Structural Integrity Assessment of Helicopter Rotor Blade

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Abstract— A helicopter main rotor or rotor system is the combination of several rotary wings (rotor blades) and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight. A comprehensive study of the vibration phenomena includes determining the nature and extent of vibration response levels and verifying theoretical models and predictions. The main aim of this project is to extract the normal modes of a Helicopter's Main Rotor Blade and compare them for different materials such as Aluminum, Steel, Titanium and Composite using the finite element method. As using the modal analysis alone we cannot conclude the better material, static structural analysis is carried out using gravity loads to further give knowledge about the behavior of the blade in different material conditions, and there by evaluating the integrity of the design by this process.

Key words: Rotary Blades, Pro-E, ANSYS and Structural Analysis

I. Introduction

Advanced composite materials have been used in rotor blades mainly because of their high strength-to-weight ratio, but their superior damage tolerance and fatigue properties are also desirable [1]. Another more promising aspect of composites is their anisotropy, which allows designers substantial freedom to tailor the stiffness properties of structures. Currently, rotor blade designs utilize the unique elastic tailoring of composites to improve aero elastic response, to reduce vibratory loads, and to prolong fatigue life [2]. While the application of composites provides many opportunities to improve aircraft flight performance, the application of composites introduces a host of new challenges to researchers. Although rotor blades are designed with the properties of composites in mind, their full potential is far from being explored. The primary reason is that analysis methods for predicting the behavior of composite blade have not been validated to the point where the industry is comfortable to use them. Therefore, most rotor blade design optimization employs a simplified box-beam model. The results of such design are not accurate enough. Many necessary analyses and simulations have to be conducted after optimization. Once the detailed analysis denies a design resulting from the optimization, the design cycle has to start again. Therefore, the blade design requires a relatively long cycle [3]. Imperfections are inevitably introduced in manufacturing processes. As a result, structural dimensions, shapes, and material properties deviate from their desired values. Such deviations can substantially influence the performance of the aircraft structure. In recent years, such potential hazards have been realized by many researchers. Much work has been conducted to investigate and quantify the effects of uncertainties on the global response of fixed-wing aircraft. However, little work has been done on composite helicopter rotor blades. The primary reason is short of an efficient and high-fidelity tool. The uncertainty of structures and materials are small in aerospace industry due to the strict quality control. The tool must be capable of capturing the small changes of blade structure performance resulting from the small perturbations. To investigate and quantify the uncertainty influence, stochastic methods have to be employed that generally require thousands and millions of simulations to obtain confident solutions. Therefore, an efficient and high-fidelity tool is vital for this task [4].

The geometry generator can generate a typical realistic cross-section for helicopter blades, and the VABS tool can best achieve the balance between the accuracy and efficiency for rotor blade analysis. Based on this design tool, three comprehensive design procedures for composite rotor blades are proposed [5]. The first one is to incorporate manufacturing constraints into the design optimization. The next is a design method that integrates fatigue analysis into current rotor blade structural design optimization. Finally, the manufacturing uncertainty influence on rotor blade design is explored and a probabilistic design method is proposed to manage the uncertainty of blade structural performance.

II. Experimental Details

A. Material Used

- Aluminum
- Steel
- Titanium
- Composites

B. Profile of Blade

1) Main Rotor Blade dimensions

- Rotor Diameter = 25ft 2in
- Blade Chord (width) =7.2 in
- Blade Twist = 8°
- Tip Speed at 100 % RPM = 672 ft/s (458mph)

C. Material Properties

Material Properties			
Material	Young's Modulus (GPa)	Poisson's Ratio	Density(g/cm³)
Aluminium	70.3	0.35	2.7
Steel	208	0.3	7.84
Titanium	168	0.38	21.45
Composite	70	0.3	2.5

Table 1: Mechanical properties of the materials

As the materials used here to compare the results are Aluminum, Steel, titanium and composite. The Aluminum grade used here is 2024, as it is widely used in aerospace applications due to its light weight and high strength. In case of steel AISI 304 stainless steel has been considered for the analysis. Due to their high tensile strength to density ratio, high corrosion resistance, and ability to withstand moderately high temperatures without creeping, titanium alloys are used in aircraft, armor plating, naval ships, spacecrafts and missiles. Here as well titanium has been considered to be one of the materials for testing. And another material taken for these analyses include composite.

