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Physical mechanisms for near-field blast mitigation with fluid containers: Effect of container geometry

Huon Bornstein [a,b,*], Shannon Ryan [a], Adrian Mouritz [b]

[a] *Defence Science and Technology Group, 506 Lorimer St, Fishermans Bend, Melbourne 3207, Australia*
[b] *Sir Lawrence Wackett Aerospace Research Centre, School of Engineering, RMIT University, GPO Box 2476, Melbourne 3001, Australia*

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ABSTRACT

The use of external fluid containers for reducing the deformation of steel targets subjected to near-field explosive blast loading was investigated through experimental testing and numerical simulation. The fluid containers were placed between the explosive charge and steel target to mitigate both the transient and permanent deformation of the target. The effect of fluid container geometry on blast mitigation was evaluated by varying both the height and width of the containers while maintaining a constant volume of fluid, as well as by varying the height and width independently. The best performing container geometry provided a 65% reduction in the dynamic deformation to a reference steel target, which is more than twice the reduction provided by a steel applique panel of equivalent areal density. The blast mitigation effectiveness of the fluid containers was dependent on their geometry; for the same container volume, variations in container geometry were found to affect the peak dynamic deformation of the steel target by up to 100%. Numerical simulation of the blast experiments was performed using ANSYS® AUTODYN® and validated through comparison with temporally-resolved deformation signals. The validated numerical model was used to identify the physical mechanisms responsible for blast mitigation. The time-scale of the loading was computed to be too short for container break-up, proving that momentum extraction and water evaporation were not significant mitigation mechanisms. Whilst the loading time-scale was also too short for water cavitation to be a major mitigation mechanism, the development and collapse of cavitation bubbles were predicted to affect the loading on the steel targets. The major mitigation mechanisms were analysed to be shadowing of the detonation products and the generation of rarefaction waves, both of which are influenced by the container geometry. Whilst the fluid itself does not act as an energy absorber, the sound speed of the fluid is important due to the shock-impedance mismatch between the air and the water container and the subsequent pressure wave transmission at sonic speed through the fluid.

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1. Introduction

The use of fluids to mitigate the damaging effects of explosive blasts has been the subject of investigation for several decades. Water walls, which are placed between the explosive charge and the target structure, have been used to mitigate blast loading [1–3]. A water wall provides the same mitigation as a rigid wall, indicating that water walls mitigate the blast loading via diffraction and deflection of the blast wave (shock wave and detonation products) around the structure. In these cases, the barrier creates a low pressure (or shadow) region that extends approximately four times the length of the barrier perpendicular to the blast wave direction [4]. Bulk water placed in close proximity to an explosive can also be used to mitigate the effect of a confined, partially-confined, or free-field explosion via a range of mechanisms, including evaporation, momentum extraction, and suppression of after-burning [5]. Grujicic et al. [6] suggested that momentum extraction leads to the break-up of water into droplets, the subsequent evaporation of which is primarily responsible for reducing the peak pressure of a blast wave in the far-field. Within the near-field, however, these mechanisms may not be relevant, given the short time between detonation and interaction of the blast with the target. Whilst definitions of the near-field for blast vary, we will refer to it as the region within the fireball (typically 10–20 charge radii [7,8]). Bornstein et al. [9] recently reported that there is insufficient time for a water container to break-up and evaporate prior to a target being completely loaded in the near-field. In addition, studies [10,11] have shown that when an explosive charge is surrounded by water in the near-field, then the bulk water can significantly increase the loading on a target, highlighting the changes in loading and mitigation mechanisms in the near-field.

This investigation focused on determining the importance of the fluid container geometry in mitigating near-field blast loading on

* Corresponding author. Defence Science and Technology Group, 506 Lorimer St, Fishermans Bend, Melbourne 3207, Australia. Tel.: +613 9626 8647; Fax: +613 9626 8999.
E-mail address: Huon.bornstein@dsto.defence.gov.au (H. Bornstein).

