

Aerocapture Earth Demonstration Design to Support Future Planetary Mission Needs

Soumyo Dutta, Rohan Deshmukh, Andrew Hinkle, James Scoggins, Eli Shellabarger, Justin Shafner, Dominic Trombetta
NASA Langley Research Center

James Corliss, Min Qu, Evan Roelke, Alejandro Pensado, Nicholas Vitullo, and Joseph Williams
Analytical Mechanics Associates

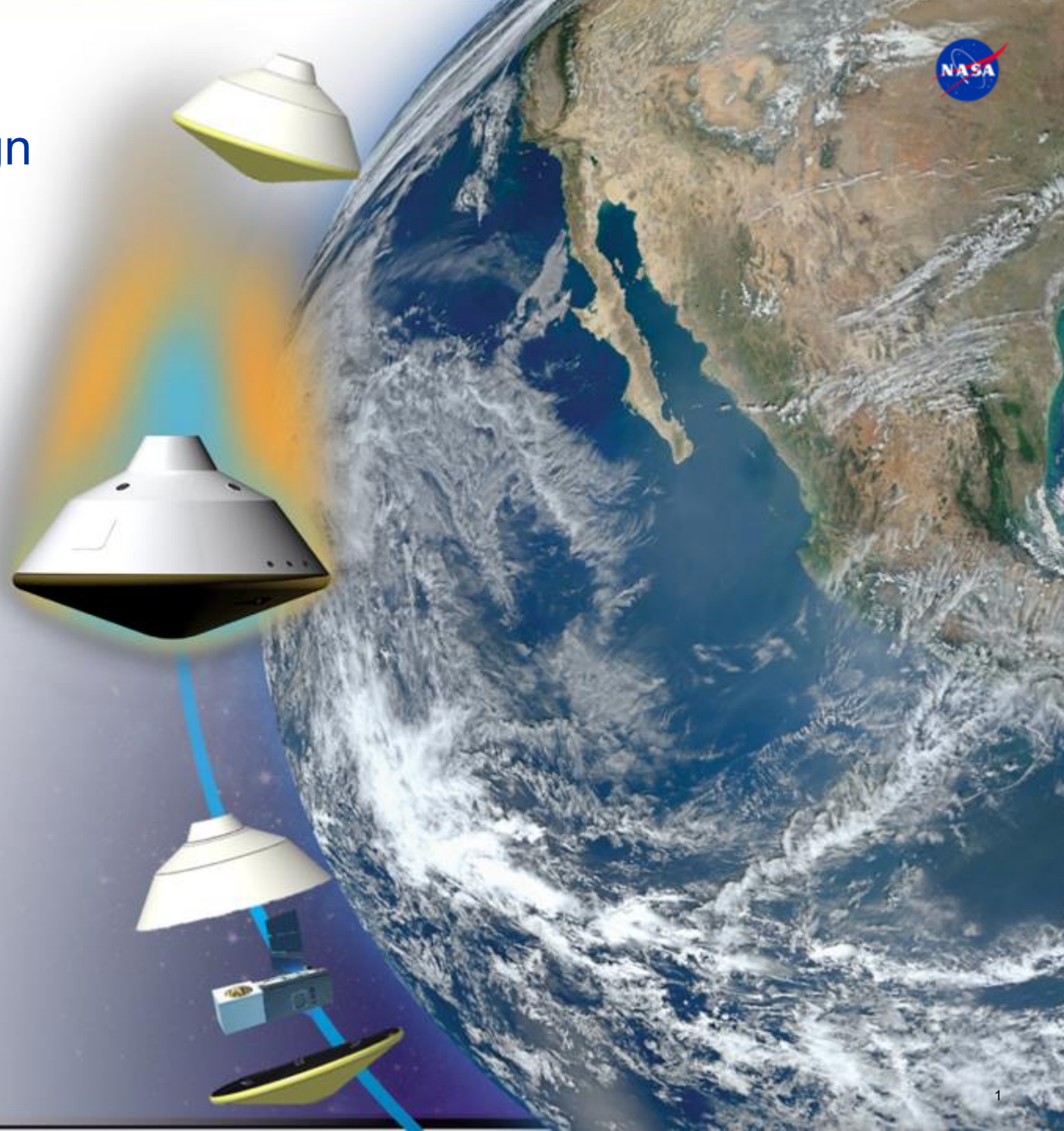
Jonathan Morgan, Todd White
NASA Ames Research Center

Julia Briden
Amentum Technologies

Daniel Matz
NASA Johnson Space Center

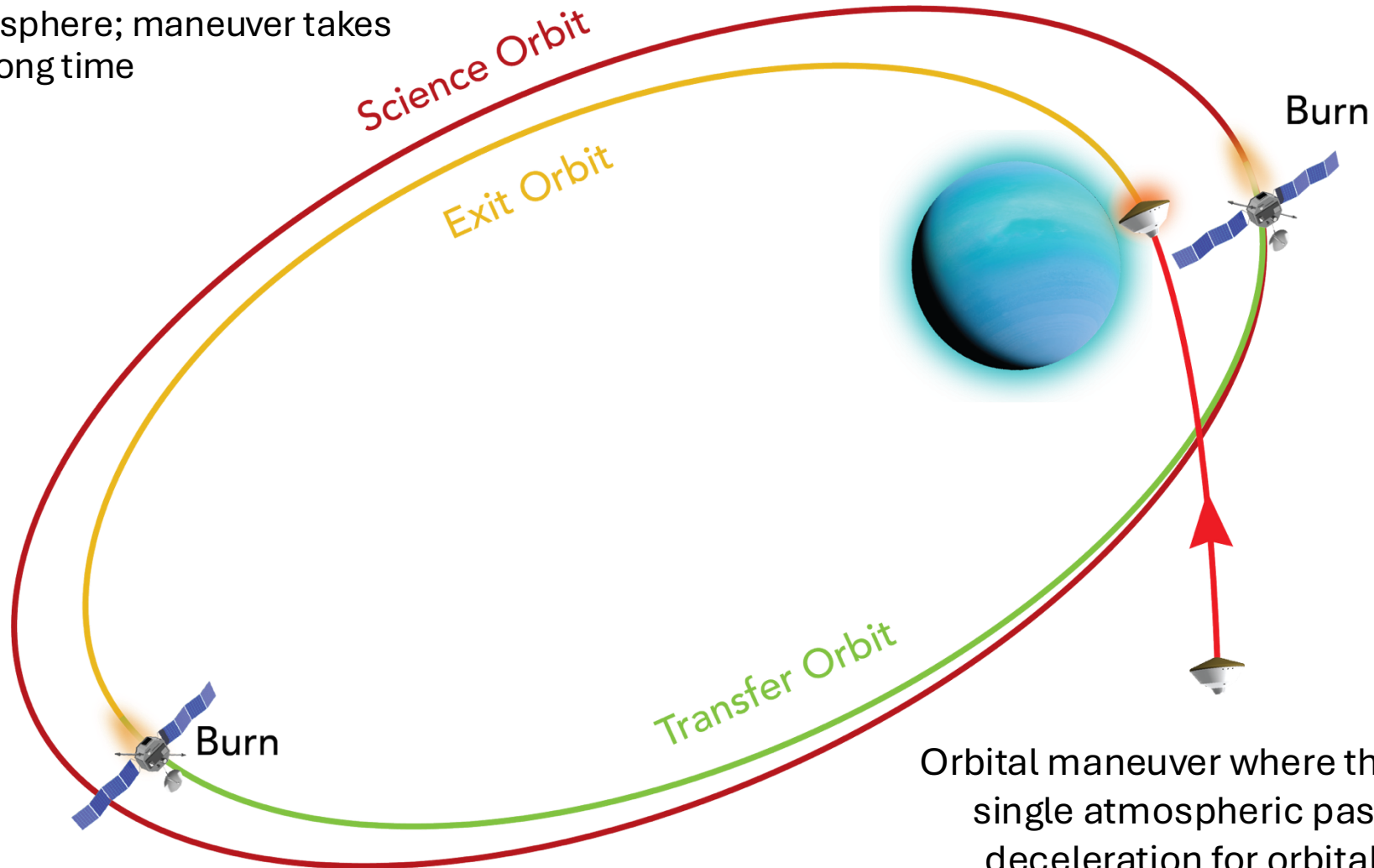
Sarah Agam and Mihirkumar Patel
ViGYAN Inc.

