National Aeronautics and Space Administration

A COMMON PROBE DESIGN FOR MULTIPLE PLANETARY DESTINATIONS

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Common Probe Study Team Members

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  - Jay D. Feldman
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- **NASA Goddard Space Flight Center (GSFC)**
  - Michael J. Amato
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- **Jet Propulsion Laboratory (JPL)**
  - David H. Atkinson
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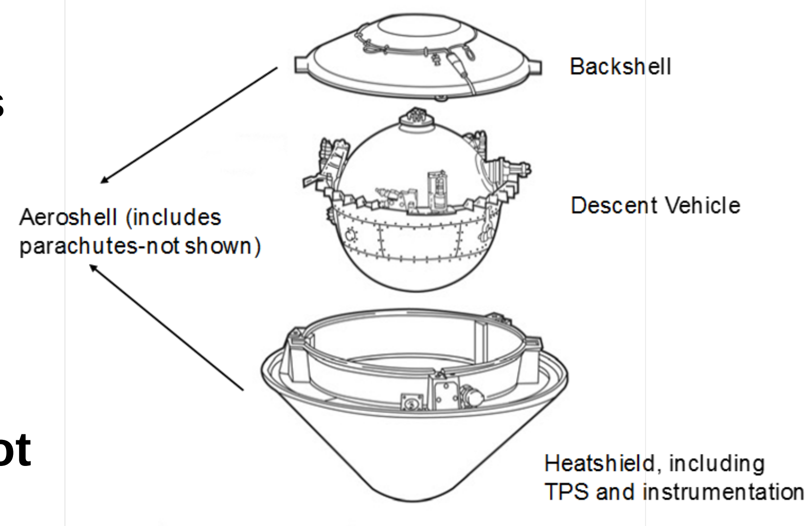
Background and study goals

- **At IPPW-14 (in 2017), during the Outer Planets session it was noted that many of the atmospheric probe designs seemed similar**
  - Are we designing the same probe over and over again?
  - Can we increase efficiency by designing one probe and using that design at multiple destinations?
  - Can we further increase efficiency by building multiple copies of that probe and store them for future use (and offer to mission designers as GFE)?
  - What potential risks or inefficiencies are introduced by using a common design and building multiple copies?
- **The Planetary Science Division of the NASA Science Mission Directorate funded a study from October 2017 – June 2018, involving 4 NASA Centers (ARC, GSFC, JPL, and LaRC), to address these issues**

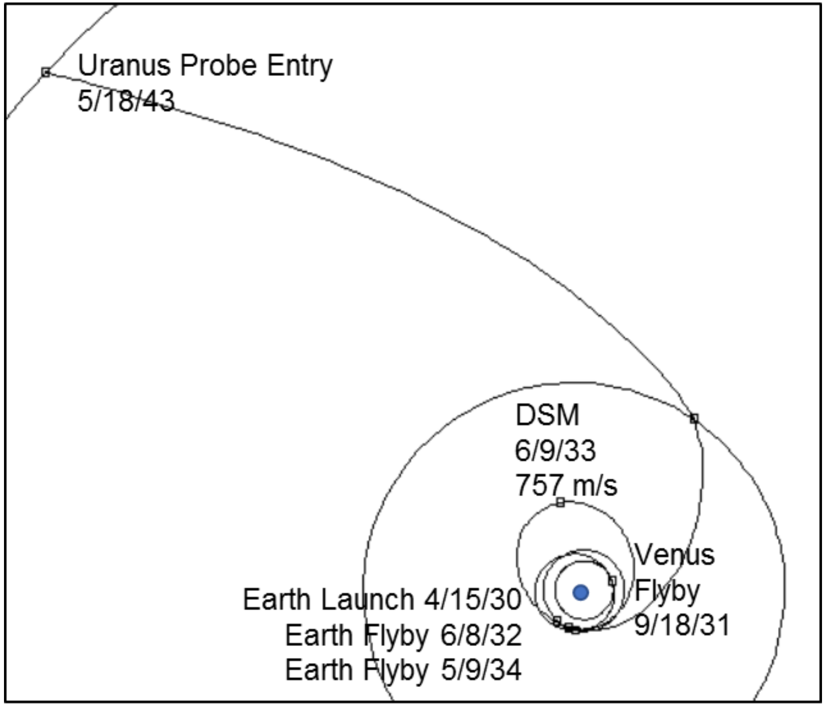
Study scope and assumptions

- **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.)

