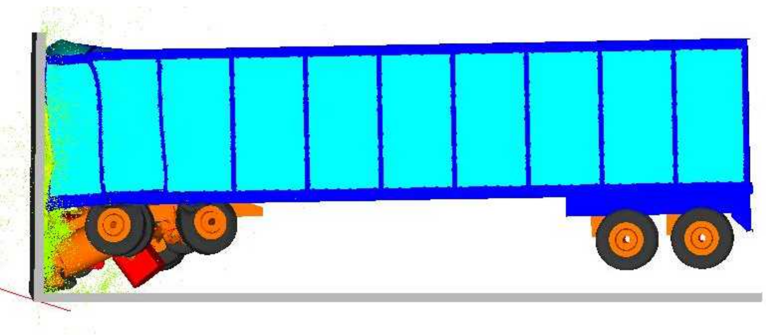
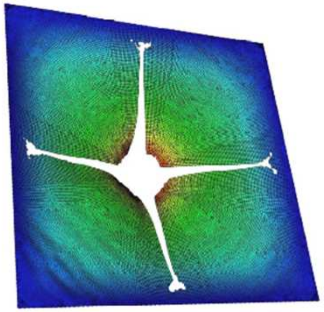
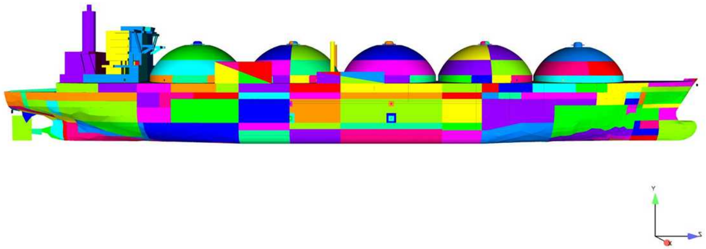
SAND2015-0450PE

Exceptional service in the national interest







Mechanics Simulation Capabilities at Sandia National Laboratories

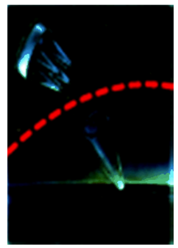
Speaker: Michael R. Tupek, PhD

Sandia National Laboratories

The Nuclear Weapons Program is the principal driver for Sandia's Computational Simulation efforts

Delivery

Separation shock/ Aerodynamic Heating

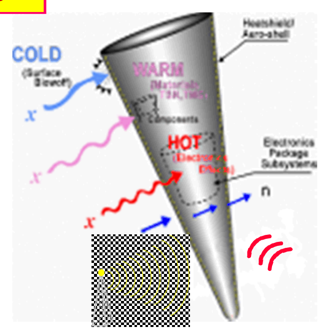


Staging shock

Random vibration

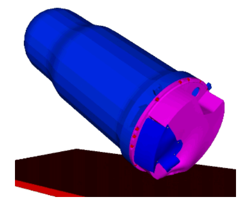
Survivability

Radiation Effects



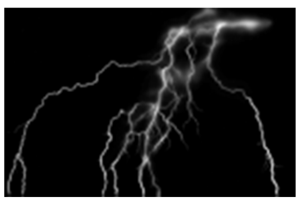
Assured Performance & Manufacturing

Assured Safety and Security



Mechanical Impact

Thermal Load



Electromagnetic Pulse

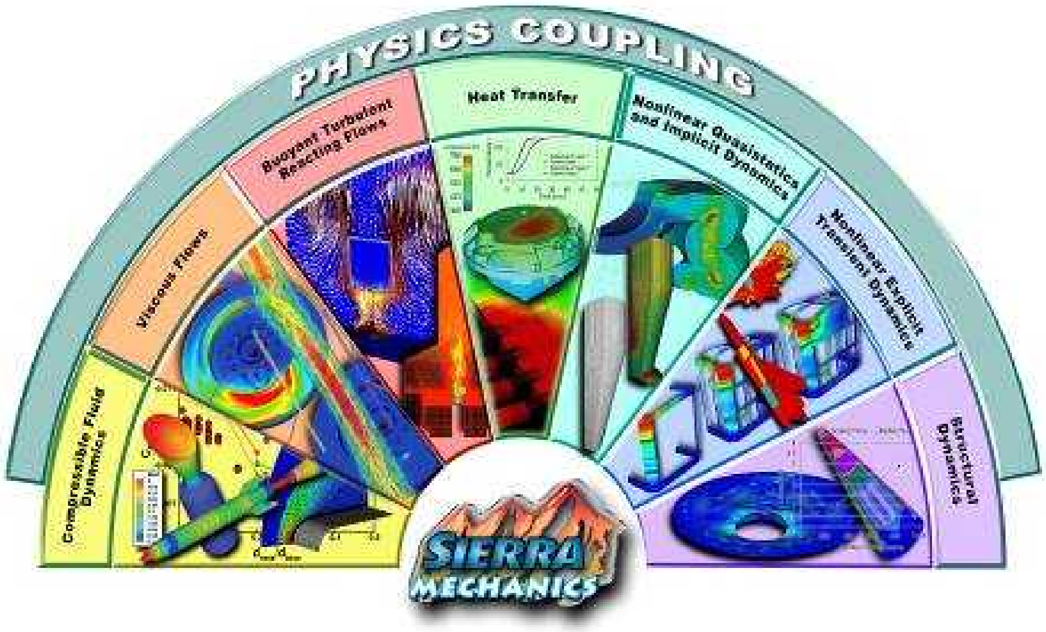
Security Components

Safe & Secure Transport

SNL Engineering Codes are positioned to support the engineering needs of the complex

