This document presents results from an off-equator deployment study for ALSEP and presents recommended design changes and predicted thermal performance for the central station and associated experiments for Apollo flights 13 through 16. Emphasis is placed on required modifications to thermal control system designs and to alignment devices. The effect on central station performance by variations in local lunar terrain (such as craters, rocks, and slopes) are also evaluated. The ALSEP off-equator thermal study was authorized under BxA CCP's 216 and 229 to Contract 9-5829.

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1.0 INTRODUCTION AND SUMMARY

The original Apollo Lunar Surface Experiments Package (ALSEP) is designed to operate within ±5 degrees latitude of the lunar equator. However, many of the proposed primary and alternate landing sites for Apollo Flights 13 to 16 are outside the ±5 degree latitude requirement and up to a possible maximum 45 degree latitude. Consequently, NASA/MSC LSPO requested (reference 1) that Bendix conduct a preliminary study to assess the impact on the designs of the ALSEP central station and experiment packages at the new increased latitude landing sites.

For the central station and for current system alignment requirements, study results indicated that the original central station open thermal design should be modified for the Apollo 14 Littrow Rille landing site (North 22° latitude) and all subsequent landing sites outside the ±5° latitude envelope. The design modification consists basically of closing the enclosure facing the lunar equator and sun with a third side curtain and of reducing the width of the insulation mask on the thermal plate facing the closest lunar pole. The modification is required primarily to prevent the direct impingement of solar energy on surfaces within either enclosure, which in turn causes excessive temperatures of such critical central station components as the thermal plate, specular reflector, and side curtains.

A revised sun compass has been installed on the central station to permit alignment by the astronauts at the higher deployment latitudes.

For the ALSEP Array B, C, A-2, and D experiments, design modifications are required due to thermal or scientific considerations for the SIDE, LSM, HFE, and CPLEE at latitudes greater than 5 degrees. The specific modifications are outlined in subsequent sections. Also, changes to the PSE, SWE, LSM, and HFE alignment devices and procedures will be implemented for off-equatorial deployment. The PSE will receive a new compass rose, while new sun compasses or shadowgraphs will be incorporated into the LSM and HFE packages. In addition a bubble level will be installed on the HFE to improve the vertical alignment of this experiment from the original ±12° to ±5°. New bubble levels will also be installed on the SIDE and CPLEE for off-equator deployment. The nature of the SWE alignment modification is not fixed at this time.

Due to the presence of numerous craters, obstructions, and local variations in the slope of the lunar surface, the effects of these parameters on central station thermal performance were investigated. In general, lunar slopes greater than 5 degrees significantly affect central station temperatures.

This ATM supersedes Bendix IM 69-210-207 (reference 2), which documented preliminary study results.

Information presented in this report is applicable as of 15 March 1970. It should be noted that future changes in landing sites and experiment arrays may invalidate some of the information herein.

2.0 CONCLUSIONS

2.1 Deployment Within ±5 Degrees Latitude of Lunar Equator

1. The ALSEP Flight 3 open design thermal configuration is recommended for the Apollo 13 prime landing site of Fra Mauro (W17°- S4°) and all subsequent flights that have landing sites within ±5° latitude of the equator.

2. The original ALSEP central station and experiment alignment devices are adequate at latitudes within ±5° of the equator.

3. The ALSEP open design for Apollo 13 should not be deployed between the LM and the lunar equator, but emplaced east or west of LM (west is preferred).

2.2 Deployment at Latitudes Beyond ±5 Degrees

2.2.1 Central Station Design

1. A modified closed side 2 central station thermal design is proposed for ALSEP Flight 4 and all subsequent flight models which will be deployed outside the ±5 degree latitude range.

2. The modified C/S should be deployed east or west of LM (west is preferred) with the handle facing the closest lunar pole.

3. A new sun compass alignment device will be installed on the Flight 4 C/S and on all subsequent models.

2.2.2 Experiment Designs

1. PSE. A new compass rose will be installed for ALSEP Flight 4, to permit alignment at the Apollo 14 landing site (Littrow Rille, E29° - N22°), and for all subsequent flights.

2. SWE. A preliminary investigation indicates a new sun compass for Apollo Flight 15.

3. SIDE. The support legs will be redesigned and a new leveling bubble added for vertical alignment for Apollo Flights 14 and 15.

4. LSM. A sunshade will be installed, and a new shadowgraph is planned for Apollo Flights 15 and 16.

5. HFE. A new sunshield thermal design, new sun compass, and leveling bubble will be installed for Apollo Flight 16.

6. CPLEE. The support legs will be redesigned, and a leveling bubble will be added for vertical alignment for Apollo Flight 14.

7. ASE. No design modifications are required due to off-equator deployment. However, a new bubble level will be installed on ALSEP Flights 4 and 5 to insure proper mortar box alignment prior to firing.

8. CCGE. No design changes are required since no deployment sites greater than 5° latitude from the equator are planned for this experiment.

2.3 Deployment Configuration

1. Avoid deployment within any crater with a slope over 5 degrees. For example, even a shallow 5° slope crater may increase the central station thermal plate temperature swing more than 10°F.

2. Avoid deployment in an area with obstructions (e.g., rocks), especially if the obstructions have a height which is greater than 1/12 of the distance to any ALSEP component.

3. If feasible, deploy the central station on top of a local mound or on a crater rim.

4. Avoid local slopes if possible, though this is not critical for the open design central station if the slope is continuous in one direction. For the closed side 2 configuration, the slope is not critical if it is away from the open side 1 enclosure.

5. Deploy within ± 15° of the LM east-west axis (within a 30° cone with LM as the apex) but as close to the axis as possible without being in the LM shadow.

6. For the closed side 2 configuration, tilt the C/S up to 5° from the vertical in a north-south direction towards the equator (handle faces the closest pole), if possible. This tilt angle can be increased at latitudes beyond 10°.

3.0 SUMMARY OF RESULTS

The original ALSEP central station was designed to operate with the side curtains facing an east-west direction and within the following environmental and alignment tolerances:

1. ±5° for variation of landing site latitude from the equator.
2. ±5° for vertical alignment.
3. ±5° for alignment with the equator (East-West alignment).
4. ±1.5° for variation of solar ecliptic from the lunar equatorial plane.
5. Local lunar surface slopes less than ±5°.
6. Deployment site removed from craters, local slopes greater than ±5°, and obstructions.

A study was conducted to evaluate the effect of deployment sites beyond 5° latitude on central station thermal performance, with the results presented in following sections. The influences of the environmental and alignment tolerances were considered in the study.

Trade-off studies were conducted to evaluate the effect of the following parameters on the ALSEP thermal performance.

1. Lunar latitude from 0 to 60 degrees.
2. Central station misalignment with respect to the lunar equator and to the local lunar vertical.
3. Solar variation from the lunar equator.
4. Craters with slopes from 5° (aspect ratio = 23:1) to 30° (aspect ratio = 3.5:1).
5. Local slopes from -30° to +30°.
6. Obstructions with equivalent slopes from 0° to 30°.
7. Local elevations (mounds) with slopes from 0° to 30°.

Study results, which indicated that all of the above parameters can have a significant influence on thermal performance, are summarized in the following sections. Proposed modifications to thermal designs and alignment devices are also presented.

3.1 ALSEP Design Modifications for Off-Equator Deployment

If the open ALSEP configuration is deployed at off-equator Apollo landing sites, alignment tolerances and temperature limits on certain components may be exceeded. For example, at latitudes beyond 15 degrees, sufficient solar energy can enter the central station enclosure facing the equator to cause the thermal plate temperature to reach unacceptable levels. Misalignment and variation of the solar ecliptic from the lunar equatorial plane can add to this problem since their effects are often similar to locating the equipment off the equator.

3.1.1 Central Station Thermal Design Modification for Off-Equator Deployment

The following basic central station thermal configurations (illustrated schematically in Table 3-4) were evaluated in order to optimize the C/S design at off-equator landing sites:

1. Original open design.

2. Second surface mirrors instead of S13G white paint on the thermal plate exposed to direct solar illumination.

3. Insulation mask over entire thermal plate surface exposed to solar illumination, with remaining thermal plate uncovered except for small mask required for lunar night temperature control.

4. Insulation curtain over the central station enclosure facing the lunar equator, which eliminates direct solar illumination of enclosure surfaces. Insulation mask over entire thermal plate within closed-off enclosure and over part of thermal plate in open enclosure. Central station enclosures are those two separate regions bounded by the reflector, side curtains, insulation mask, and exposed thermal plate.

For latitudes beyond 5 degrees from the lunar equator, the configuration with a closed-off side 2 enclosure facing the equator and with a 1.5" mask on the side 1 thermal plate is recommended for thermal control for the ALSEP central station. Side 2 refers to that enclosure with the cut-off corner on the thermal plate. Reasons for selecting this design are outlined in Section 3.4, while details on the design changes involved in this modification are presented in Section 5.1.

3.1.1.1 Recommended C/S Thermal Configurations for Apollo Flights 13, 14, 15, and 16

Table 3-1 presents the recommended C/S thermal configurations along with predicted thermal performances for ALSEP deployed at the current proposed lunar landing sites for Apollo Flights 13, 14, 15, and 16. Temperatures are based on the worst possible central station misalignment and solar variation from the lunar equator with no effects from dust and variations in local lunar terrain. The maximum thermal plate temperature levels during the lunar day occur at noon, when the sun is at the zenith.

As shown by Table 3-1, predicted thermal plate temperatures range as high as 135°F for the primary landing sites, which is 10°F higher than the 125°F nominal Exhibit B specification value but below the 140°F design limit for ALSEP deployed on the lunar equator. However, note that the open design thermal plate temperature will exceed the 140°F design limit if either of the alternate landing sites for Apollo 13 are selected. The open design was selected for these alternate sites since time did not permit modifications to the Flight 3 design to improve thermal performance.

The highest predicted reflector temperature of 230°F occurs with the open design and is below the recommended maximum service limit for Mylar of 300°F. The 655°F side curtain temperature for the open design is well below the recommended 750°F maximum service limit for Kapton. Note that the closed side 2 design causes a significant decrease in maximum reflector and side curtain temperatures. Side curtain and reflector temperatures as a function of latitude and radiation properties are presented in Section 3.2.3.

3.1.2 Central Station Alignment at Off-Equator Landing Sites

For optimum thermal performance, the C/S should be perfectly aligned with respect to the lunar equator and local vertical; i.e., the

TABLE 3-1

RECOMMENDED CENTRAL STATION THERMAL CONFIGURATIONS AND THERMAL PERFORMANCES FOR APOLLO FLIGHTS 13, 14, 15, and 16

Apollo Flight No.	Nominal Landing Site*	Longitude - Latitude	ALSEP Array/ Flight No.	Recommended Thermal Configuration	Average Thermal Plate Temperature Range - °F **	Maximum Specular Reflector Temp. - °F	Maximum Side Curtain Temp. - °F	Deployment Recommendations
13	Fra Mauro (Alphonsus) (Hyginus Rille)	W17°-S4° W4°-S13° E6°-N8°	B/F-3 B/F-3 B/F-3	Open Design Open Design Open Design	0 to 135 0 to 156 0 to 143	180 230 205	655 655 655	Align C/S with equator (not sun). Improve ±5° vertical alignment tolerance. Do not deploy in any crater with slope over 5°. Avoid deployment in region with obstructions higher than 6".
14	Littrow Rille	E29°-N22°	C/F-4	Closed Side 2 with 1.5" Mask on Side 1	0 to 128	140	140	Tilt C/S as much as feasible up to 15° from vertical in a north-south direction towards the equator (handle faces nearest pole). Do not deploy in any crater with slope over 5°. Avoid deployment in region with obstructions higher than 6".
15	Davy Rille	W6°-S11°	A-2/A-2	Closed Side 2 with 1.5" Mask on Side 1	0 to 132	140	140	Same as for Apollo 14 except do not tilt C/S more than 5°.
16	Marius Hills	W57°-N15°	D/F-5	Closed Side 2 with 1.5" Mask on Side 1	0 to 131	140	140	Same as for Apollo 14 except do not tilt C/S more than 10°.

* Names shown in parentheses are alternate landing sites.

**Highest temperatures occur at lunar noon and are the maximum predicted values for deployment on a level surface with worst case central station misalignment and with nominal undegraded radiation properties of enclosure surfaces. Effects from variations in local terrain (i.e., craters, local slopes, and obstructions) are not included in this table but are presented in Section 3.3. Lunar night temperatures are not affected by misalignment or by variations in lunar terrain.

package should be level, and the front and back should be parallel to the equator. However, in addition to the ±5° vertical and east-west alignment tolerances, the original gnomon/compass rose alignment device aligns the C/S with the sun and does not correct for the tilted gnomon effect induced by off-equator deployment. If the package is located off the equator and/or if the solar ecliptic varies from the lunar equatorial plane, east-west alignment error can occur. For latitudes less than ±5°, this misalignment causes no significant effect on the thermal plate temperature but can cause the specular reflector and side curtain temperatures to approach allowable service limits due to direct impingement of solar energy on these components. At higher latitudes, the present alignment procedure could result in direct impingement of solar energy on the thermal plate, which could cause thermal plate temperatures to exceed the 140°F design limit. To improve east-west alignment for ALSEP central stations, alignment devices have been or will be modified as outlined in Table 3-2. For further details on these devices, refer to Section 5.2.

TABLE 3-2

CENTRAL STATION ALIGNMENT AT OFF-EQUATOR LANDING SITES

Apollo Flight No.	ALSEP Flight No.	Modified Alignment Device	Remarks
13	3	None Recommended	No modification recommended because landing site is located within ±5° of equator.
14	4	Two sun compasses added to sunshield	This design will allow deployment at any proposed landing site within ±45° latitude. Proper azimuth reading of gnomon shadow must be supplied to astronaut.
15-19	A-2 on	Two sun compasses will be added to sunshield	Same as for ALSEP Flight 4.

3.1.3 Effect of Off-Equator Deployment on ALSEP Experiments

The effect of off-equator deployment on the ALSEP experiments is currently being studied. Table 3-3 lists the predicted thermal performances of the experiments and outlines required modifications in the thermal designs and alignment devices.

3.2 Central Station Thermal Performance at Off-Equator Latitudes

3.2.1 Thermal Plate and Electronic Temperatures for No Misalignment

Figure 3-1 presents the thermal performance of the open design along with test limit and piece part rating temperatures. As illustrated by the Figure, the predicted average thermal plate temperature swing exceeds the ALSEP Exhibit B specification nominal value of 125°F at off-equator landing sites up to 45 degrees latitude. Furthermore, the swing exceeds the 140°F test limit at latitudes from 20 to 45 degrees and could reach values in excess of 160°F at some latitudes.

The thermal performances of the candidate modified C/S designs are presented in Figure 3-2 and Table 3-4 in terms of average thermal plate temperature, temperature gradients, and selected critical electronic temperatures. The schematics in Table 3-4 illustrate the candidate modified central station designs which were analyzed. The design modifications are based on the 0°F lunar night thermal plate temperature of the open design in order to establish an equivalent comparison basis for all configurations. Analysis results, which were based on a 250°F lunar surface temperature at lunar noon at all latitudes, were used only to compare the various design modifications.

As shown by Figure 3-2 and Table 3-4, the configuration with side 2 closed and with a 1.5" mask on the side 1 thermal plate (henceforth referred to as the closed side 2 configuration) produces the lowest thermal plate temperature swing and temperature gradients for latitudes beyond about 10 degrees, providing that side 2 faces the equator. The predicted thermal performance, based on actual lunar surface temperatures (not a constant 250°F) at the various latitudes, of the closed 2 design is compared to the open design performance in Figure 3-1.

TABLE 3-3

DESIGN MODIFICATIONS TO ARRAY A, B, C, A-2, AND D EXPERIMENTS RESULTING FROM OFF-EQUATOR DEPLOYMENT

Experiment	Array	ALSEP Flight	Apollo Flight	Specification Operating Temperature Range, °F	Alignment Requirements, Degrees		Reasons for Design Modifications				Remarks
					Vertical	East-West	Thermal	Scientific	Alignment	Performance Affected	
PSE	A, B, C, A-2, D	1, 3, 4, A-2, 5	12, 13, 14, 15, 16	107 to 143	±5	± 5 (E-W) ∓ 1 (Position)			Yes	Yes	The sun compass will be modified for ALSEP Flights 4, A-2, and 5.
SWE	A, A-2	1, A-2	12, 15	-13 to 162	± 5	± 5			Yes	Yes	An alignment modification must be implemented for off-equator deployment
SIDE	A, C, A-2	1, 4, A-2	12, 14, 15	-40 to 176	±5	±5		Yes	Yes	Yes	For scientific reasons, a new swing-out support leg and leveling bubble will be added to ALSEP Flight 4 and A-2 models to align the top surface of the experiment with the solar ecliptic.
LSM	A, A-2, D	1, A-2, 5	12, 15, 16	-22 to 144	±3	±3 (E-W) ± 1 (Position)	Yes		Yes	Yes	For thermal reasons, a new sun-shade will be suspended between the three boom hinge joints for ALSEP Flights A-2 and 5. The PRA shade will be widened for deployment latitudes between 5° and 20°, and the PRA facing the equator will be completely masked for latitudes greater than 20°. A new tilting shadowgraph will be added for off-equator deployment.
HFE	B, D	3, 5	13, 16	-14 to 140	±12*	±5	Yes		Yes	Yes	Based on analysis results, the ALSEP Flight 5 enclosure facing the equator will be closed off, the electronics mounting plate will be remasked, and a new sun compass and bubble level will be installed.
CPLEE	B, C	3, 4	13, 14	-50 to 150	±2.5	±2	Yes	Yes	Yes	Yes	For scientific considerations, new support legs and leveling bubble will be added to ALSEP Flight 4 model for vertical alignment to keep experiment orientation the same as at the equator.
ASE	C, D	4, 5	14, 16	-76 to 185	±10	-			Yes	Yes	A new leveling bubble will be installed on Flight 4 and subsequent flights to provide ± 5° vertical alignment.
CCGE	B	3	13	-45 to 165	±5	±5				Yes	No flights planned where deployment location is greater than ±5° latitude from lunar equator.

*This alignment tolerance will be changed to ±5 degrees for Array D.

