Abstract

This comparative study presents a comparative analysis of NACA (National Advisory Committee for Aeronautics) and NREL (National Renewable Energy Laboratory) airfoils, specifically focusing on their performance and stability characteristics for small wind turbines. The study aims to evaluate and compare the performance metrics of these airfoils, including parameters such as maximum glide ratio, angle of attack, and percentage deviation from the stall point. By conducting XFOIL analysis using Matlab software, relevant data is obtained to facilitate the comparison between the two airfoil families. The comparative study findings highlight the strengths and weaknesses of each airfoil type in terms of average performance and stability criteria. The outcomes of this study are expected to provide valuable insights for engineers and designers in selecting the most suitable airfoil design for small wind turbines, thus contributing to the enhancement of their overall efficiency and reliability in various applications.

Table of Contents

List of Figures

List of abbreviations

NACA: National Advisory Committee for Aeronautics

NREL: National Renewable Energy Laboratory

CAD: Computer Aided Design

HAWT: Horizontal Axis Wind Turbines

CD: Coefficient of Drag

CL: Coefficient of Lift

GL: Glide Ratio

LD: List-To-Drag Ratio

Chapter - 1

Introduction

In the quest for sustainable and renewable energy sources, small wind turbines have emerged as promising solutions for decentralized power generation. These compact and versatile machines harness the power of the wind to generate electricity, making them ideal for a wide range of applications, from remote areas with limited grid access to powering small-scale facilities. However, the efficiency and stability of small wind turbines heavily depend on the design of their airfoils, which play a critical role in converting wind energy into rotational power.

In this context, the comparative analysis of NACA and NREL airfoils for small wind turbines takes center stage, aiming to explore new frontiers in performance and stability. The National Advisory Committee for Aeronautics (NACA) and the National Renewable Energy Laboratory (NREL) have long been recognized as pioneers in airfoil research, each contributing unique insights and innovations to the field.

This study delves into the fascinating world of airfoil design, seeking to unravel the mysteries behind optimal performance and stability for small wind turbines. By examining parameters such as maximum glide ratio, angle of attack, and the percentage deviation from the stall point, we embark on a journey to uncover the strengths and weaknesses of NACA and NREL airfoils, providing valuable insights into their comparative advantages.

Through the use of advanced computational analysis tools, such as XFOIL and Matlab software, we dive deep into the intricate aerodynamics of these airfoil designs. The resulting data allows us to conduct a comprehensive evaluation of their performance and stability characteristics, enabling us to draw meaningful comparisons between the two airfoil families.

The implications of this comparative study are far-reaching. By identifying the most efficient and stable airfoil design for small wind turbines, we can revolutionize the renewable energy landscape, enhancing the viability and scalability of these clean energy solutions. This research not only provides valuable guidance for engineers and designers but also contributes to the overall advancement of small wind turbine technology, ensuring its seamless integration into our energy infrastructure. (Povl Brondsted, 2013)

1.1 Renewable Energy’s Significance

Renewable energy has a vital role in today world problems. As we continue to grapple with the impacts of climate change, depleting fossil fuel reserves, and increasing energy demand, the importance of renewable energy becomes increasingly apparent. Here are some key reasons why renewable energy is significant:

- **Change in Climate:** Replacing fossil fuels, which are the primary contributors to climate change, with renewable energy, we can significantly reduce carbon dioxide and other harmful emissions. This shift is essential in reducing change in climate and limiting global warming to manageable levels.

- **Energy Security and Independence:** Relying on renewable energy sources helps reduce dependence on fossil fuels, which are often imported from politically unstable regions. By diversifying our energy mix, we can enhance energy security and reduce the vulnerability of nations to fluctuations in fuel prices and geopolitical conflicts. Moreover, many renewable energy sources are available domestically, enabling countries to harness their own resources and achieve greater energy independence.

- **Environmental Benefits:** Unlike traditional energy sources, renewable energy has minimal environmental impact. Generating electricity from renewable sources avoids harmful pollutants, such as sulfur dioxide, nitrogen oxides, and particulate matter, which contribute to air pollution and various health issues. Additionally, renewable energy systems have a smaller ecological footprint, reducing habitat destruction, water pollution, and the overall strain on ecosystems.

- **Economic Opportunities and Job Creation:** The renewable energy sector offers significant economic opportunities. Investments in renewable energy projects spur job creation, foster technological innovation, and attract private investment. As the sector expands, it generates employment across various fields, including engineering, manufacturing, installation, maintenance, and research. The renewable energy industry can stimulate local economies and contribute to sustainable development.

- **Energy Affordability and Accessibility:** Renewable energy technologies have witnessed substantial advancements, leading to cost reductions and improved efficiency. As a result, renewable energy is becoming increasingly affordable and competitive with fossil fuels. This affordability translates into lower energy costs for consumers, making electricity more accessible to a broader population. In rural and remote areas, renewable energy solutions can provide decentralized power systems, enabling communities without access to traditional grid infrastructure to meet their energy needs.

