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DRAFT

Lunar Reconnaissance Orbiter (LRO)

General Thermal Subsystem Specification

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ACRONYM & ABBREVIATION DEFINITION

BOL	Beginning-Of-Life
BU	Boston University
CBE	Current Best Estimate
C&DH	Command and Data Handling
CPL	Capillary Pump Loop
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
Diviner	Lunar Radiometer Experiment
DT	Development Team
EOL	End-Of-Life
ESS	Edge Space Systems, Inc.
FAC	Scale factor card used in SINDA
FOV	Field Of View
GMM	Geometric Math Model
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
ICD	Interface Control Document
I/F	Interface
IKI	Institute for Space Research
IM	Instrument Module
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LHP	Loop Heat Pipe
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
PDE	Propulsion and Deployables Electronics
PSE	Power Systems Electronics
PM	Propulsion Module
RGMM	Reduced Geometric Math Model
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
SAA	Solar Array Assembly
S/C	Spacecraft
SCS	Sequencing & Compressor System
SDT	Spacecraft Development Team
SINDA	Systems Improved Numerical Differencing Analyzer
SwRI	Southwest Research Institute

TBD	To Be Determined
TBR	To Be Reviewed
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 SCOPE

1.1 GENERAL

This General Subsystem Thermal Specification defines and controls the top level thermal requirements for all components on the Lunar Reconnaissance Orbiter (LRO) spacecraft. The specification places requirements on both sides of the spacecraft-to-component interface to insure mission thermal safety. More details are controlled at lower level specifications such as the Thermal Interface Control Documents (ICD) specified in Table 1-1. This document outlines:

a. Temperature Requirements
b. Bounding Environmental Parameters
c. Thermal Test Requirements
d. Thermal Analysis Requirements (bounding inputs and required outputs)
e. Thermal Report Requirements
f. Component Thermal Hardware Drawings and Diagrams Requirements

1.2 PURPOSE

The purpose of this specification is to clearly define what is expected of every powered component to be flown on LRO to satisfy that the component is safe to fly on LRO. Details of each component's implementation of these requirements shall be provided elsewhere. This document is focused on the thermal interface to the spacecraft but also requires that analysis be performed to show thermal safety throughout the powered component during all mission modes.

1.3 APPROVAL

Approval of this Specification by the Configuration Control Board shall baseline the overall General Thermal Subsystem Specification.

1.4 RESPONSIBILITY

The Goddard Space Flight Center (GSFC) has the final responsibility for the LRO mission, the Orbiter, its subsystems, and any requirements specifically assigned to LRO in this document.

LRO systems engineering and project management have the ultimate authority to specify thermal requirements. This document shall be the vehicle by which changing thermal requirements are tracked.

1.5 CHANGE AUTHORITY

Written revision requests are submitted to the LRO Project (GSFC Code 431). Dispositional changes shall reflect program decisions and will document new, changed, and/or deleted requirements. Internal changes to the instruments, Propulsion Module (PM), or LRO that do not affect external form, fit, function, or the requirements of this document are not subject to this restriction. It is the responsibility of the LRO Project Manager or designee to distribute the revision requests to the Configuration Control Board for impact evaluation. Upon joint approval of one or more changes, a letter revision of this specification will be prepared and distributed by the LRO Project. This Specification, with all revisions incorporated, will be stored and maintained by the Code 431 Configuration Management Office. The original issue of this approved Specification shall be effective until modified by revision action.

1.6 APPLICABLE DOCUMENTS

The following documents form a part of this Specification to the extent specified herein.

Table 1-1: Applicable Documents

DOCUMENT NO.	TITLE
TBD	LRO <specific> Thermal Hardware Specification
TBD	LRO General Thermal Hardware Specification
431-RQMT-000092	Lunar Reconnaissance Orbiter (LRO) Thermal Math Model Requirements
GEVS-SE Rev A	General Environmental Verification Specification for STS & ELV Payloads, Subsystems and Components
TBD	LRO Thermal Balance/Thermal Vacuum Test Plan
TBD	Thermal ICDs
431-ICD-000114	LROC Thermal Interface Control Document
431-ICD-000115	LAMP Thermal Interface Control Document
431-ICD-000116	Diviner Thermal Interface Control Document
431-ICD-000117	LOLA Thermal Interface Control Document
431-ICD-000118	CRaTER Thermal Interface Control Document
431-ICD-000119	LEND Thermal Interface Control Document

2.0 TEMPERATURE REQUIREMENTS

These requirements apply to all flight powered components. To clarify the language used, a brief discussion of temperature limits vocabulary will explain the different types of limits.

2.1 TYPES OF TEMPERATURE LIMITS

There are four (4) sets of operational limits and four (4) sets of survival limits associated with critical locations and the spacecraft-to-instrument thermal interface locations, defined as follows:

a. Hard Limits: The absolute minimum and maximum temperatures that may be experienced without inflicting damage or permanent performance degradation.

b. Qualification Temperature Limits: The minimum and maximum temperatures that are exactly 10°C wider than the flight predict limits, over which, the responsible hardware manager guarantees that the hardware will operate or survive over the mission lifetime. This will be confirmed by testing that induces the limits stated. The ±10°C is to provide margin for modeling/analysis inaccuracies and manufacturing variations and to help compensate for the less than lifetime thermal cycling performed before launch. The responsible hardware manager shall induce the qualification temperature limits in thermal vacuum testing prior to delivery to verify that the hardware can operate and survive over the entire specified temperature range.
c. Flight Design Limits: The minimum and maximum temperatures bounding the temperature range over which the CBE limits, might vary. While the CBE limits might vary with design updates, the flight predict limits are treated as an "allocation" in the sense that the responsible hardware manager commits to not exceed them by design. The flight design limits must be at least 10°C inside the hard limits in order to qualify the component.
d. Current Best Estimate (CBE) Limits: The CBE of the expected minimum and maximum temperatures based on testing and/or analyses using the S/C conduction and radiation boundary conditions provided. Any model or test result typically has 5-10°C of uncertainty added to it to address modeling technique compromises and systemic uncertainties. Uncertain decreases with increased testing and modeling fidelity typically by decreasing the uncertainty from 10°C to 5°C in all CBEs.

