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INVESTIGATION OF HUMAN BODY EXPOSED TO BLAST WAVE DERIVED FROM IMPROVISED EXPLOSIVE DEVICES

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Abstract

The analysis of contemporary military conflicts shows, that the most dangerous threat for soldiers are Improvised Explosive Devices (IEDs). Blast resistance of military vehicles and structures is broadly discussed in many articles. However, information about human body response to impact loading is hard to find and very general. Both experimental trials with dummies and numerical analyses are needed. To design and develop better protection system it is necessary to identify and measure the effects of blast wave impact on crew of military vehicle.

This paper presents numerical simulation results of special armoured vehicle subjected to mine threat of 8 and 10 kg of TNT. Possible effects of mine explosion on human body are described. Review of modern-mine and IED countermeasure solutions is presented. The analysis is conducted using LS-DYNA explicit code. Only vehicle's hull is considered with suspension and turret is modelled using mass. Gravity is taken into account. Numerical model of Hybrid-III dummy is used. Accelerations and forces in tibia, neck and spine were calculated. HIC-36 criterion was also evaluated Different types of possible seat configuration are examined. Results show convergence between explosive size and injury risk.

Keywords: *vehicle safety, mine resistance, Improvised Explosive Device, occupant safety, FEM analysis*

1. Introduction

Harm to human body caused by Improvised Explosive Devices (IED) is often injuries in a battlefield, especially where asymmetric conflict, terrorist and guerrilla operations take place [1]. Several factors have influence on vehicle's crew survivability, like explosion size, type and complexity of injury caused by different acceleration components (acceleration, deceleration, rotation, toss and drop movements), wounds caused by fragments, due to impact and injuries due to chemicals and burns. Loss of armour integrity usually leads to fatal injury to the crew due to not only fragments and projectiles but also rapid decompression caused by depressurization of compartment/cabin (Fig. 1).

2. Requirements for contemporary military vehicles

The design idea of modern military vehicles is to ensure high power/mass ratio, which allows better mobility, improved traction, and provide sufficient protection of soldiers' health and life. The goal is to provide structure with low mass, high firepower and maximum possible protection level.

Until now, military vehicles have traditional armour enhanced with extra steel plates. This constant trend of including additional amours leaded to significant increase of weight preventing air transportation. Among wide variety of newer solutions offering high crew survivability rate and vehicle performance, one of the most promising are new materials for add-on armours especially those made of composites.

Fig. 1. Explosion effects under military vehicle: A – direct effects of explosion, B – toxic gas, C – overpressure due to detonation, D – fragments and projectiles [2]

3. Explosion effects on special military vehicles analysis

Explosive charge detonation under vehicle or near it causes a shock wave that propagates in all directions at velocity higher than speed of speed. This wave, travelling along vehicle's hull, causes dynamic loads of vehicle structure leading to accelerations inside crew compartment. During explosion several negative factors can occur.

As well as shock wave, there are also arising pressure, fragments that can penetrate crew compartment and high acceleration reaching a few hundred of g in period of milliseconds. That kind of load can lead to death or serious injury, e.g. compressive spine fracture. Explosion also causes upward movement of occupant and, depending on forces transferred by seat, leads to head and spine injury causing disability or death. The upward movement of hull's centre of gravity depends on explosive size. Effective protection of occupants against high acceleration should allow relative movement of seat and vehicle [3, 4].

4. Explosion and IED counter-measures

The problem of mine resistance of military vehicle is broadly discussed in international research and has been intensively investigated by Polish scientists. In order to develop effective mine protection, the effects of explosion on both structure and human body must be recognized.

Modification of vehicle's structure enables some major modifications enhancing blast protection. The most common are adding a v-shaped bottom structure, adding a deflector under vehicle's hull and increasing the standoff between hull and the ground. Another preferable solution is "citadel" design of capsule for crew attached to chassis or monocoque solutions. Both are build using armour steel that have extraordinary impact resistance.

