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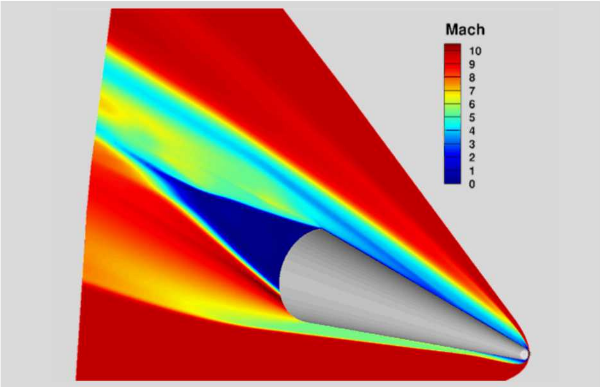
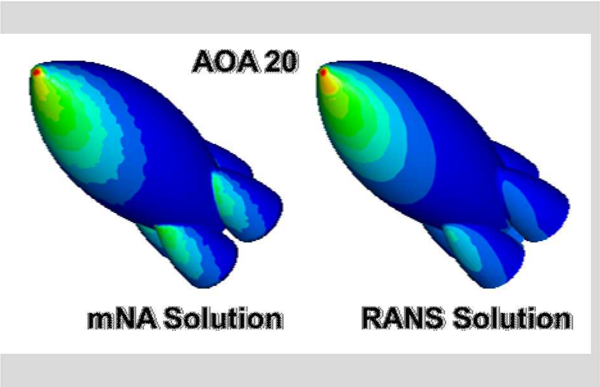
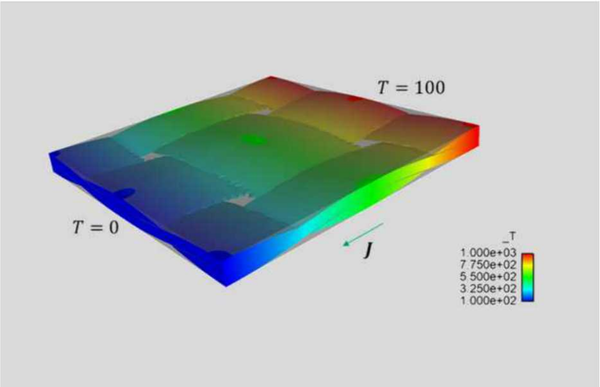






Hypersonic Research at Sandia National Labs

Engineering Sciences Center

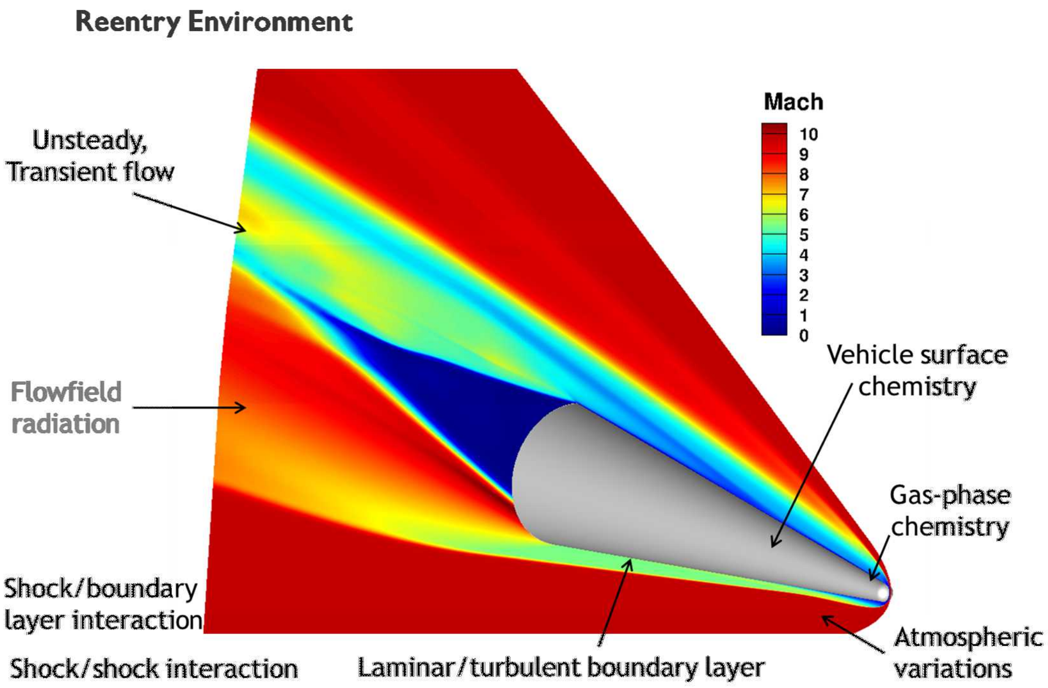
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Hypersonics Research Areas

