Interplanetary Small Satellite Conference
beyond LEO

Aeroassist Technologies for Small Satellite Missions

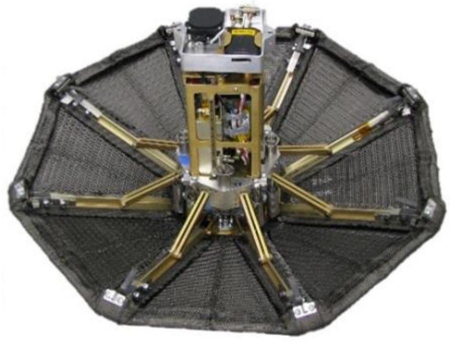
Alan Cassell[1], Alicia Dwyer Cianciolo[2]
[1]Entry Systems and Vehicle Development Branch
NASA Ames Research Center
Moffett Field, CA 94035
[2]Atmospheric Flight and Entry Systems Branch
NASA Langley Research Center
Hampton, VA 23681

Outline

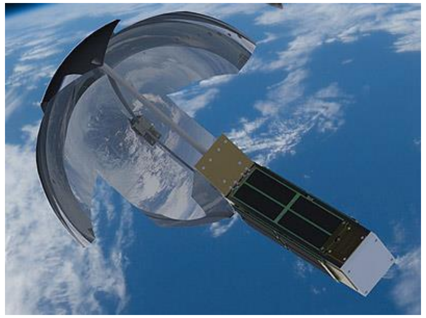
- Aeroassist Overview
- Small Sat Class Entry Vehicle Technologies
  - Rigid Aeroshells
  - Deployable Entry Vehicles
  - New Entry System Technologies
- Summary

Rigid Aeroshells- HEEET

Inflatable DEVs- HIAD



Mechanical DEVs-ADEPT



Drag Devices- ExoBrake

Interplanetary Small Satellite Conference
beyond LEO

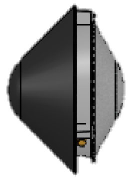
Aeroassist Overview

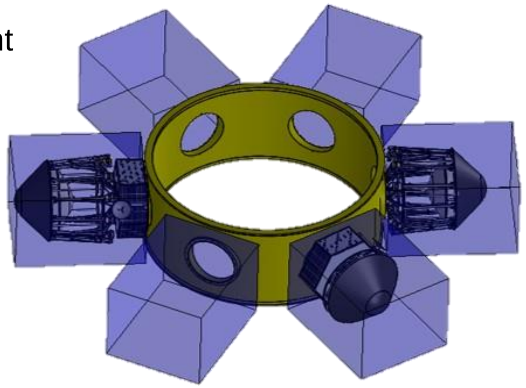
- **Aeroassist** refers to the use of an **atmosphere to accomplish a transportation system function** using techniques such as **aerobraking, aerocapture, aeroentry,** and **aerogravity** assist.

- **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.

