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Coupled Fluid/Solid Computations Using Tetrahedral Finite Elements

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Outline

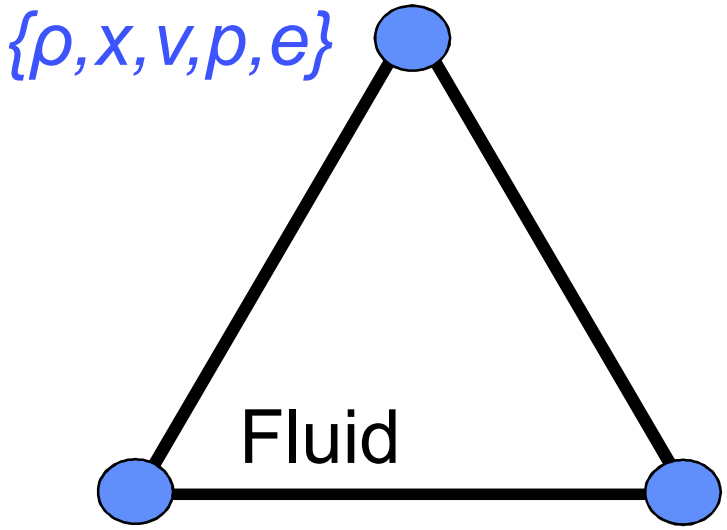
- Motivation
- Fluid Capabilities
- Solid Capabilities
- Coupled F/S: Overview
- Example: Piston Problem
- Example: Blast to Structure

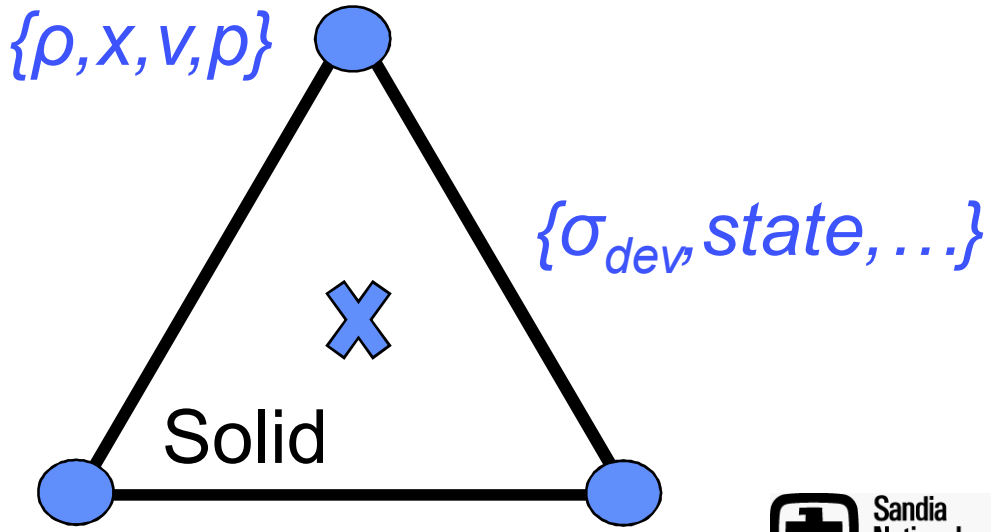
Motivation

- Tetrahedral meshing is generally much more automated and robust than hexahedral meshing
- We have demonstrated a robust Lagrangian/ALE fluid solver on tet meshes for fluids
  - Single-material Euler flow with ideal gas EOS, but also potential for multi-material, multi-phase
- A similar Lagrangian solver for solids has also been presented (see Scovazzi presentation in earlier session)
  - Solid mechanics on tet meshes to simplify fluid/solid coupling
- A combined fluid/solid coupled capability is desired:
  - Fully coupled (when needed)
  - Blast to structure
  - Aero-structural design

Fluid and Solid Comparison

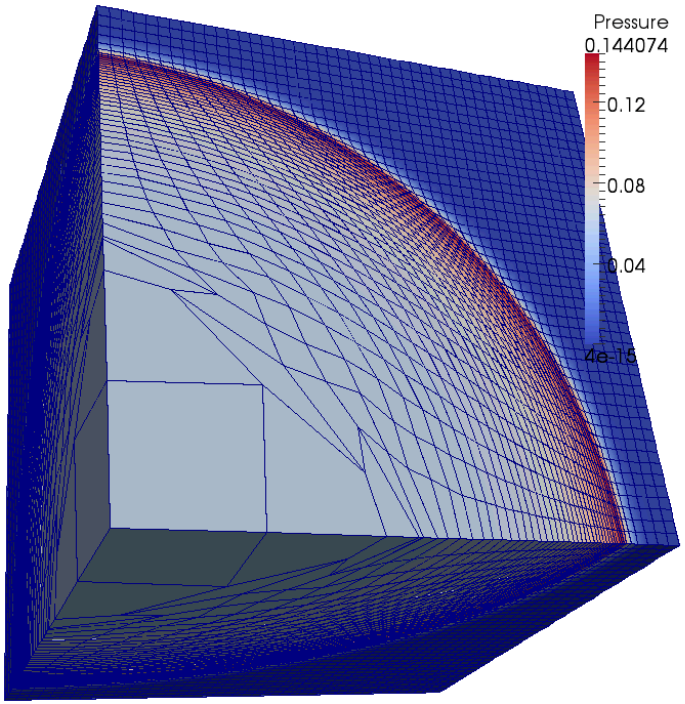
- For the fluids algorithm, all DOFs are at the nodes
- In the solids case, the stress is split:
  - Hydrostatic pressure is at the nodes
  - Deviatoric stress is at the element integration points, as well as any state variables (EQPS)



