ENGINEERING TRANSACTIONS • *Engng. Trans.* • **65**, 4, 579–585, 2017
Polish Academy of Sciences • Institute of Fundamental Technological Research (IPPT PAN)
National Engineering School of Metz (ENIM) • Poznan University of Technology

TKI 2016

Impact of Soldiers' Inventories on the Risk of Injury During IED Blast Under a Light Armored Vehicle

Michał BURKACKI[1)], Sławomir SUCHOŃ[1)], Kamil JOSZKO[1)],
Bożena GZIK-ZROSKA[2)], Marcin WOJTKOWSKI[3)],
Wojciech WOLAŃSKI[1)], Marek GZIK[1)]

[1)] *Department of Biomechatronic*
Faculty of Biomedical Engineering
Silesian University of Technology
F.D. Roosevelta 40, 41-800 Zabrze, Poland
e-mail: {michal.burkacki, slawomir.suchon, KJoszko, WWolanski, MGzik}@polsl.pl

[2)] *Department of Biomaterials and Medical Devices Engineering*
Faculty of Biomedical Engineering
Silesian University of Technology
F.D. Roosevelta 40, 41-800 Zabrze, Poland
e-mail: BGzik-Zroska@polsl.pl

[3)] *Military Institute of Medicine*
Szaserów 128, 04-141 Warszawa, Poland
e-mail: MWojtkowski@wim.mil.pl

Model studies concerning the assessment of soldiers' safety are mainly focused on the examination of vehicle construction and designing energy consuming materials that reduce acceleration pulse affecting soldiers during an explosion. Authors of this paper focus on ergonomic factors that have a significant impact on the safety of the soldiers during the explosion of improvised explosive devices (IED) under the vehicle. The study examined the impact of the equipment carried by the soldiers on the injuries incurred by them. The research was conducted in the Madymo software program. Simulations indicate a high risk of serious head and neck injuries caused by a wrong weapon position.

Key words: soldier modeling, madymo, multibody modeling, injury assessment.

1. Introduction

Improvised explosive devices – IEDs were the main cause of soldiers' death and serious injuries incurred during missions in Afghanistan and Iraq according to data presented in [8]. Current model studies on soldier safety concentrate on the examination of vehicle construction [7], energy consuming materials like i.e. alluminium foams [8] and also injury assessment of lower limb [1, 3] to reduce the impact of acceleration on soldiers during an explosion. Studies conducted on crew compartment has shown that from injury risk viewpoint, preventing leg and foor plate contact in the moment of explosion is crucial and ankle torque for dorsiflexion may be increased by footrest [1]. Studies shown that there is strong influence of ergonomic set-up and other factors related to body position on injury risk. Also it was proven that multipoint seat belts can preent head and neck injuries [3]. However, in this paper the authors attempt to examine the impact of equipment on the injury level in a light armored vehicle. In NATO agreement TR-HFM-090 [5] it is stated that the crew should 'avoid any loose objects inside the vehicle'. The NATO study also shows that equipment during an explosion (0.5 kg TNT placed on the ground at a distance of 0.5 m from a 10 mm steel plate) can achieve a velocity of approximately 25 m/s (Fig. 1), which becomes a very dangerous projectile. The purpose of this study was to identify the impact of unattached guns during the IED explosion of a light armored vehicle in the crew compartment.

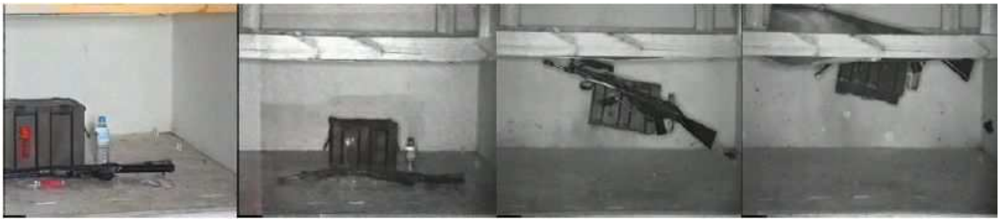

Fig. 1. Illustration of loose objects risk [5].