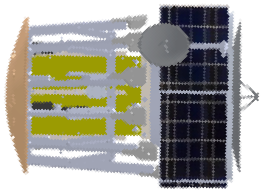
Conventional Blunt Body Capsule





ESPA Accommodation Volume

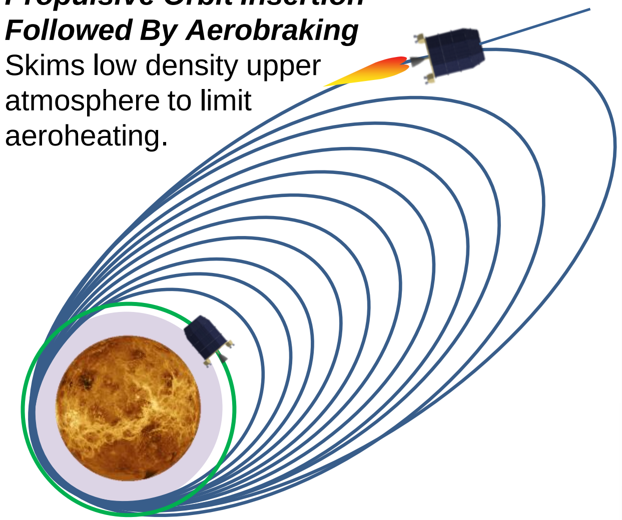
ADEPT with Carrier S/C



Interplanetary Small Satellite Conference
beyond LEO

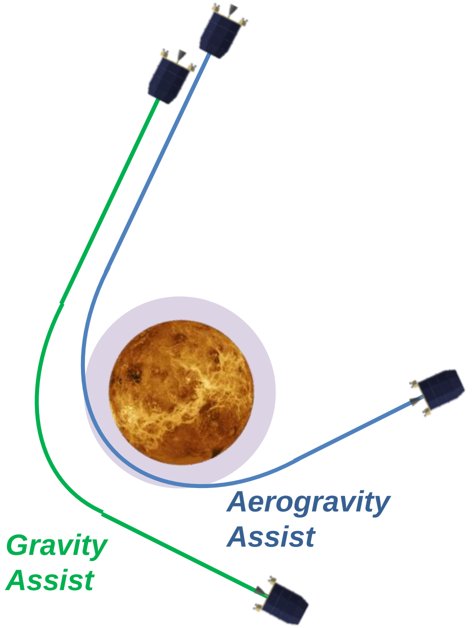
Aeroassist Overview

Aerobraking



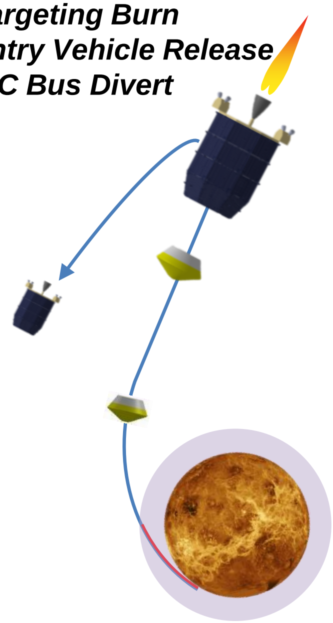
- **Substantial Propulsion Required**
- **Does Not Need High Performance Entry System Technologies**
- **Example- Mars Orbiters**

Aerogravity



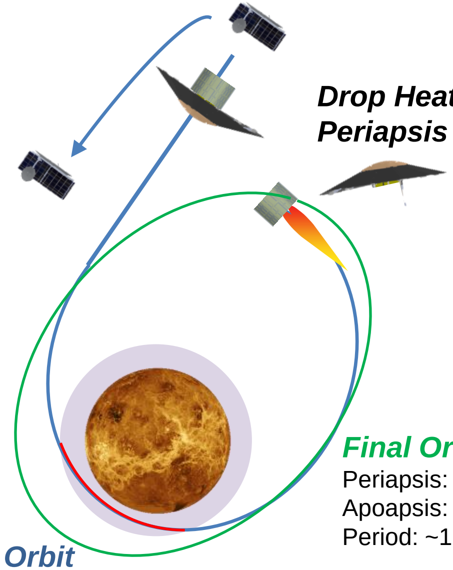
- **Aerogravity Assist requires entry system technologies**
- **Can reduce required launch energy and propulsion requirements**
- **Aerogravity assist has not been demonstrated**

Aeroentry



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

Aerocapture

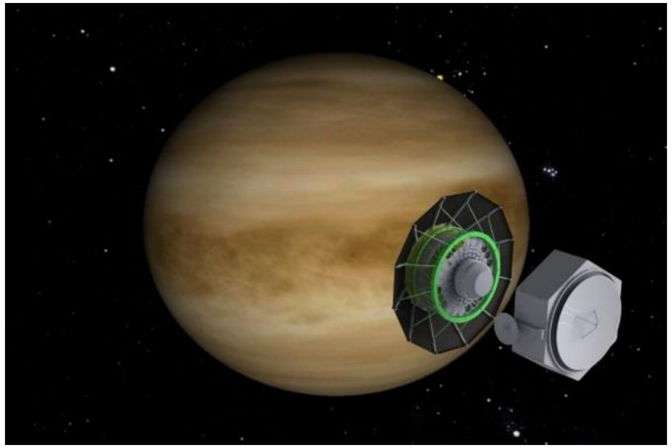


- **Aerocapture saves substantial propellant for orbit insertion**
- **Entry system can utilize lifting entry vehicle or drag-modulated vehicle for orbit insertion.**
- **Human Mars landers are baselining aerocapture followed by entry.**

