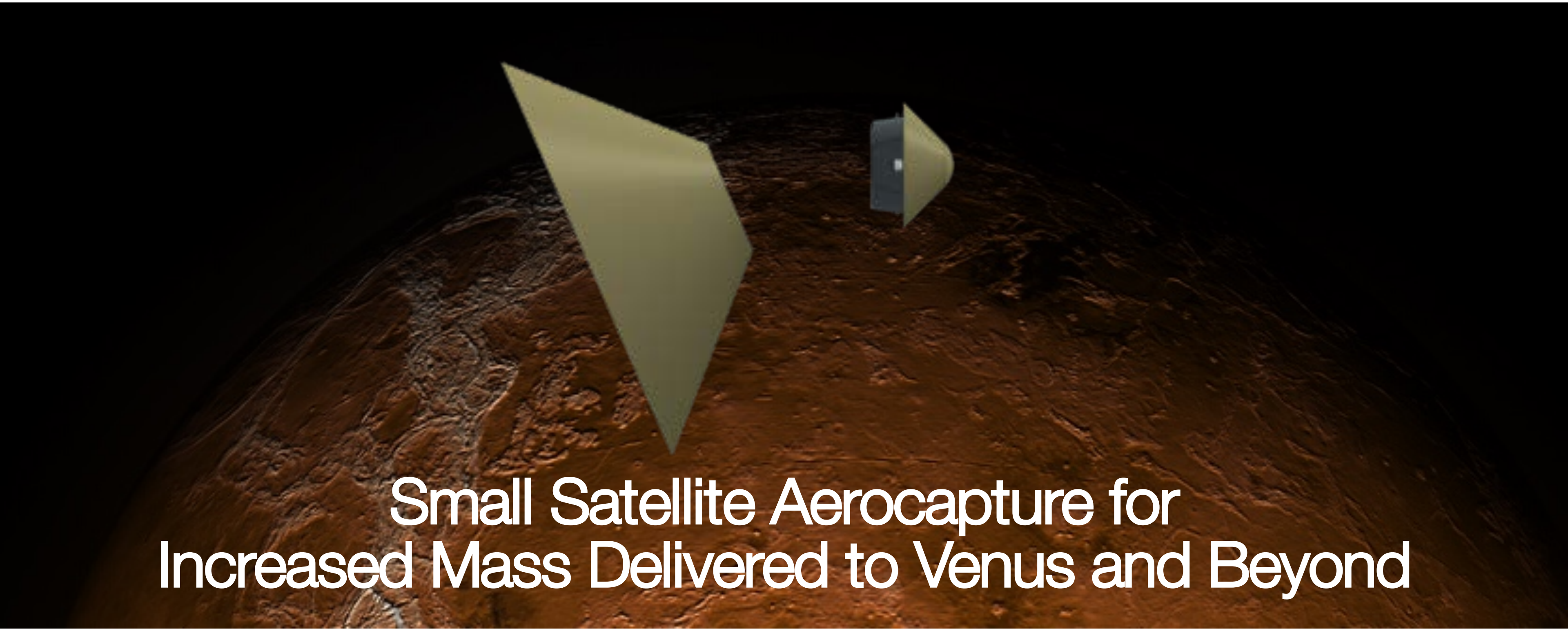

Small Satellite Aerocapture for Increased Mass Delivered to Venus and Beyond

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University of Colorado Boulder

