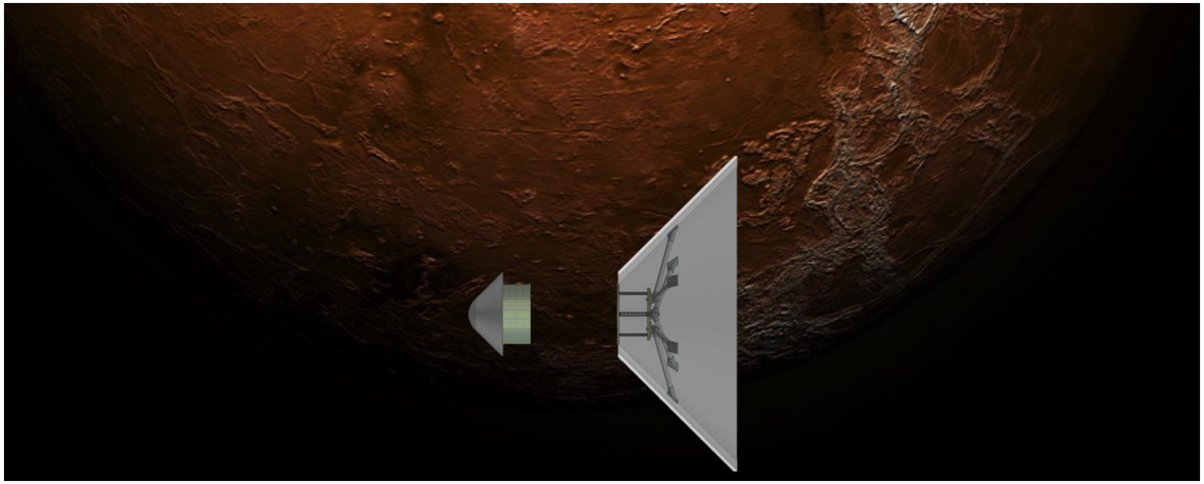
Studies in Support of Venus Aerocapture Utilizing Drag Modulation



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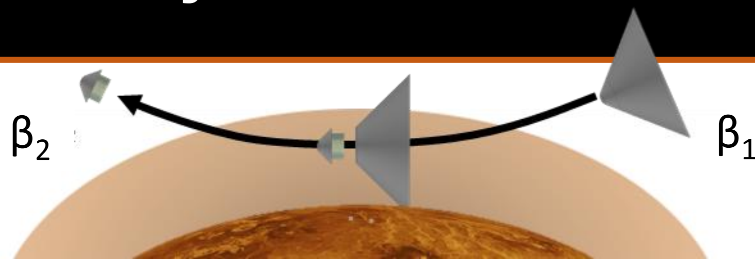
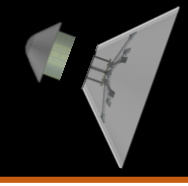
Project Overview



- The goal is to identify and address the technology challenges to enable a simple, single-event drag modulated aerocapture at Venus for a small satellite science mission
- Partnership with JPL and University of Colorado, Boulder
- Focus is on Venus science, mission design, mechanical system design, guidance, navigation, and control
- While aerocapture at Venus is more challenging than Mars or Titan, the opportunity for piggybacking as a secondary payload is more frequent for Venus than other destinations due to its use in gravitationally assisted flybys during interplanetary transit

- *NASA Ames Research Center has unique expertise in aerodynamics, aerothermodynamics, ballistic range testing, and thermal protection materials and systems*

Central Questions



1. Is the vehicle stable before, during, and after the single-event jettison? If using a separable drag skirt, what is the likelihood that it will re-contact the vehicle following jettison?
   - ***This is addressed through aerodynamic stability analysis, Monte Carlo simulations, and ballistic range testing***

