



## Overview of Ablation Modeling at NASA

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<sup>1</sup>NASA Ames Research Center

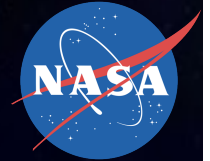
<sup>2</sup>NASA Johnson Space Center

# Outline



- Stakeholders
- Ablation Tools and Applications
- University Support
- Takeaways

# Ablation Modeling Stakeholders



Ablation modeling at NASA has a broad range of stakeholders – government organizations, research & flight projects, and universities/institutes

## Government Organizations

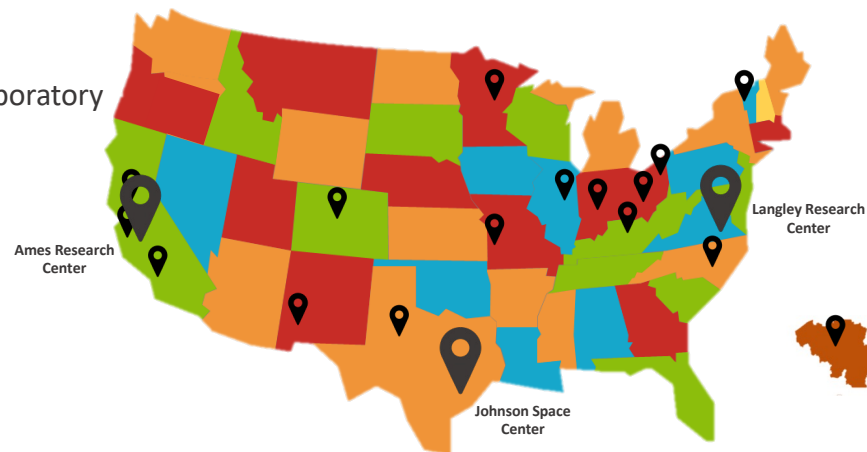
NASA Ames Research Center  
NASA Langley Research Center  
NASA Johnson Space Center  
NASA Glenn Research Center  
Sandia National Laboratories  
Lawrence Livermore National Laboratory  
Air Force Research Laboratory

## Missions/Flight Projects

Dragonfly/DrEAM  
Commercial Crew/Orion  
Mars2020/MEDLI2  
Mars Sample Return  
DAVINCI  
KREPE

## NASA Research Projects

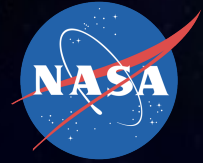
Entry System Modeling Project (ESM)



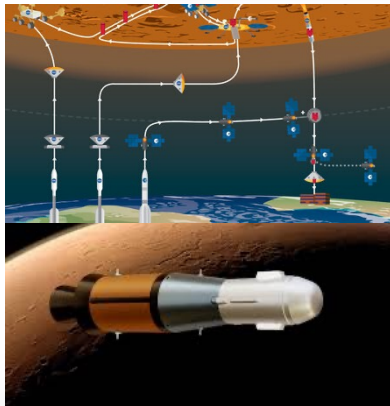
## Universities/Institutes

University of Colorado Boulder  
University of Kentucky  
University of Illinois Urbana Champaign  
Stanford University  
University of Minnesota  
University of California Los Angeles  
Purdue University  
Von Karman Institute for Fluid Dynamics  
Missouri University of Sci. & Tech.  
University of Virginia  
University of North Carolina

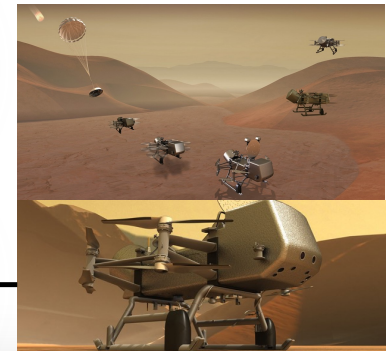
# A Few Mission Timelines



Mars2020/MEDLI2



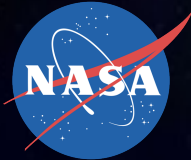
Mars Sample Return (MSR)



Dragonfly/DrEAM



# Entry/Ablation Challenges



**Mars2020/MEDLI2**

**Challenge**  
Flight data from instrumentation showed influence of silicone overcoat on ablation – required development of models accounting for new chemistry

**Challenge**  
Strict reliability requirements and use of new woven TPS for the Earth Entry System (EES) – requires quantifying property variability and understanding MMOD risks

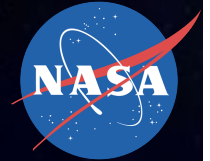
**Mars Sample Return (MSR)**

**Dragonfly/DrEAM**

**Challenge**  
Unique high radiation environment at Titan heats main seal beyond qualified limits – requires multi-D modeling of complicated geometries.

