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Lunar Reconnaissance Orbiter (LRO)

Thermal Math Model Requirements

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ACRONYM & ABBREVIATION DEFINITIONS

BU	Boston University
CBE	Current Best Estimate
CPL	Capillary Pump Loop
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
Diviner	Lunar Radiometer Experiment
ESS	Edge Space Systems, Inc.
FAC	Scale factor card used in SINDA
GMM	Geometric Math Model
GSFC	Goddard Space Flight Center
IDT	Development Team
I/F	Interface
IKI	Institute for Space Research
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LHP	Loop Heat Pipe
LMTO	Lockheed Martin Technical Operations
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
MLI	Multi-Layer Insulation
NAC	Narrow Angle Component
NASA	National Aeronautics and Space Administration
NU	Northwestern University
OB	Optical Bench
S/C	Spacecraft
SCS	Sequencing & Compressor System
SINDA	Systems Improved Numerical Differencing Analyzer
SWALES	Swales Aerospace
SwRI	Southwest Research Institute
TMM	Thermal Math Model
TSS	Thermal Synthesizer System
UCLA	University of California, Los Angeles
VCHP	Variable Conductance Heat Pipe
VDA	Vapor Deposited Aluminum
VDG	Vapor Deposited Gold
WAC	Wide Angle Component

1.0 INTRODUCTION

The purpose of this document is to provide the general requirements for preparing geometric math models (GMM) and thermal math models (TMM) of the spacecraft and instruments for the Lunar Reconnaissance Orbiter (LRO) program. Any questions or issues pertaining to the information presented in this document should be directed to the individuals listed in Table 1-1.

Table 1-1: Contact List

CONTACT	PHONE	EMAIL
Charles Baker	(301)286-2065	charles.l.baker@nasa.gov
Bill Chang	(301)286-5703	wschang@mscmail.gsfc.nasa.gov

2.0 GEOMETRIC MATH MODELS (GMM)

Each Instrument Development Team (IDT) shall provide their respective instrument GMM in Thermal Synthesizer System (TSS) format version 11.01E or higher.

2.1 TSS INPUT FILES

The GMM shall be delivered with the following TSS files:

a. File containing the TSS geometry (*.tssgm)
b. A minimum of two files containing the hot and cold thermo-optical properties (*.tssop)
c. File containing the TSS material data (*.tssma). This can be just the TSS default file.

2.2 GMM FILE NAMING CONVENTION

The geometry model and associated property and material files shall conform to the following naming conventions:

a. TSS geometry file names shall have the format

INST_CONFIG_INTEXT_MMDDYY.TSSGM

where *INST* is the name of the instrument (e.g., LAMP, LROC, etc.). *CONFIG* is used to designate the configuration as either "STOW" for stowed, "DEPL" for deployed, or "NA" for not applicable. *INTEXT* is used to designate whether the geometry model is internal ("INT"), external ("EXT") , or both ("BOTH"). *MMDDYY* is the date stamp.

b. TSS thermo-optical property file names shall have the format

INST_PROP_MMDDYY.TSSOP

where *INST* is the name of the instrument (e.g., LAMP, LROC, etc.). *PROP* is used to designate whether the thermo-optical properties are "COLD", "HOT", or "NOM" for nominal properties. *MMDDYY* is the date stamp.

c. TSS material property file names shall have the format

INST_MMDDYY.TSSMA

where *INST* is the name of the instrument (e.g., LAMP, LROC, etc.) and *MMDDYY* is the date stamp.

All associated GMM files shall have the same date stamp. Even if one or more files have not changed, simply copy the file and rename it with the same date stamp as the other files. This will help to avoid any confusion with respect to file association.

2.3 MODEL COORDINATE SYSTEM

All geometry models shall utilize the LRO Mechanical Coordinate System defined in Figure 2-1 with +Z nadir pointing, +X in the thrust direction and +Y completing the right hand rule. All relevant (0,0,0) local origins shall be clearly identified in the model documentation that accompanies the model.

