/Flight models. (See Figure 7.2)

7.1.2 Test Background

The CPLEE DVT model thermal vacuum tests were performed during the period of 9 October 1967 through 13 October 1967 at the Manned Spacecraft Center, Houston, Texas. The tests were directed by BSR and BRLD personnel and were supported by MSC technical personnel.

7.1.3 Test Conditions

The CPLEE DVT model was tested under seven different thermal test conditions. These conditions, summarized in Table 7.1, simulated various phases of the lunar cycle and various modes of experiment operation.

7.1.4 Lunar Surface Simulation

The lunar surface was simulated by a metal plate (34×30 in^2) with 8 inch vertical sides. The simulated lunar surface was mounted vertically in the chamber so that the DVT model was in a proper orientation with the lunar surface. The lunar surface was coated with black paint and was heated by infrared lamps directed toward areas not viewed by the experiment. Different sun angles were achieved by rotating the lunar surface with respect to the incident solar beam. Figure 7.1 gives a layout of the test installation.

7.1.5 Vacuum Chamber

The cold vacuum of space was simulated by a chamber approximately 8.5 feet in diameter. A vacuum of between 10^{-6} and 10^{-8} torr was maintained. The walls of the chamber were painted black to simulate the emissivity of space and liquid nitrogen was circulated in them to maintain a -300°F simulation of the temperature of space.

7.1.6 Solar Simulation

Solar simulation was achieved by using a carbon arc lamp. Since the carbon arc lamp is the best available approximation to the frequency distribution of the sun's radiation, no attempt was made to adjust the intensity of the lamp to compensate for differences between the carbon arc and solar spectrums. The lamp was adjusted until the total intensity of radiation incident on a radiometer mounted inside the chamber measured 130 watts/ft^2 or 1 sun.

7.1.7 CPLEE Mounting

The lunar plane was mounted vertically in the chamber. The DVT model had to be secured to the lunar surface by 10 mil stainless steel wires. A teflon knob was inserted into each leg tube and then bolted to the lunar surface to prevent shifting. Figure 7.1 gives a schematic of the method used to attach the experiment.

7.1.8 Thermocouples and Thermistors

Fifteen thermocouples were used to measure temperature. The thermocouples were grouped in pairs at geometrically similar locations to provide redundancy in case of thermocouple failure. Four thermistors were used to measure electronics temperatures. Location descriptions and final temperature readings are listed in Table 7.2 for each test.

7.1.9 DVT Test Result Correlation With Analytical Studies

Table 7.3 gives corresponding experimental and analytical temperatures. The correlation between the analytical and experimental temperatures is reasonably good.

7.1.10 Lunar Night Tests

The correlation between predicted and measured thermal plate temperatures is reasonably good for lunar night tests. The calculated temperatures were warmer than the experimental ones by 8°F and 6°F for lunar night operation and lunar night survival respectively. There were three probable reasons for this.

1. Emittance degradation on the polished surfaces of the thermal plate.

2. Heat leak through the support wires and thermocouple and thermistor leads.

3. Heat leak through the legs, outer cover, insulation, and cable greater than that predicted by theory.

It is improbable that the emittance of the aluminum tape and/or polished gold could degrade beyond $\epsilon = 0.1$. This amount of degradation would affect the thermal plate temperature less than 1°F.

The amount of heat loss through the thermistor and thermocouple leads and through the support wires can be estimated by assuming them to be one-dimensional, conducting radiating fins. These calculations yield a combined heat leak through these leads and wires to agree with the required amounts needed to explain the discrepancies between analysis and experiment.

There was no evidence to warrant re-evaluation of the predicted heat losses through the legs and cables.

7.1.11 Lunar Noon Operation Tests

In Table 7.3, the largest differences between analysis and experiment occur for the lunar noon test. The lunar noon operation test yielded a thermal plate temperature 15°F warmer than that predicted by analysis. Additional heating could have been brought about in four ways:

1. Heat input through the support wires and thermocouple leads.
2. Heat input through the outer cover, legs, and cables above that predicted by theory.
3. Incorrect calibration of the carbon arc lamps.
4. Increased solar absorptance because of degraded solar absorptance of the thermal plate.

The heat gains through the support wires and thermocouple leads were calculated. The resulting calculations yield a value of 0.53 watts for these combined heat gains. This value alone is not enough to account for the differences between the theoretical and experimental thermal plate temperature.

Of the legs, cable, outer cover, and insulation, the only possible sources of heat gain above that predicted were the legs. The legs were spread to a maximum angle of 40° instead of the 20° assumed in the calculations.

The carbon arc lamp is the best available approximation to the frequency distribution of the suns radiation and is an unlikely candidate.

A visual inspection of the aluminized tape indicated that it had become dull and had formed small wrinkles during application.

The probable cause of the difference between predicted and measured thermal plate temperatures at lunar noon were degradation of solar absorbtances on the thermal plate, conduction through the support wires and thermocouple leads, and the legs because of large deployment angles.

7.2 Qual SB Test

The CPLEE model tested during Qual SB was similar to the original model designed and tested during the DVT with the exception that the legs supporting the CPLEE structure had been removed from the radiator plate and placed on the fiberglass case bottom. (See Figure 7.4)

7.2.1 Test Background

The Qual "SB" Thermal Vacuum tests were performed during the period of 11 December 1968 to 14 December 1968 at the Bendix Aerospace Systems Division.

7.2.2 Test Conditions

The Qual "SB" test consisted of two test conditions summarized in Table 7.4.

7.2.3 Lunar Surface Simulation

The lunar surface was simulated by the 14 x 14 ft sq metal floor with 6 inch high vertical lips of the Bendix Thermal Vacuum Testing Chamber. The floor surface is coated with black paint and heated with electric heaters.

View factors of the CPLEE to the simulated lunar surface will vary somewhat from those view factors actually experienced on the lunar surface. This is a result of the finite dimensions of the chamber lunar surface simulation (14 x 14 ft sq). The resulting view factors are summarized along with percentage differences from the actual lunar surface in Table 7.6. Figure 7.7 indicates the location of CPLEE and dimensions of the chamber surface. The differences in view factors were not considered significant enough to have an effect on the radiator plate or electronics temperatures.

7.2.4 Vacuum Chamber

The vacuum of space is simulated in the 20 by 27 ft space chamber. A vacuum of less than 10^{-6} torr can be maintained. The walls of the chamber are painted black to simulate the emissivity of space and liquid nitrogen is circulated in them to maintain a -300°F temperature which is a reasonable approximation to the effective temperature of deep space.

7.2.5 Solar Simulation

Solar simulation is achieved by using Tubular Quartz Infrared Lamps. The infrared lamps emit the majority of their radiation at different wavelengths than that of the sun; therefore, a method of compensating for this difference was developed. A radiometer surface is coated with coatings in equal percentages to the coatings of the surface being tested. The infrared lamps are then adjusted until the radiometer indicates an absorbed heat flux equal to that anticipated on the lunar surface. An attempt was made to adjust the infrared lamps to 162.5 watts/ft^2 or 1.25 suns.

7.2.6 Thermocouple Locations

Five thermocouples were used to measure temperature. These locations are indicated in Figure 7.6. Table 7.5 lists the thermocouple locations and their maximum or minimum reading for each test.

7.2.7 Correlation of Test and Analytical Data

Lunar night condition was found to correlate quite well with analysis. Lunar noon test radiator plate ran about 22°F cooler than analytical data indicated. There are perhaps three reasons for this discrepancy.

