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BLADE DESIGN CALCULATIONS BASED ON BLADE ELEMENT MOMENTUM THEORY OF HORIZONTAL AXIS WIND TURBINE FOR BAUCHI AND KATSINA STATES NIGERIA

*[1]P.J. Manga, [1]P.B. Teru, [1]M.U. Hashimu, [1]R.O. Amusat, [4]Daniel S., [2]F.W. Burari, [2]A.M. Tijjani, [3]Adisa A. Bello

[1]Department of Physics, University of Maiduguri, Borno State – Nigeria
[2]Department of Physics, Abubakar Tafawa Balewa University, Bauchi, Bauchi State - Nigeria
[3]Department of Mechanical Engineering, Abubakar Tafawa Balewa University, Bauchi, Bauchi State - Nigeria
[4]Department of Science Laboratory Technology, Abubakar Tatari Ali Polytechnic, Bauchi, Bauchi State - Nigeria

*Corresponding Author Email Address: 2016peterjohn@unimaid.edu.ng

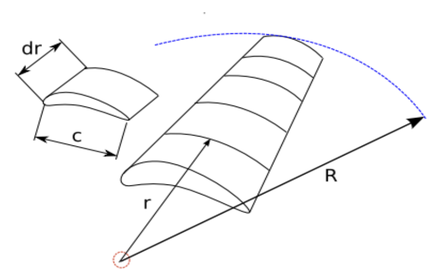
ABSTRACT
In this study, we focus on the design calculation of a wind turbine blade based on blade element momentum theory by the means of improving the efficiency of a wind turbine performance for some cities in Nigeria. The aerodynamic aerofoils of a wind turbine blade are essential tools in influencing the aerodynamic efficiency of wind turbine generator. The Blade element momentum theory, involves the process of dividing a wind turbine blade into sectional aerofoil for the purpose of blade design. The NACA 4418 aerofoil profile is considered for the analysis of wind turbine blades. Q-blade software was used to obtain Lift and Drag Coefficient at 6^0 angles of attack. The blade design parameter such as twisted angle, blade setting angle, aerofoil thickness, chord length, and linearization of the chord length were all calculated and the blade was designed for each selected station. The results of this research can be used for the design and construction of wind turbine blades for the purpose of surface wind electrification.

Keywords: Aerofoil; Angle of Attack; Twisted Angle, Blade Setting Angle, and Aerofoil Thickness.

Nomenclature

a'	Angular induction factor	B	Number of blades	c	Aerofoil chord length
an	Axial induction factor	$\propto$	Angle of attack	R	Blade radius
C_L	Lift coefficient	C_D	Drag Coefficient	$c\lambda_r$	Blade chord length
$F\lambda_r$	Prandtl tip function	$\mu L(\varphi)$	Dimensionless function	$U_{-\infty}$	upstream velocity
r	Distance of element to the rotation axis	$\sigma\lambda_r$	Solidity	φ	Blade setting angle
CT	Local thrust coefficient	dQ	Torque force	dT	Thrust force

INTRODUCTION
An aerofoil can be defined as the cross-section of a body that can minimize drag force and increase lift when placed in an airstream to produce some useful aerodynamic forces efficiently as possible Bazilevs *et. al.,* (2011). The cross sections of wings, propeller blades, windmill blades, compressors, and turbine blades in a jet engine and hydrofoils are examples of aerofoils Bossy *et. al.,* (2016). The basic geometry of an aerofoil is shown in Figure 1.



