Abstract

This thesis describes the development of light-based, non-interfering interrogation tools for quantitative assessment of density variations in hypersonic flows over the test models of interest in aerodynamics. Since flow around such models contains shock wave which typically has large density gradients, a plane wave illuminating the flow exits with distortion in the wave front which contains information on the flow density variations behind the shock wave. To start, a shadow casting technique is developed wherein shadows of a random dot pattern and a crossed sinusoidal grating cast by the distorted wave are captured. The recorded shadows are processed either by cross-correlation or Fourier- and windowed Fourier transform for extracting local slopes of the distorted wave front. The relative merits of using random dot pattern and crossed grating, along with the different processing techniques employed are fully discussed. It is found that continuous-tone grating has the advantage of not losing information pertaining to regions with large variations in phase, whereas sampling introduced by the dot pattern limits the maximum frequency of phase variation that can be recovered. The computed distributions of slopes are further processed to recover smooth wave front. In addition to this, phase of the exiting wave is also recovered from the measured axial transport of intensity with the help of deterministic and stochastic schemes. Using a ray-tomography algorithm the smooth wave front is inverted to recover the refractive index distribution in the flow, which, in turn, is converted to density distribution. This method is proven in experiments conducted in a hypersonic shock tunnel with atmospheric flow at Mach numbers 5.8 to 8.9 obstructed by a blunt cone object. The recovered shocks and their boundary layer are presented. Tomographic inversion is carried out either using the deterministic Gauss-Newton algorithm or a stochastic optimization algorithm. The results from these methods are compared with the density distribution got by solving the Naiver-Stokes equation for flow using standard CFD software. From this, it is observed that the stochastic algorithm, because it does not rely on derivatives in the usual sense and accounts for noise in a probabilistic setting, always outperformed the Gauss- Newton algorithm in quantitative accuracy and noise insensitivity. To take forward this development to commercially viable flow diagnostic equipment a handheld camera is constructed which has provision for imaging distorted shadows of the mask which is part of the optics of the camera. This device is also proven through experiments in shock tunnels.