In most recent constructions there are also additional special structures designed to absorb explosion energy. Such features can be found in Combat Tactical Vehicle, which is equipped with dampers and anti-vibration mounts in between capsule and external vehicle (Fig. 2). Their aim is to suppress energy from force impulse transferred to the crew in the initial phase of explosion [5].

Another important explosion counter-measure is special seats with energy-absorption mechanisms. Their task not only is to absorb the energy transferred from explosion but also during impact of flying vehicle to the ground. Both mounting and seat placement have influence on effectiveness so different types of mount are used. Depending on space and compartment shape, seat can be mounted to roof, wall or bottom. Sample solutions are shown in Fig. 3. The most recent seats automatically measure mass of occupant and adjust absorbers to achieve the most efficient protection.

Fig. 2. Crew compartment (capsule) with set of anti-vibration mounts [5]

a) b)

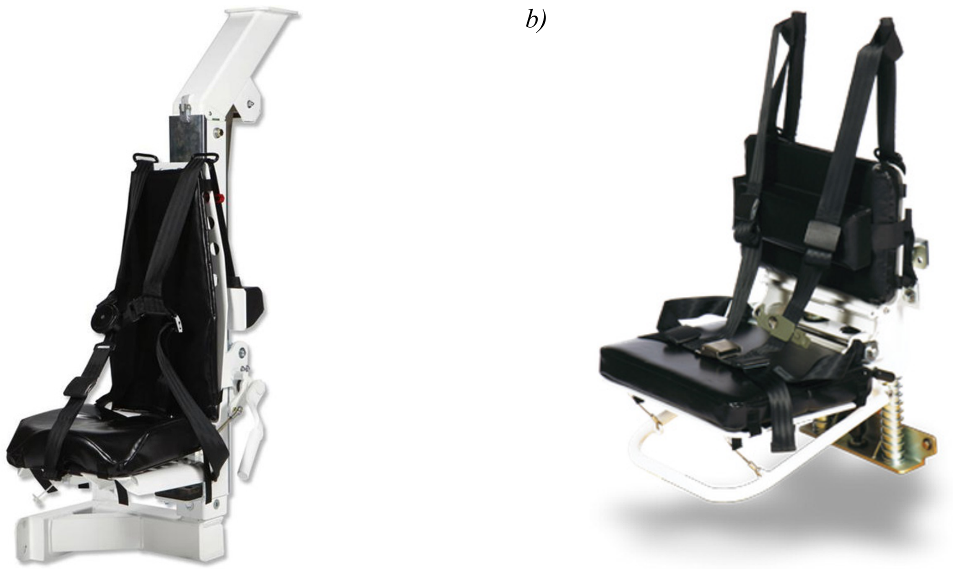

Fig. 3. Seat systems reducing overloads designed by Allen Vanguard: a) roof-mounted seat b) side-mounted seat [6]

Among additional solutions, special cushions for lower limbs are used. They are efficient against both mines and IED's (Fig. 4). They are called universal because they can be applied to any vehicle. Their role is extremely important in flat-bottomed light armoured vehicles. Cushions have inner core made of energy-absorbing materials (Fig. 4) which have special geometrical and material design that maximizes absorption by deformation. The cushion is compressed by force caused by feet and legs inertial force.

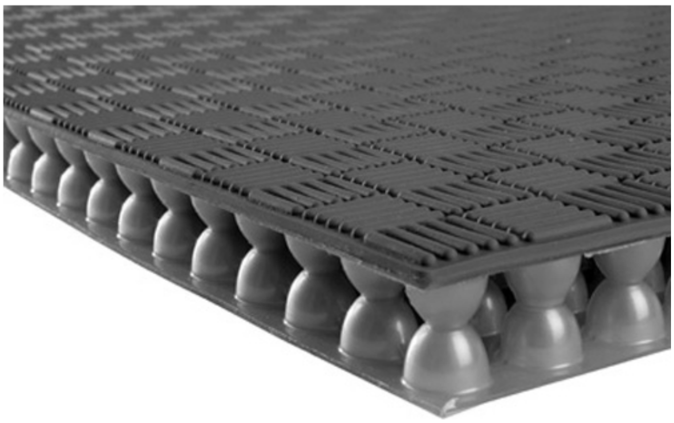

Fig. 4. Cushion panel designed by Skydex, outer layers made of rubber, inner core – elastomeric [7]

