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Aerospace Systems Division

ALSEP Flight 1 PSE Thermal Anomaly Study

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This ATM summarizes the results of the BxA study conducted to investigate the ALSEP Flight 1 PSE Thermal Anomaly. The purpose of the study was to 1) correlate the Flight 1 PSE sensor lunar performance results, 2) determine the most probable cause of the out-of-tolerance temperature condition, and 3) recommend possible thermal modifications to the Flight 3 PSE for Apollo 13 and subsequent models. This interim report has been generated in response to MSC directive BG 931/L115-70/T94, Analysis of Apollo 12 PSE Data Anomalies, dated 13 February 1970.

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1.0 INTRODUCTION

An analytical transient thermal model of the Passive Seismic Experiment (PSE) and lunar subsurface has been developed to correlate the Flight 1 (Apollo 12) thermal data presently being transmitted from the moon, as shown in figure 1-1.

The effort is required due to the occurrence of anomalies in the thermal performance of the experiment during both lunar day and night. The temperature of the PSE sensor increased from the first lunation maximum of 134°F at a sun angle of approximately 125 degrees to a level of 145°F during the third day as shown in figure 1-2. The specified upper operating temperature limit of the PSE is 143°F which is also the upper limit of the telemetry range. The night time temperature of the sensor has gone below the lower limit of the PSE telemetry range of 107°F. Through curve fitting of the experiment's temperature profile during transition from lunar evening to night the estimated temperature level of the sensor is 75°F which is outside the specification lower operating temperature limit of 107°F. The design goal for the PSE is 126.0 ± 0.4°F. By actively commanding on the PSE sensor z axis leveling motor and dissipating an additional 3.05 watts inside the experiment, the seismometer temperature has stabilized at 125.9°F for both the 3rd and 4th lunar nights.

The out-of-tolerance temperature variation of the seismometer reduces the possibility of obtaining full tidal data of the lunar surface. In addition to the loss of tidal data, a considerable amount of signals were recorded during terminator crossing at lunar sunrise and sunset which may possibly be attributed to the sensor pulling on the instrument due to thermal expansion and contraction of the insulation layers of the thermal shroud. The reasons for both of the temperature related anomalies have been reviewed in the report with the primary emphasis placed on the out-of-tolerance sensor temperature condition.

To improve upon the present thermal design a good model is a basic requirement to evaluate the effects of possible modifications. Added to the complexity of thermally simulating the experiment is the task of properly modeling the lunar subsurface beneath it. With thermophysical data of lunar soil and rock presented recently, it has been possible to better simulate the lunar subsurface. However, due to the variance of the soil thermal properties with sample type and investigator, the determination of nominal thermal properties still remains open.

FIGURE 1-1

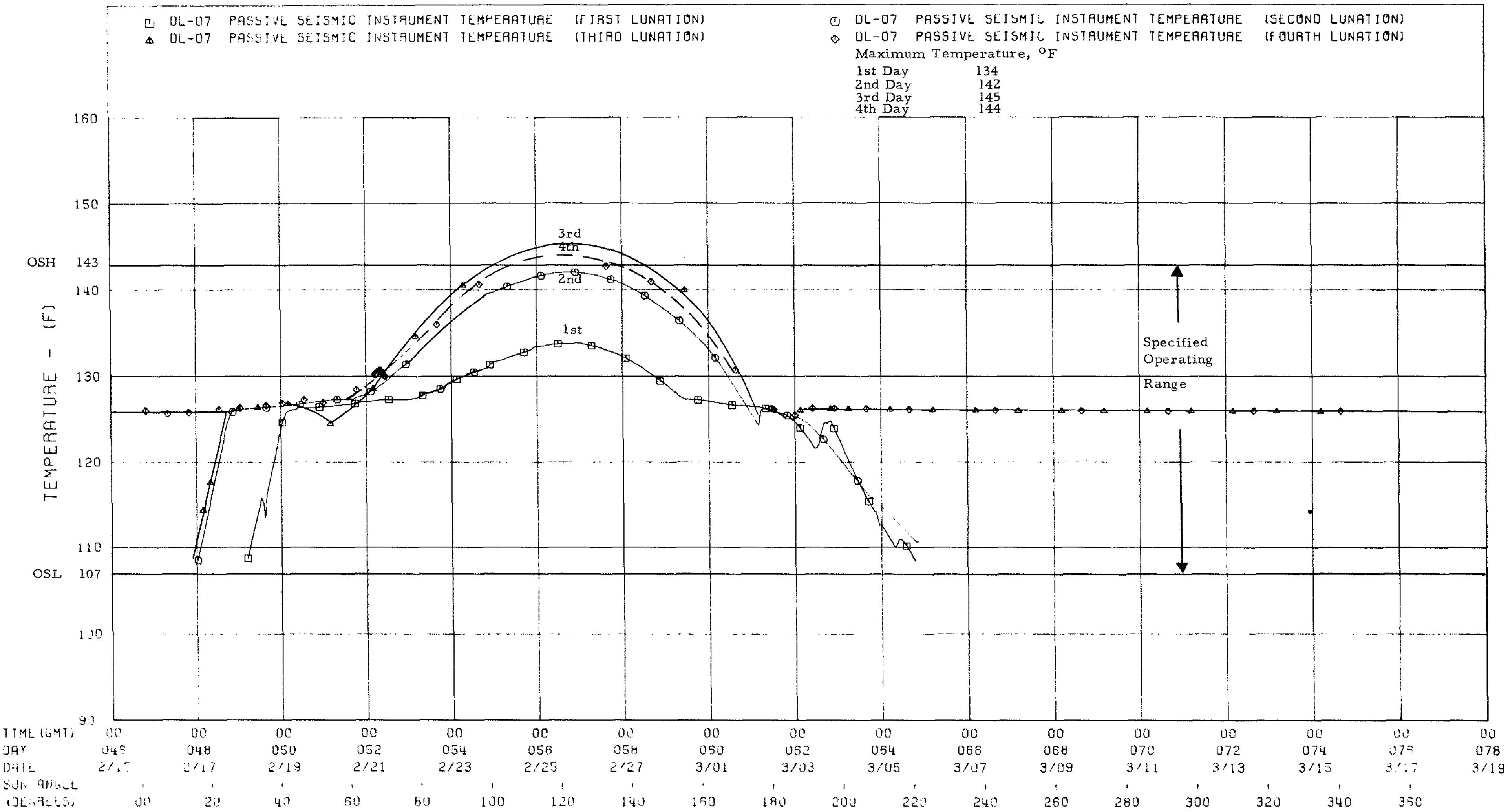
FIGURE 1-2

BENDIX AEROSPACE SYSTEMS DIVISION - THERMOPHYSICS GROUP

APOLLO LUNAR SURFACE EXPERIMENTS PACKAGE (FLIGHT 1 - APOLLO 12) - 4 TH ALSEP LUNATION

SUNRISE DAY 046 (FEBRUARY 15, 1970) AT 1600 GMT

SUNRISE DAY 076 (MARCH 17, 1970) AT 0600 GMT



Consequently, any one parameter or combination of several may be responsible for the observed thermal anomalies. The object of this investigation, therefore, is to select the combination of parameters that most nearly correlate with ALSEP Flight 1 data, thereby providing an analytical basis to evaluate the effect of future modifications.

