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Integration of Aeroheating and Thermal Protection System Simulation with Thermal Desktop

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August 2006

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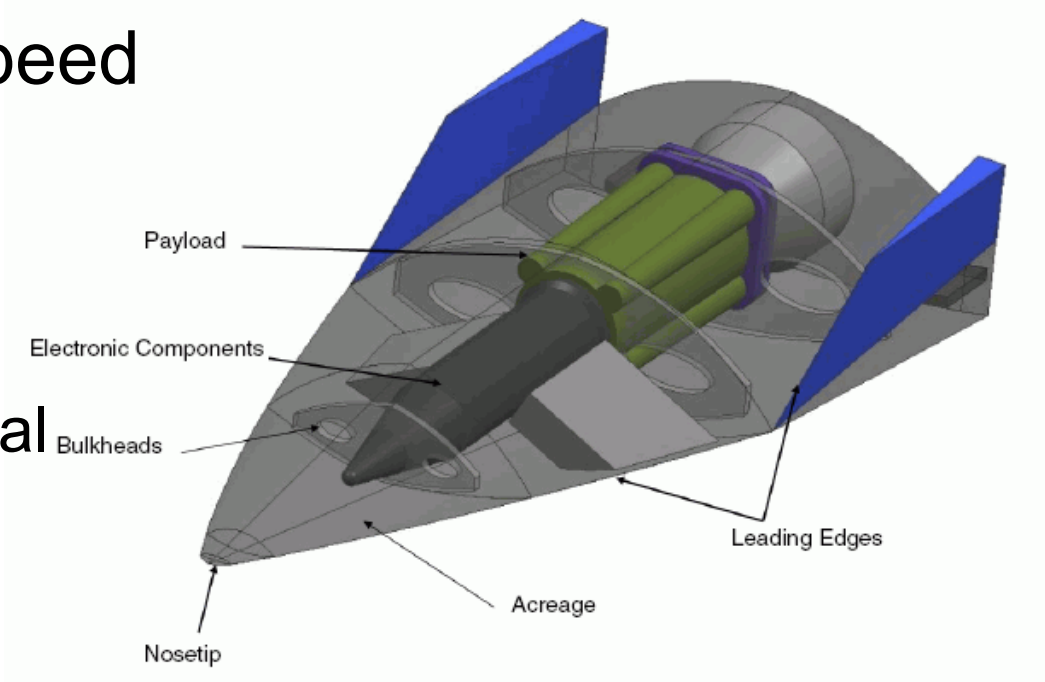
Background

- Complex physics of analyzing high speed vehicles
  - Aerothermal
  - TPS
  - Thermal/Structural Response



Background (cont.)

- Aerothermal Calculations
  - Full CFD Approach: Great for the inviscid flow field
    - Able to handle complex vehicles and angles of attack
    - Must include empiricisms at the wall to avoid excessive meshing
    - Intractable for transients or even many design points
    - Not of interest to CFD vendors: government-developed codes only
  - Engineering Method: Great for the boundary layer
    - Good speed and accuracy if used appropriately
    - Difficult to include complex vehicles, detached leeward side flows

Background (cont.)

- TPS Response Simulations
  - Complex physics for charring ablators but (except for nose and leading edges) 1D simulation is adequate

Background (cont.)

- Thermal/Structural Response Simulations
  - Requires detailed geometry (CAD integration), and communication with structural analyzers
    - Thermal Desktop is widely used for this today

The Generic Problem: *Any* High Speed Vehicle

- Lack of standard tool set
  - CMA and its derivatives are the preferred tools for charring TPS simulations, but does not have widespread commercial deployment
  - Thermal Desktop (TD) is a standard thermal analyzer for spacecraft and launch vehicles
  - *However, no consensus exists on "the right tool" for aerothermal calculations*
- Little to no integration of tools exists
  - TPS *sometimes* integrated into engineering aerothermal codes (ATAC, Miniver)
  - Coarse TPS *sometimes* integrated into thermal codes
  - Specialists in different disciplines are not cooperative: they don't want nonspecialists doing their job and are protective of their own tools/methods
- The result: haphazard collection of in-house tools and limited or labor-intensive methods
  - Being one of the few commercial sources in this field, C&R
    - has been approached repeatedly by agencies (chiefly NASA, Lockheed Martin, Raytheon) seeking improvements
    - has been investigating the problem for several years but (until now) hasn't found a viable starting point

The Specific Problem: Trajectory Shaping Vehicles

- Complex Vehicles
  - Lack of axisymmetry challenges some ATAC assumptions
  - Simple single-point sizing methods for TPS are less appropriate
- Long Missions and Soak Times
  - The entire trajectory needs to be analyzed transiently
    - In reality, *many* such trajectories and scenarios will need to be evaluated for sizing TPS (even for fixed material systems)
  - Vehicle-level analyses are required
    - Also required: appropriate local detail to specific sensors and other vulnerable hardware
- The upshot: current design technology is inappropriate
  - Simulations must not only be integrated, they must be *fast*

Our Solution, Part 0

- Cullimore And Ring Technologies teamed with ITT (Huntsville AL) and Zona Technology (Scottsdale AZ) to produce the following solution to the previously presented problems.
  - This solution is being funded under Air Force SBIR funds (Contract Number FA940106P0129). Phase II work has just begun in June 2006.
  - Initial beta release will be approximately June 2007

Our Solution, Part I

- Part I: The Aerothermal Problem
  - How do we analyze complex vehicles in transients with the fast solution speeds needed for sizing or sensitivity perturbations?

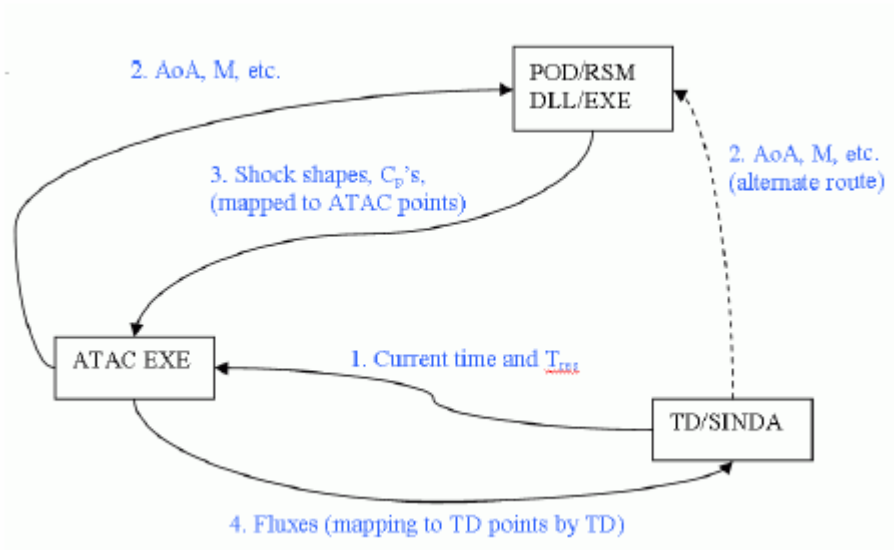
1. Run a limited set of CFD cases for various speeds, angles
   - Only fast-to-solve inviscid solutions needed, using CFL3D (e.g.)
   - This step is optional for first-order preliminary design: skip to #3
2. Use Zona's POD/RSM technology to intelligently interpolate in order to generate a full trajectory
   - No need to rerun CFD cases for moderate trajectory changes
3. Inject these pressure coefficients into ITT's ATAC as C_p's
   - Use CFD for the "far field" solution
   - Use ATAC for the "near field" solution*, including integrated TPS response*

