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A study for the effect of slat installation on aerodynamic performance of S809 airfoil

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Abstract: Leading edge slat is a device that is installed upstream of the main airfoil to control the flow over the airfoil passively or actively in order to improve its aerodynamic performance. The present study aims to investigate the effect of using leading edge slat on controlling the flow separation over the airfoil and hence the overall performance of the airfoil for small HAWT. Ansys 2019 software is used to numerically simulate the flow over S809 airfoil. According to NREL, S809 airfoil is a good choice for small HAWT. The current study considers the effect of angle of attack of the leading edge as a geometrical parameter which has an obvious effect on its performance. Based on previous study by the authors, slat of chord length of 15mm, is located at +18mm distance in y direction relative to the base airfoil chord which is 185mm, is studied while varying its installation angle **β** in range of -10° to +10°. Slat angle of +5° has the best effect on the performance of the airfoil. It moves the point of flow separation forward all the way to the trailing edge of the base airfoil. As a result of improving the flow behavior, lift coefficient is increased by 40% at AoA=17.2° at the same angle relative to the condition without slat.

Keyword: Leading edge slat, Slat angle, S809 airfoil, CFD, HAWT

Nomenclature

Symbols	Description	SI units	Symbols	Description
Roman			**Abbreviations**	
A	Airfoil area	m^2	CFD	Computational Fluid Dynamics
AoA	Angle of attack	°	SST	Shear Stress Transport
C_p	Pressure coefficient	-	2D	Two Dimensional
C_l	Lift coefficient	-	3D	Three Dimensional
C_d	Drag coefficient	-	C-H	A topology of the grid used
Re	Reynolds number	-	NREL	National Renewable Energy Laboratory
U	Free stream velocity	m/s		
Greek				
ν	Kinematic viscosity	m^2/s		
ρ	Air density	kg/m^3		
β	Slat angle	°		

1. Introduction

Recently, global warming has been one of the most worrying issues that humanity has had to deal with. On the other hand, there is an urgent need to find a clean and sustainable energy source due to air pollutions and other harmful emissions as a result of fossil fuel usage. Over the last few decades, wind energy has played a significant role in the answer of finding alternate energy sources [1].

Small scale wind turbines are used widely in converting renewable energy to electrical energy. Reynolds number is the main criteria that constrains usage of small scale wind turbines [2]. Generally, for small scale wind turbines operating Reynolds number is below 500,000 at the tip of the blade. S809 airfoil is a good choice for this study at a low Reynolds number [3] [4].

Due to viscous friction and adverse pressure gradient the boundary layer of the flow separates from the airfoil surface causing a reduction in lift force acting on it and in turn lowering the aerodynamic performance of the airfoil [5]. Therefore, controlling the flow is a need in order to delay or suppress flow separation.

Flow can be controlled in an active or passive way. Active methods operate by an external power source. Many technologies are applied to control the flow actively such as synthetic jet actuators [6], dielectric barrier discharge plasma actuators [7], and active trailing edge flaps [8]. The passive flow control methods are simpler and more effective as there is no need for any external power to be activated. Different passive technologies such as Gurney flap [9] [10] and vortex generator [11] [12] were studied by many researchers.

Leading edge slat is a device that is added upstream of the base airfoil in order to control the flow. It can be used to control the flow in active or passive condition[13]. Some researchers studied the effect of active slat on delaying or cancelling the flow separation[13][14][15]. Passive flow control by slat also was investigated by other researchers and it showed a noticeable control of the flow separation, hence it shows an improvement in the aerodynamic performance of HAWT[16][17][18]. Wang et al.[19] studied the effects of three geometric parameters of the slat namely, slat angle S_β ,Slat location in x axis S_L and slat location in y axis S_H, with only three values for each. From previous review it is concluded that the geometric parameters of the slat need more consideration and therefore the purpose of the present research is to investigate how installing angle of a fixed leading edge slat could affect the flow behavior over the base airfoil. Installation angles (**β**) of (-10°, -5°, 0°, +5°, +10°) for the slat are studied.

2. Numerical Model

The flow around the airfoil S809 is assumed to be two dimensional, steady and incompressible. Mass conservation and Reynolds averaged Navier-Stokes equations are used with pressure based solver.

2.1 Turbulence Model

The shear stress transport SST k-□ turbulence model is used. That model is chosen for its suitability in simulating flow near the wall in the viscous sub-layer as it uses k-□□model in the inner region of the boundary layer and uses the k-□ model in the regions far away from the wall which is perfect to predict the flow behavior in this location [20].

2.2 Geometric Parameters

S809 airfoil is chosen for the present study because of the advantages mentioned before. Angle of leading edge slat **β**is the main parameter considered. Based on previous studies by authors [21], slat chord length of 15mm is located upstream of the base airfoil with a chord length of 185mm at its tip taking into consideration that the total chord length is the sum of both which is 200mm. Slat is located at +18mm in y axis. **Error! Reference source not found.** shows all parameters used. In the present calculations **β**varies from -10° to +10°. Positive values of **β**are measured counterclockwise.

