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Numerical FE Modelling of Occupant Injury in Soil-Vehicle Blast Interaction

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Introduction

In ensuring occupant safety, analysis of blasts in soils has become increasingly important in evaluating the influence of the soil properties on the structural integrity of nearby structures. The proliferation of IED's (improvised explosive devices) and land mines in areas where soil properties are unknown poses a significant threat to the occupants of armoured vehicle. The current study aims to incorporate a multi-physics blast FE simulation in LS-DYNA to investigate the interaction of soil blast with an idealised V-Hull vehicle. Using the Hybrid III Anthropomorphic Test Devices (ATD) model the authors evaluated the dynamic response index (DRIz) and the head injury criterion (HIC), along with the acceleration and forces on the vehicle's underbody, to assess the suitability of numerical modelling as a tool to optimise hull shape and reduce occupant injury.

Hybrid III 50th Percentile Male Model

STANAG 4569 and its Mine Threat annex AEP-55 Vol2 specifies a number of human injury criteria that must be evaluated for vehicle platform certification to particular mine threat sizes and positions. For this initial investigation the DRIz and HIC criteria were selected as output metrics. These criteria were determined within the model by the inclusion of a 50th% Hybrid III ATD. This model has virtual accelerometers mounted within its pelvic block and head cavities that measure the accelerations required as inputs for the injury calculations.

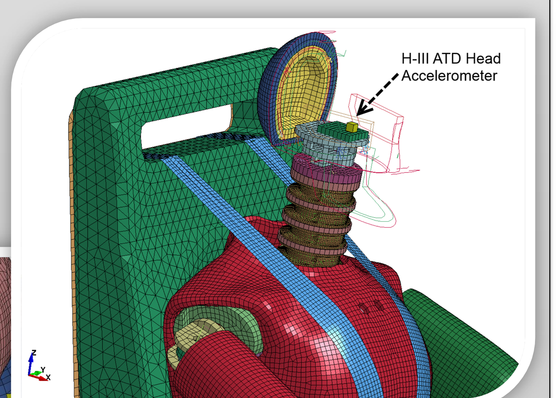
The DRIz is determined via the pelvic acceleration and by solving the following equation for displacement:

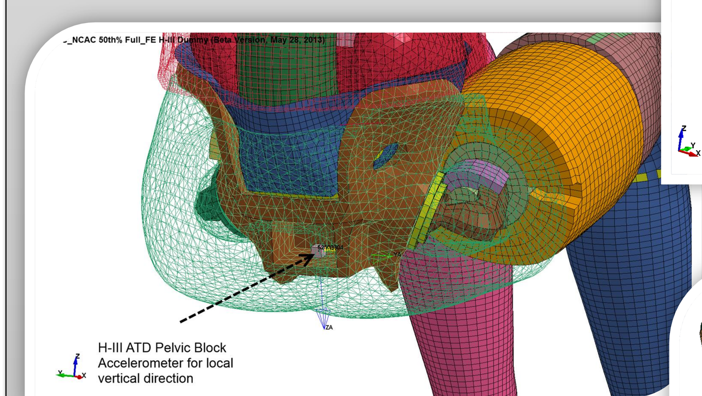
$$\ddot{Z}(t) = \ddot{\delta} + 2.\zeta.\omega_n.\dot{\delta} + \omega_n^2.\delta$$

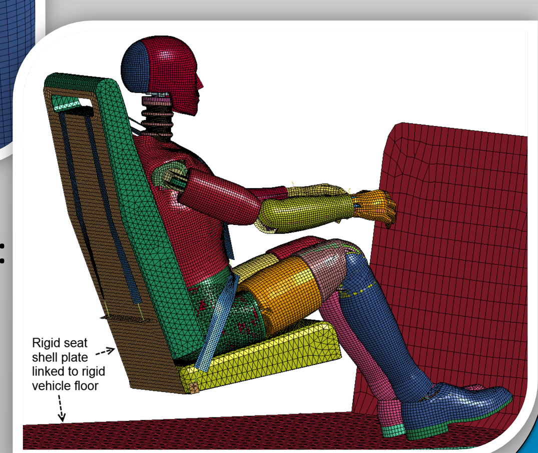
and via the relationship:

$$DRI_z = \frac{\omega_n^2.\delta_{\max}}{g}$$

where g is standard gravity.







