Density measurements using the background oriented schlieren for shock waves and vortex ringses

T. Mizukaki
Department of Aeronautics and Astronautics, Tokai University, 1117, Kitakaname, Hiratsuka, 259-1292 Japan

Flow diagnostic tools that are non-intrusive and quantitative, as well as applicable to real life full-scale flows are required for experimental aerodynamics and ballistics research. Experiments on high-speed projectiles and explosion are performed in the open air. For research on explosives, temporal sequence of entire visualization of the propagation and injection of shock waves generated by explosions is quite helpful in evaluating the strength of explosives. For development of aircraft, entire visualization of the shock waves developing from objects suspended under wing towards fuselage is required for the development of supersonic military aircraft.

Quantitative visualization methods that have spread to experimental techniques for shock wave research in laboratories. On the other hand, the methods have not spread to the techniques in the open air because of vulnerability issue of optics. Stability and solidness of the optical system for quantitative visualization are significantly required to carry out precise measurement. Measurement accuracy degrades when vibration and displacement of the optical system are occurred during measurements. For example, in ballistic experiments in the 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 firings of guns. The researcher who attempts to apply quantitative visualization methods for the experiments in the open air must pay huge attention to avoiding vibration and displacement of the optical system. Questions to be solved, for promoting the dissemination of quantitative visualization method in the open air, remain.

The background oriented schlieren (BOS) that has been recently proposed would provide a quantitative visualization method for the experiments in the open air. Improvements in CCD technology and fast computers for image acquisition and analysis have resulted in an implementation of simple optical system for quantitative visualization for the experiments in the open air. In 1999, Meier proposed the Background Oriented Schlieren (BOS) 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.

This paper 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. The diffracted shock waves and vortex rings were induced by the shock waves with incident shock Mach number of 1.4. A diaphramless shock tube was chosen to generate shock waves and vortex rings, which generates shock waves with high repeatability. The test and the driver gas for this experiment were room air and dyed-air, respectively. The imaging was achieved by means of a commercially available Nikon D200 digital still camera with 10.2 megapixel resolution. The illumination was achieved by means of a high-intensity-short-duration Xe flash lamp with less than 1 µs flash duration. With the shutter of the digital camera opening, the flash was synchronized with the discharges of shock wave from the open-end of the shock tube. For the BOS, a structured background to focus on was created by means of a normal random number generator. This generated a matrix, 2000 × 2000 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.

The diffracted shock waves and the vortex rings discharged from the open end of the shock tube were quantitatively detected. Figure 1 show the obtained images at 200 µs after the discharge of shock waves from the open end of the shock tube.

In the full paper, we will discuss both the visualized images and the resulting density maps of developing vortex rings and diffracted shock waves.

![Figure 1. The averaged displacement field. Left: indication by intensity. Right: indication by vectors.](image)

References