

Aeroassist Technologies for Small Satellite Missions



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Outline

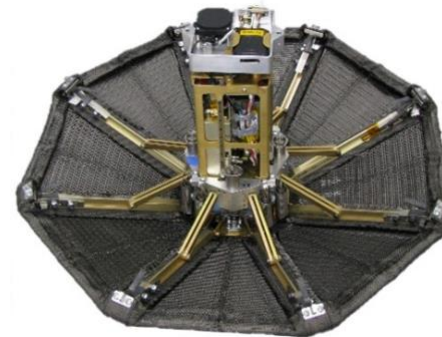
- Aeroassist Overview
- Small Sat Class Entry Vehicle Technologies
 - Rigid Aeroshells
 - Deployable Entry Vehicles
 - New Entry System Technologies
- Summary



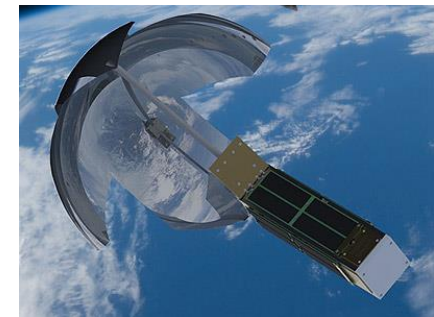
Rigid Aeroshells- HEEET



Inflatable DEVs- HIAD



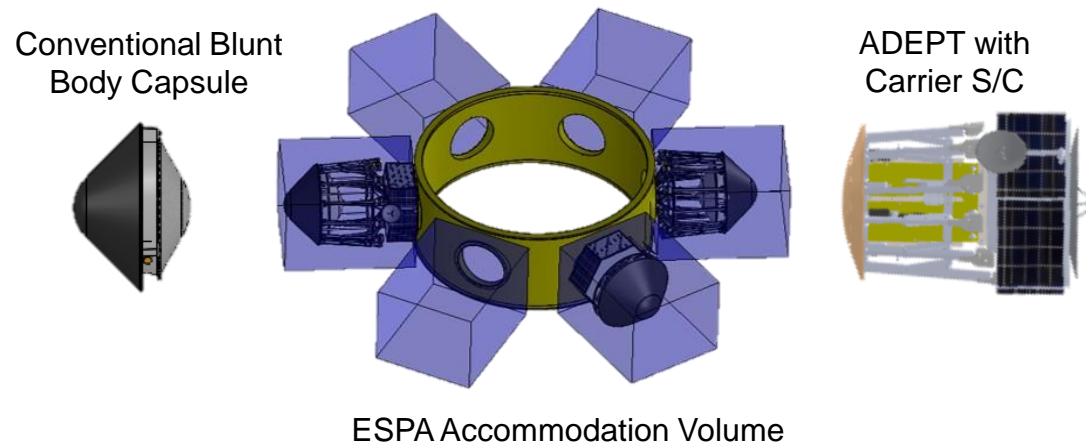
Mechanical DEVs-ADEPT



Drag Devices-
ExoBrake

Aeroassist Overview

- **Aeroassist** refers to the use of an **atmosphere to accomplish a transportation system function** using techniques such as **aerobraking, aerocapture, aeroentry, and aerogravity assist**.
- **Aeroentry and Aerocapture offer an alternative approach for large ΔV maneuvers** and could revolutionize the use of SmallSats for exploration missions and increase the science return while reducing costs for orbital or entry missions to Mars, Venus and return to Earth.
- **Aeroassist technologies are power efficient and tolerant to the radiation and thermal environment** encountered in deep space, can be integrated around or within SmallSat geometries, and can be packaged in secondary payload accommodation volumes.

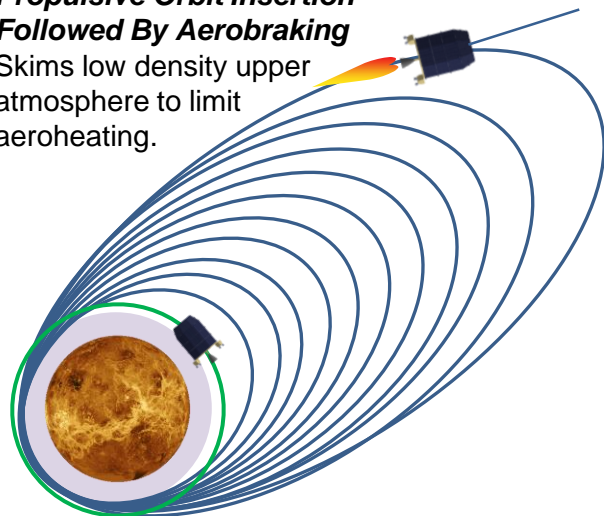


Aeroassist Overview

Aerobraking

Propulsive Orbit Insertion Followed By Aerobraking

Skims low density upper atmosphere to limit aeroheating.

