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Design and Analysis of Vertical Axis Wind Turbine Blade

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Abstract

Wind is used from a very long time as a source of electricity. Lots of efforts have been made to develop the horizontal axis wind turbines but vertical axis wind turbines did not get much attention over the past couple of decades. In the current era of energy crisis it has acquired more significance. Blade is the most important component of a wind turbine which controls a wind turbine 's performance and the design of other components that are attached to it. Current work introduces a concept for the design of a twisted unsymmetrical blade for a small-scale vertical axis wind turbine with beam theories for analytical modeling and a commercial program MSC NASTRAN, PATRAN for numerical modeling. The design parameters of the blade such as solidity, aspect ratio, pressure coefficient etc. are calculated with the goal of the 1 kW power output and the blade design was tested under extreme wind conditions where maximum deflection and bending stress values were calculated at peak aerodynamic and centrifugal forces values. Mainly the design considered achieving the structural strength i.e. reduction of deflections and bending stresses. This blade design has high strength and lower material consumption to achieve the low cost of complete wind turbine rotor assembly which actually covers over 50 percent of total wind turbine costs.

Keywords: Wind turbine, Nastran, Unsymmetrical blade and Analysis of turbine blade.

1. Introduction

Wind power is a form of solar power. Wind or wind power defines the mechanism by which wind is used for electricity generation. Wind turbines convert mechanical power to the kinetic energy in the wind. Mechanical power can be transformed into electricity by a generator Mechanical control can also be specifically used for particular tasks such as water pumping. Wind is caused by the uneven heating of the atmosphere by the variations in the surface of the earth and the earth's rotation. The National Wind Technology Center (NWTC) is the nation's leading testing facility for wind energy technology. The goal of NWTC's research is to help the industry cut energy costs so that the wind can complete with traditional energy sources, providing a clean, renewable alternative for the energy needs of our nation. The bulk of the wind industry is actually dominated by horizontal axis wind turbines. Horizontal axis means the wind turbine's rotating axis is horizontal, or parallel, to the ground. Horizontal axis wind turbines are the dominant type of turbine for big wind farms or industrial customers. However, vertical axis turbines have a role in smaller or industrial wind applications.[1−4] The benefit of the horizontal axis is that it can actually generate substantially more energy from a given amount of wind. A downside of turbines with horizontal axes is that they are usually heavier and do not produce much power in turbulent winds. Hence their location plays a big part in how successful the turbine will be and how much energy it will generate. Vertical axis wind turbines, or VAWT, work differently, as the turbine 's rotational axis stands vertically or perpendicular to the ground. As previously mentioned, turbines with vertical axes are primarily used in smaller or residential installations. Wind coming from all 360 degrees drive the vertical axis turbines. In certain situations, when the wind is blowing from top to bottom, vertical axis turbines can be powered. Due to their versatility, wind turbines with vertical axes are thought to be ideal for installations where wind conditions are not consistent.[5−9].

2. Computational Fluid Dynamics Analysis

To help validate the results obtained from QBlade, a simple two-dimensional computational fluid dynamics simulation was carried out using ANSYS CFX. The two-dimensional analysis is not as accurate as a full three-dimensional analysis, but does allow for greatly reduced computational demands. The meshing setup is an essential part of a CFD analyze. Because the forces on the turbine blades (i.e., lift and drag forces) are guided by the effects of the boundary layer, the mesh around the blades must be fine enough to catch these effects with precision. The approximate boundary-layer thickness for a laminar flow is given by the following formula:

$$\partial = 4.91x/\sqrt{Re_x} \quad (1)$$

Where ∂ is the boundary-layer thickness, is the characteristic dimension (in this case, the position along the chord of the airfoil), and Re_x is the Reynolds number in terms of the characteristic dimension. For turbulent boundary layers, the thickness is given by:

$$\partial \approx 0.382x/Re_x^{1/5} \quad (2)$$

The thickness of the boundary layer on the VAWT blade from the leading edge to the trailing edge was calculated shown in the Fig.1.

