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SMALL CALIBER MUNITIONS
PICATINNY ARSENAL, NEW JERSEY

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
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Malcolm Baldrige National Quality Award
2007 Award Recipient

FINITE ELEMENT MODELING OF THICK PLATE PENETRATIONS IN SMALL CAL MUNITIONS

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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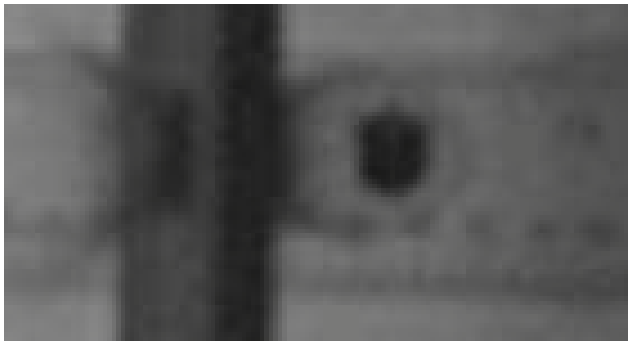
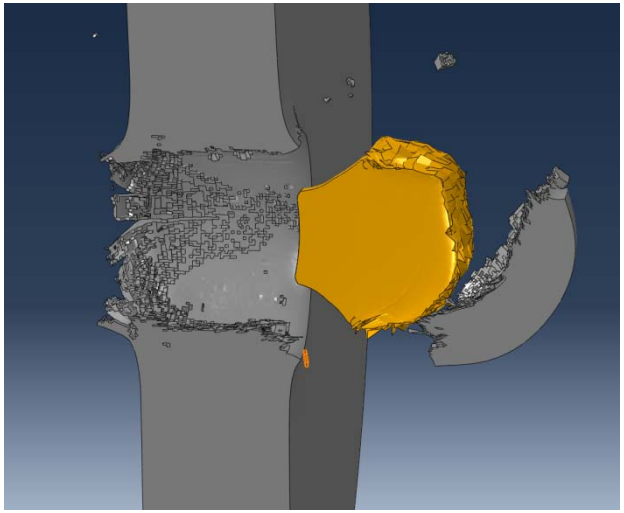
Why Finite Element Modeling?

- Reduced testing costs and iterations
- Reduced time between geometry and material design changes
- Allows fast comparison of multiple concepts
- Allows for visualization of events high speed cameras are incapable of capturing

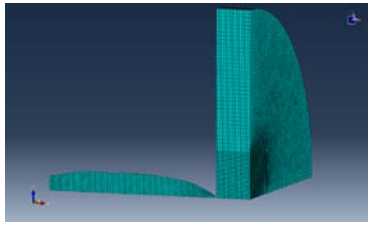


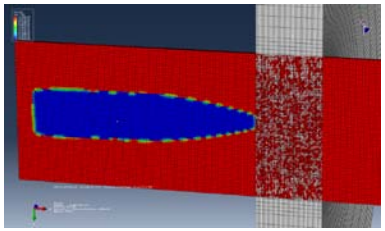


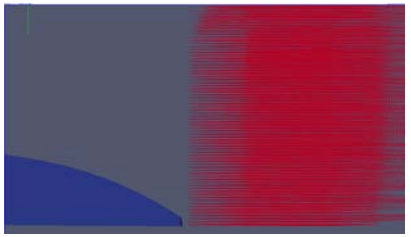
FEA Penetration Modeling Weaknesses

- Material Properties
  - Penetration modeling is highly material properties dependant
  - Large strain rates encountered require use of complex constitutive models
  - Damage parameters settings can greatly effect model results

- Meshing Techniques and Contact Issues
  - Large Variety of meshing techniques to chose from - Eulerian, Lagrangian, SPH
  - Contact Issues arise from mesh density and time step

