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Challenges in blast protection research

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ABSTRACT

This paper presents a view of some of the challenges that are presented in investigating protection methodologies against explosive blast effects. In particular, the paper is concerned with experimental efforts that can aid in the understanding of complex blast effects in typical real world scenarios. Current progress in the implementation of blast mitigation methodologies in the landward defence environment is reviewed.

1. Introduction

The use of explosives worldwide in terror campaigns has rekindled international interest in blast research. The need to protect innocent civilians and peacekeepers from such acts requires in-depth knowledge of blast effects from explosives in complex scenarios, as well as ways to prevent or mitigate damage [1]. The CSIR in South Africa has been investigating this field, mainly in an empirical way, for some time and have obtained recognition for pioneering work performed on early MRAP concepts [2]. The blast research conducted by the CSIR is aimed at advising the SANDF on matters concerning explosive blast threats and aim to characterise the effects of such threats in surrogate conditions by whatever experimental means available. In the course of such investigations, it is attempted to assimilate the current state of the art knowledge in blast science and it has been realised that significant challenges still exist in this field.

In this paper, the various challenges identified will be highlighted and reviewed. These areas are by no means exhaustive and are limited to the expertise field of the CSIR. In terms of blast protection research, for instance, it is realised that by far the biggest challenges lie in the explosive device detection and neutralisation field, since in the case of an IED there is no better protection than to prevent the device from functioning. However, these aspects will not be addressed in this paper and it will be assumed that by blast protection it is implied that an explosive blast wave is the ultimate threat.

Research into blast protection from explosive threats can essentially be divided into two domains. These are (a) understanding the propagation and loading from blast and shock waves through and in complex media and geometries, and (b) mitigation mechanisms to minimise the damage from the shock and blast loading [3]. Each of these domains is packed with multidisciplinary study fields. In the former, chemistry, physics, mathematics, computational mechanics and fluid dynamics feature heavily, while in the latter material science, structural response, fracture mechanics, computational mechanics and human response is paramount.

It is therefore obvious that academic institutions will have an acute interest in blast protection research, since many aspects in these domains require basic research to enhance the fundamental knowledge to adequate levels, for use in technology solutions. However, the inherent complexity of real world events in these domains also requires a comprehensive research approach for implementation of solutions and therefore it has become the trend to have research collaboration across the spectrum of academic and industrial institutions [4].

2. Challenges

2.1. Modelling of complex blast scenarios

Great strides have been made with mathematical models and computational methodologies to simulate complex blast scenarios

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Abbreviations

CFD	Computational Fluid Dynamics
CSIR	Council for Scientific and Industrial Research
DBEL	Detonics Ballistics and Explosive Laboratory
IED	Improvised Explosive Device
HSV	High-Speed Video
kPa	kiloPascal
LS	Landwards Science
MRAP	Mine Resistant Armour Protected
SANDF	South African National Defence Force
VLIP	Vertically Launched Impulse Plate

[5–7]. Most of the tools available rely on the solving of the Euler conservation equations for mass, momentum and energy and differ only in the description of the source terms, the boundary conditions and the numerical approach to the computation [6]. The efficient treatment of the blast propagation through 3-D numerical meshes and the use of new CFD techniques, as well as the availability of improved computer processing power, have allowed the investigation of complex interaction of blast and shock waves with material configurations and structures [8–10]. Further investigation of new computational techniques with artificial neural networks is also explored for blast effects prediction [11].

Some major challenges still exist in this field despite the increased sophistication of the computational tools. A particular requirement is the implementation of non-ideal energetic behaviour in the longer time frame that typically occurs with explosive mixtures used in IEDs. In these instances, a number of factors are important:

(a) accounting for the time-dependent energy release from the explosive source itself,
(b) accounting for the aerobic energetic behaviour of the gaseous explosive products,
(c) estimating energy release from the re-energizing of the explosive products when subjected to successive reflection waves in confined and semi-confined space.