2.2 LOCATION OF FLIGHT TELEMETRY

There shall be temperature limits on all flight telemetry points during all phases of monitoring. However, it is the responsibility of the Orbiter thermal subsystem to only manage telemetry and limits at thermal interfaces that are specified in ICDs or subordinate specifications. These locations are designated by drawings or sketches provided by the responsible hardware manager. This location may be where the component attaches to a S/C module deck or on the outside of a mutually agreed up location of the component that shall be clearly defined. Within the component itself, there is likely to be other telemetry which may or may not be monitored by the spacecraft, which shall be the responsibility of the responsible hardware manager. It is the responsibility of the hardware manager to analytically or via test determine that all other temperature limits within the component are met as long as the system thermal interface is maintained within limits (qualification or acceptance).. Locations of the temperature limits as defined by the use of telemetry shall be defined by diagram or figure provide in the end item data package prior to delivery of the component to the orbiter assembly in an as-built location. All orbiter controlled telemetry shall be defined in Document #TBD ("LRO Thermal Hardware Specification") or component specific documentation.

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2.3 FLIGHT INTERFACE DESIGN TEMPERATURE LIMITS

Table 2-1 lists the design temperature limits at the spacecraft thermal interface.

Table 2-1: Spacecraft Temperature Range

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
Mechanical	Comp. Propulsion Module	+90 to -65	+90 to -65
	Comp-Avionics Module	+90 to -65	+90 to -65
	Comp. Instrument Module	+90 to -65	+90 to -65
	Fasteners	+90 to -65	+90 to -65
Mechanisms	HGA Gimbals	-10 to +50	-20 to +60
	HGA Boom	-10 to +50	-20 to +60
	HGA Relase & Deploy	-10 to +50	-20 to +60
	S/A Gimbals	-10 to +50	-20 to +60
	S/A Boom	-10 to +50	-20 to +60
	S/A Relase & Deploy	-10 to +50	-20 to +60
Power	PSE	-10 to 40	-20 to 50
	Battery	10 to 30	0 to 40
	S/A Cells/Cover Glass	+135 to -155 TBR	+135 to -155 TBR
	S/A Substrate & Motor Controller	+135 to -155 TBR	+135 to -155 TBR
ACS	Star Trackers	-30 to +50	-30 to +60
	Inertial Measurement Unit	-30 to +65	-30 to +75
	Reaction Wheels	-10 to +50	-30 to +60
	Coarse Sun Sensors	-10 to +50	-130 to +90
PDE	Attitude Control Electronics (PDE)	-10 to +40	-20 to +50
	S/A HGA Control Electronics	-10 to +40	-20 to +50
		-10 to +40	-20 to +50
	EVD CARD	-10 to +40	-20 to +50
		-10 to +40	-20 to +50
		-10 to +40	-20 to +50
	Backplane	-10 to +40	-20 to +50
	Box and MTG Hardware	-10 to +40	-20 to +50
Propulsion (Dry Mass)	Hydrazine Tank 1	+10 to 40	N/A
	Hydrazine Tank 2	+10 to 40	N/A
	Pressure Tanks (Comment)	+0 to 50	N/A
	90N Thrusters	N/A	N/A
	22N Thrusters	N/A	N/A
	High Press Transducers	+10 to 40	N/A
	Low Press tranducer	+10 to 40	N/A

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
	Gas Latch Valve	+10 to 40	N/A
	Liquid Latch Valve	+10 to 40	N/A
	Fill and Drain	+10 to 40	N/A
	Gas System Filters	+0 to 50	N/A
	Liquid Filters	+10 to 40	N/A
	Pressure Regulators	+0 to 50	N/A
	Plumbing Lines	+10 to 40	N/A
	NC Pyro Valves, Pressurant	+0 to 50	N/A
C&DH	SBC Card	-10 to 40	-20 to 50
	COMM Card	-10 to 40	-20 to 50
	Single SSR	-10 to 40	-20 to 50
	LISIC	-10 to 40	-20 to 50
	HIDEC Card	-10 to 40	-20 to 50
	LVPC Card	-10 to 40	-20 to 50
	Backplane	-10 to 40	-20 to 50
	Box amd MTG HDWR	-10 to 40	-20 to 50
S Comm	TT&C XPDR Stack (xmit)	-10 to +55	-20 to 65
	USB Diplexer	TBD	TBD
	USB RF Switch	TBD	TBD
	USB Coupler	TBD	TBD
	USB Hybrid	TBD	TBD
	USB Terminator	TBD	TBD
	TT&C Omni Antenna	TBD	TBD
	USB Isolator	TBD	TBD
	TT&C Coax Cables	TBD	TBD
Ka Comm	Ka Baseband Modulator	TBD	TBD
	Ka RF Exciter	TBD	TBD
	Ka SSPA TWTA w/EPC	TBD	TBD
	Ka Bandreject Filter	TBD	TBD
	WG-34 Ka Band Waveguide	TBD	TBD
	High Gain Antenna	TBD	TBD
CRaTER	Instrument Pkg.#1	-30 to +35	-40 to +50
	Instrument Elect. #1	-30 to +35	-40 to +50
Diviner	Instrument Pkg.#2	-20 to +50	-70 to +80
	Instrument Elect. #2	-20 to +50	-70 to +80
LAMP	Instrument Pkg.#3	-10 to +40	-20 to +40
	Instrument Elect. #3	-10 to +40	-20 to +40
LEND	Instrument Pkg.#4	-20 to +50	-40 to +70
	Instrument Elect. #4	-20 to +50	-40 to +70
LOLA	Optics Package	+0 to +30	-20 to +40
	Instrument Electronics	-10 to 40	-20 to +50
LROC	NAC (2)	-35 to +30	TBD to +60

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
	WAC	-35 to +30	TBD to +60
	SCS	-35 to +60	-55 to +60

2.4 TEMPORAL GRADIENT REQUIREMENTS

Table 2-2 lists the temporal gradient requirements.

