Open-Source Computational Mechanics

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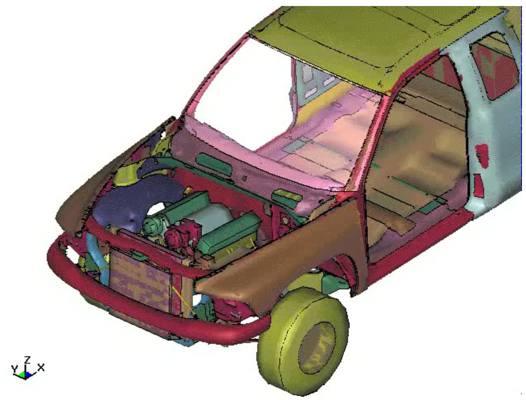
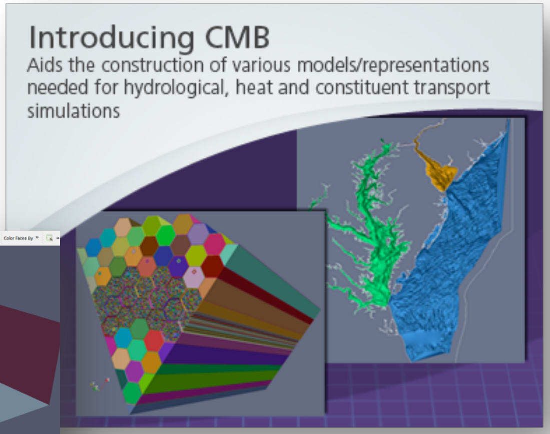
Overview

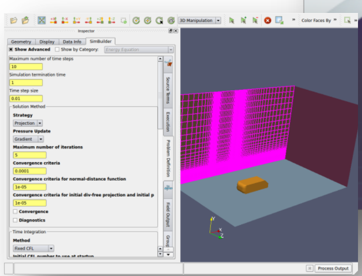
- Open-Source Computational Mechanics
- Hydra Design and Application Spaces
- Getting Started -- Funding Possibilities

Open-Source Computational Mechanics

- Develop a broad-based open-source computational mechanics capability and community
  - Fluid dynamics (compressible/incompressible)
  - Solid/structural dynamics
  - Coupled physics problems
- Focus on advanced architectures
  - Ability to move quickly relative to ISV's, National Labs
  - Combine with ParaView, Catalyst for industries that are dependent on high-performance computing
    - Crash worthiness is one good example
- Advanced agile development processes (CMake, CTest, CDash, gerrit, etc.)
- Leverage scalable visualization tools, meshing efforts







