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Aerothermal Modeling Plans for SIERRA Mechanics

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC-04-94AL85000.

Motivation for Current Work

- Hypersonic Aerodynamics/Aerothermodynamics
  - Aerodynamic forces and moments
  - Heat transfer
- Ablative thermal protection systems
  - Surface material removal to reduce overall heat load
  - Shape change is usually significant
- Ablation depends on:
  - Initial vehicle shape -- aerodynamics
  - Material for thermal protection system -- aerothermodynamics
  - Flight environment -- trajectory

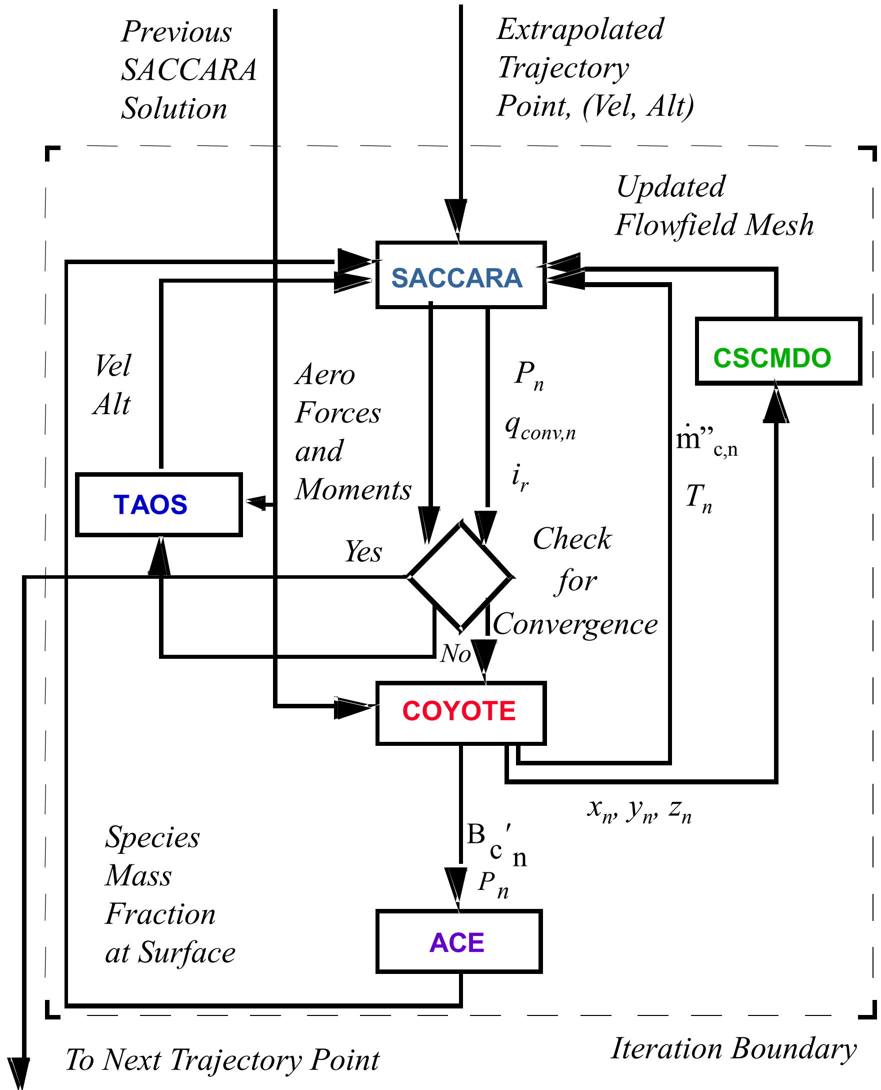
In general, the above effects are not separable and are usually tightly coupled

Background

- Historically, ablation prediction and coupling mechanisms have taken many forms
  - Engineering methods -- “simple” geometries
    - “Cold wall” inviscid/boundary layer techniques
    - 1-D or 2-D material thermal response hot wall corrections
  - High fidelity methods -- “complex” geometries
    - “Hot wall” flow field predictions (VSL, PNS, Full NS)
    - Coupled, multi-dimensional material thermal response with energy and mass transfer (with and without shape change)

- Ablation is frequently computed independent of the trajectory
  - The trajectory in many cases is determined a priori
  - Shape change and ablation chemistry effects are not accounted for in the aerodynamics or trajectory analysis

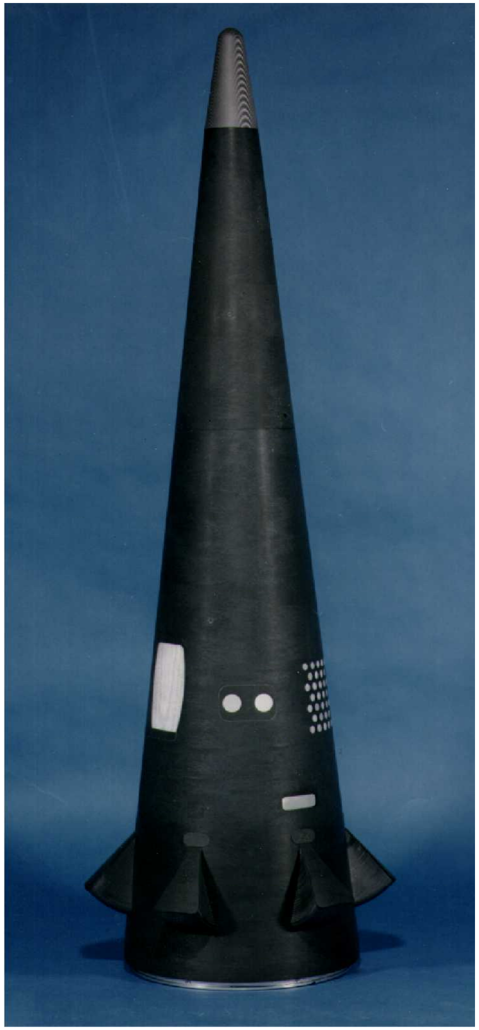
SACCARA / COYOTE / TAOS -- Iterative Aero/Thermal Coupling