- **Resource Sustainability and Conservation:** Renewable energy sources are inherently sustainable as they rely on naturally replenishing resources. Unlike fossil fuels, which are finite and non-renewable, renewable energy draws from sources that are virtually limitless. By harnessing solar radiation, wind, water flows, or heat from the Earth's core, we can generate power without depleting finite resources or causing long-term environmental harm.

- **Technological Innovation and Advancement:** Embracing renewable energy necessitates advancements in technology and infrastructure. This shift drives innovation, research, and development in fields such as energy storage, grid integration, and smart systems. As we strive for greater renewable energy penetration, breakthroughs in these areas will pave the way for a more resilient, flexible, and efficient energy system. (Ajoko, 2016)

1.2 Introduction of Wind Turbine

A wind turbine is a sophisticated mechanical device designed to harness the kinetic energy present in wind flows and convert it into electrical power. Comprising a tall tower and a rotor assembly, it operates on the principles of aerodynamics and electromechanical conversion.

The tower, constructed with high-strength materials, provides structural stability and elevation, optimizing the capture of wind resources. It also accommodates various components necessary for operation and maintenance, such as the nacelle, drive train, and control systems.

Atop the tower, the nacelle houses critical elements of the wind turbine. It houses the main shaft, which connects the rotor assembly to the drive train. Additionally, the nacelle accommodates the gearbox, which increases the rotational speed of the rotor to match the generator's requirements. It also contains the brake system, yaw mechanism, and other auxiliary components that facilitate efficient and safe turbine operation.

The rotor assembly, consisting of multiple aerodynamically designed blades, transforms the kinetic energy of the wind into rotational mechanical energy. The blades, typically made of lightweight composite materials, are engineered to maximize energy capture and optimize the conversion efficiency. Their angle of attack and pitch angle can be adjusted to optimize performance based on wind conditions.

The mechanical energy generated by the rotating rotor is then transmitted through the main shaft to the drive train. The drive train typically includes a gearbox or a direct drive system, depending on the turbine design, to increase the rotational speed of the rotor and achieve optimal generator speed.

Within the nacelle, the generator receives the mechanical power from the drive train and converts it into electrical power. Most wind turbines employ synchronous generators or doubly fed induction generators for this purpose. These generators utilize magnetic fields and electrical circuits to produce alternating current (AC) electricity, which is then conditioned and transmitted to the electrical grid through power electronics and transformers.

Sophisticated control systems are integrated into the wind turbine to ensure optimal operation and protection. These systems monitor various parameters such as wind speed, temperature, power output, and turbine health. They dynamically adjust the blade pitch, yaw position, and turbine operation to maximize power production while ensuring safe and reliable operation. (Eppler, 1990)

1.3 Problem Statement

Small wind turbines play a crucial role in decentralized energy generation, particularly in off-grid and remote areas. The selection of an appropriate airfoil design significantly impacts the performance and stability of these turbines. In this context, a comparative analysis of NACA and NREL airfoils for small wind turbines from a performance and stability perspective is essential. This study aims to address the knowledge gap regarding the comparative performance and stability characteristics of NACA and NREL airfoils in the context of small wind turbines. By investigating parameters such as maximum glide ratio, angle of attack, and percentage deviation from stall point, this research seeks to provide valuable insights and inform the design and selection of airfoils for small wind turbines. The outcomes of this study are expected to contribute to the advancement of efficient and stable small wind turbine systems, ultimately enhancing their effectiveness and reliability in diverse applications.

1.4 Objective of Research

The objective of the comparative study on the topic "Comparative Analysis of NACA and NREL Airfoils S-Series for Small Wind Turbines Performance and Sustainability" is to conduct a comprehensive study and evaluation of the performance and sustainability aspects of NACA and NREL airfoils from the S-Series specifically designed for small wind turbines.

- **Performance Analysis:** The comparative study aims to compare the aerodynamic performance characteristics of NACA and NREL airfoils from the S-Series when used in small wind turbines. This analysis includes evaluating factors such as lift and drag coefficients, stall characteristics, and the impact of varying wind speeds on airfoil performance. By conducting this comparative analysis, the study seeks to identify the airfoil design that exhibits superior performance in terms of power generation, efficiency, and power output under different wind conditions.

- **Structural Analysis:** In addition to performance, the comparative study intends to assess the structural integrity and mechanical behavior of NACA and NREL airfoils when subjected to varying wind loads and turbulent conditions. This analysis involves examining factors such as fatigue life, material stress, and deformation patterns to determine the robustness and durability of the airfoil designs. By evaluating these structural aspects, the study aims to identify the airfoil that demonstrates enhanced resilience and longevity, contributing to the long-term sustainability of small wind turbines.

- **Sustainability Evaluation:** The comparative study seeks to investigate the sustainability aspects associated with the NACA and NREL airfoils for small wind turbines. This evaluation encompasses various factors, including material selection, manufacturing processes, and end-of-life considerations. By analyzing the environmental impact, energy consumption, and carbon footprint associated with the airfoil designs, the study aims to identify the airfoil with a lower environmental footprint and higher sustainability credentials.

