

Michael Werner / Bryce Woollard / Anirudh Tadanki / Swapnil Pujari / Dr. Robert Braun  
Space Systems Design Laboratory, Georgia Institute of Technology

Rob Lock / Adam Nelessen / Ryan Woolley  
Jet Propulsion Laboratory, California Institute of Technology

### Aerocapture Benefits & Control

- Benefits of Aerocapture**
- Minimal propellant requirements
  - Potential large savings in mass and cost
  - Studies have shown conceptual & technical viability

Lack of flight demonstration inhibits use of aerocapture on actual missions

- Aerocapture Control: Drag Modulation**
- Ballistic coefficient changes used to alter vehicle's trajectory
  - Simple to implement compared to traditional lifting methods:
    - No CG offset required
    - Simple avionics algorithms

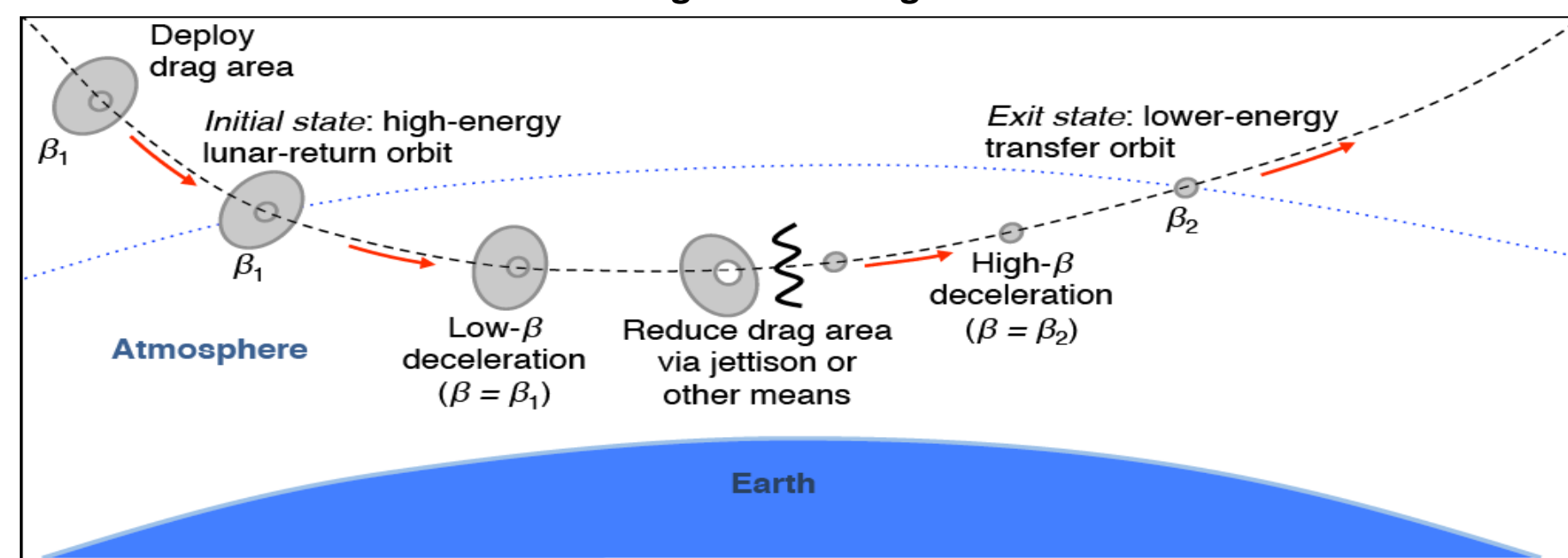
Example Aerocapture ("A/C") Mass Savings

Mission	A/C Mass (kg)	Non-A/C Mass (kg)	% Increase
Venus Low-Circular Orbit	5078	2834	79
Venus Elliptical Orbit	5078	3542	43
Mars Low Circular Orbit	5232	4556	15
Jupiter Low Circular Orbit	2262	N/A	Enabling
Saturn Circular Orbit	494	N/A	Enabling
Titan Circular Orbit	2630	691	280
Uranus Elliptical Orbit	1966	618	218
Neptune Elliptical Orbit	1680	180	832

