DESIGN AND ANALYSIS OF VERTICAL AXIS WIND TURBINE BLADE

Y.Dinesh[1], J.Srinivas[2], K.Abhinav[3], B.Manikanta[4], P. Sri Gowri Padmaja[5]

[1,2,3,4]B.Tech, [5]Assistant Professor, Aditya College of Engineering & Technology, Surampalem, A.P, India, 533437

ABSTRACT

Wind energy has been utilized for an extensive period and has gained heightened importance amidst the current energy scarcity. While horizontal axis wind turbines have received significant attention, vertical axis wind turbines have been comparatively neglected in recent decades. The blade stands out as the pivotal component governing turbine performance and the design of associated elements. This study introduces a novel approach to crafting a straight, symmetrical blade for a small-scale vertical axis wind turbine. Leveraging beam theories for analyticalmodelingandtheANSYS11.0 software for numerical simulation, there search focuses on determining blade parameters such as solidity and aspect ratio, targeting a 1kWpoweroutput.Detailed analysis encompasses extreme wind conditions, identifying peak deflection and bending stresses under aerodynamic and centrifugal forces. Optimization efforts prioritize structural integrity, aiming to minimize deflections and bending stresses while ensuring high strength and reduced material usage for cost-effective rotor assembly, a substantial portion of the overall turbine expenditure.

1. INTRODUCTION

The continuous improvement of this world is based on technological advancement. And the technological advancement is directly related to the utilization of energy. The demand of energy is creeping up every day due to increase of population, industrial and agricultural advancement. But the conventional energy sources are becoming limited which is ultimately making them more expensive. In addition to this, everyone is concerned about global climate change. This whole scenario is pushing the world to find the alternative sources of energy.

1.1 Alternative Energy

Alternative sources involve natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat. Solar and Wind power are the most popular among the various sources of renewable energy. Only these two kinds of alternative sources can generate most of the world's electricity within next 50 years, on the other hand which can also help the climate change condition.

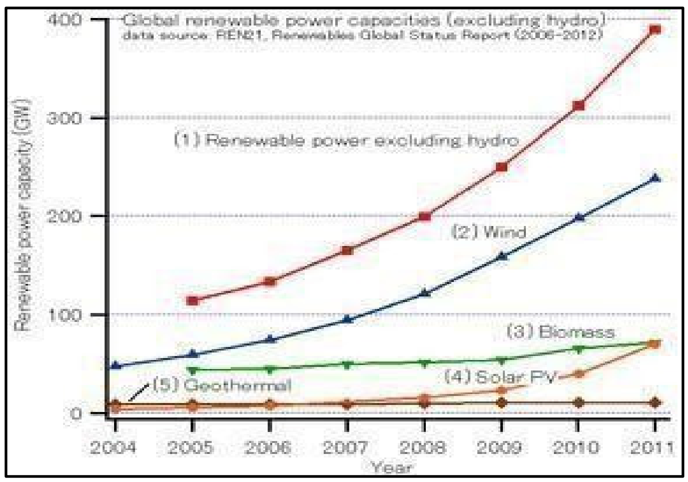


FIGURE 1-1: Global Renewable Power Capacity (REN21 2014)

1.2 Wind Energy

Wind energy has the potential to resolve the power demand of the entire world if it can be converted into electricity efficiently. Wind is going to be the most popular alternative energy source; because of its availability throughout place and time. As a pollution free and sustainable source, wind is getting importance in energy policy too. The disadvantages are its lower efficiency and high installation cost. But the ultimate cost would be lowered if it operates continuously and small scale turbines can be installed in any corner of the world.

1.3 Wind Turbine and Types

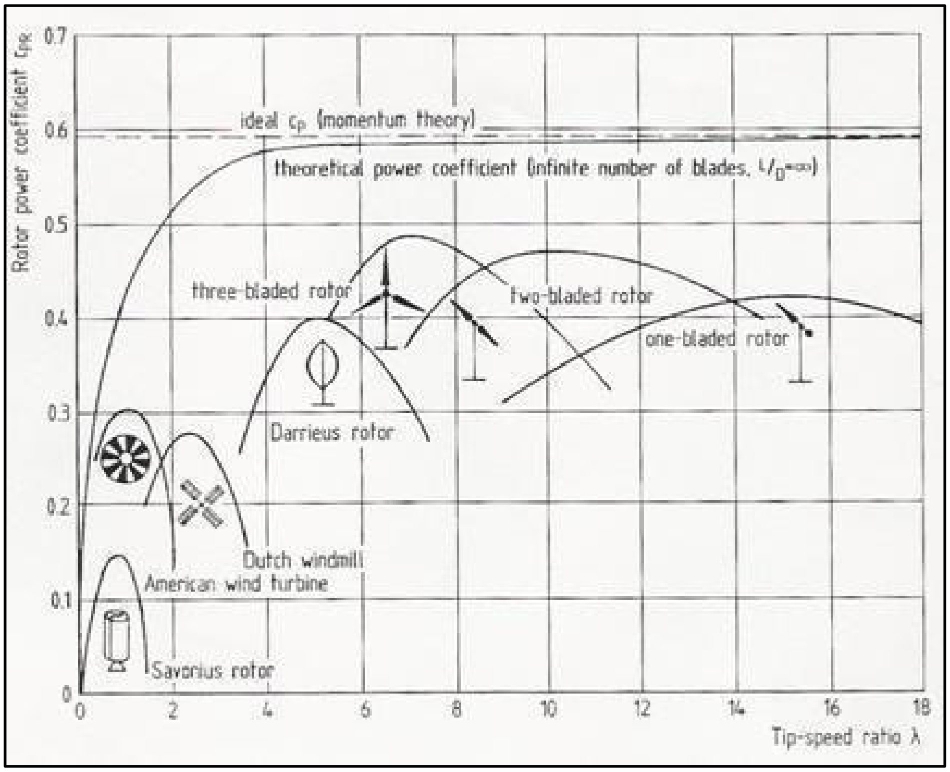
Wind turbine converts the wind energy into mechanical energy and that mechanical energy is used for the production of electricity. There are two types of primary wind turbine; they are horizontal-axis wind turbine (HAWT) and vertical-axis wind turbine (VAWT), both of which boast of being better than the other.

HAWTs include both upwind and downwind configuration with various performance enhancers such as diffusers and concentrators. HAWT is more popular because they have better efficiency, but only suitable for places with high wind speed. In contrast, VAWT works well in places with relatively lower strength, but constant wind (Reigler 2003). The blades are not needed to orient in wind direction as it can work always in the same direction though wind comes from any direction. (Ragheb 2012)

Due to better aerodynamic behavior and more efficient in the large scale, HAWT was the popular choice of the researchers. But several factors are turning the head of researchers towards the field of VAWT. They are, VAWT may be more appropriate than HAWT in small scale. VAWTs are suitable for electricity generation in the conditions where traditional.

HAWTs are unable to give reasonable efficiencies such as low wind velocities and turbulent wind flows. VAWT can operate without any dependence on wind direction. The quiet behavior is more attractive for highly populated places. The cost of complex structure of HAWT blades is higher than simpler VAWT blades. Because of the stalling behavior it can withstand gust wind, which makes it much safer during those weather conditions. This type of rotor can be installed in remote places, away from the main distribution lines and places where large wind farms cannot be installed due to environmental concerns. Some place needs small scale dispersed generation units where VAWT is suitable. (Bishop and GAJ 2008)

FIGURE 1-2: Power Coefficient (Cp) vs. Tip Speed Ratio (λ) For Various Wind Turbines.



1.4 Vertical Axis Wind Turbines

In general, VAWT is driven by two types of forces of wind, drag and lift force. Savonius rotor is the simplest kind of VAWTs is a drag-type configuration and a bit complex type is Darrieus rotor which is lift-type configuration.

Savonius Rotor: The operation of Savonius rotor depends on the difference of drag force when the wind strikes the concave and convex part of the semi-spherical blades. The flow energy utilization of Savonius rotor is lower than that of Darrieus rotor. Hence this type of turbine is generally not used for high-power applications and usually used for wind velocimetry applications (Islam, Ting and Fartaj 2008). The greatest advantage of a Savonius rotor is its ability to self-start in contrast to other 'Lift type' VAWTs (Mohamed, et al. 2011).Recently, some generators with high torque at low rotational speed, suitable for small-scale wind turbines, have been developed, suggesting that Savonius rotors may yet be used to generate electric power (T. Hayashi, et al. 2004).

Darrieus Rotor: The energy is taken from the wind by a component of the lift force working in the direction of rotation. Lift force is perpendicular to the resultant of two velocity component of wind velocity and relative velocity of airfoil to the shaft. These types of turbines have highest values of efficiency among VAWTs and the tip speed ratio can be much higher resulting in a much higher rpm. But generally suffer from problems of low starting torque and poor building integration.

Combined Savonius and Darrieus Rotor: Since the Darrieus rotor is not self-starting; a blended design with Savonius blade can make the hybrid which can make it starting and more efficient than any of the single rotor.

1.5 Wind Energy Utilization

Wind is the generating electricity currently less than 3.5% of US and barely 4.5% of world electricity consumption. Though the popularity of wind as energy source is increasing rapidly but it will still generate a few portions of US and world electricity requirements by 2030. The scarcity of resources, increasing demand of energy and concern of global climate change is pushing hard to increase the efforts to find viable energy alternatives. Some of the renewable energies may not be achievable or sustainable, some are local and limited. Other than fossil fuel the only hope is solar and wind. To be the significantly larger contributor to generate global electricity, the wind power needed to be more efficient.