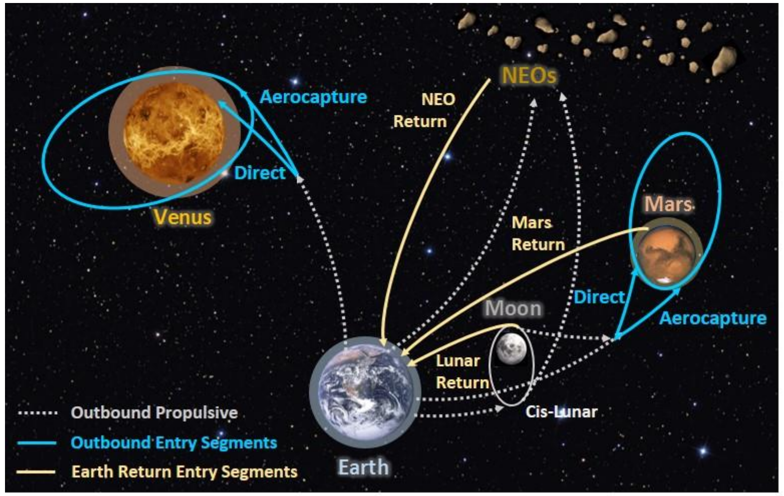
Interplanetary Small Satellite Conference
beyond LEO

