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EXPERIMENTAL COMPARATIVE ANALYSIS OF NACA 4-SERIES TWISTED VERTICAL AXIS TURBINE BLADES

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Abstract: Low velocity vertical axis wind turbines need to be analysed in both the ways, in that one is twisted angle and second one is wind velocity. The comparison of twisted blades of 4 series with geometrical deviations need to observe and the variations should be considered. Present study is a comparison of two NACA 4-series profiles NACA4412, NACA 4418 with twisted profiles to check the affect of twist on lift and drag parameters. Primary work with CFD in ANSYS workbench has been considered for the comparison with twisted angle deviation ranging from 5,10,15 degrees. The twisted profile investigated with aerodynamic environment with different velocities ranging from 5-8m/s. NACA 4412 given good results in CFD with at low speeds compare with NACA 4418. The approach further carried-out for the experiment to check the evaluation of twist angle and optimum velocity. The experimental work has been carried-out for the twist of 5^0 which is better in simulation and at an attacking angle of 15^0. The results obtained shows better enhancement nearly 14% when compare with straight blade without any twist.

Key words: VAWT, NACA-4412,4418, Low velocity.

1.0 Introduction

In recent years, there has been a notable increase in the number of investigations on the Vertical Axis Wind Turbines (VAWTs), which has given the VAWT technology a new rebirth. While the Horizontal Axis Wind Turbines (HAWTs) has acquired a significant portion of the wind power market, the VAWT concept is estimated to play a dominant role in the next 2–3 decades [1]. In particular, the VAWTs feature many potential advantages, especially for operating in the urban environment and the offshore floating platforms [2]. However, in general, VAWTs currently suffer from lower efficiencies than the HAWTs [3]. Therefore, intensive research on improving the aerodynamics of the VAWTs has been observed in recent years. The VAWTs can be classified as two configurations, i.e., the Savonius and Darrieus designs [4,5]. The Darrieus designs rely on the lift generated from the aerofoil-profiled blades, while the Savonius designs are driven by the drag from bucket-shaped vanes [6]. Generally, Savonius turbines have lower efficiencies, although they have better startup characteristics than the Darrieus turbines [4]. However, the Darrieus type VAWTs offer significant advantages over Savonius turbines, have a much higher power coefficient, and are suitable for large-scale operations [4]. Since the driving elements of Darrieus type VAWTs are the aerofoil-profiled blades, the turbine performance is strongly dependent on the incident angle of the flow relative to the blade chord, also is referred to as the baled Angle of Attack (AOA). Therefore, an accurate estimation of the incident flow direction and the AOA during turbine operation is critical for turbine design optimization [7]. There is intensive research interest in improving the straight-bladed VAWT efficiency through controlling the blade AOA during its rotation

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around the vertical axis. Especially for highly efficient operations at low Tip Speed Ratios (TSRs), which rely on the appropriate design of the turbine blade pitching angle [8] or applying the variable pitch to the blade control [9]; For example, the variable pitch based on the cycloidal kinematics has been widely investigated [10–12]. Erickson et al. [13] obtained a 35% enhancement in the turbine efficiency using a first-order sinusoidal pitch; Liu et al. [14] improved the turbine performance using a sinusoidal pitch with low amplitude. Paraschivoiu et al. [15] found that the turbine's annual energy production could be increased by about 30% using an optimized variable pitch based on a suggested polynomial of sinusoidal functions.

