431-SPEC-000091
Revision -
Effective Date: To be added upon Release
Expiration Date: To be added upon Release

DRAFT

Robotic Lunar Exploration Program
Lunar Reconnaissance Orbiter

General Thermal Subsystem Specification

May 5, 2005

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

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REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
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List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1	Page 1-1, Section 1.4.1	Provide document numbers to replace TBDs Can this wait? It doesn't affect any other customer other than ourselves and we are a long way from needing these documents.		
2	Page 1-2, Section 1.4.2	Provide document number to replace TBD Can this wait? It doesn't affect any other customer other than ourselves and we are a long way from needing these documents.		
3	Page 2-2, Section 2.2	Provide document number to replace TBD Can this wait? It doesn't affect any other customer other than ourselves and we are a long way from needing these documents.		
4	Page 2-2 & 2-4, Table 2-2	Verify values and update. I need to update before release.		
5	Page 2-5, Table 2-2	Provide Temporal Gradient values to replace TBDs		
6	Page 2-5 & 2-6, Table 2-3	Provide Spatial Gradient values to replace TBDs		
7	Page 2-6, Section 2.7	Review information and update		
8	Page 3-8, Section 3.2	Provide document number to replace TBDs		
9	Page 3-9, Table 3-1	Provide information to replace TBDs/TBRs		
10	Page 3-10, Table 3-2	Provide values to replace TBDs		
11	Page 3-11, Section 3.2.6	Review and update information		
12	Page 3-11, Section 3.2.8	Review value and update information		
13	Page 3-11 & 3-12, Table 3-3	Provide values to replace TBDs		
14	Page 3-12, Table 3-4	Provide values to replace TBDs, verify TBR information and update		
15	Page 3-13, Table 3-5	Provide values to replace TBDs, verify TBR information and update		
16	Page 4-2 to 4-4, Table 4-3	Provide values to replace TBDs		
17	Page 5-5, Section 5.1	Verify values and update		
18	Page 5-7, Section 5.10, 2nd paragraph	Verify information and update		

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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 (SC). The specification places requirements on both sides of the SC-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 Section 4.1. 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 SC but also requires that analysis be performed to show thermal safety throughout the powered component during all mission modes.

1.3 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.

1.4 DOCUMENTS

1.4.1 Applicable Documents

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

431-RQMT-000092	Lunar Reconnaissance Orbiter Thermal Math Model Requirements
431-SPEC-**TBD**	LRO Project <Specific> Thermal Hardware Specification
431-SPEC-**TBD**	LRO General Thermal Hardware Specification

1.4.2 Reference Documents

GSFC-STD-7000	General Environmental Verification Standards (GEVS) for Flight Programs and Projects
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
431-PLAN- **TBD**	LRO Project Thermal Balance/Thermal Vacuum Test Plan

2.0 TEMPERTURE 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 three sets of temperature limits associated with critical locations and the SC-to-instrument thermal interface locations, defined as follows:

a. Survival Limits: The minimum and maximum non-operating temperatures that may be experienced without inflicting damage or permanent performance degradation. Components must demonstrate that they can operate properly in thermal vacuum after exposure to cold survival limits. Survival limits must be at least as wide as qualification temperature limits.

b. Qualification Temperature Limits: The minimum and maximum over which the responsible hardware manager has proven the component works thru qualification. 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 flight design limits must be at least 10°C inside the qualification limits, except for actively controlled components. The flight design limits are treated as an “allocation” in the sense that the responsible hardware manager commits to not exceed them by design.

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 SC 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 SC, 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 (EIDP) prior to delivery of the component to the orbiter assembly in an as-built location. All orbiter-controlled telemetry shall be defined in the Lunar Reconnaissance Orbiter Thermal Hardware Specification (431-SPEC-**TBD**) document or component specific documentation.

