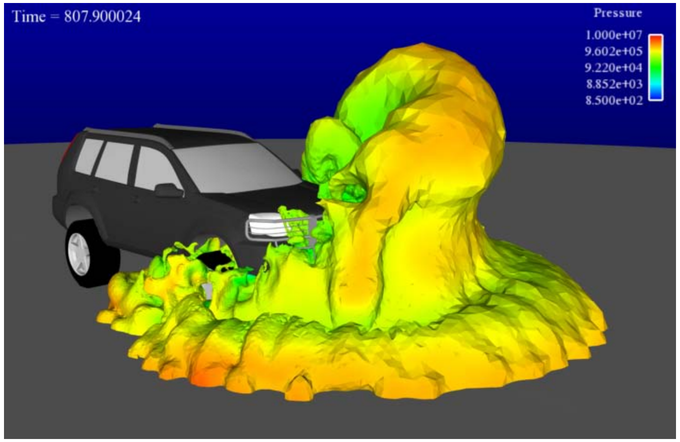
Analysis of Underbody Blast and Blast in Urban Areas Using the MSU Loci/BLAST Code



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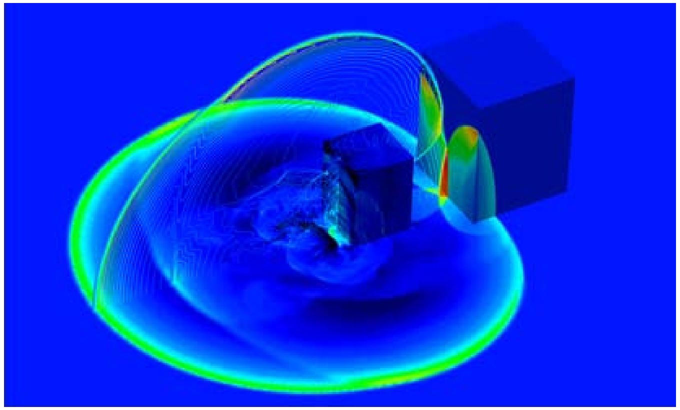
Center for Advanced Vehicular Systems (CAVS)
Mississippi State University

Jian Kang
U.S. Army TARDEC



NDIA Physics Based Modeling in Design and Development for U.S. Defense

Denver, Colorado
November 6, 2012

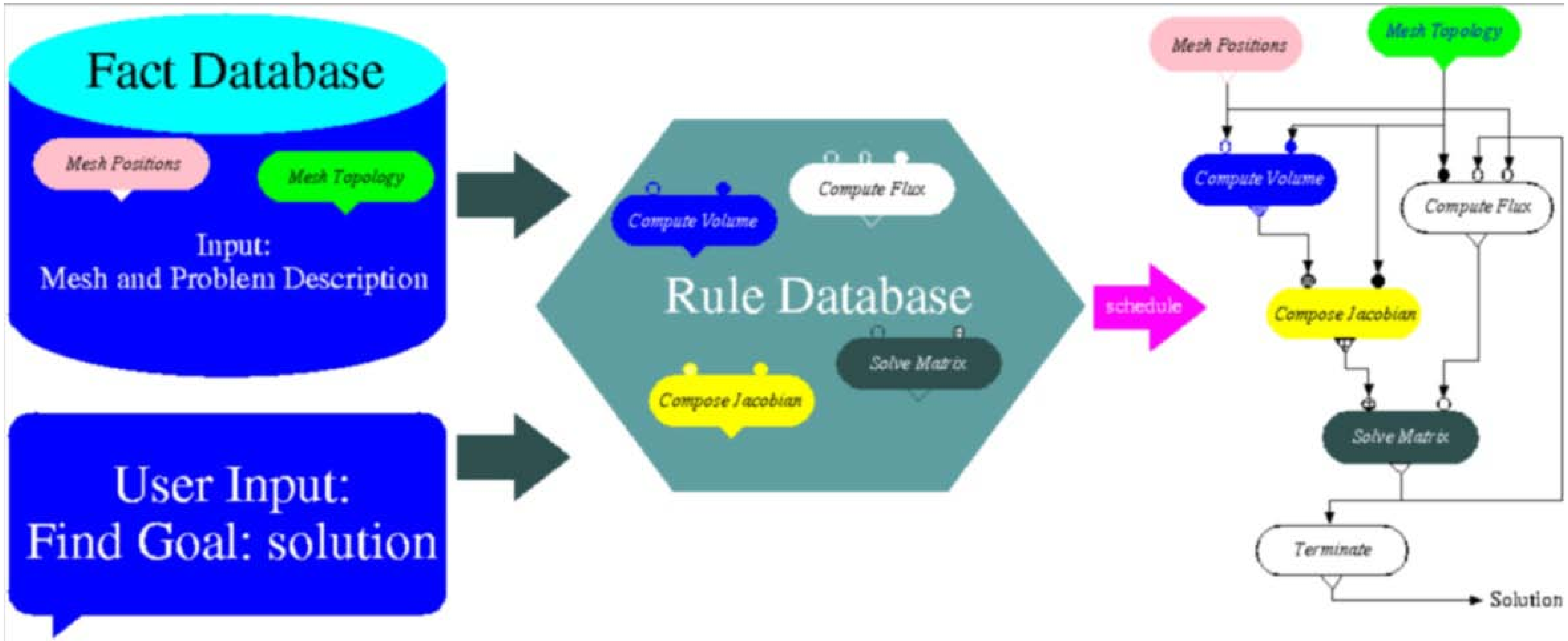
Loci/BLAST: Overview

- 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
    - Demonstrated scalability to 1000s of processors/cores
  - Lowers cost of developing complex multi-physics applications
- Derivative of Loci/CHEM
  - Highly-parallel, full-featured Eulerian CFD code for chemically reacting flow simulations
  - Loci/CHEM is a major production simulation tool used by NASA, USAF, Army and other Gov't labs along with Boeing and other small aerospace companies
- Loci/BLAST developed over the past four years under TARDEC and DHS/SERRI funding

Loci Multi-Physics Framework

- Developers define computational kernels as rules
- Framework assembles rules into applications at runtime and schedules execution
- Advantages:
  - AI features 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 for most cases automatic
  - Optimizes low level calculations for higher levels of cache use

Applications as Knowledge Repositories



Loci Rules Example

- Loci rules mimic mathematical notation

```
// 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 + ΔtR^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/BLAST/CHEM: 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
- Mesh deformation and multi-body 6 DOF modeling
- 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/CHEM: Capabilities

- 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 ABAQUS and LS-DYNA for Fluid-Structure Interaction (FSI)
- Coupled Lagrangian particle model for particulate flows
- Extensive V&V using Method of Manufactured Solutions and comparisons with experiment and other codes.
