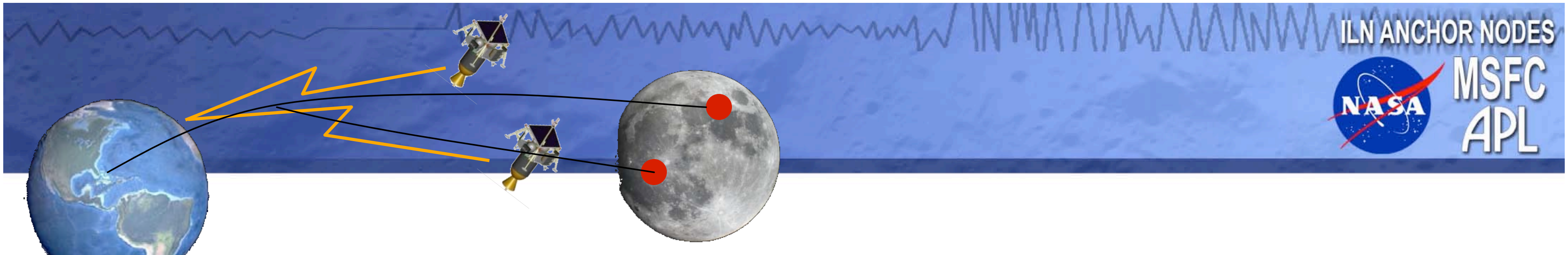

Robotic Lunar Landers for Science and Exploration

Dr. Barbara Cohen
MSFC
Brian Morse
JHU/APL

NLSI Lunar Science Forum 2010

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International Lunar Network (ILN)

