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Lunar Reconnaissance Orbiter Project

Mission Requirements Document

November 2, 2006

LRO GSFC CMO

November 3, 2006

RELEASED

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

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CM FOREWORD

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Questions or comments concerning this document should be addressed to:

LRO Configuration Management Office
Mail Stop 451
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

11/2/05

Martin Houghton — Date
LRO Deputy Mission Systems Engineer
GSFC/NASA, Code 431

Reviewed by:

Igor Mitrofanov — Date
Principal Investigator, LEND
ISR, Moscow

Harlan Spence — Date
Principal Investigator, CRaTER
Boston University

David Smith — Date
Principal Investigator, LOLA
NASA/GSFC, Code 690

Mark Robinson — Date
Principal Investigator, LROC
Northwestern University

David Paige — Date
Principal Investigator, Diviner
UCLA

alan
~~Allen~~ Stern — Date
Principal Investigator, LAMP
SwRI

Approved by:

11/10/05

Gordon Chin — Date
LRO Project Scientist
GSFC/NASA, Code 431

11/13/2005

Craig Tooley — Date
LRO Project Manager
GSFC/NASA, Code 431

Signature Page

Prepared by:

Original signed by 11/2/2005
Martin Houghton Date
LRO Deputy Mission Systems Engineer
GSFC/NASA, Code 431

Reviewed by:

Mitrofanov 11/10/05
Igor Mitrofanov Date
Principal Investigator, LEND
ISR, Moscow

Harlan Spence Date
Principal Investigator, CRaTER
Boston University

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SwRI

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UCLA

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SwRI

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Gordon Chin Date
LRO Project Scientist
GSFC/NASA, Code 431

Craig Tooley Date
LRO Project Manager
GSFC/NASA, Code 431

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Prepared by:

Original signed by 11/2/2005
Martin Houghton Date
LRO Deputy Mission Systems Engineer
GSFC/NASA, Code 431

Reviewed by:

Igor Mitrofanov Principal Investigator, LEND ISR, Moscow	Date	Harlan Spence Principal Investigator, CRaTER Boston University	Date
David Smith Principal Investigator, LOLA NASA/GSFC, Code 690	Date	Mark Robinson Principal Investigator, LROC Northwestern University	Nov 7 2005 Date
David Paige Principal Investigator, Diviner UCLA	Date	Allen Stern Principal Investigator, LAMP SwRI	Date

Approved by:

Gordon Chin LRO Project Scientist GSFC/NASA, Code 431	Date	Craig Tooley LRO Project Manager GSFC/NASA, Code 431	Date

Signature Page

Prepared by:

Original signed by ____________ 11/2/2005
Martin Houghton Date
LRO Deputy Mission Systems Engineer
GSFC/NASA, Code 431

Reviewed by:

Igor Mitrofanov Principal Investigator, LEND ISR, Moscow	Date	Harlan Spence Principal Investigator, CRaTER Boston University	Date
David Smith Principal Investigator, LOLA NASA/GSFC, Code 690	Date	Mark Robinson Principal Investigator, LROC Northwestern University	Date
David Paige Principal Investigator, Diviner UCLA	11/8/05 Date	Allen Stern Principal Investigator, LAMP SwRI	Date

Approved by:

Gordon Chin LRO Project Scientist GSFC/NASA, Code 431	Date	Craig Tooley LRO Project Manager GSFC/NASA, Code 431	Date

Signature Page

Prepared by:

Original signed by 11/2/2005
Martin Houghton Date
LRO Deputy Mission Systems Engineer
GSFC/NASA, Code 431

Reviewed by:

Igor Mitrofanov Date
Principal Investigator, LEND
ISR, Moscow

Harlan Spence Date
Principal Investigator, CRaTER
Boston University

David Smith Date
Principal Investigator, LOLA
NASA/GSFC, Code 690

Mark Robinson Date
Principal Investigator, LROC
Northwestern University

David Paige Date
Principal Investigator, Diviner
UCLA

Alan Stern 11/07/05 Date
Principal Investigator, LAMP
SwRI

Approved by:

Gordon Chin Date
LRO Project Scientist
GSFC/NASA, Code 431

Craig Tooley Date
LRO Project Manager
GSFC/NASA, Code 431

LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

Rev Level	Description of Change	Approved By	Date Approved
Rev -	Released per 431-CCR-000011	C. Tooley	11/1/2005
Rev A	Released per 431-CCR-000115	C. Tooley	11/1/2005
Rev B	Released per 431-CCR-000186, 431-CCR-000187, 431-CCR-000253	C. Tooley	9/18/2006
Rev C	Released per 431-CCR-000295	C. Tooley	11/2/2006

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date

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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-RLEP-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 an Evolved Expendable Launch Vehicle (EELV) into a low altitude parking orbit and then injected into a lunar trajectory by the EELV's final 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 50 ± 20 kilometers (km) for one earth year. The 3-axis stabilized SC will fly a nadir-pointing attitude with off-nadir maneuvers as required by the observing instruments.

2.0 DOCUMENTS

The following documents apply only to the extent that they are cited within the body of this document.

2.1.1 Applicable Documents

431-OPS-000042 LRO Mission Concept of Operations
431-PLAN-000005 LRO Systems Engineering Management Plan
431-PLAN-000101 LRO Orbiter Verification Plan
431-PLAN-000110 LRO Contamination Control Plan
431-PLAN-000182 LRO Data Management Plan
431-PROC-000179 LRO Project Configuration Management Procedure
431-RQMT-000045 Radiation Requirements for the Lunar Reconnaissance Orbiter
431-RQMT-000174 LRO Project Mission Assurance Requirements Document
431-SPEC-000008 Electrical Systems Specification
431-SPEC-000012 LRO Mechanical Systems Specification
431-SPEC-000091 LRO Thermal Systems 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-000397 LRO Launch Vehicle System Requirements

2.1.2 Reference Documents

CCSDS 102.0-B-5 CCSDS Packet Telemetry Specification
CCSDS 701.0-B-3 Advanced Orbiting Systems, Networks and Data Links: Architectural Specifications
CCSDS 727.0-B-2 CCSDS File Delivery Protocol (CFDP): Blue Book
ECSS-E-50-12-A Space Engineering: SpaceWire - Links, Nodes, Routers and Networks
ESMD-RLEP-0010 Lunar Reconnaissance Orbiter (LRO) Requirements
GSFC-STD-1000 Rules for the Design, Development, Verification, and Operations of Flight System
NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft
NPG 8010.12C Planetary Protection Provisions for Robotic Extraterrestrial Missions
NPR 8705.4 Risk Classification for NASA Payloads
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, the Avionics Module, and the Instrument Module.
Payload - 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 orbiter level.

Subsystem: A functional subdivision consisting of two or more components. Science instruments and experiments are considered subsystems.
Segment: The major pieces of the LRO System are called segments. There is the ground segment, the flight segment, and the launch segment.
System: The system is the entire set of hardware and software required to execute the LRO mission.
Ground Segment: The ground segment is all of the hardware and software in the LRO system that remains on the ground. It includes the Mission Operations Center, the Science Operations Centers, the Flight Dynamics Facility, and the ground stations.
Space Segment: The LRO Orbiter, including the instruments, is the space segment.
Launch Segment: The vehicle which puts the LRO Orbiter into space, plus all of the associated infrastructure on the ground (such as the launch pad) is the 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."

