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Robotic Lunar Exploration Program

Lunar Reconnaissance Orbiter Project

Mission Requirements Document

July 22, 2005

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter (LRO) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LRO CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
MRD-39	Radiometric Tracking	LRO and its GDS shall achieve a radiometric Doppler measurement accuracy of less than 8 mm/sec, over a 10 s integration period, with a range accuracy measurement of no more than 15 m. (TBR)	M. Houghton/ GSFC	8/15/2005
MRD-40	High Accuracy Tracking	LRO shall support 10 cm, 1 sec average, tracking for a minimum average of 5 hours/day. (TBR)	M. Houghton/ GSFC	8/15/2005
MRD-52	Sun Avoidance	LRO shall avoid slewing instrument solar fields of regard through the sun at less than 0.1 deg/s. (TBR)	M. Houghton/ GSFC	8/15/2005
MRD-157	Clock Stability	The orbiter clock shall be sufficiently stable over the duration of a LOLA laser pulse time of flight. (TBR)	M. Houghton/ GSFC	8/15/2005

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1.0 INTRODUCTION

This document defines the Lunar Reconnaissance Orbiter Mission Level Requirements and flows down directly from the Level 1 National Aeronautics and Space Administration (NASA) Headquarters (HQ) requirements document (ESMD-RLEO-0010).

The LRO mission objective is to conduct investigations that will be specifically targeted to characterize future lunar landing sites and identify potential resources in support of the NASA's Exploration Initiative.

1.1 LUNAR RECONNAISSANCE ORBITER OVERVIEW

The LRO mission will be launched from the Kennedy Space Center (KSC) on a Delta II class Expendable Launch Vehicle (ELV) into a low altitude parking orbit and then injected into a lunar trajectory by the ELV's third stage. After a trans-lunar trajectory phase of approximately 100 hours the spacecraft (SC) will be inserted into lunar orbit using the on-board propulsion system. The primary mission will be conducted in a circular polar mapping orbit with an altitude of 30-50 kilometers (km) for one earth year. The 3-axis stabilized SC will fly a nadir-pointing attitude with off-nadir maneuvers if required by the observing instruments.

2.0 DOCUMENTS

2.1.1 Applicable Documents

430-PG-1410.2.1	Robotic Lunar Exploration Program Configuration Management Procedure
430-RQMT-000006	Robotic Lunar Exploration Program Mission Assurance Requirements Document
431-ANYS-000010	Radiation Analysis for the Lunar Reconnaissance Orbiter
431-OPS-000042	LRO Mission Concept of Operations
431-PLAN-000002	LRO Project Plan
431-PLAN-000005	LRO Systems Engineering Management Plan
431-PLAN-000100	LRO Integration and Test Plan
431-PLAN-000101	LRO Observatory Plan
431-PLAN-000110	LRO Contamination Control Plan
431-PLAN-000131	LRO Spacecraft Performance Assurance Implementation Plan
430-PROP-000001	Lunar Reconnaissance Orbiter Payload Proposal Information Package (PIP)
431-RQMT-000045	Radiation Requirements for the Lunar Reconnaissance Orbiter
431-RQMT-000092	Lunar Reconnaissance Thermal Math Model Requirements
431-SOW-000017	LRO Propulsion Subsystem Statement of Work and Specification
431-SPEC-000008	Electrical Systems Specification
431-SPEC-000012	LRO Mechanical Systems Specification
431-SPEC-000091	LRO Thermal Systems Specification
431-SPEC-000102	LRO 1553 Bus Specification
431-SPEC-000103	LRO SpaceWire Specification
431-SPEC-000112	LRO Technical Resource Allocation Specification
431-SPEC-000113	LRO Pointing and Alignment Specification
431-RQMT-000048	LRO Detailed Mission Requirements for LRO Ground System

2.1.2 Reference Documents

	Master Equipment List
CCSDS 727.0-B-2	CCSDS File Delivery Protocol (CFDP): Blue Book
CCSDS 701.0-B-3	Advanced Orbiting Systems, Networks and Data Links: Architectural Specifications
CCSDS 102.0-B-5	Packet Telemetry

ECSS-E-50-12-A	Space Engineering: SpaceWire – Links, Nodes, Routers and Networks
ESMD-RLEP-0010	LRO Requirements
GPR-7120.5A	System Engineering Goddard Procedural Requirements
GSFC-STD-1000	Rules for the Design, Development, Verification, and Operations of Flight System
GSFC-STD-7000	General Environmental Verification Standards (GEVS) for Flight Program and Projects
MDC 00H0016	Delta II Payload Planners Guide
MDC-**TBD**	LRO ELV Mission Specification
NPR 8000.4	Risk Classification NASA Procedural Requirements
NPD 2810.1	NPD – Security of Information Technology

2.2 DEFINITIONS

Throughout this document, the term Orbiter (or LRO Orbiter) will be defined as the LRO Spacecraft and LRO Payload.

Throughout this document, the term Spacecraft (or LRO Spacecraft) will be defined as the Spacecraft Bus, Solar Array System and High Gain Antenna System.

Throughout this document, the term Payload (or LRO Payload) will be used to describe the instrument suite consisting of CRaTER, Diviner, LAMP, LEND, LOLA, LROC and the technical demonstration payload of opportunity, Mini-RF.

Throughout this document, Spacecraft Bus (or LRO Spacecraft Bus) will be defined as the Propulsion module and Instrument Module.

Instrument - Suite of 6 instruments selected and technical demonstration payload of opportunity

Component: A component is a self-contained combination of items performing a function. Examples are electronic box, transmitter, gyro package, motor, and battery. For the purposes of this document, the term component is used generically to represent an analyzable or testable level of assembly below the observatory level.

