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Increasing Efficiency of a Twisted Blade Vertical Axis Wind Turbine (VAWT) by Changing Various Parameter

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Abstract- *This qualitative research deals with moderation of vertical-axis wind turbine (VAWT) of Darrieus type. We performed a research in which three twisted bladed vertical axis wind turbines (VAWT) were designed and tested for optimal performance at various wind speeds. A blade with twist will have a variation in angle of attack from hub to tip because of the variation of distance from the hub. The lift and drag have optimum values for a single angle of attack so a blade without twist is less efficient than a blade with the proper twist to maintain a nearly constant angle of attack from hub to tip. Even the blades were twisted and the pitch angle will change from hub to tip to improve the efficiency. Wind energy has to compete with many other energy sources in future. To compete with others it had to cope with the least affirmative conditions to maximum positive conditions. Usual challenge for the turbines is performing at low wind speed. So far we have achieved 22rpm at 1.8m/s wind speed when the blades are wider and twisted by 120 degree. While twisted by 70 degree we got no rpm at 1.8m/s wind speed. It implies that the former condition produces better performance.*

Keywords: VAWT, Wind, Blade, Performance, Twist.

1. INTRODUCTION

Wind turbines have become a viable technology for power generation. Wind power energy is getting more shares in the total energy production every year. The goal of this project was to design a wind turbine specifically for low wind speed sites. Wind turbine does not run on low wind speed which possesses such a statement that wind power is not stable power source [1]. If wind is available we could not extract energy from wind due to its design. The aerodynamic design of blade is the key factor for using both drag force and lift force of wind flow in same turbine. This kind of blade is called “smart blade” [2]. Here we work on vertical axis wind turbine by varying various parameter of blade we increased its range of producing rpm and enabled of self-starting quality. This hybrid turbine has established a new benchmark of self-starting on low wind speed. We fabricated three turbines one gets self-starting at 2.75m/s another two get self-starting at 1.8m/s but both of them have different rpm. it is possible because of smart design of blades and changing various parameters. If this works out properly then small wind turbines can achieve such suitable advantage to produce power in such a low wind speed. Thus we can achieve remedy for the earlier described drawback. According to rotational concept wind turbines can be classified into two categories such as one is horizontal axis wind turbine (HAWT) and another is vertical axis wind turbine (VAWT). A vertical axis wind turbine has several advantages over the more traditional horizontal wind turbine, especially in uneven wind conditions where a horizontal wind turbine has to change directions,. In contrast, the VAWT is propelled by wind from any direction, and gravitational stresses on the vertical axis turbine are even, allowing lighter and larger construction. VAWT might be Omni directional but HAWT couldn’t. “On the basis of acting force VAWT can be branched into two sectors; they are lift force and drag force.” [2]. our turbine will work on both drag and lift force including self-starting quality to extract maximum potentialities from wind.

2. TURBINE PARAMETER

2.1. Swept Area

The swept area is the section of air that encloses the turbine in its movement; the shape of the swept area usually depends on the rotor configuration, this way the swept area of regular straight-bladed vertical axis wind turbine. The swept area has a rectangular shape and is calculated

$$S = 2 \times R \times L \qquad (1)$$

[3]

2.2. TIP SPEED RATIO

It can be defined as the ratio between the tangential speed at blade tip and the actual wind speed

$$TSR = \frac{Tangential\ speed\ at\ the\ blade\ Tip}{Actual\ Wind\ Speed} = \frac{R \times \omega}{Vo} \qquad (3)$$

[3]

Each rotor design has an optimal tip speed ratio at which the maximum power extraction is achieved.

2.3. Blade Chord

The chord is the length between leading edge and trailing edge of the blade profile

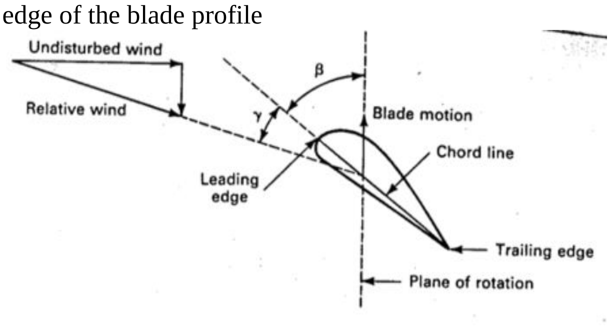


Fig.1: Wind turbine blade profile [3].