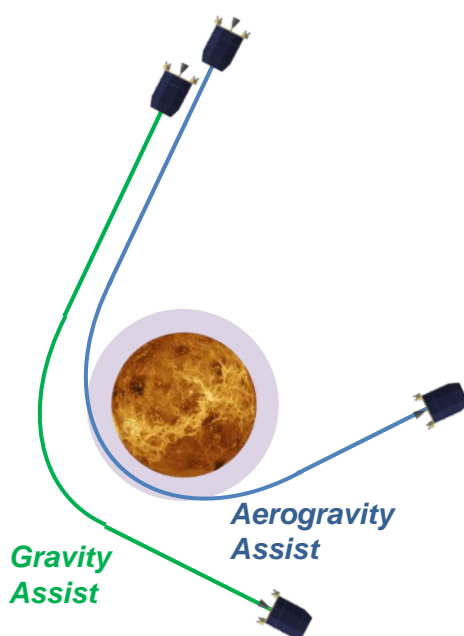


Final Orbit

Achieved after many skims through atmosphere along with circularization.

- Substantial Propulsion Required
- Does Not Need High Performance Entry System Technologies
- Example- Mars Orbiters

Aerogravity



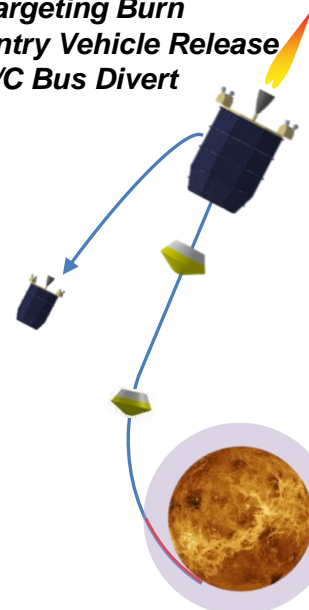
Gravity Assist

Aerogravity Assist

- Aerogravity Assist requires entry system technologies
- Can reduce required launch energy and propulsion requirements
- Aerogravity assist has not been demonstrated

Aeroentry

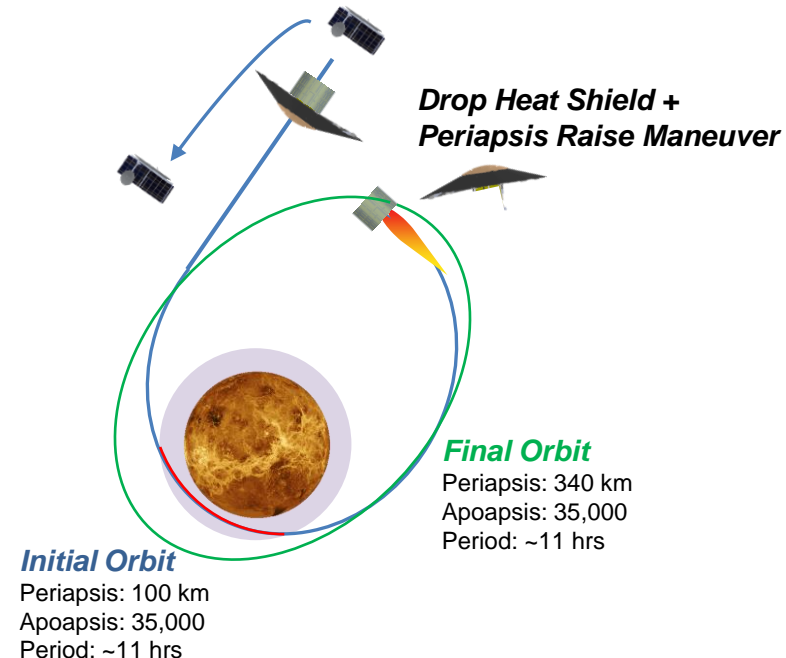
- Targeting Burn
- Entry Vehicle Release
- S/C Bus Divert



Delivery of lander or in-situ aerial platform

- Entry can be ballistic or guided depending upon the mission requirements
- All landers and aerial platforms require high performance entry systems