Our Solution, Part II

- Part II: Aerothermal/Thermal Integration Problem
  - How do we couple the aero/TPS solution to the thermal/structural response?
  - This is traditionally attempted at the outer (ablating) surface
    - The TPS simulation is integrated into the thermal analyzer
    - interpolations or iterations are required to handle uncertainties in surface temperature implicitly
- Instead, we will close at the inner (bond line) surface
  - Aero/TPS integration is already handled within ATAC, and this is a more natural location due to the complexity of interactions while ablating (especially with catalytic effects). ATAC/CMA results are only weakly sensitive to changes in “reservoir” temperature.
  - Communications are simple at the bond line: fluxes and temperatures

Our Solution, Part II (Cont'd)

1. Use Thermal Desktop as the ATAC model builder
   - This has the commercially synergistic advantage of providing ATAC with a CAD-based GUI
2. Run all 3 codes as an integrated product



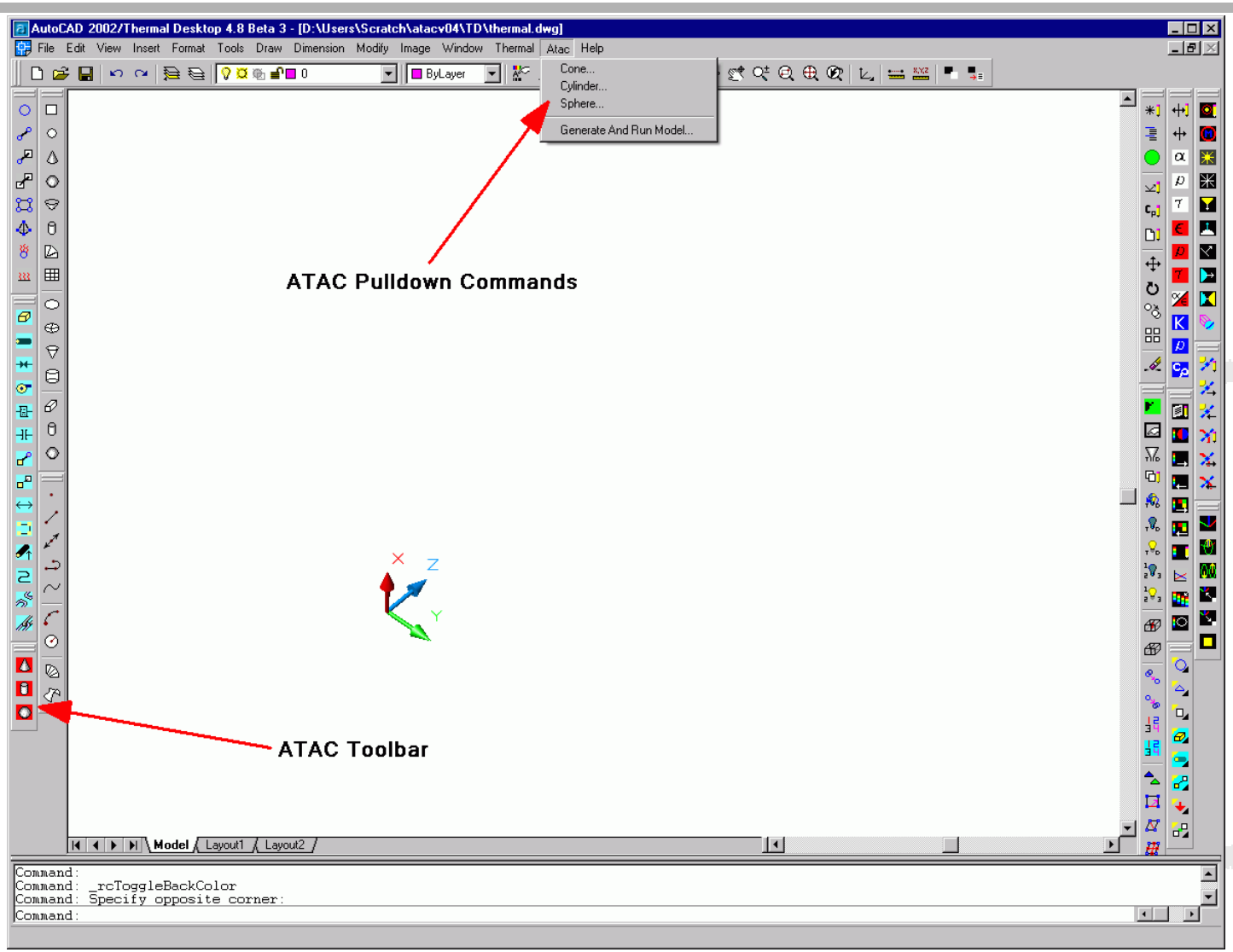
Result of this integration

- AeroTPS
  - Integrated product using Thermal Desktop, ATAC, and POD/RMS

Phase I Demonstration

- Simple Axisymmetric Vehicle (RV)
  - Allows ATAC-only analysis
  - Keeps TD improvements within scope
    - TPS definitions such as thermochemistry likely to be limited to file import
  - CFD-corrected solution (via POD/RSM method) will be prototyped, compared with ATAC-only method
  - Methods for including catalytic effects will be investigated
- Objectives
  - Verify validity of approach
  - Identify deficiencies to influence Phase II plans
  - Provide a useful tool in its own right

