National Aeronautics and Space Administration

COMMON PROBE DESIGN STUDY AND FOLLOW-ON ACTIVITIES

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Workshop on In-Situ Exploration of the Ice Giants

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Common Probe Study Team Members

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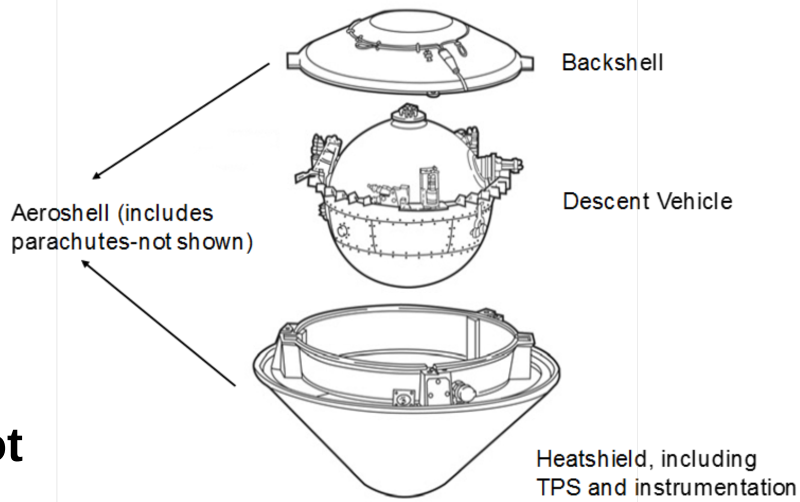
Background and study goals

- **The Planetary Science Division of the NASA Science Mission Directorate funded a study involving 4 NASA Centers (ARC, GSFC, JPL, and LaRC), to address if a common aeroshell design could be utilized at multiple destinations instead of optimizing a design for a specific mission.**
  - Proof of concept desired—could a common aeroshell design be flown at Venus, Jupiter, Saturn, Uranus, and Neptune?
  - What efficiencies and risks would be involved for usage by missions?
  - If this common design were built with multiple copies, could NASA realize cost savings? Would mission proposers be interested in having an “off-the-shelf” aeroshell available?

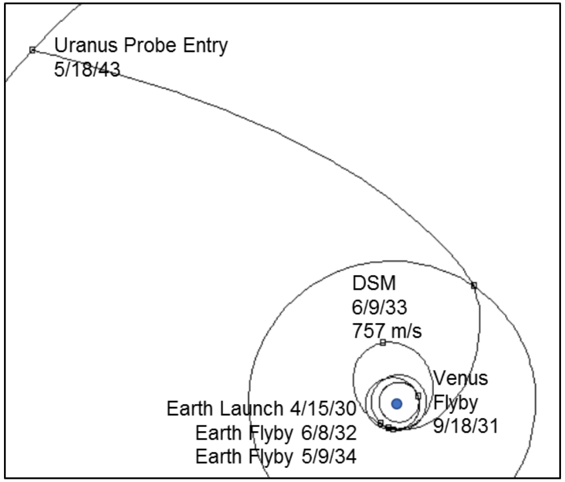
Study scope and assumptions

- **Venus, Jupiter, Saturn, Uranus, and Neptune as destinations considered**
  - In scope: missions with direct, ballistic entries
  - Out of scope:
    - Earth return, Mars, and Titan as destinations
    - Aerocapture
    - Large landers at Venus
- **Carrier spacecraft provides power and communications during cruise (details not studied)**



- **Mass and instrumentation for descent vehicle considered, but detailed mechanical design and interface out of scope of study**
- **Leverage previous missions and studies for detailed analysis, otherwise use mid-fidelity tools for design estimates**
  - Utilize current methods and technologies for design basis (*e.g.*, composite structures, heritage materials, etc.)