2.3 FLIGHT INTERFACE DESIGN TEMPERATURE LIMITS

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

Table 2-2.1. 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
	Com-Avionics to Propulsion	+30 to -40	+40 to -50
	Comp. Instrument Module	+90 to -65	+90 to -65
	Fasteners	+90 to -65	+90 to -65
Mechanisms	High Gain Antenna (HGA) Gimbals	-10 to +50	-20 to +60
	HGA Boom	-10 to +50	-20 to +60
	HGA Release and Deploy	-10 to +50	-20 to +60
	Solar Array (S/A) Gimbals	-10 to +50	-20 to +60
	S/A Boom	-10 to +50	-20 to +60
	S/A Release and Deploy	-10 to +50	-20 to +60
Power	Power Subsystem Electronics (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 and Motor Controller	+135 to -155 **TBR**	+135 to -155 **TBR**
Attitude Control System (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
Propulsion and Deployables Electronics (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

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
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 Transducer	+10 to 40	N/A
	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 Solid State Recorder (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 and Mounting Hardware	-10 to 40	-20 to 50
S Comm	TT&C XPDR Stack (xmit)	-10 to +55	-20 to 65
	USB Diplexer	TBD	TBD
	USB Radio Frequency (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

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)	
		Operational	Survival
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
	HGA	TBD	TBD
Cosmic Ray Telescope of the Effects of Radiation (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
Lyman-Alpha Mapping Project (LAMP)	Instrument Pkg.#3	-10 to +40	-20 to +40
	Instrument Elect. #3	-10 to +40	-20 to +40
Lunar Exploration Neutron Detector (LEND)	Instrument Pkg.#4	-20 to +50	-40 to +70
	Instrument Elect. #4	-20 to +50	-40 to +70
Lunar Orbiter Laser Altimeter (LOLA)	Optics Package	+0 to +30	-20 to +40
	Instrument Electronics	-10 to 40	-20 to +50
Lunar Reconnaissance Orbiter Camera (LROC)	Narrow Angle Component (NAC) (2)	-35 to +30	**TBD** to +60
	Wide Angel Component (WAC)	-35 to +30	**TBD** to +60
	Sequencing and Compressor System (SCS)	-35 to +60	-55 to +60

2.4 TEMPORAL GRADIENT REQUIREMENTS

Table 2-2 below lists the temporal gradient requirements.

Table 2-2.2. Temporal Gradient Requirements

SUBSYSTEM	COMPONENT	TEMPORAL GRADIENT (°C)
CRaTER	Instrument Pkg.#1	
Diviner	Instrument Pkg.#2	
	Instrument Elect. #2	

SUBSYSTEM	COMPONENT	TEMPORAL GRADIENT (°C)
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 2-3 below lists the spatial gradient requirements.

Table 2-2.3. 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
	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 SC, when powered "OFF", the SC Thermal Control System shall maintain the instruments within the design survival temperature limits. If necessary, the SC 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 2-4 specifies the number of SC 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 2-2.4. Thermistor Allocation

Subsystem	Components	Number of Telemetry Points
Mechanical		**45**
	Comp. Propulsion Module	
	Comp. SC Bus Module	
	Comp. Instrument Module	
	Fasteners	
Mechanisms		**14**
	HGA Gimbals	
	HGA Boom	
	HGA Release and Deploy	6
	S/A Gimbals	
	S/A Boom	
	S/A Release and 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 (SC 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	

Subsystem	Components	Number of Telemetry Points
C&DH		**2**
	Backplane	2
	Box and Mounting Hardware	
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 SSOA TWTA w/PC	2
	Ka Bandreject Filter	
	WG-34 Ka Band Waveguide	
	HGA	3
CraTER	INST #1	2
Diviner	INST #2	5
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 one 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 SC configuration.

3.2 SPACECRAFT CONTROLLED THERMAL CONTROL HEATER POWER

The SC shall control several heater power circuits. These heater power circuit sizes and locations are detailed in the Lunar Reconnaissance Orbiter Thermal Hardware Specification (431-SPEC-**TBD**) document. 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 Spacecraft Operational Thermal Control Heat Power Description

This switch is intended to service SC 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 SC components will be ones that may be switched off during lunar eclipse or safe hold 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 needs tighter stability during certain fully operational modes or components that are

