SAND2007-4563P

SIERRA Mechanics Overview

Jim Redmond
Manager, Strategic Initiatives
Solid Mechanics/Structural Dynamics Group
Sandia National Laboratories
Albuquerque, NM
jmredmo@sandia.gov

Playing the role of

Joseph Jung
Manager, Computational SM/SD.

July 10, 2007

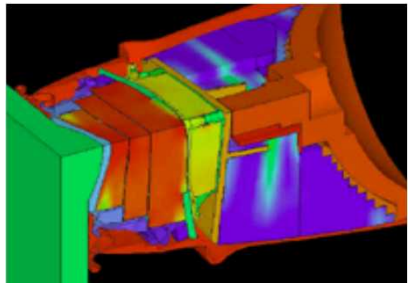
SAND Number: 2007-3496 P

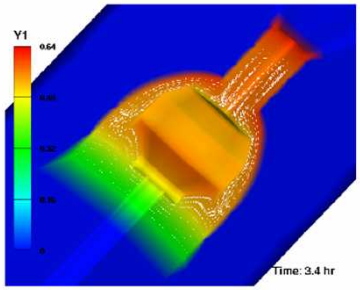
Sandia National Laboratories

Engineering Sciences at Sandia National Laboratories

Mission:

***Provide Validated, Science-Based, Engineering Solutions Across The Product Life Cycle* to Meet the Mission Needs of Sandia National Laboratories.**





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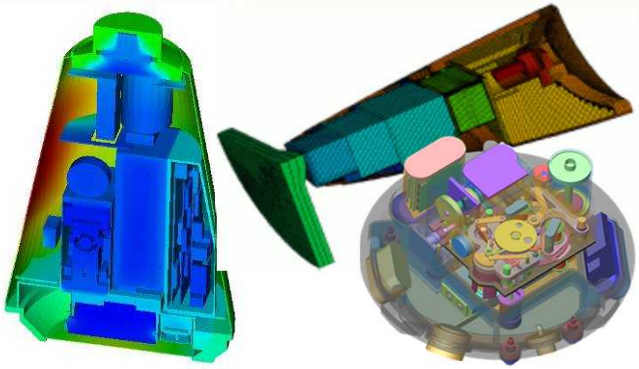
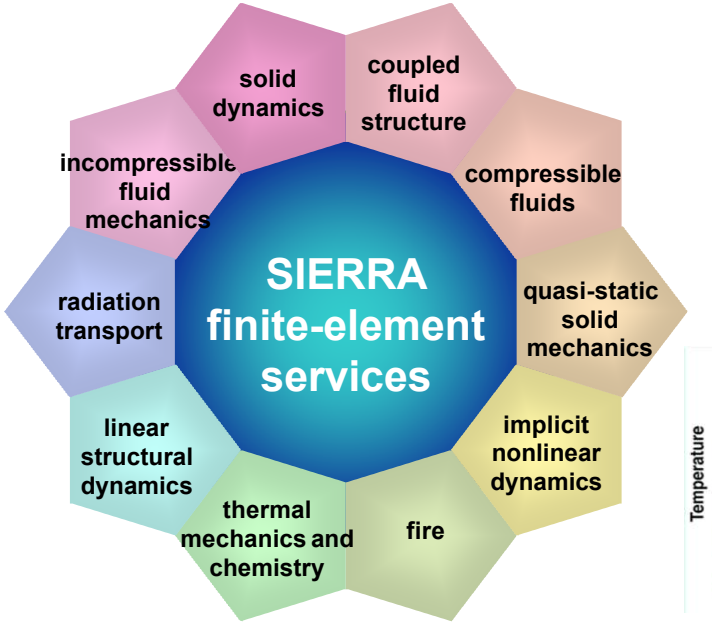
Engineering Sciences Capability Areas

Engineering Modeling & Simulation

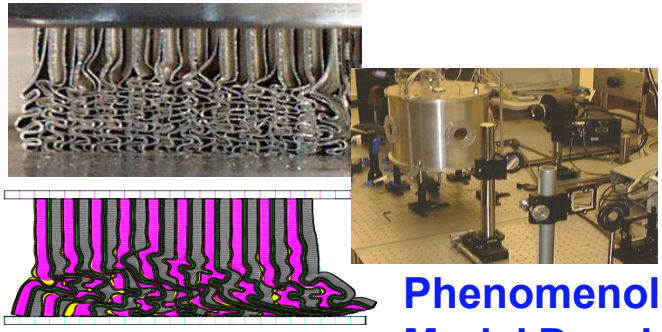


Large-Scale Test /Qualification

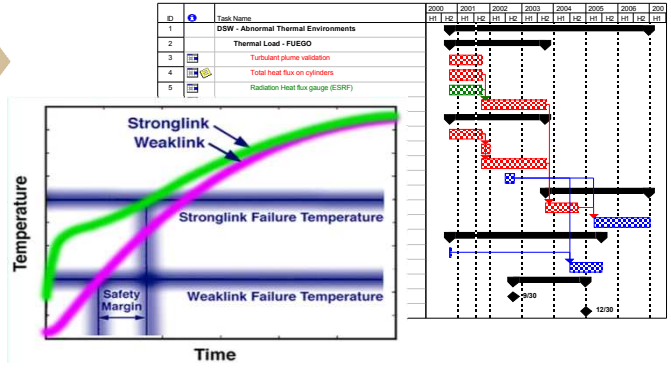
Code Development



Phenomenology & Model Development



Uncertainty Quantification/ Verification & Validation



Sandia National Laboratories

Engineering Sciences Center in New Mexico

01500 Engineering Sciences Center
Art Ratzel, *Director*

01055 Business Operations and Ancillary Services
Rebecca Hunter, *Dept. Manager*

01510 Thermal, Fluid & Aero Sciences
Wahid Hermina, *Level II Mgr.*

01512 Thermal, Fluid, and Experimental Sciences
Rob Tachau, Dept. Mgr.

01513 Microscale Science and Technology
Dan Rader, Actg., Dept. Mgr.

01514 Multiphase & Nanophase Transport
Joel Lash, *Dept. Mgr.*

01515 Aerosciences Dept.
Basil Hassan, *Dept. Mgr.*

01516 Thermal and Reactive Processes
Eugene Hertel, *Dept. Mgr.*

01517 Aerosol Sciences
Richard Griffith, *Dept. Mgr.*

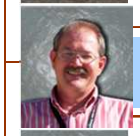
01520 Solid Mechanics/ Structural Dynamics
Pete Wilson, *Level II Mgr.*

