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AERODYNAMIC PERFORMANCE ENHANCEMENT OF HAWT (HORIZONTAL AXIS WIND TURBINE) BLADE BY PASSIVE FLOW SEPARATION CONTROL TECHNIQUE: A REVIEW

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ABSTRACT
The purpose of this review paper is firstly to give an overview of aerodynamic performance of HAWT and description of recent developments and current status of the drag-reduction research. The wind energy is deemed as one of the most durable energetic variants of the future because the wind resources are immense. Therefore research in this field must be continuous and interdisciplinary. The objective of these investigations is to improve the wind turbines aerodynamic performance and increase their operational range by inducing complete or partial flow reattachment. Through CFD simulations for a horizontal axis wind turbine, this study is trying to analyse the flow field around the wind turbine blade. Current efforts focus on increasing their aerodynamic efficiency and operational range through passive flow control techniques.

KEYWORDS: NACA aerofoil, Drag and Lift Coefficient, Flow separation control techniques.

INTRODUCTION
A portion of my research is focused on investigating passive flow control strategies in order to provide wind turbine manufacturers with effective approaches to enable them to increase the amount of energy that can be captured by a wind turbine. In this paper we focus on exploring the way of increasing the aerodynamic performance of HAWT blade aerofoil. Several methods to achieve this goal that has been demonstrated to enhance the aerodynamics of wind turbine aerofoils. There are two important factors that need to be considered in order to evaluate the effectiveness of an aerofoil, the lift-to-drag ratio and the maximum lift coefficient. The combined action of viscous forces and an adverse pressure gradient produces a reverse of the flow next to the surface, which causes separation of the adjacent flow from the surface. The presence of the boundary layer separation has produced many problems in all areas of fluid mechanics. The most intensive investigations have been directed toward its effect on the lift and drag of airfoil. Different techniques have been developed to manipulate the boundary layer, either to increase the lift or decrease the drag. Boundary layer control includes any mechanism or process which the boundary layer of a fluid flow is behave different when the flow develops naturally along a smooth straight surface. Methods of flow control to achieve transition delay, separation postponement, lift enhancement, drag reduction etc. The scope of flow separation control on an aerofoil is to achieve more lift coefficient and less drag coefficient and consequently, aerofoil higher performance by increasing the lift to drag ratio. Control methods of boundary layer are divided into two categories: passive flow separation control, requiring no auxiliary power and no control loop, and active flow separation control, requiring energy expenditure. Numerous studies have been conducted on flow separation control techniques. Some of them listed below.

NUMERICAL STUDY OF BLOWING AND SUCTION SLOT GEOMETRY OPTIMIZATION ON NACA 0012 AIRFOIL.
By (*Kianoosh Yousefi, Reza Saleh and Peyman Zahedi)*
The effects of jet width on blowing and suction flow control were evaluated for a NACA 0012 airfoil. RANS equations were employed in conjunction with a Menter's shear stress turbulent model. Tangential and perpendicular blowing at the trailing edge and perpendicular suction at the leading edge were applied on the airfoil upper surface. The jet widths were varied from 1.5% to 4% of the chord length, and the jet velocity was 0.3 and 0.5 of the free-stream velocity.

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Results of this study demonstrated that when the blowing jet width increases, the lift-to-drag ratio rises continuously in tangential blowing and decreases quasi-linearly in perpendicular blowing. The jet widths of 3.5% and 4% of the chord length are the most effective amounts for tangential blowing, and smaller jet widths are more effective for perpendicular blowing. The lift-to-drag ratio improves when the suction jet width increases and reaches its maximum value at 2.5% of the chord length.

The effects of suction control flow on the aerodynamic characteristics of NACA 0012 aerofoil were subsequently investigated. In suction larger amplitude results in larger effect on the flow field around the airfoil, particularly at high angles of attack. Owing to the use of perpendicular suction, not only the lift-to-drag ratio increases dramatically but also the stall angle improves effectively from 14° to 22°. From a jet width perspective the suction jet width improvement leads to a significant augmentation in the lift-to-drag ratio, and separation effectively travels toward downstream. The lift-to-drag ratio increases continuously until a jet width of 2.5% of the chord length and then decreases. By employing the suction control flow technique, the lift coefficient increased by approximately 75% and the drag coefficient decreased by 56% under H = 2.5%, A = 0.5, and Lj = 0.1C from the leading edge, with an angle of attack of 18°. The most effective jet width for achieving all desirable effects is 2.5% to 3% of the chord length for suction at the airfoil leading edge.

LIFT ENHANCEMENT OF AIRFOIL AND TIP FLOW CONTROL FOR WIND TURBINE.

By *(Ya-lei BAI, Xing-yu MA, Xiao MING)*

In this paper two techniques that improve the aerodynamic performance of wind turbine airfoils are described. The airfoil S809, designed especially for wind turbine blades, and the airfoil FX60-100, having a higher lift-drag ratio, are selected to verify the flow control techniques. The flow deflector which is fixed at the leading edge is employed to control the boundary layer separation on the airfoil at a high angle of attack. For the evaluation purpose multi-island genetic algorithm is used to optimize the parameters of the flow deflector. The results shows that the flow deflector can suppress or postponed the flow separation, delay the stall, and enhance the lift. The characteristics of the blade tip vortex, the wake vortex, and the surface pressure distributions of the blades are analysed. The vortex diffuser is installed at the blade tip to control the blade tip vortex.

