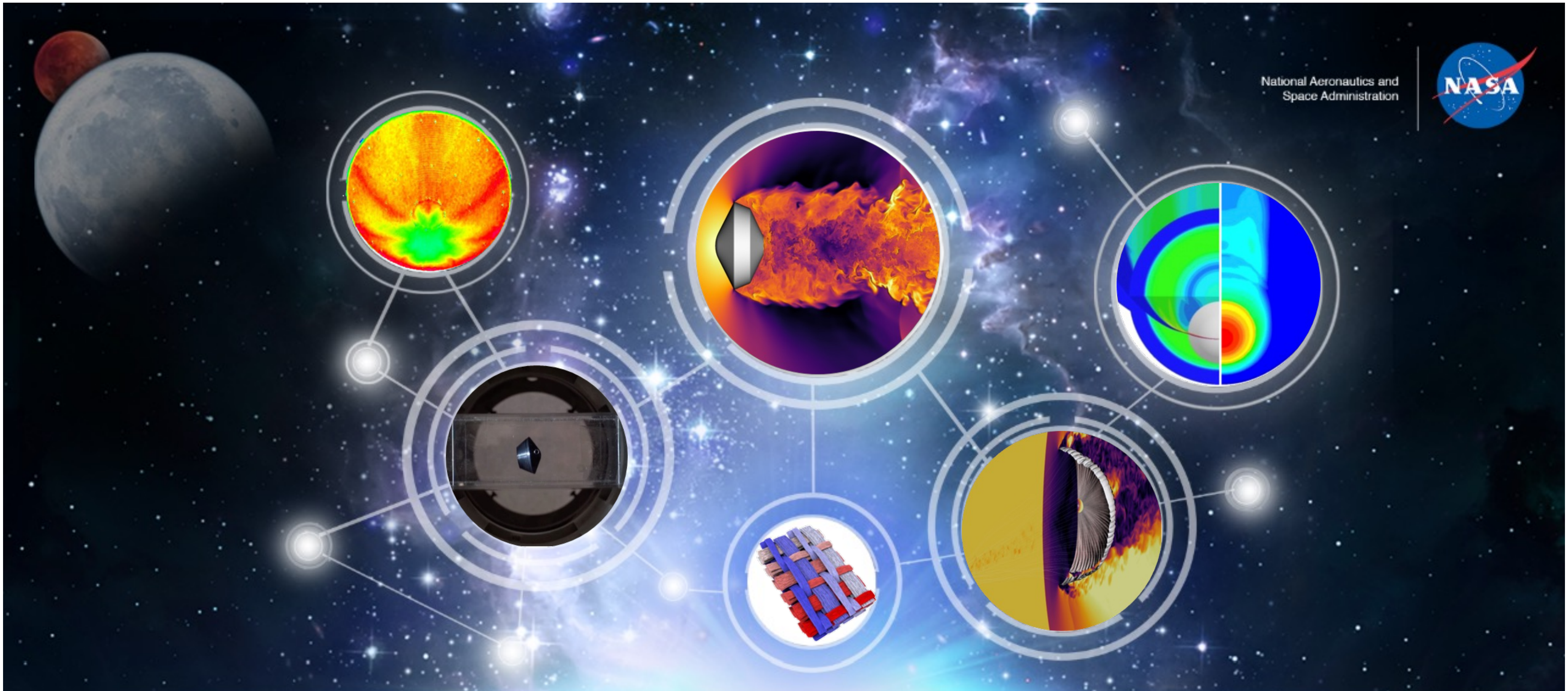


Space Technology Mission Directorate

Game Changing Development Program

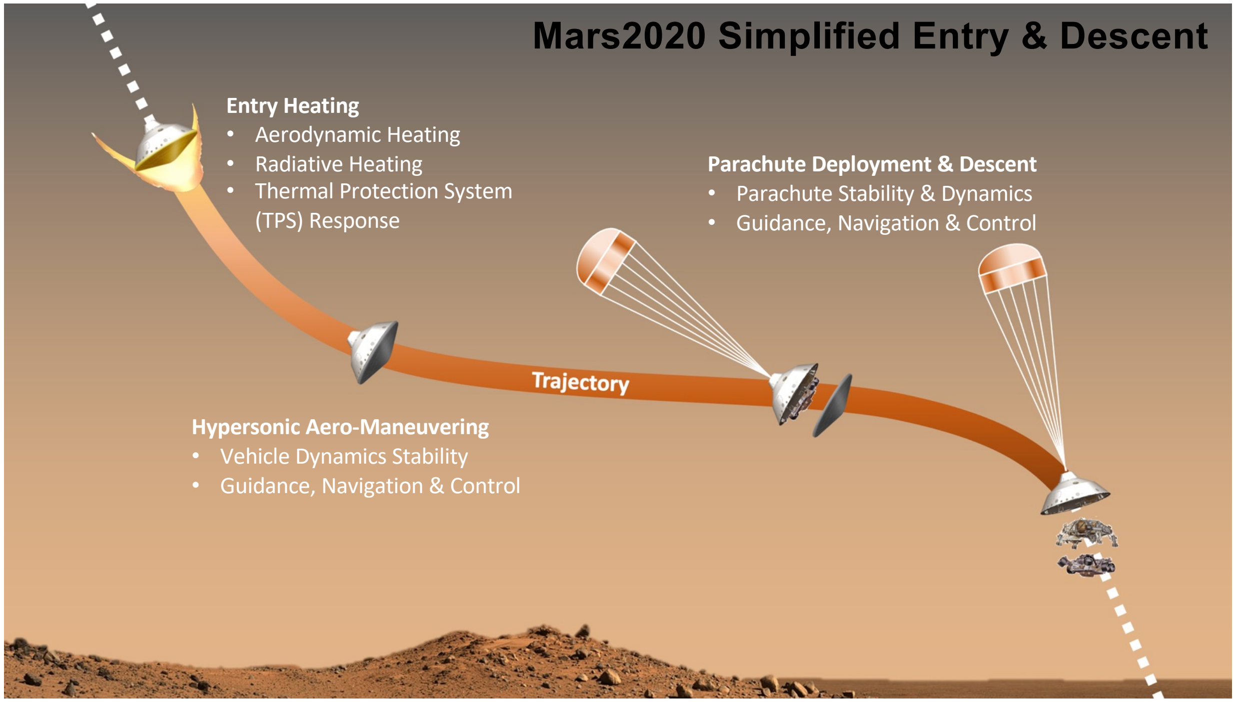
Justin Haskins, Aaron Brandis, Monica Hughes, Tom West | Entry Systems Modeling Project | Annual Program Review | September 10-12, 2024

Challenges for Entry, Descent, and Landing (EDL)

Timer

EDL comprises a relatively small portion of a mission's timeline, however, it is typically among the largest risks. Flying through a body's atmosphere reliably and accurately – from orbit to ground or via aerocapture – is a critical step toward successful in situ exploration.

- EDL is a multi-stage process that can be unique to a given mission and destination
- Each stage presents challenges – high velocity, large thermal gradients, and complex maneuvers
- Ground testing does not provide comprehensive data on EDL – validated models required for ground to flight traceability



Entry Systems Modeling (ESM) Project Overview

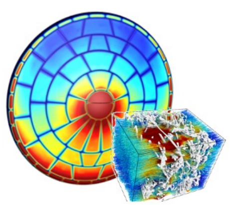
Timer

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

ESM Technical Scope consists of *4 capability areas* and *various special topics*

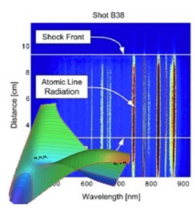
Technical Capability Areas

TPS Materials Modeling



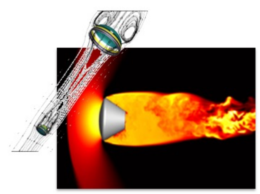
multiscale models of TPS material reliability and performance

Shock Layer Kinetic and Radiation



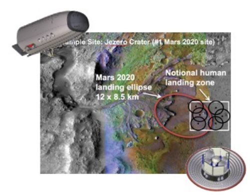
high-temperature gas physics of entry systems from quantum to engineering scales

Aerosciences



parachute dynamics, vehicle dynamics & stability, turbulent heating, advanced numerical methods

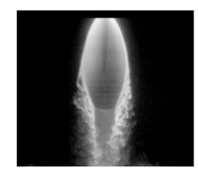
Guidance, Navigation, and Control



end-to-end simulation capability for multiple mission EDL concepts of operation

Special Topic

Hypersonic Wake Flows



simulation and experimental interrogation of unsteady wake flows

ESM Goals and Objectives

Timer

- Goals and objectives map to five technical capability areas – will be updated for the next project cycle starting in FY25
- Objectives address a wide range of technology needs – 17 EDL Capability Gaps

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

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

Alignment with STAR EDL Capability Gaps

Timer

KPP ID, Name	SCLT EDL Gap ID
4.1.1: Error between measured and computer FiberForm wedge recession	163, 295,296,323,329
4.1.2: Dusty flow augmented erosion	163, 295, 296, 323, 329
4.2.1: Fidelity of air model - backshell	163, 326, 329
4.2.2: Fidelity of CO2 model - forebody	324, 329
4.2.3: Fidelity of CO2 model - backshell	324, 329
4.3.1: MSWT pitch damping coefficient	327, 411
4.3.2: FF pitch damping coefficient - subsonic	
4.3.3: FF drag coefficient - subsonic	
4.3.4: MRR augmentation model uncertainty fo	
4.3.5: MRR augmentation model uncertainty fo	
4.3.6: FSIP ASPIRE comparison	310
4.5.1: Radiometer flux	324
4.5.2: Near surface TCs	324
4.5.3: Backshell pressure	327
4.6.1: Experimental surface heat transfer	163, 324, 328
4.6.2: Surface heating simulations	163, 324, 328
4.7.1: Tensile strength of virgin HEEET	163, 295, 296, 323, 329, 414, 1440
4.7.2: Cross sectional create area of impacted HEEET	163, 295, 296, 323, 329, 414, 1440

