Retraction

Retraction: Optimization of Winglet of a Wind Turbine Blade
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This article (and all articles in the proceedings volume relating to the same conference) has been retracted by IOP Publishing following an extensive investigation in line with the COPE guidelines. This investigation has uncovered evidence of systematic manipulation of the publication process and considerable citation manipulation.

IOP Publishing respectfully requests that readers consider all work within this volume potentially unreliable, as the volume has not been through a credible peer review process.

IOP Publishing regrets that our usual quality checks did not identify these issues before publication, and have since put additional measures in place to try to prevent these issues from reoccurring. IOP Publishing wishes to credit anonymous whistleblowers and the Problematic Paper Screener \cite{1} for bringing some of the above issues to our attention, prompting us to investigate further.

\cite{1} Cabanac G, Labbé C and Magazinov A 2021 arXiv:2107.06751v1

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Optimization of Winglet of a Wind Turbine Blade

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Abstract. Sustainable energy resources are becoming a growing and rapidly expanding source of energy. Research into clean and renewable energy resources, such as solar and wind energy, is a key topic in the production of alternative energy. The problem being addressed is the design, optimization, construction, and testing of a different angle of winglet configuration. The Blade Element Momentum (BEM) method can be used to compute the output of a propeller blade. The BEM method formulas and procedures are presented and their implementation is also illustrated using a NACA5514 airfoil shape. From this analysis, a reasonably good agreement in terms of power coefficients of airfoil can be found from the results of the computation.

Keywords: Wind Turbine, Blade Element Momentum, Winglet, NACA5514, Aerodynamic Performance

1. Introduction

There are different ways and techniques that can be used to measure the efficiency of wind turbines. While the approach of computational fluid dynamics (CFD) could have the most precise results, it has an incredibly high cost of calculation, time of study, and experience required. The blade element momentum (BEM) method remains the most common method for forecasting wind turbine performance, despite these variables.

To evaluate aeroplane propeller efficiency, the BEM was first formulated by [1]. The propeller blade is fractionated into many parts by using the BEM, serving as a two-dimensional (2D) airfoil. On each component, forces and moments are measured and the total forces and moments are estimated by combining the forces and moments on these components. In addition, some corrections need to be made to make it acceptable to the construction of wind turbine blades, such as correction of tip loss, correction of hub loss, etc.

Therefore, the output in terms of lift and drag coefficients of each blade part (airfoil) is required to calculate the turbine blade performance using the BEM process. The knowledge is usually gained from a sample experiment. However, only a small range of Angle of Attack can be done for the experiment (AoA). Consequently, to obtain the lift and drag coefficients for the entire spectrum of AoA, it is necessary to extrapolate the initial data collected from an experiment.

An airfoil type of NACA5514 is used to illustrate the computation process. Then the Coefficient of Power can be numerically calculated for the various Winglet angles 30°, 45°, 60°, 90°. The results are compared and discussed.

Lots of studies on developing aerodynamic efficiency using a number of innovative concepts. Some work which form the background for this project. [2] analysed the effect of dimpled surface in
the aerodynamic performance. [3] used CFD method to simulate noise propagation to the far fields, [4] of MEXICO wind turbine, [5] studied about the switching strategy and integration of distributed wind power and EVs, [6] studied the flow separation in very thick Wind turbine aerofoils. [7] has stated a new method for the determination of AoA [8] has studied the pressure distribution over an aerofoil with the help of LDV (Laser Doppler Velocimetry) system. [9] has studied an aerofoil with varying AoA and found out the relation between Lift and Drag. [10] has analyzed sinusoidal wavy leading edge motivated by Humpback whale flipper. [11] has studied the performance of the wind turbine blade with and without Winglet. [12] has studied the pressure-load inverse design method for a small wind turbine in the urban environment.

