

## Space Technology Mission Directorate Game Changing Development Program

Michael Barnhardt | Tom West | FY22 Entry Systems Modeling Annual Review Presentation | 09.15.2022  
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# Entry Systems Modeling (ESM)

## Project Overview

### ➤ Technology Product Capability

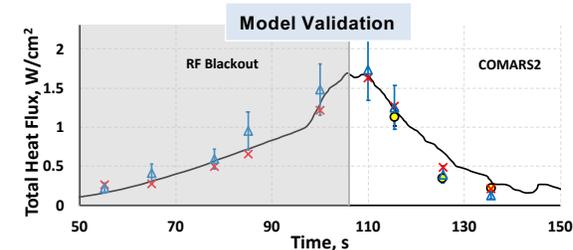
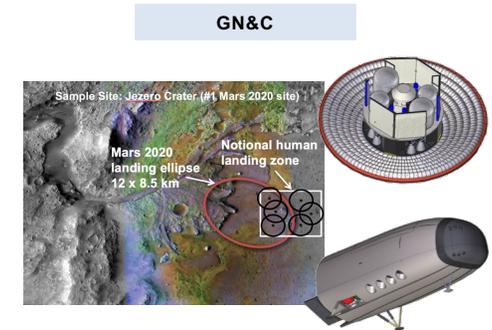
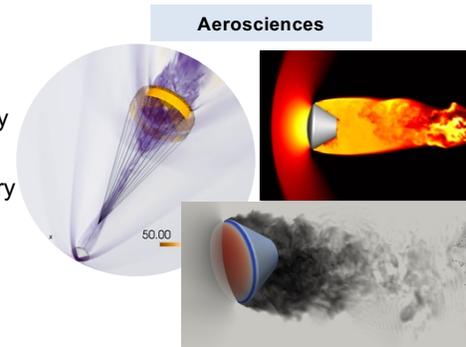
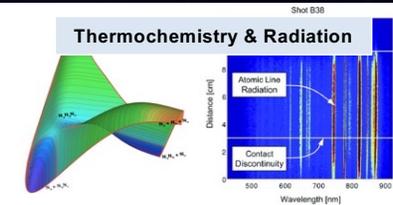
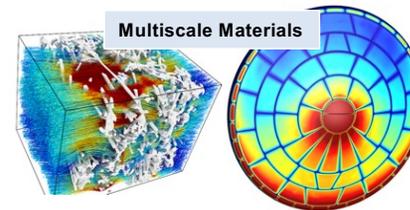
- Cross-cutting tools and technologies for modeling entry systems that improve performance, reduce mission risk, and enable new system capabilities across the Solar System

### ➤ Technical Capabilities

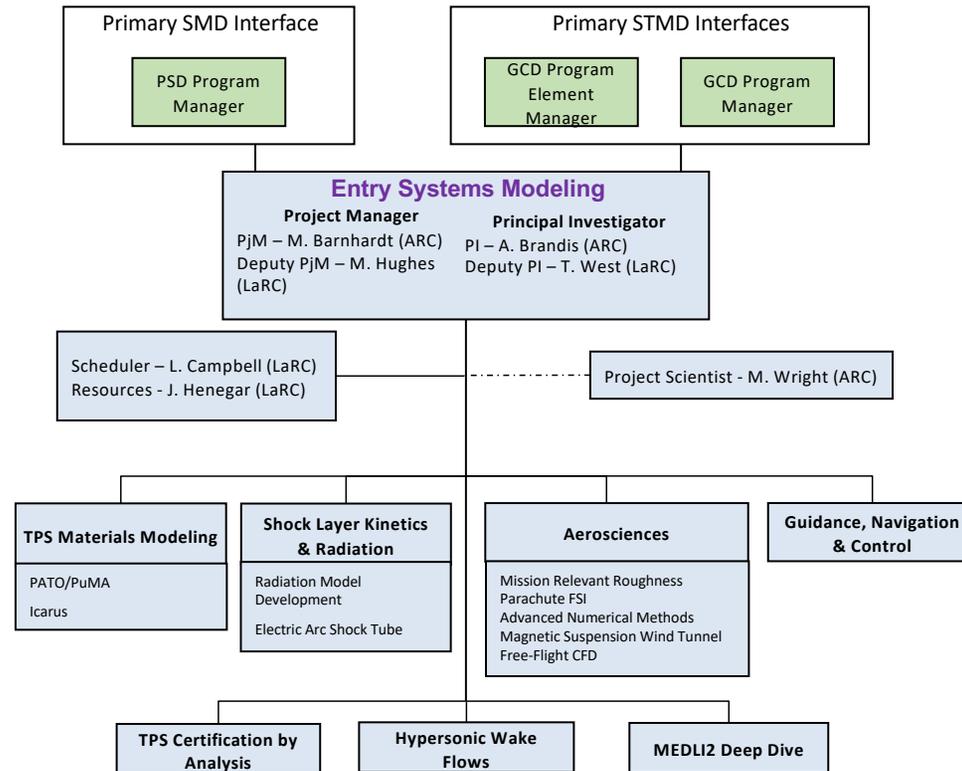
- **Predictive Material Modeling:** Multiscale models of thermal protection material performance and reliability
- **Shock Layer Kinetics & Radiation:** High-temperature gas physics of entry systems, from quantum to engineering scales
- **Computational & Experimental Aerosciences:** Parachute dynamics, entry vehicle dynamics and stability, turbulent heating, advanced computational methods
- **Guidance, Navigation & Control:** End-to-end simulation capability for multiple mission entry, descent, and landing concepts of operations
- **Ground Test Validation:** Focused ground testing at all scales to support uncertainty quantification across technical areas; requires unique facilities and specialized diagnostics

