

# NUMERICAL ANALYSIS OF A LIGHTARMOURED VEHICULAR PERSONNEL CARRIER LOADED WITH A MINE OR IED EXPLOSION ON A HUMAN TRANSPORTED IN IT

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## **Abstract**

*The armed forces involvement in stabilization operations conducted either in Europe (Kosovo) or in Africa (Iraq) or in Asia (Afghanistan) caused uncovering of weak points of the used equipment which was not constructed for the purpose of partisan war. This fact resulted in equipment modernisation in the form of additional armouring and protection against mines and improvised explosive device as well as in NATO adopting the standards determining the protection level assuring by the given vehicle. The most popular military standard in the scope of ballistic protection against the pressure wave coming from a mine or improvised explosive device detonation is standard NATO – STANAG 4569. This standard determines to a great degree also the charge size and position.*

*Civil solutions are based not on the evaluation of the vehicle destruction level but on the evaluation of some parameters determining the injuries of the human moving in a vehicle which had an accident.*

*These parameters will be used to evaluate the injuries of the human moving in a lightarmoured vehicular personnel carrier which is subjected to the influence of wave pressure wave coming from the detonation of a mine or improvised explosive device. The finite elements model of a dummy Hybrid III 95% Male and Ls-Dyna software will be used for this purpose. There will be considered the complex model in which there is not only a human and vehicle model but also a charge, air and ground.*

**Keywords:** explosion, vehicle, ground, dummy

## **1. Introduction**

The numerical methods development, including finite elements methods, along with a great increase of computers calculation power in recent years allows modelling various physical – chemical – mechanical phenomena in real systems.

One of such systems is a lightarmoured vehicle along with the crew which is subjected to the influence of a blast wave rising after a mine explosion. This system consists of two fundamental elements. The first element describes geometry of the considered system (vehicle, system, ground, air, charge). The second one describes the properties of applied materials.

The behaviour of the surrounding consisting of air, charge and ground is described with the use of Euler equations of continuum mechanics or ALE (Arbitrary Lagrange – Euler method) [1]. ALE method provides a greater accuracy than the classic approach – solving Euler equations of continuum mechanics. However, behaviour of the right – interesting for us object, in this case, the vehicle with the crew, is usually described in this type of problems with the use of Euler equations of continuum mechanics.

One of possible software allowing realization such a complex problem is Ls-Dyna [1]. This software includes the explicit implementation of the finite elements method. It allows modelling of complex phenomena from the field of classic mechanics, fluid mechanics, dynamic phenomena as well as interaction of strong discontinuities on different kinds of structures.

Hybrid Dummy III 95% Male (Fig. 1) was used in calculations. This model was developed and tested to the needs of an automotive industry. It is applied in the investigations on the increase the drivers, passengers as well as participants of accidents safety.

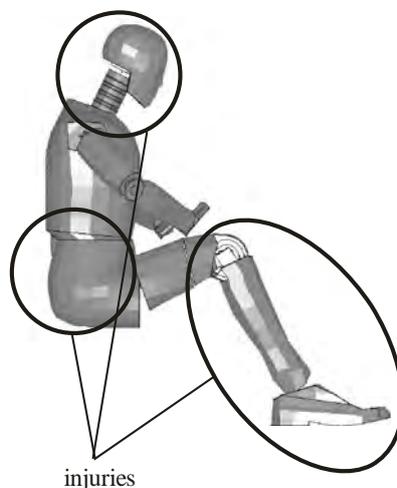


Fig. 1. Model Hybrid Dummy III 95% Male with marked places which are the most subjected to the injuries

There are three fundamental areas of the highest dangers for a human related to the contact surfaces movement. The first group involves lower limbs, the second one involves a pelvis area and a lower part of the spine.