Mission Design

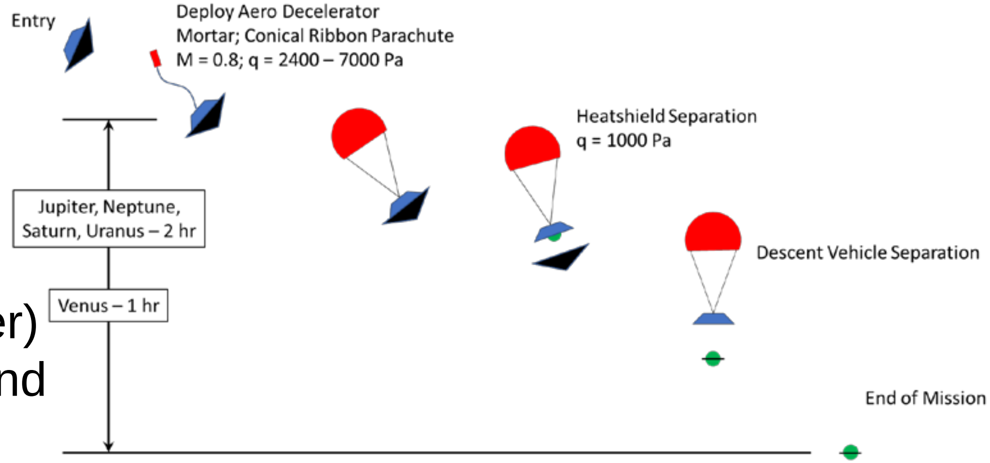


*Note: Uranus entries are retrograde

Assumptions

- Launch vehicle with current all-chemical capabilities (ΔV)
- Time of flight < 15 years
- “Shallow” (50-g) and “steep” (150 – 200-g) trajectories for each destination

- Two different Entry and Descent scenarios investigated
- Using one main chute (2.0 m diameter) feasible for Venus, Saturn, Uranus, and Neptune



“INTERPLANETARY TRAJECTORY DESIGN FOR NASA’S COMMON PROBE STUDY,” K. Hughes, *et al.*, IPPW 2018.
“EVALUATION OF COMMON PROBE TRAJECTORIES AT MULTIPLE SOLAR SYSTEM DESTINATIONS,” A. Cianciolo, *et al.*, IPPW 2018

Strawman Payloads (1)

- Science and payload team (JPL, GSFC) examined potential instruments for missions to 5 destinations and prioritized based on Tier 1 and 2 science
- Estimated a descent module of 0.75 m diameter could accommodate the payload at the 5 destinations based on packaging ratios from previous missions and studies → aeroshell diameter ~ 1.5 m

	Instrument	Measurement
Tier 1	Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
	Atmospheric Structure Instrument (ASI)	Pressure and Temperature → Thermal Structure, Density, Stability Entry Accelerations → Density
Tier 2	Radio Science Experiment	Atmospheric dynamics: winds and waves; atmospheric absorption → composition
	Nephelometer	Cloud structure, aerosol number densities & characteristics
	Net Flux Radiometer	Net radiative fluxes: Thermal IR, solar visible

"SCIENCE GOALS AND PAYLOADS FOR COMMON PROBE MISSIONS TO VENUS AND THE GIANT PLANETS," D. Atkinson, *et al.*, IPPW 2018

Strawman Payloads (2)

- **Ice Giants Pre-Decadal Survey Mission Study Report by M. Hofstadter et al. considered fewer instruments and thus a smaller descent vehicle size, leading to a smaller and lighter probe (1.2m diam, ~325 kg). This was considered the "minimum" size probe for a flagship-class mission.**
- **Should the 1.2m diam aeroshell size be considered (vs 1.5m diam)?**

