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Design And Material Optimization Of Wind Turbine Blade

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***Abstract*:**

Wind turbine is a device which converts kinetic energy from the wind into electrical power. Wind turbines generate electricity through asynchronous machines that are directly connected with the electricity grid. Composite wind turbine blades have high strain energy because it has less Young's modulus and density compared to Aluminum turbine blade. Due to light weight and non-corrosiveness in nature the life and durability is high.

A Composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite passes superior properties which are not available with single constituted material. Composite material plays an important role in automobile industry, aerospace application because of its exotic properties like high strength, erosive resistance and light weight.

The goal of this project is to develop the geometry of the wind turbine blade, to improve the capacity, strength and to reduce weight. Initially literature survey and data collection has been done to understand the problem rectification methodology and selection of material. 3D model has been prepared using CMM points collected from NACA specifications. Different types of geometry's are implemented on the same and exported to Ansys for further study. A structural analysis is done on various geometric profiles of blade segment @200 Kmph and 400 Kmph (double velocity) for the validation. It is observed that the deflections of composite turbine blade are greater and stresses are less as compared to aluminum turbine blade for the same loading conditions. A 15% reduction in weight can be obtained by replacing an aluminum turbine blade with a composite turbine blade.

I. INTRODUCTION

1.1 Wind Turbine

A wind turbine is a machine that converts kinetic energy from the wind into electrical power. There are mainly two types of wind turbine: horizontal axis and vertical axis. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) are classified or differentiated by the axis of rotation of the rotor shafts.

Horizontal Axis wind turbines- Horizontal axis wind turbines, also known as HAWT type turbines have a horizontal rotor shaft and an electrical generator which is both located at the top of a tower.

Vertical Axis wind turbines- abbreviated as VAWTs, are designed with a vertical rotor shaft, a generator and gearbox which are placed at the bottom of the turbine, and a uniquely shaped rotor blade that is designed to harvest the power of the wind no which direction is it blowing.

1.2 Components of A Wind Turbine

Wind turbine usually has six main components: the rotor, the gearbox, the generator, the control and protection system, the tower and the foundation.

Rotor- the rotor is an elegant aero foil shaped blades which take the wind and aerodynamically converts its kinetic energy into mechanical energy through a connected shaft.

Gearbox- The gearbox alters the rotational velocity of the shaft to suit the generator.

Generator- The generator is a device that produces electricity when mechanical work is given to the system.

Control and Protection System- The protection system is like a safety feature that makes sure that the turbine will not be working under dangerous condition. This includes a brake system triggered by the signal of higher wind speeds to stop the rotor from movement under excessive wind gusts.

Tower- The tower is the main shaft that connects the rotor to the foundation. It also raises the rotor high in the air where we can find stronger winds. With horizontal axis wind turbines, the lower houses the stairs to allow for maintenance and inspection.

Foundation- The foundation of the base supports the entire wind turbine and make sure that it is well fixed on to the ground or the roof for small house hold wind turbines. This is usually consists of a solid concrete assembly around the tower to maintain its structural integrity

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1.3 Wind Energy

Wind is just moving air. This mass, having a certain velocity, owns kinetic energy. The energy can be converted, through a specific device, into a more useful type. Therefore, it is possible to produce electricity, moving parts with mechanical energy, pump water or provide heat for instance.

1.4 History

Humans had the first approach with wind power thousands of years ago, propelling their sailboats with it. Since the 7th century AD, wind was used by windmills to pump water or mill grains in Persia. Wind energy has been adopted for pumping water from wells for steam trains, and it is still able to provide it for isolated houses or off-grid locations. Only at the end of 19th century the concept of modern wind turbine arises, converting the kinetic energy of the wind into electricity.

Wind energy industry born officially in 1979, with the first serial production of Danish turbines. Since then, the trend followed by wind turbine manufacturers was designing bigger devices. Increasing the diameter of the rotors and using higher towers were the main paths followed until now. Turbines with bigger diameters are able to capture more wind; higher towers elevate the rotor out of vegetation and buildings influence, leading to an increased average wind speed.

Models from 1979 were having only 12-20 kW of power output; today the largest turbine (Enercon E-126) has a rated power of 7 MW and it is 198 meters high. Nowadays, modern wind turbines achieved a quite common baseline for their design: horizontal axis, 3 blades, upwind, variable speed, pitch controlled and with active yawing system. Of course then each company prefers to adopt certain materials, different sets of airfoils, rated wind speed or tip wind speed ratio, but the most straightforward relation to approximate the rated power of a device is from the rotor diameter.

Lately it looks like the wind turbine manufacturers approach changed its trend. Making a higher tower and increasing the rotor diameter does not lead to the same improvements had until now. Probably, with the current materials and technology, we are close to the maximum size possible (still considering the economic aspect of course). From physics, the power output of a wind turbine **P**, neglecting gearboxes and generators efficiencies, can be described by:

$$P[W] = \frac{1}{2}\rho\ S\ V^3 C_p$$

Where _ ρ[kg/m3] is the air density, **S** [m2] is the swept area of the rotor (thus S=_D2/4), **V** [m/s] is the wind speed and **C_p** [-] is the coefficient of performance. The power output then scales with the square of the rotor diameter. The mass instead scales with the cube of the rotor diameter, in fact creating a limit above which increasing the size is not economically profitable anymore. Due to technology improvements, throughout the years the real coefficients have been 2.155 and 2.6, respectively.

The new designs focus on other aspects than "size". For instance, improving the efficiency of the blade reduces the fatigue loads, increasing the life cycle of the components, as well as more accurate internal blade design can reduce the amount of material utilised, making the rotor lighter and cheaper. Advanced aerodynamic technologies are also embraced to achieve better and cheaper results. Development of smart rotors, winglets, flaps, gurney flaps, micro tabs and vortex generators is a daily basis topic. All these technologies are meant to control or limit the harmful loads, leading to less fatigue and therefore longer life cycle or less materials.

