

Volumetric measurement of vortical structures in the reattachment region of a laminar separation bubble using stereo scanning PIV

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In the present study the locally confined flow separation with a turbulent reattachment on the suction side of an SD7003 airfoil is investigated. The laminar boundary layer detaches due to an adverse pressure gradient. Further downstream this separated shear layer rolls up such that vortex structures evolve in the vicinity of the reattachment region (O'Meara & Mueller, 1987). The vortical structures move downstream and develop highly intricate flow patterns.

The scanning PIV technique is applied to capture the spatial and temporal evolution of the vortex dynamics at the downstream end of the separation bubble. This technique uses a moving light sheet to detect the velocity distribution within a distinct volume. The scanning light sheet is generated by 5 laser diodes that can be pulsed consecutively. To detect the three velocity components within one light sheet a stereo set-up with two CMOS high-speed cameras is used. The light-sheet thickness is approximately $\Delta s = 0.5\text{mm}$ and the distance between the light sheets is adjusted to $\Delta z = 1\text{mm}$. The images are taken at a maximum frame rate of 462 frames per second and a resolution of 1024×1024 pixels. Compared to the average velocity in the flow region of interest, the scanning speed is extremely large and allows detecting a true volumetric velocity distribution. The measurements were carried out in a Göttingen type water tunnel at Reynolds numbers in the order of 10^4 – 10^5 based on the airfoil chord of $c = 200\text{mm}$ and angles of attack ranging from 4° to 8° . To fulfill stereo PIV measurements in water, liquid filled prisms are essential (Prasad et al. 1995). We use Plexiglas prisms with a movable front plate to adjust the angle of the prisms for each investigated angle of attack. PIV post processing is done with an adaptive cross-correlation with window shifting and window deformation, leading to 42×63 vectors per plane. So, the measurement volume of $40 \times 60 \times 5\text{mm}^3$ is resolved with 13,230 vectors.

The results obtained by the stereo scanning PIV technique show the dynamic and spatial mutual interaction of the separation bubble and the vortex system emerging from this region of interest. The existence of c-shape vortices as predicted in former measurements (see Burgmann et al, 2006) is confirmed. Exemplarily, a c-shape vortex is depicted in figure 1 by instantaneous streamlines that wrap around the vortex. Beside the c-shape vortices mentioned above, secondary vortex structures appear. One of these structures is governed by entrainment of fluid from the freestream region towards the wall. The winding up of the entrained fluid at the spanwise ends of a c-shape vortex leads to the development of screwdriver vortices as shown in figure 2.

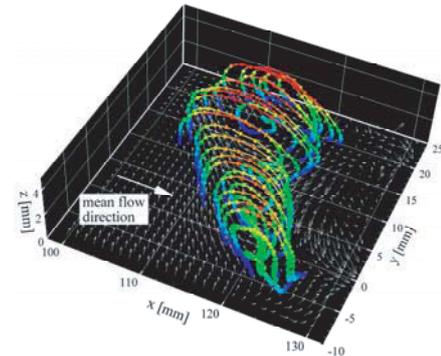


Fig. 1 c-shape vortex in the vicinity of the reattachment line ($\alpha = 6^\circ$ and $u_\infty = 0.1\text{m/s}$), color indicates z position

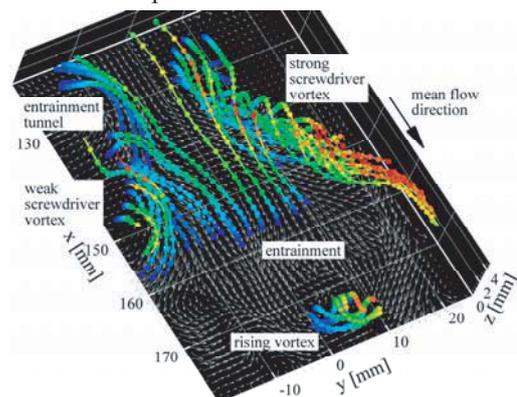


Fig. 2 Example of screwdriver vortex downstream of a c-shape vortex ($\alpha = 4^\circ$, $u_\infty = 0.1\text{m/s}$)

The aforementioned results showed the evolution of vortical structures in the reattachment zone of a laminar separation bubble. The existence of c-shape vortices, as stated in former studies, is confirmed via 3C-3D-scanning PIV measurements. Furthermore, this measurement technique allows detecting vortical structures arising from the interaction of vortices within the separated region and the freestream fluid. Distinct types of vortical structures like the c-shape vortex and the screwdriver vortex do regularly appear.

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