Blade Element Momentum (BEM) Theory

The Blade Element Momentum (BEM) theory is used for the evaluation of airplane propellers or power extraction by wind turbines based on mechanical and geometric parameters as well as the inflow characteristics Branlard *et. al.,* (2017). BEM theory comprises two theories; blade element theory and momentum theory. Formerly it was introduced by (William, M. *et. al.,* 2011) to study wind turbines from a local point of view. In this framework, the wind turbine blade is divided into sections, the blade elements governed by empirical models. This approach results in the expressions of forces exerted on the blade element, as functions of the flow characteristics and blade geometry. The coefficient of lift and drag forces are the fundamental quantities of this empirical model, which account for the force of the cross-section as a function of the angle of attack (AOA). AOA is the relative angle between the undisturbed flows to the rotating blade Branlard *et. al.,* (2016). The global obtained values are the integrated results along the blade. The momentum theory, also known as Disk Actuator (DA) Theory or Axial Momentum (AM) Theory, this theory adopts a macroscopic point of view to predict the behavior of a fluid passing through a turbine. Nikolay joukowsky, Frederick W. Lanchester, and Albert Betz first adopted the approach independently to formulate the Betz – joukowsky Limit, which gives the theoretical optimal efficiency of a rotor blade. A combination of these two approaches was carried out by Buhl, M.L (2005) and formalized by Hermann Glauert (1983), who also precise the momentum theory by including the rotation of the fluid induced by its interaction with the turbine Evan, G *et. al.,* (2020). The resulting Blade element momentum (BEM) theory is based on two decompositions: i. radial decomposition of the fluid column, which is considered a concentric ring that is not interacting with one another ii. Decomposition of fluid / turbine system into macroscopic part via momentum theory and local planar part via Blade Element Theory given by Glauert's theory, Hermann Glauert (1983). The local events taking place at the actual blades and the momentum theory are coupled by the blade element momentum theory. The airstream tube introduced in the 1-D momentum theory is discretized into N annular elements" Though old, Glauert's model is still currently in used to evaluate turbine efficiency,

Due to billions of naira's that has been wasted by wind power plan investors which arise as a result of poor estimation of blade design parameters, called for more research in improving the performance and efficiency of a wind turbine by capturing more freely wind. Glauert developed simple correctional model of momentum theory which has been accepted and adopted as an approach to compare the complex phenomenon that results in to couple turbine or fluid system. Glauert work dependent on 3D flow fluid or structure interaction problems which is a major challenge, that blade element momentum (BEM) reduces to 0D computations with the aid of 2D static data namely, lift and drag coefficients. This is obtained by solving 2D partial differential equations, typically stationary Navier-strokes, or more often than not, by using experimental data from wind tunnel profiles tests Hansen (2015). The numerical efficiency of this method is more crucial as turbine models are mostly implemented as part of design procedures, through iterative optimized loops. This means equations has been simplify in many ways to form a simpler formulation which is called blade element momentum (BEM) suitable for blade design. Blade element momentum theory continues to be widely used for aerodynamic analysis; conceptual design, loads and stability analysis, and control design Madsen *et. al.,* (2020).

There are other proposed models based on Joukowsky where the axial wake velocity is said to be constant. We extensively presented the model with a historical perspective with a significant increase in power computing as well as theoretical advancement obtained in the field of fluid structures interaction simulation which makes it possible now are days to simulate 3D models based on the Navier – Stokes equation. Alternatively, BEM models have been combined with Lagrangian stochastic solvers, multiple vortex cylinder models, or adapted scaling leading to grid-based variants for large BEM rotor blades. Because of the numerical solution of blade element momentum theory (BEM), it has been reduced to one scalar equation Maniaci (2011). A similar theory was subjected to Darrieu's type of vertical axis wind turbine. The significance of this article is to analyse the blade element momentum theory for the calculation of blade design parameters from the mathematical point of view. The obtained results of the analysis elucidate issues related to the well-posedness of the model, and the numerical solution of the model is for better blade design Mc. William *et. al.,* (2011).