The chord line is the straight line connecting the leading and trailing edges of an airfoil. The plane of rotation is the plane in which the blade tips lie as they rotate. The blade tips actually trace out a circle which lies on the plane of rotation. Full power output would normally be obtained when the wind direction is perpendicular to the plane of rotation [4].

2.4. NUMBER OF BLADES

The number of blades has a direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamic loads. The four-bladed design has better behavior at low rpm, but the three bladed rotors present a much quicker response.

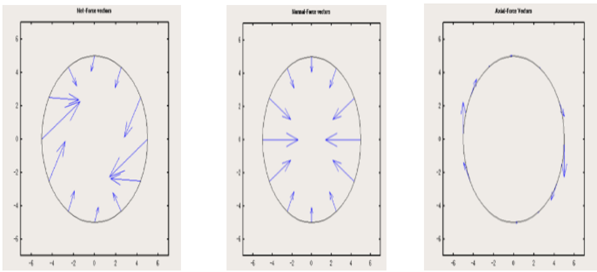
2.5. ANGLE OF ATTACK

The angle of attack is defined as the angle between the blade chord and the resultant air velocity. A positive initial angle of attack broadens the range of angular speed operation and a negative one shortens it, this is interesting when fixing the maximum rpm. One important parameter of a blade is the pitch angle, which is the angle between the chord line of the blade and the plane of rotation. The pitch angle is a static angle, depending only on the orientation of the blade. Angle of attack is a dynamic angle, depending on both the speed of the blade and the speed of the wind [4].

Table 1: Turbine parameters

parameter	Turbine-1(T-1)	Turbine-2(T-2)	Turbine-3(T-3)
Blade length(bl)	0.445m	0.445m	0.48m
Chord length(cl)	.03m	.06m	.07m
Rotor radius	0.1m	0.1m	0.1m
Turbine length	0.445m	0.445m	0.48m
Swept area	$0.089m^2$	$0.0924m^2$	$0.096m^2$
Angle of attack(degree)	10˚-40˚	5˚-50˚	50˚-80˚
Pitch angle	30˚	30˚	120˚
Blade number	3	3	3
Coefficient of lift(C_l)	0.70[6]	0.75[6]	0.75[6]
Coefficient of drag(C_d)	0.30[6]	0.50[6]	1.7[6]

3. THEORETICAL BACKGROUND



(A) (B) (C)

Fig.2: Force Diagram: A) Net force vectors B) Normal force C) Axial force [7].

The action of this apparent flow on each foil section generates both a lift and drag force, the sum of which is shown in the Fig. 2(A). Each of these net force vectors can be split into two orthogonal vectors: a radial component and a tangential component, shown here as "Normal force" as in Fig. 2(B) and "Axial force" in Fig. 2(C) respectively. The normal forces are opposed by the rigidity of the turbine structure and do not impart any rotational force or energy to the turbine. The remaining force component propels the turbine in the clockwise direction, and it is from this torque that energy can be harvested [5].

3.1. LIFT AND DRAG FORCE

Lift and drag coefficients are dependent on the Reynolds number and the angle of attack. When the lift and drag coefficients are determined, the lift and drag forces can be calculated using the following equations, respectively.

$$Fl=0.5\times \rho\times W^2\times cl\times bl\times C_l \quad (4)$$

$$Fd=0.5\times\rho\times W^2\times cl\times bl\times C_d \quad (5)$$

[6]

The lift and drag forces were then resolved into components parallel and perpendicular to the blades path of rotation. The following four equations were used to resolve the lift and drag forces into parallel and perpendicular components.

$$F_{l,help} = F_l \cos\left[\left(\frac{90\pi}{180}\right) - \left(\frac{\alpha\pi}{180}\right)\right] \quad (6)$$

$$F_{l,circ} = F_l \sin\left[\left(\frac{90\pi}{180}\right) - \left(\frac{\alpha\pi}{180}\right)\right] \quad (7)$$

$$F_{d,hurt} = F_d \cos\left(\frac{\alpha\pi}{180}\right) \quad (8)$$

$$F_{d,circ} = F_d \sin\left(\frac{\alpha\pi}{180}\right) \quad (9)$$

[6]

Finally, parallel forces are added, and perpendicular forces are added to obtain expressions for F_1 and F_2, as given by equations

$$F_1=F_{l,help}-F_{d,hurt} \quad (10)$$

$$F_2=F_{l,circ} + F_{d,circ} \quad (11)$$

[6]

Where F_1: forces contributing to torque (N)

F_2: centrifugal forces (N)

The resulting forces, F_1 and F_2, are the forces experienced by a turbine with one blade rotating about a central axis. [6].