### ➤ Exploration & Science Applicability

- All exploration/science missions with Entry, Descent, and Landing (EDL): Orion, Mars Sample Return – EES and SRL, Dragonfly
- Collaborate with other STMD technology projects as needed



# ESM Team/Project Organization



# Mission Infusion & Partnerships



ESM is a successful, multi-year collaboration between **STMD** and **SMD**

## Centers

Ames  
Langley  
Johnson  
Glenn

## Universities

6 Early Career Faculty  
7 Early Stage Innovations  
1 Space Technology Research Institute  
10 NSTGRO  
6 EPSCoR  
6 ESM grants

## OGA

Air Force Office of Scientific Research  
Office of Naval Research  
Missile Defense Agency  
Sandia  
Lawrence Berkeley  
Lawrence Livermore

## International

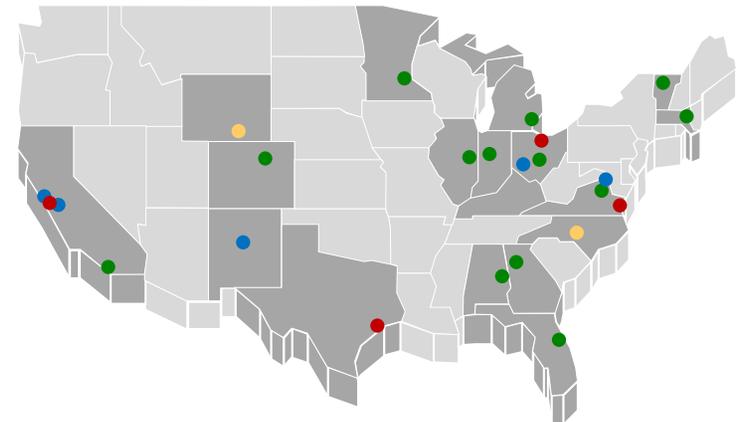
German Aerospace Center  
Ecole CentraleSupelec  
Von Karman Institute  
University of Queensland  
Oxford University  
Instituto Superior Tecnico

## SBIR/STTR

Scientific Simulations, LLC  
Corvid Technologies

## Exploration & Science Applicability

- Orion *[Ongoing]*
- Mars 2020 *[Completed]*
- Mars Sample Return – Earth Entry System and Sample Retrieval Lander *[Ongoing]*
- Dragonfly *[Ongoing]*
- DAVINCI *[Potential]*
- STMD technology projects: e.g., MEDLI2, LOFTID, and others as warranted



# Academic Partnerships



# Entry Systems Modeling

## Technology Goals & Project Objectives



### Technology Goals

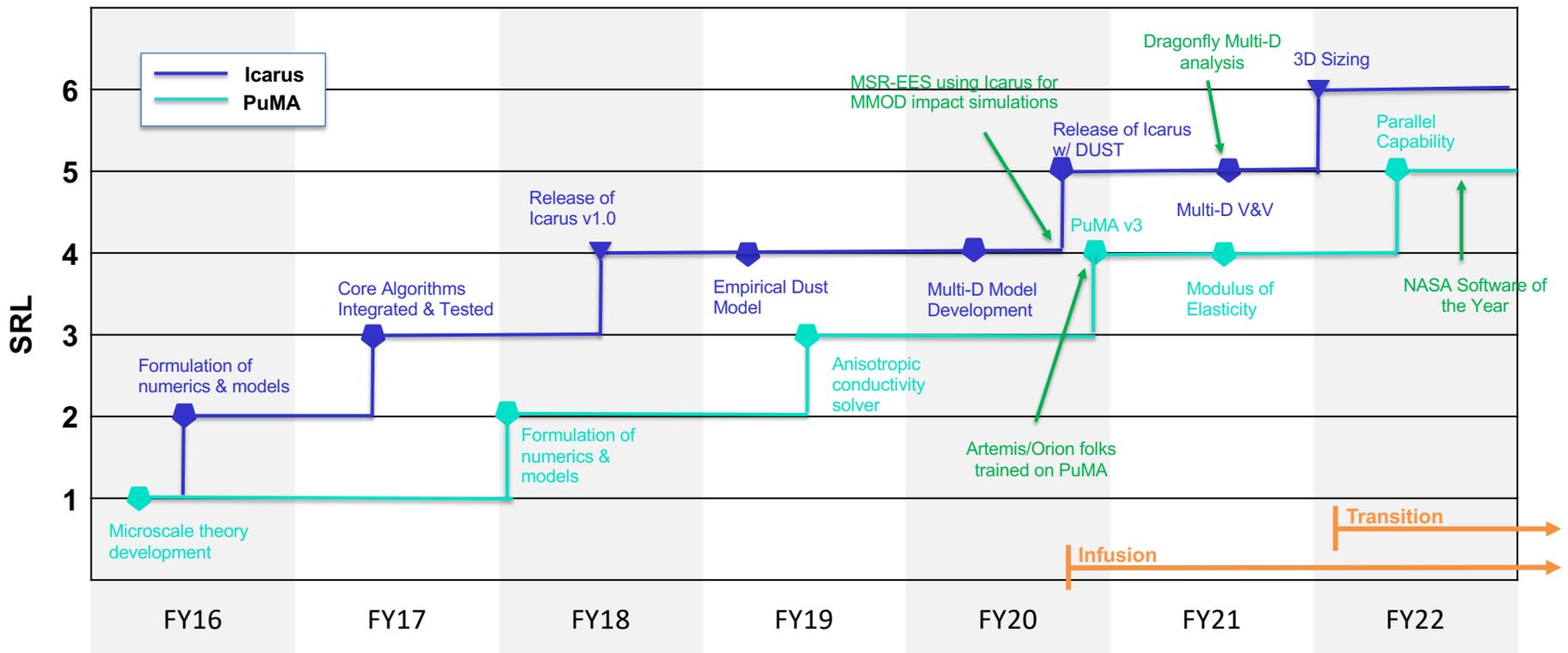
<b>Goal #1</b>	Produce high-fidelity TPS material models to reduce mission risk and improve design reliability
<b>Goal #2</b>	Develop physics-driven models of high-temperature gas chemistry and radiation relevant to EDL missions
<b>Goal #3</b>	Develop tools for simulating complex, unsteady aerodynamic phenomena
<b>Goal #4</b>	Create end-to-end simulation capability for multiple mission EDL concepts of operation
<b>Goal #5</b>	Deliver tools & capabilities to stakeholders with quantified uncertainty models