In this research we used two versions of Glauert's model, the simplified model and the corrected model. The former model allows us to describe the main features of our approach, whereas it couples with some corrections usually considered to remedy the mismatch between the simplified model and experimental observations. In this, we try to give a brief exposition of the derivation of the model which is focused on the algebraic system Ning *et. al.,* (2015). The key point of this analysis is to deeper look into Glauert's macroscopic–local decomposition by reformulating the equation into a single equation that contains two distinct terms: Universal term, independent of the turbine under the macroscopic part of the model with the experimental term that depends on the blade characteristics and associated with the local part of the model. On this context, we show that solving the equations associated with Glauert's model means an angular value that will equalize the two terms Ning *et. al.,* (2014). These results agree with some conclusions reported that were not formalized mathematically and later used for a pedagogic purpose. In contrast, our analysis gives rise to new theoretical and numerical results. This formulization enables us to identify explicitly which assumptions are related to the turbine design parameter that can guarantee the existence of the solution.

METHODOLOGY

The research is built based on Glauert's proposed model to describe the interaction between a design wind turbine blade and its flow characteristics. In this, the introduction of some important variables leads us to the equations of the models Okulov *et. al.,* (2015). The versions of the models considered for this study were given as.

Variables

The blade element momentum (BEM) theory aims to establish algebraic relations that characterize the interaction between a flow and a rotating blade named a turbine. Glauert's model couples two descriptions: a global macroscopic model that describes the evolution of fluids rings crossing the turbine, and a local one, that summarizes in 2D the behavior of a section of a rotor blade, a blade element, under the action of the fluid Glauert (1983). The fluid is incompressible and constant in time. The characterization of the fluid velocities in the left and right neighborhoods of the wind turbine is said to have the same valueU_0. The upstream and the downstream velocities are $U_{-\infty}\ and\ U_{+\infty}$ respectively. Though not considered in this study, the tangential velocity can also be studied. The jump of variable caused by the actuator disk is often recorded and can be modeled using momentum theory Okulov *et. al.,* (2012). As BEM Model does not take account of interactions between blade elements and assumes that Ω and U_∞ are constant, in this study a fixed blade element and a fixed value of the local speed ratio

$$\lambda r = \frac{\Omega \mathrm{r}}{U_{-\infty}} \quad (1)$$

Where r is the distance of the element to the rotation axis, with $r \leq R$, Where R is the radius of the blade. Practically, a wind turbine works at a constant Tip Speed Ratio (TSR): Ω is controlled through torque exerted by the generator such that the

$$TSR = \frac{\Omega \mathrm{r}}{U_{-\infty}} \quad (2)$$

Is kept constant for various values of $U_{-\infty}$. Follow by the value of λr subjected to one element only depends on r. In the sequel, we consequently use the variable λr to describe the location of a blade element Song *et. al.,* (2013).

Macroscopic variables and BEM unknowns

Glauert's model consists of a system that links three variables together such as $a, a', and\ \varphi$ associated with a ring of fluid. The two are formerly called the axial and angular induction factors respectively Song *et. al.,* (2013). They are defined by

$$a = \frac{U_{-\infty} - U_{0\cdot}}{U_{-\infty\cdot}}, a' = \frac{\omega}{2\Omega} \quad (3)$$

Where ω is the rotation speed of the ring fluid? The angle φ is the relative angle of the ring, defined by

$$tan\varphi = \frac{1-a}{\lambda_r(1+a')} \quad (4)$$

For the sake of simplicity and to emphasize their role of unknowns in Glauert's model, omit the dependence variable $a, a', and\ \varphi$ (and α is what follows) on λ_r in the notation. We can define φ as

$$U_{rel} = \frac{U_0}{sin\varphi} \quad (5)$$

This variable is not defined when $\varphi = 0$ and as the intermediate quantity, will not appear in the final model. For a given blade profile, the lift and drag coefficients C_L and C_D are defined by