4. MATERIALS

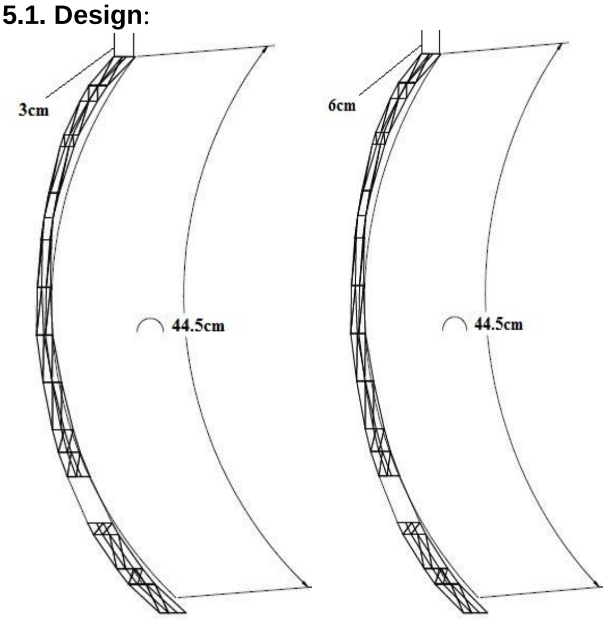
On this VAWT we used various types of material and set up. We also measured various types of parameters on this case. We evaluated this design on various processes.

Materials:

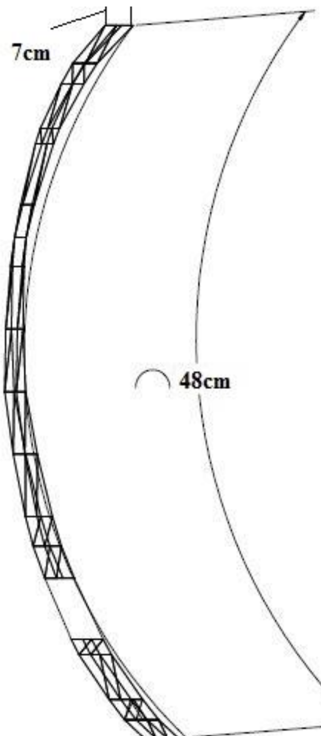
1. Aluminum, 2.Stainless steel, 3.Bearings 4. Bolts connections

5. DESIGN AND FABRICATION

5.1. Design:

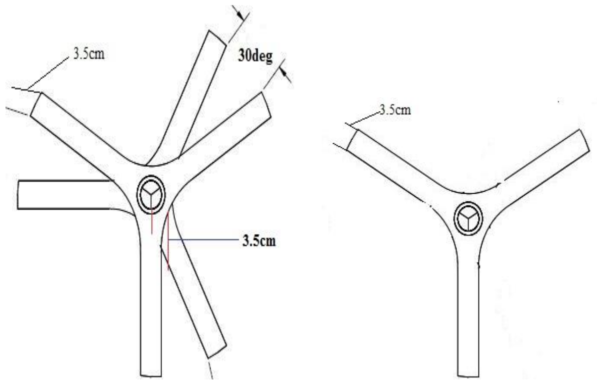


1. (I) (II)



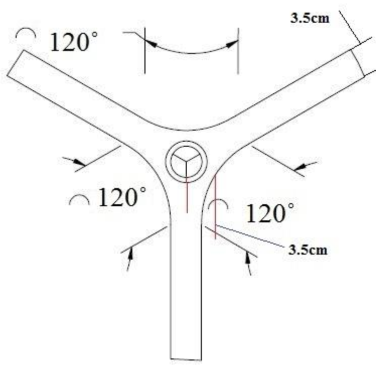
(III)

Fig.4: (a)(I)T-1's blade;(I)T-2's blade; (I)T-3's blade;