Likewise HIC is evaluated from the head acceleration and relationships:

$$HIC_{15} = \max_{t_1,t_2}\left(\left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2-t_1)\right)$$

$$where: a(t) = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Soil Model for blast-vehicle interaction

The prairie semi-cohesive soil is described through a modified Mohr-Coulomb model, *MAT_FHWA, with the yield surface described by:

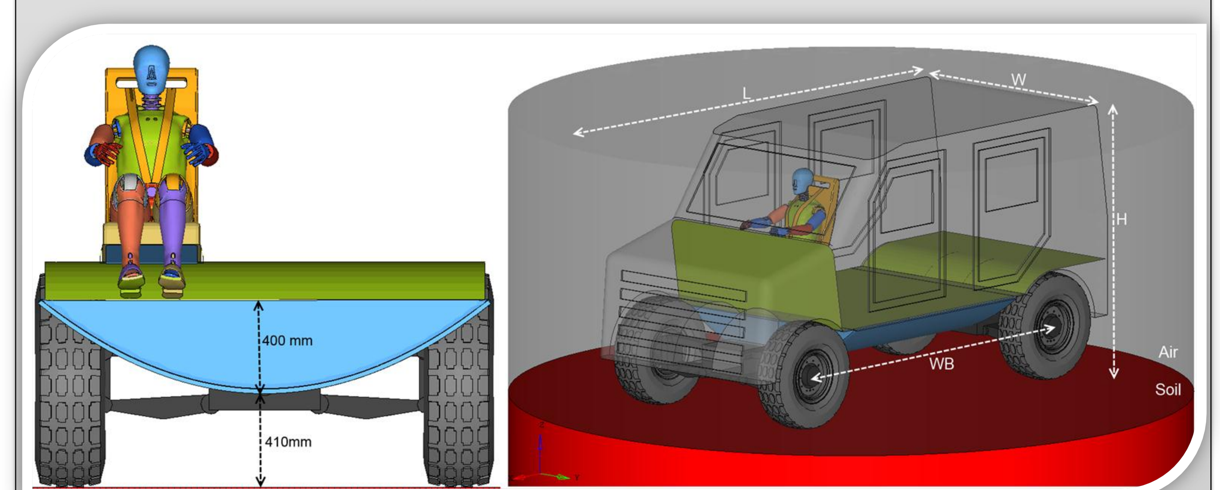
$$\sigma_y = -P\sin\phi + \sqrt{J_2 K(\theta)^2 + a^2\sin^2\phi} - c\cos\phi = 0$$

Where σ_y is the yield surface, P is the pressure, $K(\theta)$ is a function based on the Lode angle and θ is equal to $\frac{1}{3}cos^{-1}\left(\frac{3\sqrt{3}}{2}\frac{J_3}{J_2^{3/2}}\right)$, c,ϕ are the cohesion and angle of shear resistance respectively and the 'a' parameter is used to correct the hyperbolic Mohr-Coulomb approximation and is equal to $a \le \frac{c}{20}\cot(\phi)$. The model accounts for moisture content and computes the pore pressure as a function of the volumetric strain and the collapsing air voids which, in the absence of permeability formulations, causes the pore (water dependent) pressure to rise.

variable	value	variable	value
P (density soil)	2200 kg/m3	Φ (friction angle)	9.27°
ρ_w (density water)	1000 kg/m3	D1	1E-4
SG (specific gravity)	2.65	D2	2.43E-4
G (shear modulus)	3.764 MPa	MCONT (moisture fraction)	0.1
K (bulk modulus)	5.457 MPa	Dint (strain at initial damage)	5E-4
Kskeleton	0.273 MPa	Vdfm (void energy)	20
C (cohesion)	0.114 MPa	Φ_{res} (residual friction angle)	1.5°

