Bendix

Aerospace Systems Division

LEAM Thermal Design Report

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SUMMARY

Historical development of the LEAM thermal design started with investigations of possible forward film candidates for the dual sensors and analysis of the conceptual base line design. The next step was narrowing down the film selection and refining the base line design. Step three consisted of building and testing a thermal DVT model to update the thermal math model. Lastly, the math model was used to generate the qualification thermal design.

Principal thermal control features include a superinsulation blanket between the internal and external structures, a five square inch second surface mirror radiator, low emittance films in the sensor openings, a low conductive flange between the internal and external structures and low conductive manganin wire between the electronics and very cold running components.

The present thermal design is expected to keep the LEAM electronics between -30°C and +65°C when operational and above -55°C during the survival mode. In addition, the maximum night time power requirement is less than the allocated 7 watts.

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TABLES

1.0 HISTORICAL DEVELOPMENT

Thermal design theory for LEAM at the onset was aimed at isolating the experiment from the lunar environment. This was done basically by minimizing the night heat leak and dissipating excess day energy gains with a radiator.

It became immediately apparent that the forward thin [1] Parylene films for the Up and East dual sensors became a very integral part of the isolation problem. Not only was it necessary to select film surface properties that would not damage the film but it was also necessary to select properties that would not drive the experiment out of the range specified by ARD 463 for either the lunar day or lunar night conditions.

The first thermal analyses therefore were directed toward bounding film surface properties. Results of the study showed that the films should be opaque to infrared radiation to minimize the night heat leak; should be nearly opaque to solar energy to minimize noon heating; and should have α_s/ϵ_H [2] ≤ 2.5 to keep the film from melting. Further analysis showed, however, that a higher α_s/ϵ_H ratio could be tolerated if the film laminate were bonded to a 6 mil beryllium copper grid (1/8" x 1/8" mesh). Verification of this fact was an outgrowth of the LEAM front film development test. [3]

Concurrent with the generation of a thermal math model for the experiment, a film development program [4] was undertaken by Union Carbide in an attempt to meet the film thermal requirements. The film selected for the thermal DVT test was 1800Å (angstroms) of Parylene C overcoated with 1000Å of vacuum deposited silver and finally with 200Å of Parylene C. The qualification model front film selection will be discussed in a subsequent paragraph.

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[1] Between 1000 and 4000 angstroms

[2] Solar absorptivity/infrared hemispherical emittance

[3] See Reference 1

[4] See Reference 2

The DVT engineering model developed in part with the aid of the math model was compromised because of schedule requirements. Physical description of the model is given in the thermal DVT test report[1], but the following thermally oriented highlights are noted. The interior aluminum structure was partially isolated from the outer fiberglass structure with 4 titanium clevis joints. Radiative coupling between the two structures was blocked by a superinsulation blanket. Low emittance films faced the moon and/or space from the three sensor openings. A 37 wire manganin cable connected the central electronics simulator to an externally located printed circuit board. A 10 square inch second surface mirror radiator faced space and the external structure was painted with a low α_s/ϵ_H white paint.

The thermal DVT test was run in March 1971 in the BxA 4' by 8' chamber. During the test, simulations were made for the lunar night, the lunar sunset and the lunar noon conditions, encompassing 16 thermal cases.

Results of the test were threefold. The thermal math model was updated, the forward films were redefined, and several design concepts were verified. A more elaborate description is given in the thermal DVT test report.

Redefinition of the forward films was made because of low temperature failures of the silver coated laminates. The film chosen for the qual model is 3050Å of Parylene C overcoated with 700Å of aluminum and 3250Å of silicon oxide. The α_s/ϵ_H ratio is .25/.10.

Updating the DVT thermal math model included redefining the heat leak through the titanium clevis brackets, increasing the radiative coupling between the forward frames and the structure, including losses from the squibs, increasing the losses from the bubble level, and incorporating several changes from the physical model. These changes included:

1. Holes in the forward films
2. Direct view of space from forward frame edges

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[1] See Reference 3.

3. Masking that did not fit properly

4. Direct view of space from the thermal bag flange

5. Use of 24 gage vs. 28 gage wire in the manganin inserts

6. Use of 3M velvet coat instead of S13G on the external structure.

The updated math model was then used to correlate results from the test for the survival, night, and noon cases. Correlations for the sunset case were not possible because of an inconsistency in test data. Design changes as a result of the correlation work included:

1. Redesign of the interface bracket from fiberglass instead of titanium

2. Movement of the squib attach points to the external structure.

3. Movement of the bubble level away from the interface bracket

4. Redesign of the East and West sensor openings to cover the frame edges

5. Redesign of the masking to cover the thermal bag flange.[1]

During vibration testing of the engineering model it was found that the forward films could not survive the vibrational amplitude. In order to damp out the effect, foamed Polyurathane pads were placed between the Lexan members of the forward grid and film frames. Although the thermal conductivity of the foam is low, since only 45 mils separates adjacent frames the net effect of the foam addition allows more heat to be lost to space through the frame system.

