Aerothermodynamics of EFPs Research Task Status

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Introduction

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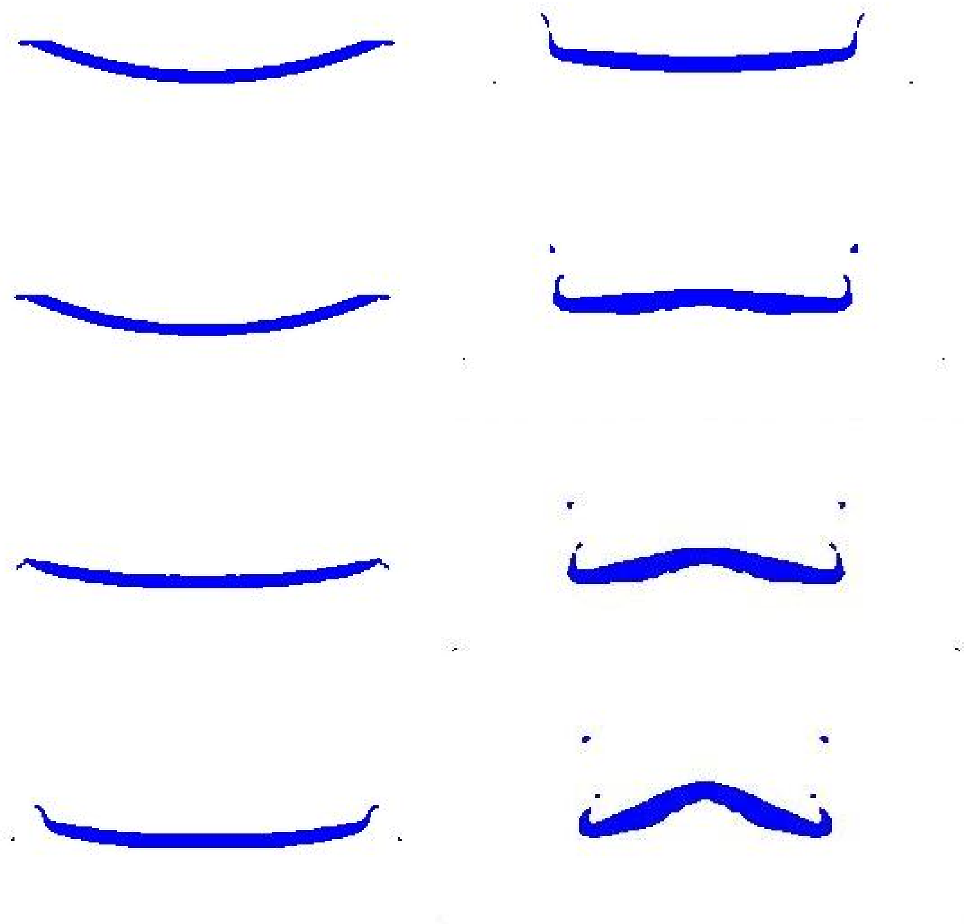
- **Purpose**
  - **Progress report for EFP Aerostability Laboratory Research Task**
- **Objectives**
  - **Discuss:**
    - **Moving body algorithm development/results**
    - **Validation Calculations**



Outline

- Level Set AMR research for moving bodies
- Simplified static body EFP simulation
- Hypersonic flow validation problem

Numerical Method

- LESLIE3D
    - 3D Large Eddy Simulation
    - Finite-Volume
    - Explicit
    - Locally Dynamic subgrid Kinetic energy Model (LDKM)
    - Capable of Capturing shocks via an automatic adaptable algorithm
        - HLLC/E Approximate Riemann Solver for flow regions near discontinuities
        - 2^{nd}/4th order MacCormack solvers for smooth regions of the flow
        - Extensively validated for the Richtmyer-Meshkov instability problem
    - Fully Parallel
    - Multi-block and arbitrary structured grids
    - Code also has other features (not used in the current effort)
        - Finite-rate chemistry
        - Fully coupled dispersed and gas phases for problems involving evaporating reactive droplets, or solid particulates
        - Dense dispersed phase algorithm for energetics problems

Level Set AMR Research

Current Status:

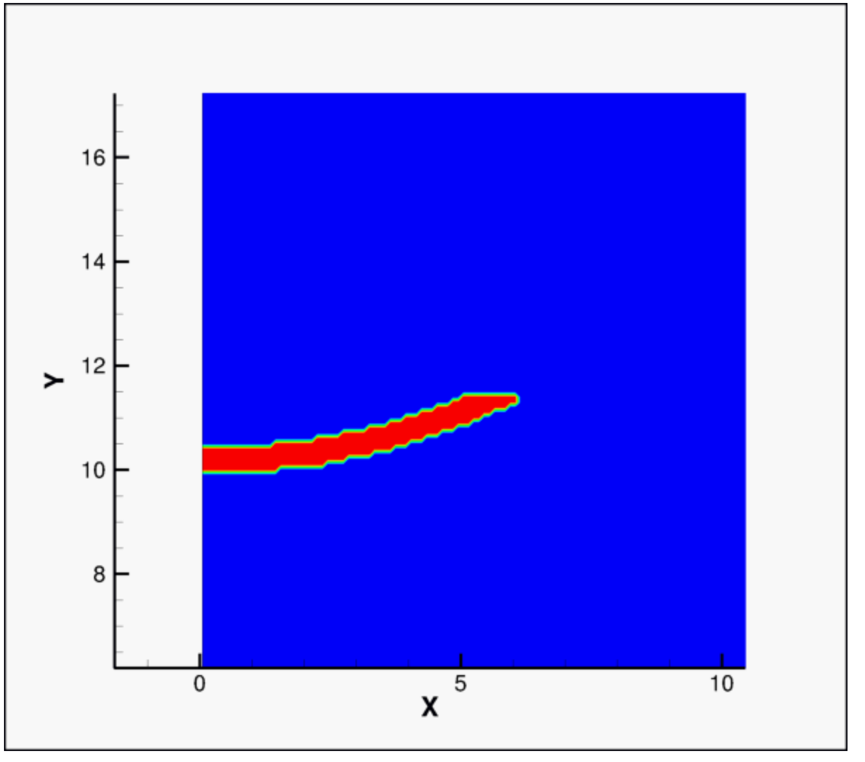
- Rewriting level set AMR routines to speed execution
- Cut-cell AMR is working in time accurate mode
- Current work is to reduce computational cost of refinement
- Modifying the compressible Subgrid Kinetic Energy Model
    - Installation of jump conditions to limit production
    - Modifying dissipation term to deplete excess SKE
    - Testing new SKE model with Linear Eddy Mixing model

Validation:

- Simulating hypersonic flow around a sphere at Mach 6
- Massively parallel exercise (4356 domains, 1.1+ billion cells)
- Awaiting a new allocation of HPC computer hours

2D Deforming Body Simulation

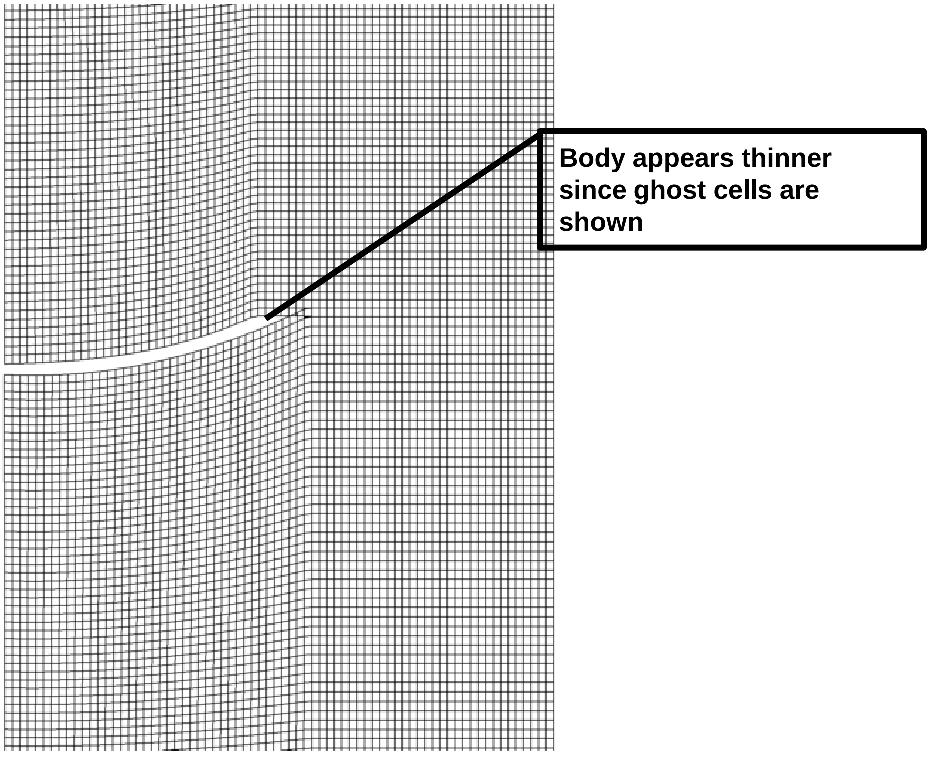
- Test Case setup:
  - Body shape changing at hypersonic speed
- Initial study done for flow over the stationary body for two cases:
  - Mach 4 and Mach 6 flow
- Effect of shape change studied with Level Set AMR cut-cell method (with multi-level refinement)