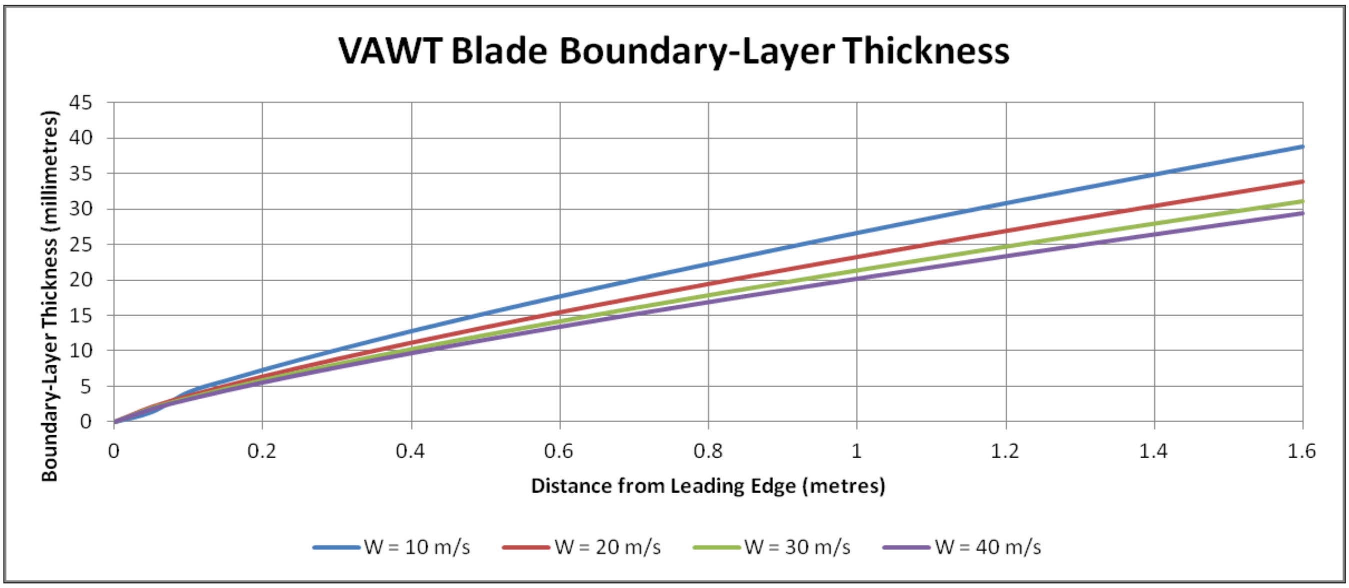

Fig.1 - Boundary-layer thickness at various stream speeds

2.1 Domain and Interface Setup

ANSYS CFX allows a number of schemes for modelling the interface between the rotary and stationary domain shown in fig.2.. These are:

- Frozen rotor
- Stage
- Transient rotor-stator

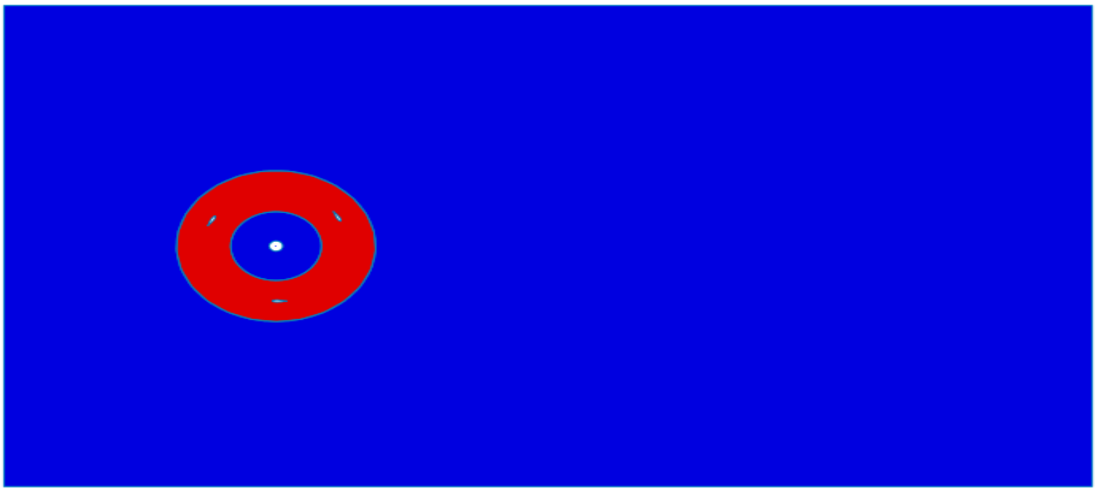

Fig.2 - CFD analysis domain setup.

2.2. Boundary Condition

To simulate an incoming wind velocity, an inlet boundary condition was placed at the upstream end of the stationary domain. This inlet has assigned a constant velocity. The opposite end of the stationary domain was assigned as an outlet, allowing flow to exit against atmospheric pressure. The simulation has refined to ensure that the outlet was sufficiently far downstream for the fluid wake to stabilize prior to exiting the simulation. The sides of the stationary domain were given .[3−6].a free-slip wall condition. This allows the fluid to move freely parallel to the wall, but requires that the velocity normal to the boundary be zero is shown in figure.3.

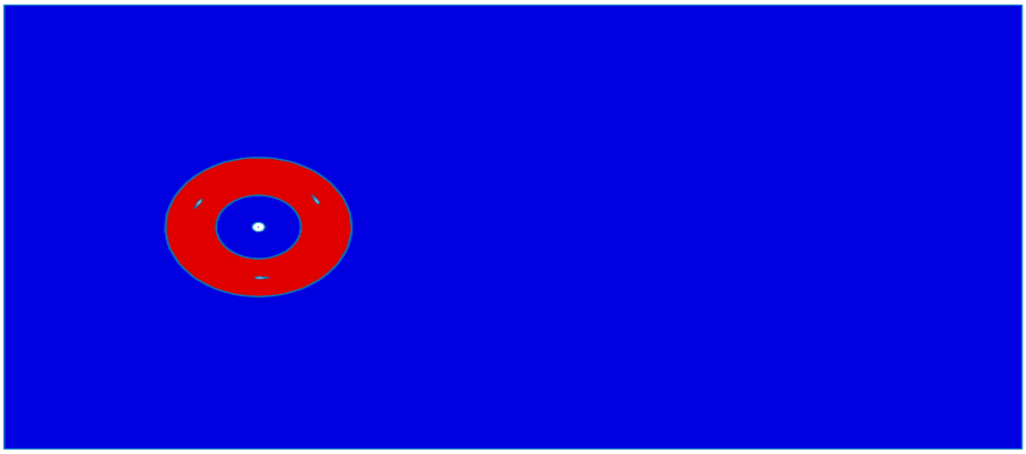

Fig.3 - Outer boundary conditions

2.3 Solver Setup and Result

The solver was run for approximately 3 turbine revolutions, or at 35 RPM for 5 seconds. All domains were given an initial inlet velocity equal to that. It took the simulation about eight hours to run. Since the simulation is in two dimensions, the raw data per unit length is in terms of torque. To achieve the results below, the raw output was multiplied by the blade length of 20 metres.