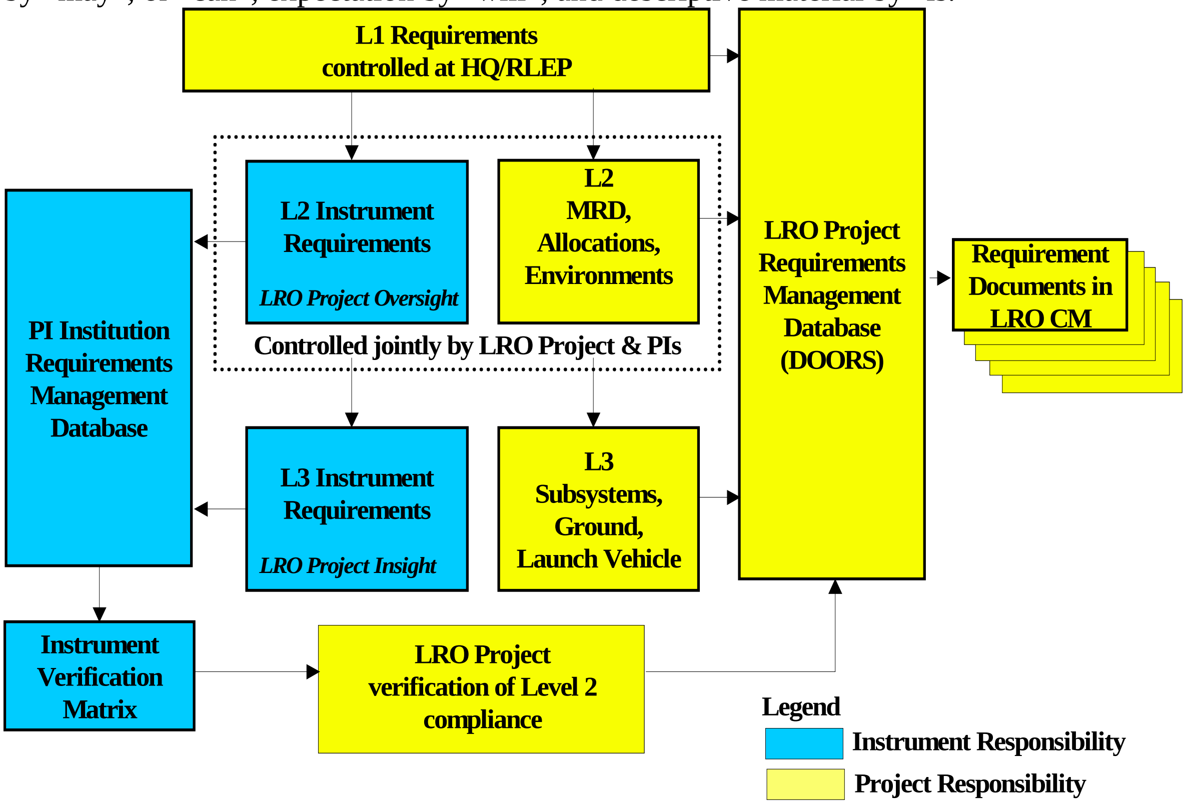

Figure 3-1. Requirements Flow

The above figure shows the requirement flow for LRO. The NASA Headquarters-controlled Level 1 requirements flow to Level 2 instrument requirements and Level 2 project requirements. The Level 2 requirements are signed by both the LRO project and the Principal Investigators (PI). The PI institutions manage the instrument requirements. The project manages this document (the Mission Requirements Document (MRD)); the allocations contained in the LRO Pointing and Alignment Specification (431-SPEC-000113) and the LRO Technical Resource Allocations (431-SPEC-000112); and the environment requirements contained in the Mechanical Systems Specification (431-SPEC-000012), the Electrical Systems Specification (431-SPEC-000008), the Thermal Systems Specification (431-SPEC-000091), and the Radiation Requirements Document (431-RQMT-000045).

The project manages its requirements in the DOORS database, with final verification of Levels 1-3 tracked in the database. The instrument teams provide their Level 2 compliance information, which the LRO project approves, then documents the verification of Level 1 requirements.

3.1 MISSION DERIVED REQUIREMENTS

3.1.1 Mission Design

3.1.1.1 Launch Mass

MRD-1 LRO's launch mass shall not exceed 1944 kg.

Rationale: Maximum mass supported by 2 TDRSS tanks at 98.5% fill fraction with max temp of 40C performing 1258 m/s of delta V.

3.1.1.2 Launch Vehicle

MRD-2 LRO shall be designed to fly on an EELV.

Rationale: Direction from HQ in November 2005.

3.1.1.3 Launch Trajectory

MRD-3 LRO shall utilize a direct lunar transfer trajectory.

Rationale: Provides adequate performance while minimizing transfer time and complexity.

3.1.1.4 Launch Window

MRD-4 The LRO launch window shall be constrained such that the resulting lunar orbit has a sun beta-angle of less than 20 deg at the lunar solstice.

Rationale: Maximizes seasonal data return over the lunar polar regions, aiding in the identification of permanently shadowed and permanently lit regions.

3.1.1.5 Propulsive Despin

MRD-5 LRO shall have the ability to despin from rates as high as 5 rpm in any axis.

Rationale: Contingency for extreme tip-off or other anomaly. Needed in case residual momentum exceeds momentum storage capability.

3.1.1.6 Non-Propulsive Ops

MRD-6 LRO shall have the ability to handle body rates of at least 2 deg/s, per axis, without firing thrusters.

Rationale: Eliminates the need for autonomous thruster firings.

3.1.1.7 Deployables

MRD-7 LRO's deployables shall be capable of deploying with body rates as high as 2 deg/s, per axis.

Rationale: Provides flexibility to deploy array autonomously.

3.1.1.8 Sun Pointing

MRD-8 The LRO design shall be capable of putting the orbiter into a known orientation with respect to the sun without knowing its inertial position.

Rationale: Provides for sun pointing without the need for a valid ephemeris or inertial sensors.

3.1.1.9 Inertial Pointing

MRD-9 The LRO design shall be capable of putting the orbiter into a known orientation with respect to inertial space.

Rationale: Needed, first, for course corrections, but also, later, for instrument calibrations, etc.

3.1.1.10 Propulsive Maneuvers

MRD-10 LRO shall have the ability to do course corrections, lunar orbit insertion, station-keeping, and momentum management using an onboard propulsion system.

Rationale: Onboard propulsion is required to do any long term lunar mission.

3.1.1.11 Low Maintenance Orbit

MRD-11 LRO shall make use of a low maintenance orbit for instrument commissioning.

Rationale: Conserves fuel prior to nominal mission. Same orbit may be used for extended mission.

3.1.1.12 Mission Orbit

MRD-12 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).

Rationale: Lowest practical altitude and tolerance given fuel considerations.

3.1.1.13 Orbit Inclination

MRD-13 The orbit inclination shall be 90 degrees +/- 1 degree.

Rationale: Poles are of greatest interest, but lunar polar orbits wobble.

3.1.1.14 Nadir Pointing

MRD-14 The LRO design shall be capable of putting the orbiter into a known orientation with respect to the lunar surface.

Rationale: Will be used for normal operations, including "off-nadir" observations.

3.1.1.15 Solar Array Tracking

MRD-15 LRO shall be capable of pointing its solar array at the sun while maintaining a lunar referenced orientation.

Rationale: Must be power positive during normal ops.

3.1.1.16 Antenna Tracking

MRD-16 LRO shall be capable of pointing its HGA to Earth ground stations while maintaining a lunar referenced orientation.

Rationale: Must be able to simultaneously take and send data.

3.1.1.17 Momentum Management

MRD-17 LRO shall be capable of going at least 2 weeks (goal of 4) without a momentum management maneuver.

Rationale: Plan to do all maneuvers within view of Earth. Goal is to minimize impact on science.

3.1.1.18 Yaw Maneuvers

MRD-18 Twice a year, LRO shall perform a 180 deg yaw maneuver, reversing its direction of flight.

Rationale: Must be done to keep the sun on the correct (solar array) side of the spacecraft.

3.1.1.19 Lunar Eclipses

MRD-19 LRO shall be capable of withstanding a worst case lunar eclipse (160 min), twice a year, on average.

Rationale: Lunar eclipses will occur throughout the mission. Some form of hibernation is acceptable.

3.1.1.20 Spacecraft Safing

MRD-20 LRO shall detect faults and autonomously transition to progressively safer configurations in response to status telemetry from SC subsystems.

Rationale: Some form of fault detection/correction must be implemented to increase probability of mission success. Power, attitude, and ground comm. are critical.

3.1.1.21 Recoverable Failures

MRD-158 In the event of any recoverable system failure, LRO shall not go uncontrolled for more than 60 seconds.

Rationale: Control must be regained before spacecraft attitude deviates too severely from nominal in order to protect instruments and subsystems. LOLA can handle sweeping the sun at rates higher than 1 degree per second. At 1 degree per second, it will take 60 seconds to enter the 30 degree cone of concern for LOLA if the sun is 90 degrees from the z-axis.

3.1.1.22 Mission Duration

MRD-21 LRO shall be designed to have a minimum mission duration of 14 months.

Rationale: Predicted 2 month commissioning phase plus minimum 12 month mapping mission.

3.1.1.23 Extended Mission

MRD-22 LRO shall carry sufficient consumables to allow for a 3 year extended mission in a low maintenance orbit.

Rationale: Design augmentations will be made on a case-by-case basis to bolster the probability of meeting a 3 year extended mission goal.

3.1.1.24 End of Mission

MRD-23 LRO's mission shall be terminated in a manner that meets NASA's Planetary Protection Policy, as described in NPD 8020.7F and NPG8020.12C for a class I mission.

Rationale: NASA Policy

3.1.2 <u>Launch Vehicle</u>

3.1.2.1 Vehicle Performance

MRD-24 The launch vehicle shall be capable of delivering a 2000 kg payload to a trajectory with a C3 > -1.85.

Rationale: Provides boundary conditions for Flight Dynamics and Propulsion for Trans Lunar Injection (TLI). For delta V of less than 1328 m/s, the launch mass is greater than 1845 kg. 2000 kg was based on eliminating the 125 m/s extended mission delta V.

3.1.2.2 Insertion Accuracy

MRD-25 TLI accuracy at orbiter separation from the LV shall be within +/- 3 m/sec (3-sigma) of target inertial velocity.

Rationale: TLI injection errors will be corrected by spacecraft at MCC1. Above requirement is allocated in dV budget.

3.1.2.3 --

MRD-26 Deleted.

Rationale: -

3.1.2.4 Tip Off rates

MRD-27 The LV induced tip-off rates shall be < 2 deg/sec in the transverse axes and < 1 deg/sec about the thrust axis at separation.

Rationale: Low tip off rates required to assure tip off capture by wheels.

3.1.2.5 Vehicle Interfaces

MRD-28 LRO shall be compatible with all LV operations, interfaces, and environments as specified in the LRO Launch Vehicle System Requirements (431-RQMT-000397) and in the Launch Vehicle ICD (TBD). In the event of a conflict, the Launch Vehicle ICD, then the LRO Launch Vehicle System Requirements take precedence over this document.

