Modeling and Simulation Advances in Large Caliber Muzzle Brake Development

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NDIA Gun & Missile Systems Conference & Exhibition

April 6-9, 2009, Kansas City, MO

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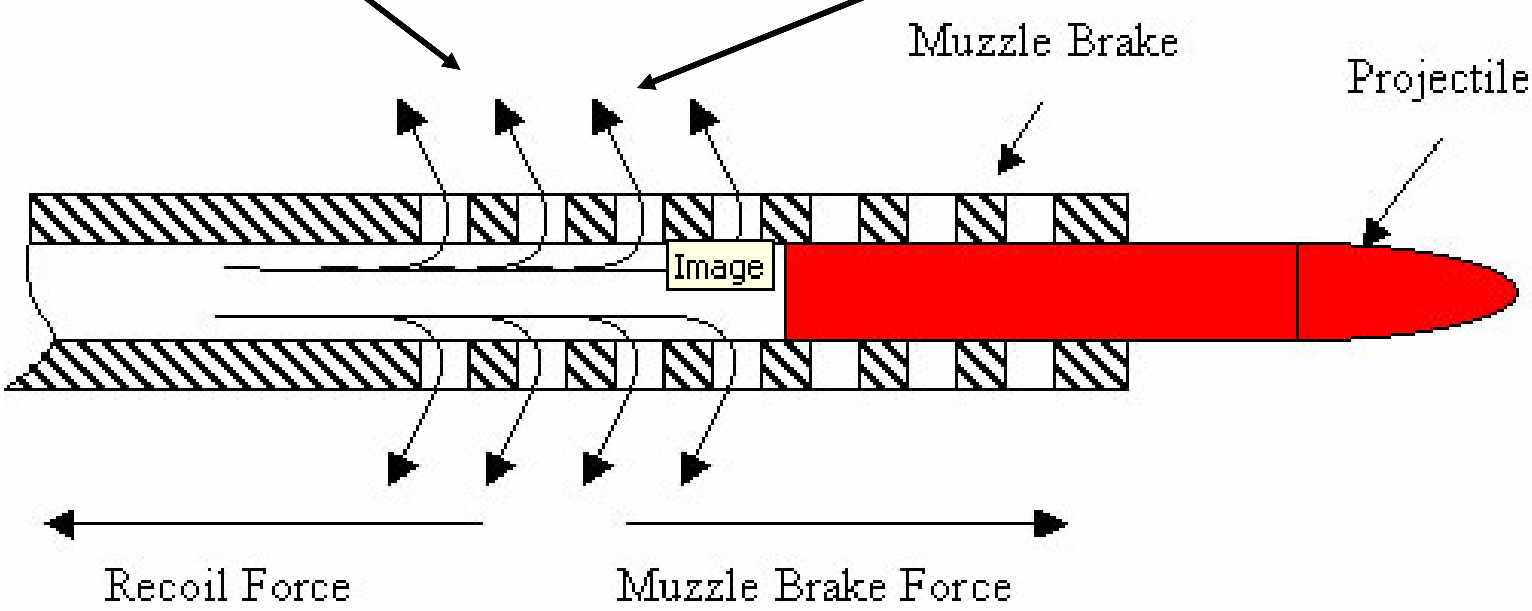
Outline

- Basic Muzzle Brake Design Principles
- Impulse Reduction Modeling
- CFD Based Blast Modeling
- Empirical Blast Modeling
- One-Way Structural-Thermal Modeling
- Two-Way Fluid-Structure Modeling

Muzzle Brake Design Principles

Reduced gun impulse

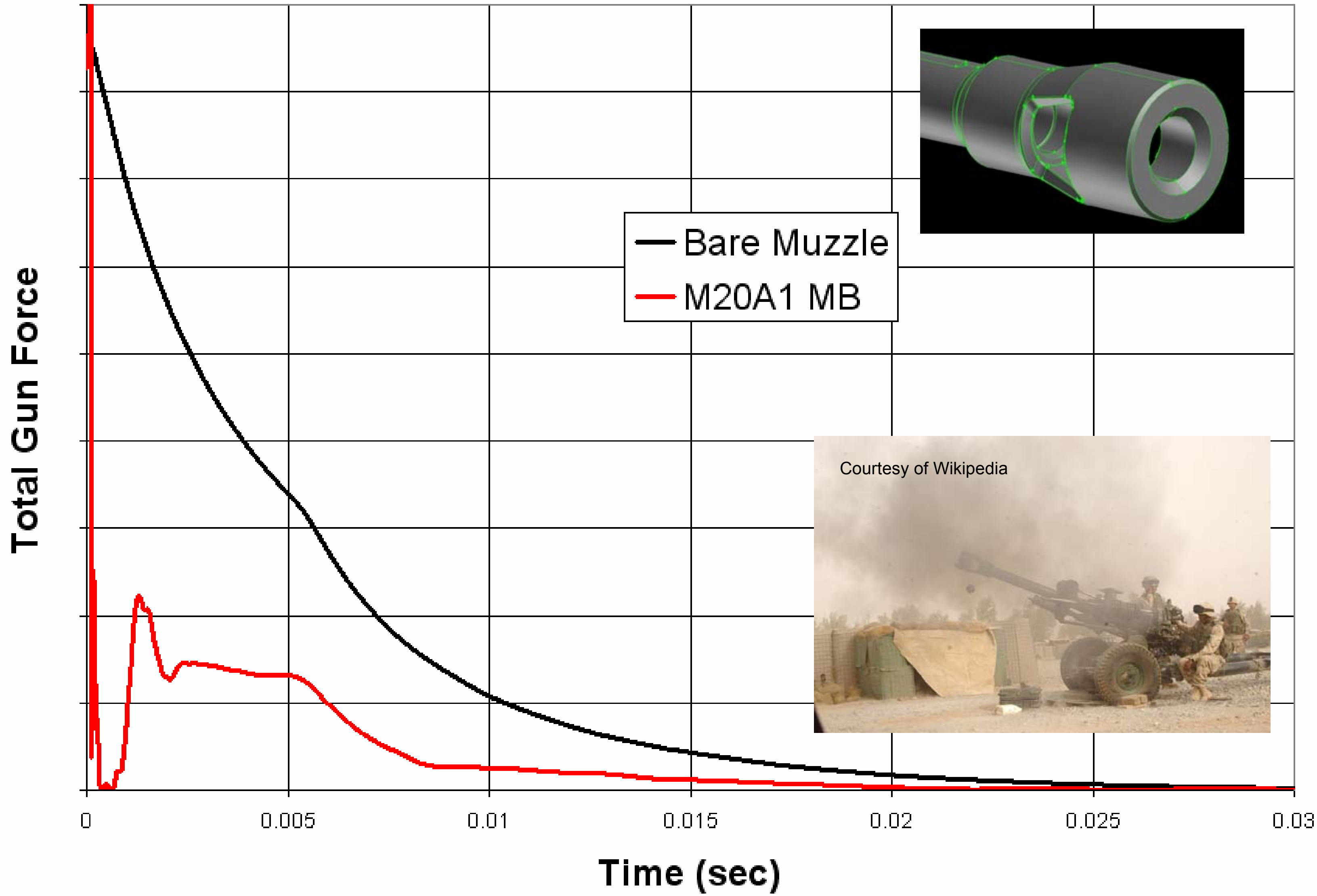
Minimize blast effects



Minimize gun weight

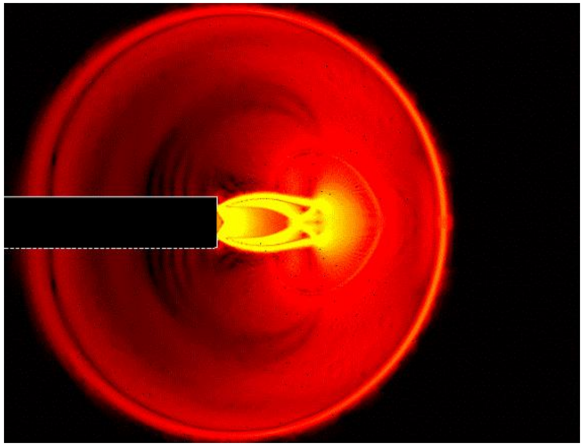
Minimize flash

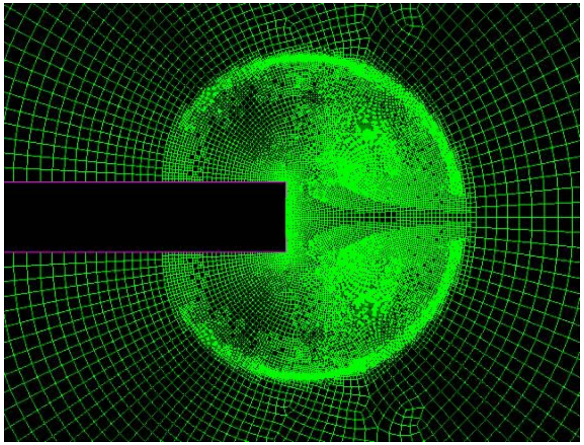
M119 - M20A1 Baseline Impulse Study Unsteady 3-D CFD Simulation Results



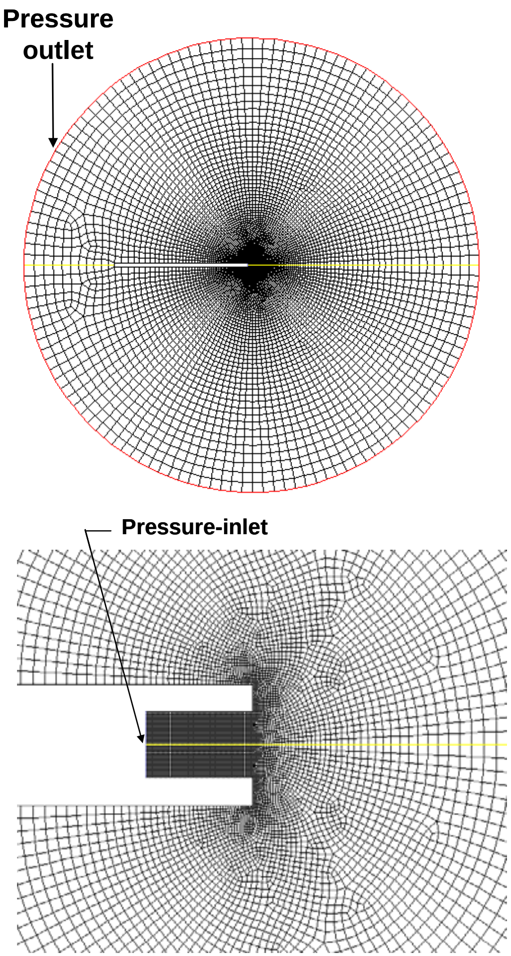
CFD Based Blast Modeling

- **Blast - Moving Shock Wave**
  - **Propagates at Faster than Speed of Sound**
  - **Very Fine Structures (0.5 mm thick)**
  - **Very High Pressures (7,000 – 15,000 psi at muzzle)**
- **CFD Requirements**
  - **Shock Wave is a Discontinuity in Flow Field**
  - **Requires**
    - **Very Fine Grid**
    - **High-Order Spatial Resolution**
    - **Very Large 3-D Flow Domains**
  - **Fixed Grids are Not Feasible for 3-D Gun Simulation**
  - **Higher Order Solvers Typically Not Stable at Gun Pressures**
  - **Dynamic Grid Adaption is Only Realistic Option**
  - **Highly Specialized Codes is a Second Option**
- **Dynamic Grid Adaption**
  - Refine and Coarsen Mesh as Blast Wave Propagates Through Flow Domain
  - Based on Flow Field Gradients and Properties
  - Solution Based Automatic Adaption

