UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING AND APPLIED SCIENCE

SCHOOL OF ENGINEERING SCIENCES

Doctor of Philosophy

OPTICAL SURFACE PRESSURE MEASUREMENT USING PRESSURE SENSITIVE PAINT

by James Wright Holmes

The thesis details the development of a surface pressure measurement system that can be applied to aerodynamic surfaces with minimum disruption. The aim was to provide a comprehensive surface pressure distribution with a high spatial resolution to allow the fine structure of the distribution to be visualised. The most suitable method was found to be optical pressure measurement using pressure sensitive paint. A paint, the luminescence of which is dependent on air pressure, is applied to the surface of a model and the pressure distribution is obtained from the image produced. The method relies upon the ability of oxygen to quench the luminescence and assumes there is a uniform and stable oxygen concentration in the airflow. The technique was developed to improve stability and correct for model displacement under load through the advance of paint formulations and imaging techniques.

The technique of Fluorescent Lifetime Imaging (FLIM), as developed in this research has been analysed and implemented for optical pressure measurement. FLIM illuminates the paint with a modulated light source and captures the image with a modulated detector. Unlike other radiometry techniques this developed technique is not sensitive to surface displacement under load, unstable light sources nor unstable paints as both the images required to correct for illumination variation are acquired together. The pressure accuracy of the developed technique is ±3 kPa, measured in the wind tunnel and is limited primarily by thermal effects. The spatial resolution has a theoretical limit of 5 times the paint thickness and the present technique has observed 1 mm features on aerodynamic structures. The spatial accuracy is dependent on the optical system and was not tested but is reputed to be 0.5% full-scale using image resection algorithms.

During the course of this research several paint formulations based on chelated ruthenium in silicon rubber were formulated and characterised by the author. The paint has been calibrated between 0.1 and 2.5 bar. The paint's physical range has been tested between 0.1 and 3.5 bar, although the upper limit is likely to be significantly greater. The paint has a luminescent-intensity thermal sensitivity of 1.1% reading K^{-1}. The paint has negligible photo-degradation when excited using blue light emitting diodes but is degraded by UV light with a wavelength < 400 nm. The paint, when applied to a surface, is typically 20 µm thick with a surface roughness of 0.5 µm Ra, but the characteristics are dependent on the application technique. The paint acts as a low pass filter to pressure changes with a time constant that is proportional to the rate of oxygen diffusion and thickness of paint. A stabilisation time of 1 s is recommended for steady state measurements. The frequency response has not been tested, as an exposure time of around 4s is required when making measurements at a distance of 1.5 m from the surface.

The results presented here pioneer the use of fluorescent lifetime imaging for optical pressure measurement using pressure sensitive paint. The techniques developed by the author have been applied successfully to supersonic and subsonic flows in industrial wind tunnels, engine nozzles and in flight. The ability to continuously display pressure-maps in real time significantly simplifies the preparation and so reduces the time taken to install an experiment using pressure sensitive paint. The apparatus being small, light weight and robust allows surface pressure measurement to be considered for an increasingly diverse range of aerodynamic applications.