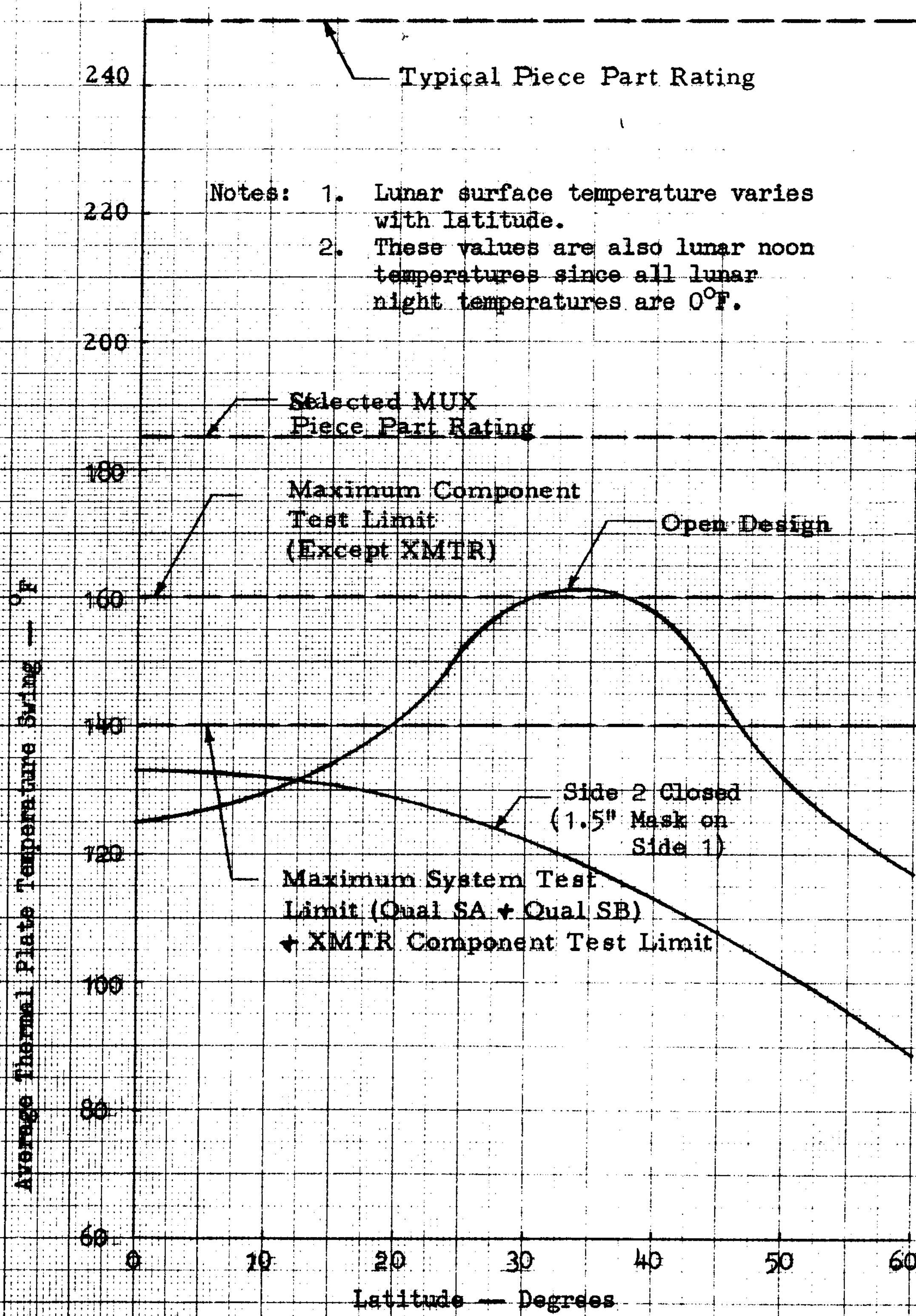


Figure 3-1. Comparison of Thermal Performances for Open and Closed Side 2 Configurations

Notes: 1. Values are based on a 250°F lunar surface temperature at lunar noon at all latitudes.
2. These values are also lunar noon temperatures since all lunar night temperatures are 0 °F.

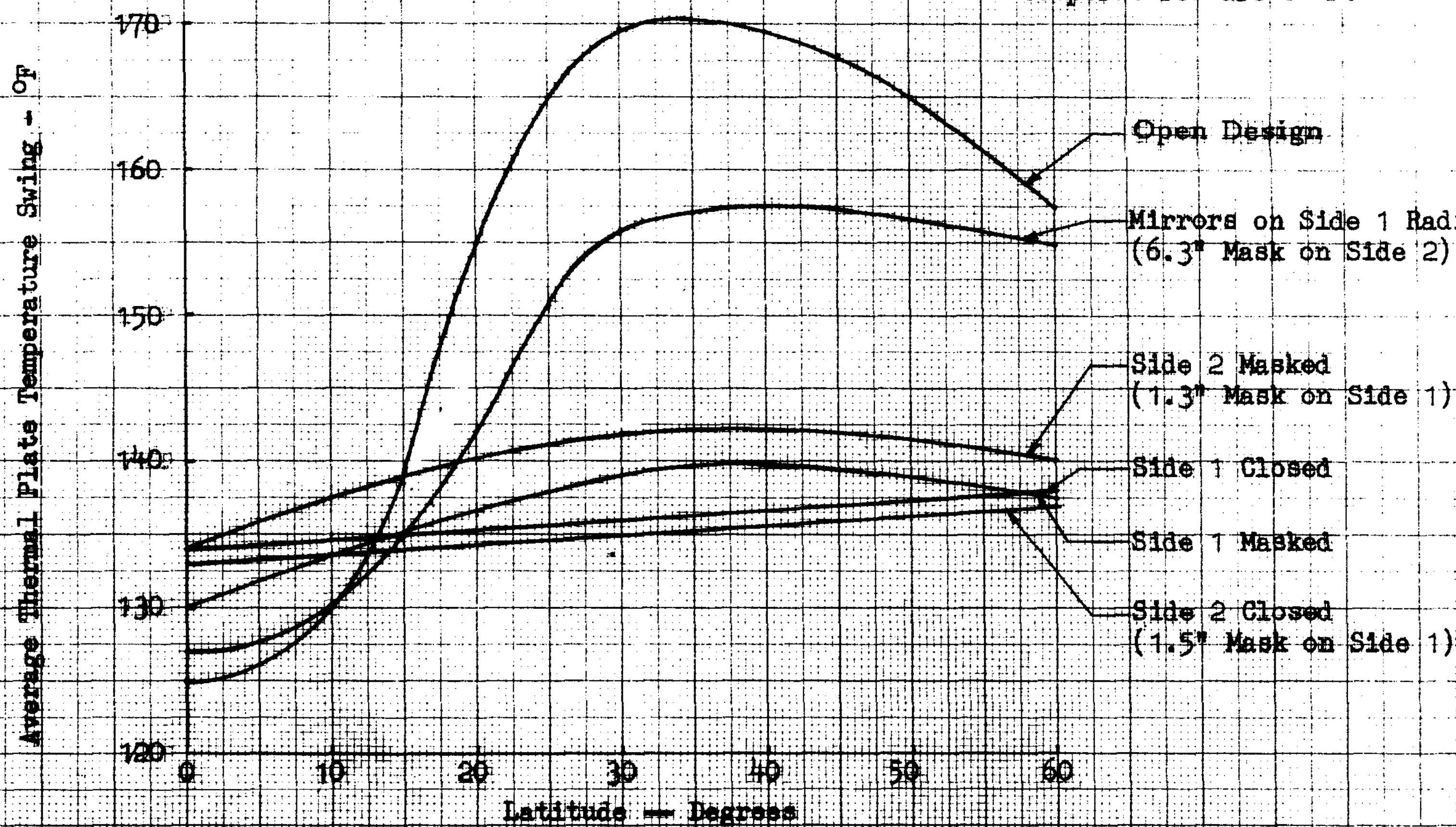
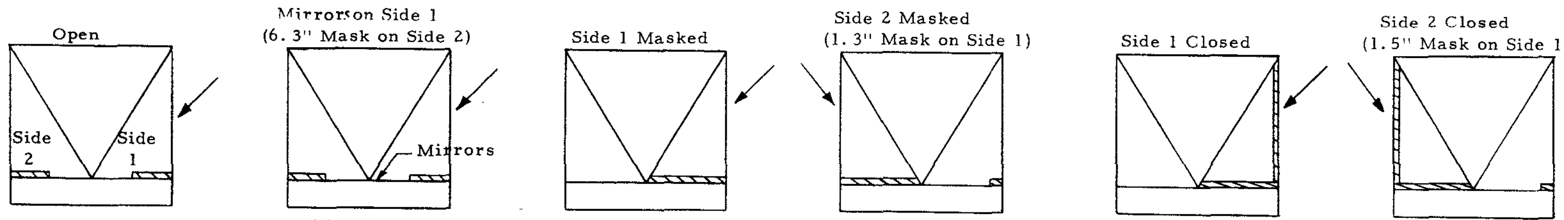


Figure 3-2. Predicted Average Thermal Plate Temperature Swing vs. Latitude for Various Central Station Thermal Designs

TABLE 3-4

AVERAGE THERMAL PLATE AND CRITICAL ELECTRONIC COMPONENT TEMPERATURES
FOR CANDIDATE ALSEP CENTRAL STATION THERMAL DESIGNS



NOTES;

1. Indicates thermal plate mask.

2. Indicates direction of solar energy.

3. Exposed thermal plate areas coated with S13G white paint unless noted otherwise.

4. Values are for constant 250°F lunar surface temperature.

Design	Latitude, Degrees	Thermal Plate, °F Noon	Thermal Plate, °F Night	Thermal Plate, °F Swing	PCU, °F Noon	PCU, °F Night	PDU, °F Noon	PDU, °F Night	Transmitter, °F Noon	Transmitter, °F Night
Open	0	125 ± 8	0 ± 8	125 ± 16	183	55	151	24	130	2
	15	139 ± 8	0 ± 8	139 ± 16	194	55	162	24	138	2
	30	169 ± 10	0 ± 8	169 ± 18	228	55	195	24	169	2
	45	168 ± 10	0 ± 8	168 ± 18	225	55	193	24	167	2
	60	158 ± 9	0 ± 8	158 ± 17	215	55	183	24	158	2
Mirrors on Side 1 (6.3" Mask on Side 2)	0	127 ± 6	0 ± 8	127 ± 14	183	56	151	24	130	3
	15	135 ± 7	0 ± 8	135 ± 15	191	56	158	24	137	3
	30	156 ± 7	0 ± 8	156 ± 15	213	56	180	24	157	3
	45	157 ± 7	0 ± 8	157 ± 15	213	56	180	24	157	3
	60	155 ± 7	0 ± 8	155 ± 15	212	56	180	24	156	3
Side 1 Masked	0	130 ± 13	0 ± 14	130 ± 27	191	60	159	28	121	-10
	15	135 ± 15	0 ± 14	135 ± 29	196	60	164	28	125	-10
	30	139 ± 16	0 ± 14	139 ± 30	201	60	169	28	128	-10
	45	140 ± 15	0 ± 14	140 ± 29	201	60	169	28	128	-10
	60	137 ± 15	0 ± 14	137 ± 29	198	60	166	28	126	-10
Side 2 Masked (1.3" Mask on Side 1)	0	134 ± 6	0 ± 15	134 ± 21	185	51	153	29	144	-9
	15	139 ± 8	0 ± 15	139 ± 23	189	51	157	29	151	-9
	30	142 ± 8	0 ± 15	142 ± 23	192	51	160	29	154	-9
	45	142 ± 8	0 ± 15	142 ± 23	192	51	160	29	154	-9
	60	140 ± 7	0 ± 15	140 ± 22	190	51	158	29	152	-9
Side 1 Closed	0	134 ± 15	0 ± 15	134 ± 30	195	61	163	30	124	-10
	15	135 ± 14	0 ± 15	135 ± 29	196	61	164	30	125	-10
	30	136 ± 14	0 ± 15	136 ± 29	197	61	165	30	126	-10
	45	137 ± 14	0 ± 15	137 ± 29	198	61	166	30	127	-10
	60	138 ± 14	0 ± 15	138 ± 29	199	61	167	30	128	-10
Side 2 Closed (1.5" Mask on Side 1)	0	133 ± 8	0 ± 5	133 ± 13	183	50	151	17	145	12
	15	134 ± 5	0 ± 5	134 ± 10	184	50	152	17	146	12
	30	135 ± 5	0 ± 5	135 ± 10	185	50	153	17	147	12
	45	136 ± 5	0 ± 5	136 ± 10	186	50	154	17	148	12
	60	137 ± 5	0 ± 5	137 ± 10	187	50	155	17	149	12

Based on the thermal plate temperatures shown in Figure 3-1, the open design should be used at latitudes up to approximately 10 degrees with the closed design used at all higher latitudes. However, additional studies on the temperatures of critical C/S enclosure materials have shown that the side curtains and specular reflector in the open design enclosure may exceed their maximum allowable service temperatures at latitudes between 5 and 10 degrees. Consequently, from overall C/S temperature considerations, the open design is proposed for use at latitudes up to 5 degrees and the closed side 2 design for use at all higher latitudes.

3.2.2 Effects of Dust and Misalignment on Thermal Plate Temperatures

During crew deployment of the central station on the lunar surface, dust may accumulate on surfaces within the open enclosures even though the C/S is designed to keep dust off these surfaces after deployment. Since dust contamination increases the solar absorptance of the affected surfaces, the solar load within an enclosure would rise above the nominal expected level and cause an undesirable rise in thermal plate temperature. Also, the accuracy with which the C/S is aligned can influence the thermal plate temperature in two ways: east-west and vertical alignment affect the amount of solar radiation which enters an enclosure, and vertical misalignment of the closed C/S design will increase or decrease the view to space of the exposed thermal plate. Consequently, a study was conducted to evaluate the effects of C/S misalignment and dust contamination on thermal plate temperature for both the open and closed side 2 designs, the results being presented in Figure 3-3. This figure applies for a lunar noon condition, which is when dust and misalignment produce a maximum effect on the thermal plate. Values in Figure 3-3 were based on the following assumptions:

1. The C/S is vertically misaligned 5 degrees.

2. The sun is at a solstice condition (the solar ecliptic is 1.5 degrees off the lunar equatorial plane).

3. Only the outer 7 inches of enclosure surfaces are dust-covered; i.e., dust penetrates to a distance of 7 inches into the enclosure from the outer edges of the insulation masks.

4. Dust increases the insulation mask solar absorptance from 0.15 to 0.9.

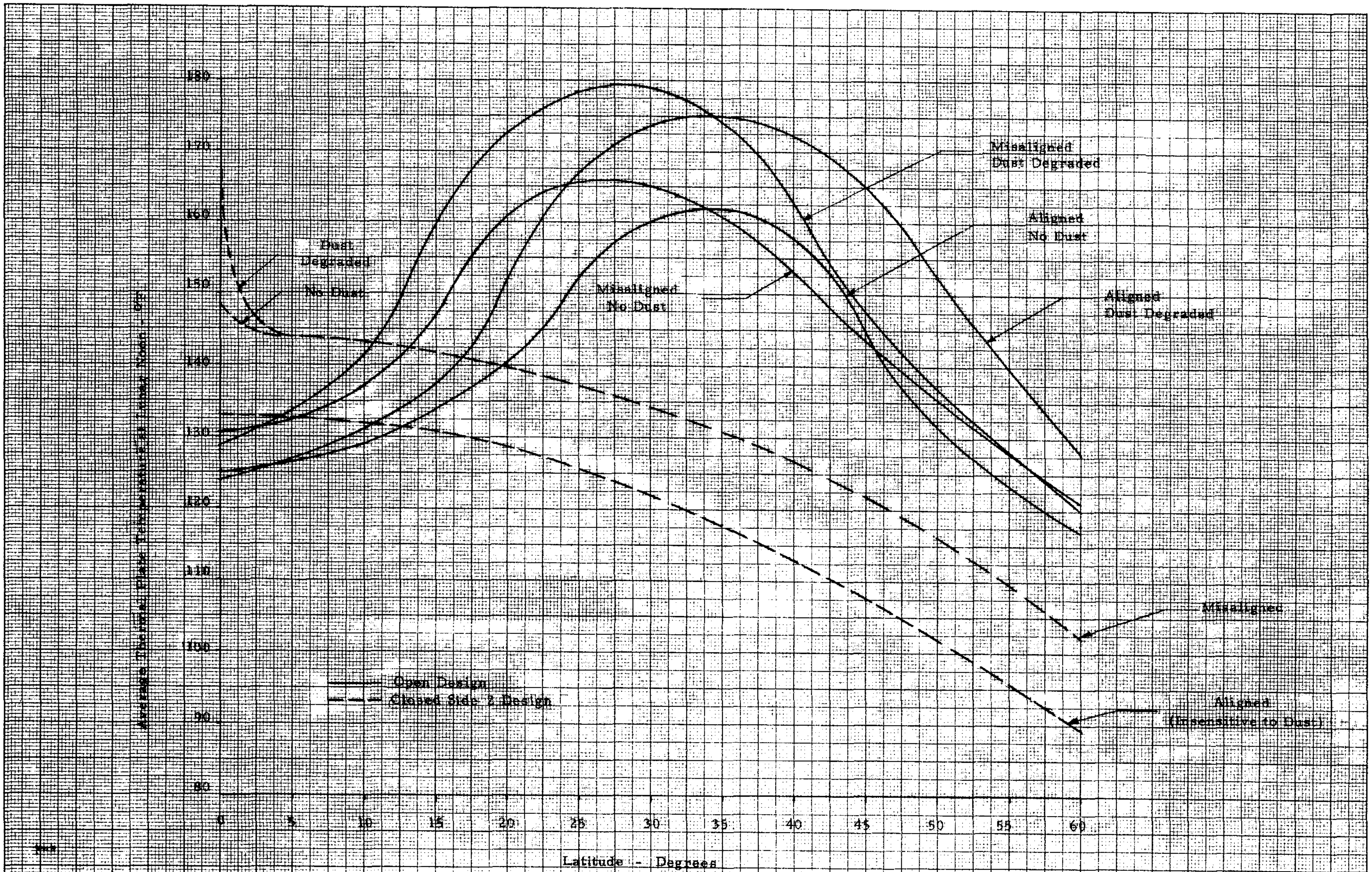


Figure 3-3. Predicted Thermal Plate Temperature for Dust Degradation and C/S Misalignment

5. Dust increases the insulation mask infrared emissivity from 0.6 to 0.9.

6. Dust increases the thermal plate solar absorptance from 0.2 to 0.6.

For each latitude, the worst-case alignment configuration and solstice conditions were the basis for temperature predictions. East-west misalignment was ignored since it has negligible effect on the maximum thermal plate temperatures that occur at lunar noon.

