9.16 Volume PIV

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The formation and development of a turbulent spot in a laminar boundary layer flow is governed by the self-organization of generic substructures like hairpin-vortices and spanwise alternating wall bounded low- and high-speed streaks which effectively produce new turbulent flow structures out of the oncoming laminar flow reaching the spot at the rear edge. Although the main flow structures are identified and the exchange topologies in wall normal directions inside the spot are depicted roughly the principle growth mechanism of the turbulent spot itself is still not fully understood [242]. The analysis of this growing process would also help to understand the function of very similar structures for the turbulent exchange in fully developed turbulent boundary layer flows [384].

In this feasibility study the volume (tomographic) PIV technique [230] has been applied to time resolved PIV recordings in order to capture the development of the flow structures especially the rapid formation process of hairpin vortices at the rear edge of the spot in a time series of a whole volume of the boundary layer flow. This measurement method offers the unique possibility to determine the complete three-dimensional velocity gradient- tensor within the measurement volume.

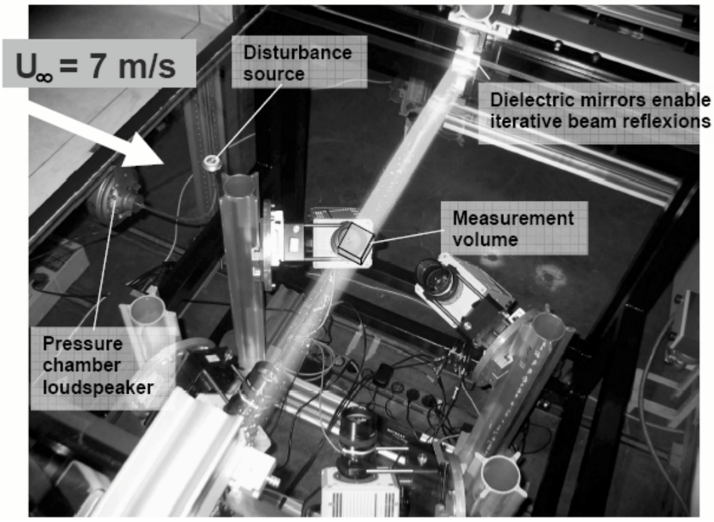

Fig. 9.81. Experimental setup at a flat plate boundary layer flow at a free stream velocity of $U = 7\,\mathrm{m/s}$ consisting of four Photron APX-RS CMOS cameras enabling time resolved tomographic PIV measurements of turbulent spots at the open test section of the 1m-wind tunnel of DLR Gttingen.

Four high speed CMOS cameras are imaging tracer particles which were illuminated in a volume inside a boundary layer flow at 5 kHz by using two high repetitive Nd:YAG pulse lasers (see figure 9.81). The instantaneously acquired single particle images of these cameras have been used for a three dimensional tomographic reconstruction of the light intensity distribution of the particle images in a volume of voxels (volume elements) virtually representing the measurement volume. Each of two subsequently acquired and reconstructed particle image distributions are cross-correlated in small interrogation volumes using iterative multi-grid schemes with volume-deformation in order to determine a time series of instantaneous 3D-3C velocity vector fields. The measurement volume with a size of $\sim 34 \times 19 \times 30\,\mathrm{mm}^3$ was located near the wall in a flat plate boundary layer flow with zero pressure gradients and downstream of a local disturbance source. At a free stream velocity of $U = 7\,\mathrm{m/s}$ a turbulent spot grows downstream inside a laminar flat plate boundary layer flow after introducing a short initial flow injection and convects through the measurement volume. The time resolved tomographic PIV method enables capturing the spatio-temporal development of the complete flow structures and in particular the rapid formation process of hairpin-like vortices at the trailing-edge of the spot (see figure 9.82).

This step to a full 3D-3C and time resolved PIV measurement technique demonstrates the applicability of optical measurement techniques as an im-

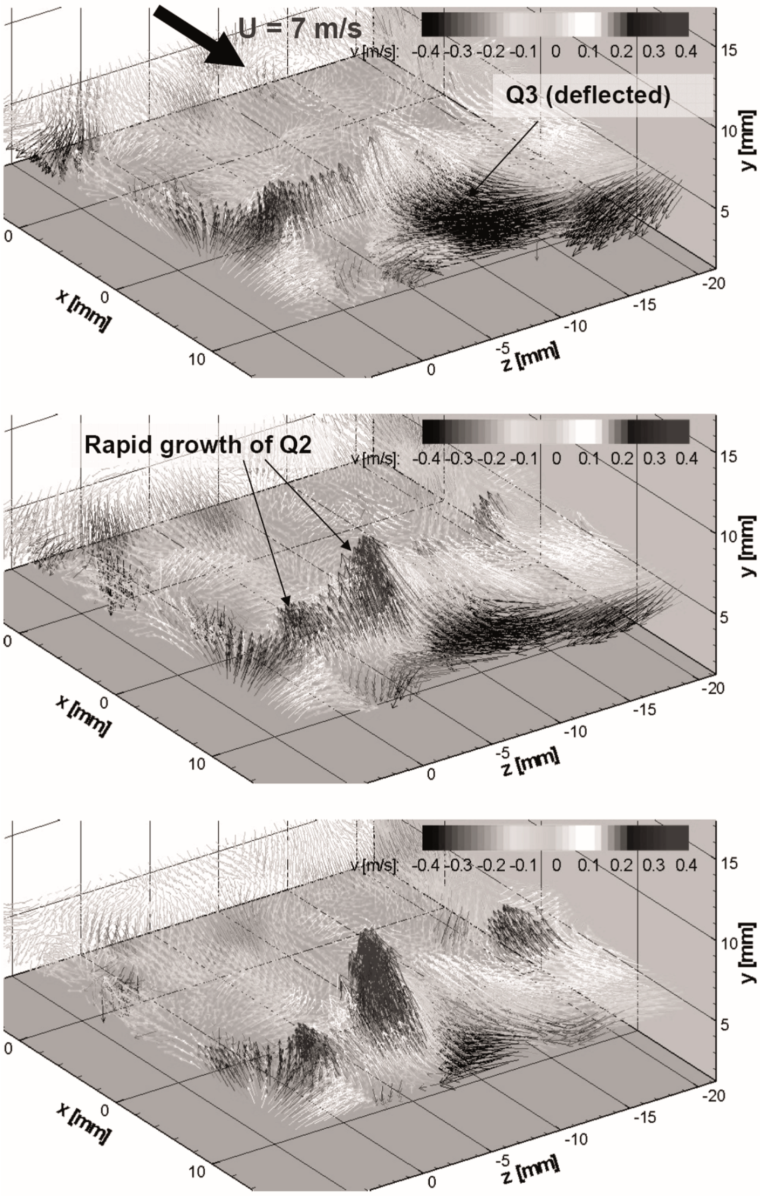

Fig. 9.82. Three instantaneous 3D-3C- velocity vector fields at y = 5.6, 6.1 and 6.6 mm of the same turbulent spot at T = 87.4 (top), 87.8 (center) and 88.2 ms (bottom) after initial disturbance showing rapid growth of Q2 events or hairpin-like vortices at the TE ($u_\infty = u - 6.6$ m/s, Vy gray scaled.).

portant tool and complementary data source to CFD for the understanding of wall bounded turbulence at high Reynolds numbers and more in general of complex and unsteady phenomena in fluid mechanics.