NASA's Robotic Lunar Lander Develpoment Project: An Update

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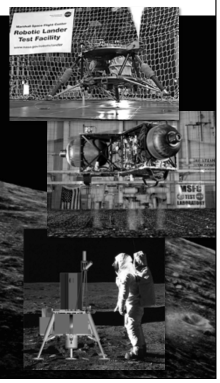
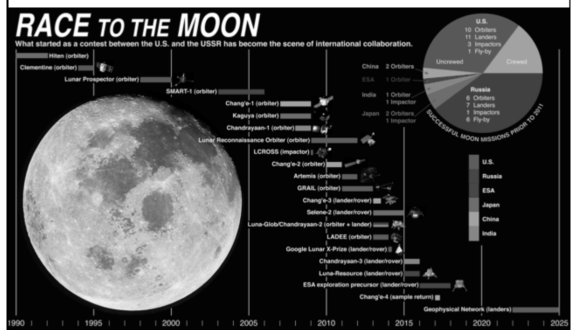


Robotic Lunar Missions



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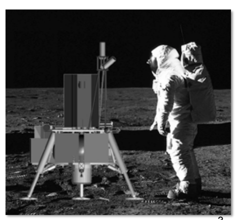
Future Robotic Lander

- 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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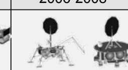
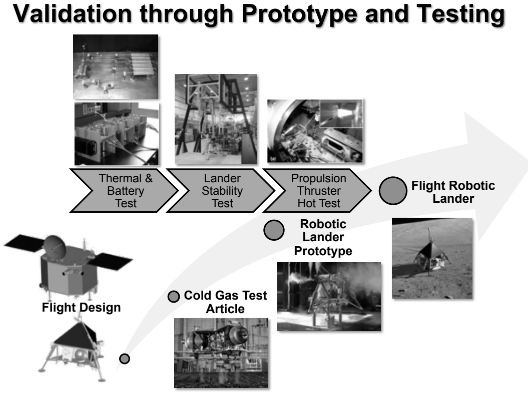
MSFC/APL Lander Development History

	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

Validation through Prototype and Testing



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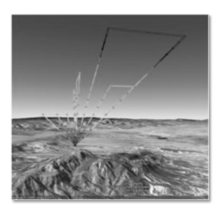
GN&C - Helicopter Field Testing

- 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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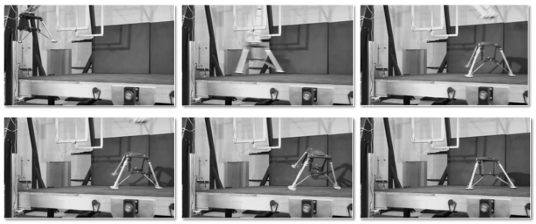
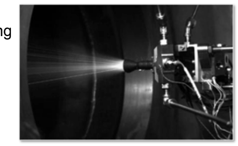
Structures - Lander Stability

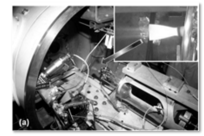
- Analysis capability to accurately predict the dynamics of touchdown in a stable manner, given a variety of landing scenarios
- 3-D simulation and testing of a subscale lander with rigid- and energy-absorbing legs completed to anchor ADAMS models to test results



Propulsion – DACS Thruster Tests

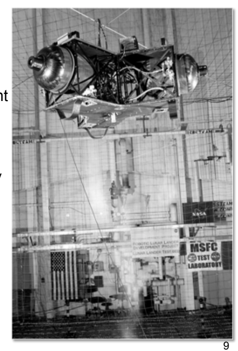
- For small landers, DACS thrusters used for primary landing propulsion
- DACS thrusters have not operated for long durations; limited performance data is available
- Conducted vacuum tests of MDA DACS thrusters for landing (100 lb) and ACS (6 lb) to evaluate performance and thermal characteristics
- 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





Cold Gas Test Article Overview

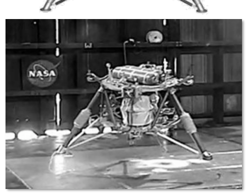
- First Flight September 2009
- Mass: 107 kg dry / 146 kg wet
- Approximately 10s of flight time
- Compressed-air propulsion emulates flight system with pulsed operation
  - 3 Descent thrusters (~37lbf ea)
  - 6 ACS thrusters (~12lbf ea)
  - Central throttleable thruster offsets gravity
  - 3 compressed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



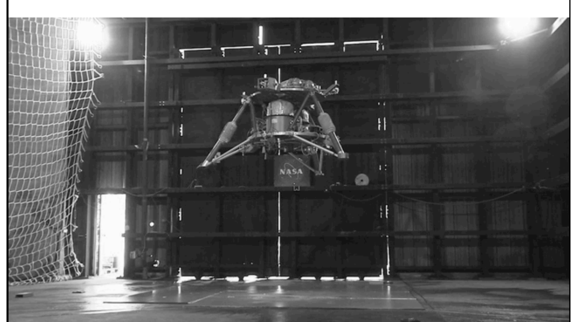
Cold Gas Test Article Flights

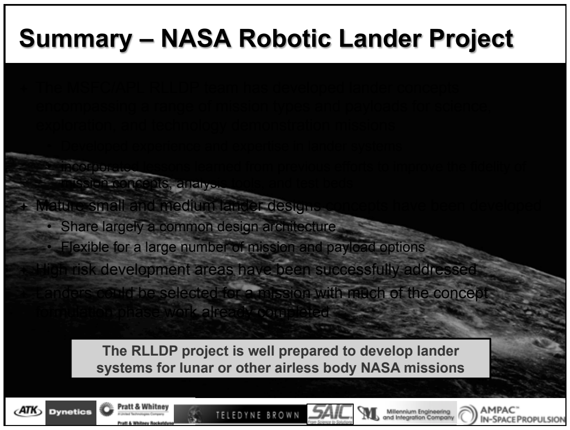
Warm Gas Test Article Overview

- 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
ATK
Dynetics
Pratt & Whitney
TELEDYNE BROWN
SAIC
Millennium Engineering and Integration Company
AMPAC IN-SPACE PROPULSION