SAND2008-6290P

NAVY FSST

Progress report: SIERRA Mechanics Capabilities

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SIERRA support of Navy FSST : Goal

Couple Gemini with Sierra Mechanics (Presto)
to run the quarter scale model

SIERRA support of Navy FSST : Tasks

Develop coupled Gemini+Presto capability,

- Gemini for underwater/surface blast loading
- Couple Gemini to SIERRA via SIERRA Gemini coupler
- Connect Presto capability to SIERRA Gemini coupler

Enhance Presto for Navy ship models,

- Triangular shell elements
- Constraint equations (foundational capability)
- RBEs (connecting Mass to structure)

and…

SIERRA support of Navy FSST : Tasks

…demonstrate on Navy FSST-Acceptance Test Suite

- ❑ Huang cylinder (verification)
- ❑ Hydrobulge (validation)
- ❑ Underwater charge against plate (validation)
- ❑ Barge/IFSP (validation)
- ❑ Quarter scale, UHWM, ship model (validation)

Coupled Gemini+Presto capability : Approach

Leverage effort already underway,

Navy Enhanced Sierra Mechanics (NESM)

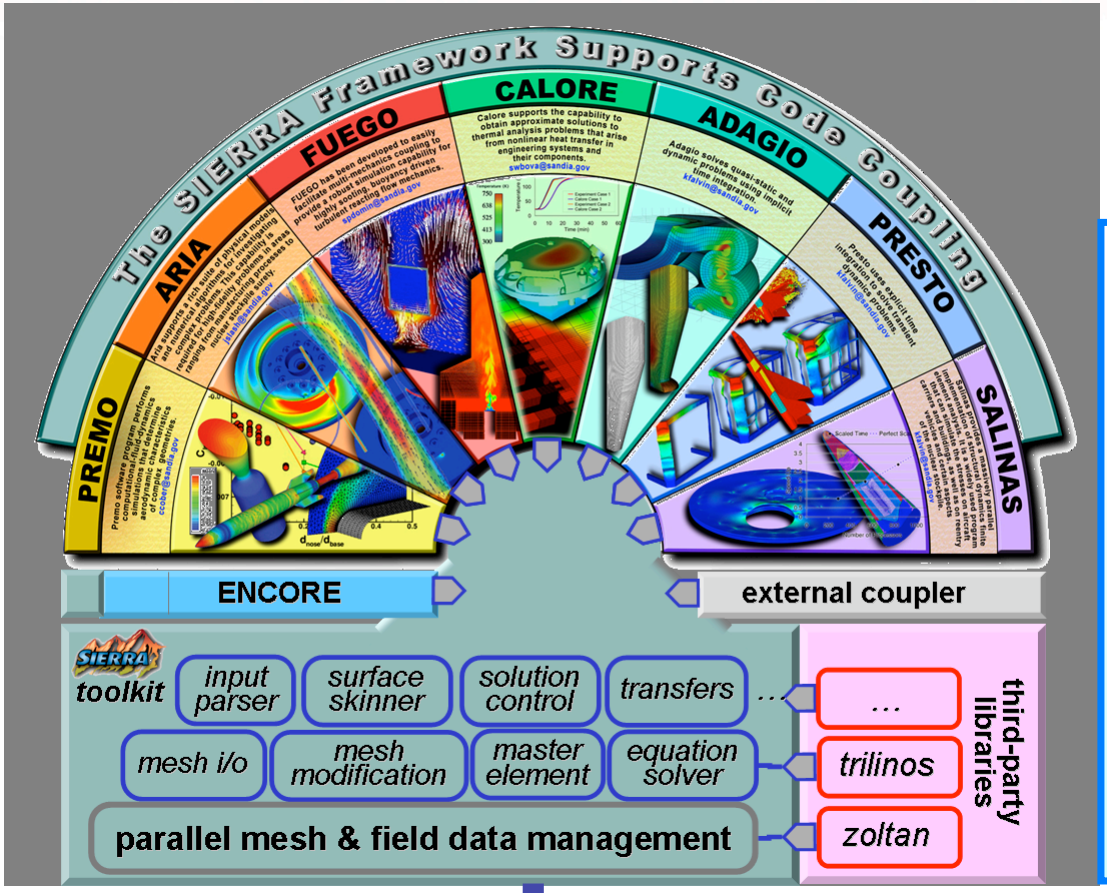
- coupled Gemini+Salinas capability developed this year for Use Case 1
- Leverage Nastran–to–Salinas conversion tool (NASGEN)

Salinas and Presto are modules of the SIERRA mechanics suite…

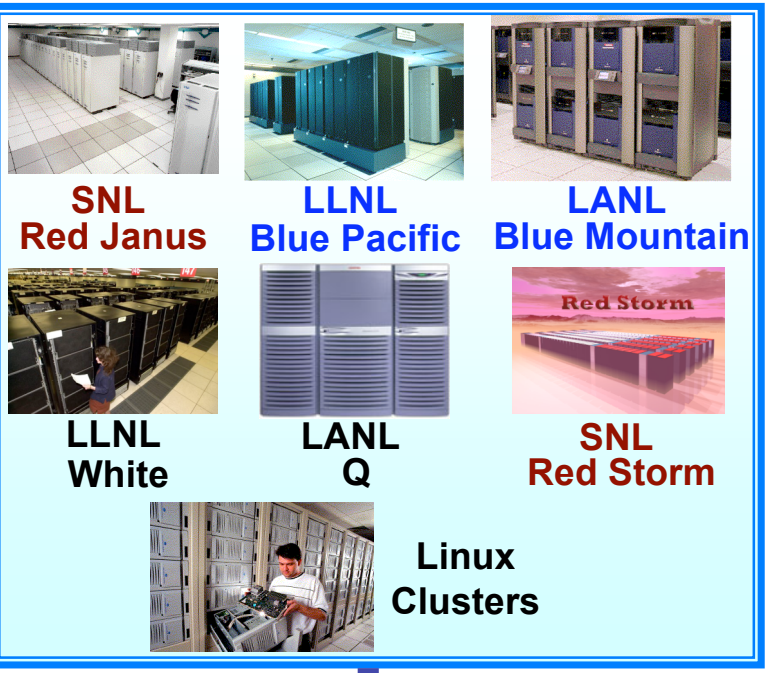
SIERRA Mechanics overview

DOE ASC program funded for ~10 years

Massively parallel multi-physics capabilities for Sandia's engineering science mission

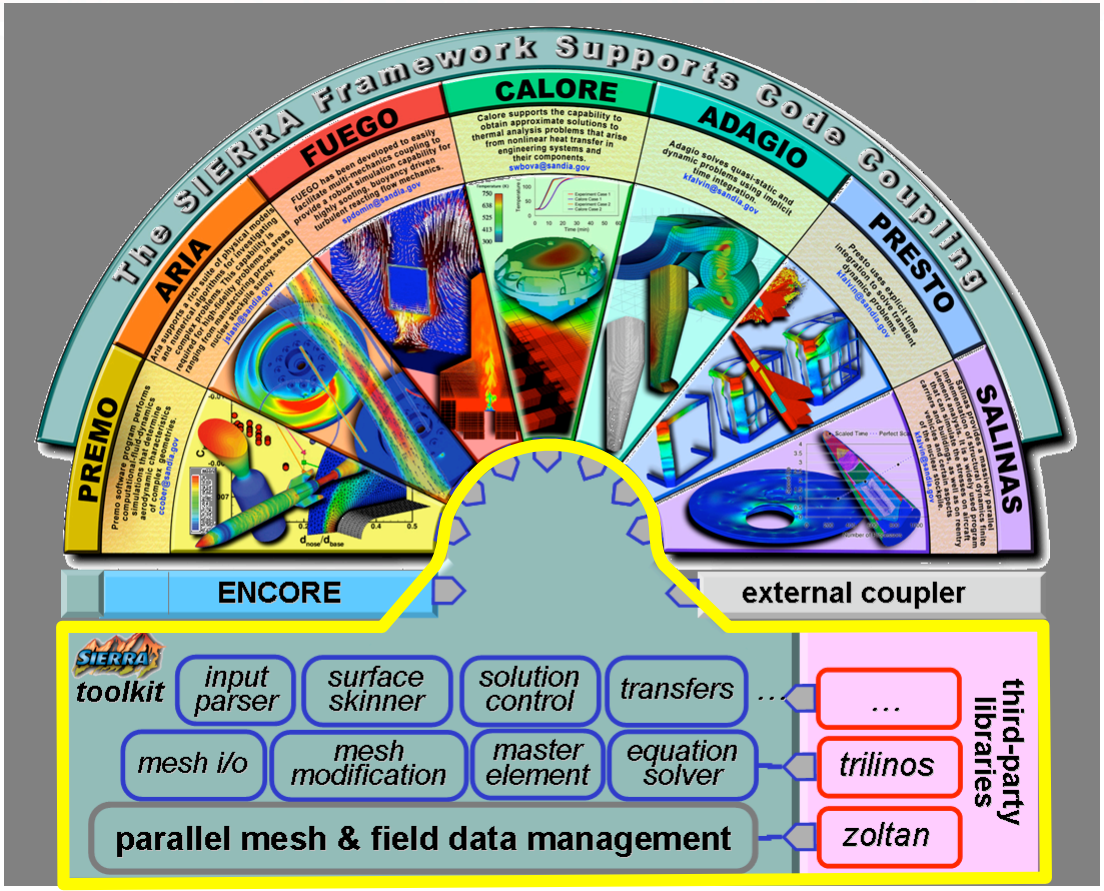


Designed and developed for MP hardware



SIERRA Mechanics foundation

SIERRA_toolkit
FE application code services



Capabilities:

Mesh & field data management (parallel, distributed)

Services provided to Mechanics applications

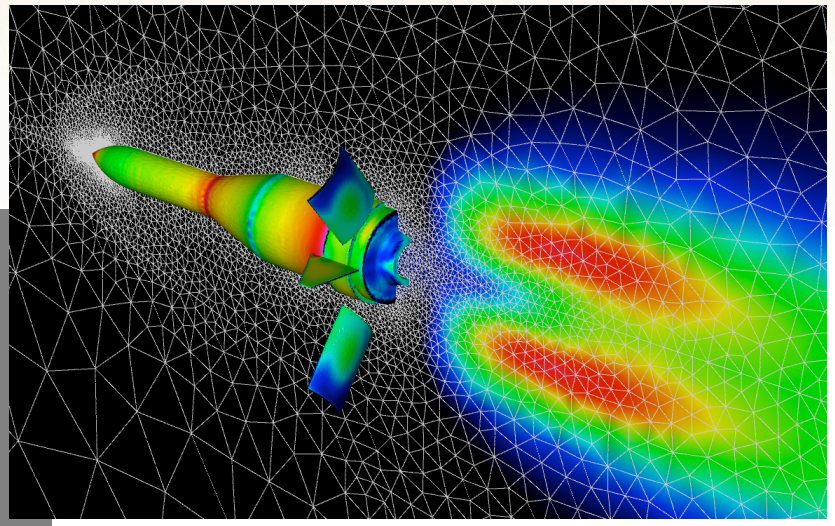
Transfer operators for mapping field variables from one mechanics to another

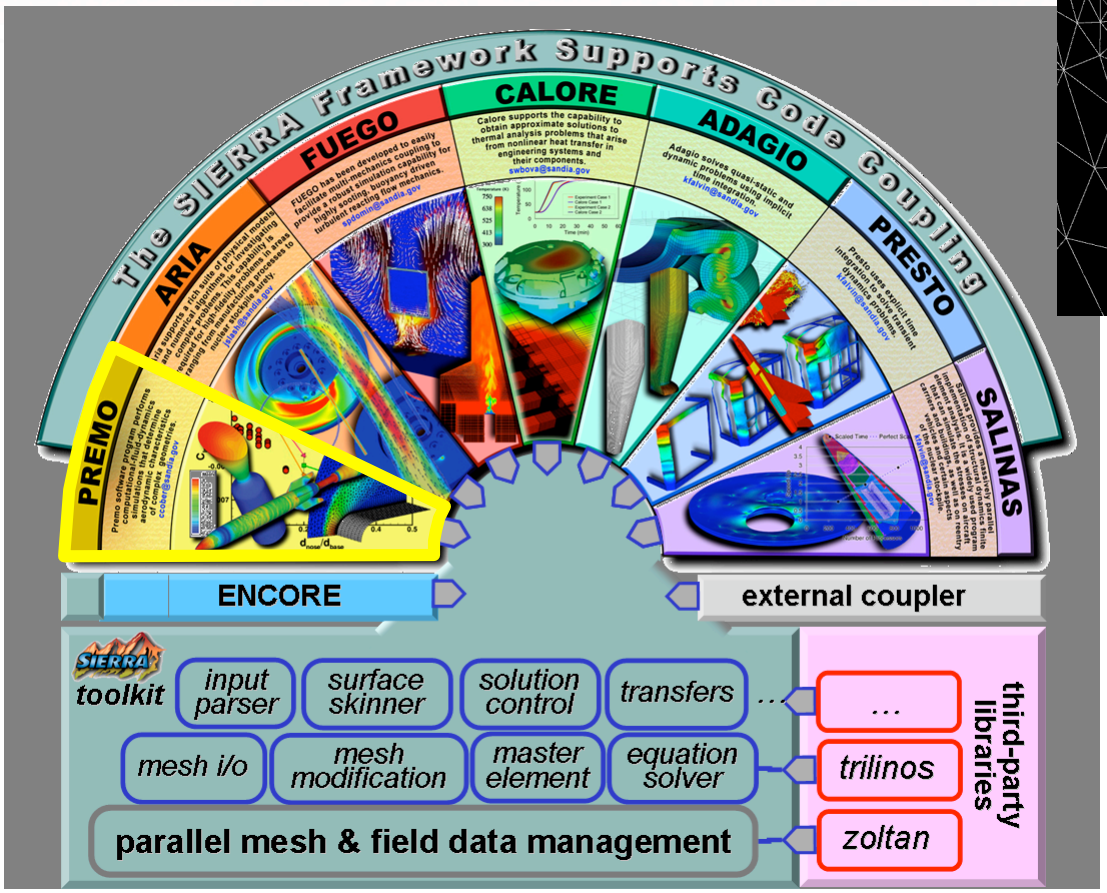
Solution controller for code coupling

Includes third party libraries (e.g. solver libraries, MPI communications package)

SIERRA Mechanics modules

SIERRA_Premo
Compressible Fluid Mechanics





Capabilities:

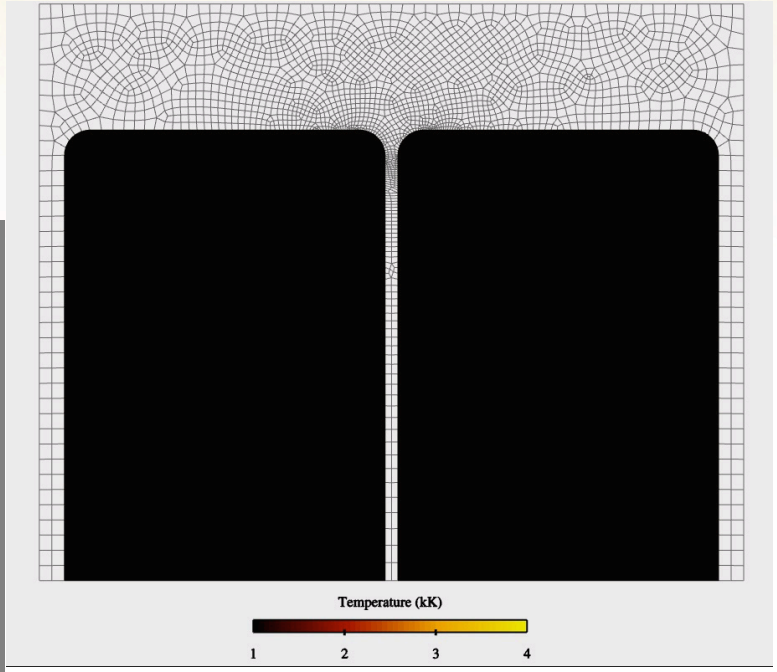
Subsonic through hypersonic

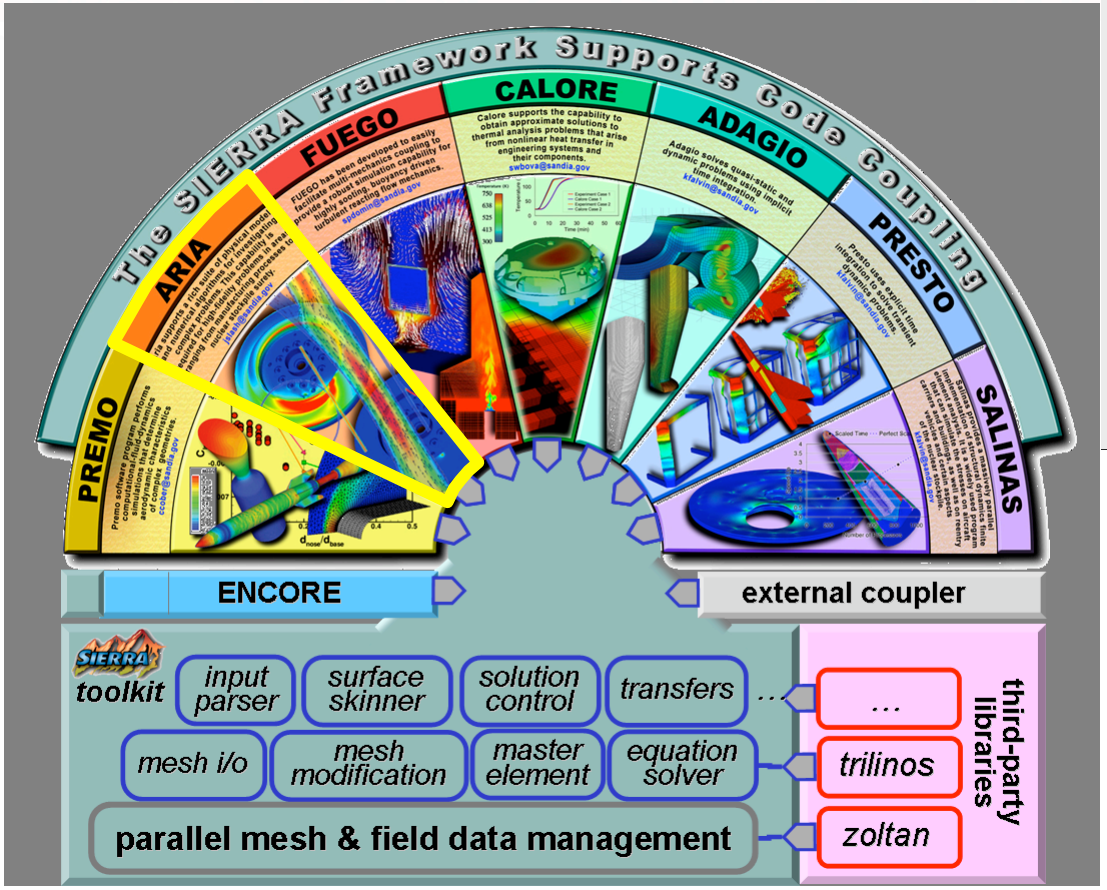
Laminar and turbulent

Unstructured mesh

SIERRA Mechanics modules

SIERRA_Aria
Non-Newtonian flow





Capabilities:

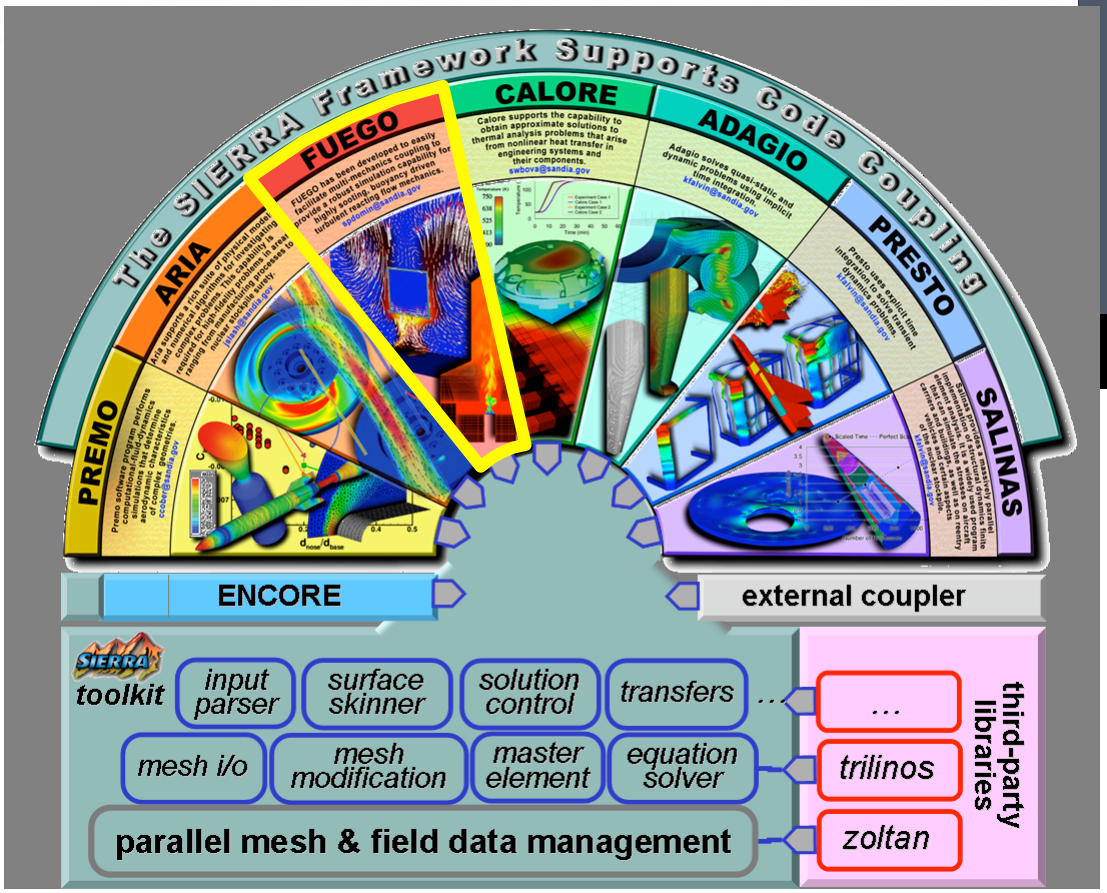
Chemically Reacting flows, Level sets for free-surface tracking

Complex material response

Basic Physics: Navier-Stokes (variable ρ), Energy, Species, Electrostatics

SIERRA Mechanics modules

SIERRA_Fuego
Low Mach number, finite-volume fluid dynamics



Problem description:

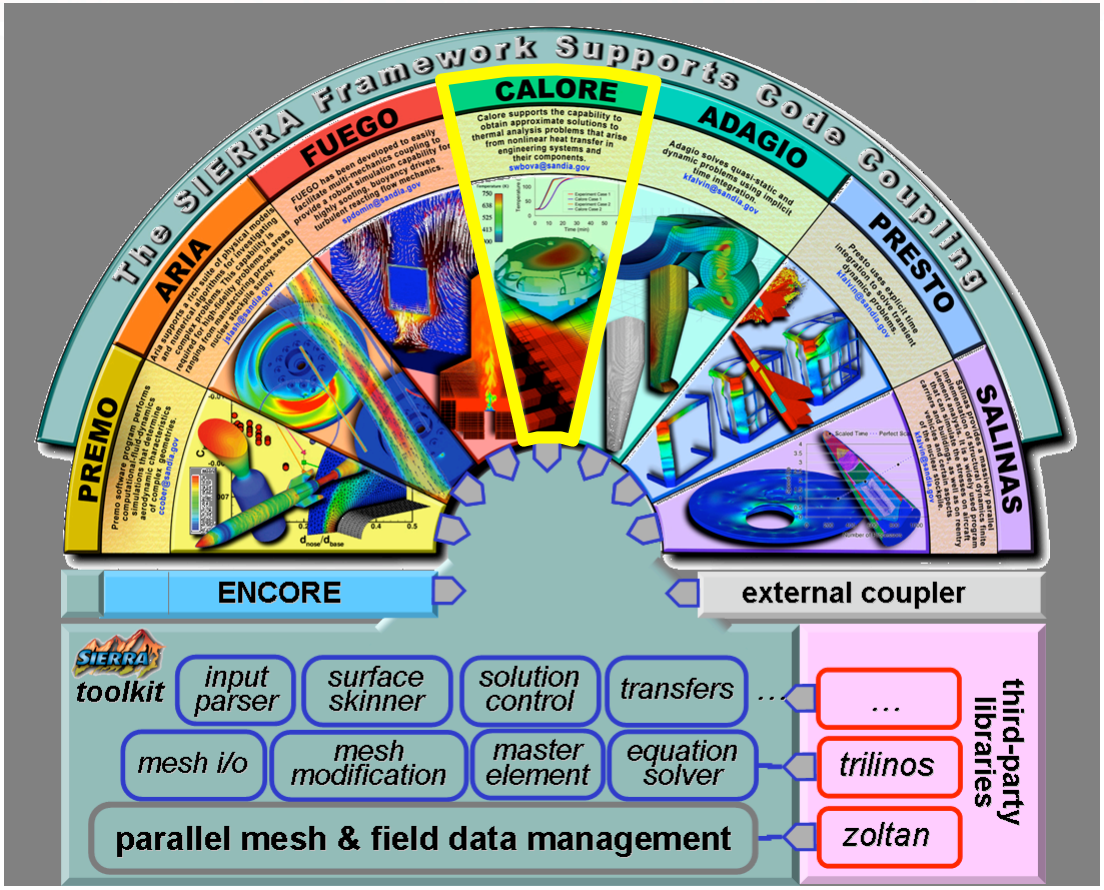
Hydrocarbon pool fire, 400M DOFs, 5000 procs. on Red Storm

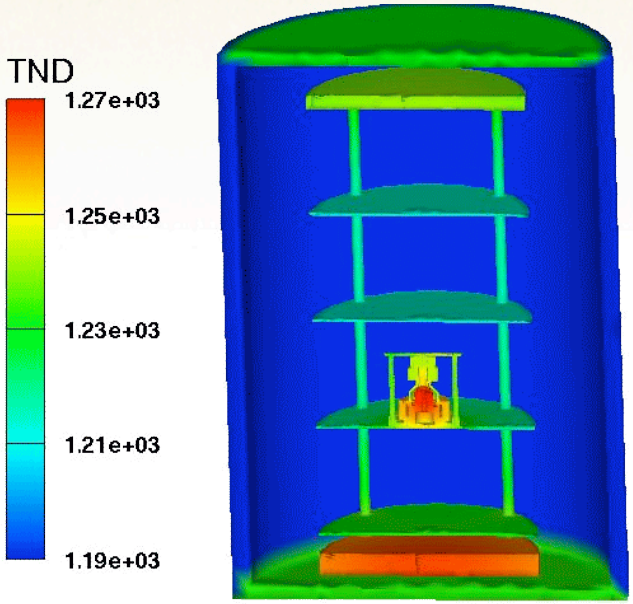
Capabilities:

Turbulent reacting flow with coupling to participating media radiation and heat conduction, RANS and LES-based turbulence models

SIERRA Mechanics modules

SIERRA_Calore
Heat transfer





Problem description:

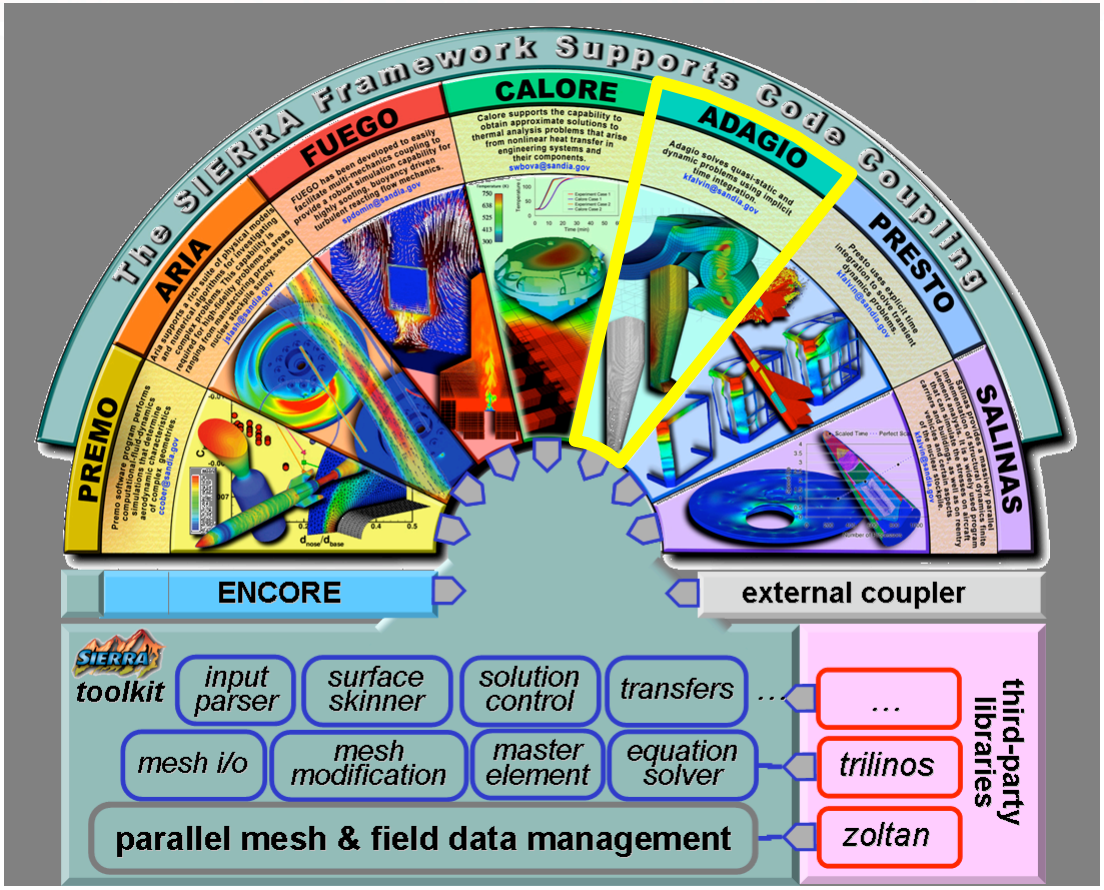
Braze furnace process optimization

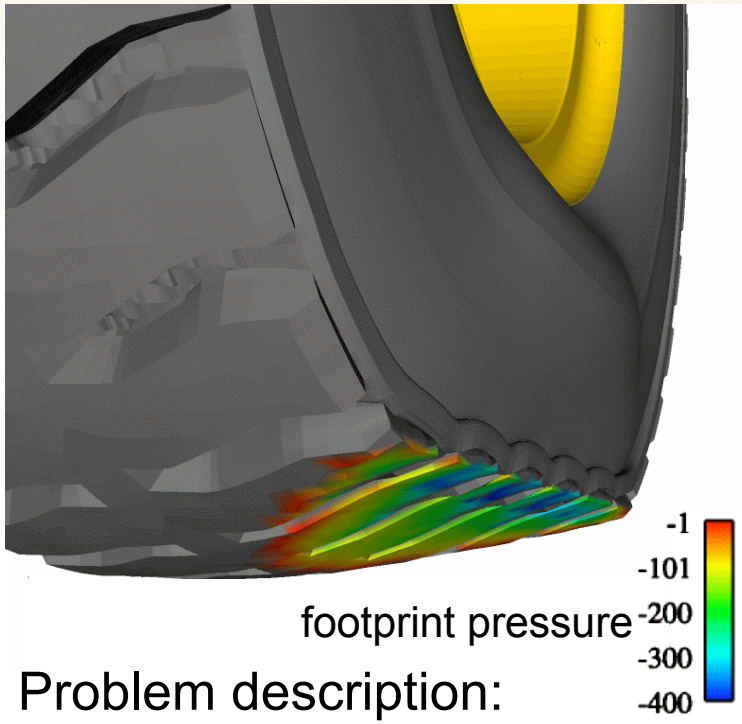
Capabilities:

Steady/Unsteady, conduction, limited convection, chemistry, enclosure radiation, thermal contact, h-adaptivity

SIERRA Mechanics modules

SIERRA_Adagio
Non-linear Solid mechanics





footprint pressure

Problem description:

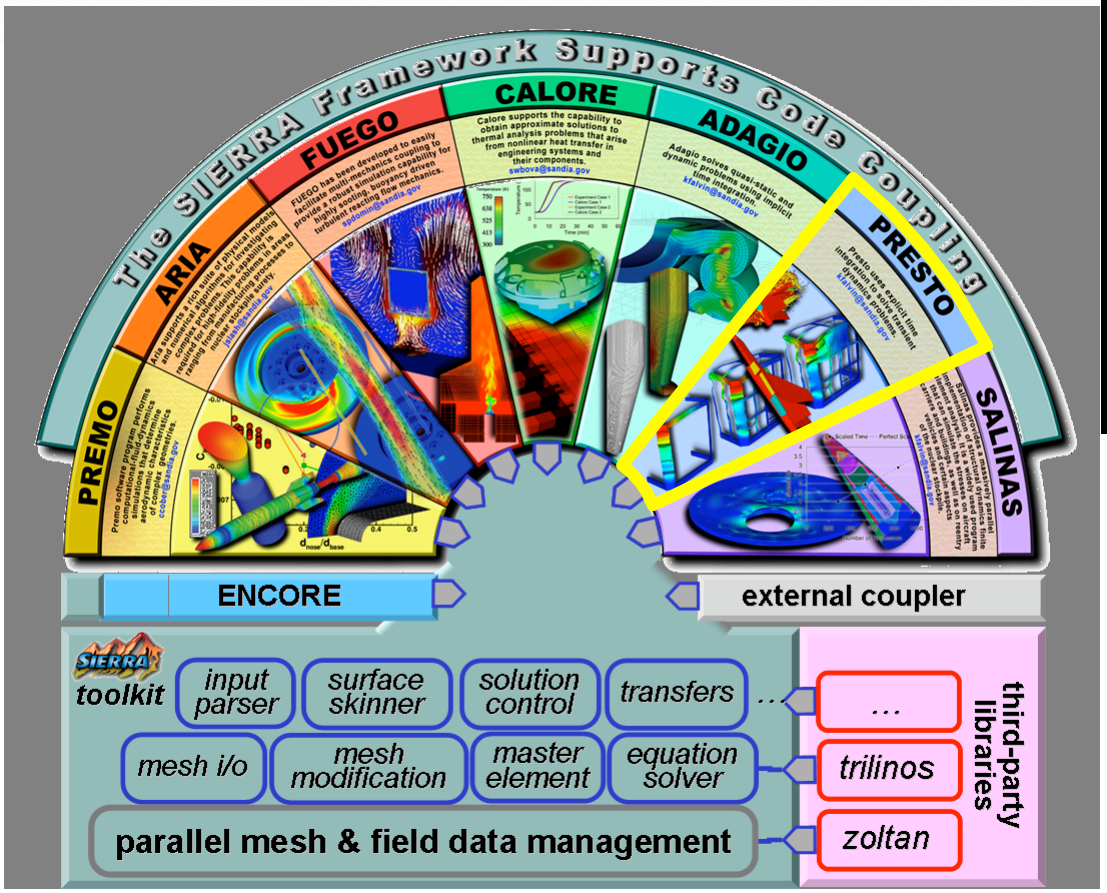
Tire performance modeling, camber angle = 18°