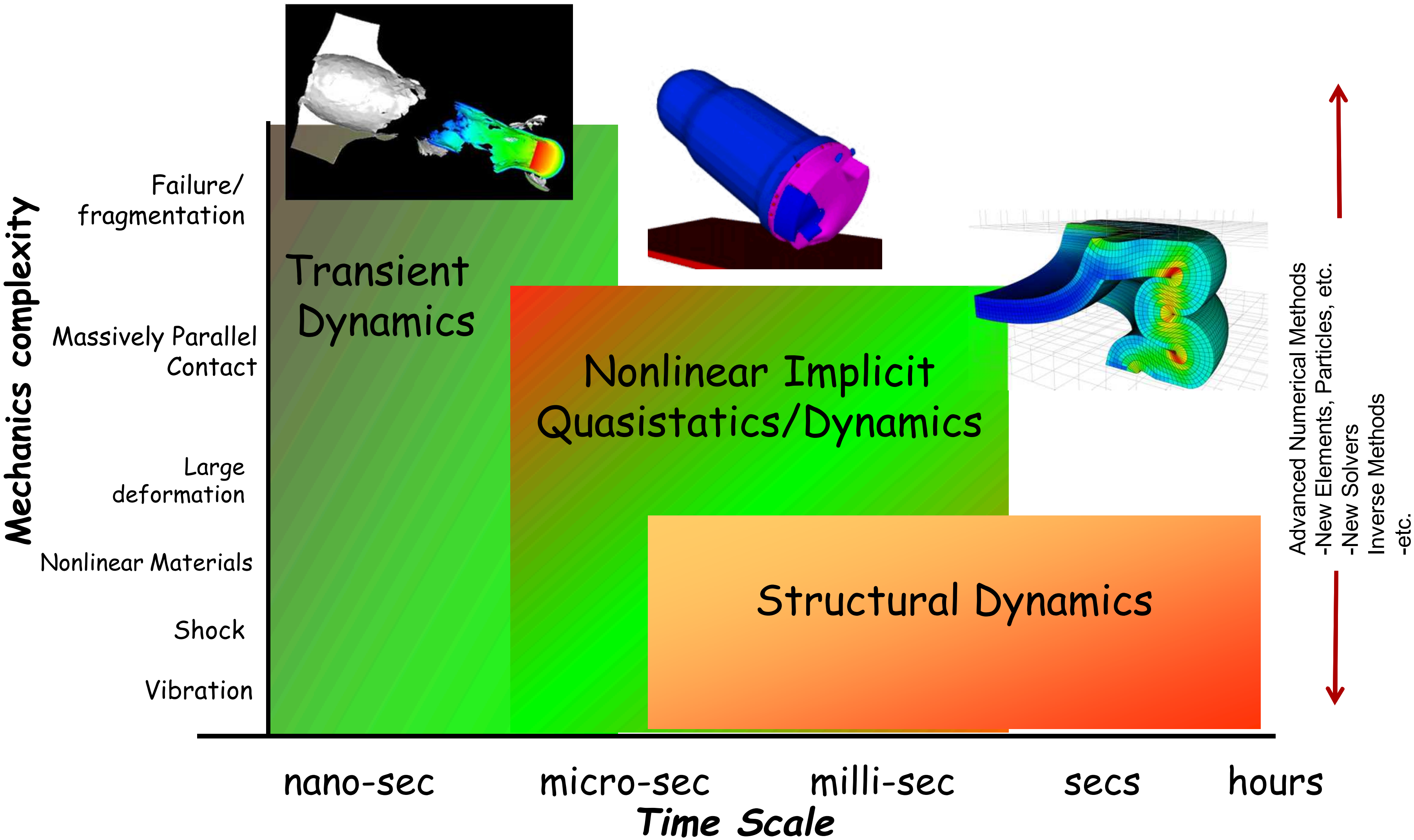
SIERRA coupled physic software

- Thermal/fluids/aerodynamics
  - Compressible fluid mechanics with subsonic through hypersonic flows
  - Non-newtonian reacting flow with free surfaces and complex material response
  - Low mach number turbulent reacting flow participating media radiation
  - Heat transfer with limited convection, chemistry, and enclosure radiation



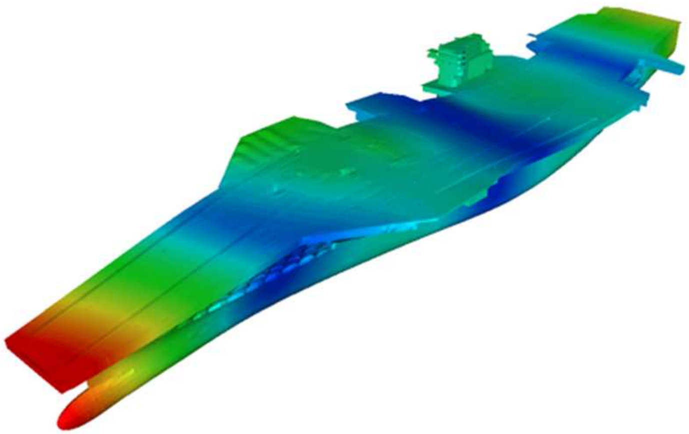
- Solid mechanics/structural dynamics
  - Nonlinear solid mechanics, quasistatics, implicit dynamics, failure and tearing
  - Nonlinear solid dynamics with explicit time integration, nodal-based tets, remeshing, particle methods, cohesive surface elements, contact, and material failure
  - Linear structural dynamics and modal analysis of complex structures

Sierra includes solid mechanics and structural dynamics capabilities

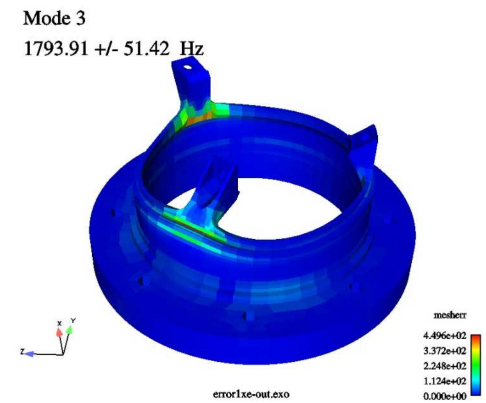


Sierra/SD: Structural Dynamics

- Predicts the response of a system under dynamic conditions.
  - Time and Frequency Response
  - Stresses (particularly in the operating regime)
  - Fatigue
  - Energy dissipation in joints
  - Rotating Systems
- Efficient for very large problems
  - Many millions of coupled equations
  - Serial, direct matrix solutions scale to order N^3
  - Parallel, iterative solvers are typically more complex, but scale as O(N)
    - FETI
    - GDSW Solvers (Sandia)
- Structural-Acoustics
  - Infinite Elements
- Inverse Problem Capability
  - Source Inversion for Structural-Acoustics
  - Material Property
  - Shape