01521 Experimental Structural Dynamics
David Clauss, *Dept. Mgr.*

01522 Experimental Mechanics/NDT Diagnostics
Rodney May, *Dept. Mgr.*

01523 Analytical Structural Dynamics
Thomas Baca, *Dept. Mgr.*

01524 Solid Mechanics Engineering
John Pott, *Dept. Mgr.*



01525 Strategic Initiatives
Pete Wilson, *Acting Dept. Mgr.*

01526 Applied Mechanics Development
James Redmond, *Dept. Mgr.*

01530 Validation and Qualification Sciences
Anthony Thornton, *Level II Mgr.*

01532 Fire Science and Technology
Sheldon Tieszen *Dept. Mgr.*

01534 Mechanical Environments
Jeff Cherry, Actg., Dept Mgr.

01535 Diagnostic Applications
Mike Valley, *Dept. Mgr.*

01540 Computational Simulation Sciences
Hal Morgan, *Level II Mgr.*

01541 Thermal/Fluid Computational Engineering Sciences
Steven Gianoulakis, *Dept. Mgr.*

01542 Computational Solid Mechanics & Structural Dynamics
Joe Jung, Dept. Mgr.

01543 Advanced Computational Mechanics Architectures
Jim Stewart, *Dept. Mgr.*

01544 Validation & Uncertainty Quantification Processes
Martin Pilch, *Dept. Mgr.*

330+ staff and management

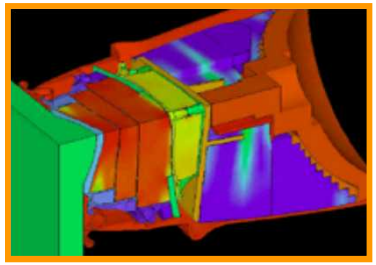
Sandia National Laboratories

1520- Solid Mechanics/Structural Dynamics

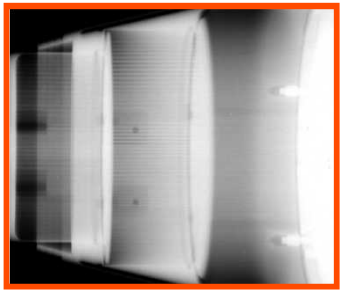
Mission

Provide the research, development, and applications expertise in solid mechanics and structural dynamics required for Sandia's to accomplish its mission in nuclear weapons and other national security areas

Solid Mechanics



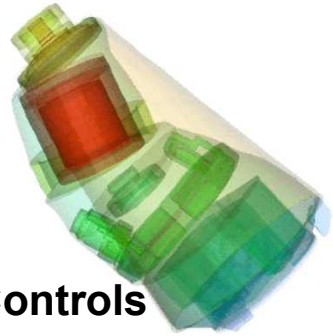
- Nonlinear Computational Mechanics
- Experimental Solid Mechanics
  - Diagnostic Development & Application
  - Production Testing
  - Certification & Failure Margin Testing & Discovery



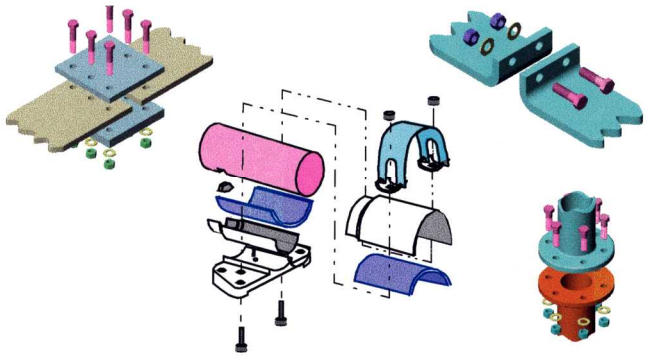
- Material Response

Structural Dynamics

- Modal, Shock & Vibration, acoustics
  - Computational
  - Experimental



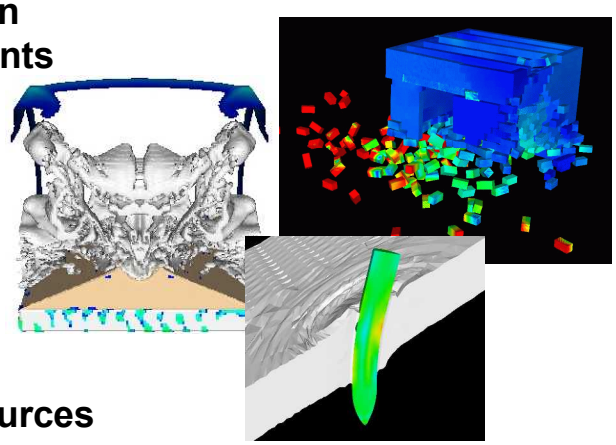
- Nonlinear Structural Dynamics
- Smart Structures & Controls
- Nondeterministic Methods & Optimization



Solid Mechanics and Structural Dynamics Strategic Initiatives Department

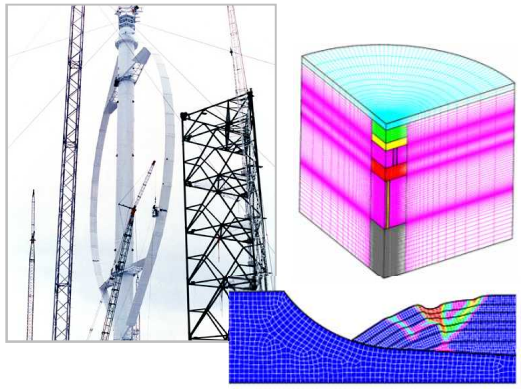
Mission: ***Proactively engage partners across SNL mission space to ensure effective utilization of distinguishing analytical and experimental capabilities to meet customer needs.***

Blast, Impact, and Penetration Assessments

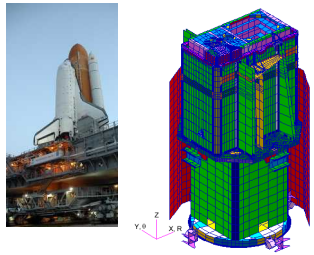


Stockpile Integrity

Energy Resources and Geomechanics



Space Systems Technology



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Modeling and Simulation at Sandia