### Project Objectives

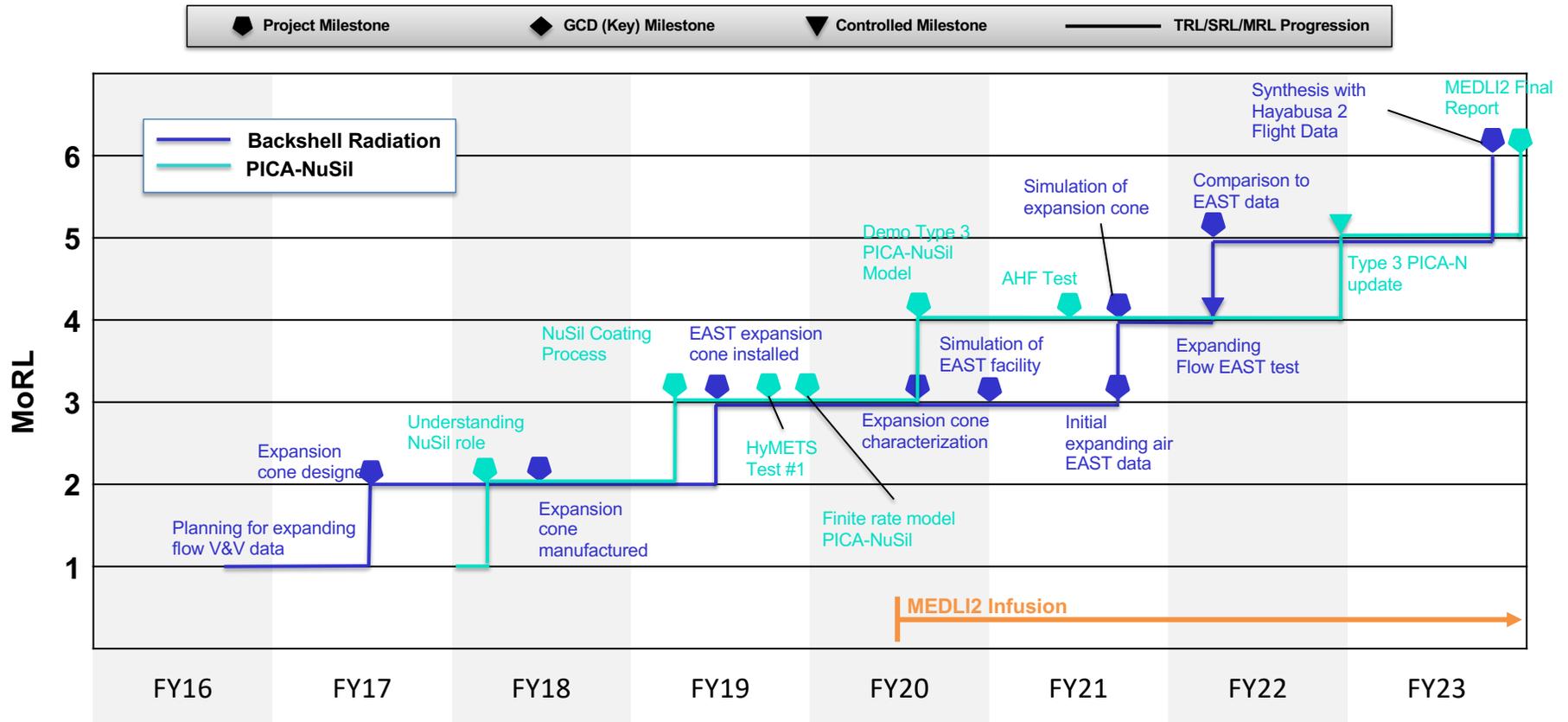
<b>Objective #1</b>	Develop and validate next-gen PATO, Icarus, PuMA, and SPARTA codes for multiscale material modeling
<b>Objective #2</b>	Generate comprehensive chemistry and radiation databases for all Solar System EDL targets using computational chemistry and testing in the Electric Arc Shock Tube
<b>Objective #3</b>	Develop and validate next-gen CFD methods for analysis of unsteady flows: Wake flows, jet interactions, vehicle dynamics, parachute dynamics, high-order numerical schemes
<b>Objective #4</b>	Implement multi-threading in POST2 simulation software and develop interoperability framework to couple with external applications