- Demonstrated parallel scalability to ½ billion cells and 3000 processors on large HPC systems

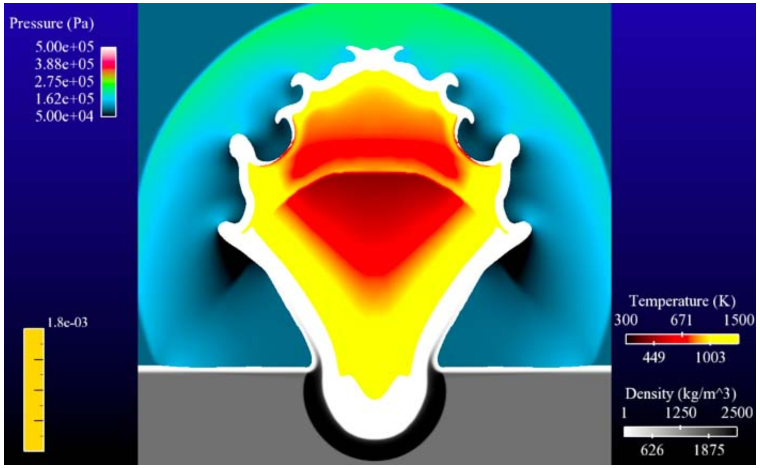
Underbody Blast Applications

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

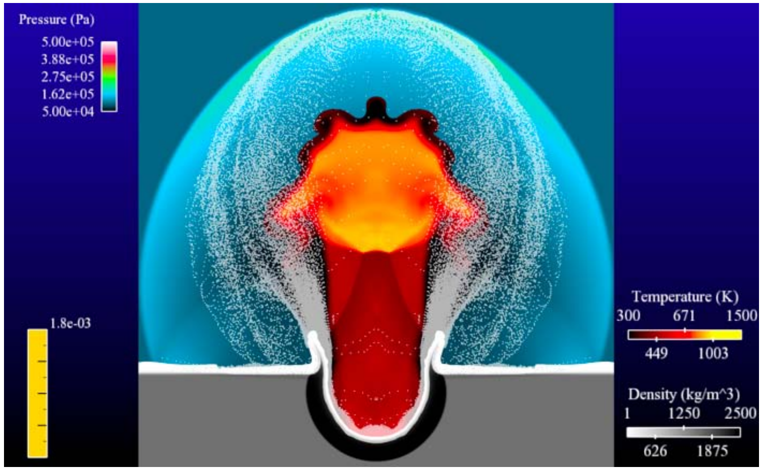
Loci/BLAST Soil Model

- Soil modeled as mixture of solids, water and air
  - Solids composed of organic mater, clay particles, and sand. Component properties not well characterized. Present study assumes solids have same elastic modulus as quartz.
  - Water modeled using Modified Tait EOS
    - Supports broad range of pressures including cavitation regions
  - Air modeled as a perfect gas
  - Mixture mass fractions derived from the assumption that the soil pore volume can be determined from dry soil, as moisture is added assume air is replaced by water
  - Supports both single phase and multi-phase models
    - Multi-phase model uses Lagrangian particle model for soil fragments
