

The NASA logo is centered in the background, featuring the word "NASA" in white, bold, sans-serif capital letters. The logo is set against a blue circular field with white stars and a white orbital path. A red and white swoosh, representing a spacecraft trajectory, cuts across the logo from the bottom left to the top right. At the top of the slide, there is a horizontal bar with a blue gradient and a red border.

SMALL SPACECRAFT IN SUPPORT OF THE LUNAR PROGRAM

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SMALL SPACECRAFT

- **Commercial Electronics Have Enabled Small Spacecraft (Moore's Law)**
- **Many 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**



Robotic Precursor Architecture Summary

- Mission 1:** Lunar Reconnaissance (e.g. LRO) [2008]
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

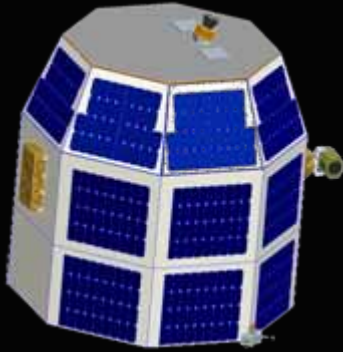
A small spacecraft architecture might support Missions 2, 3 and 4 with several (e.g. 4-10) small missions and an accelerated overall schedule and with reduced cost:

Mission 2 could be supported by two small fixed landers,

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:

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

OBJECTIVE:

Initiate a series of small Lunar Missions with a budget of less than \$100M per mission

APPROACH:

Short Schedule, Incremental Development, and Aggressive Testing

Leverage Existing Systems to Minimize Risk



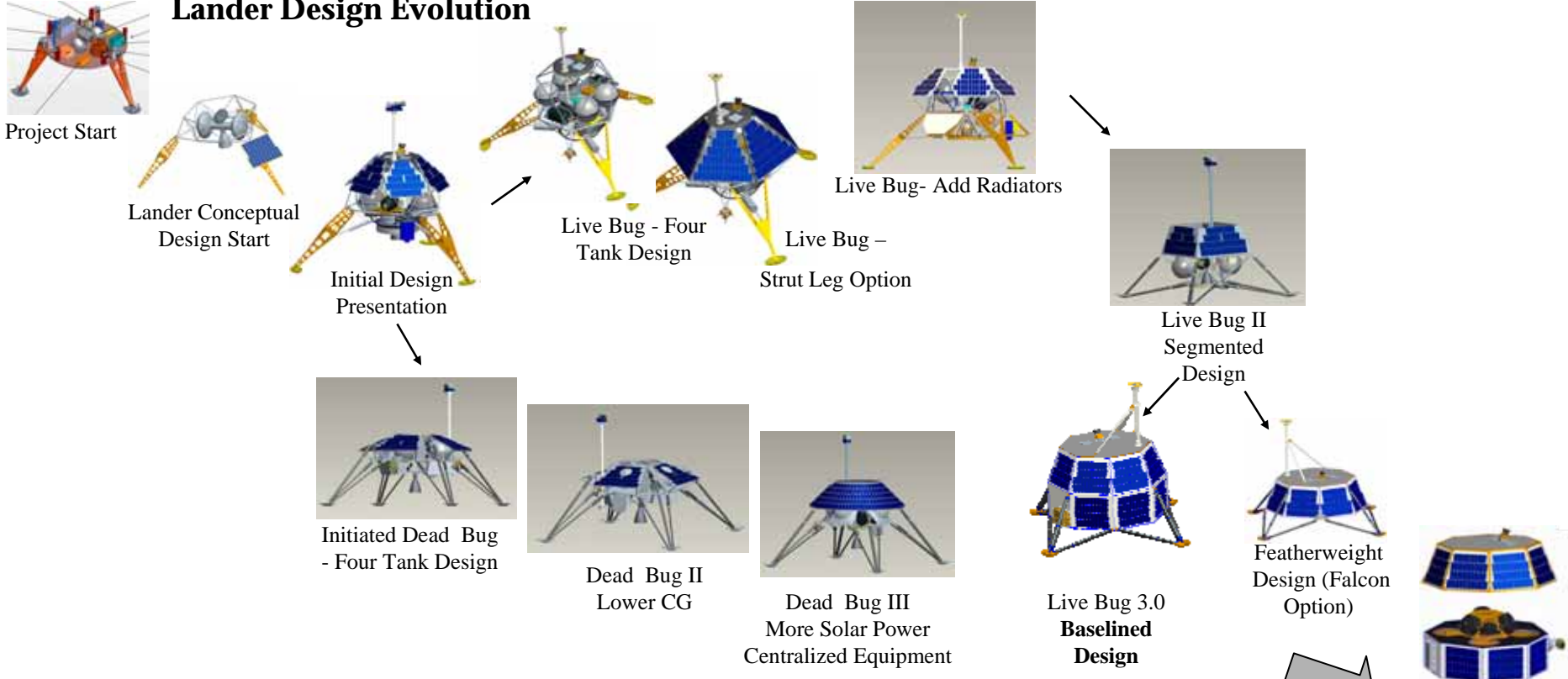
Mission Requirements

- 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: IOC: one lunar day (14 earth days) plus 1 hour into dusk (to measure the dust phenomena of the terminator passage)**
FOC: 1-3 Year
- 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)**

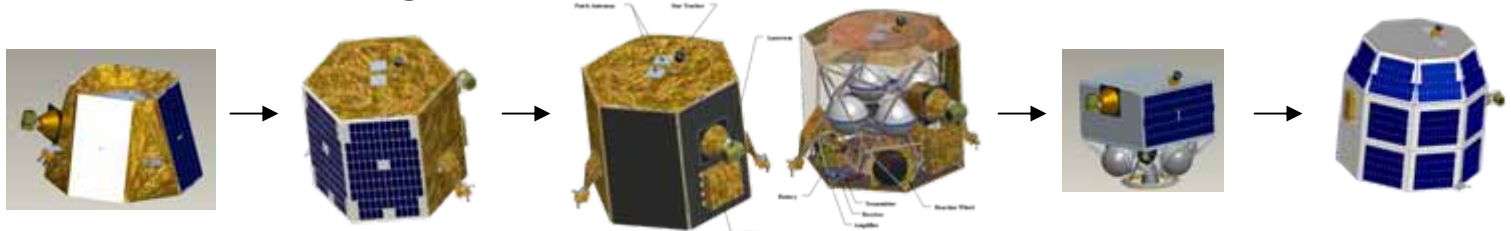


Design Evolution

Lander Design Evolution



Orbiter Design Evolution

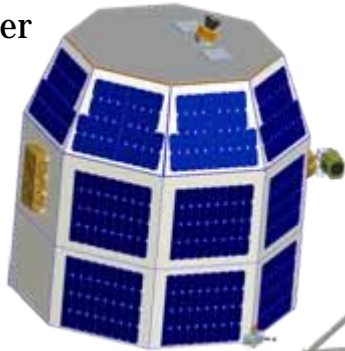


Modular Bus Design



Common Spacecraft Bus – Modular Approach

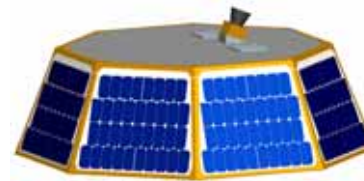
- Orbiter



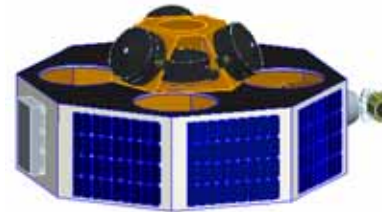
- Small Lander



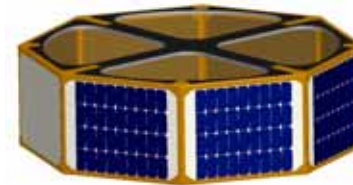
- Featherweight Lander



- Bus Module



- Payload Module



- Extension Module



- Propulsion Module



- Legs

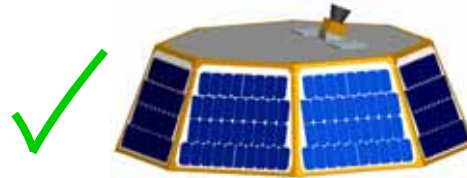
Multi-Mission Capability enabled by Modular Bus Design – Select Modules to meet Mission Requirements



