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Integration of Optimum Power for Wind Turbine Blade at Different Cross Section

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Abstract

This research analysis and optimizes the main wind horizontal turbine blade parameters for high-performance altitude with variable pitch blade angle for different blade cross-section unsymmetrical airfoil NACA 4412 and unsymmetrical airfoil supercritical Eppler 417. For deep specification, some wind horizontal turbine parameters kept constant through the proses method to integrate the highest behavior of windmill turbine power coefficient. The procedure analysis with FORTRAN.90 code ,then compare with German code and then optimized using Schmitz and Betz method for blade chord and lift to drag for blade pitch angle. From theoretical results discussion, important conclusions figured; also a recommendation for further work was suggested. Best optimization methods were Schmitz chord optimization and Lift/Drag twist optimization which increases the Cp 10.3% for Eppler 4417 and 9.5% for NACA 4412.All results were tabulated and plotted for all optimization results

Keywords: Optimal Design, Algorithms, Betz Schmitz Lift/ Drag optimization, Wind Power, Computational Fluid Dynamics, Aerodynamic.

Symbol	Definition	Uints
a	$Interference\ factor$	…..
a'	$Tangential\ Interference$	…..
B	$No\ of\ Blade$	… …
C	$Chord\ Length$	m
P	$Power$	$watts$
r	$Radius$	m
U	$Wind\ Speed$	m/sec
u	$Axial\ Speed$	m/sec
v	$Normal\ Speed$	m/sec
n	$Rotational\ Speed$	$1/_{sec}$
n	$Rotational\ Speed$	$1/_{sec}$
Ω	$Angular\ Speed$	$Rad/_{Sec}$
λ	$Tip\ Speed\ Ratio$	………
φ	$Setting\ Angle$	deg
Q_P	$Pitch\ Angle$	deg
Q	$Torque$	N/m
Cl	$lift\ coefficient$	… … …
Cp	$Power\ Coefficient$	… … …
ρ	$density$	kg/m^3
α	$e\ of\ Attack$	deg

1. Mathematical Analysis

The analysis is used for blade element and momentum theory. Momentum theory refers to the forces at the blade based on the conservation of angular and linear momentum. Blade element theory refers to an analysis of forces at a blade section. The results of this approximation can be combined into blade element momentum (BEM) theory. This theory can be used to calculate the extract power from the wind [1].

1.1Momentum theory

By considering conservations of momentum, forces which are the rate of change of momentum the forces on a wind turbine blade and flow conditions at the blades can be derived. The axial and angular induction factors are assumed to be functions of the radius, ***r***. The conservation of linear momentum to the control volume of radius ***I*** and thickness dr is an expression for the differential contribution to the thrust [2]:

$$dT = \rho U^2 4a(1-a)\pi r dr \tag{1}$$

And the differential torque, Q, is:

$$dQ = 4a'(1-a)\rho U \pi r^3 \Omega dr \tag{2}$$

Equations (1) and (2), are defined the thrust and torque on an annular section of the rotor. [3].

1.2 Blade Element Theory

The function of lift and drag coefficients as wall as the angle of attack are expression to the forces on the blades of a wind turbine. As illustrated in Figure **(1),** for this analysis, the blade is assumed to be separated into ***N*** elements. Where the following assumptions are made:

*there is no interaction between elements

*the forces on the blades are determined by the lift and drag property of the airfoil shape of the blades [4]

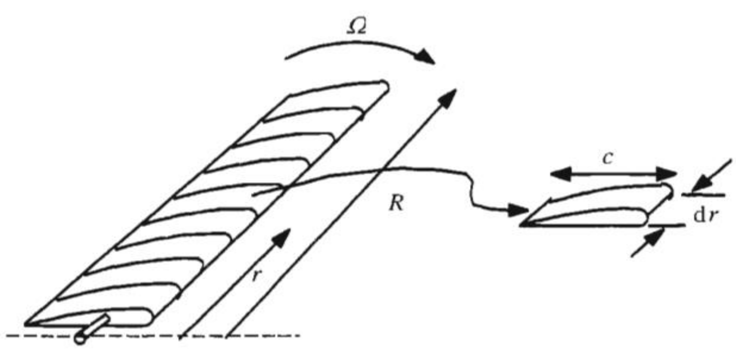


Figure (1):- Schematic of blade elements. fig source [4]

In analyzing the forces on the blade section, it must note that the lift is perpendicular and drag forces is parallel to the relative wind. The relative wind is the vector resulted from the wind velocity vector at the rotor, **U (1-*a*)**, and the wind velocity due to rotation of the blade. This rotational component is the vector sum of the blade section velocity, ***Qr***, and the induced angular velocity at the blades from angular momentum, $\omega_r/2$[5].

$$\Omega r + \left(\frac{\omega}{2}\right) r = \Omega r + \Omega a' r = \Omega r(1 + a') \qquad (3)$$

The overall flow situation is shown in Figure (**2)** and the relationships of the various forces, angles, and a velocity at the blade looking down from the blade tip, are shown in Figure (**2).**

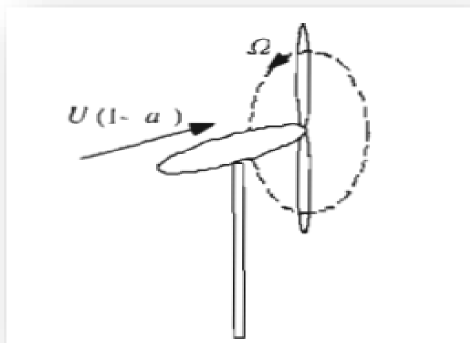


Figure (2) Overall geometry for downwind horizontal axis wind turbine .figure source [4]

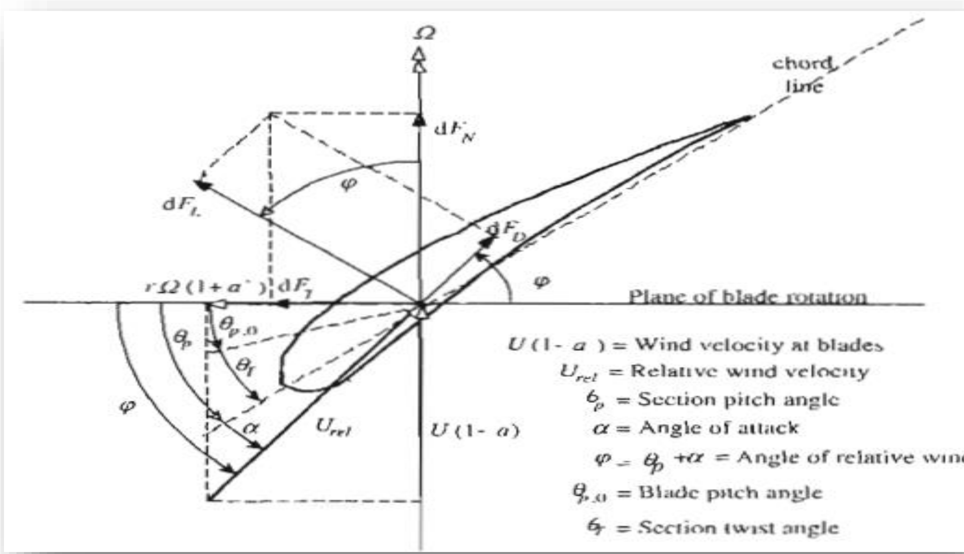


Figure (3) Blade angles for analysis of a horizontal axis wind turbine; fig source [1]

For the definition of variables [6]

$$Q_T = Q_P - Q_{po} \tag{4}$$

Note also that, here, and the blade twist angle,Q_T is defined relative to the blade tip (it could be defined otherwise). Therefore:

$$\varphi = Q_P + \alpha \tag{5}$$

From the figure, it can determine the relationships below: [1]

$$tan\varphi = \frac{U(1-a)}{\Omega r(1+a')}\frac{1-a}{(1+a')\lambda_r} \tag{6}$$

$$U_{rel} = \frac{u(1-a)}{sin\varphi} \tag{7}$$

$$dF_L = cl\,\frac{1}{2}\rho {U_{rel}}^2 cdr \tag{8}$$

$$dF_D = cd\frac{1}{2}\rho {U_{rel}}^2 cdr \tag{9}$$

$$dF_N = dF_L cos\varphi + dF_D sin\varphi \tag{10}$$

$$dF_T = dF_L sin\varphi + dF_D cos\varphi \tag{11}$$

If the rotor has B blades, the total normal force on the section at distance r, from the center is

$$dF_N = B\frac{1}{2}\rho {U_{real}}^2(C_1 cos\varphi + cdsin\varphi)cdr \tag{12}$$

The differential torque due to the tangential force operating at a distance r, from the center is given by

$$dQ = BrdF_r \tag{13}$$

$$dQ = B\frac{1}{2}\rho {U_{rel}}^2(Cl\ sin\varphi - Cd\ cos\varphi)crdr \tag{14}$$

Note that the effect of drag is to decrease torque and power, but to increase the thrust loading.

