Lunar Reconnaissance Orbiter (LRO) Project
Mission Requirements Document

430-REQT-00011
Revision (-)

Effective Date: TBD
Expiration Date: TBD

Prepared by:

National Aeronautics and
Space Administration

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1.1	**Mission Design**					
1.1.10	Launch Mass	LRO's launch mass shall not exceed 1480 kg.	Upper end of Delta II performance, assuming 9.5 ft fairing, 5 kg yo-yo, and direct transfer.			
1.1.14	Launch Envelope	LRO shall fit within a 9.5 ft (diameter) fairing.	Tied to Launch Mass. If changed, Launch Mass must be reassessed.			
1.1.18	Launch Trajectory	LRO shall utilize a direct lunar transfer trajectory.	Provides adequate performance while minimizing transfer time and complexity.		FD	RLEP-LRO-P20. RLEP-LRO-P30
1.1.22	Launch Window	The LRO launch window shall be constrained such that the nominal spin direction at separation is within 15 deg of either the sun or anti-sun.	Protects against immediate sun exposure down the instrument boresights (assumes instruments are perpendicular to spin axis).			
1.1.26	Propulsive Despin	LRO shall have the ability to despin autonomously, propulsively, from rates as high as 360 deg/s, one axis, at LV separation.	Needed in case residual momentum exceeds momentum storage capability (LV yo-yo failure, for example). Must avoid flat spin to ensure sun avoidance on instruments.			
1.1.30	Non-Propulsive Ops	LRO shall have the ability to handle body rates of at least 2 deg/s, per axis, without firing thrusters.	Gives reasonable chance of avoiding early (autonomous) thruster firings.			
1.1.34	Deployables	LRO's deployables shall be capable of deploying with body rates as high as 2 deg/s, per axis.	Would like to deploy the array, for example, as soon as possible after LV separation.			
1.1.38	Sun Pointing	The LRO design shall include a mode capable of putting the observatory into a known orientation with respect to the sun without knowing its inertial position.	Provides for sun pointing without the need for a valid ephemeris or inertial sensors.			
1.1.42	Inertial Pointing	The LRO design shall include a mode capable of putting the observatory into a known orientation with respect to inertial space.	Needed, first, for course corrections, but also, later, for instrument calibrations, etc.			
1.1.46	Propulsive Maneuvers	LRO shall have the ability to do course corrections, lunar orbit insertion, station-keeping, and momentum management using an onboard propulsion system.	Onboard propulsion is required to do any long term lunar mission.		FD, Prop	MRD 2.5.1
1.1.50	Low Maintenance Orbit	LRO shall make use of a low maintenance orbit for instrument commissioning.	Conserves fuel prior to nominal mission. Same orbit may be used for extended mission.			
1.1.54	Mission Orbit	The primary mission shall be conducted in a circular mapping orbit with a nominal mean altitude of 50 +/- 20 km (altitude is measured to mean lunar surface).	Lowest practical altitude and tolorance given fuel considerations.		Prop, ACS, FLT DYN, Thermal	RLEP-LRO-P50
1.1.58	Orbit Inclination	The orbit inclination shall be 90 degrees +/- 1 degree.	Poles are of greatest interest, but lunar polar orbits wabble.		FLT DYN, ACS, Thermal, Prop	RLEP-LRO-P50
1.1.62	Nadir Pointing	The LRO design shall include a mode capable of putting the observatory into a known orientation with respect to the lunar surface.	Will be used for normal operations, including "off-nadir" observations.		ALL	RLEP-LRO-P70
1.1.66	Solar Array Pointing	LRO shall be capable of pointing its solar array at the sun while maintaining a lunar referenced orientation.	Must be power positive during normal ops.			
1.1.70	Antenna Pointing	LRO shall be capable of pointing its HGA at the Earth while maintaining a lunar referenced orientation.	Must be able to simultaneously take and send data.			
1.1.74	Momentum Management	LRO shall be capable of going at least 2 weeks (goal of 4) without a momentum management maneuver.	Plan to do all maneuvers within view of Earth. Goal is to minimize impact on science.			

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1.1.78	Yaw Maneuvers	Twice a year, LRO shall perform a 180 deg yaw maneuver, reversing its direction of flight.	Must be done to keep the sun on the correct (solar array) side of the spacecraft.			
1.1.82	Lunar Eclipses	LRO shall be capable of withstanding a worst case lunar eclipse (160 min), twice a year, on average.	Lunar eclipses will occurr throught the mission. Some form of hibernation is an option.			
1.1.86	Mission Duration	LRO shall be designed to have a minimum mission duration of 14 months.	Predicted 2 month commissioning phase plus minimum 1 year mapping mission.		ALL	RLEP-LRO-P10
1.1.90	Extended Mission	LRO shall carry sufficent consumables to allow for a 4 year extended mission in a low maintainance orbit.	It may be desirble to use LRO as a communication relay for follow on RLEP mission or alternatively continue primary LRO observations beyond the baseline 1 year.	Baseline extended mission as comm relay, not measurements. Any extra mass will be carried as fuel at launch. That fuel can be used for extended measurements after the primary mission. However, relay comm Is the primary extended mission.	ALL	RLEP-LRO-P10
1.1.94	End of Mission	LRO's mission will be terminated in a manner that meets NASA Planetary Protection Requirements as stated in NPD 8020.7F	LRO Mission is Category 1 based on NPR 8020.12C, section A.1. If certified as Category 1 by The Associate Administrator for Space Science, no additional requirements apply	The current scientific consensus is that the potential for indigenous life on the Moon is negligible, and that forward and back contamination resulting from lunar exploration are not concerns	GNC	RLEP-LRO-P10
1.2	**Launch Vehicle**					
1.2.10	Vehicle Performance	The launch vehicle must be capable of delivering a 1480 kg payload to a trajectory with a $C_3 > -1.85$	Provides boundry conditions for Flight Dynamics and Propulsion for Trans Lunar Injection (TLI). Bounds S/C launch mass.	C3 can range from -1.85 to -2.0 based on monthly and seasonal variations	LV, FLT DYN, PROP	2.1.1 (TLI)
1.2.14	Insertion Accuracy	TLI accuracy at orbiter separation from the LV third stage shall be within +/- 3 m/sec (TBR) (3-sigma) of target inertial velocity.	TLI injection errors will be corrected by spacecraft at MCC1. Above requirement is allocated in dV budget.		LV, FLT DYN, PROP	2.4.1 (TLI)
1.2.18	De-Spin	The LV shall despin LRO to a rate < 2 rpm.	Provides some chance of being able to avoid early (autonomous) thruster firings.	Requires detailed knowledge of orbiter MOI's and will require both analysis and dynamic measurments	LV, FLT DYN, PROP, ACS	Derived
1.2.22	Tip Off rates	The LV induced tip-off rates shall be < 2 deg/sec (3σ), in the transverse axes, at separation.	Assume LV has de-spun Orbiter to approximately zero rate prior to separation. Low tip off rates required to assure tip off capture by wheels.	Requires detailed knowledge of orbiter MOI's and will require both analysis and dynamic measurments	LV, FLT DYN, ACS, Instruments	MRD 2.4.4
1.2.26	Vehicle Interfaces	LRO shall be compatible with all LV operations, interfaces, and environments as specified in Delta II Payload Planners Guide and the LRO ELV Mission Specification. In the event of a conflict the Mission Specification takes precendence.	Payload Planners Guide is the generic source of Delta II performance and interface data, the Mission Specification is the standard Boeing format ICD between the Orbiter and the ELV.		ALL	RLEP-LRO-P40

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1.3	**Accommodation**					
1.3.10	Mass Allocations	Subsystems/instruments shall not exceed the mass allocations given in TBD.	Mass budget is managed outside of the MRD.	Reference Mass Budget/ Allocation requirement	ALL Components	2.4.1 (LV mass), 2.7.1.6 Resource Margins
1.3.14	Power Allocations	Subsystems/instruments shall not exceed the power allocations given in TBD.	Power budget is managed outside of the MRD.	Reference Power Budget/ Allocation requirement.	ALL Components	2.6.3 Power provision, 2.7.1.6 Resource Margins
1.3.16	Electrical Interfaces	Subsystems/instruments shall comply with all LRO Electrical System Specifications.	All electrical interfaces must be managed and coordinated to ensure mission success.	Includes grounding.	ALL Components	
1.3.18	Thermal Interfaces	Subsystems/instruments shall comply with all LRO Thermal System Specifications.	All thermal interfaces must be managed and coordinated to ensure mission success.		ALL Components	
1.3.20	Low-Rate Data	LRO shall utilize a MIL-STD-1553 network per 431-SPEC-000102 for telemetry and control..	Minimizes backplane and harness connections between boards and boxes. Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth			
1.3.22	High-Rate Data	LRO shall utilize a SpaceWire network per 431-SPEC-000103 for high rate data.	Minimizes backplane and harness connections between boards and boxes. Industry standard interfaces simplify instrument interfaces, improve flexibility and support future growth			
1.3.26	Data Storage	LRO shall have a data storage capability of at least 400 Gbits for storing measurement data.	SSR Storage requirement: (Based on 4 ground station passes back to back, each 45 minutes long with the time between last and first pass is ~1044 minutes). SSR needs to store 6.4 Mbps average data rate (includes all instruments and S/C engineering) for at least 1044 minutes. Gives approximately 391 Gbits (assuming max LROC data, 16 NAC pairs per orbit).			
1.3.30	Data Volume	LRO and its Ground Data System shall be capable of transmitting 1200 Gbits of data to the ground per day.	Total capability (based on 4-ground stations passes, 45 minutes each dumping ~115 Mbps (Data + RS) = ~1212 Gbits/Day		COMM, C&DH, INSTR, FSW, GND	2.1 Orbit, 2.5.2 Mission Phases
1.3.34	Ranging Accuracy	LRO and its GDS shall achive a radiometric doppler measurement accuracy of less than 1 mm/sec.	Per LRO Flight Dynamics, Doppler accuracy of 8 mm/sec is sufficient to maintain LRO's stated orbital knowledge. However, in order to have the future capability to improve the tracking data utilizing a more accurate gravity model, a Doppler accuracy or 1 mm/sec is required.		FLT DYN, COMM	RLEP-LRO-M30; RLEP-LRO-P130
1.3.38	Orbit Determination	LRO shall have a minimum Orbit Determination Accuracy of 500/18m (Total Position RMS/Radial RMS), 1-sigma, post-processed.	Knowledge assuming LP100K gravity model and existing S-band RF tracking capabilities.		Prop, ACS, FLT DYN, COMM	RLEP-LRO-M30
1.3.42	Time Correlation	LRO shall provide a mechanism for time correlation of Orbiter time to UTC time accurate to 3 (TBR) msec	Time corrolation is required to ensure lunar mapping with sufficient geodetic accuracy		C&DH, FSW	2.1 Orbit, 2.5.2 Mission Phases
1.3.46	Pointing Accuracy	LRO shall provide 60 arc-sec (3_), per axis, inertial pointing accuracy at the instrument interface.	This is sufficient to support all types of data collection.	The Orbiter will normally point the instruments to th LVLH nadir direction to within this accuracy.	GNC, Mech, Thermal	MRD 2.5.5
1.3.50	Pointing Knowledge	LRO shall provide 30 arc-sec (3_), per axis, inertial pointing knowledge at the instrument interface.	This is sufficient to support all types of data collection.		GNC	MRD 2.5.5