Aerocapture



Initial Orbit

Periapsis: 100 km
Apoapsis: 35,000
Period: ~11 hrs

Drop Heat Shield + Periapsis Raise Maneuver

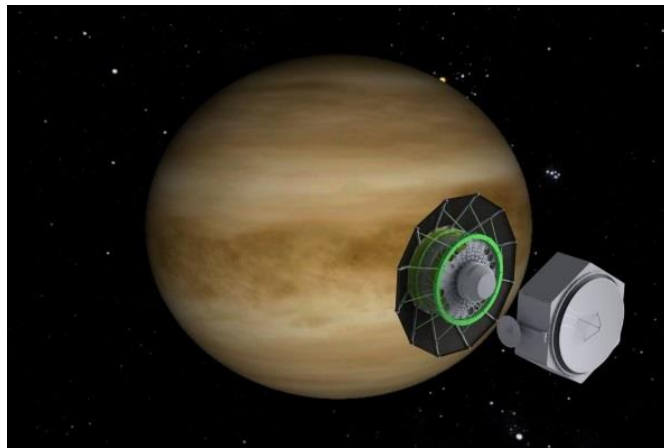
Final Orbit

Periapsis: 340 km
Apoapsis: 35,000
Period: ~11 hrs

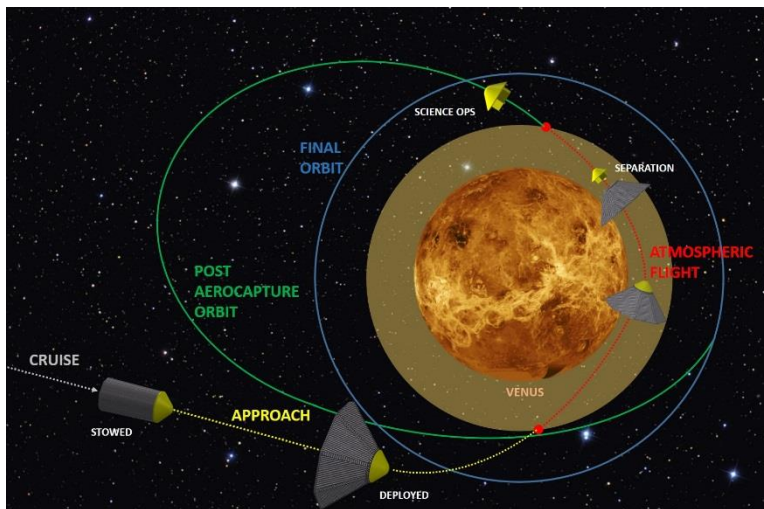
- Aerocapture saves substantial propellant for orbit insertion
- Entry system can utilize lifting entry vehicle or drag-modulated vehicle for orbit insertion.
- Human Mars landers are baselining aerocapture followed by entry.

