EVOLUTION OF OCCUPANT SURVIVABILITY SIMULATION FRAMEWORK USING FEM-SPH COUPLING

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14. ABSTRACT

?Approximately 60% of Coalition Deaths in Iraq and 75% of casualties in Afghanistan stem from IEDs [1,2,3] ?Wish to simulate the blast-event from an IED on an armored vehicle ?Need for increased simulation efficiency and accuracy ?Aspiration to evaluate commercial off-the-shelf software effectiveness ?Perform an end-to-end soldier centric occupant survivability solution ?Simulate explosion, with vehicle and occupant response

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Outline

- Introduction
- Objective
- Blast Modeling
- Blast Validation
- Vehicle Modeling
- ATD & Human Modeling
- Conclusions

Introduction

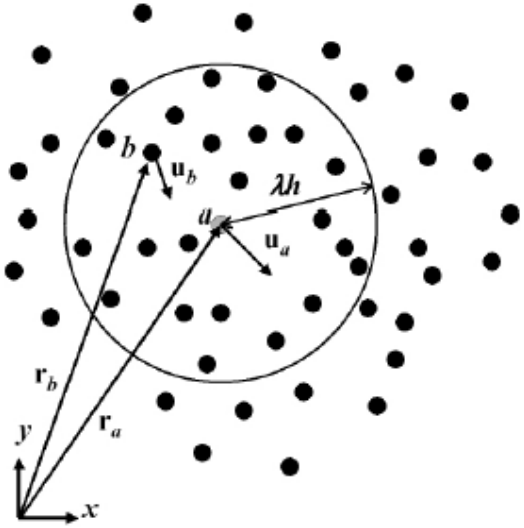
- Approximately 60% of Coalition Deaths in Iraq and 75% of casualties in Afghanistan stem from IEDs [1,2,3]
- Wish to simulate the blast-event from an IED on an armored vehicle
- Need for increased simulation efficiency and accuracy
- Aspiration to evaluate commercial off-the-shelf software effectiveness
- Perform an end-to-end soldier centric occupant survivability solution
  - Simulate explosion, with vehicle and occupant response

Blast Modeling

- Buried-mine problem poses several challenges
  - Complex interactions between soil, vehicle, and occupant
  - Complicated explosive material chemistry
- IEDs in the soil contributes higher energy towards the target as compared to IEDs in open air
  - Soil imposes most of the loading on structure
  - Material properties of soil critical
- Primarily concerned with loading and damage probability
- Smooth Particle Hydrodynamics (SPH) used to deal with large deformation/displacements and material failure

Soil-Blast Interaction

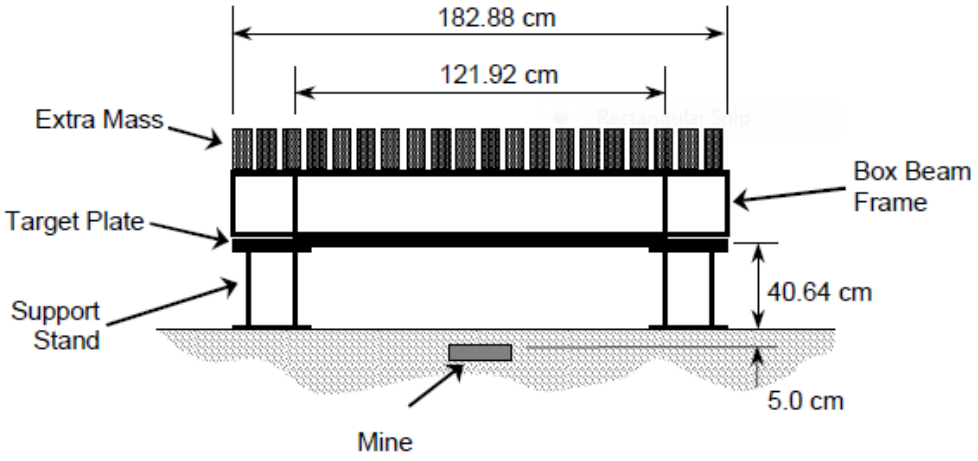
- SPH option in PAM models based on continuum mechanics in 3-dimension Cartesian geometries
- Sphere of influence, defined by kernel function, allows particles to interact with neighbors
- SPH is a meshless method
- Interaction between particles and finite elements modeled with existing PAM interface algorithms
- Jones-Wilkins-Lee state equation used:



$$p = A\left(1-\frac{\omega}{R_1\ dF}\right)e^{-R_1\ dF} + B\left(1-\frac{\omega}{R_2\ dF}\right)e^{-R_2\ dF} + \omega\frac{E_i}{V}$$

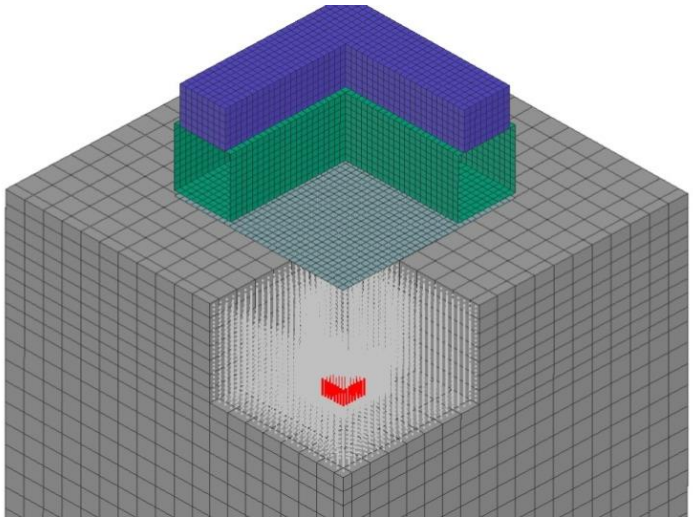
Reference Validation Set

- DRDC R&D Canada blast test
- 6’ by 6’ plate of 5083-H131 aluminum armor subjected to mine blast
- Test plate on support stand with additional mass on top
- All other configuration details as in the test [5]