ATAC Interface



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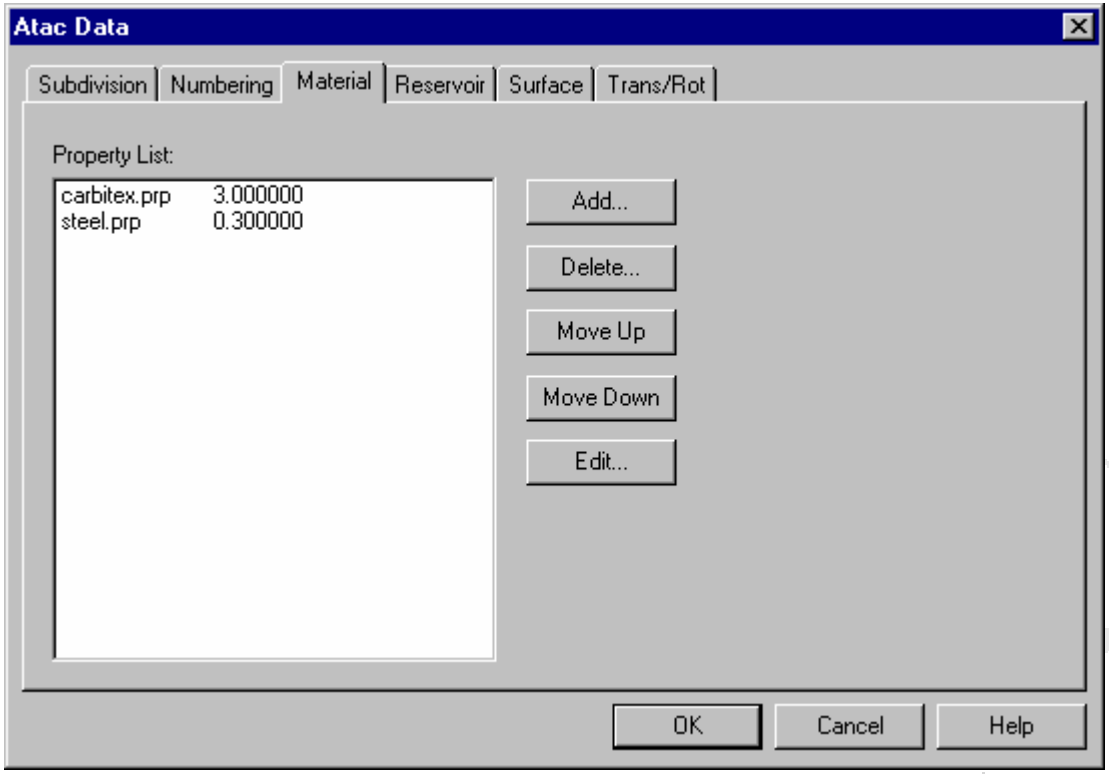
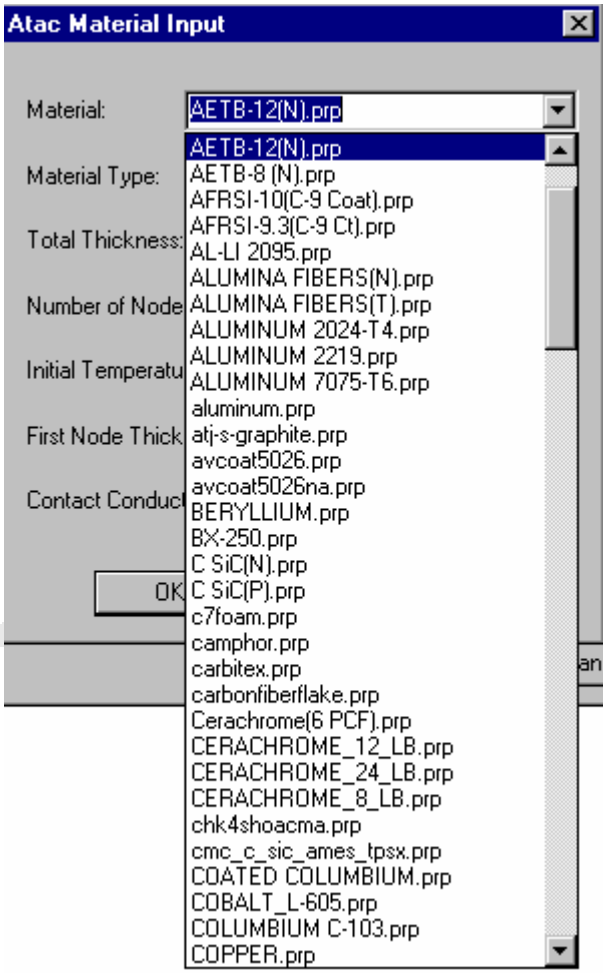
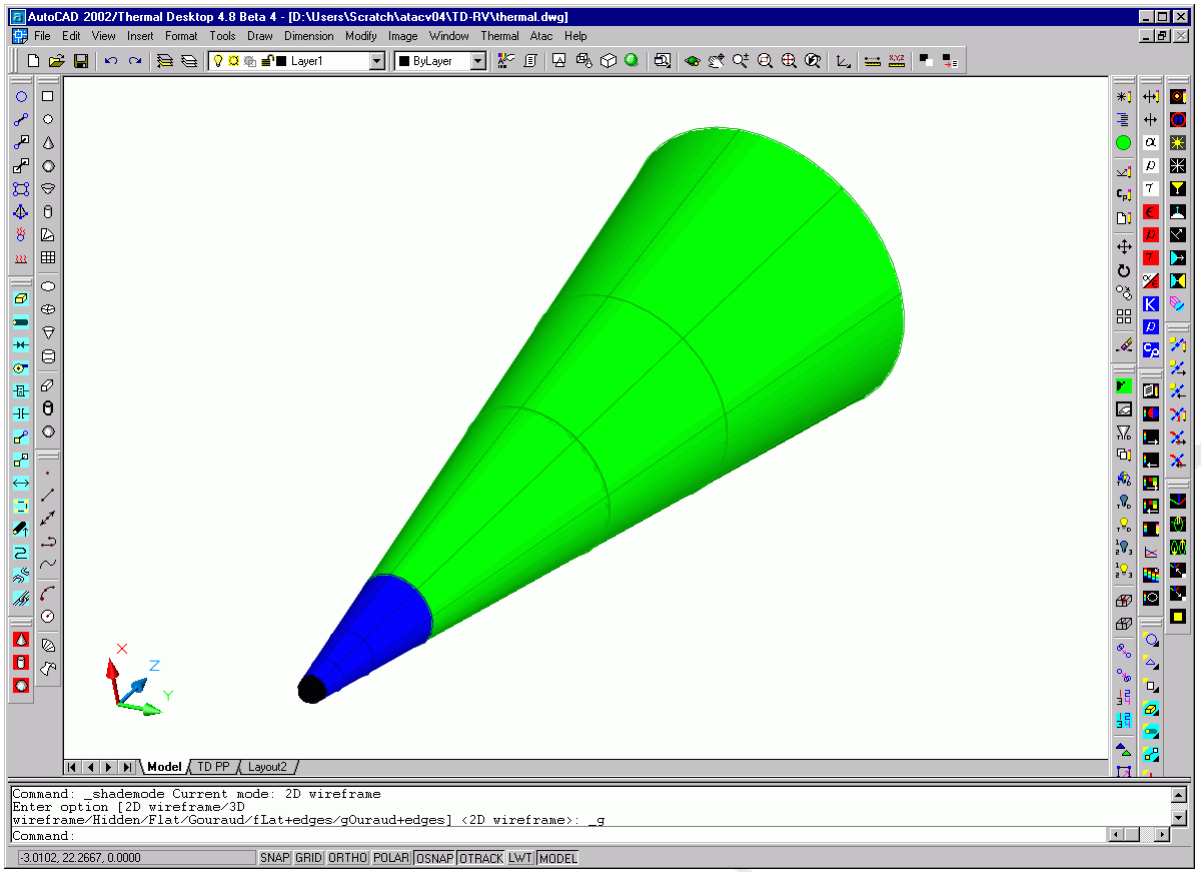
ATAC Interface





