SmallSat Aerocapture Demonstration

Development of an Earth SmallSat Flight Test to Demonstrate Viability of Mars Aerocapture

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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

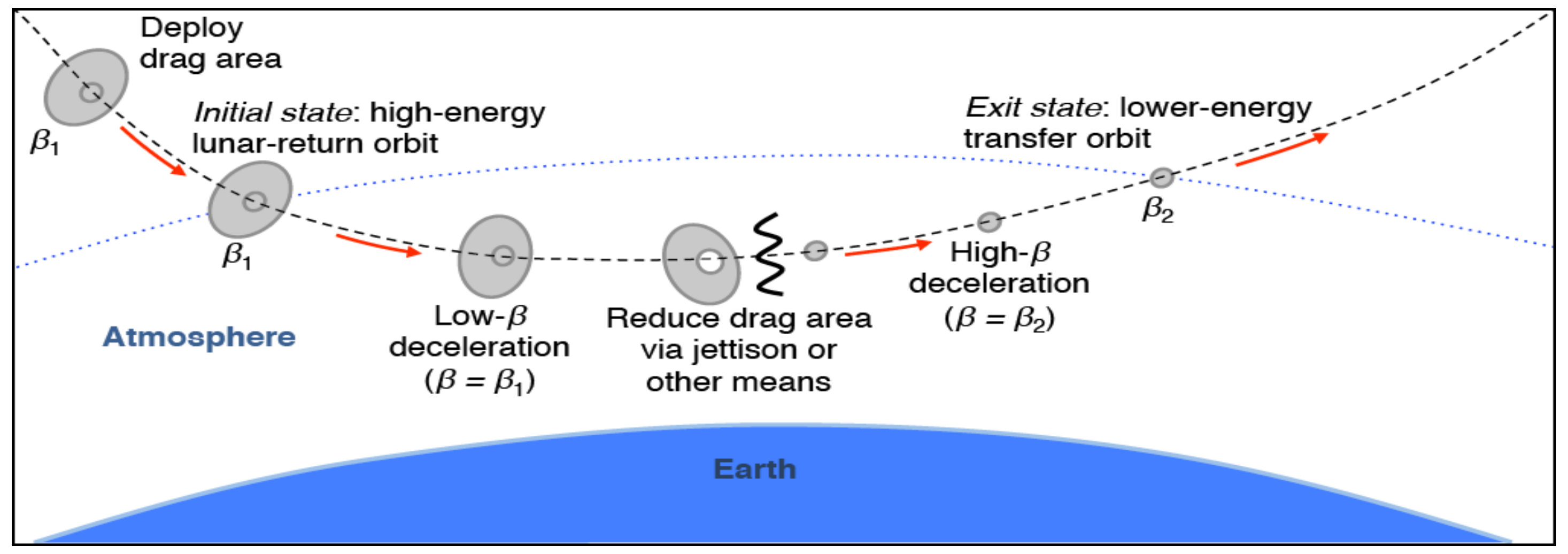
So easy, a SmallSat can do it

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

Discrete Single-Event Drag Modulation



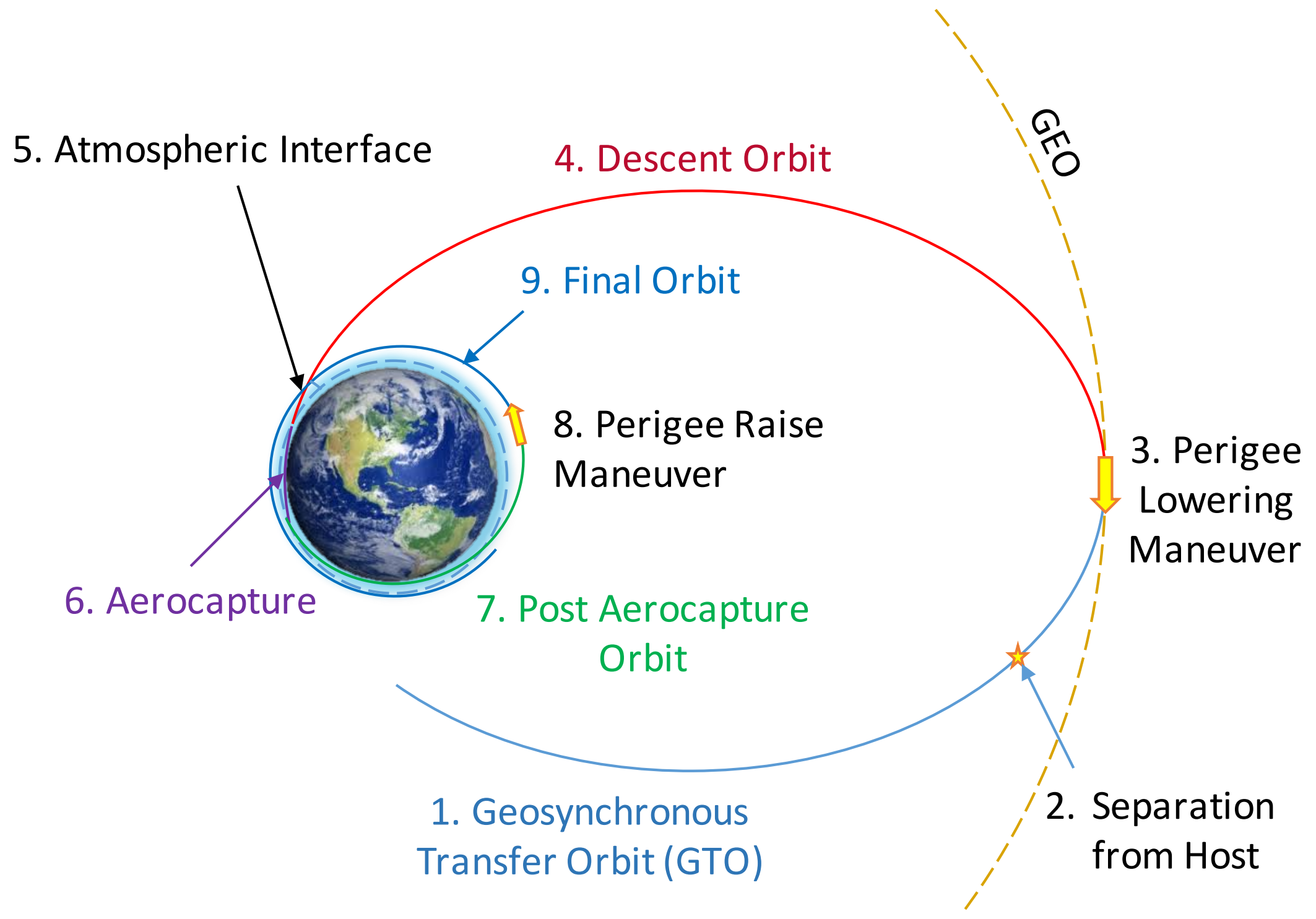
Mission Concept

Purpose: Develop SmallSat mission concept for flight test demonstrating aerocapture at Earth
Philosophy: Prioritize simplicity & affordability
Requirements:
1. Aerocapture ΔV: ~2 km/s
2. Successful raise maneuver
3. 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)	ΔV: ~10 m/s
4	Descent Orbit	Duration: 5 hrs
5	Atmospheric Interface	Altitude: 125 km Velocity: 10.3 km/s
6	Aerocapture	ΔV: ~2000 m/s
7	Post-Aerocapture Orbit	60 km x 1750 km
8	Perigee Raise Maneuver (PRM)	ΔV: ~40 m/s
9	Final Orbit	200km x 1750 km