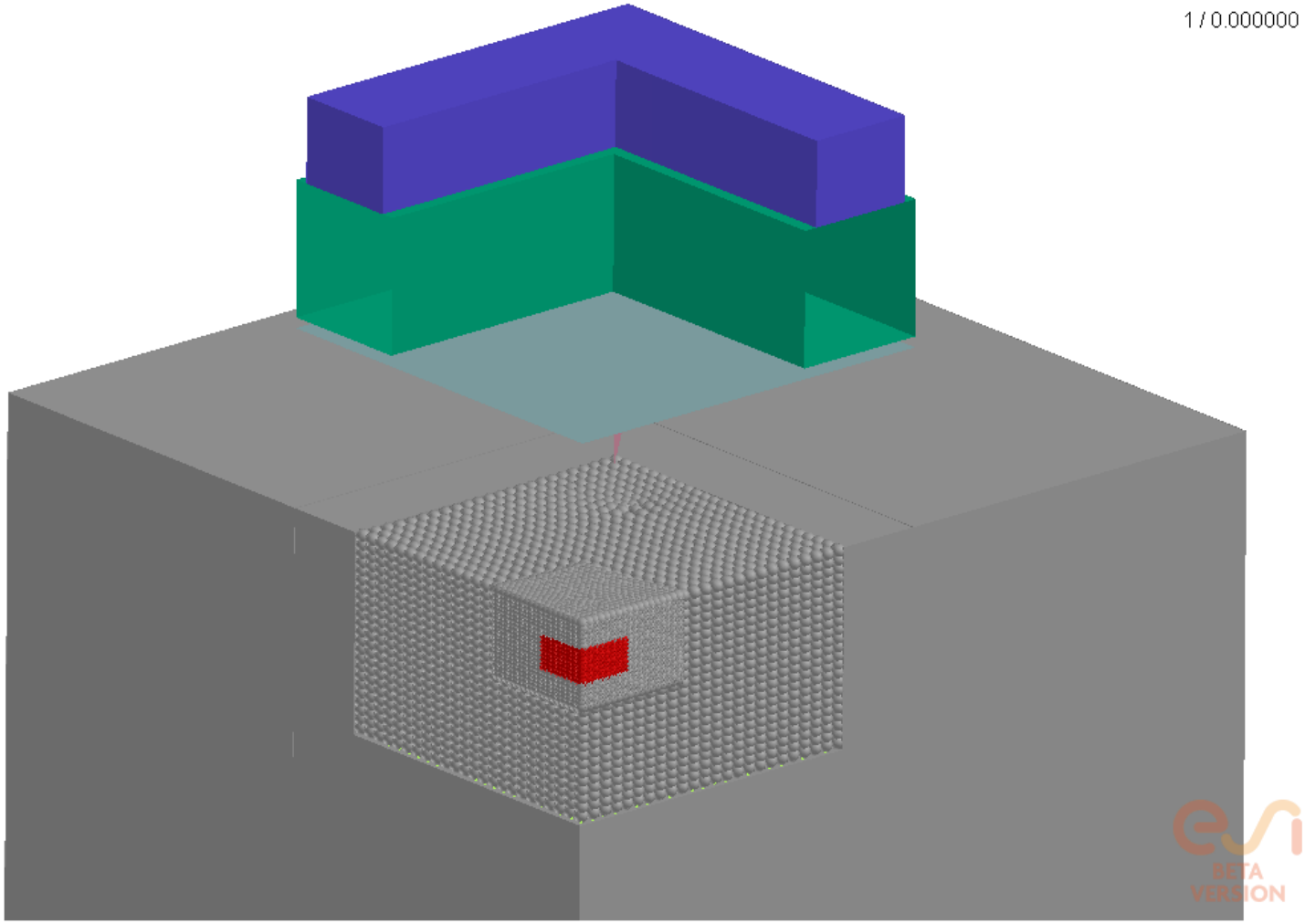


Blast Modeling

- Quarter model used with symmetry boundary conditions to minimize simulation time
- Belytschko-Tsay element formulation selected
- Explosive charge and surrounding soil represented by SPH particles
- Used scaled TNT properties to realistically simulate C4
- Momentum of soil and explosive transferred to surrounding objects through contact definition