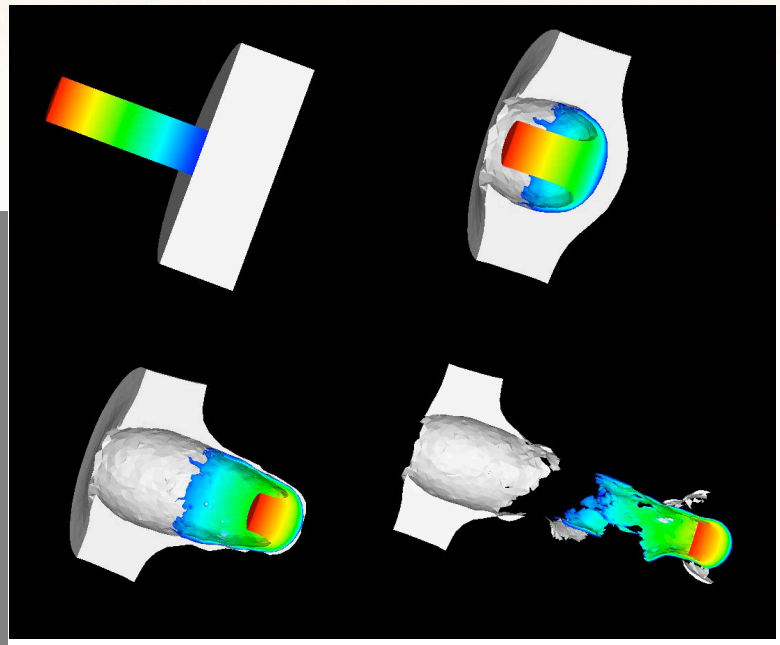
Capabilities:

Quasistatics, implicit dynamics, Parallel non-linear implicit solvers, contact, >50 material models, failure & tearing

SIERRA Mechanics modules

SIERRA_Presto
Non-linear Solid transient dynamics





Problem description:

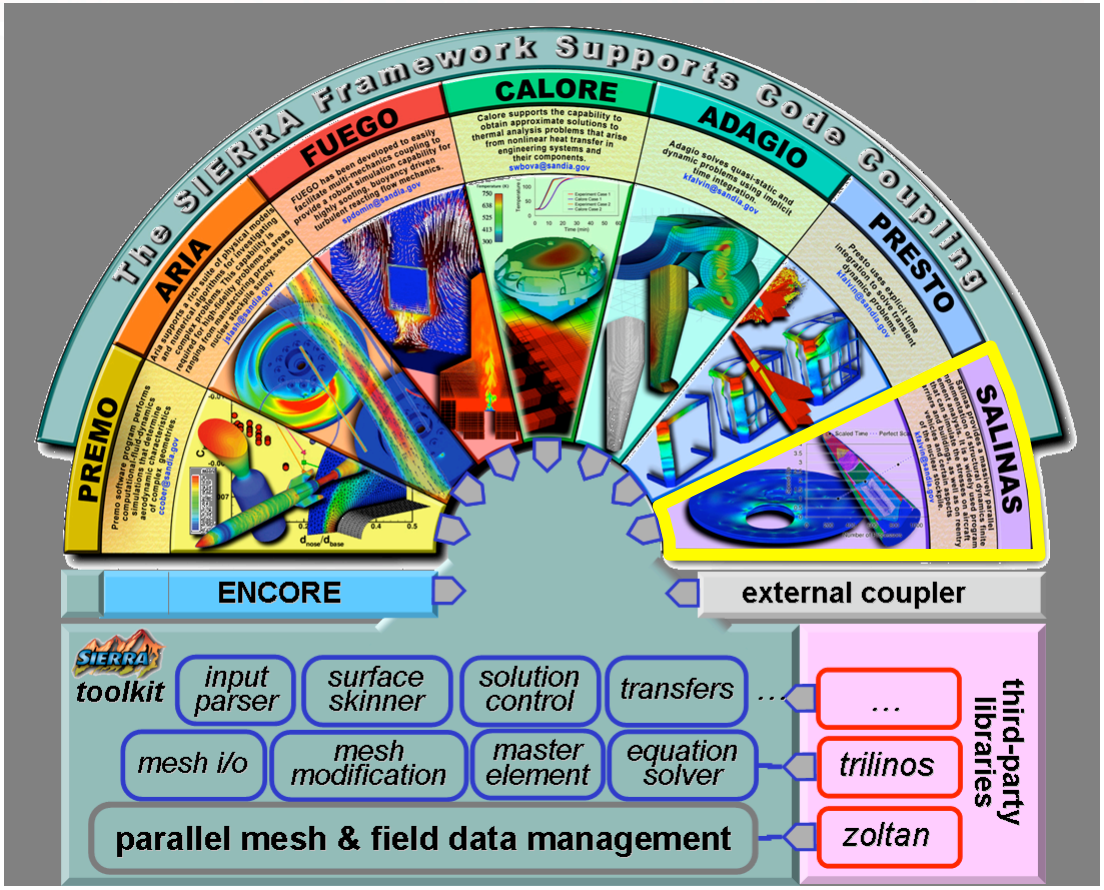
Tungsten rod impacting steel plate @2500 m/s

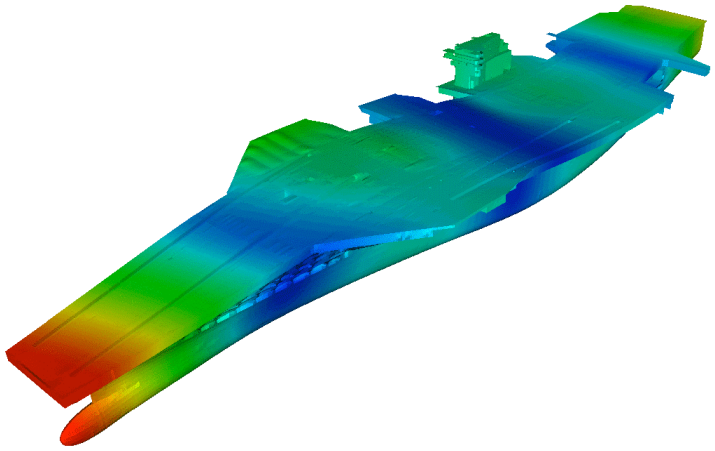
Capabilities:

Explicit time integrator, Nodal-based tet w/ remeshing, particle methods, cohesive surface elements, spot welds, contact, material failure

SIERRA Mechanics modules

SIERRA_Salinas
Linear structural dynamics





Problem description:

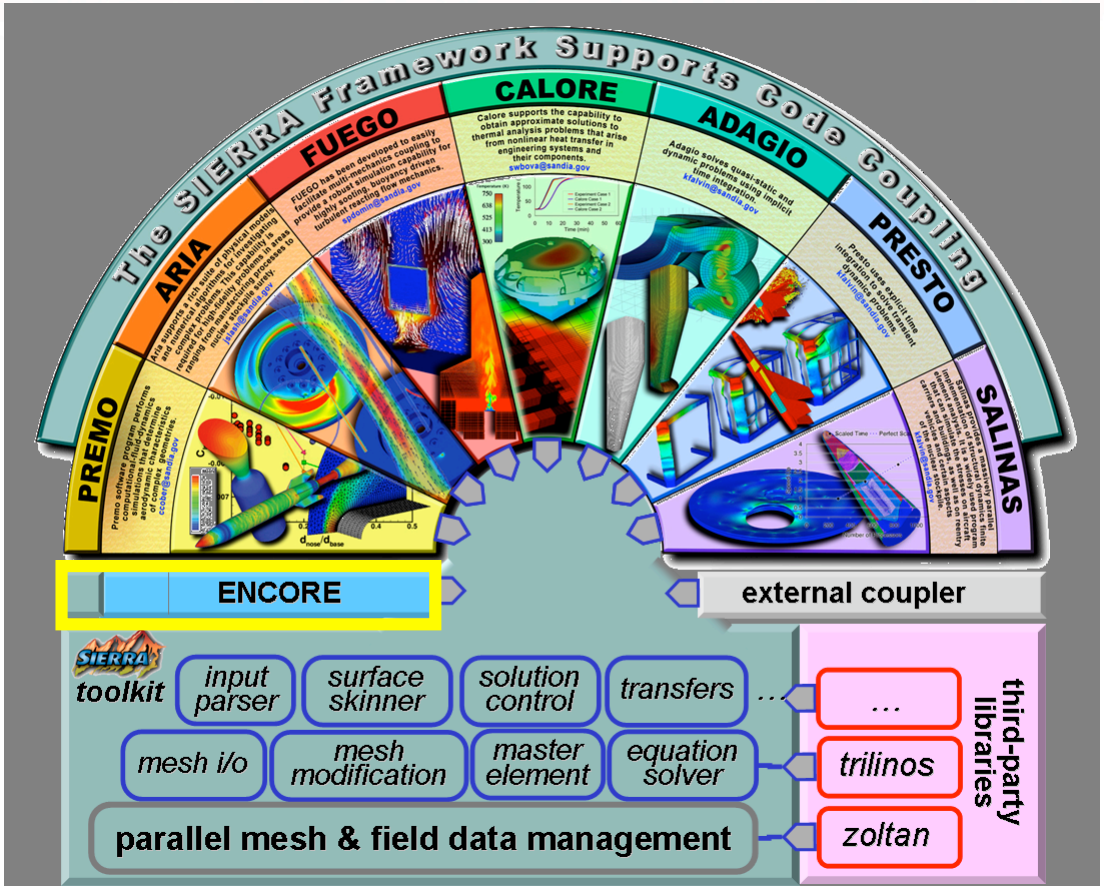
Modal solution of complex structures (1000's of material regions, offset shells and beams)

2.0M DOFs, solved on 64 processors

Acoustics

SIERRA Mechanics modules

SIERRA_Encore
FE error measures



Capabilities:

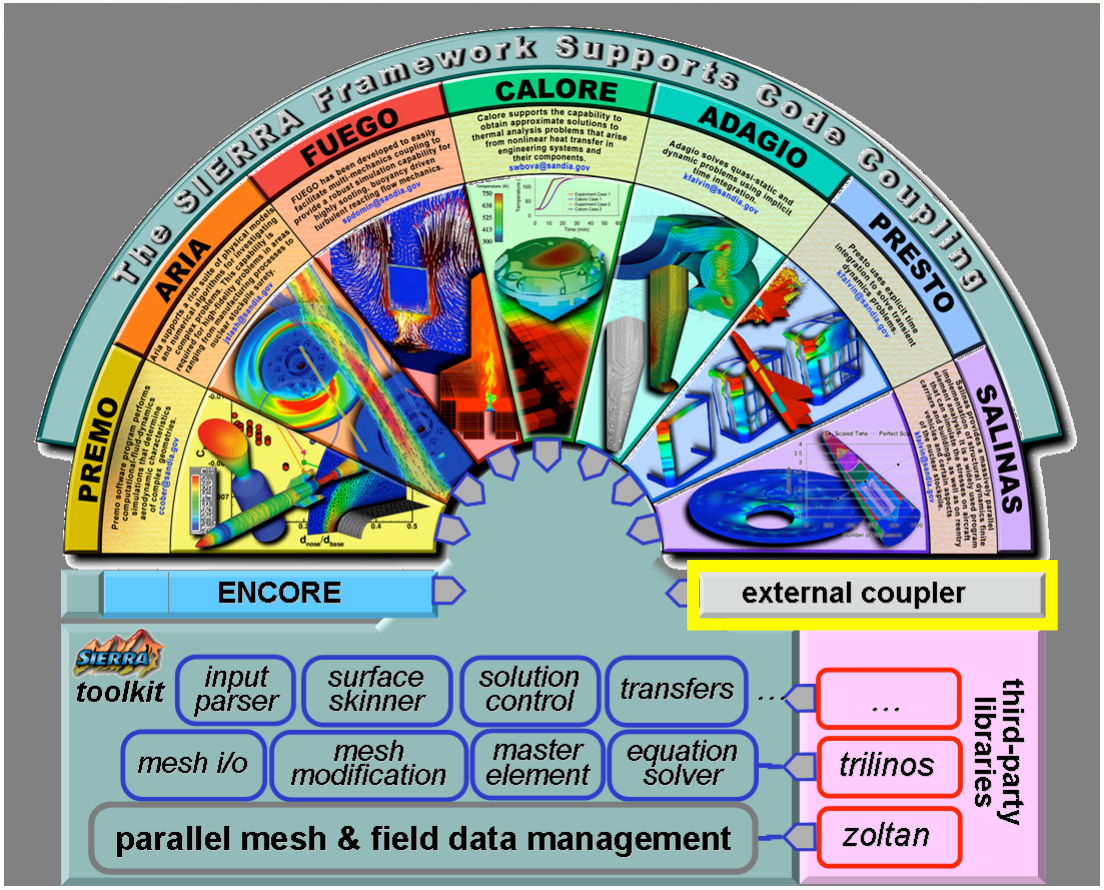
Differencing multiple FE solutions (convergence)

Error measures (field variable norms)

General mapping capability between dissimilar meshes (on same geometry)

SIERRA Mechanics coupling

SIERRA_external coupler
coupling to external codes



Capabilities:

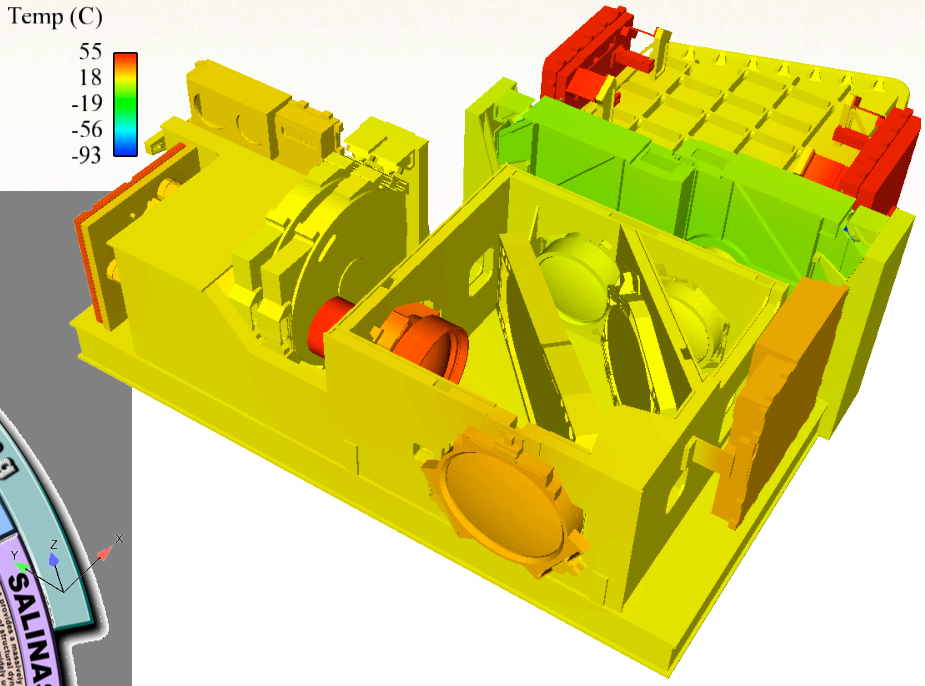
Accesses parallel mesh & field data management for transfer of SIERRA nodal and element variables to/from external code

