



Sandia Aerothermal Program Overview



PRESENTED BY

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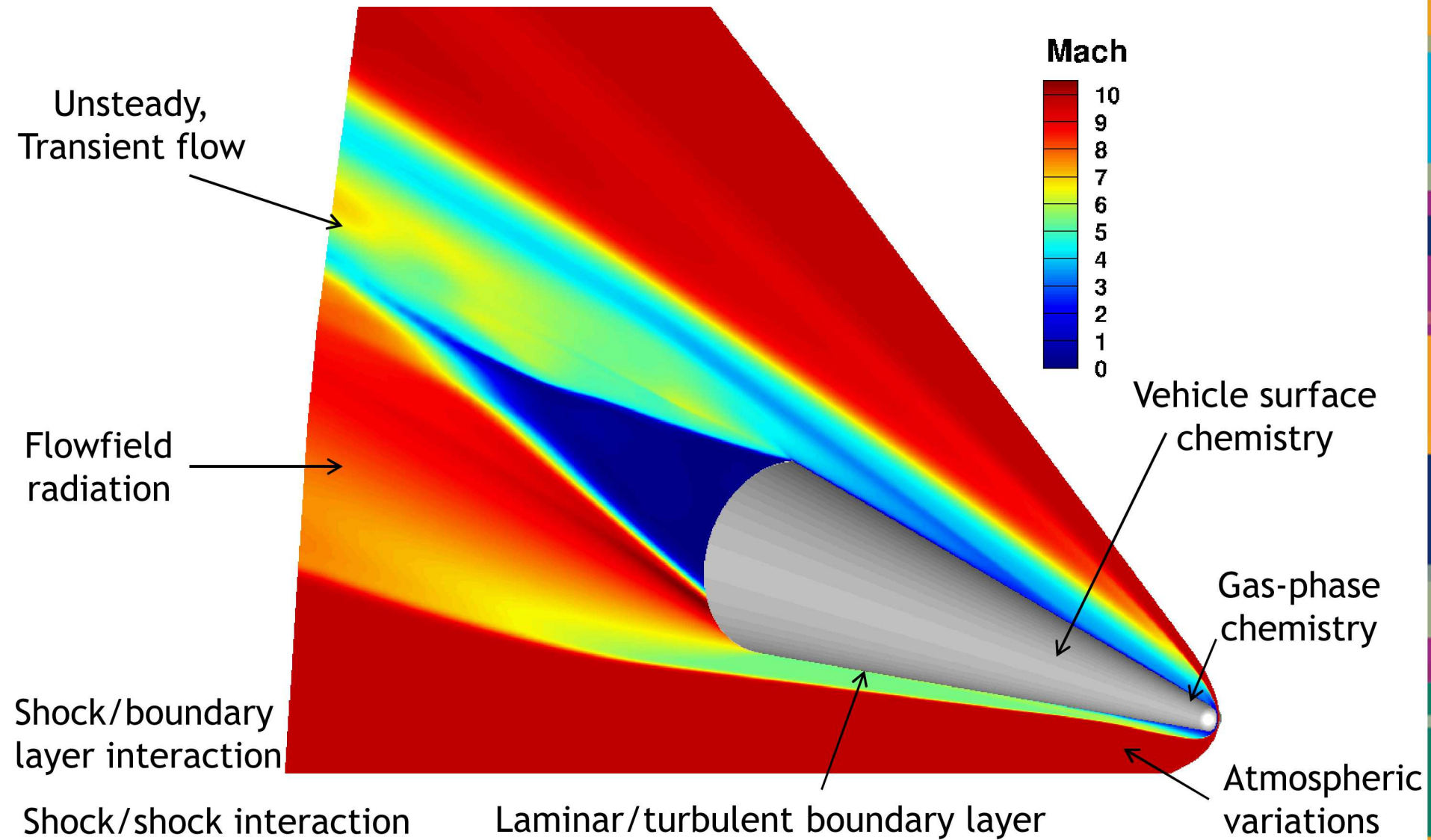
Reentry environments

Simulation tools

Current research and development areas

Validation

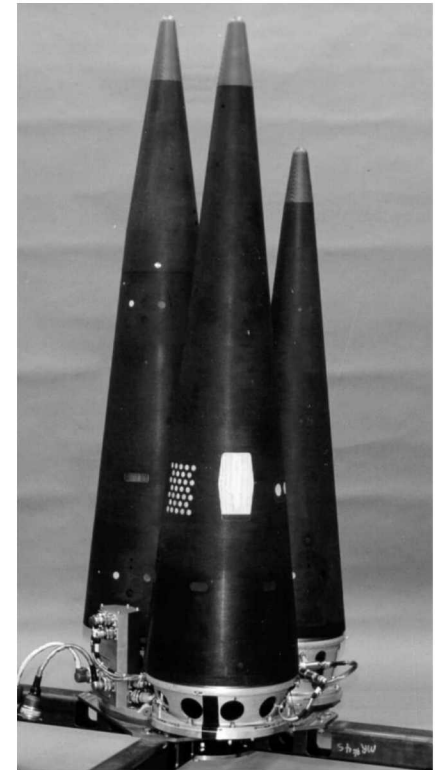
- SPARC flow validation
- Arc-jet modeling
- Flight Vehicle Simulation



