People's Democratic Republic of Algeria

Ministry of higher Education
Scientific Research

University Echahid Hamma Lakhdar of
El-OuedFaculty of Technology

Report Presented in

Partial FulfilmentOf the

Requirements of the

MASTER ACADEMIC

Domain: Technology
Option: Mechanical Engineering
Specialist: energetic mechanics

Theme

Aerodynamic shape optimization of small wind turbine blades using BEM theory

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University year: 2021/2022

Dedicate

We dedicate this humble work: to our mothers and fathers

To our brothers and sisters and to all our families, each in his name to all the professors of the Mechanical Engineering Department, especially Prof. Dr. Gharbi Mohammed Tahar, Dr. Daghoum Khalil

Head of the Mechanical Engineering Department

To all members of the evaluation committee, professors and doctors to my dearest friends and all my colleagues.

Thanks

First of all, we thank Allah, who helped us complete the memorandum and illuminated our path and success in our scientific thesis.

We thank the good parents who gave us all the incentives to complete this note

We also thank Dr. Gharbi

Mohamed taher and Dr. Doghum Khalil.

We thank all the professors and employees of Hama Al-Akhdar University for what they have provided for education in our university, especially the dean and professors of the Faculty of Science and Technology, especially the Mechanics Department, and the head of the department for all. . Masters.

Also, don't forget our sincere thanks to all your classmates

Abstract

Wind energy is an important resource in the field of renewable energies. In this study, two different methods were adopted to study wind turbines and compare them to determine the simplest and most accurate. Using the theory of blade element momentum (BEM), the blade of a wind turbine with a power of 10 kW was analyzed to calculate the power coefficient and torque coefficient as well as calculate the power. According to the obtained results, it was found that the BEM theory is simpler and easier to use by relying on a 2D blade element. In contrast, it more accurate in describing the studied model. observed.

Key words: Q Blade, Computational Fluid Dynamics , Horizontal wind turbine, Blade Element Momentum (BEM), Wind Energy.

ملخص

تعد طاقة الرياح موردًا مهًما في مجال الطاقات المتجددة. في هذه الدراسة تم اعتماد طريقة لدراسة توربينات الرياح ، تم تحليل شفرة توربين ومقارنتها باستخدام نظرية زخم عنصر الشفرة (BEM) لتحديد الأبسط والأكثر دقة. لحساب معامل القدرة ومعامل عزم الدوران وكذلك حساب القدرة الرياح بقوة 10كيلو وات وفقًا للنتائج التي تم الحصول عليها، وجد أن نظرية أبسط وأسهل في الاستخدام من خلال الاعتماد على عنصر شفرةBEM

الكلمات المفتاحية :

,تربينات الرياح الافقية, زخم عنصر الشفرة(BEM) , ديناميكيات السوائل الحسابية QBLADE,
طاقة الرياح

Résumé

L'énergie éolienne est une ressource importante dans le domaine des énergies renouvelables. Dans cette étude, deux méthodes différentes ont été adoptées pour étudier les éoliennes et les comparer pour déterminer la plus simple et la plus précise. En utilisant la théorie de la quantité de mouvement des éléments de pale (BEM), la pale d'une éolienne d'une puissance de 10 kW a été analysée pour calculer le coefficient de puissance et le coefficient de couple ainsi que pour calculer la puissance. Selon les résultats obtenus, il a été constaté que la théorie BEM est plus simple et plus facile à utiliser

Mots-clés : QBlade, dynamique des fluides de calcul, éolienne horizontale, élan de l'élément lame (BEM), énergie éolienne.

List of Symbols

N	Number of blades
D	Blade Diameter (m)
P	Mechanical Power (W)
V	Upstream wind-speed (m/s)
C_P	Power coefficient
C_Q	Torque coefficient
c	Cross section Area at radius r (m^2)
λ, λ_0	tip-speed ratio, optimum
F_L	Lift force (N)
F_D	Drag force (N)
C_L	Lift coefficient
C_D	Drag coefficient
F_T	Tangential force (N)
τ_r	Torque per unit-length (N)
V_{rel}	Relative wind speed (m/s)
R	Radius of the rotor (m)
Φ	Angle of relative wind (deg)
β	Pitch angle (deg)
ω	Rotational Speed (rad/s)
A	Area (m^2)
R_r	External radius to internal radius ratio (r / R)
V	Average wind speed (m/s)
a	Axial Induction factor
a’	Radial Induction factor
C_{line}	Chord line
AoA	Angle of Attack
Re	Reynolds number
F_x	Axial force
F_θ	Tangential force
Q	Tip loss correction factor
X	Axial coordinate

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Chapter I : Generality about wind turbine.

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Chapter III : Result and discussion.

General introduction

General introduction

Renewable energies are among the most important sustainable and inexhaustible natural resources. These energies include hydro, wind, tidal and geothermal energy. As harnessing these energies reduces our dependence on fossil fuels, reducing carbon dioxide emissions into the atmosphere.

Currently, the largest generation of renewable energy is found through dams in hydroelectric stations, followed by wind turbines in wind power fields. One of the most important advantages of wind power is that it is renewable energy and does not produce emissions that harm the environment, as 95% of the land used to generate energy by wind turbines is used for agriculture and grazing. She goes.

A wind turbine is a power generation device that is powered by the kinetic energy of the wind. Wind turbines generally fall into two categories: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). Both types use rotors with blades of various designs that drive a shaft into a generator that uses electromagnetic induction to produce voltage.

Despite the great development of wind turbines, it has not received great circulation in the countries of the world, even though it is found in low rates, and this is due to the large cost and complex maintenance as compared to other sources.

The main objective in this topic is to work on making wind blades more efficient, which contributes to increasing energy productivity and reducing costs. Based on the basic mathematical relationships of wind turbines and using the QBLAD program, we will simulate the blades and work on improving them.

In the first chapter, a set of definitions and concepts of wind turbines were presented, where we got acquainted with the origin, origin and types of wind turbines. We also defined wind blades and mentioned their types.

The second chapter provides a descriptive view of the aerodynamics of wind turbines. In this we will show the forces acting on the blade's lift, drag, torque... in addition to mentioning the equations related to each force. We will also mention the equations related to the BEM theory used in the correction.

The third chapter will focus on the study of wind blades through BEM theory and using QBLADE, a program for wind turbines only, which allows the user to draw ailerons and integrate them directly into the design and simulation, where the necessary data were collected in the process of comparison and improvement based on previous studies.

Chapter I :

Generality about wind turbine.

I.1.Introduction:

Wind energy is a free, renewable, clean, and non polluting source of electricity. Since earliest recorded history, wind power has been used to move ships, grind grains, and pump water. Wind energy was used to propel boats along the Nile Rivera searly5000B.C. Simple windmills were used in china to pump water.

All electricity-generating wind turbines, regardless of size, consist of a few basic components: the part that actually rotates in the air, the electric generator, the speed control system, and the tower.[1] Over the past two decades, a variety of wind power technologies have been developed, which have improved the conversion efficiency and reduced the costs for wind energy production. The size of wind turbines has increased from a few kilowatts to several megawatts each. In addition to onshore installations, larger wind turbines have been pushed to offshore locations to harvest more energy and reduce their impact onshore use and landscape.[2,3].

I.2.Bibliographic search on wind turbines:

Hani Muhsen and all [15]: This work aims to design and optimizing the performance of small horizontal axis wind turbines to obtain a power factor (CP) above 40% at a low wind speed of 5 m/s. Two identical wings, S1223 and S1210, were used to obtain the optimal final airfoil. The blade element momentum theory was used to optimizing the design.

Rajendra Roul and all [16] : The focus here is on the study of the aerodynamic and compositional analysis of wind turbines by combining computational fluid dynamics (CFD) and finite element analysis (FEA). Unidirectional coupling is chosen for fluid structure interaction (FSI) modeling. The investigation is conducted using ANSYS commercial applications. Structural analysis was also performed and performance parameters such as deformation and Von-Mises filaments were found.

Chien-Kuo Chiu and all [17]: This study first reviewed and analyzed data in relevant engineering documents. Similar external cases were also reviewed to identify common causes of turbines Blade failure incidents. The structural mechanisms of WT ciphers were then analyzed using Behavioral models to identify the mechanisms of damage.

Wang Xudong and all [18]: This paper presents a design tool for optimizing wind turbine blades. The design is based on aerodynamic/elastic code incorporating blade structural dynamics and blade element momentum (BEM) theory. In BEM theory, a polished model is used to correct for tip loss. The calculated aerodynamic results were compared with experimental data for the rotor used in the project model experiments. The optimizing showed that the energy cost of the main rotors can be reduced.

MANOJ KUMAR CHAUDHARYand all [19] : In this research paper, the main focus is on the blade performance of small mixed-wing wind turbines such as SG 6043 and NACA 4412 and various composites that have been compared using Numerical. Dim Elemental Momentum Theory (BEM) was developed on the basis of MATLAB . software

.**Ali Cemal Benim and all [20]:** The purpose of this study is to develop an automated procedure to improve the two-dimensional airfoil shape of a small horizontal axis wind turbine (HAWT), focusing on high thrust and aerodynamically stable performance.

Mohamed Khaled Mohamed and all [21]: This thesis presents an A design method based on Blade Element Momentum Theory (BEM) illustrating the blades of a small horizontal axis wind turbine (HAWT) model. The method was used to optimizing the chord distribution and torsion of wind turbine blades to improve the aerodynamic performance of wind turbines. FORTRAN software was developed to use BEM in the modeling of a horizontal axis wind turbine (HAWT). The NACA 4412 aileron aileron was selected for the wind turbine blade design

Chi-Jeng Ba and all [22]: The purpose of this study is to develop Small horizontal axis wind turbine (HAWT) suitable for local wind conditions in Tainan, Taiwan. Wind energy potential was first identified by Weibull wind speed distribution and then adapted Turbine blade design. Two numerical approaches Certified in the design and analysis of HAWT turbine blades. Razor Element Momentum Theory BEMT was used to draw the shape of the turbine blades (S822 and S823 ailerons).

S. Kapuria and all [23]: In this paper, a comprehensive numerical study is presented on the use of bending and torsion coupling of composite fan blades to improve their hydrodynamic efficiency in off-design conditions. The analysis is carried out on a complete fan with a diameter of 4.2 meters. Open water performance is estimated. Deformation analysis is performed. The structural fluid interaction was incorporated in an iterative manner.

Xinzi and all [24]: This paper presents a straightforward method for blade design and optimization of a small wind turbine. An aerodynamic mathematical model was developed in which the analysis of the wing profile was incorporated into this approach. Reynolds number effects, tip and axis effects, and drag effects were taken into account when optimizing the design. Optimum ropes and torsion angles are provided. This approach integrates code design and airfoil analysis process.

I.3.Historical Development wind turbines:

I.3.1. Windmills:

The first uses of wind as energy by man are due to windmills as shown here in Fig I.1 Windmills appeared in the year 600 first in the East and then in Egypt, where they produced mechanical energy that was used to grind grain and also to pump water to irrigate crops.

Windmills appeared in Europe a little before the year 1000 in Great Britain and then spread in the 12th century throughout Europe. It is built on a vertical axis wind turbine model.

Fig I.1: Windmill, Goscinny France. 1756.

I.3.2. The first wind turbine:

The first wind turbines did not really appear until the end of the 19th century, in experimental form. It was Charles F. Bosch is the first to invent this device for supplying electricity to his home in 1888. Wind turbines operate with vertical axis blades as shown here in the figure. I.2 and several accumulators (batteries) to store the energy produced. Subsequently, Charles F.'s machine was seized. Bosch was designed by the Danish Paul La Cor, who designed several industrial wind turbines, one of which sold 72 copies at the beginning of the 20th century. These wind turbines aim to produce hydrogen using wind energy to convert it into chemical energy through the process of electrolysis.

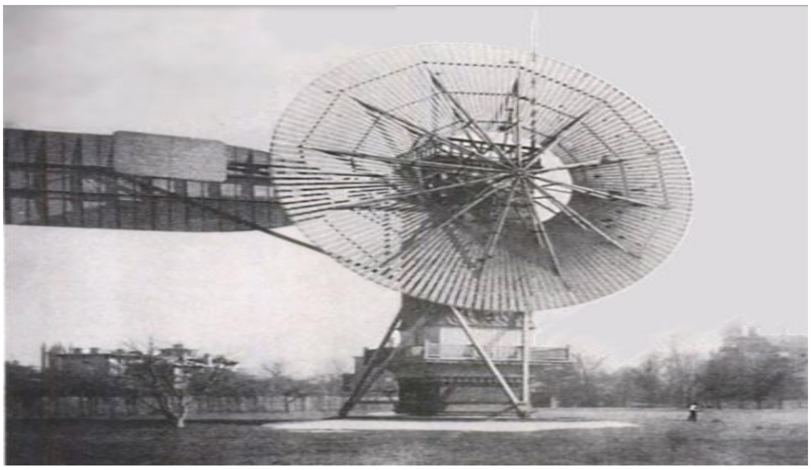


Figure I.2: Charles' first wind turbine. F.Brush

I.3.3. from 1900 to today:

During the twentieth century, many tests will be carried out. In 1957, Johannes Jules created a turbine called Gedser identical to the one in the figure and still serving today as a model for modern wind turbines. In the United States, Britain and France, wind turbines with a power of up to 1,000 kW will be built.

Unfortunately, the wind energy market hampered its development during most of the twentieth century due to the high consumption of oil and coal. In the 1970s, the first oil shocks and a sharp increase in fossil fuel prices brought new life into wind power.

Figure I.3: Geedser wind turbines.

I.4.Definition wind turbine:

A wind turbine is a device for converting the kinetic energy of the wind into mechanical energy. They are generally used to generate electricity and fall into the category of renewable energy.
The representation in Figure. I.4 gives a fine lattice model characterizing the conversion of wind energy into electrical energy [4].

Fast-spinning wind turbines, generally two-bladed or three-blade, currently constitute the popular category of wind turbines, and are primarily intended for the production of electricity, hence their more common name "wind generators".

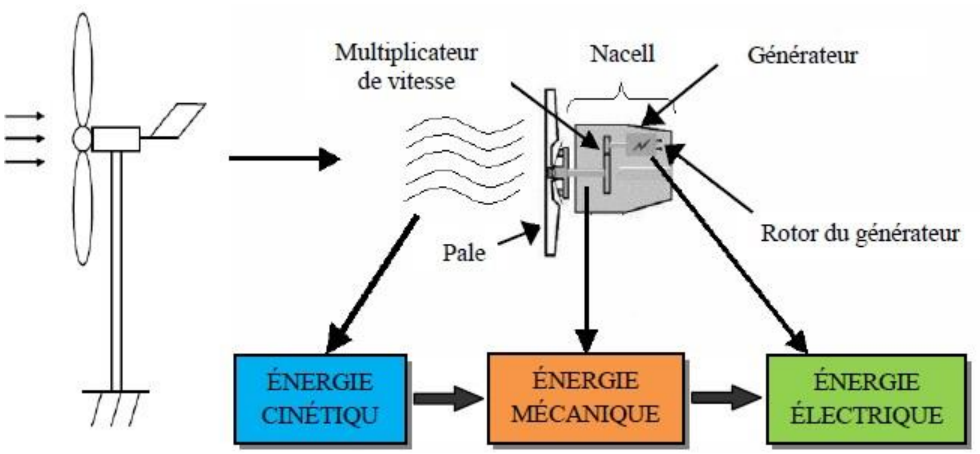


Figure. I.4. wind power generation procedure .