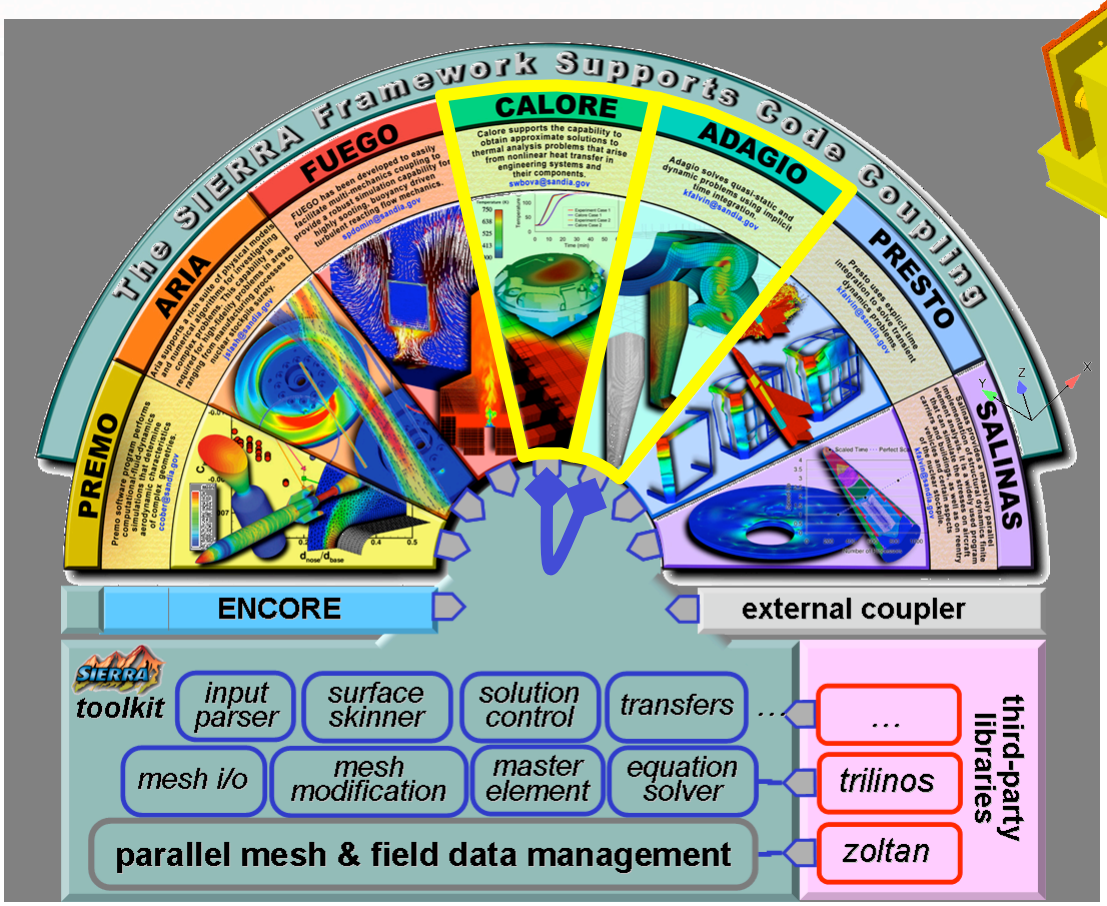
Implementation specific to external code as needed

Note: this allows access to <u>all</u> SIERRA mechanics modules

SIERRA Mechanics coupling

SIERRA_CoupledMechanics
Thermo-Structural Response



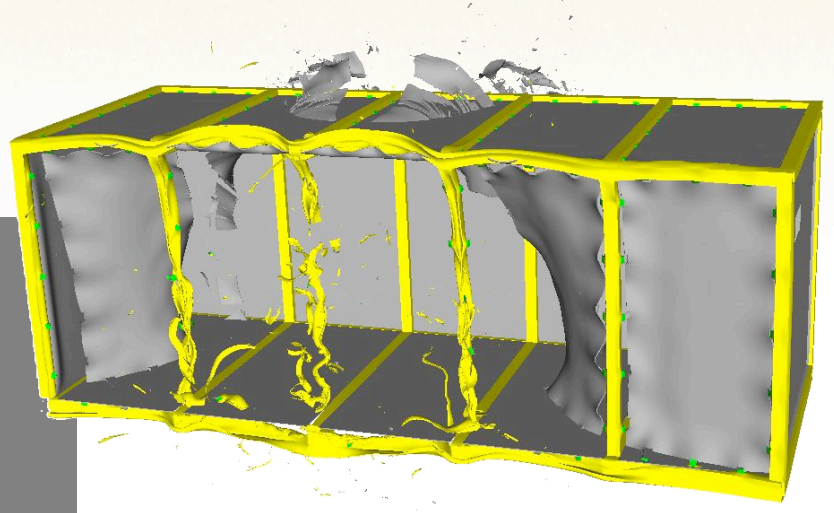


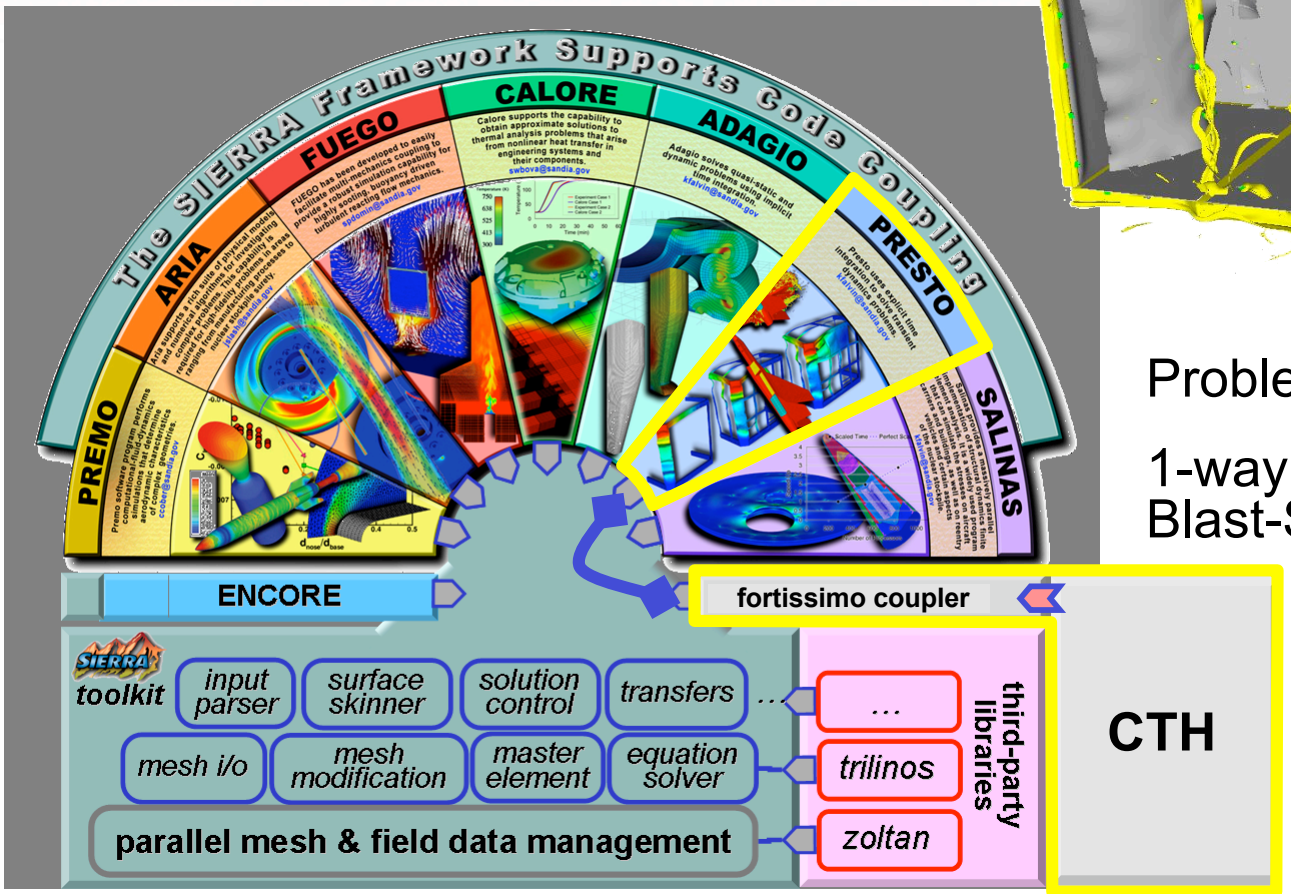
Problem Description:

Coupled Thermal-Mechanical response of a satellite Optical Bench Assembly subjected to normal orbital thermal loads and onboard heating

SIERRA Mechanics coupling

SIERRA_Fortissimo
Blast-Structural failure Response



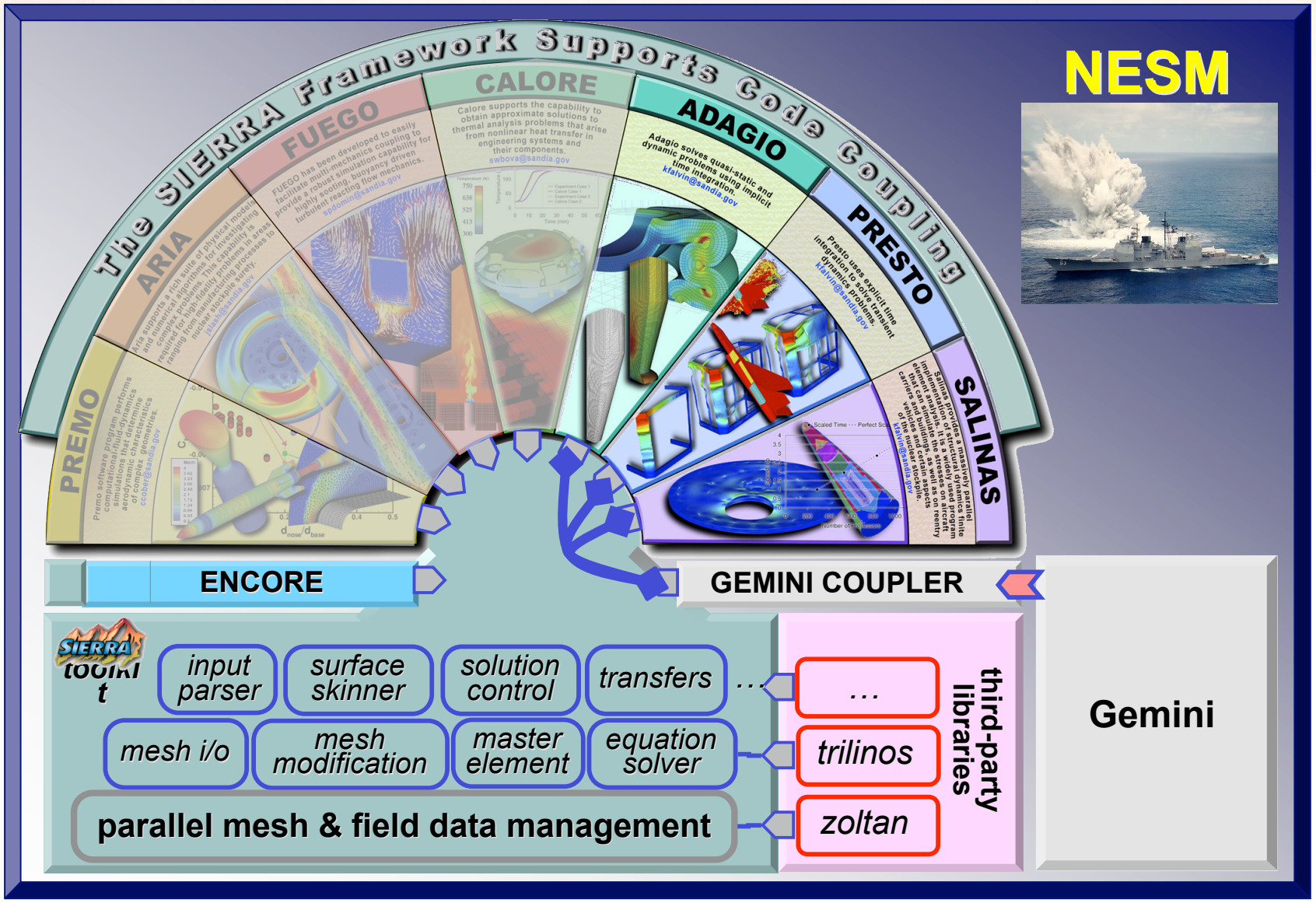


Problem Description:

1-way & 2 way coupled Blast-Structural calculation of a welded 5-panel steel box, predicting failure mechanics & post failure response

CTH capability: shock-hydrodynamics

Navy Enhanced SIERRA Mechanics



Coupled Gemini+Presto capability : status

Gemini for underwater/surface blast loading

- compiled and running on workstation & TBIRD (SNL's parallel cluster), done – Gemini system calls (now removed) occasionally caused system hang

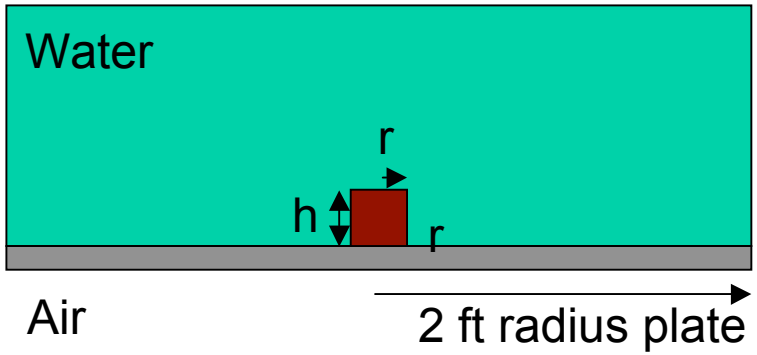
Couple Gemini to SIERRA

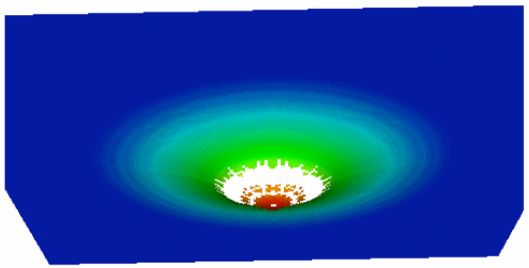
- coupling via SIERRA Gemini coupler & SCI, done
- pressure mapped to Presto, done (see verification & validation examples)

Coupled Gemini+Presto capability : status

Connect Presto capability to standard coupler interface

- ❑ updated surfaces (due to element death) mapped to Gemini, not complete: testing is underway





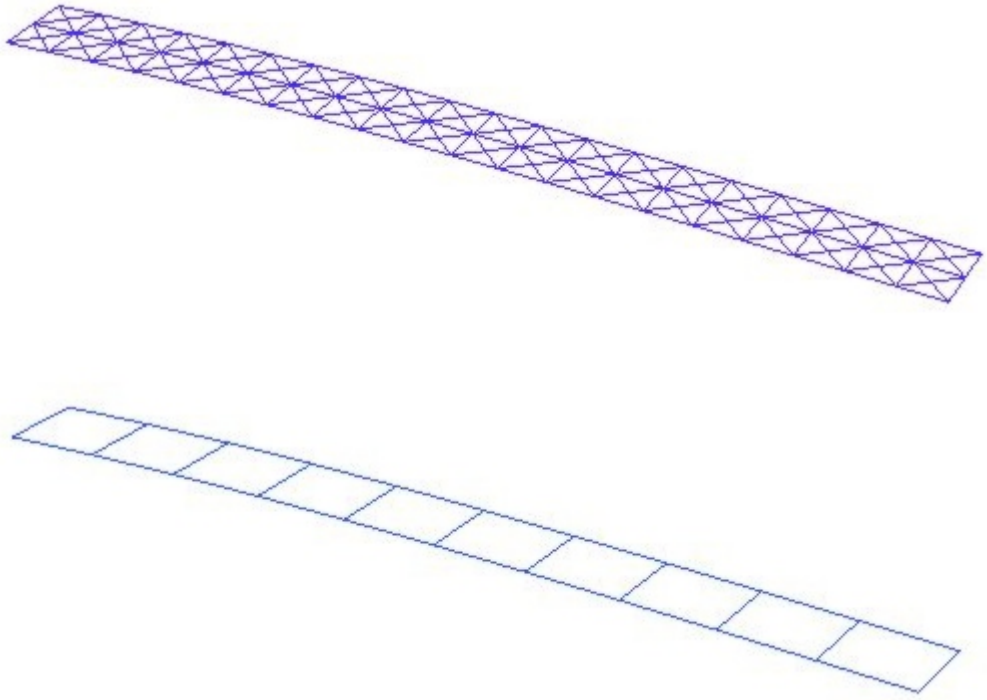
1/2 lb C4 Cylindrical Charge in contact w/ ¼" thick HY100 plate

Preliminary result: Updated surface (due to Presto element death) mapped to Gemini

Still need to verify capability !

