SAND2013-8359C

# Sandia, Engineering Sciences Center and Sierra Mechanics Overview

**J. Jung**
**Manager, Computational Solid Mechanics and Structural Dynamics**

**PSU**
**October 4, 2013**

Sandia National Laboratories

*Exceptional service in the national interest*

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

# Sandia's History

THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract the direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic weapons program, is of extreme importance and urgency in the national defense, and should have the best possible technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.


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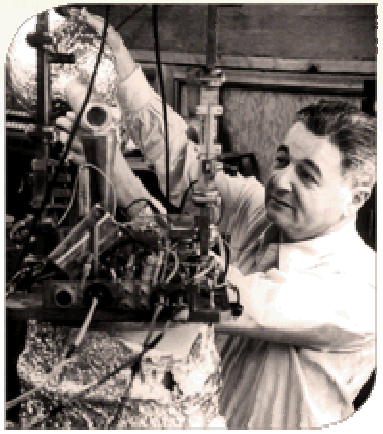


# Sandia's Governance Structure


**Sandia Corporation**

- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–present
- Existing contract expired: Sept. 30, 2012
- One-year contract extension: Sept. 30, 2013
- Two additional 3-month options: March 31, 2014

**Government owned, contractor operated**



**Federally funded research and development center**



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# Sandia's Sites

*Albuquerque, New Mexico*

*Livermore, California*

*Kauai, Hawaii*


*Waste Isolation Pilot Plant, Carlsbad, New Mexico*

*Pantex Plant, Amarillo, Texas*

*Tonopah, Nevada*



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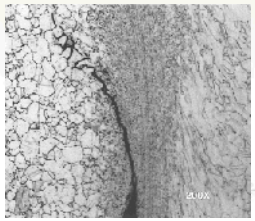
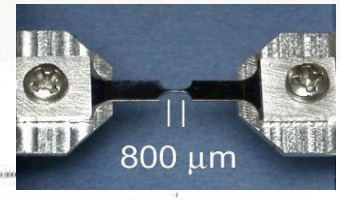
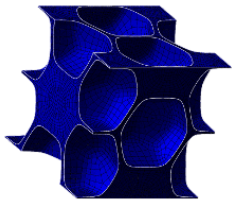
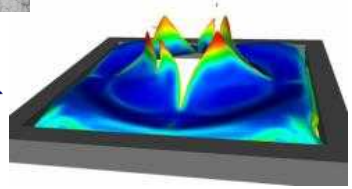
# Technical Focus Themes for Engineering Sciences: Theory, Analysis, Experimentation



