The Effects Of Aerofoil Profile Modification On A Vertical Axis Wind Turbine

Amit Kumar Thakur, Ajay Kumar Kaviti, Jayashri N Nair

Abstract: This study focuses on optimizing the NACA-0015 aerofoil that would be easily used in wind turbines on a vertical axis. The profile changes considered are the amalgam of both the inward dimple and the Gurney flap on the NACA-0015's higher pressure surface. For optimization, a total of seven forms of modifications were considered. Data generated from the aerofoil profile analysis of computational fluid dynamics are used for optimization. To ensure that the optimization is decisive, CFD simulations are validated against existing experimental results.

Index Terms: NACA-0015; VAWT; Gurney flap; Dimple; Optimization.

1 INTRODUCTION

Two different types of wind turbines are the horizontal and vertical axis, based on their axis of rotation. Wind turbines with horizontal axes are used to produce large quantities of energy, whereas wind turbines with vertical axes are best suited for small and micro-generation [1].Shukla and Kaviti [2] presented a detailed review of different analyses on wind turbines. Sheldal et al.[3] report experimental investigations of the NACA-0015 vertical axis wind turbine. They focused primarily on VAWT's aerodynamic characteristics. Under dynamic flow conditions Gharali et al. [3] and Ahmad et al. [5] investigated the dynamic aerodynamic effect of VAWT blades. Two prominent profile modifications were proposed independently by various researchers working in aerofoil applications in wind turbines. The first modification is the addition of a vertical flap at or near the tail end. This modification is called a Gurney flap, and researchers have performed several experiments. It was observed that with 1.25% of the length of a chord height, Gurney flap augments the lift with a small boost in drag. And on 2% and above chord length height, Gurney flap rapidly increases drag [6-9]. The second change is dimpling on the aerofoil's low-pressure surface. This alteration helps in vortex generation, which helps to improve the coefficient of lift [10-13]. This paper is mainly aimed at introducing both the modifications mentioned above combined to NACA-0015 at the trailing edge by varying height of the Gurney flap and changing the position of Gurney flap from the trailing side. A total of seven modifications are considered in this study to obtain the optimized aerofoil profile modification to perk up the performance of vertical axis wind turbines.

2 MODELING AND SIMULATION METHODOLOGY

We get the coordinates for NACA-0015 from UIUIC NACA coordinates the official site. Using those coordinates, we have drafted the aerofoil using ANSYS design modeler with 400 mm chord length, 10 mm span length, and 0% camber, as shown in Fig. 1(a). Further modifications were introduced by inward dimple and a Gurney flap to the lower aerofoil sheet, as shown in Fig. 1(b). In the next process, an analysis of the aerofoil at various angles of attack (ranging from 0^0 to 20^0) is done. Height of a gurney flap ranges from 1 to 2 percent of the aerofoil's chord length, and the dimple radius is deemed to range from 0.25 to 1.5 percent of the chord length. All seven modifications are shown in Table 1.

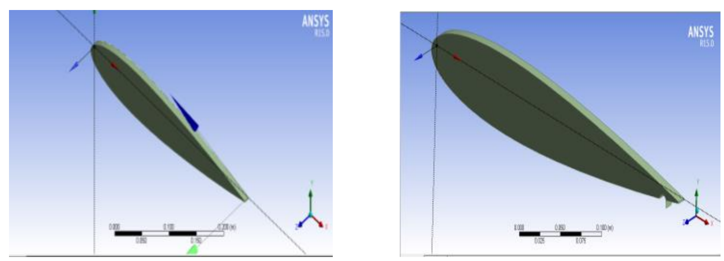

***Fig 1**. Standard model and modified model of NACA-0015*

***Table.1**. Modifications considered in aerofoil NACA-0015*

Modification	Gurneyflap height(mm)	Dimple radius(mm)	Distance from trailing edge(mm)
MOD1	8	6	40
MOD2	8	6	20
MOD3	6	6	20
MOD4	4	6	20
MOD5	8	4	20
MOD6	6	4	20
MOD7	4	4	20

Enclosure parameters are considered in a rectangular domain with a 10x6 m^2 domain area. Body influence is found in a circular area with 2.5 m in diameter, as shown in Fig. 2. The next step after generation of geometry is to discretize the domain into a finite number of parts, which is called as mesh generation. This is very important in the computational fluid dynamic analysis because the high quality structured mesh is required, especially where accurate flow physics needed to be captured. The sweep mesh method has been used for meshing the aerofoil and its domain region. Body of influence is used for more fine mesh, and the maximum face considered is 0.002m.

