The effect of vortex generators on the flow around a circular cylinder

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The effect of circular low-profile vortex generators for rotorcraft application has been investigated on a circular cylinder at a high Reynolds number of Re₀ = 220,000. These so called Leading Edge Vortex Generators (LEV oGs) have shown significant reductions on the impact of dynamic stall on a pitching helicopter airfoil. However, the principle of operation of such devices remained unclear. In order to understand the aerodynamic phenomena, a wide range of experimental techniques such as oil flow visualization, infrared thermography, surface pressure measurements and stereo particle image velocimetry were employed. In addition, several post-processing approaches such as the proper orthogonal decomposition method were selected.

The LEV oGs were found to significantly alter the flow around the cylinder. Depending on the azimuth angle of the vortex generators, the flow conditions could be classified into three categories, each with characteristic features: Flow condition I for LEV oG azimuth angles of 2° ≤ Φ ≤ 15°, flow condition II for LEV oG azimuth angles of 15° ≤ Φ ≤ 78° and flow condition III for LEV oG azimuth angles of 78° ≤ Φ ≤ 90°.

For flow conditions I and III a characteristic unsteady grouping of vortex generator wakes was found. Figure 1 depicts a result of the infrared thermography where the bundling of the wakes is visible.

The bundles reorganize quickly and move in spanwise direction. This behavior was also found in a pervious experiment on a helicopter blade with LEV oGs at high angles of attack. The unsteady structures result in a later separation and hence a lower minimum pressure coefficient compared to the clean case. Bundling and separation delay are at this more pronounced for flow condition III.

For flow condition II (intermediate angles of incidence of the vortex generators) a rather stable flow pattern was found. Figure 2 depicts an oil flow visualization with an azimuth angle of the vortex generators of Φ = 60°. The turbulent wakes of the LEV oGs break through the laminar separation line of the flow between the vortex generators, resulting in a counter rotating pair of vortices on each side of the wake. These vortices cause turbulent reattachment of the laminar separated flow and later turbulent separation. Due to the later separation, a lower minimum pressure coefficient can be reached compared to flow condition I and III.

Figure 3 depicts the ζ-vorticity distribution of the flow at a LEV oG position of Φ = 37.5° (flow condition II). The black contour line, corresponding to the lightest blue and red tones in the present plot, depicts the same vorticity intensity of the clean case.

It was found that at all vortex generator positions the region of the same vorticity elongates compared to the clean case. However, while the shear layers moves closer to the wake center for flow condition II as in figure 3, the opposite is the case for flow condition I and III.

Employing the snapshot Proper Orthogonal Decomposition (POD) method, the vector fields were decomposed in a periodic and a random contribution to the total flow energy. It was found that the vortex generators reduced the periodic Reynolds stress components v'v'U∞² and u'v'U∞² for all three cases. For the cases where bundling was present, the size and peak values of the periodic u'v'U∞² component was increased significantly compared to the clean case. This means that the vortex generators almost only influence the periodic motion of the flow under these conditions.

Even though the principle of operation couldn’t be entirely cleared, the present study sheds some light onto the various mechanisms in the flow around such devices.