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# Blast and Fragmentation Capabilities for National Security Applications

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**Physics-Based Modeling in Design & Development for U.S. Defense Conference**

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# Presentation Overview

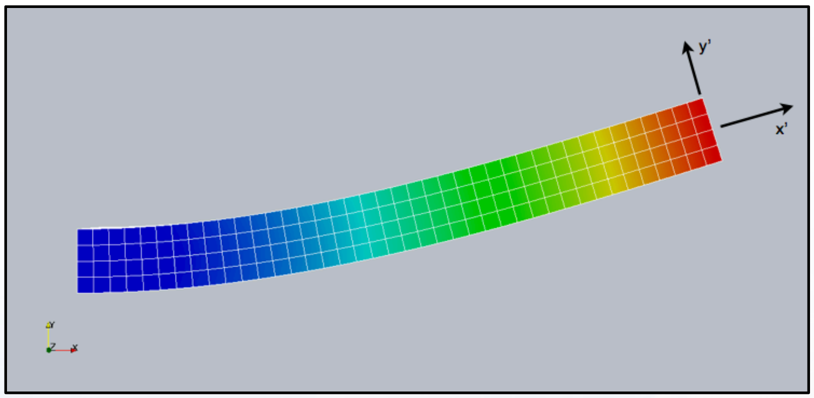
- Technical overview of the problem
  - The motivations for blast and fragmentation analyses
  - Eulerian versus Lagrangian versus other viewpoints
  - The finite element/difference/volume taxonomy
- Current and near-term Sandia R&D in this field
  - Sierra/SM and its finite element capabilities
  - Fortissimo, Forte, and other coupling schemes
  - Non-local methods, e.g., peridynamics
- Where do we go from here?
  - Many problems still resist solution
  - Lots of research and development work still to do

# Problem Motivation

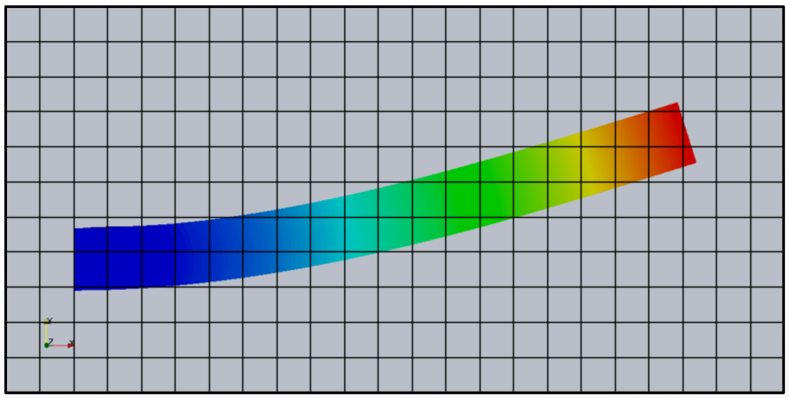
- The obvious: weapons and targets
  - Modern weapons depend on blast and fragmentation
  - For design of both offensive weapons and defensive countermeasures, we need to be able to create accurate models of these weapons effects
- The not-so-obvious: weapons as targets
  - It is essential to prevent weapons systems from serving as targets, i.e., fratricide
  - Thus need similar models for blast and fragmentation
- A word about technical content
  - Demonstrations of capability quickly become OUO…
    - Here's a snapshot of problems we are currently solving

# A Word about Coordinate Systems

- **Lagrangian and Eulerian world views**
  - General rule is that we use Lagrangian for solids and Eulerian for fluids, but many counterexamples exist



