DESIGN AND ANALYSIS OF WINDMILL OPERATED WATER PUMP WITH 2 DIFFERENT AIRFOILS

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ABSTRACT

A wind turbine is a device that transforms the kinetic energy of the wind into electrical energy. A diverse array of vertical and horizontal axis varieties are used to manufacture wind turbines. Battery charging for auxiliary power for watercraft or caravans, as well as the operation of traffic warning signs, are among the applications for the smallest turbines. Turbines that are slightly larger can be employed to contribute to a domestic power supply while simultaneously reselling any unused power to the utility supplier through the electrical grid. The primary rotor shaft and electrical generator are located at the summit of a tower in horizontal-axis wind turbines (HAWTs) and must be oriented towards the wind. A straightforward wind vane is used to aim small turbines, while large turbines typically employ a servomotor and wind sensor. The blades' sluggish rotation is converted into a faster rotation that is more suitable for driving an electrical generator by the gearbox found in the majority of these machines. In this project, the DESIGN FOIL tool is employed to obtain the coordinates of the airfoil shape. The model was designed using CATIA V5 and analysed using ANSYS WORKBENCH. Wind turbines are constructed using a variety of computer modelling techniques. In order to create the model, we selected two airfoil configurations (NACA-63215 and NACA-63210) with blade angles of 15, 14, 5, and 15.5 degrees. The carbon fibre material will be used to analyse each model, and the results will be calculated, including deformations, tension, and strain values. Ultimately, it is possible to determine which airfoil configuration is the most effective.

Keywords- Wind Turbine Design; Kinetic Energy Conversion; Electrical Energy Production; Horizontal-Axis Wind Turbines (HAWT)

INTRODUCTION

A wind turbine is a device that transforms the kinetic energy of the wind into electrical energy. A diverse array of vertical and horizontal axis varieties are used to manufacture wind turbines. Battery charging for auxiliary power for watercraft or caravans, as well as the operation of traffic warning signs, are among the applications for the smallest turbines. Turbines that are slightly larger can be employed to contribute to a domestic power supply while simultaneously reselling any unused power to the utility supplier through the electrical grid. Many countries are utilising wind farms, which are arrays of large turbines, as a component of their strategy to decrease their dependence on fossil fuels. These wind farms are becoming an increasingly significant source of intermittent renewable energy. The study demonstrated that wind has the "lowest relative greenhouse gas emissions, the least water consumption demands, and... the most favourable social impacts" in comparison to photovoltaic, hydro, geothermal, coal, and gas.

It is probable that wind power was employed in Persia (present-day Iran) between 500 and 900 AD. One of the earliest documented instances of wind propelling a mechanism in history is the windwheel of Hero of Alexandria. Nevertheless, the first practical wind power facilities were constructed in Sistan, an Eastern province of Iran, during the 7th century. The "Panemone" were vertical axle windmills that featured rectangular blades and lengthy vertical drive shafts. These windmills, which were employed in the grist milling and sugarcane industries, were constructed with six to twelve sails that were covered in reed matting or cloth material. They were designed to grind grain or draw water.

During the Middle Ages, wind power was first introduced to Europe. The initial historical records of their use in England date back to the 11th or 12th centuries, and there are reports of German crusaders transferring their windmill-making expertise to Syria around 1190. Dutch windmills were utilised to evacuate regions of the Rhine delta by the 14th century. Fausto Veranzio, a Croatian inventor, described advanced wind turbines. He described vertical axis wind turbines with curved or V-shaped blades in his book Machinae Novae (1595).

In July 1887, Scottish academic James Blyth installed the first electricity-generating wind turbine, a battery charging mechanism, to illuminate his vacation house in Marykirk, Scotland. After consulting with local university professors and colleagues Jacob S. Gibbs and Brinsley Coleberd, American inventor Charles F. Brush was able to construct the first automatically operated wind turbine a few months later. He also successfully obtained peer-review for the blueprints for electricity production in Cleveland, Ohio.Wind turbines were more cost-effective in countries with widely dispersed populations, despite the fact that Blyth's turbine was deemed uneconomical in the United Kingdom.

The Wind Power Density (WPD) is a quantitative measure of the amount of wind energy that is available at any given location. It is a tabulation of the mean annual power available per square metre of swept area of a turbine for various heights above ground. The impact of wind velocity and air density is accounted for in the calculation of wind power density. A specific area is characterised as "Mean Annual Power Density at 50 Metres" and color-coded maps are generated. The results of the aforementioned calculation are incorporated into an index known as "NREL CLASS" in the United States, which was devised by the National Renewable Energy Laboratory. The WPD is regarded higher by class as it increases in size. The classes are classified as follows: Class 1 (200 watts per square metre or less at 50 m altitude) and Class 7 (800 to 2000 watts per square metre). Commercial wind farms are typically located in Class 3 or higher areas, although it may be feasible to exploit isolated sites in an otherwise Class 1 area.