The Hydra Toolkit – Agile Development for Advanced Scientific Applications

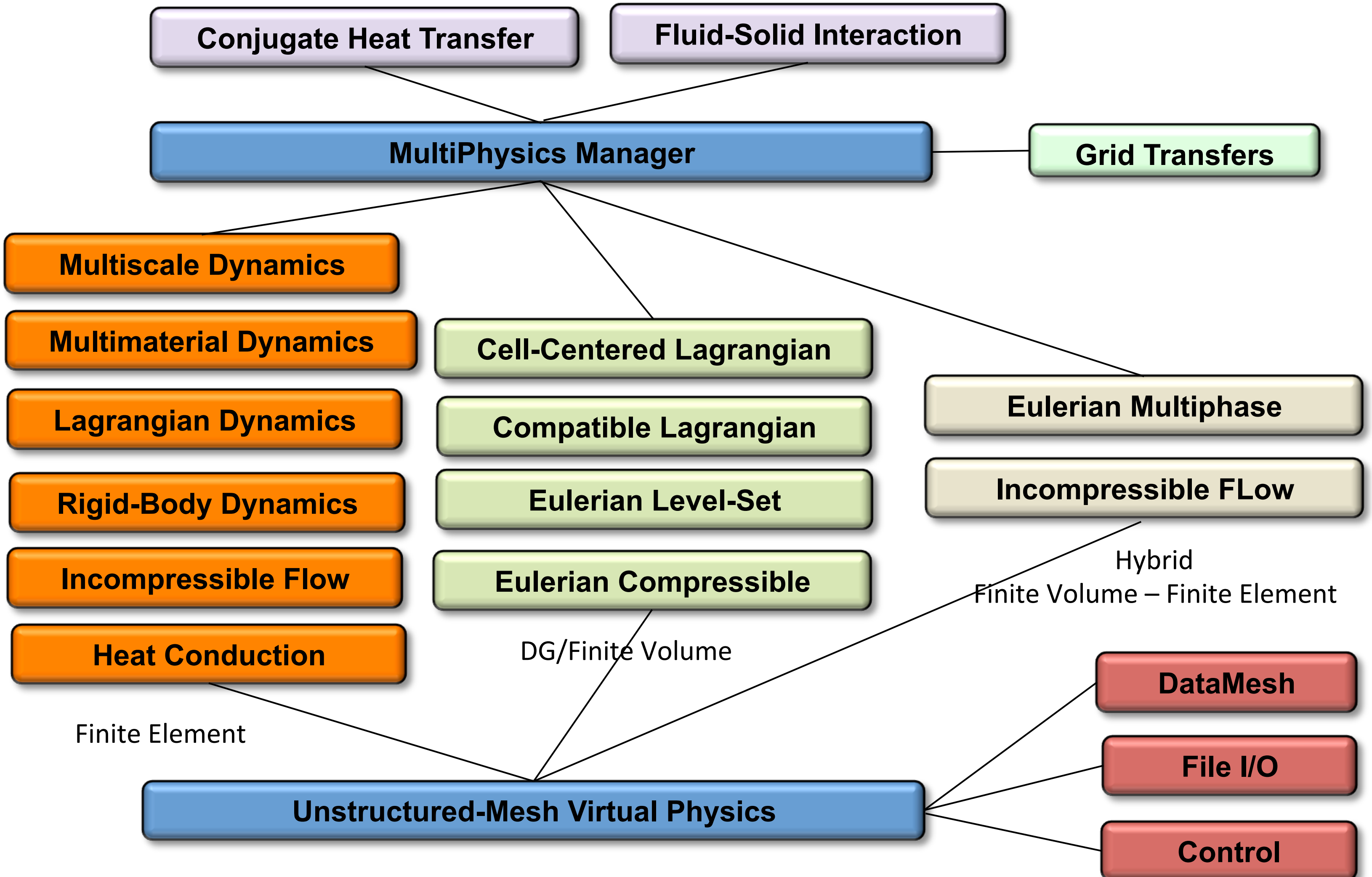
- Hydra is an extensible C++ toolkit that provides a rich suite of scalable software components for rapid application development
- Hydra physics spans a broad problem space ranging from thermal and flow design analysis to shock hydrodynamics, material strength and multiphase flows
- Hydra is parallel by design and scalable across platforms and applications

  Toolkit Design Targets:
  - $\sim 10^6$ elements in ~ 2 GByte memory ($10^3 - 10^6$ elements per core)
  - Parallel scaling: 10's to many 10,000's of cores
  - Grid sizes: $> 10^9$ elements
  - Discretization/solution method is physics specific in Hydra, i.e., **you choose what works best for your specific application!!!**

Hydra for Multiple Physics and Multi-Physics

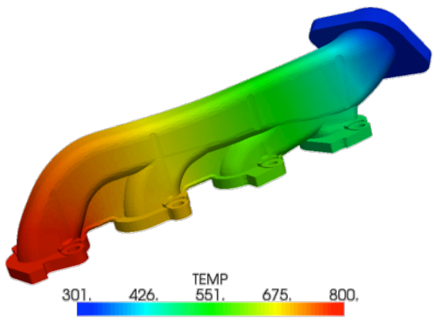
All Physics Except Eulerian Multiphase and Cell-Centered Lagrangian were in 2011 Open Source Version of Hydra

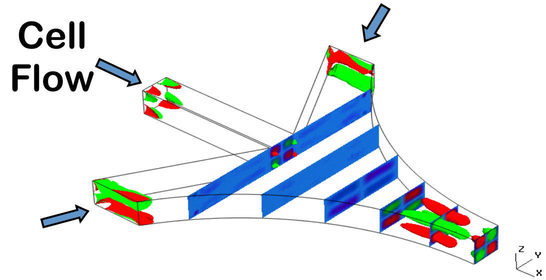
- Agile environment, able to create single-physics vertical applications quickly



