SAND2007-6669C

Fire Science & Technology Program at Sandia National Laboratories

Overview

International FORUM of Fire Research Directors

October 15, 2007

Dr. Sheldon Tieszen, Manager
Fire and Aerosol Sciences Department

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Organization
  - People and funding
- Phenomenology Thrusts
  - Fire in the context of engineering sciences
- Modeling and Simulation Thrusts
  - Fire & multiphysics simulation
- Experimental Thrusts
  - New facility & diagnostics - Tour on Tuesday

Fire Science and Technology Program
Fire and Aerosol Sciences Dept.

- Personnel: 25
  - 20 are core fire dynamics/heat transfer people
  - 5 are aerosol dynamics people
- Fire people:
  - 9 PhD, 2 MS, balance are technicians & administrative
  - Areas:
    - Fire dynamics/thermal loads analysis: 3
    - Physics model development: 2
    - Experimental/testing: 5
  - Budget: ~$8M USD annually

Fire Science and Technology Program
Engineering Sciences Support

- Thermal/chemical/fluid
  - Fire/Structure response analysis: 5 people
  - Fire code development: 3 people
  - Multiphysics framework development: 6 people
  - Diagnostics development: 3 people

- Impact/penetration/crush/structural safety
  - Analysis: ~ 12 people
  - Numerical code development: ~ 5 people
  - Experimental: ~ 12 people

- Engineering science safety related budgets (beyond fire dynamics): ~$15M USD annual

Fire Science and Technology Program Funding Outlook

- Historical
  - Strong growth from 1994 to 2004
    - Increasing inward focus:
      - From 50% USDOE funded to ~ 90% USDOE funded
  - Stable from 2004-2008
    - ~90% USDOE funded
    - Funding shifting from weapons to energy
- Future
  - Continued shifting of funding from weapons to energy and to other government sources
  - Stable size

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Fire Science and Technology Program Phenomenological Thrusts

- Heat Transfer in Fires
  - Validation quality data sets
  - Object response including organic material response

- Hydrocarbon fires
  - Wind driven fires
  - Moving to include flowing liquid dynamics

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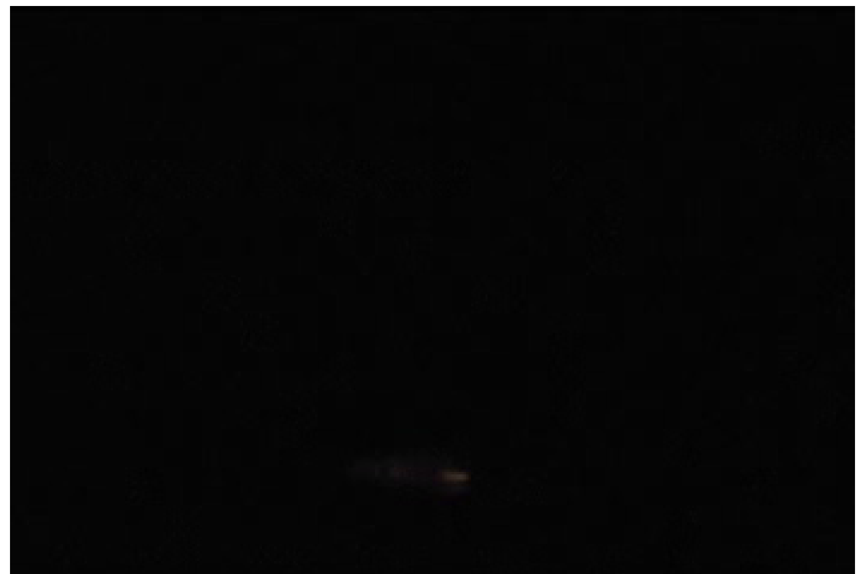
Fire Science and Technology Program
Phenomenological Thrusts

- **Propellant fires - Atmospheric burning including Aluminum combustion**



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Fire Science and Technology Program Phenomenological Thrusts

- High consequence failure of engineered systems
  - Linking primary impact through fire to quasi-static failure
    - Real transportation/industrial fire related accidents are almost always multiphysics in nature
      - Dynamic impact/failure
      - Fuel dispersal/transport
      - Fire
      - Quasi-static structural collapse
- Mitigation
  - Suppression with water spray

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Modeling and Simulation Thrust

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Fuego Mechanics Module
Overview

- Low Mach number, variable density, unstructured (finite-volume) fluid dynamics
  - Turbulent reacting flow with coupling to participating media radiation (PMR) and heat conduction
- RANS and LES-based turbulence models
  - k-ε, low Re k-ε, v2-f, PANS, Ksgs, Dynamic Smagorinsky
- Reacting flow suite
  - Eddy dissipation concept, mixture fraction-based models, CMC being implemented
- Multiple element types
  - Hexahedron, tetrahedron, pyramid, wedge
- Pressurization, low speed compressibility

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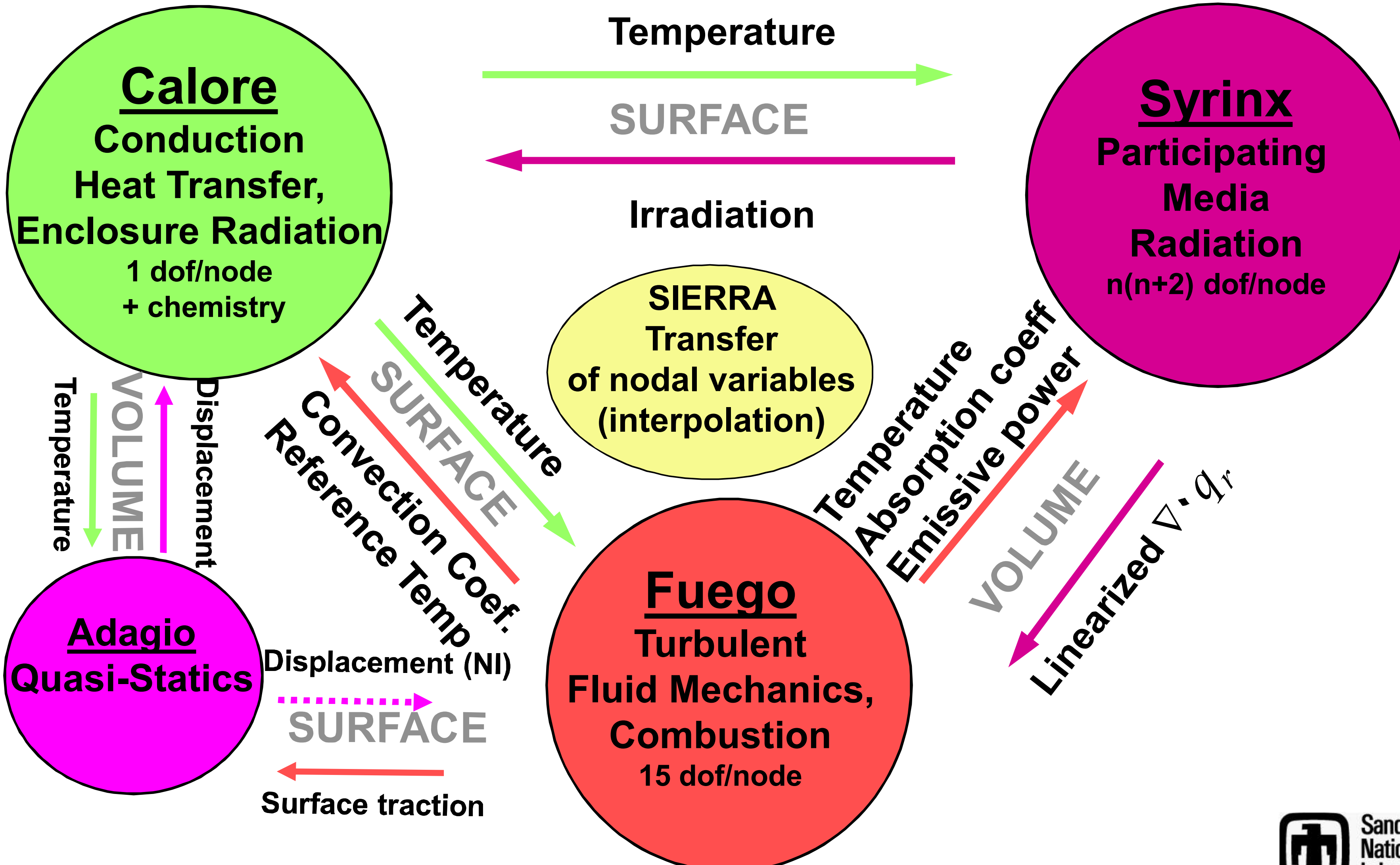
Coupled-Mechanics
Object-in-Fire with Structural Response