- **Full-system multi-physics**
  - » Physics couplings, e.g.,
    - Fluid/Thermal/Solid Mechanics/Blast
      - Fire
      - Material thermal decomposition
      - Structural loading response and failure
- **Scalable tools**
  - » From single workstation to 1000's processors
- **Multi-scale (nano-to-macro scales)**
- ***Predictive* capability**
  - » Uncertainty Quantification
  - » Verification and Validation (V&V)
  - » Modeling and Simulation in conjunction with appropriate experiments

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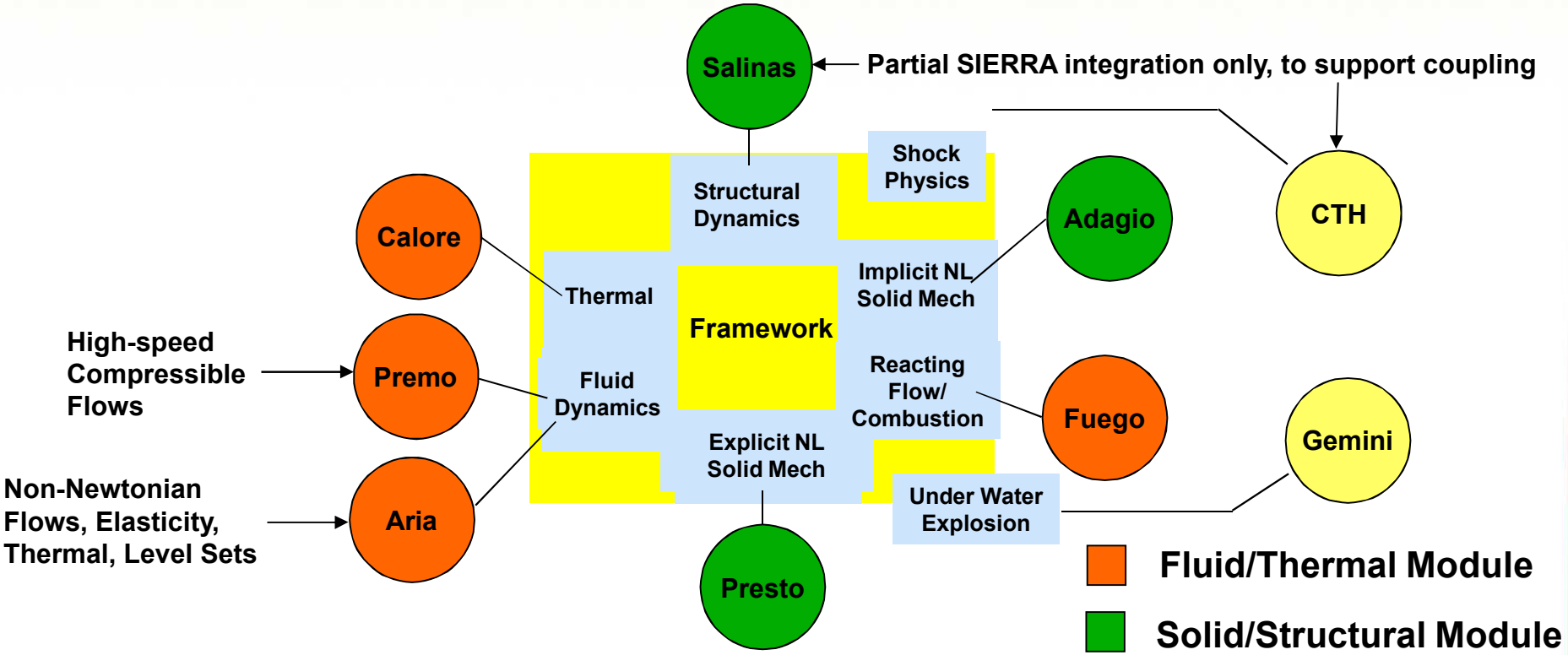
SIERRA Mechanics: The Big Picture

- *SIERRA Mechanics* consists of the following modules:



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

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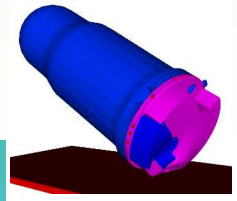
SIERRA Solid/Structural Modules Notional Overview



Mechanics complexity

Failure/ fragmentation

Yielding

Contact

Large deformation

Shock

Vibration

Presto (Transient Dynamics)

Adagio/Andante (Nonlinear Implicit Quasistatics/Dynamics)

Salinas (Structural Dynamics)

nano-sec micro-sec milli-sec secs hours

Time Scale

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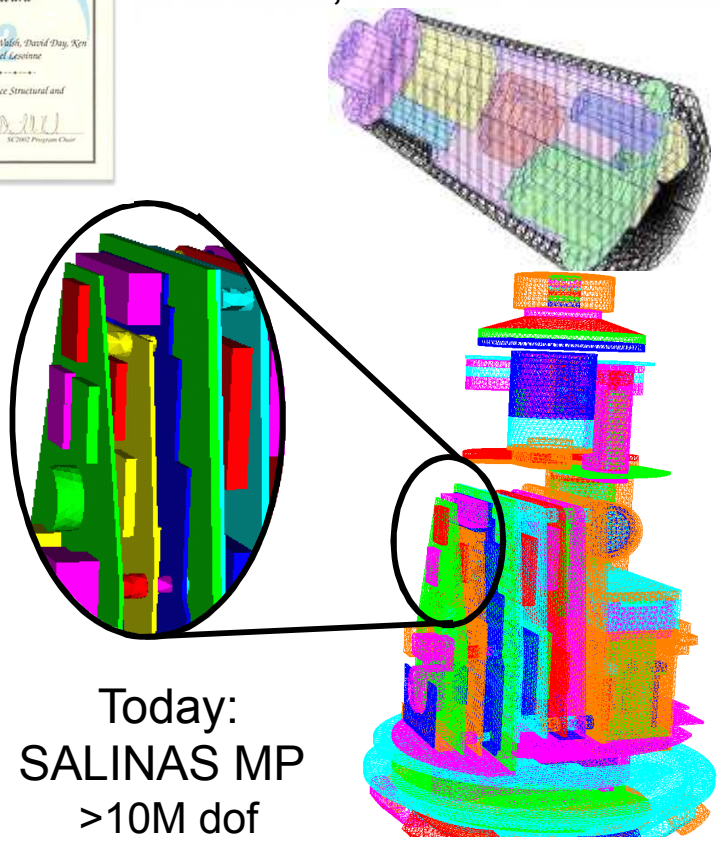
Structural Dynamics - Salinas