Subsystem: A functional subdivision consisting of two or more components. Science instruments and experiments are considered subsystems.

System

Mission

Ground Segment

Space Segment

Launch Segment

3.0 MISSION REQUIREMENTS

In this document, a requirement is identified by “shall,” a good practice by “should”, permission by “may”, or “can”, expectation by “will”, and descriptive material by “is.”

PLACEHOLDER FOR REQUIREMENTS FLOW DIAGRAM

WITH SUPPORTING TEXT

3.1 MISSION DERIVED REQUIREMENTS

3.1.1 Mission Design

RQMT#	Title	Requirement	Rationale
MRD-1	Launch Mass	LRO's launch mass shall not exceed 1480 kg.	Upper end of Delta II performance, assuming 9.5 ft fairing, 5 kg yo-yo, and direct transfer.
MRD-2	Launch Vehicle	LRO shall be designed to fly on a Delta II 2925H, with a 9.5 ft fairing.	Tied to Launch Mass. If changed, Launch Mass must be reassessed.
MRD-3	Launch Trajectory	LRO shall utilize a direct lunar transfer trajectory.	Provides adequate performance while minimizing transfer time and complexity.
MRD-4	Launch Window	The LRO launch window shall be constrained such that its nominal spin vector at separation is within 15 deg of either the sun or anti-sun.	Protects against immediate sun exposure down the instrument boresights (assumes instruments are perpendicular to spin axis).
MRD-5	Propulsive Despin	LRO shall have the ability to despin autonomously, propulsively, from rates as high as 5 rpm, one axis, at LV separation.	Needed in case residual momentum exceeds momentum storage capability (LV yo-yo failure, for example). Must avoid flat spin to ensure sun avoidance on instruments.
MRD-6	Non-Propulsive Ops	LRO shall have the ability to handle body rates of at least 2 deg/s, per axis, without firing thrusters.	Gives reasonable chance of avoiding early (autonomous) thruster firings.
MRD-7	Deployables	LRO's deployables shall be capable of deploying with body rates as high as 2 deg/s, per axis.	Would like to deploy the array, for example, as soon as possible after LV separation.
MRD-8	Sun Pointing	The LRO design shall be capable of putting the observatory into a known orientation with respect to the sun without knowing its inertial position.	Provides for sun pointing without the need for a valid ephemeris or inertial sensors.
MRD-9	Inertial Pointing	The LRO design shall be capable of putting the observatory into a known orientation with respect to inertial space.	Needed, first, for course corrections, but also, later, for instrument calibrations, etc.
MRD-10	Propulsive Maneuvers	LRO shall have the ability to do course corrections, lunar orbit insertion, station-keeping, and momentum management using an onboard propulsion system.	Onboard propulsion is required to do any long term lunar mission.

RQMT#	Title	Requirement	Rationale
MRD-11	Low Maintenance Orbit	LRO shall make use of a low maintenance orbit for instrument commissioning.	Conserves fuel prior to nominal mission. Same orbit may be used for extended mission.
MRD-12	Mission Orbit	The primary mission shall be conducted in a circular mapping orbit with a nominal altitude of 50 +/- 20 km (altitude is measured to mean lunar surface).	Lowest practical altitude and tolerance given fuel considerations.
MRD-13	Orbit Inclination	The orbit inclination shall be 90 degrees +/- 1 degree.	Poles are of greatest interest, but lunar polar orbits wobble.
MRD-14	Nadir Pointing	The LRO design shall be capable of putting the observatory into a known orientation with respect to the lunar surface.	Will be used for normal operations, including "off-nadir" observations.
MRD-15	Solar Array Tracking	LRO shall be capable of pointing its solar array at the sun while maintaining a lunar referenced orientation.	Must be power positive during normal ops.
MRD-16	Antenna Tracking	LRO shall be capable of pointing its HGA to Earth ground stations while maintaining a lunar referenced orientation.	Must be able to simultaneously take and send data.
MRD-17	Momentum Management	LRO shall be capable of going at least 2 weeks (goal of 4) without a momentum management maneuver.	Plan to do all maneuvers within view of Earth. Goal is to minimize impact on science.
MRD-18	Yaw Maneuvers	Twice a year, LRO shall perform a 180 deg yaw maneuver, reversing its direction of flight.	Must be done to keep the sun on the correct (solar array) side of the spacecraft.
MRD-19	Lunar Eclipses	LRO shall be capable of withstanding a worst case lunar eclipse (160 min), twice a year, on average.	Lunar eclipses will occur throughout the mission. Some form of hibernation is acceptable.
MRD-20	Spacecraft Safing	LRO shall be designed to detect faults and autonomously move to progressively simpler control states, shed loads, etc., in response to status telemetry from SC subsystems.	Some form of fault detection/correction must be implemented to increase probability of mission success. Power, attitude, and ground comm. are critical.
MRD-21	Mission Duration	LRO shall be designed to have a minimum mission duration of 14 months.	Predicted 2 month commissioning phase plus minimum 12 month mapping mission.

RQMT#	Title	Requirement	Rationale
MRD-22	Extended Mission	LRO shall carry sufficient consumables to allow for a 4 year extended mission in a low maintenance orbit.	It may be desirable to use LRO as a communication relay for subsequent RLEP mission, or, alternatively, to continue primary observations beyond the baseline mission. Additional design augmentations may be made, on a case-by-case basis, to bolster the probability of having a successful extended mission.
MRD-23	End of Mission	LRO's mission will be terminated in a manner that meets NASA Planetary Protection Requirements as stated in NPD 8020.7F	LRO Mission is Category 1 based on NPR 8020.12C, section A.1.