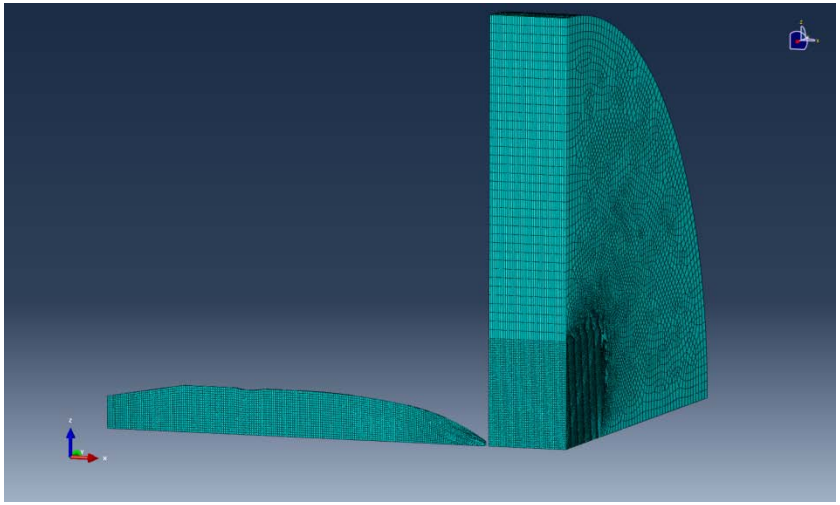


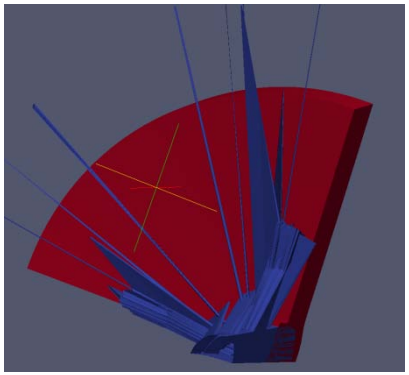


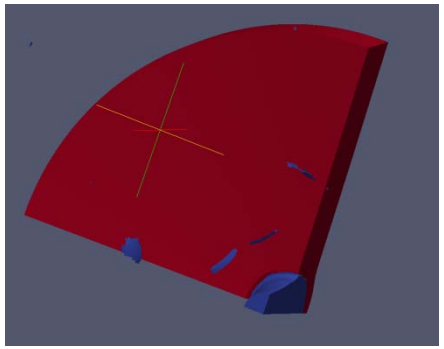


Meshing Techniques - Lagrangian

- Lagrangian mesh contains the material on the mesh
  - Mesh and material move together
  - Excessive element deformation requires deletion for run stability
    - Element deletion also results in mass loss of the model
  - Allows for the smallest overall model size and run times