Enhance Presto capabilities for Navy FSST : status

Implement triangular shell element : done



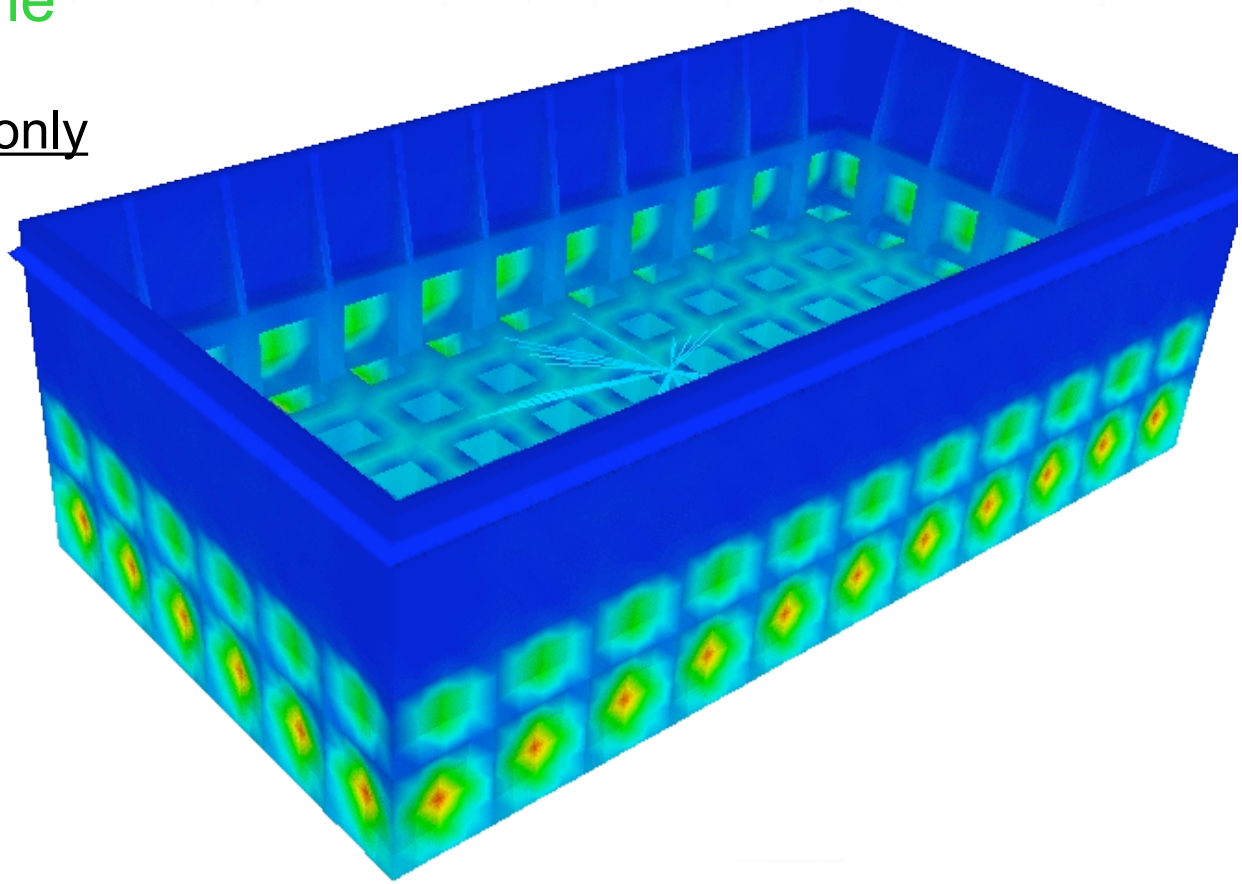
Triangular shell benchmarked against quadrilateral shell

Enhance Presto capabilities for Navy FSST : status

Foundational development for constraint equation capability : done

Verification of Presto-only model of Barge:

- Barge loaded w/ uniform pressure below waterline
- MPC enforced between mass point and floor of Barge



Enhance Presto capabilities for Navy FSST : status

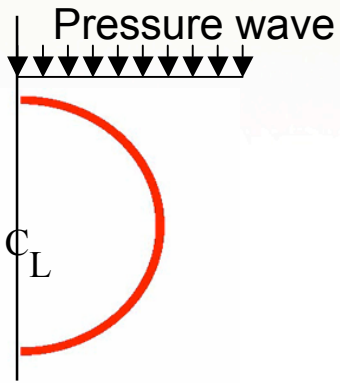
Implement RBEs : not complete

- Translational dof MPC (Slave nodes –to– Master node) : done
- Rotational dof MPC (Slave nodes –to– Master node) : done
- Flexibility for specifying RBE, combination(s) of Translational and Rotational MPCs : not complete

Demonstrate SIERRA mechanics capabilities on Navy FSST-ATS

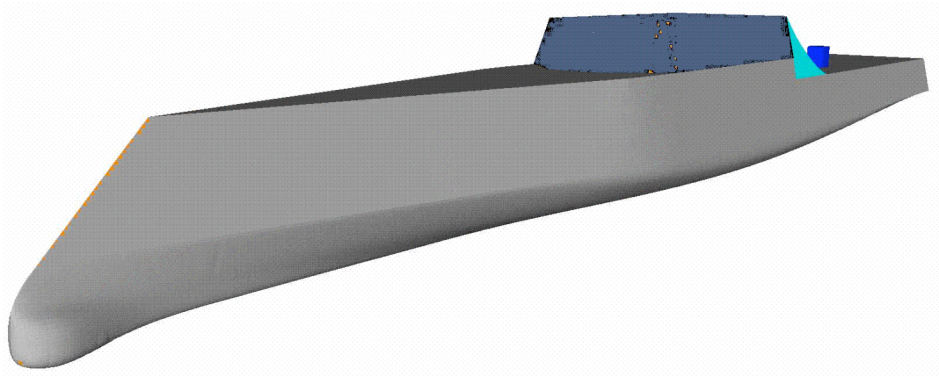
Verification problems

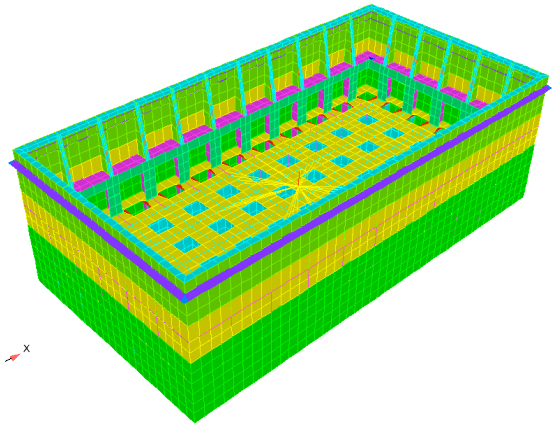
- ❑ Huang cylinder, done



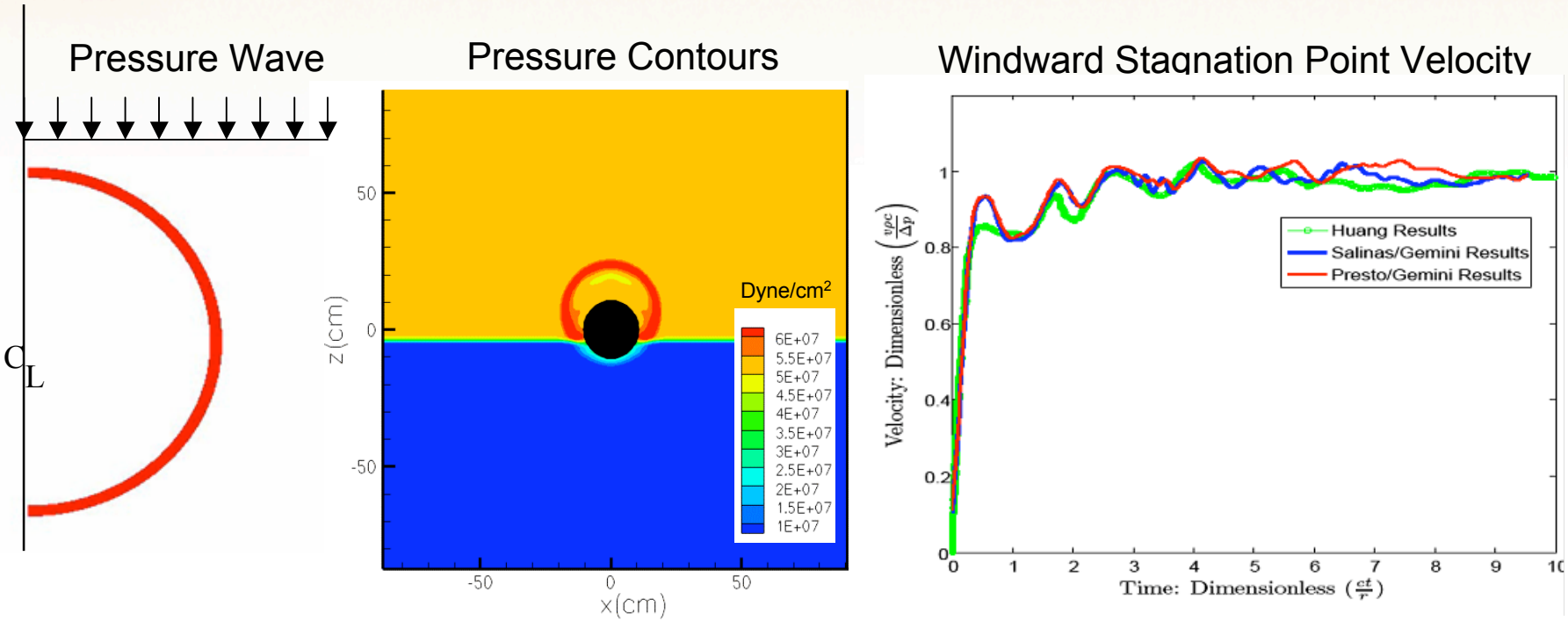
Validation problems

- ❑ Hydrobulge, done
- ❑ Barge/IFSP, tbd 12/08
- ❑ Quarter scale, tbd 12/08





Huang Cylinder Verification problem



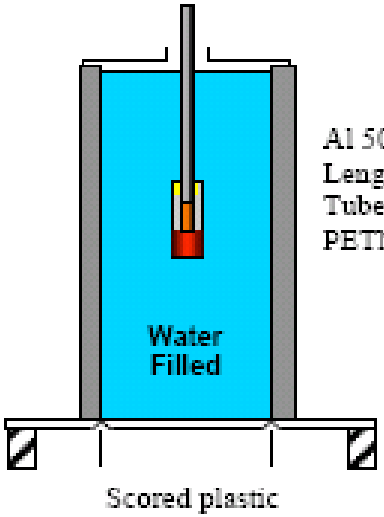
Plane shock wave (50:1 pressure ratio) interacts with a linear elastic circular cylinder.

Numerical derived results with an acoustic wave [1].

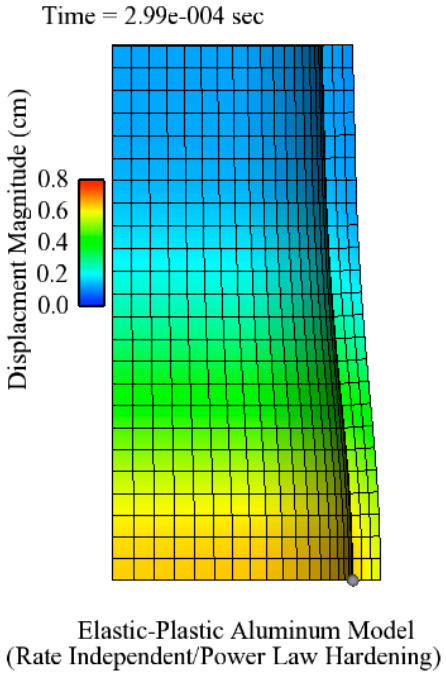
[1] H. Huang. An exact analysis of the transient interaction of acoustic place waves. *J. Appl. Mech.*, 37(4):1091–1099, 1970.

Hydrobulge Validation Problem (With Linear And Non-Linear Models)

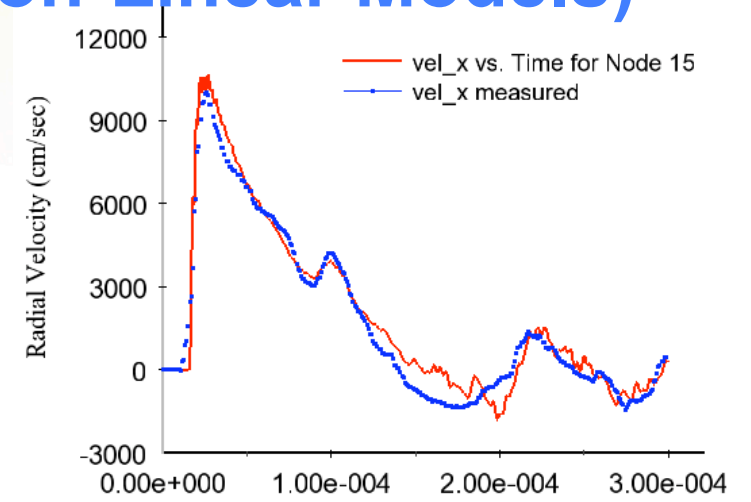
Water filled cylinder with a charge of PETN detonated.

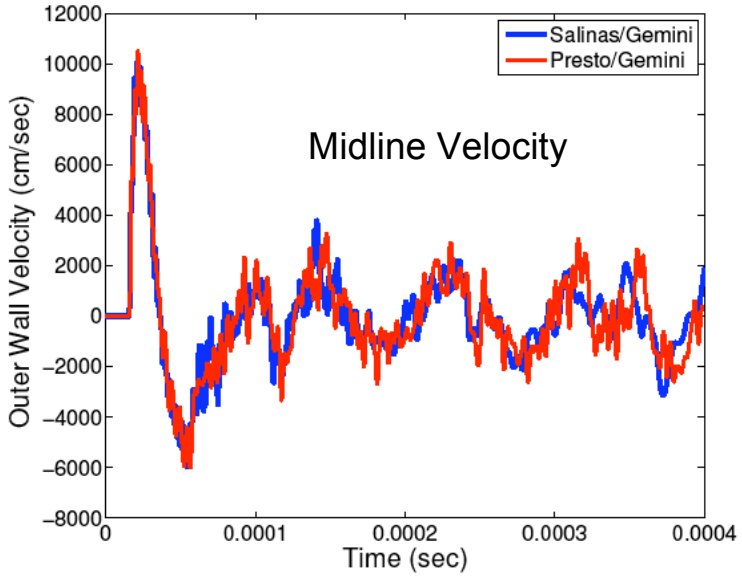


[2] G. Champers, et al. Pressure measurements on a deforming surface in response to an underwater explosion. *Shock Compression of Condensed Matter*, Ed. Schmidt, Dandekar, Forbes, American Institute of Physics, 1998.



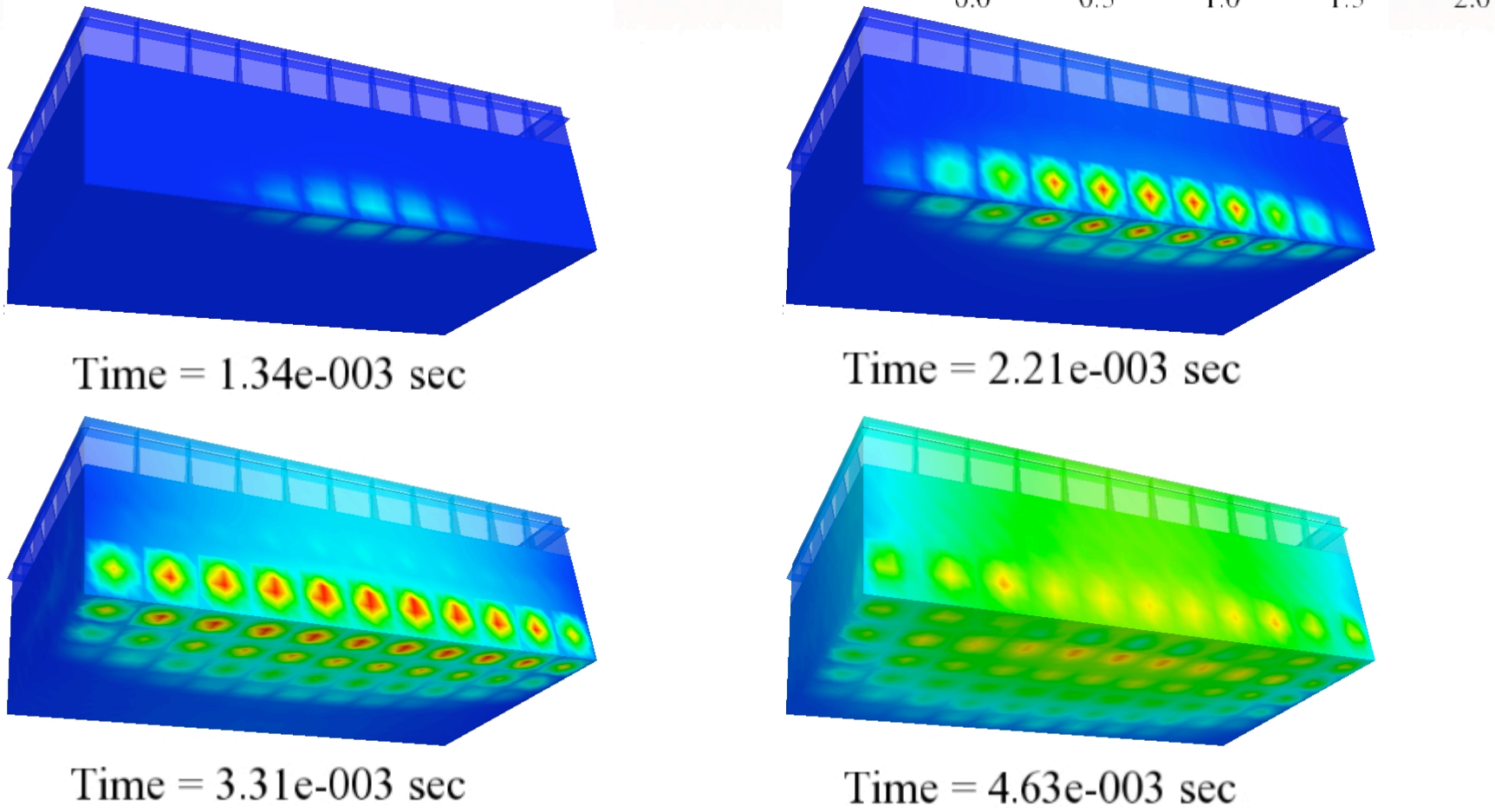
Elastic-Plastic Aluminum Model
(Rate Independent/Power Law Hardening)



