Robotic Lunar Lander Development Project Status

Project Description

Lunar Science mission in pre-formulation performing engineering tests and risk reduction activities to support the development of a small lunar lander for lunar surface science.

March 1, 2010
Performing extensive engineering analyses and tests to reduce risk in the development and implementation phases of the project

- **Robotic Lander Test Bed**: Hardware in the Loop (HWIL) testing with landing algorithms and thruster positions
- **GNC Test Bed**: Closed-loop, real-time bench testing with the integrated development and test system.
- **GN&C**: validation of landing algorithms with simulations and HWIL
- **Propulsion**: thruster testing in relevant environment, pressure regulator valve performance characterization in relevant environment
- **Thermal**: variable heat transport and lunar heat rejection testing
- **Structures**: composite coupon testing, lander leg stability testing
- **Power**: thermal and life battery testing
- **Avionics**: testing of a low power, high speed communications, and large data storage capacity processor
Robotic Lunar Lander Development Project

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 flight 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 3 ACS thrusters

Robotic Lander Testbed - Cold Gas Test Article available now to International Partners and industry for hardware demonstration, software and model validation or technology testing

Provides a platform to develop and test algorithms, sensors, avionics, and systems to support autonomous landings on airless bodies, where aero-braking and parachutes are not options (e.g. the moon, asteroids)
Test bed provides for autonomous closed loop control to demonstrate landing capability on airless bodies to build confidence and reduce overall risk.
Warm Gas Test Article (Summer 2010) adds to Cold Gas Test Article Functionality:

- Began WGTA September 2009; Completed 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 cFE which allows for modular software applications, including GNC, for ease of integration and test.
- 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 and testing of software for real-time Guidance Navigation & Control Landing algorithms reduces risk for flight Robotic Lander:

- Integrated system for development and testing of real-time lander GN&C software:
  - Develop embedded software for GN&C algorithms designed for descent and landing.
  - Develop and incorporate real-time image processing algorithm to support nulling lateral motion during descent.
  - Execute and test the embedded software in a flight-like avionics processor, characterize performance.
  - Develop GN&C testbed hardware/software that monitors thruster commands from the avionics flight software, models lander dynamics, and injects real-time simulated sensor data and images into the avionics.
  - GN&C testbed includes camera controller and camera emulator to support evaluating cameras and simulating lunar images.

- Three phases of testing lander GN&C software:
  - Closed-loop, real-time testing with the integrated development and test system.
  - Flight testing of GN&C and image processing algorithms with Warm Gas Test Article.
  - Field tests with cameras and camera controller to test image processing algorithm with high rates of lateral motion.
### Cruise

- Slow spin, 6 RPM
- Spin axis normal to ecliptic

*Tested by closed-loop simulation (typical for other missions)*

### Braking Burn

- Initial Altitude: 16.6 km
- Final Altitude: 3 km
- Initial Velocity: 2.5 km/s
- Final Velocity: 0.105 km/s
- Initial Mass: 1136.6 kg
- Final Mass: 456 kg

*Tested by closed-loop simulation, numerous Monte Carlos*

### Descent

Initial Altitude: 3 km
- Initial Velocity: 0.105 km/s
- Initial Mass: 380.6 kg

*Tested by closed-loop simulation and high velocity field test 2011*

### Terminal Descent

- Final Mass: 343.5 kg
- Touchdown Vel.: < 1 m/s

*Tested by closed-loop simulation and with Cold Gas and Warm Gas Test articles for HIL closed-loop testing (2009-2010)*
Flight Propulsion System Risk Reduction Tests

- **Flight Robotic Lunar Lander Thruster Hot-Fire Tests**
  - On September 15, 2009, MSFC completed a matrix of 12 hot-fire tests one week ahead of schedule.
  - The test included a mission profile representing a lunar lander duty cycle. This profile spanned 995 seconds and included pulses, coasts, and steady-state burns.
  - The test program fully accomplished its objectives, including evaluation of combustion stability, engine efficiency, and the ability of the thruster to perform a lunar lander duty cycle.
  - Figure (a) is the Test Setup in Vacuum Chamber at White Sands Test Facility for DACS Thruster Hot-Firing and Comparison of Engine Envelope.
  - Figure (b) is a conventional (LEROS 2B) Thruster and figure (c) is the DACS Thruster developed by the Missile Defense Agency.
  - Additional tests planned for July 2010.

- **Pressure Regulator Testing**
  - Objective of the regulator test is to assess the ability of an available heritage regulator to meet the ILN mission requirements. The regulator is an unmodified commercial unit.
  - Test activities have already begun and will be completed by June 2010.
Flight Thermal Management Testing

Compact radiators that reject lander waste heat during hot lunar noon thermal conditions
- Lunar surface temperatures as high as 390K
- Unknown landed attitudes and surface topology; radiator views of hot regolith and the sun
- Lunar dust degradation of radiator optical properties
- Completed thermal performance analysis of standard and novel radiators, locations/orientations and enhancements and key sensitivities. Two baseline options beginning prototype radiator fabrication.
  - Horizontal flat radiator with removable, protective dust cover
  - Stacked, vertical parabolic, radiator with attitude adjustment capability

Passive, variable conductance heat transport capability that thermally couples/decouples the main electronics compartment with heat rejection radiators
- ~5kg of power system mass for each watt of heater power required during lunar night
- Shadows ranging from 14 earth days to permanent
- Lunar surface temperatures from 100 – 390K
- Concept studies at multiple suppliers examined various thermal switch/transport technologies.
- Two loop heat pipe concepts and one variable conductance heat pipe concept selected for fabrication & testing

ALSEP Magnetometer Stacked Parabolic Radiator

RLLD Stacked Parabolic Radiator