1.3 Blade Shape for Ideal Rotor (without Wake):

To design tip speed ratio, the required number of blades, B, the diameter of D or radius of R, and an airfoil with known lift and drag coefficients as need to be chosen. Angle of attack (and, thus, a lift coefficient at which the airfoil operates) is also chosen. This angle of attack should be selected where CL\CD, is maximum in order to most closely approximate the assumption that [7]

Cd = 0. These choices allow the chord and twist distribution of a blade that would provide Betz limit power production to be determined. With the assumption a = 1/3, thus

$$dT = \rho U^2 4\left(\frac{1}{2}\right)\left(1-\frac{1}{2}\right)\pi r dr = \frac{\rho U^2 8}{9\pi r dr} \quad (15)$$

And from blade element theory (Equation (12), with cd=0)

$$dF_N = B\frac{1}{2}\rho {U_{rel}}^2 (Cl\, cos\varphi) Cdr \quad (16)$$

A third equation, Equation (7), be used to express U_{rel} in terms of other known variables:

$$U_{rel} = \frac{U(1-a)}{sin\varphi} = \frac{2U}{3\sin\varphi} \quad (17)$$

BEM theory or strip theory refers to the determination of wind turbine blade performance by combining the equations of momentum theory and blade element theory. In this case, equating Equations (15) and (16) and using Equation (17), yields [8]:

$$\frac{ClBc}{4\pi r} = tan\varphi sin\varphi \quad (18)$$

A fourth equation, Equation (6), which relates a, a' and q based on geometrical considerations, can be used to solve the blade shape. Equation (6), with a' = 0 and $a = 1/3$

$$tan\varphi = \frac{2}{3\lambda_r} \quad (19)$$

Therefore

$$\frac{ClBc}{4\pi r} = \left(\frac{2}{3\lambda_r}\right) sin\varphi \quad (20)$$

Rearranging, and noting that $\lambda_r = \lambda(\frac{r}{R})$one can determined the angle of the relative wind and the chord of the blade for each section of the ideal rotor:

$$\varphi = tan^{-1}\left(\frac{2}{3\lambda_r}\right) \tag{21}$$

$$c = \frac{8\pi r sin\varphi}{3BCl\lambda_r} \tag{22}$$

The relative velocity can be expressed as a function of the free stream wind using Equation (7). Thus, Equations (12) and (14) from blade element theory can be expressed as:

$$dF_N = \sigma'\pi\rho\frac{U^2(1-a)^2}{sin\varphi^2}(C_1cos\varphi + cdsin\varphi)rdr \tag{23}$$

$$dQ = \sigma'\pi\rho\frac{U^2(1-a)^2}{sin\varphi^2}(C_1sin\varphi + cdcos\varphi)r^2dr \tag{24}$$

Where σ' is the local solidity, defined by?

$$\sigma' = B\ c\ /\ 2\pi r \tag{25}$$

1.4 Blade Element Momentum Theory

In the calculation of induction factors, a and a', accepted practice is to set Cd equal to zero. For airfoils with low drag coefficients, this simplification introduces negligible errors. So, when the torque equations from momentum and blade element theory are equated (Equations (2) and (24)), with $Cd = 0$, one gets [9]:

$$\frac{a'}{1-a} = \frac{\sigma' Cl}{4\lambda_r sin\varphi} \tag{26}$$

By equating the normal force equations from momentum and blade element theory (Equations 1 and 23), one can obtain:

$$\frac{a'}{1-a} = \frac{\sigma' Cl\ cos\varphi}{4sin\varphi^2} \tag{27}$$

(which relates a, a', φ and λ, based on geometric considerations) and Equations (26) and (27), the following useful relationships result:

$$Cl = 4sin\varphi\frac{(cos\varphi - \lambda_r sin\varphi)}{\sigma'(sin\varphi - \lambda_r cos\varphi)} \tag{28}$$

Other useful relationships that may be derived include:

$$a' = \frac{1}{\left\{\left(\frac{cos\varphi}{\sigma' Cl}\right) - -1\right\}} \tag{29}$$

1.5 Calculation of Power Coefficient

Has been obtained from each section, where the overall rotor power coefficient may be calculated by the following equation [10]

$$Cp = (8/\lambda^2)\int_{\lambda_h}^{\lambda} {\lambda_r}^3 a'(1-a)\left[1-\left(\frac{Cd}{Cl}\right)cot\varphi\right]d\lambda_r \qquad (30)$$

Using the expression for the differential torque from Equation (24) and the definition of the local tip speed ratio:

$$Cp = (2/\lambda^2)\int_{\lambda_h}^{\lambda} \sigma' Cl(1-a)^2(1-sin\varphi)\left[1-\left(\frac{Cd}{Cl}\right)cot\varphi\right]{\lambda_r}^2\, d\lambda_r \quad (31)$$

Note that when$Cd = 0$, this equation for Cp is the same as the one derived from momentum theory, including wake rotation, we get:

Optimized From the analysis of wind turbine design, it's necessary to specify some parameters which have a major effect on power coefficient and keep some other fixed through the analysis as shown below.

Parameters	
Fixed	Variables
Radius of Rotor=1.07 m	Blade Cross Section
Number of Blade=3	Blade Chord
Hub Diameter = 0.19m	Pitch Angle
Tip seep Ratio =7	Angle of Attack

1.6 Blade Cross Section

The main parameters for choosing the wind turbine blade airfoil are:

1. Thickness to chord ratio (t/c).
2. Lift to drag ratio (cl/cd).
3. The intensity of roughness.
4. Low Noise.
5. Stall condition.

To compare the behavior of the unsymmetrical and supercritical blade cross section for high-performance power generation.

There are two fundamental assumptions necessary to extend the analysis:

1. The flow in each stream tube is independent of that the other stream tube.
2. The forces acting on each blade element are the same as those on the airfoil of the same section, the angle of attack, and effective velocity.

The two-airfoil section selected which has been used previously in many wind turbines as shown below.

Airfoil	t/c	Max L/D	Stall angle	Noise	Description
NACA 4412	12% at 30% chord	129.37 at $\alpha = 5.25^{o}$	15 deg	less	Unsymmetrica l
Eppler 417	14.2% at 38.3% chord	135.9 at $\alpha=2.25°$	13.5 deg	more	Super Critical

Airfoils geometry is shown in the figure (4) and Figure (5) and their Characteristic Figure (6) to Figure (7)

1.7 Lift to Drag Ratio

The fox point was to select highest L/D zone for an airfoil with their related angle of attack which is obviously different from airfoil to airfoil depend on the lift to drag behavior. These selected angles were distributed along the wind turbine blade radius to obtain approximate equal lift/drag ratio for each section to optimize the power coefficient. Best airfoil gives high lift/drag ratio at a low angle of attack behind the stalling angle which gives the benefit that any change in wind angle the airfoil will be still working.

NACA 4412 gives a lift to drag zone with (133.8 L/D) at (6 deg) of the angle of attack and (0.107 m) blade length, (125.13 L/D) at (3.75 deg) of the angle of attack and (1.07 m) blade length (Fig. 6).

Eppler 417 gives a lift to drag zone with (148.60 L/D) at (2.25 deg) angle of attack and (0.107 m) blade length, (91.545 L/D) at (0 deg) angle of attack and (1.07 m) blade length (Figure (6)).

From Figure (7) to Figure (12) it appears that the best lift, drag and lifts to drag ratio selected to optimize the power coefficient for NACA 4412 and Eppler 417 respectively.

Equal lift to drag ratio along the wind turbine blade radius reduces the tip loss factor and the blade behavior becomes less noisy for that NACA 4412 perform better than EPPLER 417 in the noise field.

1.8 Twist angle

The twist angle is the angle between the plane of rotation of the blade and the elements chord line, sometimes is termed as pitch angle. The Twist angle depends on tip speed ratio and airfoil angle of attack. Pitch angle usually high at the root of the blade and at the tip of the blade to decrease tip loss factor and reduce the noise. From the calculations it is found that NACA 4412 required (0.158 m) chord at (6 deg) angle of attack at the root and (3.75 deg) and(0.045m) at the tip, Eppler 417 required (0.22047 m) at (2.25 deg) angle of attack at the root and (0deg), (0.796m)chord at tip at the same radius section. That mean NACA 4412 thinner than Eppler 417 and less cost but Eppler

417 behavior better than NACA 4412in facing the wind stream because haveing a less setting angle, as shown in Figures (13) and (14).

1.9 Chord length

The most powerful parameter in the wind turbine blade for aerodynamic and structural design, high lift root airfoil to minimize inboard solidity and enhance starting torque. Obviously, the setting angle at the blade root be high and then die at the tip to decrease the tip loss factor and air noise. From the calculations, it is found that the taper ratio equal to (0.2), also found a good starting design point of view. The comparison of the two airfoils chord length distributed along blade radius has been presented in figure (7).

1.10 Optimization

From the analysis, it is found that two main parameters that improve the aerodynamic principle behavior of wind turbine blade to capture the wind energy more effectively were the twist angle and chord length, so it must optimize this two parameters using the lift to drag method for twist angle, Schmitz, and Betz for chord length.

According to Betz method, the blade length should become increase thick as it approaches the hub, where the Schmitz method show that the blade length starts thin closest to the hub, reaches a maximum about 13% of the blade length and begins to decrease again.The difference in pitch angle is greatest at the hub of the turbine blade a difference of about 20 degrees at 5% of the blade length. The difference decreases after about 50% of the blade length when the two lines are within a degree of one another since the hub of the turbine with likely consumes the first 10% of blade length. It appears that is a small variation in results regardless of the method.

The optimization methods have been applied to the two airfoils NACA 4412 and Eppler 417 airfoils and with the following cases:

1- Nontwist optimization, Schmitz chord optimization chord.

2- Nontwist optimization, Betz chord optimization method.

3- Lift/drag twist optimization method, non-chord optimization.

4- Lift/drag twist optimization method, Schmitz chord optimization.

5- Lift/drag twist optimization method, Betz chord optimization.

The effect of these optimization methods on the two airfoils performance and the resultant power coefficient and thrust coefficients for the non-optimization case and overall above optimization methods has been presented in figures from (15) to (27), also tables from (7) to (12).

Conclusions:

It can be concluded from the previous analysis, which can behave the further wind turbine design.

1. The main factor has power affects on wind turbine power airfoil section and its characteristic are (Lift, Drag, L/D , angle of attack, blade chord length and blade pitch angle).
2. EPPLER 417 airfoil behavior better in turbulent and has a lower angle of attack than NACA4412.
3. EPPLER 417 is more costly than NACA4412 because it's had bigger geometry.
4. Pitch angle highly at the root (43^o) and approximately zero at the tip in order to integrate better angle of attack distribution.
5. Equal Lift to drag distribution on blade length decreases the tip loss and higher power coefficient.
6. EPPLER 417 airfoil has low starting speed a NACA4412 du to optimum lift value at a low angle of attack.
7. Thicker root chord and thinner root chord increase solidity, decrease tip low ration and decrease tip wake generation (noise).