- **Predicts the response of a system under dynamic conditions.**
  - **Deformation, Acceleration, Stresses**
  - **Random Vibration and Fatigue**
  - **Energy dissipation in joints**
- **Efficient for very large problems**
  - **Many millions of coupled equations**
  - ***Linear Statics***
  - ***Vibration Eigen-Analysis***
  - ***Implicit Dynamics***
  - ***Frequency-Domain Methods***
  - ***Nonlinear Statics/Dynamics***
  - ***Structural Acoustics***
  - *Parallel Iterative Solvers Scalable to Many millions of coupled equations*
    - » FETI (Farhat)
    - » CLIP, CLOP Solvers (Sandia)
    - » Tied constraint

Recent Past:
NASTRAN MC2912
30,000 dof

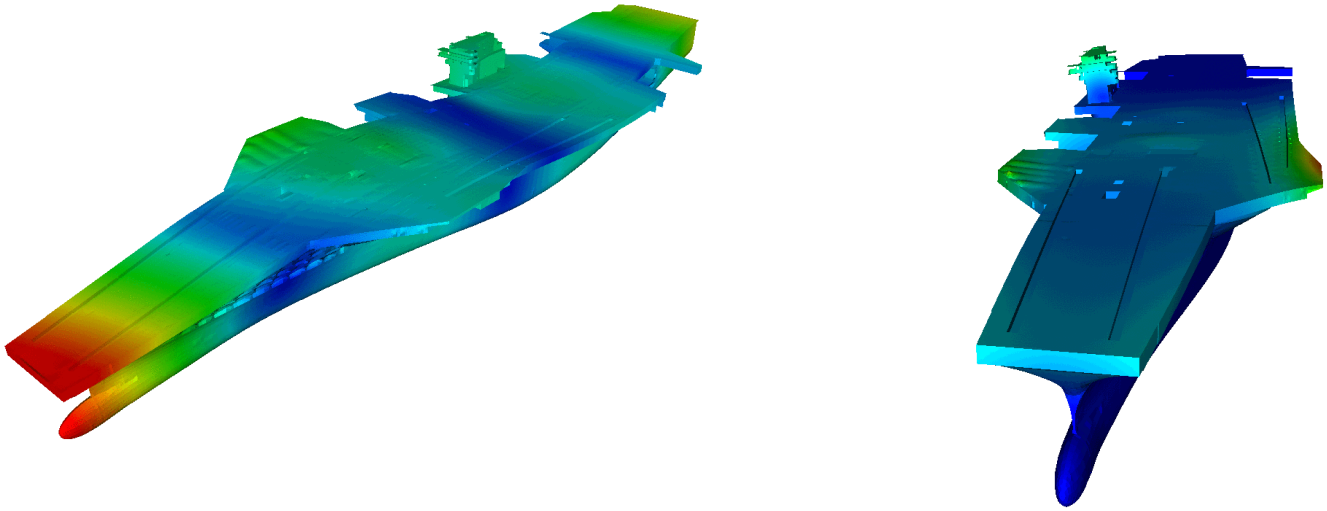


Today:
SALINAS MP
>10M dof

Salinas is scalable and fast, allowing it to handle very large models

Modal Analysis of an Aircraft Carrier

- **Extremely complex model**
  - 1000's of material regions
  - Complex geometry
  - Hexs, off-set shells, beams
- **2.0M DOFs, solved on 64 processors**



Von Mises Stresss Overlaid on Mode Shapes

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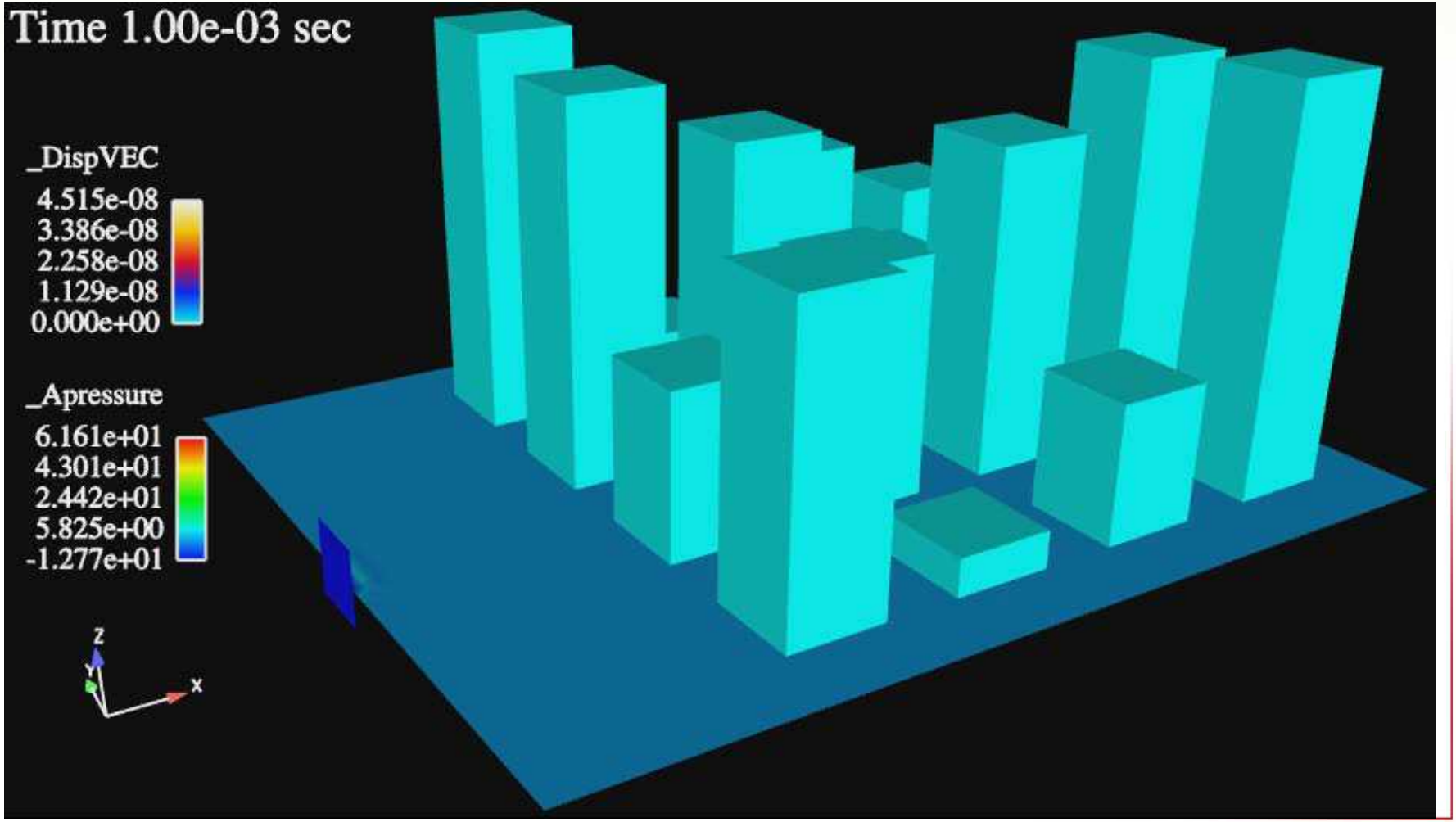
Transport of Acoustic Energy from a Ground Blast