1. Simulated solar flux is less than than on the lunar surface

2. Assumed plate absorptances higher than actual

3. Plate emittance values higher than assumed.

7.2.8 Simulated Solar Flux

Calculations indicate that a simulated solar flux of 0.78 suns would result in a lunar noon test temperature of 122°F. Investigation of the absorptance of the radiometer used in the Qual "SB" and Flight Acceptance tests indicates the average radiometer absorptance was higher than the absorptance of the CPLEE radiator plate. The infrared lamps would be reduced in power to give the desired absorbed flux on the radiometer. This would account for the CPLEE test maintaining a 24°F colder plate temperature than it would experience in lunar service.

7.2.9 Plate Absorptances

The absorptances used for radiator plate coatings were actually measured values. This would rule out absorptances as a source of error unless degradation had taken place in the coatings prior to test and there is no evidence to support this.

7.2.10 Plate Coating Emittance Values

Calculations were made substituting the least conservative values thought possible for emittance values. This decreased the plate temperature by only 5°F. The emittance values assumed for the coating were obtained from testing the actual radiator plates used on flight models. These values should be accurate. A summary of test values and predicted values is tabulated in Table 7.5.

7.3.0 Flight Acceptance Tests - Flight 3, Flight 4 and Flight 4 Retest

7.3.1 Model Configuration

The CPLEE model used for the Flight 3 Acceptance Test was of the equator-deployment type similar to that used in the Qual "SB". The model used for the Flight 4 Acceptance Test is of the off-equator deployment type. This model allows two legs to fold outward orienting the CPLEE radiator plate toward the sun. The legs themselves have no effect on the critical CPLEE temperature; however, orienting CPLEE at an angle to the lunar surface does have an effect. This effect is considered in off equator deployment studies. (See Figure 7.8)

7.3.2 Testing Condition

All testing conditions for Flight Acceptance Tests are similar to the Qual "SB" Test and will not be discussed further. One exception is the use of nominal lunar surface temperatures (i.e., 250 instead of 280°F) and nominal solar flux (i.e., 130 watt/ft^2 instead of 162.5 watt/ft^2) which will be experienced on the lunar surface.

7.3.3 Physical Analyser Temperature

A thermistor is mounted to the physical analyser and monitored during each Flight Acceptance Test. The maximum and minimum values for each test condition are presented in Table 7.7.

7.3.4 Correlation of Test Results with Analytical Predictions

7.3.4.1 Lunar Noon

There is a 20°F discrepancy between analytical and test results for the lunar noon condition. Undersimulation of the solar flux incident on CPLEE occurred because of a higher absorptance value on the CPLEE radiometer as in the Qual SB Test.

7.3.4.2 Lunar Night

Lunar night calculations were made to include the effect of the RTG which is present during the Flight Acceptance Tests. Calculations have shown the temperature of the fiberglass case facing the RTG to be 230°F warmer than the unexposed side. This causes the temperature of the CPLEE radiator plate to increase by 7.6°F.

Configuration factors from CPLEE to the RTG were presented in reference 14. The positioning of the RTG and CPLEE on the chamber floor are indicated in Figure 7.7. Calculated configuration factors used in test correlation studies are listed in Table 7.8.

The Flight 3 lunar night plate temperature was 6.7 degrees warmer than the calculated value. The radiometer test data indicated 10 watt/sq ft of extraneous heat flux at lunar night. This would account for the increase in radiator plate temperature.

Test No.	Test Description	Solar Conditions	CPLEE Power Mode	Lunar Surface Temperature	Dust Cover Position
	Dust Cover On-Power Off	I = 130 watts/ft^2* Sun Angle = 45°	No Power	+200°F	On
2	Dust Cover On-Power On	I = 130 watts/ft^2 Sun Angle = 45°	Operating Power	+200°F	On
3	Lunar Morning Operation	I = 130 watts/ft^2 Sun Angle = 45°	Operating Power	+200°F	Off
4	Lunar Night Operation	No Sun	Operating Power + Heaters	-250°F	Off
5	Lunar Night Survival	No Sun	Survival Heaters	-250°F	Off
	Lunar Noon Operation	I = 130 watts/ft^2 Sun Angle = High Noon	Operating Power	+250°F	Off
7	Lunar Noon Degraded	I = 195 watts/ft^2** Sun Angle - High Noon	Operating Power	+250°F	Off

*I = 130 watts/ft^2 corresponds to the total intensity of the sun's radiant energy at one astronomical unit.

**I = 195 watts/ft^2 corresponds to a 50% increase in the solar absorptance of the thermal paint.

TABLE 7.1 - THERMAL-VACUUM TEST CONDITIONS - DVT

TEMPERATURE (°F)

Temperature Sensor Location	Condition #1 Dust Cover On Power Off	Condition #2 Dust Cover On Power On	Condition #3 Lunar Morn. Operation	Condition #4 Lunar Night Operation	Condition #5 Lunar Night Survival	Condition #6 Lunar Noon Operation	Condition #7 Lunar Noon Degraded
TC1 (Leg)	180.5	184.2	162.7	-161.8	-162.8	186.7	210.4
TC2 (T. Plate)				-70.6	-71.6		
TC3 (Leg)	104.0	106.4	121.5	-178.1	-174.6	160.9	197.5
TC4 (T. Plate)							
TC5 (Cable)	74.0	77.5	98.2	-167.9	-170.5	151.7	178.7
TC6 (T. Plate)				-70.8	-71.1		
TC7 (T. Plate)							
TC8 (T. Plate)							
TC9 (T. Plate)	103.6	113.3	93.7	-68.2	-70.2	133.0	159.0
TC10 (Lower Frame)	106.0	120.2	107.0	-44.9	-44.7	146.2	165.7
TC11 (Lower Frame)	104.7	118.1	106.0	-43.0	-49.2	145.4	164.8
TC12 (Upper Frame)	105.0	116.6	100.8	-53.3	-57.6	140.5	162.7
TC13 (Upper Frame)							
TC14 (Case)							
TC15 (Case)	66.1	67.9	66.6	-212.3	-213.8	117.1	119.7
HK5 (Logic)	DATA		105.0	-40.9	-57.1	140.0	154.0
HK6 (L. V. P. S.)*	NOT		108.5	-38.2	-50.8	145.5	160.0
Sw. P. S. **		RECORDED	115.0	-40.0	-44.5	146.4	163.0
V. Analy.			104.0	-63.4	-65.2	137.0	162.0
Lunar Surface Bottom	192.9	193.5	195.1	-240.3	-244.9	249.4	253.2
Lunar Surface Sides	190.6	193.1	196.7	-249.8	-252.5	247.8	248.7
Cold Wall	-244.0	-244.0	-247.0	-293.0	-293.3	-233.7	-238.9

TABLE 7.2 - THERMAL VACUUM TEST TEMPERATURES - DVT

* Low Power Voltage Supply

** Switchable Power Supply

TABLE 7-3

PREDICTED AND MEASURED CPLEE INTERNAL TEMPERATURES (STEADY STATE) OF THE DVT.

