Visualization of discharged shock waves and vortex rings using the background oriented schlieren

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1 Introduction

Quantitative visualization methods have been spread to experimental techniques of shock wave research in laboratories. On the other hand, the methods have not spread to the techniques in open-air because of vulnerability issue of optics. Stability and solidness of optics are significantly required for qunatitative visualization or measurement accuracy degrades when vibration and displacement of the optical system are occurred during measurements. For example, in ballistic experiments in open air, disturbances must cause accuracy to degrade. They include small deformations of optics caused by ambient temperature change, and vibration and fragments produced by explosions and gun fireings. The researcher who attempts to apply quantitative visu-alization methods for the experiments in open-air must pay huge attention to avoiding vibration and displacement of the optics. Questions to be solved, for promoting the dissemination of quantitative visualization method in open-air, remain.

This report is an attempt to apply BOS to the quantitative visualization for experimental aerodynamic and ballistics research. As the first step, BOS has been applied to the density measurement of the flow field induced by diffracted shock waves and vortex rings discharged from the open end of a shock tube.

2 The background oriented schlieren method (BOS)

Recently, the background oriented schlieren (BOS), a quantitative visualization technique, has been proposed and would provide a quantitative visualization method for the experiments in open-air. Improvements in CCD technology and fast-processing-personal computers for image acquisition and analysis have resulted in an implementation of simple optical system for quantitative visualization for the experiments in open-air. In 1999, Meier[1] proposed the background oriented schlieren technique, which has the potential to determine the density field with a simple optics. BOS determines the density field of interest flows by the image analysis that detects the small displacement of background. A major advantage of this technique is that it requires only a digital still camera with adequate resolution. BOS is expected to apply to the density measurement of real life full-scale flows.

3 Experimatal method

Figure 1 shows a schematic diagram of experimental setup.

In this report, the diffracted shock waves and vortex rings were induced by shock waves discharged from an open-end of a shock tube with incident shock Mach number of 1.4. A Diaphragmless shock tube, which generates shock waves with high repeatability, was used to generate the incident shock waves. The test and the driver gas were room air and dyedair, respectively. Imaging was performed by a high-speed video camera with 16000 fps (Vision Research Phantom V7.1, maximum 160000 fps). The illumination was achieved with tow high-intensity-lamps for phtograpy (500 W). Trigger of the video camerahe was synchronized with the discharges of shock wave from the open-end of the shock tube with the pressure transducer (PG3) at 250 mm from the ope-end. For the BOS, a structured background to focus on was cre-ated by means of a normal random number generator. This generated a matrix, 6000 × 6000 in size, of random numbers whose elements were normally distributed with zero mean, unit variance and standard deviation. The images were analyzed by means of a cross-correlation algorithm developed for the purpose.

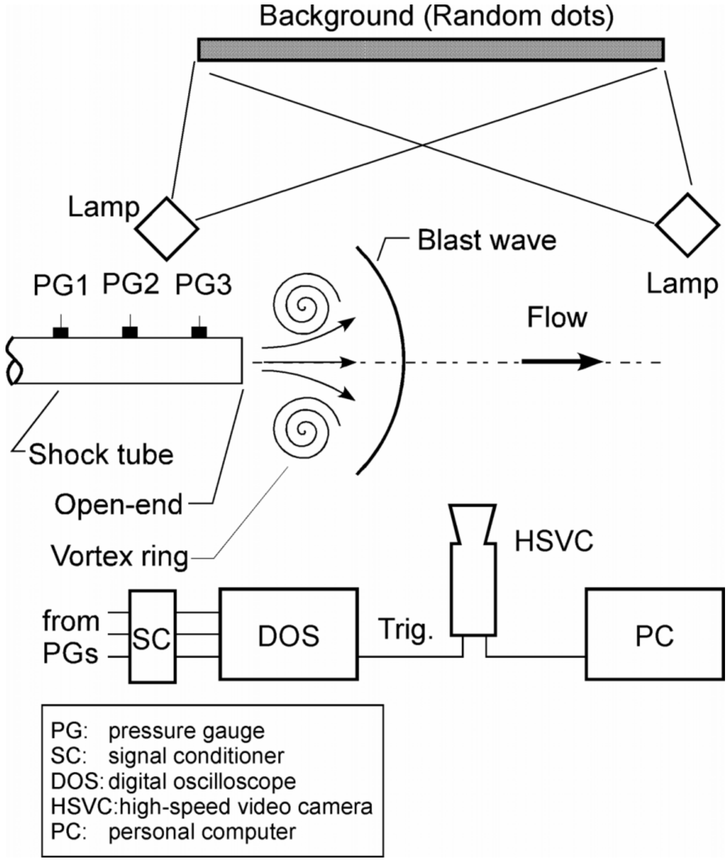


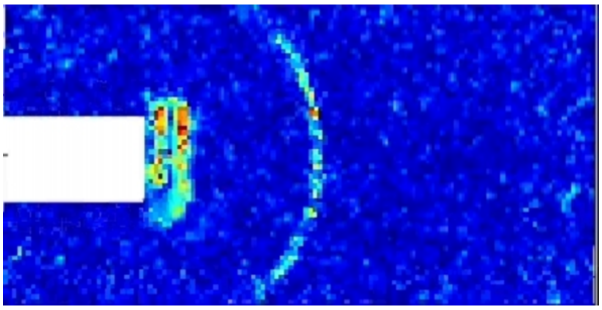
Figure 1: Experimental setup for visualization with BOS.

4 Experimental results

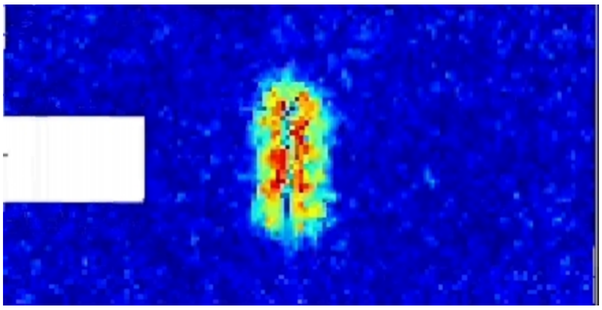
The diffracted shock waves and the vortex rings discharged from the open end of the shock tube were clearly visualized. Figure 2 shows the obtained images after the discharge of shock waves from the open-end of the shock tube.

References

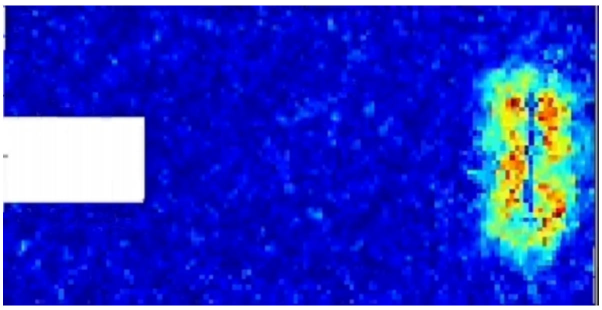
[1] Meier, G.E.A. (1999). In Proc 8^{th} Int Symp Flow Visualization, Sorrento, Italy, 1-4 Sept., Paper 226



(a) $t = 924\,\mu$s



(b) $t = 1848\,\mu$s



(c) $t = 3432\,\mu$s

Figure 2: Visualized images of diffracted shock waves and vortex rings.