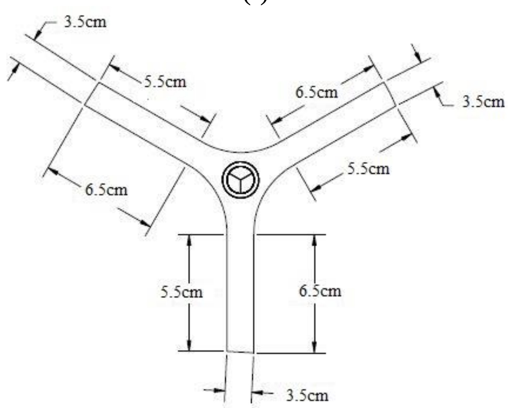


(I) (II)

Fig.4: (b)(I)T-1 &T-2's rotor; (II) T-3's rotor



(I)



(II)

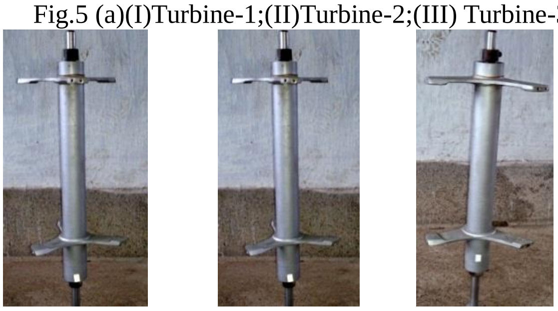
Fig.4: (c)(I)Angular deviation rotor;(II)Rotor dimensions

5.2Fabrication

Due to this research we fabricated three individual turbines. Fabrication process for each turbine is same; we molded the shaft with our desired dimension and the rotor. There are two rotors one is at the top and another at the bottom, bottom one is flexible we can change the pitch angle through this rotor. We rotated the pitch angle 30degree for turbine-1 and turbine-2 and rotated 120degree for turbine -3.We used aluminum mold casting for this part. We fabricated nine blades from stainless steel for three turbine each turbine consists three similar blade.T-1's blades are inclined 70 degree from horizontal axis and width is 3cm with 1.1mm thickness,T-2's blades are inclined 70 degree from horizontal axis and width is 6cm with1.1mm thickness.T-3's blade are inclined 54 degree from horizontal axis and width is 7cm with 1.3mm thickness. Then we assembled each part with the turbine and form each turbine.

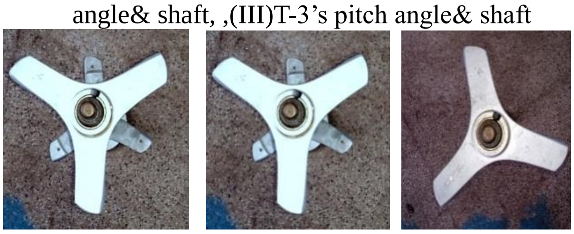
(I) (II) (III)

Fig.5 (a)(I)Turbine-1;(II)Turbine-2;(III) Turbine-3



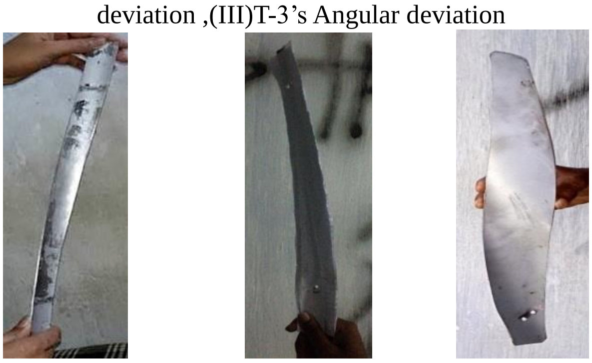
(I) (II) (III)

Fig.5: (b) (I)T-1's pitch angle& shaft,(II)T-2's pitch angle& shaft, ,(III)T-3's pitch angle& shaft



(I) (II) (III)

Fig.5: (c) (I)T-1'sAngular deviation (II)T-2's Angular deviation ,(III)T-3's Angular deviation



(I) (II) (III)

Fig.5: (d)(I)T-1's blade;(II)T-2's blade;(III)T-3's blade

6. Experimental Setup:

As we mentioned earlier we fabricated three turbines with different parameters.at first we go for turbine -1 which is placed at a significant distance from wind source to get our desired wind speed. When we find our self-starting wind speed for the turbine, we install that turbine inside the wind tunnel to get other data .we similarly set up turbine-2 and turbine-3 and get self-starting wind speed and then install the turbine inside the wind tunnel and get the desired data to compare among the turbines.