2. Methodology

For the development of a numerical simulation the authors used the Madymo software program which is dedicated to modeling car accidents, however, recently it has been also used to analyze the effects of explosions [1, 5]. The software allows analysis with a Multibody method using both deformable and rigid elements. This kind of approach reduces computational time compared to finite element modeling which provides possibility to analyze more cases at the same time. The software contains models of Hybrid III dummy family including modified Mil-Lx leg, which has more biofidelic response than standard Hybrid III leg in the case of an underbelly explosion.

Modeling process consisted of the following stages: (I) obtaining material properties from a strength testing machine – for example obtaining characteristics of helmet foam, (II) 3D scanning of Polish army weapons of the crew inside an armored personnel carrier 'KTO Rosomak', (III) determination of boundary conditions – acceleration obtained in an experimental test performed on a vehicle with a 10 kg TNT explosion under it, (IV) model formulation in the Madymo software program, (V) analysis of the results. In results the authors focused on Head Injury Criteria (HIC_{15}), acceleration acting on the soldiers' heads, torque and force acting on the cervical spine.

3. Numerical modeling

The model created in the Madymo software package consisted of the APC 'KTO Rosomak' exterior body with a crew compartment, which included 6 soldiers. Each soldier was represented by a detailed model of the Hybrid III, with modified limb MiL-LX and helmet wz.2005 [2]. The seats were equipped with a 4-point seat belt with a width of 50 mm and a thickness of 1 mm. The compartment also included the landing equipment in the form of weapons: Beryl, PKM, RPG-7, Sako sniper rifle. The weapons were placed to reflect real conditions of their transfer (Fig. 2). Contacts implemented in the model can be divided into the following groups:

1) contacts within the dummy (eg. head-to-hand) – contact characteristics were taken from a dummy model;
2) contacts between the soldier and the environment (eg. floor-leg, pelvis-seat, head-helmet) – surrounding objects were defined as not-deformable except seats;
3) contacts between the soldiers;
4) contacts between the weapon and the soldier.

Fig. 2. Model used in simulation reflecting conditions in the vehicle.

Acceleration pulse which was applied to the vehicle had a peak value of 300 g – which reflects explosion of 10 kg of TNT under center of vehicle. Simulation time was fixed at 200 ms. Each of the dummies was pre-simulated to stabilize the dummy relative to present contacts.

4. Results and discussion

The obtained results were analyzed in terms of the safety of each soldier and the impact of equipment during the explosion. For conducted simulations maximum value of Head Injury Criteria HIC_{15} was 1462 for soldier No. 3 (Fig. 3) when a gun was held in the soldier's hands (Table 1). Every soldier exceeded the limits of HIC_{15}, which is stated to be 250 units by STANAG HFM-148 [6]. The figures below show the following results. Figure 4 shows the courses of acceleration for each soldier, Fig. 6 includes the course of force F_Z acting on the cervical spine and Fig. 5 consists of bending moment M_Y acting on the cervical spine for all the soldiers. Limit exceeded for the highest value of HIC_{15} – 1462 indicates the scale of AIS 5 injury which creates a strong possibility of the skull fracture along with extensive hemorrhage. Limit values for tensile force F_Z in the cervical spine were exceeded for each soldier with a peak value of 7661 N for soldier No. 3. The permitted torque M_Y was exceeded for soldiers 1, 3 and 5. Maximum value was 361 $\mathrm{N \cdot m}$, which was acquired for soldier No. 3. This indicates a high risk of neck injury. In TR-HFM-090 authors conducted an experiment in which a fire extinguisher hit the head of a dummy during an explosion. Maximum bending moment acquired in the simulation was 420 $\mathrm{N \cdot m}$ which corresponds to the value obtained in the simulations taking into account the fact that the fire extinguisher has similar weight to presented weapon.