- **Optimization and Recommendations:** Based on the comparative analysis and evaluation of the NACA and NREL airfoils, the research aims to provide optimization strategies and recommendations for the selection and design of airfoils for small wind turbines. This includes proposing improvements or modifications to the existing airfoil designs to enhance performance, durability, and sustainability. The objective is to offer practical guidance and insights to wind turbine manufacturers, designers, and stakeholders for selecting the most suitable airfoil design for small-scale wind energy systems.

Overall, the research objective is to contribute to the understanding of the performance and sustainability characteristics of NACA and NREL airfoils from the S-Series for small wind turbines. By conducting a comparative analysis and providing recommendations, the study aims to advance the development of efficient, durable, and sustainable airfoil designs, ultimately facilitating the wider adoption and optimization of small wind turbines in renewable energy applications.

1.5 Research Methodology

1.5.1 Modeling of Airfoils

Through studying different researches, this comparative study aims to analyze and predict the performance of an airfoil specifically designed for a horizontal-axis wind turbine and compare their performance. To achieve this objective, the airfoil models will be examined using MatLab.

Chapter - 2

Literature Review

The focus of this comparative study centers on the selection of airfoils and experiments conducted on different profile geometries using cost-effective materials. Various perspectives from different researchers have been considered, with the aim of utilizing the insights gained from previous research to inform and advance the objectives of this comparative study.

Wind power, a form of renewable energy, is derived from the conversion of wind kinetic energy into mechanical energy through wind turbines. The mechanical power generated can be harnessed for electricity production using generators. Wind energy also finds applications in direct mechanical power utilization, such as water pumping.

The wind is influenced by several factors, including differential surface heating by the sun, changes in surface topology, and the planet's rotation. Geographical features such as mountains, vegetation, and bodies of water further impact wind patterns. Wind turbines employ rotating blades, resembling propellers, to convert wind energy into electricity. The rotating blades drive a shaft, which in turn rotates a generator, producing electricity. Wind velocity, static pressure, and system efficiency are the key variables influencing turbine performance. (Spera, 2009)

The engineering requirements for wind turbine airfoil selection are diverse. These requirements encompass aerodynamic performance, structural integrity and stiffness, manufacturability, and maintainability. Aspects related to other rotor characteristics, such as electromagnetic interference, acoustic noise generation, and aesthetic considerations, are often considered of secondary importance. Typically, high lift and low drag are desired for airfoils, as indicated by the lift-to-drag ratio (L/D). However, the application of airfoils in wind turbine rotors differs from those used in aircraft wings. Comprehensive rotor performance analysis indicates that the product of the chord and lift coefficient (CCL) is a critical factor. Therefore, operating at a higher lift coefficient allows for the use of narrower blades, provided other variables like tip-speed ratio and diameter remain constant. It should be noted that reducing the blade width may not necessarily lead to lower viscous power losses, as the airfoil's L/D ratio plays a crucial role in controlling these losses.

2.1 Overview of Airfoils – NACA & NREL

The early NACA airfoil series, including the 4-digit, 5-digit, and modified 4-/5-digit series, were generated based on analytical equations describing the camber and thickness distribution along the length of the airfoil section. Prior to the development of these NACA airfoil series by the National Advisory Committee for Aeronautics (NACA), airfoil design was largely based on empirical knowledge and experimentation.

NREL airfoil families, on the other hand, exhibit relatively lower sensitivity to roughness effects, resulting in slightly lower annual energy losses. These airfoils are often optimized for performance by increasing the airfoil thickness, which can yield unexpected performance characteristics. For stall-regulated turbines, using low-gradient blade tip airfoils can further enhance performance, allowing for a larger swept rotor area with a given generator size. NREL's S-Series airfoils are available in both thin and thick families. Thin airfoil families are suitable for stall-regulated wind turbines where airfoil stall characteristics are crucial. In variable-pitch and variable-speed turbines, airfoil stall characteristics are less critical. The primary airfoil usually retains its original shape around 75 percent of the blade radius, while the tip airfoil remains predominantly circular around 95 percent of the radius. Interpolation methods are employed to define airfoil shapes between these three pure airfoils. The tip airfoil is usually maintained along the blade tip, with some allowances made for special tip shapes. The root airfoil requires a greater thickness ratio (maximum thickness to chord ratio) to address blade structural considerations, while the thickness ratio decreases toward the tip to reduce drag and losses due to airfoil stall. (cantwell)

This comparative study aims to demonstrate a comparison between different NACA and NREL airfoils through experimental analysis. Each experiment will be based on specific criteria, such as glide ratio at a Reynolds number of 1x10^5, glide ratio at a Reynolds number of 3.3x10^5, lift coefficient at maximum lift-to-drag ratio, stall point, percentage deviation of lift-to-drag ratio from maximum value, and difference in angle of attack, among others.