# ESM Software Development

## Icarus and PuMA



# ESM Model Development Backshell Radiation and PICA-NuSil



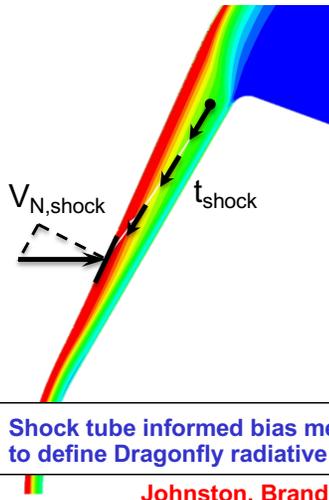
# Accomplishments

## Dragonfly Infusion



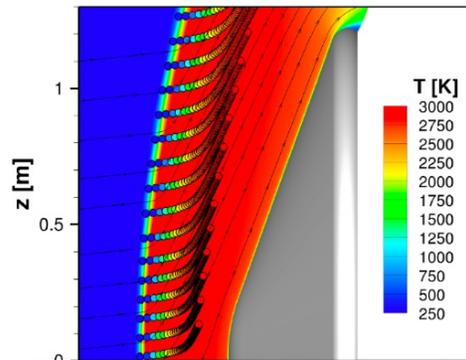
### ➤ Key FY22 Technical Achievements

- Shoulder/PICA tooth material response
- Free-flight CFD
- Dusty flow risk mitigation
- Shock tube informed bias



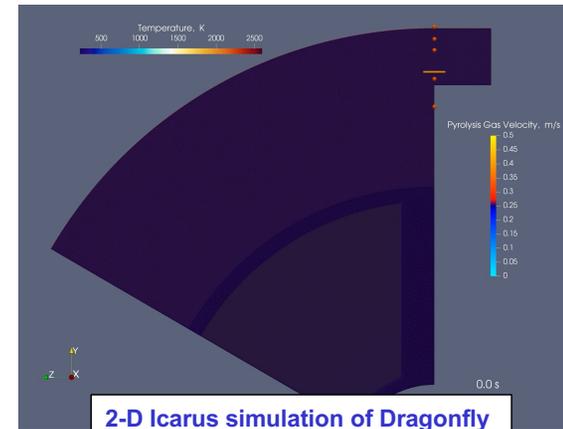
Shock tube informed bias methodology used to define Dragonfly radiative heating margin

Johnston, Brandis



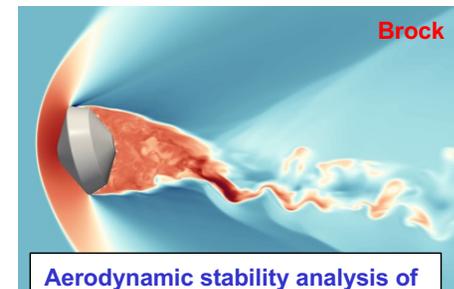
DUST used to mitigate risk of augmented heat flux or recession for Dragonfly

Palmer



2-D Icarus simulation of Dragonfly main seal / shoulder

Stern



Aerodynamic stability analysis of Dragonfly with Free-flight CFD

# Accomplishments

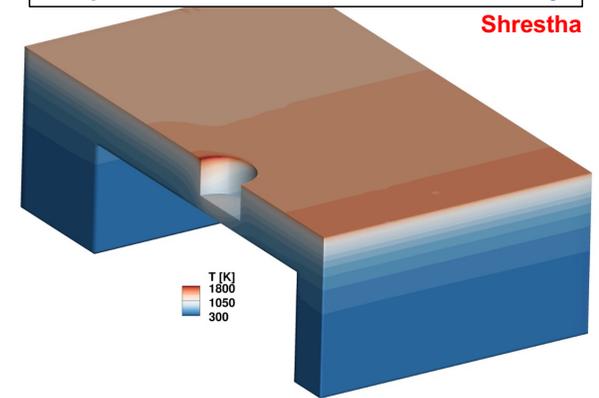
## MSR – Earth Entry System (EES) Infusion