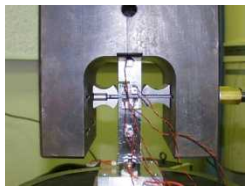


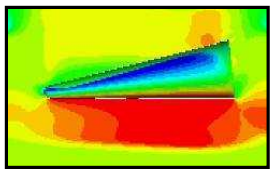

**Solid Mechanics**



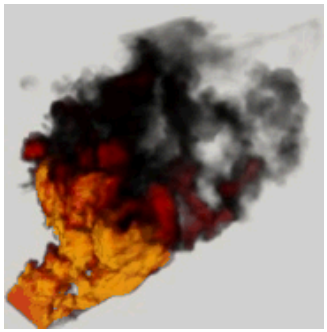


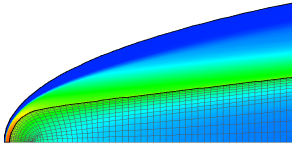
**Structural Dynamics**

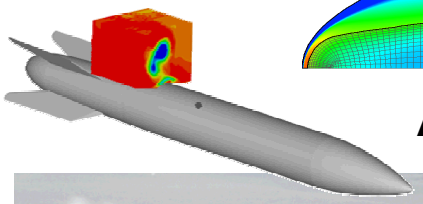




**Thermal & Fire Sciences**

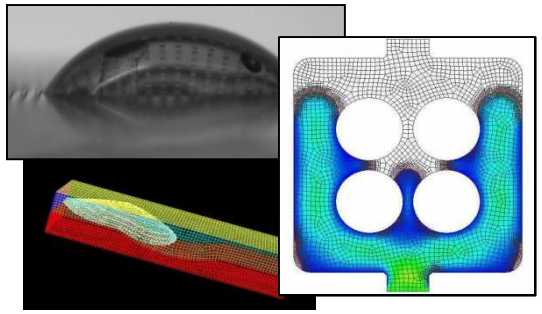






**Aerosciences**

**Fluid Mechanics**



**Disciplines**: Mechanical, Aerospace, & Chemical Engineering, Computer Science, Applied Math

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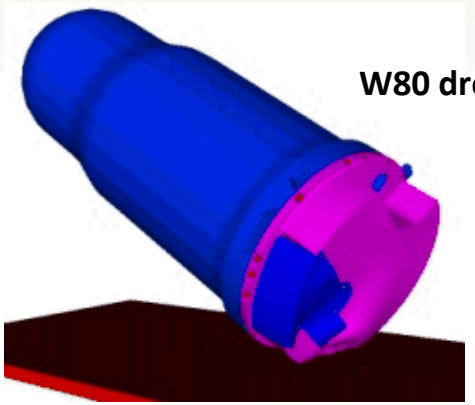
# Engineering Sciences supports all Sandia missions

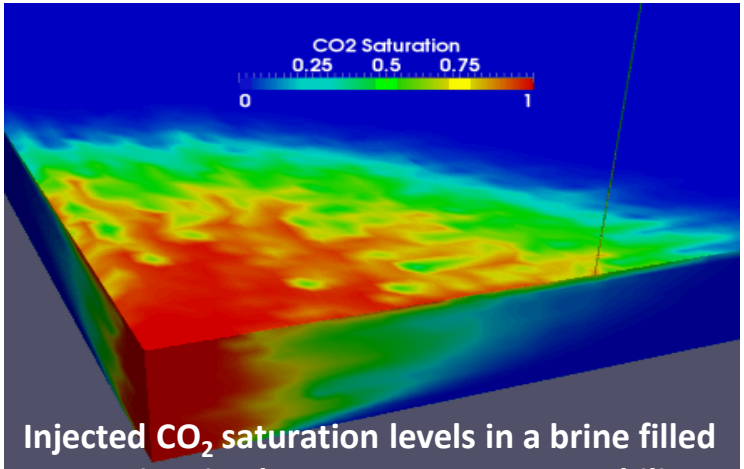
## Nuclear Weapons



W80 drop simulation

## Defense Systems


## Energy




Injected $CO_2$ saturation levels in a brine filled reservoir using heterogeneous permeability

## Homeland security - infrastructure

LNG Test 2 - De-coupled LNG pool spreading and fire spreading

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# The national code strategy establishes Sandia as the engineering simulation capability provider

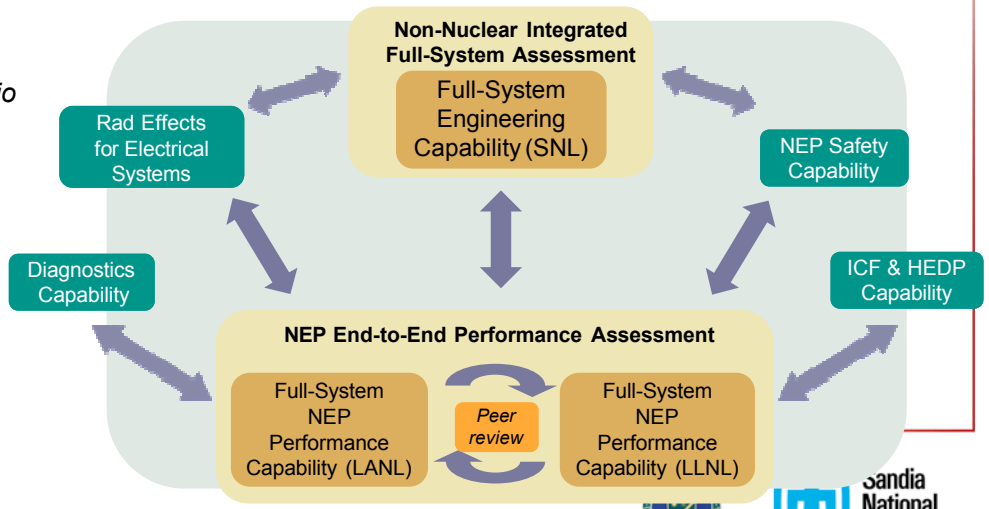
| Focus Areas | Current State | Strategies | Future State |
|---|---|---|---|
| Integrated Simulation Capabilities (Application Codes) | • 14 modern + numerous legacy codes across 6 broad application areas<br>• Core physics simulation competencies established | Establish the National Simulation Portfolio for Stockpile Certification | • 7 modern national capabilities<br>• End legacy development<br>• Core competencies sustained |
| Computational Science | • Tera scale computational science established (MPI programming model)<br>• Basic capabilities for uncertainty quantification | Advance computational algorithms to enable predictive simulation and QMU | • Algorithms & programming models supporting predictive simulation at petaFLOP and exaFLOP scales<br>• Advanced capabilities for uncertainty quantification and QMU studies |
| Scope of Applications | • ASC simulation capabilities focused on certification for tail numbers | Broaden the impact of ASC simulation capabilities in national security | • Capabilities for broader national security applications, including NNSA nuclear security and non-proliferation missions |

