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Lunar Reconnaissance Orbiter Project

Thermal System Specification

LRO GSFC CMO

April 3, 2007

RELEASED

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

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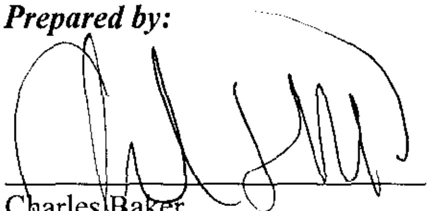

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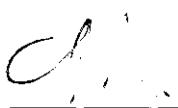

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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Rev –	Released to 431-CCR-000022	C. Tooley	11/17/2005
Rev A	Released to 431-CCR-000105	C. Tooley	6/7/2006
Rev B	Released to 431-CCR-000225	C. Tooley	9/15/2006
Rev C	Released to 451-CCR-000360	C. Tooley	4/3/2007

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1	Section 1.4.2	Provide document number to replace TBD for LRO Thermal Balance/Thermal Vacuum Test Plan	C. Baker/ GSCF	8/1/2006
2	Section 5.2	Thermal Coatings Table has TBDs	W. Peters/ GSFC	12/1/2006
3	Table 2.1a	Revise CSS Op and Survival Limits based on Pre-IT Thermal Analysis Results	C. Baker/GSFC	4/1/2007
4	Table 2.1a	Revise Structural Qual Temperature based on Pre-IT Thermal Analysis Results	C. Baker/GSFC	4/1/2007

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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:

- Temperature Requirements
- Bounding Environmental Parameters
- Thermal Test Requirements
- Thermal Analysis Requirements (bounding inputs and required outputs)
- Thermal Report Requirements
- Component Thermal Hardware Drawings and Diagrams Requirements
- Instrument Allocated Operational and Survival Heater Power

1.2 PURPOSE

The purpose of this specification is to clearly define what is expected of every temperature sensitive component to be flown on LRO and the LRO thermal control system to satisfy that the component is safe to fly on LRO. 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-OPS-000042	Lunar Reconnaissance Orbiter Mission Concept of Operations
431-RQMT-000092	Lunar Reconnaissance Orbiter Thermal Math Model Requirements
431-SPEC-000008	Lunar Reconnaissance Orbiter Electrical Systems Specification
431-SPEC-000112	Lunar Reconnaissance Orbiter Technical Resource Allocations Specification

451-SPEC-000913 Lunar Reconnaissance Orbiter General Thermal Hardware Specification

431-SPEC-**TBD** Lunar Reconnaissance Orbiter Project <Specific> Thermal Hardware Specification

1.4.2 Reference Documents

431-ICD-000114 Lunar Reconnaissance Orbiter Camera Thermal Interface Control Document

431-ICD-000115 Lyman-Alpha Mapping Project Thermal Interface Control Document

431-ICD-000116 Diviner Lunar Radiometer Experiment Thermal Interface Control Document

431-ICD-000117 Lunar Orbiter Laser Altimeter Thermal Interface Control Document

431-ICD-000118 Cosmic Ray Telescope for Effects of Radiation Thermal Interface Control Document

431-ICD-000119 Lunar Exploration Neutron Detector Thermal Interface Control Document

431-PLAN-**TBD** Lunar Reconnaissance Orbiter Project Thermal Balance/Thermal Vacuum Test Plan

431-SPEC-000012 Lunar Reconnaissance Orbiter Mechanical Systems Specification

GSFC-STD-7000 General Environmental Verification Standards (GEVS) for Flight Programs and Projects
MIL-R-39009 General Specification for Resistors, Fixed, Wire-Wound (Power Type, Chassis Mounted)

NASA GSFC S311-641 Switch, Thermostatic, Bimetallic, SPST, Narrow Differential, Hermetic

NASA GSFC S311-P-079 Procurement Specification for Thermofoil Heaters

431-ICD-000159 Mini-RF to Spacecraft Thermal Interface Control Document

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:

TSS-45 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.

Qualification Temperature Limits: The minimum and maximum over which the responsible hardware manager has proven the component works thru qualification. The Qualification limits are 10 C outside of the Flight Limits. Acceptance Limits are 5 C outside of the Flight Limits. Any component that may be considered for Acceptance testing must present the case to the LRO Thermal Systems Lead that the same design component has been qualified in a relevant environment for LRO. 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.

Flight Operational Limits: The flight operational limits must be at least 10°C inside the qualification limits, except for actively controlled components. The flight operational 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 applicable component mechanical interface drawings 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. Inside box/ component locations are acceptable if installed by component development team and reflected in the appropriate electrical ICD.

TSS-1762 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).

TSS-1763 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.

TSS-1764 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

TSS-51 Table 2-1 below lists the design temperature limits at the SC thermal interface.

Table 2-1. Spacecraft Interface Temperature Range

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)		
		Op I/F Limit	Qual I/F Limit	Surv I/F Limit
Power	Power Subsystem Electronics S/C I/F at PSE	-10 to +40	-20 to +50	-20 to +50
	S/C I/F at Battery	+10 to +30	+0 to +40	+0 to +40
Attitude Control System (ACS)	S/C I/F at Star Trackers (Radiator I/F temp not Optical Bench temp)	-30 to +50	-35 to +55 Acceptance	-40 to +60
	S/C I/F at Inertial Measurement Unit	-10 to +50	-15 to +55 Acceptance	-20 to +60
	S/C I/F at Reaction Wheels	0** to +50	-10 to +60	-10 to +60
	S/C I/F at Coarse Sun Sensors	-80 to +80	-90 to +90	-135 to +90
Propulsion and Deployables Electronics (PDE)	S/C I/F at PDE	-10 to +40	-20 to +50	-20 to +50
	S/C I/F to Insertion Thrusters (at bracket)	-25 to +50	-25 (survival) to +50 Hot Fire	N/A
	S/C I/F to ACS Thrusters (at bracket)	-25 to +60	-25 (survival) to +60 Hot Fire	N/A
C&DH	S/C I/F at C&DH	-10 to +40	-20 to +50	-20 to +50
	S/C I/F at 9500 Oscillator	-10 to +40	-15 to +45 Acceptance	-20 to +50
S Band Comm	S/C I/F at S-band components	-10 to +50	-20 to +60	-20 to +60

