National Aeronautics and Space Administration



A Case for High-fidelity Material Response Modeling

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International Planetary Probe Workshop | 06.14.2018

Acknowledgements

Ethiraj Venkatapathy

CHAR Team

- Adam Amar
- Brandon Oliver
- Giovanni Salazar
- Ben Kirk

Icarus Team

- Eric Stern
- Joey Schulz
- Grant Palmer
- Justin Haskins
- Josh Monk

FIAT Team

- Frank Milos
- Y-K Chen

PATO/PuMA/SPARTA-N Team

- Nagi Mansour
- Francesco Panerai
- Joseph Ferguson
- Arnaud Borner
- Jeremie Meurisse
- Josh Monk
- Jean Lachaud

Academic Partners

- Doug Fletcher
- Deborah Levin
- Alexandre Martin
- Tim Minton
- Marco Panesi
- Tom Schwartzentruber
- Michael Tonks

A Brief History of Thermal Protection Material Modeling

AN ANALYSIS BOUNDA By	OF THE COUPLED CHEMICALLY REACTING RY LAYER AND CHARGEING ABLATOR Part I Copyign © 1997, American institute of Astronautica and Astronautica, Inc.	 CMA,1960s The "original" material response model FIAT, 1997 Implicit numerics makes CMA model much more robust CHAP Joanue PATO and more
Distribut informati resides i	Ablation and Thermal Response Program for Spacecraft Heatshield Analysis Y. K. Coo' wit Post 3. Mile' Densel Posts for Without and Spinner Bunch NATA Asses Research Cours Mother Posts. Co. With: 1000	 CHAR, ICarus, PATO and more Three-dimensional, unstructured Parallel computing architecture Pyrolysis gas flow
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	Les encriters et file cognitibilité et file ('Derring ribines Enqueues UDEE') code la presented. CD enc., true, auté filers discutionel entries terrel continues l'échelse laite résoure i leur contentes en tion adres with bold discut and inscrue mode. Additionally, (CDE') and the content bases offers les discutions et diverses partents (theories and advects discution et les discutions and granual en lise derringene queues, generality quartities, solicitate boundes, discutionalités incluinges, entreis and the deringene queues, generality quartities, solicitate boundes, discutionalités incluinges, granual en lise deringene queues, generality quartities, solicitate boundes, discutionalités incluinges et and addition and contact territories, and exemple simulations are included. Finally, a discussion et o discutaminant effects is presented.	A preliminary settification and validation of a new number of texponent model to presented. This models, to press, is interacted its investigation of the theory and production or advantation of the state interaction of texponent or advantation of the state interaction of texponent of texponent of the state interaction of texponent or advantation of the state interaction of texponent of texponent of texponent of texponent of texponent of texponent or advantation of the state interaction of texponent of texpone

Material response models have been very effective for TPS design for 50+ years

Characteristics of a High-fidelity Model

Calibrated fundamental experiments inform physics-based models







Micro-scale simulations provide material statistics and effective properties

Macro-scale simulations enable analysis of complex, fully-featured systems





Mission-specific TPS Material Optimization



TPS Failure and Reliability Modeling

Schematic of Mars Sample Return Earth Entry Vehicle (MSR-EEV)



- Planetary Protection: 1 in 10⁶ reliability requirement for MSR
- Multi-element campaign demands higher reliability for each element in the operational sequence





How do defects, damage, and features in TPS become failures?

Engineering Science Data Return

Avcoat heatshield is instrumented with thermocouples, pressure ports, and radiometers to enable aerothermal environment reconstruction and TPS performance assessment

Aerothermal environment reconstructions are no more accurate than the material response model

 Inverse algorithms employ material response model to reconstruct surface environments from in-depth thermocouple data

Sufficiently accurate reconstruction requires better models than presently exist. Higher fidelity models should include

- 1. In-depth condensation models for carbon and water
- 2. Kinetic gas-surface interaction models with multiple condensed species (silica and carbon)
- 3. More accurate high temperature material properties
- 4. Effects of surface coatings such as paint, pore sealer, and tape
- 5. Multi-dimensional modeling of thermal interference effects
- 6. Uncertainty quantification on final environment reconstruction

Realizable mission impacts

- Mass margin reduction
- Increased downrange
- Higher entry velocities
- Greater range of entry flight path angles

Apollo post-flight density profile. Increased density near surface indicates presence of condensed carbon (NASA TN D-5969)





Avcoat arcjet specimen showing carbon and silica at the surface (Courtesy of Alunni and Gökçen, AIAA 2016-3534)

Engineering Science and Data Return

- The MSL heatshield, including the MEDLI plugs, were coated with a silicone-based coating called NuSil CV-1144-0 (RTV Silicone Protective Oxygen Overcoat).
- The MEDLI2 plugs will also be coated with NuSil, impeding MEDLI2's ability to achieve its Level 1 requirement for aeroheating reconstruction.
- NuSil fundamentally changes the surface material properties of the PICA material and therefore the material thermal response.
- A validated high-fidelity PICA-N response model can enable MEDLI2 to meet its requirement, while also increasing our understanding of original MEDLI data



NASA Vision 2040 Report



Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and Systems

Prepared under Contract NNC15BA06B

NASA CR 2018-219771