Mission Concepts with Aerocapture & Entry Segments

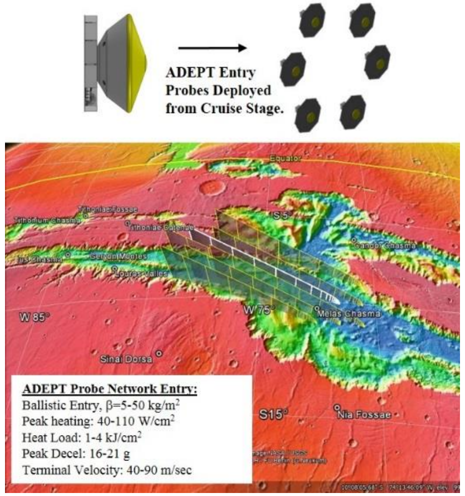
Venus AeroEntry



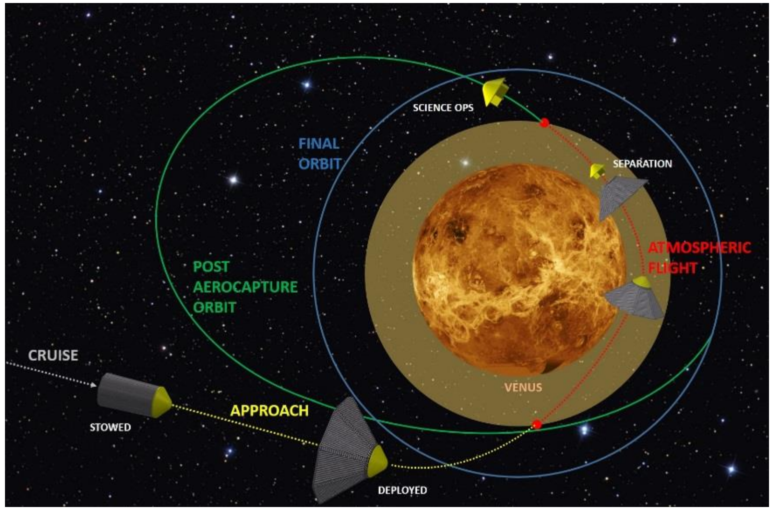
Inner Planet Aeroassist Options



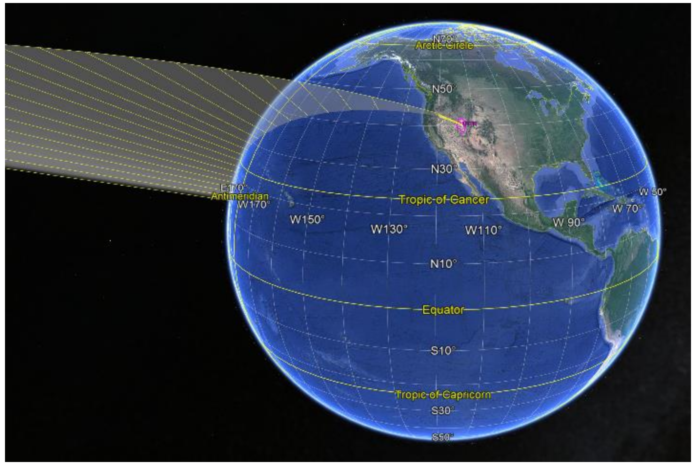
Mars Aeroentry network probe mission



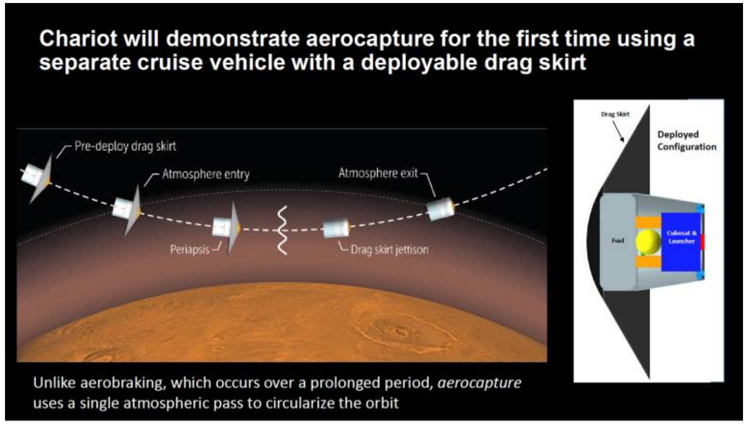
Venus Aerocapture



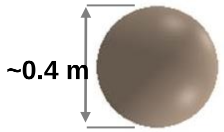
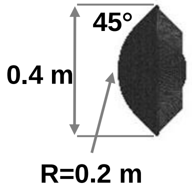
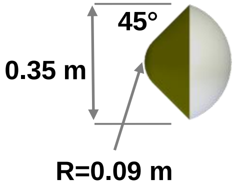
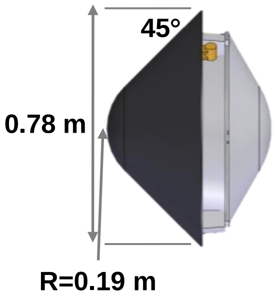
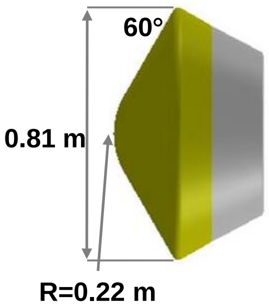
Sample Return Missions



