

IMPACT OF NASA'S ENTRY SYSTEMS MODELING PROJECT ON GAS GIANT PROBE DESIGN AND ANALYSIS

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Introduction: The giant planets are key destinations of interest to the planetary science community for their potential to provide insight into the formation and evolution of our Solar System, as well as extrasolar planetary systems. To date, the Galileo atmospheric probe is the only purpose-built entry probe to a giant planet. Post-flight analysis of Galileo's performance showed that there was significant recession of the thermal protection system (TPS), well beyond what was predicted on the flank, and this was due in part to insufficient modeling capabilities for estimating the flight environment and TPS response. While Galileo ultimately survived its flight, the example serves to highlight the great challenge of designing successful missions for environments that are poorly understood or where models have not yet been validated. NASA's Entry Systems Modeling (ESM) Project is tasked with investigating such considerations for planetary science missions across the Solar System, and in recent years has begun to do so for giant planets. This talk provides an overview of the ESM project and highlights the impact of ongoing and future investments through a reevaluation of the Galileo Probe TPS performance prediction and a comparison with available flight data.

Entry Systems Modeling Project Overview: The most distinctive features of the giant planets, from an entry system perspective, are the atmospheres composed primarily of hydrogen and helium. The entry velocities of proposed missions are generally very large and can therefore be expected to result in significant convective and radiative heating generated by the vehicle's shock layer. Yet thermochemical behavior of the hydrogen-helium system is not well understood under such conditions. The ESM project is leading efforts to develop accurate thermochemical databases based on state-of-the-art measurements in the Electric Arc Shock Tube and detailed computational chemistry. The large heat fluxes anticipated by missions have driven interest in new TPS materials, in particular woven materials, which may be enabling but have never been flown before. Consequently, multiscale models are in development to describe properties and performance of the materials from micro- to system-scale. The goal is to not only provide accurate thermal response but also to inform thermostructural reliability predictions for extreme entries. Additionally, new computational models have been developed to evaluate performance of non-destructive evaluation techniques which are vital to establishing acceptance of systems to be free of manufacturing faults like material cracking, voids, and debonding. In the area of guidance and control, aerocapture has been shown conceptually to provide a number of mission benefits, including reducing transit time and increasing payload fraction. The ESM project is building a launch-to-landing trajectory simulation capability to enable detailed studies of aerocapture maneuvers in the context of giant planets missions.

Galileo Probe Revisited: To assess the impact of previous ESM investments, several state-of-the-art modeling approaches were applied to an evaluation of the Galileo Probe entry. These included coupled ablation modeling, TPS recession due to ablation, full angular integration of radiation, high-fidelity diffusion modeling, ionization potential lowering of hydrogen, state-specific hydrogen modeling, and precursor absorption in the freestream. Results of this study are shown in Fig. 1. This figure shows a comparison with flight data [1] and pre-flight predictions [2]. The impact of

improved diffusion modeling and the coupled shape change in the vehicle outer mold line due to ablation were shown to have significant impact on heat and surface recession.

Figure 1 also shows uncertainty bounds on the current baseline recession prediction. Uncertainties in physical quantities, such as kinetic rates, lines strengths of atomic species, oscillator strengths of molecular species, heats of formation, carbon phenolic char rate, and turbulent Schmidt number were considered as part of the uncertainty analysis on TPS recession. At the stagnation point, the uncertainty is dominated by the radiation sources, in particular, the photoionization cross section of hydrogen and oscillator strengths of the C₃ systems. On the flank, radiation modeling accounts for about 30% of the uncertainty, while the heats of formation and char rate uncertainties account for 15% and 5%, respectively. The effect of turbulent Schmidt number uncertainty accounts for 50% of the overall uncertainty on the flank, where the intensity of boundary layer mixing and diffusion rate are affected.

The current analysis provides the most accurate recession prediction for the Galileo Probe TPS material to date. The inclusion of these uncertainties, along with the improved baseline modeling approach provides a remarkable prediction of TPS recession when compared to the flight data, which has yet to be achieved by previous studies. Although a Jupiter probe will experience a much different environment compared to a probe entering the other gas giants, this work highlights not only the impact of ESM project investments, but also, as part of the uncertainty analysis, has identified areas of investment to reduce risk for future gas giant probes.

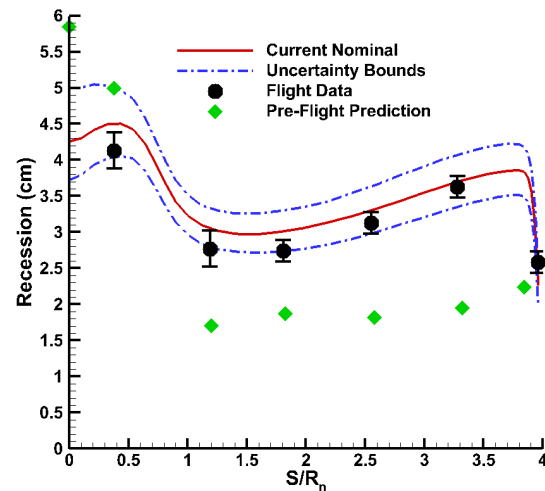


Figure 1. Predicted recession with uncertainty compared to flight data and pre-flight predictions.

References:

- [1] Milos, F. S., "Galileo Probe Heat Shield Ablation Experiment", *Journal of Spacecraft and Rockets*, Vol. 34, No. 6, 1997, pp. 705-713, doi. 10.2514/2.3293
- [2] Moss, J. N. and Simmonds, A. L., "Galileo Probe Forebody Flowfield Predictions", AIAA paper 82-0874, 1982.