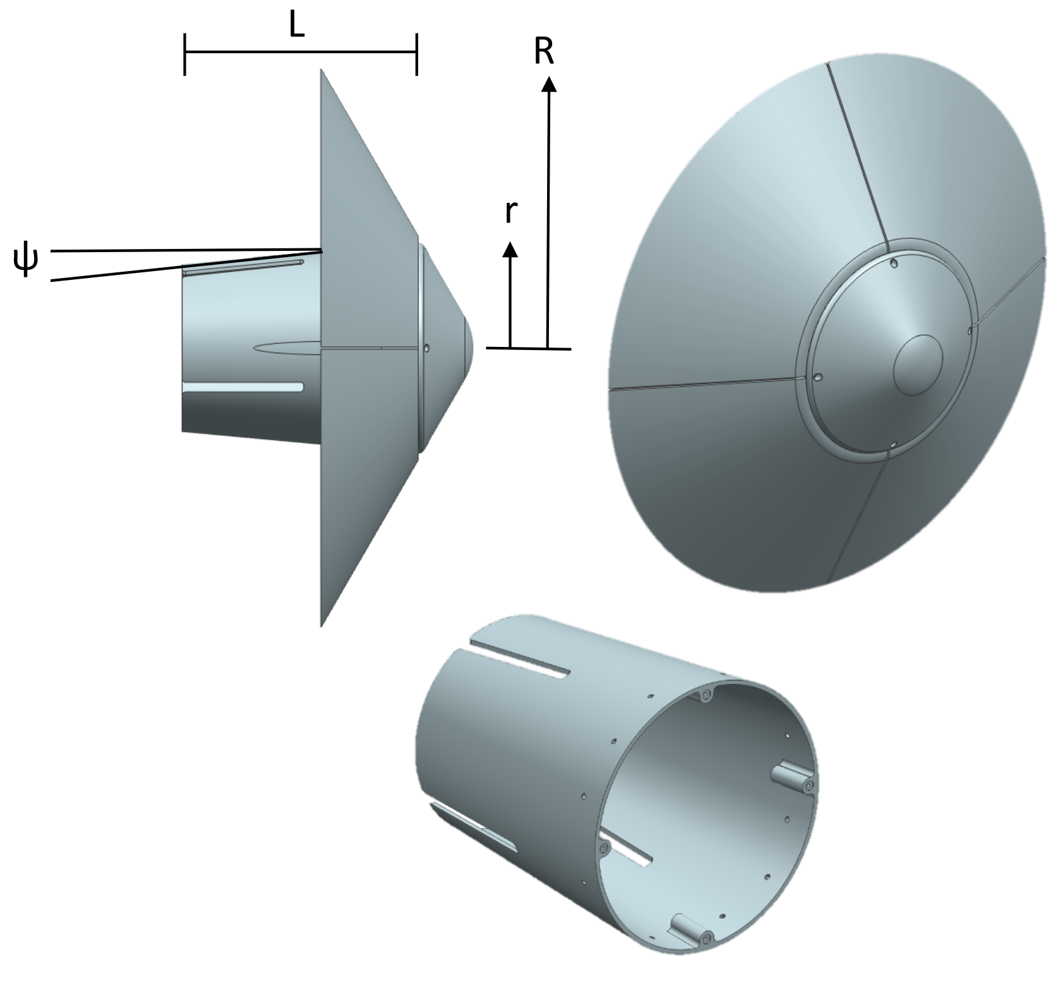
GTO to LEO
Aerocapture ΔV: 2 km/s

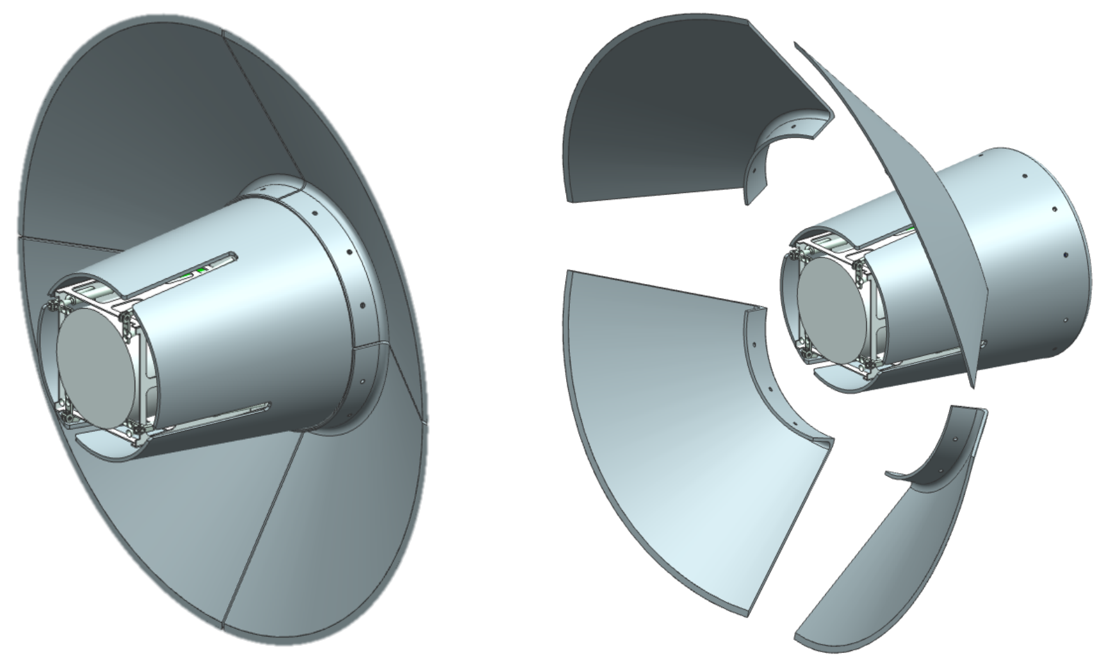
Flight System Overview

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
Foreshell	Blunted Cone Angle	60°
	Inner Radius (r)	10 cm
	Nose Radius	5.625 cm
	Shoulder Radius	1 cm
Backshell	Length (L)	22.7 cm
	Backshell Taper (ψ)	5.3°