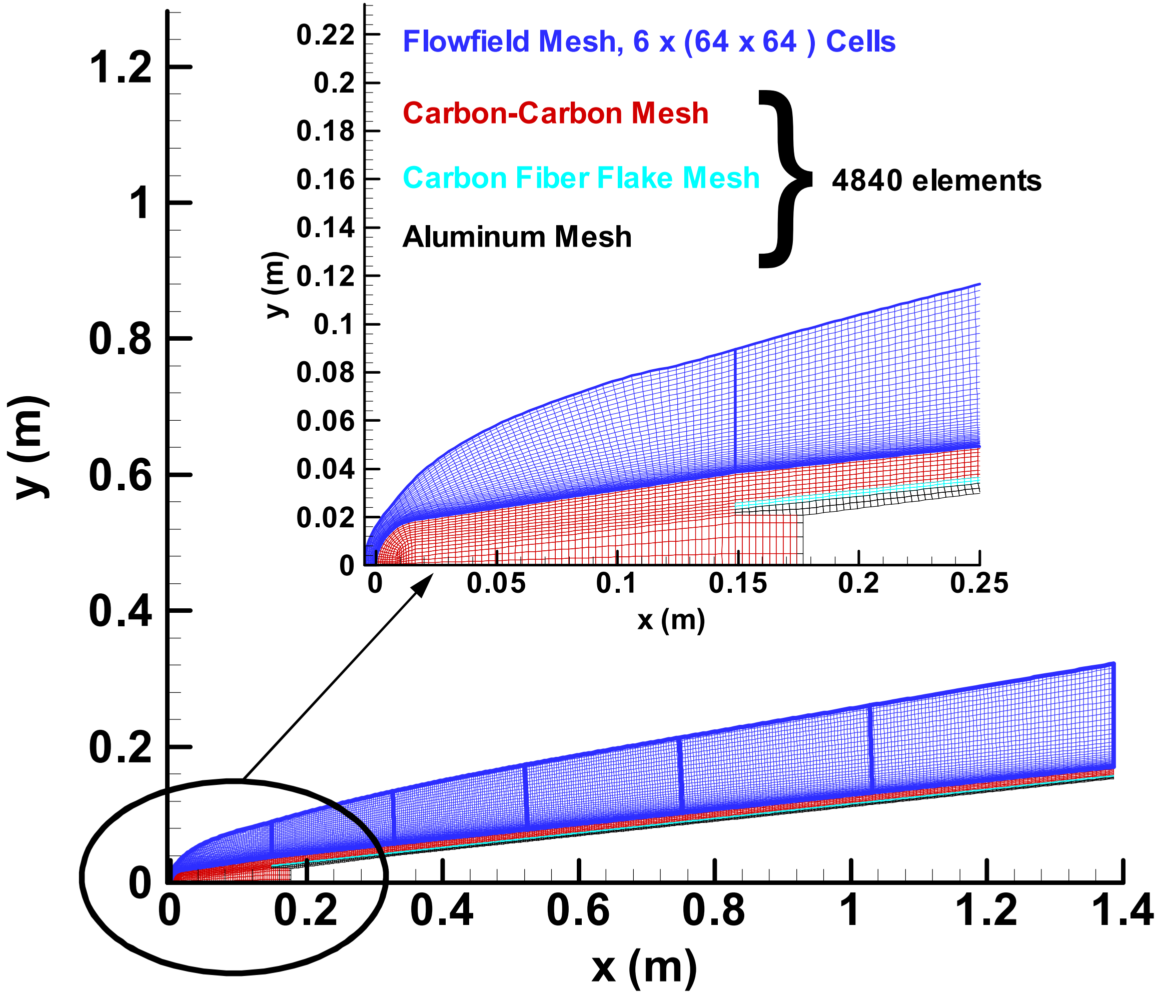


SACCARA / *COYOTE* / TAOS -- Iterative Aero/Thermal Coupling

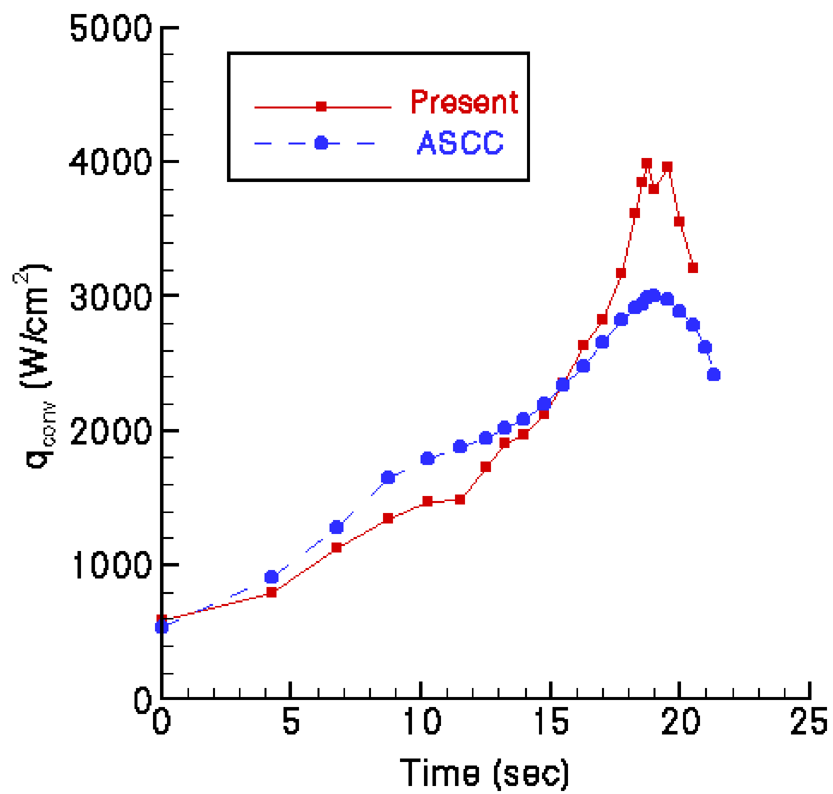
- User chooses initial trajectory point and time intervals
- Extrapolation initially used to estimate surface properties and aerodynamic coefficients at Trajectory Point n+1
- *COYOTE* and *TAOS* integrated in time from Trajectory Point n to n+1, assuming linearly varying properties from *SACCARA*
  - heat transfer, pressure, recovery enthalpy for *COYOTE*
  - aerodynamic coefficients for *TAOS*
- Updated properties from *COYOTE* and *TAOS* at Trajectory Point n+1 used as boundary conditions for *SACCARA*
  - surface shape, temperature, mass flux, and mass fractions from *COYOTE*
  - altitude and freestream velocity from *TAOS*
- Iteration continued until surface properties and aerodynamic coefficients converge to less than 1% difference