2.2 Aerodynamic Performance of NACA &NREL Airfoils

The choice of the aerofoil play a crucial role in achieving optimum power output, especially for the inherently low-efficient turbines such as the Darrieus wind turbine. For this purpose, different airfoils belonging to NACA and NREL families have been investigated in terms of their Aerodynamic Performance. Although NREL airfoils are mainly used for the Horizontal Axis Wind Turbines, in the present study, their effect on the Darrieus type Vertical Axis Wind Turbine has been examined. In this way, the influence of the various airfoils and their thickness on the turbine performance in different operating ranges has been evaluated using Computational Fluid Dynamics. Furthermore, by considering the low and high tip speed ratios, the instantaneous blade torque coefficient, and the contours of the pressure coefficients for the selected airfoils have been analyzed to provide further understanding. The research findings show that although conventional airfoils such as NACA0015 and NACA0021 exhibit better power output at optimum and high tip speed ratios, NREL aerofoil lose their advantages due to higher efficiency losses at high tip speed ratios. Additionally, thicker Airfoils such as NACA002 1 and S814 yield more power output at low tip speed ratios compared to their counterpart profiles due to higher pressure difference achieved between their suction and pressure sides.

2.3 Efficiency of NACA Airfoils

NACA (National Advisory Committee for Aeronautics) airfoils have proven to be highly efficient in various aerodynamic applications. These airfoils, developed through extensive research and testing, offer superior performance in terms of lift, drag, and overall efficiency. The NACA airfoil series, characterized by their four-digit designations, allows engineers to select an airfoil shape that best suits their specific requirements. By carefully designing the camber and thickness distribution, NACA airfoils provide enhanced lift generation and reduced drag, resulting in improved aircraft performance, increased fuel efficiency, and greater maneuverability. These airfoils have found wide application in both aviation and wind turbine industries, where their superior efficiency and performance contribute to enhanced aerodynamic characteristics and optimal energy conversion.

The efficiency of NACA (National Advisory Committee for Aeronautics) airfoils is a critical aspect in the field of aerodynamics. NACA airfoils are specifically designed geometries that optimize the lift and drag characteristics of an aircraft wing or blade.

Efficiency, in the context of NACA airfoils, refers to the ability of the airfoil to generate lift while minimizing drag. Lift is the upward force created by the pressure difference between the upper and lower surfaces of the airfoil, allowing an aircraft to stay airborne. Drag, on the other hand, is the resistance encountered by an aircraft as it moves through the air, which consumes energy and reduces overall performance.

NACA airfoils achieve high efficiency by utilizing various design parameters such as camber, thickness distribution, and the location of the maximum thickness along the chord length. The camber refers to the curvature of the airfoil's upper and lower surfaces, with positive camber generating more lift at lower speeds. Thickness distribution defines how the thickness of the airfoil varies along its chord length, affecting both lift and drag. The location of the maximum thickness influences the airfoil's ability to delay flow separation and reduce drag.

Efficiency is typically quantified using parameters such as the lift coefficient (Cl) and the drag coefficient (Cd). The lift coefficient represents the ratio of the lift force to the dynamic pressure of the air, while the drag coefficient represents the ratio of the drag force to the dynamic pressure. Higher lift coefficients indicate greater lift generation, while lower drag coefficients indicate reduced drag.

NACA airfoils, through careful design, aim to achieve high lift coefficients and low drag coefficients across a range of angles of attack (AOA). The AOA is the angle between the chord line of the airfoil and the oncoming airflow. By optimizing the airfoil's shape, NACA airfoils can maintain favorable lift and drag characteristics over a wide range of AOAs, allowing for efficient performance during takeoff, cruising, and landing phases.

The efficiency of NACA airfoils has been extensively studied and validated through wind tunnel testing and computational simulations. These techniques enable engineers to analyze and refine airfoil designs, balancing the trade-off between lift and drag to maximize overall performance. The data obtained from these studies is crucial for aircraft designers, as it helps them select the most efficient NACA airfoil profiles for specific applications, whether it's for commercial airplanes, gliders, wind turbines, or other aerodynamic systems.

In summary, the efficiency of NACA airfoils is achieved by carefully optimizing their shape and characteristics to generate high lift coefficients and minimize drag coefficients. This allows for improved aerodynamic performance, enhancing the overall efficiency and effectiveness of aircraft wings and blades.

2.4 Efficiency of NREL Airfoils

NACA (National Advisory Committee for Aeronautics) airfoils have proven to be highly efficient in various aerodynamic applications. These airfoils, developed through extensive research and testing, offer superior performance in terms of lift, drag, and overall efficiency. The NACA airfoil series, characterized by their four-digit designations, allows engineers to select an airfoil shape that best suits their specific requirements. By carefully designing the camber and thickness distribution, NACA airfoils provide enhanced lift generation and reduced drag, resulting in improved aircraft performance, increased fuel efficiency, and greater maneuverability. These airfoils have found wide application in both aviation and wind turbine industries, where their superior efficiency and performance contribute to enhanced aerodynamic characteristics and optimal energy conversion."

Airfoils serve as the cornerstone of modern aerodynamic design, with the National Renewable Energy Laboratory (NREL) leading the pack in developing advanced, high-performance airfoils. The efficiency of these airfoils is determined by several parameters, including their lift-to-drag ratio, turbulence modeling, and their performance at varying wind speeds and angles of attack.

