Vane-type Rectangular Vortex Generators modeled by jBAY

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Abstract: - A study of the production of vortices and their effects by vane-type vortex generators (VGs) located on a three-dimensional flat plate with negligible gradient pressure is carried out. The effects of a conventional vortex generator and a sub-boundary layer vortex generator are implemented by using a source term in the corresponding Navier-Stokes equations of momentum and energy according to the so-called jBAY Source Term Model. The influence of the vortex generator onto the computational domain flow is modeled through this source term developed by Bender, Anderson and Yale. The , the implementation of the Source Term Model represents an advantage over a fully Mesh-Resolved Vortex Generator Model for certain applications as a result of a meaningful decrease in the cell number of the computational domain which implies saving computational time and resources.

Key-Words: - Vortex generators, flow control, source term model, aerodynamics.

1 Introduction

A Vortex Generator (VG) is considered as a passive flow control device which modifies the boundary layer fluid motion bringing momentum from the outer region into the inner region. Through this transfer of energy, the velocity of the inner region is increased at the same time as the boundary layer thickness is decreased, which in turn causes the separation of the flow is delayed, Rao et al. [1]. Furthermore, Lin et al. [2] showed the Drag reducing and the Lift increasing effect of sub boundary layer VGs.

Vortex generators are applied on wind turbine blades with the major aim to delay or prevent the separation of the flow and to decrease roughness sensitivity of the blade. They are usually mounted in a spanwise array on the suction side of the blade and have the advantage that they can be added as a post-production fix to blades that do not perform as expected. So, adding VGs is a simple solution to improving the performance of a rotor, Schubauer et al. [3] and Bragg et al. [4].

In order to design a wind turbine blade, and to optimize the position of the VGs on the blade, Computational Fluid Dynamics (CFD) tools can be used. However, modelling the fully-meshed VGs on a full rotor computation becomes prohibitively expensive. Indeed, the Vortex Generators size is often similar to the boundary layer thickness and many small cells are needed in the VG geometry in order to have a reliable modelling of the flow. An alternative way of modelling VGs in CFD is to model the influence of the vortex generator on the boundary layer using body forces.

Bender et al. [5] developed a source term model based on the Joukowski lift theorem and thin airfoil theory, called the BAY Model. This model was presented for simulating vane Vortex Generators in a finite volume the Navier-Stokes code that eliminates the requirement to define the geometry in the mesh. For the calibration of the model, a test case was created by Bender et al. [5] for comparison of the results with a modelled VG and the gridded VG. This test case consisted in a pipe with 24 VGs mounted circumferentially in a co-rotating configuration. The study showed very promising results for a wide range of industrial applications.

Subsequently, a new improved version of the BAY model was developed by A. Jirásek [6], called jBAY Model. This new version was based on the lift force theory of Bender et al [5] and provided a more capable method for simulating the flow with rows of VGs. Jirásek [6] used a simplified technique for defining the model control points, so in this way it was easier to implement the model and the results were more accurate. The model was tested with a single VG on a flat plate, in an S-Duct air intake in a high-lift wing configuration. The results showed very good agreement between experimental data and CFD computations. Afterwards, an empirical model of VGs was incorporated into the Wind-US Navier-Stokes CFD code by Dudek [7] and in 2011 a simplified implementation was developed by Dudek [8] .With the implementation of the BAY model in the CFD code, the effects of the VGs using fine mesh are simulated by adding lift forces in the region of cells at the VG position. With this simplification the reduction of mesh cells can reach 30% of the fine mesh needed with a resolved VG, Wallin [9].

2 Problem Formulation

In a wind turbine, vortex generators are often used to improve the performance of the blades by minimizing the effects of the boundary-layer separation and the adverse pressure gradients. So, computational fluid dynamics (CFD) methods are used to simulate the flow and to predict the blade performance. Together with experiments in wind tunnel, it is a very useful tool for parametric studies of VG lay-out, however, these CFD methods are very time consuming in the computations and in generating a high level quality mesh, See also the work of Fernandez-Gamiz et al [10,11].

In the current work we introduce the jBAY of [6] based on the Bay Model, developed by Bender et al. [5].The main idea of the BAY Model is to replace the VG geometry by a sub-domain at the original VG location and to apply the force distribution in this region, as shown in figure 1. Previous similar studies of Fernandez-Gamiz et al. [12] have shown a promising potential tool for wind turbine applications.

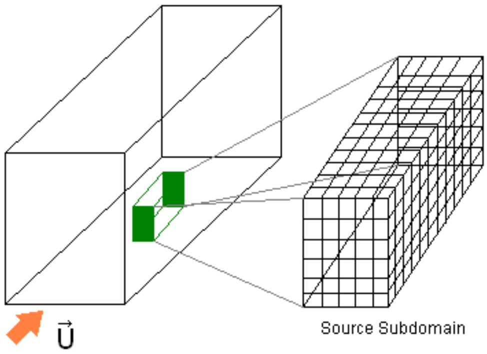

Figure 1: BAY Model source subdomain on a flat plate.