2.0 SUMMARY OF RESULTS

2.1 THERMAL MODEL DEVELOPMENT AND CORRELATION

A comprehensive study of the thermal-physical data of the lunar samples obtained from the Apollo 11 mission has been made. The results have been evaluated and nominal lunar thermal properties selected for use in the lunar subsurface model. The nominal values of lunar thermal properties used in this analysis are:

(1) $k = 1.1 \times 10^{-3}$ Btu/hr/ft°F

(2) $C_p = 0.2$ Btu/lb °F

(3) $\rho = 6.14 \times 10^{-2}$ lb/in.^{3}

With this data the temperature time history of the lunar subsurface as well as the adiabatic depth and adiabatic temperature were determined using a one-dimensional model. The adiabatic depth and associated temperature are 8 inches and -55°F, respectively.

Using the subsurface and PSE nodal model shown in figure 2-1 correlation with the second day, Flight 1 PSE thermal data has been attained within 3°F. A 24-hour phase lag of the thermal model peak temperature with respect to flight data is present, suggesting minor modeling errors or improper selection of parametric values. However, the usefulness of the simulation to analytically evaluate possible design modifications is not diminished.

Thermal model results indicate that the Flight 1 PSE reaches a low temperature of 73°F just before lunar sunrise. This temperature was unknown since the off-scale lower limit is 107°F, but was previously estimated by curve fitting methods to be approximately 75°F. The model predicts a maximum temperature of 142.5°F whereas a Flight 1 maximum of 142.0°F is reported for the second day.

During the time intervals in which the sensor is below the set point (i.e., either heating up at lunar sunrise or cooling off at sunset), the temperature rise or decay rates compare very favorably. Thermal model and Flight 1 temperature rise rates are 0.85°F/hr.