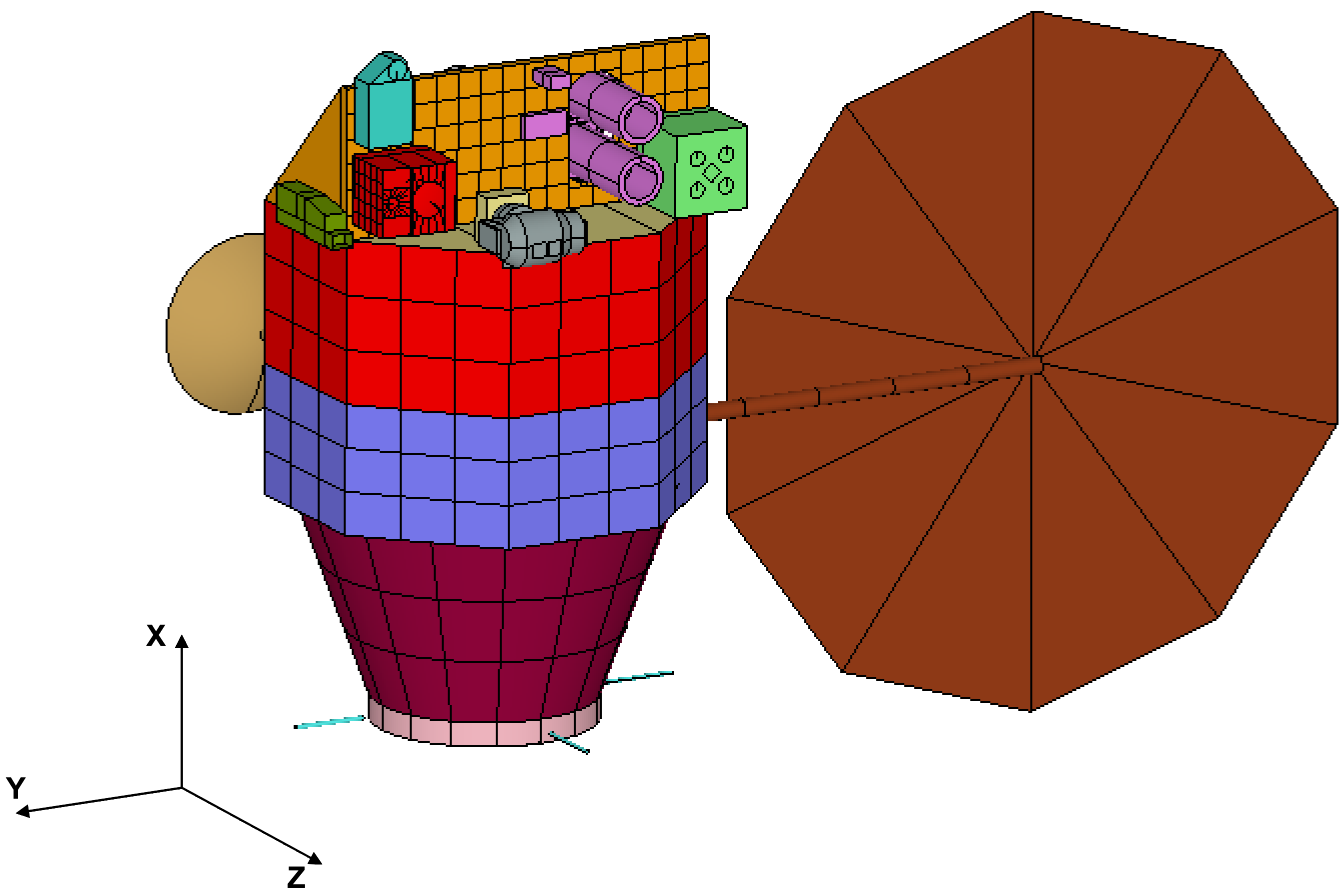

Figure 2-1: LRO Coordinate System Definition

2.4 SURFACE AND ASSEMBLY NAMING CONVENTION

All surfaces shall be placed in an assembly other than the "Model.1" default assembly. The surface and assembly names should reflect the subassembly, component or part being represented (e.g., LRO_ACS_RAD, LROC_NAC1_BAFFLE, etc.). Avoid using the default primitive names such as rectangle, cylinder, disc, etc.