- Current model works best for dryer materials
- No material strength in current model

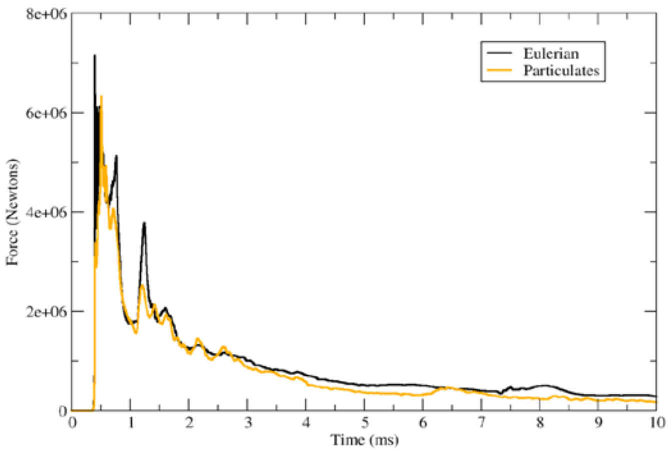
Soil Model Results



Single Phase T=1.8ms



Multi-phase T=1.8ms

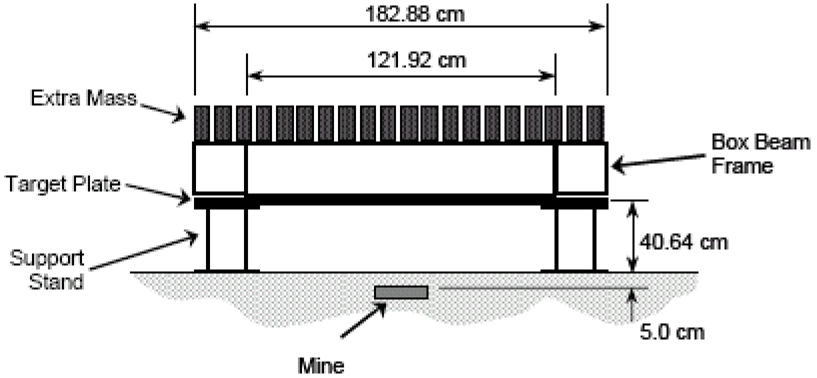


Impulse Pendulum Results

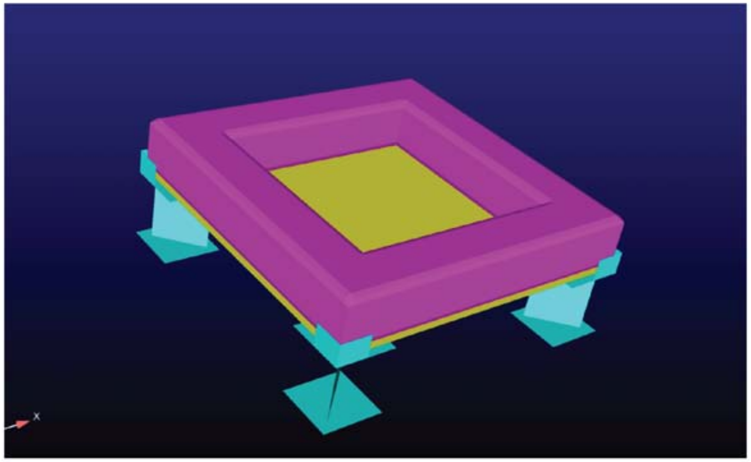
DRDC Plate Experiment

- 6kg C4 at 5 cm DOB
- 31.75mm thick AL5083-H131 target plate
- Soil density of 2300kg/m^3

- Large weight used to restrict target
- 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)

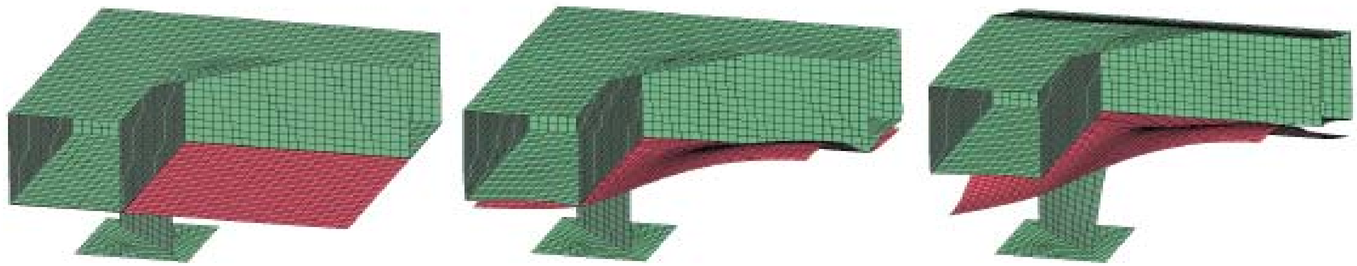


LS-DYNA Model

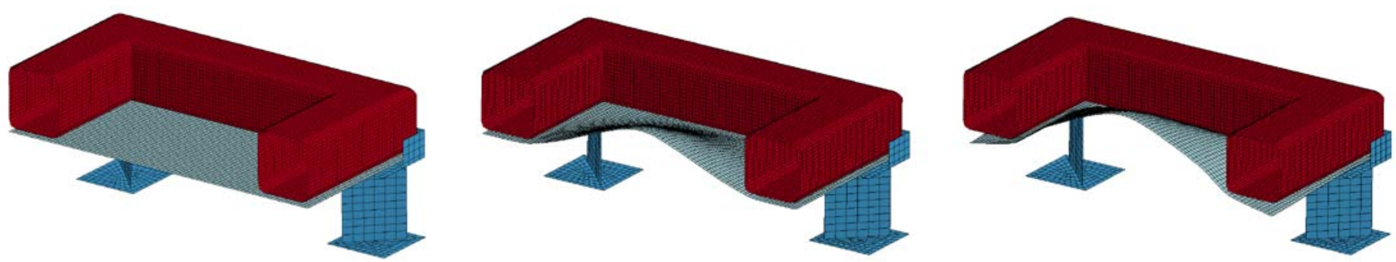
DRDC Plate Response Comparison

	Initial	1ms	2ms

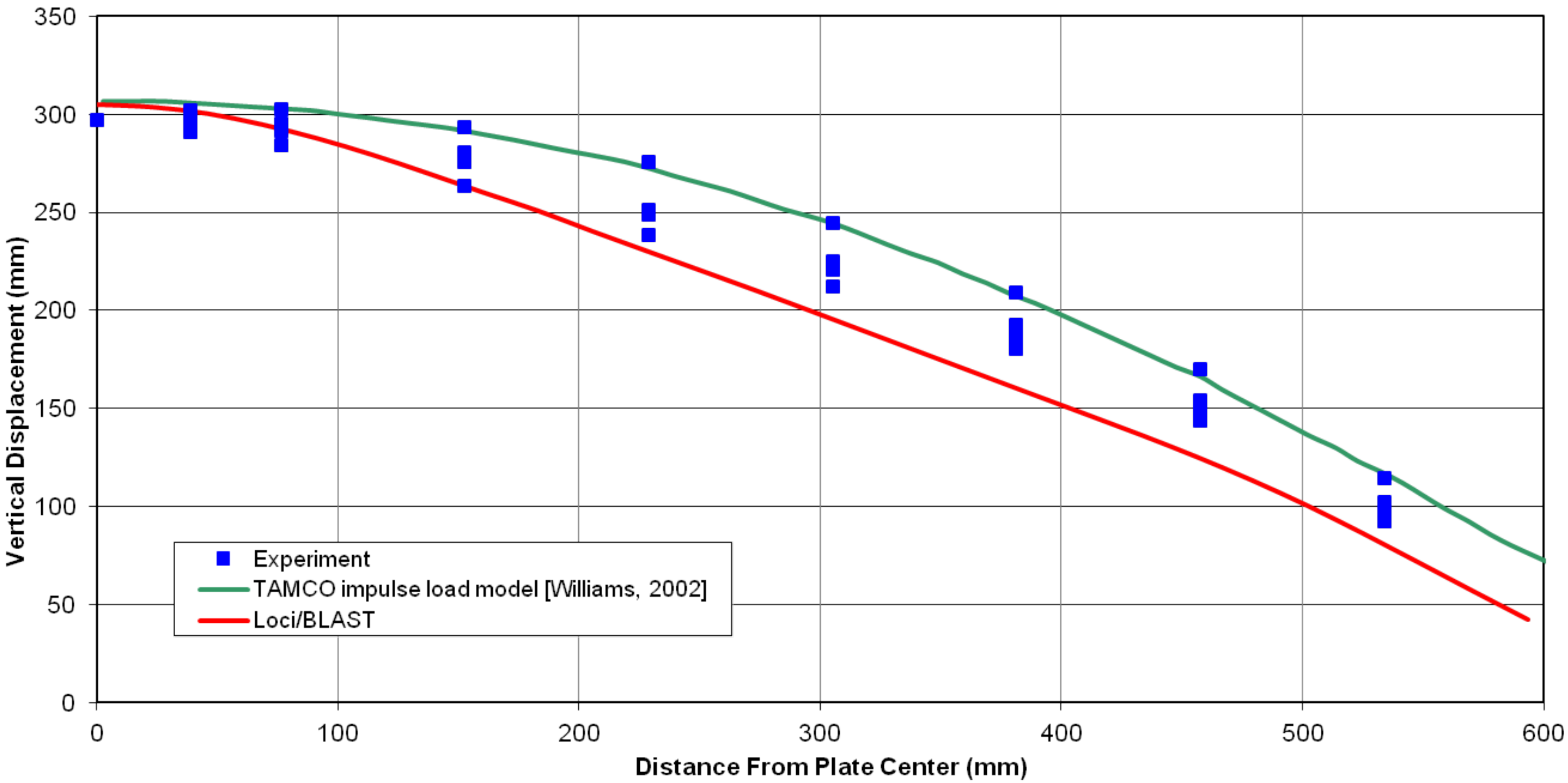
Williams (2002)



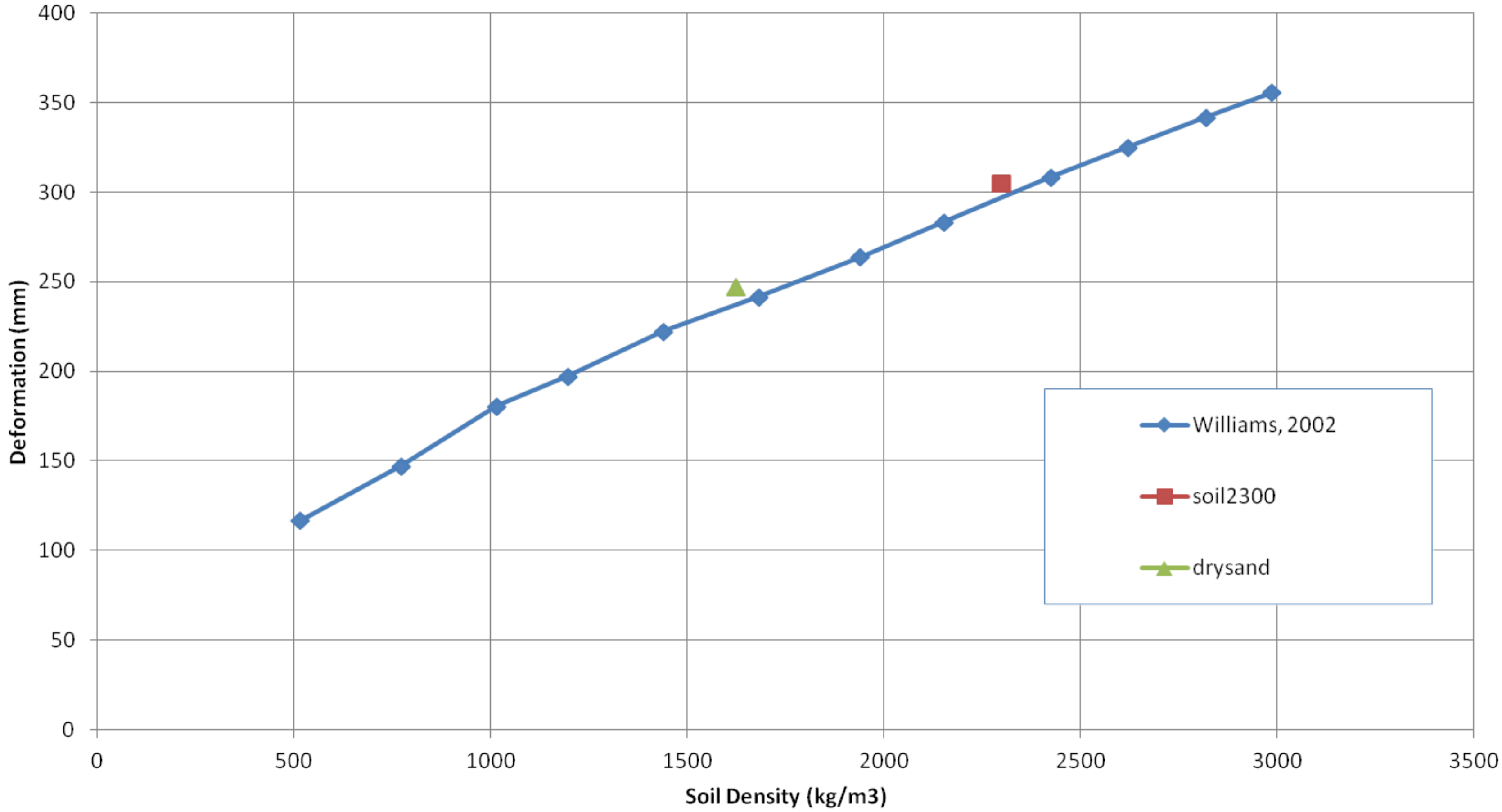
Loci/BLAST - LSDYNA



DRDC Plate – Vertical Displacement



DRDC Plate – Soil Density Effects



TARDEC Generic Hull Simulations

- Geometry represents a notional Army vehicle
- Test conditions:
  - Charge: 6kg cylinder of C4
    - STANAG 4569 Level 2 mine blast threat
      - (see wikipedia.org/wiki/STANAG_4569)
  - 2 inch DOB
  - Soil taken to be dry sand (70% quartz by volume fraction)
- Two way coupled Loci/BLAST – LS-DYNA analysis
  - Conformal meshes (1 to 1 match of CFD and CSM meshes)
  - 192 Loci/BLAST processors – 1 LS-DYNA processor

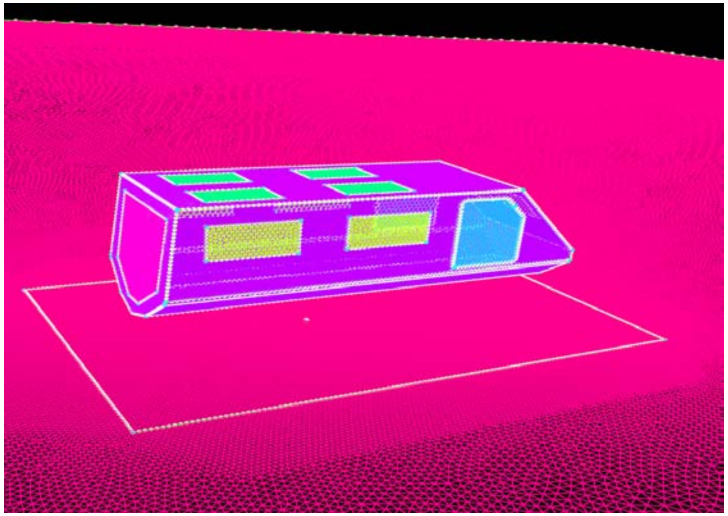
TARDEC Generic Hull FSI

Three different near body mesh spacings used

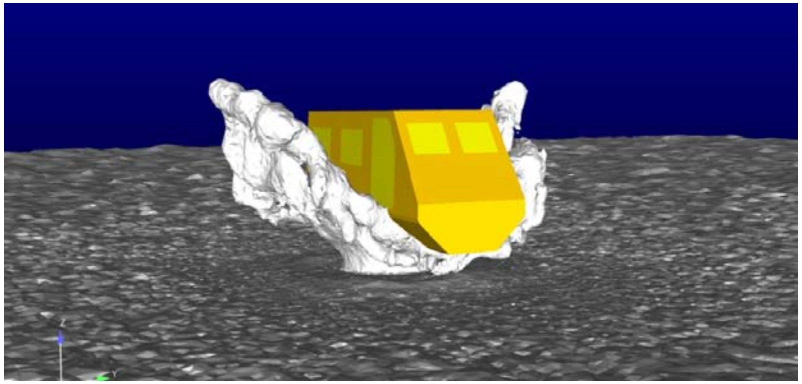
Course (5.0cm – 12M cells)
Medium (2.5cm – 29M cells)
Fine (1.25cm – 12M cells)

Simulation time = 5ms

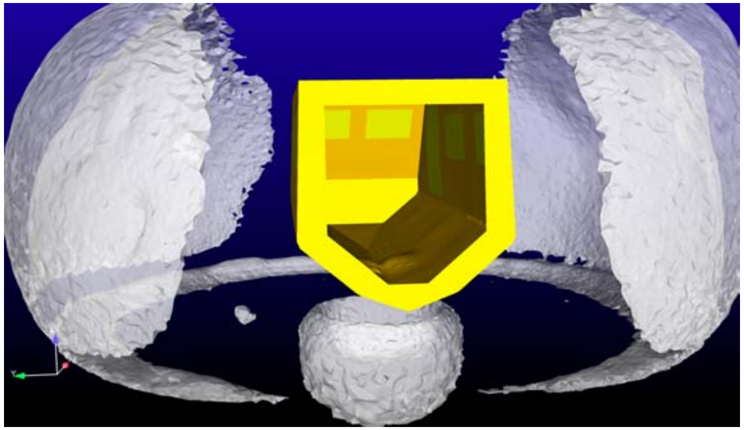
Soil extends 3 ft below ground plane



Mesh

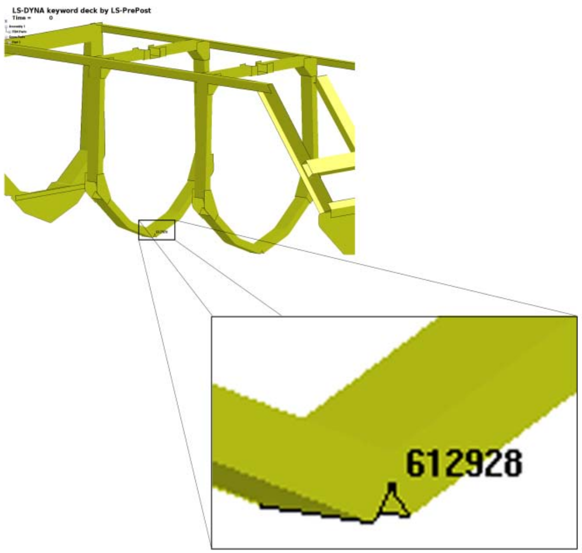


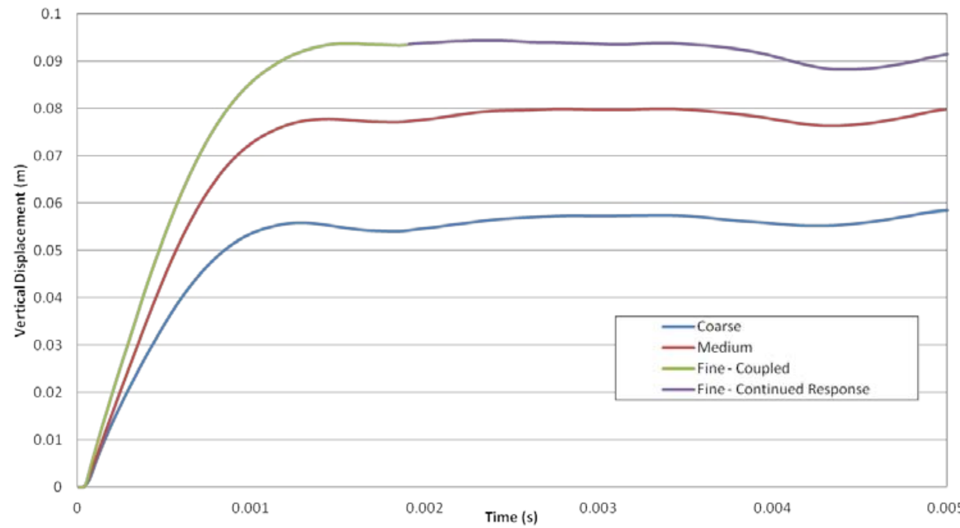
Soil Volume Fraction T=5ms

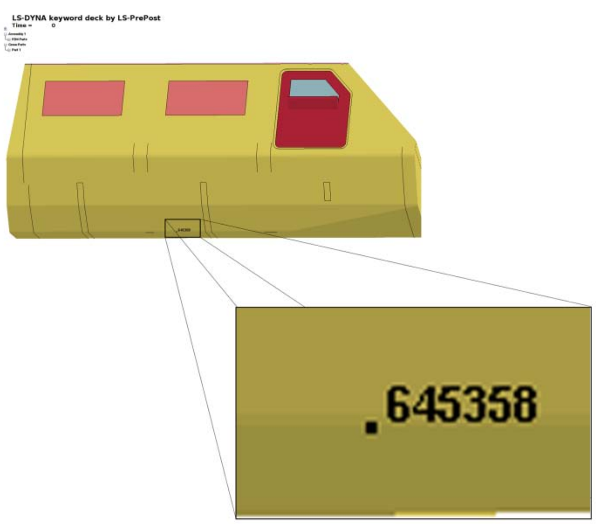


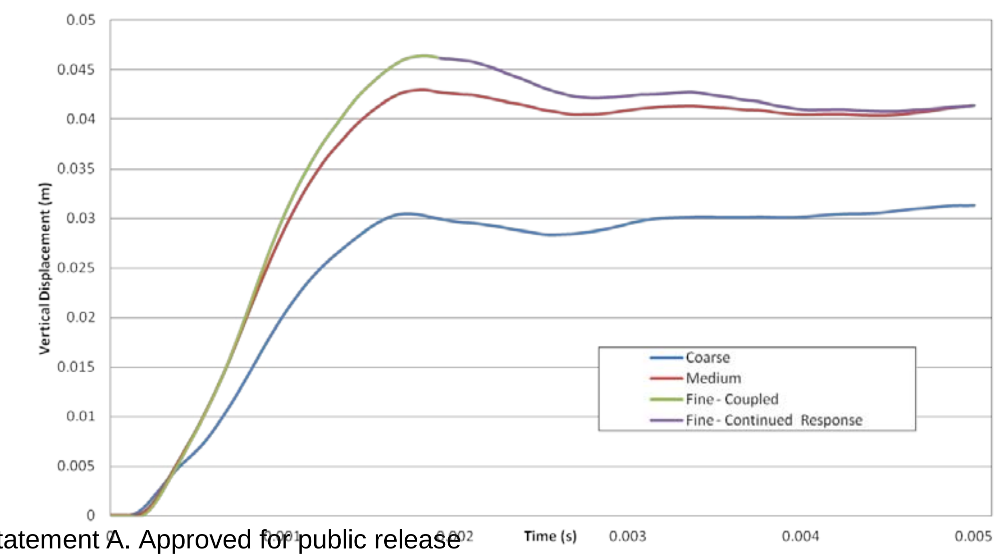
Blast Front T=5ms

Frame and Hull Displacements