Applications: Thermal, Single, and Multiphase Flow Analysis

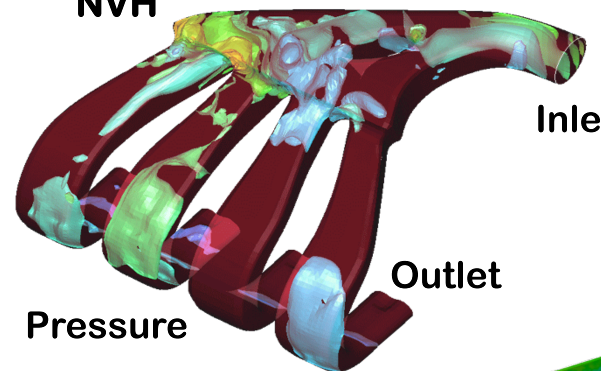
Exhaust Manifold

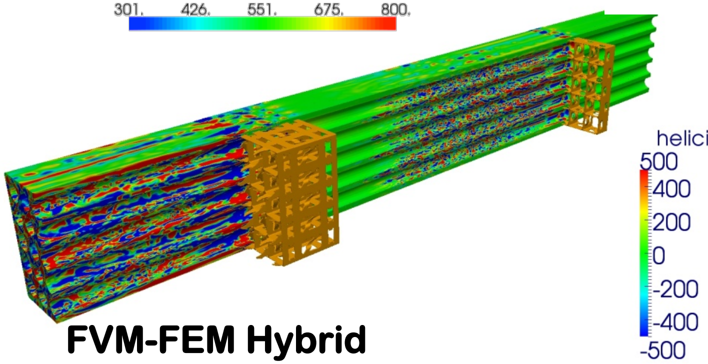




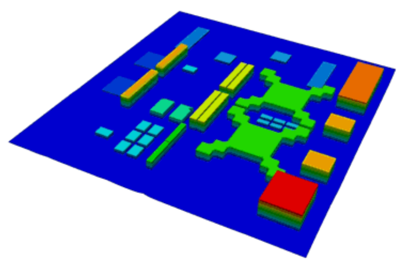
Flow Cytometry

Automotive NVH



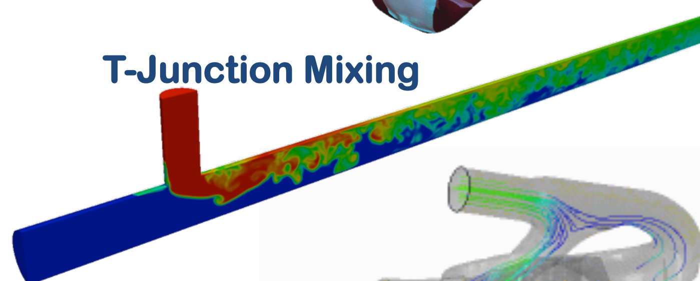


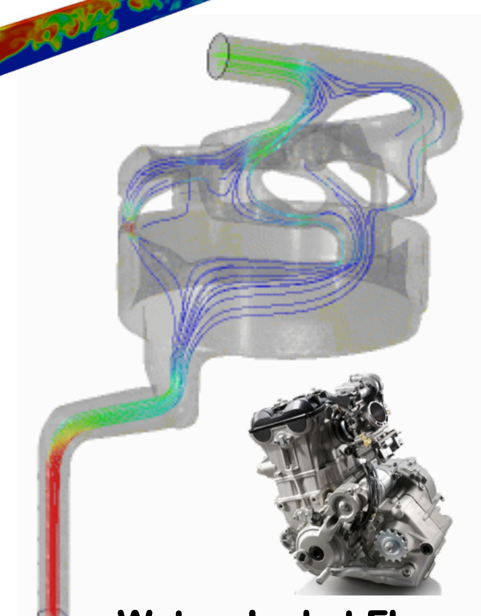
FVM-FEM Hybrid Navier-Stokes



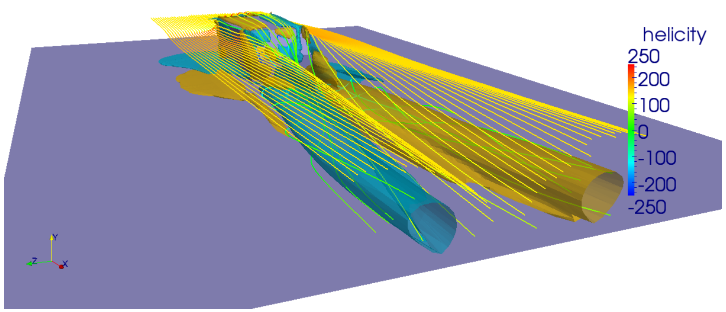
Electronics Cooling

T-Junction Mixing

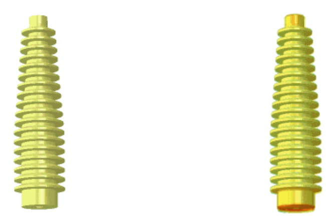




Water-Jacket Flow



Exterior Aero/Drag

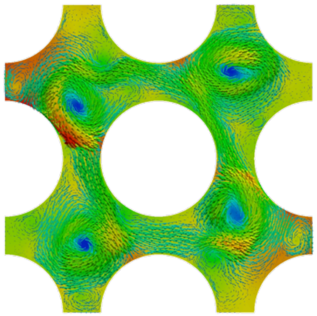


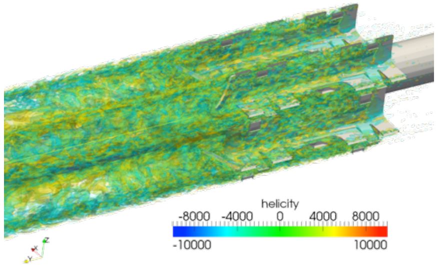
Pressure **Temperature**

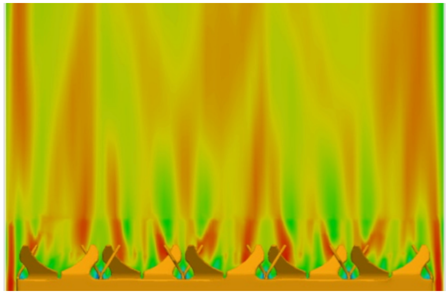
High-Voltage Power Line Insulator