17 STMD EDL Capability Gaps addressed by project content

SCLT EDL Gap ID	Gap Name
163	High-Reliability Earth Entry Vehicles for Robotic Missions
295	Thermal Protection System Performance Modeling and Optimization for Human Mars Exploration
296	Thermal Protection System Performance Modeling and Optimization for Robotic Missions
310	Supersonic Parachute Systems and Modeling
311	Subsonic Parachute Systems and Modeling
	/TPS Reliability Prediction
	Aerothermodynamic Prediction for Human Mars EDL
	Aerothermodynamic Prediction for Robotic Mission
	Aerodynamics for Crew Return EDL at Earth
327	Validated Static and Dynamic Aerodynamics Prediction from Supersonic to low Subsonic Speeds
328	Validated Wake Models, Including Reaction Control Thruster Effects
329	Multi-disciplinary / coupled EDL performance models
330	High End Computing Capability for EDL Modeling
349	Entry GN&C Modeling for Planetary Entry EDL
411	Supersonic Dynamics Test Facility
414	Cost Efficient TPS Certification
1440	Validated Thermostructural Modeling for TPS Integrated into the Aeroshell

Alignment with New STMD Shortfalls

Timer

- STMD reclassified and updated Gaps into Shortfalls: “identified technology areas that require further development to meet future exploration and science mission needs”
- List of 13 EDL Shortfalls were released: current/planned content aligns with 5 shortfalls

ID	Shortfall Title
1568	Entry Modeling and Simulation for EDL Missions
1574	Validated Performance Models for Planetary Parachutes
1569	High-Mass Mars Entry and Descent Systems
1565	Assessment and Validation Capabilities for Integrated Precision Landing Systems
1563	Aerocapture for Spacecraft Deceleration and Orbit Insertion

Stakeholders and Partners

Timer

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

Centers

- Ames
- Armstrong
- Langley
- Johnson
- Glenn

NASA Spaceflight and Technology Projects

Orion
Artemis/Commercial Crew
Mars2020*
Mars Sample Return – Earth Entry System (MSR-EES)*
Mars Sample Return – Sample Retrieval Lander (MSR-SRL)
Dragonfly
DAVINCI
STMD technology projects: MEDLI2*, LOFTID*, DrEAM, VISTA

Universities

28+ major university partners:
– ESM funded grants
– Early Stage Innovation Program
– Early Career Faculty Program
– NASA Space Technology Graduate Research Opportunity
– Established Program to Stimulate Competitive Research
– NASA and Center-led Internship Programs
– Pathways Program

OGA

- Air Force Office of Scientific Research
- Air Force Research Labs
- Office of Naval Research
- Missile Defense Agency
- Sandia National Labs
- Lawrence Berkeley National Lab
- Lawrence Livermore National Lab

NASA ECI

- Enhancing Parachutes by Instrumenting the Canopy (EPIC)

SBIR/STTR

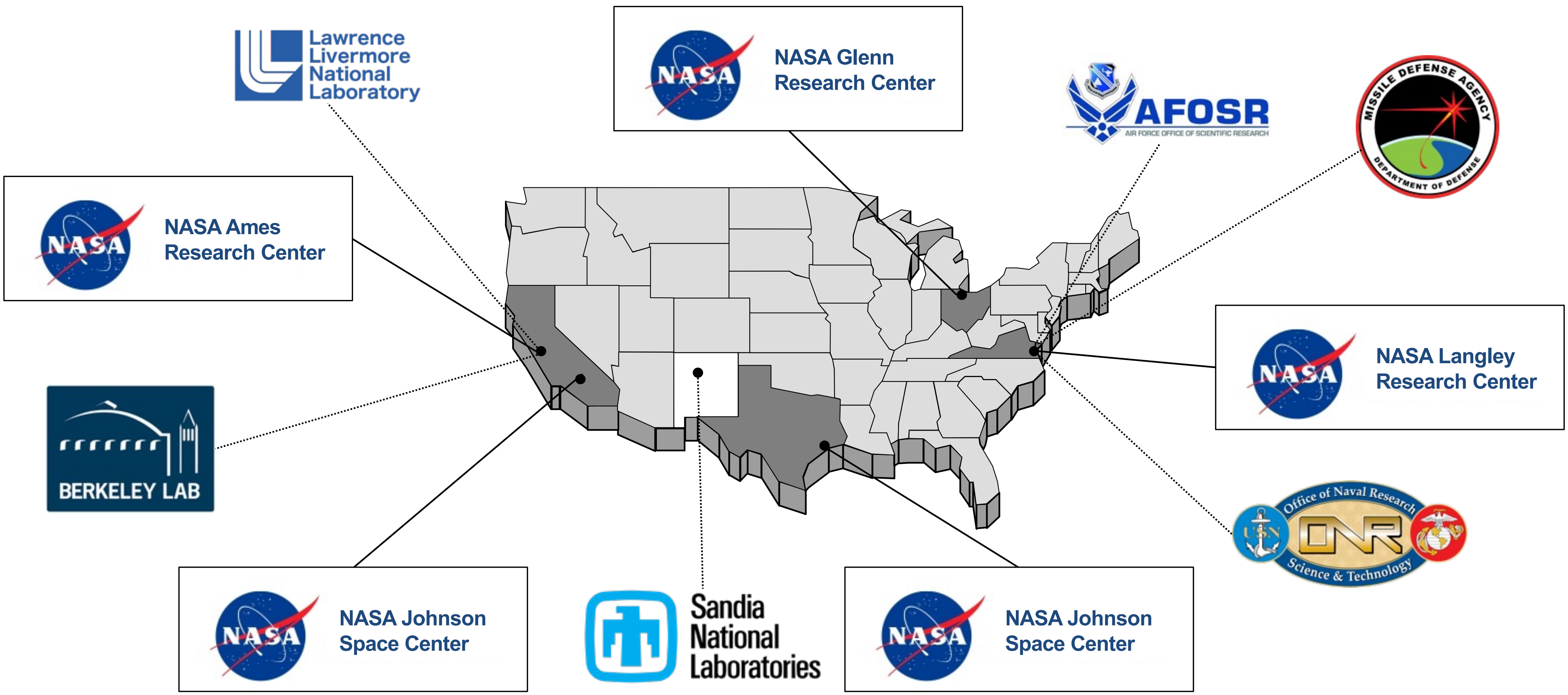
- Corvid Technologies
- ATA
- CFDRC
- M4
- Metrolaser

International

- DLR (German Aerospace Center)
- Ecole CentraleSupelec
- Von Karman Institute
- University of Queensland
- Oxford University*
- Instituto Superior Tecnico
- European Space Agency
- JAXA (partnered with Orion)

NASA Centers and OGAs

Timer



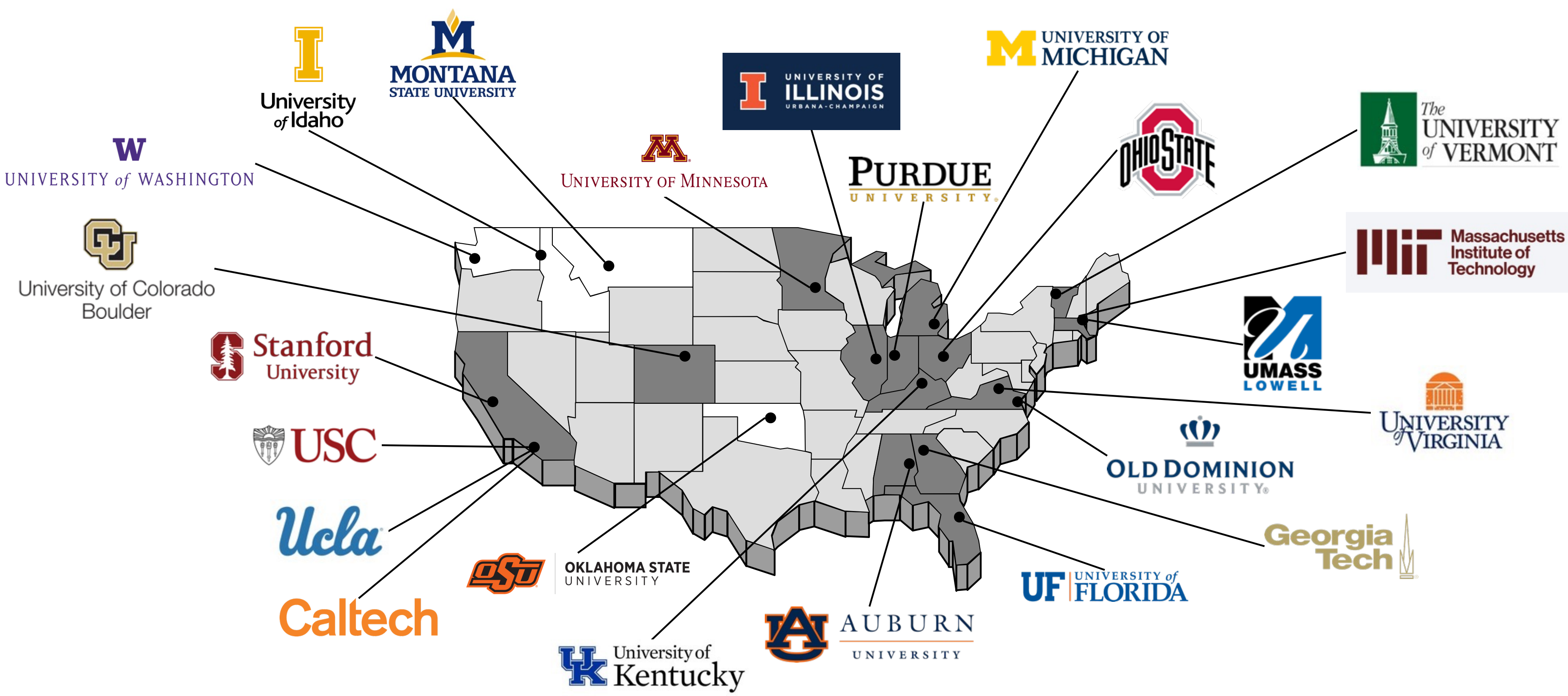
Mission Infusion and Transition

Timer

Orion/Artemis	○ Advanced Avcoat TPS Material Performance Models ○ Subsonic Parachute Descent Dynamics Models ○ Backshell Radiative Environment Models
Mars Sample Return Earth Entry System (EES) Sample Retrieval Lander (SRL)	○ Advanced Woven and PICA-Nusil TPS Material Performance Models ○ Multi-physics TPS Design Tools ○ Supersonic Parachute Dynamics Models to Assess Stability
Dragonfly	○ Capsule Dynamic Stability Models and Tools ○ Multi-physics TPS Design Tools ○ Shock Layer Radiation Models
SMD and HEO Futures: Mars, Gas Giants, and Venus	○ Advanced Woven TPS Material Performance Models ○ Shock Layer Radiation Models ○ Advanced Guidance, Navigation, and Control Algorithms and Tools