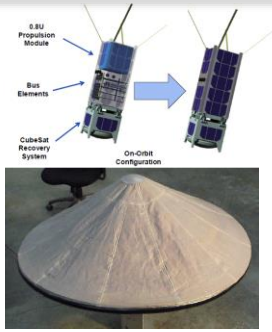
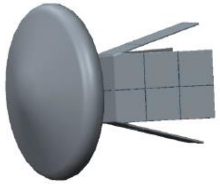
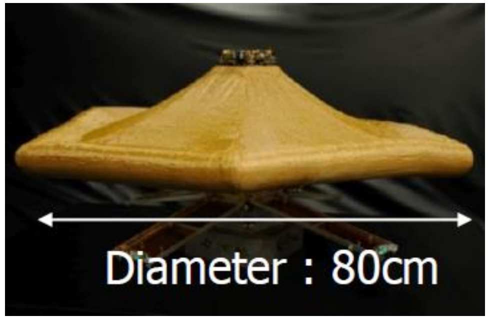
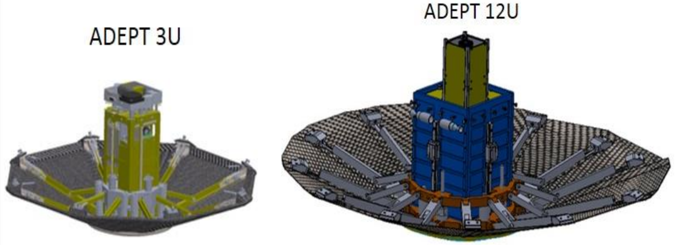
Mars Aerocapture for SmallSat Constellations



Small Sat Class
Rigid Aeroshell Entry Vehicles

ENTRY PROBES	EARTH  LUNA 16 LUNA 20 LUNA 24	EARTH  HAYABUSA HAYABUSA-2 (2020 Return)	MARS  Deep Space 2	VENUS  Pioneer Venus Small Probe	EARTH  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

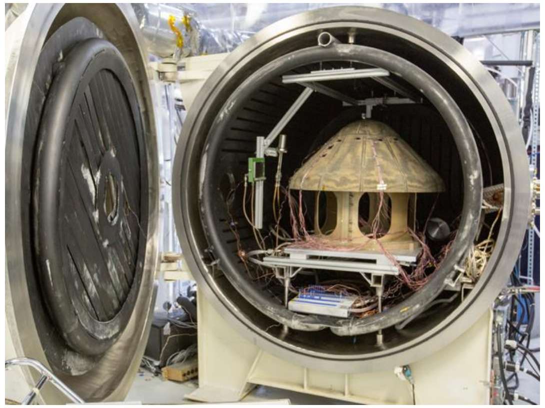
	TechEdSat	Deorbit and Recovery System	HIAD w/in 6U	JAXA-EGG	ADEPT CubeSat Class
	 M. Murbach, SmallSat 2016	 J. Andrews, SmallSat 2011	 S. Hughes, et al, IPPW 2016		
CubeSat Configuration	3.5U	3U	6U	3U	3U+ (could package around dispensers)
Entry System Volume	1.5U ExoBrake de-orbit system	1U	3U	1U	Integrates 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	• Does not survive entry • SPQR concept in development	• Designed for LEO entries • 3 U EDU Developed	• Concept Design • Based on HIAD & IRVE heritage	• Low Ballistic Coefficient < 5 kg/m^2 • More details needed to determine feasibility for high speed entries	• Capable of high speed entries (~11 km/s) • Technology also useful for Aerocapture

Heatshield for Extreme Entry Environments Technology (HEEET)

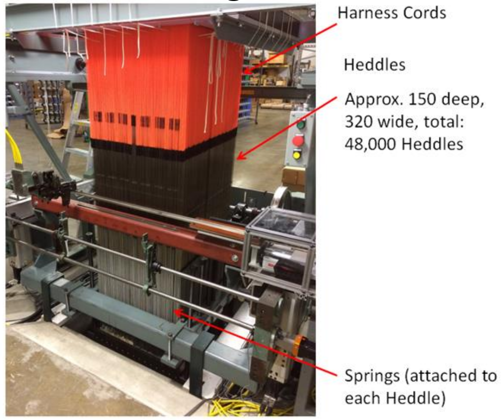
- Leverages **advanced 3-D weaving** and **resin infusion.**
- A dual layer system - **robust and mass efficient** across a range of **extreme entry environments.**
- TRL 6 and ready for mission infusion.
- Development includes:
  - Requirements and verification
  - Testing – Aerothermal and Thermo-structural
  - 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