3.1.2 Launch Vehicle

RQMT#	Title	Requirement	Rationale
MRD-24	Vehicle Performance	The launch vehicle must be capable of delivering a 1480 kg payload to a trajectory with a $C_3 > -1.85$	Provides boundary conditions for Flight Dynamics and Propulsion for Trans Lunar Injection (TLI). Bounds SC launch mass.
MRD-25	Insertion Accuracy	TLI accuracy at orbiter separation from the LV third stage shall be within +/- 3 m/sec (3-sigma) of target inertial velocity.	TLI injection errors will be corrected by spacecraft at MCC1. Above requirement is allocated in dV budget.
MRD-26	De-Spin	The LV shall despin LRO to a rate < 2 rpm.	Provides some chance of being able to avoid early (autonomous) thruster firings.
MRD-27	Tip Off rates	The LV induced tip-off rates shall be < 2 deg/sec (3σ), in the transverse axes, at separation.	Assume LV has de-spun Orbiter to approximately zero rate prior to separation. Low tip off rates required to assure tip off capture by wheels.
MRD-28	Vehicle Interfaces	LRO shall be compatible with all LV operations, interfaces, and environments as specified in Delta II Payload Planners Guide and the LRO ELV Mission Specification. In the event of a conflict the Mission Specification takes precedence.	Payload Planners Guide is the generic source of Delta II performance and interface data, the Mission Specification is the standard Boeing format ICD between the Orbiter and the ELV.

3.1.3 Accommodation

RQMT#	Title	Requirement	Rationale
MRD-29	Mass Allocations	Subsystems/instruments shall not exceed the mass allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).	Mass budget is managed in the LRO Technical Resource Allocations Spec.
MRD-30	Mechanical Interfaces	Subsystems/instruments shall comply with the LRO Mechanical System Specification (431-SPEC-000012).	All mechanical interfaces must be managed and coordinated to ensure mission success.
MRD-31	Power Allocations	Subsystems/instruments shall not exceed the power allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).	Power budget is managed in the LRO Technical Resource Allocations Spec.
MRD-32	Operating Voltage	Subsystems/instruments shall operate nominally at 21-35 VDC.	Power system will nominally output 22-35 VDC. This gives an appropriate cushion to allow for line losses.
MRD-33	Electrical Interfaces	Subsystems/instruments shall comply with the LRO Electrical System Specification (431-SPEC-000008).	All electrical interfaces must be managed and coordinated to ensure mission success. This includes grounding, magnetics, charging, etc.
MRD-34	Thermal Interfaces	Subsystems/instruments shall comply with the LRO Thermal System Specification (431-SPEC-000091).	All thermal interfaces must be managed and coordinated to ensure mission success.
MRD-35	Low-Rate Data	LRO shall utilize a MIL-STD-1553B network per 431-SPEC-000008 for telemetry and control < 300 kbps.	Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth
MRD-36	High-Rate Data	LRO shall use SpaceWire (ECSS-E-50-12A) per 431-SPEC-000103 for telemetry and control > 300 kbps.	Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth
MRD-155	Real-Time Data	LRO shall collect and send real-time, housekeeping data to the ground.	Real-time HK data is needed to monitor and control the observatory.
MRD-37	Data Storage	LRO shall have the ability to store at least 17.5 hours worth of data.	Based on the assumption that bulk data will be transmitted to 1 station.
MRD-38	Data Transfer	LRO and its Ground System shall be capable of transferring 24 hrs worth of data to the ground in 6.5 hours.	Based on the assumption that bulk data will be transmitted to 1 station.

RQMT#	Title	Requirement	Rationale
MRD-39	Radiometric Tracking	LRO and its GDS shall achieve a radiometric Doppler measurement accuracy of less than 8 mm/sec, over a 10 s integration period, with a range accuracy measurement of no more than 15 m. (**TBR**)	Sufficient to meet LRO's orbit determination requirements.
MRD-40	High Accuracy Tracking	LRO shall support 10 cm, 1 sec average, tracking for a minimum average of 5 hours/day. (**TBR**)	In order to support the Level 1 requirement for geodetic grid, some higher accuracy tracking is required.
MRE-41	Orbit Determinatio n	LRO shall have a minimum Orbit Determination Accuracy of 500/18m (Total Position RMS/Radial RMS), 1-sigma, post-processed.	Knowledge assuming LP100K gravity model and existing S-band RF tracking capabilities.
MRD-42	Time Knowledge	The Orbiter and ground system shall provide knowledge of the Orbiter time with respect to UTC to an accuracy of 3 ms.	Meets LOLA reconstruction requirement.
MRD-43	Time Maintenance	Orbiter time shall be maintained to within 100 ms of UTC at all times.	Allows instrument stored commands to go off within 100 ms of desired time.
MRD-157	Clock Stability	The orbiter clock shall be sufficiently stable over the duration of a LOLA laser pulse time of flight. (**TBR**)	To meet the range accuracy of each LOLA measurement.
MRD-44	–	Deleted	–
MRD-45	–	Deleted	–
MRD-46	–	Deleted	–
MRD-47	–	Deleted	–
MRD-48	–	Deleted	–
MRD-49	Pointing Allocations	Subsystems/instruments shall meet all pointing-related allocations given in the LRO Pointing and Alignment Specification (431-SPEC-000113).	All pointing and alignment budgets (including solar array and high gain antenna) are managed in the LRO Pointing and Alignment Spec.
MRD-50	Mission Phases	LRO and its mission elements shall be designed to support all mission phases defined in the LRO Mission Operations Concept Document (431-OPS-000042).	The operations concept is captured in the Mission Ops Concept Document and drives numerous design aspects.