University Partners

Timer



* Not counting NSTGRO

ESM Organizational Chart

Timer

Science Mission Directorate

PESTO Program Manager–
E. Montbach

Space Technology Mission Directorate

EDL Systems Capability Lead –
M. Wright, M. Munk
GCD Program Element Manager –
W. May

Entry Systems Modeling Project

Project Manager

PM – J. Haskins (ARC)
DPM – M. Hughes (LaRC)

Principal Investigator

PI – A. Brandis (ARC)
DPI – T. West (LaRC)

Schedule – L. Campbell, A. Majcher (LaRC)

Resources – J. Henegar (LaRC)

TPS Materials

- Predictive Material Modeling
- Coupled Material Response
- TPS Experiments for V&V
- Fracture & Failure of TPS

Shock Layer Kinetics & Radiation

- Radiation Model Development
- Electric Arc Shock Tube
- Quantum Chemistry

Aerosciences

- Mission Relevant Roughness
- Parachute FSI
- Advanced Numerical Methods
- Free-Flight CFD
- Magnetic Suspension Wind Tunnel

Guidance, Navigation & Control

- Unconventional Entry Systems Guidance Algorithm Development
- Novel Guidance Scheme Implementation and Validation
- POST2 Development and Verification

Hypersonic Wake Flows

Timer

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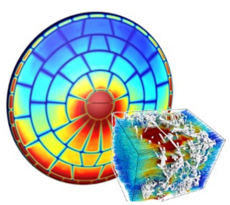
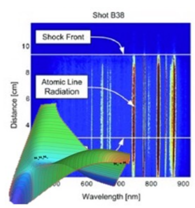


multiscale models of TPS material reliability and performance

Shock Layer Kinetic and Radiation



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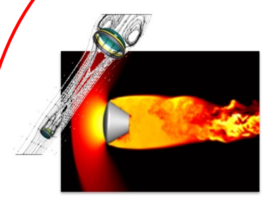

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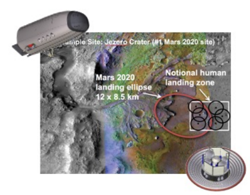
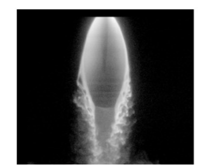


end-to-end simulation capability for multiple mission EDL concepts of operation

Special Topic

Hypersonic Wake Flows



simulation and experimental interrogation of unsteady wake flows

Accomplishments

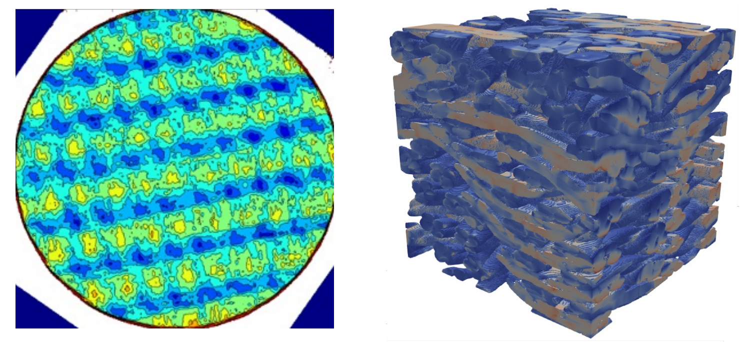
Advanced Woven Thermal Protection System Material Models

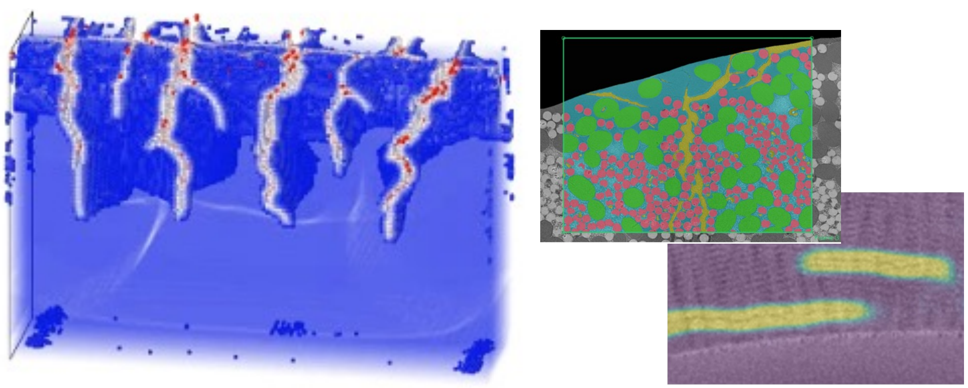
Timer

New capabilities developed for characterizing woven Thermal Protection System materials, targeting Mars Sample Return Earth Entry System and Uranus Orbiter Probe mission applications:

- **Multiscale Modeling:** ability to predict thermo-mechanical properties from non-destructive imaging of the material [Fraile Izquierdo, Abbott]
- **Fracture Models:** predict fracture and failure modes activation in materials given thermal and mechanical loads [Santos, Abbott, Haskins]
- **Shape Change Evaluation:** coupled CFD-material simulation capability, using the Ares tool, of the heatshield shape change during entry [Schulz, Shrestha]

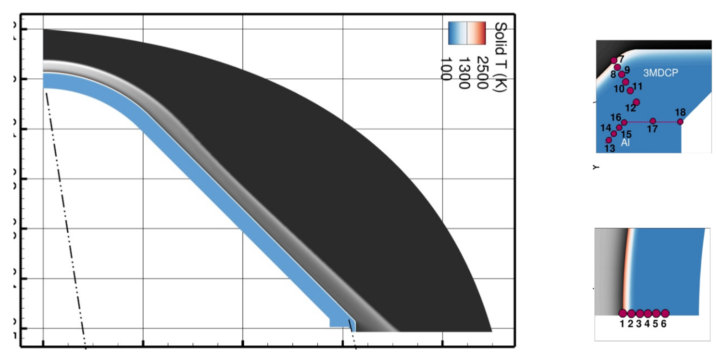
Multiscale Characterization of Structure and Thermo-mechanical Properties





Fracture Imaging and Coupled Fracture-Ablation Simulations

Demo of Heatshield Shape Change Capability for Mars Sample Return Earth Entry System

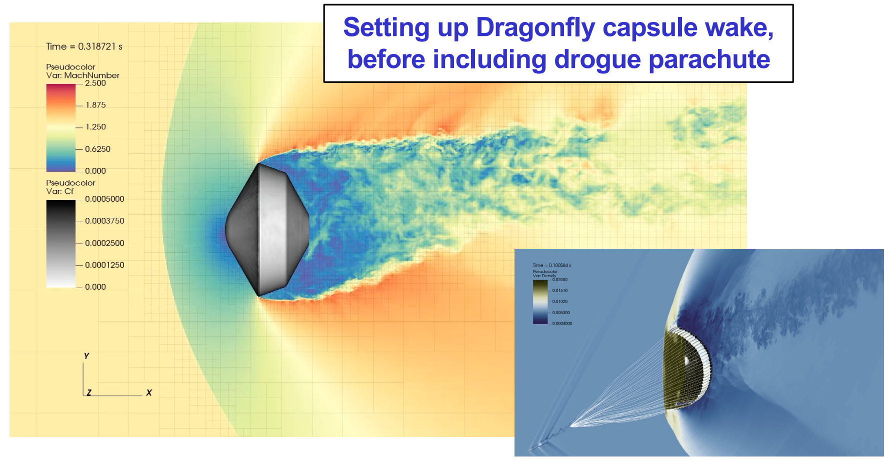


Accomplishments

Advanced Woven Thermal Protection System Material Models

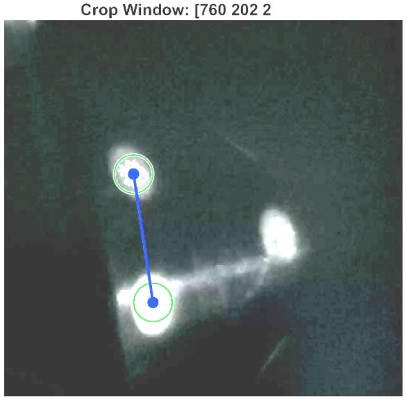
Timer

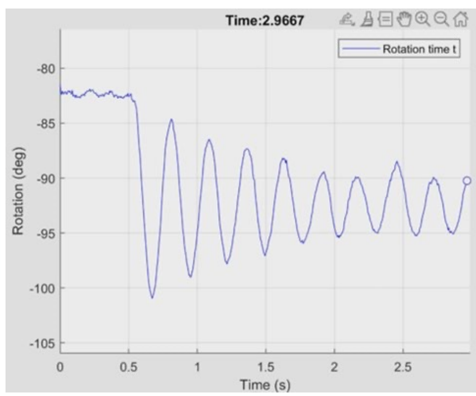
- **Parachute Dynamics:** updated simulations, using the LAVA code, to ASPIRE flight test comparisons, now including deceleration [Cadieux, Barad]
- **Magnetic Suspension Wind Tunnel:** performance demonstrated for free flight testing, now transitioning to spaceflight project support [Schoenenberger]