2.0 Review of research

The interactions between the wind and the VAWT rotations lead to very complex time-variant aerodynamic phenomena around the spinning blades. However, several studies have analyzed the instantaneous power and torque generation over one rotating cycle [16–22]. A more detailed aerodynamics analysis and, in particular, the effects of instantaneous AOA are required to understand the aerodynamic reasons for the differences in the power generation efficiency between different turbine designs of the VAWTs. A range of different-fidelity analyses has been used to investigate both fixed and variable pitch VAWTs and the estimations of the AOAs. These include the stream tube-based models [23–25], the vortex method [26,27], the Computational Fluid Dynamics (CFD) analysis [17,20,21,28–31], and the high-computational cost Large Eddy Simulation (LES) [22,32]. However, the 2D CFD analysis, based on the Reynolds-averaged Navier–Stokes (RANS), is widely used because of its reasonable accuracy and moderate computational cost [28]. In the blade aerodynamics analysis, the AOA could be estimated assuming that the approaching wind velocity to the blade is constant and parallel to the undisturbed wind flow velocity. This simple calculation ignores the effects of the rotor on the flow, particularly the blade wake interactions existing in the VAWT operation, which can lead to a significant error in the prediction of the performance of the turbine blades. While this simplified calculation of the AOA is widely used [18–20,33–37], a more realistic estimation of the AOA is needed that considers the variation of the magnitude and direction of the approaching wind velocity vector to the blade at different azimuthal positions. Kozak [38] calculated the AOA based on the CFD data using two different methods. These are based on the calculated lift coefficient, pressure ratio between the suction and pressure sides of the blades. However, validation of these methods limited to the study of a pitching motion with a geometric AOA between 0° and 8°; Bianchini et al. [39] used the CFD data for the estimation of the AOA based on the location of the pressure peak by comparing it to the location of the pressure coefficient peak obtained by the panel method. To account for the virtual camber effect, the original aerofoil coordinates are transformed to a virtual aerofoil, and then the panel method is used for the pressure coefficient calculations [39]. Although this method agrees with the Blade Element Momentum (BEM) results, it involves many intermediate tasks. Edwards et al. [7] presented an estimation method of the corrected AOA based on the cycle-averaged CFD velocity flow-field. This method involves discarding the distorted velocity near the blade trajectory then interpolating the flow field. While this method provides a good estimation of the AOA, it ignores the instantaneous variation of the velocity flow field and involves many intermediate tasks. Gosselin et al. [17] claimed a good estimation of the AOA using CFD data based on the averaged velocity vector at a single point located on the divergent trajectory at a distance of two-chord

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lengths in front of the blade. However, a distance of two-chord lengths appears to be large, especially for high solidity turbines with a high chord to radius ratio. It is noted that most of the estimation methods of the AOA that are available in the literature have two common drawbacks, namely.

(i) the lack of a reference for comparison and validation of the methods and thus can lead to relatively large errors, and (ii) the need for extensive post-processing. Finally, the new method has been applied successfully to evaluate the lift and drag coefficients for fixed and variable pitch two-bladed VAWT configurations to analyse the differences in the performance between the two configurations.

2.1 Objective

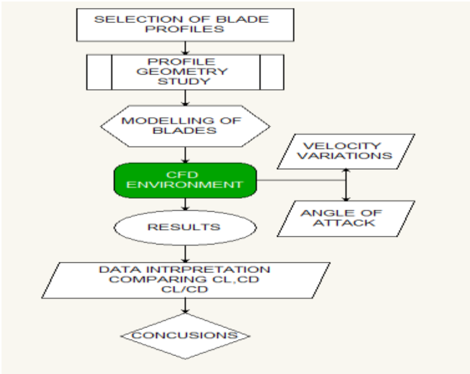
This paper presents a new method for the estimation of the AOA which uses the CFD simulated flow field data at two well selected reference points around the blade. The new method has a minimal error and more accurate estimation of the AOA compared to all the existing method tested. In addition, the new method could be integrated into the CFD solver to provide a computational inexpensive calculation in order to extract the instantaneous AOA variations along the blade flying path for efficient blade aerodynamic analyses and optimization.