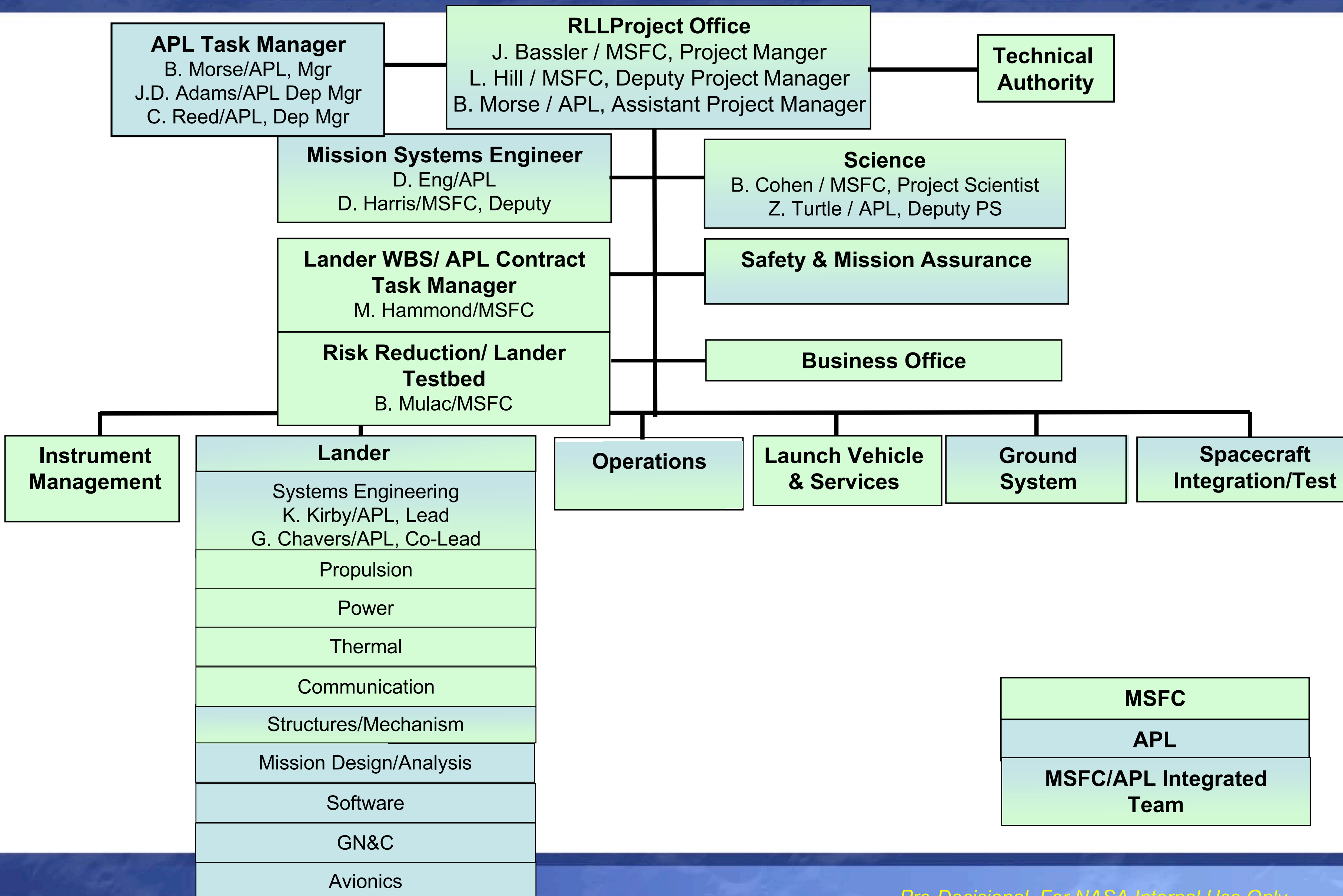
ILN ANCHOR NODES MSFC APL

- **A series of US and International Partner provided Lunar Landers which act as common science nodes in a lunar geophysical network**
- **Each Lander in ILN will provide a minimum core suite of instruments**
- **NASA would provide 4 anchor nodes**
  - 2nd Mission of Lunar Quest Program – Directed to MSFC/APL Team
- **Letter of intent signed with eight other space agencies: Canada, Britain, Germany, France, Italy, Japan, India and Korea**
  - Four Working Groups: Enabling Technology, Communications, Core Instrumentation and Site selection
  - Initial Working Group reports at Steering Committee meeting in Yokohama Japan in March 2009

ILN Anchor Node Mission

- **MSFC/APL team performed a pre-phase A study with a technology risk reduction program starting in the Spring 2008**
- **Initial Trade Study Report in the Fall of 2008**
- **Final Science Definition Team report released in January 09**
- **Promising candidate designs were developed and more fully matured**
  – Solar battery powered
  – ASRG powered
- **Risk Reduction plans were developed, prioritized and initiated**
- **A technical and costing review was conducted by NASA PA&E in June 2009**
  – Extensive technical progress beyond usual Pre-phase A
  – Cost estimates consistent with the design
- **Anchor Node Mission on hold awaiting Decadal Survey prioritization**
- **Robotic Lunar Lander Project team examining lander bus applications to other lunar science missions and continuing Risk Reduction**

Robotic Lunar Lander Project Organization



Other Mission Design Concepts Completed

- **Lunar Polar Rim (LPR) – single point lander to demonstrate on a crater rim**
  - Polar location to characterize environment such as lighting, radiation, regolith composition and properties, micrometeoroid, and dust environment
  - Demonstrate technologies for precision landing

- **Lunar Polar Volatiles Stationary (LPVS) – single point lander to study volatiles in a Permanently Shaded Region (PSR)**
  - Conduct a detailed inventory of volatile species to determine the present state and sources of polar volatiles such as water ice
  - Incorporated ILN like seismic measurements
  - Demonstrate technologies for precision landing

- **Decadal Survey**
  - **Lunar Geophysical Network (LGN)**
    - Next-generation lunar geophysical network to determine the initial composition, crustal formation, and magmatic evolution of a differentiated planet
  - **Lunar Polar Volatiles Mobility (LPVM) – a lander with rover to study volatiles at multiple locations in a Permanently Shaded Region (PSR)**
    - LPVS plus acquire knowledge about spatial variation and total abundance of volatiles
  - **Mercury Lander (APL Led) – stationary lander to conduct first in situ studies of Mercury's surface**
    - Measure bulk composition, magnetic field, surface history, internal structure, and surface-solar wind interactions