D. Modes of Different Materials

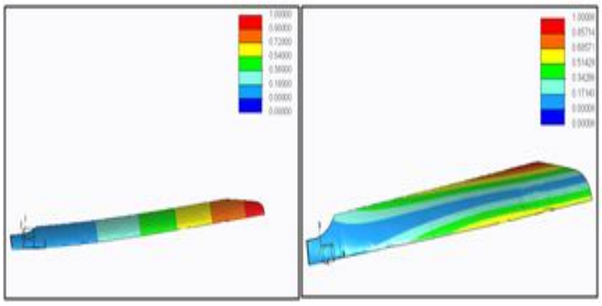

Fig. 1: Modes 1 & 5 of Aluminum

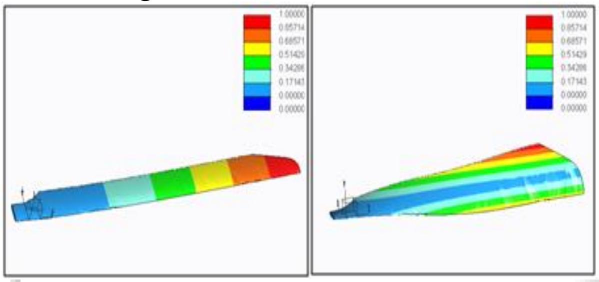

Fig. 2: Modes 1 & 5 of Titanium

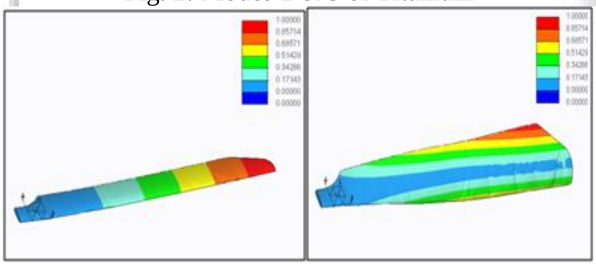

Fig. 3: Modes 1 & 5 of Composites

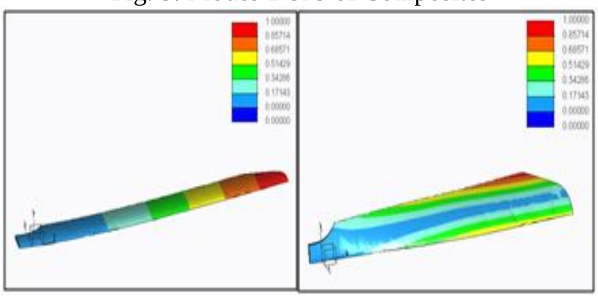

Fig. 4: Modes 1 & 5 of Steel

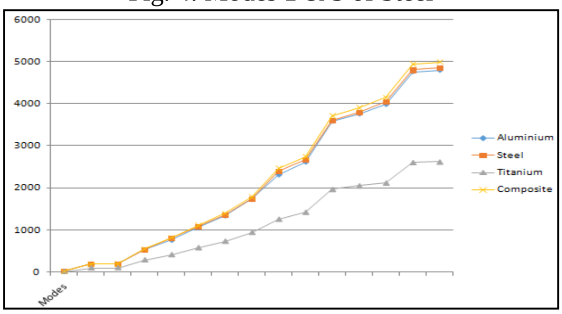

Fig. 5: Graph of mode frequencies of 4 materials

When the results window is opened, it shows all the frequencies obtained at different modes in the analysis carried out, which can be noted and used for plotting difference between the materials. Here, 1 & 5 modes are considered to plot the frequencies of the modes to obtain the graph and to be able to validate with the previously published data which has been used as reference here.

E. Structural Analysis of the rotary blade with pressure loading

Considering the constraints we have considered for modal and g load analysis, we have to apply the pressure load and start the analysis for each material. To apply the pressure on the surface, select the pressure tab on home screen of Creo simulate. Then select the surface on which pressure is to be applied and specify the pressure as shown in the figure below.

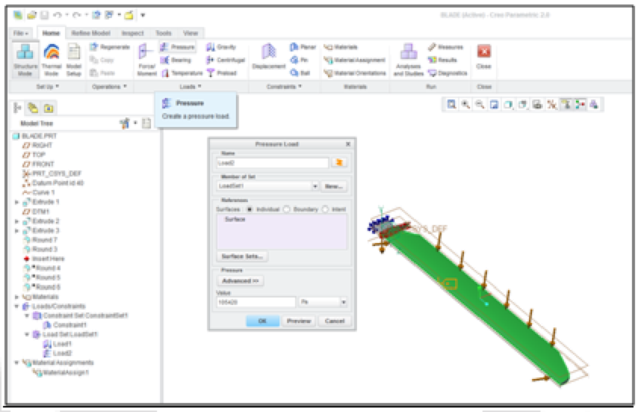

Fig. 6: Applying pressure load

Once the load is applied, the structural analysis is carried out for different materials by the method used in g load analysis. After the analysis carried out, the results are then viewed to check the stresses and displacements that are obtained on different materials.

