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Evaluation of the blast mitigating effects of fluid containers

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ABSTRACT

A series of small scale explosive experiments were performed to evaluate the potential for water filled containers and tyres to mitigate blast loading on armoured vehicles. The experiments compared the effects of an empty water container, a full water container, a full water container at a standoff from the plate, an air-filled tyre, and a water-filled tyre on the momentum transfer and deformation on a steel plate. Both the water containers and addition of water to the tyre reduced the global motion of the plate, but this was only by the same amount as the increase in mass of the system. Hence an equivalent increase in the vehicle mass would provide the same effect. In contrast, the air-filled tyre was able to mitigate the momentum transfer by a larger amount than the increase in mass it provided. The localised deformation experiments found that the use of a water filled container was likely to be more effective at mitigating the deformation of a steel plate than an equivalent increase in mass of the steel. The timescale of the loading indicated that the primary mitigation mechanism of the water was momentum extraction as there was insufficient time for water breakup and evaporation to occur prior to target loading. Further work is still required to confirm the scalability of the results, but this work indicates the potential to use water tanks as part of the blast mitigation system of an armoured vehicle.

1. Introduction

The use of buried Improvised Explosive Devices (IEDs) against vehicles in recent conflicts has led to a re-examination of protection strategies to reduce the transmission of explosive loading, and thus better protect the occupant. Injuries to an occupant within a vehicle subjected to a buried IED attack are typically a result of four major structural responses (Fig. 1): 1) hull rupture, which results in the ingress of detonation products and potential blast overpressure injuries; 2) localised deformation, which can result in injuries to occupants' lower legs due to floor deformation, spinal injuries due to deformation of the seat mounting points causing large accelerations of the pelvis, or head and neck injuries due to deformation of the seat mounting points resulting in contact between the head and interior structure of the vehicle; 3) Global motion, which can result in spinal injuries due to the change in velocity of the vehicle over a short time period (either in the initial upwards acceleration or the subsequent set down), and; 4) Tertiary effects such as secondary projectiles impacting the occupant. Hull rupture and localised deformation are the result of localised explosive loading to the hull, while the global motion is the result of the total impulse (momentum transfer) imparted to the vehicle hull. The spatial and temporal distribution of loading is the result of a loading profile that is dependent on a range of parameters, such as the explosive type, shape, standoff and soil properties such as density and moisture content for buried charges. Whilst, both the impulse and localised deformation are dependant on the profile of the explosive load, mitigation techniques may not be equally effective for both mechanisms. Hence, the effectiveness of a mitigation technique should be evaluated in terms of both impulse and localised deformation.

Water has been used as part of a vehicle blast mitigation strategy since at least the Rhodesian Bush War, where the tyres of vehicles were filled with water [2] to aid in protection against buried landmines. The water in the tyres was thought to reduce the loading on the vehicle by cooling the blast as well as “deflecting the pressure waves, causing the blast to flatten out and disperse away from the vehicle” [2]. Work by Hlady et al. [3]. concluded that there was no difference in the blast protection provided by standard, run flat and water filled tyres. However, this work only assessed the impulse transferred to a fixture and did not look at the effects of the tyres on localised deformation.

A number of studies have shown the effectiveness of water in reducing the overpressure of a blast wave when placed in contact, or close contact to an explosive charge. A review of this work is provided by Kailasanath et al. in Ref. [4]. An example is the work

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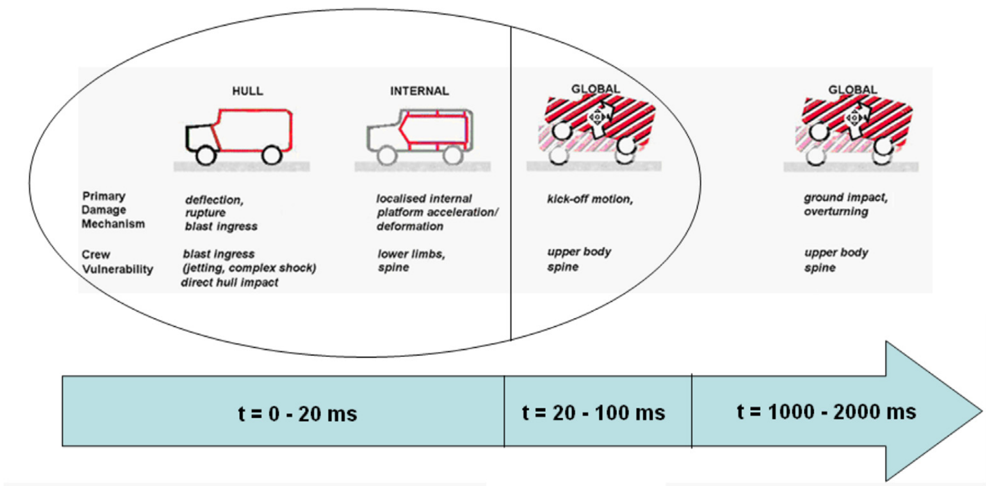