2.5 THERMO-OPTICAL PROPERTIES

2.5.1 LRO APPROVED THERMO-OPTICAL PROPERTIES

All proposed thermo-optical properties used must be approved by the GSFC coatings committee. Table 2-1 provides a listing of the coatings and associated properties that have been approved by the GSFC Coatings Committee for use on LRO. For the baseline analysis, the hot absorptance values for thirteen (13) months apply. IDT's are by no means limited to these coatings. Candidate coatings not listed in Table 2-1 must be submitted to Charles Baker, LRO Lead Thermal Systems Engineer for approval.

Table 2-1: LRO Coating Properties

NAME	DESCRIPTION	COLD		HOT 13 mo. (5 yr.)		SPEC.	
		α_S	ε_H	α_S	ε_H	SOL	IR
Coatings							
lro_black_anodize	Black Anodize	0.80	0.88	0.92	0.83		
lro_clear_anodize	Clear Anodize	TBD	TBD	TBD	TBD		
lro_irridite	Irridite	0.10	0.19	0.25	0.11		
lro_z307_cond_black	Z307 Conductive Black	0.95	0.89	0.97	0.85		
lro_msa94b_cond_black	MSA94B Conductive Black	0.94	0.91	0.96	0.87		
lro_z306_black	Z306 Black	0.94	0.89	0.95	0.85		
lro_z93p_white	Z93P White Paint	0.17	0.92	0.25 (0.36)	0.87		
lro_ns43c_cond_white	NS43C Conductive White	0.20	0.91	0.26 (0.37)	0.87		
lro_vda	Vapor Deposited Aluminum	0.08	0.05	0.10	0.03	0.98	0.98
lro_vdb	Vapor Deposited Beryllium	TBD	TBD	TBD	TBD		
Films and Tapes							
lro_kapton_3mil	Kapton, 3-mill	0.45	0.80	0.51 (0.60)	0.76		
lro_osr_pilkington_5mil	OSR Pilkington, 5-mill	0.07	0.80	0.12 (0.19)	0.78	1.0	---
lro_osr_ito_pilkington_5mil	OSR/ITO Pilkington, 5-mill	0.08	0.80	0.15 (0.23)	0.78		
lro_ag_tef_tape_5mil	Silver Teflon Tape, 5-mil	0.08	0.78	0.25 (0.33)	0.73	1.0	---
lro_ag_tef_tape_10mil	Silver Teflon Tape, 10-mil	0.09	0.87	0.27 (0.35)	0.83	1.0	---

NAME	DESCRIPTION	COLD		HOT 13 mo. (5 yr.)		SPEC.	
		α_S	ε_H	α_S	ε_H	SOL	IR
lro_ag_tef_5mil	Silver Teflon, 5-mil	0.08	0.78	0.11 (0.14)	0.73		
lro_ag_tef_10mil	Silver Teflon, 10-mil	0.09	0.87	0.13 (0.27)	0.83		
lro_black_kapton_3mil	Black Kapton, 3-mil	0.91	0.81	0.93	0.78		
lro_germ_black_kapton	Germanium Black Kapton	0.49	0.81	0.51	0.78		
Miscellaneous							
lro_solar_cell	Solar Cell Triple Junction	0.86	0.87	0.90	0.77	1.0	---
lro_m55j_composite	M55J Composite, Bare	0.90	0.79	0.93	0.75		
lro_k1100_composite	K1100 Composite, Bare	0.88	0.71	0.88	0.71		
lro_fused_silica	Fused Silica	TBD	TBD	TBD	TBD		
lro_sapphire	Sapphire Lens	TBD	TBD	TBD	TBD		
lro_int_fuel_line	Internal Fuel Line	1.0	0.15	1.0	0.15		

2.5.2 Property Naming Convention

Table 2-1 presents a partial list of LRO coatings with pre-assigned names. These property names shall be used where applicable. If it becomes necessary to add a coating not listed in the table, then assign a name to the coating using the convention described below.