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1.3.54	Pointing Stability	LRO shall provide pointing stability (3_), of 5 arc-sec /axis over 1 ms, 10 arc-sec/axis over 100 ms, 20 arc-sec/axis over 4 sec.	This is sufficient to support all types of data collection.		GNC, Mech, Thermal	MRD 2.5.5
1.3.58	Mapping Accuracy	*The Orbiter shall provide TBD arc-sec (3_) lunar pointing accuracy per axis for the instrument interface modes.*	need to correctly describe how well we'll point at what we planned to	*Explain relationship with OD & tracking*	Mech, Thermal, Instruments	
1.3.62	Mapping Knowledge	*The Orbiter shall provide TBD arc-sec (3_) lunar pointing knowledge per axis for the instrument interface during mission science modes*	describe how well we'll know what /where we did point to.	*Explain relationship with OD & tracking*		
1.3.66	Mission Phases	The Orbiter and mission shall be designed to support all mission phases defined in the LRO Mission Operations Concept Document. 431-OPS-000042.	Ops concept is managed outside of the MRD.		ALL	
1.3.68	Continuous Operations	LRO and its Ground Data System shall be designed to support continuous operations during the primary mission, except for planned outages for momentum and orbit adjusts, and instrument calibrations.	Ensures the maximum data return.	Note continuous operations does not mean continous Orbiter communications or 24/7 mission operations staffing		
1.3.72	Sun Avoidance	LRO shall not slew the instruments through the sun at less than 1 deg/sec, nor continuously put the sun within 30 deg of the instrument boresights or directly on thermal radiators for (TBD) period of time.	LOLA requires < 1deg/s rate. LAMP requires no continuous sun within 11 deg of its boresight. No continuous sun pointing within 30 degrees of the NACs and a minimum slew rate of 0.1 deg/sec in the instrument boresight for LROC. (Continue to flush out.)	The launch window will ensure this is met prior to separation. After that it's up to onboard systems. Overall requirement envelopes instruments.	FD, Thermal, Power, Mech	MRD 2.5.1, Inst Sun Aviod
1.3.74	Maneuver Notification	LRO shall safe the instruments, as required, prior to any thruster operations.	In general, maneuvers will require off-nadir pointing. Also may be contamination concern.	Instrument safing for structural, thermal, or contamination concerns.	PROP, ACS, C&DH	
1.3.78	Data Completeness	LRO shall provide sufficient science data collection to the instrument science centers and PDS to meet the level 1 mission requirements over a 1 year period commencing after instrument commissioning.	*Repeatd passes over the lunar poles is required to met the resolution requirements. Repeated passes are also required to provide the required coverage maps of the surface*		GND, C&DH, COMM	
1.3.82	Data Product Delivery	The mission shall deliver all data products specified in the LRO Level 1 requirements to the Planetary Data System for archiving and distribution.	The PDS is the final clearing house for all LRO measurement data.		Instruments	RLEP-LRO-P120, MRD 2.5.4
1.3.86	Information Assurance	The Lunar Reconnaissance Orbiter communication system shall provide Information Assurance in compliance with NASA policies, specifically NPD 2810.1 and GPD 2810.X?	This NASA Procedural Requirements (NPR) implements the NASA Policy Directive (NPD) 2810, Security of Information Technology. The NPR describes the NASA IT Security Program, providing 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	Can't find any reference to GPD 2810		
1.3.90	Comm Relay Function	LRO shall be capable of operating as a comm relay for any compatible missions conducted during its life.	Flowed down from RLEP-LRO-P170 & TBD RLEP doc.			

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1.4	**QA Guidelines**					
1.4.10	Risk Classification	LRO shall meet the NPR8705.4 Appendix B requirements for Class C payloads with the exception of Test Program and EEE Parts requirements which shall meet the requirements for Class B payloads	LRO is a "Discovery Class" mission, but is of vital importance to Exploration. Step will be taken, within budget, to increase its reliability.			
1.4.14	Mission Assurance	The LRO mission shall meet the S&MA requirements in the RLEP MAR 430-RQMT-000006.	Mission Assurance is handled outside of the MRD.		All	
1.4.18	Configuration Control	LRO configuration shall be controlled in accoradnce with the RLEP CM Plan 430-PG-1410.2.1.	Configuration Management is handled outside of the MRD.			2.7.1 MAR
1.4.22	Requirements Control	Derived subsystem requirements and specifications, to the component level, require the review & approval of the LRO Mission Systems Engineer or designate.	Ensures a cohesive set of requirements throughout the mission (Golden Rule).	Subs and instrumenters will develop lower level requirements and specs.	ALL	2.7.1.2 SMA, 2.7.1.3 CM
1.4.26	Margins/Reserves	Technical margins and reserves shall be maintained per the LRO Systems Engineering Management Plan (SEMP) 431-PLAN-000005.	Careful management of margins and reserves is critical to mission success.	Required technical resource margins at launch are specified in Table # 1		2.7.1
1.4.30	Coordinate Systems	All subsystems and instruments must reference the common coordinate system shown in figure TBD.	This will aid in clear, concise communication between subsystems and with instrumenters.	LRO Coordinate System is defined in figure # 1	ALL	2.7.1.3 CM
1.4.34	Units Policy	All LRO subsystems and Instruments shall adhere to the units policy detailed in the LRO SEMP 431-PLAN-000005.	Addresses the need to plan for and prevent the misapplication of English and Metric units in all aspects of mission development & operations.	Mechanical in english units with metrical units in paranthetics. Put in SEMP.	ALL	NASA NPD 8010.2C
1.4.38	Environmental Testing	LRO shall undergo environmental verifiaction testing in accordance with GSFC-STD-7000 (GEVS).	This is Goddard policy.			
1.4.42	Dynamic Loads	The orbiter shall survive the dynamic loads of the mission as specified in LRO Structural Load and Mechanical Environments, 431-SPEC-000022.	Derived from Delta II enveloping case to include Atlas V considerations. Covers all mission phases per Ops Concept Doc.		Orbiter	RLEP-LRO-P40
1.4.46	Thermal Environments	The orbiter shall survive the mission thermal environmentsas specified in the LRO Thermal Environments Specification, 431-SPEC-0000##.	Provides temp predicts for components and environments for all mission phases.		Orbiter	Derived
1.4.50	Radiation Environment	The spacecraft shall survive the mission radiation environments as specified in the LRO Radiation Environment Specification, 431-SPEC-000020.	Provides radiation environment for all mission phases. Sets total dosage, SEU, SEL levels.		ALL	MRD 2.1.1, 2.2.1, 2.5.2
1.4.54	EEE Parts	All subsystems utilizing EEE parts shall meet the requirements of the LRO Radiation Requirements Doc 431-RQMT-00045.	EEE Parts have unique concerns that must be handled appropriately.		Orbiter	MRD 2.3.3
1.4.58	Magnetics	LRO and its subsystems shall meet the magnetic requirements put forth in the LRO Electrical Systems ICD 431-ICD-000018.	Field generation and susceptibility must be addressed to avoid any negative interactions between subsystems and instruments.		Orbiter	Derived
1.4.62	Charging	Deep Dielectric and Surface Charging of the Orbiter and its subsystems shall be controlled per LRO Electrical Systems ICD 431-ICD-000018.	Charging due to radiation effects can damage unprotected components.	Reference 431-REQT-00045	Orbiter	MRD 2.3.3
1.4.66	Contamination Control	Acceptable contamination levels shall be maintained on the Orbiter and its subsystems, at all times, per the LRO Contamination Control Plan (Doc # TBD).	Particulate and molecular contaminants can limit functional life of components (solar arrays, UV instruments, etc.).		Orbiter	Derived