2. DESIGN OF WIND TURBINE BLADE

2.1Design Parameters of Aluminum Wind turbine blade

Parameter	**Value**
Material-selected – Aluminum	A360.0f
Tensile strength (N/mm^2)	370
Yield Strength (N/mm^2)	165
Young's modulus E (N/mm^2)	71000
Density of the material (kg/mm^3)	2.680*10^{-6}
Poisson's ratio	0.33

Table 2.1 Parameters of Aluminum wind turbine blade

2.2 Materials Selection

Materials constitute nearly 60%-70% of the blade cost and contribute to the quality and the performance of the turbine. Even a small amount in weight reduction of the blade, will reduce the unwanted side effects of the blade. Composite materials are proved as suitable substitutes for aluminum in connection with weight reduction of the blade and increase the strength of the blade. Hence, the composite materials have been selected for leaf spring design.

2.2.1 Fiber Selection

The commonly used fibers are carbon, glass, keviar, etc... Among these, the glass fiber has been selected based on the cost factor and strength. The types of glass fibers are C-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish.

S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries. The E-glass fiber is a high quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. Thus, E-glass fiber was found appropriate for this application.

2.2.2 Resins Selection

In a FRP leaf spring, inter laminar shear strengths is controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction, fiber do not influence inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo set resins such as polyester, vinyl ester, epoxy resin are being used for fiber reinforcement plastics (FRP) fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties. Hence, epoxy resin is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classifieds, based on the mechanical properties.

Among these grades, the grade of epoxy resin selected is Dobeckot 520 F and the grade of hardener used for this application is 758. Dobeckot 520 F is a solvent less epoxy resin. This in combination with hardener 758 cures into hard resin. Hardener 758 is a low viscosity polyamine. Dobeckot 520 F, hardener 758 combinations are characterized by

- Good mechanical and electrical properties.
- Faster curing at room temperature.
- Good chemical resistance properties.

2.3 Introduction to Airfoil

The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.

2.4 Properties of E-Glass / Epoxy S-Glass Epoxy Composites:

S No.	Properties	Value
1.	Tensile modulus along X-direction (Ex), MPa	34000
2.	Tensile modulus along Y-direction (Ey), MPa	6530
3.	Tensile modulus along Z-direction (Ez), MPa	6530
4.	Tensile modulus along material MPa	900
5.	Compressive strength of the material, MPa	450
6.	Shear modulus along XY-direction (Gxy), MPa	2433
7.	Shear modulus along YZ-direction (Gyz), MPa	1698
8.	Shear modulus along ZX-direction (Gzx), MPa	2433
9.	Poisson ratio along XY-direction (NUxy)	0.217
10.	Poisson ratio along YZ-direction (NUyz)	0.366
11.	Poisson ratio along ZX-direction (NUzx)	0.217
12.	Mass density of the material (ρ), kg/mm^3	$2.6*10^{-6}$
13.	Flexural modulus of the material, MPa	40000
14.	Flexural strength of the material, MPa	1200

Table 2.2 Material properties of E-Glass/Epoxy

S No.	Properties	Value
1.	Tensile modulus along X-direction (Ex), MPa	18800
2.	Tensile modulus along Y-direction (Ey), MPa	18900
3.	Tensile modulus along Z-direction (Ez), MPa	7830
4.	Mass density of the material (ρ), kg/mm^3	$2.46*10^{-6}$
5.	Poisson's ratio	0.23

6.	Specific heat J/g°c	0.737
7.	Thermal conductivity/m-k	1.45
8.	Shear modulus, MPa	3189
9.	Tensile modulus along the material, MPa	4890
10.	Elastic modulus of the material, MPa	$8.69*10^5$

Table 4.3 Material properties of S-2 Glass/Epoxy

2.4.1 Four - digit series

The NACA four-digit wing sections define the profile by:

First digit describing maximum camber as percentage of the chord. Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord. Last two digits describing maximum thickness of the airfoil as percent of the chord.

For example, the NACA 4415 airfoil has a maximum camber of 4% located 40% (0.4 chords) from the leading edge with a maximum thickness of 15% of the chord. Four-digit series airfoils by default have maximum thickness at 30% of the chord (0.3 chords) from the leading edge.

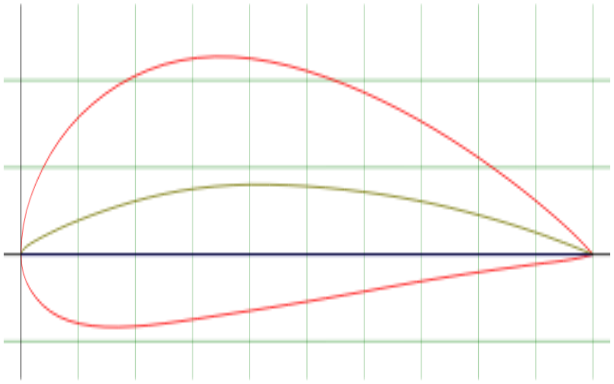


Fig.2.1 NACA 4415 Airfoil

The cross-sectional shape obtained by the intersection of the wing with the perpendicular plane is called an **airfoil.** The major design features of an airfoil is the **mean camber line**, which is the locus of points halfway between the upper and lower surfaces, as measured perpendicular to the mean camber line itself. The most forward and rearward points of the mean camber line are the leading and trailing edges, respectively. The straight line connecting the leading and trailing edges is the **chord line** of the airfoil, and the precise distance from the leading to the trailing edge measured along the chord line is simply designated the **chord** of the airfoil, given by the symbol **c**. the camber is the maximum distance between the mean camber line and chord line, measured perpendicular to the chord line. The camber, the shape of the mean camber line, and to a lesser extent, the thickness distribution of the airfoil essentially controls the lift and moment characteristics of the airfoil.