Temperatures (°F)						
Test Description	Thermal Plate	Low Voltage Power Supply	Switchable Power Supply	Logic	Vertical Analyzer	
Lunar Noon Operation	118 133	139 145	133 147	128 140	118 138	Predicted Measured
Lunar Night Survival	-63 -71	-29 -38	-41 -40	-32 -41	-63 -63	Predicted Measured
Lunar Night Survival	-65 -71	-53 -57	-54 -44	-52 -51	-65 -65	Predicted Measured

TABLE 7-4

THERMAL VACUUM TEST CONDITIONS-QUAL "SB"

Test Description	Solar Condition	CPLEE Power Mode	Lunar Surface Temperature	Crywall Temperature	Elapsed Time (Hr.
Start Test	No sun	----	Ambient	Ambient	0.0
Lunar Noon	I=162.5 watt/ft^2	Operating Power	275°F	-300°F	74.0
Lunar Night	No sun	Operating Power and Heaters	-300°F	-300°F	155.0
End Test	No sun	----	Ambient	Ambient	199.0

TABLE 7-5

COMPARISON OF QUAL "SB" TEST VERSUS PREDICTED TEMPERATURE VALUES

Location	Temperature (°F) Lunar Noon	Lunar Night	
Radiator Plate TC1	122.0 146.3	-38.1 -39.1	Tested Predicted
Radiator Plate TC2	122.7 146.3	-38.0 -39.1	Tested Predicted
Radiator Plate TC3	123.0 146.3	-39.7 -39.1	Tested Predicted
Electronics TC4	127.4 160.1	-28.3 -16.2	Tested Predicted
Electronics TC5	131.7 160.1	-21.3 -16.2	Tested Predicted

TABLE 7-6

COMPARISON OF CPLEE QUAL-SB/FLIGHT 3 AND 4 CONFIGURATION FACTORS TO ACTUAL LUNAR SURFACE

Case	Test Surface	Lunar Surface	% Difference
End	.51371	.5	2.74
Side	.48375	.5	-3.25
End	.46336	.5	-7.33
Side	.50903	.5	1.81
Radiator Plate			
End	.44408	.5	-11.2
Side	.43968	.5	-12.1
End	.40623	.5	-18.8
Side	.44723	.5	-10.6
Eave	.61378	.61735	- .58
Eave	.61103	.61735	- 1.02

TABLE 7-7

PHYSICAL ANALYSER TEMPERATURES FOR
FLIGHT ACCEPTANCE TESTS 3 AND 4

	Temperature (°F)		
	Lunar Noon	Lunar Night	
Flight 3	100 120	-10 -16.7	Tested Predicted
Flight 4	97 120	-23* -16.7	Tested Predicted
Fight 4 Retest	103 120	-17 -16.7	Tested Predicted

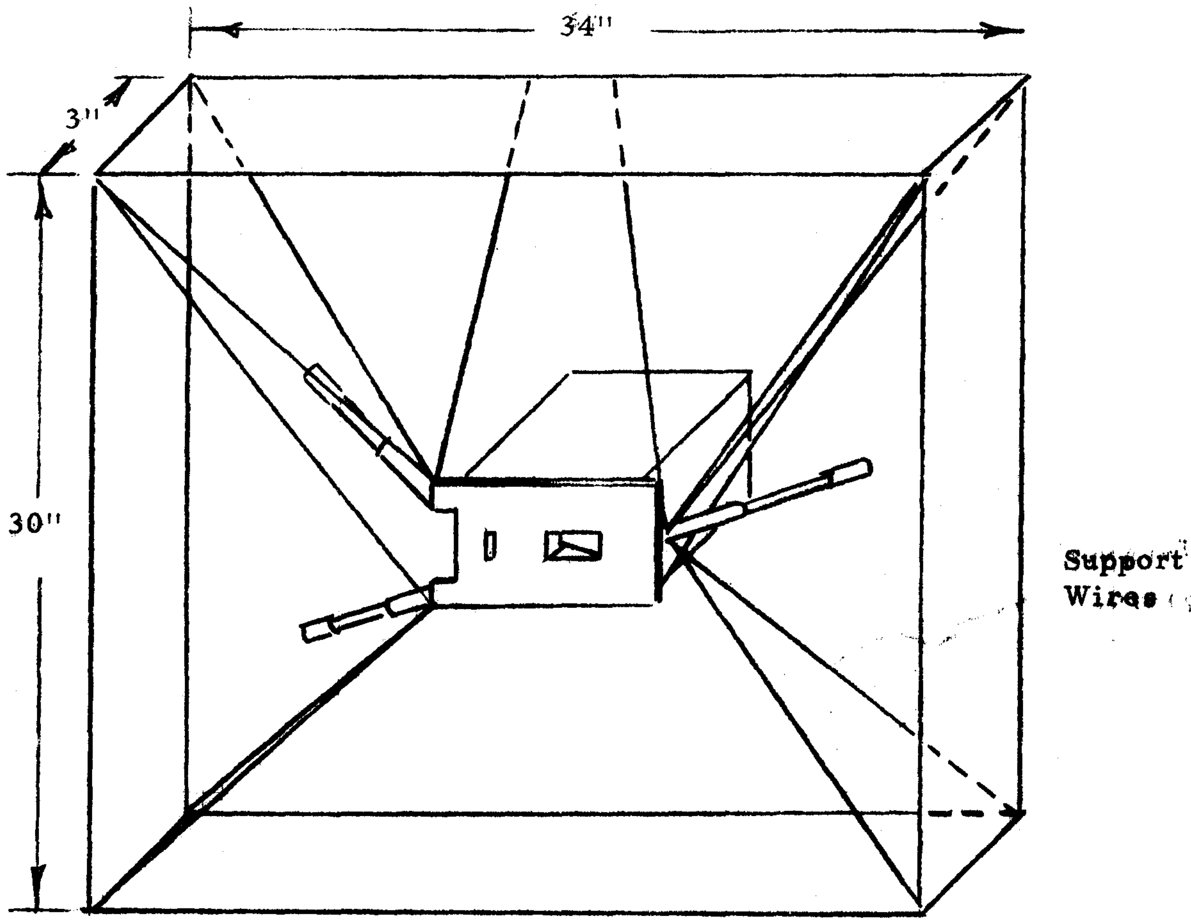
* Inconsistant data at this point

TABLE 7-8

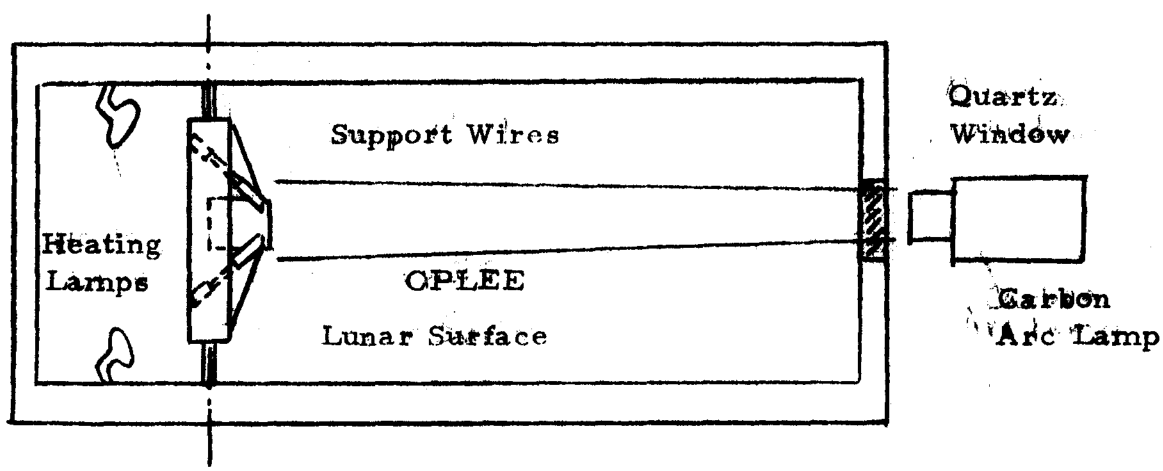
CONFIGURATION FACTORS OF CPLEE TO RTG FOR FLIGHT 3 AND 4 THERMAL VACUUM DEPLOYMENT