Rationale: The LRO Launch Vehicle System Requirements define the interface requirements for launch vehicle procurement. The Launch Vehicle ICD will carry more details after a vehicle is selected.

3.1.3 <u>Accommodation</u>

3.1.3.1 Mass Allocations

MRD-29 Subsystems/instruments shall not exceed the mass allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).

Rationale: Mass budget is managed in the LRO Technical Resource Allocations Spec.

3.1.3.2 Mechanical Interfaces

MRD-30 Subsystems/instruments shall comply with the LRO Mechanical System Specification (431-SPEC-000012).

Rationale: All mechanical interfaces must be managed and coordinated to ensure mission success.

3.1.3.3 Power Allocations

MRD-31 Subsystems/instruments shall not exceed the power allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).

Rationale: Power budget is managed in the LRO Technical Resource Allocations Spec.

3.1.3.4 Operating Voltage

MRD-32 Subsystems/instruments shall operate nominally at 21-35 VDC.

Rationale: Power system will nominally output 22-35 VDC. This gives an appropriate cushion to allow for line losses.

3.1.3.5 Electrical Interfaces

MRD-33 Subsystems/instruments shall comply with the LRO Electrical System Specification (431-SPEC-000008).

Rationale: All electrical interfaces must be managed and coordinated to ensure mission success. This includes grounding, magnetics, charging, etc.

3.1.3.6 Thermal Interfaces

MRD-34 Subsystems/instruments shall comply with the LRO Thermal System Specification (431-SPEC-000091).

Rationale: All thermal interfaces must be managed and coordinated to ensure mission success.

3.1.3.7 Low-Rate Data

MRD-35 LRO shall utilize a MIL-STD-1553B network per 431-SPEC-000008 for telemetry and control < 300 kbps.

Rationale: Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth

3.1.3.8 High-Rate Data

MRD-36 LRO shall use SpaceWire (ECSS-E-50-12A) per 431-SPEC-000103 for telemetry and control > 300 kbps.

Rationale: Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth

3.1.3.9 Real-Time Data

MRD-155 LRO shall collect and send real-time, housekeeping data to the ground.

Rationale: Real-time HK data is needed to monitor and control the orbiter.

3.1.3.10 Data Storage

MRD-37 LRO shall have the ability to store at least 17.5 hours worth of data.

Rationale: Based on the assumption that bulk data will be transmitted to 1 station.

3.1.3.11 Data Transfer

MRD-38 LRO and its Ground System shall be capable of transferring 24 hrs worth of data to the ground in 6.5 hours.

Rationale: Based on the assumption that bulk data will be transmitted to 1 station.

3.1.3.12 Basic Doppler

MRD-39 LRO and its GDS shall achieve a radiometric Doppler measurement accuracy of better than 4 mm/sec, 1 sigma, over a 5 s integration period, from all LRO ground stations.

Rationale: Sufficient to meet LRO's orbit determination requirements.

3.1.3.13 Improved Doppler

MRD-159 LRO and its GDS shall achieve a radiometric Doppler measurement accuracy of better than 1 mm/sec, 1 sigma, over a 5 s integration period, from at least one LRO ground station.

Rationale: Needed in order for LRO’s data products to be fully registered.

3.1.3.14 Ranging

MRD-160 LRO and its GDS shall achieve a radiometric range measurement accuracy of better than 15 m, 1 sigma, over a 40 s integration period, from all LRO ground stations.

Rationale: Sufficient to meet LRO's orbit determination requirements.

3.1.3.15 High Accuracy Ranging

MRD-40 LRO shall provide relative range measurements between the Earth and the LRO spacecraft when the spacecraft is in view of the Laser Ranging Earth station, at better than 10cm precision, 1 sigma, in a 1 second integration period.

Rationale: In order to support the Level 1 requirement for geodetic grid, some higher accuracy tracking is required.

3.1.3.16 Orbit Determination

MRD-41 LRO shall have an Orbit Determination Accuracy of better than 500/18m (Total Position RMS/Radial RMS), 1-sigma, post-processed.

Rationale: Knowledge assuming LP100K gravity model and existing S-band RF tracking capabilities.

3.1.3.17 Gravity Model Update

MRD-168 LRO shall produce, within 6 months of the start of science operations, a gravity model with sufficient accuracy to calculate knowledge of spacecraft position to within 50 m along track, 50 m cross track, and 1 m radial, all numbers 1 sigma.

Rationale: 6 months provides an opportunity to use the improved gravity model to more accurately target LROC image taking later in the mission, when it will be necessary to fill in missed gaps. This is the accuracy required of laser ranging to meet LOLA's science objectives.

3.1.3.18 Time Knowledge

MRD-42 The Orbiter and ground system shall provide knowledge of the Orbiter time with respect to UTC to an accuracy of 3 ms.

Rationale: Meets LOLA reconstruction requirement.

3.1.3.19 Time Maintenance

MRD-43 Orbiter time shall be maintained to within 100 ms of UTC at all times.

Rationale: Allows instrument stored commands to go off within 100 ms of desired time.

3.1.3.20 Clock Stability

MRD-157 The orbiter clock shall be stable to <2e-12 over a one hour period.

Rationale: To meet the range accuracy from Earth over the visible portion of an orbit using the laser ranging system.

3.1.3.21 Time Epoch

MRD-162 LRO and its ground system shall use a time epoch of Jan 1, 2001 00:00:00 UTC.

Rationale: This epoch is used by several recent missions. 2001 is better than 2000, since 2000 was a leap year.

3.1.3.22 –

MRD-44 Deleted

Rationale: -

3.1.3.23 –

MRD-45 Deleted

Rationale: -

3.1.3.24 –

MRD-46 Deleted

Rationale: -

3.1.3.25 –

MRD-47 Deleted

Rationale: -

3.1.3.26 –
MRD-48 Deleted
Rationale: -

3.1.3.27 Pointing Allocations
MRD-49 Subsystems/instruments shall meet all pointing-related allocations given in the LRO Pointing and Alignment Specification (431-SPEC-000113).
Rationale: All pointing and alignment budgets (including solar array and high gain antenna) are managed in the LRO Pointing and Alignment Spec.

3.1.3.28 Mission Phases
MRD-50 LRO and its mission elements shall be designed to support all mission phases defined in the LRO Mission Design Handbook (431-HDBK-000486).
Rationale: The top-level operations concept is captured in the Mission Design Handbook and drives numerous design aspects.

3.1.3.29 Continuous Operations
MRD-51 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.
Rationale: Ensures the maximum data return.

3.1.3.30 Lights-Out Operations
MRD-156 LRO shall be capable of operating normally for at least 72 hrs between stored command loads.
Rationale: Allows for unmanned operations over a 3-day weekend.

3.1.3.31 Sun Avoidance
MRD-52 LRO shall never intentionally allow the Sun to enter, move through, or remain in the instrument solar fields of regard.
Rationale: Minimum rate is set by LOLA and LROC, but better to simply try to avoid the zones all together.

3.1.3.32 Sun Avoidance During Launch
MRD-161 The launch vehicle shall not allow the Sun to enter, move through, or remain in the instrument solar fields of regard.
Rationale: LOLA and LROC could potentially be damaged by sun near their boresights.

3.1.3.33 Power Negative Ops
MRD-99 All power negative operations shall be limited such that the battery depth of discharge does not exceed 30%.
Rationale: Avoids battery degradation caused by repeated deep discharge.

3.1.3.34 Thermally Off-Nominal Ops

MRD-100 All off-nominal operations shall be limited such that component temps can be maintained within set limits.

Rationale: Avoids damage caused by inadvertent heating or cooling of SC components. Thermal limits includes gradients.

3.1.3.35 Maneuver Notification

MRD-53 LRO shall safe the instruments, as required, prior to any off-nominal operations (including maneuvers).

Rationale: In general, maneuvers will require off-nadir pointing. May be contamination concern.

3.1.3.36 Data Loss

MRD-54 LRO and its mission elements shall adhere to the Data Loss Allocations given in the LRO Technical Resource Allocations Specification (431-SPEC-000112).

Rationale: Data loss budget is managed in the Technical Resource Allocations Spec.

3.1.3.37 Collection Efficiency

MRD-165 LRO shall collect science data during 95% of its 12 month primary science mission. Science data collection includes off-nadir science data collection as described in MRD-167.

Rationale: Reasonable collection efficiency, given allocation for yaw turns, orbit maneuvers, calibrations, and time in sun safe mode.

3.1.3.38 Data Delivery Efficiency

MRD-166 LRO and its ground system shall deliver 98% of the collected science data.

Rationale: Reasonable delivery efficiency, given the large recorder size and a single ground station.

3.1.3.39 Off-Nadir Data Collection

MRD-167 LRO shall accommodate off-nadir science data collection up to +/- 20 degrees cross-track up to 3 times per day for no more than 20 minutes each.

Rationale: Agreement among LROC and the rest of the science team for LROC to acquire targets of opportunity.

3.1.3.40 Data Product Delivery

MRD-55 The mission shall deliver all data products specified in the LRO Level 1 requirements to the Planetary Data System for archiving and distribution per the LRO Data Management Plan (431-PLAN-000182).

Rationale: The PDS is the final archive for all LRO measurement data.

3.1.3.41 Information Assurance

MRD-56 LRO and its ground system shall provide Information Assurance in compliance with NASA policies, specifically NPD 2810.

