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Planar wave propagation in shock tubes for replicating blast injury

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Injuries from blast trauma are the leading cause of mortality and morbidity in recent military conflicts [1]. In order to replicate and assess injuries under these conditions in the laboratory, a shock tube is often used. Shock tubes typically implement or a region of high pressure behind a burst membrane to initiate shock formation. The propagating shock is assumed to be planar upon impingement to replicate an impacting Friedlander air blast. The Friedlander wave represents an idealized pulse with near-instantaneous rise to peak pressure followed by exponential decay back to ambient and slight underpressure region. Shock tube cross section and specimen position are variable across the literature, and it is often not clear whether this assumption has been considered. This generates conflicting results and makes injury mechanisms difficult to elucidate. The objectives of this study are to quantify regions in the shock tube system where planar shock propagation is valid and guide future blast research.

A circular and square shock tube with matched hydraulic diameter (D = 76 mm) were constructed both physically and *in silico*. These represent the two most common cross sections encountered in literature. Physical tubes were constructed from aluminum and include a pressurized driver section filled with driver gas. The driver is separated from the length of the shock tube, or driven section, by variable-thickness polyethylene terephthalate (PET) membranes (Figure 1). When the membranes burst, a shock is propagated down the driven section and impacts the specimen. By varying the driver size, tube length, membrane thickness, and driver gas, the peak pressure and impulse can be tightly controlled.

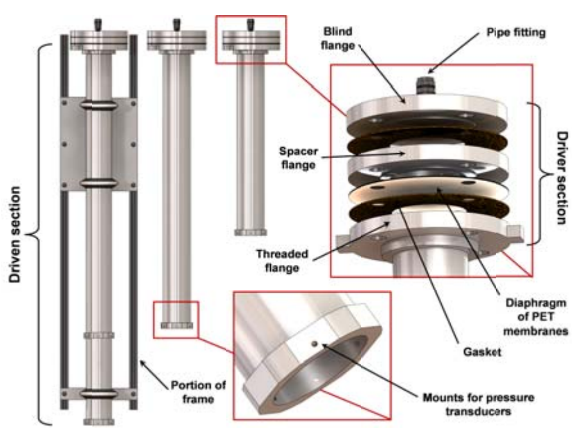

Figure 1. Circular shock tube design

Tubes were replicated *in silico* using a fluid-structure interaction and arbitrary Lagrangian-Eulerian approach (FSI-ALE). Hexahedral elements with ambient air properties and a gamma equation of state were used initially in both the driver and driven sections. The driver section was allowed to fill to high-pressure. Membrane failure was tuned via an inverse approach to initiate fracture in line with deformation observed experimentally (Figure 2).

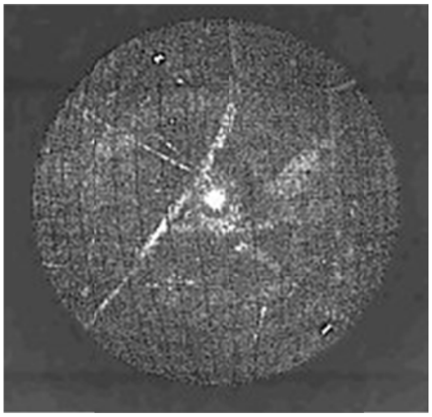

Figure 2. Membrane immediately before burst as captured by high-speed video. Surface contour measured by 18 grid lines spaced equally across diameter.

Helium gas at 8300 kPa was used to pressurize driven sections with membrane thicknesses of 0.76, 1.27, and 1.78 mm. Transducers at the end of the driven section measured incident pressure of the propagating shock wave. A pie plate with an incident pressure transducer was adjusted along the length of the driven section into the free field to measure shock wave formation and compare against an ideal Friedlander pulse. Results of the finite element models were in good agreement (Figure 3 top). Pressure contours at tube exit were also shown to exhibit good planarity across the cross section in the circular case (Figure 3 bottom).

Blast cases corresponded to developed incident overpressure and duration of 375, 565, 753 kPa and 1.20, 1.38, 1.56 ms, which is in good agreement with scaled blast cases [3].

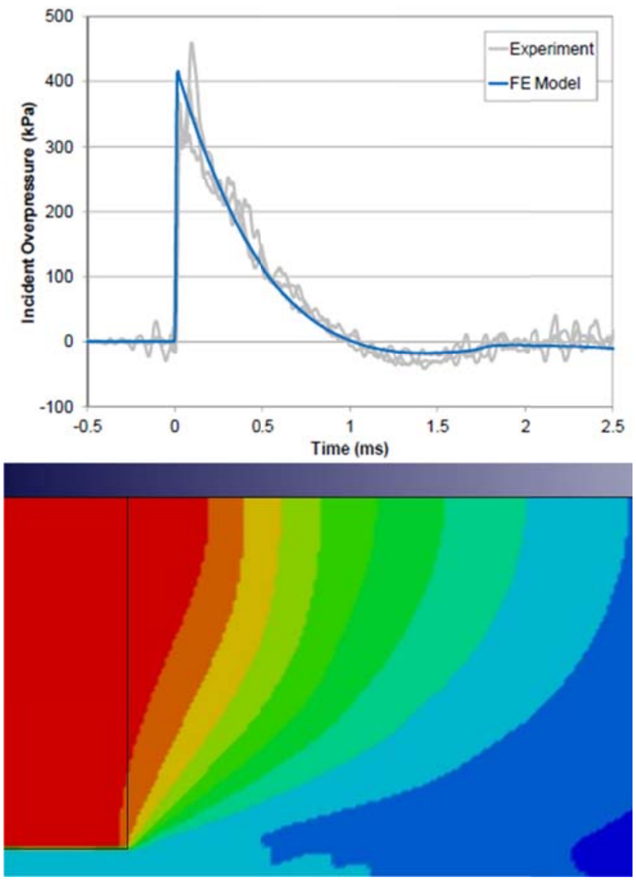

Figure 3. Top: FE vs. experimental incident pressure at the tube end [2]. Bottom: Exit pressure contour for the circular case.

In order to assess the validity of shock tube models observed in the literature, two shock tube models were developed both physically and *in silico*. These models indicate that the rarefaction waves at the corners of the square shock tube complicate the shock tube output. The axisymmetric circular tube allows for elimination of these waves as the shock develops. Additionally, shock formation results suggest a length of approximately ten tube diameters down the driven section to achieve planarity. These results can be used to inform future shock tube models and generate reliable input conditions.

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