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

Kumar Kulkarni[1], Sanjay Kankanalapalli[1], Venkatesh Babu[1], Jai Ramalingam[1], Ravi Thyagarajan[2] PhD

[1]Army DEVCOM Ground Vehicle Systems Center, Warren, MI
[2]Texas A&M University, College Station, TX

ABSTRACT

This paper reviews the Army Generic Hull [1-5] as a vital developmental tool for underbody blast modeling and simulation applications. Since 2010, it has been used extensively to help calibrate and validate various numerical software codes and methodologies. These are being used extensively today in the development of underbody armor, as well as mine blast subsystems such as seats, to protect both military vehicles and their occupants. In the absence of easily shareable information in this domain due to data classification, this specially formulated product is a valuable part of any toolset for underbody blast development and product design.

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1. INTRODUCTION

It is common knowledge that underbody blasts have become one of the most widespread reasons for warfighter casualties in recent wars. Lumbar spine and lower leg tibia injuries to occupants have particularly increased in theater from these roadside blast incidents. To support the design and development of military ground vehicles, mine blast underbody hull kits and mine blast seats, a suite of underbody modeling software and methodologies have been developed over the past decade [6-36]. These modeling and simulation (M&S) methodologies are being continuously enhanced with ever-increasing capabilities to predict vehicle structural and occupant injury responses, including fast running models for the same [25-29].

Like with all analytical software codes and methodologies, underbody blast (UBB) M&S tools need to be validated against a set of known benchmark models prior to being used for product design and test assessments. Especially with blast scenarios, the exceedingly high-speed events involve large forces and accelerations, with materials in extreme dynamic environments. One of the more well-known benchmark problems is often referred to as the *DRDC Flat Plate test* [6]. Experiments were carefully conducted by Defense R&D Canada (DRDC) – Valcartier in which Aluminum and RHA flat steel plate test articles were subjected to buried mines. Deformation histories of various known locations were recorded using a series of piezo pins. While this experiment provided much more pertinent information for buried charges than the pressure histories from the CONWEP experiments for exploding charges in air, it was a rather simple shape and not representative of more complicated underbody hull shapes such as the V-Hull which became a common design feature in the Iraq and Afghanistan wars.

Due to the sensitive nature of the work performed by the Department of Army, data generated from testing fielded military vehicles is Classified, making it difficult to share the data freely. Because of this, the Army has had difficulty informing the industry and academia on the severity of the dynamic effects of underbody blast events.

To alleviate this, starting around 2010, the Army Tank Automotive Research and Development and Engineering Center (TARDEC), now called the Army Ground Vehicle Systems Center (GVSC) fabricated a generic military vehicle hull with typical design features, shapes and sizes and performed a series of underbody blast tests with the express intent to:

a) Subject it to underbody mine blast tests with standard charges for benchmarking
b) Share the data publicly
c) Leverage industry and academic partners to evaluate blast mitigating technologies
d) Provide benchmark data for the development and validation of software codes for underbody blast M&S

This paper serves as a review of the Army Generic Hull (AGH) since its original inception in 2010 [1,2]. Section 2 provides a general description of the test asset and its M&S counterpart, as well as the information that is publicly available for use by government, academia and industry [3-5]. Section 3 provides a look at some of the different ways the AGH has been leveraged by the community at large in the validation of software codes and methodologies.

2. THE ARMY GENERIC HULL (AGH)

Figure 1 is a representative view of the Army Generic Hull (AGH), better known previously as the TARDEC Generic Hull. With the renaming of TARDEC to GVSC, it is perhaps more appropriately called the AGH henceforth.

Figure 1: Representative view of AGH

As may be seen from Figure 1, this asset is purely a hull with no propulsion, transmission, suspension subsystems, etc., and rests on 6 stands. The AGH is designed to accommodate up to six seats and occupants as shown in Figure 2.

The approximate dimensions of the AGH are 4.8 meters (fore-aft), 1.7 meters (side-side) and 2.3 meters (bottom of hull to roof). It is composed mostly of RHA steel and weighs 6825 kg (without seats, occupants etc.) In reality, there have been a few iterations of the AGH over the past 10 years or so [1-5], the latest publicly available version is from 2016 [2, 4, 5]. The AGH data package is composed of four main sections, as outlined below.

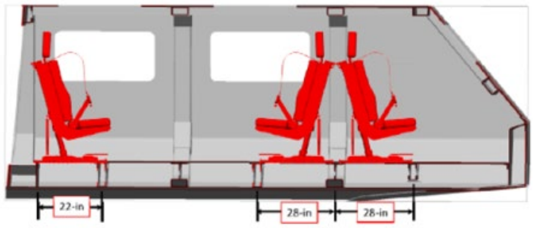

Figure 2: Representative seating arrangement within the AGH

2.1 AGH: GEOMETRY

Drawings from the AGH geometry are included which describe the various components of the hull in three dimensions, as well as thicknesses, material composition, how they are welded together, etc., as shown in Figure 3. This data is also available electronically in STandard for the Exchange of Product model data (STEP) computer-aided design (CAD) format. This information may be used by our partners to create a finite element or other computer model of their choice for physics-based computer-aided performance analysis.

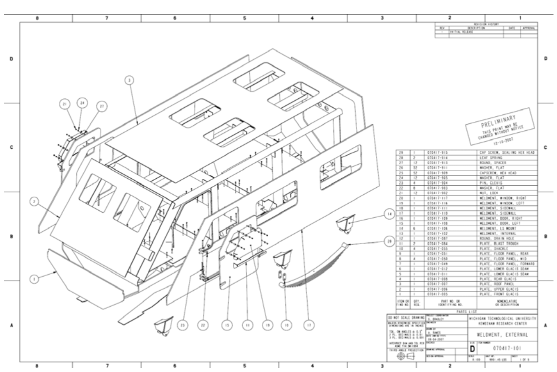

Figure 3: CAD Drawings

2.2 AGH: FINITE ELEMENT MODEL

A fully assembled Finite Element Analysis Model (FEA/FEM) is included for direct analysis in LS-DYNA keyword format (Figure 4). This text datafile can be viewed in any standard word processor such as Word, Notepad, etc., and visualized using any standard FEA pre/post processor such as HYPERMESH, LS-PREPOST, etc. This model may be readily integrated with other FEA models of seats, occupants, soil/charge configurations, as appropriate.

