LRO Mission Overview

Craig Tooley - GSFC/431
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2008 Lunar Reconnaissance Orbiter (LRO)
First Step in the Robotic Lunar Exploration Program

LRO Objectives

- Characterization of the lunar radiation environment, biological impacts, and potential mitigation. Key aspects of this objective include determining the global radiation environment, investigating the capabilities of potential shielding materials, and validating deep space radiation prototype hardware and software.

- Develop a high resolution global, three dimensional geodetic grid of the Moon and provide the topography necessary for selecting future landing sites.

- Assess in detail the resources and environments of the Moon’s polar regions.

- High spatial resolution assessment of the Moon’s surface addressing elemental composition, mineralogy, and Regolith characteristics.

Objective: The Lunar Reconnaissance Orbiter (LRO) mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon.
Investigation Background

• **LRO provides major scientific and exploration benefit by 2009**
  – Apollo provided only a small glimpse of Moon; much to be explored
  – LRO address *both* science and exploration objectives
  – LRO brings many benefits (e.g., future landing sites, polar resources, safety, science)

• **LRO selected instruments complement other foreign efforts**
  – Six instruments competitively selected (“next-generation payload”)
  – Comparison to foreign systems demonstrate uniqueness and value
  – LRO will also accommodate a HQ directed Technology Demonstration payload, the Mini-RF (SAR) instrument.

• **LRO will enhance our knowledge of the Moon and increase the safety of future human missions.**
  – 3D maps of terrain and hazards, as well as of localized resources (ice) will tell us where to land (and at what precision).
  – Exploration of new sites where resources may be available requires new and timely knowledge of those sites at scales never before possible.

• **Current state of knowledge does not allow us to reduce the risk and cost of humans landing and working on the Moon.**
  – Equatorial environment (terrain, thermal, lighting) is different from polar region.
  – Apollo Program flight system capability limited to equatorial region (capability)
Benefit Example: Identifying Landing Sites & Resources

Resource imaging

Temperature mapping (find cold traps)

Polar Topography/shadow mapping

Polar Shadows

Landing Sites

Resources

Regolith Properties

High-Resolution Topography

Current Impact Rate

100 km

100 km
• Launch in late 2008 on a Delta II rocket into a direct insertion trajectory to the moon.
• On-board propulsion system used to capture at the moon, insert into and maintain 50 km altitude circular polar reconnaissance orbit.
• 1 year mission
• Orbiter is a 3-axis stabilized, nadir pointed spacecraft designed to operate continuously during the primary mission.

Nominal Cis-lunar Trajectory
Solar Rotating Coordinates
LRO Mission Overview

Orbiter

LRO Instruments

- Lunar Orbiter Laser Altimeter (LOLA) Measurement Investigation – LOLA will determine the global topography of the lunar surface at high resolution, measure landing site slopes and search for polar ices in shadowed regions.

- Lunar Reconnaissance Orbiter Camera (LROC) – LROC will acquire targeted images of the lunar surface capable of resolving small-scale features that could be landing site hazards, as well as wide-angle images at multiple wavelengths of the lunar poles to document changing illumination conditions and potential resources.

- Lunar Exploration Neutron Detector (LEND) – LEND will map the flux of neutrons from the lunar surface to search for evidence of water ice and provide measurements of the space radiation environment which can be useful for future human exploration.

- Diviner Lunar Radiometer Experiment (Diviner) – Diviner will map the temperature of the entire lunar surface at 300 meter horizontal scales to identify cold-traps and potential ice deposits.

- Lyman-Alpha Mapping Project (LAMP) – LAMP will observe the entire lunar surface in the far ultraviolet. LAMP will search for surface ices and frosts in the polar regions and provide images of permanently shadowed regions illuminated only by starlight.

- Cosmic Ray Telescope for the Effects of Radiation (CRaTER) – CRaTER will investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to background space radiation.