AIAA SciTech 2026, Orlando, FL
January 12th, 2026



What is Aerocapture?

Aerocapture is different than aerobraking
Which skims atmosphere; maneuver takes
a long time



Orbital maneuver where the drag from a
single atmospheric pass provides
deceleration for orbital insertion

Human Exploration: Human-scale Mars Missions

- Human-scale missions can have **reduced trip time** with a faster interplanetary trajectory and have **increased on-orbit mass**

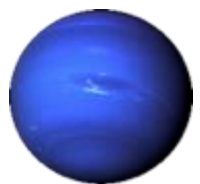


SmallSat: Planetary SmallSat Missions

- Typically, volume and mass constrained; propellant systems are a heavy burden
- Aerocapture systems: Can reduce necessary propellant – **50-80% more useful mass on-orbit** depending on the orbit



Planetary Science: Uranus and Neptune



Typical Fully-Propulsive Mission

- Fast interplanetary speeds for outer planets
- **Need 50% or more mass** for fully-propulsive orbit insertion (requires ΔV of 1-2 km/s)
- Typical mission **require long cruise phase** (13-17 years)

Aerocapture Enabled Mission

- Reduced propellant need; **increase on-orbit mass by 40%**
- Aerocapture less sensitive to faster interplanetary trajectories – **reduce trip time by 3-5 years**
- Savings used for launch vehicle choice or increased on-orbit science payload
- Fit a larger cap mission into smaller cap. e.g., **Flagship class mission in New Frontiers cap**

Aerocapture is an undemonstrated maneuver; demonstration of aerocapture will alleviate risks



Outline

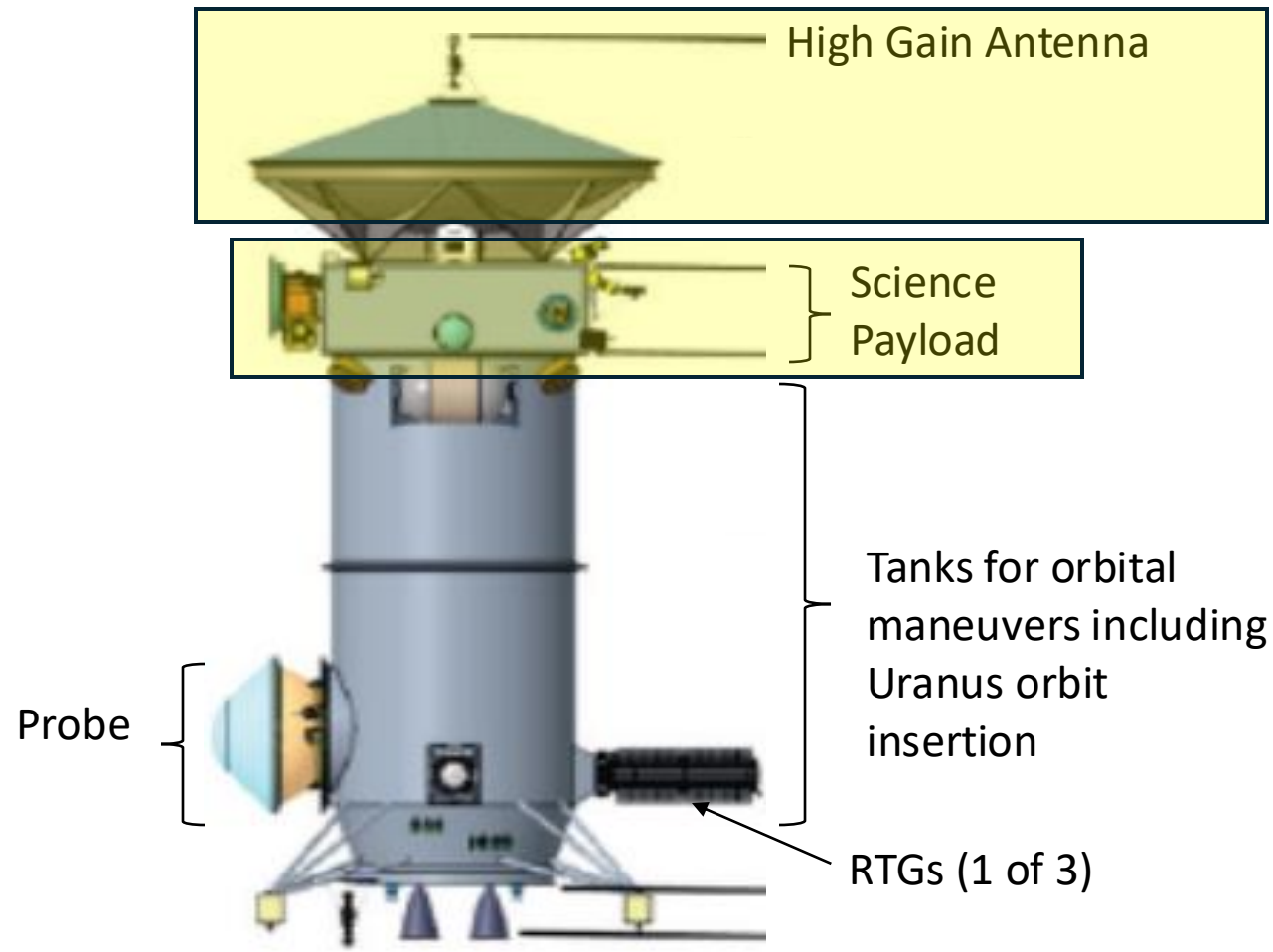
National Aeronautics
and Space Administration



