ROBOTIC LUNAR EXPLORATION PROGRAM
CONFIGURATION CHANGE REQUEST

431-CCR-000016	**DATE INITIATED**: 7/28/2005	**CCR REV.:**	**CCR REV DATE**: ___________
CCB SECRETARY: Deb Yoder	**PROPRIETARY?** ☐ Yes ☒ No	**ITAR SENSTIVE?** ☐ Yes ☒ No	**CCR DUE DATE**: 8/5/2005

CCR TITLE (Brief Description): Release the Baseline Version of the Lunar Reconnaissance Orbiter Flight Software Requirements, 431-RQMT-000139

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EXTERNAL ORGANIZATION CCR#:	**EXTERNAL ORGANIZATION:**

DOCUMENT (INCLUDE THE DOC. # AND TITLE), CONTRACT, SOFTWARE AFFECTED:

431-RQMT-000139 Lunar Reconnaissance Orbiter Flight Software Requirement

EFFECTIVITY: ☐ ALL ☐ ACS ☐ ACS ANALYSIS ☒ C&DH ☐ COMMUNICATIONS ☐ ELECT. HARNESS ☐ FLT DYNAMICS ☐ GN&C ☐ I&T ☐ LAUNCH VEHICLE ☐ MECHANICAL ☐ MECH. ANALYSIS ☐ EGSE ☐ MGSE ☒ SPACECRAFT ☐ THERMAL ☐ PAYLOAD/INSTR. ☐ POWER ☐ PROPULSION ☒ SOFTWARE ☒ FLIGHT OPERATIONS ☐ OTHER ________________________

Change Class	**Criticality**	COST? ☒ **NO** ☐ **YES** **If yes, select one basis for estimate:**
☒ Class I	☐ Emergency	☐ **In-House** ☐ **Actuals** ☐ **ROM** ☐ **Historical Averages** ☐ **Other****
☐ Class II	☒ Urgent	**** If "Other" is chosen for the Basis of Estimate, please explain in Proposed Solution box below:**
	☐ Routine	

PROBLEM:

The attached draft version of the Lunar Reconnaissance Orbiter Flight Software Requirements (431-RQMT-000139) requires baselining by Level 3A (LRO) CCB.

PROPOSED SOLUTION:

Release the draft version of the Lunar Reconnaissance Orbiter Flight Software Requirements (431-RQMT-000139) by the Level 3A (LRO) CCB. Future changes will be initiated by submittal of CCRs. The LRO CMO/Code 431 shall maintain this document.

TYPE OF CHANGE: ☐ Schedule ☐ Interface ☒ Document ☐ Weight ☐ Contract ☐ Other ________________

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BOARD ACTION: ☐ APPROVED ☐ APPROVED WITH CHANGE ☐ DISAPPROVED ☐ WITHDRAWN ☐ DEFERRED

Comments

CCB APPROVAL LEVEL REQUIRED [Check appropriate box(es)]:

☐	LEVEL 1 NASA HQ	**Signature:**	**Date:**
☐	LEVEL 2 RLEP	**Signature:**	**Date:**
☒	LEVEL 3A LRO	**Signature:**	**Date:**
☐	LEVEL 3B Mission 2	**Signature:**	**Date:**

431-RQMT-000139
Revision -
Effective Date: To be added upon Release
Expiration Date: To be added upon Release

DRAFT

Robotic Lunar Exploration Program

Lunar Reconnaissance Orbiter Project

Flight Software Requirements Document

July 28, 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.

Questions or comments concerning this document should be addressed to:

LRO Configuration Management Office
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LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Rev -			

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1	Sections 2.1, 3.2.1.2, & 3.2.9.14	FSWR-5 Provide document # for the LRO Fault Detection and Correction Interface Control Document	M. Blau/ GSFC	10/15/2005
2	Sections 2.1, 3.2.6.1, & 3.2.6.5	FSWR-60&64 Fill in Doc name and number for SSR ICD	M. Blau/ GSFC	10/15/2005
3	Section 3.2.3.2	FSWR-23 Define the number of ATS buffers	M. Blau/ GSFC	10/15/2005
4	Section 3.2.3.3	FSWR-24 Define #bytes and #commands in each ATS buffer	M. Blau/ GSFC	10/15/2005
5	Section 3.2.3.7	FSWR-28 Define # of RTS buffers, and # bytes in each buffer	M. Blau/ GSFC	10/15/2005
6	Section 3.2.4.4	FSWR-33 Determine if AOS grade 2 service is correct	M. Blau/ GSFC	10/15/2005
7	3.2.4.5 & 3.2.4.7	FSWR-34&36 Fill in correct section of Ops Concept Doc.	M. Blau/ GSFC	10/15/2005
8	Section 3.2.5.3	FSWR-52 Determine required bit error rate	M. Blau/ GSFC	10/15/2005
9	Section 3.3.1.1	FSWR-107 Fill in control law execution rate	D. McComas/ GSFC	10/15/2005
10	Section 3.3.1.4	FSWR-110 Fill in control law execution rate	D. McComas/ GSFC	10/15/2005
11	Section 3.3.6.1	FSWR-149 Finalize SA data processing rate	D. McComas/ GSFC	10/15/2005
12	Section 3.3.6.2	FSWR-150 Finalize SA data processing rate	D. McComas/ GSFC	10/15/2005
13	Section 3.3.7.1	FSWR-153 Finalize HGA data processing rate	D. McComas/ GSFC	10/15/2005
14	Section 3.3.7.2	FSWR-154 Finalize HGA data processing rate	D. McComas/ GSFC	10/15/2005

Item No.	Location	Summary	Ind./Org.	Due Date
15	Section 4.0	Table 4-1 Complete Verification Matrix Table	M. Blau/ GSFC	12/15/20005
16	Appendix B	Complete Traceability Matrix	M. Blau/ GSFC	10/15/2005

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1.0 INTRODUCTION

This document defines the Lunar Reconnaissance Orbiter Flight Software (FSW) Level Three Requirements and flows down directly from the Level 2 Lunar Reconnaissance Orbiter Mission Requirements Document (431-RQMT-000004).