Table (1) Calculated Aerodynamic Data for Eppler-417

NO	I	ALFA	i	Chord	r	CL(I)	CD(I)	L/D
1	36.67198	30.67198	6	0.15788	0.107	1.1238	0.0084	133.7857
2	23.69178	17.94178	5.75	0.13715	0.214	1.1017	0.00821	134.1619
3	16.97556	11.47556	5.5	0.10861	0.321	1.07882	0.00804	134.1196
4	13.10254	7.85254	5.25	0.08848	0.428	1.05499	0.00789	133.6881
5	10.63026	5.63026	5	0.07468	0.535	1.03	0.00775	132.9032
6	8.92833	4.17833	4.75	0.06493	0.642	1.00367	0.00761	131.8051
7	7.68974	3.18974	4.5	0.05783	0.749	0.97582	0.00748	130.4361
8	6.74978	2.49978	4.25	0.05253	0.856	0.94626	0.00734	128.8391
9	6.01288	2.01288	4	0.04852	0.963	0.9148	0.0072	127.0555
10	5.42006	1.67006	3.75	0.04548	1.07	0.88125	0.00704	125.1248

Table (2) Calculated Power Data for Epler-417

ALO	CF	CM	CP	TORQUE
1	0.2208	-0.0118	-0.0118	-0.0213
2	0.1755	0.0101	0.0202	0.0139
3	0.2886	0.0482	0.1446	0.0596
4	0.5192	0.083	0.332	0.0973
5	0.6896	0.0869	0.4347	0.0987
6	0.7949	0.0801	0.4809	0.0891
7	0.8727	0.0708	0.4954	0.0774
8	0.9042	0.061	0.4878	0.066
9	0.9008	0.0527	0.4744	0.0565
10	0.8771	0.0461	0.4611	0.0491
11	0.8403	0.0407	0.4476	0.0431
12	0.7152	0.0349	0.4193	0.0368
13	0.665	0.0308	0.4005	0.0323
14	0.6031	0.0266	0.3719	0.0278
15	0.5285	0.0221	0.3311	0.023
16	0.4439	0.0174	0.2783	0.0181
17	0.3498	0.0126	0.2137	0.013
18	0.2228	0.0064	0.1145	0.0066
19	0.0947	0.0007	0.0139	0.0008
20	0.0926	0.001	0.0207	0.0011

Table (3) Calculated Aerodynamic Data for NACA 4412

NO	I	ALFA	i	Chord	r	X	Y	CD(I)	CL(I)	L/D
1	36.67198	34.42198	2.25	0.22047	0.107	0.18186	0.12463	0.00542	0.80477	148.6024
2	23.69178	21.69178	2	0.19265	0.214	0.17901	0.07121	0.0055	0.7843	142.6
3	16.97556	15.22556	1.75	0.15405	0.321	0.14865	0.04046	0.00561	0.76057	135.59
4	13.10254	11.60254	1.5	0.12725	0.428	0.12465	0.02559	0.00573	0.7336	128.1397
5	10.63026	9.38026	1.25	0.10936	0.535	0.1079	0.01782	0.00583	0.70337	120.6863
6	8.92833	7.92833	1	0.09728	0.642	0.09635	0.01342	0.0059	0.6699	113.5424
7	7.68974	6.93974	0.75	0.08912	0.749	0.08847	0.01077	0.00592	0.63317	106.9214
8	6.74978	6.24978	0.5	0.08379	0.856	0.08329	0.00912	0.00587	0.5932	100.9702
9	6.01288	5.76288	0.25	0.0807	0.963	0.0803	0.0081	0.00574	0.54997	95.80402
10	5.42006	5.42006	0	0.0796	1.07	0.07924	0.00752	0.0055	0.5035	91.54546

Table (4) Calculated Power Data for NACA 4412

ALO	CF	CM	CP	TORQE
1	0.2667	-0.0119	-0.0119	-0.0216
2	0.2536	0.0149	0.0297	0.0204
3	0.3634	0.0562	0.1685	0.0695
4	0.3367	0.0349	0.28	0.0409
5	0.5616	0.0633	0.4166	0.0719
6	0.7785	0.0756	0.4539	0.0841
7	0.852	0.0685	0.4797	0.075
8	0.8384	0.0598	0.4784	0.0647
9	0.7904	0.0523	0.4709	0.0561
10	0.7168	0.0456	0.4562	0.0486
11	0.6245	0.0392	0.4309	0.0415
12	0.5092	0.0328	0.3937	0.0346
13	0.3805	0.0265	0.3443	0.0278
14	0.2225	0.0195	0.2729	0.0204
15	0.0494	0.0128	0.1925	0.0134
16	-0.111	0.0066	0.1056	0.0069
17	-0.2903	-0.0038	-0.0646	-0.0039
18	-0.2847	-0.0047	-0.0842	-0.0048
19	-0.208	-0.0028	-0.0523	-0.0028
20	-0.3216	-0.0092	-0.1848	-0.0095

Table (5) Blade with Twist and Chord optimization only/Shmiz

	NACA 4412			Eppler 417		
Sec No	**Radius**	**Chord**	**Twist**	**Radius**	**Chord**	**Twist**
1	0.0	0.166919	43.39	0.0	0.287904	48.4291
2	0.104	0.156825	23.14	0.104	0.269966	28.0198
3	0.17	0.136238	16.72	0.17	0.234985	21.7185
4	0.27	0.109743	10.91	0.27	0.189287	15.9082
5	0.37	0.0904607	7.42	0.37	0.158887	12.7042
6	0.47	0.0764537	5.11	0.47	0.131868	10.1101
7	0.57	0.065998	3.47	0.57	0.113837	8.4723
8	0.67	0.0579645	2.25	0.67	0.00999	7.2524
9	0.77	0.0516232	1.31	0.77	0.0890403	6.30934
10	0.87	0.0465043	0.56	0.87	0.0802111	5.55887
11	0.97	0.0422921	-0.05	0.97	0.0729559	4.94766
12	1.07	0.038769	-0.56	1.07	0.0668693	4.4037

Table (6) Blade with Twist and Chord optimization only/Bitz

	NACA 4412			Eppler 417		
Sec No	Radius	Chord	Twist	Radius	Chord	Twist
1	0.0	0.25	43.39	0.0	0.2	48.4291
2	0.104	0.201076	23.14	0.104	0.345	28.0198
3	0.17	0.159467	16.72	0.17	0.275051	21.7185
4	0.27	0.12009	10.91	0.27	0.207133	15.9082
5	0.37	0.095833	7.42	0.37	0.168725	12.7042
6	0.47	0.0795659	5.11	0.47	0.137236	10.1101
7	0.57	0.0679529	3.47	0.57	0.117206	8.4723
8	0.67	0.0592666	2.25	0.67	0.102224	7.2524
9	0.77	0.052533	1.31	0.77	0.0906096	6.30934
10	0.87	0.0471643	0.56	0.87	0.0813495	5.55887
11	0.97	0.0427857	-0.05	0.97	0.0737972	4.94766
12	1.07	0.0391476	-0.56	1.07	0.0675223	4.4037

