Investigation of Improvised Explosive Device Effects on a Section Hull of Armored Military Vehicle

İsmet Kutlay ODACI, Samet Emre YILMAZ, İlker KURTOĞLU

FNSS Savunma Sistemleri A.Ş.
Ankara / TÜRKİYE

1 Abstract

Military vehicles and their occupants in conflict zones face a significant risk from improvised explosive devices (IEDs). Simulating IED risks on armored military vehicles requires employing various modeling approaches. However, to ensure the accuracy and effectiveness of these approaches, it is crucial to accurately transfer the explosive load onto the vehicle structures. This study aims to address this critical point by developing a methodology for selecting the appropriate vehicle components for load transfer and evaluating the proximity of the analysis model to live fire test results.

To investigate the efficiency of the established methodology, two numerical models representing different regions of a complete vehicle hull were constructed, mirroring the ones used in live fire tests. Test data obtained from the Hybrid III dummy, along with the plastic deformations occurring in the hull and subsystems, were compared with the analysis results. The findings revealed consistent outcomes between the test data and analysis results, validating the accuracy of the methodology.

The results emphasize the significance of accurately selecting the structures onto which the blast load is transferred during the modeling phase. Such precision plays a crucial role in designing military vehicles that meet structural integrity requirements and ensure occupant protection. This study contributes to enhancing the understanding of IED risks and provides valuable insights for optimizing military vehicle design and occupant safety measures.

2 Introduction

The utilization of non-conventional threats such as IEDs necessitates the accurate and effective application of the finite element method in the continuous enhancement of armored vehicle protection system design against these threats. For the design phase to progress efficiently, it is essential to accurately transmit the blast load onto vehicle structures. In this stage, various methods such as CONWEP [1], Arbitrary Lagrangian Eulerian (ALE) [2-5], Structured Arbitrary Lagrangian Eulerian (S-ALE), and Smooth Particle Hydrodynamics (SPH) [6] or combination of these methods are employed to model the blast load.

In this study, `*LOAD_BLAST_ENHANCED` method is used to generate side blast load on the section hulls. In order to distribute the applied load onto the structures effectively, various loading configurations were formulated and the resulting outcomes were systematically assessed. The analyses performed using the validated methodology showed good agreement with the experimental results. Subsequently, utilizing this approach, efforts were directed towards improvement initiatives encompassing vehicle structural integrity, personnel safety, and enhancements in subsystem bolted connections.

3 IED Blast Experimental Set-Up

The section hulls were produced by FNSS Savunma Sistemleri A.Ş. to investigate effects of side blast attacks on the vehicle structure and the personnel. The section hulls shown in Figure 1(a) and (b), represent a section of a long-wheeled vehicle and a section of a short-wheeled vehicle, respectively. The testing targets consist of hull reinforcements, add-on armor systems, and predetermined subsystems. The total mass of the section hull configurations was set to a certain amount by adding additional weight plates on the roof to satisfy the weight requirement.

(a) (b)

Fig.1: *The section hulls of a full vehicle: (a) long and (b) short.*

In Figure 2 (a) and (b), the locations of the subsystems in the section hulls are given. In the test configuration, original or dummy forms of subsystems such as personnel seats, section floor plates, communication systems, ammunition stowage, and fire suppression systems have been employed. Additionally, high-speed cameras were strategically installed within the vehicle to capture the behaviors of these subsystems throughout the testing process. For the purpose of measuring the forces exerted on personnel, Hybrid III dummy was positioned within the section hull. Explosive was placed equidistant from the section hulls and both hulls were simultaneously subjected to detonation.

