Neptune Odyssey Mission and Entry Descent Trajectory Design

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Introduction

Neptune is a prime destination for future exploration missions. This study developed the mission concept including the Flagship-class orbiter and atmospheric probe to Neptune. The results of this study will be used as the Decadal Survey considers NASA's planetary science priorities from 2022-2032. This poster will focus on the design of the entry and descent sequence for the atmospheric probe.

Mission Design

- **Launch opportunities**: 2030 – 2040
- **Minimum Delivery Mass**: 3400 kg (after Neptune Injection)
- **Launch Selected to Study**: 2033 (stress case)
- **Arrival Date:** 2049
- **Approach Phases**: (1) Separation of atmospheric probe (SEP), (2) Divert Maneuver (DM), (3) establishment of communication with atmospheric probe during descent (Link), (4) Neptune Orbit Insertion (NOI)
  - Approach Maneuver was designed to meet atmospheric entry conditions.
- **Deployment**: Hyperbolic Approach

Probe Trajectory and Concept of Operations

- EDL trajectory is shaped to maintain communications between the probe and orbiter while meeting acceptable maximum sensed acceleration, heat flux, and heat load requirements.
- The duration of the trajectory was designed such that there was enough time to uplink data from the probe to the orbiter -- telemetry is only possible during descent.