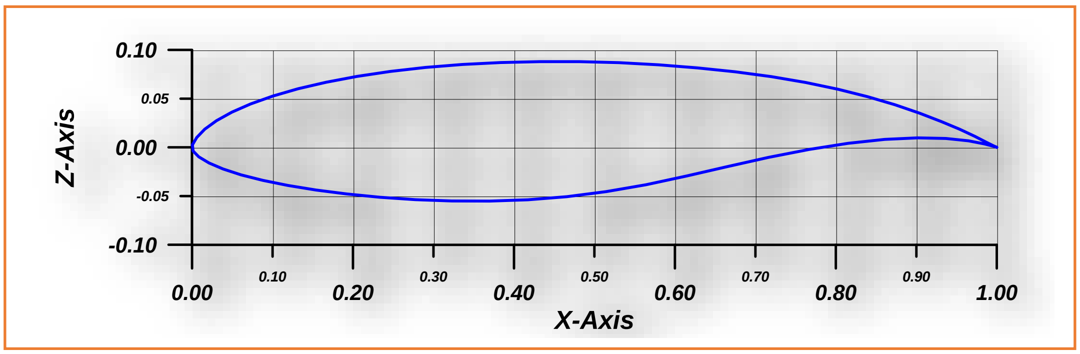


Figure (4) EPPLER 417 airfoil

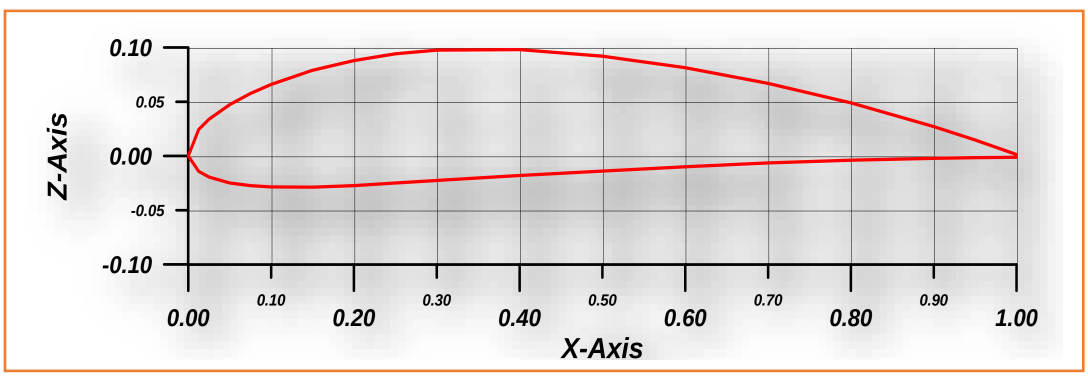


Figure (5) NACA 4412 airfoil

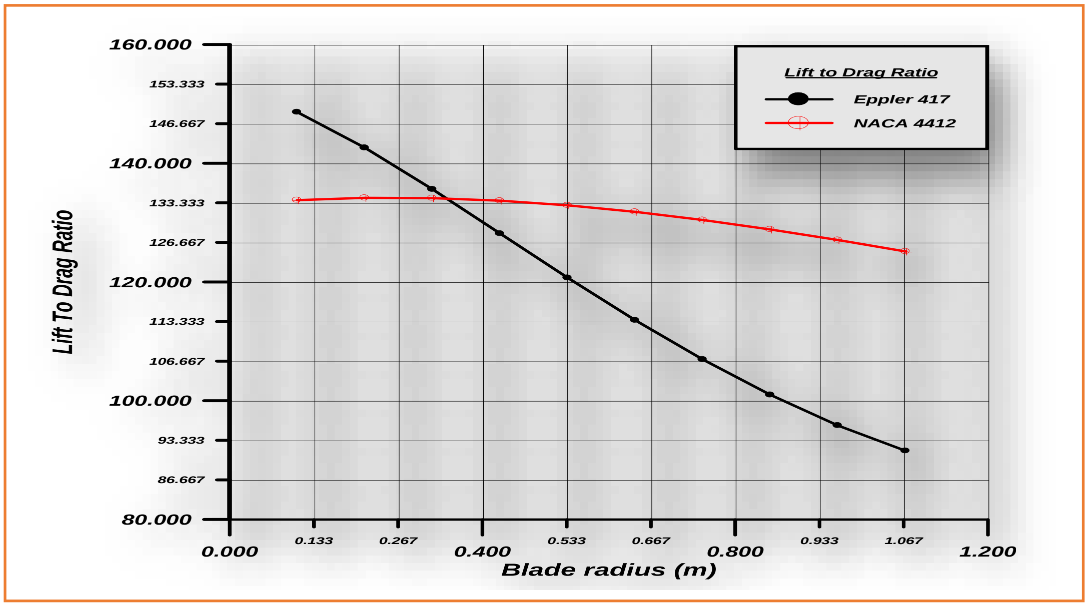


Figure (6) Lift to Drag Comparison

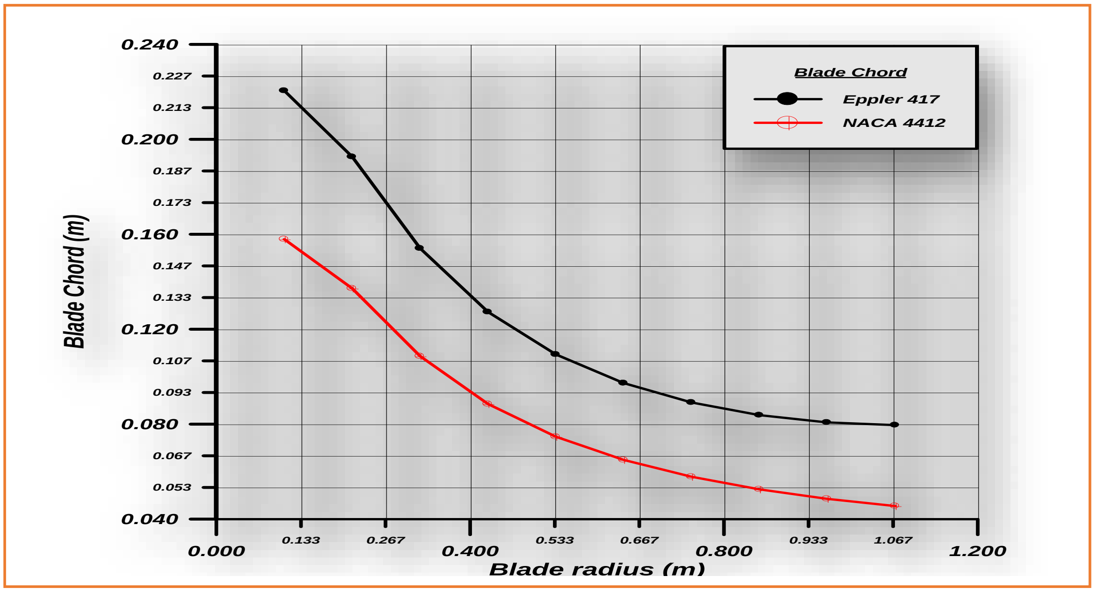


Figure (7) Relation between Blade Chord and Blade Radius

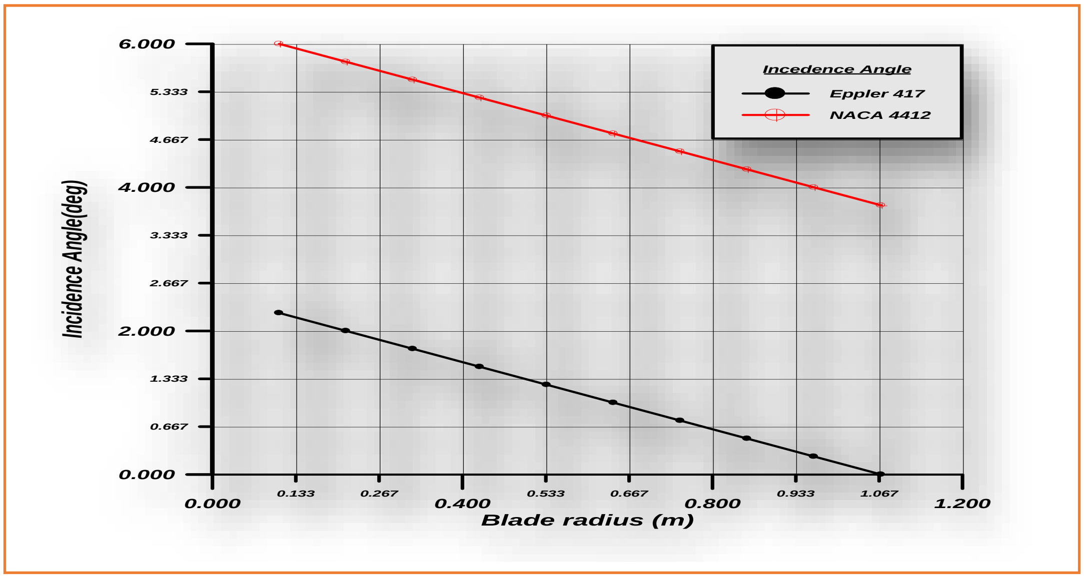


Figure (8) Relation between incidence Angle and Blade Radius

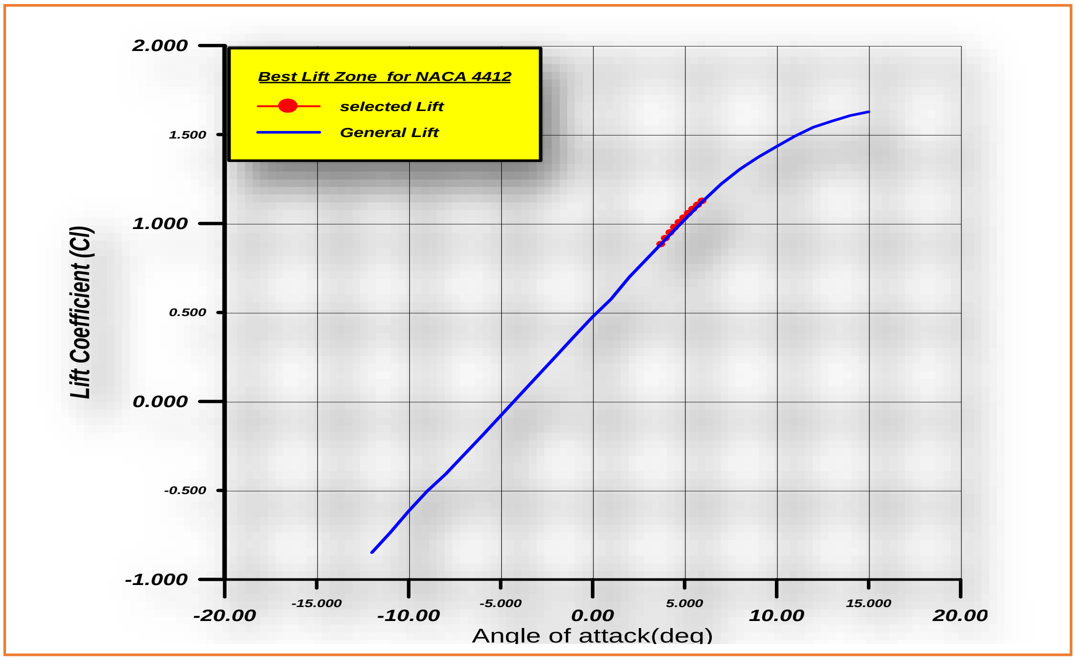