RQMT#	Title	Requirement	Rationale
MRD-51	Continuous Operations	LRO and its Ground System shall be designed to support continuous operations during the primary mission, except for planned outages for momentum and orbit adjusts, and instrument calibrations.	Ensures the maximum data return.
MRD-156	Lights-Out Operations	LRO shall be capable of operating normally for at least 72 hrs between command loads.	Allows for unmanned operations over a 3-day weekend.
MRD-52	Sun Avoidance	LRO shall avoid slewing instrument solar fields of regard through the sun at less than 0.1 deg/s. (**TBR**)	Instrument solar fields of regard encompass instrument fields of view. Rate is driven by LOLA and LROC.
MRD-99	Power Negative Ops	All power negative operations shall be limited such that the battery depth of discharge does not exceed 30%.	Avoids battery degradation caused by repeated deep discharge.
MRD-100	Thermally Off-Nominal Ops	All off-nominal operations shall be limited such that component temps can be maintained within set limits.	Avoids damage caused by inadvertent heating or cooling of SC components. Thermal limits includes gradients.
MRD-53	Maneuver Notification	LRO shall safe the instruments, as required, prior to any off-nominal operations (including maneuvers).	In general, maneuvers will require off-nadir pointing. May be contamination concern.
MRD-54	Data Loss	LRO and its mission elements shall adhere to the Data Loss Allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).	Data loss budget is managed in the Technical Resource Allocations Spec.
MRD-55	Data Product Delivery	The mission shall deliver all data products specified in the LRO Level 1 requirements to the Planetary Data System for archiving and distribution.	The PDS is the final clearing house for all LRO measurement data.
MRD-56	Information Assurance	LRO and its ground system shall provide Information Assurance in compliance with NASA policies, specifically NPD 2810.	Provides direction designed to ensure that safeguards for the protection of the integrity, availability, and confidentiality of IT resources (e.g., data, information, applications, and systems) are integrated into and support the missions of NASA.

3.1.4 Mission Success

RQMT#	Title	Requirement	Rationale
MRD-57	Risk Classification	LRO shall meet the NPR8705.4 Appendix B requirements for Class C payloads with the exception of Test Program and EEE Parts requirements which shall meet the requirements for Class B payloads	The modified Class C classification is consistent with and appropriate for the cost/schedule constraints established when the mission was defined.
MRD-58	Mission Assurance	The LRO mission shall meet the S&MA requirements in the Robotic Lunar Exploration Program Mission Assurance Requirements (430-RQMT-000006).	Mission Assurance aspects are handled in the Mission Assurance Requirements Document.
MRD-59	Configuration Control	LRO configuration shall be controlled in accordance with the RLEP CM Procedure 430-PG-1410.2.1.	Configuration Management aspects are handled in the Configuration Management Plan.
MRD-60	Requirements Control	Derived subsystem requirements and specifications, to the component level, require the review & approval of the LRO Mission Systems Engineer or designate.	Ensures a cohesive set of requirements throughout the mission.
MRD-61	Margins/ Reserves	Technical margins and reserves shall be maintained per the LRO Systems Engineering Management Plan (431-PLAN-000005).	Management of margins and reserves is critical to mission success.
MRD-62	Coordinate Systems	All subsystems and instruments must reference the common coordinate system defined by the thrust direction (+X), the nadir viewing deck (+Z) and the right hand rule (+Y).	This will aid in clear, concise communication between subsystems and with instrument providers.
MRD-63	Units Policy	All LRO subsystems and Instruments shall adhere to the units policy given in LRO SEMP 431-PLAN-000005.	Addresses the need to plan for and prevent the misapplication of English and Metric units in all aspects of mission development & operations.
MRD-64	Verification Testing	LRO shall undergo verification testing in accordance with the LRO Verification Plan (431-PLAN-000101).	Per Mission Assurance Requirements Document.
MRD-65	Mechanical Environments	The orbiter shall function nominally within the mechanical environments of the mission as specified in LRO Mechanical Systems Specification (431-SPEC-000012).	Derived from Delta II enveloping case to include Atlas V considerations and covers all mission phases per Ops Concept Document.

RQMT#	Title	Requirement	Rationale
MRD-66	Electrical Environments	The orbiter shall function nominally within the electrical environments of the mission as specified in the LRO Electrical Systems Specification (431-SPEC-000008).	Covers electrical environments for all mission phases.
MRD-67	Thermal Environments	The orbiter shall function nominally within the thermal environments of the mission as specified in the LRO Thermal Systems Specification (431-SPEC-000091).	Provides temperature predicts for all components and environments for all mission phases.
MRD-68	Radiation Environments	All subsystems shall meet the requirements given in the LRO Radiation Requirements Document (431-RQMT-00045).	Provides details on the radiation environment and planned mitigation, including EEE parts selection.
MRD-69	Contaminatio n Control	Acceptable contamination levels shall be maintained on the Orbiter and its subsystems, at all times, per the LRO Contamination Control Plan (431-PLAN-000110).	Particulate & molecular contaminants can limit functional life of components (solar arrays, UV instruments, etc.).