Thermal control compensation of the loss was achieved by aluminum taping major portions of the outboard suppressor grids and by reducing the exposed radiator area to 5 square inches.

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[1] The thermal bag flange is now part of the interface bracket.

2.0 QUALIFICATION MODEL THERMAL DESIGN

Thermal control design of the LEAM qualification model was based on the updated math model resulting from the thermal DVT test. Design changes have been analytically integrated into the model and updated mission predictions have followed. The passive segment of the thermal design is summarized by the following 16 points:

1. External Structure: - Painted on outside with S13G thermal paint ($\alpha_s/\epsilon_H = 0.2/0.9$). Inside surfaces covered with aluminized tape.

2. Internal Structure: - Sensor cavities painted with 3M Velvet Coat ($\epsilon_H = 0.9$). Surfaces facing superinsulation bag covered with aluminized tape.

3. Radiator: - Five square inches of second surface mirrors exposed to space (α_s[1]$/\epsilon_H = .07/.80$) and mounted to a 60 mil aluminum plate.

4. Radiator Masking: - Twenty-one layers of 1/4 mil aluminized Mylar separated by 20 layers of silk separators. Blanket enclosed by single layers of 2 mil aluminized Teflon. Outer layer has Teflon side out ($\alpha_s/\epsilon_H = .20/.69$) and inner layer has aluminized side facing experiment ($\epsilon_H = .05$).

5. Corner Support Masking: - Same construction as above.

6. Thermal Bag: - Forty-one layers of 1/4 mil aluminized (both sides) Mylar separated by 40 layers of silk separators. Outside layer is 5 mil aluminized Kapton with aluminized side out. Inside layer is 2 mil aluminized Kapton with aluminized surface facing internal structure. ($\epsilon_H = .05$)

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[1] Average properties for entire radiator.

7. Up and East Sensor Forward Films: - A laminate consisting of 3050 angstroms of Parylene coated with 700 angstroms of aluminum covered by 3250 angstroms of silicon oxide ($\alpha_s/\epsilon_H = .25/.1$).

8. Up and East Sensor Rear Films: - Three mil molybdenum foil sand blasted ($\epsilon_H = .06$).

9. West Sensor Film: - Three mil molybdenum foil coated with vacuum deposited aluminum ($\alpha_s/\epsilon_H = .10/.03$).

10. Up and East Sensor Outboard Suppressor Grids: - Outside face covered with aluminized tape.

11. East Sensor Film Shields: - Faced with aluminized tape (76%) and S13G paint (24%) (average $\alpha_s/\epsilon_H = .124/.254$).

12. West Sensor Suppressor Grid: - Outside face covered with aluminum tape (76%) and S13G paint (24%).

13. Up and East Sensor Frames With Visibility of Sun: - Painted with S13G.

14. West Sensor Frames: - Covered with aluminum tape (76%) and S13G paint (24%).

15. Grid and Film Frames With <u>NO</u> Visibility of Sun: - Painted with 3M velvet coat.

16. External Hardware Including the Bubble Level, UHT Socket, and Legs: - Painted with S13G.

Heater distribution for the qualification model is as follows:

1. East Sensor Nominal

   A 0.60 watt heater located on the internal structure behind the East sensor rear electronics.

2. West Sensor Nominal: - A 1.90 watt heater located on the rear of the West Sensor electronics shield.

3. West Sensor Survival: - A 0.95 watt heater located next to 2 (above).

4. Radiator Nominal: - A 0.60 watt heater located on the internal structure near the radiator and south of the central electronics.

5. Radiator Survival: - A 0.95 watt heater located next to 4 (above).

3.0 THERMAL MATH MODEL

The thermal math model which conceptually describes the LEAM experiment is composed of approximately 97 nodes and has about 428 conductive and radiative resistances. The nodal breakdown is listed in Table 3-1.

Computation of radiation resistances was assisted by the Confac II[1] program, which computed view factors, and the Absorp[2] program, which calculated script F[3] values. Surface coatings and finishes for principal components with associated thermal surface properties are listed in Section 2.

Conductive resistances for the math model were computed by scaling drawings describing various components of the experiment and by applying the appropriate conductivities. The conductivity values used in the analysis appear in Table 3-2.

Solar inputs for the various cases were computed by multiplying selected projected areas times the local α_s and then by the solar constant, 442 BTU/hr. ft^2. Heat dissipation inputs were taken from current power dissipation figures and are listed in Table 3-3.

