A Simple Ejection Mitigation Device to Increase Survival of Standing Gunner

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Abstract

It is a challenging task to provide warfighters protection due to impact related injuries such as skull fracture, lower leg and ankle fractures and neck and spinal injuries, which might occur during underbody blast. Tremendous improvements in design of ground vehicles have minimized these injuries. Further improvement can be achieved by new technology solutions by adding a simple passive device to existing design with minimal changes in order to mitigate occupant ejection for a vehicle occupant experiencing underbody blast while standing at nametag, defilade through round hatch opening as part of their operational duty. The patented device is an energy absorbing box with corrugated sheets in all four sides and welded to the top and bottom plates. The top and bottom plates are connected with brackets. The top plate and the brackets are connected with tension failure plates. The corrugated sheets act like energy absorbing (EA) bellows. The EA capacities can be increased by adding collapsible stiffeners inside the box. The device is virtually evaluated in an occupant standing position in a vehicle using LS-DYNA® and LS-PrePost®. The standing occupant is modeled using ATD from LSTC. Modeling of the Gunner Restraint System (GRS) used to keep the occupant in position is developed by using Seatbelt Fitting application module in LS-PrePost. An acceleration pulse is applied to the vehicle in order to represent the effect of blast load. The EA mechanism is evaluated for various side plate thicknesses and heights of the device. The reductions in tibia force and head excursion relative to hatch are presented.

INTRODUCTION

It is an important mission and challenging task to provide warfighters protection due to impact related injuries such as skull fracture, lower leg and ankle fractures and neck and spinal injuries, which might occur during underbody blast. Tremendous improvements in design of ground vehicles have been achieved in the past decade in minimizing these types of injuries and improved occupant survivability. Further improved occupant survivability outcomes against present and future IED threats can be achieved by innovative new technology solutions with minimal cost. Particularly this new technology solution help mitigate occupant ejection for a vehicle occupant experiencing underbody blast while standing at nametag, defilade through a round hatch opening as part of their operational duty.

The sequence of the blast event and its mechanism are shown in Figure 1 [Ref. 1]. During underbody blast, the occupant may be propelled and might hit other parts of the vehicle resulting in tertiary injury [Ref.2]. In addition to hitting parts, the free-standing occupant as shown in Figure 2 in an ingress/egress hatch opening is prone to be ejected.

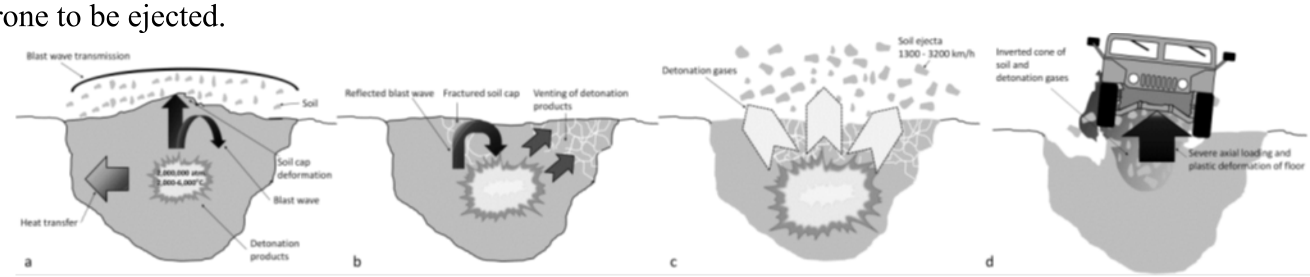


Figure 1. Blast Mechanism [Ref 1]

Figure 2. Standing Occupant in an ingress/egress opening.

The seated occupants are required to use restraint systems attached to vehicle structure and the standing gunner is required to use Gunners Restraint System (GKS) shown in Figure 3 to keep the occupant in position during rollover and mitigate ejection during explosion event. In general, the standing occupant is freely standing as shown in Figure 2 or using restraint system which is anchored to the platform as shown Figure 4 in order to mitigate ejection out of the vehicle due to underbody explosion.