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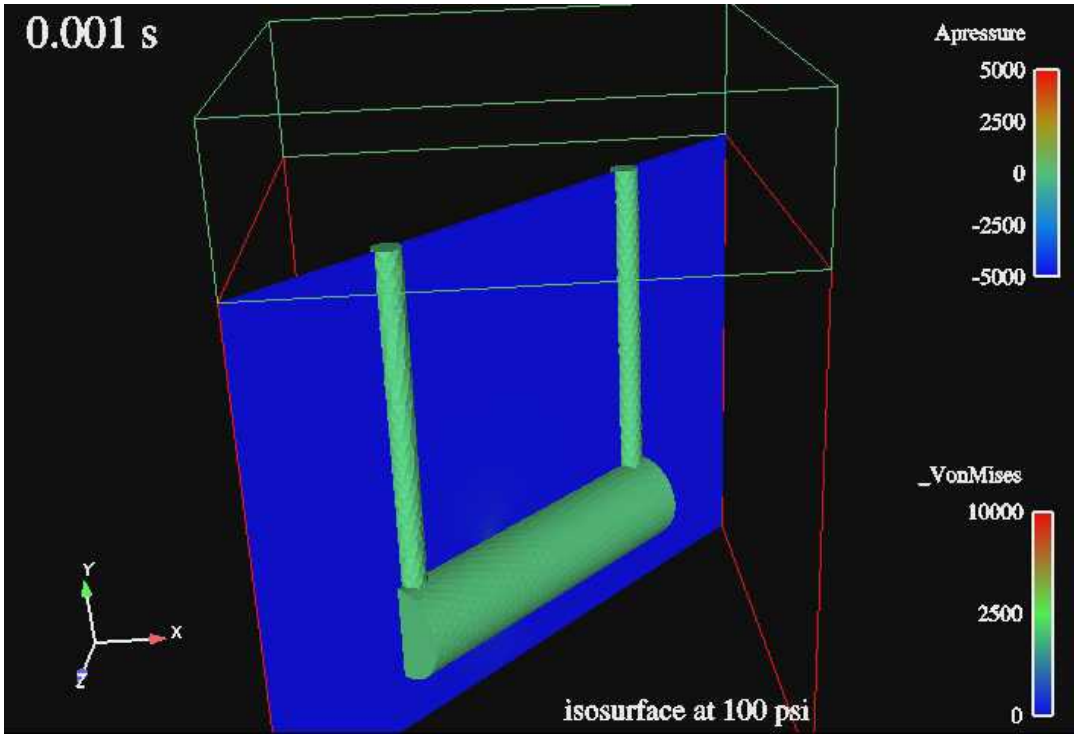
Noise Detection in an Underground Bunker

- **Strong coupling between (*nonlinear*) acoustic (air) and structural (soil) fields; absorbing BC's**
- **1.2M DOFs, solved on 80 processors**



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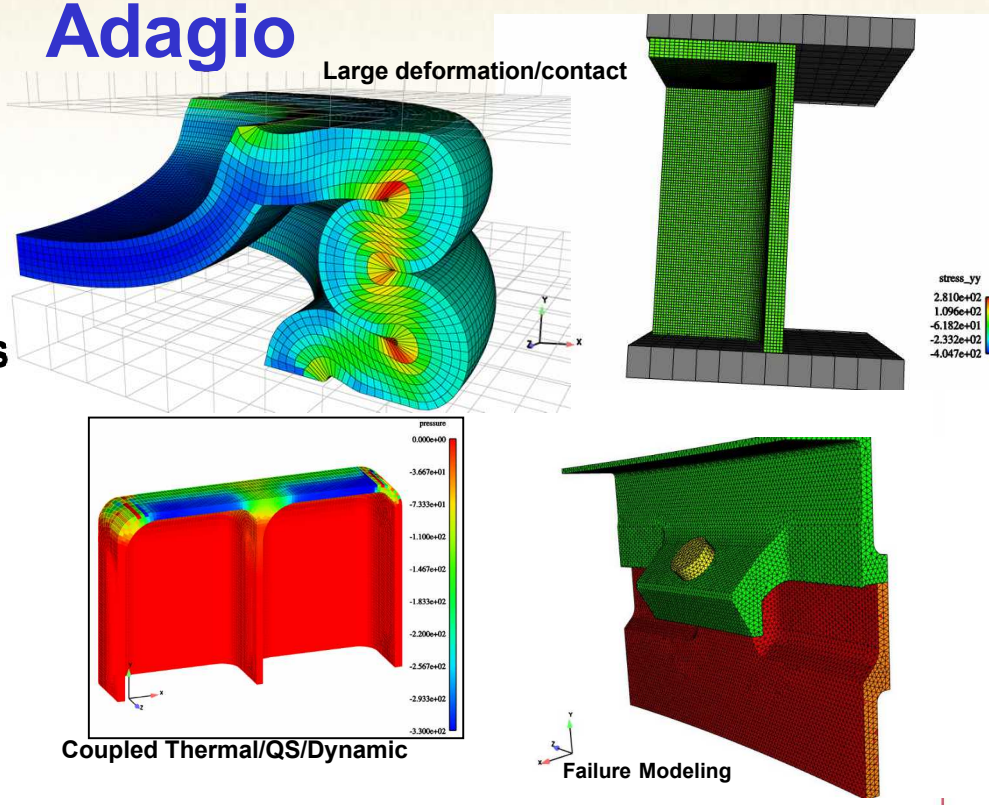
Quasi-static Structural Mechanics - Adagio