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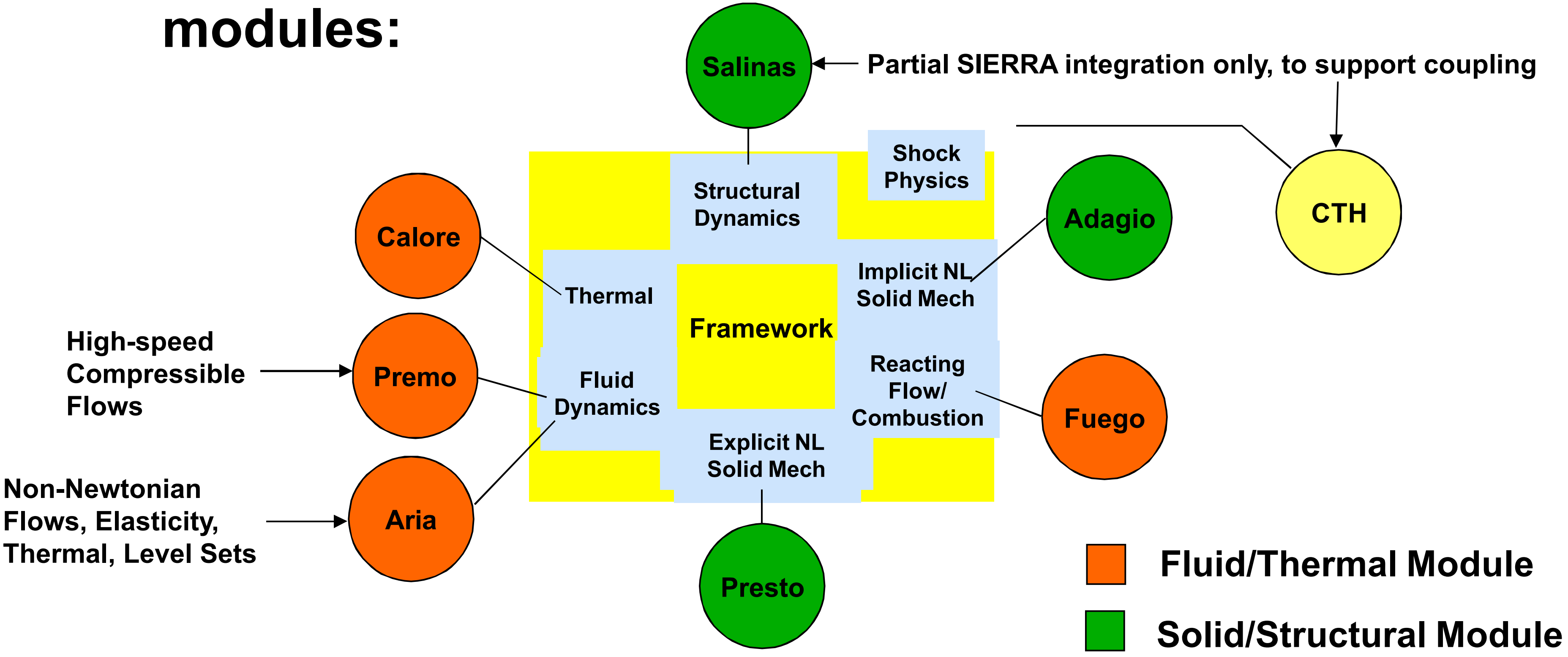
SIERRA Mechanics: The Big Picture

- *SIERRA Mechanics* consists of the following modules:



- Modules can readily be coupled for multi-physics applications
- Strategic activities underway to combine modules

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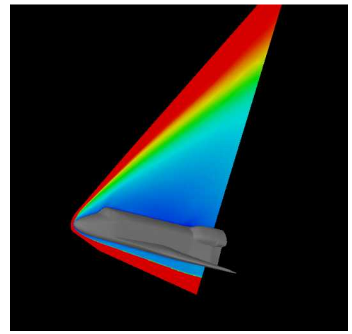
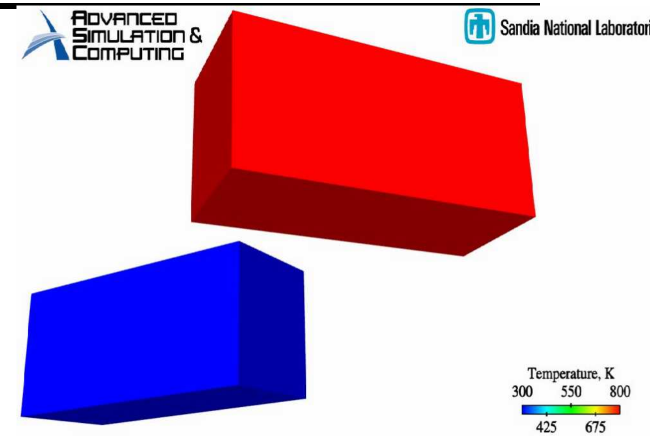
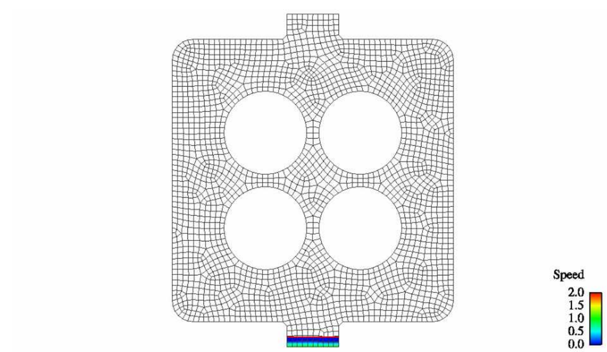
Sierra Thermal/Fluids Capabilities