## Strategic Components

1. Establish the National Simulation Portfolio for Weapons Science and Engineering, and Stockpile Certification
   - *Define the core simulation capabilities needed*
   - *End development funding for legacy codes*
   - *Establish the capability to couple between codes of national portfolio*
2. Advance Computational Algorithms to Enable Predictive Simulation and QMU
   - *Advance scalability of computational algorithms*
   - *Collaborate on evolution of programming models*
   - *Deliver advanced capabilities for QMU and UQ*
3. Broaden the Impact of ASC Simulation Capabilities in National Security
   - *Develop a business "prospectus" for major capabilities*
   - *Develop and support interagency partnerships*
   - *Develop enhanced capabilities for expanded national security missions*

## Objectives

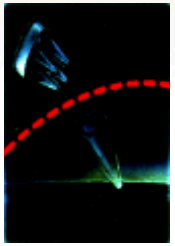
1. *Advance world-leading predictive science*, providing the capability to sustain stockpile stewardship without returning to underground nuclear testing as weapons age and we move further from the test base.
2. *Enable Quantification of Margins and Uncertainties (QMU)-based certification*, transforming the broader certification process to allow more effective and selective use of aboveground experiment, certification tests, flight tests, and other tests.
3. *Catalyze a responsive infrastructure* through pervasive simulation across all aspects of the stockpile lifecycle, such as design, certification, manufacturing, Significant Finding Investigation resolution, transportation, security, safe dismantlement, outputs and environments, etc.
4. *Enable a broadened national security mission*, in which simulation tools extend beyond stockpile stewardship and enable the next-generation mission of the Complex

