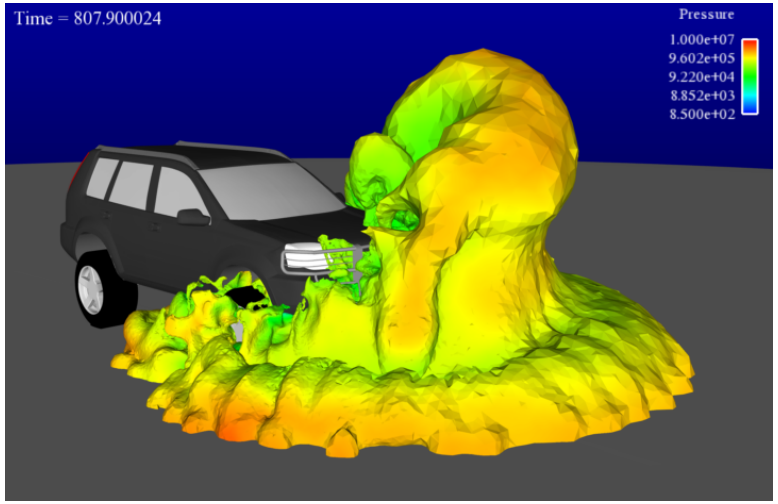
A Conformal, Fully-Conservative Approach for Predicting Blast Effects on Ground Vehicles



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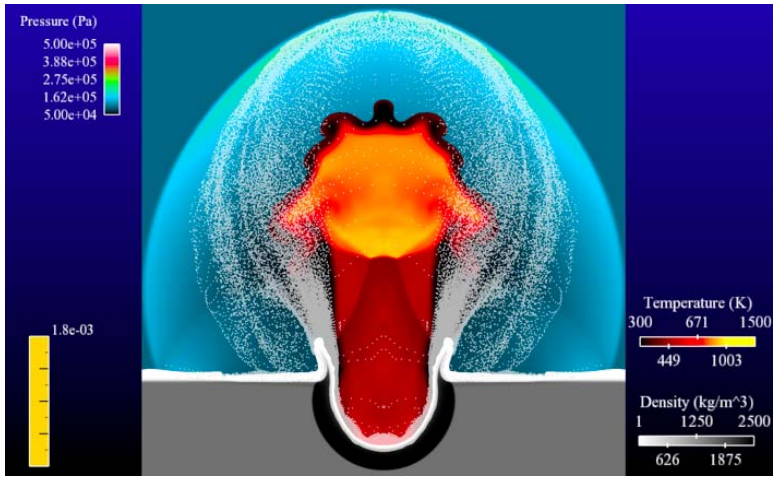


NATO AVT-221/RSM-032: Design and Protection Technologies for Land and Amphibious NATO Vehicles

Copenhagen, DK
Apr 7-9, 2014

Acknowledgements

- This material is based on work supported by the U.S. Army TACOM Life Cycle Command under Contract No. W56HZV-08-C-0236, through a subcontract with Mississippi State University, and was performed for the Simulation Based Reliability and Safety (SimBRS) research program. Any opinions, finding and conclusions or recommendations in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Army TACOM Life Cycle Command.

