Blast Overpressure Effects of PE4 on a Simplified Rigid Torso

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Abstract

Primary Blast Injuries (PBI) are caused by the propagating shock wave, associated with High-order Explosives (HE), that moves through the body, affecting gas-containing and fluid-surrounded organs, such as the lungs, the middle ear, the brain and the gastrointestinal tract. The extent of the resulting PBI depends on various environmental aspects such as the Height of Burst (HOB), the Stand of Distance (SOD), as well as the type of the explosive device used, like Improvised explosive devices (IEDs) [1-2]. The use of IEDs has been the main cause of PBI causing up to 60% lethality of US forces during Operation Enduring Freedom, in Afghanistan, and Operation Iraqi Freedom, in Iraqi [3].

In a free-field environment, the pressure-time history, have a well-known shape, called the Friedlander profile [1]. IEDs can however result in more complex wave forms, with multiple reflections interaction onto the soldier, leading to more severe primary blast injuries. This is because IEDs can contain either HE, Low-order Explosives (LE), or sometimes even both. Examples of HE include TNT, C-4, nitro-glycerine, and ammonium nitrate fuel oil (ANFO) [4]. In the interest of developing equipment that will protect soldiers during IED attacks, it is important to understand the complexity, paths and pressure range of the blast waves associated with different explosives used in IEDs.

Various injury criteria's, such as Bowen [5], Bass and Rafaels [6,7], Yelverton and Axelsson [8,9] and Stuhmiller [10], have been established to predict injuries from Blast overpressure (BOP). For these studies a simplified rigid human torso model, called the Blast Test Device (BTD), are used to measure the pressure waves. The BTD is a cylindrically-shaped device, roughly the length of a 50th percentile human torso, and instrumented with four or more pressure sensors around the circumference.

In previous studies, the Council for Scientific and Industrial Research (CSIR) has commissioned and modelled a Blast Test Device (BTD) and studied the blast over pressure effects of 300g PE4 [12,13]. These results were validated with results from literature. Three different HOBs (220mm, 440mm, 880mm), with the BTD at a SOD of 2m, were compared. These specific HOBs were selected to reproduce scenarios typically incurred on the battlefield of a charge positioned close to the ground, a charge positioned at mid-sternum human height and a charge positioned at an intermediate height. Pressure profiles ranging from simple to complex are thus generated [1,14,15].

In this study 1kg PE4 was detonated at the same SOD and HOBs. The experimental results were compared with respect to incident and reflected pressures, as well positive phase durations. An increase in incident pressure were observed for decreasing HOB. Reflected pressures were observed for HOB 880mm, resulting in complex blast waves. Positive phase durations for the HOB 220mm and 440mm were similar, but a longer positive phase duration were observed for the 880mm. The injury predictions of each test were compared for the different injury criteria. The previous tests of 300g resulted in no injury predictions, however, for the 1kg charges, severe injuries were predicted.

References

[1] Boutillier J, De Mezzo S, Deck C, Ehrhardt L, Magnan P, Naz P, Willinger R (2016). Shock-wave interaction with reduced-scale simplified torso surrogates. In IRCOBI Conference Proceedings.

[2] Lemonick DM (2011). Bombing and Blast Injuries: A Primer for Physicians. American Journal of Clinical Medicine, p 134-140.

[3] Belmont PJ, Schoenfeld AJ, Goodman G. (2010) Epidemiology of Combat Wounds in Operation Iraqi Freedom: Orthopaedic Burden of Disease. Journal of Surgical Orthopaedic Advances.

[4] Singh AK, Kofsky NG, York JD, et al (2016). Blast Injuries: From Improvised Explosive Device Blasts to the Boston Marathon Bombing. RadioGraphics, Vol 36 Issue 1, p1-3.

[5] Bowen IG, Fletcher ER, Richmond DR (1968). Estimate of man's tolerance to the direct effects of air blast. Lovelace foundation for medical education and research, Albuquerque NM.

[6] Bass CR, Rafaels KA, Salzar RS (2008). Pulmonary injury risk assessment for short-duration blasts. Journal of Trauma and Acute Care Surgery, 65(3), p.604-615.

[7] Rafaels KA, Cameron R, Panzer MB, Salzar RS (2010). Pulmonary injury risk assessment for long-duration blasts: a meta-analysis. Journal of Trauma and Acute Care Surgery, 69(2), p.368-374.

[8] Yelverton, J.T. (1993): Blast overpressure studies with animals and man: Final report – Biological response to complex blast waves. U.S. Army Medical Research and Development Command, Fort Detrick.

[9] Axelsson H, Yelverton JT (1996). Chest wall velocity as a predictor of nonauditory blast injury in a complex wave environment. Journal of Trauma and Acute Care Surgery, 40(3S), p.31S-37S.

[10] Stuhmiller JH, Ho KHH, Vander Vorst MJ, Dodd KT, Fitzpatrick T, Mayorga M (1996). A model of blast overpressure injury to the lung. Journal of biomechanics, 29(2), p.227-234.

[11] Pandelani T, Schutte Z, Wium E (2018). Experimental and Numerical Validation of a Simplified Rigid Torso used for Investigating the Fluid-Structure Interaction of Air Blast Waves. Eleventh South African Conference on Computational and Applied Mechanics.

[12] Pandelani, Schutte Z (2018). Blast overpressure effects of different explosives using the Blast Test Device. Symposium 2018 of the South African Ballistic Organization.

[13] Boutillier J, De Mezzo S, Deck C, Ehrhardt L, Magnan P, Naz P, Willinger R (2016). New experimental data on blast interaction with instrumented structures. In Military Aspects of Blast and Shock Symposium MABS24. Halifax, Canada.

[14] Ehrhardt L, Boutillier J, Magnan P, Deck C, De Mezzo S, Willinger R, Naz P. Numerical simulation of the air blast interaction with simplified structures.

[15] Boutillier J, De Mezzo S, Deck C, Ehrhardt L, Magnan P, Naz P, Willinger R (2016). Shock-wave interaction with reduced-scale simplified torso surrogates. In IRCOBI Conference Proceedings.