LRO Preliminary Design

Preliminary LRO Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Mass</td>
<td>1317 kg</td>
</tr>
<tr>
<td>Mass, Dry</td>
<td>603 kg</td>
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<tr>
<td>Mass, Fuel</td>
<td>714 kg</td>
</tr>
<tr>
<td>Power</td>
<td>745 W</td>
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<tr>
<td>Measurement Data Volume</td>
<td>575 Gb/day</td>
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</table>
## Competitively Selected LRO Instruments Provide Broad Benefits

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>Measurement</th>
<th>Exploration Benefit</th>
<th>Science Benefit</th>
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</thead>
<tbody>
<tr>
<td>CRaTER (BU+MIT)</td>
<td>Tissue equivalent response to radiation</td>
<td>Safe, lighter weight space vehicles that protect humans</td>
<td>Radiation conditions that influence life beyond Earth</td>
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<tr>
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<td>Safe landing site selection, and enhanced surface navigation (3D)</td>
<td>Geological evolution of the solar system by geodetic topography</td>
</tr>
<tr>
<td>Diviner (UCLA)</td>
<td>300m scale maps of Temperature, surface ice, rocks</td>
<td>Determines conditions for systems operability and water-ice location</td>
<td>Improved understanding of volatiles in the solar system - source, history, migration and deposition</td>
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<tr>
<td></td>
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<td>Locate potential water-ice in lunar soil and enhanced crew safety</td>
<td></td>
</tr>
<tr>
<td>LAMP (SWRI)</td>
<td>Maps of frosts in permanently shadowed areas, etc.</td>
<td>Locate potential water-ice (as frosts) on the surface</td>
<td></td>
</tr>
<tr>
<td>LEND (Russia)</td>
<td>Hydrogen content in and neutron radiation maps from upper 1m of Moon at 5km scales, Rad &gt; 10 MeV</td>
<td>Locate potential water-ice in lunar soil and enhanced crew safety</td>
<td></td>
</tr>
<tr>
<td>LOLA (GSFC)</td>
<td>~50m scale polar topography at &lt; 1m vertical, roughness</td>
<td>Safe landing site selection, and enhanced surface navigation (3D)</td>
<td></td>
</tr>
<tr>
<td>LROC (NWU+MSSS)</td>
<td>1000’s of 50cm/pixel images (125km²), and entire Moon at 100m in UV, Visible</td>
<td>Safe landing sites through hazard identification; some resource identification</td>
<td>Resource evaluation, impact flux and crustal evolution</td>
</tr>
</tbody>
</table>
LRO Spacecraft Systems Block Diagram
LRO Spacecraft Systems Capabilities

LRO Overview
6 Instruments and 1 Technical Demonstration
3 Spacecraft Modules – Instrument, Propulsion, Avionics
2 Deployable Systems – High Gain Antenna, Solar Array
2 Data Buses – Low Rate 1553, High Rate Spacewire
2 Comm Links – S Band, Ka Band
Monopropellant System – Hydrazine, Single Tank design

LRO Capability Highlights
Mass: 1480 kg
Power: 823 W orbit average @ 35V
Battery: Lithium Ion Chemistry
80 Amp-Hour Capacity
Data Storage Capacity: 400 Gb
Data Rate: 100 Mbps Down – Ka Band
2.186 Mbps Up/Down – S Band
Timing relative to UTC: 3ms
Delta V Capability: 1326 m/sec
Pointing Accuracy: 60 Asec relative to GCI
Pointing Knowledge: 30 Asec relative to GCI
Ground System Architecture Overview

- **Mission Operations Center**
  - T&C System
    - ITDS/CFDP
      - Telemetry Monitoring
      - Command Management
      - Automated Operations
      - CFDP processing
  - Trending System
    - Ingest raw data
    - Trend data points
    - Produce plots and reports
    - Remote access
  - Data Storage
    - Central storage system
    - Accessible for all systems
    - Short/long term storage
  - Data Distribution
    - Distribute measurement data
    - Distribute mission products

- **Flight Dynamics**
  - Orbit Determination
  - Attitude Determination
  - Maneuver

- **Ground Network**
  - S-Band Sites
    - Prime (Commercial Sites)
  - Backup (Deep Space Network)
  - LRO WSC Ground Station
  - Ka-Band System
  - S-Band System
  - Orbiter CnCs
  - Real-Time Housekeeping
    - Telemetry
    - Station Status
    - Packets
    - CFDP Control
    - And Status
  - Stored Measurement
    - Data Files
  - Stored Housekeeping
    - Data Files
  - Flight Dynamics
    - Products
  - Spacecraft
    - Telemetry
    - Mission
    - Products
  - Tracking
    - Data
  - Acq.
    - Data

- **Legend**
  - Blue: Delayed/Post-processing Link
  - Red: Real-time Link
  - Yellow: LRO Ground System Element
  - Orange: External Interfaces

- **Instruments**
  - LOLA SOC (GSFC)
  - LAMP SOC (SwRI, CO)
  - LEND SOC (Kharmsk, Russia)
  - LROC SOC (NU)
  - Diviner SOC (UCLA)
  - CRaTER SOC (BU)

- **Mini-RF**
  - (APL)

