Blast Overpressure Mitigation Strategies (BOMS) for Infantry Mortar Personnel: A Research and Development Study of the Pelta-6™ Personal Protective Device

Todd Strader, Timothy Grossman
OverPressured, LLC OverPressured.com
Allison Nelson, Dr. Pamela VandeVord
Virginia Tech, Dept. of Biomedical Engineering, Virginia Tech University
USA

1.0 ABSTRACT

Servicemembers that occupationally fire mortars are exposed to excessive amounts of low-level blast overpressure when firing these weapons and most of these exposures occur in the training environment which could amount to thousands of exposures in a single enlistment. Overpressure exposure occurs when the pressure from a blast wave quickly exceeds normal atmospheric values and agitates the brain by moving it rapidly inside the skull, damaging it at a sub-cellular even genetic level. Research by Department of Defense (DoD) Health suggests a strong relationship to chronic brain injury sequela and the cumulative effects of these excessive occupational blast exposures.

On August 8th, 2024, the DoD issued Memorandum, "Requirements for Managing Brain Health Risks from Blast Overpressure" (BOP), mandating, "[implementation of] standards and procedures for training and operations that incorporate BOP risk management to minimize the risk to brain injury, including at a minimum…personal protective equipment for firers, trainers, and other personnel at an increased risk of exposure".

The Pelta-6™ by OverPressured LLC, aims to mitigate the cumulative deleterious effects of these exposures to a currently unprotected yet vital region of the brain that is especially vulnerable when firing mortars, with field tests showing a 44% reduction. Designed and engineered to protect the warfighter where they are currently positioned when firing the mortar without detracting from what makes the weapon effective in its role. The Pelta-6 quickly attaches or detaches to the rear of a soldier's helmet, created to shield the vital and delicate cranio-cervical junction (CCJ) which is especially vulnerable to blast when firing mortars.

2.0 INTRODUCTION

The impulse noise and resultant wave produced by heavy weapons is generally referred to as blast overpressure (BOP) - the rapid and violent change in air pressure that occurs as a result of an explosion. Explosive blasts or explosions are physical phenomena that result in a sudden release of energy. This process causes a near instantaneous compression of the surrounding medium (e.g., air or water) and an increase in pressure ("overpressure") above atmospheric pressure, resulting in an overpressure wave (or blast wave)[1] measured in pounds per square inch (psi) or kilopascals (kPa), accounting therefore for peak, impulse, and incident overpressure.

It also is key to note, the term "occupational blast overpressure exposure," is intended to denote repeated exposures to low-level explosive blast events that occur as part of training and operational activities experienced by personnel in designated roles in the military[2].

In a first of its kind study, Kamimori et al. (2017), observe BOP exposure for various military and law enforcement sources in operational training environments. Peak overpressure and impulse data are presented including mortar fire missions and data is recorded via BlackBox Biometrics Blast Gauge Sensors. The authors note, "sheer number of rounds fired during training may result in an excessive cumulative exposure" reflects threshold considerations for injury and structural damage considerations by mortar crews during training and in operations[3].

Likewise, Skotak, et al (2020) work on the effects of the blast waves using computational methods demonstrated that impulse loading of the head even when equipped with Kevlar-based Advanced Combat Helmet (ACH), the Enhanced Combat Helmet (ECH) (introduced in 2013), which could lead to tissue level deformation (strain and stress), and by extension, lead to neurological effects[4]. The focus of study on blast overpressure (BOP) exposure from high-explosives and heavy weapon systems has resulted in questions concerning overpressure inside the helmet. While Gupta & Przekwas (2013) addressed blast wave physics, injury biomechanics, and the neurobiology of brain injury as a foundation for a more detailed discussion of multiscale mathematical models of primary biomechanics and secondary injury via computer-generated image of a simulated shock wave traveling through the skull[5].

