

TWIST ANGLE ANALYSIS OF HELICAL VERTICAL AXIS WIND TURBINE (VAWT) USING Q-BLADE

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ABSTRACT:

In this paper the analysis of DU-06-W200 and NACA 0018 , NACA 0021 airfoil using Q-Blade & analytical method is investigated . The power produced by 1 kw wind turbine with Helical blade for the twist angle (ψ) 30° , (ψ) 60° (ψ) 90° (ψ) 120° configurations are analyzed with Q-Blade open source simulator software. The basic principal of double -multiple stream tube model (DMS) utilized for determination of energy extracted by wind blade from the fluid by reducing its velocity. The blades of the rotor pass through stream tubes twice due to circular path of VAWT. The blade design simulation tool found as reliable and less expensive alternative to experimental method in determining blade configuration.

INDEX TERMS: Twist angles (ψ), DMS, Benz limit, Angle of attack (AOA), Vertical Axis Wind Turbine (VAWT).

1. INTRODUCTION:

Wind energy benefits our local and national economy by creating jobs and reducing reliance on imported energy. Studies have shown that wind energy provides more jobs per rupees invested or per kilowatt-hour (kWh) generated, than most conventional resource options. The ability of VAWT to capture wind from all directions the small scale wind mills becomes popular to cater Electricity demand of urban areas The Blade design simulators has been widely used in wind turbine optimization [1] and proves cost effective tool as compared to wind tunnel testing. The 3D Blade simulation for wind airfoil is widely used to evaluate the angle of attack coefficient of performance and Power extracted by turbine. and momentum coefficients. The values obtained can be validated with experimental values obtained from wind tunnel test.

1.1 ANALYTICAL CALCULATIONS OF LIFT AND DRAG FORCED:

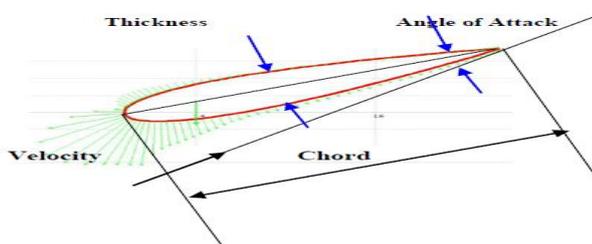


Fig 1: Airfoil Parameters

The angle between chord line and the direction of motion of plane is called as Angle of attack. It is an important parameter which affects the coefficient of lift and drag.

Lift coefficient is a dimensionless coefficient which depends upon the lifting force on the body, fluid velocity, surface area and the density of the fluid in which body is immersed.

Drag coefficient is a dimensionless coefficient which relates the drag force on the body to its velocity, surface area and the density of the fluid in which it is moving.

Albert Bentz [2] German physicist define limit which indicates maximum possible extraction of kinetic energy available in the wind. The maximum theoretical efficiency of wind turbine as per Bentz limit is 0.593. The data obtained from Qblade simulation can be used to design wind turbine parameters with efficiency closure to Bents limit.

1.2 ANALYTICAL CALCULATIONS:

Albert Bentz [3] German physicist define limit which indicates maximum possible extraction of kinetic energy available in the wind. The maximum theoretical efficiency of wind turbine as per Bentz limit is 0.593. The data obtained from Qblade simulation can be used to design wind turbine parameters with efficiency closure to Bents limit The power calculated for the turbine with twist angle ($\psi= 0^\circ$) is as below . [4] The Blade shape factor changes with change in twist angle of the turbine

1.2.1 POWER OBTAINED FROM TURBINE (P):

The VAWT model with blade height 2.4 m and rotor diameter 1.9 m consider for simulation and analytical investigation.

