Aerothermal Capabilities at Sandia National Laboratories

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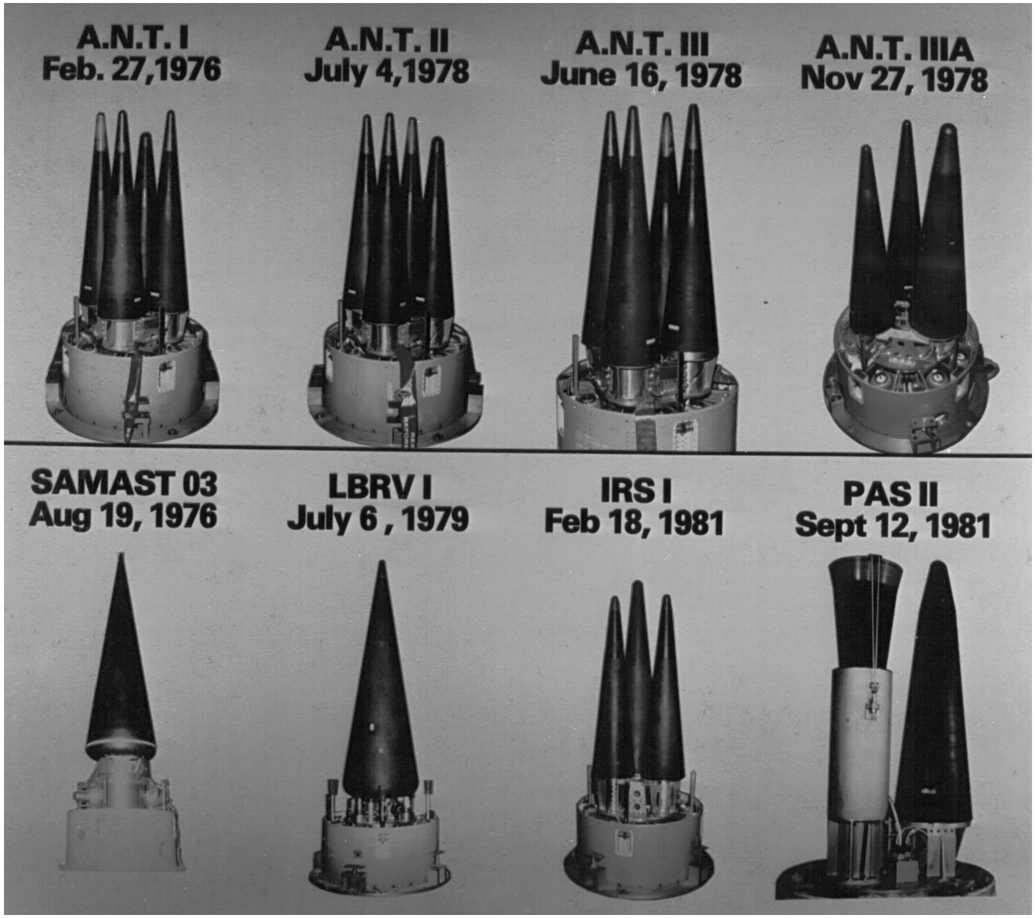
Sandia's Historical Roots in Hypersonic Reentry Systems

U.S. RV Performance
- Ballistic vehicle dynamic behavior
- Component environments and performance

Materials Development
- Heatshields
- All carbon-carbon vehicles
- Antenna windows
- Nosetips

Hypersonic Vehicle Recovery
- Pioneered the soft recovery of hypersonic vehicles for post-flight inspection



Aerothermal
Flight Vehicle Support

Minuteman Launch
from VAFB

MaST Recovery
Vehicle

MaST
Payload

- More than 100 Instrumented RV/RB's flown (1968-present)
- 7 Carbon-Carbon vehicles
- 6 RV's soft recovered
- 10 RV's on 9 AO's [USAF;MM III & PK]
- 9 RB's on 4 DASO's [USN]
- Most vehicles, One-of-a-kind, unique R & D tests
- High risk, excellent track record [>96% of flight test objectives satisfied]

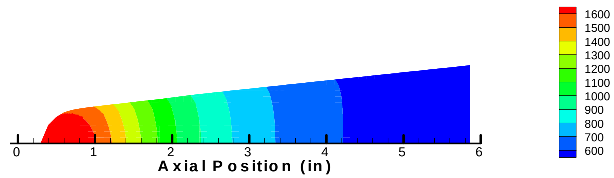
SAMAST/MINT
All Carbon-Carbon
Vehicle

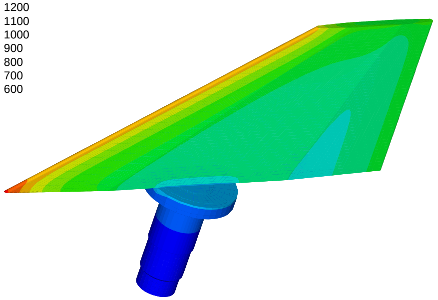
GRANITE

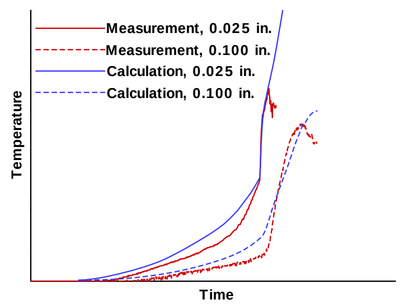
NASA SHARP-B01
Vehicle

Presentation Topics

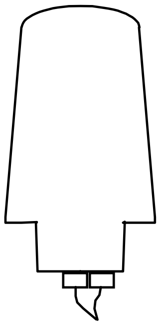
- **Aerothermal Analysis Tools**

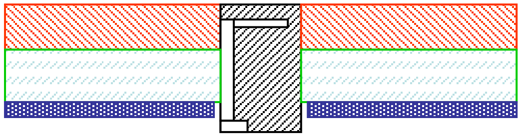


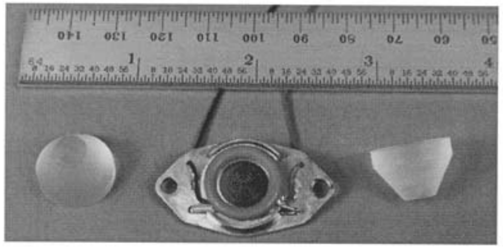




- **Aerothermal Flight Vehicle Instrumentation**





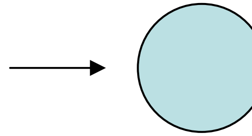


Aerothermal
Analysis Tools

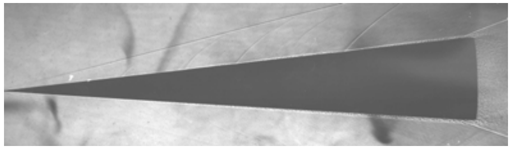
- Flowfield/Aerodynamic Heating
- Material Thermal Response
- Nosetip Heating/Ablation
- RF Attenuation
- Analysis Tools Currently Under Development