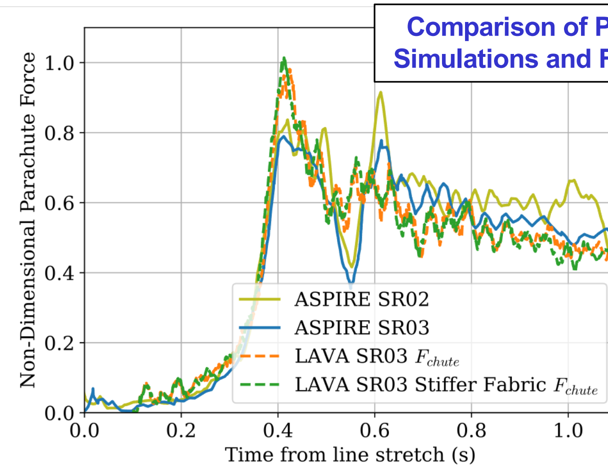
Setting up Dragonfly capsule wake, before including drogue parachute

Crop Window: [760 202 2





Magnetic Suspension Wind Tunnel aeroshell performance demonstration



Comparison of Parachute Simulations and Flight Data

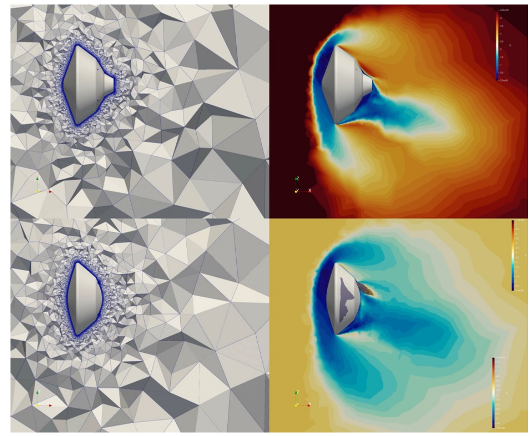
Accomplishments

Wake Flow: Backshell Heating and Dynamics

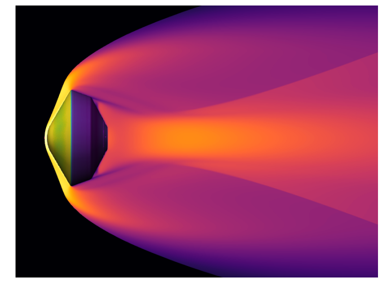
Timer

Simulation tool and experimental technique advances have allowed better characterization of wake flow heating and dynamics to understand vehicle stability:

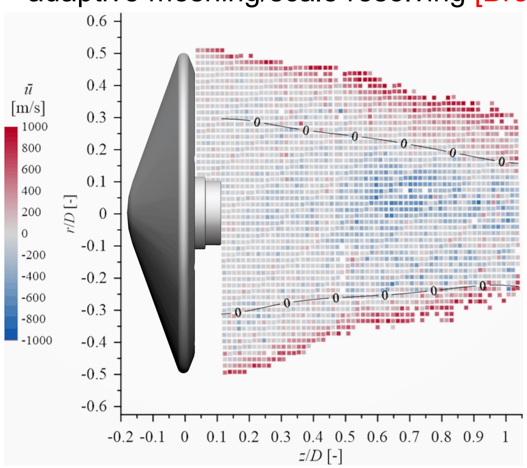
- **Wake Flow Data:** experimental data for computational fluid dynamics (CFD) heating and free flight dynamics validation obtained from wind tunnel testing [Rodrigues, Danehy, Hinkle]
- **Adaptive Meshing:** MIMIC tool used for automated grid refinement of complicated wake flow structure [Ekelschot]
- **Solution Accuracy:** free flight CFD (FF-CFD) solution of Mars Sample Return Earth Entry System (MSR-EES) wind tunnel tests improves adaptive meshing/scale resolving [Brock, Rathakrishnan]

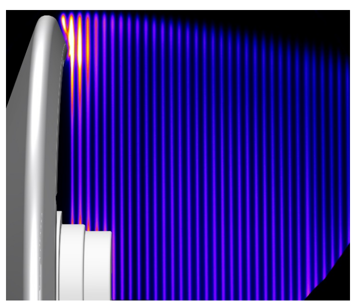


Visualizing MIMIC grid adaptation

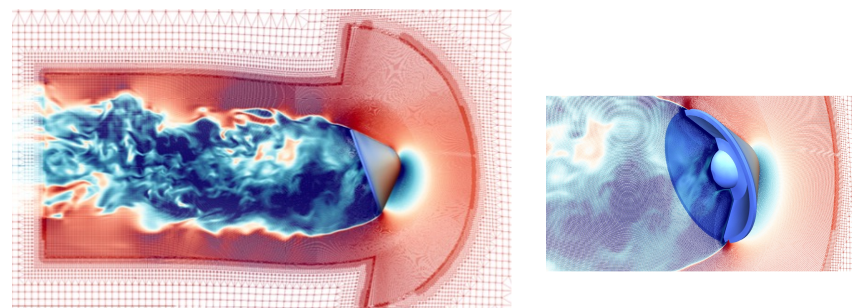


Detailed Dragonfly Geometry with Hypersolve





Experimental PLIF Wake Visualization using Velocity Measurements



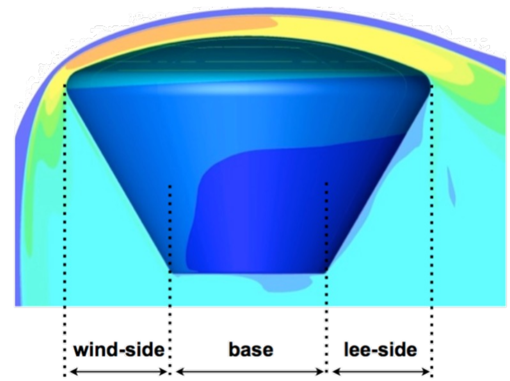
Visualization of computational mesh and resolved wake for MSR-EES 1-DoF simulation

Accomplishments
Artemis Aerothermal Reconstruction

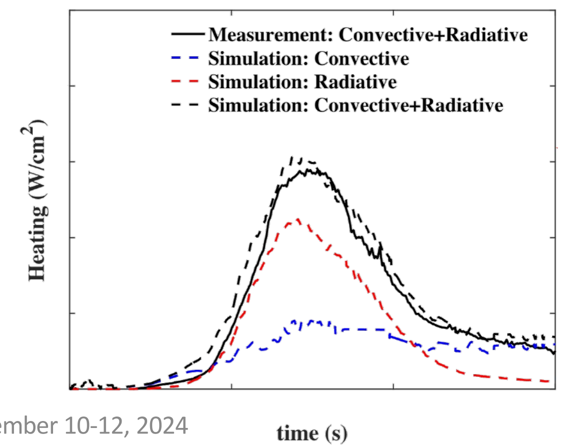
Timer

The Artemis-1 Development Flight Instrumentation (DFI) provides a unique opportunity for Lunar return heat flux data to validate ESM predictions that radiative heating is significant for Artemis and justify its inclusion in design.

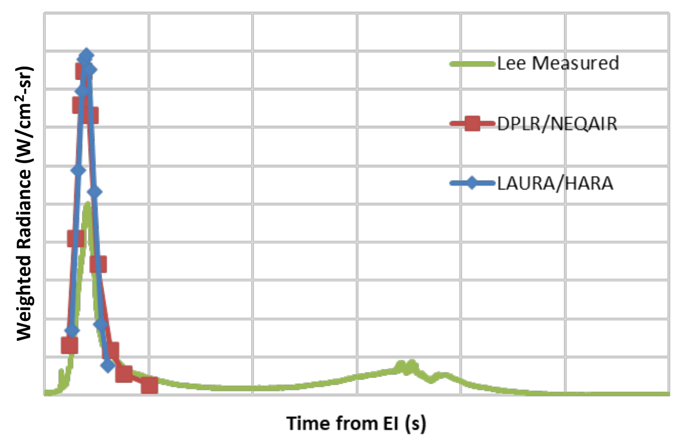
- **Spectrometer on future flights:** ESM work (and funding) has led to the inclusion of a spectrometer on upcoming Artemis flights
- **Radiometer comparison:** Artemis radiometer measurement converted to an equivalent weighted radiance and compared with simulations. Clear blockage visible inside radiometer ports, but unclear when these particles were introduced [Cruden]
- **Wake radiative heating:** Analysis of backshell TCs confirmed the significance and magnitude of radiative heating on the Orion backshell, that was neglected in previous designs [Johnston]



The lee-side radiation component is especially significant relative to convective heating.