Tier	Instrument	Measurement
Tier 1	Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
	Atmospheric Structure Instrument (ASI)	Pressure and Temperature → Thermal Structure, Density, Stability Entry Accelerations → Density
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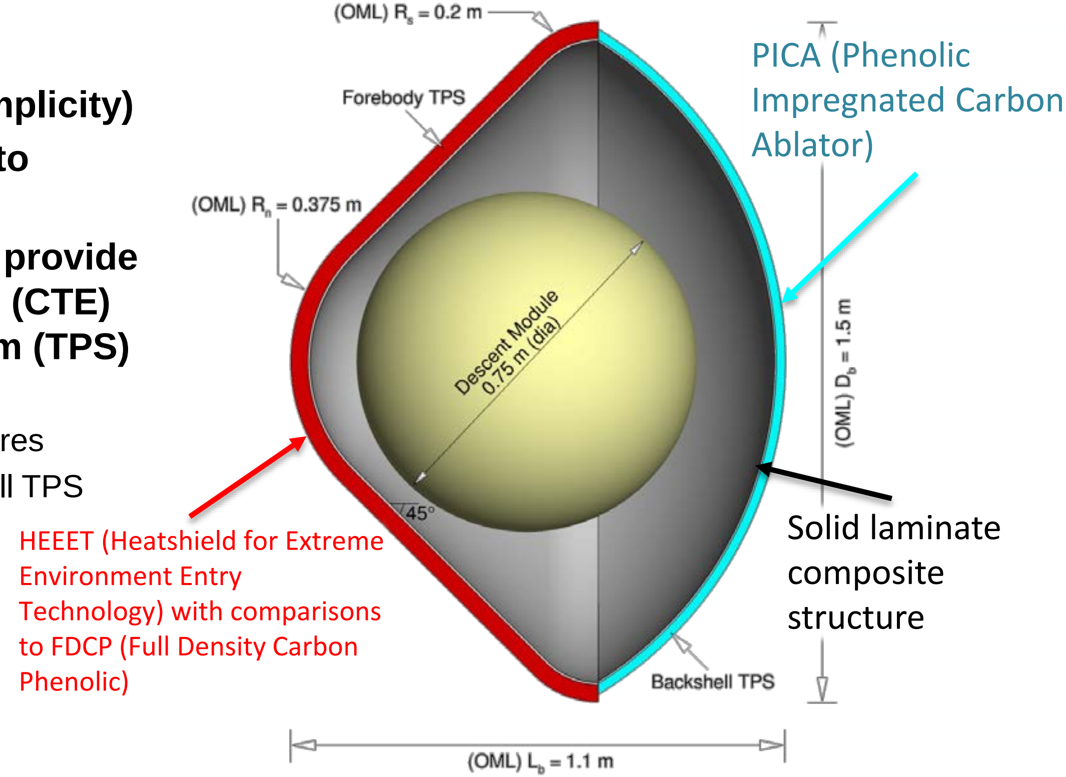
"SCIENCE GOALS AND PAYLOADS FOR COMMON PROBE MISSIONS TO VENUS AND THE GIANT PLANETS," D. Atkinson, *et al.*, IPPW 2018

Aeroshell Design (1)

- **45°-sphere cone forebody (aerodynamic stability)**
- **Hemispherical-cap backshell (design simplicity)**
- **Probe diameter and nose radius similar to Pioneer Venus Large Probe (PVLP)**
- **Structure is solid laminate composite to provide a better coefficient of thermal expansion (CTE) match with the thermal protection system (TPS) materials**
  - Pioneer Venus and Galileo were metallic structures
  - Mass of structure assumed to be the same for all TPS thickness



	Base diameter (m)	Nose radius (m)	Ballistic Coefficient (kg/m²)	Entry mass (kg)
Common Probe	1.5	0.375	216	400
PVLP	1.42	0.36	188	316
Galileo	1.26	0.222	256	335

Aeroshell Design (2)

- **Nose radius, vehicle diameter and entry mass (ballistic coefficient) are consistent with recommendations from D. Prabhu, "Exploration of Atmospheric Entries at Uranus & Neptune with HEEET as Heatshield TPS," Workshop on In-Situ Ice Giants Exploration (presentation given on Tuesday).**