Fig. 3. Gunners Restraint System [Ref. 3].

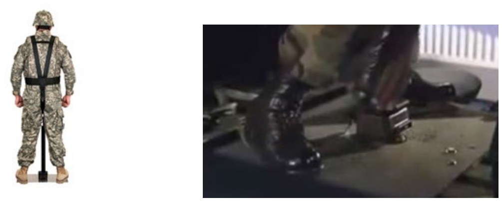


Fig. 4. GRS anchor

Tremendous amount of work has been done on evaluation of the effect of underbody blast to Military Vehicle structures and their occupants in the past decade. Selected works are explained in Reference 4-8. Majority of these investigations are based on numerical methods coupled with some field and drop tests applied to sitting occupant represented by Hybrid III 50th percentile Anthropomorphic Test Device (ATD) under blast load. BMI defense system [9] shows an effective Energy Attenuating gunner platform as shown in Figure 5 and the company states that this EA seat protects soldiers against spinal injuries from the destructive shock of an IED blast beneath the vehicle. Active blast mitigation system called Active Blast Defeat System (ABDS) are being evaluated [Ref. 10]. All these devices both active and passive are to be integrated during vehicle manufacturing stage. However, the vehicles which are already in wide use can be easily modified with minimal change by adding a passive mitigation device. This device can minimize injury of a standing gunner due to underbody blast.

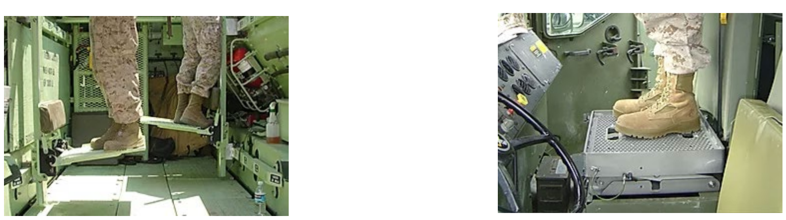


Figure 5. Energy Attenuating System [Ref. 9].

The purpose of this paper is to present the development and virtual evaluation of a simple ejection mitigation device (patent pending) using LS-DYNA, LS-PrePost and LSTC 50th percentile standing dummy. The device should be effective for occupants experiencing a vehicle vertical lift-off velocity of up to 8.0 meters/second (m/s) in a g-force acceleration environment. In addition, the head excursion should not be more than 100mm with respect to the center of hatch opening.

Mitigation Device Development by Simulation

The device is a rectangular energy absorbing box as shown in Figure 6 (patent pending) that can easily be fitted to the top plate of existing platform as an additional part minimizing the assembly time.

Figure 6a – 6b.. Energy Absorbing Box

The device consists of corrugated sheets that are connected to the top and bottom plates with brackets as shown in Figure 6a-6b. The top plate is connected to bottom plate with tension failure bolts. The heights of the box can be varied by changing the height of the corrugated sheets. The corrugated sheets act like bellows. The top plate can be stiffened by thin strips welded to the plate. The interior of the box can be filled with additional energy absorbers such as springs, energy absorbing plastic cones etc.

The device was developed using HUMVEE Finite Element Model created from the cad data [Ref. 11] as shown in Figure 7. The LSTC standing ATD (Fig. 8) was used to represent standing gunner. The GRS belt system (Fig. 9) was fitted using 'Seatbelt Fitting' module of LS-PrePost. The standing occupant with seatbelt fitted is shown in Figure 10. Standing occupant in the vehicle is shown in Figure 11.

