ATMOSPHERIC ENTRY STUDIES FOR URANUS.

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Introduction: Ever since Voyager-2 flew past Uranus in January 1986 and gave us our first glimpse of the planet, there have been no follow-on missions to any of the Ice Giants – Uranus and Neptune. Since a clear understanding of the atmosphere and other attributes of these planets are highly valued and desired by planetary scientists, a Flagship mission (including an atmospheric entry probe) to Uranus has been called out in the National Research Council's Planetary Science Decadal Survey[1] as one of the three highest priority Flagship missions in the period 2013-2022.

To better understand the technology requirements for a Uranus atmospheric entry probe, NASA's Entry Vehicle Technology project funded an internal study with a team drawn from three NASA Centers – Ames, Langley, and JPL. The study team was made up of subject matter experts in the areas of planetary science, orbital mechanics, entry trajectory analysis, aerothermodynamics, and thermal protection materials. The main objectives for this study were: (1) to determine the entry trade space through parametric studies; and (2) to identify entry technologies including Thermal Protection System (TPS) materials that could be used to enable a mission that would meet at least the Tier 1 science objectives described in the Decadal Survey[2].

Since Uranus has an 84-year orbital period, a wide ring system, and a 98^0 axial tilt, the technology requirements for atmospheric entry probe are driven by the launch and arrival dates. Therefore, two different arrival windows in 2029 and 2043, corresponding to launches in 2021 and 2034 respectively, were considered in the study. As part of this study, an improved engineering model is developed for the Uranus atmosphere. This improved model is based on reconciliation of data available in the published literature and covers an altitude range of 0 km (1 bar pressure) to 5000 km[3]. Two different entry scenarios are considered: 1) direct ballistic entry, and 2) aerocapture followed by entry from orbit. For ballistic entry a range of entry flight path angles (EFPA) are considered for probe entry masses ranging from 130 kg to 300 kg and diameters ranging from 0.8 m (Pioneer-Venus small probe scale) to 1.3 m (Galileo scale). The larger probes, which offer a larger packing volume, are considered in an attempt to accommodate more scientific instruments. By varying the EFPA for range of ballistic coefficients a large trade space consisting of thousands of trajectories was created to understand the direct ballistic entry options in the Uranian atmosphere. Figure 1 shows the example of trade space for 130 kg probe and recommended zones for TPS materials. Various TPS options were examined for this trade space and a mid-density TPS ablator was found to be suitable for Uranus missions. PICA in its current form has a very small operating window due to pressure requirements. For selected cases that bound the atmospheric entry a detailed CFD and TPS sizing analysis was performed. The study revealed that the pressure and deceleration load are very high for direct ballistic entry and constraint the EFPA to -41^0 or lower depending on the ballistic coefficient. The study also showed that the majority of aerothermal heating is due to convection and unlike Jupiter the heating due to radiation is negligible. In general, the magnitude of heatflux is significantly lower compared to Jupiter and Venus entry.

For aerocapture a single case is studied to explore the feasibility and benefits of this option. The study shows that there are several potential benefits for aerocapture options that includes, enabling the use of low density ablator like PICA, significantly lower deceleration and pressure loads, potential mass savings in fuel and beneficial for larger communication time.

References:

[1] National Research Council, *Visions and Voyages for Planetary Science in the Decade 2013-2022*, National Academies Press, 2012.

[2] Hubbard, W. B., Planetary Science Decadal Survey Mission Concept Study Final Report," Ice Giants Decadal Study": http://sites.nationalacademies.org/SSB/SSB_059331, June 2010.

[3] Allen G. A., Marley M.S., and Agrawal P. , "Uranus Atmospheric Model for Engineering Application, to be presented at IPPW-11, Pasadena CA.

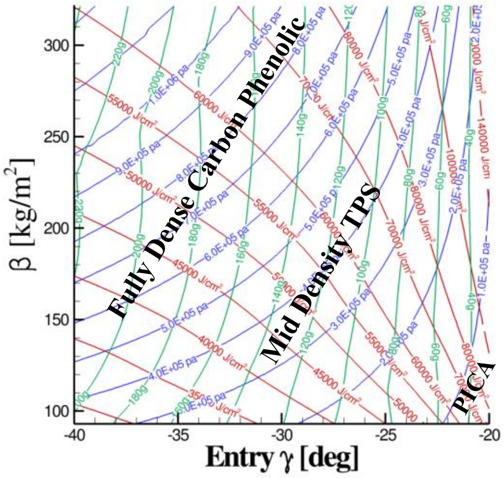

Figure 1 - Contours of peak stagnation pressure (blue lines), total heat load (red lines), and peak deceleration load (green lines) for 130 kg probe.