Table 2-2: Temporal Gradient Requirements

SUBSYSTEM	COMPONENT	TEMPORAL GRADIENT (°C)
CRaTER	Instrument Pkg.#1	
Diviner	Instrument Pkg.#2	
	Instrument Elect. #2	
LAMP	Instrument Pkg.#3	
LEND	Instrument Pkg.#4	TBD
LOLA	Optics Package	TBD
	Instrument Electronics	
LROC	NAC (2)	TBD
	WAC	TBD
	Instrument Electronics	

2.5 SPATIAL GRADIENT REQUIREMENTS

Table 2-2 lists the spatial gradient requirements.

Table 2-3: Spatial Gradient Requirements

SUBSYSTEM	COMPONENT	SPATIAL GRADIENT (°C)
CRaTER	Instrument Pkg.#1	
Diviner	Instrument Pkg.#2	
	Instrument Elect. #2	
LAMP	Instrument Pkg.#3	
LEND	Instrument Pkg.#4	TBD
LOLA	Optics Package	TBD
	Instrument Electronics	
LROC	NAC (2)	TBD

SUBSYSTEM	COMPONENT	SPATIAL GRADIENT (°C)
	WAC	TBD
	Instrument Electronics	
ACS	Star Cameras	
COMM	Hi-Gain Gimbals	

2.6 TURN ON TEMPERATURE AND SURVIVAL

When powered "OFF", each component shall be capable of surviving indefinitely when its temperatures are within the qualification survival limits without damage or permanent performance degradation.

All components shall also survive indefinitely, without damage or permanent performance degradation, if powered "ON" anywhere within the specified survival limits.

For components that are conductively coupled to the spacecraft, when powered "OFF", the spacecraft thermal control system shall maintain the instruments within the design survival temperature limits. If necessary, the spacecraft will use survival heating as described in Section 3.2.6 to maintain the low limit.

2.7 ALLOCATION-OF SPACECRAFT MONITORED TEMPERATURE SENSORS

Table 2-3 specifies the number of spacecraft monitored temperature sensors allocated to each component. The current baseline for temperature sensors is YSI 44900 3KΩ Thermistor S-311-P-18 -04S7R6 or PRT (TBR) as specified by the LRO Thermal Subsystem lead. The thermistor shall be capable of being read over the all temperature ranges specified.

Table 2-4: Thermistor Allocation

Subsystem	Components	Number of Telemetry pts
Mechanical		45
	Comp. Propulsion Module	19
	Comp. Spacecraft Bus Module	22
	Comp. Instrument Module	4
	Fasteners	
Mechanisms		14
	HGA Gimbals	
	HGA Boom	
	HGA Relase & Deploy	6
	S/A Gimbals	
	S/A Boom	
	S/A Relase & Deploy	6
	S/A HGA Control Electronics	2
Thermal		42
	Heat Pump	
	Thermal Control Heaters	5
	Fuel Tank Heaters	9
	Fuel Line Heaters	10
	20# Valve heaters	1
	5# Valve Heaters	8
	S/A Gimbal thermal Control	
	High Gain Gimbal thermal Control	
	Survival Heater Power (Instr I/F)	9
	Survival Heater Power (S/C elec)	
Power		8
	PSE	2
	Battery	3
	S/A Substrate	3
ACS		16
	PDE	2
	Star Trackers	4
	Inertial Measurement Unit	2
	Reaction Wheels	8
	Coarse Sun Sensors	
C&DH		2
	Backplane	2
	Box amd MTG HDWR	
S Comm		6
TT&C	TT&C XPDR Stack (xmit)	2
	TT&C XPDR Stack (Rec)	
	Relay Omni Antenna	4
	Relay MGA Antenna	
	Relay Coax Cables	
Ka Comm		9
	Ka Baseband Modulator	2
	Ka RF Exciter	2
	Ka SSPA TWTA w/EPC	2
	Ka Bandreject Filter	
	WG-34 Ka Band Waveguide	
	High Gain Antenna	3
CRaTER	**INST #1**	2
Diviner	**INST #2**	4
LAMP	**INST #3**	2
LEND	**INST #4**	2
LOLA	**INST #5**	4
LROC	**INST #6**	8

3.0 THERMAL POWER

3.1 THERMAL DISSIPATED POWER PER MISSION MODE

Thermal dissipative power is different from electrical power allocation due to the need to identify the location where the electrical power is dissipated. The purpose for this section is to handshake with the responsible hardware manager what inputs are used in the overall thermal model during which mission mode. Embedded into thermal dissipative power is the need to analyze the worst case orbit average power both high and low even if it is just for 1 orbit. Table 3-1 shows power dissipations by component without margin. It also details all mission mode that the components shall experience including pointing and S/C configuration.