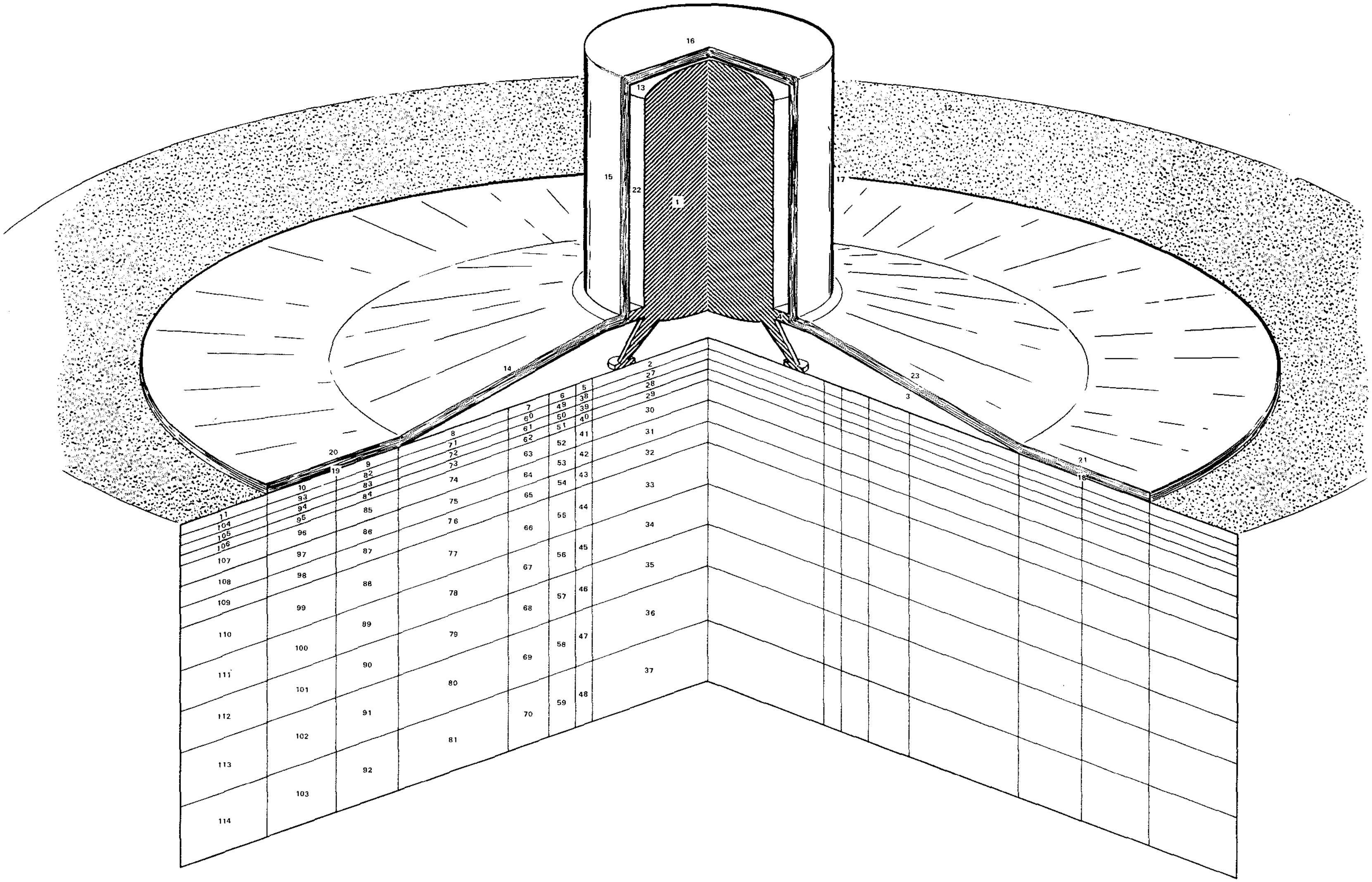


FIGURE 2-1 PSE SENSOR AND LUNAR SUBSURFACE THERMAL MODEL

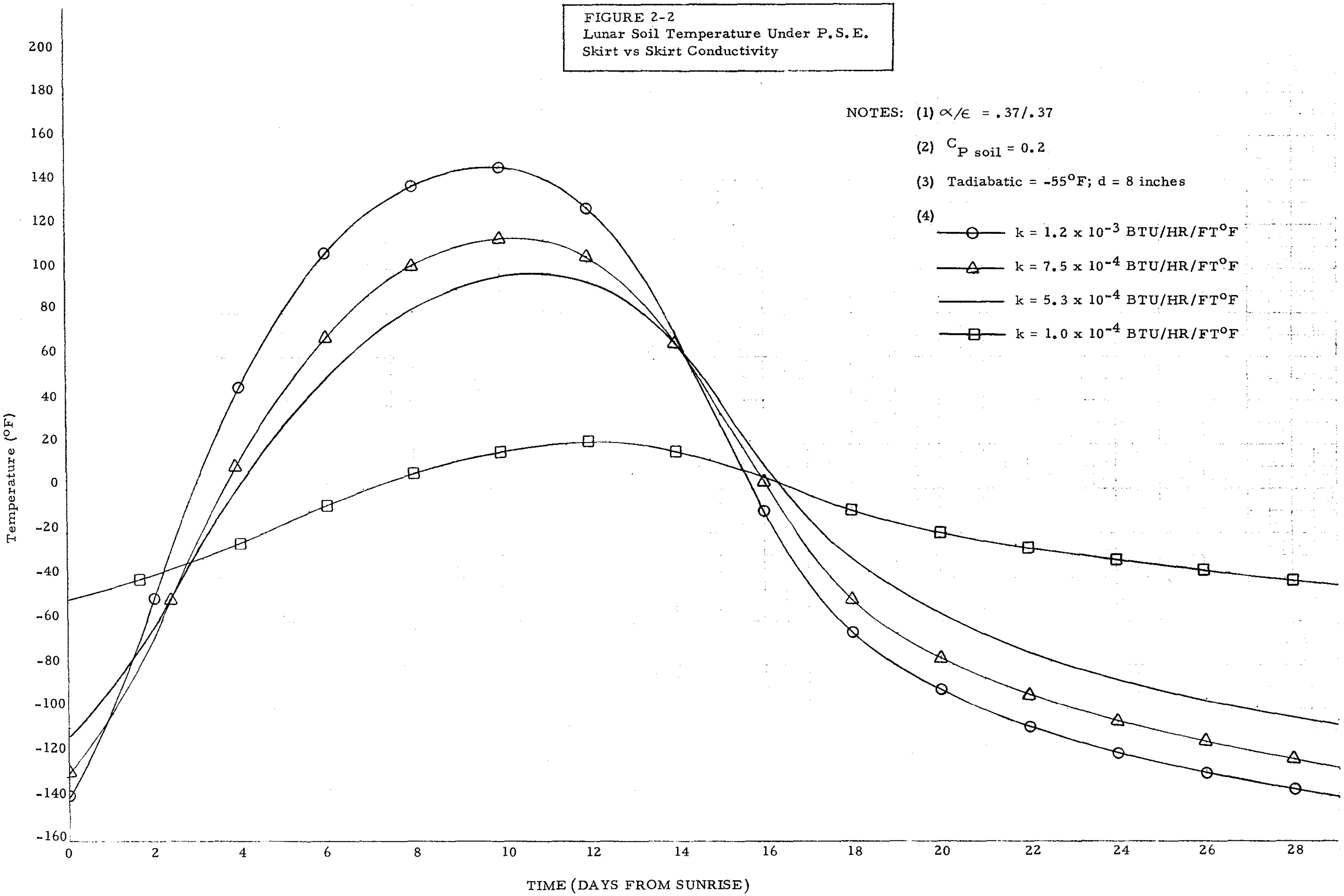


FIGURE 2-2
Lunar Soil Temperature Under P.S.E.
Skirt vs Skirt Conductivity

NOTES: (1) α/ϵ = .37/.37

(2) $C_{P\ soil}$ = 0.2

(3) Tadiabatic = -55°F; d = 8 inches

(4)
- ○ $k = 1.2 \times 10^{-3}$ BTU/HR/FT°F
- △ $k = 7.5 \times 10^{-4}$ BTU/HR/FT°F
- $k = 5.3 \times 10^{-4}$ BTU/HR/FT°F
- □ $k = 1.0 \times 10^{-4}$ BTU/HR/FT°F

2.2 PARAMETRIC TRANSIENT THERMAL ANALYSES

A parametric thermal study has developed in the search for parameter combinations which must closely correlate with ALSEP-1 (Apollo 12) PSE temperature data.

The parameters which have been varied in the study are the following:

(1) solar absorptance of shroud and skirt (external surfaces)

(2) infrared emittance of shroud and skirt (external surfaces)

(3) aluminized mylar vs. aluminized teflon

(4) skirt conductivity (day and night)

(5) shroud conductivity (day and night)

(6) sensor specific heat

(7) lunar soil specific heat

(8) soil density

(9) soil conductivity

(10) lunar soil adiabatic depth

(11) lunar soil adiabatic temperature

(12) internal power dissipation (day and night)

(13) cable and stool thermal resistance

(14) multilayer insulation blanket

A summary of the maximum and minimum sensor temperature extremes as a function of the above parameters is presented in Table 2-1.

TABLE 2-1 SUMMARY OF PASSIVE SEISMIC EXPERIMENT THERMAL MODEL RESULTS

Run #	α/ϵ		Skirt Conductivity (BTU/hr./ft.°F)		Shroud Conductivity (BTU/hr./ft.°F)		C_p (BTU/°F)		Soil Density (lbm/in^3)	Soil Conductivity (BTU/hr./ft.°F)	Source of Lunar Surface Properties	Sensor Power Dissipation (Watts)		Sensor Temp. (°F)	
	Shroud	Skirt	Day	Night	Day	Night	Sensor	Soil				Ti < 126°F	Ti > 126°F	Max.	Min.
1	.2/.73	.2/.37	5.3×10^{-4}	5.3×10^{-4}	5.3×10^{-4}	5.3×10^{-4}	0.38	0.2	3.24×10^{-2}	2.42×10^{-3}	LED-520	3.25	1.0	126.5	93
2	.2/.73	.37/.37	1.2×10^{-3}	5.3×10^{-4}	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	141	96
3	.2/.73	.37/.37	"	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	"	"	"	"	"	"	"	138	68
4	.2/.73	.2/.73	"	5.3×10^{-4}	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	126.5	93
5	.2/.73	.37/.73	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	126.5	90
6	.73/.73	.37/.37	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	166	99
* 7	.2/.73	.37/.37	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	139.6	104
8	.2/.73	.2/.73	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	"	"	"	"	"	"	"	126.5	126.5
9	.73/.73	.73/.73	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	"	"	6.14×10^{-2}	1.1×10^{-3}	APOLLO 11	"	"	126.5	126.5
10	.2/.73	.37/.37	1.2×10^{-3}	5.3×10^{-4}	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	142.5	99.5
11	.2/.73	.37/.37	"	"	1.2×10^{-3}	5.3×10^{-4}	0.28	"	"	"	"	"	"	145.7	98
12	.2/.73	.37/.37	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	126.5	89
13	.2/.73	.37/.37	"	"	1.2×10^{-3}	5.3×10^{-4}	0.38	0.05	"	"	"	"	"	160	91.6
** 14	.2/.73	"	"	"	1.2×10^{-3}	5.3×10^{-4}	"	0.2	"	"	"	"	"	142	80
15	E .73/.73 T .73/.73 W .2/.73	"	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	160.5	100
16	E .37/.73 T .2/.73 W .2/.73	.37/.37	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	0.38	0.2	6.14×10^{-2}	1.1×10^{-3}	APOLLO 11	3.25	1.0	139.5	69
17	.2/.73	"	"	"	1.2×10^{-2}	1.2×10^{-3}	"	"	"	"	"	"	"	138	69
18	E .73/.73 T .73/.73 W .2/.73	"	7.5×10^{-4}	7.5×10^{-4}	"	"	"	"	"	"	"	"	"	148	71
19	E .37/.73 T .37/.73 W .2/.73	"	"	"	"	"	"	"	"	"	"	"	0.75	128	61

* with multilayer blanket
** 1/2 leg and cable resistance

TABLE 2-1 SUMMARY OF PASSIVE SEISMIC EXPERIMENT THERMAL MODEL RESULTS (CONT)