5. Numerical model of vehicle with occupant

Numerical model was prepared for simulation using LS-DYNA commercial code. This software allows non-linear simulation of dynamic behaviour of systems.View of numerical model is shown in Fig. 5. Welds were not considered in this simulation. Vehicle's steel hull was modelled using Johnson-Cook model implemented as MAT_15. Armox 500T ballistic steel was used. Properties required for numerical model were obtained from literature. Constants used for constitutive model and Mi-Gruneisen equation of state are shown in Tab. 1.

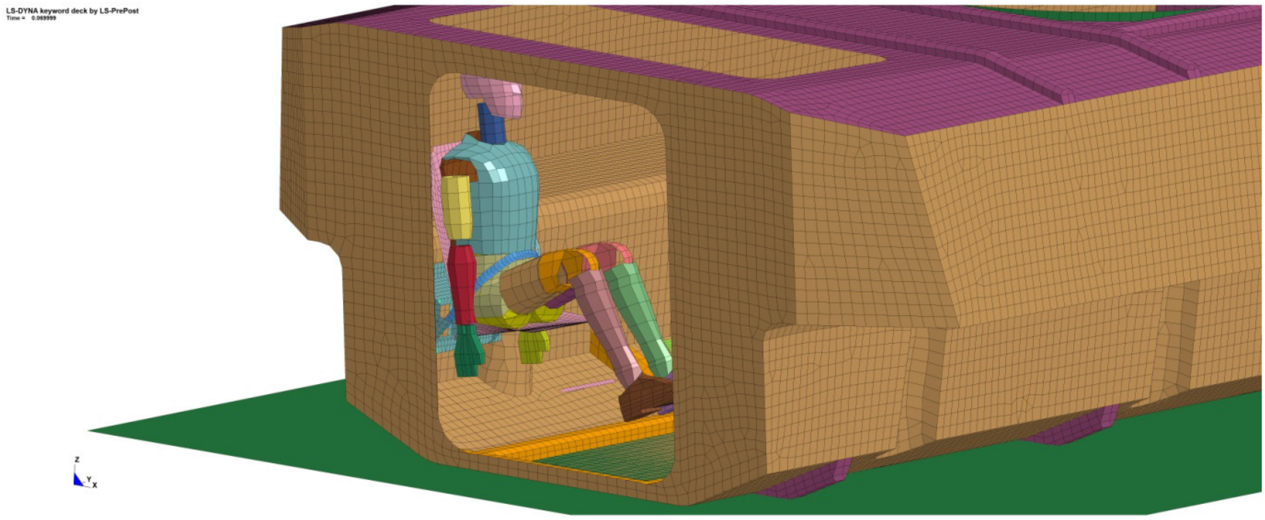

Fig. 5. Numerical model

Tab. 1. Material constants for Armox 500T steel and Mie-Gruneisen equation of state coefficients

Name		Value
Johnson Cook	Mass density, RO	7.85e-6
	Shear modulus, G	79.6
	Scale yield stress, VP	0
	Flow stress: A B N C M	0.849 1.34 0.0923 0.00541 0.870
	Melt temperature, T_M	1800
	Room temperature, T_R	239
	Quasi-static threshold strain rate, EPS_0	0.001
	Specific heat, C_P	450
EOS	Gruneisen gamma $GAMMA_0$	1.93
	First order vol. correction, A	0.5
	Initial internal energy, E_0	0
	Initial relative volume, V_0	1