Flight Vehicle Analyses

Flight vehicle analysis steps

- Aero model development
 - Vehicle forces and moments as functions of Mach number, boundary layer state (laminar or turbulent), and vehicle orientation
- Trajectory calculation
 - Integration of newton's laws of motion to determine vehicle flight history
- Aerothermal environment calculation
 - Determination of the thermal environment surrounding the vehicle
- Material thermal response calculation
 - Computation of vehicle temperatures and shape change due to ablation
- Structural response to flight environment
 - Determination of the vehicle's substructure and internal components to flight environment loading



MaST Flight Vehicles

Reentry environments

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Simulation Tools

Fluid flow simulation

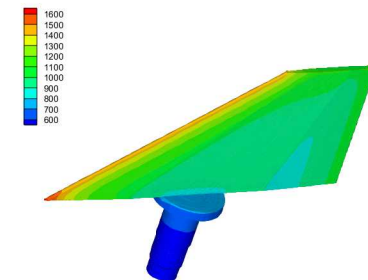
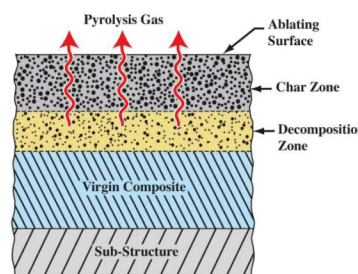
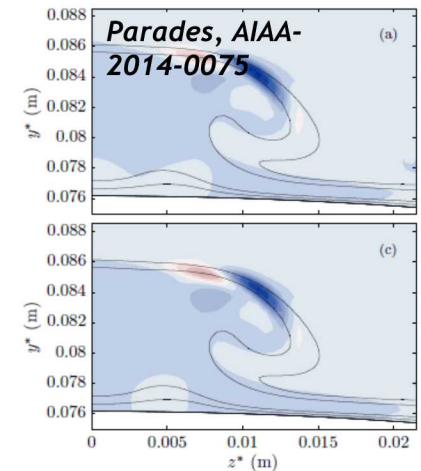
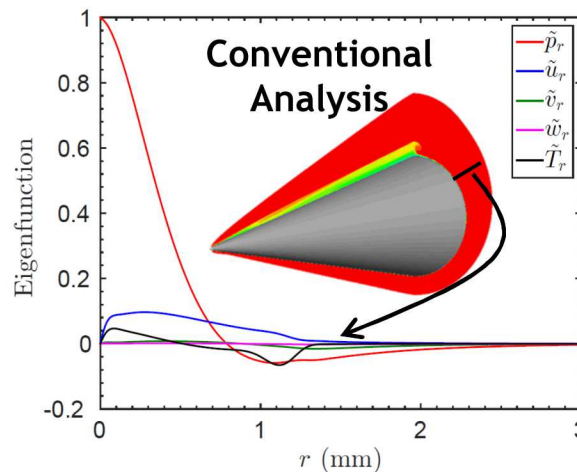
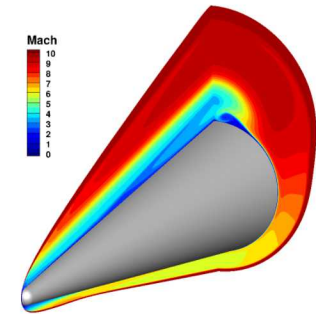
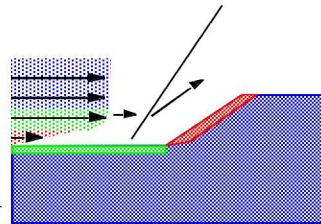
- Correlations, 2IT-SANDIAC-HIBLARG
- MYSTIC, SPRINT
- DPLR, US3D, SPARC
- Icarus, SPARTA

Boundary layer stability analysis

- Correlations
- STABL2D, LASTRAC
- STABL3D
- BiGlobal solver

Material thermal response

- CMA, Chaleur
- ParCMA, ParChaleur
- ASCC, SMITE
- Coyote, SPARC



Understand

- Engineering codes like 2IT-SANDIAC-HIBLARG, CMA, and EMLOSS work for previous flight preparation and post-test analysis
- Benefit from understanding the methods and assumptions

