Finite Element Method for Analyzing Axial Fan Blade with Different Twist Angle and Chord Length

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***Abstract* - The past decade has experienced a boom in industries and engineering. This has led to an increase in demand for power. The major power generators are wind farms, thermal power plants and hydro-electric power plants. All these industries employ a common method of harnessing power - Turbines. The efficiency of these turbines can be improved by reducing the material used or by increasing the longevity of the blades by either changing the chord length or the twist angle of the turbine blades. Based on the applications of the turbine, these blades have different geometries i.e. different airfoils, different chord lengths and different degrees of twists. The current paper attempts to analyze the effect of chord length and angle of twist on the von-mises stress distribution over the wing of a thin airfoil, namely NACA 5504 using finite element methods. The blade is assumed to be made of aluminum material.**

Keywords –Axial Fan, taper, twist, NACA airfoil, finite element method.

I. INTRODUCTION

A revolution in the 19th century introduced a belt-driven fan in which wooden or metal blades were attached to the shaft. One of the first mechanical fans was built in 1832 and it was tested in coal mines. Further, developed fans have been utilized in diverse fields based on their application. These developments have been applied in various parts of the fan such as blades within which the twist angle and the shape of the cross section are of primary importance.. The blades are generally characterised by the airfoil used, the chord length and the span of the blade. Many simulations have been done on the effect of chord length on the stress distribution [3] but the effect of twist is yet to be analyzed. The twist of the blade is very important to determine the mass flow rate over the blades.

Airfoils [1] are streamlined bodies which are generally the cross-section ofwings of an aircraft, a sail or a windmill. These mainly create a pressure difference between the upper and lower surfaces of the aero foil section so that the entire body experiences a force from the lower pressure side to the upper pressure side. The airfoils of a wing basically work on Bernoulli's principle [1]. The shortest length between the blunt leading edge (LE) and the sharp trailing edge (TE) is called the chord (C). The relative angle between the free stream and the [2].

The National Advisory Committee for Aeronautics (NACA) is one of the premiere institutes to develop airfoils. The airfoils developed by NACA are characterized into series. Our case is only limited to the NACA 4_digit series, which is the word "NACA" followed by four digits. Each digit represents one characteristic feature of the geometry of the airfoil. In NACA four digit series, the first digit represents the maximum camber as a percentage of the chord; the second digit represents the distance of the maximum camber from the leading edge in tens of percentage of the chord. The last two digits represent the maximum thickness of the airfoil as a percentage of the chord.

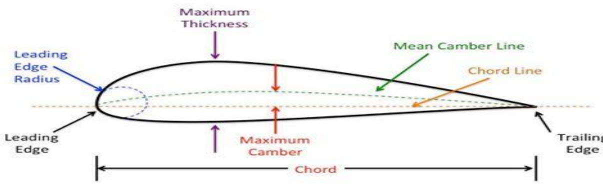

Fig1 Airfoil nomenclature

*source :*Image from introduction to aerodynamics by John D. Anderson

There were many previous attempts to optimize the parameters of the wings. In 1980, the dynamic stress induced in rotating twisted and tapered wings was studied. This study employed finite element technique and was later verified by experimental methods [4]. Later, theoretical methods were verified and validated by experimental methods.

Later in 1994, a relationship was developed between the thickness and maximum lift generated by the airfoil. This was later verified by experimental results from the low speed, low turbulence wind tunnel in Pennsylvania state university [5].

In later years, studies were done on the roughness effect on the lift characteristics [6]. In 2006, a method to obtain optimal chord length by use of genetic algorithms for wind turbine [7]. In 2011 blade thickness effects were also performed in which two fan blades with different thicknesses were examined. The blades were tested in a test bench designed according to ISO - 5801 standard. It was observed that the thin blade had a higher efficiency as compared to the thick blade although the thick blade had a higher flow rate range and lower total level of fluctuations [8].

In May 2013, analysis was performed on a NACA 5514 for determining the effect of chord length and twist angle on the stress distribution over the wing [3].

II. Materials And Methods

In this study, a blade of NACA 5504 airfoil is analyzed for the Von Mises stress distribution and how it varies as a function chord length and twist degree. The blade is made of aluminum. It has a length of 446.5mm and has a cross sectional profile of NACA 5504 airfoil. The primary chord length before variation was 130mm. Later, it was varied till 82mm. The twist angle was gradually changed in increments of 10 from 0 deg to 40 deg.The blade is made of aluminum.