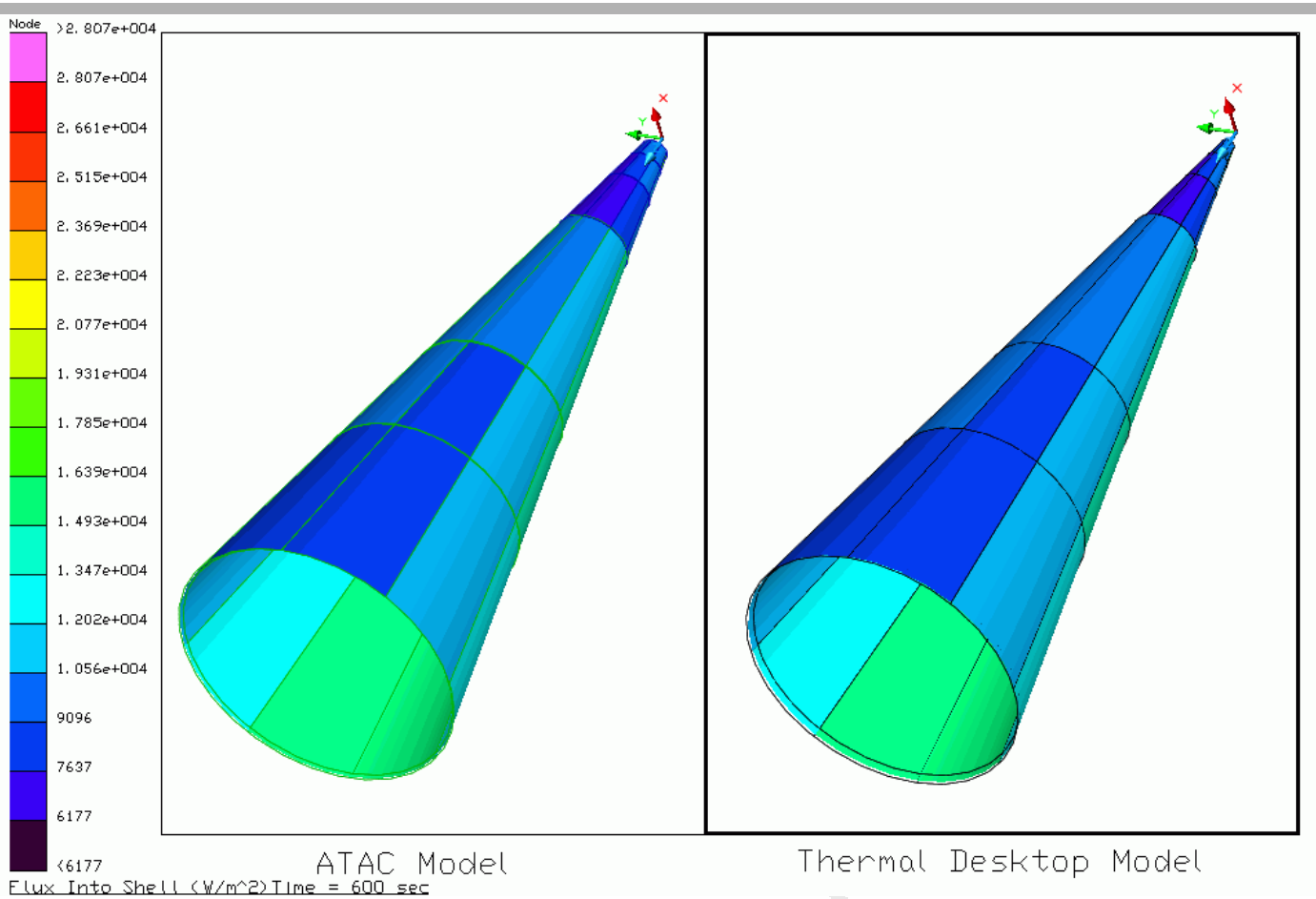
ATAC entity properties

ATAC Interface



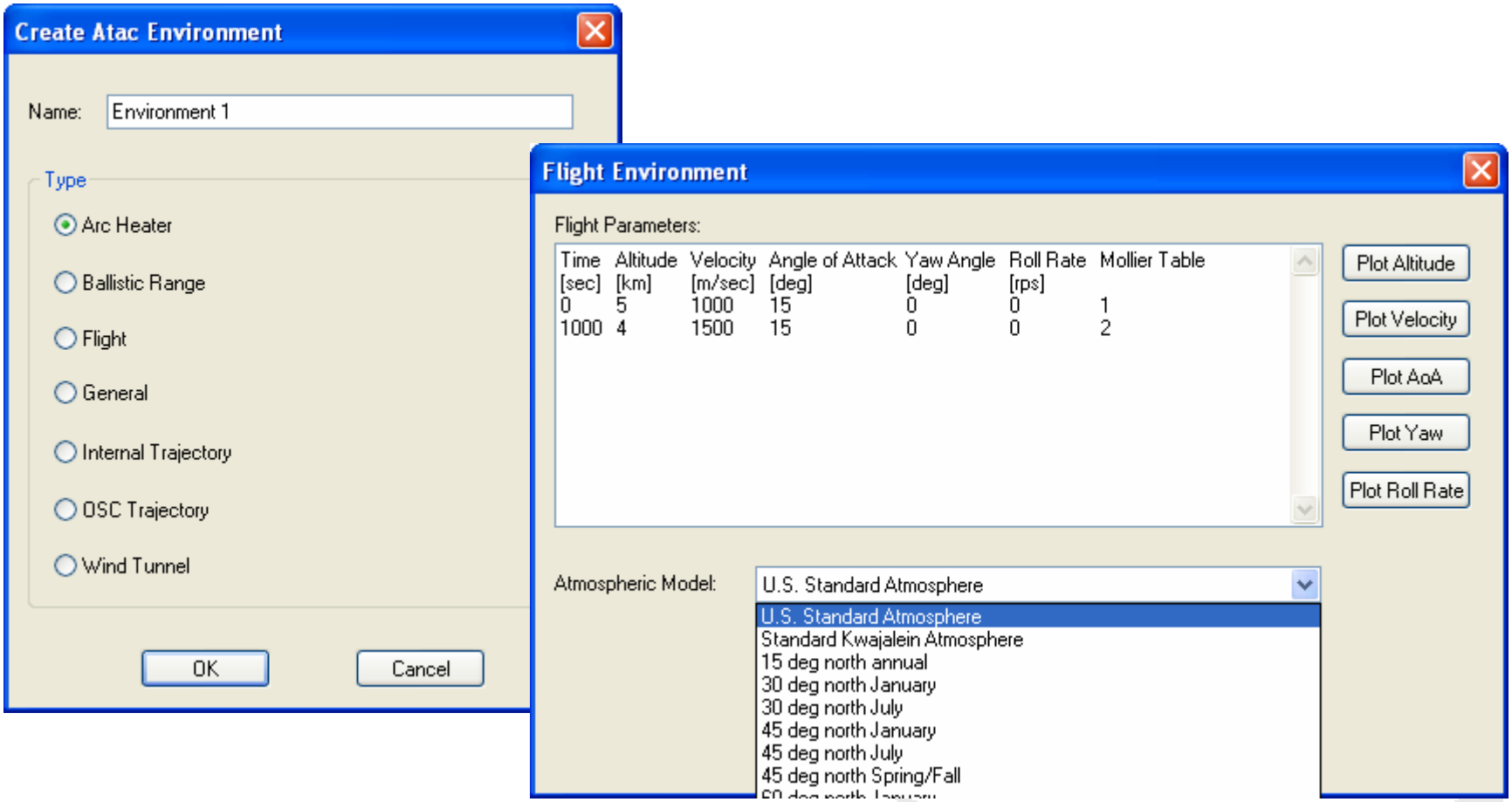
Simple ATAC Model inside of Thermal Desktop using ATAC Sphere and Cone Objects

ATAC Interface



Flux at bondline from ATAC model mapped onto TD model.