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 National Aeronautics and Space Administration's (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

431-HDBK-000053	LRO Telemetry and Command Format Handbook
431-ICD-000104	Cosmic Ray Telescope for the Effects of Radiation Data Interface Control Document
431-ICD-000105	Diviner Data Interface Control Document
431-ICD-000106	Lyman-Alpha Mapping Project Data Interface Control Document
431-ICD-000107	Lunar Exploration Neutron Detector Data Interface Control Document
431-ICD-000108	Lunar Orbiter Laser Altimeter Data Interface Control Document
431-ICD-000109	Lunar Reconnaissance Orbiter Camera Data Interface Control Document
431-OPS-000042	LRO Mission Concept of Operations
431-PLAN-000005	LRO Systems Engineering Management Plan
431-RQMT-000004	Lunar Reconnaissance Orbiter Mission requirements Document
431-RQMT-000174	Lunar Reconnaissance Orbiter Mission Assurance Requirements Document
431-SPEC-000008	LRO Electrical Systems Specification
431-SPEC-000078	LRO CFDP Implementation Specification
TBD	Solid State Recorder User’s Guide
TBD	LRO Fault Detection and Handling Interface Control Document

2.1.2 Reference Documents

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	CCSDS Blue Book - Packet Telemetry
NPR 7150.2	NASA Software Development Procedural Requirements

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 (SA) System and High Gain Antenna (HGA) System.

Throughout this document, the term Payload (or LRO Payload) will be used to describe the instrument suite consisting of Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Diviner, Lyman-Alpha Mapping Project (LAMP), Lunar Exploration Neutron Detector (LEND), Lunar Orbiter Laser Altimeter (LOLA), Lunar Reconnaissance Orbiter Camera (LROC) and the technical demonstration payload of opportunity, Mini-Radio Frequency (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.

3.0 SOFTWARE 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 GENERAL SOFTWARE REQUIREMENTS

3.1.1 Mission Assurance

FSWR-1: The development of FSW for the LRO mission shall adhere to the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174) document and NASA Software Development Procedural Requirements Procedural Requirements (NPR 7150.2).

Rationale: NASA and Goddard Space Flight Center (GSFC) software (SW) process control requirements.

3.1.2 Single String

FSWR-2: The LRO command and data handling (C&DH) FSW shall be designed to operate on a single string data system. SW designs and test plans must be sufficiently robust to give reasonable confidence that LRO will meet minimum mission success criteria without redundant data system hardware (HW).

Rationale: SC single string design due to mass and power restrictions.

3.1.3 Units

FSWR-3: The LROC implementation shall use standard metric units (kilogram [kg], meter [m], second [sec.], degrees centigrade [deg C], etc.) as the standard unit convention. Controlled use of hybrid units will be allowed per Lunar Reconnaissance Orbiter Systems Engineering Management Plan (431-PLAN-000005).

Rationale: One set of units selected to avoid confusion.

3.2 COMMAND AND DATA HANDLING SOFTWARE REQUIREMENTS

3.2.1 Initialization Requirements

3.2.1.1 Power-On Startup

FSWR-4: The C&DH FSW shall provide a capability to detect and report a power on startup of the FSW.

Rationale: Onboard processors must begin operation without ground intervention.

3.2.1.2 Cold Reset

FSWR-5: The C&DH FSW shall provide a capability to affect a cold reset of the FSW, restarting all FSW tasks and restoring all data to default values.

Rationale: On power-up or after errors, the FSW should restart everything to maximize the chance of a clean startup.

3.2.1.3 Hardware Init

FSWR-6: The FSW shall initialize the C&DH HW on cold reset, including the RAD750 microprocessor, the uplink and downlink HW, the 1553 data bus, and the SpaceWire data links.

Rationale: Need to start with hardware in a known good state.

3.2.1.4 Warm Reset

FSWR-7: The C&DH FSW shall provide a capability to effect a warm reset of the FSW.

Rationale: System design to minimize operational impacts and maximize data return when handling exceptions, errors, and upsets.

3.2.1.5 Default Values

FSWR-8: The C&DH FSW shall provide default values for proper initialization of all key operating parameters following a power on or cold reset.

Rationale: Onboard processors must begin operation without ground intervention.

3.2.1.6 Reset Data Retention

FSWR-9: The C&DH FSW shall retain the state of key operating parameters through a warm reset.

Rationale: System design to minimize operational impacts and maximize data return when handling exceptions, errors, and upsets.

3.2.1.7 PROM to EEPROM Loader

FSWR-10: The Programmable Read-Only Memory (PROM) based boot loader shall provide a capability to validate the contents of the two Electrically Erasable Programmable Read-Only Memory (EEPROM) banks and run the code in the bank that passes validation.

Rationale: The data retention reliability of the EEPROM for the life of the LRO mission is suspect. The PROM based boot loader significantly reduces the reliability concerns regarding EEPROM bit and page errors.

3.2.2 <u>Command Ingest Requirements</u>

3.2.2.1 Ground Commands

FSWR-11: The C&DH FSW shall have the capability to receive and execute commands from the ground system in order to carry out mission operations.

Rationale: Operations (Ops) concept includes frequent contacts with ground control.

3.2.2.2 Command Protocol

FSWR-12: The C&DH FSW command link shall utilize the Consultative Committee for Space Data Systems (CCSDS) command path service protocol; both Command Operation Protocol #1(COP-1) and bypass modes shall be supported.

Rationale: CCSDS selected for compatibility with existing ground infrastructure.

3.2.2.3 Command Data Rate

FSWR-13: The C&DH FSW shall support an uplink rate of 4 kilobits per second (kbps).

Rationale: Max command rate supported by most S-band transponders.

3.2.2.4 Command Validation

FSWR-14: The C&DH FSW uplink command checking shall be such to preclude the execution of an invalid command.

Rationale: Don't want bit errors on uplink to cause damage to LRO.

Note: Command Ingest task verifies checksums, Applications verify command parameters.

3.2.2.5 Command Link Security

FSWR-15: The C&DH FSW uplink command path shall include appropriate security measures to prevent the execution of any unauthorized command sequences.

Rationale: NASA "asset protection" requirement.