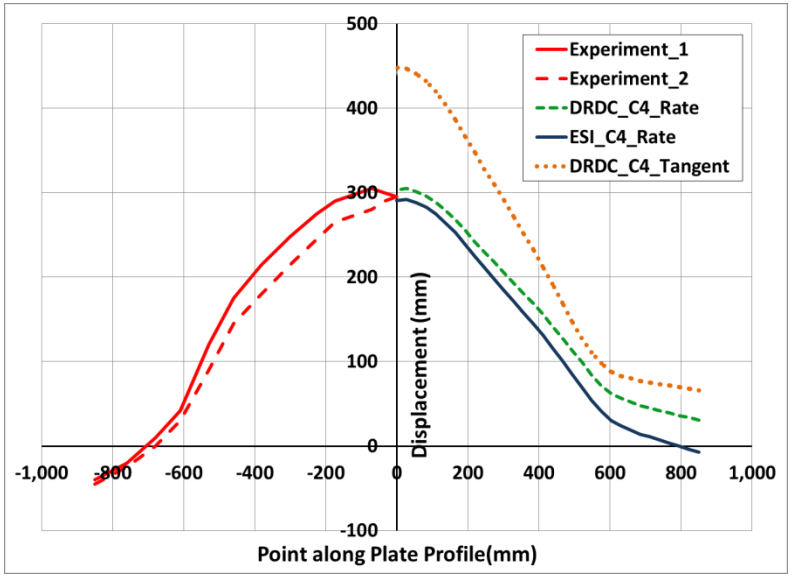


Blast Plate Simulation



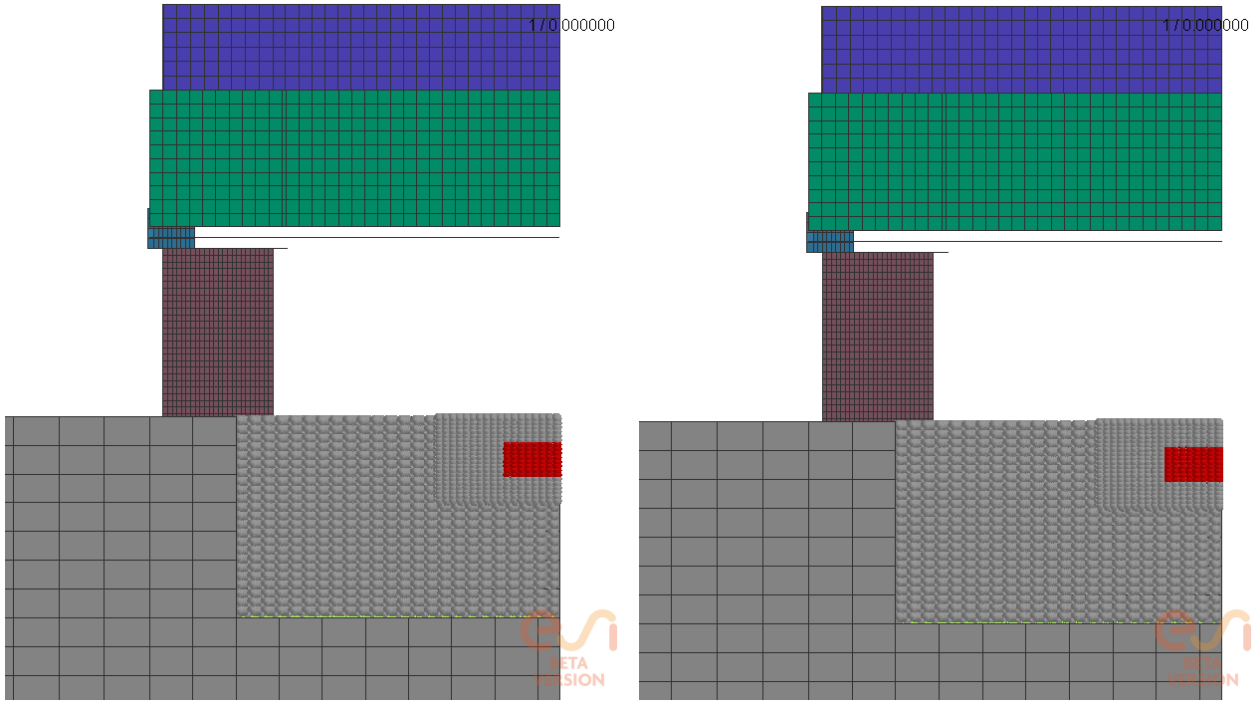
Blast Plate Validation with Experimental Test

- Resulting final deformation profiles taken of the plate centerline
- Reference does not provide rate dependent material properties
  - Limits ability to replicate test conditions
- Rate dependent material properties added to the aluminum for realistic response through stress-strain curves



Two soil models used to bound uncertainty

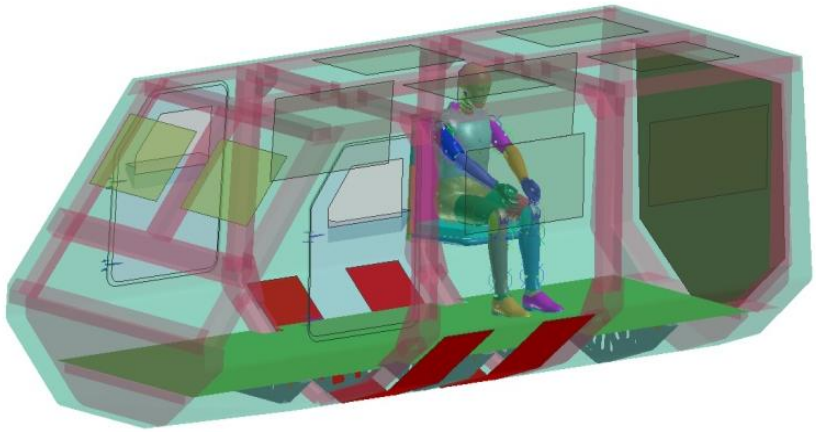
- Due to real-life soil variation, different soil properties explored in simulation -DRDC on left, ESI on right



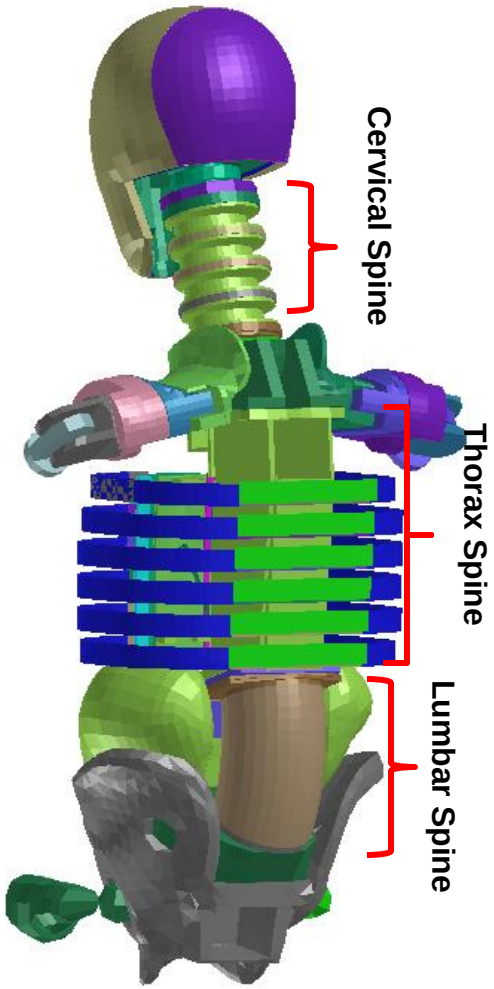
Sim Label	*Density*	*Shear Modulus*	*Bulk modulus*
DRDC	2176	4.06E+10	5.00E+10
ESI	2500	1.48E+10	1.83E+11

Vehicle Modeling and Occupant Response

- Generic hull fabricated by TARDEC [4] to evaluate blast mitigation technologies
- Total mass: *15,000 lbs*; Ground clearance: *18 inches*
- Vehicle represented in PAM-SHOCK modeling environment and given the same size/dimensions.

