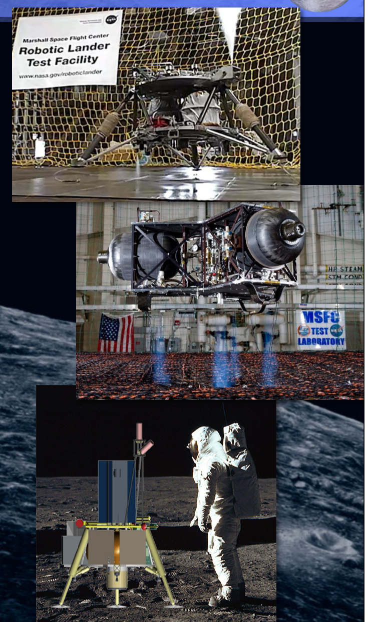
NASA's Robotic Lunar Lander Development Project



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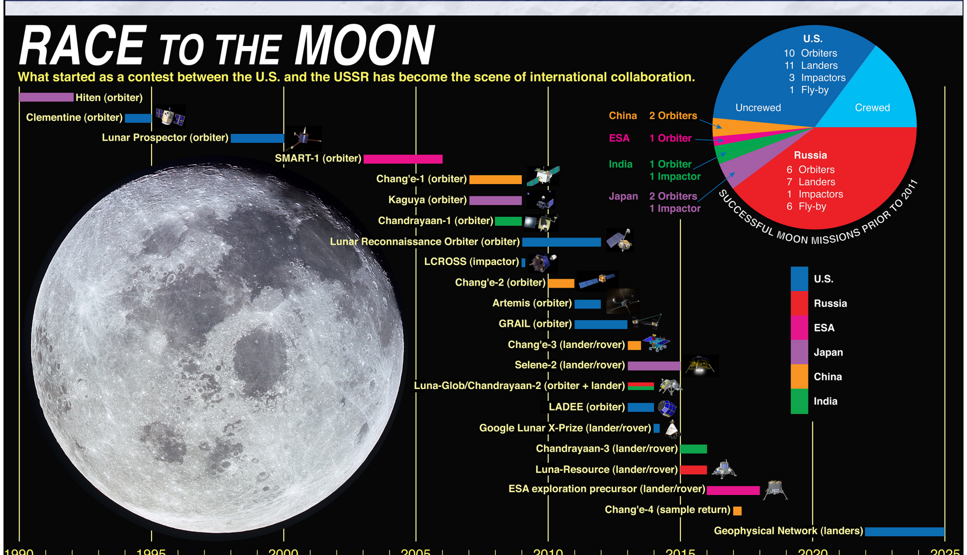
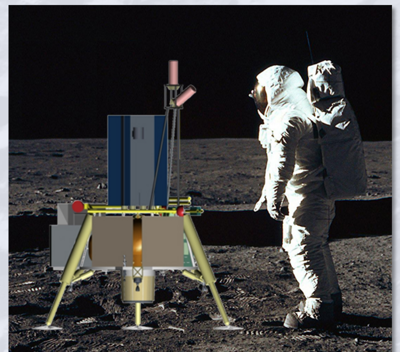
Robotic Lunar Missions