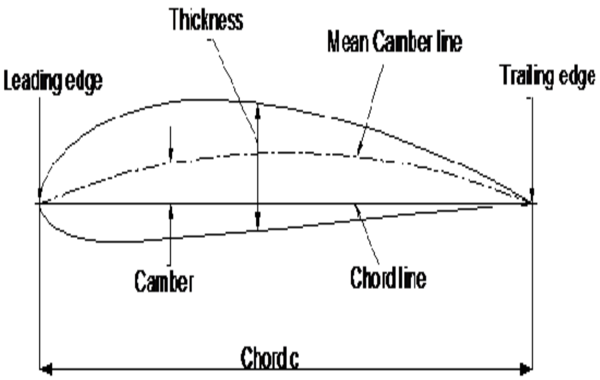
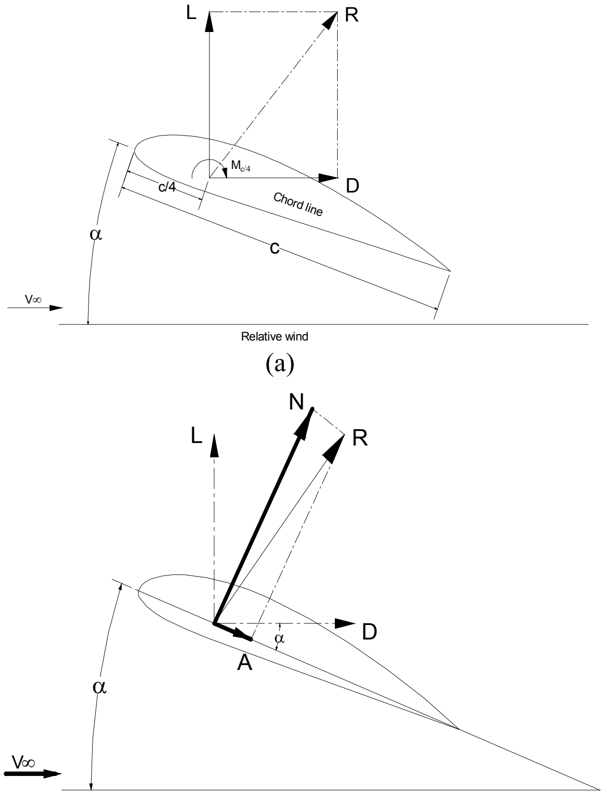


Fig.2.2: Airfoil nomenclature, The Shape shown here is an NACA 4415 airfoil.



(a)

(b)

Fig.2.3: The sketches showing the definitions of

(a) Lift, drag, moments, angle of attack, and relative wind
(b) Normal and axial force.

The free-stream velocity V_∞ is the velocity of the air far upstream of the airfoil. The direction of V_∞ is defined as the relative wind. The angle between the relative wind and the chord line is the angle of attack α of the airfoil. The aerodynamic force created by the pressure and shear stress distributions over the wing surface. This resultant force is shown by the vector R. In turn, the aerodynamic force R can be resolved into two forces, parallel and perpendicular to the relative wind. The drag D is always defined as the component of the aerodynamic force parallel to the relative wind. The lift L is alwasys defined as the component of the aerodynamic force perpendicular to the relative wind.

In addition to lift and drag, the surface pressure and shear stress distributions create a moment M which tends to rotate the wing. To see more clearly how this moment is created, consider the surface pressure distribution over an airfoil, as sketched in Fig. (We will ignore the shear stress for this discussion). Consider just the pressure on the top surface of the airfoil. This pressure gives rise to a net force F_1 in the general downward direction.

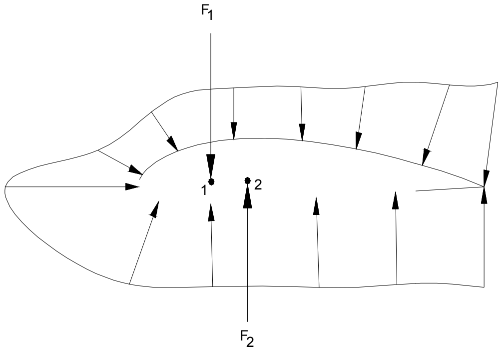


Fig.2.4: The physical origin of moments of an airfoil.

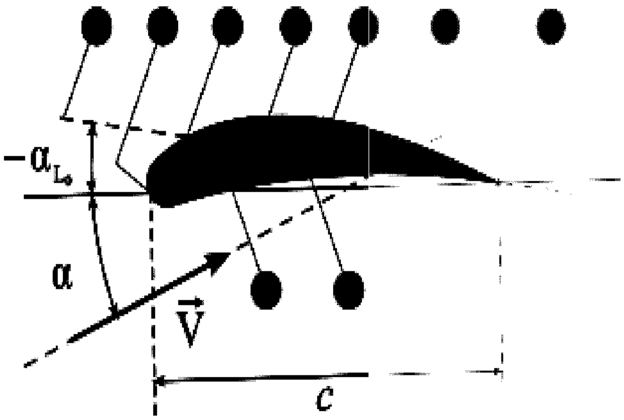
Moreover, F_1 acts through a given point the chord line, point 1, which can be found by integrating the pressure times distance over the surface (analogous to finding the centroid or center of pressure from integral calculus). Now consider just the pressure on the bottom surface of the airfoil. This pressure gives the rise to a net force F_2 in the integral upward direction, acting through point 2. The total aerodynamic force on the airfoil is the summation of F_1 and F_2, and lift is obtained when $F_2 > F_1$. However, note from Fig 1.3 that F_1 and F_2 will create a moment that will tend to rotate the airfoil. Moreover, the value of this aerodynamically induced moment depends on the point about which we choose to take moments. For example if we take moments about the leading edge, the aerodynamic moment is designated M_{LE}. It is more common in the case of subsonic airfoils to take moments about a point on the chord at a distance c/4 from the leading edge, the quarter-chord point. This moment about the quarter chord is designated $M_{c/4}$. In general $M_{LE} \neq M_{c/4}$. Intuition will tell you that lift, drag and moments on a wing will changes as the angle of attack α changes. In fact the variation of these aerodynamic quantities with α represent some of the most important information that an airfoil designer needs to know. M_{LE} and $M_{c/4}$ are both functions of α, there exists a certain point on the airfoil about which moments essentially do not vary with α. This point is defined as the aerodynamic center, and the moment about the aerodynamic center is designated M_{ac}. By definition,