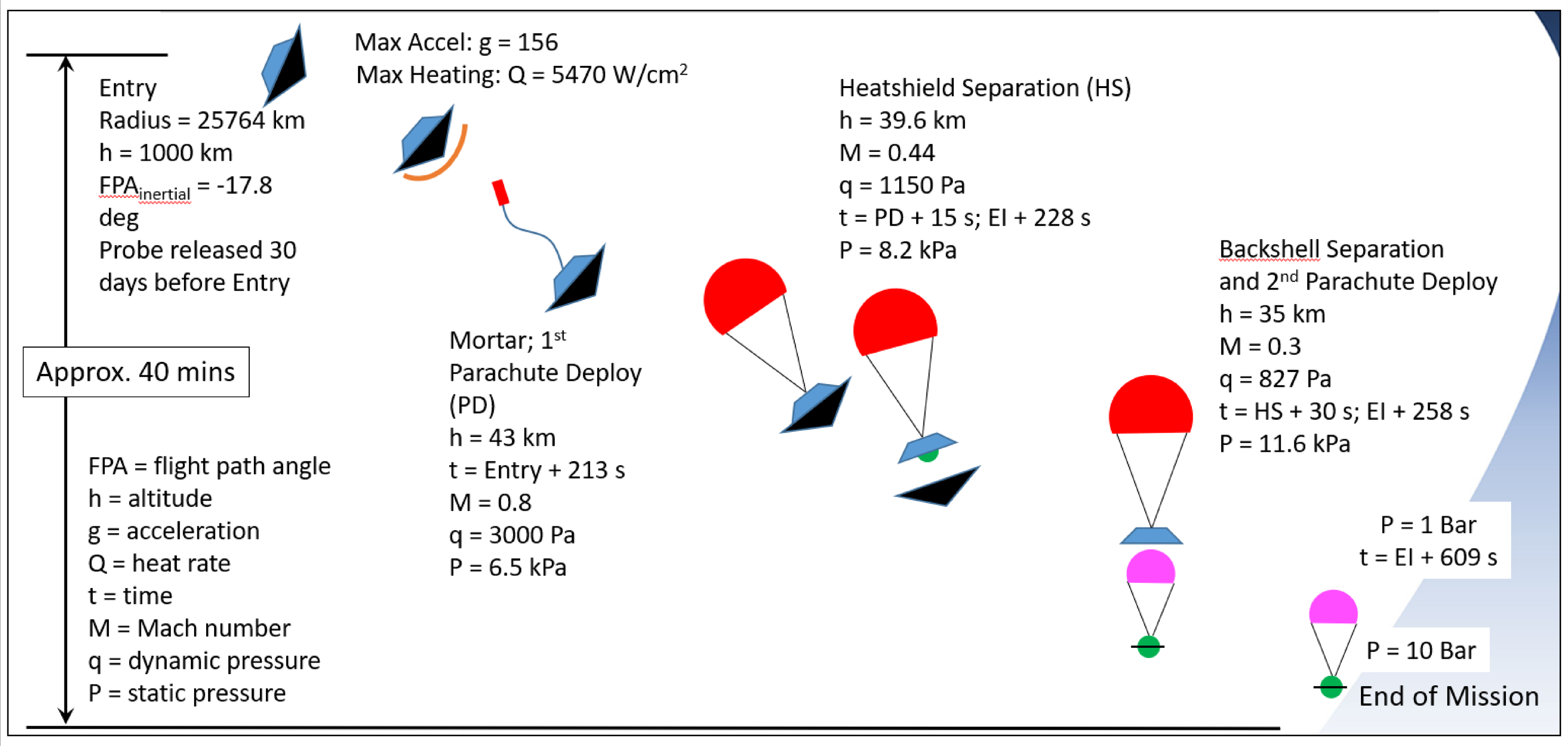

Fig 5. Probe trajectory and concept of operations

Thermal Protection System Design

- HEEET has been qualified up to ~3600 W/cm² and ~5.4 bar pressure.
- Extension to ~5000 W/cm² (unmargined) and ~ 6.5 bar pressure is considered low risk.
- While HEEET was tested at 14 bars pressure and did not fail, material response was uncharacterized.