Rationale: 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

3.1.4.1 Risk Classification

MRD-57 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

Rationale: The modified Class C classification is consistent with and appropriate for the cost/schedule constraints established when the mission was defined.

3.1.4.2 Mission Assurance

MRD-58 The LRO mission shall meet the S&MA requirements in the LRO Mission Assurance Requirements (431-RQMT-000174).

Rationale: Mission Assurance aspects are handled in the Mission Assurance Requirements Document.

3.1.4.3 Configuration Control

MRD-59 LRO configuration shall be controlled in accordance with the LRO Project Configuration Management Procedure (431-PROC-000179).

Rationale: Configuration Management aspects are handled in the Configuration Management Plan.

3.1.4.4 Requirements Control

MRD-60 Top level instrument requirements and derived spacecraft subsystem requirements (to the component level) require the review and approval of the LRO Mission Systems Engineer or designate.

Rationale: Ensures a cohesive set of requirements throughout the mission.

3.1.4.5 Margins/ Reserves

MRD-61 Technical margins and reserves shall be maintained per the LRO Systems Engineering Management Plan (431-PLAN-000005).

Rationale: Management of margins and reserves is critical to mission success.

3.1.4.6 Coordinate Systems

MRD-62 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).

Rationale: This will aid in clear, concise communication between subsystems and with instrument providers.

3.1.4.7 Units Policy

MRD-63 All LRO subsystems and Instruments shall adhere to the units policy given in LRO SEMP 431-PLAN-000005.

Rationale: Addresses the need to plan for and prevent the misapplication of English and Metric units in all aspects of mission development & operations.

3.1.4.8 Verification Testing

MRD-64 LRO shall undergo verification testing in accordance with the LRO Mission Verification Plan (431-PLAN-000003).

Rationale: Per Mission Assurance Requirements Document.

3.1.4.9 Mechanical Environments

MRD-65 The orbiter shall function nominally within the mechanical environments of the mission as specified in LRO Mechanical Systems Specification (431-SPEC-000012).

Rationale: Covers all mission phases per Ops Concept Document.

3.1.4.10 Electrical Environments

MRD-66 The orbiter shall function nominally within the electrical environments of the mission as specified in the LRO Electrical Systems Specification (431-SPEC-000008).

Rationale: Covers electrical environments for all mission phases.

3.1.4.11 Thermal Environments

MRD-67 The orbiter shall function nominally within the thermal environments of the mission as specified in the LRO Thermal Systems Specification (431-SPEC-000091).

Rationale: Provides temperature predicts for all components and environments for all mission phases.

3.1.4.12 Radiation Environments

MRD-68 All subsystems shall meet the requirements given in the LRO Radiation Requirements Document (431-RQMT-00045).

Rationale: Provides details on the radiation environment and planned mitigation, including EEE parts selection.

3.1.4.13 Contamination Control

MRD-69 Acceptable contamination levels shall be maintained on the Orbiter and its subsystems, at all times, per the LRO Contamination Control Plan (431-PLAN-000110).

Rationale: 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 <u>Mechanical</u>

3.3.1.1 Structural Stability

MRD-70 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).

Rationale: The structure is an integral part of the overall pointing budget.

3.3.1.2 Fields of View

MRD-71 The LRO structure shall provide clear FOVs for all components/instruments as required by their MICDs.

Rationale: Many components and all instruments require a FOV external to the SC.

3.3.1.3 Flexible Modes

MRD-72 The LRO structure shall be sufficiently stiff to avoid excitation by the attitude control system or any other moving parts on the spacecraft.

Rationale: Care must be taken to ensure that structure's lowest frequency mode is outside the controller bandwidth (typically at least 1 decade above).

3.3.1.4 Accessibility

MRD-73 The LRO structure shall provide access to components/instruments, as needed, for GSE and test while integrated to the SC.

Rationale: It will be necessary to test and calibrate several components at various stages of development.

3.3.1.5 Disturbance Torques

MRD-74 All mechanism torques (disturbances) shall be managed or limited so as to prevent interference with spacecraft pointing requirements.

Rationale: Torque disturbances must be managed so that pointing requirements can be met.

3.3.1.6 Mass Properties

MRD-75 LRO mass properties (including CG migration) shall be managed in such a way so as to prevent interference with spacecraft control requirements.

Rationale: Momentum build-up at the moon and weight shift due to fuel usage will have significant impacts on the LRO design.

3.3.1.7 Support Equipment

MRD-76 LRO mechanical ground support equipment shall be provided for use in I&T, transportation, and launch site operations.

Rationale: MGSE will be needed at various stages of LRO development, including launch site operations.

3.3.1.8 Mechanical Surrogates

MRD-77 LRO shall make use of mass simulators, fit-check templates, baseplates, and wiring mock-ups, as appropriate.

Rationale: This will help to ensure proper structural and interface compliance.

3.3.2 Thermal

3.3.2.1 Operational Ranges

MRD-78 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).

Rationale: Must maintain proper temperature ranges to ensure functionality of all components and instruments.

3.3.2.2 Survival Ranges

MRD-79 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).

Rationale: Must maintain proper temperature ranges to avoid damaging any component/instrument.

3.3.2.3 Minimum Bus Voltage

MRD-80 The LRO survival heaters shall be sized for a minimum bus voltage of 27 V.

Rationale: Prevents over sizing of heaters at maximum bus voltage. Battery voltage not expected to drop below 27 V.

3.3.2.4 Monitoring

MRD-81 LRO shall monitor temperature sensors for all components and critical structural elements.

Rationale: Must have knowledge of LRO temperatures to aid in post-processing and/or troubleshooting.

3.3.2.5 Ground Support

MRD-82 LRO thermal GSE shall be provided for use in I&T, transportation, and launch site operations.

Rationale: TGSE will be needed at various stages of LRO development, including launch site operations.

3.3.2.6 –

MRD-83 Deleted

Rationale: -

3.3.3 <u>Guidance, Navigation, and Control</u>

3.3.3.1 Attitude Control System

MRD-84 The attitude control system shall maintain LRO's orientation, as well as that of its solar array and high gain antenna, throughout the mission.

Rationale: LRO's orientation must be carefully controlled throughout the mission to maintain the integrity of all systems and to meet mission objectives.

3.3.3.2 ACS Hardware

MRD-85 The ACS sensors and actuators shall be controlled via the Low Speed Bus.

Rationale: Utilizing simplest possible interfaces increases system reliability.

3.3.3.3 ACS Software

MRD-86 The ACS software shall be hosted on the LRO Single Board Computer.

Rationale: Sharing the abundant resources of the SBC significantly reduces avionics costs/complexity.

3.3.3.4 Propulsion Control

MRD-87 The GN&C subsystem shall control and monitor the propulsion system.

Rationale: The propulsion system is part of the GN&C subsystem.

3.3.3.5 Initial Stabilization

MRD-88 The GN&C subsystem shall autonomously stabilize the orbiter after separation from the LV.

Rationale: Must avoid flat spin to ensure sun avoidance on instruments, etc.

3.3.3.6 Sun Pointing Latency

MRD-89 The ACS shall maneuver LRO from any orientation to a power positive one within 30 min of initialization.

Rationale: This mode is nominally only entered when it is imperative that the sun be put on the solar array. 30 minutes is short enough to not overly discharge the battery and long enought to not drive the ACS design.

3.3.3.7 Sun Pointing Accuracy

MRD-90 When sun pointing, the ACS shall maintain the sun within 15 deg of the specified position.

Rationale: This angle is sufficient to ensure that enough sun gets onto the solar array.

3.3.3.8 Default Mode

MRD-91 The ACS default mode shall maintain the sun within 15 deg of a specified position.

Rationale: In the event of an anomaly, this is the safest orientation for the SC to be put into.

3.3.3.9 Thrust Pointing

MRD-92 The ACS shall hold pointing to within 5 deg of the desired orientation during thruster operations.

Rationale: Pointing must be maintained to ensure that the resultant thrust is in the desired direction.

3.3.3.10 Delta-V Budget

MRD-93 The detailed Delta-V budget shall be documented in the LRO Technical Resource Allocations Specification (431-SPEC-000112).

Rationale: Flight Dynamics determines the fuel requirements in terms of Delta-V.

3.3.3.11 Fuel Budget

MRD-94 The detailed propellant budget shall be documented in the LRO Technical Resource Allocations Specification (431-SPEC-000112).

Rationale: The actual fuel budget factors in all subsequent effects (cosine losses, residual fuel, etc.).

3.3.3.12 Minimum Thrust

MRD-95 The propulsion system shall be capable of producing 160 N of thrust, in such a way that allows for lunar capture, with backup, as determined by Flight Dynamics.

Rationale: Minimum thrust required for lunar capture. Without it, LRO can’t brake at the moon. This is the number used in the flight dynamics analysis.

3.3.3.13 Thruster Locations

MRD-96 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.

Rationale: Impingements can cause unwanted forces and torques, as well as heating issues.

3.3.3.14 Momentum Management

MRD-97 The GN&C subsystem shall be capable of adjusting momentum within 5 N-m-s of a desired set-point.

Rationale: Momentum management is critical for lunar missions due to lack of magnetic field (i.e. continuous capability).

3.3.4 <u>Power</u>

3.3.4.1 Power Distribution

MRD-98 The power system shall distribute primary power to the subsystems as required by their EICDs.