According to the World and European Wind Energy Associations, installed global wind capacity reached 197, Giga-watts by the end of 2010, with just over 3,000 MW of that total located offshore. World wind power generation capacity in 2013 was estimated at 318 GW, which is 13% higher than previous year (REN21 2014)

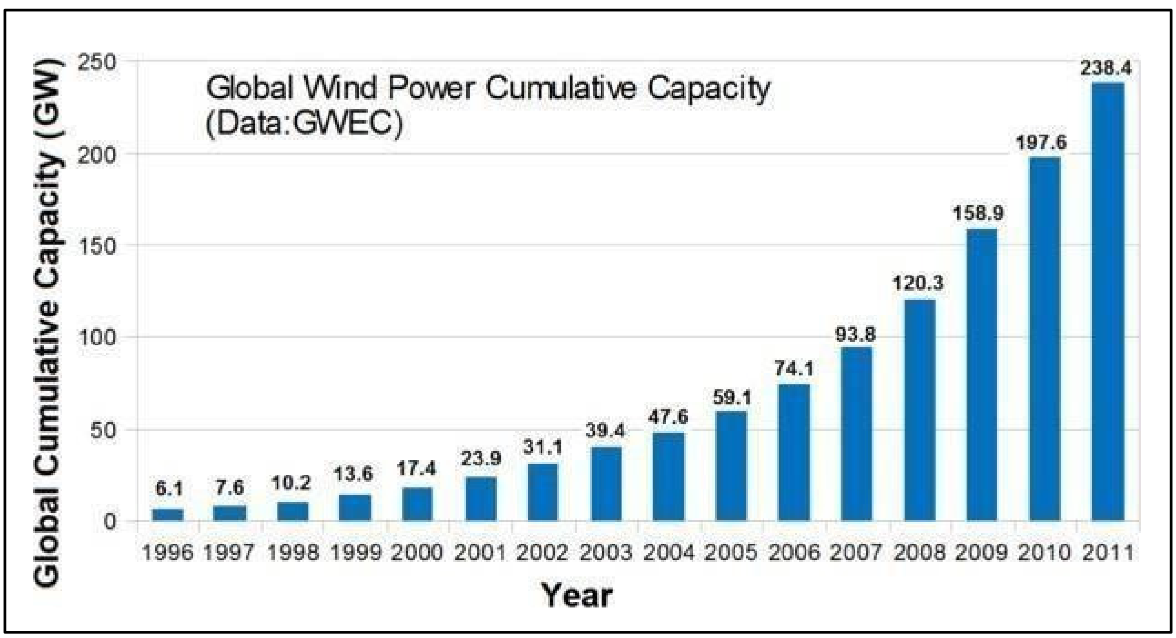


FIGURE 1-3: Global Cumulative Capacity of Wind Energy

Renewable energy sources provided about 12% of total U.S. utility-scale electricity generation in 2013. The largest share of the renewable-generated electricity came from hydroelectric power (30%), followed by biomass (25%) and wind (19%) (Administration 2013). According to U.S. energy reports, US wind power generation capacity in 2005 was 17 GW; it had grown to 167 GW by 2013.

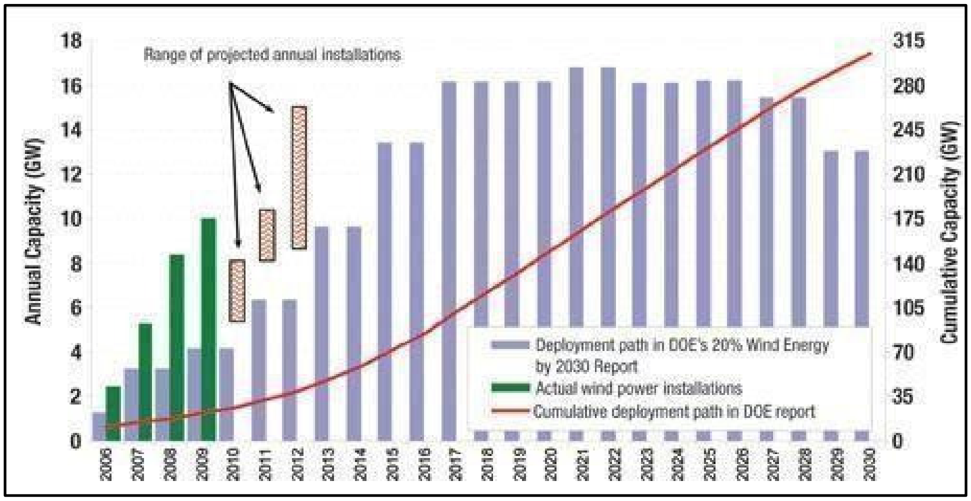


FIGURE 1-4: Projected and Actual Installation of Wind Energy by DOE

China has the highest capacity in wind energy generation, followed by the United States, Germany and Spain.

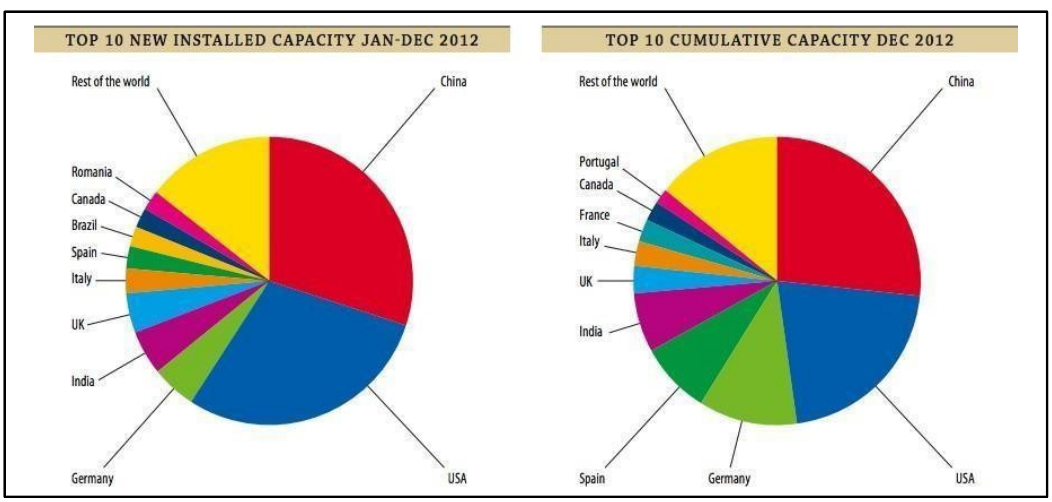


FIGURE 1-5: Wind Energy Generation Capacity by Country

2. LITERATURE REVIEW

2.1 Introduction

Researchers have been conducting lots of experiments on HAWT, because of its high efficiency. In some way, researchers have been trying their best to find the best from Darrieus rotor. Meanwhile, significant numbers of researchers have been working to improve the aerodynamic characteristics of Savonius turbine. These researches are numerical and theoretical prediction for flow around the wind turbines and from that it varies from research laboratories to full scale simulation. The extensive amount of work has been carried to find a sustainable solution of wind energy. Around the globe researchers have been experimenting on HAWT and Darrieus rotor for large scale energy production and Savonius rotor for small scale usage. Based on the conclusion of those experiments, hybrid turbines are also a focus of the researchers. A brief discussion of Numerical analysis and experimental work on VAWT will be discussed in this chapter.

2.2 History of Wind Turbine

2.2.1 The Wind Turbine

Windmills were used in Persia (present-day Iran) as early as 200 B.C. Pumping water had been the role of wind turbine for many centuries. The Netherlands used wind mills for dewatering large areas from the 13th century onwards. The ending of the nineteenth century divided the two development periods; the earlier is known as ancient development period and later as the modern development period. In July 1887, Scottish academic James Blyth installed the first electricity-generating multi bladed HAWT to charge his battery for holiday light in Scotland. (Price 2009). By 1900, there were about 2500 windmills almost produced 30 MW of electricity for mechanical loads such as pumps and mills in Denmark. By 1908 there were 72 wind-driven electric generators from 5 kW to 25 kW and by 1930 wind farms for electricity were common in USA.

2.2.2 Vertical Axis Wind Turbine

From history book, it was found that about 1300 A.D a Syrian cosmographer Al-Dimashqi drew a vertical axis windmill (Shepherd 1990). It was a two storied wall structure with milestones at the top and a rotor at the bottom. It had latter with spooked reel with 6 to 12 upright ribs that covered with cloth. It was found that this type of windmill had been in operation in 1963 which used to produce an estimated 75 hp (at efficiency of 50% at wind speed 30 m/s). Each windmill milled one ton of grain per day (Wulff 1966).

2.2.3 Savonius and Darrieus Type Wind Turbine

The Savonius wind turbine was first used by a Finnish Engineer S. J. Savonius in 1931 (Savonius 1931). The design of his rotor was S-shaped with two semi-circular buckets with small overlap. At that time this rotor was successfully used as an ocean current meter. In 1931, G. J. M. Darrieus in France patented another VAWT named Darrieus vertical axis rotor. This type of rotor was not self-starting.

2.3 Review on Savonius Rotor

The optimum output from the wind energy is the key objective of the investigation and different aerodynamic shapes of the blades are designed to verify the outcome. Numerous investigations had been carried out in the past to study the performance characteristics of

Savonius rotor. These investigations included wind tunnel tests, field experiments and numerical studies. Blade configurations were studied in wind tunnels to evaluate the effect of aspect ratio, number of blades, overlap and gap between blades, effect of adding end extensions, end plates and shielding.

2.3.1 Changing the Overlap Ratio of Blade

The performance of two bladed Savonius turbine with five overlaps of 16.2%, 20%, 25%, 30% & 35% were investigated. Among them 16.2% overlap condition showed maximum power extraction. The pressure drop across the rotor from upstream to downstream as well as, maximum pressure difference across the returning bucket was displayed in the same condition which eventually indicated the better overall aerodynamic torque and power. (Gupta, Das, et al. 2012). Three bladed Savonius rotor with different overlap ratio was taken care for another experiment. Ratio of 0.0, 0.12 and 0.26 had been used for different Reynolds number (Re). The model with no overlap ratio showed better torque coefficient for lower Re, better power coefficient at higher Re and with the increase of tip speed ratio. (K. N. Morshed 2010) (Biswas et al. 2007) conducted the experiment on three bladed Savonius turbine in front of sub-sonic wind tunnel with no overlap and for overlap conditions in the range of 16% to 35%. They found out that, at no overlap condition, maximum power factor is 36% without blockage correction at TSR of 0.50, and 28% with blockage correction at TSR of 0.46. With the increase of overlap ratio, the values of power-coefficient decreased for blockage effects. Power coefficients increased with the increase of overlap ratio up to a certain limit and afterwards start decreasing even the overlap is increased. From this experiment, the maximum power coefficient was found 47% without blockage correction and 38% with blockage correction at 20%

overlap.