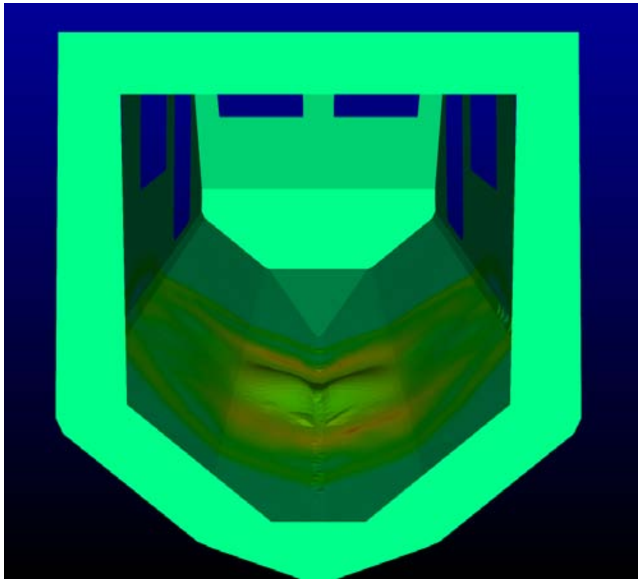




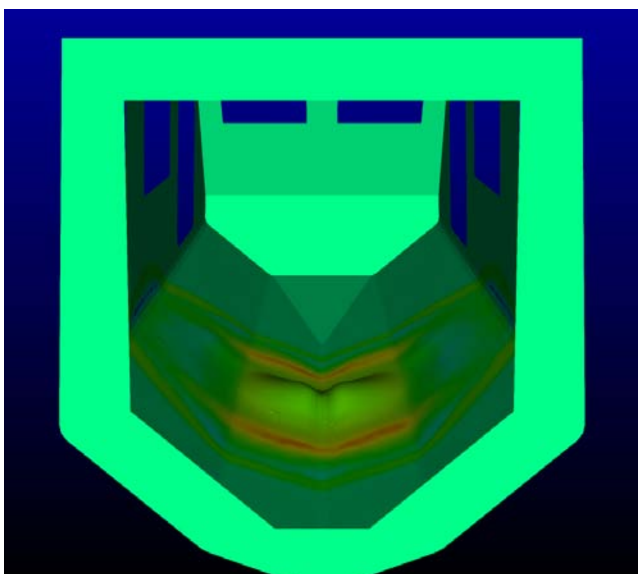
Pressure and Deflection for 3 meshes

Log_{10} hull surface pressure –1ms

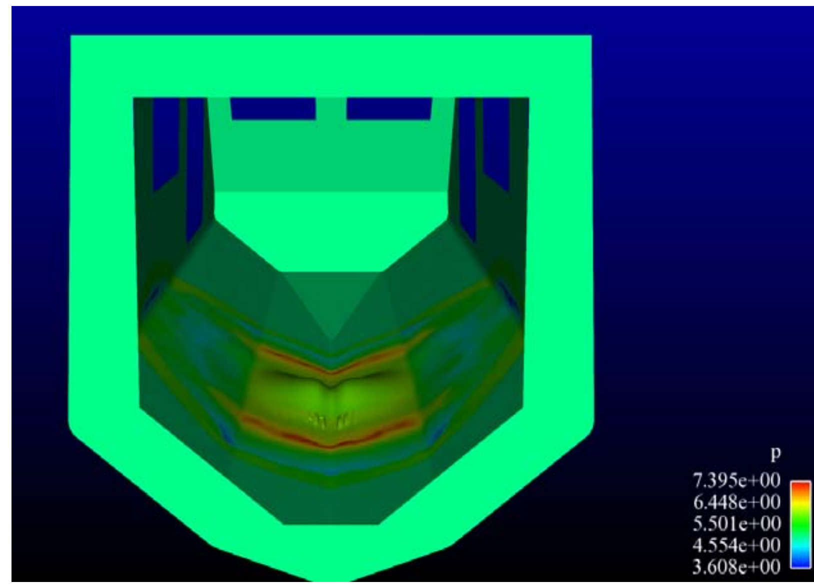
50mm



25mm



12.5mm



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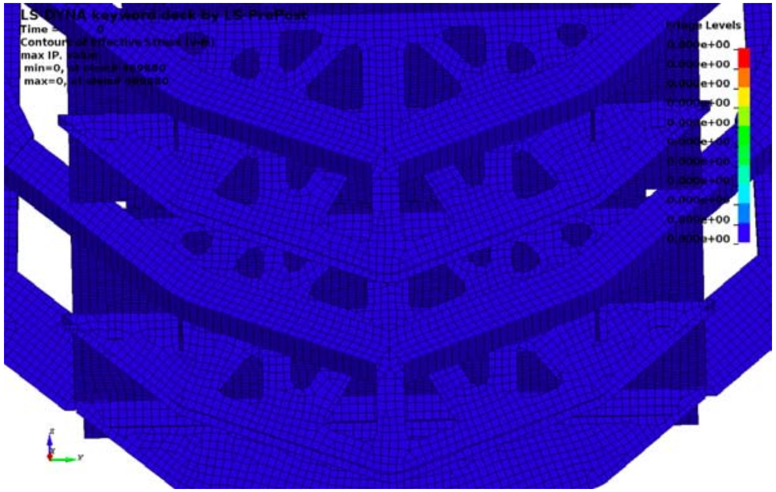
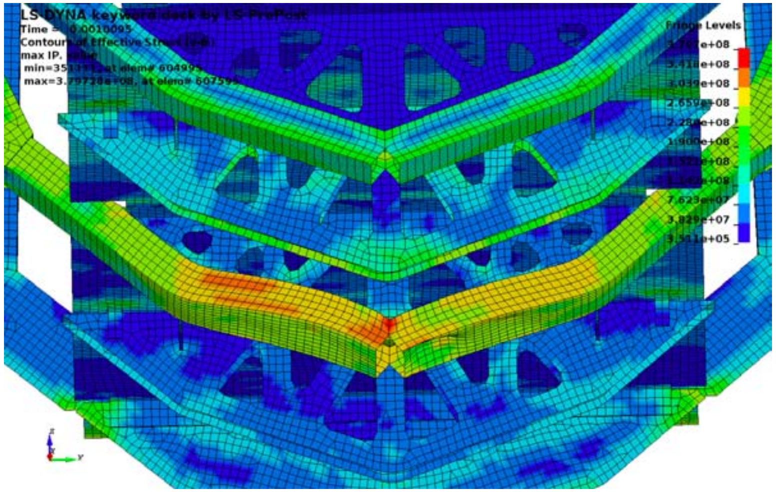
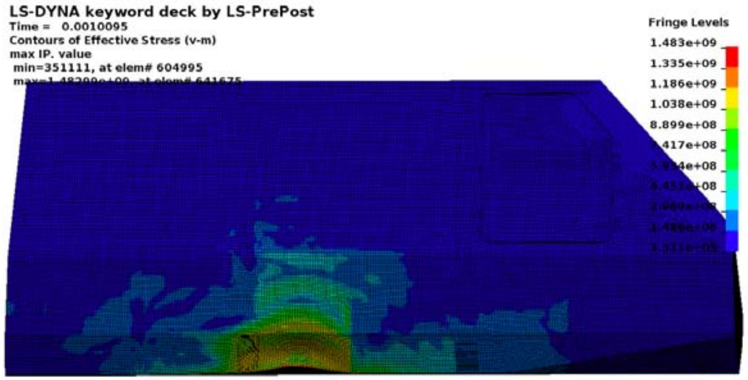
Frame and Hull Stresses T=1.5ms



Initial Frame configuration



Frame Stress and Deflection

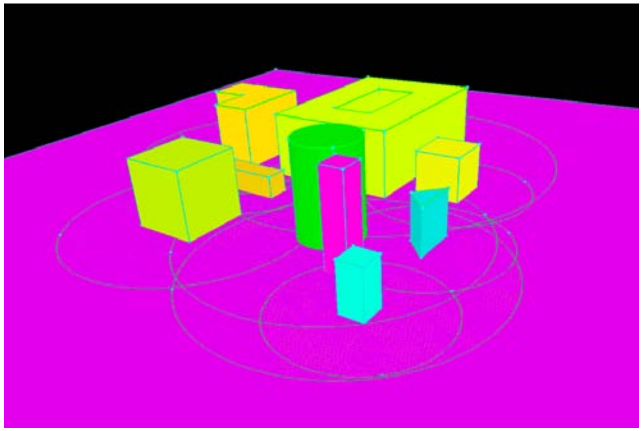


Hull Stress and Deflection

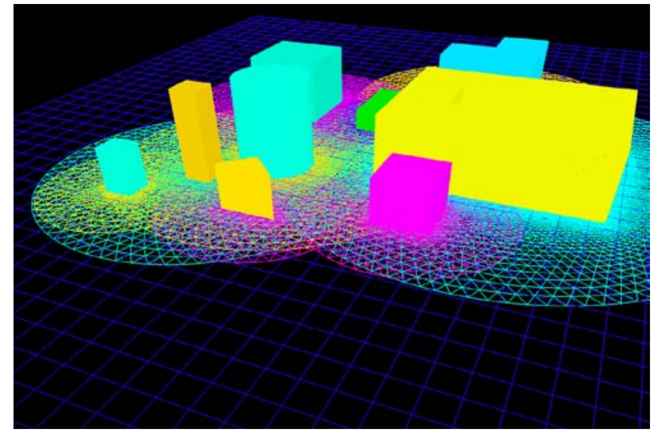
Urban Blast Applications

- Work performed under DoE/DHS SERRI program funding in conjunction with Army ERDC
- Developed suite of high-fidelity and fast-running engineering codes to support urban blast analysis
  - Loci/BLAST extended for high-fidelity analysis of urban blast
  - MSU developed new gridding tools (BlastScape and MeshScape) to support urban blast analysis