3.2 INSTRUMENT REQUIREMENTS (LEVEL 2'S)

- REMOVED TO INSTRUMENT REQUIREMENTS DOCUMENTS -

3.3 SPACECRAFT REQUIREMENTS (LEVEL 2'S)

3.3.1 Mechanical

RQMT#	Title	Requirement	Rationale
MRD-70	Structural Stability	The LRO structure shall provide a stable mounting surface and alignment platform for all subsystem components and instruments that meets mission pointing requirements per the LRO Pointing and Alignment Specification (431-SPEC-000113).	The structure is an integral part of the overall pointing budget.
MRD-71	Fields of View	The LRO structure shall provide clear FOVs for all components/instruments as required by their MICDs.	Many components and all instruments require a FOV external to the SC.
MRD-72	Flexible Modes	The LRO structure shall be sufficiently stiff to avoid excitation by the attitude control system or any other moving parts on the spacecraft.	Care must be taken to ensure that structure's lowest frequency mode is outside the controller bandwidth (typically at least 1 decade above).
MRD-73	Accessibility	The LRO structure shall provide access to components/instruments, as needed, for GSE and test while integrated to the SC.	It will be necessary to test and calibrate several components at various stages of development.
MRD-74	Disturbance Torques	All mechanism torques (disturbances) shall be managed or limited so as to prevent interference with spacecraft pointing requirements.	Torque disturbances must be managed so that pointing requirements can be met.
MRD-75	Mass Properties	LRO mass properties (including CG migration) shall be managed in such a way so as to prevent interference with spacecraft control requirements.	Momentum build-up at the moon and weight shift due to fuel usage will have significant impacts on the LRO design.
MRD-76	Support Equipment	LRO mechanical ground support equipment shall be provided for I&T, hoisting, transportation, etc.	MGSE will be needed at various stages of LRO development, including launch site operations.
MRD-77	Mechanical Surrogates	LRO shall make use of mass simulators, baseplates, and wiring mock-ups (etc.), as appropriate.	This will help to ensure proper structural and interface compliance.

3.3.2 Thermal

RQMT#	Title	Requirement	Rationale
MRD-78	Operational Ranges	The LRO thermal control system shall maintain all component and structural interface temperatures to be within their appropriate limits during normal operations as specified in the Thermal Systems Specification (431-SPEC-000091).	Must maintain proper temperature ranges to ensure functionality of all components and instruments.
MRD-79	Survival Ranges	The LRO thermal control system shall maintain all component and structural interface temperatures to be within their survival limits during all phases of the mission as specified in the Thermal Systems Specification (431-SPEC-000091).	Must maintain proper temperature ranges to avoid damaging any component/instrument.
MRD-80	Minimum Bus Voltage	The LRO survival heaters shall be sized for a minimum bus voltage of 24V.	Prevents over sizing of heaters at maximum bus voltage
MRD-81	Monitoring	LRO shall monitor temperature sensors for all components and critical structural elements.	Must have knowledge of LRO temperatures to aid in post-processing and/or troubleshooting.
MRD-82	Ground Support	LRO thermal GSE shall be provided to support I&T, transportation, etc., as required by the ground flow.	TGSE will be needed at various stages of LRO development, including launch site operations.
MRD-83	Thermal Simulators	Thermal simulators shall be used in verifying performance of systems during orbiter level testing.	Orbiter level testing must be done in space-like environments to ensure mission success.

3.3.3 Guidance, Navigation, and Control

RQMT#	Title	Requirement	Rationale
MRD-84	Attitude Control System	The attitude control system shall maintain LRO's orientation, as well as that of its solar array and high gain antenna, throughout the mission.	LRO's orientation must be carefully controlled throughout the mission to maintain the integrity of all systems and to meet mission objectives.
MRD-85	ACS Hardware	The ACS sensors and actuators shall be controlled via the Low Speed Bus.	Utilizing simplest possible interfaces increases system reliability.
MRD-86	ACS Software	The ACS software shall be hosted on the LRO Single Board Computer.	Sharing the abundant resources of the SBC significantly reduces avionics costs/complexity.
MRD-87	Propulsion Control	The GN&C subsystem shall control and monitor the propulsion system.	The propulsion system is part of the GN&C subsystem.
MRD-88	Initial Stabilization	The GN&C subsystem shall autonomously stabilize the orbiter after separation from the LV.	Must avoid flat spin to ensure sun avoidance on instruments, etc.
MRD-89	Sun Pointing Latency	The ACS shall maneuver LRO from any orientation to a power positive one within 10 min of initialization.	This mode is nominally only entered when it is imperative that the sun be put on the solar array.
MRD-90	Sun Pointing Accuracy	When sun pointing, the ACS shall put the sun within 15 deg of the specified position.	This angle is sufficient to ensure that enough sun gets onto the solar array.
MRD-91	Default Mode	The ACS default mode shall put the sun within 15 deg of a specified position.	In the event of an anomaly, this is the safest orientation for the SC to be put into.
MRD-92	Thrust Pointing	The ACS shall hold pointing to within 5 deg of the desired orientation during thruster operations.	Pointing must be maintained to ensure that the resultant thrust is in the desired direction.
MRD-93	Delta-V Budget	The detailed Delta-V budget shall be documented in the LRO Technical Resource Allocations Specification (431-SPEC-000112).	Flight Dynamics determines the fuel requirements in terms of Delta-V.
MRD-94	Fuel Budget	The detailed propellant budget shall be documented in the LRO Technical Resource Allocations Specification (431-SPEC-000112).	The actual fuel budget factors in all subsequent effects (cosine losses, residual fuel, etc.).
MRD-95	Minimum Thrust	The propulsion system shall be capable of producing 140 N of thrust, in such a way that allows for lunar capture, with backup, as determined by Flight Dynamics.	Minimum thrust required for lunar capture. Without it, LRO can't brake at the moon.

RQMT#	Title	Requirement	Rationale
MRD-96	Thruster Locations	The LRO thrusters shall be configured such that they provide the necessary control authorities (thrust and torque) without impinging upon any SC structure or components.	Impingements can cause unwanted forces and torques, as well as heating issues.
MRD-97	Momentum Management	The GN&C subsystem shall be capable of adjusting momentum within 1 N-m-s of a desired set-point.	Momentum management is critical for lunar missions due to lack of magnetic field (i.e. continuous capability).

