Density field visualization of a Micro-explosion using background-oriented schlieren

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SHORT PAPER

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1 Introduction

The determination of flow field properties of large-scale explosions which is necessary for better understanding and flow modeling is rather challenging and difficult. Recent studies show that micro-explosions can be an acceptable substitute. However, quantitative determination of the flow field is still a challenge given the extremely short duration and spatio-temporal evolution of the flow. Determination of shock wave propagation properties from a blast using available flow diagnostic techniques is difficult. The complex nature of the chemical reaction process and spatial and temporally varying flow field imposes serious

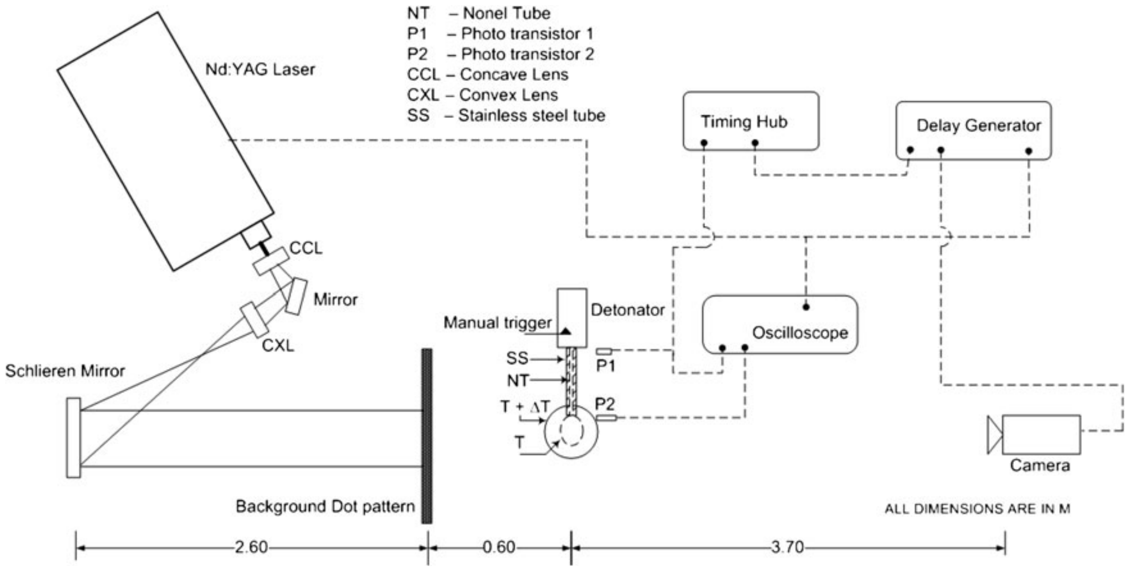

Fig. 1 Schematic diagram of the experiment

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limitations on applied diagnostics. Most of the earlier works are qualitative in nature (Dewey 2001; Kleine et al. 2003; Klingenberg 1977) where the blast wave properties are derived through Rankine–Hugoniot relations. Sommersel et al. (2008) and Mizukaki et al. (2011) have used the Natural Background Oriented Schlieren technique on large and laboratory scale blasts respectively. They used the BOS technique to get the time-radius relationship of the blast wave; however no direct quantitative density field could be obtained. In this study, density field of a spatial-temporally evolving blast wave generated from a small micro-explosion (Obed et al. 2012) is documented using Background Oriented Schlieren (BOS). A preliminary attempt at application of BOS to a micro-explosion was carried out by Suriyanarayanan et al. (2011). In the present study the three dimensional density field was reconstructed using the filtered back projection technique at several instants of time in order to capture the evolution of the density field of the blast wave.