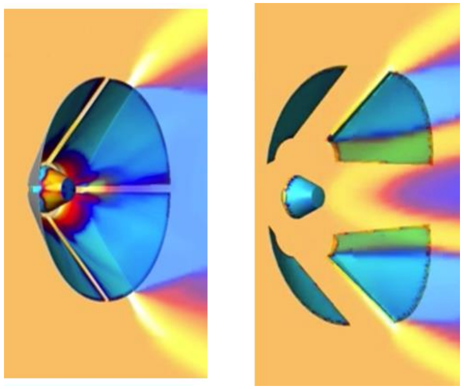
2. Is the guidance and control scheme sufficiently robust in achieving the target science orbit despite navigational, G&C, and atmospheric uncertainties?
   - ***This is addressed through statistical Monte Carlo simulations performed in DSENDS, the institutional JPL tool suite for EDL flight dynamics simulation***

3. Can mass-efficient and robust thermal protection system (TPS) materials maintain acceptable temperature limits on the aerocapture vehicle at Venus?
   - ***This is addressed through aerothermal assessments at various levels of fidelity, and TPS sizing performed by experts at NASA Ames***

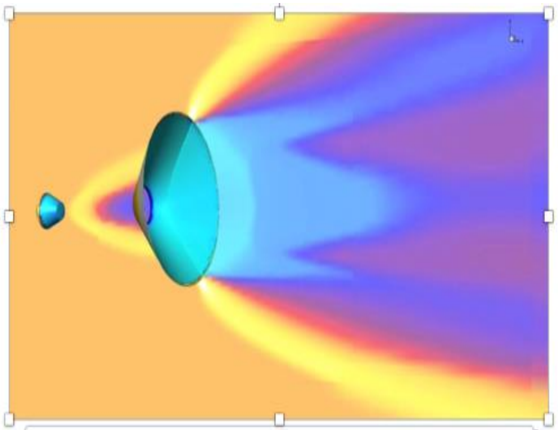
Multi-body Analyses

- Separation of the skirt from the center body during the atmospheric entry is a critical event.
  - The skirt could be a single contiguous element that separates from the center body as a single piece or it could be made of multiple petals that separate into multiple bodies.
  - The desire is for the separation to be simple and avoid re-contact
  - Analysis showed smoother separation for a single-piece skirt
- CART3-D is a computational simulation tool that can deal with complex and multiple bodies.
  - The code is designed to compute aerodynamic coefficients as part of the evolving system and use them to compute the trajectories of the multiple bodies