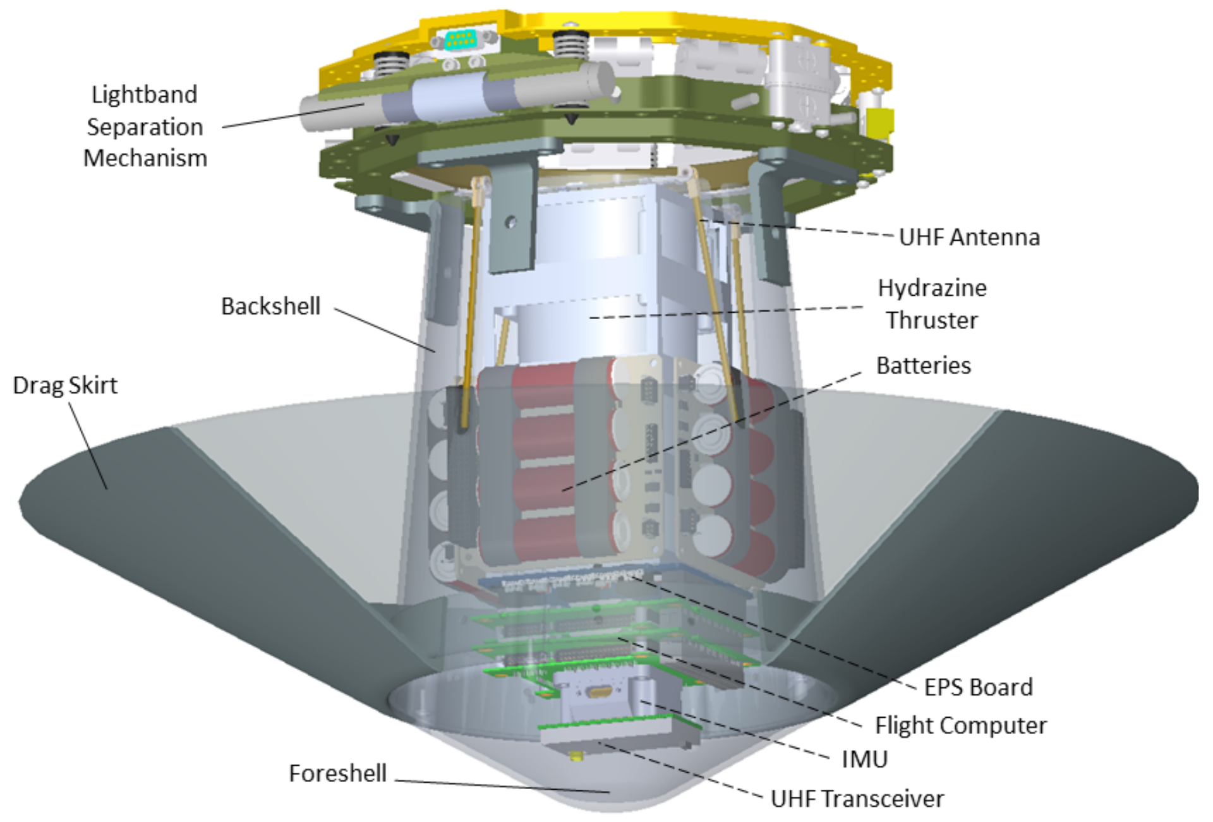
Drag Skirt & Jettison Mechanism
- Drag skirt broken into 4 quadrants
- Jettison accomplished via 3 staggered M3 pyrotechnic bolts per quadrant
- Spring loaded at interface to ensure safe detachment

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
	150	58.64
Post-Jettison	150	7.98
	200	8.52
	250	11.34
	300	-3.31
	350	-243.88