	Base diameter (m)	Nose radius (m)	Ballistic Coefficient (kg/m²)	Entry mass (kg)
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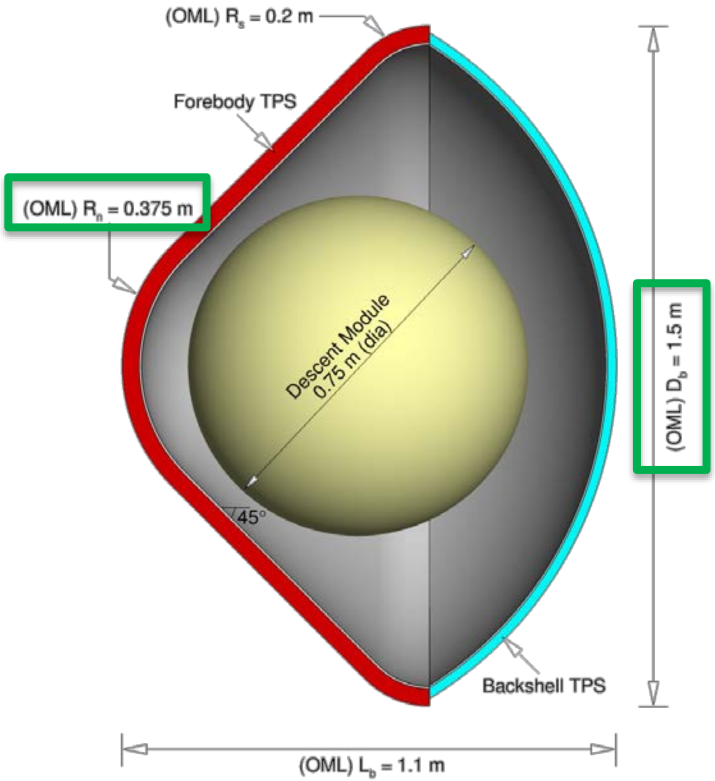
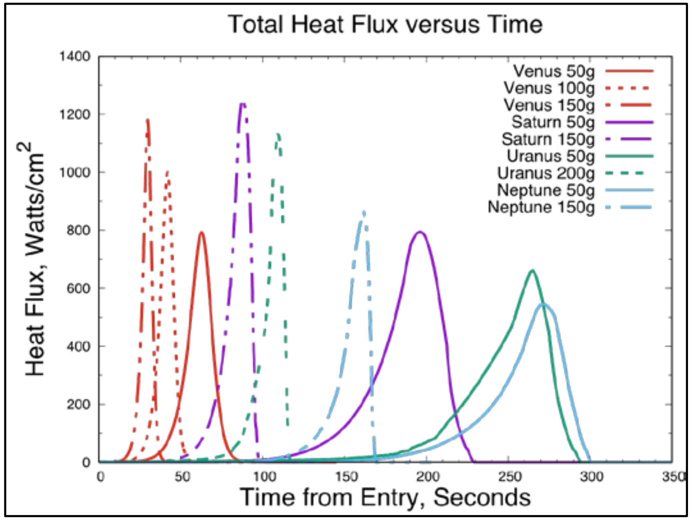
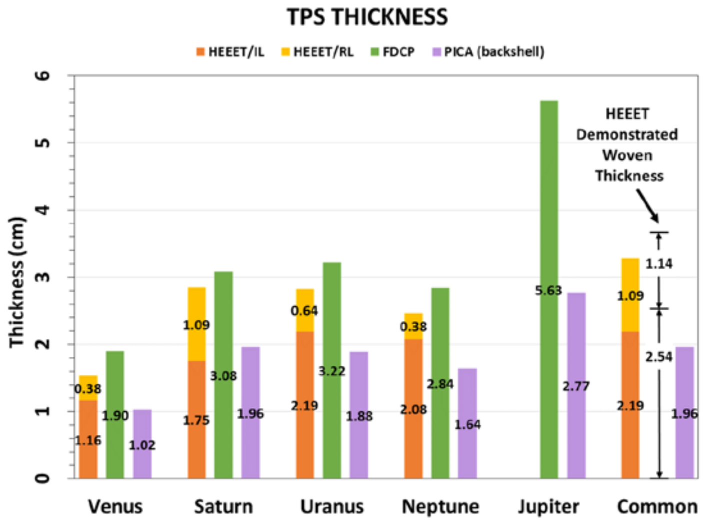


Thermal Protection System (TPS) sizing

- Aerothermal environments (radiative + convective heating) estimated on the forebody stagnation point using a 3DOF simulation, TRAJ
- 2 forebody materials considered: HEEET and FDCP, sized using FIAT
- Backshell TPS assumed to be PICA: mass estimated based on forebody stagnation point environments
- Common TPS thickness viable for 4 destinations but not Jupiter (heat loads 10x higher)—both Uranus and Neptune are within weavable limits for HEEET





"AEROTHERMAL DESIGN OF A COMMON PROBE FOR MULTIPLE PLANETARY DESTINATIONS," G. A. Allen, Jr., *et al.*, IPPW 2018

New Paradigm, New Risks

- **Typically, probes are designed and optimized based on specific mission needs.**
- **Building a probe once a decade has sustainability issues**
  - Maintaining heritage material availability (*e.g.*, precursor and constituents to carbon phenolic)
  - Skilled labor for assembly and integration (HEEET requires use of gap fillers and specially-developed integration techniques)
- **Building multiple copies of a common design can alleviate the sustainability issues, but introduces new risks:**
  - Long term storage and aging of the system
    - Will HEEET and a cyanate ester composite structure age at the same rate when bonded together?
    - Can accelerated aging coupon tests be performed?
    - Galileo and Phoenix are data points for ground storage
  - Qualification of the design across multiple destinations