$$M_{ac} = \text{const}$$

independent of the angle of attack. The location of the aerodynamic center for the real aerodynamic shapes can be found from experiment. For low-speed subsonic airfoils, the aerodynamic center is generally very close to the quarter-chord point.

From Fig. the resultant aerodynamic force R can be resolved into components perpendicular and parallel to the relative wind, namely, the lift and drag, respectively. An alternative to this system is to resolve R into components perpendicular and parallel to the chord line. These components are called the normal force and axial force and are denoted by N and A, respectively.

The NACA 0015 airfoil is symmetrical, the 00 indicating that it has no camber. The 15 indicates that the airfoil has a 15% thickness to chord length ratio: it is 15% as thick as it is long.



Profile geometry – 1: Zero lift line; 2: Leading edge; 3: Nose circle; 4: Camber; 5: Max. Thickness; 6: Upper surface; 7: Trailing edge; 8: Camber mean-line; 9: Lower surface

Equation for a symmetrical 4-digit NACA airfoil

The formula for the shape of a NACA 00xx foil, with "xx" being replaced by the percentage of thickness to chord, is:

$$y_t = \frac{t}{0.2}c\left[0.2969\sqrt{\frac{x}{c}} + (-0.1260)\left(\frac{x}{c}\right) + (-0.3516)\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + (-0.1015)\left(\frac{x}{c}\right)^4\right]$$

Where:

- *c* is the chord length,
- *x* is the position along the chord from 0 to *c*,
- *y* is the half thickness at a given value of *x* (centerline to surface), and
- *t* is the maximum thickness as a fraction of the chord (so 100 *t* gives the last two digits in the NACA 4-digit denomination).

Note that in this equation, at (*x*/*c*) = 1 (the trailing edge of the airfoil), the thickness is not quite zero. If a zero-thickness trailing edge is required, for example for computational work, one of the coefficients should be modified such that they sum to zero. Modifying the last coefficient (i.e. to −0.1036) will result in the smallest change to the overall shape of the airfoil. The leading edge approximates a cylinder with a radius of:

$r=1.1019t^2$.

Now the coordinates (x_u, y_u) of the upper airfoil surface, and (x_L, y_L) of the lower airfoil surface are:

$x_u = x_L = x$, $y_u = +y_t$ and $y_L = -y_t$

Equation for a cambered 4-digit NACA airfoil

The simplest asymmetric foils are the NACA 4-digit series foils, which use the same formula as that used to generate the 00xx symmetric foils, but with the line of mean camber bent. The formula used to calculate the mean camber line is:

$$y_c = \begin{cases} m\frac{x}{p^2}\left(2p - \frac{x}{c}\right) & 0 \le x \le p\,c \\ m\frac{c-x}{(1-p)^2}\left(1 + \frac{x}{c} - 2p\right) & p\,c \le x \le c \end{cases}$$

Where:

- *m* is the maximum camber (100 *m* is the first of the four digits),
- *p* is the location of maximum camber (10 *p* is the second digit in the NACA xxxx description).

For this cambered airfoil, because the thickness needs to be applied perpendicular to the camber line, the coordinates (x_u, y_u) and (x_L, y_L), of respectively the upper and lower airfoil surface, become:

$$x_u = x - y_t \sin\theta, \qquad y_u = y_c + y_t \cos\theta,$$

$$x_L = x + y_t \sin\theta, \qquad y_L = y_c - y_t \cos\theta,$$

Where:

$$\theta = \arctan\left(\frac{d\,y_c}{d_x}\right),$$

$$\frac{d\,y_c}{d_x} = \begin{cases} \frac{2m}{p^2}\left(p - \frac{x}{c}\right), & 0 \le x \le p\,c \\ \frac{2m}{(1-p)^2}\left(p + \frac{x}{c}\right), & p\,c \le x \le c \end{cases}$$

For an airfoil at any span wise location, the edgewise stiffness is always much higher than the flap wise stiffness. Consequently, increasing the height of the airfoil, hereon defined as thicker profile, would positively affect the flap wise stiffness, leaving almost unchanged the span wise one, which is the less critical.

2.4.2 Using a thicker airfoils leads to 3 main different benefits

1) Having a stiffer blade, therefore increasing its length can be an option;
2) Using cheaper materials with lower stiffness and strength properties, but resulting in a similar overall stiffness;
3) Reducing the thickness of the layers, leading to a mass reduction.

The thicker airfoil does not have the same aerodynamic performances of the reference profile. Here BLS technology comes into play. The porous material is applied in such a way that the aerodynamic performances of thicker airfoils with BLS are as close as possible to the performances of thinner airfoils without BLS. In this way, the end product is a new blade performing like the reference one, but due to BLS technology has at least one of the benefits described above.

