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Exploration of Atmospheric Entries at Uranus & Neptune with HEEET as Heatshield TPS

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Background

NASA recently completed a comprehensive study [1] on possible missions to the Ice Giants – Uranus and Neptune. The study explored mission architectures, science instruments, atmospheric probes, *etc*. The atmospheric probes considered in the study were blunted 45° sphere-cones (1.2 m base diameter), and were scaled versions of NASA's successful Galileo probe [2], which entered Jupiter's atmosphere in 1995. In addition to considering Galileo-heritage material FDCP (full-density carbon-phenolic) for the probe heatshield, and PICA (Phenolic-Impregnated Carbon Ablator) for the backshell, the Ice Giants Study also considered a new thermal protection material called HEEET (Heatshield for Extreme Entry Environment Technology) [3] as an alternate, especially since the legacy material is no longer manufactured for NASA's planetary science missions. HEEET is a dual-layer woven material that is significantly more mass efficient than full-density carbon-phenolic, and towards the end of its development cycle; target for TRL 6 is April 2019. The two layers of HEEET are: (a) an outer layer composed of a dense carbon fiber intended to handle the high heat flux of atmospheric entry, and (b) an inner (insulation) layer consisting of a lower density, lower thermal conductivity weave of blended carbon and phenolic fibers intended to manage the heat load of atmospheric entry (reduce the temperature at the bondline between the TPS and the structure to which it is attached). The primary advantage of HEEET is that the thicknesses of the woven layers can be customized to a specific mission in order to optimize mass.

Objective and Methodology

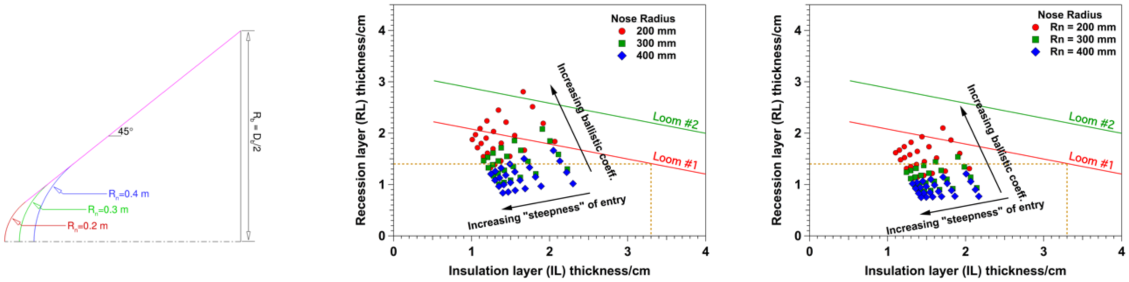
One important observation from the Ice Giants Study was that the predicted and margined thicknesses of HEEET were greater than could be woven with the currently established loom capabilities. Since the cost of a loom upgrade would be substantial, the present work explored the entry trajectory space to determine what combinations of entry parameters would result in HEEET thicknesses that fit within the existing loom infrastructure. Toward this end, the entry trajectory space, parameterized by ballistic coefficient and entry flight path angle, was systematically explored for 45° sphere-cone geometries of 3 different radii – 0.2 m, 0.3 m, and 0.4 m – which covered the range from Galileo-derived probes considered in the Ice Giants Study, and a follow-on study [4] on the possibility of using a single probe architecture (in terms of size and mass) for various destinations, including Venus, Saturn, Uranus, and Neptune. The entry velocities, latitudes, and azimuths at Uranus and Neptune used in the present work were taken from the Ice Giants Study [1]. For each 3DOF trajectory generated by a NASA Ames in-house code, *TRAJ* [5], the material response and thickness were computed using another NASA Ames code, *FIAT* [6], along with a margins policy proposed by the HEEET project [7]. In the present work, ballistic coefficients ranging from 200 kg/m^2 to 350 kg/m^2 were considered along with entry flight path angles ranging from -16° to -36° (primarily to allow deceleration loads to vary between 50 g and 200 g).

Results and Conclusions

Sample results from these exploratory computations are shown in Fig. 1. The loom weaving limits are shown as solid lines, and the predicted (and margined) thicknesses of HEEET are shown as closed symbols for the various nose radii, entry ballistic coefficients and entry flight path angles.

- For the cases explored here, there are several possible HEEET solutions that fall within the current manufacturing capabilities, *i.e.*, no upgrade is required beyond the present loom capability.
    - Additional manufacturing development work (other than weaving) may be required if the estimated thicknesses of the recession layer deviate substantially from the currently demonstrated capability
- The entry flight path angle determines the maximum deceleration and pressure loads. Therefore, the entry flight path angle will be limited by the ability to demonstrate material performance in ground-test facilities, *e.g.*, arc jets. Note: HEEET has been successfully tested beyond 5 bar and up to a heat flux of 3.6 kW/cm^2.

  - Ultimate pressure capability of HEEET has not been established, and future tests should be able to expand the currently known HEEET performance envelop
- Regardless of entry flight path angle considerations, HEEET is most mass efficient for low ballistic coefficients. Ballistic coefficients between 200 and 250 kg/m^2 (±25 kg/m^2) work for the cases explored here
  - The ballistic coefficient selected can be translated into either a mass (given the base diameter) or a diameter (given the entry mass)
- In addition to limiting the ballistic coefficient to lie between 200 and 250 kg/m^2, it is better to keep the nose radius between 0.3 m and 0.4 m
  - The convective heating of the deceleration module decreases because of increased bluntness, and
  - The HEEET constraint of a demonstrated forming to a minimum spherical radius of 0.25 m is satisfied
  - Radiative heating is likely to be negligibly small for Uranus and Neptune entries.



(a) Probe geometries **(b) HEEET for Uranus entries** **(c) HEEET for Neptune entries**

Figure 1. (a) 45° sphere-cone geometries – the base diameter is determined from the definition of ballistic coefficient for a given mass; (b) HEEET recession and insulation layer margined thicknesses for equatorial entry at Uranus for an entry velocity of 22.3 km/s; and (c) HEEET recession and insulation layer margined thicknesses for equatorial entry at Neptune for an entry velocity of 24.7 km/s. All sizing has been performed assuming a 3.8 mm thick layer of HT-424 adhesive and 3.2 mm thick Al-2024 structure to which HEEET is bonded. The structural component can be easily switched to another material. The impact on sizing will depend on the heat capacity of the new structural material relative to Al.

Future work

The cases explored here were limited to a representative entry velocity at each destination (dictated by the interplanetary trajectories available). Sensitivity of material sizing to entry velocity has to be explored. The heating estimates used in sizing HEEET were derived from engineering correlations. Verification of these correlations against results from detailed flow computations remains to be done.

Acknowledgments

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References:

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