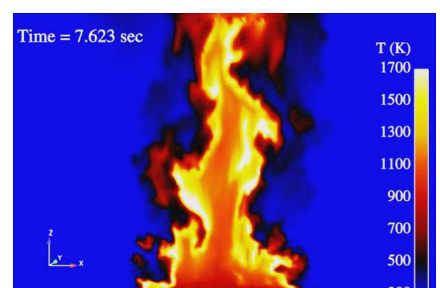
- Calore – Heat Transfer, Enclosure Radiation and Chemistry
  - Dynamic enclosures
  - Element birth death
  - Contact
- Premo – Compressible Fluid Mechanics
  - Subsonic through hypersonic
  - Laminar and turbulent
  - Unstructured mesh



- Aria – Non-Newtonian, Chemically Reacting, and Free Surface Flows
  - Complex material response
  - Level sets for surface tracking
  - Flexible coupling schemes
- Fuego – Low Speed, Variable Density, Chemically Reacting Flows (Fire)
  - Eddy dissipation and mixture fraction reaction models
  - RANS and LES based turbulence models
  - Unstructured Mesh
  - Pressurization models







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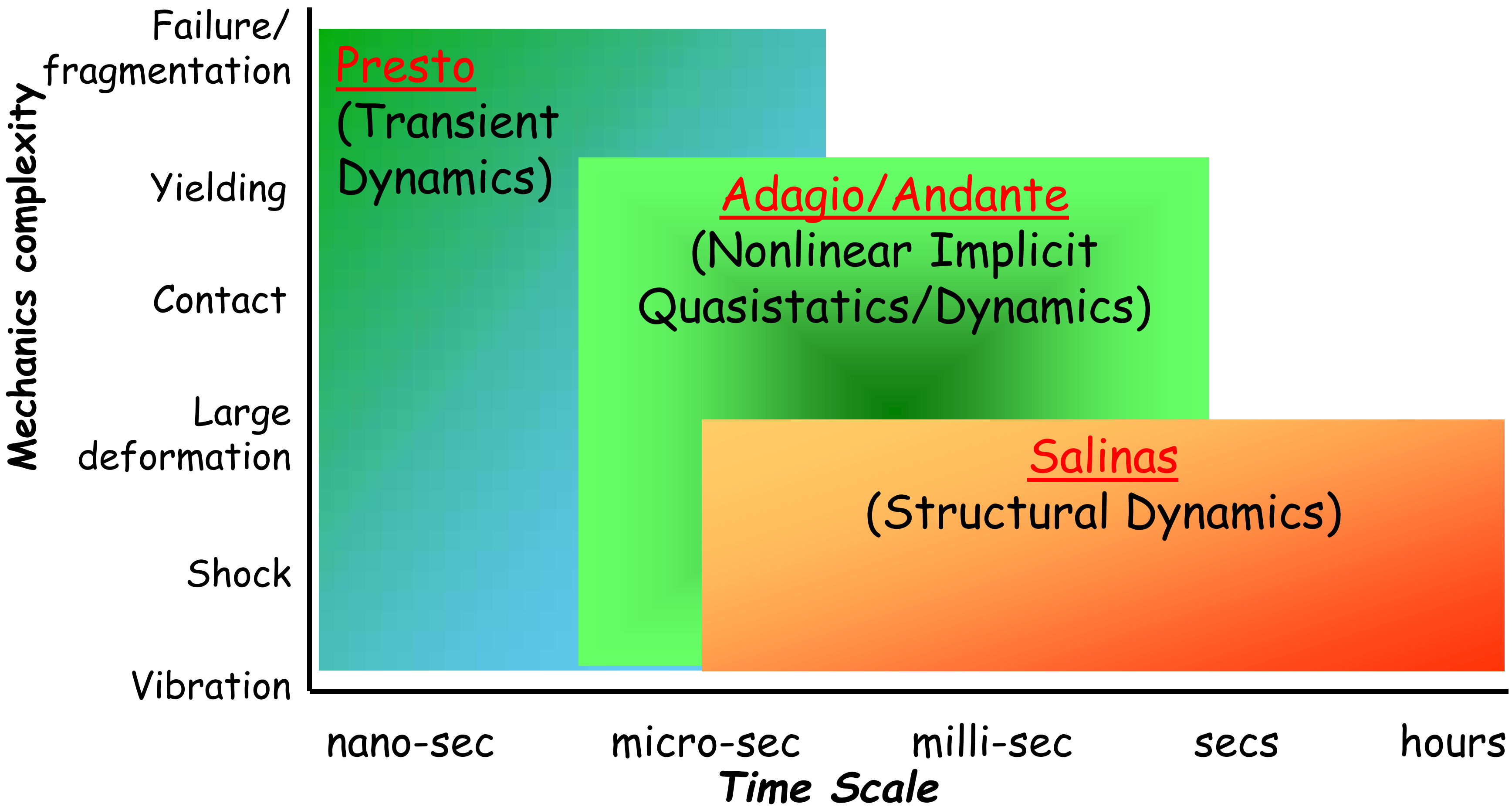
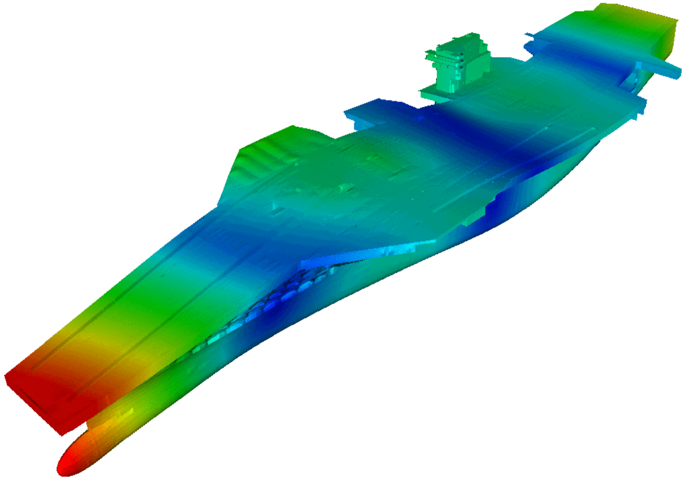
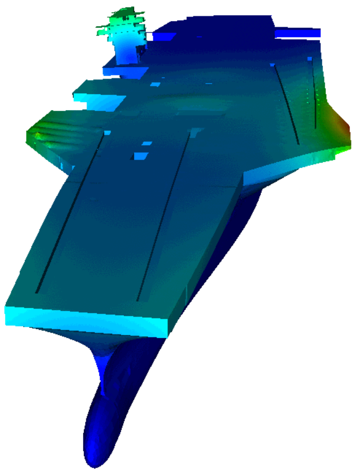
SIERRA Solid/Structural Modules Notional Overview