Vehicle model and ALE domain coupling

The vehicle is modelled using rigid shell elements with the exception of the 20 mm thick V-hull on the underside of the vehicle, modelled with solid elements. The V-hull is intended to divert the force of the blast away from the vehicle and plastically deform to absorb the blast energy. The vehicle is represented by a Lagrange model while the TNT charge , soil and air are represented by an Eulerian domain comprising 1.7 Million elements. A modified version of the Johnson-Cook model, MJC, by Børvik et al is used herein to model the deformable hull using ARMOX 500T material data.

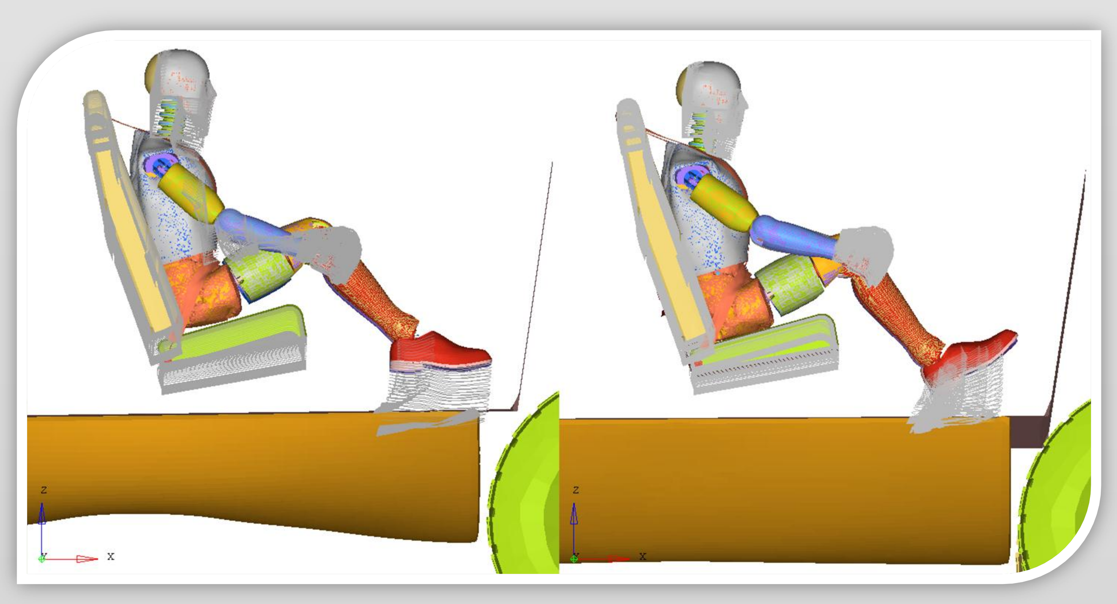


ATD and Vehicle position for Under vehicle blast simulation

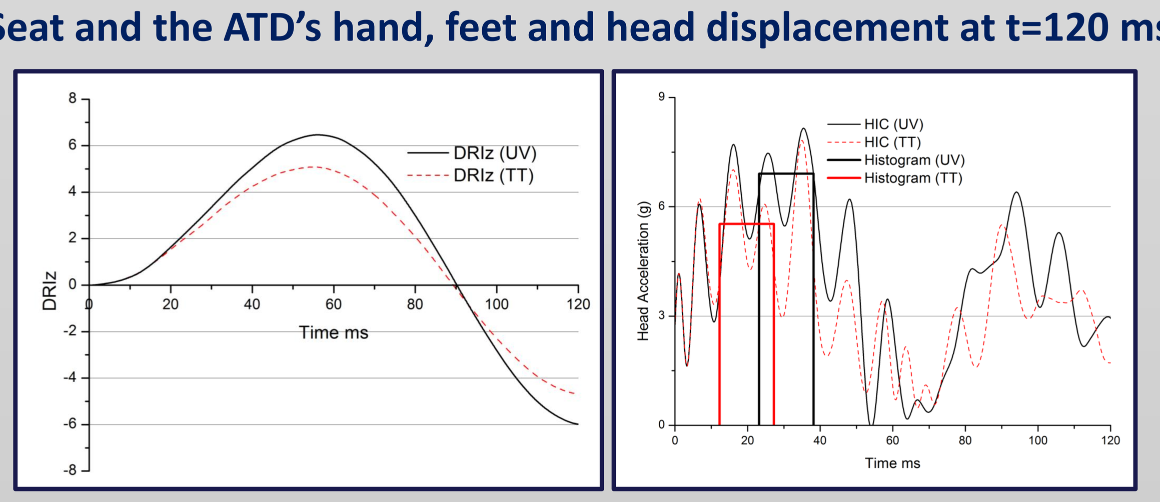
vehicle	value
Overall width	1968 mm
Overall height	2384 mm
Overall length	4450 mm
Wheel base	3122 mm
C.G. of vehicle (Under Vehicle simulation)	X: -162.9 , Y: -7.4, Z: 2994.8
C.G. of charge	X: 0 , Y: 0, Z: 1671.8
Mass of vehicle	7362.85 kg
Mass of deformable belly plate	875.32 kg

Results and Discussion

Hybrid III ATD response: The most serious vehicle occupant injuries and their fatalities occur most frequently as a consequence of hull-floor rupture. In addition to generating floor-material fragmentation, floor rupture allows the ingress of flame and toxic (detonation products) gases. Contact between a bulged hull plate and the lower limbs can cause severe injury, this phenomena can be alleviated through separation of a floating floor and hull plate. In the initial loading phase the dominant contribution to the acceleration is found in the z-direction (vertical).This is bolstered by the confining effects of the crater formation with the soil ejecta interacting in the initial stages, 1-3 ms ,and imparting the bulk of the impulse load.



