Physics-Based Simulations of Fluid/Structure/Dynamics Interactions in Scenarios Associated with Blast

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This material is based upon 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, findings and conclusions or recommendations expressed 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.

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**Sponsoring Agency:** TACOM/TARDEC

**Distribution Statement:** Approved for public release, distribution unlimited.

**Security Classification:**
- Report: unclassified
- Abstract: unclassified
- This Page: unclassified

**Number of Pages:** 15
Objectives

- Develop vehicle occupant blast load simulation
  - Fast and accurate - Physics and HPC
  - Cost efficient – Open source code
  - Flexible and User-friendly
Outlines

- Background
- Technical Approach
- Results and Discussion
- Summary
Improvised Explosive Device (IED)
- Over 60% of the blast injury in OEF and OIF in 2009
- Penetration and direct injuries
- Remains weapon of choice and major threats
- Survival rate increased with armor (head, body)

Blast Traumatic Brain Injury (TBI)
- “Signature” injury in OEF and OIF
- Primary blast injury caused by blast-induced pressure change
- Battle field and in-theater innovations in treatment lowered killed:wounded ratio
- Simulation to further enhance vehicle occupant survivability
Gas Dynamics - CFD
- Spatial (three-dimensional) and temporal (time accurate)
- High pressure ratio wave of small time scale
- Pressure wave numerical resolution in 3D
- Moving/deforming immersed boundary
- Computationally intensive

Computational Structural Dynamics - CSD
- Spatial (three dimensional) and temporal (time-accurate)
- Materials dynamic behavior
- Large deformation or fragmentation
- Computationally intensive

Motion Dynamics – 6DOF
- Kinematics and dynamics of body motion
- Six degree of freedom (6DOF) motion equations

Computationally intensive
Fluid Dynamics and Structural Dynamics

Virtual Test Facility (VTF) from Cal Tech

- Developed at Cal Tech’s Center for Simulation of Dynamic Response of Materials.
- 3D dynamic response of materials subjected to strong shocks and detonation waves propagate in fluids
- Explicitly coupled Eulerian-Langrangian simulations
- Adaptive mesh refinement for Cartesian finite volume fluid solver
- High order sub-division FE thin-shell structure solves
- Fracture and fragmentation
- Highly paralleled CFD and CSD solvers
- Open-source
**Simulation Platform (2)**

**Rigid Body Motion Dynamics**

**WMU Enhanced Solver**
- Geometry flexibility
- Directly coupled to VTF with multiple bodies
- Open-source

**Coupled Fluid/Structure/Dynamics Solver**
- Vehicle Occupants Blast Load
- High Performance
- Low Cost

**Massively Parallel Computing**
Free Air Blast Wave Propagation

- $P_{\text{TNT}} = 2.89 \text{ GPa}$
- Base Mesh: 200x150x50
- Two Pressure Loads

\[\text{Pressure Load}\]

\[\text{Pressure Load}\]

$68.08 \text{ g TNT}$
Metal Plate in TNT Blast (1)

- 150 g C4
- Two standoff distances
- AL6XN SS plate thickness 1.9 mm
- 8 Compute Node

Pressure Contours at $T_0$, $T_0^+$, $T_0^{++}$

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Metal Plate in TNT Blast (2)

SS Plate Centerpoint Deformation History

SS Plate Deformation Contours

plate thickness 1.9 mm

- Present method
- Experimental data

Standoff distance 75 mm
Standoff distance 150 mm

Computational Engineering Physics Lab.

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Blast Over Hemisphere Dome (1)

Adaptive CFD Mesh

pressure sensor

Rooftop Pressure Load

Blast Wave Pressure at Sensor

free field propagation
inside the hemisphere

Computational Engineering Physics Lab.

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Blast Over Hemisphere Dome (2)

- 3 Level of adaptive mesh refinement
- Total # of cell adapt to accuracy need
- Efficient parallel-computing simulation

The number of cells (Million)

- the number of cells of level 1
- the number of cells in level 2
- the number of cells in level 3
- the total number of cells

Time (mSec)

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Blast off Boxes (1)

- Two boxes with one centrally located inside the second
- The outer box deforms elastically; the inner box rigid and fixed in space
Blast off Boxes (2)

- Blast initiated under a single rigid box
- Unconstrained body motion by 6-DOF

Body 6-DOF Motion & Pressure Contours
Concluding Remarks

- Developed physics-based computer simulations of the effects of fluid-structure interactions due to blast
  - Open-source software offers accurate and fast simulations
  - CFD in multiply connected domain
  - Generic geometries

- Developed fluid-structure-dynamics interactions multi-physics solver
  - Vehicle occupant motion and deformation due to direct/indirect exposure to blast wave

- In the future,
  - Apply to realistic dummy model
  - Develop and couple multi-body dynamics capability for human-like dummy model
  - Deliver software for time-accurate vehicle occupant blast wave load simulations to TARDEC