Error Estimation



Recent Past:
NASTRAN
MC2912
30,000 dof

→

Today:
Sierra MP
>1B dof

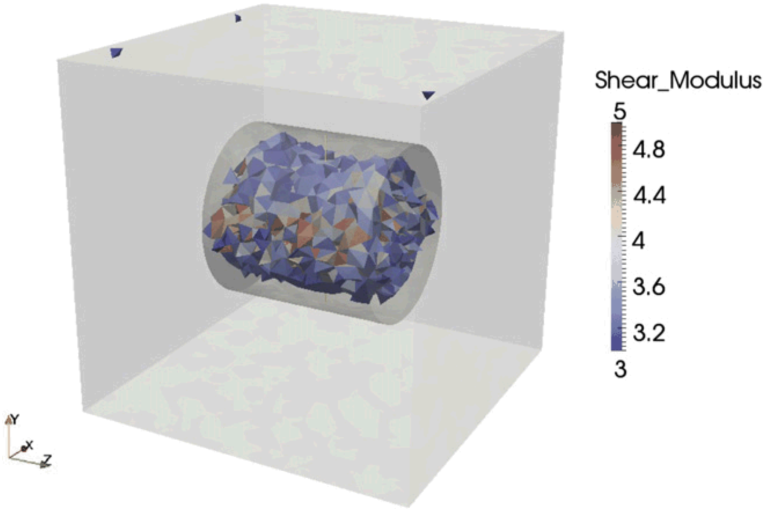
PDE Constrained Optimization:

Acoustic Source Inversion:

Solve inverse problem to obtain acoustic patch inputs that produce the given 17 experimental microphone measurements.

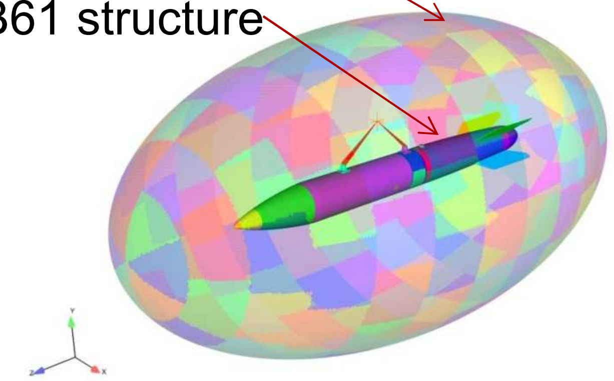
Material property inversion:

Solve inverse problem to determine spatially varying material properties given structural response.

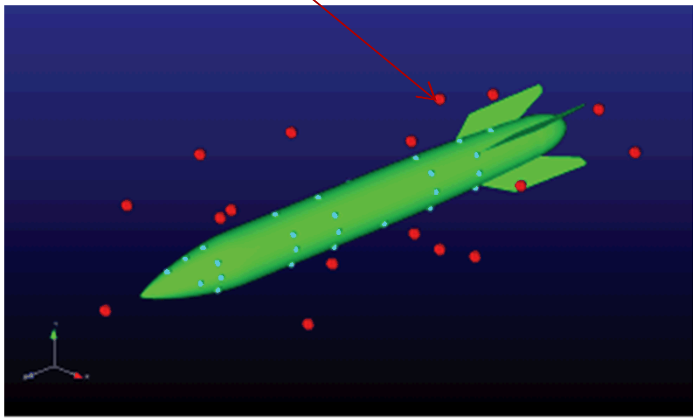


Surface with 174 acoustic patches

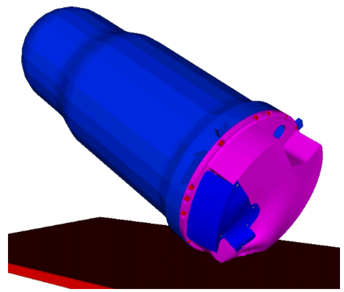
B61 structure



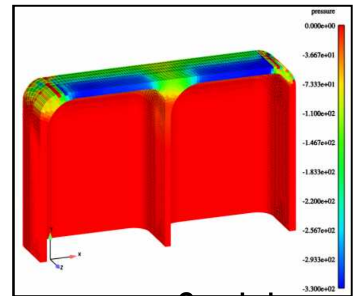
17 Microphone locations



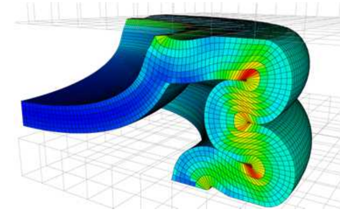
Sierra/SM: Explicit and Implicit quasi-statics and Dynamics Solid Mechanics