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2.1	CRaTER					
	Cover LET Spectra Range	CRaTER shall characterize energy deposition between approximately 250 KeV and 1.35 Gev.	The energy range is determined by the noise floor (tens of KeV) and the maximum energy deposit expected by an iron nucleus at a large angle of incidence.		CRaTER	
	Resolve LET Spectra	The pulse height analysis of the energy deposited in each detector shall have an energy resolution of better than 1/300 the maximum energy of the detector.	A high resolution measurement of the energy deposited is required to characterize the LET spectra and to distinguish between the effects of the primary readiation and secondaries produced through interactions.		CRaTER	
	Sheilding Effects	CRaTER shall be sufficiently shielding to block protons with energies below 10 MeV.	Solar and galactic cosmis rays with energies exceeding 10 MeV have the most significant biological effects. Shielding below a minimum energy is set to prevent the desired measurements from being lost in the high rate of lower energy particles buring periods of heightened solar activities.		CRaTER	
	Biological Effects	The LET spectra will be measured at different distances through material with radiation absorptive properties representative of human tissue.	The use of material with radiation absorptive properties allows measurements of the resulting LET spectra afdter the primary solar and galactic cosmic rays pass through"human tissue."	Considering measurements in the 10-100MeV range. Need PI concurrence to add in requirement?	CRaTER	
	Pathlength Constraint or Modeling Accuracy	The uncertainty in the length of the material traversed by a particle seen by a detector on either side of a section of material will be less than 10%.	This is sufficient accuracy for subsequent modeling efforts to reproduce the observed LET spectra based on direct measurements of primary particle spectrum.	Want to re-write requriement. Would like to spec modeling accuracy and allow CRaTER to derive this requirement at a lower level.	CRaTER	
	Measurement Stability	CRaTER shall maintain the stability of the LET measurements over the entire mission.	Will lead to their internal calibration requirment. This is the link between measure accuracy and the need for internal cal. May be able to remove and just put accuracy number in measurement requirement.	Need to quantify stability number.	CRaTER	
	FOV	The CRaTER full-width field of view shall be no greater than 35 degrees on the zenith side and 80 degrees on the nadir side.			CRaTER; Mech	
	Pointing	The spacecraft shall notify CRaTER of any pointing excursions greater than 35 degrees off the nadir.	As long as the S/C boresight is pointed within 35 degrees of nadir, the entire 80 degree instrument FOV will completely see the lunar surface.		CRaTER; FSW; GNC	
	Pointing Knowledge	The spacecraft shall provide knowledge of the pointing of CRaTER to within 10 degrees.	CRaTER will examine the possibility of directionality of the primary radiation.		GNC; GND	
	Solar Flare Operations	CRaTER shall continue to operate and take data during particle enhancements at 1 AU associated with solar flares.	Radiation environment during periods of solar activity is particularly important to understanding risks associated with manned missions.		CRaTER	
	Event Rate	The S/C shall support an event rate from CRaTER of 1200 events per second.	Predicted rate during intense particle event at 1 AU.		CRaTER; FSW; C&DH	
	Data Link	CRaTER shall receive all commanding and distribute all telemetry over the 1553B low speed bus.	CRaTER data rate and heritage adapt better to the low speed bus, than the high speed bus.		C&DH; CRaTER	
	Data Rate	The S/C shall support a maximum telemetry rate of 100 kbps.	Event rate corresponds to approx 100 kbps rate.		C&DH; CRaTER	
	Thermal	CRaTER shall be thermally coupled to the S/C.			CRaTER; Thermal	
	Microphonics	CRaTER may be susceptible to microphonics. This is a placeholder for a requirement as studies are completed.	Mechanical vibrations in the instrument can translate into noise in the data.		CRaTER; Mech	

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2.2	Diviner					
	Temperature Mapping	Diviner shall conduct direct temperature mapping at ~300m resolution with minimum detectable temperatures of 24K over an entire diurnal cycle.	This enables the detection and characterization of cold traps in the polar shadowed regions		Diviner	RLEP-LRO-M60
	Landing Site Safety	Diviner shall determine rock abundances of up to 50 selected potential landing sites.			Diviner	RLEP-LRO-M80
	Polar Region Illumination	Diviner shall provide polar region illumination maps derived from reflected solar and emitted thermal radiation measurements.			Diviner	RLEP-LRO-M90
	Equator Crossing Signal	S/C shall provide time for one equator crossing signal per orbit accurate to ± 10 seconds, at least 10 minutes prior to the event.	Initiates one orbit of instrument observations, controlled by internal tables		FSW; GNC; GND	
	Sun Avoidance	The S/C shall safe Diviner for any off-nadir operations during mapping, with the exception of targeting rolls of < 20 degrees	Prevents damage to Diviner focal plane by inadvertent sun viewing		C&DH, FSW, GNC, GND	
	Freeze Commands	The S/C shall issue freeze/unfreeze commands to prevent Diviner motion	Used to prevent jitter during LROC imaging (if necessary)		FSW; C&DH; GND	
	In-Flight Calibration	The spacecraft shall provide cross-track space views for Diviner 90° from nadir in the anti-sun hemisphere	Space and internal BB target calibration views required 10 times per orbit		Mech	
	Mechanical Interface	Diviner shall be mounted to the IM to ensure the Solar Calibration Reflectance Target (SCRT) can be fully illuminated by the sun each orbit using the Diviner Az gimbal.	Solar calibration required once per orbit, accomplished by Az and El gimbals.		Mech	
		The spacecraft shall have the capability to withold the 1 PPS from Diviner	Alternate to safe command for safing Diviner in emergency	Diviner has no problem with the 1 Hz pulse and could use it to safe in emergencies if it is withdrawn	C&DH, FSW	
	Pointing	Pointing requirements (pitch, roll, and yaw) Control 6.0 mrad, Knowledge 3.0 mrad, Stability 1.5 mrad in 0.128 seconds	Needed for image registration and reconstruction, and to reduce FOV smearing		GND, GNC	
	Knowledge	Reconstruction knowledge in lunar centered coordinates: Tangential <150 m, Radial < 300 m	Needed for image registration and reconstruction		GND, GNC	3.2.1
	Timing	1 Hz pulse/tick discrete (hardware or software ?) from spacecraft		Move to C&DH requirement	FSW, C&DH	
		1 Hz serial time command from S/C referenced to pulse		MCS/MRO design can not handle 1 Hz serial commands. We would like something slower (60±10seconds ?).	FSW, C&DH	
	Commanding / Telemetry	Diviner shall receive all commanding and distribute all telemetry over the 1553B low speed bus.			C&DH; FSW; Diviner	
	Data Rate	Diviner shall provide telemetry to the spacecraft continuously at a constant rate not to exceed 28 kbps			C&DH; FSW; Diviner	
	Contamination Purge	Diviner shall not be without Grade B GN2 purge for more than 8 hours per occurrence and 24 hours total during I&T. A second 24 hours is permitted for Pad Operations.			I&T	