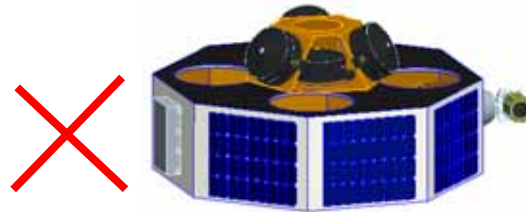
Small Lander Configuration



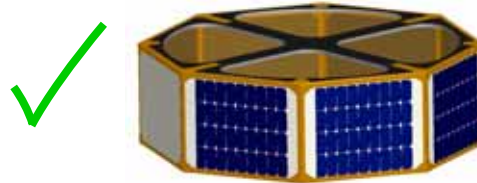
• Baseline/Small Lander



• Bus Module



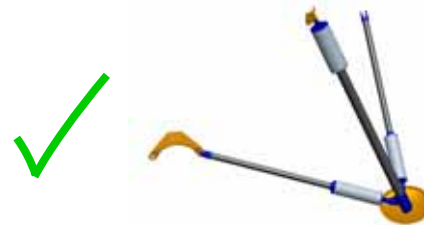
• Payload Module



• Extension Module



• Propulsion Module



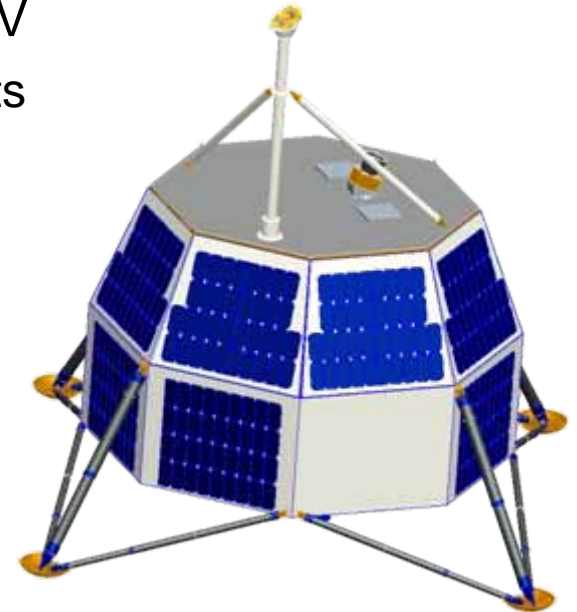
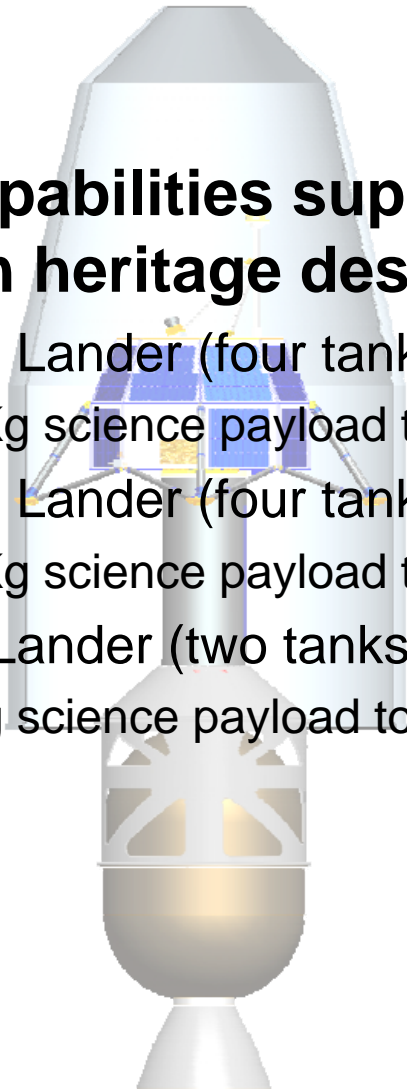
• Legs



Lunar Lander Mission Scenario

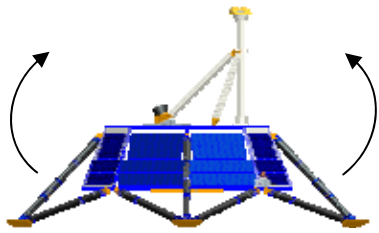
Current capabilities support three common heritage designs:

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

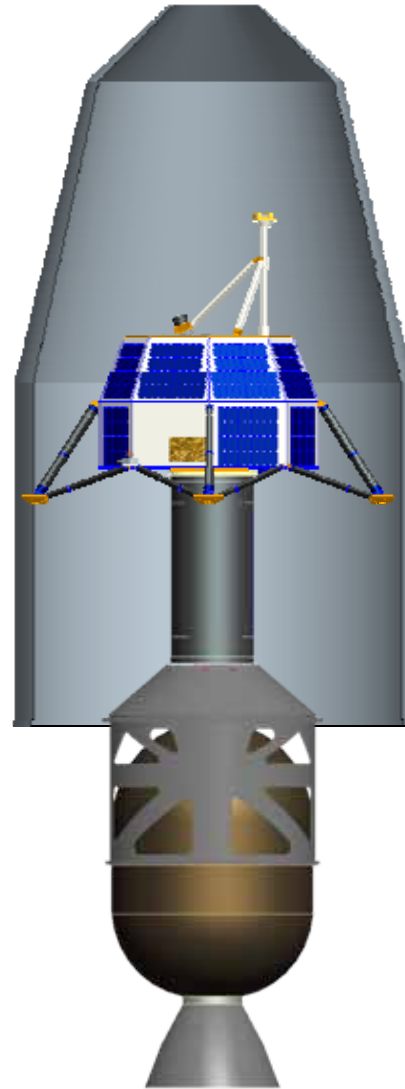
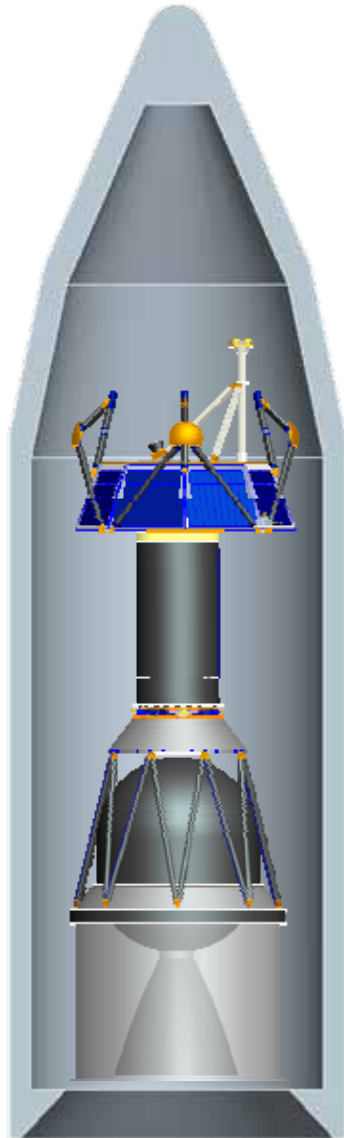