(ii) Proposed methodology of variants and Boundary conditions:

Angle of attack- constant (Normal to the blade profile)

Blade twisted angles-0^0, 5^0,10^0,15^0; Wind velocity-5,5.5,6,6.5,7,7.5,8m/sec

Pressure- operating-101325 pa; Fluid density-1.177[Kg/m^3]
Reynolds number-10^6; Model- Realizable Ķε
Viscosity of fluid- 1.009x10^{-5}



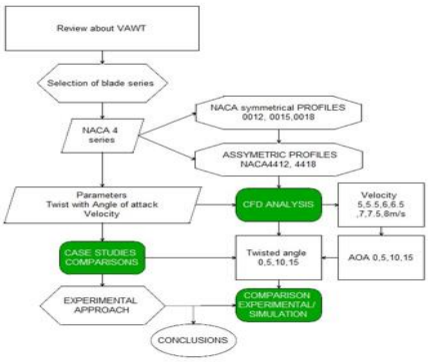
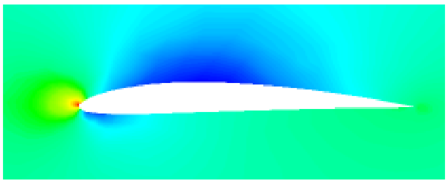


Figure1 shows methodology and Schematics of (a) the incident flow around a static aerofoil and (b) the computational domain for the static aerofoil case (not to scale)

3.0 Profile geometry and CFD approach



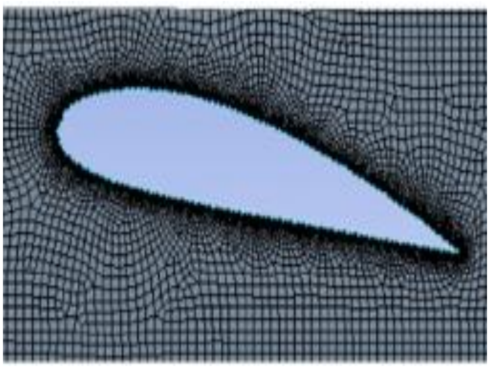


Figure2 shows the deviation between NACA 4412 and 4418

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3.1Twisted geometries of 4412 and 4418

The majority of wind turbine research is focused on accurately predicting efficiency. Various computational models exist, each with its strengths and weaknesses that attempt to predict a wind turbine's performance accurately. Predicting wind turbine performance numerically offers a tremendous benefit over classic experimental techniques, the significant benefit being that computational studies are more economical than costly experiments.

3.2 Experimental set up

Rotor Diameter = 19cm

Rotor Height = 21cm

Blade length = 18.5cm

Blade width = 7.5cm

Max. Speed of Wind Tunnel = 25m/s (Low Speed Wind Tunnel)

Test Section Area = 30cmx30cm.