4-petal skirt



Single piece skirt

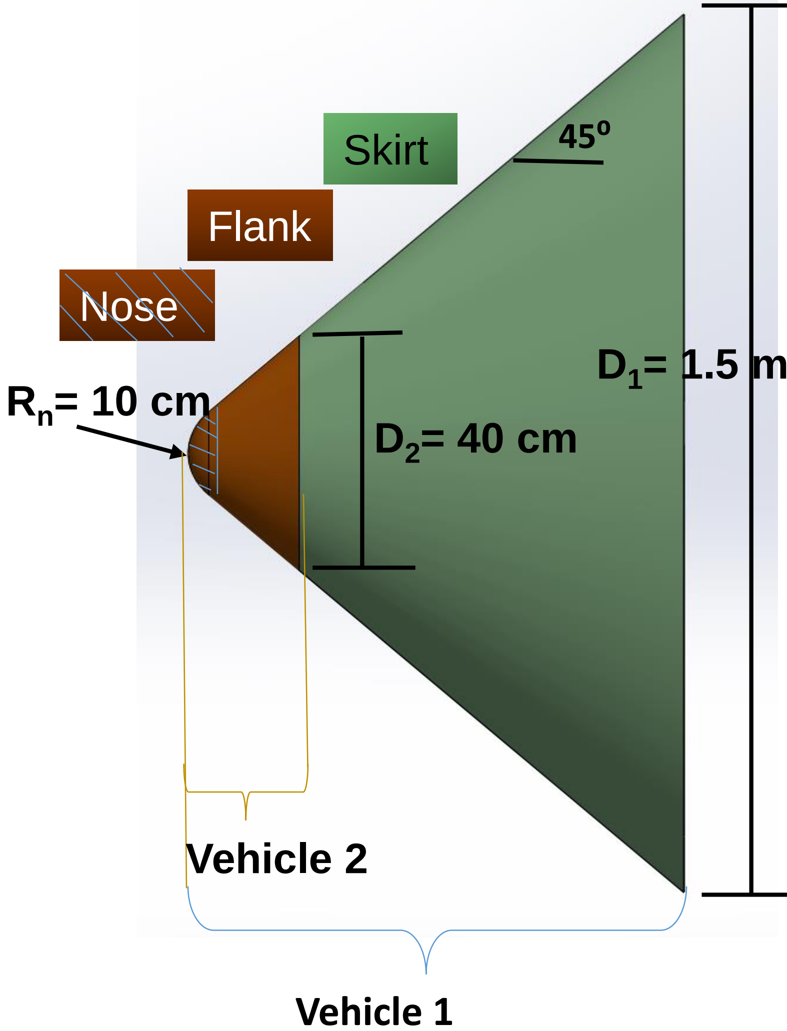


- CART3-D provided to CU with mentoring provided
  - Michael Werner will be at Ames as a summer intern

Baseline Configuration and Trajectory

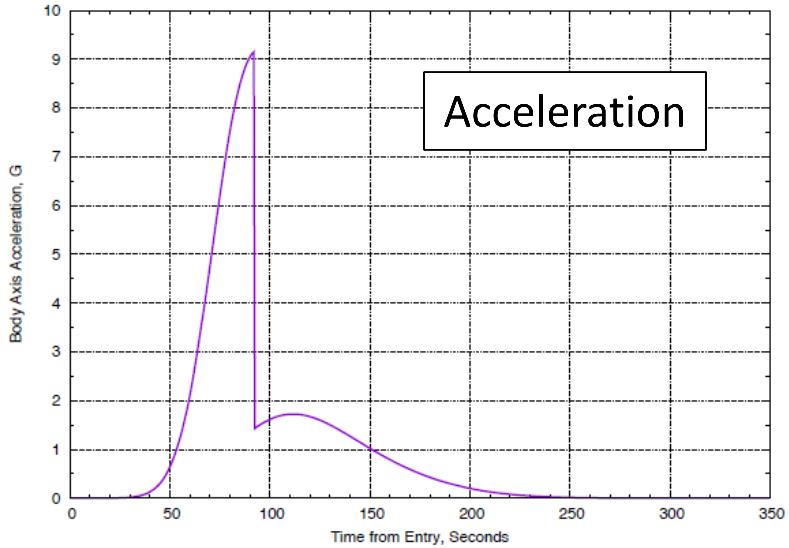
- Configuration
  - Vehicles are both 45˚ sphere cones
  - Vehicle 2 has Pioneer-Venus shape (Rn=0.5* Rb)
  - Pre-jettison Mass (Vehicle 1) = 72 kg, Newtonian aerodynamics
  - Post-jettison Mass (Vehicle 2) = 34.7 kg, P-V aero database

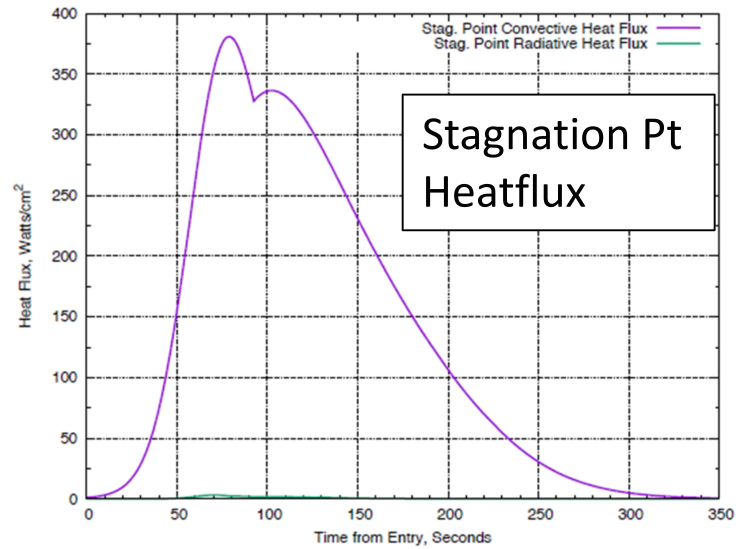
- Basic mission to Venus, @150 km
  - V = 11 km/s
  - FPA = -5.5˚
  - Long/Lat = 0˚ / 0˚
  - Entry date January 1 2025
  - Jettison at time to reach 2000km apoapsis



