Design and Analysis of a Vertical Axis Wind Turbine Blade

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ABSTRACT

One of the most important design parameters for cost-effective VAWT is selection of blade material. VAWT blades must be produced at moderate cost for the resulting energy to be competitive in price and the blade should last during the predicted lifetime (usually between 20 and 30 years). At present, Aluminum blades fabricated by extrusion and bending are the most common type of VAWT materials. The major problem with Aluminum alloy for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decrease quite markedly at increasing numbers of cyclic stress applications. Under this backdrop, an attempt has been made in my project to investigate alternative materials as VAWT blade material.

In my project, required properties of the VAWT Blade Materials are first identified. Then available prospective materials are shortlisted and assessed. Subsequently, comparisons are made between the available materials based on their mechanical properties and costs. Finally, comparisons have been made between the design features of a VAWT with Aluminum and the alternative material blades using one of the prospective airfoils. The results of the design analyses demonstrate the superiority of the alternative blade material over conventionally used Aluminum. Structural and modal analyses have been conducted using advanced finite element methods.

Key words: Vertical Axis Wind Turbines (VAWT), horizontal Axis Wind Turbines (HAWTS)Self-starting, Mild steel turbine

INTRODUCTION
Introduction of Vertical Axis Wind Turbine

Today, the wind energy market is dominated by horizontal axis wind turbines (HAWTS). AWTS tend to work best in more open settings, offshore or on land in rural areas where the wind is not disturbed by buildings or trees. In contrast, vertical axis wind turbines (VAWTS) are more suited for built-up urban areas. They have lower wind start-up speeds, can be located nearer to the ground making maintenance easier, work in any wind direction and are relatively quiet. However, market penetration has been slow due in part to their high cost. In order for VAWTS to become more attractive to consumers and governments; manufacturers will have to make them more affordable, efficient, durable and sustainable.

Vertical axis wind turbine (VAWT) is one of the simplest types of turbo machines which are mechanically uncomplicated. As shown in Figure 1, fixed-pitch VAWT has only three major physical components, namely (a) blade;

(b) supporting strut; and (c) central column. One of the most important design parameters for cost-effective VAWT is selection of blade material. SBVAWT blades must be produced at moderate cost for the resulting energy to be competitive in price and the blade should last during the predicted lift-time (usually between 20 and 30 years).

Though horizontal axis wind turbines (HAWTs) work well in rural settings with steady uni-directional winds, VAWTs have numerous advantages over them. Unlike HAWTs, fixed-pitch VAWTs are mechanically simpler and they do not require additional components (like yaw mechanics, pitch control mechanism, wind-direction sensing device). Furthermore, almost all of the components requiring maintenance are located at the ground level, facilitating the maintenance work appreciably. The maintenance cost is minimal with VAWT in comparison to diesel gensets typically used as a backup or off-grid power source. At present, Aluminium blades fabricated by extrusion and bending are the most common type of VAWT materials. The major problem with Aluminium alloy for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decrease quite markedly at increasing numbers of cyclic stress applications. Under this backdrop, an attempt has been made in this paper to investigate alternative materials as VAWT blade material.

Horizontal versus Vertical Axis Wind Turbines

The HAWT is the most common turbine configuration. The propellers and turbine mechanisms are mounted high above the ground on a huge pedestal. It is a matter of taste as to whether they enhance the landscape. However, there is no denying that the height at which their mechanisms are located is a disadvantage when servicing is required. Also, they require a mechanical yaw system to orient them such that their horizontal axis is perpendicular to and facing the wind. As potential power generation is related to the swept area (diameter) of the rotor, more power requires a larger diameter. The blades experience large thrust and torque forces, so size is limited by blade strength. Figure 1.0 shows GE Wind Energy's 3.6 Megawatt HAWT. Larger wind turbines are more efficient and cost effective.

Figure 1.0. GE Wind Energy's 3.6 Megawatt HAWT.

A VAWT does not need to be oriented into the wind and the power transition mechanisms can be mounted at ground level for easy access. Figure 1.1 shows a picture of an H-Darrius Rotor VAWT.

Figure 1.2. An H-Darrius rotor VAWT.

The perceived disadvantage of the VAWT is that they are not self-starting. However, it could be argued that the HAWT is also not self-starting since it requires a yaw mechanism for orientation. Currently, VAWT are usually rotated automatically until they reach the ratio between blade speed and undisturbed wind speed (Tip Speed Ratio or TSR) that produces a torque large enough to do useful work. Through the use of drag devices and/or variable pitch blade designs, it is hoped that a VAWT will be able to reach the required TSR without the use of a starter.

How Wind Energy is Harnessed

Turbines relying on drag, such as the anemometer and Savonius models, cannot spin faster than the wind blows. Other turbines, rely on lift to produce a positive torque. This is possible because the natural wind is vector summed with the wind opposing the forward velocity of the airfoil. This combined velocity is known as the relative wind.

How Turbines Work

The wind imposes two driving forces on the blades of a turbine; lift and drag. A force is produced when the wind on the leeward side of the airfoil must travel a greater distance than that on the windward side. The wind traveling on the windward side must travel at a greater speed than the wind traveling along the leeward side. This difference in velocity creates a pressure differential. On the leeward side, a low-pressure area is created, pulling the airfoil in that direction. This is known as the Bernoulli's Principle. Lift and drag are the components of this force vector perpendicular to and parallel to the apparent or relative wind, respectively. By increasing the angle of attack, as shown in figure 1.2, the distance

that the leeward air travels is increased. This increases the velocity of the leeward air and subsequently the lift.

Required Properties of the Blade Materials

VAWT blades are exposed to diversified load conditions and dynamic stresses are considerably more severe than many mechanical applications. Based on the operational parameters and the surrounding conditions of a typical VAWT for delivering electrical or mechanical energy, the following properties of the VAWT blade materials are required:

- It should have adequately high yield strength for longer life
- It must endure a very large number of fatigue cycles during their service lifetime to reduce material degradation
- It should have high material stiffness to maintain optimal aerodynamic performance
- It should have low density for reduced amount of gravity and normal force component
- It should be corrosion resistant
- It should be suitable for cheaper fabrication methods
- It must be efficiently manufactured into their final form and
- It should provide a long-term mechanical performance per unit cost

Among all these requirements, fatigue is the major problem facing both HAWTs and VAWTs and an operating turbine is exposed to many alternating stress cycles and can easily be exposed to more than 108 cycles during a 30 year life time. The sources of alternating stresses are due to the dynamics of the wind turbine structure itself as well as periodic variations of input forces.

Prospective Materials

The smaller wind turbine blades are usually made of aluminum, or laminated wood. Metals were initially a popular material because they yield a low-cost blade and can be manufactured with a high degree of reliability, however most metallic blades (like steel) proved to be relatively heavy which limits their application in commercial turbines. In the past, laminated wood was also tried on early machines in 1977. At present, the most popular materials for design of different types of wind turbines are aluminum and fiberglass composites that are briefly discussed below:

Aluminum:

Aluminum blades fabricated by extrusion and bending are the most common type of VAWT materials. The early blades of Darrieus type VAWTs were made from stretches and formed steel sheets or from helicopter like combinations of aluminum alloy extrusions and fiberglass. It has been reported by Parashivoiu that the former were difficult to shape into smooth airfoil, while the latter were expensive. The major problem that aluminum alloy for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decreases quite markedly at increasing numbers of cyclic stress applications when compared to other materials such as steel, wood or fiberglass reinforced plastics.