Maintain

- Small effort to modernize code syntax and methods
- Ensure that these tools are available moving forward
- Tools are continuously used for both research and applications

Improve when possible

- Time-to-solution is much shorter than modern codes
- Enables large data set generation for Monte-Carlo analysis
- Swap solvers in integrated code suites when possible
 - 2IT-SANDIAC-HIBLARG and BLIMP to full Navier-Stokes
 - CMA to 3D SPARC where appropriate



NS Solvers becoming production methods

- Many validation efforts currently ongoing
- Aided in development of flight vehicle aerodynamic database
- Used to assess flight data for laminar/turbulent flow
- Delivering surface heating data to MTR codes
- Provides a good, high-fidelity research tool

Stability analysis methods

- Working on validation of physics-based transition analysis

Multi-dimensional material thermal response

- Currently under development
- Utilizing arc-jet data as well as flight data

Reentry environments

Simulation tools

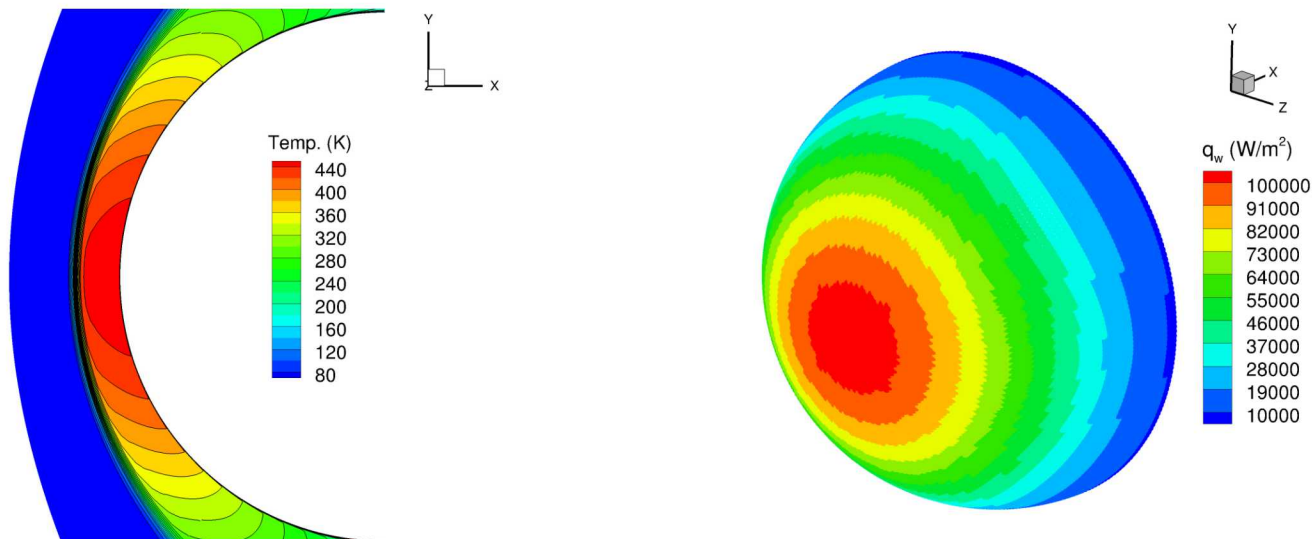
Current research and development areas

Validation

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Flow solver

- Perfect and reacting gas models
 - 5 species air, 11 species weakly ionized air
- Turbulence modeling: RANS models (now), hybrid RANS-LES (planned)
 - Spalart-Allmaras, SST
- Research on high-order accurate numerical schemes
- Validation of flow solver
- Enable trajectory simulations
- Shock and boundary layer tailoring and inline refinement



