Journal of Visualization, Vol. 12, No. 4 (2009) 289-290

Short Paper

Schlieren Visualization of High-Speed Flows using a Continuous LED Light Source

Estruch, D.*, Lawson, N. J.*, MacManus, D. G.*, Garry, K. P.* and Stollery, J. L.*

* Department of Aerospace Sciences, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, U.K.
E-mail: d.estruch@cranfield.ac.uk

Received 30 March 2009

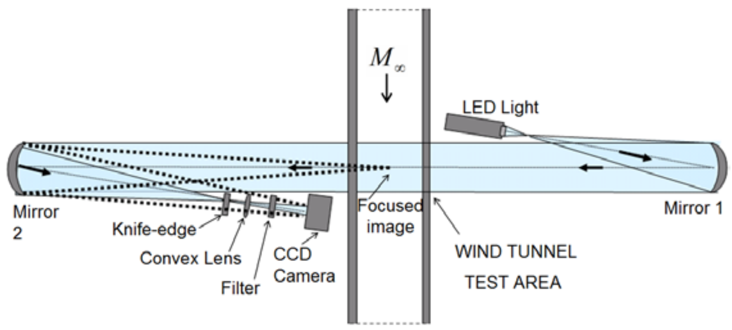
1. Introduction

The schlieren technique is widely used for visualizing compressible flows (Heinzel et al., 2007; Chashechkin and Stepanova, 2008). The light source in this technique has a strong effect on the quality of the visualizations. Common white light sources used in schlieren systems have included incandescent lamps, arc lamps and spark gaps (Smith, 1994). Laser light sources are not particularly suitable due to their coherence and given that one of the bases of this technique is the translation of phase differences into amplitudes (Settles, 2001). In large field schlieren applications, extended light sources have been generally used (Weinstein, 2000).

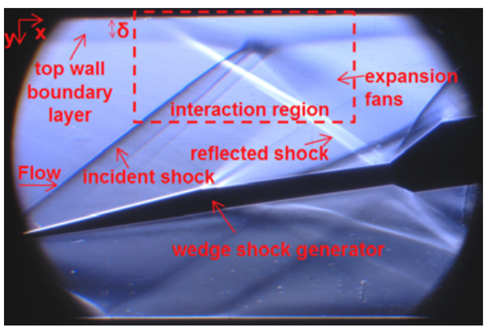
The suitability of light emitting-diodes (LEDs) for schlieren imaging in wind tunnel testing is shown in the present work. A low-cost off-the-shelf LED is used in a continuous mode to capture flow visualization images. A system is thus obtained which does not require synchronization between the light source and the capturing device. A sample visualization of a complex shock-wave/turbulent boundary-layer interaction with separation is presented. Based on these results, the use of high-power LEDs for schlieren imaging is proven to offer an inexpensive, simple but highly effective solution for high-speed wind tunnel labs.

2. Experimental rig

The present application was performed in the Cranfield University 2.5" x 2.5" Supersonic Wind Tunnel. This facility is an intermittent, blow-down wind tunnel with a test section of 2.5 inches x 2.5 inches (63.5mm x 63.5mm). The freestream Mach number (M_∞) during the tests was 2.42. The stagnation pressure in the tunnel settling chamber was 99.7kPa and atmospheric temperature was 295K. A Toepler schlieren arrangement (Settles, 2001) was used as shown in Fig. 1(a). The main items of the system included the LED light source (NSPW510BS Nichia white LED, 9200mcd, 20º viewing angle), two parabolic mirrors (1036mm focal length, 101.6mm diameter), a horizontal knife-edge and a digital single-lens reflex (DSLR) camera (Nikon D80) that was operated at shutter speeds of 1/1000s. The LED was fixed on a small box which facilitated the alignment of the system and it was powered by a 9-volt AC/DC supply. The flowfield visualized was that of an oblique shock wave created by a 13º-deflected shock generator and the turbulent boundary layer on the working section top wall. The Reynolds number based on the boundary layer thickness just ahead of the interaction (δ=5mm) was 2.6x10^4. A schlieren image of the test region is shown in Fig. 1(b) indicating the configuration of the shock generator and the general aspect of the flow in the working section.



(a) Diagram of schlieren optical arrangement



(b) Schlieren image of test area

Fig. 1. Experimental test case.

3. Flow visualization

Incident shock-wave/turbulent boundary-layer interactions take place in transonic, supersonic and hypersonic aerodynamic bodies when a shock wave impinges on a surface boundary layer. Interactions in which the adverse pressure gradient imposed by the incident shock is strong enough to cause the separation of the boundary layer from the surface are of special importance not only due to the resulting increase in local thermal and pressure loads but also to their unsteady nature.