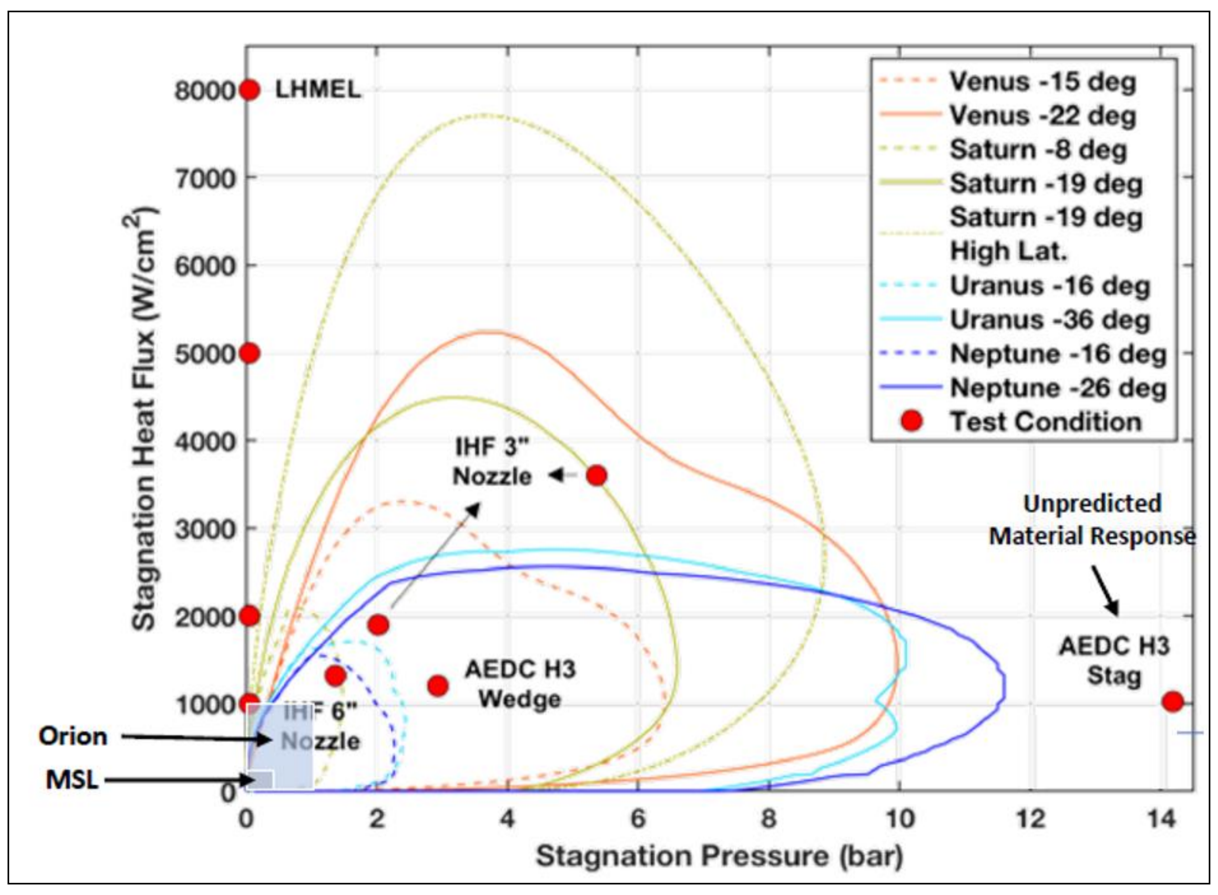

Fig 8. HEEET Arc Jet Testing Overview with Notional Mission Environments

- The 0.3 m nose, 325 kg probe case results in HEEET thickness at the limit of manufacturing capability.
- Reducing probe mass results in more favorable environment which allows for a more readily manufacturable HEEET thickness (See Fig 9).
- All 0.4 m nose radius cases (consistent with current design) are more readily manufacturable than the 0.3 m nose cases.