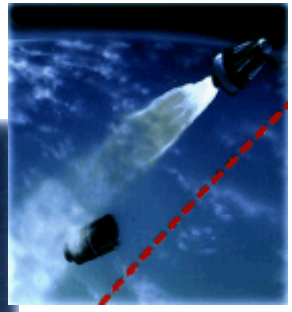


# The Nuclear Weapons Program is the principal driver for Sandia's Computational Simulation efforts

**Delivery**

Separation shock/ Aerodynamic Heating



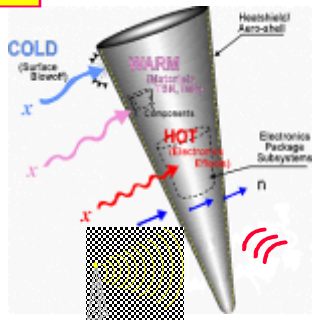


Staging shock

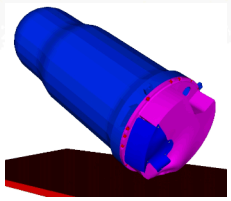
Random vibration

**Survivability**

Radiation Effects




**Assured Safety and Security**



Mechanical Insult

Thermal Insult

Electromagnetic Insult

Security Components

**Assured Performance & Manufacturing**

Safe & Secure Transport

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

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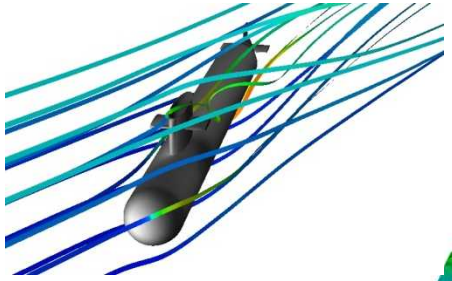
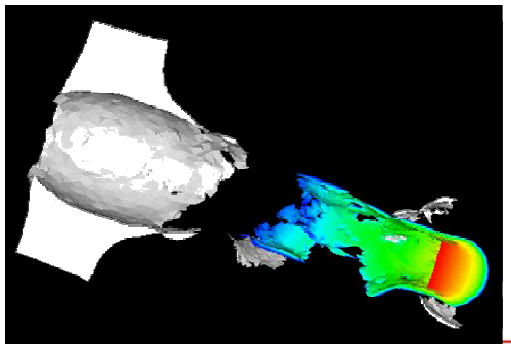
# Non-NW customers contribute significant resources

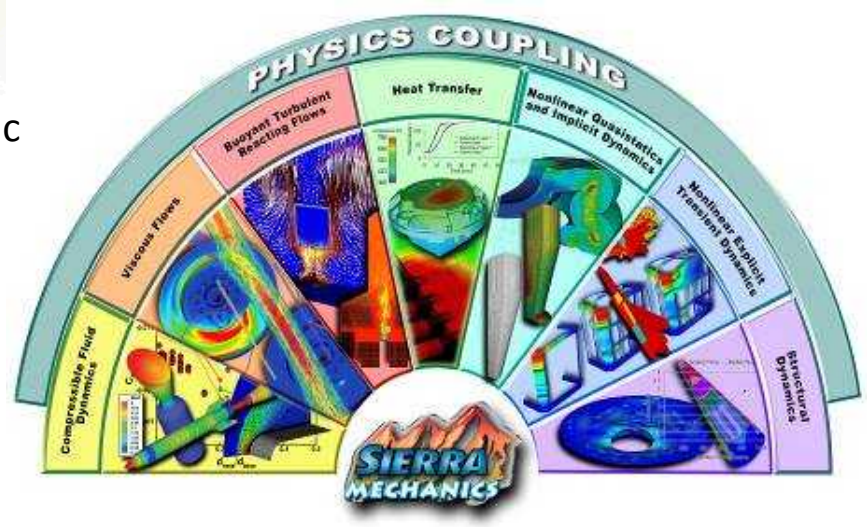
- Other  Sandia mission areas and projects, for example
  - Energy
  - LNG
  - Satellite programs
- Industry
  - Goodyear,
  - Proctor & Gamble,
- DoD
  - CREATE
  - ARDEC Picatinny, ARL, etc
- NASA
- AWE