Run #	α/ϵ		Skirt Conductivity (BTU/hr./ft.°F)		Shroud Conductivity (BTU/hr./ft.°F)		C_p (BTU/°F)		Soil Density (lbm/in^3)	Soil Conductivity (BTU/hr./ft.°F)	Source of Lunar Surface Properties	Sensor Power Dissipation (Watts)		Sensor Temp. (°F)	
	Shroud	Skir	Day	Night	Day	Night	Sensor	Soil				Ti < 126°F	Ti > 126°F	Max.	Min.
20	E. 3/.73 T.37/.73 W.2/.73	.37/.37	5.3×10^{-4}	5.3×10^{-4}	1.2×10^{-2}	1.2×10^{-3}	0.33	0.2	6.14×10^{-2}	1.1×10^{-3}	APOLLO 11	3.25	1.0	126.5	62
21	E.73/.73 T.37/.73 W.15/.73	"	"	"	"	"	"	"	"	"	"	"	"	126.5	62
22	E.73/.73 T.37/.73 W.2/.73	"	"	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	129.5	85
23	E.73/.73 T.73/.73 W.2/.73	"	"	"	5.3×10^{-4}	"	"	"	"	"	"	"	"	140	85
24	E.73/.73 T.73/.73 W.2/.73	"	"	"	1.2×10^{-3}	7.5×10^{-4}	"	0.1	"	"	"	"	"	152	70
25	E.73/.73 T.9/.73 W.2/.73	"	"	"	"	"	"	"	"	"	"	"	"	154	70
26	E.73/.73 T.9/.73 W.2/.73	"	"	"	"	"	"	0.2	"	"	"	"	"	142.5	73
27	E.73/.73 T.73/.73 W.2/.73	"	"	"	7.5×10^{-4}	"	"	"	"	"	"	"	"	143.5	73
**28	E.73/.73 T.73/.73 W..2/.73	"	"	"	"	"	"	"	"	"	"	"	"	151	75
29	E.2/.73 T.2/.73 W.2/.73	"	1.2×10^{-3}	5.3×10^{-4}	"	"	"	"	"	"	"	"	"	152	75

** No cable or legs

As a result of the parametric study, it has been possible to determine the lunar surface temperature beneath the PSE blanket and sensor. These temperature transients are presented in figure 2-2. It has been shown that the temperature of the covered lunar surface is a function primarily of the skirt thermal conductivity and the skirt α_s/ϵ_{ir} ratio for a given subsurface model.

2.3 ANALYTICAL EVALUATION OF POTENTIAL DESIGN MODIFICATIONS

The addition of a layer of aluminized teflon to the outer side of the skirt as a quick fix has been evaluated analytically. The improvement of skirt optical properties from $\alpha_s/\epsilon_{ir} = 0.2/0.37$ to $\alpha_s/\epsilon_{ir} = 0.2/.73$ results in a sensor temperature level which can be maintained at 126.0°F during daytime operation. The sensor temperature during lunar night operation would not be affected significantly by this modification.

To improve upon present lunar night thermal performance, additional alterations to the present design are required. Feasible modifications to subsequent units such as an additional heater or a sufficient number of multilayer insulation layers added to attain an effective thermal conductivity of $k \leq 1.0 \times 10^{-4}$ Btu/hr/ft°F have been evaluated. Results of the thermal simulation of the PSE incorporating these design changes indicate operation within the acceptable range of +107°F to +143°F. Furthermore, the results show that the sensor can be maintained at the design goal of 126.0°F during the entire lunar cycle.

3.0 RECOMMENDATIONS

3.1 POTENTIAL IMMEDIATE MODIFICATIONS

Based on simulation results, a possible quick fix for ALSEP-3 (Apollo 13) is the addition of a single layer of aluminized teflon (teflon side out) to the outside of the present skirt. Measurements of the solar absorptance, α_s, and infrared emittance, ϵ_{ir}, of aluminized 2-mil teflon at BxA indicate nominal values of 0.18 and 0.73, respectively (ref. 9, 11). Similar measured values for aluminized 1/2 mil mylar results in nominal values of 0.2 and 0.37, respectively (ref. 9, 10). Hence, the ratio

$$\frac{\alpha_s}{\epsilon_{ir}}\left(\text{alum. teflon}\right) = \frac{0.18}{0.73} = 0.247 \quad \text{is less than} \quad \frac{\alpha_s}{\epsilon_{ir}}\left(\text{alum. mylar}\right) = \frac{0.2}{0.37} = 0.540.$$

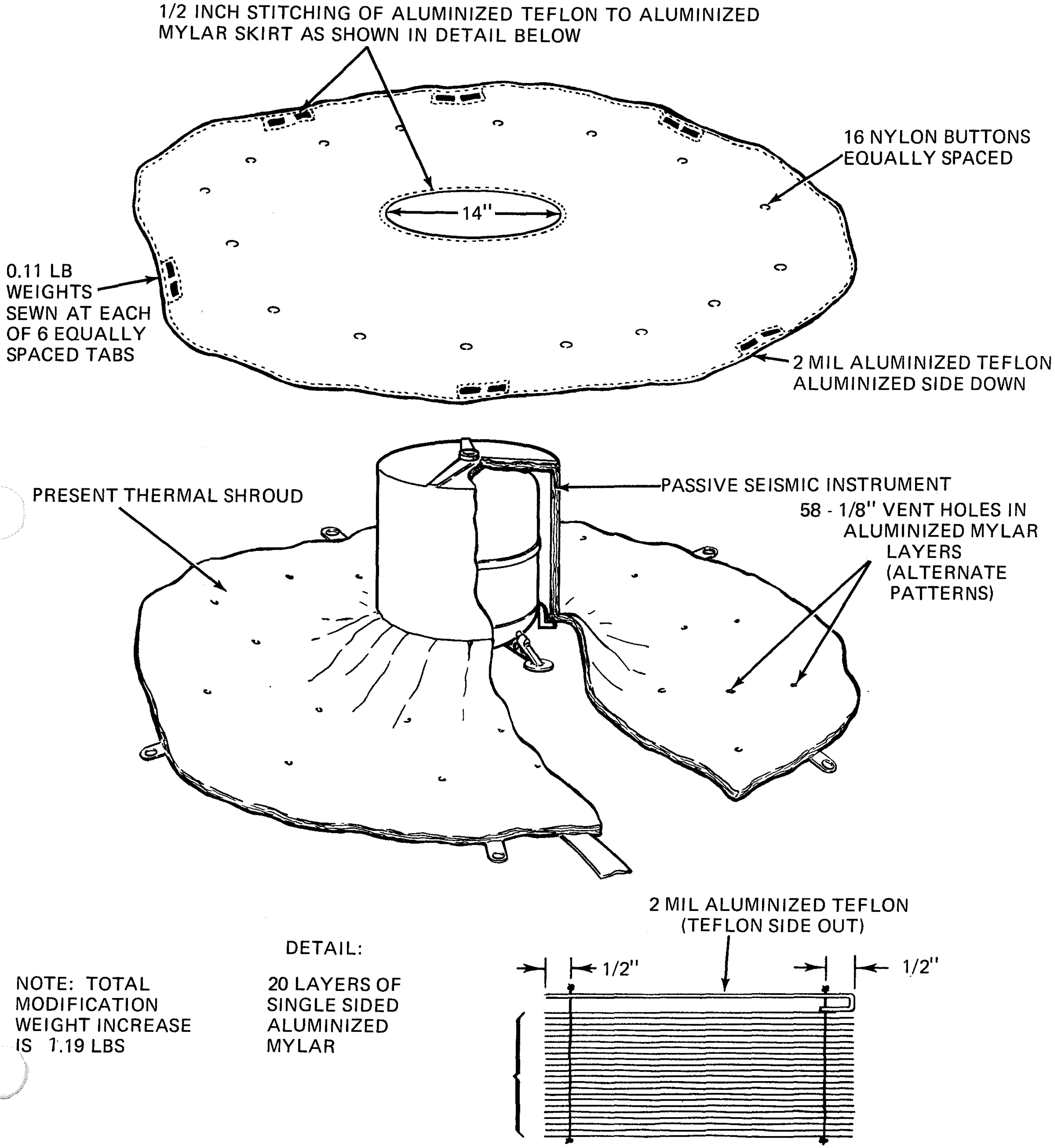
Qualitatively, this change should result in a decrease of sensor temperature during the lunar day. Quantitatively, this has been verified and shown that it is possible to maintain 126°F during lunar day operations.