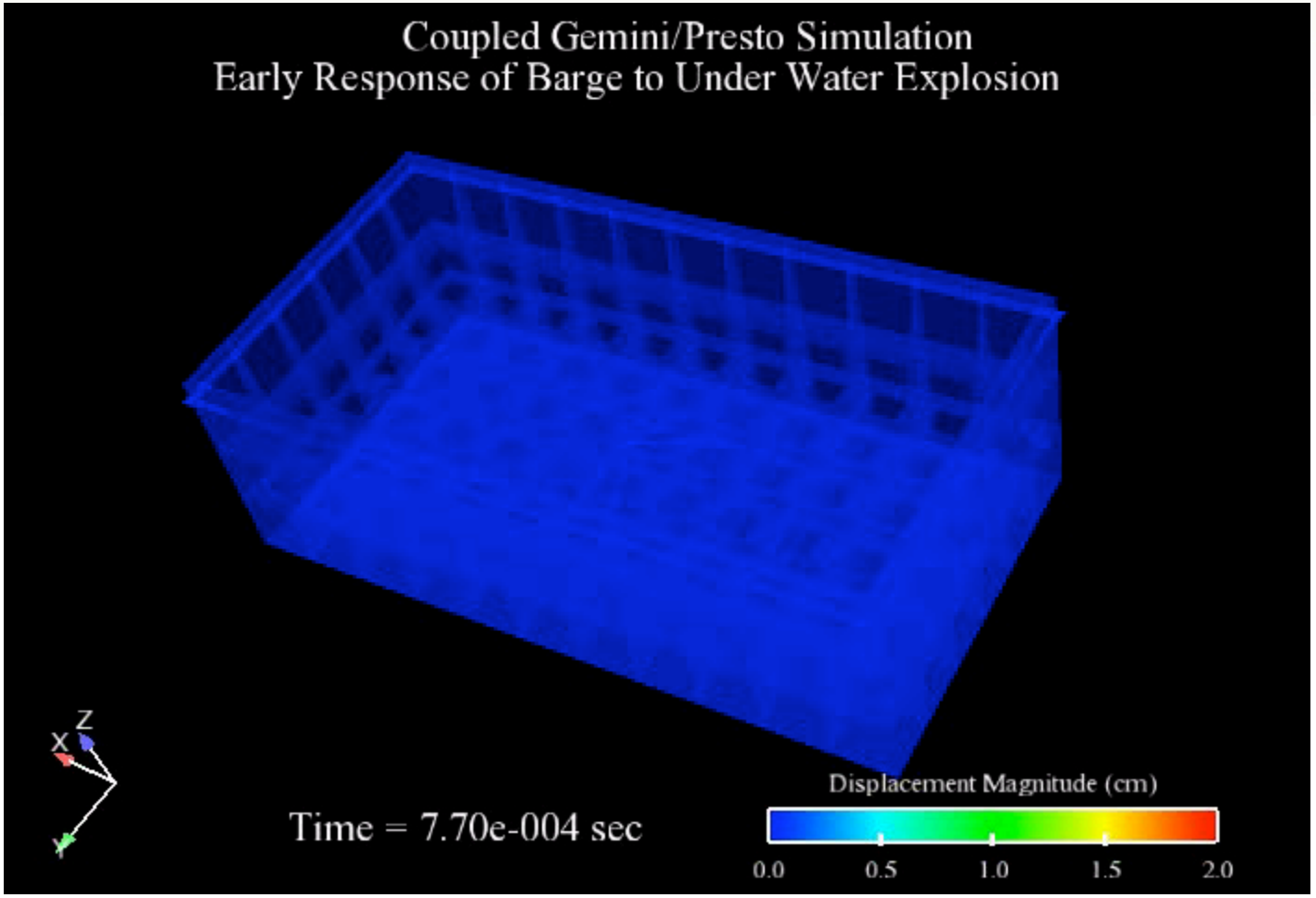


Barge/IFSP Validation Problem

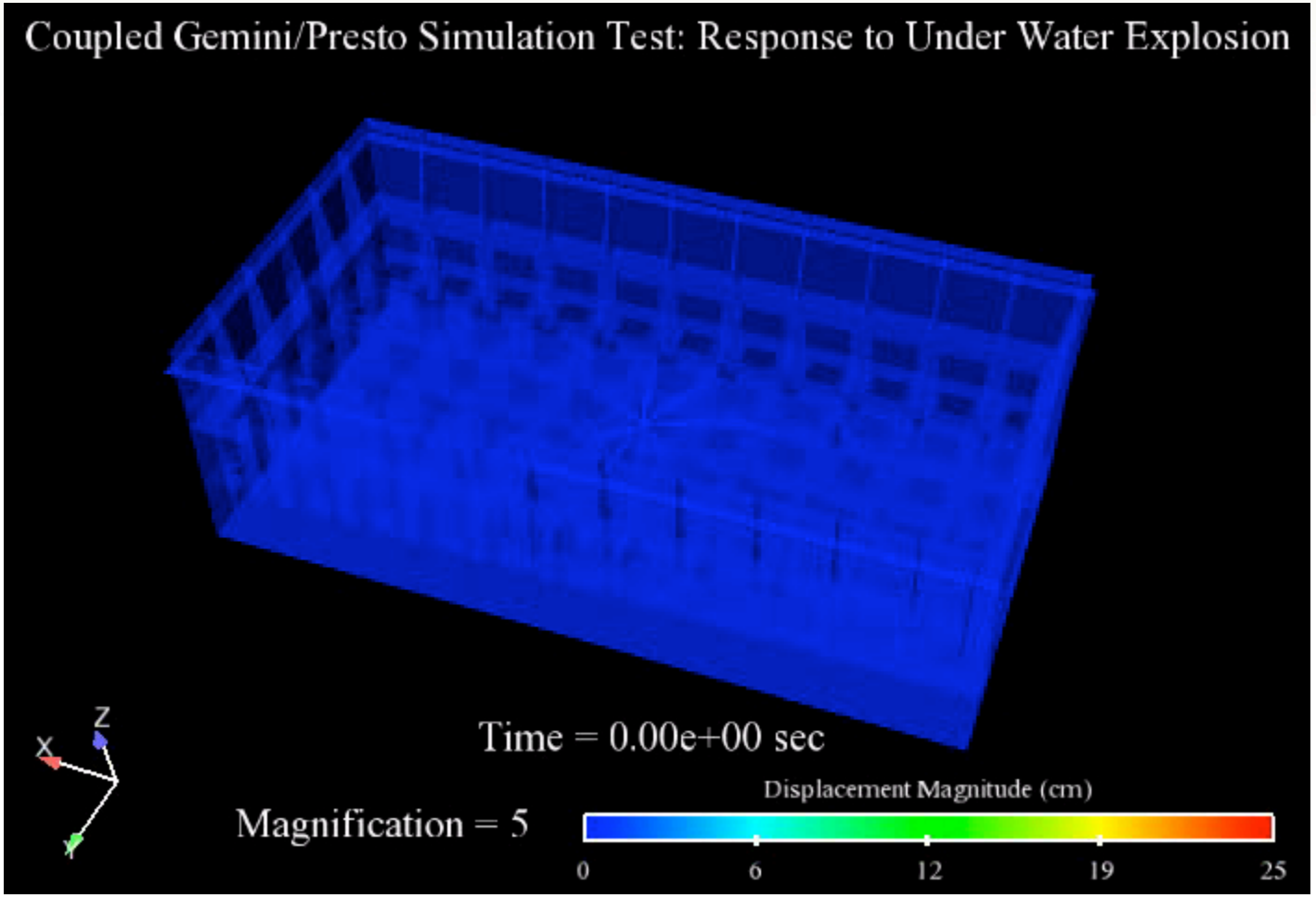
Coupled Gemini-Presto simulation:
underwater explosion (early time response)



Barge/IFSP Validation Problem



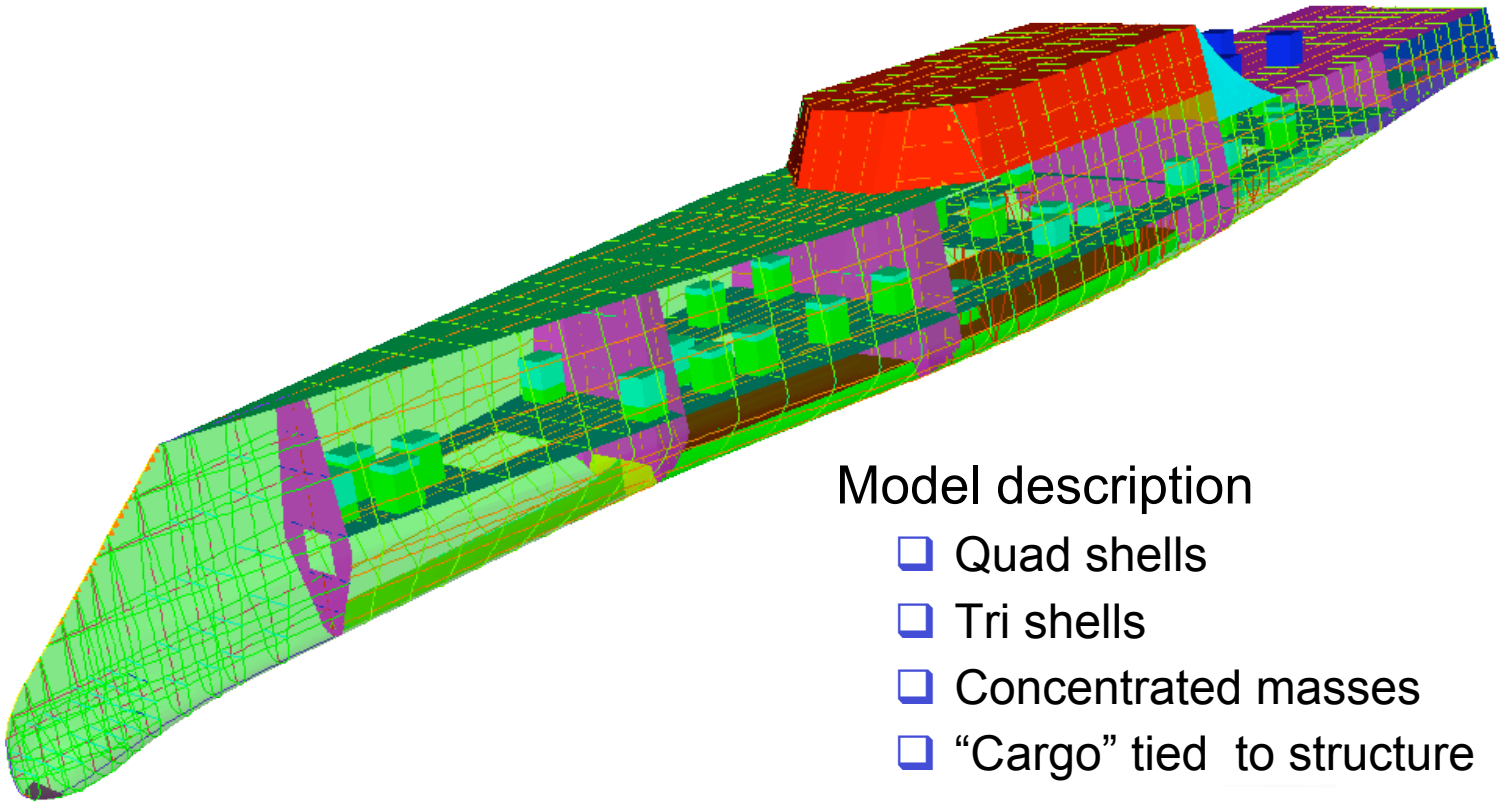
Barge/IFSP Validation Problem



Quarter scale (UHWM) Problem

Coupled Gemini-Presto simulation: underwater explosion

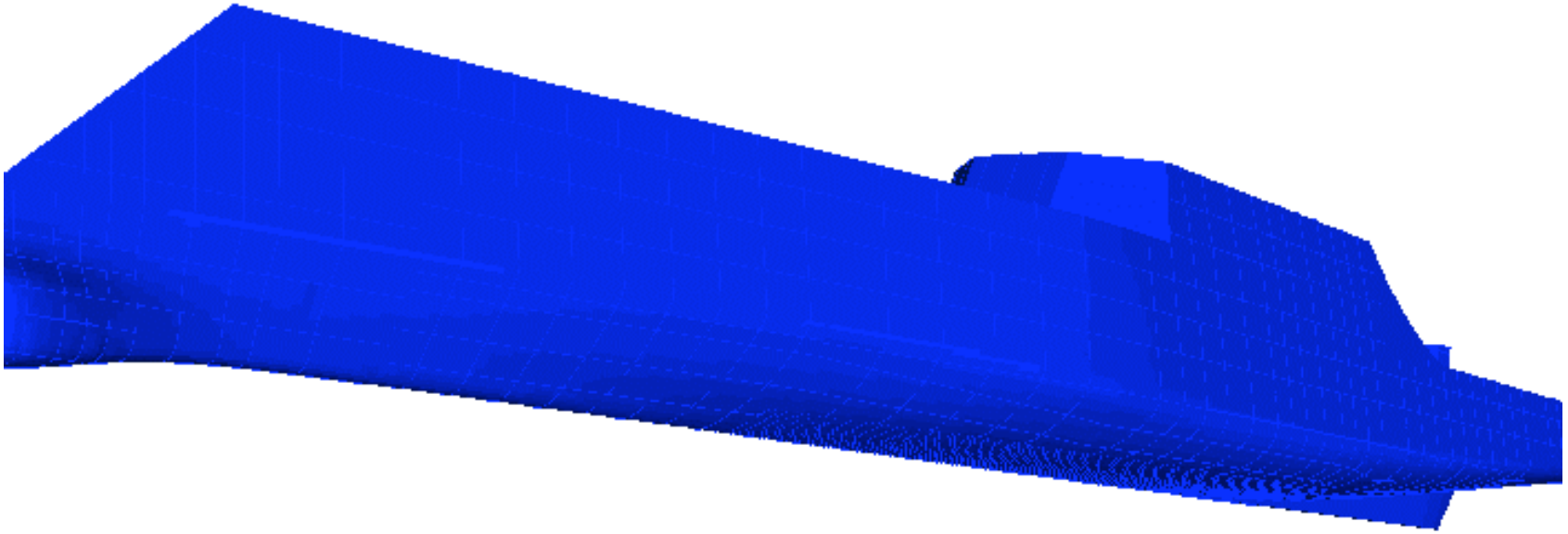
Progress so far: Presto model verified w/ uniform pressure below waterline



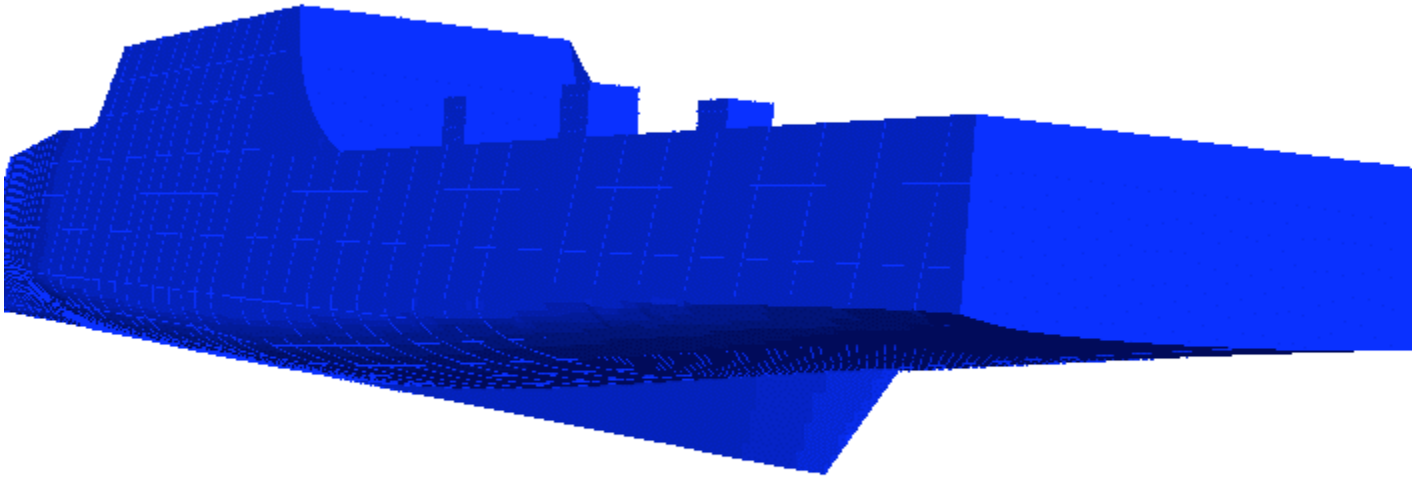
Model description

- Quad shells
- Tri shells
- Concentrated masses
- “Cargo” tied to structure

Quarter scale (UHWM) Problem
Presto-only results



Quarter scale (UHWM) Problem
Presto-only results



Navy Gemini-SIERRA training : August 19-20 in Albuquerque

Participants from NSWC/IH and NSWC/CD.