### ➤ Key FY22 Technical Achievements

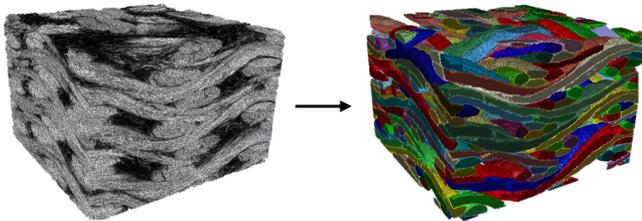
- Shoulder analysis
- MMOD arcjet simulations
- Free-flight CFD of EES dynamics
- 3MDCP failure with Hydra; Thermal property estimates
- Hayabusa analysis addresses EES aerothermal uncertainty

Temperature distribution around MMOD cavity



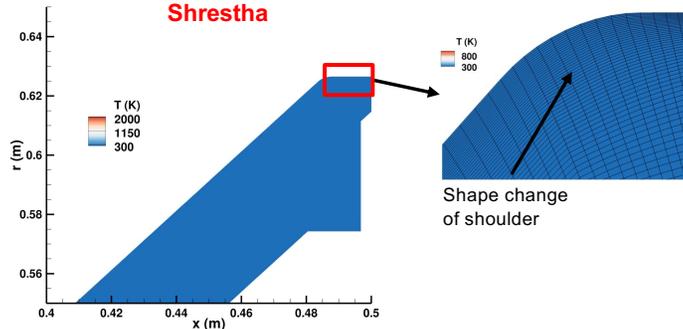
CT scan of EES woven TPS segmented to form a computational model

Fraille Izquierdo, Abbot, Ricks



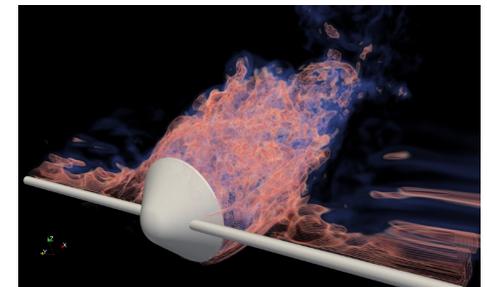
Ablation near EES shoulder region

Shrestha



Simulations of EES dynamics testing

Brock



# Accomplishments

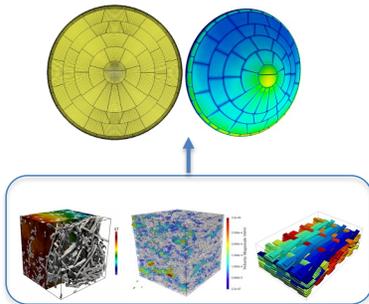
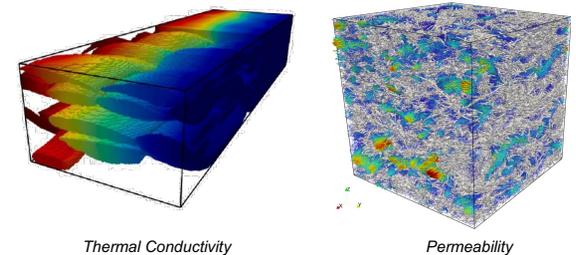
## Porous Microstructure Analysis (PuMA)



### ➤ Key FY22 Technical Achievements

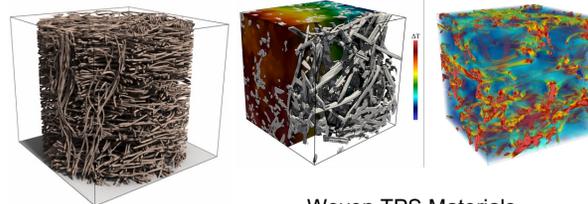
- **2022 NASA Software of the Year!**
- A new capability was added to compute permeability of materials
- Effective elasticity: The PuMA elasticity solver functionality was extended to include imposed shear forces.
- Material Properties During Decomposition: Tomography of FiberForm resolved in 3D and in time