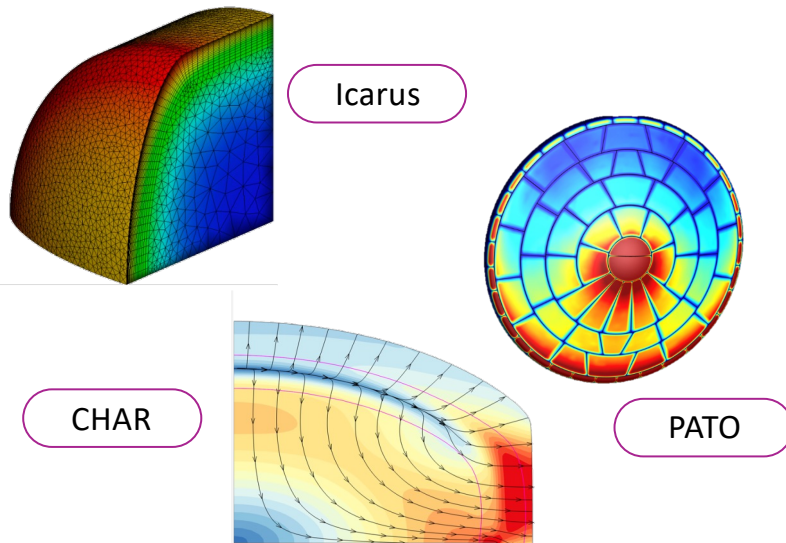


# Research & Development Strategy

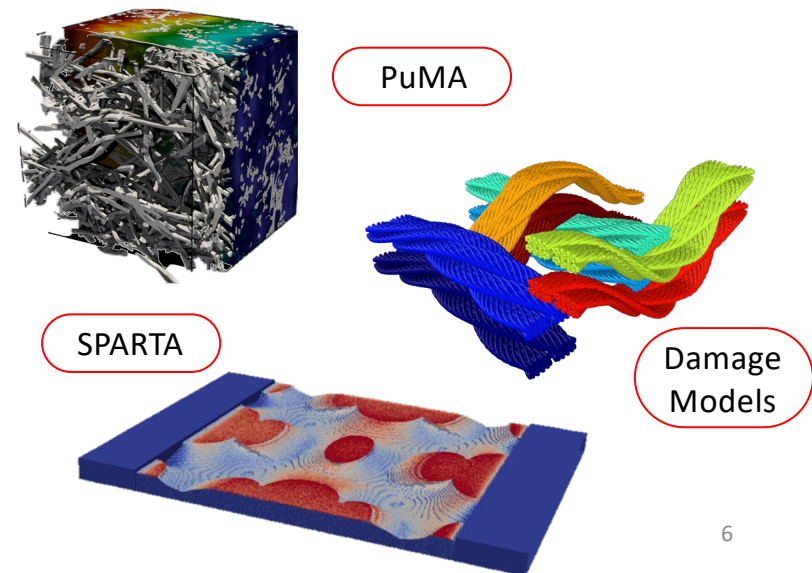


Recent investments in TPS ablation tool development focused on meeting challenges of flight projects – mediated by the Entry Systems Modeling (ESM) and flight projects