(a) (b)

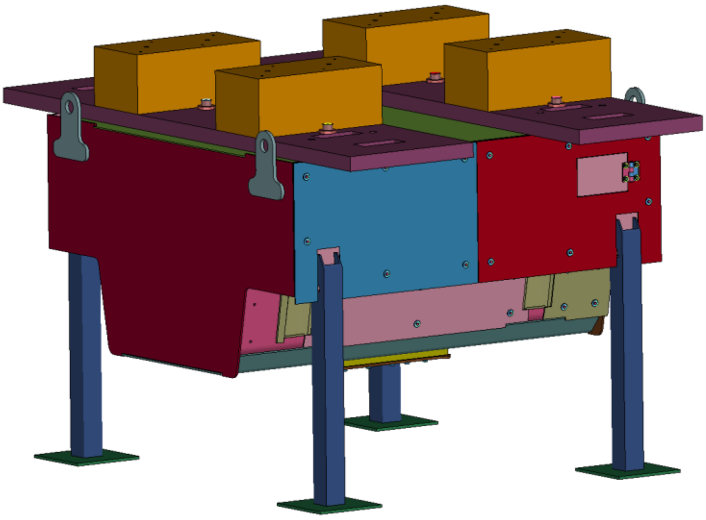
Fig.2: *The location of dummy and the subsystems in section hulls: (a) long and (b) short.*

4 Finite Element Model of the Section Hulls

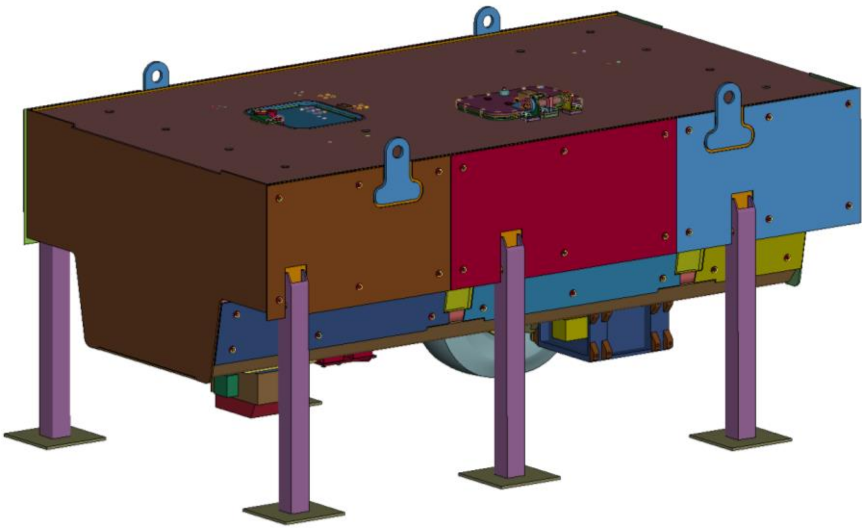
The explicit full numerical models of section hulls are shown in Fig. 3 (a) and (b), respectively. The components in the numerical model, except the bolts were meshed using quad solid elements. For the bolted connections, the bolt heads and nuts were meshed using quad solid elements, however, the bolt shank was modelled with spotweld-beam elements (ELFORM=9). **`*MAT_SIMPLIFIED_JOHNSON_COOK`** material model, material type 98, was used to model aluminum and steel alloys. The full Johnson and Cook (JC) flow stress model is given as (1)

$$\sigma_y = \left[A + B\varepsilon_p^n\right]\left[1 + C ln \dot{\varepsilon_p}^*\right]\left[1 - T_H^m\right] \qquad (1)$$

where, ε_p is the equivalent plastic strain, $\dot{\varepsilon_p}^*$ is the equivalent plastic strain rate ratio and T_H is the normalized temperature. Since the material type 98 does not consider the temperature effect only first brackets of Eq. (1) is considered. The material model parameters were determined by quasi-static and high strain rate Split Hopkinson Pressure Bar tests. **`*MAT_SPOTWELD`** material model, material type 100, with axial and shear force resultant at failure was used to model the bolt shanks. The contacts were assumed to be perfectly bonded and a **`*TIED_SURFACE_TO_SURFACE_OFFSET`** contact algorithm was attained between welded components. ***AUTOMATIC_SURFACE_TO_SURFACE_MORTAR** contact was defined between bolt shank beam elements and solid components. ***ERODING_SINGLE_SURFACE** contact definition was selected in order to consider self-contacting interfaces.