The model does not include lower chasis, suspension, wheels and turret. These elements were simulated by mass elements contacted to the structure using interpolation constraints. Mass of entire system was around 16 tons. The dummy used was 50-centile Hybrid-III male implemented separately into LS-DYNA. Hybrid-III dummy placed on seat with footrest and seatbelt. One additional configuration or 8 kg of TNT without footrest were also analysed. Dummy positioning is depicted in Fig 6. It was placed on rigid seat mounted to wall of vehicle. Simulated explosion centre was localized below rear axle at 800 mm distance from vehicle's bottom. Different explosive sizes were considered – 8 and 10 kg. Explosion was modelled using CONWEP function implemented in LS-DYNA. The function generates pressure impulse on vehicle's bottom. As gravity was also considered, the dummy was stabilized and after 100 ms detonation occurred. Total simulation time was 200 ms. Computations were conducted on multiprocessor cluster at Department of Mechanics and Applied Computer Science.

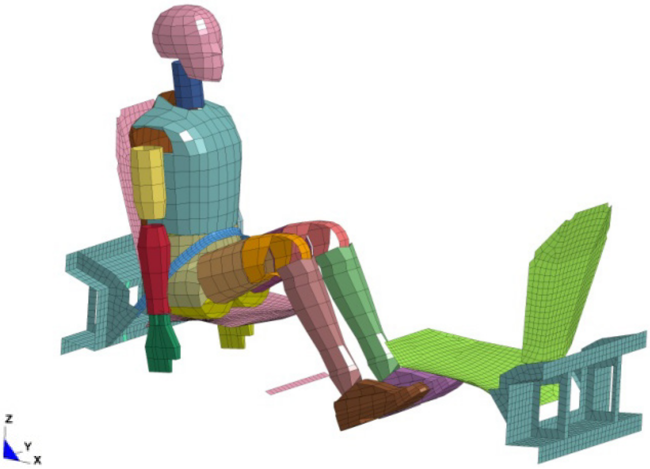

Fig. 6. Dummy positioning

6. Numerical simulation results

As a result of simulations deformation of vehicle hull and behaviour of Hybrid-III dummy were observed. For each load case (different mass of TNT), several parameters were calculated:
- axial and transverse force in upper-neck,
- axial force left and right tibia,
- HIC criterion value.

As previously mentioned, termination time for the analysis was 200 ms.

Deformation of vehicle and behaviour of Hybrid-III dummy in subsequent moment of time for 8 kg TNT charge (explosion phase) are shown in Fig. 7. Plots of calculated Hybrid-III dummy parameters during the detonation are depicted in Fig. 8-9. Calculated HIC criterion value was 191.