Figure 3: a) Experimental set-up b) experimental study in rotor

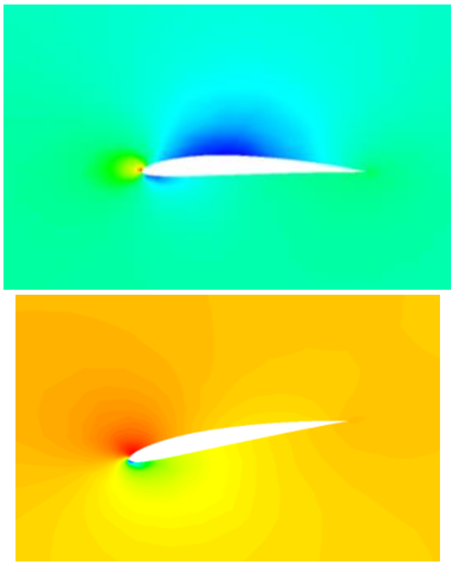

Figure4:Shows the Naca 4412 with twisted profile geometry from 0 to 15 degrees

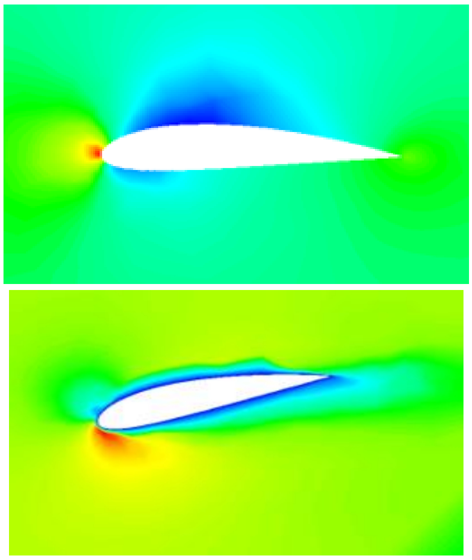

Figure5: Shows the Naca 4418 with twisted profile geometry from 0 to 15 degrees

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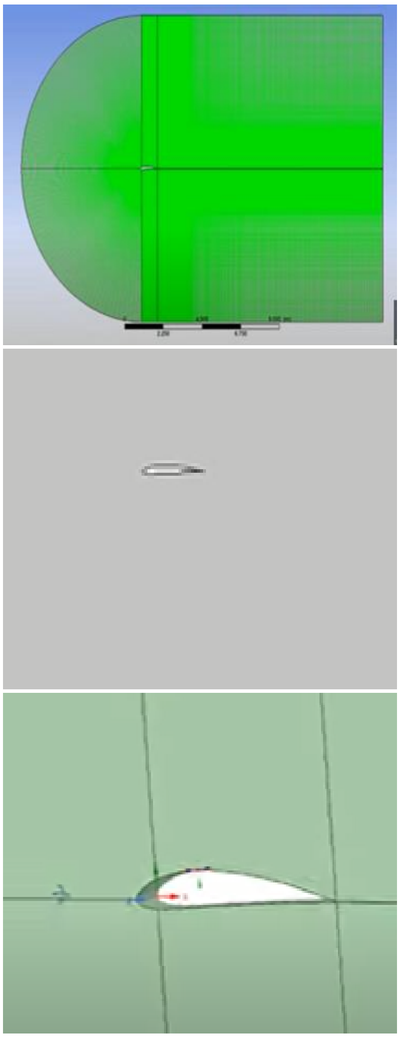
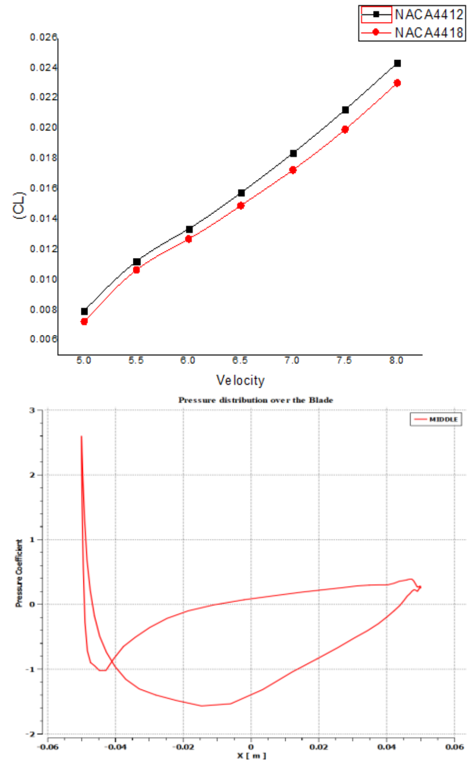
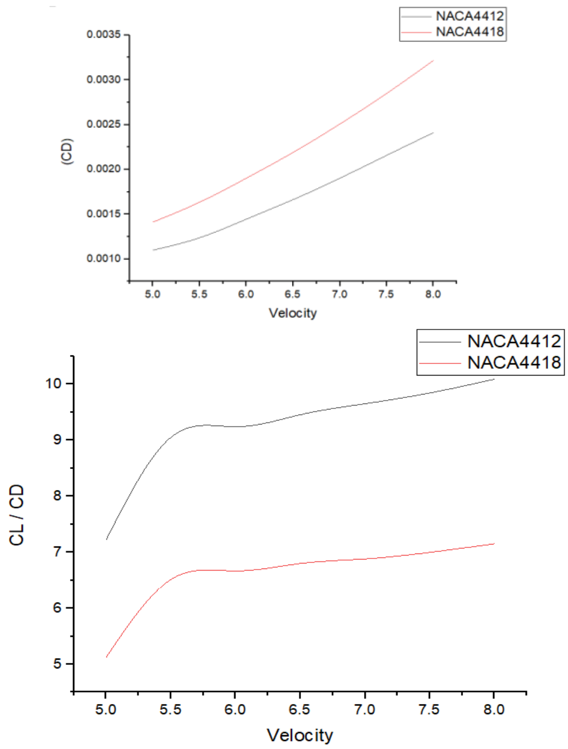