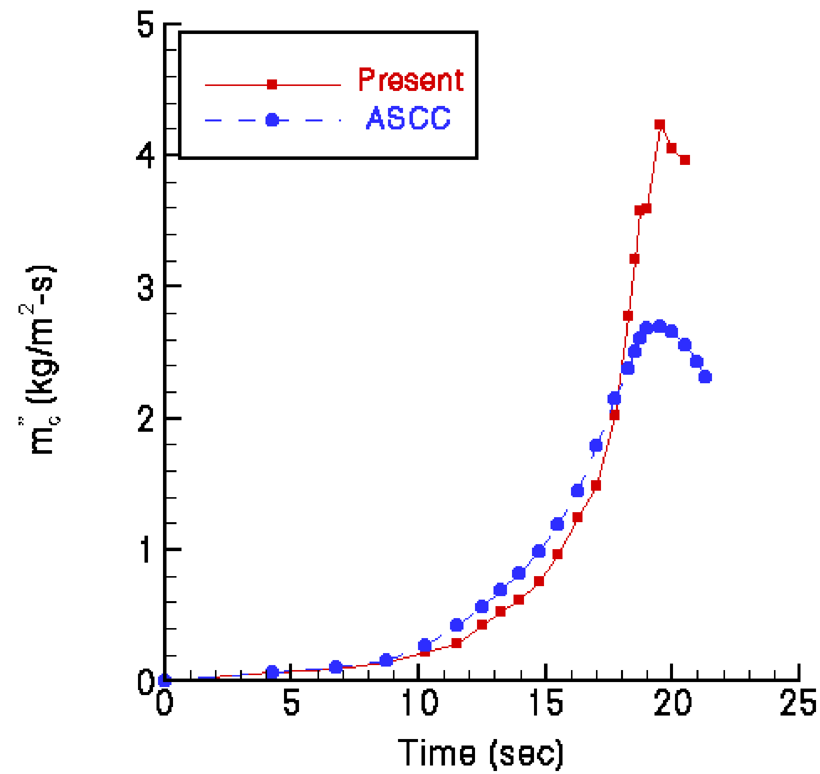
IRV-2 Vehicle and Numerical Meshes





SACCARA / COYOTE
-- Stagnation Point Results





SACCARA / COYOTE
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