PIV compared to classical measurement techniques using the example of turbulent flow in the wake of an air outlet

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The objective of this study was the analysis of the main flow structures and the turbulent kinetic energy existing in the wake of an Air Outlet (AO). A flapped AO (Fig. 1) is used for internal flow systems of aircraft and basically consists of a rectangular channel with a deflection of 45° and an adjustable flap. In total three different flap angles and passive flow control devices were investigated using particle image velocimetry (PIV) and hot-wire anemometry (HWA). Measurements were made for flap angles of 21, 33 and 45 degree, whereas the flow control devices were tested only for a flap angle of 33 degree. A flap angle of 33 degree is the maximum angle in flight and was chosen for comparison of flow control devices due to the larger flow structures compared to 21 degree. As flow control device guide vanes in the bend of the AO, a dump-diffusor before the AO and a flap cover were tested. All configurations were tested with a mass flow through the rectangular channel of 0.6 kg/s. In total four different measurement planes were investigated for all tested configurations. 2C2D-PIV measurements were made in flow direction downstream of the flap at the centerline (y/d = 0) and at the edge of the flap (y/d = 0.5), whereas 3C2D-PIV measurements were made in transverse direction downstream of the flap at x/d = 2 and x/d = 2.5. In order to validate the turbulent kinetic energy derived from 2C2D- and 3C2D-PIV, HWA measurements at x/d = 2 for different z-positions were carried out to compare both techniques.

Experiments were performed in a Göttingen type wind tunnel with a test section of 0.80 m x 0.80 m (Tu = 0.2% at 53 m/s and 0-25 kHz) located at the Technische Universität Braunschweig. Free stream velocity was constantly set to Mach = 0.34 giving a Reynolds number of Re₉ = 98.10⁶. Mean velocity profiles for a flap angle of 33 degree at y/d = 0 are in good agreement for both measurement techniques. Only in two regions minor deviations are visible. An increase in interrogation window size result in an edge shape profile for 3C2D-PIV, whereas for 2C2D-PIV the profiles are visible identical. For the mean in-plane fluctuation component 2C2D-PIV shows good agreement with the HWA results for an interrogation window size of 32x32. In case of 3C2D-PIV the divergence to HWA is much more apparent for all window sizes (Fig. 2). The basic flow structures are a main shear layer, a non-uniform flow distribution between the tip of the flap and the channel long wall and recirculation zones at the edge of the outlet-wall connection and from the interaction of the first recirculation zone with the upper channel flow and the main shear layer. Moreover, a mushroom like flow structure is present in the 3C2D-PIV measurements for the configurations with no flap cover. Due to the lower pressure at the flap sides the flow on the flap shows a diverging behavior and leaves the flap under an angle. This transverse flow component together with the free flow forms a longitudinal vortex at both sides of the flap forming this kind of flow structure. The mean turbulent kinetic energy over the field of view increases with an increasing flap angle with a higher turbulent kinetic energy at the outer sides (y/d = 0.5) of the AO. It was shown that the computation of the mean fluctuation component and hence the turbulent kinetic energy from PIV data without comparison to classical measuring techniques can lead to significant errors especially for 3C2D-PIV measurements due to high frequency noise (Fig. 2). For 2C2D-PIV a study of the right interrogation window size is strongly recommended, were the right window size is always a compromise between the number of particles inside the window, the particle shift and noise from the PIV measurement chain. In future experiments measurements with no particle shift should be undertaken in order to determine the noise without any particle motions which then can be subtracted from the measurements with particle motion. This procedure covers only a part of the noise sources but should lead to more accurate results. Results for the mean velocity show a quite good agreement for all measurement techniques and are much less sensitive to the interrogation window size. Results of the turbulent kinetic energy calculated from 2C2D-PIV measurements show that a flap cover reduces the mean turbulent kinetic energy in the wake of about 20% whereas guide vanes and the dump diffuser lead to an increase of turbulent kinetic energy in the wake. The advantage of the flap cover is the massive decrease of the flap vortices resulting in a wider but smoother wake. Finally, the flow is relatively insensitive against small changes of the geometry. In order to improve the flow characteristics massive changes of the geometry are necessary or flow control devices such as flap covers or guide vanes need to be installed.