Simulation of flow over a sphere

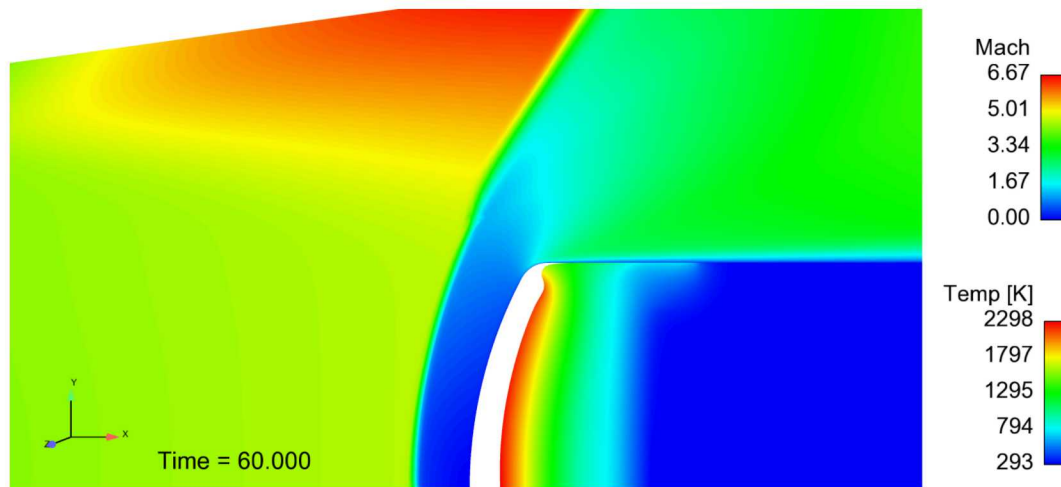
SPARC Development

Material solver

- 1D solver frame to mimic legacy solvers
- Implementing monolithic thermal solver
 - Solve heat transfer and gas continuity equation with the same system
- High-level redesign for modularity

Numerical solver techniques

- Automated CFL controller
- Matrix-free method to accelerate convergence
- Working with Trilinos development team to incorporate modern linear solvers



Arc-jet simulation of TACOT

Full Trajectory Analysis

Develop code suites to analyze a vehicle's aerothermal performance from pierce point to impact

- Legacy methods exist – serve as a guide
- Improve capability by utilizing high-fidelity methods, NS and DSMC

Utilize automation where possible

- Freestream condition adjustment
- Grid adjustment for freestream conditions

Bridge the gap between regimes

- DSMC used for high altitude cases
- NS used for low-mid altitude cases

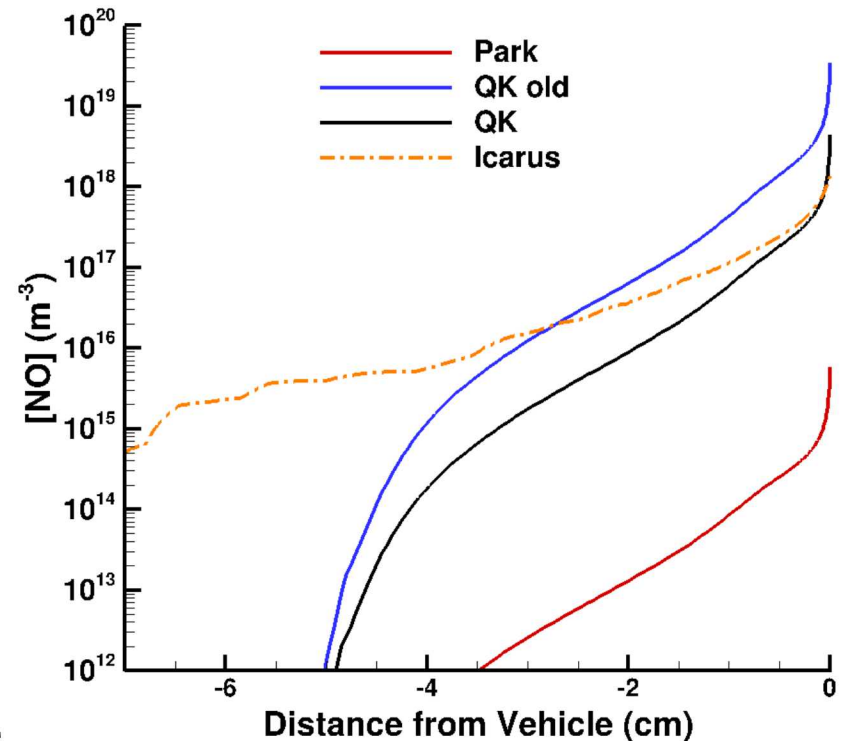
Material shape change

- Couple fluid to thermal solvers to capture vehicle shape change throughout flight