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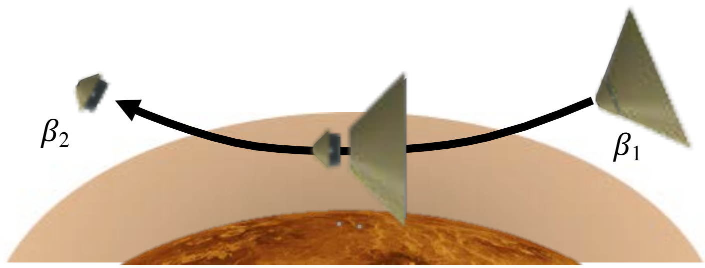
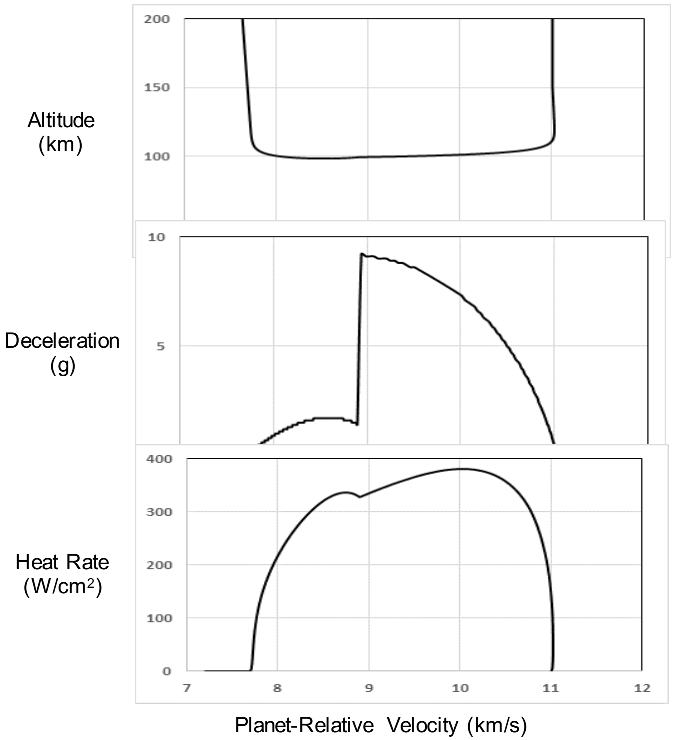
Overview

- A multi-organizational team is developing an aerocapture system for Small Satellites
  - Currently in year 1 of a 2-year effort
- Utilize drag modulation flight control to mitigate atmospheric & navigation uncertainties
  - Initially studied by Putnam and Braun in "Drag Modulation Flight Control System Options for Planetary Aerocapture"
  - Simplest form is the single event jettison
  - Ballistic coefficient ratio $(\beta 2/\beta 1)$ provides control authority
- Study addresses key tall tent pole challenges
  1. Orbit targeting accuracy
  2. Thermal protection system feasibility
  3. Stability before, during, and after jettison event
- Technology development has so far been "mission-agnostic"
  - Pursue a notional flight system design and target orbit to demonstrate existence proof
  - Design and tools can be custom-tailored for a range of possible science missions

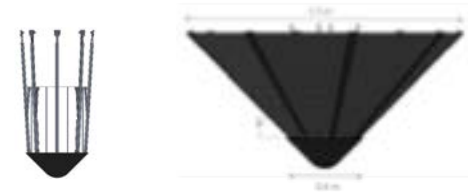




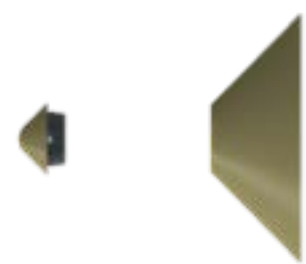
Mission Applicability

- Potential Destinations:
  - Venus
  - Earth
  - Mars
  - Titan
  - Ice Giants
- Vehicle Options:
  - HIAD
  - Mechanical deployable drag skirt
  - Rigid drag skirt
- Delivery Schemes:
  - Dedicated launch & cruise
  - Delivery by host spacecraft

Mechanical deployable drag skirt



Rigid drag skirt



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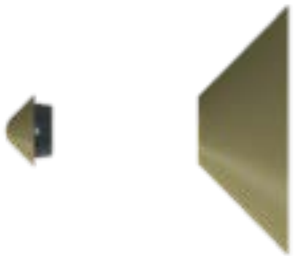
Mechanical deployable drag skirt