Summary

- **The Common Probe aeroshell design was deemed to be feasible for atmospheric probe missions to Venus, Saturn, Uranus, and Neptune**
  - Risk trade: recommend design and multiple build of common design to offset sustainability issues, but need to further investigate aging and long term storage effects
  - Including all instruments in Tier 1 and 2 categories led to analyzing a large aeroshell
- **The final report is forthcoming and will be published as a NASA TM**

What Should Be the Next Step?

- **NASA PSD has requested a recommendation for the follow-on activities to the Common Probe feasibility study**
- **In order to gather community feedback, we have put together a list of 5 questions in a survey which will be emailed to you—please email your responses back!**
  - Help set the priority of what design(s) to consider as a common aeroshell
  - Indicate your feedback and consideration of using a common aeroshell if it were ready to use “off the shelf” vs customized design for individual mission

Survey: Pre-amble

Common Probe Next-Steps:

The Common Probe Study was funded by NASA's Planetary Science Division. It was determined that a 1.5m diameter aeroshell at 400kg was feasible for missions to Venus, Saturn, Neptune, and Uranus, but not Jupiter. The recommendation was to design and build multiple copies of the aeroshell to be stored for future mission use.

Based on the Planetary Science Decadal Survey Studies, the following classifications were used to determine instrument payloads for the atmospheric probes and the scientific measurements:

Instrument	**Measurement**	**Tier**
Mass spectrometer	Elemental and chemical composition, especially noble gases and key isotopes	1
Atmospheric structure instrument (ASI)	Pressure and temperature (thermal structure, density, stability) Entry accelerations (density)	1
Radio Science Experiment	Atmospheric dynamics: winds and waves Atmospheric absorption (composition)	2
Nephelometer	Cloud structure, aerosol number densities and characteristics	2
Net flux radiometer	Net radiative fluxes: thermal infrared, solar visible	2

Survey: Question 1

1. The Common Probe Study baselined a 1.5m, 400 kg aeroshell which could accommodate both Tier 1 and Tier 2 instruments. What size aeroshell should be analyzed next?

- ○ Same size (1.5 m diameter, 400 kg) to accommodate comprehensive instrument suite
- ○ Smaller size (~ 1 m), for Tier 1-only instruments, smaller mass spectrometer, small Venus landers, multi-probe missions, etc.
- ○ Very small size (~ 0.5 m), applicable for cube sats, multi-probe missions, etc.
- ○ Same size + a smaller size
- ○ Other (please specify)

Survey: Question 2

2. Assembling and storing multiple copies of a common probe design may be the lowest cost option for NASA, but could potentially introduce storage and aging risks. What is your preference for state of assembly of the common probe? (Aeroshell includes both heatshield and backshell.)

- ○ Entire aeroshell assembled and stored
- ○ Aeroshell designed and HEEET tiles and gap fillers constructed, but heatshield not assembled or bonded
- ○ Aeroshell designed with sufficient HEEET material woven for heatshield, but no tiles machined or assembled
- ○ Other (please specify)

Survey: Question 3

3. A unipiece HEEET assembly, versus a tiled heatshield, may be possible to construct but would limit the overall aeroshell size to < 1.3 m. This smaller size may not be able to accommodate both Tier 1 and Tier 2 science instruments. How important would a unipiece construction of HEEET be for consideration of using the common aeroshell design?

- ○ A tiled HEEET heatshield meets the mission requirements (do not need a unipiece HEEET heatshield construction)
- ○ Unipiece heatshield essential for mission (a tiled HEEET heatshield design does not meet requirements)
- ○ Other (specify)

Survey: Question 4

4. In the past, NASA has offered incentives to proposers to utilize NASA-developed technologies. How would the following incentive options influence your decision to use the common aeroshell design? Assume that the "no development risk" option is the same as in past Announcements of Opportunities, meaning that risks associated with the readiness of the technology will not impact the evaluation of the risk of the mission proposing to use that technology. However, in all cases, the risk of accommodating the technology in the proposed mission environment will be evaluated.

