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Modeling and Analysis of a 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 “ALUMINIUM and STEEL” using the finite element method.***

Keywords: Catia, Hyper mesh, Ansys 14.5.

1. Introduction

A helicopter is a type of rotorcraft in which lift and thrust are supplied by rotors. This allows the helicopter to take off and land vertically, to hover, and to fly forward, backward, and laterally. These attributes allow helicopters to be used in congested or isolated areas where fixed-wing aircraft and other forms of vertical takeoff and landing aircraft cannot perform. The word helicopter is adapted from the French language hélicoptère, coined by Gustave Ponton d'Amécourt in 1861, which originates from the helix/helik- "twisted, curved" and pteron "wing". English-language nicknames for helicopter include "chopper", "helo", "heli" and "whirlybird"

Helicopters were developed and built during the first half-century of flight, with the Focke-Wulf Fw 61 being the first operational helicopter in 1936. Some helicopters reached limited production, but it was not until 1942 that a helicopter designed by Igor Sikorsky reached full-scale production, with 131 aircraft built. Though earlier designs used more than one main rotor, it is the single main rotor with anti-torque tail rotor configuration that has become the most common helicopter configuration. Tandem rotor helicopters are also in widespread use due to their greater payload capacity. Quad rotor helicopters and other types of multi copter have been developed for specialized applications such as unmanned drones.

2. Literature Survey

The earliest references for vertical flight have come from China. Since around 400 BC,Chinese children have played with bamboo flying toys. The bamboo-copter is spun by rolling a stick attached to a rotor. The spinning creates lift, and the toy flies when released. The 4th-century AD Daoist book Baopuzi by Ge Hong "Master who Embraces Simplicity" reportedly describes some of the ideas inherent to rotary wing aircraft.

In 1861, the word "helicopter" was coined by Gustave de Ponton d'Amécourt, a French inventor who demonstrated a small, steam-powered model. While celebrated as an innovative use of a new metal, aluminum, the model never lifted off the ground. D'Amecourt's linguistic contribution would survive to eventually describe the vertical flight he had envisioned. Steam power was popular with other inventors as well. In 1906, two French brothers, Jacques and Louis Breguet, began experimenting with airfoils for helicopters.

In 1907, those experiments resulted in the Gyroplane No.1. Although there is some uncertainty about the dates, sometime between 14 August and 29 September 1907, the Gyroplane No. 1 lifted its pilot into the air about two feet (0.6 m) for a minute. The Gyroplane No. 1 proved to be extremely unsteady and required a man at each corner of the airframe to hold it steady. For this reason, the flights of the Gyroplane No. 1 are considered to be the first manned flight of a helicopter, but not a free or un-tethered flight.

Tandem rotors are two horizontal main rotor assemblies mounted one behind the other with the rear rotor mounted slightly higher than the front rotor. Tandem rotors achieve pitch attitude changes to accelerate and decelerate the helicopter through a process called differential collective pitch. To pitch forward and accelerate, the rear rotor increases collective pitch, raising the tail and the front rotor decreases collective pitch, simultaneously dipping the nose. To pitch upward while decelerating (or moving rearward), the front rotor increases collective pitch to raise the nose and the rear rotor decreases collective pitch to lower the tail. Yaw control is developed through opposing cyclic pitch in each rotor; to pivot right, the front rotor tilts right and the rear rotor tilts left, and to pivot left, the front rotor tilts left and the rear rotor tilts right.

Coaxial rotors are a pair of rotors turning in opposite directions, but mounted on a mast, with the same axis of rotation, one above the other. The advantage of the coaxial rotor is that, in forward flight, the lift provided by the advancing halves of each rotor compensates for the retreating half of the other, eliminating one of the key effects of dissymmetry of lift; retreating blade stall. However, other design considerations plague coaxial rotors. There is an increased mechanical complexity of the rotor system because it requires linkages and swash-plates for two rotor systems.