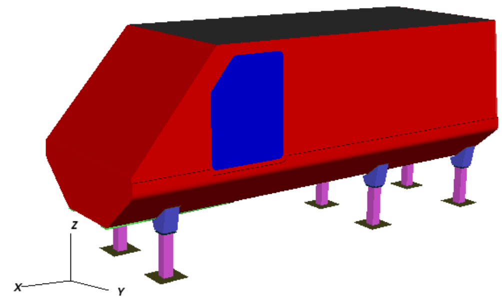

Figure 4: FEA Model

2.3 AGH: TEST SETUP

Figures 5a and 5b show representative views of the AGH exterior and interior, respectively, prior to the underbody blast development test.

Figure 5a: AGH Exterior (pre-test)

Figure 5b: AGH Interior (pre-test)

This section describes in detail the various pre-test configuration parameters, for example, occupant setup (sizes, PPE, etc.), seat configurations and mountings, vehicle sensor types and exact locations on the side walls, floor, etc., of the AGH.

Because any good blast simulation requires well-characterized soils, also included is laboratory test data on mechanical and index property tests on soil specimens used in the AGH test [30]. These tests may be used to characterize the strength and compressibility properties of the soil for inclusion in the M&S of the event using the FEA software of choice.

2.4 AGH: TEST RESULTS

Figure 6 shows a view of the bottom of the deformed V-Hull of the AGH asset after the test.

Figure 6: Deformed underside of AGH

This section provides information on vehicle and occupant responses from the test in Aberdeen Proving Grounds. Some of the information included are:

(i) Hull deformation values at specified locations
(ii) Average Sidewall Velocity histories
(iii) Side wall and floor vertical accelerations using different accelerometer sensor types at various locations on AGH
(iv) Pelvic and head accelerations, and Tibia and lumbar compression loads for the six occupants.

3 USAGE OF AGH IN ONGOING UBB RESEARCH

As mentioned previously, even a brief literature survey of UBB research in the past decade reveals the extensive usage of the AGH for the purpose that it was intended for, namely as a benchmark example for verification, validation and accreditation (VV&A) of underbody software codes and methodologies. The following are some of the reported examples of these activities by various researchers in the blast community.

3.1 LS-DYNA

The first reported usage of the AGH in UBB development was in employing the Arbitrary Lagrangian Eulerian (ALE) formulation in LS-DYNA in conjunction with the Fluid-Structure Interaction (FSI) between the blast products and the hull. By the time the first AGH was produced, the Army had successfully applied the ALE-FSI construct in LS-DYNA to a number of existing and new military vehicles to develop armor and mine-attenuating seats to protect the vehicle and occupants [7]. But the AGH tests afforded the first opportunity to systematically validate the M&S results against the benchmark. Figure 7a shows a typical ALE-FSI simulation using LS-DYNA for the AGH, while Figures 7b (displacement contours) and 7c (before and after comparison of hull bottom section directly above the charge) shows the favorable comparison of the hull bottom deformations between the simulation and the physical test.

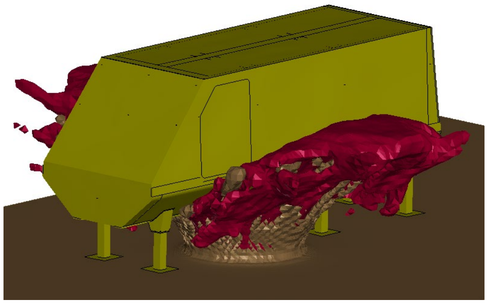

Figure 7a: M&S for AGH using ALE/FSI

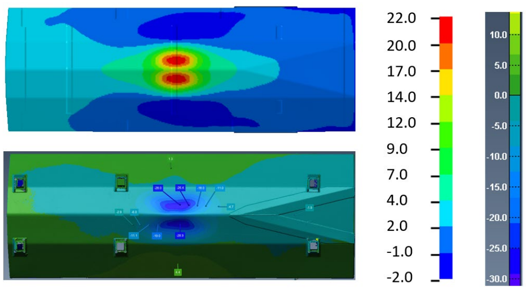

Fig 7b: Deformation comparison between M&S (top) and Test (bottom) Note: sign reversal due to different coordinate frame of reference

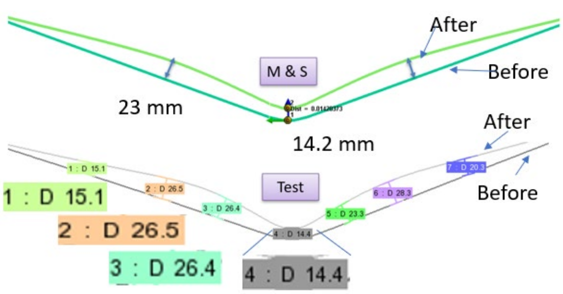

Fig 7c: A comparison of sections; M&S (top) and Test (bottom) through the hull bottom before and after blast loading

In a different study, the CONWEP loading function in LS-DYNA was used to create a new structural design featuring energy absorbing and decoupling mechanisms [9,14]. This resulted in a reduced system weight and increased blast-worthiness. This study uses simplified three-DOF Dynamic Response Index (DRI) model for estimating occupant injury as shown in Figures 8a and 8b.

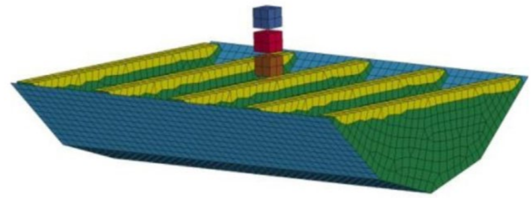

Figure 8a: Use of CONWEP loading and 3-DOF lumbar spine model with AGH [9,14]