2.3.2 Changing the Shape of Blade

(Qasim et al. 2011) worked with impeller scoop-frame type with movable vanes wind turbine VAWT. The objective was to maximize the drag factor by closing the vanes on convex shape and open when air hit the concave part. Due to movement of vanes for and against of wind, a higher drag factor had worked on the impeller scoop-frame type with movable vanes, and had higher efficiency than flat vanes.

(Manzoor et al. 2008) experimented on Savonius rotor to compare the performance of twisted blade. Initially they carried the experiment with two vertical, semi-circular curved blades and then with twisted blade with the angle ranging from 0° to 60°. From the analysis of wind flow over various configurations of the rotor blades they have concluded that, the maximum efficiency of 33.85% had been found at θ=45° compared to 25.6% without twist. This twist increases the positive wetted part in the side projected area which results an increase in the average projected area. At the same twist angle, both the RPM and torque were also obtained higher than without twist.

(Saha et al. 2006) studied the performance of twisted blade. All the tests were carried out in a three-bladed system with a blade aspect ratio of 1.83. The study showed that, a potential of smooth running, higher efficiency and self-starting capability had been there for twisted blades compared to semicircular blades. Comparatively larger twist angle provides maximum power and better starting characteristics at lower wind velocity. The optimum performance is displayed at low airspeeds of 6.5 m/s and twist angle of α =15° in terms of starting acceleration and maximum no load speed.

(Ghatage and Joshi 2012) have done further experiment by changing twist of blade as well as the number of blade. They have studied with both regular blade and twisted blade. The experiment concluded that two blades with twist enhance the efficiency of turbine. In their experiment the two-bladed 30° twisted bladed turbine gave the better power coefficient. It was concluded that the twisted blade attributes relatively higher drag on the turbine surface.

2.3.3 Changing the Stage

(Ghosh, et al. 2009) have experimented Single- and three-stage modified Savonius rotors, which are extensively tested in front of an open jet wind tunnel. With the increase in the Reynolds number both the single- and three-stage rotors shows higher coefficient of power. The three-stage rotor showed positive and uniform coefficient of static torque. Here the number of blade also had some effect. The coefficient of static torque differed with the change of blade number in a three-stage rotor.

(Hayashi et al.2005) experimented a wind tunnel test to improve the starting characteristics of Savonius rotor with and without guided vanes. They have concluded that, the three staged rotor had better torque coefficient than single stage rotor. The guide vanes further increased the torque coefficient.

(Kumbernuss, et al. 2012) studied two-staged Savonius-type turbines with different number of blades, the shape of the blades, the overlap ratio and the phase shift angle. The wind turbines were tested under four different wind speeds of 4m/s, 6m/s, 8m/s and 10m/s. There were three turbines with the overlap ratios of 0, 0.16 and 0.32. Before testing those in an open wind tunnel, the wind turbines were adjusted to the phase shift angles (PSA) of 0, 15, 30, 45 and 60 degrees under different air velocities. The overlap ratio of 0.16 produced the better performance among the three, followed by the 0.32 overlap ratio. At lower air velocities the larger phase shift angles and at higher air velocities smaller phase shift angles will produce better performance of the turbines.

(Saha et al. 2008) conducted a wind tunnel test to assess the aerodynamic performance of Savonius rotor systems with different stages. Both semicircular and twisted blades had been used in each case. Experiments were carried out to optimize the different parameters like number of stages, number of blades (two and three) and geometry of the blade (semicircular and twisted). It was concluded from this experiment that, two-stage rotor showed a better performance characteristics when compared the three-stage rotor. As the number of stages was increased, the inertia of the rotor was found to increase thereby reducing its performance. This was independent on the blade geometry. Two-bladed system gave optimum performance and in a two bladed system, the performance of twisted-bladed rotor was superior to the semicircular-bladed rotor.

2.3.4 Aerodynamic Characteristics

(Diaz et al. 1991) analyzed to find the drag and lift coefficients of a Savonius wind turbine to find the aerodynamic performance. They found that at a tip-speed ratio of $\lambda = 1$ the rotor operated with maximum efficiency, in terms of power coefficient. For either increase or decrease of tip-speed ratio the drag coefficient decreases sharply. They also suggested that, around tip-speed ratio $\lambda = 1$, Savonius rotor operates most efficiently, where there is almost no effect of change of lift force due to the coefficient remains constant at 0.5.

(M. Rahman, K. N. Morshed, et al. 2009) (2010) experimented on the Drag and Torque characteristics of three bladed Savonius Wind Turbine. The turbines with no overlap has better drag and torque characteristics. They also performed Aerodynamic performance analysis on three bladed Savonius wind turbine and concluded that higher reynold number showed better aeorodynamic behavoir for no overlaping blades.

(Carrigan, et al. 2012) had the objective to introduce and demonstrate a fully automated process for optimizing the air foil cross-section of a VAWT. The objective was to maximize the torque while enforcing typical wind turbine design constraints such as tip speed ratio, solidity, and blade profile. This work successfully demonstrated a fully automated process for optimizing the air foil cross-section of a VAWT. As this experiment was not an extensive study, so they had suggested further research and development.

2.4 Review on Darrieus Rotor

Like Savonius, many experiments have been studied to find the optimum performance of Darrieus rotor. These investigations included mostly numerical studies and some are simulated in wind tunnel as well as in field. Aerodynamic characteristics were studied to evaluate the effect of blade shape and angle, material and configurations. Some researchers tried to change the external factors to improve the starting characteristics of Darrieus rotor.

2.4.1 General Findings

(Howell, et al. 2010) experimented on small scale Darrieus rotor. A combined experimental study in wind tunnel and computational study was done to find the aerodynamics and performance. In this experiment they changed wind velocity, tip-speed ratio, solidity and rotor blade surface finish. It was found that, below a critical wind speed (Reynolds number of 30,000) a smooth rotor surface finish degraded the performance of the turbine. The tests also showed that both two and three bladed rotor models had produced highest performance coefficient, but the three bladed models did so at a much reduced Tip Speed Ratio.

Considering errors and uncertainties in both the CFD simulations and the wind tunnel measurements, computational study displayed reasonably good agreement with the experimental measurements. Stronger tip vortices were created at phases with higher amounts of lift present.

(Beri and Yao 2011) studied to show the effect of camber airfoil for a self-starting Darrieus turbine. For this purpose they have used three bladed NACA 2415 camber airfoil and simulated in different tip speed ratio. The experiment results showed that, camber airfoil have the characteristics of self-starter. Though for same power coefficient the efficiency was less than the non-self-starting airfoils.

2.4.2 Changing the Shape of Blade

(Hameed and Afaq 2012) designed a straight symmetrical blade for a small scale Darrieus rotor using beam theories. They changed the design parameters of the blade like solidity, aspect ratio, pressure coefficient etc. for experiment purpose. Then the blade design was analyzed at extreme wind conditions where maximum values of deflection and bending stresses were determined at peak values of aerodynamic and centrifugal forces. It was concluded that keeping the maximum stresses and deflection within acceptable range, the wall thickness of the blade could be optimized by reducing weight of the blade. (Armstrong et al. 2012) investigated the aerodynamics of a high solidity Darrieus rotor through wind tunnel tests limited at Re >500,000 for full size operating turbine. Straight blades and canted blade showed different flow separation behavior. Canted blades experiencing less flow reversal on their upwind pass and recovering attached flow before $\theta = 180^0$. Much less flow separation was noted relative to the straight blades at the same blade speed ratios even for the peak blade ratio $\lambda = 2.1$. Canted blades increased the power and reduced the blade speed ratio at which peak power occurred. The addition of fences, which acted to impede span wise flow on the swept blades, reduced the blade speed ratio at peak power to about $\lambda = 1.9$, presumably with a flow that is more similar to the straight blade case.

2.4.3 Different Other Numerical Investigations

(Castelli, et al. 2013) presented a model for the evaluation of aerodynamic and inertial contributions to a VAWT blade deformation. Solid modeling software, capable of generating the desired blade geometry depending on the design geometric parameters, is linked to a finite volume Computational Fluid Dynamic (CFD) code for the calculation of rotor performance and to a Finite Element Method (FEM) code for the structural design analysis of rotor blades. Flow field characteristics were investigated for a constant unperturbed free-stream wind velocity of 9 m/s, determining the torque coefficient generated from the three blades. The computed inertial contribution to blade deformation resulted quite higher with respect to the aerodynamic one for all the analyzed blade shell thicknesses. Both inertial and aerodynamic displacements resulted higher at blade trailing edge than at leading edge. They suggested for further investigation on the influence of this blade section deformation on the aerodynamic performance.

(Carrigan, et al. 2012) had the objective to introduce and demonstrate a fully automated process for optimizing the airfoil cross-section of a VAWT. The objective was to maximize the torque while enforcing typical wind turbine design constraints such as tip speed ratio, solidity, and blade profile. This work successfully demonstrated a fully automated process

for optimizing the airfoil cross-section of a VAWT. As this experiment was not an extensive study, so they had suggested further research and development.

2.5 Review on Hybrid Rotor

(Wakui, et al. 2005) experimented to find a suitable hybrid configuration of Darrieus lift type and Savonius drag-type rotors for stand-alone wind turbine-generator systems. They experimented with Savonius rotor inside the Darrieus rotor and Savonius rotor outside the Darrieus rotor. The maximum power coefficient points showed that Savonius rotor inside the Darrieus rotor had fine operating behavior to wind speed changes and could be compactly designed because of a shorter rotational axis. This is an effective way for stand-alone small-scale systems. The results of evaluating the net power extraction under field wind conditions confirmed that Savonius rotor outside had been more effective in a small-scale system.

However, under wind conditions involving short blowing duration, Savonius rotor inside had been more effective due to the drop in the effective electric power coefficient. Also the Savonius rotor outside had some starting problem.

(Gupta et al. 2008) has compared one simple Savonius and the other combined Savonius–Darrieus wind rotors. The Savonius rotor was a three-bucket system having provisions for overlap variations. The Savonius–Darrieus rotor was a combination of three-bucket Savonius and three-bladed Darrieus rotors with the Savonius placed on top of the Darrieus rotor. This comparative study showed that, there had been a definite improvement in the power coefficient for the combined Savonius–Darrieus rotor without overlap condition. Combined rotor without overlap condition provided an efficiency of 0.51, which was higher than the efficiency of the Savonius rotor at any overlap positions under the same test conditions.