I.5.Principle of operation:

Wind turbines consist of a group of blades connected to a rotor, which together form the rotor; This rotor deflects the air flow, which creates a force on the blades, which, in turn, produces torque on the shaft, and the rotor rotates around a horizontal axis, which is mainly connected to the gearbox and generator. These are located inside the nacelle, which is at the upper end of the tower, along with many other electrical parts. The generator generates electricity, which is transmitted from The tower and its output to an available transformer, so that it can be switched from the output Voltage (usually about 700V) for some voltage for any of the country Network (33,000 volts) or for any personal use (about 240V) [5].

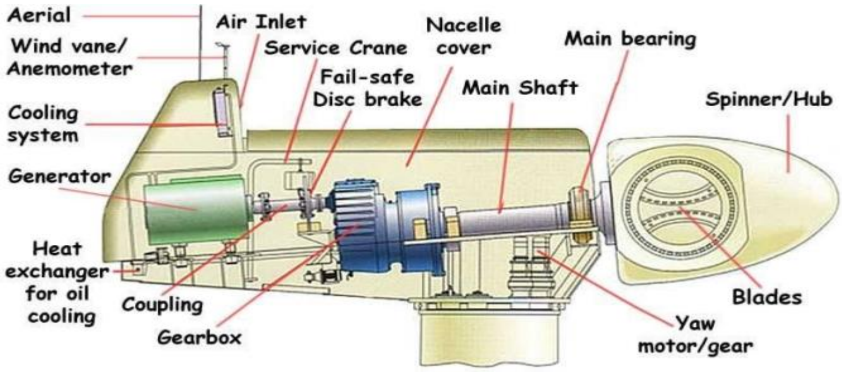


Figure I.5: Operating parts of a horizontal axis wind turbine

I.6.Constituent elements of a wind turbine:

Wind turbines mainly consist of three parts, namely nacelle, mast and foundation.

I.6.1 nacelle:

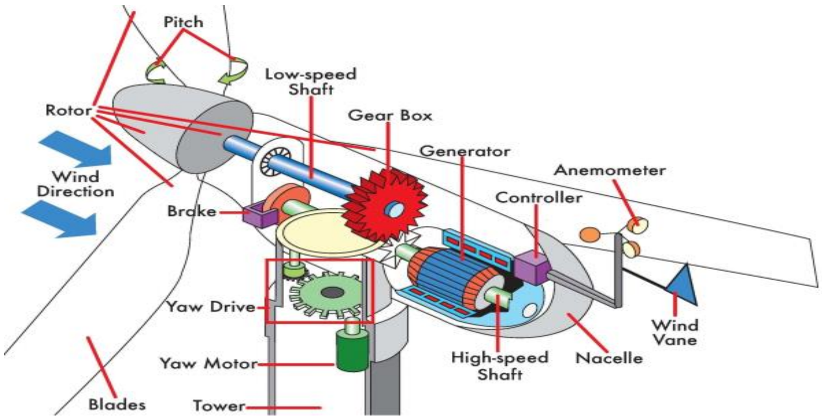


Figure I.6: Structure of the horizontal axis wind turbine nacelle.

The nacelle includes all the mechanical elements that convert the mechanical energy generated by the rotation of the blades into electrical energy. The blades, anemometer and rotor are mounted on the nacelle. Also inside it is the gearbox, alternator, control systems, temperature sensor, vibration sensor and speed sensor [6]. The items included in the nacelle are:

Rotor: on which the wind turbine tip blades are fixed.

Rotor Lock System: The brake is activated when the wind speed is greater than 25m/s thus preventing the rotor from working.

Main axis: it is driven by the blades and rotates at a relatively low speed but with an important moment.

Multiplier: The main shaft transmits very large torque to the multiplier. Thus, this converts this moment from a rotation at a low speed and a strong moment, to a rotation at a high speed and a weak moment.

Fast Tree: The link between the generator and the multiplier. Its rotation speed is about 1500 revolutions per minute.

Generator: Its function is to convert mechanical energy into electrical energy.

Weather vane and anemometer: These two tools are used to measure wind speed and direction. Located behind the blades. They take measurements between two segments of the code and establish the average of the recorded values.

Axis Direction: Allows the wind turbine to advance the propeller against the wind, regardless of its direction [6].

I.6.2.mast:

Figure I.7: Wind turbine mast

The mast consisted of three parts, connected by bolts that were not tightened to the maximum to allow for extension. Screws expand over time, so they must be tightened regularly. A direct current of about 690 volts is produced at the top of the wind turbine. It is carried to the bottom of the wind turbine via the mast via cables, and then converted to 20,000 VAC by a transformer. So the mast must be strong enough in case of overload due to weather condition (frost or strong wind).

The first part of the mast contains a computer. This is used to control the operation of wind turbines. With information measured by an anemometer and a wind vane, a computer stops the blades if the wind becomes too fast by tilting them or by guiding the rotor against the wind. A spin counter is connected to a computer and allows, if the wind turbine has always been spinning in the same direction for a long time, the ability to run the wind turbine in the opposite direction in order to prevent cable twisting [6].

I.6.3 the foundation:

The foundations are built of reinforced concrete. They are blocks of 100 tons or more buried 5 to 6 meters deep. A plate is formed to install the first part of the wind turbine mast. For a wind turbine with a height of 80 m, 400 tons of concrete is required [6]:

Figure I.8: Wind turbine basis.

I.7. Types of Wind Turbines:[7]

Wind turbines are classified into two major categories: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs)

The HAWT category includes wind turbines with upwind rotors, wind turbines with downwind rotors, windmill turbines, wind wheel turbines, and turbines with high tip-velocity ratios ranging from 1 to 8. The three distinct types of VAWTs are those that contain On the configurations of the Savonius rotor, the Darrieus wind turbine and the Giromill wind turbine:

I.7.1Horizontal axis wind turbines:

There are single-blade, two-blade and three-blade wind turbines and multi-blade pumped wind turbines. Most of these wind turbines are oriented against the wind thanks to drift (direction).

It consists of a fan perpendicular to the wind mounted on a mast. In addition, the number of blades does not change the power of the machine, which is proportional to the area swept by the rotor and thus its diameter [8], but the three-blade rotor has advantages:

- ✓ Better starting torque:
- ✓ Wind turbines start to spin at a low wind speed.
- ✓ Less mechanical stress compared to a two-blade rotor
  Aesthetic.

- ✓ More harmonious and better movement

Disadvantages of horizontal-axis:

- ✓ Generator and gearbox should be mounted on a tower, thus restricting servicing, and
- ✓ More complex design required due to the need for yaw or tail drive.

Figure I.9.Horizontal axis wind turbine.

Depending the relative position of the rotor and wind direction, two types of horizontal wind turbines can be distinguished:

- ***Upwind*:**

The rotor is facing the wind direction, the basic disadventage of this design is that the blades need to be strong, inflexible and placed away to avoid hiting the tower during high wind conditions. Also, this type needs yaw system to keep the rotors facing the wind. By far the majority of wind turbines have this design

- ***Downwind***:

The wind controls the yaw (left– right motion), i.e., it orients itself with respect wind direction. But the shadowing effects of the tower causes the blade to flex, thus resulting in fatigue, noise and reduces power output.

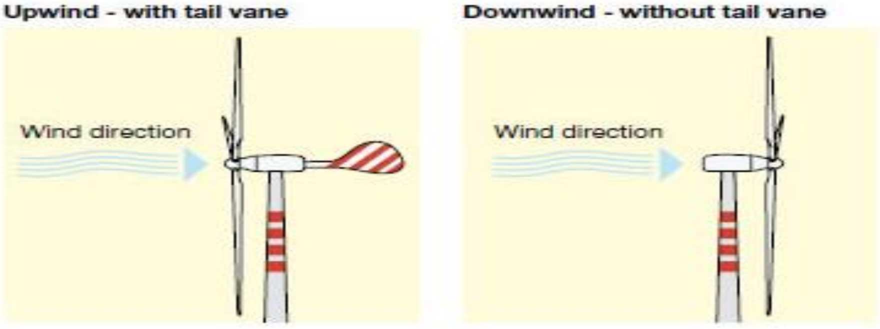


Figure I.10: Upwind HAWT and Downwind HAWT

I.7.2 Vertical axis wind turbines:

Do not know a steering system with respect to the face, but are generally of a rather complex design [9]

- ***Savonius wind turbines:***

Are vertical axis wind turbines. It was invented by the Finnish engineer Sigurd Savonius in 1924 and confirmed in 1929 [8]. The operation of the Savonius rotor is based on aerodynamic torque generated by the deflection of the flow on the blades.

- ***Darrieus wind turbine:***

The principle is a vertical axis rotor that turns at the center of a finned stator. This type of solution significantly reduces noise while allowing operation with winds higher than 220km/[8].

Figure I.11: Savonuis wind turbines.

Figure I.12: Darius-type wind turbine

Advantages of the of vertical axis wind turbine [10, 11]:

Easy maintenance for ground mounted generator and gearbox, Receive wind from any direction (No yaw control required), and Simple blade design and low cost of fabrication. Disadvantages of vertical axis wind turbine are:

- ✓ Not self starting, thus, require generator to run in motor mode at start.
- ✓ Lower efficiency (the blades lose energy as they turn out of the wind).
- ✓ Difficulty in controlling blade over speed, and Oscillatory component in the aerodynamic torque is high

I.8.Benefits and Disadvantages of Wind Turbine Technology:

I.8.1.Benefits:[7]

Compared to other energy sources wind turbine technology offers affordability, pollution-free and maintenance-free operation. Major benefits of wind turbine technology can be briefly summarized as follows:

- ✓ Saves big money on utility bills.
- ✓ Providing environmentally friendly and efficient electric power at a low cost, especially in areas where electrical networks are not available.
- ✓ Installation does not jeopardize the value of the home, office building or commercial building. .
- ✓ The turbine does not require frequent or intermittent maintenance or employment of operational personnel.

Despite these benefits, wind turbine technology has some shortcomings. We mention some of them:

I.8.2.Disadvantages:

It would be unfair not to identify potential defects or impending defects. Consistent noise is the most annoying factor.

They are dangerous to birds flying less than 350 feet above the ground. , the technician must be extremely vigilant while working in tight spaces at elevations of more than 235 feet, in the presence of high voltage electrical cables and spinning metal components. Turbine tower does not have an elevator. Reaching the top is only possible by climbing up the stairs on a narrow steel ladder inside the tower. Wind turbine technicians face inherent dangers while working alone nearly 300 feet in the air with little support. However, wind turbine technicians are paid annual salaries in six figures.

I.9.Aerodynamic descriptions of a wind turbine blade:

I.9.1.Wind turbine blade engineering:

The most important component of a fast or slow wind machine is the blade, the study of the blade leads to the study of the profiles corresponding to the cross section of the blade, first of all we begin by giving some definitions related to the profile on the following scheme [12]:

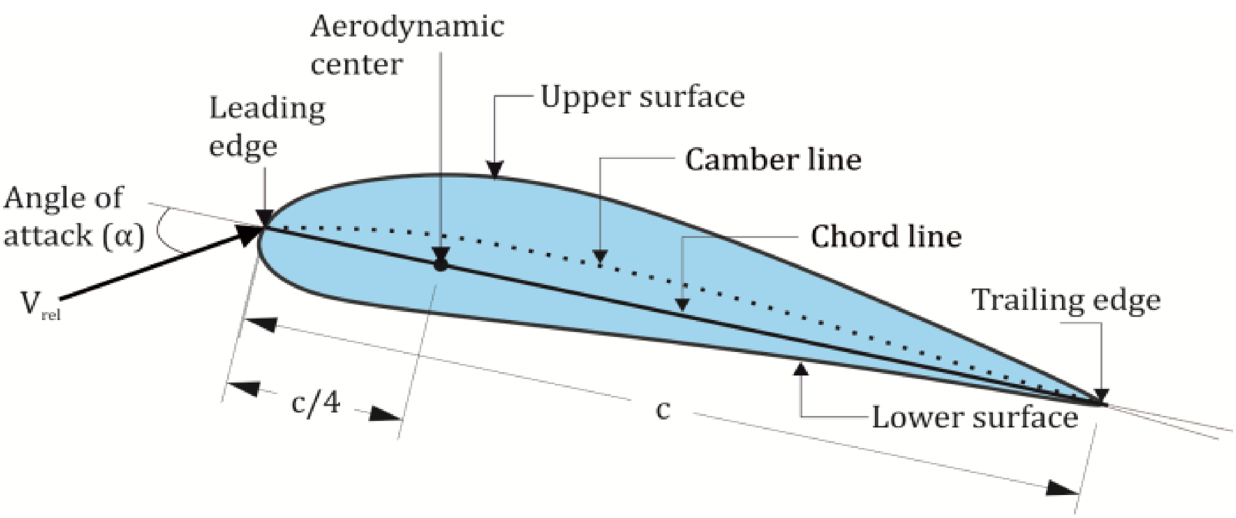


Figure I.13: Profile of a blade

I.9.2.Types of blades:

Code profiles are categorized according to the shape of intrados and extrados:

The flat convex profile holds up well even with a low incidence but is a bit unstable. Mainly used in general aviation

Figure I.14: Planar-convex profile

The asymmetric-convex profile also holds up well, even at zero incidence and is very stable. It is widely used in recreational flying.

Figure I.15: Asymmetric convex profile.

The convex or hollow profile is very crowded but also quite unstable, when the angle of attack increases, it tries to escalate.

Figure I.16: Hollow convex profile.

The symmetrical biconvex profile does not wear out in the low and very low profiles. It is only interesting for control surfaces and acrobatics.

Fiugre I.17: Symmetrical convex profile.

The double bending (self-stable) shape has the advantage of large stability but medium lift and rather strong drag [12].

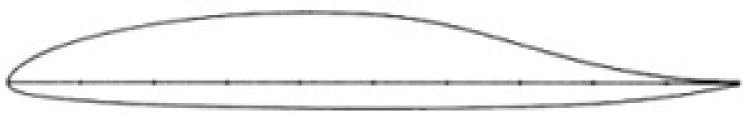


Figure I.18: Double curvature profile.

I.10.Metals used in the manufacture of wind turbines:

Increasing demand for raw materials The following minerals are used in the production of wind turbines located on coastal wind farms: aluminum, boron, chromium, lead, limestone (for concrete) [13], manganese, iron, nickel, cobalt, Copper, molybdenum, rare earths (praseodymium, neodymium, terbium and dysprosium) and zinc. Figure I..19 shows where these metals are used in wind turbines.

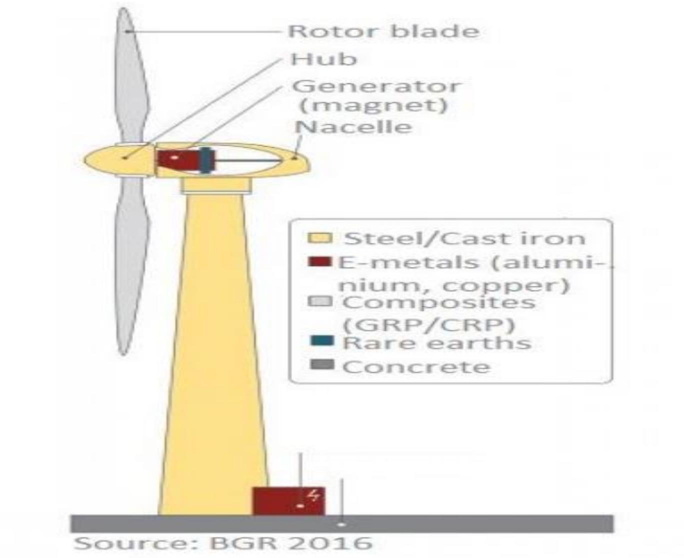


Figure I.19 :Raw materials used in wind turbines.