Fibreglass Composites:

Composites constructed with fibreglass reinforcements are currently the blade materials of choice for wind turbine blades of HAWT types. This class of materials is called fibreglass composites or fibre reinforced plastics (FRP). In turbine designs they are usually composed of E-glass in a polyester, vinyl ester or epoxy matrix and blades are typically produced using hand-layup techniques. Recent advances in resin transfer moulding and pultrusion technology have provided the blade manufacturers to examine new procedures for increasing the quality of the final product and reducing manufacturing costs. The characteristics that make composites, especially glass fiber-reinforced and wood/epoxy composites, suitable for wind turbine blades are:

- low density
- good mechanical properties
- excellent corrosion resistance
- tailorability of material properties and
- versatility of fabrication methods.
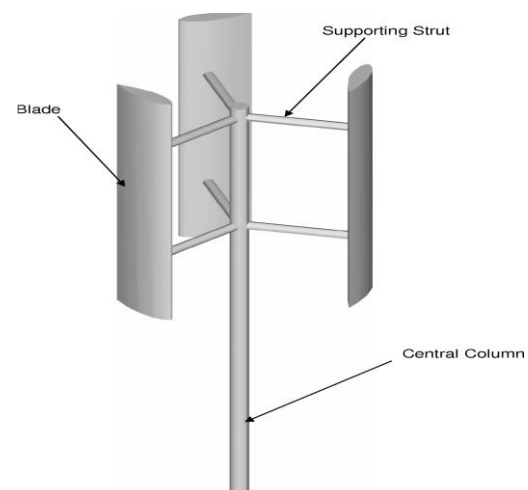
The Main Components of a Typical VAWT

1.6 INTRODUCTION TO UNI-GRAPHICS

Overview of Solid Modeling

The Unigraphics NX Modeling application provides a solid modeling system to enable rapid conceptual design. Engineers can incorporate their requirements and design restrictions by defining mathematical relationships between different parts of the design.

Design engineers can quickly perform conceptual and detailed designs using the Modeling feature and constraint based solid modeler. They can create and edit complex, realistic, solid models

interactively, and with far less effort than more traditional wire frame and solid based systems. Feature Based solid modeling and editing capabilities allow designers to change and update solid bodies by directly editing the dimensions of a solid feature and/or by using other geometric editing and construction techniques.

Advantages of Solid Modeling

Solid Modeling raises the level of expression so that designs can be defined in terms of engineering features, rather than lower-level CAD geometry. Features are parametrically defined for dimension-driven editing based on size and position.

Features

- Powerful built-in engineering-oriented form features-slots, holes, pads, bosses, pockets-capture design intent and increase productivity
- Patterns of feature instances-rectangular and circular arrays-with displacement of individual features; all features in the pattern are associated with the master feature

Blending and Chamfering

- zero radius
- Ability to chamfer any edge
- Cliff-edge blends for designs that cannot accommodate complete blend radius but still require blends

Advanced Modeling Operations

- Profiles can be swept, extruded or revolved to form solids
- Extremely powerful hollow body command turns solids into thin-walled designs in seconds; inner wall topology will differ from the outer wall, if necessary
- Fixed and variable radius blends may overlap surrounding faces and extend to a Tapering for modeling manufactured near-net shape parts

- User-defined features for common design elements (Unigraphics NX/User-Defined Features is required to define them in advance

General Operation

- **Start with a Sketch**

  Use the Sketcher to freehand a sketch, and dimension an "outline" of Curves. You can then sweep the sketch using Extruded Body or Revolved Body to create a solid or sheet body. You can later refine the sketch to precisely represent the object of interest by editing the dimensions and by creating relationships between geometric objects. Editing a dimension of the sketch not only modifies the geometry of the sketch, but also the body created from the sketch.

- **Creating and Editing Features**

  Feature Modeling lets you create features such as holes, slots and grooves on a model. You can then directly edit the dimensions of the feature and locate the feature by dimensions. For example, a Hole is defined by its diameter and length. You can directly edit all of these parameters by entering new values. You can create solid bodies of any desired design that can later be defined as a form feature using User Defined Features. This lets you create your own custom library of form features.

- **Associatively**

  Associatively is a term that is used to indicate geometric relationships between individual portions of a model. These relationships are established as the designer uses various functions for model creation. In an associative model, constraints and relationships are captured automatically as the model is developed.For example, in an associative model, a through hole is associated with the faces that the hole penetrates. If the model is later changed so that one or both of those faces moves, the hole updates automatically due to its association with

the faces. See Introduction to Feature Modeling for additional details.

- **Positioning a Feature**

Within Modeling, you can position a feature relative to the geometry on your model using Positioning Methods, where you position dimensions. The feature is then associated with that geometry and will maintain those associations whenever you edit the model. You can also edit the position of the feature by changing the values of the positioning dimensions.

- **Reference Features**

You can create reference features, such as Datum Planes, Datum Axes and Datum CSYS, which you can use as reference geometry when needed, or as construction devices for other features. Any feature created using a reference feature is associated to that reference feature and retains that association during edits to the model. You can use a datum plane as a reference plane in constructing sketches, creating features, and positioning features. You can use a datum axis to create datum planes, to place items concentrically, or to create radial patterns.

- **Expressions**

The Expressions tool lets you incorporate your requirements and design restrictions by defining mathematical relationships between different parts of the design. For example, you can define the height of a boss as three times its diameter, so that when the diameter changes, the height changes also.

- **Boolean Operations**

Modeling provides the following Boolean Operations: Unite, Subtract, and Intersect. Unite combines bodies, for example, uniting two rectangular blocks to form a T-shaped solid body. Subtract removes one body from another, for example, removing a cylinder from a block to form a hole. Intersect creates a solid body from material shared by two solid bodies. These operations can also be used with free form features called sheets.

- **Undo**

You can return a design to a previous state any number of times using the Undo function. You do not have to take a great deal of time making sure each operation is absolutely correct, because a mistake can be easily undone. This freedom to easily change the model lets you cease worrying about getting it wrong, and frees you to explore more possibilities to get it right.

- **Additional Capabilities**

Other Unigraphics NX applications can operate directly on solid objects created within Modeling without any translation of the solid body. For example, you can perform drafting, engineering analysis, and NC machining functions by accessing the appropriate application. Using Modeling, you can design a complete, unambiguous, three dimensional model to describe an object. You can extract a wide range of physical properties from the solid bodies, including mass properties. Shading and hidden line capabilities help you visualize complex assemblies. You can identify interferences automatically, eliminating the need to attempt to do so manually. Hidden edge views can later be generated and placed on drawings. Fully associative dimensioned drawings can be created from solid models using the appropriate options of the Drafting application. If the solid model is edited later, the drawing and dimensions are updated automatically.

- **Parent/Child Relationships**

If a feature depends on another object for its existence, it is a *child* or *dependent* of that object. The object, in turn, is a *parent* of its child feature. For example, if a HOLLOW (1) is created in a BLOCK (0), the block is the parent and the hollow is its child. A parent can have more

than one child, and a child can have more than one parent. A feature that is a child can also be a parent of other features. To see all of the parent-child relationships between the features in your work part, open the Part Navigator.

Creating A Solid Model

Modeling provides the design engineer with intuitive and comfortable modeling techniques such as sketching, feature based modeling, and dimension driven editing. An excellent way to begin a design concept is with a sketch. When you use a sketch, a rough idea of the part becomes represented and constrained, based on the fit and function requirements of your design. In this way, your design intent is captured. This ensures that when the design is passed down to the next level of engineering, the basic requirements are not lost when the design is edited.

The strategy you use to create and edit your model to form the desired object depends on the form and complexity of the object. You will likely use several different methods during a work session. The next several figures illustrate one example of the design process, starting with a sketch and ending with a finished model. First, you can create a sketch "outline" of curves. Then you can sweep or rotate these curves to create a complex portion of your design.

