

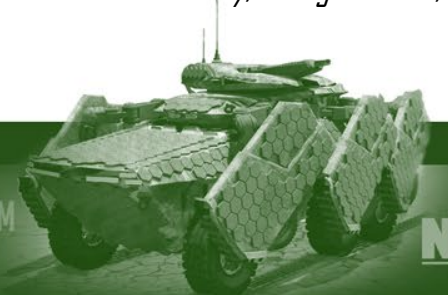


THE ARMY GENERIC HULL AS A VITAL DEVELOPMENTAL TOOL FOR UNDERBODY BLAST APPLICATIONS

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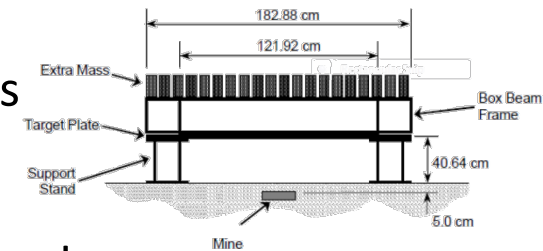
- Introduction / Background
- The Army Generic Hull (previously TARDEC Generic Hull)
 - Geometry
 - Finite Element Model
 - Test Setup / Results
- Usage of AGH in ongoing UBB research
 - LS-DYNA
 - IMPETUS
 - CTH
 - PARADYN/ALE3D/FEusion
 - EPIC
 - Other
 - PAM/SHOCK
 - MADYMO
 - LOCI/BLAST
 - ParaAble/MineX3D
 - DYSMAS
- Conclusions / Recommendations





- Underbody blasts (UBB) one of the most widespread reasons for warfighter casualties in recent times
- Vast suite of UBB software and methodologies developed over the past 15 years

- Need to be validated against a set of known benchmarks
- DRDC Flat Plate test a good start, but has limitations



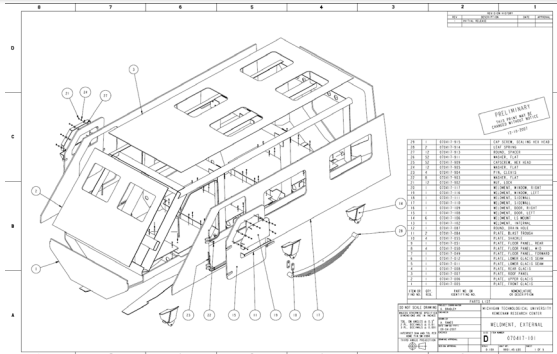
- Circa 2010, Army GVSC (then TARDEC) fabricated a *generic* and *typical* military vehicle hull with the intent to:

- Subject it to underbody mine blast tests with standard charges for benchmarking
- Share the data publicly
- Leverage industry and academic partners to evaluate blast-mitigating technologies
- Provide benchmark data for the development and validation of UBB software codes

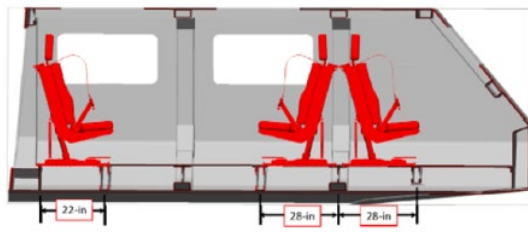




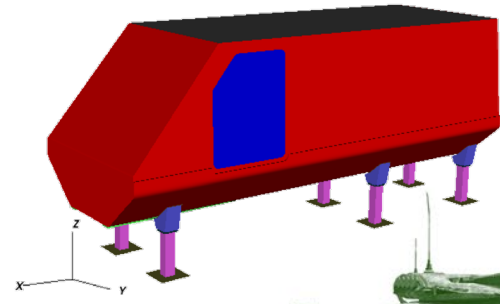
- Approx. dimensions of AGH (2016 version) are 4.8m (F/A), 1.7m (S/S), 2.3m (V); weighs 6825 kg
- Purely a hull with no propulsion, transmission or suspension
- Accommodates up to 6 seats and ATDs
- CAD data available as drawings and STEP format, including welding/assembly details
- Fully assembled FEA model in LS-DYNA keyword data format is also available with representative material data