Based on a 5° vertical misalignment and the 1.5° variation of the solar ecliptic from the lunar equatorial plane, solar energy can enter the open enclosure of the closed side 2 design only at latitudes less than 6.5 degrees. However, the effect of dust contamination on the closed design thermal plate temperature at these low latitudes can be considerable, as shown by Figure 3-3. Beyond 6.5°, only the vertical alignment significantly affects this configuration, with the worst-case misalignment being a 5° vertical tilt of the open side 1 towards the lunar surface. For a perfectly aligned closed side 2 C/S, dust has a negligible thermal effect since very little solar energy can enter the open enclosure.

The impact of dust and vertical misalignment on the open design thermal plate temperature is relatively small at low latitudes but becomes large at latitudes beyond 10 degrees.

Table 3-5 summarizes the effects of dust and misalignment on the open and closed design temperature levels for latitudes between 0° and 45°.

3.2.3 Specular Reflector and Side Curtain Temperatures

As the solar impingement angle to the plane of the open sides of the open C/S design is increased due to latitude, solar variation, vertical misalignment, and/or east-west misalignment, the kapton and mylar enclosure materials approach and may even exceed their maximum allowable service temperatures as shown in Figure 3.4. For example, at a 30° latitude with a 5° east-west misalignment condition, the undegraded mylar specular reflector and kapton side curtains achieve maximum temperatures of 285°F and 650°F as compared to their recommended maximum service temperatures of 300°F and 750°F, respectively. If the mylar and Kapton surfaces were

TABLE 3-5

EFFECT OF DUST AND MISALIGNMENT ON THERMAL PLATE TEMPERATURES AT VARIOUS LATITUDES

Configuration	Deployment Condition	Thermal Plate Average Temperature-°F			
		0° Lat.	15° Lat.	30° Lat.	45° Lat.
Open	Aligned-No Dust	125	134	160	145
	Aligned-Dust Degraded	124	138	174	165
	Misaligned-No Dust	131	147	165	144
	Misaligned-Dust Degraded	129	160	179	148
Closed Side 2	Aligned-No Dust	133	131	122	108
	Aligned-Dust Degraded	133	131	122	108
	Misaligned-No Dust	148	142	134	122
	Misaligned-Dust Degraded	167	142	134	122

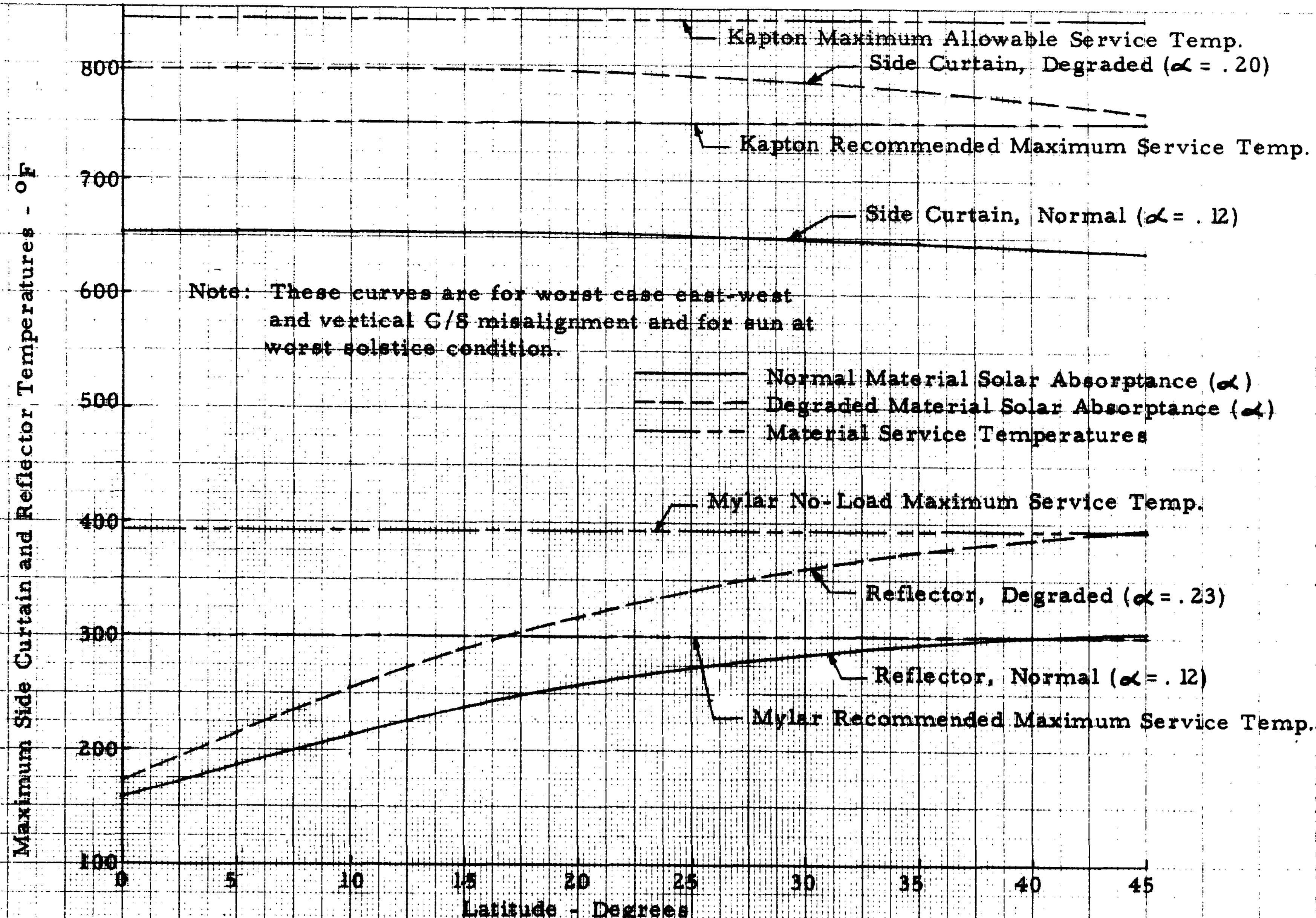


Figure 3-4. Effect of Latitude on Specular Reflector and Side Curtain Temperatures for Open Configuration

to become degraded to the low extent indicated in Figure 3-4, the reflector and side curtains could reach temperature levels of 360°F and 785°F, respectively.

As shown by Table 3-6, temperatures of enclosure materials in the closed side 2 design are considerably lower than for the open design at latitudes greater than 5 degrees due to the elimination of direct impingement of solar energy on components within the enclosures and due to negligible effect from degradation of surface properties. Due to the difficulty of accurately establishing the interreflection of solar energy within the exposed enclosure and due to the thermal sensitivity of the materials to solar degradation, it is recommended that the open design be used at latitudes within ± 5 degrees of the equator and the closed design be used at all higher latitudes.

To minimize the misalignment effect on enclosure temperatures for ALSEP, modifications to the present east-west alignment devices and procedures have been made to improve alignment of the central station with the lunar equator (refer to Sections 3.1.2 and 5.2 for details).

3.3 Effect of Lunar Surface Terrain on Central Station Thermal Performance

Craters, mounds, and local slopes can have a significant effect on central station thermal performance. Blockage of the horizon by rocks, hills, etc. produce the same effect as a slope. Table 3-7 summarizes the effect of 0° to 30° crater slopes, local slopes, and mound (elevated region) slopes on thermal plate temperatures for the open and closed side 2 C/S configurations with no misalignment. As illustrated in the table, positive local slope designates that the lunar surface on side 1 slopes upward towards the vertical to the thermal plate, while a negative sign indicates a downward slope from the vertical on side 1. Of course, all craters slope upward toward the vertical on both sides, while mounds slope away from the vertical on both sides.

The effect of lunar surface terrain on thermal plate temperature is also illustrated in the following figures:

TABLE 3-6

EFFECT OF LATITUDE ON SPECULAR REFLECTOR AND SIDE CURTAIN TEMPERATURES

		Temperature - °F *			
		Mylar Reflector		Kapton Side Curtain	
Configuration	Latitude, Degrees	Undegraded $\alpha = .12$	Degraded $\alpha = .23$	Undegraded $\alpha = .12$	Degraded $\alpha = .20$
Open	0	158	174	653	795
	5	185	215	654	796
	15	238	289	654	797
	30	285	360	650	785
	45	303	395	637	760
Side 2 Closed (1.5" Mask on Side 1)	0	166	182	661	803
	5	140	140	142	142
	15	138	138	140	140
	30	123	123	129	129
	45	108	108	115	115

* Kapton Recommended Maximum Service Temperature = 750°F

* Kapton Maximum Allowable Service Temperature = 840°F

* Mylar Recommended Maximum Service Temperature = 300°F

* Mylar No Load Maximum Service Temperature = 390°F

* These temperatures are for worst-case misalignment and solstice conditions.

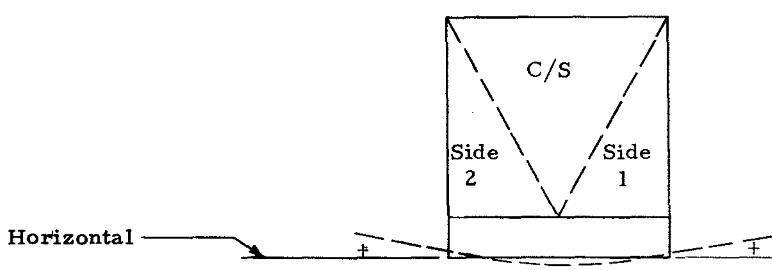
α = Solar absorptance

TABLE 3-7

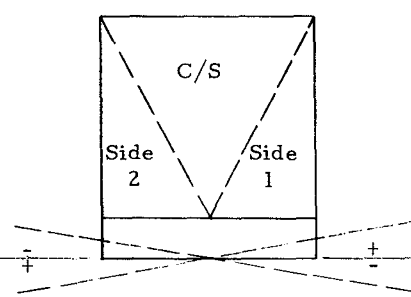
EFFECT OF CRATERS, LOCAL SLOPES, AND
MOUNDS ON THERMAL PLATE TEMPERATURE

C/S Configuration	Latitude, Degrees	Thermal Plate Average Temperature Swing - °F*														
		Crater Slope - Degrees				Local Slope - Degrees							Mound Slope - Degrees			
		0	5	15	30	-5	-15	-30	0	+5	+15	+30	0	5	15	30
Open	0	125	135	162	213	125	125	125	125	125	125	125	125	113	101	85
	15	134	141	168	219	134	134	134	134	134	134	134	134	119	108	94
	30	160	164	193	240	160	160	160	160	160	160	160	160	149	140	130
	45	145	151	187	233	145	145	145	145	145	145	145	145	136	129	119
Closed Side 2 (1.5" Mask on Side 1)	0	133	144	168	221	129	118	103	133	144	168	221	133	129	118	103
	15	131	143	168	221	128	117	102	131	143	168	221	131	128	117	102
	30	122	137	165	220	120	110	97	122	137	165	220	122	120	110	97
	45	108	125	157	214	107	98	87	108	125	157	214	108	107	98	87

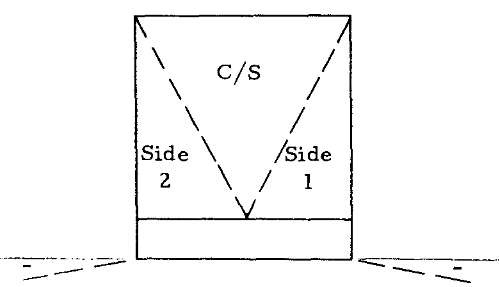
*Temperature swing and Lunar Noon Temperature are the same since all Lunar Night Temperatures are 0°F.



Crater Effect



Local Slope Effect



Mound Effect

Figures	Description
3-5 & 3-6	Crater Effect on Open Central Station Thermal Performance
3-7 & 3-8	Crater Effect on Closed Side 2 Central Station Thermal Performance
3-9 & 3-10	Negative Local Slope Effect on Closed Side 2 Central Station Thermal Performance
3-11 & 3-12	Mound Effect on Open Central Station Thermal Performance

The table and figures show the following results:

1. Thermal performance of the open central station design is essentially unaffected by local slope.

2. The closed side 2 configuration is thermally sensitive to local slope, with positive slope being detrimental and negative slope being beneficial. It is recommended that a closed side 2 central station design never be deployed on a positive slope greater than 5° but be deployed on a negative slope wherever possible.

3. Central stations for both configurations exhibit significant deterioration in thermal performance for operation in craters. Neither design should ever be deployed in craters with slopes greater than 5°.

4. A positive local slope exerts essentially the same influence on the thermal performance of the closed side 2 design as a crater with an equal slope, while a negative local slope exerts the same influence as a mound.