3.3.4 Power

RQMT#	Title	Requirement	Rationale
MRD-98	Power Distribution	The power system shall distribute primary power to the subsystems as required by their EICDs.	Power architecture shall be used to supply over-current protected power to all the loads.
MRD-101	Voltage Supply	The power system shall provide unregulated 22-35 VDC power at all the power supply outputs.	Subsystems/instruments shall operate nominally at 21-35 VDC. This gives an appropriate margin for line losses.
MRD-102	Launch & Early Ops	The battery shall be able to support the SC during launch operations and until a power positive condition has been achieved.	LRO will require a certain size battery (A-Hr). It must be enough to support all mission phases.
MRD-103	Nominal Operations	The power system shall be designed to support full mission load of 823 W (orbit average) after 14 months.	Provides sufficient margin beyond the allocated/predicted load demands.
MRD-104	Minimum Load	The power system shall carry a minimum load of 180 W whenever the solar array is illuminated.	Insures compliance with voltage specifications.
MRD-105	Peak Power	The power system shall be capable of supporting a 1500 W peak power load for up to 5 minutes.	The power system must be able to handle the peak power load.
MRD-106	Switched Power	Switched power services shall have re-settable over-current protection.	Power system protection.
MRD-107	Switched Cutoffs	The power system shall switch off any switched service that exceeds its max sustainable current, and keep it off until commanded otherwise.	To protect the power services.

3.3.5 Command and Data Handling System

RQMT#	Title	Requirement	Rationale
MRD-108	Processing Platform	The C&DH Single Board Computer shall provide an adequate processing platform for the execution of all Flight Software, including ACS Flight Software.	C&DH and GN&C flight software require significant processor resources.
MRD-109	Bus Controller	The C&DH Single Board Computer shall operate as the Bus Controller for the 1553 network.	Mechanism for redundant configurations to prevent two simultaneous BCs.
MRD-110	Data Protocols	The C&DH shall support CCSDS telecommand, telemetry, and CFDP.	Standard protocols used by flight and ground data and comm. systems.
MRD-111	Hardware Decoding	The C&DH shall support hardware decoding of critical commands	Method for recovery from anomalous conditions.
MRD-112	Telemetry Encoding	The C&DH shall support telemetry encoding.	The LRO communications scheme will likely utilize telemetry encoding.
MRD-113	Hardline Interface	The C&DH shall provide hardline interface(s) for use in ground testing, through spacecraft umbilical.	Needed throughout I&T and at the launch site.
MRD-114	Mission Time Counter	The C&DH shall provide a Mission Elapsed Time (MET) counter with a resolution of 1 sec, which cannot be adjusted, and is capable of operating for 5 years without rolling over.	MET shall always increment and never be adjusted to provide unambiguous time reference.
MRD-115	Pulse Per Second	The C&DH shall provide a 1Hz pulse as required by the instruments.	Mechanism for synchronizing operations, and time-tagging data.
MRD-116	Time Messages	The C&DH shall generate an Orbiter Time of Pulse message for each instrument as required.	Mechanism for synchronizing operations, and time-tagging data.
MRD-117	LAMP Interface	The C&DH shall support LAMP's heritage serial interfaces, as defined in LAMP's EICD.	Acceptance of existing interfaces simplified instrument development with little cost to SC.
MRD-118	Backup H/K Storage	The C&DH SBC shall be capable of storing 2 hours of H/K data.	Covers periods when the mass storage device is unavailable.
MRD-125	Comm. Relay Capability	The C&DH shall provide an interface for a potential comm. relay.	It may be desirable to operate LRO as a comm. relay in extended mission.

3.3.6 Communication

RQMT#	Title	Requirement	Rationale
MRD-119	Operational TT&C	LRO shall provide communication to support operational mission telemetry, tracking and command.	TLM / CMD is required to support LRO operations.
MRD-120	TLM/CMD Links	LRO Shall provide command and telemetry links to support TLM / CMD functions.	Bidirectional communication is required to support LRO's operations concept.
MRD-121	Radiometrics	LRO shall provide radiometric tracking capabilities.	The LRO Flight Dynamics Team requires range and range-rate measurement to determine LRO's orbit.
MRD-122	Command Link	LRO shall provide a 4 kbps forward communication link, operating in the Near-Earth S-Band, with a bit error rate of not greater than $1x10^{-5}$, and a design link margin of not less than 3 dB, to support vehicle commanding.	This is a sufficient command link required to support LRO operations.
MRD-123	Telemetry Downlink	LRO shall provide a 2.186 Mbps return communication downlink, operating in the Near-Earth S-Band, with a bit error rate of not greater than $1x10^{-9}$, and a design link margin of not less than 3 dB, to support vehicle operational telemetry.	This is a sufficient telemetry link required to support LRO operations.
MRD-124	High Rate Downlink	LRO shall provide a 100 Mbps return communication downlink, operating in the Near-Earth Ka-Band, with a bit error rate of not greater than $1x10^{-9}$, and a design link margin of not less than 3 dB, to support mission science offload.	This is a sufficient high rate link required to support LRO operations.
MRD-126	Concurrent Downlink	The LRO mission communication system shall support the simultaneous downlink of operational TT&C and high rate mission data.	LRO requires near-continuous TT&C while in view of the LRO ground system. LRO's CFDP high rate downlink protocol requires a command uplink to transmit file ACK/NAK indicators to the spacecraft.