    - Uses overset grid technology to simplify grid generation
  - ERDC developed UrbanFX fast running engineering tool
- Verified for urban blast analysis against ERDC one and two building small scale tests and SHAMRC analyses
  - Baylot et al, 74th Shock and Vibration Symposium Limited Proceeding, 2003
- ERDC performed analysis of EMRCT Urban Canyon large scale tests (limited distribution data)

Blastscape Grid Preprocessor



Supports generic building shapes

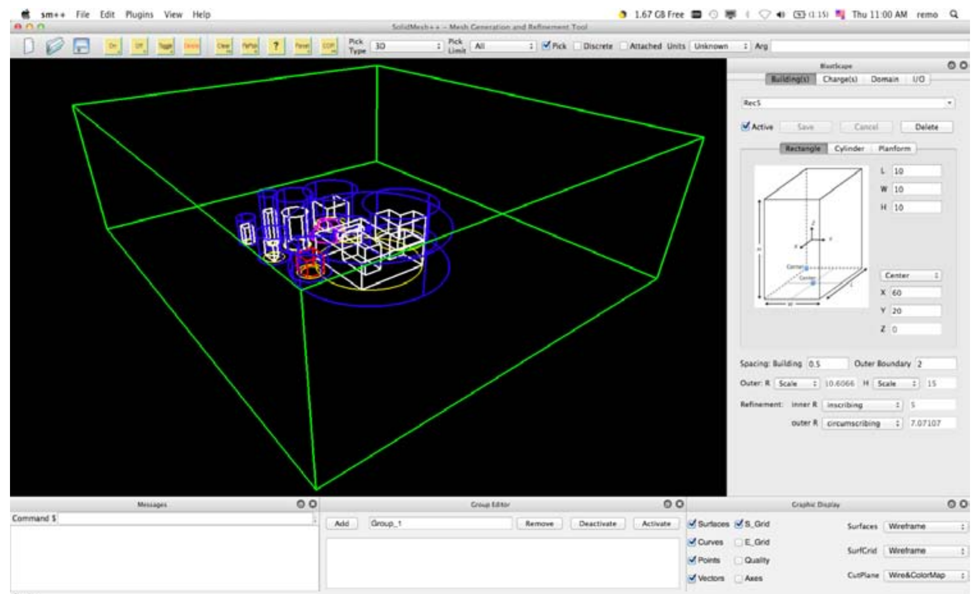


Overlap of overset meshes

Utilizes MSU SolidMesh unstructured grid software

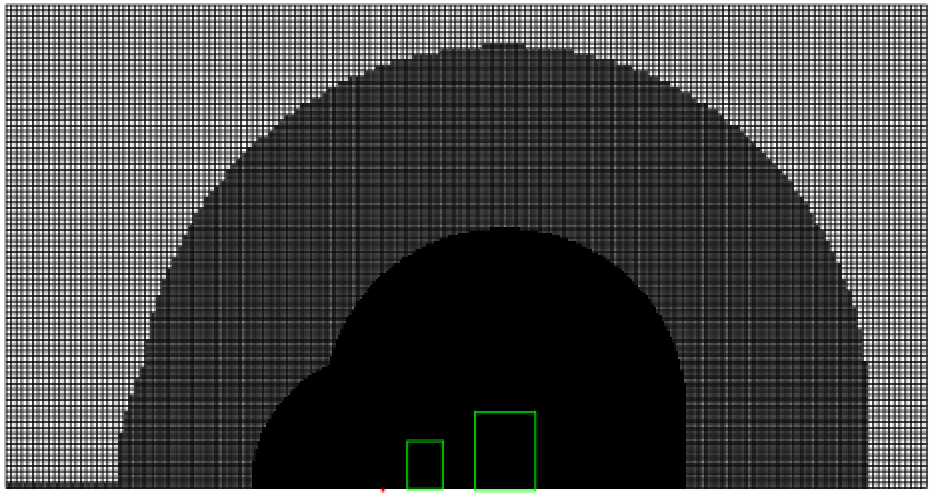
Enables rapid placement of buildings and charge for a given scenario

Interfaces with MeshScape to generate final meshes

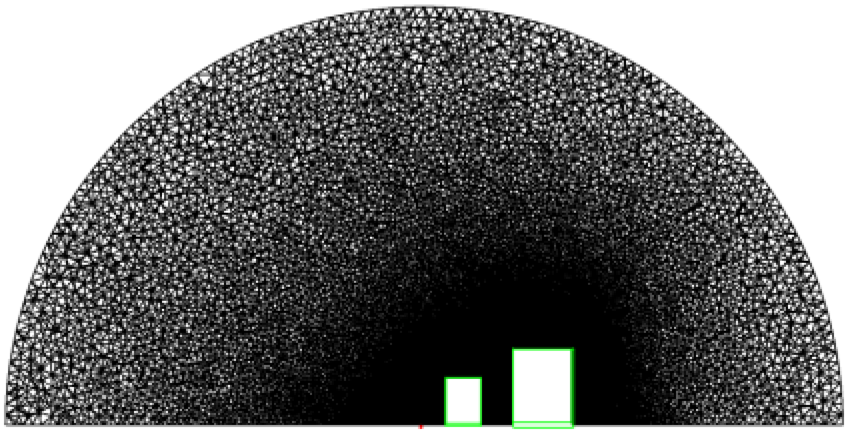


BlastScape GUI

Overset and Single mesh grids for two building cases



Overset mesh

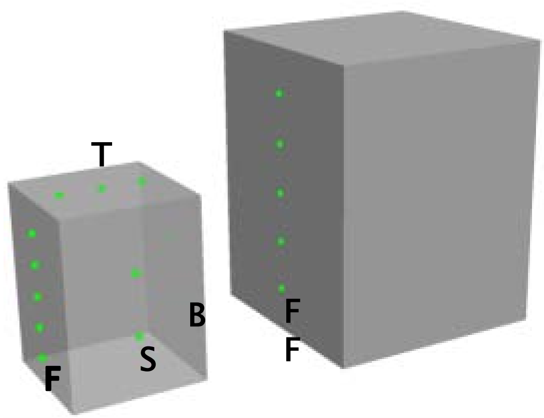


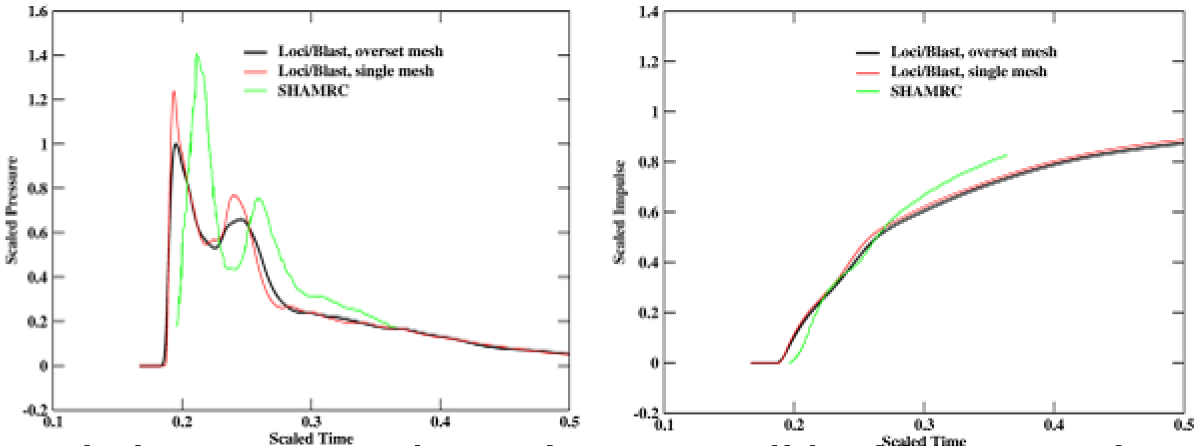