Ka Band Comm	S/C I/F at Ka Baseband Modulator	-10 to +50	-20 to +60	-20 to +60
	S/C I/F at Ka TWT	-10 to +60	-20 to +70	-20 to +70
	S/C I/F at EPC	-10 to +50	-20 to +60	-20 to +60
Mechanisms	S/C I/F at Gimbal Control Electronics 1 (Hi-Gain)	-10 to +40	-20 to +50	-20 to +50
	S/C I/F at Gimbal Control Electronics 2 (S/A)	-10 to +40	-20 to +50	-20 to +50
Cosmic Ray Telescope of the Effects of Radiation (CRaTER)	S/C at I/F to CRaTER	-30 to +25*	-40 to +35	-40 to +35
Diviner	S/C at I/F to Diviner Instr	-20 to +45	-30 to +55	-35 to +55
	S/C at I/F to remote electronics box	-10 to +45	-20 to +55	-20 to +55
Lyman-Alpha Mapping Project (LAMP)	S/C I/F at base of LAMP's feet	-30 to +30	-40 to +40	-40 to +40
Lunar Exploration Neutron Detector (LEND)	S/C at I/F to LEND	-20 to +40	-30 to +50	-30 to +50
Lunar Orbiter Laser Altimeter (LOLA)	S/C at I/F to Optics Package	-30 to +30	-40 to +40	-40 to +40
	S/C at I/F to Instrument Electronics	-30 to +40	-40 to +50	-40 to +50
Lunar Reconnaissance Orbiter Camera (LROC)	S/C at base of NAC	-30 to +30	-40 to +40	-40 to +40
	S/C I/F at base of WAC	-30 to +30	-40 to +40	-40 to +40
	S/C I/F at base of SCS	-30 to +30	-40 to +40	-40 to +40
Mini RF	S/C I/F at base of antennae's feet	-50 to +50	-60 to +60	-60 to +60
	S/C I/F at base of electronics feet	-20 to +30	-30 to +40	-30 to +40

*Operation in-air will allow the CRaTER operational temperature to be raised to +35 C
**During Lunar Eclipses,CSS Survival Temperature Limits are -190 C and will be survival cycled to this limit

Table 2-2. Component Design Temperature Range

SUBSYSTEM	COMPONENT	TEMPERATURE RANGE (°C)		
		Operational	**Qualification**	**Survival**
Mechanical	Structure Propulsion Module	-50 to +60 TBR	-60 to +70	-60 to +70
	Structure -SC Bus Module	-50 to +50 TBR	-60 to +60	-60 to +60
	Structure, Instrument Module	-40 to +40	-50 to +50	-50 to +50
Mechanisms	High Gain Antenna (HGA) Gimbal Motor Housing	-0 to +60	-10 to +70	-20 to +70
	HGA Boom	-45 to +70	-55 to +80	-55 to +80
	HGA Dampers	-15 to +50	-60 to +60	-60 to +60
	HGA Rotary Joint (adjacent to Actuators)	-20 to +50	-25 to +55 (acceptance) -30 to +60 (surv)	-30 to +60
	HGA Cable Wraps	-10 to +50	-20 to +60	-40 to +60
	HGA Rotary Joint (adjacent to Hinge)	-30 to +40	-35 to +45 (acceptance) -40 to +50 (surv)	-40 to +50
	Solar Array (S/A) Gimbal motor housing	0 to +60	-10 to +70	-20 to +70
	SAS Cable Wraps	-10 to +50	-20 to +60	-40 to +60
	SA Dampers	-15 to +50	-60 to +60	-60 to +60
Propulsion System (wetted components only)	Hydrazine Tank 1 +2	+10 to +40	+5 to +45 Acceptance	N/A
	Pressure Tank	+0 to +50	-5 to +55 Acceptance	N/A
	90N ThrustersValves (non-firing)	+10 to +50	+5 to +55 Acceptance	N/A

	22N Thrusters Valves (non-firing)	+10 to +50	+5 to +55 Acceptance	N/A
	All Gas Components upstream of regulator except fill and drain	-40 to +40	-45 to +45 Acceptance	N/A
	All Gas Components downstream of regulator	+10 to +50	+5 to +55 Acceptance	N/A
	All Fill an Drain	+10 to +50	+5 to +55 Acceptance	N/A
	Gas System Filters	+0 to +50	-5 to +55 Acceptance	N/A
	Liquid Filters	+10 to +50	+5 to +55 Acceptance	N/A
	Pressure Transducers	+10 to +40	+5 to +45 Acceptance	N/A
	Pressure Regulators	+0 to +50	-5 to +55 Acceptance	N/A
	Plumbing Lines	+10 to +50	N/A	N/A
	NC Pyro Valves	-10 to +40	-15 to +45 Acceptance	-20 to +50
Ka Comm	HGA	-140 to +145	-140 to +145	-170 to +145
	Wave Guide	-50 to +50	N/A	-60 to +60
S-Band Comm	TT & C Omni Antenna	-120 to +80	-125 to +85 Acceptance	-130 to +90
Laser Receiver	Receiver Telescope	-30 to +80	-40 to +90	-40 to +90
	Fiber Optic and Fiber Optic Cable Connectorse	-45 to +70	-55 to +80	-55 to +80
Power	Solar Array	-148 to +135 (shunted) +123 (unshunted)	-158 to +145	-192 to +145

* Hi-Gain Antenna temperatures need to be updated based on the latest design and coatings (when predicts are available)

2.4 TEMPORAL GRADIENT REQUIREMENTS

TSS-254 Table 2-3 below lists the temporal gradient requirements. Temporal gradient rates shall be evaluated over 6 minute average time periods minimum.

Table 2-3. Temporal Gradient Requirements

SUBSYSTEM	COMPONENT	TEMPORAL GRADIENT (°C/min)
CRaTER	SC I/F to the Instrument	None
Diviner	Remote Electronics Box Baseplate	1.0
	SC I/F to Diviner Instrument	None
LAMP	SC I/F to LAMP Instrument	None
LEND	Instrument Baseplate	2.0
LOLA	Optics Package	None
	Instrument Electronics	None
LROC	NAC (2)	None
	WAC	None
	Instrument Electronics	None
Mini-RF	Antennae	None
	Electronics Box	None

2.5 SPATIAL GRADIENT REQUIREMENTS

TSS-305 Table 2-4 below lists the spatial gradient requirements between mounting feet.