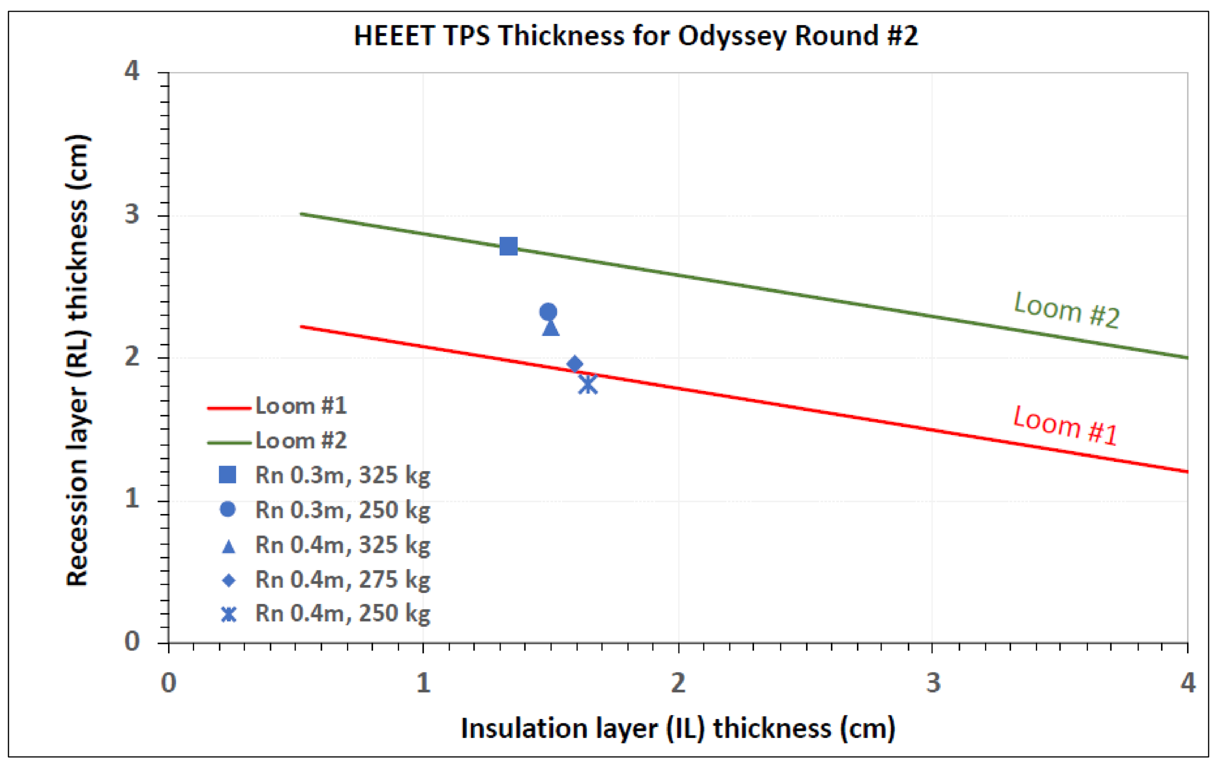

Fig 9. TPS Sizing and HEEET Weaving Capability

Entry, Descent, and Landing Assumptions

- **3 degree of freedom trajectory analysis**
- **Entry Vehicle**
  - 45 deg half-angle-sphere cone (Heritage from high velocity entries such as Pioneer Venus and Galileo at Jupiter)
  - Entry Body Diameter: 1.26 m
  - Nose Radius: 0.4 m
  - Ballistic Coefficient: 220 kg/m²
- **Parachutes**
  - 1st Parachute: Canonical Ribbon: 2.5 m
    - Deploy at Mach 0.8
    - Mortar deployed
    - Used for separation system – separate heatshield and then probe from backshell
    - Heritage from Pioneer Venus and Galileo (Jupiter)
  - 2nd Parachute: Ringsail: 1.5 m
    - Deploy at Mach 0.2
    - Increase descent time by 10 min
    - Inflates as backshell separates (not mortar deployed)
    - Heritage from Earth flights at low subsonic conditions
- **Atmosphere**: Neptune GRAM 2004 atmosphere
- **Descent Probe**: Diameter 0.7 m

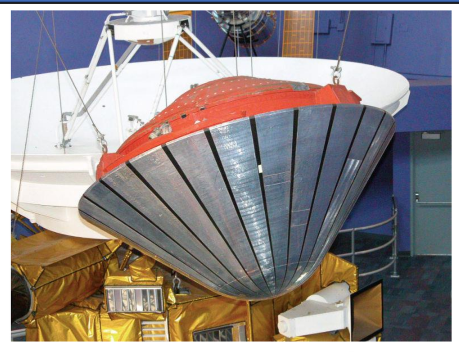

Fig 1. Pioneer Venus Credit: NASA

Fig 2. Probe Concept Design. Credit: APL

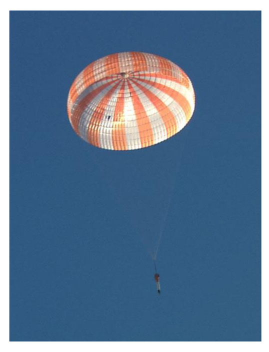

Fig 3. Ringsail Parachute. Credit: NASA

Fig 4. Conical Ribbon Parachute. Credit: NASA

Probe Communication to the Orbiter

- During peak deceleration, probe and orbiter potentially have occultation based on geometry.
- Communication reduction due to plasma blackout during that phase is expected.
- The analysis is based on pure geometry between probe and orbiter, which has favorable orientation once vehicle is on parachute.