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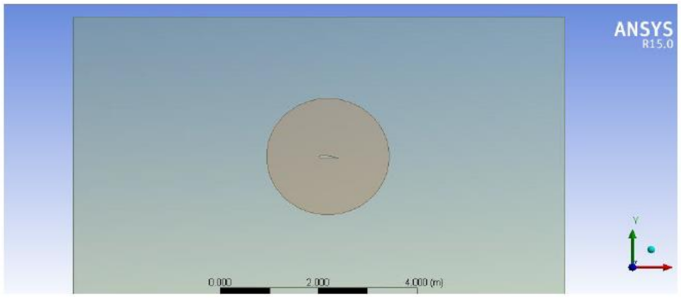

Fig. *2. Enclosed rectangular domain*

Edge sizing is done on the aerofoil profile using several divisions, as shown in Fig. 3. ANSYS meshing workbench has many tools and options to support the production of high-quality inflation layers. Inflation is done, taking the maximum thickness as 0.01m. After meshing is done, we give a name to respective sections to provide inputs at the time of solving the problem.

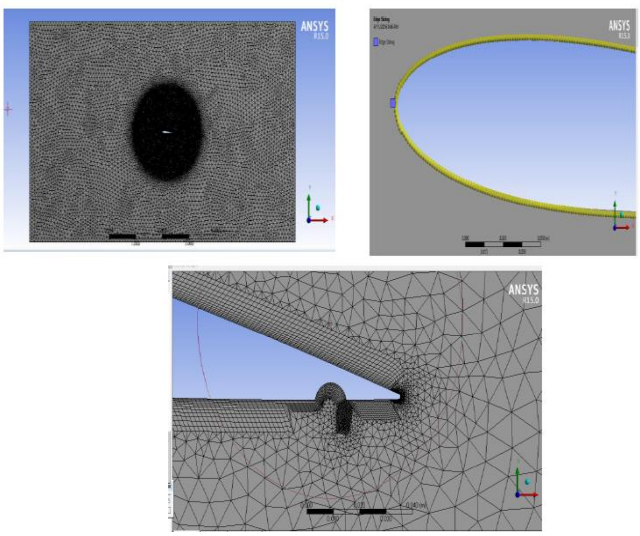

Fig. *3. Mesh generation in aerofoil and its domain*

3 Results And Discussion

The research was performed at varying angles of attack from 0^0 to 20^0 at two different chordal Reynolds, $Re_c = 2.5 \times 10^5$ and $3.6 \times 10^{5,}$ respectively. In this study, seven modifications are considered using the grouping of Gurney flap and dimple flap to achieve optimized profile modification to boost wind turbine efficiency with the vertical axis. Fig. 4 shows the velocity contours of standard NACA-0015 with chordal Reynold's number, $2.5 \times 10^{5,}$ for different angles of attack.

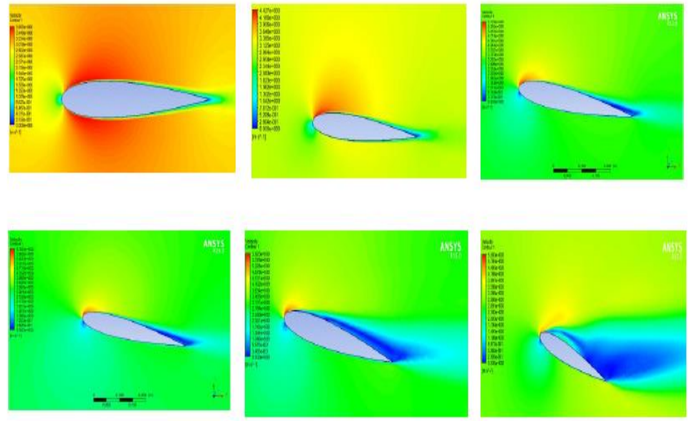

Fig. 4*. Velocity profiles of NACA-0015 at the various angle of attack (0^0, 5^0, 10^0, 12^0, 15^0, 20^0)*

Gurney flap and dimple are employed to create turbulence, which results in delayed boundary layer separation. Thus, the stall condition is delayed, which in turn increases the values of the tangential force. Turbulence generation is higher for the case of a modified aerofoil with combined Gurney flap and dimple due to higher flow separation, and recirculation and velocity contours for different angles of attack are shown in Fig. 5.