$$P = (1/2 \rho A V^3 C_P) \times (C_g) \times (C_m) \times (A_f)$$

Where, P	- Lift Force in W	
ρ	- Density of air	= 1.225 kg/m ³
V	- Velocity of air	= 12 m/s.
A	- Swept Area	= 4.56 m ²
C_P	- Coefficient of Performance	= 0.274656
C_g	- Generator Efficiency	= 0.95
C_m	- Mechanical Efficiency	= 0.85
A_f	- Blade Shape Factor	= 0.96

$$P = 0.5 \times 1.225 \times 4.56 \times 12^3 \times 0.2746 \times 0.95 \times 0.85 \times 0.96$$

$$P = 1027.3 \text{ W}$$

2. PROBLEM STATEMENT AND PARAMETER SELECTION:

To perform 3D simulation on airfoil DU-06-W200 and NACA 0018 , NACA 0021 airfoil using Q-Blade [5] determine power generated for helical bade at twist angle (ψ) 30° , (ψ) 60° (ψ) 90° (ψ) 120° degree with wind speed 12 m/s . The chord length 0.3 m is selected for the airfoil geometry.

2.1 TURBINE GEOMETRIC PARAMETER SELECTION:

To perform the analysis using Q-Blade following VAWT specification of VAWT are selected.

Table 01 specifications of VAWT

Parameters	Specifications
Axis of rotation	Vertical
Blade height	2.4 m
Rotor Diameter	1.9 m
Blade type	Helical twisted
Twist angle	0,30,60,70,90,120
No of blades	3
Swept area	4.56 m ²
Blade material	Fiberglass
Rated power	1000 W
Cut in wind speed	3.5 m/s
Cut out wind speed	25 m/s
Rated wind speed	11 m/s
Rated blade RPM	180 RPM

3. VAWT BLADE DESIGN PROCESS:

The simulation work presented in this paper was carried out by using QBLADE v 0.963 64 Bit open source software modules[6].

Q-Blade analysis involves following steps.

1. Airfoil Design: Select NACA airfoil 0018, NACA 0021, DU-200 4 digits and Number of panels 100
2. Xfoil direct analysis:
3. Polar Extrapolation to 360°
4. VAWT Rotor blade Design
5. Rotor DMS simulation
6. Multi parameter rotor DMS simulation
7. Turbine DMS simulation
8. Nonlinear Lifting Line Simulation.

3.1 AIRFOIL DESIGN:

The first step is to create a wind turbine blade using 2-D airfoil data available in Insert NACA foil section. Click on foil from menu and select NACA Foils. The NACA Foils window appears then type four digits ex. 0021 and number of panels 100. NACA airfoil 2-D Geometry eneredated .Similarly generates NACA 0018 Airfoil. The DU-200 airfoil generated using DAT file.

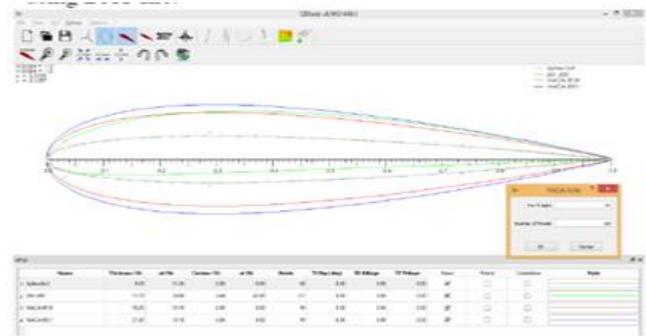


Fig : 02 Screen shot 2D Airfoil Generation using Airfoil Design Module

3.2. XFOIL DIRECT ANALYSIS:

In this analysis the angle of attack (AoA) from range -20 degree to 20 degree analyzes. The graph of angle of attack alpha Vs ratio of lift to drag coefficient [7] generated for all three airfoil. The maximum lift to drag ratio at higher angle of attack observed for NACA 0018 airfoil graph shown in fig.no.03 DU-200, NACA0018, NACA0021 airfoil.