Given the aforementioned investigation into computational models of blast wave simulation and actual testing on helmets, Skotak, et al. (2020) continue,

> "Frontal orientation consistently demonstrated the highest aggregate peak overpressure, and it was more than two times higher than for the back orientation (presumably due to the contribution of the eye mounted sensors). At the same time, we observed much smaller impulse variability. None of the helmets [tested] offer any protection compared to the bare head form. The sum of the peak overpressure for helmeted specimens was, in all cases, higher than for the unprotected head form".

These results suggest that standard issued equipment such as helmets worn by military personnel have little impact to reduce the peak overpressure experienced such as those peak overpressures experienced during the routine employment of mortar systems. In a more recent study, resxearcher noted a limitation of modern helmets in preventing bTBI is the underwash effect. In this phenomenon, areas under the helmet experience higher overpressure due to interactions of the shock wave between

[1] Cernak I. Blast Injuries and Blast-Induced Neurotrauma: Overview of Pathophysiology and Experimental Knowledge Models and Findings. In: Kobeissy FH, editor. Brain Neurotrauma: Molecular, Neuropsychological, and Rehabilitation Aspects. Boca Raton (FL): CRC Press/Taylor & Francis; 2015. Chapter 45. PMID: 26269895.
[2] Kamimori, et al (2017).
[3] Kamimori, et al (2017).
[4] Skotak, Maciej, et al. "Factors Contributing to Increased Blast Overpressure inside Modern Ballistic Helmets." MDPI, Multidisciplinary Digital Publishing Institute, 15 Oct. 2020, www.mdpi.com/2076-3417/10/20/7193.
[5] Gupta, Raj K, and Andrzej Przekwas. "Mathematical Models of Blast-Induced TBI: Current Status, Challenges, and Prospects." Frontiers in neurology vol. 4 59. 30 May. 2013, doi:10.3389/fneur.2013.00059

the head and helmet as the wave moves over the head and gets trapped underneath the helmet (Thomas, et al (2024) citing Azar et al., 2020; Hosseini-Farid et al., 2020; Li et al., 2020; Skotak et al., 2020).[6]

3.0 THE PELTA-6™

OverPressured LLC, has developed innovative, patent-pending personal protective equipment to mitigate the cumulative deleterious effects of these exposures to a currently unprotected yet vital region of the brain that is especially vulnerable when firing of Tier1 heavy weapons. The Pelta-6® (Figure 2) protects the operator ***without diminishing current operational efficiency***. Our foundational design goal is to protect the warfighter where they are currently positioned when firing the weapon without detracting from what makes it effective in its role.

Figure 2. *Army helmet with Pelta-6 attachment on test mannequin equipped with Blast Gauge Sensors. JBLM May 2024*

The Pelta-6 has the potential to mitigate the damaging effects that these blasts can have on the health and capabilities of our warfighters in a practical, effective and relatively low-cost way.

We call it Pelta, old Greek for "little shield" because our design and materials are inspired by ancient engineering genius and 6 because it protects a soldier's "six o'clock" (i.e., the back). The Pelta-6 is a modular, lightweight, and durable helmet attachment. Using blast dampening composites, it is thoughtfully simple and practical in design, yet also an effective personal protective solution designed by a disabled veteran that once fired these weapons while in service, and has personally suffered its effects.

The Pelta-6 quickly attaches or detaches to the rear of a soldier's helmet, created to shield the vital and delicate area of Cranio-Cervical Junction (CCJ) which is usually bare and exposed to blast when firing Tier1 weapons, particularly mortars. Our targeted area of protection includes the posterior/base of the skull, the cerebral arterial and vascular processes, cerebellum, medulla oblongata, and the cerebral cortex. Recent research (McEvoy, et al, 2024) has also found that this region of the brain is sensitive to repetitive low-level blast and that damage done to this region can initiate multiple pathways of neurodegeneration[7].