- Aerodynamic Model Development
- Ablation & Thermal Response
- Random Vibration
- Boundary Layer Transition
- Multi-Fidelity Methods
- Wake Flows
- DSMC
- Multi-Physics Coupling

- Experimental Efforts
  - Materials
  - Wind Tunnel Testing
  - Flight Testing

- Future Effort
  - Weather Effects
  - Turbulence Models (Machine Learning)



Ablation Modeling

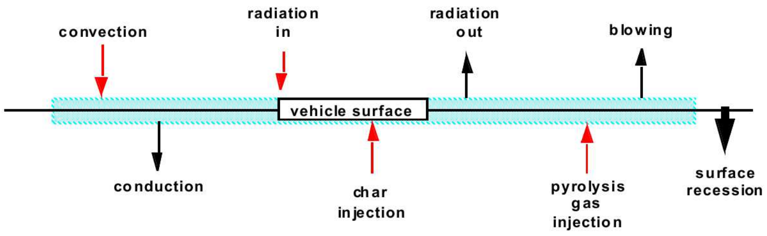
- Sandia designs, builds, tests, and analyzes thermal protection system (TPS) materials of atmospheric flight vehicles
  - TPS materials fall into 4 categories:
    - Non-Ablating (e.g. metals in low-heating environments)
    - Subliming/Melting Materials (e.g. Teflon)
    - Surface-Ablating Materials (e.g. Carbon-Carbon)
    - In-Depth Decomposing Materials (Composites, e.g. Carbon-Phenolic)

- A thermal response calculation consists of:
  - Aerodynamic flowfield
    - Convective heat transfer
    - Pressure
    - Shear
  - Material thermal response
    - Ablation
    - In-depth conduction

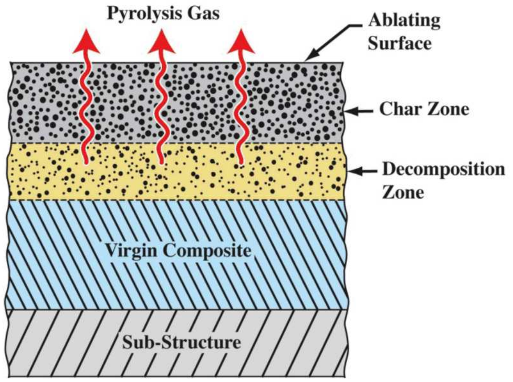
Ablation Modeling

- Convective heating / cooling is calculated from the flowfield code:
  - SPARC, US3D, : Full 3D Navier-Stokes CFD with real-gas chemistry
- Specialized thermal response tools are used for ablation calculations
  - SPARC (3D), CMA (1D), Chaleur (1D)
  - Solve the surface energy balance, accounting for convection, conduction, radiation, material decomposition, ablation
  - Material Properties used in the calculation:
    - Thermal conductivity (fn. of temperature)
    - Specific heat (fn. of temperature)
    - Emissivity (fn. of temperature)
    - Density (single value for non-decomposing ablators) (decomposition model vs. temperature for decomposers)
    - Surface chemistry calculated with equilibrium model
- Complex conduction calculations performed by coupling to Aria