Rationale: Power architecture shall be used to supply over-current protected power to all the loads.

3.3.4.2 Voltage Supply

MRD-101 The power system shall provide unregulated 22-35 VDC power at all the power supply outputs.

Rationale: Subsystems/instruments shall operate nominally at 21-35 VDC. This gives an appropriate margin for line losses.

3.3.4.3 Launch & Early Ops

MRD-102 The battery shall be able to support the SC during launch operations and until a power positive condition has been achieved.

Rationale: LRO will require a certain size battery (A-Hr). It must be enough to support all mission phases.

3.3.4.4 Nominal Operations

MRD-103 The power system shall be designed to support full mission load of 823 W (orbit average) after 14 months.

Rationale: Provides sufficient margin beyond the allocated/predicted load demands.

3.3.4.5 Minimum Load

MRD-104 The power system shall carry a minimum load of 180 W whenever the solar array is illuminated.

Rationale: Insures compliance with voltage specifications.

3.3.4.6 Peak Power

MRD-105 The power system shall be capable of supporting a 1500 W peak power load for up to 5 minutes.

Rationale: The power system must be able to handle the peak power load.

3.3.4.7 Switched Power

MRD-106 Switched power services shall have re-settable over-current protection.

Rationale: Power system protection.

3.3.4.8 Switched Cutoffs

MRD-107 The power system shall switch off any switched service that exceeds its max sustainable current, and keep it off until commanded otherwise.

Rationale: To protect the power services.

3.3.5 Command and Data Handling System

3.3.5.1 Processing Platform

MRD-108 The C&DH Single Board Computer shall provide an adequate processing platform for the execution of all Flight Software, including ACS Flight Software.

Rationale: C&DH and GN&C flight software require significant processor resources.

3.3.5.2 Bus Controller

MRD-109 The C&DH Single Board Computer shall operate as the Bus Controller for the 1553 network.

Rationale: Mechanism for redundant configurations to prevent two simultaneous BCs.

3.3.5.3 Data Protocols

MRD-110 The C&DH shall support CCSDS telecommand, telemetry, and CFDP.

Rationale: Standard protocols used by flight and ground data and comm. systems.

3.3.5.4 Hardware Decoding

MRD-111 The C&DH shall support hardware decoding of critical commands.

Rationale: Method for recovery from anomalous conditions.

3.3.5.5 Telemetry Encoding

MRD-112 The C&DH shall support telemetry encoding.

Rationale: The LRO communications scheme will likely utilize telemetry encoding.

3.3.5.6 Hardline Interface

MRD-113 The C&DH shall provide hardline interface(s) for use in ground testing, through spacecraft umbilical.

Rationale: Needed throughout I&T and at the launch site.

3.3.5.7 Mission Time Counter

MRD-114 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.

Rationale: MET shall always increment and never be adjusted to provide unambiguous time reference.

3.3.5.8 Pulse Per Second

MRD-115 The C&DH shall provide a 1Hz pulse as required by the instruments.

Rationale: Mechanism for synchronizing operations, and time-tagging data.

3.3.5.9 Time Messages

MRD-116 The C&DH shall generate an Orbiter Time of Pulse message for each instrument as required.

Rationale: Mechanism for synchronizing operations, and time-tagging data.

3.3.5.10 LAMP Interface

MRD-117 The C&DH shall support LAMP's heritage serial interfaces, as defined in LAMP's EICD.

Rationale: Acceptance of existing interfaces simplified instrument development with little cost to SC.

3.3.5.11 Backup H/K Storage

MRD-118 The C&DH SBC shall be capable of storing 2 hours of H/K data.

Rationale: Covers periods when the mass storage device is unavailable.

3.3.5.12 Deleted

MRD-125

Rationale:

3.3.6 Communication

3.3.6.1 Operational TT&C

MRD-119 LRO shall provide communication to support operational mission telemetry, tracking and command.

Rationale: TLM / CMD is required to support LRO operations.

3.3.6.2 TLM/CMD Links

MRD-120 LRO Shall provide command and telemetry links to support TLM / CMD functions.

Rationale: Bidirectional communication is required to support LRO's operations concept.

3.3.6.3 Radiometrics

MRD-121 LRO shall provide radiometric tracking capabilities.

Rationale: The LRO Flight Dynamics Team requires range and range-rate measurement to determine LRO's orbit.

3.3.6.4 Command Link

MRD-122 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.

Rationale: This is a sufficient command link required to support LRO operations.

3.3.6.5 Telemetry Downlink

MRD-123 LRO shall provide a return communication downlink, with rates up to 1.093 Mbps, 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.

Rationale: This is a sufficient telemetry link required to support LRO operations, and the highest rate supports some contingency scenarios.

3.3.6.6 High Rate Downlink

MRD-124 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.

Rationale: This is a sufficient high rate link required to support LRO operations (data rate does not include R-S or convolutional encoding, but does include CCSDS Overhead).

3.3.6.7 Concurrent Downlink

MRD-126 The LRO mission communication system shall support the simultaneous downlink of operational TT&C and high rate mission data.

Rationale: 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.

3.3.6.8 Contingency Uplink

MRD-163 LRO shall have 3 dB of margin for the reception of commands over 90% of the 4 pi steradians around the spacecraft when using the DSN ground stations.

Rationale: Allows the ground to get commands into the spacecraft during contingency situations.

3.3.6.9 Contingency Downlink

MRD-164 LRO shall have 3 dB of margin for the transmission of telemetry over 90% of the 4 pi steradians around the spacecraft when using the DSN ground stations.

Rationale: Allows the ground to receive telemetry from the spacecraft during contingency situations.

3.3.7 <u>Flight Software</u>

3.3.7.1 Software Initialization

MRD-127 The flight software shall initialize and support operations without the need of an upload from the ground.

Rationale: Essential aspect of LRO operations.

3.3.7.2 Reprogrammability

MRD-128 The flight software shall be reprogrammable during flight.

Rationale: Allow correction of SW errors or adding new SW features post-launch.

3.3.7.3 Processor Utilization

MRD-129 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.

Rationale: Allow room to add software functions post-launch.

3.3.7.4 Software Organization

MRD-130 The flight software shall be organized such that functional units of code can be modified on orbit in modular form.

Rationale: Ease of management of configuration settings.

3.3.7.5 Absolute Time Sequence

MRD-131 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.
Rationale: Essential aspect of LRO operations.

3.3.7.6 Relative Time Sequence

MRD-132 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.
Rationale: Essential aspect of LRO operations.

3.3.7.7 Telemetry Monitoring

MRD-133 The flight software shall support monitoring of any telemetry point and initiate stored command in response to pre-defined conditions.
Rationale: Flexibility is necessary to support autonomous error recovery conditions that may not be known until after launch.

3.3.7.8 Diagnostic Tlm Support

MRD-134 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.
Rationale: Flexibility is necessary to support debugging conditions that may not be known until after launch.

3.3.7.9 File Management

MRD-135 The flight software shall provide commands to allow operators to manage the on-board file systems (directory listing, and file move/copy/delete).
Rationale: 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

3.4.1.1 System Support

MRD-136 The ground system shall provide ground system capability for supporting all mission phases.
Rationale: Support pre-launch testing and post-launch operations

3.4.1.2 Data Delivery

MRD-137 The ground system shall deliver measurement data to the instrument SOCs within 24-hours of ground receipt.
Rationale: Deliver data in a timely manner for measurement data processing. Ensures ground can deliver data without backlog.

3.4.1.3 Critical Operations

MRD-138 The ground system shall provide essential capabilities to support all critical LRO operations.

Rationale: Verify health and safety of orbiter. Ensure proper coverage for all critical operations

3.4.1.4 Testing & Verification

MRD-139 The ground system shall perform and support verification testing, operations testing, and mission rehearsal testing.

Rationale: Ground system and operations verification

3.4.1.5 Data Protocols

MRD-140 The ground system shall support CCSDS telecommand, telemetry, and CFDP.

Rationale: Standard protocols used by flight and ground data and comm. systems.

3.4.2 Mission Ops Center

3.4.2.1 Support Functions

MRD-141 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

Rationale: Basic operational functions needed for LRO

3.4.2.2 Center Location

MRD-142 The dedicated MOC shall be located at GSFC.

Rationale: Available infrastructure reduces development and test schedule

3.4.2.3 H/K Data Storage

MRD-143 The MOC shall store orbiter housekeeping data for the life of the mission.

Rationale: Needed for anomaly and trend investigations

3.4.2.4 Command Origination

MRD-144 All commands sent to the orbiter shall originate from the MOC.

Rationale: Security and eliminates the need for command priority

3.4.2.5 SOC Interfaces

MRD-145 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

Rationale: Required for higher level measurement products and basic mission operations

3.4.3 Flight Dynamics

3.4.3.1 Mission Planning

MRD-146 The ground system shall provide trajectory, orbit and maneuver support during all mission phases.

Rationale: Support planning and measurement processing

3.4.3.2 Orbit Determination

MRD-147 The ground system shall provide orbit determination support during all mission phases.

Rationale: Support planning and measurement processing

3.4.3.3 Attitude Determination

MRD-148 The ground system shall provide attitude determination support during all mission phases.