W80 drop test



Coupled Thermal/QS/Dynamic

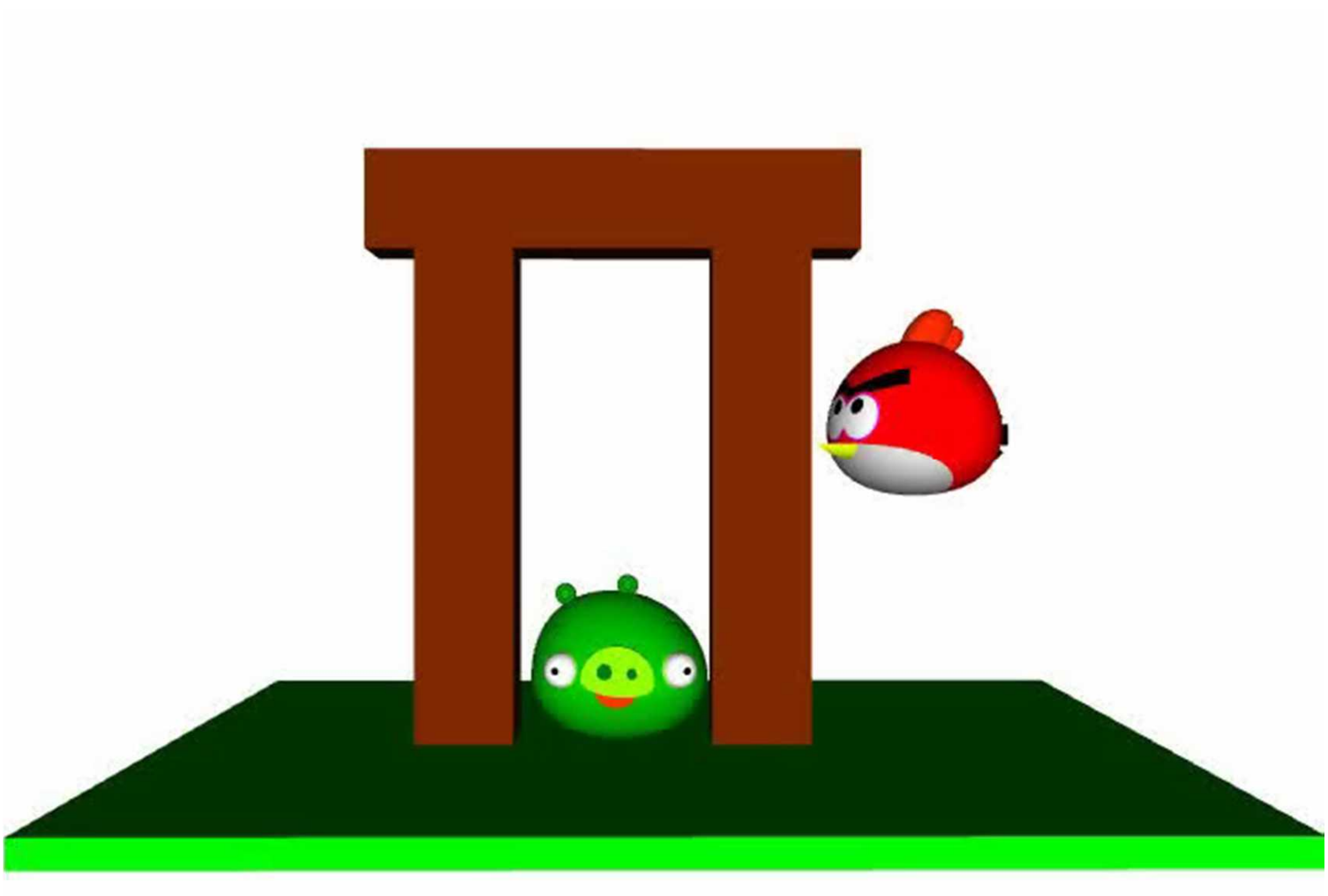


Large deformation/contact

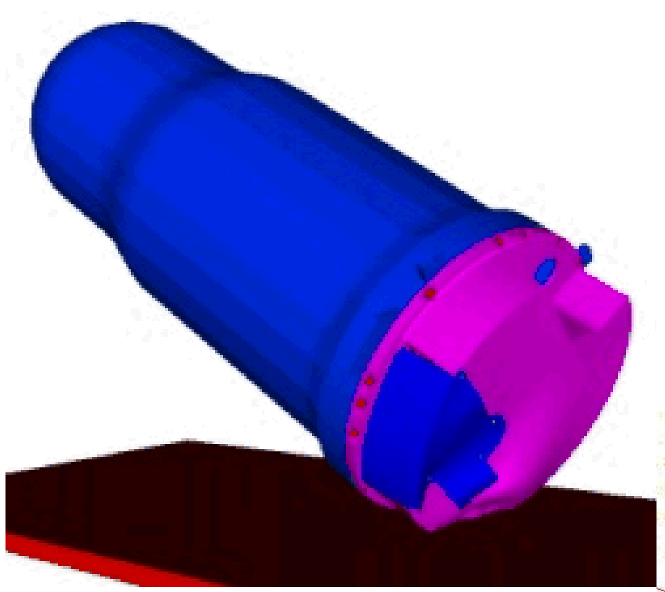
- Fully Three-Dimensional
- Finite Elements and Particles
  - Hex and Nodal Based Tets
  - Shell and Beams
  - SPH, RKPM, Peridynamics
- 50 + Material models
- Explicit and Implicit contact: Massively parallel, accurate friction response
- Explicit Failure modeling:
  - Material failure/element death
  - Cohesive zones (elements, contact surfaces)
  - Phenomenological models (spot weld, line weld)
  - Automatic remeshing
  - X-FEM (pervasive failure modeling)
- Quasi-static failure modeling

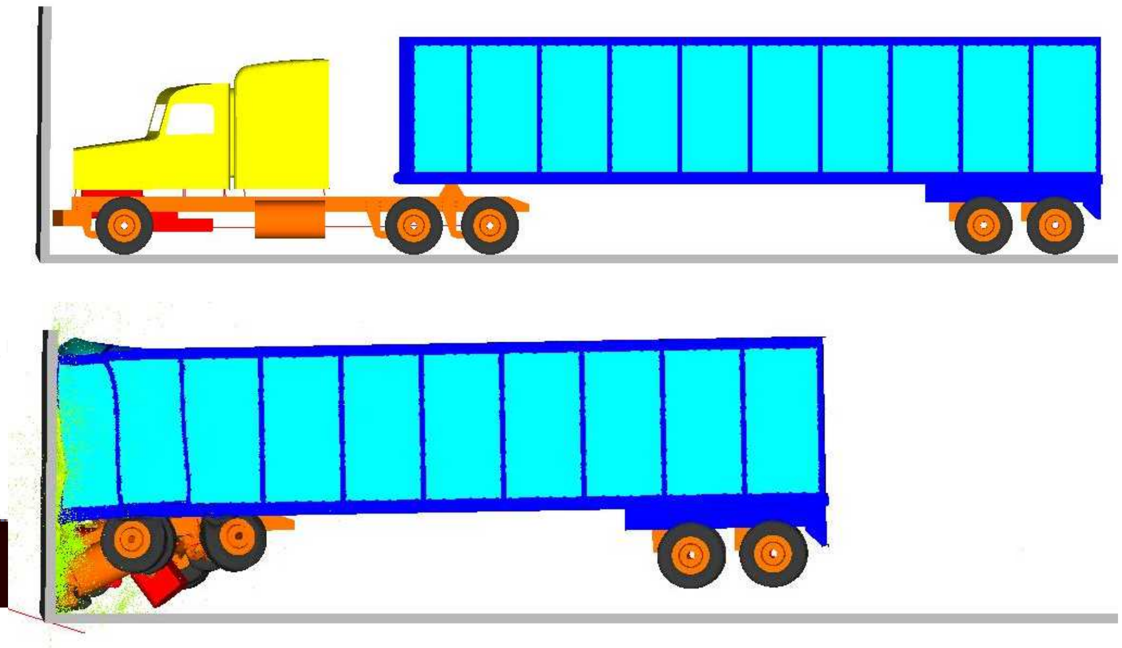
- Scalable parallel solvers for nonlinear problems
  - Contact
  - Nonlinear material response
  - Large deformation
- Coupling to internal and external modules
  - Sierra/TF
  - CTH (Blast)
- Multi-scale approaches