3. **INTRODUCTION TO ANSYS DESIGN MODELER**

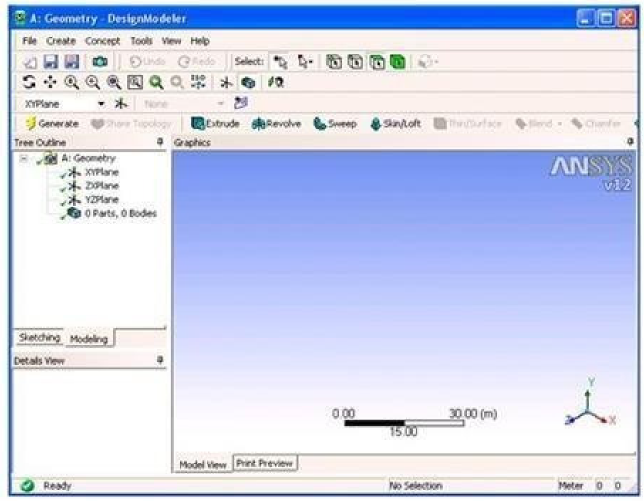
3.1 Introduction to Ansys Design Modeler:

To study Ansys Design Modeler Geometry We will focus on following fundamental areas like Geometry import, Sketch Mode and 3D Geometry

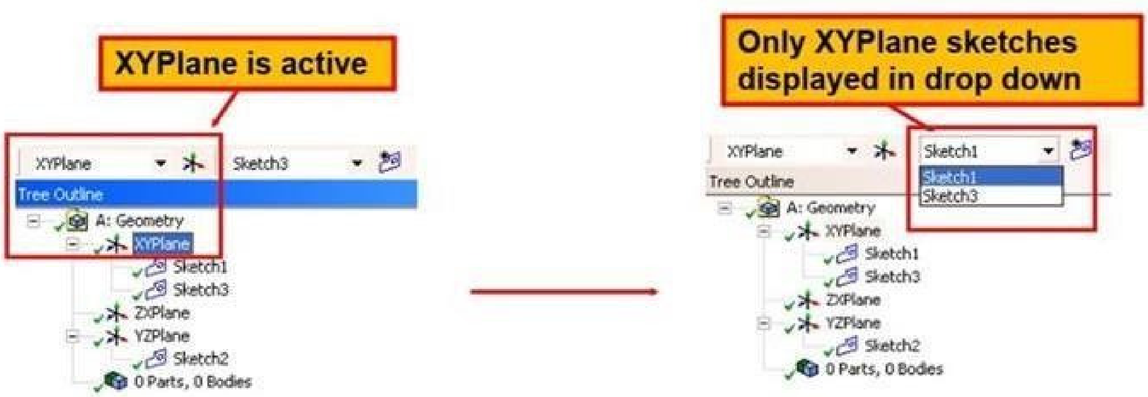
Geometry import is nothing but importing geometry from other programs like Solidworks, Catia etc in STEP or IGS format. Sketch Mode is drawing sketch in 2D as per specifications and Convert them into 3D Models. 3D Geometry derived from Sketch entities such as extrusions, revolves and surface models etc

Length Units: When a new DM session is started a dialog box allows selection of the

Desired length unit can be set as default and units cannot be changed in mid-session.



DM sketches are created on planes. In a new DM session there are three default orthogonal planes in place at the global origin xy, zx and yz. Users may create and position new planes as needed by defining origin. Users can create as many planes as needed. New Sketch creates new one on the active plane. There are placed in Tree beneath their associated plane. Drop down list references sketches on currently active plane.

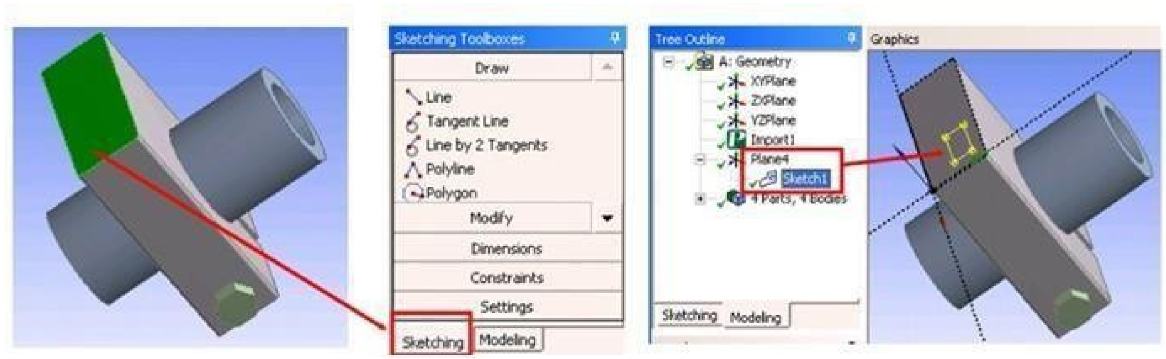


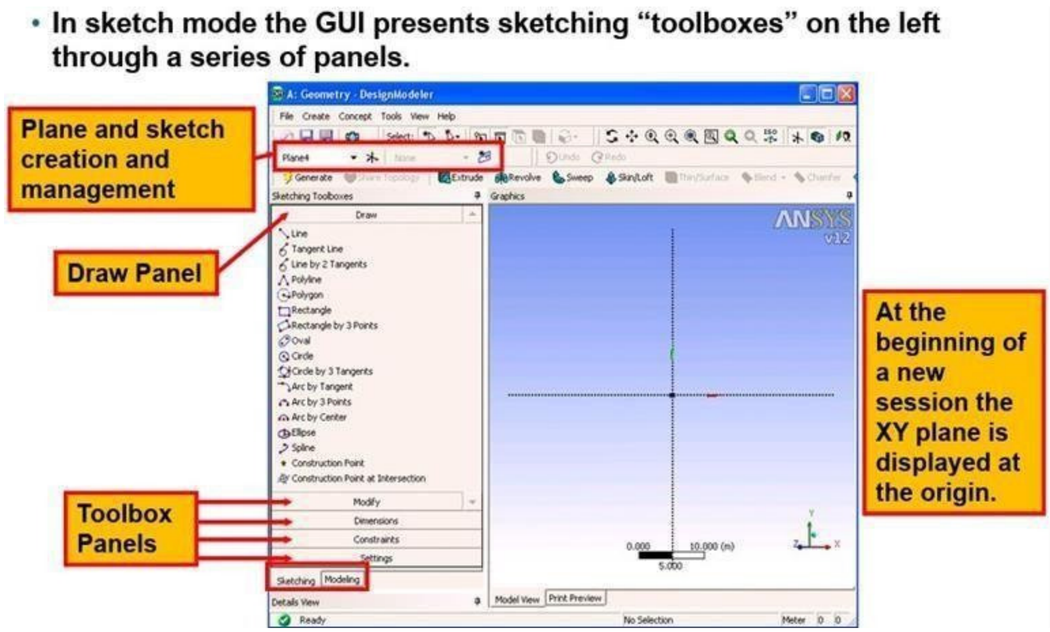
Shortcut to create a new from face plane and sketch using existing geometry:

Highlight desired surface to place new plane

Switch to the sketch tab and begin sketching

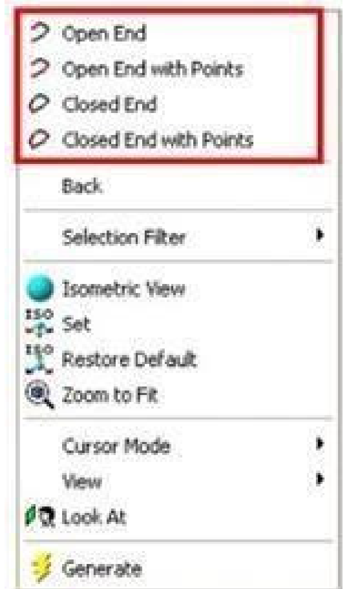
New Plane and sketch are automatically created





By default DM is in auto-constraint mode. Auto constraints allow new sketch entitites to automatically snap to a location or orientation. The cursor indicates the kind of constraint that will be applied.

Once a plane and sketch have been specified you can begin creating new geometry from the draw tool box. Remember some operations will require a right click to complete



Move function allows placement of dimension to be modified. Animate to view dynamic changes applied to the selected dimension. Dimensions can be displayed as the dimension can be displayed as the dimension value and or name.

3D Modelling:

Bodies and parts 3D Features

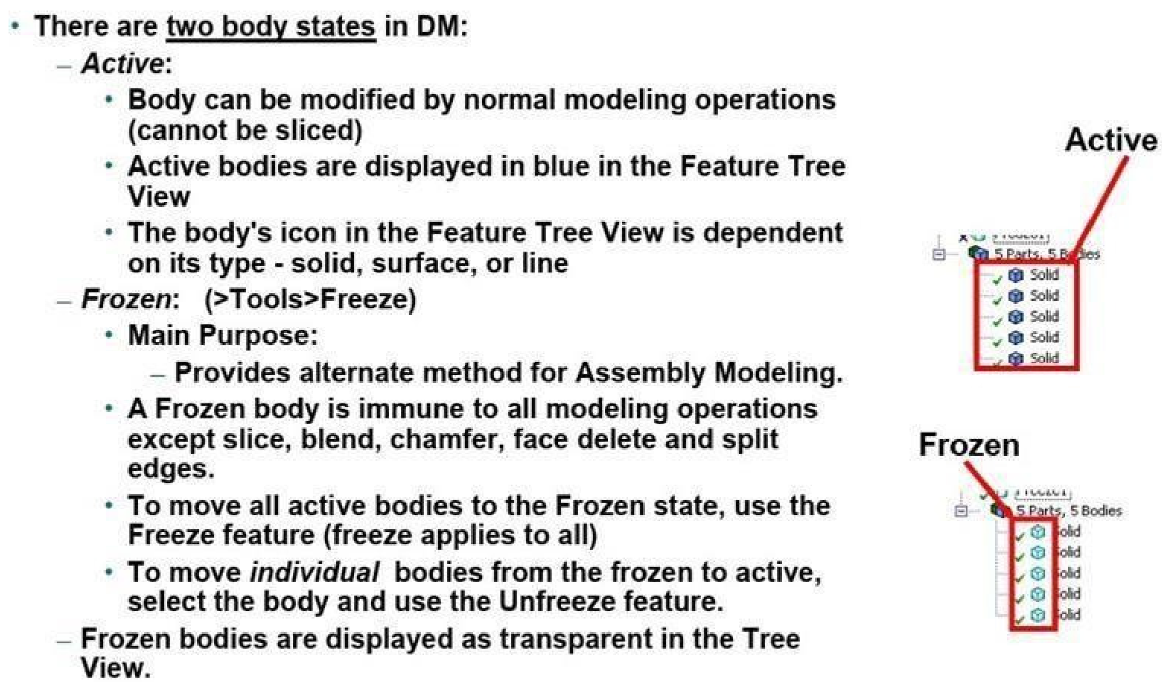
Boolean Operations Feature Direction Feature Type Primitives