Table I.1 shows the amounts of various minerals and metals needed to create a turbine, measuring this in the kg per material to create one MW of turbine production capacity. These figures are subject to change over time given the continuous innovation and increase in efficiency within the wind energy sector. Nevertheless, the numbers provide a base from which to calculate the mineral and metal costs for the increased production of wind energy.

The large amounts of specific materials needed to produce wind energy, as in the case of steel, shows that the demand for specific metals is likely to grow significantly with the push towards greater wind capacity Current offshore wind turbines in the Netherlands have a capacity of 4MW, but improvements in efficiency are expected to increase to increase this to 10MW by 2030.

Based on: World Bank 2017[14]

Table I.1: Amounts of minerals and metals used in wind turbine.

Metal	Wind turbine manufacturing estimateskg/MW
Aluminum	Unknown
Boron	0.8 - 7.0
Chromium	789 - 902
Cobalt	Unknown
Copper	1,140 - 3,000
Dysprosium	2.8 - 25.0
Iron(inmagnet)	52 - 455
Iron (cast)	20,000 - 23,900
Lead	Unknown
Manganese	32.5 - 80.5
Molybdenum	116 - 136
Neodymium	0 - 186
Nickel	557 - 663
Praseodymim	4 - 35
Steel	103,000 - 115,000
Terbium	0.8 - 7.0
Zinc	5,150 - 5,750

I.11.Potential Applications of Small Wind Turbines:

Small-scale wind turbines are best suited for applications where electrical power consumption does not exceed 10 kW, for example:

- ✓ Remotely located homes
- ✓ Telecommunication transmitter sites
- ✓ Offshore platforms
- ✓ Cathodic protection
- ✓ Performance monitoring sites
- ✓ Water pumping
- ✓ Utility-connected homes and businesses
  Remote military posts

I .12. Conclusion:

In this chapter, we talked about the nature of tribal studies, as well as the development of wind turbines in general, and we touched on the types of turbines and the geometric shapes of the blades. We also mentioned

Chapter II : Aerodynamic of wind turbine and BEM theory

II.1.Introduction:

A wind turbine is a device for extracting kinetic energy from the wind. By removing some of its kinetic energy the wind must slow down but only that mass of air which passes through the rotor disc is affected. Assuming that the affected mass of air remains separate from the air which does not pass through the rotor disc and does not slow down a boundary surface can be drawn containing the affected air mass and this boundary can be extended upstream as well as downstream forming a long stream-tube of circular cross section. No air flows across the boundary and so the mass flow rate of the air flowing along the stream-tube will be the same for all stream-wise positions along the stream-tube. Because the air within the stream-tube slows down, but does not become compressed, the cross-sectional area of the stream-tube must expand to accommodate the slower moving air .[25]

In this chapter, we will make a study on the wind blade. which is the main component of the wind turbine. We will study the forces applied to the wind blade and the mathematical equations for each force.

II. 2. Aerodynamic Forces:

Wind turbines exploit the aerodynamic forces which arise when the wind blows on the rotor blades, and the blades move relative to the wind.

Any body which is immersed in a fluid stream will be subject to forces and moments (turning forces). The forces and moments depend on the shape of the body and its orientation and its movement or rotation in relation to the stream.

II.2.1 Definition of lift:

A fluid flowing around an object exerts a force on it. Lift is the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is the component of the force parallel to the flow direction. Lift conventionally acts in an upward direction in order to counter the force of gravity, but it can act in any direction at right angles the flow. see Figure II.1

II.2.2 Definition of drag:

Both aircraft engineers who build aircraft wings and propellers, and wind turbine engineers who design rotor blades are concerned with aerodynamic drag. Drag is always important when an object moves rapidly through the air. Aircraft should have good fuel economy, and wind turbine rotor blades must have high tip speeds to work efficiently. Therefore it is critical, that both aircraft wings and rotor blades have low aerodynamic drag The figure II.1 shows the direction of drag.[26]

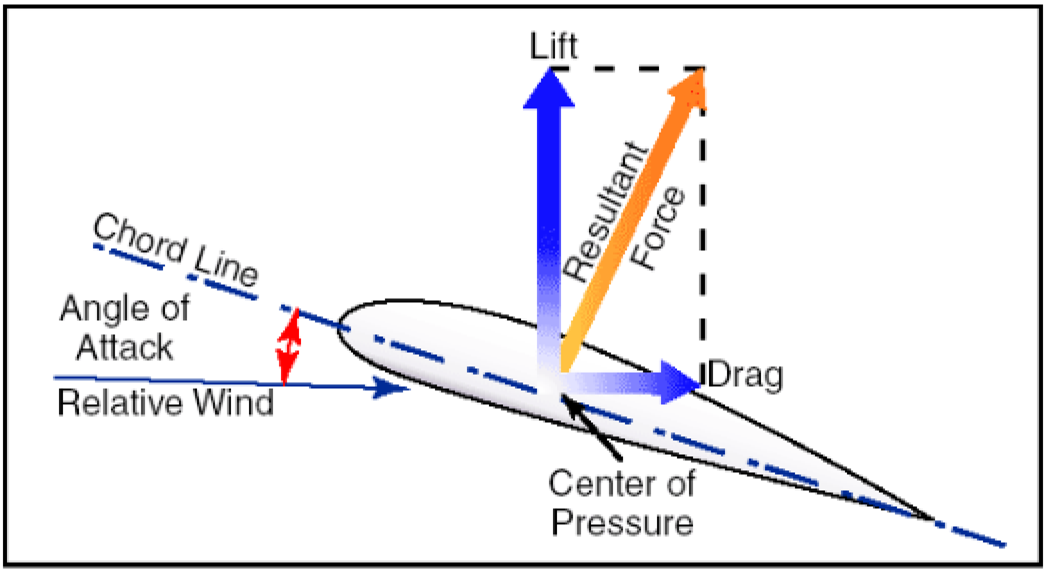


Figure II.1 Definition lift and drag.

If the aerofoil is designed for an aircraft it is obvious that the L/D ratio shouldbe maximized. The lift is the force used to overcome gravity and the higher the lift the higher the mass that can be lifted off the ground. In order to maintain a constant speed the drag must be balanced by a propulsion force delivered from an engine, and the smaller the drag the smaller the required engine. Lift and drag coefficients Cl and Cd are defined as:[26]

$$C_L = \frac{L}{\frac{1}{2}\rho V_\infty^2 C} \tag{II.1}$$

$$C_d = \frac{D}{\frac{1}{2}\rho V_\infty^2 c} \tag{II.2}$$

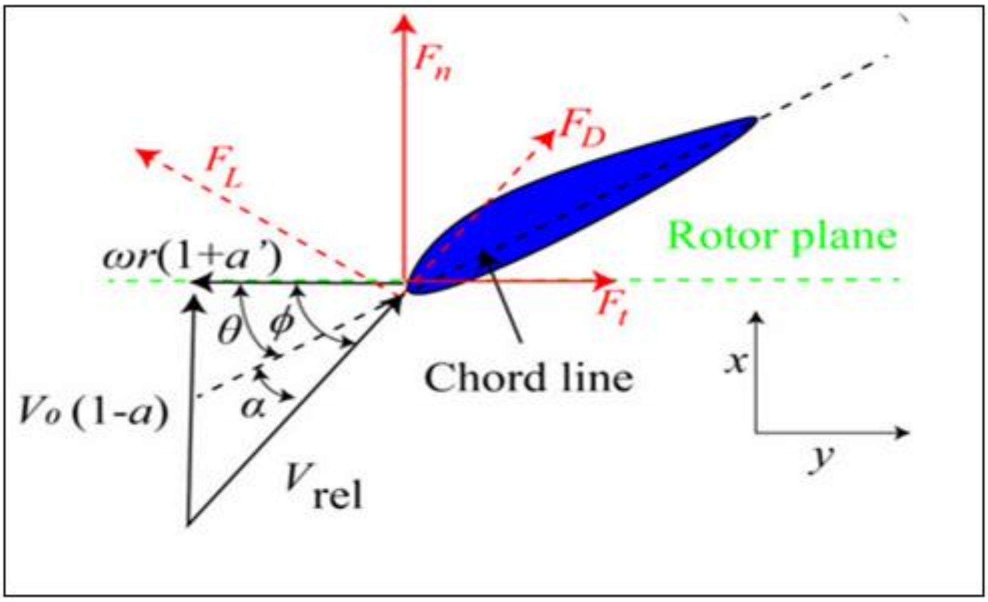


Figure II..2: Forces On The Turbine Blade.

The forces on the blade element are shown in figure II..2, note that by definition the lift and drag forces are perpendicular and parallel to the incoming flow. For each blade element one can see: [28]

$$dF\theta = dL\cos\beta - dD\sin\beta \quad \text{(II. 3)}$$

$$dFx = dL\sin\beta + dD\cos\beta \quad \text{(II.4)}$$

where dL and dD are the lift and drag forces on the blade element respectively.dL and dD can be found from the definition of the lift and drag coefficients as follows:

$$dL = C_L \frac{1}{2}\rho W^2 cdr \quad \text{(II.5)}$$

$$dD = C_D \frac{1}{2}\rho W^2 cdr \quad \text{(II.6)}$$

Lift and Drag coefficients for a NACA 0012 aerofoil are shown in Figure II.3, this graph shows that for low values of incidence the aerofoil successfully produces

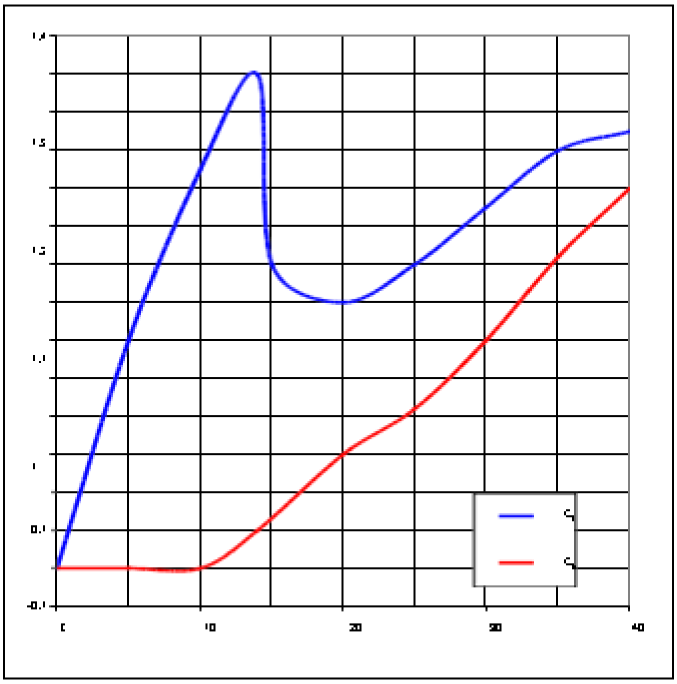


Figure II.3: Lift and Drag Coefficients for a NACA 0012 Aerofoil.

large amount of lift with little drag. At around i = 14° a phenomenon known as stall occurs where there is a massive increase in drag and a sharp reduction in lift.

$$dF_x = B\frac{1}{2}\rho W^2 (C_L \cos\beta + C_D \sin\beta) cdr \qquad \text{(II.7)}$$

$$dF_\theta = B\frac{1}{2}\rho W^2 (C_L \cos\beta - C_D \sin\beta) cdr \qquad \text{(II.8)}$$

II.2.3Axial force:

Consider the stream tube around a wind turbine shown in Figure II.4. Four stations are shown in the diagram 1, some way upstream of the turbine, 2 just before the blades, 3 just after the blades and 4 some way downstream of the blades. Between2 and 3 energy is extracted from the wind and there is a change in pressure as a result. 4 the flow is frictionless so we can apply Bernoulli's equation.

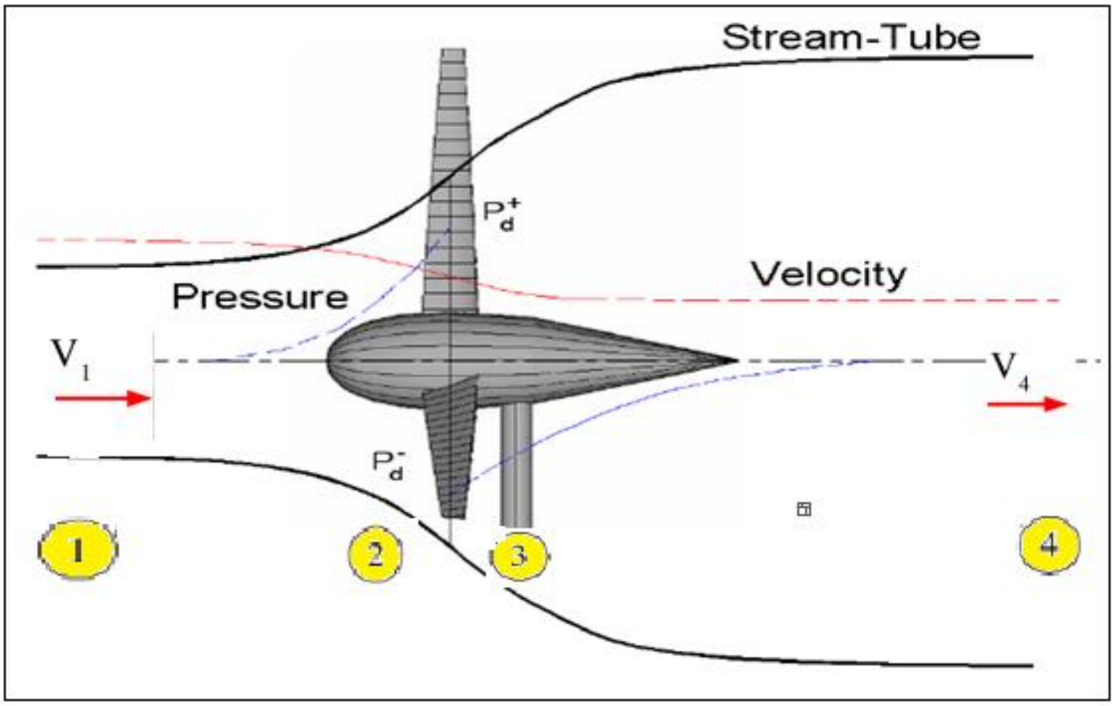


Figure II.4: Axial Stream tube around a Wind Turbine

Assume $p_1 = p_4$ and that $V_2 = V_3$. We can also assume that between 1 and 2 and between 3 and After some algebra:

$$p_2 - p_3 = \frac{1}{2}\rho(v_1^2 - v_4^2) \quad \text{(II .9)}$$

Noting that force is pressure times area we find that:

$$dF_x = (p_2 - p_3)dA$$

$$dF_x = \frac{1}{2}\rho(v_1^2 - v_4^2)dA \quad \text{(II.10)}$$

Define *a* the axial induction factor as:

$$a = \frac{V_1 - V_2}{V_1} \quad \text{(II.11)}$$

It can also be shown that:

$$V_2 = V_1(1-a) \quad \text{(II.12)}$$

$$V_4 = V_1(1-2a) \quad \text{(II .13)}$$

Substituting yields:

$$dF_X = \frac{1}{2}\rho V_1^{\,2}[4a(1-a)]2\pi r dr \qquad \text{(II.14)}$$

The Torque on an element, dT is simply the tangential force multiplied by theradius.

$$dT = B\,\frac{1}{2}\rho W^{\,2}(C_L \cos\beta - C_D \sin\beta)crdr \qquad \text{(II.15)}$$

The effect of the drag force is clearly seen in the equations, an increase in thrust force on the machine and a decrease in torque (and power output).