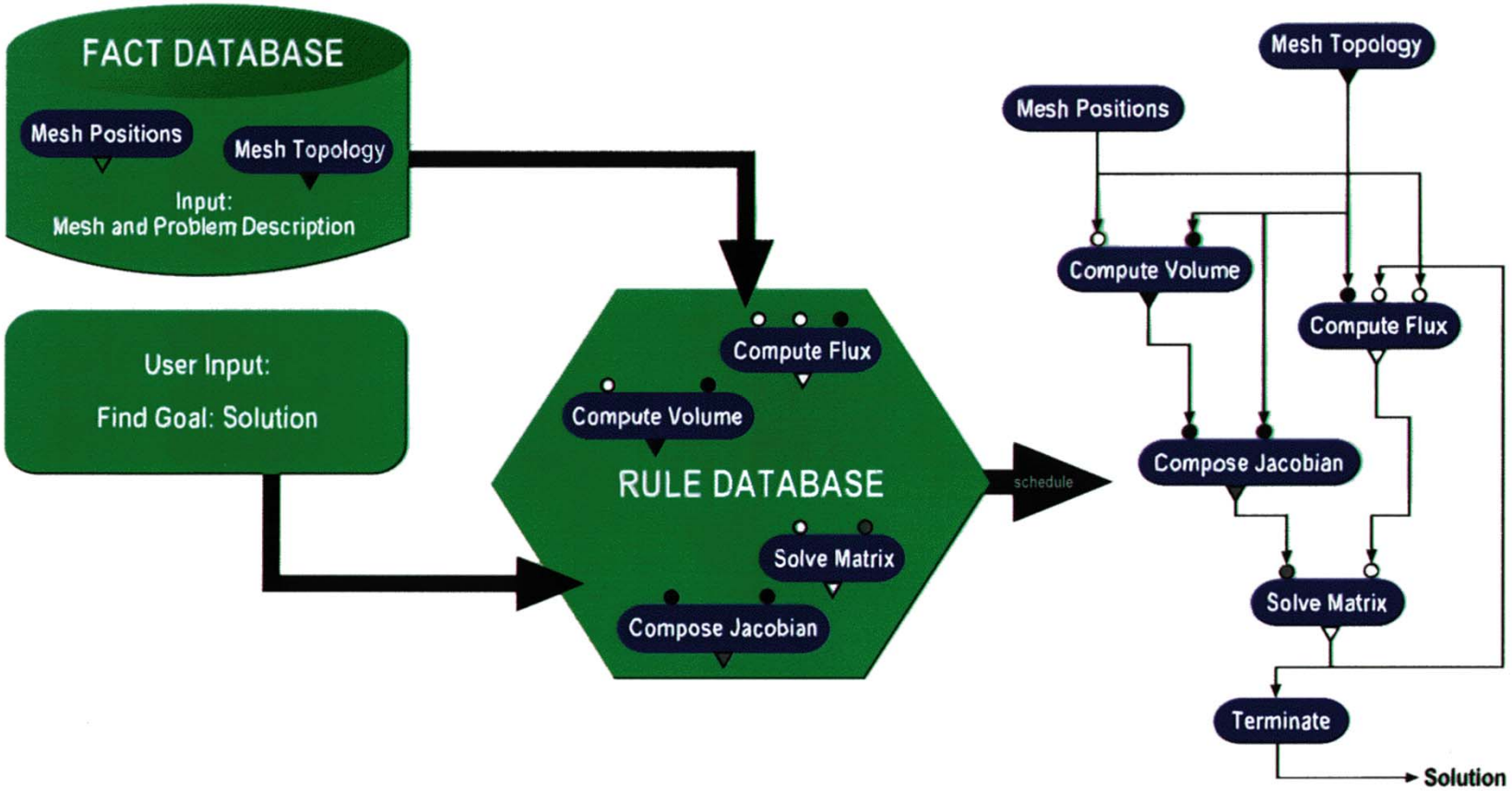
- Additional support was provided by the Dept. of Homeland Security under Department of Energy Interagency Agreement 43WT0301, Contract No. DE-AC05-00OR22725 as part of the DHS/DoE Southeast Region Research Initiative (SERRI) program.

Loci/BLAST: Overview

- Based on Loci multi-physics code development framework
  - Treats applications as relational databases of *facts* (irregular data) and *rules* (procedures that operate on the data)
  - Provides automatic code generation, parallelization, dynamic memory management and cache optimization
  - Lowers cost of developing complex multi-physics applications
- Loci/CHEM: Parent of Loci/BLAST
  - Highly-parallel, full-featured Eulerian CFD code for chemically reacting flow simulations
  - Used by NASA, USAF, Army and Gov't labs along with Boeing and several small aerospace companies
  - Extensive V&V using MMS

Loci Paradigm

- Define computational kernels as rules
  - Framework assembles rules into applications at runtime and schedules execution



Loci Rules Example

- Loci rules mimic mathematical notation
  - Parallelization occurs automatically as Loci operates on collections of entities

```
// Numerically solve the partial differential equation: ∂u/∂t = ν ∇ · ∇u
// Using Forward Euler time integration

// Set Initial Value:  u^{n=0} = u_initial
$rule pointwise(u{n=0}<-u_initial) { $u{n=0} = $u_initial ; }

// Forward Euler time-step:  u^{n+1} = u^n + Δt R^n
$rule pointwise(u{n+1}<-u{n},R{n},dt) { $u{n+1} = $u{n}+$dt*$R{n} ; }

// Define residual (diffusion operator):  R = ν div(grad(u))
$rule pointwise(R<-nu,div(grad(u))) { $R = $nu*$div(grad(u)) ; }
```

Loci Multi-Physics Framework

- Advantages:
  - AI detects bugs introduced by logically inconsistent specification of numerical models
  - Decouples computations from their mappings onto distributed data structures
  - Databases of rules become knowledge bases for composing increasingly complex simulations
  - Parallelization effort is greatly simplified and is automatic
  - Optimizes low level calculations for higher levels of cache use

Loci/BLAST Capabilities

- Cell-centered, finite-volume method for general polyhedral elements
  - Overset meshes with automated hole cutting
- 2nd-order TVD Runge-Kutta time integration
- Approximate Riemann Fluxes (HLLE, HLLC)
  - Robust mixture model for multi-material flows
- Multiple Equations of State
  - Perfect Gas
  - Novel tabular EOS based on Bezier surfaces
  - JWL EOS for explosive materials
  - Linear Barytropic EOS for solids
  - Multi-phase EOS for soils
  - Modified Tait EOS for water