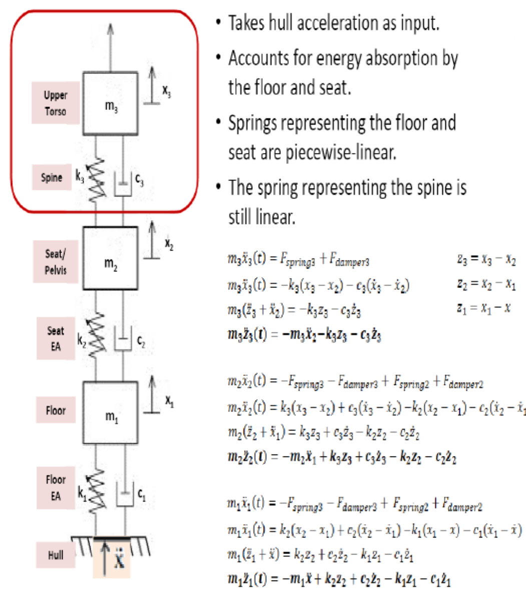

Figure 8b: DRI – 3-DOF Mechanical Model

In [10], the authors compared the effect of sensitivity of particle size in the performance of the Discrete Element/ Particle Gas Method (DEM_PGM) blast simulation to that of the ALE method. Both simulations were conducted using LS-DYNA. The main focus of this study was to understand the strengths of DEM_PGM method and identify the limitations/strengths compared to ALE. Figure 9 shows the snapshot of interaction between the particles of soil (black) and explosive products (red) with the AGH.

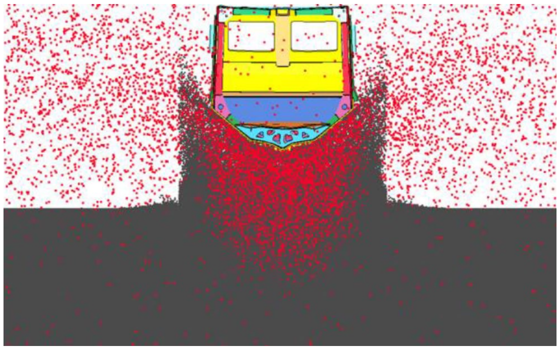

Figure 9: DEM_PGM M&S with AGH [10]

To investigate the new Structured ALE method introduced in LS-DYNA, an analysis was reported of comparative occupant responses between ALE and S-ALE methods [11]. An occupant with full Personal Protective Equipment (PPE) was seated on a typical stroking seat as shown in Figure 10a. The study concluded that normalized occupant injury values (Figure 10b) and vehicle responses were very similar in both formulations.

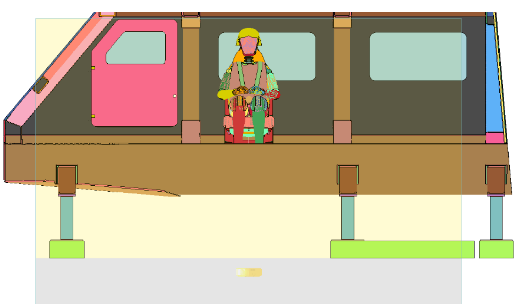

Figure 10a: Blast model setup with AGH and Occupant with full PPE [11

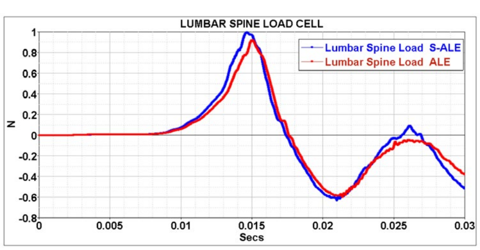

Figure 10b: Lumbar load response [11]

A similar analysis in LS-DYNA was reported with ALE, S-ALE and DEM models for Magnetically Attached IED (MAIED) threat [12]. The objective of the study was to develop a faster method for simulation of military vehicles exposed to fragmenting underbody IED threats, and the AGH was used for this purpose. Figure 11 shows the snapshots over three instants of time of the MAIED fragment interactions with the AGH underbody

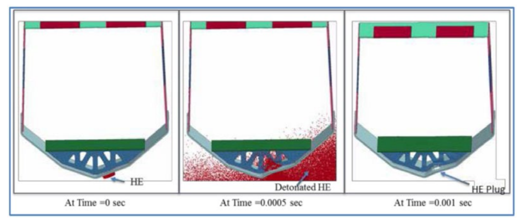

Figure 11: Snapshot animation of MAIED frags interacting with AGH [12]

A methodology was developed to perform computationally efficient full vehicle simulations in LS-DYNA for the entire blast event, from lift-off through slam-down [13]. In this study, the AGH was enhanced with chassis, suspension and wheels from a HMMWV model, as shown in Figure 12a.

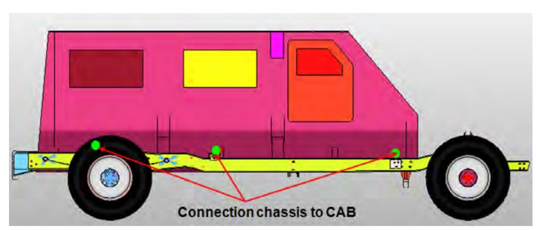

Figure 12a: AGH Model integrated with chassis and suspension [13]

Figure 12b shows the kinematics of the vehicle throughout the event. The total simulation time for this event was 2500ms. The energy transmitted from the explosive to the structure causes the vehicle to lift off the ground. The charge being off-center from the

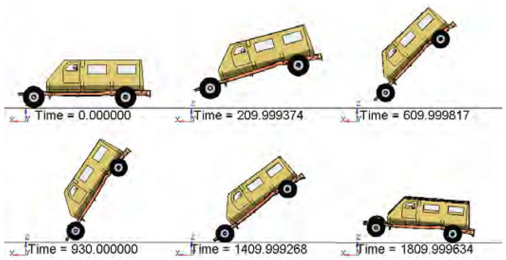

Figure 12b: Vehicle Kinematics during the full blast event [13]

center of gravity of the vehicle causes a large rotation about the pitch axis. Gravity causes the vehicle to slam back to the ground. An interesting phenomenon, not necessarily intuitive, should be noted here. While it is expected that an rear-of-cg blast location will rotate the vehicle in a counter-clockwise direction on the way up (210 to 610 ms), it may be observed that this counter-clockwise rotation continues even on the vehicle's way down (610 to 930 ms).