Flowfield/Aerodynamic Heating Codes

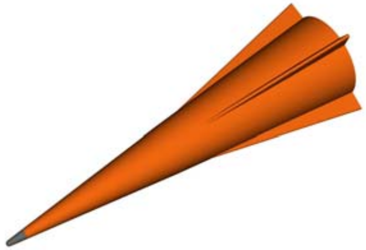
- **HANDI**
  – **Set of correlations for computing heating on several standard geometries (spheres, flat plates, cylinders, . . .)**



- **BLUNTY**
  – **Correlation-based heating code for sphere-cone geometries**
  – **Ideal for trade studies and quick investigations**



- **2IT/SANDIAC/HIBLARG**
  – **Set of inviscid/integral boundary layer codes**
  – **Used for spherically-capped analytical geometries at angle-of-attack**



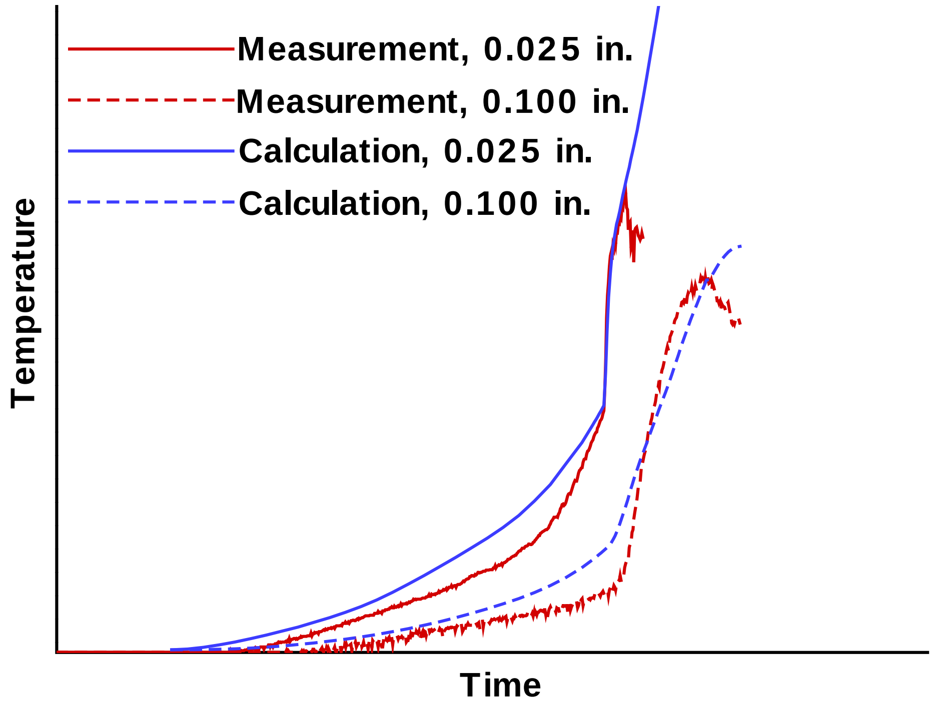
- **SACCARA**
  – **Finite-volume Navier-Stokes code**
  – **Used for obtaining flowfield solutions on complex geometries at all speed ranges**

Material Thermal Response Codes

- **Charring Materials Ablation code (CMA)**
  - One-dimensional code with in-depth decomposition
  - Q* and equilibrium chemistry ablation models available
- **Sandia One-Dimensional Direct and Inverse Thermal code (SODDIT)**
  - One-dimensional code with direct and inverse capabilities
  - Q* and equilibrium chemistry ablation models available
  - Radiation gap model included
- **Ablating Version of COYOTE**
  - Two and three-dimensional finite element code modified to include aeroheating and ablating boundary conditions and moving mesh capabilities for modeling surface recession
  - Used as both production tool and research tool for investigating coupling approaches for aerothermal problems

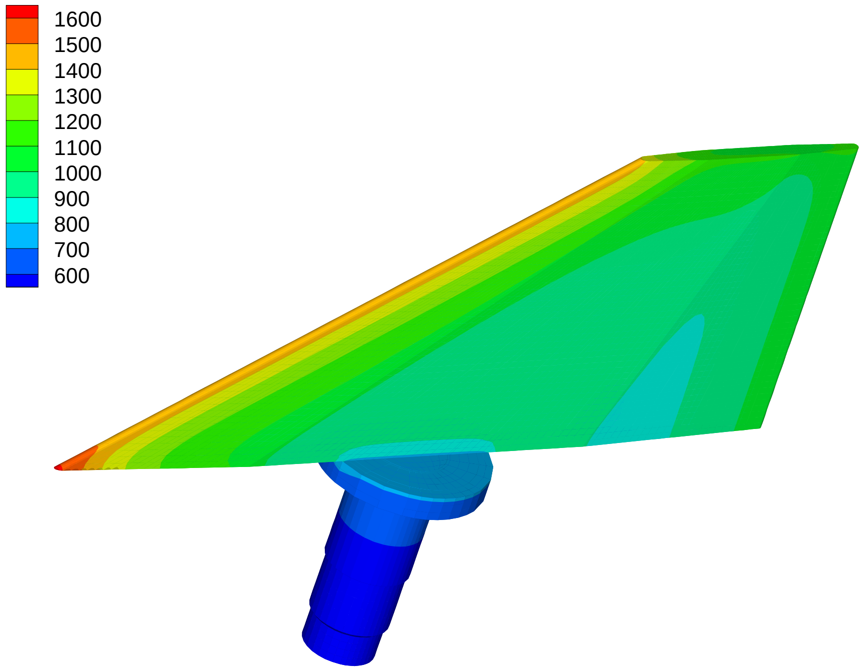
Material Thermal Response Codes

- **Sample Results:**
  - **Reentry vehicle thermal response**
  - **Heating computed with 2IT/SANDIAC/ HIBLARG**
  - **Heatshield response computed with CMA**



