Improved diagnostics for air-blast loading experiments

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Abstract. This paper describes collaboration into experimental techniques for measuring spatial impulse distribution across target plates subjected to air-blast. In South Africa, the transient responses were obtained from digital image correlation and stereo-imaging of a flexible target plate. Specific impulse distributions were inferred from the velocity profiles. At the University of Sheffield, scaled blast tests employed a Hopkinson pressure bar array to obtain directly measured values at discrete locations across a rigid target. The findings demonstrate the usefulness of improved diagnostics and techniques in blast experiments, and demonstrate the potential of high speed imaging and DIC for determining impulse profiles.

Introduction

Improved diagnostics for measuring structural response and loading characteristics resulting from explosive detonations are critically important. High fidelity experimental data is critical in supporting the efforts of blast engineers and researchers in understanding and predicting blast loading and its effects on structures and materials. There are considerable challenges in measuring and recording data, including the high pressures and temperatures, the short load duration, excessive vibrations introduced into mounts, triggering challenges, electromagnetic interference, and the bright explosive flash. In recent years, improvements in instrumentation and novel experimental approaches have provided renewed impetus to the chase for better experimental measurements from laboratory scale explosion tests [1-3]. This paper reports on tests performed in a single-blind study at the Universities of Sheffield and Cape Town which aimed to measure the impulse distribution resulting from explosive detonations in air.

Brief experimental description

The experiments performed at Sheffield used the Characterisation of Blast Loading (COBL) apparatus [1] to measure pressure at discrete locations across a rigid target plate. The COBL rig comprises a 100 mm thick steel target plate which acted as a nominally rigid boundary. Seventeen EN24 steel Hopkinson pressure bars (each 10 mm diameter, 3.25 m long) were mounted through holes drilled in the target plate and set with their loaded faces flush with the underside. The COBL tests involved detonations of spherical (100g PE4) and 3:1 cylindrical (78g PE4) charges located at stand-off distances from the charge surface of 55.4 mm and 168 mm respectively.

Experiments at BISRU (Cape Town) involved detonating 50g spherical and 3:1 cylindrical PE4 charges at SODs of 44 mm and 145 mm respectively. The blast loading was directed at deformable Domex 355MC steel plates with a circular exposed area (diameter 300 mm) that were mounted via a clamp frame to a pendulum. The global impulse transfer to the plate was estimated from the pendulum swing, while the transient response was obtained from high-speed stereo images of the rear face motion, shown in Fig. 1, following the methods developed by Curry and Langdon [2]. The Cape Town experiments were performed single-blind, without knowledge of the Sheffield test results.

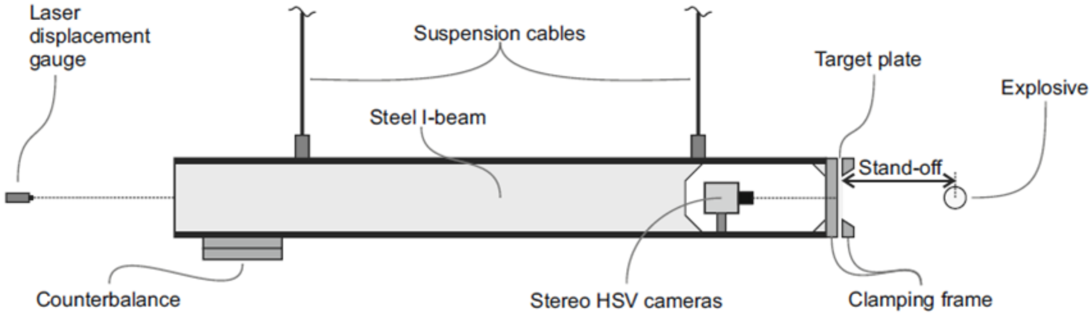

Figure 1: Schematic (side view) of the transient response blast pendulum at BISRU

Results

Digital Image Correlation (DIC) was used to post process the images obtained from the BISRU blast tests. The displacement and velocity profiles across the plates were obtained. The transient displacement histories exhibited a sharp increase in displacement up to a peak displacement, followed by an elastic recovery of the plate, as expected. It was evident that the spherical detonations produced repeatable responses in the plates, while the cylindrical detonations show more variation.

