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Design and Analysis of Propeller Blade for Aircrafts

R.J. Golden Renjith Nimal and A. Venkatesan

Abstract--- *In order to conserve natural resources and economize energy, weight reduction has been the main focus of aerospace manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The propeller blade is one of the potential items for weight reduction in aerospace as it accounts for 10% - 20% of the unspring weight. This achieves the aircraft with more fuel efficiency and improved riding qualities. The introduction of metal alloys was made it possible to reduce the weight of blade without any reduction on load carrying capacity and stiffness. Since, the composite has more elastic strain energy storage capacity and high strength to weight ratio as compared with those of aluminium, it can used as the blades for aerospace. Modelling and analysis of the composite blade will be done in this project.*

Keywords--- *Blade for Aircrafts, Design and Analysis, Composite Materials, Turboprop Aircraft.*

I. Introduction

1.1 Propeller Blade

An aircraft propeller converts rotary motion from a piston engine, a turboprop or an electric motor, to provide propulsive force. Its pitch may be fixed or variable. Early aircraft propellers were carved by hand from solid or laminated wood, while later propellers were constructed of metal. Modern designs use high-technology composite materials.

The propeller is attached to the crankshaft of a piston engine, either directly or through a reduction unit. A light aircraft engine may not require the complexity of gearing, which is essential on a larger engine or on a turboprop aircraft.

1.2 Theory and Design of Aircraft Propellers

A well-designed propeller typically has an efficiency of around 80% when operating in the best regime. The efficiency of the propeller is influenced by the angle of attack (α). This is defined as $\alpha = \Phi - \theta$, whereθ is the helix angle (the angle between the resultant relative velocity and the blade rotation direction) and Φ is the blade pitch angle.

Very small pitch and helix angles give a good performance against resistance but provide little thrust, while larger angles have the opposite effect. The best helix angle is when the blade is acting as a wing producing much more lift than drag.

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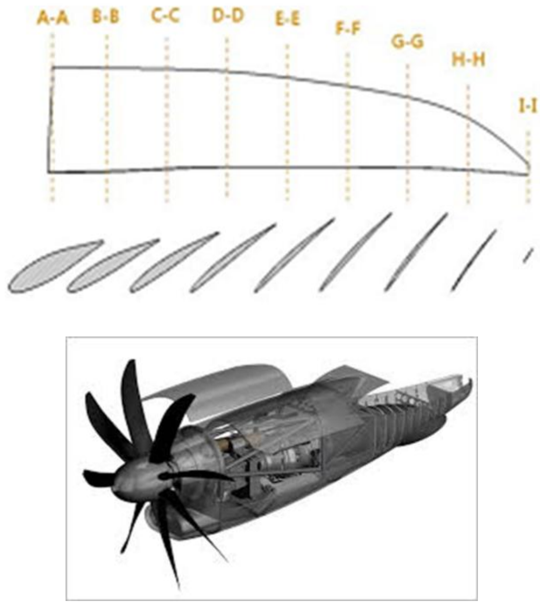


Fig 1.1: Airfoil Sections Of Propeller Blade

Propellers are similar in aerofoil section to a low-drag wing and as such are poor in operation when at other than their optimum angle of attack. Therefore some propellers use a variable pitch mechanism to alter the blades' pitch angle as engine speed and aircraft velocity are changed.

A further consideration is the number and the shape of the blades used. Increasing the aspect ratio of the blades reduces drag but the amount of thrust produced depends on blade area, so using high-aspect blades can result in an excessive propeller diameter.

A further balance is that using a smaller number of blades reduces interference effects between the blades, but to have sufficient blade area to transmit the available power within a set diameter means a compromise is needed. Increasing the number of blades also decreases the amount of work each blade is required to perform, limiting the local Mach number - a significant performance limit on propellers.