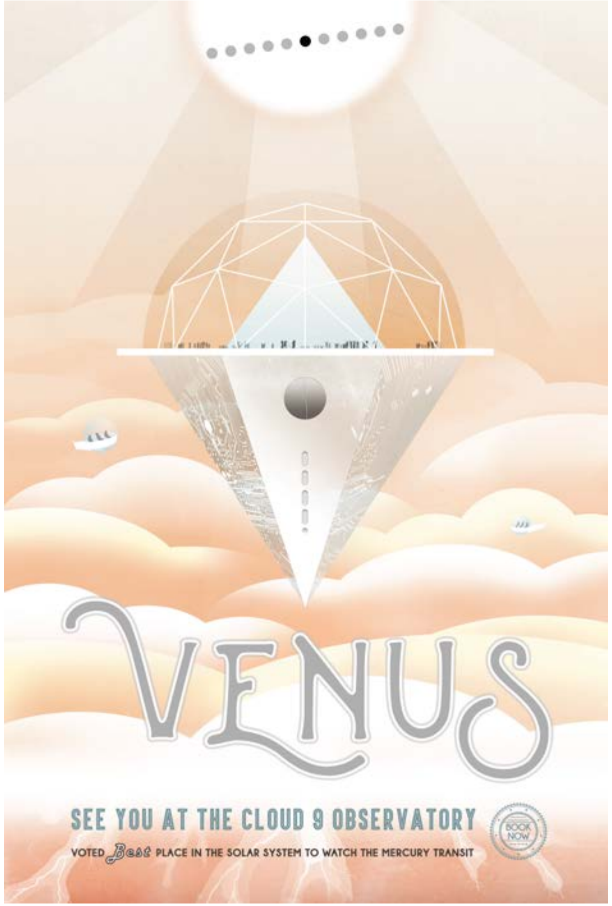
	Highly likely	Likely	Neutral	Unlikely	Highly unlikely
Aeroshell offered at reduced cost	○	○	○	○	○
Aeroshell offered at no cost to proposers	○	○	○	○	○
Aeroshell offered as "no development risk" to proposers	○	○	○	○	○

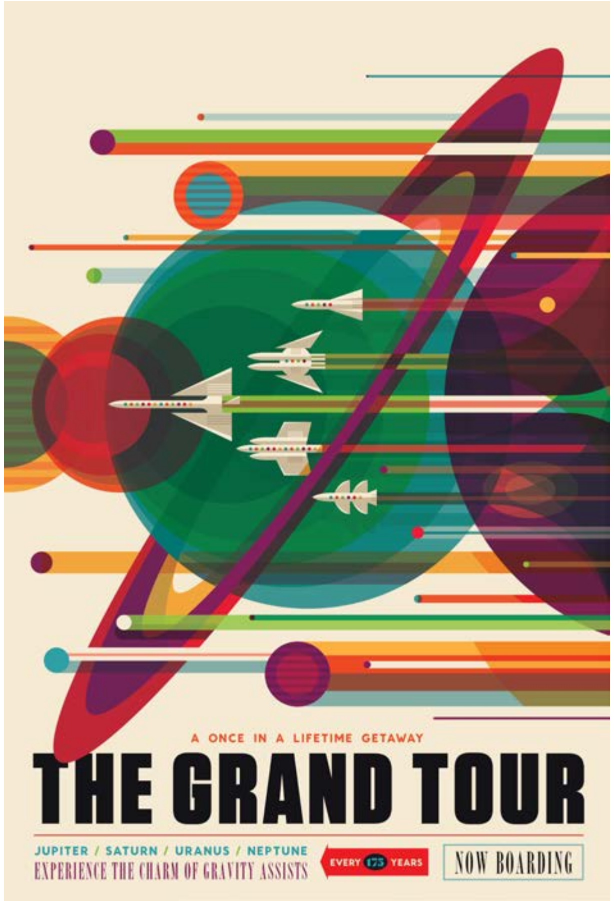
Comments:

Survey: Question 5

Do you have any other suggestions about "next steps" NASA should undertake for a common probe design?