The initial velocity profiles were used to infer a continuous specific impulse distribution which, after suitable scaling, were compared to measured (COBL) specific impulse distributions from the spherical tests at the University of Sheffield (show in Fig.2a), where good agreement is demonstrated. The specific impulses measured using COBL also showed greater spread for the cylindrical tests. Imaging of the fireball enabled Rigby et al [4] to attribute these differences to surface instabilities in the expanding detonation product cloud [4]. The variations were significant enough to influence the transient displacement profile obtained using DIC, resulting in similar differences in impulse distribution (Fig.2b). This work shows that the two measurement techniques (COBL and high speed video/DIC) give excellent agreement and are both suitable methods for obtaining the spatial impulse distribution across a target structure.

With high-speed imaging techniques, the target structure needs to be flexible enough to be sensitive to changes in the initial velocity distribution and the imaging system needs to be sufficiently fast to capture the initial velocity (that is, a high frame rate and low exposure time). The system in Cape Town gives repeatable and accurate impulse distributions across a central strip of a panel, useful for model validation. Rigby et al [5] have used this to derive an energy equivalent impulse approach that accounts for the additional energy imparted to a structure from a spatially non-uniform blast load and accurately predicts plate deflection. Additionally, the University of Sheffield has now expanded its diagnostic capability to include high-speed imaging and DIC, with the goal of expanding the area of the structure that can examined (to account for the observed asymmetries in the impulse distribution for the case of cylindrical detonations).

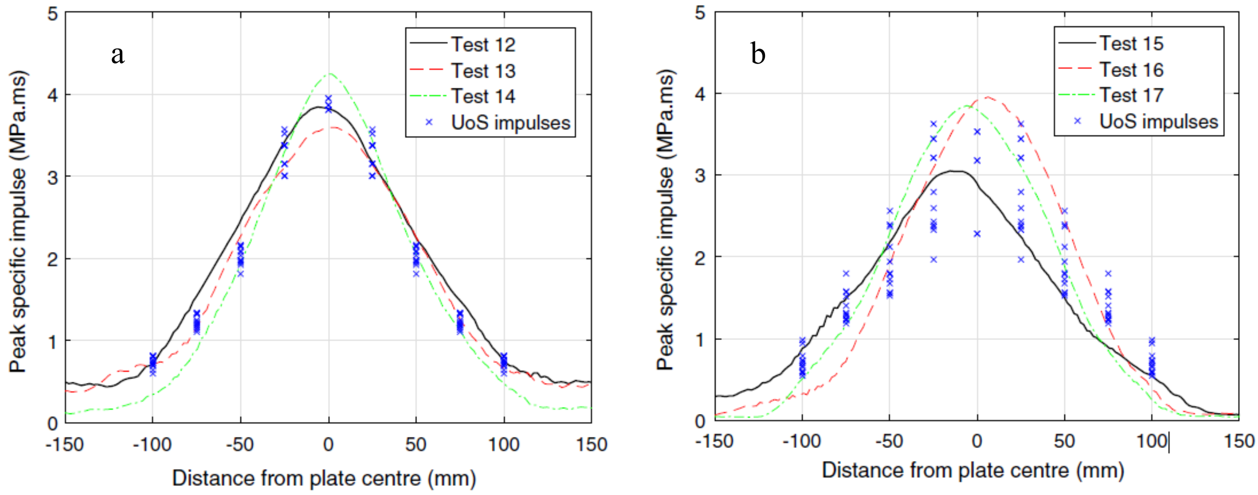

Figure 2: Measured (COBL) and inferred (BISRU) specific impulse distributions for (a) spherical detonations (b) cylindrical detonations

Conclusions

The findings show significant progress in the chase for better experimental measurements that characterize the loading and transient response of structures subjected to near-field explosions. The initial velocity profiles obtained using stereo-imaging and DIC techniques produced inferred specific impulses that matched well with the discrete specific pressure and impulse measurements obtained using COBL at the University of Sheffield. The inferred impulse method seems to be sensitive enough to detect spatial variations in loading caused by surface instabilities in the expanding detonation product cloud from cylindrical charge detonations. We will use this approach to better investigate localised variations in loading, their causes and prominence, and the sensitivity of flexible targets to these.

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