Lagrangian view: coordinate system attached to material



Eulerian view: coordinate system attached to spatial domain

# And There are Other Possibilities

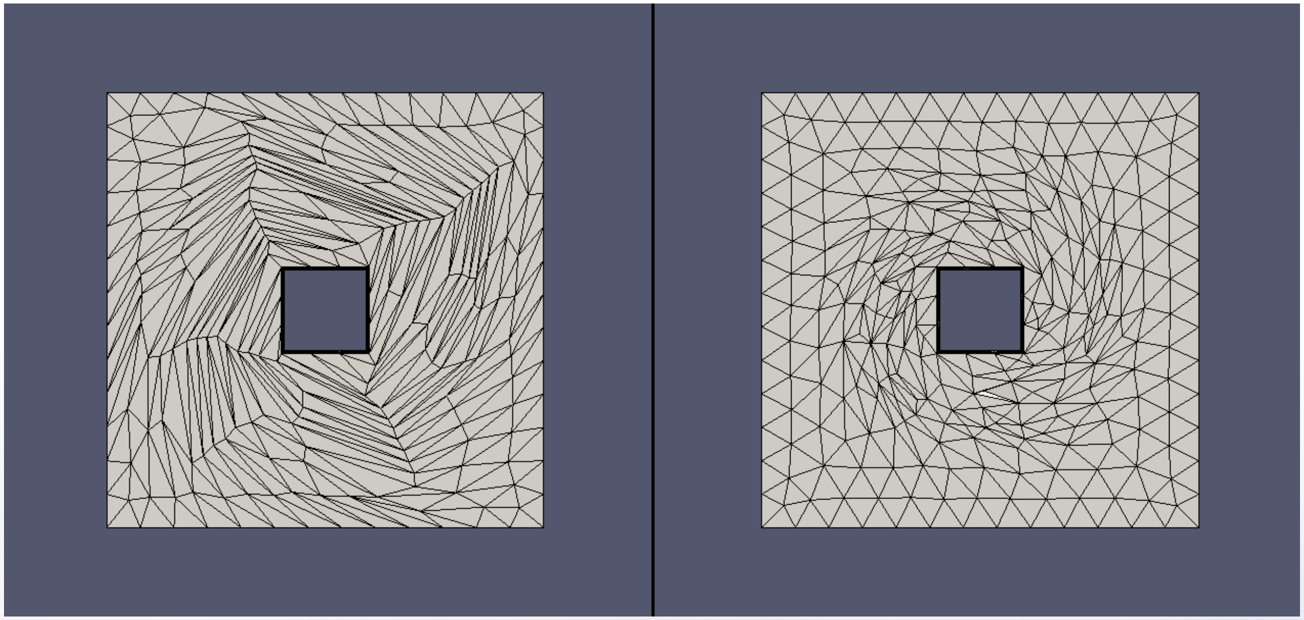
- **ALE techniques**
  - Arbitrary Lagrangian-Eulerian strategies attempt to combine the best features of each viewpoint
  - Can capture material interfaces (as in Lagrangian) while handling large distortions (as in Eulerian)
- **Composite/Hybrid Approaches**
  - General and powerful technique that combines many of the best features of both world views
  - CTH is good example of this approach: mechanics performed on structured grid using a Lagrangian formulation, followed by an accurate remap of convected material back to the structured grid

# Finite Elements: Good, Bad, and Ugly

- Finite element models have many advantages
  - Optimal error-minimization properties
  - Solution is defined globally in space and time
  - Convergence is cast in terms of stresses and strains
  - These properties arise from the finite element mesh
- In blast and fragmentation settings, the FE mesh can become a serious problem
  - Mesh tangling resulting from large deformations
  - Remeshing is difficult, expensive, and prone to error
  - Need to extend finite element techniques to liberate the solution from the confines of the connected mesh

# Strategies for Resolving Mesh Problems

- **Rezoning and remapping works for many types of elements (here, nodal-based tetrahedra)**

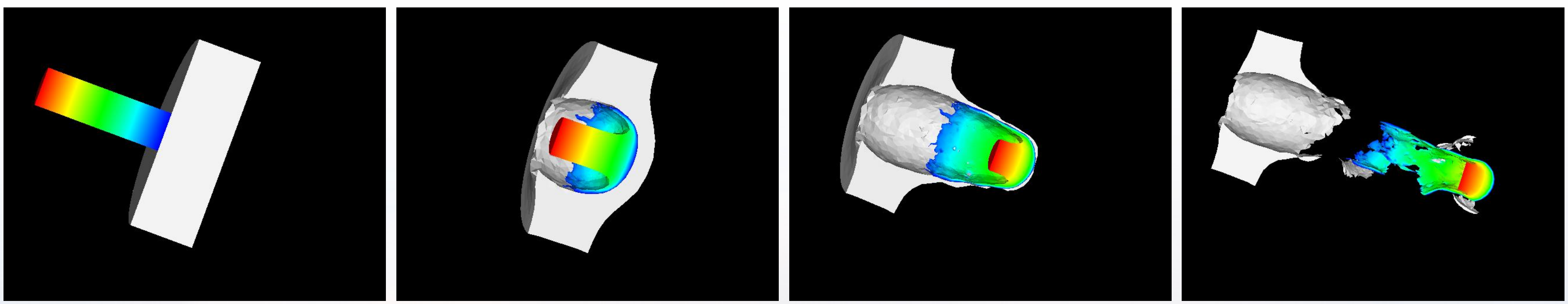


**Large rotations without remeshing: *mesh tangling***

**Rotations with remeshing: *minimal tangling***

# FE Improvements: Nodal-Based Tets

- **Provides for advantages of tetrahedral elements (e.g., simpler meshing), while facilitating remapping and fragmentation capabilities**
  - **Very useful for large deformation problems such as blast and fragmentation analyses**