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2.3	LAMP					
	Performance	Spectral passband shall be at least 1200-1800 ±10 Å.				
		Effective area shall have a peak >0.2 cm2 around 1250 Å.				
		Slit FOV shall be 0.2 ± 0.02° x 6.0 ± 0.1°.				
		Spectral resolution (PSF) shall be <20 Å FWHM (non-Nyquist sampled) averaged across the passband.				
		Spatial resolution (PSF) shall be Nyquist-sampled to 1 deg or less except at the slit edges.				
		Filled slit spectral resolution shall be <40 Å FWHM (non-Nyquist sampled), averaged across passband.				
		Stray light rejection ratio (detector count rate at specified off-axis angle to the detector count rate at 0 degrees boresight) averaged across the LAMP spectral passband shall be <10-5 at 7 deg off-boresight perpendicular to the slit spatial axis.				
		Detector global dark count rate over the total array shall be <20 counts/sec as measured in vacuum during ground calibration.				
		Detector output shall be a continuous, time-tagged pixel list with "ping-pong" memory fill.				
		A Lunar Terminator Sensor (LTS) shall be provided to allow safing the instrument from bright signals near and at the lunar terminator that could damage the LAMP detector/MCP-stack over time.				
		LTS FOV shall be 10 deg x 1 deg (x2).				
	Mechanical Interface	LAMP shall be mounted on a stable instrument bench with its main aperture boresighted in the nadir direction (+z) and the spatial dimension of the LAMP slit normal to the direction of motion in flight along the lunar surface.			Mech	
		LAMP shall have a 40º full angle nadir centered clear (i.e. no obstacles) field of regard with the angle apex specified in the LAMP MICD.			Mech	
		The LAMP LTS shall have a 40º full cone (TBR) field of regard (the angle apex location relative to the LAMP FOR specified in the LAMP MICD).			Mech	
		There are two LTS FOVs, each shall be pointed in the direction of the spacecraft velocity vector, one FOV each fore and aft, relative to the LAMP boresight, by TBD seconds of ground track time.			Mech	
	Alignment	Instrument boresight shall be aligned to S/C reference to within ±0.1° (3 sigma) in all three axes (TBD).			Mech	
		Instrument shall have alignment knowledge to S/C reference to within ±0.01° (3 sigma) in each of the three axes (TBD).			Mech	
		Alignment shall be performed using the LAMP optical cube as the reference.			Mech	
	Thermal	LAMP shall be thermally isolated from the spacecraft.			Thermal, Mech	
		The spacecraft shall provide survival heater switch service.			Thermal, Power	
		Operational heater switch service shall be provided by TBD.			Power, Thermal	
	Power	The spacecraft shall provide two each switch services to LAMP – one for LAMP power A and one for LAMP power B.			Power	
		LAMP shall switch power internally for actuator and decontamination heaters.			LAMP, Power	
	Science Data	LAMP shall transmit a 64 kbyte block of non-CCSDS formatted science data at each transfer.			C&DH, FSW	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
2.3(2)		LAMP shall transmit a block of science data at a physical clock rate of 1 MHz ± 1%.			C&DH, FSW	
		LAMP shall transmit science data using LVDS compliant driver chips.			C&DH, FSW	
		LAMP shall transmit science data at an average rate of one block (64 kbytes) every 26 seconds.			C&DH, FSW	
		LAMP shall transmit science data at a maximum rate of one block every 2 seconds.			C&DH, FSW	
		LAMP shall support a redundant science data interface (TBD).			C&DH, FSW	
	Electrical	LRO shall accommodate all commanding and distribution of all LAMP telemetry over the unique heritage system from the Pluto ALICE Instrument.			C&DH, FSW	
	Housekeeping Data	LAMP shall transmit housekeeping data over an asynchronous 38.4 kbaud low speed RS-422 data bus.			C&DH, FSW	
		The telemetry housekeeping messages shall be packetized in an ITF frame containing a 7-byte header.			C&DH, FSW	
		The telemetry housekeeping message shall be transmitted once per second.			C&DH, FSW	
	Timing / Command	Telecommands and time messages shall be transmitted to LAMP over an asynchronous 38,400 Baud RS-422 compliant parallel redundant low speed serial bus.			C&DH, FSW	
		Telecommands shall consist of general LAMP operational, memory load and memory dump functions.			C&DH, FSW	
		The telecommand size shall be between 8 and 144 bytes.			C&DH, FSW	
		The telecommand and time messages shall be packetized in an ITF frame containing a 7-byte header.			C&DH, FSW	
		S/C shall provide 1 PPS signal over RS-422 data bus.			C&DH, FSW	
	Safe / Arm	A safe/arm capability shall be provided to safe the one-time actuation and HVPS functions of the LAMP instrument.			LAMP	
		The spacecraft shall provide a harness from the LAMP safe/arm connector to a location that is easily accessible during I&T and launch campaign activities.			Elect; I&T	
		A plug-out configuration shall arm the actuator power and HVPS for flight.			I&T, Power, FSW	
	Simulators	Lamp shall provide a mass simulator of the LAMP instrument to the S/C.			Mech, LAMP	
		A LAMP Instrument Interface simulator shall be provided to the LRO project for the purpose of verifying electrical and software interfaces.			LAMP, C&DH, FSW	
	GSE	The spacecraft shall provide attachment points for the LAMP MGSE vacuum manifold assembly for LAMP end-to-end tests.			Mech, I&T	
		The spacecraft shall provide attachment points for LAMP MGSE UV lamp/collimator assembly for end-to-end tests.			Mech, I&T	
		LRO project shall provide a spacecraft simulator simulating the LAMP data interfaces.			I&T, C&DH, FSW	
		LRO project shall provide an ITOS based GSE computer (TBD).			I&T, C&DH, FSW	
	Nominal Ops	LAMP shall be operated in the nadir-pointing mode with the LTS enabled and detector high voltage activated on the night side of each pass with detector high voltage lowered for the dayside pass.			LAMP, Power	
		LAMP shall perform airglow observations with the spacecraft pointing off –nadir near the limb.			LAMP	
		LAMP shall perform heater decontamination activities every TBD weeks.			LAMP	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
2.3(3)		LAMP shall perform an in-flight calibration every month. (see section 5.3).			LAMP	
	In-Flight Calibrations	In flight calibration shall be performed using standard UV stars to determine instrument sensitivity and pointing boresight.			LAMP	
		In flight calibration shall also be performed using UV stars/solar flux to characterize instrument stray light performance.			LAMP	
	Sun Avoidance	The LAMP boresight shall not be pointed to within 15 deg of the Sun with the aperture or fail-safe doors open.			GNC	
		The LAMP boresight shall not be pointed to within 20 degrees of the Sun with the aperture and/or fail-safe doors open and the detector high voltage greater than 2000 V.			LAMP	
	Data Products	LAMP shall provide albedo maps of all permanently shadowed regions with resolutions down to 500 m			LAMP	RLEP-LRO-M60
		Develop water-frost concentration maps of the lunar polar regions. Mapping resolutions as good as 3 km for frost abundances down to 1.5%.			LAMP	RLEP-LRO-M70
2.4	**LEND**					
	Radiation Environment Data Products	Develop maps of water ice column density on polar regions of the Moon with spatial resolution from 5-20 km			LEND	RLEP-LRO-M10
	Water Ice Data Products	Determine hydrogen content of subsurface at polar regions with spatial resolution from HWHM=5 km and with variation sensitivity from 100 ppm			LEND	RLEP-LRO-M70
	Resource Identification Data Products	LEND shall receive all commanding and distribute all telemetry over the 1553B low speed bus.			LEND	RLEP-LRO-M110
	Telemetry Link	LEND shall provide telemetry to the spacecraft at a 30 bits/sec rate.			LEND	
	Telemetry Rate				LEND	
2.5	**LOLA**					
	Ranging Measurement Accuracy	LOLA shall perform ranging measurements at a sampling rate of < 30m at the 50km nominal Orbiter altitude.	Range measurements required to assemble a lunar global topographical map.		LOLA	RLEP-LRO-M30, RLEP-LRO-M40
	Sampling Rate	LOLA shall provide the ranging measurement continuously at >90% detection probability.	Minimum sampling rate dictated by Level 1 requirement.		LOLA	RLEP-LRO-M30, RLEP-LRO-M40
	Surface Coverage	Provide global digital elevation model of the moon with 1 m vertical resolution and 100 m horizontal resolution with 1 km average cross track sampling at the equator.	Detection probably at continuous rate predicts average crosstrack spacing at equator for 50km oribt.		LOLA	RLEP-LRO-M30, RLEP-LRO-M40
	Ranging Data Products	Provide digital elevation model of topography in permanently shadowed polar regions with 50 m horizontal resolution, 1 m vertical resolution	Dictated by Level 1 requirement.		LOLA	RLEP-LRO-M30, RLEP-LRO-M40
	PSR Topography Data Products	LOLA shall provide lunar surface reflectance measurements to the laser pulses at <10% accuracy per laser spot.	Dictated by Level 1 requirement.		LOLA	RLEP-LRO-M60
	Surface Reflectance Measurement	Provide reflectance data from the PSRs to identify surface ice signatures at a limit of 4% ice surface coverage by area.	Increased surface reflectance could reflect surface water ice.		LOLA	RLEP-LRO-M70
	Surface Reflectance Data Product	LOLA shall provide slope and surface roughness characteristics per laser spot.	Dictated by Level 1 requirement.		LOLA	RLEP-LRO-M70
	Slope and Surface Roughness Measurements	Co-Align at-least one of LOLA's laser spot to be within the overlap between the two LROC NACs.	Slope and surface roughness will assist in safety assessment of potential landing sites. Reference Apollo mission landing near surface slope.		LOLA	RLEP-LRO-M80
	Co-Alignment with LROC	Provide topography, surface slopes, and surface roughness at 25-m spacing over a 70-m wide FOV swath at up to 50 selected potential landing sites.	Assess landing sites to within meter scales features. LOLA will add slope and surface roughness at larger scales to LROC's meter-scale featured images.		LOLA, LROC	RLEP-LRO-M80