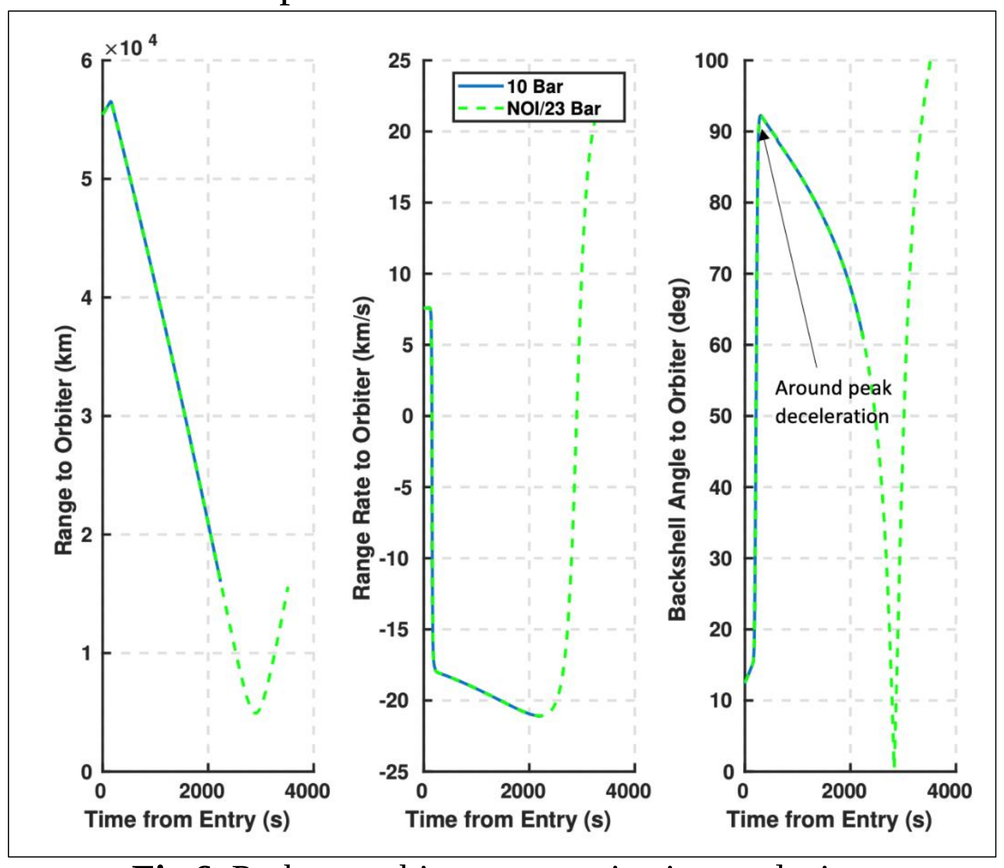

Fig 6. Probe to orbiter communication analysis

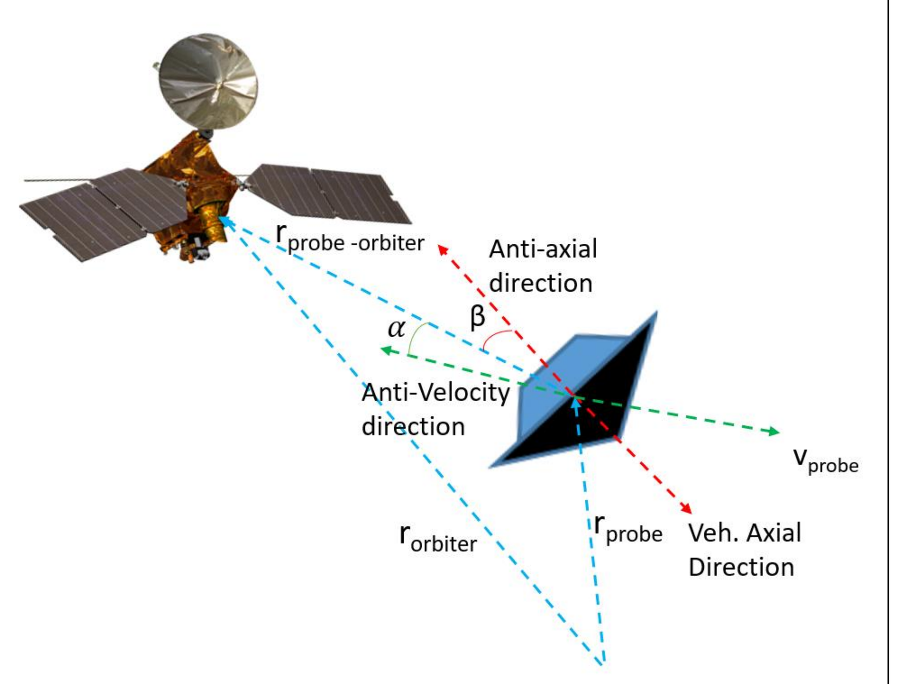

Fig 7. Probe to orbiter frame definition

HEEET Overview

- HEEET (Heatshield for Extreme Entry Environment Technology) is an integrally 3-D woven, dual-layer, resin infused, ablative system.
  - An efficient, optimized, carbon phenolic TPS using modern manufacturing & materials.
- Dense outer recession layer (RL) is designed to be robust in highest heat flux & pressure environments.
- Inner insulation layer (IL) handles the heat load with its lower density & thermal conductivity yielding reduced TPS mass fraction.
- Missions must consider weave thickness limitations (~5.5 cm), derived from current 3D loom capabilities, although upgrades can increase this
- Tiled arrangement requires seams.
- Scalable & tailorable for a wide variety of missions.
  - A full campaign of aerothermal + structural testing, system testing, & model validation enabled TRL 6 for tiled HEEET to approximately 4m diameter.

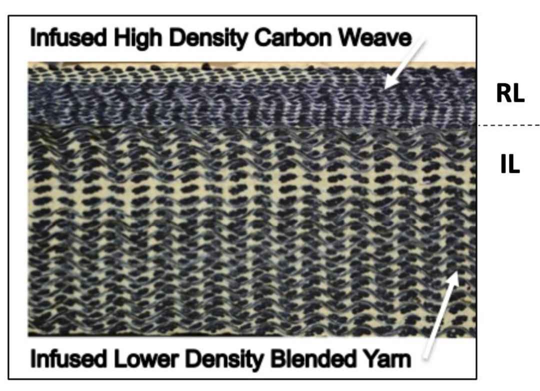

Fig 10. HEEET cross-section. Credit: NASA

Fig 11. HEEET 3D Woven Preform. Credit: NASA

Estimated Environments & HEEET Sizing

- Case # 1 results in stagnation pressure (6.7 bar) far enough from existing HEEET testing (up to 5.4 bar) that qualification risk becomes higher.