Adapted from: Hall et al, "Cost-Benefit Analysis of the Aerocapture Mission Set", Journal of Spacecraft & Rockets, 2005

So easy, a SmallSat can do it

Discrete Single-Event Drag Modulation



### Mission Concept

**Purpose:** Develop SmallSat mission concept for flight test demonstrating aerocapture at Earth

**Philosophy:** Prioritize simplicity & affordability

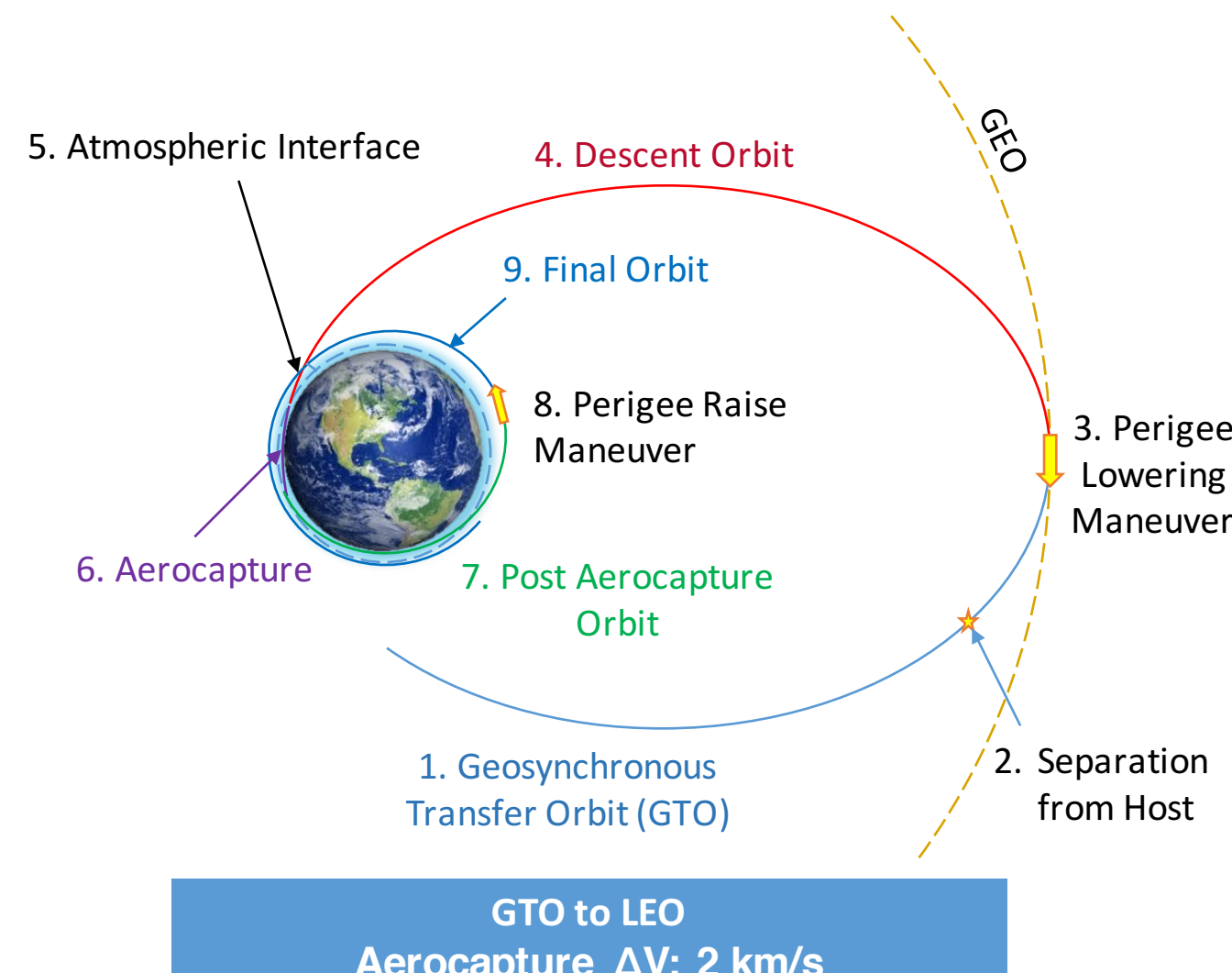
**Requirements:**

- Aerocapture  $\Delta V$ :  $\sim 2$  km/s
- Successful raise maneuver
- Telemetry data return

