Micro High Energy Upper Stage (MHEUS)

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"MUSE"

The Reason for MHEUS

- Independently Targeted High Energy Space Access for Very Small Satellites
  - Ride Share Not Required
- How Far Can Existing Hardware and Systems Be Extrapolated
  - Payload Assumed to be Micro Class (20 – 90 kg)
- Investigate Limitations And Flexibilities of Current Hardware
  - Mission
  - Operational
- Maximize the Lessons Learned from the LADEE and IBEX Missions
  - Small, Minimized High Energy Missions
- Present Performance Opportunity to Small Satellite Community

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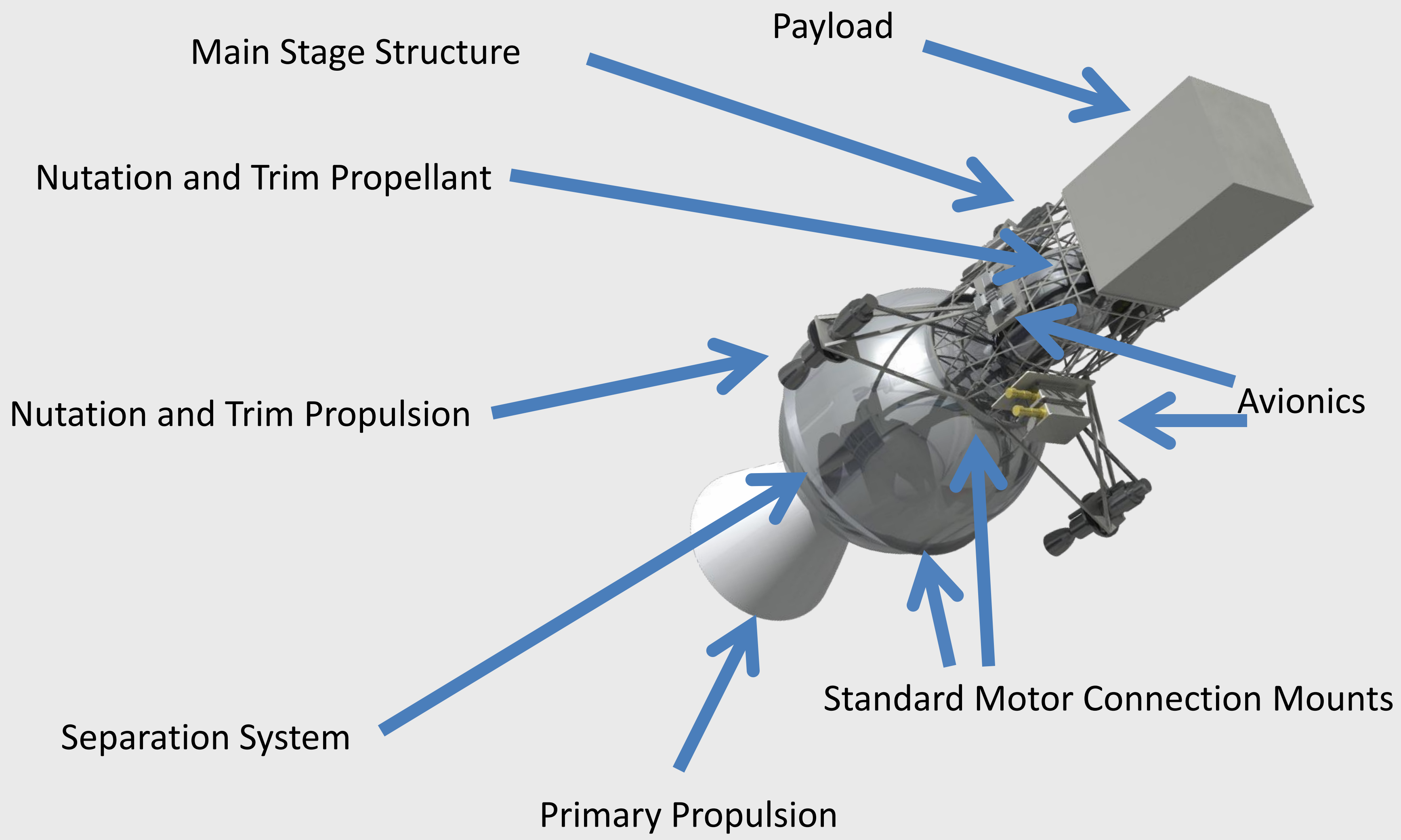
MHEUS