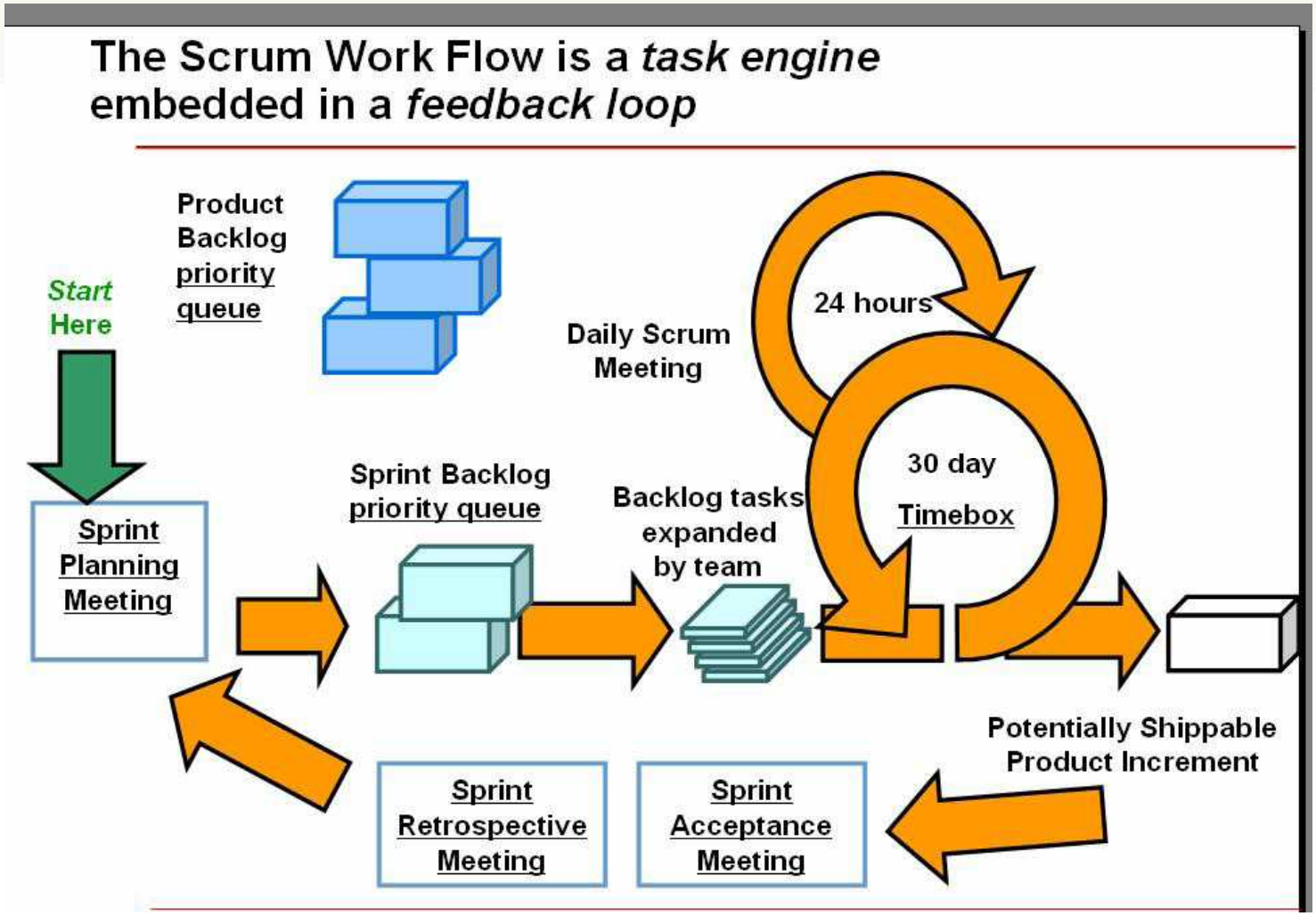
# SIERRA has a wide range of coupled mechanics simulation capabilities