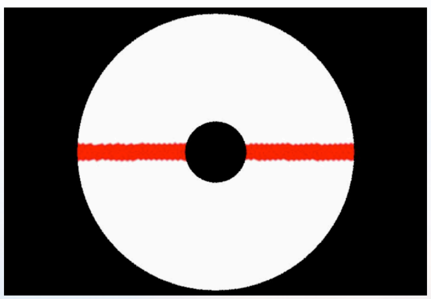


**Application: Impact loading of tungsten cylinder on steel plate at 2500 m/s**

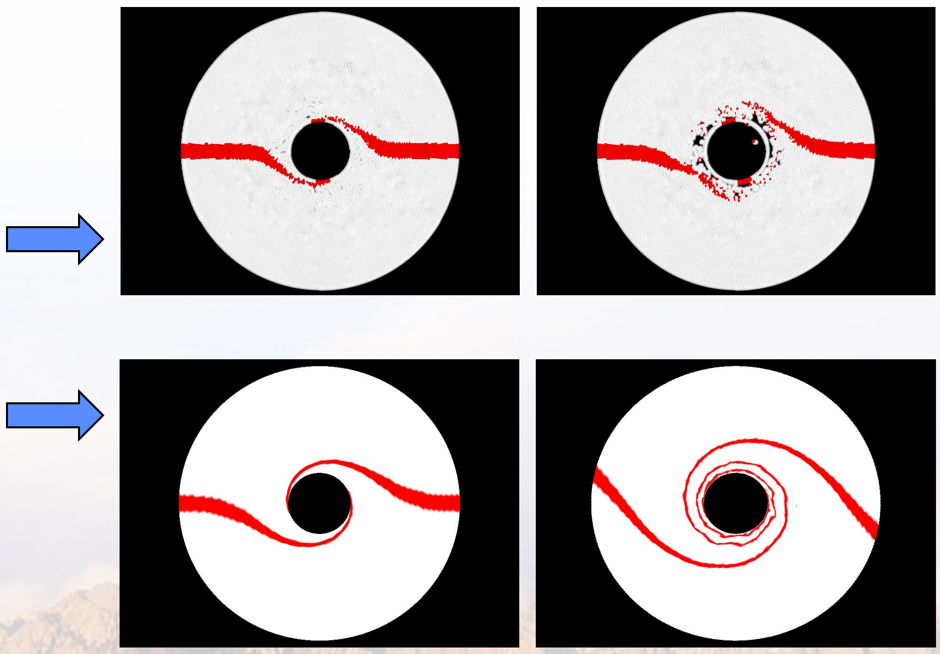
# FE Improvements: SPH

- **Smooth-Particle Hydrodynamics (SPH) provides a Lagrangian capability for fluid response**
  - Cost of fluid response is the usual difficulty in tracking material interfaces under large deformations

**Rotating viscoelastic material test**



**(asphalt viscosity test)**



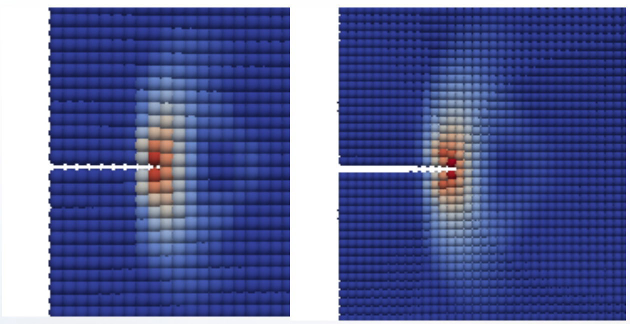
**Smooth particle hydro simulation results**

**Nodal-based tet with remeshing simulation results**

# FE Improvements: Peridynamics

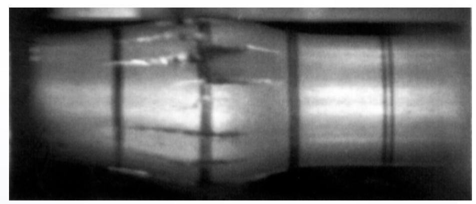
- **Peridynamics is a non-local integral theory that unifies the mechanics of continuous media, cracks, and discrete particles**

