SAND2018-10124C

Sandia Aerothermal Program Overview

PRESENTED BY

Justin Smith

Aerosciences Dept., Sandia National Labs

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

Reentry environments

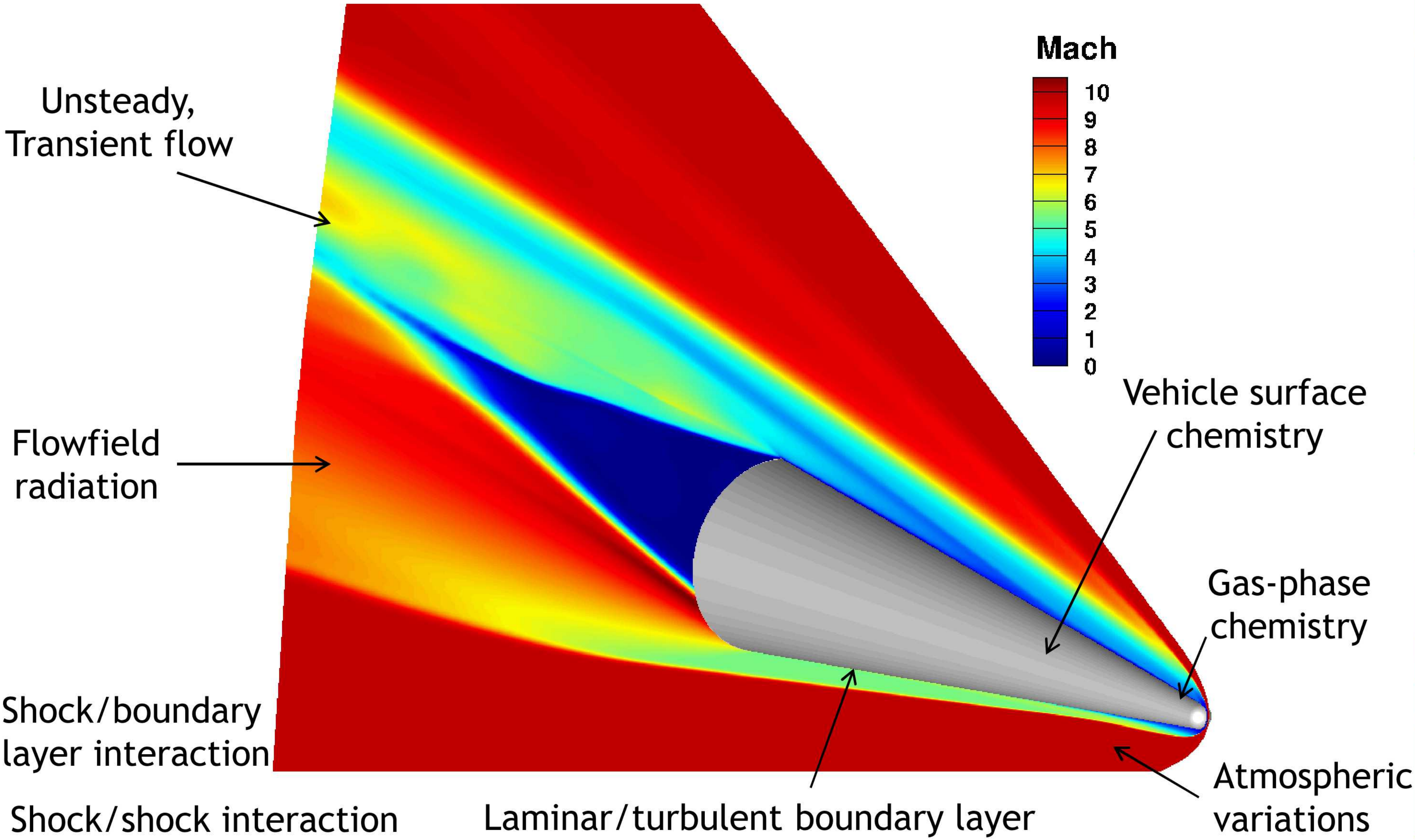
Simulation tools

Current research and development areas

Validation

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

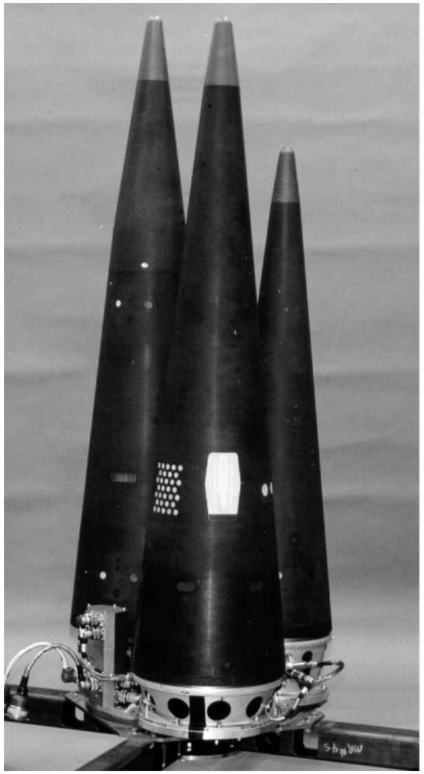
Reentry Environment



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

Outline

Reentry environments

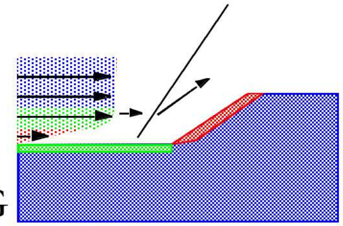
Simulation tools

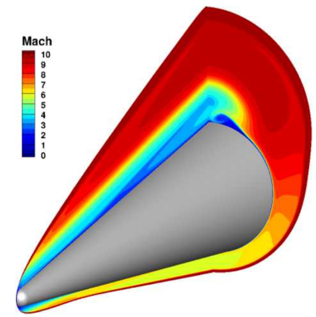
Current research and development areas

Validation

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

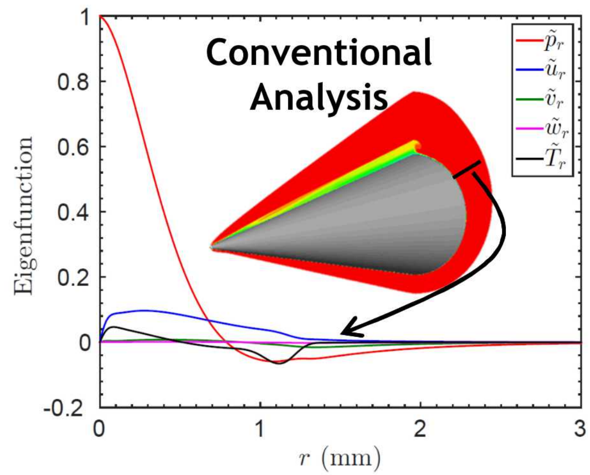
Simulation Tools