Table 3-1: Component Thermal Power Dissipations

	Safe Hold Powers (W)	Lunar Eclipse Powers (W)	Max Op Diss Pwr (Eclipse no margin)	Min Op Diss Pwr (No Eclipse no margin)		TBD Mission Mode		1.1 Thermal Vacuum Configuration	1.2 Ground in-air testing	2.1 Pre-Lift off	2.2 Lift off and Ascent	2.3 Separation	2.4 De-Spin	2.5 S/A Deployment
S/C Power Config								All	All	Safe Hold	Safe Hold	Safe Hold	Safe Hold	Safe Hold
S/C Pointing								X and Y axis horizontal	Y and Z axis horizontal	+X VV	+X VV to 60 RPM roll	>+0.1 deg/sec Rotation	>+0.1 deg/sec Rotation	>+0.1 deg/sec Rotation
Hi-Gain deployed?								Deattached	Varies	N	N	N	N	N
S/A deployed?								Deattached	Varies	N	N	N	N	N
Thermal Cooling Method								Targets	Convection & A/C	Convection & Fairing	Radiation	Radiation	Radiation	Radiation
Time Duration of mode										L-5 min on Battery	L + 1400 s 3rd Stg Burn, L + 1600 s Sep	<10 minutes	N/A on the S/C	<15 minutes
Levelness Requirement								<+0.1" / 2 meters	None	None	None	None	None	None
Deployment Htrs On/Off										On	On	On	On	On
S/C Op Htrs On/Off										Off	Off	Off	Off	Off
Instr Op Htrs On/Off										Off	Off	Off	Off	Off
Thermal Dissipation (W)														
C&DH (w/o COMM card)	51.8	51.8	51.8	51.8						51.8	51.8	51.8	51.8	51.8
S-Band Comm Peak (in CD&H)	0.625	0.625	0.625	0.625						0	0	0	0	0
K-Band Comm Peak (in CD&H)	0	0	5.6	5.6						0	0	0	0	0
SSR (in CD&H)	0	0	42	42						0	0	0	0	0
S-Band Transponder	14.64	14.64	14.64	8						8	8	8	8	8
Ka Band Transmitters (20 W TWTA)	0	0	31.9	0						0	0	0	0	0
RWAs (4)	30	30	30	30						30	30	30	30	30
Star Trackers (2)	0	0	20	20						0	0	0	0	0
IMU/GYRO	32	32	32	32						32	32	32	32	32
Battery (From T. Spitzer's 3/16/03)	30	30	43.3	0						30	30	30	30	30
PSE (From T. Spitzer's 3/16/03)	35.4	35.4	35.4	27						35.4	35.4	35.4	35.4	35.4
PDE (includes Gimbal drivers)	36	36	46	46						20	20	20	20	20
S/A Gimbal	10	10	10	10						0	0	0	0	0
Hi-Gain Gimbal	0	0	10	10						0	0	0	0	0
CRaTER	0	0	15	12						0	0	0	0	0
Diviner	0	0	11	11						0	0	0	0	0
LAMP	0	0	4.3	4.3						0	0	0	0	0
LEND	0	0	13	13						0	0	0	0	0
LOLA	0	0	26.2	26.2						0	0	0	0	0
LROC	0	0	22	22						0	0	0	0	0
Total Instr Mod	32	32	143.5	140.5						32	32	32	32	32
Total Avionics Mod	153.825	153.825	224.725	173.025						137.2	137.2	137.2	137.2	137.2
Total Prop	44.64	44.64	76.54	38						38	38	38	38	38
Total Others	10	10	20	20						0	0	0	0	0
Total non-heaters	240.465	240.465	464.765	371.525						207.2	207.2	207.2	207.2	207.2
Total Thermal Dissipative power	276.065	276.065	500.365	407.125						207.2	207.2	242.8	242.8	242.8

	2.6 Sun Acquisition/ Safe Hold	2.7 Lunar Cruise	2.8 Lunar orbit Insertion	3.1 S/C Activation & Commissioning	3.2 Instr Activation & Commissioning	4.1 Measurement Ops	4.2 Station Keeping/momentum dumps	4.3 Lunar Eclipse	4.4 Yaw Maneuvers	4.5 ? Off Nadir Pointing	5.0 Extended Mission	6.0 End-of-Mission Disposal
S/C Power Config	Mod #1 Safe Hold	Mod #2 Safe Hold	Mod #2 Safe Hold	Modified Op #1	Op	Op	Modified Op #2	Safe hold	Modified Op #2	Op	Modified Op #3	Safe Hold #3
S/C Pointing	+/-15° -Y on sun line	+/-5° -Y on sun line, Yaw to fire thrusters (sun can be on all X and Y surfaces	<200 km orbit, nadir pointing, Yaw to fire thrusters (sun can be on all X and Y surfaces for TBD (30) minutes	<200 km orbit, nadir pointing, could be any Beta	<200 km orbit, nadir pointing, could be any Beta	50+/-20 km Nadir Pointing +/-1 arcminute	50+/-20 km Nadir Pointing +/-1 arcminute will require 180 degree yaw (sun may get on the anti-sun)	50 +/-20 km Nadir +/-5 to 10 deg TBR	50 +/-20 km Nadir (sun kept off anti-sun during 180 deg yaw)	50 +/-20 km Nadir +/-20 off yaw must return to nadir in less than 15 minutes	Nadir Pointing ~200 km	Nadir pointing, sun may be on anti-sun side
Hi-Gain deployed?	N	N	N	Y	Y	Y	Y	Y	Y	Y		
S/A deployed?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Thermal Cooling Method	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation
Time Duration of mode	<15 minutes	5.2 Days	TBD Maximum Thruster fire	1 month	Weeks	Weeks	1 Orbit	160 minute + eclipse	1 Orbit	<20 minutes	~1 year	<30 minutes
Levelness Requirement	None	None	None	None	None	None	None	None	None	None	None	None
Deployment Htrs On/Off	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off
S/C Op Htrs On/Off	Off	Off	Off	On	On	On	On	On	On	On	On	On
Instr Op Htrs On/Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On
Thermal Dissipation (W)												
C&DH (w/o COMM card)	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8	51.8
S-Band Comm Peak (in CD&H)	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625	0.625
K-Band Comm Peak (in CD&H)	0	0	0	5.6	5.6	5.6	5.6	0	5.6	5.6	0	0
SSR (in CD&H)	0	42	42	42	42	42	42	0	42	42	0	0
S-Band Transponder	14.64	14.64	14.64	14.64	14.64	14.64	14.64	14.64	14.64	14.64	14.64	14.64
Ka Band Transmitters (20 W TWTA)	0	0	0	31.9	31.9	31.9	31.9	0	31.9	31.9	0	0
RWAs (4)	30	30	30	30	30	30	30	30	30	30	30	30
Star Trackers (2)	0	20	20	20	20	20	20	0	20	20	0	0
IMU/GYRO	32	32	32	32	32	32	32	32	32	32	32	32
Battery (From T. Spitzer's 3/16/03)	30	30	30	43.3	43.3	43.3	43.3	30	43.3	43.3	30	30
PSE (From T. Spitzer's 3/16/03)	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4	35.4
PDE (includes Gimbal drivers)	36	36	36	46	46	46	46	36	46	46	36	36
S/A Gimbal	10	10	10	10	10	10	10	10	10	10	10	10
Hi-Gain Gimbal	0	0	0	10	10	10	10	0	10	10	0	0
CRaTER	0	0	0	0	15	15	15	0	15	15	0	0
Diviner	0	0	0	0	11	11	11	0	11	11	0	0
LAMP	0	0	0	0	6.3	4.3	4.3	0	4.3	4.3	0	0
LEND	0	0	0	0	13	13	13	0	13	13	0	0
LOLA	0	0	0	0	26.2	26.2	26.2	0	26.2	26.2	0	0
LROC	0	0	0	0	72	22	22	0	22	22	0	0
Total Instr Mod	32	52	52	52	195.5	143.5	143.5	32	143.5	143.5	32	32
Total Avionics Mod	153.825	195.825	195.825	224.725	224.725	224.725	224.725	153.825	224.725	224.725	153.825	153.825
Total Prop	44.64	44.64	44.64	76.54	76.54	76.54	76.54	44.64	76.54	76.54	44.64	44.64
Total Others	10	10	10	20	20	20	20	10	20	20	10	10
Total non-heaters	240.465	302.465	302.465	373.265	516.765	464.765	464.765	240.465	464.765	464.765	240.465	240.465
Total Thermal Dissipative power	276.065	338.065	338.065	408.865	516.765	464.765	464.765	276.065	464.765	464.765	276.065	276.065