$P=T\omega$

Where P is the power, T is Torque and ω is angular velocity.

At a wind speed of 10 metres per second and a rotational speed of 35 RPM, the average power output was approximately 140 kW. Applying a 96% efficiency to account for generator losses, the output becomes 134 kW.

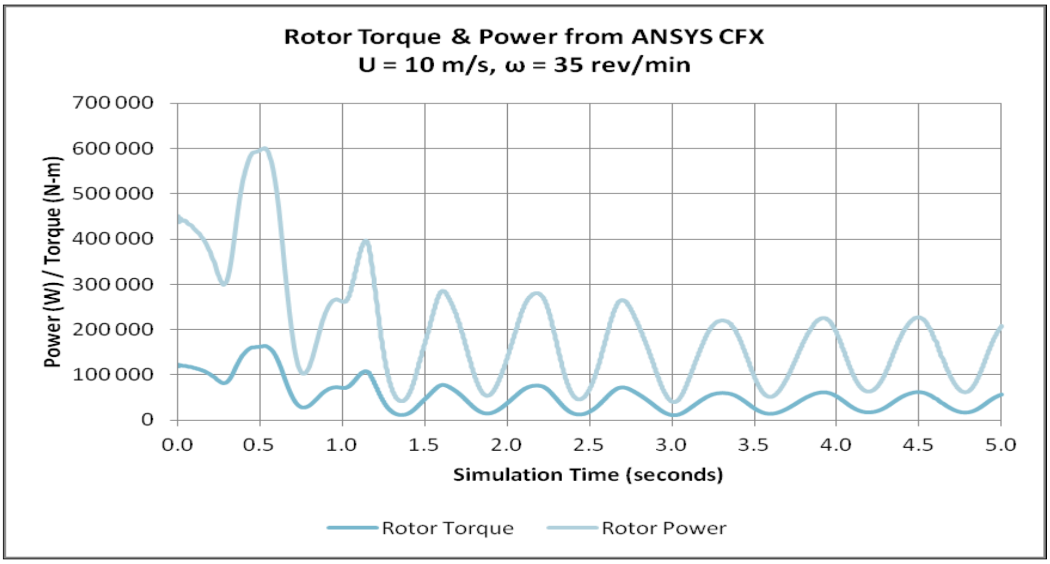

Fig.4 - Results of CFX simulation, 10 m/s wind speed

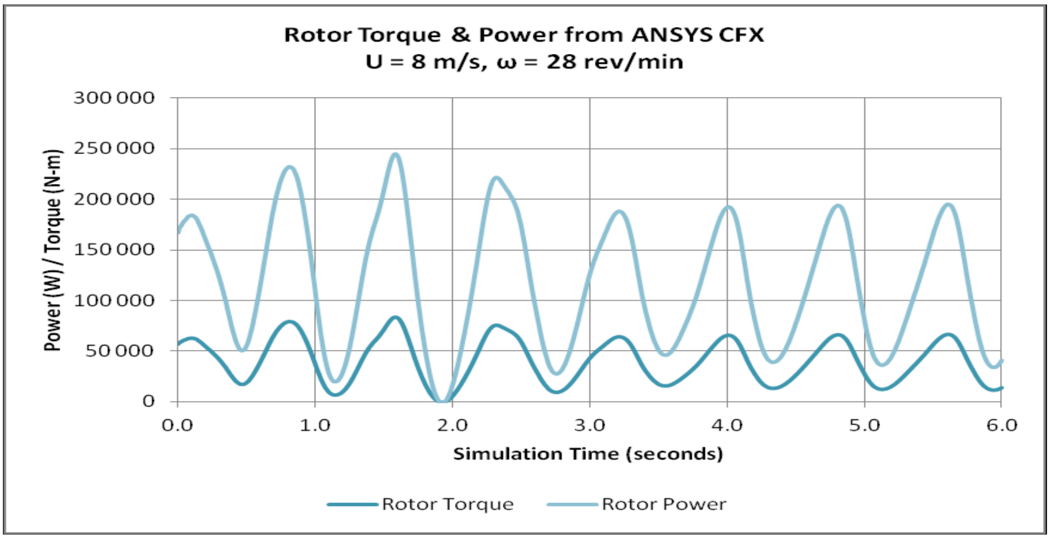

Fig.5 - Results of CFX simulation, 8 m/s wind speed

3 Structural Analysis

In addition to operating at peak aerodynamic efficiency it is important to design a VAWT that can withstand lift forces, drag forces and wind loads. Structural analysis was performed on individual VAWT components because different loads were placed on each element.

3.1 Blade Structural Design

Structural blade design determines the cost of manufacturing a blade, load bearing capacity and hence overall structural performance (in terms of reliability and robustness). Extreme loading analysis (i.e. tip deflections and buckling) accompanied by fatigue and modal analysis is the latest state of the art for structural blade design in terms of criticality; In blade design process, fabric (laminate) and inter-fibre failure (static strength analysis) along with aero-elastic stability (such as flutter) play a secondary role. Laminates consist of different ply layers of fibers stacked in a specific direction on top of one-another.

3.2 Analysis and Methodology

This part of the report deals with the procedure and approach used for calculating aeroelastic loads (briefly), blade layout for Finite Element Analysis (FEA) and various branches of rotor blade computer modeling with special emphasis on Fatigue.

3.3 Blade Analysis

A typical blade of airfoil cross-sections is composed of fig.6 .. Within the blade is strengthened to preserve the airfoil's original shape during service. The airfoil parts belong to the rest of the blade, and the aerodynamic efficiency is determined. Selecting suitable cross-section shape, taper angle, and twist angle plays an significant role in maintaining aerodynamic forces. A complete methodology for selecting the blade geometry, profile, and dimensions is described in this section when designing it for the required power output.