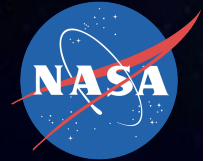
## Modernizing Material Response Codes



## Maturing Microscale Capabilities

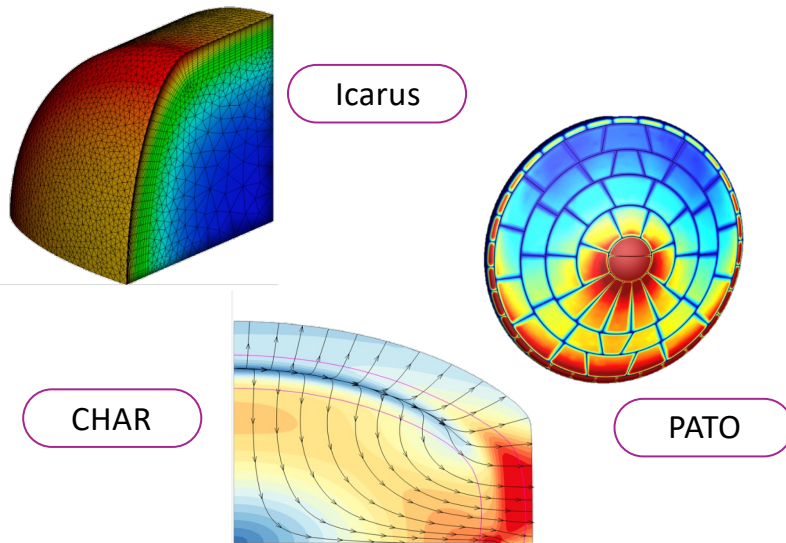


# Research & Development Strategy

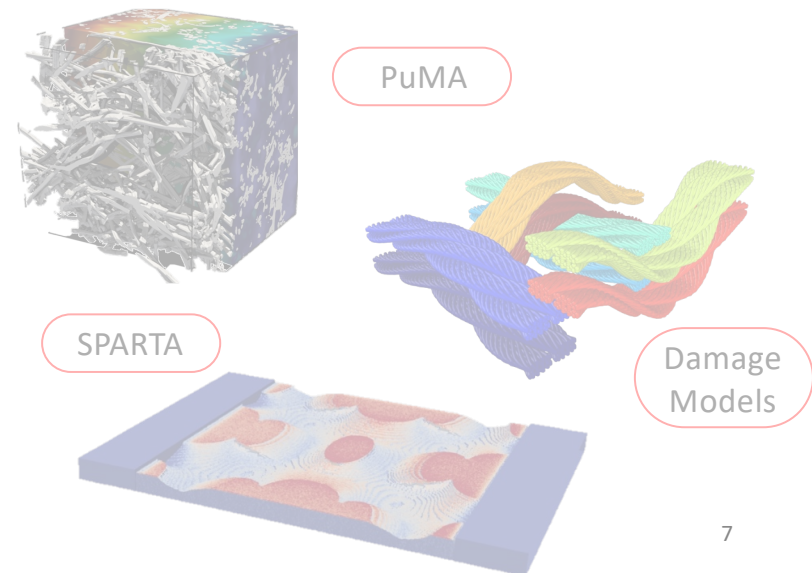


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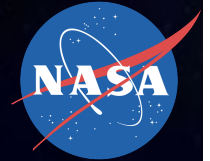
## Modernizing Material Response Codes



## Maturing Microscale Capabilities



# Material Response Code Timeline



## CMA

- Charring Materials Ablation
- Moyer & Rindal (1968)
- Aerotherm
- Finite Difference
- Node-dropping ablation



## Titan & 3dFIAT

- 2D & 3D FIAT
- Chen & Milos (2001,2005)
- Coupled with GASP/DPLR

## FIAT

- Fully Implicit Ablation and Thermal response program
- Chen & Milos (1999)
- Implicit time stepping
- Finite Volume
- Grid Compression
- MSL, Stardust, Mars2020, many others



## PATO

- Lachaud & Mansour (2014)
- multi-D, finite volume, OpenFOAM
- Simple to implement new models
- Collaborate with partners

## CHAR

- Amar et al. (2016)
- multi-D, finite element
- Used for Orion/Commercial Crew

## Icarus

- Schulz et al. (2017)
- multi-D, finite volume, parallel
- US3D integration
- mission design tool

1968

1999

2000's

2010's



# Icarus Material Response Solver



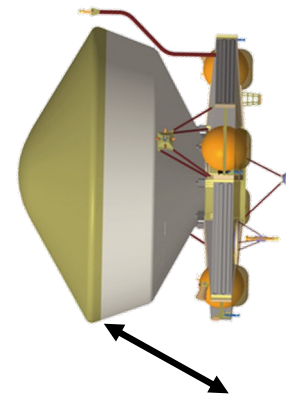
## Principal NASA user base is focused on design for science missions and other flight projects

- Design for Dragonfly and MSR-EES
- Limited distribution on an as-need basis for primarily government/contractor use

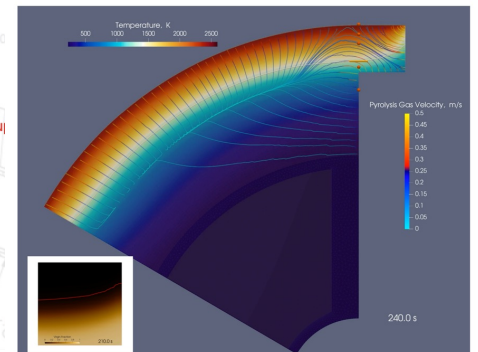
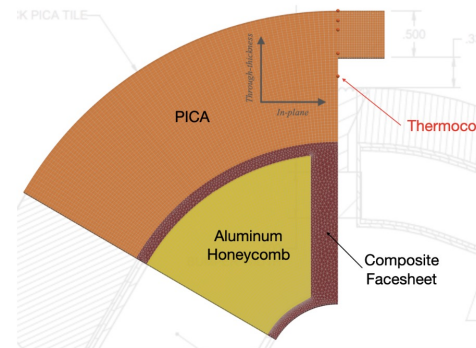
## Three-dimensional, unstructured, finite volume material response solver

- NASA developed through ESM with efficient suite of solvers and parallelism developed
- Models ablating, pyrolyzing, vaporizing, or melting materials with wide-ranging boundary conditions
- Other enabling features include coupling to US3D, Mutation++, and DAKOTA/SALib

## Current research activities include examination of MMOD effects on ablation, integration of dust erosion effects, and refinement of coupling to US3D packages



PICA "tooth" design being traded for Dragonfly heatshield to provide protection of main seal – performance assessment requires multi-D capability



# Icarus Material Response Solver



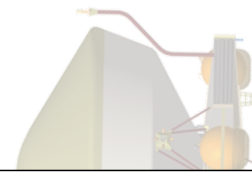
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Three-dimensional material response

