Lunar Precursor and Robotic Program
Industry Day

Tony Lavoie/Program Manager
Julie Bassler/Deputy Program Manager
Leslie Curtis/Chief Engineer

October 20, 2006
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Company/Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 – 9:30</td>
<td>LPRP Presentation</td>
<td>Tony Lavoie</td>
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<tr>
<td>9:30 – 9:45</td>
<td>Press Q&amp;A</td>
<td>Steve Roy</td>
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<tr>
<td>9:45 – 10:00</td>
<td>Break</td>
<td>Convene to 1st floor Conference Room</td>
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<tr>
<td>10:00 – 10:30</td>
<td>Northrop-Grumman</td>
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<td>10:30 – 11:00</td>
<td>Cisco Systems</td>
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<td>11:00 – 11:30</td>
<td>Harris Corporation</td>
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<td>11:30 – 12:00</td>
<td>Center for Space Power</td>
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<td>12:00 – 12:45</td>
<td>Lunch</td>
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<td>12:45 – 1:15</td>
<td>General Dynamics</td>
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<td>1:15 – 1:45</td>
<td>ATK</td>
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<td>1:45 – 2:15</td>
<td>Boeing</td>
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<td>2:15 – 2:30</td>
<td>Break</td>
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<td>2:30 – 3:00</td>
<td>Draper Labs</td>
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<td>3:00 – 3:30</td>
<td>Ball Aerospace</td>
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<td>3:30 – 4:00</td>
<td>Teledyne Brown</td>
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<td>4:00 – 4:30</td>
<td>Raytheon</td>
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</table>
Primary responsibility of the NASA Lunar Precursor Robotic Program is to develop and execute missions to achieve NASA’s robotic lunar exploration objectives.

This will be accomplished by:

- Defining a robust and sustainable architecture for robotic precursor missions that accomplish defined objectives
- Identifying key assumptions and guidelines
- Identifying system interfaces
- Building constituencies in the lunar exploration community
- Defining specific requirements for each precursor mission
- Establishing and overseeing projects to execute mission design, development, integration, test and operation
- Reduce risk for future human missions (Constellation program) through technology validation
“Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities”, NSPD-31

Robotic missions:
Provide early strategic information for human missions
  Key knowledge needed for human safety and mission success
  Infrastructure elements for eventual human use
  Data will be used to plan and execute human exploration of the Moon

Resolve the unknowns of the lunar polar regions
  Knowledge of the environment – temperature, lighting, etc.
  Resources/deposits – composition and physical nature
  Terrain and surface properties - dust characterization
  Emplace support infrastructure – navigation/communication, beacons, teleoperated robots

Make exploration more capable and sustainable
  Emplace surface systems
  Demonstrate new technologies that will enable settlement (ie, ISRU)
  Operational experience in lunar environment
  Create new opportunities for scientific investigation
Objectives for lunar robotic missions:
Global mapping of the lunar surface
Identify optimal landing site(s) on the Moon for robotic and human explorers
Find and characterize resources that make exploration affordable and sustainable
  Locate and characterize lunar volatiles
  Characterize sunlight and surface environment of poles
Field test new equipment, technologies and approaches (e.g., dust and radiation mitigation)
Support demonstration, validation, and establishment of heritage of systems for use on human missions
Determine how life will adapt to space environments
Emplace infrastructure to support human exploration
Gain operational experience in lunar environments
Provide opportunities for industry, educational and international partners
Apollo had three (Ranger, Lunar Orbiter and Surveyor) robotic exploration programs with 21 precursor missions from 1961-68

1. Ranger hard landers took the first close-up photos of the lunar surface
2. Lunar Orbiters provided medium & high resolution imagery (1-2 m resolution), acquired to support selection of Apollo and Surveyor landing sites
3. Surveyor soft landers made surface environmental measurements including physical characteristics and chemical composition

Exploration needs the above information to go to new sites AND resource data to enable sustainable exploration
Lunar Precursor and Robotic Program
LPRP in context of NASA’s Exploration Architecture