Surface	Configuration Factor
Case End	0.03187
Case Side	0.01023
Plate End	0.03395
Plate Side	0.01055
Plate Eave	0.00117
Plate Top	0.00148

(Ref. No. 14)

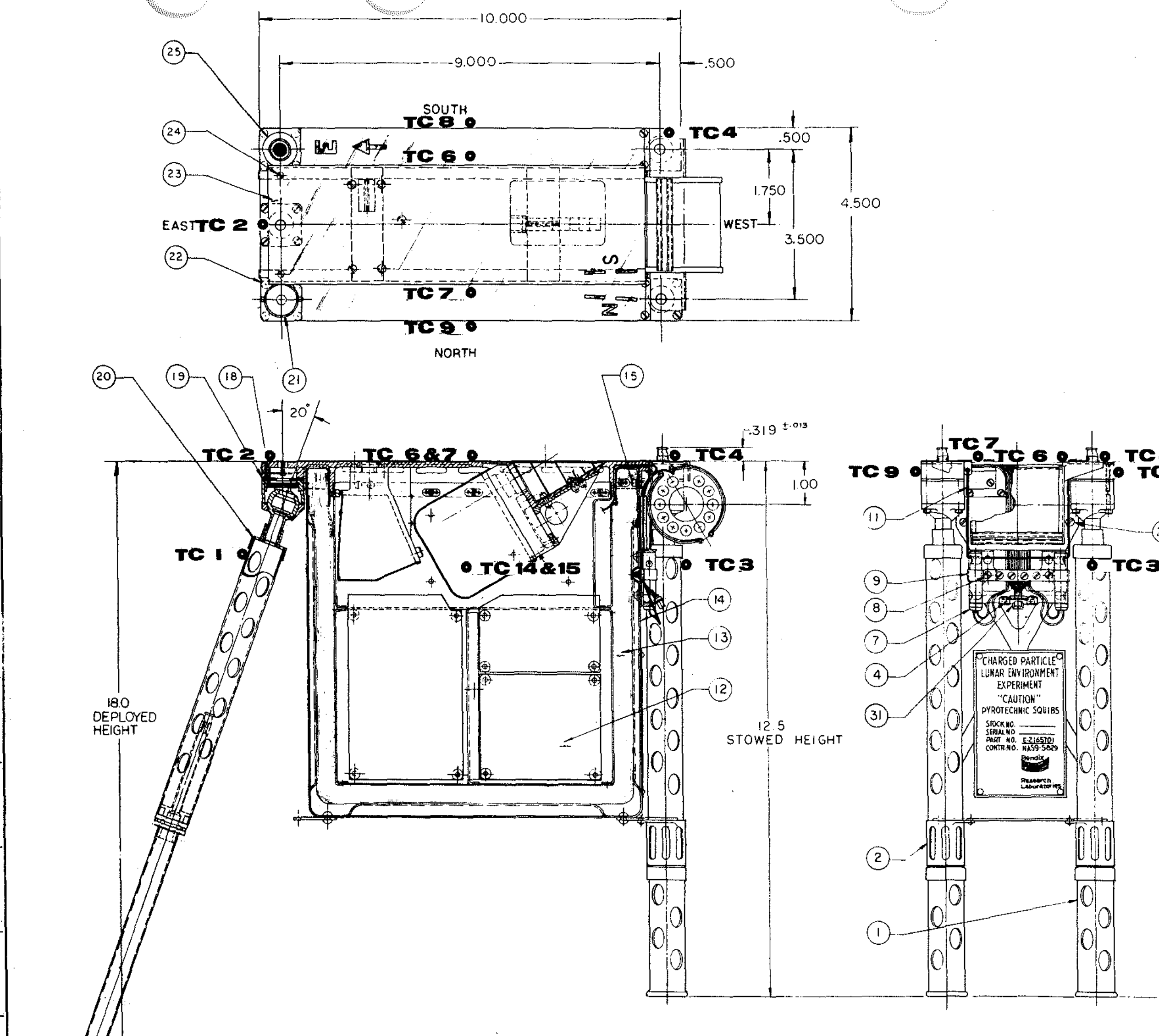


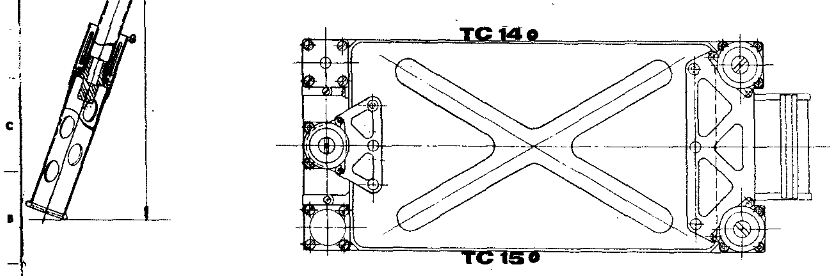
CPLEE Mounting Scheme



DVT Test Installation Scheme

Figure 7-1





Design Verification Test
Thermocouple Locations (External)
Figure 7-2.

5. REF. NUMERICAL DRAWING LIST #DL 2165701
4. FOR DESIGN REQUIREMENTS SEE MASTER LIST DS 771
3. CHECK MTG HOLES USING MASTER TOOL #TP2323520-01
2. FOR ASSEMBLY PROCEDURE SEE MASTER LIST P.S. 682
1. FOR TEST PROCEDURE SEE MASTER LIST P.S. 681

NOTES:

QTY REQD	DWG SIZE	PART NO.	DESCRIPTION	MATERIAL DESCRIPTION & SPECIFICATION	CODE IDENT	ITEM NO.
1	C	2167951	JUMPER PLUG			31
2	B	2169537	WASHER - FLAT			30
2	–	STOCK	SCREW - FLAT HD. 82°	#2-56 UNC x .375 LG. S ST		29
						28
						27
						26
1	B	2165605	LEVEL-CIRCULAR			25
2	–	STOCK	SCREW-PAN HD.	#2-56 UNC X .25 LG. SST.		24
1	C	2167322	DUST COVER ASSY.			23
8	–	STOCK	SCREW-FLAT HD.	#4-40 UNC X .38 LG. SST.		22
1	B	2165606	INSERT- TOOL			21
1	D	2165624-1	LEVELING LEG ASS'Y.			20
3	B	2166129	INSULATOR SPACER			19
12	–	STOCK	SCREW-FLAT HD.	#4-40 UNC X .69 LG SST.		18
						17
						16
24	–	STOCK	SCREW-FLAT HD.	#2-56 UNC X .25 LG. SST.		15
1	D	2166021	COVER ASS'Y.			14
1	D	2166134	INSULATOR ASS'Y.			13
1	E	2165410	ELECTRONIC ASS'Y.			12
1	-	STOCK	REEFER LINE			11
						10
1	B	2166131	RETAINER			9
2	–	STOCK	SCREW-ROUND HD.	# 2-56 UNC X .25 LG. SST		8
2	–	STOCK	REEFER CUTTER	ATLAS CHEMICAL COMPANY PART NO. SE-166-G 4.0		7
						6
						5
2	–	STOCK	SCREW LOCK ASSY	ITT CANNON ELECT. INC PART NO. 322-9300-000		4
						3
1	D	2165624-3	LEVELING LEG ASSY.			2
1	D	2165624-2	LEVELING LEG ASSY.			1

LIST OF MATERIAL

QUALITY SYMBOL USAGE

INTERPRET PER QUALITY SPECIFICATION NO. 1000, NOT FOR VENDOR USE UNLESS SPECIFIED ON PROCUREMENT DOCUMENTS.