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[1] See Reference 4

[2] See Reference 5

[3] A mathematical concept that accounts for the inter-reflections in a radiative network. See Reference 6.

TABLE 3-1 NODAL DESCRIPTION FOR THE ANALYSIS

DEFINITION	NODE #	DEFINITION	NODE #
UP SENSOR		EAST SENSOR	
OUTER FRONT GRID FRAME	1	OUTER FRONT GRID FRAME	101
FRONT FILM	2	FRONT FILM	102
FRONT FILM FRAME	3	FRONT FILM FRAME	135
FRONT FILM GRID	35	FRONT FILM GRID	135
INNER FRONT GRID FRAME	4	INNER FRONT GRID FRAME	104
FORWARD ELECTRONICS		FORWARD ELECTRONICS	
SOUTH	5	SOUTH	105
WEST	6	TOP	106
NORTH	7	NORTH	107
EAST	8	BOTTOM	108
REAR GRID FRAME	9	REAR GRID FRAME	109
REAR FILM - CENTER	30	REAR FILM - CENTER	130
REAR FILM - EDGE	31	REAR FILM - EDGE	131
REAR FILM FRAME	11	REAR FILM FRAME	111
REAR ELECTRONICS	13	REAR ELECTRONICS	113
HEAT TRANSFER PLATE	25	HEAT TRANSFER PLATE	125
SUPPORT STRUCTURE		SUPPORT STRUCTURE	
SOUTH	14	SOUTH	114
WEST	15	TOP	115
NORTH	16	NORTH	116
EAST	17	BOTTOM	117
SENSOR ENCLOSURE		SENSOR ENCLOSURE	
SOUTH	18	SOUTH	118
WEST	19	TOP	22
NORTH	20	NORTH	120
EAST	21	BOTTOM	121
BOTTOM	22	REAR	122

TABLE 3- ont.)

DEFINITION	NODE #
WEST SENSOR	
GRID FRAME	209
FILM 1 x 4	230
FILM 3 x 4	231
FILM FRAME	211
REAR ELECTRONICS	213
HEAT TRANSFER PLATE	225
SENSOR ENCLOSURE	
TOP	22
BOTTOM	221
REAR	222
RADIATOR - SECONDARY	23
RADIATOR - PRIMARY	24
CENTRAL ELECTRONICS	32
INTERFACE BRACKET CORNERS	
SOUTHWEST	41
NORTHWEST	42
NORTHEAST	43
SOUTHEAST	44
FIBERGLASS ENCLOSURE	
SOUTH	61
WEST	62
NORTH	63
EAST	64
BOTTOM	65
FIBERGLASS ENCLOSURE CORNERS	
SOUTHWEST	51
NORTHWEST	52
NORTHEAST	53
SOUTHEAST	54
TOP FLANGE UNDER SECONDARY RADIATOR	33
TOP FLANGE UNDER PRIMARY RADIATOR	34

DEFINITION	NODE #
SUPERINSULATION INSIDE	
SOUTH	71
WEST	72
NORTH	73
EAST	74
BOTTOM	75
SUPERINSULATION OUTSIDE	
SOUTH	81
WEST	82
NORTH	83
EAST	84
BOTTOM	85
SECONDARY RADIATOR MASKING	93
PRIMARY RADIATOR MASKING	94
SUPERINSULATION OVER CORNER MOUNTS	
SOUTHWEST	141
NORTHWEST	142
NORTHEAST	143
SOUTHEAST	144
OUTER SECTION OF CORNER MOUNTS	
SOUTHWEST	241
NORTHWEST	242
NORTHEAST	243
SOUTHEAST	244
SQUIB FIBERGLASS FLANGES	56, 57
SQUIBS	58, 59

TABLE 3-2 CONDUCTIVITY VALUES USED IN THE ANALYSES

MATERIAL	K (BTU/FT^2.HR. °F/FT)
Aluminum 2024	109
Aluminum 6061	99
Aluminum-Pure	135
Beryllium Copper	68
Copper-Pure	226
Epoxy Fiberglass	0.25
Lexan	0.11
Molybdenum	84.5
Quartz (Fused Silica)	0.68
Polyurathane Foam	0.038
Stainless Steel Screws	9.4

TABLE 3-3 POWER DISSIPATION VALUES USED IN THE ANALYSIS

Definition	Dissipation-Watts Noon	Night	Survival
Up Sensor			
Forward Electronics	0.32	.34	0
Rear Electronics	0.28	.30	0
East Sensor			
Forward Electronics	0.32	.34	0
Rear Electronics	0.28	.30	0
Microphone Heater	0	0.60	0.60
West Sensor			
Electronics	0.27	0.29	0
Microphone Heater	0	1.90	1.90
Survival Heater	0	0	0.95
Central Electronics	1.70	1.82	0
Radiator			
Nominal Heater	0	0.60	0.60
Survival Heater	0	0	0.95
Total	3.17	6.49	5.00

4.0 DISCUSSION OF ANALYTICAL RESULTS

Table 4-1 presents the analytical results from the thermal model for the noon, night and survival cases. Additional case temperatures are shown for a solar angle 10° past sunrise and 10° before sunset.