Sierra/SM Explicit Contact Mechanics addresses real world problems



Sierra/SM Contact Mechanics addresses system level contact



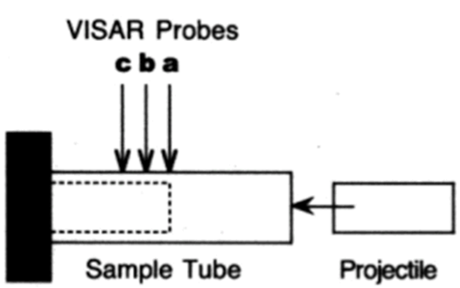


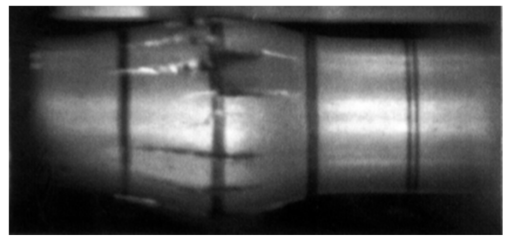
Meshless Capabilities

- Peridynamics is a non-local continuum method with great promise for handling fracture and damage

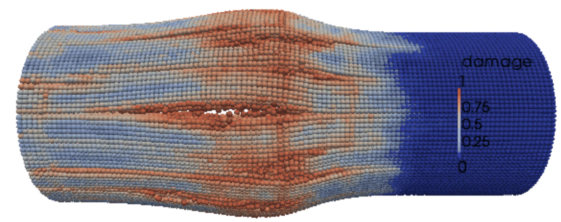
Expanding Tube Experiment

- Lexan discs impact w/in tube
  - Discs modeled with FE
  - Johnson-Cook with EOS
- AerMet high strength steel tube
  - Tubes model is peridynamics
  - Elastic-plastic with hardening
  - Bond failure on critical stretch

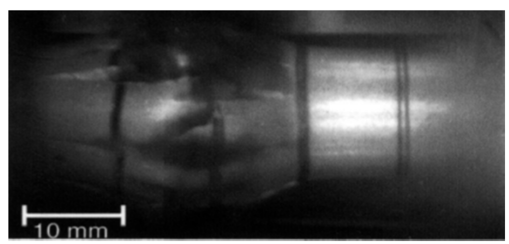




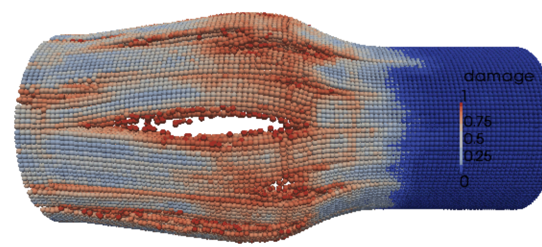
Experimental image
[Vogler et. Al]



Simulation
15.4 microseconds



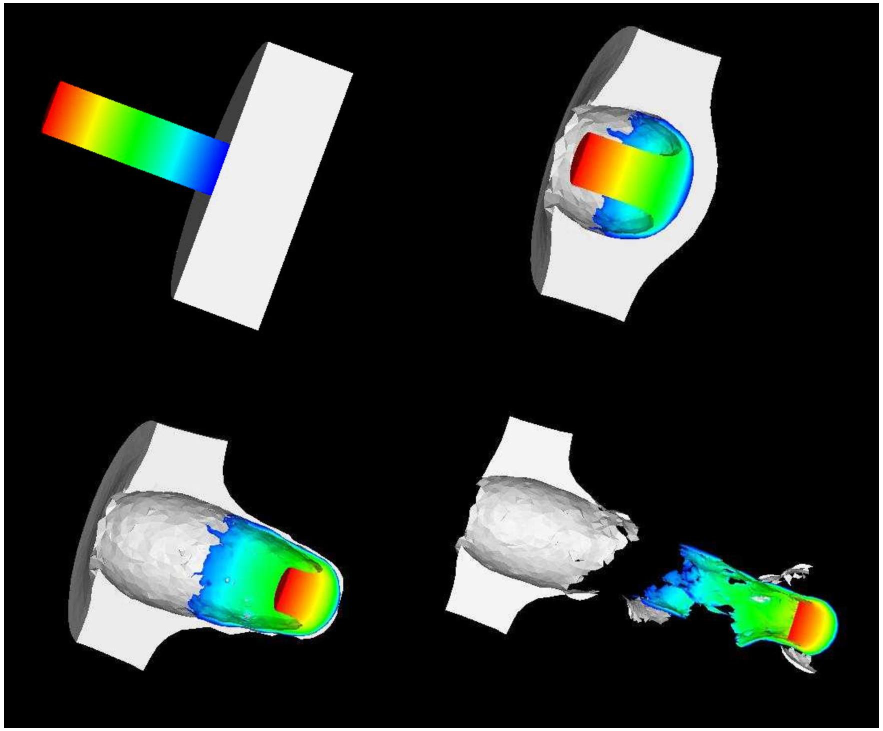
Experimental image
[Vogler et. Al]



Simulation
23.4 microseconds

Nodal-Based Tetrahedra (NBT)

- This element blurs the boundary between element and particle methods, and has advantages of both
  - **Since all data resides at nodes, amenable to remeshing**