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
2.5(2)	Slope and Surface Roughness Data Product	LOLA shall receive all commanding and distribute all telemetry over the 1553B low speed bus.	Dictated by Level 1 requirement.		LOLA	RLEP-LRO-M80
	Telemetry Link	LOLA shall provide telemetry to the spacecraft at a 12 kbits/sec rate.				
	Telemetry Rate					
2.6	**LROC**					
	Nominal Ops	LROC shall be operated in the nadir-pointing mode on the day side of each pass (with 5 degrees latitude night side imaging at each pole).			GNC, GND	
		The S/C shall perform off-nadir pointing to enable LROC to acquire stereo data and mosaics.		TBR. Need more specifics.	GNC	
	Sun Avoidance	The S/C shall not continously point the S/C within 30 degrees of the LROC NACs.			GNC	
		The S/C shall have a minimum slew rate of 0.1 degrees/sec if the sun entires the instrument boresight.			GNC	
	Calibration	Absolute calibration shall be performed using standard stars to determine instrument sensibility and poiting boresight once a month.			GND	
		Dark characterization shall be performed by imaging night time on the farside once a month.		Frequency and timing issue. Must be done of farside of moon. Must be done at night. Earthshine precludes dark environment.	GND	
		Scattered/stray light characterization by imaging illuminated limb.		Possibly during commissioning orbits.	GND	
	Mechanical I/F	LROC shall be mounted on a stable platform boresighted in the nadir direction with the detectors normal to the direction of the velocity vector in flight along the lunar surface.			Mech	
	FOV	The LROC NACs shall have a 60 degree full angle nadir centered clear field of regard (no obstacles) with the angle apex specified in the LROC MICD.			Mech	
	Alignment	The LROC boresight shall be aligned to the S/C reference to within ± 0.1 degrees (3 sigma) in all three axes (TBD).			Mech	
	Pointing Knowledge	LROC shall have alignment knowledge to the S/C reference to within ± 0.01 degrees (3 sigma) in all three axes (TBD).			Mech	
	Thermal I/F	LROC shall be thermally isolated from the S/C.			Thermal	
	Survival Heaters	The S/C shall provide survival heater switch service which is thermostatically controlled.		Move to Thermal Section	Thermal	
	Op Heaters	Operational heater switch service shall be provided by TBD.		Move to Thermal Section	Thermal	
	Power Services	The S/C shall provide 5 switch services to LRC. One for instrument power, 1 for survival power, 2 for decontamination heaters, and 1 for operational heaters.		Need to scrub.	Power, C&DH	
	Science Data	LRCO shall provide science data packets to the S/C via the SpaceWire interface			C&DH, FSW, LROC	
	Data Rate	LROC shall provide telemetry to the spacecraft at a 32 (TBD) Mbits/sec rate.			C&DH, FSW, LROC	
	GSE	LRO project shall provide a spacecraft simulator simulating the LROC data interfaces.			I&T, C&DH, FSW	
		LRO project shall provide an ITOS based GSE computer (TBD).			I&T, C&DH, FSW	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.1	**Mechanical**					
3.1.10	Spacecraft Structure	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 Budget.	The structure is an integral part of the overall pointing budget.		MECH	
3.1.14	Fields of View	The LRO structure shall provide clear FOVs for all components and instruments as required by their specifications.	Many components and all instruments require a FOV external to the spacecraft.		MECH, ELEC	
3.1.18	Launch Shift	The LRO structure shall be designed to maintain its allignment specifications through the launch event.	One time static alignment offset error. Allows for 1g offset, on-orbit thermal settling, launch shift, and ground measuremetn error effects.		MECH	
3.1.22	Gradients	The LRO structure shall be designed to maintain its allignment specifications throughout the mission.	The structure must be capable of handling thermal gradients, etc. without violating its allignment budget.		MECH, Thermal	
3.1.26	Flexible Modes	The LRO structure shall be sufficiently stiff to avoid excitation by the attitude control system or any other moving parts on the spacecraft.	Care must be taken to ensure that structure's lowest frequency mode is outside the controller bandwidth (typically at least 1 decade above).			
3.1.30	CG Migration	LRO shall be designed in such a way that the CG migration over the course of the mission does not negate thruster control authority.	LRO will need to carry a significant amount of fuel to do its mission. The weight shift, as this fuel is used up, will be significant.			
3.1.34	Support Equipment	LRO mechanical ground support equipment shall be proived for I&T, hoisting, transportation, etc.	MGSE will be needed at various stages of LRO development, including launch site operations.			
3.1.38	Accessability	The LRO structure shall provide access to instrument and subsystem components (as needed) for test and support equipment while integrated to the S/C.	It will be necessary to test and calibrate several components at various stages of development.		MECH, INSTR	
3.1.42	Mechanical Surrogates	LRO shall make use of mass simulators, baseplates, and wiring moch-ups (etc.), as appropriate.	This will help to ensure proper structural and interface compliance.			
3.2	**Thermal**					
3.2.10	Operational Ranges	The LRO thermal control system shall maintain all component and structural temperatures to be within their appropriate limits during normal operations.	Must maintain proper temperature ranges to ensure component/instrument functionality.		THERMAL, MECH	
3.2.14	Survival Ranges	The LRO thermal control system shall maintain all component and structural temperatures to be within their survival limits during all phases of the mission.	Must maintain proper temperature ranges to avoid damaging any component/instrument.	Includes loss of operational heater monitoring and control.	THERMAL, C&DH, POWER	
3.2.18	Minimum Bus Voltage	The LRO survival heaters shall be sized for a minimum bus voltage of 24V (TBR).	Based on minimum bus voltage out of eclipse due to 1 battery cell failure.	Check against Elec Spec. Add comments to add 70% duty cycle.	THERMAL, POWER	
3.2.22	Monitoring	LRO shall provide monitoring thermistors for all components and critical structural elements.	Must have knowledge of LRO temperatures to aid in post-processing and/or troubleshooting.			
3.2.26	Ground Support	LRO thermal ground support equipment shall be provided to support I&T, transportation, etc.	TGSE will be needed at various stages of LRO development, including launch site operations.	Battery conditioning?		
3.2.30	Thermal Simulators	Thermal simulators shall be provided for use in verifying performance of LRO systems.	Orbiter level testing must be done in space-like environments to ensure mission success.	T-Vac environmental sims	THERMAL, GSE	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.3	**GN&C**					
3.3.10	Attitude Control System	The attitude control system shall maintain LRO's orientation, as well as that of its solar array and high gain antenna, throughtout the course of the mission.	LRO's orientation must be carefully controlled throught the mission to maintain the integrity of all systems and to meet mission objectives.	Derive from OD and Science	ACS, FLT DYN	
3.3.14	ACS Hardware	The ACS sensors and actuators shall be controlled via the LRO Low Speed Bus or discrete connections.	Utilizing the simplest possible infaces increases system reliability.	Specified in LRO Software Implementation Plan	ACS, C&DH, FSW	
3.3.18	ACS Software	The ACS software shall be hosted on the LRO Single Board Computer.	Sharing the abundant resources of the SBC significantly reduces avionics costs/complexity.		ACS	
3.3.22	Propulsion Control	The GN&C subsystem shall control and monitor the propulsion system.	The propulsion system is part of the GN&C subsystem.	Specified in LRO General Electrical Interface Definitions & LRO ACS-to-C&DH Electrical ICD	ACS, C&DH, FSW	
3.3.26	Initial Stabilization	The GN&C subsystem shall autonomously stabilize the orbiter after separation from the LV.	Must avoid flat spin to ensure sun avoidance on instruments, etc.	Specified in LRO LRO ACS to Propulsion ICD # TBD	ACS, C&DH, FSW, PROP	
3.3.30	Sun Pointing Latency	The ACS shall be capable of acquiring the sun, from any orientation, within 10 min of initialization.	This mode is nominally only entered when it is imparitive that the sun be put on the solar array.	Battery sizing. Add requirement of no thrusters?	ACS, FLT DYN	
3.3.34	Sun Pointing Accuracy	When "Sun Pointing", the ACS shall put the sun within 15 deg of the specified position.	This angle is sufficient to ensure that enough sun gets onto the solar array.		ACS, FLT DYN	
3.3.38	Default Mode	The ACS default mode shall put the sun within 15 deg of a specified position and wait for further command.	In the event of an anomoly, this is the safest orientation for the S/C to be put into.	Derived from Com pointing requirements	ACS, COMM	
3.3.42	Thrust Pointing	The ACS shall hold pointing to within 5 deg of the desired orientation during thruster operations.	Pointing must be maintained to ensure that the resultant thrust is in the desired direction.	from AO. Alignment cube.	ACS	
3.3.46	Delta-V Budget	The detailed Delta-V budget shall be documented in TBD.	Flight Dynamics determines the requirements on fuel in terms of Delta-V.	Requirements specified in table # 4	PROP, FLT DYN	
3.3.50	Fuel Budget	The detailed propellant budget shall be documented in TBD.	The actual fuel budget factors in all subsequent effects (cosine losses, residual fuel, etc.).	Addresses changing CM over mission life due to fuel consumption	ACS, PROP, FLT DYN, MECH	
3.3.54	Minimum Thrust	The propulsion system shall be capable producing the minimum thrust required for lunar capture, with backup, as determined by Flight Dynamics.	Flight Dynamics determines this number. Without it, LRO can't brake at the moon.	140 N (?)	PROP, FLT DYN	
3.3.58	Thruster Locations	The LRO thrusters shall be configured such that they provide the necessary control authorities (thrust and torque) without impinging upon any S/C structure or components (typically +/- 45 deg).	Impingments can cause unwanted forces and torques, as well as heating issues.	With margin.	PROP, ACS, FLT DYN	
3.3.62	Propulsion Inhibits	The propulsion system shall include multiple inhibits on all thruster & isolation valves.	Set allocations and meet GOLD requirements. Ground test and pre-launch operations safety.		PROP, FLT DYN, MECH	
3.3.66	Cat Bed Heaters	The cat bed heaters shall have proper thermal control protection to prevent inadvertent overheating.	Oxidation issue on ground. Ask Prop.		GSE, PROP, THERMAL, C&DH	
3.3.70	Power Negative Ops	Any maneuver that puts LRO in a power negative orientation shall be limited to TBD minutes (60?).	The time constraint is imposed so that the battery is not dangerously discharged.		PROP, ACS, FLT DYN	
3.3.74	Momentum Management	The GN&C subsystem shall be capable of adjusting momentum within 1 N-m-s of a desired set-point and handling system momentum up to 70 N-m-s (TBR).	At the moon (without magnetics), momentum management is critical. Biased torques allow for twice the overall accumulation capability.			

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.4	**Power**					
	Power Generation	Provide sufficient power generation to support the Orbiter in all mission phases.			POWER	
		The power system shall have the capability to support 824W (TBR) orbit average power load at the end of the nominal mission life (14 months).			POWER	
		The power system shall have the capability to support TBD W orbit peak power load.		Need peak load requirement	Power	
	Power Storage	Provide sufficient power storage to support the Orbiter in all mission phases.			POWER	
		The battery shall not exceed a total of TBD cycles of TBD% depth of discharge as part of qualification, acceptance, and pre-launch testing and mission ops.		Protects Li-Ion battery degradation	POWER	
		TBD cycles shall be allocated for testing(I&T) with the remaining cycles reserved for flight per Battery cycle allocation document TBD.	Maintain DOD and cycle budget.		POWER	
		The battery shall be able to provide TBD W for TBD minutes as part of the launch/ascent phase in order to allow Orbiter to acquire power positive orientation after launch.	Initial acquisition power and timing budget.	Better to control Amp-Hrs?	POWER	
		The battery shall provide at least TBD W for TBD minutes at EOL to support safehold power contingency.	Wrap up into worst case?		POWER	
		The battery shall provide at least TBD W for TBD minutes at EOL to support worst case eclipses without load shedding instruments	Wrap up into worst case?	Worst case in science mode.	POWER	
		The battery shall provide at least TBD W for TBD minutes at EOL to support worst case eclipses. Load shedding will be permitted.	Wrap up into worst case?	Worst case in extended mode. Driven by required power for disposal?	POWER	
	Power Distribution	The Orbiter shall provide the capability to distribute power throughout the Orbiter			POWER	
		The output of the power system shall be a nominal 30 VDC (with a range of 22 - 35V) power to all Orbiter subsystems and components.		At Tom's connector	POWER	
		All components shall be qualified to a voltage bus range of 21-35V.	Reduced power output by 1W (TBR) due to projected line losses. Specify voltage at subsystem interface not at PSE chassis.	22 accounts for line loss. Verify with Kinder.	E-SUBSYS, INSTR	
		The Orbiter power system shall utilize distributed power architecture with primary power distributed to Orbiter subsystems for further distribution as required.	Distributed power architecture shall be used to supply redundant over-current protected power to all the loads.	Only hit subsystem with high current. Can make case for high current draw components.	POWER	
		Redundant power harness to support operational power and survival power. Provide appropriate isolation.		Split out iso requirement. Primary power and retrun shall be isolated from S/C chassis at all points, except single point ground and the PSE.	POWER	
		Unswitched power shall be appropriately fused to prevent damage to or loss of the Orbiter power system due to excessive current draw.			POWER	
		Switched power services shall have re-settable "circuit breakers" for power system proctection.			POWER, C&DH, FSW	
		The power system shall provide the capability for TBD Orbiter controlled switches and TBD unswitched high power services.	Reference switch and power allocation document.		POWER	
		Power interface to subsystems and instruments shall be as specified in the EICD?		Specified in LRO General Electrical Interface Definitions # TBD	E-SUBSYS, INSTR	
		If any non-essential switched load exceeds 1.25x its average power, that load shall be switched off. That load shall remain off-line until it is determined what has caused the over-current condition.	Under normal conditions, no load should exceed 1.25x its average current. If it does, it could indicate a short circuit condition.	Two Reqts: Size switches. S/W to monitor points. Add persistence and reaction time.	POWER, E-SUBSYS, C&DH, FSW	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.4(2)	Load Shedding	The Orbiter shall be designed with the capability to execute a predetermine hierarchy of load shedding operations based on power system status telemetry.		Capability independent of central processor and low speed bus? Move to Health and Safety.	POWER, FSW, C&DH	
	Constraints	Limits will be imposed to avoid exceeding peak discharge rates on the battery.		remove	POWER	
		In-rush current specification per Electrical System Spec.			POWER, E-SUBSYS	
3.5	**C&DH System**					
	System Architecture	The top level overall architecture is specified in figure # 2.	Reference latest block diagram		C&DH	
	High Speed Bus (HSB)	System shall use a SpaceWire network compliant with ECSS-E-50-12A to transfer high rate (125 Mbps) instrument data to the SSR and communication subsystems.	HSB for commanding and science data to/from instruments. Data rate TBD pending selection of instruments.		C&DH, INSTR, COMM	
	Low Speed Bus (LSB)	System shall use a Mil-STD-1553B bus to interconnect subsystems and instruments for telemetry, low speed instrument data, and commanding.	LSB for commanding and housekeeping to/from spacecraft subsystems and instruments as required. Network used to minimize harness weight.		C&DH, COMM, INSTR, All components	2.6.7 C&DH Std Svcs
	Housekeeping I/O	System shall provide discrete analog and digital data collection and control signaling as specified in Table # 5	Digital commanding, Digital and Analog telemetry gathering not done over LSB.		C&DH	2.6.7 C&DH Std Svcs
	SBC	Shall provide TBD MIPS processing platform for C&DH and GN&C software.	C&DH and GN&C software operations require processor.	Luers. Review deletion of FSW with Phil.	C&DH	2.6.7 C&DH Std Svcs
		Shall provide min. 1 (TBR) MB of non-reprogrammable (in-flight) non-volatile storage of boot code.	Storage for boot code.	PROM issue w/ redundancy. Luers	C&DH	2.6.7 C&DH Std Svcs
		Shall provide min. 2 (TBR) MB reprogrammable (in-flight) non-volatile storage for application code.	Storage for Operating System (OS) and baseline applications code. Reprogrammable for post-launch maintenance.		C&DH	2.6.7 C&DH Std Svcs
		Shall provide min. TBD MB of volatile storage for executable code or data.	Storage for applications code, data tables, data.		C&DH	2.6.7 C&DH Std Svcs
		Shall operate as either BC or RT on 1553.	Mechanism for redundant configurations to prevent two simultaneous BCs.	Only if some other subsystem act as the BC.	C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide a test interface for debugging during integration and test.	Method for monitoring performance and debugging anomalous conditions during integration and test.		C&DH, FSW	2.6.7 C&DH Std Svcs
		Add watchdog timer requirement	reset processor			2.6.7 C&DH Std Svcs
	Ka & S Band Communication Assembly					
	S-band Card Uplink	Shall accept telecommand data from communication subsystem. Support CCSDS telecommand format. Detect codeblock errors. Generate validated command stream to SBC via HSB.	Consistent with requirements of flight software and communications.		COMM, C&DH, FSW, GND	
		Shall perform hardware decoding of critical commands. Generate (# TBD) discrete 5-volt differential pulse outputs, active for TBD ms.	Method for recovery from anomalous conditions. TBD pending safehold and recovery scenario studies.	Better describe how many things are checked. Luers. Need to understand how to perform clear text hardware commands.	COMM, C&DH, FSW	2.6.5 Comm Std Svcs
		Shall provide hardline interface for ground test.	Method for integration and test of spacecraft and instruments without using RF communications.	Want hard test.	COMM, C&DH, GSE	2.6.5 Comm Std Svcs
	S-Band Card Downlink					2.6.5 Comm Std Svcs
		Shall accept downlink telemetry data from HSB.	Science data and housekeeping data source.		COMM, C&DH, FSW, GND	
		Shall generate downlink I&Q data streams with NRZ-L or Bi-Phase-L physical encoding.	Either or both are supported by ground stations.		COMM, C&DH, FSW, GND	2.6.5 Comm Std Svcs
		Shall provide hardline interface for ground test.	Method for integration and test of spacecraft and instruments without using RF communications.		COMM, C&DH, GSE	2.6.5 Comm Std Svcs