Table 2-4. Spatial Gradient Requirements

SUBSYSTEM	COMPONENT	SPATIAL GRADIENT Between Mounting Feet (°C)
CRaTER	SC I/F to the Instrument	None
Diviner	SC I/F to Remote Electronics Box	None
	SC I/F to Diviner Instrument	None
LAMP	SC I/F to LAMP Instrument	None
LEND	Instrument Pkg.#4	None
LOLA	Optics Package	None
	Instrument Electronics	None
LROC	NAC (2)	None

	WAC	None
	Instrument Electronics	None
ACS	Star Cameras	None
COMM	Hi-Gain Gimbals	None
Mini-RF	Antennae	None
	Electronics Box	None

2.6 TURN ON TEMPERATURE AND SURVIVAL

TSS-364 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.

TSS-365 All components shall also survive indefinitely, without damage or permanent performance degradation, if powered "ON" anywhere from the minimum survival temperature to 10°C above the maximum operating temperature.

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

TSS-368 451-SPEC-00093 specifies the number of SC monitored temperature sensors allocated to each component. The telemetry types listed only apply to the column in the table labeled "Number of Telemetry Points'. The 'Internal Box Telemetry' sensors can be alternative telemetry types since they may be read by alternative avionics. The current baseline for temperature sensors is 2252 ohms 311P18-02-A-101 or Platinum Resistance Thermistor (PRT) (0118MF2000AC + 00118-1009-2003 (36in), 2000 ohms @ 0°C) as specified by the LRO Thermal Systems Lead.

TSS-3040 The thermistor/PRT shall be capable of being read over the all temperature ranges specified.

TSS-3041 The thermistor sensors shall be accurate within 1.5 degree C from -40 to +75 C.

TSS-3042 The PRT sensors shall be accurate within 3.0 degree C from -170 to +145 C.

The thermistor electrical interface shall be per the relevant electrical ICD and that the physical placement of each thermistor is per the relevant thermal ICD.

Table 2-5. Please refer to Thermal Hardware System Specification 451-SPEC-000913 for details on Orbiter thermal telemetry

3.0 THERMAL POWER

3.1 GENERAL HEATER CIRCUIT REQUIREMENTS

TSS-928 Sizing of operational and survival heaters on orbiter shall be based on a maximum of 70% duty cycle at 31 volts (V)and 27 volts (V) bus voltage respectively and under worst case cold thermal conditions. Heater elements must be capable of operating over the voltage range of 28±7V.

TSS-929 Each component shall provide space for mounting thermostats, heaters and temperature sensors.

TSS-1768 Heaters, if Kapton film heaters, shall comply with NASA GSFC S311-P-079.

TSS-1769 Heaters, if Vishay Dale Ohm, shall comply with Military/Established Reliability, MIL-R-39009 Qualified, Type RER, R Level, Aluminum Housed, and be Standard (ERH).

TSS-1770 Mechanical Thermostats, if used, shall comply with NASA GSFC S311-641.

TSS-930 Watt densities of the operational and survival heaters shall be appropriate for the type of heater and bonding method.

TSS-1771 Watt densities (calculated at the maximum voltage) above 0.16 Watts per centimeters squared (W/cm2) (1.0 Watts per inch squared [W/in2]) 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/cm2 (8.0 W/in2).

3.2 THERMAL DISSIPATED POWER PER MISSION MODE

TSS-932 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 modes that the components shall experience including pointing and SC configuration.

3.3 SPACECRAFT CONTROLLED THERMAL CONTROL HEATER POWER

TSS-934 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.

3.3.1 Instrument Operational Heater Power Description

TSS-936 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 during different regular operational modes. In the cold case, this heater power is necessary to offset the losses from the instrument to the environment and the variation in power based on different operational modes.