Fig 1.2: View of Propeller Blade

Table 1.1: Engine Specification

Rotation Speed [RPM]	980
Velocity [m/s]	142
Thrust [kN]	10.36
Power [HP]	2229
Efficiency	0.89
Diameter [m]	4.07
Number of Blades	8
Blade root chord [m]	0.347

Propeller's performance suffers as the blade speed nears the transonic. As the relative air speed at any section of a propeller is a vector sum of the aircraft speed and the tangential speed due to rotation, a propeller blade tip will reach transonic speed well before the aircraft does. When the airflow over the tip of the blade reaches its critical speed, drag and torque resistance increase rapidly and shock waves form creating a sharp increase in noise. Aircraft with conventional propellers, therefore, do not usually fly faster than Mach 0.6. There have been propeller aircraft which attained up to the Mach 0.8 range, but the low propeller efficiency at this speed makes such applications rare.

There have been efforts to develop propellers for aircraft at high subsonic speeds. The 'fix' is similar to that of transonic wing design. The maximum relative velocity is kept as low as possible by careful control of pitch to allow the blades to have large helix angles; thin blade sections are used and the blades are swept back in a scimitar shape (Scimitar propeller); a large number of blades are used to reduce work per blade and so circulation strength; contra-rotation is used. The propellers designed are more efficient than turbo-fans and their cruising speed (Mach 0.7–0.85) is suitable for airliners, but the noise generated is tremendous.

1.3 Forces Acting on a Propeller

Five forces act on the blades of an aircraft propeller in motion, they are:

- **Thrust bending force** - Thrust loads on the blades act to bend them forward.
- **Centrifugal twisting force** - Acts to twist the blades to a low, or fine pitch angle.
- **Aerodynamic twisting force** - As the centre of pressure of a propeller blade is forward of its centreline the blade is twisted towards a coarse pitch position.
- **Centrifugal force** - The force felt by the blades acting to pull them away from the hub when turning.
- **Torque bending force** - Air resistance acting against the blades, combined with inertial effects causes propeller blades to bend away from the direction of rotation.

1.4 Composite Material

A common example of a composite would be disc brake pads, which consist of hard ceramic particles embedded in soft metal matrix. Another example is found in shower stalls and bathtubs which are made of fiberglass. Imitation granite and cultured marble sinks and countertops are also widely used. The most advanced examples perform routinely on spacecraft in demanding environments. Wood is a natural composite of Cellulose fibers in a matrix of lignin.

The earliest man-made composite materials were straw and mud combined to form bricks for building construction. This ancient brick-making process was documented by Egyptian tomb paintings. Composites are made up of individual materials referred to as constituent materials. There are two categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. Engineered composite materials must be formed to shape. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mould cavity or onto the mould surface. The matrix material experiences a melding event, after which the part shape is essentially set. Depending upon the nature of the matrix material, this melding event can occur in various ways such as chemical polymerization or solidification from the melted state. A variety of molding methods can be used according to the end-item design requirements. The principal factors impacting the methodology are the natures of the chosen matrix and reinforcement materials.

Another important factor is the gross quantity of material to be produced. Large quantities can be used to justify high capital expenditures for rapid and automated manufacturing technology. Small production quantities are accommodated with lower capital expenditures but higher labour and tooling costs at a correspondingly slower rate. Many commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numerous variations. The most common are known as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, PEEK, and others. The reinforcement materials are often fibres but also commonly ground minerals. The various methods described below have been developed to reduce the resin content of the final product, or the fibre content is increased. As a rule of thumb, lay up results in a product containing 60% resin and 40% fibre, whereas vacuum infusion gives a final product with 40% resin and 60% fiber content. The strength of the product is greatly dependent on this ratio.

1.4.1. Characteristics

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Typical composite materials are composed of inclusions suspended in a matrix. The constituents retain their identities in the composite. Normally the components can be physically identified and there is an interface between them. Many composite materials offer a combination of strength and modulus that are either comparable to or better than any traditional metallic materials. Because of their low specific gravities, the strength weight-ratio and modulus weight-ratios of these composite materials are markedly superior to those of metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerances of many composite laminates excellent. For these reasons, fiber composite have emerged as a major class of structural material and are either used or being considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. Another unique characteristic of many fiber reinforced composites is their high internal damping.