Comparison of ESM predictions with Artemis flight data. First flight validation of ESM wake radiation predictions included in TPS design



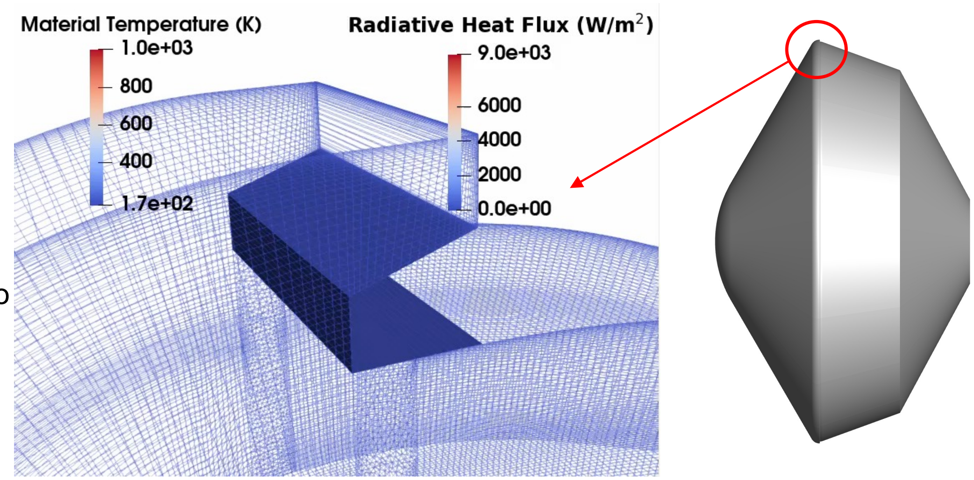
Accomplishments

Enclosure/Cavity Simulation Capability

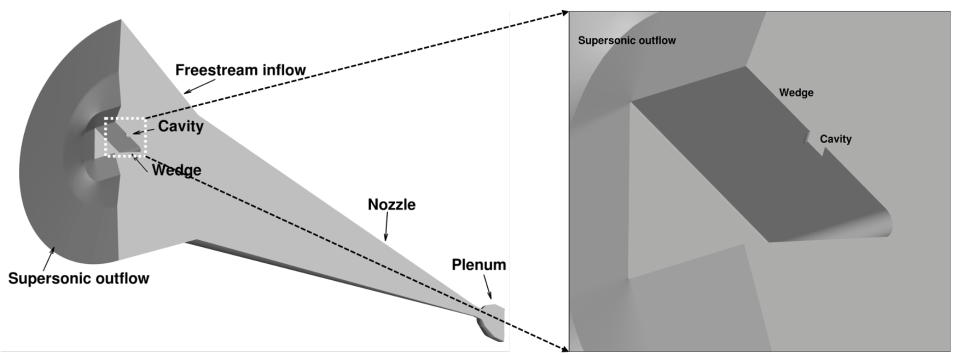
Timer

A multi-physics simulation capability is necessary to model complex aeroshell features such as cavities, domes and seals.

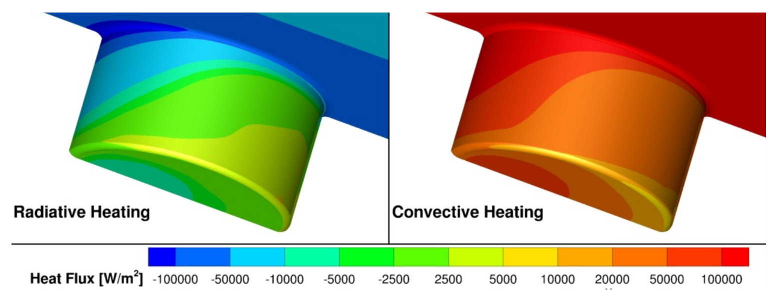
- A new enclosure capability in NERO/Ares allows for modeling of re-radiation on complex geometries with material response coupling.
- Can inform engineering design of TPS for cavity geometries and model enclosure radiation.
- This simulation capability has already been used by the Dragonfly team to analyze several aeroshell features, including the shoulder/main seal and backshell radome. [Schroeder]



The Dragonfly shoulder/tooth example shows that the walls radiate to each other and will impact design.



Test Case: An arc jest shear model with cylindrical cavity is modeled at facility max conditions



Radiative heating can account for up to ~25% of the cavity heating.

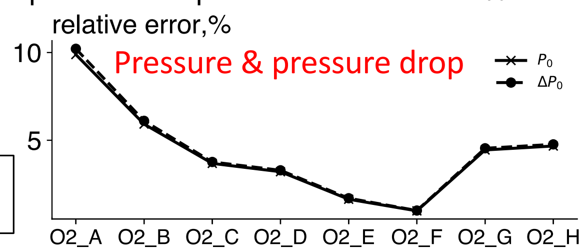
Accomplishments

Unified Solver: Removing Heritage Coupling Assumptions

Timer

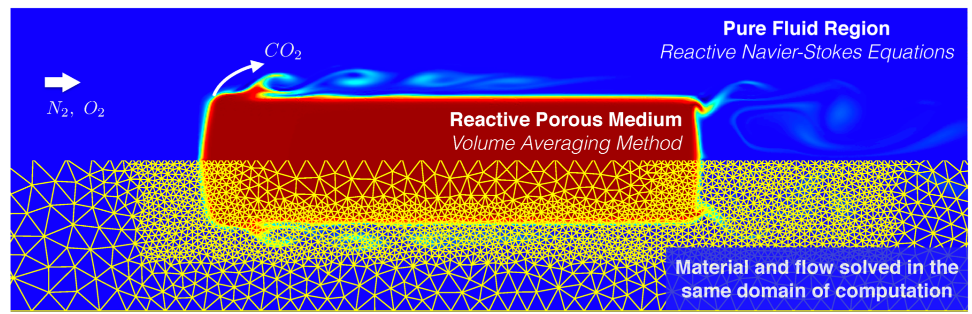
Develop and validate an oxidation model within the unified flow-material solver [Dias]

- Provide a higher fidelity model for coupling flow and material response
- The unified solver including the oxidation model can replicate the 10-minute flow tube experiment in a reasonable time.
- The simulated surface and volume ablation agree with the experimental results.
- The upstream pressure and pressure drop error is less than 10%.

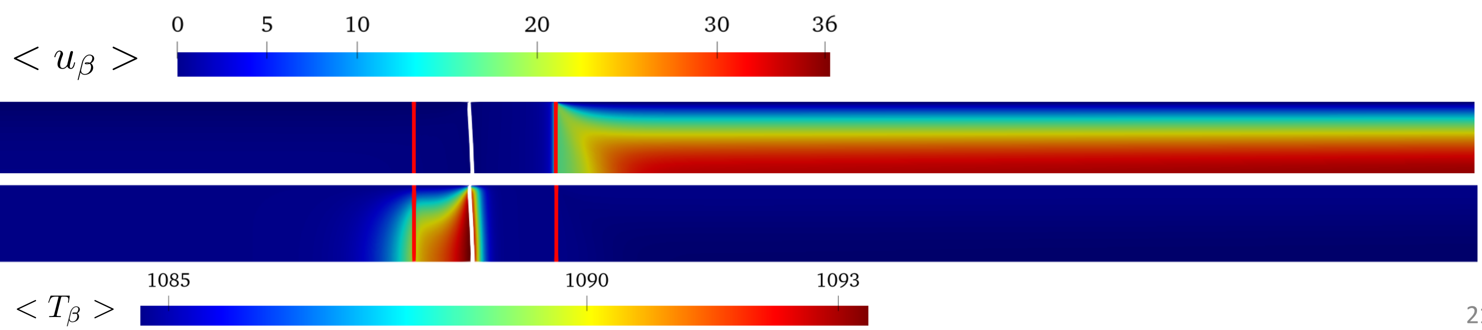


Excellent agreement with upstream pressure

Material and flow solved in the same computational domain



Simulating FiberForm oxidation in oxygen at 1085 K



Accomplishments

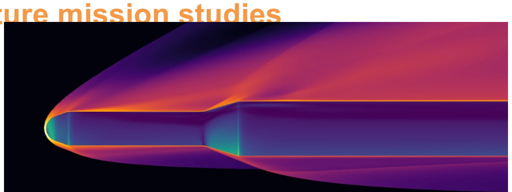
Software Updates

Timer

HyperSolve

- Chemical nonequilibrium and RANS capabilities ported from LAURA to HyperSolve and verified via suite of 3D simulations (CEV and MSL).
- Unstructured mesh ray tracing procedure implemented for use with HyperSolve and verified functional equivalence with LAURA using HARA.
- Higher-order time integration scheme implemented in HyperSolve for use with future HRLES capabilities.
- Applied particle and radiation analysis tools implemented in HyperSolve and applied to scattering radiation scenarios in Mars entry.

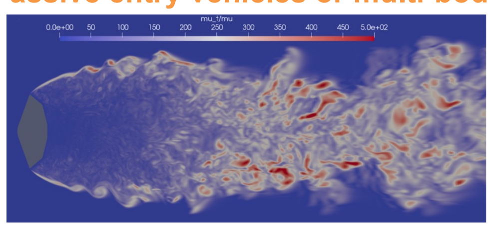
Mission Applications: Complicated CFD simulations, Dragonfly, MSR-SRL/MAV, future mission studies



Free Flight Tool

- Free-flight CFD has established its value to flight missions and the first release is now available on https://developer.nasa.gov
- US3D + MIMIC have been applied to many problems, including the study of RCS jet interactions with the wake
- Free-flight CFD has been used to understand the dynamics of missions, including ADEPT, Dragonfly and MSR-EES.
- The benefit of Free-flight CFD to mission design and fundamental analysis has been further enhanced by the Pynamics utility.

Mission Applications: Dragonfly, EES, Passive entry vehicles or multi-bodies



POST2

- Application Programming Interface between POST2 (ascent/landing high fidelity simulation) with Copernicus (interplanetary flight search tool)
- API-enabled optimization using external programs. Lunar ascent + lunar orbit study.