CAD Drawings / STEP



Representative seating arrangement



Finite Element Model





- AGH test asset rests on 6 stands to provide the right hull clearance
- Test parameters available in detail such as
 - Occupants' setup
 - Seats' configurations / mountings
 - Sensor types and locations (floor, walls, roof etc.)
- Detailed characterization data for the soil is also available
- Test results provided in detail such as
 - Underbody hull deformations
 - Sidewall velocity histories
 - Wall and floor vertical accelerations
 - ATD pelvic/head accelerations, Tibia and lumbar compression loads for all occupants



AGH Exterior (pre-test)



AGH Interior (pre-test)

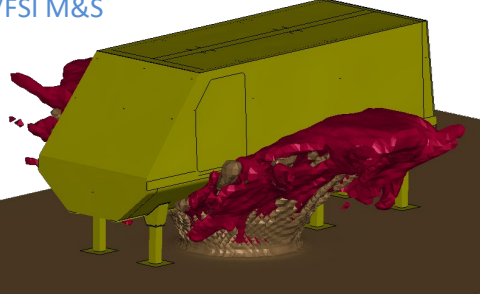


Deformed Underside

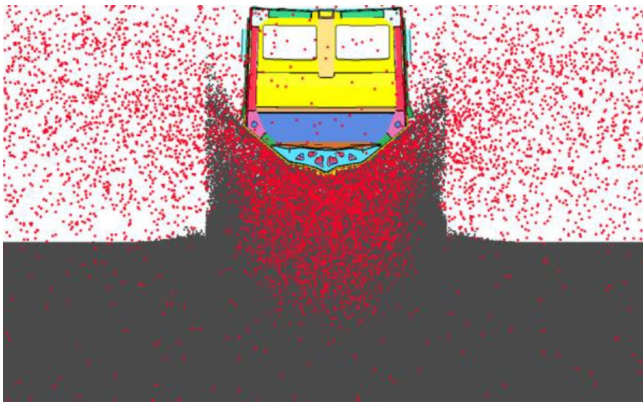
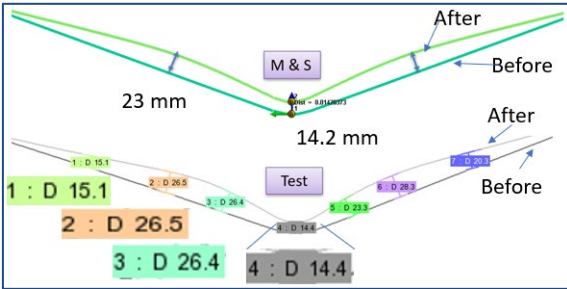




ALE/FSI M&S



Underbody Deformations

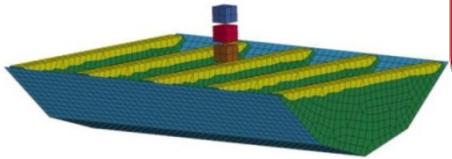


Discrete Element / Particle Gas Method

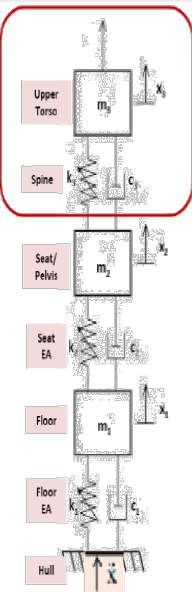
- First reported usage of M&S for full-system UBB was in the use of LS/DYNA's Arbitrary Lagrangian Eulerian (ALE) with Fluid-Structure Interaction (FSI)
- AGH provided the ability to benchmark this methodology with physical tests for vehicle impulse, hull deformations and eventually occupant injuries

- DEM/PGM method compared to the ALE/FSI with respect to strengths and also limitations.
- Soil shown in black, Explosive Particles in red. These are modeled directly as particles that interact with the AGH hull.
- Number of particles follows law of diminishing returns