The NREL airfoils, particularly those used in wind turbines like the S-Series, demonstrate remarkable efficiency enhancements by optimizing aerodynamic characteristics. These airfoils are specifically designed to minimize drag, maximize lift, and operate efficiently under a wide array of wind conditions, thus enhancing the overall performance of wind turbines.

The lift-to-drag (L/D) ratio is a crucial parameter in assessing airfoil efficiency. The lift force propels the turbine blades, while the drag force opposes this motion. An ideal airfoil should generate high lift with minimal drag. NREL airfoils achieve high L/D ratios through careful design and optimization of the airfoil shape, enhancing the overall efficiency of the wind turbine.

Turbulence modeling is another critical aspect of airfoil design. The flow of air around an airfoil is complex and often turbulent, especially at high wind speeds. NREL employs advanced computational fluid dynamics (CFD) and boundary layer modeling techniques to predict and optimize the airfoil's performance under various turbulent flow conditions. This enables the design of airfoils that can withstand turbulent winds while maintaining high efficiency.

Performance under varying wind speeds and angles of attack is a significant challenge in airfoil design. Wind conditions are rarely static, and the airfoil must adapt to these changes to maintain high efficiency. NREL airfoils are designed to operate efficiently under a wide range of wind speeds and angles of attack. They employ technologies such as variable pitch and adaptive materials to adjust to changing wind conditions and maintain optimal performance.

NREL also focuses on the aerodynamic noise produced by these airfoils. Noise is a significant concern in wind turbine operations, and reducing it without affecting the airfoil's efficiency is a challenging task. Using computational methods and experimental data, NREL develops airfoil designs that minimize noise generation while maintaining high efficiency.

Chapter - 3

METHODOLOGY

When designing a wind turbine, the primary parameter under consideration is the average wind speed. However, it is essential to also account for atmospheric pressure, air density, air viscosity, and the dimensions of the generator. To characterize the airflow, a key parameter known as the Reynolds number (Re) is employed. The Reynolds number for the turbine blade can be defined as follows:

$$\mathrm{Re} = \frac{\rho v C}{T}$$

Where:

- **ρ** represents the density of air
- **v** denotes the velocity of air
- **C** represents the chord length of the blade
- **T** signifies the dynamic viscosity of air

In addition to the Reynolds number, another significant performance measure of an airfoil is the Glide Ratio (GR), also known as the lift-to-drag ratio. A higher lift-to-drag ratio is desirable as it increases the rotor torque and reduces the bending moments exerted on the rotor blade for a given lift value. The Glide Ratio can be calculated using the following equation:

$$GR = \frac{L}{D} = \frac{C_L}{C_D}$$

The lift force (L) and drag force (D) acting on an airfoil are influenced by the coefficient of lift (CL) and coefficient of drag (CD) respectively. To compare different airfoils, one of the primary metrics used is the maximum value of the glide ratio (GR) at a low Reynolds number. This parameter is particularly significant for small wind turbines operating in low wind speed regions, as it provides valuable insights into the cut-in speed of the respective wind turbine.

In this study, ten airfoils from both the NACA and NREL airfoil families are selected and analyzed. The aim is to determine which airfoil exhibits the highest maximum glide ratio at low Reynolds numbers. By comparing the performance of these airfoils, we can gain valuable information about their suitability for small wind turbines operating under low wind speed conditions.

Therefore, Figure 1 and 2 present the lift-to-drag ratio plotted against the range of angle of attack (alpha) at a Reynolds number (Re) of 1x10^5 for NACA and NREL airfoils respectively. These curves provide insights into the power generation capabilities of the airfoils under lower wind resource conditions. The figures illustrate that the NACA 6409 airfoil exhibits the highest maximum glide ratio among all the airfoils considered in this analysis. However, the curves for NREL airfoils appear smoother and exhibit a more distinct shape. It is important to note that certain NACA airfoils display ridges in their curves, which may lead to noise generation and discontinuities in power generation for stall-controlled wind turbines.

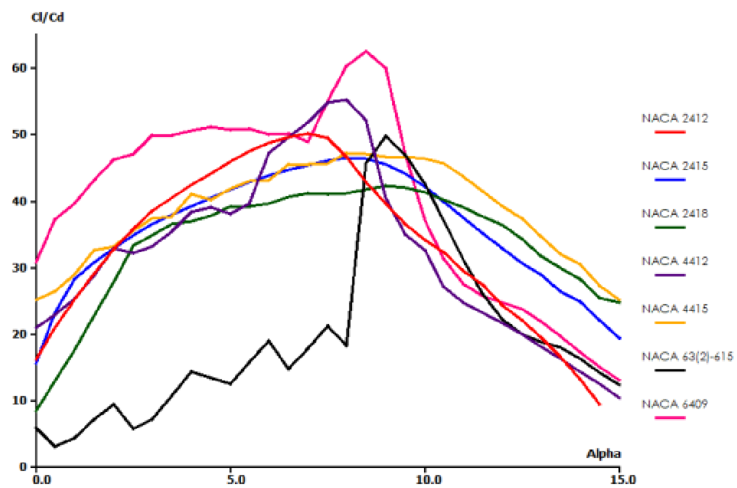

Figure 1:- Glide Ratio Vs. Angle of Attack at Reynolds Number of $1x10^5$ for NACA airfoils

