SHORT COMMUNICATION: STAPP CAR CRASH CONFERENCE

An Exploration of Military Armored Vehicle Blast Event Timing for the Inclusion of Active and Passive Safety Systems

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ABSTRACT – Recent conflicts have led defence forces around the world to increase their vehicle protection to mitigate injury. However, the adoption and adaption of automotive safety technology to enhance survivability of personnel in armored military vehicles has been limited. In this study, a light armored military vehicle was blast tested and the vehicle response investigated to identify timeframes where automotive active and passive safety systems could be used to improve occupant survivability both in blast scenarios and military driving incidents. Internal and external high-speed cameras tracked the movement of the vehicle, the seats and anthropomorphic test devices over the entire blast event. The analysis demonstrates that there are timeframes that could be used for safety systems such as automotive airbags in novel applications. The addition of these protective systems may also show benefit in vehicle crash and rollover scenarios.

INTRODUCTION

The threat of landmines and improvised explosive devices (IED's) to military vehicles and their crew is of urgent and great importance. Recent conflicts have led defence forces around the world to increase their armored vehicle protection to mitigate injury (Human Rights Watch 2023; Ramasamy et al. 2009). However, the adoption and adaption of automotive active and passive safety technology to enhance survivability of personnel in armored military vehicles has been limited. Investigating the timing of the blast response of these vehicles and their occupants is required to develop understanding of where safety systems such as airbags, crumple zones and stability control could be used to improve occupant survivability in military scenarios.

An experimental investigation into the blast response of an armored military vehicle was conducted by the Australian Department of Defence – Defence Science and Technology Group (DSTG). This study explores the three phases of an armored military vehicle subjected to an underbelly buried blast event (Cimpoeru et al. 2015). Here the key timeframes of the vehicle, seat, and anthropomorphic test device (ATD) movement were investigated, to explore potential opportunities that may allow for the implementation of improved safety measures.

METHODS

A light armored military vehicle was blast tested in accordance with NATO STANAG 4569 AEP-55 Vol. II mine threat procedures (2014a; 2014b). Vertical poles with high contrast tracking markers were installed on each corner of the vehicle, as illustrated in Figure 1, to enable the continued observation of vehicle motion throughout the blast event.

Figure 1: Illustration representing the test vehicle with vertical poles and tracking markers installed.

The blast testbed was constructed with compacted layers of soil and sandy gravel with controlled density and moisture content. To ensure a repeatable blast input loading, the testbed underwent impulse calibration prior to the vehicle test event, in accordance with the established NATO procedures.

Two Hybrid III 50th Percentile ATDs fitted with the FAA straight spine and adjustable neck were placed in the vehicle: one in the Driver seat (right-hand side) and one in the Commander seat. The ATDs were wearing military helmets and body-armor vests and were restrained by four-point harness seatbelts. The helmets were coated with colored zinc to enable head strike witness marks.

High-speed cameras were installed both internal and external to the vehicle cabin. Four external high-speed cameras were used. Three cameras captured the side, oblique, and rear views. The fourth camera was placed on the ground focusing on the initial blast propagation underneath the vehicle. Multiple cameras were installed inside the vehicle to enable the seat and ATD motion to be tracked relative to the vehicle cabin.

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Motion tracking analysis was performed on the high-speed footage using the manual point tracking function within Photron PFV4 software (Photron 2020). Fixed markers on the vehicle were used to calibrate each view. Additionally, the internal camera footage was stabilized prior to tracking. Markers were tracked in 2D from each camera angle for the duration of the blast event and the vertical coordinate data is presented in this paper. The seats are suspended from the roof, held in place with straps at the top and bottom. The dynamic behavior of the straps was observed using high-speed cameras, and points were tracked on the strap anchors noting the transition from slack to taut. Multiple markers were tracked on both ATDs.