Rationale: Support planning and measurement processing

3.4.3.4 Mission Products

MRD-149 The ground system flight dynamics systems shall generate the required mission products for mission planning, calibration, and data processing functions.

Rationale: Support planning and measurement processing

3.4.4 Ground Network

3.4.4.1 Ka-Band Services

MRD-150 The ground system shall provide Ka-Band ground services.

Rationale: Support current ConOps

3.4.4.2 S-Band Services

MRD-151 The ground system shall provide sufficient S-Band Tracking, Telemetry, and Command (TT&C) to support the mission.

Rationale: Support current ConOps

3.4.4.3 Telemetry & Command

MRD-152 The ground network shall support all telemetry and command modes throughout the mission phases.

Rationale: Support current ConOps

3.4.5 Data and Voice Networks

3.4.5.1 Data Networks

MRD-153 The ground system shall provide all data networks to support the mission from pre-launch through mission disposal.

Rationale: Needed to support mission from pre-launch through mission disposal.

3.4.5.2 Voice Networks

MRD-154 The ground system shall provide all voice networks to support the mission from pre-launch through mission disposal.

Rationale: 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 contained in this document per the definitions above. The table also defines the level of verification. The levels of verification are (1) system, (2) segment, (3) subsystem, and (4) component.

Any verifications involving both the Orbiter and the Mission Operations Center (MOC) are designated “system”. End-to-end testing (described later) is an example of system-level testing.

Segment verifications involve the Orbiter by itself or the ground system by itself. The spacecraft functional test (described later) is a segment-level test, since it does not involve operations with any part of the flight operations system, even though the Orbiter’s command and telemetry

Ground Support Equipment (GSE) is nearly identical to the MOC's control system. Another example of segment-level testing would be data flows between a ground station and the MOC.

Subsystem verifications are performed across a subsystem prior to Orbiter integration. Software acceptance testing is an example of subsystem verification.

Component-level verification occurs on an electronics box or such stand-alone unit before it is integrated with the spacecraft.

Table 4-1. Verification Matrix Table

Verification Method:		Level:
Inspection	(I)	1 System
Analysis	(A)	2 Segment
Demonstration	(D)	3 Subsystem
Test	(T)	4 Component

Requirement Number		Object Heading	I	A	D	T	Re On
MRD-1	3.1.1.1	Launch Mass				2	Mo
MRD-2	3.1.1.2	Launch Vehicle	2				Sy
MRD-3	3.1.1.3	Launch Trajectory	2				Fli Dy
MRD-4	3.1.1.4	Launch Window		2			Fli Dy
MRD-5	3.1.1.5	Propulsive Despin		2			GN
MRD-6	3.1.1.6	Non-Propulsive Ops		2			GN
MRD-7	3.1.1.7	Deployables		2			Mo
MRD-8	3.1.1.8	Sun Pointing		2			GN
MRD-9	3.1.1.9	Inertial Pointing		2			GN
MRD-10	3.1.1.10	Propulsive Maneuvers		2			GN
MRD-11	3.1.1.11	Low Maintenance Orbit		2			Fli Dy
MRD-12	3.1.1.12	Mission Orbit		2			Sy
MRD-13	3.1.1.13	Orbit Inclination		2			Fli Dy
MRD-14	3.1.1.14	Nadir Pointing		2			GN
MRD-15	3.1.1.15	Solar Array Tracking		2			Sy
MRD-16	3.1.1.16	Antenna Tracking		2			Sy

Requirement Number		Object Heading	I	A	D	T	Re On
MRD-17	3.1.1.17	Momentum Management		2			GN
MRD-18	3.1.1.18	Yaw Maneuvers		2			Sy
MRD-19	3.1.1.19	Lunar Eclipses		2			Sy
MRD-20	3.1.1.20	Spacecraft Safing				2	Sy
MRD-158	3.1.1.21	Recoverable Failures		2		2	Sy
MRD-21	3.1.1.22	Mission Duration		2			Sy
MRD-22	3.1.1.23	Extended Mission		2			Sy
MRD-23	3.1.1.24	End of Mission		2			Sy
MRD-24	3.1.2.1	Vehicle Performance		2			La Pr
MRD-25	3.1.2.2	Insertion Accuracy		2			La Pr
MRD-26	3.1.2.3	--					
MRD-27	3.1.2.4	Tip Off rates		2			La Pr
MRD-28	3.1.2.5	Vehicle Interfaces		2			Sy
MRD-29	3.1.3.1	Mass Allocations				3	Su ru
MRD-30	3.1.3.2	Mechanical Interfaces				3	Su ru
MRD-31	3.1.3.3	Power Allocations				3	Su ru
MRD-32	3.1.3.4	Operating Voltage				4	Su ru
MRD-33	3.1.3.5	Electrical Interfaces				4	Su ru
MRD-34	3.1.3.6	Thermal Interfaces	2			3	Su ru
MRD-35	3.1.3.7	Low-Rate Data			2		Sy
MRD-36	3.1.3.8	High-Rate Data			2		Sy
MRD-155	3.1.3.9	Real-Time Data				1	Sy
MRD-37	3.1.3.10	Data Storage		2			Sy
MRD-38	3.1.3.11	Data Transfer		1			Sy
MRD-39	3.1.3.12	Basic Doppler		1			Sy
MRD-159	3.1.3.13	Improved Doppler		1			Sy
MRD-160	3.1.3.14	Ranging		1			Sy
MRD-40	3.1.3.15	High Accuracy Ranging		1			La
MRD-41	3.1.3.16	Orbit Determination		1			Fli Dy
MRD-168	3.1.3.17	Gravity Model Update		1			La

Requirement Number		Object Heading	I	A	D	T	Re On
MRD-42	3.1.3.18	Time Knowledge				1	Sy
MRD-43	3.1.3.19	Time Maintenance		1		1	Gr
MRD-157	3.1.3.20	Clock Stability				2	Sy
MRD-162	3.1.3.21	Time Epoch			1		Sy
MRD-44	3.1.3.22	–					
MRD-45	3.1.3.23	–					
MRD-46	3.1.3.24	–					
MRD-47	3.1.3.25	–					
MRD-48	3.1.3.26	–					
MRD-49	3.1.3.27	Pointing Allocations		2		2	Sy
MRD-50	3.1.3.28	Mission Phases			1		Sy
MRD-51	3.1.3.29	Continuous Operations		1			Sy
MRD-156	3.1.3.30	Lights-Out Operations		2			Sy
MRD-52	3.1.3.31	Sun Avoidance		2			GN
MRD-161	3.1.3.32	Sun Avoidance During Launch		2			La Pr
MRD-99	3.1.3.33	Power Negative Ops		2			Sy
MRD-100	3.1.3.34	Thermally Off-Nominal Ops		2			Th
MRD-53	3.1.3.35	Maneuver Notification			1		Sy
MRD-54	3.1.3.36	Data Loss		1			Sy
MRD-165	3.1.3.37	Collection Efficiency		1			Sy
MRD-166	3.1.3.38	Data Delivery Efficiency		1			Sy
MRD-167	3.1.3.39	Off-Nadir Data Collection		1			Sy
MRD-55	3.1.3.40	Data Product Delivery			2		Ins
MRD-56	3.1.3.41	Information Assurance		1			Sy
MRD-57	3.1.4.1	Risk Classification		2			Sy
MRD-58	3.1.4.2	Mission Assurance			1		Mi As
MRD-59	3.1.4.3	Configuration Control			1		Ma
MRD-60	3.1.4.4	Requirements Control			1		Sy
MRD-61	3.1.4.5	Margins/ Reserves			1		Sy
MRD-62	3.1.4.6	Coordinate Systems			3		Su ru
MRD-63	3.1.4.7	Units Policy			3		Su ru
MRD-64	3.1.4.8	Verification Testing			1		Sy
MRD-65	3.1.4.9	Mechanical Environments				2	Sy
MRD-66	3.1.4.10	Electrical Environments				2	Sy
MRD-67	3.1.4.11	Thermal Environments				2	Sy al

Requirement Number		Object Heading	I	A	D	T	Re On
MRD-68	3.1.4.12	Radiation Environments		4			Su rur
MRD-69	3.1.4.13	Contamination Control				2	Co
MRD-70	3.3.1.1	Structural Stability		2			Me
MRD-71	3.3.1.2	Fields of View		2			Me
MRD-72	3.3.1.3	Flexible Modes		2			Me
MRD-73	3.3.1.4	Accessibility			3		Me
MRD-74	3.3.1.5	Disturbance Torques		2			Me
MRD-75	3.3.1.6	Mass Properties		2			Me
MRD-76	3.3.1.7	Support Equipment			3		Me
MRD-77	3.3.1.8	Mechanical Surrogates			3		Me
MRD-78	3.3.2.1	Operational Ranges		2		2	Th
MRD-79	3.3.2.2	Survival Ranges		2		2	Th
MRD-80	3.3.2.3	Minimum Bus Voltage		3			Th
MRD-81	3.3.2.4	Monitoring				2	Th
MRD-82	3.3.2.5	Ground Support			3		Th
MRD-83	3.3.2.6	–					
MRD-84	3.3.3.1	Attitude Control System		2			GN
MRD-85	3.3.3.2	ACS Hardware			3		GN
MRD-86	3.3.3.3	ACS Software			3		GN
MRD-87	3.3.3.4	Propulsion Control			3		GN
MRD-88	3.3.3.5	Initial Stabilization		2			GN
MRD-89	3.3.3.6	Sun Pointing Latency		2			GN
MRD-90	3.3.3.7	Sun Pointing Accuracy		2			GN
MRD-91	3.3.3.8	Default Mode		2			GN
MRD-92	3.3.3.9	Thrust Pointing		2			GN
MRD-93	3.3.3.10	Delta-V Budget			2		Sy
MRD-94	3.3.3.11	Fuel Budget			2		Sy
MRD-95	3.3.3.12	Minimum Thrust		3			Pr
MRD-96	3.3.3.13	Thruster Locations		2			GN
MRD-97	3.3.3.14	Momentum Management		2			GN
MRD-98	3.3.4.1	Power Distribution			3	2	Po
MRD-101	3.3.4.2	Voltage Supply				2	Po
MRD-102	3.3.4.3	Launch & Early Ops		2			Sy
MRD-103	3.3.4.4	Nominal Operations		2			Po
MRD-104	3.3.4.5	Minimum Load		2			Sy
MRD-105	3.3.4.6	Peak Power		3		3	Po
MRD-106	3.3.4.7	Switched Power			3		Po
MRD-107	3.3.4.8	Switched Cutoffs				3	Po
MRD-108	3.3.5.1	Processing Platform		3			So

