Robust and Mass Efficient Thermal Protection Systems for Future Venus Missions

E. Venkatapathy[1], M. Gasch[1], M. Stackpoole[1], M. Suman[1], and J. Morgan[1].
[1]NASA Ames Research Center, Moffett Field, CA 94035, USA. Ethiraj.Venkatapathy-1@nasa.gov

Introduction: International missions, both orbiter and in-situ probe missions, to Venus are in the works after prolonged absence. Future missions are expected to be long duration lander missions as well as balloon missions to investigate the cloud layer. The entry mass for these in-situ missions will be significantly more, and the aeroshells will be large. Two cardinal requirements govern the selection and use of thermal protection system (TPS), namely, robustness to assure mission safety during entry and mass efficiency so that the useful mass for science is maximized. One cannot trade mission safety for mass when it comes to TPS. The robustness of the TPS is a paramount requirement as it is a single point of failure system. At the same time, TPS mass is required all the way prior to entry, and any excess mass of the TPS is at the cost of the science payload. Future missions will benefit enormously from TPS capabilities far beyond what is currently proposed for the DAVINCI+ mission, advanced carbon-carbon (ACC), due to its performance and mass efficiency.

NASA, STMD and SMD together, invested in the development of 3-D woven thermal protection systems in the last decade, and as a result, the heat-shield for extreme entry environment technology (HEEET) has been matured to TRL 6. It is ready for future mission use including Venus. The HEEET project focused on developing a broad technology base, applicable for missions not only to Venus, but also to Saturn, the Ice Giants, and higher speed sample return missions such as Mars requiring extreme robustness due to biohazards. The dual-layer HEEET (DL-HEEET) has been proven to be extremely robust. At conditions for arc jet and laser testing where heritage carbon-phenolic fails, the dual layer HEEET did not. HEEET also proved to be mass efficient compared to Carbon-Phenolic.

Recently, the principal author was invited to present his perspectives to the 2023-2032 Planetary Sciences Decadal Venus subcommittee on the currently state of TPS for future Venus missions [1]. In addition to pointing out successful TPS and other developments in the last decade in support of entry systems, the principal author made two findings: 1) importance of and need to sustain TPS capabilities that took nearly a decade to develop and 2) the opportunity to further optimize TPS mass without sacrificing robustness to further enable future in-situ missions.

The proposed VEXAG talk will focus on the above two recommendations and provide the rationale for them. The intent of the talk is to seek VEXAG's advocacy.

TPS Capability Sustainment: HEEET development was necessitated by the atrophy of heritage carbon-phenolic. Atrophy has impacted other TPS as well. Avcoat, the TPS that successfully allowed astronauts to explore the Moon in the 1960s and 70s, took nearly a decade and 10s of $M to recover. One of the most used TPS, SLA, has had to be recovered twice, once prior to its use on Mars Pathfinder and once after the failure experienced related to Mars Science Laboratory (MSL). The TPS that replaced SLA on MSL, PICA, has undergone multiple replacement and recovery due to constituent rayon changes. Recently, NASA invested in a domestic rayon replacement program and also invested in FMI to consolidate PICA capability for NASA missions, as a result of FMI's decision to discontinue commercial FiberForm, which is needed for PICA.

The TPS used for planetary missions are unique and have no commercial or other use. In addition, low mission cadence also is a driver for TPS atrophy. Hence, NASA, as the steward, must take steps to ensure and sustain TPS capabilities. In this talk, steps will be outline steps NASA can take to keep abreast of emerging risks and target risk mitigation steps to ensure TPS capability for Venus and other extreme environment missions.

Next Generation of Mass efficient and Robust TPS: NASA invested in alternate to PICA development based on felt-technology called Conformal-PICA which has the potential to save 30% - 50% mass compared to PICA. The development was discontinued at a TRL of ~ 5. The 3MDCP (3D Mid-Density Carbon Phenolic, which uses a single layer of HEEET (SL-HEEET), the insulating part of the 3-D woven formulation, is 30% more mass efficient and the baseline for the Mars Sample Return Mission due to its mass efficiency. Currently, SL-HEEET is limited to aeroshell diameters of < 1.3m. The SL-HEEET was compared to dual layer HEEET (DL-HEEET) in the recent ADVENT flag-ship class mission study in support of the Planetary Science Decadal. As a result of over 30% mass savings for both the balloon as well as lander missions, SL-HEEET was recommended. Given C-PICA and SL-HEEET have reliability and mass efficiency, advocacy from VEXAG is sought for completing the advanced TPS development in this decade so as to enable future missions.

References:

1. Venkatapathy, E., "Entry Systems, TPS and Parachute Technologies for Venus," presentation to the Planetary Science and Astrobiology Decadal Survey 2023-2032 Panel on Venus, July 14, 2021.