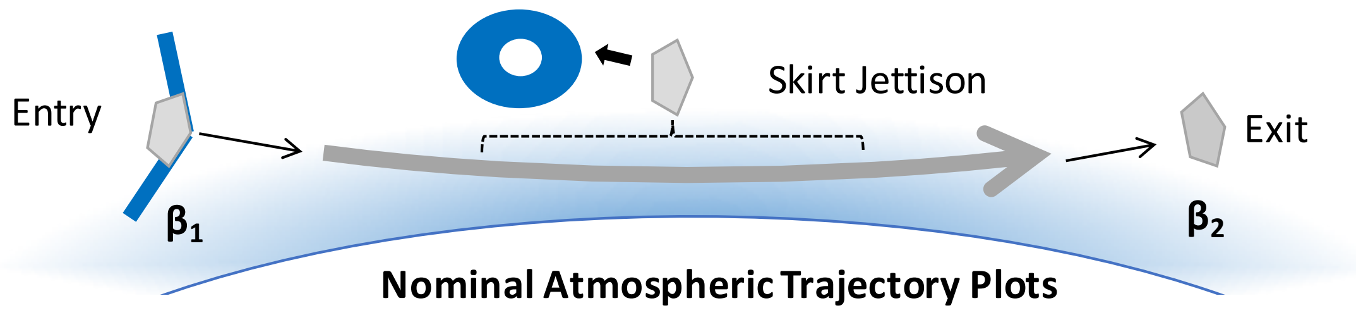


Nominal Flight System
- Aerojet MPS-120XL Hydrazine Propulsion
- Sensonor IMU
- ISIS On-Board Computer
- GomSpace EPS & Batteries
- Astrodev UHF Radio
- GomSpace UHF Dipole Antenna

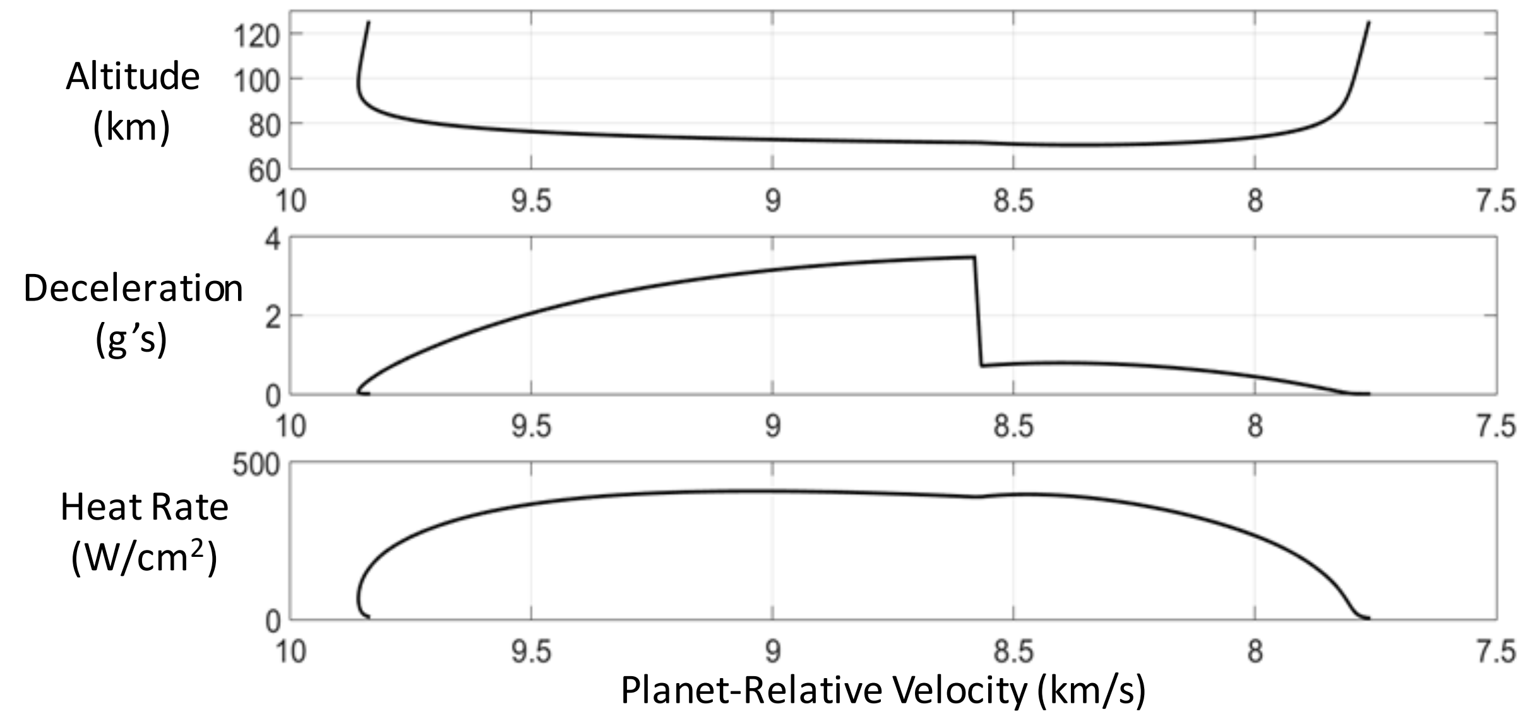
A <25 kg flight system based on COTS CubeSat hardware meets all mission requirements