NEXT ASSY	FINAL ASSY
APPLICATION	

CONTRACT NUMBER BASD 100-S0-0178

UNLESS OTHERWISE SPECIFIED

- INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-D-70327
- DIMENSIONS ARE IN INCHES
- DIMENSIONS TO BE MET AFTER PLATING
- MACHINED SURFACES TO BE SQUARE & PARALLEL TO DATUM A WITHIN .005 PER IN.
- MACHINED DIAMETERS TO BE CONCENTRIC WITH DATUM A WITHIN .005 T I R

TOLERANCES
DECIMAL .X ± .040 .XX ± .020 .XXX ± .010
ANGLES ± 0°-30' EXCEPT SPECIFIED CHAMFER ± 10°
SURFACE FINISH MICROINCHES R H R

DRAWN	R. DeVine	2-4-67
CHECKED	H. MARTIN	8-2-67
GROUP LEADER	W. Moe	2-9-67
ELEC ENGR		
MECH ENGR		
PROJ ENGR	[illegible]	2-4-67

APPROVED

APPROVED

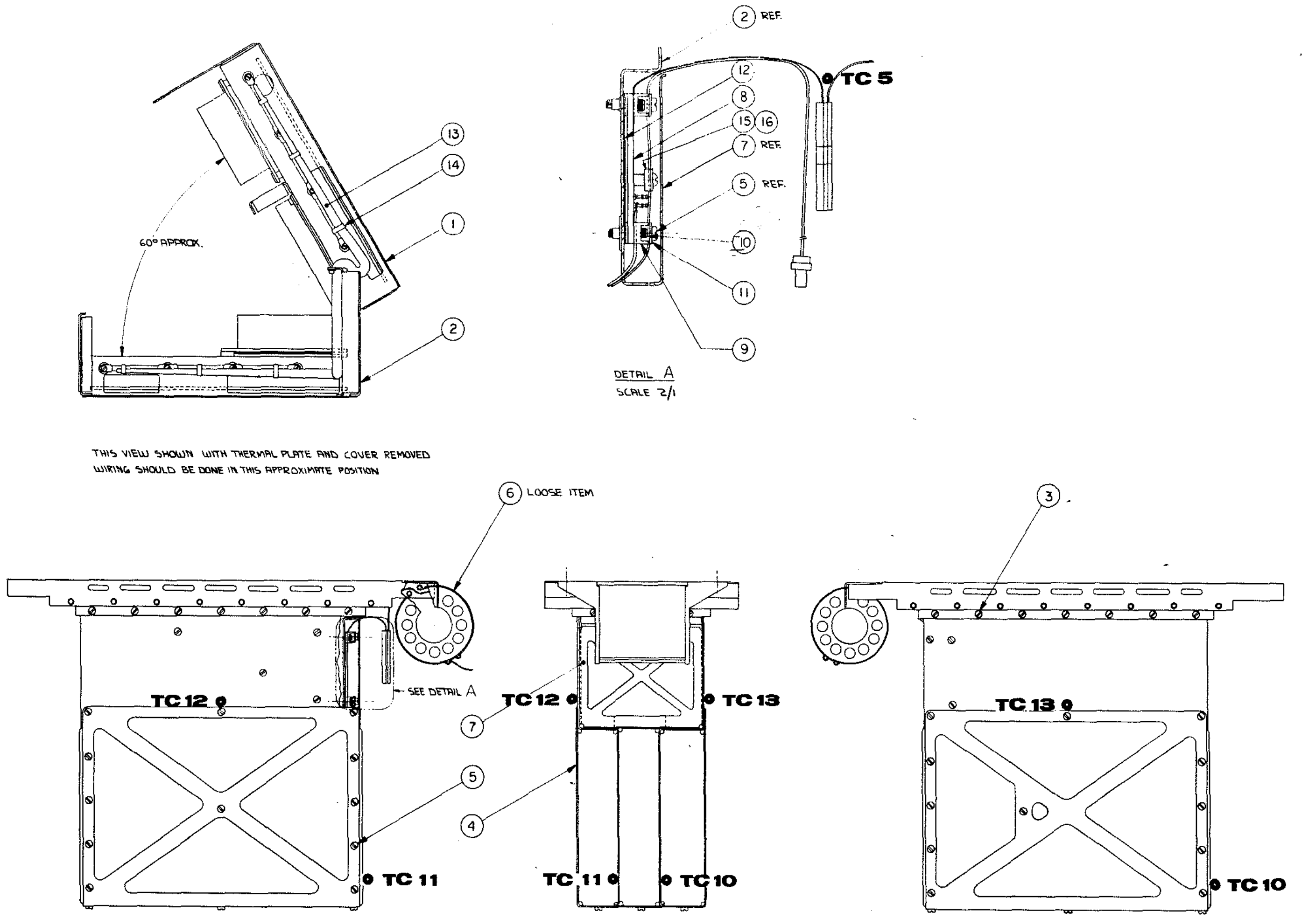
THE Bendix CORPORATION
RESEARCH LABORATORIES DIVISION
SOUTHFIELD, MICHIGAN

TITLE CPLEE ASSEMBLY

CODE IDENT NO. 11272 | SIZE E | 2165701 | X

SCALE FULL | WT | SHEET 1 OF 1

CPLEE PROTOTYPE QUAL & FLIGHT MODEL DEPT NO. 820



Design Verification Test
Thermocouple Locations (Internal)
Figure 7-3.

QTY REQD	DWG SIZE	PART NO.	DESCRIPTION	MATERIAL DESCRIPTION & SPECIFICATION	CODE IDENT
2		STOCK	SCREW - RD. HD.	0-80UNF×.187LG PIC*Y2-0-5-LL	
1	B	2167340	HOLDER-CABLE CLAMP		
AS REQD		STOCK	LACING		
1	D	2167977	WIRING HARNESS ASS'Y.		
1	C	2167005	INSULATOR		
3	B	2165450	CABLE CLAMP-TEST		
2		STOCK	SCREW - SOC. HD.	*2-56 UNC×.312 LG S.ST	
1	C	2166386	CABLE CLAMP-BOTTOM		
1	C	2165411	CABLE TERM & P.W. BOARD ASS'Y		
1	C	2166716	COVER CABLE		
1	C	2166133	CABLE SPOOL ASS'Y		
39		STOCK	SCREW - PAN HD.	*2-56 UNC×.187 LG	
1	D	2166590	COVER - FRAME		
11		STOCK	SCREW - FLAT HD.	*2-56 UNC×.281 LG	
1	E	2167060	DOUBLE COMPARTMENT ASS'Y		
1	E	2167030	SINGLE COMPARTMENT ASS'Y		