Small Lander in Shroud



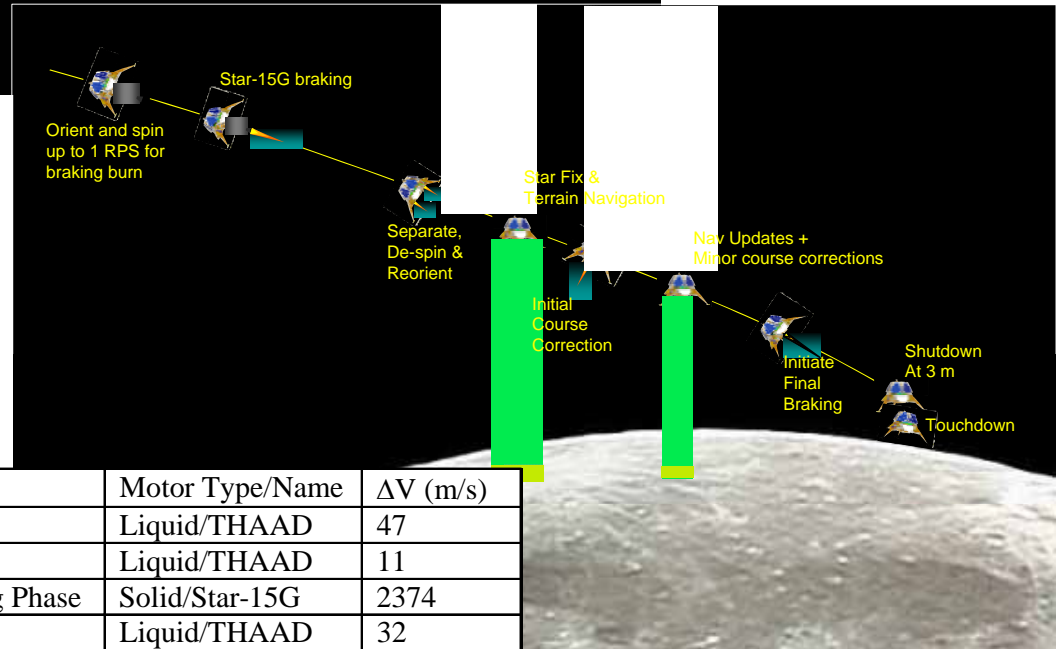
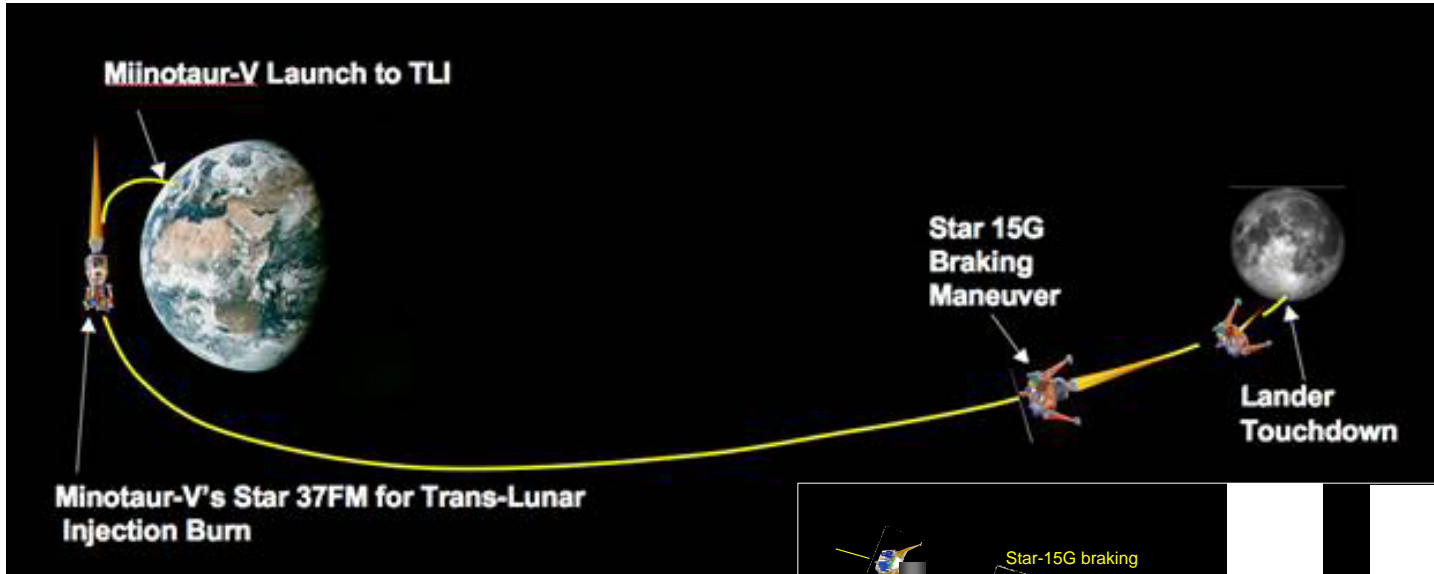
Falcon 1