**Deliverable:** Fully-documented mission concept in anticipation of future SmallSat proposal opportunities

Mission Timeline

#	Event	Details
1	GTO	Period: 10 hrs
2	Separation from Host	1 hr before apogee
3	Perigee Lowering Maneuver (PLM)	$\Delta V$ : $\sim 10$ m/s
4	Descent Orbit	Duration: 5 hrs
5	Atmospheric Interface	Altitude: 125 km Velocity: 10.3 km/s
6	Aerocapture	$\Delta V$ : $\sim 2000$ m/s
7	Post-Aerocapture Orbit	60 km x 1750 km
8	Perigee Raise Maneuver (PRM)	$\Delta V$ : $\sim 40$ m/s
9	Final Orbit	200km x 1750 km



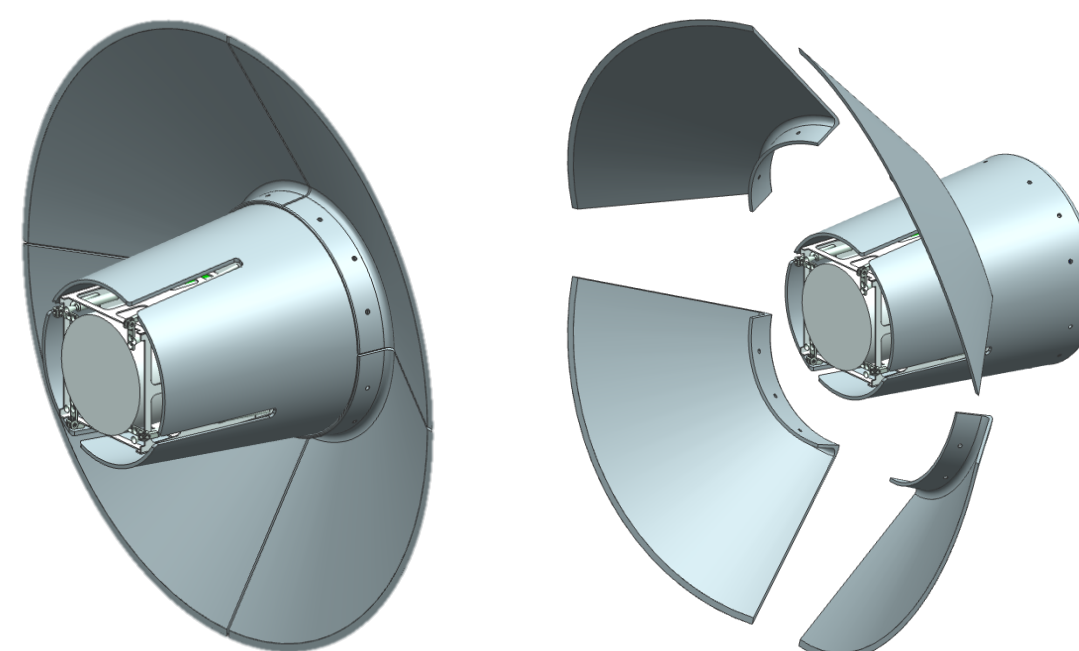
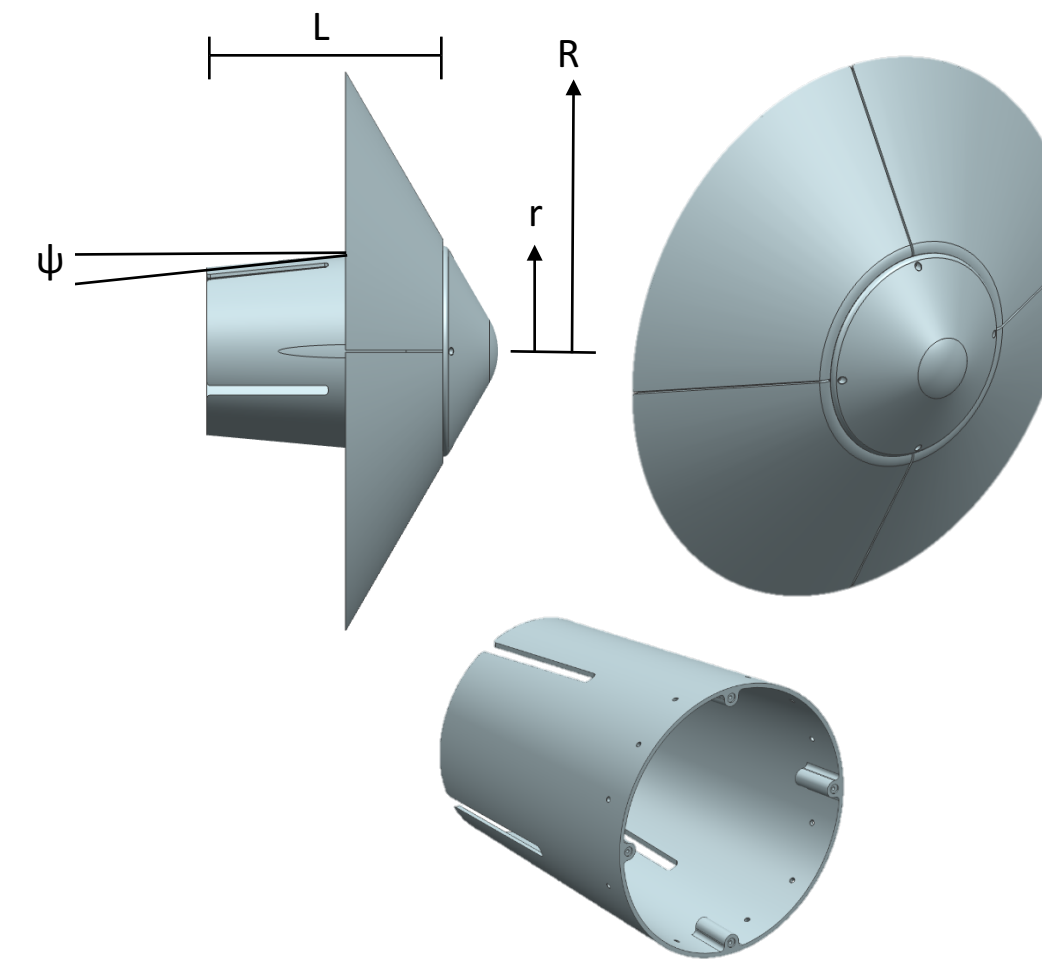
### Flight System Overview