This leads, directly or indirectly, to a cost reduction of the wind turbine, reducing in fact the price of energy produced.

3. INTRODUCTION TO CAD AND PRO-ENGINEERING

3.1 Computer-Aided Design (Cad)

It also known as computer-aided design and drafting (CADD), is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations.

CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixilated) environments.

Computer-aided design is used in many fields. Its use in electronic design is known as Electronic Design Automation (EDA). In mechanical design is known as Mechanical Design Automation (MDA), it is also known as computer-aided drafting (CAD) which describes the process of creating a technical drawing with the use of computer software.

3.2 Pro-Engineering

Pro/Engineer is the software product of PTC (Parametric Technology Corporation). Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

- More advance drafting software in the market.
- Powerful drafting tool in Eng. Industry.

- Is a solid modeler-has volume and surface area.
- Allows user to input mass properties as part of model design.

4. MODELS OF WIND TURBINE BLADE

4.1 Introduction

Aluminum, E-Glass/Epoxy and S-2 Glass composite wind turbine blades are modeled using Pro-E Wildfire 5.0. and Creo 2.0. Isometric view of Composite Wind turbine blades is shown in Figure 4.1

4.2Modeling of Wind Turbine Blade In Pro/Engineer:

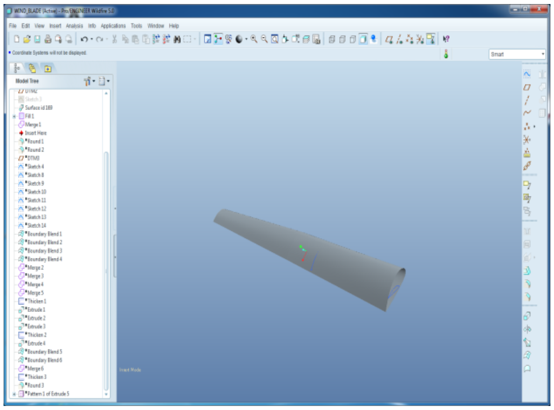


Figure 4.1: The above image shows the designing of wind turbine blade first segment

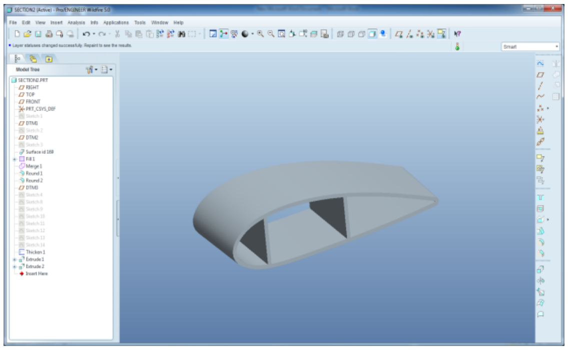
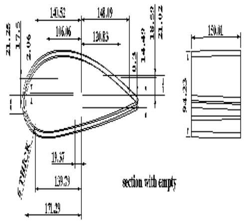
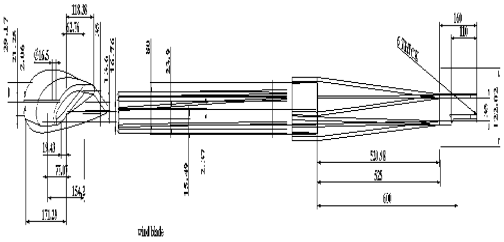


Figure 4.2: The above image shows the two rib blade section for analysis purpose

4.3 Drafting of Blade Sections:



section with empty



wind blade

5.ANALYSIS OF WIND TURBINE BLADE

5.1 Engineering Analysis:

Engineering analysis involves the application of scientific analytic principles and processes to reveal the properties and state of the system, device or mechanism under study. Engineering analysis is decompositional, it proceeds by separating the engineering design into the mechanisms of operation or failure, analysing or estimating each component of the operation or failure mechanism in isolation, and re-combining the components according to basic physical principles and natural laws.

5.2 Structural Analysis:

It consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation as in.

5.3 Vibration Analysis:

It is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibration frequency of the material which, in turn, may cause resonance and subsequent failure.

Fatigue analysis helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur. Failure due to fatigue may also show the damage tolerance of the material.

5.4 Heat Transfer Analysis:

It models the conductivity or thermal fluid dynamics of the material or structure. This may consist of a steady-state or transient transfer. Steady-state transfer refers to constant thermo properties in the material that yield linear heat diffusion.

5.5 Structural Analysis using Aluminum Alloy:

Wind turbine blade model is imported from Pro-E in the format of IGES (Initial Graphical Exchange Specification) in Ansys software as shown in figure 5.1

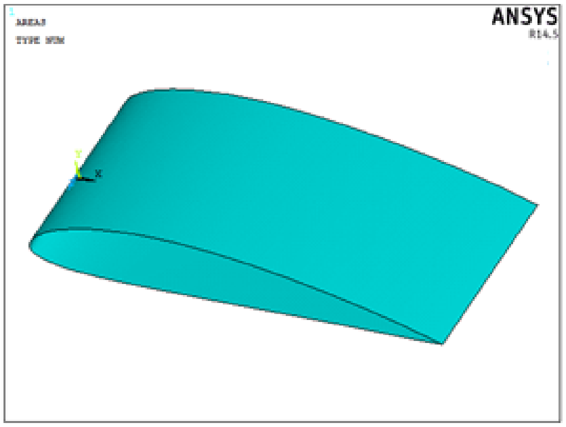


Fig.5.1 Shows Imported IGES Model of Wind turbine blade

The imported IGES model of turbine blade is meshed to divide the object into no. of elements.. Default solid Brick element was used to mesh the components. The shown mesh method was called Tetra Hydra Mesh. Meshing is used to deconstruct complex problem into number of small problems based on finite element method.