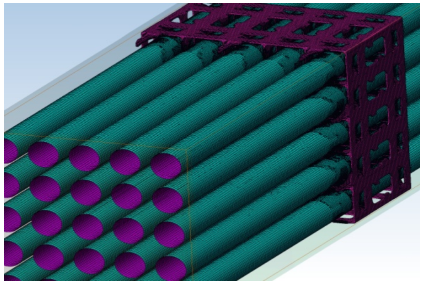
Applications: Hydra-TH – A Vertical for Thermal-Hydraulics

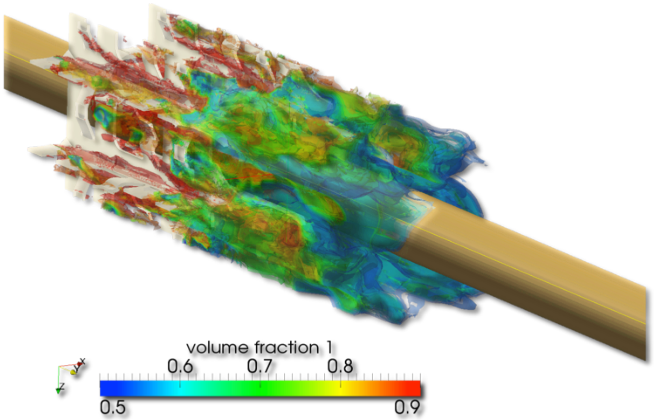
- Single-phase flow w. multiple turbulence models
  - Projection for transients, fully-implicit for slow transients
  - ILES, WALE, DES, STDk-ε, Non-Linear k-ε, RNG k-ε, Spalart-Allmaras
- Multi-phase (N-field) code base in place
  - Fully-implicit under development
  - Beginning to integrate closure terms
  - Scaled to 192M 3x3 rod bundle on 36,000 cores
- Advanced Closure Models
  - Mechanistic multiphase boiling models
  - Integrated drag/lift forces
- Experimentally Supported Closure Models
  - Closure model development and validation
  - Single and multiphase validation experiments