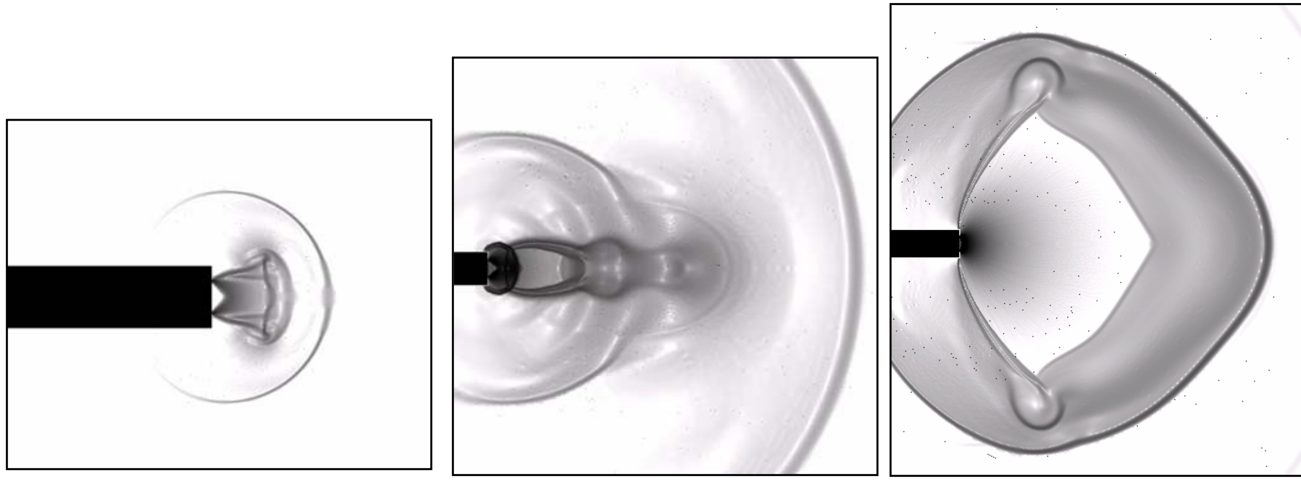




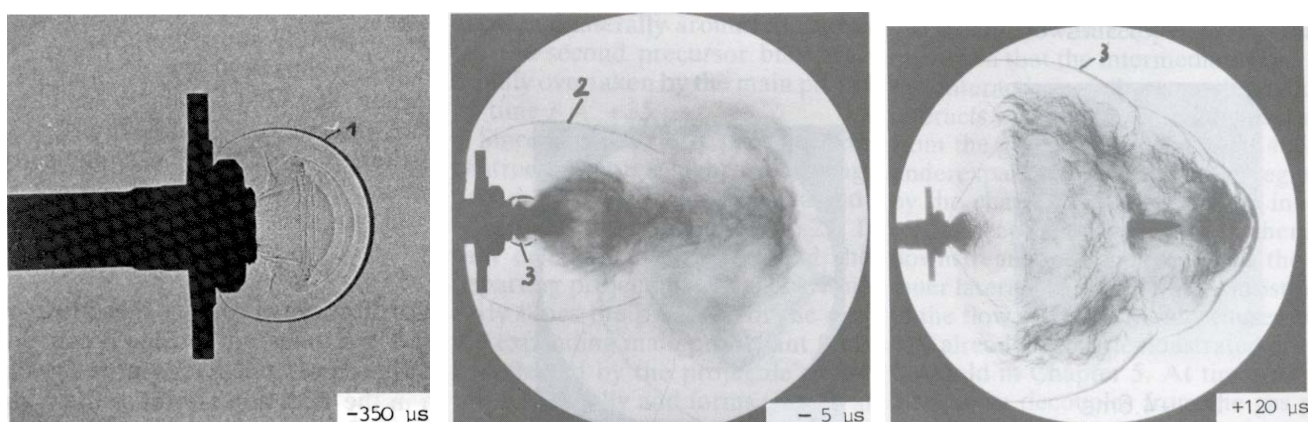
CFD Blast Analysis – Fluent
7.62 NATO G3 with DM41 Round



1st Pre-Cursor | 2nd Pre-Cursor | Main blast wave



FLUENT: t = -350 μsec | t = -5 μsec | t = +120 μsec



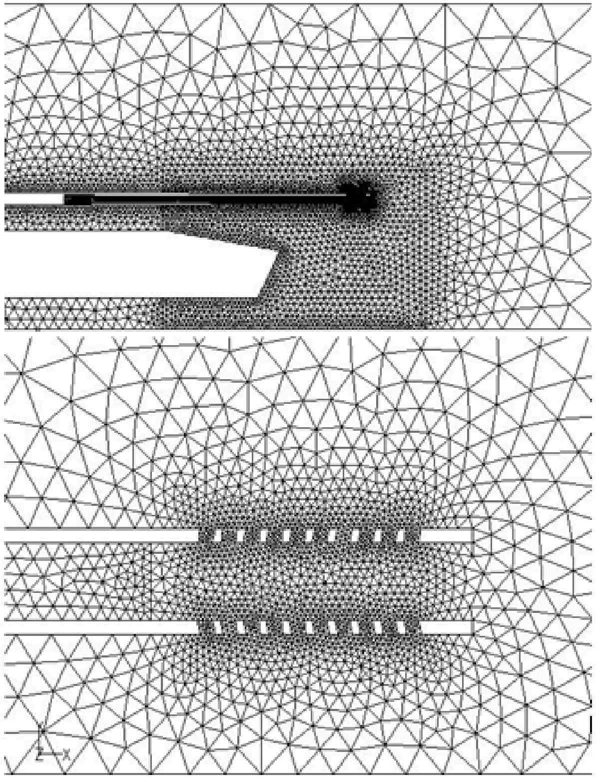
Experiment

Ref: Gun Muzzle Blast and Flash, *Progress in Astronautics and Aeronautics, Vol. 139; Klingenberg, Gunter, Heimerl, Joseph M., Seebass, A. Richard Editor-in-Chief, AIAA*

BWIP
Mesh and Solution-based Adaption Parameter

Solution-based Blast Wave Identification Parameter (BWIP)

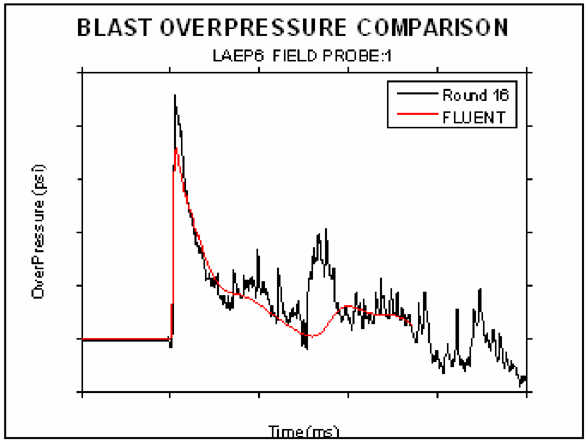
- ANSYS-Fluent CFD Solver
- Add-on to Improve Adaption
- Find Shock Location
  - Mach Number Near 1
  - Large Pressure Gradient
- Control Adaption
  - Better Coarsening
  - Better Refinement
- Reduce Total Cell Count
- Reduce Solution Time
- Improve Quality With Finer Resolution