3.2.2.6 Command Distribution

FSWR-16: The C&DH FSW shall provide a capability to receive, decode, validate and distribute real time commands to all observatory subsystems.

Rationale: Standard C&DH requirement.

Note: This requirement relates to commands for other (non-FSW) subsystems.

3.2.2.7 Codeblock Layer

FSWR-17: The C&DH FSW shall implement the CCSDS coding layer as specified in the LRO Telemetry and Command Format Handbook (431-HDBK-000053).

Rationale: For compatibility with existing ground infrastructure.

3.2.2.8 Frame Layer

FSWR-18: The C&DH FSW shall implement the CCSDS Transfer Frame Layer as specified in the LRO Telemetry and Command Format Handbook (431-HDBK-000053).

Rationale: For compatibility with existing ground infrastructure.

3.2.2.9 Packet Layer

FSWR-19: The C&DH FSW shall implement the full CCSDS Telecommand Packetization Layer as specified in the LRO Telemetry and Command Format Handbook (431-HDBK-000053).

Rationale: For compatibility with existing ground infrastructure.

Note: The FSW does not support CCSDS command packet segmentation.

3.2.2.10 HW Command Log

FSWR-20: The C&DH FSW shall detect the receipt of "special" HW commands and report the command number in housekeeping (HK) telemetry.

Rationale: These are critical commands, so their receipt must be reported. But, the HW command decoder has no direct access to telemetry.

3.2.2.11 Command Link Telemetry

FSWR-21: The C&DH FSW shall telemeter sufficient statistics data from the uplink HW to determine the overall health of the forward command link.

Rationale: Health of the uplink is mission critical. Ground must be able to diagnose any problems.

3.2.2.12 Command Verification

FSWR-22: The C&DH FSW shall routinely make available in telemetry sufficient status information to verify the receipt and execution of all commands.

Rationale: Safe operation of the Observatory requires command verification.

3.2.3 Stored Command Requirements

3.2.3.1 Stored Commands

FSWR-23: The C&DH FSW shall provide a stored command capability to receive, store, and later execute sequences of commands.

Rationale: LRO is not always visible from Earth.

3.2.3.2 Absolute Time Sequence Buffers

FSWR-24: The C&DH FSW shall provide at least **TBD** absolute time sequence (ATS) command buffers with an accuracy of 1 second command execution relative to Universal Time Code (UTC).

Rationale: Ops concept requires uploading one ATS buffer while another buffer continues to execute.

3.2.3.3 Absolute Time Sequence Sizing

FSWR-25: The C&DH FSW shall provide an ATS command buffer capability of at least **TBD** commands totaling **TBD** bytes.

Rationale: Calculated from SC and Instrument Ops concepts with margin, based on 72 hours capacity.

3.2.3.4 Absolute Time Sequence Loading

FSWR-26: The C&DH FSW shall accept ground loads and edits to modify the ATS buffers.

Rationale: Allows for emergency re-planning of daily schedule without uplinking the entire large command buffer.

Note: The word "edit" means that individual commands within a load can be added and deleted after the load has been uplinked to the SC.

3.2.3.5 Relative Time Sequences

FSWR-27: The C&DH FSW shall provide relative time sequences (RTSs) of commands with an accuracy of 1 second command execution relative to the previous command in the sequence.

Rationale: Needed to properly time propulsion burns and science campaigns.

3.2.3.6 Relative Time Sequence Sizing

FSWR-28: The C&DH FSW shall provide **TBD** RTS command buffers, each with a size of at least **TBD** bytes.

Rationale: RTSs reduce uplink requirements for command sequences that are repeated frequently. They also allow autonomous error recovery sequences to be pre-defined but easily modified.

3.2.3.7 Stored Command Verification

FSWR-29: The C&DH FSW shall verify the integrity of each stored command before distribution.

Rationale: ATS and RTS commands may sit in memory for long periods, making them susceptible to bit errors from radiation effects.

Note: This implies checksum validation of each command.

3.2.4 Telemetry Requirements

3.2.4.1 Provide Telemetry

FSWR-30: The C&DH FSW shall have the capability to transfer data from the SC to the ground system in order to carry out mission operations.

Rationale: Primary purpose of the mission is to return science data.

3.2.4.2 Sufficient Housekeeping

FSWR-31: The C&DH FSW shall downlink sufficient HK engineering data to the ground to allow nominal SC operation and performance evaluation, as well as anomaly investigation and resolution.

Rationale: Ground controllers need enough visibility into SC status to be able to operate the mission.

3.2.4.3 CCSDS AOS Protocol

FSWR-32: The C&DH FSW shall format the HK downlink telemetry as recommended by the CCSDS Advanced Orbiting Systems, protocol(CCSDS 701.0-B-3).

Rationale: For compatibility with existing ground infrastructure.

3.2.4.4 Grade 2 Service

FSWR-33: The C&DH FSW shall format the HK telemetry to comply with the CCSDS AOS Grade 2 (**TBD**) service.

Rationale: For compatibility with existing ground infrastructure.

3.2.4.5 Virtual Channels

FSWR-34: The C&DH FSW shall send downlink data to the ground on different virtual channels, as specified in the LRO Mission Operations Concept Document (431-OPS-000042) section **TBD**.

Rationale: Allows for flexibility in routing data within the ground network.

3.2.4.6 Simultaneous Real-Time and Playback

FSWR-35: The C&DH FSW shall support the simultaneous downlink of both real time and stored HK data through all mission phases.

Rationale: Avoids gaps in science data.

3.2.4.7 Downlink Rates

FSWR-36: The C&DH FSW shall support downlink rates specified in the LRO Mission Operations Concept Document (431-OPS-000042) section **TBD**.

Rationale: FSW should support all rates implemented by the HW.

Note: LRO Rates are: **TBD** kbps, **TBD** kbps, etc.

3.2.4.8 Housekeeping

FSWR-37: The C&DH FSW shall provide the capability to collect and downlink HK telemetry through all phases of the mission.

Rationale: Need continuous monitoring of SC health.

3.2.4.9 Real-Time Telemetry

FSWR-38: The C&DH FSW shall collect and transmit Observatory HK telemetry to the ground station in (near) real-time.