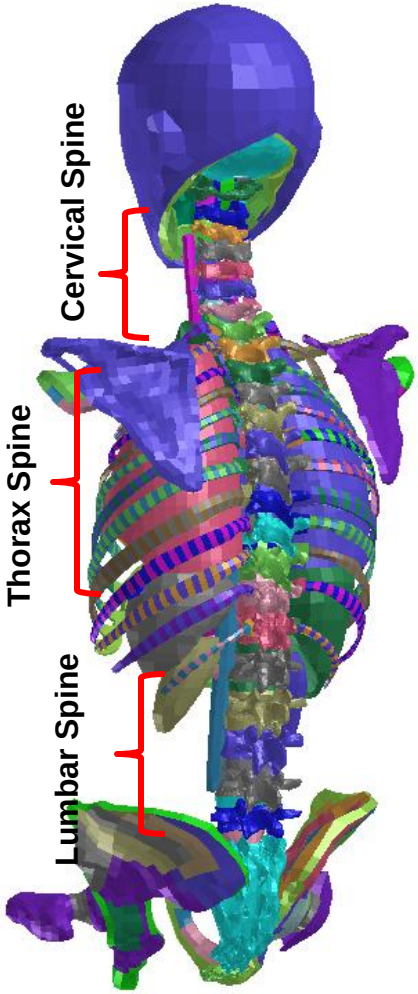


Response Due to Uniform Acceleration Loading



The Vertical Loads subjected by the blast event would require a more bio-fidelic spine representation.

- Cervical Spine:
  - ATD dummy Model is represented with steel disc (C1-7) and rubber bushings (Intervertebral Disc). Cable bars representing one single ligament.
  - Human model is represented with seven rigid bodies (C1-7). Connected with 6DOF spring beam elements(Intervertebral Disc), ligaments are represented by 1D spring elements.
- Thorax Spine:
  - ATD Dummy model is represented with a spine box. No segments.
  - Human model is represented with 12 rigid bodied (T1-12). Connected with 6DOF spring beam elements and Ligaments.



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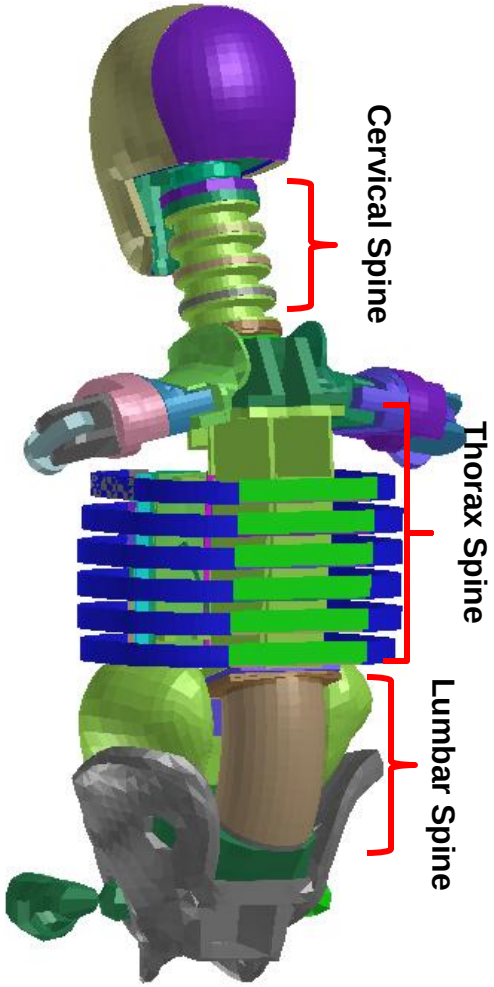
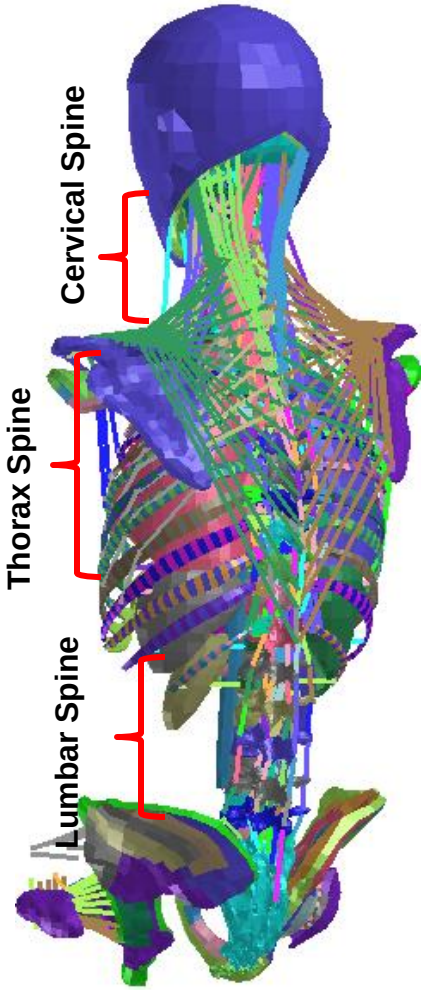


- Lumbar Spine:
  - ATD dummy Model is represented with Lumbar spine rubber and cable bars representing ligaments.
  - Human model is represented with five rigid bodies (L1-5). Connected with 6DOF spring beam elements and ligaments.