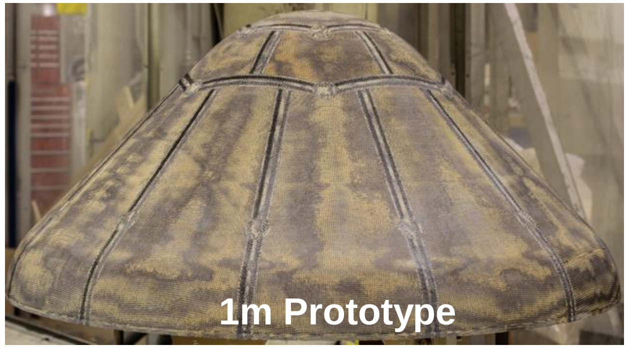
3d Weaving of Pre-form



Woven Pre-form

Arc Jet Tested Specimen

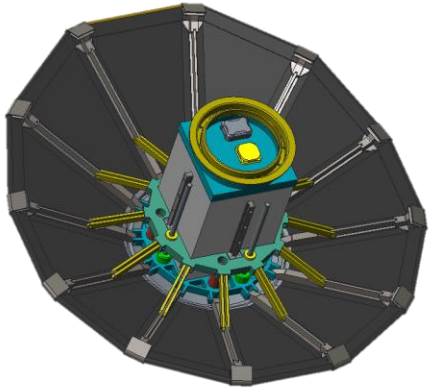
IHF 3" Stag Model
3600 W/cm^2; 5.3 atm



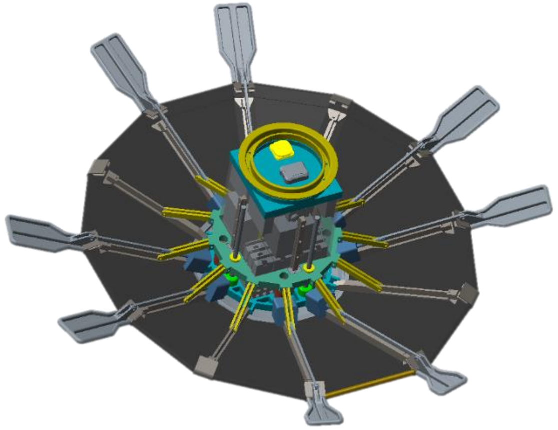
Pterodactyl- Guidance & Control System Integration onto Deployable Entry Vehicles