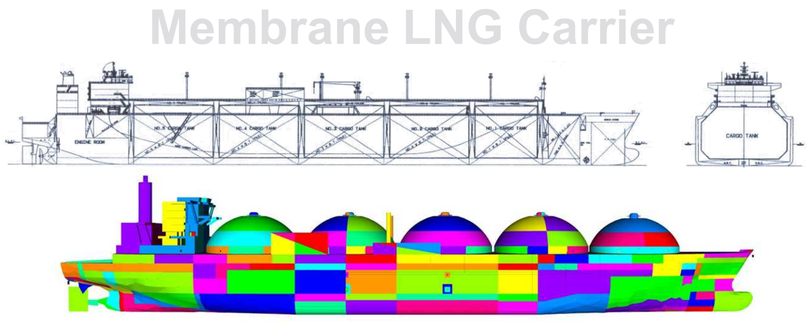


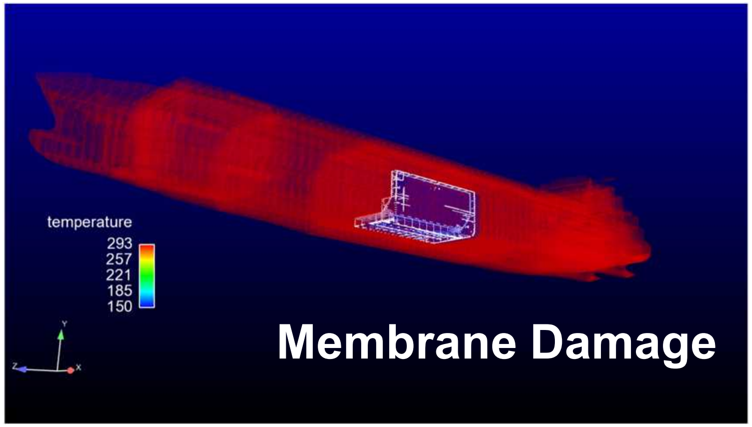
Nodal-based tet transient analysis of impact of tungsten bar on steel plate

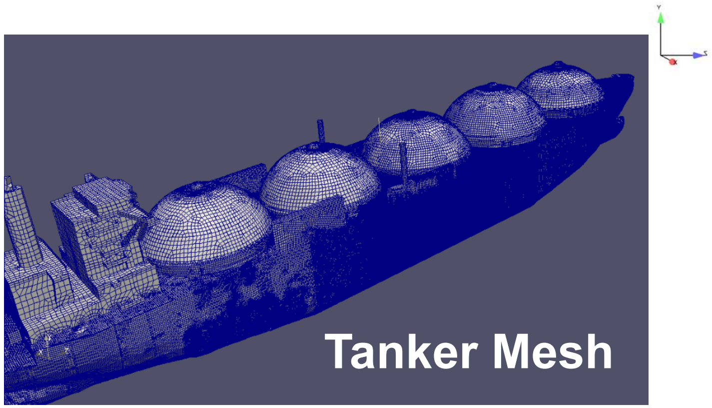
Impact velocity is 2500 m/s, and explicit dynamics (Presto) code is used with pervasive remeshing

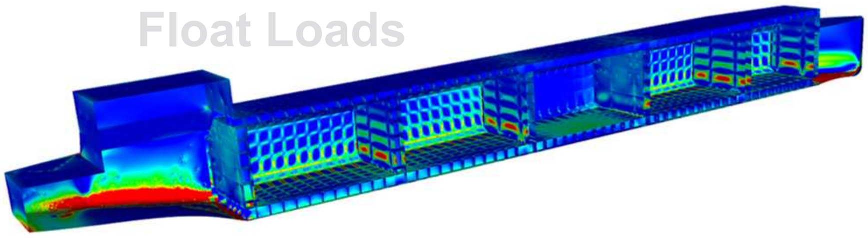
Complex Systems Models

- Example large-scale coupled system model
  - LNG tanker analysis for disaster simulation response