Rationale: Allows operators to respond quickly to changing SC behavior.

3.2.4.10 Playback Command

FSWR-39: The C&DH FSW shall have the capability to playback stored telemetry to the ground station upon command.

Rationale: Need to return data for periods when the SC is not visible from Earth.

3.2.4.11 Simultaneous Record / Playback

FSWR-40: The C&DH FSW shall support the capability to collect and store HK telemetry while playing back stored telemetry to the ground station.

Rationale: Avoids gaps in HK data.

3.2.4.12 Reconfigurable Telemetry

FSWR-41: The C&DH FSW HK telemetry rates shall be reconfigurable via ground command.

Rationale: For anomaly resolution, may want to see some data more often.

Note: Implies the use of packet filter tables.

3.2.4.13 Packet Data Format

FSWR-42: The C&DH FSW shall format telemetry as CCSDS packets as specified in the CCSDS Blue Book - Packet Telemetry (CCSDS 102.0-B-5).

Rationale: For compatibility with existing ground infrastructure.

3.2.4.14 Packet Time Stamp

FSWR-43: The C&DH FSW shall time stamp telemetry packets accurate to +/-10 milliseconds (ms) relative to UTC.

Rationale: This accuracy is easy to achieve and is more than good enough for HK data.

3.2.4.15 Data Format CADUs

FSWR-44: The C&DH FSW shall format telemetry as CCSDS Channel Access Data Units (CADUs).

Rationale: For compatibility with existing ground infrastructure.

3.2.4.16 Sequence Number Filtering

FSWR-45: The C&DH FSW shall provide sequence number based filtering of telemetry packets.

Rationale: Simple method to slow down telemetry packets to avoid over-filling available bandwidth.

3.2.4.17 Time Filtering

FSWR-46: The C&DH FSW shall provide time based filtering of telemetry packets.

Rationale: Allows filtered packets to be synchronous even if sequence counts are out of sync.

3.2.4.18 Fill VCDUs

FSWR-47: The C&DH FSW shall not send fill Virtual Channel Data Units (VCDUs) when there is no other telemetry to send.

Rationale: The Comm card HW does this, so FSW shouldn't duplicate this function.

3.2.4.19 Redundancy

FSWR-48: The C&DH FSW shall be able to re-route real-time data to the Ka-band downlink HW by ground command.

Rationale: Backup mode in case of S-band downlink problems.

3.2.4.20 Filter Tables

FSWR-49: The C&DH FSW shall maintain separate telemetry packet filter tables for real-time telemetry and recorded HK data.

Rationale: Real-time telemetry rate is variable, not always matching the desired storage rate.

3.2.5 Local Data Storage Requirements

3.2.5.1 Manage Local Storage

FSWR-50: The C&DH FSW shall store 2 hours of HK data in local Single Board Computer (SBC) memory for later transmission to the ground station.

Rationale: This storage is used during Launch and Early Orbit (L&EO), before Solid State Recorder (SSR) is turned on. Also useful if the SSR gets turned off for load shedding in an emergency.

3.2.5.2 Record Rate

FSWR-51: The C&DH FSW shall have the capability to record HK telemetry at a sampling rate of up to 32 kilobits per second (kbps).

Rationale: 32 kbps is twice the planned rate - gives a healthy margin.

Note: FSW must support 32 kbps. This does not imply a hard ceiling at 32kbps enforced by FSW.

3.2.5.3 Memory Scrub

FSWR-52: The C&DH FSW shall provide memory scrubbing for the local processor Random Access Memory (RAM) to provide a bit error rate of less than 1x10-9(**TBD**) errors per bit day.

Rationale: HW Error Detection and Correction (EDAC) can correct single bit errors. We must catch single errors before we get another error in the same word.

3.2.5.4 Reconfigurable Storage

FSWR-53: The local RAM HK telemetry collection/storage rate and content shall be reconfigurable via ground command.

Rationale: Different mission phases require different combinations of HK packets and rates.

3.2.5.5 Data Recovery

FSWR-54: The C&DH FSW shall attempt to recover recorded data in local RAM on warm and cold resets.

Rationale: The data recorded just before a reset may be very important to determining the cause of the reset.

3.2.5.6 Data Storage Format

FSWR-55: The C&DH FSW shall store HK data in files in CCSDS packet format.

Rationale: Ground systems already understand CCSDS format. No need to invent another format.

3.2.5.7 Playback Command

FSWR-56: The C&DH FSW shall transmit all files or a specified file of stored HK data on command.

Rationale: Multi-file playback for normal use, single file playback for special cases.

3.2.5.8 Playback Format

FSWR-57: The C&DH FSW shall transmit stored data files to the ground using the CCSDS File Data Protocol (CFDP) protocol (class 1 or 2 service), as defined in CCSDS 727.0-B-2 (CCSDS File Delivery Protocol (CFDP): Blue Book) and 431-SPEC-000078 (LRO CFDP Implementation Specification).

Rationale: Reliable file transfer over a standard protocol.

3.2.5.9 Data Retransmission

FSWR-58: The C&DH FSW shall maintain played back data for retransmission on command. The data can be stored until released by command or overwritten with new data.

Rationale: When debugging an unplanned reset, must keep this data until we are sure it has been received.

3.2.5.10 Selectable Overwrite

FSWR-59: In the event the local RAM is full, the C&DH FSW shall either delete the oldest data file or discard the new data, selectable by ground command.

Rationale: Nominal use is a two hour circular buffer (overwrite). But, after a reset we want to "stop on full".

3.2.6 Solid State Recorder Management Requirements

3.2.6.1 Initialize Recorder

FSWR-60: The C&DH FSW shall initialize the SSR on command, according to the Solid State Recorder User's Guide (doc name and number **TBD**).

Rationale: SSR boots to a minimal mode to allow for code updates. C&DH must finish the init process.

3.2.6.2 Create Partitions

FSWR-61: The C&DH FSW shall create up to 16 partitions on the SSR according to a configuration table that can be modified from the ground.

Rationale: May want to change partition sizes post-launch.