3. Approach

3.1 Design of a blade

Achieving fairly low maximum lift coefficients. The viscous drag component, represented approximately by the coefficient $C_{d0,}$ minimized by carefully controlling the airfoil pressure distribution and maximizing the chord wise extent of laminar flow, at least for a range of low to moderate lift coefficients.

Also, environmental factors tend to produce insect accretion and blade erosion at the blade leading edge, which can cause premature boundary layer transition and reduce the run of laminar flow in any case. In some circumstances surface roughness can adversely alter other aspects of the airfoil characteristics such as by lowering Cl_{max} and changing the stall characteristics.

A powerful parameter affecting the profile power of the rotor is the airfoil thickness. Using 2-D airfoil measurements given by Abbott and Von Doenhoff 1949, the zero-lift sectional drag coefficient for NACA 0012symmetric series can be approximated by the equation

$$C_{d0} \simeq 0.007+(t/c)$$

Where t/c is the thickness-to-chord ratio

The result is valid in the range 0.06 <= t/c >= 0.24. The effects of Mach number compound the behavior of the drag, but at moderate angles of attack below the drag divergence Mach numbers the effects of compressibility are small and are more sensitivity to Reynolds numbers.

Assume, for example that a blade tapers in thickness from an airfoil with a 12% thickness-to-chord ratio at root to an 8% ratio at the tip. Therefore, using above Equation the drag coefficient can be written as

$C_{d0}(r)=0.007+0.025(0.12-0.04r)=0.01-0.001r$

The profile power coefficient can now be estimated using the blade element model where

$C_{p0} = \frac{1}{2}$ sigma $\int_0^1 c_{d0}\, r^3 dr = \frac{1}{2}$ sigma $\int_0^1 (0.01-0.001r)\, r^3$ dr.

An 8% reduction in profile power without use of thickness variation. Rotor power or shaft torque, this would offer a 0.5-1.5% increase in overall vertical lifting capability

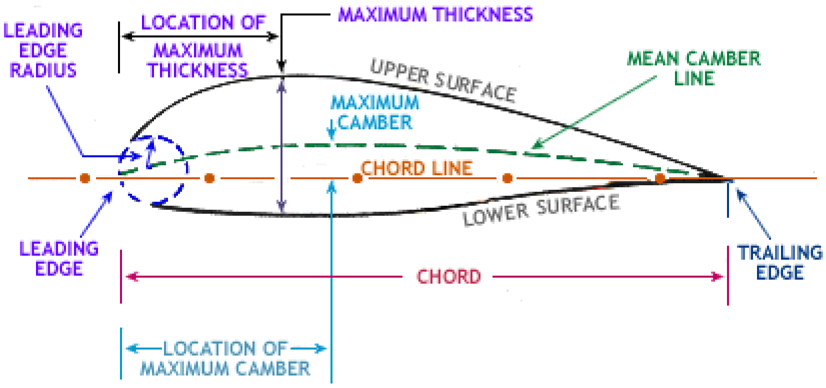

Figure 1: cross-section of airfoil

Main Rotor Blade dimensions

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

4. Methodology

4.1 Profile Blade

NACA-0012
Maximum camber (%) = first digit 0 to 9.5 %
Maximum Camber position (%) = second digit 0 to 90 %
Thickness (%) = 1.2 (Third and Fourth digits 1 to 40 %

4.2 Thickness Distribution

$\mathbf{y_t = T/0.2\, (a_0x^{0.5}+a_1x^2{}_{+}a_3x^3+a_4x^4)}$

$a_0 = 0.2969$
$a_1 = -0.126$
$a_3 = 0.2843$
$a_4 = -0.105$ (or) -0.1036

Where T/0.2 is to adjust the count required thickness a_0 to a_4 for 20% thickness airfoil At the trailing edge (x=1) there is a finite thickness of 0.0021 chord width for a 20% airfoil.

