Control of separation and of wake vortex shedding

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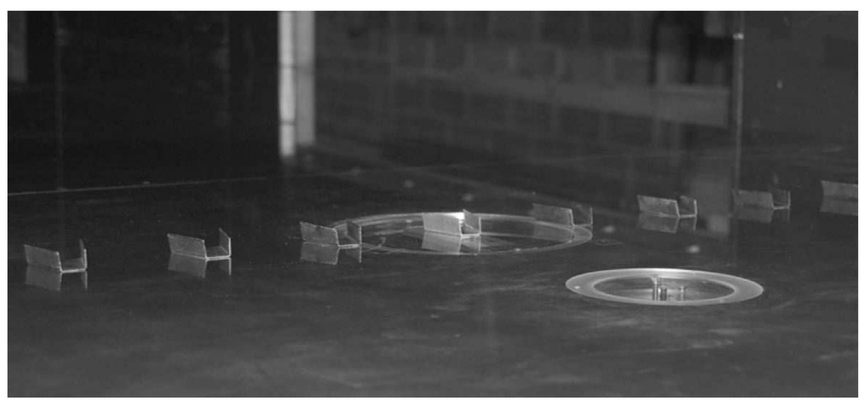
Introduction

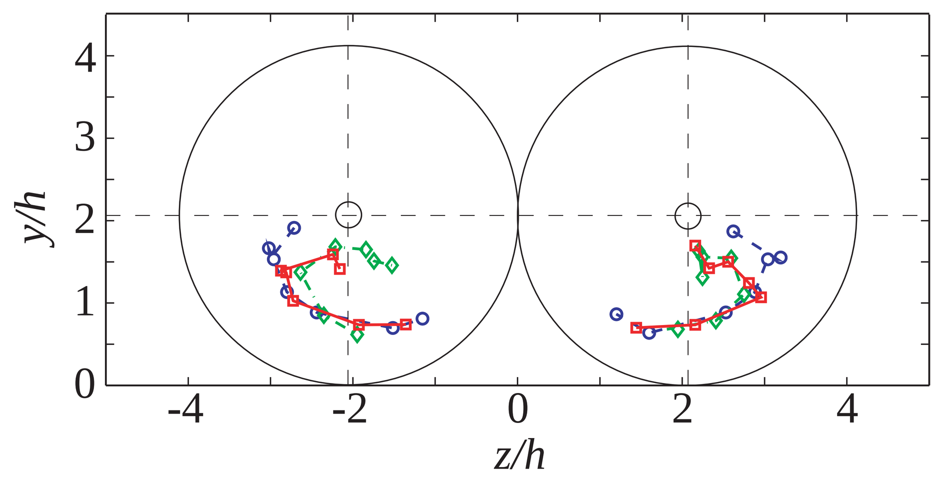
The operational envelope in aeronautical and other engineering designs is in many cases limited by turbulent boundary layer separation. The possibility of controlling and delaying the separation enables more efficient designs that can be used for improving the performance or for optimizing the design in order to reduce drag and weight.
The three projects presented here all deal with flow control. Two of them study vortex arrays applied to delay separation; first experimentally and then numerically. The third project uses blowing and suction to control the wake flow of a cylinder.