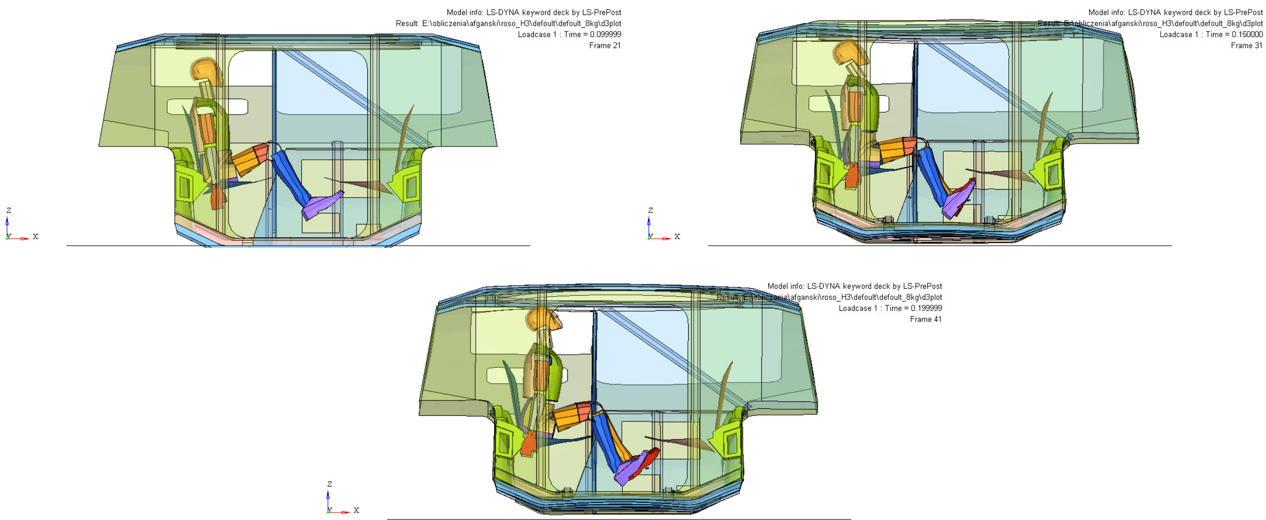

Fig. 7. Hull deformation and dummy behaviour for subsequent moments of time during detonation of 8 kg of TNT

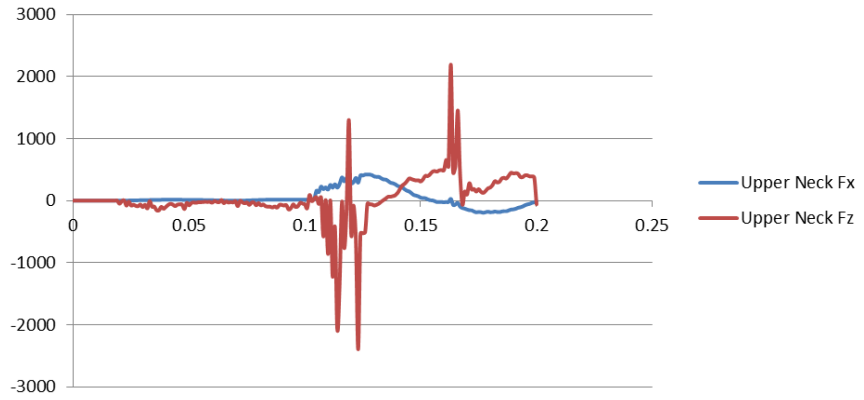

Fig. 8. Axial and transverse force in upper neck [N] during detonation of 8 kg of TNT

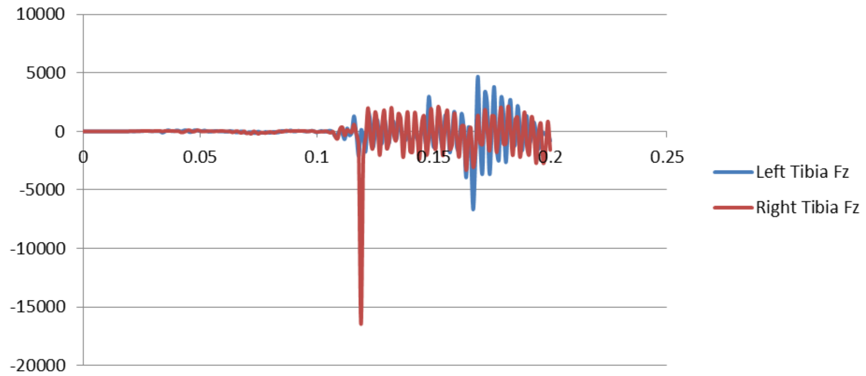

Fig. 9. Axial force in tibias [N] during detonation of 8 kg of TNT

Deformation of vehicle and behaviour of Hybrid-III dummy in subsequent moment of time for 10 kg TNT charge are shown in Fig. 10. Plots of calculated Hybrid-III dummy parameters during the detonation are depicted in Fig. 11-12. Calculated HIC criterion value was 202.