Modal Analysis of an Aircraft Carrier

- Extremely complex model (1000's of material regions, offset shells and beams)
- 2.0M DOFs, solved on 64 processors





Von Mises Stresss Overlaid on Mode Shapes

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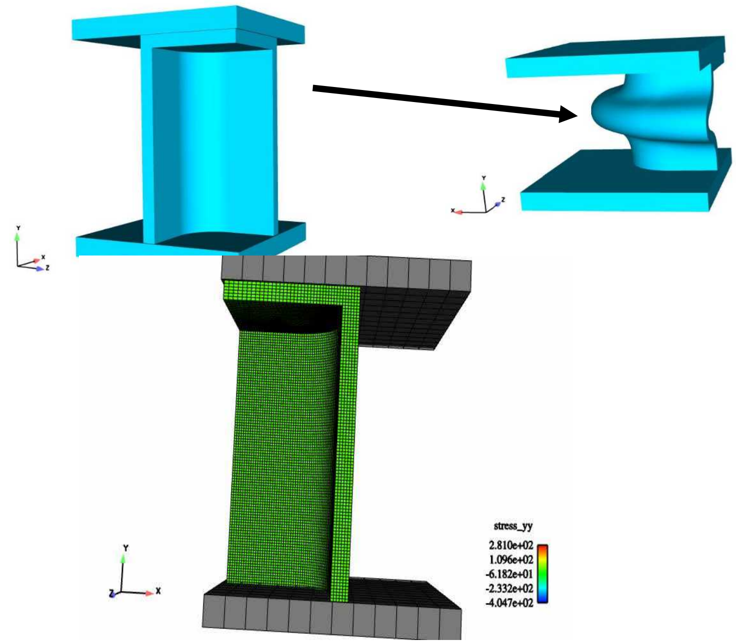
Quasi-static Structural Mechanics - Adagio

- Implicit (quasi-static & dynamic) solid mechanics finite element code
- Provides scalable parallel solvers for highly nonlinear problems
  - Contact
  - Nonlinear material response
  - Large deformation
- Utilizes services provided by the Sierra Framework to enable
  - Coupled physics
  - H-adaptivity (under development)
  - Multi-length scale modeling techniques (under development)



- Design of energy absorbing barrier
- Uses multilinear elastic-plastic constitutive model
- Demonstrates frictional contact, geometric and material nonlinearities, parallel scalability

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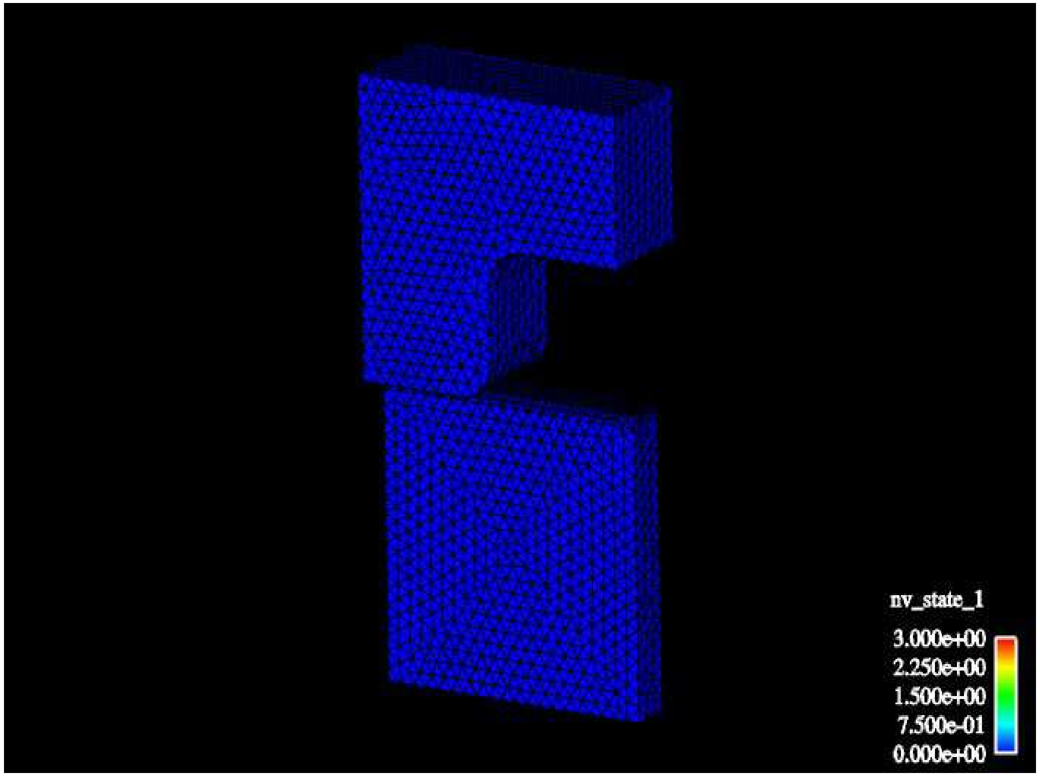
Explicit Dynamics - Presto

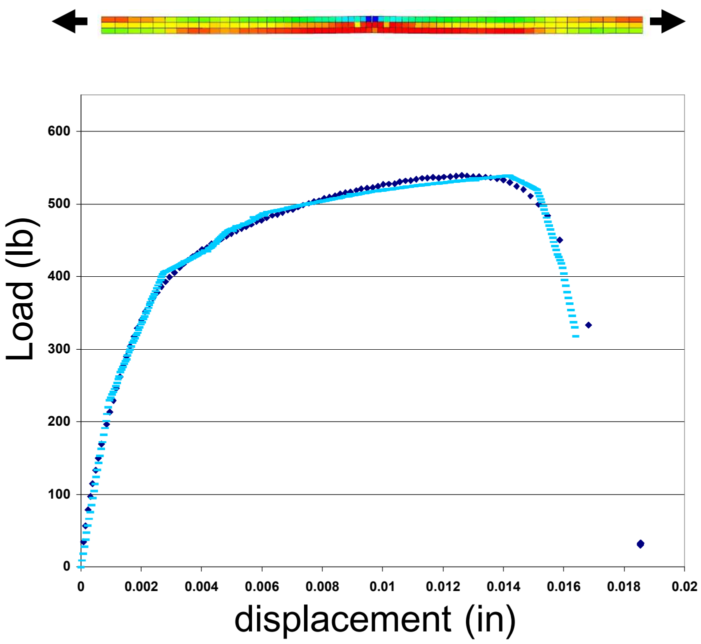
- Fully Three-Dimensional
- Massively Parallel
  – Thousands of processors
- Finite Elements and Particles
  – SPH particles
  – Other particle methods planned (e.g., GPA, HPM, RKPM)
- Material models: 40+, including energy-dependent materials
- Contact: Massively parallel, momentum balance, accurate friction response
- Boundary conditions:
  – Kinematic and Force
  – Specialized: cavity expansion, silent BC
- Failure modeling:
  – Material failure/element death
  – Cohesive zones (elements, contact surfaces)
  – Phenomenological models (spot weld, line weld)