Mission Applications: Dragonfly, MSR-SRL, future mission studies

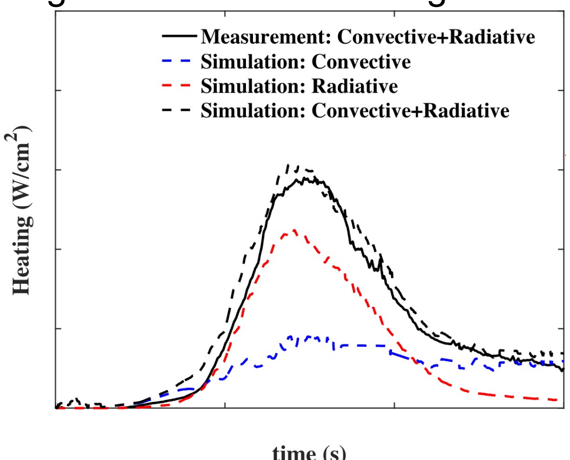
NEQAIR/HARA

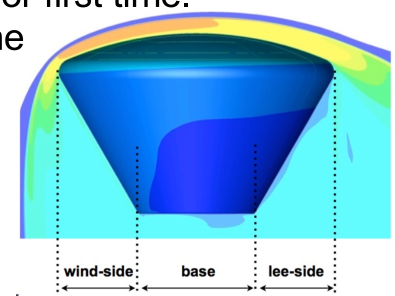
- NEQAIR 15.3 beta release: updates to rates, non-Boltzmann model, improvements for radiometer calculations.
- NEQAIR / HARA continue to be workhorse codes for mission aerothermal design.
- Used for postflight analysis of OSIRIS-REx, Hayabusa-2 and Artemis-1

Mission Applications: Artemis/Orion reconstruction. Design of MSR, Dragonfly, all entry missions.

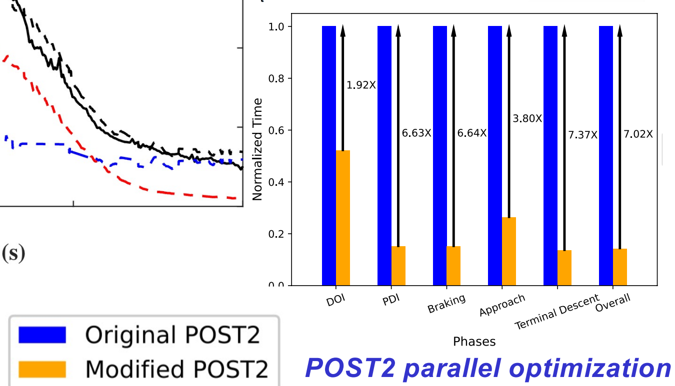
Artemis Backshell Design

ESM research highlighted wake radiation as a significant (often dominant) contributor to afterbody heating, and this was included in the **Artemis-1** backshell TPS design for first time. Flight measurements confirmed the significance of this heating.





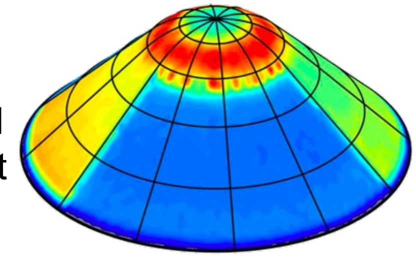
Excellent agreement with Orion DFI



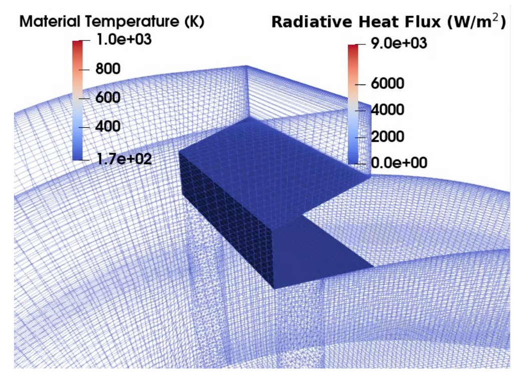
POST2 parallel optimization for lunar ascent & orbit

Mission Roughness for Artemis

Tools and techniques developed for ESM roughness testing in LAL applied to **Artemis-I** post flight study to look at char-loss induced "roughness"



Augmented heating measured

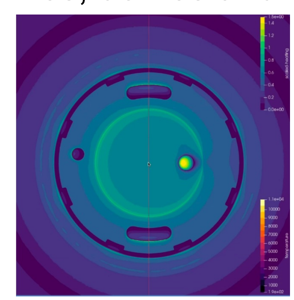


Detailed Geometry Simulation

A multi-physics simulation capability developed to model complex **Dragonfly** aeroshell features such as cavities, domes and seals.

GN&C

Dragonfly using ESM improved version of POST2. Algorithm development useful for UOP trade studies. Coupling with Copernicus (and Monte) for improved mission design through-put.



Education and Public Outreach Summary

Timer

- **66 conference publications and/or presentations* to disseminate project content so far, highlights include:**
  - 21 at the Ablation Workshop in November 2023
  - 16 at AIAA SciTech January 2024
  - 5 at the 2024 International Planetary Probe Workshop
    - Kyle Thompson won best paper with his work entitled: Hypersolve: An Automated Mesh Adaptation Workflow for Aerothermal Analysis.
  - 10 at 2024 AIAA Aviation/ASCEND
- **39 grants* funded and/or supported by the project, highlights include:**
  - 8 funded by ESM
  - 15 funded by Space Technology Research Grant ECF/ESI with oversight or collaboration from ESM
  - 10 funded by Established Program to Stimulate Competitive Research with oversight or collaboration from ESM
  - 1 NASA Space Technology Research Institute – Advanced Computational Center for Entry System Simulation (ACCESS)
- **83 students* mentored and/or supported by the project highlights include:**
  - 23 NASA Space Technology Graduate Research Opportunity Fellows
  - 6 Post-docs
  - 27 FY24 Summer Interns Across Centers
  - 2 Pathways
  - 2 High School Volunteers
- **Key awards for project supported initiatives and outcomes, including:**
  - 3 NASA Exceptional Achievement Medals (Stern, Abbott, Schwenke)
  - NASA Outstanding Leadership Medal (Barnhardt)
  - STMD Innovation Award 2024 (Brandis, Cruden, Johnston, West)
  - AIAA Aerodynamic Measurement Technology 2024 (Danehy)
  - Entry Systems and Technology Division Group Achievement Award: Artemis I Heatshield Investigation (Semeraro, Ferguson, Fraile Izquierdo, Hiss, Borner, Bessire)
  - Rodrigues et al. Applied Optics journal article won 2nd place for 2024 AIAA Hampton Roads Section Laurence J. Bement Young Professionals Paper Competition

* Raw data recorded in tables in subsequent charts

Upcoming Events: 6 Month Look-Ahead		Status
GCD Annual Program Review	September 2024	Presenting
ESM Workshop	October 2024	Hosting/Presenting
PESTO Annual Symposium	October 2024	Presenting
VEXAG	November 2024	Attendance Only
AIAA SciTech 2025	January 2025	Presentations/Papers

ESM Assessment Summary

Timer

Project Name	Performance				Comments
	C	S	T	P	
Annual					**Schedule** – The project schedule is predominantly on track except for select milestones that rely on NASA facility testing.

	Oct	Nov	Dec	Jan	Feb	MYR	Apr	May	Jun	Jul	Aug	APR
C												
S												
T												
P												

NASA test facilities leveraged by the project – wind tunnels, arc jets, shock tubes – are aging and prone to failures that require extended down-time for repair. Issues with multiple facilities this year have delayed a select number of milestones reliant on test data. Most of the facilities in question are returning to service imminently, and the project will rephase milestones accordingly.

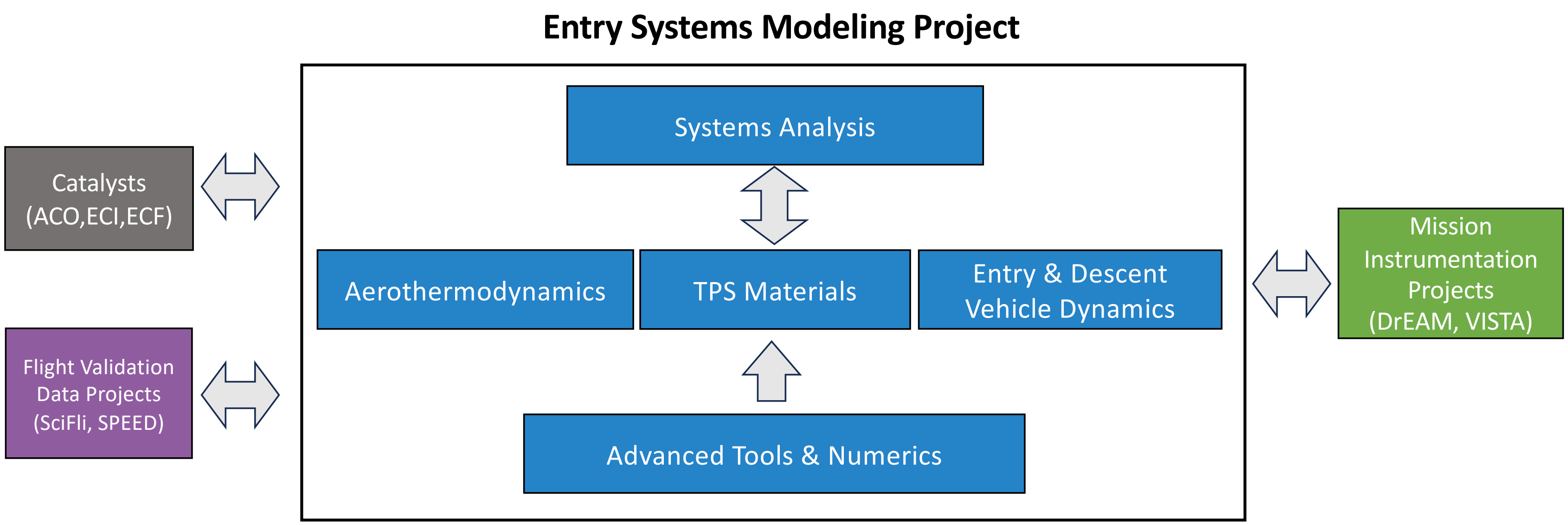
ESM FY24 Summary

Timer

ESM continues to bring value to the Agency's Entry, Descent, and Landing capability area by (1) *advancing modeling and tool capabilities*, (2) *continually transitioning and infusing developments*, and (3) *actively participating in outreach activities to spur innovation* and engage the next generation of early career scientists and engineers.