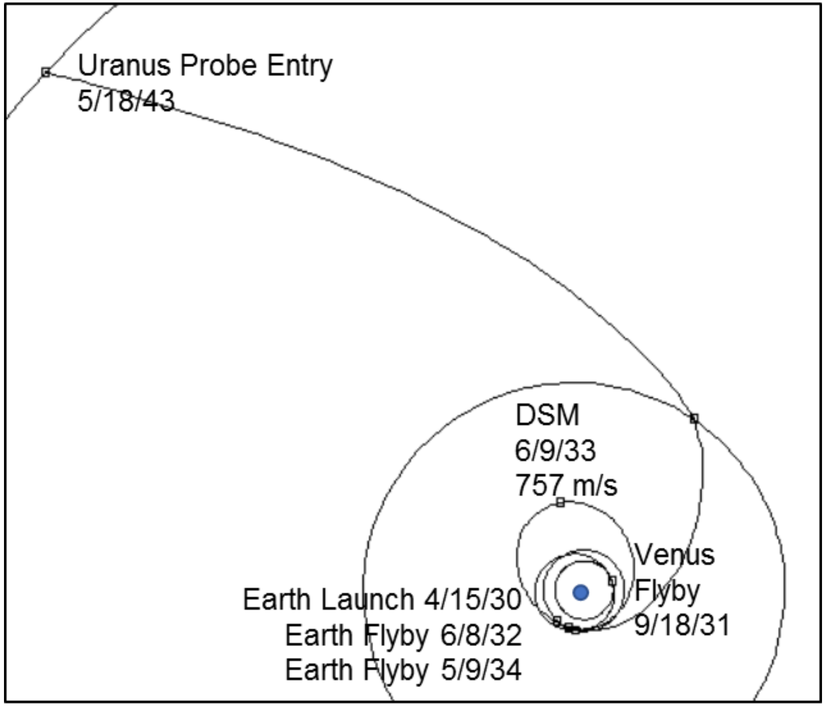
Questions?





Images:
NASA/JPL-Caltech

Interplanetary Trajectories



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Assumptions

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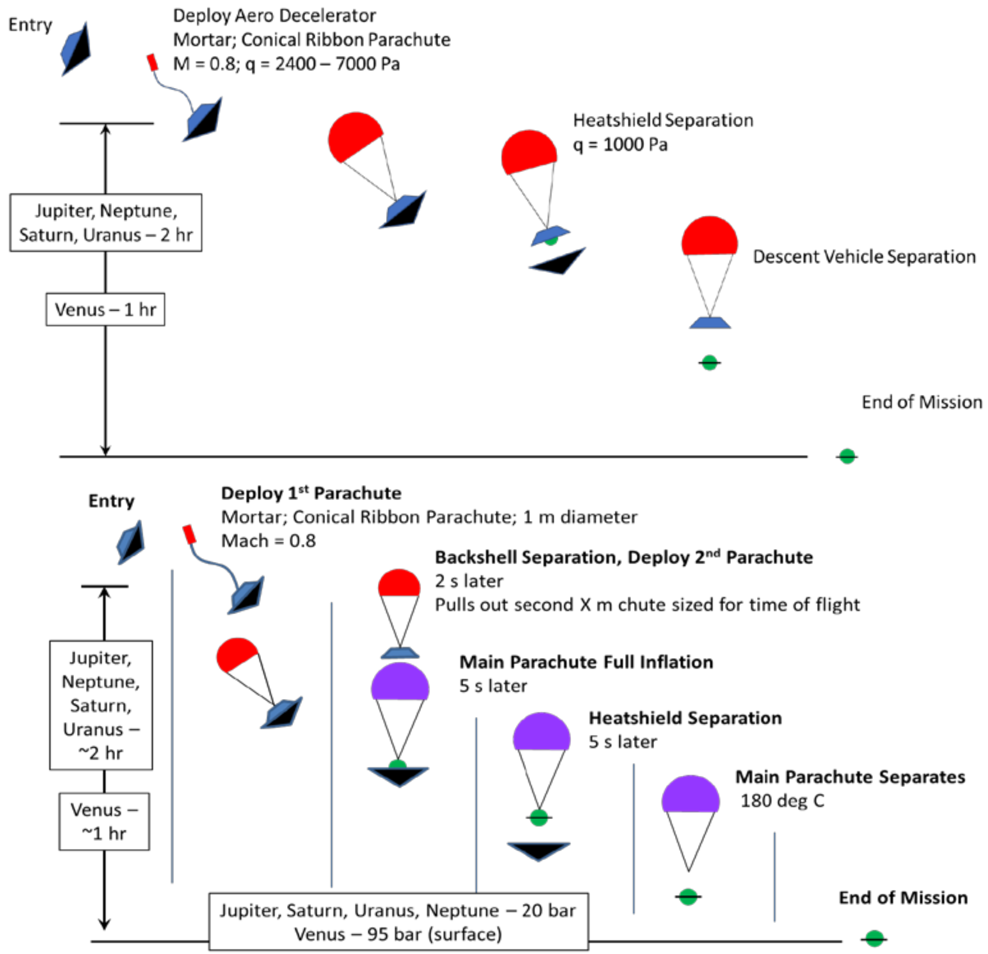
EDL ConOps + Mission Design