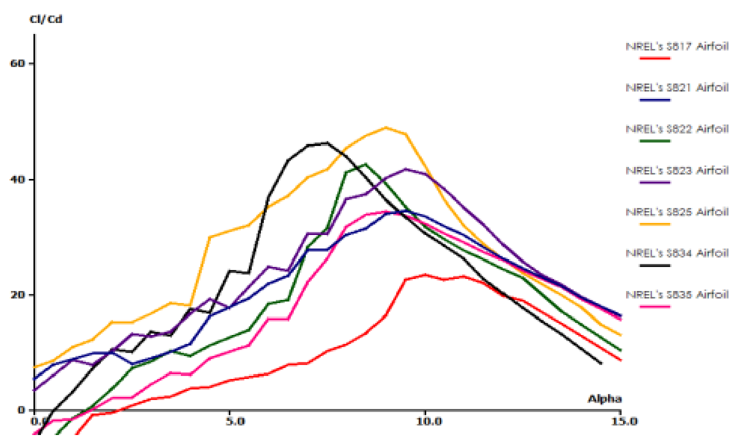

Figure 2:- Glide Ratio Vs. Angle of Attack at Reynolds Number of $1x10^5$ for NREL airfoils

Furthermore, the second criterion for comparing airfoils involves examining the maximum value of the glide ratio at a higher Reynolds number. A higher maximum lift-to-drag ratio at this point indicates the peak power generation capability of a wind turbine. Figure 3 and 4 illustrate, Ratio of Lift-To-Drag against the Angle of Attack range is plotted at a Reynolds number of 3.3x10^5 for NACA and NREL airfoils respectively. These figures provide insights into the performance of the airfoils in terms of power generation. Notably, besides the values of the maximum glide ratio, the curves of NACA airfoils appear smoother in comparison to those of NREL airfoils.

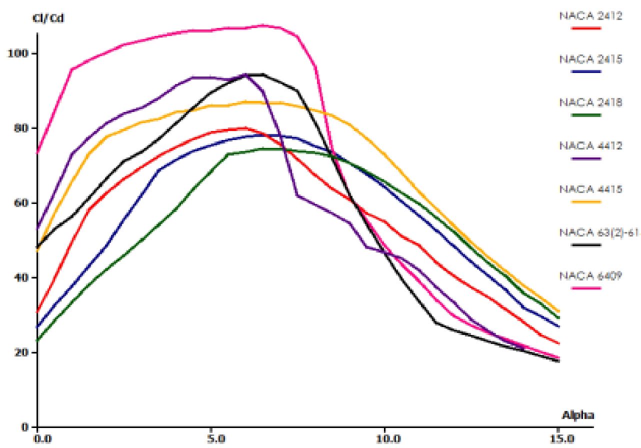

Figure 3:- Glide Ratio Vs. Angle of Attack at Reynolds Number of $3.3x10^5$ for NACA airfoils

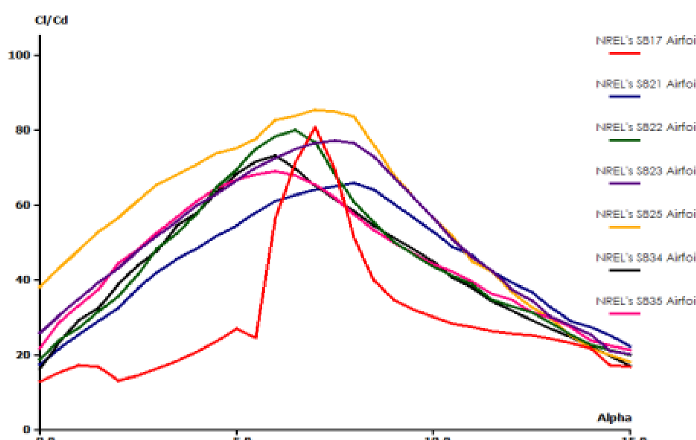

Figure 4:- Glide Ratio Vs. Angle of Attack at Reynolds Number of $3.3x10^5$ for NREL airfoils

It is important to ensure that the airfoil to be used in designing wind turbine blade must not incur any instability in operation. Specially, in case of pitch controlled wind turbine, it is necessary to keep angle of attack more or less constant to uphold the operability in the fullest sense. Henceforth the third criteria describe difference of angle of attack at maximum GR between Re 1x10^5 and 3.3x10^5. The lower the value of difference of angle of attack, higher is the possibility of sable operation of the wind turbine [10]. Fig 5 and 6 illustrate such phenomenon in form of bar graph.