(a)



(b)

Fig.3: *The numerical model of the section hulls: (a) long and (b) short.*

To simulate the mine blast, the ***LOAD_BLAST_ENHANCED** feature in LS-DYNA was utilized, incorporating the air burst with ground reflection option. Parameters pertaining to the explosive, such as its type, quantity, height of burst, and standoff distance, were configured to replicate the experimental conditions accurately. The initiation of the detonation occurred once the bolt pretension stage was completed. The loading interface was defined through the ***BLAST_SEGMENT_SET** feature, with various segment sets employed to align with the experimental outcomes.

In Figure 4, the seating arrangement of the Hybrid III dummy is presented. This configuration was established to correspond to the experimental setup. Default properties for dummies were applied to simulate vehicle personnel. The ***AUTOMATIC_SURFACE_TO_SURFACE** contact was established between vehicle components and the dummy.

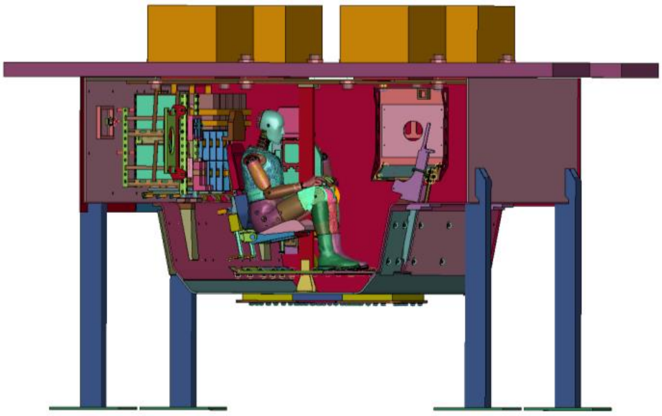


Fig.4: *The seating configuration of the Hybrid III dummy.*

5 Result and Discussion

The deformations of the section hulls and subsystems in the experiment and numerical model were compared to verify the numerical results. At the initial stages of the numerical studies, the **`*BLAST_SEGMENT_SET`** was defined to the components that are positioned in the direction of the explosive as shown in Fig. 5. However, when the experimental results were compared with numerical results, it was observed that the behavior of subsystem mounted on the roof differed from the test behavior. To address this discrepancy, segment definitions were also applied to the roof in order to mitigate this disparity. The new segment set for the blast load is also depicted in the same figure.