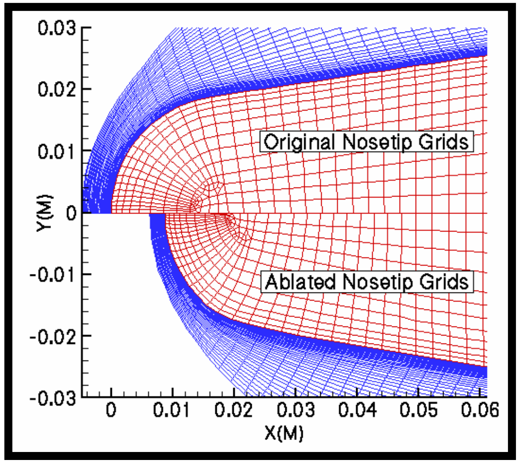
Material Thermal Response Codes

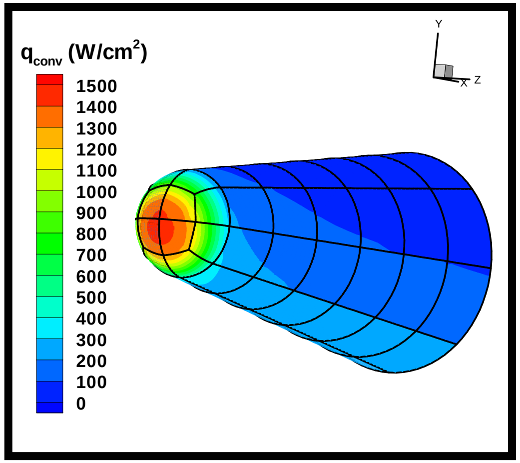
- **Sample Results:**
  - **Hypersonic vehicle control fin thermal response**
  - **Heating computed with HANDI**
  - **Fin thermal response computed with the ablating version of COYOTE**