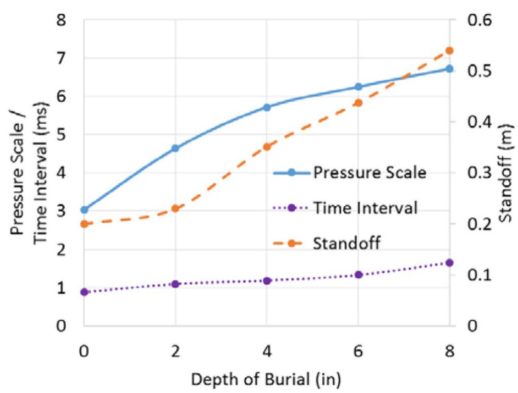

Figure 13: Parameters for distributed free-air blasts (AGH example)

Another fast-running loading methodology for UBB events was discussed to capture the loading effects from charges in buried soil without having to employ high detailed and computationally expensive models for the same [26]. The idea was to match buried blast loading patterns using commonly available free-air blast datasets. Figure 13 shows the optimal parameters from LS-OPT for distributed free-air blasts that provide comparable results to full ALE simulations.

3.2 PAM-SHOCK

After AGH's first usage in LS-DYNA, the next major high speed dynamic software to use the AGH was PAM-SHOCK using its Smoothed Particle Hydrodynamics (SPH) methodology [8]. SPH is a mesh-free Lagrangian method that has been thought to be more configurable with direct input of variables such as the soil density and explosive size without extensive tuning of parameters. Figure 14 shows a snapshot of the SPH blast loading to the hull at the 10 ms instant after initiation.

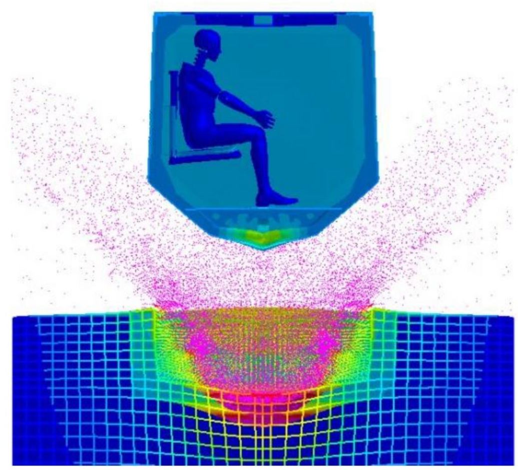

Figure 14: SPH Blast loading @10 ms [8]

Another project also involved PAM-SHOCK and SPH modeling of charge/soil to derive hull concepts to mitigate occupant acceleration in a vehicle blast event [15]. In this study, a second hull was added to the AGH with a spring-damper connection between the two hulls, as shown in Figure 15a. Results indicate that both the occupant kinematics (Figure 15b) and the actual injuries can be improved by optimal choice of the spring-damper systems.

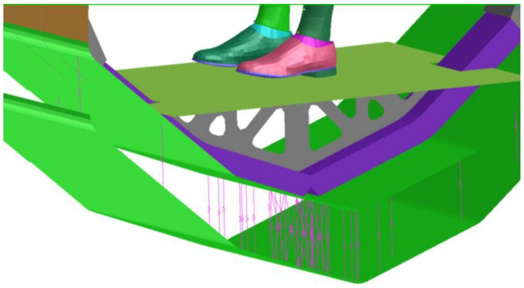

Figure 15a: Double Hull concept using AGH

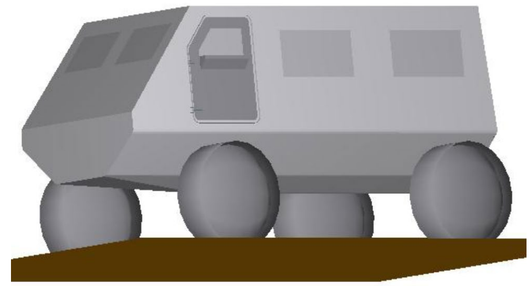

Figure 16a: MADYMO model for AGH [23]

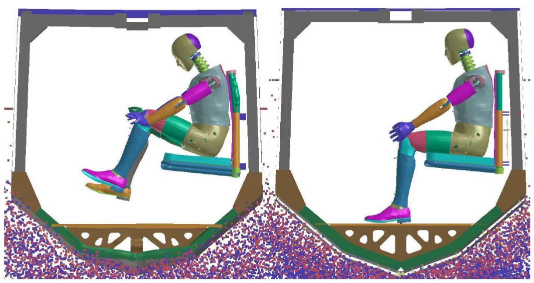

Figure 15b: Occupant kinematics: Single (Left) vs Double (Right) hull [15]

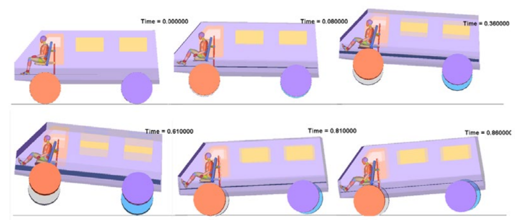

Figure 16b: Kinematics through the entire blast event [23]

3.3 MADYMO

A reduced order modeling method for rapid simulations of UBB rollover events of a ground vehicle and occupants used the commercial software MADYMO [23]. In many aspects, the objectives of this study are similar to [13], except that the approach used here is to use rigid body models integrated with finite elements to predict the behavior of the vehicle and occupant system over the entire blast event, that is, from blast-off to slam-down. Again, like in [13], a simple suspension/wheel subsystem was also integrated to the AGH as shown in Figure 16a. Vehicle kinematics including that of the driver dummy are shown in Figure 16b.