Table 3-1. Component Thermal Power Dissipations and Thermal Mission Modes

Updated 02/20/07 based on Resource Tracker from: 12/01/06 + add power to RWA during Lunar Eclipe +Diviner +LROC Update 8/18/06 + 10/23/06 Systems Update: Lower Battery to 12 W hot, Lower RWAs to 47 W Hot, Star Trackers should range from 14 to 10 W	Sun Acq Powers max (W)	Safe Hold Powers min (W)	Lunar Eclipse Powers (W)	Max Op Diss Pwr (allocation)	Min Op Diss Pwr (cold CBE)	Section Numbers are from 431-OPS-000042	3.0 Thermal Vacuum Configuration	3.0 Ground in-air testing	3.2 Pre-Lift off	4.1 Lift off and Ascent	4.2 Separation	4.3 Initial Sun Acq	4.3 S/A Deployment	4.3 Early to Mid Lunar Cruise	4.4 Late Lunar Cruise	4.5 Lunar orbit Insertion	5.1 S/C Activation & Commissioning	5.2 Instr Activation & Commissioning	6.2 Measurement Ops	6.2.3 Off Nadir Pointing	6.3 Station Keeping	6.4 Momentum dumps	6.5 Instrument Calibration	6.6 Lunar Eclipse	6.7 Yaw Maneuvers	6.8 Safe Hold	7.0 Extended Mission	8.0 End-of-Mission Disposal
							All	All	Launch Safe Hold	Launch Safe Hold	Safe Hold	Safe Hold	Safe Hold	Safe Hold w/PDE	Safe Hold w/CRaTER, Lend, Gimbals	Safe Hold w/CRaTER, Lend, Gimbals	SC Op, Instrument Surv	Op	Op	Op	Op	Op	Op	Launch Safe Hold	Op	Safe Hold Cold	Safe Hold Hot	Safe Hold Hot
S/C Pointing							X and Y axis horizontal	Y and Z axis horizontal, X and Y axis horizontal	+X VV	+X VV Sun is on -Z hemisphere (Sun is -Z axis +/-90 in both x and y directions @185 km LEO)	Sun is on -Z hemisphere (Sun is -Z axis +/-90 in both x and y directions @185 km LEO)	-Y is within 15 deg of sun.	-Y is within 15 deg of sun. Solar Array deployment and HGAS deployment with 2 hours	Reorient +/- 5° -Y on sun line	+/-5° -Y on sun line, Yaw to fire thrusters (sun can be on all X and Y surfaces)	100 to 3000 km orbit Launch dependant Beta decreasing to 30 x 216 km orbit, nadir pointing, Yaw to fire thrusters, Sun	30 x 216 km orbit (see details in 5.2), nadir pointing, could be any Beta, May off point 5° for gyro calibration, off slews will not drive thermal	30x216 km altitude about the moon. the periselene, 30 km, over the lunar south pole. it will vary by no more than 3 deg over the month. also, orbit shape varies from 26x216 to 45x197 Nadir pointing is nominal	50+/-20 km Nadir Pointing +/-1 arcminute Positive Beta Angles 0 to 90 deg +X to 'vV, Negative Beta Angles -X to VV	50 +/-20 km Nadir +/-20 off yaw about X axis must return to nadir in < 20 minutes, Non-nadir pointing otherwise available in moon's shadow	50+/-20 km Nadir Pointing +/-1 arcminute will require 180 degree yaw (sun may get on the anti-sun - slews take 10 min each way, 5 min dwell)	50+/-20 km Nadir Pointing +/-5 degrees off nadir possible for up to 5 min	Off Nadir pointing not allowed to drive thermal but TBD	Sun Acq Attitude max roll off -Y to sun for 172 minutes is <10 degrees for all three axises (depending on <2 deg starting tolerance)	50 +/-20 km Nadir (sun kept off anti-sun during 10 minute 180 deg yaw)	-Y sun pointing +/- 15°	Nadir Pointing 30 x 216 km see instrument activation	Nadir pointing, sun may be on anti-sun side. No targeting necessary.
Hi-Gain deployed?							Deattached	Varies	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	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	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	Radiation	Radiation	Radiation
Time Duration of mode									L-30 min on Battery	L + 2700 to 5400s	<10 minutes	<10 minutes	<1 hr	~1 day	~4 Days	50 min Maximum Thruster fire	1 month	1 month	1 year	<20 minutes	1 Orbit total	1 Orbit total	25 minutes max	160 minute + eclipse	1 Orbit total	Variable	~4 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	None	None	None
Deployment Htrs On/Off									On	On	On	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
S/C Op Htrs On/Off									Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	Off	On	Off	On	Off
Instr Op Htrs On/Off									Off	Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	Off	On	Off	On	Off
Thermal Dissipation (W)																												
C&DH -9600 oscillator off + COMM card	132.00	87.4	87.4	132.00	110.28				87.4	87.4	87.4	87.4	87.4	87.4	132.0	132.0	132.0	132.0	132.0	132.0	132.0	132.0	132.0	87.4	132.0	87.4	132.0	132.0
Ultra Stable Oscillator 9500	4.1	4.0	4.0	4.1	4.0				4.0	4.0	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.0	4.0	4.0	4.1	4.0	4.1	4.1
S-Band Transponder (6/21/05)	43.3	10.0	10.0	27.9	10.0				10.0	10.0	43.3	43.3	43.3	43.3	43.3	43.3	43.3	27.9	27.9	27.9	43.3	43.3	43.3	10.0	27.9	10.0	43.3	43.3
Ka - EPC 6/21	0.0	0.0	0.0	4.1	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	4.1	4.1	4.1	0.0	0.0	0.0	4.1	0.0	0.0	0.0
Ka - TWT 6/21	0.0	0.0	0.0	27.3	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3	27.3	27.3	27.3	0.0	0.0	0.0	27.3	0.0	0.0	0.0
Ka - Modulator 6/21	0.0	0.0	0.0	17.7	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.7	17.7	17.7	17.7	0.0	0.0	0.0	17.7	0.0	0.0	0.0
RWAs (4)	47.0	20.0	20.0	47.0	20.0				0.0	0.0	47.0	47.0	47.0	20.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	20.0	20.0	20.0	47.0	20.0	47.0	47.0
Star Trackers (2)	28.0	0.0	0.0	28.0	20.0				0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	28.0	28.0	28.0	28.0	20.0	20.0	0.0	28.0	0.0	28.0	28.0
IMU/GYRO	27.5	25.0	25.0	27.5	25.0				25.0	25.0	25.0	27.5	27.5	25.0	27.5	27.5	27.5	27.5	27.5	27.5	27.5	25.0	25.0	25.0	27.5	25.0	27.5	27.5
Battery (From T. Spitzer's 6/05 with 823 Hot, 700 W Cold bus)	12.0	0.0	6.0	12.0	0.0				10.0	10.0	10.0	38.0	38.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	6.0	12.0	0.0	12.0	12.0
PSE (From T. Spitzer's07/06/05)	85.1	69.0	66.0	85.1	69.0				45.0	45.0	45.0	69.0	69.0	69.0	85.1	85.1	85.1	85.1	85.1	85.1	85.1	69.0	69.0	66.0	85.1	69.0	85.1	85.1
Hi-Gain Controller	13.1	0.0	0.0	13.1	10.5				0.0	0.0	0.0	0.0	0.0	10.5	13.1	13.1	13.1	13.1	13.1	13.1	13.1	10.5	10.5	0.0	13.1	0.0	13.1	13.1
Solar Array Controller	13.1	0.0	0.0	13.1	10.5				0.0	0.0	0.0	0.0	10.5	10.5	13.1	13.1	13.1	13.1	13.1	13.1	13.1	10.5	10.5	0.0	13.1	0.0	13.1	13.1
PDE	11.0	10.0	0.0	11.0	10.0				10.0	10.0	10.0	8.0	8.0	8.0	8.0	14.0	14.0	11.0	11.0	11.0	11.0	10.0	10.0	0.0	11.0	10.0	11.0	11.0
S/A Actuator Az (Rotates about Y)	0.0	0.0	0.0	6.0	0.3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	6.0	0.3	0.3	0.0	6.0	0.0	0.0	0.0
Hi-Gain Actuator X (rotates about Y)	0.0	0.0	0.0	6.0	0.3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	6.0	0.3	0.3	0.0	6.0	0.0	0.0	0.0
S/A Actuator Elev (Rotates about Z or X)	0.0	0.0	0.0	0.4	0.3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.3	0.3	0.0	0.4	0.0	0.0	0.0
Hi-Gain Gimbal Y (Rotates about Z or X)	0.0	0.0	0.0	0.5	0.3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.3	0.3	0.0	0.5	0.0	0.0	0.0
CRaTER	9.0	0.0	0.0	9.1	6.0				0.0	0.0	0.0	0.0	0.0	0.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	6.0	6.0	0.0	9.1	0.0	0.0	0.0
Mini-RF Elec Analog Rcrv + Exc	0.0	0.0	0.0	1.3	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.3	1.3	1.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Mini-RF Elec Cntrol, Digital, WFG	0.0	0.0	0.0	2.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
Mini-RF Elec Box PA	0.0	0.0	0.0	4.6	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.6	4.6	4.6	0.0	4.6	0.0	0.0	0.0	0.0	0.0
Diviner per M. Foote 8/8/06	0.0	0.0	0.0	9.4	7.4				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	9.4	9.4	9.4	9.4	9.4	0.0	0.0	0.0	0.0	0.0
Diviner Remote E-box per H. Awaya 8/17/06	0.0	0.0	0.0	8.3	7.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	8.3	8.3	8.3	8.3	8.3	0.0	0.0	0.0	0.0	0.0
LAMP	0.0	0.0	0.0	4.8	4.4				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	4.8	4.8	4.8	4.4	4.4	0.0	0.0	0.0	0.0	0.0
LEND	0.0	0.0	0.0	9.5	9.5				0.0	0.0	0.0	0.0	0.0	0.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	0.0	9.5	0.0	0.0	0.0
LOLA MEB	0.0	0.0	0.0	20.4	17.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.4	20.4	20.4	20.4	20.4	20.4	0.0	20.4	0.0	0.0	0.0
LOLA OTA	0.0	0.0	0.0	16.5	14.8				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5	16.5	16.5	16.5	14.8	14.8	0.0	16.5	0.0	0.0	0.0
LROC decontam (NAC only 38 W a piece)	76.0	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LROC NACs for both Per K. Schaeffner 8/18/06	0.0	0.0	0.0	13.6	11.1				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	13.6	13.6	13.6	11.1	11.1	0.0	13.6	0.0	0.0	0.0
LROC WAC per K. Schaeffner 8/18/06	0.0	0.0	0.0	2.5	2.1				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	2.5	2.5	2.1	2.1	0.0	2.5	0.0	0.0	0.0
LROC SCS per K. Schaeffner 8/18/06	0.0	0.0	0.0	4.5	3.7				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	4.5	4.5	4.5	3.7	3.7	0.0	4.5	0.0	0.0	0.0
Total Instr Mod	85.0	0.0	0.0	90.3	76.0				0.0	0.0	0.0	0.0	0.0	0.0	18.6	18.6	18.6	166.3	90.3	90.3	90.3	81.4	81.4	0.0	76.1	0.0	0.0	0.0
Total ITP Mod	376.2	225.4	212.4	426.1	276.3				181.4	181.4	261.7	286.2	296.7	277.7	373.2	379.2	379.2	426.1	426.1	426.1	441.4	332.6	340.5	212.4	409.9	225.4	376.2	376.2
Total Gimbal	0.0	0.0	0.0	12.9	1.3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	12.9	12.9	12.9	1.3	1.3	0.0	12.9	0.0	0.0	0.0
Total Other Avionics	40.0	0.0	6.0	40.0	20.0				10.0	10.0	10.0	38.0	38.0	20.0	32.0	32.0	32.0	40.0	40.0	40.0	40.0	20.0	20.0	6.0	40.0	0.0	40.0	40.0
Total Thermal Dissipation	501.2	225.4	218.4	569.2	373.6				191.4	191.4	271.7	324.2	334.7	297.7	423.8	429.8	429.8	645.2	569.2	569.2	584.6	435.3	443.2	218.4	538.8	225.4	416.2	416.2
Electrical Dissipation Total	476.9	201.4	209.4	545.1	348.6				169.1	169.1	249.4	273.9	284.4	285.4	399.5	405.5	405.5	620.9	544.9	544.9	560.3	423.0	430.9	200.1	514.5	213.1	391.9	391.9
Outputs																												