3.2.6.3 Create Directories

FSWR-62: The C&DH FSW shall create up to 16 subdirectories within each SSR partition according to a configuration table that can be modified from the ground.

Rationale: Subdirectories allow for logical organization of different data types within one partition.

3.2.6.4 Mirror Housekeeping Data

FSWR-63: The C&DH FSW shall copy local HK data files to the SSR.

Rationale: Local storage is only two hours. LRO is out of ground contact much longer.

3.2.6.5 Solid State Recorder Communication

FSWR-64: The C&DH FSW shall communicate with the SSR over the Spacewire Bus as specified in the Solid State Recorder User's Guide (doc name and number **TBD**).

Rationale: Spacewire is the only interface to the SSR.

3.2.6.6 Store Science Data

FSWR-65: The C&DH FSW shall store science data in files on the SSR, formatted as specified in the applicable instrument data ICD.

Rationale: File-based storage makes data analysis easier on the ground.

3.2.6.7 Manage Solid State Recorder Files

FSWR-66: The C&DH FSW shall provide file/directory management ground commands for files stored on the SSR.

Rationale: Ground must be able to manage the SSR.

3.2.6.8 CFDP Messages

FSWR-67: The C&DH FSW shall forward CFDP protocol messages from the ground to the SSR.

Rationale: SSR has its own CFDP engine for downlink.

3.2.7 1553 Bus Control Requirements

3.2.7.1 Command Distribution

FSWR-68: The C&DH FSW shall use the 1553 bus to communicate with the relevant Observatory subsystems as specified in the Lunar Reconnaissance Orbiter Electrical System Specification (431-SPEC-000008).

Rationale: Observatory architecture requires the use of the 1553 bus.

3.2.7.2 TDM Schedule

FSWR-69: The C&DH FSW shall support a table driven time division multiplexed (TDM) Input/Output (I/O) scheme for scheduling 1553 bus transactions based on a one (1) second cycle.

Rationale: Predictable schedule makes testing of the remote terminals easier.

3.2.7.3 Redundancy

FSWR-70: The C&DH FSW shall support commands to configure operation of the redundant 1553 HW.

Rationale: Redundant feature are built into the 1553 HW, but must be configured by SW.

3.2.7.4 1553 Low-level Operations

FSWR-71: The C&DH FSW shall support a command to perform single 1553 protocol level transactions including mode codes.

Rationale: Needed for diagnostics of remote terminal problems.

3.2.8 Time Maintenance and Distribution Requirements

3.2.8.1 Timekeeping

FSWR-72: The C&DH FSW shall maintain an onboard SC time driven from the HW mission elapsed timer (MET).

Rationale: The oscillator driving MET is much more accurate than the processor clock.

3.2.8.2 Spacecraft Time Correlation

FSWR-73: The C&DH FSW shall support the ability to synchronize the SC time clock to ground-based UTC.

Rationale: Simplifies planning of mission ops, stored command loads.

3.2.8.3 Time Drift Correction

FSWR-74: The C&DH FSW shall support the ability to adjust and maintain the SC time clock to compensate for onboard time drift and stability effects.

Rationale: No oscillator is perfect.

3.2.8.4 Time Distribution via 1553

FSWR-75: The C&DH FSW shall distribute a time at the tone message at a 1 Hertz (Hz) rate via the 1553 and Spacewire data busses.

Rationale: When combined with an accurate 1Hz pulse, provides precise knowledge of SC time to the instruments.

3.2.8.5 Report Command Barker Time

FSWR-76: The C&DH FSW shall report the UTC of the last command barker sequence latched by the C&DH HW.

Rationale: Used to determine the difference between SC clock and ground time.

3.2.8.6 Time Adjustments

FSWR-77: The C&DH FSW shall provide the ability to modify the SC time via delta adjust or jam commands.

Rationale: Used to synchronize SC clock with ground time.

3.2.8.7 1Hz Delta Adjust

FSWR-78: The C&DH FSW shall provide the ability to increment or decrement the SC time by specified value at a 1 Hz rate.

Rationale: Used if the oscillator develops a constant or predictable drift rate.

3.2.9 Health and Safety Requirements

3.2.9.1 Fault Detection and Correction

FSWR-79: The C&DH FSW shall possess sufficient onboard autonomy to allow basic fault detection and correction (FDC).

Rationale: LRO will not always be visible from Earth.

3.2.9.2 Emergency Telemetry

FSWR-80: The C&DH FSW shall be designed to support low rate telemetry modes for emergency SC recovery operations.

Rationale: Emergency mode requires low rate telemetry output and telemetry filtering.

3.2.9.3 Software Monitoring

FSWR-81: The C&DH FSW shall monitor task execution and effect a reset if one or more critical tasks fails to execute.

Rationale: A problem with a critical task could prevent ground contact, so we must recover autonomously from this condition.

3.2.9.4 Event Messages

FSWR-82: The C&DH FSW shall monitor both HW and SW for performance and execution anomalies and, when detected, generate an event/error message or counter increment.

Rationale: For important but non-critical problems, we notify the ground and wait for instructions.

3.2.9.5 Event Monitoring

FSWR-83: The C&DH FSW shall monitor event messages and effect a reset for selected event messages.

Rationale: Certain events may indicate critical errors.

3.2.9.6 Maintain Watchdog Timer

FSWR-84: The C&DH FSW shall maintain the flight watchdog timer.

Rationale: HW will re-boot processor if SW doesn't service the watchdog.

3.2.9.7 Cold Reset

FSWR-85: Upon time-out of the watchdog timer, the C&DH FSW shall affect a cold reset.

Rationale: Watchdog timeout indicates a bad problem. So, we want to initialize everything to maximize the chance of clearing the problem.

3.2.9.8 CPU Performance Monitor

FSWR-86: The C&DH FSW shall provide a performance monitor to compute the flight Central Processing Unit (CPU) utilization.

Rationale: This may help with debugging problems in flight.

3.2.9.9 Memory Checksums

FSWR-87: The C&DH FSW shall periodically compute checksums for all required memory areas to include RAM and EEPROM.

Rationale: Attempt to catch memory upsets before the bad data causes a serious problem.