The term afterburning is usually used to refer to the ability of the products of an explosive to continue to release energy when either mixing with the surrounding atmosphere or with an inherent delayed reaction over longer time span. The normal way of addressing the energy release in the computational tools, is to use an equation of state to determine the release parameters at a fixed position and time. Several modifications of this approach have been investigated [12–15]. A relatively successful approach is to use additional thermochemical codes to predict the additional chemical energy release potential from either the aerobic mixture of the explosive products, or the latent time-dependent energy release from the products itself. This energy release is then added to the computation with general thermodynamic rules.

At the DBEL facility of the CSIR a semi-confined chamber is used to study the detonation of explosive charges in partially confined conditions [16]. The evolution of the explosive product boundary (fireball) after the detonation of 0.5 kg cylindrical composition B charge was observed together with simultaneous pressure measurements at the chamber walls [17]. In Fig. 1 below a collage of high-speed video footage is shown with images depicted 3 ms apart starting at 1 ms after the detonation of the charge. The charge was suspended from a cradle centrally in the chamber and was detonated in the downward direction.

It can be observed that the detonation products remain confined to the centre of the chamber (apart from the jet in the downward direction) and exhibits renewed energetic behaviour after each recompression cycle of the reflected blast wave from the chamber walls.

In Fig. 2 the pressure measurements in the same chamber from a 2 kg total mass HMX based charge and a 2 kg RDX based charge containing aluminium powder, is shown. The measurements were taken at the same position in the chamber wall approximately 2 m away from the detonation of the charge.

The pressure recordings in Fig. 2 shows the effect of enhanced reaction of the product cloud containing aluminium at longer times when the reflection waves pass through the cloud, but also show activity for the HMX products at similar times. This enhanced activity is a combination of the aerobic reactions, the secondary expansion after the rarefaction waves collapse the centre of the fireball and recompression of the products by the reflected pressure waves from the wall of the chamber.

It is obvious that there is a need to be able to model the contributions from reflected waves re-energizing the products of detonations in the longer time frame. In the light of detonations in complex environments where it is required to estimate the yield of the threat, there can be a substantial difference compared to the free field case.

2.2. Effect of charge geometry and detonation direction at short standoff

Many IED instances concern explosive charges in very close proximity to the target and small-scale blast tests are mostly performed at close standoff distances. The anomalies of blast characteristics as a function of geometry at short standoff have been addressed in earlier studies [18–20]. Significant differences in the blast yield are found for cylindrical charges compared to spherical charges, at even quite large scaled distances [21]. This has important implications in protection research where it is a normal occurrence to expect non-spherical charges as the threat and shorter application standoff distances. Another significant issue that needs to be addressed is the dynamic loading from larger charges due to such circumstances.

In Fig. 3 below the pressure distribution in the product cloud of a cylindrical 0.5 kg composition B charge of $L/D = 1$ is shown at 116 μs after initiation, as predicted by the LS-Dyna hydrocode. The charge symmetry axis is on the centreline and it was initiated in the centre on the left face.

The peak pressure at this time in the frontal direction of the expansion is about twice that of the lateral and rear expansion envelopes and about 3–5 times that of the bridge waves. The loading from such a charge will be strongly dependent of the orientation of target with respect to the charge at this time.

Furthermore, whereas the product cloud velocity in the case of a spherical charge rapidly decreases with distance and typical blast arrival times from scale tables can be obtained at scaled distances of approximately $Z = 1\ \mathrm{m/kg^{1/3}}$, the product propagation velocity in the forward direction for cylindrical charges remain higher for much larger scaled distances. This has implications for the dynamic loading in this particular direction. In Fig. 4, a collage of high-speed photographs (10 μs intervals) is shown for a 1 kg cylindrical composition B charge with the field of view over the forward direction. At early times, the actual detonation product boundary is obscured by the ionisation light around the charge but from approximately 40 μs, the progression of the frontal boundary of the products can be obtained. The velocity of this boundary was measured from recordings of tests with 0.5 kg, 1 kg and 4 kg composition B charges and is shown in Fig. 5. Predictions from the

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