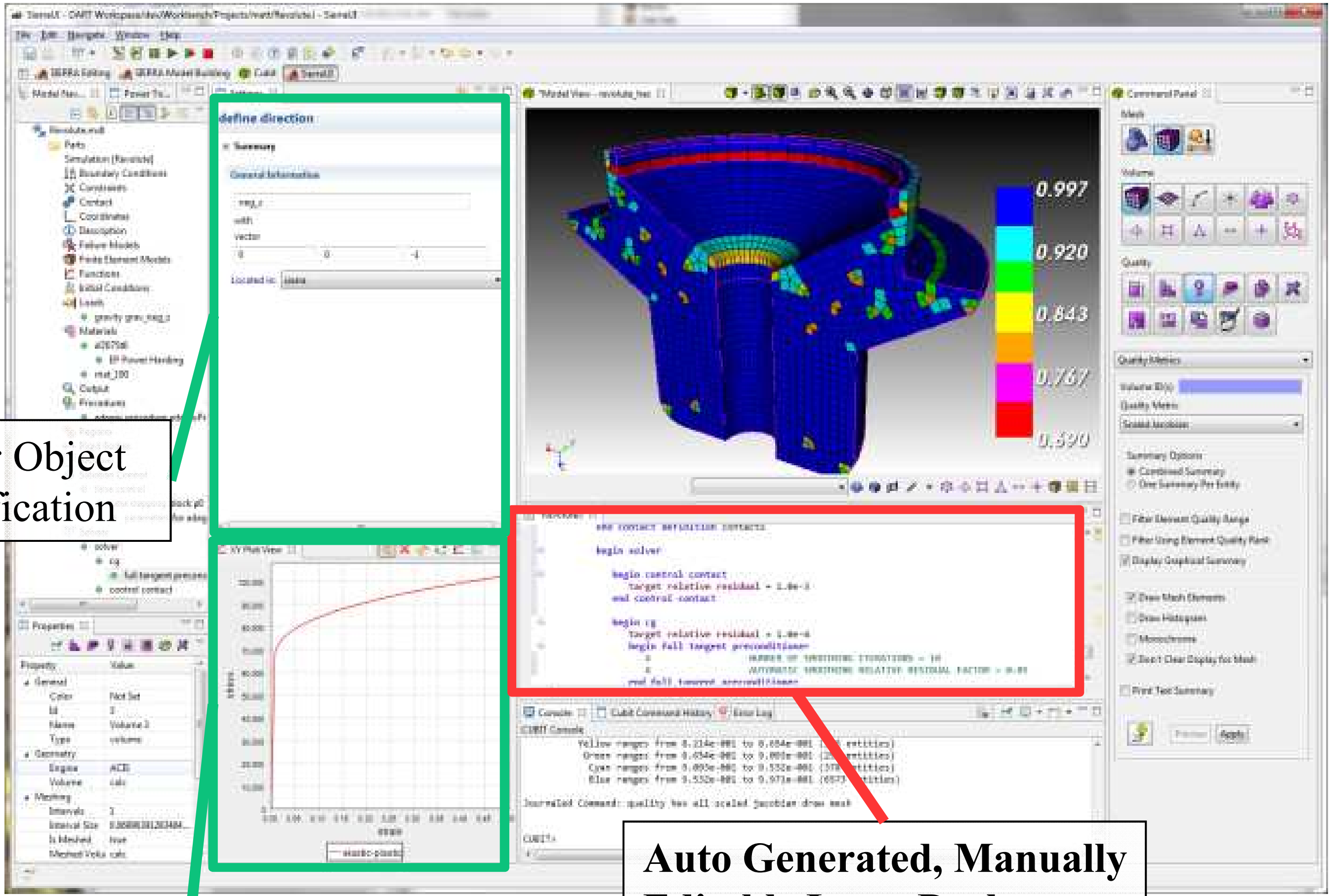
CompSimUI

Integrated Workflow Product

Synchronized Model

Customizable Solver Input

Workflow Controls



Solver Object Specification

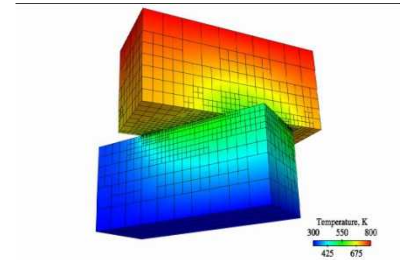
Function Editor

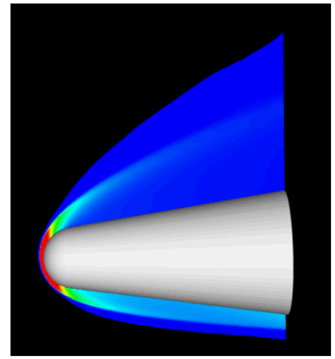
Auto Generated, Manually Editable Input Deck

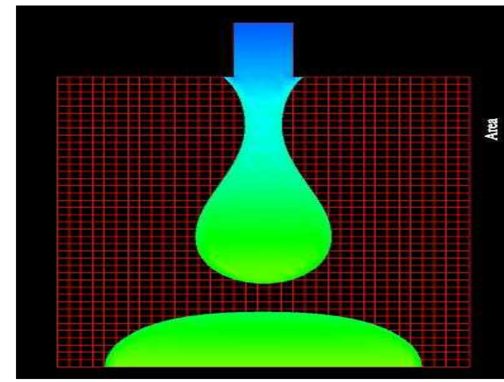
Computational Thermal & Fluid Mechanics

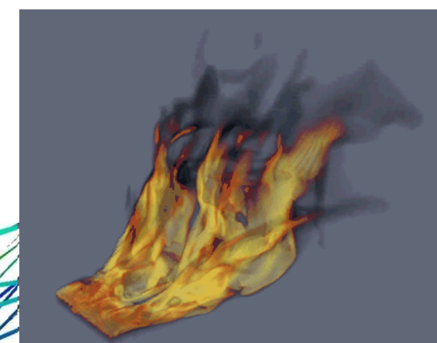
Sandia National Laboratories

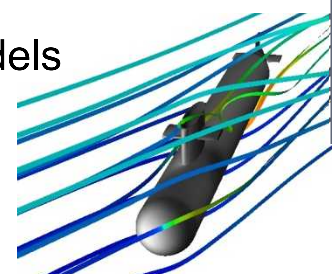
- Heat transfer, enclosure radiation and chemistry
  - Dynamic enclosures
  - Element birth/death
  - Contact
- Compressible fluid mechanics
  - Subsonic through hypersonic
  - Laminar and turbulent
  - Unstructured mesh
- Non-Newtonian, free surface, and porous media flows
  - Complex material response
  - Level sets for surface tracking
  - Flexible coupling schemes
  - Porous media, with chemical reactions and phase change
- Low Mach number, high Reynolds number, variable density, chemically reacting flows
  - Eddy dissipation and mixture fraction reaction models
  - RANS and LES based turbulence models
  - Unstructured Mesh
  - Pressurization models