5. Both central stations have significant improvements in thermal performance if located on an elevated site (mound).

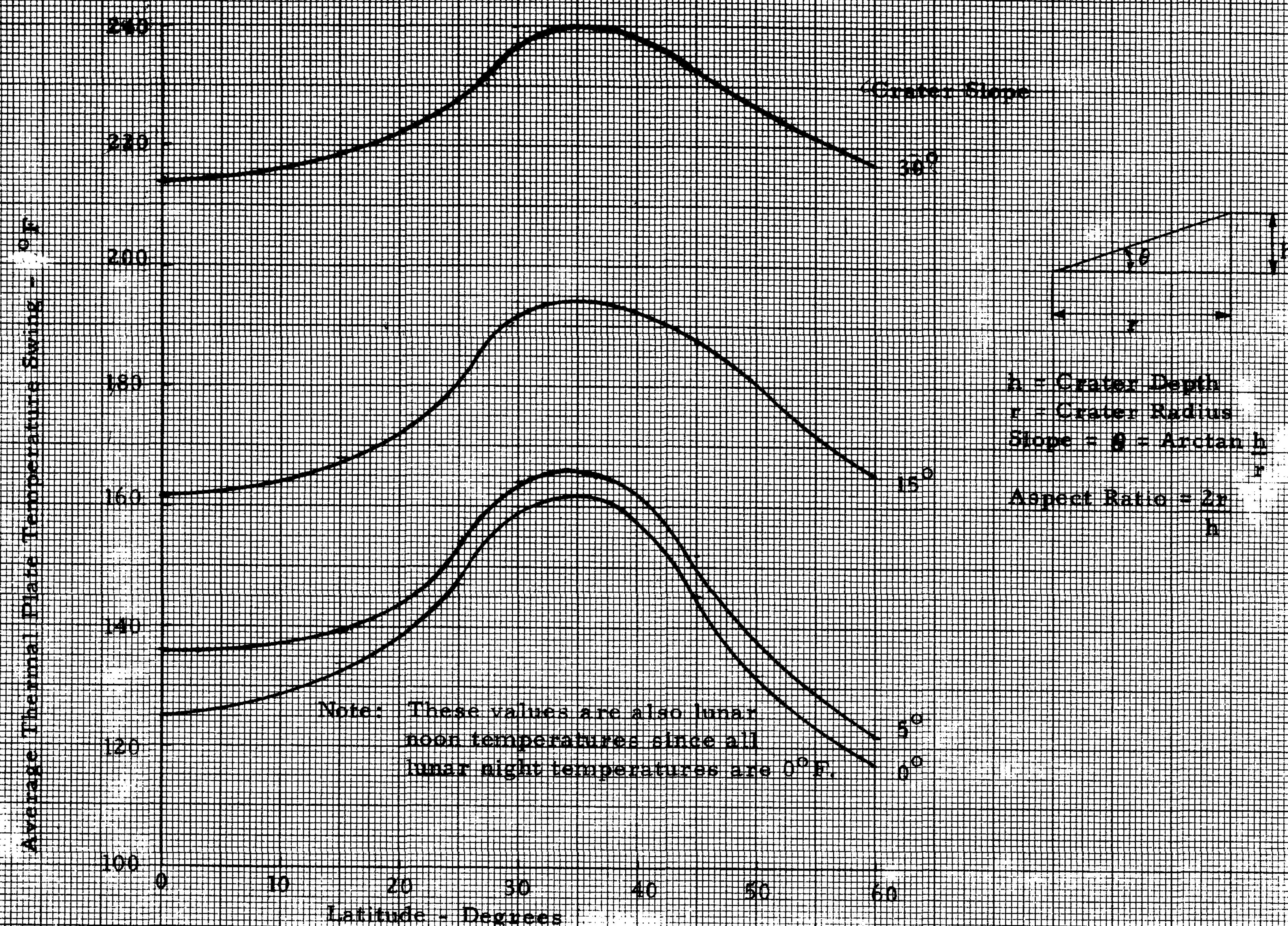


Figure 3-5. Effect of Craters on Open Configuration Thermal Performance

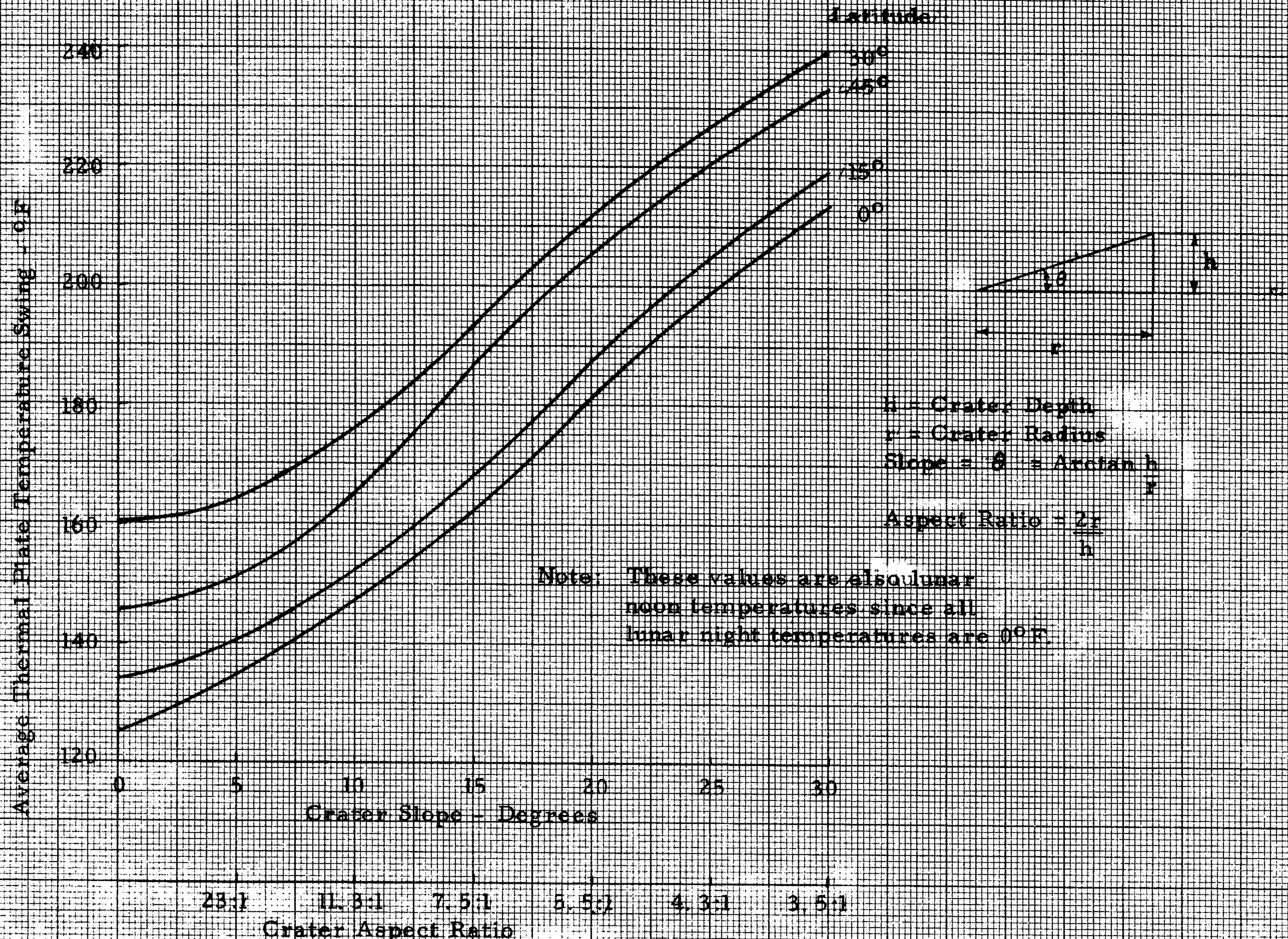


Figure 3-6. Effect of Craters on "Open" Configuration Thermal Performance

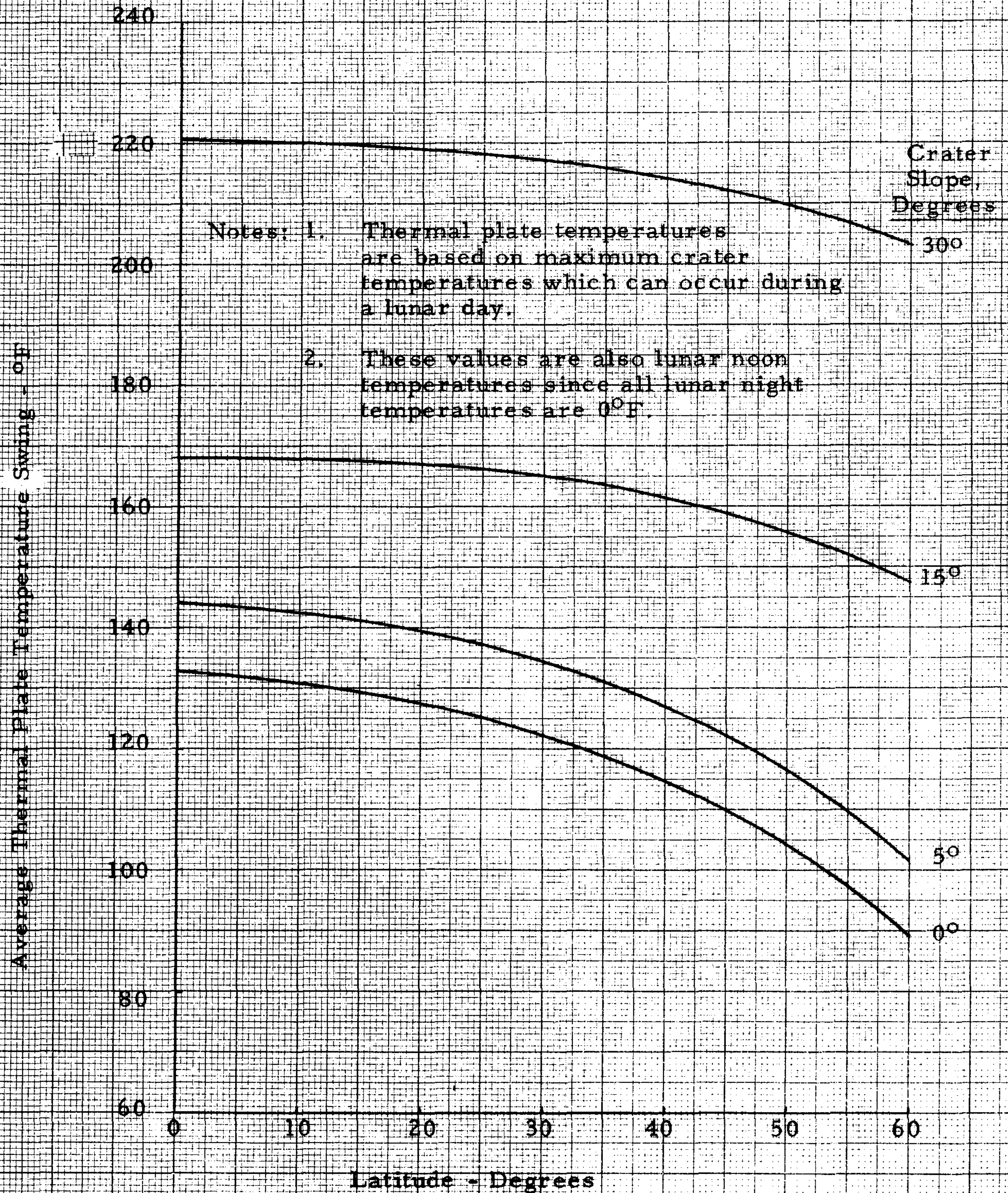


Figure 3-7. Effect of Craters on Central Station Thermal Performance of Closed Side 2 Configuration (1.5" Mask on Side 1)

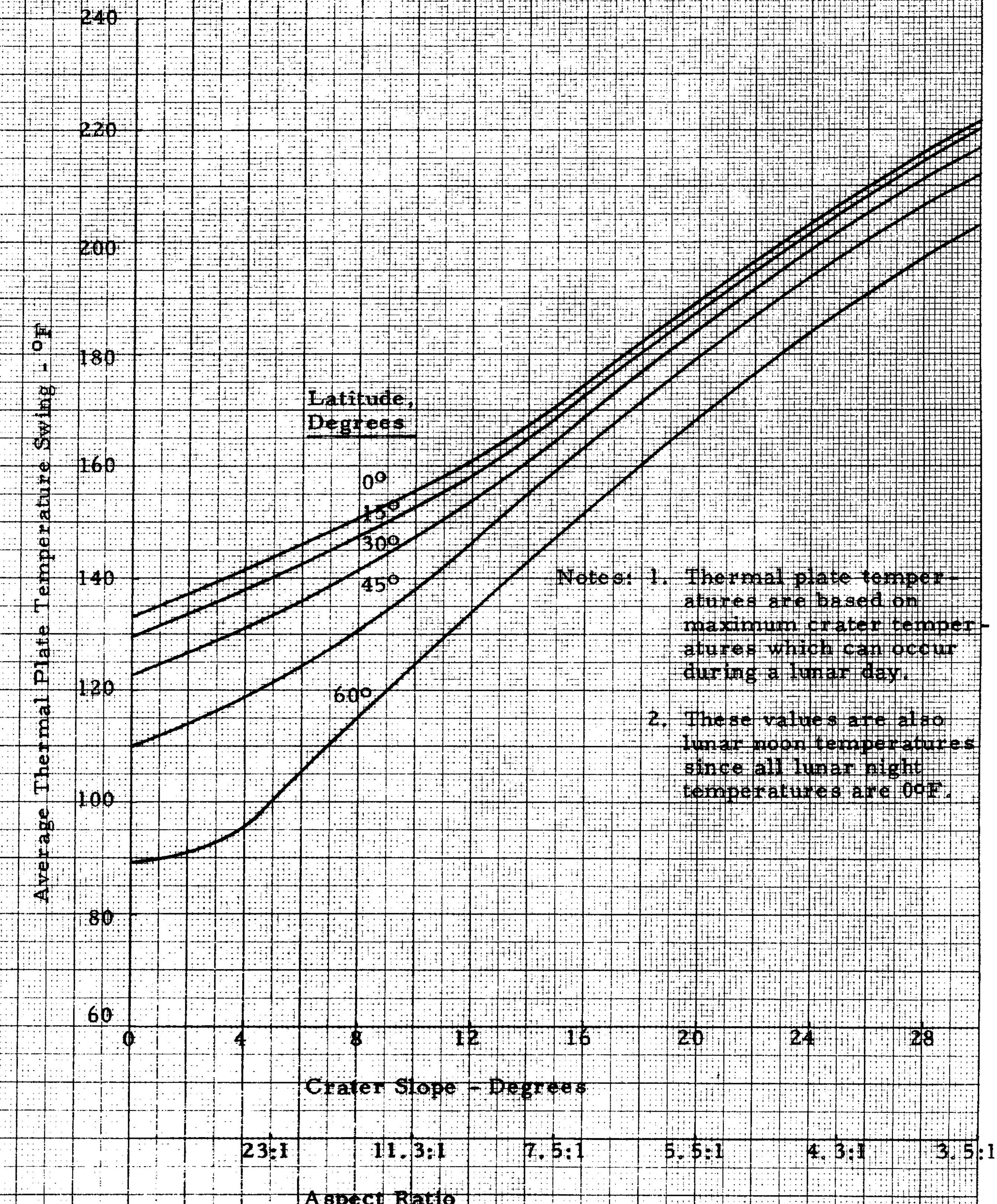


Figure 3-8. Effect of Craters on Central Station Thermal Performance of Closed Side 2 Configuration (1.5" Mask on Side 1)

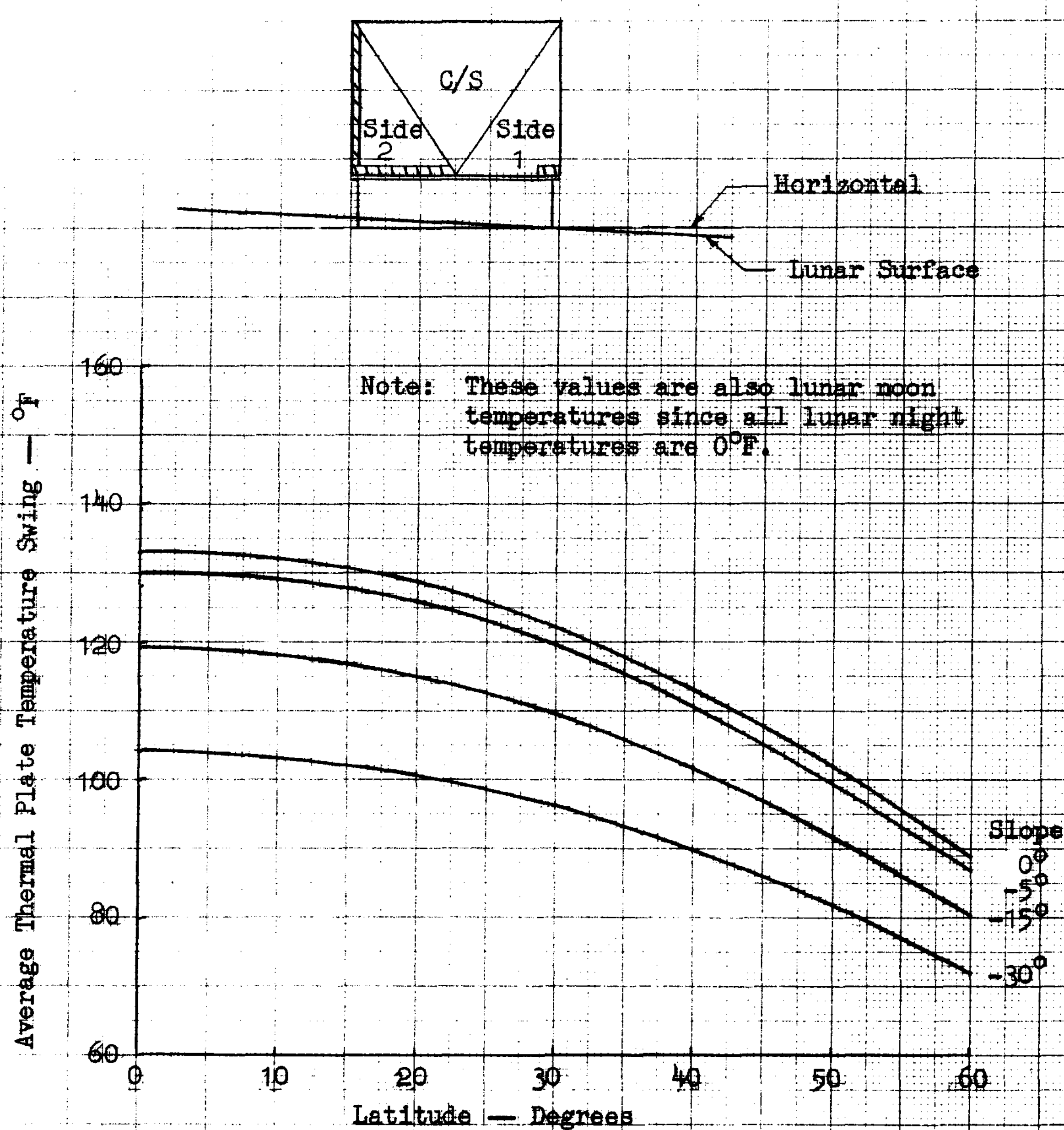


Figure 3-9. Effect of Negative Local Slope on Thermal Performance of Closed Side 2 Configuration with 1.5 inch Mask on Side 1

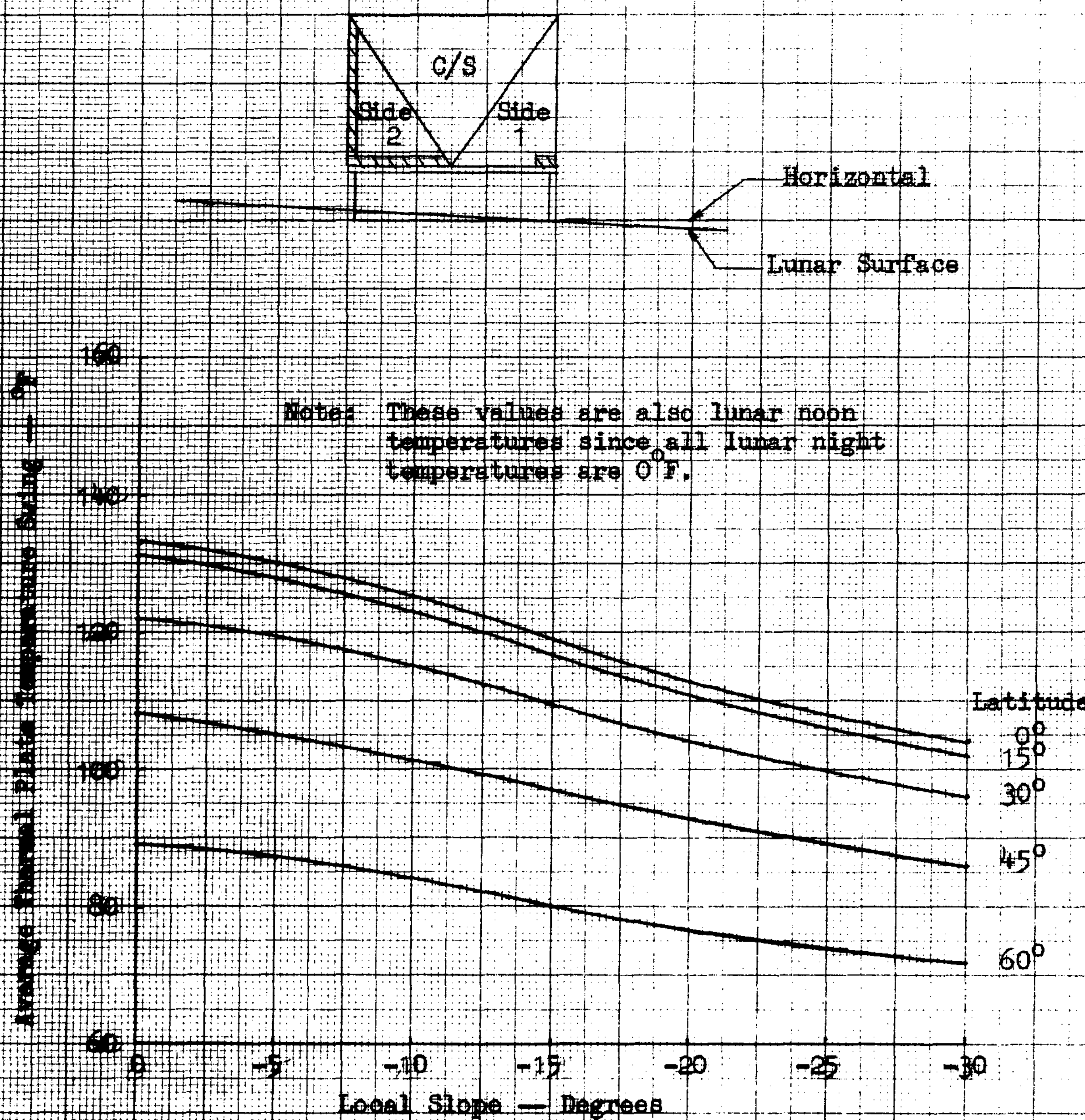


Figure 3-10. Effect of Negative Local Slope on Thermal Performance of Closed Side 2 Configuration with 1.5 inch Mask on Side 1