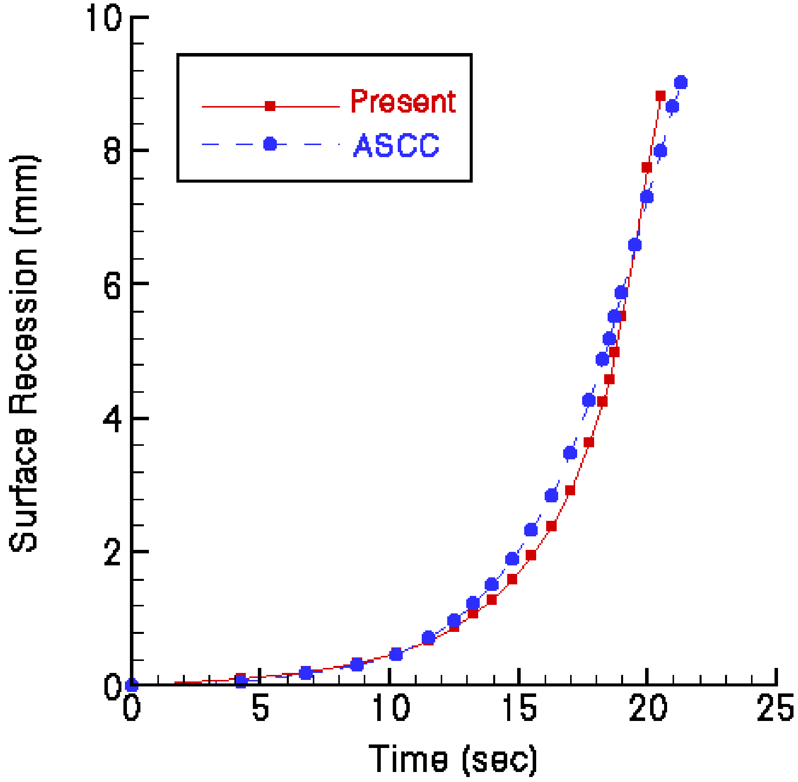
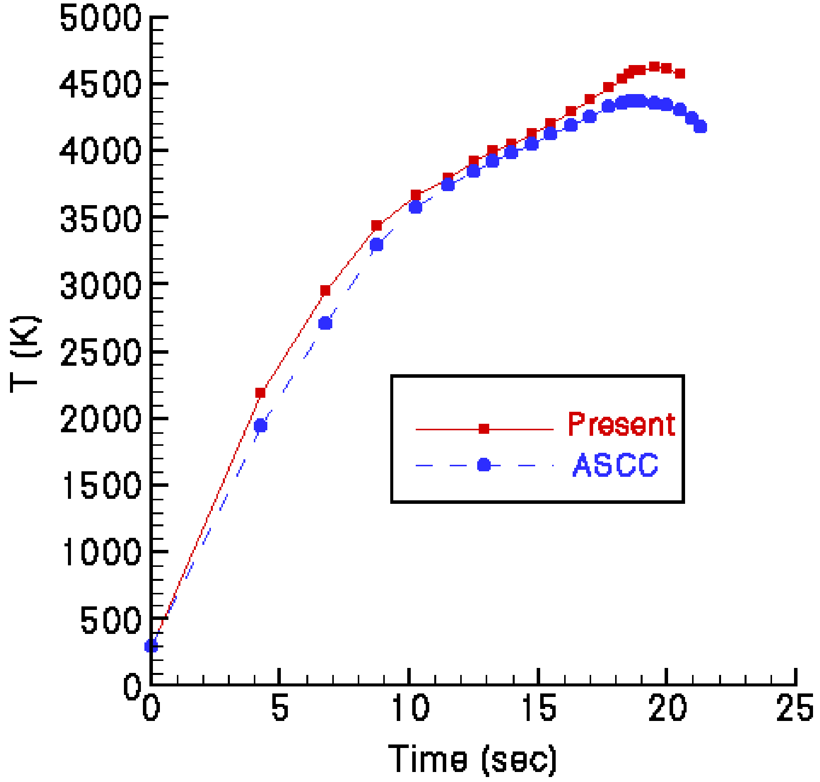
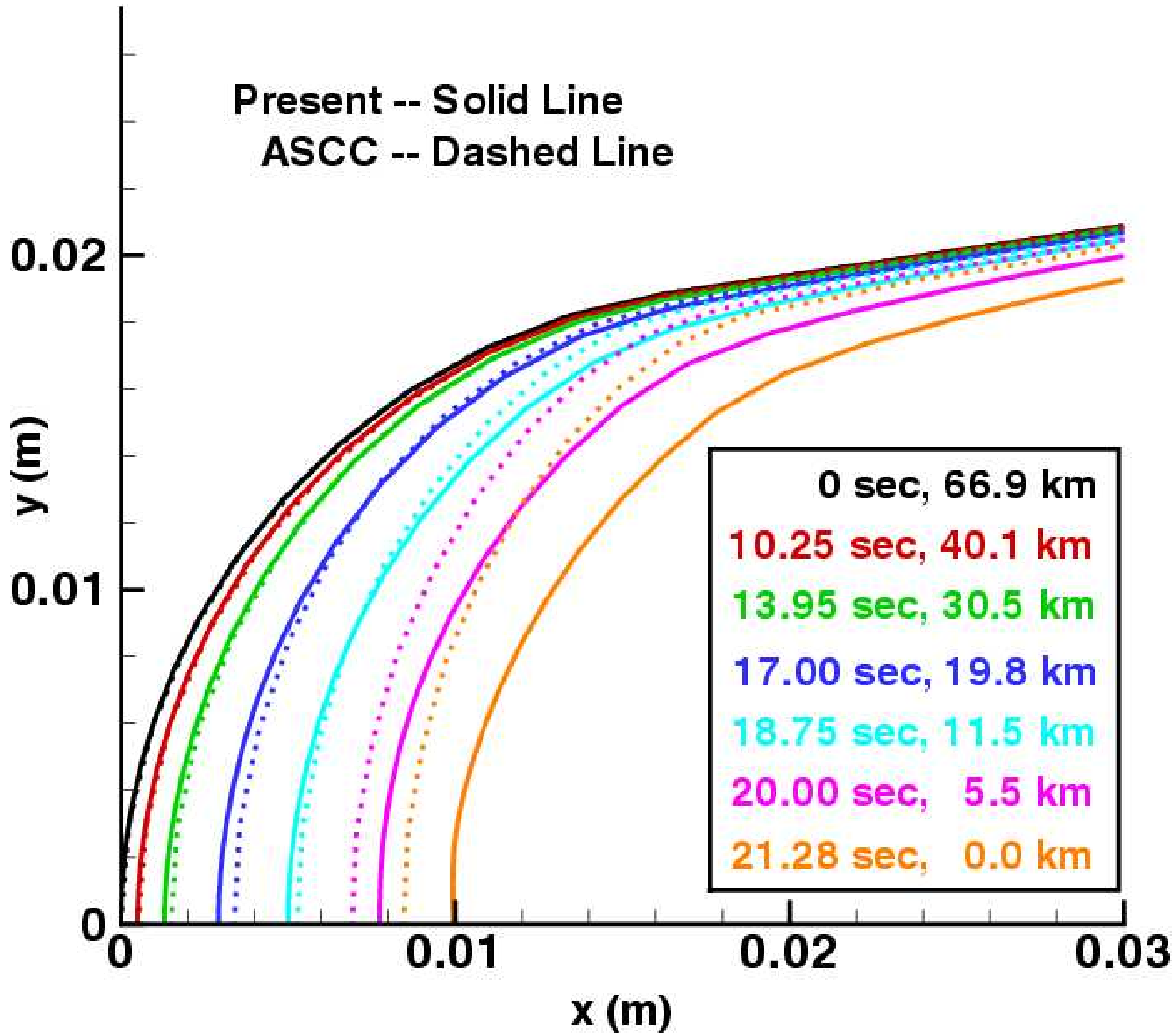
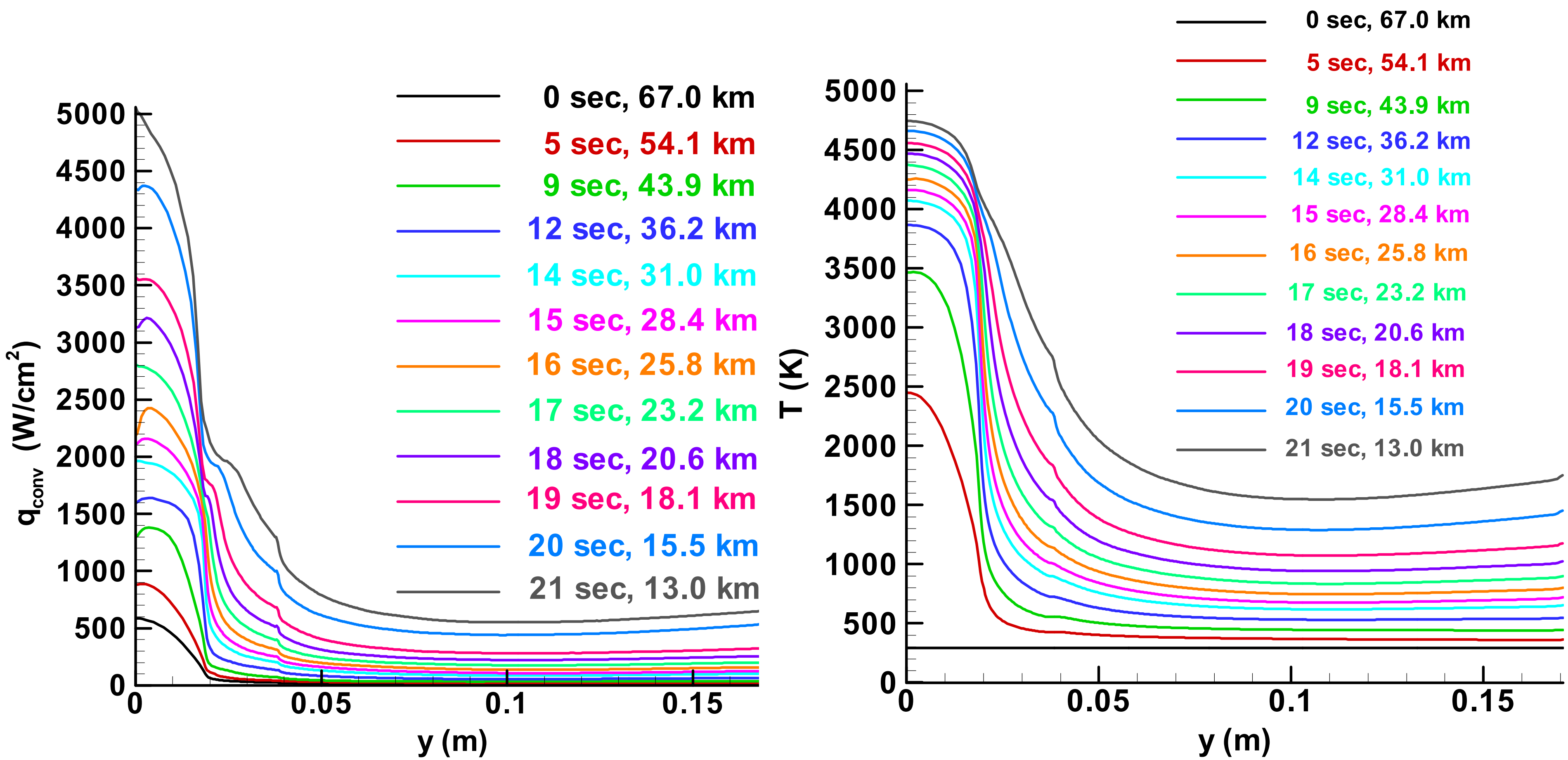