3.4 IMPETUS

Research in modeling fragmentation of a 155 mm artillery shell buried in a mine blast event was undertaken to accurately simulate soil interaction with the explosive ejecta [16]. This work was performed using the commercial software IMPETUS Afea solver, using finite element and discrete particle method (DPM) techniques. The shell casing and the AGH are modeled using solid elements that take advantage of the “node splitting” algorithm to accurately account for damage, crack propagation, and fragmentation of the artillery shell (Figure 17a). The interaction between the ejecta particles and the AGH and occupant system is shown in Figure 17b

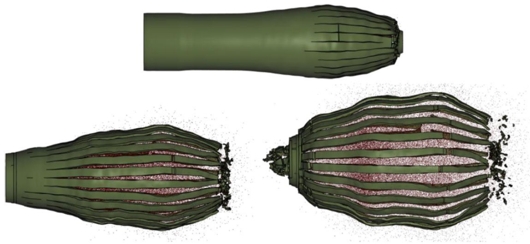

Figure 17a: Development of the fragmentation for the M795 artillery shell @50, 100, 150 μsec [16]

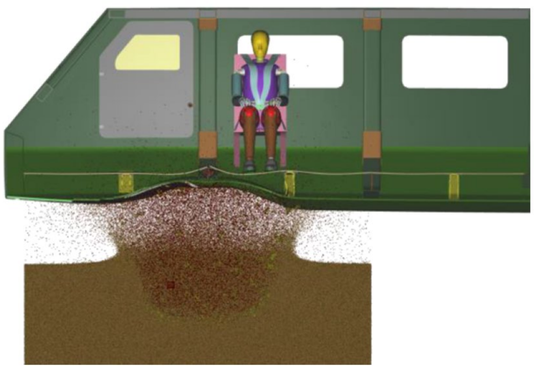

Figure 17b: Interaction between ejecta and AGH underbody [16]

In another study, numerical parameter characterization of a buried mine blast event was conducted with further emphasis on IED shapes and soil bed conditions [17]. 14 design variables such as soil density, packing, inter-particle parameters, friction, charge size/type/geometry, etc., were included. All UBB analyses were conducted for the AGH, and IMPETUS Afea solver was used as previously. One of the significant findings was that the inter-particle friction was an important soil parameter in the amount of Blast Impulse imparted to the vehicle, as shown in Figure 18.

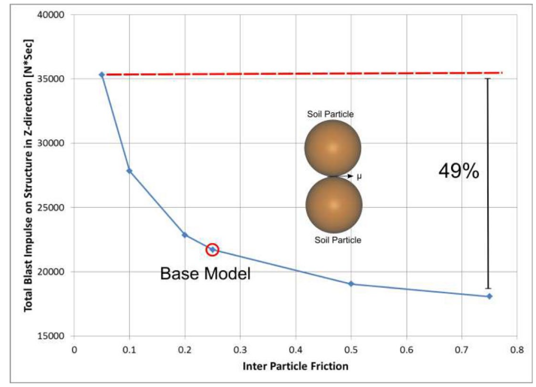

Figure 18: Effect of inter-particle friction on Blast Impulse [17]

A very similar study to the above was conducted for a numerical parameter characterization of a buried mine blast event, but this time with further emphasis on sympathetic detonation and layered soil bed conditions [18]. As before, the Blast Impulse imparted to the AGH was chosen as the response parameter to be monitored. Figure 19 shows how the impulse varies as the height of topsoil is varied from 0 to 100 cm, as well as the relatively constant impulses for dry and wet soil beds. When compared to [17], this study employs a more flexible algorithm which enables ability to model multiple layered beds as well as sympathetic detonation in a mine blast event.

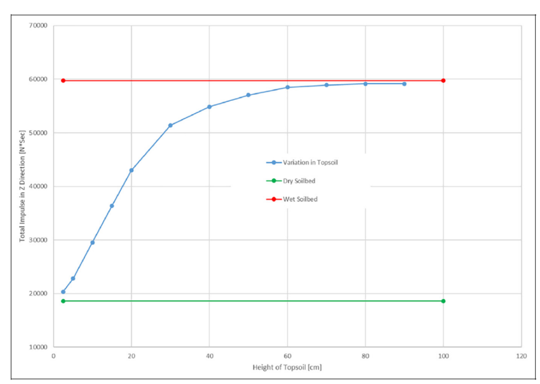

Figure 19: Blast Impulse to the AGH as a function of topsoil height [18]

3.5 CTH

Improvements to the Sandia CTH hydrocode pertaining to UBB analysis is the subject of a research study to support protective design of military vehicles [21]. One of these improvements was a one-way coupling procedure from CTH to LS-DYNA whereby blast pressure loads generated from CTH were used to load the Lagrangian AGH hull in LS-DYNA, thus avoiding the complexities associated with ALE simulations. Figures 20a and 20b show the deformed shapes of the external hull and the internal frame of the AGH at 5 ms, respectively.

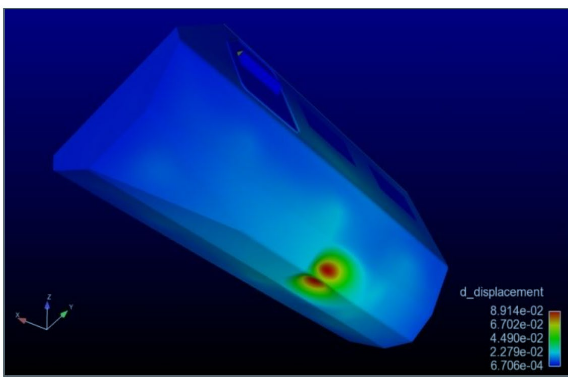

Figure 20a: Deformed shape contours of AGH external hull [21]

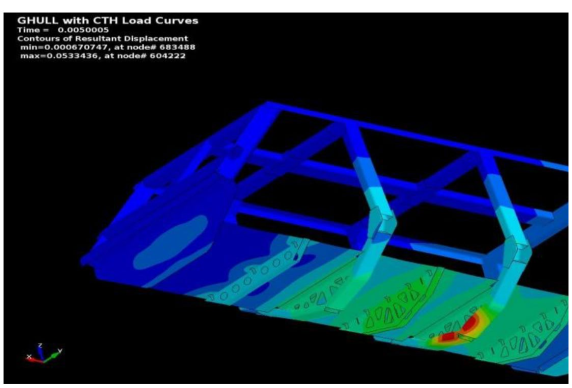

Figure 20b: Deformed shape contours of AGH internal frame [21]

3.6 LOCI/BLAST

In an exercise very similar to Sec 3.5 with CTH, blast pressure loads from LOCI/BLAST software code were used to load the Lagrangian AGH hull in LS-DYNA [22]. LOCI/BLAST is a fully-conservative, computational fluid dynamics code with the capability to model soil and blast using a multispecies formulation with advanced equations of state. One important difference from Sec 3.5 is that this coupling is two-way and conformal coupling, so expected to be more accurate. Figure 21a provides a look at the interaction between the ejecta and the AGH which translates to pressure loads being applied to the external skin of the hull. Figure 21b shows the pressure loading on the hull as a function of the hull mesh size.