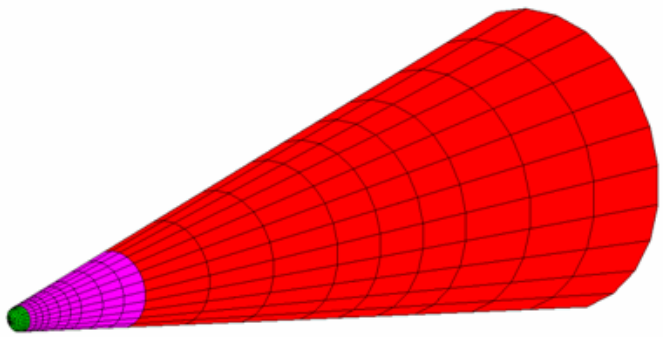
ATAC Interface

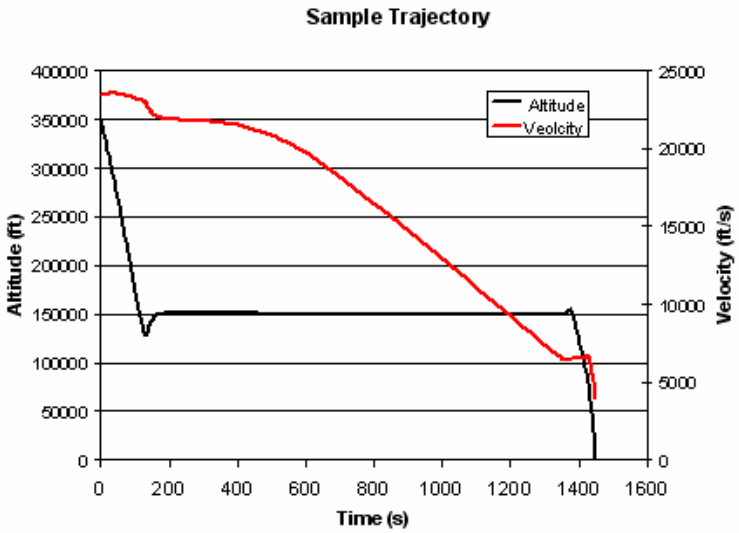


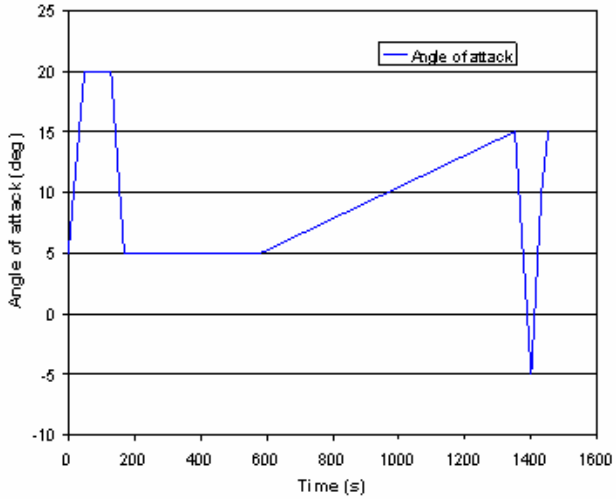
ATAC environment input forms

Phase I Sample Model

- Sphere cone configuration
  - Rn = 1.5 inches
  - Theta = 10 deg
  - Length = 100 inches
  - Graphite nosetip
  - Carbon phenolic heat shield
- Trajectory simulates TSV flight