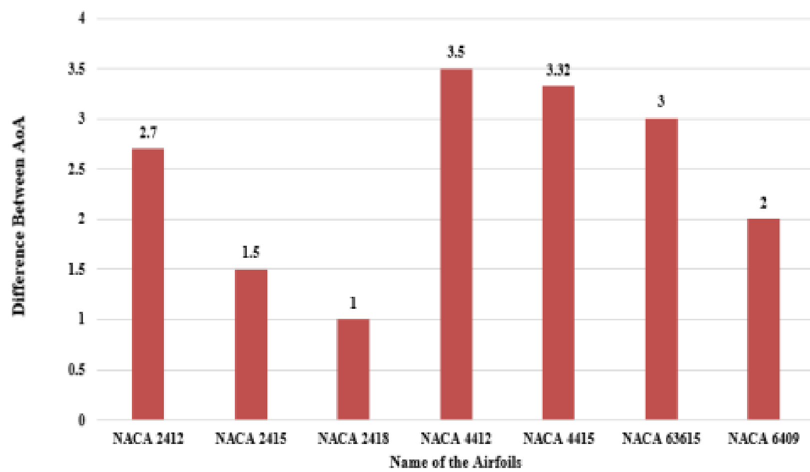

Figure 5:- Difference of Angle of Attack at maximum Glide ratio for NACA airfoils

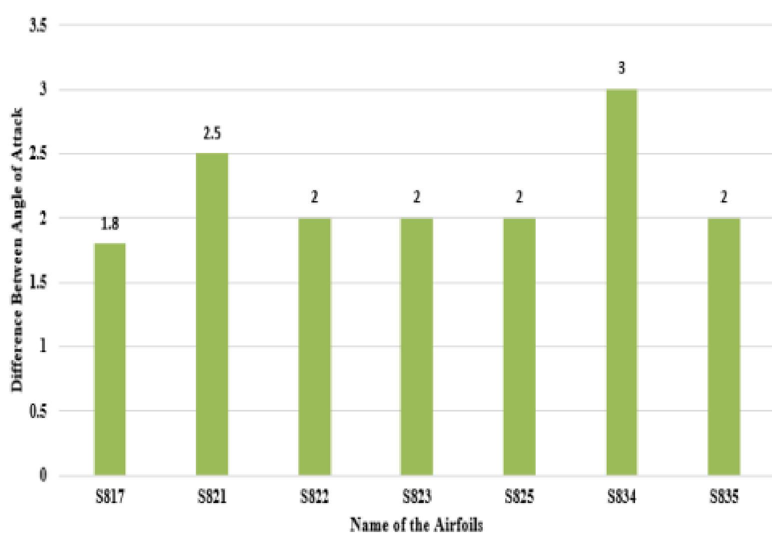

Figure 6:- Difference of Angle of Attack at maximum Glide ratio for NREL airfoils

Lastly, the fourth point of comparison involves examining the percentage deviation of the maximum glide ratio from both sides of the stall point. The stall point represents the angle of attack where the airfoil experiences a significant decrease in lift and an increase in drag. A smaller range of angle of attack, approximately 0.5 degrees, is considered around the stall point. A higher deviation in percentage indicates a greater instability factor for the corresponding wind turbine. (Salgado Fuentes, Troya, Moreno, & Molina, 2016) This phenomenon is illustrated in the form of a bar graph in Figure 7 and 8. These graphs visually depict the extent of deviation from the maximum glide ratio for both NACA and NREL airfoils, providing insights into the stability characteristics of the airfoils at and around the stall point.

To

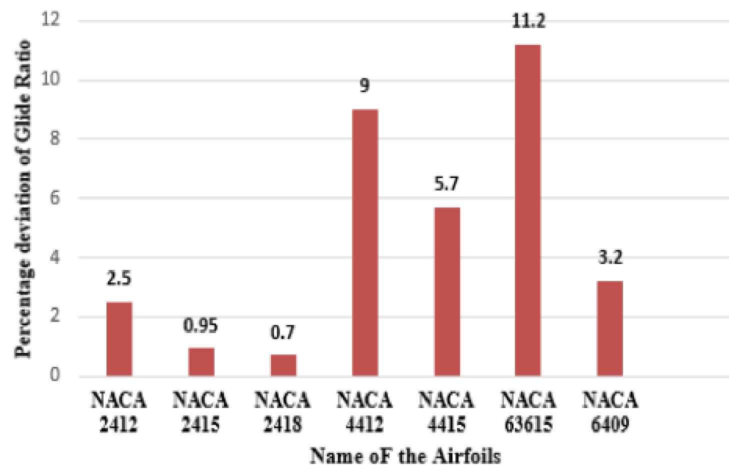

Figure 7:- percentage deviation of maximum GR from both side of stall point for NACA

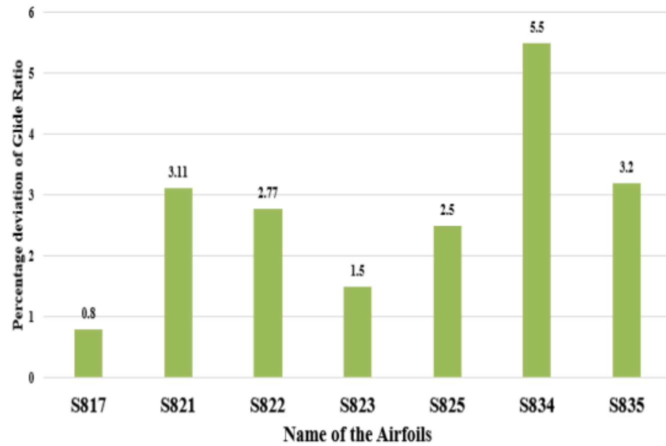

Figure 8:- percentage deviation of maximum GR from both side of stall point for NREL