Future Robotic Lander Uses

- 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



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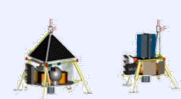
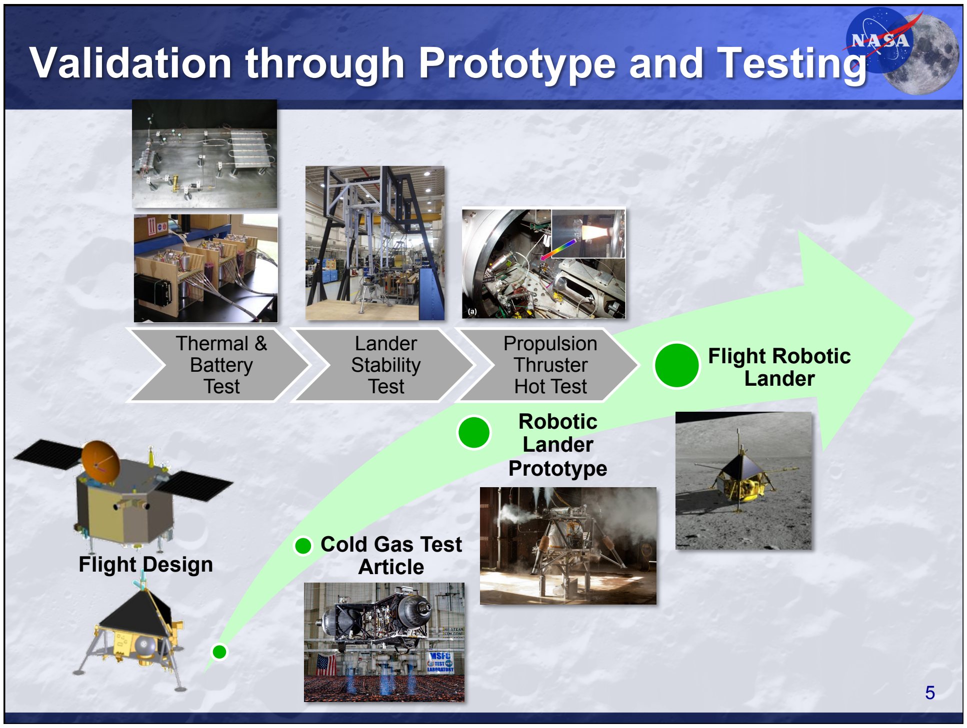
MSFC/APL Lander Development History

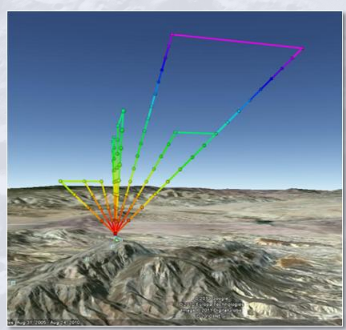
	ESMD RLEP	ESMD LPRP	SMD ILN	SMD RLLDP XPRP
	2005-2006	2006-2008	2008-2010	2010-Present
				
Project Objective	Human Precursor to South Pole • Crater rim experiments "See the light" • Crater floor volatiles "Touch the water"	Continue to Support Human Precursor Efforts • Incremental approach – Crater rim then Crater floor with rover • Technology Development	• Develop Anchor Nodes for a Lunar Geophysical Network • Engage other centers and industry to explore options • Conduct risk reduction efforts	• Complete and test WGTA • Complete high priority risk reduction efforts • ILN, xPRP, Lunar Polar Volatiles, Mercury, and NEA mission concepts
Primary Tasks	• 13 concept trade space • Early concepts focused on extensibility to support human missions • Later concepts were more focused (crater rim or crater floor)	• Common lander development • Delta II mission study • ALHAT Precursor • GN&C concept development • TRN concept development • Landing gear and energy absorbing materials trades	• Concept trades looking at ASRG and solar battery concepts • Risk reduction efforts for all subsystem areas • Developed cold gas lander test-bed to integrate subsystems and identify system level risks	• WGTA hover test completed April 14, 2011 • DACS testing completed • Completed work in several risk reduction areas • Supported planetary decadal study
Lessons Learned	• Direct descent most mass efficient (like Surveyor)	• Common lander for crater rim and crater floor mission is feasible • ALHAT Precursor is feasible	• 4 ASRG Landers Feasible on Atlas V 401 • 2 Solar Battery Landers Feasible on Falcon 9 B2 • DoD propulsion technology highly desirable for mass and packaging	• RLLD risk reduction efforts are applicable for airless body lander missions • Validated design. No major design changes required as a result of rigorous 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.