A. Finite Element Analysis

Finite element analysis is a technique used for approximating the differential equations to continuous algebraic equations by a finite number of variables [9]. This is a very common and practical method of analyzing structures with many degrees of freedom. These problems can be solved analytically but are not accurate and are time consuming. Hence, we use commercially available solvers which have higher computational accuracyand. There are many software packages but the one which we are going to use is ABAQUS. The solver is used to study the Von Mises stress distribution over the wing.

B. Mesh Convergence Study

A mesh is created to divide the computational domain into discrete elements. If we use too fine a mesh i.e. large number of elements for our mesh, we increase the computational time. But, if we use a very coarse mesh i.e. very few elements for our analysis, we may not get accurate results. Hence, a mesh convergence study is done to determine the optimum number of elements for the analysis.

The number of elements was gradually increased from 88 to 50,000 elements. The Von Mises stress was observed to increase from 1.3 MPa to 2.6 MPa. It was observed that after 30,000 elements, the variation in stress is uniform and the total stress is constant hence, the the number of elements was taken to be 30,000. The number of elements is plotted against the Von Mises stress and the graph is as shown in Fig 2.

Fig 3Demonstrates a meshed blade with 30,000 elements.

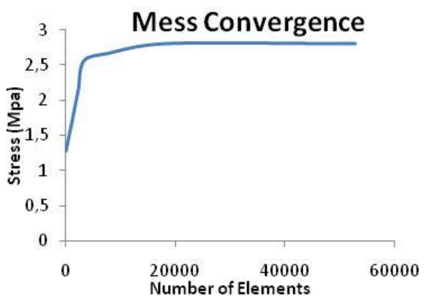

Fig 2 Trend line of mesh convergence study

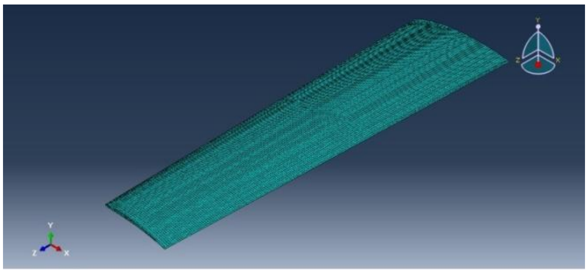

Fig 3 Meshed blades with 30000 elements

III. Results And Discussion

Changing the chord length and the twist angle changes the Von Mises stressover the wing. The base chord length was chosen to be 130mm from experimental data. The chord length is changed gradually to a minimum value of 82 mm. Similarly, for different chord lengths, the twist angle was also changed from 0 deg to 40 deg at intervals of 10 degrees.

Fig 4 shows a case scenario where the chord length is 82 mm i.e. the smallest and there is no twist angle.

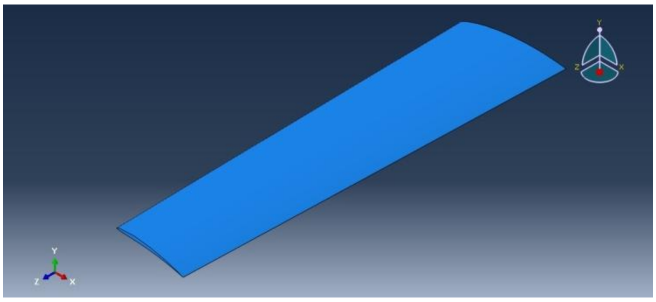

Fig 4CAD geometry for 0^0 twist and 82 mm chord length

The Von Mises stress is very important in the design and analysis of axial blades. The stress distribution of the wing depends on the shape of the wing. A load of 500 kPa is applied on the lower surface of the wing as shown in figure 5.

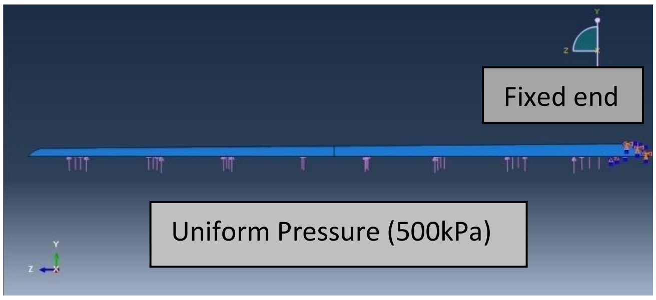

Fig5 Load on the wing

The wing is loaded with the same load and analyzed for different geometrical configurations. The graph in fig 6. Shows that as the chord length is increased from 82mm to 106 mm, the stress increases. The maximum stress is observed to be 3.4 MPa when the blade has no twist and has a chord length of 106mm. Fig 6 shows the stress variation with respect to the change in chord length.