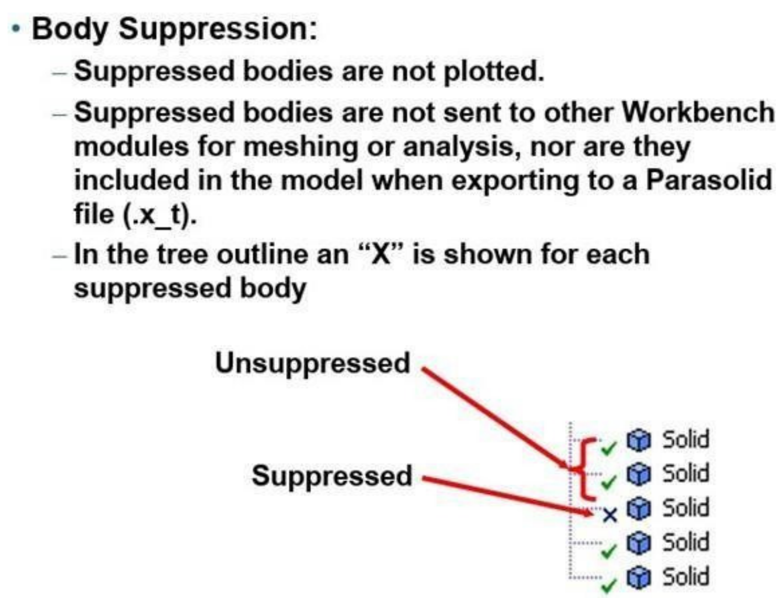
Design Modeler is primarily intended to provide geometry to an analysis environment. For this reason we need to see how DM treats various geometries. Design Modeler contains three different body types like solid body – body has surface area and volume. Surface body-body has surface area but no volume. Line body-body consists entirely of edges, no area, and no volume.

By default, DM places each body into one part by itself. Individual parts will always be meshed separately. If bodies in separate bodies share faces, the meshes on those shared faces will not be matched. Multiple bodies in a single part will have matched meshes on shared faces when meshed.

By default, DM will merge new geometry with existing geometry to maintain a single body. This can be controlled by working with either frozen or active bodies

You can toggle between frozen and active states for using the Freeze and Unfreeze tools.

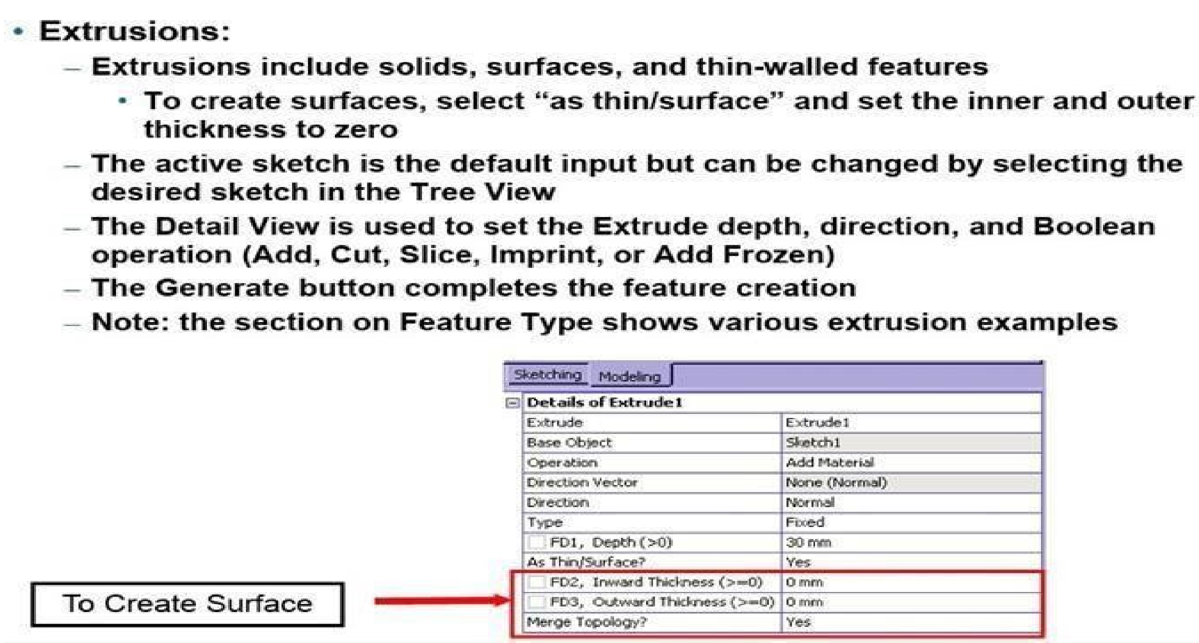




3D Features:

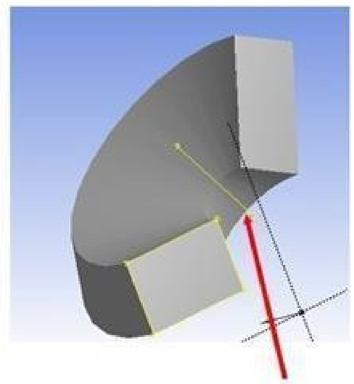
3D features are Extrude, Sweep, Revolve, Skin/Loft, Thin/Surface.

The effect of the feature creation is determined by the type of the feature, the Boolean operations performed as it is created, and the extent of the feature – fixed, to next, through all etc.



REVOLVE:

- **Revolve:**
  - **Active sketch is rotated to create 3D geometry**
  - **Select axis of rotation from details**
    - **If there is a disjoint (free) line in the sketch, it is chosen as the default axis of revolution**
  - **Direction Property for Revolve:**
    - **Normal: Revolves in positive Z direction of base object**
    - **Reversed: Revolves in negative Z direction of base object**
    - **Both - Symmetric: Applies feature in both directions. One set of angles will apply to both directions**
    - **Both - Asymmetric: Applies feature in both directions. Each direction has its own angle property**
  - **The Generate button completes the feature creation**



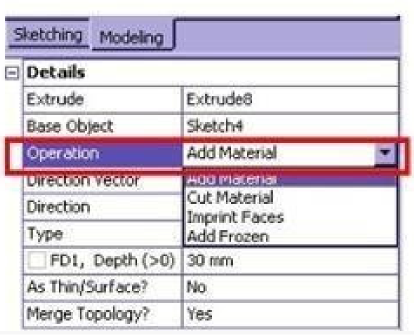
Sketch with Disjoint Line

BOOLEAN OPERATIONS:

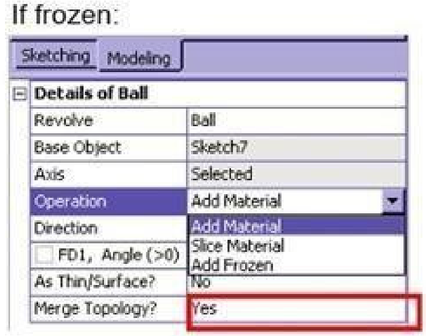
PRIMITIVES:

You can apply five different Boolean operations to 3D features:

- **Add Material : creates material and merges it with the *active* bodies.**
  - **It is always available**
- **Cut Material: removes material from *active* bodies**
- **Slice Material: slices *frozen* bodies into pieces.**
  - **Available only when ALL bodies in the model are frozen**
- **Imprint Faces: Similar to Slice, except that only the faces of the bodies are split, and edges are imprinted if necessary (no new bodies created)**
- **Add Frozen: Similar to Add Material, except that the feature bodies are not merged with the existing model but rather added as *frozen* bodies**
  - **Line bodies are immune to Cut, Imprint, and Slice operations**

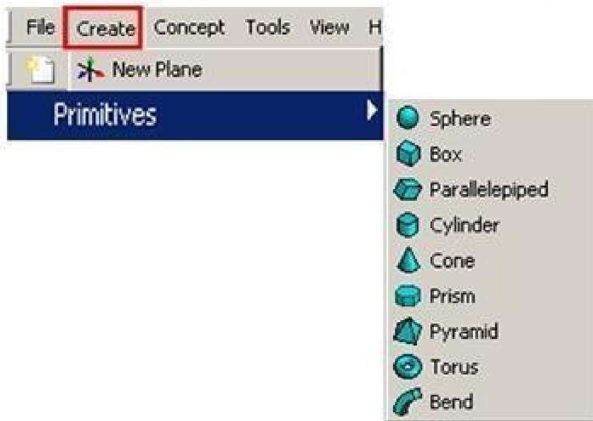


If frozen:

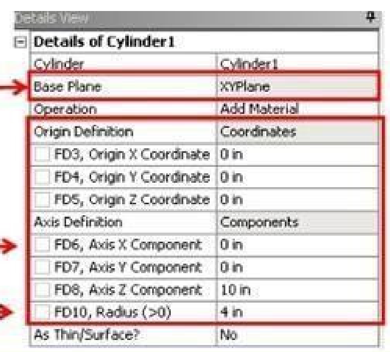


Primitive Shapes: *Create>Primitives*

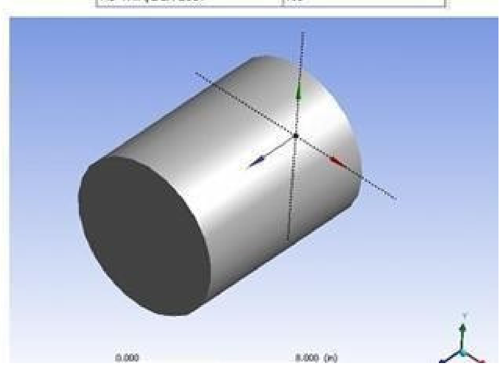
- Quickly create models by defining primitive shapes like spheres, cylinders etc..
- Does not require sketches
- Requires a *Base Plane* and several point and / or direction inputs
- Inputs can be defined by typing in coordinates or by selecting existing geometry.