Fig. 1. Major structural responses of armoured vehicle to blast loading from a buried charge, including crew vulnerability and timescales (adapted from Ref. [1]).

performed by Joachim & Lunderman [5]. They conducted a series of small scale explosive experiments to investigate the effect of water to mitigate explosions occurring in munitions storage facilities. Numerical simulations were performed by Chong et al. [6] in an attempt to replicate the experiments conducted in Ref. [5]. The studies found that mitigation increased when the water was placed in contact with the charge, rather than at a standoff. They also concluded that increasing the water mass to charge ratio resulted in improved mitigation although there appeared to be an upper limit, beyond which the water provided no additional mitigation. Small scale experiments conducted by Resnyansky & Delaney [7] found an 80% reduction in the peak incident pressure for an explosive charge encased in water. In both cases the assessment was made at a significant distance from the charge with only the side-on pressure considered.

Grujicic et al. [8] presented a number of mechanisms by which water could potentially mitigate blast loading, with momentum extraction and evaporation (phase transformation) primary amongst them. The authors proposed that the transfer of momentum from the detonation products to the water is the major mechanism for water droplet breakup, a key step in the evaporation of the water and subsequently in the mitigation of a blast load. In addition to the effect of water evaporation on the blast wave, Salter [9] describes the use of water to defeat a projectile via momentum extraction. The projectile momentum is shown to be redistributed by the water in all directions rather than solely along the path of the projectile. This momentum extraction technique may also be a relevant mechanism for the use of water in reducing blast loading.

Schwer & Kailasanath [10] conducted a numerical modelling investigation into the blast mitigation provided by water mist. They analysed the effect of evaporation by altering their model properties to both allow and constrain evaporation of the water mist. They found that the effect was minimal compared to the momentum extraction the water mist had on the blast wave. Ananth et al. [11] conducted a numerical modelling investigation into the mechanism of water droplet breakup on the performance of water mist as a blast mitigant. In conflict with [10], the momentum transfer was found to be of secondary importance compared to the evaporation of the water droplets in this investigation. Based on the analysis by Grujicic et al. [8], these artefacts are interrelated and it's likely that both play a significant role in the reduction of blast overpressure in the far-field. Grujicic et al. [8] also provides an analysis on the timescales of the water droplet breakup and subsequent evaporation. For targets placed closer to the explosive (near-field), depending on their proximity, their may not be enough time for the extraction of energy from the blast wave through evaporation.

Kirkpatrick et al. [12] experimentally assessed the performance of a number of potential blast mitigants, including water, via a momentum pendulum. This test condition is more representative of the loading expected from an explosive IED, although in this case the mitigant was placed in direct contact with the explosive charge. The results indicated that water transfers significantly more momentum to a target in the near-field than an unmitigated charge. Similar results have been found in buried charge investigations by Fox et al. [13] and Fourney et al. [14], where the performance of an explosive in varying soil media is compared to that in water. Wilcox [15] conducted experiments in an enclosed space using water as a mitigant and found that whilst they achieved a "blast shock suppression" of greater than 90% in their initial tests results, there was additional damage due to the momentum of large slugs of water. Further testing in Ref. [15] indicated by using an optimal arrangement of the water it was possible to also reduce the damage by taking advantage of a design to promote momentum extraction.

The main focus of the present investigation was to assess the performance of water in mitigating potentially injurious loading on an armoured vehicle hull from an explosive charge.

2. Experimental setup

2.1. Impulse experiments

A series of flying plate experiments were used to examine the effect of a water container or tyre on the impulse transferred from a blast. The test conditions evaluated were: 1) steel plate with no container, 2) steel plate with an empty container, 2) steel plate with a full container, 4) steel plate with a full container at 50 mm standoff, 5) steel plate with an air-filled tyre, and 5) steel plate with a water filled tyre. The experimental setup is shown in Figs. 2 and 3. The full test matrix for the flying plate experiments is shown in Table 1. The container used in the experiments was a 20 L commercial plastic water jerry, approximately rectangular in shape with dimensions of 400 mm × 330 × 175 mm and weighing 1.5 kg. It was made from nominally 3 mm thick high-density polyethylene (HDPE). The tests using the water containers were intended to represent potential scenarios whereby a water tank was placed on the exterior of an armoured vehicle. The tyre used in the test was a commercially available wheelbarrow wheel assembly that weighed 3.25 kg. For simplicity, the entire wheel assembly will be referred to