Seat and the ATD's hand, feet and head displacement at t=120 ms

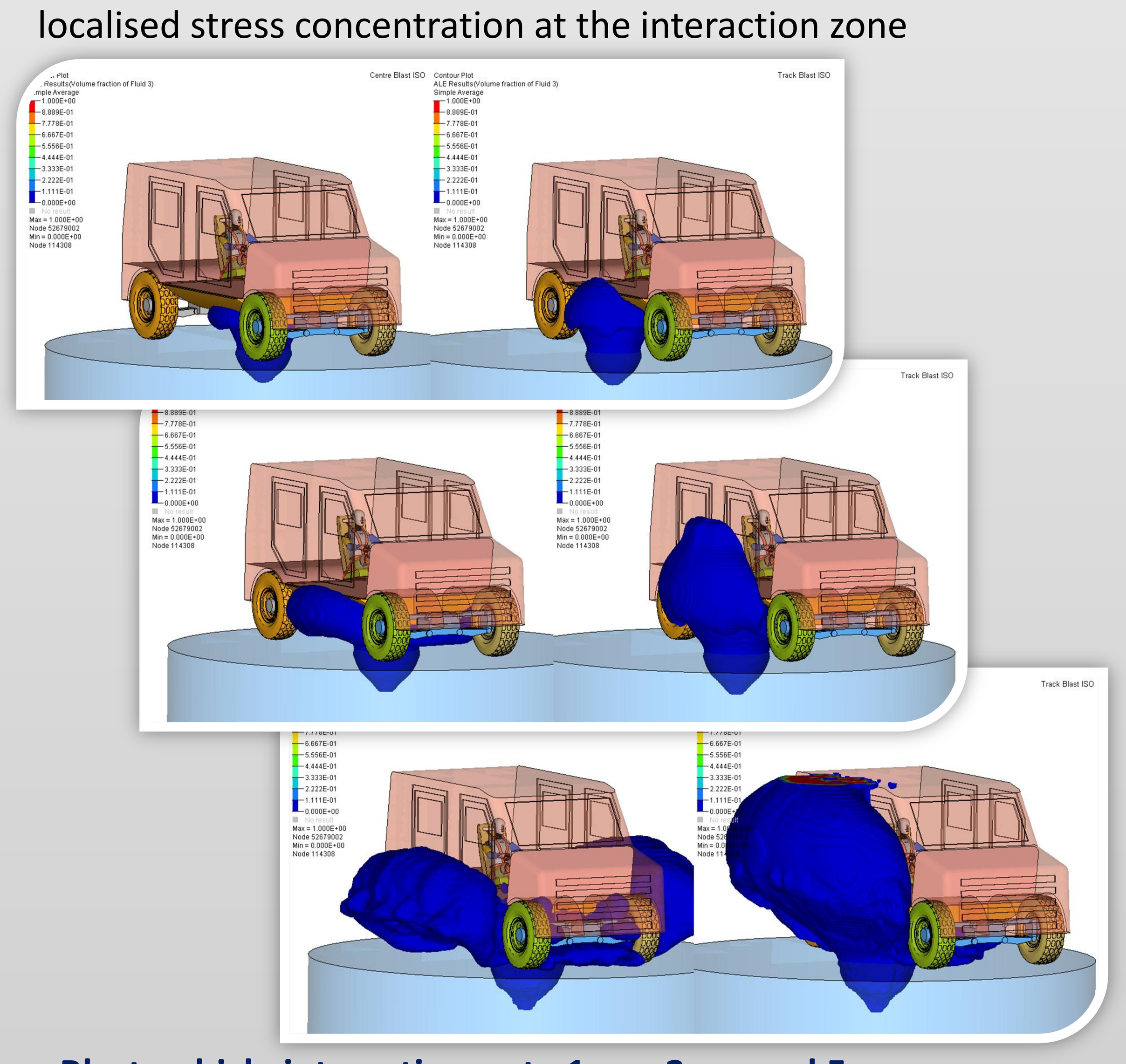


DRIz (Left) and HIC (Right) for the under vehicle (UV) and tyre track (TT) simulations

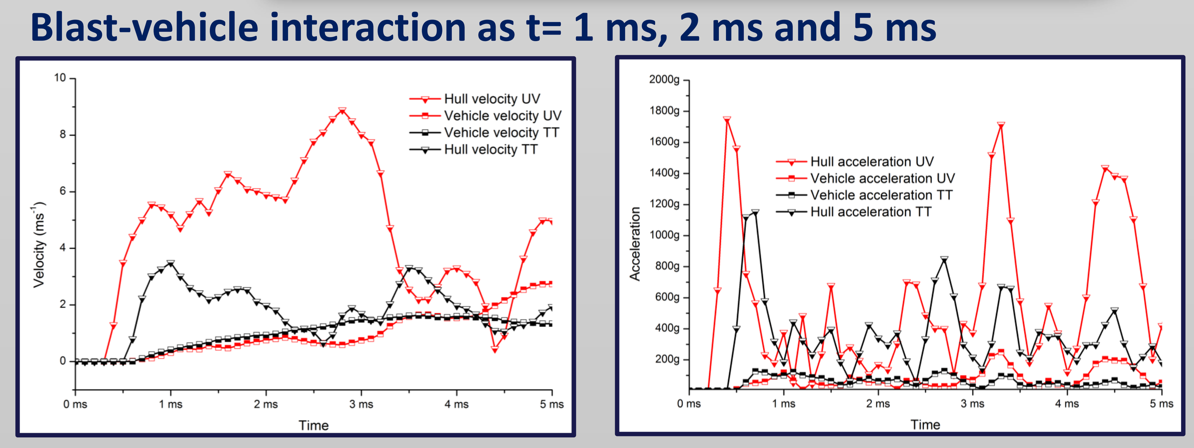
DRIz: The peak value of the DRIz trace is 6.47 corresponding to the under vehicle simulation. When compared against the upper limit of 17.7 as permitted by AEP-55 an assessment can be made as to the severity of any injuries and qualify various components for energy absorption. This limit of 17.7 represents a 10% risk of an AIS 2+ (Abbreviated Injury Scale) severity injury.