Hands-on training included the following topics:

- ❑ translating Nastran to Exodus using NASGEN
- ❑ running analysis using NESM
- ❑ visualizing results using Paraview

Documentation

- ❑ How-to use the SIERRA Gemini coupler

SIERRA mechanics support of Navy FSST : Summary

Coupled Gemini+Presto capability,

- ❑ Two-way coupling done

Enhance Presto for Navy ship models…

- ❑ Need to complete implementation of RBEs

…demonstrate on Navy FSST-ATS

- ❑ Hydrobulge, Huang cylinder done
- ❑ Barge/IFSP ready to compare w/ experimental results
- ❑ Need to run ¼ scale ship model (UHWM)

Could be of interest…

SIERRA_SolidMechanics failure modeling approaches

ASC FY08 Generalized Pervasive Failure Modeling

This milestone will focus on

- deployment of mesh independent element death approach embodied in the Multi-Linear Elastic Plastic Failure (MLEPF) material constitutive model.
- development and deployment of a dynamic element to particle conversion approach for failure modeling
- development and deployment of a Nodal-based Tet element w/ deformation induced remeshing
- development and deployment of dynamically activated/inserted cohesive surface elements for continuum hex and tet meshes.
- development and deployment of Explicit Control Modes (ECM) algorithm, a multi-scale dynamic modeling approach
- demonstrating material failure capabilities on a series of problems defined in an acceptance test suite.

ASC Pervasive Failure Modeling

Mesh independent element death

What is it?

- Material failure via element deletion
- Failure criterion is a material model state variable (e.g. MLEPF w/ tearing parameter, crack orientation, crack opening strain)

Usage guidelines

- Available for solid & shell elements
- Crack opening state variable must be tuned to mesh size
- Suitable only where mass deletion has negligible effect on solution
- Must use block skinning for contact w/ exposed surfaces

Benefits

- **Simplicity**
- Exposed surfaces included in contact

ASC Pervasive Failure Modeling

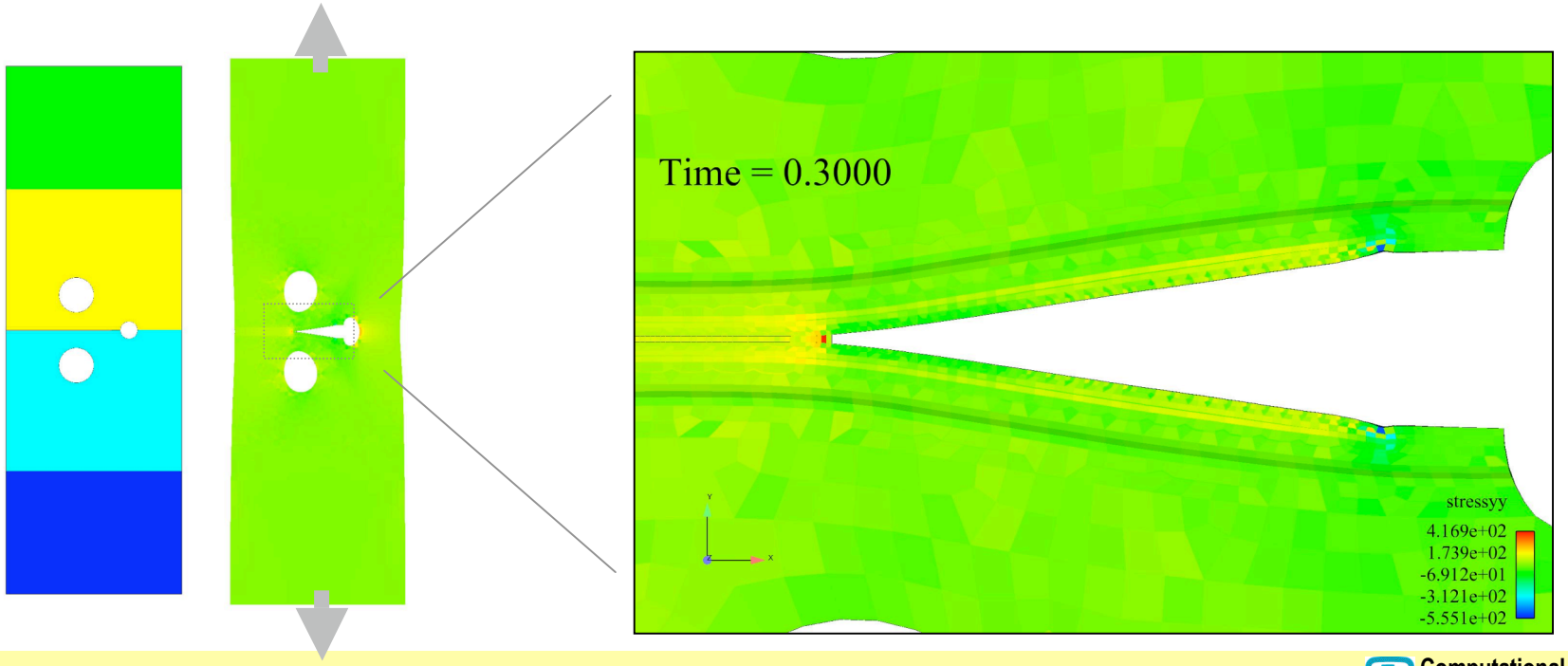
Mesh independent element death

Readiness

Tested on numerous problems in test suite:
wedge problem, 3-hole tension test, …

Further verification & validation needed !

Example (Multi-linear Elastic Plastic failure model)

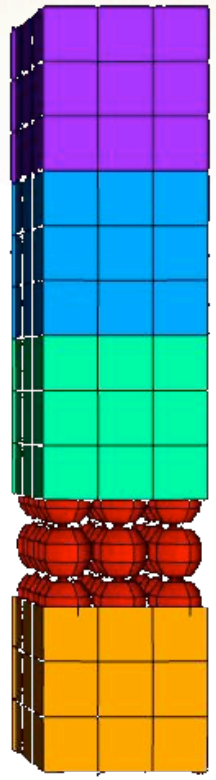


ASC Pervasive Failure Modeling

Element death to particle conversion

What is it?

Conversion of elements to mass or SPH particles upon reaching failure criterion



Usage guidelines

Available for solid & shell elements

Suitable where mass must be accounted for

Parallel rebalancing for computational efficiency recommended

User specifies contact interaction w/ particles by specifying a mesh around particle location

Benefits

No loss of mass

Failed material (particles) are able to cause secondary impacts

ASC Pervasive Failure Modeling

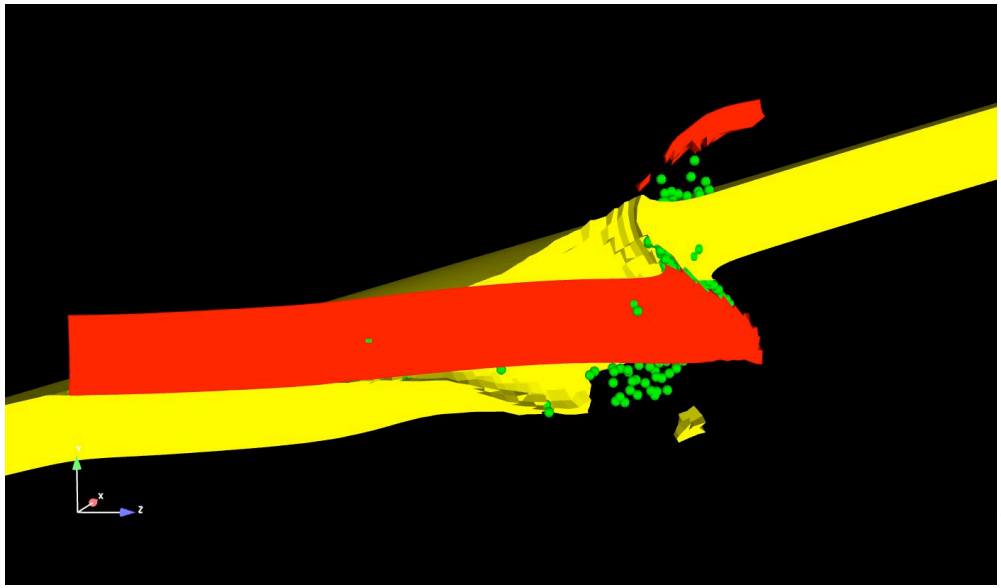
Element death to particle conversion

Readiness

Tested on numerous problems in test suite:
rod impacting plate, …

Robustness, performance/scalability, V&V study needed !

Example (conversion to SPH)

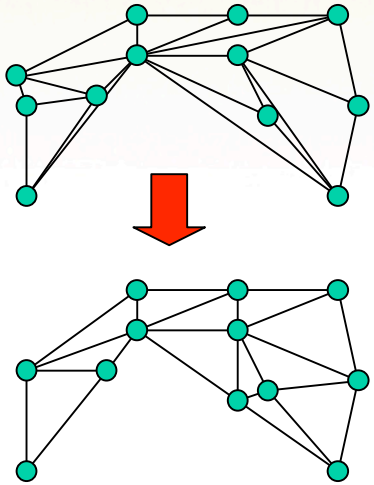


ASC Pervasive Failure Modeling

NBTet with remeshing

What is it?

Automated remeshing of tetrahedral topology with minimal state advection



Usage guidelines

Available for nodal-based tet elements only

Used w/ block skinning

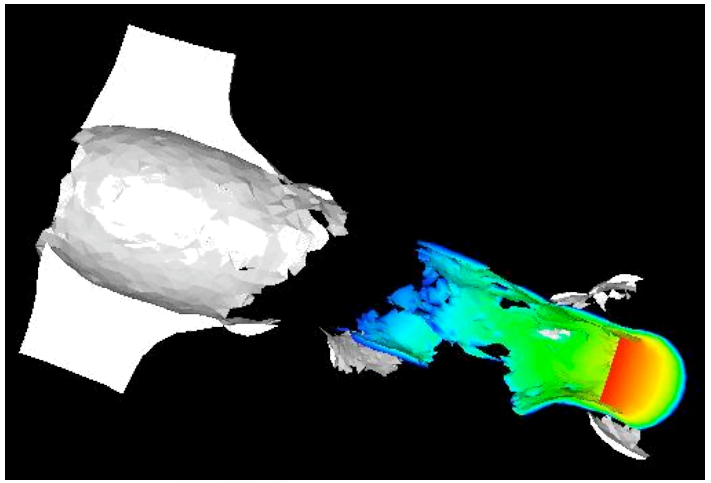
Topology repair currently sent to 1 processor

Frictionless and Coulomb friction

Benefits

Large deformation capability

Suitable for plastic flow w/ failure & fragmentation



Ballistic_penetration

ASC Pervasive Failure Modeling
NBTet with remeshing

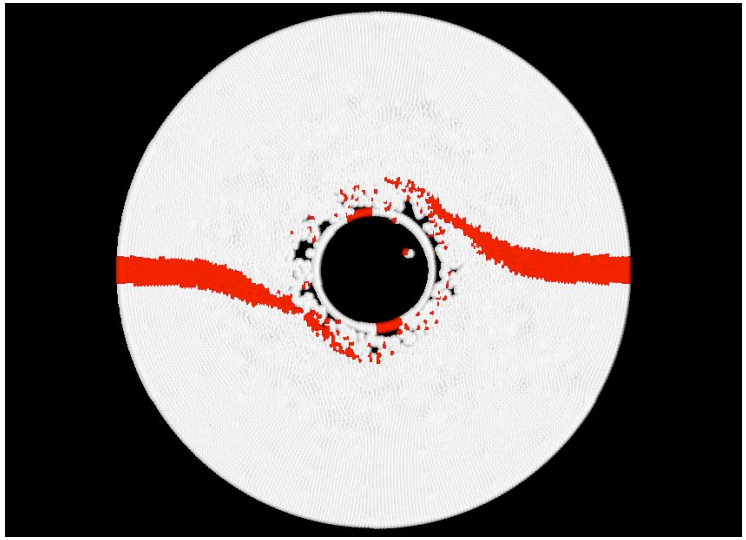
Readiness

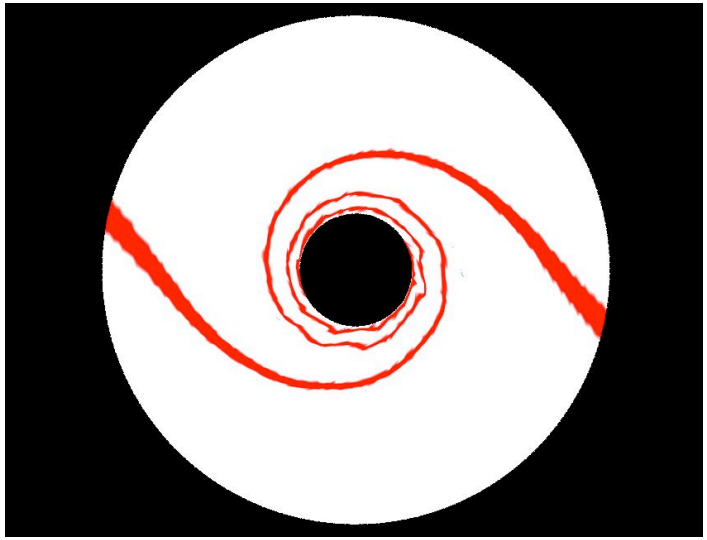
Tested on NBTet remeshing test suite
viscous disc, rod impacting plate, …

Parallel robustness, Performance/Scalability study, V&V needed !

Example (demonstrating benefit vs. SPH)

SPH





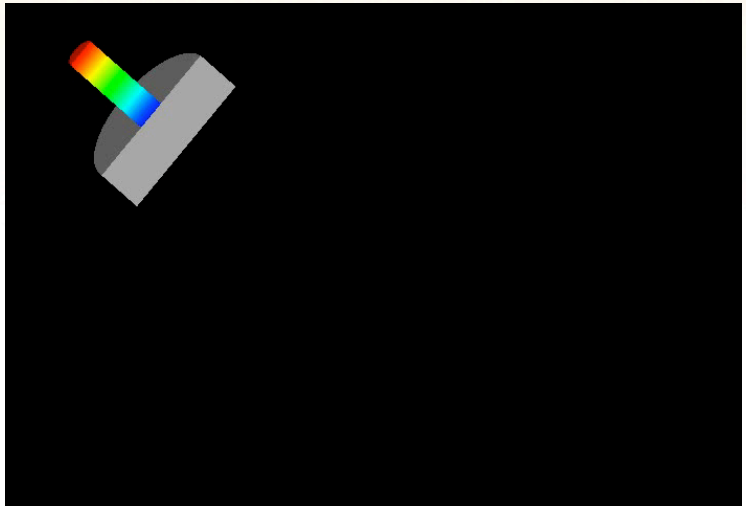
NB-Tet w/ remeshing

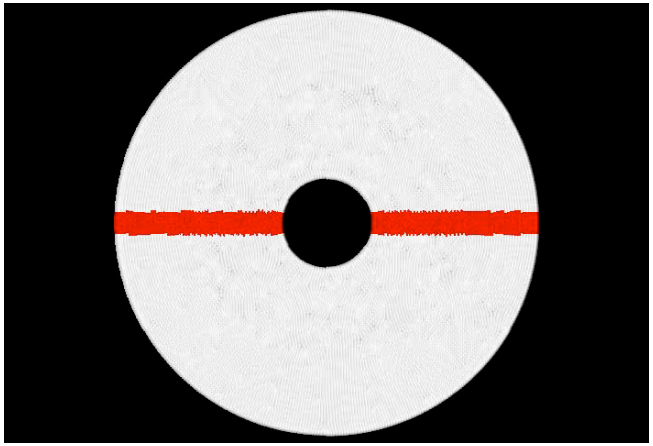
Viscous_disc

ASC Pervasive Failure Modeling

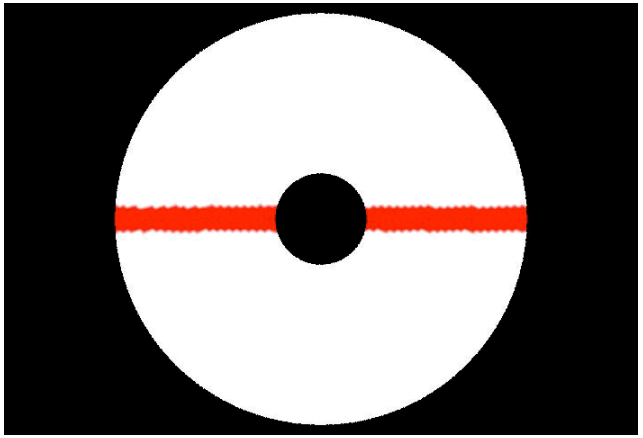
NBTet with remeshing

Rod Penetration





SPH



NBT

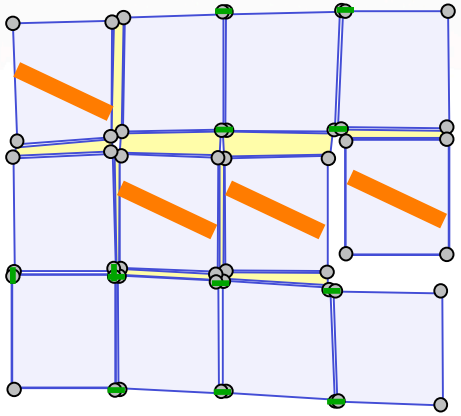
Viscous Disk

ASC Pervasive Failure Modeling

Dynamically inserted cohesive surface elements

What is it?