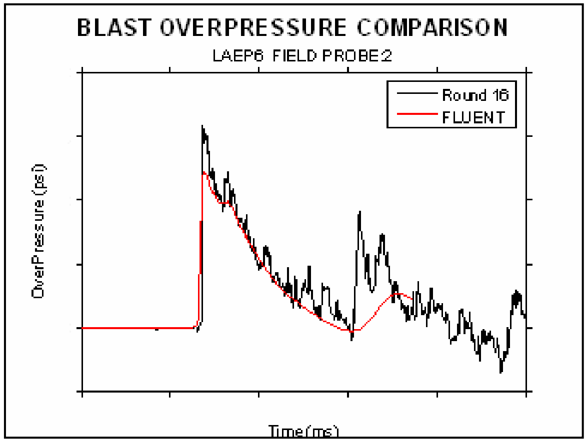


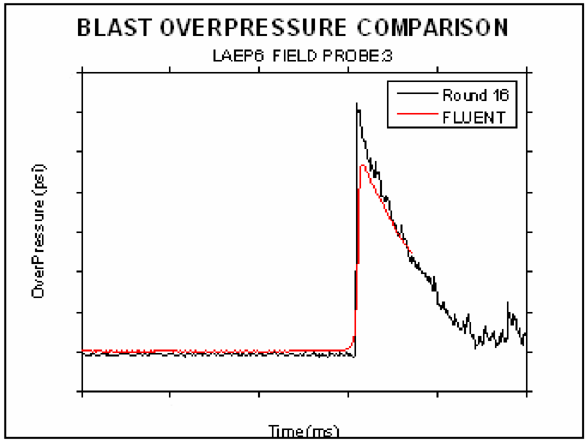
XM-360 Gun on
FCS MCS Chassis

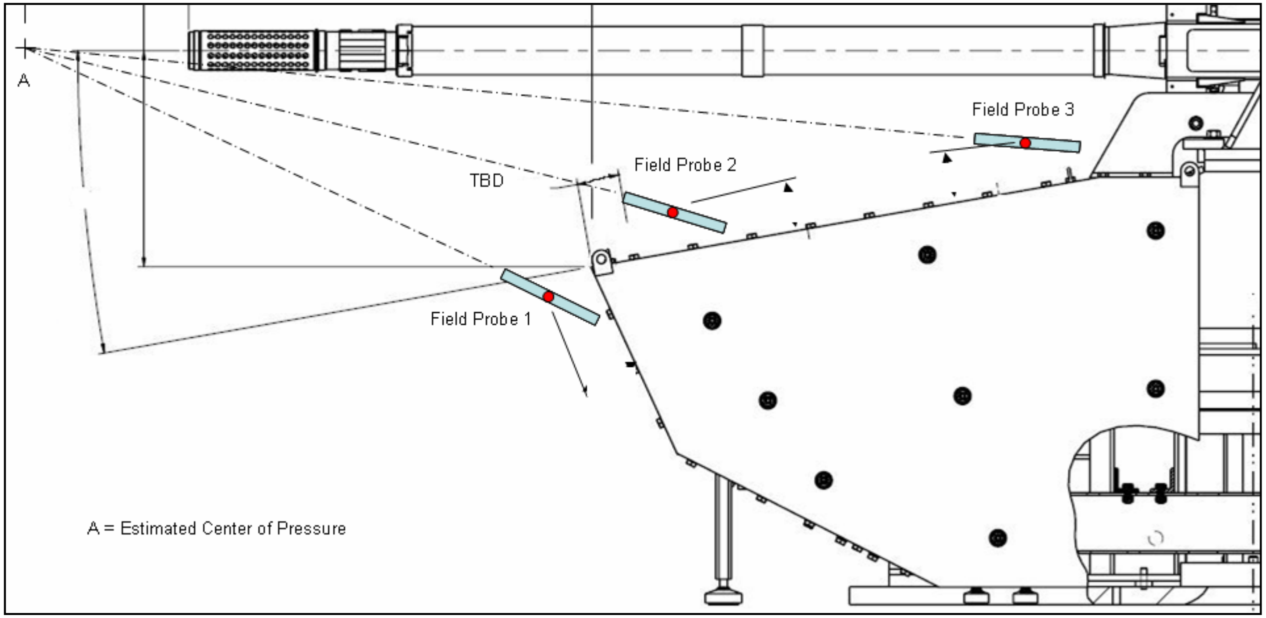
BWIP Validation

Overpressure for XM-360 on FCS MCS Chassis

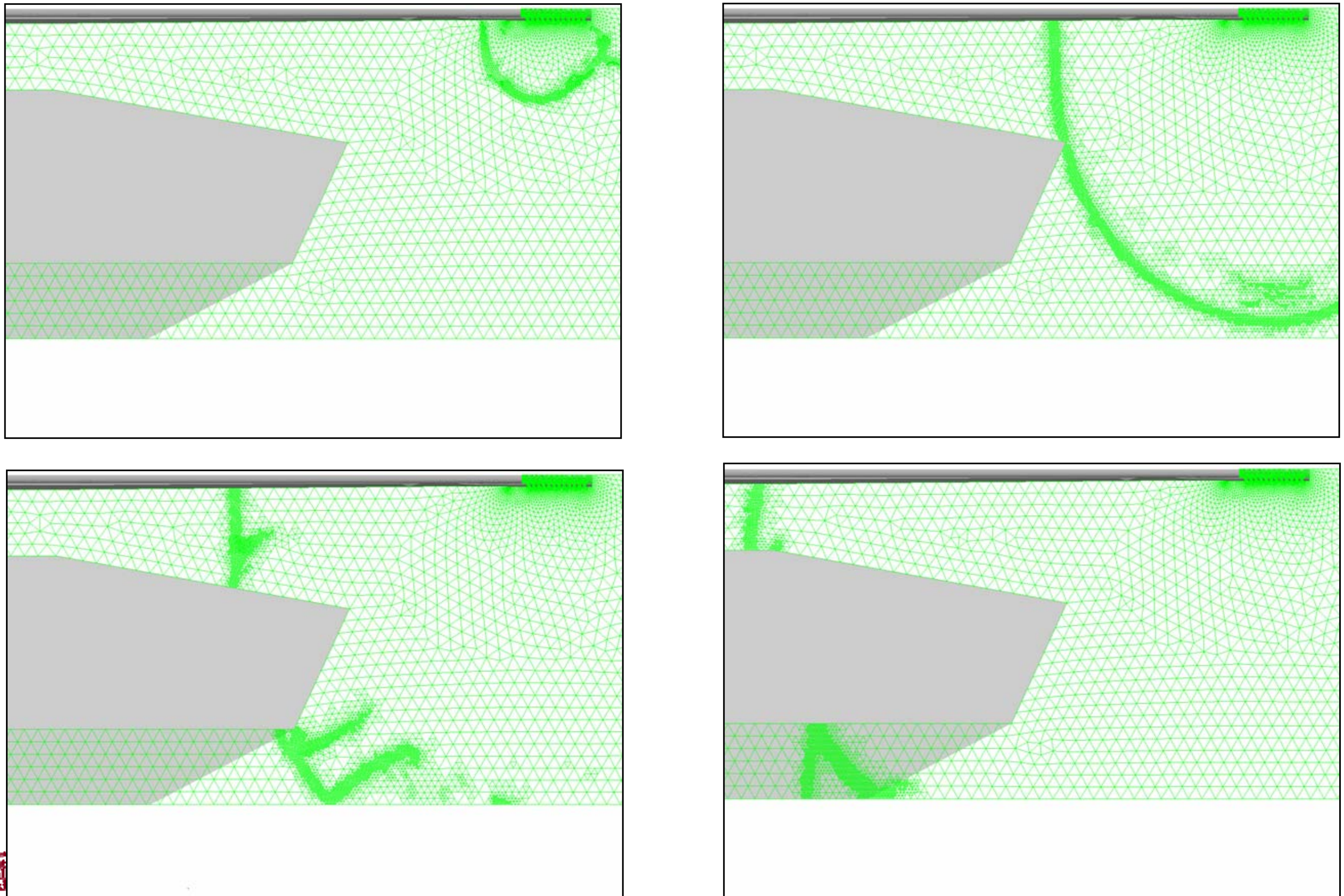




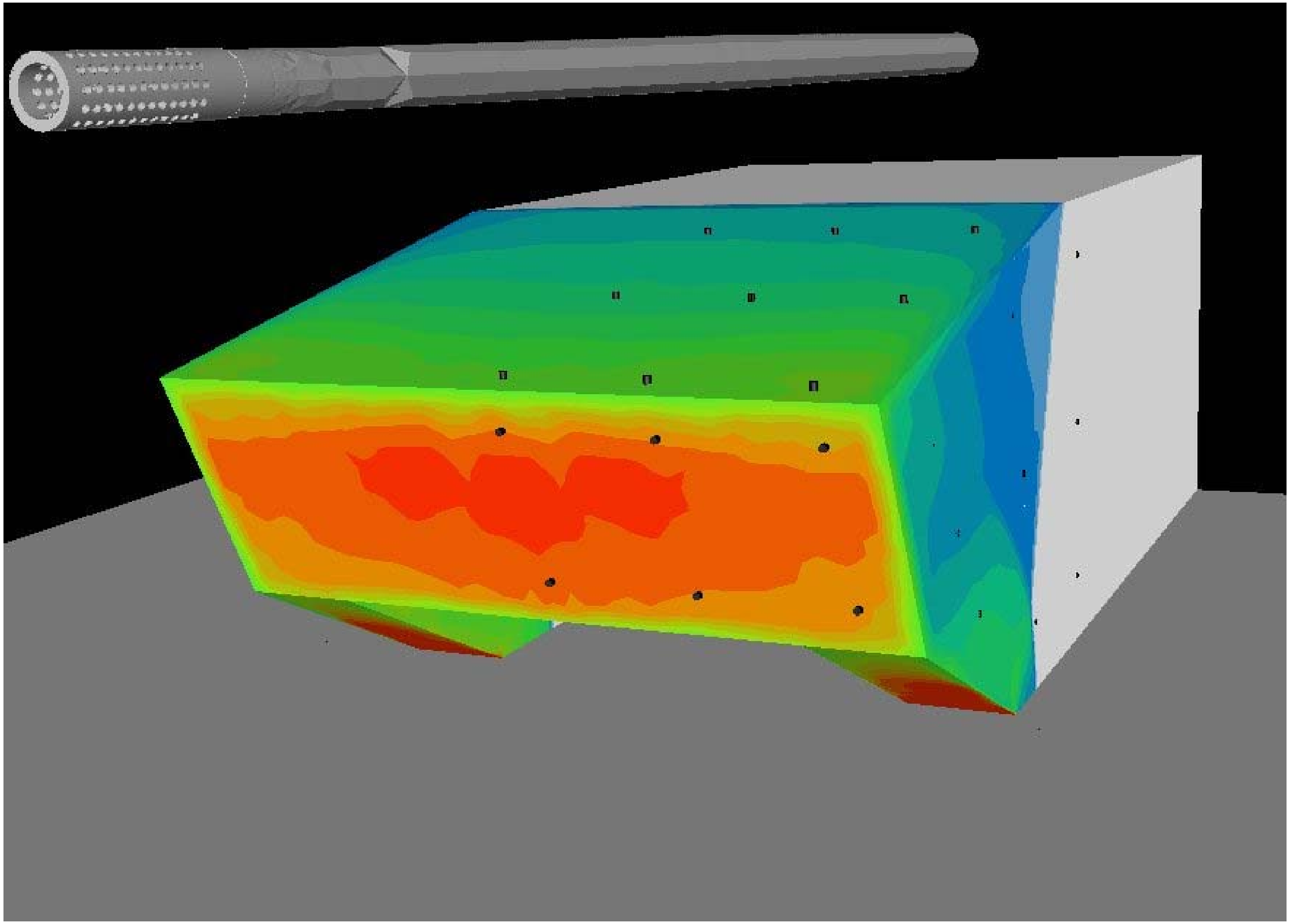




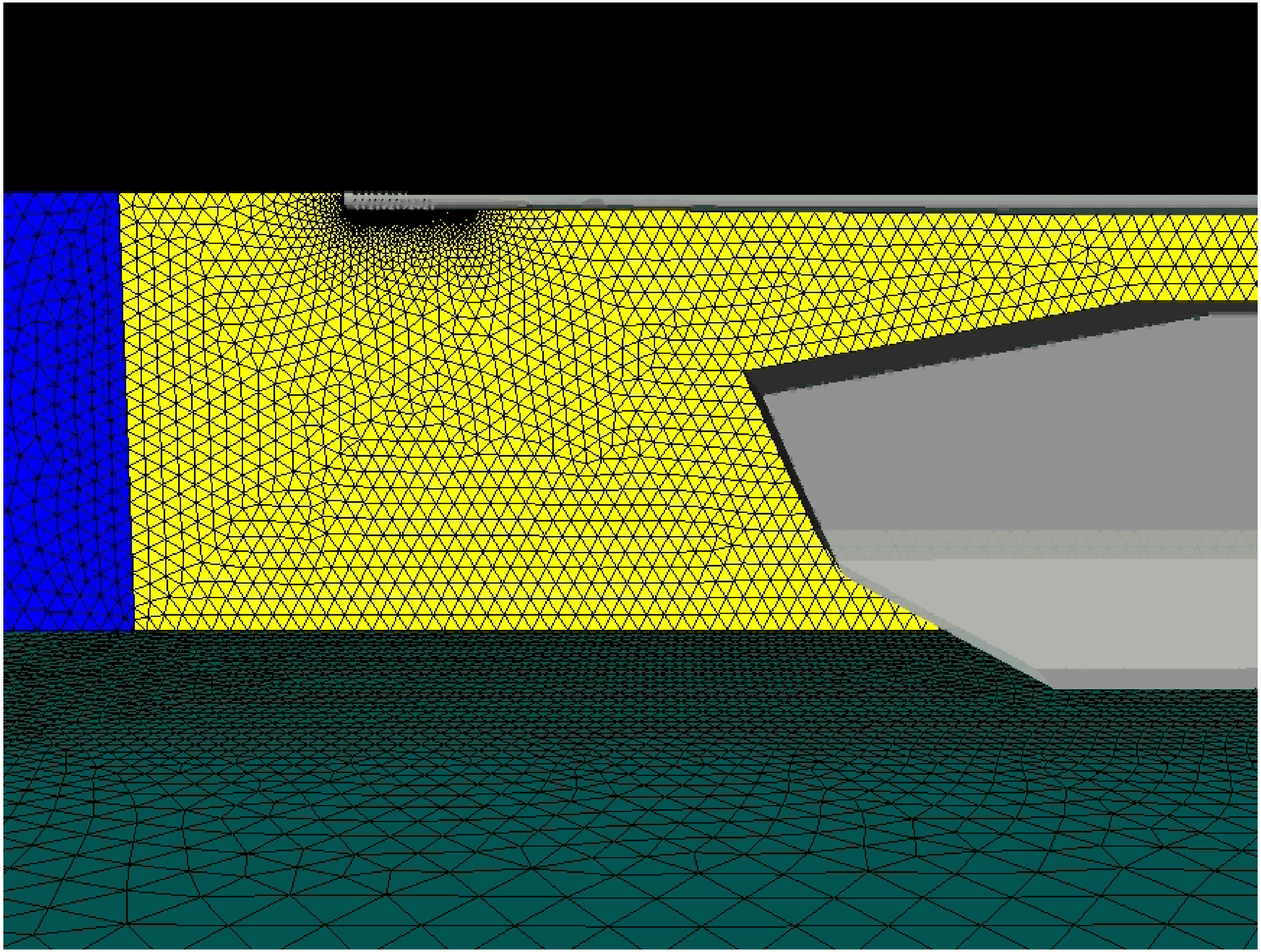
BWIP Validation
Dynamic Grid Adaption – XM360



BWIP Validation
Peak Overpressure Contour Plot – XM360

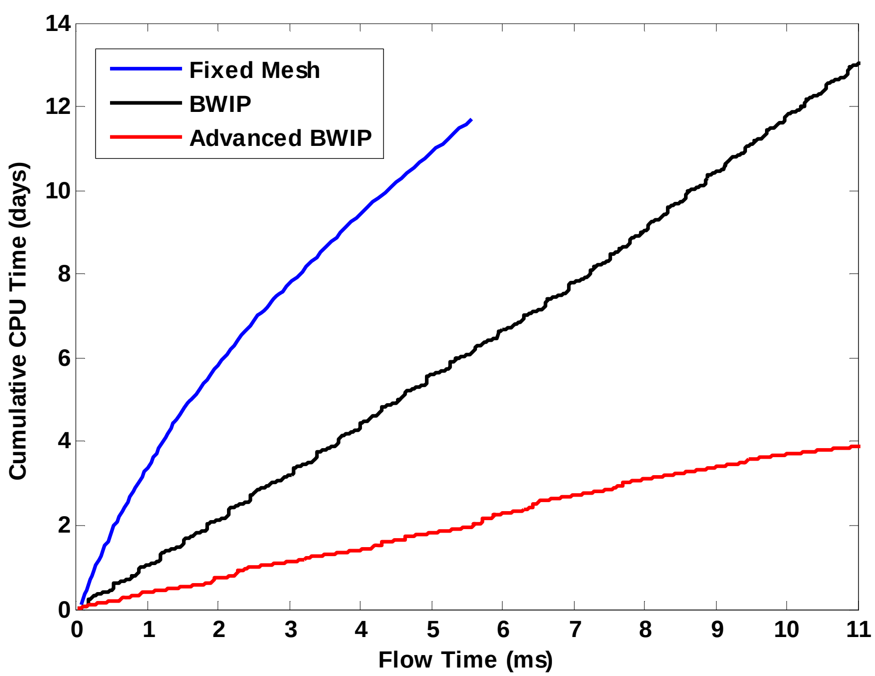


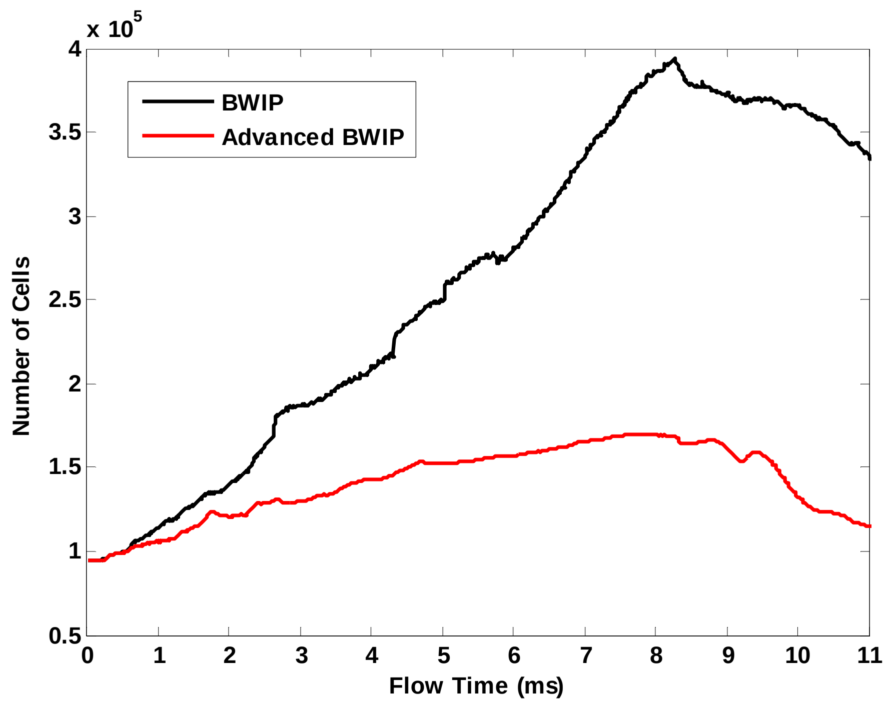
BWIP Validation
Dynamic Grid Adaption – XM360



BWIP 2-D Simulation Computational Performance Comparison