Figure (9) Best Lift Zone for NACA 4412

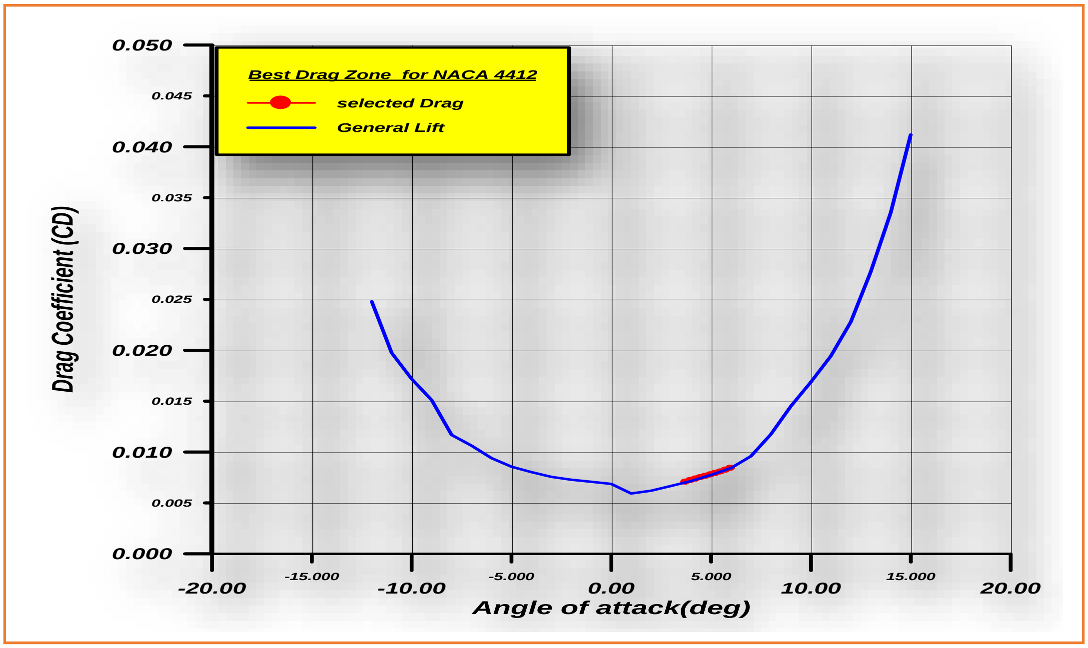


Figure (10) Best Drag Zone for NACA 4412

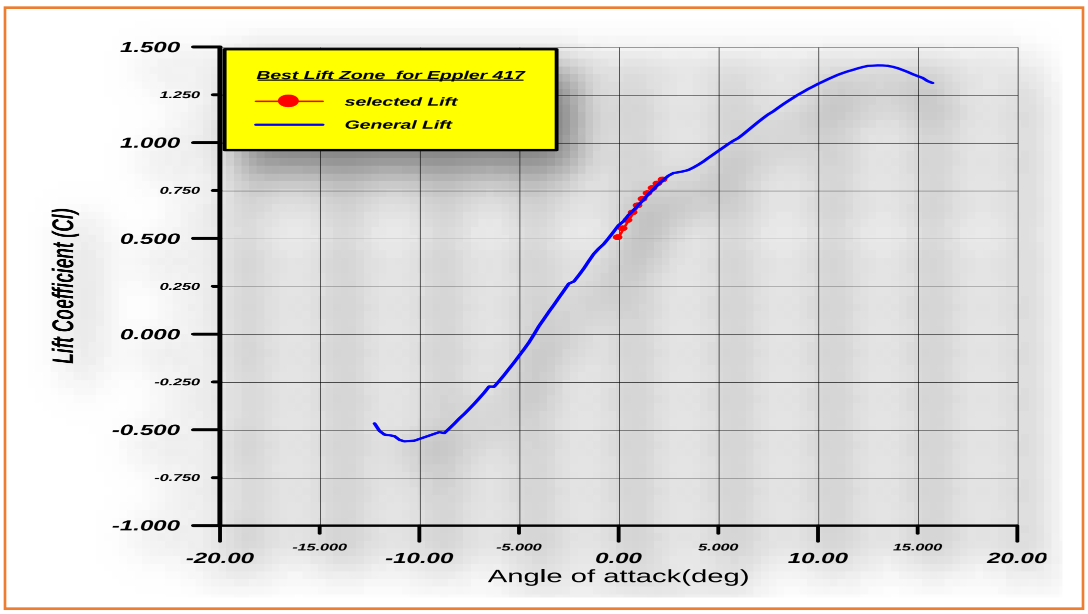


Figure (11) Best Drag Zone for NACA 4412

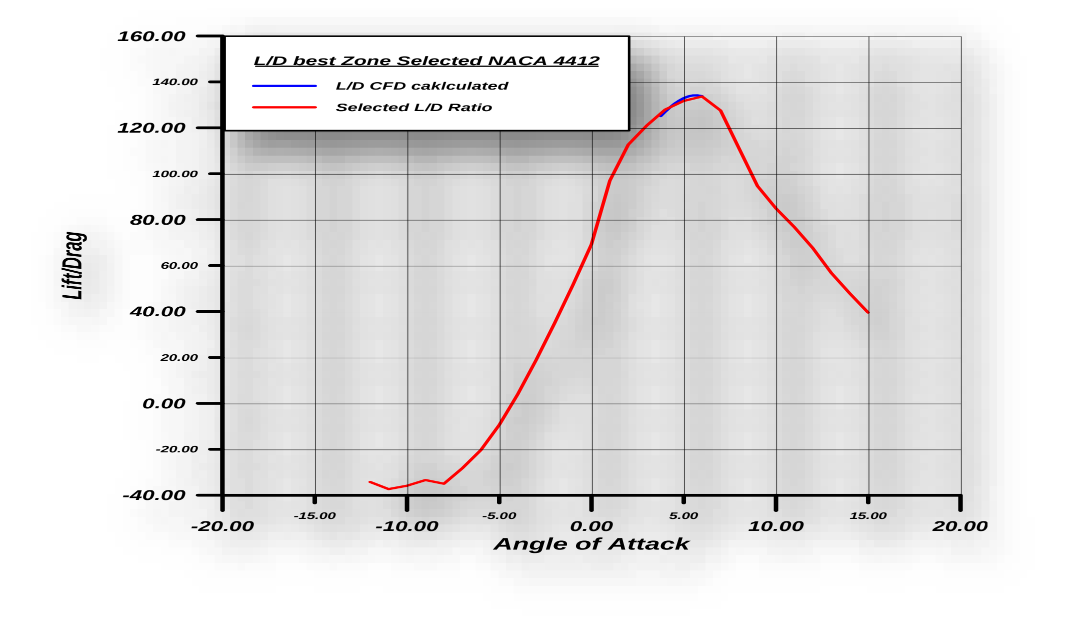


Figure (12) Best Drag Zone for Eppler 417

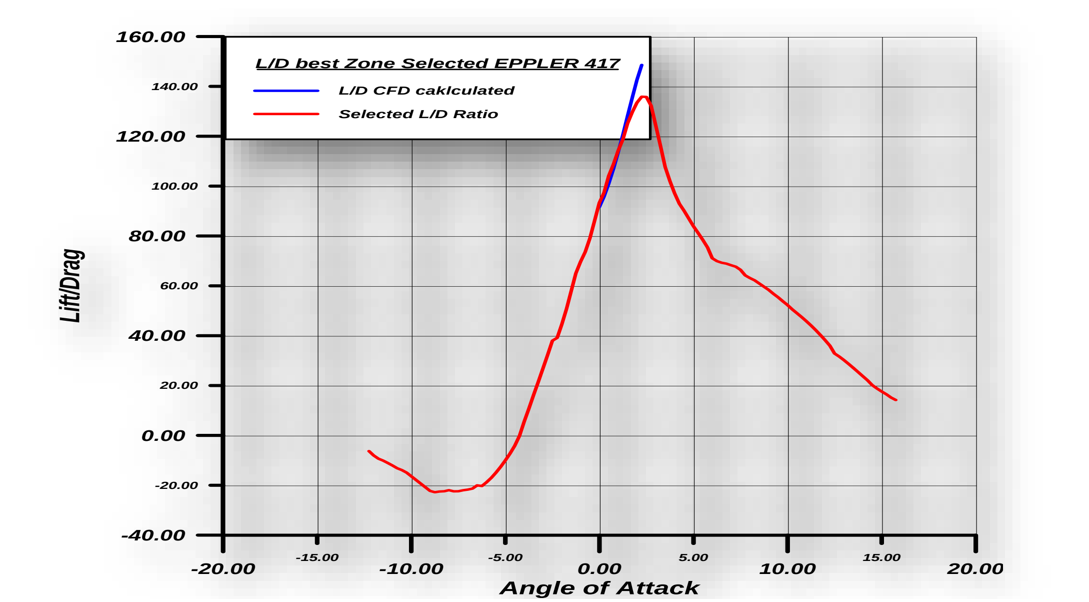


Figure (13) Best Lift/Drag Zone for NACA 4412

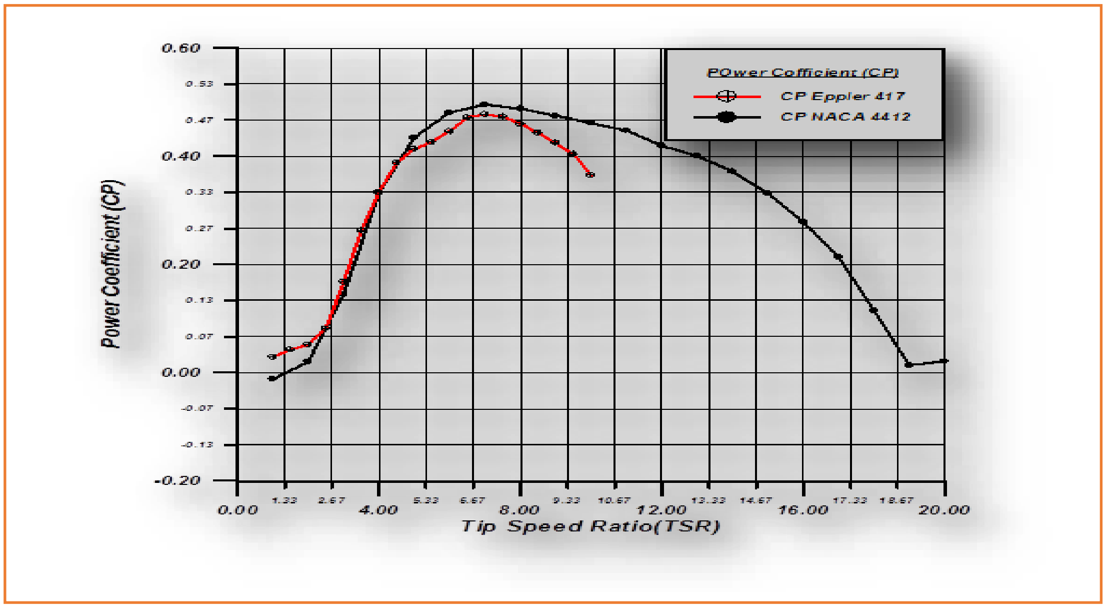


Figure (14) Best lift/Drag Zone for Eppler 417