7. RESULTS AND DISCUSSION

7.1Results:

By using the equation (5) and [4), turbine specification & wind speed the following drug force, and lift force are found:

Table 2: F_l and F_d of T-1, T-2, and T-3

Wind speed(m/s)	Turbine-1's lift force(F_l) & drag force(F_d)(N)	Turbine-2's lift force(F_l) & drag force(F_d)(N)	Turbine-3's lift force(F_l) & drag force(F_d)(N)
1.8	F_l =0.0171	F_l =0.038	F_l =0.0461
	F_d =0.00733	F_d =0.0255	F_d =0.1056
2.75	F_l =0.03992	F_l =0.089 N	F_l =0.108 N
	F_d =0.0171	F_d =0.0595	F_d =0.2441
3.5	F_l =0.0646	F_l =0.145	F_l =0.1744
	F_d =0.02772	F_d =0.0961	F_d =0.3953
6	F_l =0.1900	F_l =0..425	F_l =0.5126
	F_d =0.0815	F_d =0.284	F_d =1.1618
8	F_l =0.3379	F_l =0.756	F_l =0.9112
	F_d =0.1448	F_d =0.504	F_d =2.065
9.5	F_l =0.4765	F_l =1.066	F_l =1.2850
	F_d =0.2042	F_d =0.711	F_d =2.9126
11	F_l =0.6389	F_l =1.430	F_l =1.7227
	F_d =0.2738	F_d=0.953	F_d=3.9050

By using equation (6), (7),(8),(9),(10),(11) we get F1 and F2

Table 3: F1 and F2 of T-1, T-2, and T-3

Wind speed	T-1		T-2		T-3	
1.8	F1	F2	F1	F2	F1	F2
	0.01	0.015	0.018	0.042	0.101	-0.056
2.75	.0237	0.037	0.043	0.098	0.234	-.129
3.5	0.038	0.059	0.07	0.159	0.379	-.208
6	0.151	0.078	0.207	0.251	1.112	-.611
8	0.269	0.138	0.37	0.835	1.977	-1.088
9.5	0.283	0.44	0.51	1.173	2.01	-1.53
11	0.366	0.59	0.698	1.57	3.735	-2.056

Wind speed	Turbine-1		Turbine-2		Turbine-3	
	RPM	*TSR*	*RPM*	*TSR*	RPM	TSR
1.8	0	0	9	0.052	22	0.157
2.75	25	0.095	29	0.110	45	0.171
3.5	60	0.179	65	0.194	78	0.233
6	84	0.146	91	0.158	118	0.205
8	125	0.163	138	0.180	195	0.255
9.5	212	0.233	248	0.273	290	0.319
11	308	0.293	333	0.317	390	0.371