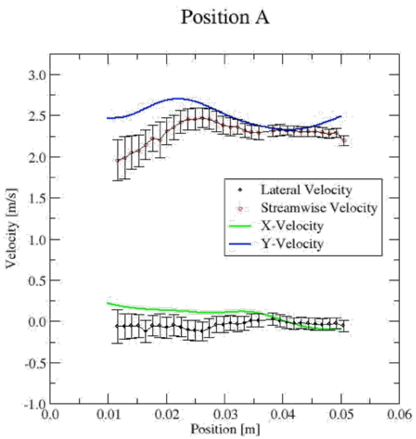


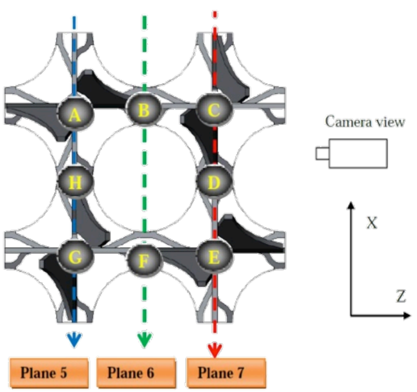






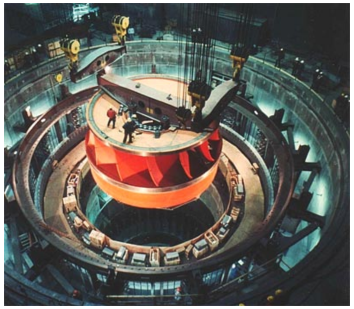


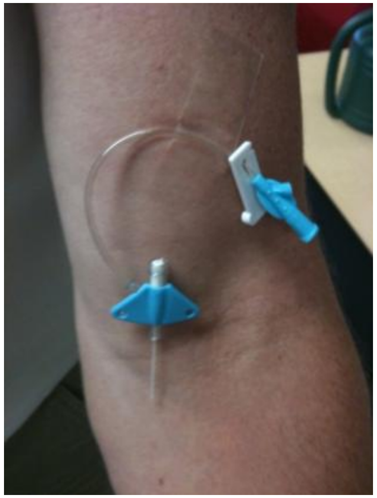


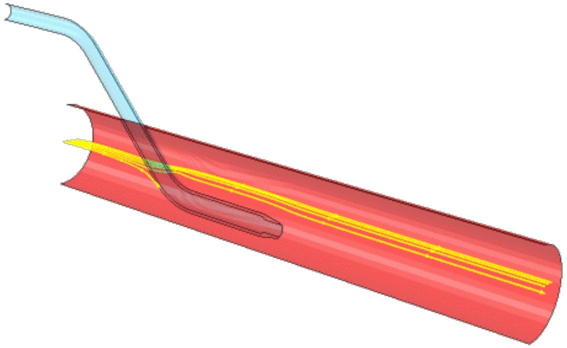


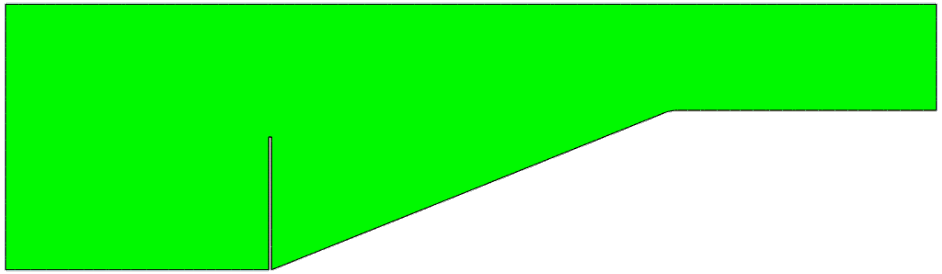
Applications: Fluid-Structure Interaction