HIC: The AEP-55 stipulates a maximum HIC_{15} injury criterion of 250, in light of this the current results are thought to be less critical in evaluating occupant injury, where no head impact occurs, and are more aligned to the global response of the vehicle. Moreover, whilst the charge in the TT simulation is in closer proximity to the ATD, the resultant head accelerations are less than those of the UV simulation.

Vehicle-soil Interaction: The UV blast simulation shows a prolonged FSI in comparison to the tyre track simulation where the blast products travel across the side of the vehicle. Evolution of the stresses and strains in the deformable hull shows a large buckling response of the hull plate in the UV simulations with a pronounced plastic strain region along the centre line. Local plastic yielding is less apparent in the TT results. The Von-Mises stresses at t=5ms are approximately 1-2 GPa and are more confined in the TT simulation indicating very localised stress concentration at the interaction zone



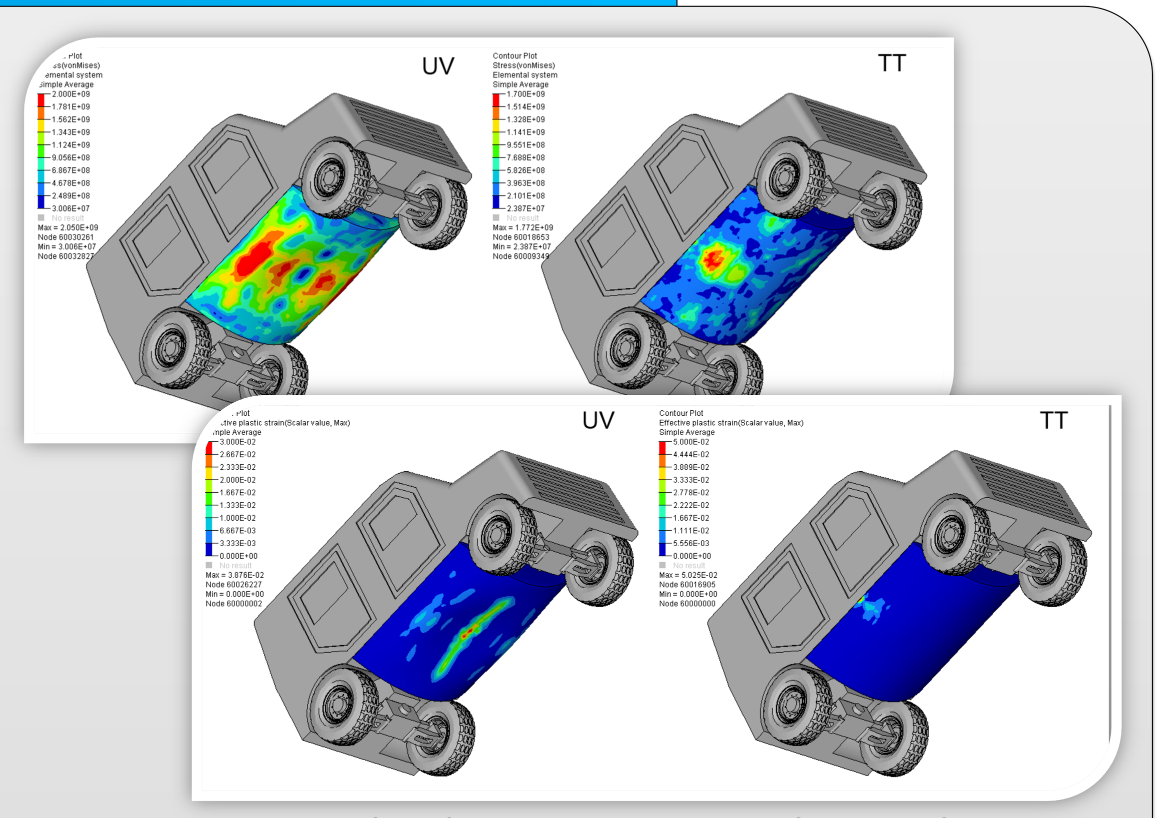
Blast-vehicle interaction as t= 1 ms, 2 ms and 5 ms