RESULTS

The blast loading phase and the deformation phase

The initial blast loading phase timing was determined from high-speed camera footage (Figure 2). The blast was observed to impact the vehicle within the first millisecond and then continue to load the hull, resulting in elastic and plastic deformation, mainly evident within the first six milliseconds. Plastic deformation was witnessed after the event by residual permanent deformation on the hull.

Figure 2: Initial blast loading impacting the vehicle.

The global motion phase of the vehicle

The momentum transfer during the blast event causes the vehicle to move vertically, known as the global motion phase. This vertical motion was tracked throughout the event by the four pole tracking markers, and a section of this timeframe is presented in Figure 3. As the blast was not directly under the center of the vehicle, the vertical motion of the vehicle was not symmetrical. This is shown by the varying amplitudes of each of the four tracking markers.

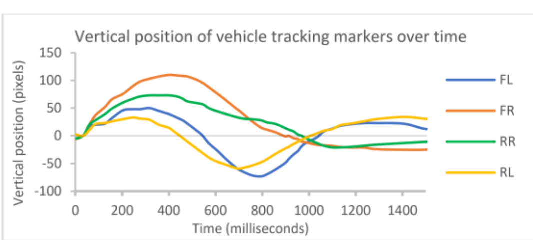

Figure 3: Vertical motion tracking using the pole tracking markers positioned on all four corners of the vehicle – Front Left (FL), Front Right (FR), Rear Right (RR), Rear Left (RL).

The start of the global motion phase was identified by the observed onset of vertical motion of the first marker. The peak of the global motion is displayed as a range within which the vertical motion-peaks of all four markers were observed. The beginning of vehicle ground impact is when the vehicle was observed to makes first contact with the ground during its descent. The end of global motion was determined when most observable motion ceased. Key timings of blast event stages, and vehicle motion are shown in Table 1.

Table 1: Key timeframes for the vehicle during the blast event.

Vehicle key stages	**Timing (ms)**
Initial blast loading and vehicle deformation	0 to 24
Start of vehicle global motion	24
Peak vertical motion	320 to 384
Beginning of vehicle ground impact	741
End of vehicle motion	2976

Motion of the Driver seat and ATD relative to the vehicle cabin

Seat Motion. Due to the suspended mounting design, the seat was observed to move vertically relative to the cabin body. In the early stage of the event the seat moved downwards, and the under-seat retention straps became slack. The top straps suspending the seat increased in tension and the seat then moved upwards, where at its highest point the under-seat retention straps were observed to appear most taut from 143 to 178 milliseconds.

ATD Motion. Markers on the ATDs were tracked in relation to the vehicle cabin. The peak vertical motion of the Driver ATD head was observed at 250 milliseconds, denoted with the first red dot in Figure 4, and a head-strike against the sidewall of the vehicle was witnessed at 1197 milliseconds, denoted with the second red dot.

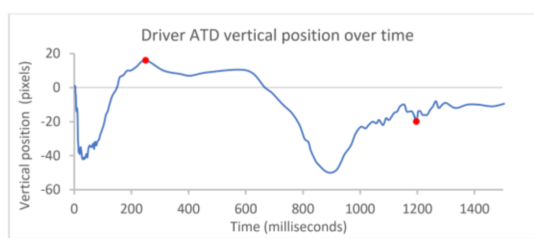

Figure 4: Vertical motion tracking of the Driver ATD head. Red dot 1: Vertical peak of the ATD head motion. Red dot 2: Helmeted ATD head-strike against the vehicle side wall.

DISCUSSION

Blast event and safety system timeframes

Time 0 to 24 milliseconds – Vehicle blast loading and deformation. To deploy a countermeasure response to act against a failure mode, a process of sense, compute, and deploy would need to occur. To reduce the likelihood of false triggering, detection algorithms often require the positive agreement of multiple sensors for a duration of time. Only after this can a response then be triggered. The sensor detections recorded in this early phase can trigger safety systems that would be effective in later timeframes. To mitigate injury occurring during this early phase timeframe, vehicle structural design elements in armored military vehicles such as the V-shaped hull and isolation design elements such as blast attenuating seats play a more significant role in withstanding the early blast effects. In this underbelly blast context where loadings are vertical, space for crumple zones to be effective and dissipate energy is limited.

