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Passive Flow Control using Three different Vortex Generators to delay Stall on a 3D Wind Turbine Blade

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SUMMARY:
With wind energy becoming a major contributor as a future energy source and industries looking to achieve net-zero, it is important to work towards innovation, which will reduce costs of generating wind energy. One way of doing this is by delaying flow separation using a passive flow control technique. This paper uses vortex generators as a passive flow control device employed to delay stall that occurs on the suction side of a wind turbine blade. NREL Phase VI wind turbine blade having an *s809* airfoil section equipped with a pair of vortex generators of three different shapes (rectangular, triangular and airfoil) is investigated using steady-state CFD simulations on an open-source CFD solver, OpenFOAM. A very small aspect ratio of the wing is used. Aerodynamic characteristics and flow visualization on a 3D wing with/without VGs are presented to show preliminary results. Comparison between different shapes of the VGs is presented.

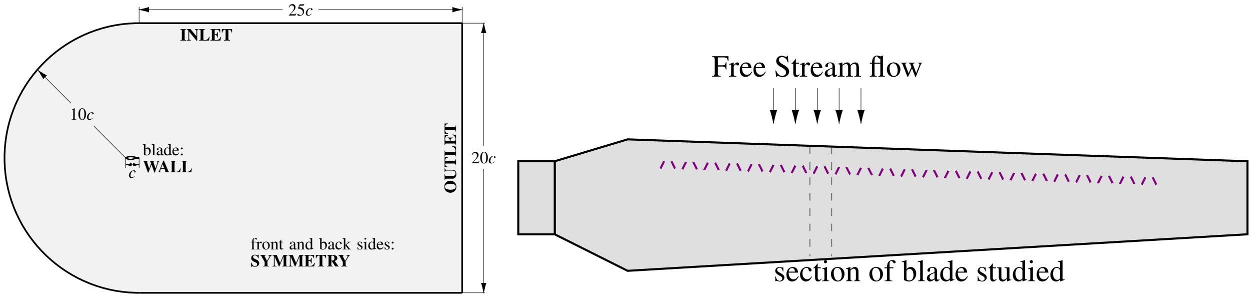
Keywords: Vortex Generators, Flow Separation, Wind Turbines.

1. INTRODUCTION

Flow separation is an undesirable phenomenon which reduces the aerodynamic performance of wind turbines blades leading to detrimental effect on their structures. Vortex Generators (VGs) are the passive flow control devices installed on the wind turbine blades to prevent the attached flow from separating. The stream-wise vortices generated when fluid passes over a VG re-energies the low-momentum region close to the surface by introducing high-energy fluid from free-stream. This mixing enhances the boundary layer by increasing its kinetic energy. Consequently, the onset of stall can be delayed which is accompanied by improvement in the aerodynamic performance and hence, the energy output. Wang et al. (2017) computationally studied application of single and double layout VGs on s809 airfoil and found that the considerable increment in CL is achieved with introduction of VGs and the emergence of stall is delayed. Double VGs controls the separation with better performance. Though enough studies signify the usage of VGs to restrain separation, the solution for overcoming the drag penalty associated with VGs are not sufficiently discussed, attempting which Hansen et al. (2016) experimentally compared aerodynamically shaped VGs based on 11.7% thick CLARK-Y airfoil with the conventional rectangular and triangular VGs on delaying flow separation. Newly shaped VGs are efficient than the ordinary ones in terms of aerodynamic characteristics and can reduce drag considerably. Wind tunnel testing was conducted for comparison between rectangular, triangular and airfoil-shaped VGs by Soto et al. (2021) on a research-level turbine model. Airfoil-VGs performance was in-between rectangular and triangular VGs. The current study involves comparison of aerodynamic performance of conventional vane-type VGs & airfoil-shaped VG and its effectiveness to retard the emergence of stall on a wind turbine blade section.