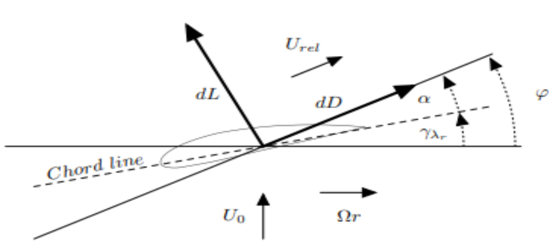
$$dL = C_L(\propto)\frac{1}{2}\rho U_{rel}^2 c\lambda_r dr, \quad dD = C_D(\propto)\frac{1}{2}\rho U_{rel}^2 c\lambda_r dr \quad (6)$$

Where ρ is the mass density of the fluid, dL, and dD are the elementary lift and drag forces applying to a blade element of thickness dr and chordc_{λ_r}. The angle of attack is denoted by a parameter (α) and defined as the angle between the undisturbed flows to the chord of an aerofoil Sorensen (2011). Hence satisfied the relation below

$$\propto = \varphi - \gamma\lambda_r \quad (7)$$

Where $^{-\pi}/_2 < \gamma\lambda_r < ^{+\pi}/_2$ the twisted angle of the rotor blade is (also called local pitch). The coefficient C_L and C_D correspond to the ratio of lift and drag forces, that is the force that is associated with kinetic energy, which is determined by the blade profile Sorensen J. (2011). Once it is done, the blade design parameter is c_{λ_r} and$\gamma\lambda_r$.

The coefficients C_L and C_D are assumed to be constant $\propto$ which affects the Reynolds number (R_e). This is rarely considered in the monographs, where R_e is assumed to be constant concerning $\propto$ as soon as $U_{-\infty}, \lambda_r, \Omega,$ and c_{λ_r} are fixed. For simplicity, we also neglect the changes in R_e in the study. However, the results can be extended to non-constant Reynolds numbers Sorensen J. (2016). That is in situations where the functions $(\propto, R_e) \rightarrow C_L(\propto, R_e)$ and $\propto \rightarrow C_D(\propto, R_e)$ have to be taken into account. Practically, R_e is either assumed to be known a prior and used for the selection of the corresponding C_L and C_D.



Blade Element Profile and Associated Angles, Velocities, and Forces.

Iteratively together with C_L and C_D will give a more accurate result. The examples of variations of C_L and C_D depend on Reynolds number (R_e).

Though changing from one profile to the other, the behaviors of C_L and C_D as functions $\propto$ can be described qualitatively in a general way. There is an increase in the coefficient of C_L linearly for $\propto$ to a critical angle $\propto_s$ at $0 < \propto_s < ^{\pi}/_2$, at this the stall phenomenon is said to occur; C_L then decreases is attributed to a drag force, which is positive and defined for all angles Sun *et. at.,* (2017). This coefficient usually slightly increases with $\propto$ up to $\propto = \propto_s$, and then becomes very large. Though most designs do not the blade inner to become stall at condition $\varphi - \gamma\lambda_r < \propto_s$ is usually considered in the blade design. Noted, the angle of attack is applied in the final part of our analysis such that C_L is positive. Some properties of C_L and C_D are given in the following assumption Sun. *et al.,* (2017).

Assumption 1: For some $\beta \in \mathbb{R}^+$, the function $\propto \rightarrow C_L(\propto)$ is continuous on $I_\beta = (-\beta, \beta)$, and positive on $I_\beta \cap \mathbb{R}^+$. The function $\propto \rightarrow C_D(\propto)$ is defined, as continuous and non-negative on $\mathbb{R}$. If $C_L(0)$ is assumed to be positive, which is equivalent to the angle of attack corresponding to zero negative lift. This assumption is true for the design of wind turbines Vankuik (2018).

Glauert's Modeling: For the sake of completeness, we can recall that the purpose by which Glauert's is introduced is to model the interaction within a turbine and the flows. To extend on this theory presentation, we denote it by dT and dQ is the infinitesimal thrust and torque that is applied on the blade element of thickness dr under consideration Glauert (1983).