- 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

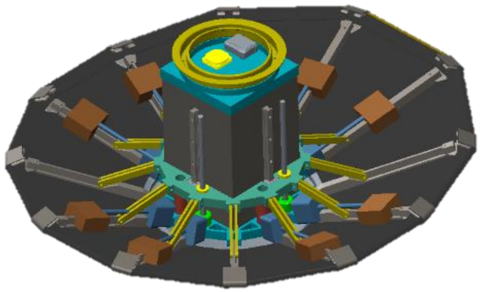
REACTION CONTROL THRUSTERS



CONTROL SURFACES



MASS MOVEMENT



NASA ARC POC- Sarah D'Souza

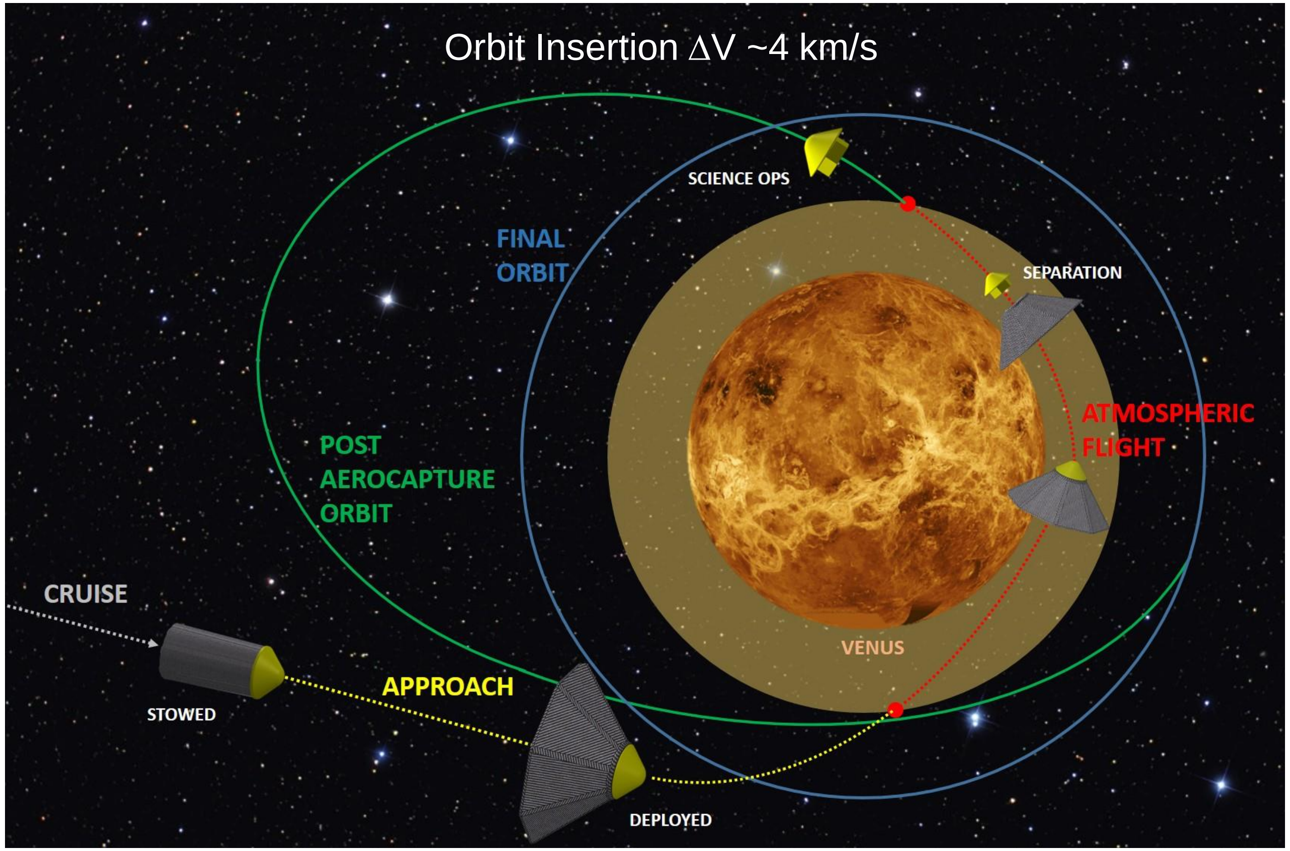
Summary

- 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.