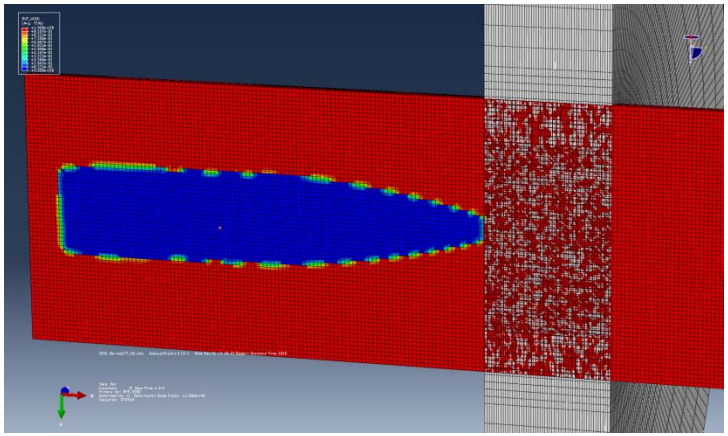


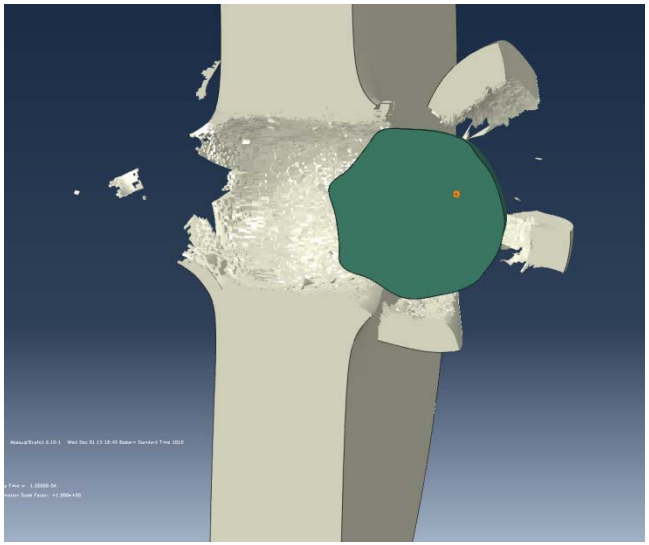




Meshing Techniques - Eulerian

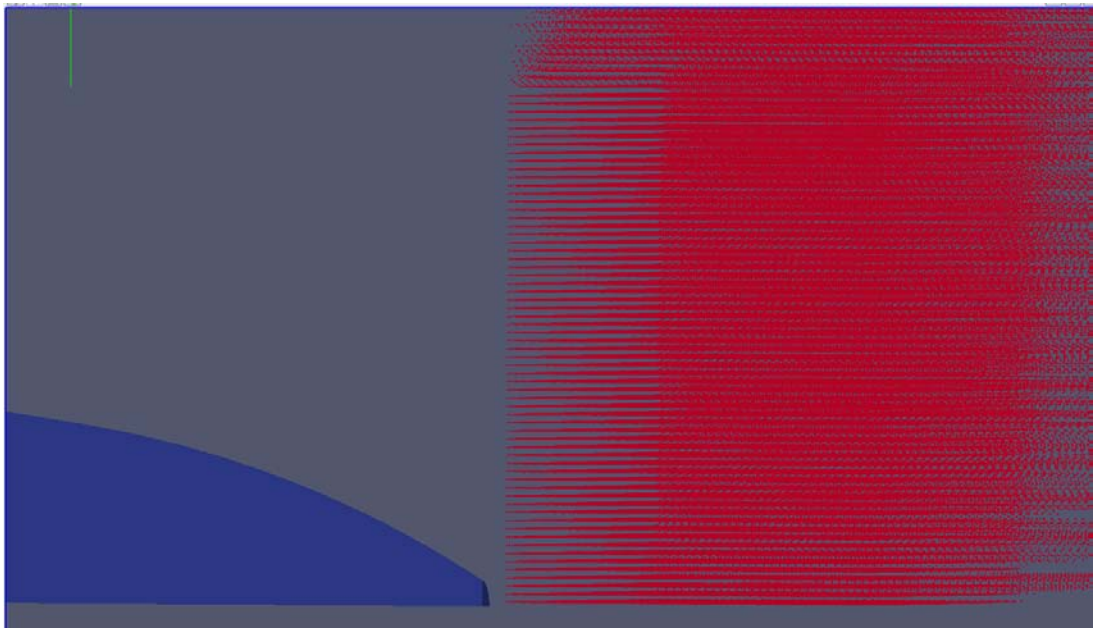
- Eulerian mesh contains the material in the mesh
  - Mesh stays constant and material flows through the mesh
  - Eliminates the need for element deletion as the actual elements no longer expand or contract
  - Mesh size needs to be large enough to capture the entire modeling event – this often leads to large computationally expensive models
  - Advection errors can also occur in elements with partial void fills





Meshing Techniques – Smoothed Particle Hydrodynamics

- SPH contains particles instead of elements
  - Particles have an initial mass and radius and interact with one another through a kernel function
  - Particles do not deform so element deletion is not necessary
  - Smaller number of total particles needed than an Eulerian mesh
  - Some codes allow for particle conversion of Lagrangian elements on element death or embedding of particles at the beginning of an analysis