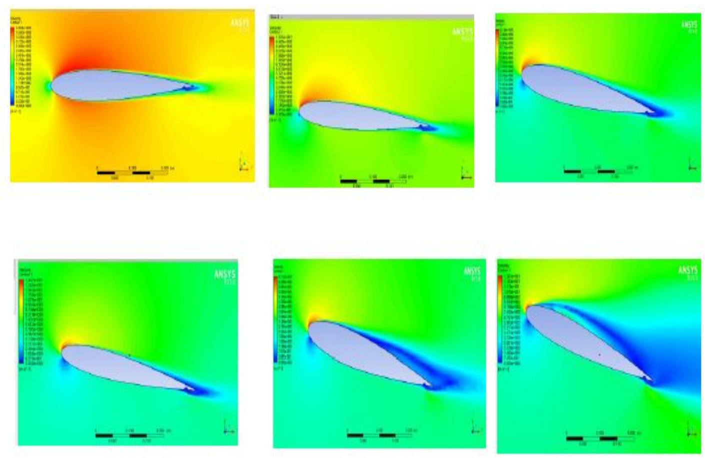

Fig. *5. Velocity profiles of modified NACA-0015 at various angles of attack (0^0, 5^0, 10^0, 12^0, 15^0, 20^0)*

Fig. 6 depicts the coefficient of lift (C_L) for standard NACA-0015 and seven different modifications. It was observed from the figure that coefficient of lift increased for standard NACA-0015 and in all seven modifications with an increase in the angle of attack until it reached 12^0. After that value of the coefficient of lift decreased. It is also seen that Gurney flap of 6 mm height and dimple of radius 6 mm at 20 mm from trail edge results in the highest coefficient of lift.

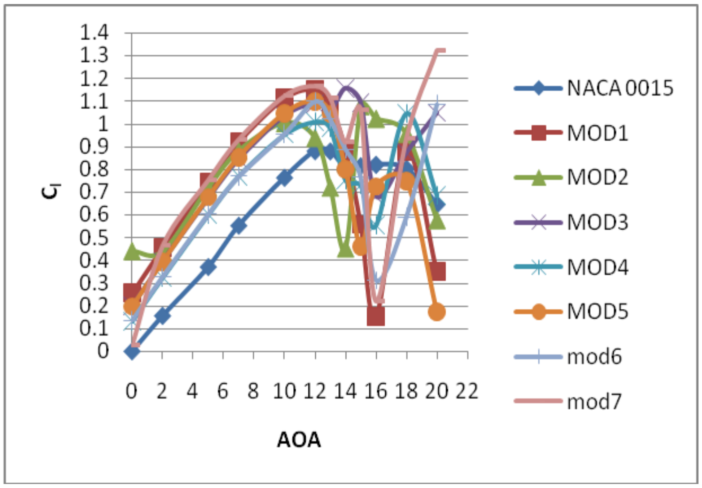

Fig. 6. *Graphical illustration of the coefficient of lift (C_L) Vs. the angle of attack for standard and modified aerofoils of NACA-0015 at chordal Reynolds number, $Re_c = 2.5 \times 10^5$*

Fig. 7 demonstrates the coefficient of lift (C_L) for standard NACA-0015 and seven modifications. It was observed from the figure that the value of the coefficient of lift increased for standard NACA-0015 and in all seven modifications with an amplified value of the angle of attack until it reached 14^0. After that value of the coefficient of lift decreased. It is observed that Gurney flap of 8 mm height and dimple of radius 6 mm at 20 mm from trail edge results in the highest coefficient of lift.