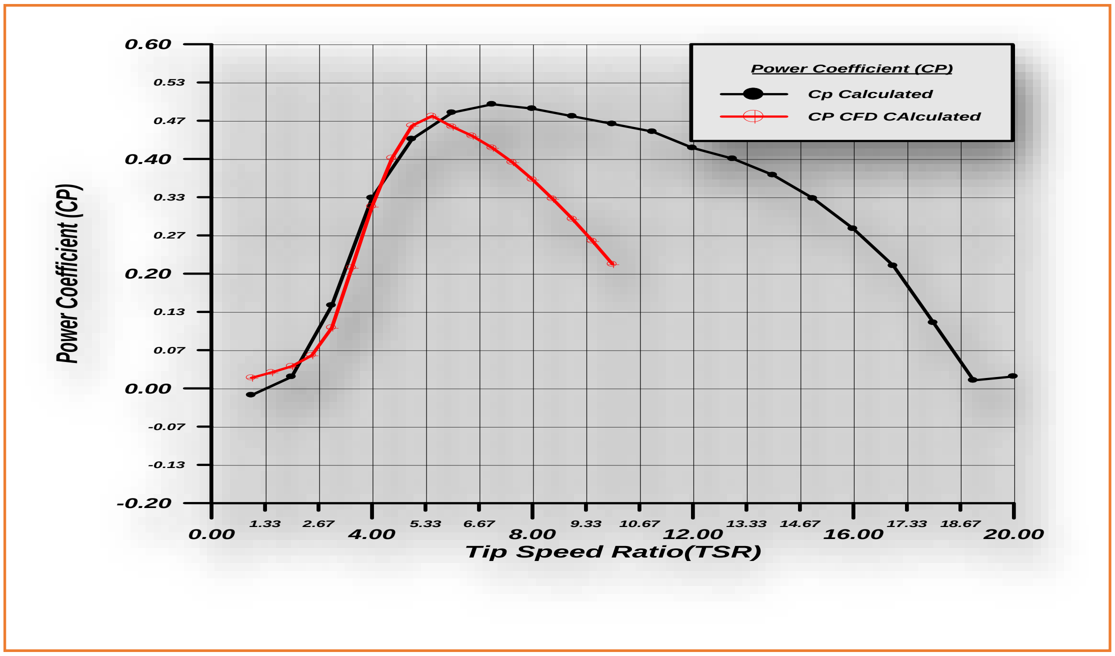


Figure (15) coefficient of Power Comparison

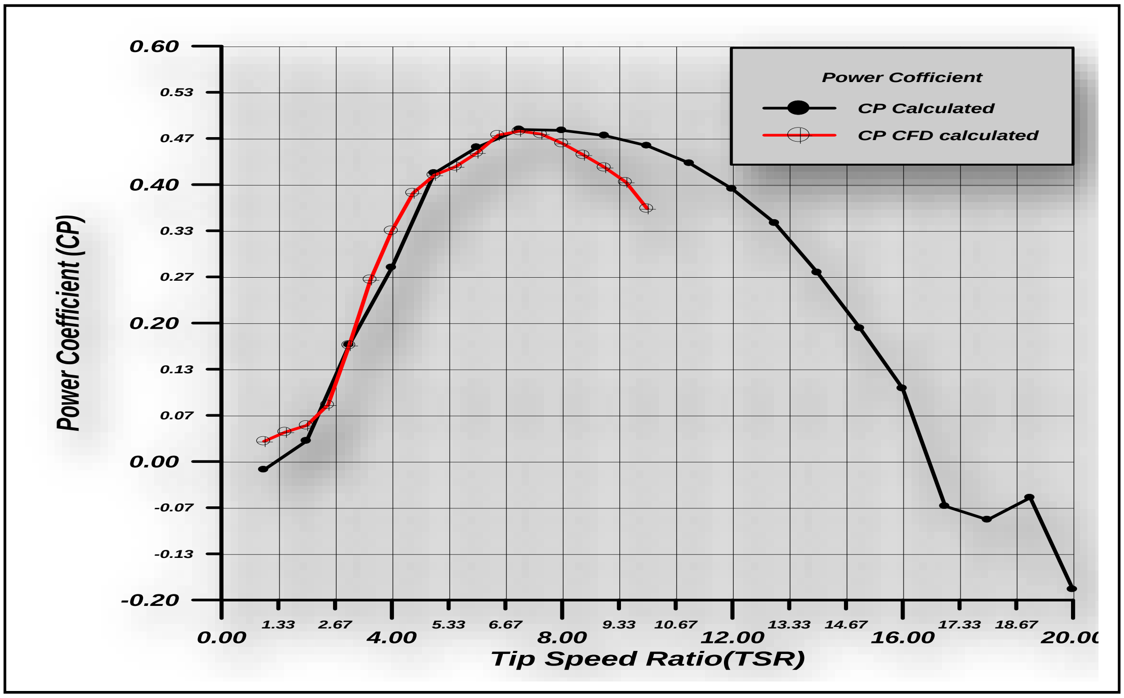


Figure (16) Lift to Drag Comparison Calculated CP and CFD calculation

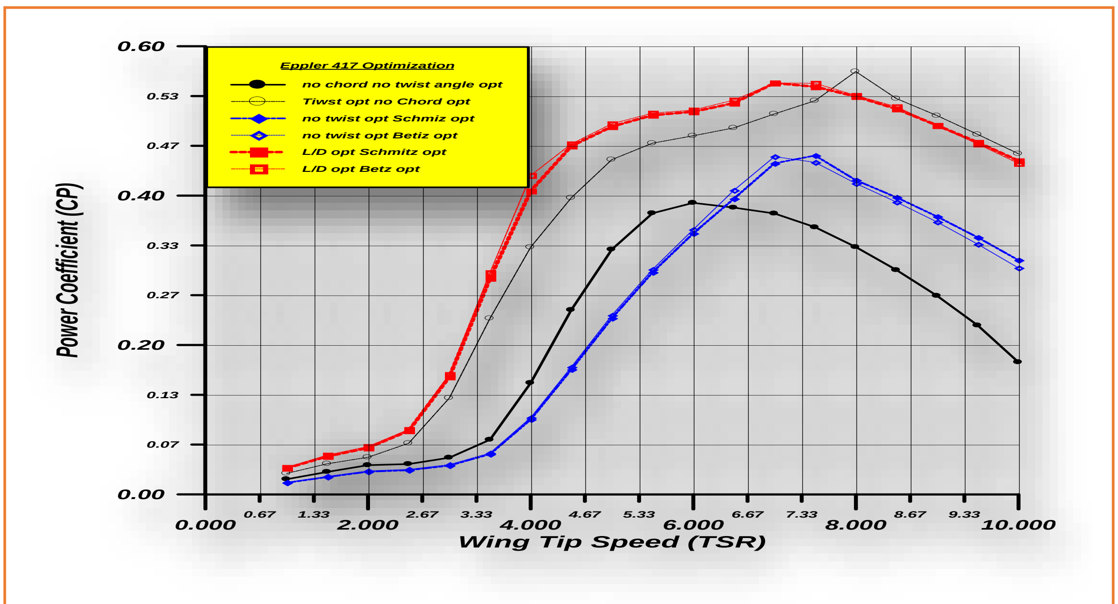


Figure (17) Lift to Drag Comparison Calculated CP and CFD calculation

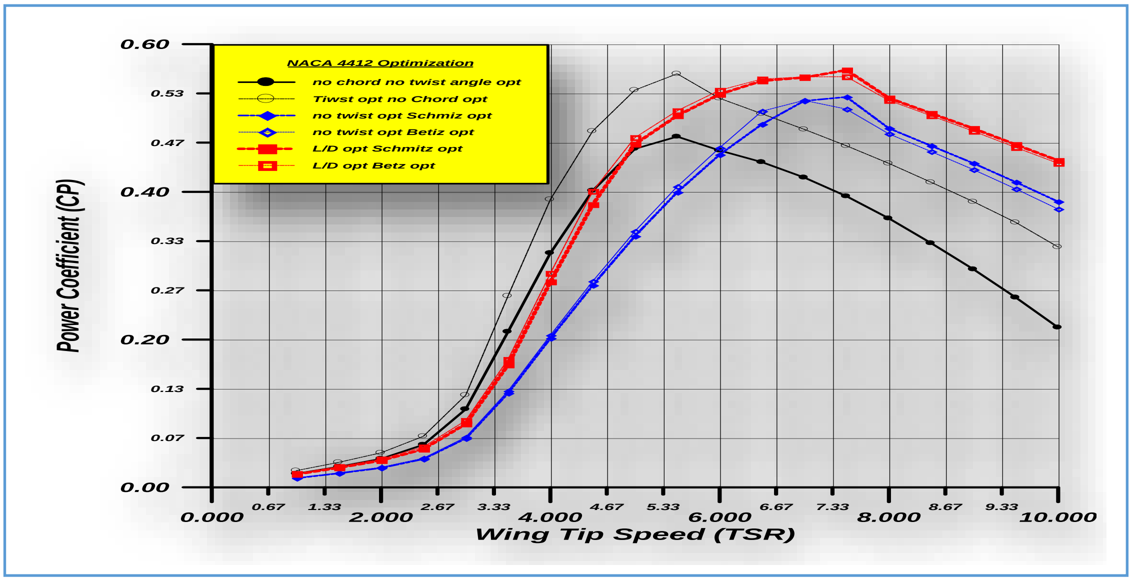


Figure (18) CP Coefficient Comparison for Different optimization Method/EPPLER 417