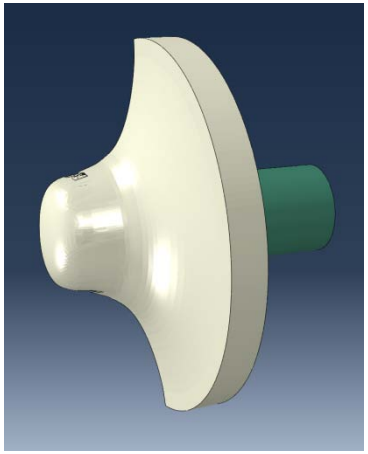
Constitutive Models

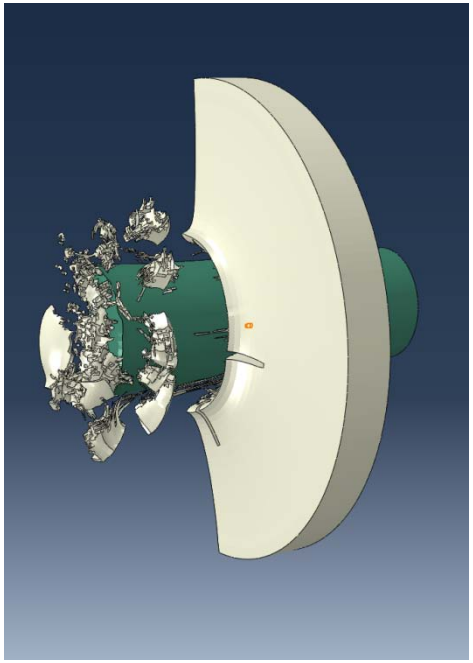
- Johnson-Cook typically used as it takes strains, strain rates, and heating effects into account

- Johnson-Cook shows excellent damage behavior in compression.

- In tension Johnson-Cook can lead to overly “stretchy elements”

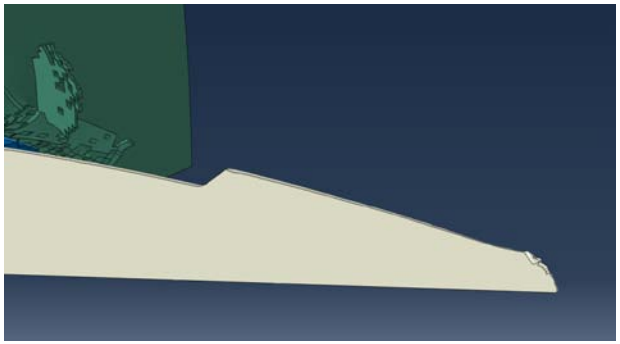
- To more accurately correlate to test data we typically need to add in a tensile failure stress or strain parameter

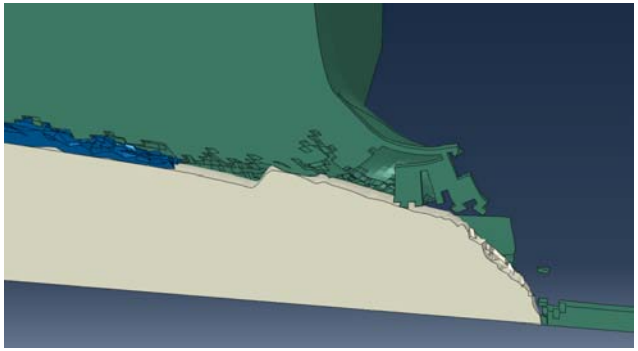




Material Properties

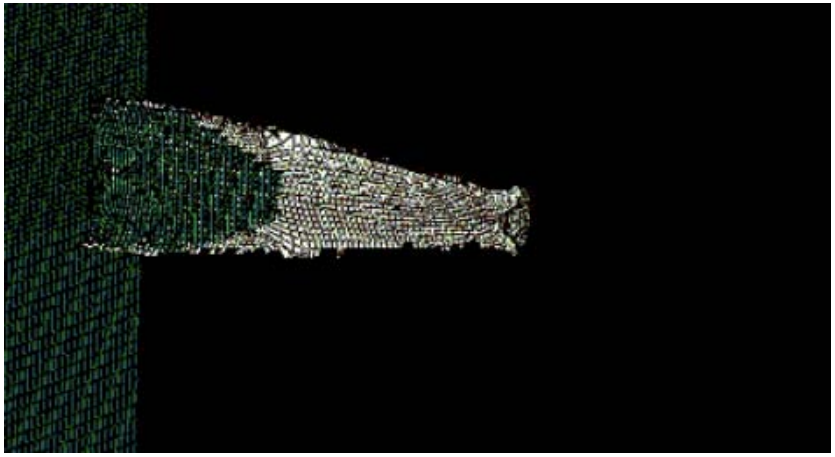
- Material Properties typically need to be calibrated with test data
  - Parameters used from standard material properties testing do not correlate to test data
  - Use Limit Velocity or residual velocity obtained from live fire data as primary calibration criteria
  - Also use final penetrator shape and entrance and exit hole diameters as secondary criteria
  - Calibration across different material strengths and impact velocities prove challenging