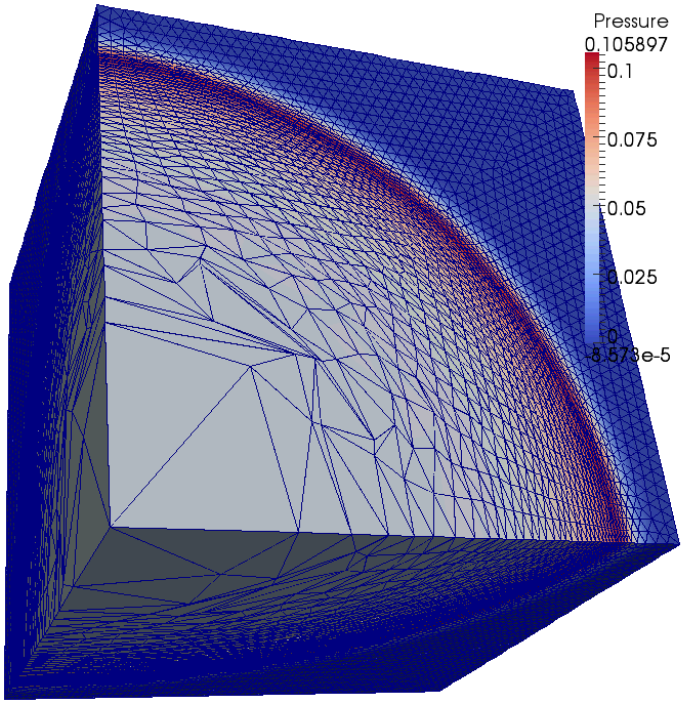


Fluid Capabilities

- A variational multi scale (VMS) approach is used to stabilize the nodal pressure (all fields are nodal)
- Enables calculations on unstructured tet meshes in complex geometries (same code base also works for hexes)



3D Sedov test (Lagrangian, hex8)



3D Sedov test (Lagrangian, tet4)

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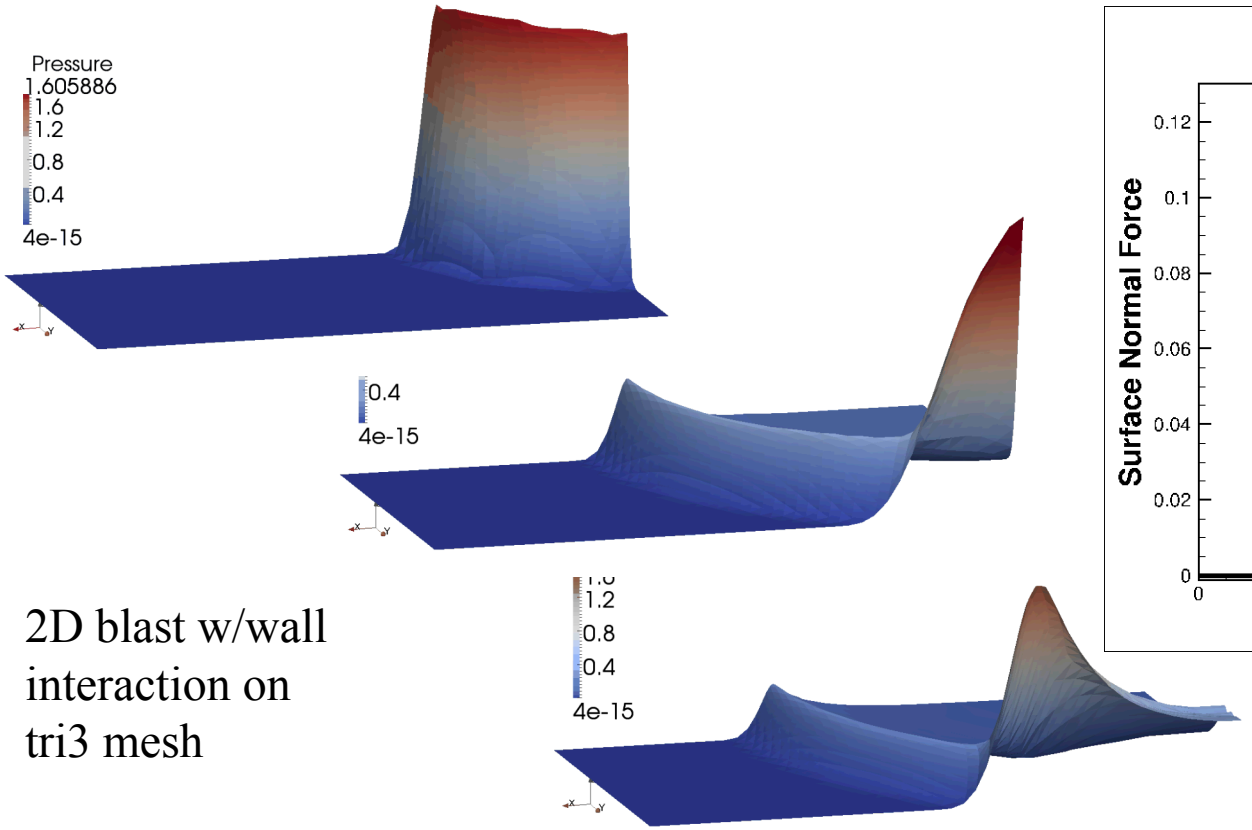
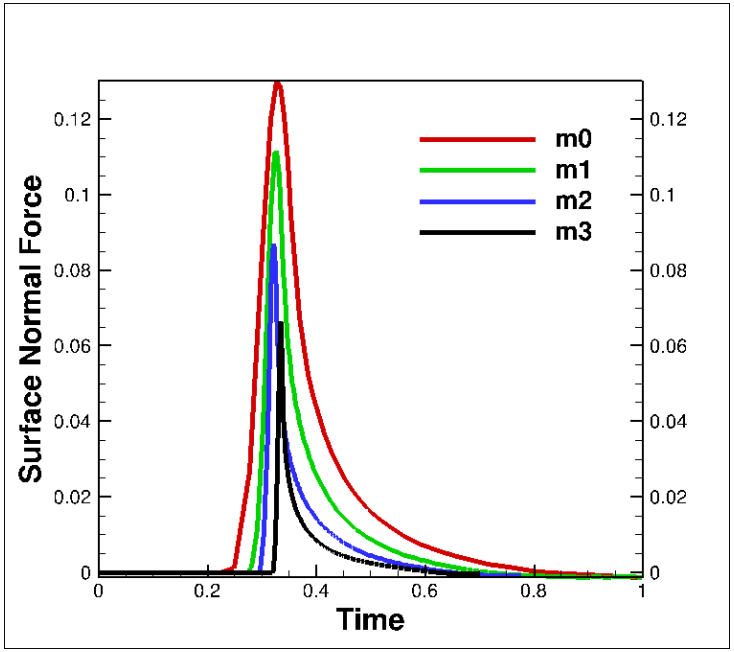
Fluid Capabilities (2)