**Mesh-independent material response at crack tip**

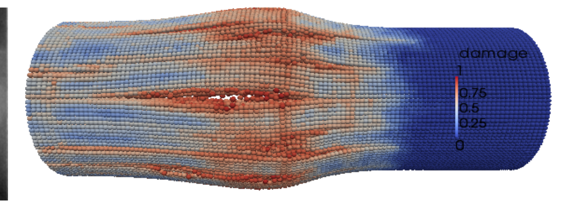


**Equivalent plastic strain contours under tensile loading**

**Failure of Blast Loaded Cylinder**



**Experimental image [Vogler, et. al]**

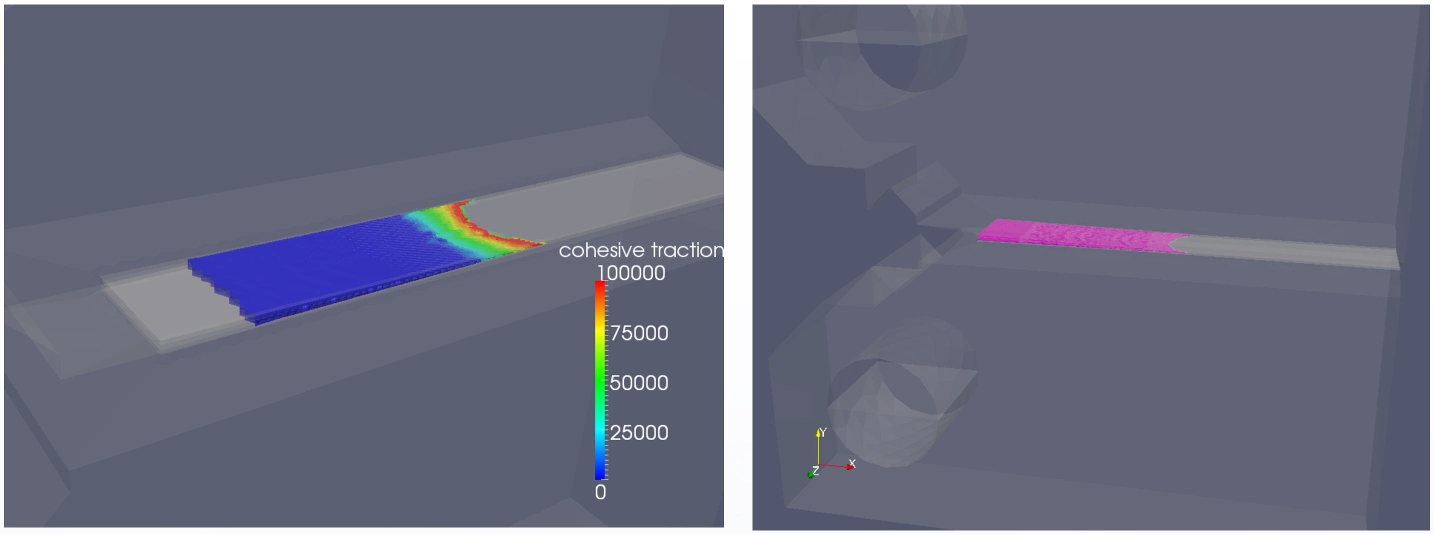



**Peridynamics simulation**

**Scalable peridynamics capability is now part of Sierra/Solid Mechanics toolkit**

# FE Improvements: XFEM

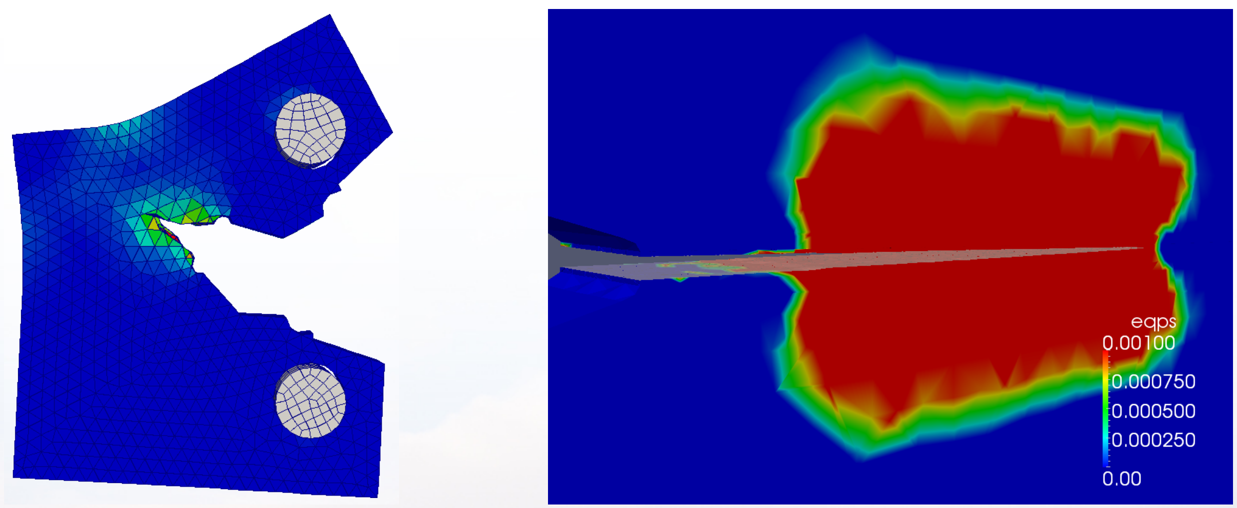
- **Extended Finite Element Methods (XFEM) permit dislocations within elements, which supports fragmentation analysis capability**