3.2 S/C CONTROLLED THERMAL CONTROL HEATER POWER

The S/C shall control several heater power circuits. These heater power circuit sizes and locations are detailed in Document # TBD ("LRO Thermal Hardware Specification"). This specification provides details with respect to orbit average heater dissipation and peak power dissipation.

3.2.1 Instrument Operation Heater Power Description

This switch is intended to service operational heaters in the instrument module. Nominally, the heaters will be located at the component. The sizing of the heaters will be designed such that all components are maintained thermostatically at the low end of the operational temperature range regardless of the actual power that the component is dissipating. In the cold case, this heater power may be close to the orbit average power dissipation of the instrument plus any additional power that is necessary to offset the losses from the instrument to the environment. In the hotter Beta angles, this heater power will be reduced. This heater service will not directly service the Gyro and Star Trackers on the instrument deck due to their need of operation separate from most instruments. When the instruments are not operating, this heater switch will be switched off to preserve power such as during the lunar eclipse.

3.2.2 S/C Operational Thermal Control Heat Power Description

This switch is intended to service spacecraft components regardless of where they are located (propulsion module, Avionics deck, or instrument module). This switch feeds the separately wired thermostatically controlled operational heaters. These heaters will also provide some heater power to components during cold operational periods that prevent components from exceeding their cold operational temperature due to losses from those components to the cold environment. These spacecraft components will be ones that may be switched off during lunar eclipse or safehold modes of operation. This heater circuit may be switched off during lower power modes such as lunar eclipse or safe hold and therefore should only service components that either need tighter stability during certain fully operational modes or components that are switched off automatically during lunar eclipse or safe hold conditions. Examples of these components are the Star Trackers operational, Hi-Gain gimbal operational, and TWTA operational heaters.

3.2.3 Tight bandwidth C&DH and software controlled heater

An additional 5 tight temperature control circuits have not been allocated a location as of this draft. The intention of these heater circuits is to resolve thermal control/stability issues that arise later in the program.

Table 3-2: Five Tight Control Heaters powered by C&DH

Heater # / Max Amp	COMPONENT	Orbit Avg Power at 24 V/Peak Power at 35 V
1/5 amp	TBD	TBD
2/2 amp	TBD	TBD
3/2 amp	TBD	TBD
4/2 amp	TBD	TBD
5/2 amp	TBD	TBD

3.2.4 Prop System Heaters Primary and Redundant Description

This switch is intended to service the propulsion system heaters and is redundant. The heaters will be located on the thruster valve heaters, propulsion lines, propulsion tanks, and the propulsion pressurization tank. These heaters shall be enabled during all mission modes as they are designed to prevent the Hydrazine from freezing.

3.2.5 Deployment Heaters Description

This switch controls operational thermostatically controlled heaters at the deployment mechanisms and hinges to ensure deployment within the operational range. These heaters will be switched off after deployment to preserve heater power.

3.2.6 Essential Heaters Prime and Redundant Description

These unswitched services are designed to prevent components that are always enabled (essential) during all mission modes from exceeding the lower operational temperature limit and to prevent S/C components that may be switched off from exceeding their lower survival temperature limit. The two thermostatically controlled heater circuits shall be offset in setpoint so that their operation can be verified separately during observatory thermal vacuum testing and to prevent the higher peak which would result if the two redundant thermostats sets were to possible snap closed at the same time. Examples of heaters on this circuit would be: C&DH operational heaters, Battery operational heaters, Solar Array gimbal operational heaters, S-Band operational heater, and Ka band transmitter survival heaters. Heaters for the Gyro (TBR) will be on this circuit.

3.2.7 Instrument Survival Heaters Description

This service will primarily service the instruments and instrument module to maintain all the instruments within their cold survival temperature. These heaters shall be wired out from the common service to two separate heater services located on the instruments. It is expected that these services will be thermostatically controlled and may be located on the instruments themselves.

3.2.8 General Requirements

Sizing of operational and survival heater capacity shall be based on 70% duty cycle at 24V (TBR) bus voltage and cold case thermal conditions. Heater elements must be capable of operating over the voltage range of 28±7V.

Each component will provide space for mounting thermostats and temperature sensors.

Watt densities of the operational and survival heaters shall be appropriate for the type of heater and bonding method. Watt densities (at the maximum voltage) above 0.16 W/cm^2 (1.0 W/in^2) shall be approved by the GSFC LRO Lead Thermal Engineer and may require (if a Kapton heater) bonding with Stycast 2850FT and aluminum over-taping up to 1.24 W/cm^2 (8.0 W/in^2).

3.3 S/C HEATER ALLOCATION

The heater allocation listed in Table 3-2 is very preliminary and will be updated.