- Initial CEV Capability
- 1st Human CEV Flight
- Lunar Outpost Buildup
- Lunar Robotic Missions
- Science Robotic Missions
- Commercial Crew/Cargo for ISS
- Space Shuttle Ops
- CEV Development
- Crew Launch Development
- Early Design Activity
- CEV Production and Operations
- Lunar Lander Development
- Lunar Heavy Launch Development
- Earth Departure Stage Development
- Surface Systems Development
- Mars Expedition Design

LPRP Industry Day, October 20, 2006
Lunar Reconnaissance Orbiter and LCROSS

Lander Sunlight Mission

Small Satellite Mission

Lander Crater Mission with Rover
**Lunar Reconnaissance Orbiter (LRO)**

Lunar mapping, topography, radiation characterization, and volatile identification

50 km circular polar orbit

Critical Design Review: October 2006

Launch: Late October 2008

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**Lunar CRater Observation and Sensing Satellite (LCROSS)**

Investigate the presence of water at one of the lunar poles via a kinetic impactor and shepherding spacecraft

Preliminary Design Review: August 2006

Launch: Late October 2008 (co-manifested with LRO)
Lunar Precursor and Robotic Program
LRO Orbiter Overview - Configuration

National Aeronautics & Space Administration

LRO Orbiter Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (CBE)</td>
<td>1706 kg</td>
</tr>
<tr>
<td></td>
<td>Dry: 309 kg</td>
</tr>
<tr>
<td></td>
<td>Fuel: 897 kg</td>
</tr>
<tr>
<td>Orbit Average Bus Power</td>
<td>681 W (Beta 0, S&amp;Ka xmit)</td>
</tr>
<tr>
<td>Measurement Data Volume, Max Downlink rate</td>
<td>572 Gb/day, 100Mb/sec</td>
</tr>
<tr>
<td>Pointing Accuracy, Knowledge</td>
<td>60, 30 arc-sec</td>
</tr>
<tr>
<td>Mission</td>
<td>Key Exploration Capabilities</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Clementine</strong></td>
<td>High resolution and multispectral imaging</td>
</tr>
<tr>
<td></td>
<td>Topography</td>
</tr>
<tr>
<td></td>
<td>LWIR</td>
</tr>
<tr>
<td><strong>Lunar Prospector</strong></td>
<td>No imager on-board</td>
</tr>
<tr>
<td></td>
<td>Neutron Detector</td>
</tr>
<tr>
<td></td>
<td>GRS</td>
</tr>
<tr>
<td><strong>LRO</strong></td>
<td>High resolution and multispectral imaging</td>
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<tr>
<td></td>
<td>Topography</td>
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<td></td>
<td>Neutron detector</td>
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<tr>
<td></td>
<td>Thermal mapping</td>
</tr>
</tbody>
</table>
### Lunar Precursor and Robotic Program