Notional Candidate Payloads

Payload	Objective	Mass (kg)*	Power (W)*	Rim Lander	LPVS	LPVE	ILN/LGN	Mercury
ALHAT	Risk Reduction test of ALHAT system in a relevant lunar environment	48.6	260		Precision Landing Only	Precision Landing Only		
MINER	Demonstrate ISRU O2 extraction technologies, specifically oxygen extraction subsystems in a lunar environment	<60	8		Volatiles by other instruments	Volatiles by other instruments		
Rover	Provide mobility platform for instruments	Varies	Varies	Microrover class (~40 kg + payload)				
Imaging Camera	Provide data on local lighting, topography, surface composition.	1.8	2.6	Yes (3D Video)				
Radiation Monitoring	Characterize and understand surface radiation environment	6.4	9					
Exosphere Mass Spectrometer	In-situ lunar atmospheric measurements at the lunar surface	4.6	16.9					
Neutron Spectrometer	Determine the flux and energies of neutrons to determine H content of regolith	1.3	2.3	Rover or Lander based		Both lateral and vertical measurement		
Laser Retroreflector	Enhance laser ranging accuracy and gravitational physics investigations	0.9	0					
Electromagnetic Sounding	Determine the electrical conductivity structure of the lunar interior	2.6	5					
Cone Penetrometer/Shear Vane	Assess physical properties of soil	13	?					
IR Spectrometer	Detect surface mineralogy and water measurement	4.3	11					
Seismometer	Long-term monitoring of seismic activity, background levels, lunar normal modes	6.5	3.4	.				
Ground Penetrating Radar	Determine upper structure of Regolith	5	6.5	.				
Optical Comm	Demonstrate operational use of SOMD lasercom	33	122					
Drill & Sample Acquisition	Utilize a drill for subsurface sampling	32	75					
Heat Flow	Utilize a Mole to deploy a heat probe	1.5	5.7					
Gas Chromatograph/ Mass Spectrometer	Determine species of volatiles	13	47					

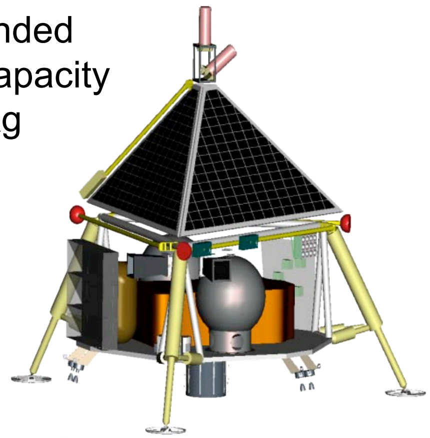
Other potential payloads include Lunar Dust Transport Package, Electromagnetic Sounding (EM probes, magnetometer, Langmuir Probes), Mechanism/Actuator Risk Reduction and Teleoperations, Pneumatic Excavation, Beacons, Microfluidics, Student/Guest Accommodations, etc.

Potential Mission Availability: *Featured in Concept* | *Compatible or Partially Included* | Incompatible