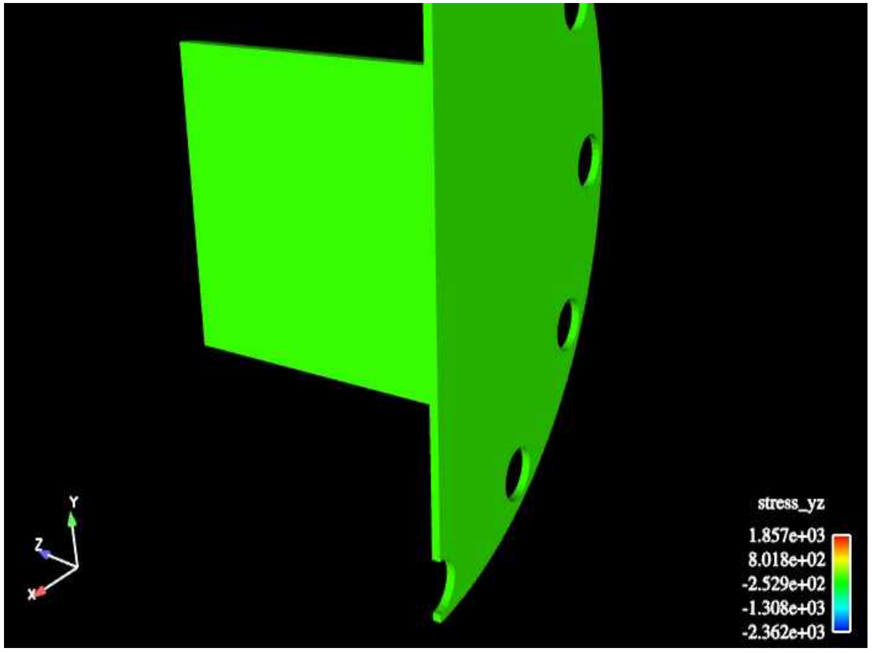
Node-based Tet: Impact Punch



Weld Failure Under Dynamics Loading

Impact against an unyielding target using spotweld interface model (calibrate against tension test data, validated against cylinder drop test)



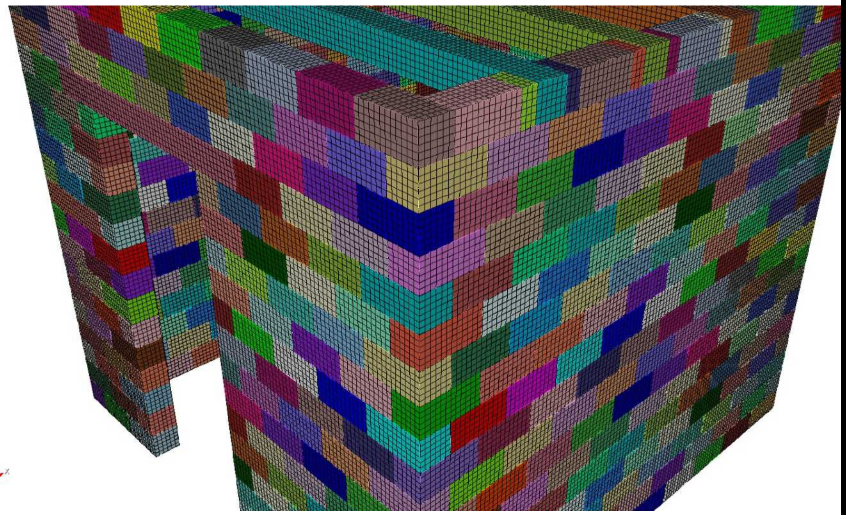


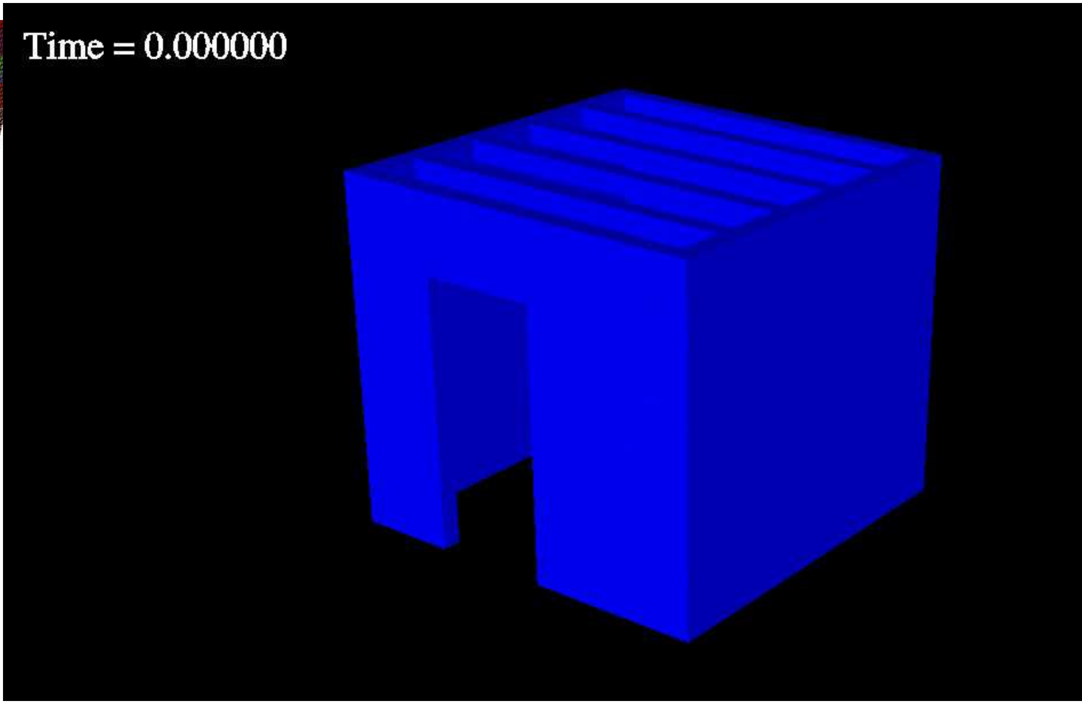
Calibration of spotweld model with tensile test data

Validating fitted failure parameters on weld test configuration in cylinder drop test

One-Way Coupled Hydrodynamics/Explicit Dynamics

- **CTH Loading: 5 kg TNT at the *center of room*, for 2.5 ms**
- **Presto Simulation**
  - **Elastic brick material, Wood beams, 293,000 Elements**
  - **Run for 2 days on 32 processors**