Once provided micro-CT data, PuMA can directly calculate material properties



PuMA's microscopic models inform macroscopic performance

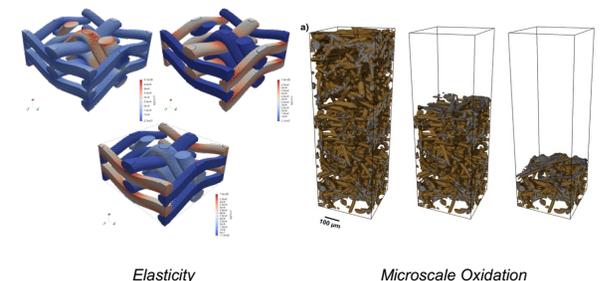
Fibrous TPS Materials



Woven TPS Materials



Ferguson, Semeraro



PuMA works for both fibrous and woven TPS materials, among many other composites

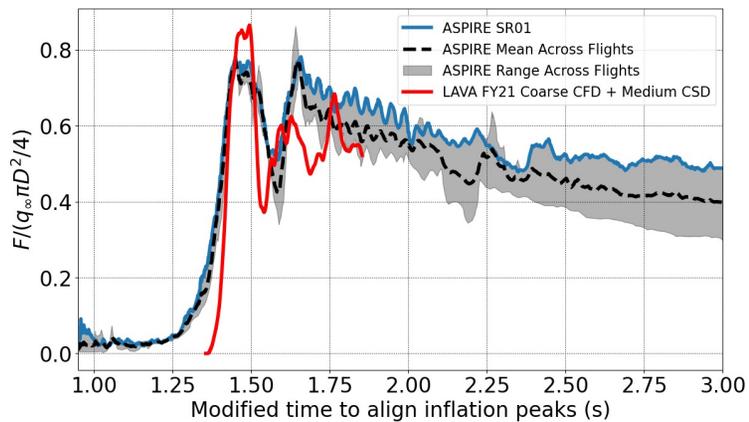
# Accomplishments

## Parachute Modeling



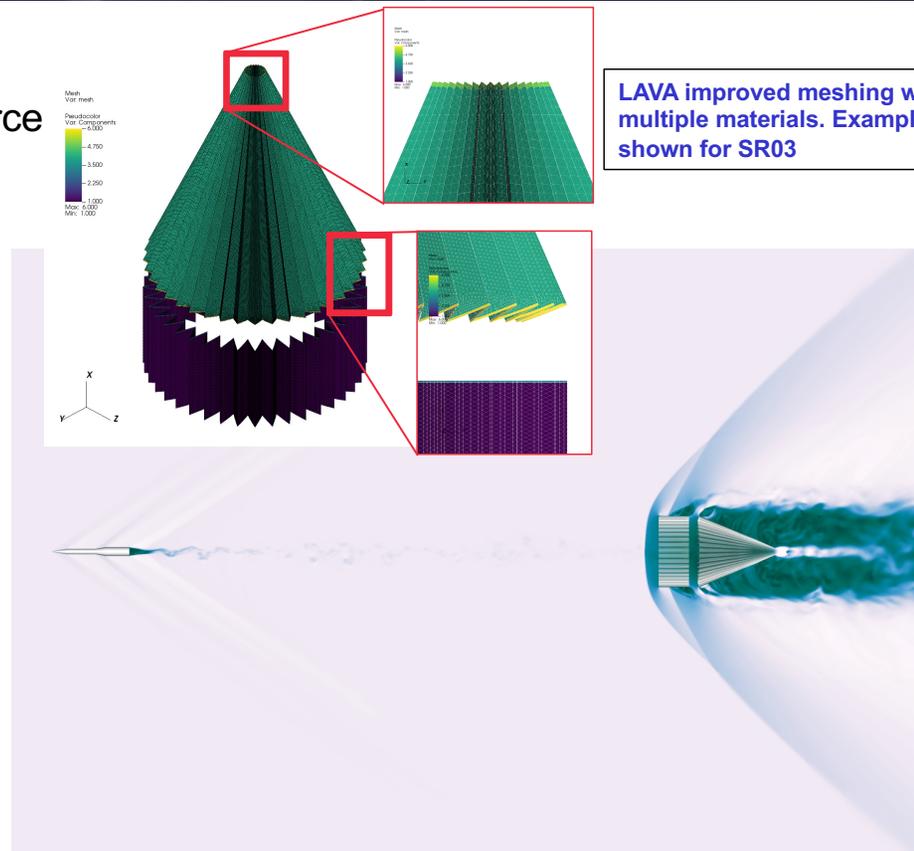
### ➤ Key FY22 Technical Achievements

- LAVA comparison to ASPIRE SR01 pull force
- Enhancement of LAVA capabilities and performance
- Extensions to subsonic Orion dynamics