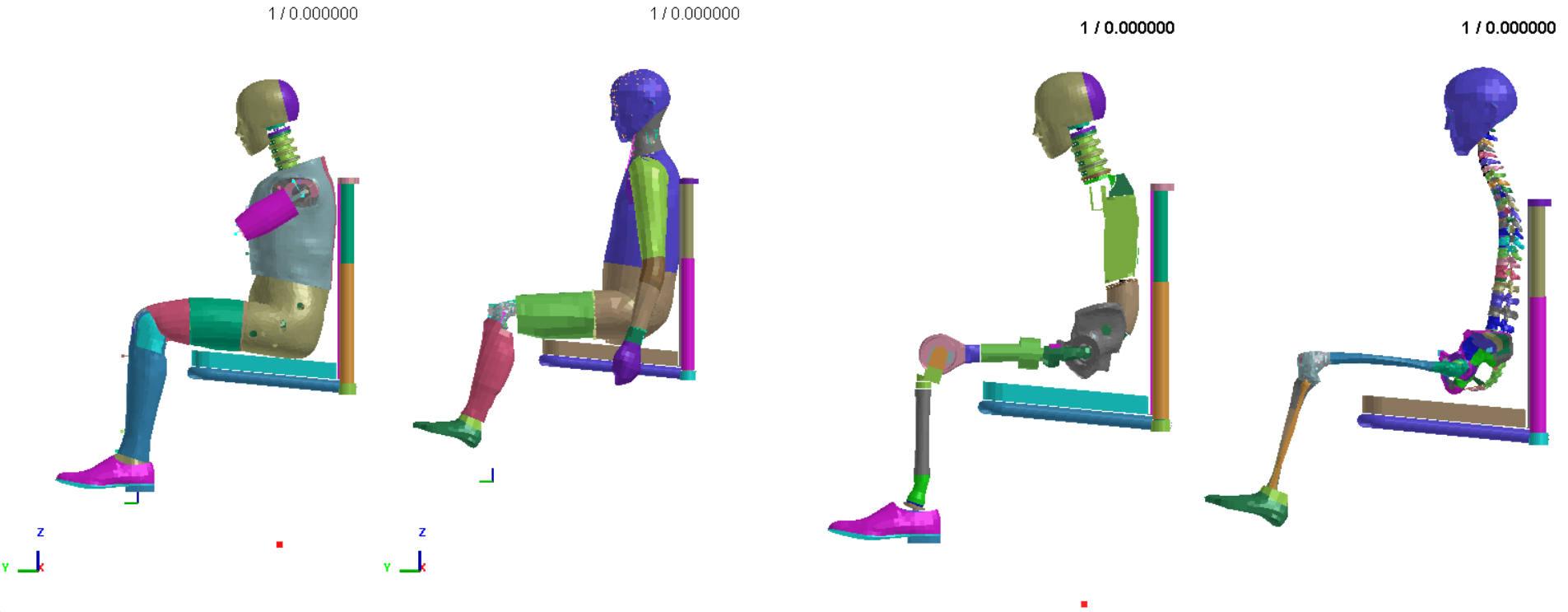
The kinematics of ATD dummy model and Human model show a major influence of ligaments representation in spine modeling (Neck flexion extension characteristics).



Response Due to Uniform Acceleration Loading

- Rigid hull subjected to vertical acceleration pulse with seat model attached to hull
- Human and dummy models placed in seats under gravity, not restrained by seatbelts
- Two occupant models: test dummy (ATD) and human model with deformable bones and tissue
- High level of detail needed to accurately determine injury stressors
- ATD has greater displacement and rotation of head, and greater flexion of neck

Response Due to Uniform Acceleration Loading



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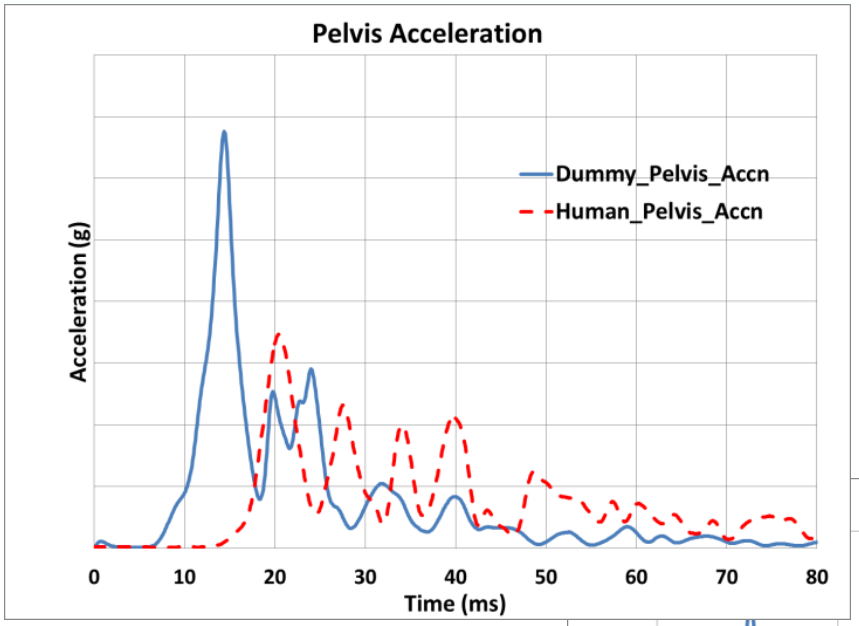
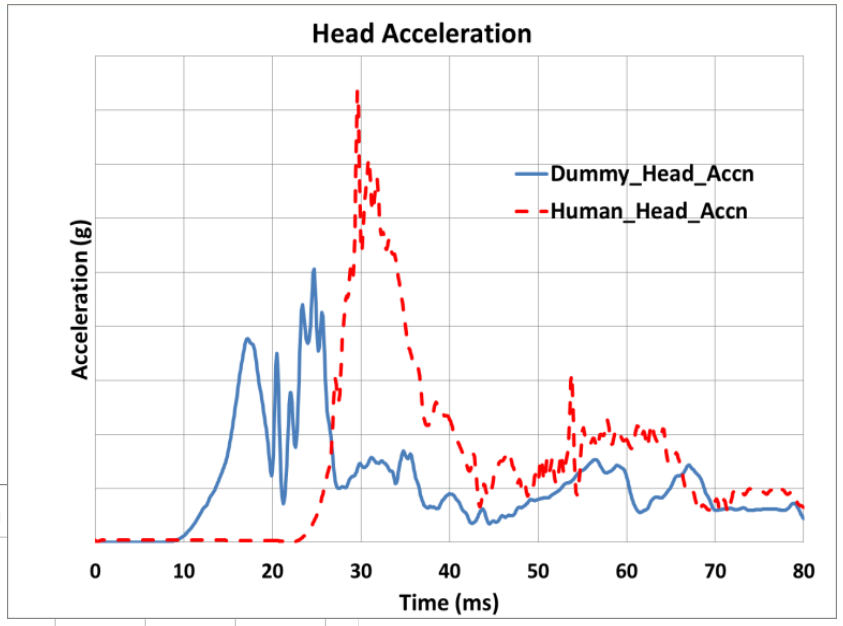
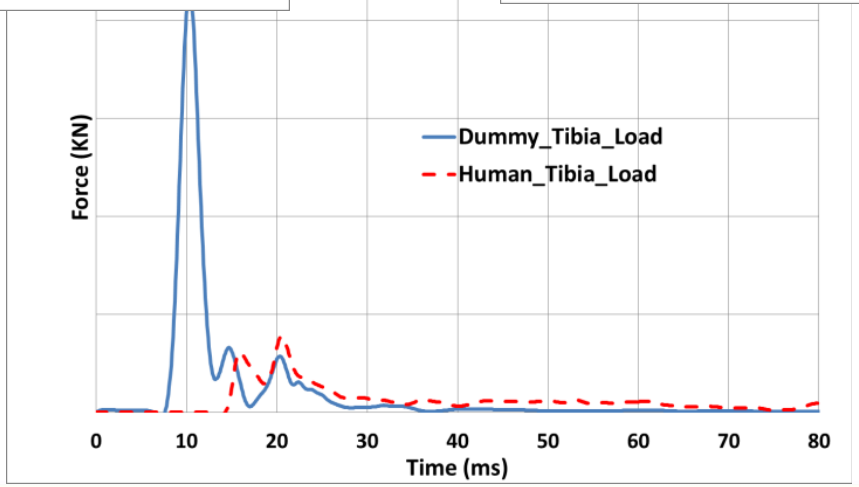