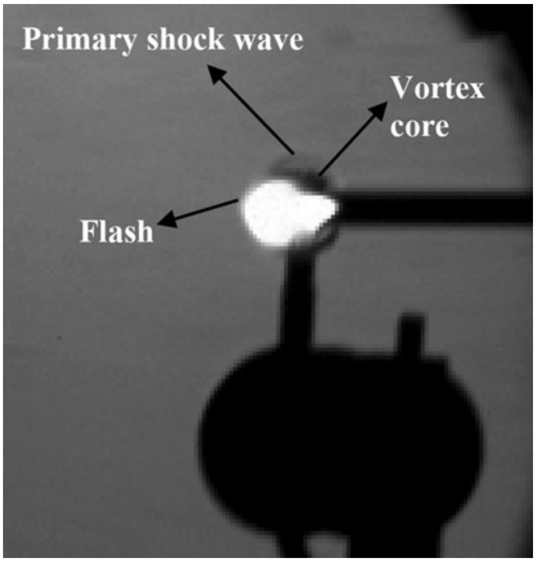

Fig. 2 Instantaneous schlieren at $t = 24\ \mu s$ showing shock front

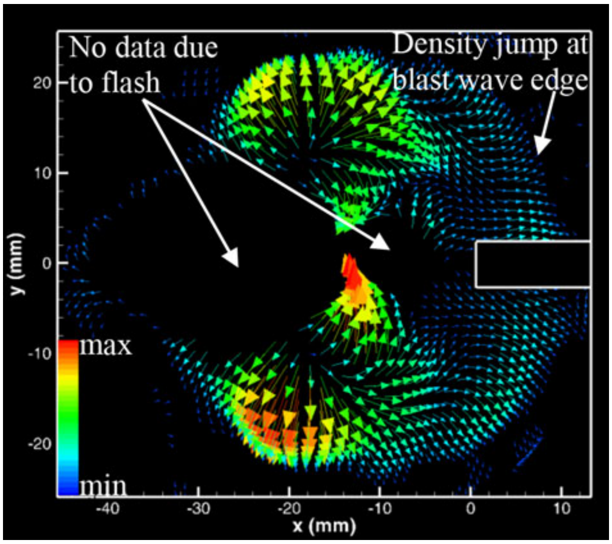

Fig. 3 Displacement field corresponding to density gradient field at $t = 24\ \mu s$