Using aluminized teflon as the outer layer, the skirt surface temperature is reduced by 125°F. Hence, the excursion during terminator crossing should be decreased by 125°F and thereby reduce the thermomechanical stressing of the skirt.

In addition to the above proposed modification, other immediate changes may result in improvement of the observed thermal anomaly apparent on ALSEP-1 (Apollo 12).

(1) Sewing together the layers of multilayer insulation skirt along its outer circumference should reduce substantially the problem of repelling layers due to electrostatic charge buildup. This stitching would also reduce the possibility of solar impingement on the aluminized side of the films, which has an α_s/ϵ_{ir} greater than one.

FIGURE 3-1A APOLLO 13 PASSIVE SEISMIC EXPERIMENT INSULATION SKIRT MODIFICATION



NOTE: TOTAL MODIFICATION WEIGHT INCREASE IS 1.19 LBS

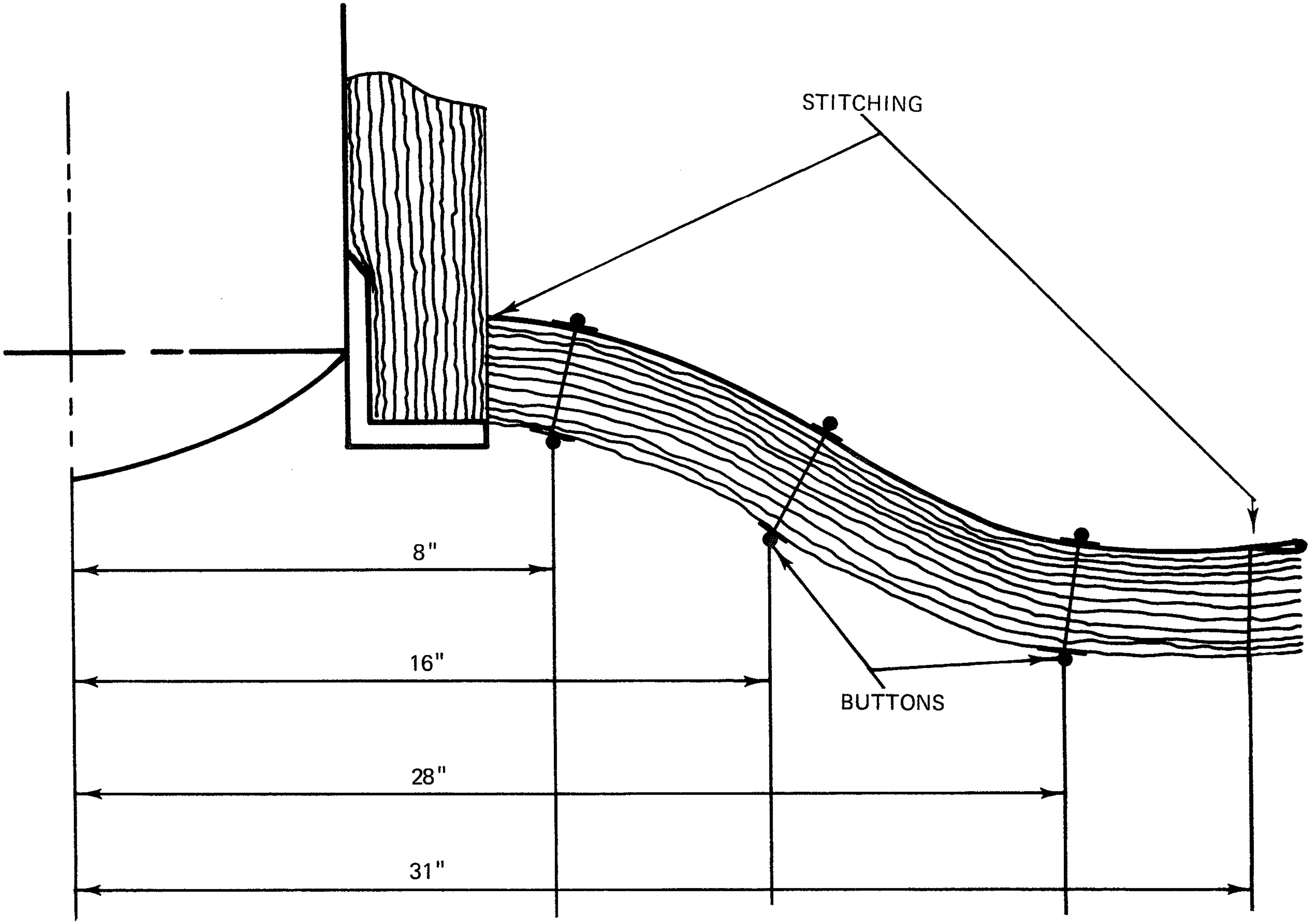


FIGURE 3-1B STITCHING AND BUTTON LOCATIONS

(2) As an aid in deployment and use in maintaining the desired location during LM ascent, it is suggested that weights be distributed and sewn in along the circumference of the skirt. Distributed weight of 1 to 2 pounds would, in addition, reduce the tunneling effect of solar and and other sources of energy to the sensor base.

(3) Positively venting the shroud by locating small holes in alternate layers of the multilayer insulation should improve the ease of skirt stowage and prevent damage due to outgassing during launch. These modifications are shown in detail in figure 3-1.

3.2 POTENTIAL LONG TERM DESIGN MODIFICATIONS

(1) Thermal performance of the PSE during lunar night is not significantly improved with the immediate modifications listed above. The addition of the layer of aluminized teflon to the skirt decreases its effective conductivity, but the original specified conductivity of $k = 2.0 \times 10^{-5}$ Btu/hr/ft °F is not attained. Based on the thermal simulation results, it has been shown that with $k = 1.0 \times 10^{-4}$ Btu/hr/ft °F and additional heat dissipation within the sensor it is possible to maintain the instrument temperature at 126 °F. ALSEP-4 (Apollo-14) and subsequent missions should be modified to include the installation of a heater and additional layers of multilayer insulation to achieve $k \leq 1.0 \times 10^{-4}$ Btu/hr/ft °F. The additional heater would require approximately 3 watts of power.

(2) To further reduce outside surface temperatures of the shroud, other thin metalized films having better optical properties could be used. One such film under consideration is silverized teflon which has an $\alpha_s/\epsilon_{ir} = \frac{0.07}{0.66} = 0.106$.