**Cohesive crack propagation arising from fatigue crack**

# FE Improvements: XFEM

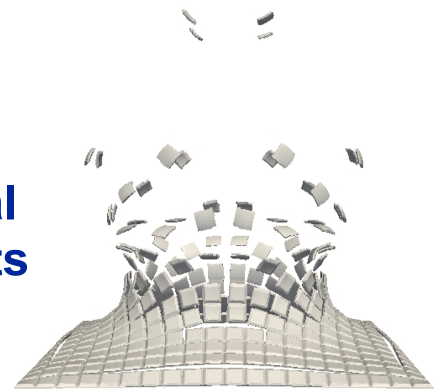
- XFEM is a generalization of FE method, so it preserves the well-known advantages of FE analysis, e.g., large deformation inelasticity

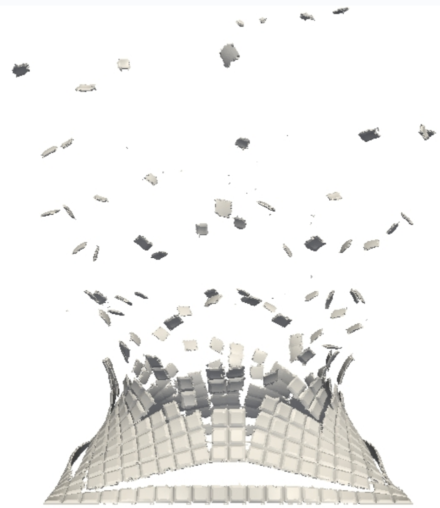



XFEM plastic strain generation at crack dislocation

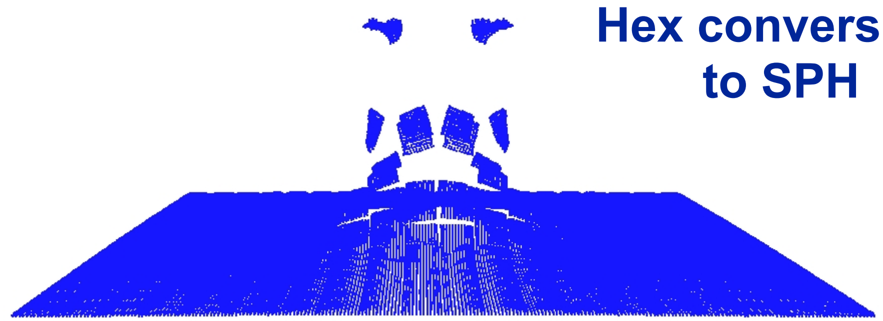
# Blast Element Comparison (CONWEP)