- NASA development of solver
- Models material
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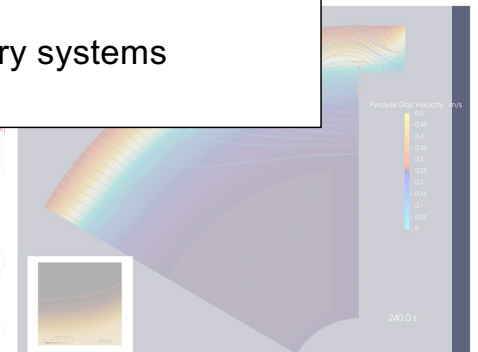
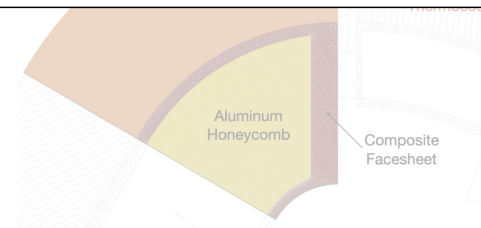
main seal –  
segment  
ability

Talks on Icarus:

**Eric Stern** – Overview and recent developments of Icarus

**Joseph Schulz** – Material response simulations of the Dragonfly capsule using Icarus

**Olivia Schroeder** – Ares: A multi-physics modeling framework for entry systems



# PATO – Porous material Analysis Toolbox based on OpenFOAM



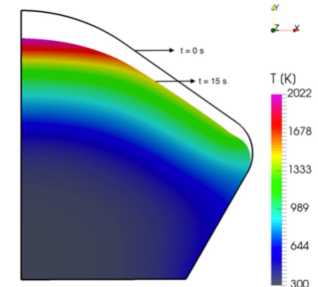
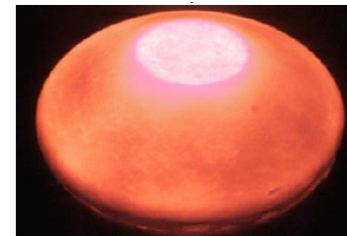
## Principal NASA user base is focused on developing new models for TPS material analysis

- Evaluated the influence of NuSil coating on ablation
- Open distribution and a collaborative platform for interacting with industry/academia

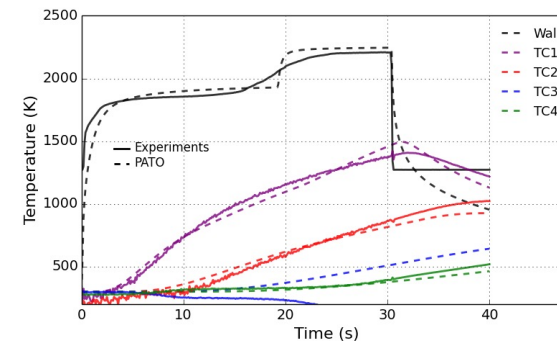
## One-, two-, and three-dimensional, unstructured, finite volume material response solver

- NASA developed through ESM and built on OpenFOAM
- Rich array of boundary conditions with finite-rate capability and advanced material models (fracture)
- Other enabling features include coupling to DPLR, Mutation++, and DAKOTA

## Current development efforts include new physical models accounting for shear erosion, RTV fencing, and coating surface chemistry as well as improved coupling to CFD for reconstruction analysis



**PATO characterization of NuSil coating on PICA in arc jet test conditions – geared to develop better models for recession of MSL and Mars2020**



# PATO – Porous material Analysis Toolbox based on OpenFOAM



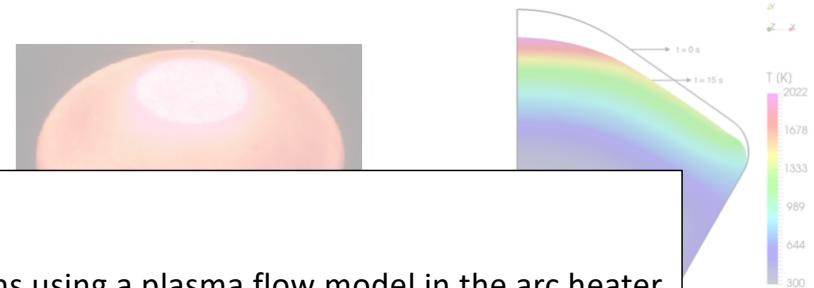
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One-, two-, and three-dimensional finite volume

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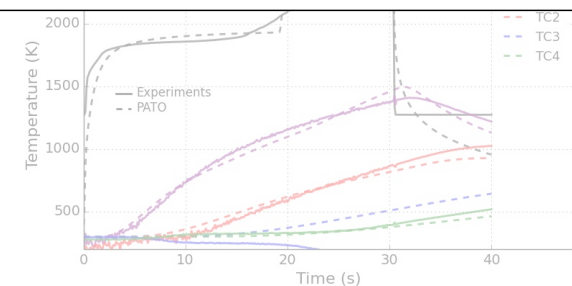
Posters on PATO:

**Jeremie Meurisse** – Arc jet CFD/ablation simulations using a plasma flow model in the arc heater

**John Thornton** – Coupling CFD and Material Response for Analysis of Mars Entry

**Sergio Fraile Izquierdo** – Mechanical Erosion Modeling of TPS Materials

in arc models



# CHAR – Charring Ablator Response Code



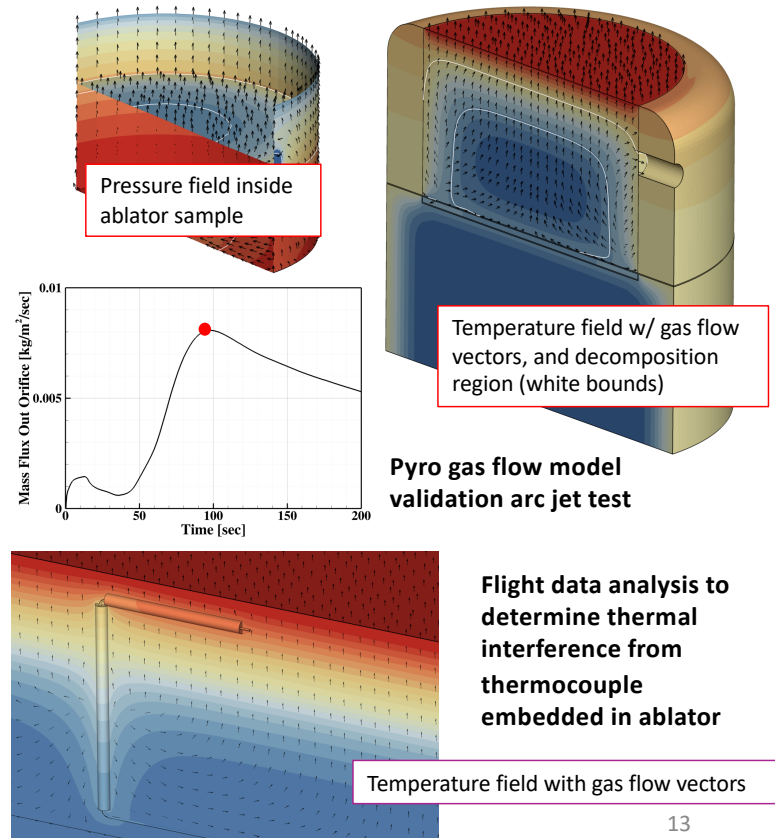
## Principal NASA user base is in Orion and Commercial Crew Programs

- Vehicle design, ground testing, flight data analysis
- Licensed across industry only to US govt. contractors

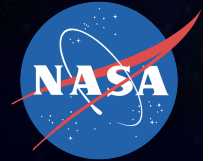
## One-, two-, and three-dimensional direct and inverse unstructured finite element thermal and ablation solver

- NASA-led development with contributions from ATA Engineering and Corvid Technologies
- Rich suite of boundary conditions including surface-to-surface radiation exchange, contact interfaces, and multiphysics coupling (ATA led)
- Other features include adaptive mesh refinement, and coupled thermo-electric solver

## Current development efforts include mesh motion, in-depth chemical non-equilibrium and condensation, mechanistic decomposition modeling, and automatic differentiation

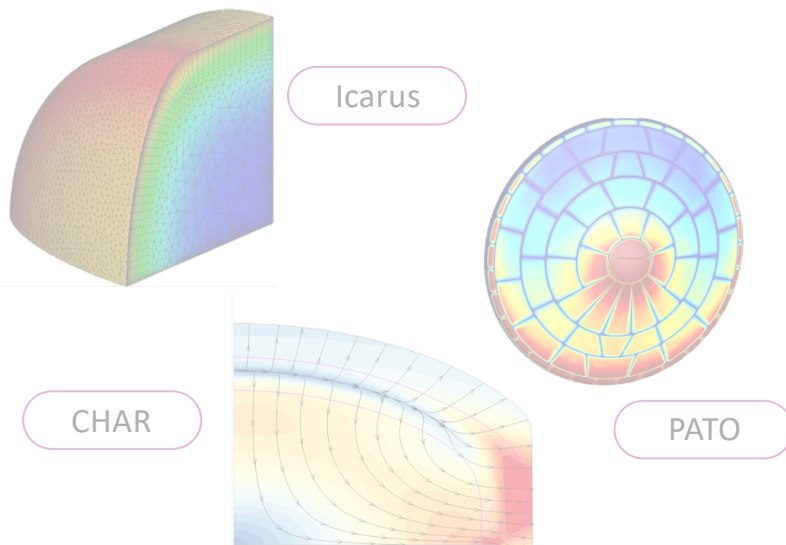


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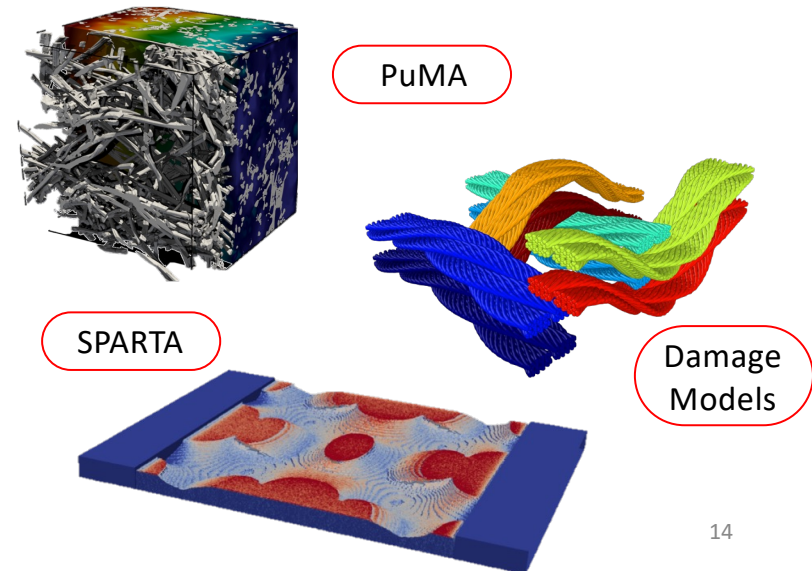