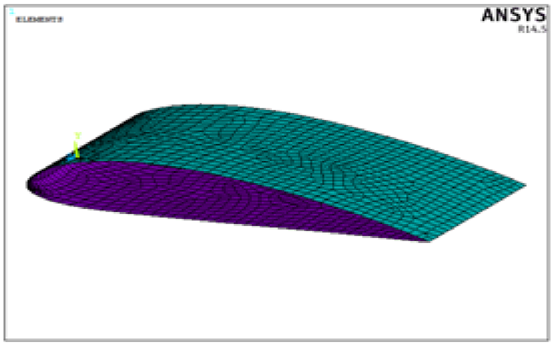


Fig.5.2 Shows wind turbine blade model after Meshing

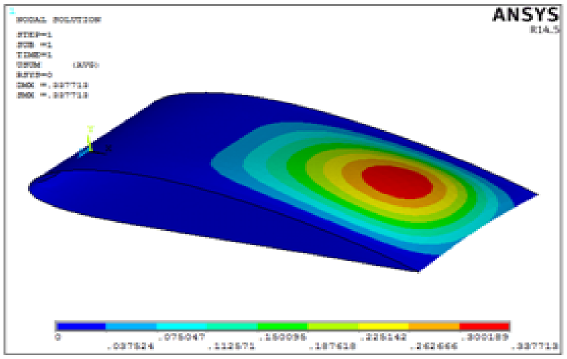


Fig.5.3 Shows displacement at maximum load

5.6 Structural Analysis of E–Glass Epoxy Wind turbine blade:

Initially the IGES model imported from the Pro-e Wildfire 5.0. Default Shell 8node 281 element was used to mesh the components. After solving the problem maximum displacement, von-misses stress and strain of an E-Glass Epoxy wind turbine blade is observed at the maximum load conditions.

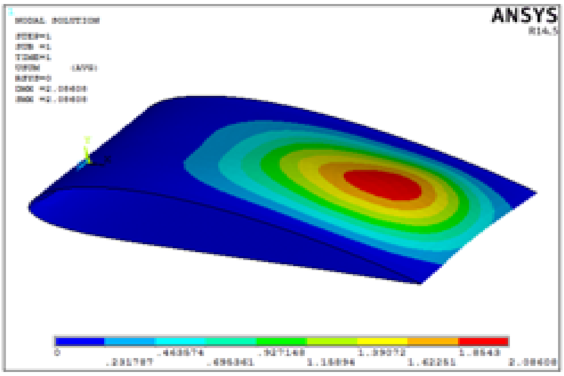


Fig.5.4 Maximum Displacement value at maximum load=2.08608mm

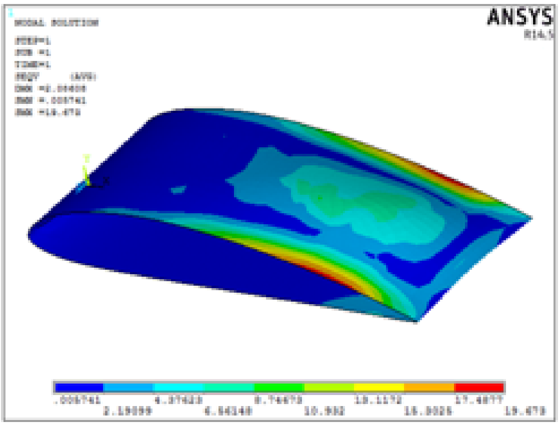


Fig.5.5 Maximum Von-misses stress at maximum load=19.673N/mm^2

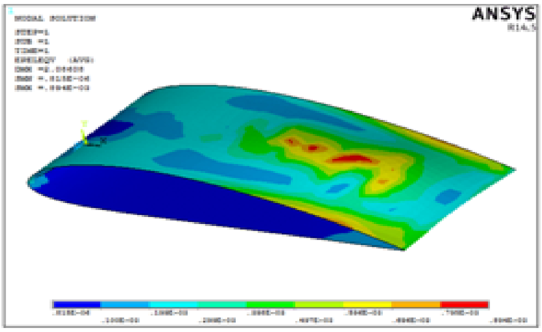
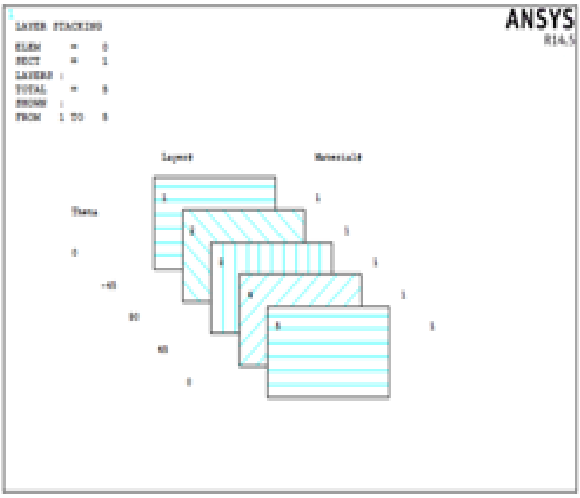


Fig.5.6 Maximum Strain at maximum load conditions=0.00894

5.7 Structural Analysis using E-glass epoxy with 5 layers:

Initially the IGES model imported from the Pro-e Wildfire 5.0. Default Shell 8node 281 element was used to mesh the components. After solving the problem maximum displacement, von-misses stress and strain of an E-Glass Epoxy wind turbine blade is observed at the maximum load conditions.