In the hotter Beta angles, this heater power will be reduced and eliminatedas the environment warms up. When the instruments are not operating, this heater switch will be switched off to preserve power such as during the lunar eclipse.

3.3.2 Spacecraft Operational Thermal Control Heat Power Description

Deleted

3.3.3 Tight Bandwidth Command and Data Handling and Software Controlled Heater

TSS-943 An additional five tight temperature control in C&DH and six in the PSE circuits have been allocated per Table 3-2 and Table 3-3. This allows tailoring of these five thermal control points to fine tune thermal control. 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 31 V/Peak Power at 35 V
1/5 amp	**LEND Radiator**	11
2/2 amp	**Instrument OP Bench**	**4**
3/2 amp	**Instrument OP Bench**	**4**
4/2 amp	**Instrument OP Bench**	4
5/2 amp	**Instrument OP Bench**	4

Table 3-3. Six Tight Control Heaters Powered by PSE

Heater # / Max Amp	COMPONENT	Orbit Avg Power at 31 V/Peak Power at 35 V
1/2 amp	OP Bench #1(Star Cam I/F)	4
2/2 amp	OP Bench #2(Star Cam I/F)	4
3/2 amp	OP Bench #3(Optical Bench I/F)	4
4/2 amp	OP Bench #4(Optical Bench I/F)	4
5/2 amp	NAC #1 Metering Structure	20
6/2 amp	NAC #2 Metering Structure	20
7/5 amp	RWA Warmup and OP heaters	103 @ 27 V
8/10 amp	ITP Warmup and Op heaters	180 @ 27 V

3.3.4 Propulsion System Heaters Primary and Redundant Description

TSS-971 This unswitched service 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. The propulsion system cylinder heaters will not be explicitly redundant but will allow a loss of any one heater or T-Stat will still maintaining the propulsion system within limits. These heaters shall be enabled during all mission modes as they are designed to prevent the Hydrazine from freezing.

3.3.5 Essential Heater Description

TSS-975 The Essential Heater Bus is unswitched. It is backup thermostatic heaters on the ITP (Avionics Panel), Battery, and RWAs to enable them to survive safe mode. The heaters are not large enough to survive Lunar Eclipse. Separate heater services in the Software Controlled PSE switches (see above) shall be sized large enough to survive Lunar Eclipse on the spacecraft. These heaters are sized for 27 V minimum and 70% duty cycle maximum.

3.3.6 Instrument Survival Heaters Description

TSS-977 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. This bus also includes survival heater for the de-coupled optical bench and S/C interface heater control for LEND and CRaTER.

