Design and Analysis of Helicopter Rotor Spar using Composite Material

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***Abstract*— This thesis presents the analysis of the tail rotor spar of a helicopter. Here we design the helicopter tail rotor spar by modelling software. The spar consists of various parts with different materials. The materials we use here are carbon fiber, matrix composite and stainless steel. Helicopter engine manufacturers are always seeking to increase power and efficiency of their engine designs via lighter engine components. Current engine designs use traditional aircraft metal alloys that are pushed to their design limits of temperature and weight. The purpose of increasing engine specifications is to improve the efficiency of the helicopter .In this project we are going to compare the composite rotor spar with the generally using spar .The manufacture of rotor blades begins with the ultrasonic profiling of partially cured fiber reinforced plastics known as pre-pregs, which allows the production of advanced shaped and sectioned blades. Such components are virtually impossible to fabricate economically from metal**

Keywords—Helicopter rotor spar design, Composite material, Finite element analysis, Metal matrix composite.

I. INTRODUCTION

In the earlier days the helicopter tail rotor spar is manufactured using wood materials. But the material they use may differ. The helicopter tail rotor spar will cause accident when it fails to work properly. This may occur even when the spar is damaged. Helicopter engine manufacturers are always seeking to increase power and efficiency of their engine designs via lighter engine components. Current engine designs use traditional aircraft metal alloys that are pushed to their design limits of temperature and weight. The purpose of increasing engine specifications is to improve the efficiency of the helicopter. Here we have another solution to increase it. That is just by material of the rotor spar. Here we analyze the tail rotor spar of the helicopter by a metal matrix composite. Aerodynamic and inertia forces act on the helicopter blade in forward flight. These forces deform the helicopter blade and as a result, the aerodynamic forces distribution changes. The new aerodynamic forces distribution deforms the blade. In addition, that changes the aerodynamic forces distribution again. At a certain instant the aerodynamic and inertia forces and elasticity forces will be balanced.

The manufacture of rotor blades begins with the ultrasonic profiling of partially cured fiber reinforced plastics known as pre-pregs, which allows the production of advanced shaped and sectioned blades. Such components are virtually impossible to fabricate economically from metal. The contoured pre-pregs are then positioned, using a specific 'lay-up' pattern, within a mould. This is then closed, crushing the material into the desired shape and form, and an external hydraulic pressure is applied. Curing is completed by means of a computer-controlled process, during which the pressure is maintained and the temperature slowly increased to 125ºC. Finally, the blade construction is finished with the simple adhesion of the honeycomb core between the two constituent blade layers. Many other desirable properties and characteristics are achieved by the use of composites, including good strength-to-density ratios, which are four to six times greater than those of steel or aluminium. The specific modulus of certain composites is also far greater than those of steel and aluminium, leading to composite blades that are up to 45% lighter than their metal equivalents. In addition, complex blades are much easier to process and manufacture, are joined with adhesives, negating the need for riveting and simplifying assembly and can be produced using much cheaper tooling than for metals. Developments in composite materials such as carbon fiber have allowed the creation of rotor blades that far surpass their predecessors in every way, and continued research into new areas of Materials Science will no doubt improve on these blades in the future.

a. TAIL ROTOR

The tail rotor is a smaller rotor mounted vertically or near- vertically on the tail of a traditional single-rotor helicopter. The tail rotor either pushes or pulls against the tail to counter the torque. The tail rotor drive system consists of a drive shaft powered from the main transmission and a gearbox mounted at the end of the tail boom.

Fig 1.1 Helicopter tail rotor spar

The drive shaft may consist of one long shaft or a series of shorter shafts connected at both ends with flexible couplings. The flexible couplings allow the drive shaft to flex with the tail boom. The gearbox at the end of the tail boom provides an angled drive for the tail rotor and may also include gearing to adjust the output to the optimum rotational speed typically measured in revolutions per minute (rpm) for the tail rotor. On some larger helicopters, intermediate gearboxes are used to angle the tail rotor drive shaft from along the tail boom or tailcone to the top of the tail rotor pylon, which also serves as a vertical stabilizing airfoil to alleviate the power requirement for the tail rotor in forward flight.

II. FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a reliable numerical technique for analyzing engineering designs. FEM replaces a complex problem with many simple problems. It divides the model into many small pieces of simple shapes called elements.Elements share common points called nodes. The behavior of these elements is well-known under all possible support and load scenarios. The motion of each node is fully described by translations in the X, Y, and Z directions. These are called degrees of freedom (DOFs). Analysis using FEM is called Finite Element Analysis (FEA).

Ansys formulates the equations governing the behavior of each element taking into consideration its connectivity to other elements. These equations relate the displacements to known material properties, restraints, and loads. Next, the program organizes the equations into a large set of simultaneous algebraic equations. The solver finds the displacements in the X, Y, and Z directions at each node. Using the displacements, the program calculates the strains in various directions. Finally, the program uses mathematical expressions to calculate stresses.

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition.In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

There are generally two types of analysis that are used in industry: 2-D modelling, and 3-D modelling. While 2-D modelling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modelling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modelling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

III. MODELLING PROCEDURE

The modelling procedure is done with the modelling software Pro-E. In the 1st step the model is sketched with the required dimension. Various commands are used to sketch the model in the software.