Figure:6 Shows the CFD environment for profiles selected

4.0 Results and discussions



Graph 1: Comparison of coefficient lift at 0 degree twist with different velocities and pressure distribution at maximum twist



Graph2: Comparison of coefficient drag at 0 degree and CL/CD at 0 degree

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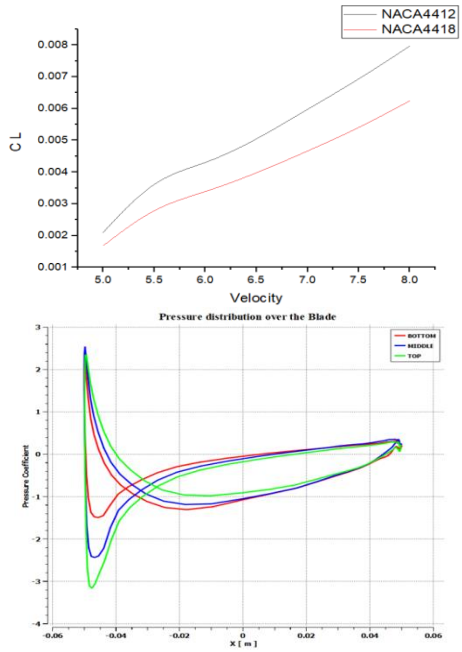
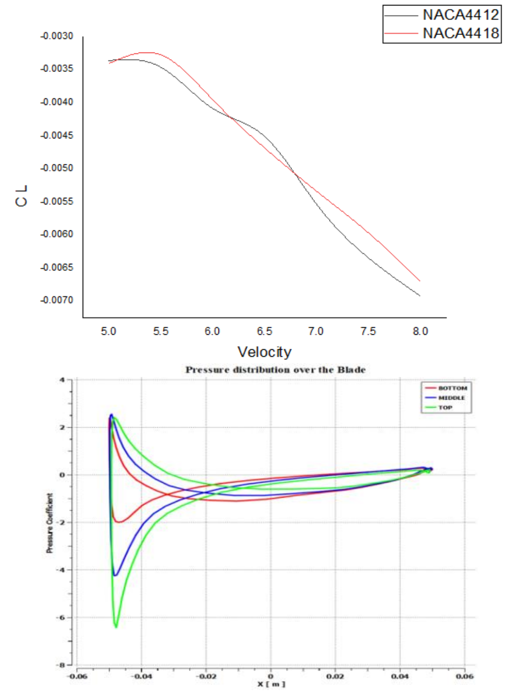
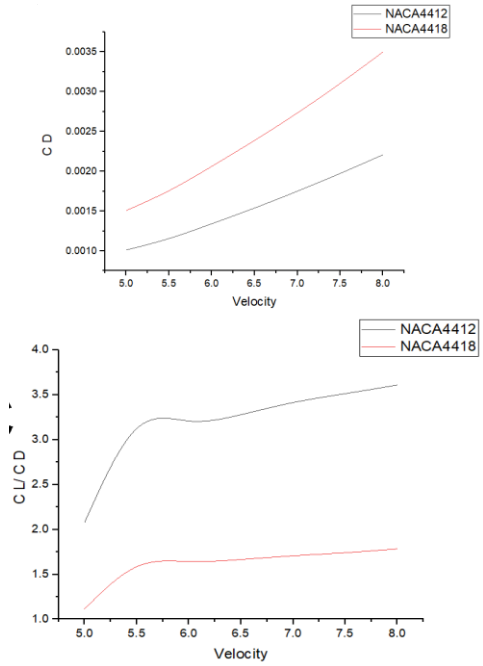