Naming of thermo-optical properties should include as much information as possible to allow someone to easily ascertain what the coating is. All names shall be in lower case letters. In addition, to prevent accidental overwriting of similar property names upon model integration, each IDT shall preface the property names with the name of their instrument. Table 2-2 shows some examples of property names. Note that the thermo-optical properties of the proposed coating must be submitted to the LRO Thermal Systems Lead Engineer for approval.

Table 2-2: Example Thermo-Optical Property Names

PROPERTY NAME	DESCRIPTION
crater_germ_black_3mil	CRaTER instr. – 3-mil black Germanium
diviner_alum_kapton_3mil	Diviner instr. – 3-mil aluminized Kapton
lro_alum_tape_5mil	LRO S/C – 5-mil aluminum tape
lola_vdg	LOLA instr. – vapor deposited gold
lro_k13c_composite	LRO S/C – K13C composite

2.5.3 Submodel Naming Convention

In order to avoid potential naming conflicts upon integration of all instrument models with the spacecraft model, all GMMs delivered to GSFC shall utilize submodels. The obvious choice for the submodel name is that of the instrument (e.g., LEND, LAMP, LOLA, etc.). If warranted, more than one submodel may be used. In such cases, each submodel must be prefaced with the name of the instrument (e.g., LROC_SCS, LROC_WAC, etc.).

3.0 THERMAL MATH MODELS (TMM)

Each IDT shall deliver their respective instrument TMM in SINDA/FLUINT format version 4.0 or higher.

3.1 SINDA/FLUINT INPUT FILES

The TMM shall be delivered with the following SINDA/FLUINT files:

a. Input file(s) shall be provided (*.inp). It is preferable that a single input file be provided containing logic for running hot, cold and safe-hold cases and be capable of carrying out both steady-state and transient analyses. However, if the logic for distinguishing between hot, cold, and survival cases is too cumbersome, then separate files for these cases will be allowed.

   Information in the input file that will be replaced upon integration with the S/C model should be placed in separate files and imported into the input data deck via “INCLUDE” or “INSERT” statements. The types of data affected are TSS generated orbital heat rates and radiation couplings.

b. Temperature output files (*.out) shall be provided that were generated by executing the supplied input file. Separate output files shall be provided for the mission operational hot and cold cases and the relevant safe-hold case.

3.2 TMM FILE NAMING CONVENTION

The thermal models and associated support files shall conform to the following naming conventions:

a. SINDA input data file names shall have the format

   INST_CONFIG_INTEXT_MMDDYY.INP

   where *INST* is the name of the instrument (e.g., LAMP, LROC, etc.). *CONFIG* is used to designate the configuration as either “STOW” for stowed, “DEPL” for deployed, or “NA” for not applicable. *INTEXT* is used to designate whether the thermal model is internal (“INT”), external (“EXT”), or both (“BOTH”). *MMDDYY* is the date stamp.

b. SINDA temperature output file names shall have the format

   INST_CONFIG_INTEXT_CASE_MMDDYY.OUT

   where *INST, CONFIG,* and *INTEXT* are as described in (a) above. *CASE* is used to provide a short descriptor indicating what case was analyzed (e.g., COLD, HOT, SURV, BETA45, etc.). *MMDDYY* is the date stamp.

c. Include file names for radiation coupling generated by TSS shall have the format

   INST_CONFIG_INTEXT_CASE_MMDDYY.RADK

   where *INST, CONFIG, INTEXT, CASE*, and *MMDDYY* are as described in (b) above.

d. Include file names for environmental heat rate arrays and the associated VARIABLES 1 logic generated by TSS shall have the format

   INST_CONFIG_CASE_MMDDYY.HR

where *INST, CONFIG, CASE*, and *MMDDYY* are as described in (b) above.