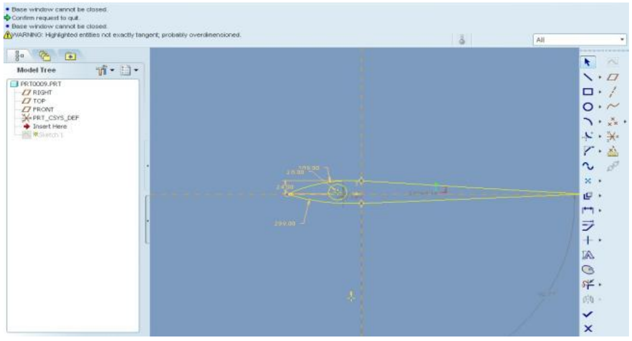

Fig 3.1 Sketch mode of tail rotor spar in pro-E

In the next step the model is being extruded by using the EXTRUDE command,Then the interior structures of the model is created.

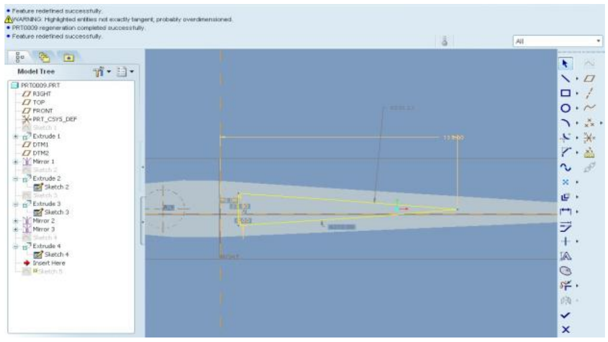

Fig 3.2 Creating the interior structure

After the creation of the interior structures, the shaft hole is created for the fixing of the shaft. The shaft is created using the CIRCLE command and then it is extruded, the extruded shaft is inserted in the shaft hole and then the final model is obtained.

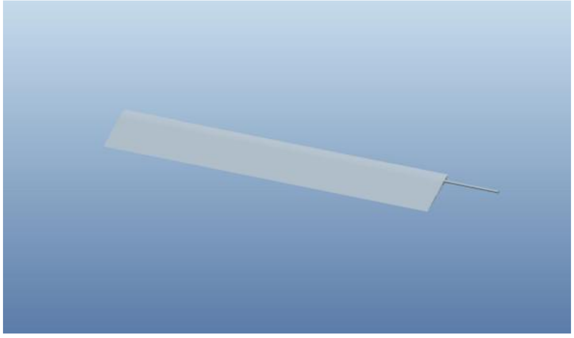

Fig 3.3 Spar model in PRO-E

Figure 3.3 shows the 3D view of the final model in Pro-E

IV. RESULTS AND DISCUSSION

The model designed in Pro-E is analysed using the Ansys v11.The analysing is carried out with the "conventional materials" and the "composite materials". Titanium alloy is taken as the conventional material and Carbon fiber is chosen as the composite material. The table 4.1 shows the material property of the composite material taken here.

a. Carbon Fibre (High Modulus)

Carbon fiber, alternatively graphite fiber or CF, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.

Mechanical Properties

Young's modulus(MPa)	E_1=4.0e+5,E_2=4.35e+4, E_3=3.9e+4
Poisson's ratio	v_{12}=0.36,v_{23}=0.38, v_{13}=0.353
Density	6000 kg/m^3
Shear modulus	1.4706e+5 MPa
Bulk modulus	4.7619e+5 MPa

Table 4.1 mechanical properties of carbon fiber

The model is analysed with the 2 material and then the Total deformation, Equivalent elastic strain and the Equivalent stress is found out. The following figures show the result for the analysis of the rotor spar.