Recent investments in TPS ablation tool development focused on meeting challenges of flight projects – mediated by the Entry Systems Modeling (ESM) and flight projects

## Modernizing Material Response Codes



## Maturing Microscale Capabilities



# PuMA – Porous Microstructure Analysis



## Principal NASA user base is focused on improved characterization of TPS material properties

- Treats fibrous, woven, Avcoat-type, foam TPS
- Open distribution and a collaborative platform for interacting with industry/academia

## Finite volume, microstructure-based property calculations

- NASA developed through ESM support
- Structures generated through micro-CT or artificially generated (woven, fibrous, etc)
- Properties computed include porosity, permeability, thermal conductivity, and elastic mechanical

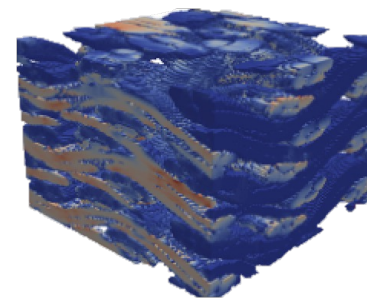
**Current development efforts include extension to more complex thermo-mechanical properties and to treatment of emerging TPS materials (weaves, additively manufactured, etc)**

## NASA Software of the Year 2022!

Micro-CT Scan

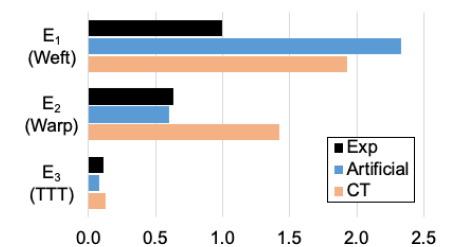


Stress Distribution



**PATO used to analyze mechanical properties of woven TPS material for MSR-EES using micro-CT data**

Normalized Young's Modulus



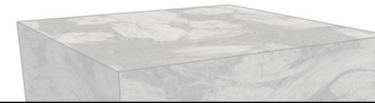
# PuMA – Porous Microstructure Analysis



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Micro-CT Scan



PATO used to analyze mechanical properties

Posters on PuMA:

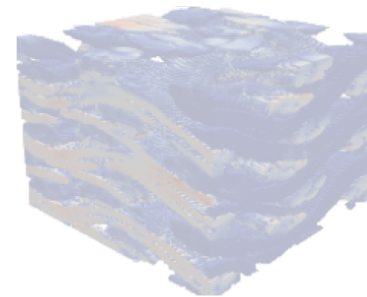
**Federico Semeraro** – Computing the effective elasticity of anisotropic porous media from X-ray computed micro-tomography images

Finite volume calculations

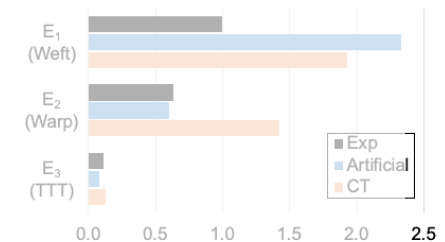
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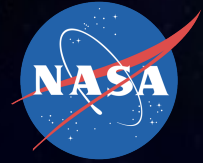
Stress Distribution



Normalized Young's Modulus



# SPARTA – Stochastic PArallel Rarefied-gas Time-accurate Analyzer



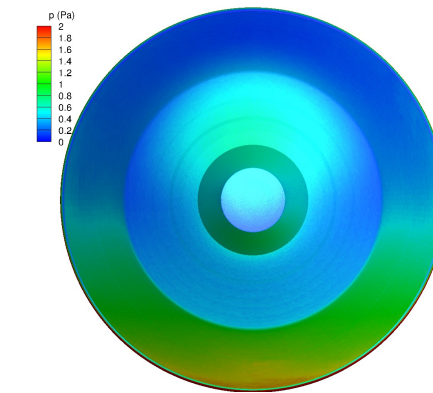
## Principal NASA user base is focused on improved characterization of rarefied flows (surface and in-depth) and gas-surface interactions

- Evaluating surface pressure, stresses, and reaction rates
- Open distribution from SNL with select developments being limited distribution