Introduction to Drafting

The Drafting application is designed to allow you to create and maintain a variety of drawings made from models generated from within the Modeling application. Drawings created in the Drafting application are fully associative to the model. Any changes made to the model are automatically reflected in the drawing. This associativity allows you to make as many model changes as you wish. Besides the powerful associativity functionality, Drafting contains many other useful features including the following:

- An intuitive, easy to use, graphical user interface. This allows you to create drawings quickly and easily.
- A drawing board paradigm in which you work "on a drawing." This approach is similar to the way a drafter would work on a drawing board. This method greatly increases productivity.
- Support of new assembly architecture and concurrent engineering. This allows the drafter to make drawings at the same time as the designer works on the model.
- The capability to create fully associative cross-sectional views with automatic hidden line rendering and crosshatching.
- Automatic orthographic view alignment. This allows you to quickly place views on a drawing, without having to consider their alignment.
- Automatic hidden line rendering of drawing views.
- The ability to edit most drafting objects (e.g., dimensions, symbols, etc.) from the graphics window. This allows you to create drafting objects and make changes to them immediately.
- On-screen feedback during the drafting process to reduce rework and editing.
- User controls for drawing updates, which enhance user productivity.

Finally, you can add form features, such as chamfers, holes, slots, or even user defined features to complete the object.

- **Updating Models**

A model can be updated either automatically or manually. Automatic updates are performed only on those features affected by an appropriate change (an edit operation or the creation of certain types of features). If you wish, you can delay the automatic update for edit

operations by using the Delayed Update option. You can manually trigger an update of the entire model. You might, for example, want to use a net null update to check whether an existing model will successfully update in a new version of Unigraphics NX before you put a lot of additional work into modifying the model. (A net null update mechanism forces a complete update of a model, without changing it.)

The manual methods include:

- The Unigraphics NX Open C and C++ Runtime function, UF_MODL_update_all_features, which logs all the features in the current work part to the Unigraphics NX update list, and then performs an update. See the *Unigraphics NX Open C and C++ Runtime Reference Help* for more information.

- The Playback option on the Edit Feature dialog, which recreates the model, starting at its first feature. You can step through the model as it is created one feature at a time, move forward or backward to any feature, or trigger an update that continues until a failure occurs or the model is complete.

The Edit during Update dialog, which appears when you choose Playback, also includes options for analyzing and editing features of the model as it is recreated (especially useful for fixing problems that caused update failures).Methods that users have tried in the past that has led to some problems or is tricky to use:

- One method uses the Edit Feature dialog to change the value of a parameter in each root feature of a part, and then change it back before leaving the Edit Feature dialog. This method produces a genuine net null update if used correctly, but you should ensure that you changed a parameter in every root feature (and that you returned all the parameters to their original values) before you trigger the update.

- Another method, attempting to suppress all of the features in a part and then unsuppressed them, can cause updates that are not net null and that will fail.The failures occur because not all features are suppressible; they are left in the model when you try to suppress all features. As the update advances, when it reaches the point where most features were suppressed, it will try to update the features that remain (this is like updating a modified version of the model). Some of the "modifications" may cause the remaining features to fail. For these reasons, we highly recommend that you do not attempt to update models by suppressing all or unsurprising all features. Use the other options described here, instead.

ASSEMBLIES CONCEPTS
Components

Assembly part files point to geometry and features in the subordinate parts rather than creating duplicate copies of those objects at each level in the assembly. This technique not only minimizes the size of assembly parts files, but also provides high levels of associativity. For example, modifying the geometry of one component causes all assemblies that use that component in the session to automatically reflect that change. Some properties, such as translucency and partial shading (on the Edit Object Display dialog), can be changed directly on a selected component. Other properties are changed on selected solids or geometry within a component. Within an assembly, a particular part may be used in many places. Each usage is referred to as a *component* and the file containing the actual geometry for the component is called the *component part* .

- **Top-down or Bottom-up Modeling**
You are not limited to any one particular approach to building the

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assembly. You can create individual models in isolation, then later add them to assemblies (bottom-up), or you can create them directly at the assembly level (top-down). For example, you can initially work in a top-down fashion, then switch back and forth between bottom-up and top-down modeling.

- **Design in Context**

When the displayed part is an assembly, it is possible to change the *work part* to any of the components within that assembly (except for unloaded parts and parts of different units). Geometry features, and components can then be added to or edited within the work part. Geometry outside of the work part can be referenced in many modeling operations. For example, control points on geometry outside of the work part can be used to position a feature within the work part. When an object is designed in context, it is added to the reference set used to represent the work part.

- **Associativity Maintained**

Geometric changes made at any level within an assembly result in the update of associated data at all other levels of affected assemblies. An edit to an individual piece part causes all assembly drawings that use that part to be updated appropriately. Conversely, an edit made to a component in the context of an assembly results in the update of drawings and other associated objects (such as tool paths) within the component part. See the next two figures for examples of top-down and bottom-up updates.

- **Mating Conditions**

Mating conditions let you position components in an assembly. This mating is accomplished by specifying constraint relationships between two components in the assembly. For example, you can specify that a cylindrical face on one component is to be coaxial with a conical face on another component. You can use combinations of different constraints to completely specify a component's position in the assembly. The system considers one of the components as fixed in a constant location, then calculates a position for the other component which satisfies the specified constraints. The relationship between the two components is associative. If you move the fixed component's location, the component that is mated to it also moves when you update. For example, if you mate a bolt to a hole, if the hole is moved, the bolt moves with it.

- **Using Reference Sets to Reduce the Graphic Display**

Large, complex assemblies can be simplified graphically by filtering the amount of data that is used to represent a given component or subassembly by using reference sets. Reference sets can be used to drastically reduce (or even totally eliminate) the graphical representation of portions of the assembly without modifying the actual assembly structure or underlying geometric models. Each component can use a different reference set, thus allowing different representations of the same part within a single assembly. The figure below shows an example of a bushing component used twice in an assembly, each displayed with a different reference set.

When you open an assembly, it is automatically updated to reflect the latest versions of all components it uses. Load Options lets you control the extent to which changes made by other users affect your assemblies. Drawings of assemblies are created in much the same way as piece part drawings. You can attach dimensions, ID symbols and other drafting objects to component geometry. A *parts list* is a table summarizing the quantities and attributes of components used in the current assembly. You can add a parts list to the

assembly drawing along with associated callout symbols, all of which are updated as the assembly structure is modified. See the following figure.

- **Machining of Assemblies**

Assembly parts may be machined using the Manufacturing applications. An assembly can be created containing all of the setup, such as fixtures, necessary to machine a particular part. This approach has several advantages over traditional methods:

- It avoids having to merge the fixture geometry into the part to be machined.
- It lets the NC programmer generate fully associative tool paths for models for which the programmer may not have write access privilege.

It enables multiple NC programmers to develop NC data in separate files simultaneously

LITERATURE REVIEW

J. Cotrell: had published on "The Mechanical Design, Analysis, and Testing of a Two-Bladed Wind Turbine Hub". Researchers at the National Wind Technology Center (NWTC) in Golden, Colorado, began performing the Unsteady Aerodynamics Experiment in 1993 to better understand the unsteady aerodynamics and structural responses of horizontal-axis wind turbines. The experiment consists of an extensively instrumented, downwind, three-bladed, 20-kilowatt wind turbine. In May 1995, I received a request from the NWTC to design a two-bladed hub for the experiment. For my thesis, I present the results of the mechanical design, analysis, and testing of the hub. The hub I designed is unique because it runs in rigid, teetering, or independent blade-flapping modes. In addition, the design is unusual because it uses two servomotors to pitch the blades independently. These features are used to investigate new load reduction, noise

reduction, blade pitch optimization, and yaw control techniques for two-bladed turbines.