- Implicit (quasi-static & dynamic) solid mechanics finite element code
- Provides scalable parallel solvers for highly nonlinear problems
  - Contact
  - Nonlinear material response
  - Large deformation
  - Interface mechanics
- 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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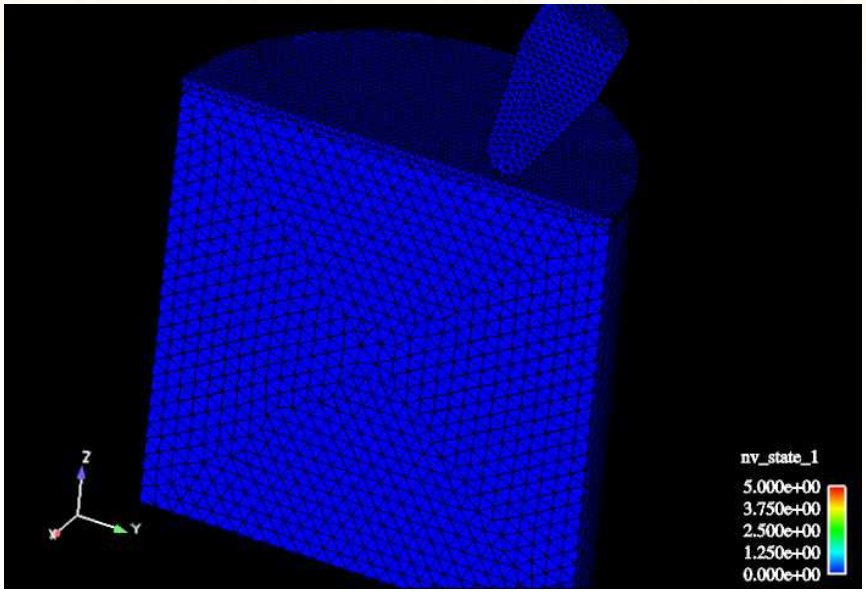
Explicit Dynamics - Presto

- Fully Three-Dimensional
- Massively Parallel
- Finite Elements and Particles
  - SPH particles for liquid dispersion
  - Other particle/meshless methods underdevelopment
- Extensive materials library
- Contact:
  - Massively parallel
  - accurate friction response
  - Interface models
- Boundary conditions:
  - Kinematic and Force
  - Specialized: cavity expansion
- Failure modeling:
  - Material failure/element death
  - Cohesive zones (elements, contact surfaces)
  - Phenomenological models (spot weld, line weld)



Penetration simulation using the node-based tet4 element with re-meshing. This element provides similar accuracy as the hex8.

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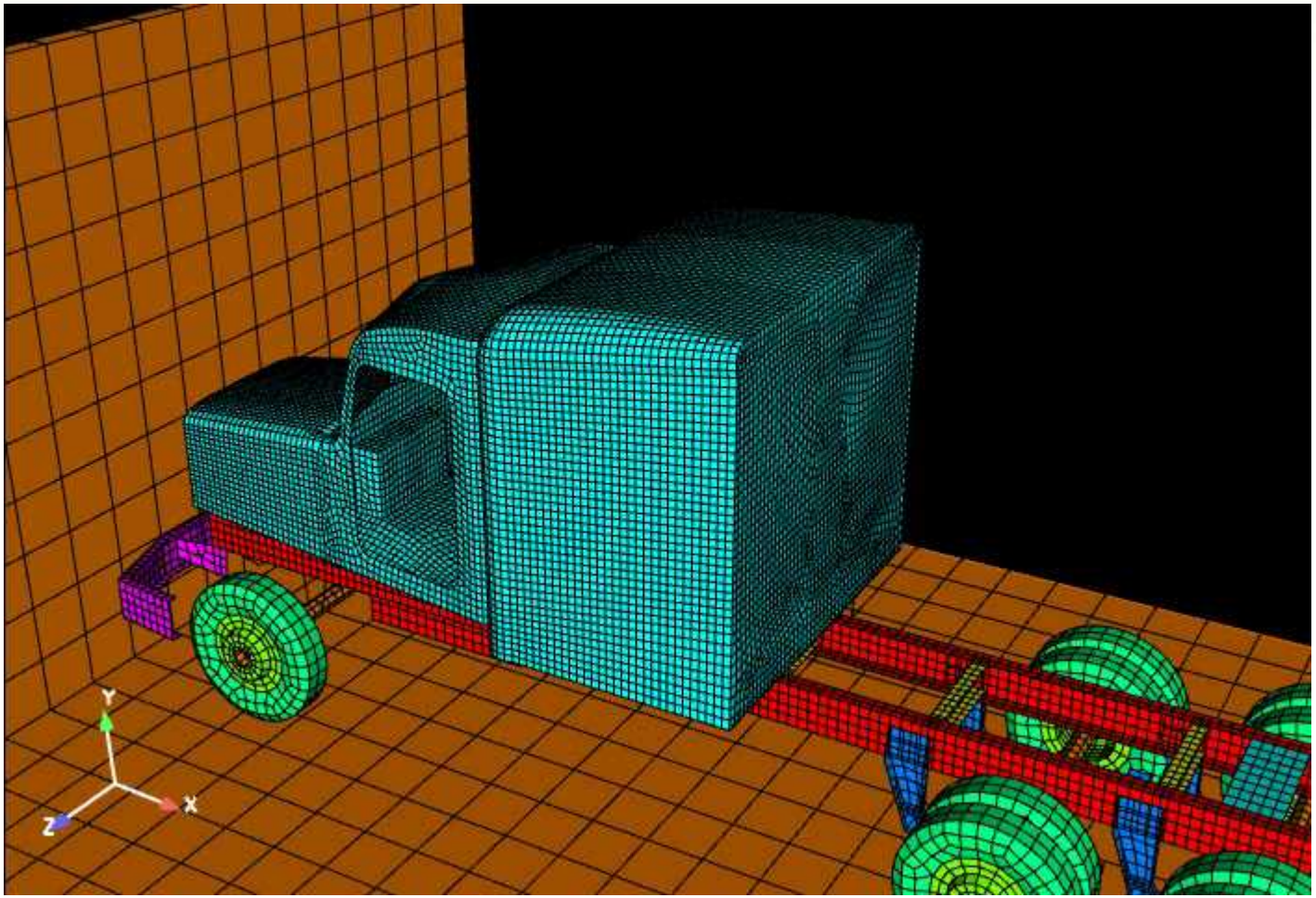
Presto Crash Dynamics