Table 4: RPM and TSR of T-1, T-2, and T-3

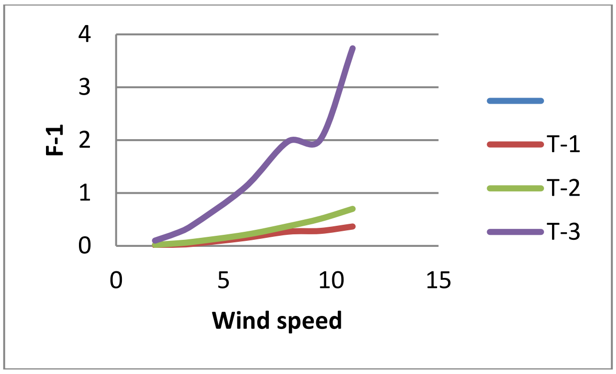


Fig 5: (a) Wind speed vs. F-1 of T-1,T-2,T-3

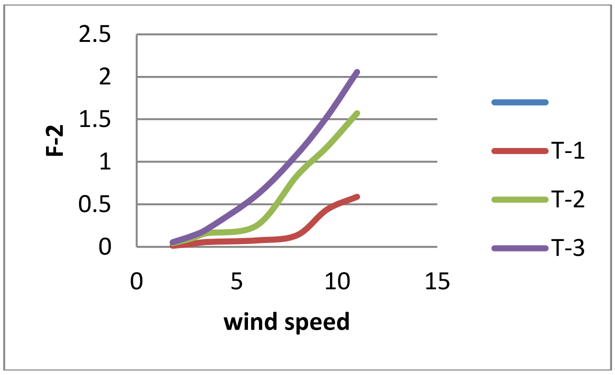


Fig 5: (b) Wind speed vs. F-2 of T-1,T-2,T-3

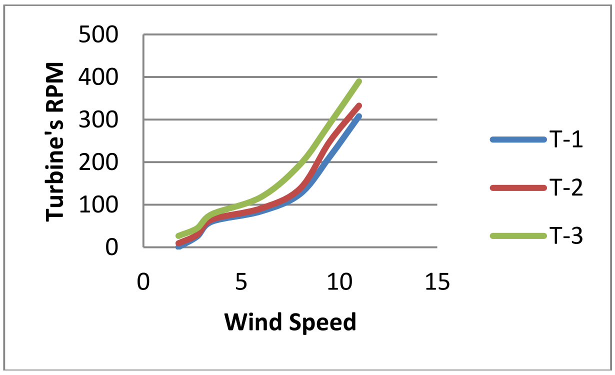


Fig 5:(c) Wind speed vs. RPM of T-1,T-2,T-3

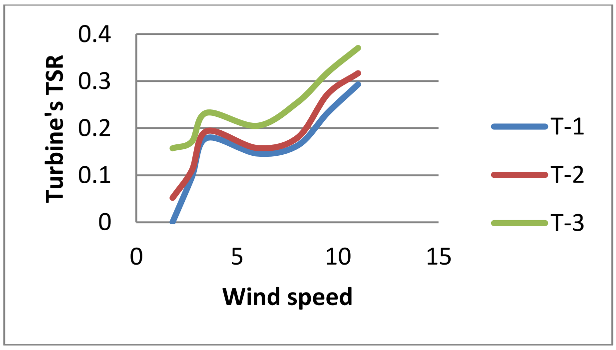


Fig 5:(d) Wind speed vs. TSR of T-1,T-2,T-3

7.2Discussion*:*

Through the graphs and tables we can evaluate that our modification in design really impacts on result. We able to combine both drag and lift force through the design and which offer a better performing turbine than previous one.by changing design we can improve the turbine's performance which is proofed through these graphs. As we are moving on right direction we hope we can modify the performance of turbine more that's why we should looking forward with this research.

8.CONCLUSION

We accomplished as we mention, we increased VAWT's self-starting region just by design. Our achievement is not up to the mark yet, we can claim much more better performance by evaluating parameters .we will attain better performance as we find so far from previous one.

9. ACKOWLEDGEMENT

During this project we are highly helped and co-operated by a couple teachers of the mechanical department and lab assistants. We like to especially grateful to Professor Dr. Sajal Chandra Banik. We are always ought to show proper respect to our department and Mr. Gaffar for engineering works.

10. REFERENCES

[1] Experimental Tests of a Vertical-Axis Wind Turbinewith Twisted Blades. "Gabriele Bedon, Marco Raciti Castelli, Ernesto Benini"
World Academy of Science, Engineering and Technology 78 2013

[2] C T. Carper "Design and construction of vertical axis wind turbine using dual layer vacuum forming. "dspace.mit.edu/bitstream/handle/1721.1/59899/676694167. Pdf"

[3] J Castilo "Small scale vertical axis wind turbine Design.upcommons.upc.edu/pfc/bitstream/2099.1/19136/4/memoria.pdf.

[4] "Wind Energy Systems: chapter -4" by G. L. Johnson

[5] http://en.wikipedia.org/wiki/Gorlov_helical_turbine

[6] MECH 4010 Design Project:Vertical Axis Wind Turbine J D Coste, D McKay ,B Robinson, and S W, S Wright "Vertical Axis Wind Turbine".

[7] Mekside » Wings Redux, mekside.com

NOMENCLATURE

Symbol	Meaning	Unit
F_l	lift force	N
F_d	drag force	N
Bl	blade length	m
C_l	lift coefficient	dimension less
C_d	drag coefficient	dimension less
Fl,help	Force in direction of travel	N
Fl,circ	Force contributing to centrifugal force	N

Fd,hurt	Force opposing motion of blade travel	N
Fd,circ	Force contributing to centrifugal force	N
TSR	Tip speed ratio	dimension less
ω	angular speed	rad/sec
		m
R	rotor radius	m/s
Vo	ambient wind speed	m^2
S	swept area	