Right Tibia

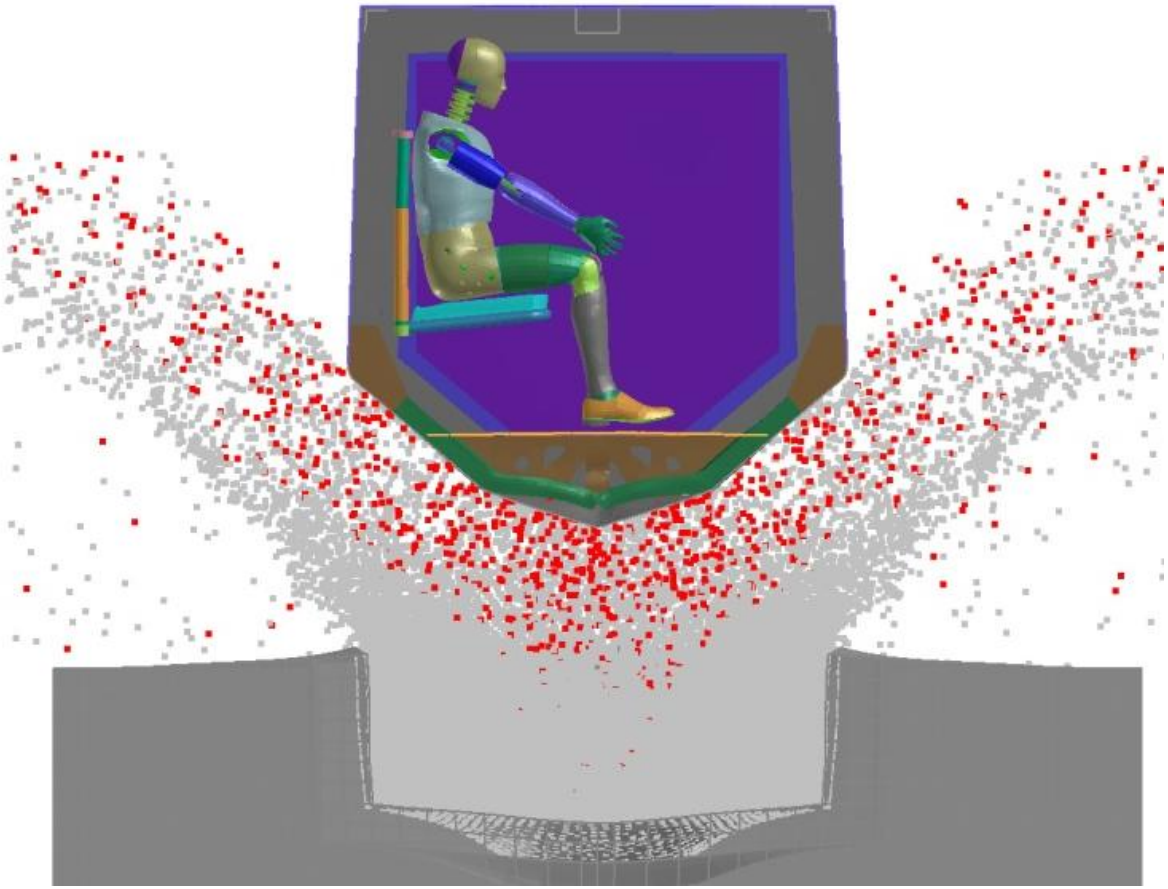


Response Due to Uniform Acceleration Loading

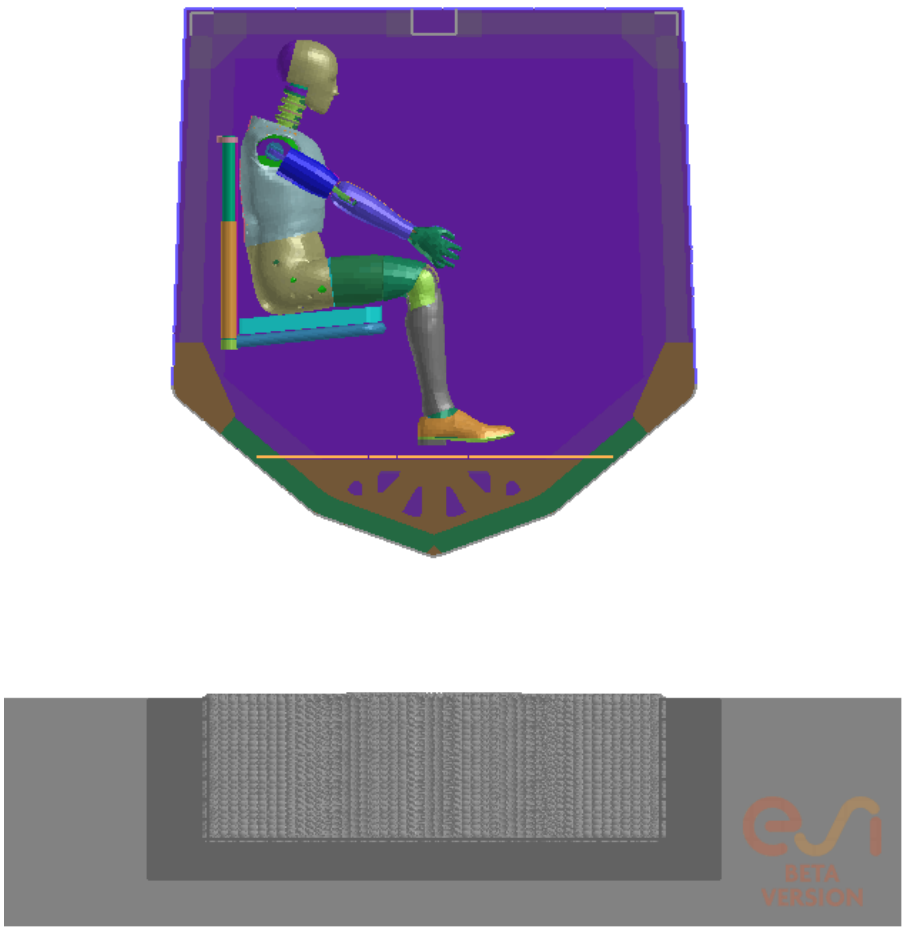
- Head acceleration, pelvis acceleration, and tibia force calculated and compared
  - Human model peak head acceleration ~70% greater than ATD
  - Human peak pelvis acceleration ~50% of ATD peak
  - For both left and right leg, ATD peak tibia force 6.5 to 7.5 times peak force in human tibia
- Differences can be attributed to the level of detail in the models