This leads to better vibration energy absorption within the material and results in reduced transmission of noise and vibration to neighboring structures. High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort. Among the other environmental factors that may cause degradation in the mechanical properties of some polymeric matrix composites are elevated temperatures, corrosive fluids, and ultraviolet rays. In many metal matrix composites, oxidation of the matrix well as adverse chemical reaction between fibers and matrix are of great concern at high temperature applications.

1.4.2. Applications

Commercial and industrial applications of composite s are so varied that it is impossible to list them all. The major structural application areas, that include aircraft, space, automotive, sporting goods, and marine engineering. A potential for weight saving with composites exists in many engineering field. The first major structural application of composite is the corvette rear piston in 1981. A uni-leaf E-glass – reinforced epoxy has been used to replace a ten-leaf steel piston with nearly an 80 % weight savings.

Other structural chassis components, such as drive shafts and road wheels, have been successfully tested in the laboratories and are currently being developed for future cars and vans. The metal matrix composites containing either continuous or discontinuous fiber reinforcements, the latter being in the form of whiskers that are approximately 0.1-0.5 μm in diameter and have a length to diameter ratio up to 200. Particulate-reinforced metal matrix composites containing either particles or platelet that ranges in size from 0.5to 100 μm. Dispersion-strengthened metal matrix composites containing particles that are less than 0.1 μm in diameter. And metal matrix composites are such as directionally

II. METHODOLOGY

2.1 Methodology

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers.

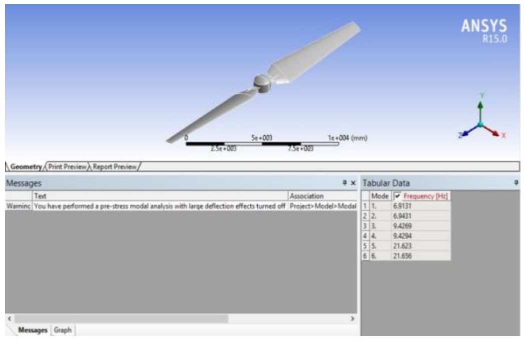


Fig 2.1: Design of Propeller Blade Using Ansys (A)

Similarly in the same preprocessor, finite element model (a.k.a. mesh) which is required for computation is generated. After defining loadings and carrying out analyses, results can be viewed as numerical and graphical.ANSYS can carry out advanced engineering analyses quickly, safely and practically by its variety of contact algorithms, time based loading features and nonlinear material models.

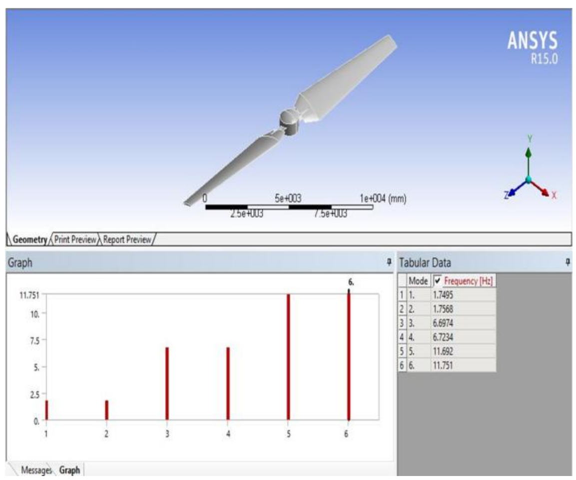


Fig 2.2: Design Of Propeller Blade Using Ansys(B)

ANSYS Workbench is a platform which integrates simulation technologies and parametric CAD systems with unique automation and performance. The power of ANSYS Workbench comes from ANSYS solver algorithms with years of experience. Furthermore, the object of ANSYS Workbench is verification and improving of the product in virtual environment.