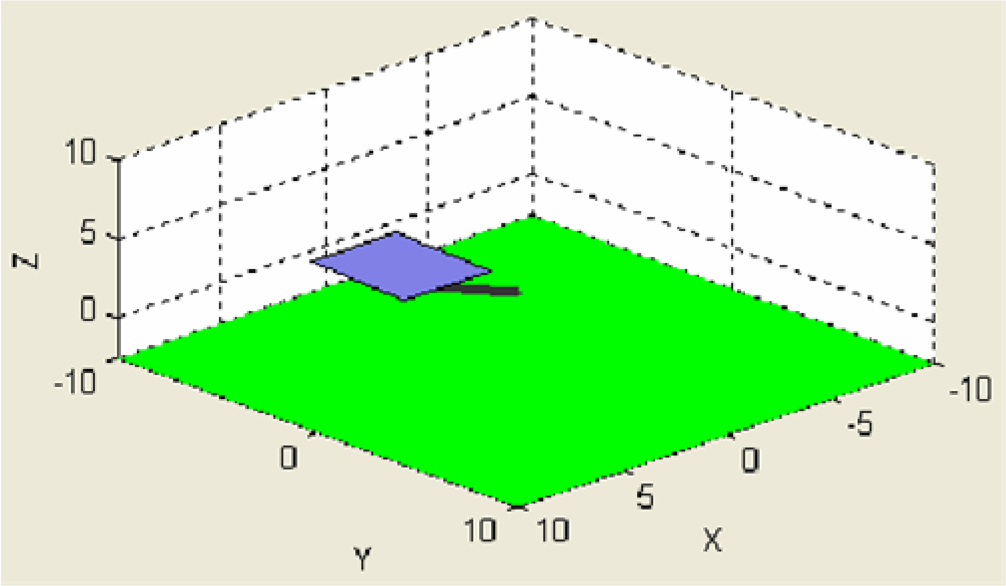
- 2-D simulation of Fixed Mesh, BWIP and Advanced BWIP.
- Advanced BWIP is one order of magnitude faster than a fixed mesh.
- Extrapolating to 3-D, we can see BWIP would be two or more orders of magnitude computationally faster than fixed mesh



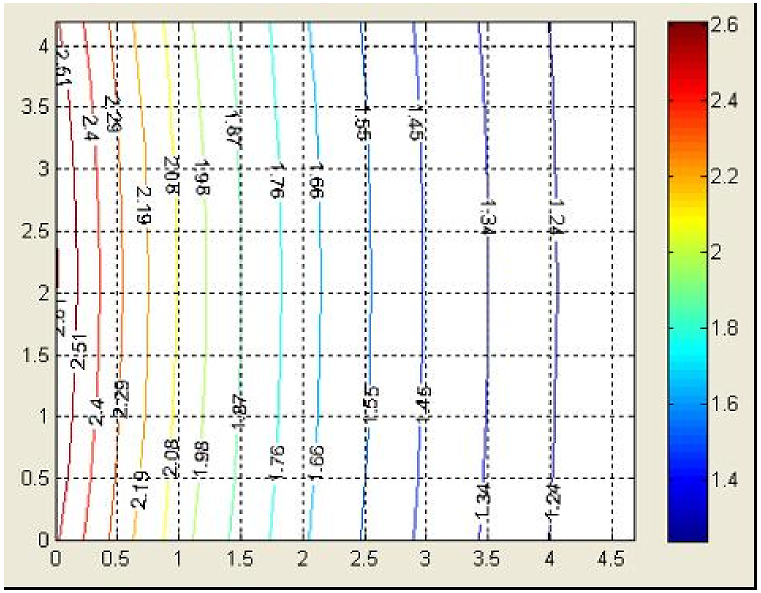


Empirical Blast Wave Modeling 3-D Fansler Blast Code

- Simplified Empirically Based Scaling Based On Fansler Blast Code
- Mat-Lab Based GUI Front End
- Input Parameters
  - Gun Geometry, Elevation and Azimuth
  - Vehicle and Ground Reflection Planes
  - Interior Ballistics
  - Muzzle Brake Efficiency