- Example of Aerocapture at Planetary Destination
- Current Aerocapture Risk Posture
- Capabilities for Aerocapture Demonstration
- Demonstration Concept of Operations
- Demonstration Design



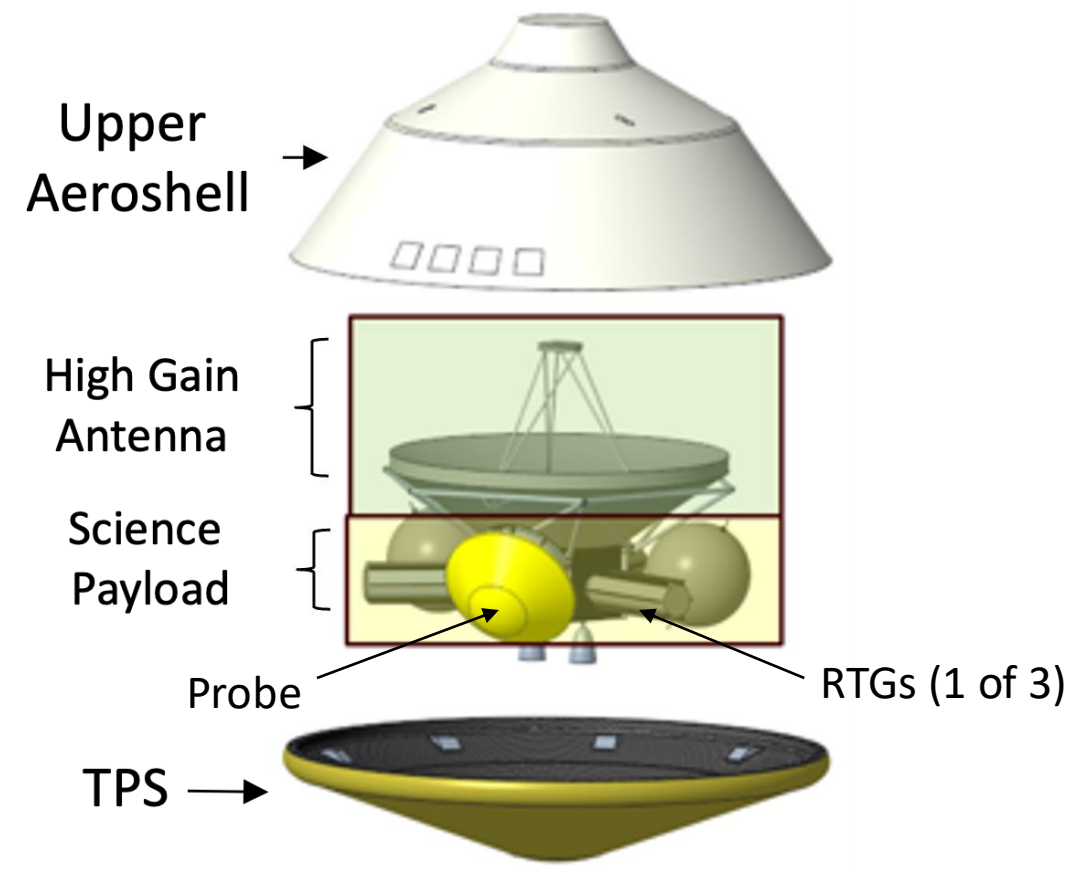
Aerocapture at Planetary Destination: Uranus Orbiter and Probe



2022 Uranus Orbiter and Probe Concept

RTG = Radioisotope thermoelectric generator

TPS = Thermal Protection System



Aerocapture Concept
AIAA 2025-1508



Current Risk Posture for Aerocapture

National Aeronautics
and Space Administration



	Risk Statement	Type	Level of Risk
1	If the atmospheric density profile uncertainty is too large, then trajectory or flight-path calculations based on the blunt-body heritage would be in error.	Development	High
2	If the aerocapture implementation heat shield TPS performance and sizing requires more mass than studies assumed, then the dry mass will exceed the allocation.	Development	Low
3	If the aerocapture implementation requires more mass for ancillary systems (e.g., g-load mitigation, separation mechanisms, packaging, heat dissipation), then the dry mass will exceed the allocation.	Development	Medium
4	If the aerocapture uncertainties are too high, then the cost (\$, mass) of implementation with sufficient capability will be too high.	Development	High
5	If the aerothermodynamics of the target body are not well understood/modeled, then heat shield performance will be compromised.	Mission	High
6	If the aerothermodynamics of the target body are not well understood/modeled, then the control actuators may not have sufficient control authority to maintain the flight path angle and the lift vector orientation.	Mission	Medium
7	If the entry heating (integrated heat flux and soak-back) cannot be accommodated, then components may overheat resulting in failures.	Mission	Medium
8	If autonomous optical navigation cannot correctly correlate the atmosphere altitude to the planet barycenter, then the density will not be as expected and may exceed the ability of the spacecraft to compensate.	Mission	Low



Atmospheric uncertainties



System uncertainties of aerocapture



Aerothermodynamic uncertainties



Aerocapture Mission Developmental Areas

National Aeronautics
and Space Administration



Requirements for planetary missions	Earth-based demonstration behavior
Hypersonic guidance for target orbit	
Thermal Protection System (TPS)	
Autonomous periapsis raise maneuver	
Control systems demonstration	
Aeroshell separation after aerocapture	
Targeting tight entry corridor	
Packaging payload in aeroshell	