LIST OF MATERIAL

2. FOR WIRING INFORMATION SEE DWG. *E 2166597
1. TORQUE ITEM Nº 3,5 & 10 TO 12 IN.OZ.
NOTE:

E 2165701	E 2165701
NEXT ASSY	FINAL ASSY
APPLICATION	
CONTRACT NUMBER	NAS-9 5829

UNLESS OTHERWISE SPECIFIED
- INTERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY MIL-D-70327
- DIMENSIONS ARE IN INCHES
- DIMENSIONS TO BE MET AFTER PLATING
- MACHINED SURFACES TO BE SQUARE & PARALLEL TO DATUM A WITHIN .005 PER IR.
- MACHINED DIAMETERS TO BE CONCENTRIC WITH DATUM A WITHIN .005 T I R

TOLERANCES
DECIMAL .X ± .040 .XX ± .020 .XXX ± .010
ANGLES ± 0°-30' EXCEPT SPECIFIED CHAMFER ± 10°
SURFACE FINISH MICROINCHES R H R

DRAWN DREW ... 4-12-67
CHECKED P. Bal... 4/13/67
GROUP LEADER ... 4-13-67
ELEC ENGR ... 4/13/67
MECH ENGR ... 4/13/67
... 4-13-67
APPROVED
APPROVED

THE Bendix CORPORATION
RESEARCH LABORATORIES DIVISION
SOUTHFIELD, MICHIGAN

TITLE
ELECTRONICS PACKAGE ASS
CPLEE

CODE IDENT NO. 11272 | SIZE E | 2165410
SCALE FULL | WT — | SHEET 1 OF 1

Pride Requires Increased Defect Elimination PROTO
3311- MOD | DEPT NO. 320

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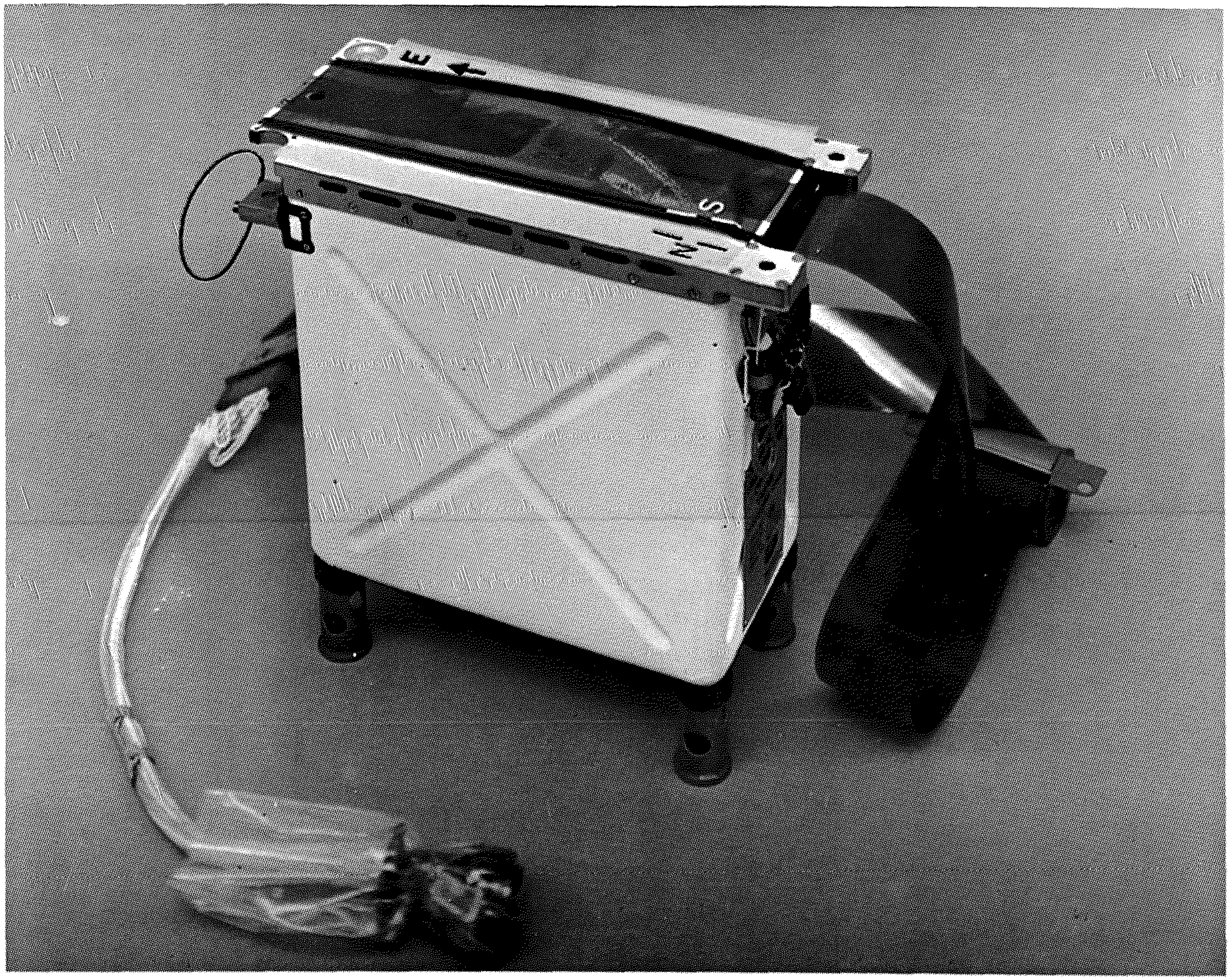