Vortex generators and turbulent layer separation control

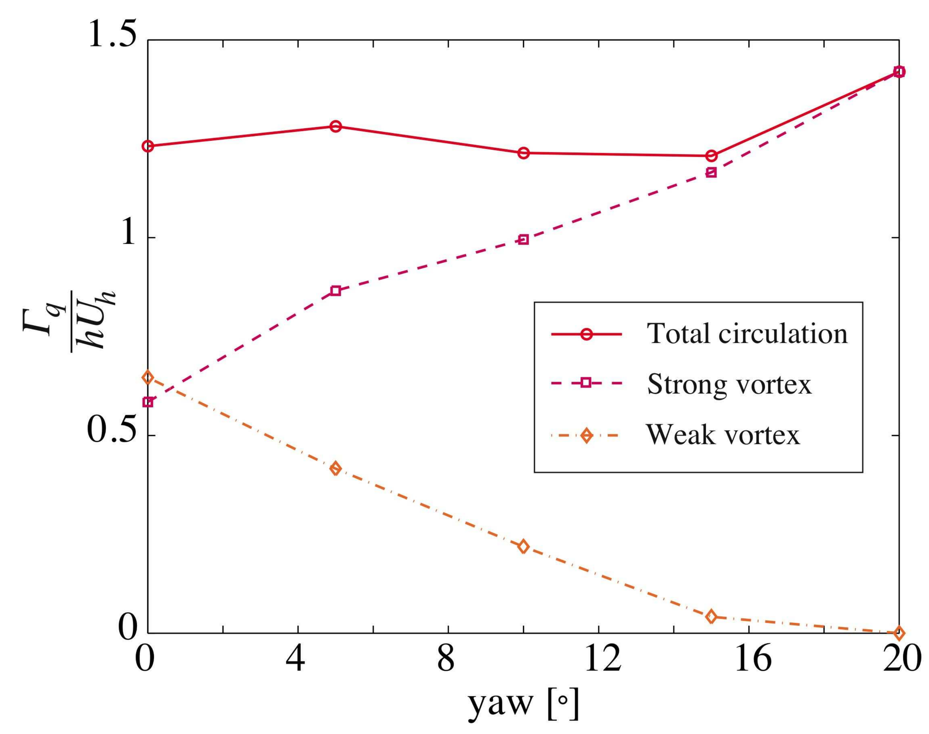
Ola Lögdberg



An efficient way to stop or postpone separation is to generate an array of longitudinal vortices submerged in the boundary layer. The vortices transport high momentum fluid down to the wall and thus energise the near wall region and makes it better able to withstand a adverse pressure gradient. One of the simplest ways to produce the vortices is to put angled vanes on the wall, as shown in the picture above. In this experiment 15° vortex generators, producing counter-rotating pairs, were studied both in zero pressure gradient (ZPG) and in different adverse pressure gradients (APGs).



In the ZPG case it was shown that the vortex centre paths collapse when they are scaled with the vortex generator height. In the figure above the centre paths of the vortices produced by vortex generators with vane heights of 6, 10 and 18 mm, respectively, are plotted. The small circles in the figure show the position of the vortex centers if the vortices of the array are assumed to tend towards an equidistant state as they develop downstream. There seem to be a tendency of the measured centre to move towards the predicted positions.

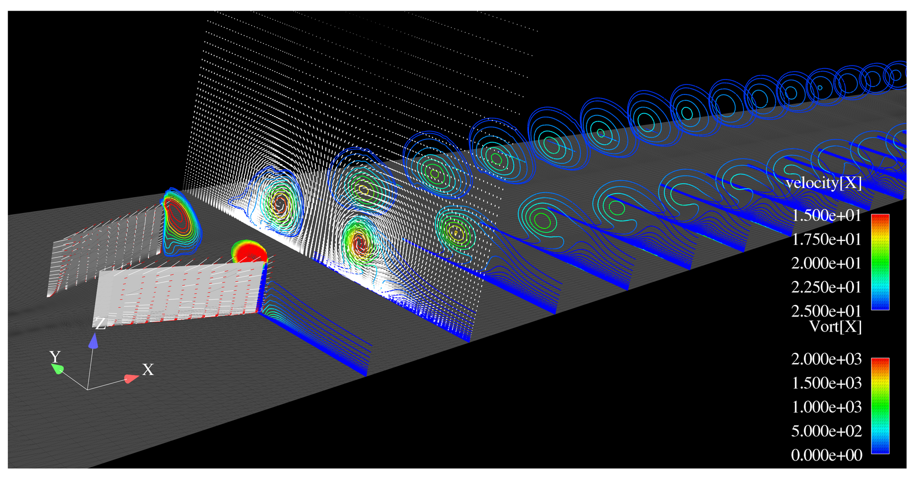


If vortex generators are applied on a ground vehicle they will operate in a yawed condition most of the time. Therefore the generated circulation was measured at yaw angles up to 20°. In the figure above the circulation of the two vortices produced by one vortex generator device is plotted, both separately and summated. Note that the total circulation is constant up to 15° yaw. This makes a flow control system based on vortex generators very robust.