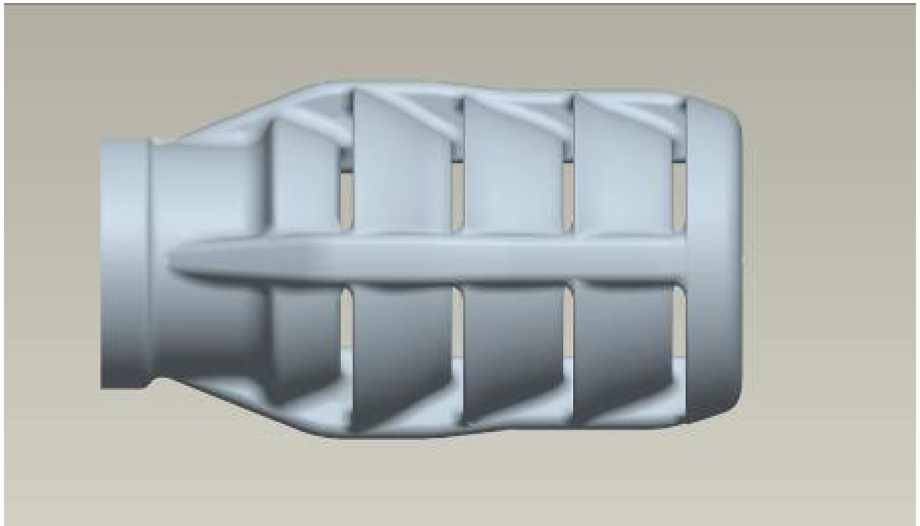
M256 Gun With M1 Abrams Turret Plane
Gun at 20 Degrees Elevation



Turret Peak Incident Pressure (psi)

XM-324 NLOS-C Muzzle Brake Thermal-Structural Analysis

- 3.5 Caliber Optimized Muzzle Brake
    - Maximum Efficiency
    - Short Length
    - Minimum Weight

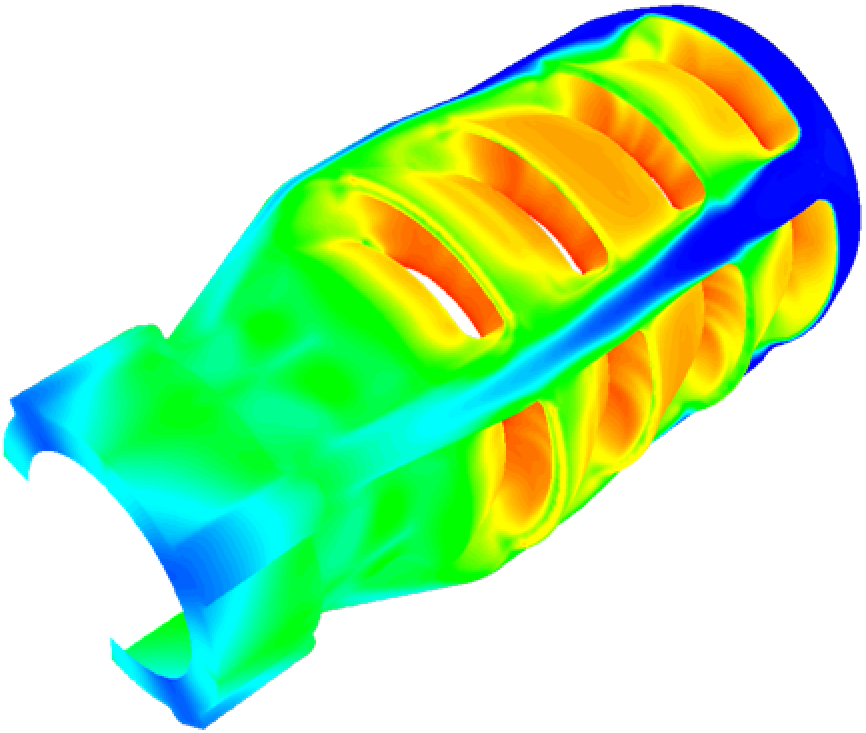


XM-324 NLOS-C Muzzle Brake Thermal-Structural Analysis

- High rate of fire cannon
  - 6 rounds/minute
  - Standard magazine
  - Standard reload
- Determine Temperature Field Prior to Last Shot
- Reduced Structural Properties
- Unsteady Structural Model For Last Shot
- Determine Peak Stresses and Structural Integrity
- Reduce Muzzle Brake Material In Low Stress Regions

Step 1: Fluent CFD Steady-State Convective Heat Transfer Analysis

- Steady-State Fluent Analysis
  - Vary Muzzle Pressure
  - Vary Wall Temperature
- Output
  - Surface Average Heat Transfer
  - 33 Separate Model Surfaces
- Utilizes Designed Experiments to Make Polynomial Models

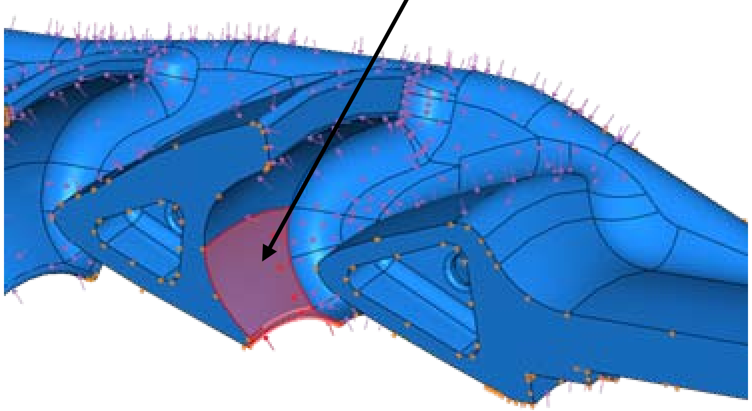


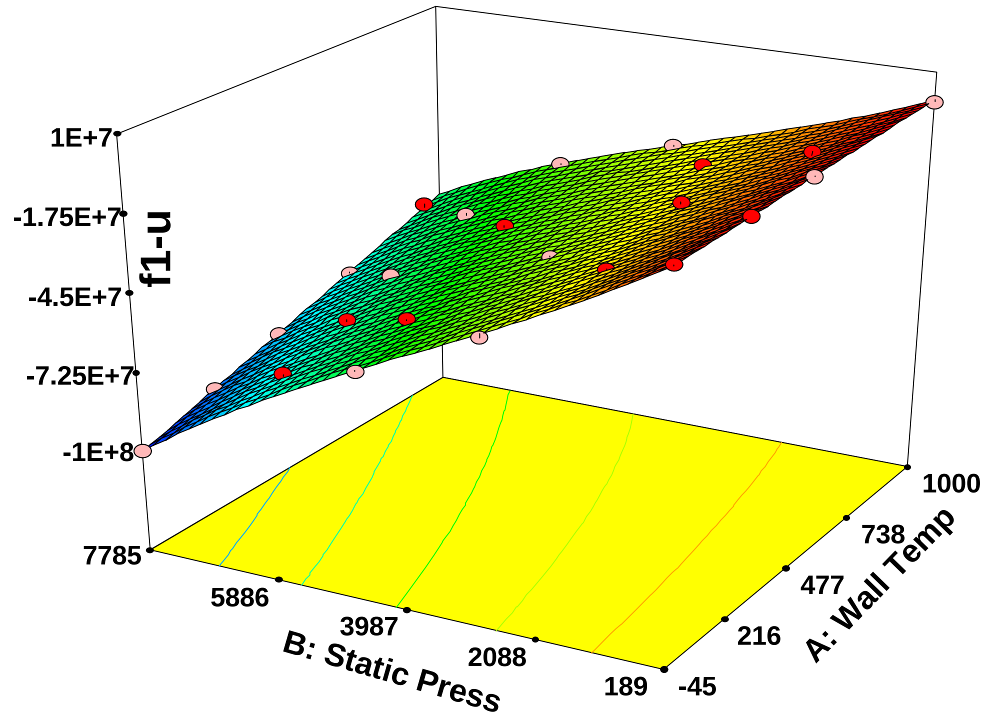
Contour Plot of Surface Total Temperature

Step 2: Develop Polynomial Models from Fluent Heat Transfer Data

- Develop a single cubic polynomial model of surface heat transfer for each of the 33 sub-surfaces.
  - Based on Muzzle Static Pressure
  - Based on Surface Wall Temperature
- Example polynomial model shown below for one surface.