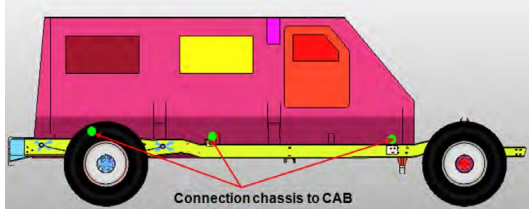


Use of CONWEP loading and 3-DOF lumbar spine model

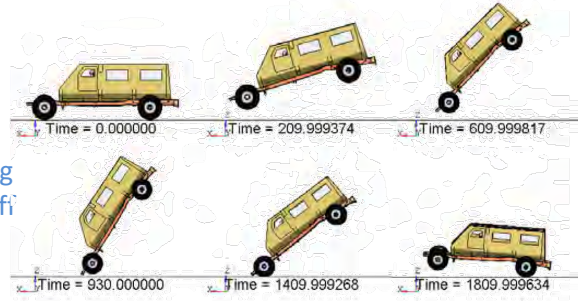


- Takes hull acceleration as input.
- Accounts for energy absorption by the floor and seat.
- Springs representing the floor and seat are piecewise-linear.
- The spring representing the spine is still linear.

$$\begin{aligned}
 m_3 \ddot{x}_3(t) &= F_{spring3} + F_{dampers} & z_3 &= x_3 - x_2 \\
 m_3 \ddot{x}_3(t) &= -k_3(x_3 - x_2) - c_3(\dot{x}_3 - \dot{x}_2) & z_2 &= x_2 - x_1 \\
 m_3(\ddot{z}_3 + \ddot{x}_2) &= -k_3 z_3 - c_3 \dot{z}_3 & z_1 &= x_1 - x \\
 m_3 \ddot{z}_3(t) &= -m_3 \ddot{x}_2 - k_3 z_3 - c_3 \dot{z}_3 \\
 \\
 m_2 \ddot{x}_2(t) &= -F_{spring3} - F_{dampers} + F_{spring2} + F_{dampers2} \\
 m_2 \ddot{x}_2(t) &= k_3(x_3 - x_2) + c_3(\dot{x}_3 - \dot{x}_2) - k_2(x_2 - x_1) - c_2(\dot{x}_2 - \dot{x}_1) \\
 m_2(\ddot{z}_2 + \ddot{x}_1) &= k_3 z_3 + c_3 \dot{z}_3 - k_2 z_2 - c_2 \dot{z}_2 \\
 m_2 \ddot{z}_2(t) &= -m_2 \ddot{x}_1 + k_3 z_3 + c_3 \dot{z}_3 - k_2 z_2 - c_2 \dot{z}_2 \\
 \\
 m_1 \ddot{x}_1(t) &= -F_{spring3} - F_{dampers2} + F_{spring2} + F_{dampers2} \\
 m_1 \ddot{x}_1(t) &= k_2(x_2 - x_1) + c_2(\dot{x}_2 - \dot{x}_1) - k_1(x_1 - x) - c_1(\dot{x}_1 - \dot{x}) \\
 m_1(\ddot{z}_1 + \ddot{x}) &= k_2 z_2 + c_2 \dot{z}_2 - k_1 z_1 - c_1 \dot{z}_1 \\
 m_1 \ddot{z}_1(t) &= -m_1 \ddot{x} + k_2 z_2 + c_2 \dot{z}_2 - k_1 z_1 - c_1 \dot{z}_1
 \end{aligned}$$



AGH integrated w/chassis & suspension



Vehicle Kinematics during the full blast event (lift-off to slam-down)

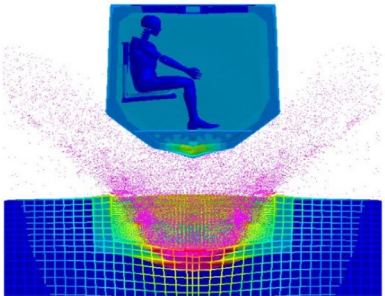
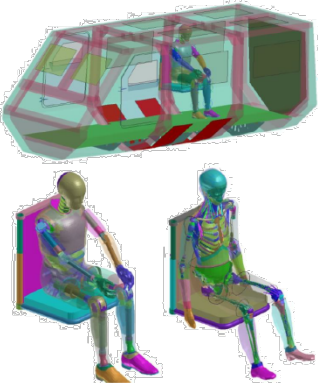
- CONWEP loading on AGH lower underbody
- Simplified 3-DOF (floor, seat, upper torso) model to evaluate DRI injury (Dynamic Response Index)
- New structural design featuring energy absorbing and decoupling mechanisms
- Reduced system weight and increased blast-worthiness