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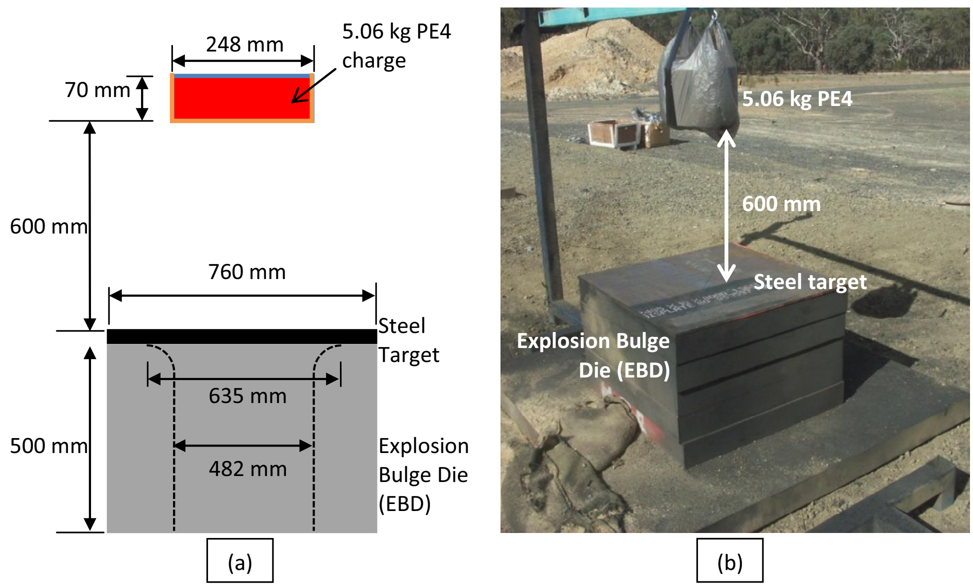

Fig. 1. (a) Schematic of the experimental set-up. (b) Photograph of the experimental set-up.

flat steel targets through experimental testing and numerical simulation. The container surface area, height and volume were independently varied to assess their influence on the blast mitigation. In addition, the results were used to validate a physics-based numerical model, which was then used to analyse and identify the underlying physical mechanisms responsible for near-field blast mitigation.

2. Experimental setup

Three series of experiments were conducted to assess the effect of fluid container geometry on the mitigation it provides against air-blast loading of a flat steel target in the near-field. The basic experimental set-up is shown in Fig. 1, where the suspended explosive charge was placed at 600 mm stand-off above the flat steel target plate. The stand-off is defined as the distance from the base of the charge to the top surface of the target. A 5.06 kg PE4 cylindrical charge was used in all tests, with a diameter of 248 mm and height of 70 mm. The proprietary steel target was 760 mm long, 760 mm wide, 10 mm thick plate which had a yield strength of 800 MPa and elongation-to-failure of 26% when measured at a quasi-static strain rate The stand-off distance was sufficiently small for the steel target to experience near-field blast loading, defined by dynamic loading from both the shock wave and detonation products.

In experiments with fluid containers, the containers were always completely filled with water and placed on the top centre of the steel target as indicated in Fig. 2. The target was placed on an explosion bulge die (EBD), which represents a slip boundary condition as the target was not fixed to the die. The EBD was assembled from 5×100 mm thick Bisplate® 400 plates, bolted together to limit separation and movement. The EBD measured 760×760 mm laterally, and had a 482 mm diameter cavity through-the-thickness. At the upper edge (top 100 mm thick plate), the diameter of the cavity increased to 635 mm with a uniform radius, as per Mil-STD-2149A [12]. A laser displacement transducer (LDT) was used to record the transient deformation at the target centre. The LDT was a Micro-Epsilon ILD 2300-200 operated at a sampling rate of 20 kHz and displacement range of 200 mm. The LDT was isolated and protected from shock, vibration and fragmentation during the explosive event through placement in an aluminium container that was packed

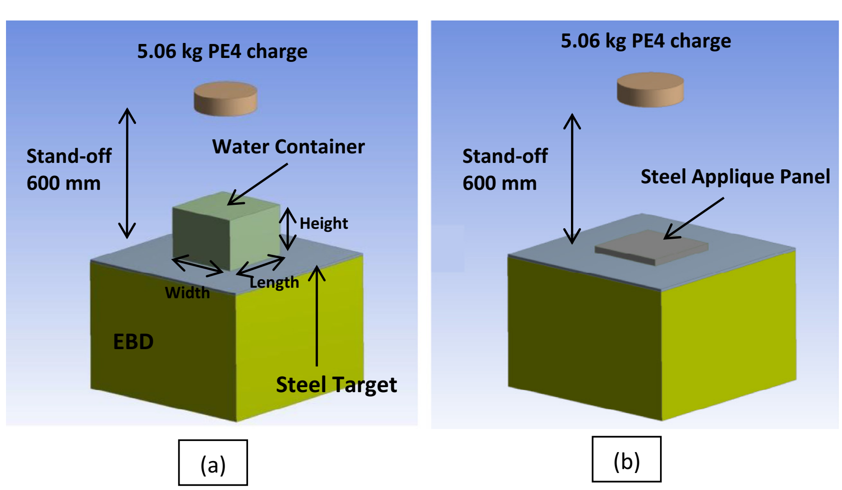

Fig. 2. (a) Schematic of experimental setup with a water container. (b) Schematic of experimental setup with a steel applique panel.

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