Minotaur V

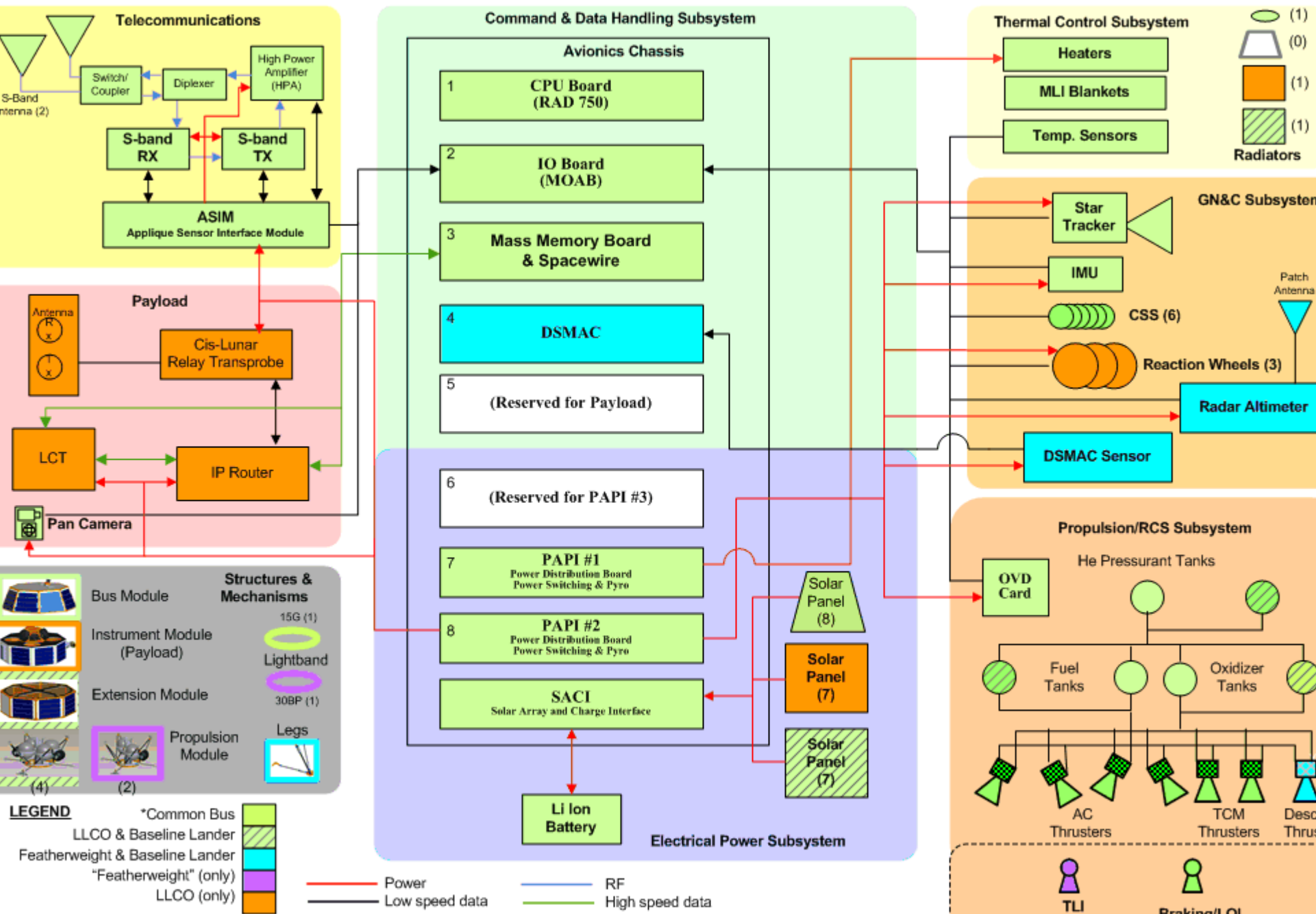


Trajectory



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

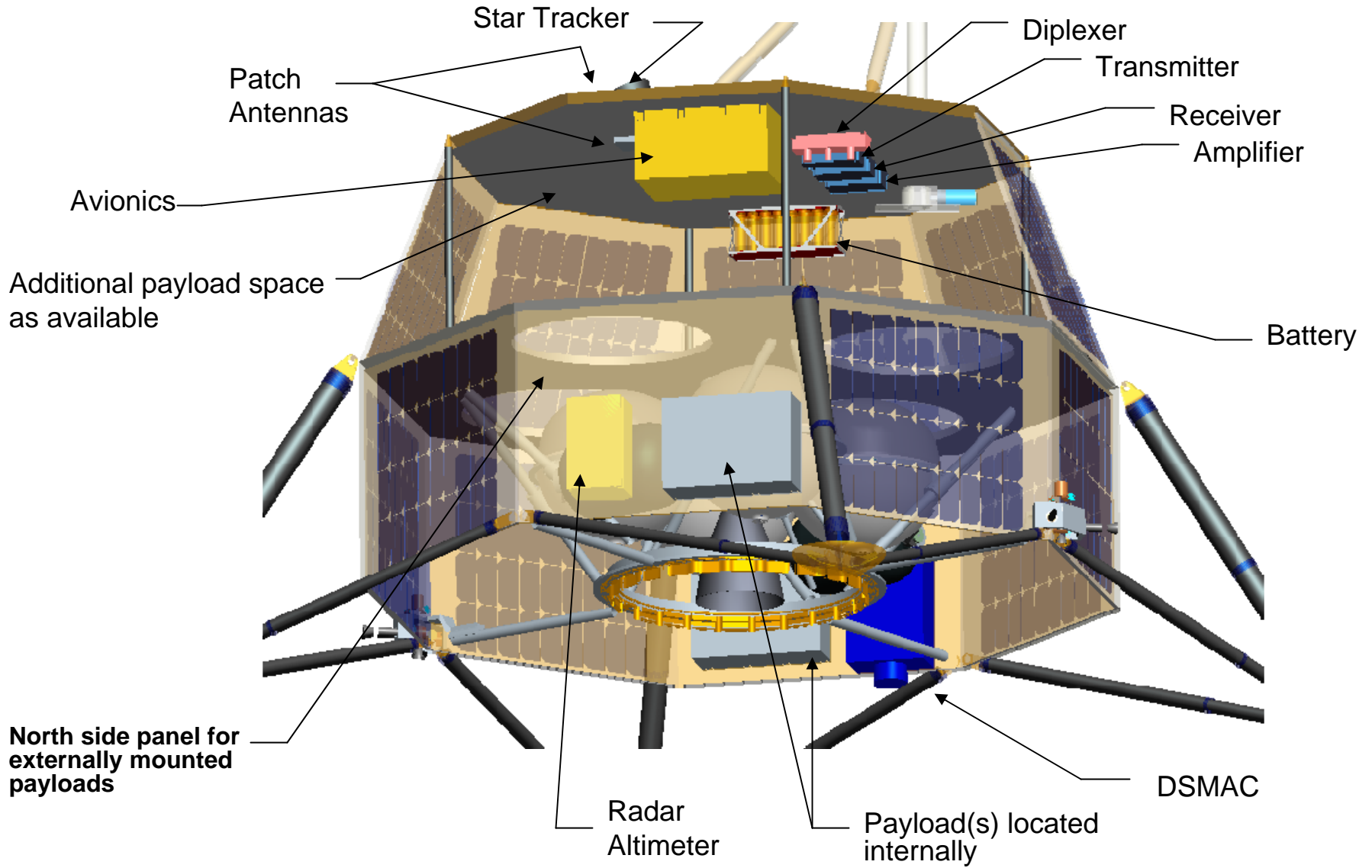
Small Satellite — Common Bus Architecture Functional Block Diagram



*Note: A component/subsystem annotated as Common Bus is common to all three configurations unless otherwise annotated in the legend: Configurations are: (1) Lander ("Featherweight") (Common-Lite) Bus; (2) Lander "Baseline" Common Bus; and (3) LLCO Common Bus.