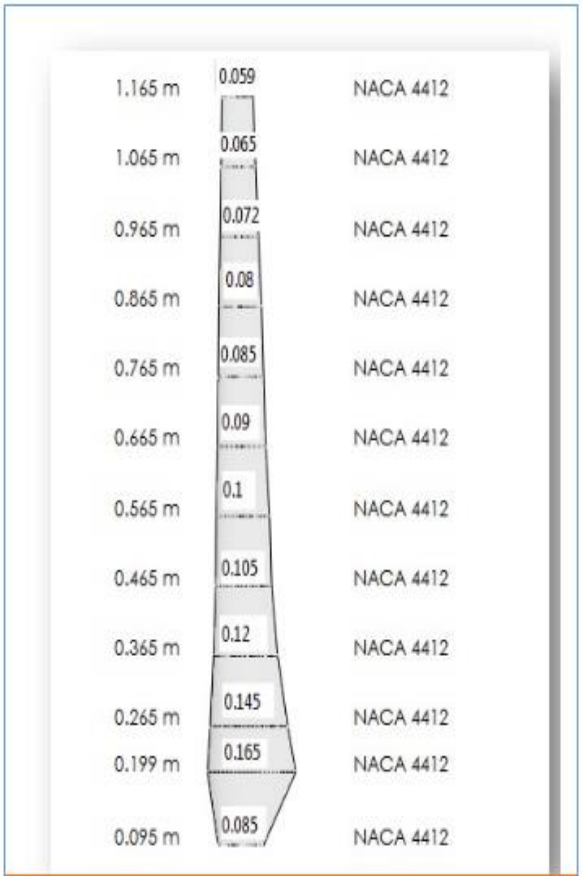


Figure (19) Blade Shape without Optimization

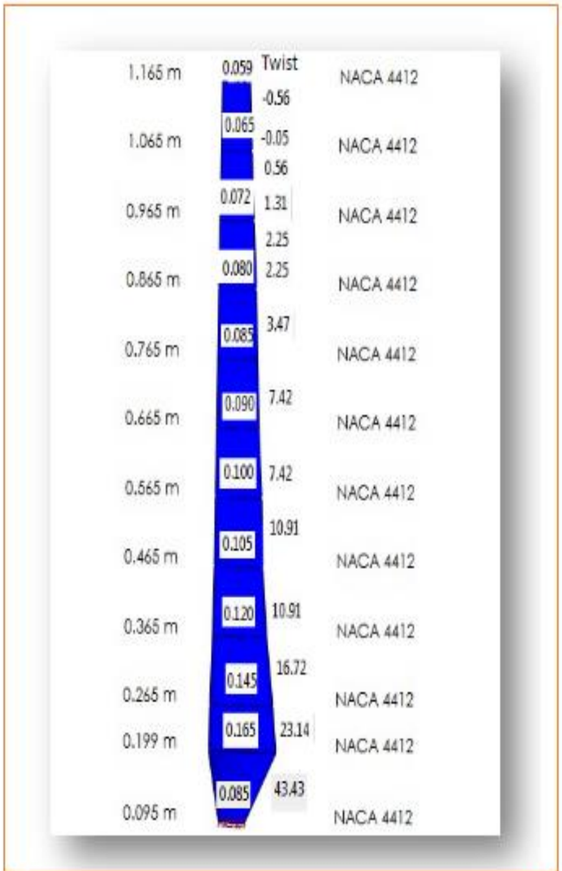
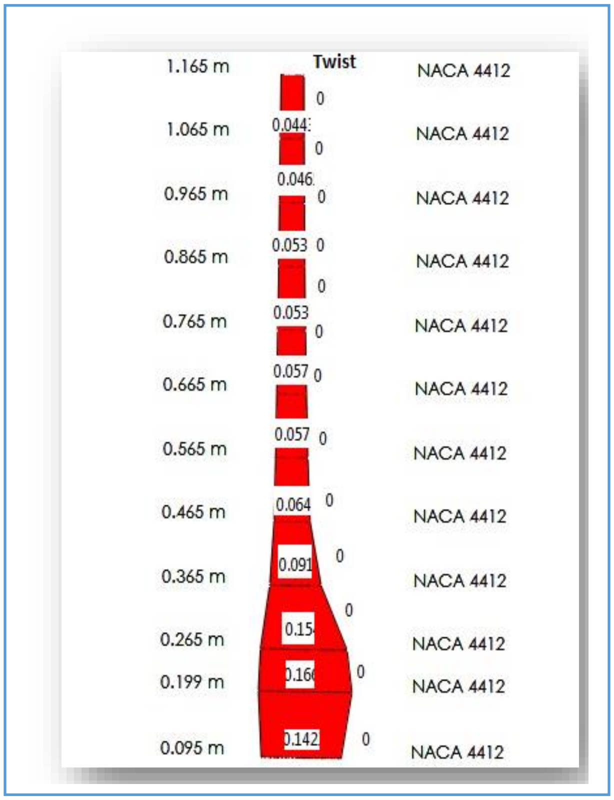


Figure (20) Blade Shape with Twist Optimization only



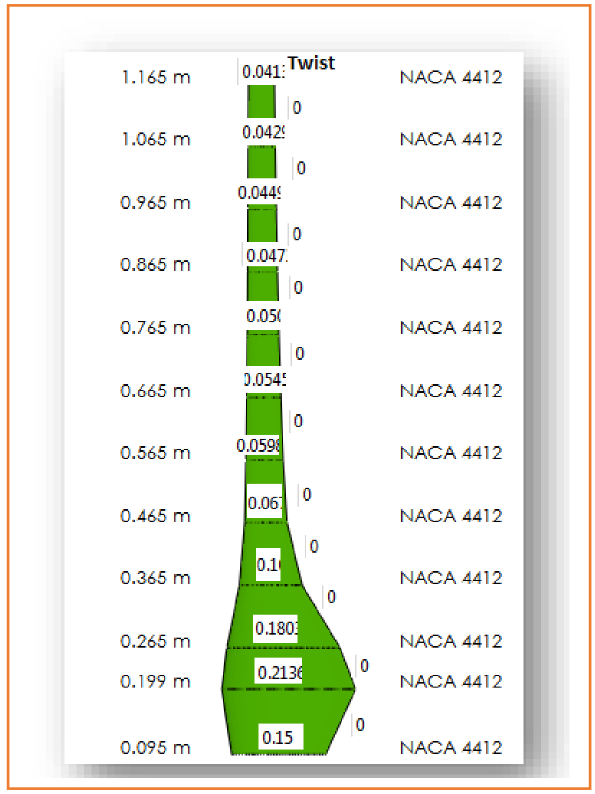
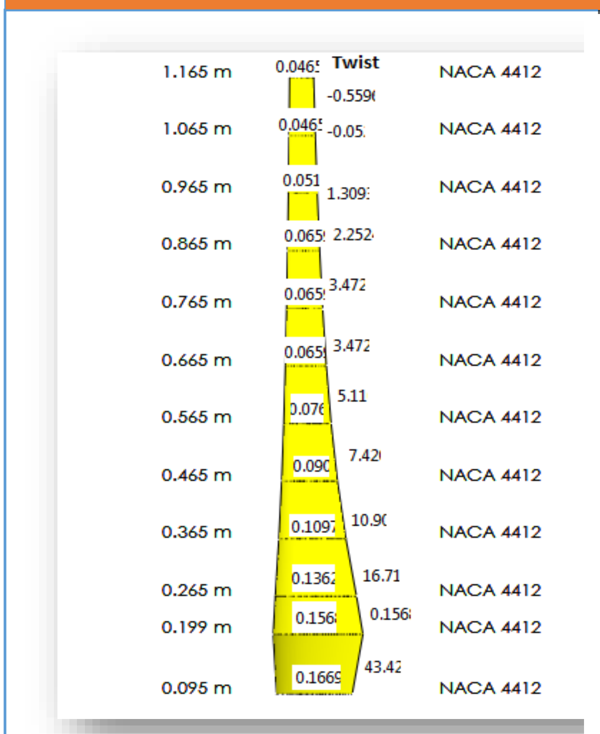