Loci/BLAST Capabilities

- Coupled Lagrangian particle model for particulate flows
- Prescribed burn and ignition and growth reactive burn models for explosive detonation
  - Secondary combustion model for non-ideal explosives
- One-way and two-way coupling with LS-DYNA for Fluid-Structure Interaction (FSI) simulations
  - Conservative load transfer between Loci/BLAST and LS-DYNA
  - Robust deformation of CFD mesh in response to structural deflection
  - Simple socket protocol provides communication between the two applications

Loci/BLAST Soil Model

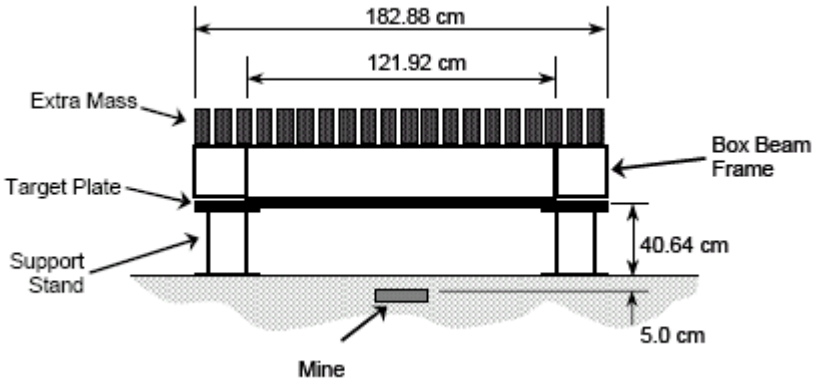
- Soil modeled as mixture of solids, water and air
  - Solids composed of organic mater, clay particles, and sand
    - Currently, solids have same elastic modulus as quartz
    - No material strength in current model
  - Water modeled using Modified Tait EOS
  - Air modeled as a perfect gas
  - Mixture mass fractions derived assuming that the soil pore volume can be determined from dry soil
  - Current model works best for dryer materials
- Soil model validated using mine impulse pendulum results

Underbody Blast Applications

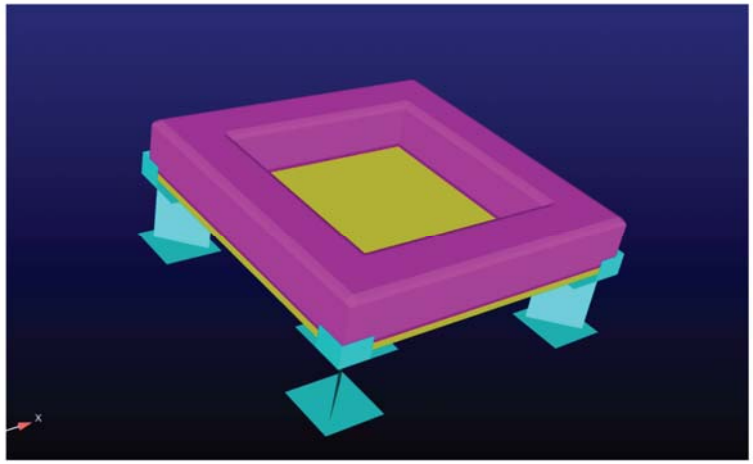
- Loci/BLAST-LS-DYNA two-way coupling validated using DRDC Plate experiment
  - DRDC plate deflections compared to results of Williams et al (7th International LS-DYNA Users Conference, 2002) for TACOM Impulse Loading model (Westline, 1972)
- TARDEC Generic Hull geometry used to verify coupling for realistic configurations
  - Qualitative results only

DRDC Plate Experiment

- Large weight used to restrict target
- 6kg C4 at 5 cm DOB
- 31.75mm thick AL5083-H131 target plate
- Soil density of 2300kg/m^3
- Various soil compositions tested
- Tabular EoS
- Johnson-Cook material strength inputs
- 4-noded Belytschko-Tsay shell elements
- 0.5 cm surface resolution



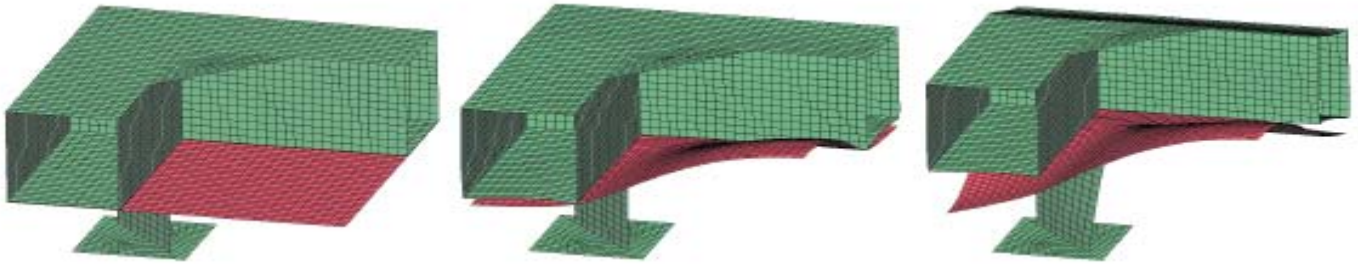
DRDC Experiment (Williams, 2002)