Nav FT equipment rack in rear cabin



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

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Structures - Lander Stability

- 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

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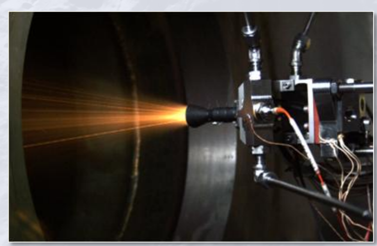
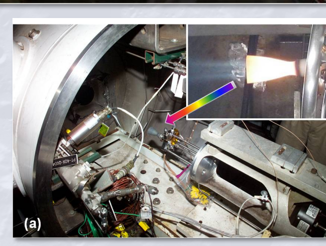
Propulsion – DACS Thruster Tests

- 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





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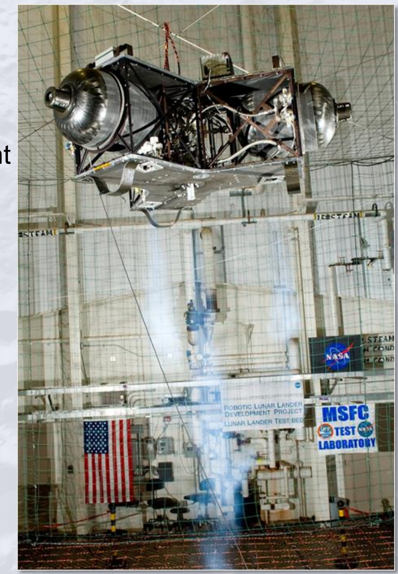
Cold Gas Test Article Overview

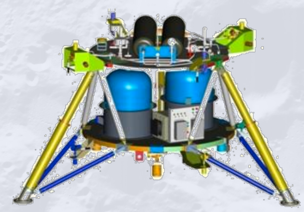
- First Flight September 2009
- Mass: 107 kg dry / 146 kg wet
- Approximately 10s of flight time
- Compressed-air propulsion emulates flight system with pulsed operation
    - 3 Descent thrusters (~37lbf ea)
    - 6 ACS thrusters (~12lbf ea)
  - Central throttleable thruster offsets gravity
  - 3 compressed 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



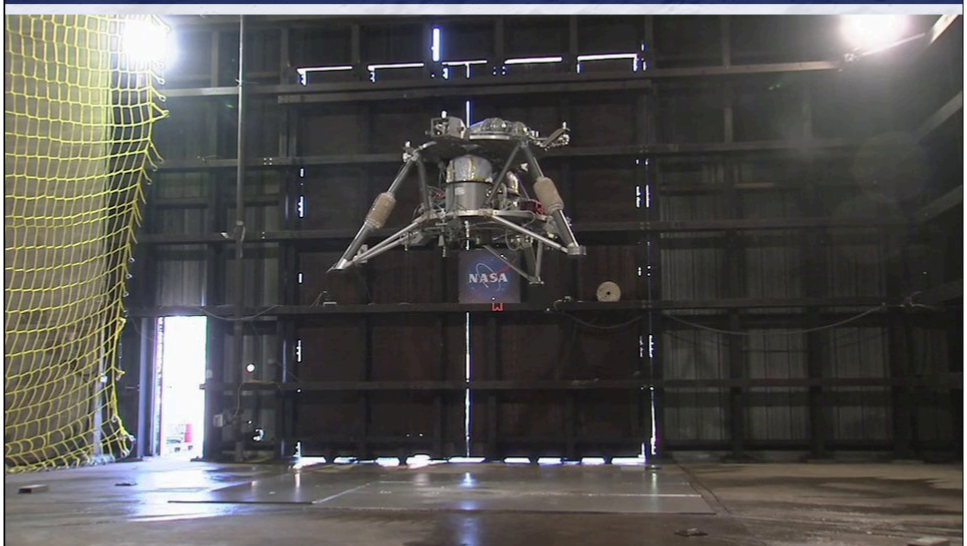
Cold Gas Test Article Flights

Warm Gas Test Article Overview

- 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



Summary – NASA Robotic Lander Project

- 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

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