Example sub-surface

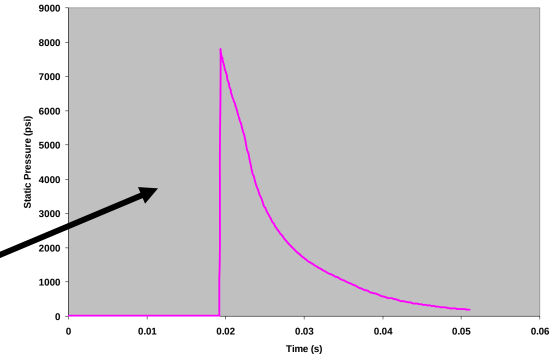


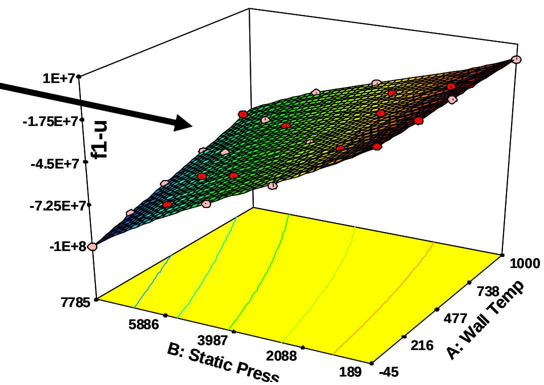


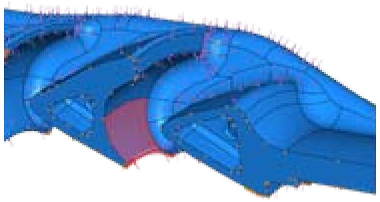
Step 3: ABAQUS Unsteady Thermal

<u>Goal – Determine Peak Temperature after Round 95</u>

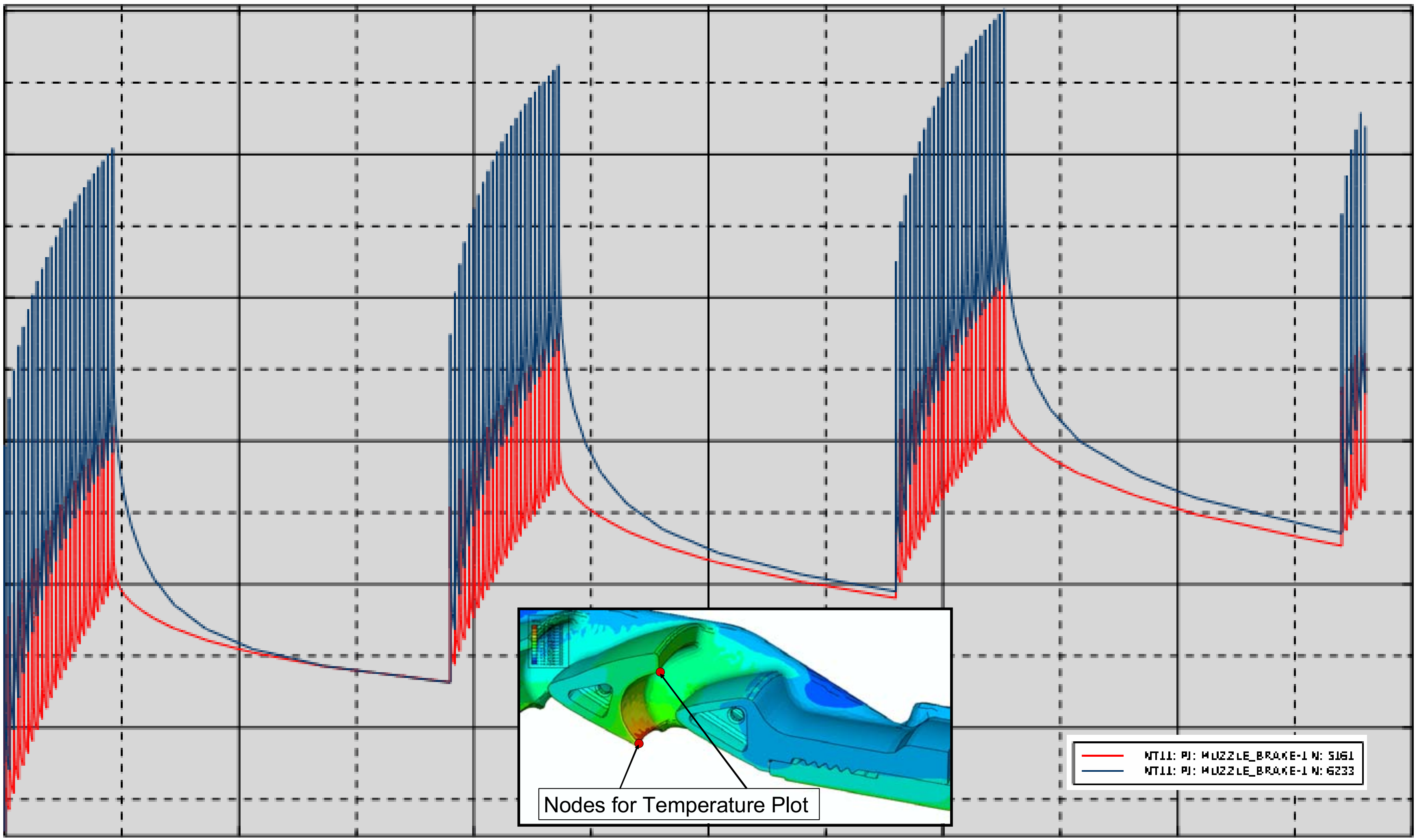
- Boundary Conditions
  - Firing Conditions
    - Forced convection heat transfer
    - Driven by polynomial pressure curve
    - Heat transfer boundary condition from Fluent polynomial model
  - Between Shot Conditions
    - Natural Convection Heat Transfer
    - Temperature dependent natural convection (no wind)
    - Solar radiation heat flux
    - Radiation to ambient
    - Ambient air temperature ≈ 54ºC







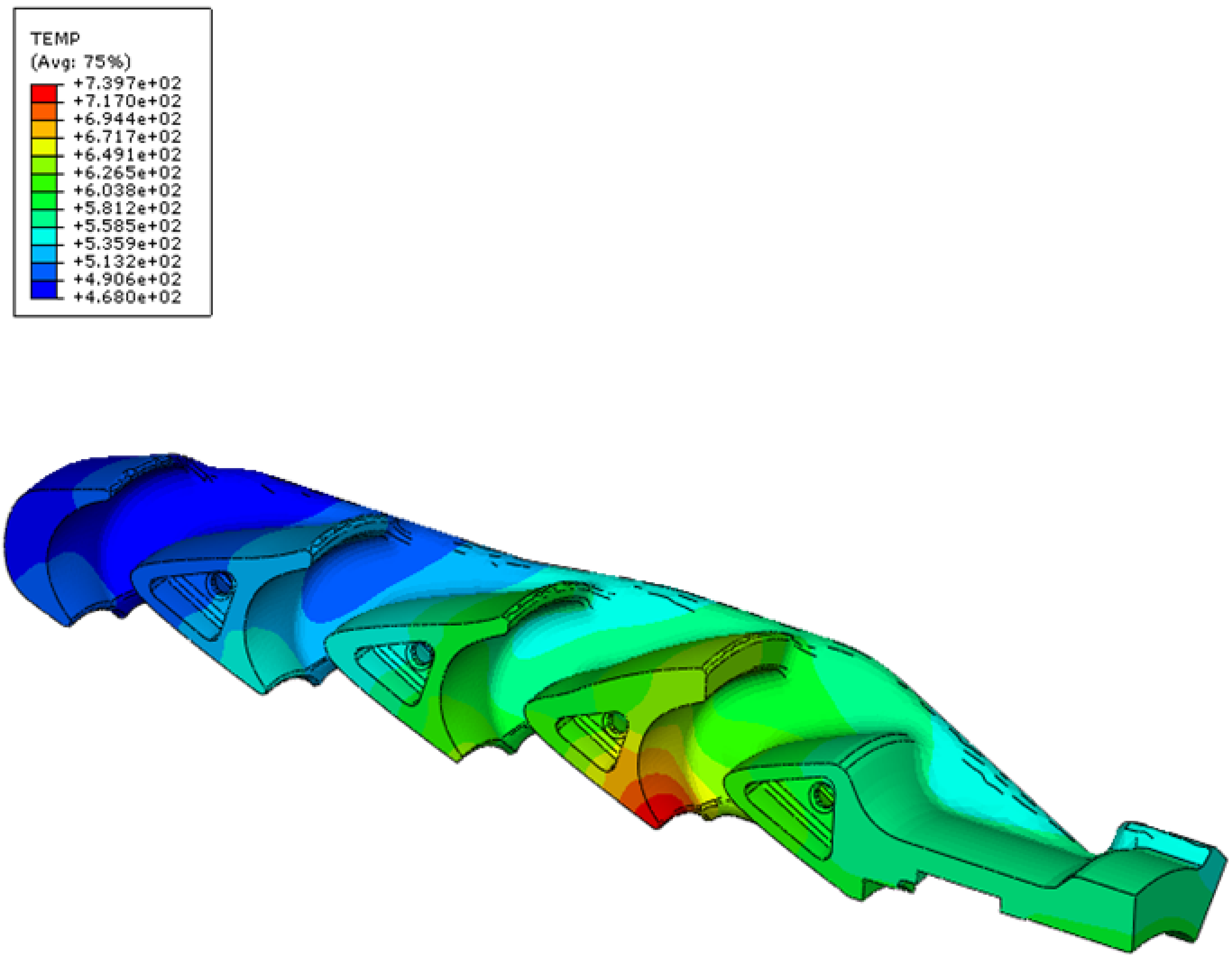
Step 3: ABAQUS Unsteady Thermal Surface Temperature vs Time



Step 4: Fluent Unsteady Loading Model

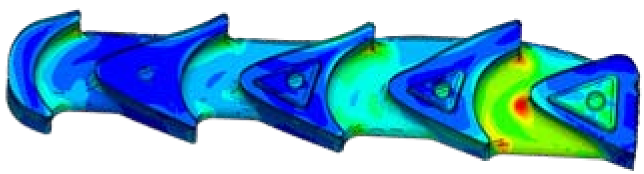
- Temperature and pressure patched into gun barrel based on projectile ready to enter muzzle brake.
- Flow allowed to expand using unsteady, coupled-explicit inviscid solver.
- Surface average pressure vs. time recorded during run for multiple surfaces.
- Used as input for unsteady ABAQUS structural model.

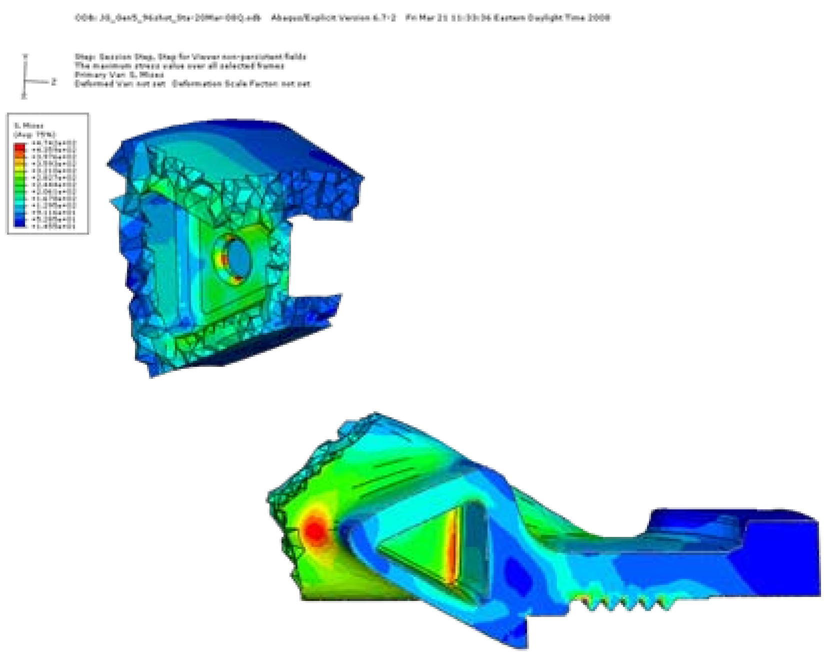
Step 5: ABAQUS Unsteady Structural Input Temperature Conditions



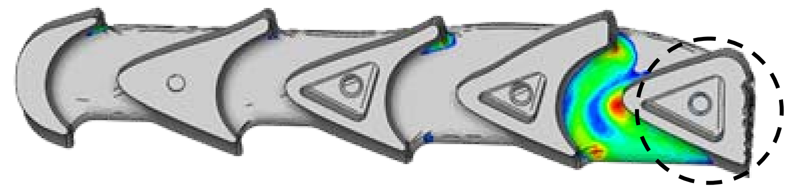
Step 5: ABAQUS Structural FEA Peak Stress Results