- Biomedical, e.g., drug delivery systems, hemodynamics
- Fluid-mechanical systems, e.g., valves, turbines, etc.
- Aero-elastic systems
- Manufacturing processes



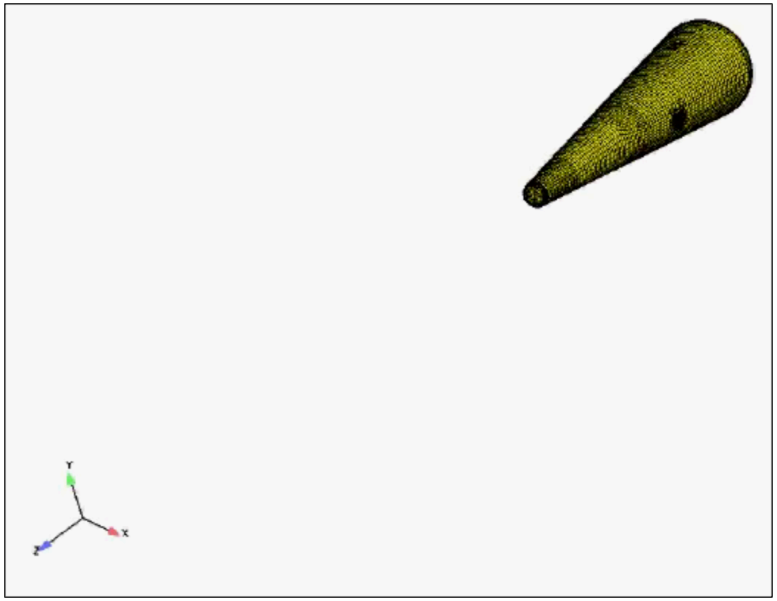




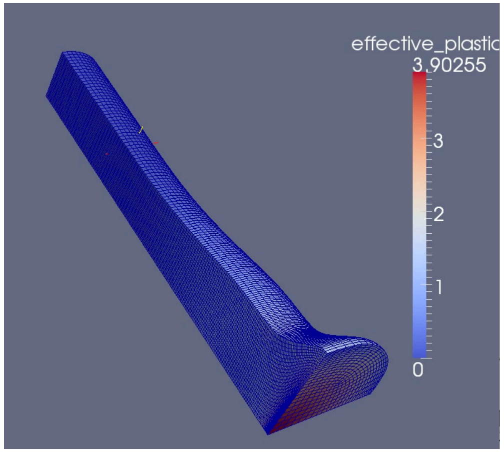


Applications: Lagrangian Hydrodynamics

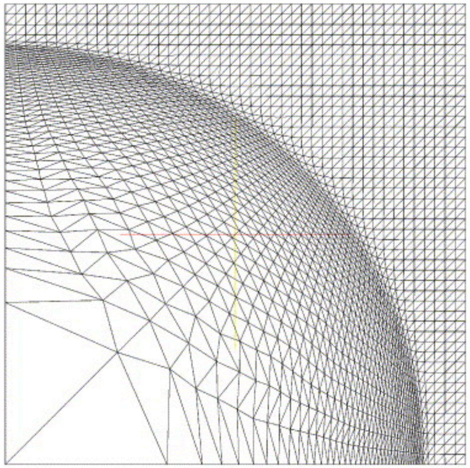
- Rigid Body Dynamics
- FEM (DYNA-Style) Lagrangian Hydro
- Variational Multiscale (VMS) Lagrangian Hydro
  - (Scovazzi, Christon, Hughes, Shadid, CMAME, 2007)
- Cell-Centered (Riemann-based) Hydro
  - 3 options: Burton (FLAG), Christon, or Maire's schemes

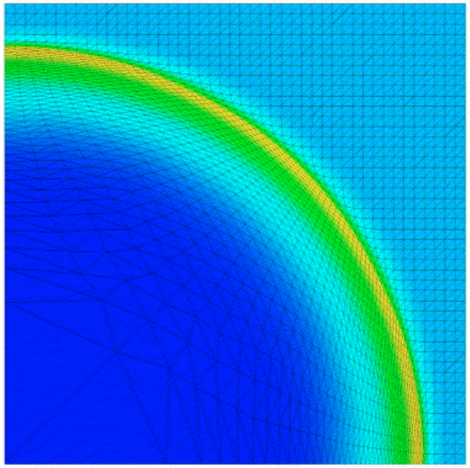


Rigid-Body Dynamics (for FSI problems)