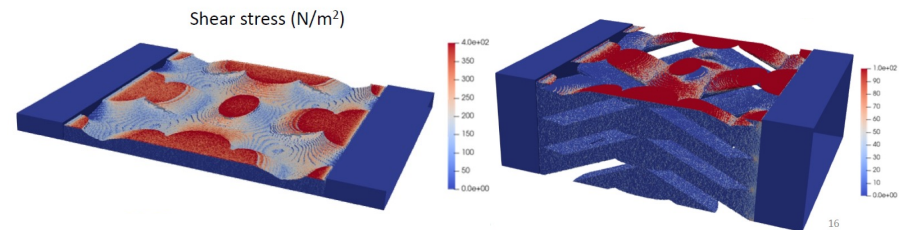
## Direct simulation Monte Carlo solver

- Initiated at SNL, co-developed at NASA through ESM support
- Massively parallel and treated flow of billions of particles and grid cells
- Used to characterize flow, gas-surface collisions, finite-rate reactions, and recession in porous media

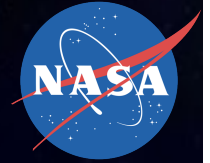
## Current development efforts include extension to include oxidation influence on mechanical degradation of carbon materials and improving description of finite rate reactions



SPARTA used for accurate characterization of Mars2020 backshell and shear stress on woven TPS for MSR-EES to inform spallation

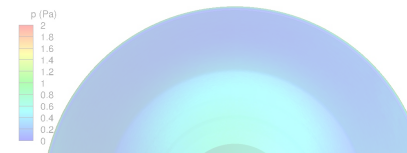


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- Open development



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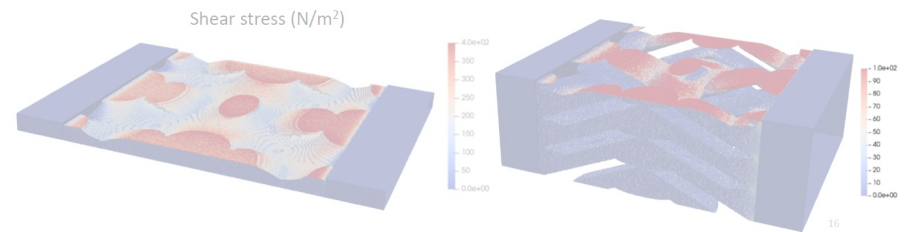
Talk on SPARTA:

**Krishnan Swaminathan Gopalan** – Implementation of active sites to capture pitting of oxidizing carbon materials in DSMC

Direct simulation

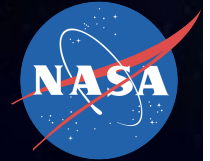
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# Damage Modeling

Lauren will talk about this

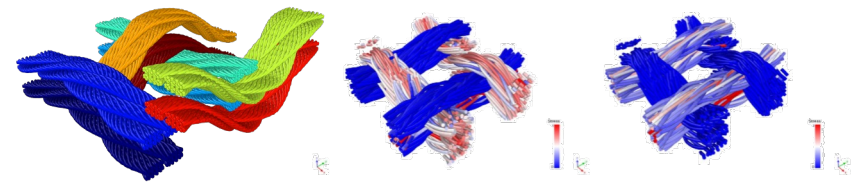


## Principal NASA user base is focused on treatment of damage in woven TPS for MSR-EES

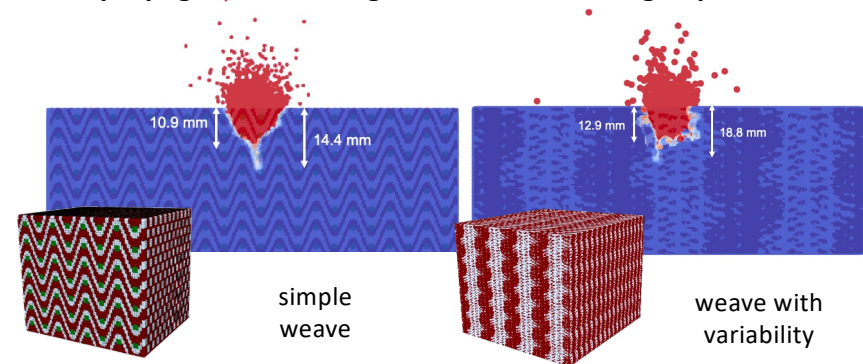
- Supported through ESM
- Investigating mechanical failure, damage influence on properties, and impact

## Variety of codes in development to characterize damage progression and failure in TPS materials

- Code developments through ESM support
- LAMMPS – particle-based impact/crack propagation for MMOD damage and discrete element models of woven TPS
- NASMAT – cell-based approach for treatment of properties and progressive damage in TPS materials
- HYDRA – in-house code with specialized damage models for woven TPS materials

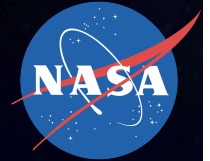


LAMMPS and HYDRA employed to study mechanical-mediated failure of weaves and the damage and propagation resulting from ballistic testing impacts