One of the parameter determining the possibility of a head injury is HIC (head injury criterion) [2]:

$$HIC = \max \left[ (t_2 - t_1)^{-1} \int_{t_1}^{t_2} a dt \right]^{2,5} (t_2 - t_1), \quad (1)$$

where:

$a$  - acceleration expressed in multiplicity of acceleration of free fall

$t_2 - t_1$  - time range in which this parameter is determined. This range is selected as to maximize the value of HIC parameter in the time range including whole event, but not greater than 36 ms. A safe limit of this parameter is assumed as 1000.

Accidents analysis conducted by Hertz in 1993 led to determining the probability of skull bone fracture depending on the parameter mentioned above [3]:

$$p_{fracture} = N \left( \frac{\ln(HIC) - \mu}{\sigma} \right), \quad (2)$$

where:

$N$  - integral normal distribution,

$\mu = 6.96352$ ,

$\sigma = 0.84664$ .

When HIC parameter = 1000 the probability of skull bone fracture amounts to 47%, when HIC = 2000 the probability is 60%, and when HIC is 4000 the probability is 98%.

## 2. Numerical model

Figure 2 presents the model of the considered system.

The air behaviour was described with the use of Mie-Gruneisen equation [4]:

$$p = p_0 + \gamma \rho E, \quad (3)$$

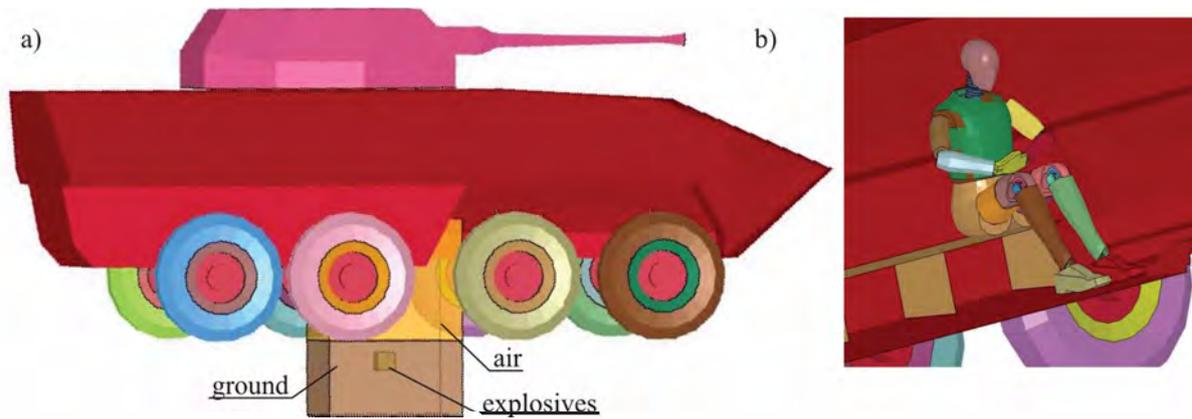


Fig. 2. The model of the considered system (a) with Hybrid Dummy model (b)

where:

$p$  - pressure,

$p_0$  - initial pressure,

$\gamma$  - Gruneisen coefficient,

$\rho$  - density,

$E$  - specific internal energy.

The following values were taken into consideration in equation (3) [4, 5]:  $\gamma = 1.4$ ,  $\rho = 1.185 \text{ kg/m}^3$ ,  $p_0 = 1013 \text{ hPa}$ .

To describe the ground behaviour there was used a model developed by Reid and others in Nebraska University [1, 6]. The model is the modification of Drucker-Prager model. It takes into account material strengthening during loading, weakening during occurring fractures in the material including destruction, material strengthening related to deformation velocity. It includes relations describing the influence of both the voids and ground humidity on material strength properties. A yield stress is described with the use of modified Mohr-Coulomb relation. The detailed model description is included in [6].

If we are interested in the phenomena occurring during charge re action and the processes occurring on the blast wave front, the approximation of programming burning model can be used to describe the detonation process [7]. In such an approximation one must know: charge detonation velocity, initiation place, parameters on the blast wave front – parameters in Chapman-Jouguet point – as well as the equation describing the detonation products behaviour. In this approach the blast wave front moves with set constant velocity and creates a strong discontinuity surface. Regarding this there can be considered only the cells with an overreacted charge which were undergone by the detonation wave front. In the cells on this front there are set the values of pressure, density and energy corresponding to the values in Chapman-Jouguet point. Such an approach allows application of not very dense calculation meshes (greater time step) without an influence on the calculation accuracy.