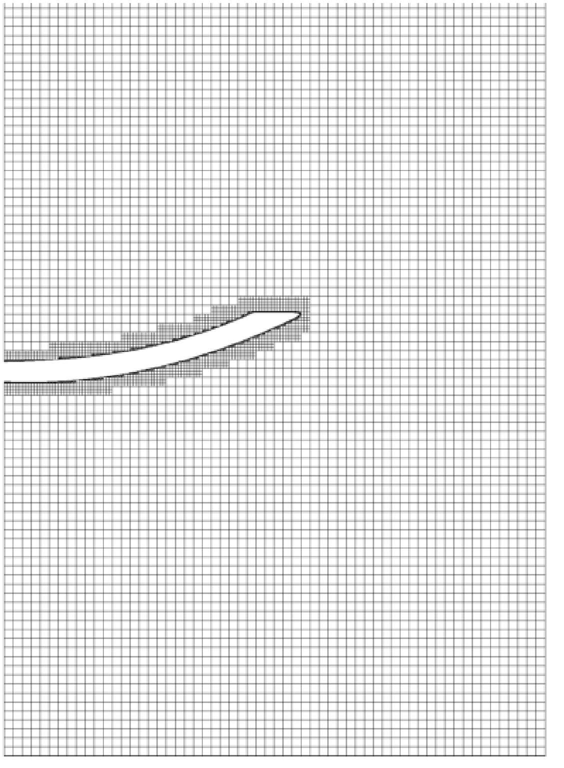
2D Deformable Body: Mesh configurations

Mesh Configurations

Body-fitted mesh



Cut-Cell Mesh



- Body fitted mesh employed for studying the stationary flow
- Cut-cell mesh used for studying shape change

RESULTS – 2D Deforming Body

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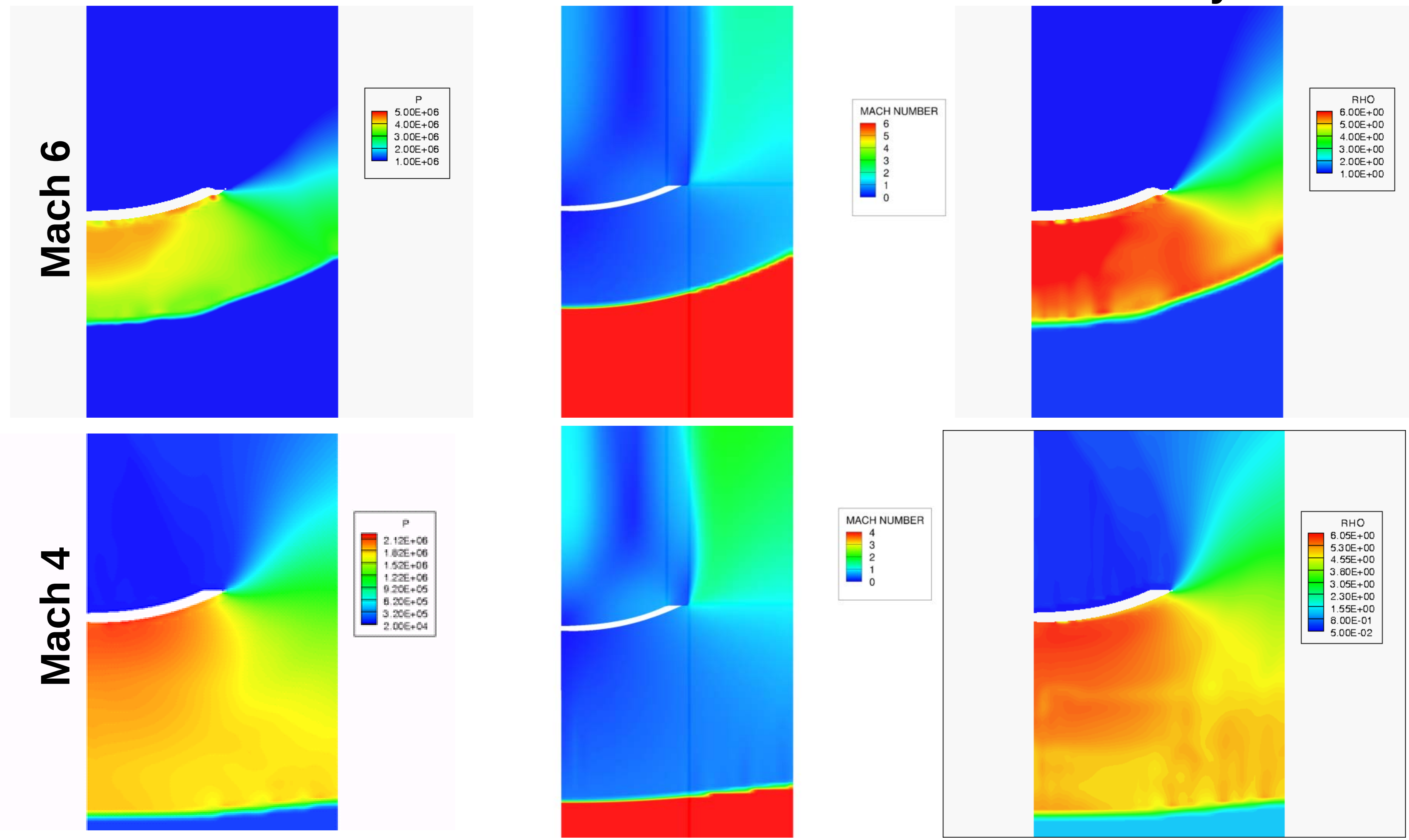
Pressure | Mach Number | Density