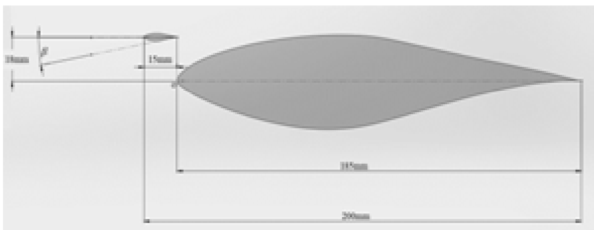

Fig 1: Parameters of the combined geometry

2.3 Computational Grid and Mesh Independence Test

C-H grid type is a common one to be used in computational study. **Error! Reference source not found.**shows the dimensions of the domain used.

In order to ensure that number of elements does not affect the results, mesh independence test is carried out for each configuration in the present study. The lift coefficient C_l is calculated for every number of elements to get the suitable number to be used at which the solution can be considered to be grid independent. **Error! Reference source not found.** is an example for configuration without slat and the suitable number of cells selected for this configuration is 69370 for less computation time with mesh independency.

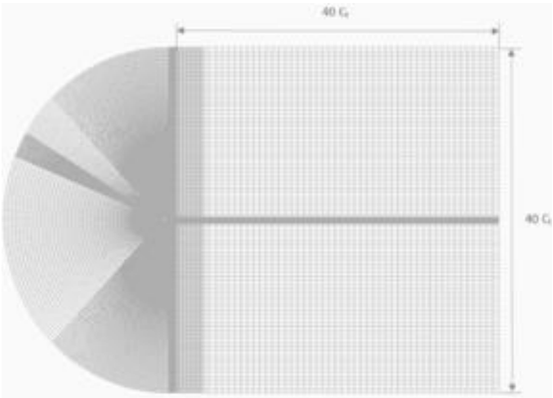

Fig 2: C-H mesh grid dimensions

Table 1: Mesh independence test of no slat configuration at AoA 14.1º.

Number of nodes	C_l	Deviation of C_l (%)	C_d	Deviation of C_d (%)
47400	0.993	-	0.0835	-
69370	0.992	-0.0877	0.0829	-0.6133
80000	0.991	-0.0049	0.0828	-0.1941

2.4 Model Verification

Lift coefficient of the present simulation for the S809 airfoil is compared with the experimental data by NREL wind tunnel data [22] at Reynolds number 3×10^5. **Error! Reference source not found.** shows a good consistency between experimental measurements and the present numerical results.

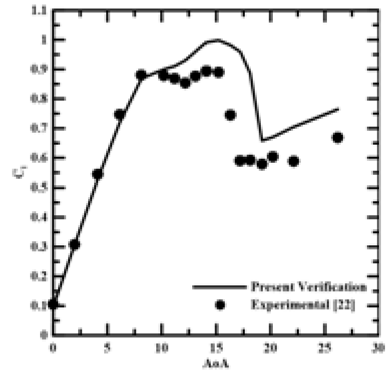

Fig 3: Lift coefficient for present numerical and NREL experimental data at Re $= 3 \times 10^5$.

3. Results and Discussion

The effect of slat angle **β** is discussed in this chapter. Slat located at angles **β= -**10°, -5°, 0°, +5° and 10° is numerically investigated and results are discussed below.

3.1 Lift and Drag Coefficients

There is an obvious effect of changing the slat angle **β**on the lift and drag coefficients of the airfoil. **Error! Reference source not found.** shows the lift and drag coefficients for the combined geometry at different slat angles **β**. Figure 4-a shows that the lift coefficient is hardly affected by the slat up to AoA=8°. For larger angles the slat causes a considerable increase of C_l for all setting angles **β**for slat. The increase of C_l continues up to AoA=26°. Figure 4-b confirms the fact that the use of the slat causes an increased drag. Positive values of **β**show a significant increase in C_d due to the increase of the area facing the flow. Negative values show less increase in drag coefficient in addition an increase in C_l.

At slat angle **β**=+5° the largest increase in lift coefficient is reached as C_l increases by 40% at AoA=17.2° relative to the main airfoil. At higher angles of attack AoA> 19.2°, the effect of using slat on the drag coefficient is decreased. The maximum increase in lift coefficient of **β**=0° is less than that of **β**=+5°, however installing the slat at **β**=0° shows a more stability in the increase of the lift coefficient than that of **β**=+5°.