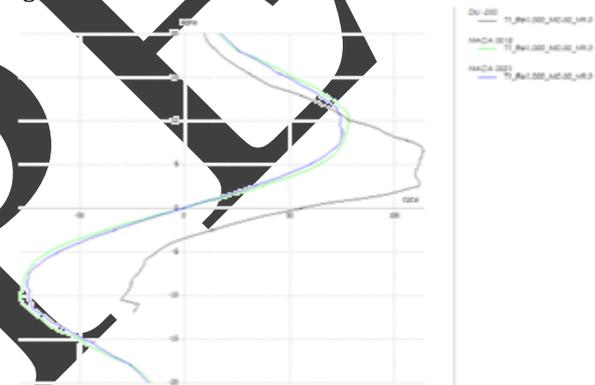


Fig: 03 Graph of angle of attack alpha Vs ratio of lift to drag coefficient

3.3 POLAR EXTRAPOLATION TO 360°:

The wind airfoil polar refer to the aerodynamic performance of the airfoil over wide range of wind flow angles. In this module lift, drag and moment polar coefficients[8] are extrapolated for 360° of wind flow angle range .The blades of vertical axis wind turbine always operate on high wind flow angles in the wind field. The fig 04 shows maximum lift coefficient at lower AoA the airfoil DU-200 as compare to NACA0018,NACA0021 .

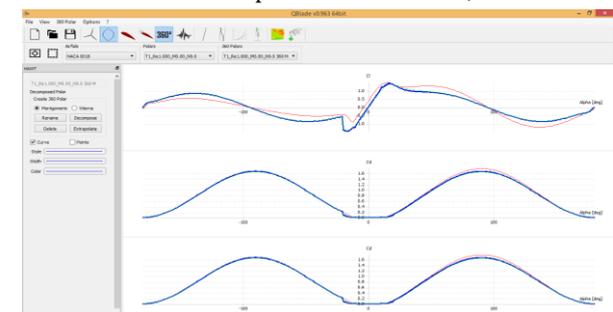


Fig: 04 Polar Extrapolation Modules

The lift and drag polars are extrapolate the angle of attack range using a curve fit. The polar extrapolation is essential as wind turbines operate in rainy season or high wind conditions at very high AoA and deep stall [9]. The accurate simulation need to iterate over various values of α which are outside the -20 to 20 degrees or so that we actually close to on field operating conditions . After opening the file, click on the 360° tab in Qblade. In the toolbar under Airfoils, make sure NACA 0021,NACA0018,DU-200 has been selected. Click on "Extrapolate" in the VAWT side bar. The window should refresh and look similar to the Fig 04

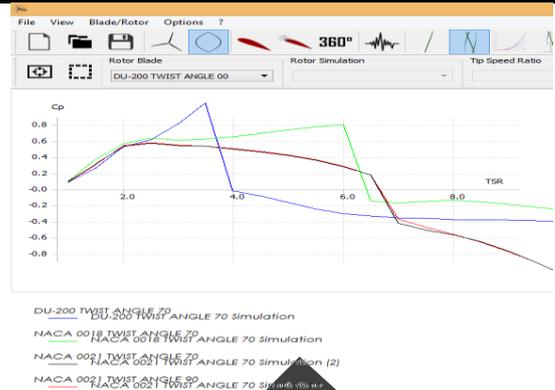


Fig: 06 Graph of CP vs TSR

3.4 VAWT ROTOR BLADE DESIGN:

In the blade design module the helical blade with twist angle (ψ) 30° , (ψ) 60°, (ψ) 70°, (ψ) 90°, (ψ) 120° are designed. The blade design and optimization submodule allows the rotor design for different airfoil types. A blade consists of a 40 number of blade sections. The following parameters are used to design blade

- Blade Height 2.4 m
- Chord 0.03m
- Radius 0.95 m
- Twist angle 0-70
- Foil DU-200, NACA0018, NACA 0021
- Number of Sections 40

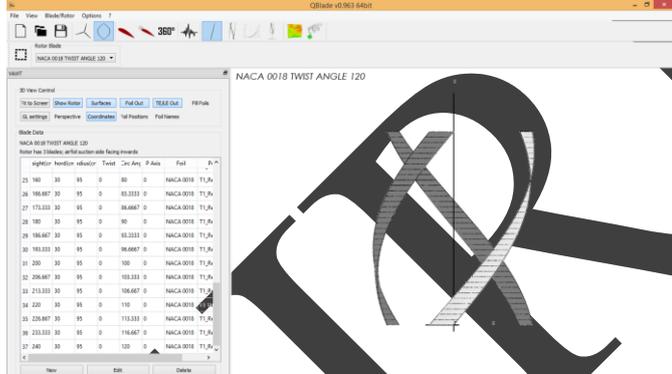


Fig: 05 Screen shot of Rotor Blade Design Module

3.5. ROTOR DMS SIMULATION:

In the turbine definition and simulation submodule, the user can define and simulate a wind turbine. To define a wind turbine, a rotor blade must be present in the runtime database and the turbine parameters have to be specified. The parameters that define a turbine are:

- _ rotor blade 3 Nos.
- _ cut-in wind speed 3.5 m/s
- _ cut-out wind speed 25 m/s
- _ turbine offset -
- _ fixed and variable losses 0.95

The graph shown in fig 06 indicates maximum TSR 6 at maximum coefficient of performance 0.8 with NACA 0018 airfoil helical rotor. VAWT rotor specifications at twist angle 70° consider for analysis shows Maximum cp 0.42 at 1.49 calculated TSR.

3.6. MULTI PARAMETER ROTOR DMS SIMULATION:

In the rotor simulation submodule, the user can commit rotor blade simulations over a range of tip speed ratios. A rotor simulation can only be defined when at least one rotor blade is present in the runtime database. When defining a rotor simulation, the user has to select the desired corrections to the DMS algorithm and the simulation parameters. Once a simulation is defined, the user can select a range of l-values (tipspeed ratios), and the incremental step for the simulation. A rotor simulation is always dimensionless.

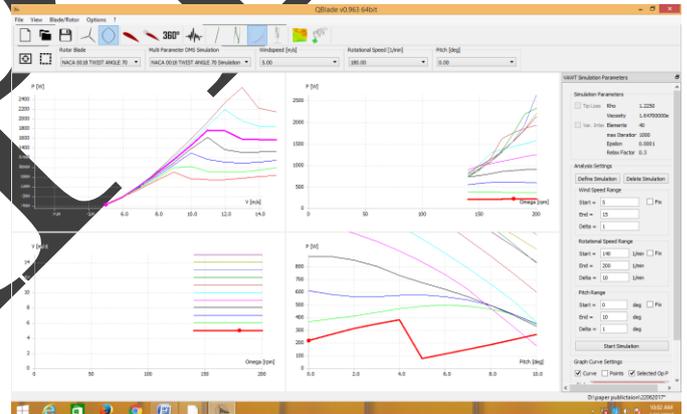


Fig: 07 ROTOR DMS Simulation Module.

3.7. TURBINE DMS SIMULATION:

The Double-Multiple Stream tube Model is basically derived from actuator disk theory and the blade element theory. The stream tube flowing through the VAWT rotor is splitted up into a set of smaller stream tubes. The blades of the rotor pass through each of these stream tubes on their 360 degree path and extract energy from the fluid by reducing its velocity. Thus, the standard actuator disk theory can be applied for every streamtube[9] in particular. Due to the circular path of a VAWT blade, it passes each streamtube twice. These two steps of energy extraction are taken into consideration in the DMS model by dividing the rotor into an upstream and downstream half. Each one is represented by a separate rotor disk. This double disk acts like two single actuator disks in tandem.

The subsequent iteration algorithm is hence executed twice for every streamtube.

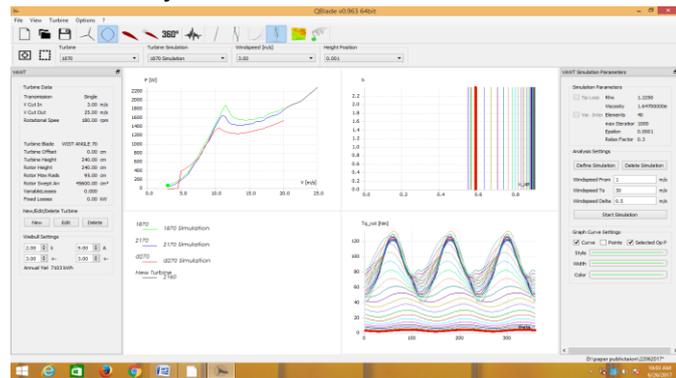


Fig: 08 ROTOR DMS Simulation Module

3.8. NONLINEAR LIFTING LINE SIMULATION METHOD:

The term nonlinear refer to the non linear lift and drag polars are used to compute bounded vortices along the lifting line.