Energy Balance at surface of an ablating TPS



Decomposing Ablator

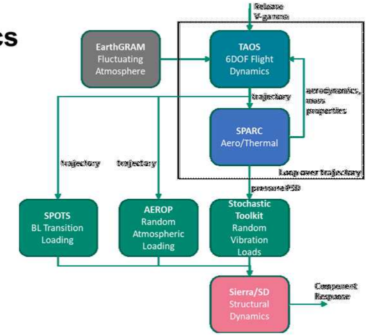


SPARC

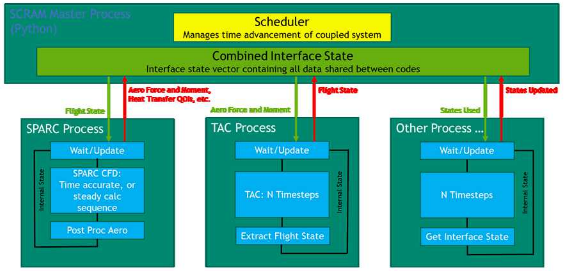
- SPARC (Sandia Parallel Aerodynamics and Re-Entry Code)
  - Compressible reacting flow CFD + three-dimensional TPS material response
  - Finite-volume solver covering transonic to hypersonic flight regimes
  - RANS, Hybrid RANS-LES, LES, and DNS turbulence modeling capability
  - Performance portability via Kokkos to run on next generation HPC platforms

- Multi-Physics Coupling
  - Trajectory – Aerodynamics – Ablation/Thermal
  - Future: Random Vibration, Structural Dynamics

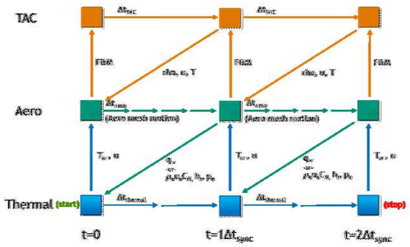
Multi-Physics Analysis:



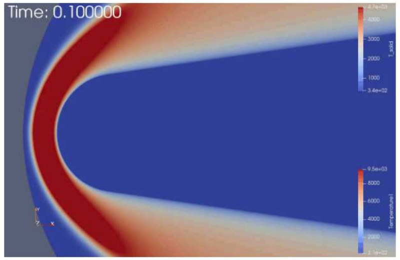
Coupling Architecture



Staggered Coupling Methodology

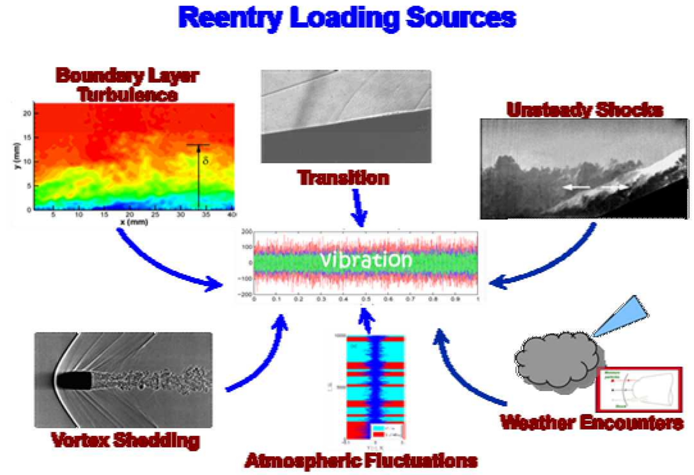


Generic RV Nosetip Analysis

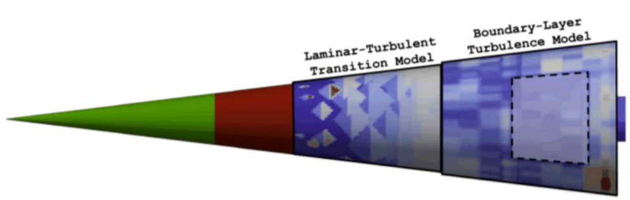


Random Vibration

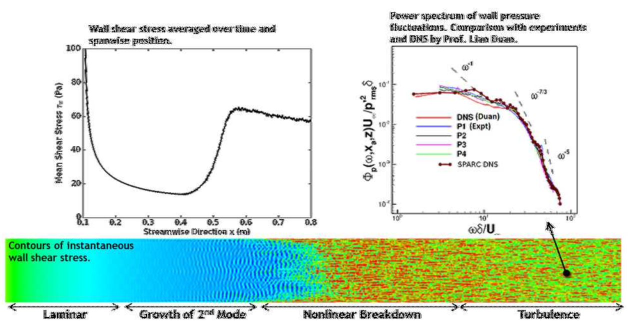
- Reentry Random Vibration
  - Structural response of an RB and internal components
  - Random Aerodynamics Loads
    - Boundary Layer Transition
    - Turbulent Boundary Layer
    - Atmospheric Fluctuations
    - Weather



Reduced-Order Models



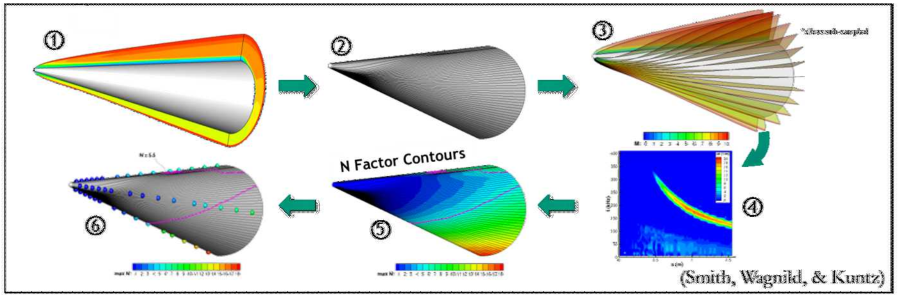
Direct Numerical Simulation



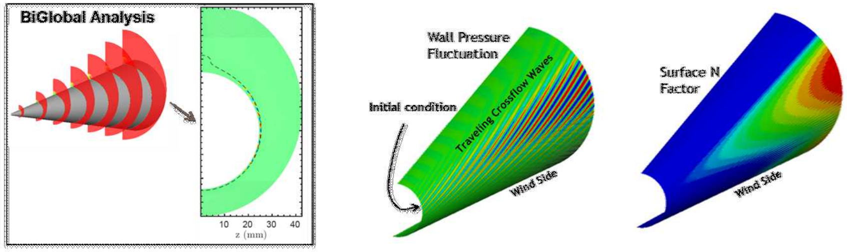
Boundary Layer Transition

- **Objective:** Develop mechanism-based boundary layer transition methods
- State-of-the-Practice: Correlation-based methods
- Going a step further: Physics-based methods with e^N transition correlation
  1. Conduct laminar CFD
  2. Estimate paths of propagation of instabilities
  3. Extract 2D flow slices along disturbance propagation paths
  4. Perform stability analysis on each slice
  5. Integrate growth of instabilities one each slice
  6. Interpolate N factors and transition prediction onto geometry

Each step requires user intervention and expertise and may introduce errors



- State-of-the-Art: Optimization (Input/Output) Methods for Bi-Global Stability Analysis
  - Method more integrated into analysis workflow (less user-intervention)
  - Enable analysis of multiple transition mechanisms at once



Multi-Fidelity Toolkit

PI(s): Ross Wagnild

Duration: FY18-FY19

Generate high-fidelity data based on low-fidelity data at a fraction of the computation cost

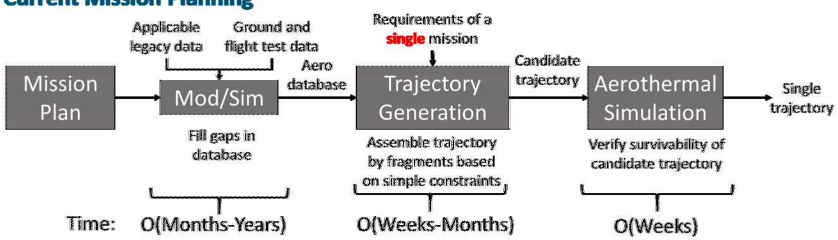
Goal:

- Develop the multiphysics solver SPARC to be capable of computing Quantities of Interest (QoIs) with at least three different levels of fidelity
- Develop a controller program to generate input files, execute SPARC, gather QoI's, perform multi-fidelity interpolation

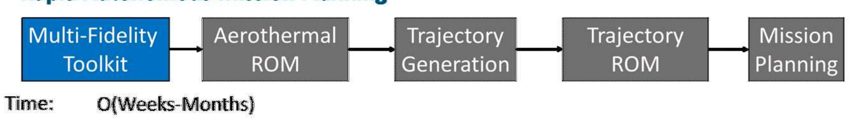
Uniqueness:

- Combine multi-fidelity interpolation methods with hypersonic flow physics

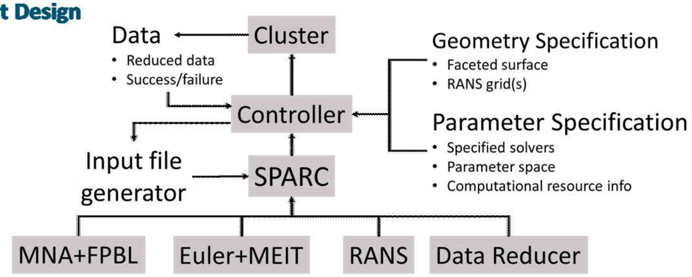
Current Mission Planning



Rapid Autonomous Mission Planning



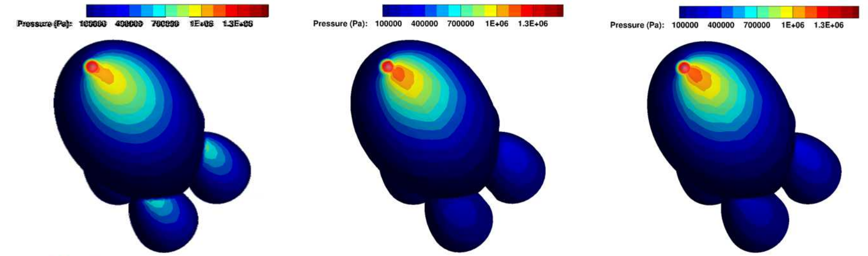
Toolkit Design



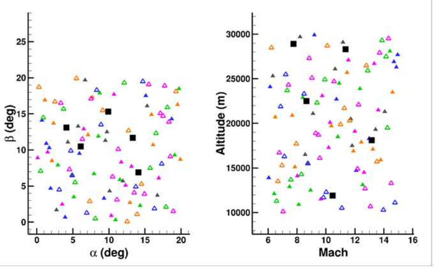
Project Achievements:

- Full implementation and refinement of MNA + FPBL model;
- Euler solve and transfer complete, initial framework for MEIT solver
- Ability to calculate forces, moments, and heat flux at each solver level
- Development of controller software: Generate input files, gather QoIs, Parallel dispatch
- Demonstrate simple and intelligent parametric sweeps of flow conditions
- Implemented and demonstrated Hierarchical Kriging interpolation
- Path forward for automatic refinement

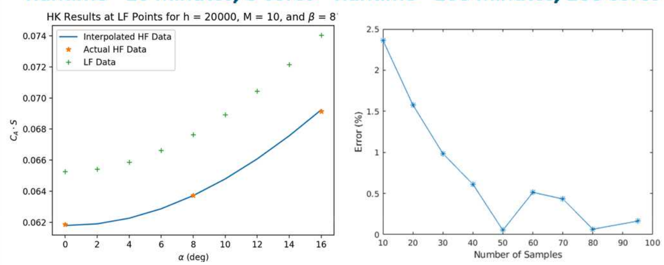
Rocket ship at angle of attack of 16°, yaw of 8°, Mach 15, altitude 20 km



