Investigation of vortex-generators within a turbulent boundary layer flow using time-resolved tomographic PIV

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The present paper describes the application of time-resolved tomographic PIV to a turbulent boundary layer flow influenced by vortex generators with the objective to control the flow. Flow control is a promising means to increase the performance of aerodynamic systems. Both active (e.g. suction) and passive (e.g. vortex generator vanes) devices have successfully been used in aerodynamic research as well as commercial applications. One big area of application is the suppression or at least delay of separation of the flow around airfoils at high angles of attack. As a general rule passive devices have the advantage of being cost-effective and simple to setup. Successful examples to this are vortex generator vanes. The principle of operation is based on the increase of momentum exchange from the free flow into the boundary layer. For a deeper understanding and the optimization of these mechanisms, three-dimensional measurements of the flow can provide valuable information. Instantaneous recordings of the complete volume can serve as a data basis for numerical simulations, especially if the data is also time-resolved.

In cooperation between TU Delft Aerospace Engineering and Mechanical Engineering Aerodynamics Laboratories, DLR Göttingen Institute of Aerodynamics and Flow Technology and LaVision GmbH the measurements are performed in a 60*60 cm² test section water tunnel at the TU Delft. A vertical 80*250 cm² acrylic glass plate of 2.5 cm thickness with leading elliptic edge divides the test section at 25% of its width. The flow on the observation side is tripped directly behind the leading edge and adjusted for a zero pressure gradient by a trailing flap at the end of the plate. As a result, in the free flow of approximately 0.5 m/s a turbulent boundary layer of 40 mm thickness is established at the observation position. Three pairs of triangular plates (20 mm long, up to 8 mm high) located in the turbulent boundary layer at four different distances (106 mm, 202 mm, 537 mm and 1010 mm) upstream of the measurement volume serve as vortex generators (Fig. 1). Being tilted in opposite direction by 18° from the main flow, each pair of vanes induces a counter-rotating pair of vortices. The measurement volume itself is centered at 209 cm downstream of the leading edge of the plate. It is imaged by 6 Photron CMOS high-speed cameras. Starting with the surface of the plate, the measurement volume has a thickness of 20 mm and an area of 63*68 mm². From the top of the water tunnel, passing a window on the water surface, the volume is illuminated by the expanded beam of a Quantronix Darwin-Duo Nd:YLF laser with 2*25 mJ/pulse at 1 kHz repetition rate. Light is scattered by 56 µm polylamide seeding particles submerged in the water.

Fig. 1
Vortex generator array

Vortex generator array

Fig. 2
Averaged flow field behind the Vortex generator array

Data is recorded in a time series of 2048 images at 1 kHz making a total observation time of 2 seconds. Using the MART-algorithm with 5 iterations, the light intensity distribution inside the volume is reconstructed. The subsequent PIV evaluation is done with the three-dimensional versions of the well-established multi-grid correlation and image deformation algorithms, resulting in a final interrogation window size of 32³ voxels (corresponding volume: 2.7*2.7*2.7 mm³).

The velocity vector information gained is analyzed averaged as well as instantaneously. An example image (Fig. 2) shows the time-averaged momentum exchange towards the plate being increased (blue) behind the central vortex generator pair and decreased between the vortex generator pairs (red). The counter-rotating vortices are visualized by the iso-surfaces.