These equations can be made more useful by noting that β and *W* can be expressed in terms of induction factors etc.

$$dF_X = \sigma\pi\rho\frac{V^{\,2}(1-a)^2}{\cos^2\beta}(C_L \sin\beta + C_D \cos\beta)rdr \qquad \text{(II.16)}$$

$$dT = \sigma\pi\rho\frac{V^{\,2}(1-a)^2}{\cos^2\beta}(C_L \cos\beta - C_D \sin\beta)rdr \qquad \text{(II.17)}$$

where σ is called the local solidity and is defined as:

$$\sigma = \frac{Bc}{2\pi r} \qquad \text{(II.18)}$$

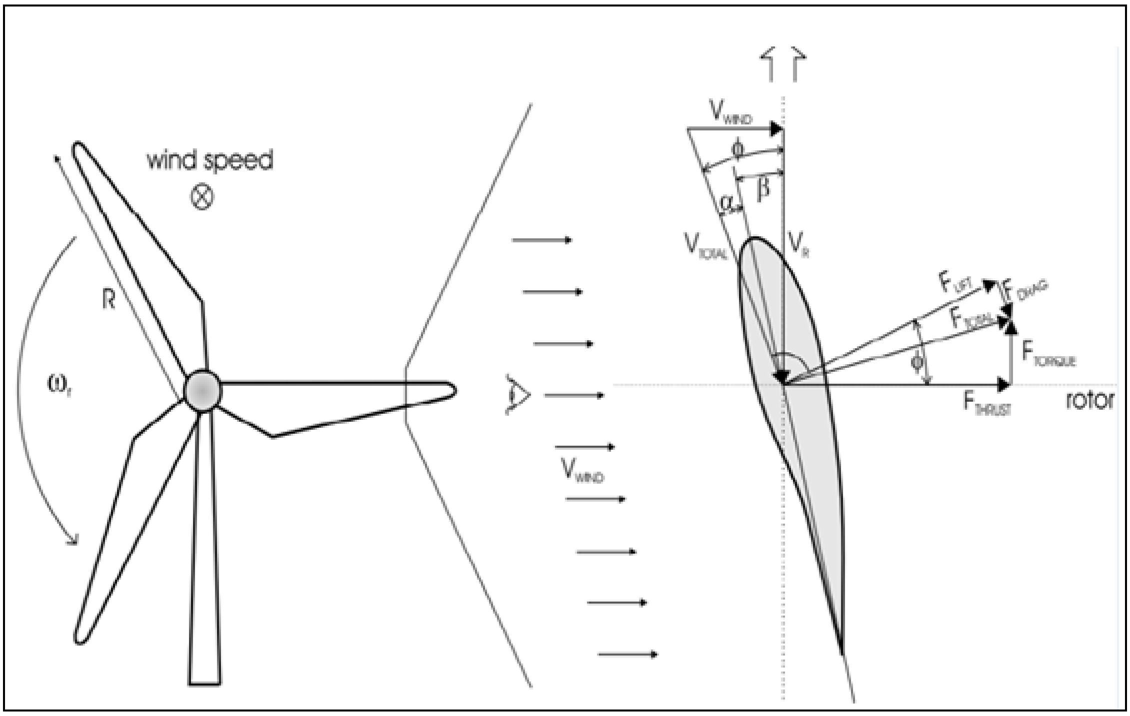


Figure II.5: Relationships of blade parameters element[32]

II 2.4.Thrust and power on annular area of blade:

The expression for the thrust on an annular area (2 π rdr) can be written as:

$$dT = [(4\pi r^3 \rho V^2 a)(1-a)dr] \qquad \text{(II.19)}$$

Since the moment imparted to the fluid equals the torque (dT), expression for the power in this infinite annular area can be written as:

$$dP = [(4\pi r^3 \rho V V_{ang}^2][a'(1-a)dr] \qquad \text{(II.20)}$$

Based on the relationships shown in Figure 4.1, the expression for the elemental torque and power [1] for N rotor blades of chord dimension c is:

$$dT = [(\rho/2)V_{rad} Nc(C_L \cos\varphi + C_D \sin\varphi)dr] \qquad \text{(II.21)}$$

$$dP = [(\rho/2)V_{rad}^2 Nc(C_L \sin\varphi - C_D \cos\varphi)rV_{ang} dr] \qquad \text{(II.22)}$$

When the corresponding terms in Equations (4.5) and (4.7) and Equations (4.6)and (4.8) are equated, the result is:

$$[(a/1-a))] = [\lambda(1+\varepsilon\tan\varphi)\cot\varphi\cos\varphi] \qquad \text{(II.23)}$$

$$[(a'/1-a')] = [\lambda(1+\varepsilon\cot\varphi)\sin\varphi] \qquad \text{(II.24)}$$

where λ is the blade loading coefficient, ε is the drag-to-lift coefficient ratio, a is theaxial interference factor, a′ is the tangential interference factor, and φ is the flow angle. The blade loading coefficient is defined as:

$$\lambda = [NcC_L / 8\pi r] \qquad \text{(II.25)}$$

where N is the number of blades, C is the chord length, r is the radius of the blade, and C_L is the coefficient of lift. The expression for the power coefficient can be written as

$$C_P = [(dP/dr)/(2\pi r\rho V^3/2)] = [4a(1-a)X\ (\tan\varphi - \varepsilon/1+\varepsilon\tan\varphi)]$$

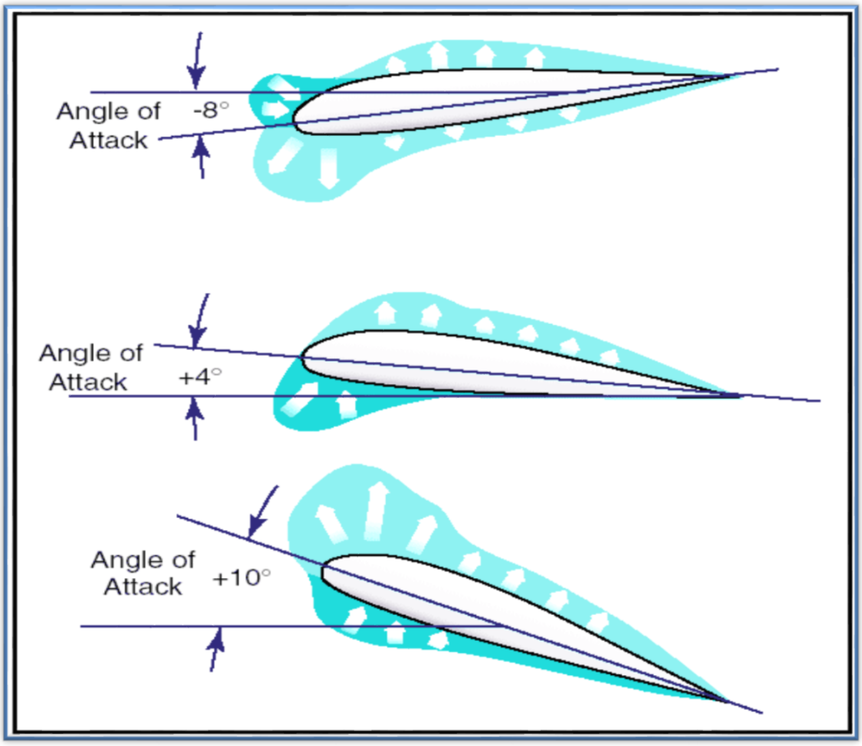
(II.26)

Where:

$$X = [r\ V_{ang}/V] \qquad \text{(II.27)}$$

II .3.Pressure distribution:

From experiments conducted on wind tunnel models and on full size airplanes, it has been determined that as air flows along the surface of a wing at different angles of attack, there are regions along the surface where the pressure is negative, or less than atmospheric, and regions where the pressure is positive, or greater than atmospheric. This negative pressure on the upper surface creates a relatively larger force on the wing than is caused by the positive pressure resulting from the air striking the lower wing surface. Figure II.6 shows the pressure distribution along an airfoil at three different angles of attack. In general, at high angles of attack the center of pressure moves forward, while at low angles of attack the center of pressure moves aft. In the design of wing structures, this center of pressure travel is very important, since it affects the position of the airloads imposed on the wing structure in low angle-of-attack conditions and high angle-of-attack conditions. The airplane's aerodynamic balance and controllability are governed by changes in the center of pressure.



FigureII.6: Pressure distribution on an airfoil.

The center of pressure is determined through calculation and wind tunnel tests by varying the airfoil's angle of attack through normal operating extremes. As the angle of attack is changed, so are the various pressure distribution characteristics.

II .4.BEM Theory:

The most commonly used approach to describe the aerodynamics of the wind-turbines blades is the BEM method, Figure II **.7** shows the blade sectional aerodynamic angles and force coefficients. The tangential which results on the blade is given by Equation (1). The tangential force is dependent on the chord of the airfoil, air density, relative wind velocity, global pitch angle, local twist angle, lift coefficient, and drag coefficient. Furthermore, the tangential force is obtained by a combination of the drag and lift forces. Since the drag and lift coefficients are nonlinearly dependent on the Angle of Attack (AoA), the ratio of the lift to the drag coefficient can decrease and cause the turbine to stall after fulfilling the maximum thresholdof the AoA: [27]

$$df_T = 0.5\rho \cdot c \cdot v_{rel}^2 (C_L \cos(\beta) + C_D \sin(\beta))dr \qquad \text{(II.28)}$$

where ρ is the air density, c is the chord length, V_{rel} is the relative wind speed between the blade section and the wind, the C_L is the lift coefficient, the C_D is the drag coefficient, and β

is the relative angle between the lift and drag coefficients.[27]

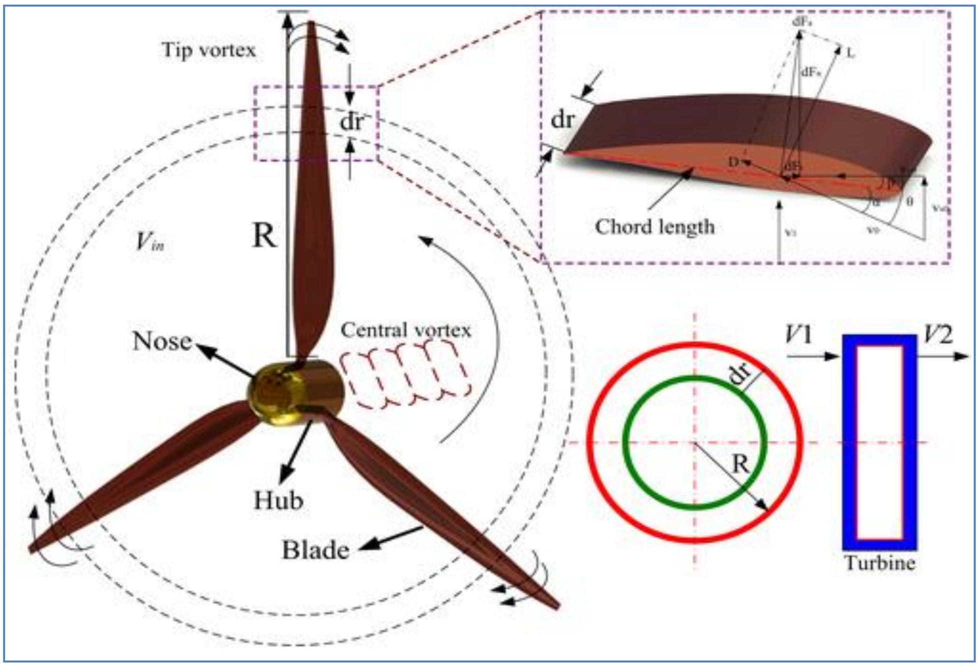


Figure II .7: Blade sectional aerodynamic angles and forces coefficients, where indicates parallel relationand indicates perpendicular relation.

In order to calculate the mechanical torque on the profile of the blade, the tangential force is multiplied by the radial distance between the axis of rotation and the internal radius of the rotor. Therefore, it can be expressed as:

$$d\tau_T = df_T \cdot r = \frac{1}{2} \cdot \rho \cdot c \cdot r \cdot V_{rel}^2 (C_L \cos(\beta) - C_D \sin(\beta)) \cdot dr \qquad \text{(II.29)}$$

The torque coefficient can be expressed as follows:

$$C_Q(\lambda, \beta) = C_L \cos(\beta) - C_D \sin(\beta) \qquad \text{(II.30)}$$

Hence, the mechanical torque acting on an infinitesimal blade profile can be given by:

$$d\tau_T = \frac{1}{2} \cdot \rho \cdot c \cdot r \cdot V_{rel}^2 \cdot C_Q(\lambda, \beta) \cdot dr \qquad \text{(II.31)}$$

where *c* represents the cross-section area at radius *r*. The relationship between the power coefficient $C_P$and the torques coefficient C_Q satisfies:

$$C_Q = \frac{C_p}{\lambda} \tag{II .32}$$

The previous equations have been written in terms of the pitch angle β and the tip speed ratio λ, whichis defined as:

$$\lambda = \frac{w \cdot R}{V_{rel}} \tag{II.33}$$

The mechanical power of HAWT in Watt can be derived by integrating the mechanical torque of theblade multiplied by the rotational speed of the blades and the number of blades N:

$$P = N \cdot w \cdot \int_{rHub}^{R} d\,\tau_T\, dr \tag{II.34}$$

where *R* is the rotor radius, *N* is the number of the blades, and ω is the rotational speed. The relative wind velocity can be found as follows:

$$V_{rel} = V \sqrt{(1-a)^2 + (r \cdot w \cdot (1+a')/V)^2} \tag{II.35}$$

where *a* is the axial induction factor, a' is the radial induction factor, and V represents the upstream wind-speed. Consequently, the angle of relative wind velocity can be expressed as:

$$\tan(\varphi) = V\,(1-a)/(r \cdot w\,(1+a')) \tag{II.36}$$

where ϕ represents the relative flow angle and it can be expressed as the summation of the twist angle, AoA, and the pitch angle. According to the previous equations, the parameters of the cost function that have been selected were: C_Q, *R*, α, λ, and *V*. [27]

II.5.Conclusion:

In this chapter, we presented the definition of the wind blade and the forces affecting it, and we got acquainted with the mathematical equations for each force, as we studied the method of BEM

Chapter III :
Result and discussion

III.1.Introduction:

Turbine blade optimization plays an important role in the design and performance of wind turbine systems. In this chapter, we improve the aerodynamic performance of 10 kW HAWT blades by Element Momentum Theory (BEMT) and performed by Qblade software.

III.2.Definition Qblade software:

The software project QBlade [29] was started in 2010 at the chair of fluid mechanics ofthe TU Berlin. The motivation was to create a single tool that comprises all the functionality needed for aerodynamic wind turbine design and simulation without the need to import, convert or process data from other sources . Another focus was on embedding the code in a convenient graphical user interface to improve accessibility over comparable simulation codes. In order to facilitate research on wind turbines worldwide the software is distributed freely under a GPL license and also utilizes functions and modules from other proven and tested open-source projects.

