CHALLENGES IN QUALIFICATION OF THERMAL PROTECTION SYSTEMS IN EXTREME ENTRY ENVIRONMENTS

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Brief Presenter Biography: Milad Mahzari is an Aerospace Engineer in the Entry Systems and Vehicle Development Branch at NASA Ames Research Center. He has been involved in the design and analysis of entry vehicles and Thermal Protection Systems (TPS) for multiple NASA projects including Orion, Mars2020, HEEET and MEDLI2. He is currently serving as the TPS lead for Dragonfly, a proposed mission to Titan.

Introduction: Planetary entry vehicles employ ablative TPS materials to shield the aeroshell from entry aeroheating environments. To ensure mission success, it must be demonstrated that the heatshield system, including local features such as seams, does not fail at conditions that are suitably margined beyond those expected in flight. Furthermore, its thermal response must be predictable, with acceptable fidelity, by computational tools used in heatshield design. Mission assurance is accomplished through a combination of ground testing and material response modelling. A material's robustness to failure is verified through arcjet testing while its thermal response is predicted by analytical tools that are verified against experimental data. Due to limitations in flight-like ground testing capability and lack of validated high-fidelity computational models, qualification of heatshield materials is often achieved by piecing together evidence from multiple ground tests and analytical simulations, none of which fully bound the flight conditions and vehicle configuration. Extreme heating environments (>2000 W/cm^2 heat flux and >2 atm pressure), experienced during entries at Venus, Saturn and Ice Giants, further stretch the current testing and modelling capabilities for applicable TPS materials. Fully-dense Carbon Phenolic was the material of choice for these applications; however, since heritage raw materials are no longer available, future uses of re-created Carbon Phenolic will require re-qualification. To address this sustainability challenge, NASA is developing a new dual-layer material based on 3D weaving technology called Heatshield for Extreme Entry Environments (HEEET) [1]. Regardless of TPS material, extreme environments pose additional certification challenges beyond what has been typical in recent NASA missions.

Scope of this presentation: This presentation will give an overview of challenges faced in verifying TPS performance at extreme heating conditions. Examples include:

- Bounding aeroheating parameters (heat flux, pressure, shear and enthalpy) in ground facilities. How to certify TPS if environments can't be bounded or aeroheating parameters can't be simultaneously achieved.
- Higher uncertainties in ground test environments (facility calibration and analytical predictions) at extreme conditions
- Testing in flows similar to planetary atmosphere composition (H_2/He for Gas and Ice Giants)
- Test sample size limitations for qualifying seam designs
- Lack of computational tools capable of simulating all significant aspects of TPS performance (including initiation and propagation of failures)

This presentation will provide recommendations on how the EDL community can address these challenges and mitigate some of the risks involved in flying TPS materials at extreme conditions. Examples include:

- Dedicated activity to understanding TPS failure modes. Develop computational tools capable of modelling fluid interaction with material's thermostructural response. Validate these tools through failure testing. A better understanding of failure mechanisms may eliminate the need to fully bound all aeroheating parameters in ground testing
- Enhancements to current testing facilities to simulate flight-like ablation mechanism (ex. testing in Nitrogen at Ames Interaction Heating Facility to limit oxidation in favor of more sublimation)
- Improved characterization of test conditions with new diagnostic methods and determination of environment uncertainty through rigorous statistical analysis of available data
- Design margin policies that are directly tied to uncertainties in ground test environments and modelling fidelity

References:

[1] D. Ellerby, et al., "Overview of Heatshield for Extreme Entry Environment Technology (HEEET)", 15th International Planetary Probe Workshop, Boulder, CO, June 2018.