Lifting line method basically a type of "Vortex Method" used to Model wind flow field[8] and rotor blades. In Lifting line method the blade is modeled as single line of vortices. The lifting line simulation has much lower computational cost as compare to computational fluid dynamic (CFD) simulations

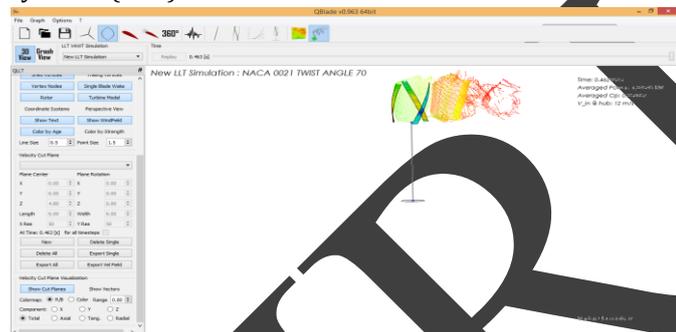


Fig: 09 Screen shot of nonlinear lifting line simulation with Vortex

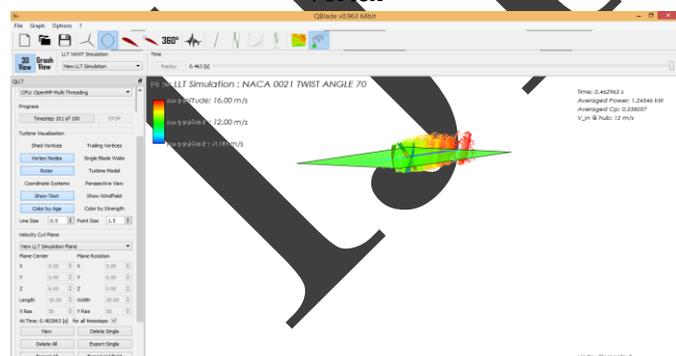


Fig: 10 Screen shot of nonlinear lifting line simulation with Velocity magnitude on cutting plane

3.9 QBLADE SIMULATION PARAMETERS:

The computational conditions are kept same for all designs of helical blade with different helix angle. Following Parameters are used to solve simulation module

Table: 1- QBlade Simulation Parameters

Airfoil	1. DU-200 2. NACA 0018 3.NACA 0021
Simulation Type	Nonlinear Lifting Line Simulation LLT
Fluid Material	Air
Temperature	300K
Kinematic Viscosity	1.4607 10-5 m2/s
Density	1.225 kg/m3
Model	DMS
Inflow Wind Speed	11 m/s
RPM Rotor	180
TSR	1.62
No. of Time Step	700
No. of Rotor Revolution	10

4 SOLUTION METHODOLOGIES:

Following four approaches are generally used to evaluate aerodynamic performance of vertical axis wind turbine

- Momentum models
- Vortex models
- Local circulation models
- Viscous models – Computational Fluid Dynamics (CFD)

Each model has its advantages and drawbacks, and requires variable computational time. Computational fluid dynamics was considered in first place but the time needed for mesh generation. Blade element theory coupled with a momentum balance over single or multiple stream tubes are widely applied in the wind turbine industry[11]. The present paper software QBlade use Vortex Model" with nonlinear lifting line simulation method. The XFOIL module enables the user to rapidly design custom airfoils and compute their polars, extrapolate the polar data with AoA to a range of 360°, and directly incorporate with a wind turbine simulation module.