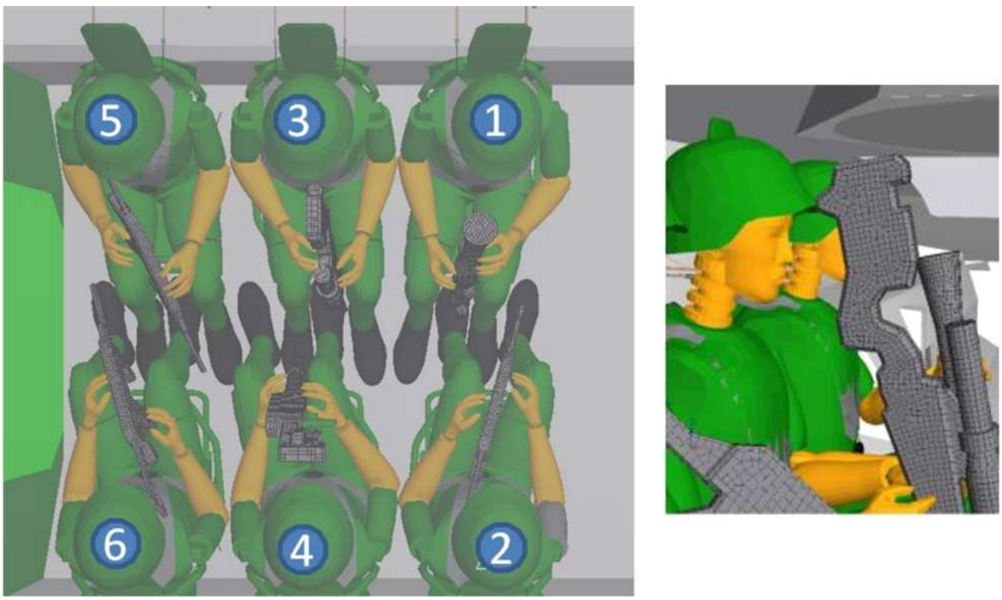

Fig. 3. Deployment of soldiers in the vehicle – left, moment of weapon hitting soldier's helmet – right.

Table 1. Injury criterion according to [6].

Criterion	HIC_{15}	Max. tensile force F_Z in cervical spine [N]	Max. torque M_Y in cervical spine [$N \cdot m$]
Llimit [5]	250	3100	98
Soldier #1	**325**	**5100**	**120**
Soldier #2	**313**	**4778**	33
Soldier #3	**1462**	**7661**	**361**
Soldier #4	**549**	**6580**	29
Soldier #5	**411**	**4836**	**135**
Soldier #6	**425**	**5748**	59

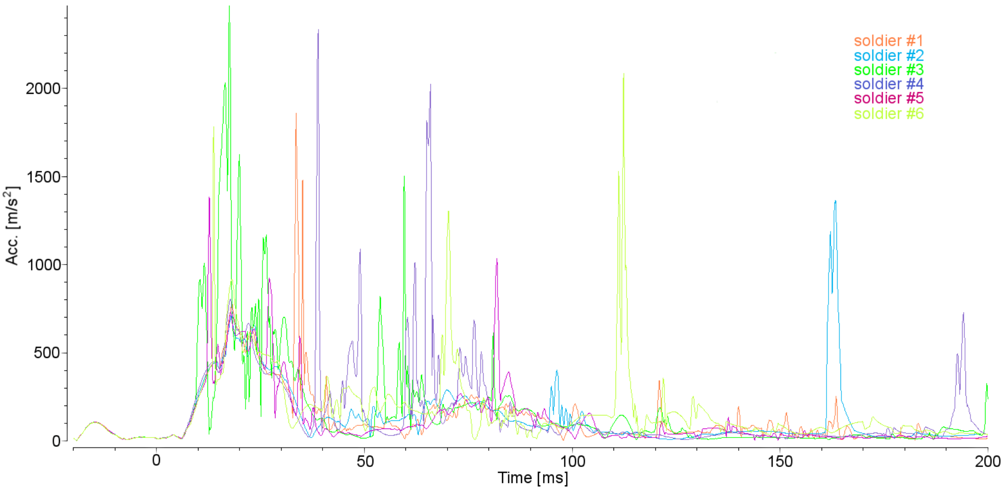

Fig. 4. Resultant head acceleration for all soldiers.