Vehicle dynamics

- Inform flight dynamics solver to enable 6 DOF simulations

Ensure continuity of modeling from entry to impact

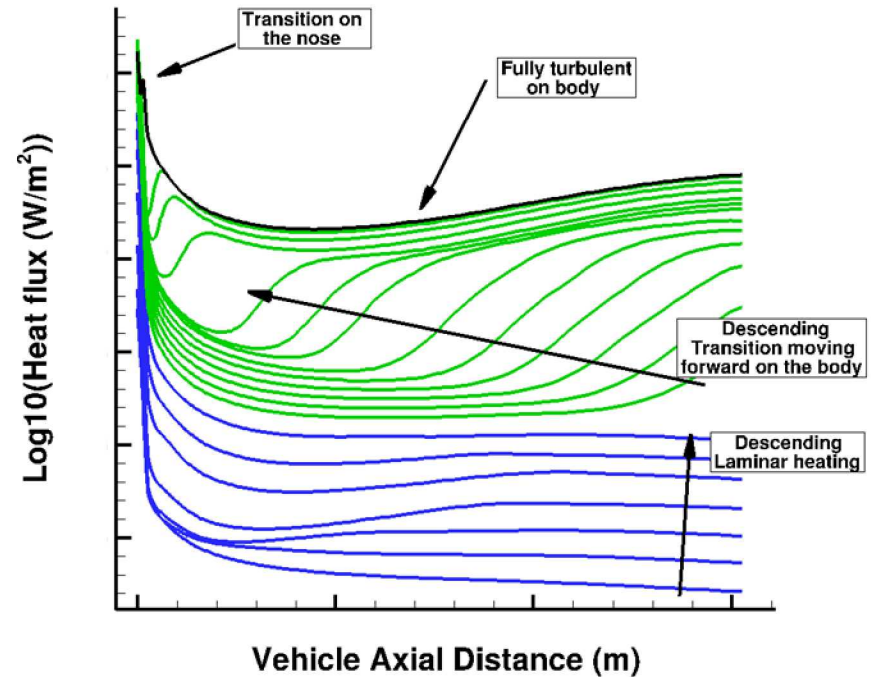


NO Concentration along the stagnation line of a sphere cone

Trajectory mode with US3D

Modifications to CFD solver

- Build an atmosphere module within the code
- Wrap flow solver with an outer loop to iterate over trajectory waypoints
- Utilize shock tailoring technique to ensure solution quality
- Assess boundary layer transition using correlation inline with the flow solver
- Ensure robust transition mechanics
- Solve trajectory using one of the following modes:
 - Standard solve for individual waypoints
 - Non-linear perturbation solver to move from one waypoint to the next
 - Continuously vary flight condition via interpolation between waypoints