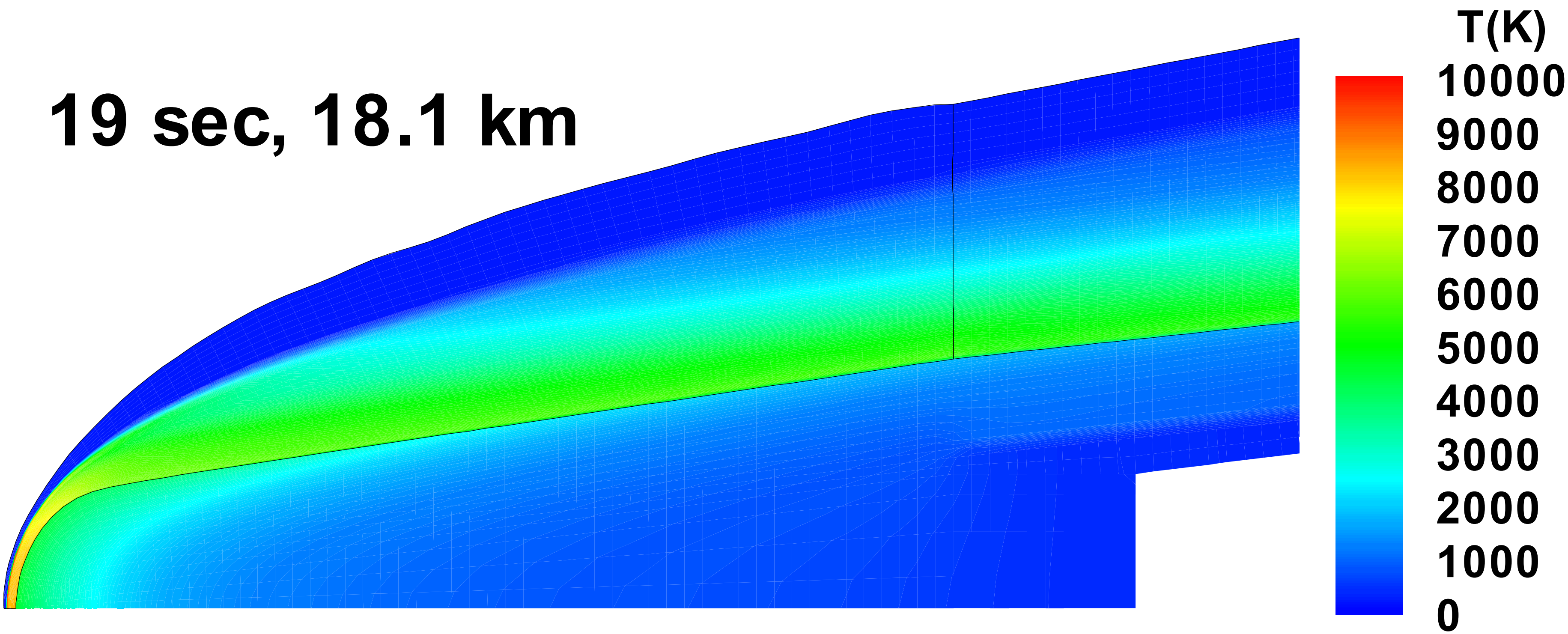
SACCARA / COYOTE -- Shape Comparison



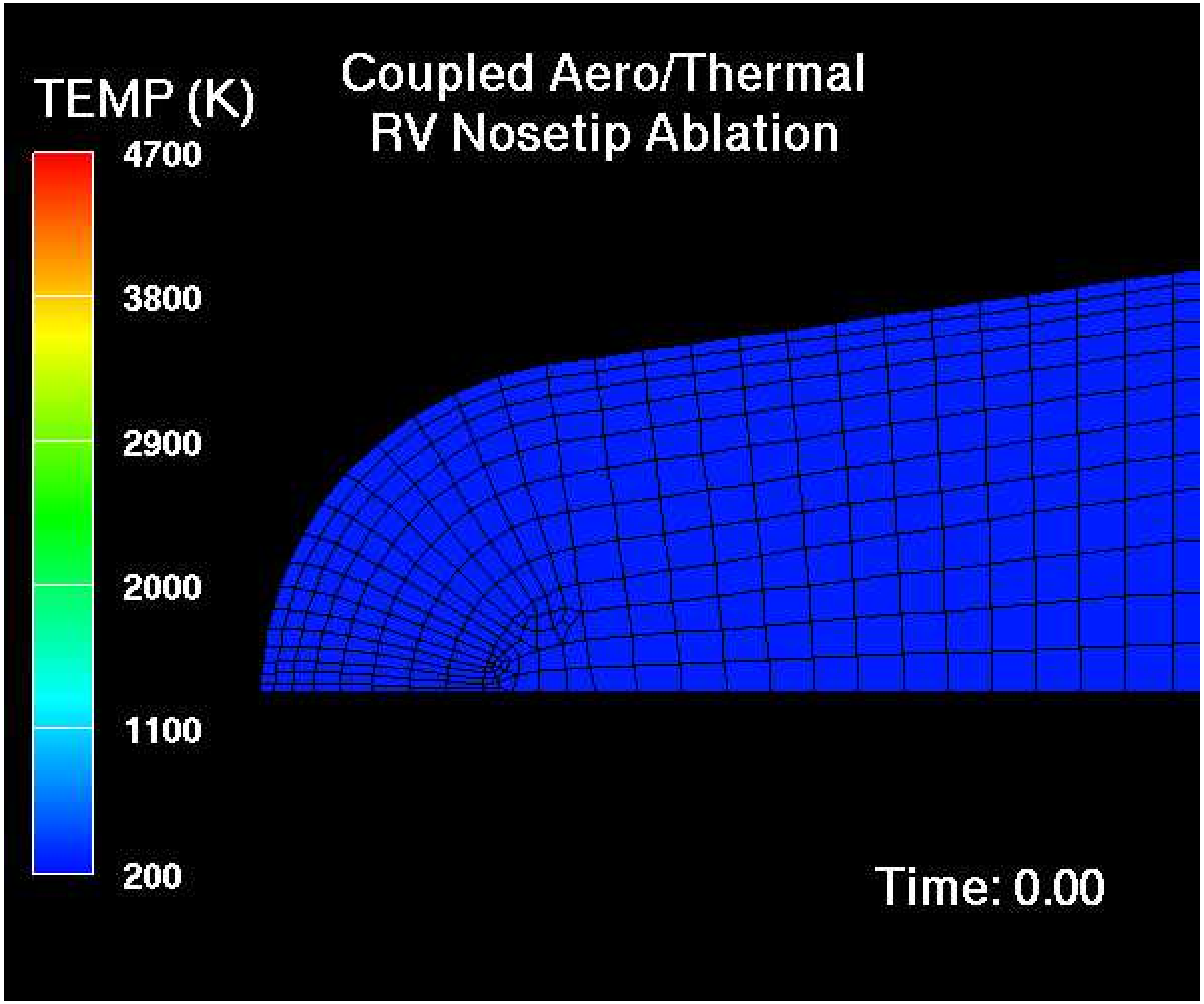
SACCARA / COYOTE / TAOS -- Heating and Temperature Profiles