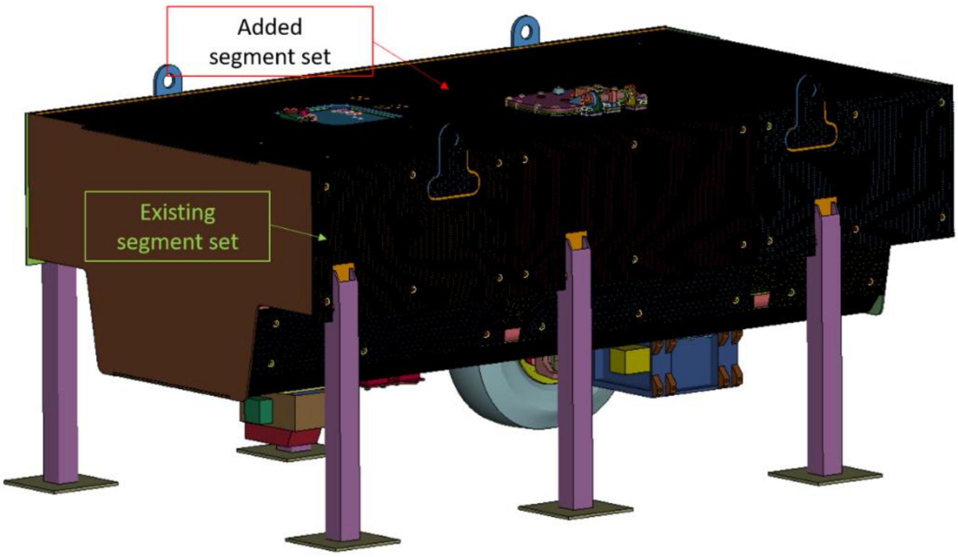


Fig.5: *The blast segment sets defined in the numerical analyses.*

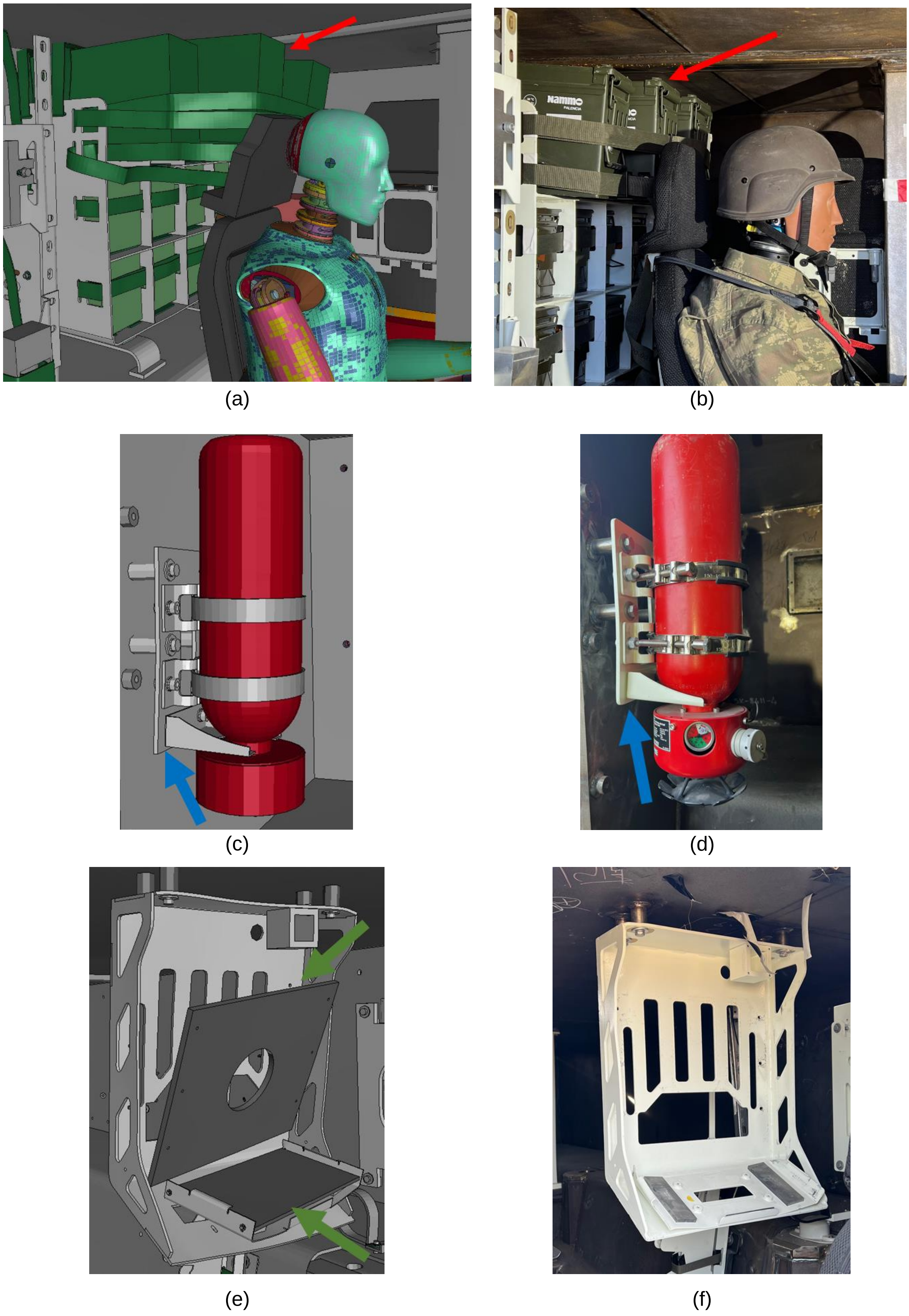


Fig.6: *Deformation comparison of numerical model and experiment.*

The deformations of subsystems in the numerical model and the experiment were given in Figure 6. When the results were investigated, it was seen that the upper ammunition boxes moved towards the personnel department in both numerical and experimental results (Fig 6 (a) and (b)). Moreover, plastic deformation was also observed around the frame and strap contact area. The observed behavior of the ammunition stowage necessitates a design improvement for personnel safety considerations. In Fig. 6 (c) and (d), plastic deformation in the bracket of the fire suppression unit was depicted. Considering the potential for the progression of plastic deformation, there is a possibility that the bracket could fail, causing damage to surrounding equipment and personnel. Therefore, a need for design improvement in response to the observed deformation has been identified.

In Fig. 6 (e) and (f), the behavior of the control unit in the numerical model and experiment was given, respectively. In both scenarios, it was determined that the bolts connecting the surrogate structures to the frame experienced failure, resulting in displacement towards the vicinity containing personnel and equipment. In light of the kinetic characteristics and mass of the mobile components, the potential for inflicting damage to both personnel and proximate equipment is considerably heightened. Consequently, it is imperative to undertake targeted mitigation measures within the scope of this particular subsystem. Upon thorough examination and comparative analysis of deformation similarities observed in both the analytical and experimental outcomes, it is evident that these concordant findings lend substantial support to the initiatives focused on advancing design improvements.

The values of Hybrid III dummy obtained from experiment and numerical analyses are summarized in Table 1. Upon examination of the experimental data and numerical results, it is observed that the values exhibit compatibility with each other. The disparity between the values can be attributed to the absence of seatbelts, material models employed for the seat, and