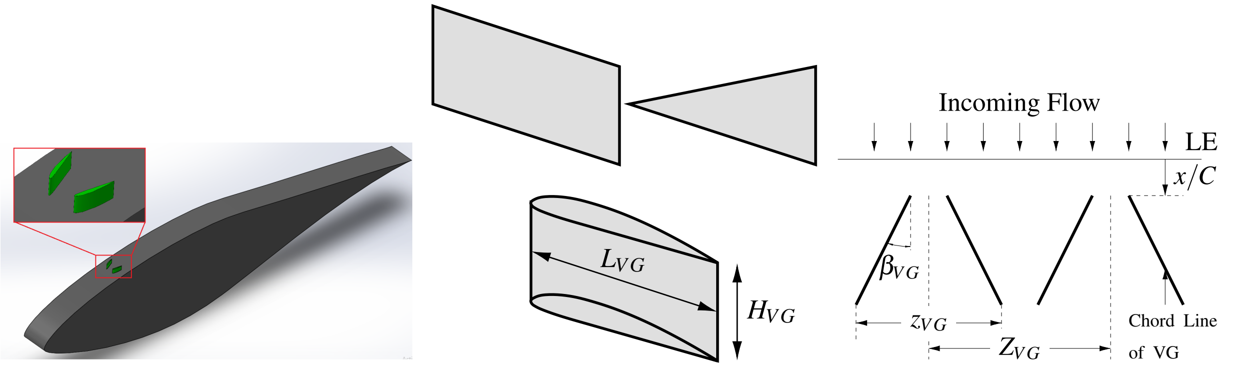
2. COMPUTATIONAL SETUP

A computational study is conducted on the wind turbine blade section having an *s809* airfoil which has a relative thickness of 21% of its chord. s809 is a wind turbine designated airfoil proposed by National Renewable Energy Laboratory (NREL) for Horizontal Axis Wind Turbine (HAWT) applications. A schematic of a full wind turbine blade having VGs on its suction side is shown in Figure 1b.



(a) Computational Domain.

(b) Schematic of a wind turbine blade to with VGs.



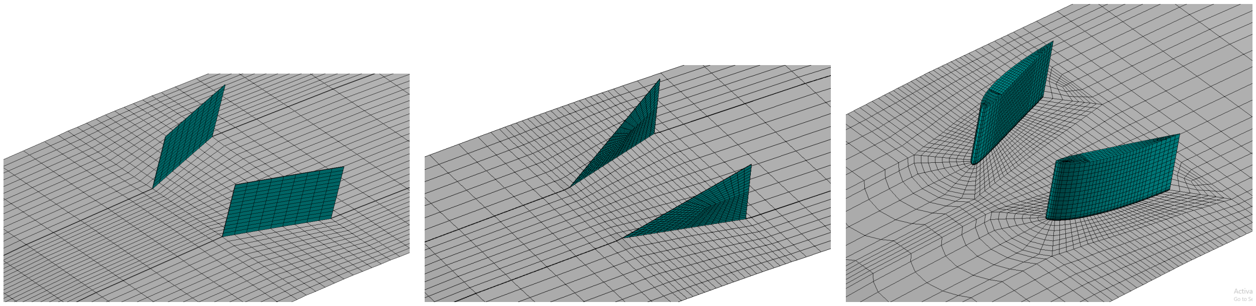
(c) CAD design of section of blade with airfoil-shaped VGs simulated.

(d) Isometric view of an three geometries investigated.

(e) Planar top view of VG pair with influencing parameters.

Figure 1. Geometric and Computational Details.

Three VG geometries studied in this work are rectangular, triangular and *ClarkY* airfoil-shaped (Méndez and Gutiérrez, 2018) which can be seen in Figure 1d. A CAD model showing the blade strip studied with airfoil-shaped VGs is presented in Figure 1c. VGs are placed at 20% of the chord from the leading edge of the blade section. VGs with height (H_{VG}) and length (L_{VG}) of 1% and 2% of chord are placed at 18° (β_{VG}) to the incoming flow. Intra-distance of a single VG pair between trailing edges (z_{VG}) is $3H_{VG}$. Geometric details of VGs can be seen in Figure 1d & 1e. The chord length and span of s809 airfoil used in the current study are 1000 *mm* and 60 *mm* respectively. The choice of span length is such that it is twice as that of intra-vane distance (z_{VG}) of a VG pair.



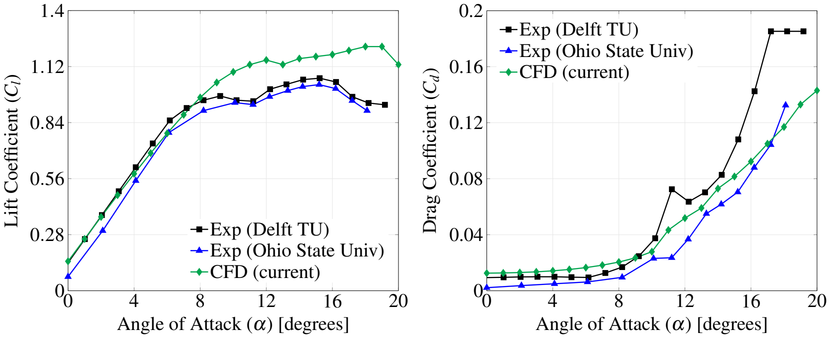
(a) Rectangular VGs **(b)** Triangular VGs **(c)** Airfoil-shaped VGs