- Prototype fluid/solid coupling: initial blast and wall shock interactions
- Shock loading to surface is verified under mesh refinement



2D blast w/wall interaction on tri3 mesh



Surface force convergence

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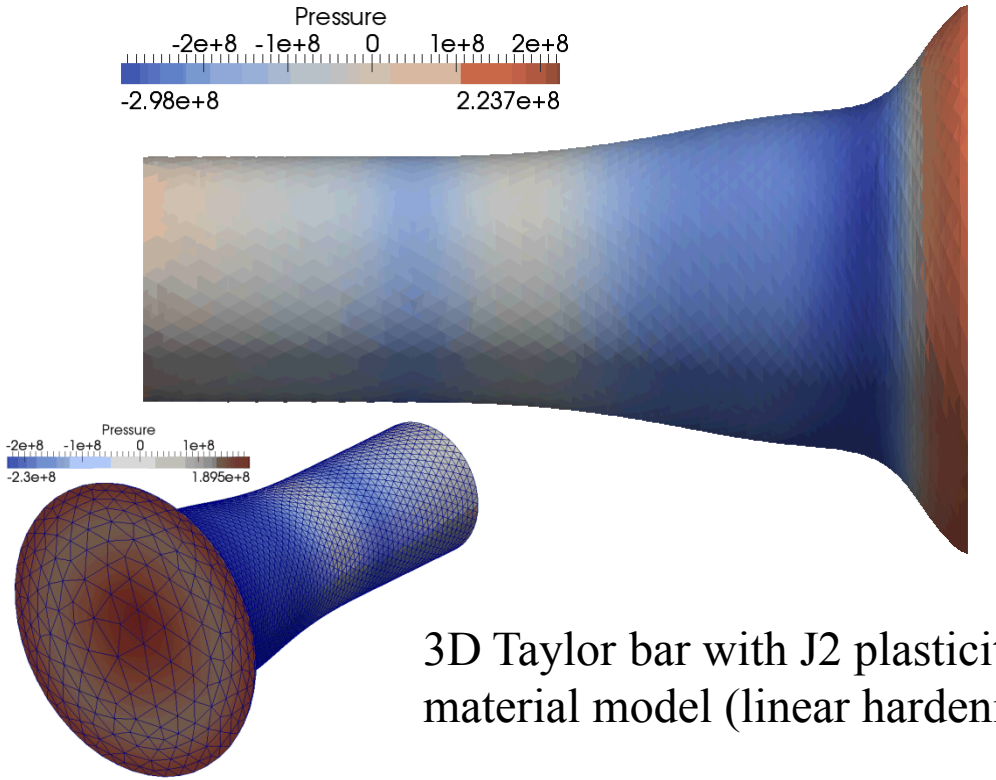
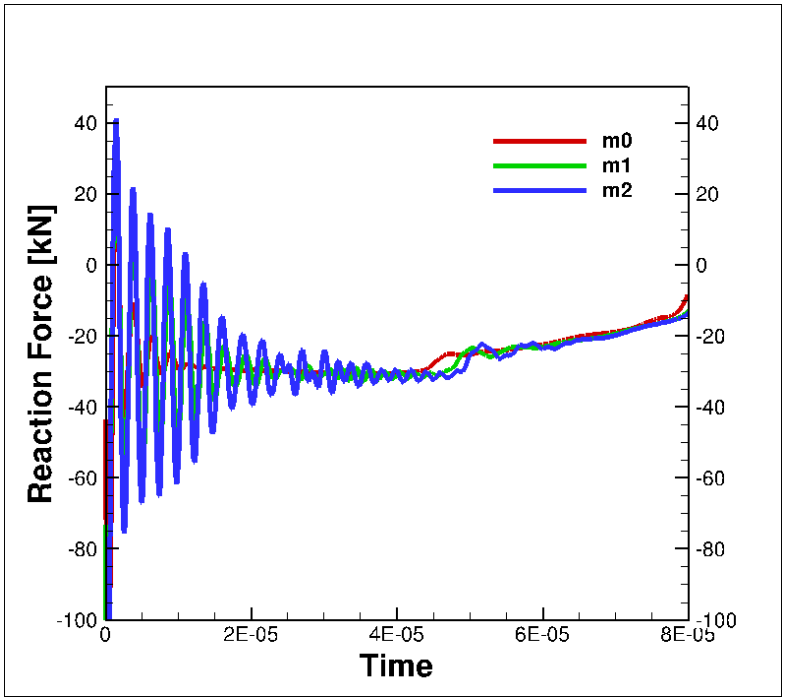
Solid Capabilities