Interplanetary Trajectories



*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

“INTERPLANETARY TRAJECTORY DESIGN FOR NASA’S COMMON PROBE STUDY,” K. Hughes, *et al.*, IPPW 2018

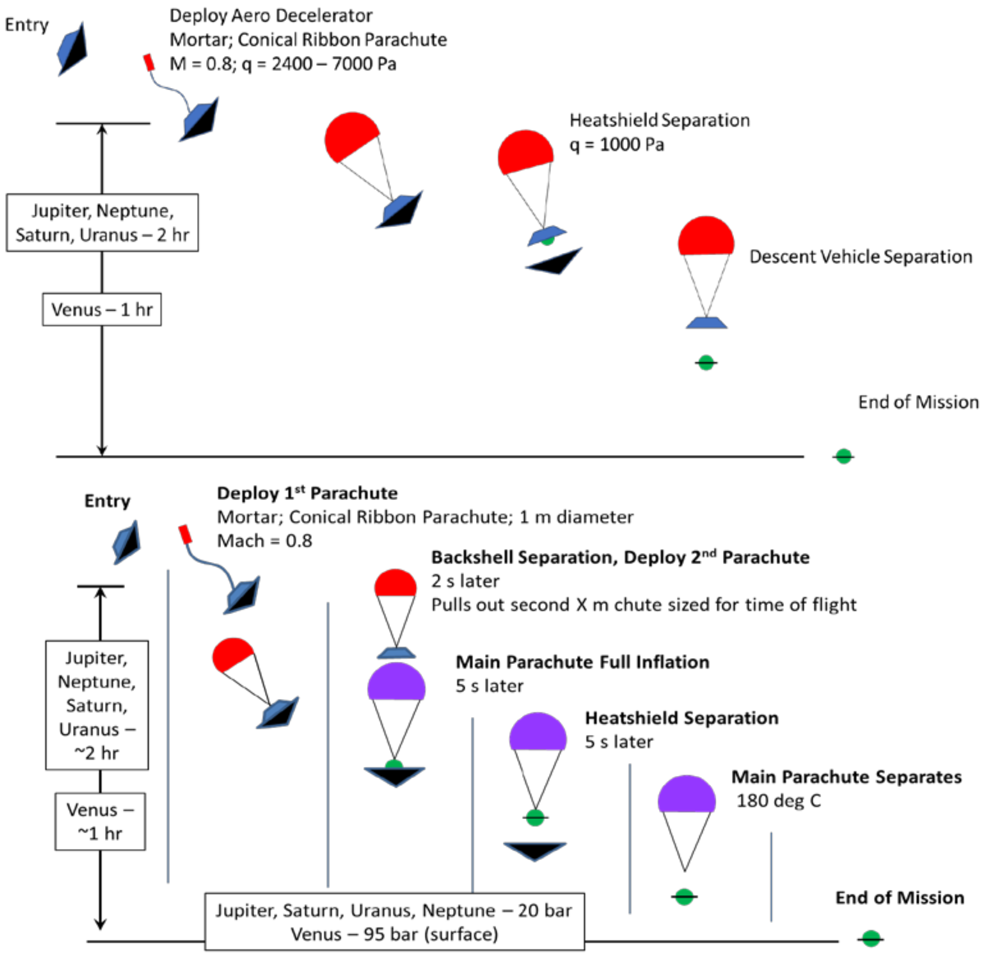
Strawman Payloads

- **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 minimum payload at the 5 destinations based on packaging ratios from previous missions and studies**

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
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