- **Planetary Data System (PDS)**
## LRO Mission Phases Overview

<table>
<thead>
<tr>
<th>No</th>
<th>Phase</th>
<th>Sub-Phases</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-Launch/ Launch Readiness</td>
<td>Space Segment Readiness, Ground Segment Readiness</td>
<td>Includes instrument I&amp;T, spacecraft/orbiter I&amp;T, space/ground segment testing as well as operations preparation and ground readiness testing leading up to launch.</td>
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<tr>
<td>2</td>
<td>Launch &amp; Lunar Transfer</td>
<td>Launch and Ascent, Separation and De-spin, Deployment and Sun Acq., Lunar Cruise, Lunar Orbit Insertion</td>
<td>Includes all activities &amp; operations from launch countdown sequence to Lunar Orbit Insertion (LOI). LOI includes all maneuvers necessary to obtain the temporary parking orbit for Orbiter activation and commissioning. During the cruise phase, initial spacecraft checkout will be performed to support activities for mid course correction (MCC) and LOI.</td>
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<tr>
<td>3</td>
<td>Orbiter Commissioning</td>
<td>Spacecraft Commissioning, Integrated Instrument Commissioning</td>
<td>Configure and checkout the spacecraft subsystems and ground systems prior to instrument turn-on. Instrument integrated activation will be developed to complete instruments turn-on and commissioning. Instrument commissioning includes any calibration activities needed in the temporary orbit.</td>
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<tr>
<td>4</td>
<td>Routine Operations</td>
<td>Measurements (Routine Ops), Station-keeping, Momentum Management, Instrument Calibrations, Lunar Eclipse, Yaw Maneuver, Safe Mode</td>
<td>One year of nominal science collection in the 50 (+/- 20) km orbit.</td>
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<td>5</td>
<td>Extended Mission Operations</td>
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<td>After 1-year of science observations, orbiter will be boosted into a higher orbit to reduce maintenance requirements. Potential purpose for extended mission operations may be to perform relay comm. operations. Alternatively additional measurement operations may be performed for a shorter period in a continued low orbit.</td>
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<tr>
<td>6</td>
<td>End-of-Mission Disposal</td>
<td></td>
<td>Includes planning and execution of end-of-life operations. LRO will impact lunar surface.</td>
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LRO Project Organization
## LRO Mission Schedule

### Mission PDR target: November 14

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<thead>
<tr>
<th>Year</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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### LRO Mission Milestones

- **AO Release**
- **AO Sel.**
- **MRD**
- **SRR**
- **Instr. PDR’s**
- **Launch**

### Milestones Details

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Timeline</th>
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<tbody>
<tr>
<td>Payload Fab/Assy/Test (7 Instruments)</td>
<td>Payload complete (Final delivery to I&amp;T)</td>
</tr>
<tr>
<td>S/C Fab/Assy/Bus Test</td>
<td>S/C complete (Final delivery to I&amp;T)</td>
</tr>
<tr>
<td>GDS/OPS Development Implemention &amp; Test</td>
<td>Payload complete (Final Delivery to I&amp;T)</td>
</tr>
<tr>
<td>Integration and Test</td>
<td></td>
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<tr>
<td>Launch Site Operations</td>
<td></td>
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<tr>
<td>Mission Operations</td>
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LRO Project Overall Status

• **Project almost fully staffed**
  – 45 civil servants & 23 support contractor at present (FTEs & WYEs)
  – Project level augmentations in-work as Program/Project resources are phased out.

• **Project infrastructure in-place**
  – Project organization and staffing being adjusted in reaction to RLEP transfer to ARC

• **Project Plan drafted for November 2004 Program review**
  – Currently being revised to reflect RLEP move to ARC & to comply with NPR 7120.5 rev. C

• **Mission SRR successfully conducted August 16-17**

• **Major system trades nearly complete**
  – C&DH Architecture
  – Propulsion System
  – Ground Network
  – Data Recorder Technology
  – High Accuracy Tracking Methodology

• **Level 2 & Level 3 Requirements established and moving thru review/approval cycles – SRR successfully completed**

• **Overall integrated mission development schedule developed and in review**
  – Baselined after PDR in preparation for Confirmation
LRO Element Development Status

- **Instruments** – high heritage proposed designs converging to preliminary designs
  - Design efforts primarily focused in two areas
    - Design modifications to adapt to LRO command/data interfaces
    - Design modifications driven by lunar thermal environment
      - Low lunar polar orbit is significantly different than Mars missions where most instrument heritage is from.
    - Interfaces with spacecraft well defined – ICDs in review/release cycle
      - Allocations released and agreed upon
    - LRO Payload Science Working Group formed and functioning
      - Consists of PI’s lead by LRO Project Scientist
        - Integral part of LRO mission operations planning