2.1.1 Meshing

Meshing involves division of the entire of model into small pieces called elements. It is convenient to select the free mesh because the blade has sharp curves, so that shape of the object will not alter. To mesh the blade the element type must be decided first. Here, the element type is solid 45. The element edge length is taken as 5 mm. The numbers of elements are taken 2225 and the total numbers of nodes are 8099.

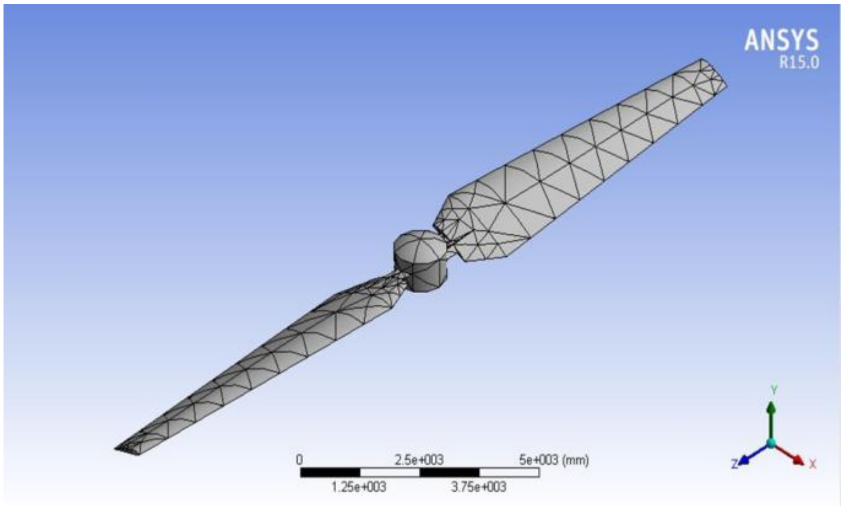
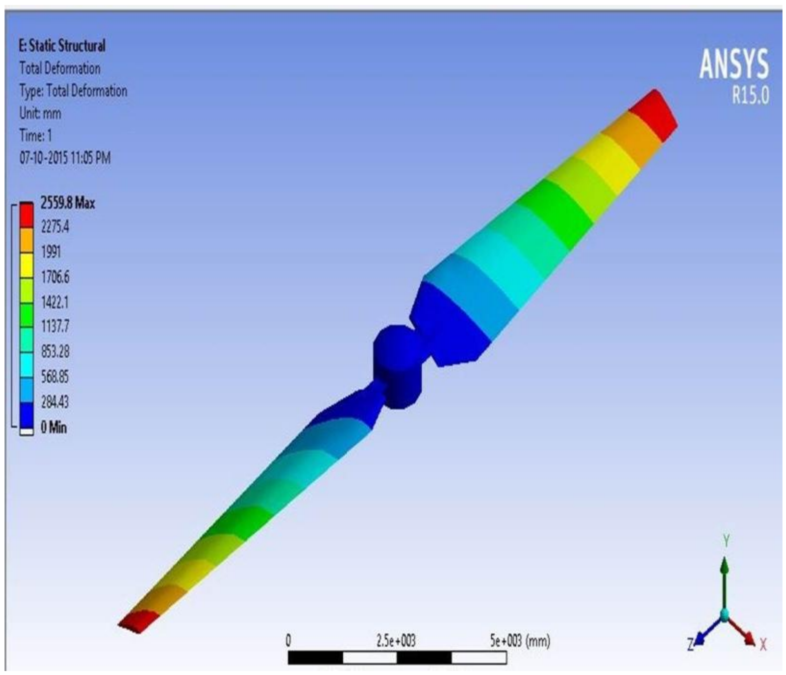


Fig 2.3: Meshed View of Propeller Blade



III. Boundary Conditions

The front eye of the blade is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the spring is connected to the shackle which is a flexible link the other end of the shackle is connected to the frame of the aircraft.

The blade is totally fixed at the centre with the help of bottom plate to the axel of aircraft. The force applied at both the eye end of blade. The link oscillates during load applied and removed. So the displacement at the both eye is constrained along the X and Z directions.