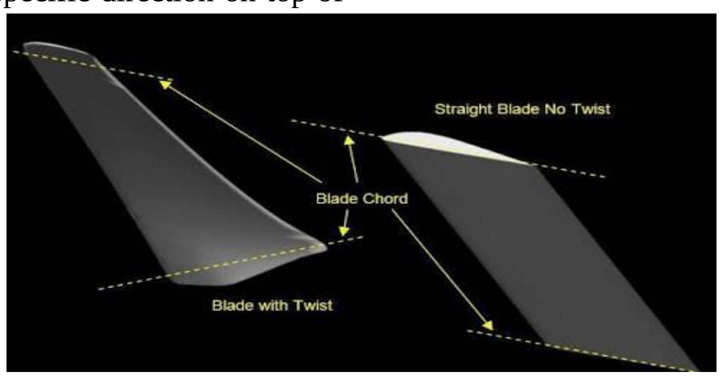

Figure.6 - twisted blade

3.4. Load Case

The high aspect ratio straight blades of H-darrieus rotor are subjected to high values of centrifugal forces.

$$F_C = 3456 \text{ N} \quad \text{- - - - - - - - - - -} \quad (3)$$

An analysis of the resultant of the normal force and centrifugal force is made for one blade in a revolution. As they have equal direction, their resultant is:

$$F_R = F_n + F_C \quad - - - - - - - - - - - (4)$$

$$F_R = 836.09 + 3456$$

$$F_R = 4292.09\ N \quad - - - - - - - - - - (5)$$

3.5 Internal Structure

The internal structure is shown in fig.7 is conceived to obtain maximum strength with the least weight; The spars are the most important structural component of the wings, since they carry the airloads during blade rotation. Blade has a Box spars is placing at 40% of blade chord which acting as the structural reinforcement for the blade to be more efficient at resisting out-of-plane shear loads and bending moment. The Blade has a chord of 0.28m; the spar is placing at 0.112m from the leading edge of blade with respect to centre position of spar.

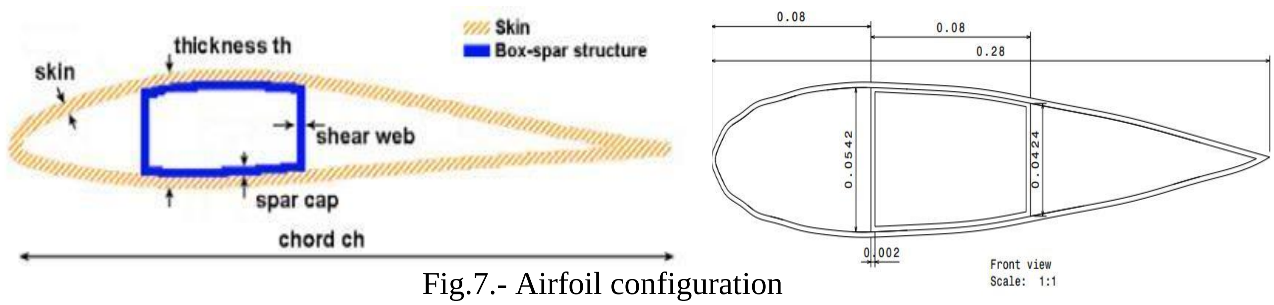

Fig.7.- Airfoil configuration

Consider a blade as 1-Dimensional Element which as fixed of support at 0.5 and 1.5 from the span wise distance.
Taking moment about B, we get

$$2.146 \times 0.5 \times \frac{0.5}{2} + R_A \times 1 = 1.5 \times 2.146 \times \frac{1.5}{2}$$

$$0.26825 + R_A = 2.4142$$

$$R_A = 2.146 \quad - - - - - - (6)$$

$$R_B = 2 \times 2.146 - \frac{1}{0.5} = 4.292 - 2$$

$$R_B = 2.292 \quad - - - - - - (7)$$

Shear Force Diagram,

$$S.F \text{ at } C = 0 \quad - - - - - - (8)$$

$$S.F \text{ just on L.H.S of } B = -2.146 \times 0.5 = -1.073\ KN$$

Shear force varies between C and B by a straight line low Shear flow just on,

$$L.H.S \text{ of } A = 1.219 - 2.146 \times 1 = -0.907\ KN \quad - - - - - - (9)$$

Shear force between A and B varies by a straight line low Shear flow just on R.H.S of

$A = -0.927 + R_A = 1.219$ KN - - - - - (10)

Shear flow at D = 1.219 -2.146 × 1.219. Shear flow at D = 0

Bending Moment at C = 0 - - - - - - (11)

Bending Moment at A = $-0.5 \times 2.146 \times \frac{1.5}{2} = 1.1513$ KNm - - - - - - (12)

Bending Moment at E (i.e at a distance y=1m from point C)

$$= -2.146 \times 1 \times \frac{1}{2} \times R_B \times (1-2.146)$$

$$= 1.073 + 2.292 \times (-1.146)$$

$$= 1.073 - 2.026$$

$$= 3.626$$ - - - - - - - (13)

Bending Moment at B = $-2.16 \times 1.219 \times \frac{1.219}{2} = -1.594$ KNm - - - - - - (14)

Two dimensional Blade analyses,

$$M = \frac{2.146 \times 0.5}{2} = 0.5365$$

Thus $P_{z,U} = -P_{Z,L} = 0.5365$

Also, $P_{y,U}=0$ and $P_{y,L}= 0$

$P_U = 0.5365$ - - - - - - - - (15)

$P_L = -0.5365$ - - - - - - - - (16)

The shear force at section 1 is 0.5 × 2.146 = 1.073 KN. This is resisted by Py,L the shear force in the web.thus shear force in web = 1.073 KN

The shear flow distribution is

$$q = \frac{1.073 \times 103}{0.06^2} = 17.306 \text{ KN/m}$$ - - - - - - - -(17)

3.6 Twisted Unsymmetrical Blade

The unsymmetrical vertical axis wind turbine blade is designed with angle of twist which is shown in Fig.8. This design is mainly considered to reduce the deflection and bending stress. To reduce the amount of material, it was important to minimize the thickness and withstand the worst possible wind loads. Bending, axial and shear stress analyses were performed to determine if these dimensions and material are suitable.