Figure 2. Structured Mesh around 3D Vortex Generators

Computational Domain (Figure 1a) is discretized using ICEMCFD software from ANSYS. A $C-H$ type meshing procedure is used to create structured hexahedral cells. The first cell above the wing surface is kept at 10^{-5} to establish that the wall y^+ value is less than one. Body fitted fully resolved meshes are generated around the vortex generators which can be seen in Figure 2. Steady, three-dimensional incompressible RANS (Reynolds-averaged Navier-Stokes) equations with $k-\omega$ SST turbulence model (Menter, 1992) are solved using an open-source C++ based CFD solver, *OpenFOAM*. Finite Volume Method and SIMPLE algorithm are used for discretization of governing equations and velocity-pressure coupling respectively. The convergence criteria is set as 1×10^{-5}. Reynolds Number is chosen to be 1 million to compare the results with the experimental data from existing literature (Hand et al., 2001).

3. RESULTS

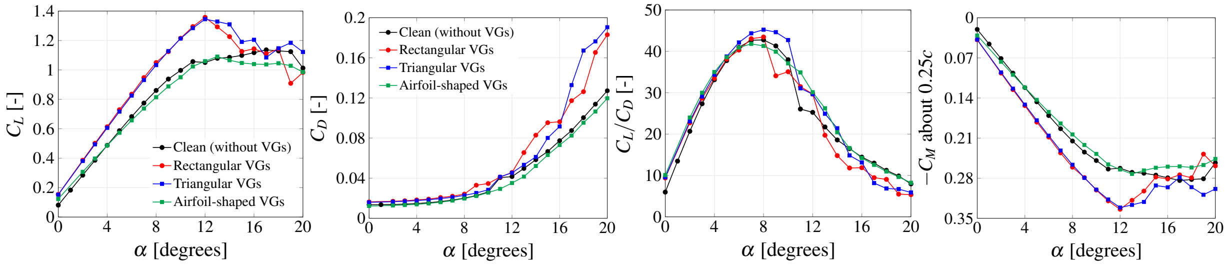
CFD simulation is run on a 2D clean airfoil without VGs and the aerodynamic characteristics obtained are compared with wind tunnel data from Delft University of Technology (DUT) and Ohio State University (OSU) (Hand et al., 2001) as shown in Figure 3.



(a) **(b)**

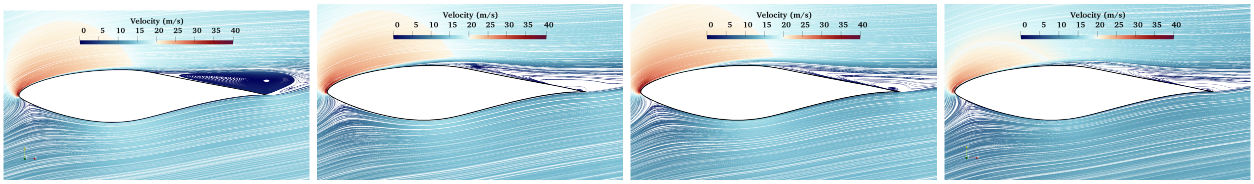
Figure 3. Aerodynamic Characteristics of 2D airfoil without Vortex Generators: (a) $C_l - \alpha$ (b) $C_d - \alpha$

Aerodynamic characteristics are now generated for a 3D wing with and without VGs as presented in Figure 4. Three different shapes of the VGs are used, which cause a difference in the aerodynamic characteristics. Flow visualization of streamline patterns for all the wings at $\alpha = 14°$ are shown in Figure 5.



(a) **(b)** **(c)** **(d)**

Figure 4. Aerodynamic Characteristics of 3D wing with Vortex Generators of different geometries: (a) $C_L - \alpha$ (b) $C_D - \alpha$ (c) $C_L/C_D - \alpha$ (d) $C_M - \alpha$ about 0.25c



(a) Clean(Without VG) **(b)** Rectangular VG **(c)** Triangular VG **(d)** Airfoil-shaped VG

Figure 5. Streamline patterns on 3D wing at $\alpha = 14°$ when clean and with VGs of different geometries

As observed, all three VG configurations delay separation quite effectively and the airfoil-shaped VG offers more resistance to the flow separation.

4. CONCLUSION

It is inferred that flow separation is delayed when the wing is equipped with vortex generators and the airfoil-shaped vortex generators yield better performance in terms of drag. Airfoil-shaped VGs effectively suppress the flow separation and stall angle is increased. Overall, VGs provide better aerodynamic performance. The following will be presented and discussed further in the final paper: (a) flow visualisation and pressure distribution (b) effect of changing the aspect ratio with additional pairs of VGs (c) the pattern of vortices formed at different downstream locations of VGs for all three VG geometries which enhances hindrance to separated flow (d) aerodynamic coefficients for remaining angles of attack.

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