The classification of wind turbines is based on the wind speed for which they are intended, ranging from class I to class IV. The turbulence is denoted by A or B.

The primary rotor shaft and electrical generator are located at the summit of a structure in horizontal-axis wind turbines (HAWTs), and they must be oriented towards the wind, as illustrated in the figure. A straightforward wind vane is used to point small turbines, while large turbines typically employ a wind sensor in conjunction with a servo motor. The blades' sluggish rotation is converted into a faster rotation that is more suitable for driving an electrical generator by the gearbox found in the majority of these machines. The turbine is typically situated upwind of its supporting structure due to the turbulence it generates.

Fig. 1 Horizontal Axis Wind Turbine (HAWT)

In order to prevent the blades from being forced into the tower by intense gusts, turbine blades are designed to be rigid. Furthermore, the blades are positioned at a significant distance from the superstructure and are occasionally inclined slightly forward into the breeze. Despite the issue of turbulence (mast wake), downwind machines have been constructed due to the fact that they do not require an additional mechanism to maintain alignment with the wind. Additionally, the blades can be permitted to deform in strong winds, which reduces their swept area and, as a result, their wind resistance. Most HAWTs are of upwind design due to the potential for fatigue failures caused by cyclical (i.e., repetitive) turbulence. The turbines utilised in wind farms for the commercial production of electric power are typically three-bladed and are directed into the wind by computer-controlled motors. These are characterised by high efficiency, low torque disturbance, and high tip velocities of over 320 km/h (200 mph), all of which contribute to their reliability. The blades are typically painted white to enhance their visibility to aircraft during the day, and they typically have a length of 20 to 40 metres (66 to 131 ft) or more. The tubular steel structures are 60 to 90 metres (200 to 300 feet) in height. The blades rotate at a rate of 10 to 22 revolutions per minute. The tip speed surpasses 90 metres per second (300 ft/s) at 22 rotations per minute. Although designs may also employ direct drive of an annular generator, a gear box is frequently employed to increase the generator's speed. Variable-speed turbines, which interface with the gearbox system via a solid-state power converter, are capable of collecting a greater amount of energy than models that operate at a constant speed.

Literature review

Small and medium-scale wind turbine blades have been the subject of extensive research, with the majority of studies employing the classical blade element momentum theory to design the blades and determine the forces acting on them. A variety of evolutionary optimising techniques have been employed to conduct extensive research on the identification of the optimal chord lengths. Here are a few works that serve as the foundation for this research: [1]. Jackson et al. conducted a preliminary design of a 50-meter-long blade. Two versions were utilised to evaluate the cost and the thickness of the cross sections in order to enhance structural efficiency: one made of fibre glass and the other of carbon composite. The computations were predicted using clean and contaminated surfaces, and the aerodynamic performance was determined using computational techniques [2].Karam and Hani optimised the design for optimum natural frequency by utilising the variables of cross section area, radius of gyration, and chord length. Multidimensional search techniques are implemented to optimise the process. The efficiency of the technique was demonstrated by the results [3].In order to enhance the aerodynamic performance of turbine rotors and reduce their susceptibility to wind surges, K.J. Johansen and N.N. Sorensen modified the apex of the rotors to a winglet [4]. Maughmer, M.D., altered the downwash distribution by tilting the blade tip to simulate the effect of winglets, which reduced the blade's induced drag and thereby increased power production [5].Mickael Edon had developed a 38-meter blade for a 1.5MW power source using BEM theory. He also proposed the chord distribution formula in his subsequent work, which I have since implemented. Given that his blade was nearly identical to my own design I select the identical airfoil profile [6]. The BEM theory was employed by M. Jureczko, M. Pawlak, and A. Mezyk to design the system, and ANSYS was employed to calculate the natural frequencies. The blades' mode shape was determined through the application of the Timoshenko twisted tapered beam element theory. The genetic algorithm was implemented to enhance blade stability, minimise blade vibration, optimise output, and reduce blade cost [7].The optimisation of blade geometry for the design of wind turbine rotors was described by Philippe Giguere and Selig. Pre-programmed software was employed to optimise structures and the cost model [8]. Tingting Guo, Dianwen Wu, Jihui Xu, and Shaohua Li utilised Matlab programming to design a 1.5 MW turbine rotor with a 35-meter blade length. They concluded that Matlab was feasible for the design of large wind turbines and compared the results with those of computational fluid dynamics (CFD). They discovered that Matlab was cost-effective for artificial design and efficiency optimisation [9]. In order to optimise the cost by maximising the annual energy production for specific turbines at a General site, Wang Xudong, et al. employed three distinct wind turbine diameters. In their research, they employed a refined BEM theory to develop an optimisation model for wind turbines that is based on the structural dynamics of blades and reduces the cost of energy. The optimization's reduction was documented as effective [10].The dynamic stresses on a blade that was designed using the blade element theory were calculated by Z.L. Mahri and Rouabah. The dynamic analysis was conducted using beam theory, while the modal analysis was conducted using finite element modelling and the blade motion equation [11]. The rotor diameter was 10 metres. The current work involves the development of a 1.5-meter-long wind turbine blade that is appropriate for a 2.0 KW tiny wind turbine, utilising the Blade Element Theory. The chord distributions, flow angles, differential power, thrust, and torque are all depicted at discrete intervals of the blade, and the chord lengths are calculated. The blade is then presumed to be a cylindrical beam with a tapered shape. The Eigen value problem is used to determine the natural frequency. The efficacy of the blade can be enhanced by affixing a winglet to the blade's extremity. The winglets are typically employed in the design of aerospace vehicles.