Figure 7-4 CPLEE Equator Deployment Model

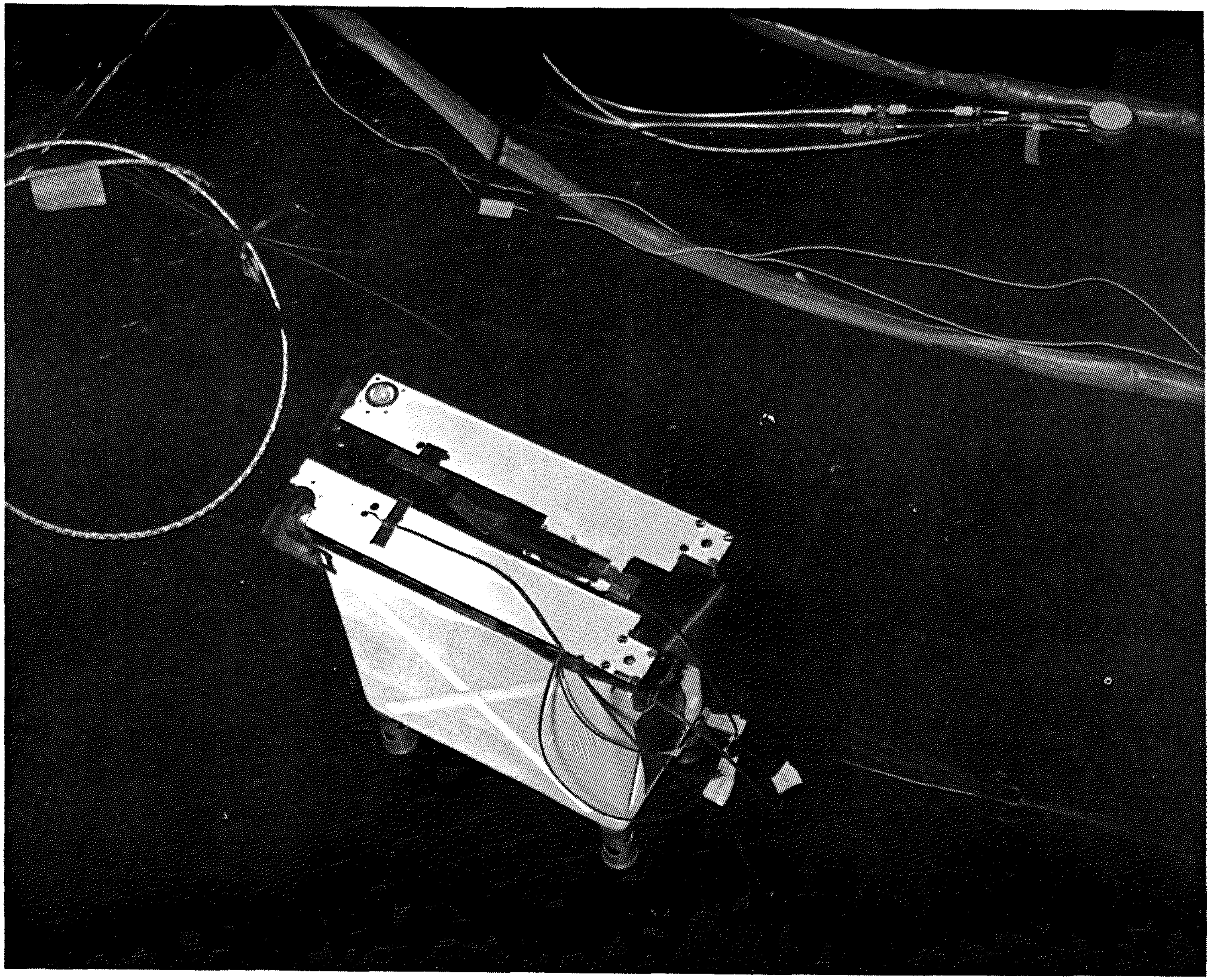
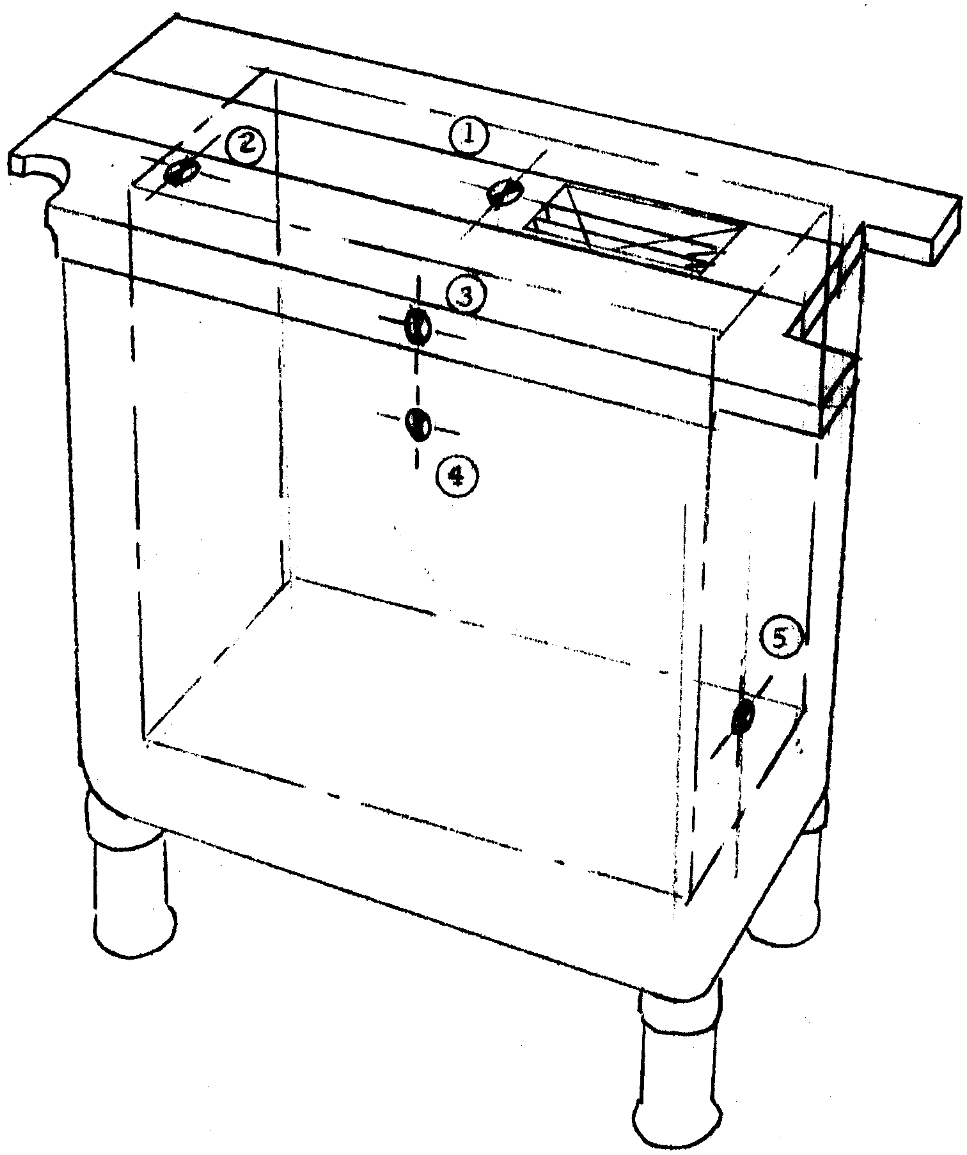