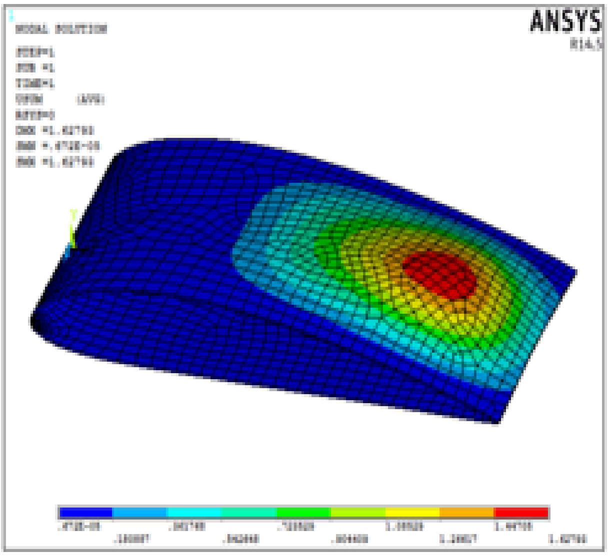


Fig.5.7 Maximum Displacement value at maximum load=1.62793mm

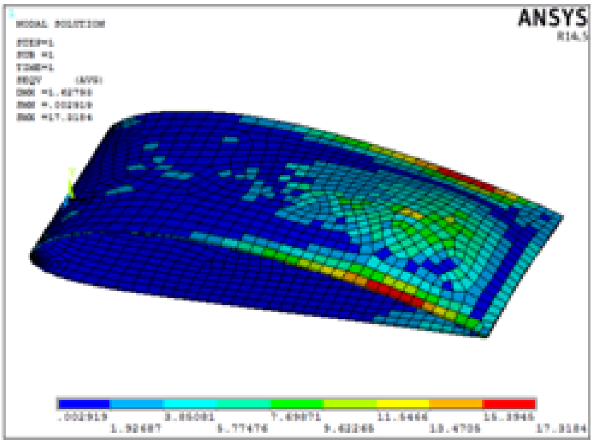


Fig.5.8 Maximum Von-misses stress at maximum load=17.3181N/mm^2

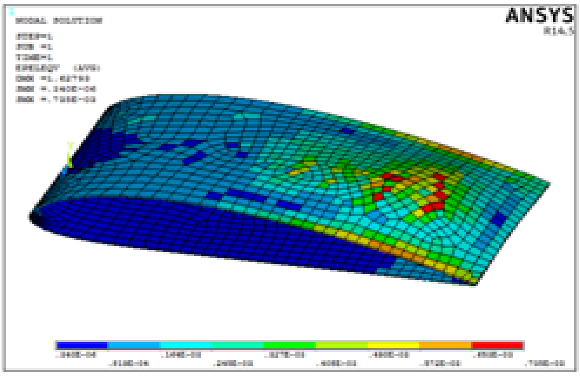


Fig.5.9 Maximum Strain at maximum load conditions=0.00735

6. RESULTS AND GRAPHS

6.1 Static Analysis of Wind turbine blade:

Deflections, Stresses and Strains of Aluminum & composite wind turbine blade at a velocity of air 200 Kmph are obtained from Static Analysis and tabulated as shown in Table 6.1

Material	Displace	Stre	Strain	F o S
Aluminu	0.337713	9.79	1.38E-	16.85
E-Glass	2.08608	19.6	8.94E-	12.707
E-Glass	2.00537	15.9	0.0011	15.645
E-Glass	1.62793	17.3	7.35E-	14.435
S-Glass	0.002811	9.97	0.115	459.8
S-Glass	0.028315	10.0	0.116	456.137
S-Glass	0.002811	10.0	0.115	458.422

Table 6.1 Static analysis results of Wind turbine blade at 200 Kmph

Compare the deflections of wind turbine blade at 200Kmph with different materials are obtained from static analysis.

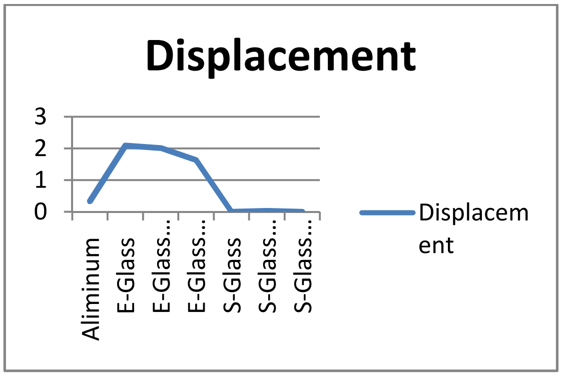


Fig.6.1 Displacement of the wind turbine blade at 200Kmph

Compare the stresses of wind turbine blade at 200Kmph with different materials are obtained from static analysis.

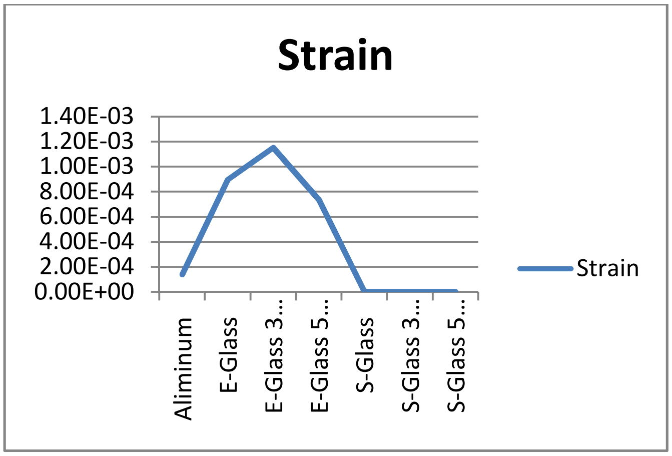


Fig.6.2 Stresses of the wind turbine blade at 200Kmph

Compare the strains of wind turbine blade at 200Kmph with different materials are obtained from static analysis.