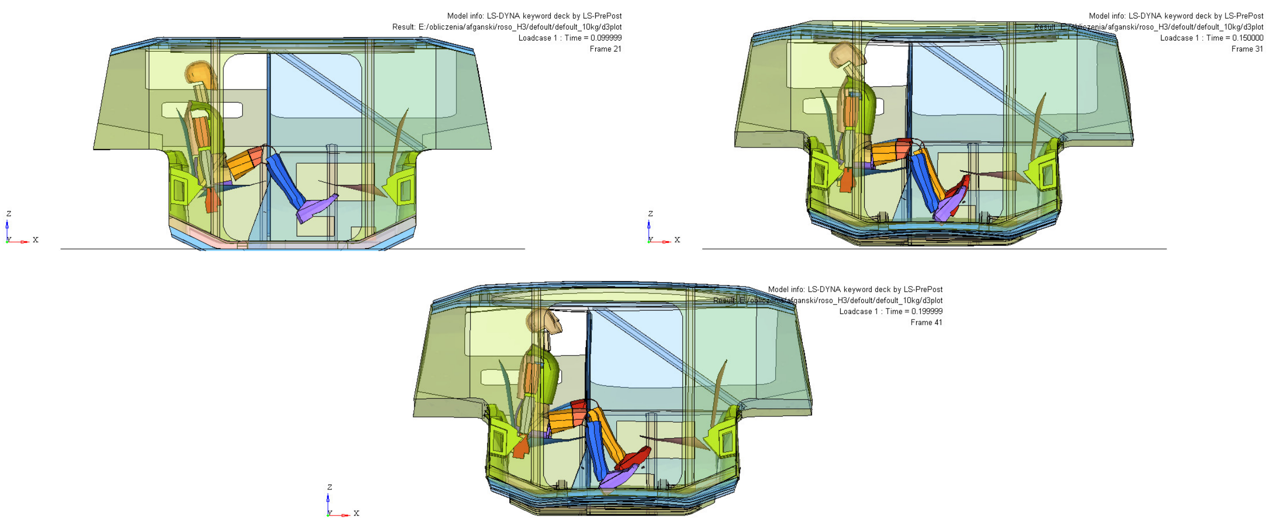

Fig. 10. Hull deformation and dummy behaviour for subsequent moments of time during detonation of 10 kg of TNT

Deformation of vehicle and behaviour of Hybrid-III dummy in subsequent moment of time for 10 kg TNT charge (explosion phase) are shown in Fig. 13. Calculated HIC criterion value was 1308.

In Tab. 2, there are the results of maximum values of forces and accelerations in pelvis, lumbar spine, upper neck and tibia. There is also calculated HIC36 value.

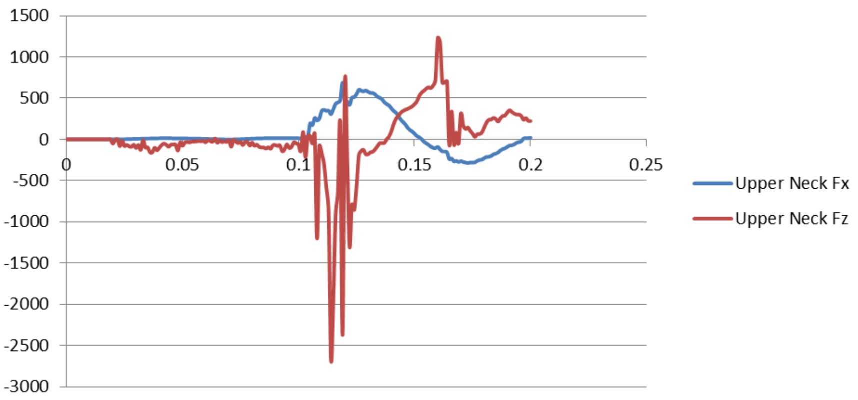

Fig. 11. Axial and transverse force in upper neck [N] during detonation of 10 kg of TNT