Single mesh

Overset mesh advantages:

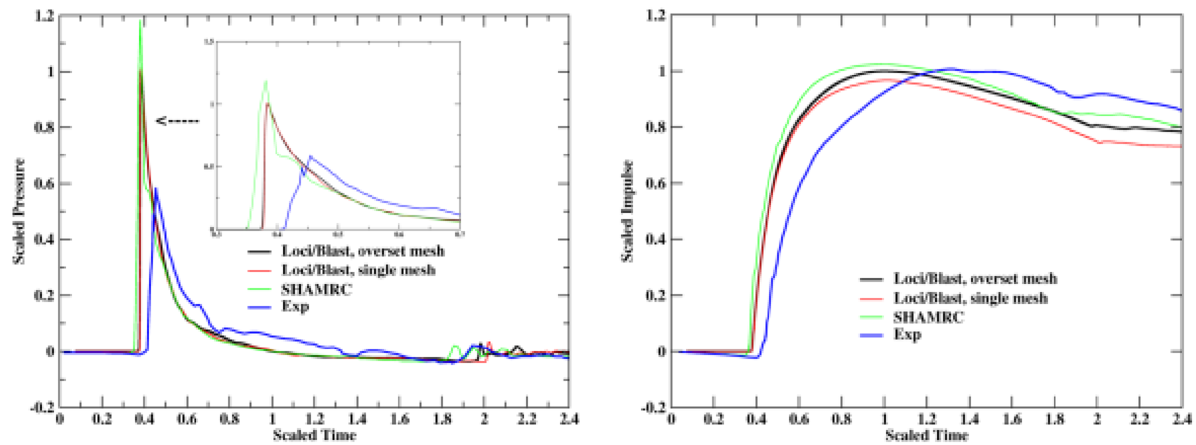
- Greater control of mesh spacing around charge and building
- Greater control of boundary placement

Comparison of Computed Pressure and Impulse with Exp. And SHAMRC



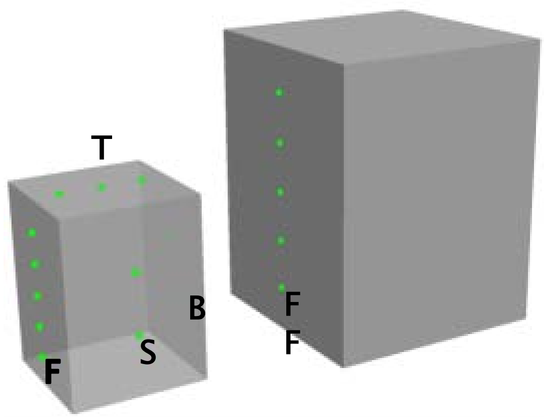


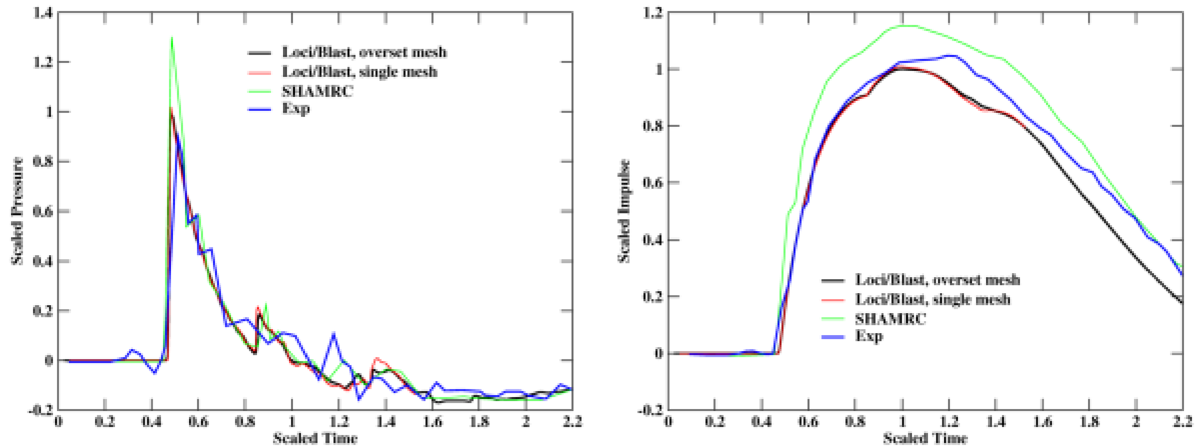
Scaled Pressure and Impulse on Small building at Probe F



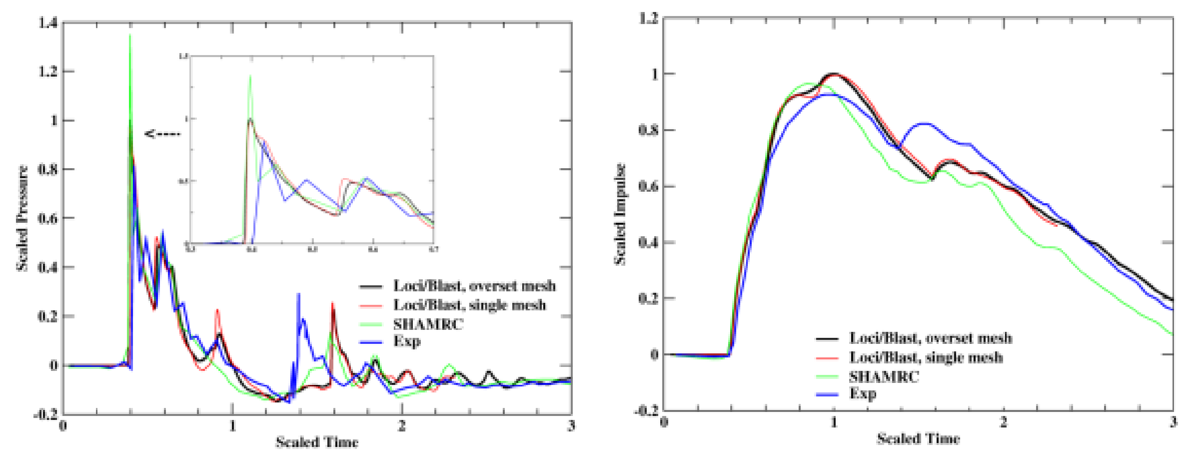
Scaled Pressure and Impulse on Small building at Probe S

Comparison of Computed Pressure and Impulse with Exp. And SHAMRC



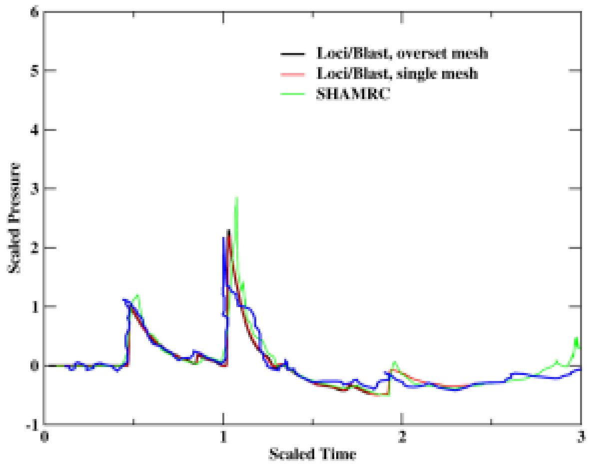


Scaled Pressure and Impulse on Small building at Probe B

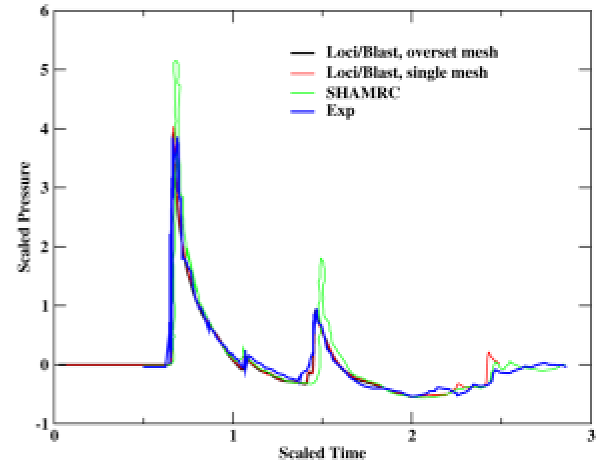


Scaled Pressure and Impulse on Small building at Probe T

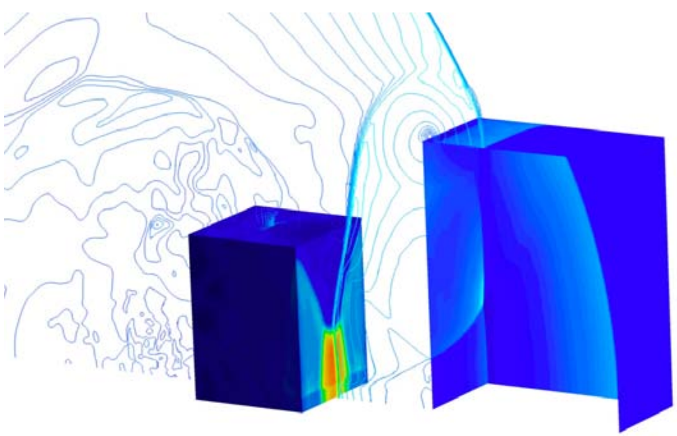
Pressures on Building 2 and Back of Building 1



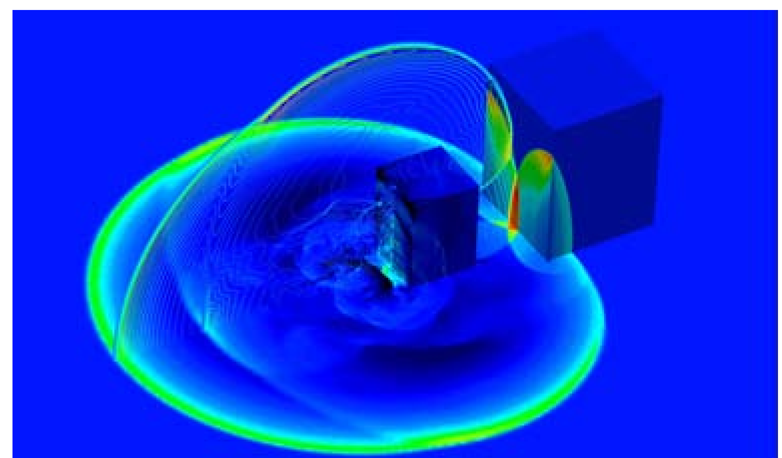
Back Pressure on Small building at Probe B



Pressure on Large building at Probe FF



Second Peak Pressure Contours Scaled T=1.0



Pressure Contours at Scaled T=0.69

Conclusions and Future Plans

- Loci/BLAST is a modern high-fidelity blast simulation tool with some unique features not found in other codes
- Extensive V&V testing demonstrated Loci/BLAST's accuracy and efficiency for a range of blast simulations
- Successfully applied the code to both underbody blast and urban blast problems
- MeshScape/BlastScape provide unique tools for grid generation of urban blast scenarios
- 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 of Loci/BLAST/CHEM

- 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
  - Richard Weed
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Acknowledgements

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Additional work was performed for 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

Other Loci Applications

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