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TOWARDS A MULTI-FIDELITY APPROACH FOR CFD SIMULATIONS OF VORTEX GENERATOR ARRAYS

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The addition of flow control devices like vortex generators (VGs) to e.g. airplane wings and wind turbines has been proven to increase their performance considerably. By the introduction of streamwise vortices the high-momentum flow in the freestream is effectively mixed with the low-momentum flow near the surface, thereby preventing flow separation and hence increasing lift forces. However, due to the large difference in scale between a VG (with a height typically smaller than the boundary layer thickness) and the surface where it is applied, inclusion of VGs in accurate CFD simulations requires locally very dense meshes and therefore induces high computational costs.

To still be able to include the effects of VG arrays in flow simulations for design purpose, often the effect of the VG is modeled rather than including the VG geometry itself into the mesh. To this end several techniques have been developed which are based on the addition of a source term to the momentum and/or energy equations in order to enforce a vortex with the desired properties. This source term can take the form of a prescribed circulation [1], velocity profile [2], additional Reynolds stresses [3] or an estimate for the side force generated by the VG [4, 5, 6]. All these approaches have proven to be able to yield qualitatively accurate predictions of the flow field downstream of the VG. However, most methods require calibration by means of experimental data in order to yield quantitatively satisfying results. Without calibration flow subtilities due to viscous effects, turbulence and complex inflow conditions are not represented correct by these simplified models.

In order to bring VG modeling to the next level, such that it can be used for detailed flow predictions already during the design phase, the development of numerical tools that are computationally efficient, flexible and highly accurate is a requisite. Therefore our current research focusses on developing a multi-fidelity approach to model the VG effects with the same accuracy as for a fully gridded CFD simulation, while keeping the computational cost in the same order as for conventional VG effect modeling techniques.

To this end we started by implementing the widely applied BAY-model [4] into the open source CFD software OpenFOAM. This model calculates the lift force the VG generates based on Joukowski's theorem and applies this force as source term in those cells that would normally contain the VG. The performance of this model and the influence of the applied turbulence model is studied for external flows over a flat plate with vane type VGs for various inflow conditions.

Afterwards a model is constructed that makes use of the exact force generated by the VG for these particular flow conditions. This exact force is extracted from a (high-fidelity) fully resolved VG model that uses the same inflow profile and is included in the approximate model in a similar fashion as for the BAY-model. By comparing the results of both approximate VG models with a fully gridded solution, conclusions are drawn regarding the effectiveness of modeling VGs by the use of a lift force source term. It is observed that although the low mesh resolution related to the use of approximate VG models reduces the achievable accuracy, better estimates for the VG force can improve the results of the BAY-model significantly. Moreover, the choice of turbulence model has a large effect on the vortex evolution and can cause deviations in results of the same order as due to the body force approach.

The next part of our research will focus on the construction of a surrogate model based on a conventional low-fidelity VG model, like the BAY-model. By coupling with a fully-gridded local model we aim to build an optimal mapping function at the start of the simulation that will be automatically calibrated during runtime. This way it should be possible to enhance the accuracy of the low-fidelity model while requiring only a minimum of additional computational cost.

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