A TPS DESIGN ANALYSIS OF ENTRY PROBE DELIVERY FROM ORBIT FOR ICE GIANT MISSIONS.

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Introduction: Previous investigation of direct delivery of a probe into Neptune's atmosphere showed said approach to be challenging due to high stagnation pressures and heat loads [1,2]. Entering at a high entry flight path angle (EFPA) results in stagnation pressure beyond current Heatshield for Extreme Entry Environment Technology (HEEET) qualification, while entering at a lower EFPA results in higher heat loads, leading to required HEEET thicknesses beyond current manufacturing capabilities. Aerocapture is an enticing alternative entry scenario because it enables a fast trip and the placement of a payload in orbit around Neptune that can also reach Triton. Here, we investigate entry conditions associated with delivering a probe from orbit to assess feasibility. We consider whether 1) this entry scenario results in reasonable conditions, and 2) HEEET single insulating layer (3D mid-density carbon phenolic, 3MDCP) can be used to decrease mass, risk, and cost.

Methods: The trajectory analysis code TRAJ was used to generate aerothermal environments experienced during entry. The entry state and aeroshell geometry parameters listed in Table 1 were kept constant, while a coarse sweep was initially conducted over inertial entry velocity, vehicle mass, EFPA, and latitude/azimuth combination (Table 2). The resulting environments were then fed into the Fully Implicit Ablation and Thermal Response (FIAT) model for TPS sizing.

Entry State	
Entry Altitude	1000 km
Entry Longitude	163.3°
Angle of Attack	0°
Bank Angle	0°
Mach # of Parachute Deployment	0.8
Heatshield Geometry	
Nose Radius	0.3 m
Corner Radius	0.00001 m
Base Radius	0.63 m
Half Angle	45°

Table 1. Entry state and aeroshell geometry parameters kept constant throughout the sweep.

Inertial Entry Velocity (km/s)	Mass (kg)	EFPA (°)	Lat & Az (°)
22.5	275	-15	0 & 247
22.7	300	-20	0 & 270
22.9	325	-25	0 & 180
			-23 & 270

Table 2. Entry state parameters used in initial coarse sweep.

Results: Required TPS thickness was found to have a strong dependence on EFPA, with smaller dependence on azimuth and negligible dependence on latitude, entry velocity, and mass within the range outlined in Table 2. Increasing EFPA caused a decrease in TPS thickness but also an increase in stagnation pressure, reaching pressures that exceed the current limits of the NASA test facilities of 6 bar. An 8% decrease in TPS thickness was associated with changing the entry azimuth from 270° to 180°. None of the cases resulted in total heat fluxes that exceeded existing TPS tested ranges. Additionally, thicknesses were well below the loom capabilities of 1.2" for 80" width.

After the coarse sweep was done, the grid was widened and refined for the two parameters that most affected the TPS thickness (EFPA and azimuth). The mass was held at 300 kg, latitude at 0°, and inertial entry velocity at 22.5 km/s. As shown in Fig. 1, the range of allowed EFPAs was found to be from -11.5° (driven by the TPS thickness) to -18.5° for retrograde or -20° for posigrade orbits (driven by stagnation pressure). An optimal entry state is shown with a star on Fig. 1. Because of the low dependence on mass, velocity, and other parameters, these can be tuned to the needs of the project without a major effect on the TPS thickness.

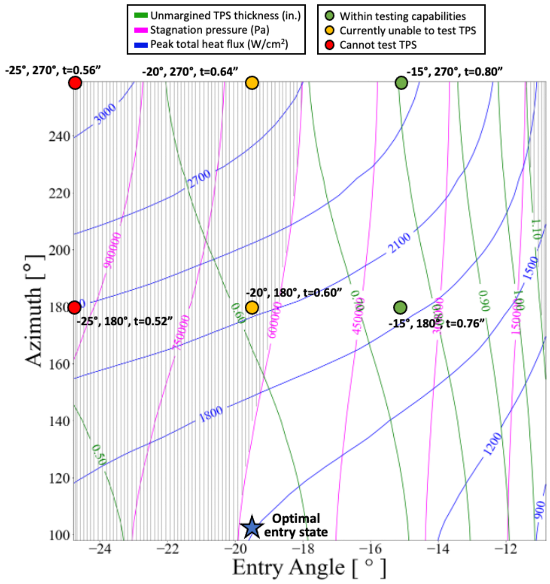

Figure 1. Contours of TPS thickness, stagnation pressure, and peak total heat flux for various EFPAs and azimuths.

These results show that entry from orbit opens the trade space in comparison to ballistic entry [3]. A similar analysis will be performed for Uranus and results will be presented in the final presentation.

References: [1] Venkatapathy, E. et al. (2020) *Space Sci Rev, 216:22*. [2] Prabhu D. (2019) *Workshop on In Situ Expl. of the Ice Giants*. [3] Ice Giants Pre-Decadal Survey Mission Study Report, NASA (2017).