4.1 ITERATION:

The iteration is carried out with variable called as interference factor u. A interference factor u is ration of upwind velocity to free undisturbed velocity of wind flow .The rotor simulation is executed for range of tip speed (TSR) 1 to 10 .The global TSR Value for present case calculated as

$$TSR = R\omega / V_{\infty} = 0.95 \times 18.85 / 12 = 1.49$$

where R is the radius (of the equator), w is the angular speed of the blade and

V_{∞} is the freestream inflow velocity. A turbine simulation is generally executed for a range of wind speeds from 1 m/s to 25 m/s. For each tip speed ratio, the iteration is executed at every height position of blade 0 to 2.4 m from for all upwind azimuthal angles (streamtubes) until the defined epsilon value 0.0001 is obtained .

5. RESULTS AND DISCUSSION:

The simulated results in table: 2 and table: 3 show that the structured grid gives better results for various angle of attack. With increases in value of angle of attack lift, and drag coefficient are increased up to stall angle.

Power contour for NACA 0018 and NACA 0021 and DU-200 airfoil are shown in fig 10. The Figure no.10 shows graph of Power in watt and velocity in m/s no. of iterations generated by rotor DMS simulation module[11]. The value of Power in watt is represents on the vertical-axis and the value of velocity in m/s on horizontal-axis. The First top curve for Rotor with NACA 0018 airfoil shows better output Nearly 1900 w at 11 m/s. The Graph obtained from DMS simulation module shows constant torque value by helically twisted rotor while same rotor with zero twist angle shows fluctuating torque. The simulated results are obtained after 700 iterations with time step 10.

5.2 RESULT COMPARISON FOR STRUCTURE AND UNSTRUCTURED GRID DOMAIN NACA 4424:

Table: 2- Average Power for Various Twist Angle

Twist angle Twist angle (ψ)	Average power Using Qblade Simulator		
	DU-200	NACA 0018	NACA 0021
	Power Kw	Power Kw	Power Kw
0	0.912289	1.32558	1.23428
30	0.921674	1.33242	1.23350
60	0.915745	1.34522	1.24420
70	0.929437	1.35138	1.24546
90	0.901230	1.36348	1.25411
120	0.898227	1.36782	1.25751

Table: 3- Average CP Using Qblade Simulator for Turbine

Twist angle (ψ)	Average CP Using Qblade Simulator for Turbine		
	DU-200	NACA 0018	NACA 0021
0	0.189024	0.274656	0.25574
30	0.190969	0.274003	0.25578
60	0.189470	0.278726	0.257798
70	0.188433	0.280030	0.258057
90	0.186733	0.282506	0.259848
120	0.186129	0.283400	0.260553

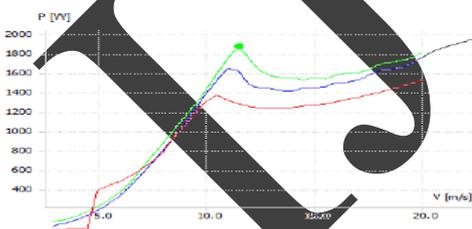


Fig : 10 Graph of power Vs Velocity

6. CONCLUSION AND OBSERVATIONS

The primary focus of this paper was on analyses a wind turbine blade airfoil using open source QBlade software.

The Helical blade for the twist angle(ψ) 0°, (ψ) 30°, (ψ) 60°, (ψ) 90°, (ψ) 120° are created using Blade Design and Optimization submodule. The blade airfoil DU-200, NACA 0018, NACA 0021 with different twist angle analyses

using nonlinear lifting line simulation module. The blade design with NACA 0018 airfoil with 120° twist angle observed with higher power kw output at 180 RPM. The two design configuration of vertical axis wind turbine Straight blade twist angle (ψ) 0°, and Helical blade twist angle (ψ) 120° observed 4% Increase in Power out put. From steady simulations, over a complete cycle, it has been observed that the Helical blades have an average torque coefficient increment equal to 8.75%. This leads the Helical VAWT to a low speed of Eventually, in the design stage of a Helical Vertical Axis Wind turbine, the nonlinear lifting line simulation using open source QBlade Software is less time consuming and can provide more information than a expensive experimental work.

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I have tried my best to present this information as clearly as possible using basic terms. I would like to extend my sincerest thanks to Mr. Yogesh Birari, Product Engineer - Manager at Cummins Emission Solutions, Pune for CFD concepts and comments that greatly improved the manuscript.

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