Macroscopic Approach: The model is used to related momentum theory and deals with the macroscopic evolution of a ring of fluid Vankuik (2018). It aims to express dT and dQ in terms $of\ a, a' and\ \varphi$. Denoted by p_- and p_+ this is the neighborhood's fluid pressure in both the left and right of the blade. Applying Bernoulli's relation between −∞ and 0− and between 0^+ and +∞ gives rise to

$$p_- - p_+ = \frac{1}{2}\rho(U_{-\infty}^2 - U_{+\infty}^2) \quad (8)$$

It is considered as the rate of change in momentum on both sides of the wind turbine, which is upstream and downstream. Secondly, the variation in the pressure can be expressed as Wood. D.H. (2018)

$$p_- - p_+ = \rho(U_{-\infty}^2 - U_{+\infty}^2)U_0 \quad (9)$$

Then the thrust force and the Torque force are defined by the equation, we obtain$U_{+\infty} = (1-2a)U_{-\infty}$.

$$dT = (p_- - p_+)2\pi dr \quad (10)$$

$$dQ = \omega\rho U_0 2\pi r^3 dr \quad (11)$$

Finally, we represent the thrust force and the Torque force as Wood (2018)

$$dT = C_T(a)U_{-\infty}^2\rho\pi r dr \quad (12)$$

$$dQ = 4a'(1-a)\lambda_r U_{-\infty}^2\rho\pi r^2 dr \quad (13)$$

Where by $C_T(a)$ is the local thrust coefficient defined by the below equation Wood. D.H. (2018)

$$C_T(a) = \frac{dT}{\frac{1}{2}U_{-\infty}^2\rho 2\pi r dr} = 4a(1-a) \quad (14)$$

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Local approach: Another set of equations can be gotten from the blade element theory, in this case, there is a need for the local expressions of the infinitesimal thrust and torque Van Treuren (2008). The combination of the elementary lift and drag expression in the rotating referential is given as

$$dT = \sigma\lambda_r \frac{(1-a)^2}{sin^2\varphi}(C_L(\varphi - \gamma\lambda_r)cos\varphi + C_D(\varphi - \gamma\lambda_r)sin\varphi) \quad (15)$$

$$dQ = \sigma\lambda_r \frac{(1-a)^2}{sin^2\varphi}(C_L(\alpha)sin\varphi - C_D(\alpha)cos\varphi)\, U_{-\infty}^2 \rho\pi r^2 dr \quad (16)$$

Whereby $\sigma\lambda_r$ is the solidity defined as B is the number of blades of the turbine

$$\sigma\lambda_r = \frac{Bc\lambda_r}{2\pi r} \quad (17)$$

Combination of local and global approaches: To get a closed system of equations, Glauert combined the results of the two last subsections. The equation can be divided into the following equations Van Treuren (2008).

$$\frac{a}{1-a} = \frac{\sigma\lambda_r}{4sin^2\varphi}(C_L(\varphi - \gamma\lambda_r)cos\varphi + C_D(\varphi - \gamma\lambda_r)sin\varphi) \quad (18)$$

$$\frac{a'}{1-a} = \frac{\sigma\lambda_r}{4\lambda_r sin^2\varphi}(C_L(\varphi - \gamma\lambda_r)sin\varphi + C_D(\varphi - \gamma\lambda_r)cos\varphi) \quad (19)$$

This is the Glauert's Blade Element Momentum (BEM) Theory.