Modified Newtonian Aero	Euler	RANS
Runtime ~10 seconds, 1 core	Runtime ~10 minutes, 8 cores	Runtime ~100 minutes, 288 cores



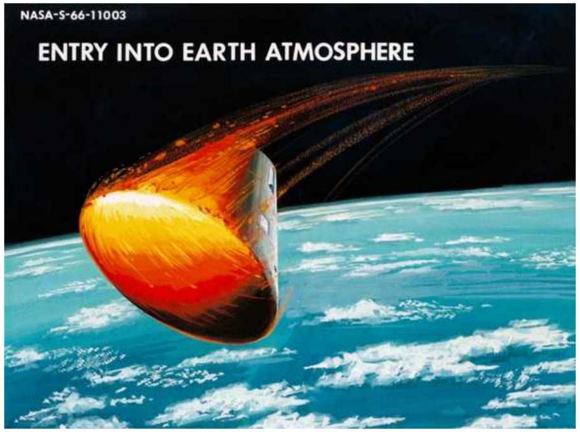
Latin Hypercube Sampling



Evaluation of Hierarchical Kriging Interpolation

Materials Research

Thermal Protection System (TPS) materials must withstand extreme environments



NASA: "Project Fire Redux: Interplanetary Reentery Test (1966) https://www.wired.com/2012/07/interplanetary-reentry-tests-1966/

How do we quickly improve our understanding of materials used?

2-fold: computation & performance characterization.

1966 FIRE REUDUX NASA: Complex problem "no substitute for testing specific configurations and materials in the actual environment of interest"

Goal: manufacture materials & improve our understanding of properties under extreme environments through experimental testing and modeling efforts

Models are using data from materials science & environmental performance to improve our understanding

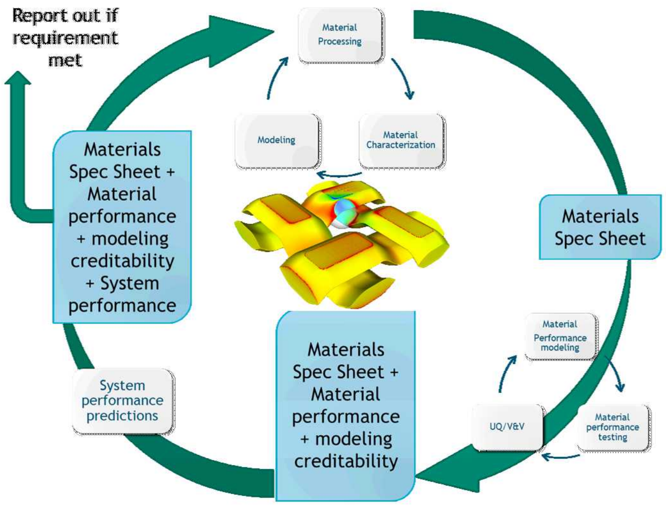
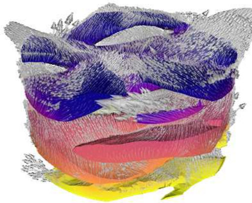
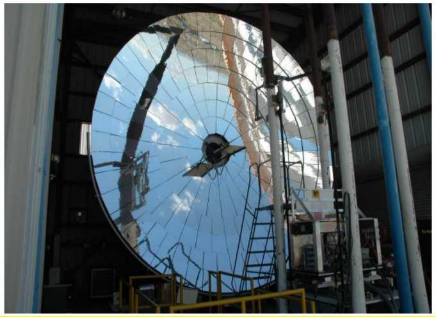


Image-based geometry

Meso-scale modeling



The power of the Sun is used to simulate reentry heating to verify performance behavior



*One of several Sandia testing facilities available to simulate extreme environments

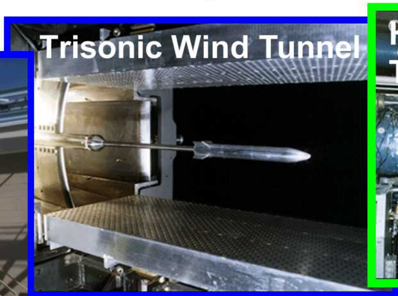
Experimental Efforts

Sandia National Laboratories

- The **Thermal, Fluid, and Aero Sciences Group** provides research, development, and applications expertise in a broad range of technology areas required for Sandia to accomplish its mission in nuclear weapons and other national security areas.