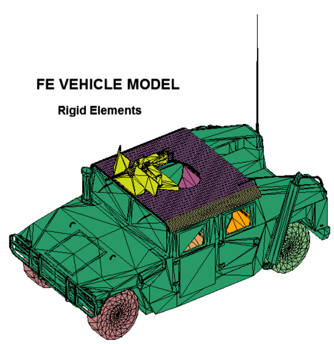


Fig. 7 Vehicle Model

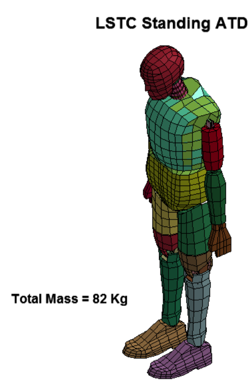


Fig. 8 Standing ATD

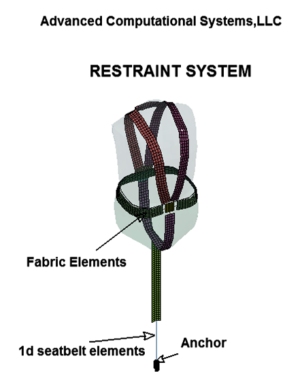


Fig.9 GRS Restraint System

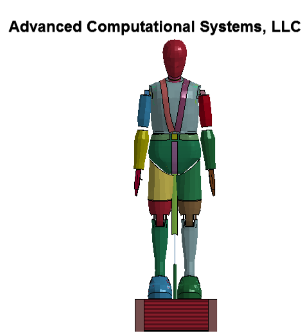


Fig. 10. Occupant with DRS

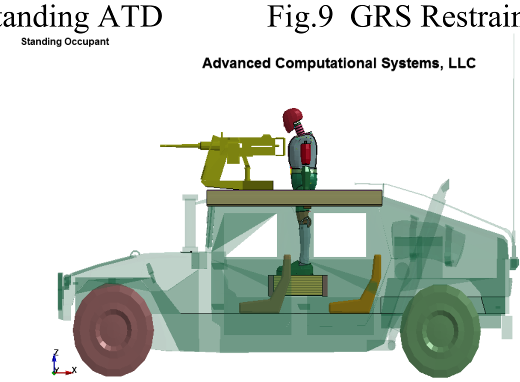


Fig. 11. FE model with standing occupant..

Due to underbody blast, the vehicle is subjected to an acceleration pulse. This pulse may be represented by 1) Haversine 2) Half sine pulse 3) A square wave pulse and 4) triangular pulse as discussed in Ref. 12. In present application, the acceleration pulse is modeled as half sine pulse.

The half sine pulse is given as

$$a = dv/dt = A \sin(pi*t/T) \qquad (1)$$

where

a = acceleration, t=time at any instant, A = maximum acceleration amplitude, T= duration of the pulse, v= velocity and pi = 3.1415

Integrating the above equation and applying initial condition, the change in velocity is obtained as

$$dV = -AT(\cos(pi) - 1)/pi = 2\,AT/pi \qquad (2)$$

From the above equation, it can be inferred that the same lift off velocity can be obtained by varying the parameters amplitude (A) and pulse duration T.

Based on the study by Sudhakar et.al [Ref. 8], two peak amplitudes, 325g and 61g are considered for evaluation. The half sine blast pulses are shown in Figure 12. These pulses give the same velocity of 8 m/sec. The time duration is 4 and 21msec for 325g and 61g pulse respectively.