- **Spacecraft bus** – AO design concept evolving to preliminary design
  - All subsystems on track for mission PDR this Fall
    - Propulsion subsystem moved in-house at GSFC – leverages HST-DM surplus hardware
    - Spacecraft Computer specified and under development on ESES contract
    - SQ-RAID (hard disk) technology selected for data recorder. Acquisition now in-work.
    - Subsystem technical Peer Review being conducted Sept. - November
    - Approximately $15M in direct procurements planned during Sept.-Dec.

- **Ground Systems** – architecture and acquisition approach defined
  - Mission Operations Center
    - Preliminary design established based on GSFC heritage systems
    - Location established, initial facility agreements in-place
  - Ground Network
    - Requirements and architecture established
    - Primary 18m antenna procurement contract in place
    - GSFC Ground Networks providing end-to-end system
      - Development tasks on NENS contract established
    - SRR Planned for November
LRO Requirements

• Mission SRR held 9/16-17/2005 – judged very successful
  – Review covered development and flow down of level 2 and 3 requirements from the NASA ESMD Level 1 requirements
    • Instruments presented flow down of Level 1 measurement and data product requirements to their level 2 and 3 performance and functional requirements
    • Project presented flow down of level 2 and 3 mission, spacecraft, and ground system requirements
    • ~ 50 RFAs/Comments, none specific to instruments.
    • Level 1 requirements being refined by ESMD with Project and assistance.
      – Ongoing work includes establishment of Mission Success Criteria
      – SRR demonstrated that instrument requirements are established, understood, and realizable.
LRO Requirements Development Roadmap

LRO Level 1 Requirements
ESMD-RQMT-0010

Project Requirements

Measurement Requirements & Instrument Specific Expected Data Products

LRO Mission Requirements Document
431-RQMT-00004

Mini-RF

Allocations

Electrical Spec

Mechanical Spec

Thermal Spec

Operations

Contamination

Radiation

Mission Assurance

Launch Vehicle

LROC

LOLA

LAMP

LEND

CRaTER

Diviner

Level 2 Performance & SOC Requirements

Level 2 Requirement Synthesis

Instrument Proposals & LRO AO/PIP
  + Instrument Questionnaires
  + Instrument-Project TIMs
  + Instrument Accommodation Review
  + Mission Trade Studies
  + Collaborative Drafting of ICDs

Instrument interface requirements & constraints on spacecraft

Spacecraft and Ground Requirements

Spacecraft, Instrument & Ground
Level 3 Requirements Documents & ICDs

Preliminary Engineering
LRO Overview

Back-Ups
LRO Lifecycle Cost Estimate

- LRO LCC estimate is in process.

<table>
<thead>
<tr>
<th>Initial Cost Estimate ($M)</th>
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</thead>
<tbody>
<tr>
<td>Management &amp; Sys. Engr.</td>
</tr>
<tr>
<td>Spacecraft</td>
</tr>
<tr>
<td>CRaTER</td>
</tr>
<tr>
<td>Diviner</td>
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<tr>
<td>LAMP</td>
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<td>LEND</td>
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<tr>
<td>LOLA</td>
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<tr>
<td>LROC</td>
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<tr>
<td>Launch Vehicle</td>
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<tr>
<td>Ground Network/MOC &amp; Mission Ops.</td>
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<tr>
<td>I&amp;T</td>
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<tr>
<td>Reserve</td>
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<tr>
<td><strong>Total</strong></td>
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**Initial Guiding Boundary Conditions**
- 2008 launch
- Delta II class LV
- Accommodate Investigations sought by ORDT/AO
- $400M cost target put forth in FAD

**Conceptual Cost Estimates**
- Parametric estimate based on historical data for recent mission with similarities
- Application of simple CERs by Project

**Initial Grassroots Estimates**
- Done at subsystem level
  - Subsystem estimates experience based
  - Instruments per proposal, C/D/E contracts

**LCC estimate for Confirmation Process**
- Results from reconciliation of Grassroots & RAO estimates. Reviewed by GSFC PMC

**Refined Grassroots Estimates**
- Done at subsystem level
  - Subsystem estimates reviewed, design based instruments per proposals, C/D/E contracts

**GSFC RAO Cost Modeling**
- Mission input data defined/delivered by Project

**In Progress**