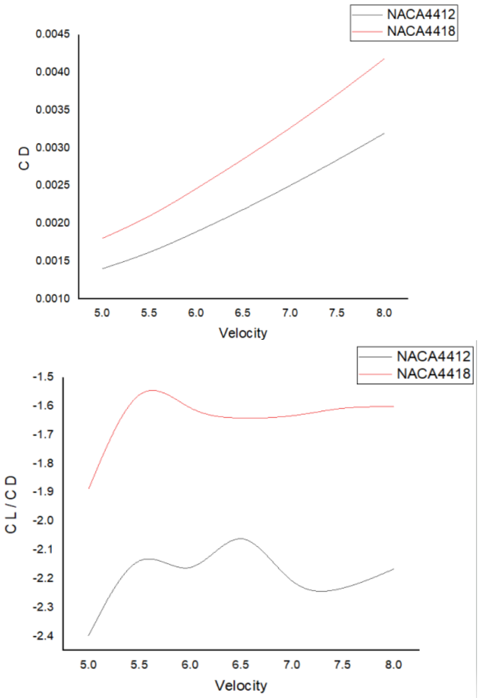
Graph3: Comparison of coefficient lift at 5 degree twist with different velocities and pressure distribution at maximum twist



Graph5: Comparison of coefficient lift at 10 degree twist with different velocities and pressure distribution at maximum twist