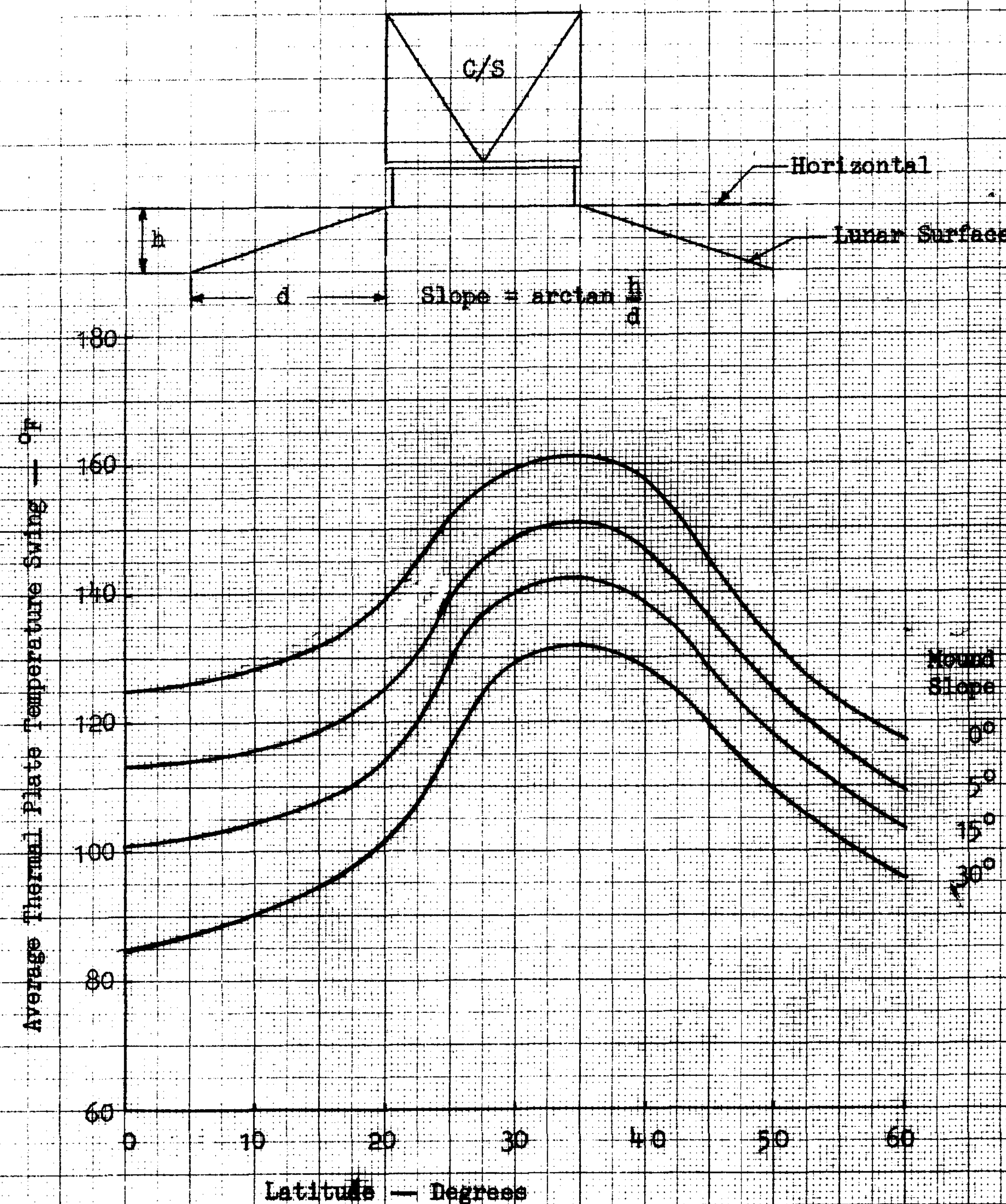


Figure 3-11. Effects of Elevated Deployment Sites (Mounds) on Thermal Performance of Open Central Station Design

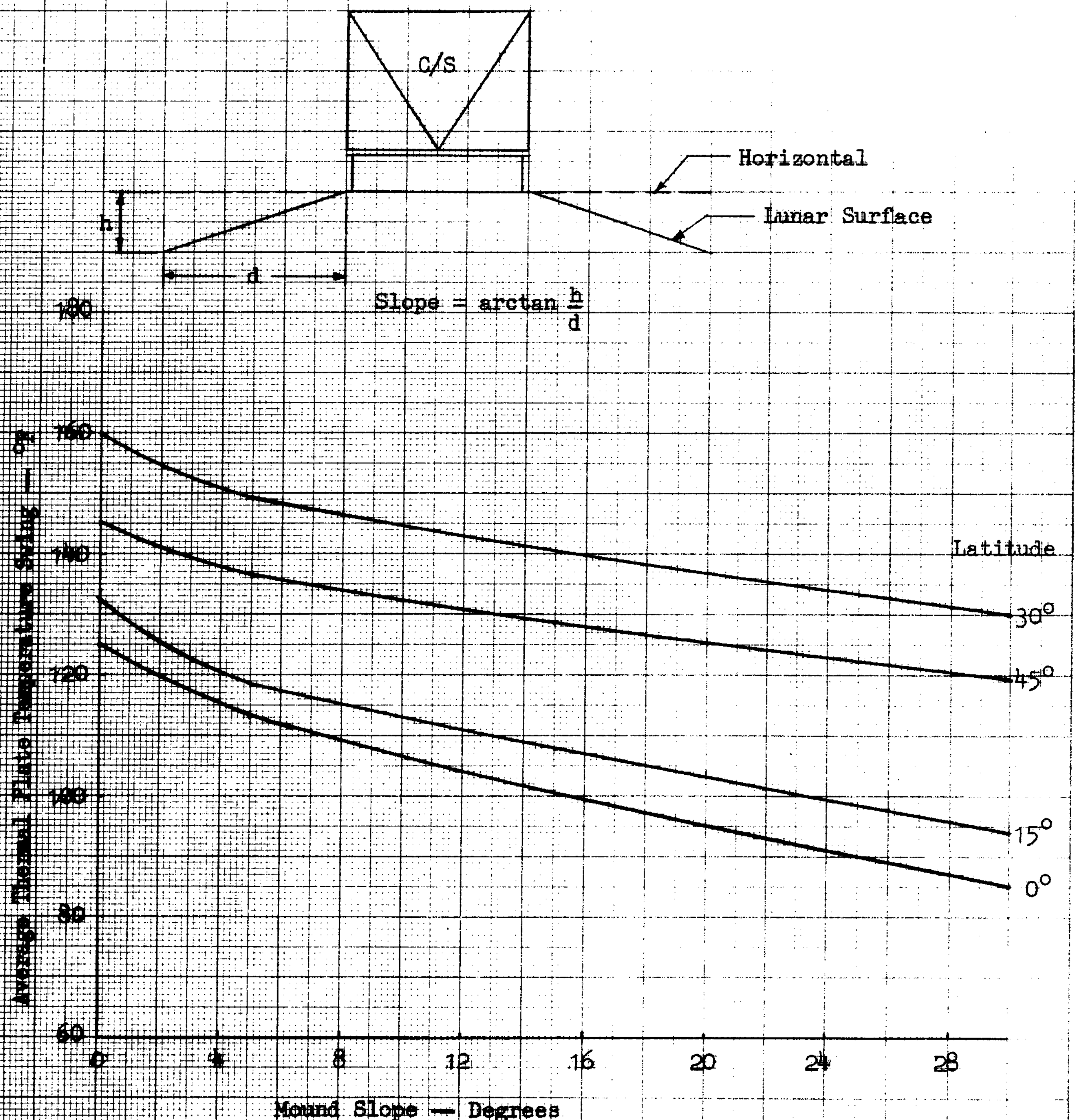


Figure 3-12. Effect of Elevated Deployment Sites (Mounds) on Thermal Performance of Open Central Station Design

3.4 Advantages of Closed Side 2 Configuration

Specific reasons why the closed side 2 configuration is recommended for Apollo Flights 14, 15, and 16 are listed below:

1. Lowest thermal plate temperature swing.

2. Least effect from central station misalignment and solar variation from the lunar equator. Only vertical alignment may affect the thermal performance.

3. Positive elimination of solar energy from the central station enclosures, which eliminates the problems of interreflection of solar energy and of possible degradation of surface radiation properties over the life of ALSEP.

4. Lowest temperatures for the critical side curtain and specular reflector components.

5. Lowest thermal plate temperature gradients. While the closed side 1 and side 2 configurations had comparable thermal plate temperature swings, the closed side 2 design exhibited lower temperature gradients.

3.5 Disadvantages of Closed Side 2 Configuration

Disadvantages of the closed side 2 design are listed below:

1. In contrast to the open design, the closed side 2 C/S is sensitive to the local slope of the lunar surface. A degradation in thermal performance occurs if side 1 is tilted towards the lunar surface.

2. At latitudes less than 5 degrees, the C/S is quite sensitive to solar energy impingement within the open enclosure since the 1.5" mask does little to prevent direct solar heating of the thermal plate. As shown by Figure 3-3 for an equatorial deployment site, the thermal plate average temperature would increase a predicted 14°F to a level of 147°F with no dust degradation for a solar solstice condition and for a vertical misalignment of 5°. Consequently, the closed side 2 configuration is not recommended for low latitude deployment

sites unless special precautions are implemented to insure near-perfect alignment and the subsequent minor solar heating effect on C/S thermal performance.

4.0 THERMAL ANALYSIS

Many of the studies performed for this report were based on a node-resistor thermal model which simulates the C/S components and the heat transfer between them. This model is described in Reference 4. Data on nodes and resistors are input to the Bendix "Thermal Analyzer" computer program along with information on solar, electronic, and PDM panel heating. The program, which employs a finite difference solution, then establishes the steady state node temperatures. The various solar heat inputs to the thermal model are described below.

4.1 Solar Heating of Central Station Enclosure at Lunar Noon

In order to evaluate the maximum thermal plate temperature for each design at off-equator latitudes, the solar energy absorbed by the illuminated C/S enclosure surfaces at lunar noon was determined by means of a computer program which considers both reflected and direct absorbed energy. The absorbed heat fluxes are tabulated as a function of latitude for the various configurations in Table 4-1. Note that only the external surface of the enclosure curtains for the closed side 1 and 2 configurations absorbs solar energy.

Figures 4-1 and 4-2 illustrate the relationship between illuminated area and latitude for the open side 1 and 2 designs. At a latitude of sixty degrees, 99% of the combined area of the radiator, mask, and the reflector within the enclosure facing the equator is illuminated.

4.2 Solar Heating of Central Station Enclosure at Lunar Sunset

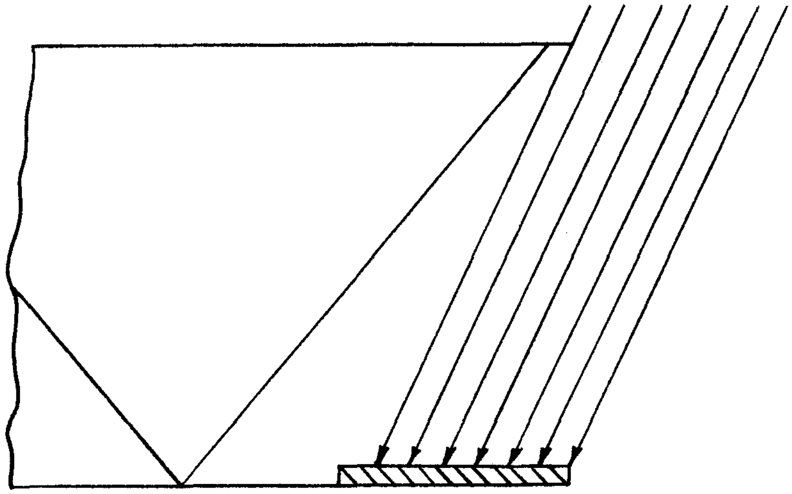
In order to evaluate the maximum side curtain and specular reflector temperatures for the original open design at off-equator latitudes, the solar energy absorbed by illuminated enclosure surfaces at lunar sunset was determined and listed in Table 4-2. The energy absorbed by the side curtains and reflector is also roughly applicable to the other open enclosure configurations.

TABLE 4-1

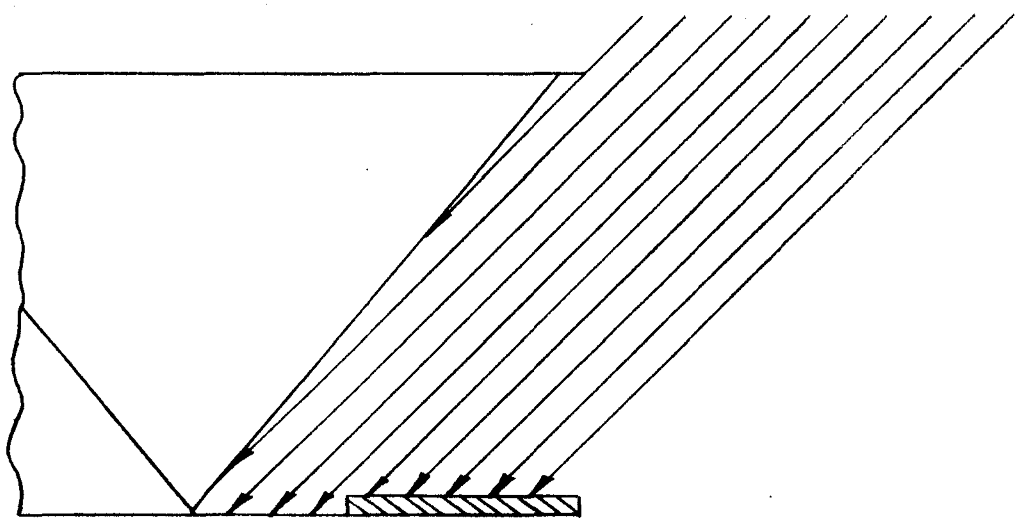
ABSORBED SOLAR ENERGY (BTU/HR) AT LUNAR NOON BY ENCLOSURE SURFACES FACING SUN FOR CANDIDATE CENTRAL STATION THERMAL DESIGNS

Configuration	Latitude, Degrees	Thermal Plate	Mask	Side Curtains	Sunshield Overhang	Specular Reflector
Open	0	0	0	0	0	0
	15	4.9	83.0	18.6	3.0	12.0
	30	76,4	81.7	30.2	4.7	46.3
	45	65.3	69.1	27.9	4.5	112.3
	60	40.4	42.5	20.2	2.5	170.5
Mirrors on Side 1	0	0	0	0	0	0
	15	2.0	83.1	18.4	3.0	12.1
	30	31.0	82.4	32.1	5.0	48.0
	45	26.5	69.6	29.5	4.7	113.7
	60	20.6	52.3	25.1	4.1	174.1
Side 1 Masked	0	0	0	0	0	0
	15	0	71.5	14.9	2.4	9.6
	30	0	139.7	31.1	4.8	47.1
	45	0	131.4	28.1	4.5	112.4
	60	0	73.1	20.7	3.4	170.9
Side 2 Masked	0	0	0	0	0	0
	15	0	69.8	20.0	2.1	10.4
	30	0	113.0	34.3	3.5	38.7
	45	0	106.6	31.2	3.2	89.9
	60	0	60.2	23.5	2.5	135.6

Notes:
1. Surfaces within the enclosures for the closed-off enclosure designs absorb no solar radiation directly due to the nature of the designs.
2. For brevity, the solar energy absorbed by the side curtains was combined for presentation in this table.