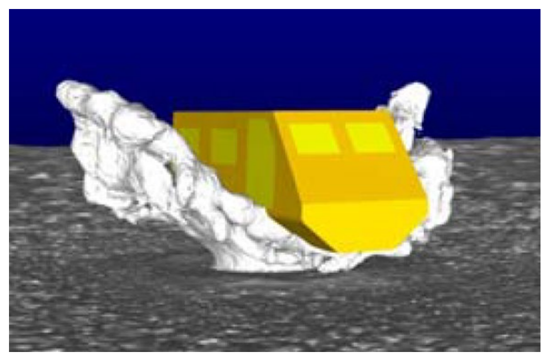
Figure 21a: Quartz Cloud (70% Volume Fraction) at t=5 ms [22]

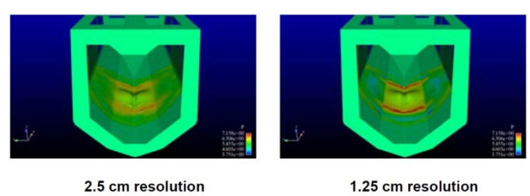

Figure 21b: Pressure on Hull Surface at t=1 ms [22]

3.7 PARADYN/ALE3D with FEusion

As part of the Army Blast Institute activities, Lawrence Livermore National Laboratory developed an embedded mesh feature library named FEusion, enabling a coupled ALE3D (background Eulerian mesh) to their massively parallel Lagrangian solver PARADYN (foreground mesh). This approach simplified model development by avoiding body fitted mesh preventing mesh tangling. Though computationally slower than traditional FSI approaches (LS-DYNA for example), emerging results using coupled ALE3D-PARADYN indicate absolutely no leakage of the explosive products through the Lagrangian hull (Figure 22). This is much improved over other codes where significant tweaking of the FSI control parameters is necessary to control these leaks.

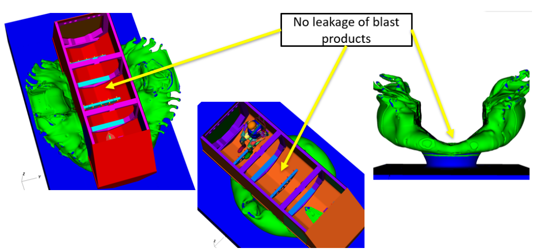

Figure 22: Interaction of blast ejecta with AGH

3.8 ParaAble / MineX3D

A second-order hexahedral (HEX)-dominant UBB model was constructed for the AGH to investigate the balance of ease of meshing with accuracy [24]. The solver used is an MPI-based parallel FE code, ParaAble [31]. The three element types used are shown in Figure 23a and the AGH hex-dominant mesh with partitions for 144 parallel cores is shown in Figure 23b to distribute near equal/clumped portions of the mesh to each parallel processing core.

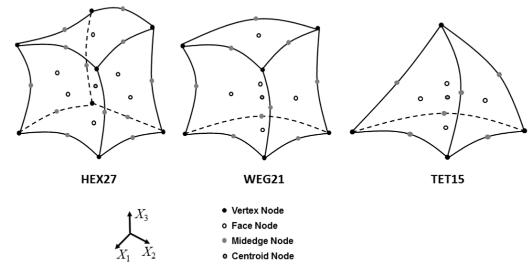

Figure 23a: Solid element types [24]

In this analysis, an Army-developed code called MineX3D [32] is used to produce pressure time histories in a methodology similar to in principle, but much more improved in practice, to the erstwhile CONWEP free-air blast pressures. MineX3D generated pressures are then applied to the external skin of the AGH

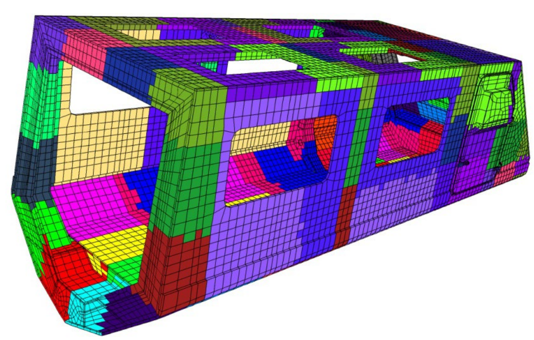

Figure 23b: AGH hex-dominant mesh [24]

3.9 EPIC

In a joint effort [36] to further expand underbody blast effects research, the U.S. Army Tank Automotive Research, Development (TARDEC) and US Army Engineer Research and Development Center (ERDC) conducted a series of underbody blast experiments utilizing the AGH. ERDC chose the Elastic-Plastic Impact Computations (EPIC) code [35] to model these events because the code was developed to simulate large deformation events and includes ERDC's Hybrid Elastic Plastic (HEP) ground shock model. The explosive and air were modeled using a generalized particle algorithm within the EPIC code for the full simulation, while the soil began as finite elements and was converted to particles once it reached a prescribed plastic strain (Figure 24). Total impulse, deformation (where applicable), soil stress, and velocity measurements were calculated in the simulations.

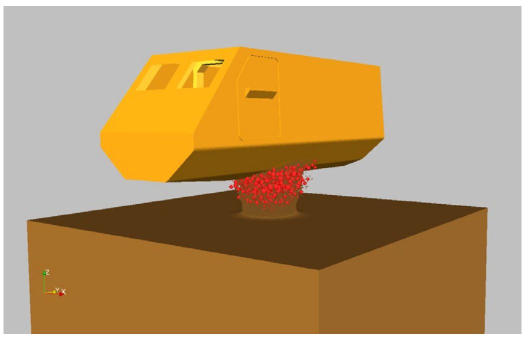

Figure 24: Underbody blast simulation using EPIC [36]

3.10 DYSMAS

As part of ERDC's Adaptive Simulation to Characterize Emerging Non-Ideal Threats (ASCENT) program, methods were developed for detonation of emerging HME threats. Two different studies were reported for simulations of the AGH using DYSMAS [33] and DYSMAS / MineX3D [34].

In the first study, free air detonations were conducted away from the AGH, and free-standing pressure sensors placed on the ground (Figure 25a), in addition to sensors on the top and side of the AGH.