The Value y_t is a half thickness and needs to applied both side of the camber line using the equation both side of the camber line using the equation above for a given value of a. it is possible to calculate the camber line position y_c the gradient of camber line and the thickness The position of the Upper and Lower surface can be calculated perpendicularly to the camber line $\Theta = a \tan (dy_c/dx)$

Upper surface : $x_4 = x_c - y_c \text{sing}\, (\Theta)$
$Y_4 = y_c + y_t \cos (\Theta)$

Lower surface : $x_1 = x_c + y_c \cos (\Theta)$
$Y_1 = y_c - y_t \sin (\Theta)$

After substituting all the value we get symmetrical airfoil as shown fig below

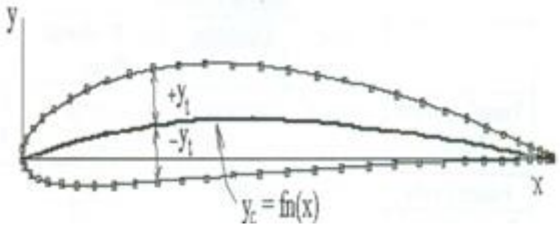

Figure 2: NACA0012 sectional shape

Air Density, ρ (slug/ft^3)	**No. of Blades in Main Rotor, N_b**	**Helicopter Gross Weight(s), W (lb)**	**Main Rotor Blade Radius, R (ft)**
.00223789(ρ_{SL})	4	4500, 4086	17.5

Table 1: Aerodynamic Characteristics

Main Rotor Solidity Ratio, σ	Blade Twist, θtw (degree)	Rotor Shaft Tilt, α_s(degree)	Blade Precone, βp (degree)	Rotor Disk Area, A (ft^2)
0.057	-8	5	2	962

Material Properties

	STELL	Aluminium
Young's Modulus N/mm^2	2.080*10^5	68.3*10^3
Poission's Ratio	0.3	0.34
Density Kg/mm^3	7.84*10^{-5}	2.67*10^5

Table 2: Material Properties

4.3 Modeling and Analysis

4.3.1. Catia

CATIA (Computer Aided Three-dimensional Interactive Application) multiplatform CAD/ CAM/ CAE commercial software suite developed by the French company DassaultSystèms. Written in the C++programming language, CATIA is the cornerstone of the DassaultSystèmes product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Creo Elements/Pro and NX (Unigraphics). CATIA (Computer Aided Three-Dimensional Interactive Application) started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CAD/CAM CAD software to develop Dassault'sMirage fighter jet. It was later adopted in the aerospace, automotive, shipbuilding, and other industries. Initially named CATI (Conception Assistée Tri-dimensional Interactive – French for Interactive Aided Three-dimensional Design), it was renamed CATIA in 1981 when Dassault created a subsidiary to develop and sell the software and signed a non-exclusive distribution agreement with IBM.

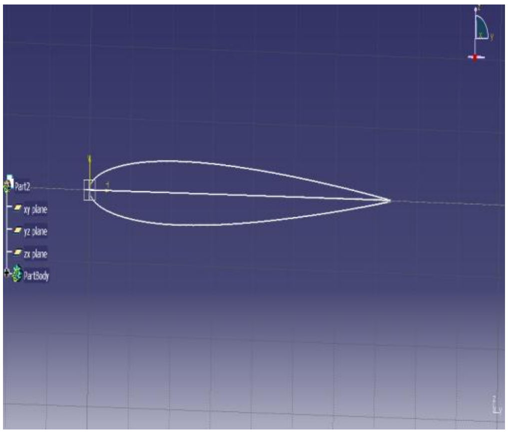

Figure 3: NACA0012 airfoil design

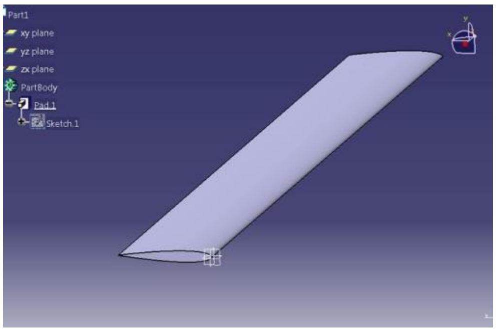

Figure 4: NACA0012 airfoil extruded part

4.3.2 Meshing

Altair Engineering is a product design and development, engineering software and cloud computing Software Company. Altair was founded by James R Scapa, George Christ, and Mark Kistner in 1985. Over its history, it has had various locations near Detroit, Michigan, USA. It is currently headquartered in Troy, Michigan with regional offices throughout America, Europe and Asia.