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IV. Results And Discussion

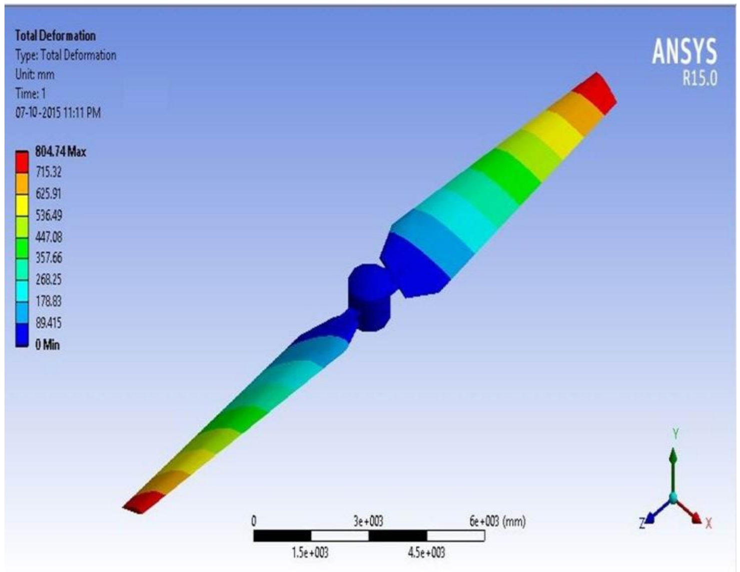

Fig 4.1: Stress Distribution of Aluminium Blade

4.1 Aluminiumblade Analysis

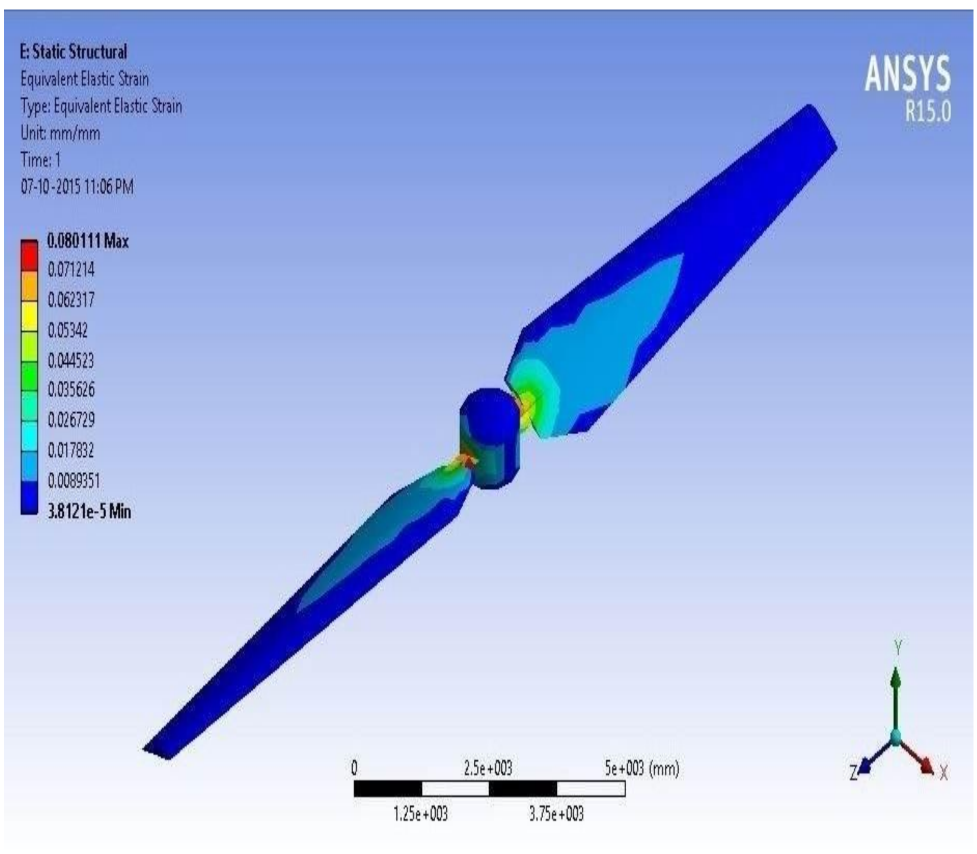

Fig 4.2: Elastic Strain Distribution of Aluminium Blade

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4.2 Epoxy Composite Material