Table 3-3.1. 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	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								All	All	Safe Hold	Safe Hold	Safe Hold	Safe Hold	Safe Hold	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								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	+/-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?								Deattached	Varies	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y		
S/A deployed?								Deattached	Varies	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Thermal Cooling Method								Targets	Convection & A/C	Convection & Fairing	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	Radiation	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	<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								<+0.1" / 2 meters	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
Deployment Htrs On/Off										On	On	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off
S/C Op Htrs On/Off										Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On
Instr Op Htrs On/Off										Off	Off	Off	Off	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	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	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	5.6	5.6						0	0	0	0	0	0	0	0	5.6	5.6	5.6	5.6	0	5.6	5.6	0	0
SSR (in CD&H)	0	0	42	42						0	0	0	0	0	0	42	42	42	42	42	42	0	42	42	0	0
S-Band Transponder	14.64	14.64	14.64	8						8	8	8	8	8	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	31.9	0						0	0	0	0	0	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	30	30	30	30	30	30	30	30	30
Star Trackers (2)	0	0	20	20						0	0	0	0	0	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	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	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	27						35.4	35.4	35.4	35.4	35.4	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	46	46						20	20	20	20	20	36	36	36	46	46	46	46	36	46	46	36	36
S/A Gimbal	10	10	10	10						0	0	0	0	0	10	10	10	10	10	10	10	10	10	10	10	10
Hi-Gain Gimbal	0	0	10	10						0	0	0	0	0	0	0	0	10	10	10	10	0	10	10	0	0
CRaTER	0	0	15	12						0	0	0	0	0	0	0	0	0	15	15	15	0	15	15	0	0
Diviner	0	0	11	11						0	0	0	0	0	0	0	0	0	11	11	11	0	11	11	0	0
LAMP	0	0	4.3	4.3						0	0	0	0	0	0	0	0	0	6.3	4.3	4.3	0	4.3	4.3	0	0
LEND	0	0	13	13						0	0	0	0	0	0	0	0	0	13	13	13	0	13	13	0	0
LOLA	0	0	26.2	26.2						0	0	0	0	0	0	0	0	0	26.2	26.2	26.2	0	26.2	26.2	0	0
LROC	0	0	22	22						0	0	0	0	0	0	0	0	0	72	22	22	0	22	22	0	0
Total Instr Mod	32	32	143.5	140.5						32	32	32	32	32	32	52	52	52	195.5	143.5	143.5	32	143.5	143.5	32	32
Total Avionics Mod	153.825	153.825	224.725	173.025						137.2	137.2	137.2	137.2	137.2	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	76.54	38						38	38	38	38	38	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	20	20						0	0	0	0	0	10	10	10	20	20	20	20	10	20	20	10	10
Total non-heaters	240.465	240.465	464.765	371.525						207.2	207.2	207.2	207.2	207.2	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	276.065	500.365	407.125						207.2	207.2	242.8	242.8	242.8	276.065	338.065	338.065	408.865	516.765	464.765	464.765	276.065	464.765	464.765	276.065	276.065

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 Command and Data Handling and Software Controlled Heater

An additional five 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 3-3.2. 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 Propulsion 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 SC 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, S/A 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 24 volts (V) (**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 Watts per centimeters squared (W/cm^2) (1.0 Watts per inch squared [W/in^2]) shall be approved by the GSFC LRO Thermal Engineer Lead 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 SPACECRAFT HEATER ALLOCATION

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

Table 3-3.3. Spacecraft Control Heater Power Allocations

SWITCH#	Circuit Description	Volt (Min/Max)	Nominal Predict Power Beta 90° (W)	GEVS Margin	Power Rqmt (W)	Power Rqmt at Beta TBD (W)	Peak Pwr @ Vmax (W)
S11	Instrument Deck Operational	24/35	60	1.4	86	**TBD**	**TBD**
S38	SC 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	SC 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 SPACECRAFT SWITCH)

The instrument heater power allocation on the SC Instrument Operational bus is outlined in Table 3-4 and described in Section 3.2.1. The power shown is at 24V and is the size of the heater with the General Environmental Verification Standards (GEVS) margin 70% duty cycle. All services shall be thermostatically controlled at the instrument. The SC is providing no active control. Heaters shall be S311-079 Kapton film heaters or Dale Ohm heaters approved by LRO Thermal Subsystem Lead. Mechanical thermostats shall have a space flight heritage and shall be approved design by the Thermal Subsystem Lead.