Room, *No Mortar*

One-Way Coupled Hydrodynamics/Explicit Dynamics

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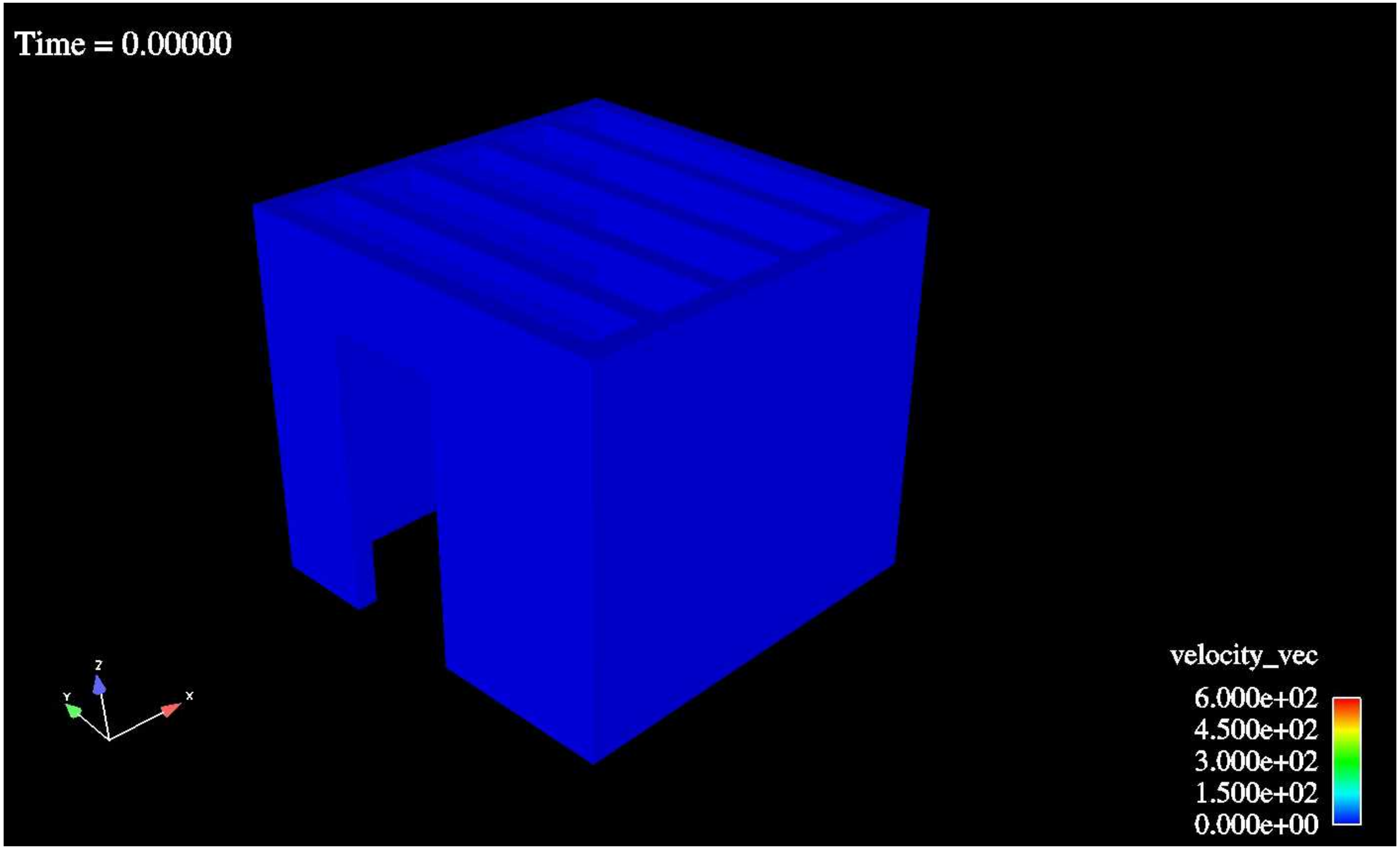

Room *With Mortar*

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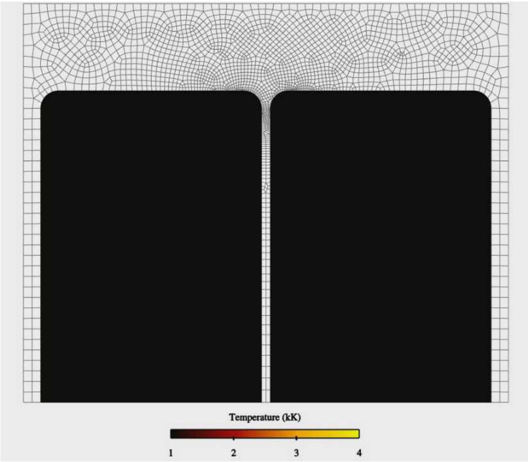
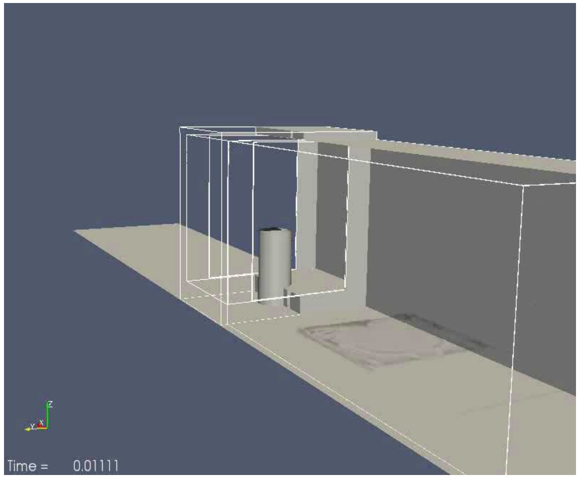
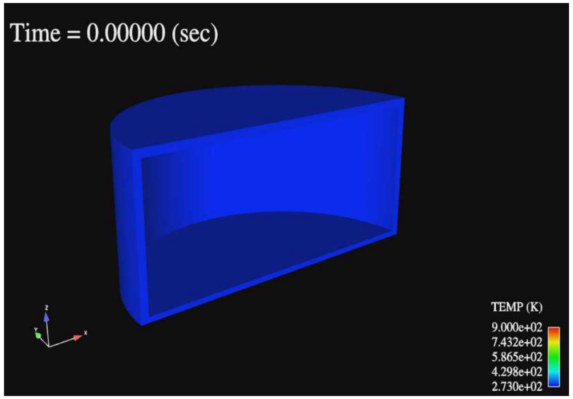
Some Coupled Physics Examples







Residual stress prediction for a laser welding process.

Coupled heat transfer, fluid mechanics, quasi-static solid mechanics.

Temperature and internal pressure prediction for an object in a hydrocarbon fire.

Coupled chemically reacting flow, heat transfer, quasi-static solid mechanics.

Internal pressure prediction for a decomposing foam in a thermal environment.

Coupled heat transfer, foam chemistry, quasi-static solid mechanics.