- **Primitive Shapes Example: Cylinder**
  - Select Base Plane
  - Define Origin
  - Define Axis (also defines the height of the cylinder)
  - Define radius
  - *Generate*



Details of Cylinder1	
Cylinder	Cylinder1
Base Plane	XYPlane
Operation	Add Material
Origin Definition	Coordinates
FD3, Origin X Coordinate	0 in
FD4, Origin Y Coordinate	0 in
FD5, Origin Z Coordinate	0 in
Axis Definition	Components
FD6, Axis X Component	0 in
FD7, Axis Y Component	0 in
FD8, Axis Z Component	10 in
FD10, Radius (>0)	4 in
As Thin/Surface?	No

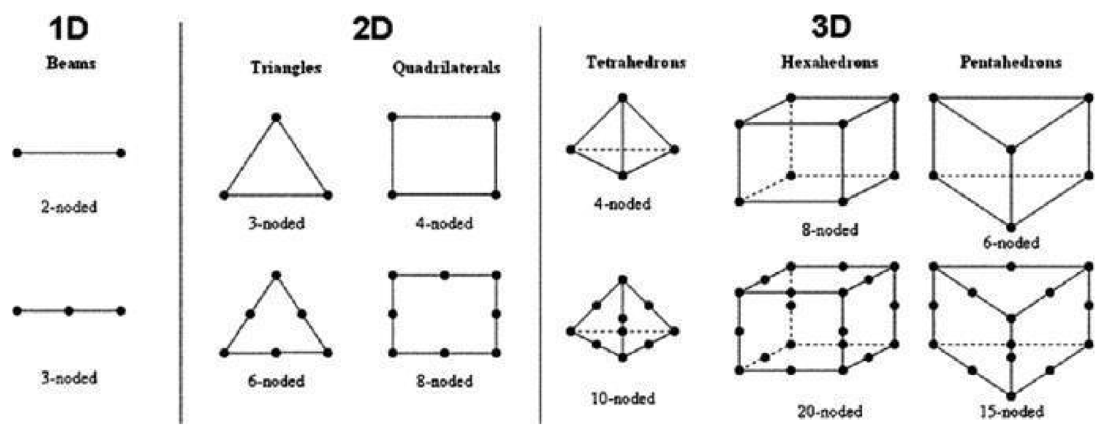


4. INTRODUCTION TO FINITE ELEMENT ANALYSIS

Introduction to Finite Element Analysis:

Finite Element Methods instils the need for comprehensive evaluation and checking when interpreting results. Engineering is at the heart of modern life. Today, engineers use computers and software in the design and manufacture of most products, processes and systems.

Finite element analysis (FEA) is an indispensable software tool in engineering design, and indeed in many other fields of science and technology. The essence of Finite Element Analysis; what is it and why do we carry out FEA?As an example of its use, we will look briefly at the case of finite element analysis



Many FEA programs also are equipped with the capability to use multiple materials within the structure such as:

- Isotropic, identical throughout

- Orthotropic, identical at 90 degrees
- General anisotropic, different throughout

4.2 Types of Engineering Analysis:

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**.**

Vibrational analysis: It is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibrational 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.

Heat Transfer analysis: 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.

Linear and nonlinear structural analysis: To determine the behavior of the structure under specific conditions.

Fatigue analysis: To determine the lifespan of the design.

Results of Finite Element Analysis:

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is far superior to the manufacturing costs which would accrue if each sample was actually built and tested.

In practice, a finite element analysis usually consists of three principal steps:

1. Preprocessing: The user constructs a model of the part to be analysed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical “preprocessor" to assist in this rather tedious chore. Some of these preprocessors can overlay a mesh on a pre-existing CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.

2. Analysis: The dataset prepared by the preprocessor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations

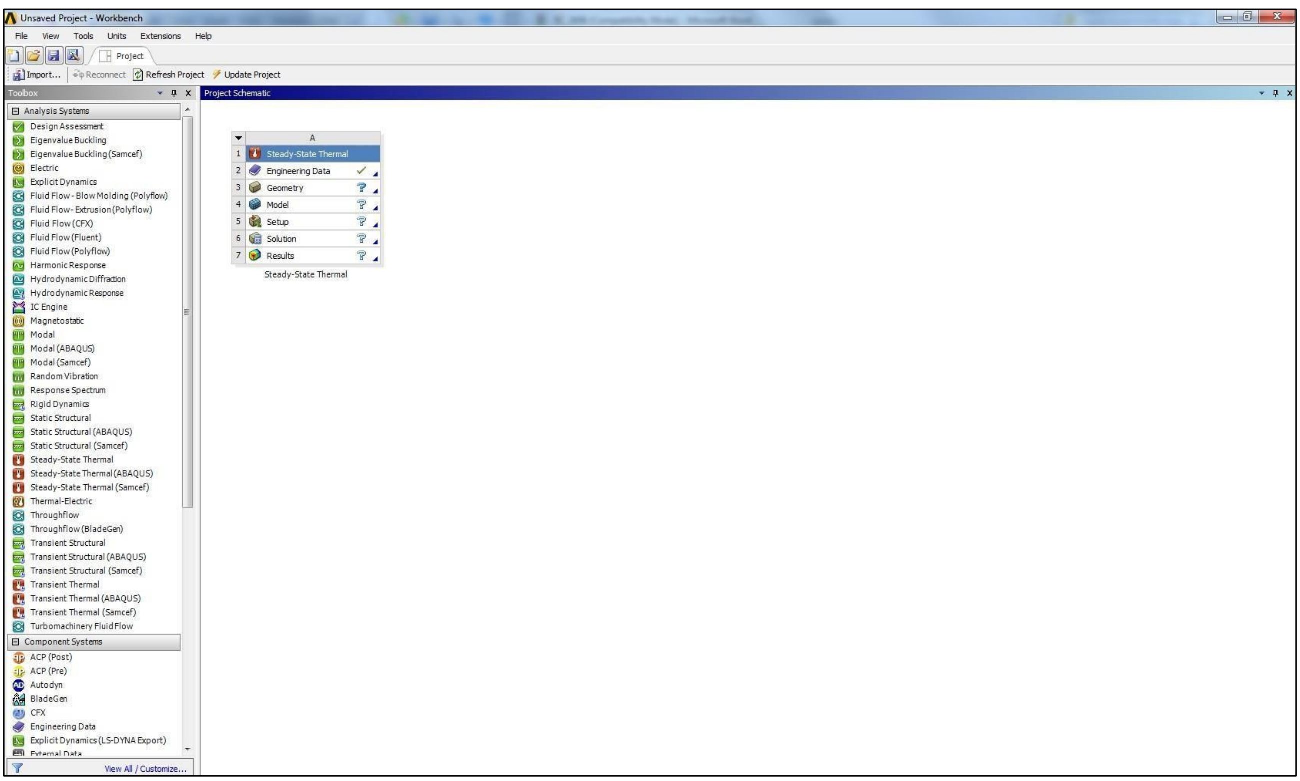
$$Kijuj = fi$$

Where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

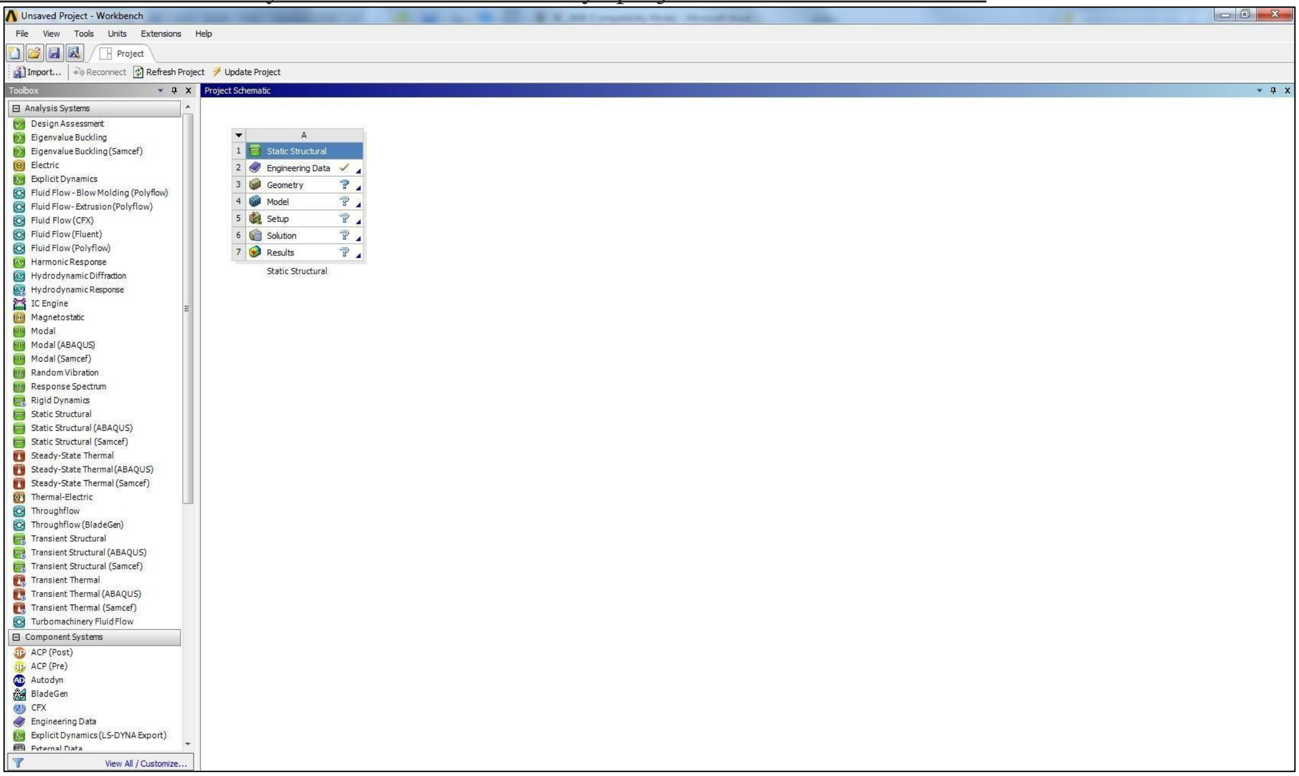
3. Post processing: In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. A typical postprocessor display overlay colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moiré experimental results.