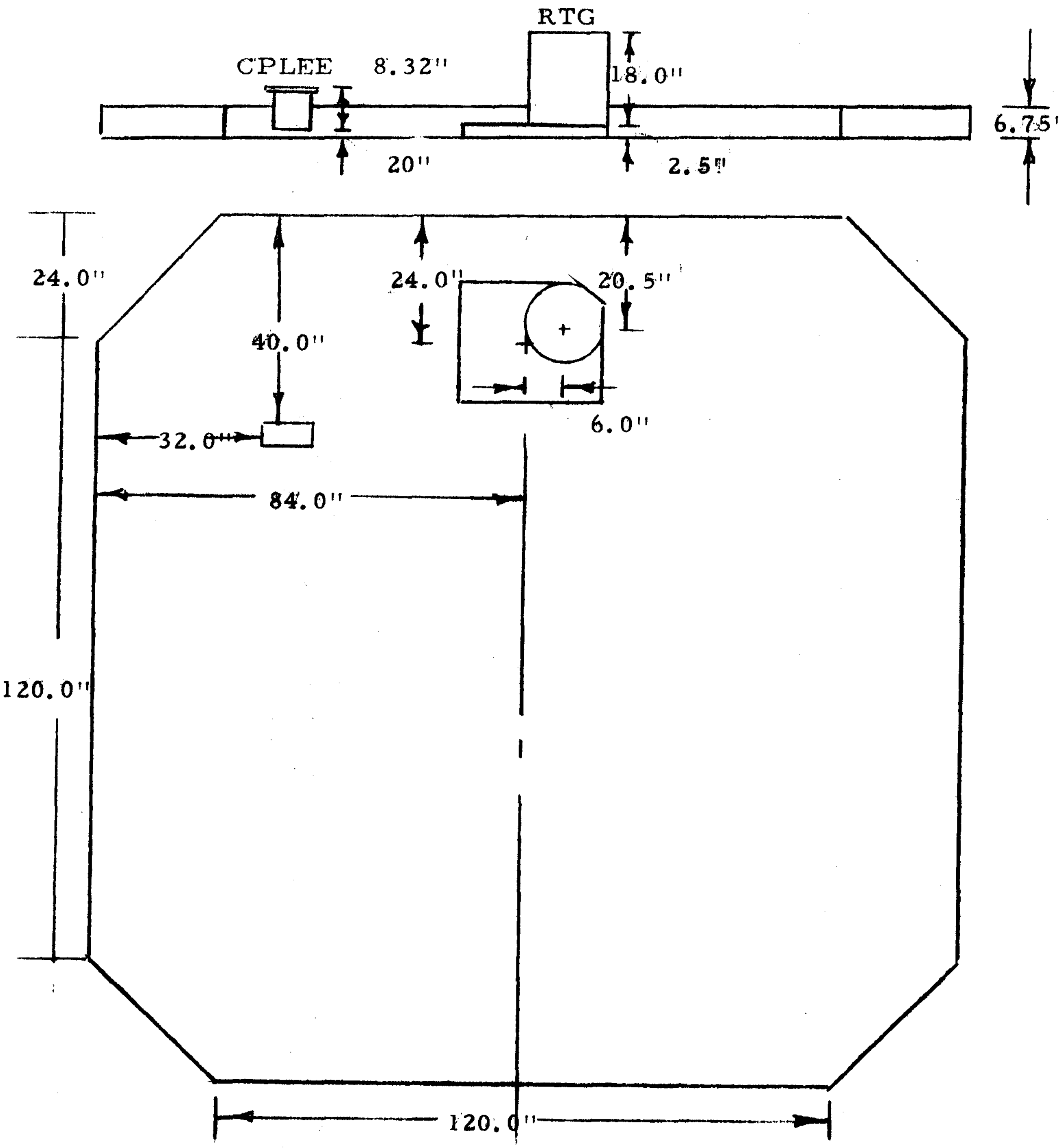
Figure 7-5 CPLEE Qual SB Model Deployed in the Thermal Vacuum Test Chamber



Qual-SB Test Thermocouple Locations

Ref. Bendix Dwg. BSX 8434

Figure 7-6



Flight 3/4 CPLEE and RTG Deployment
in the Thermal Vacuum Chamber

Figure 7-7

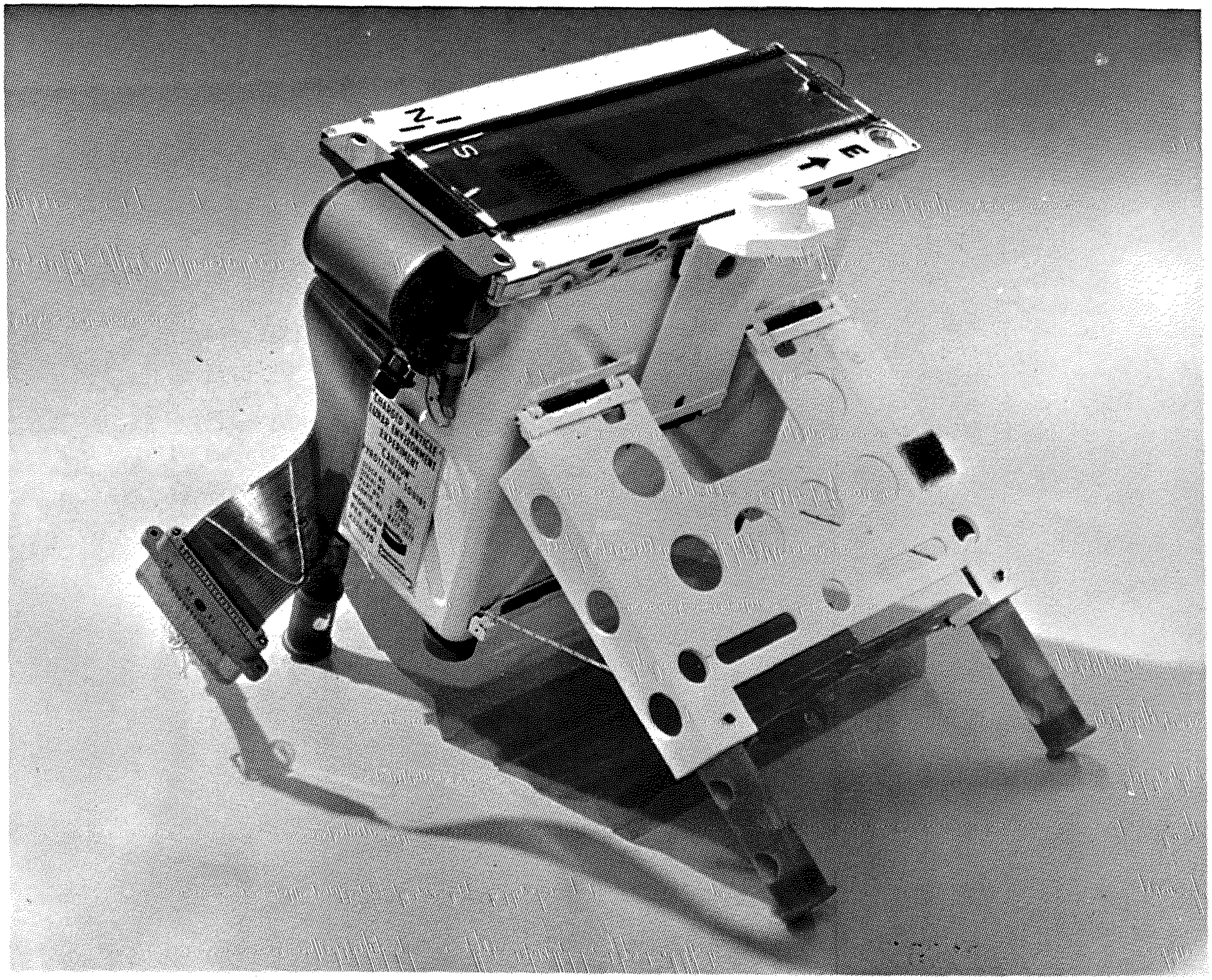


Figure 7-8 CPLEE Off-Equator Deployment Model

8.0 REFERENCES

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2. AL-260000 Rev. A. "Charged-Particle Lunar Environment Experiment Specification", 22 December 1966.

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8. BRLD Memo, "Power Profile - ALSEP/CPLEE", 10 October 1966.

9. BRLD Memo, "CPLEE Prototype Model Thermal Vacuum DVT Tests", 22 November 1967.

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11. BxA Memo 70-210-167-Rev. 1, "CPLEE Power Dissipation of Qual SB, Flight 3 and Flight 4", 28 May 1970.

12. BxA Memo 70-210-184, "CPLEE - Thermal Analyses Correlation with Qual SB, Flights 3 and 4, and Flight 4 Retest", 3 June 1970.

13. BxA Memo 70-210-194, "CPLEE Off-Equator Thermal Performance", 15 June 1970.

14. BxA Memo 9713-11-539, "CPLEE Qual-SB Lunar Surface Simulation and Flight #3 RTG Interference", 16 December 1968.

15. BxA ATM-893, "Final Report - ALSEP Dust Protection Study", 24 June 1970.