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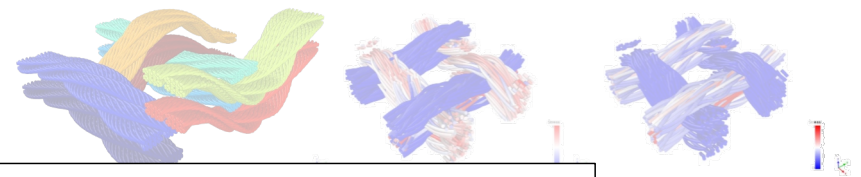
- Supported through ESM
- Investigating material property influence

Talk on Property/Damage:

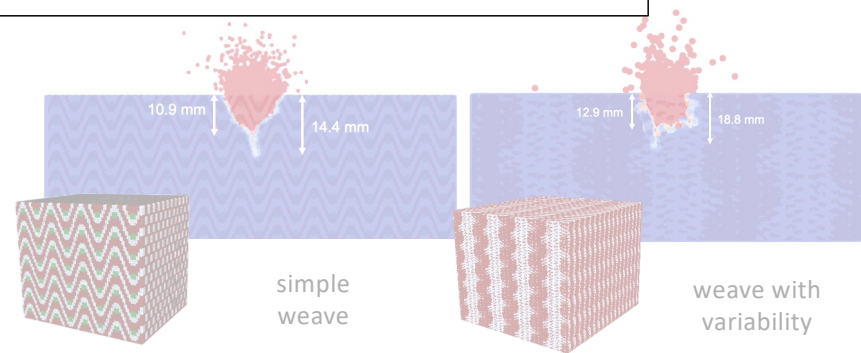
**Lauren Abbott** – TPS certification by analysis: model-driven characterization of properties and failure in woven TPS

Variety of code for damage programs

- Code developments through ESM support
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mechanical-  
age and  
impacts



# University Partnership Highlights



## NASA Space Technology Research Institute (STRI)



### Advanced Computational Center for Entry Systems Simulation (ACCESS)

Five-year institute dedicated to advancing the computational state-of-the-art of entry systems simulations. Four main thrusts investigated by a consortium of universities:

- Iain Boyd, Director (CUB)
- Alexandre Martin, TPS Lead (UK)
- Marco Panesi, Kinetics & Flow Physics Lead (UIUC)
- Graham Candler, Integration Lead (UMN)
- Alireza Doostan, UQ & Reliability Lead (CUB)

## NASA Center-Specific Summer Internship Programs

ARC regularly hosts 20-40 summer interns focused on entry systems

## NASA Space Technology Graduate Research Opportunity (NSTGRO)

10+ current students at Stanford, UIUC, CUB, UK, and UMN with focuses ranging from dust erosion to influence micrometeoroid impact on ablative response

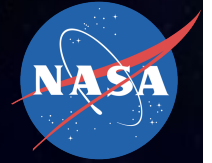
### Early Career Faculty (ECF) / Early Stage Innovations (ESI)

- Enhanced Diagnostics for Characterizing Entry Aerothermal Environments in High-enthalpy Impulse Facilities (Purdue, UCLA and University of Virginia)
- Modeling Shock Layer Radiation and Chemical Kinetics for Planetary Entry (Montana State University and University of Illinois Urbana Champaign)

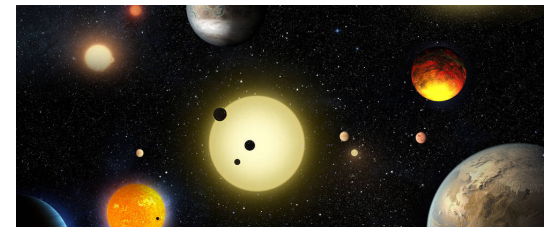
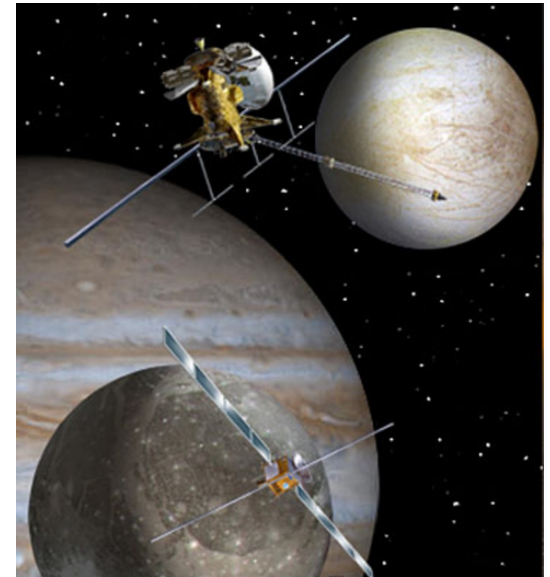
### NASA Established Program to Stimulate Competitive Research (EPSCoR)

Kentucky EPSCoRs have been awarded on topics ranging from better characterizing TPS radiation response to design, manufacture, and entry testing of probes (KRUPS/KREPE)

# Takeaways



- Strategy of modernizing macroscale and maturing microscale ablation modeling tools
- Developed tools addressing entry challenges of slated flight projects/missions
- Robust network of universities providing fundamental developments and talent pipeline
- Future challenges include preparing tools to treat aggressive entry scenarios associated with outer planet missions



Questions?

