SMALL SPACECRAFT IN SUPPORT OF THE LUNAR EXPLORATION PROGRAM

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SMALL SPACECRAFT

- Commercial Electronics Have Enabled Small Spacecraft (Moore’s Law)
- Several Countries Are Using Small Spacecraft In Civil And Military Space
- Significant Available Functionality From Wide DoD Investment

Key Features
- Low Mission Costs ($50-100M), Short Schedule <24Months
- Low Mass < 300kg, Low Cost Launch Vehicles

Benefits
- Lower Cost Enables Increased Number Of Missions
- Faster Learning Cycle, Leads to Lower Costs
- Demonstrate New Technology Sooner, Lowers Cost of Large Missions
- Lower Overall Program Risk by Providing Several Flight Opportunities for Critical Experiments
- Smaller Teams, Fewer Interfaces, Improved Collaboration

Drawbacks
- Size, Mass Eliminate Some Missions for Small Spacecraft
- Higher Individual Risk Of Missions compared with $1B Spacecraft
- Use of “Yet To Be Proven” Launch Vehicles, or Fly as a Secondary Payload
Mission 1: Lunar Reconnaissance (e.g. LRO) [2010]
Tasks: visual & topographical maps, hydrogen map, radiation environment.

Mission 2: Fixed Lander [2011]
Tasks: precision landing, dust characterization, regolith composition and thickness, lighting and thermal ground truth.

Mission 3: Comm Orbiter (co-manifested with Mission 2) [2011]
Tasks: partial coverage of south polar region.

Mission 4: Mobile Lander (North Pole) [2013]
Tasks: water presence in 20 sites of shadowed crater, radiation shielding of regolith, effects of lunar environment on life and mechanical structures.

Mission 5: Lander Rover (South Pole) [2015]
Tasks: ISRU of O2 and H2O (produce up to 1000kg), fluid experiment, 30km roving.
Robotic Precursor Architecture Summary

1. The only task (of the 15 identified in LRAS) definitely not possible with current technology on small spacecraft missions is that of large scale (e.g. > 1000 kg mass) ISRU of O2 and H2O.
2. Tasks that are in a grey area – that may be possible with small satellites but which may not be preferential to do with small missions and require further analysis – include:
   a) 30km roving
   b) Water presence in 20 sites of shadowed crater
   c) 1-year operation with periods of shadow

Analysis:
Mission 5 of LRAS needs to remain a large lander and there is a need for further study to decide whether Mission 4 could be done more cost effectively with small spacecraft or not.
LRO is proceeding as Mission 1
A small spacecraft architecture might replace Missions 2, 3 and 4 with several (e.g. 4-10) small missions and an accelerated overall schedule and with reduced overall cost:
   Mission 2 could be replaced by two small fixed landers compared with LRAS,
   Mission 3 accomplished by four small communications orbiters (which would have the added advantage of providing permanent coverage of south polar region), and
   Mission 4 by two small hopper landers (one on each pole).
Small Lunar Mission Series

GOALS:
- Achieve a robust robotic precursor program
- Help sustain the Vision
- Enable training of our systems engineers
- Reduce costs to program
- Answer critical questions for the Constellation Program

OBJECTIVE:
Initiate a series of small Lunar Missions with a budget of less than $100M per mission including launch vehicle.

APPROACH:
- Short Schedule, Incremental Development, and Aggressive Testing
- Leverage Existing Systems to Minimize Risk
Mission Requirements

- Spacecraft to be compatible with either Falcon-1 or Minotaur V launch vehicle
  - Critical mass and volume constraints derived from Falcon-1 LV
- Mission duration:
  - Orbiter: 1 Year in Lunar Orbit
  - Lander: operational during one lunar day (14 earth days) plus 1 hour into dusk (to measure the dust phenomena of the terminator passage)
- Spacecraft design to be modular to support multiple configurations
- Lander Specific Requirements:
  - Designed for either equatorial or polar landings
  - Descent Landing Requirements
    - Lander slope requirements – up to 15 degrees
      - Based on lunar surveyor landing data
    - Lander Horizontal velocity requirements < 1 m/sec (TBR)
      - Trade between GNC performance and lander stability
    - Lander vertical velocity requirements – up to 3- 4 meters for engine cutoff (TBR)
    - Lander obstacles – 10 cm min, up to 25 cm desired(TBR)
    - Lander accuracy – 1 km, 1s baseline, precision landing (TBR)
Current capabilities support three common heritage designs:

- 130 Kg Lander (four tanks) on a Minotaur V
  - 40 Kg science payload to surface, 200 Watts
- 103 Kg Lander (two tanks) on a Minotaur V
  - 15 Kg science payload to surface, 100 Watts
- 55Kg Lander (two tanks) on a Falcon 1
Small Lander in Shroud

Falcon 1

Minotaur V
Trajectory

Minotaur-V Launch to TLI

Miinotaur-V’s Star 37FM for Trans-Lunar Injection Burn

Star 15G Braking Maneuver

Orient and spin up to 1 RPS for braking burn

Separate, De-spin & Reorient

Star Fix & Terrain Navigation

Initiate Final Braking

Shutdown at 3 m Touchdown

Initial Course Correction

Nav Updates + Minor course corrections

Order | Original Orbit | Final Orbit | Motor Type/Name | ΔV (m/s)
---|---|---|---|---
1 | Trajectory Correction Maneuvers | - | Liquid/THAAD | 47
2 | Cruise Attitude Control | | Liquid/THAAD | 11
3 | Braking Burn | Lunar Landing Phase | Solid/Star-15G | 2374
4 | Landing Attitude Control | | Liquid/THAAD | 32
5 | Lunar Landing Phase | Landed | Liquid/THAAD | 451
Small Lander Configuration

- Star Tracker
- Patch Antennas
- Avionics
- Additional payload space as available
- North side panel for externally mounted payloads
- Radar Altimeter
- DSMAC
- Payload(s) located internally
- Battery
- Diplexer
- Transmitter
- Receiver
- Amplifier
## Mass Allocation

<table>
<thead>
<tr>
<th>Spacecraft subsystem</th>
<th>103.7 kg Baseline</th>
<th>Feather Weight 55.7 Kg</th>
<th>130.9 Kg Maximized minotaur</th>
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<td>55.7</td>
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Micro Lunar Lander Payload Capabilities

- **Notional Capability for 130 kg Lander**
  - Payload Mass - 40 Kg max
    - dependent on location payload on lander
    - Payload mass would need to be split between north and south side of vehicle
      - Exact split to be dependent on C.G location of each payload
  - Payload Power
    - 15 Watts continuous, 30 Watts w/50% duty cycle
    - Short duration peak power < 2 minutes: 50 Watts
  - Payload Volume
    - Internally mounted payloads: 7” W x 8”H x 5” D
    - Externally mounted payloads: 14”W x 10”H x 6” D
    - Unique payload envelopes such as drills, scoops and robotic arms would need to be evaluated on a case by case basis

- **Locations for payload mounting**
  - Extension module sidewall panels
    - Interior and exterior of north facing radiator panel
    - Interior on south facing solar panel
  - Upper radiator panel
    - Interior as available (shared with avionics)
    - Exterior (limited by radiator for thermal management)
Maximum Payload capability for externally attached payload
Max Volume: 14”W x 10”H x 6” D (shown)
Max Mass: 15 kg with C.G. not greater than 3” offset from spacecraft panel wall

Payload mounted externally on north side of vehicle

Payloads outer surface would be responsible for it’s thermal management
Maximum Payload capability for internally attached payload:

Max Volume: 7”W x 8”H x 5” D (shown)
Max Mass: 25 kg per side (50 kg total)
South mounted payloads responsible for their own heat rejection

Payload mounted internally to south side of vehicle
(location not recommended for high power payloads)

Additional Payload/ballast mounted internally to north side of vehicle
Maximum Payload capability for internally attached payload:
Max Volume: 10.5”W x 4.5”H x 10” D (shown)
Max Mass: 25 kg per side (50 kg total)