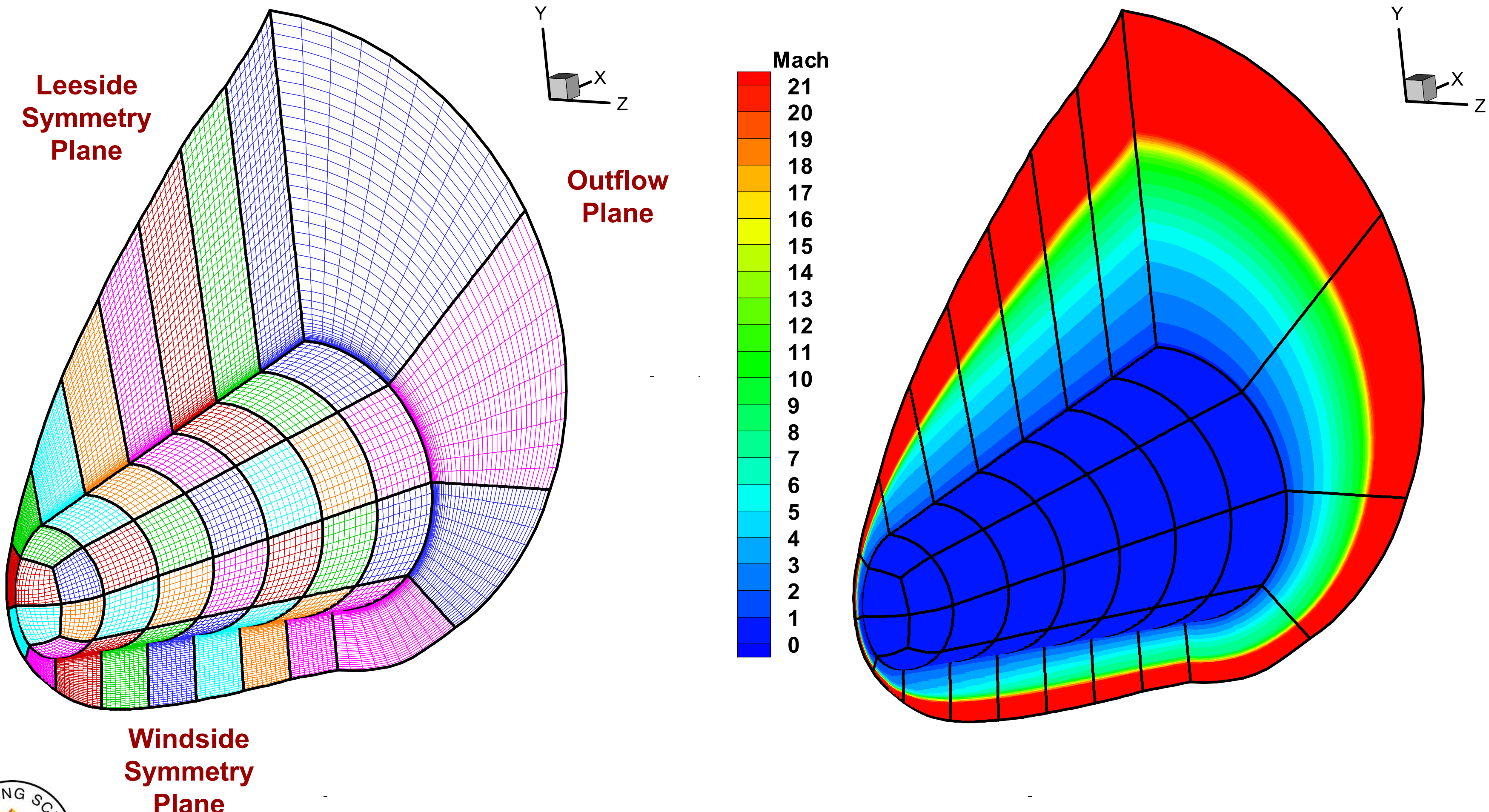
SACCARA / COYOTE / TAOS
-- Flow field and Solid Temperatures