The functionality of QBlade includes the following modules:

- ✓ Airfoil design and analysis .
- ✓ Lift and drag polar extrapolation .
- ✓ Blade design and optimization .
- ✓ Turbine definition and simulation.

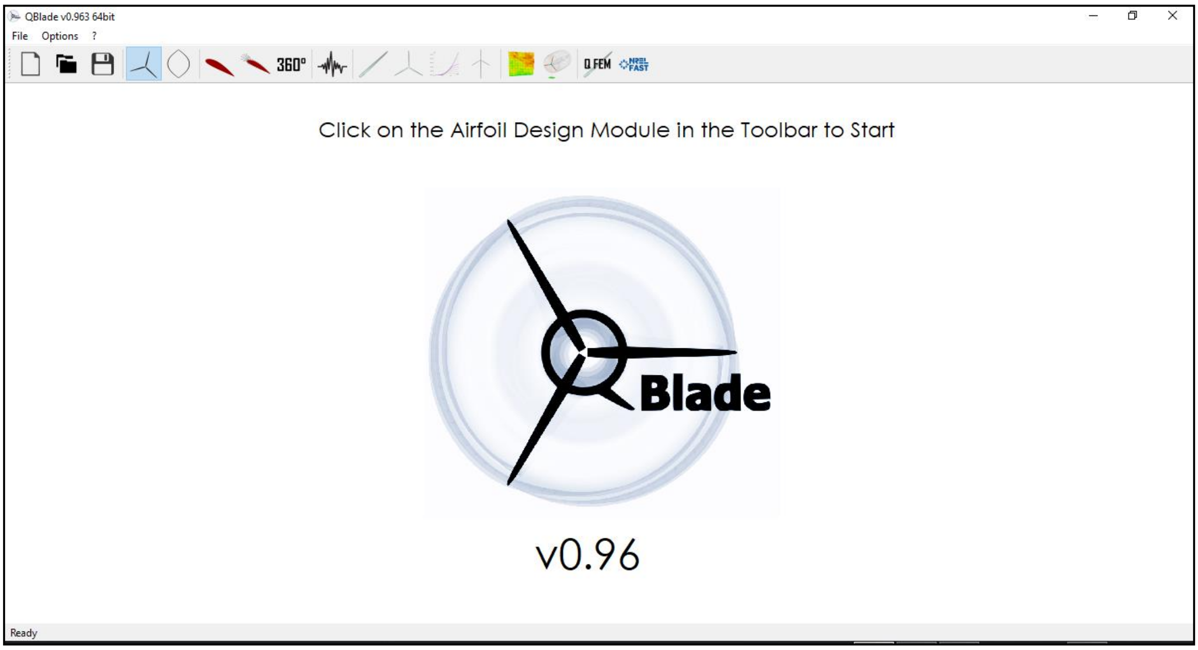


Figure III.1: Interface Qblade

III.3.Definition Blade element momentum theory:

The analysis of a HAWT is based on the classical blade element momentum method, as described by Hansen [30]. The BEM combines the blade element theory, to account for the local blade forces, with a momentum balance over the rotor disc that models the flow field. Blade forces and flow momentum are related over discrete angular rotor sections. This relation leads to a set of equations that can be solved iteratively. The BEM assumes uniform, steady state inflow and radial independence of the two dimensional airfoil sections. From these assumptions three dimensional effects, that play an important role in wind turbine aerodynamics, are not considered in the equations

III.4.NACA 4 and 5 Digital Features Family:

III.4.1.The four-digit family of NACA profiles:

In this family, a profile is represented by four digits. The first indicates the camber or maximum relative curvature in percentage of the chord; the second represents the position of this camber in percentage of the chord and the last two specify the maximum relative thickness in percentage of the chord.

For example, in the case of profile 4412:

- ✓ The 4 indicates the maximum camber (4%).
- ✓ The second (4) indicates the position of the maximum camber (40%) .
- ✓ The 12 indicates the maximum relative thickness (12%) Note that a symmetrical profile will be of type 00xx.

III.4.2.The NACA Five-Digit Family:

The 5-digit NACA series allows more complex airfoils to be described. They aredefined by the NACA code followed by five digits LPQXX [31].

1. L: the first digit defines the optimal lift coefficient, multiplied by 0.15.
2. P: the second number defines the point of maximum camber relative to the leadingedge as a percentage of the chord.
3. Q: the third digit indicates whether the profile is single (0) or double (1) camber
4. As with the 4-digit profiles, the fourth and fifth digits give the maximum thicknessof the profile as a percentage of the chord.

For example, the NACA 12018 airfoil would result in an airfoil having:

- ✓ a maximum thickness of 18%.
- ✓ the maximum camber located at 10% of the chord.
- ✓ with an expected lift coefficient of 0.15.

Table III.1.Characteristics of the NACA 4412 profile

NACA4412	
Thick (%of the cord)	12,0
Camber(%of the cord)	4,0
Trailing edge angle(degree)	14.4
Intradose thickness(%)	76.1
Maximum(L/D)	1.507
Maximum lift(CL)	57,209

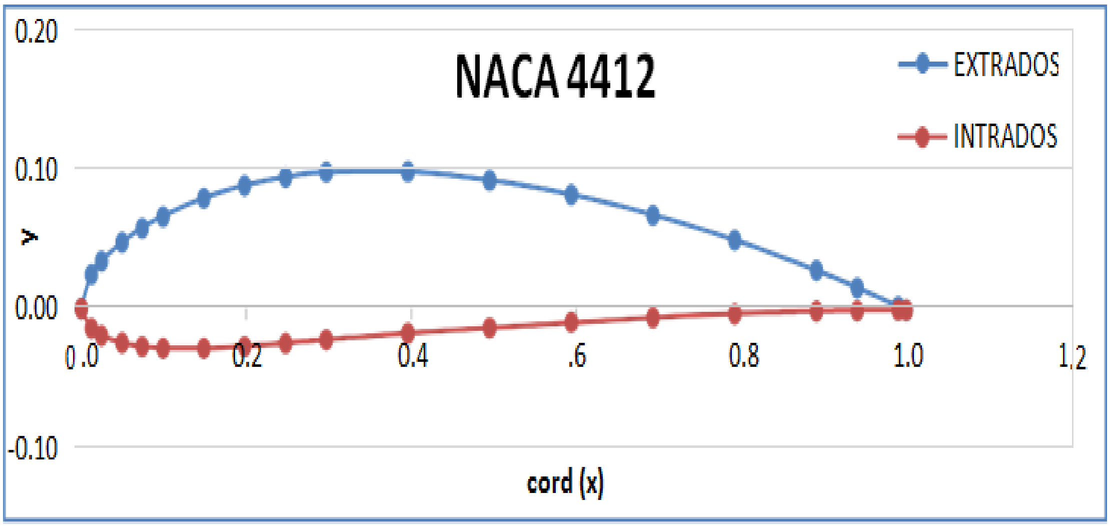


Figure III.2: NACA 4412 profile

Table .III. 2: Chord % coordinates of NACA4412 at 100% span. 26 points for the intrados,26 for the extrados.

Chord	wingspan	
X	Y Extrados	Y Intrados
0.000	0.000	0.00
0.089	0.294	-0.157
0.133	0.347	-0.197
0.222	0.434	-0.254
0.444	0.600	-0.345
0.888	0.840	-0.440
1.331	1.022	-0.486
1.775	1.171	-0.508
2.663	1.400	-0.511
3.550	1.561	-0.484
4.438	1.670	-0.445

5.325	1.732	-0.401
6.213	1.755	-0.357
7.100	1.740	-0.320
7.988	1.696	-0.285
8.875	1.632	-0.248
9.763	1.547	-0.211
10.650	1.445	-0.176
11.538	1.325	-0.144
12.425	1.189	-0.115
13.313	1.036	-0.089
14.200	0.876	-0.068
15.088	0.681	-0.051
15.976	0.479	-0.038
16.863	0.260	-0.028
17.751	0.023	-0.022

Table. III.3. Characteristics of the NACA 4415 profile.

NACA4415	
Thick (%of the cord)	15,0
Camber(%of the cord)	4,0
Trailing edge angle(degree)	14.4
Intradose thickness(%)	30.9
Maximum(L/D)	12.597
Maximum lift(CL)	1.518

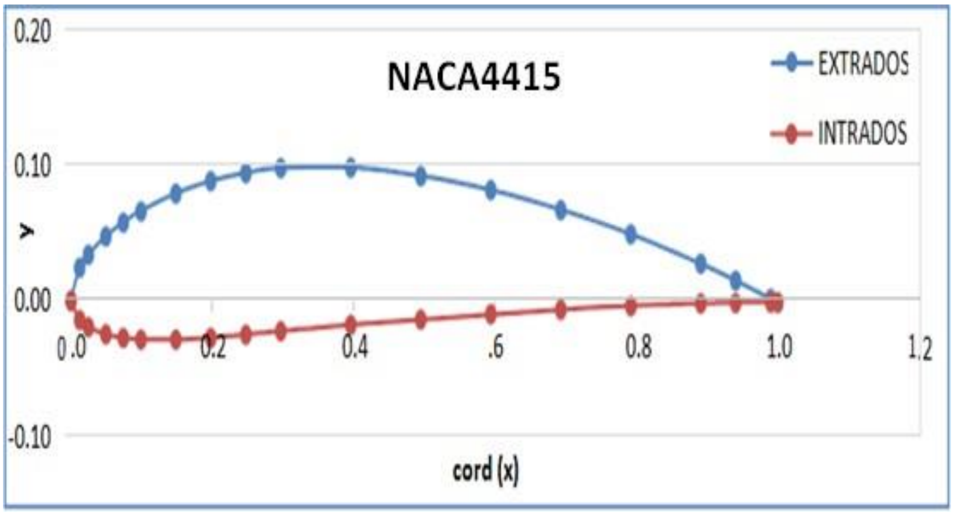


Figure III.3: NACA 4415 profile.

Table III.4: Chord % coordinates of NACA4415 at 100% span. 26 points for theintrados, 26 for the extrados.

	Chord Station	Ordinate
1	1.0000	-0.0016
2	0.9933	-0.0019
3	0.9778	-0.0025
4	0.9511	-0.0036
5	0.9262	-0.0046
6	0.9018	-0.0056
7	0.8781	-0.0067
8	0.8531	-0.0078
9	0.8272	-0.0090
10	0.8008	-0.0103
11	0.7502	-0.0128
12	0.7009	-0.0154
13	0.6504	-0.0184
14	0.5994	-0.0214
15	0.5512	-0.0242
16	0.4985	-0.0273
17	0.3997	-0.0325
18	0.2953	-0.0377
19	0.2454	-0.0400
20	0.2221	-0.0408
21	0.1977	-0.0415
22	0.1727	-0.0419
23	0.1466	-0.0417
24	0.1221	-0.0411
25	0.0967	-0.0395
26	0.0702	-0.0363

III.5.Results and discussion:

Table III.5: limit Conditions for Simulations.

Reynolds Number	1000000
Viscosity	0.00001647
Mach Number	0.8
Tip speed ratio start(m/s)	2
Tip speed ratio end(m/s)	8
Tip speed ratio delta(m/s)	0.5
Wind speed (m/s)	12

III.5.1.Results and discussion for NACA4412:

Table III.6: design parameter NACA4412

Geometry of Blade				
Section	Position (m)	Chord length(m)	Twist angle (deg)	Airfoil
1	0.150	0.075	0	Circle
2	0.300	0.075	0	Circle
3	0.467	0.250	17.4	NACA4412
4	0.783	0.376	11.1	NACA4412
5	1.100	0.319	8.2	NACA4412
6	1.417	0.273	5.2	NACA4412
7	1.733	0.228	3.2	NACA4412
8	2.050	0.195	1.9	NACA4412
9	2.367	0.170	0.8	NACA4412
10	2.683	0.150	0	NACA4412
11	3.000	0.135	-0.6	NACA4412