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.5(2)	Ka-Band Card					2.6.5 Comm Std Svcs
		Shall accept downlink telemetry data from HSB.	Science data and housekeeping data source.		COMM, C&DH, FSW, GND	
		Shall generate downlink I&Q data streams with NRZ-L or Bi-Phase-L physical encoding.	Either or both are supported by ground stations.		COMM, C&DH, FSW, GND	2.6.5 Comm Std Svcs
		Shall provide hardline interface for ground test.	Method for integration and test of spacecraft and instruments without using RF communications.		COMM, C&DH, GSE	2.6.5 Comm Std Svcs
	SSR	Shall support TBD-hours of science instrument and spacecraft housekeeping data collection.	Store data between ground contacts. Baseline 3 (TBR) contacts per 24-hour day as a minimum.		C&DH, COMM	2.6.5 Comm Std Svcs
		Shall provide resources to support file-based operations using CFDP.	Ease of operations.		C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide Error Detection and Correction (EDAC) resources to meet TBD bit error rate. Provide resource for disabling for test purposes.	Shall use EDAC to prevent data loss due to SEE in recorder. Disable implies ability to inject errors.	More robust EDAC is available with more overhead. Radiation testing and detailed characterization of environment is necessary to determine necessity.	C&DH, FSW	2.6.7 C&DH Std Svcs
	Clock Services	Shall maintain Orbiter time with a maximum drift of TBD s per 24-hours without ground correction or adjustment.	Maintain S/C time within 1 s or Earth time to meet science observing requirements and/or for ACS operations. Driver from LOLA.	May be derived from science or ACS requirements. LOLA = 1 ms off UTC.	C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide mechanism for time correlation of Orbiter time to Earth time accurate to TBD ms. Shall latch Orbiter time of transmission of every 16th VC0 transfer frame.	Mechanism for verifying drift and maintenance operations.	May be derived from science requirements. Can be done with uplink instead of downlink. Will also result in ground station and/or MOC requirements.	C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide mechanism for time correction to maintain LRO Orbiter time within TBD seconds of Earth time.	Mechanism for correcting drift as required.	May be derived from science or GN&C requirements. Move to 2.6.7 as timing requirement.	C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide a Mission Elapsed Time (MET) counter which can be reset, but not otherwise adjusted. Shall not lose time if SBC is power cycled or reset. Shall have a resolution of 1 s and be capable of operating for TBD years without rollover.	MET shall always increment and never be adjusted to provide unambiguous time reference.		C&DH, FSW	2.6.7 C&DH Std Svcs
		Shall provide a 1Hz pulse as required to support science data timetagging.	Mechanism for synchronizing operations, and timetagging data.		C&DH	2.6.7 C&DH Std Svcs
		Shall generate a message to each instrument as required that represents Orbiter time of pulse.			FSW	2.6.7 C&DH Std Svcs

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.6	**Comm**					
	Forward Error Correction	The Lunar Reconnaissance Orbiter shall employ forward error correction to all operational and mission data downlinks to improve available link margin and downlink quality of service in terms of bit error rates and frame error rates.	LRO has limited resources available onboard in terms of radiated EIRP. FEC algorithms provide for significantly improved link margin for a given EIRP due to coding gains. This allows LRO to provide improved BER and FER on both operational and mission data downlinks without requiring significant onboard resources.	The selected FEC method is concatenated CCSDS Reed-Solomon and Rate _ Convolutional coding.		
	S-Band	The Lunar Reconnaissance Orbiter shall support operational TT&C telemetry downlinks using the near-Earth (Category A) S-band Space Research frequency allocation. LRO S-Band EIRP will be not less than 24 dBW (TBR).	LRO will operate within 2 million km of Earth, and is therefore required under ITU regulations to use Category A frequencies. S-Band offers the most options for operational TT&C through compatibility with existing communication networks including TDRSS, the NASA Ground Network, NASA Deep Space Network and commercial telemetry service providers.			
	Ka-Band	The Lunar Reconnaissance Orbiter shall support high rate mission data telemetry downlinks using the near-Earth (Category A) Ka-band Space Research frequency allocation. LRO Ka-Band EIRP will be not less than 49 dBW (TBR).	LRO will operate within 2 million km of Earth, and is therefore required under ITU regulations to use Category A frequencies. Traditional (S-Band, X-Band, Ku-Band) allocations do not provide sufficient available spectrum to support LRO's expected daily data volume. A Ka-Band allocation provides the required bandwidth to enable LRO's mission data downlink.			
	Commanding Uplink - High Gain	The Lunar Reconnaissance Orbiter shall support reception and processing of operational TT&C command uplinks at rates up to 100 kilo-symbols per second through the spacecraft high-gain antenna system during nominal operations.	An available uplink rate of 100 ksps allows for a 50 kbps uplink rate once command link encryption/authentication has been applied. Ground networks are required to provide an EIRP of not less than 59dBW (TBR). Required ground station EIRP is dependent on LRO spacecraft antenna and passive losses. TBR will be closed not less than 90 days prior to LRO PDR.			
	Telemetry Downlink - Omni	The Lunar Reconnaissance Orbiter shall support operational TT&C telemetry downlinks at rates up to 16 kbps (36.8 kilo-symbols per second) through the spacecraft omni-directional antenna system.	Telemetry downlink rates of 16 Kbps will allow the LRO Flight Control Team to interact with and monitor the spacecraft during non-standard mission phases and spacecraft emergencies. Support for spacecraft emergencies may require the use of NASA Deep Space Network assets.			
	Telemetry Downlink - High Gain	The Lunar Reconnaissance Orbiter shall support operational TT&C telemetry downlinks at rates up to 100 kbps (230 kilo-symbols per second)(TBR) through the spacecraft high gain antenna system in a nominal flight condition.	LRO will downlink telemetry at rates up to 100 kbps. To achieve acceptable downlink margin, LRO will employ CCSDS Reed-Solomon (255/223) and CCSDS Rate _ Convolutional coding. The concatenated forward error correction increases the number of modulation symbols by 130%.			
	Off nominal Telemetry Downlink - High Gain	LRO shall support operational TT&C telemetry downlinks at rates up to 5 kilo-symbols per second (TBR) through the spacecraft high-gain antenna system in an off-nominal flight condition.	LRO mission phases, including trans-lunar cruise, spacecraft commissioning, and Ka-band contingency may require high rate S-band downlinks. Available spectrum limits the channel to 5 MHz (5 Msps w/ QPSK).			
	Commanding Uplink - Omni	The Lunar Reconnaissance Orbiter shall support reception and processing of operational T&C command uplinks at rates up to 16 kilo-symbols per second through the spacecraft omni-directional antenna system in a nominal flight condition.	An available uplink rate of 16 ksps allows for 8 kbps rates once command link encryption/authentication has been applied. Ground networks are required to provide an EIRP of not less than 101 dBW (TBR). Required ground station EIRP is dependent on LRO spacecraft antenna and passive losses. TBR will be closed not less than 90 days prior to LRO PDR.			

