Lunar Pallet Lander (LPL)

Detailed overview of the NASA robotic lander concept

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Joshua Moore
Greg Chavers
Getting There…

• Cruise Phase:
  – 5-day direct Earth to Moon transfer w/Deep Space Network S-band
  – Spin up to 6 deg/s using Attitude Control System (post-Trans Lunar Injection)
  – Perform system checkout
  – Perform two Trajectory Control Maneuvers (nominal)
  – Perform two Neutron Spec calibrations (nominal)

• Contingency / Off nominal
  – Allows for two (2) additional TCMs
  – Propellant margin for spin / de-spin for thermal anomalies

Earth Departure

Moon Arrival
(Direct Descent)
Mission Phases of Flight

- **Ascent**
  - Spacecraft launched powered off
  - Turn on spacecraft at separation

- **Cruise**
  - Spin stabilized attitude perpendicular to the sun
  - 6 deg/sec BBQ roll
  - Periodic TCM

- **Braking Stage Separation**

- **Terminal Descent**

- **Landed and Power Down**

- **Surface Ops**

- **Coast**
Flight Design Validation through Rigorous Prototype and Testing

- Thermal & Battery Tests
- Software and Avionics Tests
- Propulsion Thruster Hot Fire and Lander Stability test
- Initial Design
- Cold Gas Test Article
- GNC, Software, Avionics, Structures Test with a Pulsed Propulsion System

Flight Robotic Lander

Near-Earth Asteroids

Moon

Mars / Phobos-Deimos
Integration of NASA Lander Activities

Mighty Eagle

Morpheus

NASA Robotic Lander Concept

Commercial or International Partner
NASA Robotic Lander Concept

• NASA class D, requirements driven, low cost, rover delivery lunar lander (~325 kg rover + payload)
  – Single string except for personnel safety
  – This lander is low cost and will fit on a Falcon 9 V1.1
  – This lander has on-ramp or evolvable options for increased performance
  – This lander can be built with little technology development
    • Some tech development could enhance the performance

• Schedule (42 months (Funded to Launch), due to long lead items (tanks and thrusters))
  – 36 months if lander size is optimized for existing components (i.e. propellant tanks).
  – Reduced procurement cycle
Landing Site Selection

• Terrain Topography Analysis (Landing Site Selection Team, ARC)
  – Local high-resolution DEM (digital elevation model) not available for candidate sites yet.
  – Analog Malapert DEM (~5m posts) available for slope analysis.
  – New DEM commissioned of near north pole candidate site.

• Surface Features (JPL)
  – Uses LRO/NAC automated image analyses (craters, boulders).

• Hazard Assessment (MSFC, JSC, APL, ARC, JPL)
  – Compares lander capability to surface characterization maps to derive hazard risk maps
  – Extrapolates high-resolution results to low-resolution data to assess risky, but unresolved, hazards
Operations Timeline

Cruise Phase

Descent and Landing Phase

Rover Egress Phase
Lander Integration Considerations

- Integrated systems references:
  - Drawing tree
  - Master Equipment List (MEL)

- Component integration considerations:
  - Component maturity level
  - Proximity - power source/Thermal Radiator
  - Placement affects center of mass
  - Placement to reduce shadowing - cameras/sun sensors

- Integrated models - consistency throughout the team
  - Metric units
  - Assigned material properties
  - ProE - Creo. 2.0 CAD models

- Maturing subsystems affect the integrated design
  - Avionics - weight/placement
  - Thermal - radiators /MLI blankets
  - Power - solar arrays/battery
**Structures Architecture**

- Prototflight structural approach
- Prototype pallet structure build is complete
Vehicle Loads Analysis

Primary Natural Frequencies

Parameters that affect natural frequencies
- How the non-structural mass is distributed
- Placement of large mass items (as well as accuracy of the mass, i.e. propellant tanks)
- Depth of beams
- Beaded patterns in beams
  - Boundary conditions fixed at the inner ring where it would be attached to the Solid Rocket Motor.
  - Primary Natural Frequencies
    - X – 23 Hz, 15% mass participation
    - Y – 38.5 Hz, 2% mass participation
    - Z - 48 Hz, 5% mass participation
    - The axial frequency does not meet the desired 35 Hz, nor the required 25 Hz
  - However, the mass participation is low so it may not be of great concern
  - Design solutions can be worked to increase the natural frequencies in this direction

Stress

- Highest loaded areas are near the central load ring
- Other hot spots exist but need to be looked at more thoroughly as they are rigid body attach points which can produce arbitrarily high stress results
- The mass properties of subsystem components were obtained from the Master Equipment List
- The mass used is that of everything on the second stage, physically located above the Solid Rocket Motor
- Tanks and large boxes are modeled as 1D mass elements
- Other masses such as wiring, cabling, thermal insulation carried as non-structural mass smeared over the top deck
- Total wet mass = 1586 kg (3,490 lbs)
Quasi-Static Load Factors Contribution

Launch Ascent

Single load case created using 6.5 G’s axial and 2 G’s lateral inputs to envelope all load cases

Braking Burn
STAR48 Operation

<table>
<thead>
<tr>
<th>Star48 Motor</th>
<th>Lander</th>
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<tbody>
<tr>
<td>Thrust (N)</td>
<td>Mass (kg)</td>
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<td>77800</td>
<td>1312</td>
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</tbody>
</table>

• The given thrust for the STAR48 for the lander vehicle mass produces 6 G’s axial acceleration.