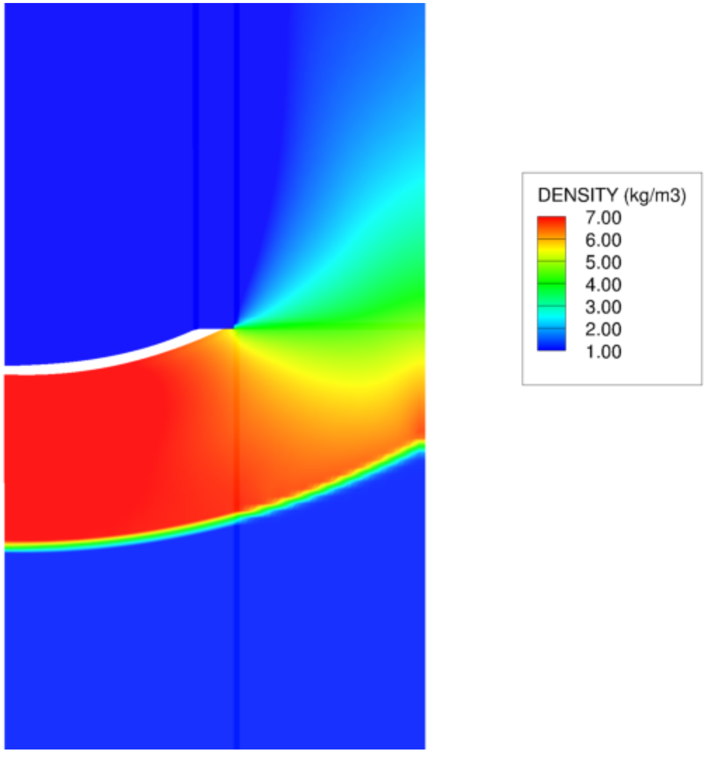
Mach 6

Mach 4

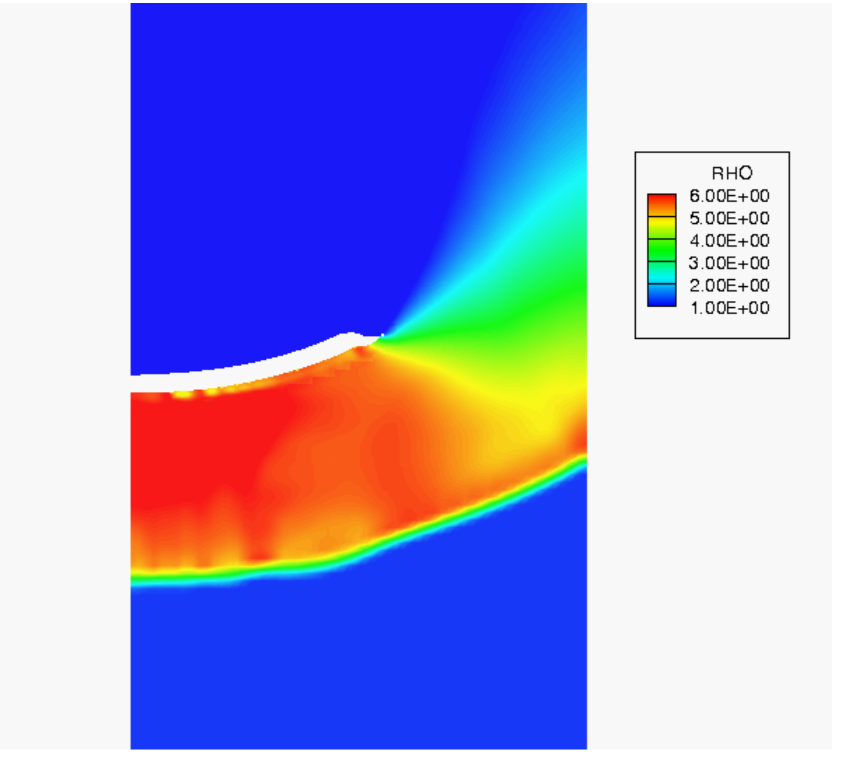


Comparison to Static Flow Mach 6

Density Contours



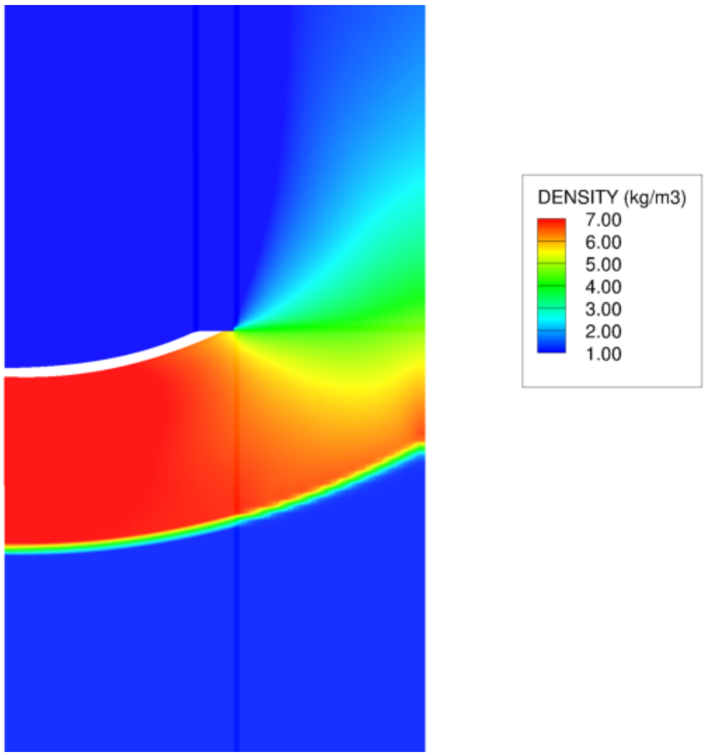
STATIC



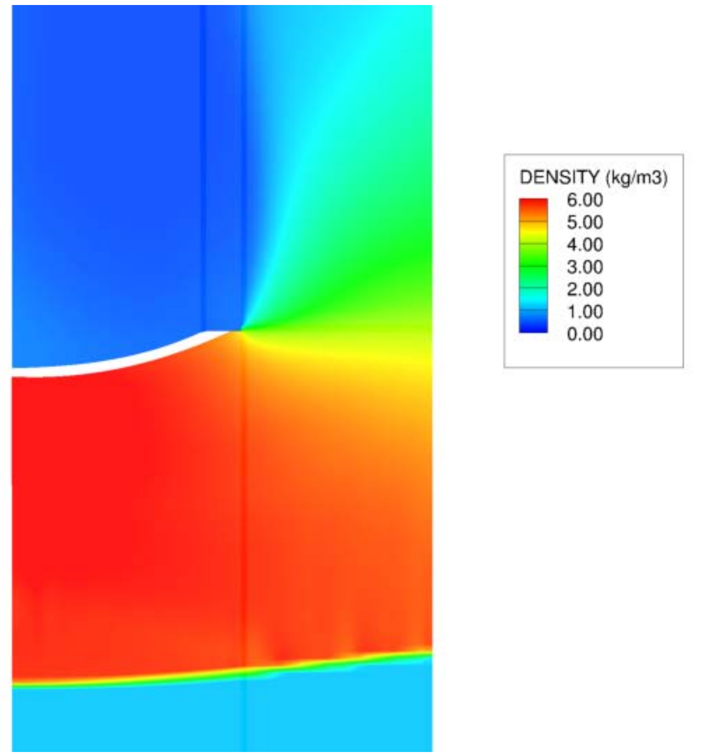
DEFORMING

2D Moving body: Contours of Density

Mach 6

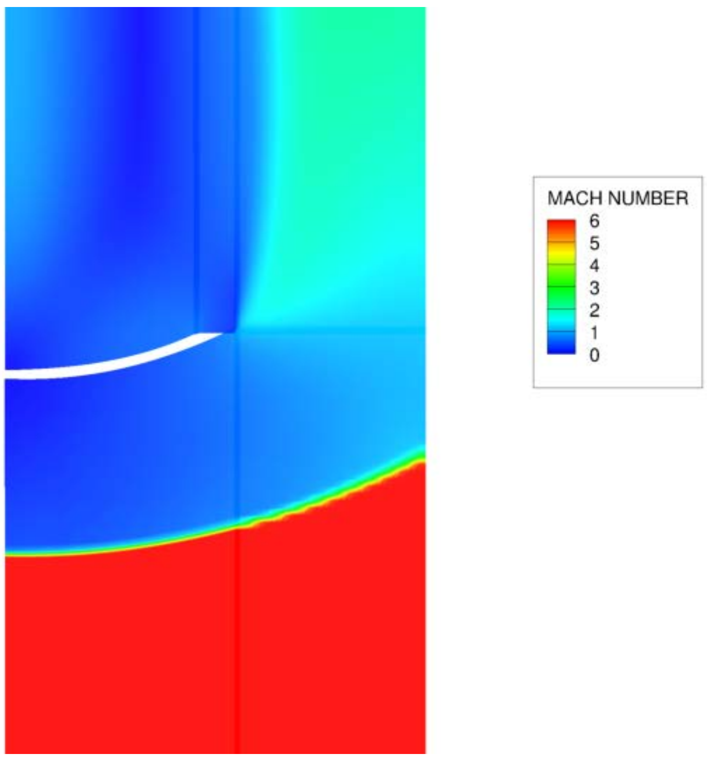


Mach 4

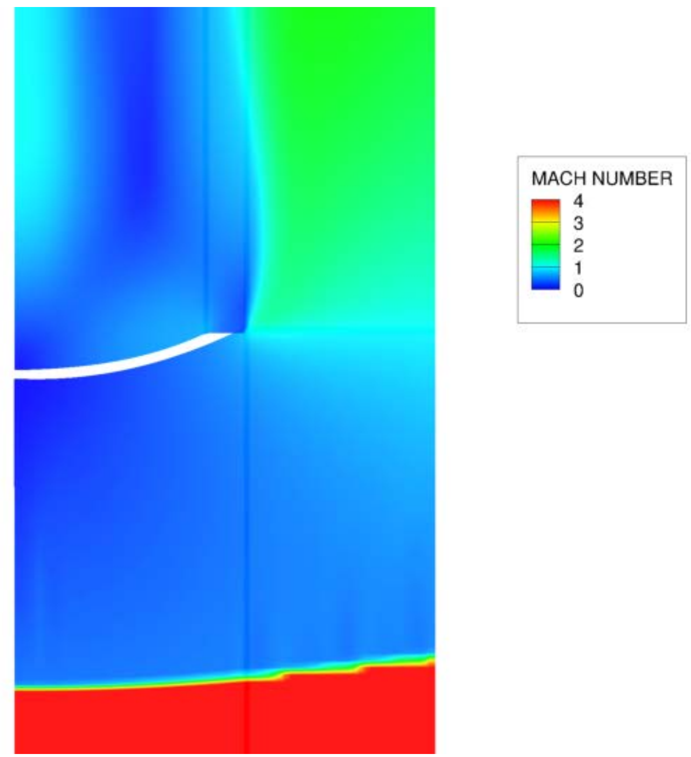


2D Moving body: Contours of Mach Number

Mach 6

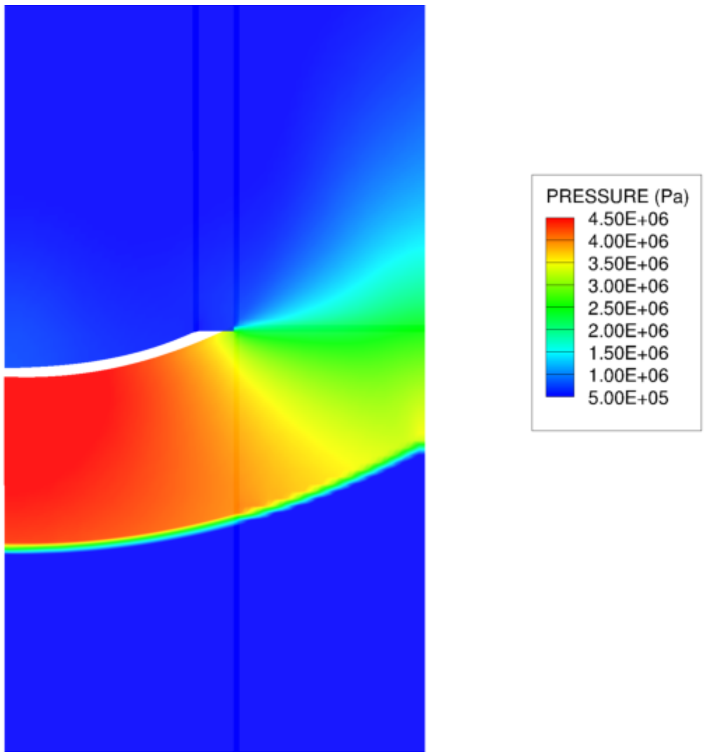


Mach 4

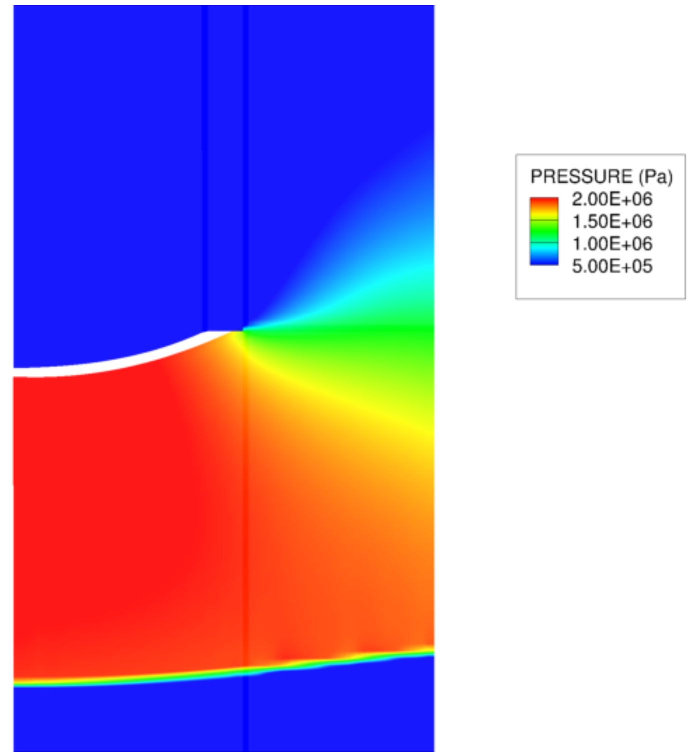


2D Moving body: Contours of Pressure

Mach 6

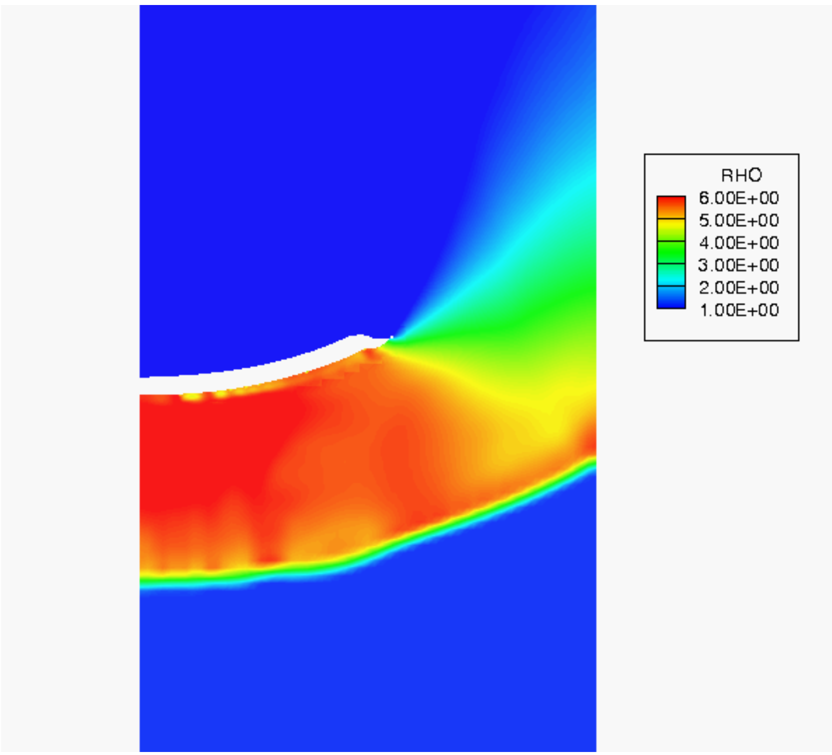


Mach 4

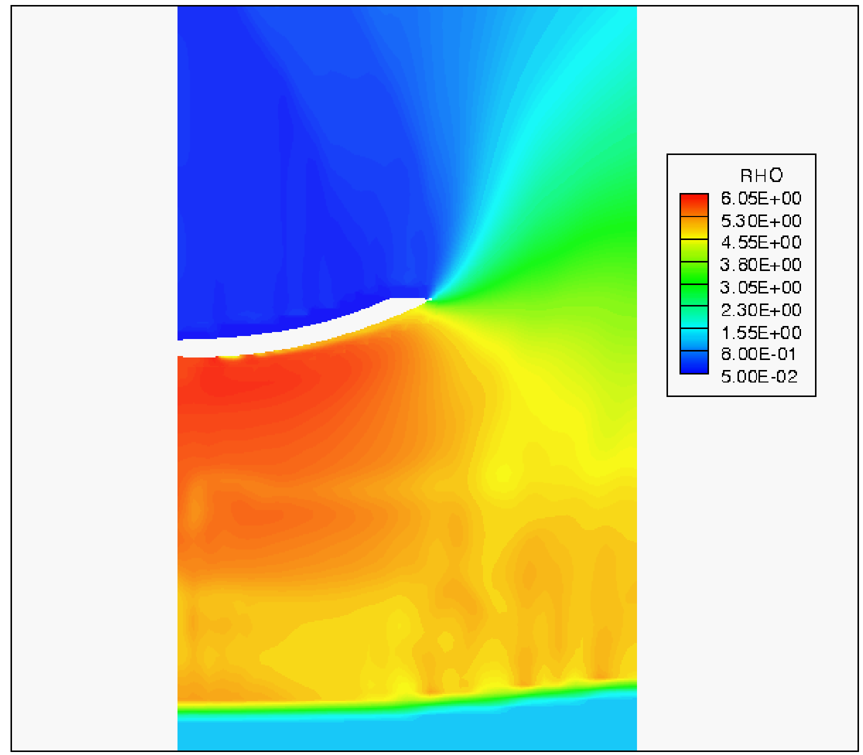


2D Moving body: Effect of shape change

Mach 6



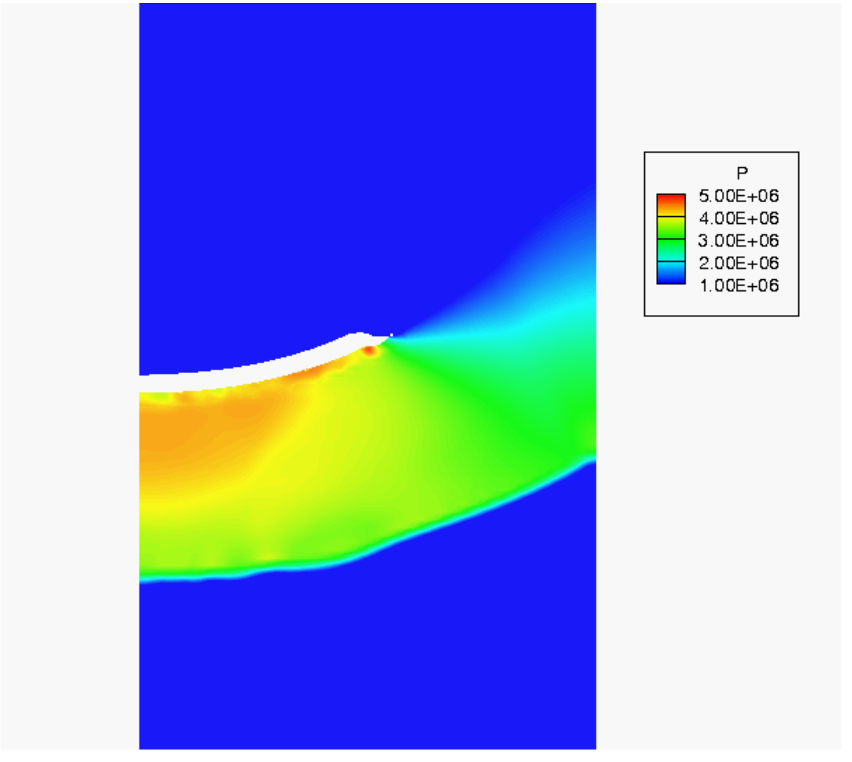
Mach 4



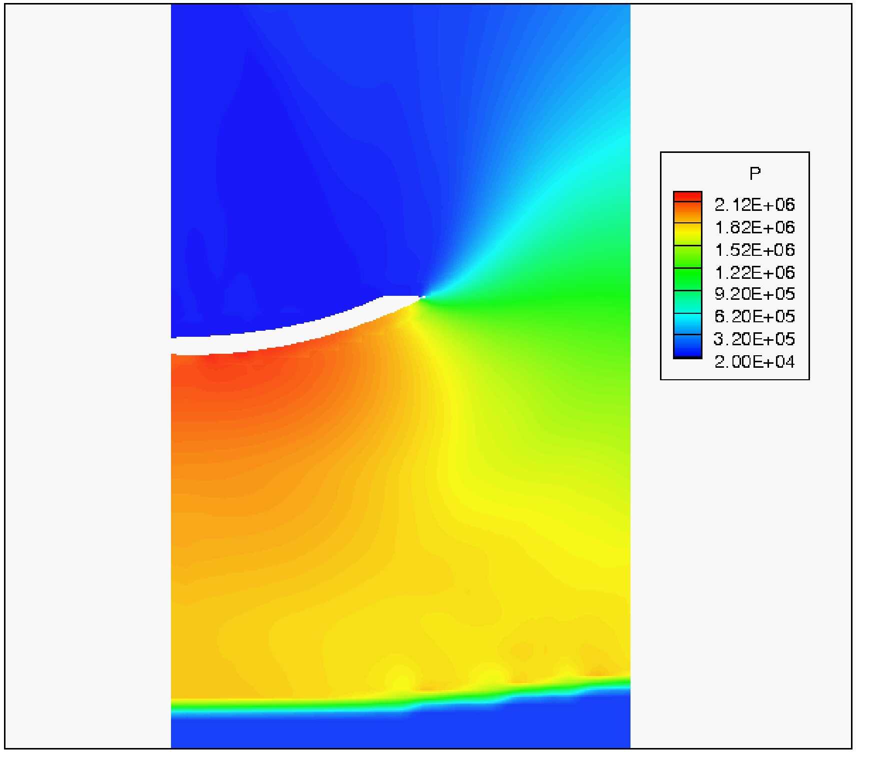
- Expansion front seen clearly for Mach 4 case
- Some shock perturbations observed – need more study

2D Moving body: Effect of shape change

Mach 6



Mach 4



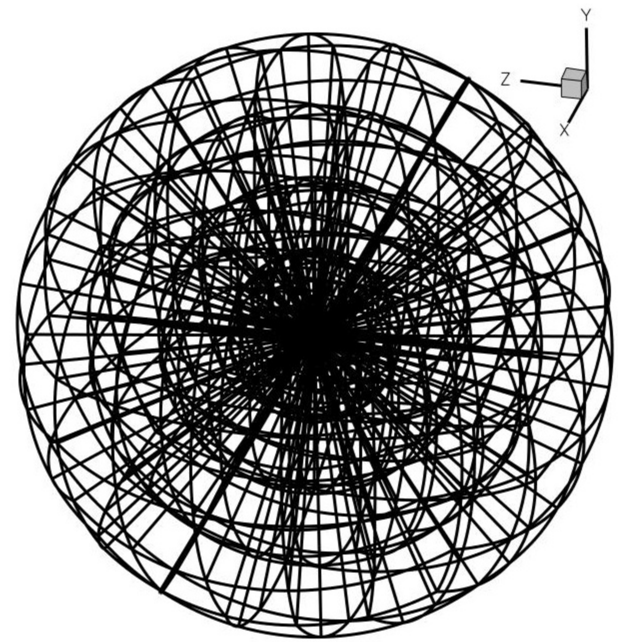
Technical Approach

Hypersonic Validation Problem

Questions have arisen on code validation at annual task reviews

Conduct validation exercise for LESLIE3D :

- **Sphere at hypersonic Mach number (6)**
- **Demonstrate massively parallel calculation**
  - **1.14 Billion Grid Cells**
- **Uses 4356 blocks**
- **Special grid generation/input coding**
  - **Grid generation takes 1,000 cores**
- **Use very fine grid spacing to resolve turbulence**
- **Use 5 species chemistry with turbulence closure**
- **Initial Calculations with 8,300 cores on Cray XE6**
- **This was much harder than expected.**