Rigid drag skirt



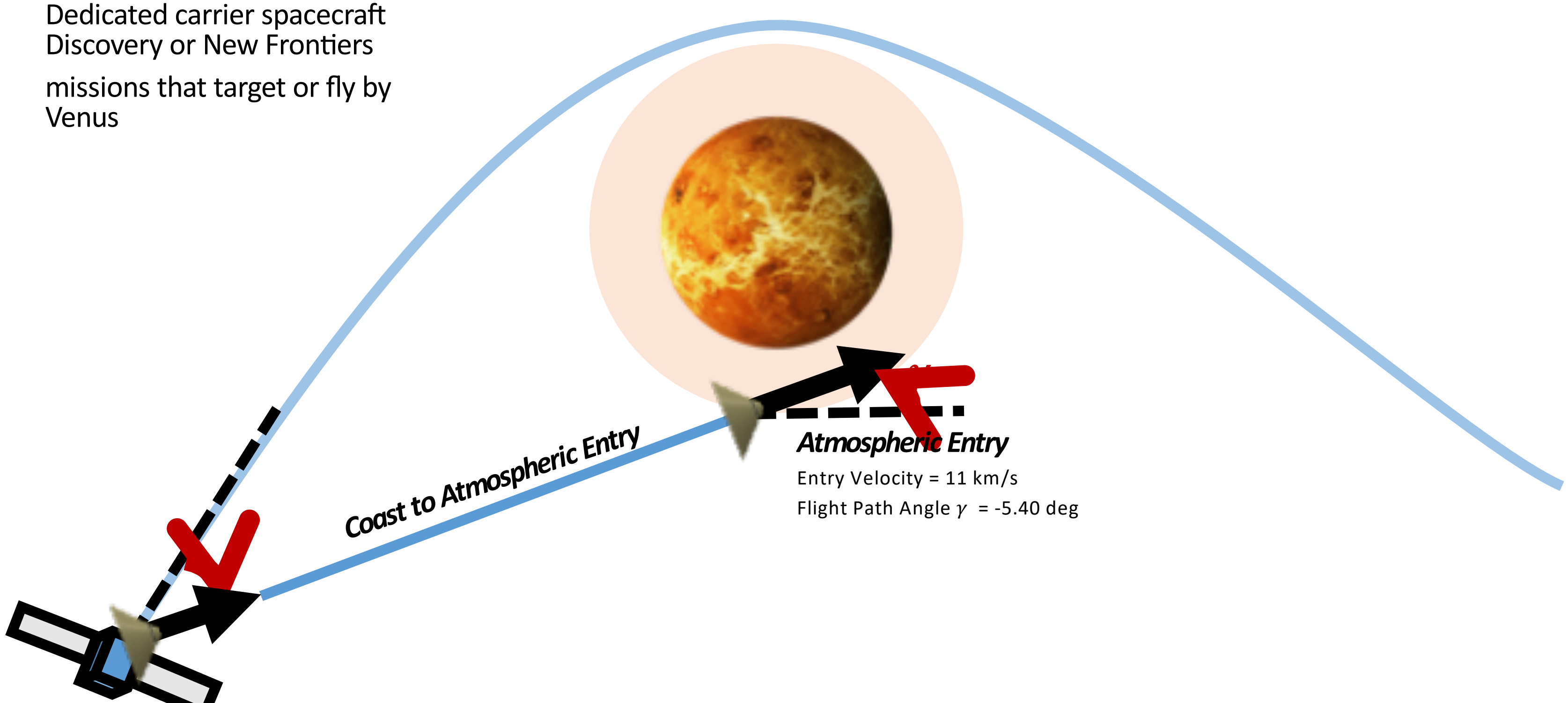
Initial Focus:

Chose Venus to bound the technology’s capability. Can scale to “easier” destinations.
Chose rigid drag skirt and host spacecraft delivery to minimize system complexity.