Introduction to the Ansys Workbench Project Schematic:

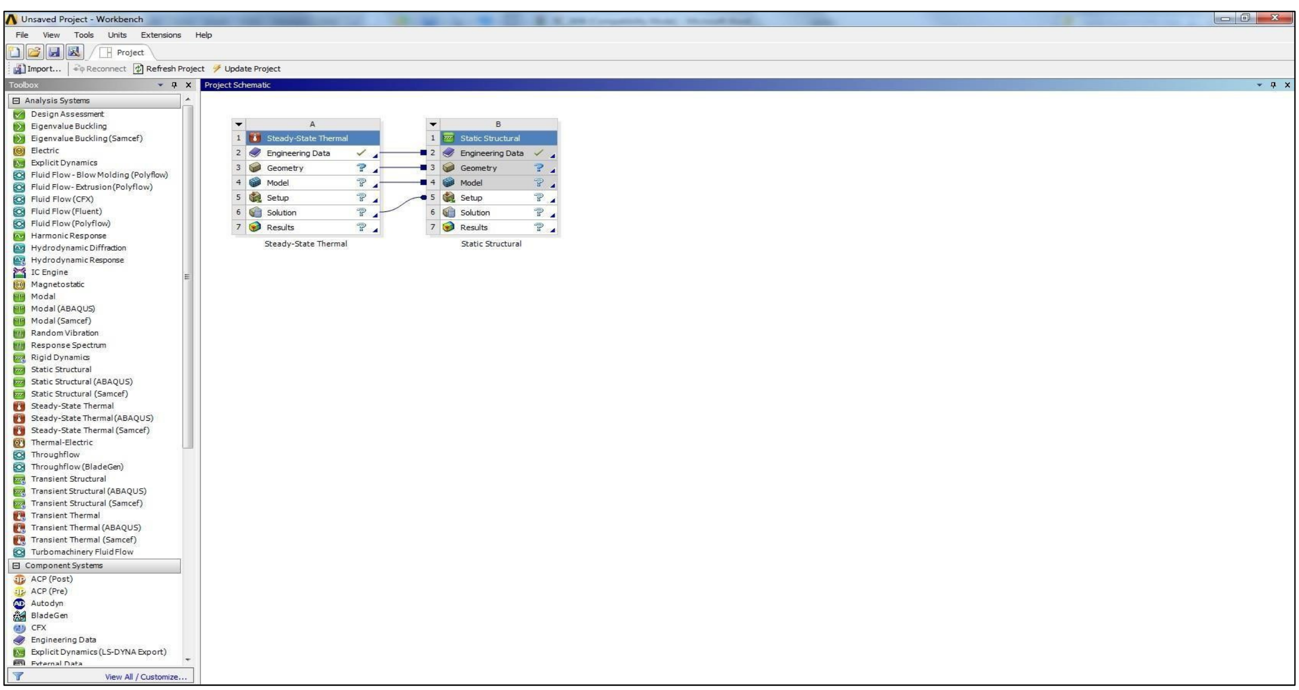
State-state thermal analysis is carried out in Ansys project schematic as follows:



Static Structural analysis is carried out in Ansys project schematic as follows:



Coupled field analysis – Combination of the Steady State thermal analysis and Static Structural Analysis is as follows:



Organization of the ANSYS program:

The ANSYS program is organized into two basic levels:

- Begin level
- Processor (or routine) level

Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When we first enter the program, we at the begin level. At the processor level, several processors are available; each processor is a set of functions that perform a specific analysis task. For example, the general preprocessor (PREP7) is where we build the model, the solution processor (SOLUTION) is where we apply loads and obtain the solution, and the general postprocessor (POST1) is where we evaluate the results and obtain the solution. An additional postprocessor (POST26), enables we to evaluate solutions results at specific points in the model as a function of time.

Material Models:

ANSYS permits a few diverse material models like:

Linear flexible material models (isotropic, orthotropic, and anisotropic).

- Non-direct material models (hyper flexible, multi straight versatile, inelastic and Viscos flexible)
- Heat moves material models (isotropic and orthotropic)
- Temperature subordinate material properties and creep material models.

Loads:

The word stacks in ANSYS phrasing incorporates limit conditions and remotely or inside applied compelling capacities, as represented in Loads. Instances of burdens in various orders are:

Structural: Removals, powers, pressures, temperatures (for warm strain), Gravity.

Thermal: temperatures, heat stream rates, convections. Inner warmth age, limitless surface.

ANALYSIS TYPES:

The accompanying kinds of investigation are conceivable utilizing ANSYS

1.Structural Analysis: Static Analysis

2.Thermal Analysis: Steady state thermal analysis

STATIC ANALYSIS:

A static analysis calculates the effects of study loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading. and response conditions are assumed, i.e., the loads and the structure's responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis include:

- Externally applied forces and pressures.
- Steady state inertial forces.
- Imposed displacement.
- Temperatures.
- Fluencies (for nuclear swelling).

System Configurations:

In the current work, the computational mathematical examination is finished utilizing ANSYS adaptation 16.0 run as standalone or workbench-host application, having 4GB RAM and 1TB hard disk with Windows 11 working framework.

5. RESULTS & DISCUSSIONS

In this Analysis Steady state Structural Analysis and Modal Analysis of the Wind Turbine blades.

Analysis: Structural Analysis of Wind Turbine blades

Material: Aluminum

Material Properties:

Young‟s Modulus (EX): 202000N/mm2

Poisson‟s Ratio (PRXY): 0.292 Density:

0.000007820kg/mm3

Selection of material properties The blade is designed with aluminum with E¼70 GPa, r¼2700 Kg/m3 and n¼0.33.

Comparison of maximum stresses at different values of wall thickness and blade mass

Wall thickness (mm) and mass of the blade (kg)—Left to Right		Max. stress (Mpa) (fixed region)				
		ANSYS		Analytical	% Error with analytical results	
		Solid45	Beam3		Beam3	Solid45
Solid	30.38	113	114	116	1.72	2.59
5	13.37	80.4	69.6	70.5	1.28	14.04
4	10.89	74.9	65.9	66.8	1.35	12.13
3	8.29	70.1	62.9	63.6	1.10	10.22
2	5.62	68.2	61.4	62.1	1.13	9.82
1	2.85	96.4	64.5	65.2	1.07	47.85

Comparison of maximum deflections different values of wall thickness and blade mass.						
Wall thickness (mm) and mass of the blade (kg)— Left to Right		**Max. stress (Mpa) (Cantilever Region)**				
		ANSYS		**Analytical**	**% Error with analytical results**	
		Solid45	**Beam3**		**Beam3**	**Solid45**
Solid	30.38	7.947	7.368	7.39	0.05	7.54
5	13.37	5.123	4.504	4.51	0.13	13.59
4	10.89	4.864	4.264	4.27	0.14	13.91
3	8.29	4.703	4.075	4.07	0.12	15.55
2	5.62	4.689	3.978	3.97	0.20	18.11
1	2.85	5.603	4.178	4.17	0.19	34.36

A. The values of maximum stress and maximum deflections start decreasing from solid cross section to hollow cross section till approximately 2 mm wall thickness but start increasing by reducing the value of wall thickness further.

B. The suitable range of wall thickness can be taken from 1 mm to 5 mm. But the exact value of the most appropriate wall thickness is not known yet for this design.

C. When the cross sections of these blades were modeled and analyzed it was observed that the distortion in the blade shape occurs at the regions of maximum deflections as shown in Fig. 6.1.

D. The values of maximum deflection and stresses are suddenly increased from 2 mm to 1 mm wall thickness. This is due to the large distortion in the shape of the blade as the wall thickness is reduced from 2 mm to further 1 mm. The solid45 element type better approximates the large distortion in the shape of the blade.

E. The distortion in shape reduces with increase in wall thickness of the blade.

F. For the optimal wall thickness of 4 mm, the maximum deflection of 4.58 mm and maximum stress of 70.5 MPa is found. The optimal thickness is found between 3 mm and 4 mm with no distortion in shape of the blade.