Technical Approach

Lesson learned from Scaling up to Large calculations

- **Scaling from 10 million to a few 100's of millions of grid cells**
  - **Required a rewrite of how we do I/O, visualization, and grid generation**
- **Scaling from a few 100's of millions to billions of grid cells**
  - **Required a second rewrite of how we do I/O, visualization, and grid generation**
- **Lesson learned – every order of magnitude of increase in problem size requires a lot of re-work for I/O, visualization, and grid generation**
  - **The physics portion of the code never really needed to be touched.**

RESULTS

LESLIE3D can now capture the effect of prescribed changes in body shape.

Feedback on the flow field is evident particularly in pressure and density (also some shock corrugation is visible; this effect requires further scrutiny and investigation) See previous chart

These effects are captured at significant numerical expense. Current work is optimize the parallel coding for cut-cell AMR and improve the execution speed for the computer code

CONCLUSIONS

- **EFP Aerostability research is ongoing but has been slowed by manpower shortages and lack of HPC hours**
- **Deformable body coding is expected complete by end of 2013**
- **Validation problem is expected to be complete in 2013 given appropriate allocation HPC hours. Calculations using 4356 processors have been ongoing but were halted by HPC hours shortage**

Challenges

- Projectile is either accelerating or decelerating
    - Need time dependent boundary conditions.
- Projectile is changing shape
    - Need deformable grid capability and eventually a FSI capability