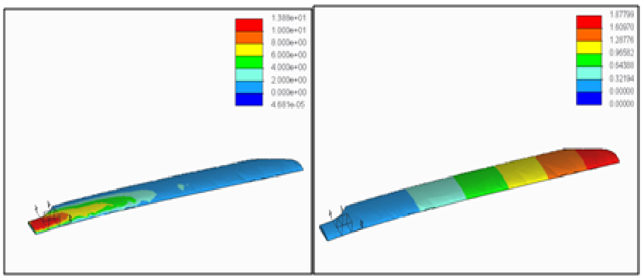

Fig. 7: Stress and Displacement results of Aluminum

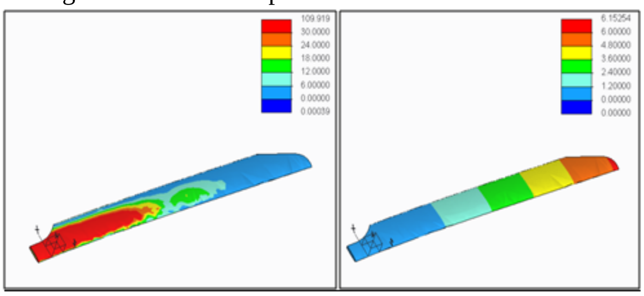

Fig. 8: Stress and Displacement results of Titanium

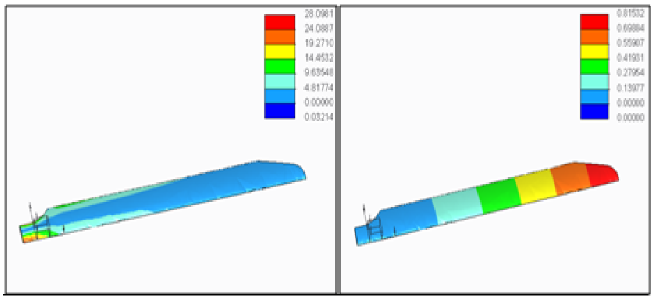

Fig. 9: Stress and Displacement results of composites

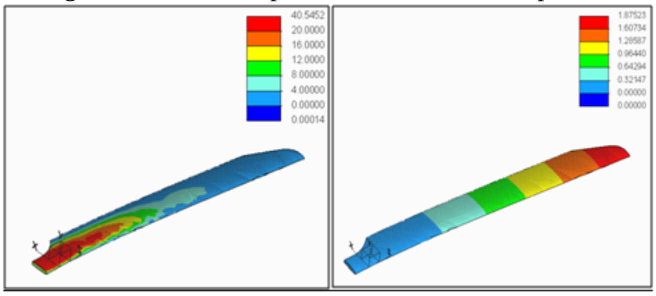

Fig. 10: Stress and Displacement results of steel

As the materials used here to compare the results are Aluminum, Steel, titanium and composite. The Aluminum grade used here is 2024, as it is widely used in aerospace applications due to its light weight and high strength. In case of steel AISI 304 stainless steel has been considered for the analysis. Due to their high tensile strength to density ratio, high corrosion resistance, and ability to withstand moderately high temperatures without creeping, titanium alloys are used in aircraft, armor plating, naval ships, spacecrafts and missiles. Here as well titanium has been considered to be one of the materials for testing.

Pressure load analysis		
Material	Von Mises Stress (MPa)	Displacement (mm)
Aluminium	28.36	0.829
Steel	30.5	0.411
Titanium	44.65	1.254
Composite	28.09	0.815

Table 2: Displacement and stress Results of Pressure Load analysis

The above table shows the maximum displacement and maximum Von Mises stress obtained on the blade for different materials. From this we can clearly see that composite has the least stress and displacement compared to the other three and also we see that although steel has more strength compared to aluminum, it experiences more stresses than aluminum. And the material titanium even proves not so good in this analysis as well. So, rightfully the glass filled fiber composite is stronger even in case of pressure load analysis case.

III. Conclusions

The research focused on the structural integrity evaluation of the helicopter rotor blade with respect to different material conditions using different analysis modes. It is an attempt to evaluate all the materials available which can be used against the widely used material which is glass filled fiber composite.

As the different analyses were carried out, it yielded that in each of the analysis cases, there was different form of results obtained. As it was clear that titanium cannot be used for a rotor blade design, as it had the least required results when compared to all the three materials. In the modal analysis case, we saw that the results stated steel was better compared to aluminum, but if we check the g load and pressure load analysis, aluminum is more feasible when it comes to rotor blade design. And as the g load and pressure load analysis are the working conditions applied, the results would suggest the use of Aluminum ahead of steel. Although these two materials have their strengths and weaknesses, glass filled fiber composite proved to be the best in all the three cases of analysis and stands out in all the analysis procedures performed.

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