Mission Concepts with Aerocapture & Entry Segments

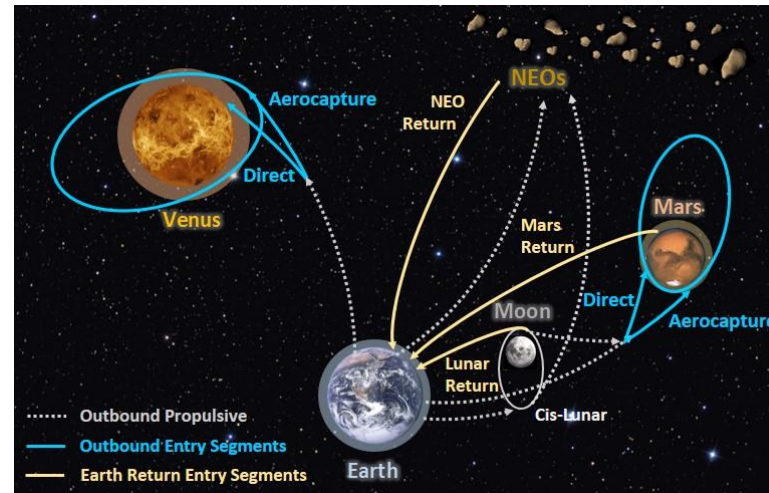
Venus AeroEntry



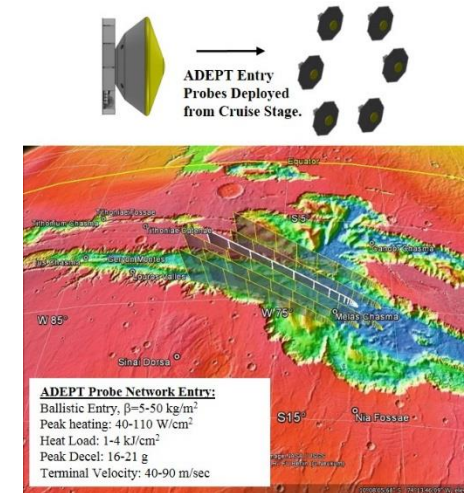
Venus Aerocapture



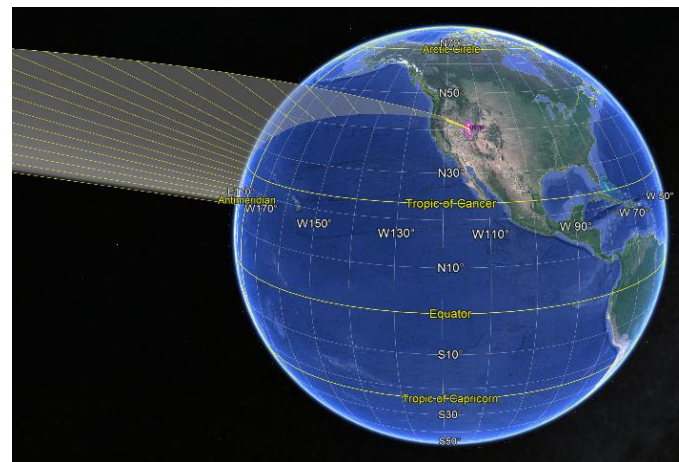
Inner Planet Aeroassist Options



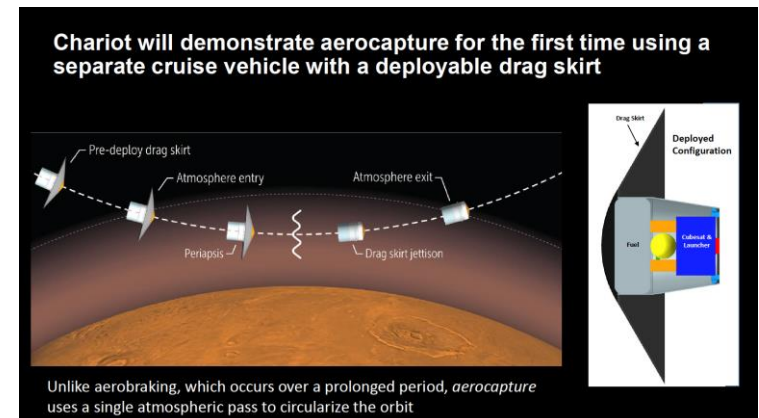
Mars Aeroentry network probe mission



Sample Return Missions

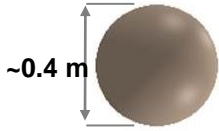
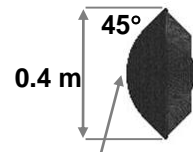
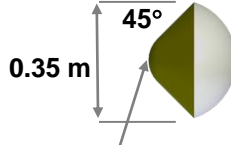
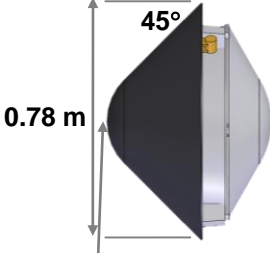
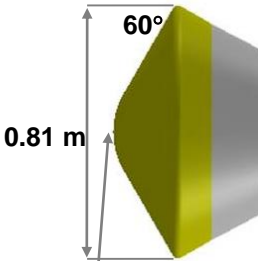


Mars Aerocapture for SmallSat Constellations

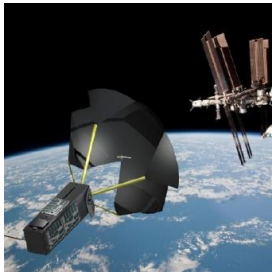
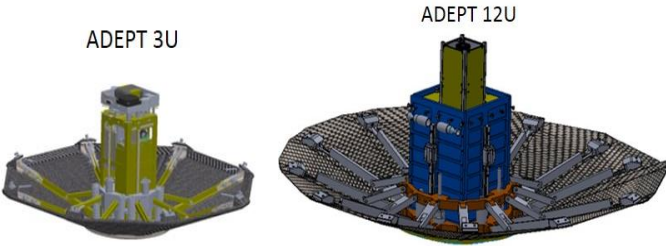