3.2.9.10 Telemetry Monitor

FSWR-88: The C&DH FSW shall provide for on-board telemetry monitoring points.

Rationale: Need to detect problems so that corrective actions can be initiated.

3.2.9.11 Monitor Point Modification

FSWR-89: The selection of the monitored points shall be table driven and configurable via ground uploads.

Rationale: Conditions may change after launch. Need flexibility to react to new situations.

3.2.9.12 Failure Events

FSWR-90: The C&DH FSW shall be able to execute autonomous recovery sequences upon detection of threshold failures in monitored telemetry.

Rationale: Some failures may indicate severe problems that must be corrected without waiting for ground commands.

3.2.9.13 Configurable Recovery

FSWR-91: The contents of recovery sequences shall be configurable via ground uploads.

Rationale: Conditions may change after launch. Need flexibility to react to new situations.

3.2.9.14 Exception Handling

FSWR-92: The C&DH FSW shall provide exception handling SW. Corrective actions will be provided as specified in the Lunar Reconnaissance Orbiter FDH Interface Control Document (doc name and number **TBD**).

Rationale: Attempt to minimize operational impacts and maximize data return when handling exceptions, errors, and upsets.

3.2.9.15 HW Diagnostics

FSWR-93: On command, the C&DH FSW shall run diagnostic tests of the C&DH HW cards.

Rationale: This may help with debugging problems in flight.

3.2.9.16 Memory Tests

FSWR-94: On command, the C&DH FSW shall run a memory test on any specified area of addressable memory.

Rationale: This may help with debugging problems in flight.

3.2.10 <u>Software Maintenance Requirements</u>

3.2.10.1 Memory Load

FSWR-95: The C&DH FSW shall provide the capability to load code and data from the ground to RAM.

Rationale: Need to validate FSW updates in temporary storage.

3.2.10.2 EEPROM Load

FSWR-96: The C&DH FSW shall provide the capability to load code and data from the ground to non-volatile memory.

Rationale: Once an update is validated, we may want to make it permanent.

3.2.10.3 Memory Dump

FSWR-97: The C&DH FSW shall provide the capability to dump onboard processor memory to the ground station.

Rationale: Used to validate loads in EEPROM or RAM.

3.2.10.4 Memory Dwell

FSWR-98: The C&DH FSW shall provide the capability to telemeter the contents of ground selectable memory locations at periodic rates.

Rationale: Required for on-orbit monitoring and anomaly investigation.

3.2.10.5 Table Management

FSWR-99: The C&DH FSW shall provide the capability to load and dump data tables.

Rationale: Decouples command data table references from physical memory addresses.

3.2.10.6 Code Patching

FSWR-100: The C&DH FSW shall be capable of being ""patched"" while executing in RAM.

Rationale: Need to validate FSW updates in temporary storage.

3.2.11 Instrument Interface Requirements

3.2.11.1 CRaTER ICD

FSWR-101: The C&DH FSW shall communicate with the CRaTER instrument over the 1553 bus as specified in the CRaTER Data Interface Control Document (431-ICD-000104).

Rationale: Following the ICD exactly will make integration go smoothly.

3.2.11.2 Diviner ICD

FSWR-102: The C&DH FSW shall communicate with the Diviner instrument over the 1553 bus as specified in the Diviner Data Interface Control Document (431-ICD-000105).

Rationale: Following the ICD exactly will make integration go smoothly.

3.2.11.3 LEND ICD

FSWR-103: The C&DH FSW shall communicate with the LEND instrument over the 1553 bus as specified in the LEND Data Interface Control Document (431-ICD-000107).

Rationale: Following the ICD exactly will make integration go smoothly.

3.2.11.4 LOLA ICD

FSWR-104: The C&DH FSW shall communicate with the LOLA instrument over the 1553 bus as specified in the LOLA Data Interface Control Document (431-ICD-000108).

Rationale: Following the ICD exactly will make integration go smoothly.

3.2.11.5 LAMP ICD

FSWR-105: The C&DH FSW shall communicate with the LAMP instruments through the instrument interface (IIF) Card as specified in the LAMP Data Interface Control Document (431-ICD-000106).

Rationale: Following the ICD exactly will make integration go smoothly.

3.2.11.6 LROC ICD

FSWR-106: The C&DH FSW shall communicate with the LROC instruments over the Spacewire bus as specified in the LROC Data Interface Control Document (431-ICD-000109).

Rationale: Following the ICD exactly will make integration go smoothly.

3.3 GUIDANCE, NAVIGATION AND CONTROL SOFTWARE REQUIREMENTS

3.3.1 Sensor and Actuator Data Processing Requirements

3.3.1.1 Separation Data

FSWR-107: The GN&C FSW shall process the vehicle separation data at the control law execution rate (**TBD**).

Rationale: The separation state must be known to the GN&C FSW so it won't command actuators until after separation.

3.3.1.2 Coarse Sun Sensor Data Processing

FSWR-108: The GN&C FSW shall read the Coarse Sun Sensor (CSS) data at the control law execution rate and compute a sun direction vector in the SC body reference frame.

Rationale: Supports a sun-pointing mode that doesn't require a valid ephemeris or inertial sensors.

3.3.1.3 Inertial Reference Unit Data Processing

FSWR-109: The GN&C FSW shall read the Inertial Reference Unit (IRU) data at the control law execution rate and compute a rate vector in the SC body reference frame.

Rationale: SC rates are recomputed for each control mode, momentum management, attitude estimation.

3.3.1.4 Star Tracker Data Processing

FSWR-110: The GN&C FSW shall read the Star Tracker (ST) data at the control law execution rate (**TBD**) and compute an estimated SC attitude and a SC rate vector in the SC body reference frame.

Rationale: The attitude supports attitude estimation and the rate serves as a backup to the IRU.

3.3.1.5 Reaction Wheel Data Processing

FSWR-111: The GN&C FSW shall read the Reaction Wheel (RW) data at the control law execution rate, monitor wheel performance, and wheel momentum in the SC body reference frame.

Rationale: RW data is required for system momentum. Wheel performance needs to be monitored for SC Health and Safety.