**LRO Comparison to Other Current Lunar Missions**

<table>
<thead>
<tr>
<th></th>
<th>Clementine</th>
<th>Lunar Prospector</th>
<th>SMART-1</th>
<th>Chang‘E-1</th>
<th>Chandrayaan-1</th>
<th>SELENE</th>
<th>Lunar Reconnaissance Orbiter</th>
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</thead>
<tbody>
<tr>
<td><strong>Camera (VIS monochrome)</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X (stereo)</td>
<td>X (stereo)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Typical resolution (low/ high, m)</strong></td>
<td>25/660</td>
<td>200</td>
<td>?</td>
<td>5</td>
<td>10</td>
<td>10000,5</td>
<td></td>
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<tr>
<td><strong>UV imaging</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>IR imaging</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Thermal (broadband) IR</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Mult-band UV-VIS-IR imaging</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Gamma Ray Spectrometer</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Neutron Spectrometer</strong></td>
<td>X</td>
<td></td>
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<td>X</td>
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<tr>
<td><strong>Alpha Particle Spectrometer</strong></td>
<td>X</td>
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<td>X</td>
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<tr>
<td><strong>X-ray Spectrometer</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
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<tr>
<td><strong>Infrared Spectrometer</strong></td>
<td>X</td>
<td></td>
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<td></td>
<td>X</td>
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<tr>
<td><strong>Radiometer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Synthetic Aperture Radar</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<td>X</td>
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<tr>
<td><strong>Radar Sounder</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Bistatic radar</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Laser Ranging/Altimeter</strong></td>
<td>X</td>
<td></td>
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<td>X</td>
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<td>X</td>
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<tr>
<td><strong>Magnetometer</strong></td>
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<td></td>
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<td></td>
<td>X</td>
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<td>X</td>
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<tr>
<td><strong>Electron Reflectometer</strong></td>
<td>X</td>
<td></td>
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<td>X</td>
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<tr>
<td><strong>High-energy Detector</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<td>X</td>
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<tr>
<td><strong>Solar Wind Detector</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Solar X-ray monitor</strong></td>
<td>X</td>
<td></td>
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<td>X</td>
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<tr>
<td><strong>Lunar Radiation Environment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Plasma Analyzer</strong></td>
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<td></td>
<td></td>
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<td></td>
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<td>X</td>
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<tr>
<td><strong>Plasma Imager (Earth’s plasmasphere)</strong></td>
<td>X</td>
<td></td>
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<td>X</td>
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<tr>
<td><strong>Radio Science (lunar ionosphere)</strong></td>
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<td></td>
<td></td>
<td>X</td>
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<tr>
<td><strong>Gravity</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>

Lunar orbital missions 1994-2008

– Data and instruments
The LCROSS uses the spent Earth Departure Upper Stage (EDUS) of the launch vehicle as a kinetic impactor and a shepherding spacecraft for control and science observation.

The shepherding spacecraft will:
- Target the kinetic impactor to a permanently shadowed region of a lunar pole
- Observe the impact and fly through the ejecta plume
- Measure the concentration of water ice in the ejecta plume
- Measure water vapor in the ejecta plume
- Measure the extended OH exosphere
- Characterize the lunar regolith within the ejecta plume
- Become a second impactor, targeting an area near the first impactor
Lunar Reconnaissance Orbiter and LCROSS

Note: The concepts for Small Satellite and Lander are only Notional. No decision on Payloads has been made, and these have been notionally defined in the following charts only to aid in maturing further concept development.

Lander Sunlight Mission

Small Satellite Mission

Lander Crater Mission with Rover
Overview
Develop common lander to land in sunlight near lunar pole to characterize environment and deposits
Lander becomes standard design for delivery of future payloads
Sunlight mission answers first-order questions about poles and provides ground truth for orbital sensing

Concept of Operations - Notional
Precision landing & hazard avoidance
Characterize sun illumination over a seasonal cycle
Direct measurement of neutron flux, soil hydrogen concentration in sunlit area for correlation with orbital mapping
Biological radiation response characterization
Characterize lunar dust and charging environment
Possible micro-rover for near-field investigation (if funded separately)
Overview
Common Lander designed to support all robotic missions with minimal modification
Mission specific “payload” capability of approximately TBD kg (driven by need to deliver rover)
Propulsion is combination of a solid rocket motor and a throttleable hypergolic bi-prop system
Power by solar arrays
Land within 100 m 3σ of a predetermined surface feature, avoiding hazards

Concept of Operations - Notional
TLI orbit by an EELV; SRM breaking burn for direct insertion and landing
Liquid propulsion system controlling terminal descent and landing
Precision navigation and hazard avoidance to progressively demonstrate the ALHAT sensor compliment.