Small Sat Class

Rigid Aeroshell Entry Vehicles

| | EARTH | EARTH | MARS | VENUS | EARTH |
|--|---|---|--|--|--|
| ENTRY PROBES |  <p>~0.4 m</p> |  <p>45° 0.4 m R=0.2 m</p> |  <p>45° 0.35 m R=0.09 m</p> |  <p>45° 0.78 m R=0.19 m</p> |  <p>60° 0.81 m R=0.22 m</p> |
| | LUNA 16 LUNA 20 LUNA 24 | HAYABUSA HAYABUSA-2 (2020 Return) | Deep Space 2 | Pioneer Venus Small Probe | STARDUST OSIRIS-REX (2023 Return) |
| HEATSHIELD MATERIAL | ? | CARBON PHENOLIC | SIRCA | CARBON PHENOLIC* | PICA |
| ENTRY MASS | ? | 16.2 kg | 3.7 kg | 91 kg | 43 kg |
| BALLISTIC COEFFICIENT | ? | 27 kg/m ² | 36 kg/m ² | 190 kg/m ² | 60 kg/m ² |
| ENTRY VELOCITY_{inertial} | ~11 km/s | 12.0 km/s | 6.9 km/s | 11.5 km/s | 12.8 km/s |
| EFPA | ? | -12 deg | -13.5 deg | - 68 deg | - 8 deg |
| EDL | BALLISTIC PARACHUTE SURFACE RECOVERY | BALLISTIC PARACHUTE SURFACE RECOVERY | BALLISTIC SURFACE IMPACT | BALLISTIC NO PARACHUTE | BALLISTIC PARACHUTE SURFACE RECOVERY |
| PAYLOAD VOLUME | ~2U | ~1U | ~1U | ~12U | ~12U |

Small Sat Class Deployable Entry Vehicles

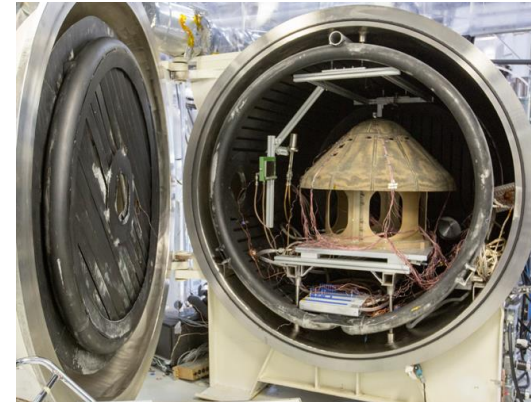
| | TechEdSat | Deorbit and Recovery System | HIAD w/in 6U | JAXA-EGG | ADEPT CubeSat Class |
|-----------------------|--|--|---|--|--|
| |  <p>M. Murbach, SmallSat 2016</p> |  <p>J. Andrews, SmallSat 2011</p> |  <p>S. Hughes, et al, IPPW 2016</p> |  <p>Diameter : 80cm</p> |  <p>ADEPT 3U ADEPT 12U</p> |
| CubeSat Configuration | 3.5U | 3U | 6U | 3U | 3U+ (could package around dispensers) |
| Entry System Volume | 1.5U ExoBrake de-orbit system | 1U | 3U | 1U | Integrates around CubeSat or CubeSat Dispenser |
| TPS Material | N/A | Ablative Coating on Flexible Fabric | Woven SiC on C-Felt | Woven Ceramics? | High Temperature Capable 3D Woven Carbon Fabric |
| Flex TPS Temp Limit | N/A | ? | ~1600 °C | ? | Test Capability Demonstrated to 2100 °C |
| Flight Heritage | TechEdSat 1-8 | N/A | N/A | Sub-Orbital Demonstration | ADEPT 3U Sub-Orbital Demo September 2018 |
| Comments | <ul style="list-style-type: none"> Does not survive entry SPQR concept in development | <ul style="list-style-type: none"> Designed for LEO entries 3 U EDU Developed | <ul style="list-style-type: none"> Concept Design Based on HIAD & IRVE heritage | <ul style="list-style-type: none"> Low Ballistic Coefficient < 5 kg/m² More details needed to determine feasibility for high speed entries | <ul style="list-style-type: none"> Capable of high speed entries (~11 km/s) Technology also useful for Aerocapture |

Heatshield for Extreme Entry Environments Technology (HEEET)

- Leverages **advanced 3-D weaving** and **resin infusion**.
- A dual layer system - **robust and mass efficient** across a range of **extreme entry environments**.
- TRL 6 and ready for mission infusion.
- Development includes:
 - Requirements and verification
 - Testing – Aerothermal and Thermo-structural
 - Manufacturing specifications from raw materials to weaving, tile fabrication (forming/resin infusion) and integration
 - Technology transfer to industry (BRM and FMI)
 - Heatshield (1m dia.) Prototype designed, built and tested
 - Material Thermal Response Model and Margins Policy
 - Validated thermo-structural tools to support design
 - Design Data Book

NASA ARC POC- Don Ellerby

Prototype in Thermal Vac Chamber



3d Weaving of Pre-form



Woven Pre-form



Arc Jet Tested Specimen

IHF 3" Stag Model
3600 W/cm²; 5.3 atm

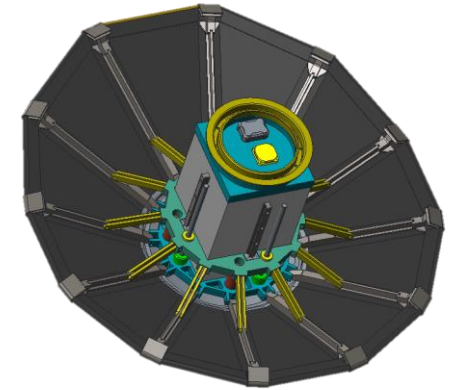


Pterodactyl- Guidance & Control System Integration onto Deployable Entry Vehicles