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Physics Model Development

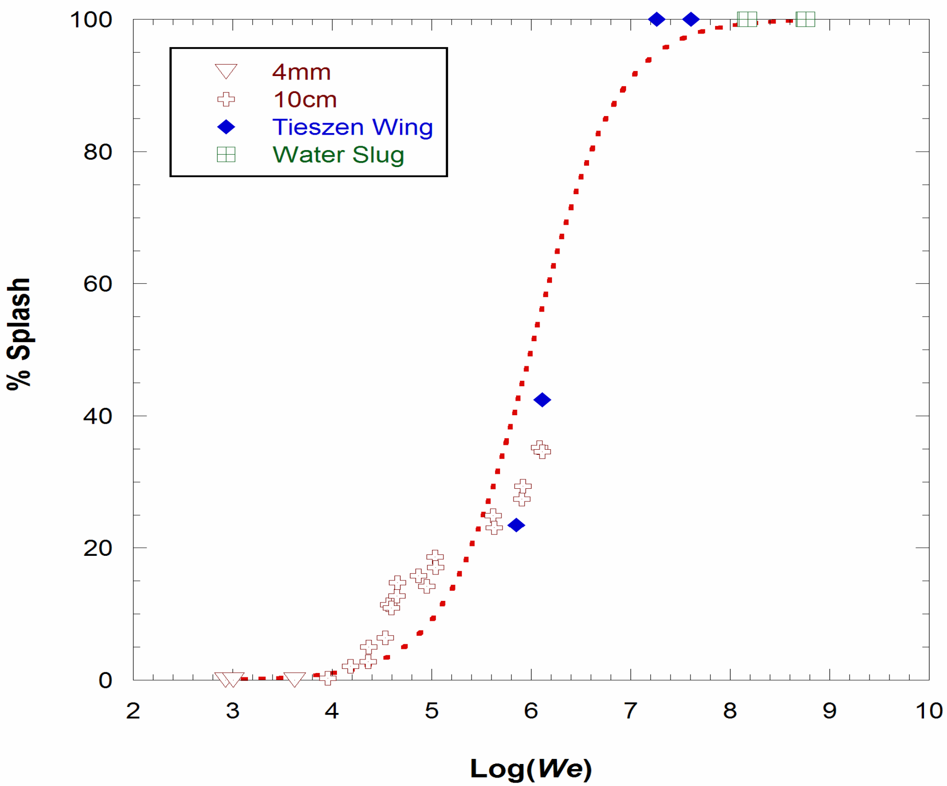
- **Modeling is necessary**
  - **Length scale range is too large to do from first principles**
  - **Multiphysics subgrid models are challenging**

- **Extensive mathematical model development is occurring**
  - **Organic material decomposition**
  - **Advanced combustion models**
  - **Spray transport and suppression**

Liquid/Solid Impact Study Summary Results

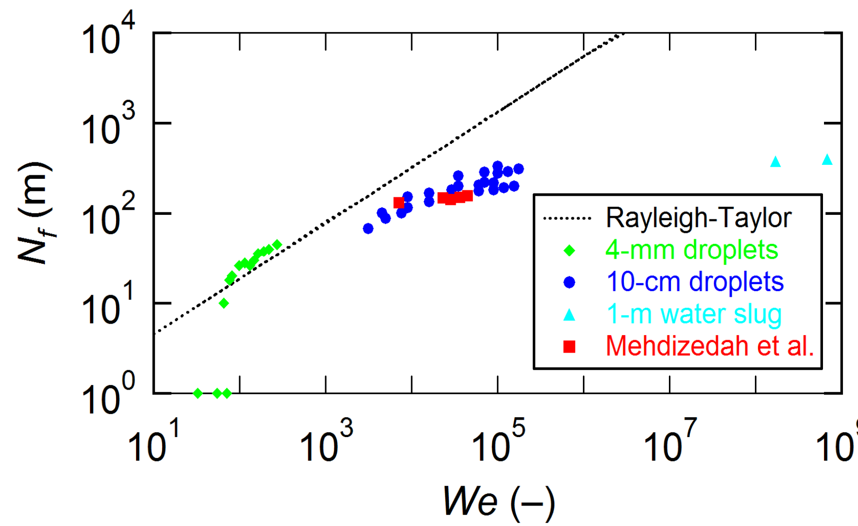
Impact results fit well to a logistic curve fit:

$$\%Splash = \frac{100}{1 + 10^{(6.0 - \log(We))*1.0}}$$



Rayleigh-Taylor assumptions appear unreliable when compared with Sandia data. New model:

$$N_f = -92.0 + 57.0 \log(We)$$



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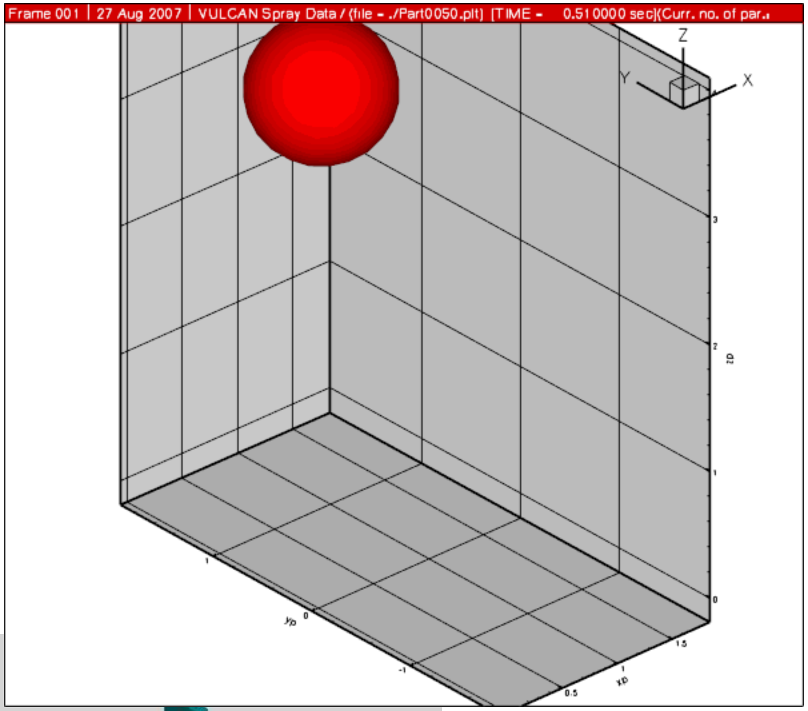
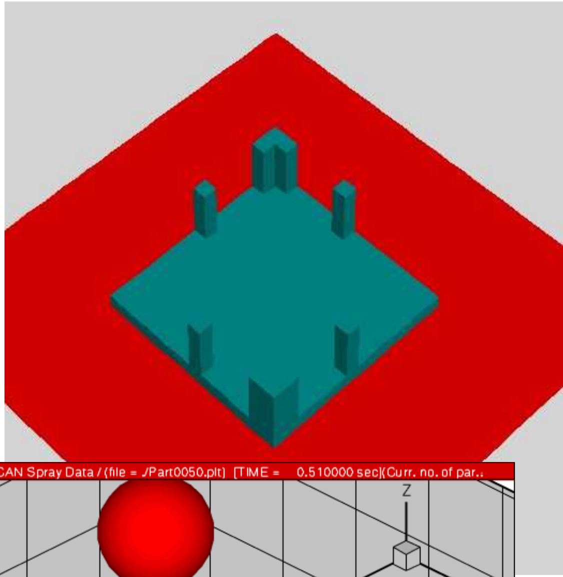
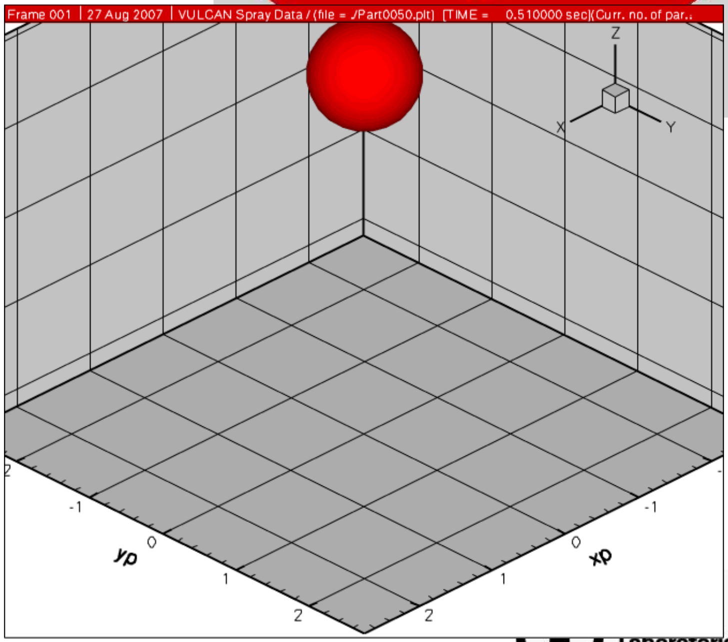
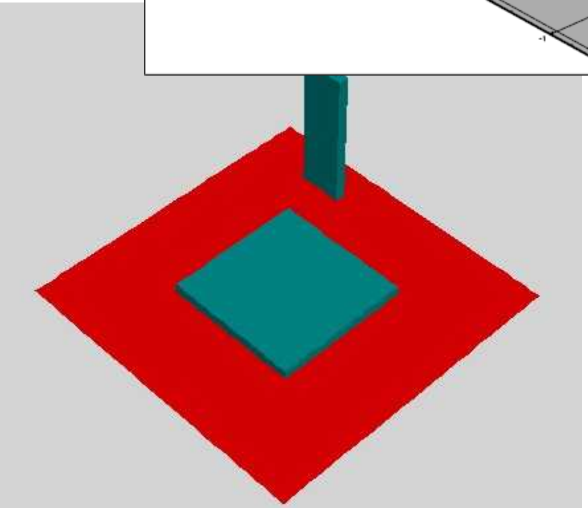
Model Behavior