Implementation:

The proposed research aims to enhance the design and functionality of windmill-operated water pumps by experimenting with two distinct airfoil profiles, NACA-63215 and NACA-63210, which have blade angles of 15, 14, 5, and 15.5 degrees. The airfoil coordinates are initially generated using the DESIGN FOIL tool, a robust software that provides the precise geometric profiling required for aerodynamic analysis. Subsequently, the airfoil shapes are meticulously modelled in CATIA V5, a top-tier CAD software that enables the integration of intricate features into the wind turbine blade design and detailed structural design.

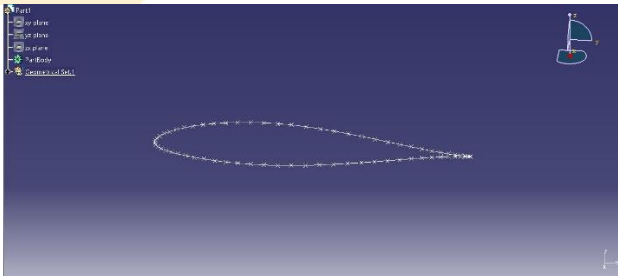


Fig 2 CATIA 63215 Developed Model by Using Key points

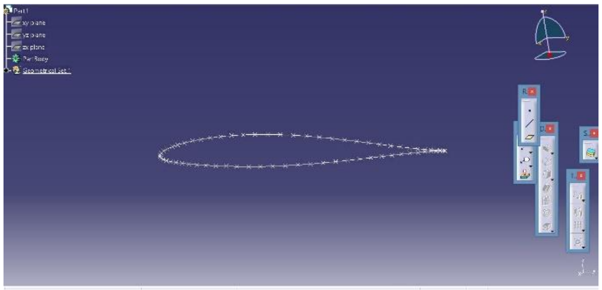


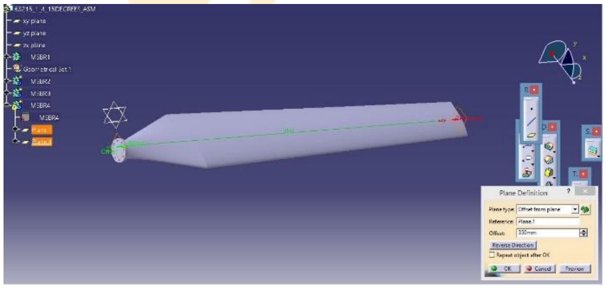
Fig 3 CATIA 63210 Developed Model by Using Key points

Then by using multi section solid option we are going to create our object Here we have airfoil chord length is 70mm based on this dimension here we developed our object

In this process we following one scale factor each time And those values are

Horizontal wind turbine tip to root ratio is 1:2

It means our tip chord length is 35mm only. And the distance between blade tips to root is 4 times to chord length it means 280mm and other side of the blade is 70mm



Plane Definition

Plane type: Offset from plane

Reference: Plane.1

Offset: 350mm

☐ Repeat object after OK

Fig 4 NACA 63215 blade

Complete blade length is 350mm it means 5 times to the chord length, and repeat the same process for the each model and save all files in IGES format