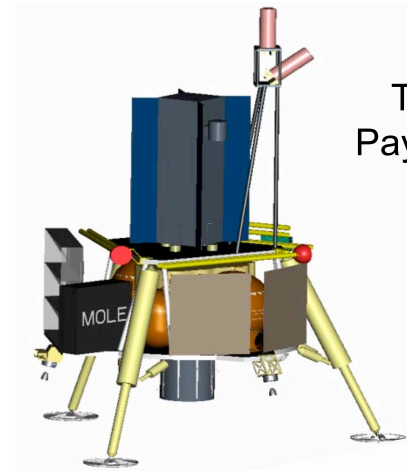
*All Mass, Power includes 30% margin

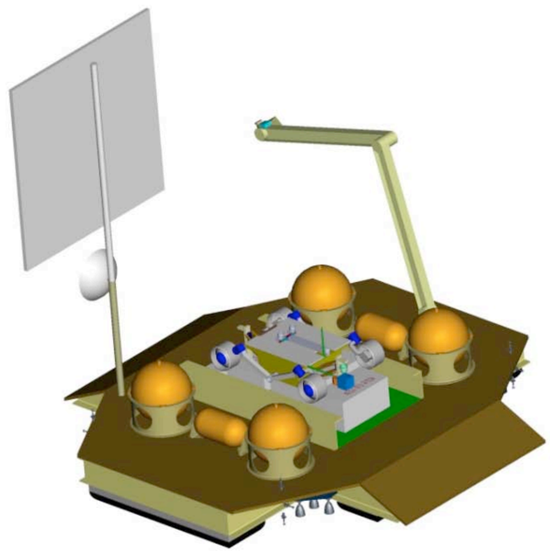
Lander Design Concepts

Total Landed
Payload Capacity
115 kg

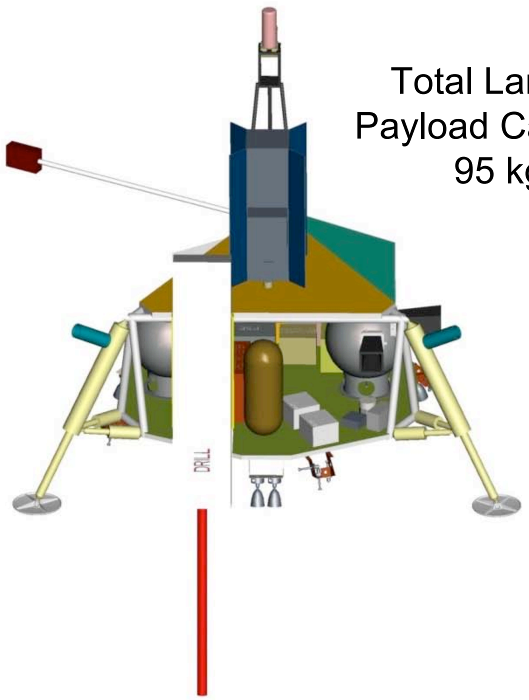


Total Landed
Payload Capacity
95 kg



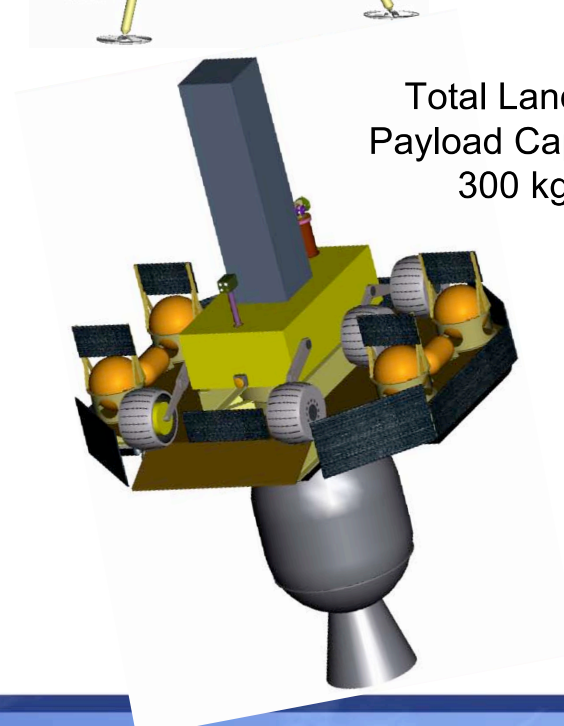


Total Landed
Payload Capacity
95 kg



Total Landed
Payload
Capacity
360 kg

Total Landed
Payload Capacity
300 kg

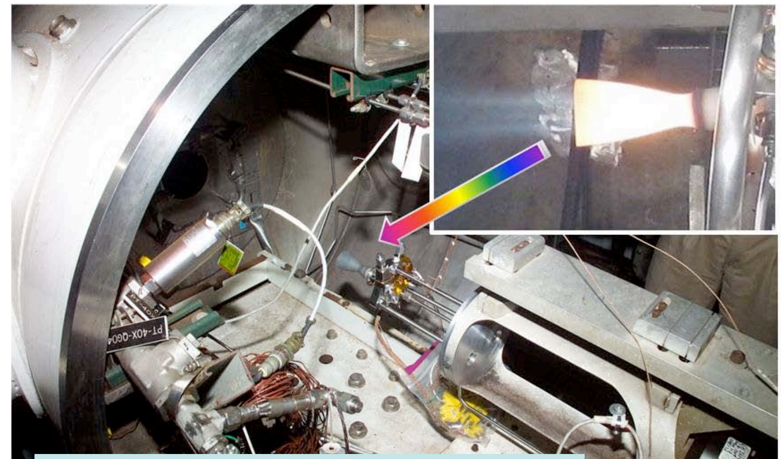


Risk Reduction Design Analysis and Test

Flight Propulsion System Risk Reduction Status

Light-Weight Thruster Hot-Fire Tests for Robotic Lunar Lander

- **Objective:** **a**) Leveraging DOD thruster technology; **b)** Test both 100-lbf descent and 6.7-lbf ACS thrusters in vacuum to assess performance, thermal, and combustion stability.
- **Accomplishment:**
  - Successfully completed a matrix of 12 hot-fire tests on 100-lbf thruster in Sept., 2009 at WSTF
  - Evaluated 100-lbf thruster characteristics in relevant environment with a representative full mission flight profile spanned 995 seconds.
  - Test plan for 7-lbf ACS thruster to be conducted in September, 2010.



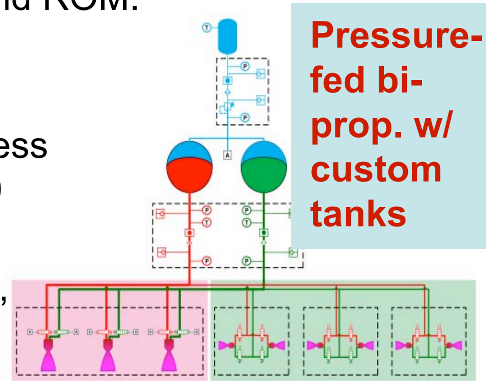
Thruster test set up at WSTF

Propulsion Concept Assessment

- **Objective:** **a**) Evaluate propulsion design concept; **b)** Independent assessment on propulsion technology maturity, work schedule, and ROM.

Accomplishment:

- Verified propulsion design concept, technology readiness level, and cost in July, 2009
- Wide participation of propulsion industry (Aerojet, AMPAC, Orion Propulsion, and PWR) in concept study.



Pressure-fed bi-prop. w/ custom tanks