All associated TMM files shall have the same date stamp. Even if one or more files have not changed, simply copy the file and rename it with the same date stamp. This will help to avoid any confusion with respect to file association.

3.3 THERMAL MODEL UNITS

In order to avoid conflicts with units during model integration at the Orbiter level, all instrument development teams shall provide models utilizing the units listed in Table 3-1.

Table 3-1: Thermal Model Units

PARAMETER	UNITS
Power	Watts
Time	Seconds
Temperature	°C
Mass	Kilogram
Length	Meters
Area	m^2
Heat Flux	W/m^2
Material Density	kg/m^3
Specific Heat	W-sec/kg-°C (J/kg-°C)
Thermal Conductivity	W/m-°C
Thermal Capacitance	W-sec/°C (J/°C)
Conduction Couplings	W/°C
Radiation Couplings	m^2
Stefan-Boltzmann Constant	5.669×10^{-8} W/m^2-K^4

3.4 MODELING THE SPACECRAFT/INSTRUMENT INTERFACE

Integration of geometry and thermal math models for all instruments with the spacecraft model shall be the responsibility of GSFC. To facilitate the integration effort, each IDT shall create an interface submodel named "IF". Each IDT is assigned a specific block of nodes to utilize. These are defined in Table 3-2.

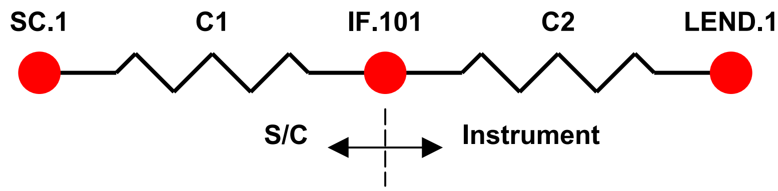

Figure 3-1: Typical Interface Conductive Coupling

Table 3-2: Interface Node Assignments

INSTRUMENT	I/F NODES
LEND	101, 102, 103, …..
LOLA (Detector)	201, 202, 203, …..
LOLA (EBOX)	211, 212, 213, …..
LROC (NAC1)	301, 302, 303, …..
LROC (NAC2)	311, 312, 313, …..
LROC (WAC)	321, 322, 323, …..
LROC (SCS)	331, 332, 333, …..
CRaTER	401, 402, 403, …..
LAMP	501, 502, 503, …..
Diviner (Detector)	601, 602, 603, …..
Diviner (EBOX)	611, 612, 613, …..

As shown in Figure 3-1, the interface nodes simply serve as dummy nodes conductively coupling the instruments to the spacecraft. The figure shows an example of coupling node LEND.1 (one of the mounting pads) to the spacecraft node SC.1 at the attach point via interface node IF.101. Conduction couplings, C1 and C2, will be specified by GSFC and the IDTs, respectively. If the IDT is responsible for providing the interface mounts, then the IDT will specify a realistic value for C2 and GSFC will specify a large value for C1 to simulate a hard mount and vice versa.

3.5 SUBMODEL NAMING CONVENTION

In order to avoid potential naming conflicts upon integration of all instrument models with the spacecraft model, all TMMs delivered to GSFC shall utilize submodels. The obvious choice for the submodel name is that of the instrument (e.g., LEND, LAMP, LOLA, etc.). If warranted, more than one submodel may be used. In such cases, each submodel must be prefaced with the name of the instrument (e.g., LROC_SCS, LROC_WAC, etc.). It should be noted that SINDA limits submodel names to only 8 characters.