    - Code changes to support prescribed motion in progress
    - Need a way to automate the grid generation.
- Surface Chemistry
    - Need boundary conditions for reactive surfaces
    - Not easy to discuss, so generalized treatments might be preferable
    - Will require extensive work inside of AFRL to transition the research
- Modeling surface imperfections and roughness
- Need to link the aerothermodynamics with the EOS for the EFP metal
    - Heat could flow both ways at different points on the body

BACK-UP CHARTS

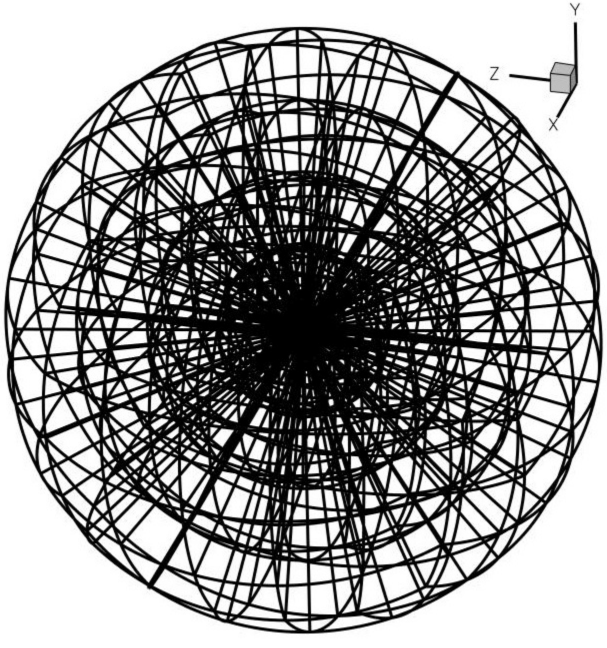
Technical Approach

Hypersonic Validation Problem

Questions have arisen on code validation at annual task reviews

Conduct validation exercise for LESLIE3D :

- **Sphere at hypersonic Mach number (6)**
- **Demonstrate massively parallel calculation**
- **Use more than 5000 blocks**
- **Special grid generation/input coding**
- **Use grid spacing to resolve turbulence**
- **Use 5 species chemistry with turbulence closure**

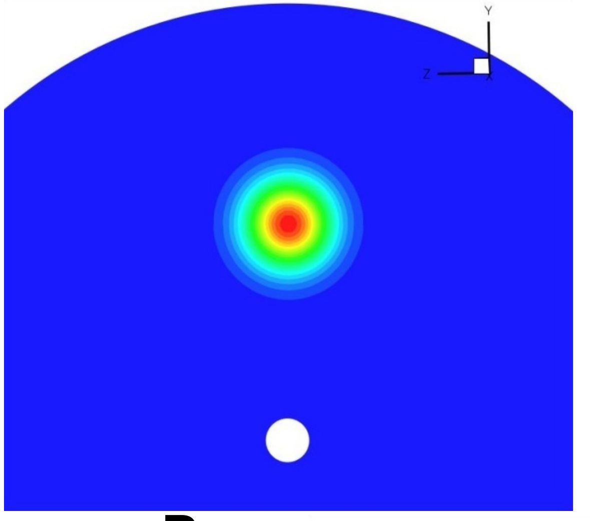


VALIDATION – HYPERSONIC FLOW

Challenge level calculation to validate LESLIE3D for hypersonic chemically reacting flow fields. Flow is simulated at Mach 6 around a solid sphere of one meter diameter

Results shown here are for a reduced size calculation of 300 domains, minimum grid spacing at the surface of 10^{-4} m

First calculation involved calculating the solution for a pressure pulse confined between two solid spherical shells. This work helped to prove out the pre-processor coding used to set initial conditions and coordinate the parallel communication between domains