- Insertion/activation of CSE around failing elements upon reaching failure criterion
- CSEs dissipate element post-failure energy decay



Usage guidelines

- Used with hexes, tets, (not yet shells)
- Suitable where post-failure energy decay is important
- Best used when mesh follows crack orientation

Benefits

- **No loss of volume (mass) or its geometry**
- CSEs can be defined @ t=0 (intrinsic) capability or dynamically inserted as deformation dictates (extrinsic)

ASC Pervasive Failure Modeling

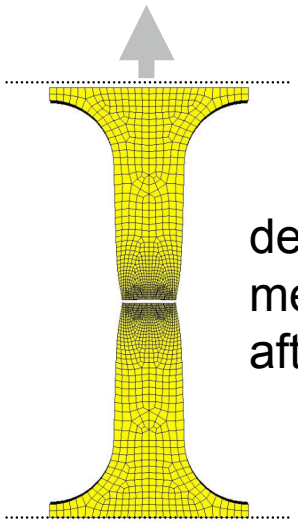
Dynamically inserted cohesive surface elements

Readiness

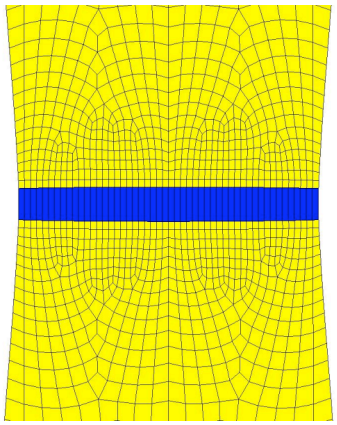
Tested on limited number of problems in test suite
dogbone specimen, 3-hole tension test

Extension to arbitrary fracture orientation, Parallel
robustness/performance/scalability study needed, V&V !

Example (intrinsic & extrinsic)



deformed mesh – just after failure



w/ Cohesive surface elements (shown in blue)

ASC Pervasive Failure Modeling

Explicit Control Modes

What is it?

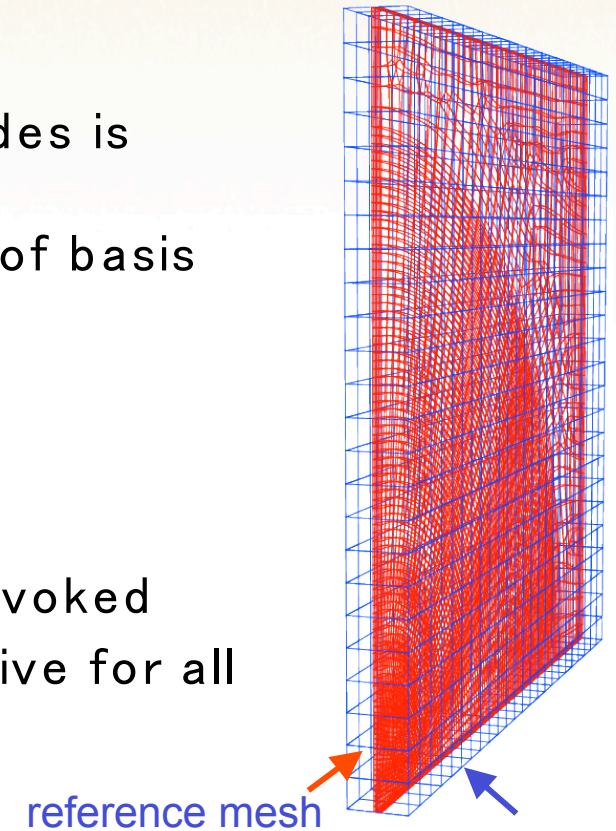
- A capability where a reduced set of modes is used to increase the stable time step
- A second (coarser) mesh used as a set of basis functions for filtering the residual

Usage guidelines

- Available for hexes & tets only
- Used w/ any of the 4 failure methods invoked
- Time step estimate not (yet) conservative for all contact problems

Benefits

- **Larger** explicit time step allowed
- Suitable for solutions w/ primarily low frequency content



ASC Pervasive Failure Modeling

Explicit Control Modes

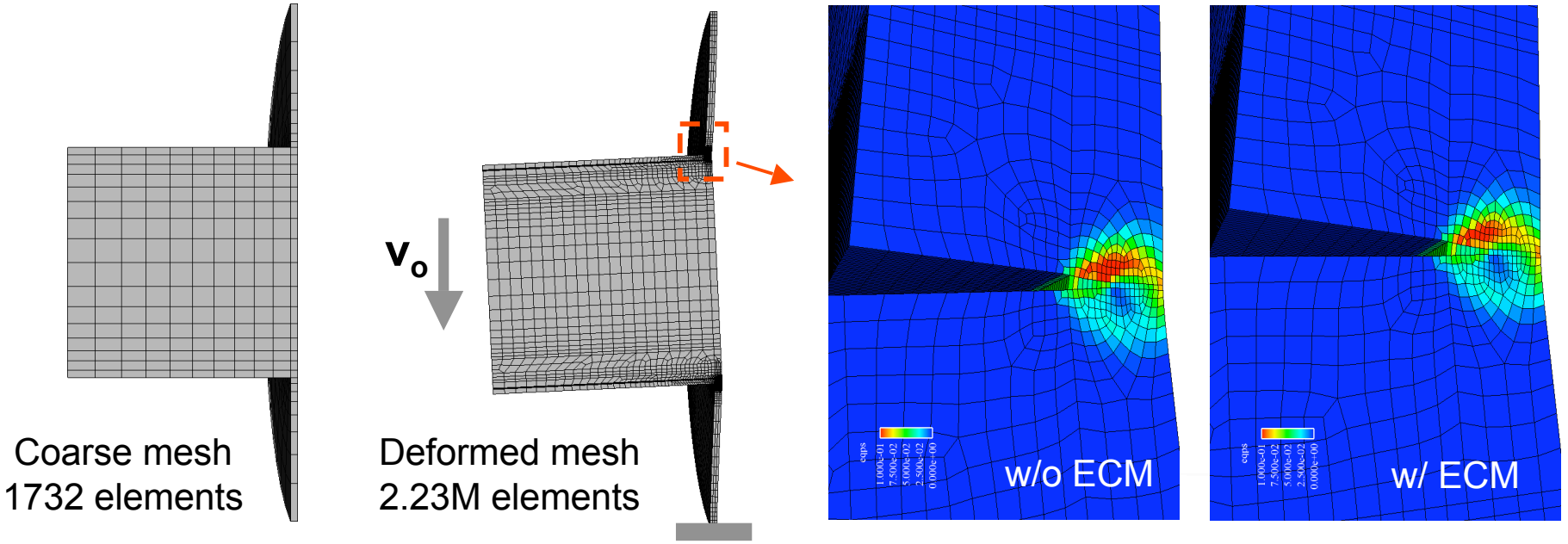
Readiness

Tested on a few problems in test suite
TSL laser weld problem, single panel problems, …

Contact problems need further development !

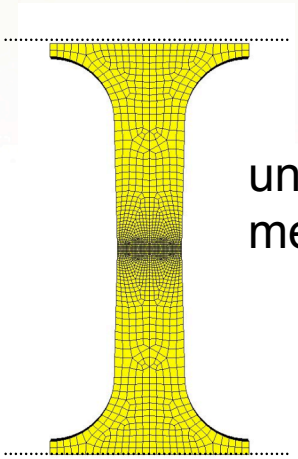
Example (200 procs, demonstrating 15x speedup)

Surrogate test for laser welds connecting TSL to fireset housing on W76-1

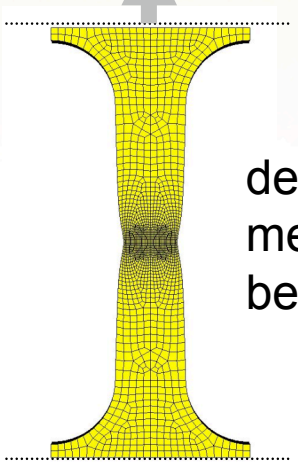


ASC Pervasive Failure Modeling

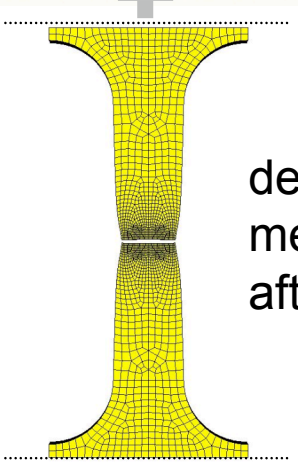
dogbone specimen results



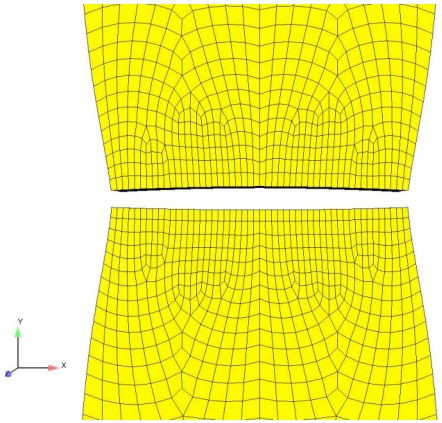
undeformed mesh



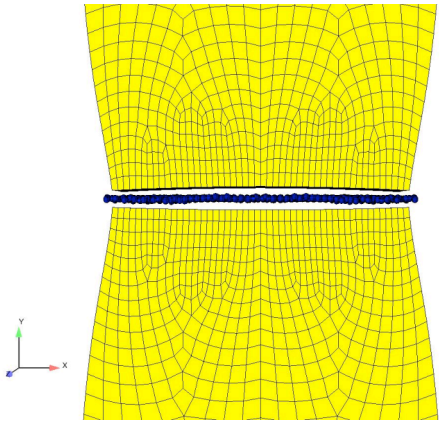
deformed mesh – just before failure



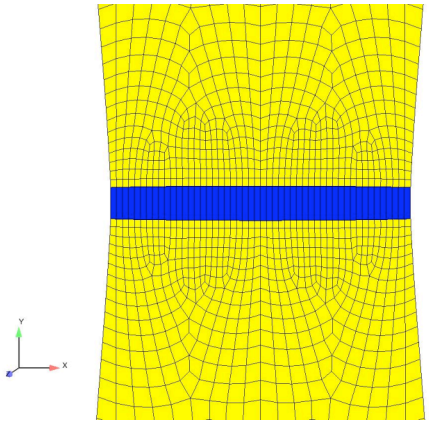
deformed mesh – just after failure



w/ Element Death



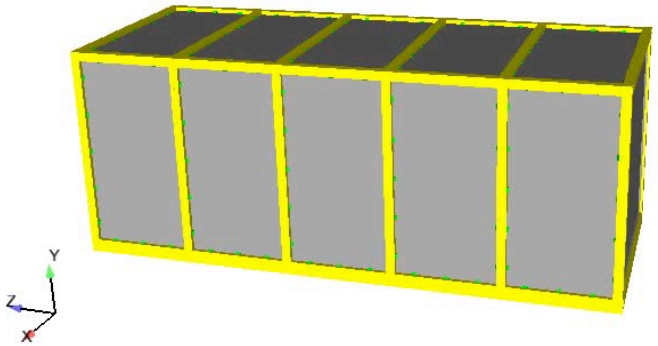
w/ Element to Particle conversion



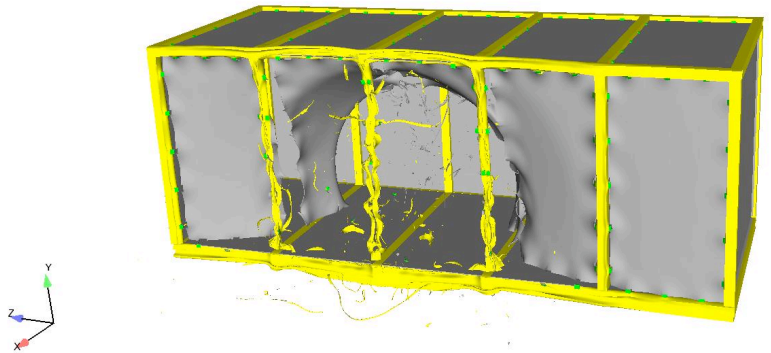
w/ Cohesive surface elements

5-Panel Box
3 hexes thru thickness, element death

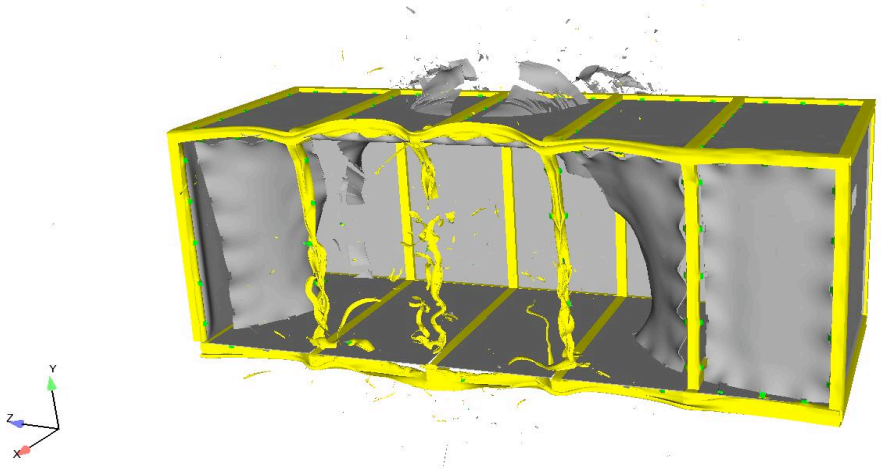
Time = 0.000000



Time = 0.00031

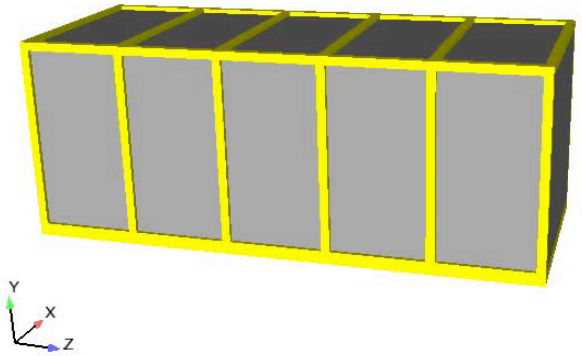


Time = 0.00048

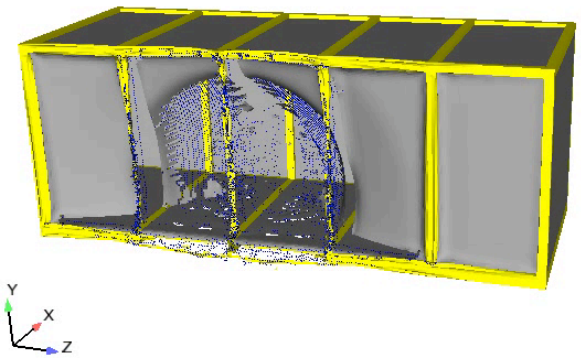


5-Panel Box
Shells, element death w/particle conversion

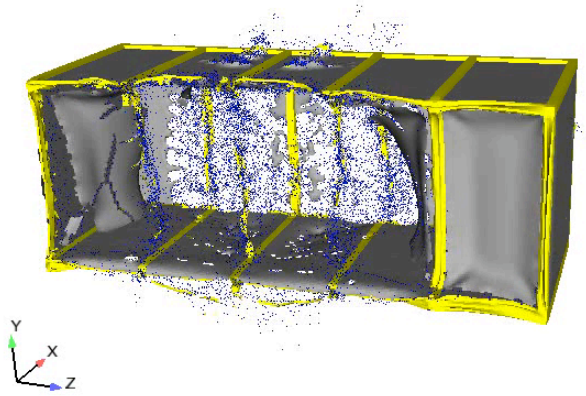
Time = 0.000000



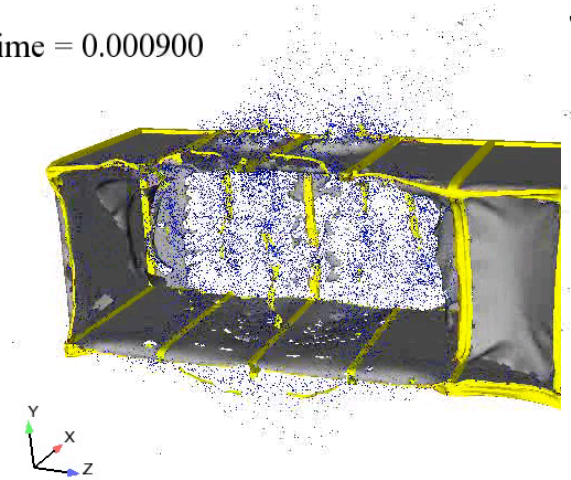
Time = 0.000300



Time = 0.000600



Time = 0.000900



Time = 0.003600