

Mitigation of Underbody Blast Injuries to the Lower Extremity by Optimization of Combat Boot Properties

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Abstract

Close quarters combat experienced in Operation Iraqi Freedom and Operation Enduring Freedom have given rise to an increase in improvised explosive device (IED) related injuries in US service members. To date, IEDs have caused roughly 50% of the casualties in Iraq and over 30% of those seen in Afghanistan. Blast resistant vehicles such as up-armored Humvees and mine-resistant, ambush-protected vehicles (MRAPs) have been deployed in these conflicts but are not fully adapted to constantly evolving blast configurations. The most common injuries seen in the lower extremity resulting from an underbody blast event involves the calcaneus, talus, and the distal tibia. These injuries occur while wearing standard issue US Army combat boots, suggesting that additional energy absorption is needed to further reduce these injuries. This research identifies optimal material properties for an energy absorbing layer that can be used in conjunction with current combat boots or floor mats to mitigate lower extremity injuries. Not only will these results prevent common injuries observed in UBB, but may also reduce injuries seen in the LX during automotive-rate collisions.

A lumped mass model of the lower extremity has been developed for high-rate loads leading to injuries unique to the underbody blast environment. This lumped mass model was combined with results taken from boot characterization tests at similar rates. This fast-running model was used in a non-linear optimization routine where the objective was to minimize a combination of forces and accelerations seen in the lower extremity while keeping the thickness of the additional material to a minimum. Several candidate materials were identified using this lumped mass optimization technique, with the final material selection confirmed using a finite element model of the human leg specially created to predict the response under high rate blast loadings. This final candidate material protects the booted lower extremity from high-rate loads by lengthening the pulse duration, yet insuring that the modified pulse is below the threshold limits for automotive injuries. To validate the injury mitigation materials, two (2) whole body PMHS tests were performed with the candidate injury mitigation material on the University of Virginia's Underbody Blast Simulator (ODYSSEY).

Preliminary analysis shows a 1-inch thick pad of the optimized material allows a 25% increase in applied energy to the bottom of the booted foot, yet maintains a 10% risk of any skeletal fracture as predicted by both recently derived risk functions for UBB, as well as the automotive-rate tibia index criterion. Conversely, for an applied acceleration pulse of 500g and a duration of 5ms, the risk of either UBB or automotive fracture injuries reduce from 10% to 2%. Whole body validation tests offer preliminary validation of these findings, though additional testing is scheduled to be performed. This energy absorbing layer may be applied to the floor of the vehicle to obtain these results without altering current boot design, or can be integrated into a new boot sole with similar effective properties with minimal effects on performance.