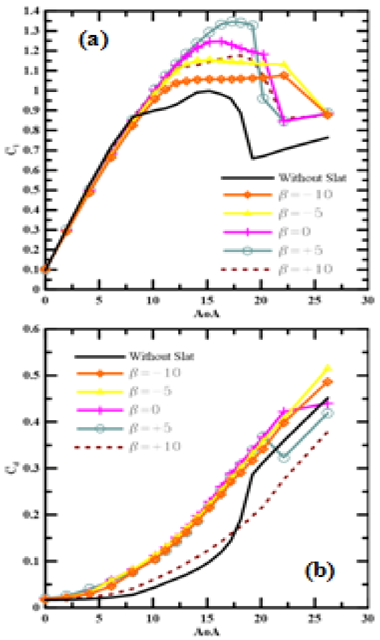

Fig 4: Effect of different β on (a) the lift and (b) drag coefficients at Re $= 3 \times 10^5$

3.2 Stream Lines and Velocity Contours

Error! Reference source not found.-7 show the effect of using slat at different angles **β** for AoA $= 14.1^0, 19.2^0$ and 26.2^0 respectively. Setting **β**at a negative value causes the flow to be attached to the upper surface of the base airfoil by injecting the air with a high momentum through the area between slat and the base airfoil. This moves the point of flow separation downward, hence improves the aerodynamic performance of the airfoil. At positive **β**the area between the slat and the base airfoil is increased which leads to a decrease in velocity of the jet injected from it to the suction side of the airfoil. As shown in Figures 5, 6 and 7 the point of flow separation is moved away from the upper surface compared to no slat configuration up to AoA $= 19.2^0$ except at **β**=+10°. It is noticed that the more increase in positive values of **β**, the more increase in the gap between the trailing edge of the slat and the leading edge of the base airfoil forming a diffuser shape in the path of the flow leading to reattach of the point of flow separation to the upper surface of the main airfoil. The sharp drop of C_l for setting angle **β**=+5° at AoA=26.2° as compared to the case of **β**=0° can be explained by the streamlines shown in Figure 7. The separation point is pushed further downstream at **β**=0° than at **β**=+5° for such high AoA.

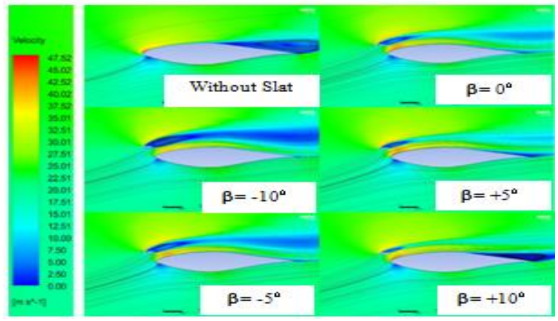

Fig 5: Streamlines and velocity contours for different **β** at Re $= 3 \times 10^5$ at AoA=14.1^0

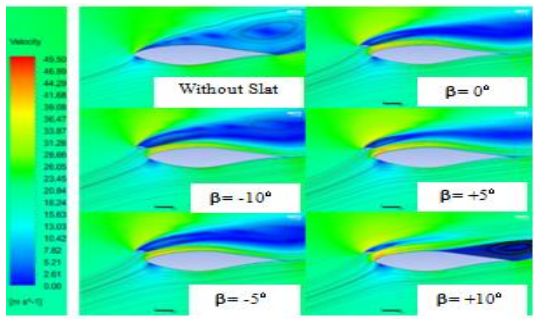

Fig 6: Streamlines and velocity contours for different **β** at Re $= 3 \times 10^5$ at AoA=19.2^0

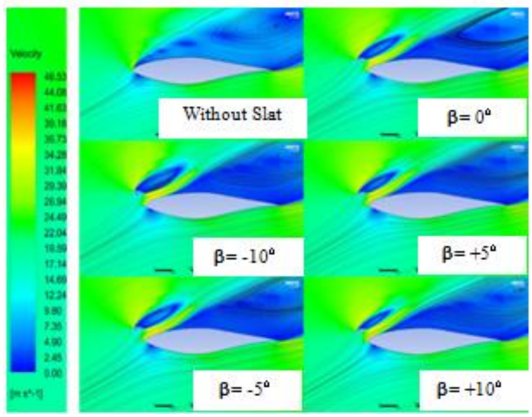

Fig 7: Streamlines and velocity contours for different **β** at Re $= 3 \times 10^5$ at AoA=26.2^0

4. Conclusions

The present study investigates numerically the effect of leading edge slat installation angle **β** at Re $= 3 \times 10^5$. Five values of **β**were tested, **β**= -10°, -5°, 0°, +5° and +10°. Installing the slat with positive or negative values of**β**increase both C_l and C_d but the increase in C_l is less due to negative ones. Further increase in positive values of **β** leads to an increase in the injection gap between the trailing edge of the slat and the base airfoil that reattaches the flow separation point again with the upper surface of the base airfoil. Installing slat at **β**=+5 delays the flow separation on the upper surface of the main airfoil hence it improves the aerodynamic performance of the combined geometry as it gives a maximum increase in the lift coefficient as C_l increases by 40% at AoA=17.2° relative to the no slat condition. Overall, Leading edge slat improves the aerodynamic performance of the airfoil relative to no slat condition

and its installation angle is a considerable parameter that aids in controlling the flow over the airfoil by delaying the point of flow separation or cancelling it completely.

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