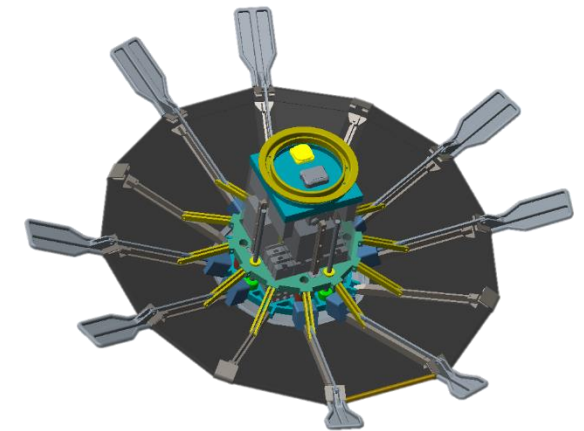
- Utilizes **ADEPT 1 m Class** design for development.
- Leverages the ability to **mount control system** hardware on **deployed structural elements**.
- Project is assessing 3 control system approaches for challenging Lunar Sample Return Design Reference Mission.
- Developing Analysis Framework to Explore Design Feasibility & Entry Environments
- Development includes:
 - Aerodynamics & Aerothermodynamics Analysis
 - 3-DOF & 6-DOF Trajectory Analysis
 - Guidance & Control Algorithm Development
 - Control System Integration onto Technology Demonstrator
 - Ground Testing of Technology Demonstrator
 - Control System Software Testing on 6-DOF Simulation Testbed