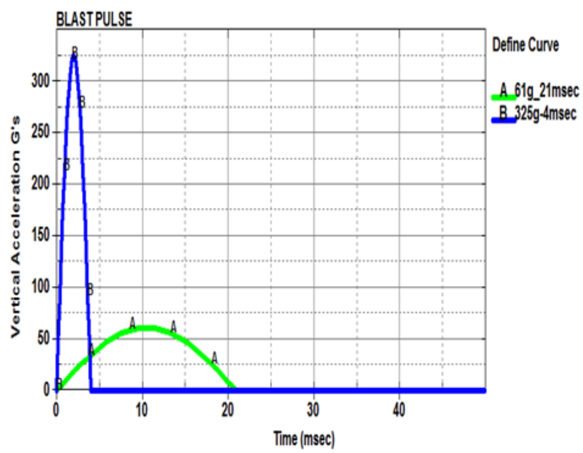
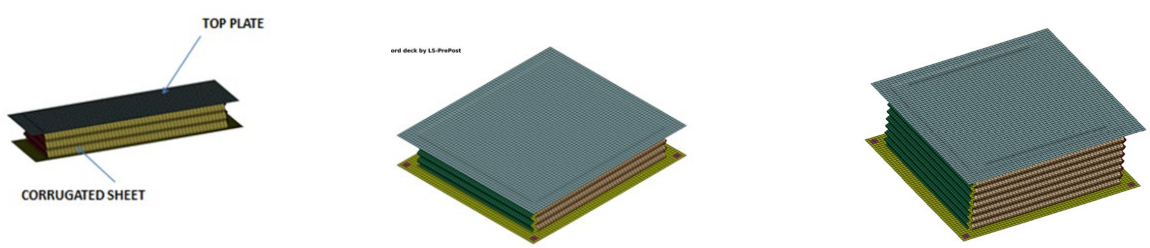


Fig. 12. Blast half sine wave pulse chosen for development.

The ejection mitigation devices with various heights are shown in Figures 13. Both top and bottom plates are welded to the corrugated sheet and this prevents from disintegration of the unit from the base during blast event.



Height = 75mm   Height = 100mm   Height = 200mm

Figure 13. Ejection Mitigation Box

The material of the box may be steel or aluminum alloy. Definitely, aluminum is much lighter than steel. The stiffness of the plates can be varied by changing thickness and stiffness is proportional to cubic power of plate thickness. In addition, the box can be filled with light materials such energy absorbing thermoplastic materials or foams. The corrugated plates help in progressive buckling in absorbing energy. The strain rate effects are accounted by using material model *MAT_JOHNSON_COOK with *EOS_LINEAR_POLYNOMIAL.

Based on available literature, it is assumed that there are two configurations that are in practice as shown in Figures 14 and 15. The occupant is restrained with GRS in the first configuration and the occupant is freely standing in the second configuration. All the simulations were done without helmet in this study.

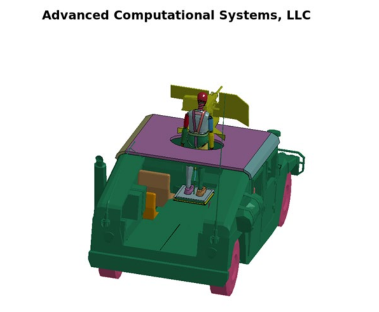


Fig. 14. Standing Gunner with GRS

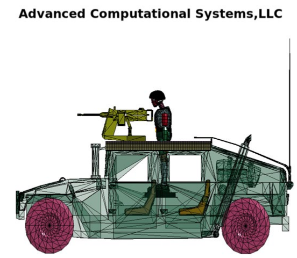


Fig. 15. Standing Gunner with Helmet

Simulation Results and Discussion

The simulation results are presented for half sine wave pulse of 325g with 4msec duration in this paper.

Standing Unrestrained Occupant:- The FE model of the vehicle shown in Figure 7 with standing occupant on a 75mm rigid box connected to the vehicle subjected to a half sine pulse with 325g peak value for 4 msec duration was used in the simulation as base model.

The occupant kinematics are shown in Figures 16 at 22msec and 120 msec. After 120 msec, the occupant hits the roof of the vehicle. The tibia force plot is shown in Figure 17. The maximum tibia force is 55 kN which is almost 9 times the acceptable marginal axial force of 6kN [Ref. 13].