Conventional
Hex Elements





Node-based
Tet Elements

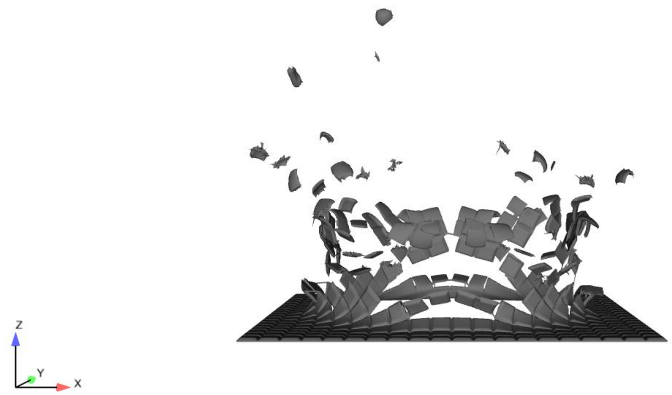


Hex conversion
to SPH

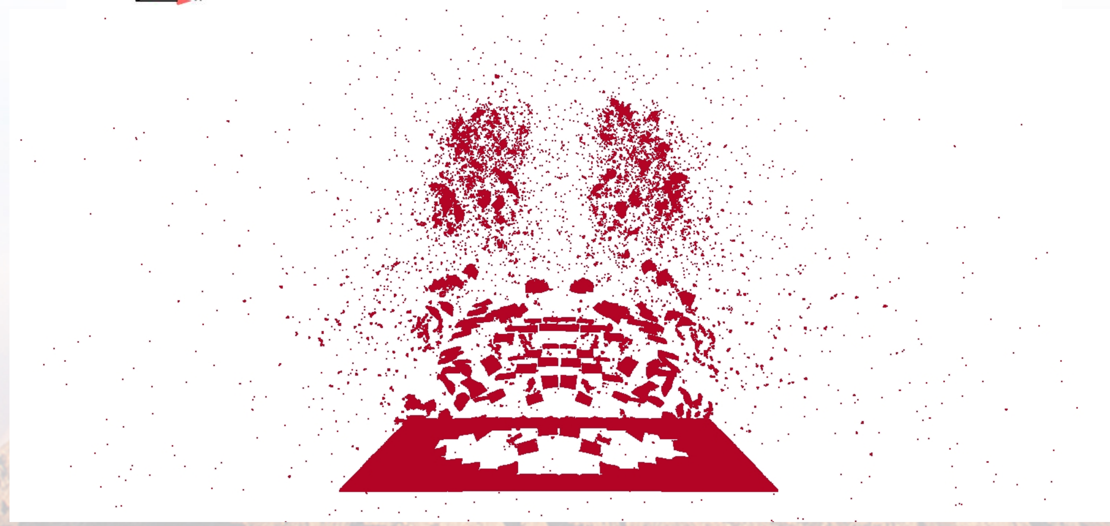
# Blast Loading via CTH/Sierra Coupling

- Compare traditional hexes to SPH technique

Hex Elements



SPH

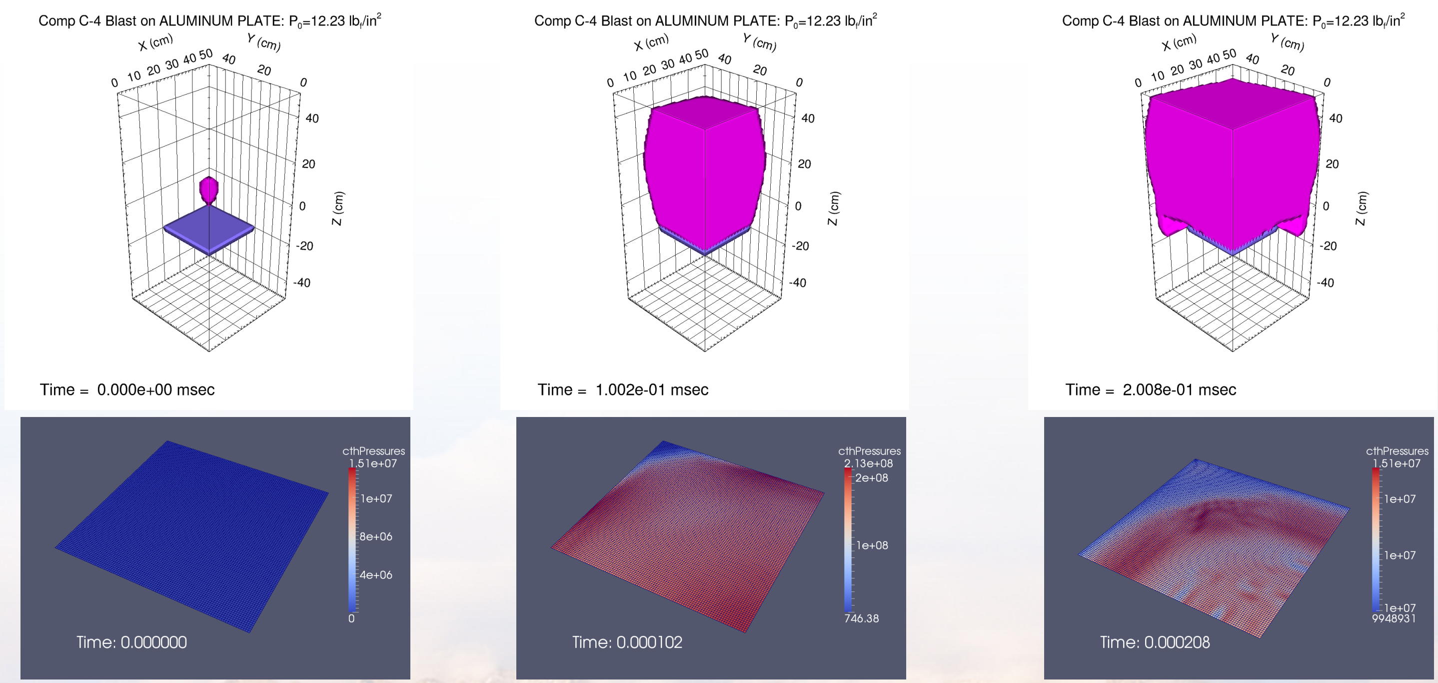


# One-way CTH/Sierra Coupling

- **Uses tracer particle capability of CTH to transfer pressures to Lagrangian analysis**