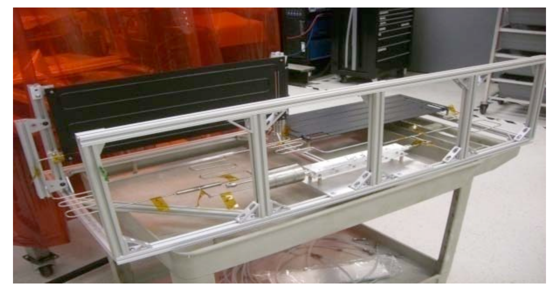
High-Pressure Regulator Characterization

- **Objective:** MSFC in-house evaluation and characterization of pressure regulator operated at high blow down ratio for light-weight propulsion system
- **Accomplishment:**
  - Received the regulator test article.
  - Obtained all components and instrumentation for test setup.
  - Completed test plan & documentation
  - Testing in late July 2010

10K psi regulator

Risk Reduction Status

- **GN&C**: Validation of landing algorithms with simulations and HWIL
  - Design Complete , Performing optimizations
  - Preparing for field testing
  - Incorporating precision navigation
- **Structures**: Composite panel fabrication and testing, lander leg stability testing, star motor vibe test
  - Coupon testing complete
  - WGTA Panels in fabrication
  - Rigid body stability testing complete – Good correlation with analysis
  - Flexible/nonlinear test article and fixtures in assembly
  - Star motor adapter design complete, in fabrication



- **Thermal**: Variable heat transport and lunar heat rejection testing
  - SRM High Temp Blankets in test at Oak Ridge
  - Variable conductance heat pipe assembly and Loop Heat Pipe assembly in test
- **Power**: Thermal and life battery testing
  - Batteries in assembly, testing starts in the fall
- **Avionics:** Testing a low power, high speed communications, and large data storage processor
  - Design Complete.
  - Boards being assembled and tested 1st delivery in August
- **Ground Systems:** Portable Mission Operations Centers **(**mini-MOCs) for control of WGTA
  - Mini-MOCs assembled. Working Screens and networking configurations