Table 3-3.4. Instrument Control Heater Power Allocations on the SC Instrument Operational Bus

INSTRUMENT	*HEATER POWER (W)*		
	Operational	DeContam.	*Survival*
CRaTER	Sized by S/C	None	*Sized by S/C*
Diviner (on S/C isolated components only)	7*	None	*13**
Diviner Gimbal base and Electronics	Sized by S/C	None	*Sized by S/C*
LROC NAC1	4	10**	*6*
LROC NAC2	4	10**	*6*
LROC WAC	4	10**	*5*
LROC SCS	4	None	*5*
LAMP	2	Dissipated thru LAMP main power feed	*5*
LEND	Sized by S/C	None	*Sized by S/C*
LOLA Combined	*32*	*None*	*37.5*

*On Diviner only separate operational and survival heater circuits

**On LROC separate de-contamination heater only circuit

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 3-5 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. Heaters shall be S311-079 Kapton film heaters or Dale Ohm heaters approved by LRO

Thermal Subsystem Lead. Mechanical thermostats shall have a space flight heritage and have an approved design by the LRO Thermal Subsystem Lead.

Table 3-3.5. Instrument Control Heater Power Allocations Drawn from the Internal Instrument Power Bus

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***
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***	***TBD***

4.0 MULTI-LAYER INSULATION BLANKETS

4.1 OUTER BLANKET COATING

All exterior facing Multi-Layer Insulation (MLI) blankets in the avionics and instrument module area shall have a 3 mil Kapton with VDA in outer coating unless approved by the LRO Thermal Systems Engineer Lead. There will be blankets in the propulsion module area that will need metallic shield outer layers.

4.2 MULTI-LAYER INSULATION BLANKET GROUNDING

All blankets shall be grounded in accordance with the Lunar Reconnaissance Orbiter Electrical Systems Interface Control Document (431-ICD-000018).

4.3 MULTI-LAYER INSULATION BLANKET DOCUMENTATION

All component MLI blankets shall have their location and shape documented in component as-built ICDs. All thermal subsystem MLI blankets shall be documented in the Lunar Reconnaissance Orbiter Project General Thermal Hardware Specification (431-SPEC-**TBD**).

4.4 ATTACHMENT OF MULTI-LAYER INSULATION BLANKETS

All exterior MLI blankets shall be mechanically constrained at least at one point or mechanically captured by another blanket or mechanical component.

5.0 THERMAL ANALYSIS

5.1 ENVIRONMENTAL CONDITIONS

5.1.1 Thermal Conditions

The LRO environment is listed in Tables 5-1 and 5-2 below. 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 5-5.1. 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 5-5.2. 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
360 (sub-solar)	1335*1*COS(θ) + 5	1114*1*COS(θ) + 5

5.1.2 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 5-1).

