Next Generation Thermal Protection Systems for Outer Planet Missions

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Introduction: Saturn Probe and Ice Giant Orbiter along with in-situ Probe Missions continue to be very high priority missions. A result of the advocacy by OPAG and other Analysis Groups, the 3D Woven, Dual-Layer HEEET thermal protection system, mature at TRL 6, has closed the TPS gap for extreme environment missions. A mid density follow on to DL HEEET, developed to meet earth entry requirements, is a Single Layer variant of the 3D woven TPS, which provides a mass efficient single layer 3D Mid-Density TPS (3MDCP) that has been baselined as the heat-shield for MSR EEV. Continued development of 3MDCP will elevate it to TRL 6 by 2025. Conformal-PICA (C-PICA) development was pursued to establish a more efficient and robust alternate to PICA, and it is at TRL 4+.

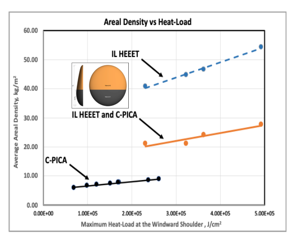
Our rationale for the next generation of TPS development is based on the on the missions needs of the next decade Outer Planet missions that are unique and more demanding than any other destinations. Taking advantage of the recent planned development of several materials, the next generation of TPS offers a much more mass efficient option for small, medium, and large class Outer Planet missions.

Saturn Probes: While mission designers are generally interested in shallow entry to maintain the g-load during entry around 50g, the heat-load for shallow entry can range between (100 kJ/cm2 – 300 kJ/cm2), two orders of magnitude higher than Venus or Sample Return missions. TPS must not only offer protection but must be mass efficient to perform reasonable science. TPS mass can quickly become 50% or more of the mass of the entire entry system. Recent analysis performed shows Saturn Probe missions could significantly benefit from the single layer HEEET (SL-HEEET/3MDCP). A DL-HEEET based heatshield mass could be ~ (40% -50%), SL-HEEET can provide additional (30% - 50%) mass savings. At the same time, C-PICA can provide (30% - 50%) mass savings on the backshell. The combined mass savings can be significant enough to carry an additional probe, if desired.

Ice Giant Aerocapture Missions: Aerocapture mission architectures can provide significant advantage over traditional propulsive insertion missions in multiple ways. 1) Reduced trip time ~ (4- 6) years (30% - 40%), 2) Enables placing the orbiter, probe, and lander, all together and 3) Allows for greater science mass (probes and landers) due to mass efficiency. The delivery of a probe from orbit makes it easier and eliminates mission design constraints by HEEET for direct entry [4] of probes and allows for more targeted in-situ science once the Orbiter is able to collect data. In the past 20 years, progress made in GN&C for lift-guided entry missions (MSL, Orion EFT1, Mars 2020) and the expertise in blunt body aerodynamics at large scale (~ 5m) has led the EDL community to conclude that aerocapture is a "go do" engineering activity. An aerocapture mission that will deplete the excess energy of a fast arrival mission will require a mass efficient TPS that can handle extreme heat-load, ~ (100 kJ/cm2 – 500 kJ/cm2). Hence TPS, feasibility as well as mass efficiency requires assessment. Utilizing the recent developments, a comprehensive, bounding analysis was done to establish the potential for SOA (HEEET) system as well as emerging new TPS such as SL-HEEET and C-PICA.

In this proposed poster, we will outline the process by which we establish bounding aerocapture trajectories for hyperbolic excess velocities ranging from 27 km/s to 35 km/s, for low L/D (~ 0.4) configurations and determine conservative/bounding estimate of aerothermal environment by using a combination of CFD simulations and stagnation point heating estimates [7]. This engineering approach allows us to assess the TPS need *vs*. TPS capability and determine the applicability of existing TPS. Once an applicable suite of TPS is determined, the TPS thickness and mass are computed.

We show that the TPS mass fraction can be as low as 5% to as high as 20%, depending on the use of advanced TPS, while HEEET is sufficient but will require 50% of the entry mass.



Areal Mass Comparison for aerocapture mission (Neptune-Triton) for SL-HEET, C-PICA and combination.

References:

1. Venkatapathy, E., Prabhu, D., Allen, G., and Gasch, M., "Thermal Protection System to Enable Ice Giant Aerocapture Mission for Delivering both an Orbiter and an in-situ Probe," a white paper submitted to the Planetary Science and Astrobiology Decadal Survey, 2020.