Incremental Development Approach for Flight Robotic Lander Design: Phase 1 (Cold Gas)

Robotic Lander Testbed - Cold Gas Test Article (Operational)

- Completed in 9 months
- Demonstrates autonomous, controlled descent and landing on airless bodies
- Emulates robotic f**light** lander design for thruster configuration in 1/6th gravity
- Incorporates **flight** algorithms, software environment, heritage avionics, and sensors
- Gravity cancelling thruster provides for reduced gravity operations that can vary with throttling
- Flight time of 10 seconds and descends from 3 meters altitude
- Utilizes 3000psi compressed air for safety, operational simplicity, and multiple tests per day
- 3 primary and 6 ACS thrusters

Accomplishments

Fully Functional, Flown >150 times

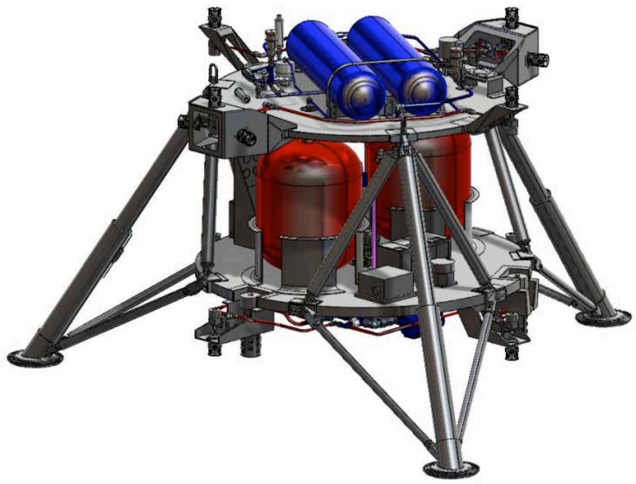
Upgraded with flight-like algorithms

Cold Gas Test Article - Autonomous Flight

Incremental Development Approach for Flight Robotic Lander Design: Phase 2 (Warm Gas)

Warm Gas Test Article (Summer 2010) adds to Cold Gas Test Article Functionality:

- Demonstrates terminal descent phase autonomous controlled
- Began WGTA September 2009 ; Critical Design Review March 2010
- Designed to emulate Robotic **Flight** Lander design sensor suite, software environment, avionics processors, GN&C algorithms, ground control software, composite decks and landing legs
- Longer flight duration (approx. 1 min) and descends from 30 meters to support more complex testing
- Can accommodate 3U or 6U size processor boards.
- Incorporates Core Flight Executive (cFE) which allows for modular software applications
- 12 thruster ACS configuration. Option to only fire 6 ACS thrusters. Provides capability to support testing of hazard avoidance or precision landing algorithms. Emulates pulse or throttle system.
- G-thruster can be set to different g levels between 1 g to zero g for descent. Therefore, can be used to emulate any airless body for descent.



Development Status

- **GN&C algorithm and model development complete**
  - Conducting Monte Carlo runs to further optimize
- **Software development testing integrated system**
  - Build 2 delivered and tested with FSW and GSW
  - End-to-end SW testing performed including data flow back to APL
- **Avionics components delivered**
  - Avionics Box Delivered and incorporated in SW testing
  - All navigation sensors in hand and integration testing in process (IMU, Altimeter, cameras)
- **Composite structures in Fabrication**
- **Propulsion team in assembly and test phase**
  - Descent and attitude control thruster testing completed
  - Pressurant system assembled and proof tested
  - Tanks wrapped and burst test complete
  - Slosh tests showed good results
- **Thermal analysis complete**

- **Testing to start in September 2010**

Summary

- NASA's ILN anchor node mission on hold awaiting Decadal Survey results
- Lander bus design has been refined and is suitable for multiple mission scenarios
- A comprehensive risk reduction effort is underway and is producing results
- NASA's new direction in space exploration may present an opportunity for a robotic lunar lander to support exploration objectives as well as science