3.3.7 Flight Software

RQMT#	Title	Requirement	Rationale
MRD-127	Software Initialization	The flight software shall initialize and support operations without the need of an upload from the ground.	Essential aspect of LRO operations.
MRD-128	Reprogram-mability	The flight software shall be reprogrammable during flight	Allow correction of SW errors or adding new SW features post-launch.
MRD-129	Processor Utilization	The flight software shall be bound by the processor margins found in table 3.07-1 of the GSFC Rules for Design, GSFC-STD-1000	Allow room to add software functions post-launch.
MRD-130	Software Organization	The flight software shall be organized such that functional units of code can be modified on orbit in modular form.	Ease of management of configuration settings.
MRD-131	Absolute Time Sequence	The flight software shall support the execution of stored command sequences that can be triggered at an absolute UTC time with 1 second resolution time tags.	Essential aspect of LRO operations.
MRD-132	Relative Time Sequence	The flight software shall support the execution of stored command sequences that can be triggered at a time relative to another event with 1 second resolution.	Essential aspect of LRO operations.
MRD-133	Telemetry Monitoring	The flight software shall support monitoring of any telemetry point and initiate stored command in response to pre-defined conditions.	Flexibility is necessary to support autonomous error recovery conditions that may not be known until after launch.
MRD-134	Diagnostic Tlm Support	To allow ground diagnosis of in-flight anomalies, the flight software shall accept ground commands to run on-board diagnostics and report the results in telemetry	Flexibility is necessary to support debugging conditions that may not be known until after launch.
MRD-135	File Management	The flight software shall provide commands to allow operators to manage the on-board file systems (directory listing, and file move/copy/delete).	Need the ability to clean up unused files before the file system fills up.

3.4 GROUND SYSTEM REQUIREMENTS (LEVEL 2'S)

3.4.1 General Ground System

RQMT#	Title	Requirement	Rationale
MRD-136	System Support	The ground system shall provide ground system capability for supporting all mission phases.	Support pre-launch testing and post-launch operations
MRD-137	Data Delivery	The ground system shall deliver measurement data to the instrument SOCs within 24-hours of ground receipt.	Deliver data in a timely manner for measurement data processing. Ensures ground can deliver data without backlog.
MRD-138	Critical Operations	The ground system shall provide essential capabilities to support all critical LRO operations.	Verify health and safety of orbiter. Ensure proper coverage for all critical operations
MRD-139	Testing & Verification	The ground system shall perform and support verification testing, operations testing, and mission rehearsal testing	Ground system and operations verification
MRD-140	Data Protocols	The ground system shall support CCSDS telecommand, telemetry, and CFDP.	Standard protocols used by flight and ground data and comm. systems.

3.4.2 Mission Ops Center

RQMT#	Title	Requirement	Rationale
MRD-141	Support Functions	The ground system shall provide a dedicated mission operations center that support the following functions: - Mission Planning - Telemetry and Command - Health and Safety - Trending - Data Storage - Data Distribution	Basic operational functions needed for LRO
MRD-142	Center Location	The dedicated MOC shall be located at GSFC.	Available infrastructure reduces development and test schedule
MRD-143	H/K Data Storage	The MOC shall store orbiter housekeeping data for the life of the mission	Needed for anomaly and trend investigations
MRD-144	Command Origination	All commands sent to the orbiter shall originate from the MOC	Security and eliminates the need for command priority

RQMT#	Title	Requirement	Rationale
MRD-145	SOC Interfaces	The MOC shall provide interfaces to the instrument SOCs for the following: - Housekeeping data - Measurement data - Mission Products used for planning and data processing - Instrument command sequence/requests	Required for higher level measurement products and basic mission operations

3.4.3 Flight Dynamics

RQMT#	Title	Requirement	Rationale
MRD-146	Mission Planning	The ground system shall provide trajectory, orbit and maneuver support during all mission phases.	Support planning and measurement processing
MRD-147	Orbit Determination	The ground system shall provide orbit determination support during all mission phases	Support planning and measurement processing
MRD-148	Attitude Determination	The ground system shall provide attitude determination support during all mission phases	Support planning and measurement processing
MRD-149	Mission Products	The ground system flight dynamics systems shall generate the required mission products for mission planning, calibration, and data processing functions	Support planning and measurement processing

3.4.4 Ground Network

RQMT#	Title	Requirement	Rationale
MRD-150	Ka-Band Services	The ground system shall provide Ka-Band ground services	Support current ConOps
MRD-151	S-Band Services	The ground system shall provide sufficient S-Band Tracking, Telemetry, and Command (TT&C) to support the mission	Support current ConOps
MRD-152	Telemetry & Command	The ground network shall support all telemetry and command modes throughout the mission phases	Support current ConOps

3.4.5 Data and Voice Networks

RQMT#	Title	Requirement	Rationale
MRD-153	Data Networks	The ground system shall provide all data networks to support the mission from pre-launch through mission disposal	Needed to support mission from pre-launch through mission disposal.
MRD-154	Voice Networks	The ground system shall provide all voice networks to support the mission from pre-launch through mission disposal	Needed to support mission from pre-launch through mission disposal.

4.0 QUALIFICATION ASSURANCE PROVISIONS

4.1 GENERAL

All requirements in this document shall be verified by one of the four methods defined below.

4.1.1 Analysis

The analysis method is used when:

- A rigorous, representative, and conclusive analysis is possible
- Test is not cost effective, and
- Inspection and demonstrations are not adequate

Analyses may include, but are not limited to, engineering analysis (which includes models and simulations), review of record, and similarity analysis.

4.1.1.1 Engineering Analysis

Engineering analysis may be quantitative, qualitative, or a combination of the two. Quantitative analysis involves the study and modeling of the physical entity whose performance is to be verified. Examples of quantitative analyses include end-to-end link analysis, structural (static and dynamic) analysis, thermal models, pointing knowledge and stability. Qualitative analyses are non-numerical and related to qualitative measure of performance, such as failure modes and effects analyses (FMEA), maintainability, and redundancy.

4.1.1.2 Validation of Records and Other Documentation Analysis

This kind of analysis uses design and manufacturing documentation to show compliance of design features and manufacturing processes. Validation of design documentation, e.g., engineering drawings, verifies that the “as-designed” hardware complies with contractual design and construction requirements. Validation of manufacturing records at end-item acceptance verifies that the “as-built” hardware has been fabricated per the approved design and associated documentation. Review and analysis of other documentation such as acceptance data packages and other compliance documentation of lower levels of assembly are valid analysis techniques.