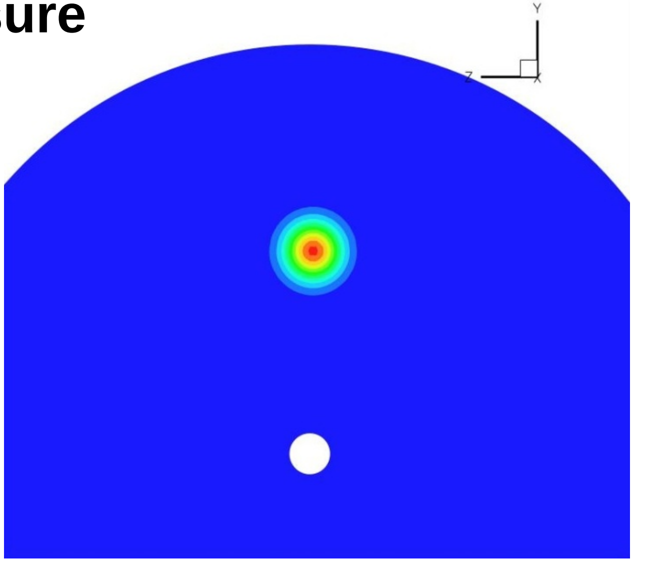


Pressure

Spherical Radii:

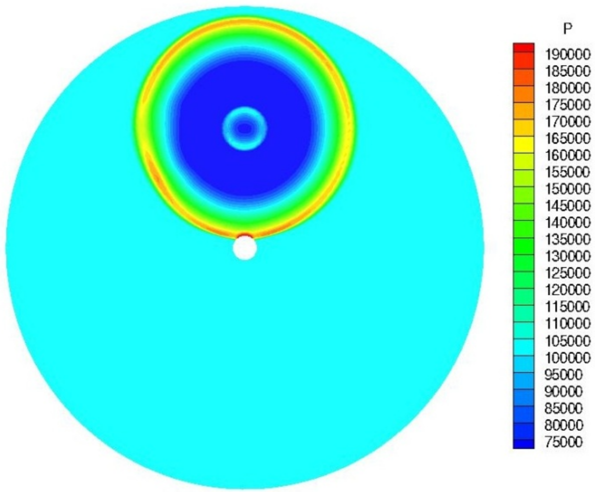
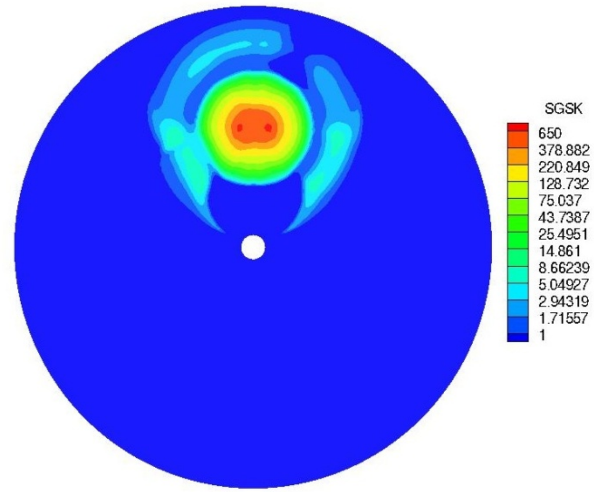
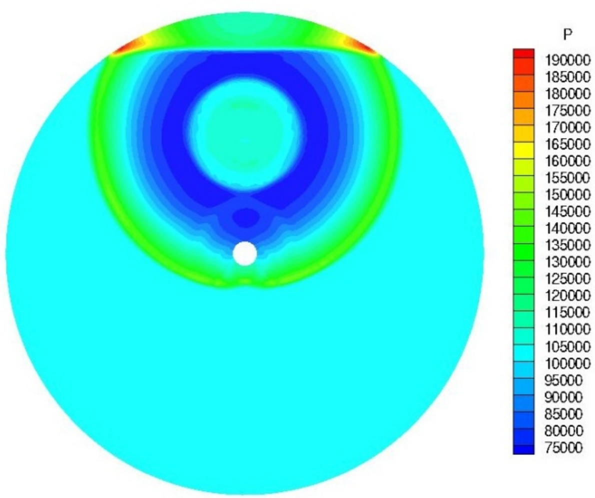
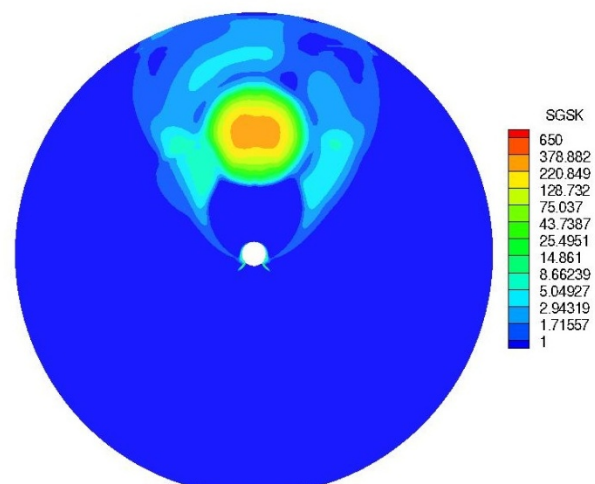
Inner: 0.5 m

Outer: 10.0 m



Subgrid Kinetic Energy

RESULTS-Confined Pressure Pulse

Solution Time	Pressure (Pa)	Subgrid Kinetic Energy (J/Kg)
4.314 ms		
8.859 ms		

RESULTS-Mach 6 External Flow

Solution involves 300 domains and 3 million cells

Freestream velocity is set at Mach 6

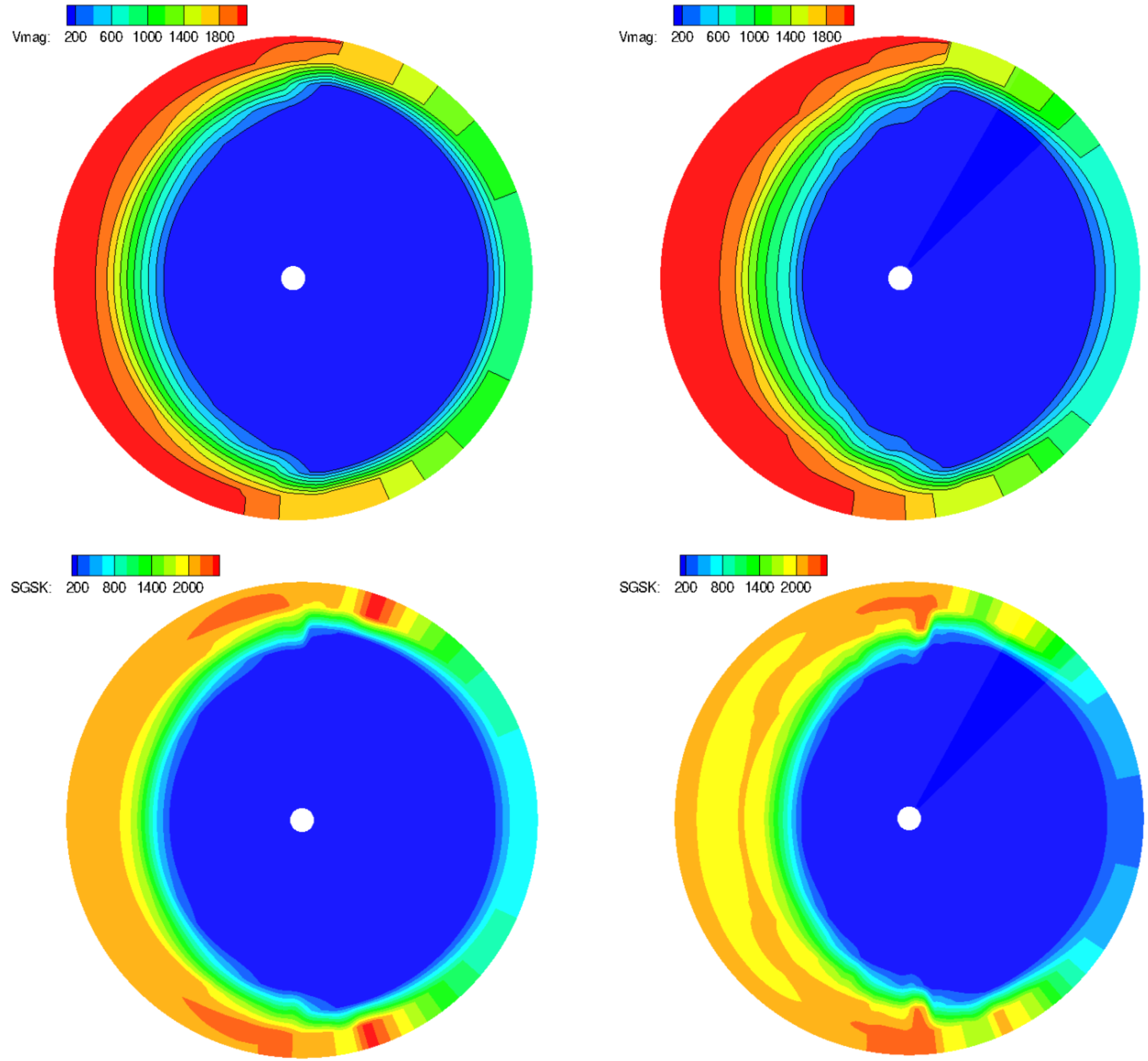
Solution uses LDKM LES turbulence with compressible closure