EDL ConOps + Mission Design

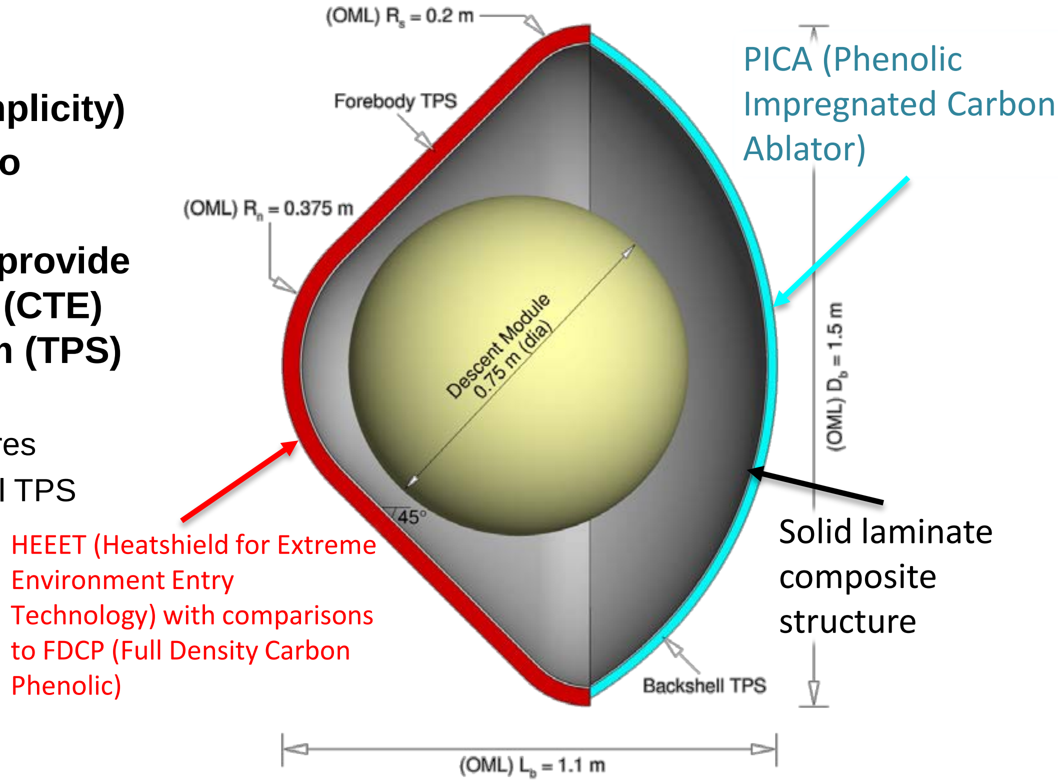


- **Two different scenarios**
  - 1 main parachute, 2.0 m diam conical ribbon, works for all 5 destinations
  - 1 pilot + 1 main:
    - Pilot is 1 m diam conical ribbon
    - Main parachute sized for destination
- **Both options are feasible, indicating flexibility in designing a concept of operations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

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

Aeroshell design assumptions

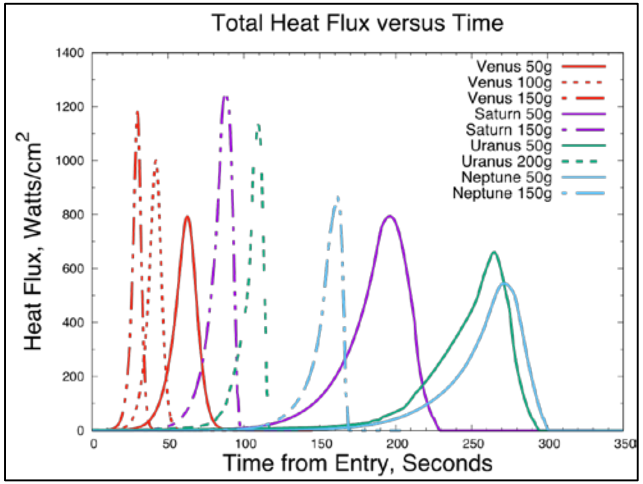
- **45°-sphere cone forebody (aerodynamic stability)**
- **Hemispherical-cap backshell (design simplicity)**
- **Probe diameter and nose radius similar to Pioneer Venus Large Probe (PVLP)**
- **Structure is solid laminate composite to provide a better coefficient of thermal expansion (CTE) match with 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

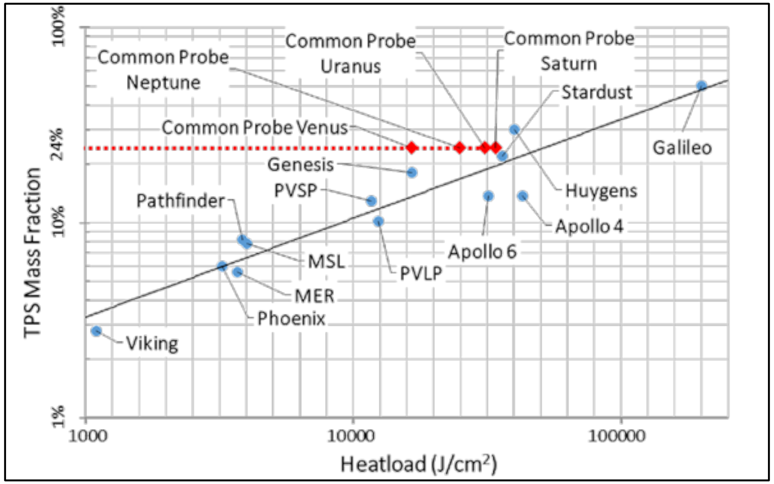


	Base diameter (m)	Nose radius (m)	Ballistic Coefficient (kg/m²)	Entry mass (kg)
Common Probe	1.5	0.375	216	400
PVLP	1.42	0.36	188	316
Galileo	1.26	0.222	256	335

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)**
- **TPS mass fraction in-family with historical missions**





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

Special considerations due to “make ahead”