To facilitate the proper selection of airfoils for small wind turbines in order to extract maximum wind energy, a comparison of average values for four criteria has been conducted between selected NACA and NREL airfoils. The results are summarized in above table:

Criteria	NACA	NREL
Average max. GR at low Re	46.4	41
Average max. GR at high Re	78	75
Average max. difference of angle of attack	2.44	2.18
Average percent deviation of GR	4.78	2.75

Table 1:- Comparison of average values of four criteria between selected NACA and NREL airfoils

The average maximum glide ratio at low Reynolds number (Re) for the NACA airfoils is calculated to be 46.4, while the corresponding value for the NREL airfoils is 41. Similarly, at high Reynolds number, the average maximum glide ratio is 78 for NACA airfoils and 75 for NREL airfoils.

The average maximum difference in angle of attack between the NACA and NREL airfoils is found to be 2.44 and 2.18 degrees, respectively. This metric provides insight into the variation in the angle at which the airfoils generate maximum lift-to-drag ratio.

Furthermore, the average percentage deviation of the glide ratio is calculated as 4.78% for NACA airfoils and 2.75% for NREL airfoils. This criterion measures the deviation from the maximum glide ratio, indicating the stability and consistency of performance for the airfoils.

By considering these average values for the four criteria, wind turbine designers and researchers can make informed decisions regarding the selection of airfoils for small wind turbines, optimizing their ability to extract maximum wind energy.

Chapter - 4

RESULT

The average maximum glide ratio (GR) at a Reynolds number (Re) of 1.0×10^5 for NACA airfoils is determined to be 46.5, whereas for NREL airfoils, it is 41. This indicates that NACA airfoils have a higher average maximum GR and thus contribute more effectively in low wind speed conditions. Similarly, at a Reynolds number of 3.3×10^5, the average maximum GR for NACA airfoils is 78, while for NREL airfoils, it is 75. These values suggest that both airfoil families are capable of achieving peak power generation.

In terms of the difference in angle of attack, NACA airfoils exhibit an average difference of 2.440 degrees, while NREL airfoils have an average difference of 2.180 degrees. This metric indicates the variation in the angle at which the airfoils reach their maximum lift-to-drag ratio.

Furthermore, NACA airfoils display an average deviation of 4.78% from the maximum GR at the stall point, while NREL airfoils have an average deviation of 2.75%. This measurement reflects the stability criteria of the airfoils, with lower deviations indicating greater stability.

Based on these findings, it can be concluded that NACA airfoils demonstrate higher average maximum GR at low Re, suggesting their suitability for low wind speed conditions. However, both NACA and NREL airfoils exhibit comparable average maximum GR at higher Re, indicating their capability for peak power generation. Additionally, NREL airfoils exhibit a smaller average difference in angle of attack and lower average deviation from the stall point, indicating their superior stability characteristics compared to NACA airfoils.

CONCLUSION

In this study, a selection of airfoils was chosen from both the NACA and NREL airfoil families for a comparative analysis based on specific performance and stability criteria. The aim was to determine which airfoil family is more suitable for small wind turbines, and the results obtained from simulations were employed for this purpose. Upon evaluating the performance criteria, it was observed that NACA airfoils yielded superior outcomes. However, when examining the stability criteria, the opposite trend was observed, with NREL airfoils displaying better characteristics in this regard.

It is important to note that this study focused on a limited set of criteria, and in the future, the inclusion of DELFT airfoils could offer a broader basis for comparison between airfoils on a more comprehensive range of criteria. Expanding the analysis to incorporate additional parameters would provide a more holistic assessment and further insights into the selection of airfoils for small wind turbines.

References

Ajoko, T. J. (2016). *Horizontal Axial Wind Turbine Blade Design.* Wilberforce Island, Nigeria: JMESS. Retrieved from http://jmess.org/wp-content/uploads/2016/08/JMESSP13420166.pdf

cantwell. (n.d.). The NACA airfoil series. Retrieved. 6. Retrieved from https://web.stanford.edu/~cantwell/AA200_Course_Material/The%20NACA%20airfoil%20series.pdf

Eppler, R. (1990). *Airfoil Design and Data.* link.springer.

Povl Brondsted, R. P. (2013). *Advances in Wind Turbine Blade Design and Materials.* ELSEVIER.

Salgado Fuentes, V., Troya, C., Moreno, G., & Molina, J. (2016). Airfoil selection methodology for Small Wind Turbines. *DTU Library* .

Spera, D. (2009). Wind Turbine Technology: Fundamental Concepts in Wind Turbine Engineering, Second Edition. doi:10.1115/1.802601