Development of an optical imaging system for pressure and temperature mapping of aerodynamic flows

K. Kontis

Experimental Aerodynamics and Advanced Measurement Technology Laboratory, School of Mechanical, Aerospace & Civil Engineering, The University of Manchester, PO BOX 88, Manchester, M60 1QD, UK

Main contact email address E-mail: k.kontis@manchester.ac.uk

Introduction

The present paper describes briefly part of the research activities related to the development of a lifetime-based imaging system for simultaneous full-field mapping of surface pressures and temperatures in the context of a vortex ring interacting with a flat plate. The system has been demostrated in unsteady, fluctuating and short duration aerodynamic flows. Other related objectives of the research efforts include: a) To characterise and analyse in depth a number of existing luminophores and porous binders typically used in PSP/TSP systems and to suggest improvements; b) To synthesise fluorescent and phosphorescent metal complexes, to characterise and analyse them and then to incorporate them in suitable binders or other appropriately prepared surfaces; c) To minimize the hysteresis, attenuation and PSP/TSP matrix stretching effects on the accuracy of PSP/TSP systems.

System and Experimental Apparatus

The FLIM system uses a 12 bit cooled CCD camera in combination with either a UV or blue or green LED light source depending on the paint optimum absorption-emission characteristics with modulation frequency up to 2000 KHz. A dual processor, 2GB memory PC runs an in-house developed image and data acquisition/processing software. The system has been successfully used with a number of existing and newly synthesized paints, e.g. a) Tris(diphenyl-1,10,phenanthroline) ruthenium(II) chloride with dichloromethane and silica gel in RTV118; and b) Tris(bipyridyl) ruthenium chloride (RuByp) in an RTV118-dichloromethane solution. The user can choose among three different acquisition modes: a) two-gated; b) three-gated; and c) four gated depending on the temperature stability during the specific measurements, degree of accuracy required, and level of unsteadiness.

The study has been conducted to investigate the flow field induced by the high speed vortex ring approaching and impinging onto a solid wall located 0.05, 0.1 and 0.2 m from the exit of the shock tube[1]. A single diaphragm circular shock tube with a 0.03 m internal tube diameter was used. The working medium was dry air and shock wave Mach number was 1.3. High-speed Schlieren photography was employed. The pressure distribution on the solid wall was monitored on 4 discreet locations using Kulite pressure transducers. Global pressure maps of the induced complex unsteady flowfield on the solid wall were obtained using the FLIM system described above with the blue-LED light source and Paint B. The paint was sprayed on an aluminium plate.

The response rate for luminescent paints is proportional to the square of the thickness[2] and traditional methods require very thin paints. The way forward was to increase the porosity by increasing the surface area to volume ratio of the binder and including micro voids[3]. This was achieved by increasing the concentration of the titanium oxide hard particles. No primer was employed. The paint thickness was approximately 20μm.

Preliminary studies indicated only very small temperature-variations, O(0.01), on the flat plate during the short running times of the shock tube. Therefore, the FLIM system run in the two-gated acquisition mode with the temperature input into the software, which solved the lifetime equations by using a priori calibration information.

Both steady and fluctuating calibrations have been performed. In the steady calibration, the paint was interrogated at 40 KHz over different time periods corresponding to 5000 and 50000 pulses inside a pressure & temperature controlled chamber. The integration ratio was then recorded over an interval of a second. In the fluctuating calibration, the paint was calibrated using an air jet, which chopped over a range of well-determined frequencies. Wheels with different number of slots/holes, ranging from 1 to 100 were turned by an electric motor creating unsteady pressure pulses between 0.5 KHz and 16 KHz.

The application of the FLIM technique to map the pressure field on the flat plate was a painstaking procedure due to the extremely small duration of the flow and unsteadiness of the induced flowfield. Two pressure transducers located along the driven section of the shock tube were used to trigger via a pulse/delay generator the light source and then the CCD camera. Simultaneous capturing of the flow field and measurement of the pressure levels at discreet locations on the flat plate accompanied the acquisition of the gated images. That unique set of discreet pressures together with the acquired schlieren image were utilised to check against the consistency of acquired gated images during the pre-set integration time.

Experimental Results

The characteristic wall-pressure signatures were analysed and related to specific flow features, i.e. an induced wall boundary layer, a wall vortex and a series of shocklets. The analysis of the schlieren images also revealed that during the passage of the reflected shock wave from the solid over the vortex ring, the part of the wave propagating through the inside of the ring-vortex was intensified spontaneously

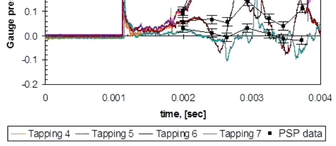

Figure 1. Pressure distributions/PSP data, 0.2 m from shock tube exit.

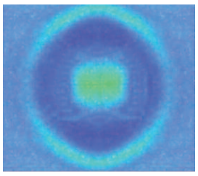

Figure 2. Global pressure map.

at a localized region. The unsteady nature of the flow is depicted in Fig. 1. The global pressure maps revealed at least qualitatively the nature and evolution of the induced flow field, Fig. 2. The results are in close agreement with the pressure transducer data. The study indicated the urgent need for fast acting "bright" smart coatings and further improvements in image acquisition technology.

References

1. K. Kontis, M. Kainuma and K. Takayama, *Shock Wave Journal* (under review) and in the proceedings of the 25th International Symposium on Shock Waves – ISSW25 in Bangalore, India as paper no. 1032, July 2005
2. Borovy *et al., Pressure sensitive paint application in shock wind tunnel,* ICIASF Record, 1995, pp 34.1-34.4
3. Ponomarev *et al., Fast responding pressure sensitive paints based on high concentration of hard particles in polymer,* 6th Annual pressure sensitive workshop, 6-8, October, 1998, Boeing, Seattle, WA

Acknowledgements

I would like to thank EPSRC, my students, colleagues and co-investigators for making this research possible.