Exploration of the Viability of HEEET as a TPS for Saturn, Neptune, and Uranus Entries

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Background and Objective

- HEEET has been developed as a replacement for full density carbon-phenolic (FDCP) material for use as a TPS for missions with extreme entry environments
- FDCP has been used successfully as thermal protection material in NASA's Pioneer-Venus and Galileo missions, but this legacy material is no longer manufactured for use in NASA planetary science missions
- HEEET is a dual-layer 3D woven material with a mid-level phenolic infusion, while FDCP is 2D woven material with a high level of phenolic infusion
- The outer layer of HEEET is a dense weave of carbon fiber intended to handle the heat flux of atmospheric entry: recession layer (RL)
- The inner layer of HEEET, a lower density weave of blended carbon and phenolic yarn, is intended to handle the heat load of atmospheric entry: insulation layer (IL)
- Weave thicknesses can be customized (withinloom constraints) to a specific mission
- HEEET, with its lower mass density and thermal conductivity, will result in more mass-efficient solutions than FDCP
- HEEET has been successfully tested in the arcjets at NASA Ames and at AEDC over a range of heat fluxes and pressures
  - Based on the testing to date, recommended max pressure is 5 bar and recommended max heat flux is 5 kW/cm² – limits can be used to constrain the steepness of entry
- A 1 m (dia) ETU has been built using a layout of HEEET tiles
- Based on manufacturing demonstrated to date, recommended minimum radius of spherical nose cap is 250 mm
- HEEET was proposed as thermal protection material in the Ice Giants Study Report (JPL D-100520, 2017) and for a proposed New Frontiers mission to Saturn
  - The estimated TPS thickness from some of these studies indicated the need for a loom upgrade beyond currently established capabilities, Looms 1 and 2 in the figure on the right

Methods

- Step #1: For given entry state (velocity, latitude & azimuth) compute 3DOF trajectories using Fixa
  - Ballistic coefficient range: 200–350 kg/m² (in steps of 50 kg/m²)
  - Inertial entry flight path angle range that covers deceleration loads between 50 and 200 g
    - Saturn: -10° to 26°
    - Uranus: -18.5° to -18.5°
    - Neptune: -16° to -26°
  - No pressure and/or heat flux constraints imposed
  - Inertial entry velocity: Saturn: 36 km/s
    - Neptune: 26.5 km/s
  - Stagnation point convective heating estimates obtained from correlations based on freestream density and velocity; radiative heating likely to be small at all three destinations
  - All trajectories terminated at flight Mach number of 0.8 (heatsield jettison)
  - Prograde equatorial entries get maximum benefit of planetary rotation
- Step #2: Size HEEET using Fixa to stagnation point aerothermodynamic environments estimated in Step #1
  - Planet-specific B’ tables for material thermal response, and a margins policy [5] that accounts for uncertainty in environments and material properties
  - Thicknesses determined with: (a) initial temperature of -10°C, and (b) a maximum allowable back face temperature of 250°C
- Step #3: Adjust stagnation point sizing from Step #2 to margin against turbulent heating on the conical flank
  - Flank heating can be as high as stagnation point heating, but at a lower (<50%) pressure level – increased material recession
  - Current solution: Scale up stagnation point recession layer thickness by 1.2, and scale down insulation layer thickness by 1.2
- Step #4: Add manufacturing margins to estimates of flank thicknesses (recession and insulation layers)
  - Manufacturing margins: 0.51 cm for the insulation layer, and 0.38 cm for the recession layer

All sizing has been performed assuming a 3.8 mm thick layer of HT-424 adhesive and 3.2 mm thick 40-1024 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.

Conclusions & Further Refinements

- For the cases explored here, there are several possible HEEET solutions that fall within the manufacturing capabilities of Looms 1 and 2, 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
- Ultimate pressure capability of HEEET has not been established, and future tests should be able to expand the 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/m² (125 kg/m²) 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/m², it is better to keep the nose radius between 300 and 400 mm
- The convective heating of the deceleration module decreases because of increased bluntness, and
- The HEEET constraint of a minimum spherical radius of 250 mm is satisfied
- 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

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