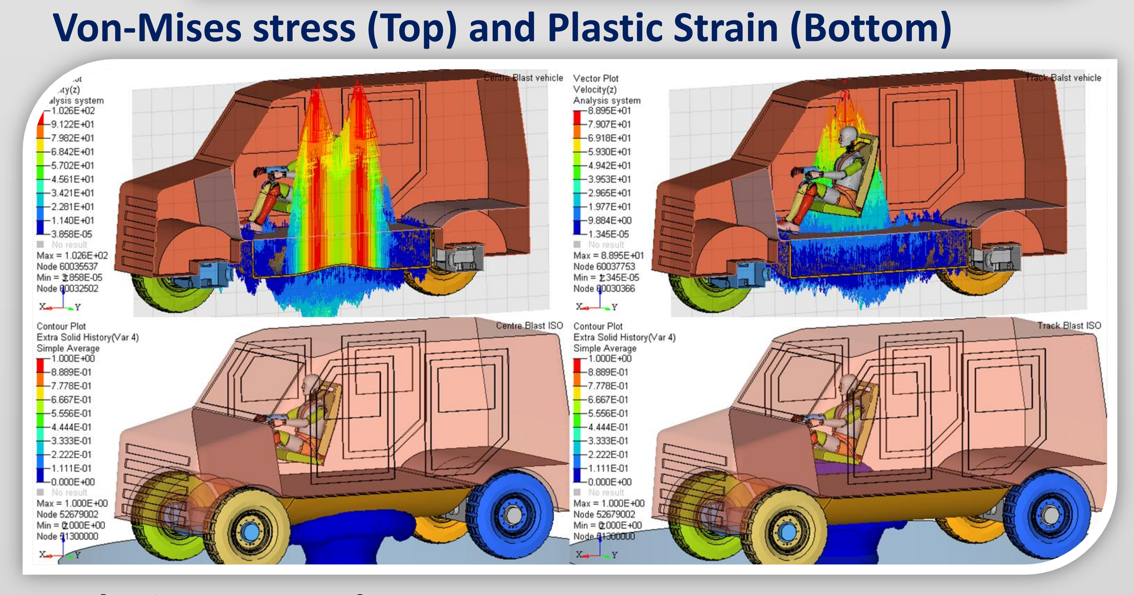
Velocity (Left) and Acceleration (Right) of Hull and vehicle

Velocity response: Localised deformation of the hull reduces the global response of the vehicle. The TT blast scenario shows a more moderated local velocity in the hull that is commensurate with the global vehicle response. Velocity vector plots indicate varying velocity propagation pattern for the two scenarios.

Acceleration response: The UV blast scenario shows significant secondary and tertiary acceleration responses due to the vibration of the V-hull and the secondary interaction of the reflected waves from the soil crater.



Von-Mises stress (Top) and Plastic Strain (Bottom)



Velocity vector plot as t= 1 ms

Conclusion and future work

- Successful use of numerical simulation to determine the injury effects upon occupants by calculating the DRIz and HIC injury criteria with reference to AEP55 thresholds . This allows for the investigation of additional energy attenuation features in future studies.
- The use of V-hull has limited ability to deflect blast energy for the TT scenario with the reduction in occupant injury more aligned to the limited exposure of the hull to the blast cone.
- The confining characteristics of the soil ensure that parts of the vehicle outside the inverted blast cone are less severely impacted. Variations of the burial depth or placement of the charge on the surface would likely change these findings further and is the subject of ongoing research.
- With the full physics path represented within the model, from charge size to human injury evaluation, the model affords the ability to directly determine the relative effect on any injury result. For vehicle designers this can be an indispensable tool in building safer vehicles for troops in combat zones.