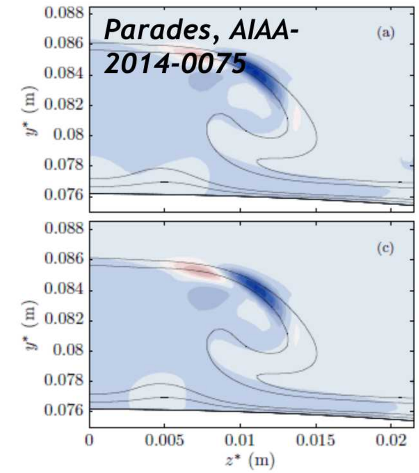




Fluid flow simulation

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



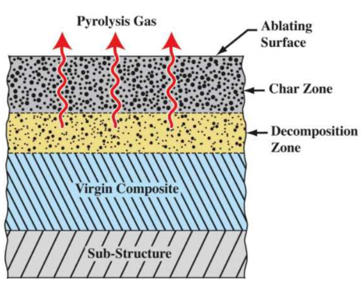


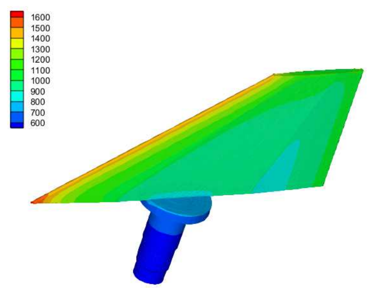
Boundary layer stability analysis

- Correlations
- STABL2D, LASTRAC
- STABL3D
- BiGlobal solver

Material thermal response

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





Legacy Methods

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

State-of-the-Art Methods

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

Outline

Reentry environments

Simulation tools

Current research and development areas

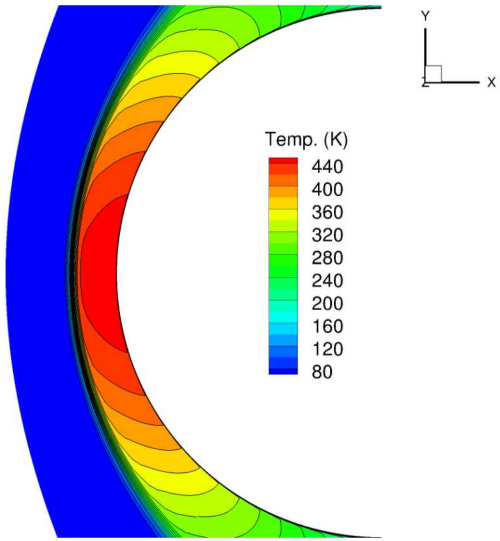
Validation

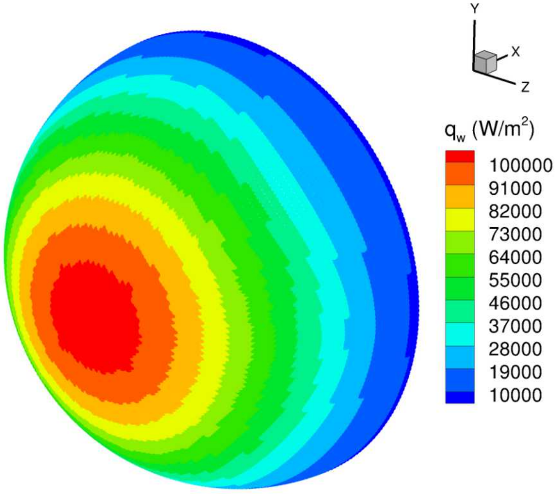
- SPARC flow validation
- Arc-jet modeling
- Flight Vehicle Simulation