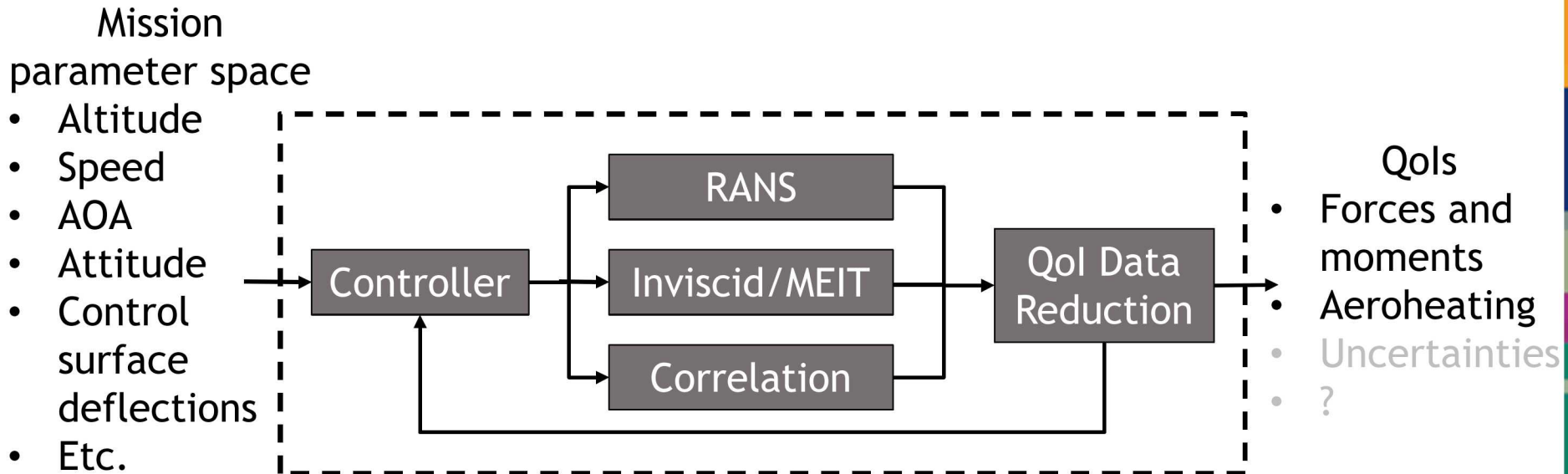


Example calculation of heat flux variation across an arbitrary trajectory

Multi-fidelity Solver

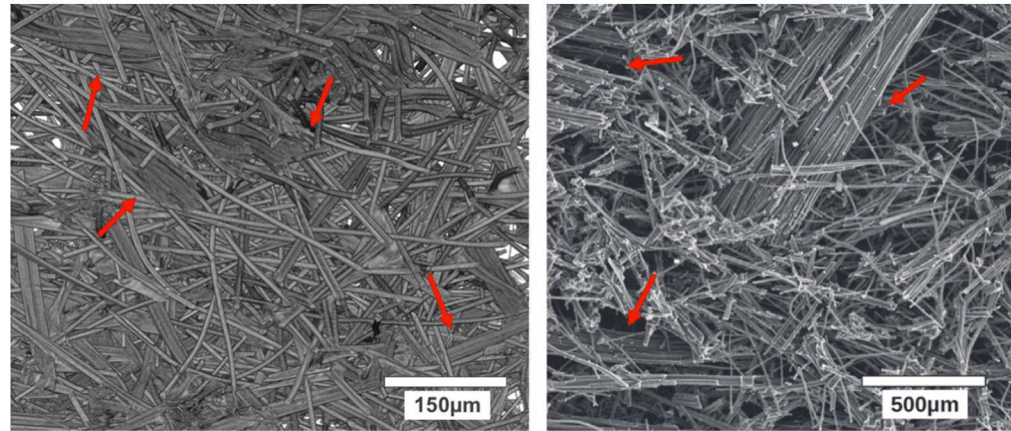
Enable rapid assessment of flight vehicle performance and thermal loading for an arbitrary trajectory

- Utilize low-, medium-, and high-fidelity solvers to populate the aerodynamic performance and thermal loading across a vehicle's intended envelope
- Take advantage of lower fidelity methods low cost and anchor against high-fidelity data
- Smartly sample a vehicle's envelope to minimize computational time
- Build a sufficient database to enable trajectory design and optimization.



Micro- and mesoscale simulation

- Utilize micro-ct and SEM to image decomposing ablators
- Analyze image to simulate fiber material and surrounding matrix
- Calculate composite material properties from pure properties
 - Conductivity
 - Macro-scale ablation rates
 - Porosity
 - Tortuosity
- Compare to sample created at Sandia of common decomposing ablators



Micro-CT and SEM scan meshes from Borner in IHJMT 2016



Sample fiber meshes for use in DSMC

Reentry environments

Simulation tools

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Validation

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Tunnel 9 Sharp cones

- Frozen laminar and turbulent flows

Double cone

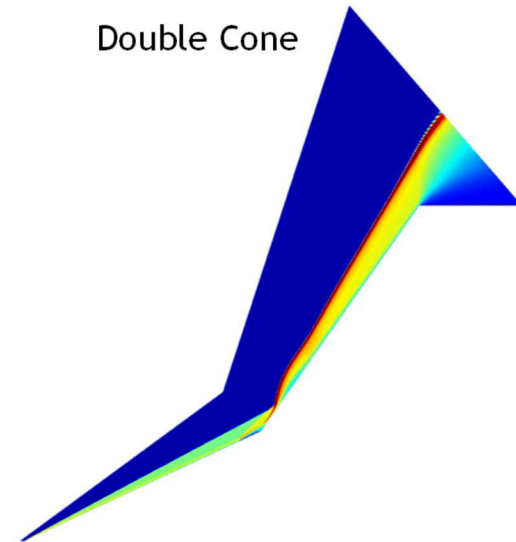
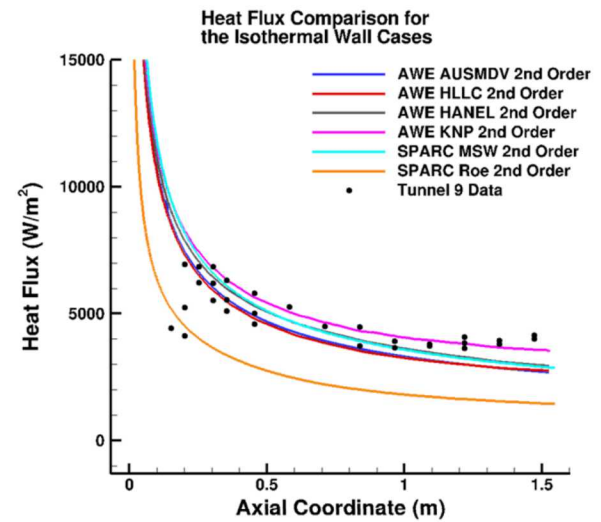
- Laminar shock/shock, shock/boundary layer interaction
- Mild to strong thermochemical non-equilibrium