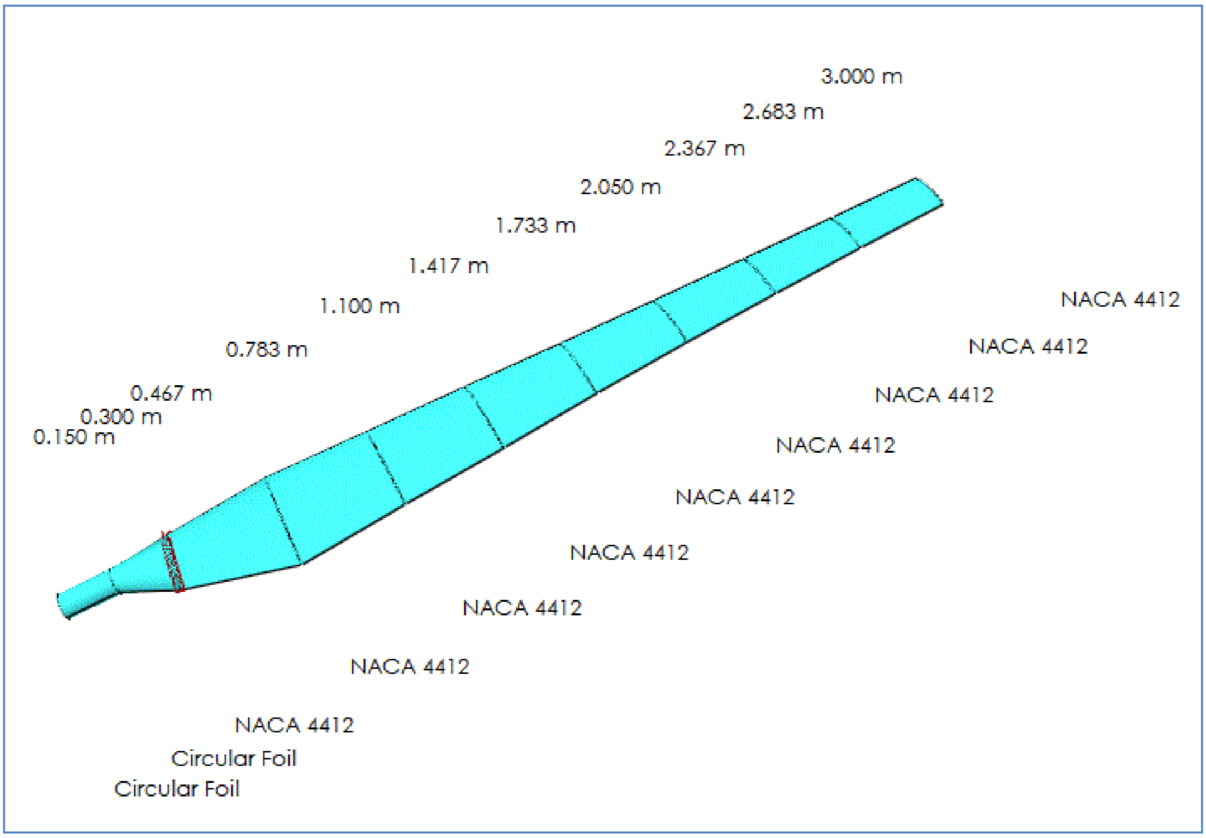


Figure III.4: NACA 4412 profile by Qblade

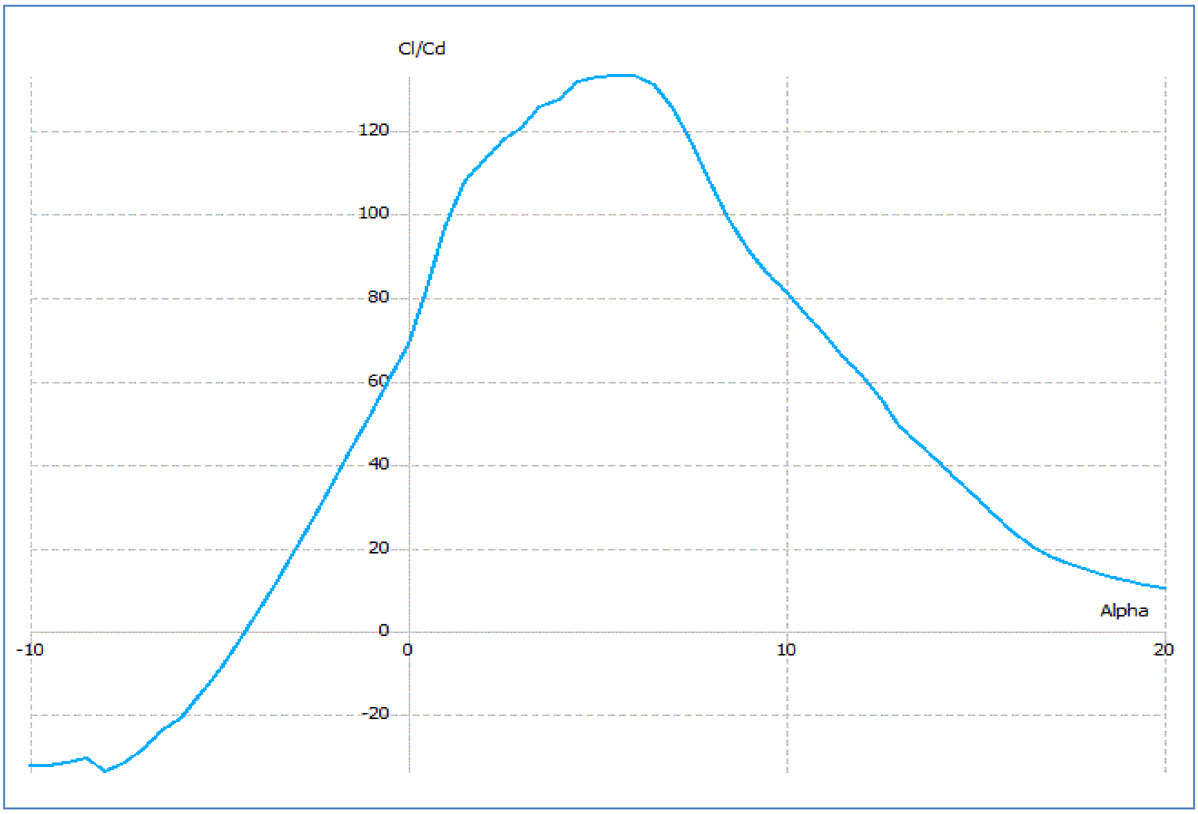


Figure III.5: C_L/C_D Values For Naca4412 Vs Angel of attack(alpha).

This statement represents the stages of changing the value of CL / CD in terms of the change in the angle of attack, where we notice an increase in the ratio of CL / CD until it reaches greater at the angle 6 °, where it was equal to 132 (without units). Then we notice a gradual decrease.

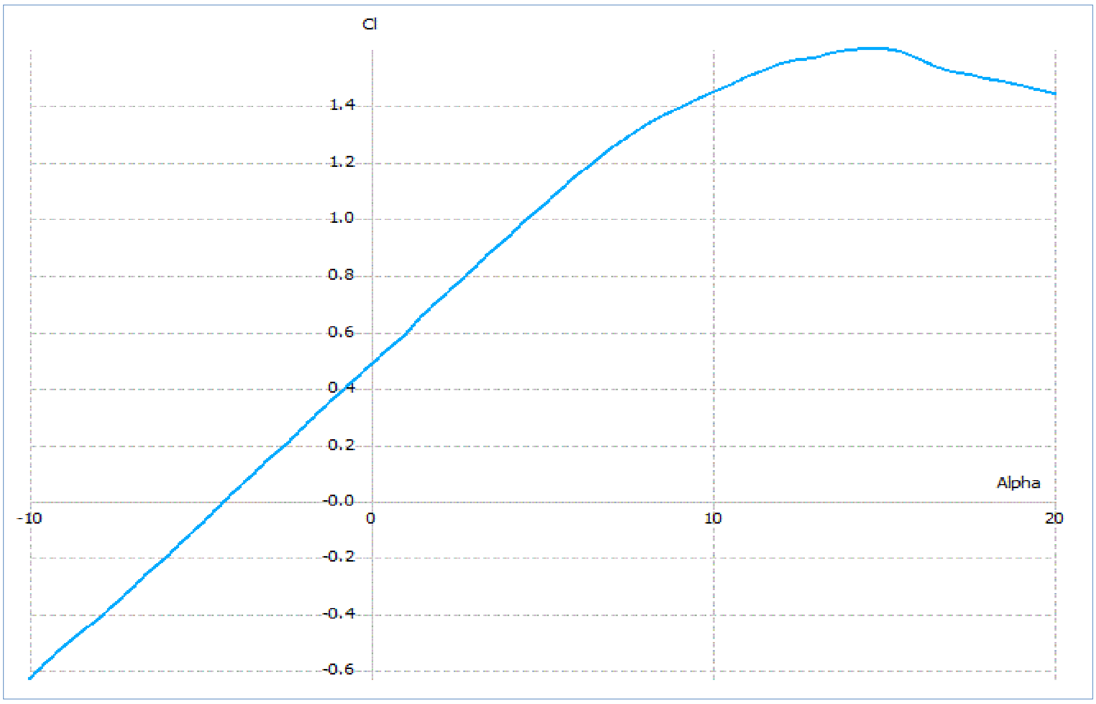


Figure III.6: CL Values For Naca4412 Vs Angel of attack(alpha).

This statement represents the stages of changing the value of the lift coefficient in terms of the change in the angle of attack (alpha), where there is an increase in the value of the lift coefficient with an increase in the angle of attack until it reaches its largest value at the angle of 14 degrees and then gradually decreases.

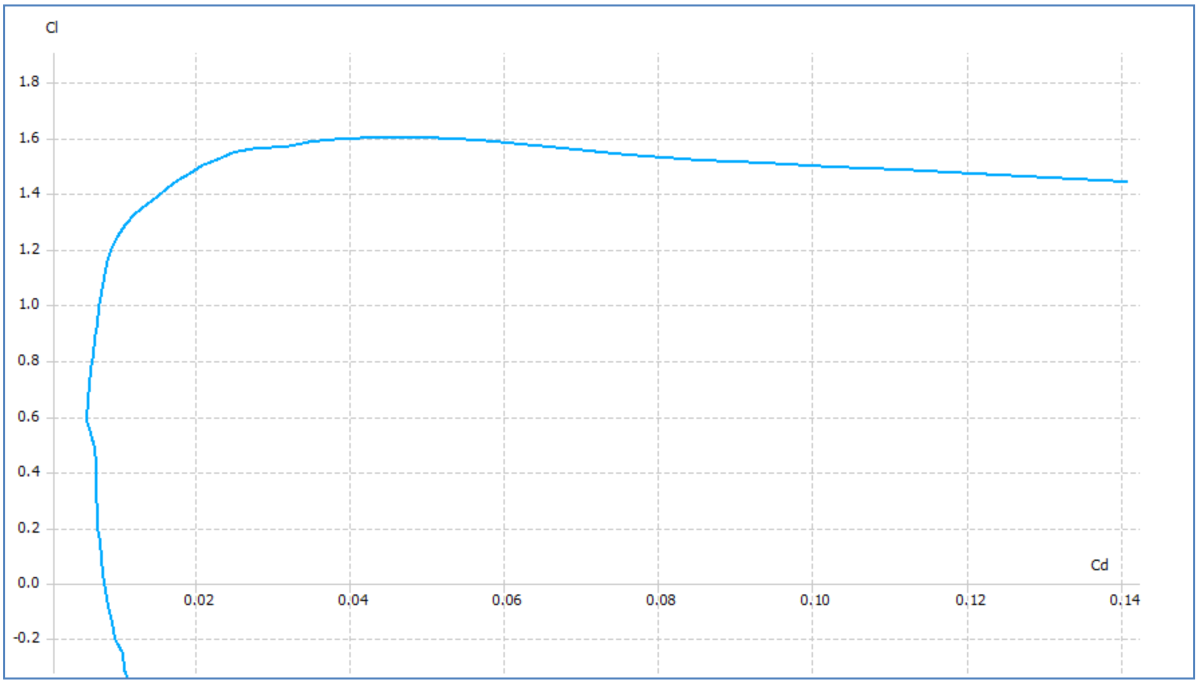


Figure III .7 :Lift coefficient Values For Naca4412 Vs Drag coefficient .

The curve represents the value of the lift coefficient in terms of the drag coefficient, as it shows a rapid increase in the value of the lift coefficient until it reaches the peak when the value of the drag coefficient is 0.04, it has the highest value at 1.5, then we note the stability in the lift value despite the increase in the drag coefficient.

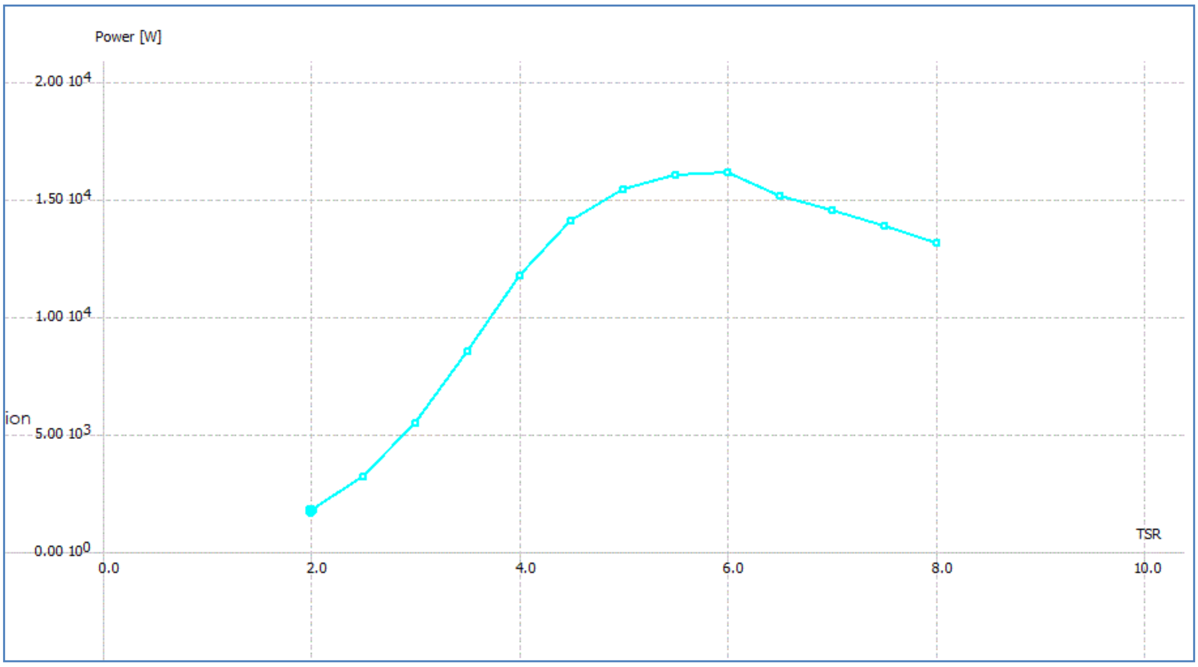


Figure III.8: Power Values For Naca4412 Vs Ti p speed ratio.

The curve represents the value of the force in terms of the terminal velocity ratio, where we notice from 2 (m / s) to 6 (m / s) an increase in the value of the force by increasing the value of the edge velocity until it reaches 6 (m / s) it has the highest value at 16.101 kilowatts, then After that, from 6 (m / s) to 8 (m / s), a decrease in the force value.

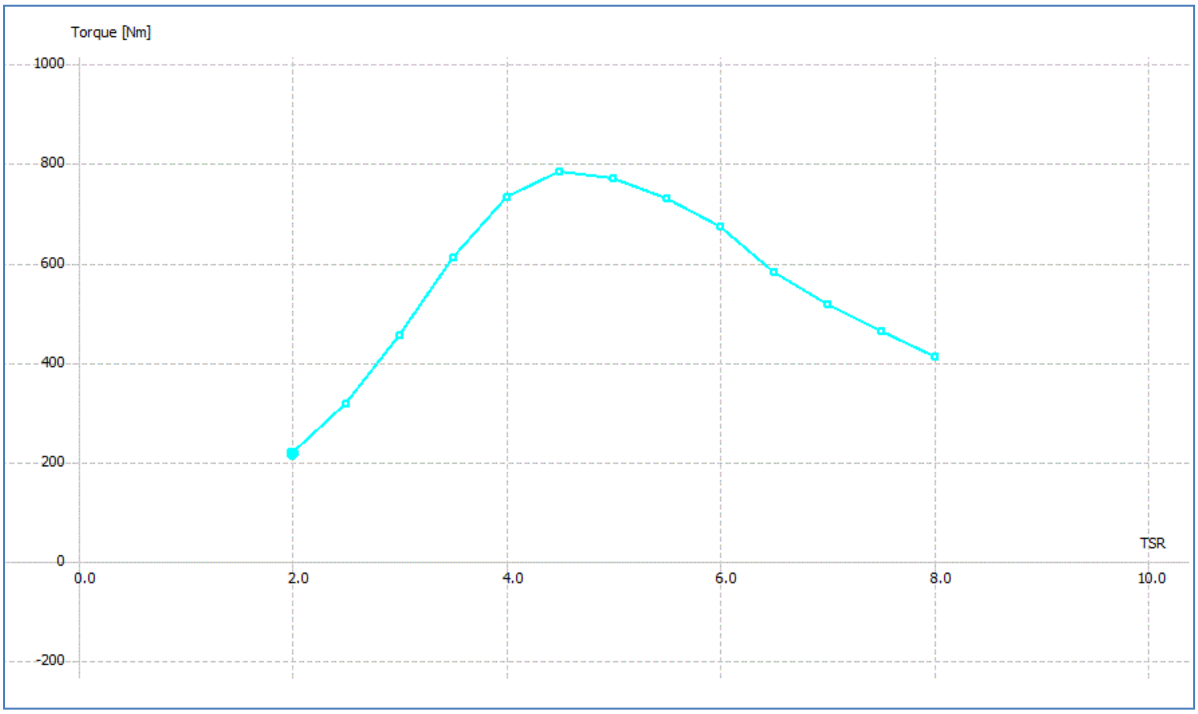


Figure III.9: Torque Values For Naca4412 Vs Tip speed ratio.