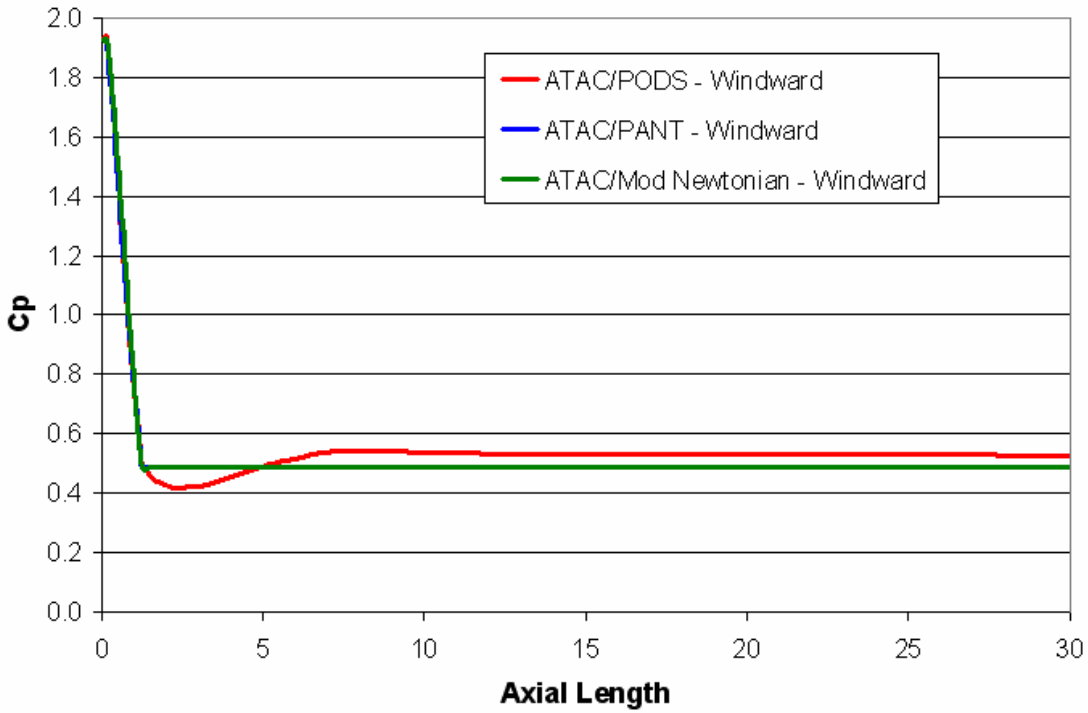






Phase I Sample Model ATAC Results

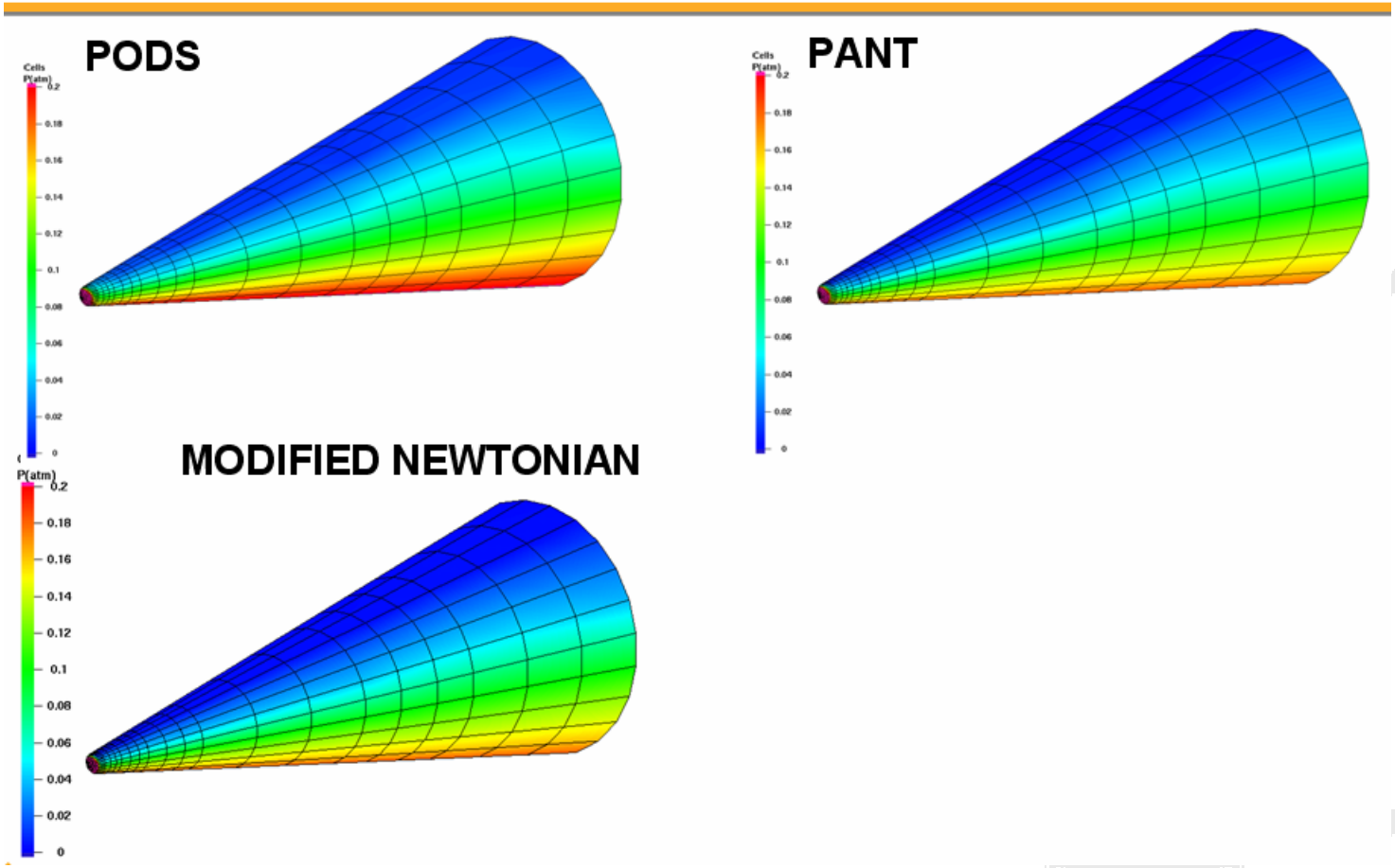
Windward Surface Pressures for α=20



PODS-Full CFD Solution
PANT and Modified Newtonian are internal ATAC solutions

Phase I Sample Model ATAC Results

Heat shield Pressure, t=150 sec



Phase I Sample Model
Thermal Desktop/SINDA Results

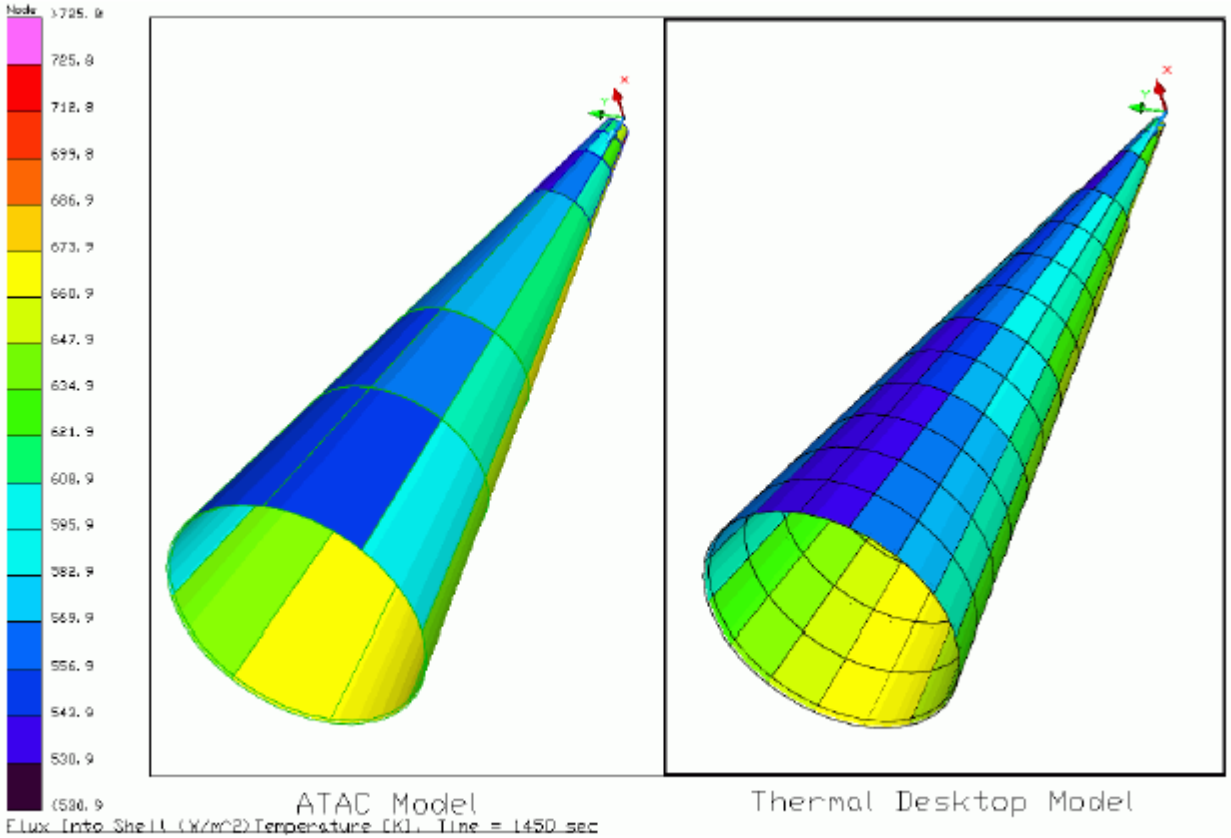
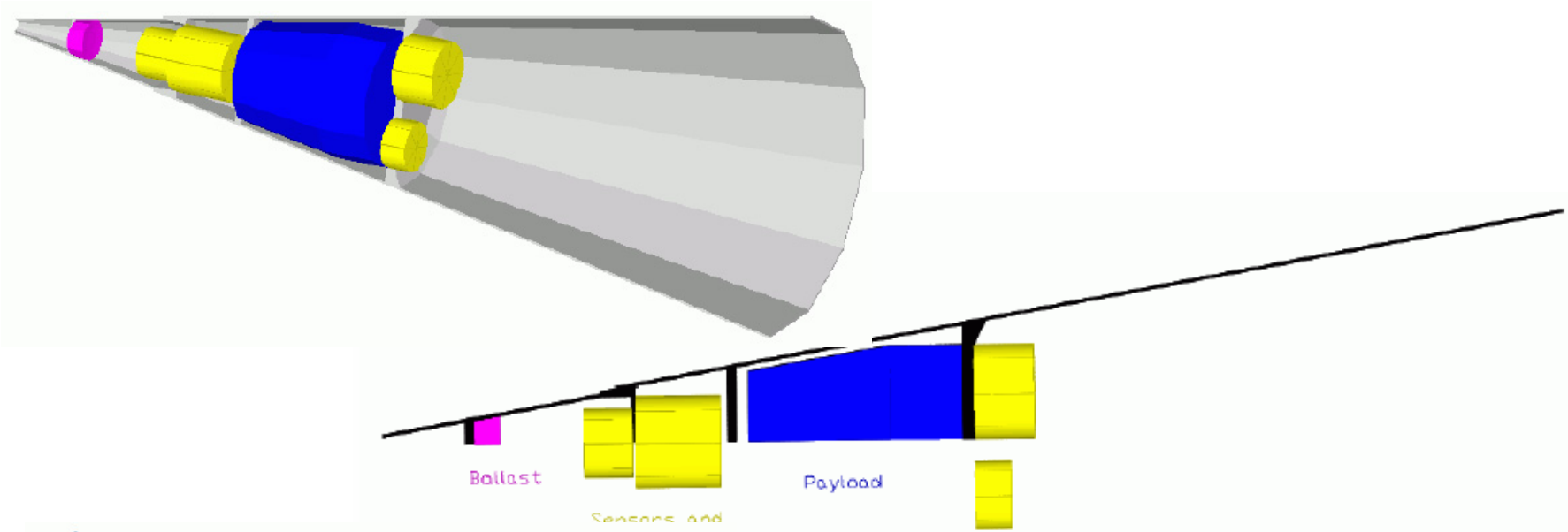
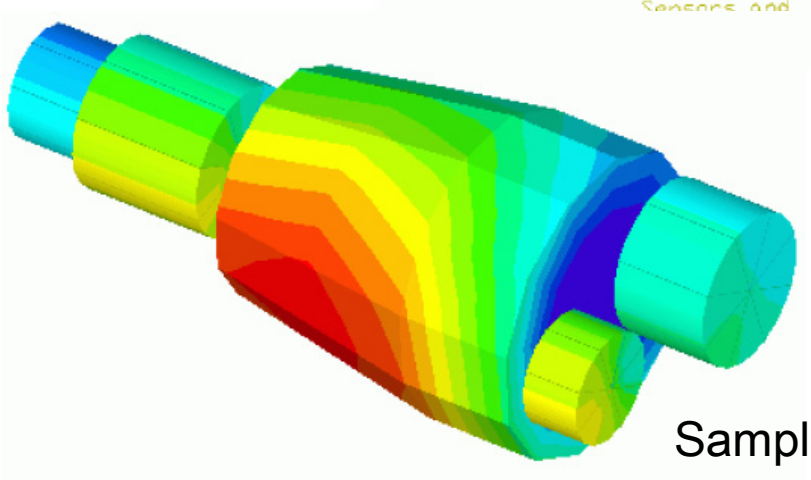