- Case # 2, with its blunter nose, reduces the stagnation pressure and thereby lowers qualification risk, and results in more readily available manufacturable HEEET thickness.
- Cases # 3 – 5 demonstrate that a lower probe mass, for consistent nose radius, reduces entry environments, eases the burden of qualification, and reduces the TPS mass required.

Table 1. HEEET Sizing Results for Various Environments

Case #	Probe Mass (kg)	Nose Radius (m)	Ballistic Coefficient (kg/m²)	Deceleration (g)	Max Stag. Pressure (bar)	Max Stag. Heat Flux (W/cm²)	Heat Load (J/cm²)	HEEET RL Thickness (cm)	HEEET IL Thickness (cm)	HEEET Mass (kg)
1	325	0.3	260	165	6.7	2696	68276	2.40	0.83	57.0
2	325	0.4	250	163	6.3	2381	61192	1.83	1.00	48.6
3	250	0.4	190	149	4.3	3085	56154	1.44	1.14	43.3
4	250	0.3	200	152	4.6	2402	63080	1.95	0.99	50.7
5	275	0.4	210	154	5.0	2191	57985	1.58	1.09	45.2

References

[1] Davies C. et al. (2006) *Planetary Mission Entry Vehicles Quick Reference Guide. Version 3.0* [2] Venkatapathy E. et al. (2020) *Entry System Technology Readiness for Ice-Giant Probe Missions, Space Sci Rev 216*, 22. [3] Sengupta A. et al. (2011) *Challenges of a Venus entry mission*, Big Sky, MT, USA. [4] Prabhu D. (2019) *Exploration of Atmospheric Entries at Uranus & Neptune with HEEET as Heatshield TPS*, Workshop on In Situ Exploration of the Ice Giants, Marseille, France. [5] http://neptuneodyssey.jhuapl.edu/