The detonation products behaviour was described with the use of JWL (Jones, Wilkins, Lee) equation [4, 7]:

$$p = A \left( 1 - \frac{\omega}{R_1 V} \right)^{-R_1 V} + B \left( 1 - \frac{\omega}{R_2 V} \right)^{-R_2 V} + \omega \rho E, \quad (2)$$

where:

$V = \rho_0 / \rho$ ,

$\rho_0$  - initial density,

$\rho$  - detonation products density,

$A, B, R_1, R_2, \omega$  - constants.

The constants for JWL equation for TNT (trinitrotoluene) used for calculation were presented in Tab. 1 [4].

Tab. 1. JWL equation constants for TNT [4]

$A$	$B$	$R_1$	$R_2$	$\omega$
[GPa]	[GPa]	[-]	[-]	[-]
373.8	3.747	4.15	0.9	0.35

The other parameters characterizing the explosive ( $D$  – detonation velocity,  $p_{CJ}$  – pressure in Chapman-Jouguet point,  $\rho_{CJ}$  – density in this point) are included in Tab. 2.

Tab. 2. Parameters characterizing TNT in calculations [4]

$\rho_0$	$D$	$p_{CJ}$	$\rho_{CJ}$
[kg/m <sup>3</sup> ]	[m/s]	[GPa]	[kg/m <sup>3</sup> ]
1630	6930	21	2230

During the vehicle model building there was conducted the process of simplifying the object geometry leaving only the elements which could be essential during the interaction of blast wave coming from a mine explosion. In this manner the numbers of finite elements were limited to approximately 3500. The body, tower, tyres and wheels parts were described with finite elements of coating type. The suspension system was simplified and modelled by beam type elements. The engine body was described with the use of solid elements. The air inside the tyres was characterised with the use of a perfect gas model under the right pressure. The body material was described applying the isotropic elastic-plastic model with hardening and the properties given for armoured steel.

Material data used for steel are presented in Tab. 3.

Tab. 3. Steel parameters used in calculations

$\rho$	$E$	$\nu$	$\sigma_y$	$E_{tan}$
[kg/m <sup>3</sup> ]	[GPa]	[-]	[MPa]	[-]
7850	210	0,3	550	0,02

### 3. Calculations results

It was assumed that in the initial moment a mine placed centrally under a crew landing compartment is detonated. The influence of mass on loads to which a human is subjected was considered.

An inert dummy movement caused by the movement of a chassis and a bench on which a dummy sits is presented in Fig. 3.

The pressure wave caused by the charge detonation gets the vehicle bottom (Fig. 3a) causing its deformation (Fig. 3b) and motion. The movement of vehicle bottom is transformed onto human limbs which, having significantly smaller inertia, takes off the ground (Fig. 3c). In the later moments an inert arms movement is also noticeable. If a person subjected to such loads had something in his hands (e.g. arms) this object can be a cause of additional serious injuries. Behaviour of selected points on the dummy body in time was recorded. Fig. 4 presents the velocity graphs of a selected point placed on the foot instep in relation to the mass of an exploding mine. Velocities reached by lower limbs are so significant that in the case of detonation of a mine of the smallest mass it is highly probable that the lower limbs will be injured in the area of an ankle and tibias.