Figure (21) Blade Shape with Chord Optimization /shmiz

Figure (22) Blade Shape with Chord Optimization /Bitz



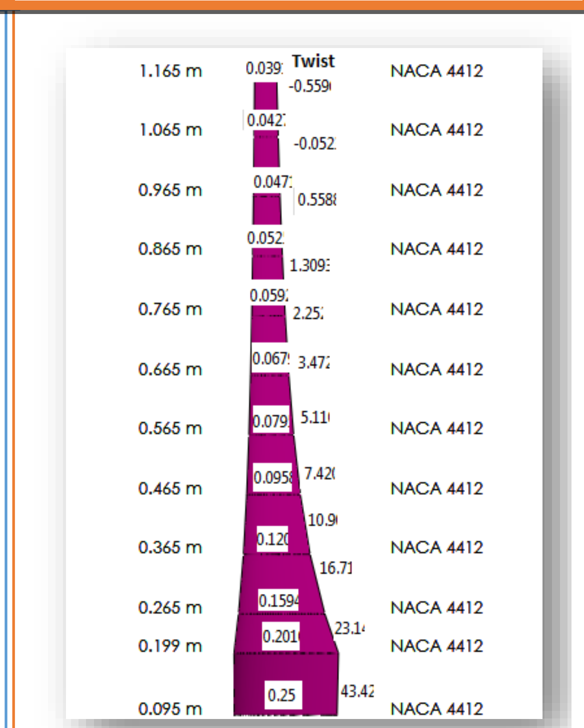


Figure (23) Blade with Twist and Chord Optimization /shmiz

Figure (24) Blade with Twist and Chord Optimization /Bitz

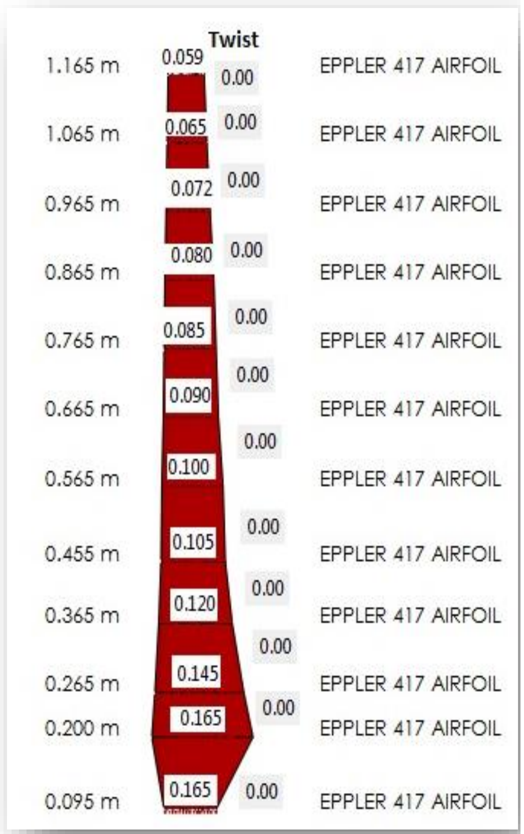


Figure (25) Blade Shape without Optimization

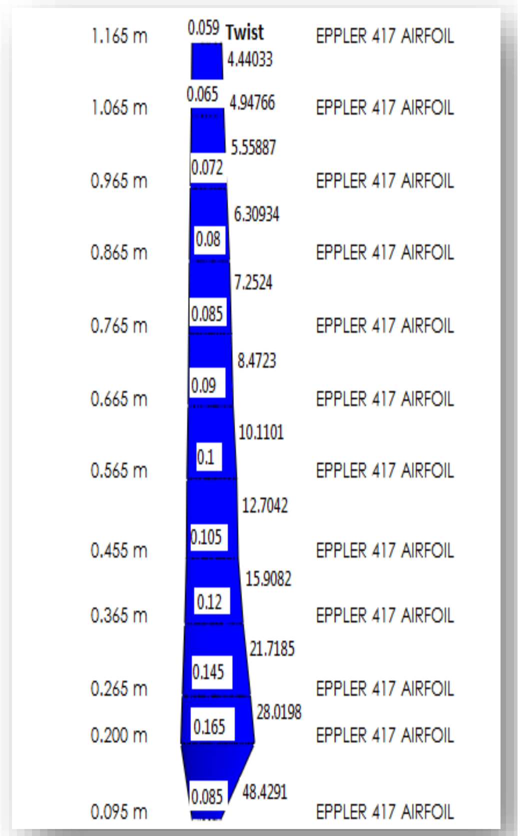


Figure (26) Blade Shape with Twist Optimization only

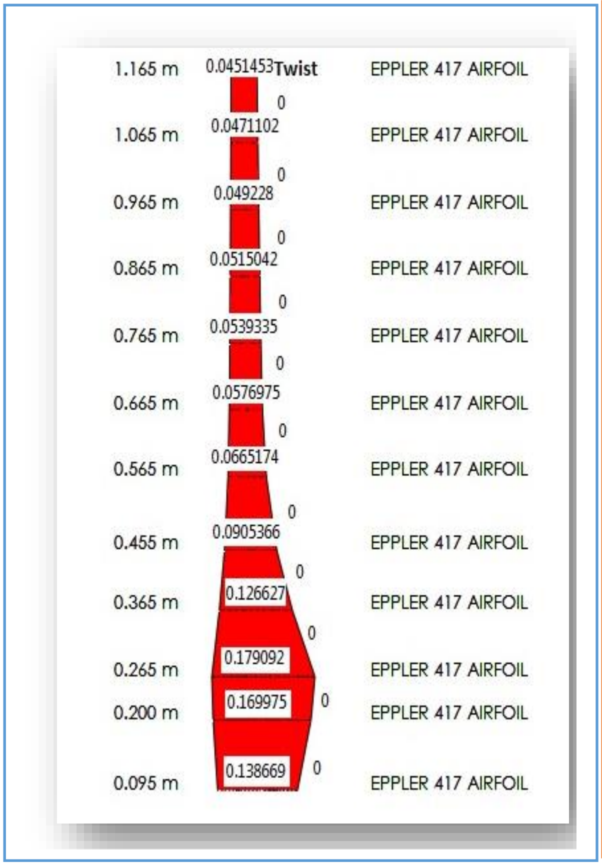


Figure (27) Blade Shape with Chord Optimization /shmiz

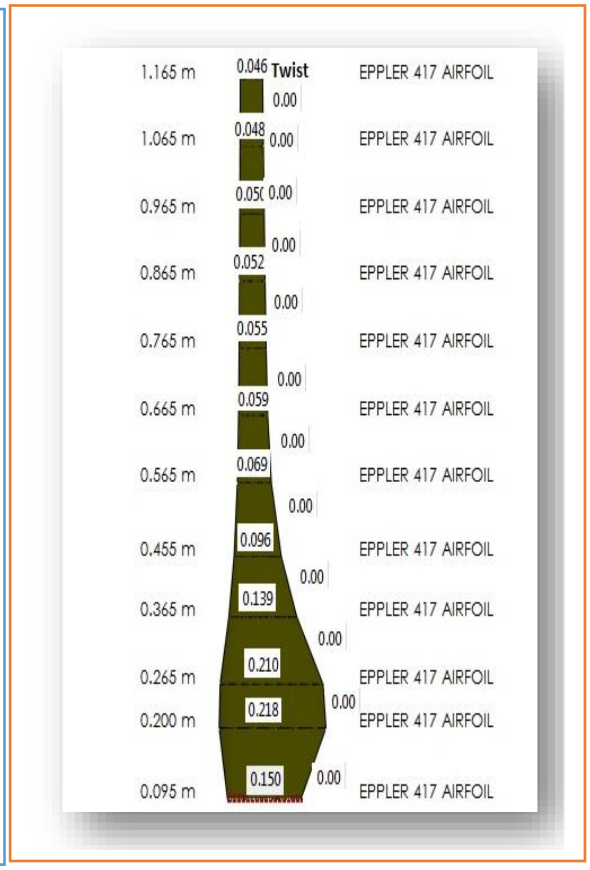
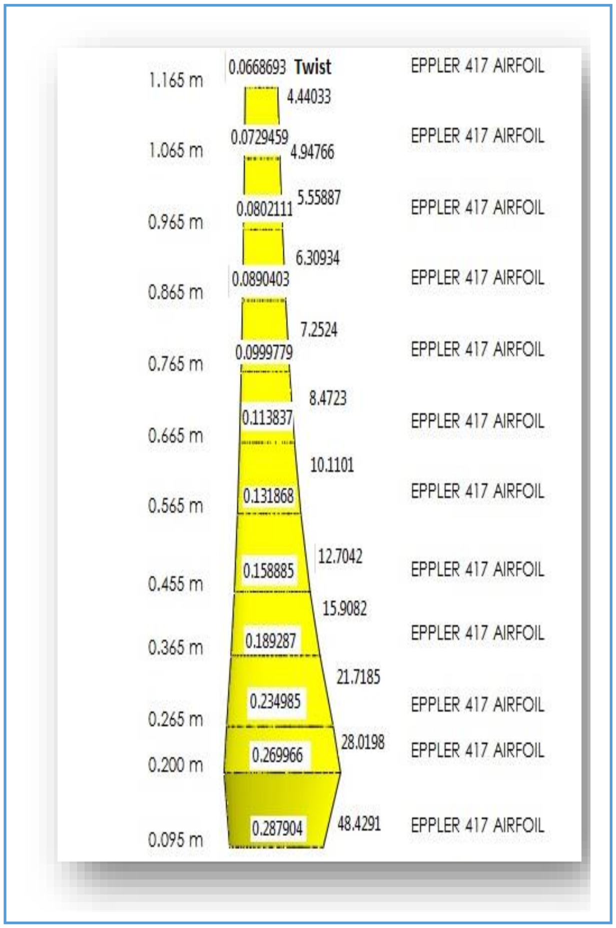


Figure (28) Blade Shape with Chord Optimization /Bitz



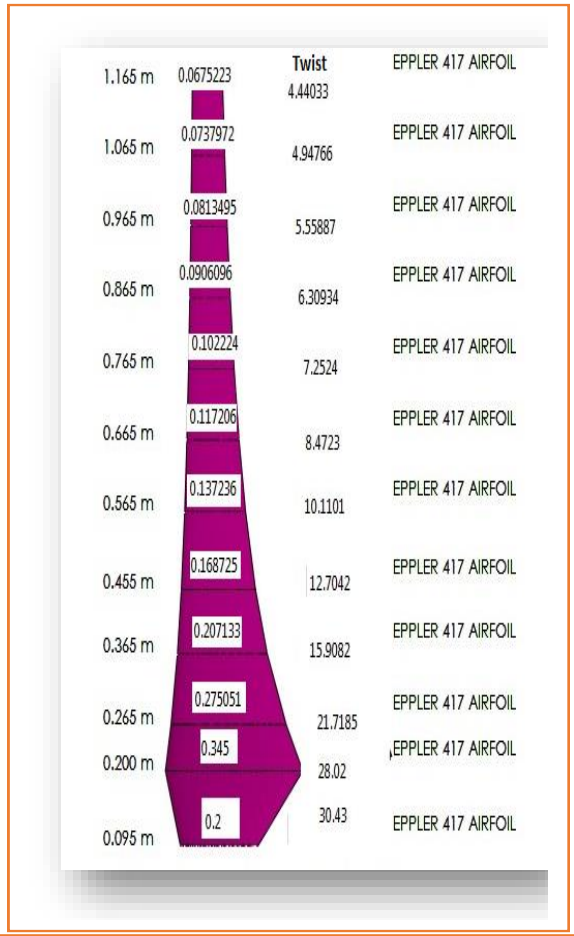


Figure (29) Blade with Twist and Chord Optimization /shmiz

Figure (30) Blade with Twist and Chord Optimization /Bitz

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الخلاصة

البحث يقوم بتحليل وتحسين براميترات الخاصة بتوربابين رياح افقي ذو اداء عالي المستوى مع تغير زاوية خطوة الريشة لمقاطع مختلفة من الريش ذو مطيار غير متماثل نوع (NACA 4412) وكذلك لمطيار غير متماثل انشطاري نوع (EPPLER 417) ومن اجل دقة أكثر تم تثبيت بعض البرامترات خلال التحليل لكي يتم التكامل والحصول على اعلى معامل قدره لتوربين الرياح. تم اجراء التحليل باستعمال برنامج (FORTRAN 90) تم المقارنة مع برنامج الماني ثم تم تحسين الاداء باستعمال طريقة شمز وبيتز الخاصة لوتر الريشة وكذلك الخاصة بالرفع والكبح ولزاوية خطوة الريشة من مناقشة النتائج النظريه تم توضيح ورسم الاستنتاجات المهمة وكذلك عمل توصيات ومقترحات مستقبلية. من خلال النتائج وجد قيم معامل القدرة ازدادت بمقدار (10.3%) لمطيار انشطاري نوع (EPPLER417) و(9.5%) لمطيار غير متماثل نوع (NACA 4412).

الكلمات المفتاحية: التصميم الأمثل، الخوارزميات، Betz Schmitz تحسين الرفع / السحب، طاقة الرياح، ديناميكيات السوائل الحاسوبية، الديناميكا الهوائية.