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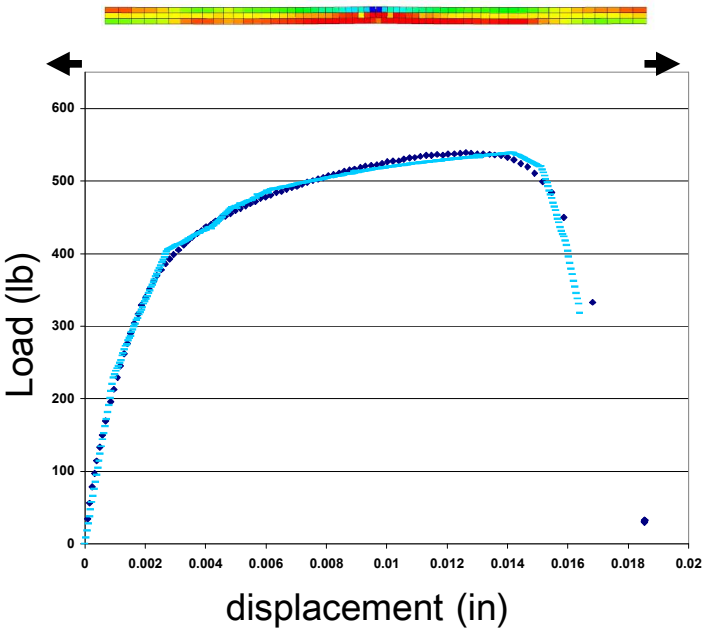
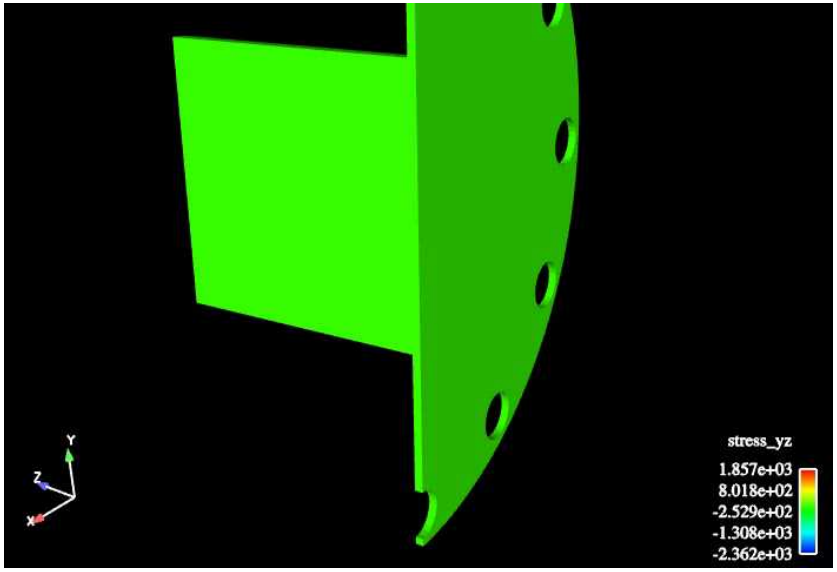
Weld Failure Under Dynamics Loading

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

Models results are experimentally validated using double blind approach in alternate configuration where practical

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One-Way Coupled CTH/Presto

Vulnerability assessments and weapons effects driving coupling of energetics and structural codes

- **CTH Loading: 5 kg TNT at the *center of room*, for 2.5 ms**

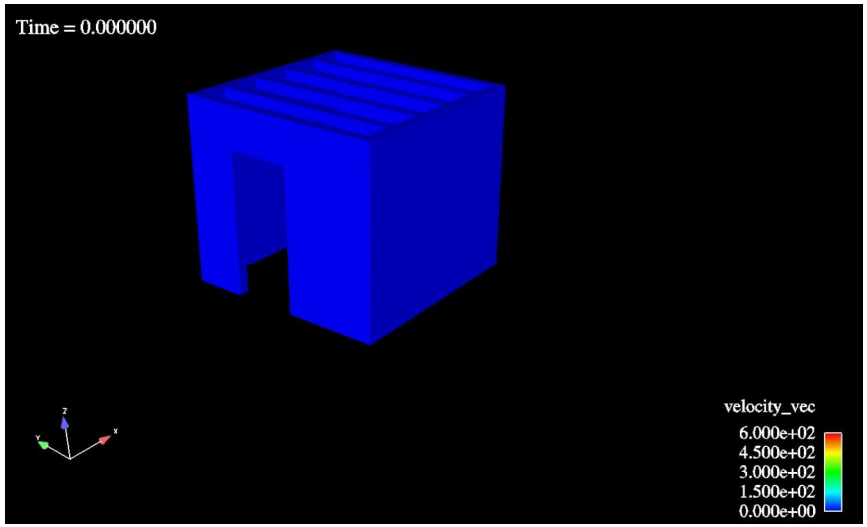
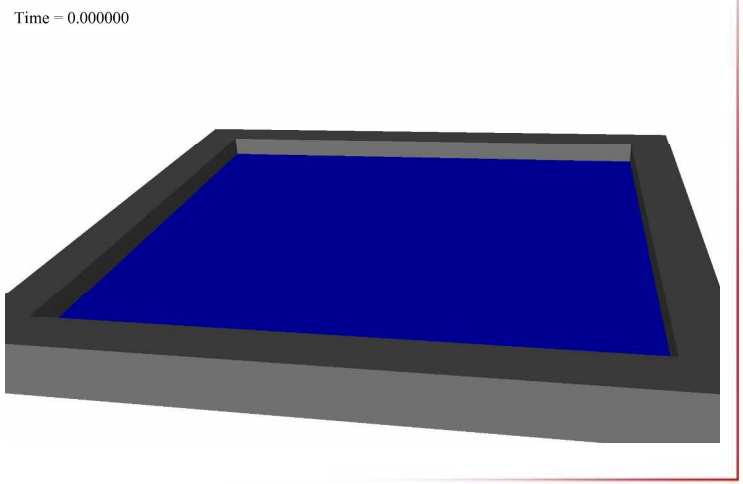