Simplified model: The contribution of drag coefficient (C_D) at some time is set to be zero. It is stated as follows

$The\ C_D$ is usually omitted when calculating physics velocities because does not contribute to the induced velocities. On the same note, the calculation of the induced factors is done and accepted at C_D equal to zero VanKuik (2015). A negligible error will be noted for an aerofoil with low drag coefficients. This assumption is justified in many cases since the design profile has minimized drag under some procedures. Firstly the twisted angle minimized lift to drag ratio

$$\gamma\lambda_r = \frac{C_D}{C_L} \quad (20)$$

Let us consider the case where $C_D = 0$. this refers to a simple model in the following ways that correspond to three equations:

$$tan\varphi = \frac{1-a}{\lambda_r(1+a')} \quad (21)$$

$$\frac{a}{1-a} = \frac{1}{sin^2\varphi}\mu L(\varphi)cos\varphi \quad (22)$$

$$\frac{a'}{1-a} = \frac{1}{\lambda_r sin\varphi}\mu L(\varphi) \quad (23)$$

The dimensionless function is given as

$$\mu L(\varphi) = \frac{\sigma\lambda_r}{4}C_L(\varphi - \gamma\lambda_r) \quad (24)$$

Corrected model: To improve on the closeness to results, a modified model was introduced, whereby we present three important corrections, namely non-zero drag coefficient C_D, tip loss correction, and treatment of large values of a. This modified model is significant in the analysis of blade design Van Treuren (2008).

Slowly increasing drag: In addition to considering C_D strictly positive, we shall assume in some parts of the analysis a slow increase of this parameter from 0 up to the occurrence of the stall phenomenon Van Treuren (2008).

Tip loss correction. The equations of momentum theory are derived by assuming that the turbine is like an actuator disk, such that the rotor has an infinite number of blades that correspond to its framework. However, in real-life situations, a modification of the flow at the tip of a blade has to be included to take into account that the circulation of the fluid around the blade must go down (exponentially) to zero when $r \to R$, where R is the turbine radius. In this way, Glauert's introduced an approximation of the Prandtl tip function $F\lambda_r$ Van Treuren (2008).

$$F\lambda_r(\varphi) = \frac{2}{\pi}\arccos\left(\exp\left(-\frac{\frac{B}{2\left(1-\frac{\lambda_r U_{-\infty}}{\Omega R}\right)}}{(\frac{\lambda_r U_{-\infty}}{\Omega R})sin\varphi}\right)\right) = \frac{2}{\pi}\arccos\left(\exp\left(-\frac{\frac{B}{2(1-{}^r/_R)}}{({}^r/_R)sin\varphi}\right)\right) \quad (25)$$

The modification of equation of (25) is given by

$$dT = 4a(1-a)F\lambda_r(\varphi)U_{-\infty}^2\rho\pi r dr \quad (26)$$

$$dQ = 4a'(1-a)F\lambda_r(\varphi)U_{-\infty}^2\rho\pi r dr \quad (27)$$

This is an approach based on extended vortex theory that has been proposed in equations 26 & 27