Both 2D axisymmetric fluid-only simulations and full 3D coupled simulations including AGH were conducted. Figure 25b shows the pressure comparison at one of the roof gauges on the AGH for a free air detonation with C-4 away from the test asset. The simulations were able to capture the vortices formed from the leading edge as well as from the wrap-around blast, as indicated in Figure 25c.

Figure 25a: Test setup with AGH for free air detonations [33]

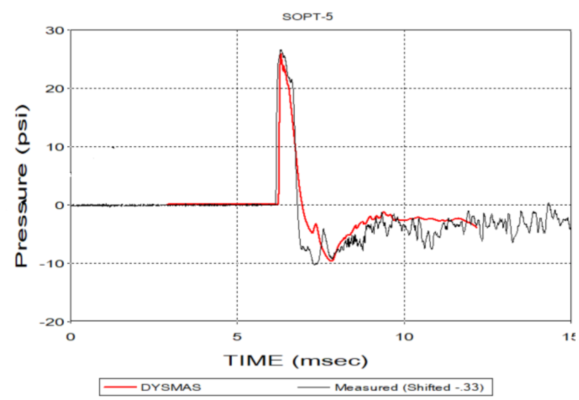

Figure 25b: Pressure comparison at a roof gauge location (test/black vs. M&S/red) [33]

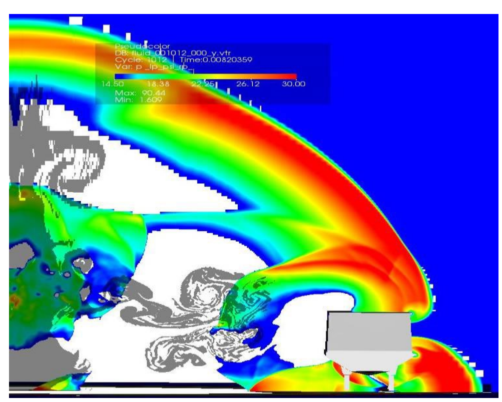

Figure 25c: Vortices predicted in DYSMAS simulations [33]

In the accompanying second study, the XLoad feature of DYSMAS was exploited which provides a capability for external programs to provide data to DYSMAS structural solvers such as PARADYN. MINEX3D also mentioned in Sec 3.8 is a fast-running engineering code used primarily for predicting blast loads on a vehicle. While originally developed for buried blast applications, it was later extended for air blasts and was used in this study via the XLoad feature. Figure 26a shows two accelerometers on the vertical wall of the AGH. Figure 26b is a comparison of the vertical velocity at these two locations between the test (black) and the DYSMAS/MINEX3D simulations.

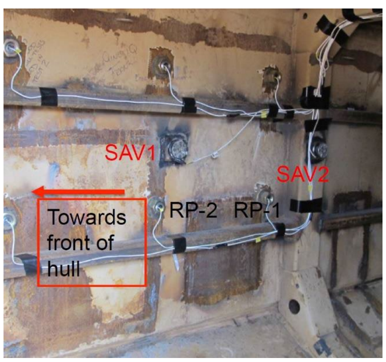

Figure 26a: Accelerometers SAV1 and SAV2 on the AGH wall [34]

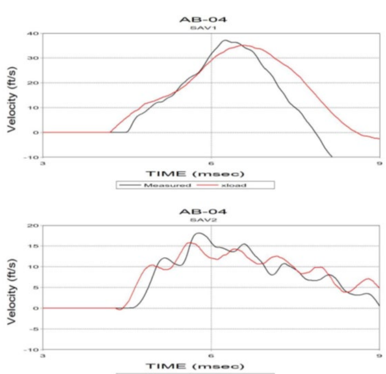

Figure 26b: Velocity Time History comparison at the two wall locations [34]

3.11 OTHER RESEARCH

A theory-based computational framework was presented by the Oden Institute at UT-Austin that defines an isogeometric analysis-suitable, quadrilateral parameterization on a surface [19, 20]. A 3-step approach is adopted to compute a feature-aligned quadrilateral mesh for a surface. This process is shown for the bulkhead beam component of the AGH in Figure 27.

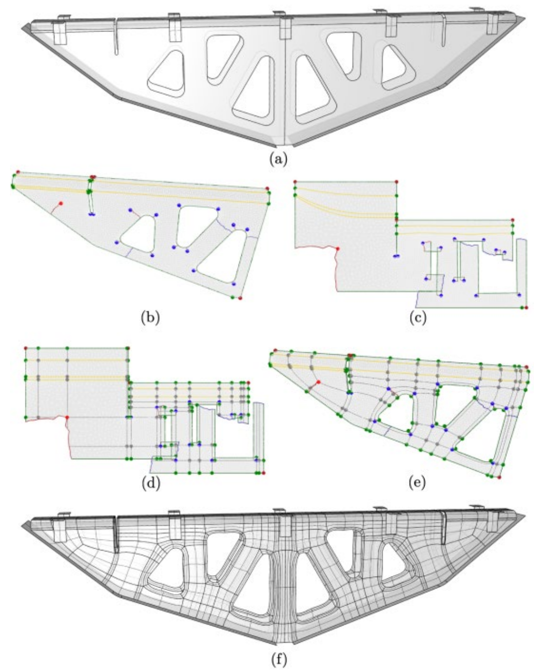

Figure 27: Process to define a feature-aligned quad mesh [19, 20]

A study was performed under the auspices of the Army High Performance Computing (HPC) Research Center at Stanford on HPC-enabled parametric studies of UBB for both high fidelity and reduced order, fast-running models [25]. An energy-preserving hyper reduction methodology was developed and verified on the AGH model, with a final size of 1117 elements (from the original ~477K elements) as shown in Figure 28a and 28b.