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.6(2)	Off nominal Commanding Uplink - Omni	The Lunar Reconnaissance Orbiter shall support reception and processing of operational T&C command uplinks at rates up to 2 kilo-bits per second through the spacecraft omni-directional antenna system in either a nominal or emergency flight condition.	An available uplink rate of 2 ksps will allow the LRO Flight Control Team to interact with and attempt fault recovery of the spacecraft. LRO will not use link encryption in emergency modes. Ground networks are required to provide an EIRP of not less than 92 dBW (TBR) in a nominal flight condition and not less than 102 dBW (TBR) in an emergency flight condition. Required ground station EIRP is dependent on LRO spacecraft antenna and passive losses. TBR will be closed not less than 90 days prior to LRO PDR. The necessary EIRP may dictate the use of a Deep Space Network asset in the event of spacecraft emergency.			
	Data Downlink - High Gain	The Lunar Reconnaissance Orbiter shall support high rate mission data telemetry downlink at rates up to 285 mega-symbols per second through the spacecraft high gain antenna system in a nominal flight condition.	A data offload rate of 125 Mbps (285 Msps after FEC) is required to meet LRO's baseline CONOPS of offloading one day's mission data during three communication contacts of less than one hour each. Individual contact duration is limited by LRO geometric visibility due to the Moon's occultation of the communication link.			
		The Lunar Reconnaissance Orbiter shall support PCM/PSK/PM modulation on the operational S-Band TT&C uplink and downlink.	LRO will use CCSDS compliant residual carrier modulations to provide interoperability with existing NASA Ground Network, NASA Deep Space Network, and commercial telemetry service providers.	Level 3?		
		The Lunar Reconnaissance Orbiter shall support BPSK and SPQN modulation on the operational S-Band TT&C uplink and downlink.	LRO will use SNUG and GNUG compliant suppressed carrier modulations to provide interoperability with the NASA Space Network, Ground Network, and future ground based communication networks.	Level 3?		
		The Lunar Reconnaissance Orbiter shall support Filtered Offset QPSK, suppressed carrier modulation on the mission data high rate downlink.	While LRO will be among the 1st users of this spectrum, the mission should still make every attempt to use bandwidth efficient modulation techniques. F-OQPSK provides 2 symbols/Hz, and is spectrally efficient. F-OQPSK is also supported by existing ground station receivers.	DELETE		
		The Lunar Reconnaissance Orbiter shall use the CCSDS File Delivery Protocol (CFDP) to ensure reliable transfer of mission data from the spacecraft to the ground.	The significant daily volume of LRO's mission data, as well as the intended downlink data rates, make it desirable to use a reliable data transfer protocol. CFDP provides the necessary reliability, and has been designed and optimized for use on space communication links	Level 3?		
	Operational Telemetry Latency to MOC	Operational telemetry will be streamed from each ground station to the LRO Mission Operations Center in real-time.	Operational telemetry is time-critical both to monitor spacecraft health and status as well as to allow visibility as to the reception, processing and results of command sequences sent by the LRO Flight Control Team.			
	MOC Command Latency	Operational commands will be streamed from the LRO Mission Operations Center in real-time and immediately transmitted to the spacecraft.	Real-time commanding is necessary to allow the LRO Flight Control Team sufficient ability to manage the spacecraft. LRO's use of CFDP for reliable file transfer requires a bi-directional link for ACK/NAK protocol traffic. The protocol's uplink path is provided by the operational TT&C link.			
	Data Telemetry Latency to MOC.	Mission data telemetry will be delivered to the LRO Mission Operations Center within 24 hours of reception by the ground station.	LRO requires rapid data availability in order to provide timely products to the LRO Science Operations Centers. Real-time transfer of high rate data will be cost prohibitive.			

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.6(3)		The Lunar Reconnaissance Orbiter communication system shall provide radiometric Doppler measurement to a threshold accuracy of 8 mm/sec (TBR) with an objective of <1mm/sec (TBR).	The LRO Flight Dyanamics Team has determined that a Doppler accuracy of not worse than 8 mm/sec is necessary to maintain LRO's stated orbital knowledge. Improvement of the Doppler accuracy will provide improved mission science data return. TBRs will be closed not less than 90 days prior to LRO PDR.			
		The Lunar Reconnaissance Orbiter communication system shall provide radiometric ranging measurement to a threshold accuracy of 15 meters (TBR) with an objective of (TBD) (TBR).	The LRO Flight Dyanamics Team has determined that a range accuracy of not worse than 15 meters is necessary to maintain LRO's stated orbital knowledge. TBRs will be closed not less than 90 days prior to LRO PDR.	REVIEW		
		The LRO mission communication system shall support the communication relay requirements (currently TBD) of RLEP missions 2 and 3.		REVIEW		
		The S-Band uplink shall have a link margin of > 3 (TBD) dB through all mission phases.	GOLD			
		The S-Band downlink shall have a link margin of > 3 (TBR) dB through all mission phases.	GOLD			
		The Ka-Band downlink shall have a link margin of > 3 TBD dB	GOLD			
		Shall generate fill frames in absence of valid transfer frame data.				
		The downlink shall support the simultaneous downlink of both real time and stored housekeeping data.				
		The downlink shall support playback of stored housekeeping data while simultaneously downlinking real time data.				
		Each uplink receiver shall always be on.				
		Full spherical command link coverage required for all mission phases.				

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.7	**Flight Software**					
	Architecture					
	Boot Code	The following flight software shall be stored in non-volatile, write protected (in-flight) memory: Safehold, Command Ingest, Health and Safety, Low-rate telemetry, Coarse time maintenance, Memory Dwell, Processor Cold Start, Processor Self Test	Minimal mode for fault recovery and re-loading normal mode code.	This must be stored in memory that cannot be corrupted. Current EEPROM technology may not be suitable. May need multiple copies of this code with a hardware switchover, etc.	FSW, C&DH	
	Initialization	The flight software shall initialize and remain in boot mode upon power-up or cold start. Transition out of boot mode via ground telecommand.	Allows recovery in the case where normal mode code has been corrupted.	Level 3. Do we need to go to normal mode without ground cmd?	FSW, C&DH	
	Initialization	The processor must running in Boot Mode TBD seconds following any restart.	Must recover quickly to re-establish spacecraft attitude control.	Derive from GN&C	FSW, C&DH	
	Reprogrammability	The flight software shall support normal mode code reprogrammability via telecommand.	Allow correction of SW errors or adding new SW features post-launch.	"normal mode" is the version of the flight software that supports all required operational features.	FSW, C&DH	
	Watchdogs and External Resets	The flight software shall reset watchdog every TBD seconds.	HW watchdog protects against hung SW.	Level 3.	FSW, C&DH	
	Software Separation Timer	Monitor separation loop and intiate a relative sequence of commands following separation from LV.	Need to get spacecraft power positive and under control even if there is a communications problem.		FSW, C&DH	
	Processor Utilization	The processor shall be idle at least 30% of the time averaged over a 5 second period.	Allow room to add software functions post-launch.	See GOLD	FSW, C&DH	
	Memory Utilization	Normal Code shall not exceed 70% of available storage.	Allow room to add software functions post-launch.	See GOLD	FSW, C&DH	
	Memory Integrity	The flight software shall scrub all EDAC-protected memory once per 120 minutes to correct bit errors.	To avoid build-up of errors that could result in uncorrectable errors we want to scrub about once per lunar orbit during normal operations.			
	Onboard Tables	The flight software shall organize on-board control structures as tables and provide simple commands to load and dump these tables.	Ease of management of configuration settings.			
	Data Integrity	The flight software shall maintain a checksum on critical data structures and validate the checksum at least once per 10 minutes.	Attempt to correct bad data values before they cause anomalous behavior.			
	SSR	The flight software shall provide resources to support file-based operations using CFDP.			FSW, C&DH	
	SSR EDAC	The flight software shall support error detection and correction	to meet BER		FSW, C&DH	
	Bad Sector Memory Mapping	The flight software shall be able to map around bad sectors of SSR.			FSW, C&DH	
	SSR Recording and Playback	The flight software shall support simultaneous recording and playback.	Don't want to stop science data collection during downlinks.		FSW, C&DH	
	Stored Commanding	The flight software shall support stored commands including RTS and ATS with 1 second resolution time tags.				
	Stored Command Capacity	The flight software shall store up to TBD stored commands with a total size of TBD bytes.	To support 96-hours of normal operations to cover a 3 day weekend.		FSW, GND	
	Event Messages/Error Messages	The flight software shall monitor both hardware and software for performance and execution anomalies. Detection shall result in generation of even/error message or counter increment. Anomalies include: TBD.	Give ground controllers quick notification of on-board anomalies. (FDC)	Level 3	FSW, C&DH	
	Health and Safety Monitoring	The flight software shall support monitoring of any telemetry point and initiate stored command sequence in response to out of bounds condition.	Flexibility is necessary to support autonomous error recovery conditions that may not be known until after launch.		FSW, C&DH	
	Memory Diagnostics	The flight software shall be capable of dumping any portion of memory.	Flexibility is necessary to support debugging conditions that may not be known until after launch.			

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.7(2)	Diagnostic Tlm Support	The flight software shall support changing the sampling rate of any telemetry point, via ground command or table load.	Flexibility is necessary to support debugging conditions that may not be known until after launch.		FSW, C&DH	
	Barker Timer	The flight software shall record time of last ground telecommand. The flight software shall execute reset of comm card and receiver if duration of time between ground commands exceeds 28 (TBR) hours.	Will perform in S/W to detect errors in uplink h/w. Reset comm card.		FSW, C&DH	
	LSB Scheduling	The flight software shall initiate predictable transactions on the LSB according to a pre-planned schedule; accurate to +/-5ms and synchronized to the 1Hz pulse.	Predictable schedule will make instrument design and testing easier.			
	File Management	The flight software shall provide commands to allow operators to manage the on-board file systems (directory listing, and file move/copy/delete).	Need the ability to clean up unused files before the file system fills up.			
	Housekeeping Collection	The flight software shall collect housekeeping data from all on-board subsystems, and format into CCSDS packets if necessary.				
	Housekeeping Telemetry	The flight software shall send the collected housekeeping data to the real-time channel on S-Band downlink.	HK data is needed in real-time to control and monitor the observatory.			
	Housekeeping Storage	The flight software shall store the collected housekeeping data for later playback.	Stored HK data is needed to monitor observatory performance during periods when ground contacts are not possible.			