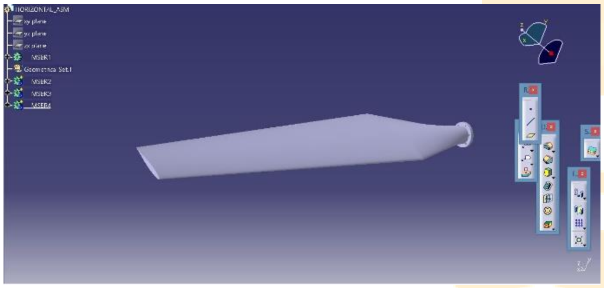


Fig 5 NACA 63210 blade

The subsequent critical phase entails the analysis of these models using ANSYS WORKBENCH, a comprehensive instrument for computational fluid dynamics and structural analysis. This stage is essential because it evaluates the efficacy of each blade configuration in simulated wind conditions. Carbon fibre materials are employed to construct the models, which are renowned for their high stiffness-to-weight ratio. This property is particularly advantageous for blades that must endure substantial mechanical stressors while retaining a minimal weight.

This analysis concentrates on critical performance indicators, including deformation, stress, and strain, that are observed on the blades at varying wind velocities and directions. The optimal blade angle for energy output and structural integrity can be determined by modestly adjusting the blade angles in the simulations. In order to guarantee that the results are pertinent to practical situations, the pressure applied during simulations is calibrated to replicate real-world operational conditions.

The ultimate goal is to incorporate these optimised blades into a windmill-operated water pump system that is operational. The system is engineered to function as a self-contained unit that can operate in remote regions without the necessity of external power sources, rendering it an exceptional solution for water provision and irrigation in off-grid locations. The pump system's durability and efficacy are evaluated under a variety of environmental conditions to guarantee its reliability over an extended period.

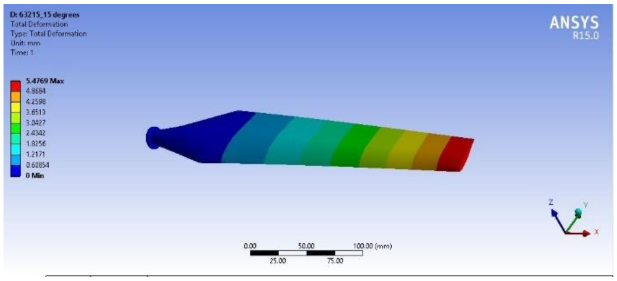
The project's ultimate objective is to produce a turbine pump system that is not only energy-efficient but also capable of operating in a variety of environmental conditions without the need for frequent maintenance. The practical implementation of theoretical aerodynamics and materials science in solving real-world problems could potentially result in advancements in renewable energy technologies for rural development and sustainable agriculture practices, as the findings from this project demonstrate.

Results:

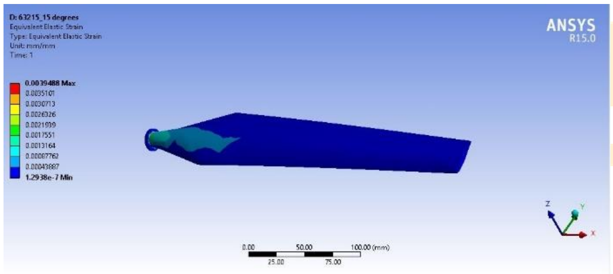
The efficacy of the two airfoil designs, NACA-63215 and NACA-63210, under varying conditions was significantly elucidated by the results of the analysis conducted using ANSYS WORKBENCH. In order to ascertain the efficacy of each airfoil in terms of deformation, strain, and stress levels under a standardised pressure of 10000Pa, which simulates realistic operational wind velocities, three blade angles—15, 14.5, and 15.5 degrees—were tested.

efficiency and durability in real-world applications.

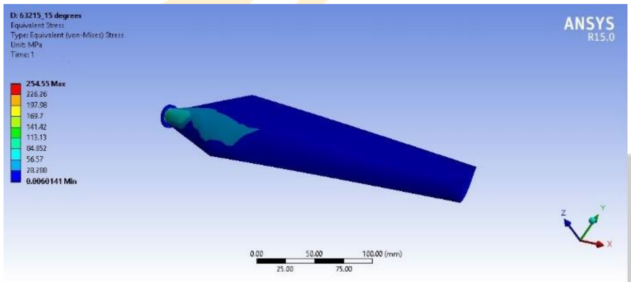
NACA 63215 model with 15 degree blade twist Deformation