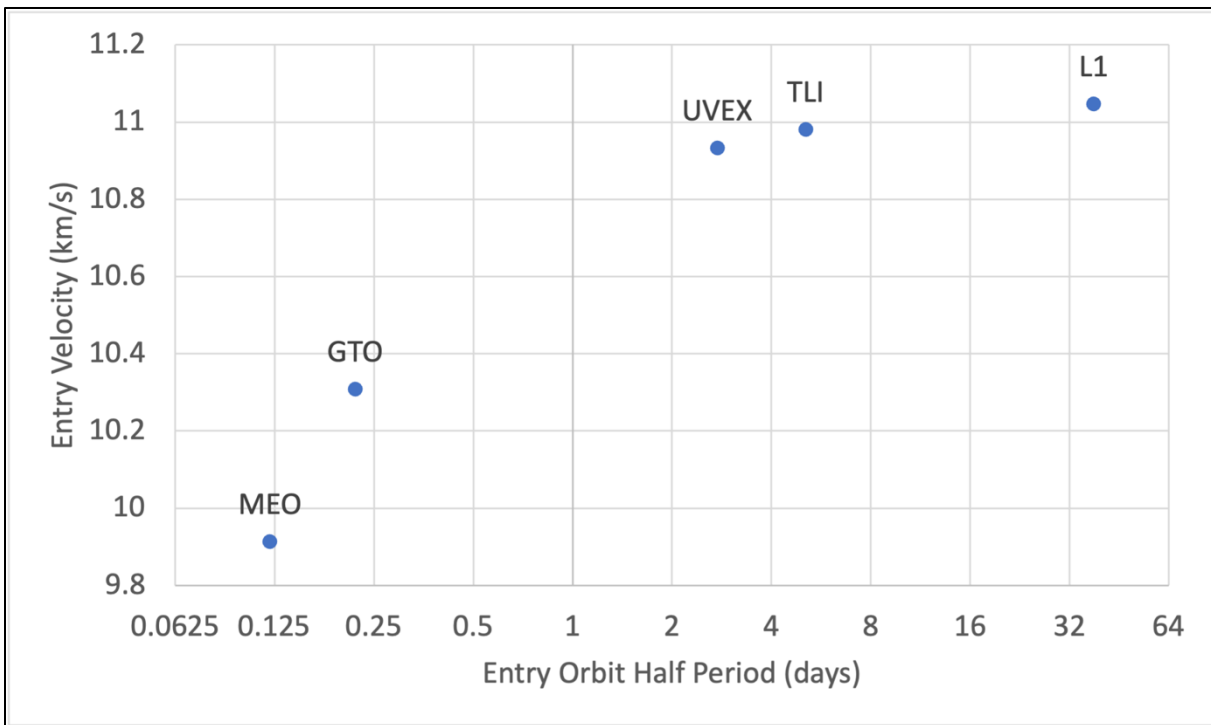
Aerocapture Mission Developmental Areas

National Aeronautics
and Space Administration



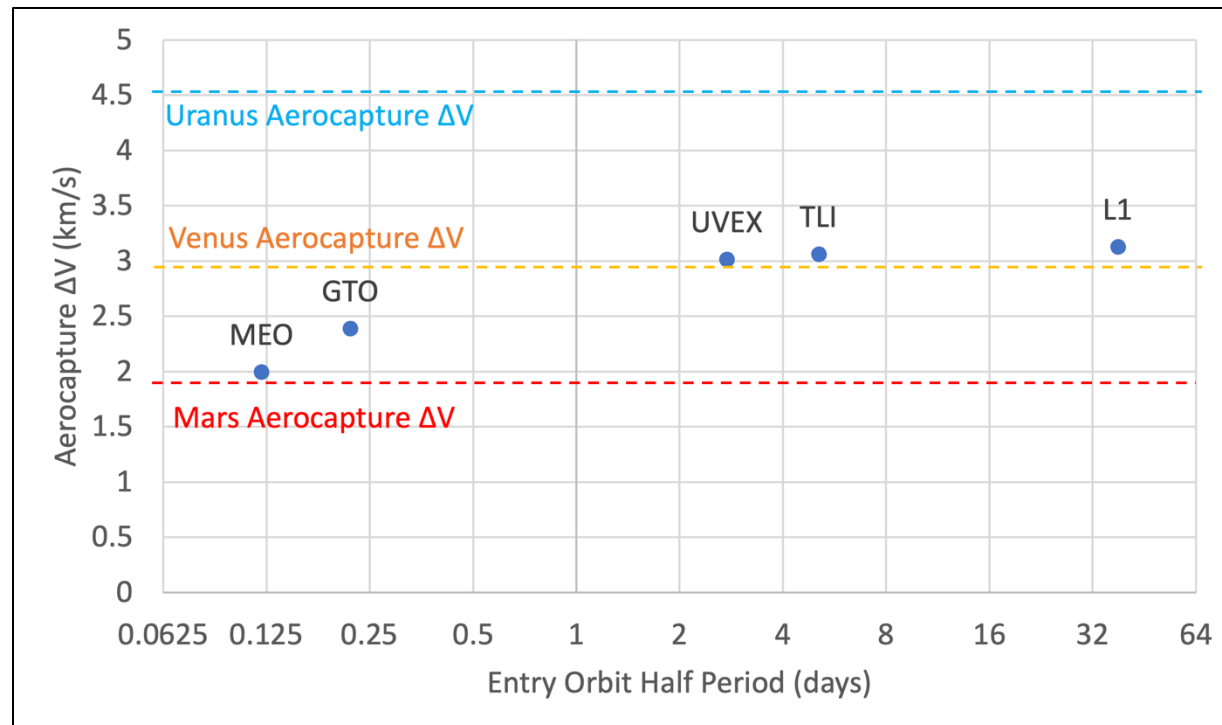
Requirements for planetary missions	Earth-based demonstration behavior
Hypersonic guidance for target orbit	Demonstrable. Aerocapture guidance similar to guidance already demonstrated at Mars and Earth
Thermal Protection System (TPS)	Demonstrable. TPS materials for planetary aerocapture missions, like PICA and C-PICA, already been demonstrated on Mars and Earth
Autonomous periapsis raise maneuver	Demonstrable. Can be demonstrated in an Earth-based test without constraints
Control systems demonstration	Demonstrable. Control systems, e.g. reaction control systems (RCS), can be demonstrated on Earth test
Aeroshell separation after aerocapture	Demonstrable. Can be demonstrated in an Earth-based test without constraints
Targeting tight entry corridor	Limited demonstration. Tight entry flight path corridors needed for planetary missions; achieved using optical navigation (opNAV) and autonomous navigation (AutoNAV) campaigns over multiple weeks. A short time duration Earth-based aerocapture demonstration does not have the time span
Packaging payload in aeroshell	Not demonstrable. Planetary aerocapture missions may need tight fitting of planetary payloads enclosed within aeroshell; small satellite chassis-based demonstration cannot show that

Earth Demonstration Options



MEO = Mid-Earth Orbit
GTO = Geostationary Transfer Orbit
UVEX = Ultraviolet Explorer (science orbiter)