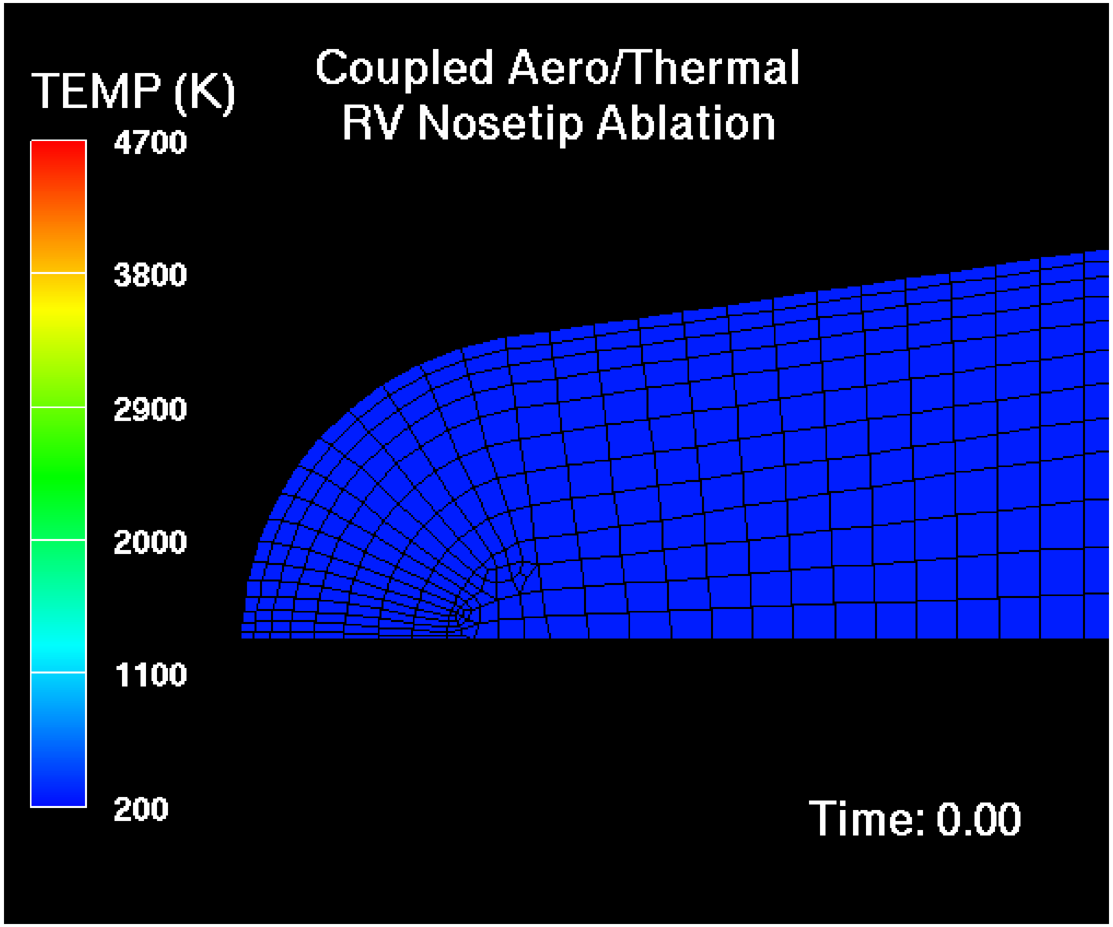


Material Thermal Response Codes

- **Sample Results: Coupled Ablation / Material Thermal Response**







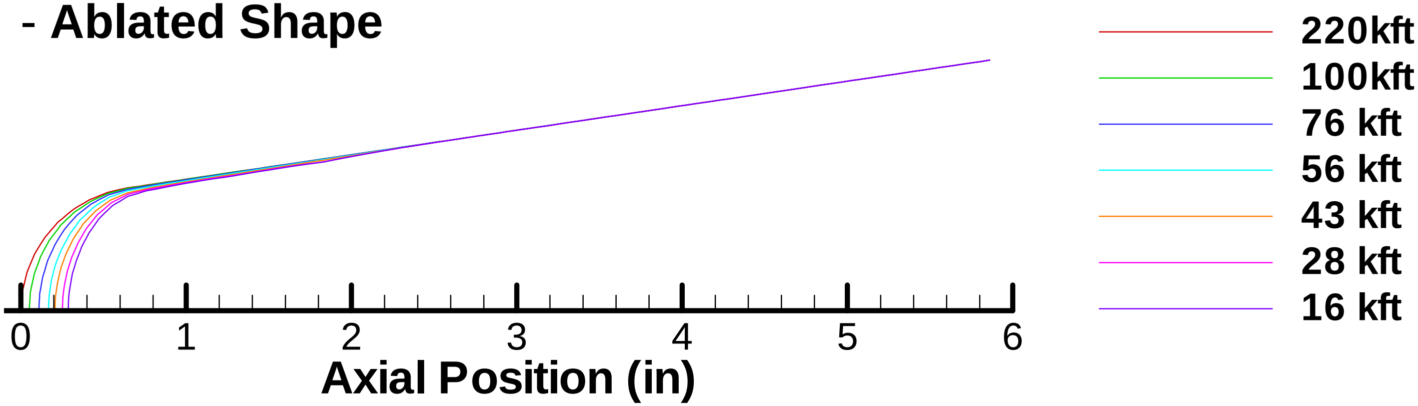
Nosetip Heating/Ablation

- **ABRES Shape Change Code (ASCC86)**
  - Inviscid flowfield computed with correlations and engineering-based approaches
  - Heating computed with Momentum/Energy Integral Technique (MEIT)
  - Steady state and transient conduction options available
  - Ablation computed with an equilibrium chemistry model
  - Numerous atmospheres and transition models available

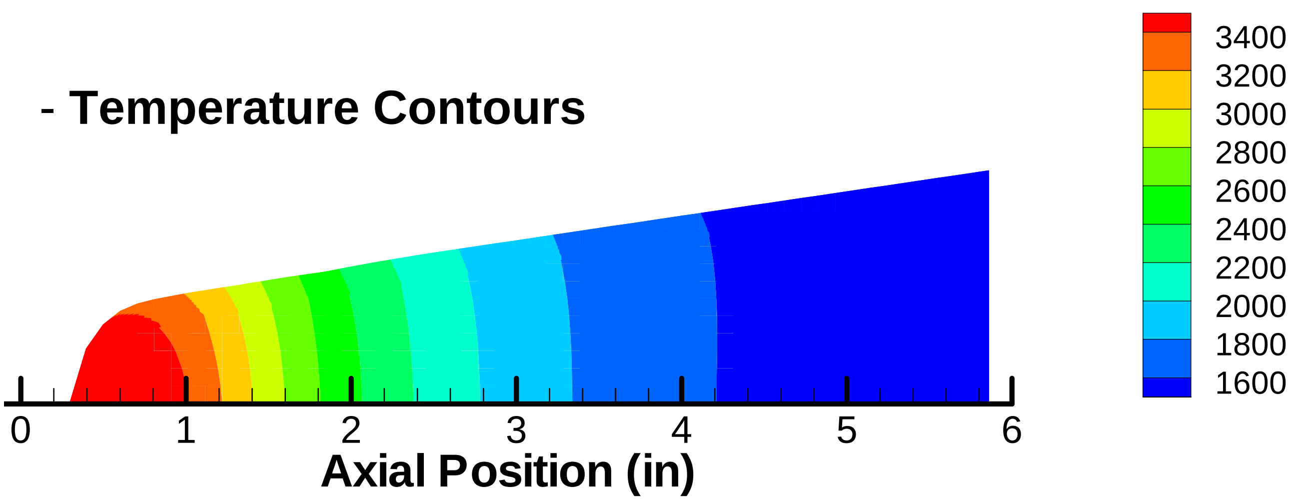
Nosetip Heating/Ablation

- **ASCC Sample Solution**

- Ablated Shape

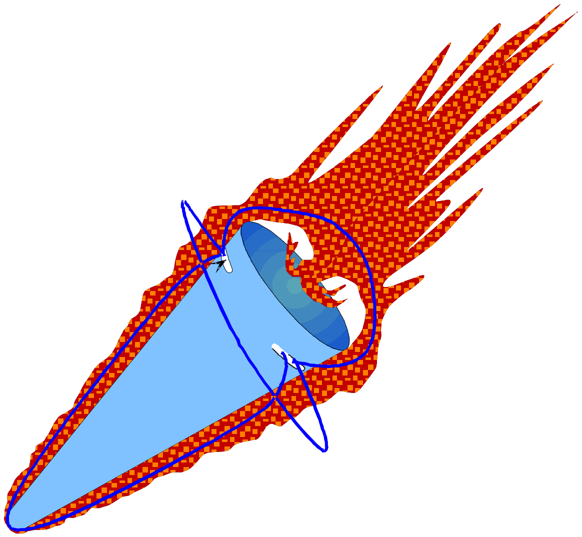


- Temperature Contours



RF Attenuation

- **Poly-Iterative Reacting Aero-Thermal Evaluation (PIRATE)**
  - **Performs iterative thermal response analysis until body surface temperature convergence is reached over the entire trajectory**
  - **Calls numerous aerothermal codes including:**
    - **TAOS/SIXDOF- Trajectory simulation program**
    - **BLUNTY - Reference boundary layer heating (used in iterative process)**
    - **2IT/SANDIAC/HIBLARG - Reference boundary layer heating**
    - **BLIMP - Reacting boundary layer blown heating**
    - **ACE – Surface chemistry**
    - **CMA - Thermal response**
    - **EMLOSS - Plane wave plasma interaction**

