Shock tube testing of deformable structures: A novel experimental set-up

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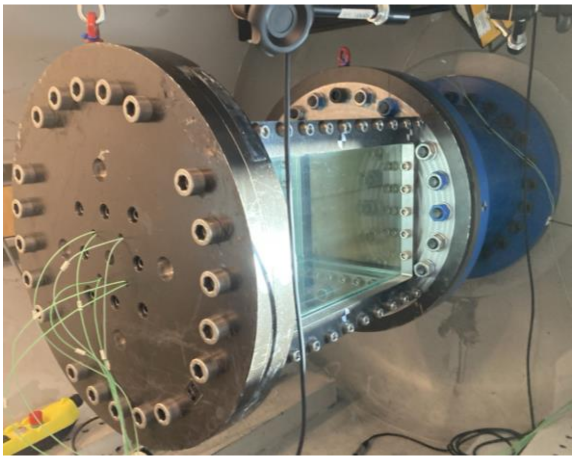
Introduction

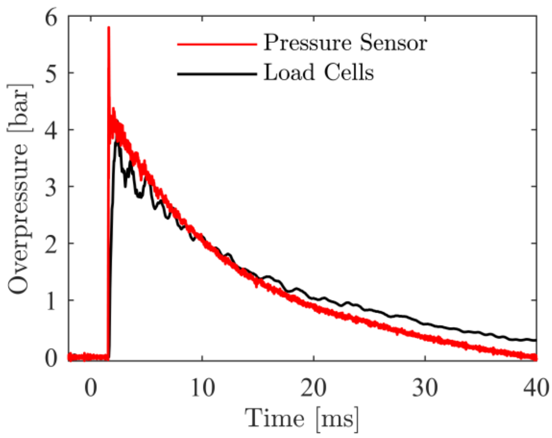
Blast load attenuation has been of academic, industrial and military interest for centuries. However, during the last decades there has also been an increased civilian interest in blast protection due to several devastating accidents and terrorist attacks. Traditionally, blast protection has been achieved by heavy steel and concrete structures, but modern architectural requirements for civilian structures require more lightweight and slender designs that offer limited protection. Two ways to achieve better protection are to use energy absorbing components, for example sacrificial claddings, and to utilize fluid-structure-interaction (FSI) effects.

In 2015, the SIMLab shock tube facility (SSTF) was installed at SIMLab, NTNU, to study structures exposed to air-blast loading [1]. This facility has been used in several studies to investigate the effects of air-blast loading on different structural components, see e.g., [2-4]. The acquired results have proved valuable for understanding the behaviour of blast loaded components, and to establish a validated framework for numerical simulations. A limitation with the current experimental set-up is that the test components are mounted such that the side facing the incoming shock wave is not visible for data collection during testing. It is also not possible to record the load transferred through the test component to the underlying structure.

This study presents a new experimental set-up using the SSTF. The shock tube was extended with a transparent section, where the front and sides of the test component are visible. A pressure plate instrumented with eight Kistler 9041a load cell washers [5] enables the measurement of forces transmitted through the test component. Fig. 1(a) shows the extension (in black) bolted to the end flange of the shock tube (in blue). Several validation and component tests have been performed to assess the capabilities and consistency of the shock tube extension. Validation tests with five Kistler 603B pressure sensors [6] mounted at the end of the extension showed that the addition of the proposed extension did not alter the formation of a plane and consistent shock wave. Good correlation was also found between the load measured by load cells and the load measured by pressure sensors, as shown in Fig. 1(b).



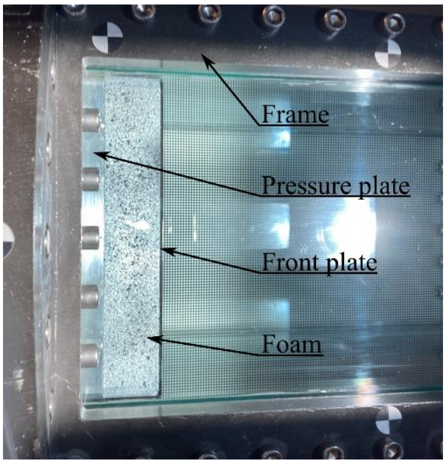
(a)

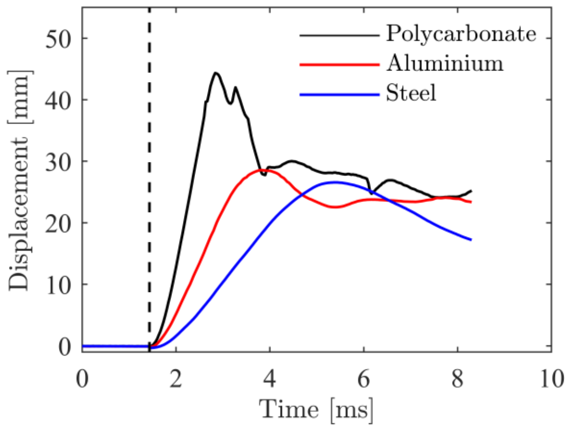


(b)

Figure 1. (a) Experimental set-up in the SSTF with the extension (in black) bolted to the shock tube end-flange (in blue), and (b) recorded pressure-time curve (in red) compared with load cell measurements (in black).

Six component tests were performed to assess the data collection capabilities of the new experimental set-up. In these component tests, 3 mm thick plates made of polycarbonate, aluminium and steel were either backed by 50 mm slabs of expanded polypropylene (EPP-5122) or free to move along the length of the extension. Fig. 2(a) show the experimental set-up with a foam component backing. Two synchronized Phantom v2511 high-speed cameras [7] recorded the test components at a frame rate of 30 kHz. In these tests, the front plate velocity and displacement were measured by point tracking from the high-speed camera images, and the surface strain in the foam was measured by 2D digital image correlation (2D-DIC). The shock wave density was visualized by background oriented schlieren (BOS), again by use of high-speed camera images, and the forces transmitted were measured by the load cell washers. Displacements of the front plates in the foam component tests are presented in Fig. 2(b). These displacements show that, as expected, the front plate velocity and displacement, as well as the maximum foam compression, are highly dependent on the front plate mass.





(a) (b)

Figure 2. (a) Details of the experimental set-up with EPP-backed plates, and (b) displacement-time curves from tests with EPP-backed plates.

The proposed experimental set-up has proven to significantly increase the experimental capabilities in the SSTF. Although the experimental results presented do not show a novel behaviour of the components, the experimental set-up is well suited for studying new protective components and FSI effects, and to gain considerably more information from each experiment. Due to the simplicity of the set-up, i.e., mainly 2D behaviour of both the component and the shock wave, the results obtained are ideal for validation of numerical and analytical models for deformable components subjected to air-blast loading.

References

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