  - Muscles and separate spine regions only modeled in the human
  - Different stiffness given for bones for ATD and human
  - Joints represented as kinematic joint for ATD; human joints have contact surfaces with ligament and muscle stabilization (human model joints dislocate and thus reduce force on bones)

Blast Load Response on Deformable Vehicle

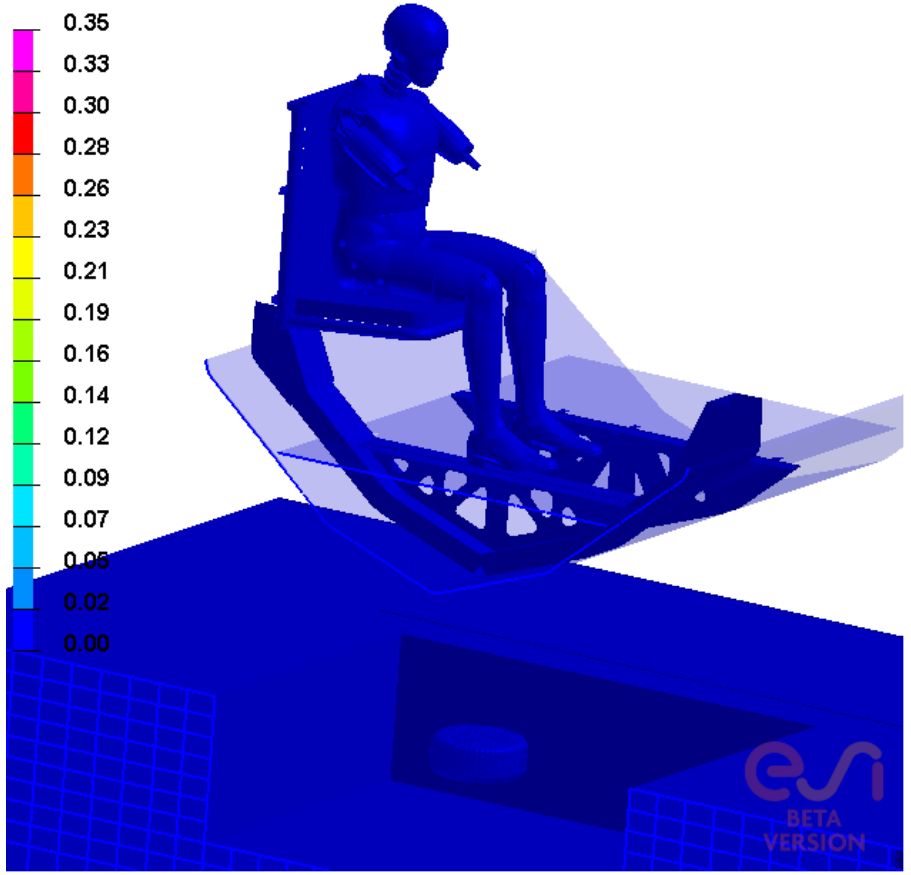
- Vehicle model positioned over a 3-dimensional mine and a soil area 12 ft by 12 ft
- This hull is completely deformable, loading applied by the blast of SPH particles