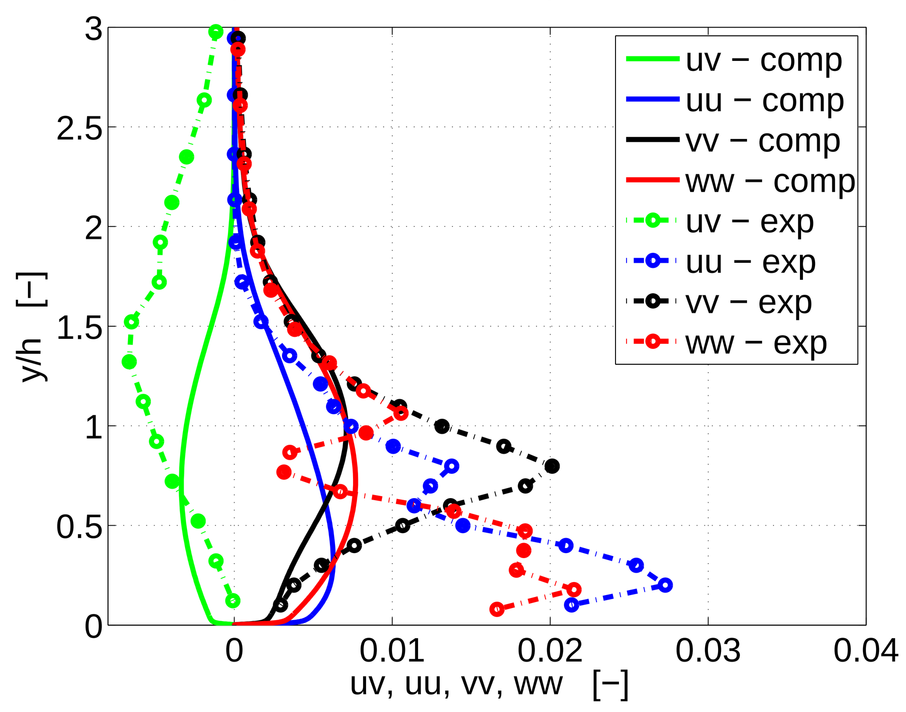
Statistical modelling of the influence of flow separation control devices

Florian von Stillfried

Turbulent boundary layers can be energized by introducing vortices by vortex generators and experimental studies as well as computations have shown the ability of controlling separation with such devices.
The computation of the flow field including vortex generators is, for most engineering cases, computationally very expensive. Therefore, more efficient approximative methods are needed. The objective with this project is to further develop and calibrate the method by Törnblom and Johansson [1] for including the generated vortices into the RANS modelling.



In particular, numerical investigations of the experiments by Ola Lögdberg are currently carried out using a 1D boundary layer solver and the CFD code Edge, see figure above. The vortex generator model induces counter-rotating Lamb-Oseen vortices that detach from the top of the trailing edge of each blade.
The circulation distribution around the vanes is estimated by use of the lifting line theory and applied for computing the vortex strength of the shedding vortices.

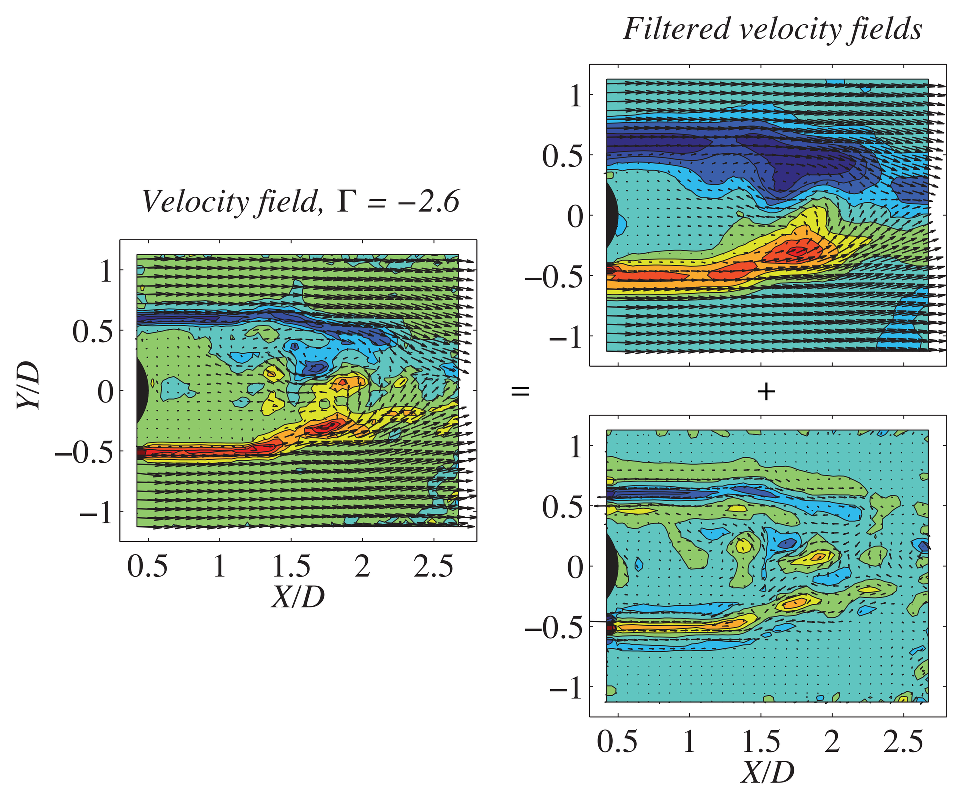


The figure above shows experimental and computed normalised total stresses $\overline{u_i u_j}$ (vortex + turbulence) at 3.3 blade heights downstream from the trailing edge plane, being the first experimental data plane. It seems that the changes in computed total stresses take place further upstream than for the experiments. As can be observed, the $\overline{uu}$ component - which is not modelled in the vortex model but computed downstream - has a non-negligible impact on results and should be taken into account for future modelling of vortex generators.