4.0 DISCUSSION

4.1 ANALYSIS AND ASSUMPTIONS

The thermal simulation of the PSE on the lunar surface is dependent upon closely simulating the experiment and the lunar soil beneath it. A brief discussion of the assumptions and numerical values of thermal parameters used to obtain the near correlation is presented in this section.

4.2 LUNAR SUBSURFACE MODEL

Until the results of the investigation of Apollo 11 lunar sample thermal properties were presented, reference (2) was used as the source of thermal-physical lunar data. The numerical values of lunar soil conductivity, density and specific heat are important parameters in the determination of the adiabatic temperature and depth. A one dimensional model of the lunar subsurface with the surface temperature given in reference (2) as a boundary condition was used to determine the adiabatic temperature and depth. Using reference (2) values of:

$k = 2.42 \times 10^{-3}$ Btu/hr/ft°F (1.0×10^{-5} cal/sec/cm°C)

$\rho = 3.24 \times 10^{-2}$ lb/in^3 (0.9 gm/cm^3)

$C_p = 0.2$ Btu/lb°F (0.2 cal/gm°C)

$\gamma = 6.06$ ft^2 °F hr$^{1/2}$/Btu (744 cm^2 °C sec$^{1/2}$/cal)

an adiabatic temperature of -48°F occurring at a depth of 17 inches was obtained.

A study of the thermal-physical data obtained from the Apollo 11 mission revealed values of k, ρ, and C_p which varied with sample type as should be expected. The selection, therefore, is dependent upon the type of subsurface assumed. It was assumed that the contents of the core tube samples better represented the "average" lunar material than any of the particular breccia or igneous rock samples. The core samples of 10 and 13.5 cm in length indicated the existence of a thick soil stratum rather than solid rock at that location.

Assuming the core sample density given in reference (3), a mean thermal conductivity at 0°F of the fines given in reference (4), and an average specific heat, a new adiabatic temperature and depth were obtained. Numerical values of these parameters are:

$k = 1.1 \times 10^{-3}$ Btu/hr/ft°F (4.55×10^{-6} cal/sec cm°C)

$\rho = 6.14 \times 10^{-2}$ lb/in^3 (1.70 gm/cm^3)

C_p = 0.2 Btu/lb°F (0.2 cal/gm°C)

γ = 6.54 ft^2 °F $\text{hr}^{1/2}$/Btu (800 cm^2 °C $\text{sec}^{1/2}$/cal)

The resulting adiabatic temperature is -55°F occurring at a depth of 8 inches.

In addition to obtaining the adiabatic depth and temperature, the one dimensional model was useful in determining the time varying temperatures imposed as boundary conditions on the subsurface model shown in Figure 2-1.

The lunar subsurface model consists of 12 cylindrical nodes beneath the PSE base, 72 annular nodes beneath the skirt and 12 exterior nodes used to impose the time varying boundary conditions.

4.3 PASSIVE SEISMIC THERMAL MODEL

Thermal simulation of the PSE assumed the 14 node model as shown in figure 2-1. A listing of the nodal breakdown and numbering scheme is as follows:

Node No.	Description
(1)	PSE sensor
(3)	inside of conical skirt
(4)	radiation barrier
(13)	inside of multilayer insulation disc
(14)	east half of sloped skirt
(15)	east half of cylindrical shroud
(16)	outside of multilayer insulation disc
(17)	west half of cylindrical shroud

Node No.	Description
(18)	west half of horizontal underside of skirt
(19)	east half of horizontal underside of skirt
(20)	east half of horizontal topside of skirt
(21)	west half of horizontal topside of skirt
(22)	inside of cylindrical shroud
(23)	west half of sloped skirt.

An important mode of heat transfer between the PSE and the covered lunar surface is radiation. An extensive amount of work has been done (reference 5) to determine the radiative exchange factors between the sensor base, underside of skirt, and the local lunar surface covered by the aluminized mylar skirt. Reference 5 presents a summary of radiation exchange factors as a function of skirt angle, sensor base emittance and skirt emittance. The exchange factors presented there for a 15° skirt angle (measured from horizontal) were used in this analysis after viewing actual photographs of the Flight 1 deployment on the moon.

Another earlier study of the internal radiation exchange factors between the cylindrical sensor cover and the cylindrical shroud was useful in developing the present model. In reference 6 a computer solution of the analytical equations used to determine view factors between concentric cylinders and discs is presented. Using these results, the desired internal exchange factors were determined assuming nominal surface properties.

An important parameter of the PSE thermal control system is the effective thermal conductivity of the multilayer insulation shroud and skirt. Nominal values of multilayer insulation conductivity were deduced from BxA thermal vacuum test data presented in references 7, 8. Best estimates of the effective insulation conductivity during lunar day and night are 1.2×10^{-3} Btu/hr/ft°F and 5.3×10^{-4}Btu/hr/ft°F, respectively. Note that the multilayer insulation is more effective at night than during the day. This dependence of thermal conductivity upon temperature has been observed in other tests of the material.

The optical properties used were those determined from absorptance and emittance measurements of samples at BxA. Results of measurements taken on exposed external surfaces such as aluminized mylar and aluminized teflon were reported in references 9, 10, and 11. The results of optical measurements taken on PSE beryllium and other internal components were presented in references 10 and 12.

4.4 FLIGHT 1 CORRELATION ASSUMPTIONS

Several items in the simulation are difficult to take into consideration and hence some basic assumptions must be made.

(1) The tunneling of solar and reflected energy to the sensor base is difficult to determine analytically, and hence assumed not to occur.

(2) The weight of the Flight 1 sensor is 19.26 pounds. Since the sensor is constructed primarily of beryllium a specific heat of 0.28 Btu/lb°F is assumed. Therefore, the value of the sensor capacitance is 5.5 Btu/°F.

(3) Nominal α_s/ϵ_{ir} measurements of aluminized mylar yield values of 0.2/0.37. However, the insulation skirt is visibly degraded by ruffles, creases and wrinkles as well as dust. To account for this non-ideal surface, the values of α_s/ϵ_{ir} are taken to be 0.37/0.37.

(4) The power dissipation within the sensor is assumed to be 1.0 watts for sensor temperatures above 126°F. This includes 0.75 watts of electronics dissipation and 0.25 watts of heater power while in the automatic mode. For sensor temperatures below the set point of 125°F an internal power dissipation of 3.25 watts is assumed.

With the above underlying set of assumptions and assumed parameter values, several transient computer runs were made. The matching of the sensor temperature decay after lunar sunset was first attempted. Using a skirt conductivity of 5.3×10^{-4} Btu/hr/ft°F and a shroud conductivity of 7.5×10^{-4} Btu/hr/ft°F for both day and night, correlation was achieved within 3°F.

At the beginning of the study it was assumed that the adiabatic temperature and depth beneath the skirt remained at -55°F and 17 inches, respectively, and not influenced by the presence of the blanket. However, if a second iteration attempt is made to determine a new adiabatic temperature and depth under the skirt assuming new surface boundary conditions, a temperature of -32°F and a depth of 8 inches is obtained.

To correlate lunar day results is a much more difficult task than lunar night. A number of other variables must be considered other than insulation conductivity. If a nominal deployment of the PSE and nominal surface properties are assumed it is not possible to get a good correlation with Flight 1 data. Uncertainties such as dust degradation of optical properties, skirt location and condition, in addition to effective skirt and shroud conductivity, make the correlation a formidable task. As a result, combinations of parameters must be evaluated separately.