**Aeroshell Design**

- Aeroshell and drag skirt made from machined aluminum
- PICA selected as TPS material

**Aeroshell & Drag Skirt Properties**

Location	Dimension	Value
Drag Skirt	Outer Radius (R)	25 cm
	Blunted Cone Angle	60°
Foreshell	Inner Radius (r)	10 cm
	Nose Radius	5.625 cm
	Shoulder Radius	1 cm
Backshell	Length (L)	22.7 cm
	Backshell Taper ( $\psi$ )	5.3°



**Drag Skirt & Jettison Mechanism**

- Drag skirt broken into 4 quadrants
- Jettison accomplished via 3 staggered M3 pyrotechnic bolts per quadrant
- Spring loaded at interface to ensure safe detachment

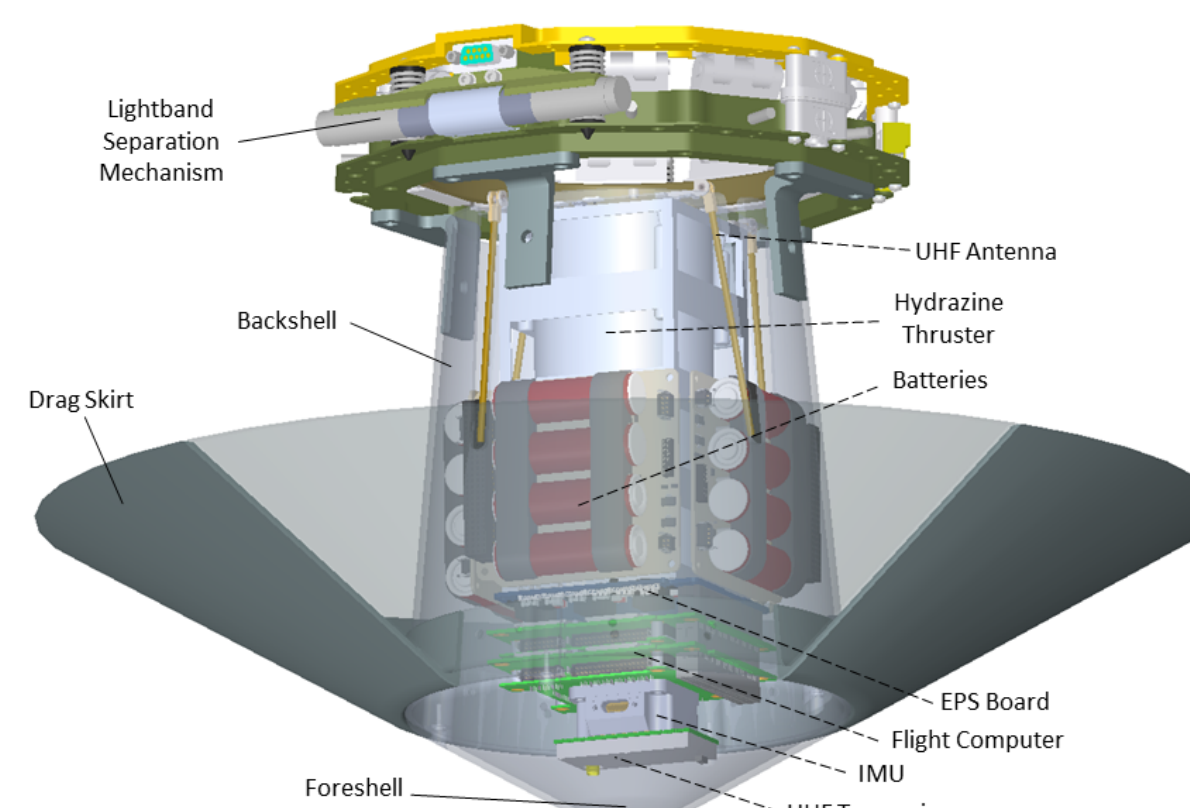
**Static Stability**

**Pre-Jettison**

- CG Location: 7.65 cm aft of nose vertex
- Backshell is shadowed from hypersonic flow by drag skirt
- Ample static margin and stability

**Post-Jettison**

- CG Location: 10.6 cm aft of nose vertex
- Exposure of backshell to flow leads to reduced static stability



Static Margin Timeline

Configuration	Time (s)	Static Margin (cm)
Pre-Jettison	0	N/A
	50	63.42
	100	58.99
Post-Jettison	150	58.64
	200	7.98
	250	8.52
	300	11.34
	350	-3.31