- Nodal hydrostatic pressure, element-based deviatoric stress
- Enables many constitutive models (plasticity, hypo-elastic)
- Smooth, stable pressure even for nearly compressible case
  - even in explicit dynamics calculations



3D Taylor bar with J2 plasticity material model (linear hardening)



Reaction force convergence

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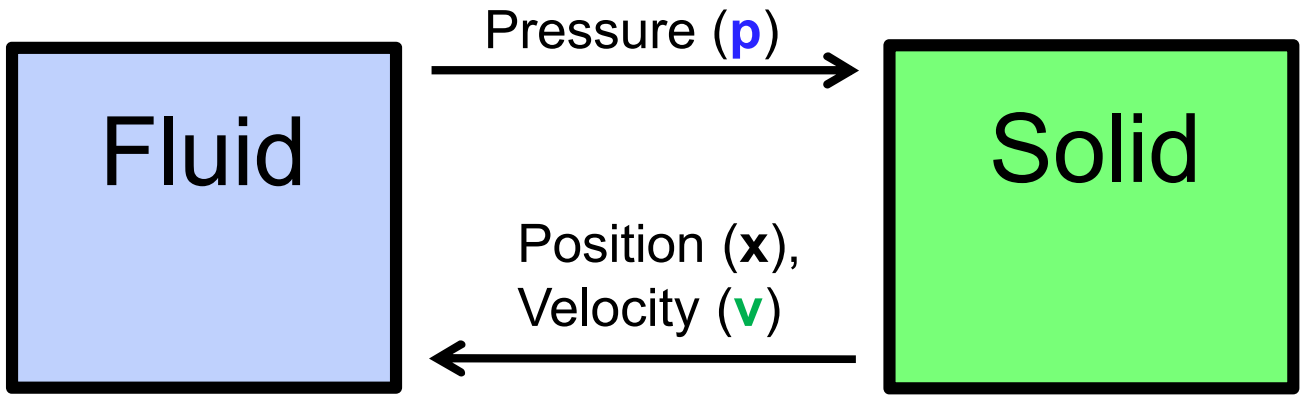
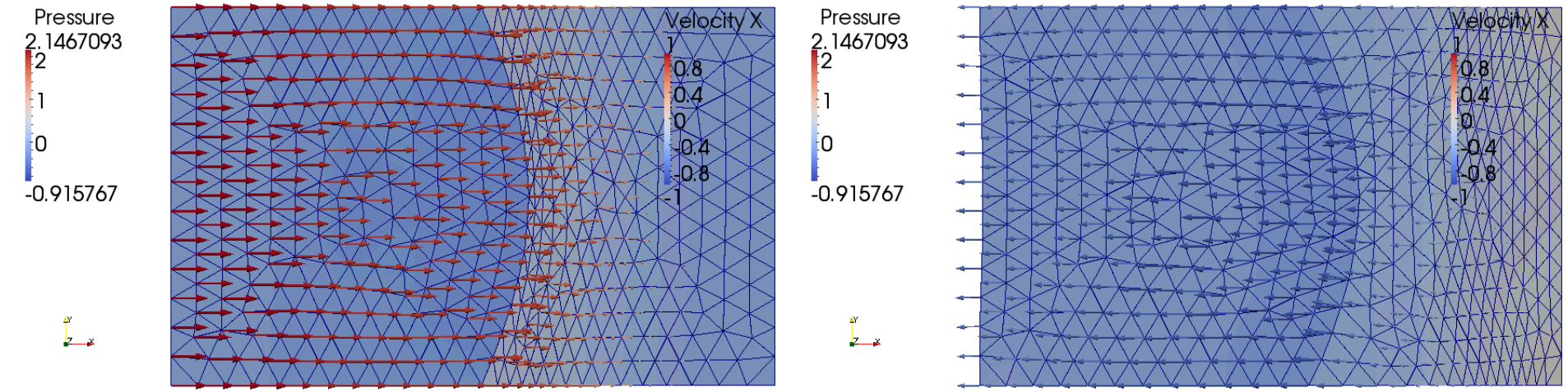
Fluid/Solid Coupling Algorithm

- Fluid provides pressure force to solid
- Solid provides normal velocity to fluid
  - Fluid can slip tangentially along solid interface
- Current implementation:
  - Parallel search locates pairs of matching F/S nodes
  - F/S nodes are fixed at all times by fluid remesh
  - Both outer/inner convergence loops