This statement represents the stages of changing the value of Torque in terms of the change in the Tip of speed ratio, where it is greatest at Tip Speed Ratio 4.5 (m/s) in therate of 782.01 (Nm)

.III.5.2.Results and discussion for NACA4415:

Table III.7: design parameter NACA4415

Geometry of Blade				
Section	Position(m)	Chord length(m)	Twist angle (deg)	Airfoil
1	0.150	0.075	0	Circle
2	0.300	0.075	0	Circle
3	0.467	0.250	17.4	NACA4415
4	0.783	0.376	11.1	NACA4415
5	1.100	0.319	8.2	NACA4415
6	1.417	0.273	5.2	NACA4415
7	1.733	0.228	3.2	NACA4415
8	2.050	0.195	1.9	NACA4415
9	2.367	0.170	0.8	NACA4415
10	2.683	0.150	0	NACA4415
11	3.000	0.135	-0.6	NACA4415

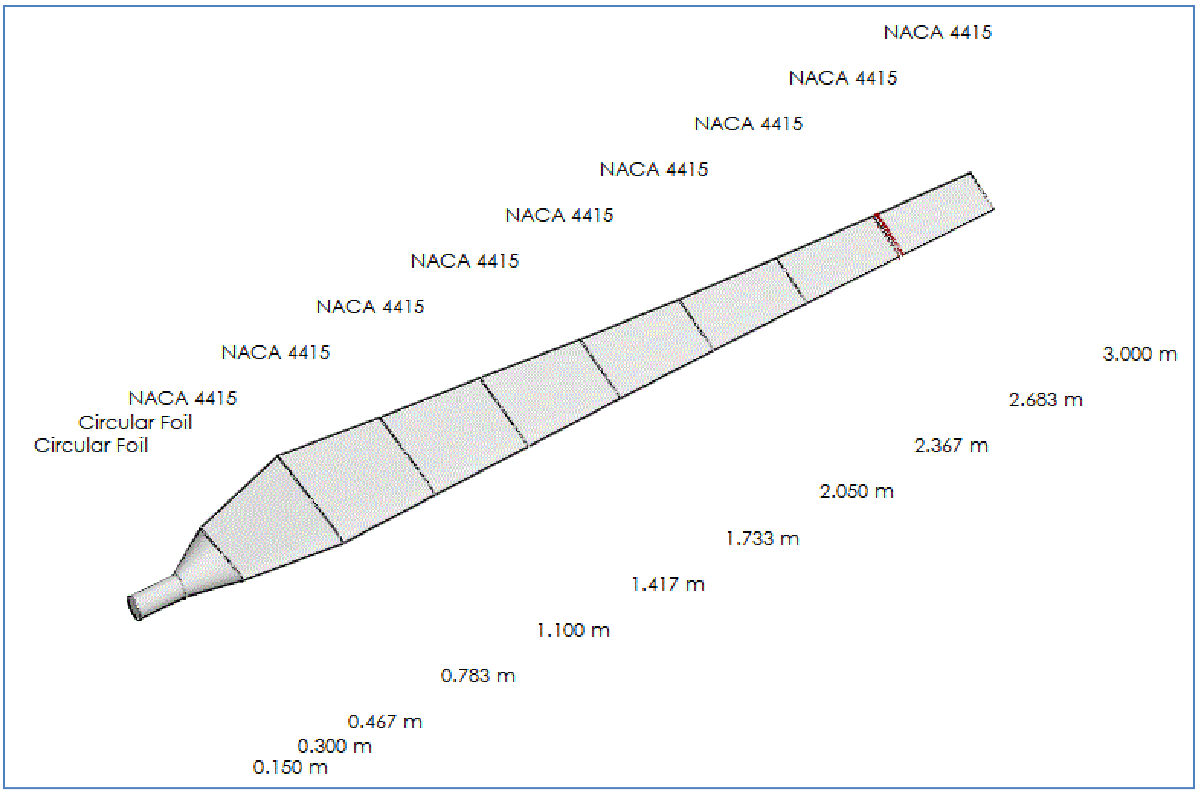


Figure III.10: NACA 4415 profile by Qblade

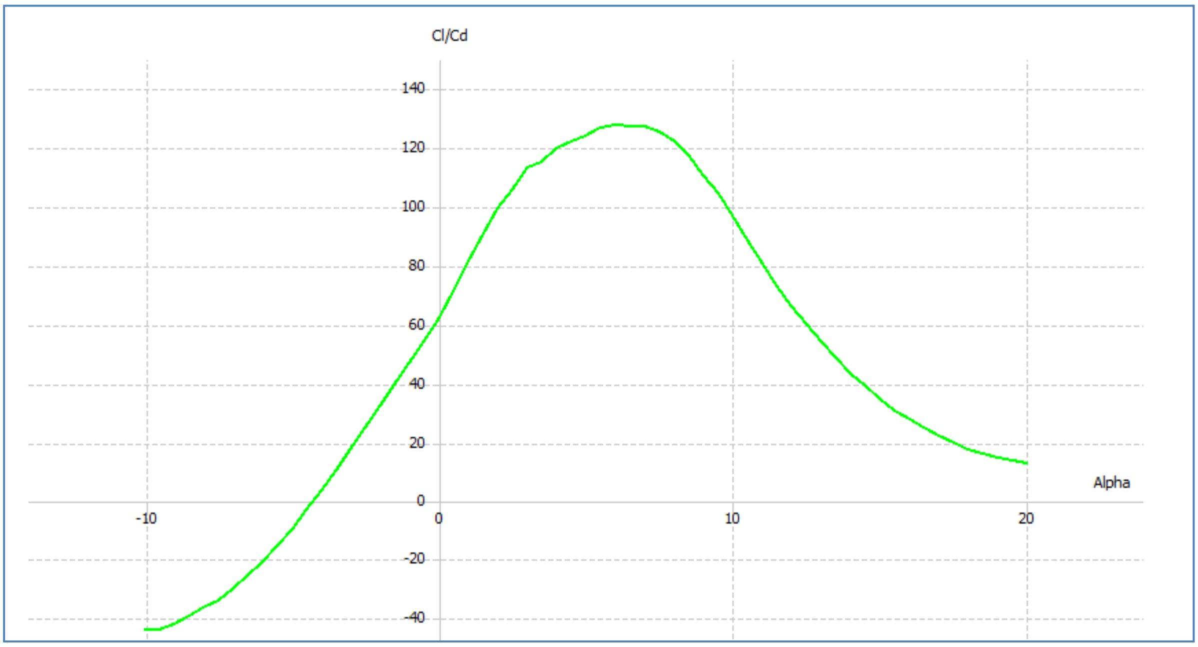


Figure III.11: *CL/ CD* Values For Naca4415 Vs Angel of attack(alpha).

The curve represents the changes of CL / CD in terms of the angle of attack, where we notice from -10 to 6 degrees an increase in the ratio of CL / CD that reaches a maximum value of 132 from 6 to 20 degrees, we notice a decrease in its proportions

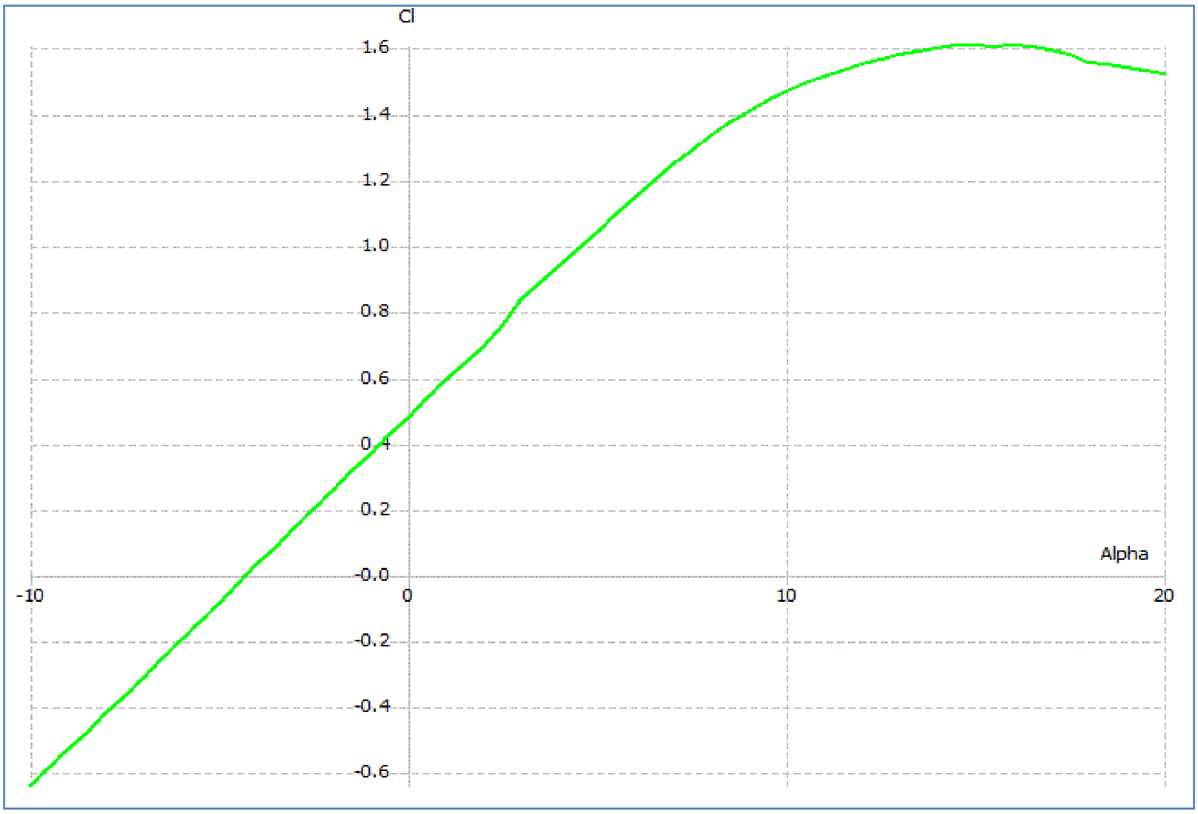


Figure III.12: Lift coefficient Values For Naca4415 Vs Angel of attack(alpha).

The curve represents the changes in the values of the lift coefficient in terms of the Angel of attack, from -10 degrees to 15 degrees. We notice that the greater the angle of attack, the higher the values of the lift coefficient until it reaches the value 1.6. From 15 to 20 degrees, we notice a decrease in the values of the lift coefficient.

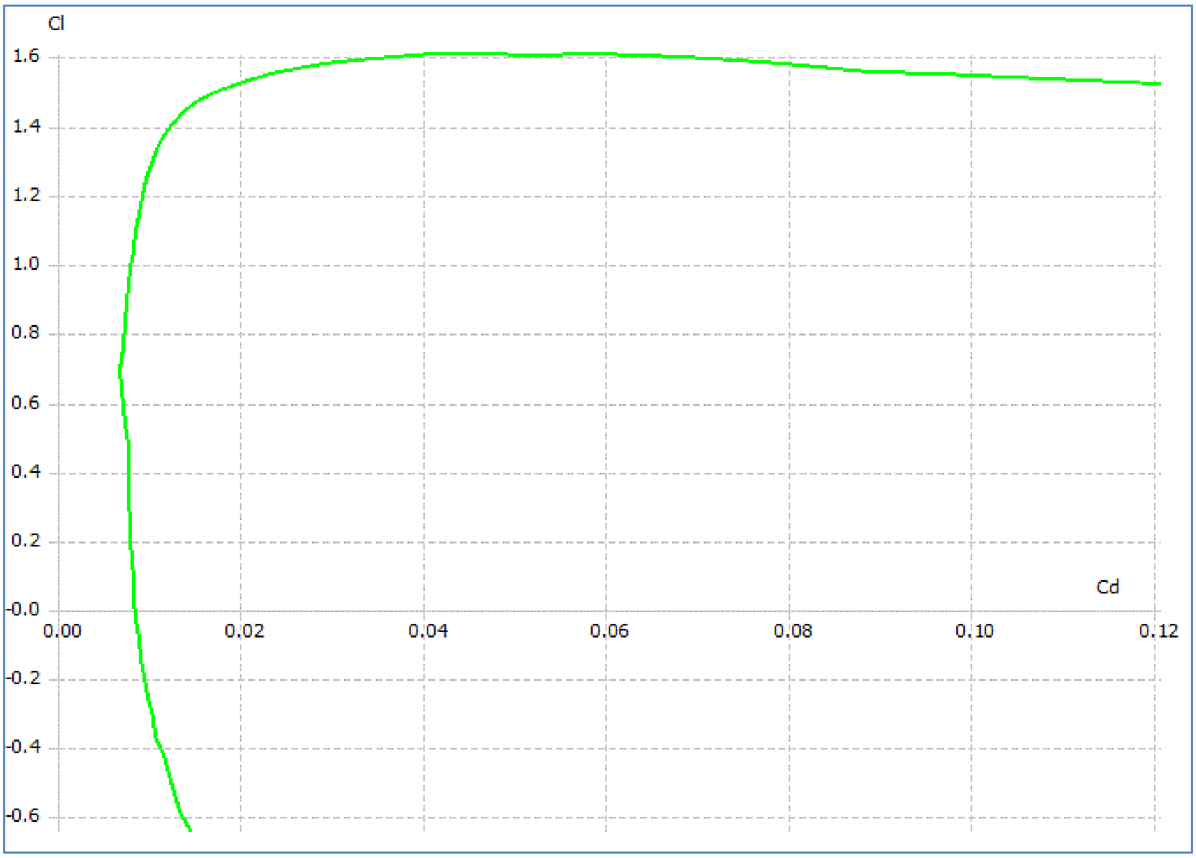


Figure III.13: Lift coefficient Values For Naca4415 Vs Drag coefficient.

The curve represents the value of the lift coefficient in terms of the drag coefficient, as it shows a rapid increase in the value of the lift coefficient until it reaches the peak when the value of the drag coefficient is 0.06, it has the highest value at 1.6, then we note the stability in the lift value despite the increase in the drag coefficient.

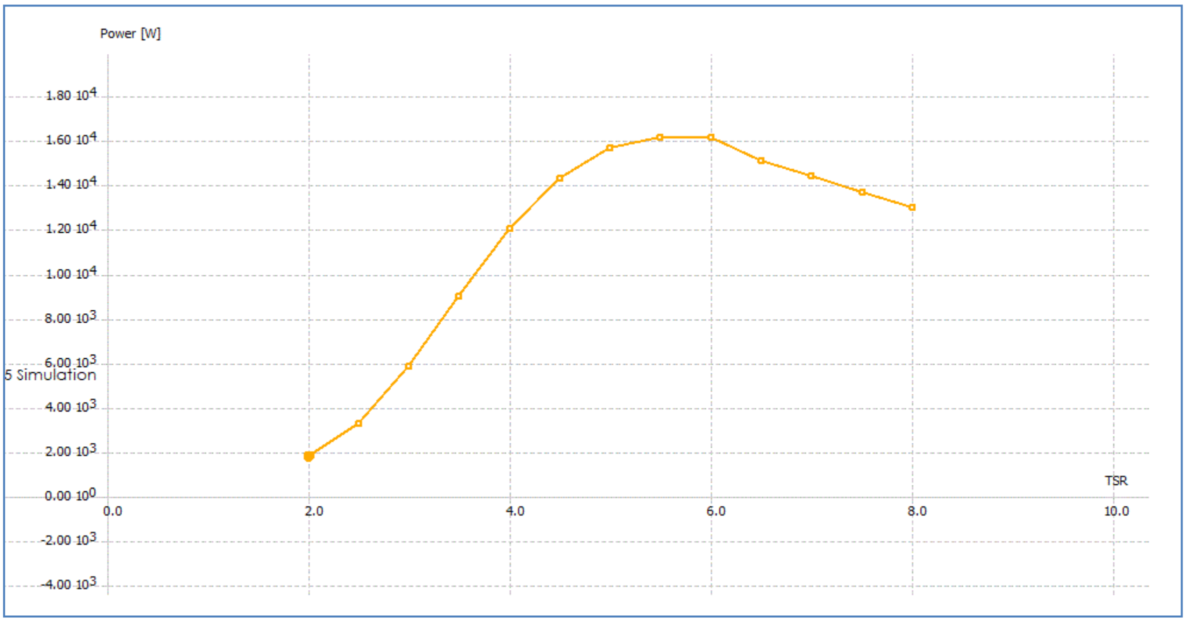


Figure III.14: Power Values For Naca4415 Vs Ti p speed ratio.