The results of the numerical simulation for the S809 airfoil show that the flow deflector can control the separation effectively and improve the aerodynamic characteristics of the airfoil. An optimum flow deflector is obtained by GA, which enhances the ability of the separation control. It is indicated that the lift coefficient of the airfoil with the flow deflector is increased by 24%, and the lift-drag ratio is increased by more than 50%. The stall of the airfoil is delayed by 2°, and the stall process become slow. The maximum lift coefficient of the FX60-100 airfoil with the flow deflector is increased by 5%, and the lift-drag ratio is increased by 24% at the angle of attack 18°. The stall of the airfoil is delayed by 6°.

ON THE SKIN FRICTION DRAG REDUCTION IN LARGE WIND TURBINES USING SHARP V-GROOVED RIBLETS.

By *(Leonardo P. Chamorro, Roger Arndt and Fotis Sotiropoulos)*

In this paper they focus on exploring the performance of riblets as a drag reduction strategy for wind turbine blades via a series of laboratory experiments. The experiments are being carried out in the wind tunnel and to understand the performance of riblets over a range of operating conditions and to understand the turbulent scale-to-scale interaction near the wall region. In this research, wind tunnel experiments were performed to quantify the drag reduction in a wind turbine airfoil using V-groove riblet structures. In this research, wind tunnel experiments were performed to quantify the drag reduction in a wind turbine airfoil using V-groove riblet structures. The CFD results validated with the laboratory experiments and will be used to guide the application of these flow control technologies.

NUMERICAL STUDY OF FLOW SEPARATION CONTROL OVER A NACA2415 AIRFOIL.

By *(M. Tahar Bouzaher)*

This study involves numerical simulation of the flow around a NACA2415 airfoil, with an 18° angle of attack, and flow separation control using a rod; it involves putting a cylindrical rod -upstream of the leading edge- in vertical translation movement in order to accelerate the transition of the boundary layer by interaction between the rod wake and the boundary layer. The problem is simulated using ANSYS FLUENT 13 version. The rod movement is reproduced using the dynamic mesh technique and an in-house developed UDF (User Define Function). The frequency

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varies from 75 to 450 Hz and the considered amplitudes are 2%, and 3% of the foil chord. The frequency chosen closed to the frequency of separation. The results showed a substantial modification in the flow behaviour and a maximum drag reduction of 61%.

PASSIVE FLOW CONTROL OVER NACA 0012 AEROFOIL USING VORTEX GENERATORS.

By *(U. Anand, Y.Sudhakar, R. Thileepanragu, V.T. Gopinathan, R. Rajasekar)*

Numerical simulations of turbulent flow over a NACA0012 aerofoil attached with vortex generators are carried out over a wide range of angles of attack at Re=5.5×105. The three-dimensional Reynolds average Navier-Stokes equations along with equations of Spalart-Allmaras turbulence model are solved using commercial package Ansys FLUENT.

Vortex generators are an array of small vanes attached perpendicularly over the suction surface of the wings and in turbo machine blades. Vortex generator enhances the ability of the fluid to stick with the wing surface even at large angle of attack.

Flow separation control over a NACA0012 aerofoil using vortex generators is studied by performing numerical simulations. The influence of VGs on bulk quantities of the flow (CL and CD) is reported and the flow field modifications are discussed. The Stream wise vortices produced from the VGs are of sufficient strength to delay the stalling for the angle of attack range considered in this study.

HORIZONTAL AXIS WIND TURBINE FLOW FIELD ANALYSIS AND PROSPECTS FOR PERFORMANCE ENHANCEMENT.

By *(Andreea Bobonea, Corneliu Berbente and Mihai Leonida Niculescu)*

In this study they focused on increasing their aerodynamic efficiency and operational range through active flow control with the help of blowing devices with constant or pulsed jets. By adding high-stored momentum air through slots into the boundary layer, they overcome adverse pressure gradients and postpone separation. Pulsed blowing sends short pulses rather than a continuous jet of fluid into the boundary layer and has been found to be more effective. Experimental investigations and 2D numerical simulations of active manipulation of separated flows over airfoils has been the focus of a number of investigations for many years.

The 3D numerical modelling of the viscous flow has been performed with the CFD commercial code FLUENT [11]. The flow was assumed incompressible and fully turbulent. The shear-stress transport (SST) k-ω turbulence model developed by Menter [12] was used in order to combine the advantages of the robust and accurate formulation of the Wilcox k-ω model [13] in the near-wall region with the free-stream independence of the k-ε model in the far field. The simulations have been carried out using the finite volume method of the incompressible Reynolds averaged Navier-Stokes equations (RANS).

CONCLUSION

In this study we have seen different techniques to control the flow separation over turbine airfoil using passive method.

We can see the improvement in aerodynamic performance of turbine airfoil using different control technique. It is essential to make HAWT blade efficient to capture maximum power from wind. A flow separation phenomenon is one of the important factors which affect aerodynamic performance of turbine blade seriously. So the research must be going on in that field to make wind turbine more efficient.

An evaluation of the turbine performance enhancement was made by monitoring the torque used to determine the power of the turbine, respectively the power coefficient for reference configuration and for active flow control control configuration. From Fig.9, it can be seen a significant increase (almost 7%) of the momentum coefficient with the help of active flow control, thus resulting a power coefficient of 0.43.

By inducing a velocity jet at the trailing edge, the boundary layer separation is delay or the flow is nicely attached to the profile.

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So for the future perspective different techniques can be used to increase the aerodynamic performance of wind turbine blade like slot in the blade to energies the boundary layer so the flow separation can be delayed.

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