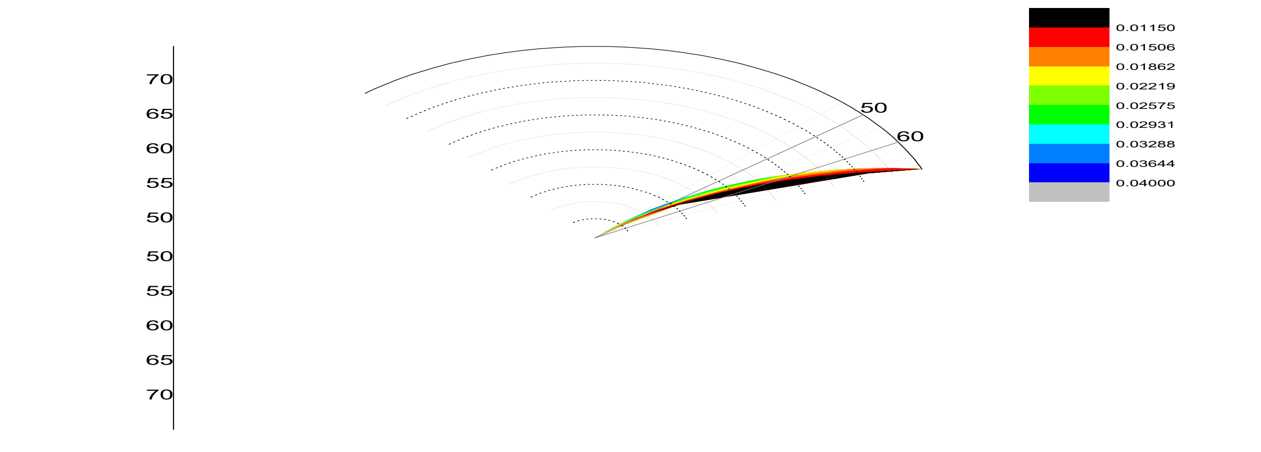
RESULTS

The results of the blade design analysis based on blade element momentum (BEM) theory for effective design of wind turbines in a way of improving the efficiency of its performances during extraction of wind kinetic energy by the rotor blade is given in **Table** (1-12); The 2D horizontal axis wind turbine (HAWT) blade has been designed for one selected station across the North-East and North-West of Nigeria based on contour plots as shown in the **Figure**s below.

Table 1: Blade Design Parameter for Bauchi

Blade section	$\propto^0$	$\gamma\lambda_r{}^0$	φ^0	c (cm)	dr(cm)	a(cm)	a' (cm)
1.0	6.0	26.39	20.39	0.1783	0.072	0.1769	0.1783
2.0	6.0	20.23	14.23	0.2089	0.02196	0.2382	0.2089
3.0	6.0	16.33	10.33	0.2396	0.04044	0.2995	0.2396
4.0	6.0	13.67	7.67	0.2702	0.03012	0.3608	0.2702
5.0	6.0	11.74	5.74	0.3009	0.02904	0.4221	0.3009
6.0	6.0	10.28	4.28	0.3315	0.02148	0.4834	0.3315
7.0	6.0	9.15	3.15	0.3622	0.02028	0.5447	0.3622

8.0	6.0	8.24	2.24	0.3928	0.01716	0.6060	0.3928
9.0	6.0	7.49	1.49	0.4235	0.0156	0.6673	0.4235
10.0	6.0	6.87	0.87	0.4541	0.01368	0.7286	0.4541



Blade Profile of Bauchi Based on Contour

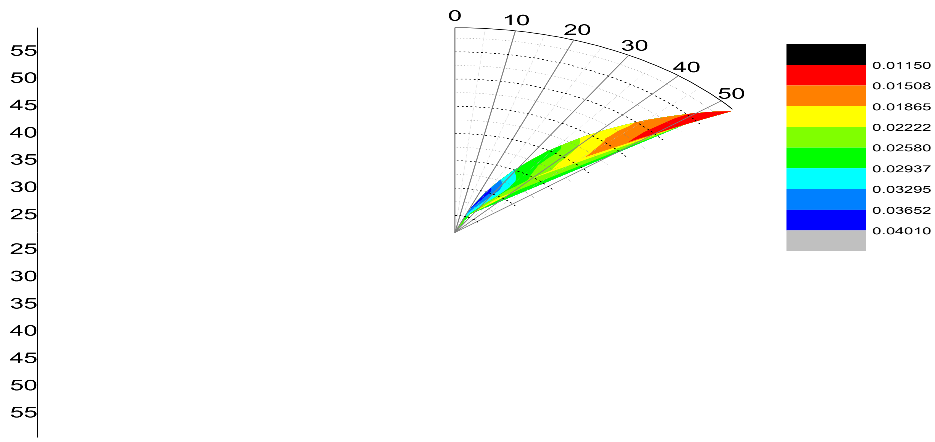
Table 1 and Figure 1; are the result of the blade element momentum analysis for Katsina Metropolis. Manga *et. al.,* (2022) conduct research works on the optimization of horizontal axis wind turbine blades. In his work, he was able to compute aerodynamic characteristics of 2D airfoil of a micro horizontal wind axis turbine blade. In his findings, he represents 2D airfoil in a computational domain of stream air. His Results shows that the stream of air passing through the upper surface of wind turbine blade travels more distance per unit time than the stream of air passing through the down surface of the wind turbine blade.