HIFiRE-1

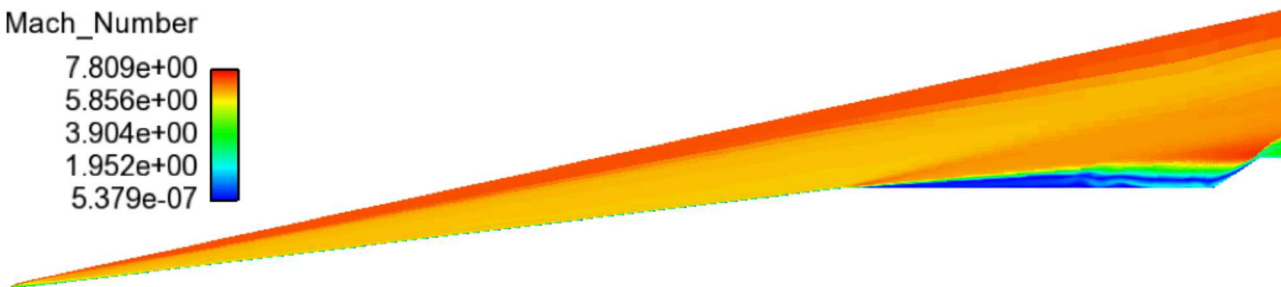
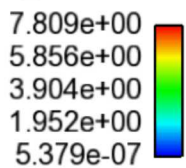
- Turbulent shock/boundary layer interaction
- Nonreacting flow

HEG Cases

- Reacting laminar flow over various shapes



Mach_Number

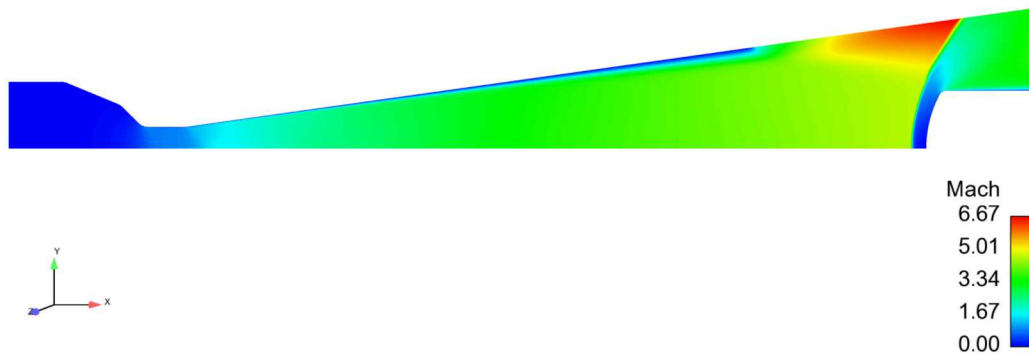


Provides validation for fluid flow and material thermal response

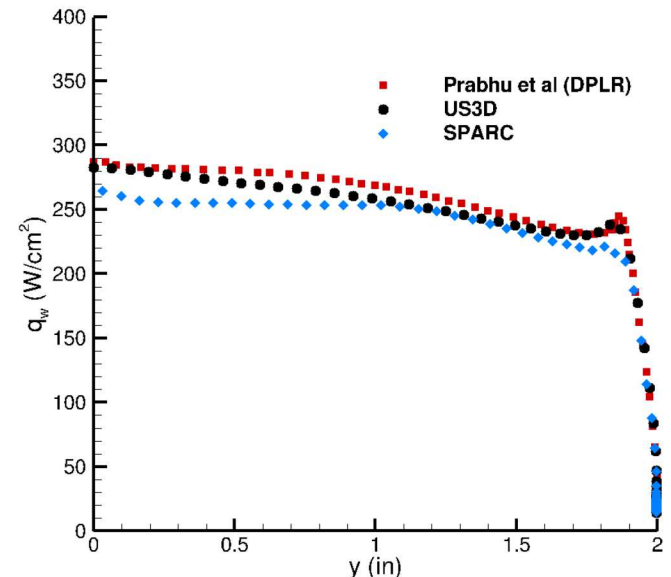
- High temperature, thermochemical non-equilibrium
- High heating rates with material ablation
- Ideal for testing fluid/thermal coupling

Current validation case

- NASA Ames AHF and IHF
- AEDC H1, H2, and H3
- DLR L2K and L3K



Simulation of NASA Ames IHF arc-jet



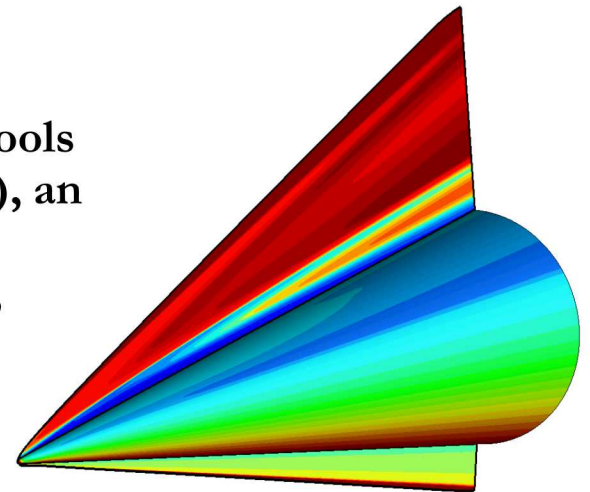
Surface heat flux comparison on an isoq sample

V & V efforts are centered around a legacy recovered ballistic reentry vehicle.