Small Lander Configuration





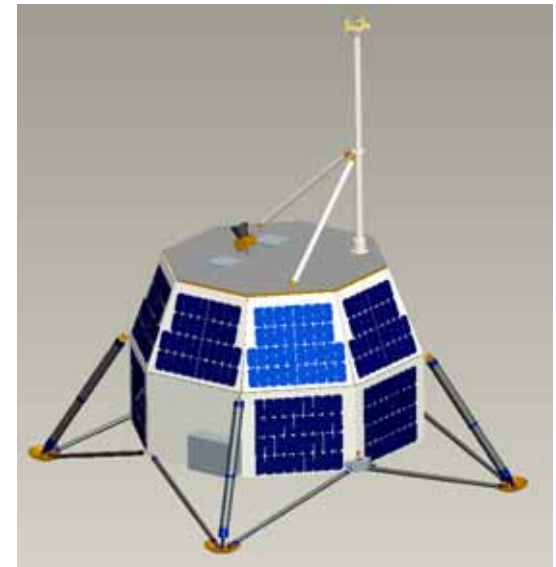
Mass Allocation

	Featherweight	Baseline	Maximized Minotaur
Subsystem			
Nav & Attitude Determination	4.5	4.5	4.5
C&DH	5.0	5	5
Comm	1.6	1.6	1.6
Harness	2.4	2.4	2.4
Power	3.1	6	6
Structure	10.2	14.9	14.9
Thermal Control	1.5	3	3
DACS Propulsion	8.6	13.6	13.6
Trapped Prop He	0.9	1.8	1.8
Payload	5.0	15	41.6
Reserve	6.8	9.8	10.4
Dry Subtotal	49.6	77.4	104.6
Usable Prop	13.2	26.3	26.3
Lander Wet	62.8	103.7	130.9



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 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)





External Payload Capability-Notional

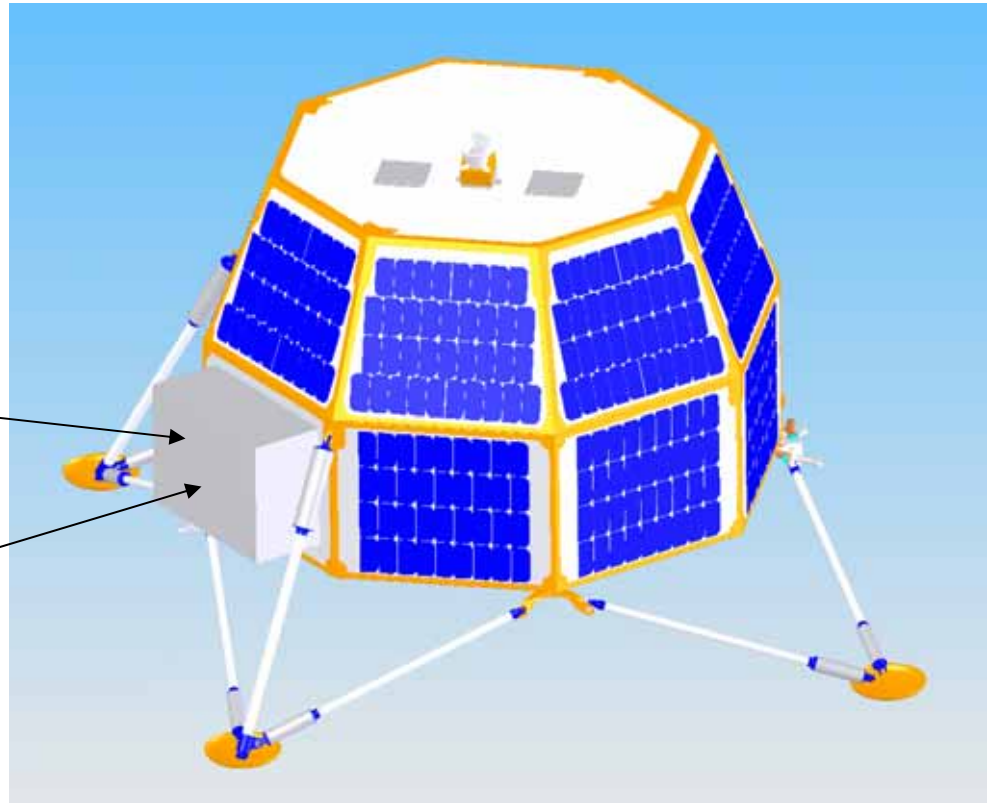
Maximum Payload capability for externally attached payload

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 its thermal management





Internal Payload Capability-Notional

Maximum Payload capability for internally attached payload:

Max Volume: 7" W x 8" H x 5" D (shown)

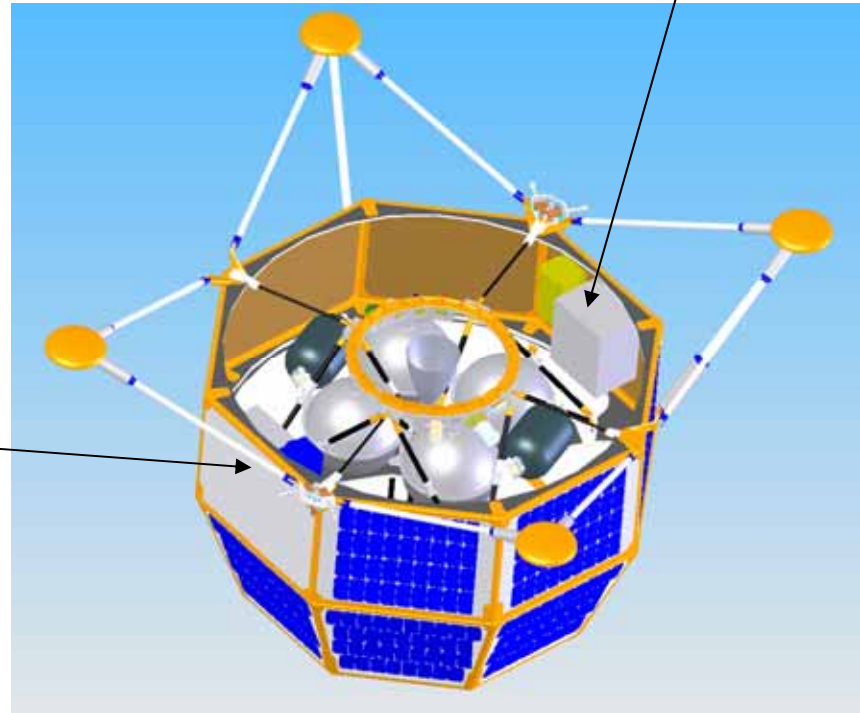
Max Mass: 25 kg per side (50 kg total)

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





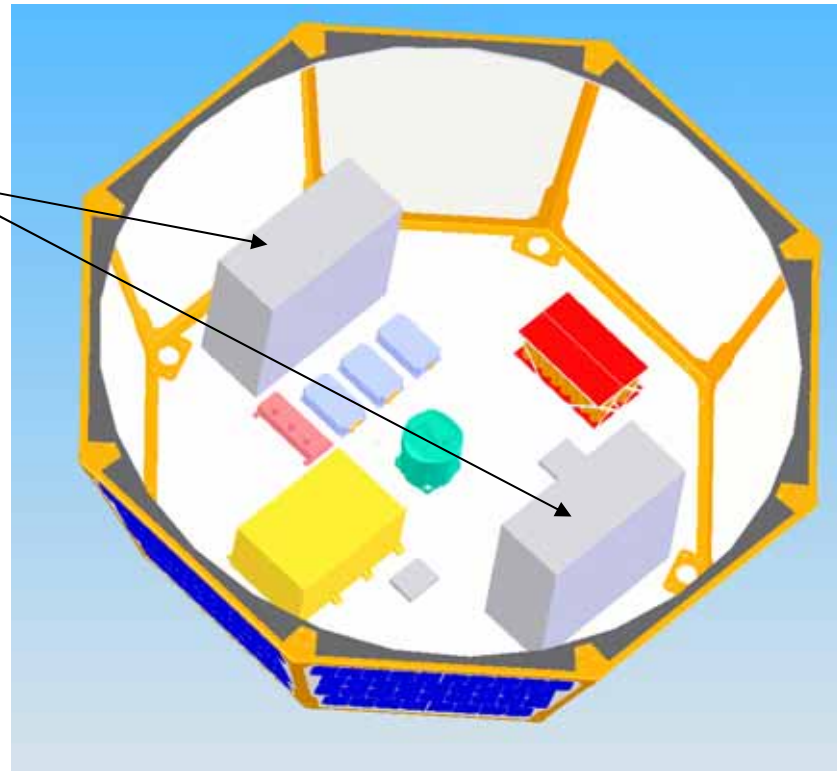
Internal Payload Capability-Notional

Maximum Payload capability for internally attached payload:

Max Volume: 10.5"W x 4.5"H x 10" D (shown)

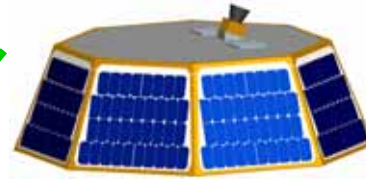
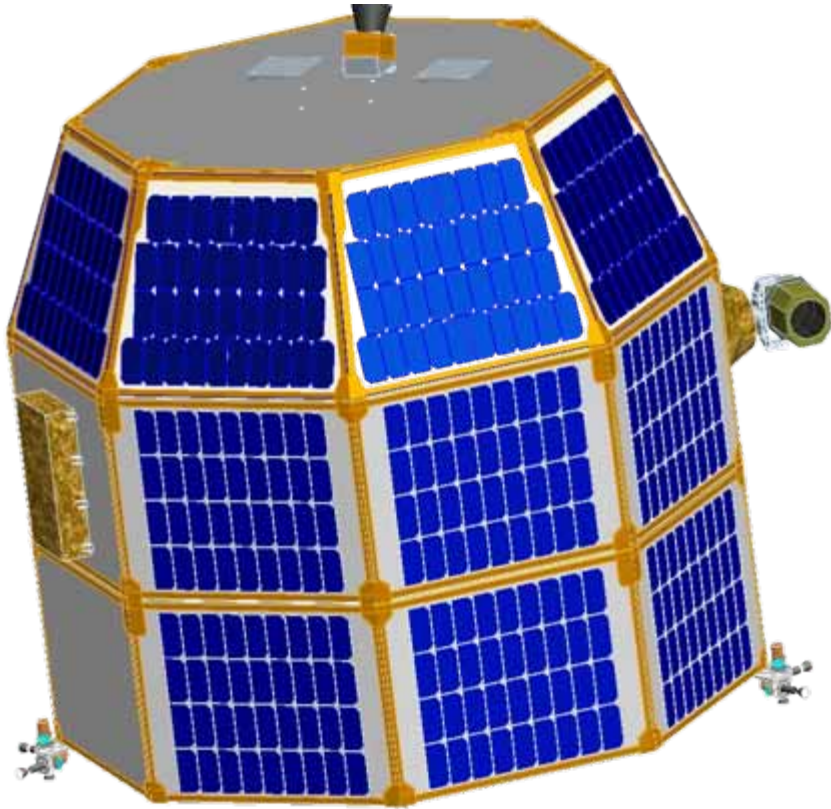
Max Mass: 25 kg per side (50 kg total)

Payloads attach directly to radiator

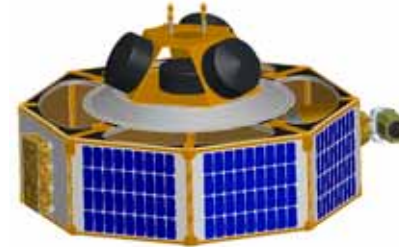




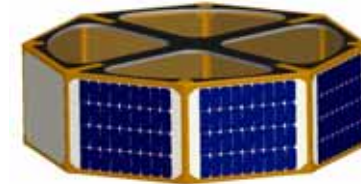
Orbiter Configuration



• Bus Module



• Payload Module



• Extension Module



• Propulsion Module



• Legs



Laser Communications Orbiter

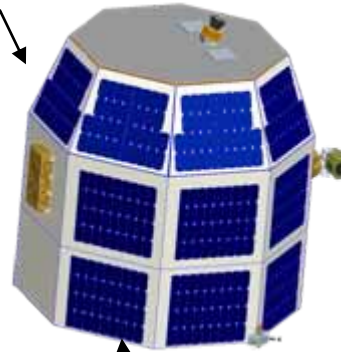
SPACE SEGMENT

Laser Communication

Data Rate: 100-1000 Mbps Down 10Mbps Up
Mass: <20Kg
Power: <70W
Aperture: 3.5 cm

UHF Selectable Radio

Comm Data
from Cis Lunar Space



Spacecraft

- Derivative of Existing Spacecraft
- Single String
- Spaceframe Structure
- Stellar-Based Attitude Determination
- Body-Fixed GaAs Solar Arrays
- cPCI-Based C&DH Design

Mission Phases

- Launch TLI, Early Orbit Check Out
- Cruise
- Lunar Orbit
- Lunar Relay

Mission Operations

- Mission Scenarios, Timelines, & CONOPS
- Space Vehicle Flight Ops at ARC
- Payload Data Processing at GSFC
- Supports Continuous Operations of Payloads
- SV Mission Operations from MOC
- Data routed to external users
- Uplink/Downlink Communications Encrypted

Launch Vehicle

- Minotaur V Launch System
- Wallops Island (WFF) Launch Site
- 30 Day Launch Processing Schedule