Experimental Aerosciences Facility

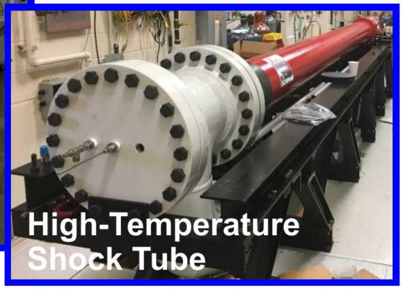
High-Altitude Chamber
- Satellite components



Trisonic Wind Tunnel
- Mach 0.5 – 3
- Gravity bombs, missiles

Hypersonic Wind Tunnel
- Mach 5, 8, 14
- Re-entry vehicles, rockets

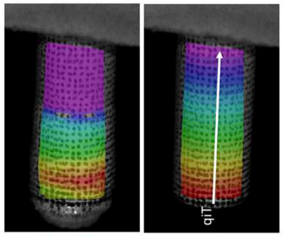
Multi-Phase Shock Tube
- Explosives research



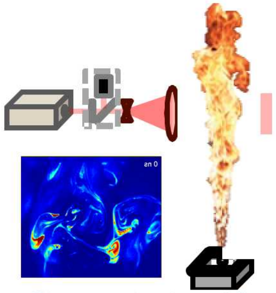
High-Temperature Shock Tube
- Soon to be a Mach 8 Shock Tunnel

Advanced Diagnostics & Simulation

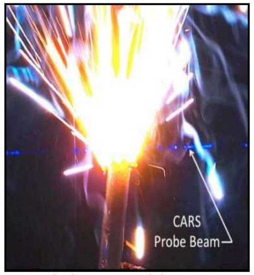
Development & application of cutting-edge diagnostics, including test design, experimental demonstration and UQ to unravel unresolved phenomenology, characterize material properties and material response as well as performance of validation experiments to support Sandia's missions.



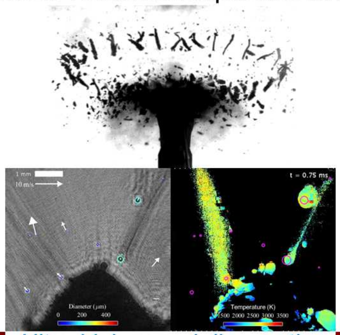
Full-field diagnostics



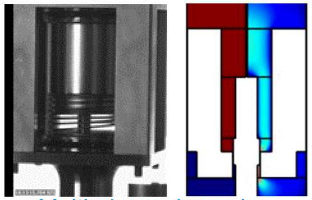
Characterization of fire & explosive environments



Advanced laser diagnostics



Ultra-high-speed diagnostics for 3D particle tracking/characterization



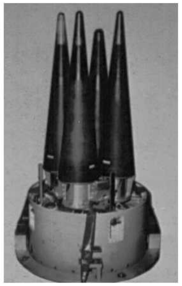
Multi-phase dynamics experiments and computations

Simultaneous Raman spectroscopy and rheology measurement capability

Flight Testing

- Sandia has an extensive history fielding one-of-a-kind flight tests
  - Technology Development
  - Capability Demonstration
  - Component Qualification
  - Stockpile Surveillance
- **New efforts add model validation and physical discovery**
- HOTSHOT Flight Test Series
  - High-frequency pressure sensors
  - Embedded thermocouples
  - Internal accelerometers
  - Thermal plugs (material & ablation testing)
  - Ultrasonic recession gages
  - Shear stress sensors


NASA SHARP-B01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