Aerothermal and TPS Sizing Results

- Skirt Jettison at 92.5 seconds @ 99.4km to achieve apoapsis @ 2000km





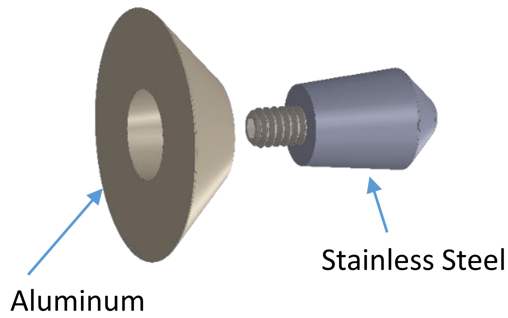
	Nose	Flank (est)	Skirt (est)
Peak Heatflux (W/cm2)	383.3	191.65	191.65
Peak Heatload (J/cm2)	45179	22590	3840
Peak Pressure (Pa)	8800	4400	3650
C-PICA thickness (cm)	2.58	1.88	0.72
PICA thickness (cm)	4.125	3.51	1.11
C-PICA mass (kg)	0.13	0.80	4.56
PICA mass (kg)	0.20	1.45	6.83

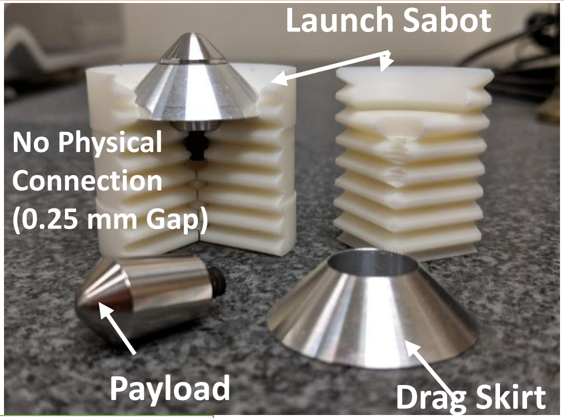
Un-margined TPS Mass (kg)	
C-PICA	5.49
PICA	8.48