Major Accomplishments	○ Matured woven Thermal Protection System material models to accelerate flight certification ○ Deployed multi-physics capabilities for mission analyses *via* Hypersolve and Icarus/Ares ○ Advanced Wake Flows models to characterize reduce uncertainty in backshell heating
Transition and Infusion	○ Multiple capabilities infused into the Mars Sample Return and Dragonfly missions ○ Demonstrated the Magnetic Suspension Wind Tunnel for assessment of vehicle dynamics ○ Working with Orion/NESC on infusing capabilities for TPS and radiation modeling ○ One new software and multiple updates to existing software released
Outreach and Recognition	○ 66 publications, presentations, posters ○ 39 grants supported through funding, collaboration, and oversight ○ 83 university students supported and mentored ○ 7 STMD and NASA Honor Awards related to project initiatives and outcomes

Changes to ESM content and technical organization will be deployed in FY25 as we begin a new project cycle and phase into the LAND/Entry Modeling and Instrumentation (EM&I) capability portfolio environment



ESM

ENTRY SYSTEMS MODELING

Supplemental Slides

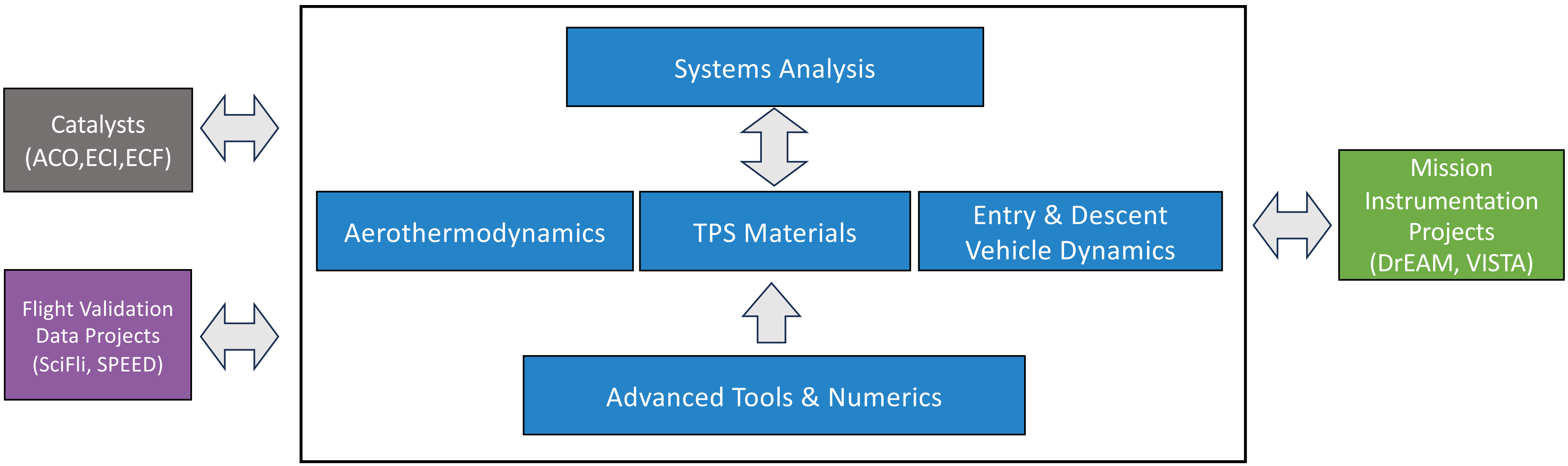
Timer

ESM in FY25

Timer

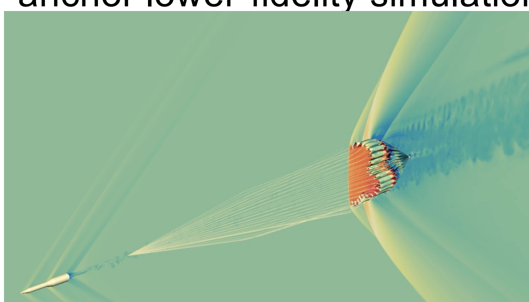
Changes to ESM content and technical organization will be deployed in FY25 as we begin a new project cycle and phase into the LAND/Entry Modeling and Instrumentation (EM&I) capability portfolio environment

Entry Systems Modeling Project



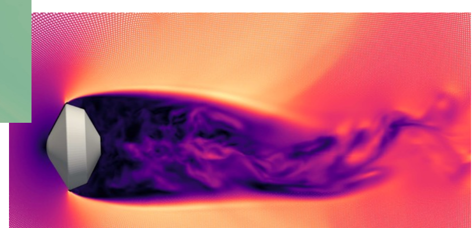
Parachute Modeling

Excellent agreement shown with ASPIRE parachute flight test **(MSR-SRL)**. Increased confidence prompting work to begin on a drogue-aeroshell simulation for **Dragonfly**. Will provide insights into dynamics and anchor lower-fidelity simulations.



FSI flow visualization

LAVA ASPIRE FSI simulation



Dragonfly Free-Flight simulation

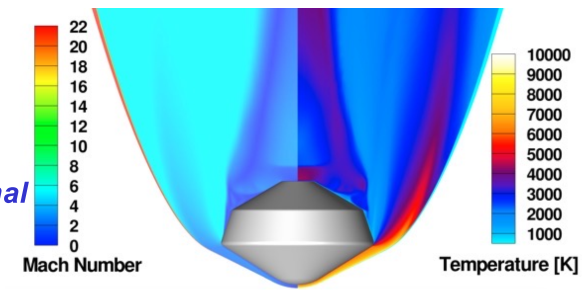
Dynamic stability

Free-Flight simulation capability a critical tool used to understand the passive entry vehicle dynamic stability of **MSR-EES & Dragonfly.**

Titan Aerothermal Environments

ESM anticipated need in advance of a Titan mission with EAST shock tube test. Enabled informed margin policy and improved models to be used by **Dragonfly** – neither would have been possible without this data.

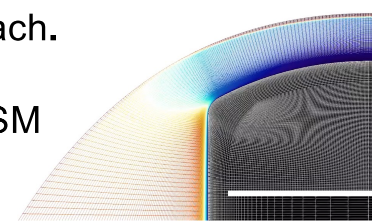
Dragonfly aerothermal flowfield



EAST Shock Tube

Multi-Dimensional Response

Dragonfly & MSR-EES have some complicated geometries that cannot be modeled with traditional 1-D approach. Coupled multi-dimensional material response tools developed within ESM being utilized.



3D Ares simulation of recessing Arc Jet coupon

Accomplishments
Software Updates

Timer

Ares / Icarus

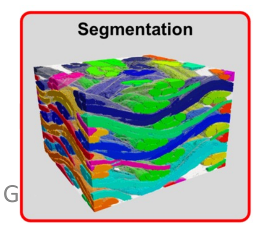
- Version 1 of Ares released to couple flow (US3D), radiative heating (NERO), and material response (Icarus), demonstration via simulation of Dragonfly trajectory.
- Coupled boundary conditions implemented to model finite-rate gas-surface interactions and ablation / shape-change
- Boundary conditions can use B-prime tables (includes utility to generate tables / convert FIAT-formatted tables) and surface coating models.
- Improvements to mesh motion: parallelization, user-directed controls to constrain non-physical motion, ability to move volume zones independently

Milestone/s: Production Ares (Icarus-US3D) Release, Solver Robustness
Mission Applications: Dragonfly shoulder design, MSR-EES recession, future mission studies

PuMA

- 3D slicer plug-in implemented in PuMA, offering a cutting-edge approach to segment 3D tomography data with minimal user input.
- Used for the calculation of effective permeability & elasticity of TPS materials
- Expanding elasticity solver to calculate stress divergence and thermal stresses.
- Implementing ability to calculate the coefficient of thermal expansion.
- Critical tool used for Artemis char loss investigation.

Milestone/s: Weave Segmentation Plugin for PuMA
Mission Applications: Artemis/Orion heat shield investigation

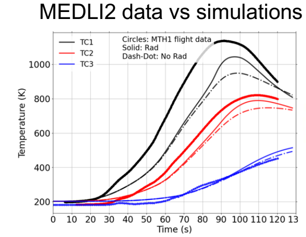


PATO

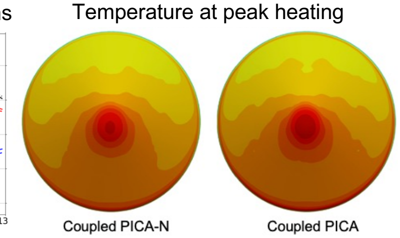
- New PATO version 1C released: added optimization (Dakota), solid mechanics (foam-extend) and new physical models, BCs, utilities, tests, and tutorials.
- Unified Solver combining fluid and material phases was developed to challenge heritage assumptions in decoupled ablation simulations.
- Critical tool used for Artemis char loss investigation (predicted char thickness within 4%)

Milestone/s: PICA-N model including blowing gas coupling compared to MEDLI2 data
Mission Applications: Artemis heat shield investigation, MSR-SRL & D'fly (PICA-N)

MEDLI2 data vs simulations



Temperature at peak heating



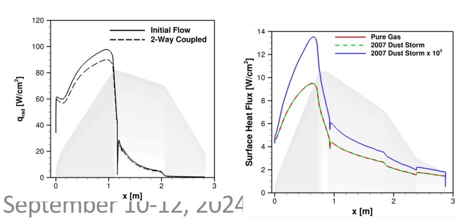
Accomplishments
Software Updates

Timer

GLUE/DUST/NERO

- High-fidelity 3D radiation solver being developed to deliver up-to 1000x speed-up
- Recent advances include expedited application to meteor entry and Dragonfly
- A new library called General-Purpose Library for Unstructured Environment (GLUE) allows data exchange between different solvers and multi-physics scenarios such as radiative heating for dusty flows.