NASA ARC POC- Sarah D'Souza

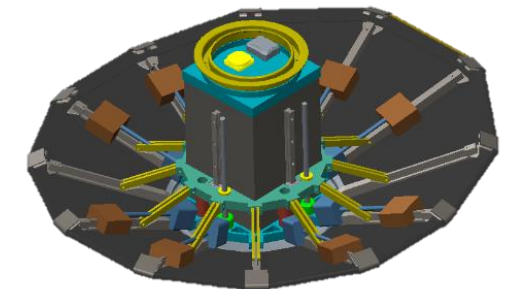
REACTION
CONTROL
THRUSTERS



CONTROL
SURFACES



MASS
MOVEMENT



Summary

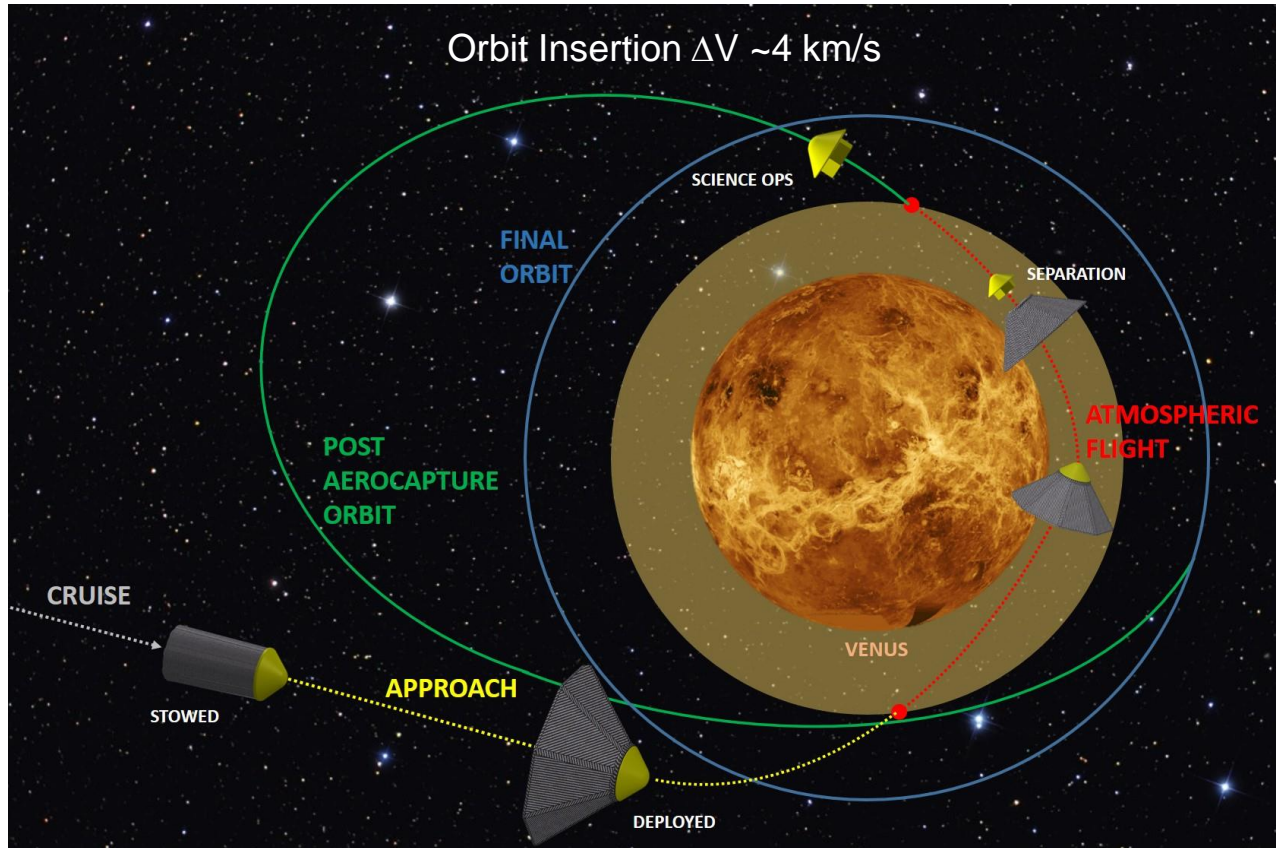
- Aerocapture and Aeroentry are mission enablers for Small Satellite missions.
- Aerocapture and Aeroentry mission segments show promise for Small Satellite mission concepts:
 - PSDS3 Mission Concept Study Awards FY18 (3 of 9 Mars & Venus concepts utilized Aeroassist)
- NASA ARC and JPL are exploring Drag Modulated Aerocapture mission concepts to advance capabilities for exploration and science objectives.
- Cis-Lunar Sample Return is another promising mission class for the Small Satellite community.
- New technologies are being developed to enable Small Satellite missions.
 - HEEET
 - ADEPT & Pterodactyl
 - HIAD
 - Drag Assist Devices
- We encourage the Small Satellite community to contact us for concept studies and partnering to help further innovate Small Satellite technology.

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Back-Up Charts

Drag Modulated Aerocapture at Venus



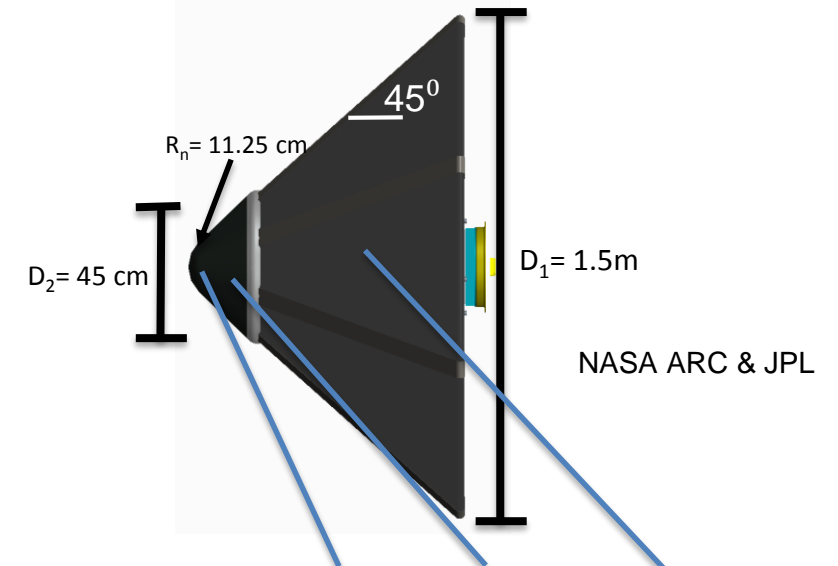
Trajectory Assumptions

- Pre-jettison Mass = 72 kg
- Post-jettison Mass = 34.7 kg, P-V aero database
- Basic mission, conditions at 150 km
 - $V = 11$ km/s, EFPA = -5.5°
- Jettison at time to reach 2000km apoapsis