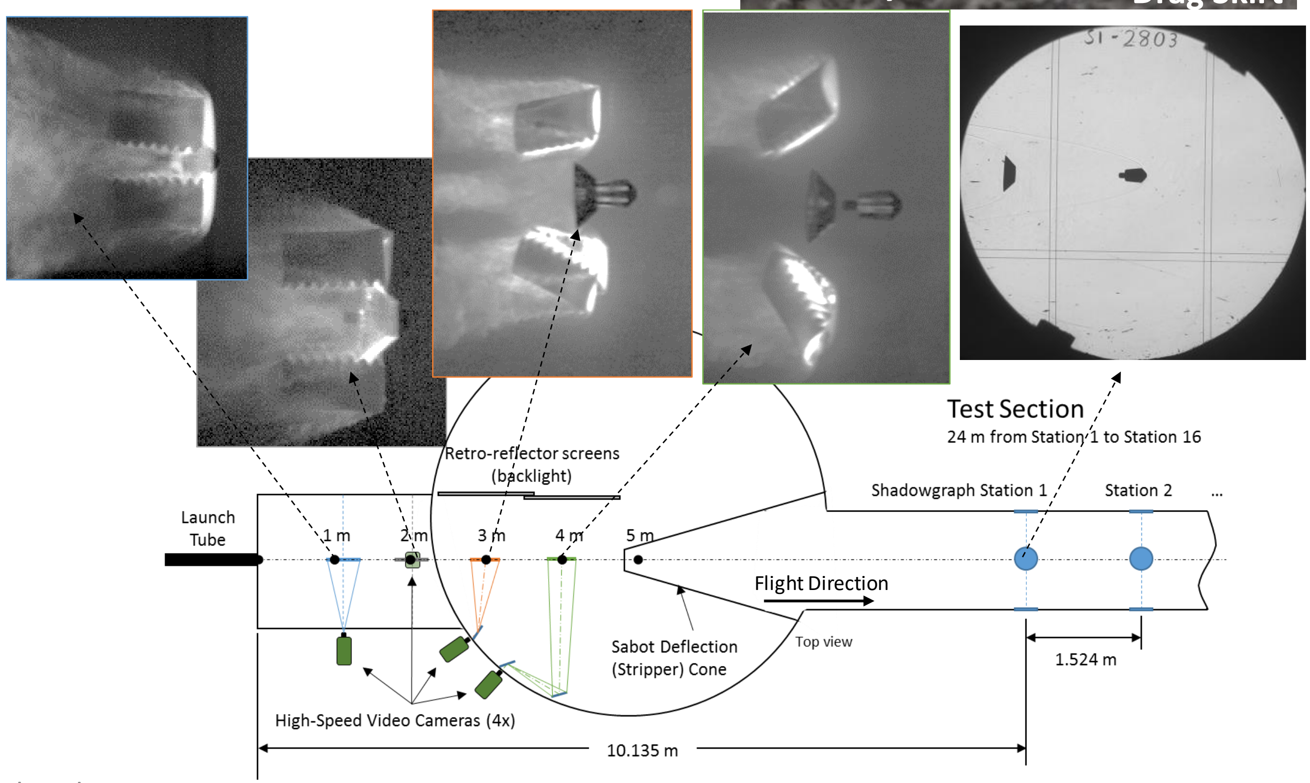
PICA mass estimate could be considered as upper bound