Table 3-3: S/C Control Heater Power Allocations

SWITCH #	Circuit Description	Volt (Min/Max)	Nominal Predict Power Beta 90° (W)	GEVS Margin	Power Req't (W)	Power Req't at Beta TBD (W)	Peak Pwr @ Vmax (W)
S11	Instrument Deck Operational	24/35	60	1.4	86	TBD	TBD
S38	S/C Operational	24/35	70	1.4	100	TBD	TBD
S28,S29	Prop System Heaters	24/35	75	1.4	107	TBD	TBD
S39	Deployment Heaters	24/35	30	1.4	43	TBD	TBD
US5,US7	S/C Survival	24/35	80	1.4	114	TBD	TBD
US6	Instrument Survival (35.3 W directly on instruments)	24/35	75	1.4	107	TBD	TBD
TBD	Instrument (TBR)						

3.4 INSTRUMENT HEATER ALLOCATION (WIRED TO S/C SWITCH)

The instrument heater power allocation on the S/C Instrument Operational bus is outlined in Table 3-3 and described in Section 3.2.1. The power shown is at 24 V and is the size of the heater with GEVS margin 70% duty cycle. All services shall be thermostatically controlled at the instrument. The S/C is providing no active control.

Table 3-4: Instrument Control Heater Power Allocations

INSTRUMENT	HEATER POWER (W)		
	Operational	DeContam.	Survival
CRaTER	None	None	*None TBR*
Diviner	Supplemental Htr	None	*7.3 TBR General 0.0 TBR AZ Motor*
LROC NAC1	TBD	50 TBR	*6 TBD*
LROC NAC2	TBD	50 TBR	*6 TBD*
LROC WAC	TBD	10 TBR	*5 TBD*
LROC SCS	TBD	TBD	*5 TBD*
LAMP	None	2 W TBR	*None TBR*
LEND	None	None	*6 TBR*
LOLA Elec	None	None	*TBD*
LOLA Op Bench/Laser	None	None	*TBD*
Total	***TBD***	***112 TBR***	***TBD***

3.5 INSTRUMENT HEATER ALLOCATION (CONTROLLED BY COMPONENTS/INSTRUMENTS)

The instrument heater power allocation drawn from the internal instrument power bus is outlined in Table 3-4 as described in the individual instrument ICDs. The power shown is at 24V and is the size of the heater with GEVS margin 70% duty cycle. The power from these heaters will come directly out of the main instrument feeds and will only be operational when the instruments are turned on.

Table 3-4: Instrument Control Heater Power Allocations

INSTRUMENT	HEATER POWER (W)	
	Operational	DeContam.
CRaTER	TBD	*None*
Diviner	TBD	*None*
LROC NAC1	TBD	*TBD*
LROC NAC2	TBD	*TBD*
LROC WAC	TBD	*TBD*
LROC SCS	TBD	*TBD*

INSTRUMENT	*HEATER POWER (W)*	
	Operational	***DeContam.***
LAMP	None	*2 W TBR*
LEND	None	*None*
LOLA Elec	10 TBR	*None*
LOLA Op Bench/Laser	15 TBR	*None*
LOLA TEC	0-3 TBR	*None*
Total	*TBD*	*TBE*

4.0 THERMAL ANALYSIS

4.1 ENVIRONMENTAL CONDITIONS

4.1.1 Thermal Conditions

The LRO environment is listed in Tables 5-1 and 5-2 below. Multi-Layer Insulation (MLI) blankets shall be analyzed using an effective ε* equal to 0.005 or 0.03 case specific that yields the worst case in the bounding thermal cases.

Table 4-1: LRO Solar Constant and Albedo Factor

PARAMETER	Cold	Hot
Solar Constant	1280 W/m^2	1420 W/m^2
Albedo Factor	0.06	0.13

Table 4-2: LRO Lunar IR

ORBIT POSITION (°)	Beta θ° (W/m^2)	
	Hot	**Cold**
0 (sub-solar)	1335*1*COS(θ) + 5	1114*1*COS(θ) + 5
30	1335*0.866*COS(θ) + 5	1114*0.866*COS(θ) + 5
60	1335*0.5*COS(θ) + 5	1114*0.5*COS(θ) + 5
90	5	5
120	5	5
150	5	5
180	5	5
210	5	5
240	5	5
270	5	5
300	1335*0.5*COS(θ) + 5	1114*0.5*COS(θ) + 5
330	1335*0.866*COS(θ) + 5	1114*0.866*COS(θ) + 5

ORBIT POSITION (°)	Beta θ° (W/m^2)	
	Hot	Cold
360 (sub-solar)	1335*1*COS(θ) + 5	1114*1*COS(θ) + 5

4.1.2 Payload Fairing Ascent Pressure Profile

All MLI blankets and thermal hardware shall be built so that the rapid launch depressurization does not detach any thermal blankets or hardware. See Figure 4-1.