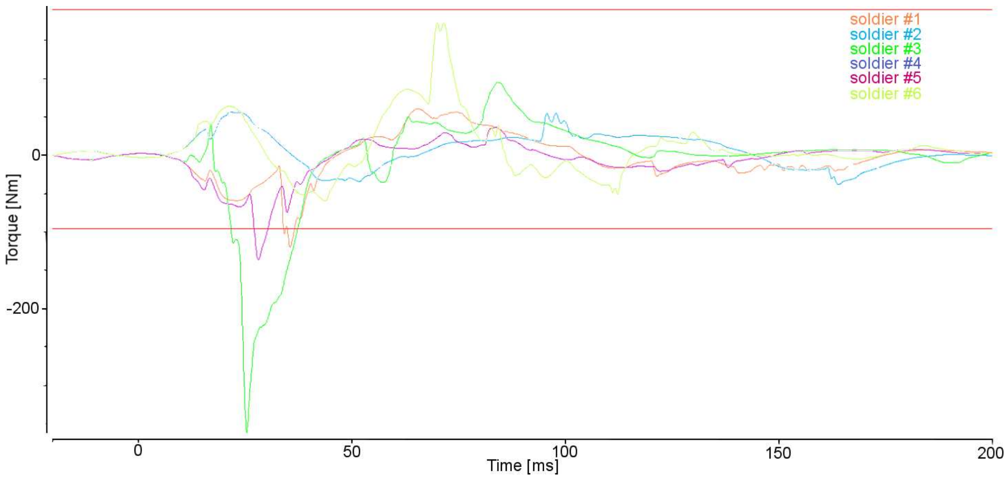

Fig. 5. Bending moment M_Y in cervical spine for all soldiers.

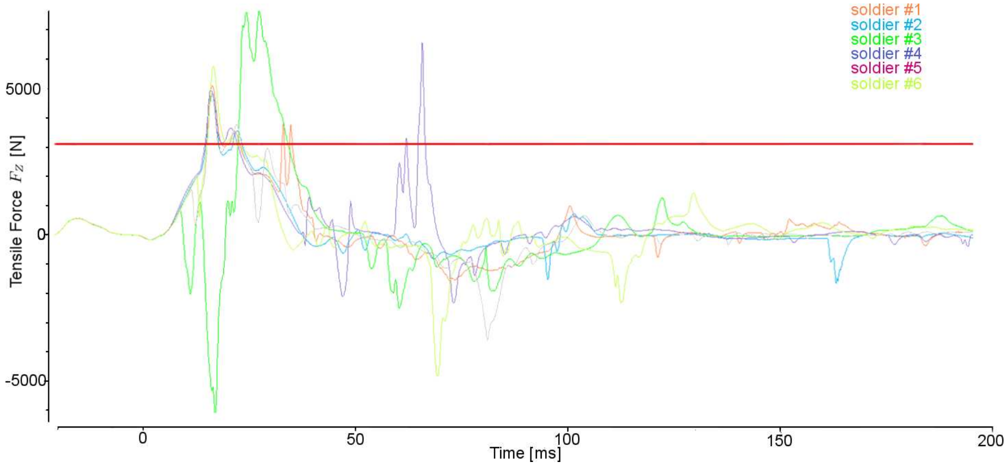

FIG. 6. Tensile Force F_Z in cervical spine for all soldiers.