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
3.8	**Deployables**					
	Solar Array Mechanism	Solar arrays shall track the sun from Beta angles 0 to 90 degrees with an accuracy of 5 degrees to support power generation over the 1 year mission.	Derives need to gimbal SA. Need to reference pointing buget document. Spec tolerance on pointing requirement +/- degrees.			
	Solar Array Deploy Mechanism	The Solar Array deploy mechanism shall deploy and maintain SA pointing accuracy per TBD document.	Maintain pointing accuracy of passive and active components			
	Solar Array Deploy Mechanism	The SA mechanisms shall maintain pointing without interfering with instrument, RF, or observatory FOVs.	Non interference during all mission phases.	Possible TBD exceptions, Special OPS?		
	Solar Array Deploy Mechanism	The Solar Array deploy mechanism shall restrain the SA and pointing mechanisms until deploy is commanded. The Mechanisms shall comply with safety requirements TBD.	Pass Safety requirements and withstand loads.			
	Solar Array Deploy Mechanism	SA mechanism torque disturbances shall be managed or limited to prevent interference with spacecraft pointing requirements TBD.	Torque disturbances.			
	Solar Array Deploy Mechanism	The SA deploy and pointing mechanisms shall be designed to function properly for a 15 month mission lifetime.	Mission life.			
	Solar Array Deploy Mechanism	The SA deploy and pointing mechanisms shall be designed to accommodate electrical power and telemetry services from the observatory to the Solar array.	Interfaces across hinge points.			
	High Gain Antenna Mechanism	The S/C shall provide hemispheric coverage for the HGA system to meet downlink requirments over the 1 year mission.	Derives need for gimballed HGA. Need to reference pointing budget document Add operational timing which will drive thermal.			
	High Gain Antenna Deploy Mechanism	The High Gain Antenna deploy mechanism shall deploy and maintain HGA pointing accuracy per TBD document.	Maintain pointing accuracy of passive and active components.			
	High Gain Antenna Deploy Mechanism	The High gain Antenna shall maintain pointing without interfering with instrument, SA, or observatory FOVs.	Non interference during all mission phases.	Possible TBD exceptions, Special OPS?		
	High Gain Antenna Deploy Mechanism	The High Gain Antenna deploy mechanism shall restrain the HGA and pointing mechanisms until deploy is commanded. The Mechanisms shall comply with safety requirements TBD.	Pass Safety requirements and withstand launch loads.			
	High Gain Antenna Deploy Mechanism	The HGA mechanism torque disturbances shall be managed or limited to prevent interference with spacecraft pointing requirements TBD.	Torque disturbances.			
	High Gain Antenna Deploy Mechanism	The HGA deploy and pointing mechanisms shall be designed to function properly for TBD mission lifetime.	Mission life.			
	High Gain Antenna Deploy Mechanism	The HGA deploy and pointing mechanisms shall be designed to accommodate electrical power, RF signal, and telemetry services from the observatory to the HGA.	Interfaces across hinge points.	(Does this belong here?)		

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
4.1	**Science Ops**					
		All instrument science operations centers (SOCs) shall deliver all level 0 and higher data to the PDS for long term storage.			GND	
		The SOCs shall have the capability to replace processing algorithms and reprocess previous recorded data		Delete?	GND	
		Prior to launch, algorithms to be used in science operations shall be tested with simulated LRO data in order to validate performance		Delete?	GND, GSE, FSW, C&DH	
		All LRO SOCs shall meet the requirements of NPG 2810.1, security of information technology for mission information			GND	
		The SOCs shall provide the capability for science mission planning and command generation			GND	
		The SOCs shall deliver all science plans and timelines to the MOC for uplink			GND	
		Level 0 data and all higher level data products shall be transferred from the PI's SOCs to the PDS	SOCs shall have an interface directly with the PDS for archiving of LRO measurement products.		GND	
		Higher level data products must be completed and delivered to the PDS within 6 months after the completion of the one year primary mission.			GND	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
4.2	**Mission Ops**					
		The LRO Mission Operations Center (MOC) shall support the following functions: - Mission Scheduling - Command load management - Command & Telemetry processing - Subsystem performance trending - Spacecraft & Instrument data storage - Level 0 processing - Level 0 data storage - Real-time and contingency operations	Basic operation functions needed for LRO.		GND	
		The MOC shall support automated operations	Allows reduced operations cost.		GND	
		The MOC shall maintain the capability for manual control of all automated functions	Provides the operations team to manual control activities at any point.		GND	
		The MOC shall monitor spacecraft and instrument housekeeping telemetry	Real-time checking of housekeeping telemetry. Alarms will be detected and operations people are alerted.		GND	
		The MOC shall store all spacecraft data for the life of the mission	Use to support long term trends and anomaly investigations.		GND	
		The MOC shall have the capability to playback, evaluate, and perform trending analysis on archived data	Support anomaly and trending operations.		GND	
		The MOC shall evaluate satellite health and safety on real-time and stored housekeeping data	Support anomaly and trending operations.		GND	
		The MOC shall provide level 0 data to each of the instrument Science operations Centers.			GND	
		The MOC shall accept instrument science timelines from each of the science support centers	Support daily command load generation.		GND	
		The MOC shall maintain a minimum of 30 days of spacecraft housekeeping data online	Temporary storage to allow for anomaly investigation and quick analysis of the housekeeping data		GND	
		The MOC shall provide at least 30 days worth of level 0 data (raw data).	Temporary storage until confirmation is received from the SOC.		GND	
		The MOC shall have the capability to receive telemetry data and send commands to LRO through the ground station network			GND	
		The MOC shall have the capability to maintain time correlation between the observatory and the ground segment			GND	
		The MOC shall encrypt and provide authentication for all outgoing commands to LRO	Ensure that commands are received sent from only the MOC. Prevents commanding from unauthorized sources.		GND	
		The MOC shall be based on GSFC.			GND	
		The ground segment shall have a backup control center that provides functions needed to monitor and maintain LRO health and safety.	In the event that the main MOC or portions of the MOC goes down for any length of time. A separate systems will be located at another site to maintain the health and safety of LRO. In this mode, routine science operations may be interrupted.		GND, FLT DYN	
		The ground system in the MOC shall be compatible with CCSDS COP-1.	Support command verifications			
		The MOC shall meet the requirements of NPG 2810.1, Security of Information Technology for the mission information category.				
		Level 0 data shall be archived at the MOC until archiving is confirmed at the SOC.			GND	
		Level 0 data shall be transferred to the PI's SOCs from the MOC in the form of data files.			GND	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
4.3	**Flight Dynamics**					
		LRO Flight Dynamics shall provide products supporting attitude determination, orbit prediction and determination, and acquisition data generation and delivery, maneuver planning.			FLT DYN	
		Flight dynamics shall provide attitude determination for verification of on-board attitude.			FLT DYN	
		Flight dynamics shall provide orbit determination processing and verify spacecraft on-board orbit propagator.			FLT DYN	
		Flight dynamics shall provide the ground network with acquisition data in the form of IIRVs.			FLT DYN	
		Flight dynamics analysis branch (FDAB) shall provide the maneuver planning and mission design support for all mission phases. Support shall include maneuver verification.			FLT DYN	
		Flight dynamics products shall be delivered to the MOC for distribution			FLT DYN, GND	

#	Title	Requirement	Rationale	Comments	Subsystem Allocation	Trace From
4.4	**Ground Network**					
		The ground station shall stored all LRO real-time and science data files for at least 7 days(TBR)	Provide ability to retransmit data in case of comm. Outage or file delivery problems		GND	
		The ground segment shall provide S-Band frequency command, telemetry and tracking functions in support of the LRO mission			GND, COMM	
		The ground segment shall provide Ka-Band frequency telemetry capture in support of LRO science operations			GND, COMM	
		The ground station shall be able to generate range tones on the uplink and receive simultaneous S-Band telemetry and ranging data modulated on an RF downlink subcarrier and carrier respectively.			GND, COMM	
		The ground station shall support a maximum S-Band command uplink data rate of 100 kbps (TBR)			GND, COMM	
		The ground station shall support a maximum Ka-Band telemetry data rate of 125 Mbps (TBR)			GND, COMM	
		The ground station shall support a maximum S-Band telemetry downlink data rate of 2.5 Mbps(TBR)			GND, COMM	
		The ground station shall receive housekeeping data in S-Band frequency and distribute in real-time to the MOC.			GND	
		The ground station shall have the capability to latch and record the VC0 frame sync time when it is received at the ground station with 10 msec (TBR) accuracy.			GND	
		The ground station shall collect instrument science data files in the Ka-Band frequency and distribute the files to the MOC			GND	
		The ground station shall employ and demonstrate a data distribution implementation with sufficient margin to support science data retransmissions	Provide margin to transmit science data files to the MOC while allowing retransmits.		GND, C&DH, FSW	
		The ground station shall be capable of autonomously relocking to the downlink in 30 seconds after a dropout.			GND, COMM	
		The ground station (S-Band) shall provide the idle pattern (continuous stream of alternating 1s and 0s) while the uplink carrier is active during supports.			GND	
		S-Band tracking stations shall provide tracking data to flight dynamics with an accuracy of at least 1 mm/sec, ranging to an accuracy of 15m (TBR)	Tracking accuracy allows flight dynamics to meet OD accuracy.		GND, FLT DYN	
		The ground station shall perform CFDP processing on data received during Ka-Band supports. CFDP processing needs to occur at the 125 Mbps rate. CFDP status information will be forwarded to the MOC for processing.			GND	