3.3.1.6 Propulsion Data Processing

FSWR-112: The GN&C FSW shall read the propulsion data at the control law execution rate and compute cumulative propulsion on-time for each thruster.

Rationale: Provide data for post-burn performance analysis.

3.3.1.7 Data Processing Fault Detection

FSWR-113: The GN&C FSW shall monitor the health of each sensor and actuator and provide status telemetry that can be monitored by the C&DH FSW.

Rationale: HW performance needs to be monitored for SC Health and Safety.

3.3.1.8 Data Processing Telemetry

FSWR-114: The GN&C FSW shall telemeter all raw and processed sensor data.

Rationale: Provide data for HW and SW performance analysis.

3.3.2 On Board Models Requirements

3.3.2.1 Spacecraft Ephemeris Updates

FSWR-115: The GN&C FSW shall accept and validate SC ephemeris tables.

Rationale: Must have onboard SC ephemeris knowledge to perform other functions such as Nadir pointing and HGA control. Use table/interpolation scheme to meet accuracy requirements and bound the errors.

3.3.2.2 Spacecraft Ephemeris Interpolation

FSWR-116: The GN&C FSW shall interpolate between SC ephemeris tables entries to compute the ephemeris for a specific time.

Rationale: The resolution of the ephemeris table entries will not be at the rate where an ephemeris solution is required.

3.3.2.3 Lunar Ephemeris Updates

FSWR-117: The GN&C FSW shall accept and validate Lunar ephemeris tables.

Rationale: Must have onboard Lunar ephemeris knowledge to perform other functions such as Nadir pointing. Use table/interpolation scheme to meet accuracy requirements and bound the errors.

3.3.2.4 Lunar Ephemeris Interpolation

FSWR-118: The GN&C FSW shall interpolate between Lunar ephemeris tables entries to compute the ephemeris for a specific time.

Rationale: The resolution of the ephemeris table entries will not be at the rate where an ephemeris solution is required.

3.3.2.5 Solar Ephemeris

FSWR-119: The GN&C FSW shall compute Solar position vectors in J2000 GCI coordinates.

Rationale: Required for SA pointing.

3.3.2.6 Ground Station Position

FSWR-120: The GN&C FSW shall compute ground station position vectors in J2000 GCI coordinates.

Rationale: Required for HGA pointing.

3.3.3 <u>Spacecraft State Determination Requirements</u>

3.3.3.1 Spacecraft Rate Vector Selection

FSWR-121: The GN&C FSW shall use either the IRU-derived or ST-derived SC rate vector for all GN&C SW functions.

Rationale: Provide backup rate source and make all GN&C results based on a single rate source.

Note: Consistent rate required for attitude estimation, momentum estimation, and attitude control.

3.3.3.2 Attitude Estimation

FSWR-122: The GN&C FSW shall maintain an estimate of the 3 axis attitude of the Observatory with respect to the J2000 GCI coordinates.

Rationale: Needed for inertial controllers, HGA pointing, and SA pointing.

3.3.3.3 Attitude Estimate Updates from Ground

FSWR-123: The GN&C FSW shall support commanded updates of the attitude estimate.

Rationale: Flight Dynamics must have a ground interface for managing the onboard attitude.

3.3.3.4 Attitude Estimate Updates from Star Tracker

FSWR-124: The GN&C FSW shall allow ST attitude estimates to be used as the FSW attitude estimate.

Rationale: Allow autonomous attitude initialization and satisfies requirement FSWR-122.

3.3.3.5 Momentum Computation

FSWR-125: The GN&C FSW shall compute the total angular momentum in the body reference frame.

Rationale: Allow autonomous attitude initialization and maintain attitude estimate during thruster maneuvers.

3.3.4 <u>Spacecraft Attitude Control Requirements</u>

3.3.4.1 Target Quaternion Table

FSWR-126: The GN&C FSW shall support use of an uplinked target quaternion table.

Rationale: Support autonomous time-based target quaternion commands. This is useful for time sequenced off-Nadir pointing, calibration maneuvers, Delta-V burn attitude profiles.

3.3.4.2 Lunar Nadir Positive-X Velocity Target quaternion

FSWR-127: The GN&C FSW shall compute a Lunar Nadir Positive-X Velocity (LNPXV) target quaternion.

Rationale: Support Nadir pointing requirement.

3.3.4.3 Sun Pointing Target Quaternion

FSWR-128: The GN&C FSW shall compute a body direction vector to sun-pointing quaternion.

Rationale: Provide an inertially controlled sun-pointing capability. Allow a sun pointing mode without "degrading" to non-inertial control mode.

3.3.4.4 Attitude Estimate Updates from Star Tracker

FSWR-129: The GN&C FSW shall allow ST attitude estimates to be used as the FSW attitude estimate.

3.3.4.5 Momentum Computation

FSWR-130: The GN&C FSW shall compute the total angular momentum in the body reference frame.

Rationale: Required for Delta-H ad failure detection.

3.3.4.6 Coarse Sun Sensor Sun Acquisition Control Mode

FSWR-131: The GN&C FSW shall provide a CSS Sun Pointing attitude control mode.

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

3.3.4.7 Coarse Sun Sensor Sun Acquisition Mode Input

FSWR-132: The GN&C FSW shall use the selected body rate vector and the CSS-derived sun direction as sensor inputs to CSS Sun Acquisition Mode.

Rationale: CSS-derived vector does not rely on inertial knowledge. Use whatever rate source is available (i.e. selected rate).

3.3.4.8 Coarse Sun Sensor Sun Acquisition Mode Output

FSWR-133: The GN&C FSW shall use the RWs for torque actuation while in CSS Sun Acquisition Mode.

Rationale: Don't want to use thrusters.

3.3.4.9 Mission Control Mode

FSWR-134: The GN&C FSW shall provide a science attitude control mode.

Rationale: Required for course corrections, calibrations, etc.

3.3.4.10 Mission Mode Input

FSWR-135: The GN&C FSW shall use the selected body rate vector, the estimated attitude, and a ground selected target quaternion as inputs to Mission Mode.

3.3.4.11 Mission Mode Output

FSWR-136: The GN&C FSW shall use the RWs for torque actuation while in Mission Mode.