4.0 PELTA-6™ FIELD EVALUATION

Pelta-6 design and development began in February 2024. Relying on years' worth of personal experience firing mortars, input from the community and an intimate knowledge of the science

[6] Thomas, Cody J H et al. "Experimental investigation of a viscoelastic liner to reduce under helmet overpressures and shock wave reflections." *Frontiers in bioengineering and biotechnology* vol. 12 1455324. 30 Aug. 2024, doi:10.3389/fbioe.2024.1455324

[7] McEvoy, Cory et al. "Cumulative Blast Impulse Is Predictive for Changes in Chronic Neurobehavioral Symptoms Following Low Level Blast Exposure during Military Training." Military medicine vol. 189,9-10 (2024): e2069-e2077. doi:10.1093/milmed/usae082

behind blast dynamics and its relevance to our targeted area of protection, unique materials and techniques were employed specifically to mitigate blast overpressure. Several iterations of models and prototypes were constructed and refined. Coincidentally, it was the 6th prototype that achieved our Gen-1 prototype goals and is what was used in the testing scenarios.

In April 2024, a Pelta-6 prototype was introduced at the Best Mortar Competition at Fort Moore GA and later with U.S. Special Operations Command (SOCOM) members at Joint Base Lewis-McChord, WA. At both events, we were very encouraged that the Pelta-6 received interest, support, and appreciation in soldiers' feedback.

An initial informal concept test was also conducted at the Best Mortar Competition at Ft. Moore; using one 120mm mortar firing one round, a senior NCO placed the Pelta-6 on the end of the trailer behind the mortar with the back of the helmet and Pelta-6 attachment facing the muzzle or blast source. Two sets of B3 Blast Gauges system were placed on the outer, unshielded Pelta-6 side while another set attached to the webbing at the rear of the helmet (target area of mitigation) in the inner shielded side. The Pelta-6 was set approximately in what would be the position of the "Squad Leader" during firing procedures (Fig. 5). The Blast Gauge App results suggest that despite the informality of the test, the concept has potential to reduce blast exposure significantly.

Figure 5. *Placement of Pelta-6 for initial live-fire test, a single round fired from a 120mm mortar. Fort Moore – Best Mortar Competition, April 2024*

In May 2024, OverPressured LLC was invited to attend an on-going 120mm mortar live fire training event being conducted by the 1st Special Forces Group Advanced Weapons Company (Figure 6). We used a non-human, head/neck test mannequin with standard protective gear and Army Advanced Combat Helmet (ACH) with the Pelta-6 attached. The test mannequin was placed on a static tripod, with the exterior of the Pelta-6 exterior facing the blast source (muzzle) and set in the approximate position of the "Ammo Bearer" during firing procedures.

In this configuration the Pelta-6 was exposed to 17 blast events which were recorded using two sets of B3 Blast Gauges, one on the exterior of the Pelta-6, facing the blast source and the other on the underside attached to the targeted area of the cranio-cervical junction (CCJ). There were several environmental variables that were dynamic and inherent to collecting data during an on-going live fire training event. For example, during the 17 blast events, the crew were in different positions, or the type of ammunition and charge was varied from event to event. Yet despite these variables, the data collected suggests a consistent and significant reduction of blast exposure to the targeted area.

Figure 6. *Pelta-6 testing with 1st Special Forces Group at Fort Lewis, May 2024*

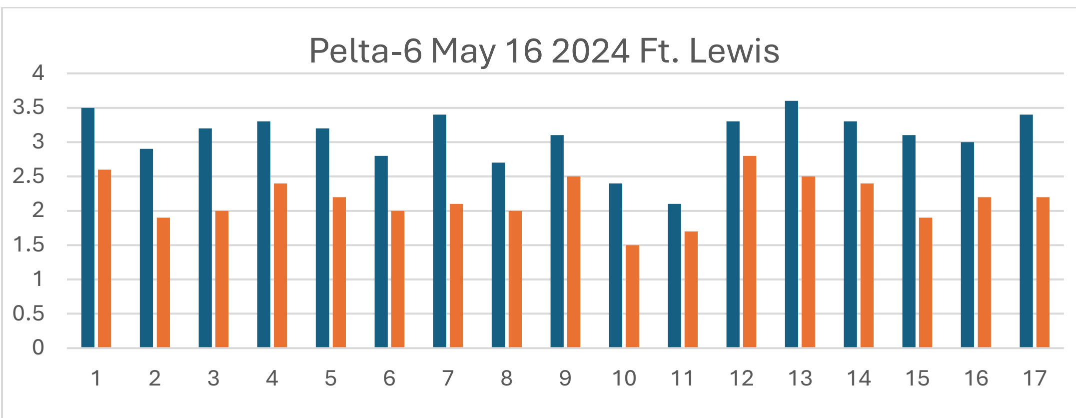

Figure 7. *Fort Lewis testing using B3 Blast Gauges over a 3-sensor average to the exterior and interior mounted positioning. Blue indicates exterior readings, Orange indicates interior reading at the Cranio-Cervical Junction (CCJ).*