3.4 SPACECRAFT HEATER ALLOCATION

The heater allocation is per the Technical Resource Allocations Specification 431-SPEC-000112.

3.5 INSTRUMENT HEATER ALLOCATION (WIRED TO SPACECRAFT SWITCH)

TSS-1046 The instrument heater power allocation on the SC Instrument Operational and Survival heater buses are outlined in Table 3-4 and described in Section 3.3.1.

TSS-3076 The operational heaters on the instruments shall be sized at 31V or lower voltage with a General Environmental Verification Standards (GEVS) margin 70% duty cycle maximum at 31V.

TSS-3077 The survival heaters on the instruments shall be sized at 27V or lower voltage with a General Environmental Verification Standards (GEVS) margin 70% duty cycle maximum at 27V.

TSS-3078 All services shall be thermostatically controlled at the instrument.

TSS-3079 Software controlled or switched heaters shall have an overtemperature thermostat in series unless safe survival can be shown with the software control heater at steady state on at 35V.

TSS-1773 Heaters shall be NASA GSFC S311-079 Kapton film heaters or Vishay Dale Ohm heaters (MIL-R-39009 Qualified) approved by LRO Thermal Systems Lead.

TSS-1774 Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Systems Lead.

Table 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 Instrument	Provided thru Instrument Main Power Feed	None	35
Diviner Electronics (DREB)	Sized by S/C	None	Sized by S/C
LROC NAC1 Metering Structure	Provided by S/C Software Control<13W	Provided separately via non-thermal switch	4
LROC NAC2 Metering Structure	Provided by S/C Software Control<13W	Provided separately via non-thermal switch	4
LROC NAC#1 Adapter Plate	4	None	None
LROC NAC#2 Adapter Plate	4	None	None
LROC NAC#1 Elec	None	None	5
LROC NAC#2 Elec	None	None	5
LROC WAC	4	Provided separately via non-thermal switch	5
LROC SCS	2	None	4
LAMP	7	Dissipated thru LAMP main power feed	10
LEND	Sized by S/C	None	Sized by S/C
LOLA Combined	30.5	None	50
Mini-RF	None	None	None

3.6 INSTRUMENT HEATER ALLOCATION (CONTROLLED BY COMPONENTS/ INSTRUMENTS)

TSS-1114 The operational 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 27V 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.

TSS-1775 Heaters shall be NASA GSFC S311-079 Kapton film heaters or Vishay Dale Ohm heaters (MIL-R-39009 Qualified) approved by LRO Thermal Systems Lead.

TSS-1776 Mechanical thermostats shall be NASA GSFC S311-641 qualified and have an approved circuit design by the LRO Thermal Systems Lead.

Instrument Control Heater Power Allocations

Table 3-5. Drawn from the Internal Instrument Power Bus

INSTRUMENT	***HEATER POWER (W)***	
	Operational	***DeContam.***
CRaTER	**None**	*None*
Diviner	6	*None*
LROC NAC1	**None**	*None*
LROC NAC2	**None**	*None*
LROC WAC	**None**	*None*
LROC SCS	**None**	*None*
LAMP	None	1.4 W
LEND	4 max	*None*
LOLA Elec	None	*None*
LOLA Op Bench/Laser	None	*None*
LOLA TEC	3 max	*None*
Total	13	1.4

4.0 MULTI-LAYER INSULATION BLANKETS

4.1 OUTER BLANKET COATING

TSS-1174 All exterior facing Multi-Layer Insulation (MLI) blankets in the avionics and instrument module area shall have a Black Germanium Kapton 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 and may use 3 mil Kapton.

4.2 MULTI-LAYER INSULATION BLANKET GROUNDING

TSS-1176 All blankets shall be grounded in accordance with the Lunar Reconnaissance Orbiter Electrical Systems Specification (431-ICD-000008).

4.3 MULTI-LAYER INSULATION BLANKET DOCUMENTATION

TSS-1178 All component MLI blankets shall have their location and shape documented in component as-built ICDs.

TSS-1777 All thermal subsystem MLI blankets shall be documented in the Lunar Reconnaissance Orbiter General Thermal Hardware Specification (451-SPEC-000913).

4.4 ATTACHMENT OF MULTI-LAYER INSULATION BLANKETS

TSS-1180 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

TSS-1184 The LRO environment is listed in Tables 5-1 and 5-2 below. MLI blankets shall be analyzed using an effective * equal to 0.005 or 0.03, case specific, that yields the worst case in the bounding thermal cases.

Table 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 5-2. LRO Lunar Infrared

ORBIT POSITION (°)	Beta θ° (W/m^2)	
	Hot	**Cold**
0 (sub-solar)	(1335-5)*1*COS(θ) + 5	(1114-5)*1*COS(θ) + 5
30	(1335-5)*0.866*COS(θ) + 5	(1114-5)*0.866*COS(θ) + 5
60	(1335-5)*0.5*COS(θ) + 5	(1114-5)*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	(1335-5)*0.5*COS(θ) + 5	(1114-5)*0.5*COS(θ) + 5
330	(1335-5)*0.866*COS(θ) + 5	(1114-5)*0.866*COS(θ) + 5
360 (sub-solar)	(1335-5)*1*COS(θ) + 5	(1114-5)*1*COS(θ) + 5

5.1.2 Payload Fairing Ascent Pressure Profile

TSS-1260 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).