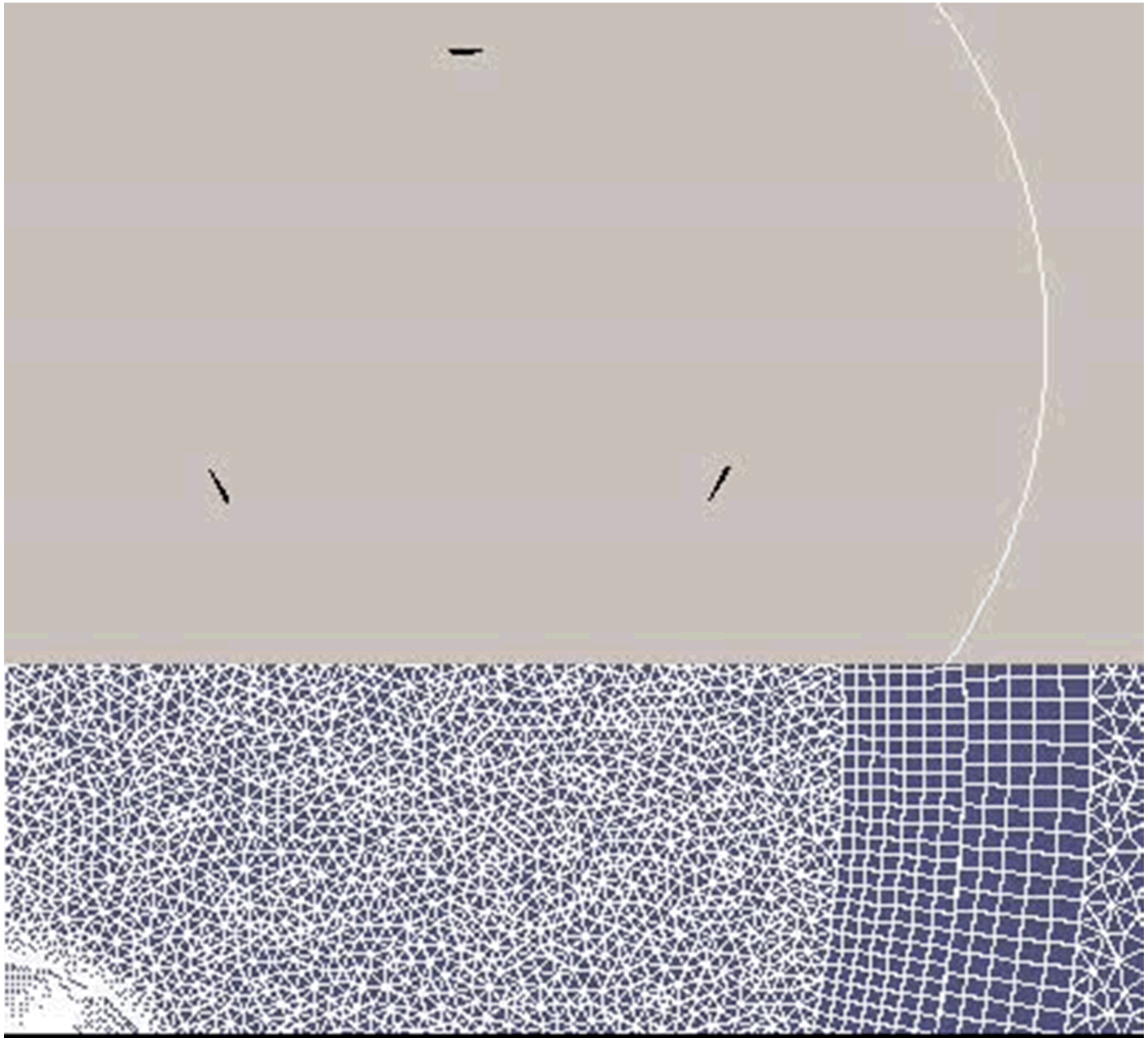




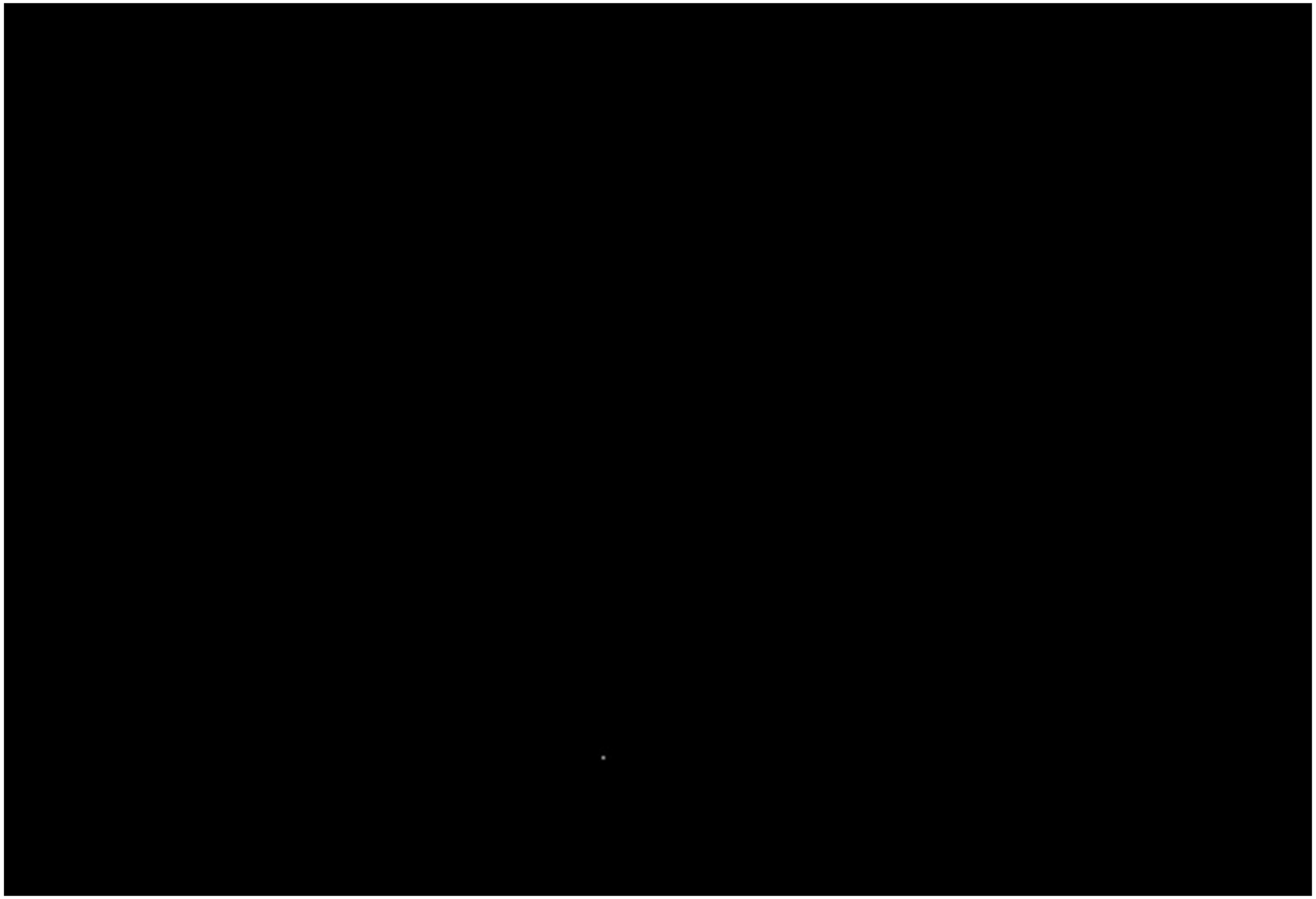




Computational Thermal & Fluid Mechanics



Computational Thermal & Fluid Mechanics



Next Generation Scientific Computing

Sandia National Laboratories

Sandia codes are undergoing refactor for next generation computer architectures

- Code capabilities include:
  - Mechanics, Electro-magnetics, Molecular dynamics, Radiation transport
  - Parallel solvers, Optimization

The architectures of the future are unknown!

- GPU clusters?
- Many-core architectures?
- ARM, other low power devices?

Modern architecture design is no longer determined by scientific computing

- Currently guided by Social Media! Facebook, Google, etc.
- Provides a unique challenge for developing and maintaining scientific codes