In Figure 7 we observe the effect of overpressure using the B3 Blast Gauges over a 3-sensor average to the exterior and interior mounted devices.

It is important to note the 3 sensors were placed strategically to ensure that entire exposed and under wash surface area[8] of the Pelta-6 was accounted for while also collecting data points which dynamically captured the effects of overpressure in real time to the exposed/targeted area. Initially, our hypothesis was that the B3 Blast Gauges would record higher readings on the exterior of the surface area of the Pelta-6™, whereas the B3 Blast Gauges would show a reduction of BOP on the underside of the Pelta-6™ due to the design and structure of the Pelta-6™'s dampening and blast wave dissipation properties.

Our results confirmed the B3 blast gauges on exterior of the Pelta-6™ recorded average blast overpressure of 3.29 psi, whereas the interior B3 blast gauges recorded an average of 1.83 psi. resulting in an approximate reduction of 55.78% of BOP to the targeted area Blast Overpressure Site/Targeted

[8] See Thomas, et al (2024)

Overpressure Site (BoSToS). Notably, the significant outliers during this test scenario were rounds 10 and 11 whereas there was deviation of approximately 1-1.5 psi deviation on the peak overpressure values and slight reduction in mitigation values. We suspect this may have been due to a change in ammunition (blue training rounds vs. incendiary rounds) or charge for these two events, crew position between firing rounds, and placement of the Pelta=6™ so as not to impede the live fire exercise, and reflection of BOP off of the ground towards the tripod without dampening/absorption which would be experienced when worn on the operator. Nonetheless these readings did not significantly skew the data we obtained during this scenario.

This preliminary finding suggests that the Pelta-6™ in simulation to the actual positioning of the servicemember in proximity to the 120mm mortar system during a live-fire scenario is highly effective in the mitigation of blast overpressure to the targeted area.

The limitations of these findings include small sample size, variation of charge and ammunition used, static as opposed to dynamic testing as worn equipment by firing teams with established controls.

5.0 PELTA-6™ LABORATORY EVALUATION

On June 13th, 2024, OverPressured, LLC provided the Pelta-6™ for testing at Virginia Tech's VandeVord Traumatic Nerve Technologies Lab (TNT). This lab is focused on innovative research that assists in the prevention, identification, and treatment of injured tissues, focusing on neurotrauma using established preclinical injury models, including Advanced Blast Simulators. During testing the staff utilized the large Advanced Blast Simulator (ABS4), utilizing high speed video and shockwave monitoring equipment (Figure 8).

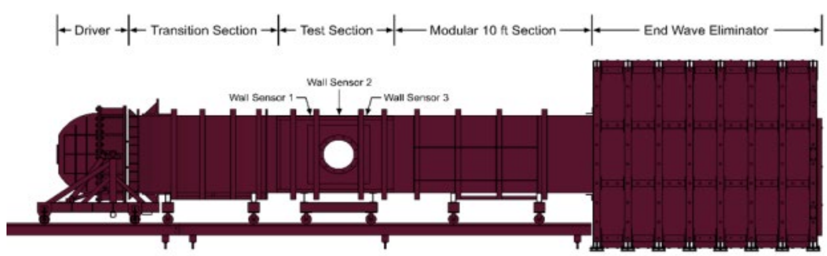

Figure 8. *The ABS4 (Stumptown Research and Development) is a 40 foot long, 5-section gas detonation-driven blast simulator.*

The Virginia Tech Preliminary Study design was comprised of the following performance protocols:

1. Perform the mid-range and high-range exposures with and without the Pelta-6 installed to judge its ability to mitigate blast wave exposure.
2. Along with environmental measurements taken with every blast, record the exposure on the surface on the skull and on the rear of the neck.
3. Analyze the impact of the Pelta-6 on the pressures measured across the headform.