Deflections, Stresses and Strains of Aluminum & composite materials of wind turbine blade at a velocity of air 400 Kmph are obtained from Static Analysis and tabulated as shown in Table 6.2

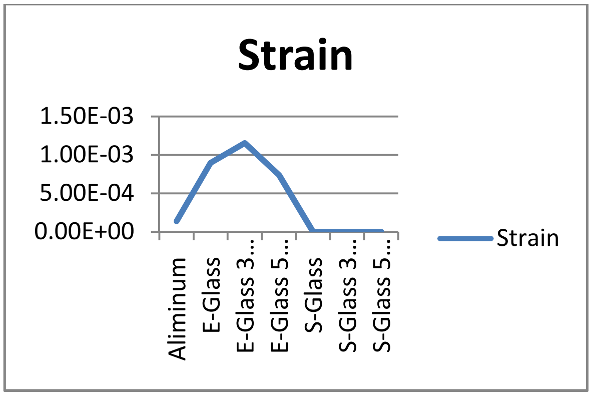


Fig.6.3 Strain of the wind turbine blade at 200Kmph

Material and layer orientation	Displacement	Stress	Strain	FOS
Aluminum	0.675426	19.5836	2.76E-04	8.4254
E-Glass	4.17217	39.3459	0.001788	6.3539
E-Glass 3-layers	4.0108	31.953	0.002368	7.8227
E-Glass 5-layers	3.25585	34.6369	0.00147	7.2177
E-Glass 5layers(90/0/90/0/90)	4.41734	23.2458	0.002593	10.7546
E-Glass 5-layers (90/45/0/45/90)	3.78125	30.3007	0.002297	8.25
S-Glass	0.0056221	19.9402	0.229 e-04	229.937
S-Glass 3-Layers	0.056626	20.0425	0.231 e-04	228.762
S-Glass 5-Layers	0.056225	20.0034	0.230 e-04	229.211
S-Glass 5-layers (90/0/90/0/90)	0.045456	16.1967	0.186 e-04	283.08
S-Glass 5-layers (90/45/90/45/90)	0.041849	14.9113	0.172 e-04	229.21

Table 6.2 Static analysis results of Wind turbine blade at 400 Kmph

	Displacement	Stress	Strain	FOS
Aluminum	0.678239	19.6324	2.77E-04	8.4044
E-Glass	4.18134	41.3497	0.001977	6.045
E-Glass 3-layers	3.74294	36.2315	0.002712	6.9
E-Glass 5-layers	3.21004	32.9017	0.001399	7.598
5 layers orient1(90/0/90/0/90)	4.34778	19.0973	0.002606	13.09
5 layers orient 2(90/45/0/-45/90)	3.69929	25.8504	0.002392	9.671
S-Glass	0.056386	19.9866	0.230 e-04	110.883
S-Glass 3-Layers	0.056785	20.122	0.232 e-04	227.86

Table 6.3 Static analysis results of Wind turbine blade with single rib at 400 Kmph

	Displacement	Stress	Strain	FOS
Aluminum	0.677106	19.5149	2.75E-04	8.1988
E-Glass	4.18606	39.1605	0.002039	6.383
E-Glass 3-layers	4.13278	37.1455	0.002295	6.7302
E-Glass 5-layers	3.3101	34.2888	0.001563	7.291
5-layers orient1(90/0/90/0/90)	4.41657	36.6808	0.002763	6.8155
5-layers orient 2(90/45/0/-45/90)	3.84854	27.2399	0.002342	9.1777
S-Glass	0.054583	19.8493	0.222 e-04	230.99
S-Glass 3-Layers	0.056677	20.0277	0.230 e-04	228.932
S-Glass 5-Layers	0.056282	19.9297	0.229 e-04	230.058
5 layers orient 1-(90/0/90/0/90)	0.045499	16.1408	0.186 e-04	284.062
5 layers orient 2(90/45/90/-45/90)	0.041888	14.8598	0.171 e-04	308.55

Table 6.4 Static analysis results of Wind turbine blade with dual rib at 400 Kmph

Material and layer orientation	Displacement	Stress	Strain	FOS
S-Glass 5layers (90/45/0/-45/90) 3 Rectangular	0.236123	51.9901	5.98E-05	88.189
S-Glass 5layers (90/45/0/-45/90) Rectangular	0.159827	46.6698	5.37E-05	98.243
S-Glass 5layers (90/45/0/-45/90) 3 sections	0.076612	24.2525	2.79E-05	189.052

Table 6.5 Static analysis results of Wind turbine blade modified model with dual rib at 400 Kmph

CONCLUSIONS

This project work deals with wind turbine blade optimization for the purpose of improvement in strength, capacity and reduction of weight.

- Initially literature survey was done to understand the problems and rectification methodology.
- 3D models are prepared using NACA Airfoil data, to conduct analysis in Ansys.
- In case one: Static structural analysis was done on airfoil segment by varying materials (aluminum, E-glass, s-glass) and by applying reinforcement angles for the composite materials @ 200kmph (general air velocity in India).
- In case two analyses was done @ 400kmph to understand structural behaviors at un-natural air velocity.
- In the next case single single rib and two rib segments was analyzed with variation in reinforcement angle values.
- In the next case different stress reliving slots are designed on airfoil segments are analyzed.
- Comparison tables along with FOS are prepared for all analysis results.
- As per obtained results this project work concludes that s-glass epoxy(CRFP) along with 90^0-45^0-0^0-45^0-90^0 of reinforced layer orientation with double ribs 3 sectioned profile is giving optimum quality for the air foil design.
- By using above said design it can bear approximate 11 times load than general/traditional material design blade profiles.
- So the length can be increased up to huge level to improve power generation.And also s-glass density is 15% lower than aluminum and e-glass materials.

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