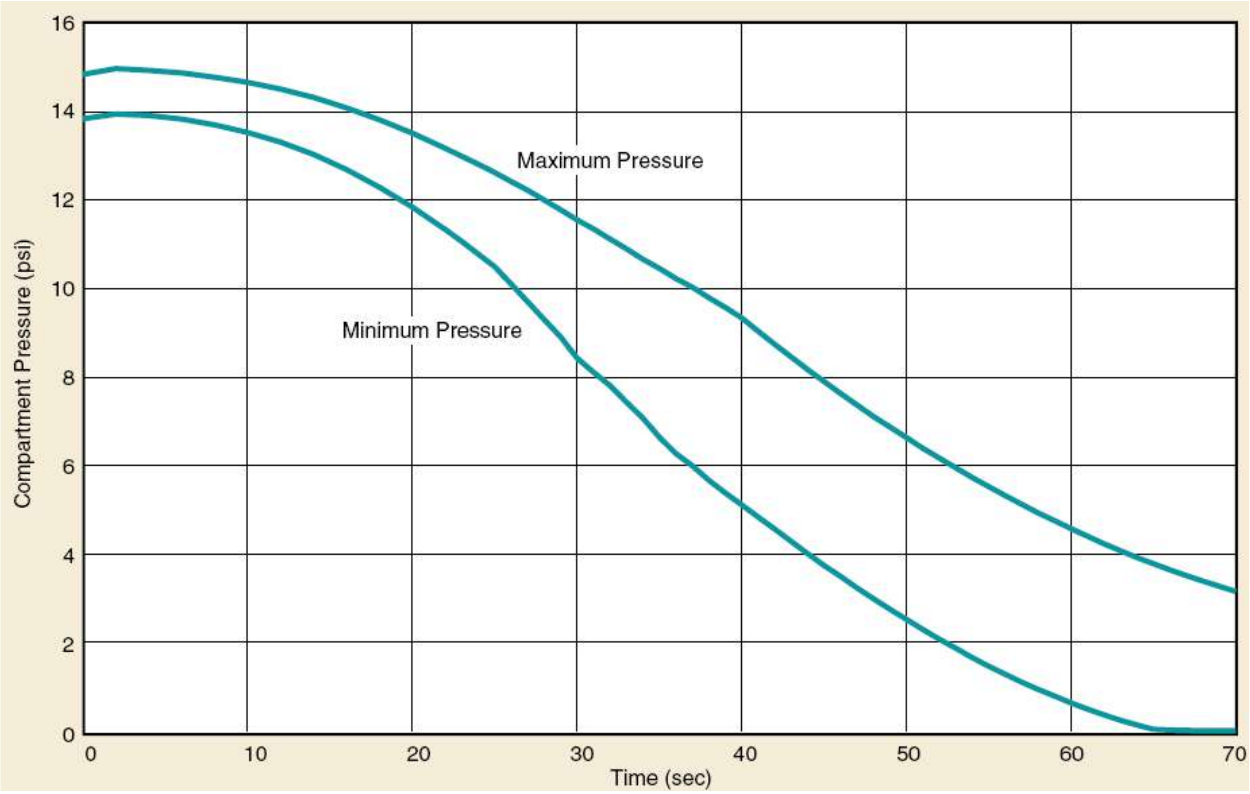

Figure 5-5.1. Delta II-Like Fairing Pressure

5.2 THERMAL COATINGS

Recommend adding lead in sentence providing purpose/description of Table.

Table 5-5.3. 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		
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		

DESCRIPTION	COLD		HOT 13 mo. (5 yr.)		SPEC.	
	α_S	ε_H	α_S	ε_H	SOL	IR
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-mil	0.07	0.80	0.12 (0.19)	0.78	1.0	---
OSR/ITO Pilkington, 5-mil	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		

5.3 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.

5.4 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.

5.5 THERMAL MODEL MARGIN

Prior to flight, 5°C is the minimum required margin for model predictions with respect to Flight Design Limits, except for heater controlled elements that demonstrate a maximum 70% heater duty cycle.

5.6 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. SC 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 Lead.

5.7 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.

6.0 COMPONENT AND ORBITER INTEGRATION AND TEST

6.1 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 through approval of the LRO Thermal Subsystem Lead.

6.2 MODEL DOCUMENTATION

The Reduced Geometric Math Models (RGMMs) and Reduced Thermal Math Models (RTMMs) delivered to GSFC shall be accompanied by appropriate model documentation as specified in the Lunar Reconnaissance Orbiter Thermal Math Model Requirements (431-RQMT-000092) document.

6.3 COMPONENT THERMAL TEST MODEL

All thermal tests shall be Thermal Synthesizer System (TSS)/System Improved Numerical Differencing Anaylzer (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.)

6.4 COMPONENT THERMAL TEST DOCUMENTATION

All final thermal qualification test plan shall be approved by the LRO Thermal Subsystem Engineer Lead. Target temperatures and overall test setup shall be discussed with the LRO Thermal Subsystem Engineer Lead.

6.5 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.