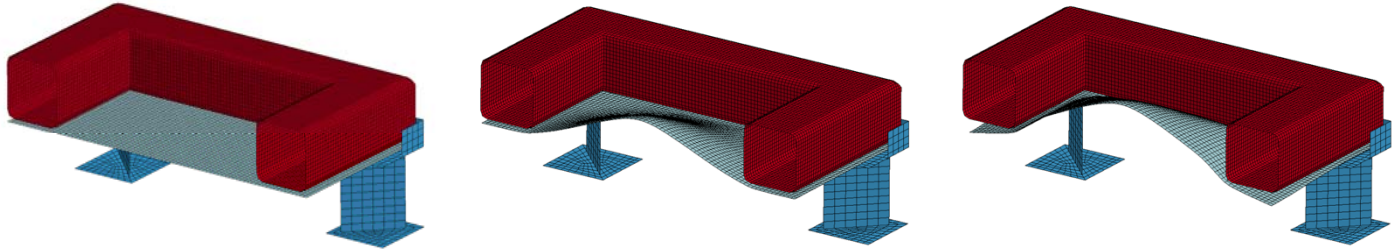
LS-DYNA Model

DRDC Plate Response

Initial t=1ms t=2ms

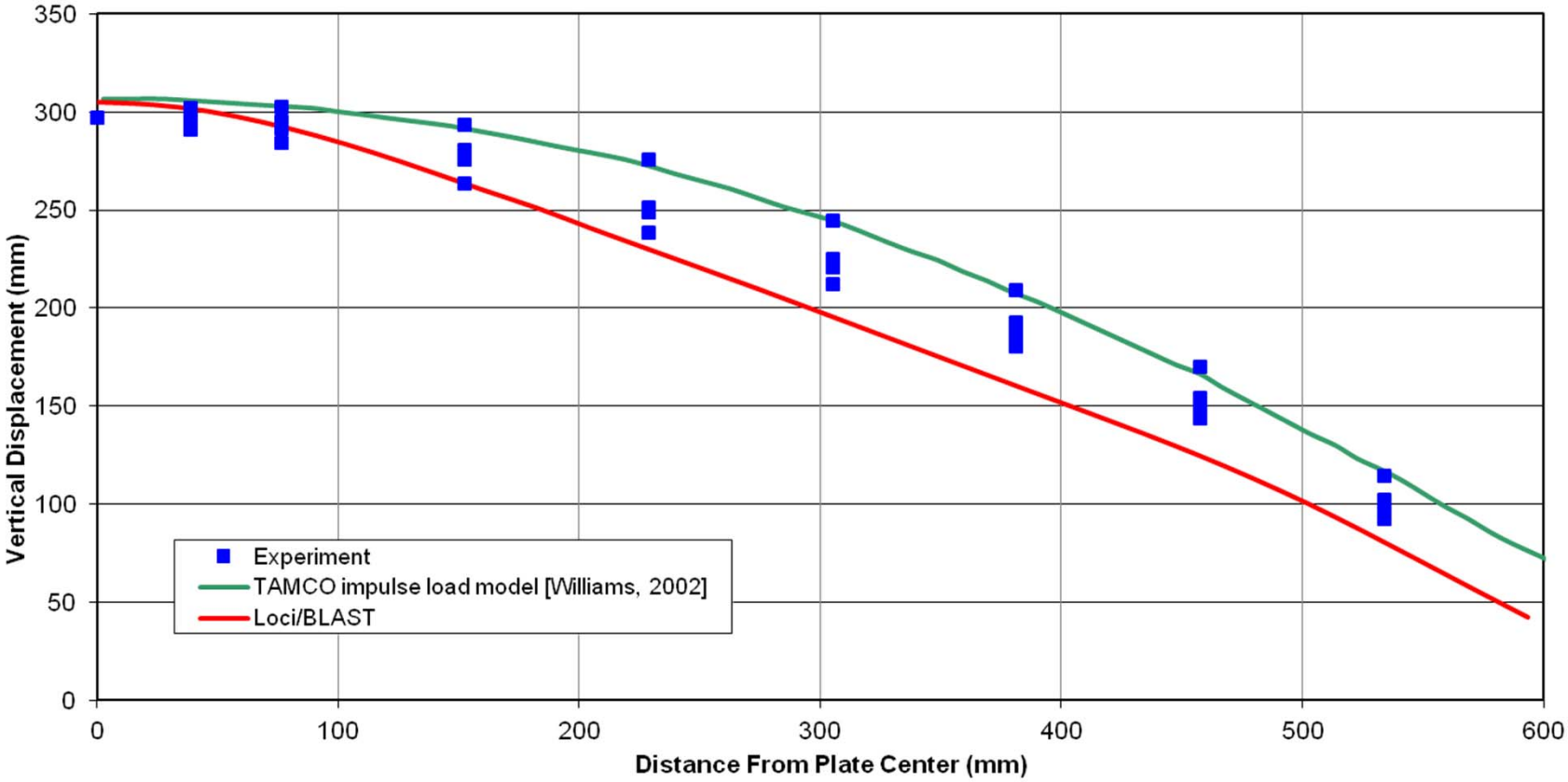


Williams (2002)