LAUNCH SEGMENT
GROUND SEGMENT

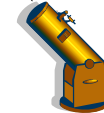
Ground System

White Sands



Command and Telemetry, Payload Data

GGAO



Payload Data



GSFC

Payload Data

Cmd/Tlm



MOC - ARC

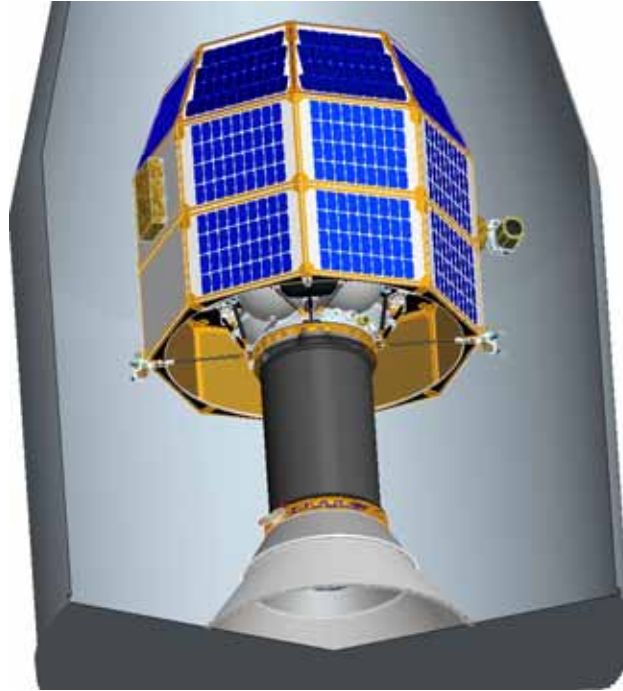
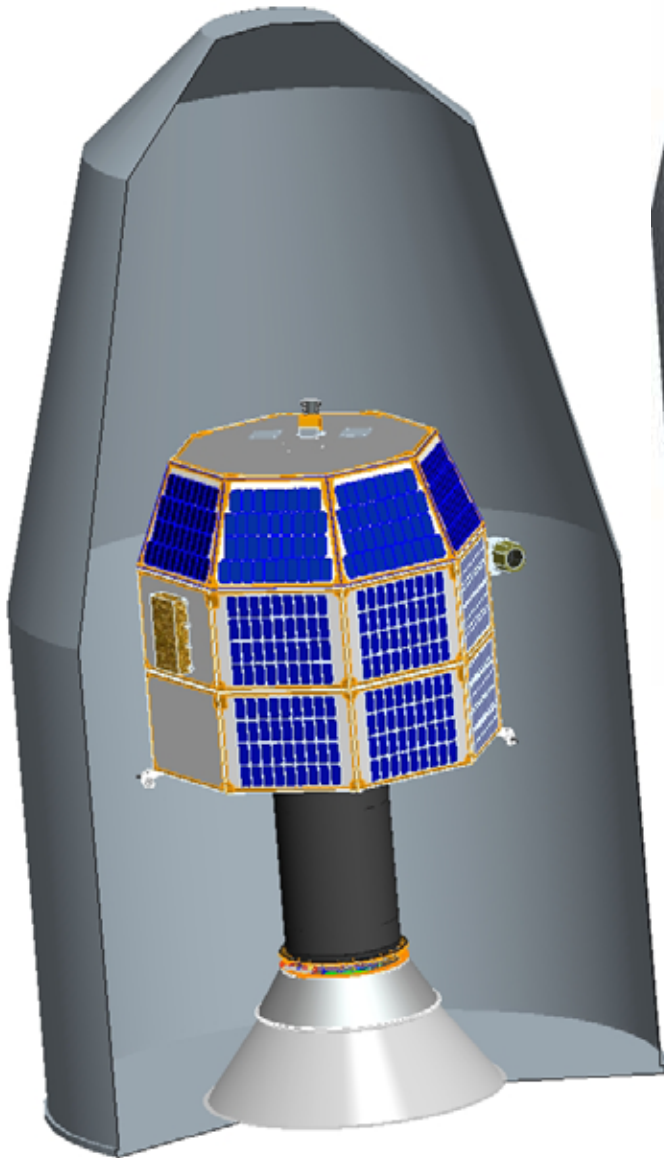
Cmd/Tlm/Data Relay



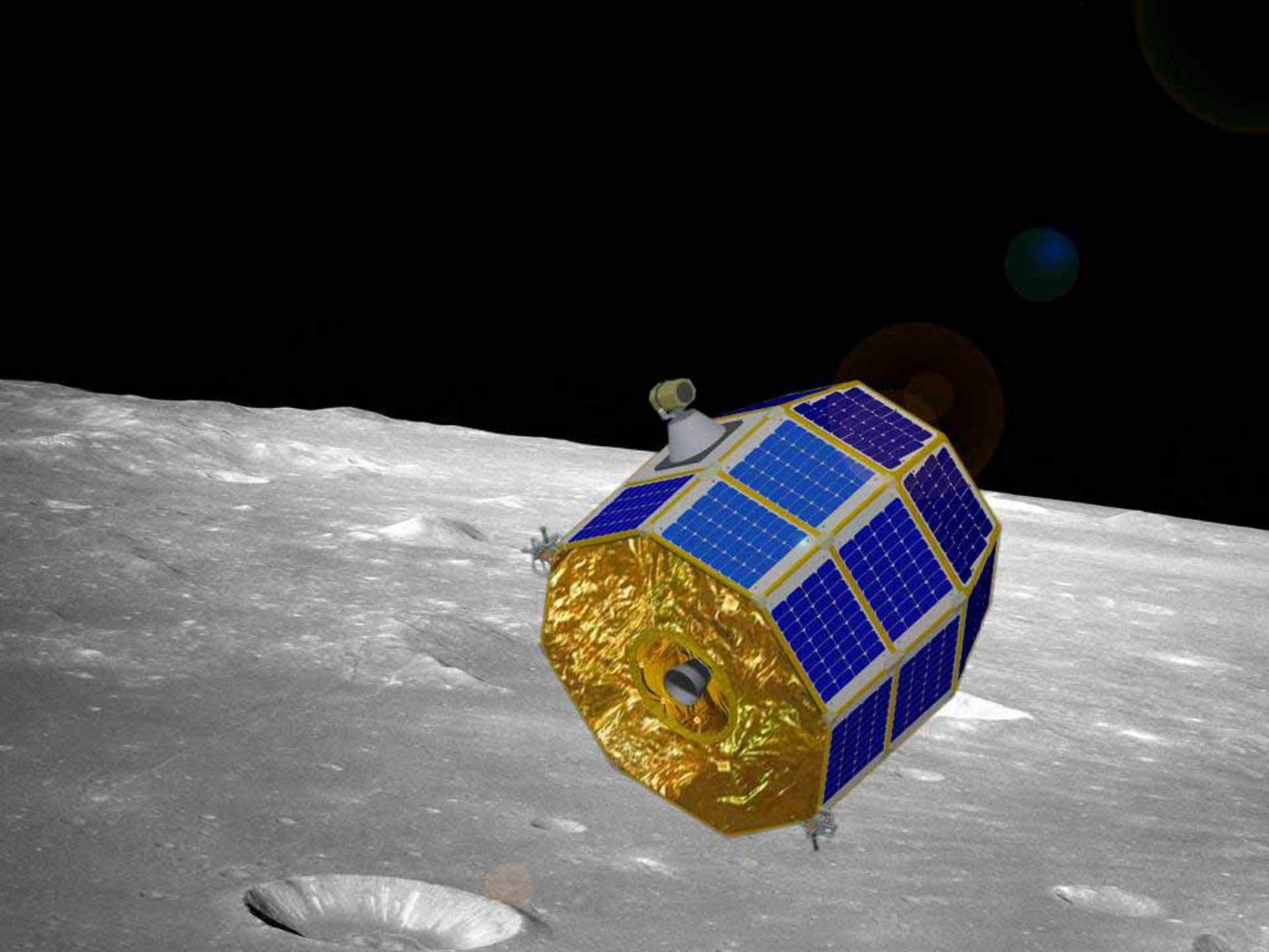
Other User: Lunar Surface Mission?