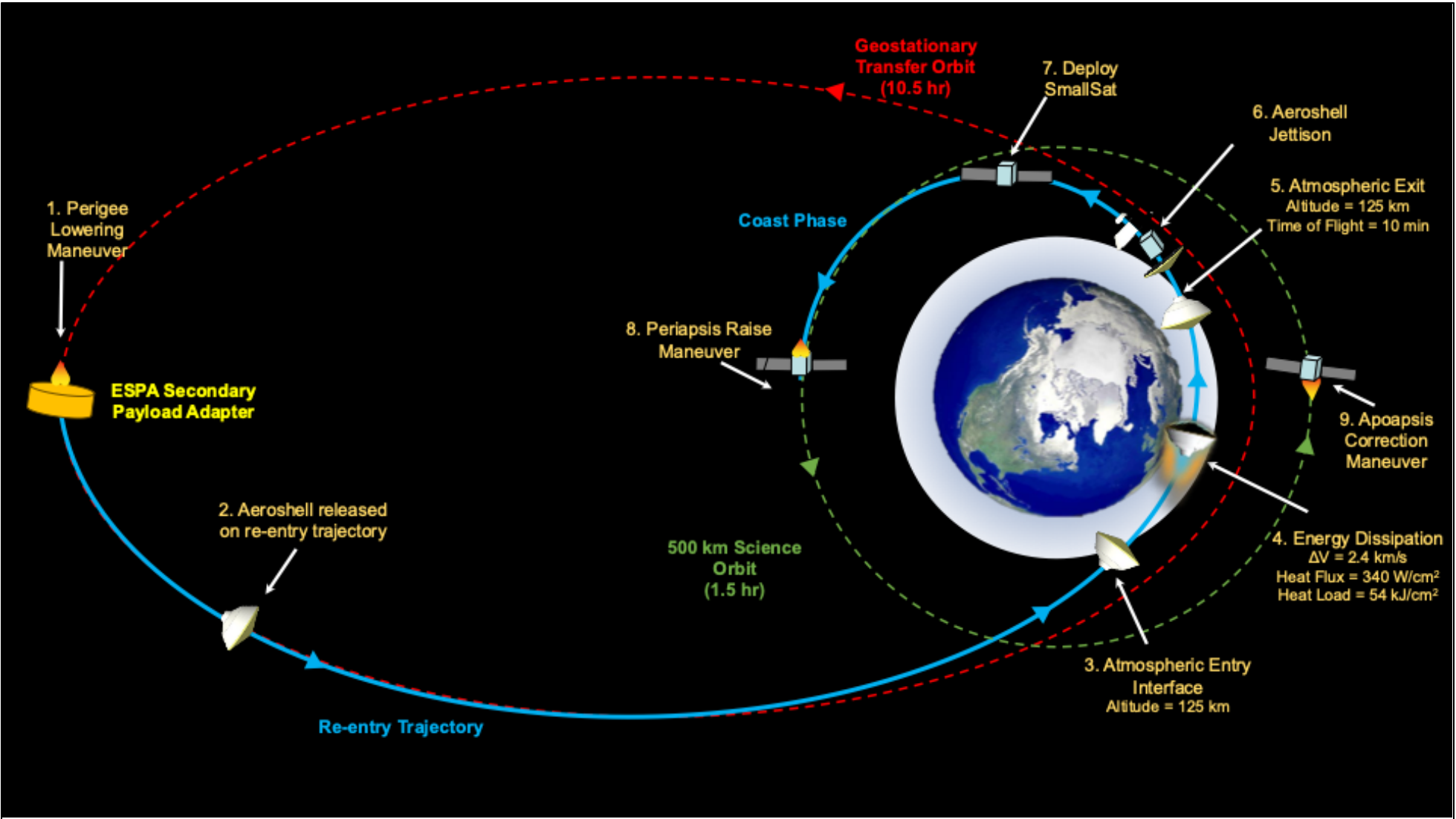
TLI = Trans-Lunar Injection
L1 = Lagrange Point-1