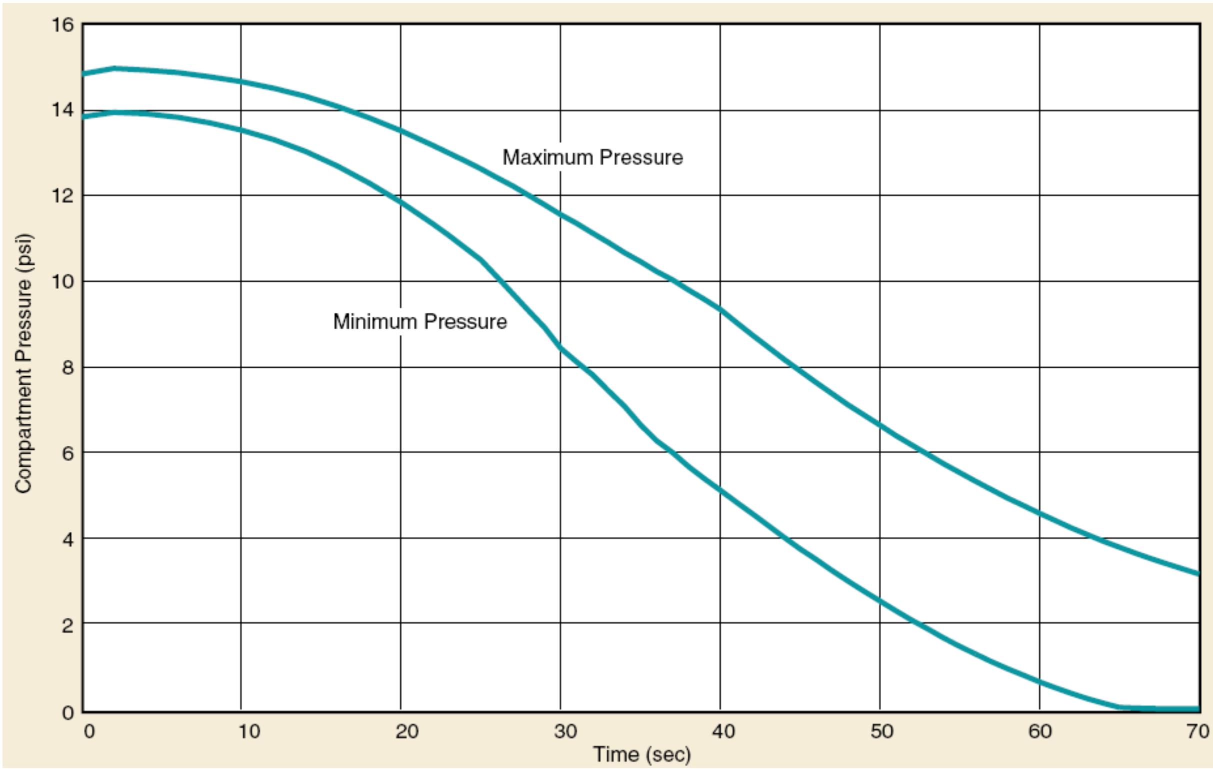

Figure 5-1. Atlas V EELV-Like Fairing Pressure

5.2 THERMAL COATINGS

TSS-3080 All thermal analysis shall use the following optical properties assumptions See Thermal Coatings Specifications in Table 5-3 below

Table 5-3. LRO Thermal Coatings

DESCRIPTION	COLD		HOT 14 mo. (5 yr.)		SPEC.	
	α_S	ε_H	α_S	ε_H	SOL	IR
Coatings						
Black Anodize Aluminum	0.7	0.82	0.86	0.78		
Clear Anodize	0.27	0.82	0.45	0.69		
Irridite Aluminum	0.10	0.19	0.57	0.06		
Z307 Conductive Black	0.95	0.89	0.97	0.85		
MSA94B Conductive Black	0.94	0.91	0.96	0.87		
Z306 Black Paint	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		
NS43G White Paint	0.26	0.90	0.32 (0.43)	0.86		
Vapor Deposited Aluminum	0.08	0.05	0.10	0.03	0.98	0.98
Vapor Deposited Gold	0.19	0.03	0.21	0.02		
BR127 Black Primer	0.96	0.85	N/A	0.81		
RM-400 Epoxy	0.33	0.87	0.4	0.83		
ITO/A276 (Back of Solar Array)	0.27	0.87	0.30 (0.35)	0.83		
A276 (Omni Antenna)	0.26	0.87	0.60 (0.60)	0.83		
Films & Tapes						
Kapton, 3-mil/VDA backing	0.45	0.80	0.51 (0.60)	0.76	0.75	
OSR/ITO Pilkington, 5-mil	0.08	0.80	0.15 (0.23)	0.78	1.0	---
ITO Kapton/VDA 3 mil	0.46	0.80	0.51 (0.62)	0.76	0.75	
Black Kapton, 3-mil	0.91	0.81	0.93	0.78		
Germanium Black Kapton	0.49	0.81	0.51	0.78		
Silver Teflon ITO 5 mil (note that this is fragile and will require frequent replacement)	0.09	0.78	0.28 (0.37)	0.73	1.0	
High Temperature E-Glass Blanket (Aluminum coated)	0.47	0.35	0.47	0.35		
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	0.73	0.88	0.69		
Fused Silica	<0.03	0.79	0.10	0.75		
Sapphire Lens	TBD	TBD	TBD	TBD		
Internal Fuel Line	1.0	0.15	1.0	0.15		
Machined Stainless Steel	0.39	0.18	0.47	0.14		
Hafnium	0.47	0.50	0.47	0.50		
Titanium Burnt	0.47	0.50	0.47	0.50		
Tiodized Titanium	0.74	0.23	0.86	0.73		

5.3 HOT AND COLD BIAS OF POWER

TSS-1485 Prior to the active measurement of operational power in a flight-like environment, the thermal design shall be able to handle a variation (due to uncertainty) in each mode power on constant power components.

TSS-3044 Powers to use in hot case and cold case shall be as follows: maximum power allocation in hot case, cold case minimum power dissipation current best estimate should be analyzed.

5.4 MISSION MODES

TSS-1487 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

TSS-1489 Prior to flight, 5°C is the minimum required margin for model predictions with respect to Flight Operational Limits, except for heater controlled elements that demonstrate a maximum 70% heater duty cycle.

5.6 THERMAL MODELING SCOPE

TSS-1491 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.

TSS-3045 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 Systems Lead.

5.7 THERMAL ANALYSIS DOCUMENTATION

TSS-1493 All thermal analysis reports shall clearly outline all assumptions or source of assumptions.

TSS-1778 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.

TSS-1779 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

TSS-1495 The components and orbiter shall be tested in the bounding thermal cases in thermal vacuum.
TSS-1780 The target temperatures shall be specified as a result of a test model analysis.
TSS-1781 All thermal hardware shall comply with the Lunar Reconnaissance Orbiter Mechanical Systems Specification (431-SPEC-000012).

6.1 COMPONENT THERMAL CYCLING REQUIREMENT

TSS-1497 All components must be thermally cycled in a thermal vacuum chamber rather than in an air filled chamber.
TSS-1782 All components shall be flight like blanketed and cycled 8 times with the thermal interface held at the qualification temperatures listed above at the thermal interface.
TSS-1783 Durations shall be as recommended in GEVS: components 4 hours, instruments 12 hours.
TSS-1784 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 Systems Lead.