15° Latitude



30° Latitude

Note: Figures are for no misalignment and Lunar noon

Figure 4-1. Solar Impingement on ALSEP Central Station Enclosure at 15° and 30° Lunar Latitudes

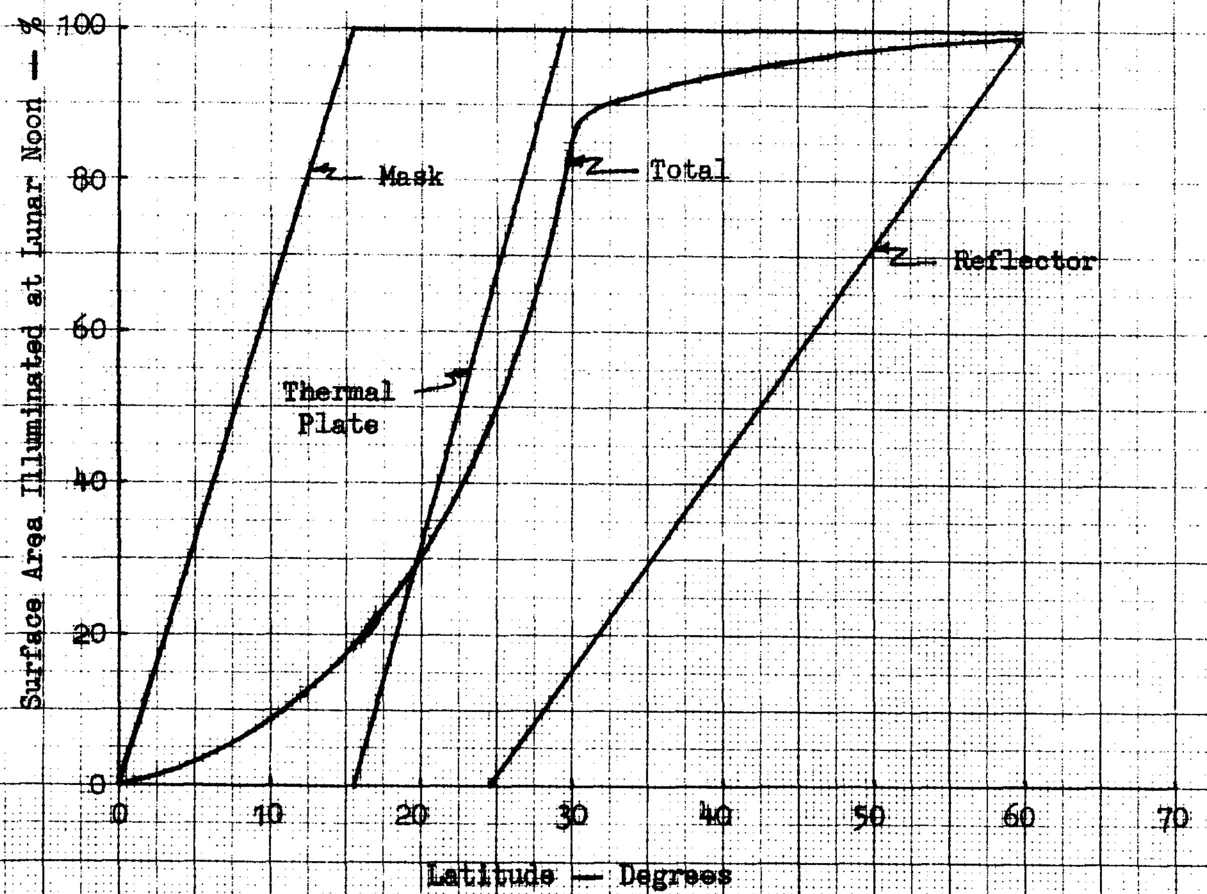
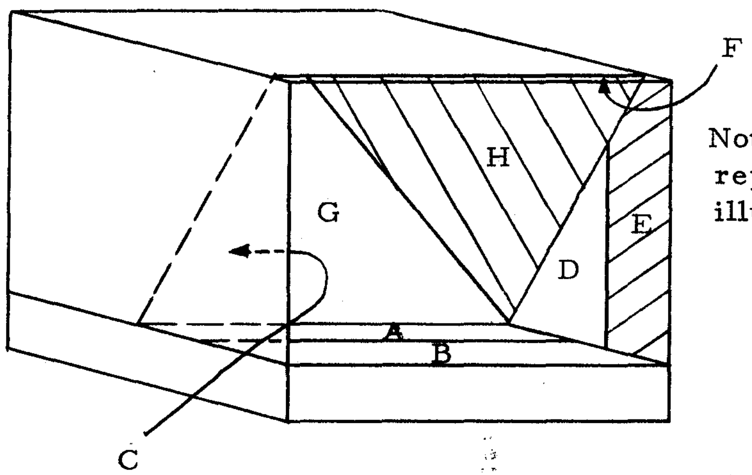


Figure 4.2. Illuminated Areas of Open Design Side 1 Enclosure Surfaces at Lunar Noon

TABLE 4-2

ABSORBED SOLAR ENERGY (BTU/HR) AT LUNAR SUNSET FOR OPEN CENTRAL STATION CONFIGURATION



Note: Shaded regions represent directly illuminated Surfaces.

Latitude, Degrees	Solar Absorptivity	Enclosure Surface A	B	C	D	E	F	G	H
0	Normal	3.0	5.3	3.0	.5	29.0	1.7	2.0	4.0
5	↓	4.3	7.7	4.2	.5	38.0	1.9	2.6	8.2
15		6.9	11.1	6.0	.5	49.3	2.9	3.7	21.6
30		11.1	12.6	7.1	.5	55.9	6.3	4.5	47.5
45		15.2	12.8	7.1	*	57.0	11.1	4.7	73.0
0	Degraded	2.6	4.8	4.6	.8	44.0	1.5	1.7	6.0
5	↓	3.8	7.0	6.4	.8	60.0	1.7	2.3	13.2
15		6.1	9.8	9.0	.8	82.8	2.6	3.3	36.1
30		9.9	11.2	10.5	.7	90.8	5.6	4.0	84.5
45		13.6	11.4	10.8	*	91.2	9.5	4.2	136.0

* Region D does not exist since the entire side curtain is directly illuminated.

5.0 DISCUSSION

5.1 Modifications to Central Station Design

5.1.1 Thermal Design Modifications

As discussed previously, a closed side 2 central station design is proposed for ALSEP Flight 4 and for any future flights where ALSEP will be deployed at latitudes greater than ± 5 degrees. To obtain the closed side 2 configuration, some minor modifications (briefly summarized below) to original C/S hardware are required.

1. Add a rear curtain, which closes off the side 2 enclosure. This curtain is comprised of the following materials:

   a. Two (2) outer layers of 1.0 mil aluminized Kapton with gold side facing out ($\alpha/\epsilon = .45/.76$).

   b. Nine (9) layers of aluminized mylar.

   c. Ten (10) silk separators.

   d. One (1) inner layer of 1.0 mil aluminized Kapton with aluminized side facing the other enclosure surfaces ($\alpha/\epsilon = .10/.02$).

2. Fasten a fitting for side 2 rear curtain attachment to the rear upper flange of the primary structure.

3. Add a rear curtain protection shield.

4. Add velcro pads for attaching the rear curtain to other central station surfaces.

5. Install new insulation masks on the thermal plate on sides 1 and 2.

Pictures of the undeployed and deployed Flight 4 closed side 2 central station are shown in Figures 5-1 and 5-2, respectively. Note the new rear curtain stowed behind the protection shield in Figure 5-1.

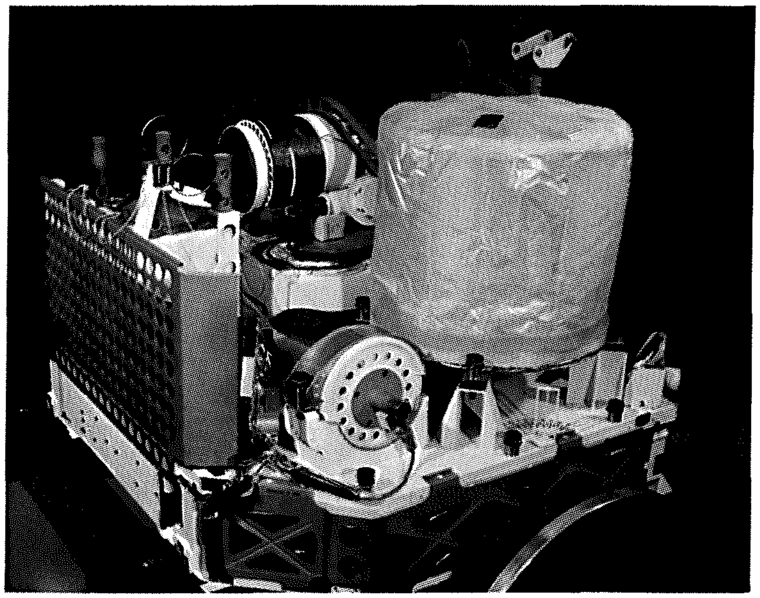


Figure 5-1. Undeployed Flight 4 Closed Side 2 Central Station

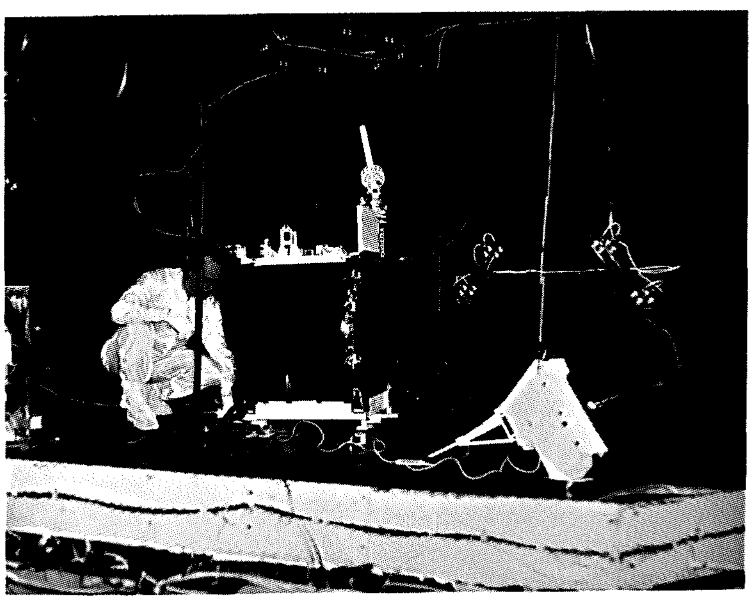


Figure 5-2. Deployed Flight 4 Closed Side 2 Central Station

5.1.2 Modification to Alignment Device

The original gnomon/compass rose alignment concept for the central station was predicated on ALSEP deployment on the lunar equator. With proper leveling of the C/S, the shadow cast by the gnomon would lie in a true east-west direction throughout the lunar day, providing the sun would be at the equinox (i.e., the solar ecliptic would coincide with the lunar equatorial plane). Thus, no shadow would occur at lunar noon when the sun is at the zenith. When the C/S is aligned with the gnomon shadow, a true east/west alignment can not be obtained if the solar elciptic does not coincide with the lunar equatorial plane or if the C/S is deployed at off-equator latitudes. For any landing site, maximum alignment errors would result when deployment occurred at a solstice, which is the point in the solar ecliptic where the sun is farthest from the equator (± 1.5 degrees on the moon).

Consequently, if ALSEP were deployed on the equator at sunrise or sunset during a solstice condition, the gnomon shadows would form an angle of 1.5 degrees to the equator. This angle would progressively increase as the sun approached the zenith. Off-equator deployment increases the angle and thus compounds the problem.

The east-west alignment is most important in regard to the mylar specular reflector in the present C/S design. The reflector temperature increases as the solar impingement angle to the plane of the open sides of the C/S (front and rear) increases, and this solar impingement angle increases with an increase in angle between the C/S east-west axis and the equator. For the Apollo 13 tentative primary landing site (Fra Mauro - W17°, S4°) and for the worst case misalignment which could occur with the alignment tolerances listed in Section 3, a 180°F reflector temperature is predicted. This 180°F value is well below the 300°F recommended maximum service temperature for mylar but is based on an optimum undegraded solar absorptivity for mylar. Over the life of ALSEP the absorptivity could increase (degrade) sufficiently, due to dust or solar radiation effects, to cause reflector temperatures to approach the 300°F limit. However, no design modification is recommended for the Flight 3 C/S alignment device since the C/S is deployed so close to the equator that no significant improvement would be achieved with a design change.

To avoid possible temperature problems at latitudes beyond ± 5° from the lunar equator, a new sun compass, which will cover all landing sites within ± 45° latitude, has been installed on the Flight 4 C/S and will be installed on all subsequent flight models. This sun compass design, depicted in Figure 5-3, actually consists of two gnomons and compass roses to provide for deployment north or south of the lunar equator. To use the new sun compass to east-west align the C/S, it is necessary to know where the sun's shadow will fall on the compass rose. As mentioned previously, the shadow's position will be controlled by the deployment latitude, sun angle (time of day) and deviation of the solar ecliptic from the lunar equatorial plane.

Reference 5 provides the method for computing the location of the gnomon shadow on the compass rose for any deployment location. The method is briefly summarized below:

1. Establish the deployment latitude and the sun angle above the local lunar horizon at the time of deployment.

2. Obtain the alignment offset from Figure 5-4, which was extracted from reference 5. The alignment offset is the deviation of the gnomon shadow from the zero line at the solar equinox (sun is directly over the lunar equator).

3. Determine the angle of inclination of the solar ecliptic plane to the lunar equatorial plane. This angle varies between approximately - 1.5° to + 1.5° at the solstice conditions and may be obtained from an Ephemeris Almanac (e.g., reference 6).

4. Adjust the alignment offset as follows:

   a. If the solar ecliptic is inclined towards the hemisphere containing the deployment site, subtract the angle of inclination from the offset value.

   b. If the solar ecliptic is inclined towards the hemisphere opposite to the deployment site, add the angle of inclination to the offset value.

5. The C/S should then be aligned with the gnomen shadow falling on this corrected offset figure.

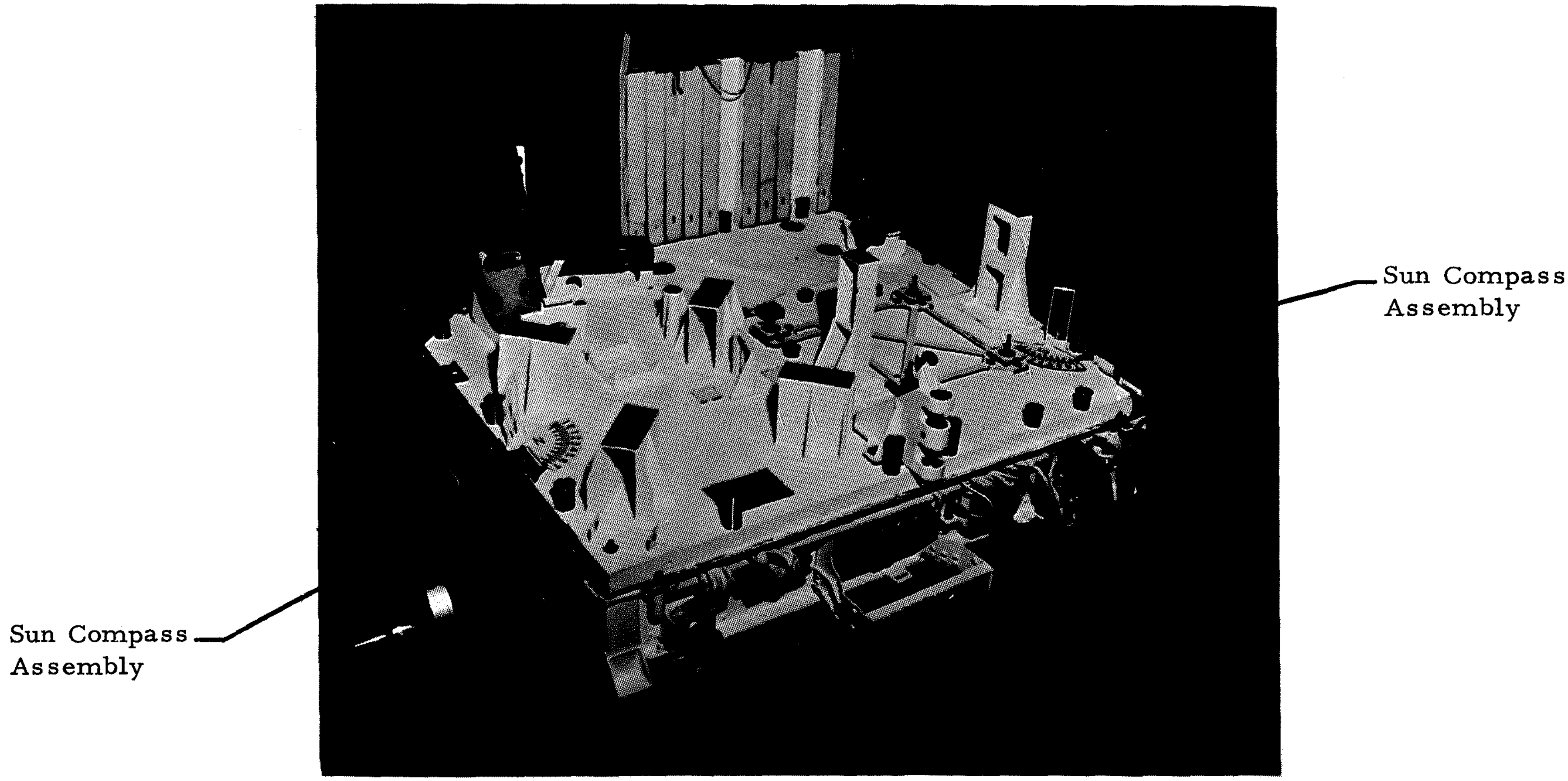


Figure 5-3. Modified ALSEP Flight 4 Central Station Sun Compass Assembly

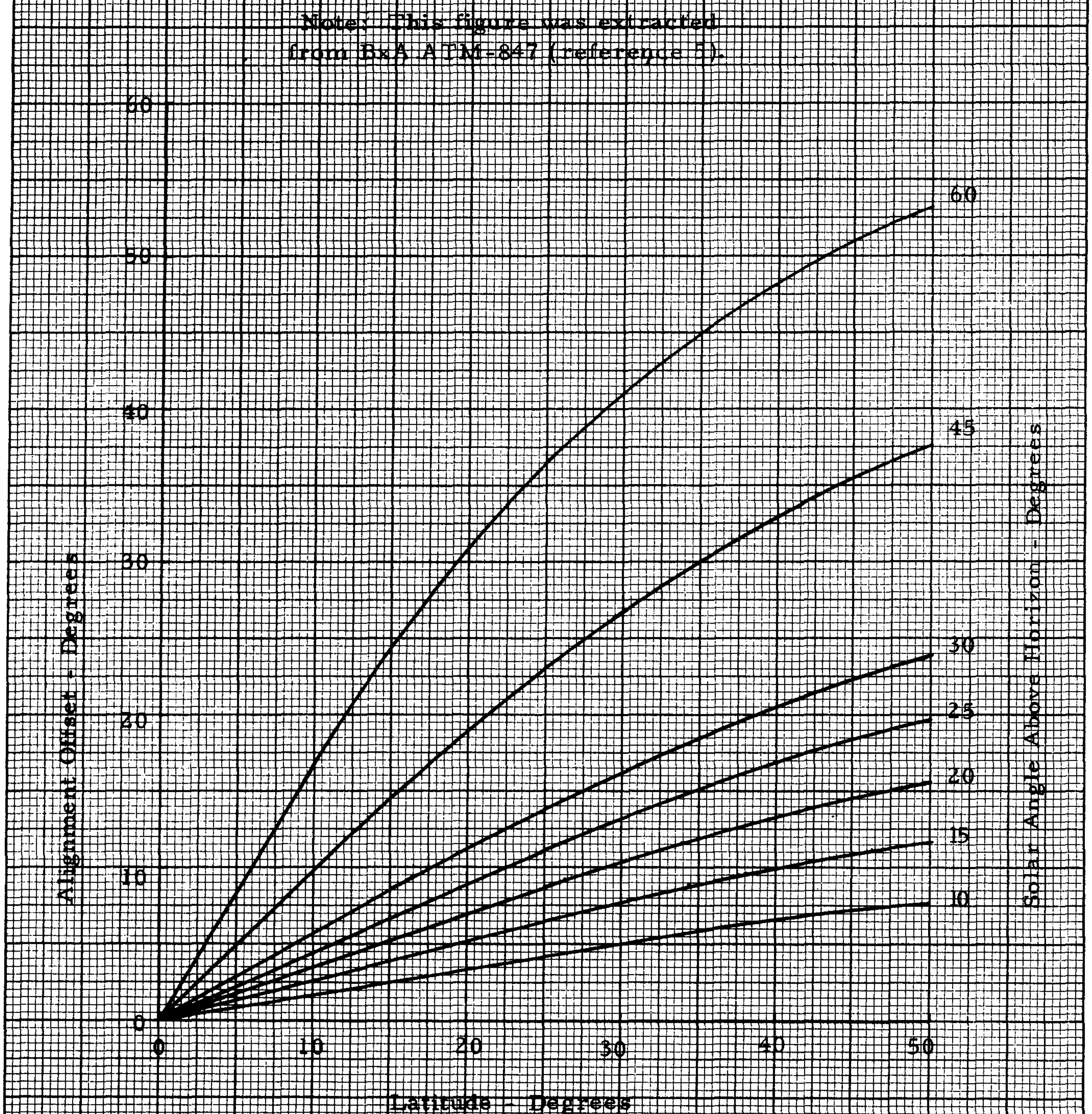


Figure 5-4. Alignment Offset as a Function of Latitude and Solar Angle

5.2 Modifications to Experiment Designs

1. Array B Experiments (ALSEP Flight 3)

No design modifications are planned for any Array B experiments since the primary landing site is Fra Mauro, which is only 4 degrees latitude off the lunar equator.