Pathfinder Ballistic Range Model and Tests

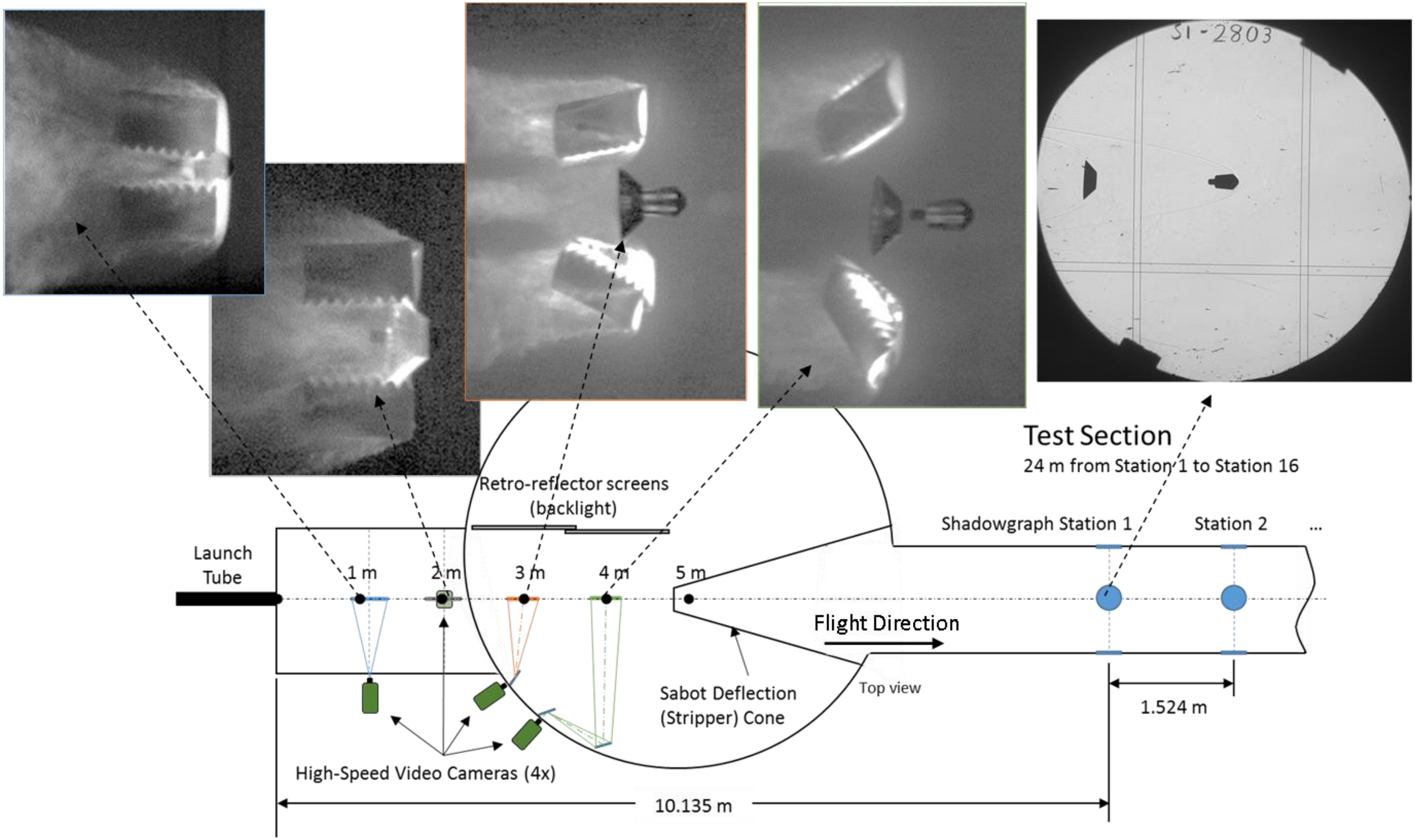
- Six tests were performed
- Freestream pressure was varied in the first three tests to control the drag skirt separation rate
- The sabot design was improved for later tests (smoother deployment)
- Launch speed was increased at the lowest pressure in the last two tests, approaching the launch-load limits for this design





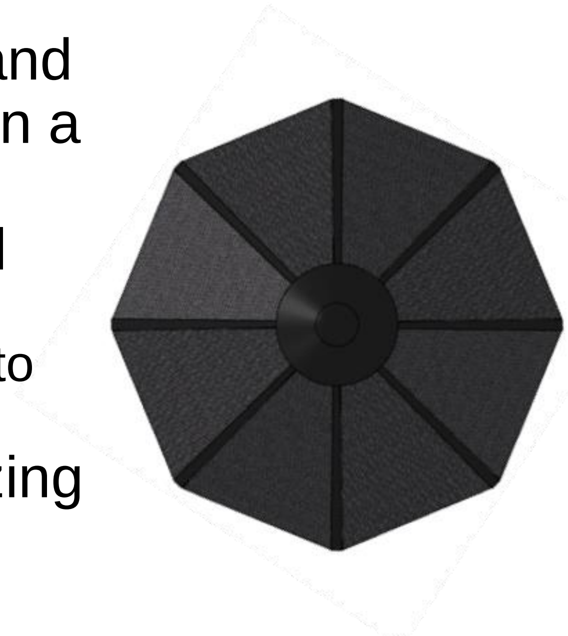


Pathfinder Ballistic Range Photos



Summary/Work to Go

- Preliminary multi-body aerodynamic free-flight and separation simulation using CART3-D resulted in a single contiguous skirt configuration.
- Pathfinder ballistic range testing was successful
  - Confirmed the simulation
  - Improved design and future testing will be tailored to retire design specific risk
- Aerothermal analysis and TPS selection and sizing has provided a mass estimate for the TPS.



- The ADEPT concept will be evaluated as part of 2nd year study
  - Allows for growth of small payloads as secondary missions
  - Will also allow for accommodation on spacecraft for future scale-up to large primary payloads.
- Year 2 Ballistic range testing will include improved design tailored to retire design specific risks