1.1 Tip-speed ratio
A WT is at the stationary position the wind easily passes through the space between the blades of the WT with a small amount of power generation [13]. Figure 1 shows the different situations between TSR and OTSR to show how the air flow will take place. When the WT is rotating at high speed the space between the blades becomes negligible because at high-speed space is always preoccupied with any of the blades [14]. So, a WT must operate in an optimum TSR to extract power at maximum efficiency as shown in equation (1).

\[
\lambda = \frac{\text{Speed of Rotor at Tip}}{\text{Wind Speed}} = \frac{\omega R}{V} \quad (1)
\]

![Figure 1. Different situations between TSR and OTSR to show how the air flow will take place.](image)

1.2 Aerofoil
Aerofoil is a structure with curved surfaces designed to give the maximum lift-to-drag ratio. The force that acts in the direction of aerofoil flow is known as Thrust (T). The force which acts in the direction of airflow is known as Drag (D). The perpendicular component to the Drag and the thrust is known as Lift (L) [15]. An optimum HAWT blade geometry is pivoted on the cross-section of the blade, chord length (c), and twist angle (\(\theta_T\)). For tip induced drag we have provided the winglet. For the study, we are altering the angle of the winglet to 30°, 45°, 60°, 90°, and study their influence on the power coefficient (\(C_p\)). For this motive, we are taking NACA5514 aerofoil as shown in Figure 2.
Figure 2. NACA5514 aerofoil

Finding the Lift and Drag coefficient for each AoA is eased by re-creating the associated expression to the fifth-order expression, as shown in equations (2) and (3).

$$C_L(\alpha) = k_0 + k_1\alpha + k_2\alpha^2 + k_3\alpha^3 + k_4\alpha^4 + k_5\alpha^5$$  \hspace{1cm} (2)

$$C_D(\alpha) = l_0 + l_1\alpha + l_2\alpha^2 + l_3\alpha^3 + l_4\alpha^4 + l_5\alpha^5$$  \hspace{1cm} (3)

For finding Lift and Drag Coefficient after the stall angle to +100° to -100° can be done by Montgorie method, as shown in equations (4-8).

$$C_L = f\cdot t + (1-f)s$$  \hspace{1cm} (4)

$$f = \frac{1}{(1+k\Delta\alpha^4)}$$  \hspace{1cm} (5)

Where

$$k = \left(\frac{f_1}{f_2} - 1\right)\frac{1}{(\alpha_2 - \alpha_m)^2}$$  \hspace{1cm} (6)

$$\alpha_m = \frac{\alpha_1 - \alpha_2}{1-\alpha_m}$$  \hspace{1cm} (7)

$$G = \frac{1}{\sqrt{\frac{f_1}{f_2} - 1}}$$  \hspace{1cm} (8)

2. Computational method

2.1 Blade Element Momentum (BEM) Theory

BEM Theory splits the blade into N components that function independently of the surrounding element and work aerodynamically as a 2D aerofoil, the aerodynamic state of which can be determined on the basis of local flow conditions [16-21]. Blade-element theory defines the strength of the blade as a result of fluid motion in terms of blade geometry.

In order to measure maximum power at a given wind speed, each blade must be separated into N components. Then the angle of flow, angle of attack, factor of tip loss, factor F, solidity rate, and induction values a and a’ are determined iteratively.

3. Methodology

3.1 Qblade

QBlade is liberal General Public Licence Design and Simulation Program for the design and analysis of aerofoil forms and aerodynamic performance characteristics.

3.2 Ratio of Lift to Drag Vs. AoA

For the aerofoil which is selected NACA5514 computation of the Coefficient of lift ($C_L$) and Coefficient of drag ($C_D$) w.r.t AoA is done and the result is shown in figure 3 and figure 4 beneath. The value of α concerning ($C_L/C_D$) is put forward in the table1. From that maximum lift to drag ratio w.r.t AoA is found out and the respective value is taken as α.
Table 1. The value of Lift to Drag ratio of NACA5514 at different Alpha

| Alpha | Cl/Cd  | Alpha | Cl/Cd  |
|-------|--------|-------|--------|
| -5    | -1.11890 | 13    | 31.9936 |
| -4    | 7.21644  | 14    | 25.5896 |
| -3    | 14.4344  | 15    | 21.6383 |
| -2    | 22.6448  | 16    | 18.8207 |
| -1    | 32.0791  | 17    | 16.5467 |
| 0     | 42.8289  | 18    | 14.9109 |
| 1     | 55.9977  | 19    | 12.9330 |
| 2     | 63.9308  | 20    | 11.1597 |
| 3     | 73.5357  | 21    | 9.40579 |
| 4     | 76.1595  | 22    | 4.20506 |
| 5     | 81.5961  | 23    | 3.99065 |
| 6     | 82.7506  | 24    | 3.86381 |
| 7     | 83.3717  | 25    | 3.70411 |
| 8     | 80.9086  | 26    | 3.65787 |
| 9     | 74.7975  | 27    | 3.49060 |
| 10    | 65.2378  | 28    | 3.42415 |
| 11    | 52.9077  | 29    | 3.32135 |
| 12    | 41.1304  | 30    | 3.23205 |
3.3 Designing of Blade and analysis