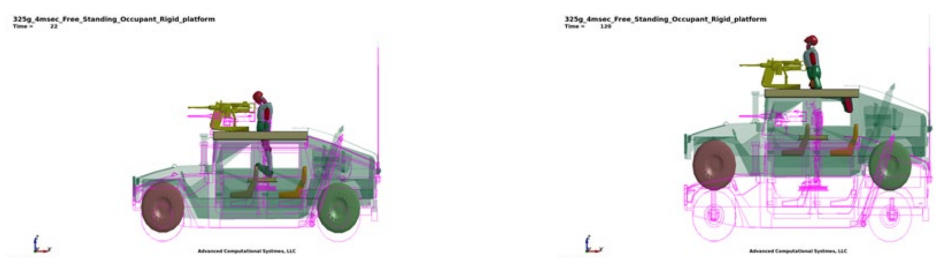


Fig. 16. The unrestrained occupant kinematics at 22 msec and 120 msec

The head excursion relative to hatch opening is shown in Figure 18. The head excursion is negative during initial period of the event due to flexion of the neck and the lower limbs. It is about 100mm. The head starts going up once the foot contact with the platform is lost.

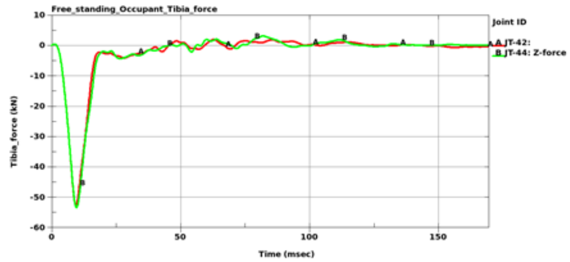


Fig. 17. Tibia Force

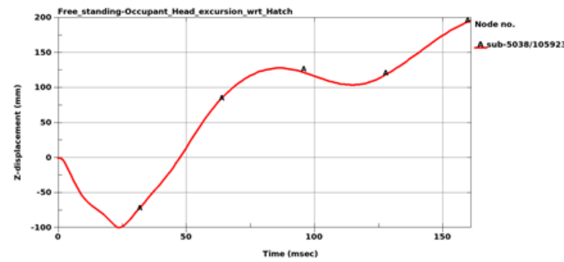


Fig. 18. Head Excursion relative to hatch.

Standing Occupant Restrained by GRS:- The standing occupant restrained by GRS on a rigid platform as shown in Figure 14 was used in the simulation. The same half sine 325g pulse with 4msec duration was applied. The kinematics of the occupant is shown in Figure 19 and 20.

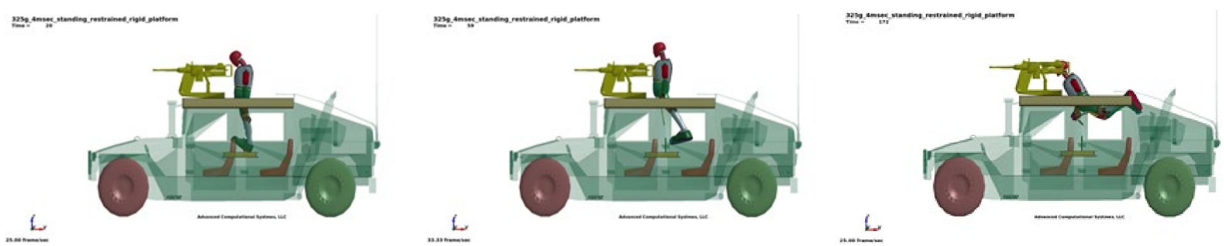


Fig. 19. The position of the Occupant with rest to vehicle.

Fig. 20. Standing occupant position relative to initial position.

The tibia force and head excursion relative to the hatch are shown in Fig. 21 and 22. The occupant moves up by 75mm with respect to hatch position. However, the occupant hits the roof and this might result in bodily injury.