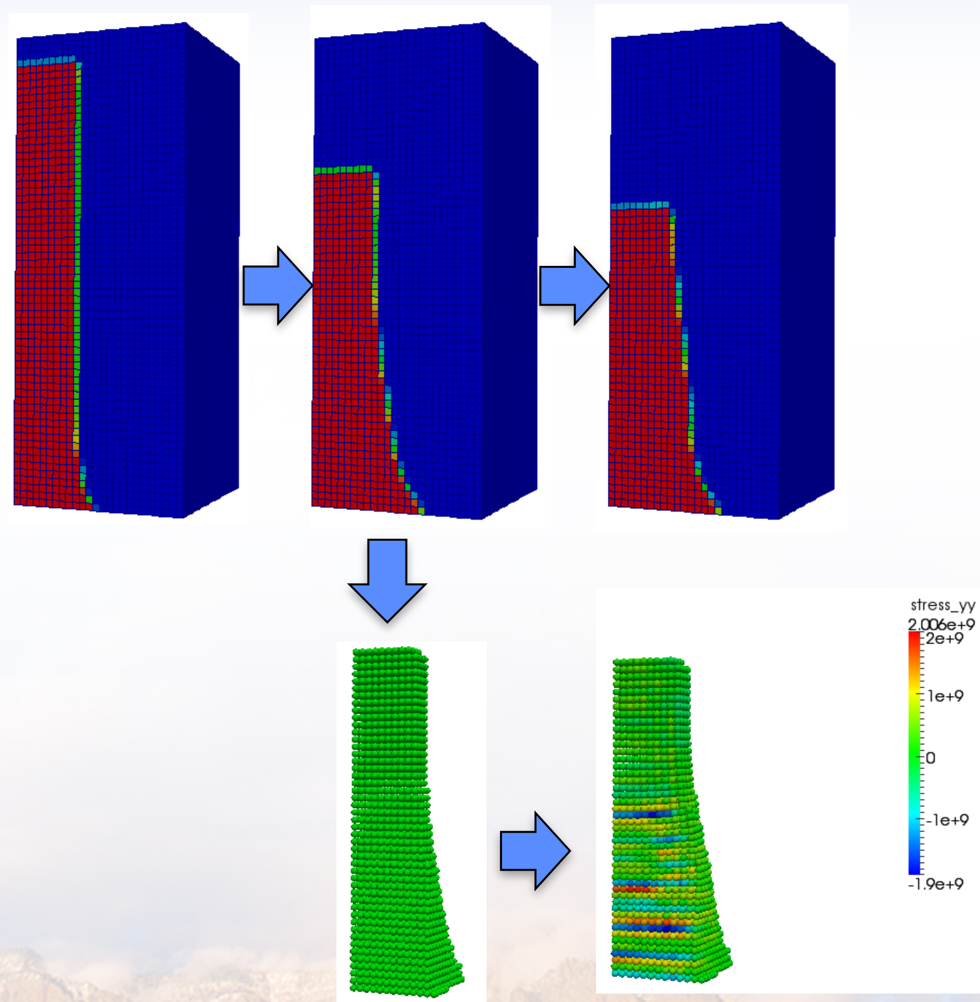
**CTH blast analysis**

**Pressure transferred to Lagrangian analysis**



# CTH to Sierra Particle Transfer

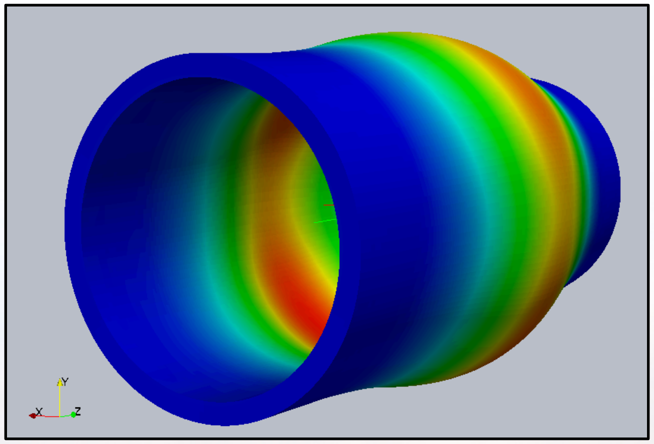
- New CTH option to transfer state as particle mesh
- Read particle mesh into Sierra/SM Lagrangian code
  - Transferred CTH state data from Taylor bar problem at mid-analysis
  - Ran second half of problem in Sierra/SM with SPH
  - Deformed shape reasonable, stresses still noisy (likely due to incompatible material models)
- This is an active Sandia R&D area



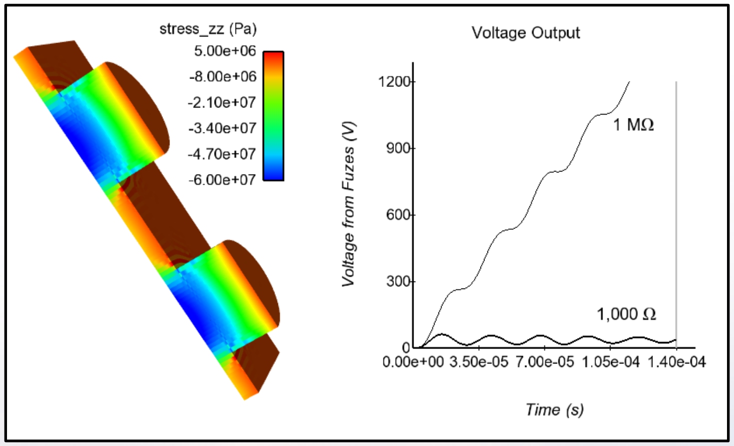

40 µs        80 µs

# Forte and Fortissimo: Fully-Coupled

- **Fortissimo is fully-coupled application using CTH for fluid and Sierra/SM for solid**
- **Forte is similar full coupling between Alegra (ALE) and Sierra/SM (Lagrangian) toolkits**