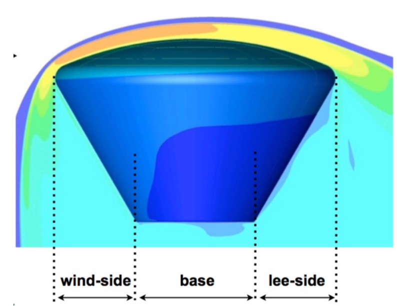
Milestone/s: NERO Demonstration, NERO Coupling, NERO Overlapping Bands
Mission Applications: Dragonfly coupling, ATAP, MSR-SRL full aeroshell calculations



NEQAIR/HARA

- NEQAIR 15.3 beta release: updates to rates, non-Boltzmann model, improvements for radiometer calculations.
- NEQAIR / HARA continue to be workhorse codes for mission aerothermal design.
- Used for postflight analysis of OSIRIS-REx, Hayabusa-2 and Artemis-1

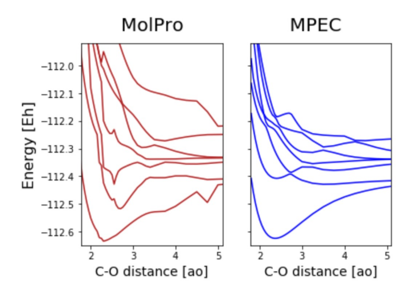
Milestone/s: Artemis-1 Radiometer Analysis
Mission Applications: Artemis/Orion reconstruction. Design of MSR, Dragonfly, all entry missions.



MPEC

- A new tool to calculate molecular electronic structure, known as the Massively Parallel Electron Correlation (MPEC) has been developed.
- The first release of MPEC is now available on software.nasa.gov
- Upcoming MPEC quantum chemistry work will focus on providing results relevant to Titan and Mars chemistry

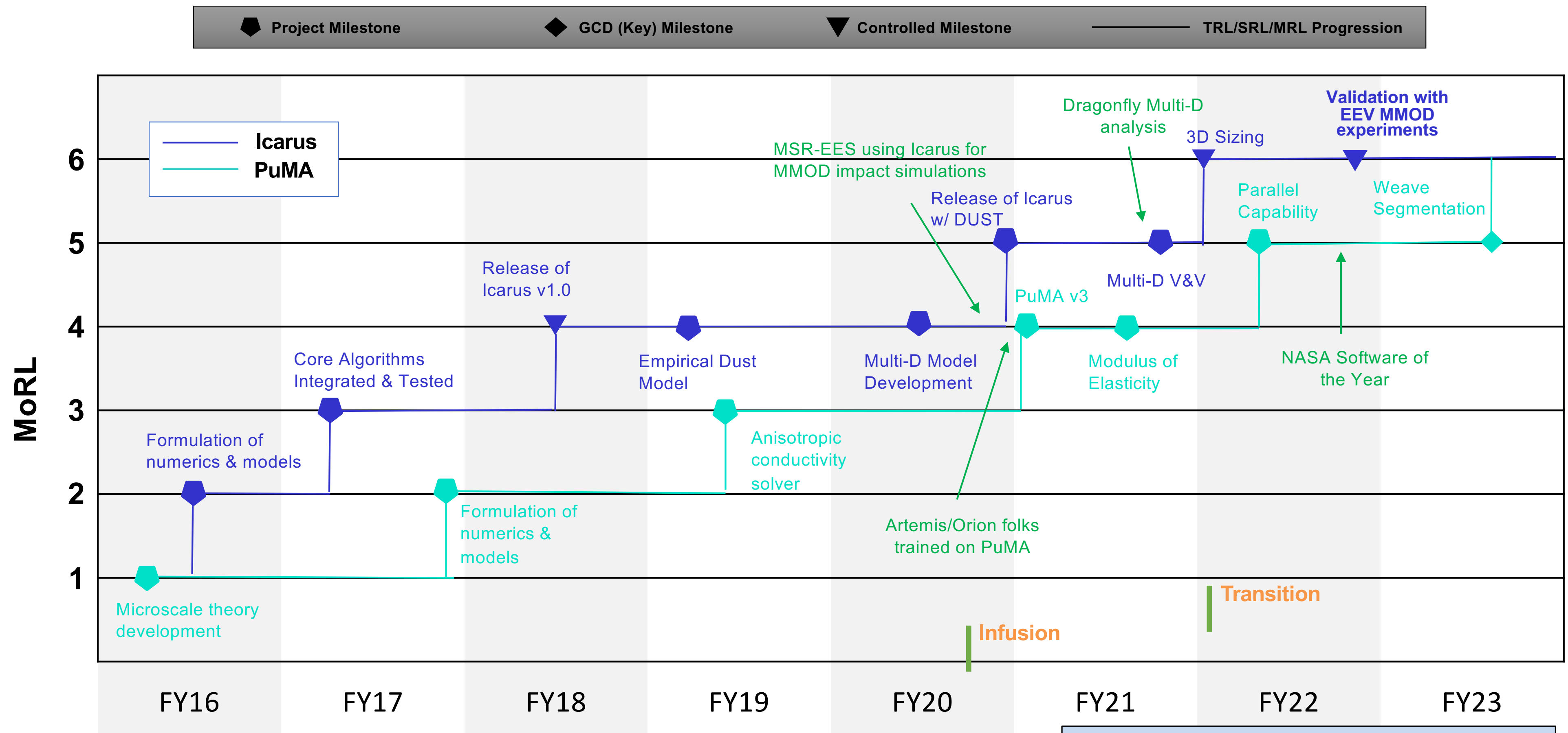
Milestone/s: Public Release of MPEC, PES for CO+CO Collisions
Mission Applications: Chemistry for current and future Mars and Titan Missions



ESM Model Development*

Icarus and PuMA

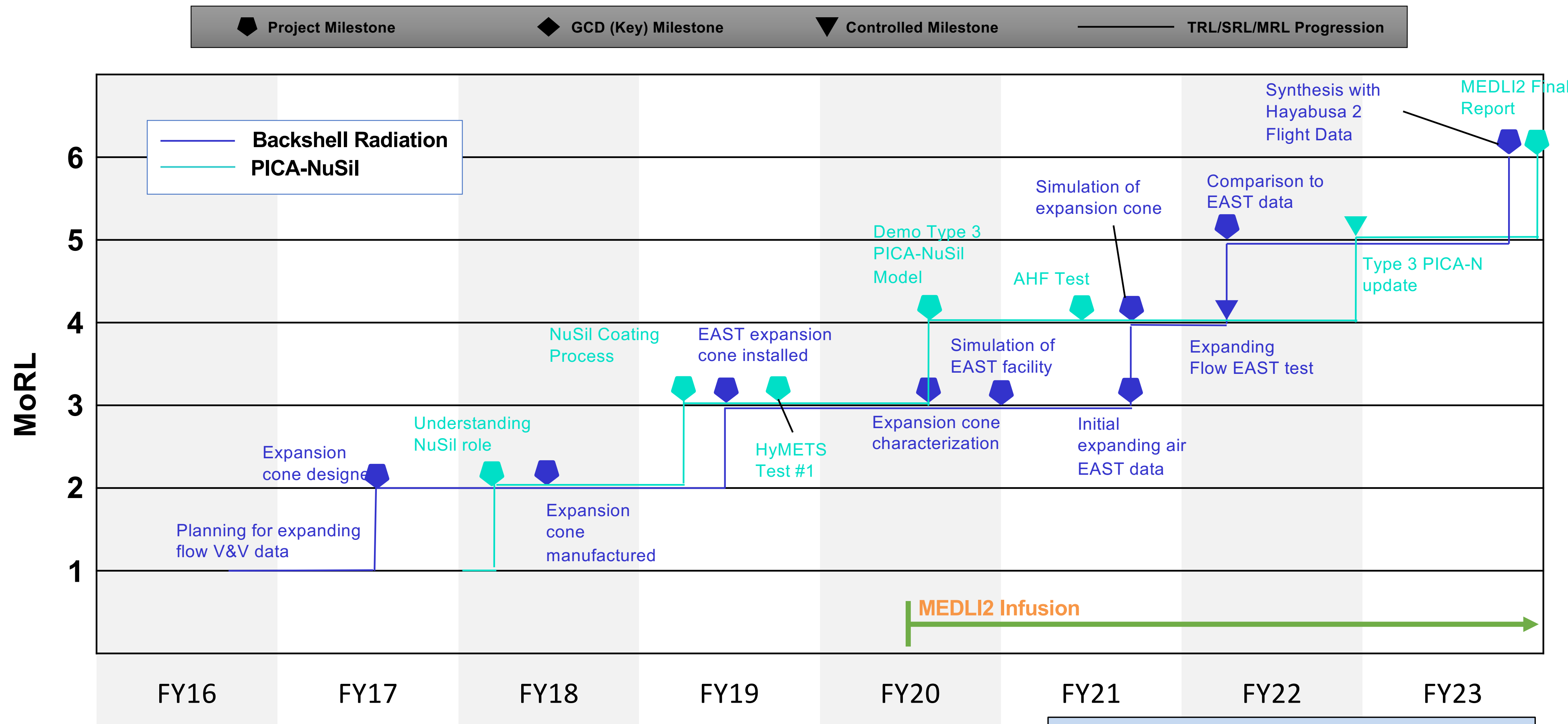
Timer



* See backup for additional TRL/SRL/MoRL charts

ESM Model Development*
Backshell Radiation and PICA-NuSil

Timer



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