- **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

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**

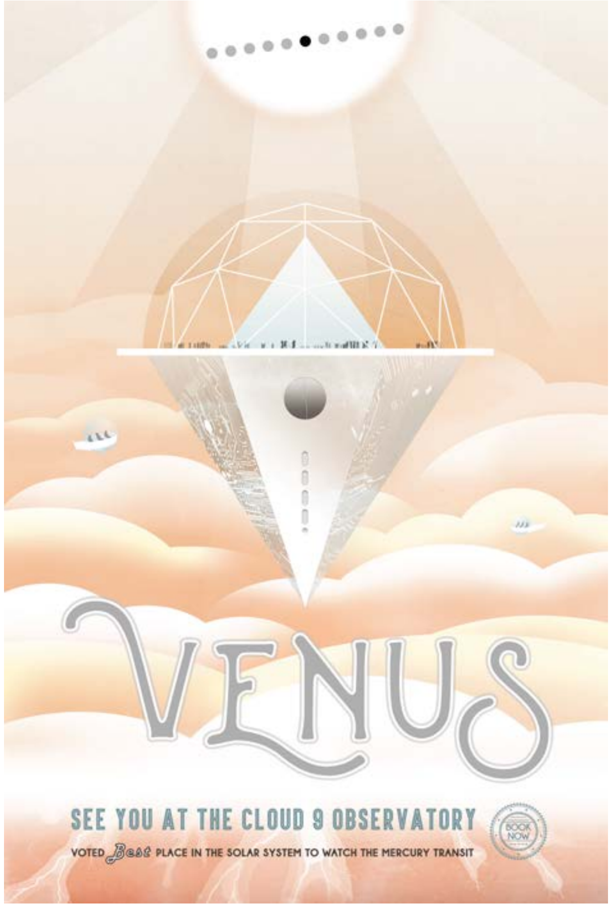
Summary and recommendations

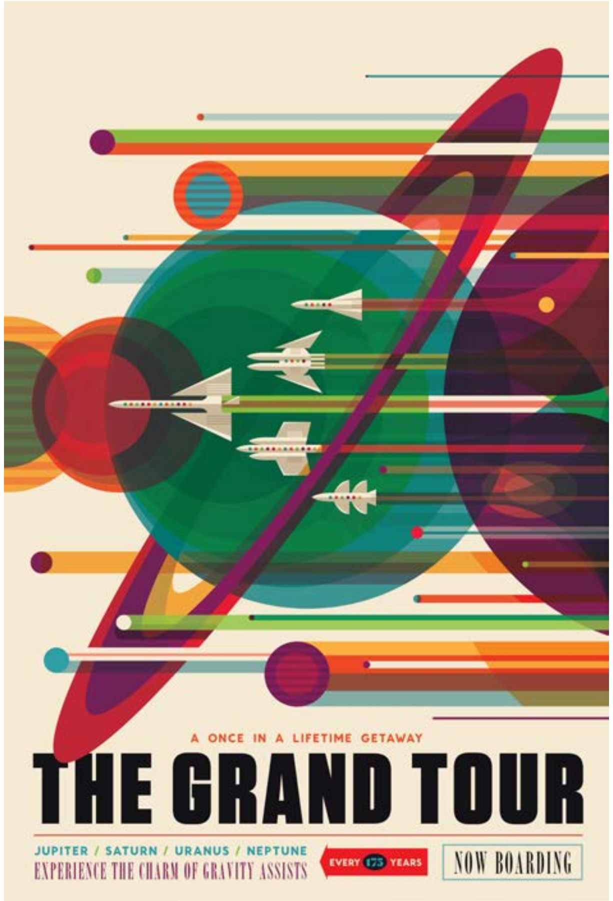
- **A common atmospheric probe design for Venus, Saturn, Uranus, and Neptune missions is feasible**
- **Missions to Jupiter should be considered separately due to heat loads**
- **Further analysis is needed**
  - Additional design cycle to account for updated masses, trajectory changes, etc.
  - Higher fidelity tools (CFD, structural analysis, etc) for better mass estimates
  - Better cost estimates
- **Using one design to build multiple copies and store for later use can offset the risk of losing skills and material resources decades downstream**
  - Venus missions in particular pay a mass penalty—but consequently may have greater mission flexibility (low-g entries)
  - Should explore optimal number of units to build based on cost and schedule
- **Risk of aging should be explored by building coupons and testing (accelerated aging?)**

Next steps

- **Report drafted and will be submitted to PSD/SMD**
  - Will be published as a NASA TM
- **Community feedback!**
  - IPPW
  - OPAG
  - VEXAG
- **Next round of analysis is desired:**
  - High fidelity analysis (CFD for convective aerothermal heating, detailed radiative heating calculations, structural sizing, costing, etc.)
  - Project formulation (~one year to scope effort to design and build multiple copies?)

Questions?





Images: NASA/JPL-Caltech