URANUS ATMOSPHERIC ENTRY PROBE THERMAL PROTECTION DESIGN STUDY

J. Monk[1], D. Prabhu[2], G. Allen, Jr.[3], J.M Thornton[4], H. Hwang[5], A. Pensado[6], S. Dutta[7] , [1]NASA Ames Research Center, Moffett Field, CA 94035, joshua.d.monk@nasa.gov, [2]AMA, Inc. at NASA Ames Research Center, Moffett Field, CA 94035, dinesh.k.prabhu@nasa.gov, [3]AMA, Inc. at NASA Ames Research Center, Moffett Field, CA 94035, gary.a.allen@nasa.gov, [4]AMA, Inc. at NASA Ames Research Center, Moffett Field, CA 94035, john.m.thornton@nasa.gov, [5]NASA Ames Research Center, Moffett Field, CA 94035, helen.hwang@nasa.gov, [6]Analytical Mechanics Associates, 21 Enterprise Pkwy., Suite 300, Hampton, VA 23666, alejandro.r.pensado@nasa.gov, [7]NASA Langley Research Center, Hampton, VA 23681, soumyo.dutta@nasa.gov,

Brief Presenter Biography: Joshua Monk is Materials Engineer at NASA Ames Research Center working in the Thermal Protection Materials Branch. Josh has a Ph.D. in Materials Science & Engineering from Virginia Tech.

Introduction

The Planetary Science Decadal Survey [1] has identified Uranus as the highest priority destination for a flagship mission in the decade 2022-2032. Significant effort was expended across multiple teams in developing the concept study. The proposed poster will focus on the entry and descent aspects of an atmospheric probe, considered as part of the mission concept, and associated trades for viable trajectory options.

Uranus Mission and Entry Probe

The Uranus Orbiter and Probe (UOP) Flagship mission concept will investigate Uranus and its surrounding moons using an orbiting spacecraft. The orbiting spacecraft will also carry a probe for *in situ* measurements of the Uranus atmosphere. Unlike previous studies [2,3], the spacecraft will be propulsively inserted into a highly elliptical orbit around Uranus. The atmospheric entry probe will be released, allowing for one hour of *in situ* measurements, and relay the acquired data to the orbiter. Upon completion of atmospheric measurements, the orbiter will transition to the moon tour phase of the mission.

A sufficiently large set of viable entry trajectories, which meet both mission and science objectives, was developed using the tool POST2 [4] for a 1.26 m diameter, 45° sphere-cone configuration of maximum expected value (MEV) entry mass 268 kg. The 45° sphere-cone geometry is a legacy configuration that has demonstrated static stability and been used successfully in missions to Venus (Pioneer-Venus) and Jupiter (Galileo) [5]. A nose radius of 0.4 m was considered primarily to reduce the heat flux at the stagnation point [6] compared to the smaller radii use din the Venus and Jupiter missions.

The set of viable trajectories was reduced by imposing additional constraints – primarily the heat flux and pressure capabilities of ground test facilities, i.e., arcjets which are used to test and qualify materials of the thermal protection system (TPS) of the entry probe.

The newly developed thermal protection material called HEEET (Heatshield for Extreme Entry Environment Technology) [7] was considered in the study. This material, which is at a technology readiness level (TRL) of 6, is highly customizable and available in two varieties: (i) a dual-layer version consisting of recession layer on top of an insulative layer, and (ii) a single-layer version consisting of the insulative layer alone, termed three dimensional medium density carbon phenolic (3MDCP). Both options were considered for the forward heatshield (the sphere-cone part) in the present study. The backshell TPS material was chosen to be NASA's Phenolic Impregnated Carbon Ablator (PICA) [8], which is at TRL 9, having been used in the Stardust mission as well as two Mars missions, MSL and M2020.

Thermal Protection Sizing Processes and Results

To provide UOP with mass estimates for the atmospheric entry probe, the TPS material was sized to ensure the bondline temperatures did not exceed the limitations of the adhesives between the TPS and structure. The requisite aerothermal parameters (pressure, recovery enthalpy, and film coefficient) for the stagnation point were determined using engineering correlations built into NASA's 3DOF trajectory code called Traj [9].

The aerothermal environments over the entire configuration were determined through the application of the high fidelity flow solver Data Parallel Line Relaxation code (DPLR)[10]. Flow computations, including laminar, turbulent, and turbulent with surface roughness, were performed at select points along flight trajectories. From the computed flow solutions, aerothermal environments were extracted at five spatial location on the forward heatshield (Fig. 1). The temporal variations of heat flux at the five body points are shown in Fig. 2 for both shallow and steep entry flight path angles (-23.2° and -25.6°). NASA's 1D Fully Implicit Ablation and Thermal (FIAT) response program [11] was used with the predicted heating environments to size the heatshield and backshell thermal protection material and predict recession. TPS sizing for the heatshield and backshell followed margin and sizing policies [12].

The results from the heatshield sizing exercise are included in Table 1. It was observed that the shoulder showed the highest heating rate; however the thickest TPS requirement occurred at the mid-nose body point. The elevated dynamic pressure at the mid-nose body point contributes to the thicker TPS requirements. In addition to the two-trajectory study, a sensitivity study on the probe mass was also conducted. The results are also provided in Table 1. It is clear that the TPS selections for this mission are able to perform in the predicted aerothermal environments, thus enabling the mission to meet the descent probe portion of this flagship mission.

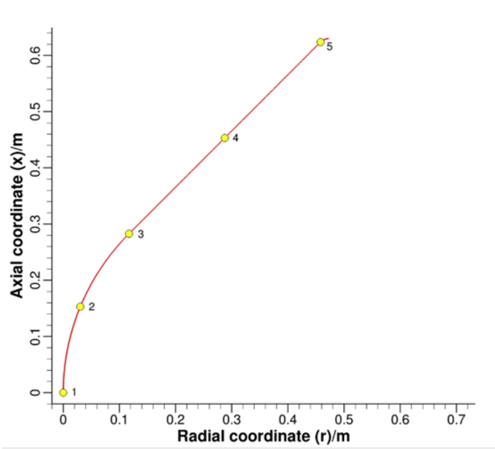

Fig. 1: Body points along outer mold line (OML) of heatshield

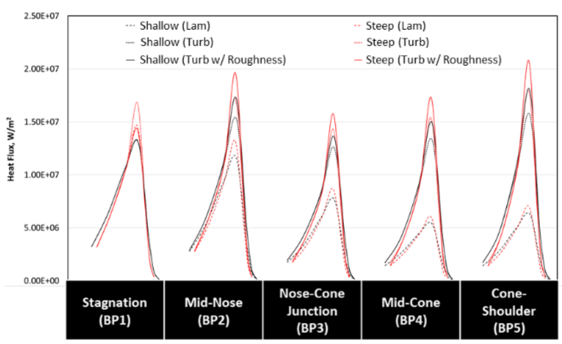

Fig. 2: Heating rate at OML body points for shallow and steep entry angles

Table 1: TPS Sizing Trade Results

	Single-layer 3MDCP		Dual-layer HEEET	
Delta from Baseline Entry Mass (kg) based on stagnation point sizing	Delta TPS Mass/kg	% Diff from Nominal	Delta TPS Mass/kg	% Diff from Nominal
-20 kg	-0.1	-0.5%	1.6	7.7%
-10 kg	0	0.0%	1.8	8.4%
Baseline (268 kg MEV)	Nominal Baseline		1.9	8.9%
+10 kg	0	0.0%	2.0	9.3%
+20 kg	0.1	0.5%	2.1	9.8%

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