- 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

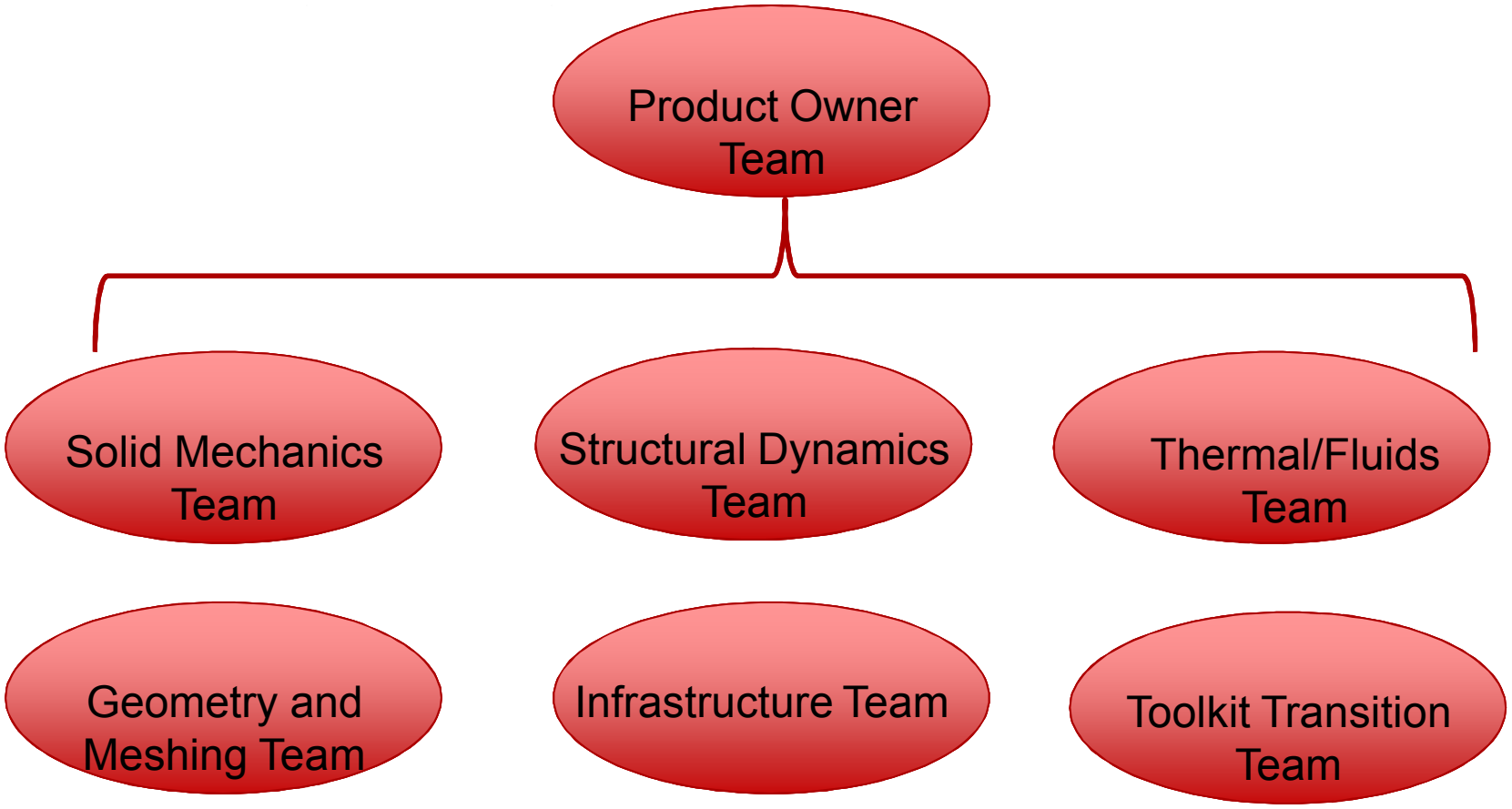



- Solid mechanics/structural dynamics
  - Nonlinear solid mechanics, quasistatics, implicit dynamics, failure and tearing
  - Nonlinear solid dynamics with explicit time integration, nodal-based tets, remeshing, particle methods, cohesive surface elements, contact, and material failure
  - Linear structural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

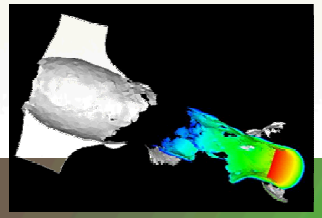
# Sierra Code Development is under a Agile SCRUM Environment

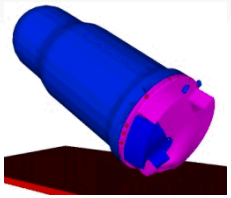


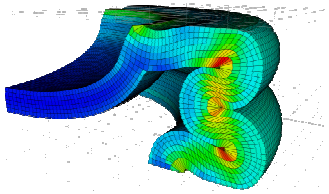
# Current Computational Simulation Group Team Structure



# Sierra includes solid mechanics and structural dynamics capabilities







Mechanics complexity

Failure/ fragmentation

Massively Parallel Contact

Large deformation

Nonlinear Materials

Shock

Vibration

Transient Dynamics

Nonlinear Implicit Quasistatics/Dynamics

Structural Dynamics

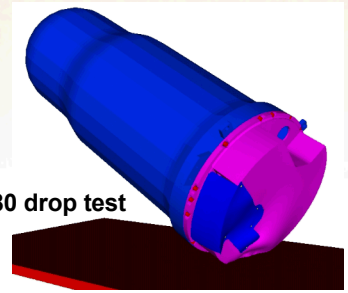
Advanced Numerical Methods
-New Elements, Particles, etc.
-New Solvers
Inverse Methods
-etc.