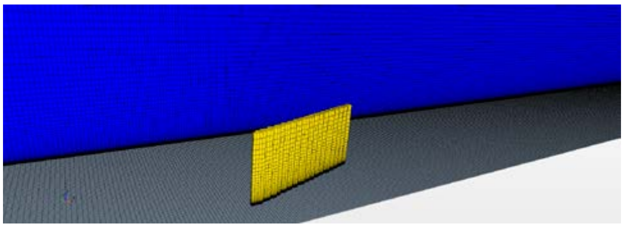
Figure 2: Vane-type Vg modelled by the jBAY.

Figure 2 shows the rectangular vane-type vortex generator modelled by the so-called jBAY source term model.

The BAY Model incorporates a source term in the momentum and/or energy equations where VGs are taken in account through the body forces exerted on a fluid.

$$Vi\frac{\Delta(\rho u)}{\Delta t}=\sum_{j}FMjSj+Li$$

$$Vi\frac{\Delta(\rho E)i}{\Delta t}=\sum_{j}FEjSj+uLi$$

The source term applies a force normal to the local flow direction, parallel to the surface which simulates the side force generated by a VG.

$$Li=c_{VG}S_{VG}\frac{V_i}{\sum V_i}\alpha\rho u^2\hat{l}$$

The variable u is the local velocity, α is the angle of the incidence of the vane, V_i is the volume of the grid cell and ΣVi is the sum of the cells where the model is applied. ρ is the local density, S_{VG} is the area of the VG and c_{VG} is an empirical constant for calibration. So, a parametric analysis was performed to determinate a reliable value of c parameter and validated with the mesh-resolved VG Model.

Figures 3a and 3b illustrates the cells (highlighted in yellow color) where the source term model has been applied in a top and side views, respectively. They has been chosen to represent a rectangular vortex generator on a flat plate.

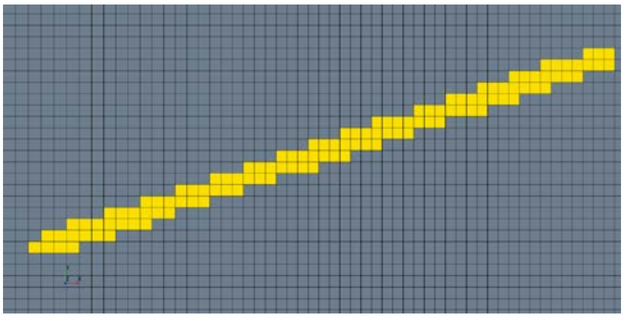

Figure 3a: Cells where the forces are applied. Top view.

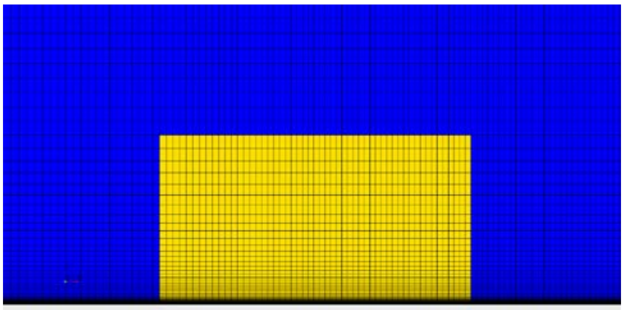

Figure 3b: Cells where the forces are applied. Side view.

3 Results

Figure 4 shows the vortex visualization based on the velocity field distribution at four planes normal to the streamwise direction and located at normalized distances x/*d* respect to the boundary layer thickness *d* from the backward-facing ramp where the domain origin is placed.

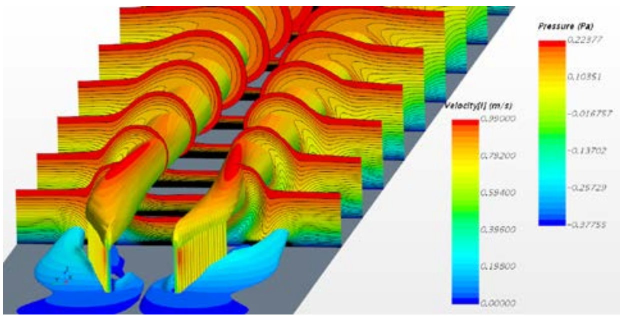

Figure 4: Velocity distribution (m/s) at planes normal to the streamwise direction

4 Conclusion

The generation of vortices and their effects by a conventional vortex generator and a sub-boundary layer vortex generator positioned on a three-dimensional flat plate with a backward-facing ramp and adverse gradient pressure has been carried out by means of CFD simulations. The influence of these vortex generators (VGs) on the computational domain flow is implemented by using a source term in the corresponding Navier-Stokes equations according to the so-called jBAY Source Term Model. Steady-state, incompressible and turbulent flow is assumed and Reynolds Average Navier-Stokes (RANS) turbulence modeling is applied in the simulations.
The Source Term Model seems to simulate relatively well the streamwise vortices along the floor of the flat plate for the two vane-type vortex generators studied of heights H1 = 80% and H2 = 20% the local boundary layer thickness *d* at the upstream edge of the ramp. The results obtained for the jBAY modeled pressure distributions are in concordance with the experiments where the influence of these VG devices is measured.

In conclusion, a new model has been implemented in the StarCCM+ CFD code and demonstrated that it saves both meshing and computational time. This method could easily be applied for complementing full rotor computation and for doing parametric study of the VG layout.

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