Blast Load Response on Deformable Vehicle

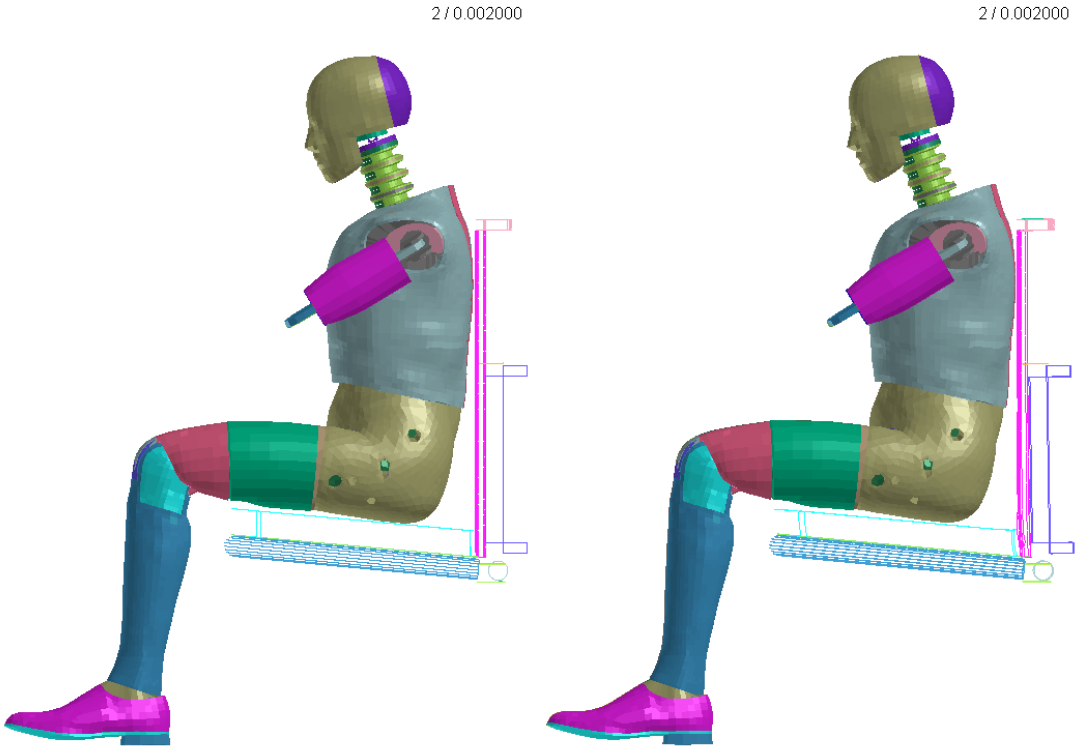


Dummy & Hull Kinematics



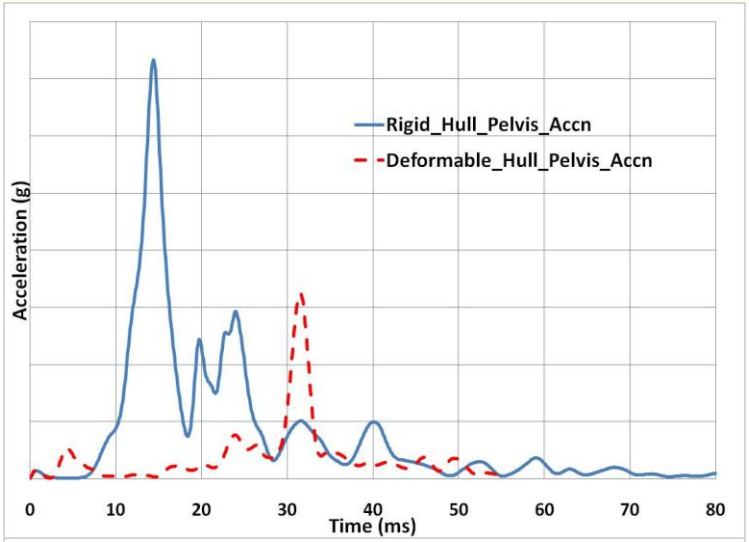
Dummy & Hull Displacement Contour

Blast Load Response on Deformable Vehicle

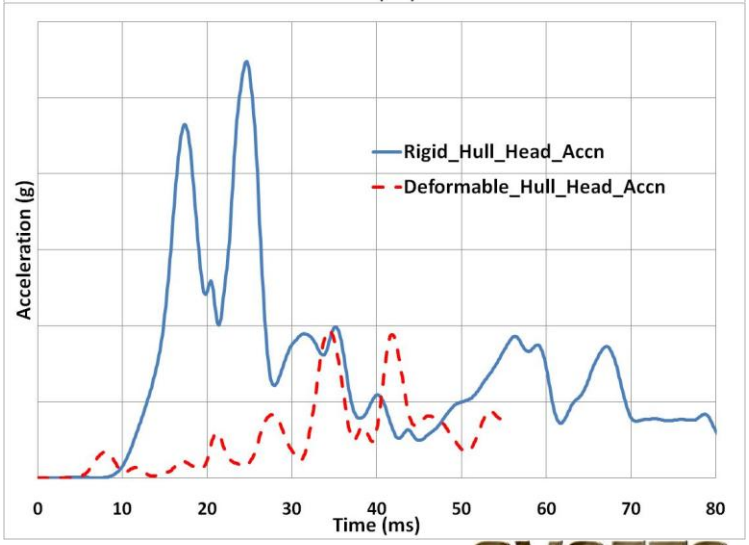


Dummy Kinematics
Rigid Hull(Left) Deformable Hull(Right)

Pelvis Acceleration



Head Acceleration



Conclusions

- PAM-SHOCK coupled Finite Element to SPH approach
- Demonstrated explosions and blast waves interacting with structures
  - Standard ATD and advanced biofidelic occupant models
- Human model kinematics likely more biofidelic than ATD models due to realistic representation of body segments and joints, needs validation tests with cadaver occupants
- Study demonstrates value of occupant-centric approach within unified Lagrangian framework
  - Intuitive input and results are physically realistic and supports vision for a system-level approach to blast modeling

References

- [1] C. Wilson, "Improvised Explosive Devices (IEDs) in Iraq and Afghanistan: Effects and Countermeasures", CRS Report for Congress, RS22330, August 28, 2007.
- [2] S. Bird and C. Fairweather, "Recent military fatalities in Afghanistan (and Iraq) by cause and nationality", MRC Biostatistics Unit, UK, February 2010.
- [3] J Farago, "IED Casualties in Afghanistan Soaring", http://www.newser.com/story/55161/ied-casualties-in-afghanistan-soaring.html, 3 April. 2009.
- [4] R. Scherer, “Vehicle and Crash-Dummy Response to an Underbelly Blast Event”, 54th Stapp Conference (Oral only).
- [5] K. Williams, et. al, “Validation of a Loading Model for Simulating Blast Mine Effects on Armoured Vehicles”, 7th International LS-DYNA Users Conference.

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