SPARC Development

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

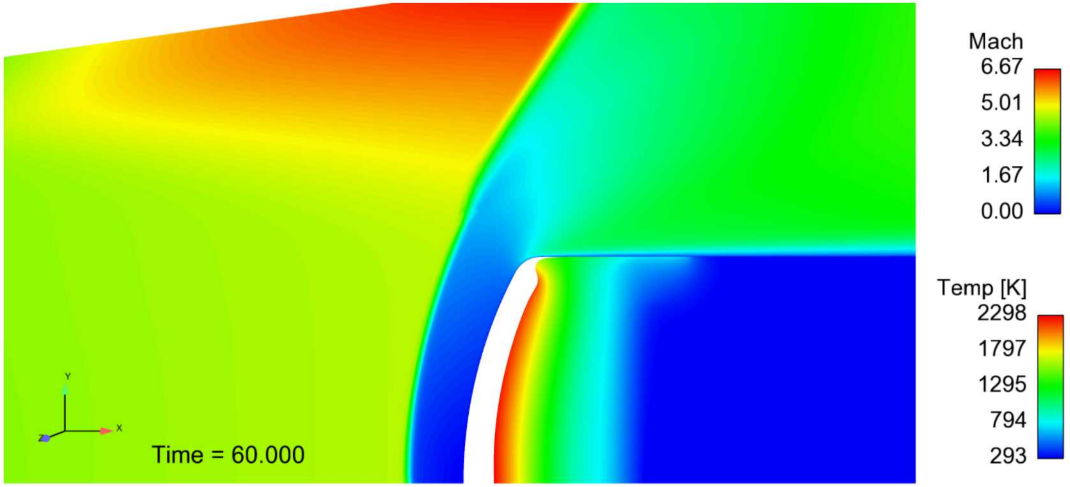
SPARC Development

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

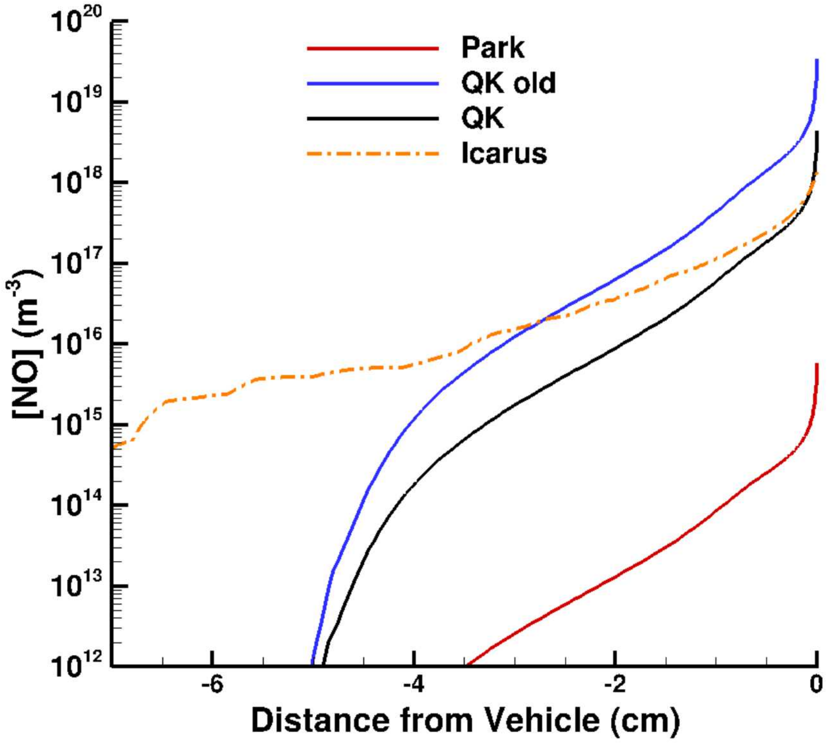
Utilize automation where possible
- Freestream condition adjustment
- Grid adjustment for freestream conditions