Loci/BLAST - LSDYNA

DRDC Plate Response



TARDEC Generic Hull

- Geometry represents a notional Army vehicle
- Test conditions:
  - Charge: 6kg cylinder of C4
    - STANAG 4569 Level 2 mine blast threat
  - 2 in DOB
  - Soil taken to be dry sand (70% quartz by volume fraction)
- Two way-coupled Loci/BLAST – LS-DYNA analysis
  - Conformal meshes
  - 192 Loci/BLAST processors, 1 LS-DYNA processor

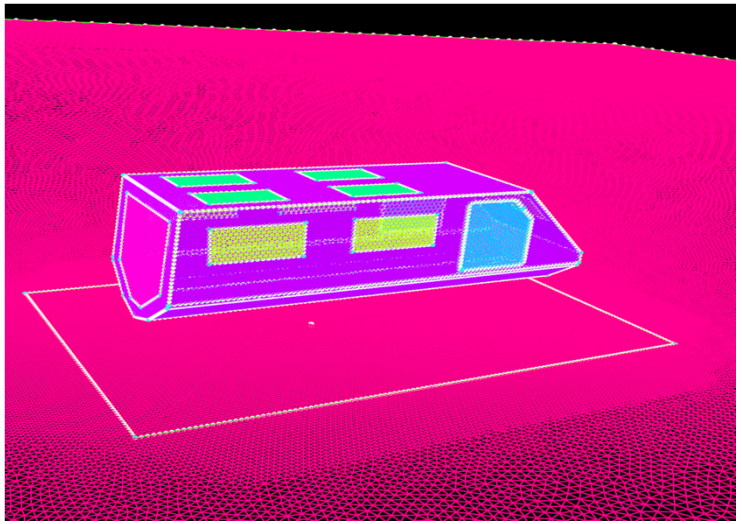
TARDEC Generic Hull

Three different near-body spacings used in CFD mesh:

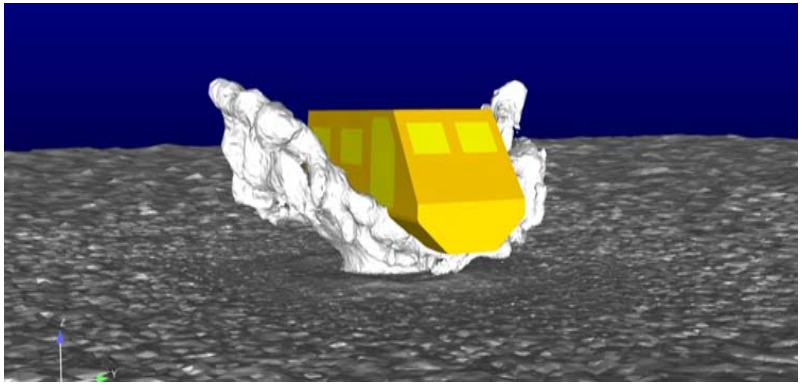
Coarse (5.0 cm – 12M cells)
Medium (2.5 cm – 29M cells)
Fine (1.25 cm – 57M cells)