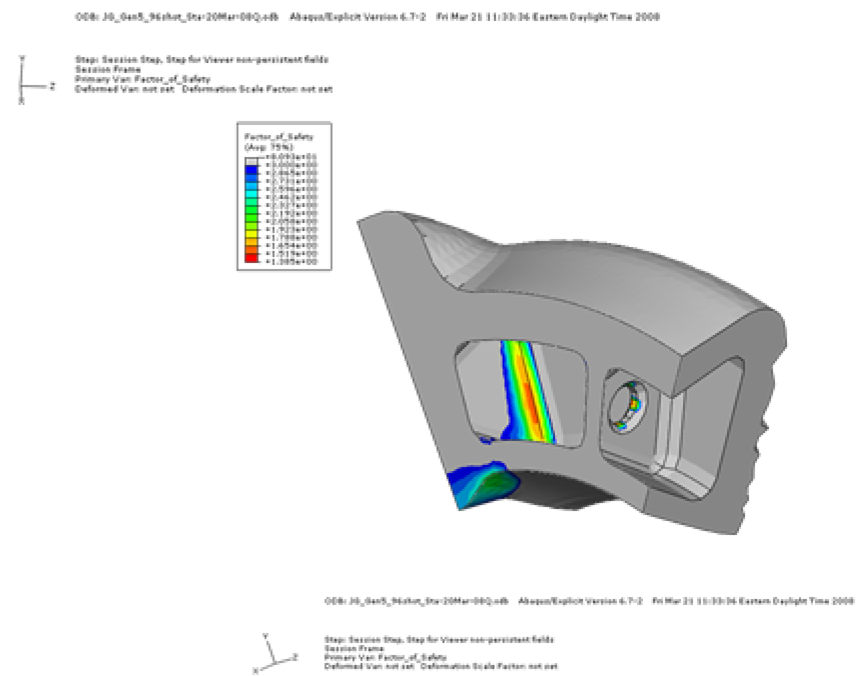
Results: Von Mises Stress





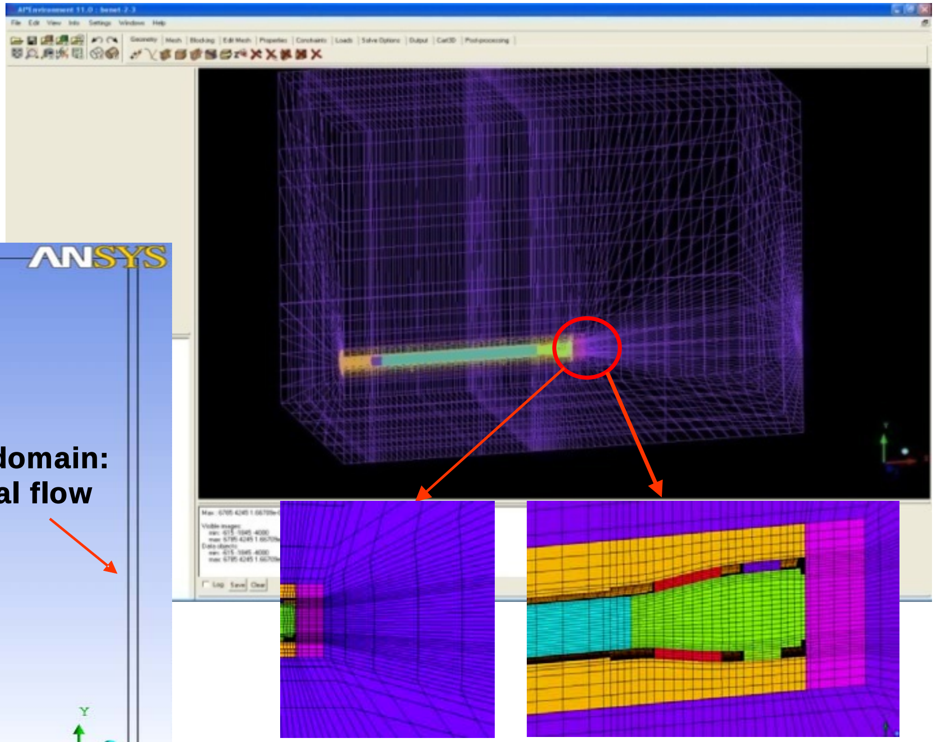
Results: Factor of Safety

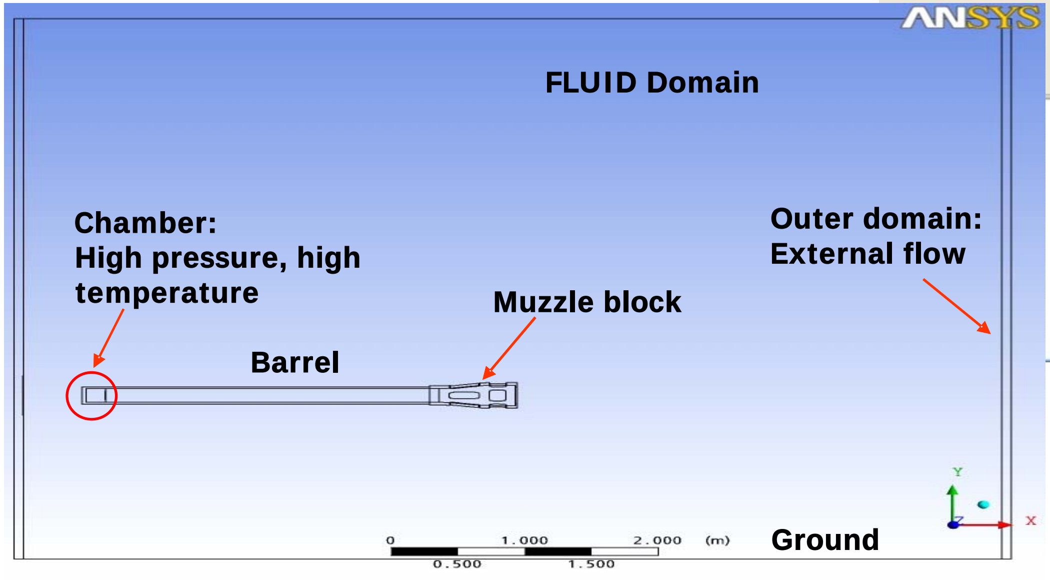




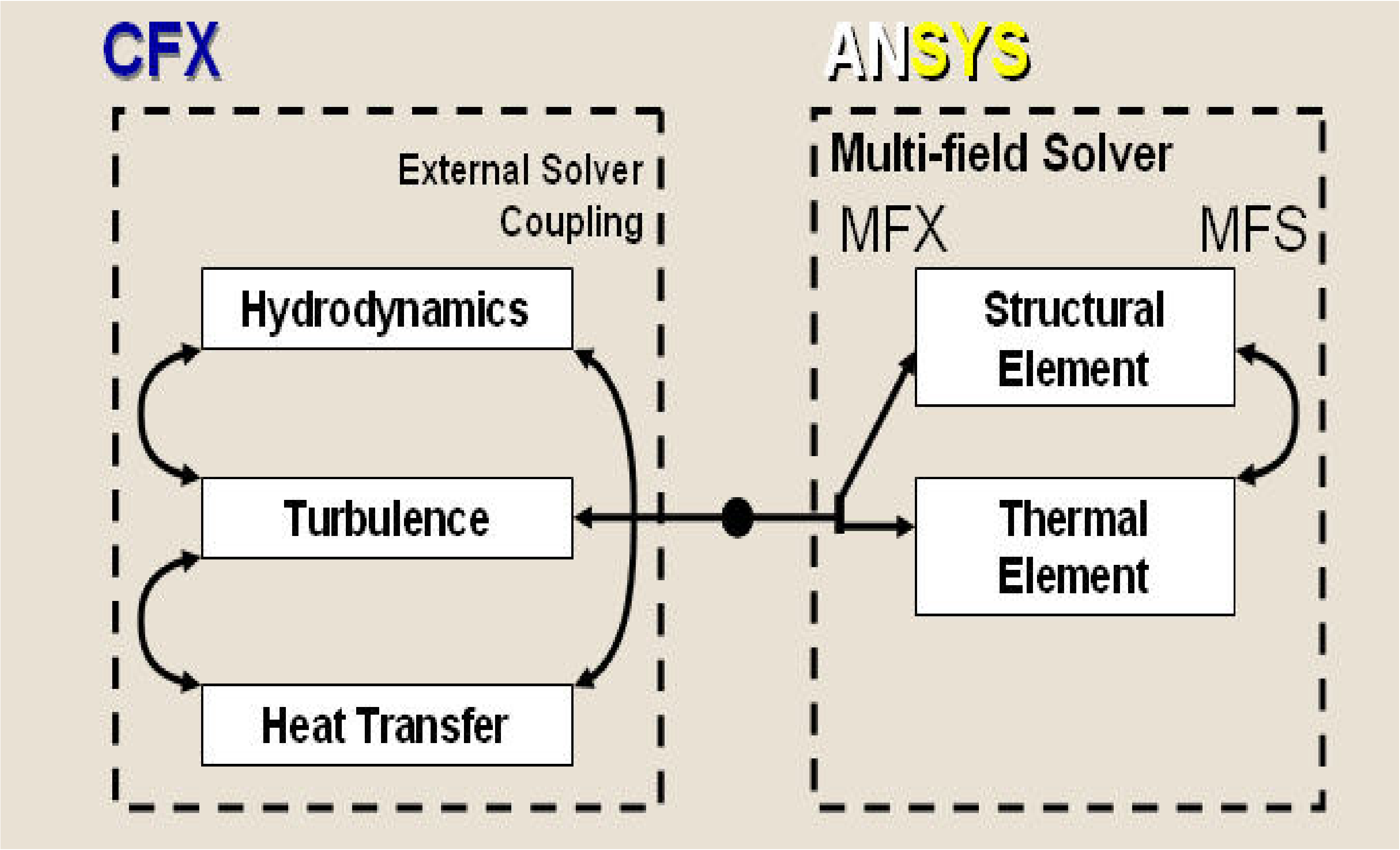
Fully Coupled Fluid-Structural Analysis Generic Barrel and Muzzle Brake

- Fluid Domain Simulated with ANSYS CFX
- Solid Domain Simulated with ANSYS Mechanical
- Full Two-way Coupling with ANSYS Multi-Physics