Joel Crawmer, Edward Miller, and Eros Linarez: Written on "The Development and Analysis of a Wind Turbine Blade". The goal of this project was to structurally analyze a smaller wind turbine blade that could potentially be used in a residential setting. The proposed blade is similar in shape to the commercial blades, but it is only 1.5 meters long as opposed to the daunting 40 meter length of larger blades. The analysis was simplified by modeling a solid aluminum blade instead of a hollow carbon fiber blade, which is commonly used. Multiple loading conditions including, a concentrated a small point load, a concentrated a large point load, a frequency analysis, and a distributed wind load, were modeled using Abaqus. The results show that a solid aluminum blade will undergo elastic deformation at small point loads with almost all of the deformation near the tip of the blade. At larger loads, the aluminum blade will plastically deform in a similar manner as the small point load condition. However, the deformation from the larger load was much worse and rendered the blade inoperable. The frequency analysis showed that the two natural frequencies of the blade were 55.47 Hz and 94.6 Hz. These natural frequencies are high and would never be excited by normal wind gusts, but it is important for engineers to know the natural frequencies of the blade design they plan to use. Lastly, the distributed wind load will cause the blade to elastically deform in a different manner than the point loads. When the wind force is distributed along the length of the blade, the maximum force actually occurs near the end face of the blade, where it will be fixed to the hub. The distributed load is perhaps the most accurate model the team

conducted and it shows that blades should be designed to handle large loads near the bottom of the blade.

James H. Sexton: Had worked out on "Wind Turbine Design, Performance, And Economic Analysis". This paper is an investigation of the economic feasibility of small scale (1 to 70 kw) wind energy conversion systems (WECS). It can be shown that the wind system productivity and therefore the relative cost of the product which it produces is completely dependent on the wind regime under consideration. The mean wind speed, standard deviation, and wind profile are the most significant parameters to be used in the investigation of cost of product from a wind system. The purpose of this work is not to find an optimum wind system, but to give the reader enough information to make an informed decision as to whether or not a wind system configuration could meet the particular need under consideration; the wind system appropriate to a residential home owner is quite different from that for a dairy farmer.

PROBLEM DEFINITION AND METHODOLOGY

VAWT blades are exposed to diversified load conditions and dynamic stresses are considerably more severe than many mechanical applications. Based on the operational parameters and the surrounding conditions of a typical VAWT for delivering electrical or mechanical energy, the selection of proper materials for the VAWT blade materials are required. If proper material not choose, it causes to failure.

METHODOLOGY
➤ Design the vertical axis turbine blade by using Unigraphics software based on 2D dimensions.

➤ Export .prt file into parasolid (.xt) file and import into Ansys software for analysis.
➤ Perform static analysis of VATB blade by using Aluminium material to calculate deformation and stresses.
➤ Perform modal analysis of VATB blade by using Aluminium material to calculate natural frequency.
➤ Perform static analysis of VATB blade by using E-GLASS/EPOXY material to calculate deformation and stresses.
➤ Perform modal analysis of VATB blade by using E-GLASS/EPOXY material to calculate natural frequency.
➤ From analysis results, best material proposed for VATB blade.