Model performs well for *challenging* cases: Angled impact (left) and oblique obstacles with tertiary impact (right).







All cases assume 4 cm diameter initial drops released every 0.5 seconds: Relative particle sizes are significantly oversized in the videos so the spray drops are visible.

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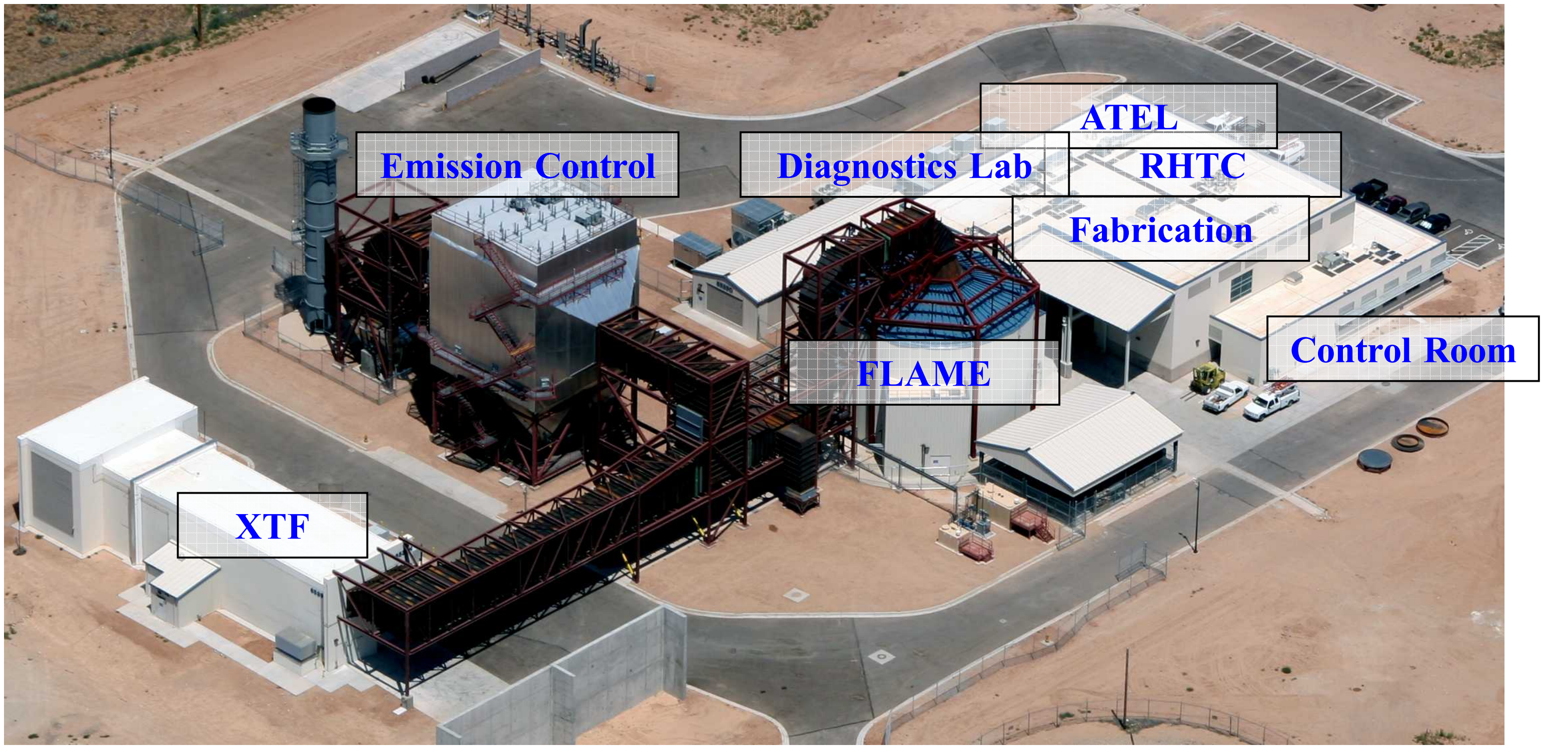
TTC – New Facility



- XTF – Horizontal Wind Tunnel for Fires in Cross Wind
- FLAME – Vertical Wind Tunnel for Fires in Calm Conditions
- RHTC – Full Scale Radiant Heat (Fire Loading Simulator) Lab
- ATEL – Abnormal Thermal Environment Lab
- Supporting infrastructure

Lurance Canyon Burn Site

• **Large open fire experimental site**

Tour Tomorrow

- Check out of hotel – you will not be coming back
- Grab and go breakfast provided
- Load luggage onto bus
  - Cameras, cell phones, etc. must be in luggage on the bus, please do not carry on.
  - No firearms, explosives, pyrotechnics, or propellants, or intoxicants, etc. (do they know us fire guys or what)
  - I need your badges back after the trip