The curve represents the value of the force in terms of the terminal velocity ratio, where we notice from 2 (m / s) to 6 (m / s) an increase in the value of the force by increasing the value of the edge velocity until it reaches 6 (m / s) it has the highest value at 16.134 kilowatts, then After that, from 6 (m / s) to 8 (m / s), a decrease in the force value.

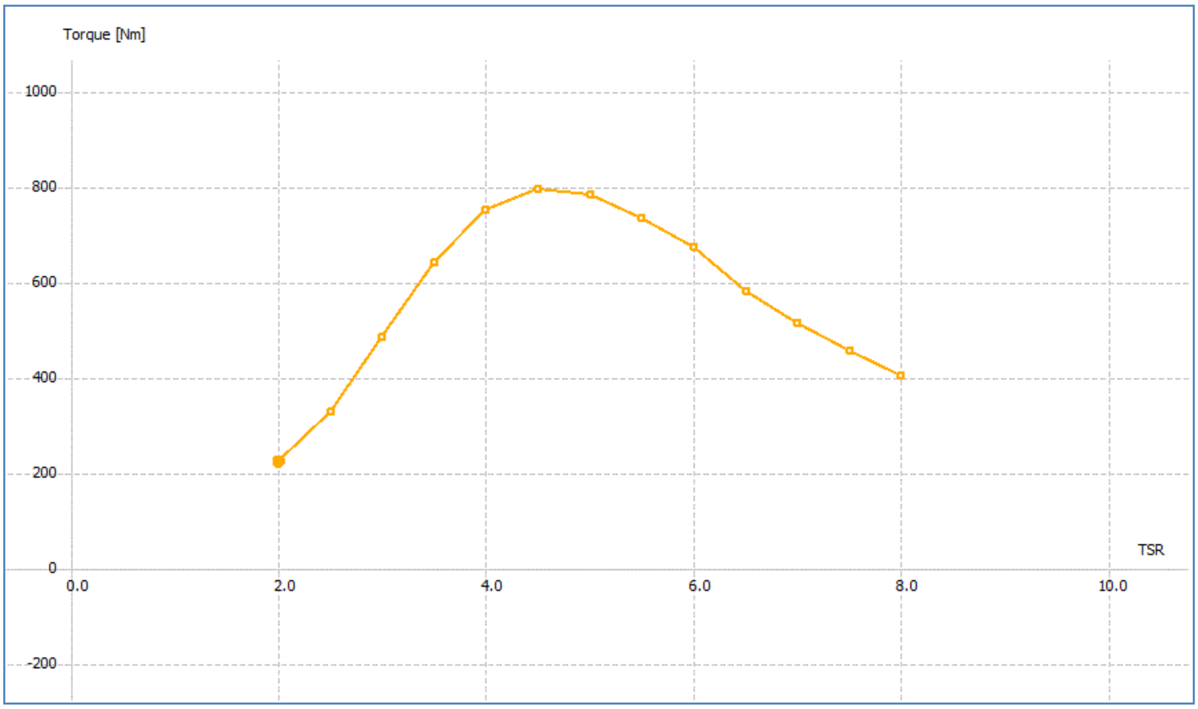


Figure III.15: Torque Values For Naca4415 Vs Tip speed ratio.

This statement represents the stages of changing the torque value in terms of the tipspeed ratito, where we notice from 2 to 4.4 an increase in the torque value by increasing the tip speed ratio until it reaches a maximum value of 793.40 (Newton meters). From 4.4 to 8 we notice a decrease in the torque values by increasing the tip speed ratio .

III.5.3.Results and discussion for NACAMIX:

Table III.8: design parameter NACAMIX

Geometry of Blade				
Section	Position(m)	Chord length(m)	Twist angle (deg)	Airfoil
1	0.150	0.075	0	Circle
2	0.300	0.075	0	Circle
3	0.467	0.544	17.4	NACA4412
4	0.783	0.354	11.1	NACA4415
5	1.100	0.293	8.2	NACA4415
6	1.417	0.239	5.2	NACA4415
7	1.733	0.203	3.2	NACA4415
8	2.050	0.175	1.9	NACA4415
9	2.367	0.154	0.8	NACA4415
10	2.683	0.137	0	NACA4415
11	3.000	0.124	-0.6	NACA4415

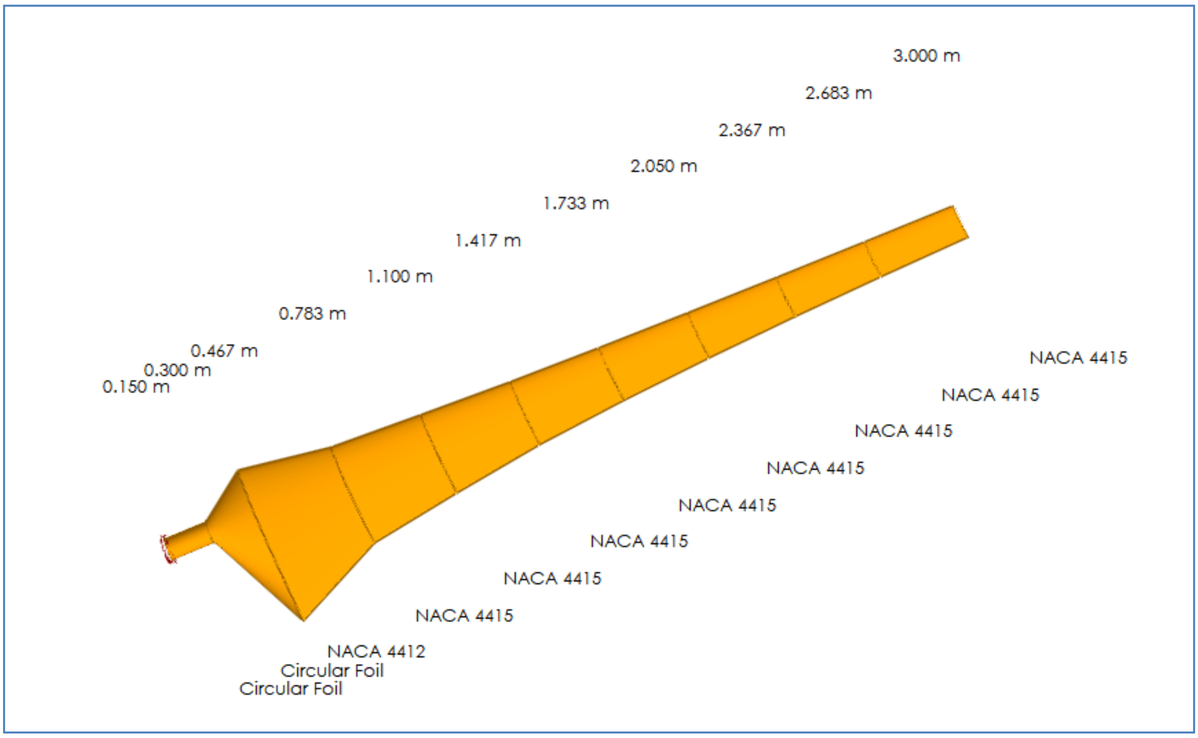


Figure III .16: NACAMIX profile by Qblade

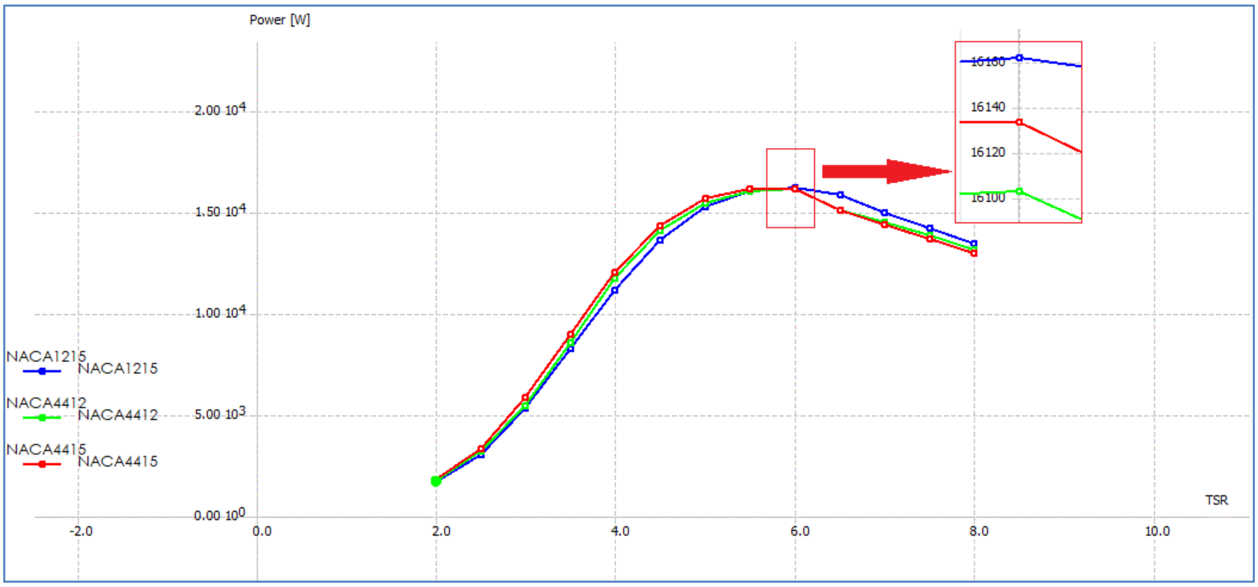


Figure III.17:Power Values For NACA4412,NACA4415 and NACAMIX Vs Tipspeed ratio.

The curve shows force changes in terms of Tip speed ratio for three types of airfoil NACA4412, NACA4415 and NACAMIX. From 2 (m / s) to 6 (m / s), where we notice that the higher the Tip speed ratio. values, the higher the force, but with different values for each airfoil at 6 (m / s). The force value of NACAMIX= 16.163 [KW],NACA4415 = 16.134[KW] and NACA4412= 16.101[KW].From 6 (m/s) to 8 (m/s), we notice a decrease in the force value with an increase Tip speed ratio.

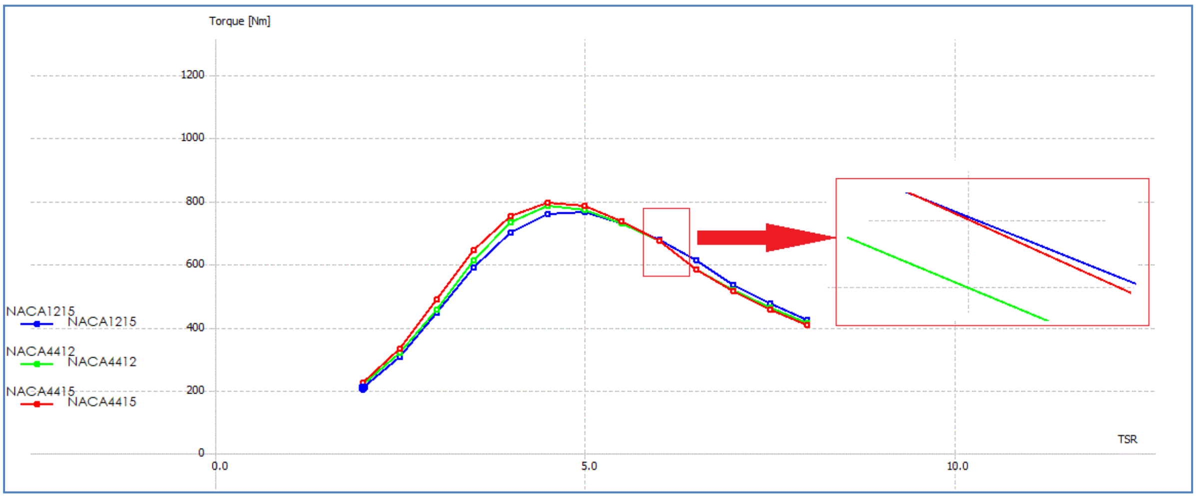


Figure III.18: Torque Values For NACA4412,NACA4415 and NACAMIX Vs Tipspeed ratio.

The curve shows torque changes in terms of Tip speed ratio. for three aileron types NACA4412, NACA4415 and NACAMIX. From 2 (m / s) to 4 (m / s), where we note that the higher the tip values, the higher the torque, but with different values for each aileron at 4 (m / s). The torque value of NACAMIX =761.3 [Nm]. NACA4415 = 793.40 [Nm]. NACA4412 =782.01 [Nm] . From 4 (m / s) to 8 (m / s), we observe a decrease in the value of the force with an increase of torque

III.6.Conclusion:

In this chapter, we used BEM theory by means of Qblade software. Two types of airfoil were used, NACA4412 and NACA4415, and the results of drag coefficient, lift coefficient and power for each aileron were shown.

We also created a mixed airfoil between NACA4412 and NACA4415 and compared the results of power and torque for 3 airfoils, we conclude that the best airfoil is the mixed one.

General conclusion

General conclusion

Wind energy is one of the oldest sources of energy used. Wind energy is produced by wind turbines, where this device convertsPart of the kinetic energy of wind (moving fluids) into mechanical energy that is Transformed by a transmission shaft into electrical energy via a generator [4]

The most important component of a fast or slow wind machine is the blade, so energy researchers are working to improve the dynamic shape of the blade.

The blade element momentum theory (BEM) is a model used to evaluate the performance of a thrust or extractive turbine on the basis of its mechanical and engineering parameters as well as interacting flow characteristics.

This model results from a combination of two theories: the blade element theory and the momentum theory.

In this note, we use QBlade as an open source framework for the simulation and design of wind turbines. QBlade uses the Blade Element Momentum (BEM) method for horizontal axis simulation and the Dual Multiple Flow (DMS) algorithm to simulate the performance of a vertical axis wind turbine. To design the custom ailerons and calculate the poles of the lift and drag coefficient of the aileron.

The aim of our work was Enhanced aerodynamic shape for compact size Horizontal axis wind turbine blades by BEM theory where three types of airfoil were used, namely NACA4412, NACA4415 and NACAMIX (a mixture of NACA4412, NACA4415). With Qblade we were able to get the following results:

- NACA4412:
  CL/ *CD* Vs Angel of attack(alpha) =132 (without unit).
  C_L Vs Angel of attack(alpha) = around 1.6.
  CL Vs *CD* = 1.5.
  Torque Vs Tip speed ratio = 782.01 [Nm] .
  Powe Vs Ti p speed ratio = 16.101 [KW].

- NACA4415:
  CL/ *CD* Vs Angel of attack(alpha) = 132 (without unit).
  C_L Vs Angel of attack(alpha) = around 1.6.

CL Vs *CD* = 1.6.

Torque Vs Tip speed ratio = 793.40 [Nm] .

Powe Vs Ti p speed ratio = 16.134 [KW].

- NACAMIX:

Torque Vs Tip speed ratio = 761.3 [Nm] .

Powe Vs Ti p speed ratio = 16.163[KW].

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