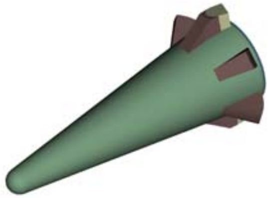


Analysis Tools Currently Under Development

- **Advanced Simulation and Computing (ASC) Codes**
  - **Premo Compressible Fluid Mechanics Code**
    - **Full Navier-Stokes capability**
    - **Unstructured mesh**
    - **Equilibrium and finite-rate chemistry (under development)**
  - **Calore Conduction Code**
    - **Unstructured mesh finite element conduction code**
    - **Aeroheating and ablating boundary conditions (under development)**
  - **ASC code architecture will allow communication between Premo and Calore for coupled aeroheating/material thermal response solutions**

Analysis Tools Currently Under Development

- **High Speed Tool for Computing Aeroheating on Arbitrary Geometries**
  - **New capability currently under development will couple Premo (inviscid solutions) with SAPHIRE (boundary layer solutions)**
  - **Coupled set of codes will permit rapid heating solutions to be computed on complex, non-spherically-capped geometries**



Analysis Tools Currently Under Development

- Chaleur
  - 1-D Material Thermal Response Code
    - Planar, Cylindrical, and Spherical Geometries
  - Q* and Equilibrium Chemistry Ablation Models
  - Aerodynamic Heating Capability
  - In-Depth Decomposition

Analysis Tools Currently Under Development

- Chaleur (cont.)
  - Differences from (Improvements over) CMA
    - Residual Formulation of Governing Equations
    - Control Volume Finite Element Spatial Discretization
    - Implicit and Trapezoidal Time Integrators
    - Contracting Grid Scheme
    - Nonlinear Iteration on Entire Equation Set
      - No thermal property or surface recession rate lag
    - Continuity Equation and Porous Flow Momentum Equation
      - Predicts pressure in porous char layer

Flight Vehicle
Thermal Instrumentation

- Thermocouple Plugs
- Acoustic Recession Gages
- Photodiode Transition Indicators

Flight Vehicle Thermocouple Plug

- **Typical Thermocouple Plug**
  - **Tungsten-5% Rhenium vs. Tungsten-26% Rhenium thermocouples**
  - **Published voltage output values up to 4,660 ^{o}R**
  - **Up to three thermocouples per plug**

Flight Vehicle Thermocouple Plug

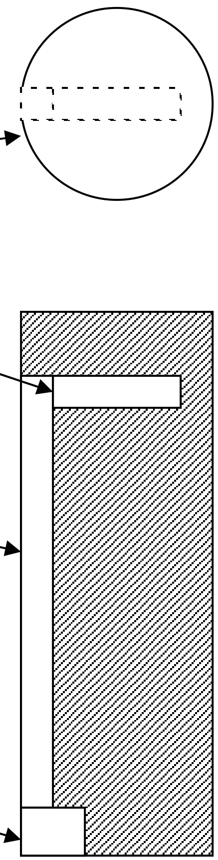
Typical Plug Design:

Heatshield Material Plug, 0.375 Dia

T/C Hole, 0.0145 Dia, 0.2 Deep

T/C Groove, 0.015 Wide, 0.047 Deep

Enlarged Hole for Wire Junction



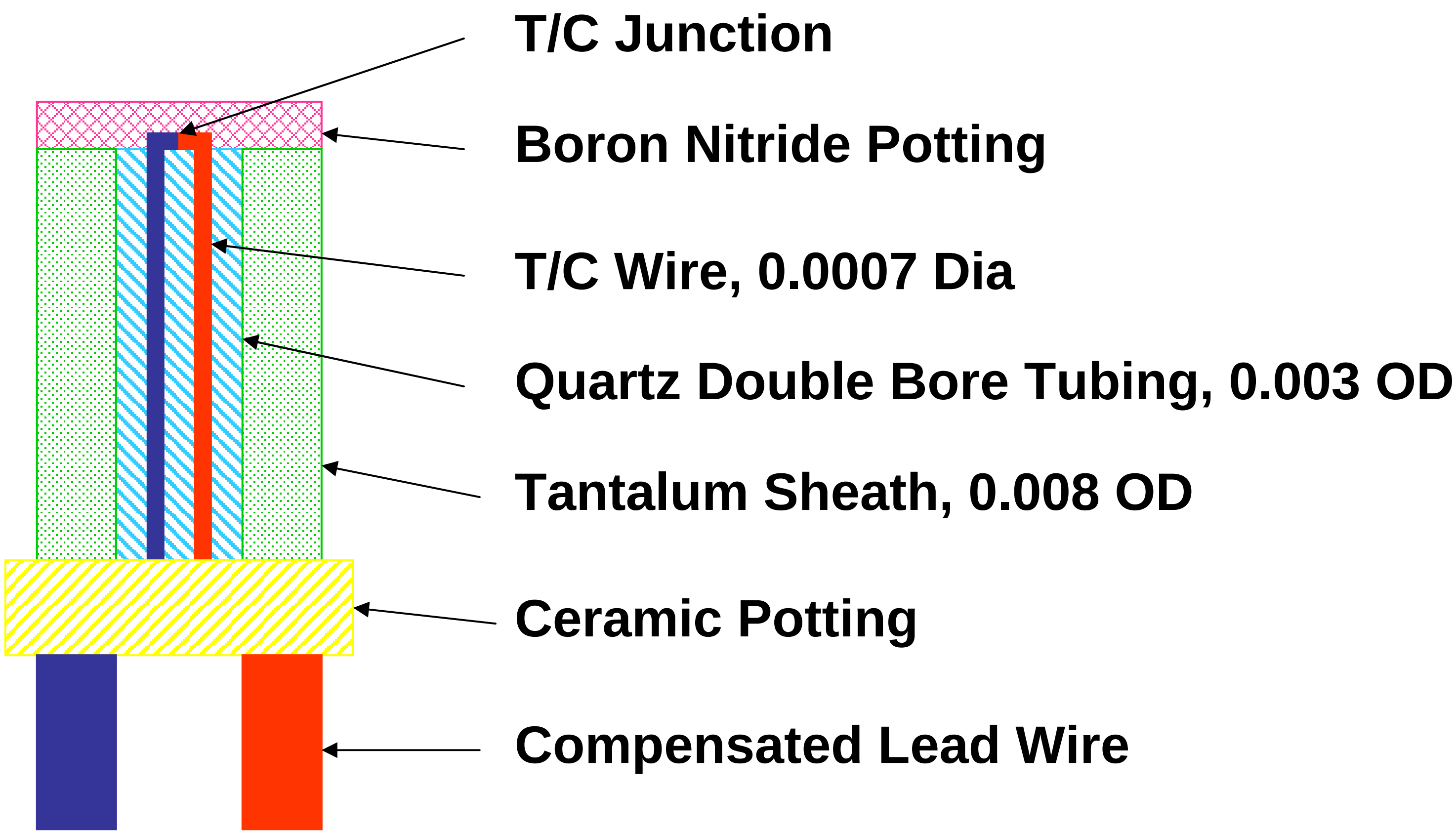
Sandia National Laboratories

NNSA National Nuclear Security Administration

Flight Vehicle Thermocouple Plug

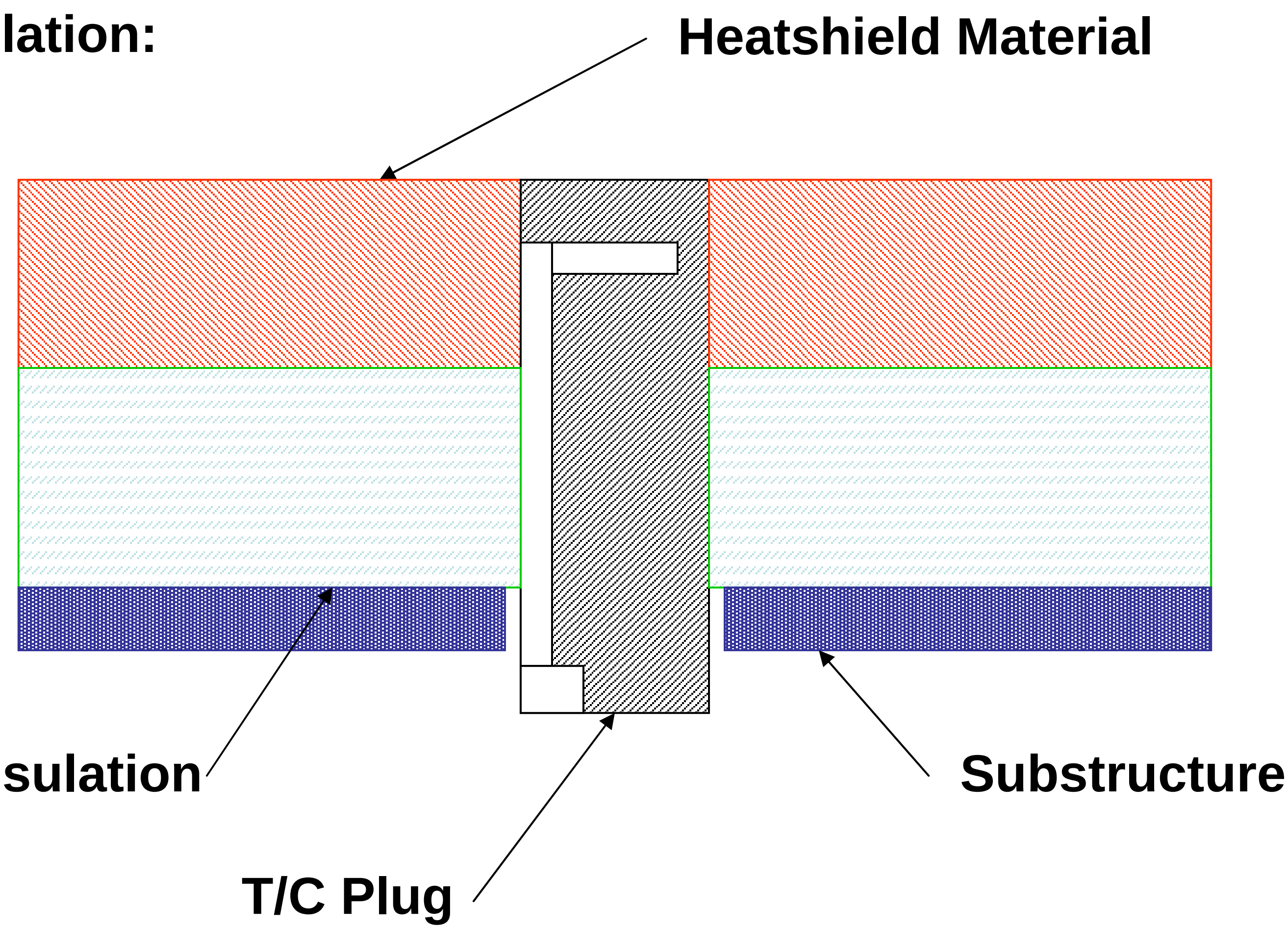
Thermocouple Design:

All Dimensions in Inches



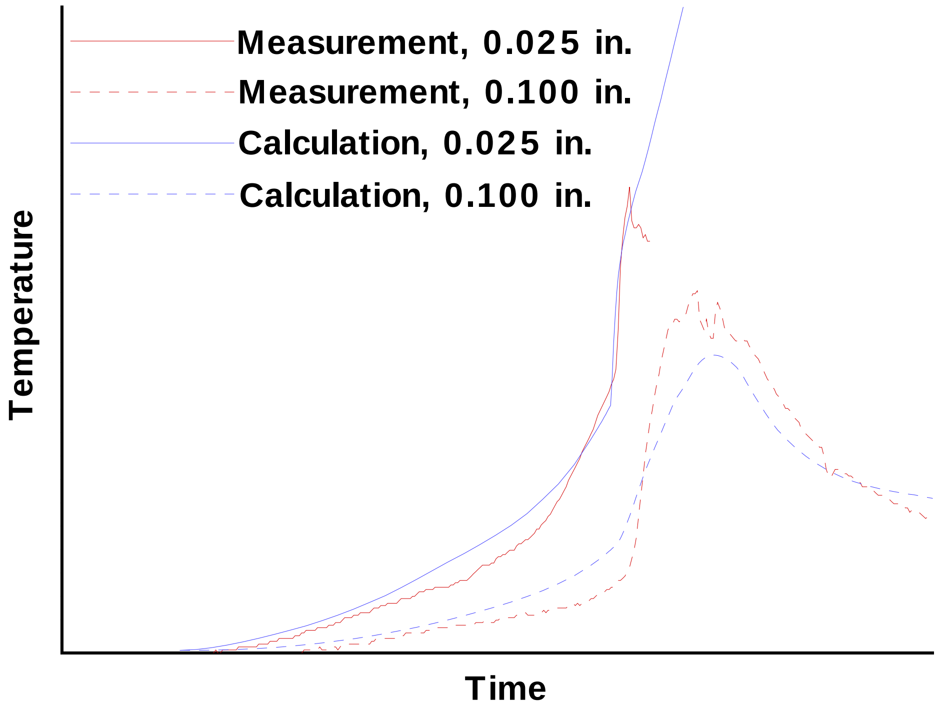
Flight Vehicle
Thermocouple Plug

Installation:



Flight Vehicle Thermocouple Plug

- **Sample Flight Data**

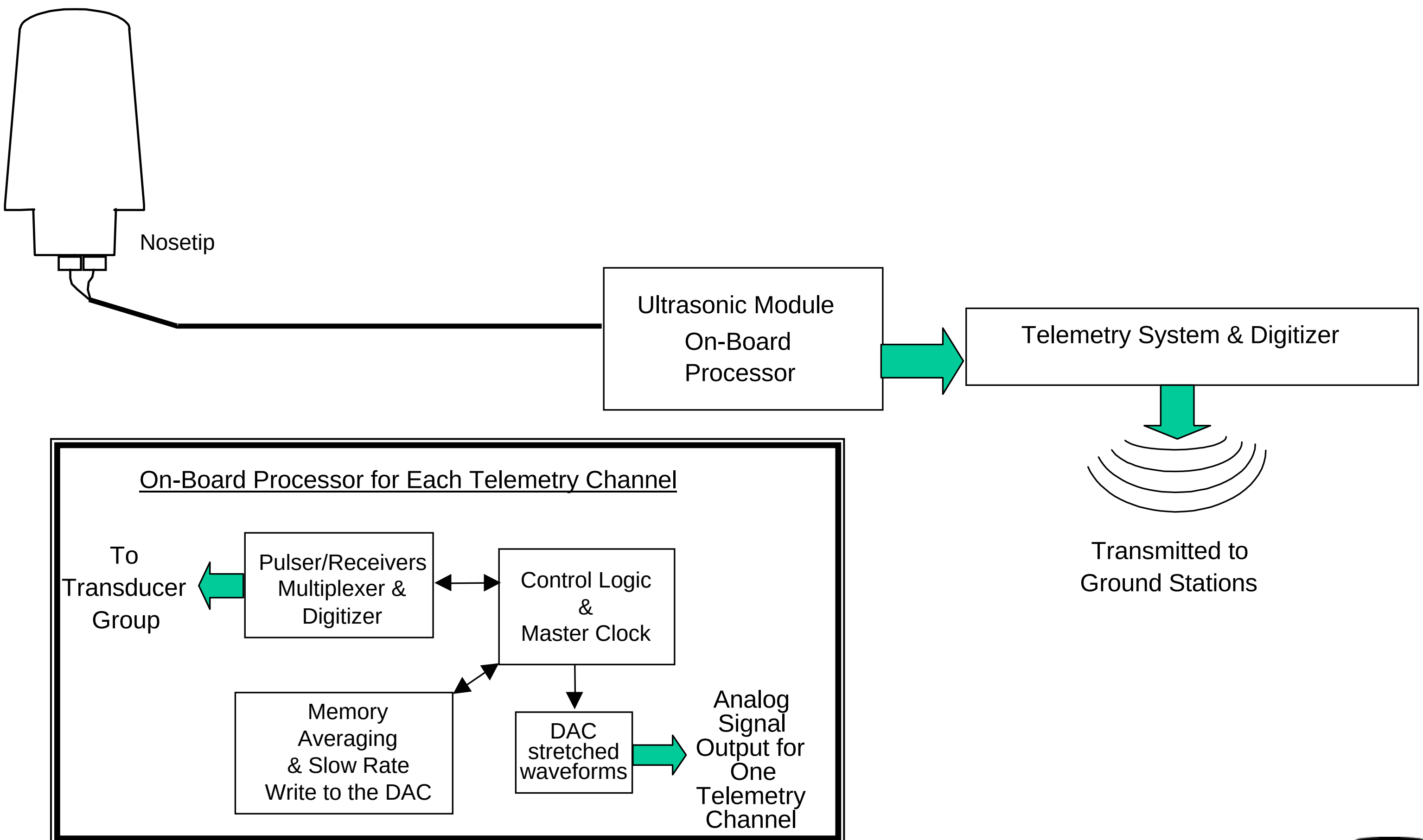


Flight Vehicle
Nosetip Recession Gage

- Acoustic Recession Gage
  - Used successfully on nosetips, antenna windows, and flaps
  - Transducer mounted directly on the back face of the ablating material
  - Acoustic wave transmitted by the transducer and reflected off the ablating surface
  - Acoustic “time of flight” used to determine instantaneous ablator thickness

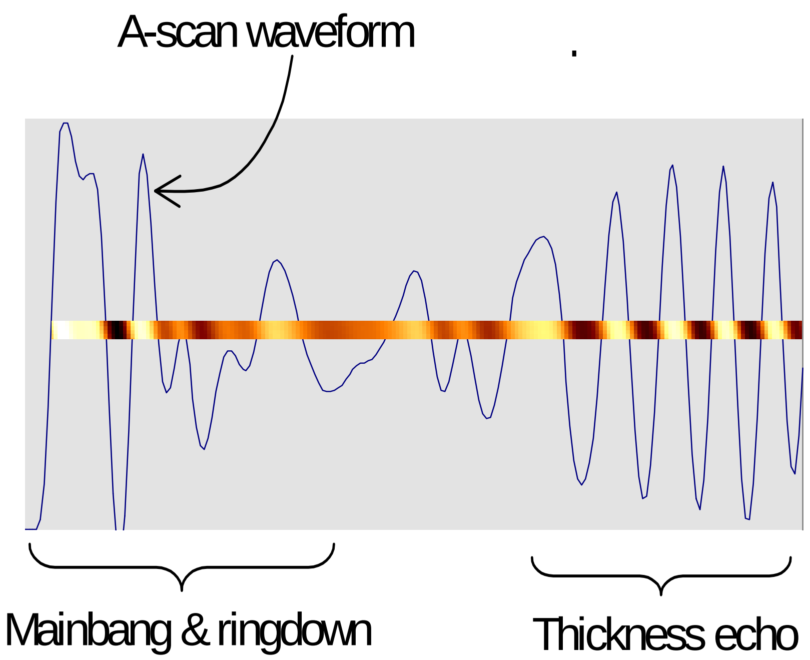
Flight Vehicle
Nosetip Recession Gage

Nosetip recession measured acoustically



Flight Vehicle
Nosetip Recession Gage

Sample Waveform:

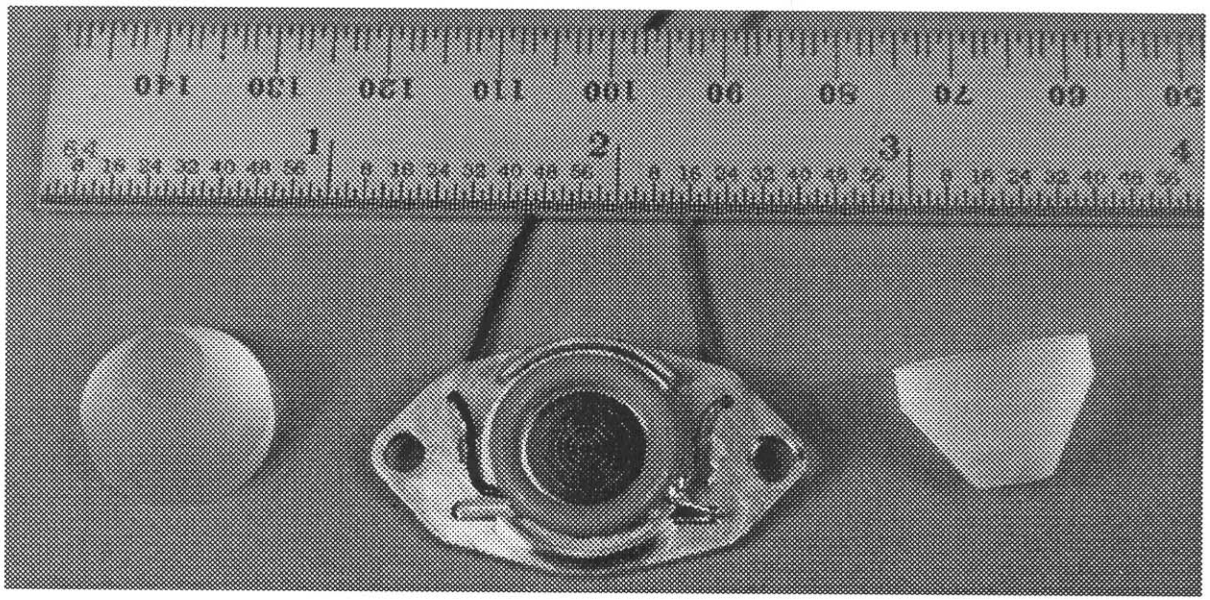


Flight Vehicle
Photodiode Transition Indicator

- **Photodiode Transition Indicator**
  - Optical technique for determining boundary layer transition
  - Photodiode mounted beneath a transparent quartz window
  - Voltage across a resistor used as the photodiode “signal”
  - Technique would require additional development to be used again

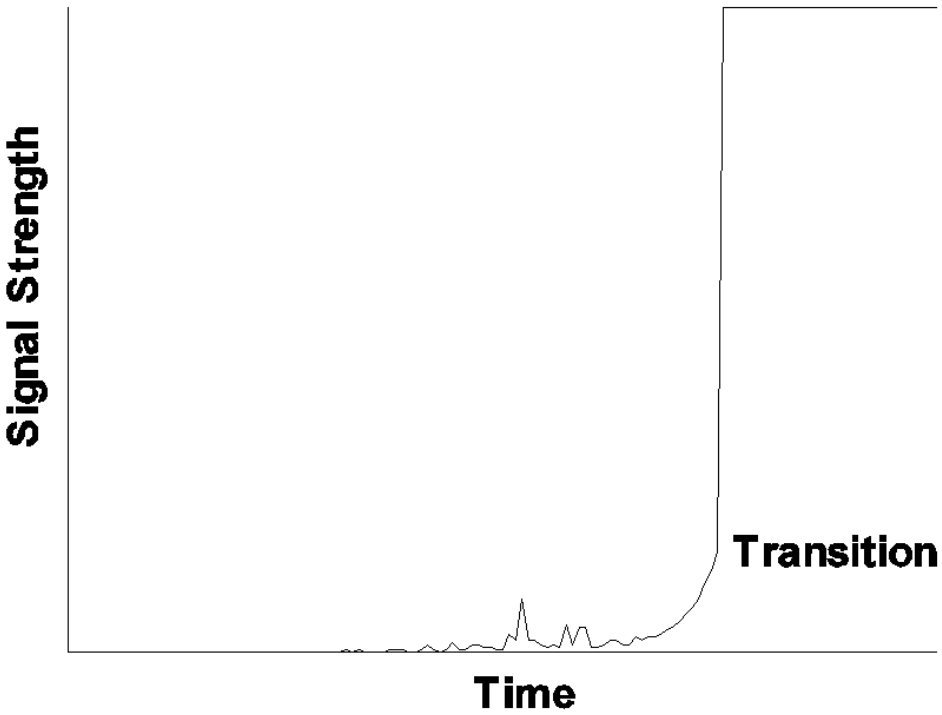
Flight Vehicle
Photodiode Transition Indicator

- **Photodiode Transition Indicator Hardware**



Flight Vehicle
Photodiode Transition Indicator

- **Sample Flight Data**



Summary

- **Sandia has extensive hypersonic and reentry vehicle flight testing experience**

- **Analysis capabilities exist which cover nearly all aspects of vehicle aerothermal performance**

- **Sandia has developed and worked with numerous types of flight vehicle instrumentation for measuring aerothermal characteristics during flight**