- Objective to perform computationally efficient full vehicle simulations for the full blast event duration of 2500 msec
- AGH enhanced with chassis, suspension and wheels from a HMMWV model
- Study identified several methods to perform the full blast event simulation in reasonable CPU times

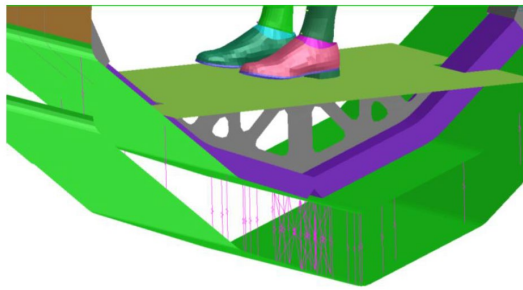




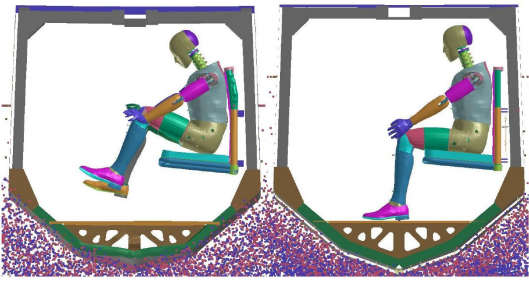
AGH Model Setup with ATD



SPH Blast Loading on AGH @10 ms after blast



Double Hull concept

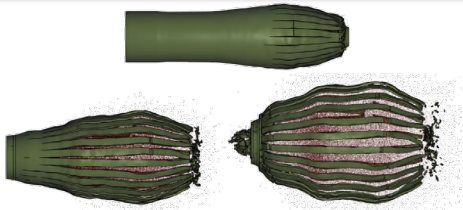


Occupant Kinematics: Single hull (L) vs. Double Hull (R)

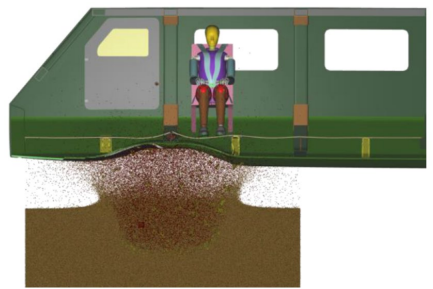
- Smoothed Particle Hydrodynamics (SPH) method used for blast loading in PAM/SHOCK
- SPH is mesh-free Lagrangian method to model explosive and soil particles, hence an unified Lagrangian framework for the entire system
- Paper looked at various occupant responses and kinematics

- SPH loading was again used to investigate different hull concepts for mitigation of occupant accelerations
- Second hull added with spring-damper connections to the primary hull
- Results indicate occupant kinematics and injuries can be improved by optimal choice of spring-dampers.