Example: Compressible Fluid and Elastic Piston

- Solid piston w/initial uniform velocity
  - Elastic material model (neo-Hookean)
- Fluid/solid constrained top/bottom/right (zero normal velocity)
- Fluid compresses and then ejects the piston
- Tested both flat, convex and concave interfaces for 2D/3D
  - Example: 2D convex interface



Solid (left) fluid (right)

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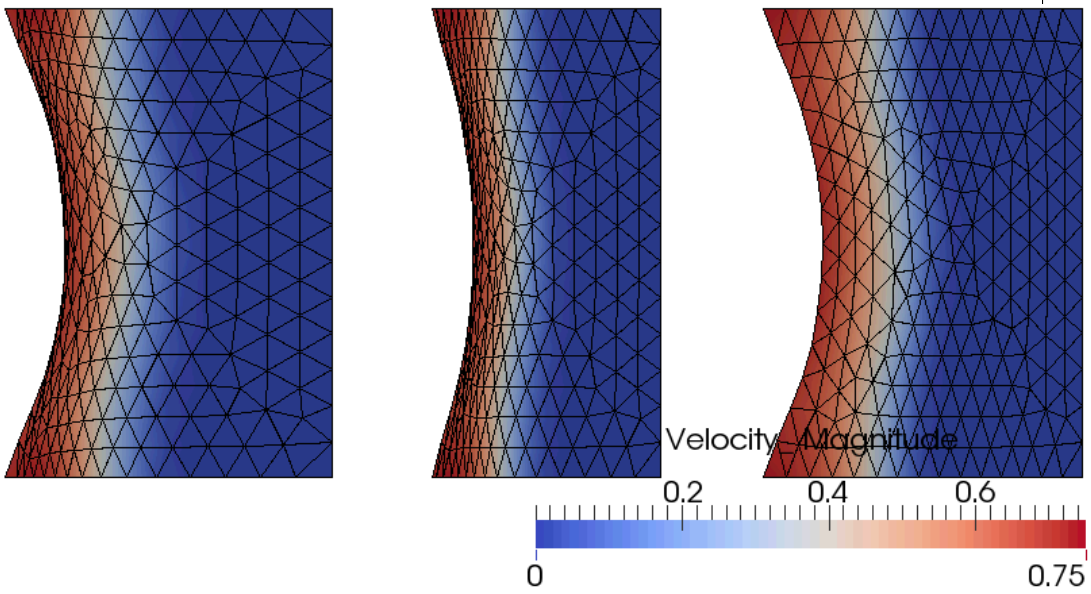
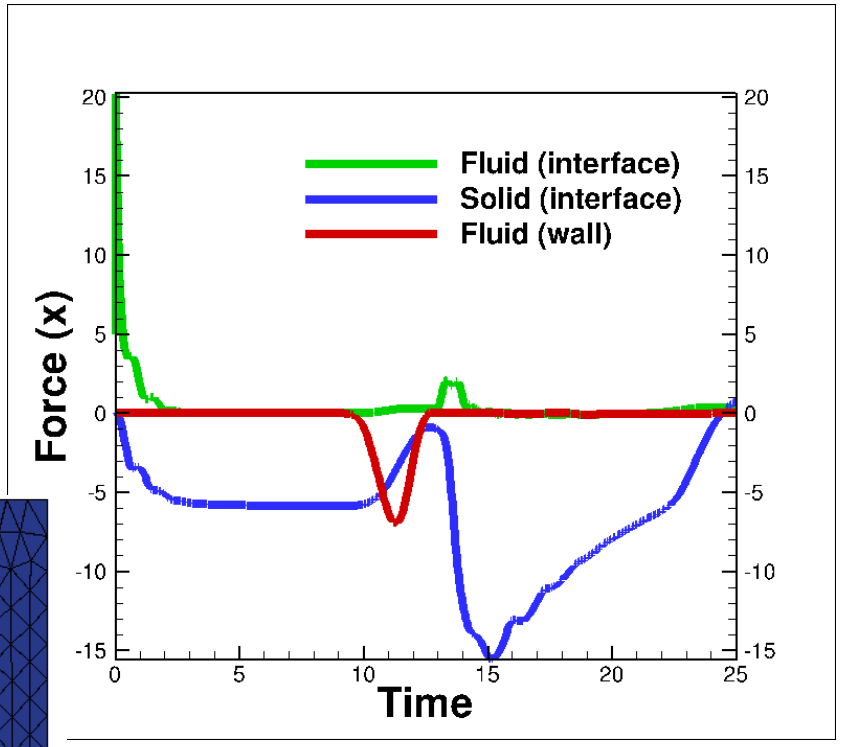
Example: Compressible Fluid and Elastic Piston (2)

- Multiple mesh rezoning algorithms are available:
  - (left) explicit Laplacian smoothing
  - (center) implicit, dynamic elasticity solve
  - (right) implicit, static elasticity solve
- Force history illustrates full two-way coupling capability