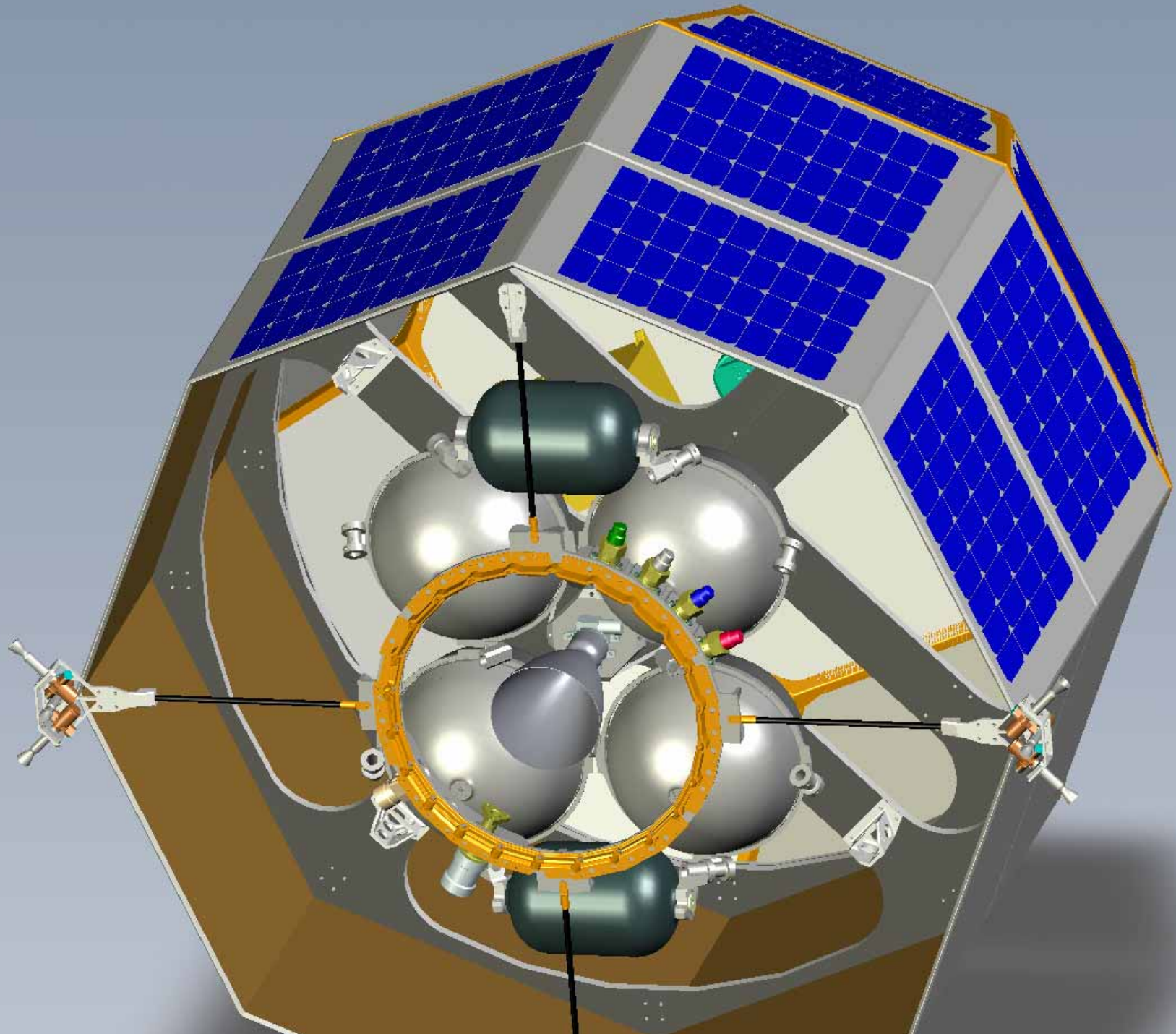


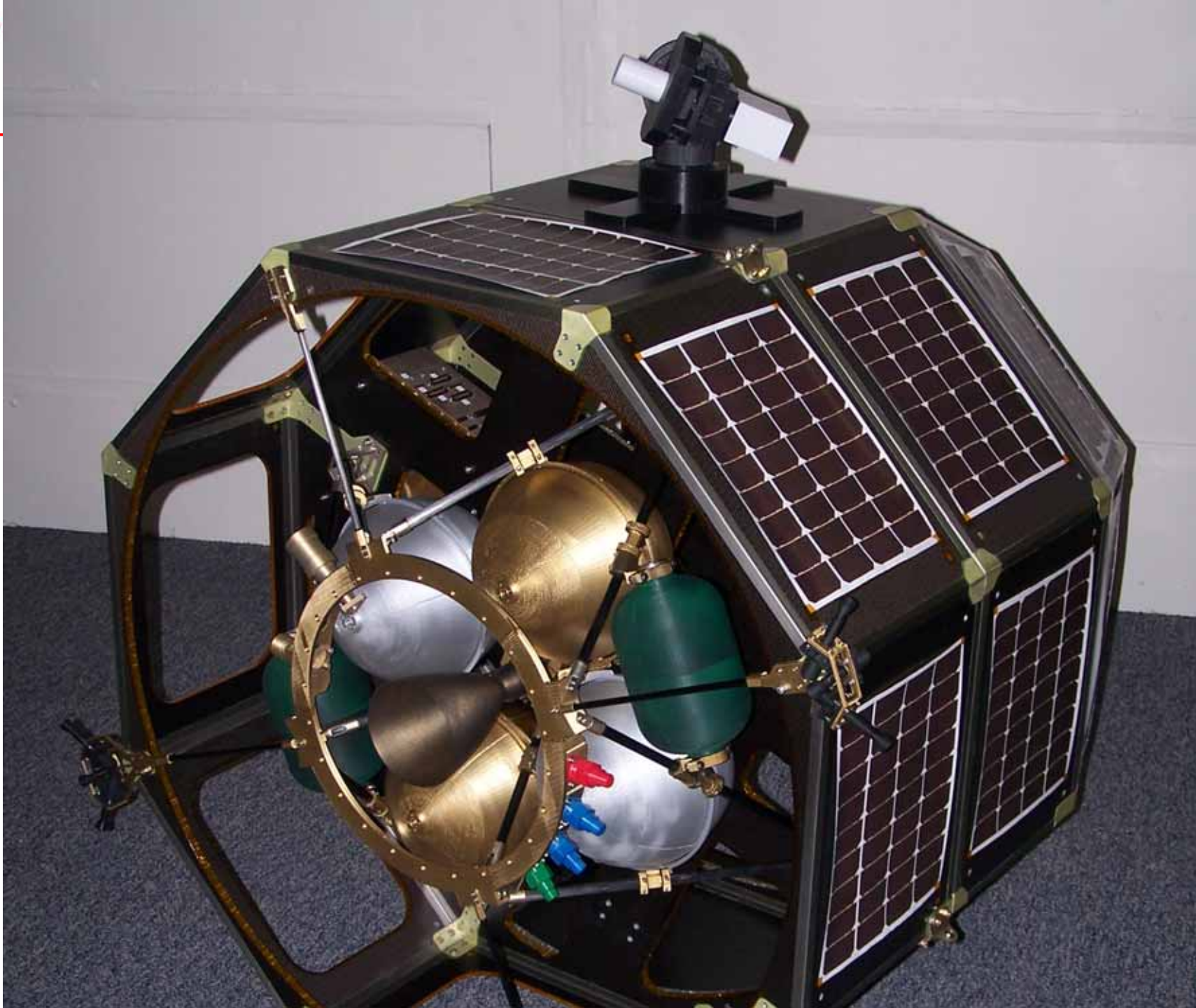
Orbiter in Shroud



Vehicle Subsystem	Mass (kg)
Navigation and Attitude Determination	14.78
Command and Data Handling	4.70
Communications	1.27
Harness	2.30
Power	9.22
Structure	17.01
Thermal Control	1.15
Propulsion	14.65
Trapped Propellant and Helium	1.65
Payload	20.00
System Reserve	13.34
Vehicle Dry Mass	100.07
Usable Propellants	25.59
Vehicle Wet Mass	125.66













CONCLUSIONS

- **LOW COST LUNAR MISSIONS ARE FEASIBLE**
 - ***\$MILLIONS not \$BILLIONS***
 - Part Count
 - Leveraging DoD investments
 - New Technologies – Design, SW, I&T
 - Clementine & Lunar Prospector are examples
 - 12-24 months vs 48-72 months
 - Small Missions Could Complement Planned efforts
 - Help lay foundation for human exploration