**Nominal Flight System**

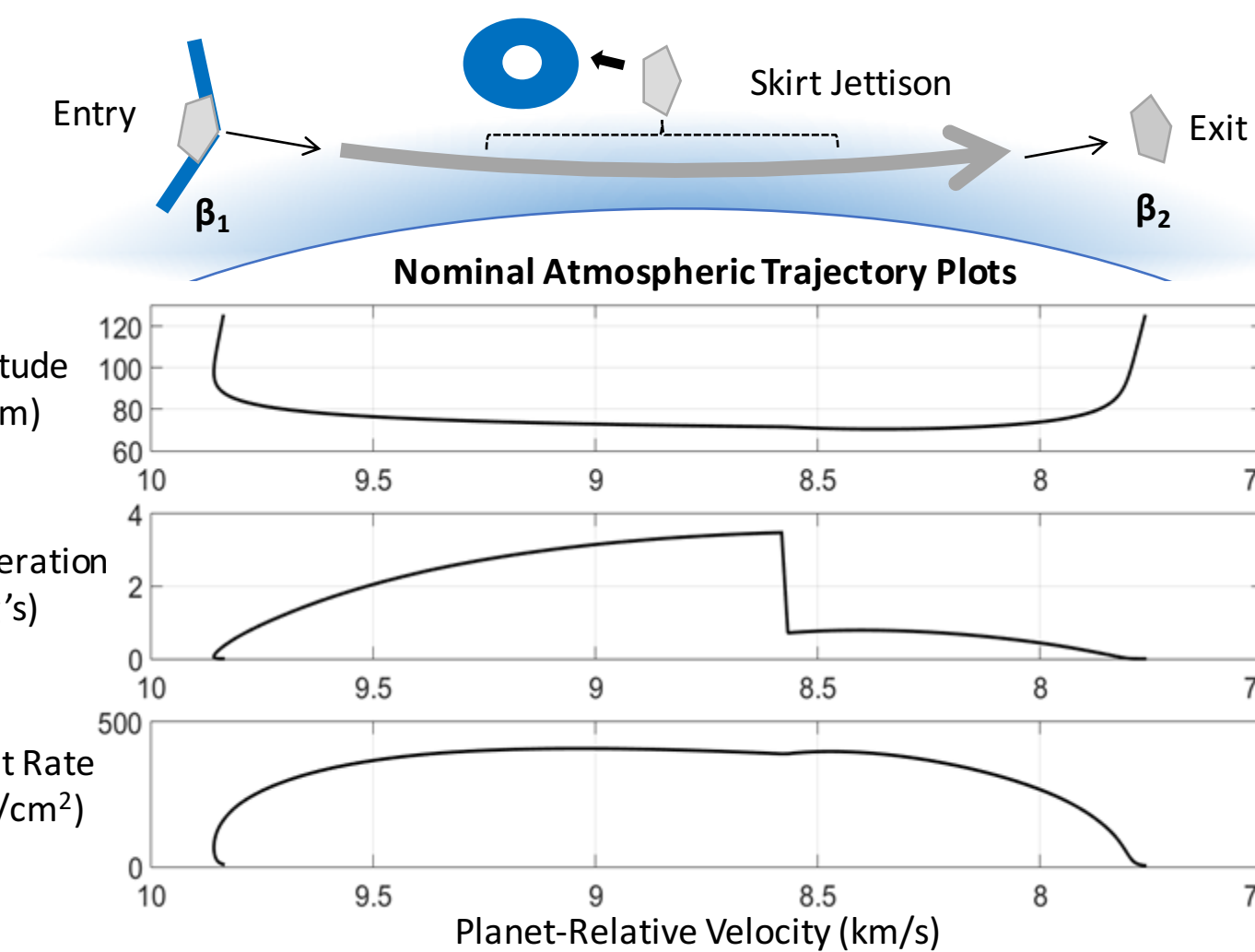
- Aerojet MPS-120XL Hydrazine Propulsion
- Sensor IMU
- ISIS On-Board Computer
- GomSpace EPS & Batteries
- Astrodev UHF Radio
- GomSpace UHF Dipole Antenna

A <25 kg flight system based on COTS CubeSat hardware meets all mission requirements

### Trajectory Modeling

**Trajectory Modeling**

- End-to-end simulation models vehicle trajectory and uncertainties
- 3-DOF integration of atmospheric equations of motion
- Key outputs:
  - Deceleration
  - Heat Rates
  - Orbit uncertainties