Force history

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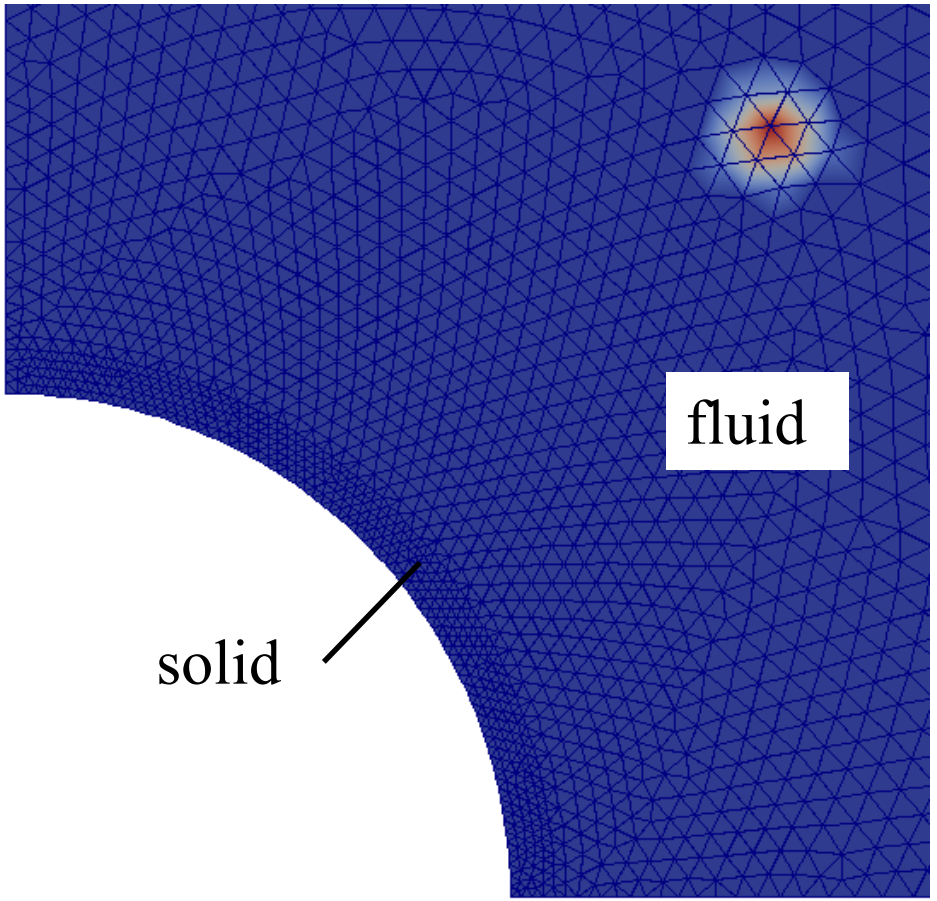
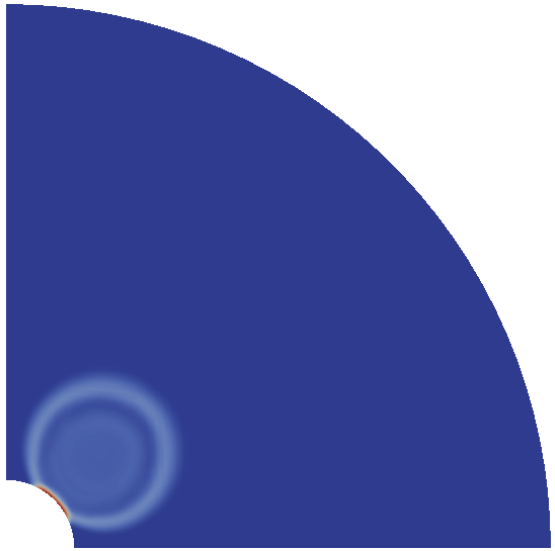
Example: Blast to Structure

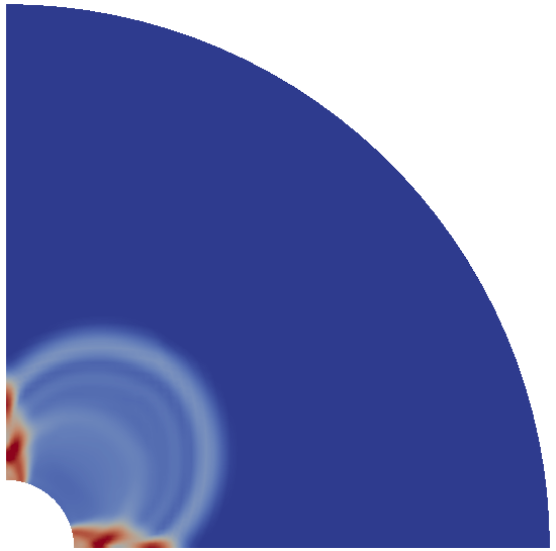
- Compressible fluid with initial localized energy source (detonation)
- Blast impacts cylindrical shell and applies pressure loading
- Structure has properties of a metal with J2 elastic-plastic material model (linear hardening)
- Additional shock interactions with vertical planes and shock/shock interactions
- We are interested in:
  - Fluid/solid evolution in time
  - Time history of surface forces
  - Solid response to blast loading