Soil extends 3 ft below ground plane

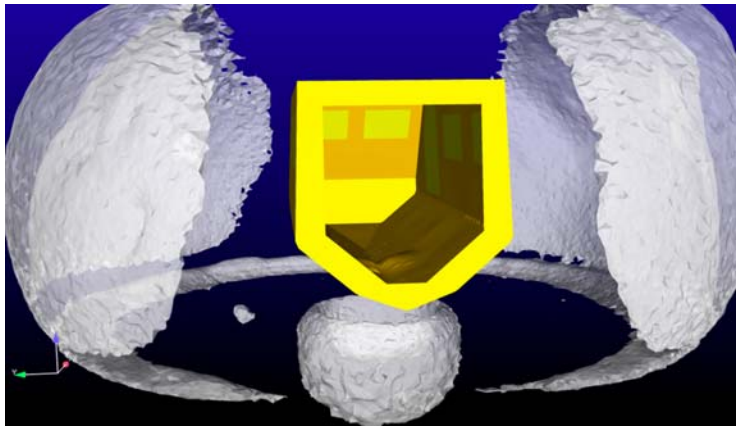
Simulation time = 5ms



Mesh

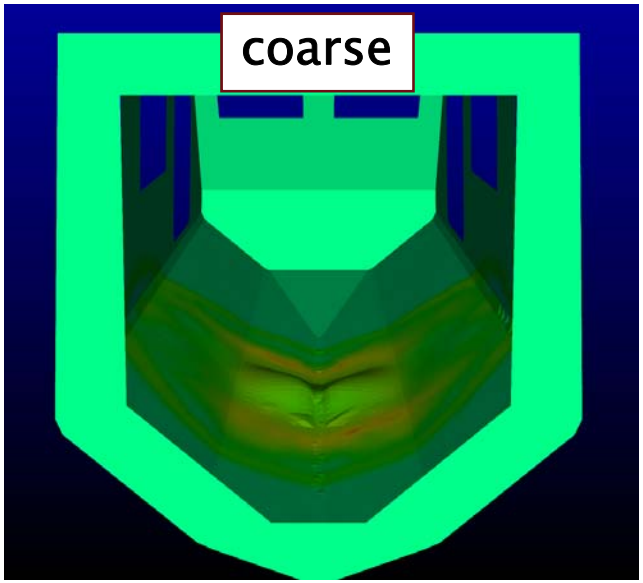


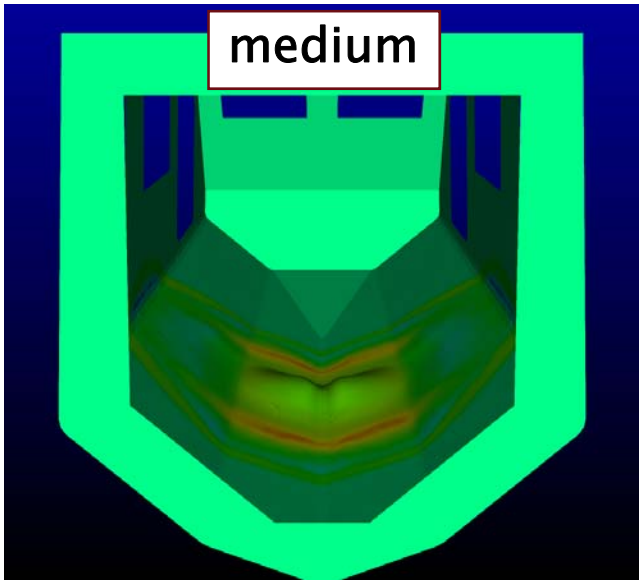
Soil volume fraction t=5 ms



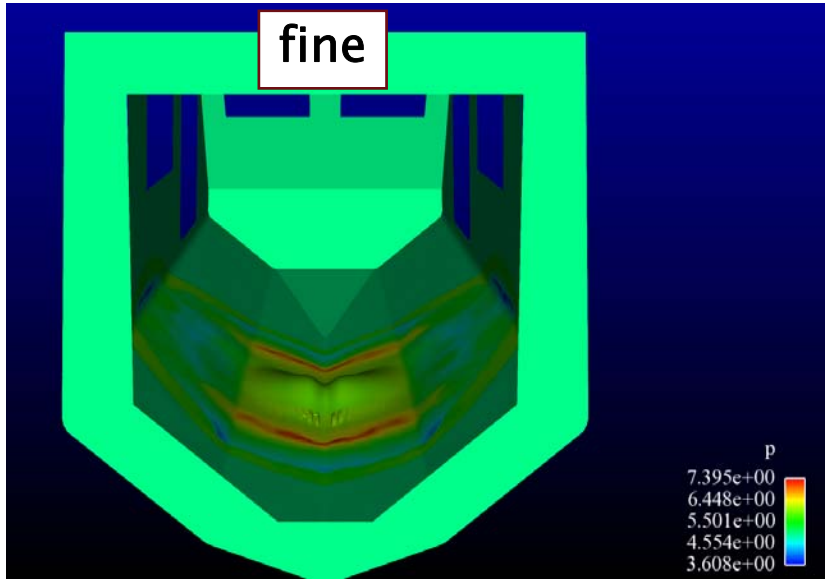
Blast front t=5 ms

Mesh Sensitivity: Hull Pressure

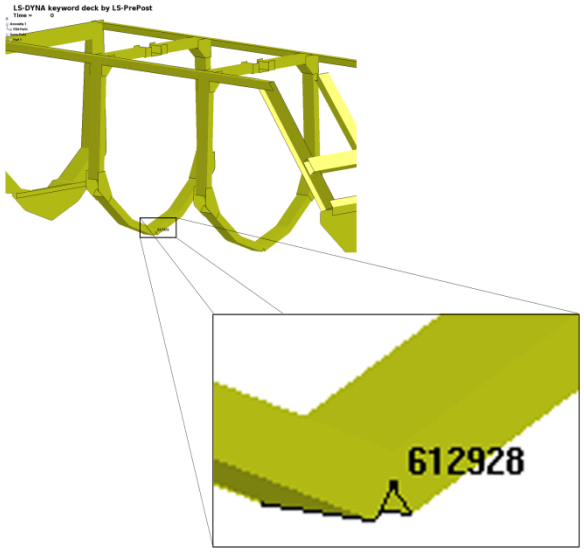


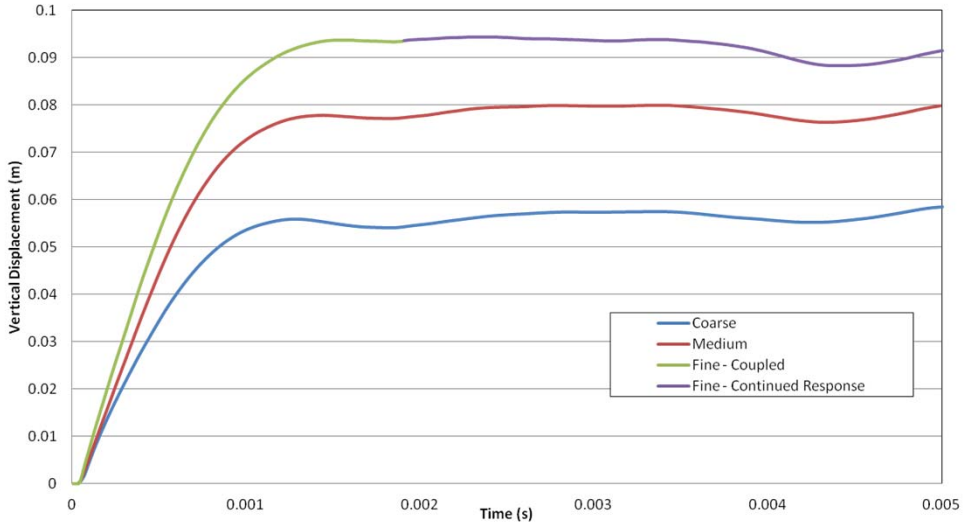


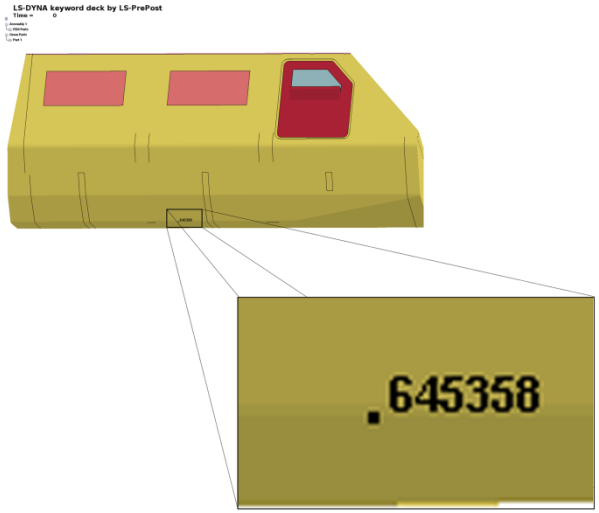
Log_{10} hull surface pressure -1ms

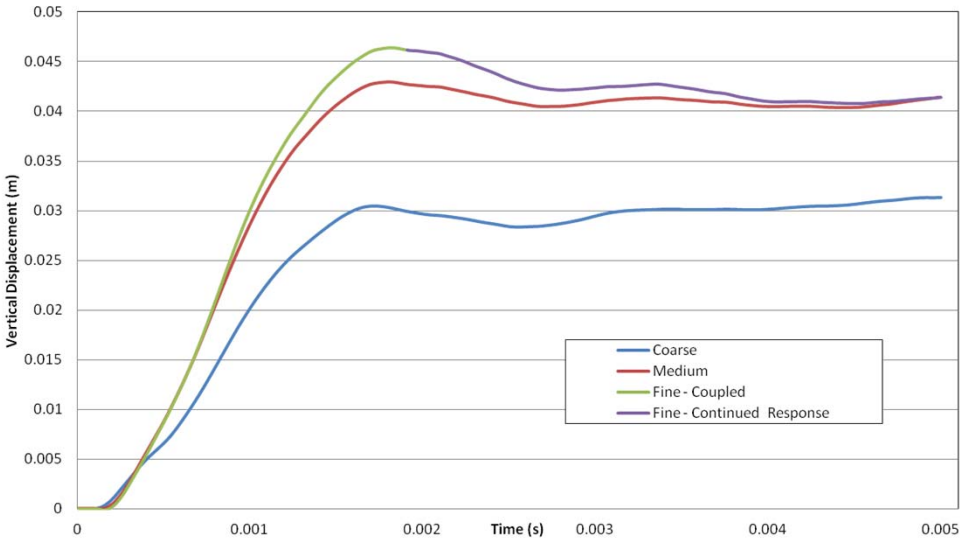


Frame and Hull Displacements

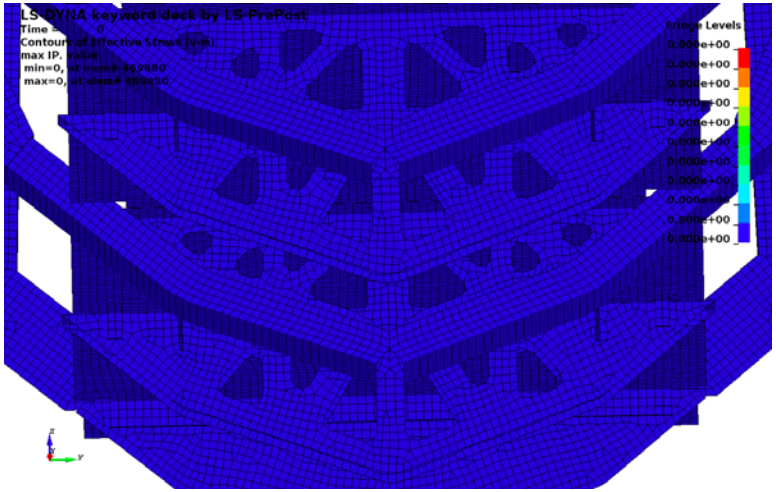




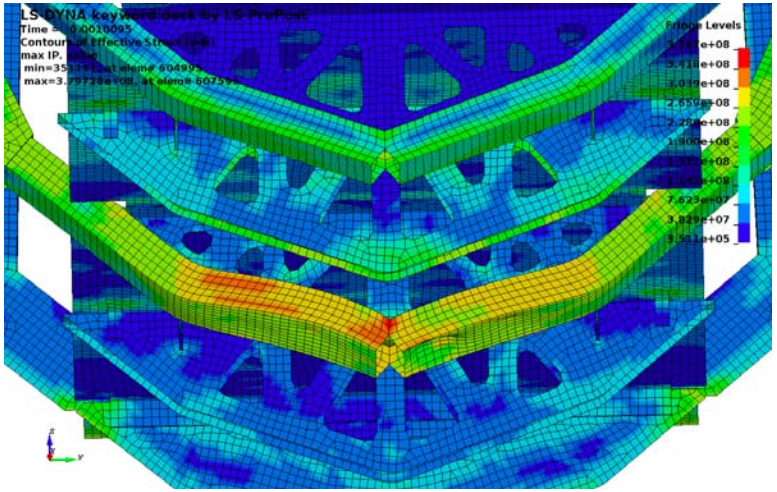




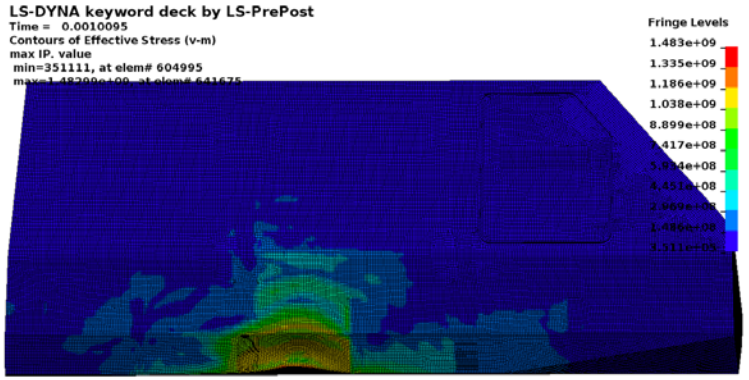
Frame and Hull Stresses t=1.5 ms



Initial frame configuration



Frame stress and deflection



Hull stress and deflection