LAVA comparison to ASPIRE flight test inflation loads

Boustani, Cadieux, Kiris



LAVA improved meshing with multiple materials. Example shown for SR03

# Accomplishments

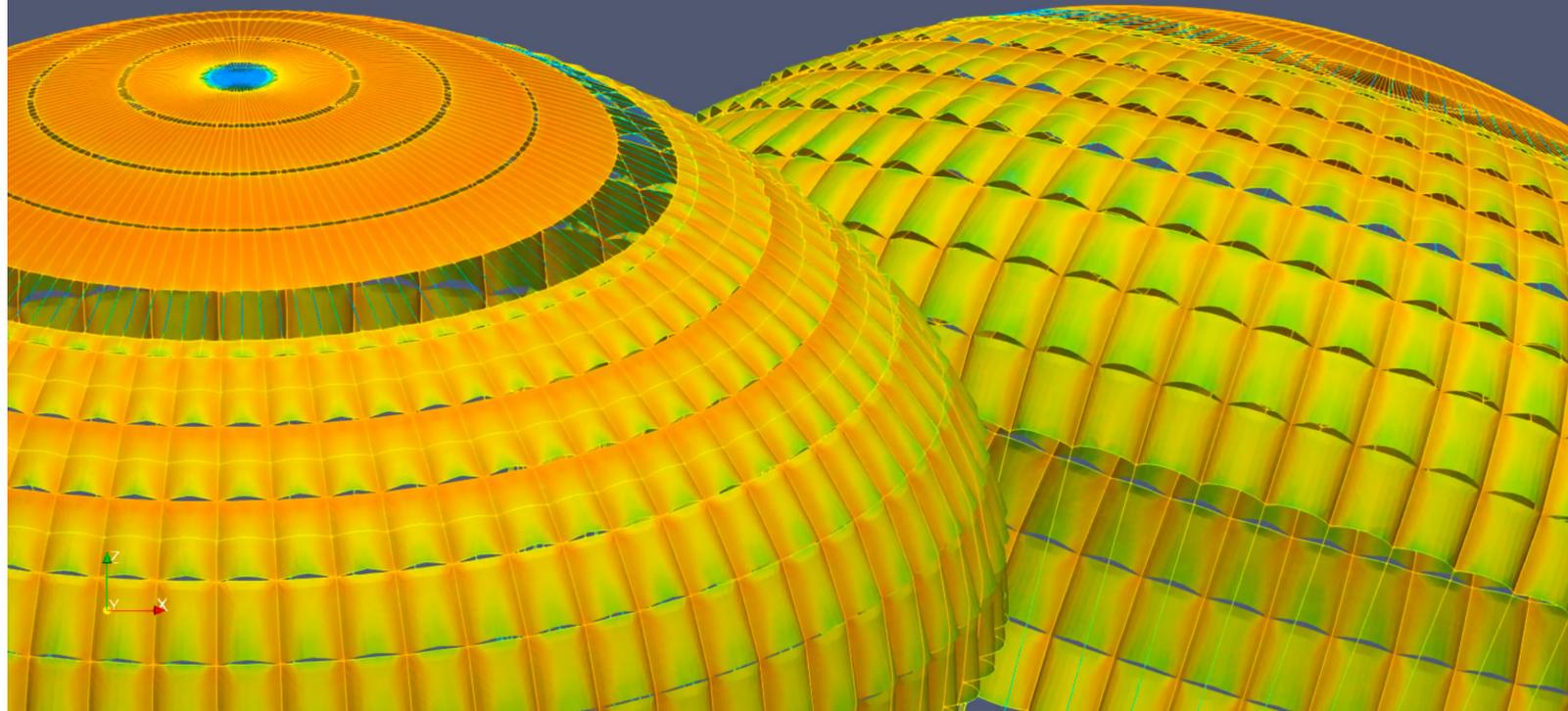
## Parachute Modeling



Time: 0.461

Canopy stresses as a function of time during subsonic descent

Farhat



# Accomplishments

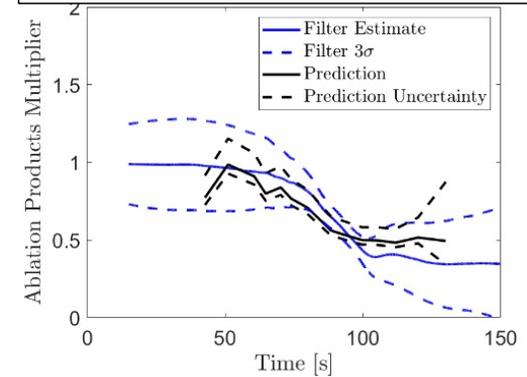
## MEDLI2 Deep Dive



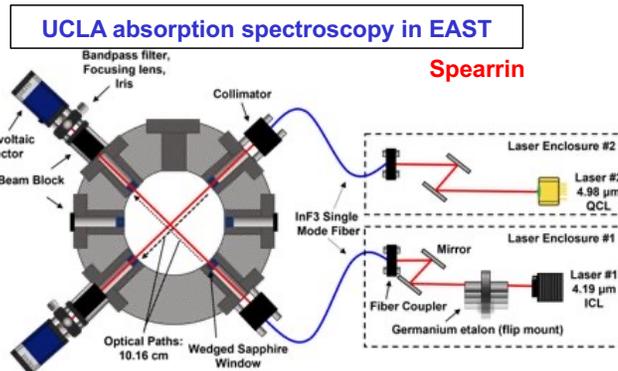
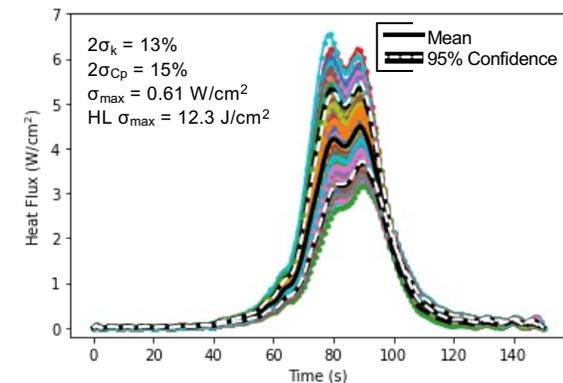
### ➤ Key FY22 Technical Achievements

- Completed first round of CO<sub>2</sub> testing in EAST. Partnered with UCLA to obtain multi-temperature measurements.
- Applied machine learning to inverse analysis of MEDLI2 thermal sensors for efficient sensitivity analysis of material properties.
- Developed a data fusion method based on Kalman filtering to reconstruct backshell heating environments around co-located MEDLI2 sensors.