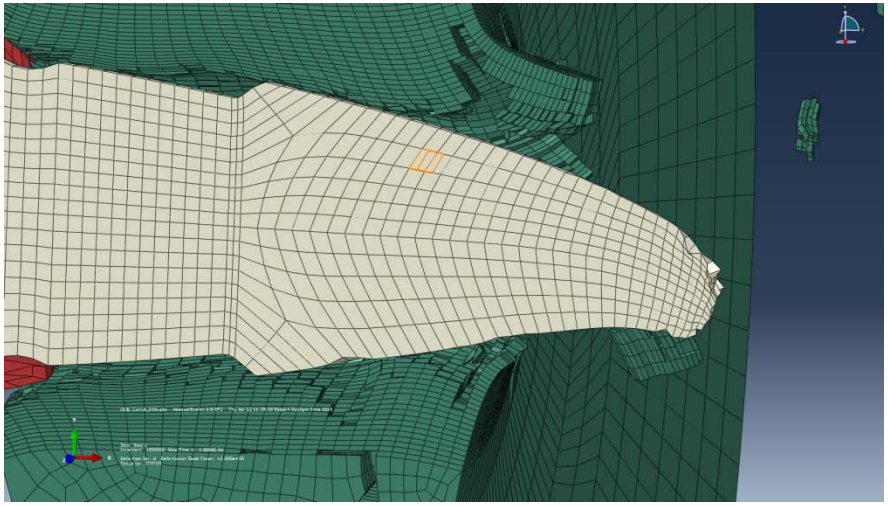




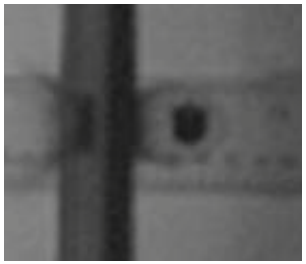
Contact issues

- Time step and mesh density needs to be adjusted so inner element penetration does not occur