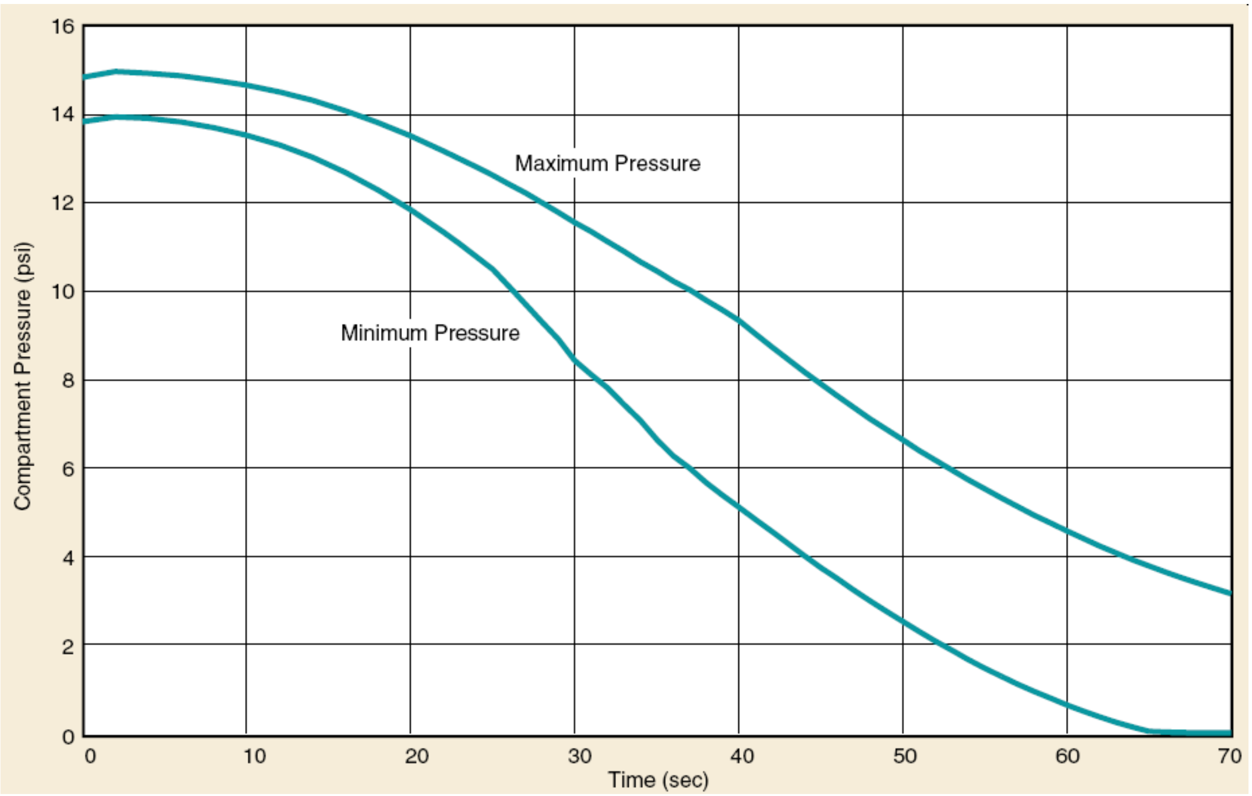

Figure 4-1: Delta II-like Fairing Pressure

4.2 THERMAL COATINGS

Table 4-3: LRO Thermal Coatings

DESCRIPTION	COLD		HOT 13 mo. (5 yr.)		SPEC.	
	α_S	ε_H	α_S	ε_H	SOL	IR
Coatings						
Black Anodize	0.80	0.88	0.92	0.83		
Clear Anodize	TBD	TBD	TBD	TBD		

DESCRIPTION	COLD		HOT 13 mo. (5 yr.)		SPEC.	
	α_S	ε_H	α_S	ε_H	SOL	IR
Irridite	0.10	0.19	0.25	0.11		
Z307 Conductive Black	0.95	0.89	0.97	0.85		
MSA94B Conductive Black	0.94	0.91	0.96	0.87		
Z306 Conductive Black	0.94	0.89	0.95	0.85		
Z93P White Paint	0.17	0.92	0.25 (0.36)	0.87		
NS43C Conductive White	0.20	0.91	0.26 (0.37)	0.87		
Vapor Deposited Aluminum	0.08	0.05	0.10	0.03	0.98	0.98
Vapor Deposited Beryllium	TBD	TBD	TBD	TBD		
Films & Tapes						
Kapton, 3-mill	0.45	0.80	0.51 (0.60)	0.76		
OSR Pilkington, 5-mill	0.07	0.80	0.12 (0.19)	0.78	1.0	---
OSR/ITO Pilkington, 5-mill	0.08	0.80	0.15 (0.23)	0.78		
Silver Teflon Tape, 5-mil	0.08	0.78	0.25 (0.33)	0.73	1.0	---
Silver Teflon Tape, 10-mil	0.09	0.87	0.27 (0.35)	0.83	1.0	---
Silver Teflon, 5-mil	0.08	0.78	0.11 (0.14)	0.73		
Silver Teflon, 10-mil	0.09	0.87	0.13 (0.27)	0.83		
Black Kapton, 3-mil	0.91	0.81	0.93	0.78		
Germanium Black Kapton	0.49	0.81	0.51	0.78		
Miscellaneous						
Solar Cell Triple Junction	0.86	0.87	0.90	0.77	1.0	---
M55J Composite, Bare	0.90	0.79	0.93	0.75		
K1100 Composite, Bare	0.88	0.71	0.88	0.71		
Fused Silica	TBD	TBD	TBD	TBD		
Sapphire Lens	TBD	TBD	TBD	TBD		
Internal Fuel Line	1.0	0.15	1.0	0.15		

4.3 HOT AND COLD BIAS OF POWER

Prior to the active measurement of operational power in a flight-like environment, all thermal design shall be able to handle a variation in each mode power +/-10% on constant power components.

4.4 MISSION MODES

All components shall meet the appropriate survival or operational limits (component and mission mode specific) per Table 3-1 during all mission modes.

4.5 THERMAL MODEL UNCERTAINTY

Any model or test result typically has 5-10°C of uncertainty added to it to address modeling technique compromises and systemic uncertainties. Uncertainty decreases with increased testing and modeling fidelity typically by decreasing the uncertainty from 10°C to 5°C in all CBEs. All documentation shall specify the uncertainty that was assumed.

4.6 THERMAL MODELING SCOPE

The thermal modeling scope for LRO will be different than for other planetary mission's conventional wisdom. Transient analysis will be required to assess hot and cold cases. Spacecraft pointing tolerances may drive safe hold cases. Steady sun angles at high Beta angles may drive spatial gradient requirements. The responsible hardware manager shall examine all relevant environments assuming worst case pointing uncertainties in order to determine bounding thermal cases using Table 3-1 and direction as requested from the LRO thermal subsystem's lead.

4.7 THERMAL ANALYSIS DOCUMENTATION

All thermal analysis reports shall clearly outline all assumptions or source of assumptions. They shall detail the modeling technique used, details on the model, Graphics and Tables showing the temperature results versus requirements and discussion of what the results are sensitive to. It shall be clear what limitations the current analysis is subjected to and what future analyses are planned.