Illustration of instrumentation and positioning are shown in Figures 9 and 10, noting the diagram of the instrumented headform, the pitot-tip sensor on the neck-back and positioning of the headform with and without the Pelta-6™ as situated in the ABS4.

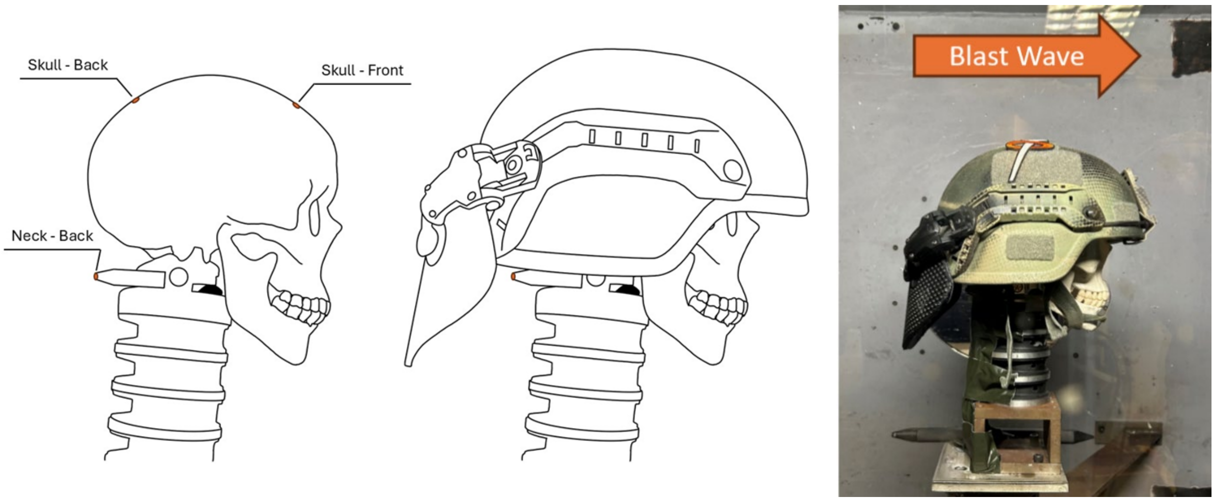

Figure 9. *Diagram of the instrumented headform. Left, the headform's sensing elements identified. Right, the headform wearing with the ACH and Pelta-6 and blast wave direction.*

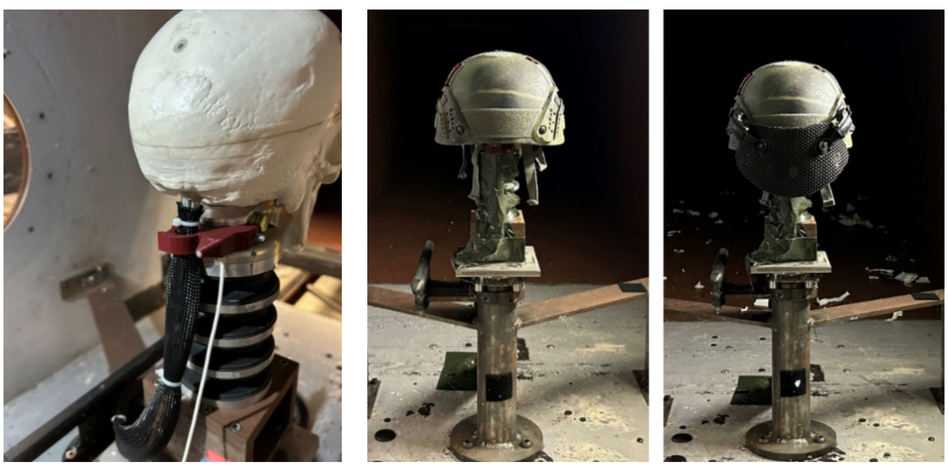

Figure 10. *Skull Headform blast wave tests conducted, with and without Pelta-6.*