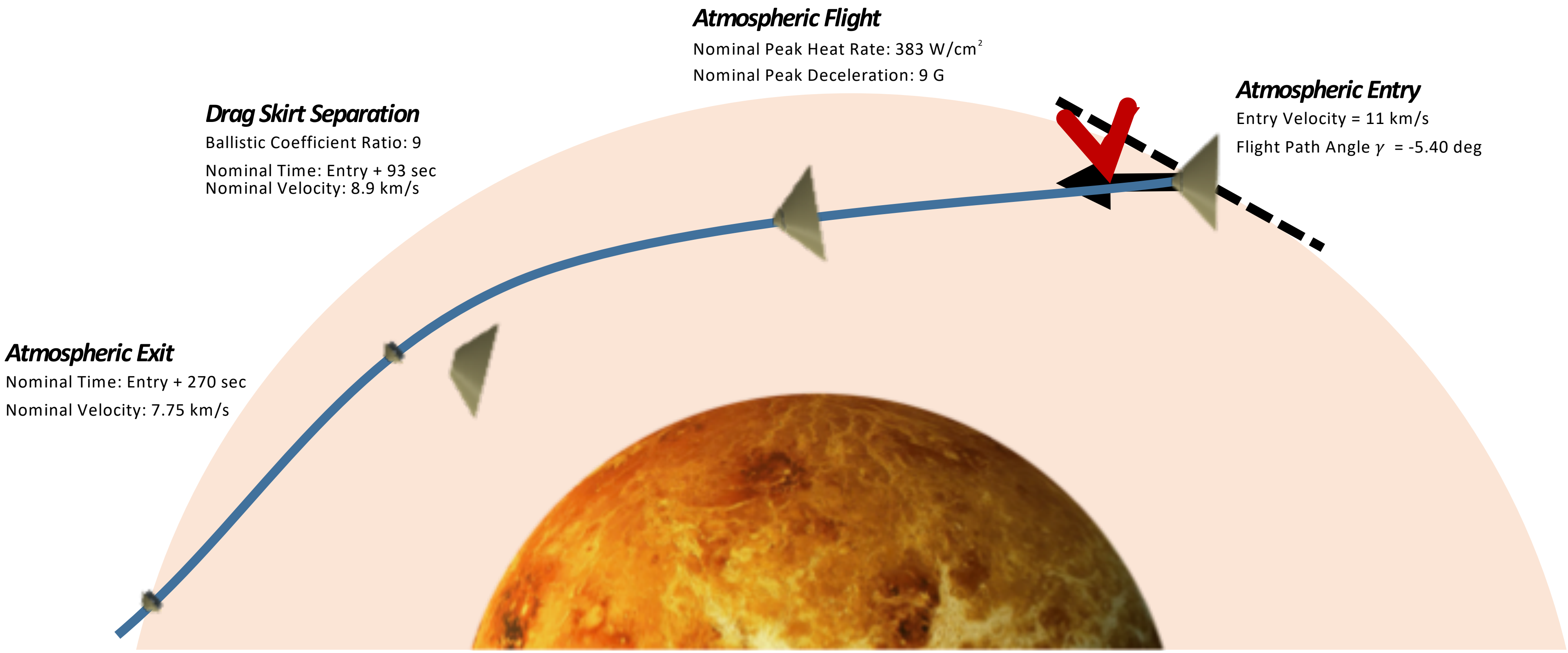
ConOps: Exo-Atmospheric

Potential Hosts:

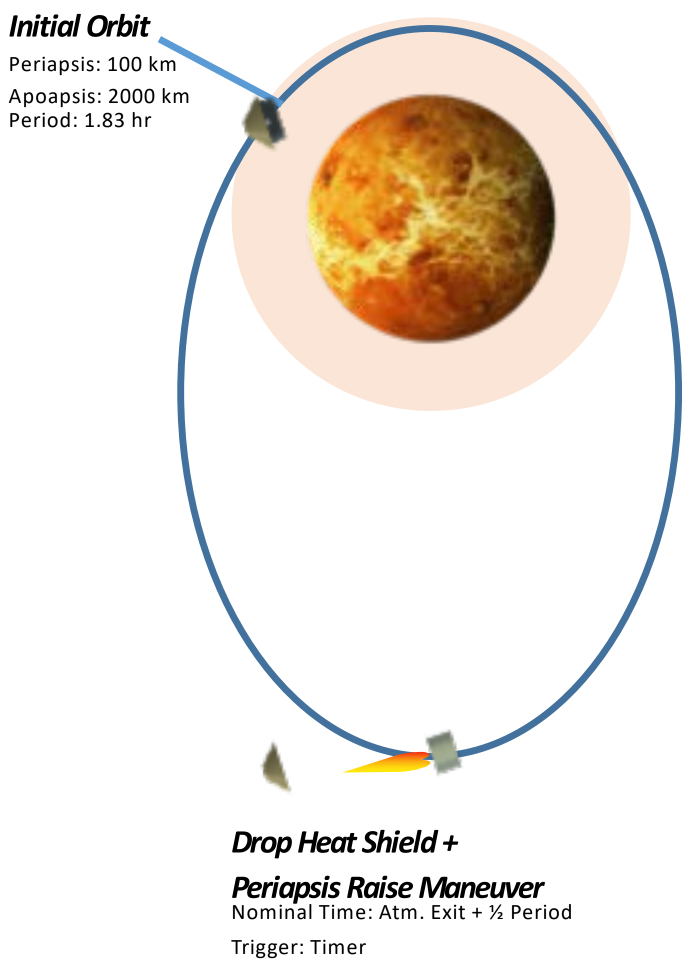
- Dedicated carrier spacecraft
- Discovery or New Frontiers missions that target or fly by Venus