nano-sec micro-sec milli-sec secs hours

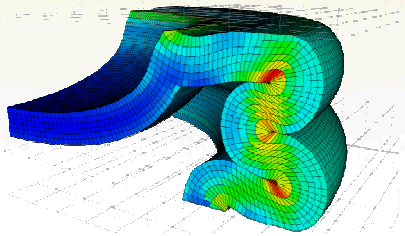
Time Scale

# Explicit transient dynamics and implicit quasi-statics and dynamics capabilities

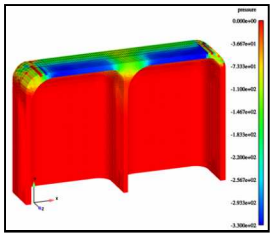
- Fully Three-Dimensional
- Finite Elements and Particles
  - Hex and Nodal Based Tets
  - Shell and Beams
  - SPH and Mass particles
- Material models: 50+, including energy-dependent materials
- Explicit and Implicit contact: Massively parallel, momentum balance, accurate friction response
- Multi-length Scale
- Boundary conditions:
  - Kinematic and Force
  - Specialized: cavity expansion, silent BC
  - CONWEP integration (Analytic Blast Pressure Loads)
- Explicit Failure modeling:
  - Material failure/element death
  - Cohesive zones (elements, contact surfaces)
  - Phenomenological models (spot weld, line weld)
  - Automatic remeshing using Nodal Based Tets
  - X-FEM (pervasive failure modeling)
- Quasi-static failure modeling



W80 drop test



Large deformation/contact

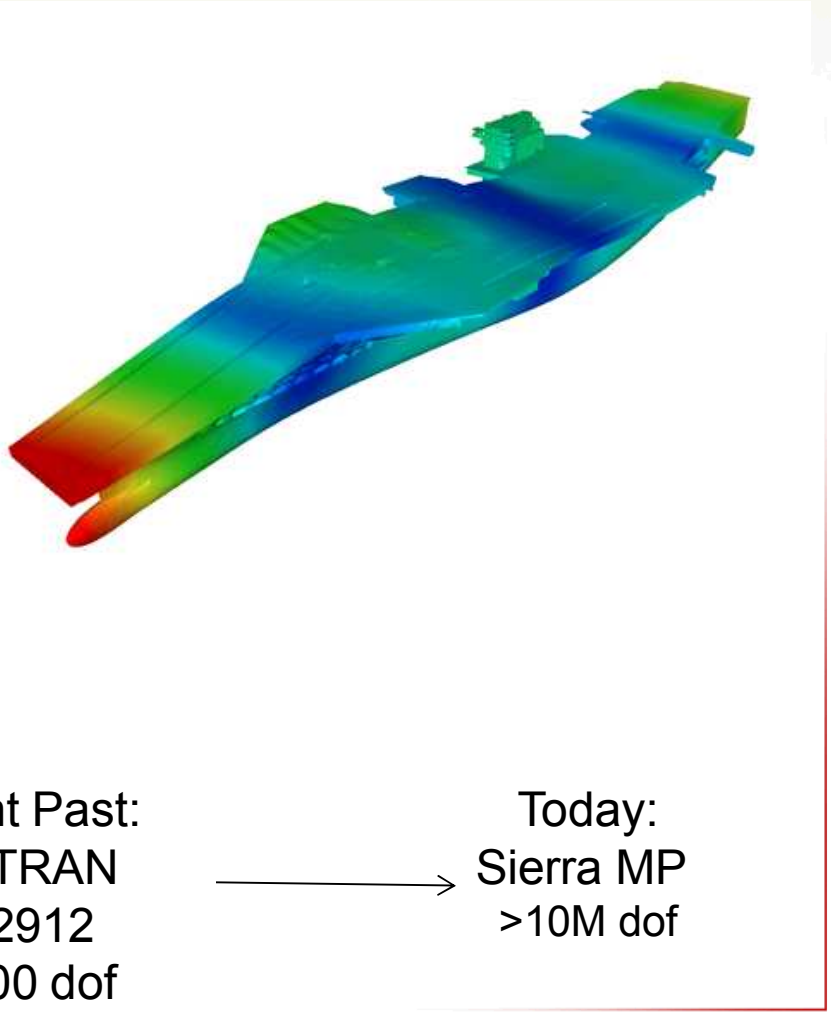


Coupled
Thermal/QS/Dynamic

- Provides a family of scalable parallel solvers for highly nonlinear problems
  - 1 to ~100K cores
  - Multi-levels
  - Contact
  - Nonlinear material response
  - Large deformation
- Utilizes services provided by the Sierra Framework/Toolkit to enable
  - Coupled physics
  - Multi-length scale modeling techniques
  - Preloading