Table.1 design parameters of twisted blade

PARAMETER	VALUE
length	2.4m
thickness	3mm
Blade weight	3kg

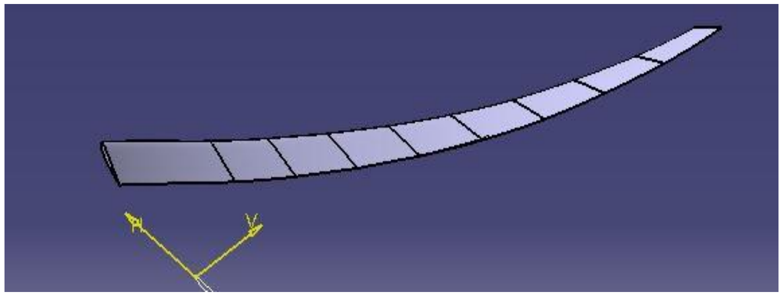

Fig.8 - VAWTs blade in CATIA V5

3.7. Centrifugal Force

Table:2 The comparative stress analysis for aluminium and composite.

Description	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Radius (m)	0.9	0.9	0.9	0.9	0.9
Angular Speed (RPM)	60	90	120	150	200
Mass (Kg)	3	3	3	3	3
Linear Speed (m/s)	2	3	4	5	6
Centrifugal force (N)	107	240	426.367	666.198	1184.35
Result Fig No	**9**	**10**	**11**	**12**	**13**