Two primary mission scenarios:
   Land at an illuminated location and perform fixed measurements over an extended period of time. Small mobility elements may be accommodated.
   Land and deploy a rover in a dark or illuminated area.
◆ Lunar Reconnaissance Orbiter and LCROSS

◆ Lander Sunlight Mission

◆ Small Satellite Mission

◆ Lander Crater Mission with Rover
Overview
Reference concept: Communications Relay Satellite Technology validation
Mission is designed to fly microsat to validate laser communications technologies, as well as packet-switched RF relay capability

Concept of Operations - Notional
Lunar orbiter microsat bus
- 3-axis Stabilized Platform
- 100-200 kg-class bus; 30-40 kg payload capacity
- Body Mounted solar arrays, ~ 100 W
- Routine Spacecraft Comm & Tracking Via Low Rate S-band
SmallSat comm relay payload and mission profile
- 2 Way RF Support For Local Users
- Optical Transmit (100 mbps) Trunk Line To Single Terrestrial Ground Terminal
- Comm Supported With Internal IP Router
- 5 Hour Dwell Over Region In 8 Hour Orbit
Science and Resource Evaluation

Bistatic Radar Imaging Experiment (using two satellites, formation flying)
Neutron spectroscopy: hydrogen mapping at high resolution (< 5 km/pixel)
Second generation remote sensing applications (e.g., low frequency radar sounding for deep structure, surface compositional mapping)
Secondary ion mass spectroscopy; provide high resolution chemical mapping of the surface
Lofted dust characterization
Lunar exosphere composition and evolution
VLF radio astronomy demonstration

Infrastructure Emplacement

Low cost advanced communications demonstrations
Lunar navigation system (GPS elements)

Technology Demonstration Missions

X-NAV (GPS using natural X-ray pulsars)
Laser Comm
Space Based Routers
Lunar Reconnaissance Orbiter and LCROSS

Lander Sunlight Mission

Small Satellite Mission

Lander Crater Mission with Rover
Overview
Reference concept: fuel cell-powered rover, ranging > 25 km and obtaining > 22 subsurface measurements (each 1,000 m apart) to map and analyze polar volatiles
Navigation by integration of coherent ranging with an overhead relay satellite, IMU, and perhaps terrain relative navigation
Navigation by flash lamps and MER style hazard avoidance or 3-D scanning LIDAR
RTG-powered options are lighter and offer extended life, but are more costly

Concept of Operations - Notional
Rover delivered directly to the crater floor by the lander (which expires shortly after rover egress)
Rover traverses to selected sites obtaining ground penetrating radar and neutron spectrometer profiles along the way
Sampling at predetermined site, rover drills and samples material approximately every 50 cm to a maximum depth of 2 m
On-board analysis of volatile content and composition
Global maps of morphology, topography, gravity

Polar deposits and physical properties from orbital sensing

Surface *in situ* analyses of the chemical and physical states of polar deposits

Survey and assay of potential resources and the future outpost site

Demonstration experiments of ISRU processing and materials handling

Engineering data from Risk reduction test objectives for the later human missions
LPRP is configured to support human lunar return by providing key strategic information, creating new capabilities, and retiring risk for future missions.

Program is well defined conceptually, but details of mission payloads, modes of operation, and specific experiments and capabilities are still being worked.

Initial missions are Lunar Reconnaissance Orbiter and LCROSS; both spacecraft will produce abundant, high-quality data requiring extensive scientific analysis to interpret and use for future exploration.

Subsequent missions will land, characterize potential outpost sites, reduce risk to the human mission, and in the process of doing those things it will conduct scientific exploration.

There is a need to develop a plan to insure that the data from the LPRP missions is properly reduced and analyzed to extract the maximum strategic information.

The global community can assist humanity’s return to the Moon by jointly participating in this exciting endeavor.
LPRP will continue coordination and formalize collaboration with:
   Exploration, Science and Space Ops Mission Directorates and their respective programs
   Science community
   International Partners and their flight programs
   Industry and the private sector
   Educational institutions

LPRP is part of a robust and sustainable lunar exploration architecture
   Critical, yet modest investment for future Constellation efforts