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Session:

Simulation of a Three-Dimensional Wing with Laminar Separation in Large-Scale Freestream Turbulence

Eike Tangermann, Markus Klein

Universität der Bundeswehr München

Laminar separation is a phenomenon to be seen frequently in aerodynamic applications. Its prediction in CFD simulations is challenging for the turbulence modelling approach. In recent studies such simulations commonly have been performed using turbulence-resolving methods such as DNS, LES or hybrid approaches [1,2]. Due to the high computational effort of these methods most of these studies are limited to quasi two-dimensional configurations. The present work features the flow around a fully three-dimensional wing to account for three-dimensional effects like wing tip vortices and their influence on the separation phenomenon. The configuration and the flow field are shown in Figure 1 for the reference case without approaching freestream turbulence.

In many situations like during flight through the atmospheric boundary layer configurations are likely to experience turbulence in the approaching freestream flow. The presence of freestream turbulence has a significant influence since it delays the separation process. Its effect depends both on the turbulence intensity as well as on the length scale of the turbulent fluctuations. In the present work the flow with turbulence of three different integral length scales will be compared with the unperturbed case. The fluctuations feature a turbulence intensity of 10% for all cases. Their integral length scale is half, once and twice the chord length, respectively, which is relatively large compared to the zone of separated flow.

Typically, configurations from external aerodynamics feature boundaries located far away from the actual focus region, which are only coarsely resolved. It appears to be impractical to convectively transport turbulent fluctuations from the boundary to the object of interest. Instead a method based on the approach proposed by Schmid and Breuer [2] has been applied, in which synthetic turbulent fluctuations are superimposed to the unperturbed flow field just upstream of the wing by temporally varying volume forces, which are introduced in the momentum equation. For the incompressible formulation the force term also needs to be considered in the pressure correction equation to accelerate convergence.

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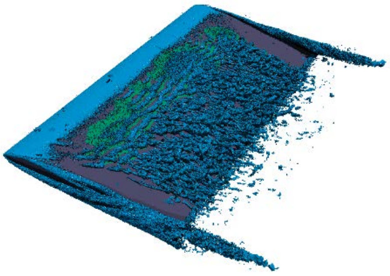

Fig. 1 Wing with separation region (green iso-surface) and iso-surfaces from Q-criterion (blue).

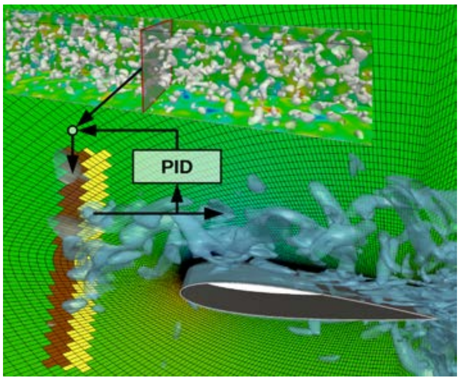

Fig. 2 Synthetic turbulence is introduced by a volume force field and adjusted within a control loop.

Since the magnitude of the resulting fluctuations depends on the width of the forcing region, a control loop has been introduced, in which the force is scaled based on the produced turbulence intensity processed by a PID control function. The method is illustrated in Figure 2.

The simulations are performed using the OpenFOAM flow solver toolbox with an incompressible formulation. The non-resolved turbulence is modelled with the Spalart-Allmaras DDES model. The computational domain comprises the wing surrounded by free-slip walls of the dimensions according to the wind tunnel setup by Herbst et al. [3]. The block-structured mesh, which, however, is treated in an unstructured way by the solver, features 10.3×10^6 hexahedral cells.

The simulations, which are currently underway, indicate a significant influence of the fluctuation length scale on the separation process. Smaller fluctuations are more likely to penetrate the boundary layer and interact with the separation than larger structures.

References

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[3] Herbst, S. L., Kähler, C. J., & Hain, R. (2017). SD7003 airfoil in large-scale free stream turbulence. In 35th AIAA Applied Aerodynamics Conference (p. 3748).