Requirement Number		Object Heading	I	A	D	T	Re On
MRD-109	3.3.5.2	Bus Controller			3		So
MRD-110	3.3.5.3	Data Protocols			3		So
MRD-111	3.3.5.4	Hardware Decoding				3	C&
MRD-112	3.3.5.5	Telemetry Encoding				3	C&
MRD-113	3.3.5.6	Hardline Interface				2	El Sy
MRD-114	3.3.5.7	Mission Time Counter		3	3		C&
MRD-115	3.3.5.8	Pulse Per Second				3	C&
MRD-116	3.3.5.9	Time Messages			3		So
MRD-117	3.3.5.10	LAMP Interface				3	C&
MRD-118	3.3.5.11	Backup H/K Storage		2			Sy
MRD-125	3.3.5.12	Deleted					C&
MRD-119	3.3.6.1	Operational TT&C			3		RF
MRD-120	3.3.6.2	TLM/CMD Links			3		RF
MRD-121	3.3.6.3	Radiometrics			3		RF
MRD-122	3.3.6.4	Command Link				1	Co Te
MRD-123	3.3.6.5	Telemetry Downlink				1	Co Te
MRD-124	3.3.6.6	High Rate Downlink				1	Co Te
MRD-126	3.3.6.7	Concurrent Downlink			1		Sy
MRD-163	3.3.6.8	Contingency Uplink				1	Co Te
MRD-164	3.3.6.9	Contingency Downlink				1	Co Te
MRD-127	3.3.7.1	Software Initialization				3	So
MRD-128	3.3.7.2	Reprogrammability				3	So
MRD-129	3.3.7.3	Processor Utilization				3	So
MRD-130	3.3.7.4	Software Organization			3		So
MRD-131	3.3.7.5	Absolute Time Sequence				3	So
MRD-132	3.3.7.6	Relative Time Sequence				3	So
MRD-133	3.3.7.7	Telemetry Monitoring				2	So
MRD-134	3.3.7.8	Diagnostic Tlm Support				1	Sy
MRD-135	3.3.7.9	File Management				3	So
MRD-136	3.4.1.1	System Support				1	Gr
MRD-137	3.4.1.2	Data Delivery		2			Gr
MRD-138	3.4.1.3	Critical Operations				1	Gr
MRD-139	3.4.1.4	Testing & Verification				1	Gr
MRD-140	3.4.1.5	Data Protocols				1	Gr

Requirement Number		Object Heading	I	A	D	T	Re Or
MRD-141	3.4.2.1	Support Functions			2		Gr
MRD-142	3.4.2.2	Center Location	2				Gr
MRD-143	3.4.2.3	H/K Data Storage		2			Gr
MRD-144	3.4.2.4	Command Origination			2		Gr
MRD-145	3.4.2.5	SOC Interfaces			2		Gr
MRD-146	3.4.3.1	Mission Planning			1		Fli Dy
MRD-147	3.4.3.2	Orbit Determination		1			Fli Dy
MRD-148	3.4.3.3	Attitude Determination		1			Fli Dy
MRD-149	3.4.3.4	Mission Products				2	Fli Dy
MRD-150	3.4.4.1	Ka-Band Services			2		Gr
MRD-151	3.4.4.2	S-Band Services		2			Gr
MRD-152	3.4.4.3	Telemetry & Command				1	Gr
MRD-153	3.4.5.1	Data Networks		2	2		Gr
MRD-154	3.4.5.2	Voice Networks		2	2		Gr

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

5.0 APPENDIX B. TRACEABILITY MATRIX

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-1 3.1.1.1 Launch Mass	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-2 3.1.1.2 Launch Vehicle	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-3 3.1.1.3 Launch Trajectory	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-4 3.1.1.4 Launch Window	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-5 3.1.1.5 Propulsive Despin	
1.19 1.0-17 RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-6 3.1.1.6 Non-Propulsive Ops	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-7 3.1.1.7 Deployables	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-8 3.1.1.8 Sun Pointing	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-9 3.1.1.9 Inertial Pointing	
RLEP-LRO-P60 3.1.2.6 Orbit	MRD-10 3.1.1.10 Propulsive Maneuvers	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime RLEP-LRO-P60 3.1.2.6 Orbit	MRD-11 3.1.1.11 Low Maintenance Orbit	
RLEP-LRO-P60 3.1.2.6 Orbit	MRD-12 3.1.1.12 Mission Orbit	
RLEP-LRO-P60 3.1.2.6 Orbit	MRD-13 3.1.1.13 Orbit Inclination	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-14 3.1.1.14 Nadir Pointing	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime RLEP-LRO-P60 3.1.2.6 Orbit	MRD-15 3.1.1.15 Solar Array Tracking	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-16 3.1.1.16 Antenna Tracking	

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P60 3.1.2.6 Orbit		
RLEP-LRO-P60 3.1.2.6 Orbit	MRD-17 3.1.1.17 Momentum Management	
RLEP-LRO-P60 3.1.2.6 Orbit	MRD-18 3.1.1.18 Yaw Maneuvers	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-19 3.1.1.19 Lunar Eclipses	
1.17 1.0-16 RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-20 3.1.1.20 Spacecraft Safing	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-158 3.1.1.21 Recoverable Failures	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-21 3.1.1.22 Mission Duration	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-22 3.1.1.23 Extended Mission	
RLEP-LRO-P10 3.1.2.1 Planetary Protection m	MRD-23 3.1.1.24 End of Mission	
RLEP-LRO-P40 3.1.2.4 Launch Site	MRD-24 3.1.2.1 Vehicle Performance	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-25 3.1.2.2 Insertion Accuracy	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-26 3.1.2.3 --	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-27 3.1.2.4 Tip Off rates	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-28 3.1.2.5 Vehicle Interfaces	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-29 3.1.3.1 Mass Allocations	

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P160 3.1.2.16 Technology Demonstration		
4.03 4.0-2 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations RLEP-LRO-P160 3.1.2.16 Technology Demonstration	MRD-30 3.1.3.2 Mechanical Interfaces	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations RLEP-LRO-P160 3.1.2.16 Technology Demonstration	MRD-31 3.1.3.3 Power Allocations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-32 3.1.3.4 Operating Voltage	
2.05 2.0-5 2.06 2.0-6 2.11 2.0-10 2.13 2.0-12 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations RLEP-LRO-P160 3.1.2.16 Technology Demonstration	MRD-33 3.1.3.5 Electrical Interfaces	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations RLEP-LRO-P160	MRD-34 3.1.3.6 Thermal Interfaces	

Parent Requirement	Requirement	Child Requirement
3.1.2.16 Technology Demonstration		
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-35 3.1.3.7 Low-Rate Data	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations RLEP-LRO-P160 3.1.2.16 Technology Demonstration	MRD-36 3.1.3.8 High-Rate Data	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-155 3.1.3.9 Real-Time Data	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-37 3.1.3.10 Data Storage	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-38 3.1.3.11 Data Transfer	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-39 3.1.3.12 Basic Doppler	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-159 3.1.3.13 Improved Doppler	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-160 3.1.3.14 Ranging	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-40 3.1.3.15 High Accuracy Ranging	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-41 3.1.3.16 Orbit Determination	
	MRD-168 3.1.3.17 Gravity Model Update	
RLEP-LRO-P80 3.1.2.8	MRD-42 3.1.3.18 Time Knowledge	

Parent Requirement	Requirement	Child Requirement
Spacecraft Instrument Accommodations		
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-43 3.1.3.19 Time Maintenance	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations MRD-40 3.1.3.15 High Accuracy Ranging	MRD-157 3.1.3.20 Clock Stability	
	MRD-162 3.1.3.21 Time Epoch	
	MRD-44 3.1.3.22 –	
	MRD-45 3.1.3.23 –	
	MRD-46 3.1.3.24 –	
	MRD-47 3.1.3.25 –	
	MRD-48 3.1.3.26 –	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-49 3.1.3.27 Pointing Allocations	
1.02 1.0-2 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-50 3.1.3.28 Mission Phases	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-51 3.1.3.29 Continuous Operations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-156 3.1.3.30 Lights-Out Operations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-52 3.1.3.31 Sun Avoidance	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-161 3.1.3.32 Sun Avoidance During Launch	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-99 3.1.3.33 Power Negative Ops	

