NASA’s Robotic Lunar Lander Development Project

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Robotic Lunar Missions

RACE TO THE MOON
What started as a context between the U.S. and the USSR has become the scene of international collaboration.
Many high-priority science and exploration objectives are uniquely met by landed lunar missions

- **International Lunar Network Mission**: Determine the composition and structure of the moon’s interior
- **Lunar Polar Volatiles Explorer**: In situ characterization of volatile species; understand current processes
- **Lunar Sample Return**: Return rocks from unexplored sites, such as lunar farside or young lava flows, to terrestrial laboratories
- **Human Exploration Precursors**: Characterize the lunar surface environment at landing sites: lighting, radiation, thermal, and dust; test technologies; demo ISRU

### MSFC/APL Lander Development History

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<th>RLEP</th>
<th>LPRP</th>
<th>ILN</th>
<th>RLLDP</th>
<th>ESMO</th>
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<tr>
<td>Project Objective</td>
<td>Human Precursor to South Pole</td>
<td>Continue to Support Human Precursor Efforts</td>
<td>Develop Anchor Nodes for a Lunar Geophysical Network</td>
<td>Complete and test WSTA</td>
<td>Complete high priority risk reduction efforts</td>
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<td>Primary Tasks</td>
<td>Common lander development</td>
<td>Incremental approach - Crater rim then Crater floor with rover</td>
<td>Technology Development</td>
<td>Concept trades looking at ASRG and solar battery concepts</td>
<td>ILN, LPRP, Lunar Polar Volatiles, Mercury, and NEA mission concepts</td>
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<tr>
<td>Lessons Learned</td>
<td>Direct descent most mass efficient (like Surveyor)</td>
<td>Concept trades looking at ASRG and solar battery concepts</td>
<td>ASRG Landers Feasible on Atlas V 401</td>
<td>4 ASRG Landers Feasible on Atlas V 401</td>
<td>RLLD risk reduction efforts are applicable for airless body lander missions</td>
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<td>Common lander for crater rim and crater floor mission is feasible</td>
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<td>ALHAT Precursor is feasible</td>
<td>2 Solar Battery Landers Feasible on Falcon 9 B2</td>
<td>Validated design. No major design changes required as a result of rigorous testing</td>
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<td>ALHAT Precursor is feasible</td>
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<td>DoD propulsion technology highly desirable for mass and packaging</td>
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Cold Gas Test Article

Flight Design

Thermal & Battery Test

Lander Stability Test

Propulsion Thruster Hot Test

Robotic Lander Prototype

Cold Gas Test Article

Flight Robotic Lander

 Validation through Prototype and Testing

GN&C - Helicopter Field Testing

+ Provides the capability to test GN&C flight hardware and software against a combination of realistic and stressing descent profiles and terrains.
+ Open-loop test data is provided to evaluate landing performance and terrain navigation capability in the GN&C high fidelity simulation as well as in a processor in the loop environment.

Example of planned flight profiles over a test site
75 degree descents
45 degree ascents
8000 ft AGL to 200 ft AGL

Nav FT equipment rack in rear cabin
Analysis capability to accurately predict the dynamics of touchdown in a stable manner, given a variety of landing scenarios

3-D simulation and testing of a subscale lander with rigid- and energy-absorbing legs completed to anchor ADAMS models to test results

- For small landers, DACS thrusters used for primary landing propulsion
- DACS thrusters have not operated for long durations; limited performance data is available
- Conducted vacuum tests of MDA DACS thrusters for landing (100 lb) and ACS (6 lb) to evaluate performance and thermal characteristics
- Thrusters successfully demonstrated RLL flight profile (also continuous 66 sec on landing thrusters, 25 sec on ACS)
  - Combustion was stable in all tests
  - Temperature measurements show performance below material thermal limit
  - Remaining modifications and tests have been identified
Cold Gas Test Article Overview

- First Flight September 2009
- Mass: 107 kg dry / 146 kg wet
- Approximately 10s of flight time
- Compressed-air propulsion emulates flight system with pulsed operation
  - 3 Descent thrusters (~37lbf ea)
  - 6 ACS thrusters (~12lbf ea)
- Central throttleable thruster offsets gravity
- 3 compressed air tanks (3000 psi)
- Carbon fiber / Al honeycomb decks
- Custom avionics (COTS components assembled in-house)
- Custom flight and ground software
- Over 150 successful flights

Cold Gas Test Article Flights
Strap-down and hover tests complete, expected drop test in summer 2011
Mass: 206 kg dry / 322 kg wet
Aluminum ortho-grid decks
Hydrogen peroxide (90%) monopropellant propulsion system
- Emulates flight system / pulsed operation
  - 3 Descent thrusters
  - 12 ACS thrusters
- Central throttleable thruster offsets gravity
Sensors
- LN200-1 IMU, Roke Manor Radar Altimeter, Illunis optical cameras, Novatel Pro-Pak GPS truth data system, Pressure transducers & thermocouples for housekeeping
Flight-like Software
- “In-Control” ground system software
- Core Flight Executive (cFE) modular software environment

Warm Gas Test Article Hover Test
The MSFC/APL RLLDP team has developed lander concepts encompassing a range of mission types and payloads for science, exploration, and technology demonstration missions.

- Developed experience and expertise in lander systems
- Incorporated lessons learned from previous efforts to improve the fidelity of mission concepts, analysis tools, and test beds

Mature small and medium lander designs concepts have been developed
- Share largely a common design architecture
- Flexible for a large number of mission and payload options

High risk development areas have been successfully addressed

Landers could be selected for a mission with much of the concept formulation phase work already completed

The RLLDP project is well prepared to develop lander systems for lunar or other airless body NASA missions