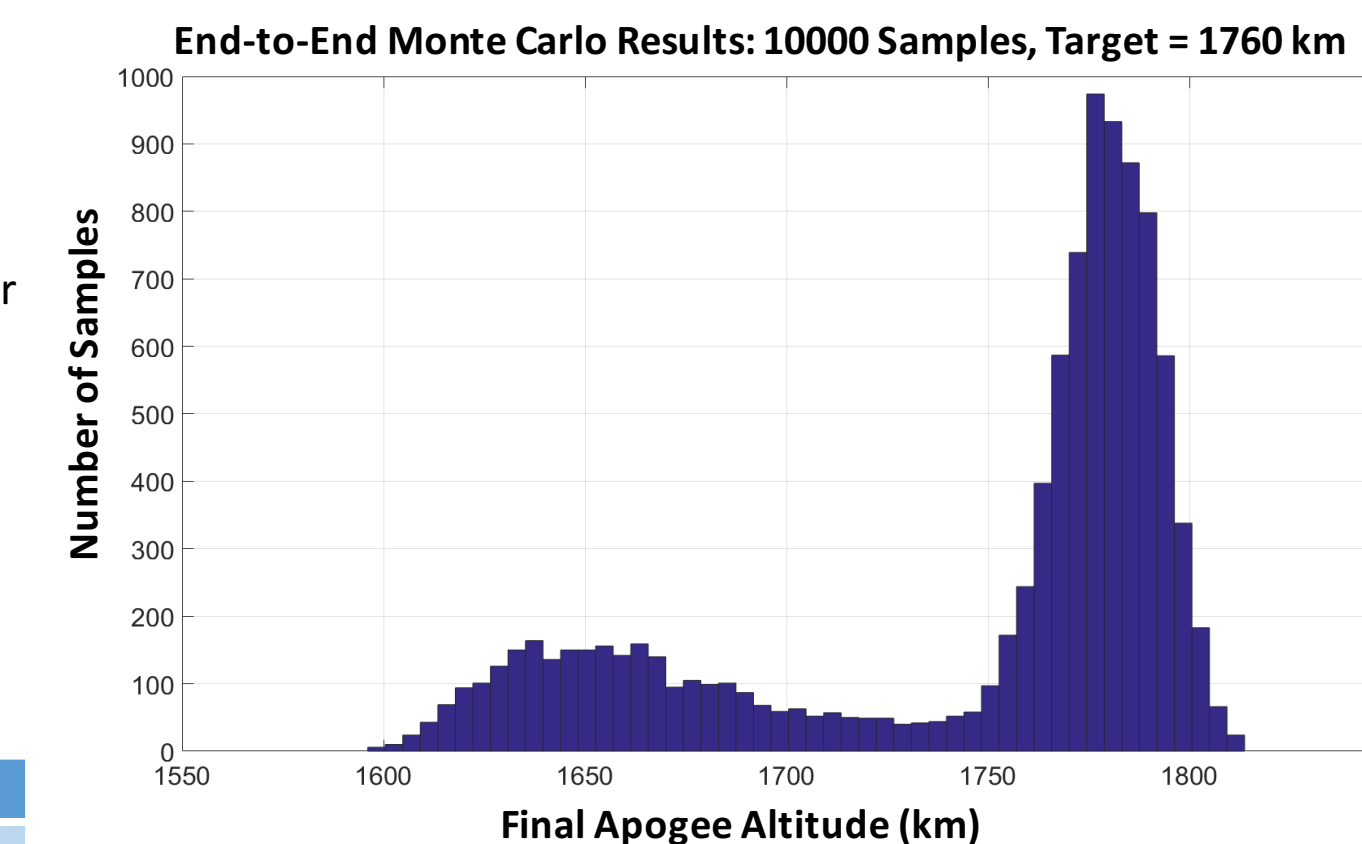


**Control Scheme**

- Jettison timing controls amount of aerocapture  $\Delta V$
- Guidance algorithm: numerical predictor-corrector
  - Only atmospheric accelerometer measurements required
- Monte Carlo results show robustness to uncertainties in entry FPA, atmosphere, and burns

Monte Carlo Summary

Parameter	Value
Mean	1746.0 km
3 $\sigma$ Error	169.4 km
Minimum	1596.1 km
Maximum	1813.7 km



Jettison guidance algorithm is able to effectively target desired orbit

### Conclusions

**Takeaways**

- A SmallSat mission featuring single-event jettison drag modulation is a promising architecture to demonstrate a  $\sim 2$  km/s aerocapture maneuver at Earth
- Structural and mission design analyses have led to a <25 kg flight system featuring COTS hardware
- Trajectory analyses and Monte Carlo results show robustness of system design to uncertainties

For more information:

Michael Werner  
mwerner9@gatech.edu