Plate Blast Response



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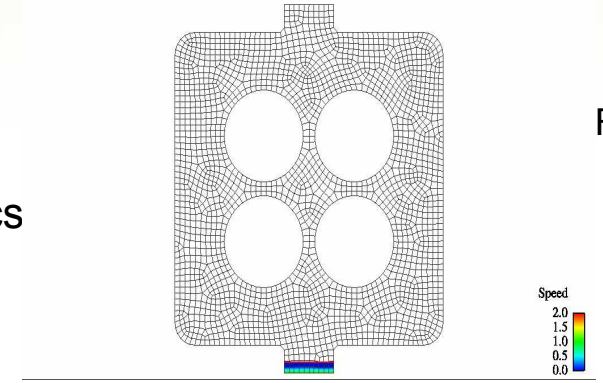
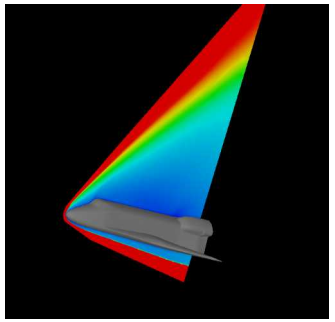
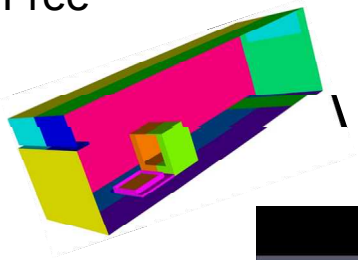
Sierra Thermal/Fluids Capabilities

- 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

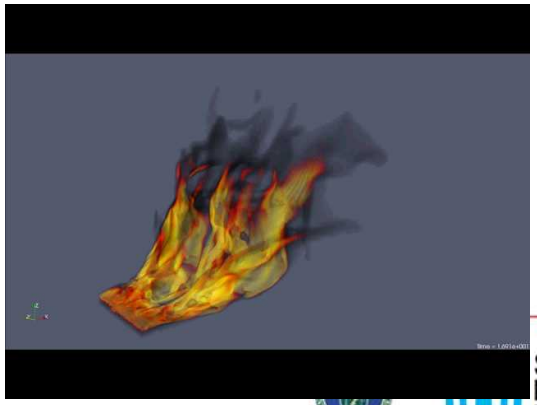


Flow field around a space shuttle during reentry



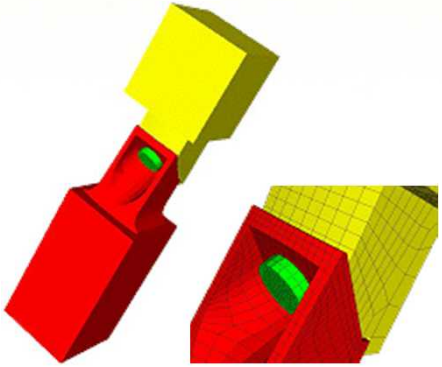


•400M DOFs, solved 5000 processors on Red Storm

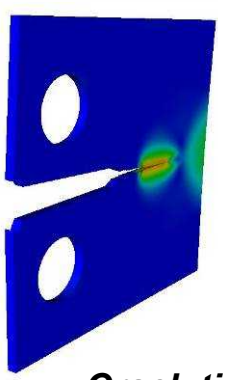


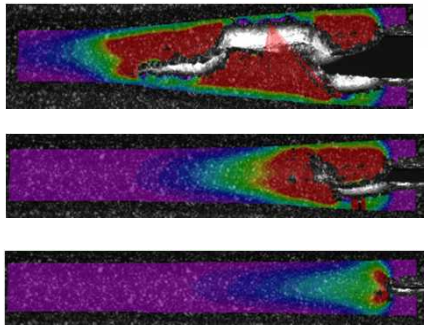
Engineering Science Research & Development is critical to predictive Mod-Sim

Codes are only as good as mechanics/science models inside

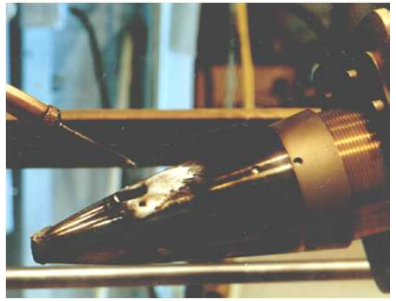


Joint Microslip

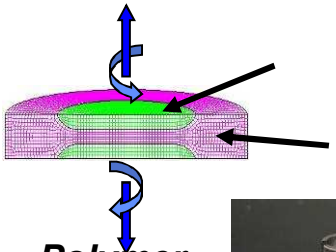




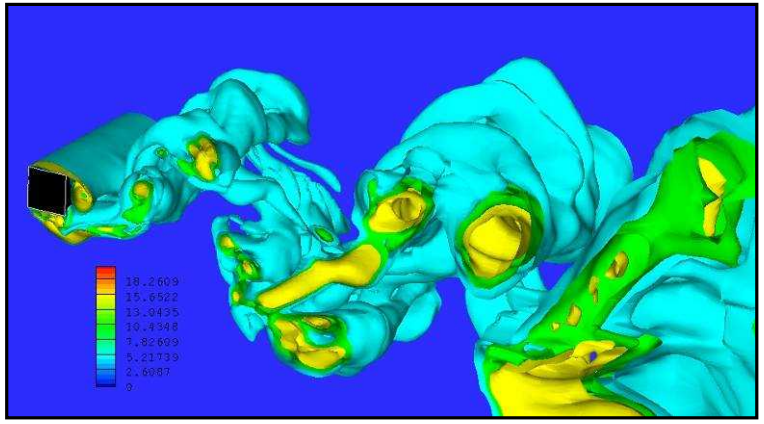
Crack tip process zone strain fields from Digital Image Correlations



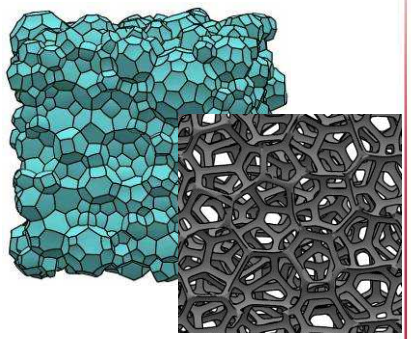
Quantifying damage from simulated Lightning strike



Polymer Interface Modeling



Hybrid Simulation Methods for Unsteady Turbulent Flows



Foam Processing and Mechanics

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Summary

- High Level Introduction to Code Capabilities and Applications
  - Sierra framework for development and integration
  - Emphasis on Structural mechanics from Quasi-statics through transient nonlinear dynamics
- Philosophy of massive scalability approaching 10,000 processors
- Adaptability and user support models under development for external customers
- Verification, validation, Uncertainty quantification are essential elements of predictive simulation

SIERRA Mechanics

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