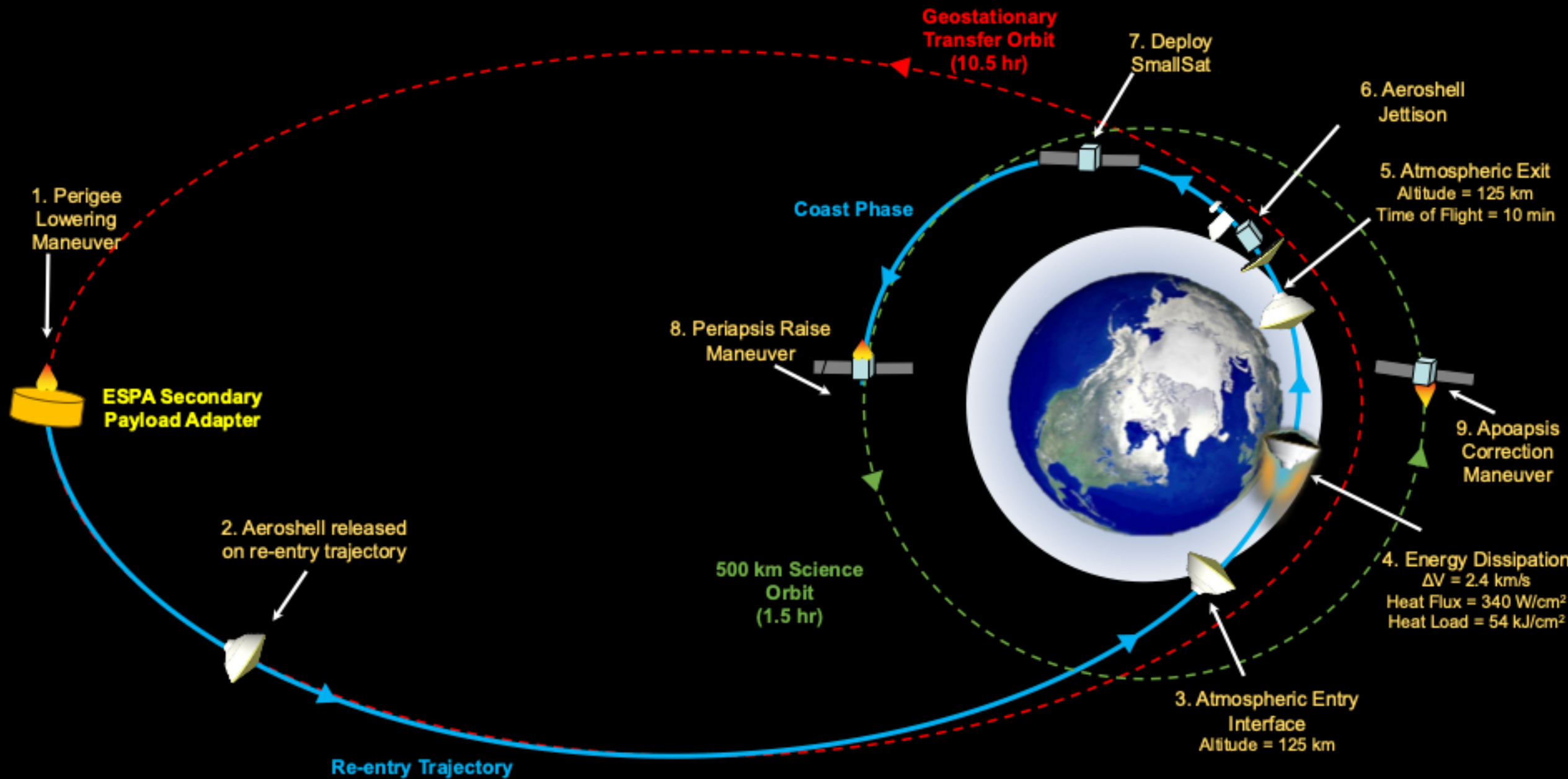


ΔV = change in velocity

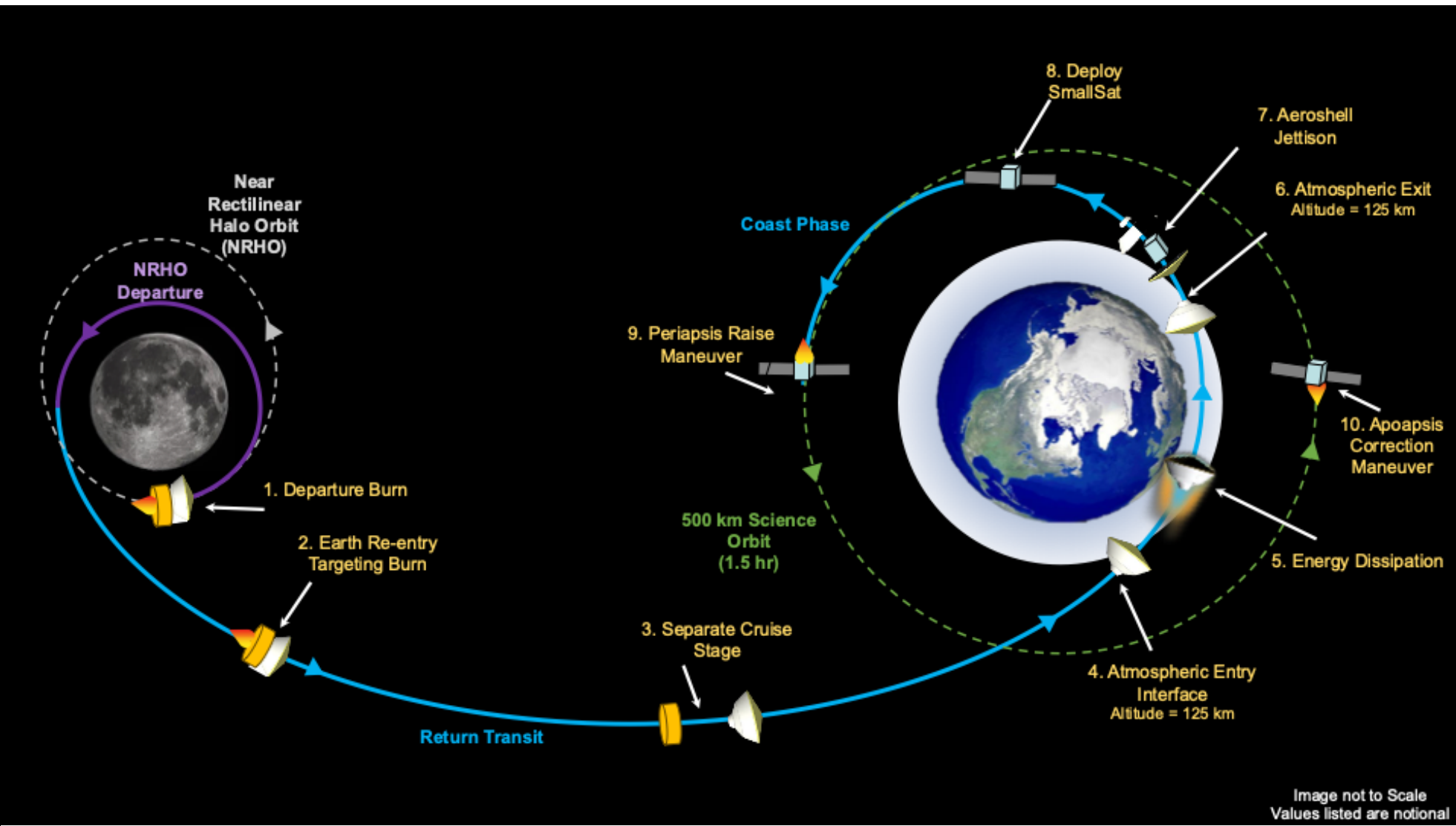
- Several Earth orbital scenarios provide means to do aerocapture demonstration that are relevant for planetary destinations
- Focus on two scenarios that broadly cover range: GTO and TLI (lunar return)

