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Wound Ballistics Modeling for Blast Loading, Blunt Force Impact, and Projectile Penetration
165554

Year 3 of 3
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Investment Area(s): Defense Systems and Assessments

Project Purpose:

Light body armor development for the warfighter is based on trial-and-error testing of prototype designs against ballistic projectiles. Torso armor testing against blast is nonexistent but necessary to protect the heart and lungs. In tests against ballistic projectiles, protective apparel is placed over ballistic clay and the projectiles are fired into the armor/clay target. The clay represents the human torso and its behind-armor, permanent deflection is the principal metric used to assess armor protection. Although this approach provides relative merit assessment of protection, it does not examine the behind-armor blunt trauma to crucial torso organs. We propose a modeling and simulation (M&S) capability for wound injury scenarios to the head, neck, and torso of the warfighter. We will use this toolset to investigate the consequences of, and mitigation against, blast exposure, blunt force impact, and ballistic projectile penetration leading to damage of critical organs comprising the central nervous, cardiovascular, and respiratory systems. We will leverage Sandia codes and our M&S expertise on traumatic brain injury to develop virtual anatomical models of the head, neck, and torso and the simulation methodology to capture the physics of wound mechanics. Specifically, we will investigate virtual wound injuries to the head, neck, and torso without and with protective armor to demonstrate the advantages of performing injury simulations for the development of body armor. The proposed toolset constitutes a significant advance over current methods by providing a virtual simulation capability to investigate wound injury and optimize armor design without the need for extensive field testing.

Summary of Accomplishments:

We developed high fidelity virtual models for the stand-alone human torso as well as a combined head-neck-torso structure in order to investigate wound injury and assess personal protective armor for the warfighter. These models exist in formats that permit their import into shock wave physics codes for simulation of blast loading and ballistic projectile impact leading to behind-armor blunt trauma. To demonstrate personal protective armor assessment, we developed prototype chest armor for the human torso model comprised of a fiber-reinforced composite hard shell with polymer foam padding to offset the hard shell from the torso.

We implemented advanced constitutive models to represent the nonlinear elastic and viscoelastic nature of the biological tissues comprising the human head, neck, and torso. Specifically, we created model representations for the brain, heart, lungs, liver, kidneys, spleen, and musculature. We fostered development and employed an equation-of-state (EOS) model to capture the volumetric response of human fluids such as blood and cerebrospinal fluid. This EOS captures the liquid-vapor phase transformation associated with impulse-induced fluid cavitation that can occur in these fluids. For the protective armor, we created a transverse-isotropic constitutive model representation for the hard shell to simulate a glass fiber-reinforced composite laminate.

We constructed a simulation methodology that allowed us to investigate injury scenarios to our human models without and with protective armor. Specifically, we simulated blast loading and ballistic projectile impact to our human models, demonstrating the details of wound injury and the ability to perform relative merit assessments of personal protective armor.

We authored and presented two peer-reviewed technical papers describing our work. The first to the 2014 Personal Armour Systems Symposium and the second to the ASME IMECE conference. We have written a final SAND report describing our accomplishments and their significance which will be dissected into multiple scientific papers for publication.

Significance:

The completion of this project allows us to expand our injury scenario simulation capabilities to address the challenges of protecting our warfighters and civilian protective forces. Our newly developed modeling and simulation capability allows us to investigate injury scenarios and conduct protective armor assessments without the need for extensive and/or expensive field testing. Furthermore, the execution of this project has attracted new as well as seasoned technical staff into the department to support the development of a center of excellence in 5400 with the intent of having Sandia recognized as a national leader in the field of warfighter protection research.

Refereed Communications:

Taylor, P., Cooper, C., Terpsma, R., and Dederman, D., "Computer Simulation of Blast Injury, Behind Armor Blunt Trauma, and their Mitigation", Proc. Personal Armour Systems Symposium (PASS), Cambridge UK, September, 2014.

Cooper, C. F. and Taylor, P. A., "Virtual Simulation of Blast, Behind-Armor Blunt Trauma, and Projectile Penetration leading to Injury of Life-Critical Organs in the Human Torso", Proc. ASME Int. Mech. Engr. Congr. & Expo. (IMECE), Houston, TX, November, 2015.

Taylor, P. A. and Cooper, C. F., "Simulation of Blast and Behind-Armor Blunt Trauma to Life-Critical Organs in the Human Torso", HPC Annual Report, Contributed Chapter, 2015.

Cooper, C. F. and Taylor, P. A., "Human Torso Model Development for Computer Simulation of Blunt Trauma, Blast Injury Projectile Penetration, and their Mitigation", 26th Rio Grande Symp. Adv. Mat., Albuquerque, NM, October 2014.

Taylor, P., Cooper, C., and Terpsma, R. "Sandia Modeling of Blast Injury, Behind Helmet Blunt Trauma (BHBT), and Torso Trauma", capabilities presentation to the Office of Naval Research (ONR), James Mackiewicz, Code 30 program manager, Arlington, VA, October 2014.

Taylor, P., Cooper, C., and Burnett, D., "Wound Ballistics Modeling for Blast Loading, Blunt Force Impact, and Projectile Penetration", Sandia National Laboratories report SAND2015-7909, September, 2015.

Cooper, C. F., "Joining of Human Head-Neck and Torso Models", presented (invited) at the University of New Mexico, Albuquerque, NM, 2015.