ANALYSIS OF TITANIUM SPAR

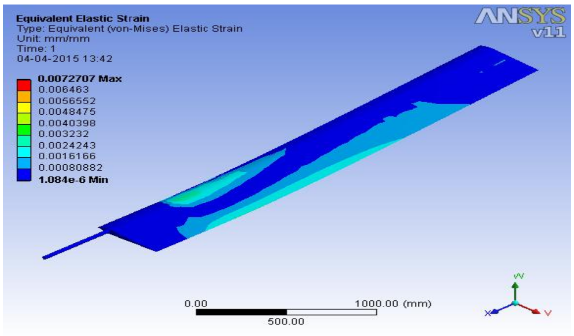

fig 4.1 Equivalent elastic strain of Ti

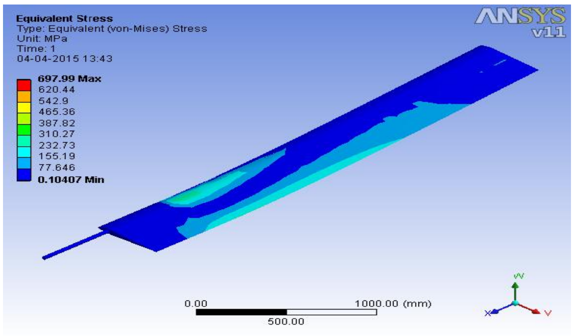

Fig 4.2 Equivalent stress for titanium alloy

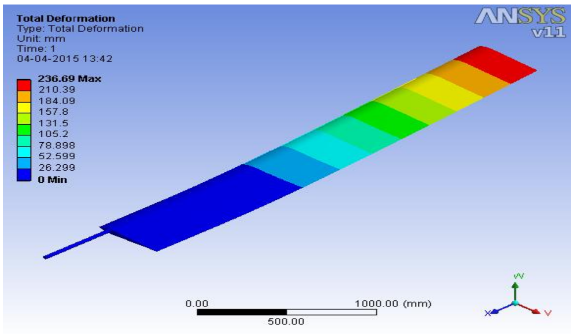

Fig 4.3 Total deformation of titanium

Fig 4.1, 4.2, 4.3 shows the equivalent elastic strain, equivalent stress and the total deformation of a Titanium alloy spar

ANALYSIS OF COMPOSITE SPAR

The material properties are applied in the software while doing the analysis of the composite materials.

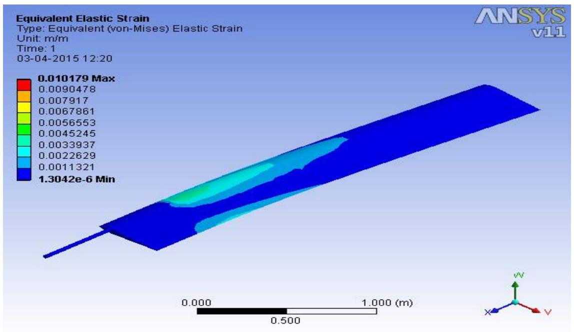

Fig 4.4 Equivalent elastic strain of Carbon fibre

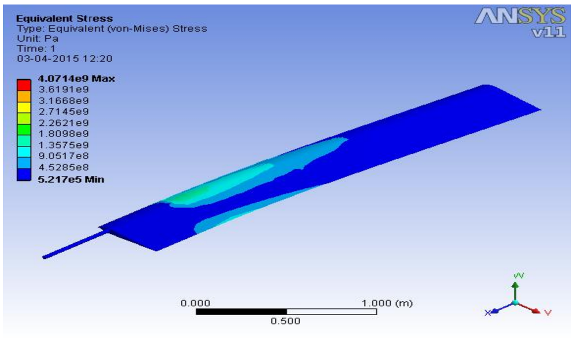

Fig 4.5 Equivalent stress of carbon fibre

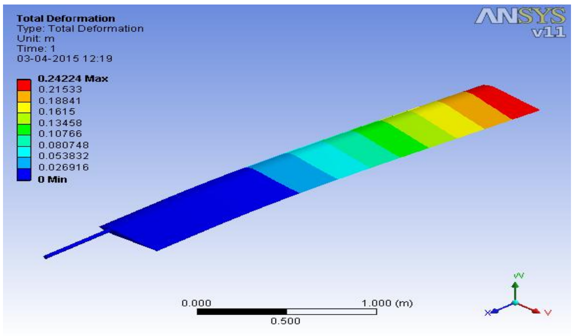

Fig 5.17 Total deformation of carbon fibre

RESULTS FOR CONVENTIONAL MATERIALS

S. N o.	Particulars	deformation (M)	Elastic Strain (M/M)	Equivalent Stress (Pa)
1	minimum	0	0	0
2	maximum	0.1525	0.0145	1.04e9

Table 5.1 Results for conventional materials

RESULTS FOR COMPOSITE MATERIALS

S. N o.	Particulars	deformation (M)	Elastic Strain (M/M)	Equivalent Stress (Pa)
1	minimum	0	0	0
2	maximum	0.03027 8	0.002488 5	9.95e8

Table 5.2 results for composite materials

By applying same load in both of the materials it is found that the composite material is more suitable than the conventionally using material, both pressure force and rotational velocity is applied in the rotor spar during the analysis procedure, the value obtained from the analysis is plotted in the above table (Table no 4.1 and 4.2).

CONCLUSION

Analyzing results from testing the helicopter rotor blade under pressure and force are listed in the Table. Analysis has been carried out by conventional and optimized helicopter tail rotor. The results such as total deformation, equivalent elastic strain and equivalent stress for each material are determined. Comparing the composite material and the conventional material, composite material has the low values of total deformation, stress and strain. Hence it is concluded that composite material is suitable for the helicopter rotor blade.

By this project we have learned 3Dmodelling software (PRO-E) and Study about the analyzing software (Ansys) to develop our basic knowledge to know about the industrial design.

FUTURE WORK

Optimization is an emerging area in the aviation industry. Most of the project which have been successful in the past are again opened up and optimized for much better results in all fields.

In our case the rotor spar is analyzed using 2 different composite materials. We have analyzed the Total deformation, equivalent strain and equivalent stress for the material and found that it has more advantages than the conventionally used materials.Hence the model can be further optimized in the future by using lighter materials and thereby reducing its overall weight. More advantageous composite material can be used to get better efficiency and good yield properties.

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