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

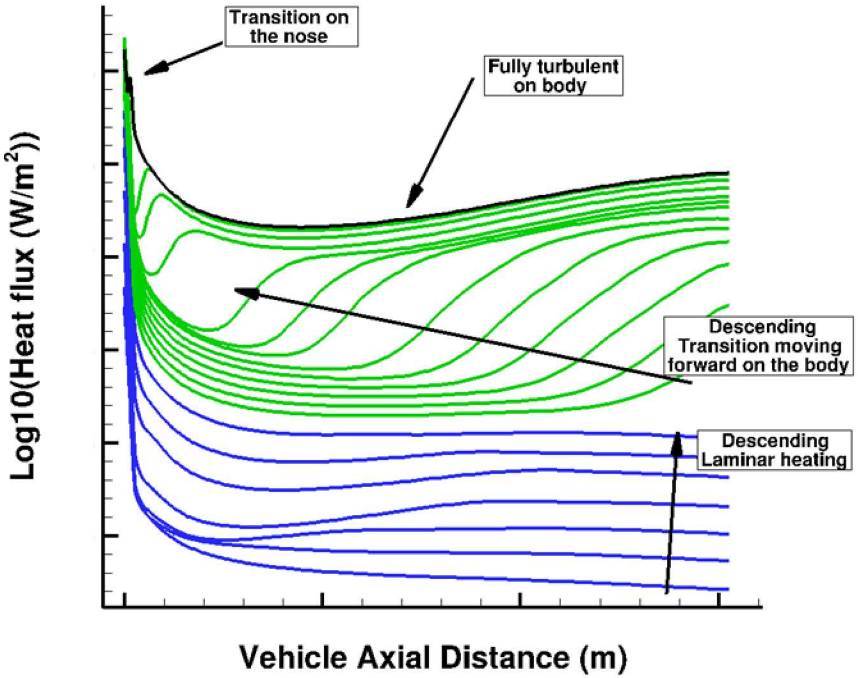


NO Concentration along the stagnation line of a sphere cone

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

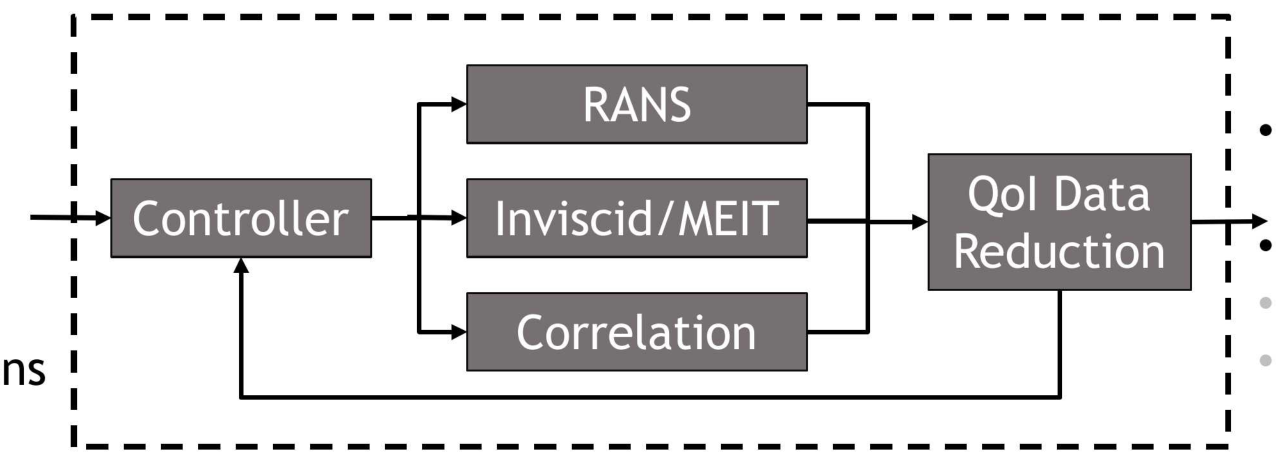
Multi-fidelity Solver

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.

Mission parameter space

- Altitude
- Speed
- AOA
- Attitude
- Control surface deflections
- Etc.



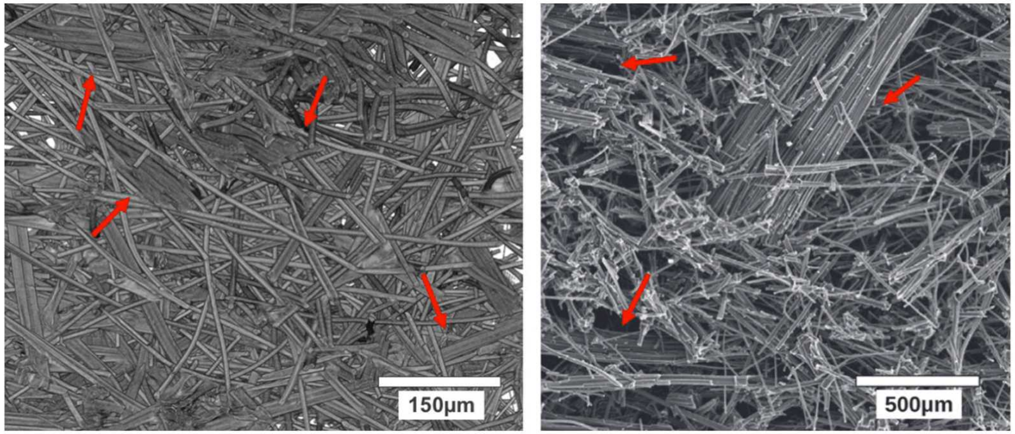
QoIs

- Forces and moments
- Aeroheating
- Uncertainties
- ?

