View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

BALLISTIC ENTRIES FOR SATURN, URANUS, AND NEPTUNE WITH HEEET TPS.

D. K. Prabhu[1], [1]AMA, Inc. at NASA Ames Research Center (Mail Stop 229-3, NASA Ames Research Center, Moffett Field, CA 94035. E-mail: dinesh.k.prabhu@nasa.gov).

Brief Presenter Biography: ***Dinesh K. Prabhu*** *is a Senior Research Scientist with AMA, Inc., an onsite contractor at NASA Ames Research Center. He received his B.Tech. in Aeronautical Engineering from the IIT Madras, India, and his Ph.D. in Aerospace Engineering from the Iowa State University at Ames, Iowa. His interests are in modeling and simulation of high-temperature hypersonic flow fields and aerothermodynamic design of ground tests and atmospheric entry vehicles*.

Introduction: 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 [1], and is towards the end of its development cycle; the target for reaching TRL 6 is May 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 could be substantial and time consuming, 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 Figs. 1 through 4. 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: The highest pressure and heat flux that can be obtained on a test coupon of 25 mm nose radius are 5 bar and 3 kW/cm^2. These constraints are independent of TPS solution. The HEEET material has performed well in ground based testing at these conditions.
  - Ultimate pressure capability of HEEET has not been established, and future tests should be able to expand the currently known HEEET performance

envelop as there are weave-able solutions with pressures greater than 5 bar

- 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) – see Table 1.
- 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, hence a blunter nose radius should be acceptable; a sharper nose would be preferable if radiative heating were a concern.

Table 1. Diameter (or mass) estimates for a ballistic coefficient of 250 kg/m^2 and a 45° sphere-cone geometry.

Est. D_b given m_E	**250 kg** 1.1	**350 kg** 1.3	**450 kg** 1.48
Est. m_E given D_b	**1.0 m** 206	**1.25 m** 332	**1.5 m** 464

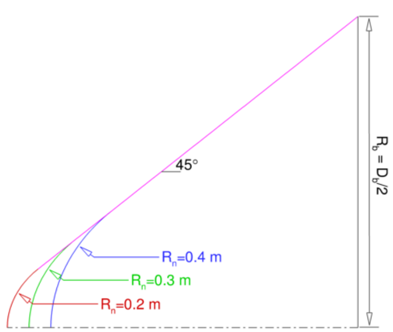

Figure 1. Probe geometry: 45° sphere-cone and 3 nose radii.

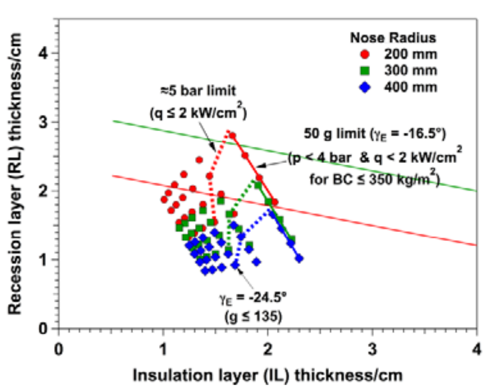

Figure 2. Margined HEEET thicknesses for Uranus entries. V_E= 22.34 km/s, latitude= 0°, azimuth = 37.7°, γ_E from -16.5° (shallow) to -36.5° (steep).

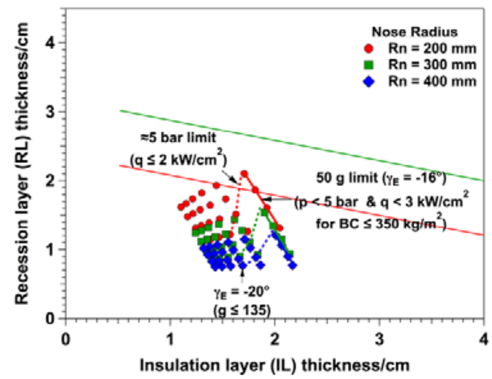

Figure 3. Margined HEEET thicknesses for Neptune entries. V_E= 24.73 km/s, latitude = -10°, azimuth = 76.9°, γ_E from -16° (shallow) to -26° (steep).

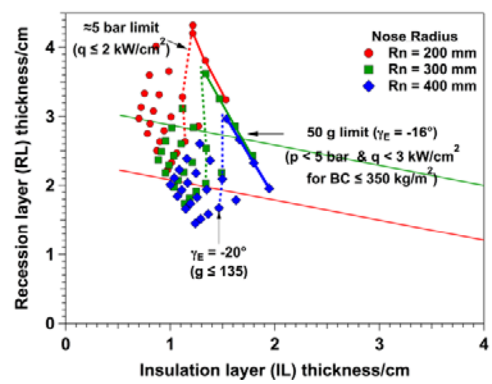

Figure 4. Margined HEEET thicknesses for Neptune entries. V_E= 26.12 km/s, latitude = 22.6°, azimuth = -86.5°, γ_E from -16° (shallow) to -36° (steep).

References: [1] Ice Giants: Pre-Decadal Survey Mission Study Report (2017), JPL D-100520. [2] Planetary Mission Entry Vehicles: Quick Reference Guide, v3.0, Ed: Carol Davies. [3] Venkatapathy, E., Ellerby, D., and Gage, P., *Workshop on In Situ Exploration of the Ice Giants*, 25-27 Feb 2019 Marseille (France). [4] Hwang, H. (2018), *15th IPPW*, Boulder, CO, June 11–15. [5] Allen, G. A., Jr., Wright, M. J., and Gage, P. J. (2005) NASA/TM-2005-212847. [6] Milos, F. S. and Chen, Y.-K. (2013) *J. Spacecraft and Rockets*, **50**(1), pp.137-149. [7] Mahzari, M. and Milos, F. (2018), *15th IPPW*, Boulder, CO, June 11–15.