5 species flow field with mixing; vertical plane shown parallel to stream

Shows evolution of subgrid kinetic energy (bottom) and velocity magnitude (top)

Left: 11,000 steps

Right: 18,000 steps



STATIC EFP CONFIGURATION

Simplified EFP configuration designed for easier grid generation and single block calculations

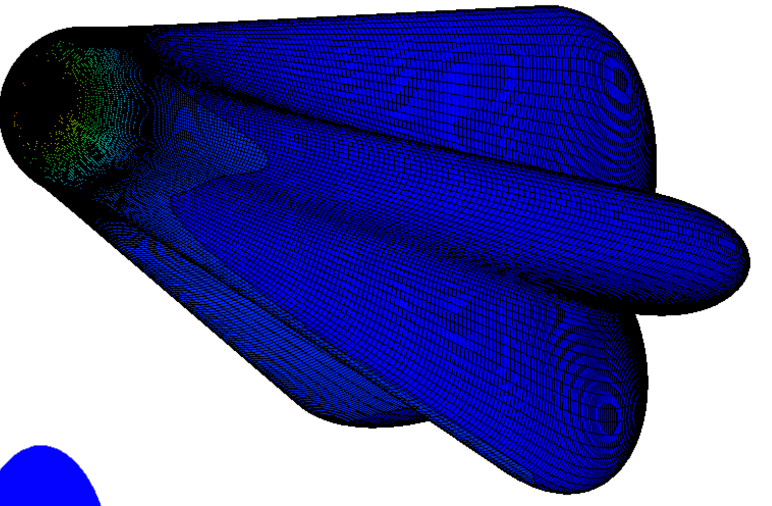
Grid generated by Hermite transfinite interpolation

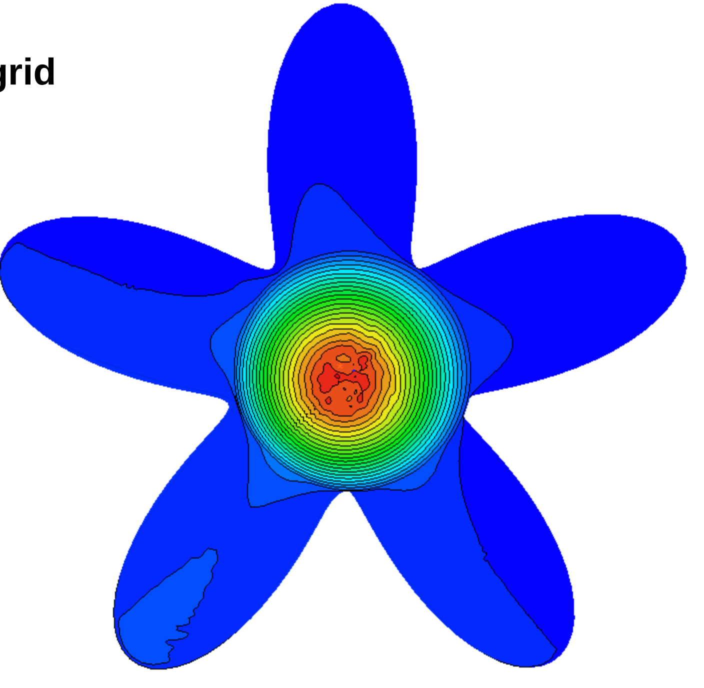
12 million cells
Minimum spacing at body surface of 10^{-5} m

Simulation is fully turbulent with subgrid kinetic energy initialized at the inflow

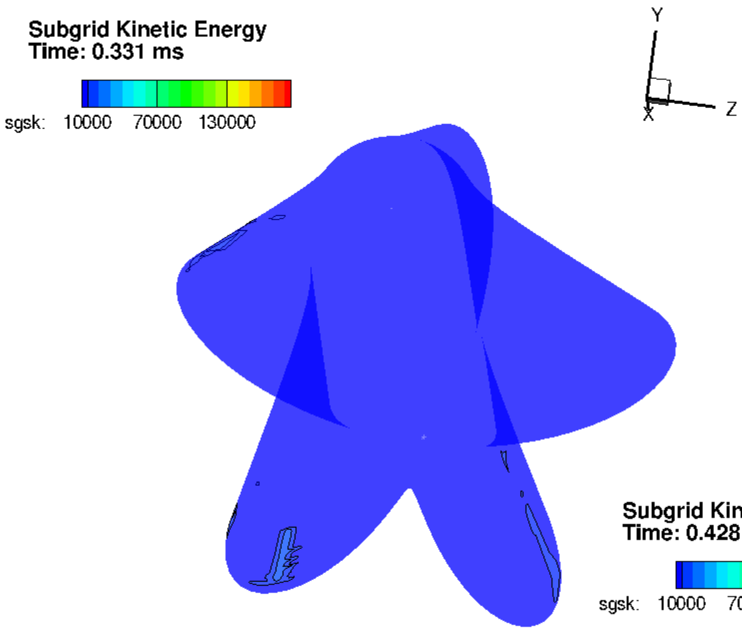
Thermally perfect gas EOS

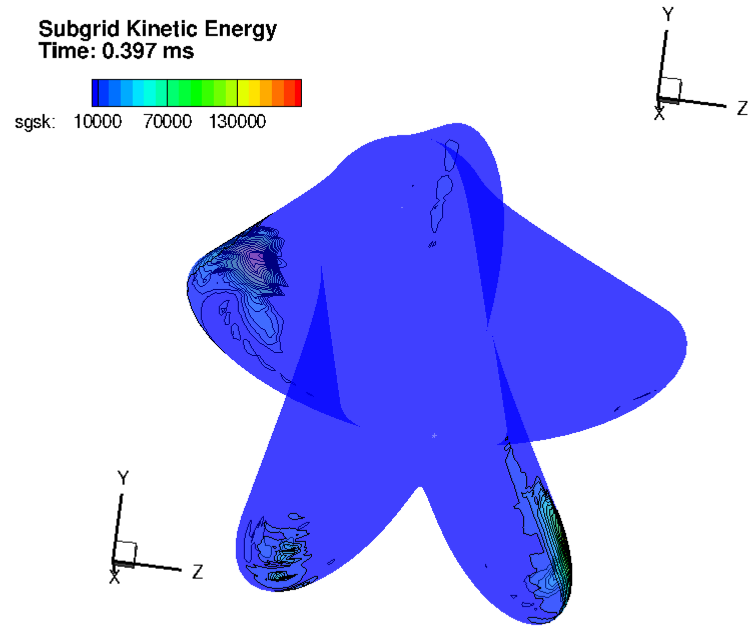
Body at 5° pitch, 5° yaw

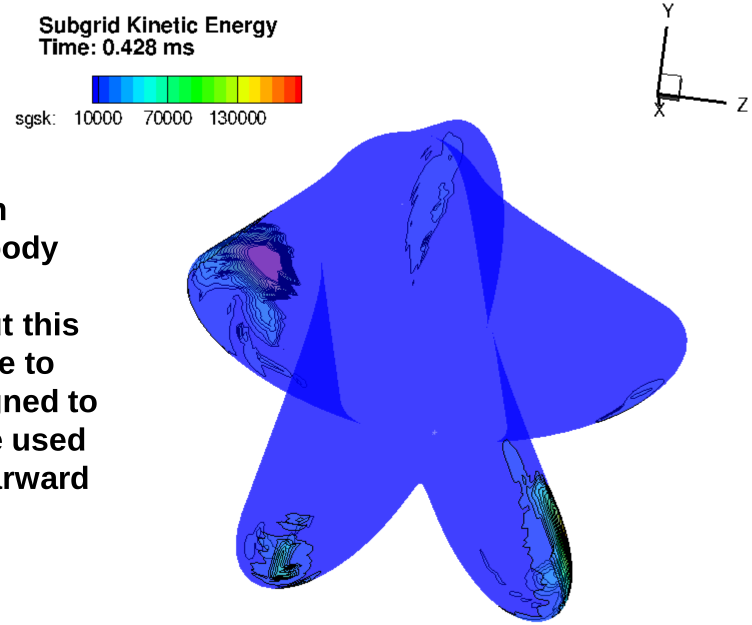




RESULTS – STATIC BODY







Solution exhibits unsteadiness in subgrid kinetic energy over the body surfaces. Solution needs to be converged to a greater extent, but this unsteadiness is still expected due to the non-zero pitch and yaw assigned to the body. Translucent images are used to resolve fluctuations on the rearward body surface