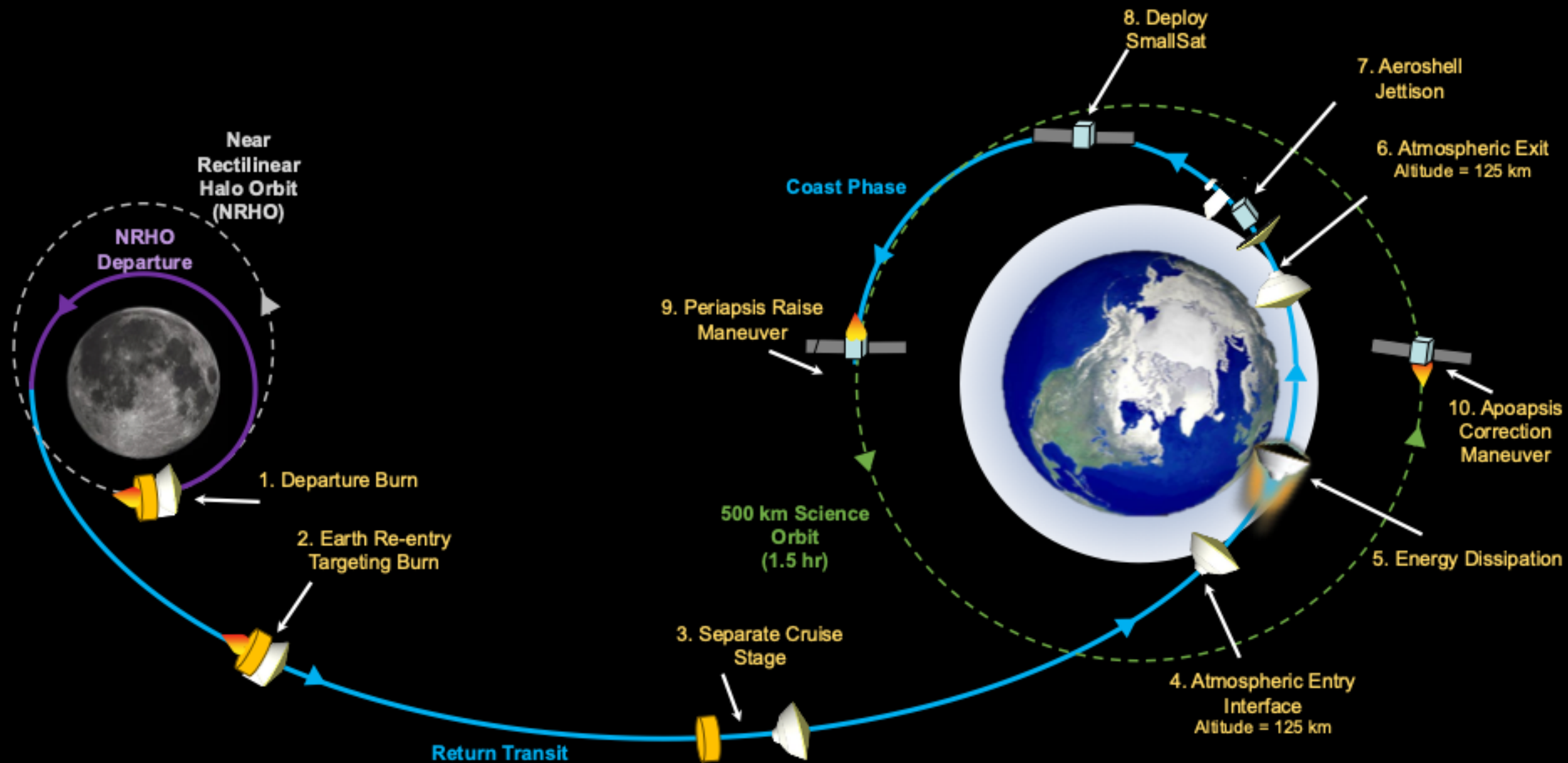
Option A: Geostationary Transfer Orbit





Option B: Lunar Return







Aerocapture Demonstration Vehicle Design

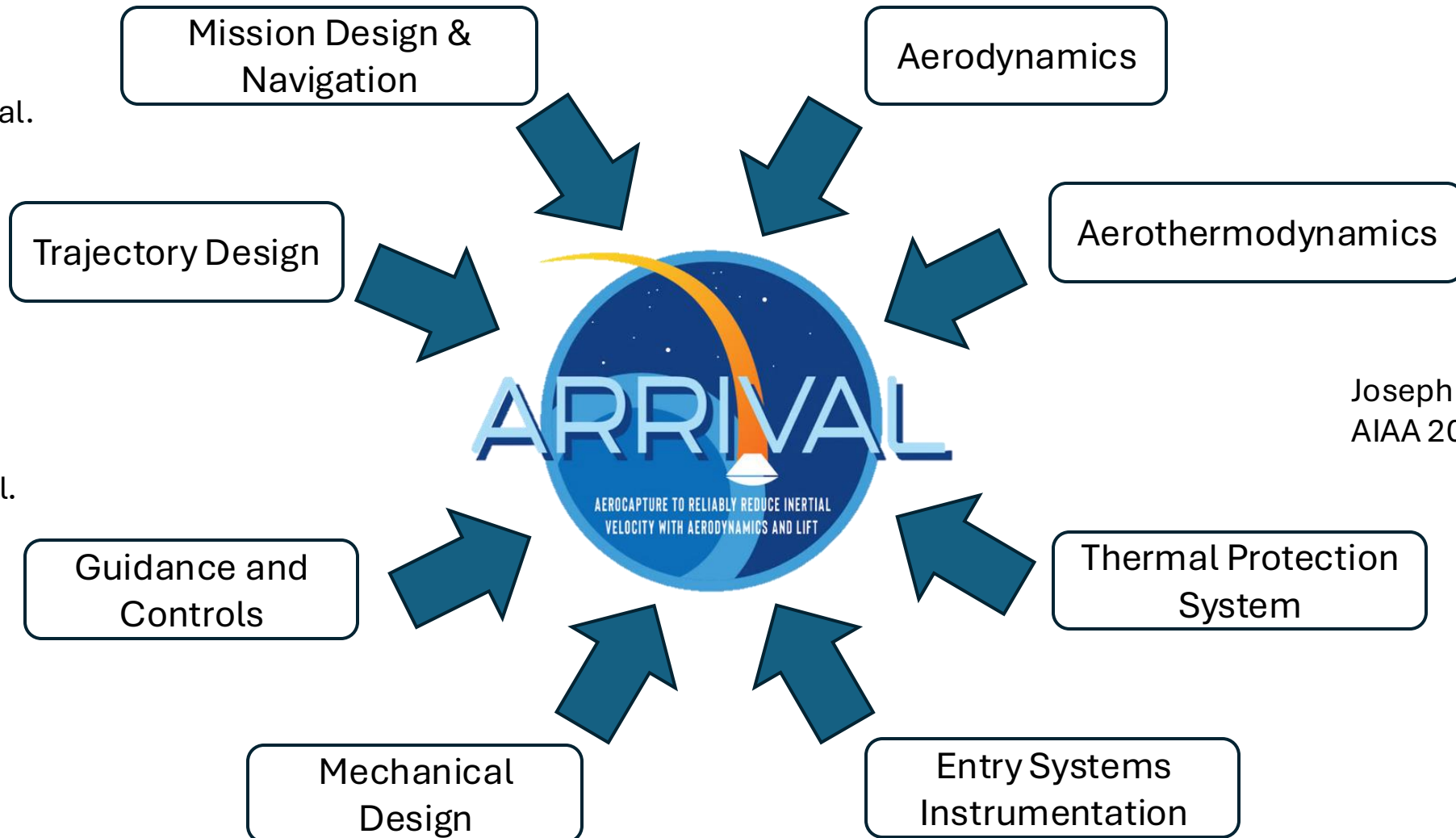
National Aeronautics
and Space Administration