# Structural Dynamics

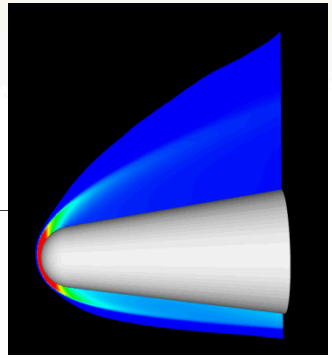
- Predicts the response of a system under dynamic conditions.
  - Stresses (particularly in the operating regime)
  - Fatigue
  - Energy dissipation in joints
- Efficient for very large problems
  - Many millions of coupled equations
  - Serial, direct matrix solutions scale to order $N^3$
  - Parallel, iterative solvers are typically more complex, but scale as O(N)
    - FETI
    - CLIP, CLOP Solvers (Sandia)
- Structural Acoustics
- Inverse Problem Capability

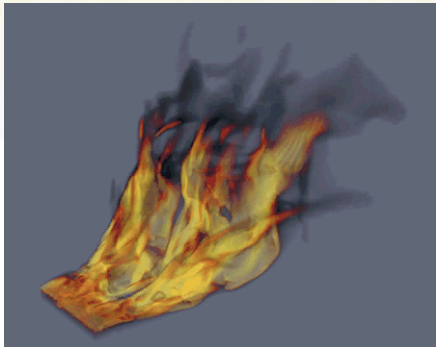


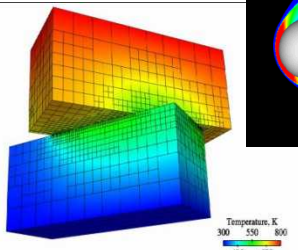
Recent Past: NASTRAN MC2912 30,000 dof → Today: Sierra MP >10M dof

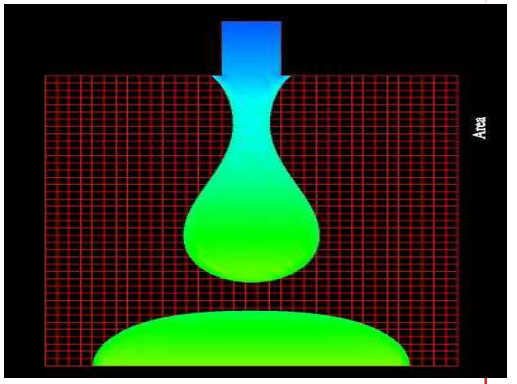
# Computational Thermal & Fluid Mechanics

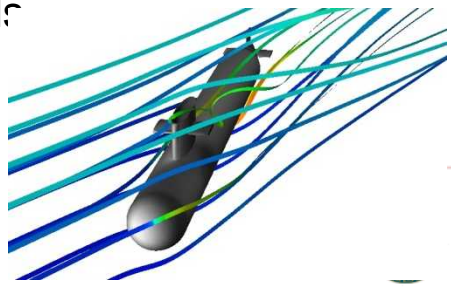
- **Thermal** – Heat Transfer, Enclosure Radiation and Chemistry
  - Dynamic enclosures
  - Element birth death
  - Contact
- **Aero** – Compressible Fluid Mechanics
  - Subsonic through hypersonic
  - Laminar and turbulent
  - Unstructured mesh
- **Multiphase** – Non-Newtonian, Multi-physics, and Free Surface Flows
  - Complex material response
  - Level sets for surface tracking
  - Flexible coupling schemes
- **Fire/Combustion** – Low Speed, Variable Density, Chemically Reacting Flows
  - Eddy dissipation and mixture fraction reaction models
  - RANS and LES based turbulence models
  - Unstructured Mesh
  - Pressurization models









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