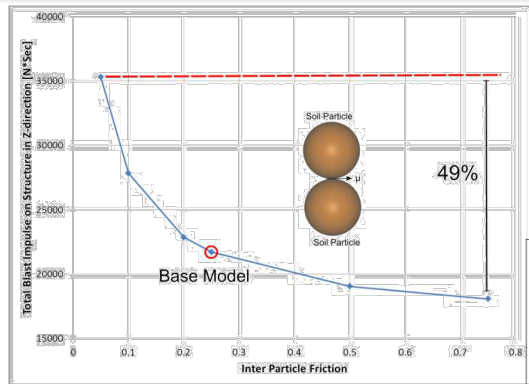




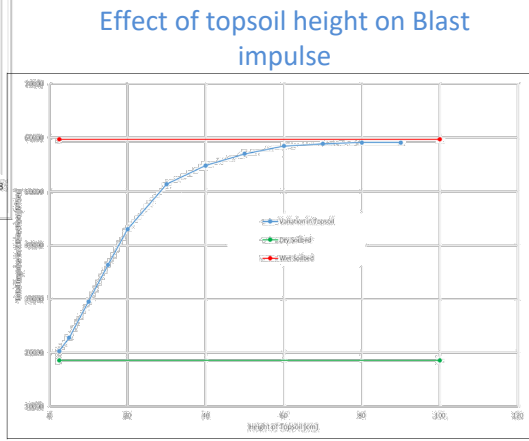
Development of fragmentation



Interaction of ejecta and AGH

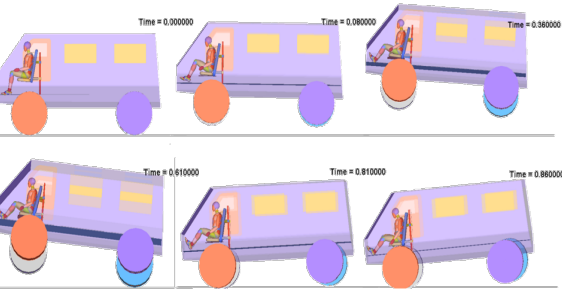


Effect of inter-particle friction on Blast impulse



- Uses higher order finite elements and discrete particle method (DPM)
- Solid elements are used, for example, to model the AGH, 155 mm artillery shell etc.
- Node splitting algorithm employed to account for damage, crack propagation, and fragmentation
- Parameter characterization of IED event with emphasis on IED shapes and soil bed conditions (density, packing, inter-particle interactions/friction, etc). The latter found to have significant effect on Blast impulse.
- Similar study placed further emphasis on sympathetic detonation and layered soil bed conditions. Effect of different heights of wet topsoil on dry beds shows increasing impulses for larger heights of topsoil

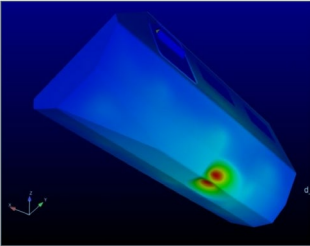




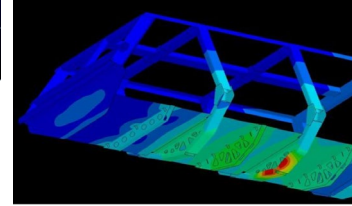
Kinematics through the full blast event

MADYMO

- Reduced order modeling method for rapid simulations of UBB rollover events, from lift-off to slam-down
- Rigid Body models combined selectively with finite elements
- Simple suspension/wheel subsystem integrated to the AGH

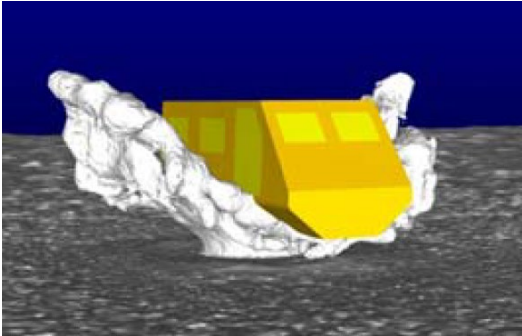


Deformed shape contours of AGH



CTH

- Enhancement to Sandia CTH hydrocode was a one-way coupling procedure (CTH to LS/DYNA)
- CTH-generated blast pressure loads on LS/DYNA Lagrangian hull
- Avoids complexities of ALE/FSI methodology

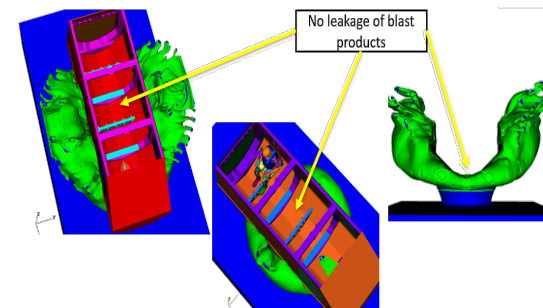


Quartz Cloud (70% Volume Fraction) at 5 ms

LOCI/BLAST

- Fully conservative CFD code
- Models soil and blast using a multi-species formulation/EoS
- LOCI/BLAST-generated blast pressure loads on LS/DYNA Lagrangian hull. Two-way conformal coupling
- Avoids complexities of ALE/FSI methodology