Strain

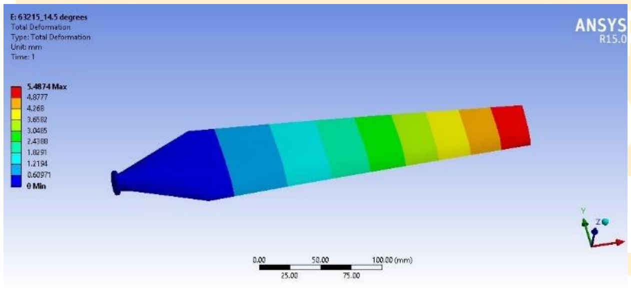


Stress

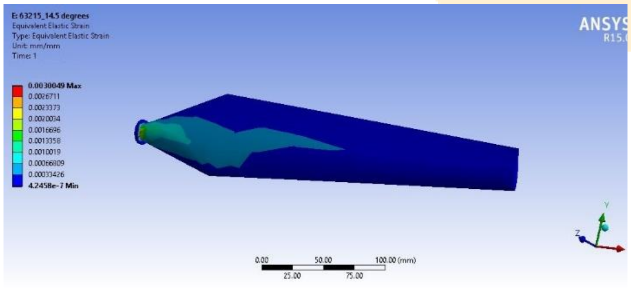


NACA 63215 model with 14.5 degree blade twist

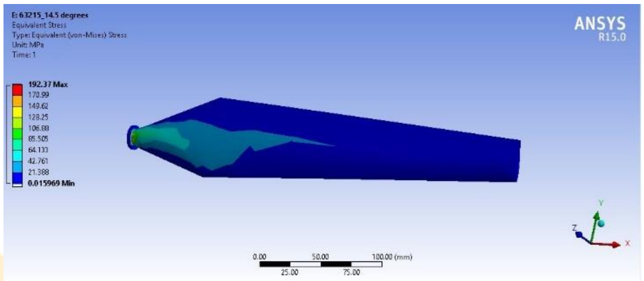
Deformation



Strain



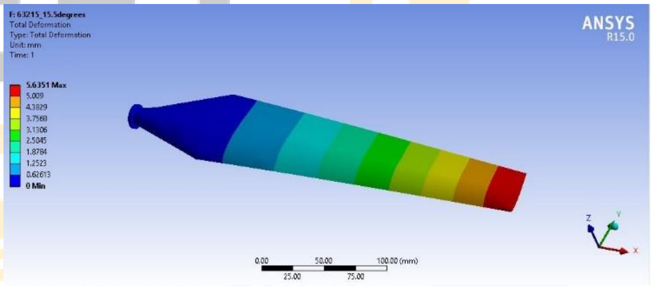
Stress



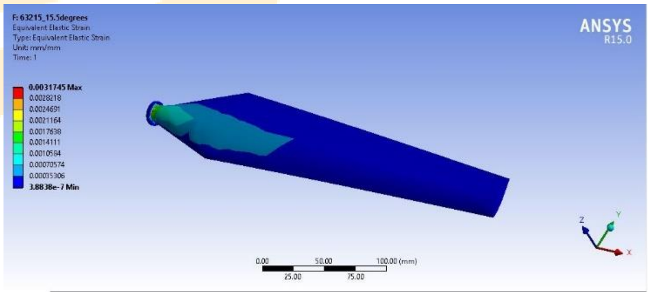
NACA 63215 model with 15.5 degree blade twist

Deformation

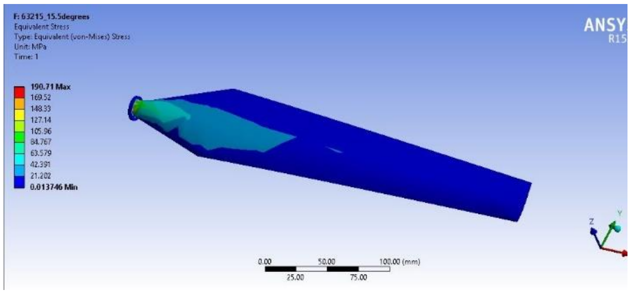
The NACA-63215 airfoil demonstrated that the 15.5-degree blade angle was the most effective in reducing structural tension. The tension level of the blade was 190.71 MPa at this angle, which was significantly lower than the 254.55 MPa observed at the 15-degree angle. The turbine's structural resilience and operational lifespan can be considerably improved by a minor increase in blade angle, as evidenced by the approximately 64 MPa reduction in stress, or approximately 25%. Additionally, the overall stress reduction outweighed the minor increases in deformation and strain values, suggesting a more optimal performance.