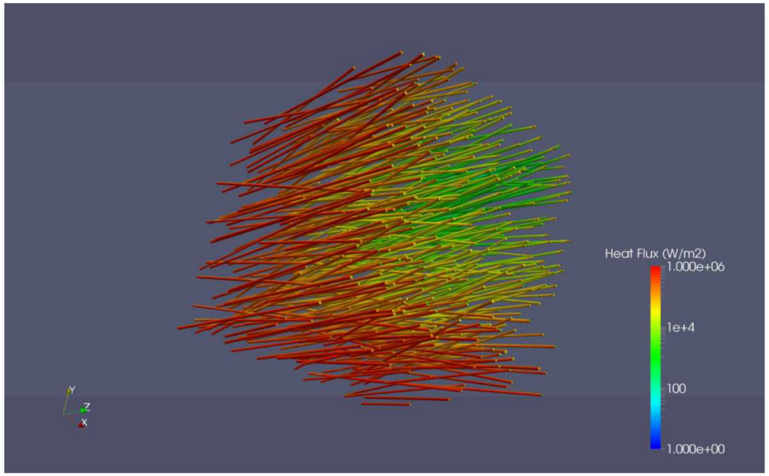
Material Modeling

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

Outline

Reentry environments

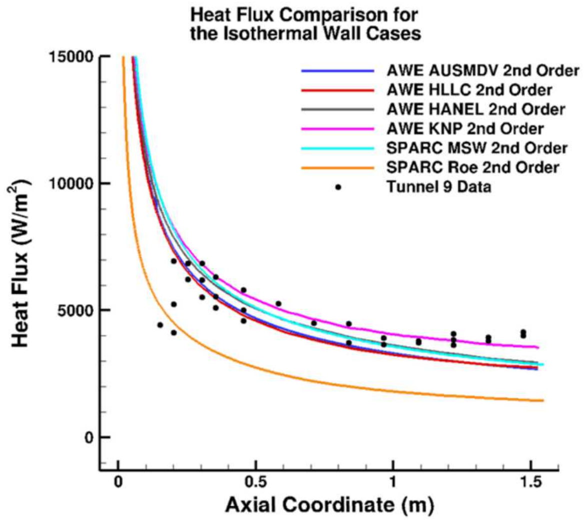
Simulation tools

Current research and development areas

Validation

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

SPARC Flow Validation Sets

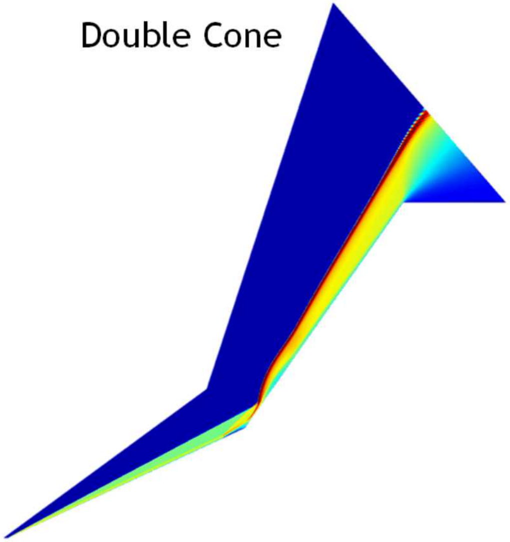


Tunnel 9 Sharp cones

- Frozen laminar and turbulent flows

Double cone

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