- **Two different scenarios**
  - 1 main parachute, 2.0 m diam conical ribbon, works for all 5 destinations
  - 1 pilot + 1 main:
    - Pilot is 1 m diam conical ribbon
    - Main parachute sized for destination
- **Both options are feasible, indicating flexibility in designing a concept of operations for Entry, Descent, and Landing**

"EVALUATION OF COMMON PROBE TRAJECTORIES AT MULTIPLE SOLAR SYSTEM DESTINATIONS," A. Cianciolo, *et al.*, IPPW 2018

Master Equipment List

Probe - Total				FLIGHT HARDWARE MASSES		
Subsystem/Component				Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
Probe						
Descent Vehicle				108.1	30.0%	140.5
Instruments				34.2	30.0%	44.5
Aeroshell				193.3	30.0%	251.2
Total Mass				335.5	30.0%	436.2

Probe - Descent Vehicle (DV)			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
C&DH	3.3	9.0	1	3.3	30.0%	4.3
Power	12.4	5.0	1	12.4	30.0%	16.2
Structure & Mechanisms	68.6	0.0	1	68.6	30.0%	89.1
Telecom	13.2	243.0	1	13.2	30.0%	17.1
Thermal	10.6	0.0	1	10.6	30.0%	13.8
Total Mass				108.1	30.0%	140.5

Probe - Instruments			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
MS	16.0	65.0	1	16.0	30.0%	20.8
TLS	6.5	35.0	1	6.5	30.0%	8.5
ASI	3.0	3.5	1	3.0	30.0%	3.9
NFR	2.0	4.5	1	2.0	30.0%	2.6
Ortho/Para	3.0	4.0	1	3.0	30.0%	3.9
Nephelometer	2.3	3.0	1	2.3	30.0%	3.0
Helium Abundance Detector	1.4	0.9	1	1.4	30.0%	1.8
Total Mass				34.2	30.0%	44.5

Probe - Aeroshell (AS)			# OF UNITS	FLIGHT HARDWARE MASSES		
Subsystem/Component	Unit Mass, kg (CBE)	Unit Power, W (CBE)	Flight Units	Total Mass, kg (CBE)	Contingency %	Total Mass, kg (CBE+Cont.)
Heatshield	144.1		1	144.1	30.0%	187.3
Heatshield structure (composite)	53.8					
Heatshield TPS (HEEET)	73.4					
Heatshield separation system	7.0					
Aeroshell instrumentation	10.0					
Backshell	25.1		1	25.1	30.0%	32.7
Backshell structure (composite)	13.4					
Backshell TPS (PICA)	11.7					
Mechanisms etc	4.0		1	4.0	30.0%	5.2
Parachutes	20.0		1	20.0	30.0%	26.0
Total Mass				193.3	30.0%	251.2

- **HEEET baselined for mass and cost (more mass efficient plus investments by NASA)**
- **Initial estimate had 400 kg for probe mass**
- **Including 30% contingency for growth allowance for all items, mass of “common” design is 436 kg (within 10% of original estimate)**
- **Additional mass is due to pressure vessel (required only for Venus)**
- **Another design iteration needed to incorporate updated masses**

Cost to build multiple copies of aeroshell

- **Preliminary costing which estimates the non-recurring vs recurring engineering portions indicates that cost savings could be realized by building multiple units at the same time**
  - Structure
  - Parachutes
  - TPS
  - EDL instrumentation
- **Storage costs not included in roll up**
- **As an example, building 5 units could reduce the cost of a probe by factor of ~3 (potentially less than $20M per probe)**
- **Higher fidelity costing is recommended as a follow-on activity**