Cell-Centered Lagrangian w. Elasto-Plastic Flows



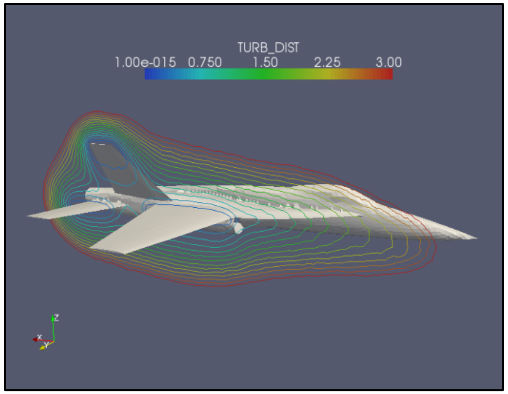


VMS Hydro Sedov Blast Wave Problem

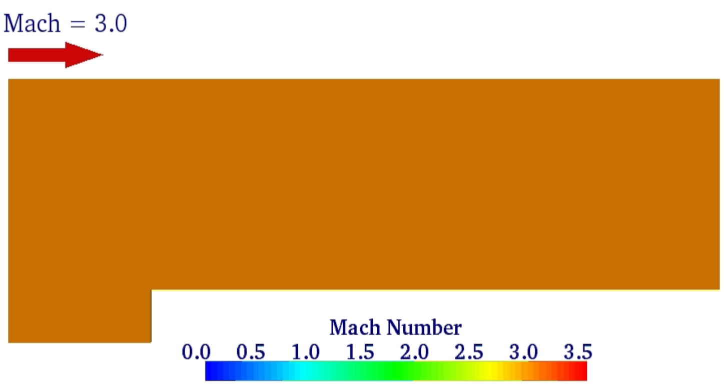
Applications: Eulerian Shock Hydrodynamics

- ❑ Explicit FVM/RK2 methods
- ❑ Interior/Exterior Flows
- ❑ Interfaces for interface tracking, e.g., FronTier
- ❑ Blast loading on structures
- ❑ FSI under shock loading

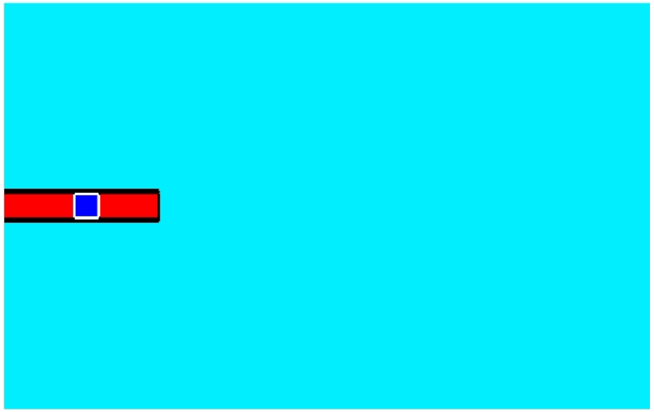
(*Tipton, Christon, Ingber, IJNMF, 2011*)