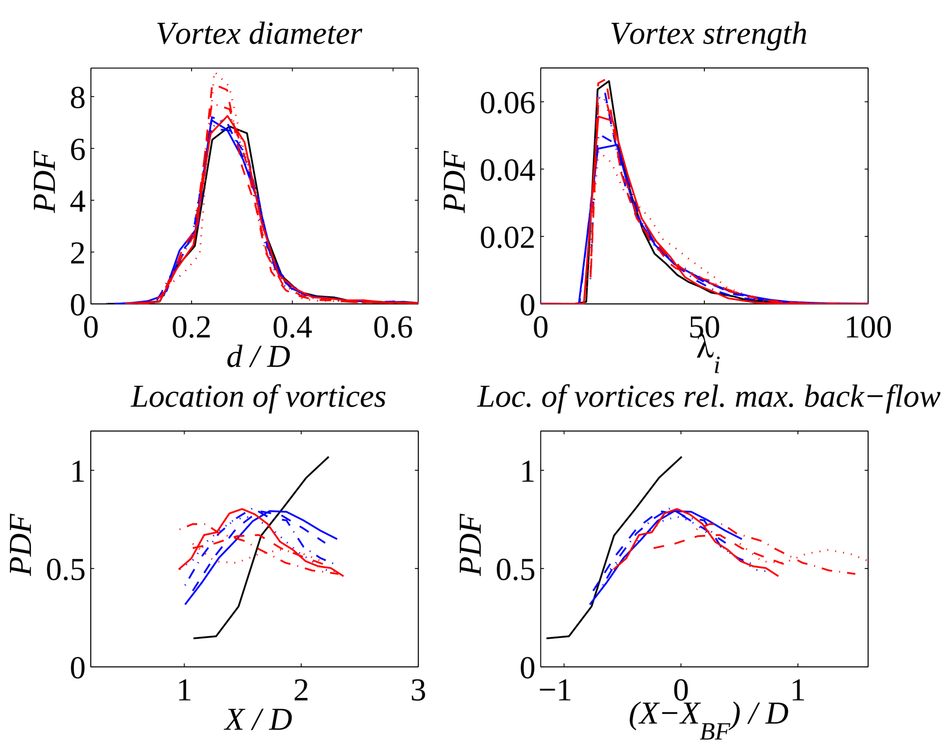
Identifying vortices in the wake behind a bluff body

Bengt Fallenius

To enhance the understanding of the wake flow behind bluff bodies wind tunnel experiments on a porous cylinder have been performed. Varying the parameter $\Gamma = V/U_\infty \times 100$, where V is the flow velocity through the cylinder surface and U_∞ is the free stream velocity, results in a change in size and length of the wake. This is also equivalent to a change in Reynolds number, Re (a positive and a negative increase in gamma may be correlated to a decrease and an increase of Re, respectively)
Instantaneous flow fields have been studied by using Particle Image Velocimetry (PIV) and by decomposing them into low- and high-pass filtered flow fields [2] the small structures hidden in the larger ones are exposed.
The figure below shows a decomposition of an instantaneous flow field for the case with a suction velocity of 2.6% of the free stream velocity. The contours show positive and negative vorticity as red and blue, respectively.



Small-scale vortices are identified by examining the areas in the high-pass filtered field where the local (2D) velocity gradient tensor has positive complex eigenvalues [3], implying that the streamlines have a closed circular path. Vortex size, location, strength etc. are stored, which makes a statistical examination of different quantities possible.
In the figure below the cases $\Gamma = [0 : -6.5]$ are compared with black as the natural case followed by blue and red with increasing suction. The vortex diameter, strength and streamwise location are shown, along with the position scaled by the point of maximum back-flow in the wake for each case.



The results show that the size and strength of the vortices are nearly unchanged for different levels of suction and the location where the highest probability of vortices to appear is close to the point of maximum back-flow (X_{BF}) in the wake.

Acknowledgments

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References

[1] O. Törnblom & A.V. Johansson, 2007 *A Reynolds stress closure description of separation control with vortex generators in a plane asymmetric diffuser*, Phys. Fluids

[2] R. J. Adrian, K. T. Christensen & Z.-C. Liu, 2000 *Analysis and interpretation of instantaneous turbulent velocity fields*, Exp. Fluids

[3] J. Zhou, R. J. Adrian, S Balachandar & T. M. Kendall, 1999 *Mechanisms for generating coherent packets of hairpin vortices in channel flow*, J. Fluid Mech.