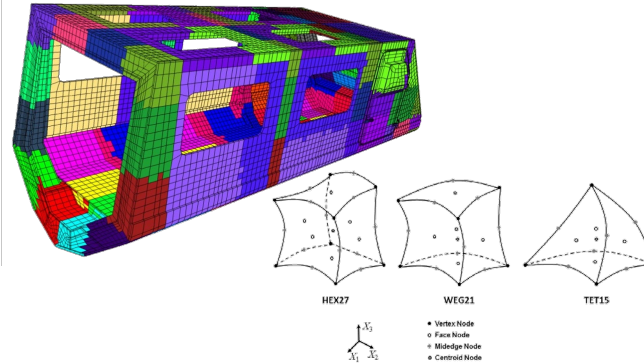




Kinematics through the full blast event

PARADYN/ALE3D w/FEusion

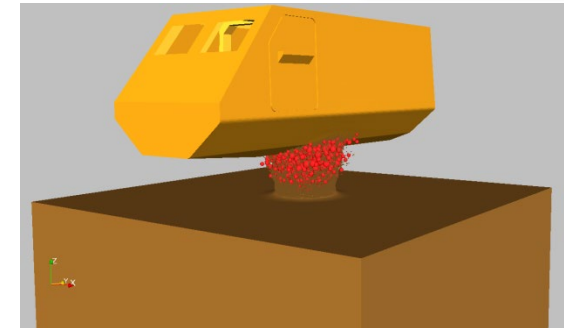
- LLNL developed FEusion, an embedded mesh feature library as part of Army Blast Institute project
- ALE3D (background Eulerian mesh) to massively parallel Lagrangian PARADYN (foreground mesh)
- Significantly superior in managing leakage of explosive ejecta through the hull



AGH Hex-dominant mesh, Solid Element types

ParaAble/MINEX3D

- 2nd order HEX-dominant model for AGH to demonstrate ease of accurate meshes
- Solver used in an MPI-based parallel FE code internal to Army
- Army-developed code MINEX3D used to produce pressure time histories applied in ParaAble to the hull underbody



UBB simulation using EPIC

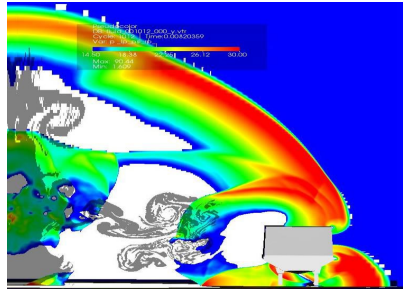
EPIC

- Developed to simulate large deformation, highly dynamic events in purely Lagrangian way
- ERDC's Hybrid Elastic Plastic (HEP) soil model. Soil starts as finite elements and converted to particles at large plastic strains
- In support of a further set of recent AGH UBB tests at Ft Polk

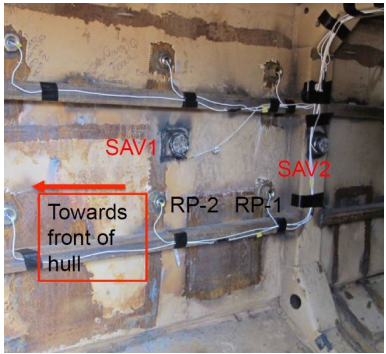




AGH Test Setup for free air detonations (top)

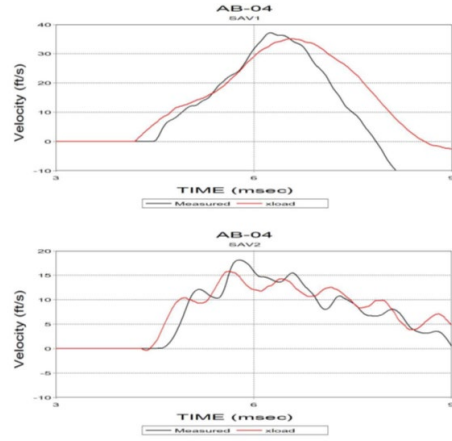


Vortices around AGH from simulations (leading edge and wrap-around)