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Core Systems of MHEUS

- Primary Propulsion:
  - STAR 27H – Stock – IBEX Flight Heritage
  - Optimal Heritage Motor Feasible on 1000 lb (450 kg) Class Launch Vehicle
  - Also Key Limiting/Enabling Factor
    - Standard Thrust Curve Assumed (Can Be Tailored)
    - 22 G Maximum Acceleration Limited Total System Inert Mass

- Trim/Nutation System
  - STAR 27H Has Inherent Total Impulse Dispersions
    - Velocity Trim Mandatory/Nutation Control May Not Be
    - Combine Systems
  - SkyBox/E-CAPS Has Nearly Ideally-Sized Propulsion System
    - Total Impulse Much Greater than STAR 27 Impulse Dispersion
    - Thruster Number Increased to Support Nutation/Pitch/Yaw Control
    - Axial Orientation for Optimal Velocity
    - “Green” Propellant Non-Toxic

Core Systems of MHEUS (Continued)

- Initial Spin
  - Launch Vehicle to Provide Initial Stage Spin-up
  - Both Pegasus and Minotaur I Inherently Capable of Required Spin Rates

- De-Spin
  - Yo-Weights Scaled from LADEE Upper Stage
  - No Roll Control Assumed

- Avionics/Guidance
  - Minimized LADEE Orbital MACH Avionics Set
  - Communications /Power Sized for LEO Initial Orbit Insertion

- Structure
  - Anisogrid Composite Lattice Structure
    - Connects LV to STAR Motor
    - Provides Core Structure for Stage

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Flight Details of MHEUS

- Pegasus was Lift Limiting Factor for Mission
  - High Flexibility for LEO Orbit
  - Minotaur I Has 30% More Mass to Orbit Capability
    - Typical Ground Launch Orbital Limitations

- Circular LEO Parking Orbit Assumed for Initial Performance Estimates
  - Details Would Depend on Final Target
  - Inclination Assumed 0 for Pegasus, 28.5 for Minotaur I

- Direct Injection of MHEUS on Minotaur I Improves Mass Performance
  - Target Specific – Optimal Trajectory Assumed
  - May Limit Target Capabilities
  - Second to Last Stage Reenters After Separation