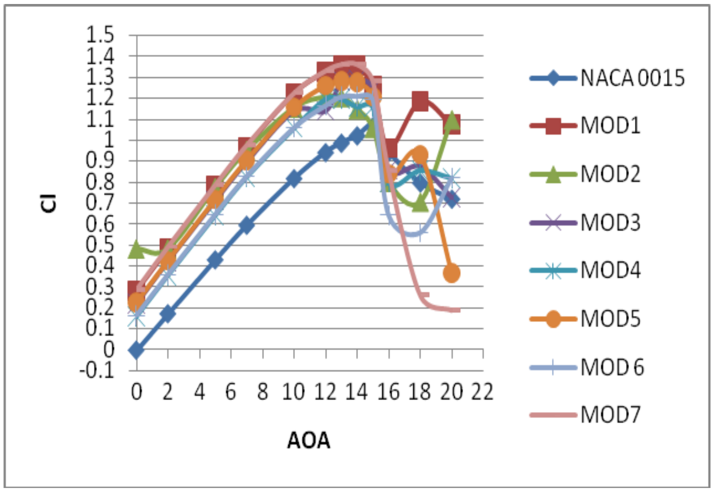

Fig. 7. *The plot of the coefficient of lift (C_L) Vs. the angle of attack for standard and modified aerofoils of NACA-0015 at chordal Reynolds number, $Re_c = 3.6 \times 10^5$*

Fig.8 shows the comparison of coefficient of torque for standard NACA-0015 and optimized modified profile. From the figure, it is clear that the optimized aerofoil coefficient of torque is higher than the standard NACA-0015 at each angle of attaching.

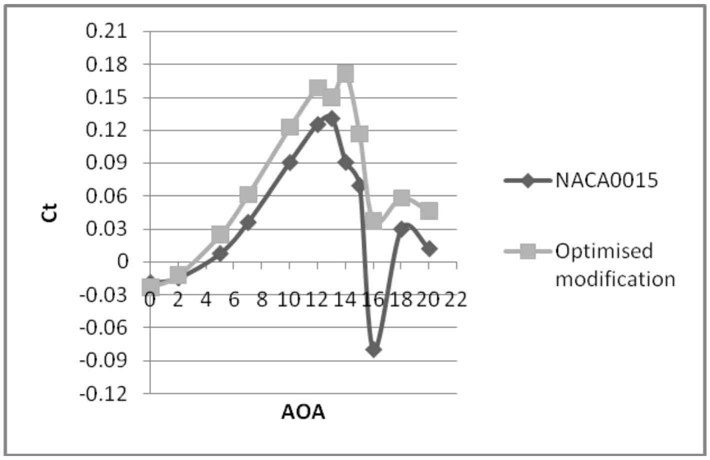

Fig. *8. Optimized coefficient of torque vs. angle of attack at chordal Reynolds number, $Re_c = 2.5 \times 10^5$*

Fig. 9 shows the comparison of coefficient of torque for standard NACA-0015 and optimized modified profile. From the figure, it is clear that the optimized aerofoil coefficient of torque is higher than the standard NACA-0015 at each angle of attaching until it reaches 16^0. After 16^0, the value of optimized coefficient torque is increasing were as standard aerofoil value is decreasing. So, there is scope to work on this area to identify the actual reason for this trend.

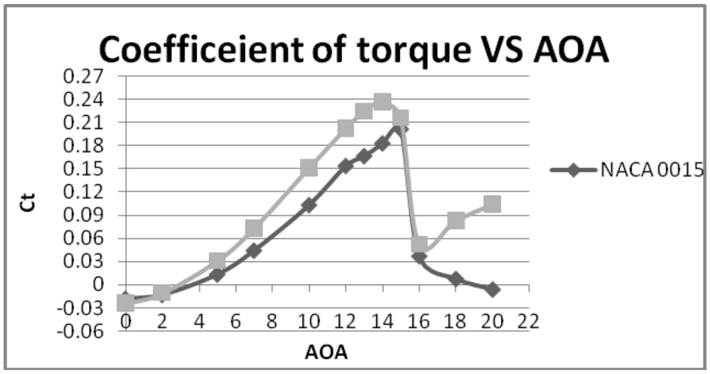

Fig. 9. *Optimized coefficient of torque vs. angle of attack at chordal Reynolds number, $Re_c = 3.6 \times 10^5$*

4 Conclusion

This research suggested the simple adjustment of the aerofoil to standard NACA-0015. In this analysis, seven types of modifications are considered with two dissimilar chordal Reynolds, Re_c= 2.5x 10^5 and 3.6x $10^{5,}$ at various angles of attack within the range 0^0 to 20^0. The torque coefficient is improved by an optimized amalgamation of the Gurney flap and the semi-circular dimple. The optimized value of Gurney flap is 6 mm, and the dimple radius is 6 mm for chordal Reynolds number, $Re_c = 2.5 \times 10^5$. Similarly, optimum values of Gurney flap, dimple radius are 8 mm and 6 mm respectively for chordal Reynolds number, $Re_c = 3.6 \times 10^5$.

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