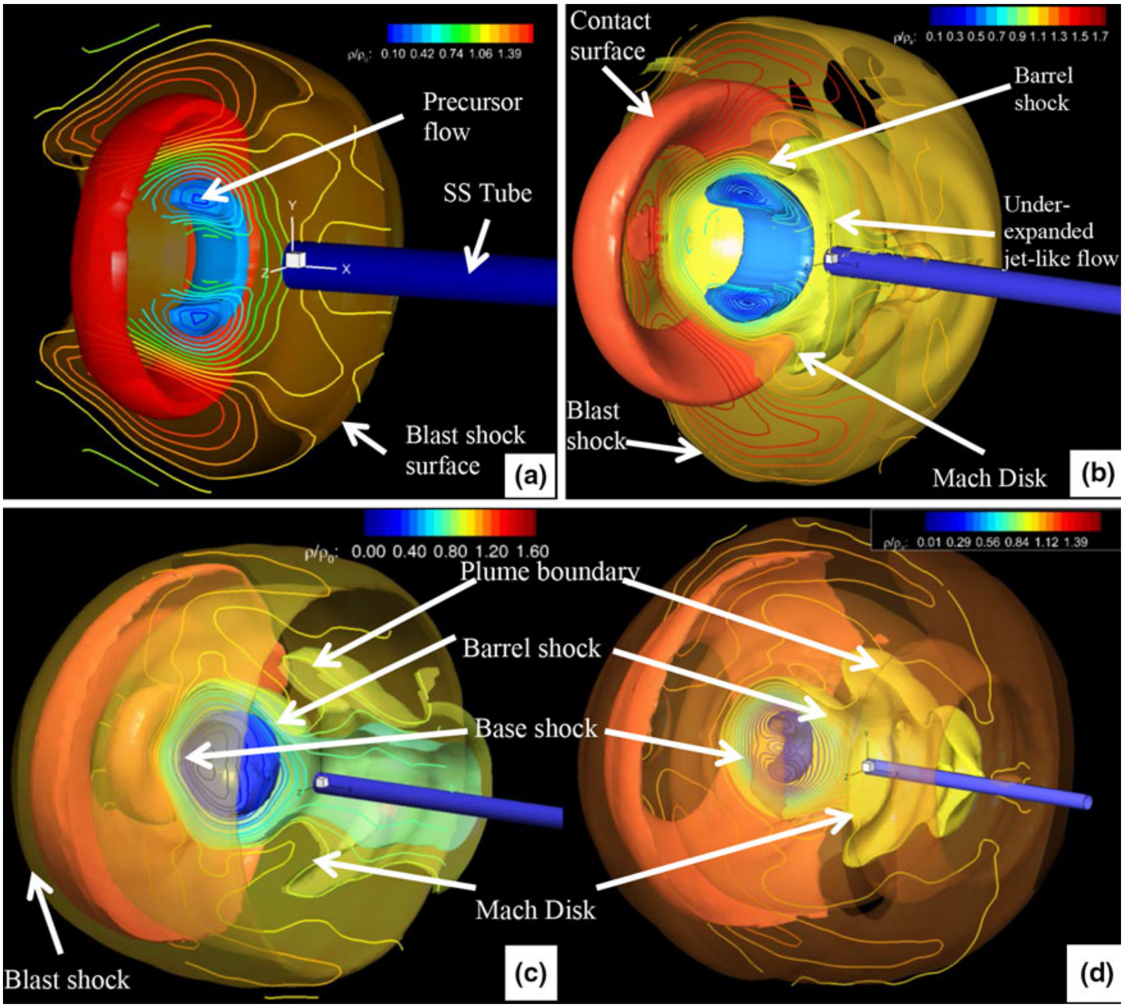

Fig. 4 Reconstructed density field at **a** $t = 24$ µs, **b** $t = 53$ µs, **c** $t = 93$ µs and **d** $t = 122$ µs

2 Experimental methods

The principle of BOS technique is based on the refractive index variation due to density gradients in the flow. Cross-correlation was carried out on images taken at no-flow and flow condition yield vectors of density gradients at each point. The line-of-sight integrated density field is obtained by solution of the Poisson equation. Later on, optical tomography (filtered back-projection) is used to determine the density field in the actual plane of interest. The reader is referred to Venkatakrishnan and Meier (2004) for a derivation of the reconstruction function. The reconstruction of the entire density field is achieved by inverse tomography (Venkatakrishnan and Suriyanarayanan 2009). The reconstructed density is non-dimensionalized using the ambient density and this gives the overdensity value for the blast wave.

The schematic diagram of the experimental setup is shown in the Fig. 1. The micro-explosion is generated using a non-electrical (NONEL) tube (M/s Dyno Nobel, Sweden) which consists of a plastic tube coated with thin layer of explosive material (HMX 18 mg/m and traces of Aluminum). An electric spark initiates detonation inside the tube and the gases are allowed to escape from the open end of the tube, thereby generating a blast wave. The spatial–temporally evolving density field is captured at several instants of time by means of a precise triggering circuit used to control the illumination and imaging. The present experiment requires exceedingly short exposure time due to the transient nature of the flow, hence an Nd:YAG pulsed laser with a pulse width of 10 ns is used as background illumination source for the BOS techniques.

3 Results and discussion

The initiation of detonation inside the Nonel® tube by means of a spark generates a wave front. This wave front compresses the air and results in the formation of multiple compression waves which coalesce to form a strong shock which expands into a spherical blast wave. Figure 2 is an instantaneous schlieren at $t = 24$ μs showing the initial development phase of the blast wave. Near the exit of tube, the high intensity of the ignited Alumina and HMX causes an occlusion of the density gradient field. However, a dark region corresponding to the vortical flow is visible. Figure 3 presents the vector field of density gradients at the same instant as obtained from BOS. The vectors point in the direction of lower density and the colors show their magnitude with red being the highest. The density gradient field agrees well with the corresponding schlieren and in addition shows the extremely high gradients in the vortex. While the presence of flash results in an absence of data in the core, the flow is easily recognizable as that similar to a precursor flow. This is emphasized on reconstruction of the density field which is depicted in Fig. 4a and its subsequent evolution in Fig. 4b. The reconstructed density field of Fig. 4a does not show the leading edge of the free-air blast wave due to the occlusion by the flash as mentioned earlier. The density field exhibits two distinct ring-shaped regions of higher and lower densities. This ring-shaped structure resembles earlier studies on supersonic vortex ring at the open end of the shock tube (Arakeri et al. 2004; Baird 1987). The outer most surface of the blast wave exhibits a shape that is similar to that obtained by Jiang et al. (2008) who carried out a numerical simulation of the muzzle blast.

At $t = 53$ μs, the flow has developed further and expansion of the gases produced due to combustion is clearly seen. The energy release is so rapid in this flow; the expansion of gases in the ambient produces an expanding blast wave which attains a spherical nature within a short duration of time (Dewey 2001). The combustion gases exiting from the tube create an under-expanded jet, with the formation of barrel shock. The under expanded jet forward expansion is terminated by the Mach disk. The presence of the Mach disk restricts the expanding gases causing it to roll up into a vortex ring which is clearer in Fig. 4b. The un-burnt explosive material undergoes combustion even after exiting from the tube and hence its contact surface is non-uniform and turbulent. A comparison is made between the flow at $t = 53$ μs and the flow field agrees well with the study of muzzle flows by Klingenberg (1977). Figure 4c, d shows that as the flow evolves, the strength of the blast wave reduces and the flow field resembles a form of muzzle blast. The results clearly demonstrate the capability of BOS in visualizing and quantifying complex density fields.

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