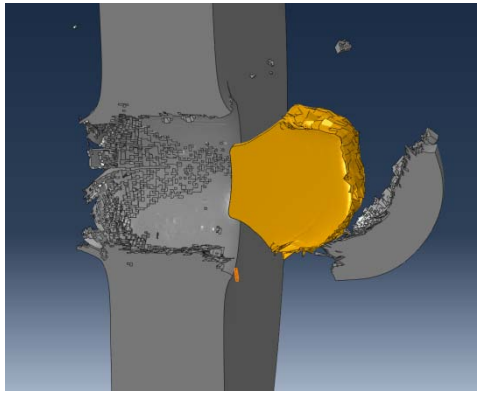




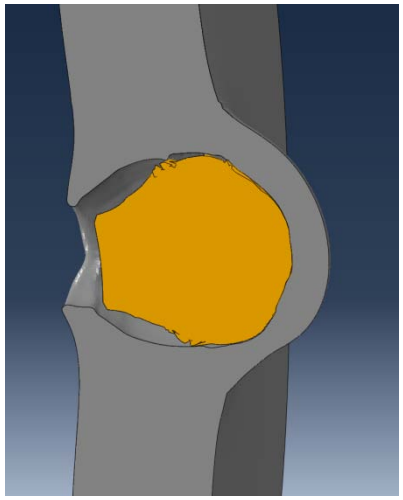
Comparing different Meshing



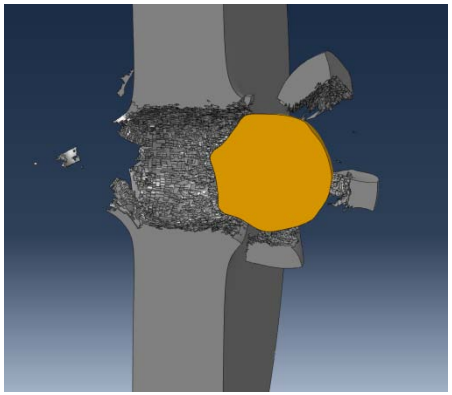
Test Data



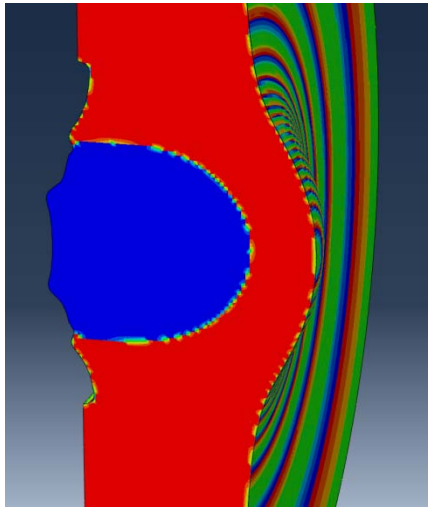
Lagrangian Plate and Bullet



Eulerian Plate with Lagrangian Bullet



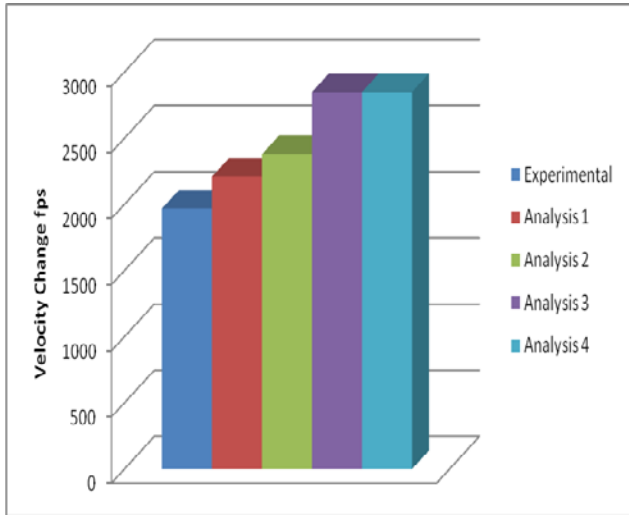
Lagrangian Plate with Eulerian Bullet



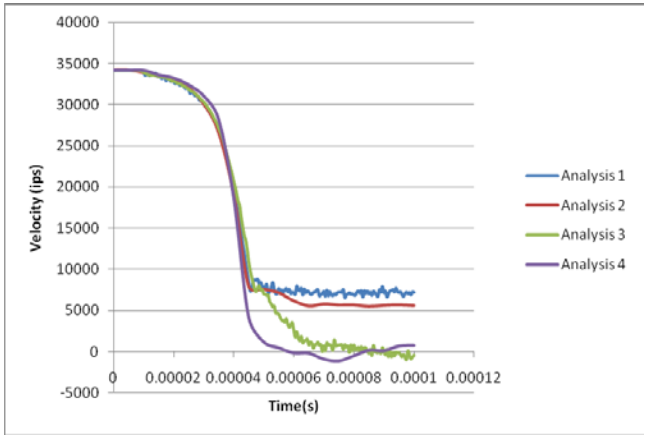
Eulerian Plate and Bullet

Comparing different Meshing

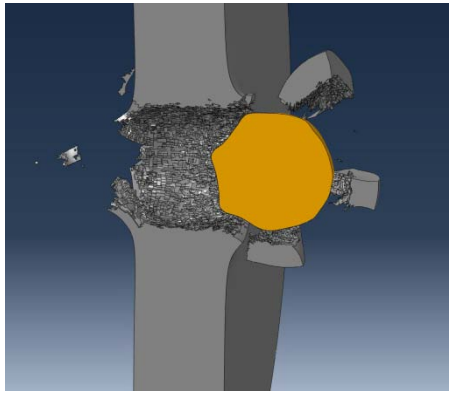
Comparison of Residual Velocities



Velocity Decay during the penetration event



Comparing different Meshing

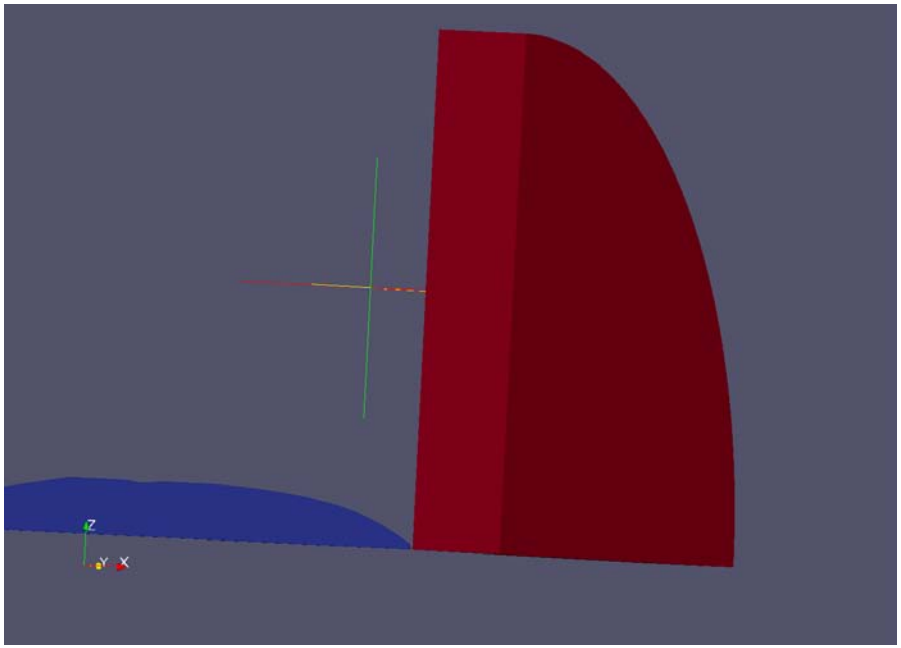


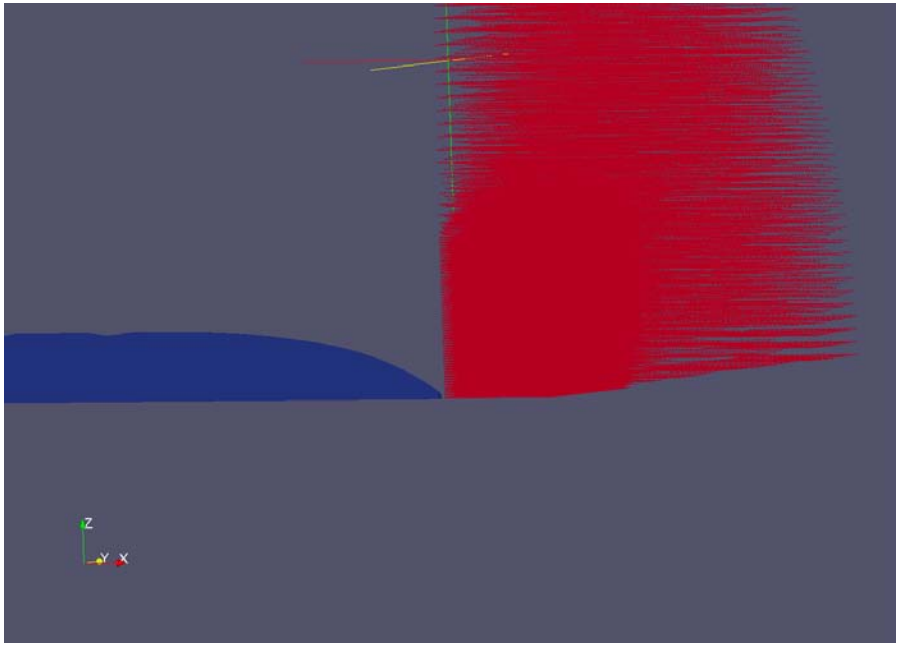
Impact Perforation

Exit Perforation

Perforation Size	Entrance	Exit
Experimental Average	0.321	0.568
Experimental Std. Deviation	.00873	.01001
Analysis 1	0.346	0.505
Analysis 2	0.347	0.492
Analysis 3	0.266	N/A
Analysis 4	N/A	N/A

Comparing different Meshing - SPH





Conclusions

- There is no 100% correct way to model plate penetration
  - Each meshing method has it's own respective strengths and weaknesses and requires significant engineering judgment regarding their uses
  - Lagrangian bullets on Lagrangian plates typically make the best starting point for material calibration and initial modeling
  - If mass loss is a significant problem during initial modeling Eulerian and SPH sections can be explored to negate these effects
  - Regardless of the meshing method used calibration to test data is essential for accurate modeling.

Questions?