ConOps: Atmospheric



ConOps: Post-Aerocapture



ConOps: Post-Aerocapture

Initial Orbit

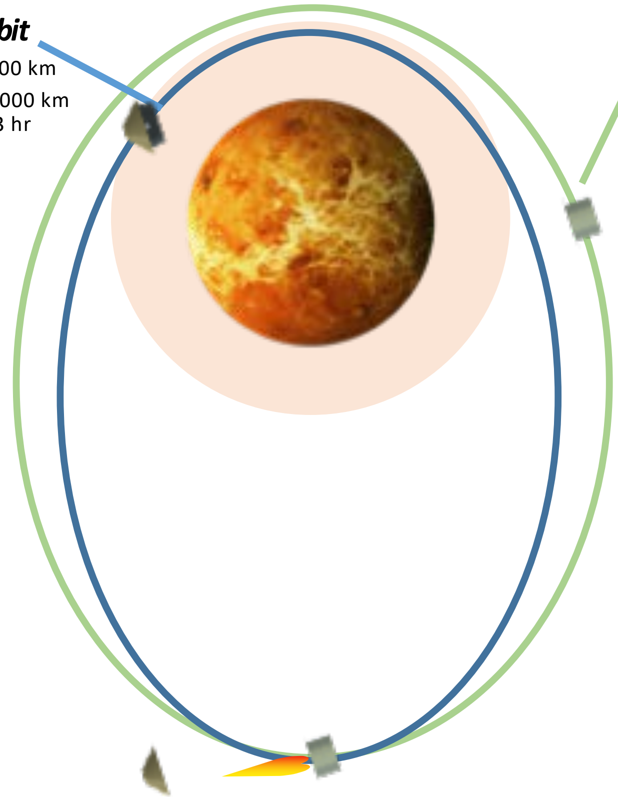
Periapsis: 100 km

Apoapsis: 2000 km
Period: 1.83 hr

Final Orbit

Periapsis: 200 km

Apoapsis: 2000 km
Period: 1.85 hr



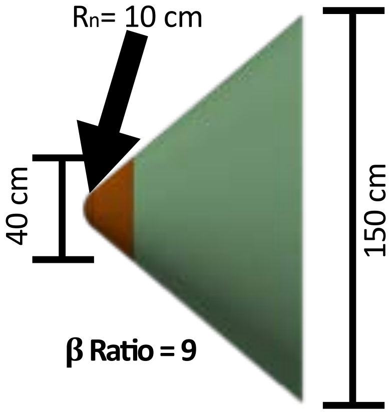
Drop Heat Shield +

Periapsis Raise Maneuver
Nominal Time: Atm. Exit + ½ Period

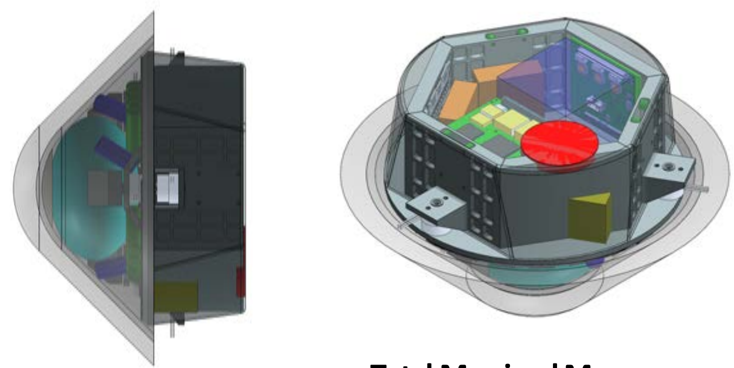
Trigger: Timer

Representative Flight System