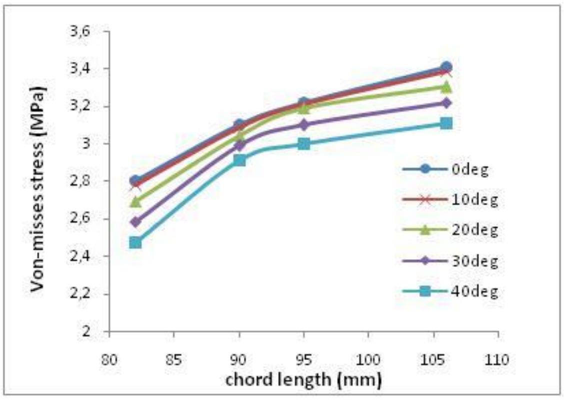

Fig 6 Stress variation with respect to change in chord length

Fig 7 shows that as we change the twist angle from 0 degree to 40 degree, the stress decreases as the angle is increased. The least stress is observed when the wing has a 40^0 twist and has an end chord length of 82mm. The minimum Von Mises stress observed is 2.4 MPa.

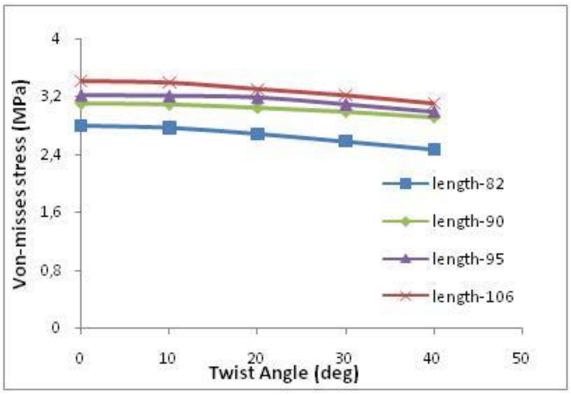

Fig 7 Stress variation with respect to change in twist angle.

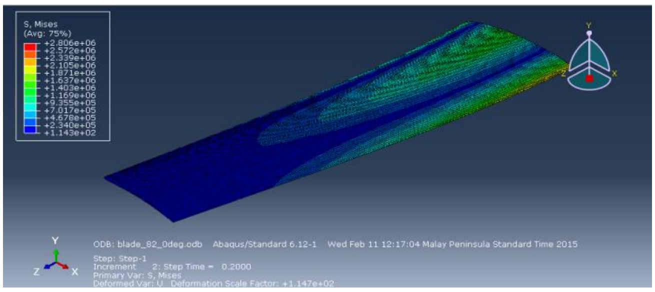

Fig 8 Stress variation over the blade with 0^0 twist and chord length 82mm

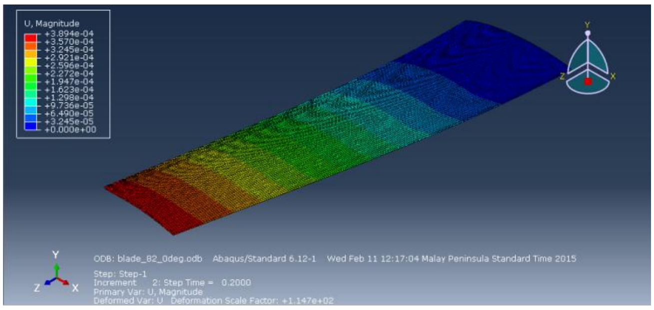

Fig9 Deflection of blade with 0^0 twist and chord length 82mm

IV. Conclusion

As the objective was to observe the variation of the Von Mises stress of NACA 5504 with respect to change in chord length and twist angle, the mentioned variables were examined using FEM. The length of the wing being studied is 446.5mm and made of aluminum.

A close investigation was done on previous experiments. Then the simulation was setup in ABAQUS software. The blade was subjected to different variations in chord length and twist angle and then it was subjected to the same pressure loading conditions.

Through a series of simulations, it was found that as the tip chord length is reduced i.e. with a higher taper ration, the Von Mises stress is increased and similarly, if the twist angle is increased, the stress is reduced. Hence, through this study, we can say that the configuration which has the least stress is that when the tip chord length is 82mm and the twist angle is 40^0.

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