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

- 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]
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
• 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
Noetip 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 °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
Flight Vehicle
Thermocouple Plug

Thermocouple Design:

All Dimensions in Inches

- T/C Junction
- Boron Nitride Potting
- T/C Wire, 0.0007 Dia
- Quartz Double Bore Tubing, 0.003 OD
- Tantalum Sheath, 0.008 OD
- Ceramic Potting
- Compensated Lead Wire
Flight Vehicle Thermocouple Plug

Installation:
- Heatshield Material
- Insulation
- Substructure
- T/C Plug
Flight Vehicle
Thermocouple Plug

- Sample Flight Data

![Graph showing temperature over time for different measurements and calculations.]

- Measurement, 0.025 in.
- Measurement, 0.100 in.
- Calculation, 0.025 in.
- Calculation, 0.100 in.
Flight Vehicle
Nose tip 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
Nose tip Recession Gage

Nose tip recession measured acoustically
Flight Vehicle
Nose tip Recession Gage

Sample Waveform:

A-scan waveform

Mainbang & ringdown

Thickness echo
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