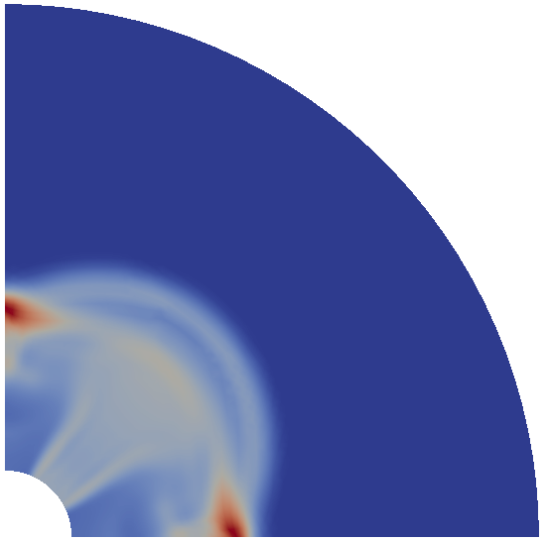


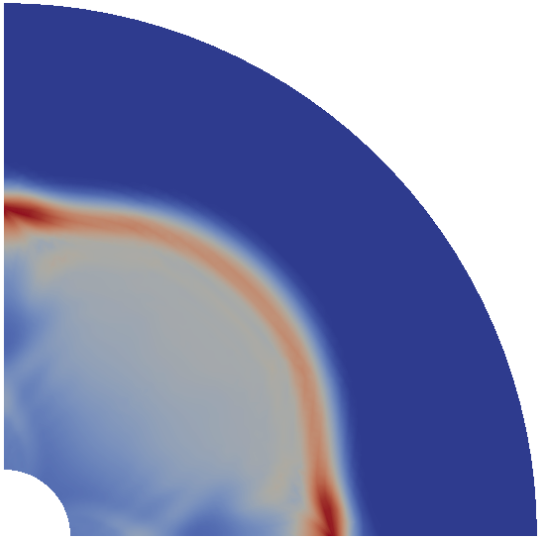
Example: Blast to Structure (2)

- Pressure wave impacts the solid shell
- Multiple shock interactions apply multiple loads to structure
- Shown: pressure at four times (solid omitted)









- High degree of symmetry on unstructured, graded meshes
  - Mesh size varies from 1mm to 20mm

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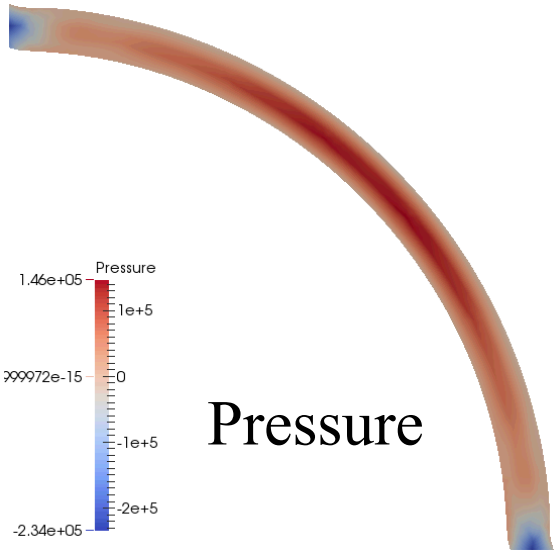
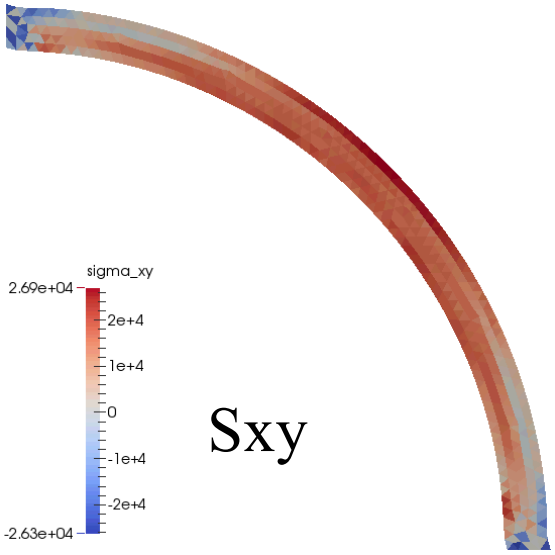
Example: Blast to Structure (3)

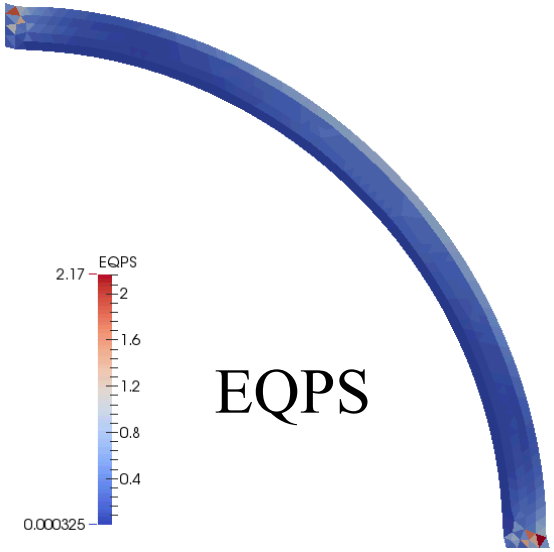
- Shown: solid response at final time (actual displacements)
- Loading is large enough to generate finite displacements and plastic deformation