2. Array C Experiments (ALSEP Flight 4)

PSE. Degree markers were added to the sun compass spider, as pictured in Figure 5-5, to substitute for those markings on the compass rose obscurred by the spider. The gnomon and gnomon supports are shown in a deployed position. The directional arrow on the girdle was also altered and is pictured in Figure 5-6. The astronaut must be supplied with the proper azimuth reading of the gnomon shadow.

SIDE. A new swing-out support leg assembly and leveling bubble, designed specifically for the Apollo 14 landing site, will be installed to allow the top surface of the experiment to be aligned with the solar elciptic. Figures 5-7 and 5-8 picture the new SIDE design in undeployed and deployed modes, respectively.

CPLEE. New swing-out support legs and a leveling bubble will be installed, as shown schematically in Figure 5-9, to keep the experiment vertical alignment the same as at an equatorial deployment site Pictures of the new design in undeployed and deployed modes are shown in Figures 5-10 and 5-11, respectively.

ASE. No modifications required other than a new bubble level to insure proper mortar box alignment prior to firing.

3. Array A-2 Experiments (ALSEP Flight A-2)

PSE. Modifications same as for ALSEP Flight 4.

SWE. Based on the current proposed Apollo landing site, an alignment modification will be incorporated into the experiment design.

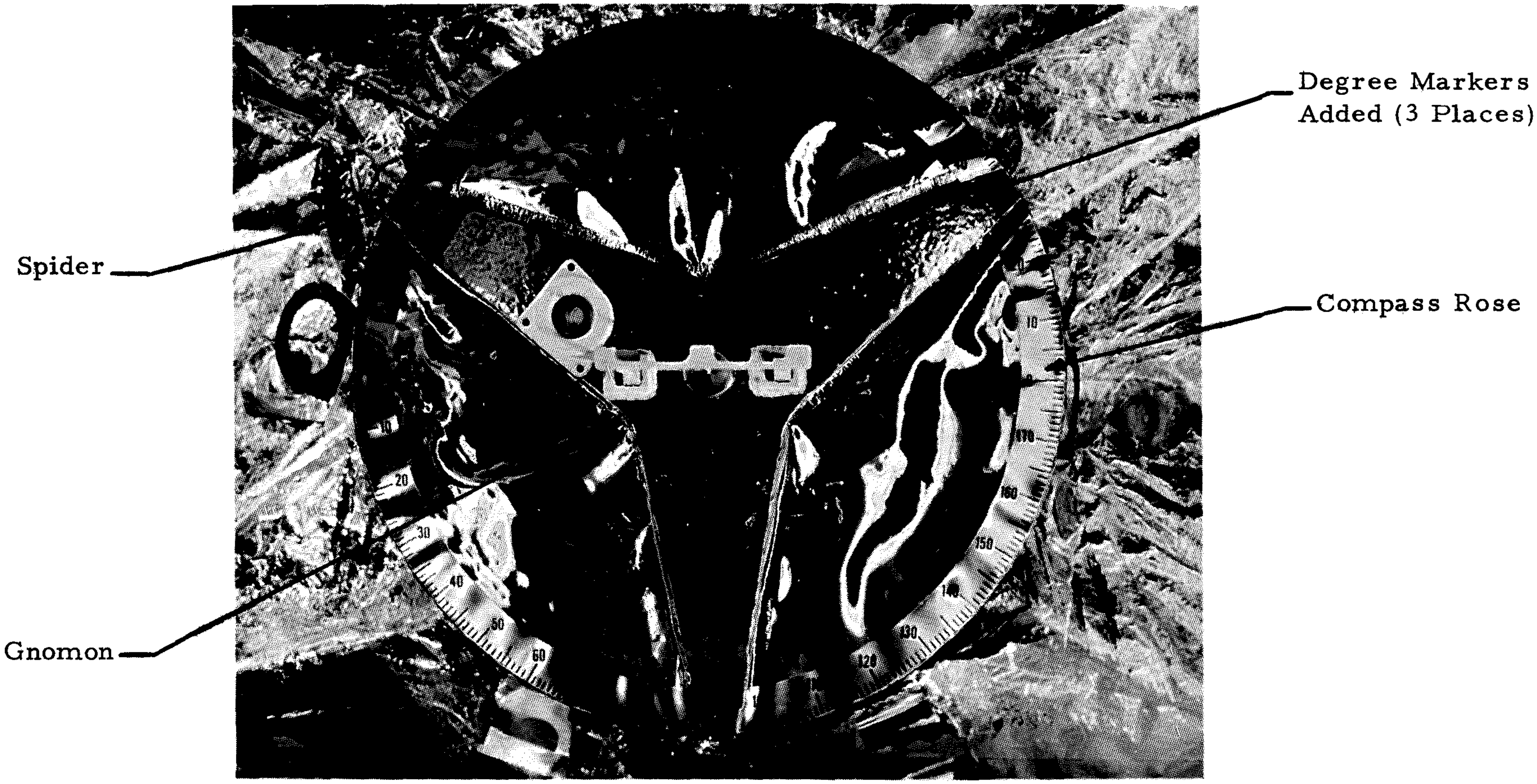


Figure 5-5. Modified PSE Sun Compass Assembly

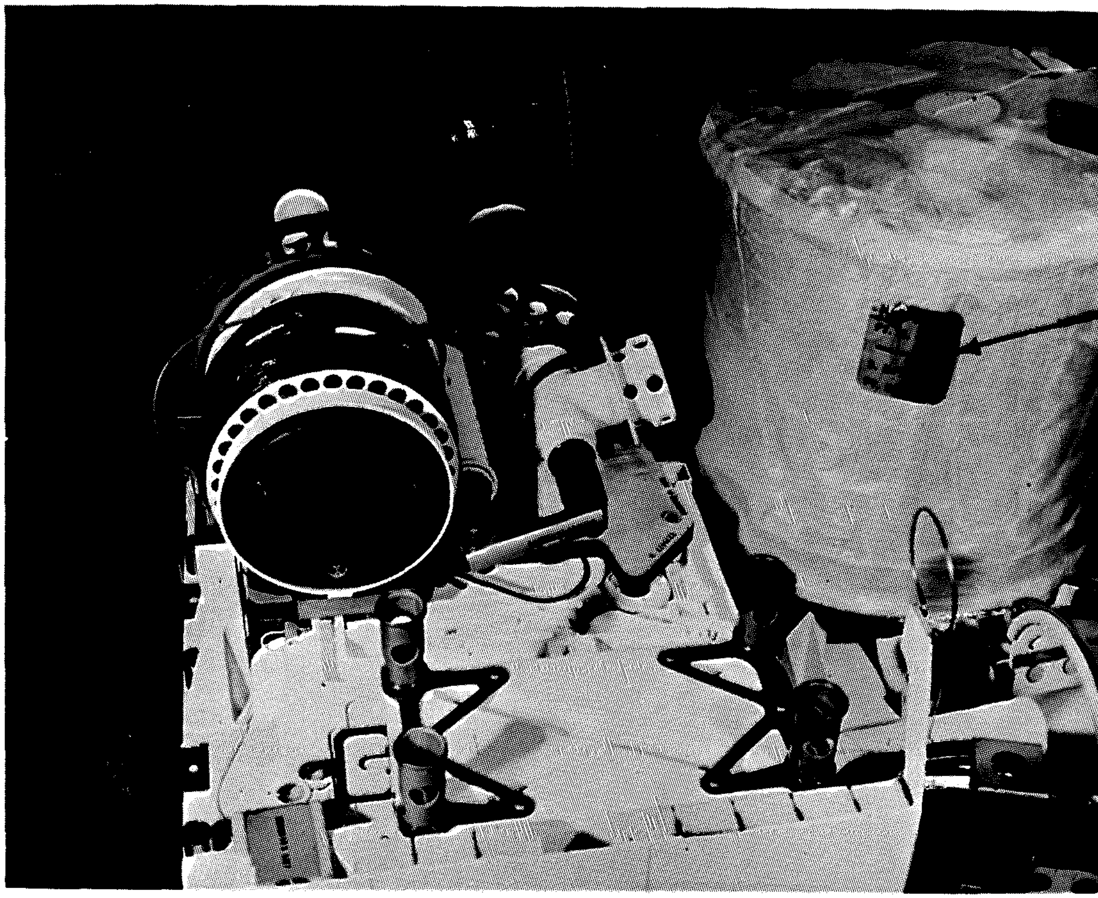


Figure 5-6. Modified Directional Arrow on PSE Girdle

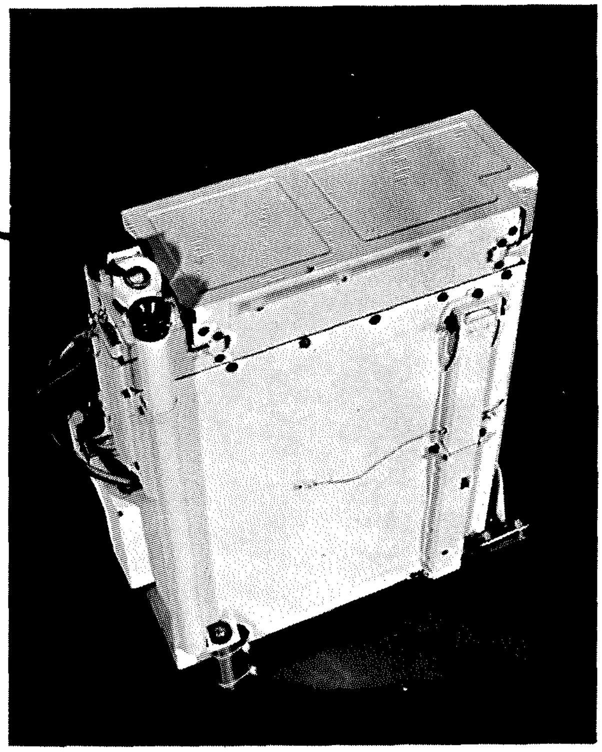


Figure 5-7. Modified SIDE Design - Undeployed Mode

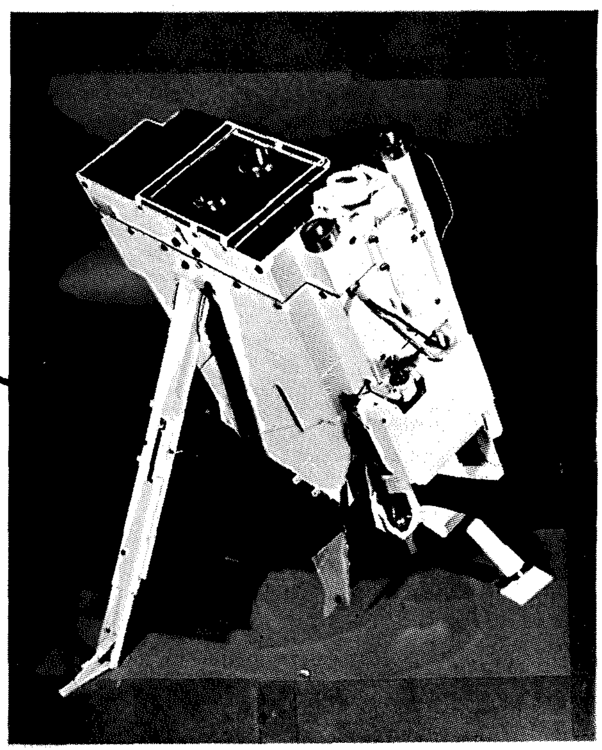
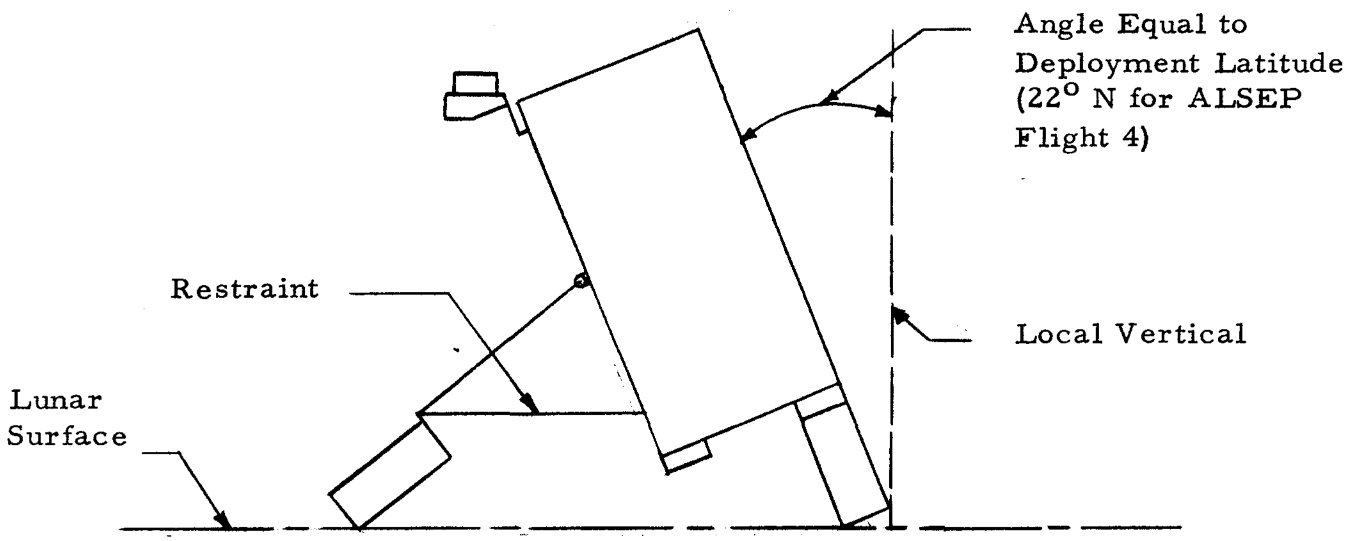
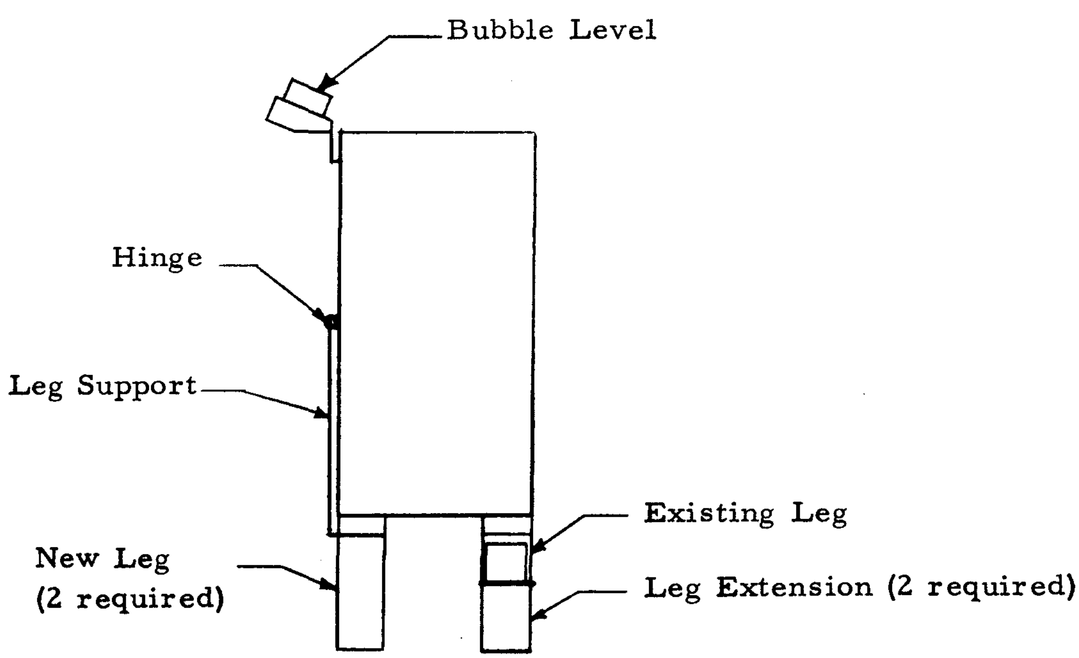


Figure 5-8. Modified SIDE Design - Deployed Mode



Deployed Configuration



Legs Undeployed

Figure 5-9. Modified CPLEE Alignment Design

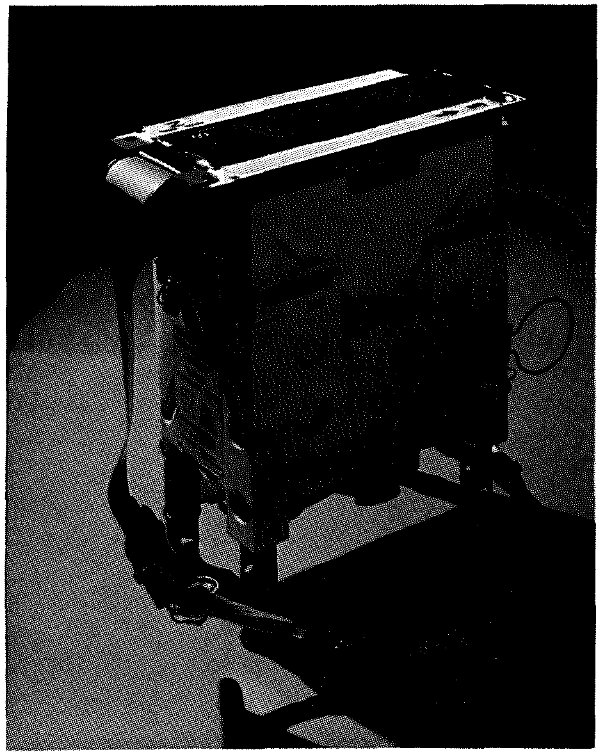


Figure 5-10. Modified CPLEE Design - Undeployed Mode

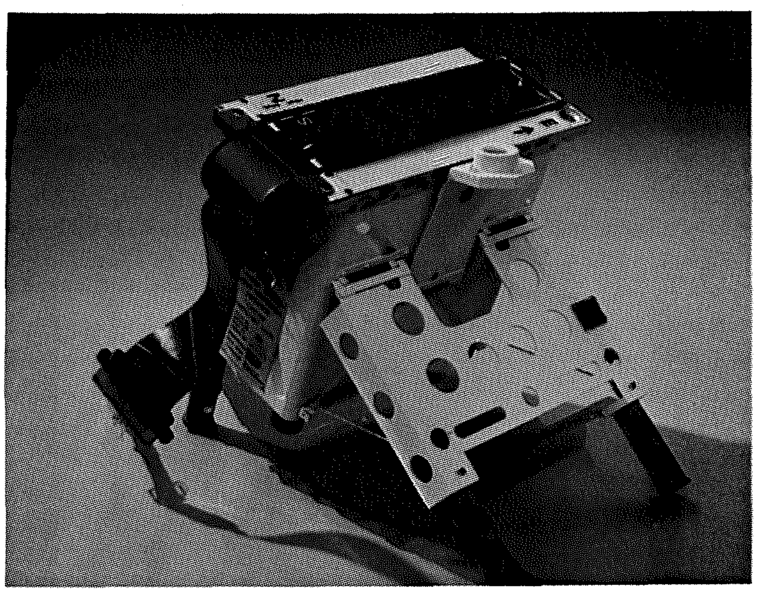


Figure 5-11. Modified CPLEE Design - Deployed Mode

SIDE. Modifications same as for ALSEP Flight 4, except the leg design will be specifically for the Apollo 15 landing site.