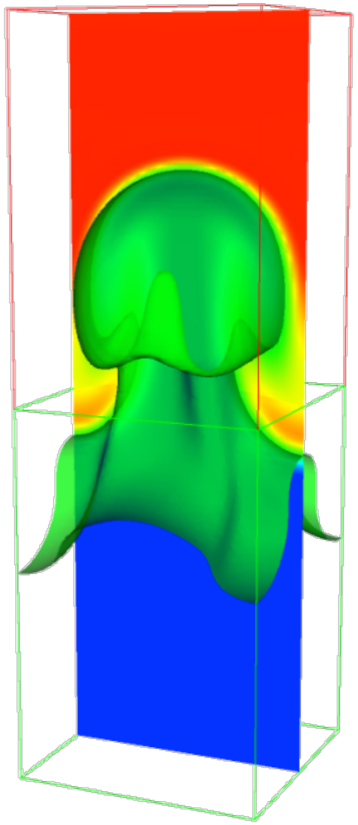
Base Euler Solver



Emery Problem



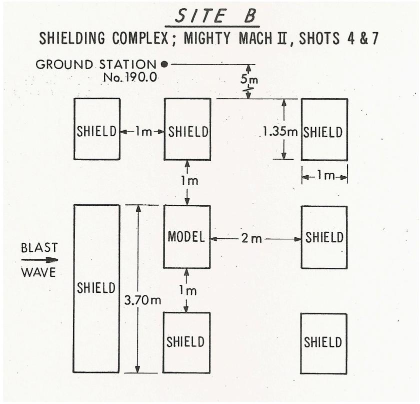
Level Set for Projectile Motion
Mach 4.0 Muzzle Velocity

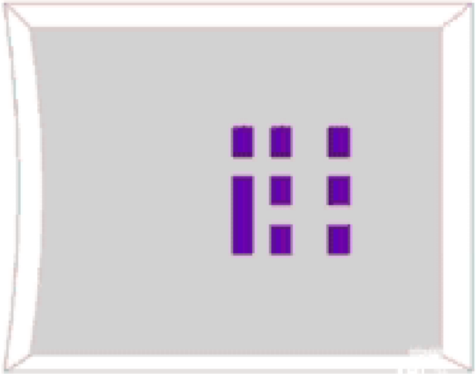


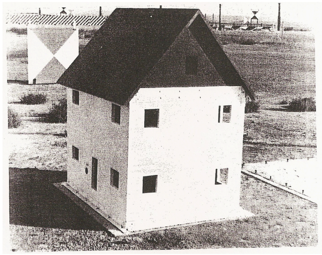
Front Tracking using FronTier

Applications: Blast Loading, Fluid-Solid Interaction

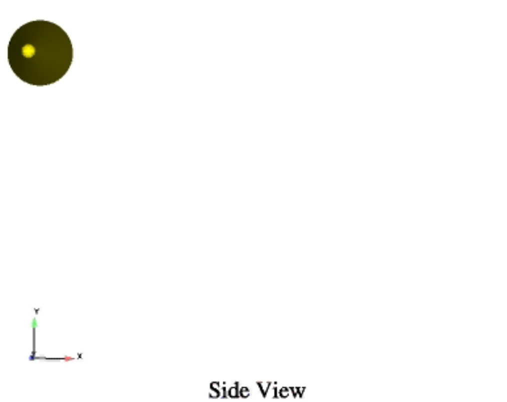
- **Mighty Mach Experiment**
  (Coulter, Ballistics Research Lab, 1980)
- **1/8th scale city complex model**
- **490 kg Pentolite charge**
- **Non-ideal airblast, equivalent energy deposition used**

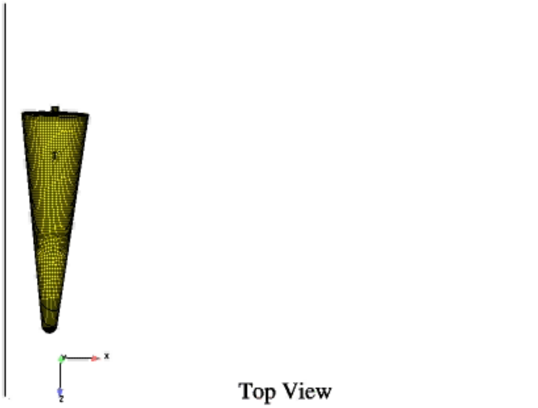






Hydra
Rigid-Body Dynamics





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Getting Started – Funding Possibilities

- ISV's are unlikely to do the necessary research for large-scale Engineering/Scientific applications on advanced architectures
- This poses a unique opportunity to impact LANL, DOE and National interests
- Develop an open-source consortium that can contribute to development of open-source computational mechanics
  - DOE National Labs: LANL, LLNL, SNL
  - DOD Labs
  - Possibly tap ISV's
  - Auto industry: Ford, GM, Mercedes, etc.
  - Proctor & Gamble, Exxon-Mobil, Chevron, Abbot labs, BD, …
  - IBM, Nvidia, …