Analysis of the Surveyor III equipment retrieved during the Apollo 12 mission showed the sandblasting effects of the LM during lunar landing (reference 13). This is an effect which would be difficult to assess analytically.

To date the correlation within 3°F of Flight 1 data has been obtained by assuming that the east side and top of the cylindrical shroud having a nominal $\alpha_s/\epsilon_{ir} = 0.73/0.73$. The west side remains in the undegraded state. The present correlation also requires the following:

(1) $k_{skirt} = 5.3 \times 10^{-4}$ Btu/hr/ft°F (day and night)

(2) $k_{shroud} = 7.5 \times 10^{-4}$ Btu/hr/ft°F (day and night)

(3) $k_{soil} = 1.1 \times 10^{-3}$ Btu/hr/ft°F

(4) $\rho_{soil} = 6.14 \times 10^{-2}$ lb/in^3

(5) $C_{p\ soil} = 0.2$ Btu/lb°F

(6) $C_{p\ sensor} = 0.28$ Btu/lb°F

(7) $\alpha/\epsilon_{\text{skirt}} = 0.37/0.37$

(8) $$Q = \begin{cases} 1.0 \text{ watts for } T_{\text{sensor}} > 126°\text{F} \\ 3.25 \text{ watts for } T_{\text{sensor}} < 126°\text{F} \end{cases}$$

The first, second and third days of lunar operation of Flight 1 are shown in Figure 4-1. Some typical parametric effects are shown in Figures 4-1 and 4-2. The best correlation to date is presented in Figure 4-3. Note the 24-hour phase shift of peak sensor temperature and the dip in temperature with respect to Flight 1 data.

4.5 ADDITIONAL STUDY

Further study is required to bring the analytical results into precise correlation with the observed data. In addition to the present parametric method of analysis, other data correlation techniques are under investigation at the present time.

The thermal properties of the Apollo 12 lunar samples and the evaluation of Flight 3 (Apollo 13) thermal performance will provide useful data for future analyses.

Specifically, areas of required study are:

1) Analytical evaluation of silverized teflon optical properties upon PSE thermal performance.

2) The determination of heater power requirements for Apollo 14 and subsequent off-equatorial landings sites as a function of latitude.

3) Complete the predictions of Flight 4 thermal performance.

4) Correlate Apollo 13 data.

Areas requiring design changes are:

1) The skirt thermal expansion and contraction problem producing undesirable noise.

2) Heater.

3) The shroud insulation.