The relative wind angle $\varphi$ is the angle between the atmosphere and the aerofoil. This can be used to find the pitch angle $\gamma$ by the following equations (9) and (10),

$$\varphi = \tan^{-1}\left(\frac{2}{3\lambda r}\right)$$  \hspace{1cm} (9)

$$\varphi = \gamma + \alpha$$  \hspace{1cm} (10)

From the 2D aerofoil NACA5514 the 3D wind turbine blade with various winglet angle 30°, 45°, 60°, 90° respectively as shown in fig. where the Outer Radius $R=2m$. The chord length and twist angle are determined based on blade element theory as in equations (11) and (12),

$$c = \frac{8\pi r \sin \varphi}{2BC\lambda r}$$  \hspace{1cm} (11)

$$\beta = \gamma - \gamma_0$$  \hspace{1cm} (12)

The chord length is checked for the solidity of blade in equation (13)

$$\sigma^* = \frac{BC}{2mr}$$  \hspace{1cm} (13)

The chord length and the angle of twist of the blades are given in the table 2.

| Pos | Chord length(m) | Angle of twist(deg) |
|-----|-----------------|---------------------|
| 1   | 0.2             | 0                   |
| 2   | 0.199995        | 0                   |
| 3   | 0.19999         | 0                   |
| 4   | 0.19998         | 0                   |
From the data obtained the blade is constructed with a spar. For the study, the blade is constructed with 6000 series aluminium as shell and 7000 series aluminium as spar. The blade is discrete into 50 elements and the Coefficient of power can be founded by the $C_p$ as in equation (14),

$$C_p = \frac{1}{2} C_D \lambda (1 - \lambda)^2$$  \hspace{1cm} (14)

The values of the $C_p$ in the matter of Angle of Winglet is put forward in the table 3.

Where $C_D$ is the sum of all drag forces on each of the elements and induced drag is taken into account. The Design Tip Speed ratio $\lambda_D$ is taken as 7. Since the $\lambda$ value changes with respect to the radius of the blade. The regional tip speed can be found by using equation (15),

$$\lambda_r = \lambda \left( \frac{r}{R} \right)$$ \hspace{1cm} (15)

The net power obtained can be calculated by equation (16),

$$P = \frac{1}{2} \eta C_p U^3 A$$ \hspace{1cm} (16)

The value of change in Power in accordance with the Winglet angle is proposed in the given table 4.

| Table 3. Winglet angle to the Coefficient of Power |
|-----------------------------------------------|
| Winglet Angle | Coefficient of Power |
|----------------|----------------------|
| 30°            | 0.387641             |
| 45°            | 0.387232             |
| 60°            | 0.387295             |
| 90°            | 0.387494             |
Table 4. Winglet angle to the Power

| Winglet Angle | Power(W)     | Change in power |
|--------------|--------------|-----------------|
| 30°          | 59.029544    | +2%             |
| 45°          | 59.095475    | +9%             |
| 60°          | 59.10509     | +10%            |
| 90°          | 59.135459    | +13%            |

4. Structural Blade design and analysis
The WT which are analysed using the BEM Theory is now analysed for the Structural stability in terms of Stress. The Structural Loading data of the blades are shown in the figures 5-8.

![Figure 5](image1.png) Stress diagram of blade with angle of winglet 30°
![Figure 6](image2.png) Stress diagram of blade with angle of winglet 45°
![Figure 7](image3.png) Stress diagram of blade with angle of winglet 60°
![Figure 8](image4.png) Stress diagram of blade with angle of winglet 90°

5. Result
From the analysis of BEM theory and Structural analysis we have come to the result that the WT blade with a Winglet of angle 90° produces $C_p=0.387494$ which far better than that of WT with any other angle of Winglet which can be seen in Figure 9.
Figure 9. Graph of Co-efficient of power to angle of winglet

6. Conclusion
The process is completed using Qblade software for NREL FAST and BEM analysis. From the outcomes of the study, we discovered,

- The Winglets of the WT is more important for the efficiency of the WT, but it is very costly when they are manufactured than normal ones.
- By using the method of BEM analysis, the WT blade with 90° is more efficient than WT blades with 30°,45°,60°.
- By Structural analysis the stress created in the WT blade with 90° is far more less than WT blades with 30°,45°,60°.

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