Accelerometers on AGH Side Wall

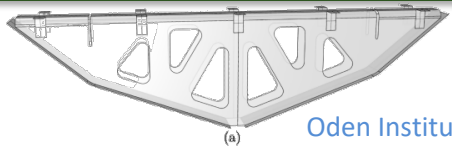
Comparison of velocities at side wall locations: Test (black), M&S (Red)



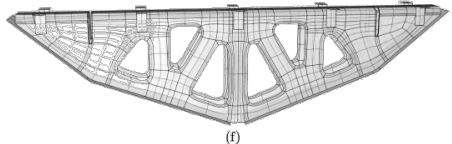
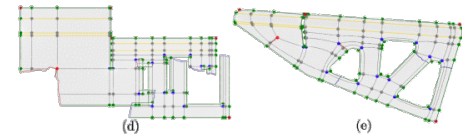
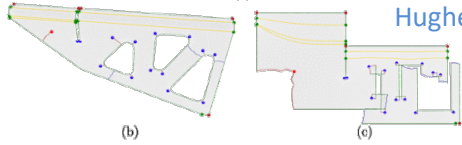
- US Navy labs use DYSMAS (Dynamic System-Mechanics Advanced Simulations) for UNDEX, FLOATEX as well as UBB of land vehicles
- Explicit, fully coupled, FSI solver
- As part of ERDC’s ASCENT program, methods were developed for emerging HME threats.
- 2D axisymmetric and full 3D coupled simulations with AGH were conducted.

- MINEX3D is a fast-running code for prediction of pressure loads for buried as well as air blasts
- MINEX3D pressure loads were then applied to the AGH using XLOAD feature of DYSMAS to its structural solvers such as PARADYN
- Results indicate good agreement of side wall velocities between test and these simulations



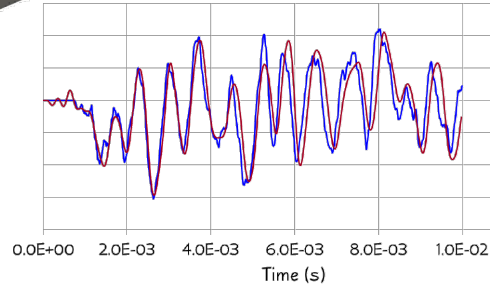
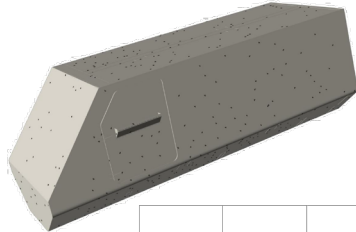


Oden Institute, UT-Austin
Hughes et al



- Theory-based computational framework for definition of an isogeometric analysis-suitable, quadrilateral parameterization on a surface
- 3-step approach to compute a feature-aligned quad mesh for a surface
- Process shown in paper for AGH bulkhead beam

Army HPCRC, Stanford
Farhat et al



- Parametric studies of UBB for both high-fidelity and fast-running ROM
- Energy-preserving hyper reduction methodology was developed and verified on AGH
- Good agreement in hull response between High Fidelity model (blue) and hyper-reduced model (red)

2021 Ft. Polk UBB experiments
Williams et al



- PRIMUS dummy originally designed for pedestrian impacts, was investigated for UBB applications
- ATD was used in AGH blast tests to provide correlation data for lab testing
- Emerging results indicate good agreement between responses of HIII and Primus dummies





- Creating the Army Generic Hull publicly shareable database has been a remarkably successful experiment
- Army Generic Hull data has been, and continues to be used broadly in the development and validation of tools and methodologies for underbody blast applications
- Indeed, in some ways, it has been deployed in even more innovative ways than originally envisioned by Army leadership
- The database is being used adequately in gaining knowledge and confidence in numerical codes, whether they pass the test of expected engineering/physics outputs, in determining stability limits and for parametric studies (**Verification**)
- On the other hand, studies on direct comparisons between simulations and the available test data in vehicle and occupant responses should be improved (**Validation**). This is imperative for successful **VV** & **Accreditation** of UBB codes and methodologies.





Thank you

Questions?





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