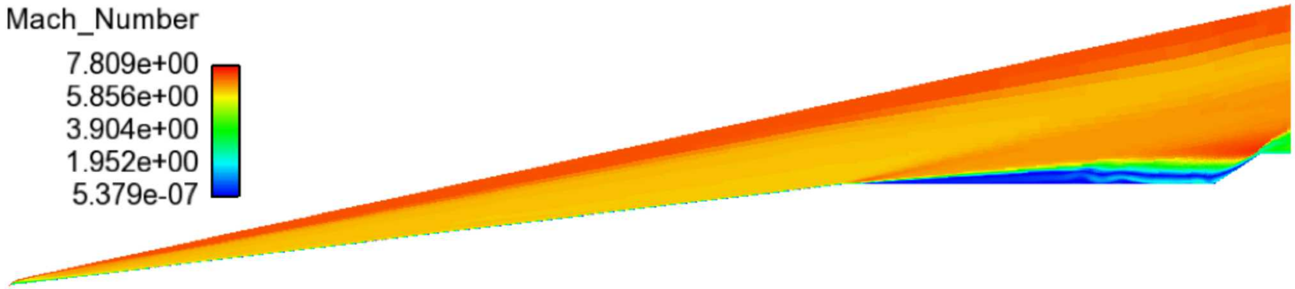


HIFiRE-1

- Turbulent shock/boundary layer interaction
- Nonreacting flow

HEG Cases

- Reacting laminar flow over various shapes



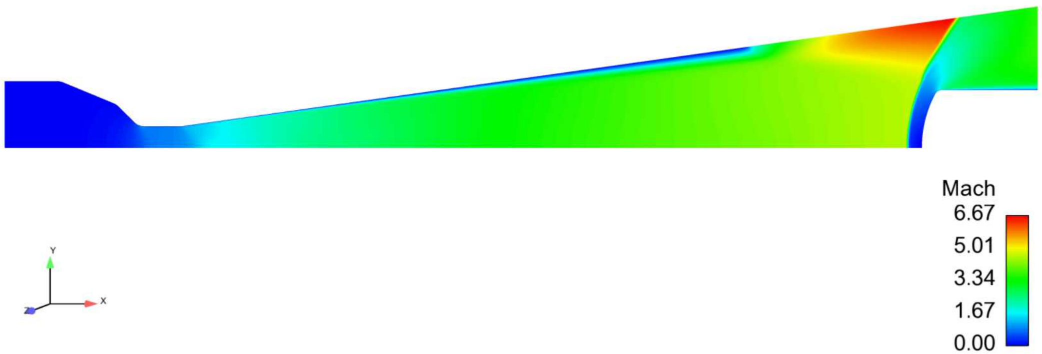
Arc-jet modeling

Provides validation for fluid flow and material thermal response

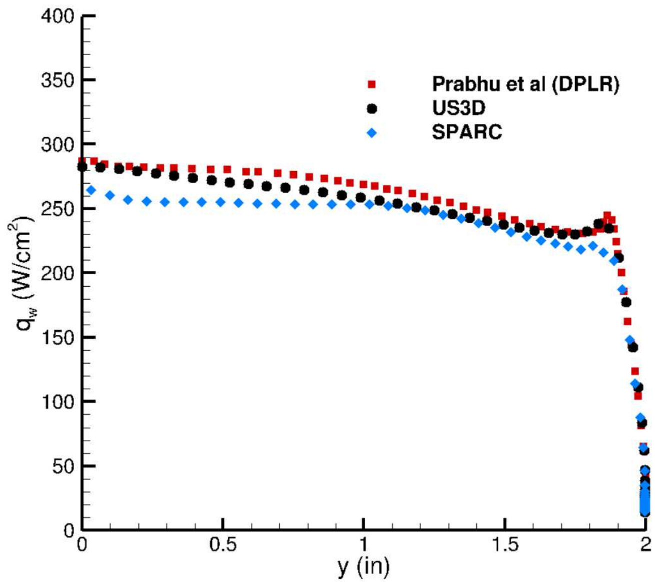
- High temperature, thermochemical non-equilibrium
- High heating rates with material ablation
- Ideal for testing fluid/thermal coupling