3D MODELING OF VERTICAL AXIS WIND TURBINE BLADE PROCEDURE
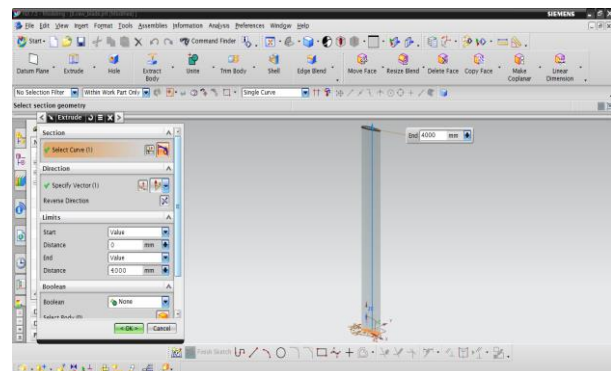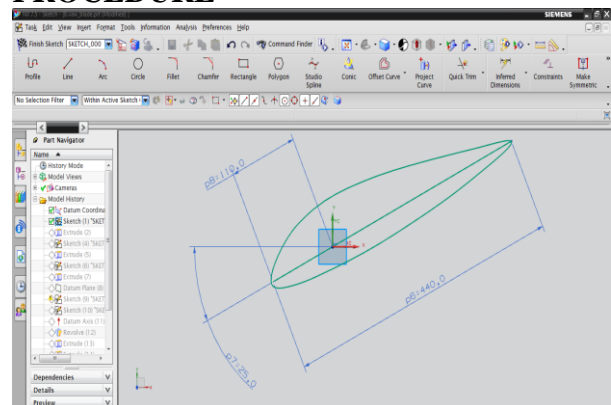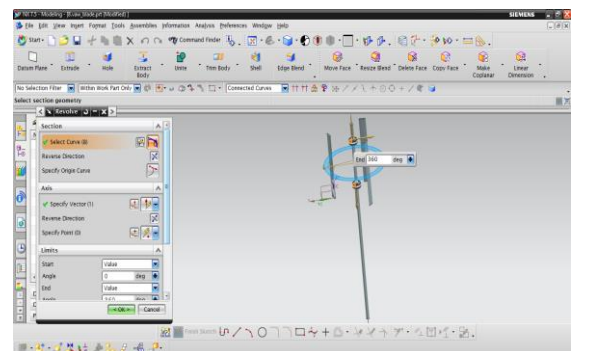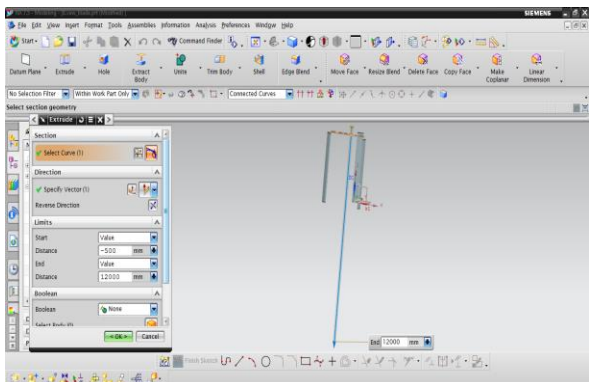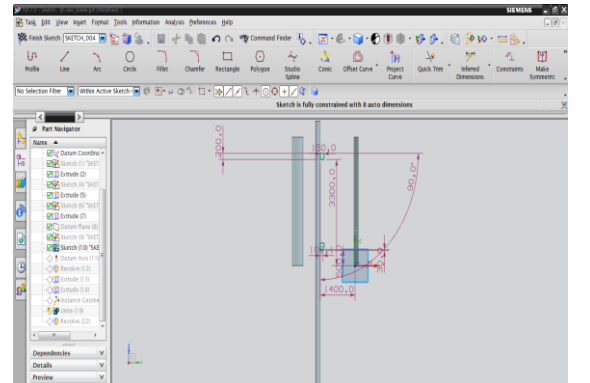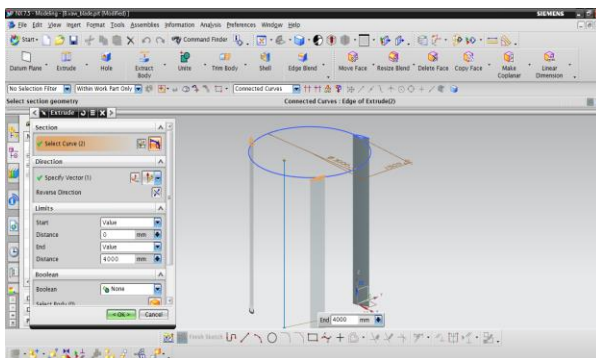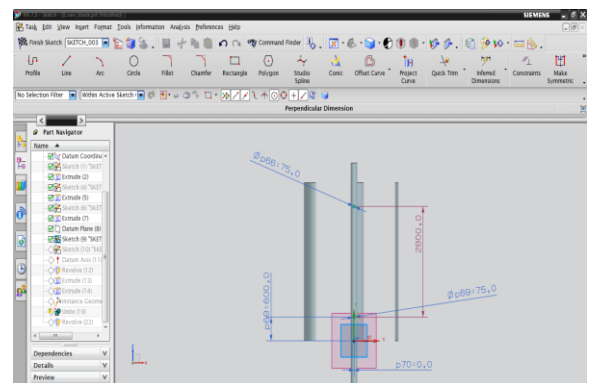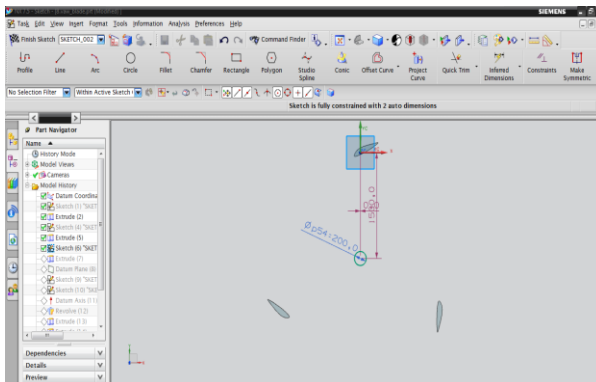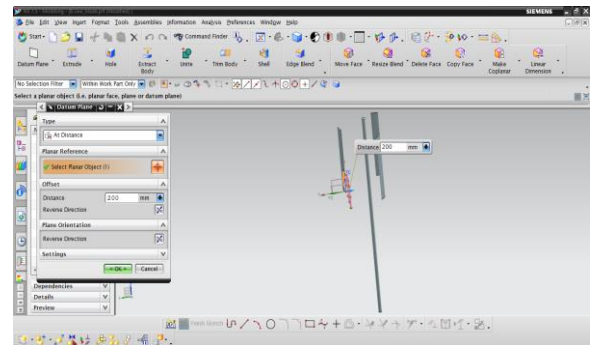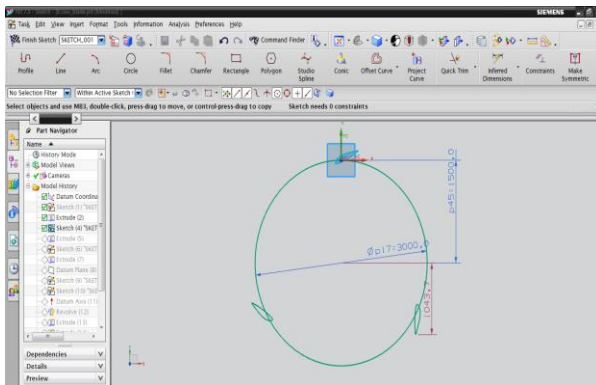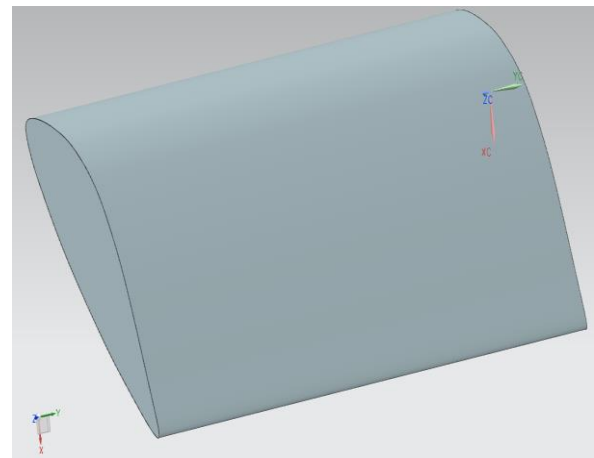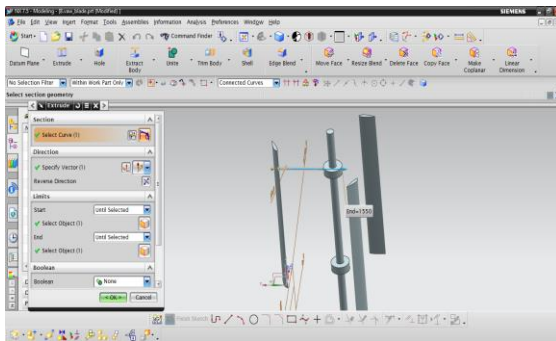
Figure: 3D model of the vertical axis wind turbine blade
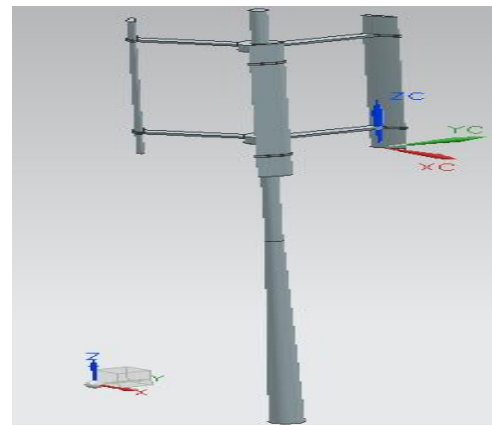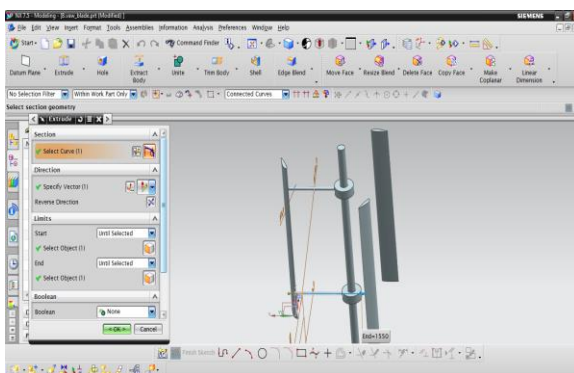
Figure: 3D model of the vertical axis wind turbine
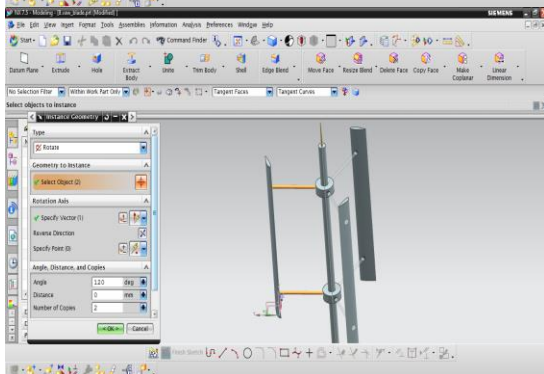
ANALYSES OF A VERTICAL AXIS WIND TURBINE

7.1 STATIC ANALYSIS OF VERTIAL AXIS WIND TURBINE USING ALUMINIUM

Element type: Solid187

No. of nodes: 8

Degrees of freedom: 3 (UX, UY, UZ)

ALUMINUM:

Mechanical properties:

Young's modulus, E (Gpa)   :   71

Poisson's ratio, υ   :   0.35
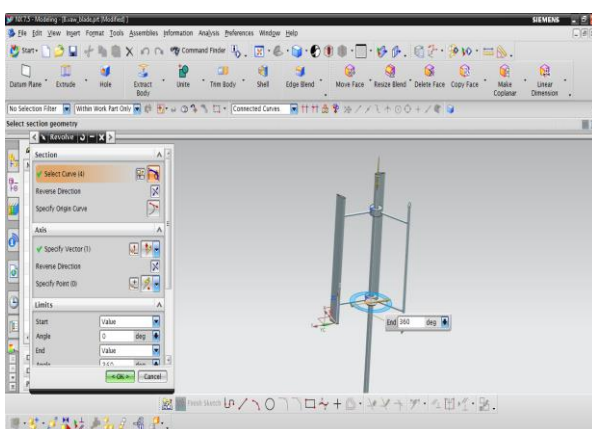
Density (g/cm^3)   :   2.65
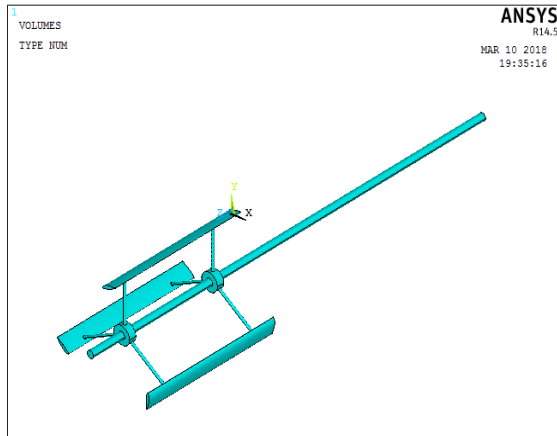
Imported model
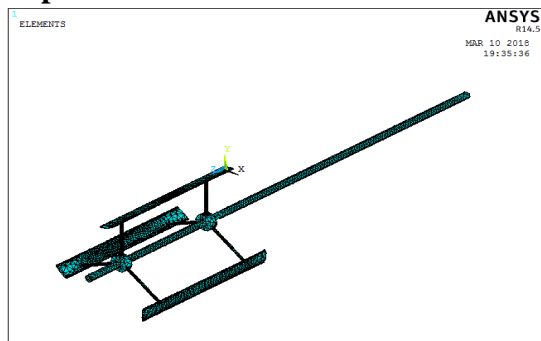
Figure: Finite element model
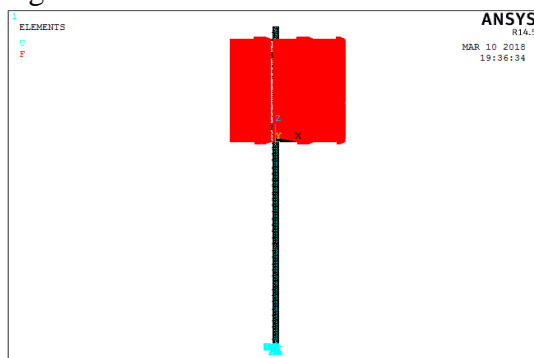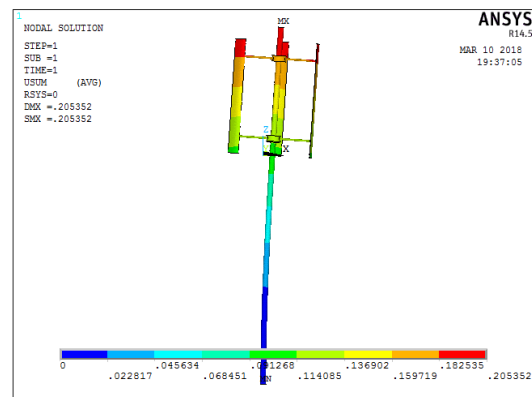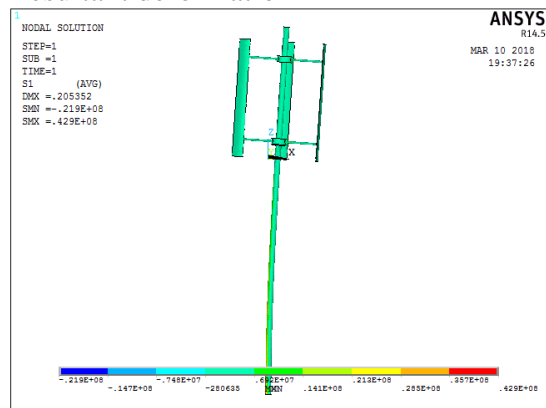
Figure: Loading conditions
Results:

Resultant deformation

1st Principle stress
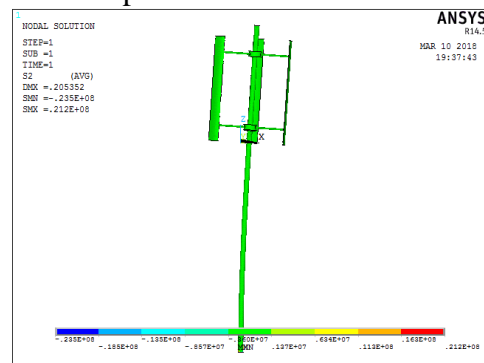
2nd Principle stress
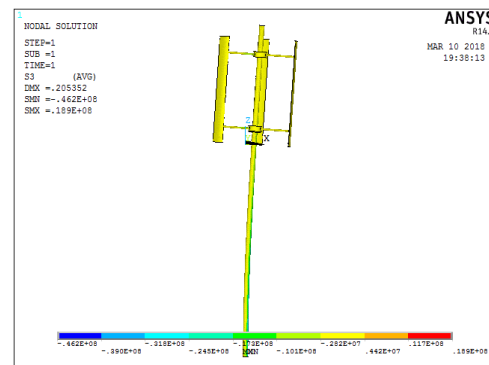
3rd Principle stress
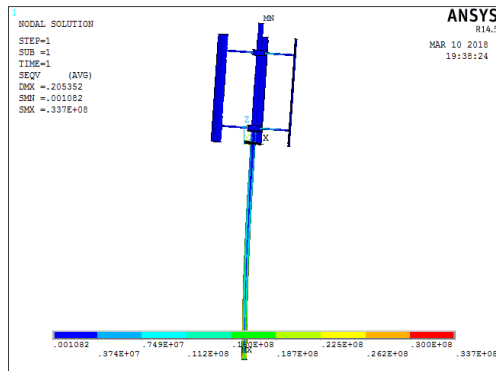
Vonmises stress

From above static analysis results, Vonmises stress formed on VAWT is 33.7MPa. Yield strength of Aluminium is 180MPa.

Factor of safety = yield strength/Vonmises stress =180/33.7 = 5.34

MODAL ANALYSIS OF VERTICAL AXIS WIND TURBINE USING ALUMINIUM:

Methodology:

➢ Develop a 3D model.
➢ The 3D model is created using UNIGRAPHICS-NX software.
➢ The 3D model is converted into parasolid and imported into ANSYS to do modal analysis.
➢ Calculate natural frequencies and plot their mode shapes.

Natural Frequency:

Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position, if there is no outside interference.

The natural frequency is calculated from the formula given below. The natural frequencies depend on stiffness of the geometry and mass of the material.

Fundamental Natural Frequency

The fundamental frequency, often referred to simply as the fundamental, is defined as the lowest frequency of a periodic waveform. In terms of a superposition of sinusoids (e.g. Fourier series), the fundamental frequency is the lowest frequency sinusoidal in the sum.

Resonance:

In physics, resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others. Frequencies at which the response amplitude is a relative maximum are known as the system's resonant frequencies, or resonance frequencies. At these frequencies, even small periodic driving forces can produce large amplitude oscillations, because the system stores vibration energy.

Resonance occurs when a system is able to store and easily transfer energy between two or more different storage modes (such as kinetic energy and potential energy in the case of a pendulum). However, there are some losses from cycle to cycle, called damping. When damping is small, the resonant frequency is approximately equal to the natural frequency of the system, which is a frequency of unforced vibrations. Some systems have multiple, distinct, resonant frequencies.