3.3.4.12 Delta-H Control Mode

FSWR-137: The GN&C FSW shall provide a Delta-H control mode.

3.3.4.13 Delta-H Input

FSWR-138: The GN&C FSW shall use the selected body rate vector, estimate attitude, and computed system momentum as inputs to Delta-H Mode.

3.3.4.14 Delta-H Input

FSWR-139: The GN&C FSW shall use the thrusters and RWs for actuation while in Delta-H Mode.

3.3.4.15 Delta-V Control Mode

FSWR-140: The GN&C FSW shall provide a Delta-V attitude control mode.

3.3.4.16 Delta-V Input

FSWR-141: The GN&C FSW shall use the selected body rate vector, the estimated attitude, and a ground selected target quaternion as inputs to Delta-V Mode.

3.3.4.17 Delta-V Output

FSWR-142: The GN&C FSW shall the thrusters for torque actuation while in Delta-V Mode.

3.3.4.18 Control Mode Fault Detection

FSWR-143: The GN&C FSW shall monitor the performance of each control mode and provide status telemetry that can be monitored by the C&DH FSW.

Rationale: Support autonomous failure detection and correction.

3.3.4.19 Control Mode Telemetry

FSWR-144: The GN&C FSW shall telemeter sufficient data to determine the status and performance of each control mode. Provide data for SW performance analysis.

3.3.5 Actuator Commanding Requirements

3.3.5.1 Reaction Wheel Commands

FSWR-145: The GN&C FSW shall send RW commands at the control law execution rate.

3.3.5.2 Reaction Wheel Command Override

FSWR-146: The GN&C FSW shall provide the capability to override the onboard RW commands with a command-supplied value.

3.3.5.3 Propulsion Commands

FSWR-147: The GN&C FSW shall send propulsion commands at the control law execution rate.

3.3.5.4 Propulsion Command Override

FSWR-148: The GN&C FSW shall provide the capability to override the onboard propulsion commands with command supplied value.

3.3.6 Solar Array Control Requirements

3.3.6.1 Solar Array Data Processing

FSWR-149: The GN&C FSW shall read SA orientation data at 1 Hz (**TBD**) and compute a SA normal to sun angle.

3.3.6.2 Solar Array Control

FSWR-150: The GN&C FSW shall command the SA gimbals at 1Hz (**TBD**) to orient the SA normal to the sunline.

3.3.6.3 Solar Array Fault Detection

FSWR-151: The GN&C FSW shall monitor the health of the SA and provide status telemetry that can be monitored by the C&DH FSW.

Rationale: Support autonomous failure detection and correction.

3.3.6.4 Solar Array Telemetry

FSWR-152: The GN&C FSW shall telemeter all raw and processed SA data and sufficient data to determine the status and performance of the SA controller.

Rationale: Provide data for HW and SW performance analysis.

3.3.7 High Gain Antenna Pointing Requirements

3.3.7.1 High Gain Antenna Data Processing

FSWR-153: The GN&C FSW shall read HGA orientation data at 5 Hz (**TBD**) and compute an HGA-pointing direction vector in the SC body frame.

3.3.7.2 High Gain Antenna Control

FSWR-154: The GN&C FSW shall command the HGA gimbals at 5 Hz (**TBD**) to point the HGA towards a ground station.

3.3.7.3 High Gain Antenna Fault Detection

FSWR-155: The GN&C FSW shall monitor the health of the HGA and provide status telemetry that can be monitored by the C&DH FSW.

Rationale: Support autonomous failure detection and correction.

3.3.7.4 High Gain Antenna Telemetry

FSWR-156: The GN&C FSW shall telemeter all raw and processed HGA data and sufficient data to determine the status and performance of the HGA controller.

Rationale: Provide data for HW and SW performance analysis.

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” HW complies with contractual design and construction requirements. Validation of manufacturing records at end-item acceptance verifies that the “as-built” HW 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 SC conditions such as configuration, cleanliness, and locking HW. 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 HW and SW 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 HW after major operations, such as transportation of flight HW 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 HW to assure that flight HW 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 HW 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 HW 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 HW-SW 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 (TBD)

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
A	Analysis
AOS	Advanced Orbiting Systems
ATS	Absolute Time Sequence
C&DH	Command and Data Handling
CADU	Channel Access Data Unit
CCB	Configuration Control Board
CCR	Configuration Change Request
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CM	Configuration Management
CMO	Configuration Management Office
COP-1	Command Operation Protocol #1
CPU	Central Processor Unit
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
CSS	Coarse Sun Sensor
D	Demonstration
EDAC	Error Detection and Correction
EEPROM	Electrically Erasable Programmable Read-Only Memory
ELV	Expendable Launch Vehicle
FDC	Fault Detection and Correction
FMEA	Failure Modes and Effects Analysis
FSW	Flight Software
GN&C	Guidance Navigation and Control
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HK	Housekeeping
HW	hardware
Hz	Hertz
I	Inspection
I/O	Input/Output
IIF	Instrument Interface
Inst	Instrument
IRU	Inertial Reference Unit
kbps	kilobits per second
kg	kilogram
km	kilometer
KSC	Kennedy Space Center
L&EO	Launch and Early Operations

Abbreviation/ Acronym	DEFINITION
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LNPXV	Lunar Nadir Positive-X Velocity
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
MET	Mission Elapsed Time
ms	millisecond
NASA	National Aeronautics and Space Administration
NPR	NASA Procedural Requirement
Ops	Operations
PDL	Product Design Lead
PPS	Pulse Per Second
PROM	Programmable Read-Only Memory
RAM	Random Access Memory
RF	Radio Frequency
RQMT	Requirement
RTS	Relative Time Sequence
RW	Reaction Wheel
SA	Solar Array
SBC	Single Board Computer
SC	Spacecraft
SSR	Solid State Recorder
ST	Star Tracker
SW	Software
T	Test
TBD	To be determined
TBR	To be resolved
TDM	Time Division Multiplexed
UTC	Universal Time Code
VDCU	Virtual Channel Data Unit

Appendix B. Traceability Matrix (TBD)

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.