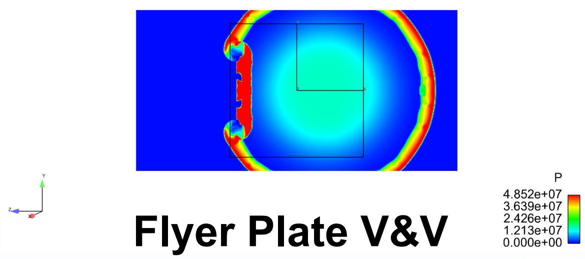
**Fortissimo Hydrobulge Analysis**



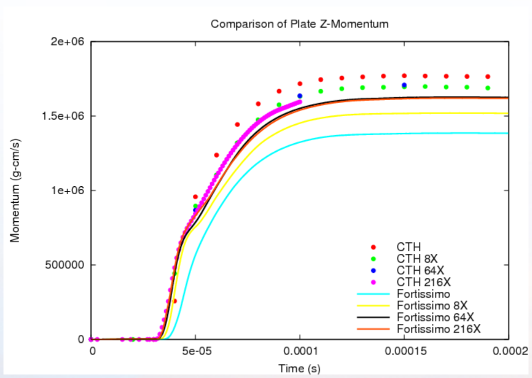

**Forte ME/EM Fuzing Analysis**

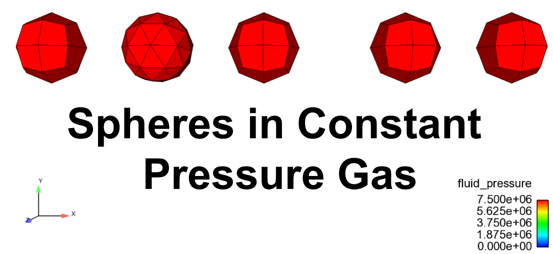
# Shock-Target Coupling Techniques

- **Goal: improvements in coupled capabilities**
  - **Result: better performance from CTH/Sierra coupling**

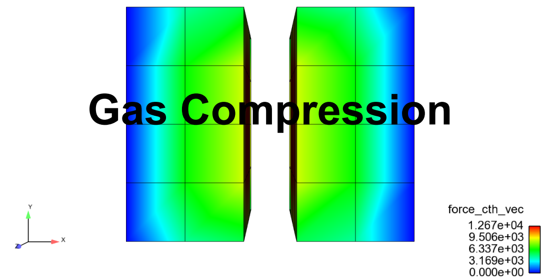



**Flyer Plate V&V**

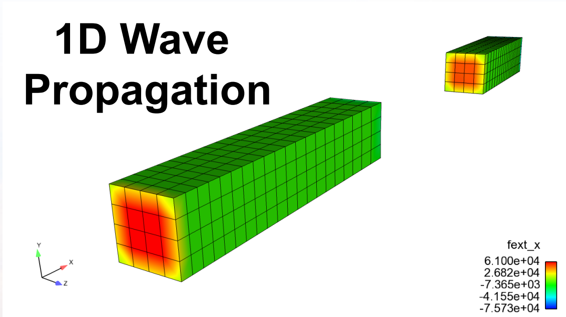


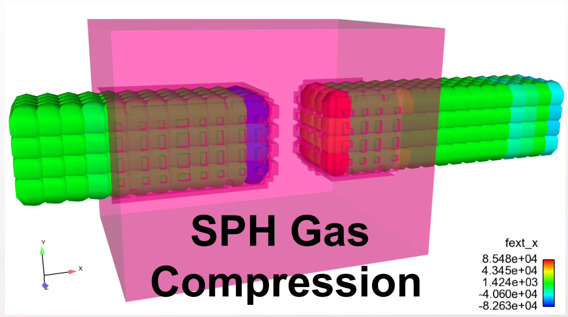

**Spheres in Constant Pressure Gas**




**Gas Compression**




**1D Wave Propagation**




**SPH Gas Compression**

# There is Still Plenty of Work to Do

- Many successes in each component field
  - XFEM in Lagrangian view
  - Interface tracking for Eulerian codes
- But many open research questions still remain:
  - How do we determine optimal coupling schemes?
  - How do we insure scalability for coupled codes?
  - Material modeling for extremes of physical response
  - Code interoperability for input and output data
- This field is often considered mature, but there are still plenty of R&D venues where researchers can make a difference

# Summary and Conclusions

- Blast and fragment analyses are essential components of modern computational engineering within national security complex
  - Targets work best in Lagrangian view
  - Blasts work best in Eulerian or ALE view
- Current technology is well-developed for each of these two world views
  - Many classes of novel finite elements, for example
- … but there are many open technical questions that need to be solved via new research

# Questions and Comments

Thank you for your time and attention

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