Since the output from TSS is used to feed into SINDA, please make sure that the submodel names used in TSS and SINDA agree with each other.

3.6 THERMAL MODEL RESTRICTIONS

3.6.1 Space Node

The global submodel name and node number assigned for space is SPACE.9999. All development teams shall use this convention.

3.6.2 Register Data Block

SINDA/FLUINT allows users to define variable names in the Register Data Block that may be used in other Data Blocks. To avoid possible conflicts with other models, each development team shall preface any variables used with the name of their instrument.

3.6.3 Global User Data Block

The Global Data Block is reserved for use by GSFC. The IDTs shall use the Register Data Block to define any variables that may be needed.

3.6.4 FAC Cards

FAC cards in SINDA allow for an easy way of scaling values in the data blocks. This is most commonly used in Conductor Data Blocks to convert from one set of units to another. In the past, mistakes have been made where a conductor or group of conductors were added without checking for the presence of a FAC card. To avoid the possibility of such mistakes, no FAC cards shall be allowed anywhere in the SINDA data deck.

3.6.5 Radiation Couplings

Radiation couplings shall be provided in terms of areas utilizing units of square meters. The integrated model will specify a Stefan-Boltzmann constant of 5.669×10^{-8} W/m^2-$°K^4$.

3.6.6 Temperature Scale

The temperature scale utilized shall be degrees Celcius. The ABSZRO parameter in SINDA shall have a value of -273.0.

3.6.7 Source Code

No proprietary software code shall be allowed. All IDTs are required to provide source code for any logic used in the thermal models.

4.0 MODEL DOCUMENTATION

All delivered geometry and thermal math models shall be documented in a User's Manual in sufficient detail to permit independent analysis. The User's Manual shall include, but not necessarily be limited to, the following information:

a. Graphical figures showing node locations and coordinate system
b. Graphical and/or table showing surface coatings matched to node numbers
c. Tables providing the following information
    - Nodal thermal capacitance
    - Linear node-to-node conductors
    - Fixed radiation node-to-node conductors (if any). It is not necessary to include any radiation couplings generated by TSS.
    - Array data not generated by TSS (e.g., temperature dependent properties, time varying power arrays, etc.)
    - Listing of nodes where operational and survival heater power is to be applied, associated nodes used for heater control, maximum heater power, heater ON/OFF set points, type of heater (bang-bang or proportional), and mission mode power profiles.
    - Detailed description of any special logic/algorithms utilized (e.g., heater control logic, VCHP logic, CPL/LHP logic, etc.). No proprietary code will be allowed.
    - Detailed description of logic and use for any user provided subroutines

- Description of user defined variables/registers along with where and how they are used
- Listing of component power dissipations and the nodes they are applied to
- Listing of materials used along with their applicable thermo-optical and material properties
- Listing correlating thermal model node(s) to each reference location where a spacecraft monitored temperature sensor will be placed

d. Table correlating SINDA node number to TSS object

e. Listing of temperature limits assigned to reference location(s) and other critical component. The appropriate node number(s) in the thermal model shall be identified and the following four (4) types of operational and survival temperature limits shall be provided. Refer to document number TBD ("LRO Thermal Interface Control Document") for a description of these temperature limits.
   - Hard limits
   - Current best estimate (CBE) limits
   - Design limits
   - Qualification limits

The GMMs and TMMs will include an adequate level of detail to predict, under worst case hot, cold, and safe-hold conditions, all critical temperatures, including those that drive operational and survival temperature limits and heater power. Worst-case conditions will include variations in season, orbit selection, orbital time, and environmental flux parameters (seasonal and spatial) and a rational combination of the effects of design tolerances, fabrication uncertainties, material differences, and degradation due to aging.

Models should use conservative property values for conduction, absorption, emission, and MLI effective emittance, and consider contact resistance. Analyses should consider cold and hot properties for external coatings.