Mode Shapes:

For every natural frequency there is a corresponding vibration mode shape. Most mode shapes can generally be described as being an axial mode, torsional mode, bending mode, or general modes. Like stress analysis models, probably the most challenging part of getting accurate finite element natural frequencies and mode shapes is to get the type and locations of the restraints correct. A crude mesh will give accurate frequency values, but not accurate stress values.
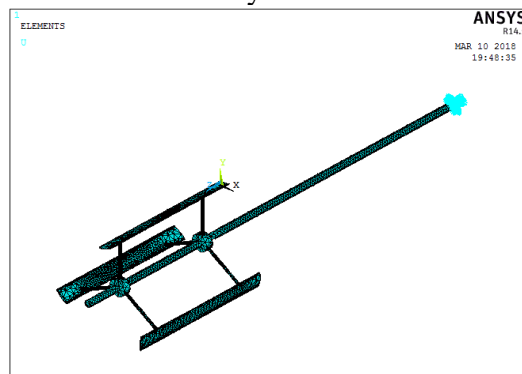
Modal Analysis:

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a

structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

Mesh model in ansys

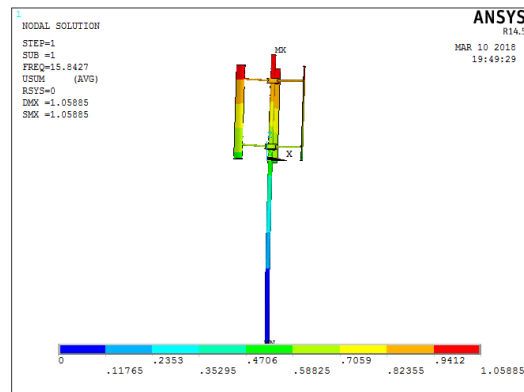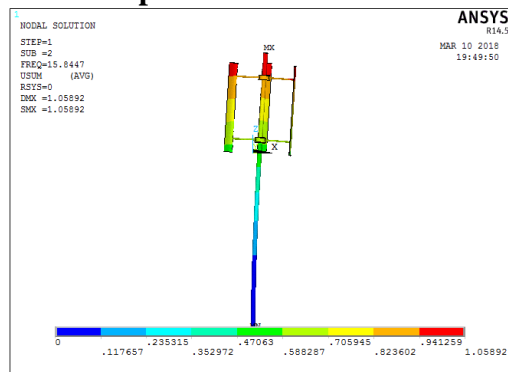Applied fixed loads at end of VAWT
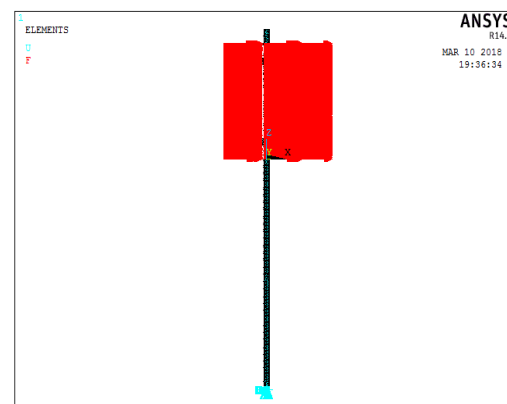
Results

Five natural frequencies

Mode shape-1

Mode shape-2
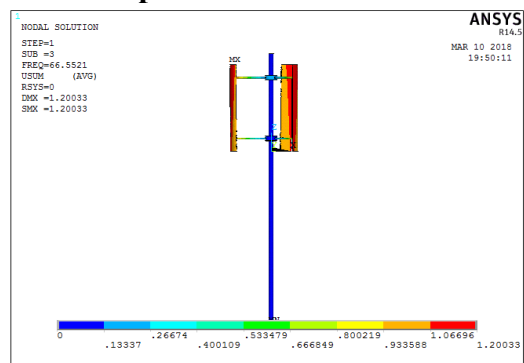
Mode shape-3
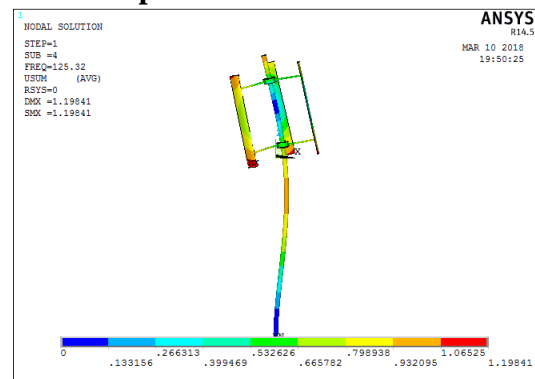
Mode shape-4
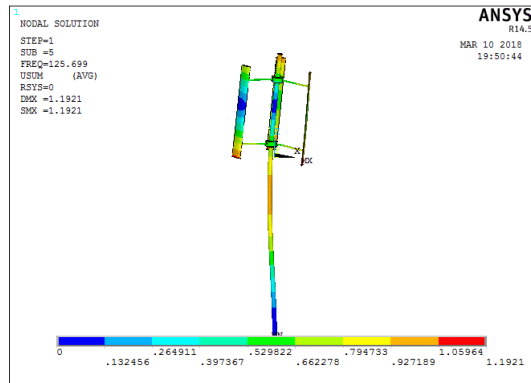
Mode shape-5
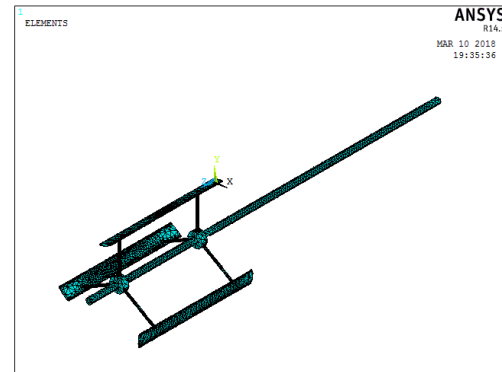
7.3 STATIC ANALYSIS OF VERTIAL AXIS WIND TURBINE USING E-GLASS/EPOXY

Element type: Solid185
No. of nodes: 20
Degrees of freedom: 3 (UX, UY, UZ)

EGLASS/EPOXY
Mechanical Properties:

Young's modulus in fiber direction E1 (GPa) :   53.8

Young's modulus in transverse direction, E2 (GPa)   :   17.9

Shear modulus, G12 (GPa)   :   8.96

Major Poisson's ratio, υ12   :   0.25

Minor Poisson's ration, υ21   :   0.08

Strength in the fiber direction, XL (MPa)
            :   1.03 X 103

Strength in the transverse direction, XT (MPa)   :   27.58

Shear strength, S (MPa)   :   41.37

Density (g/cm3)   :   2.60

Figure: Finite element model
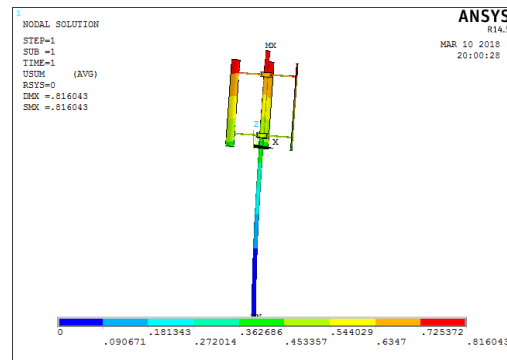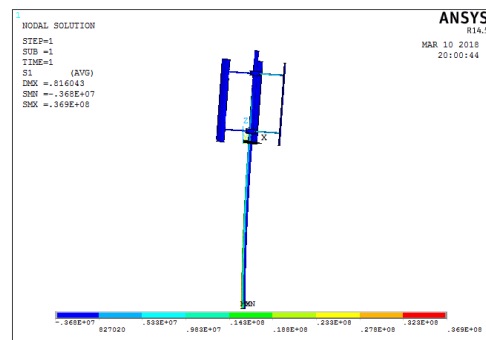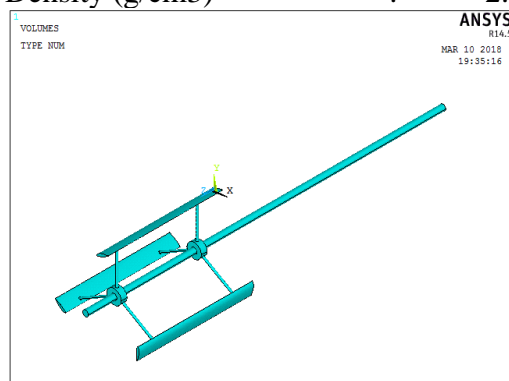
Figure: Loading conditions
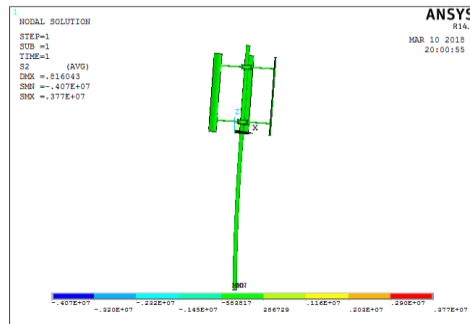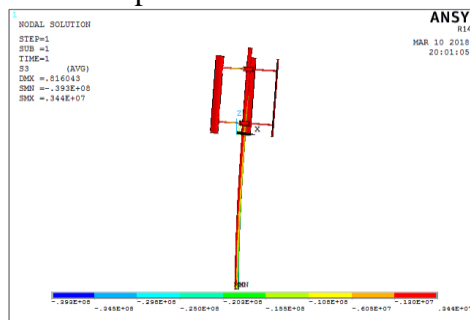
Results:

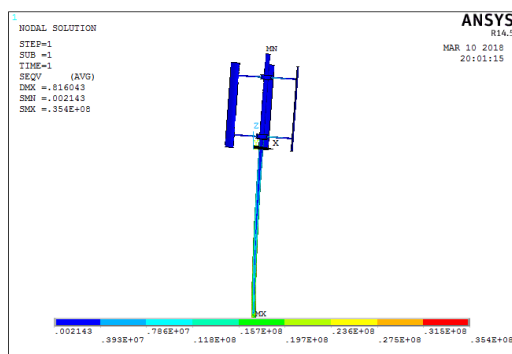Resultant deformation

1st Principle stress

2nd Principle stress

3rd Principle stress

Vonmises stress

From above static analysis results, Vonmises stress formed on VAWT is 35.4MPa. Yield strength of E-Glass/Epoxy is 800MPa.

Factor of safety = yield strength/Vonmises stress =800/35.4 = 22.6

MODAL ANALYSIS OF VERTICAL AXIS WIND TURBINE USING E-GLASS/EPOXY:

Methodology:
- Develop a 3D model.
- The 3D model is created using UNIGRAPHICS-NX software.
- The 3D model is converted into parasolid and imported into ANSYS to do modal analysis.
- Calculate natural frequencies and plot their mode shapes.

Natural Frequency:
Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position, if there is no outside interference.

The natural frequency is calculated from the formula given below. The natural frequencies depend on stiffness of the geometry and mass of the material.

Fundamental Natural Frequency
The fundamental frequency, often referred to simply as the fundamental, is defined as the lowest frequency of a periodic waveform. In terms of a superposition of sinusoids (e.g. Fourier series), the fundamental frequency is the lowest frequency sinusoidal in the sum.

Resonance:
In physics, resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others. Frequencies at which the response amplitude is a relative maximum are known as the system's resonant frequencies, or resonance frequencies. At these frequencies, even small periodic driving forces can produce large amplitude oscillations, because the system stores vibration energy.

Resonance occurs when a system is able to store and easily transfer energy between two or more different storage modes (such as kinetic energy and potential energy in the case of a pendulum). However, there are some
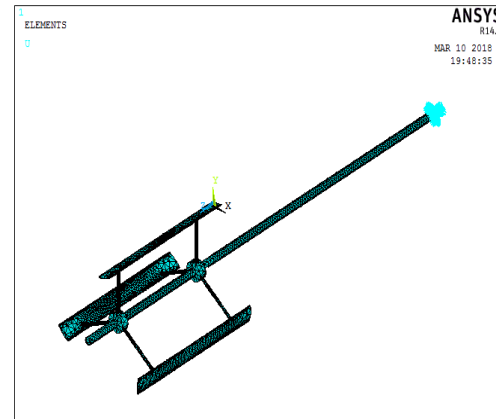
losses from cycle to cycle, called damping. When damping is small, the resonant frequency is approximately equal to the natural frequency of the system, which is a frequency of unforced vibrations. Some systems have multiple, distinct, resonant frequencies.

Mode Shapes:

For every natural frequency there is a corresponding vibration mode shape. Most mode shapes can generally be described as being an axial mode, torsional mode, bending mode, or general modes. Like stress analysis models, probably the most challenging part of getting accurate finite element natural frequencies and mode shapes is to get the type and locations of the restraints correct. A crude mesh will give accurate frequency values, but not accurate stress values.
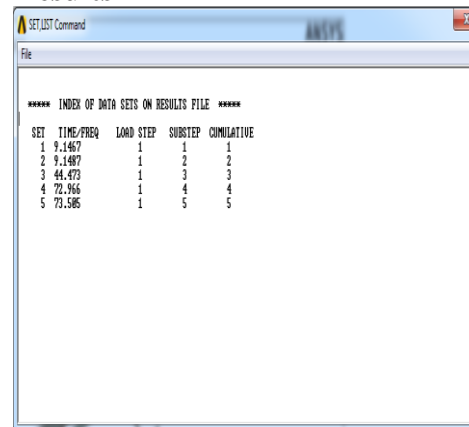
Modal Analysis:

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.
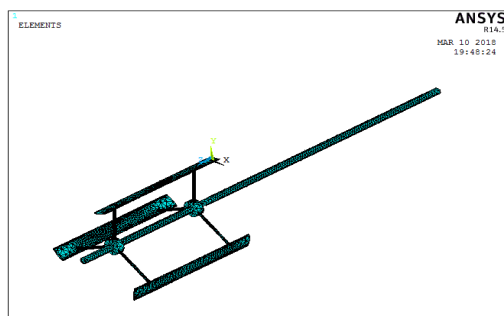

Mesh model in ansys
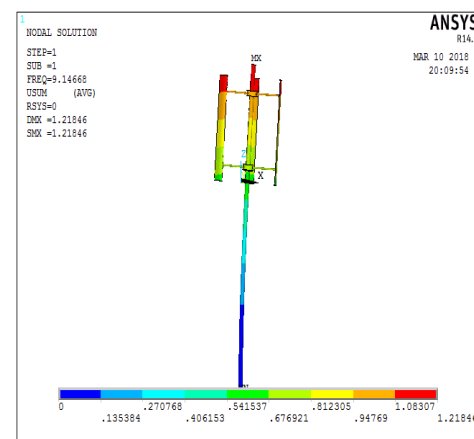

Applied fixed loads at end of VAWT

Results

Five natural frequencies

Mode shape-1

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Mode shape-2

Mode shape-4

Mode shape-3

Mode shape-5

RESULTS AND CONCLUSION

	USUM	VON MISES STRESS	NATURAL FRQEUNCY RANGE(Hz)	WEIGHT (kg)
ALUMINUM	0.63	5.32	45.65 - 80	284
E-GLASS/EPOXY	2.42	5.28	28.95	179

CONCLUSION:

Vertical axis wind turbine blade has been analyzed and compared at wind speed (2500N approximately), for the different materials. By comparing the results, stresses developed in the blade are almost same in both materials, and these stresses are within the yield strength. E-glass/epoxy blade has very less weight comparing with Aluminum. So, we can conclude that E-glass/epoxy is the best material for the wind turbine blade.

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