5.0 COMPONENT AND ORBITER INTEGRATION AND TEST

5.1 COMPONENT THERMAL CYCLING REQUIREMENT

All components must be thermally cycled in a thermal vacuum chamber rather than in an air filled chamber. All components shall be flight like blanketed and cycled 8 times (TBR) with the thermal interface held at the qualification temperatures listed above at the thermal interface. Durations shall be as recommended in GEVS: components 4 hours, instruments 12 hours. If the component is sensitive to orbit transience, component performance shall be monitored during hot to cold transitions at a rate that a flight like orbit average case might experience. Thermal Vacuum requirement can only be waived thru approval of the LRO thermal systems lead.

5.2 MODEL DOCUMENTATION

The RGMMs and RTMMs delivered to GSFC shall be accompanied by appropriate model documentation as specified in Document No. 431-RQMT-000092 ("Lunar Reconnaissance Orbiter (LRO) Thermal Math Model Requirements ").

5.3 COMPONENT THERMAL TEST MODEL

All thermal tests shall be TSS/SINDA modeled prior to starting the test to derive target temperatures. Target temperatures shall achieve heat flows and effective sink temperatures that closely resemble the flight environment. An analysis report shall be issued which outlines the derivation of the target temperatures. This analysis report should outline all cases that will be assessed in thermal vacuum (i.e. hot case steady state, hot transient, cold steady state, survival, etc.)

5.4 COMPONENT THERMAL TEST DOCUMENTATION

All final thermal qualification test plan shall be approved by the LRO thermal subsystem lead engineer. Target temperatures and overall test setup shall be discussed with the LRO thermal subsystem lead engineer.

5.5 THERMAL MODEL CORRELATION

All models shall be correlated within 2°C of every telemetry point with the thermal test model. The thermal test model shall then be reintegrated into the flight model.

5.6 REDUCED MODEL

Reduced component models shall be made available to the thermal team 30 days before the PDR, CDR, PER, and Delivery to Orbiter I&T. Models requested earlier than this requirement shall be used to pass back to components as bounding system reduced models for component reviews and therefore their delivery dates shall be based on 45 days before the first component review. These models shall utilize the latest known power levels and mechanical configuration. The models shall be correlated with any qualification testing. The reduced model shall be delivered in accordance with Document No. 431-RQMT-000092 ("Lunar Reconnaissance Orbiter (LRO) Thermal Math Model Requirements ").

5.7 IN-AIR THERMAL CONTROL

All instruments shall be capable of operating within an ambient air temperature of 20+/-5°C without degrading instrument performance. No active cooling shall be provided during instrument operation with or without blanket covering. Allowance in the instrument blanket design may be utilized to open higher heat flux areas of the instrument to the surrounding ambient air, but the blanket design shall accommodate opening and closing without blanket damage.

5.8 ORBITER THERMAL VACUUM/BALANCE LEVELNESS AND ORIENTATION REQUIREMENTS

All instruments shall be capable of operating within a thermal vacuum chamber with flight like thermal environment based on the instrument reduced models provided. The horizontal plane will be the x and y axes with instrument viewing nadir down. There is no known sensitivity to the gravity vector for proper operation during this test of any non-thermal component. Heat Pipes, if they are utilized, will require no more than a +/-0.1”/2 meter tilt in any one location from the horizontal plane.

5.9 LRO COORDINATE SYSTEM

The LRO mechanical and thermal coordinate system is shown in Figure 2-2. Unless otherwise noted, this document shall refer to the LRO coordinate system.

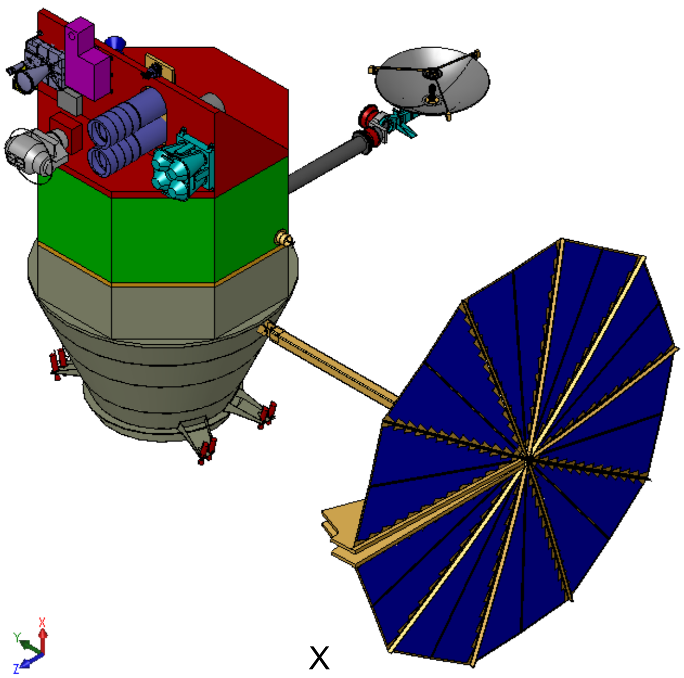

Figure 5-1: LRO Coordinate System Definition

5.10 TEST HEATERS

During Orbiter TVAC testing, the configuration of the Orbiter in the vicinity of each component may not be flight like due to placement heater panels and cold plates. The effective sink temperature for some components may be colder than during the mission. Each responsible hardware manager shall anticipate, to the extent possible, such possibilities and provide test heaters in coordination with the LRO thermal lead. Prior to component I&T the responsible hardware manage in coordination the LRO thermal lead shall make a determination of whether test heaters will be required.

In such cases, the responsible hardware manager shall supply their own test heaters, cabling and means of control (TBR). Any such heaters shall be mounted on the component, not the spacecraft. The component team shall install and control any such test heaters, as needed, to maintain the temperatures of the instrument within the survival range during TVAC.

Heater leads should be of sufficient length to allow connection to test chamber heater harnesses.

5.11 TEST SENSORS

Test sensors required to verify proper operation of the component during orbiter thermal vacuum testing shall be installed prior to deliver of the component. These sensors shall be identified on as-built drawings using orbiter approved test sensors. A plan shall be also submitted to remove some or all of these sensors before flight. The test sensors that may be read at orbiter thermal vacuum testing will be limited or reduced by the LRO thermal lead to meet the test setup requirements.