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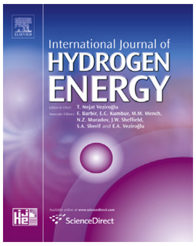

Parametric study of low-profile vortex generators

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ABSTRACT

Vortex generators (VGs) are flow control devices employed to avoid or delay flow separation. In most cases, the VG is calculated with the same height as the boundary layer (BL) thickness at the device position. However, these so-called conventional VGs may produce overload drag in some applications. The low-profile VGs can decrease the residual drag linked to this kind of passive flow control actuators. The main goal of the present work is to investigate the trajectory and size of the primary vortex produced by low-profile VGs on a flat plate with a height to length ratio of ½ and a vane incident angle of 18.5°. Hence, numerical simulations have been performed using Navier–Stokes equations at $Re = 1350$ based on the local boundary layer thickness where the VG was placed. Additionally, a prediction model has been developed to describe the progression of the vortex size behind the passive vanes.

Introduction

Wind Energy nowadays contributes to the mitigation of the climate change avoiding emissions of hundreds of tons of carbon dioxide to the atmosphere. According to the European Wind Energy Association, wind energy has around a 15% share of the total European power capacity. The growth of installed wind power, a yearly 9% in Europe for the last fifteen years, along with the growing importance of offshore wind energy shows the relevance of research in the discipline of flow control to maximize the energy output [1]. The wind related industry is generating thousands of jobs worldwide and the costs of this technology are expected to keep on declining in the coming years and onshore wind is the cheapest form of new power generation in Europe. Additionally, offshore wind will probably play a key role in Europe's power generation. Some energy researchers studied and quantified the penetration of global onshore wind energy in the next future as for instance Dai et al. [2]. In 2030, wind is expected to serve around 25% of the European electricity needs.

Nowadays, the increasingly complexity and size of the wind turbines is a widespread trend in the wind industry and a better comprehension of the aerodynamics to design efficient operational turbines is needed. The interactions of flow phenomena such as wake or atmospheric boundary layer

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effects in these new large wind turbines have to be modeled and simulated. Thus, G. España et al. [3] studied the wake behavior of a modeled wind turbine when large scale turbulent eddies are involved. Realistic simulations reproducing these flow interactions and appropriate methods of verification with will allow the design of efficient and state-of-the-art wind turbines. Technical aspects such as turbine performance, loading during extreme weather, component lifetime, noise generation or power output optimization are also key points to be analysed and further research has to be carried out. Thus, Kim et al. [4] studied the wake influence on the wind characteristics and fatigue mechanical loads in turbines. Kahla et al. [5] employed an algorithm based on particle swarm optimization in order to control the turbine's rotor side converter. Additionally, the design of control systems using the wind flow condition or algorithms to enhance the wind turbine stability are also needed. Dahbi et al. [6] developed a pitch angle control system of a variable-speed wind turbine using permanent magnet synchronous generator (PMSG) connected to the grid by means of fully controlled frequency converters to maximize the exploited wind power and to benefit from a wide range of the wind speed.

Flow separation control and the energy losses associated with the boundary layer have emerged as a key point in certain industrial fluid dynamics applications. Furthermore, the deficit of momentum in the boundary layer plays a major role in flow separation. The flow detachment from a continuous surface is governed by the adverse pressure gradient and the viscosity. If the flow must remain attached to the wall, the stream should have enough energy to overcome the adverse pressure gradient, the viscous dissipation along the flow path and the energy loss caused by the modification in momentum. This loss in energy is more prominent in the neighborhood of the surface where the momentum and energy are much less than in the most distant part of the shear layer. Therefore, if the loss is such that further advancement of the fluid is no longer possible, then the flow separates from the surface.

Vortex generators (VGs) are passive devices to control flow which are able to change the motion performance of the fluid in the boundary layer region. VGs are small vanes not aligned with the incoming flow and located neighboring the leading edge. They act by exchanging momentum from the distant flow region to the wall-closed inner region. Researchers have applied these devices in certain aerodynamics applications in the past fifty years.

In Fig. 1a and b, two pairs of rectangular and triangular vortex generators (VGs) of the most-often type used in different aerodynamics applications are shown. The customary VG height is usually similar to the local boundary layer thickness with a 1:2 height to length ratio. These devices modify the flow streamline direction creating flow vorticity. Thus, they generate downstream co-rotating or counter-rotating vortices depending on their geometrical configuration.

The installation of these vortex generators mounted on the suction side of aircraft wings or wind turbine blades may be considered a first approach to try to regulate the flow separation because they are easy to design and set-up as well as inexpensive. They can be quite easily assembled as a post-production fix to the wing or blade when the latter does not work as efficiently as expected. They are also replaceable by a simple and fast procedure and because of their small size a relatively big number of them are able to be spanwise distributed. On the other hand, active devices need an additional energy source to get the desired effect on the flow and, unlike VGs and other passive devices, active flow control needs complex algorithms to get the maximum benefit [7].

These passive flow control devices are used to augment mixing in both free-shear and wall-bounded flows by expanding the active area where the energy transport occurs, setting off possible flow instabilities, accelerating laminar to turbulent transition and intensifying the turbulence once the shear flow becomes turbulent. Vortex generators also allow the formation of auxiliary flows as a way to successfully improving blending in laminar and turbulent flows. In other cases where flow mixing is involved, like heat exchangers, turbulence generating dimpled surfaces enhance heat transfer drawing on the strengths of turbulent boundary layer properties [8].

On the other hand, VGs generate a small parasitic drag and they need a detailed understanding to be applied correctly and optimized for every flow and geometry. In the work carried by Gao et al. [9] on a 30% thick DU97-W-300 airfoil, the maximum lift coefficient was substantially increased with the insertion of passive VGs. This effect is the result from the delay or prevention of the boundary layer detachment, however, this good performance was counterbalanced by the appearance of a considerable parasitic drag.

Inflow turbulence, gusts and yaw misalignment cause dynamic stall in wind turbine blades. This process takes place with sudden increases of the angle of attack and both lift and drag coefficients rise up to values greater than the ones reached in steady state conditions. A vortex structure grows and once it's shed, the airfoil goes into deep stall state, where

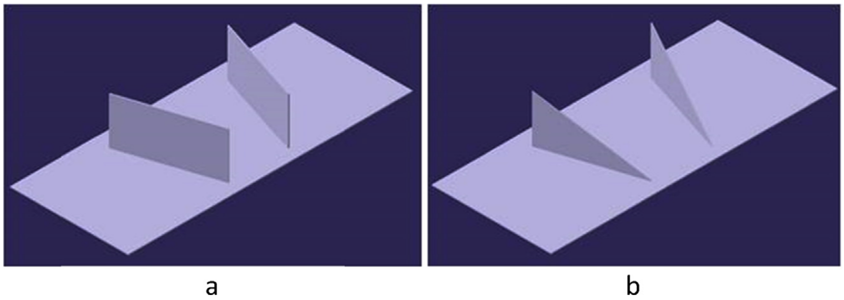

Fig. 1 – Sketch of a pair of (a) rectangular (left side) and (b) triangular (right side) counter-rotating VGs.

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