Figure 16 – End time temperatures for ATAC and Thermal Desktop with more nodalization

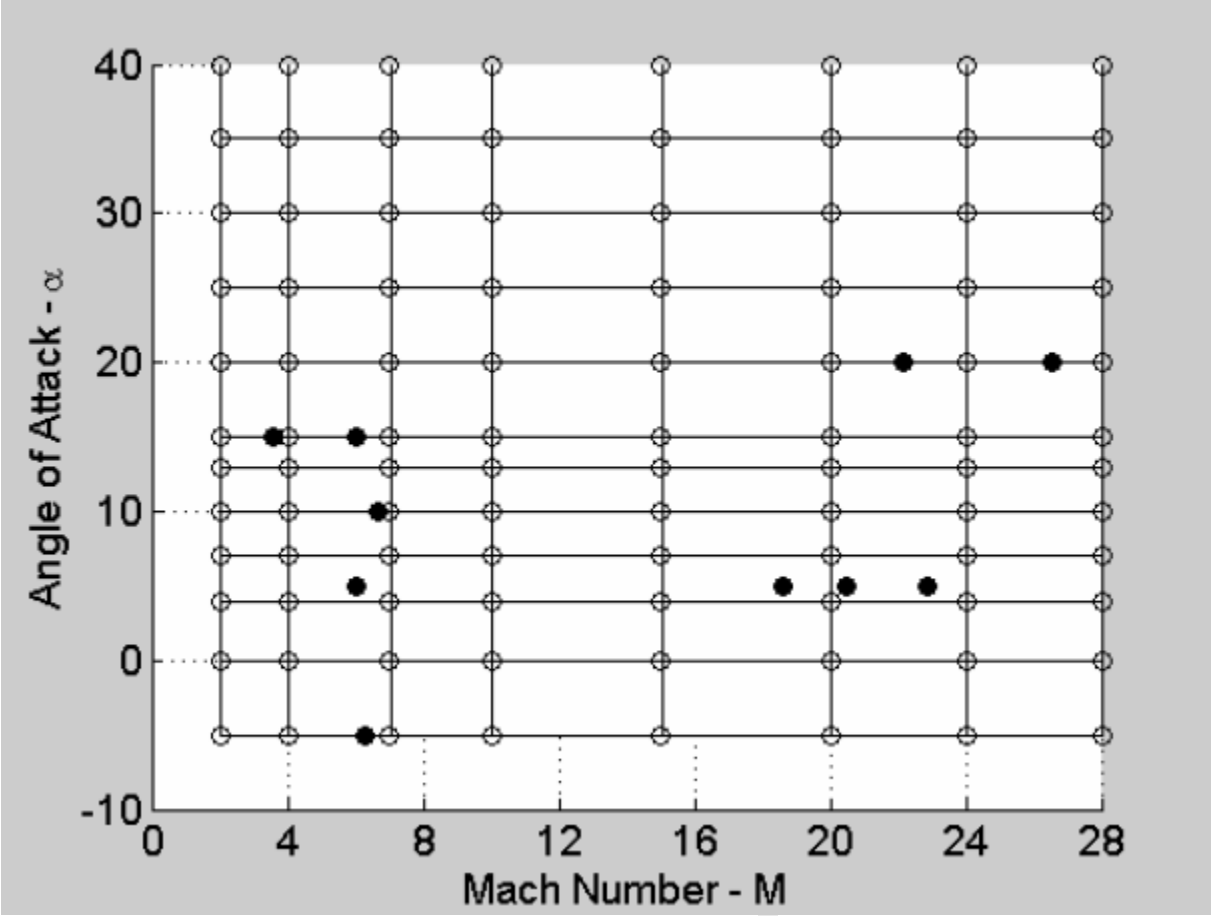
Phase I Sample Model
Thermal Desktop/SINDA Results