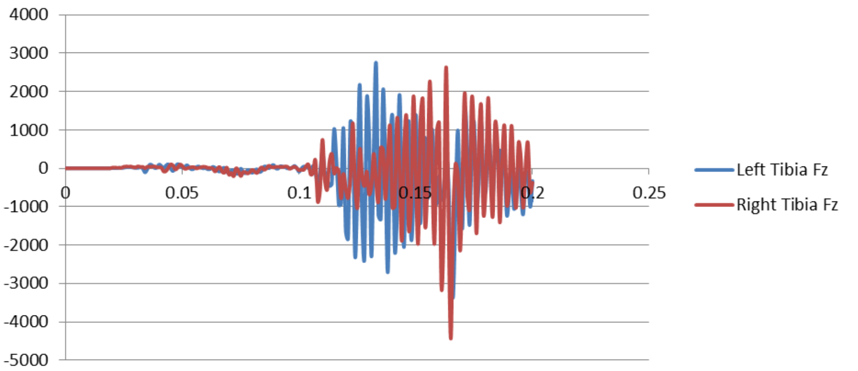

Fig. 12. Axial force in tibias [N] during detonation of 10 kg of TNT

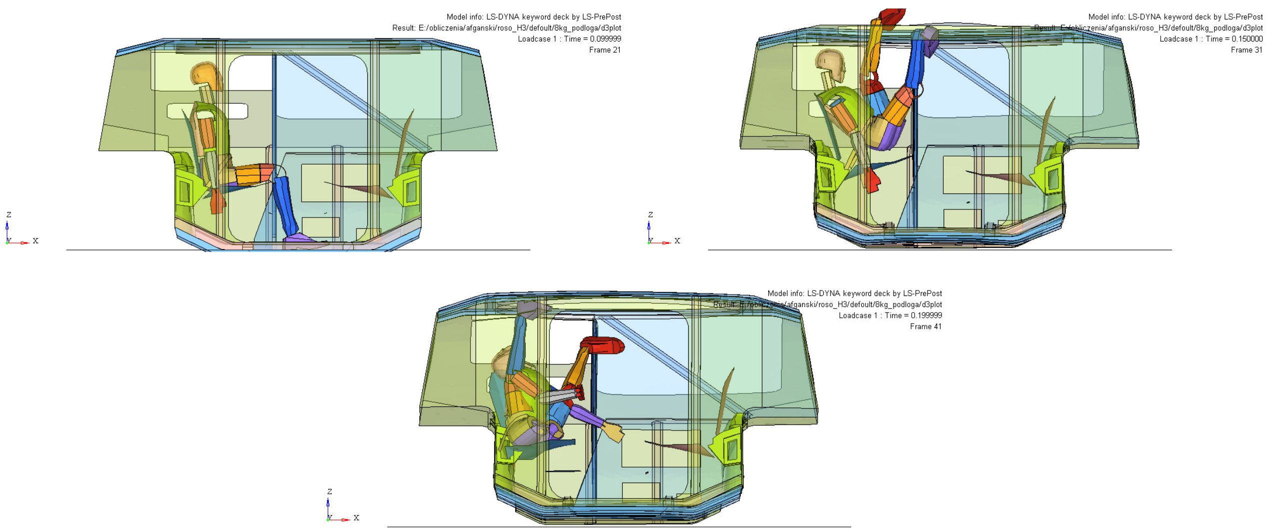

Fig. 13. Hull deformation and dummy behaviour for subsequent moments of time during detonation of 8 kg of TNT without footrest

Tab. 1. Comparison of influence of emissions of different types of transport

Charge [kg]	Pelviz „Z" acceleration [g]	Lumbar Fz [N]	Upper Neck Fz [N]	Upper Neck Fx [N]	Tibia R Fz [N]	Tibia L Fz [N]	HIC36
8 kg	110	–22500	–2400	407	–16500	–6660	191
10 kg	–137	–38600	–2670	688	–4400	–3340	202
8 kg*	–300	87200	–9750	2500	183000	10000	1308

* *without footrest*

7. Conclusions

The results show that when mass of explosive rises so does every value used to predict an injury to vehicle occupant. However, the results need validation during experimental trials to verify numerical model performance. Compared to the experiments the simulations are much cheaper and provide more knowledge about each phenomenon. Basing on the results, some conclusions can be formulated

1. Only acceleration in pelvis, transverse force in upper neck and HIC36 show consisted behaviour with explosion parameters. They are significantly higher when mass of explosive increases.
2. Other measured factors do not show clear correspondence with applied load. It may be due to lack of filtration and large spread of results.
3. Results are strongly dependent on dummy's positioning. Placing feet on the floor instead of footrest lads to force multiplication.

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