Trajectory and transition history obtained from flight data.

Aerothermal environment computed with a full set of tools including correlation-based approaches (Blunty, LoVel), an inviscid-boundary layer approach (2IT-SANDIAC-HIBLARG), and full Navier-Stokes approaches (US3D, SPARC).

- Code-to-code heating comparisons
- Angle-of-attack effects investigated
- Turbulence model comparisons for the Navier-Stokes approaches



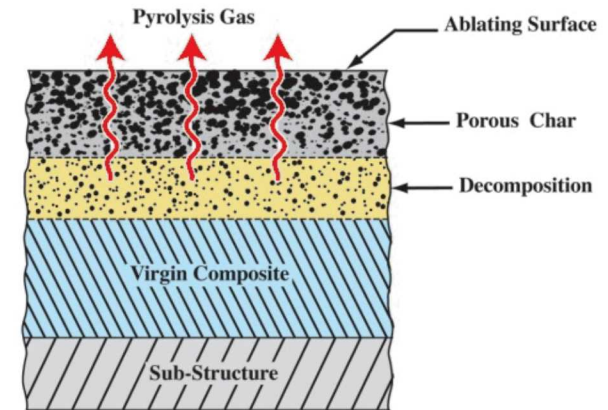
Material thermal response computed with 1-D uncoupled approaches (CMA, Chaleur, SPARC) and a coupled multi-D approach (SPARC)

- Code-to-code comparisons
- 1-D vs. multi-D comparisons
- Effects of coupling investigated

Variability and Uncertainty analysis using Dakota driving CMA

Comparisons to flight data include:

- In-depth temperature histories
- Ablation depths (pyrolysis depth, char depth, and surface recession)
- Heatshield density profiles



Develop a capability to predict thermal protection systems performance in flight environments

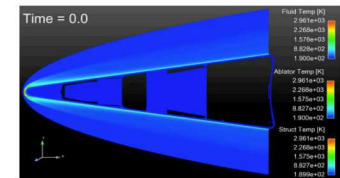
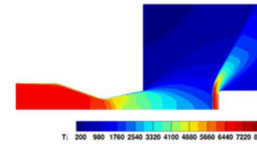
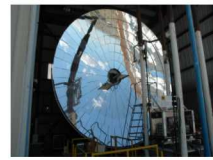
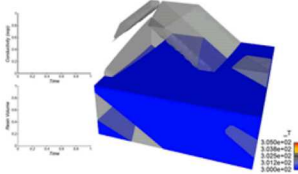
Connecting material processing to flight performance

Material processing and Characterization

Material performance and Credibility

System material response Performance (Normal and Hostile environments)

(Thermal and mechanical) \longleftrightarrow Fidelity based on customer/program requirements \longleftrightarrow (Integration of Modeling/Experiment)



Numerical Methods

Meso(fiber) Scale modeling

- Effective properties
- Mechanical behavior
- Uncertainties in properties and manufacturing

Material performance modeling

- Prediction of material response to heat and mechanical loading
- Properties and uncertainties from material processing

System Performance

- System performance across flight envelope
- Uncertainties and credibility defined

Experimental

Processing/Characterization

- Constitutive properties
- Composite properties
- Variability due to manufacturing

Experimental material performance

- Leverage national capabilities
- Material performance qualities
- Material chemistry
- Mechanical behavior

Experimental Flight performance

- Leverage ground test data
- Flight data as validation

Gaps

- Improved fiber melting, pitting oxidation measurements
- EOS of ablation products in hostile environments
- Localized reaction chemistry
- Mechanical failure characterization

- Mechanical strength and failure data and models
- Improved measurements & modeling of chemistry/decomposition
- Improved diagnostics

- Improved diagnostics
- Models for anisotropic materials
- Improved thermal-mechanical models
- UQ models for QOI's

Summary

Sandia analyzes numerous aspects of the reentry environment

- We utilize a unique combination of simulation tools and facilities to deliver results

Tool development activities are necessary to provide better solutions to the customer. We work to:

- Understand legacy models
- Maintain models to ensure they are up to date
- Utilize incremental improvements of production models to maintain a balance between performance and capability
- Improve models to solve the challenges of the future

Current R&D is focused on solving all aspects of the reentry environment, including:

- Aerodynamics
- Aerothermodynamics
- Boundary layer transition
- Thermal/Ablation
- Structural/Vibration

Verification & Validation is a necessary step toward ensuring that the highest quality simulation tools are available