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

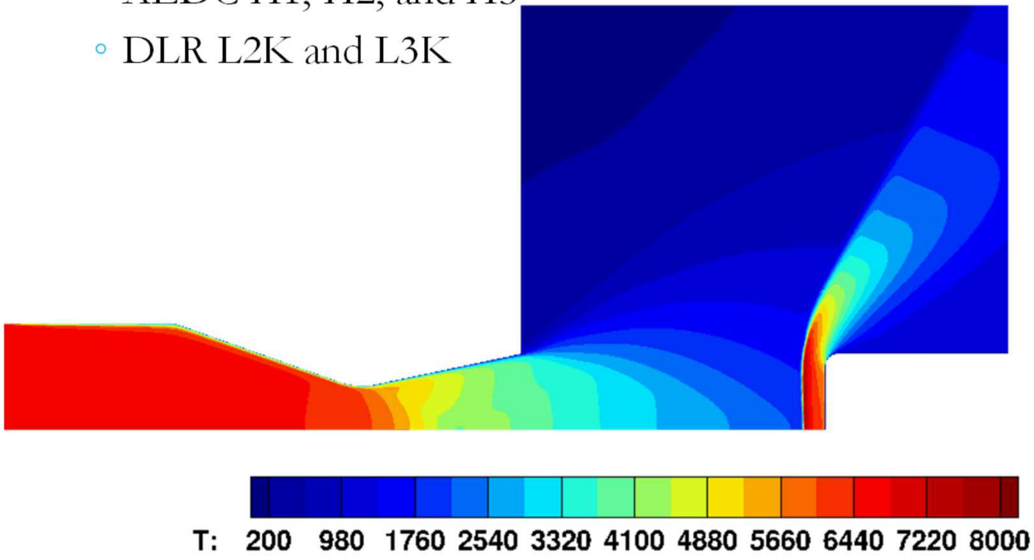
Arc-jet modeling

Provides validation for fluid flow and material thermal response

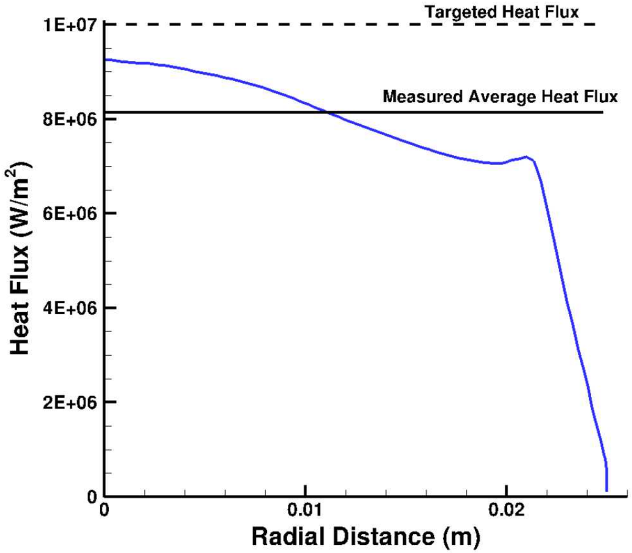
- High temperature, thermochemical non-equilibrium
- High heating rates with material ablation
- Ideal for testing fluid/thermal coupling

Current validation case

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



Simulation of DLR L3K arc-jet



Calculated Heat Flux

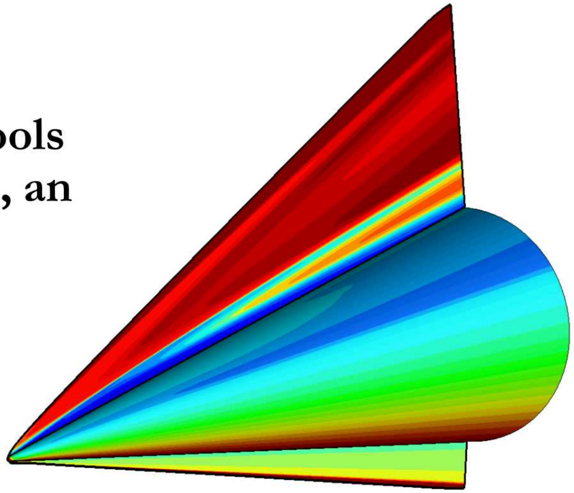
Flight Vehicle Simulation

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).

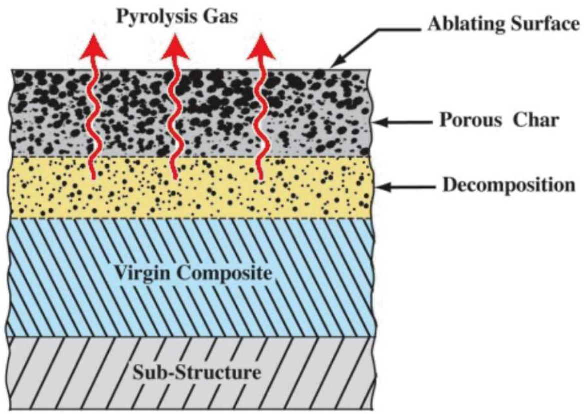
- Code-to-code heating comparisons
- Angle-of-attack effects investigated
- Turbulence model comparisons for the Navier-Stokes approaches



Flight Vehicle Simulation

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

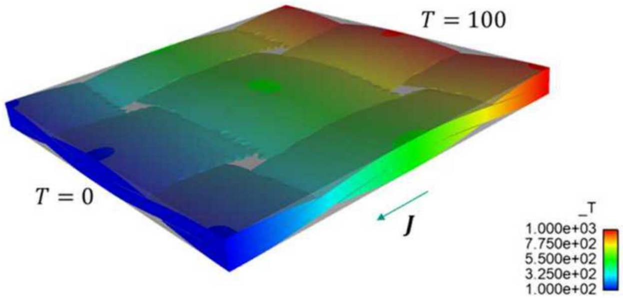


Variability and Uncertainty analysis using Dakota driving CMA

Comparisons to flight data include:

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

Additional Work



- Meso-scale modeling
  - Resolve fiber-scale phenomena
  - Determine effective properties of composites
  - Investigate failure mechanisms
  - Inform macro-scale codes (CMA, SPARC)
- DSMC
  - Simulate flow through porous media – determine effects of ablation on permeability/tortuosity
  - Investigate surface chemistry reactions
- Experiment
  - Manufacture composite materials in-house
  - Utilitze benchtop experiments to better characterize composites
  - Utilize solar furnace/environmental chamber to simulate aeroheating environment. Examine ablative behavior of composites

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
- Structural/Vibration

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