RESULTS – STATIC BODY

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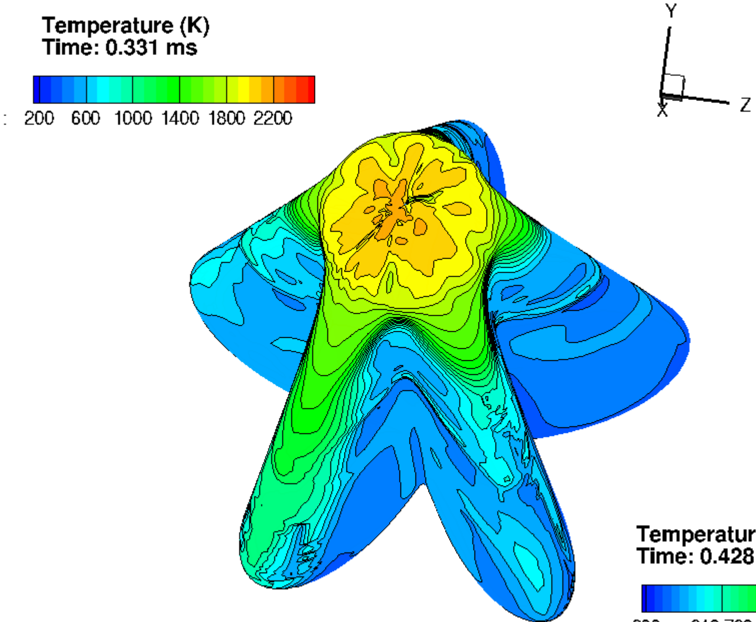
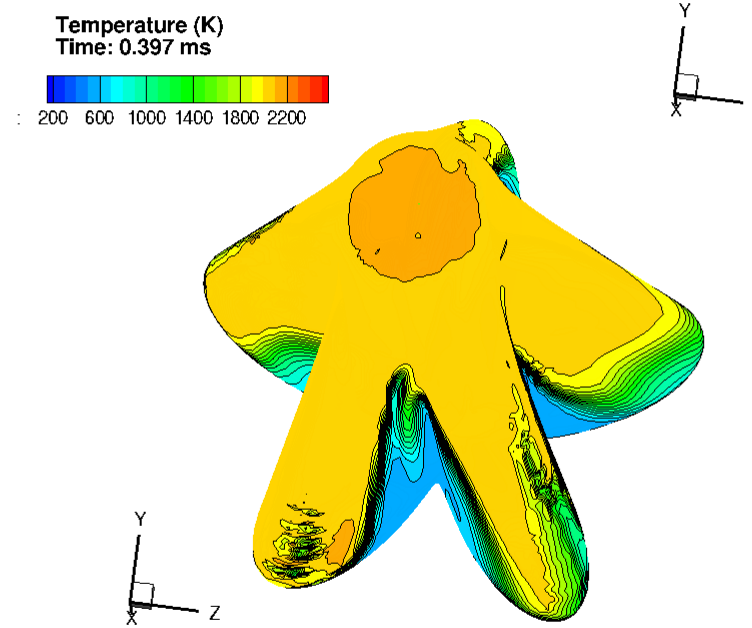
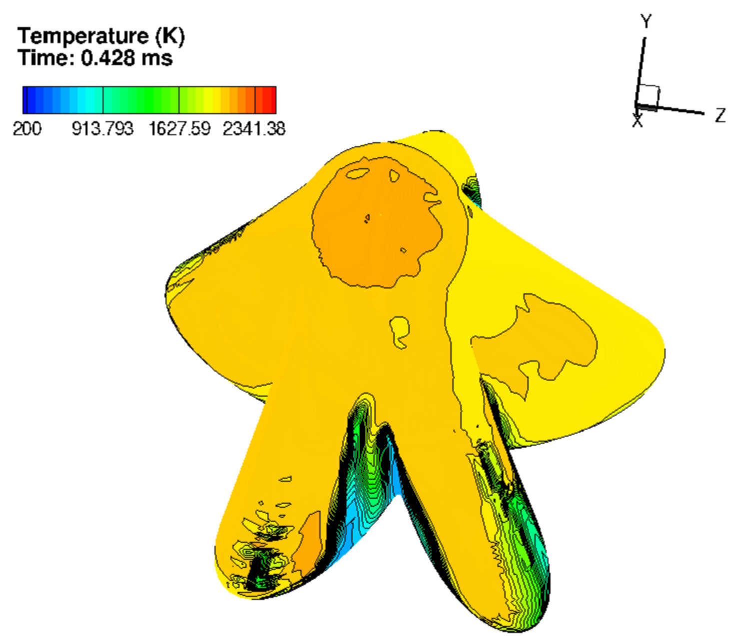
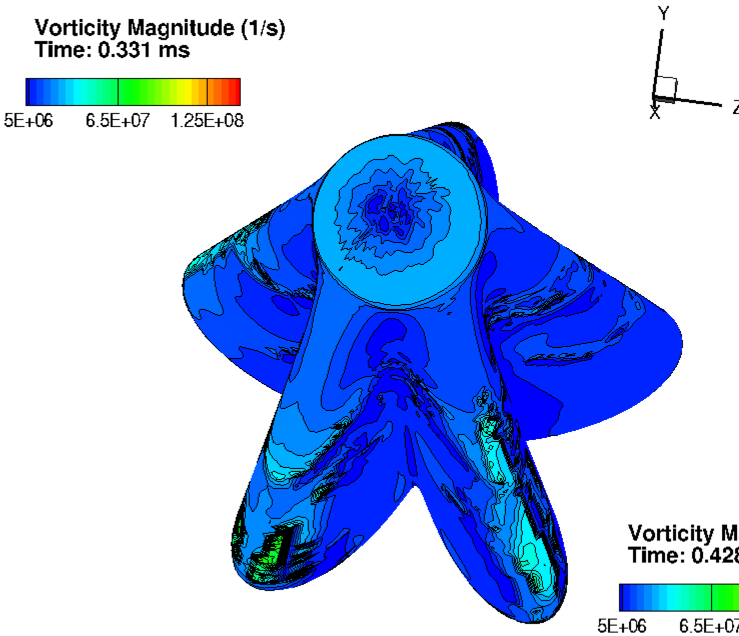


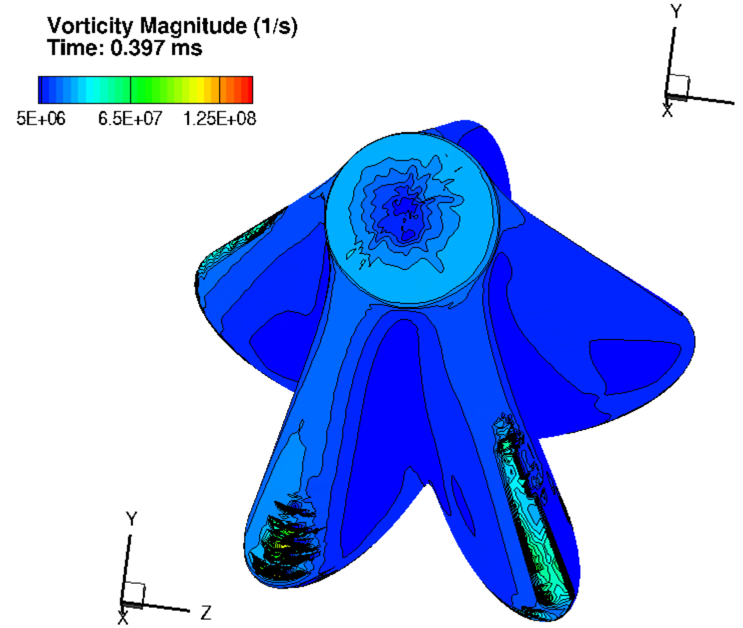


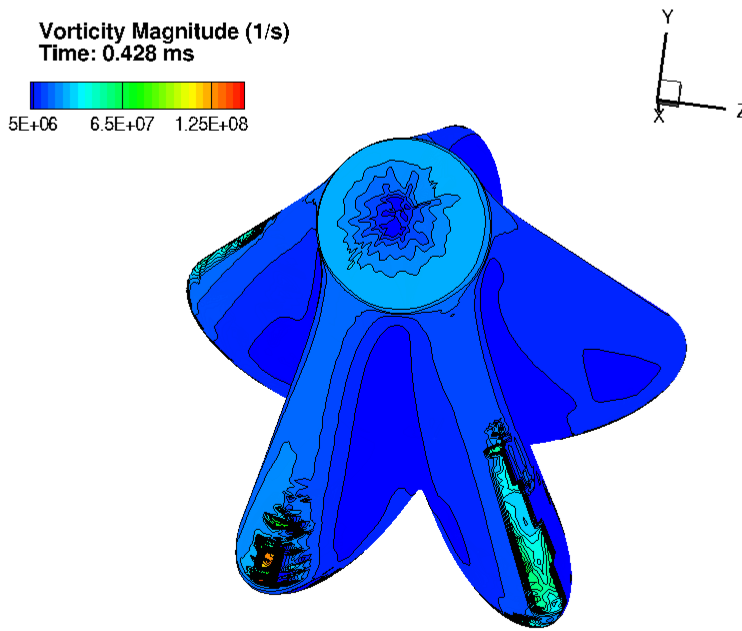


Solution exhibits temperature excursions in the range to support the presence of chemical reactions in air at the body surface.

RESULTS – STATIC BODY







Fluctuations in vorticity magnitude are exhibited by the solution in time, especially in the body's lobe regions

Results are to be published at the upcoming AIAA Biennial Forum for Weapon System Effectiveness