4.1.1.3 Similarity Analysis

Similarity is included as a valid verification/qualification method. Qualification by similarity is used in lieu of test when it can be shown that an item is similar to, or identical in design to another item that has been previously qualified to equivalent, or more stringent requirements. Formal qualification documentation of the previously qualified item must be available for assessment when planning to qualify by similarity. Furthermore, an item whose design has been qualified by similarity must undergo acceptance verification to assess workmanship.

4.1.2 Demonstration

Demonstration is a verification method that provides a qualitative determination, rather than direct quantitative measurement, of the properties or functional characteristics of an end-item. The qualitative determination is made through observation with, or without test equipment or instrumentation.

4.1.3 Inspection

Inspection is the verification method used to verify construction features, workmanship, dimension, physical characteristics, and spacecraft conditions such as configuration, cleanliness, and locking hardware. Inspection also includes simple measurements such as length, and it is performed without the use of special laboratory or precision equipment. In general, requirements specifying function or performance are not verified by inspection.

4.1.4 Test

Verification by test consists of direct measurement of performance parameters relative to functional, electrical, mechanical, and environmental requirements. These measurements are obtained, during or after controlled application of functional and environmental stimuli to the test article, e.g., payload or satellite, and using instrumentation or special test equipment that is not an integral part of the test article being verified. The test activities include reduction and analysis of the test data, as appropriate. The following paragraphs define different categories of tests including performance, functional, environmental, interface, and structural tests.

4.1.4.1 Performance Test

A performance test consists of an individual test or series of electrical and/or mechanical tests conducted on flight, or flight-configured hardware and software at conditions equal to, or less than design specifications. Its purpose is to verify compliance of the test article with the stated applicable specification requirements that are verifiable by test. Typically, a full performance test is conducted at ambient conditions at the beginning and the end of a test sequence during which the test article is subjected to applicable environmental conditions, e.g., vacuum, high/low temperature extremes, or acoustics/random mechanical excitation.

4.1.4.2 Functional Tests

A functional test is a suitably chosen subset of a performance test. Typically, functional tests are conducted at ambient conditions between environmental exposures during the qualification or acceptance test sequence. The objective is to verify that prior to application of the next environment, exposure to the environment has not adversely affected the test article. When appropriate, functional tests, or a portion thereof, are conducted while the test article is exposed to a particular thermal or vacuum environment. Functional test, or a portion thereof, may also be conducted to assess the state of health of the hardware after major operations, such as transportation of flight hardware from one location to another.

4.1.4.3 Environmental Tests

Environmental testing is an individual test or series of tests conducted on flight, or flight-configured hardware to assure that flight hardware will perform satisfactorily after it is subjected to the induced launch environments, as well as its flight environment. Examples are: vibration, acoustic, temperature cycling, thermal vacuum and vacuum outgassing certification, and Electromagnetic Interference/Compatibility. Depending on the severity of the chosen environmental conditions, the purpose of the environmental exposure is to sufficiently stress the hardware so as to verify the adequacy of the design (protoflight levels and durations) or workmanship during fabrication (acceptance levels and durations).

4.1.4.4 Special Tests

Special tests are individual tests, or a series of tests conducted on flight, or flight-configured hardware to assure satisfactory performance of a particular critical element of the system, e.g., optical alignment. The special test verification category includes structural, mechanism and communication tests. Special tests may, or may not be performed in conjunction with environmental exposure.

4.1.4.5 Interface Tests

Interface tests verify the mechanical, electrical, and/or hardware-software interface between units and elements integrated into a higher level of assembly such as a module, subsystem, element, or a system.

4.1.4.6 Structural Tests

These tests are performed on structural elements, components, or assembled subsystems before delivery of the assembled structure to the integration and test organization. Structural tests designed to verify requirements of this specification may include: (1) static structural proof tests (to verify the strength/stiffness adequacy of the primary load path), and (2) dynamic tests, such as a modal survey or acoustic response test.

4.2 VERIFICATION MATRIX TABLE

The following matrix table defines the method of verification for all requirements contain in this document:

Table 4-1. Verification Matrix Table

Verification Method:		Level:
Inspection	(I)	II System
Analysis	(A)	III Segment
Demonstration	(D)	IV Element
Test	(T)	V Subsystem

Requirement Number	Section Number	Object Heading	I	A	D	T	Responsible Org.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
CCB	Configuration Control Board
CCR	Configuration Change Request
CG	Center of Gravity
CLA	Coupled Loads Analysis
CM	Configuration Management
CMO	Configuration Management Office
dB	decibel
DOF	Degree of Freedom
ELV	Expendable Launch Vehicle
FEM	Finite Element Model
FS	Factors of Safety
g	Acceleration due to Gravity at Earth's Surface (e.g. 9.81 m/s^2)
GEVS	General Environmental Verification Specification
GN&C	Guidance Navigation and Control
Grms	Root-mean-square Response in g's
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
Hz	Hertz
ID	Identification
km	kilometer
KSC	Kennedy Space Center
lbs	pounds
LRO	Lunar Reconnaissance Orbiter
μPa	Micropascal
MECO	Main Engine Cutoff
MGSE	Mechanical Ground Support Equipment
MS	Margin of Safety
MSC	MacNeal Schwendler Corporation
N/A	Not applicable
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis
NSI	Northrop Services Incorporated (now ManTech)
PAF	Payload Adapter Fitting
RP	Reference Publication
RQMT	Requirement
SC	Spacecraft
SPC	Single Point Constraint

Appendix B. Traceability Matrix

Parent Requirement			**Requirement**			**Child Requirement**		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**

NOTE: Each Requirement must have its own Object Heading.