Strain



Stress



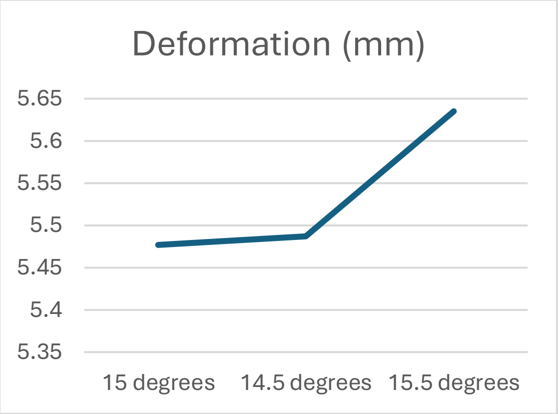
Tables

63215 model	Deformation (mm)	strain	Stress(Mpa)
15 degrees	5.4769	0.0039488	254.55
14.5 degrees	5.4874	0.0030049	192.37
15.5 degrees	5.6351	0.0031745	190.71

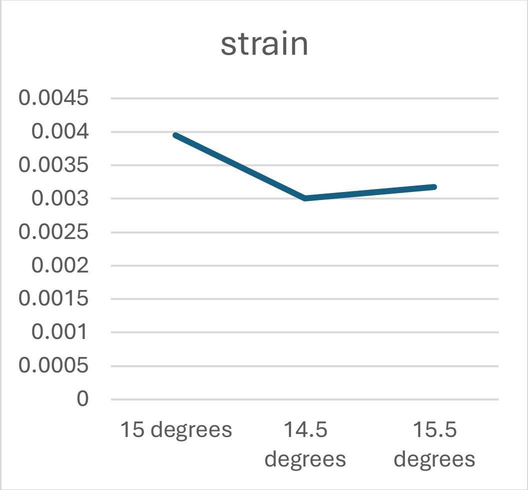
when we change our blade angle 15 to 14.5 or 15.5 we got different stress and strain values for it from these results we can say NACA 63215 with 15.5 degrees turbine blade produces much lesser stress than existing model 15 degrees.

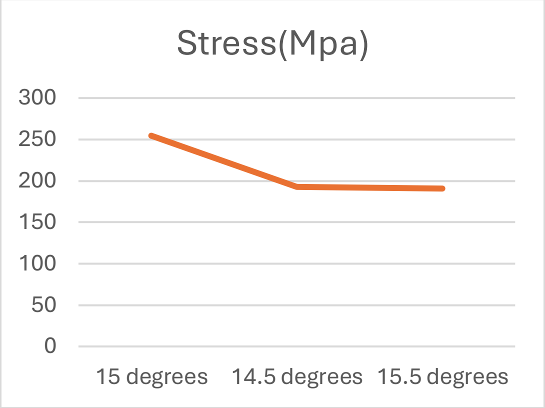
Graphs

Deformation



deformations values are high for 15.5 degrees compare to existing 15 degrees

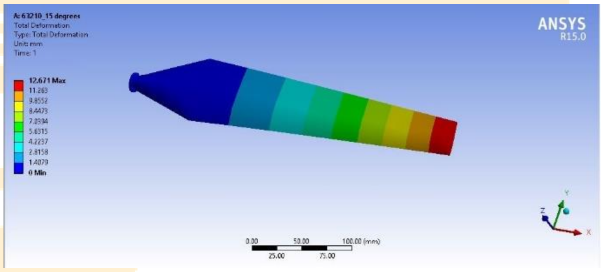




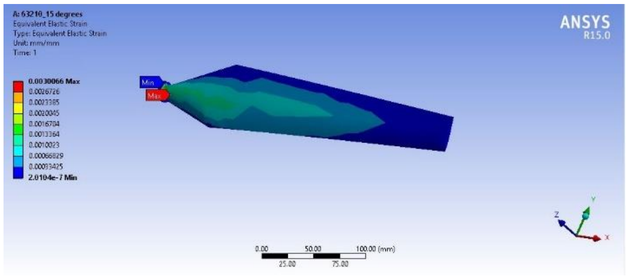
Stress values are less for 15.5 degrees model compare to existing model