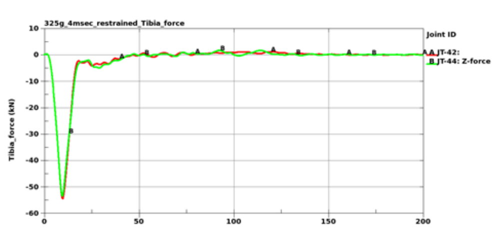


Fig. 21 Tibia force.

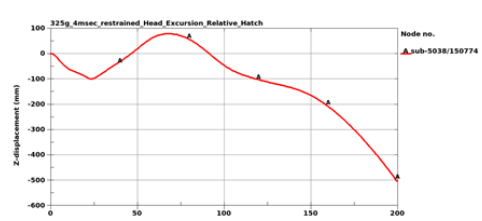


Fig. 22. Head excursion relative to hatch.

The tibia force is 55kN and is same as in previous case. The head moves down due to neck rotation and other body parts initially and then starts moving up as shown in Figure 20. The effect of the GRS can be noticed clearly.

Occupant Restrained by GRS and Standing on Deforming Platform:- The previous analysis was repeated by allowing the platform to deform for the same half sine pulse with 325g and 4msec duration. The kinematics of the occupant is shown in Figures 23 and 24 relative to vehicle and hatch positions.

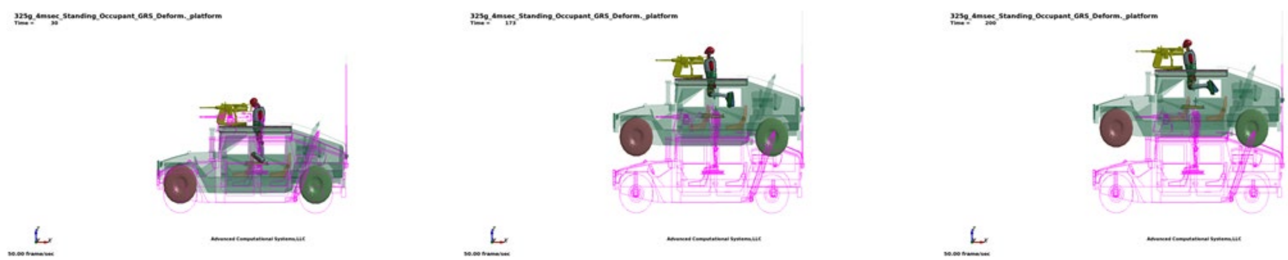


Fig. 23. Kinematics of the standing restrained occupant on 75mm height deformable platform.

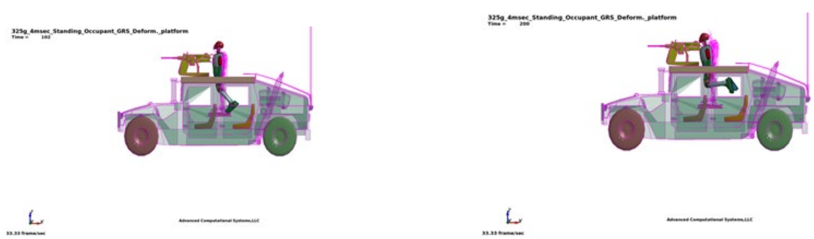


Fig. 24. Kinematics of restrained occupant relative to hatch position.

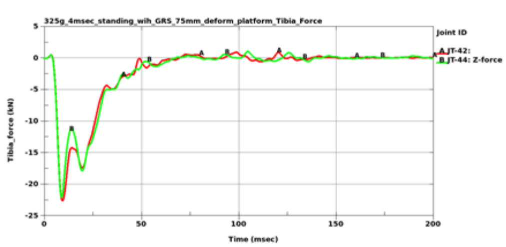


Fig. 25 Tibia Force

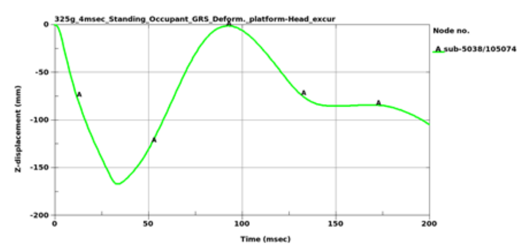


Fig. 26. Head Excursion relative hatch.