Graph4: Comparison of coefficient drag at 5 degree and CL/CD at 5 degree



Graph6: Comparison of coefficient drag at 10 degree and CL/CD at 10 degree

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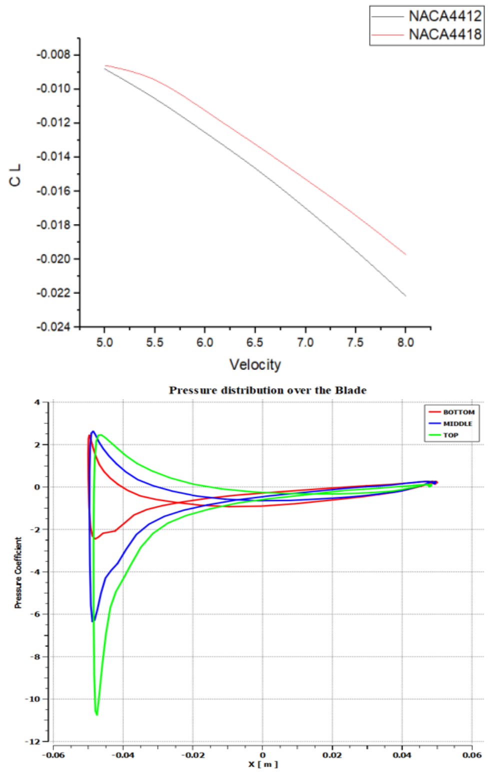
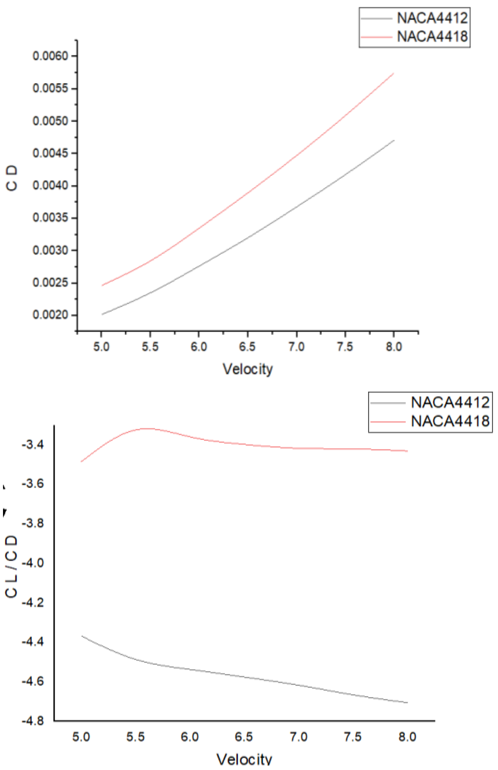
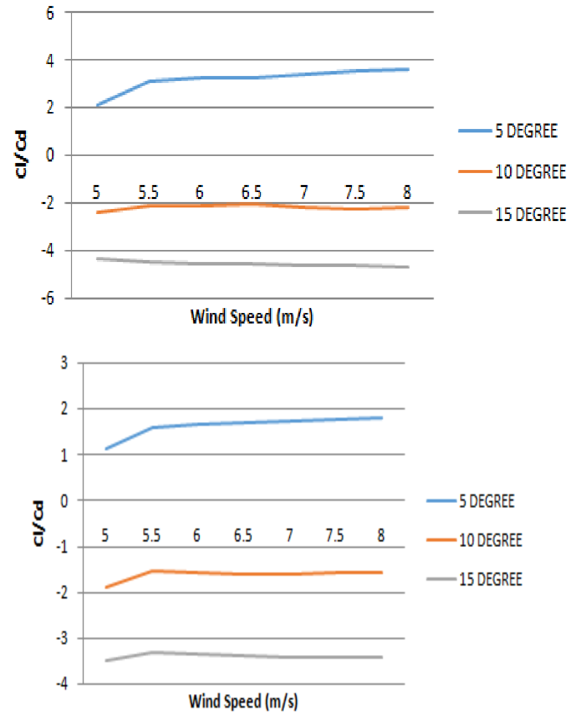


Graph7: Comparison of coefficient lift at 15 degree twist with different velocities and pressure distribution at maximum twist



Graph 8: Comparison of coefficient drag at 15 degree and CL/CD at 15 degree



Graph:9Cl/Cd NACA 4412 at various speed and twist angles and Cl/Cd NACA 4418 at various speed and twist angles

5.0 Experimental results

Table1: CL/CD comparison for different twist angles and velocity ratios NACA 4412

	Velocity of lift			
Angle of twist	5m/s	6m/s	7m/s	8m/s
5	1.5824	1.5845	1.6096	1.6357
10	1.270	1.356	1.403	1.429
15	1.0288	1.0285	1.0700	1.0890

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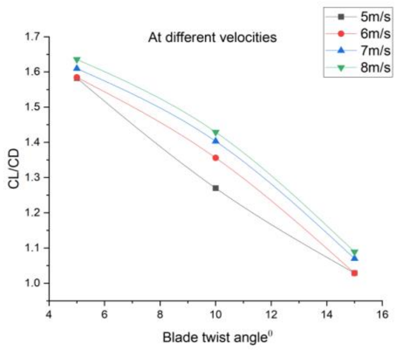

Figure7: shows the comparison of twisted CL/CD and twisted blade assembly

Experimental results at Straight blade rotor. will get D_e constant. The following values are obtained by considering N(rpm) as per the formulae. When Length of the rotor=0.28 m. The following table is modified from above by reverse engineering focusing on efficiency. So please check once sir about the torque we r getting in between 1 to 6 N-M.