parameters utilized for the seat damping mechanism. In order to address these variations, it is essential to engage in efforts focused on enhancing and validating the **`*LOAD_BLAST_ENHANCED`** methodology, along with refining the intricacies of the utilized subsystem model. However, upon comprehensive evaluation, it is apparent that the experimental and numerical results exhibit good agreement.

Table 1: Hybrid III dummy values obtained from experiment and numerical model.

Body Region	Criterion	IARV	Experiment	Numerical Model
Head	Head Injury Criterion	HIC_{15}	1	1.07
Neck	Axial Compression Force	Fz- (kN)	1	0.58
	Axial Tension Force	Fz+ (kN)	1	0.56
	Shear Force	Fx+ -/ Fy+ - (kN)	1	0.33
	Bending Moment (Flexion)	Moc_y + (Nm)	1	0.76
	Bending Moment (Extension)	Moc_y – (Nm)	1	0.74
Thorax	Thoracic Compression Criterion	$TCC_{frontal}$ (mm)	1	0.54
	Viscous Criterion	$VC_{frontal}$ (m/s)	1	0.0975
Spine	Dynamic Response Index	DRIz	1	-
Upper Leg Left	Axial Compression Force	Fz- (kN)	1	0.69
Upper Leg Right	Axial Compression Force	Fz- (kN)	1	0.66
Lower Leg Left	Axial Compression Force	Fz- (kN)	1	1.41
Lower Leg Right	Axial Compression Force	Fz- (kN)	1	1.76

6 Summary

Within this study, side blast analyses were performed utilizing the **`*LOAD_BLAST_ENHANCED`** methodology on section hulls representing comprehensive vehicle geometries. The ensuing results have been presented and subsequently compared with experimental data. In the context of this methodology study, while variations were evident in Hybrid III dummy results, a concurrence with experimental findings was observed in terms of subsystem deformations. Upon thorough examination of the entire study, it is evident that the most crucial aspect in approaching proximity to experimental results lies in the accurate selection of vehicle components where the blast load is distributed. By a correct load distribution, this modeling approach has illustrated its potential for investigating the response of section hulls subjected to IED events, confirming the integrity of subsystem connections, and facilitating measures aimed at ensuring personnel safety. To enhance the robustness and precision of this methodology, additional numerical studies across varied scenarios and vehicle body configurations are warranted.

7 Literature

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