5. Conclusion

The model studies identified a number of factors that could affect the safety of soldiers during the explosion of the IED. The most important ergonomic factors that may pose a life threat include the way of transporting weapons and equipment. Numerical simulations allowed the authors to analyze various options and thereby assess impact of these factors on the injury risk. In this paper the analysis of the impact of the soldier's inventory on the risk of injury during an underbelly explosion was carried out mainly on the basis of the head and neck injury criteria. Analyzing the results of the simulation including the whole crew, the authors reached the following conclusions:

- holding weapons in hands, regardless of their position, increases the likelihood of injury to the head and neck during the explosion;

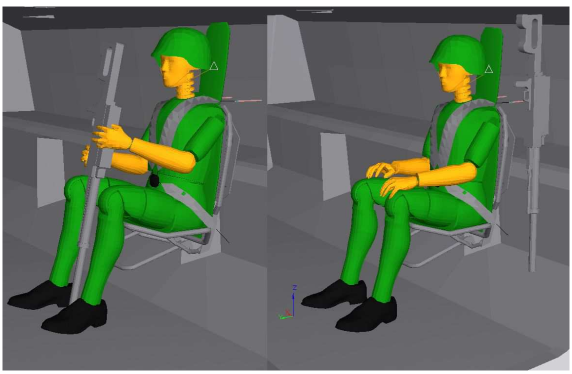

FIG. 7. Proposed weapon attachment.

- using mounts for weapons increases the safety of the soldiers during the explosion (Fig. 7).

Acknowledgment

The research was done within the project no. DOBR-BIO4/022/131449/2013 'Improving the Safety and Protection of Soldiers on Missions Through Research and Development in Military Medical and Technical Areas' supported and co-financed by NCR&D.

References

1. Gzik M., Wolański W., Gzik-Zroska B., Joszko K., Burkacki M., Suchoń S., *Risk factors influencing lower limbs injuries during IED blast*, Information Technologies in Medicine, Vol. 472 of the Series *Advances in Intelligent Systems and Computing*, pp. 299–305, 2016.
2. Gzik M., Wolański W. Gzik-Zroska B., Joszko K., Burkacki M., Suchoń S., *Soldier modeling for the biomechanical analysis of load resulting from shockwave* [in Polish: *Modelowanie żołnierza na potrzeby analizy biomechanicznej wpływu obciążenia pochodzącego od fali uderzeniowej*], In: *Bezpieczeństwo wojsk w aspekcie zagrożeń wynikających z użycia improwizowanych urządzeń wybuchowych (IED)*, pp. 79–101, Warszawa, 2014, ISBN 978-83-7523-376-6.
3. Gzik M., Wolański W., Gzik-Zroska B., Joszko K., Burkacki M., Suchoń S., *The impact of ergonomic factors influencing armoured vehicle crew safety*, 3rd Polish Congress of Mechanics & 21st Computer Methods in Mechanics, Vol. 1, pp. 223–224, 2015.
4. Krzystała E., Kciuk K., Mężyk A., *Identification of hazards of special vehicles crew during an explosion*, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji PIB, Gliwice, 2012, ISBN 978-83-7780-161-2.
5. RTO Technical Report HFM-090, *Test methodology for protection of vehicle occupants against anti-vehicular landmine effects*, 2007.
6. RTO Technical Report HFM-148, *Test methodology for protection of vehicle occupants against anti-vehicular landmine and/or IED effects*, 2012.
7. Sławiński G., Niezgoda T., Barnat W., Wojtkowski M., *Numerical analysis of the influence of blast wave on human body*, Journal of KONES Powertrain and Transport, **20**(3): 381–386, 2013.
8. Wotkowski M., Płomiński J., Waliński T., *Analysis of the injuries of the movement organs caused by explosion of the Polish military contingents – preliminary reports* [in Polish: *Analiza powybuchowych obrażeń narządu ruchu u żołnierzy polskich kontyngentów wojskowych – doniesienia wstępne*], In: *Bezpieczeństwo wojsk w aspekcie zagrożeń wynikających z użycia improwizowanych urządzeń wybuchowych (IED)*, pp. 103–112, Warszawa, 2014, ISBN 978-83-7523-376-6.

Received February 14, 2017; accepted version October 26, 2017.