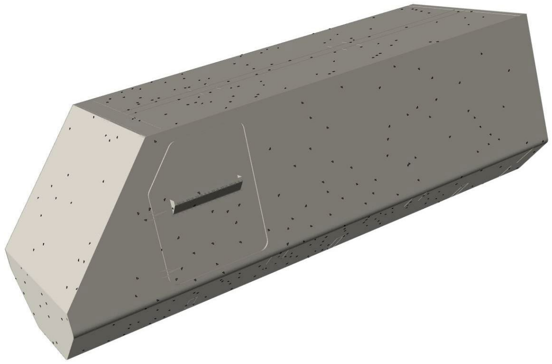

Figure 28a: Hyper-reduction on AGH mesh [25]

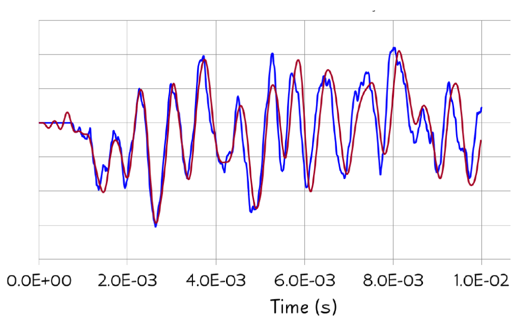

Figure 28b: Response history at the same hull location: Blue from High Fidelity model, Red from Hyper-reduced model [25]

A set of blast tests using a Generic Hull vehicle surrogate was conducted at the Fort Polk, LA test range in 2021 [36]. The PRIMUS Dummy (Figure 29) was originally designed to be used in pedestrian impacts but its use in other environments has been growing over the years to include military applications. The test was conducted to provide baseline data for a correlation study to determine laboratory to physical test comparability. Additionally, the test provided an opportunity to evaluate the PRIMUS Dummy performance in an environment of the Occupant Protection Laboratory (OPL) of GVSC. An interesting observation from the test was that the responses of the PRIMUS dummy closely match those of the more commonly known Hybrid-III Anthropo-morphic Test Device (ATD)

Figure 29: PRIMUS dummy used in live fire test using the AGH [38]

The authors are aware of AGH also being executed in other popular COTS software codes such as ABAQUS, RADIOSS, VELODYNE etc., but were unable to find any published reports in the open literature.

4. CONCLUSIONS

There are two major conclusions that may be drawn from this review paper on the Army Generic Hull, previously known as the TARDEC Generic Hull.

- Clearly, the 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, it might even be surmised that the idea of creating such a publicly shareable database has been a remarkably successful experiment. Indeed, as may be seen from Section 3, the AGH has been extensively used in far different and innovative ways than even originally envisaged by Army leadership.
- On the other hand, direct comparisons between simulations and the experimental data could be improved. As listed succinctly in Figure 30 [17],

two necessary pre-requisites for software tools to be good predictive

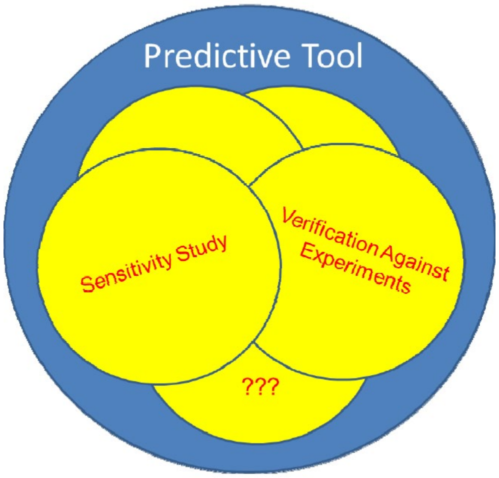

Figure 30: Two pre-requisites for software codes to be good predictive tools [17]

tools are Sensitivity studies and Verification against well-documented experiments.

It is evident that in the first aspect, the AGH database has been used adequately well in gaining knowledge about the outputs from the numerical models/codes, whether those pass the test of common engineering sense, and in determining the stability limits of the same. In the second aspect, there still remains much to be done. Since so much of the AGH test data is available, parts could be used for calibration if necessary, and the rest for verification/validation. It is strongly recommended that efforts be undertaken by the community at large for direct validation of the models and methodologies against the available experimental data.

5. DISCLAIMER

Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the Department of the Army (DoA) and shall not be used for advertising or product endorsement purposes.

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7. GLOSSARY

AGH	Army Generic Hull (aka TARDEC Generic Hull)
ALE/S-ALE	Arbitrary Lagrangian Eulerian / Structured ALE
ASCENT	The Adaptive Simulation to Characterize Emerging Non Ideal Threats
ATD	Anthropomorphic Test Device
CAD	Computer Aided Design
CONWEP	CONventional WEaPons
COTS	COmmercial Off-The-Shelf
CTH	GOTS Software from Sandia National Labs
DEVCOM	Army Combat Capabilities DEVelopment COMmand
DEM_PGM	Discrete Element/Particle Gas Method
DOF	Degree of Freedom
DRDC	Defence Research and Development Canada
DRI	Dynamic Research Index, estimate of lumbar injury
DYSMAS	Dynamic System Mechanics Advanced Simulation, GOTS software from Navy
EPIC	Lagrangian blast software from Southwest Research Institute
ERDC	Army Engineer Research Development Center
FE/FEA/FEM	Finite Element/Finite Element Analysis/Finite Element Method
FEUSION	GOTS Software from Lawrence Livermore National Labs
FSI	Fluid Structure Interaction
GOTS	Government Off-The-Shelf
GVSC	Army Ground Vehicle Systems Center, previously TARDEC
GVSETS	Ground Vehicle Systems Engineering and Technology Symposium
HEP	Hybrid Elastic Plastic
HME	Home-Made Explosives
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HPC	High Performance Computing
IED/MAIED	Improvised Explosive Device / Magnetically Attached IED
IMPETUS	COTS Software from IMPETUS Afea
LS-DYNA/LS-OPT	COTS Software from Lawrence Livermore Technology Corporation
LOCI-BLAST	Software from Mississippi State University
MADYMO	COTS Software from TASS International Software and Services
M&S	Modeling and Simulation
MineX3D	GOTS Software from ERDC
MPI	Massively Parallel Interface / Message Passing Interface
NDIA	National Defense Industry Association
OPSEC	Operations Security
PAM-SHOCK	COTS Software from Engineering System International (ESI) Group
ParaAble	GOTS Software from ERDC
PPE	Personal Protective Equipment
RHA	Rolled Homogeneous Armor
SPH	Smoothed Particle Hydrodynamics
STEP	Standard for Exchange of Product data
TARDEC	Army Tank Automotive Research, Development and Engineering Center, now GVSC
UB/UBB	Under Body/Under Body Blast
VV&A	Verification, Validation and Accreditation