Pre-Jettison Configuration



Delivered Flight System



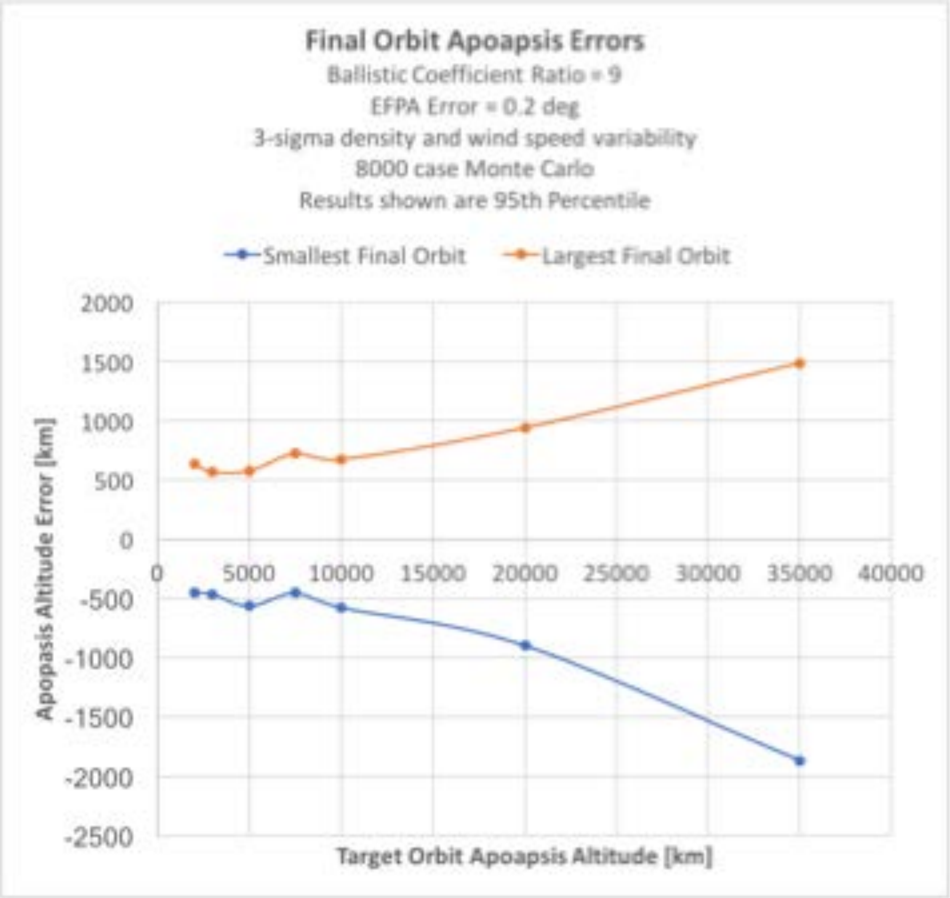
Total Margined Mass = 69kg

- Science Payload
  - ~1.5U available volume
- Telecom *(~2.5 kbps to 70m DSN)*
  - IRIS X-Band Radio
  - X-Band Patch Antenna
  - X-Band Circular Patch Array HGA
- ACS *(~10 arcsec pointing accuracy)*
  - BCT Star Tracker, Sun Sensors (x4), and Control Electronics
  - BCT Reaction Wheels (x3)
  - Sensonor IMU
- C&DH
  - JPL Sphinx Board
  - Pyro Control Board