FIGURE 4-1 PARAMETRIC EFFECTS ON PSE TRANSIENT TEMPERATURES

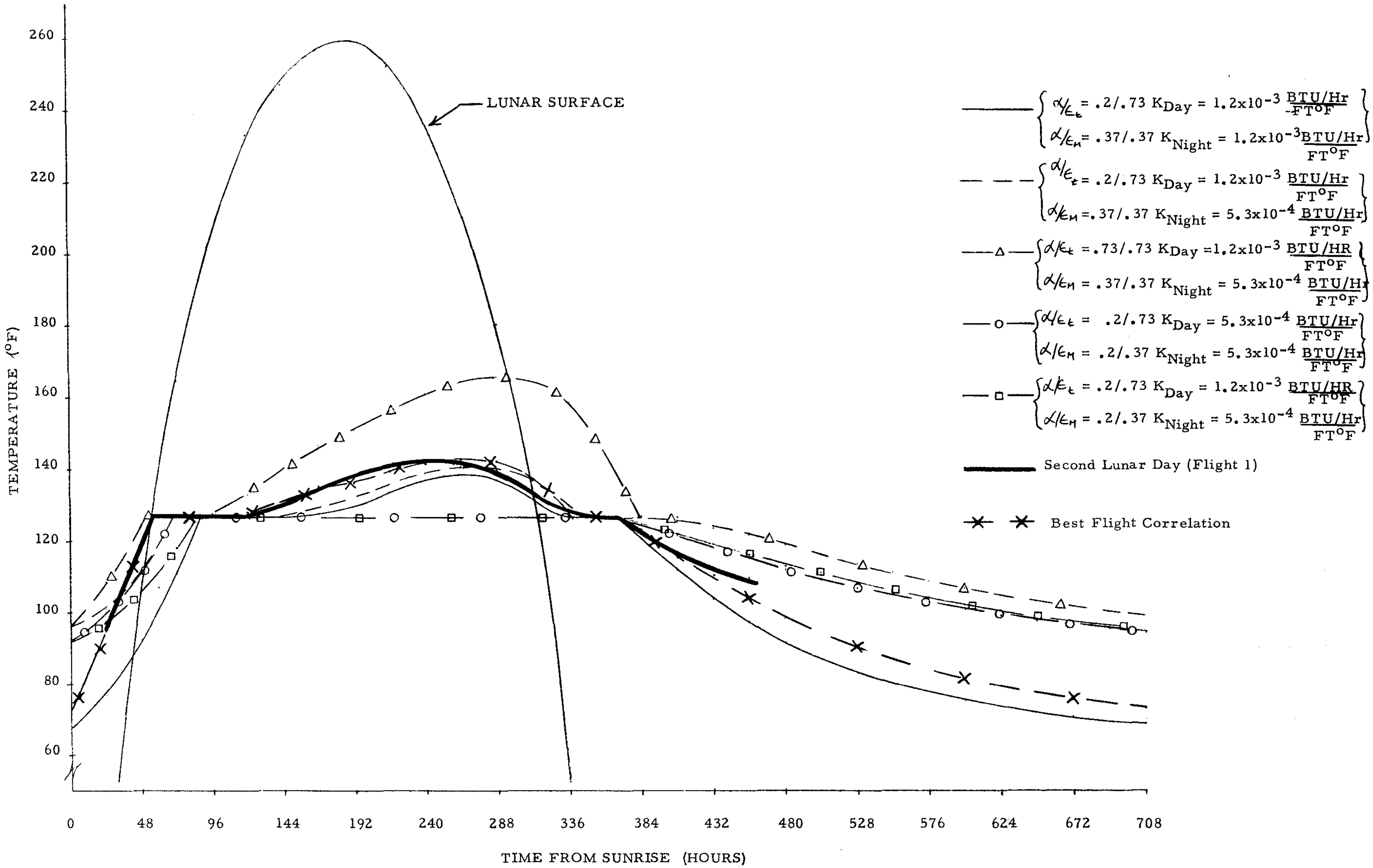


FIGURE 4-2 PARAMETRIC EFFECTS ON PSE TRANSIENT TEMPERATURES

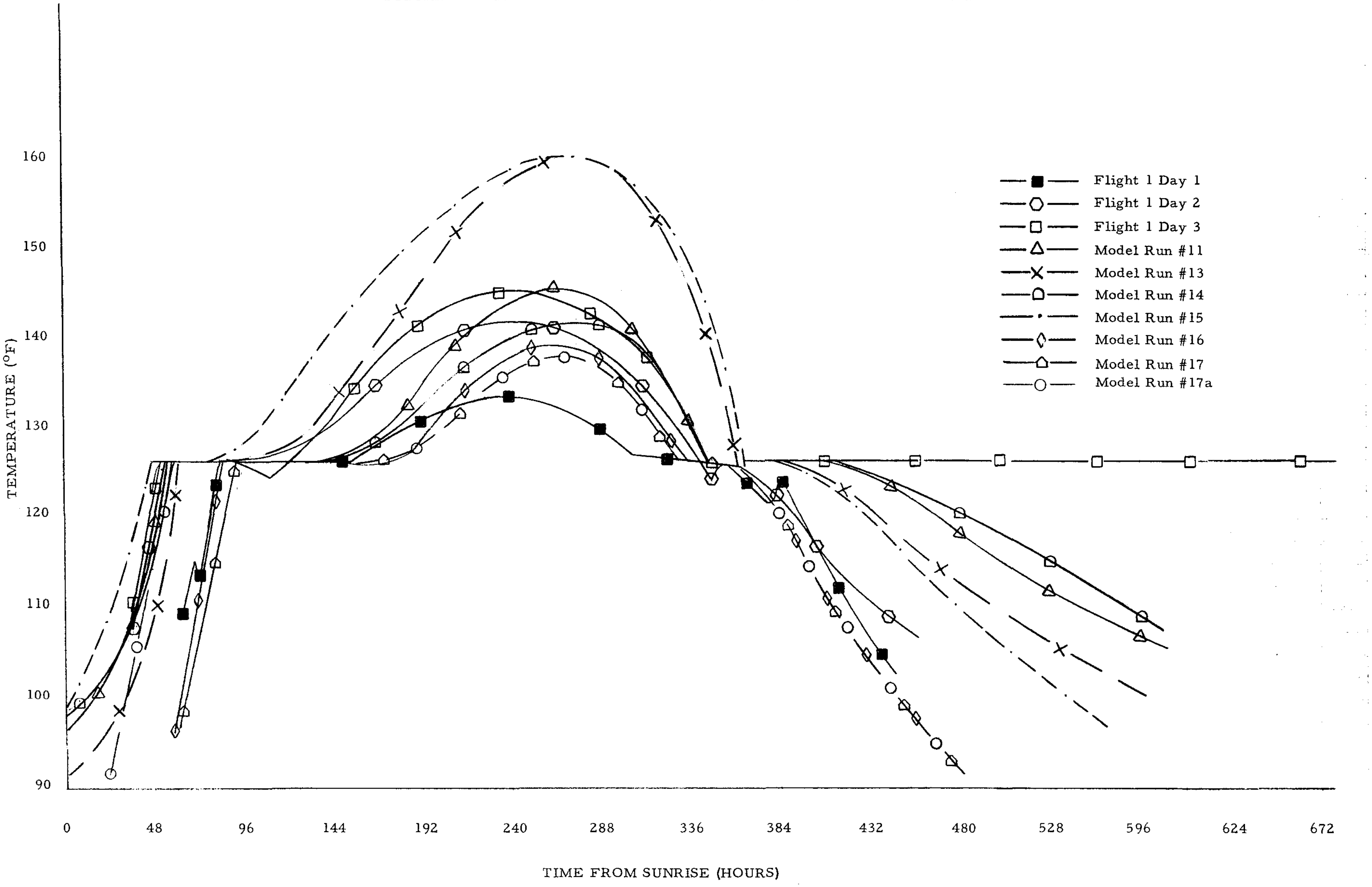
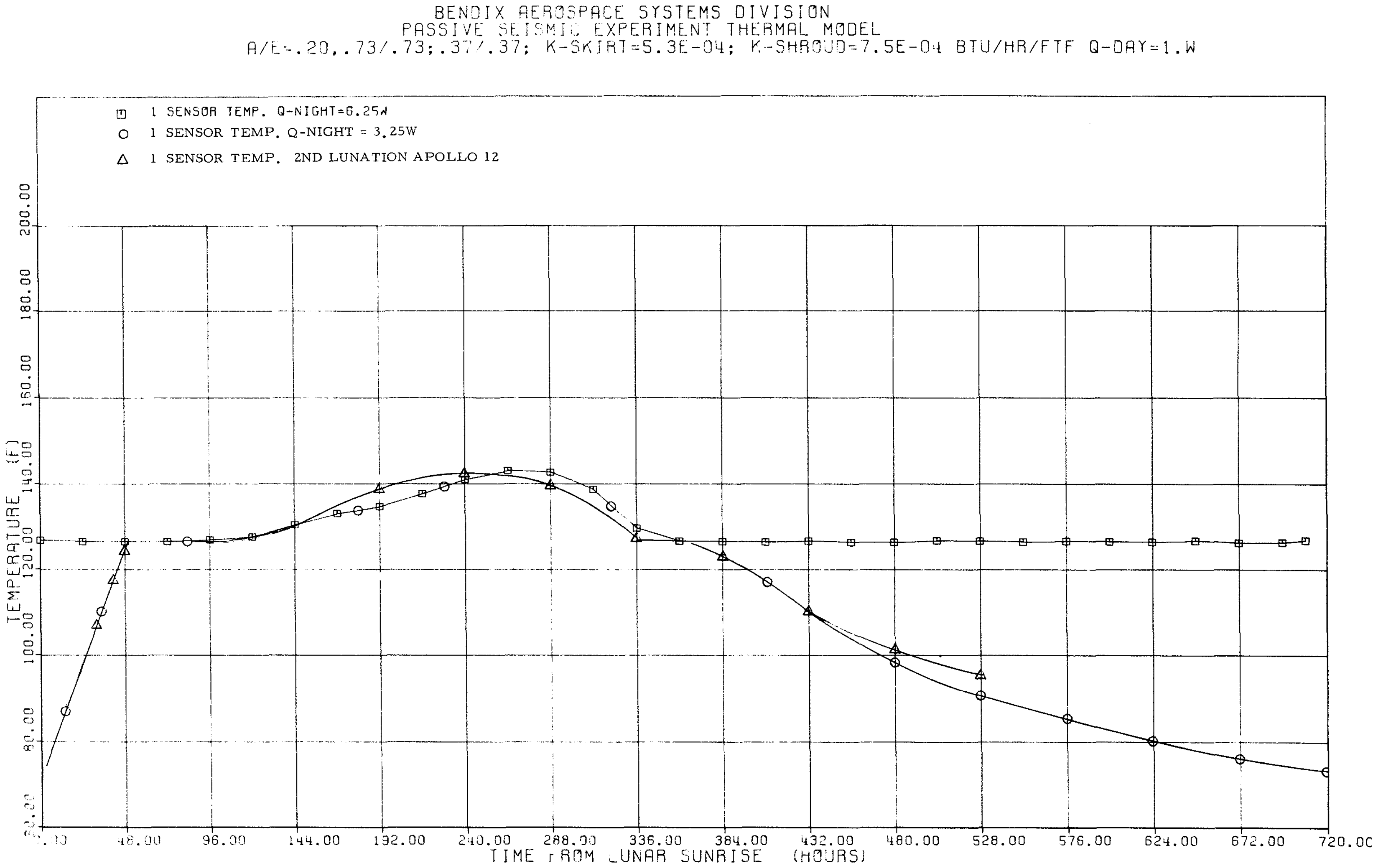


FIGURE 4-3



BENDIX AEROSPACE SYSTEMS DIVISION
PASSIVE SEISMIC EXPERIMENT THERMAL MODEL
A/E=.20,.73/.73;.37/.37; K-SKIRT=5.3E-04; K-SHROUD=7.5E-04 BTU/HR/FTF Q-DAY=1.W

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