The normalization of Neck-Back Peak Overpressure and Positive Impulse were measured whereby neck pressure metrics were normalized to the total pressure metrics of the blast they were in before statistical analysis was run. The results of neck pressure curbed with and without the Pelta-6™ equipped on the headform were also measured. As shown in (Figure 11), the blue pressure history plots are measured from the pitot tip, as a measure of the blast wave in the surrounding environment. The orange pressure history plots are measured on the neck of the headform. The pitot tip sensor is obstructed by the Pelta-6 when the Pelta-6 is donned. The results are reflected as follows in Figure 11:

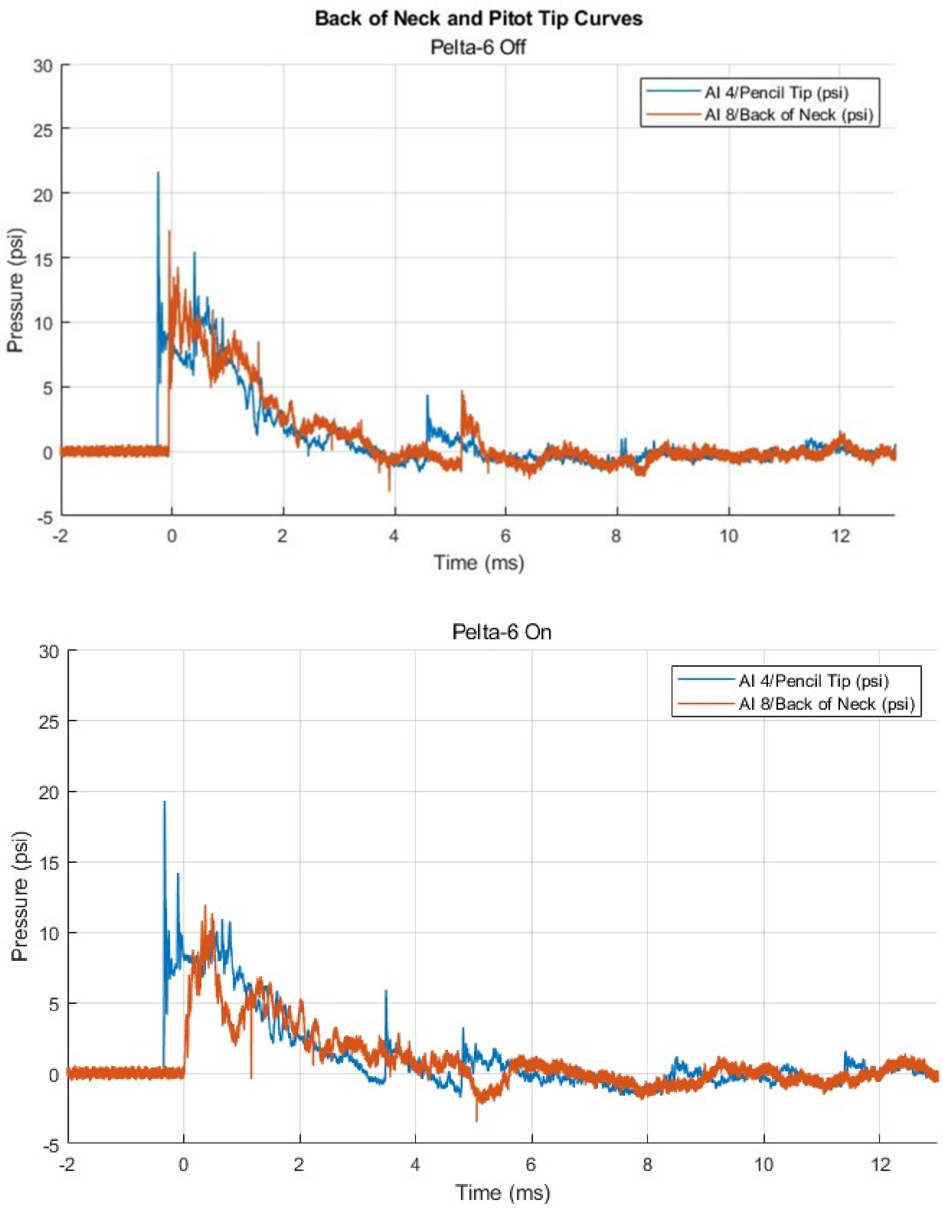

Figure 11. *Representative pressure history plots of a blast without (top) and with the Pelta-6 donned (bottom). The back of neck sensor, in orange, is plotted on top of the pencil tip sensor, in blue.*

The results of the Virginia Tech ASB testing revealed when exposed to high-range blasts, the Pelta-6™ reduced peak overpressures by 27%. Positive impulse was reduced in both mid- and high-range exposures. At mid-range, the reduction was marginal at 6%. At high range, the reduction jumped to 22%. Thus, concluding, when the Pelta-6 is present, the neck experienced a diminished peak overpressure and distortion of the blast wave. Additionally, no failure was observed even when exposed to a 26-psi static overpressure blast.

Limitations of this preliminary study include small sample size, which is easily skewed by outliers, non-optimal instrumentation whereas the neck sensor protrudes unlike the natural contour of the neck. The neck sensor was off centered due to obstructions. Pressures were higher than normal exposures. Likewise, the headform and helmet were different sizes. Thus, the under-helmet effects may not be accurately modelled.

The researchers concluded, Pelta-6™ shows potential to reduce exposures, particularly when mortar operators are exposed to high-range pressures and impulses.

> *"Pelta-6 has shown that it has potential to reduce exposure of mortarmen to the blasts generated by the mortar round launching. Current reductions of nearly 30% show that this technology may be capable of proactively reducing exposures, and therefore reducing the likelihood and severity of mTBI, for servicemembers". - Dr. P. VandeVord, Lead Researcher*