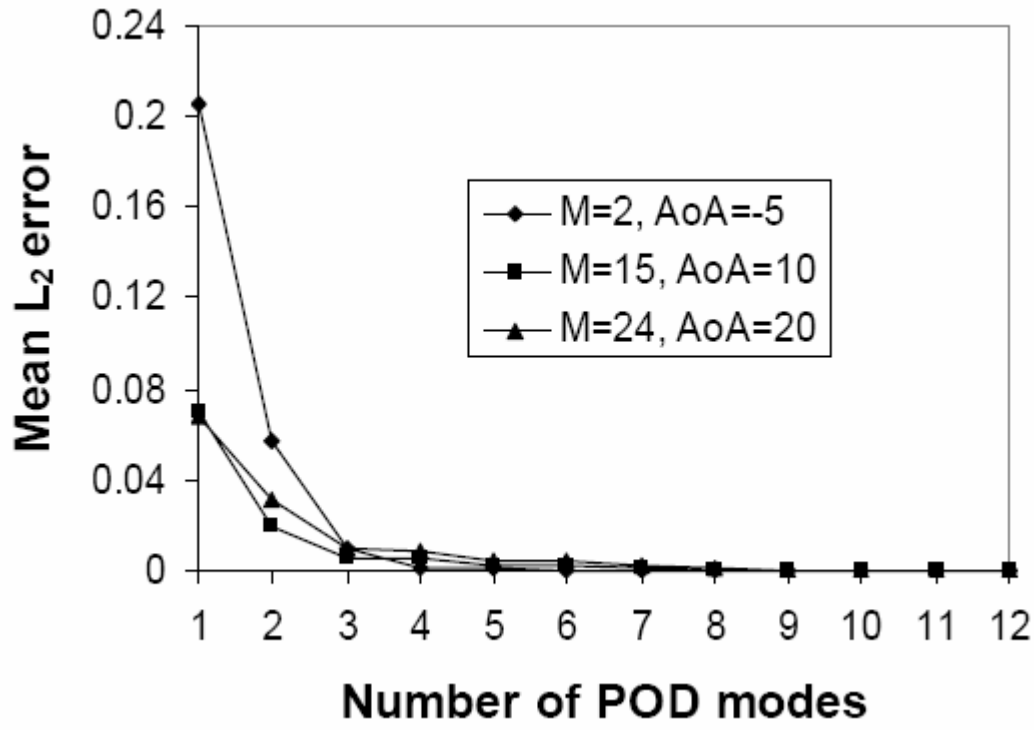
Sample model component temperatures

Phase I Sample Model PODS/RMS Results



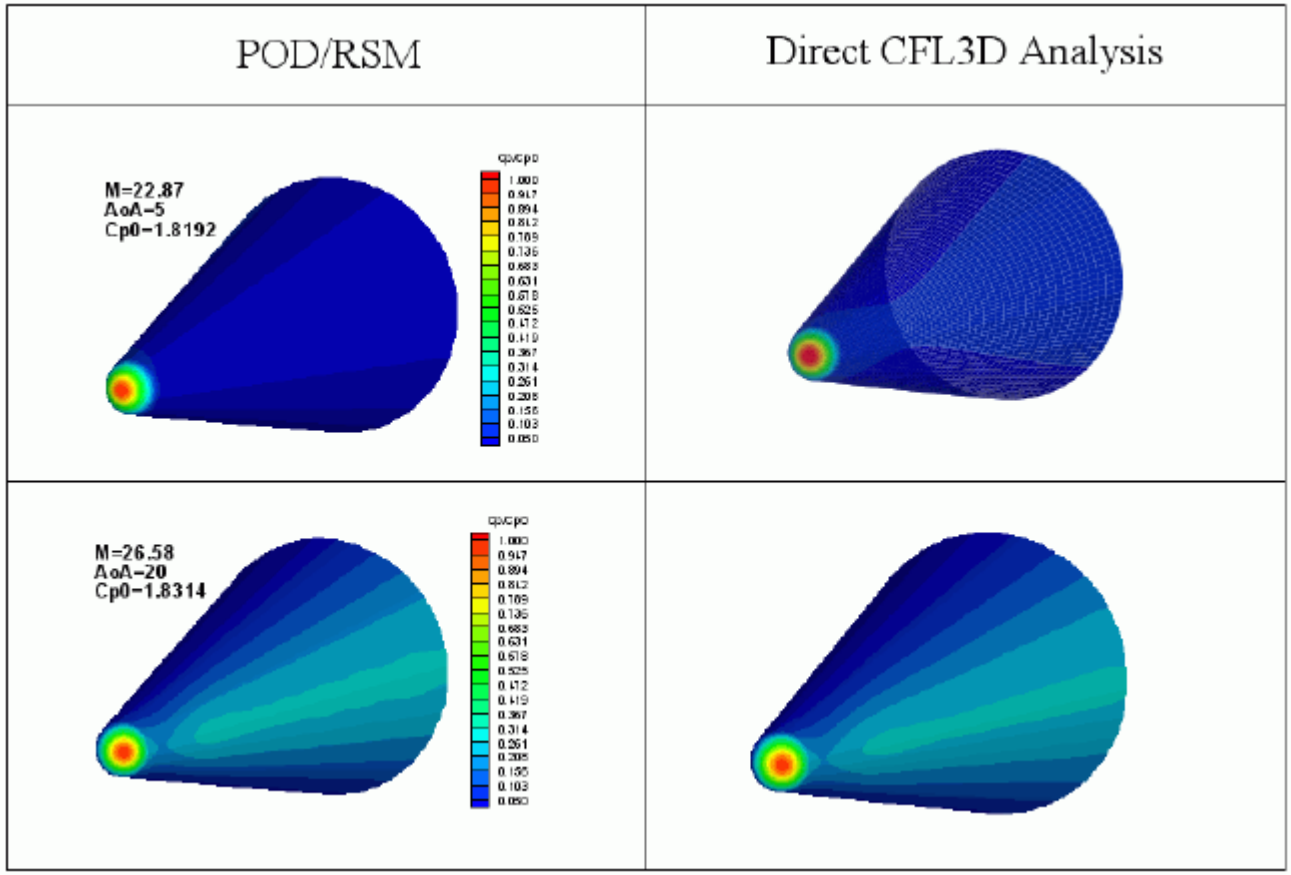
- Make CFD runs to populate the database (dark dots)

Phase I Sample Model PODS/RMS Results



Calculate the number of POD modes (eigenvalues) necessary to calculate the error.

Phase I Sample Model PODS/RMS Results



Compare POD/RMS calculations to full CFD solutions for sample points on the matrix.

C&R Phase II Work

- Complete interface to ATAC inside of Thermal Desktop
  - More Geometry inputs
    - Bi-Cubic Patches for arbitrary shape vehicles
    - Fins
    - Curves
  - Post Processing of results
  - User interface Control Manager to input other ATAC parameters
    - Analysis Environment (Flight, Wind tunnel, Arc Heater…)
    - Atmosphere
  - Import of ATAC models
- Coupling of ATAC/SINDA/POD/RSM
  - Co-solving of SINDA and ATAC for full energy conservation

ITT Phase II Work

- Shape change improvements
- Surface Catalycity improvements
- Generalized Aeroheating Code Import
  - Allow aeroheating calculations to be made with external codes and import them for calculations with ATAC
- Coupling of ATAC/SINDA/POD/RSM
  - Co-solving of SINDA and ATAC for full energy conservation
- Assisting C&R on adding ATAC Interface to Thermal Desktop

Zona Phase II Work

- Provide a Graphical User Interface to POD/RMS
- All POD/RMS to accept input from any CFD code
  - Define data formats for input
  - Use FIELDVIEW formats for CFD Mesh Inputs
- Export POD/RMS data to ATAC