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-100 3.1.3.34 Thermally Off-Nominal Ops	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-53 3.1.3.35 Maneuver Notification	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-54 3.1.3.36 Data Loss	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-165 3.1.3.37 Collection Efficiency	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-166 3.1.3.38 Data Delivery Efficiency	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-167 3.1.3.39 Off-Nadir Data Collection	
RLEP-LRO-P100 3.1.2.10 Measurement Investigation Requirements RLEP-LRO-P110 3.1.2.11 Measurement Investigation Requirements RLEP-LRO-P120 3.1.2.12 Data Policies and Validation Requirements RLEP-LRO-P130 3.1.2.13 Data Policies and Validation Requirements	MRD-55 3.1.3.40 Data Product Delivery	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime RLEP-LRO-P80 3.1.2.8	MRD-56 3.1.3.41 Information Assurance	

Parent Requirement	Requirement	Child Requirement
Spacecraft Instrument Accommodations RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements		
RLEP-LRO-P20 3.1.2.2 Mission Lifetime RLEP-LRO-P30 3.1.2.3 Launch Date RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-57 3.1.4.1 Risk Classification	
1.05 1.0-5 RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-58 3.1.4.2 Mission Assurance	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-59 3.1.4.3 Configuration Control	
1.01 1.0-1 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-60 3.1.4.4 Requirements Control	
1.06 1.0-6 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-61 3.1.4.5 Margins/ Reserves	
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1.12 1.0-11 RLEP-LRO-P100 3.1.2.10 Measurement Investigation Requirements	MRD-63 3.1.4.7 Units Policy	

Parent Requirement	Requirement	Child Requirement
1.03 1.0-3 RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-64 3.1.4.8 Verification Testing	
1.11 1.0-10 1.13 1.0-12 4.09 4.0-6 4.10 4.0-7 4.11 4.0-8 4.12 4.0-9 4.13 4.0-10 4.14 4.0-11 RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-65 3.1.4.9 Mechanical Environments	
1.11 1.0-10 1.13 1.0-12 4.08 4.0-5 5.04 5.0-1 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-66 3.1.4.10 Electrical Environments	
1.11 1.0-10 1.13 1.0-12 4.08 4.0-5 4.25 4.0-18 4.26 4.0-19	MRD-67 3.1.4.11 Thermal Environments	

Parent Requirement	Requirement	Child Requirement
4.27 4.0-20 4.28 4.0-21 5.06 5.0-3 RLEP-LRO-P60 3.1.2.6 Orbit		
1.11 1.0-10 1.13 1.0-12 2.03 2.0-3 4.08 4.0-5 RLEP-LRO-P60 3.1.2.6 Orbit	MRD-68 3.1.4.12 Radiation Environments	
1.11 1.0-10 4.01 4.0-1 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-69 3.1.4.13 Contamination Control	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-70 3.3.1.1 Structural Stability	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-71 3.3.1.2 Fields of View	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-72 3.3.1.3 Flexible Modes	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-73 3.3.1.4 Accessibility	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-74 3.3.1.5 Disturbance Torques	
RLEP-LRO-P20 3.1.2.2	MRD-75 3.3.1.6 Mass Properties	

Parent Requirement	Requirement	Child Requirement
Mission Lifetime		
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-76 3.3.1.7 Support Equipment	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-77 3.3.1.8 Mechanical Surrogates	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-78 3.3.2.1 Operational Ranges	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-79 3.3.2.2 Survival Ranges	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-80 3.3.2.3 Minimum Bus Voltage	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-81 3.3.2.4 Monitoring	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-82 3.3.2.5 Ground Support	
	MRD-83 3.3.2.6 –	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-84 3.3.3.1 Attitude Control System	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-85 3.3.3.2 ACS Hardware	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-86 3.3.3.3 ACS Software	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-87 3.3.3.4 Propulsion Control	
1.19 1.0-17 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-88 3.3.3.5 Initial Stabilization	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-89 3.3.3.6 Sun Pointing Latency	
RLEP-LRO-P70 3.1.2.7	MRD-90 3.3.3.7 Sun Pointing	

Parent Requirement	Requirement	Child Requirement
Spacecraft Pointing	Accuracy	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-91 3.3.3.8 Default Mode	
RLEP-LRO-P70 3.1.2.7 Spacecraft Pointing	MRD-92 3.3.3.9 Thrust Pointing	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-93 3.3.3.10 Delta-V Budget	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-94 3.3.3.11 Fuel Budget	
RLEP-LRO-P40 3.1.2.4 Launch Site RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-95 3.3.3.12 Minimum Thrust	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-96 3.3.3.13 Thruster Locations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-97 3.3.3.14 Momentum Management	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-98 3.3.4.1 Power Distribution	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-101 3.3.4.2 Voltage Supply	
RLEP-LRO-P50 3.1.2.5 Launch Vehicle	MRD-102 3.3.4.3 Launch & Early Ops	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-103 3.3.4.4 Nominal Operations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-104 3.3.4.5 Minimum Load	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-105 3.3.4.6 Peak Power	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-106 3.3.4.7 Switched Power	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument	MRD-107 3.3.4.8 Switched Cutoffs	

Parent Requirement	Requirement	Child Requirement
Accommodations		
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-108 3.3.5.1 Processing Platform	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-109 3.3.5.2 Bus Controller	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-110 3.3.5.3 Data Protocols	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-111 3.3.5.4 Hardware Decoding	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-112 3.3.5.5 Telemetry Encoding	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-113 3.3.5.6 Hardline Interface	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-114 3.3.5.7 Mission Time Counter	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-115 3.3.5.8 Pulse Per Second	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-116 3.3.5.9 Time Messages	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-117 3.3.5.10 LAMP Interface	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-118 3.3.5.11 Backup H/K Storage	
	MRD-125 3.3.5.12 Deleted	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-119 3.3.6.1 Operational TT&C	

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-120 3.3.6.2 TLM/CMD Links	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-121 3.3.6.3 Radiometrics	
1.06 1.0-6 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-122 3.3.6.4 Command Link	
1.06 1.0-6 RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-123 3.3.6.5 Telemetry Downlink	
1.06 1.0-6 RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-124 3.3.6.6 High Rate Downlink	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-126 3.3.6.7 Concurrent Downlink	
1.06 1.0-6 RLEP-LRO-P60 3.1.2.6 Orbit	MRD-163 3.3.6.8 Contingency Uplink	
1.06 1.0-6 RLEP-LRO-P60 3.1.2.6 Orbit	MRD-164 3.3.6.9 Contingency Downlink	
1.17 1.0-16 RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-127 3.3.7.1 Software Initialization	
RLEP-LRO-P20 3.1.2.2	MRD-128 3.3.7.2	

Parent Requirement	Requirement	Child Requirement
Mission Lifetime	Reprogrammability	
3.07 3.0-6 RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-129 3.3.7.3 Processor Utilization	
RLEP-LRO-P20 3.1.2.2 Mission Lifetime	MRD-130 3.3.7.4 Software Organization	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-131 3.3.7.5 Absolute Time Sequence	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-132 3.3.7.6 Relative Time Sequence	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-133 3.3.7.7 Telemetry Monitoring	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-134 3.3.7.8 Diagnostic Tlm Support	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-135 3.3.7.9 File Management	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-136 3.4.1.1 System Support	
RLEP-LRO-P130 3.1.2.13 Data Policies and Validation Requirements	MRD-137 3.4.1.2 Data Delivery	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-138 3.4.1.3 Critical Operations	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-139 3.4.1.4 Testing & Verification	
RLEP-LRO-P90 3.1.2.9 Measurement Investigation Requirements	MRD-140 3.4.1.5 Data Protocols	
RLEP-LRO-P80 3.1.2.8	MRD-141 3.4.2.1 Support	

Parent Requirement	Requirement	Child Requirement
Spacecraft Instrument Accommodations	Functions	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-142 3.4.2.2 Center Location	
RLEP-LRO-P110 3.1.2.11 Measurement Investigation Requirements	MRD-143 3.4.2.3 H/K Data Storage	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-144 3.4.2.4 Command Origination	
RLEP-LRO-P140 3.1.2.14 Data Policies and Validation Requirements	MRD-145 3.4.2.5 SOC Interfaces	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-146 3.4.3.1 Mission Planning	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-147 3.4.3.2 Orbit Determination	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-148 3.4.3.3 Attitude Determination	
RLEP-LRO-P100 3.1.2.10 Measurement Investigation Requirements	MRD-149 3.4.3.4 Mission Products	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-150 3.4.4.1 Ka-Band Services	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-151 3.4.4.2 S-Band Services	
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-152 3.4.4.3 Telemetry & Command	
RLEP-LRO-P130 3.1.2.13 Data Policies and Validation Requirements	MRD-153 3.4.5.1 Data Networks	

Parent Requirement	Requirement	Child Requirement
RLEP-LRO-P80 3.1.2.8 Spacecraft Instrument Accommodations	MRD-154 3.4.5.2 Voice Networks	