Coupled Aero/Thermal Reentry -- Nosetip Ablation Demonstration

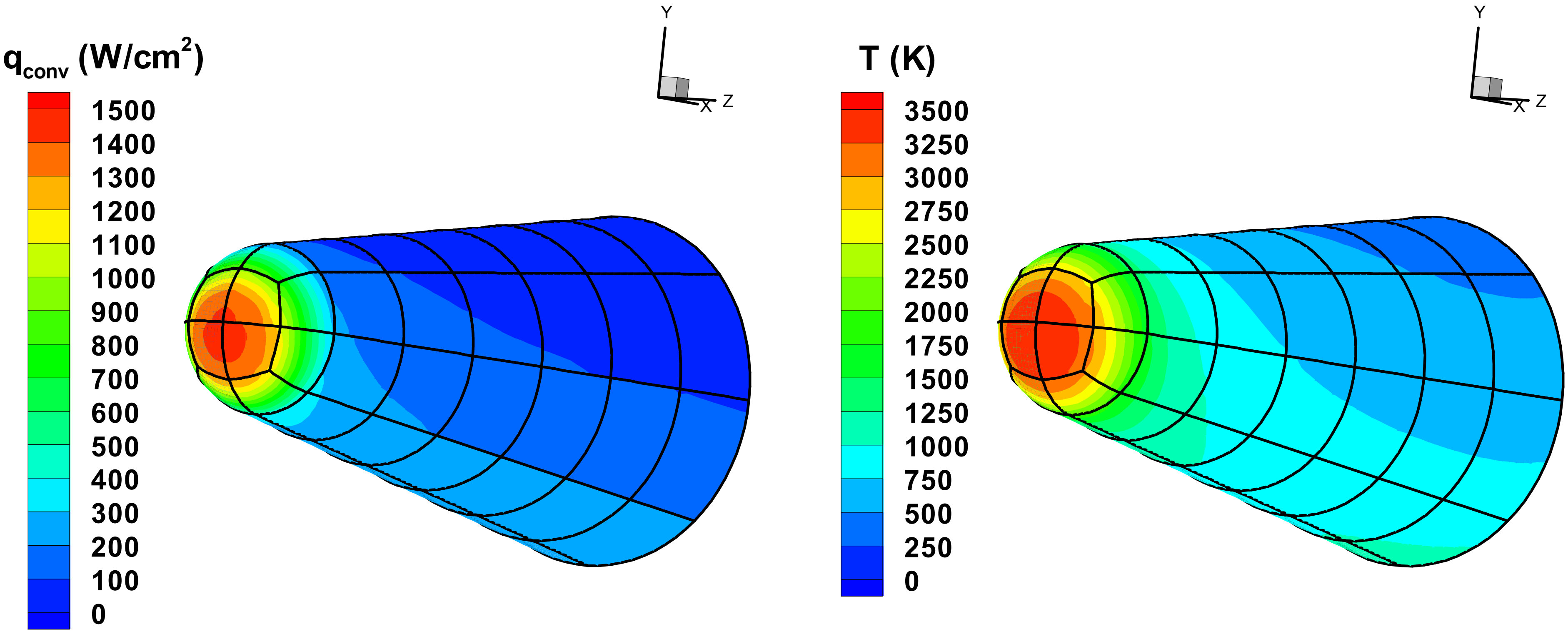


3-D Ablation
-- Initial Nosetip Mesh and Mach Contours



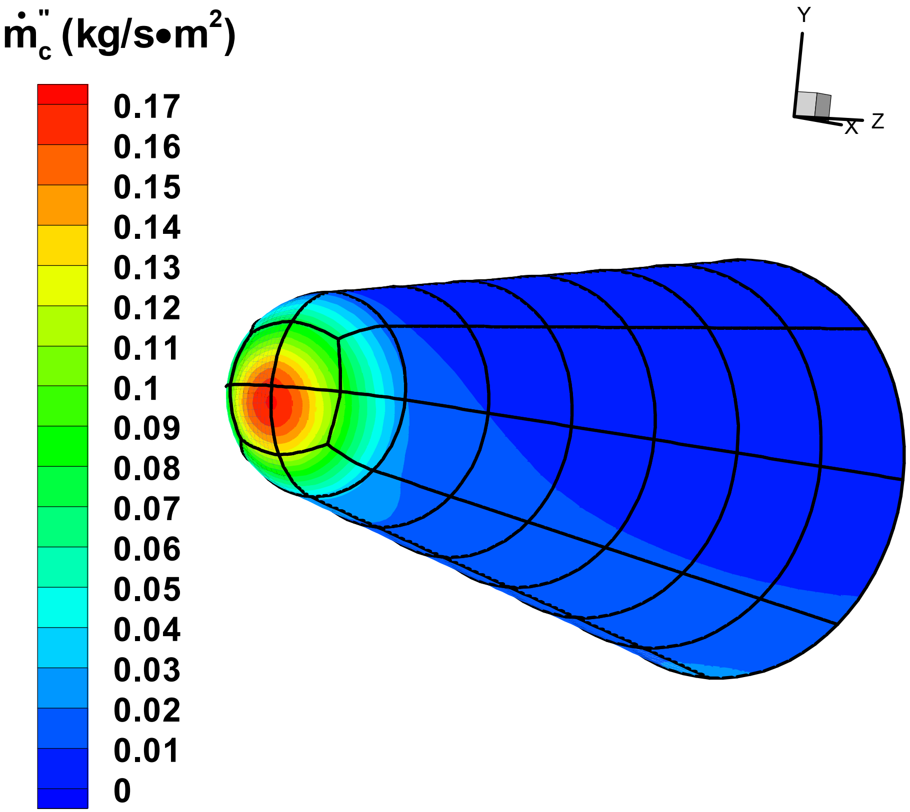
Time = 0 sec, Altitude = 67.0 km, AoA = 10 deg

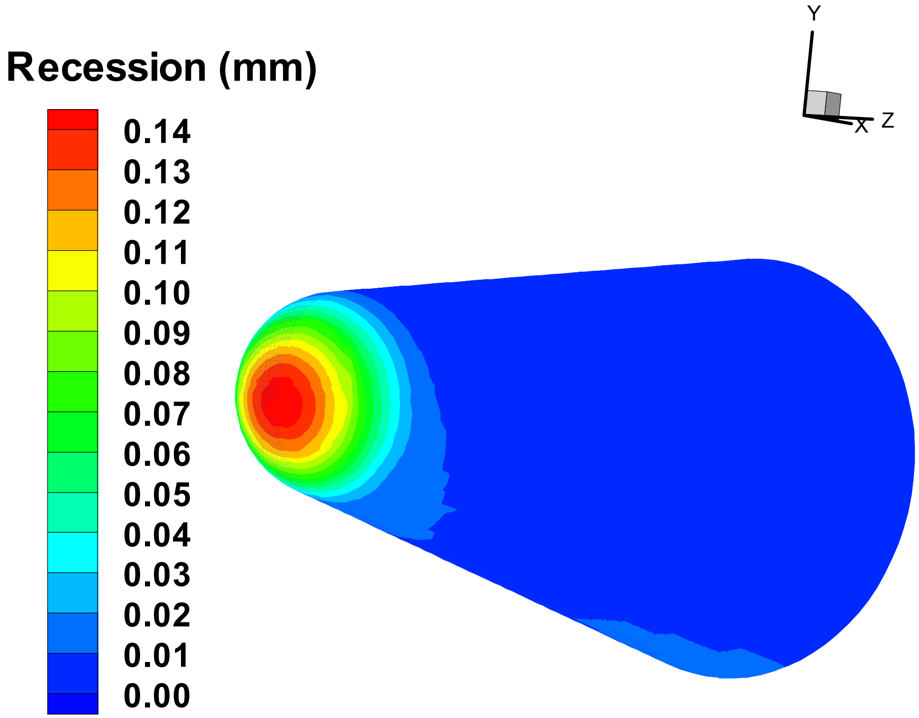
3-D Ablation
-- Surface Heat Flux and Temperature



Time = 9 sec, Altitude = 43.9 km, AoA = 10 deg

3-D Ablation
-- Surface Mass Flux and Recession





Time = 9 sec, Altitude = 43.9 km, AoA = 10 deg

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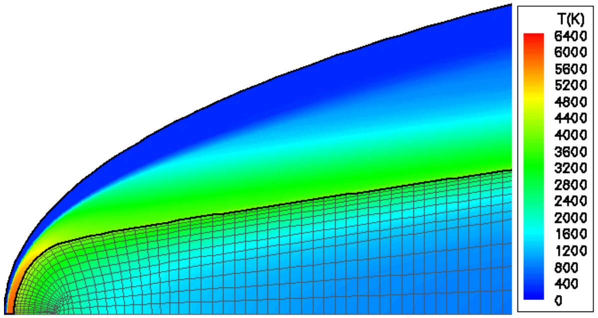
Ablation development plan

- SNL is developing a high Mach number computational aero capability under ASC in SIERRA
- This module (Aria) will be combined with the thermal analysis module to enable simulation of aerothermal reentry applications
- Current status:
  - Euler equations
  - Finite rate chemistry
  - Laminar Navier-Stokes
  - 2nd order spatial discretization
  - 1st and 2nd order time discretization



Ablation development plan

- Short-term development list (FY09)
  - Implement general chemical kinetics for air
  - Implement finite rate chemistry for Navier-Stokes
  - Surface energy balance: assume heat and mass transfer coefficients are equal
  - Conjugate heat transfer: pass surface flux to thermal and receive wall temperature back to fluids module
  - Blowing wall boundary condition with surface chemistry – ablation products will react with flow species
  - Turbulence model implementation

Ablation development plan

- Longer-term development list (FY10)
  - More sophisticated surface energy balance
  - Moving surface mesh via ALE
    - smoothing algorithm in solid to prevent tangling