NACA 63210 model with 15 degree blade twist

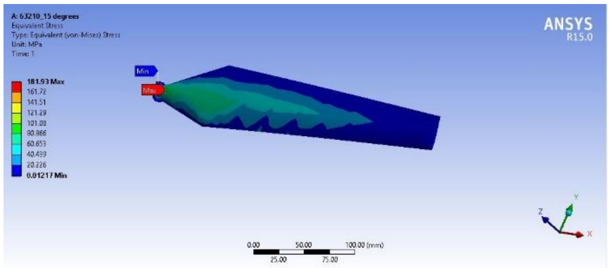
Deformation



Strain

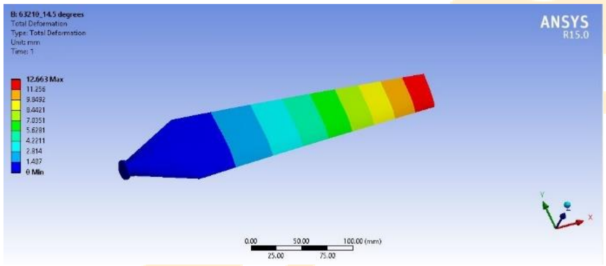


Stress

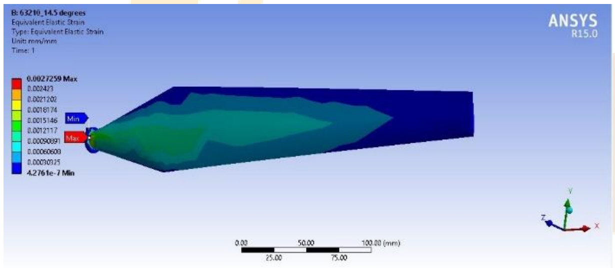


NACA 63210 model with 14.5 degree blade twist

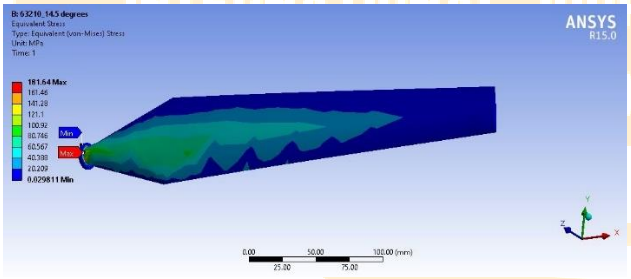
Deformation



Strain

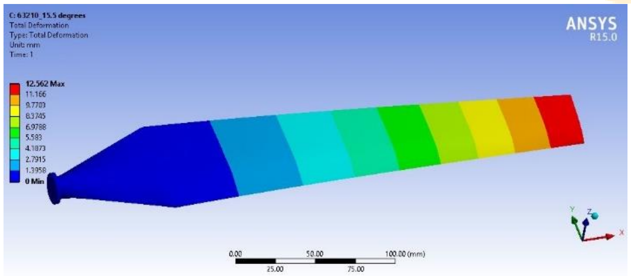


Stress

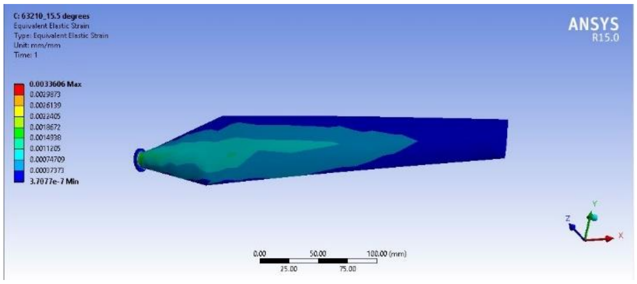


NACA 63210 model with 15.5 degree blade twist

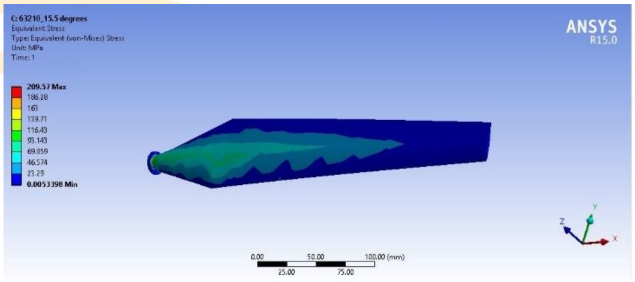
Deformation



Strain



Stress



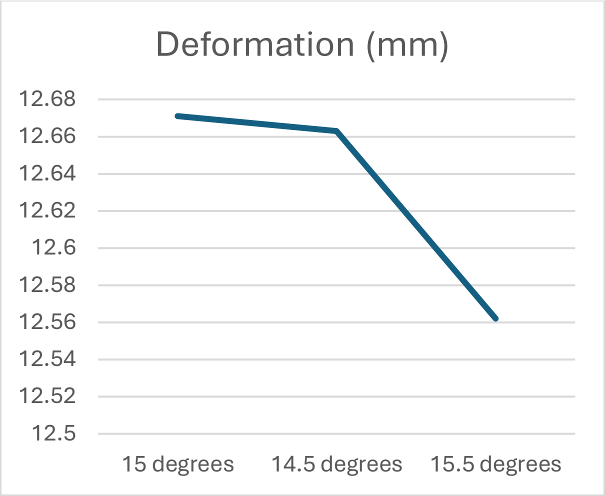
Tables

63210 model	Deformation (mm)	strain	Stress(Mpa)
15 degrees	12.671	0.0030066	181.93
14.5 degrees	12.663	0.0027259	181.64
15.5 degrees	12.562	0.0033606	209.57