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

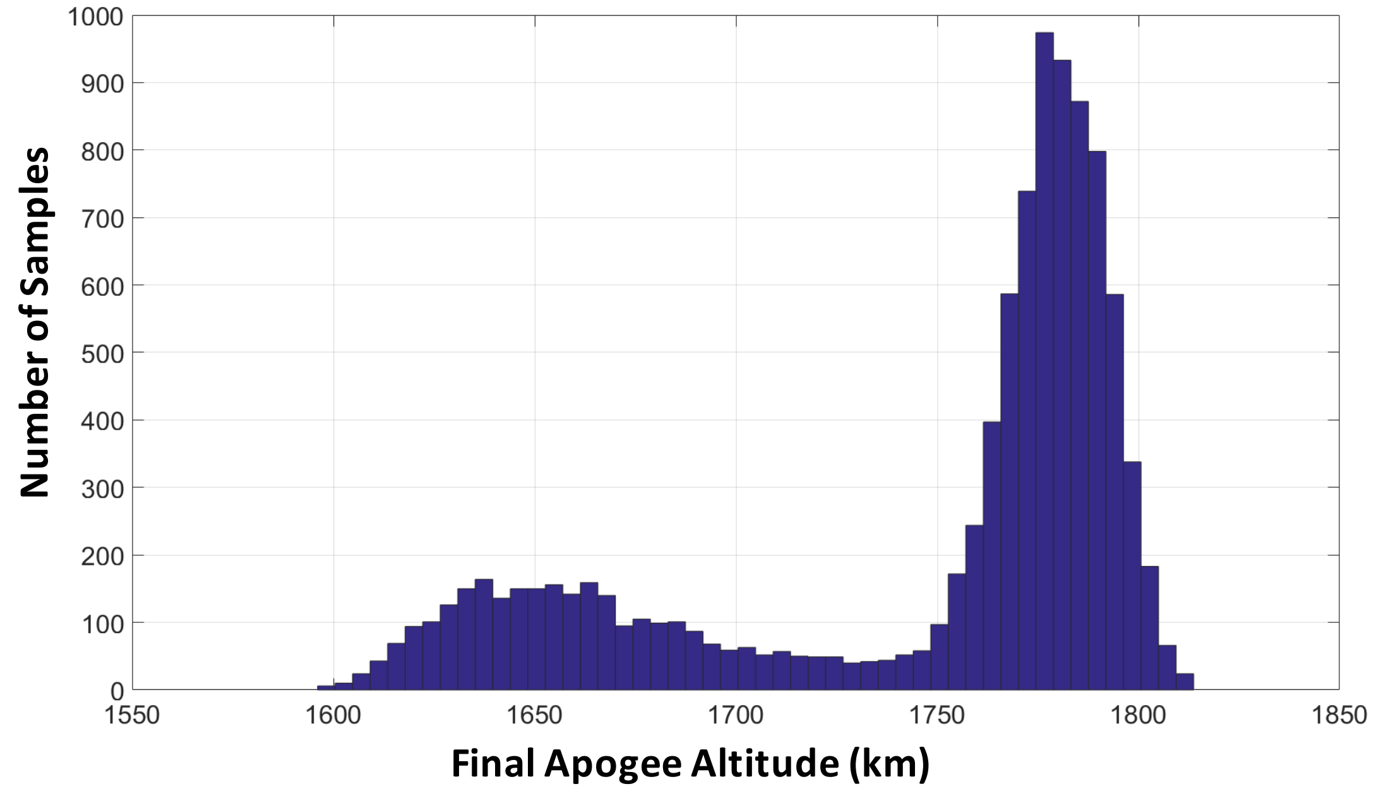


Nominal Atmospheric Trajectory Plots



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

End-to-End Monte Carlo Results: 10000 Samples, Target = 1760 km



Monte Carlo Summary

Parameter	Value
Mean	1746.0 km
3σ 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 ~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:

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