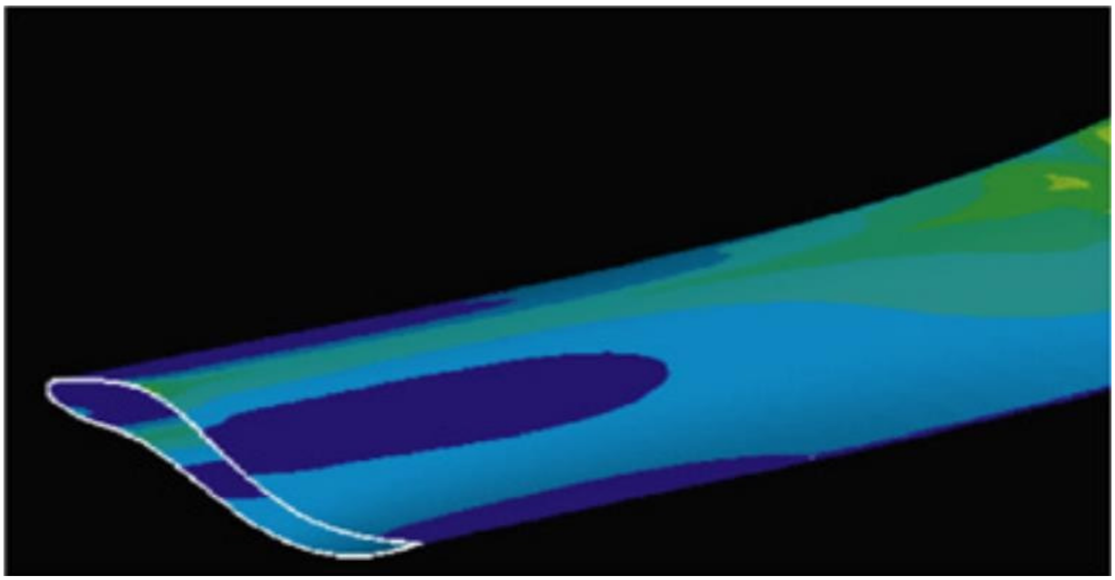


Fig 5.1 1mm Blade

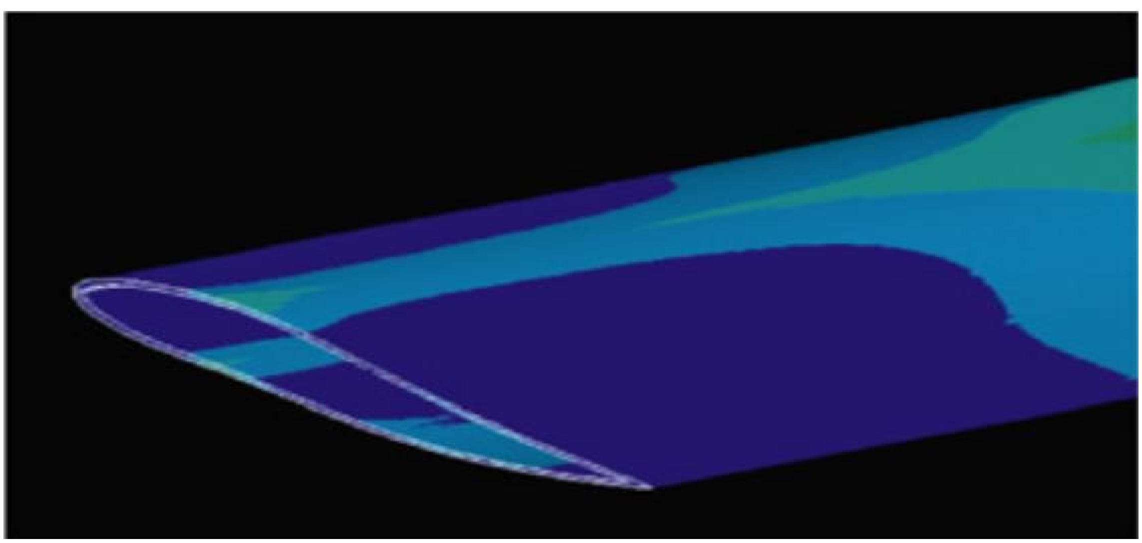


Fig 5.2 2mm Blade

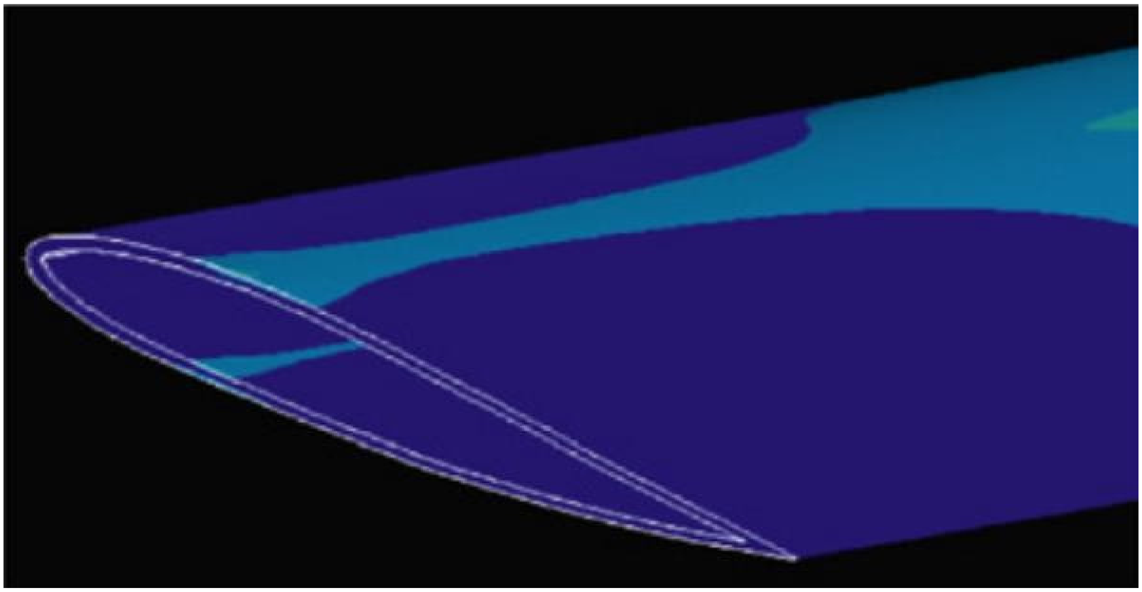


Fig 5.3 3mm Blade

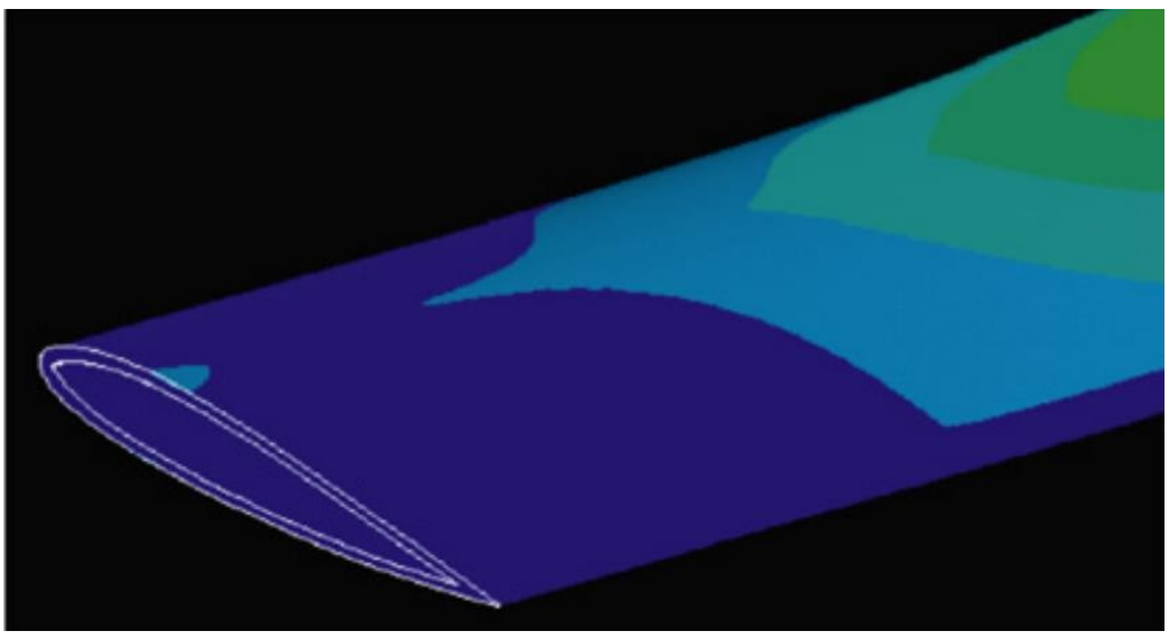


Fig 5.4 4mm Blade

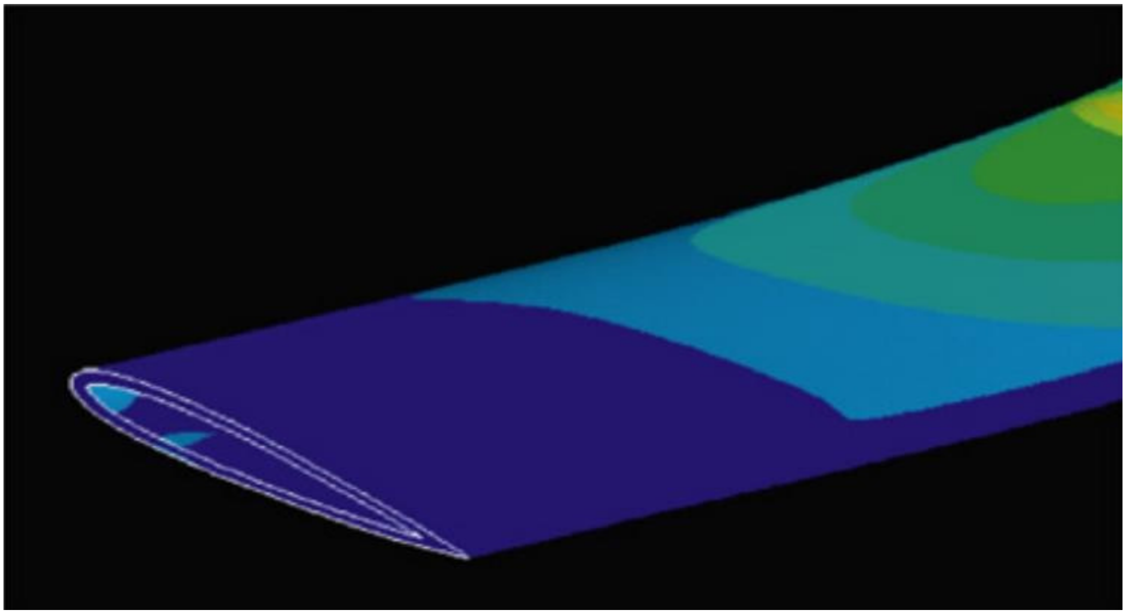


Fig 5.5 5mm Blade

Fig. 6.1. Cross sections of blades designed for different values of wall thickness after application of extreme loads.

6.CONCLUSIONS

It has been seen that in darrieus type vertical axis wind turbine the centrifugal forces play an important role. Bending stresses and deflections are not only a function of aerodynamics forces but also very dominantly controlled by centrifugal forces. Wall thickness of the blade can be optimized by reducing weight of the blade but maximum stresses and maximum deflection should be in acceptable range. Evaluation of their effect is not a simple task as reducing the wall thickness of the blade reduces the weight and subsequently the centrifugal forces but at the same time the cross sectional area reduces too which reduces the strength of the blade. Therefore, the distortion in the shape of the blade must be considered while reducing the weight and centrifugal forces acting on the blade to achieve the best optimized cross section design.

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