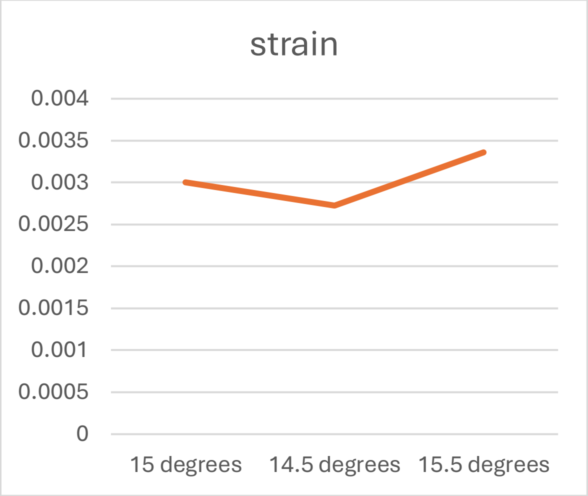
in this NACA 63210 series both 15 degrees and 14.5 degrees turbine blades produces almost same amount stress and 14.5 angle blade is having 0.30Mpa less stress compare to existing angle 15 degree. And here maximum stress is developed in 15.5 degrees.

Graphs

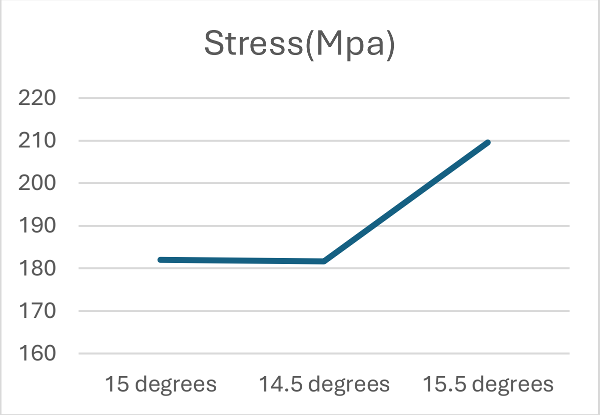
Deformation



strain



stress



In contrast, the NACA-63210 airfoil depicted an alternative pattern. The blade angle of 14.5 degrees was the most effective, with a tension level that was marginally lower than that of 15 degrees—181.64 MPa compared to 181.93 MPa. Despite the minor difference, it suggested a trend in which reduced blade angles could be advantageous under specific operational conditions. Nevertheless, the stress for this airfoil was elevated to 209.57 MPa at a 15.5-degree angle, indicating that higher angles may not always produce superior results, particularly for this particular airfoil configuration.

These results emphasise the significance of customising blade angles to specific airfoil profiles in order to enhance the performance of wind turbines. By effectively managing deformation and strain, tension can be substantially reduced, resulting in turbines that are more efficient and durable. These results are essential for the design and implementation of windmill-operated water pumps, as they establish a basis for the selection of the most suitable airfoil and blade angle combinations to optimise

CONCLUSION

In this project, two horizontal axis wind turbine blades from the NACA series (NACA 63215, NACA 63210) were developed with three distinct blade angles (15, 14.5, 15.5 degrees). To obtain the precise airfoil shape of the turbine blade, we employed a software programme called "DESIGN FOIL." This software enables us to directly export the necessary shape key points into CATIA. Our model was analysed using the CAE TOOL (Ansys Workbench) with real-time boundary conditions. Composed of carbon fibre.

We obtained a tension of 254.55 MPa when we applied 10000Pa pressure to the NACA 63215 (15-degree blade). We are unable to entirely eliminate the stress; however, we can mitigate it by implementing certain design modifications, such as blade angle adjustments. Currently, the blade angle is 15.5 degrees, resulting in a tension of 190.71 MPa. By increasing the blade angle by 0.5 degrees, the stress can be reduced by nearly 64 MPa, resulting in a nearly 25% reduction in stress.

In the alternative scenario, the NACA 63210 blade (15 degrees) experienced a stress of 181.93Mpa under the same boundary condition. However, the 14.5 blade also experienced the same stress (181.64MPa), which is nearly equivalent to 15 degrees. When the same pressure was applied to the 15.5 blade, the stress was 209.57Mpa, which is nearly 30MPa greater than the current angle.

In conclusion, the NACA 63215 with a 15.5 degree angle is significantly more optimal than a 15 degree blade. The blade with a 15-degree angle is inferior to the 14.5-degree blade in the NACA 63210 series.

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