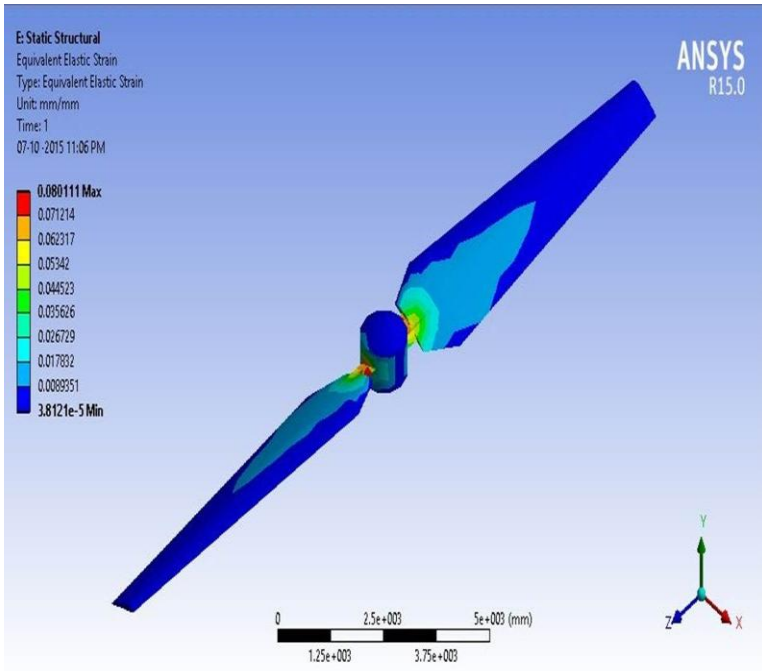

Fig 4.3: Stress Distribution of Epoxy Composite

4.3 Analysis Result

Material	**Aluminium**	**Composite**
Max StresMpa	1530	795
Equivalent Elastic Strain	0.02	0.08

Applications

Commercial and industrial applications of composites are so varied that it is impossible to list them all. The major structural application areas, which include aircraft, space, automotive, sporting goods, and marine engineering. A potential for weight saving with aluminium alloy s exists in many engineering field.

- More suitable for jet engines
- These alloys were targeted for applications which included conductive springs.
- These alloy can also be used for making machine elements, contacts and terminals for electronic, electric and automotive connectors and other electromechanical components.

4.4 Discussion

This study explains the various characteristics and properties of the composite. By means the literature survey it is well clear that the composite is best suitable for its properties. This project describes the latest and strongest alloy aerospace blade. The new alloy, containing 90% aluminium&10% zinc is an inexpensive substitute for aluminium. This work will show that successful analysis of an composite with 4 times weight reduction than aluminium.

4.5 Conclusion

The existing blade material is titanium having the density is: 4507 kg/ m^3 which having 250 Mpa of maximum stress. Some of the flights having aluminium blade material having density of 2700 kg/m^3 having stress value of 1530mpa in dynamic condition.

Composite material having maximum stress of 795 Mpa is more than the titanium but density 1700 kg/m^3 is less than the titanium.

So carbon epoxy composite blade having four times weight lesser than titanium.But stronger than titanium. Hence it is suitable for flight applications.

The weight of the composite material is 2 times less than aluminium material. Hence the riding comfort of an aerospace is increased due to the replacement of the aluminium material by composite material. No one to the best of knowledge has worked but qualitatively on how much improvement in fuel consumption/lit of passenger aircraft occurs and how much riding comfort improves.

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