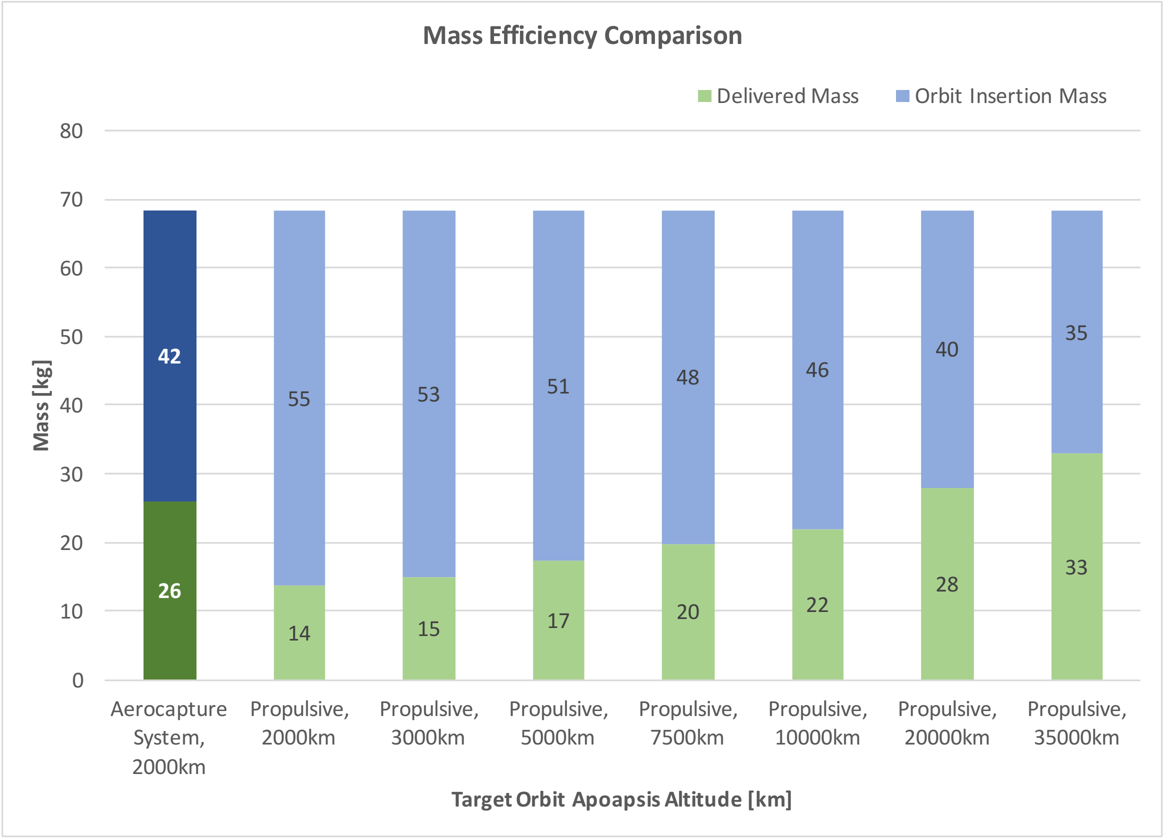
- Thermal
  - Kapton Film Heaters
  - MLI
- Power *(~25 W with body mounted solar cells)*
  - Solar Arrays
  - Clyde Space EPS
  - 18650 Li-ion batteries (x11) (~180 Wh)
- Propulsion *(~70 m/s delta-V)*
  - 0.5 N Monoprop Thrusters (x4)
- Mechanical
  - Structure, TPS, Rails, Rollers, Separation Hardware

Orbit Delivery Accuracy

- 3DOF Monte Carlo runs in trajectory tool used to assess orbit targeting accuracy
  - VenusGRAM atmospheric model with 3-sigma variability in density and wind speeds
- Options for improving orbit targeting accuracy are under investigation
  - Reduce EFPA error
  - Increase ballistic coefficient ratio
  - Improve G&C algorithm for drag skirt separation timing