Table2: Experimental study of straight blade without twist for power and efficiency

Velocity of wind(m/s)	T.S.R	τ (N-M)	D_e(m)	N(rpm)	(ω) Rad/sec	I/P(w)	O/P(w)	η (%)
5	0.79	1.76	1.127	33.90	3.55	23.97	6.26	26.11
5.5	0.84	2.20	1.127	39.44	4.13	31.89	9.09	28.50
6	0.89	2.79	1.127	45.64	4.78	41.01	13.36	32.57
6.5	0.93	3.42	1.127	51.76	5.42	52.65	18.56	35.25
7	0.95	4.51	1.127	58.15	6.08	73.13	27.42	37.47
7.5	0.98	4.88	1.127	62.45	6.54	80.88	31.95	39.50
8	1.00	5.75	1.127	67.90	7.11	98.15	40.93	41.70

Experimental results at Theta=5^0 twists. As the twist is constant will get D_e constant. The following values are obtained by considering N(rpm) as per the formulae. When Length of the rotor=0.28 m. The following table is modified from above by reverse engineering focusing on efficiency. So please check once sir about the torque we r getting in between 2 to 7 N-M

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Table3: Experimental study of straight blade without twist for power and efficiency

Velocity of wind (m/s)	T.S.R	τ (N-M)	D(m)	$N_{(rpm)}$	(ω) Rad/sec	I/P (w)	O/P(w)	η (%)
5	0.8	2.03	1.117	34.27	3.5	23.97	7.11	29.7
5.5	0.83	2.53	1.117	39.03	4.08	31.89	10.33	32.4
6	0.88	3.21	1.117	45.19	4.72	41.40	15.19	36.79
6.5	0.92	3.94	1.117	51.18	5.35	52.64	21.10	40.14
7	0.95	5.19	1.117	53.5	5.59	65.75	28.00	42.64
7.5	0.96	5.62	1.117	61.63	6.45	80.87	36.31	44.92
8	0.98	6.62	1.117	67.11	7.02	98.15	46.52	47.41

5.1 Discussions

The overall objective of the work was to successfully demonstrate a proof-of-concept optimization system capable of maximizing the efficiency of a three-bladed VAWT. Two test cases were conducted to demonstrate the robustness of the optimization system. The first test case was a 2-parameter optimization where both the solidity and tip speed ratio were fixed. The second test case was a comparative study for a fixed tip speed ratio before the final results of the optimization were presented. Finally, the results of the two optimization test cases will be introduced and compared with the performance of the baseline geometry.

The generation of NACA airfoil geometries, hybrid mesh generation, and unsteady CFD was coupled with the DE algorithm subject to tip speed ratio, solidity, and blade profile design constraints. Used the Optimization to obtain an optimized blade cross-section for 2 test cases, resulting in designs that achieved higher efficiency than the baseline geometry. The optimized design for the 1st test case achieved an efficiency 2.4% higher than the baseline geometry. The efficiency of the optimized geometry was attributed to eliminating a leading-edge separation bubble that was causing a reduction in efficiency and an increase in cyclic loading. For the 2nd test case, the VAWT was given complete geometric flexibility as both the blade shape and rotor solidity were allowed to change during the optimization process.

6.0 Conclusions

A new methodology for fast development and its associated equations has been present to study the influences of the wind on the turbine in its stopped position. This new methodology closely relates the blade profile design and the wind forces acting on the blades.

Drag, lift and torque coefficients over the whole runner for a 2D simulation shows an oscillatory behaviour with a dominant frequency that coincides neither with the runner spin frequency nor with the runner's blade-to-blade one. This dominant frequency has its origin in the non-alternating vortex shedding detected downstream the runner and, because of its amplitude, should take it into account for avoiding resonances when designing the structural system of the turbine.

The angle of twist increases lift to drag ratio CL/CD value increases in both the blade profiles compare to the both the ratio is more in 4418 profile when compared with 4412. A negative value in lift coefficient leads to thrust of wind forces is more in 4418 than 4412. NACA asymmetric profiles with twisted angle in design revels that at low velocities performance is better by observing both experimental and simulation. The power enhancement also increased with the twisted blade approximately 14% when compared with the straight blade.

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