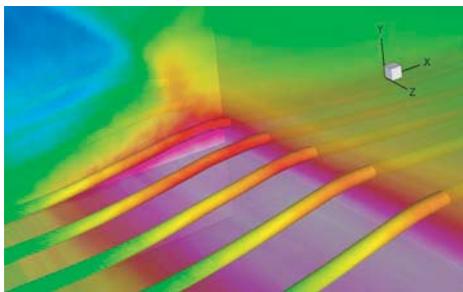


PIV measurements of a shock wave/turbulent boundary layer interaction

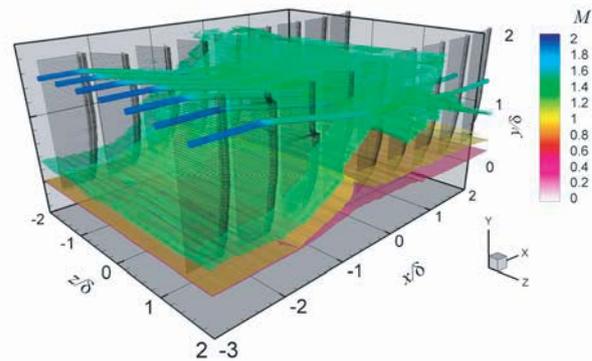
R. A. Humble¹, F. Scarano, B. W. van Oudheusden, and M. Tuinstra¹: Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands, r.a.humble@tudelft.nl**Keywords:** PIV, Shock wave, Turbulence, Boundary layer

With the continued development of high-speed long haul civil transportation systems, as well as other high-speed manoeuvring vehicles, attention remains focussed upon the problems of predicting the characteristics of shock wave/turbulent boundary layer interactions in high-speed flight. Numerous efforts over the decades have therefore sought to gain a better understanding of the complex behaviour of the shock wave/turbulent boundary layer phenomenon. Experimental studies generally remain frustrated however, by the limitations of the experimental techniques used, since without whole-field quantitative information a complete characterisation of the dynamical aspects of the flowfield cannot be made.

Two-component Particle Image Velocimetry (PIV) is therefore used to investigate the interaction between an incident planar shock wave and turbulent boundary layer developing on a flat plate at Mach 2.1. A particle response assessment under measurement conditions establishes that the particles follow the flow with fidelity. The mean velocity profile and deduced skin friction coefficient of the undisturbed boundary layer show good agreement with theory, whilst turbulence properties agree with other supersonic boundary layer measurements made using laser velocimetry and PIV. The effects of spanwise non-uniformities that are often present in nominally two-dimensional flows are also investigated, where it is found that although slight three-dimensional effects appear to exist within the separated flow region as shown in figure 1, they seem characteristic of the fluid dynamic processes present and not due to the side wall boundary layers.

**Fig 1** Flow organization of interaction region

The mean flow behaviour is described by the averaged streamwise and transverse velocity fields. The interaction region is characterized by the mean velocity field, which illustrates the impinging and reflected shock pattern, as well as the boundary layer distortion as shown in the Mach number iso-surfaces depicted in figure 2.

**Fig 2** Mach number iso-surfaces of interaction region

The instantaneous results reveal that the global structure of the interaction region varies considerably in time. The time that elapses between consecutive recordings (10Hz framing rate) is significantly greater than any characteristic flow time scale, which leads to a series of uncorrelated velocity snapshots. Patches of reversed-flow are frequently observed at several locations. The separated flow region experiences distortions mostly in the streamwise direction, although motion is also observed in the transverse direction. Although reversed-flow is measured instantaneously, on average no reversed-flow is observed.

Qualitatively, at least in some instances, the reflected shock wave appears to be displaced away from the wall when the size of the reversed-flow region increases, and moves towards the wall when the size of the reversed-flow region decreases, suggesting that the large-scale motion of the separation shock wave is associated with the shock's displacement due to the expansion and contraction of the separated flow region. The mean flow organization is therefore a somewhat simplified representation since it is constructed from a statistical analysis of an instantaneous flowfield that is highly fluctuating and significantly more complex.

Turbulence properties show the highest turbulence intensity in the region behind the impingement of the incident shock wave. Turbulence anisotropy is also found to be present, with the streamwise component dominating. The streamwise component however, recovers much more quickly than the transverse component within downstream development. A distinct streamwise-oriented region of relatively large Reynolds shear stress magnitude appears in the redeveloping boundary layer, persisting downstream for several boundary layer thicknesses. The recovery of the boundary layer towards its initial equilibrium conditions therefore appears to be a gradual process.