• Lander longitudinal accelerations assume the most conservative proportion of launch quasi-static environments at 2 G’s (1/3 axial).
Summary of Combined Loads * for Launch and Star 48

- This dynamics analysis provides an in-depth understanding of each individual component response to all mission flight events.
- Load prediction methodology allows ample flexibility to accommodate changes in spacecraft design and launch vehicle architecture.

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Axial (G)</th>
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<td>Power Box</td>
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- Denotes higher load

*This is maximum predicted environment with no margin added.
Current Thermal Control Approach & Features

The TCS architecture consists of:
- Spinning (BBQ roll) flight attitude
- Passive, centralized radiators
- Passively controlled heaters
- MLI and optical coatings
Propulsion Heater Zones and Heater Sizing

- Heater Zones: 70 total (largest contributor is propulsion with 45 zones)
- Heater zones were defined for nominal conditions, and are being evaluated for suite of other scenarios.
- Each heater is passively controlled – no redundancy assumed

Total Heater Power:
- Expected peak heater power draw (Nominal case): 185W
- Expected average heater power draw (Nominal case): 100W
Lander Level Thermal Analyses

Latest Studies

Goals:
- Investigate nominal & transient pointing cases to evaluate component temperature variations and heater power needs
- Pointing cases represent an attempt to bracket the potential behavior encountered during planned & unplanned attitude changes
- Includes all updated subsystem models
- Nominal: 6 deg/s spin with spin axis perpendicular to solar vector.

Transition from Nominal to No spin; Sun-side

- Avionics Radiator
- Solar Array
- Battery
- SRM Propellant
- Liquid Prop Tanks

Nominal and Transition from Nominal to no spin sun on side
Baseline Architecture Configuration: Cruise

Rover Direct-To-Earth Comm
(Data Umbilical + Coaxial Cable)
(All communication hardware on Rover; Lander has an omni antenna to provide coverage)

Conical spiral antennas mounted on spin axis

Rover
Lander

Deep Space Network 34m
S-Band
Current Architecture Configuration: Surface

Lander downlinks data on lunar surface before Rover egress.

DSN 34m

Uplink: S-band, 2 kbps minimum.

Downlink:
1. S-Band Dish @ 600 kbps (450 kbps user B/W) (Goal: 1.5 Mbps)
2. S-Band Omni Contingency Mode @ 2 kbps
Configuration of Lander communications

Lander Omni Antenna is only present during Cruise Phase.

Results of recent trade

**Lander/Sci. Payload**
- Element Data Storage
- Element Packetizing
- Element Flow Control Buffering

**Flow Control**
- Hardware or Software

**Rover**
- All Data Framing
- Multiplexing - Virtual Channel Prioritization
- All Data LOS Buffering
- Transmit Telemetry

Rover with Payload
Electrical Power System Layout

- Triple Junction Gallium Arsenide Cells
- ~29.5% efficient
- 6 Panels, ~488 W, 13.53 A Avg at panels
  - (2) 1.758 x 0.711(m), 24 strings, 15 cells
  - (4) 0.94 x 0.711(m), 13 strings, 15 cells

Notional Rover Shown
Energy Storage - ABSL BTP 8S52P

- Store Electrical Power
  - 78 Ampere Hour Lithium Cobalt Oxide Battery
  - 21 Kg Flight Configuration
  - 295 mm x 355 mm x 180 mm (l x w x h)
  - 416 Sony 18650HC cells, CID, PTC,
  - Burst Disc, Mandrel Safety Device

Test data for 42 day-night real time lunar cycles

Sony 18650HC
3-DoF Guidance Trajectory Performance Analysis

• Summary of results with Closed-loop Guidance, Perfect Navigation and Flight Control
  – Slow burning SRM will drive the descent starting conditions
  – Fast burning SRM will drive the liquid propellant load and liquid phase guidance logic
  – Increasing the heliocentric transfer time does not improve the initial descent conditions
    • Longer transfers go beyond the Moon’s orbit and then back
    • Stay near the Hohmann transfer time (~5 days)
  – Increasing the liquid thrusters thrust and specific impulse (Isp) does improve the payload capability
Optical Navigation Status

- Updated position and velocity estimation algorithms into a single refactored version of the APLNav algorithm that can perform both phases in order to maximize code reuse.

- Optimized the rendering algorithm C code and onboard map structures to minimize processing time for position estimation algorithm.

- Performed a benchmark test of the updated position estimation code to estimate processing load on a flight processor.
Software Overview

Flight Software

- Lander SW is composed of
  - Flight software that provides closed-loop control
  - Simulation software that supports the development and verification of the flight software
  - Test software that supports the testing and verification of flight software by providing data and control interface to flight software.

Simulation Software

- Lander Specific System & I/O Models
- Dynamics, Time, Environment Models
- Trick Simulation Core (JSC)

Linux OS

C++

Test Software

- Displays & Controls
- Scripts
- Database (postgresql)
- Command & Data Dictionary
- ITOS Infrastructure (Goddard)

Linux OS

5/5/2014
Propulsion Design Maturation

- Propulsion system layout and mechanical design
  - Completed early design of flight system
  - Released feed line system and integration drawings
  - Provided detailed Master Equipment List and propulsion/structure interfaces
Cold Flow Testing

• Testing is complete
  – Test setup is based on flight design drawings with redline on modification

*Propulsion components being installed on the lander structure*
Summary

• NASA has developed a low cost, requirements-driven robotic lander concept
  – Design and analysis are partially complete
  – NASA looks forward to a partnership for completing a robotic lunar lander for the Resource Prospector Mission