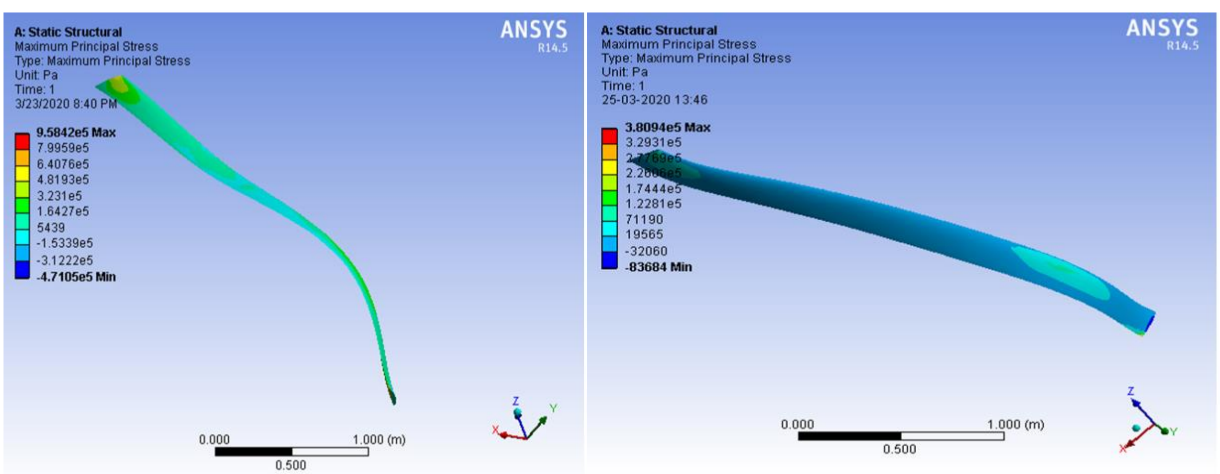

Fig.9 - comparative stress analysis for aluminium and composite in case1

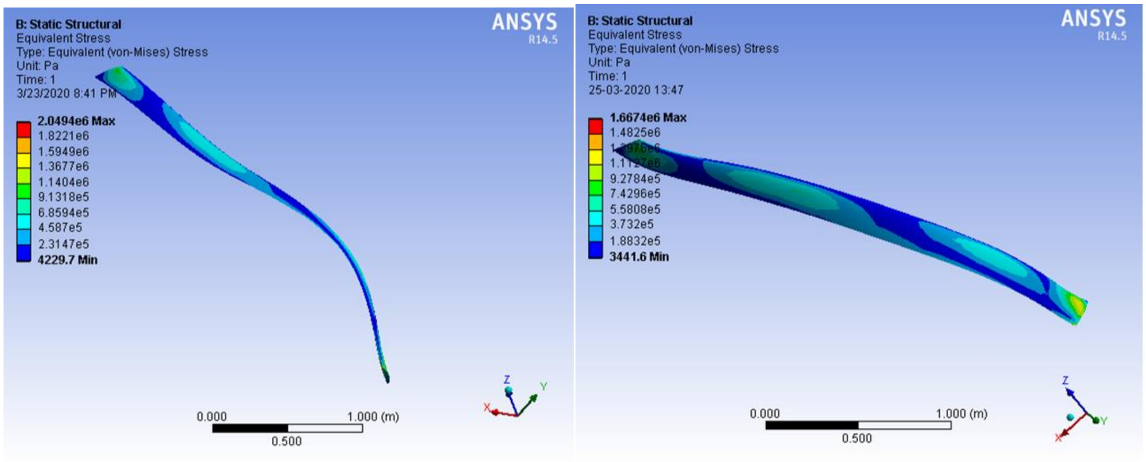

Fig.10– comparative stress analysis for aluminium and composite in case2

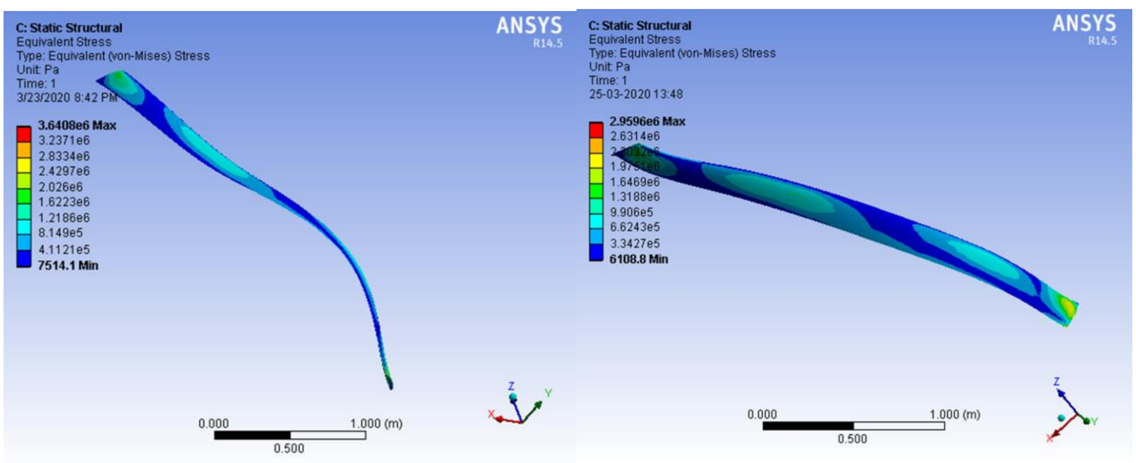

Fig.11– comparative stress analysis for aluminium and composite in case3

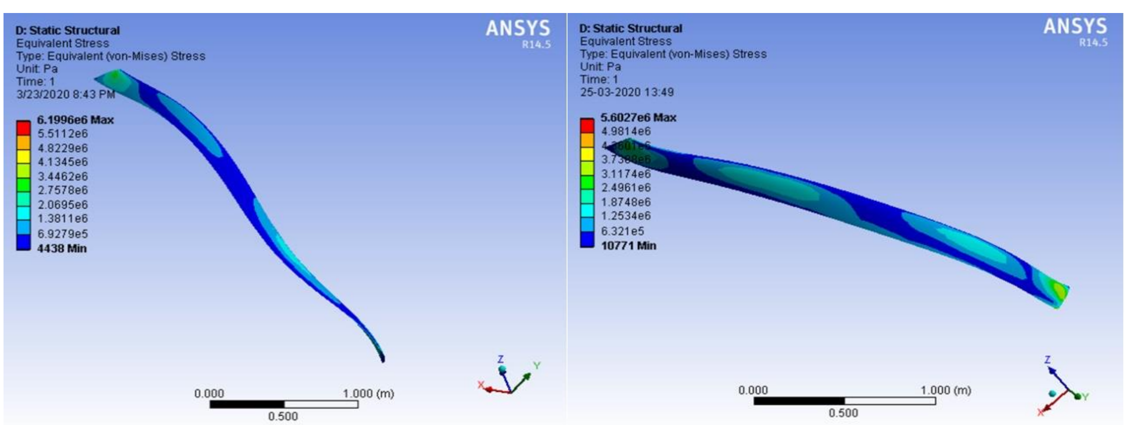

Fig.12– comparative stress analysis for aluminium and composite in case4

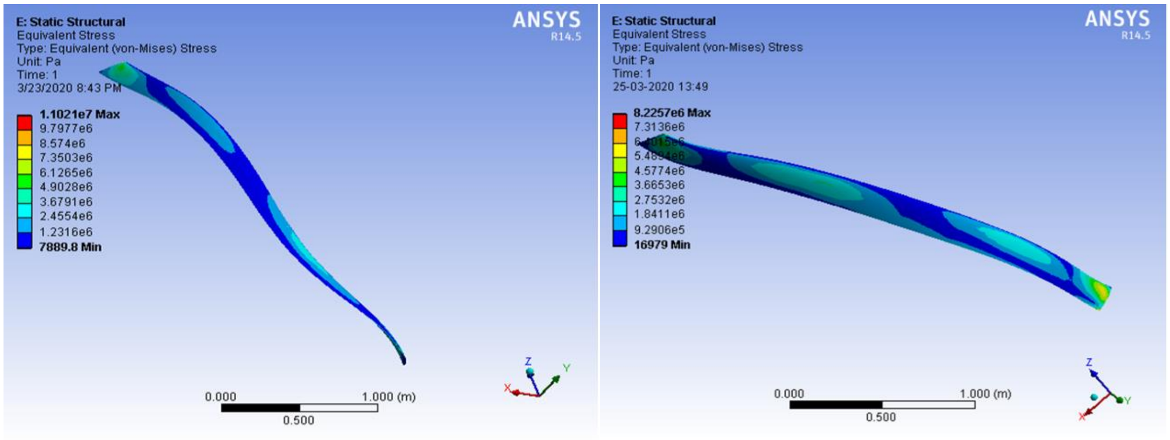

Fig.13.– comparative stress analysis for aluminium and composite in case 5

3.8 Pressure Load (Pressure input is given by Aeolus Aero Technologies)

Table 3. Calculation of Pressure load

Description	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Linear Speed (m/s)	2	3	4	5	6
(P/Pa)	1.15	1.3	1.4	1.55	1.7
Pressure Load (Pa)	116523.75	131722.5	141855	157053.75	172252.5
Result Fig No.	**14**	**15**	**16**	**17**	**18**