A close-up view of the interaction region and the corresponding schematic representation of the flow field are shown in Fig. 2. The compression caused by the incident shock is communicated upstream through the subsonic portion of the flow resulting in compression waves that form the reflected shock upstream of the shock impingement locus. The reflected shock therefore intersects with the incident shock. An expansion fan appears at the location where the incident shock reaches the boundary layer to maintain a constant pressure through it. At the point where the boundary layer is reattached to the wall a compression of the flow would also be expected which would result in the appearance of a reattachment shock. This is however not observed in the schlieren visualization given that the boundary layer reattaches further downstream.

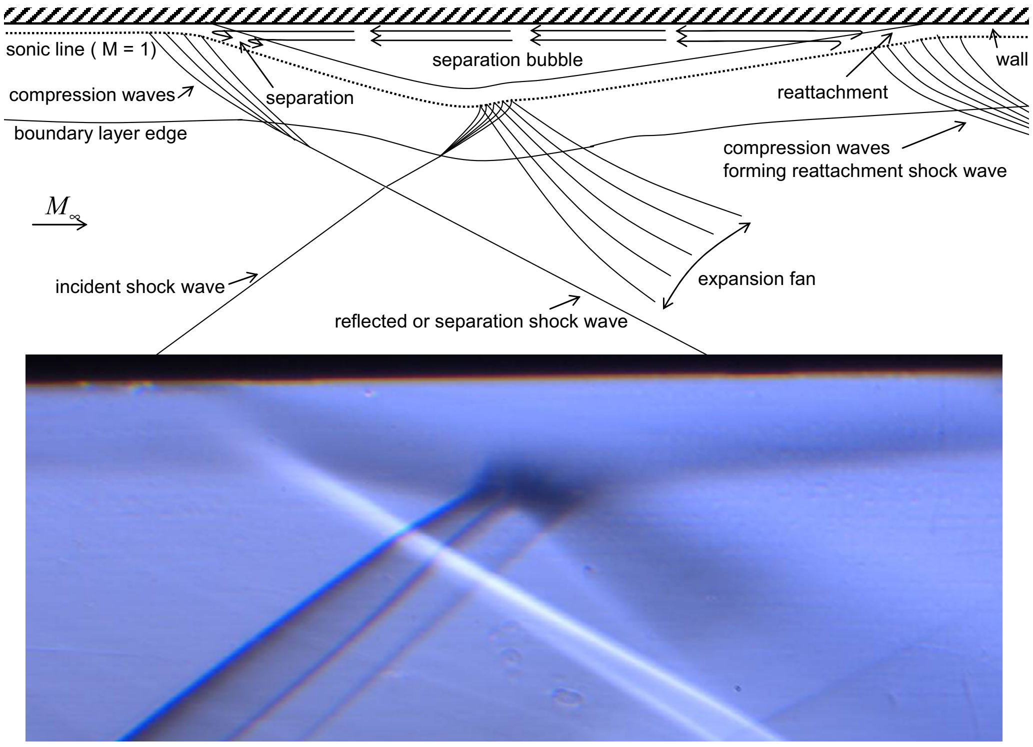


Fig. 2. Schematic representation of sample test case and corresponding schlieren image.

The use of an LED as a schlieren light source is therefore demonstrated to provide suitable visualizations of the flow under test. Important information of high-speed flows can then be obtained by using a similar system which is within the reach of most wind tunnel labs and which may even facilitate the development of high-speed schlieren arrangements (Estruch et al., 2008).

References

Chashechkin, Y. D. and Stepanova, E. V., Schlieren visualization of vortices and internal waves generated by vertical stroke oscillations of a disk, Journal of Visualization, 11(1) (2008), 6.

Estruch, D. et al. Measurement of shock wave unsteadiness using a high-speed schlieren system and digital image processing, Review of Scientific Instruments, 79(12):126108, (2008).

Heinzel, V. et al. Schlieren and "focused" shadowgraphy visualization of the shape and wake of single air bubbles freely rising in quiescent water, Journal of Visualization, 10 (1) (2007), 9.

Settles, G. S., Schlieren and Shadowgraph Techniques, (2001), Springer-Verlag Berlin Heidelberg New York, ISBN 3-540-66155-7.

Smith, L. G., Pulsed-laser schlieren visualization of hypersonic boundary-layer instability waves. In 18th AIAA Aerospace Ground Testing Conf. AIAA-94-2639, (1994).

Weinstein, L. M., Large-field schlieren visualization from Wind Tunnel to Flight, Journal of Visualization, 2 (3/4) (2000), 321-329.