Towards Thermal Protection System Certification by Analysis: Identification and Implication of Features

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Brief Presenter Biography – Justin Haskins obtained his B.E. in chemical engineering and physics from Vanderbilt University in 2007 and Ph.D. in chemical engineering from Texas A&M University in 2012. He joined NASA Ames Research Center upon graduating and has worked in areas ranging from high-energy-density batteries to high-temperature materials. Currently, he is the technical lead on various high-temperature material characterization and development efforts and serves as the deputy chief of the Thermal Protection Materials branch.

Introduction: The thermal protection systems (TPS) to be used for upcoming sample return missions (e.g., Mars Sample Return) and future crewed missions to the Moon and Mars are subject to stringent reliability criteria.[1] The certification of TPS is conducted through extensive testing, which can include Arc Jet testing to understand ablative behavior and non-destructive evaluation (NDE) to identify features that could lead to sub-optimal performance during entry. Unexpected features observed during fabrication of large-scale articles often require additional testing to certify, which in the very worst cases can impact schedule and contribute to cost.

Borrowing terminology often used for aerospace structural composite structures, “certification by analysis” is the supplemental use of theory and modeling to quantify uncertainties in reliability attributed to features or damage.[2] Although aerospace applications are focused on uncertainties in mechanical and dynamic stability, certification by analysis for TPS requires the additional consideration of thermal and ablative performance at the high temperatures associated with entry.

The paper will examine certification by analysis for TPS with regards to (1) techniques to accelerate material feature identification and (2) multiscale modeling tool development for assessing the implications of features on material behavior. Woven TPS materials are of primary interest, namely the insulation layer of the Heatshield for Extreme Entry Environment Technology (HEEET IL) or, similarly, 3D Medium Density Carbon Phenolic (3MDCP), which have emerged as leading candidates for imminent missions.

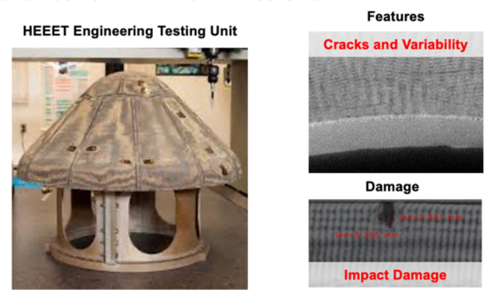

Figure 1: Examples of HEEET with variability and impact damage.

Identification of Features: The standard approach to NDE for TPS consists of low-resolution, but high data volume, CT scanning, (Figure 1) which allows the interrogation of large articles. Several features of interest are difficult to resolve with low-resolution CT, including material variability (e.g., poor infusion or irregular weave), cracks in gap filler, and porosity in bond-line adhesives. Furthermore, the analysis of large-volume CT data is human-mediated, which is time-consuming and prone to error. Alternative interrogation techniques could allow a more robust assessment of features of interest, but fabrication of articles and testing can be expensive. In this regard, the utility of computational NDE (CNDE) to evaluate the applicability of NDE techniques to given features and to allow the rapid down-selection of techniques for experimental investigation is demonstrated for cases of voids and disbonds.[3]

Implications of Features: Features that are identified through NDE often are certified through additional experimental investigation, but a full understanding of their implications on TPS performance during entry is difficult to assess. Progress is being made on the development of a computational framework that is sufficiently flexible to handle the many TPS features of interest noted from NDE through NASA’s Entry Systems Modeling project. The application of multiscale modeling tools from across the Agency to understand TPS performance is described. Of specific interest are atomistic simulations used to fill gaps in fundamental properties, microscale models used to describe mechanical behavior, and efficient tools that are in development to incorporate mesoscale variability into macroscopic material response models.[4,5]

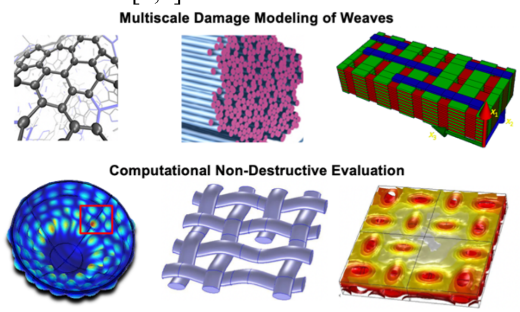

Figure 2: Examples of multiscale modeling and computational non-desctructive evaluation.

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