Next steps offered by Virginia Tech Staff include, iterate design towards more significant reductions at blasts of lower static pressures; material search, testing, and identification; geometry considerations; consider other orientations of the Pelta-6 relative to the direction of the blast wave.

6.0 RESULTS

The results of the Pelta-6™ in the field collected suggests a consistent and significant reduction of blast exposure to the targeted area whereas B3 blast gauges on exterior of the Pelta-6™ recorded average blast overpressure of 3.29 psi, whereas the interior B3 blast gauges recorded an average of 1.83 psi. resulting in an approximate reduction of 55.78% of BOP to the targeted area Blast Overpressure Site/Targeted Overpressure Site (BoSToS). The results of the Advanced Blast Simulator (ABS4), testing at Virginia Tech's VandeVord Traumatic Nerve Technologies Lab (TNT) showed reduced peak overpressures by 27%, noting positive impulse was reduced in both mid-range and high-range exposures. At mid-range, the reduction was marginal at 6%. At high range, the reduction jumped to 22%.

7.0 DISCUSSION AND FUTURE WORK

The results of the Pelta-6™ testing has demonstrated reduced peak overpressures by up to 27%. We will seek to prove the Pelta-6 continues to provide consistent and significant blast exposure mitigation without inhibiting the soldier or the weapons effectiveness. Overpressured, LLC plans to conduct more exhaustive controlled blast testing, both live and in the laboratory with the goal of discovering the limits of Pelta-6 which may inform to broader applications. Likewise, to conduct broader operational testing and analysis embedding with Army active-duty 120mm Mortar units using both control and test groups. Rigorous field testing will ensure that the Pelta-6 can withstand the day-to-day operational usage in real-world environments while maintaining its effectiveness. Additional lab data along with feedback from operational testing to inform on potential design refinements to be made to ensure peak quality assurance. Potential 3D modeling that will allow for virtual testing and machine analysis using a multitude of variables such as various types of weapon systems and ammunition. Overpressured, LLC offers the Pelta-6™ to government researchers who wish to validate the Pelta-6™ free of charge.