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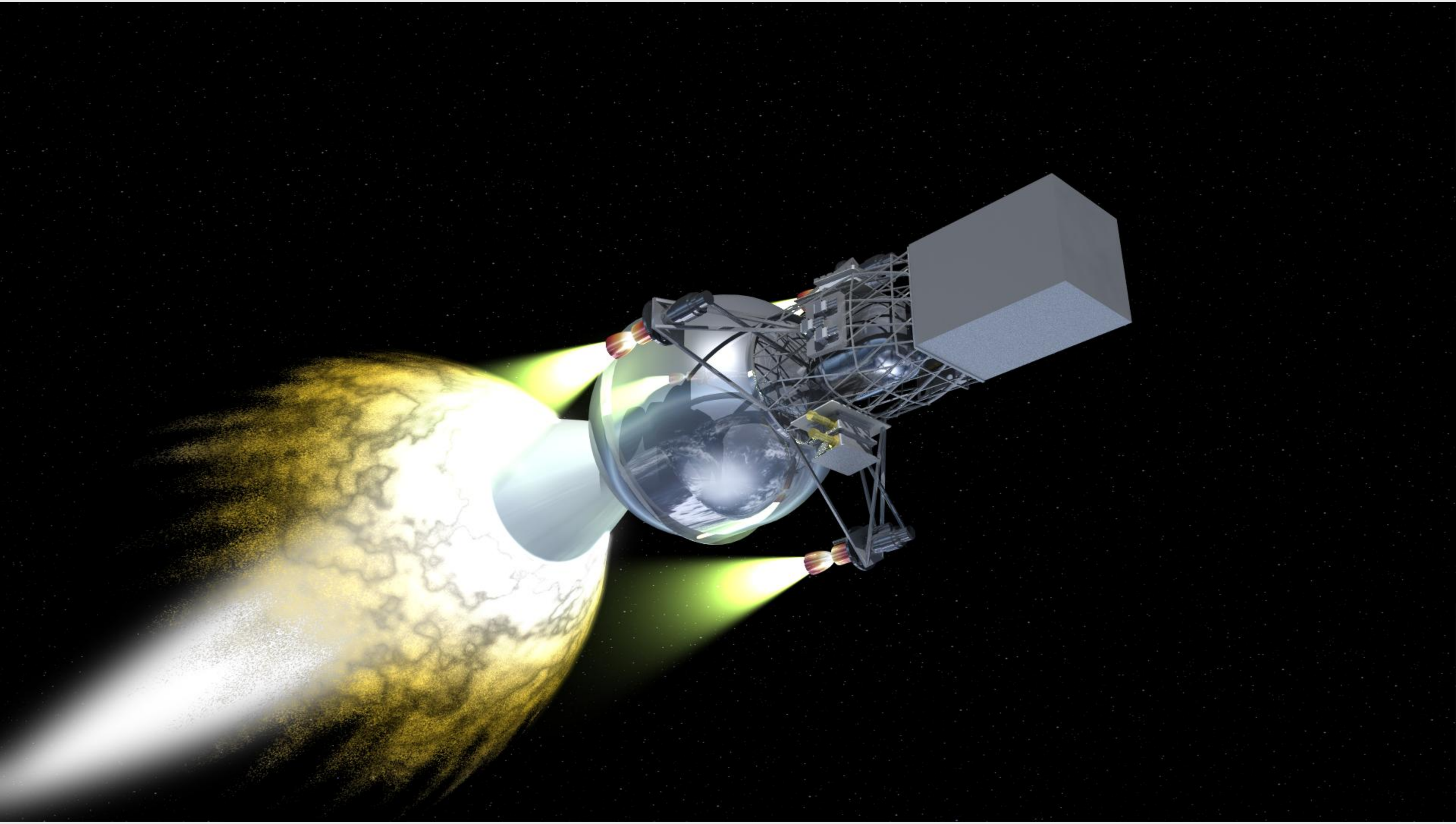
You, On Your Way to ?



Performance – Parking Orbit:

Using Pegasus as LEO Parking Orbit Insertion Vehicle

Payload Mass (kg)	C3 (km2/sec2)	Parking Orbit (km)	Max Acceleration (G's)
24	18	200	23
45	9	200	19
55	6	150	18
60	4	150	17

Using Minotaur I as LEO Parking Orbit Insertion Vehicle

Payload Mass (kg)	C3 (km2/sec2)	Parking Orbit (km)	Max Acceleration (G's)
20	24	690	23
30	19	660	22
40	15	628	20
50	11	595	19
60	8	555	18
70	4	525	17

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Performance – Direct Injection:

Using Minotaur I as LEO Direct Injection Insertion Vehicle

Payload Mass (kg)	C3 (km2/sec2)	Max Acceleration (G's)
20	33	23
30	27	22
40	22	20
50	17	19
60	13	18
70	9	17
80	5	16
90	2	15

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Example Targets

- Very High Energy – Planetary Fly Bys Might be Required
  - Saturn — C3 = 9.2 to 49 km^2/sec^2
    - Enceladus — C3 = 11.7 km^2/sec^2
    - Titan — C3 = 11.5 to 27 km^2/sec^2
  - Jupiter — C3 = 12.7 tp 80 km^2/sec^2
    - Europa — C3 = 31.1 km^2/sec^2
    - Ganymede — C3 = 12.7 km^2/sec^2
    - Io — C3 = 19 km^2/sec^2
  - Mars — C3 = 9.7 to 23.7 km^2/sec^2
  - Venus — C3 = 6.3 to 32 km^2/sec^2
  - Mercury — C3 = 0.5 to 17.5 km^2/sec^2
- High Energy
  - Asteroids — C3 = 20 to 60 km^2/sec^2
  - NEO’s — C3 = 0 to 10 km^2/sec^2
  - L-1: — C3 = -0.7 km^2/sec^2
  - Moon: — C3 = -2.6 km^2/sec^2

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Summary

- A High Energy Upper Stage, Capable of Providing Deep Space Access of Small Launch Vehicles is Achievable Today
- All the Core Technology is Flight Proven
- Highly Useful Satellites in Appropriate Size Range are Becoming Feasible
- We Just Need a Target!