In this research, results obtained satisfied the Bernoulli Principle. The streams of air on the blade will create pressure differences and this change in pressure will result into component of forces which are lift force and drag force.

The computational results show that the upper surface of the blade needs to be twisted and slightly thick to able the blade to capture more air in other to reduce the effect of aerodynamic forces acting on the blade as presented in the figure below, based on contour design. The designed blade is said to be optimized at 6.0^0 angle of attack ($\propto^{\mathbf{0}}$), the total blade twisted angle $T(\gamma\lambda_r^0)$ is 130.39^0 and the total blade setting angle(φ^0), is 70.39^0.

Table 3: Blade Design Parameter for Katsina

Blade section	$\propto^{\mathbf{0}}$	$\boldsymbol{\gamma\lambda_r}^{\mathbf{0}}$	$\boldsymbol{\varphi^0}$	$\boldsymbol{c}$ **(cm)**	$\boldsymbol{dr}$**(cm)**	a(cm)	$\boldsymbol{a'}$ **(cm)**
1.0	6.0	21.81	15.81	0.1783	0.0213	0.1728	0.2359
2.0	6.0	28.53	22.53	0.334	0.0401	0.2348	0.2302
3.0	6.0	34.5	28.5	0.2495	0.0299	0.2968	0.2246
4.0	6.0	39.72	33.72	0.2411	0.0289	0.3588	0.2190
5.0	6.0	44.26	38.26	0.1794	0.0215	0.4208	0.2133
6.0	6.0	48.19	42.19	0.1685	0.0202	0.4828	0.2077
7.0	6.0	51.59	45.59	0.1426	0.0171	0.5448	0.2021
8.0	6.0	54.56	48.56	0.1301	0.0156	0.6068	0.1964
9.0	6.0	57.15	51.15	0.1142	0.0137	0.6688	0.1908
10.0	6.0	59.42	53.42	0.0963	0.0115	0.7308	0.1852



Blade Profile of Katsina Based on Contour

Table 2 and Figure 2; are the result of the blade element momentum analysis for Katsina Metropolis. Manga *et. al.,* (2022) conduct research works on the optimization of horizontal axis wind turbine blades. In his work, he was able to compute aerodynamic characteristics of 2D airfoil of a micro horizontal wind axis turbine blade. In his findings, he represents 2D airfoil in a computational domain of stream air. His Results shows that the stream of air passing through the upper surface of wind turbine blade travels more distance per unit time than the stream of air passing through the down surface of the wind turbine blade.

In this research, results obtained satisfied the Bernoulli Principle. The streams of air on the blade will create pressure differences and this change in pressure will result into component of forces which are lift force and drag force.

The computational results show that the upper surface of the blade needs to be twisted and slightly thick to able the blade to capture more air in other to reduce the effect of aerodynamic forces acting on the blade as presented in the figure below, based on contour design. The designed blade is said to be optimized at 6.0^0 angle of attack $(\propto^{\mathbf{0}})$, the total blade twisted angle $T(\gamma\lambda_r^0)$ is 439.73^0 and the total blade setting angle(φ^0), is $379{,}73^0$.

Conclusion

This research focuses on the calculation of wind turbine blade design parameters based on blade element momentum theory governed by Glauert's mathematical model to improve the efficiency of the design turbine blade. The design blade parameters are the angle of attack, twisted angle, blade setting angle, chord length, axial induction, and tangential induction were all investigated and estimated as shown in the tables and blade contour profile. The result obeys Bernoulli principle. If an airfoil is placed in the path of the air stream, the air that travels on the upper surface of the blade will travel faster than the air on the down surface of the blade, there will be a pressure different which will result in a component of forces, which are, Lift Force and Drag Force. The result of this research has satisfied Glauert's model and Bernoulli principle.

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