Estimate of MEDLI2 Radiometer Attenuation



Neural Network Based Heating Prediction



# Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year	Yellow	Yellow	Green	Green	<p><b>Cost</b> – Mismatch between planning and CR guidelines resulted in project operating at very high risk</p> <p><b>Schedule</b> – Facility-driven delays impacted deliverables for Wake Flows and MEDLI2 Deep Dive activities</p>
Annual	Green	Yellow	Green	Green	<p><b>Schedule</b> – Same issues, but trend is improving. We are next up in Langley Mach 10 after return to operation. Ditto for HyMETS, and the project has taken mitigation steps to test with a similar capability identified at U Illinois.</p>

# Plans Forward and Transition / Infusion Plan



## Mission Partners\* & Target Applications for Infusion

- Orion *[Ongoing Partnership]*
  - *High-fidelity thermal protection material models for Avcoat*
  - *Simulation of subsonic parachute descent dynamics*
  - *Artemis radiometer and spectrometers*
- Mars Sample Return – Earth Entry System and Sample Retrieval Lander *[Ongoing]*
  - *Failure modeling of 3D woven thermal protection material [EES]*
  - *3D modeling of MMOD impact sites on heatshield [EES]*
  - *Free-flight CFD simulation of vehicle dynamics [EES]*
  - *MEDLI2 assessment of EDL performance margins [SRL]*
  - *Simulation of supersonic parachute inflation dynamics [SRL]*
  - *PICA-NuSil and SLA material models [SRL]*
  - *Aftbody aerothermal environments and material response [SRL]*
- Dragonfly *[Ongoing]*
  - *Free-flight CFD simulation of vehicle dynamics*
  - *PICA-NuSil and SLA material models*
  - *3D modeling of thermal protection system*
  - *Nitrogen/methane aerothermal environments (experiments and models)*
- DAVINCI *[Potential]*
  - *Venus shock layer radiation*
  - *Parachute modeling*

\*“Partners” generally denotes exchange of technical data and other products rather than project/program funds. In limited cases, ESM has co-funding arrangements for shared-use procurements.

# Education/Public Outreach Summary



- **PuMA: The Porous Microstructure Analysis (PuMA) software was named NASA's Software of the Year**
- **Over 60 publications\* and/or presentations (increasing participation as pandemic restrictions decrease); highlights include:**
  - **AIAA Thermophysics Best Paper:** Torres et al, "Direct molecular simulation of rovibrational relaxation and chemical reactions in air mixtures", University of Minnesota

Date	Papers/Posters/Panel Discussions	Number of Papers/Posters/Panel Discussions
11/01/2021	VEXAG 2021	1
1/3/2022	AIAA SciTech 2022	15
1/24/2022	Composites, Materials, and Structures	2
6/19/2022	FAR	5
6/27/2022	AIAA Aviation 2022	5
8/28/2022	IPPW 2022	7 Short Course and 7 Conference presentations

- **6 International Agreements**
- **31 Grants\*;** highlights include:
  - 7 funded by ESM
  - 14 ECF/ESI with oversight/collaboration from ESM
  - 5 funded by EPSCoR program with oversight/collaboration from ESM
- **Nearly 50 Students\*;** highlights include:
  - NSTGRO: ESM team members are research collaborators for 15 students
  - Supporting 2 post-docs
  - Supporting 3 Pathways students

\* Raw data recorded in tables in Backup

# Education/Public Outreach News-Worthy Events



## FY22 News-worthy Events:

- **PuMA: The Porous Microstructure Analysis (PuMA) software has been selected as NASA's Software of the Year**
- **NAS Website Publication: Simulating Supersonic Parachute Inflation for Future Mars Landings (highlighting LAVA):** [https://www.nas.nasa.gov/pubs/stories/2022/feature\\_LAVA\\_Parachutes.html](https://www.nas.nasa.gov/pubs/stories/2022/feature_LAVA_Parachutes.html)
- **NASA.gov article published on Mission Relevance Roughness Work:** <https://www.nasa.gov/feature/nasa-high-speed-wind-tunnel-testing-to-improve-heat-shield-design/>

Upcoming Activities: 6 Month Look-Ahead	
IPPW 2022	Aug 29 – Sep 2, 2022
ESM Workshop	Oct 3, 5, & 6, 2022
VEXAG	Nov 11, 2022
Ablation Workshop	Nov 15-18, 2022
AIAA SciTech, ESM Special Session	Jan 23-27, 2023

## FY23 News-worthy Events:

- **Multiple arc-jet test campaigns in HyMETS (LaRC) and AHF (ARC) to study NuSil coated PICA surface and pyrolysis chemistry**
- **Wake Flows Testing in the Langley Mach 10**
- **Artemis I post-flight aerothermal analysis and comparison to flight measurements**

# Summary



- **Project performance**

- Budget management was very challenging under CR – ESM still managed to attain >98% obligation of funds
- 9 key and controlled milestones completed; Additional 15 expected to complete at end of this month; One milestone to slip into first quarter of FY23.
  - Schedule slips almost entirely attributed to facility delays and/or COVID

- **Outreach & Recognition**

- 60+ publications in FY22 (*1 Best Paper Award from AIAA*)
- NASA Software of the Year (second time that ESM software has won)

- **Established partnerships**

- Mars Sample Return: EES and SRL
- Dragonfly
- New Space Act Agreement signed with CentraleSupélec (France); SAA with Instituto Superior Técnico (Portugal)

- **TAPR Actions (more information provided in supplement)**

- Project now tracks facility dependencies and the impact of delays
- Project has established team-level arrangements to collaborate with Orion on application of ESM tools to enhance Artemis 1 post-flight analysis