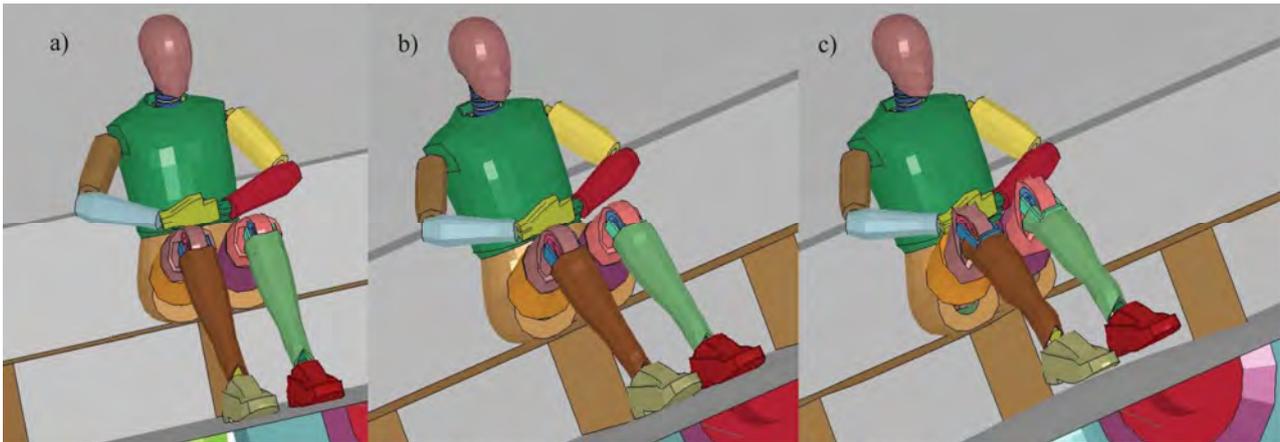


Fig. 3. The phases of the vehicle influence on a human: (a) pressure blast reaches the vehicle bottom, (b) vehicle bottom starts to subject and bulge, (c) inert limbs movement occurs

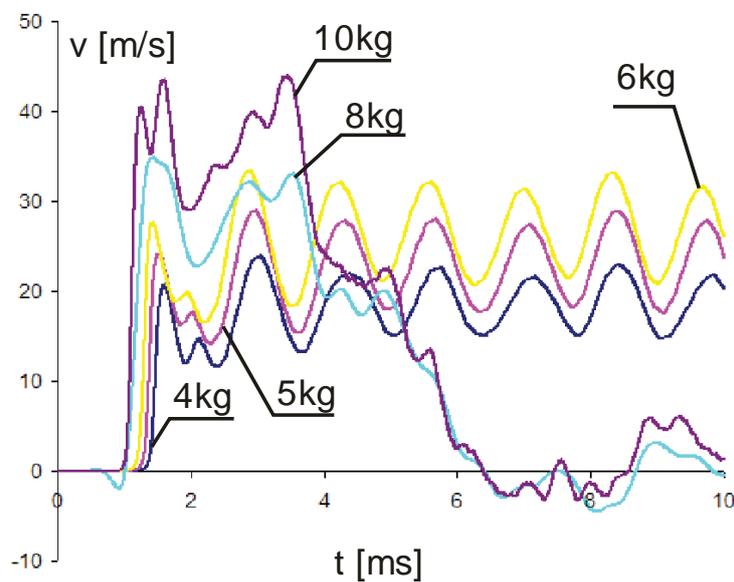


Fig. 4. Foot velocity in relation to mine mass

HIC parameter was calculated with the use of Ls-PrePost software. The calculations results were presented in Tab. 4. According to the data presented in the introduction, as a result of the explosion consequences of a mine of mass less than about 7 kg, the brain and head injuries can occur.

Tab. 4. HIC parameter values related to the explosion of mines of different masses

mine mass [kg]	4	5	6	8	10
HIC	256.4	317.9	372.1	1259	1768

#### 4. Conclusions

The explosion of the mine of 4 kg mass, in the central location, can caused significant injuries of lower limbs since such extortion gives the limbs velocities causing their injuries.

The consequences of influencing of mines of masses greater than 7 kg can be the reasons of head and brain injuries.

The results of the conducted experiments testify about the necessity of increasing the anti-mine protection of the vehicle of this type through application the right explosion energy absorbing layers as well as the right profiling of the vehicle bottom in the shape of letter V (deflector).

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