Conclusions and Future Plans

- Loci/BLAST is a modern high-fidelity blast simulation tool with unique features not found in other codes
- Successfully applied the code to two-way coupled underbody blast simulations
  - Also blast in urban environments
- Future plans
  - Continue verification and validation efforts
  - Add adaptive mesh refinement
  - Build a native structural dynamics module using Loci framework that will tightly couple with CFD components

Availability

- Loci/BLAST and Loci/CHEM are licensed as open source software and are available free of charge. They are distributed using gpg encryption to approved users under U.S. ITAR restrictions.
  - http://www.simcenter.msstate.edu/software.php
- The Loci framework is open source and available from:
  - http://www.cse.msstate.edu/~luke/loci/
- Contacts
  - Ed Luke
    luke@cse.msstate.edu
  - David Thompson
    dst@cavs.msstate.edu
  - Richard Weed
    rweed@cavs.msstate.edu

Other Loci Applications

- Loci/CHEM: Chemically reacting compressible flow solver.
  - Currently in production use by NASA for the simulation of rocket motors, plumes, and vehicles
- Loci/DROPLET: Eulerian and Lagrangian multiphase solvers
- Loci/STREAM: pressure-based solver
  - Developed by Streamline Numerics and University of Florida
- Loci/FemLib: Finite-element linear elasticity thermal stress solver
  - Developed by the Cornell Fracture Group
- Loci/Radiation model: CA-DOM non-gray radiation modeling
  - Developed in collaboration with CFDRC
- The Loci/THRUST: High-Order Discontinuous Galerkin Navier-Stokes Solver
- Various multidisciplinary simulation tool created by composing the above solvers