Alan.M.Cassell@nasa.gov
AliciaMDwyerCianciolo@nasa.gov

Back-Up Charts

Drag Modulated Aerocapture at Venus



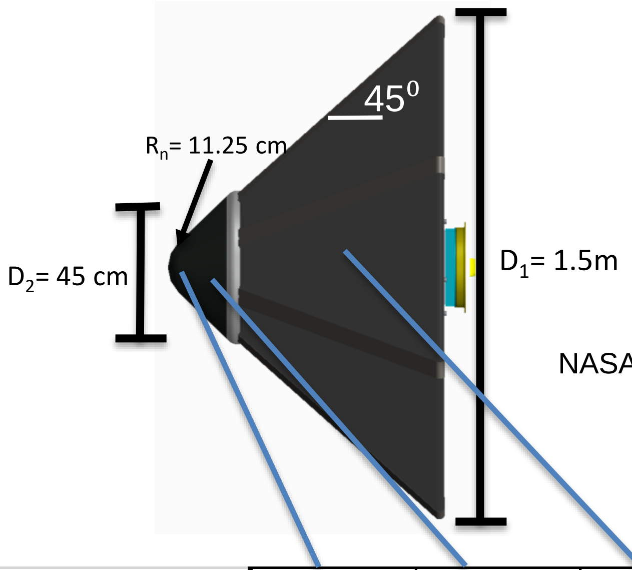
Trajectory Assumptions

- 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

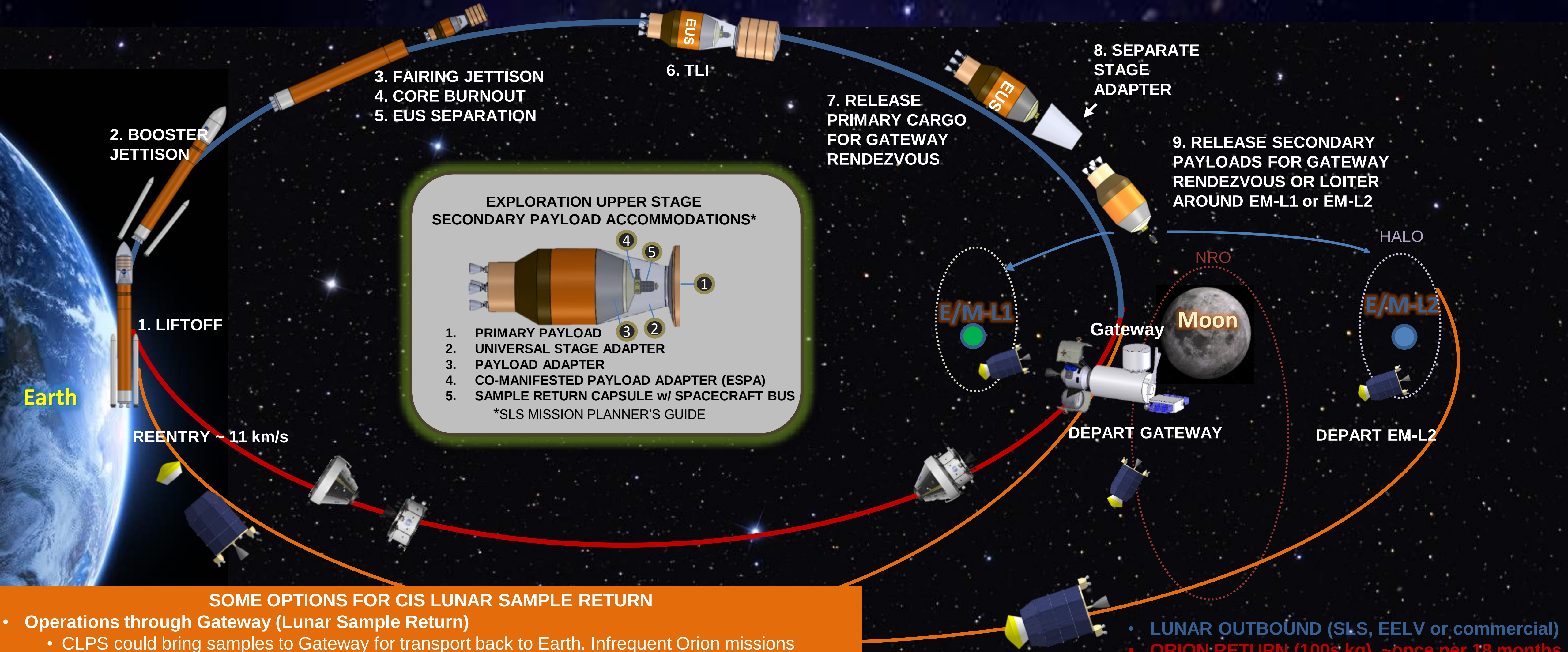


NASA ARC & JPL

	Nose	Flank (est)	Skirt (est)
Peak Heatflux (W/cm2)	383.3	191.65	191.65
Peak Heatload (J/cm2)	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

Interplanetary Small Satellite Conference
beyond LEO

Cis-Lunar Sample Return



- 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

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)**