6.2 MODEL DOCUMENTATION

TSS-1499 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

TSS-1501 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.
TSS-1785 Target temperatures shall achieve heat flows and effective sink temperatures that closely resemble the flight environment.
TSS-1786 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

TSS-1503 All final thermal qualification test plans shall be approved by the LRO Thermal Systems Lead.

TSS-1787 Target temperatures and overall test setup shall be discussed with the LRO Thermal Systems Lead.

6.5 THERMAL MODEL CORRELATION

TSS-1505 All models shall be correlated within 2°C of every telemetry point with the thermal test model.

TSS-1788 The thermal test model shall then be reintegrated into the flight model.

6.6 REDUCED MODEL

TSS-1507 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).

TSS-1789 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.

TSS-1790 These models shall utilize the latest known power levels and mechanical configuration.

TSS-1791 The models shall be correlated with any qualification testing.

TSS-1792 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

TSS-1509 All instruments shall be capable of operating within an ambient air temperature of 20±5°C without degrading instrument performance.

TSS-1793 No active cooling shall be provided during instrument operation with or without blanket covering.

TSS-1794 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

TSS-1511 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"/70" tilt in any one location from the horizontal plane.

6.9 LUNAR RECONNAISSANCE ORBITER COORDINATE SYSTEM

TSS-1513 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 thermal vacuum (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.

TSS-1795 Each responsible hardware manager shall anticipate, to the extent possible, such possibilities and provide test heaters in coordination with the LRO Thermal Systems Lead.

TSS-1796 Prior to component I&T the responsible hardware manage in coordination the LRO Thermal Systems Lead shall make a determination of whether test heaters will be required.

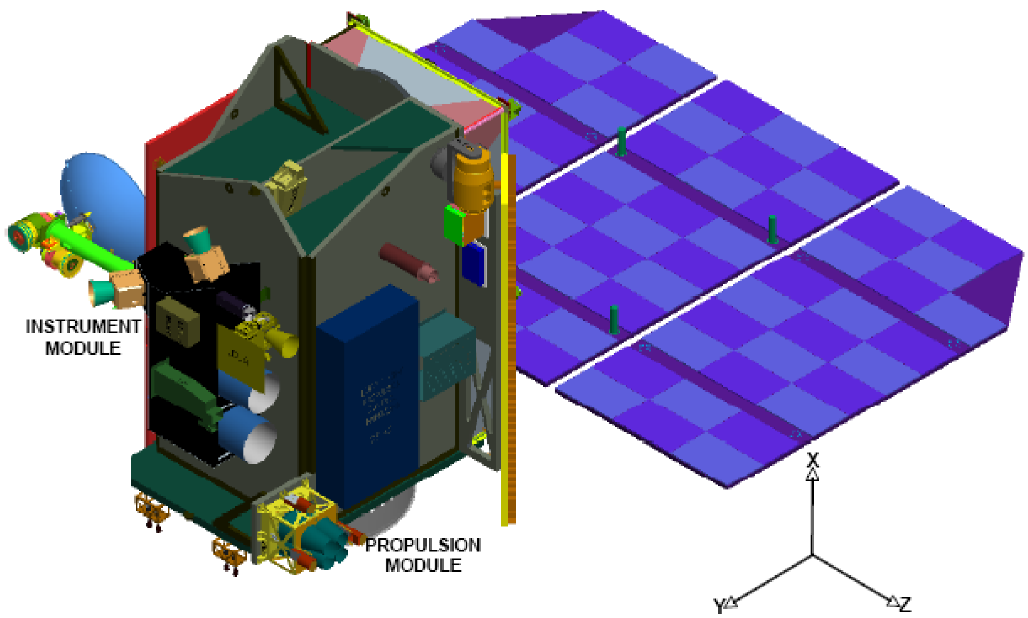

Figure 6-1. LRO Coordinate System Definition

TSS-1518 In such cases, the responsible hardware manager shall supply their own test heaters, cabling and means of control (TBR).

TSS-1797 Any such heaters shall be mounted on the component, not the SC.

TSS-1798 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

TSS-1521 Test sensors required to verify proper operation of the component during orbiter thermal vacuum testing shall be installed prior to delivery of the component.

TSS-1799 These sensors shall be identified on as-built drawings using orbiter approved test sensors.

TSS-1800 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 Systems 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	Diviner Instrument
ELV	Expendable Launch Vehicle
EPC	Electrical Power Conditioner
EVD	Engine Valve Driver
GEVS	General Environmental Verification Standards
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HKIO	House Keeping Input Output
Htrs	Heaters
I&T	Integration and Test
I/F	Interface
ICD	Interface Control Document
IR	Infared
IMU	Inertial Measurement Unit
Km	Kilometer
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LOLA	Lunar Orbiter Laser Altimeter
LROC	Lunar Reconnaissance Orbiter Camera
LRO	Lunar Reconnaissance Orbiter
LVPC	Low Voltage Power Converter
Max.	Maximum
Min.	Minimum
MLI	Multi-Layer Insulation
Mo.	Months
MTG	Mounting
N/A	Not Applicable
NAC	Narrow Angle Camera
NASA	National Aeronautics and Space Administration

NC	Normally Closed
OP	Operational
PDE	Propulsion and Deployable Electronics
PDR	Preliminary Design Review
PER	Pre-Environmental Review
PRT	Platinum Resistance Thermistor
PSE	Power Subsystem Electronics
Psi	Pounds per square inch
Pts	Points
Pwr	Power
RF	Radio Frequency
RGMM	Reduced Geometric Math Model
RTMM	Reduced Thermal Math Model
RWA	Reaction Wheel Assembly
S/A	Solar Array
SBC	Single Board Computer
SC	Spacecraft
SCS	Sequencing and Compressor System
Sec.	Seconds
SINDA	Systems Improved Numerical Differencing Analyzer
SOL	Solar
Spec.	Spectularity
SSR	Solid State Recorder
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Reviewed
TSS	Thermal Synthesizer System
TT&C	Telemetry Tracking and Control
TWTA	Traveling Wave Tube Amplifier
USB	Universal System Bus
VDA	Vapor Deposited Aluminum
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 Camera
XPDR	Transponder
V	Volt(s)