Mass Efficiency Comparison



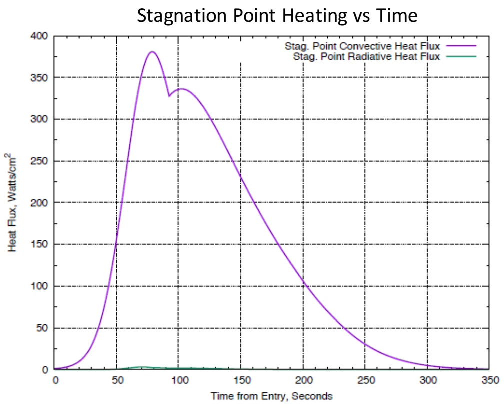
- The aerocapture-based orbit insertion system delivers 85% more useful mass to a 2000km apoapsis orbit than an all-propulsive system

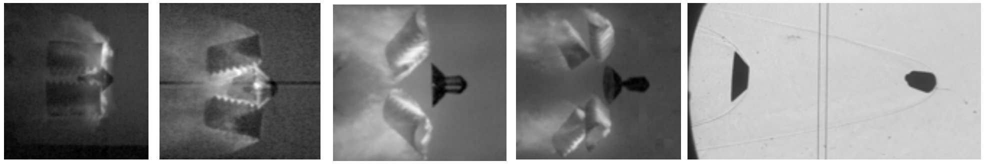
Other Activities

NASA Ames

- Aerothermal analysis
- TPS sizing
- CFD simulations
- Ballistic range test development

See Robin Beck's presentation "Studies in support of Venus aerocapture utilizing drag modulation" for more information

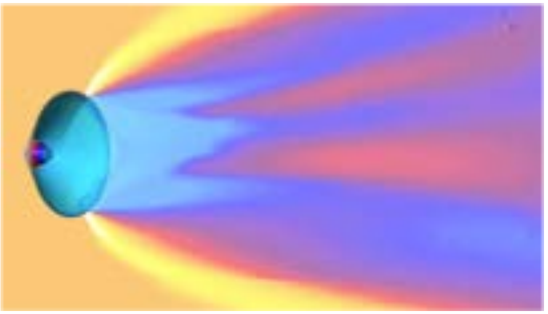




CU Boulder

- G&C algorithm development
- CFD simulations

See Michael Werner's presentation "Dynamic propagation of discrete-event drag modulation for Venus aerocapture" for more information



Conclusions and Future Work

This initiative addresses the following key challenges for drag modulation aerocapture at Venus:

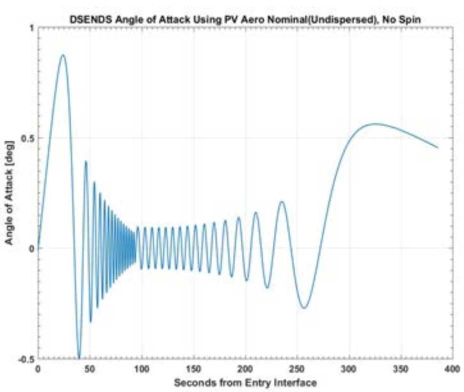
1. Orbit targeting accuracy
   - ✓ 3DOF Monte Carlo simulations of the maneuver
   - G&C algorithm improvements (Work to Go)

2. Thermal protection systems
   - ✓ Preliminary aerothermal assessment and TPS design
   - CFD detailed aerothermal assessment (In Progress)

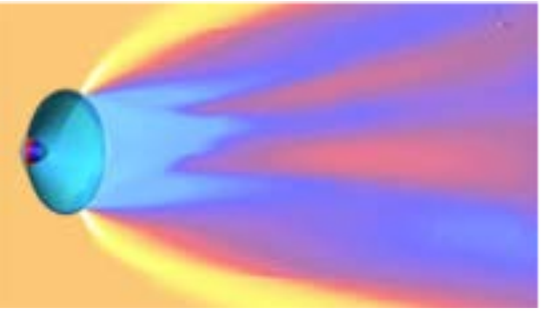
3. Stability before, during, and after jettison event
   - ✓ Preliminary 6 degree-of-freedom simulations
   - CFD analysis of dynamics of drag skirt separation (In Progress)
   - CFD aerodynamic database generation (Work to Go)
   - Ballistic range testing (Work to Go)

- To improve mission accommodation options, investigating an ADEPT-based mechanical deployable drag skirt option

6DOF Trajectory Simulation



CFD Separation Analysis



Ballistic Range Model Design

Thank you!

Internal Flight System Configuration