6.6 REDUCED MODEL

Reduced component models shall be made available to the thermal team 30 days before the Preliminary Design Review (PDR), Critical Design Review (CDR), Pre-Environmental Review (PER), and delivery to Orbiter Integration and Test (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 the Lunar Reconnaissance Orbiter Thermal Math Model Requirements (431-RQMT-000092).

6.7 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.

6.8 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.

6.9 LUNAR RECONNAISSANCE ORBITER COORDINATE SYSTEM

The LRO mechanical and thermal coordinate system is shown in Figure 6-1. Unless otherwise noted, this document shall refer to the LRO coordinate system.

6.10 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.

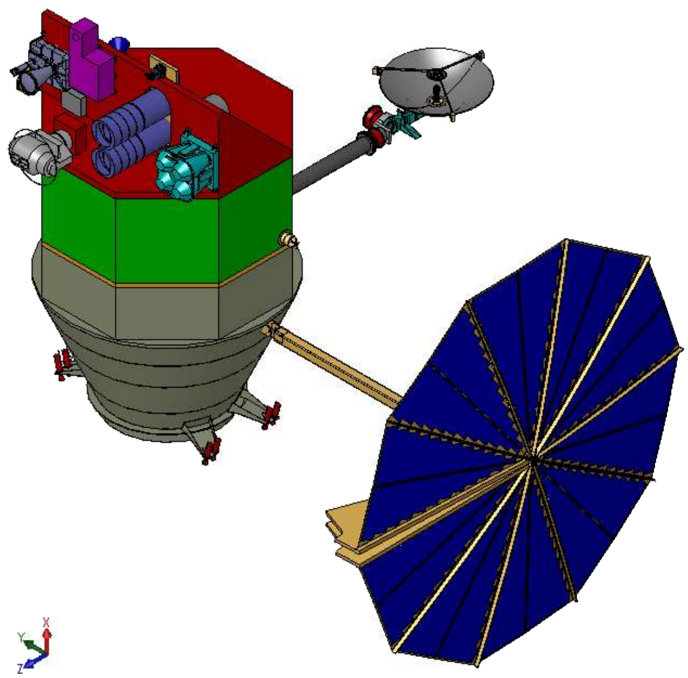

Figure 6-6.1. LRO Coordinate System Definition

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 SC. 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.

6.11 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.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ACS	Attitude Control System
ºC	Degrees Centigrade
C&DH	Command and Data Handling
CBE	Current Best Estimate
CCB	Configuration Control Board
CCR	Configuration Change Request
CDR	Critical Design Review
CM	Configuration Management
CMO	Configuration Management Office
CRaTER	Cosmic Ray Telescope of the Effects of Radiation
Diviner	
ELV	Expendable Launch Vehicle
EPC	???
EVD	???
GEVS	General Environmental Verification Standards
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HIDEC	???
Htrs	Heaters
I&T	Integration and Test
I/F	Interface
ICD	Interface Control Document
IR	???
IMU	???
Km	Kilometer
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LISIC	???
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
LVPC	???
Max.	Maximum
MGA	???
Min.	Minimum
MLI	Multi-Layer Insulation
Mo.	months
N/A	Not Applicable
NAC	Narrow Angle Component
NASA	National Aeronautics and Space Administration

Abbreviation/ Acronym	DEFINITION
NC	???
OP	???
PDE	Propulsion and Deployables Electronics
PDR	Preliminary Design Review
PER	Pre-Environmental Review
PRT	???
PSE	Power Subsystem Electronics
Psi	Pounds per square inch???
Pts	???
Pwr	Power
RF	Radio Frequency
RGMM	Reduced Geometric Math Model
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
S/A	Solar Array
SBC	???
SC	Spacecraft
SCS	Sequencing and Compressor System
Sec.	Seconds
SINDA	Systems Improved Numerical Differencing Analyzer
SOL	???
Spec.	???
SSR	Solid State Recorder
SSPA	???
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Reviewed
TSS	Thermal Synthesizer System
TT&C	???
TWTA	???
USB	???
W	Watt
w/o	Without
W/cm^2	Watts per centimeter squared
W/in^2	Watts per inch squared
W/m^2	Watts per meter squared
WAC	Wide Angle Component
XPDR	???
V	Volt(s)