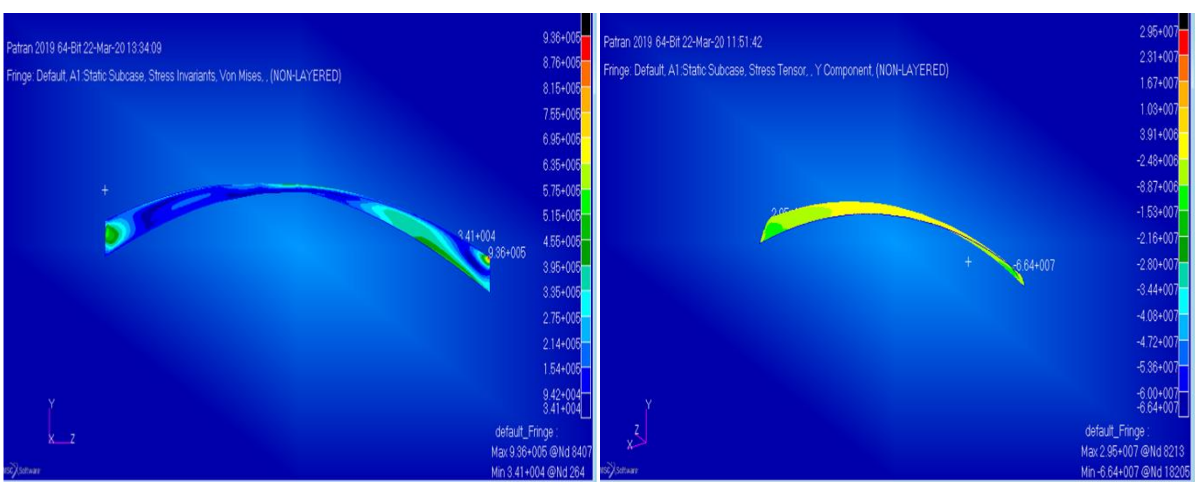

Fig14- von mises stress analysis for aluminium & stress in y component for composite

Case2: Fig.15 shows the stress analysis for aluminium and composite.

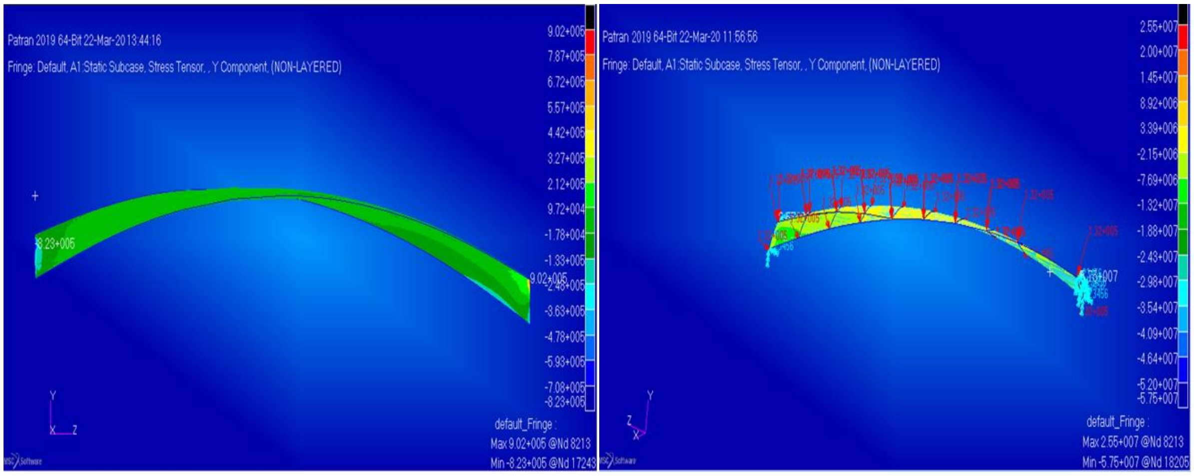

Fig.15- stress in y component for aluminium

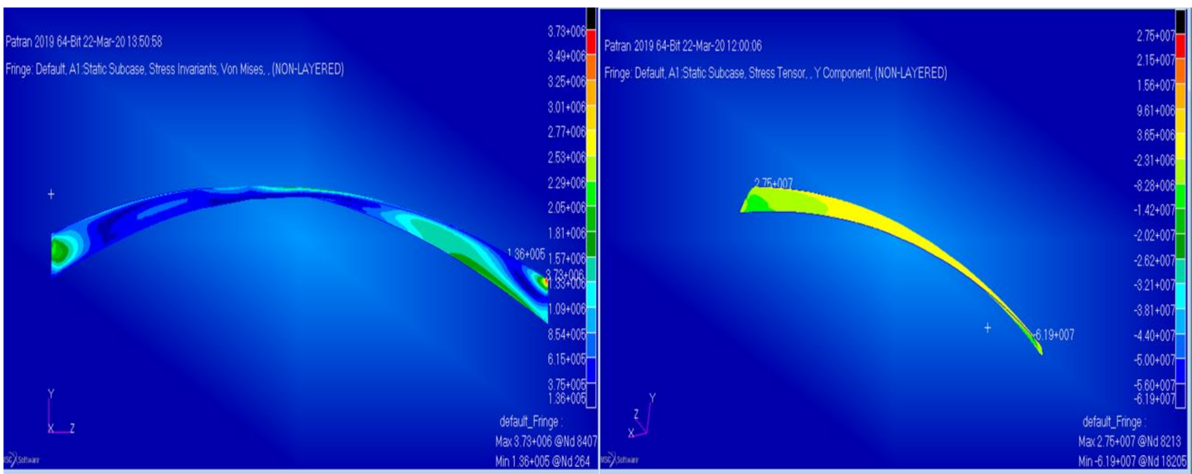

Fig.16- von mises stress analysis for aluminium & stress in y component for compositeCase4:

Figure 17 shows the stress analysis for aluminium and composite.