The tibia force and the head excursion relative to the hatch are shown in Figures 25 and 26. The maximum tibia force 22kN and this is roughly 3.5 times the acceptable marginal value of 6kN. It is interesting to note that the head excursion relative to the hatch is almost zero compared to original position as shown in Figure 24.

Occupant Restrained by GRS and Standing on Deforming Platform With Increasing Height :- The deforming aluminum box height was increased to 200mm. The analysis was repeated for half sine pulse 325g and 4msec duration.

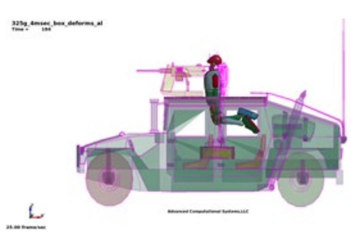


Fig. 27 Kinematics

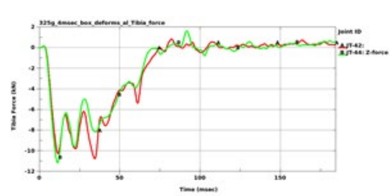


Fig. 28. Tibia Force

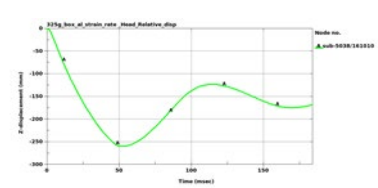


Fig. 29 Relative Head excursion

The kinematics is shown in Figure 27. The tibia force is shown in Figure 28 and the relative head excursion is plotted in Figure 29. Now the tibia force is 11kN and this is roughly twice the accepted marginal value of 6kN. Further improvements can be achieved by changing various parameters of the design such as dimensions and adjusting the tension failure of the bolts etc.

Discussion and Concluding Remarks

The development of a simple passive ejection mitigation device is presented in order to increase the occupant survivability and decrease the risk of ejection for standing occupant in hatch opening while the vehicle experiences an Improvised Explosive Device (IED) underbody blast event. This add on passive device can be easily incorporated in existing vehicles with minimal modification.

In the development of this device, a numerical finite element model was developed using Humvee truck. The response of freely standing unrestrained occupant was evaluated using half sine wave pulse of 325g with 4msec duration which resulted in 8m/sec velocity. The response of the standing gunner using Gunners Restraint System (GRS) was presented. The use of GRS showed a big improvement in head excursion of the gunner relative to hatch as shown in Figs 18 and 22. The use of GRS helped to keep the occupant within the vehicle but did not improve the tibia axial force as shown in Figures 17 and 21. The tibia forces were way high from allowable value.

A deformable box with corrugated side plates was used instead of the rigid box. The simulation showed a big reduction in the tibia axial force and reduced to 22kN from 55kN as shown in Figure 25. The head excursion reduced to almost zero compared to a value of 75mm.

The height of the box was increased from 75mm to 200mm. The tibia force evaluated from this model showed further reduction to a value of 11kN and is approximately twice the accepted marginal value. The design can further be improved by filling energy absorbing shock absorbing thermoplastic tubes, foam pieces, etc. The results of the box filled with various types of energy absorbing material will be presented in future.

In conclusion, the development of a simple ejection mitigation device was presented in order to increase the survivability of the standing gunner when the vehicle was subjected to under body blast. The device development was based on the finite element numerical simulations. The simulation was performed using LS-DYNA software. The occupant was represented by a standing ATD developed by LSTC. The preprocessor LS-PrePost was used in the development of the finite element model and post processing of the results. Even though many assumptions were made, such as rigid vehicle, the numerical evaluation provides a faster and less expensive development of new products.

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