From 24 to 741 milliseconds – Beginning of vehicle global motion to vehicle ground impact. Automotive driver airbags typically require 30 to 40 milliseconds to sense and deploy, while smaller side-airbags are faster at 20 milliseconds. Seatbelt pre-tensioner deployment timings are synchronized and adapted to work together with the airbags as a system (Reif 2014). In this experiment, the vehicle begins the global motion phase at 24 milliseconds. Figure 5 overlays the peaks of vertical motion of the seat and the vehicle, with the Driver ATD head location data. The first shaded region from 143 to 178 milliseconds is where the seat begins being restrained indicating that the motion of the vehicle and seat are momentarily synchronized. The ATD continues in an upward trajectory until it is then also restrained by the four-point harness. The red dot in Figure 5 indicates the vertical peak of the ATD head motion at 250 milliseconds. The second shaded region from 320 to 384 milliseconds shows the peak of vehicle global motion.

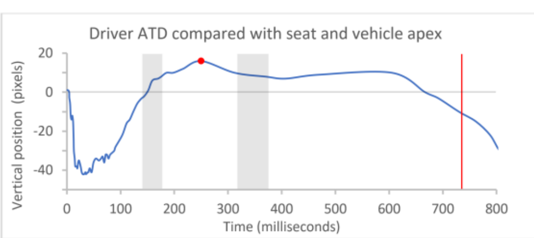

Figure 5: Vertical tracking of the Driver ATD head from the start of the blast to the beginning of vehicle ground impact (red line); the shaded areas represent the peaks of vertical motion – firstly the seat, and then the vehicle.

Headroom in the vehicle design determines whether a head impact with the roof would occur, yet currently there is no standard specifying a minimum level of head clearance in military vehicles. There is potential for head and neck injuries to be sustained due to vertical head to roof impact during a buried blast event, as witnessed in similar armored vehicle underbelly buried blast tests (Franklyn & Laing 2016). Seatbelt pre-tensioners could be used in this timeframe to tighten and remove slack in the harness ensuring the occupant is securely restrained against the seat, thereby increasing headroom. Novel airbags could also be used to mitigate head and neck injury from occupants potentially hitting their head on the roof.

From 741 to 2976 *milliseconds – Vehicle ground impact to end of motion.* The vehicle begins to hit the ground from 741 milliseconds. Movement continues until the vehicle comes to rest at approximately three seconds. Airbags could be used during vehicle ground impact for lower lumbar spine protection, and to prevent injuries from head strikes to the sidewalls, such as the head impact witnessed during this blast test. Seatbelt pre-tensioners could also be advantageous by limiting the occupant's movement in the seat and reducing the risk of impact within the vehicle. Driving in a tactical environment presents multiple challenges where crash and rollover have a high probability of occurring; this is particularly likely at the end phase of a blast event due to forward momentum of the vehicle. The addition of passive safety systems such as side-curtain airbags would show benefit in these scenarios. Active safety systems such as stability control and automatic braking may prove beneficial in preventing crash and rollover incidents during the chaotic environment of vehicle combat.

CONCLUSION

This study provides new insights into the timeframes available during underbelly buried blast events of armored military vehicles for the inclusion of automotive safety systems. During the early timeframe, vehicle structural design, occupant isolation, and initial sensing for later safety countermeasures would appear most relevant. To ensure the survival of personnel involved in a vehicle blast, the entire event timeframe needs to be considered, as there is potential for injury to occur in every phase. Throughout the vehicle global motion phase, multiple timeframes were identified that would allow for passive safety systems such as novel airbags to be used to mitigate injury. The addition of active and passive safety systems would also show benefit in reducing injuries in military scenarios where vehicle crash and rollover can occur.

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