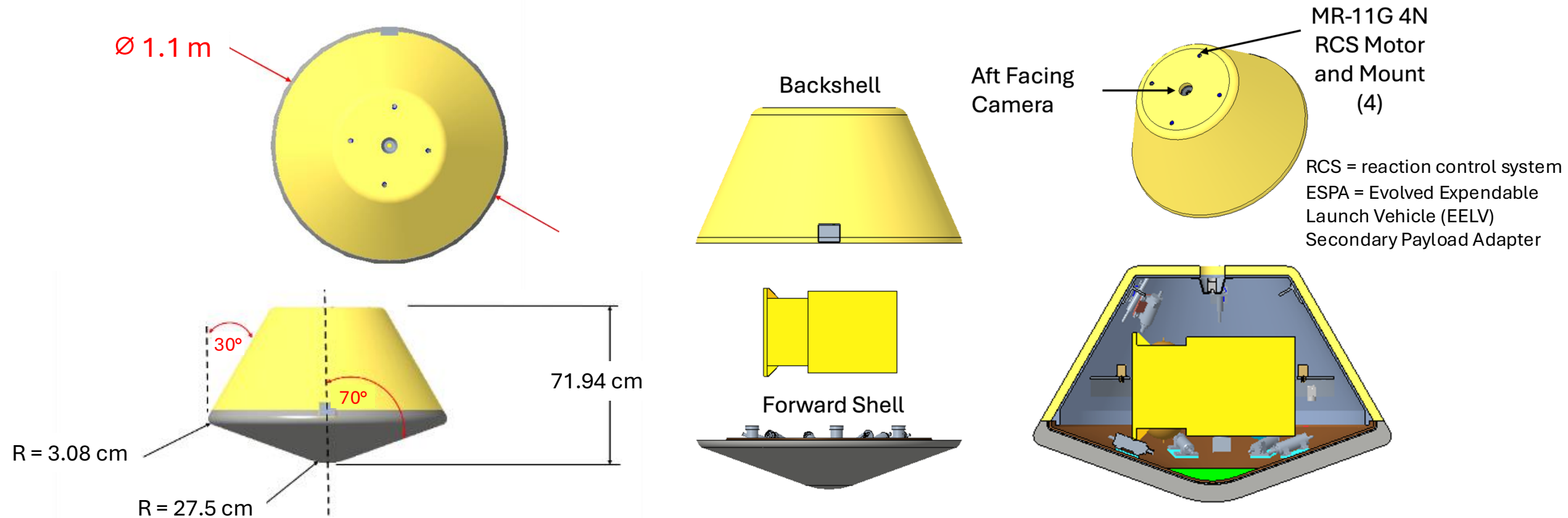


Evan Roelke et al.
AIAA 2026-xxxx

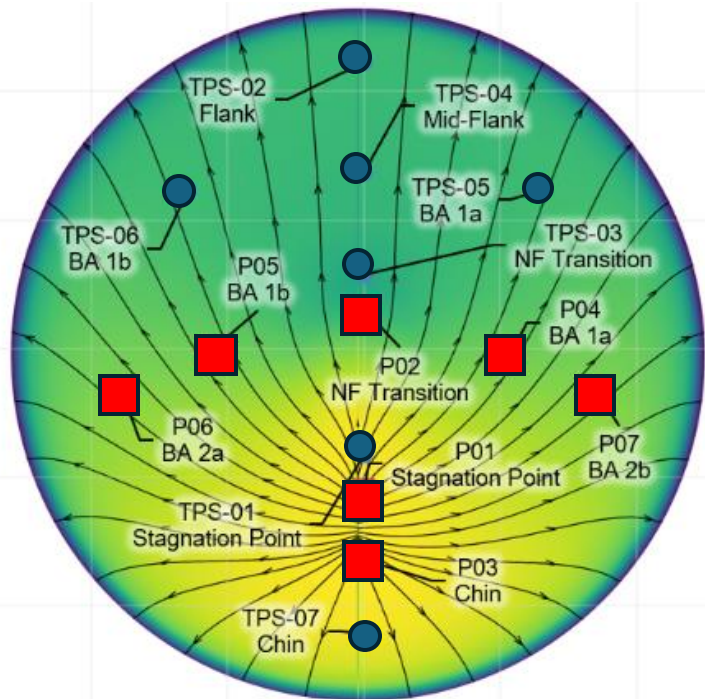
Julia Briden et al.
AIAA 2026-xxxx

Joseph Williams et al.
AIAA 2026-xxxx

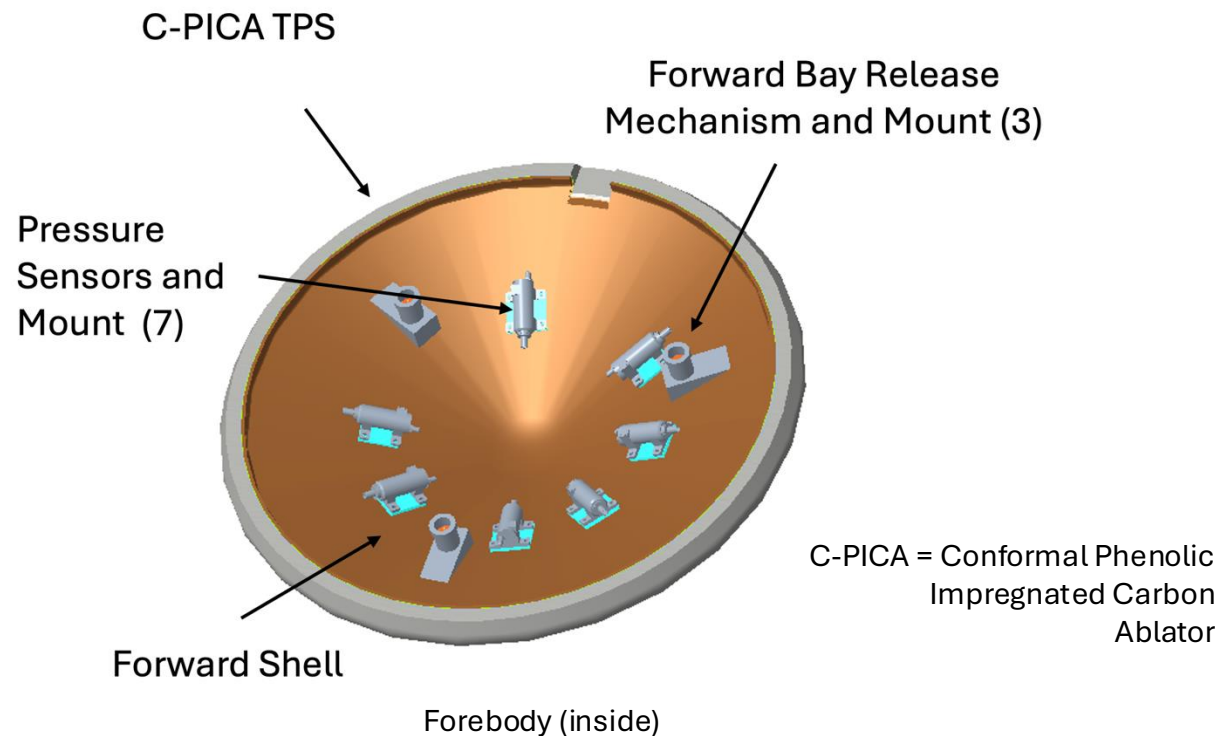




- Small satellite (NASA CAPSTONE) nestled within ~1 m diameter aeroshell
- Using 70 deg. sphere-cone, heritage blunt-body concept; flying with lift-over-drag ratio of 0.25
- Aeroshell designed to fit common secondary payload adapters (SpaceX Falcon, ESPA Grande)



Forebody Thermocouple (TPS) and Pressure Transducer (P) Locations



- Instrumentation are critical to measure aerocapture demonstration performance
- Inertial measurement unit (IMU): Capture sensed acceleration and rates during the atmospheric pass
- Pressure Transducers: Measure aerodynamics quantities of interest
- Thermocouples: Quantify aerothermodynamics and TPS material response
- Cameras: Acquire contextual video during atmospheric pass



Summary

National Aeronautics
and Space Administration



- Aerocapture is an orbital insertion maneuver that uses atmospheric forces
- Maneuver is still undemonstrated; aerocapture demonstration could reduce risk
- Several Earth demonstration opportunities span area of applicability for planetary applications; two specific concepts of operations chosen for considered
- Demonstration design uses heritage, 70-deg. sphere-cone blunt-body and fits common secondary payload adapters
- Full suite of entry systems instrumentation, including IMU, pressure transducer, thermocouples, and video, provide measurement to quantify the aerocapture maneuver
- Three additional papers on Monday (Jan. 12th) sessions of the GNC/AFM-sponsored EDL GNC special sessions will explore the design of the aerocapture system more in-depth



Questions

National Aeronautics
and Space Administration





Backup Slides