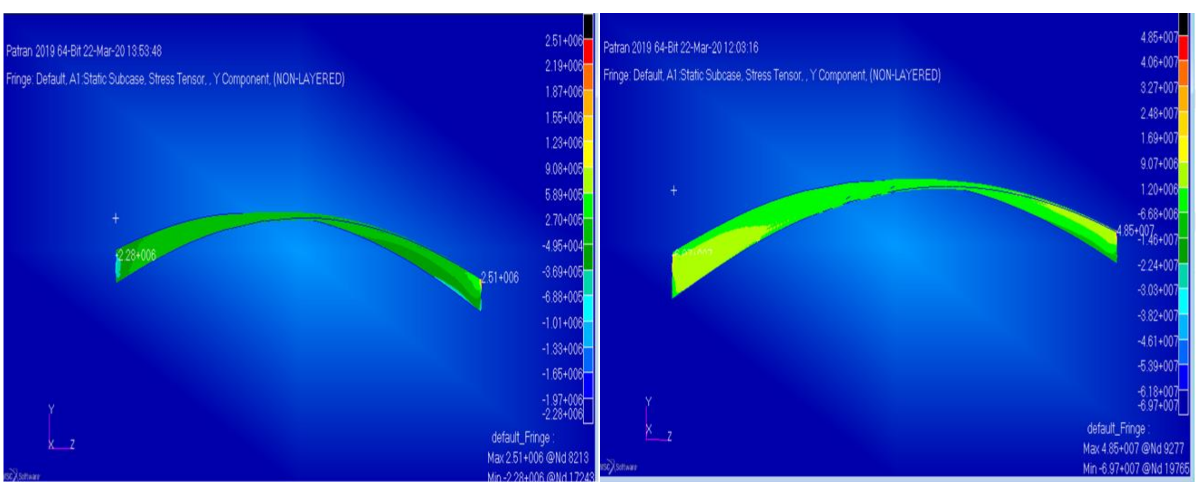

Fig.17- stress in y component for aluminium & stress in y component for composite

Case5: Figure 8.38 and 8.39 shows the stress analysis for aluminium and composite.

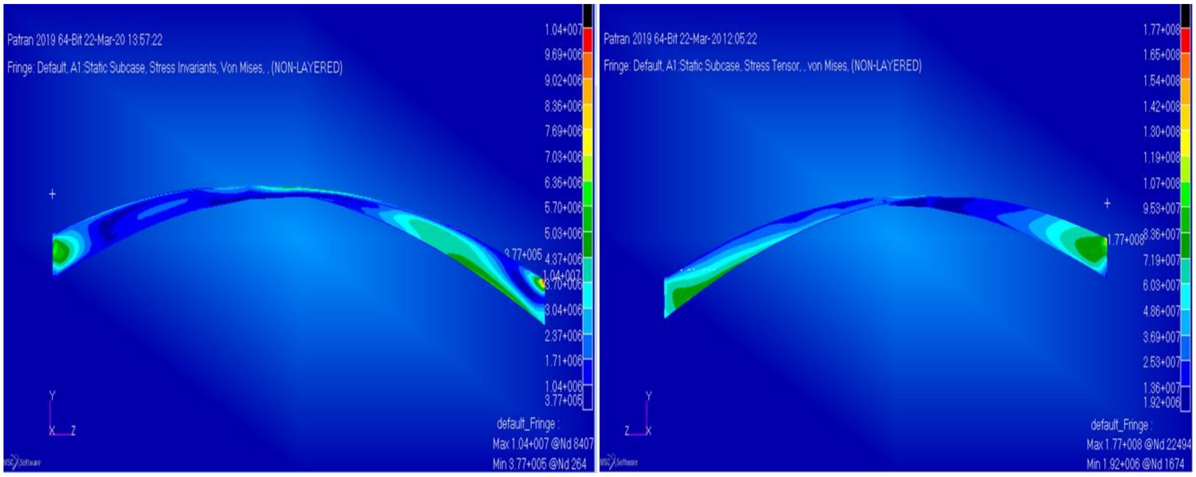

Fig.18- von mises stress analysis for aluminium & von mises stress analysis for composite

Conclusion:

The object of this project has to design a vertical-axis wind turbine with at least 1kW capacity for use in remote communities. Key aspects of the design parameters like solidity, aspect ratio, pressure coefficient were investigated and including aerodynamics and structural design Consideration has been given to non-technical factors; compliance with existing standards, environmental concerns, and an economic analysis were considered to ensure a well-rounded, socially responsible design. The comparative analysis for twisted unsymmetrical blade is done in MSC NASTRAN PATRAN and it is analysed that composite material having more strength than aluminium. It reduces 40% of weight which is more reliable and easier to manufacture. The low cost of complete rotor assembly of a wind turbine covers 50% of overall cost. While some further work is required, overall, the project met its goals and showed that a robust, enhancement lifetime VAWT capable of standing up to the harsh weather conditions.

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