Entry System Thermal Protection System Sizing

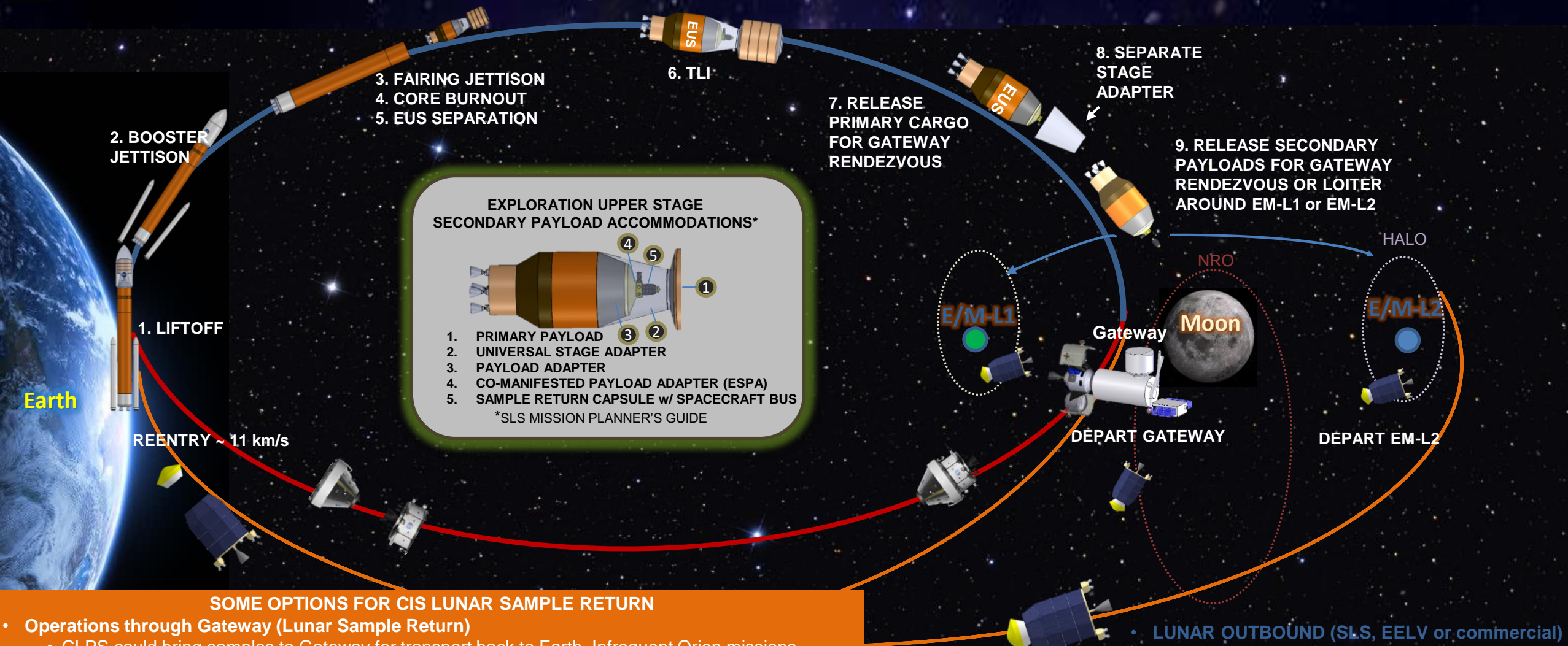
Determine environments and assign materials

- C-PICA chosen for rigid aeroshell
- Carbon Fabric for deployable aeroshell



| | Nose | Flank (est) | Skirt (est) |
|------------------------------------|-------|-------------|-------------|
| Peak Heatflux (W/cm ²) | 383.3 | 191.65 | 191.65 |
| Peak Heatload (J/cm ²) | 45179 | 22590 | 3840 |
| Peak Pressure (Pa) | 8800 | 4400 | 3650 |
| C-PICA thickness (cm) | 2.58 | 1.88 | 0.72 |
| PICA thickness (cm) | 4.125 | 3.51 | 1.11 |
| C-PICA mass (kg) | 0.13 | 0.80 | 4.56 |
| PICA mass (kg) | 0.20 | 1.45 | 6.83 |

Cis-Lunar Sample Return



- SOME OPTIONS FOR CIS LUNAR SAMPLE RETURN**
- **Operations through Gateway (Lunar Sample Return)**
 - CLPS could bring samples to Gateway for transport back to Earth. Infrequent Orion missions combined with tasking priorities suggests we should consider augmenting with a robotic sample return capability
 - **Free-flyer for Deep Space Investigations (e.g.-Bio Sample Return)**
 - **Lunar Surface Robotic Return (e.g.- Moonrise)**

- **LUNAR OUTBOUND (SLS, EELV or commercial)**
- **ORION RETURN (100s kg), ~once per 18 months**
- **SAMPLE RETURN (10s kg)**
- **LOP-G ORBIT**
- **EM-L1 ORBIT**
- **EM-L2 HALO ORBIT**