The noon case predictions show the Up sensor front film temperature at 246°F, a decrease of 55°F from the value presented at CDR. This decrease is due to the reduced solar absorptance measured for the qual-model film from 0.4 to 0.25 and greater conductive coupling between the grid and film frames. It is observed that the electronics and microphone temperatures remain below the upper specification limit for this case.

Night and survival case listings illustrate the temperature distribution for the two cold conditions and show all electronic temperatures above the appropriate lower specification limit. Comparisons between the two cases give an indication of temperature decrease in going from 6.5 watts power dissiption (night) to 5 watts (survival), and yield a temperature/power relationship of more than 20°F per watt for cold cases.

Sunrise and sunset cases are presented for reference data only. The LEAM experiment as deployed will have its east-west axis directed away from the moon east-west axis [1] while the data generated in the analysis assumed parallel alignment. The moon deployment case will cause lower temperatures for these conditions since the solar vector will be off-normal to the sensor openings.

Analytical data presented in Table 4-2 summarizes the night and day energy balances for the experiment. The small differences (.03 & .01 watts) between heat transfer data and power dissipation figures are due to computer round-off. Principal changes from the DVT model are smaller night losses through the interface bracket and radiator, and larger night losses through the Up and East Sensors. The Qualification model interface bracket is made of fiberglass while the DVT brackets were made of titanium. The current radiator size is 5 square inches while the DVT had 10 square inches. The addition of polyurathane separators between the grid and film frames cause an increased night loss through the sensors for the qual-model.

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[1] The angle has not been defined as of this writing.

Table 4-1 LEAM TEMPERATURES

		Temperature ~°F				
DEFINITION	NODE #	NOON	NIGHT	SURVIVAL	SUNRISE +*	SUNSET -**
Up Sensor						
Outer Front Grid Frame	1	107	-44	-76	-12	-32
Front Film	2	246	-41	-74	-8	-29
Front Film Frame	3	123	-38	-71	-4	-25
Forward Electronics	5	138	-10	-48	27	4
Support Structure	14	138	-10	-48	27	3
Rear Film	30	141	-5	-47	32	8
Rear Electronics	13	141	-4	-46	33	9
East Sensor						
Outer Front Grid Frame	101	133	-42	-72	53	-13
Front Film	102	134	-38	-70	203	-10
Front Film Frame	103	135	-35	-67	62	-9
Forward Electronics	105	139	-7	-44	46	7
Support Structure	114	139	-7	-44	46	7
Rear Film	130	142	-2	-43	49	11
Rear Electronics	113	142	-1	-42	49	12
West Sensor						
Grid Frame	209	128	-82	-103	-23	7
Film	230	139	-9	-42	27	37
Film Frame	211	139	-9	-41	27	26
Electronics	213	140	-7	-40	28	27
Central Electronics	32	144	2	-44	37	14
Internal Structure	22	139	-5	-40	34	7
Radiator	24	129	-13	-46	21	-2
Lunar Surface	200	250	-300	-300	5	5
Spec Limit (Electronics)		149 (65°C)	-22 (-30°C)	-67 (-55°C)		

* Solar Angle at 10°

** Solar Angle at 170° Approximate Values Since Heaters Will Be Cycling

Table 4-2 LEAM ENERGY BALANCES

COMPONENT	Heat Transfer - Watts Night	 Noon
Radiator	-0.56	-1.23
Up Sensor	-1.36	-1.16
East Sensor	-1.35	-0.44
West Sensor	-0.85	-0.26
Interface Bracket	-0.99	.06
Masking	-0.67	- .24
Superinsulation	-0.42	.09
Cable	-0.31	0
	-6.51	-3.18
Power Dissipation	6.48	3.17

5.0 CONCLUSION

The LEAM thermal design is a result of thermal math model development, DVT model testing, and math model refinement. Design theory is based on isolation of the experiment from the environment and includes a superinsulation blanket and low conductive fittings between external and internal surfaces, low emittance films in sensor openings and a 5 square inch second surface mirror radiator. Thermal analysis predicts the electronics will remain between -30°C and +65°C when operational and above -55°C during the survival mode.

6.0 REFERENCES

1. LEAM Film Development Test Report ATM-995 R. J. Simms, 7 April 1971.

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