Thermal Protection Design for Uranus Orbiter Flagship Mission: Probes and Aerocapture

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Introduction: The Decadal Strategy for Planetary Science and Astrobiology prioritized a Uranus Orbiter and Probe (UOP) as the highest-priority new Flagship mission for the 2023 – 2032 decade [1]. Missions to the outer solar system require significant interplanetary cruise durations on the order of 12 – 15 years while carrying propellant to reduce velocity by several km/s to achieve a desired orbit. Parasitic mass and travel time can be traded where faster arrival velocities require more mass expensive capture burns. Recent advancements in Thermal Protection Systems (TPS) for planetary entry enable mass-efficient designs for atmospheric probes and missions that apply aerocapture for orbit insertion.

Probes and Aerocapture: Probes enable in-situ measurements of the atmosphere: composition, temperature, pressure while descending into the planet. The rapid deceleration experienced by the probe and the exposure to denser portions of the atmosphere generates a need for robust TPS solutions.

Aerocapture reduces the need for decelerating burns upon approach by using the atmosphere of the arrival planet to create aerodynamic drag and achieve orbital insertion. This reduces interplanetary transit time by 2 -5 years (15-30%) while increasing on-orbit payload mass (more than 40%) [2,3]. The penalties are introducing planetary re-entry to mission design and its associated sub-systems: an aeroshell with the necessary TPS and guidance and control (G&C). The aeroshell is the primary mass adder and TPS, which protects against the resultant aerodynamic drag heating, is a major contributor.

Thermal Protection Systems Design: Capable ablative thermal protection materials exist which enable both in-situ probes and aerocapture at Uranus. Low and mid density material systems such as PICA (Phenolic-Impregnated Carbon Ablator) and 3MDCP (3-D Mid-Density Carbon Phenolic) are generally robust to the surface environments created by aerocapture with current flagship entry vehicle designs [4]. Higher density materials such as Heatshield for Extreme Entry Environments (HEEET) are an option for probes that experience extreme environments.

For any given mission, TPS material is typically selected by reviewing stressing heat flux, pressure, and shear levels across the aeroshell. Materials with proven capability in the appropriate environmental regimes, demonstrated through flight or ground testing, are considered. The materials are then sized for necessary thickness to retain operating temperatures in all aeroshell material systems. The most mass efficient TPS material is usually selected unless other mission requirements such as micrometeoroids and orbital debris (MMOD) robustness, must be factored.

Another important factor in TPS design is eliminating and reducing exposure to potential failure modes. Seams between material panels are the most commonly recognized feature that could introduce failure modes such as differential recession rates between seam material and the acreage material. Recent advancements of a new material, conformal PICA (C-PICA), enables forming of the TPS material around the curvature of the aeroshell which reduces the number of tiles and associated seams. Additionally, C-PICA is a less dense and lower conductivity material system than PICA, creating a more mass efficient solution.

Preliminary Results: For this abstract, preliminary TPS sizing results were completed for an aerocapture mission that uses the Space Launch System (SLS) and a MSL-derived 70°, 4.5m diameter sphere-cone aeroshell which houses the UOP payload mass. The 3600kg entry vehicle experiences approximately a 10 minute heat pulse with maximum heating rates at the stagnation point of almost 400 W/cm^2. Areal mass of the three mentioned TPS materials are: 3MDCP – 65 kg/m^2, PICA – 20 kg/m^2, and C-PICA – 14 kg/m^2. While C-PICA is the most mass efficient material, its total thickness is nearly at the manufacturing limit of 6.35 cm. Further investigations will consider a dual system of a PICA nose cap and C-PICA skirt to protect against mass increases. The presentation or poster will include TPS results for in-situ probes.

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