LSM. A sunshade, made of a corrugated or pleated piece of material, will be suspended between the three hinge joints of the booms as shown schematically in Figure 5-12. Based on the proposed landing site, the pop-up PRA (parabolic reflector array) shade will be widened, and a new shadowgraph will be installed. The shadowgraph is tilted in towards the ecliptic to compensate for the specific deployment site latitude and must be set prior to launch.

4. Array D Experiments (ALSEP Flight 5)

PSE. Modifications same as for ALSEP Flights 4 and A-2

LSM. Modifications same as for ALSEP Flight A-2, except that the shadowgraph will have a tilt angle corresponding to the Apollo 16 landing site.

HFE. The enclosure facing the lunar equator will be closed off with a fiberglass shield, and one of the specular reflectors will be removed as shown in Figure 5-13. The entire electronics mounting plate within the closed off enclosure will be masked with 20 layers of aluminized mylar. A second 20 layer mask will be installed on the backside of the remaining reflector and extended over the top of the plate mask, as shown by the figure, to give a total of 40 layers on the plate. The bottom of the sunshield and the backside of the new fiberglass enclosure curtain will be coated with vacuum-deposited aluminum. The masking width on the open enclosure thermal plate will be reduced from 2.4" to between 1" to 1.5", while the sunshield height and width will be increased as denoted in the figure. A bubble level will be added to reduce the vertical alignment tolerance from ± 12 degrees to ± 5 degrees. A new sun compass will be installed for east-west alignment considerations. An opening in the bottom of the handling tool socket will be closed to prevent the direct impingment of solar energy within the enclosure.

ASE. No modifications required other than the addition of a bubble level.

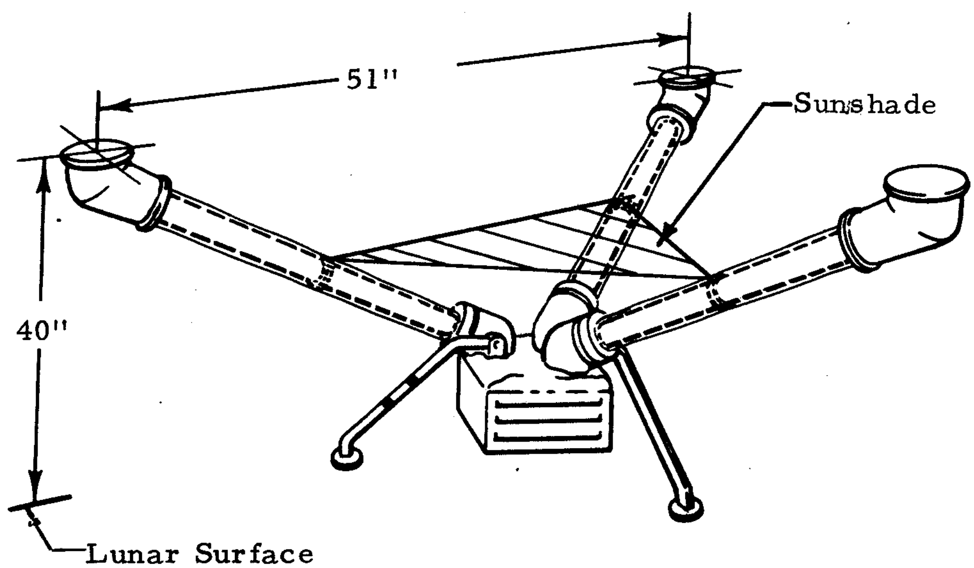
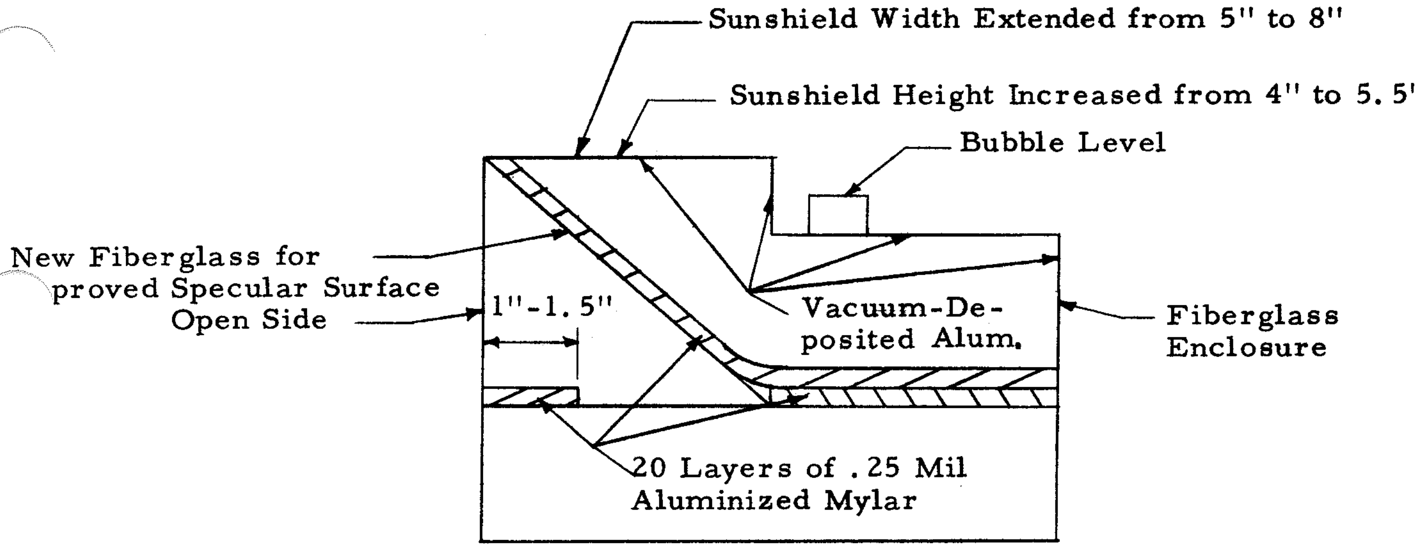
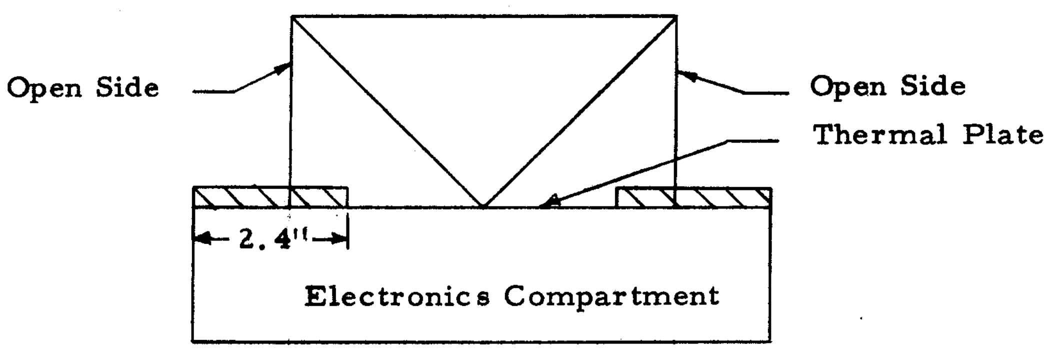


Figure 5-12. LSM Sunshade Design



Modified HFE Design
for Off-Equator Deployment



Original HFE Design
for Equatorial Deployment

Figure 5-13. Modified HFE Thermal Design

5.3 Side Curtain and Reflector Temperatures

For the open central station deployed at any given latitude, the side curtain and reflector temperatures are controlled by the angle of incident solar radiation to those components and by the lunar surface temperature. Since the largest angle of incidence occurs at lunar sunrise and sunset, one of these conditions (sunset) was chosen for the maximum temperature study. A 250°F lunar surface temperature was arbitrarily assumed for conservatism since the interreflection of solar energy within the enclosure facing the sun was difficult to accurately establish for the study.

5.4 Off-Equator and Crater Temperatures

Figure 5-14 presents the relationship between lunar surface temperature, sun angle, and latitude which was used to obtain analysis results for this report. Table 5-1 lists the maximum lunar day crater temperatures, which were used to predict ALSEP thermal performance, as a function of latitude and crater slope.

5.5 Effect on Thermal Performance of Variations in Lunar Terrain

5.5.1 Local Lunar Surface Slope

If the open central station design were deployed and leveled on continuous sloping terrain, the view to space of half of the exposed thermal plate would be reduced while the view to space of the other half would increase an equivalent amount. Consequently, negligible effect of local slopes on the open design thermal performance is anticipated.

However, the closed side 2 configuration can be affected by local slope. Since the side 2 enclosure is relatively unaffected by the slope of the lunar surface, the thermal plate temperature becomes very sensitive to changes in heat flux (which can be caused by lunar slopes) to or from the side 1 enclosure. As shown in Section 3.3, thermal plate temperature decreases when the lunar surface slopes away from side 1 but increases when the slope is towards the vertical.

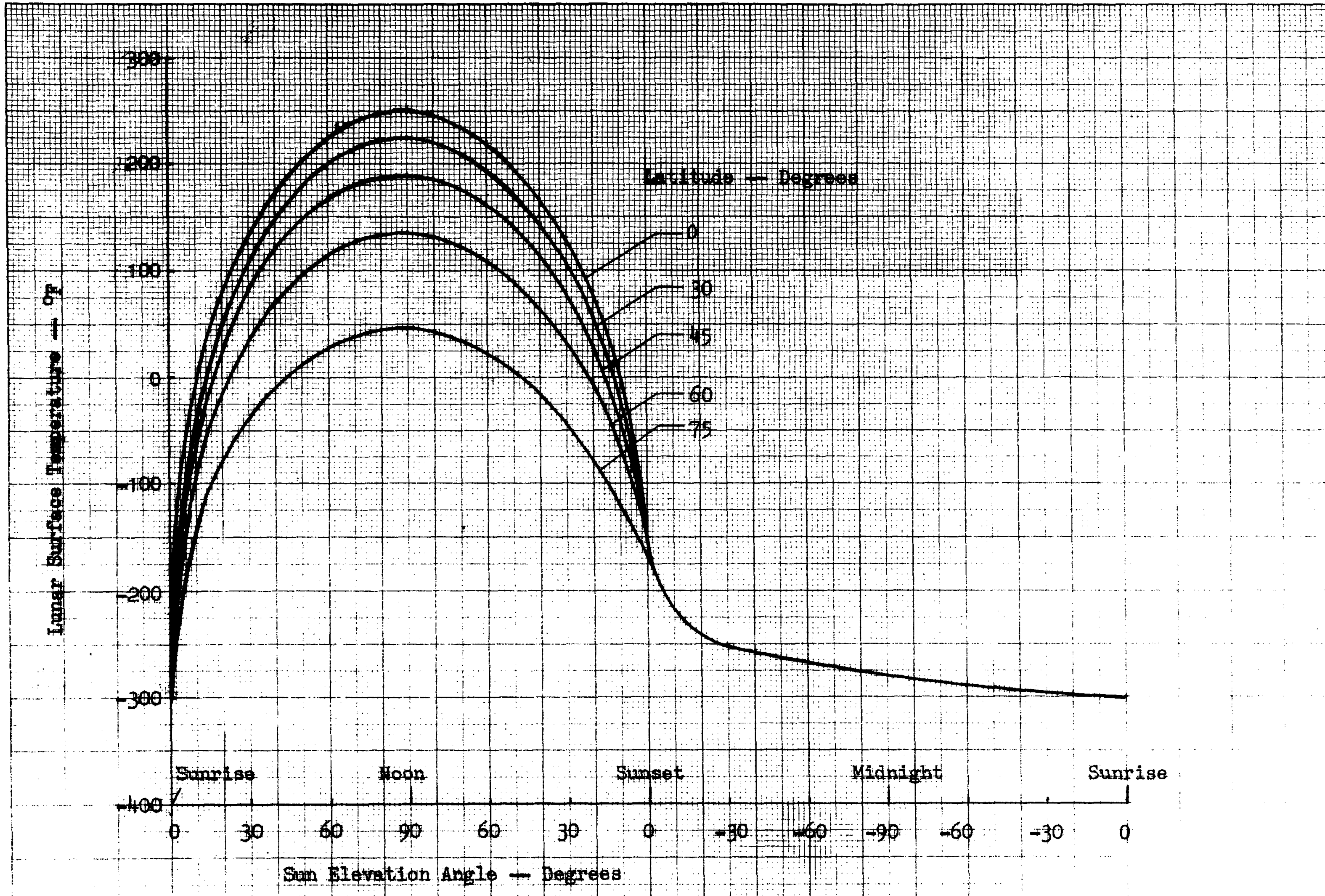


Figure 5-14. Lunar Surface Temperature vs Sun Angle and Latitude

TABLE 5-1

MAXIMUM LUNAR DAY CRATER TEMPERATURE VS LATITUDE AND CRATER SIZE

Crater Slope, Degrees	Latitude, Degrees	Maximum Crater Temperature, °F
5	0	255
(Aspect ratio	15	242
= 23:1)	30	230
	45	195
	60	140
15	0	265
(Aspect ratio	15	263
= 7.5:1)	30	257
	45	246
	60	220
30	0	300
(Aspect ratio	15	299
= 3.5:1)	30	295
	45	287
	60	270

5.5.2 Craters

For the effect of craters on central station performance, it was assumed that the C/S was positioned in the center of craters with slopes from 5 degrees (aspect ratio = 23:1) to 30 degrees (aspect ratio = 3.5:1). Slope is defined as the arctangent of crater depth divided by crater radius, while aspect ratio is crater diameter divided by depth.

5.5.3 Obstructions

Obstructions were assumed to have the same effect as lunar slopes; i.e., the equivalent slope of an obstruction was the arctangent of the obstruction height divided by the distance from the C/S to the obstruction.

5.5.4 Elevated Deployment Sites or Mounds

When the effect of elevated deployment sites (mounds) on the C/S thermal performance was analyzed, the C/S was assumed to be on the very peak of the mound with the lunar surface sloping away from the vertical as depicted in Figures 3-11 and 3-12 in Section 3.

5.6 Effect of Off-Equator Deployment on PDM Panel

A preliminary study indicates that the PDM panel temperature may range as low as - 180°F and may exceed 320°F at off-equator deployment sites with the current panel design. ALSEP Flight 1 data has shown a - 100°F to 285°F temperature range (- 100°F to 320°F with the SIDE off during the day). However, ALSEP 1 was deployed at about 3 degrees latitude, and the solar heating load on the PDM panel, which increases with increasing latitude, could cause the panel temperature to exceed the Flight 1 upper level on future flights at landing sites significantly removed from the equator. Also, future flights may have PDM power dissipations at lunar night well below the Flight 1 levels which would cause the temperature drop at night.

A detailed study should be conducted to establish whether or not the anticipated PDM thermal response for future flights is acceptable. Part of the study would be to investigate panel design modifications which would lower the lunar noon-to-night temperature swing, reduce both temperature extremes, and improve the reliability of the PDM resistors.

6.0 REFERENCES

1. MSC TWX 061A, EA/22/T375/S/B-350, September 1969.

2. McNaughton, J., "ALSEP Thermal Deployment Study, CCP 216," Bendix IM 69-210-207, October 1969.

3. Georgopulos, P., "Additional Duplication - Off-Equatorial Deployment - CCP-216," Bendix IM 9971-61, November 1969.

4. Johnson, P., "ALSEP Qual SA Thermal Vacuum Chamber Test Report," Bendix ATM-824, January 1969.

5. Heinz, F., "Alignment of ALSEP at Latitudes Off the Lunar Equator," Bendix ATM-847, December 1969.

6. Marrus, L., "Sun Compass Alignment Devices," Bendix IM 69-260-82, November 1969.

7. The American Ephemeris and Nautical Almanac for the Year 1970, U.S. Government Printing Office.