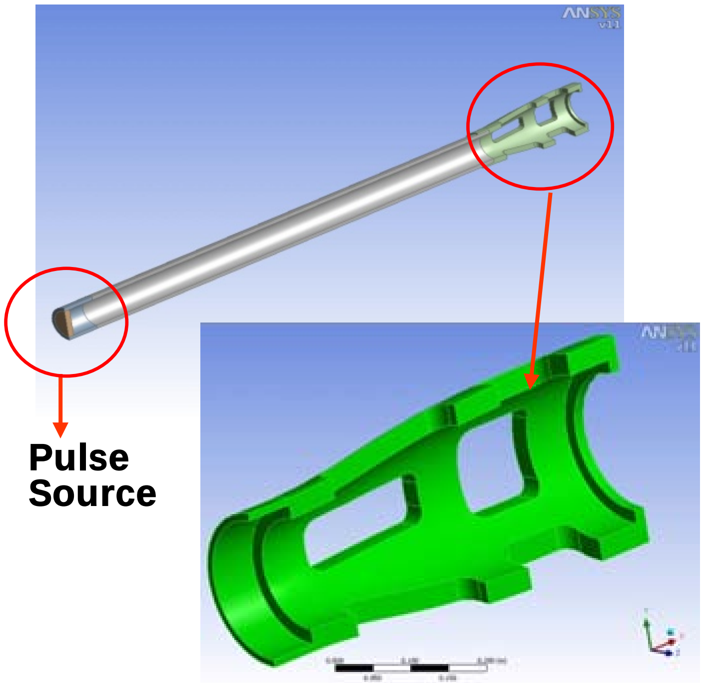


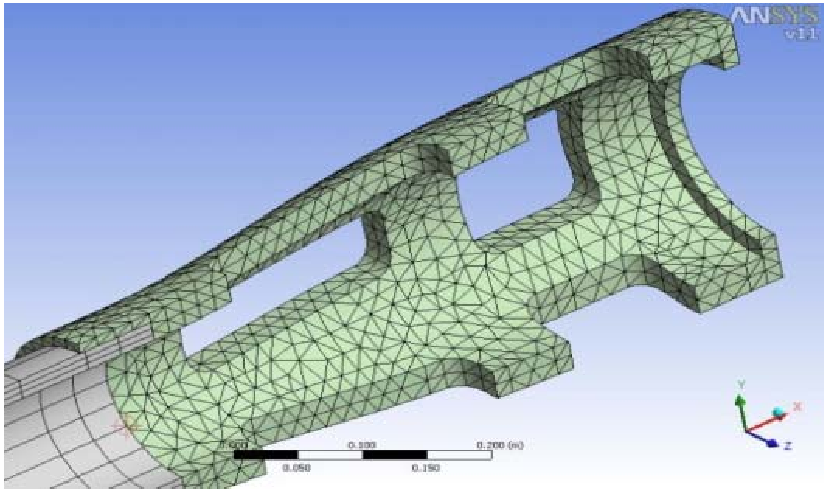
ANSYS Mechanical Multi-field Solver to CFX Coupling



Mesh and Setup

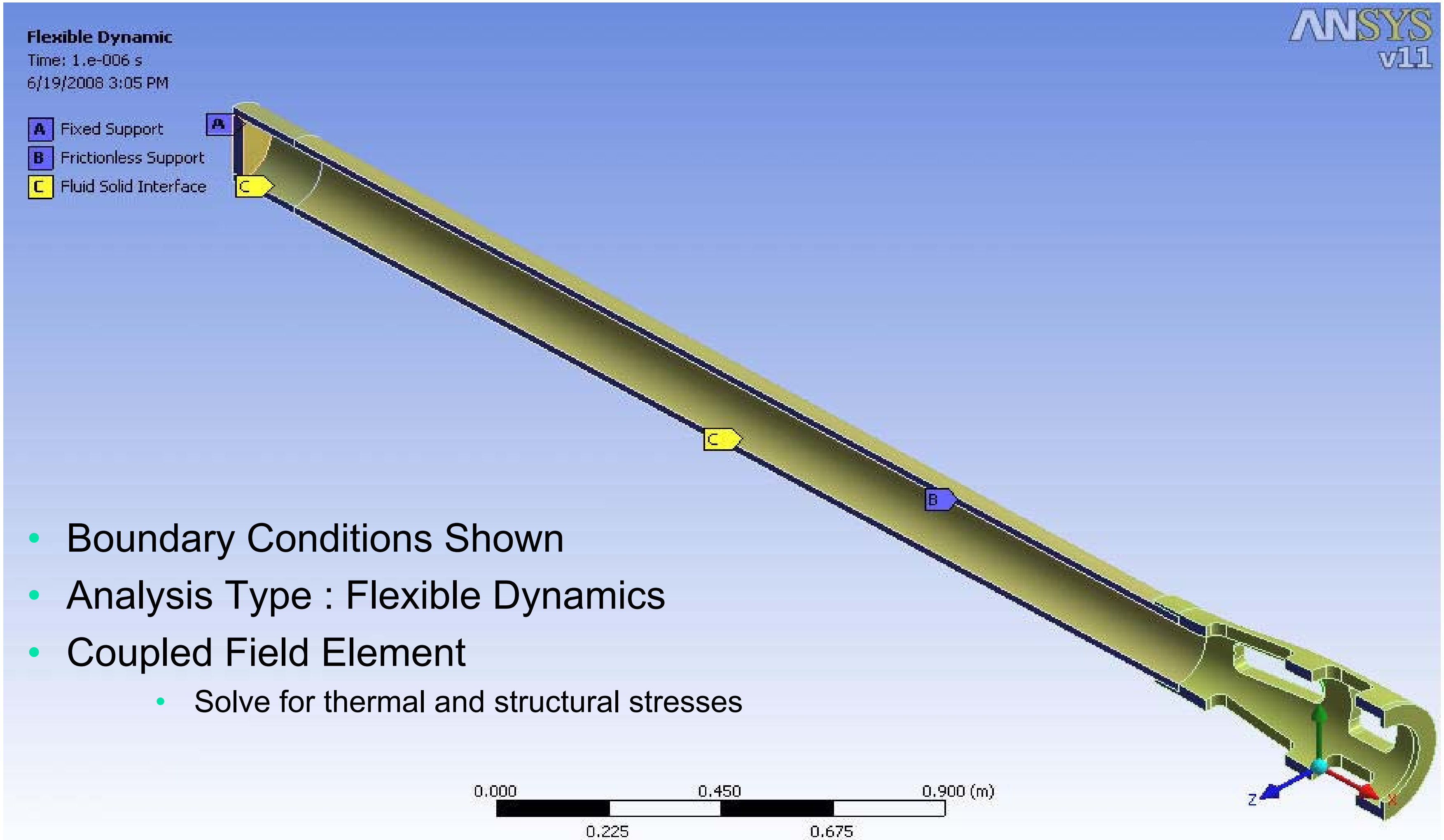
- Solid mesh developed in ANSYS Workbench.
- Fluid mesh developed in ICEM CFD.
- Coupling and interfaces of two meshes done in ANSYS Workbench
- Pulse source term used in CFX to simulate gun firing.
- Structural deformation passed between to solvers.
- Multi-round mission simulated





Workflow Snapshots

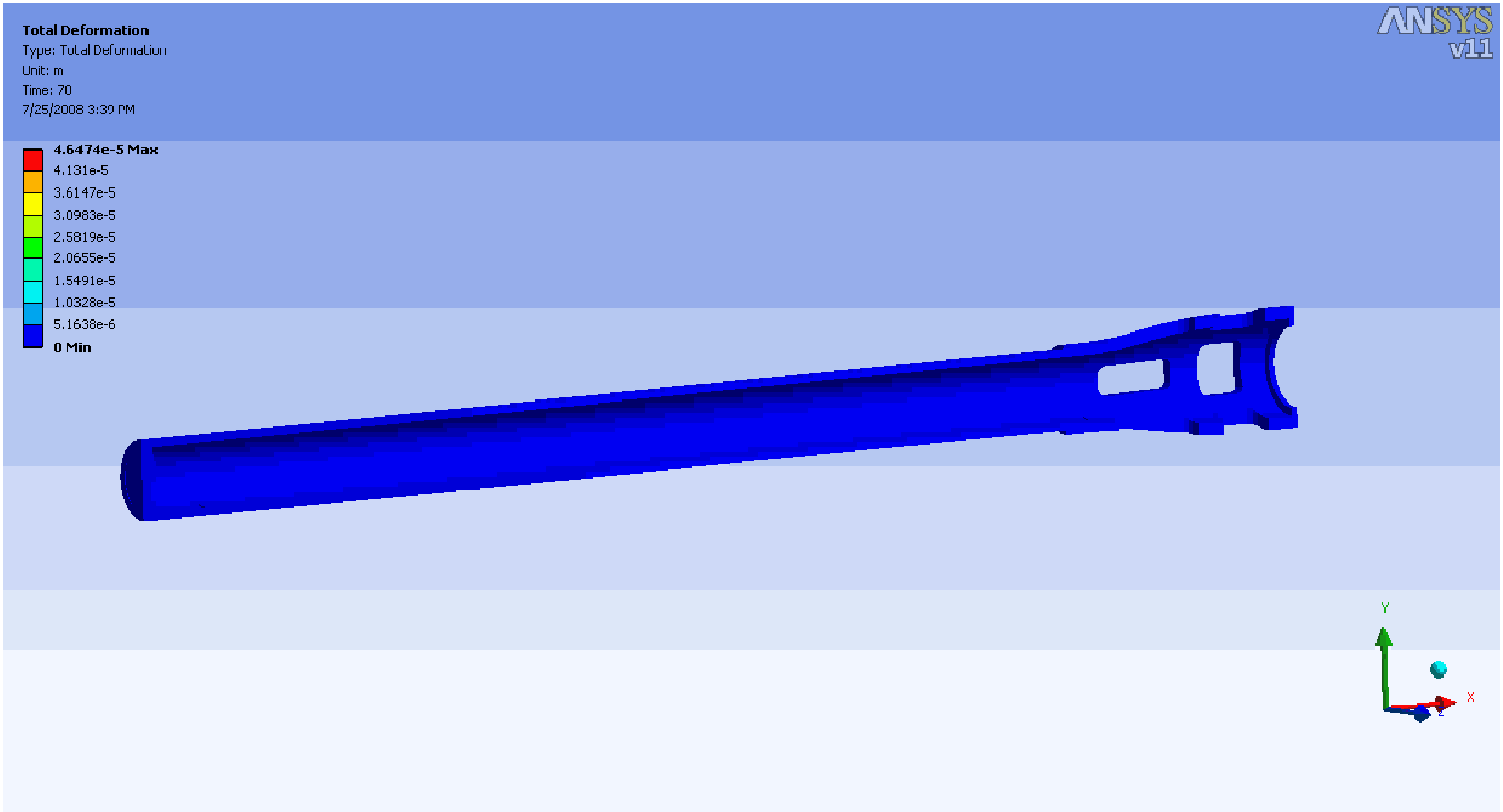
Mechanical Simulation Setup



- Boundary Conditions Shown
- Analysis Type : Flexible Dynamics
- Coupled Field Element
    - Solve for thermal and structural stresses

Workflow Snapshots

Mechanical Simulation Setup



Conclusions

- Advanced Design Tools:
  - Impulse modeling:
    - Full 3-D CFD analysis capable of predicting impulse with high degree of accuracy.
  - Blast modeling:
    - Low fidelity, quick estimates of 3-D blast fields with empirical models.
    - High fidelity models of complex 3-D blast fields with BWIP Based CFD models.
  - FSI:
    - Complex thermal-structure forced and natural convection modeling.
    - Full two-coupled structural response modeling of gun and muzzle brake structures.
- Results:
  - Higher efficiency, lower blast, lighter weight muzzle brakes.