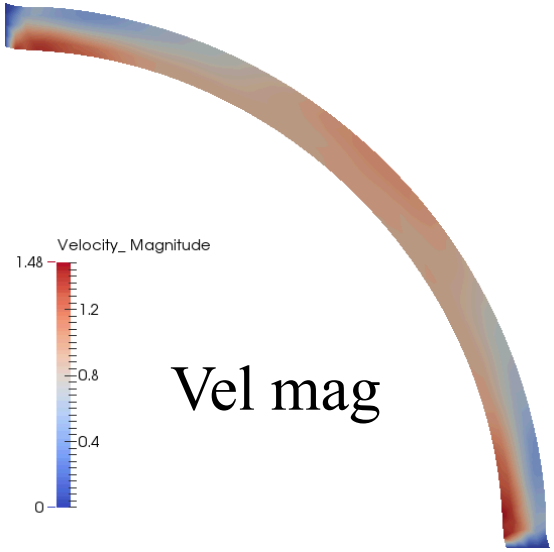
Pressure



Sxy



EQPS



Vel mag

- High degree of symmetry on unstructured, graded meshes
- Least accurate variables are element-based (stress, EQPS)

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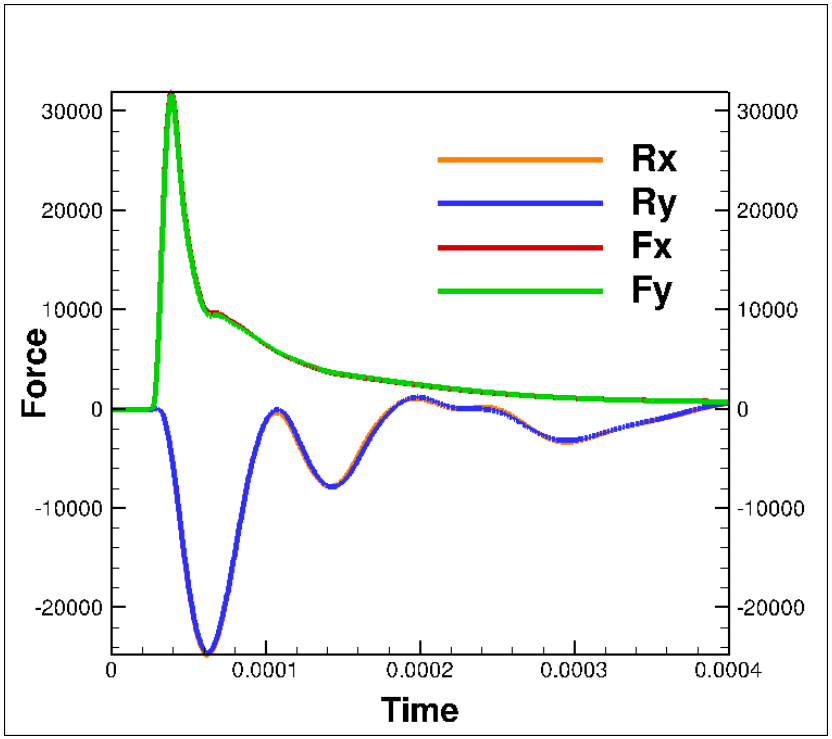
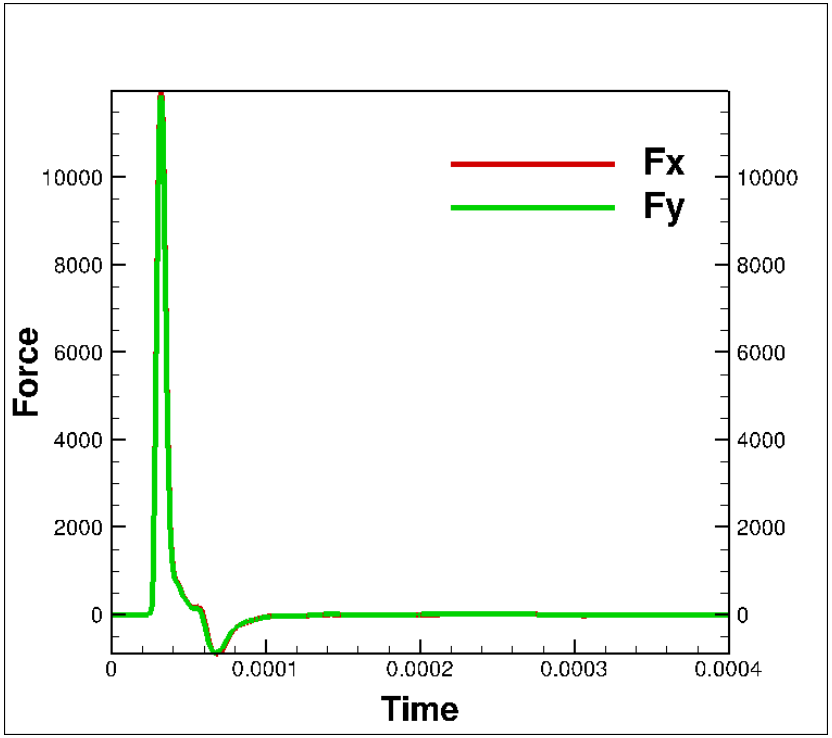
Example: Blast to Structure (4)

- Fluid and solid surface forces are highly symmetric
- Solid responds on longer time scale (could switch to uncoupled solve)





- Fluid response forces are highly symmetric, with rapid decay of surface pressure loading

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Summary & Future Work

- Fluid/solid coupling on tet meshes
  - Stable and accurate fully coupled algorithm
  - Verification using mesh refinement studies
  - Robustness using multiple mesh rezoning algs
  - Demonstration on piston and blast to structure
- Future work
  - Non-matching mesh option at the interface
  - Further robustness, performance improvements
  - Additional 3D benchmark problems