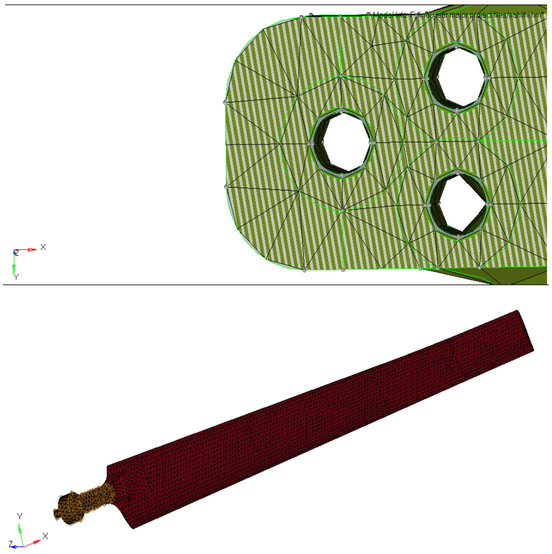

Figure 5: NACA0012 Meshed part

5. Results

The default mode extraction method chosen is the Reduced Method. This is the fastest method as it reduces the system matrices to only consider the Master Degrees of Freedom. The Subspace Method extracts modes for all DOF's. It is therefore more exact but, it also takes longer to compute (especially when the complex geometries). In this 15 nodes have been selected and at those nodes the frequency is calculated.

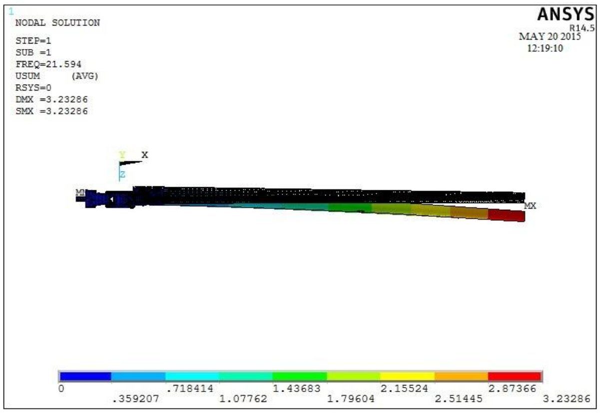

Figure 6: Contour Plot Step 1 of Steel and Aluminum

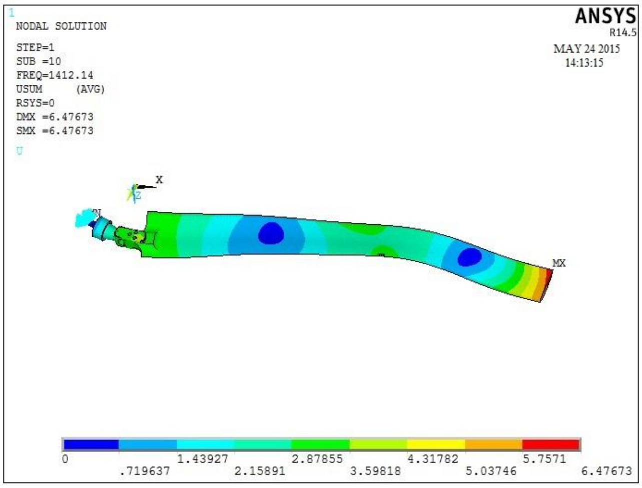

Figure 7: Contour Plot at Step 10 of Steel

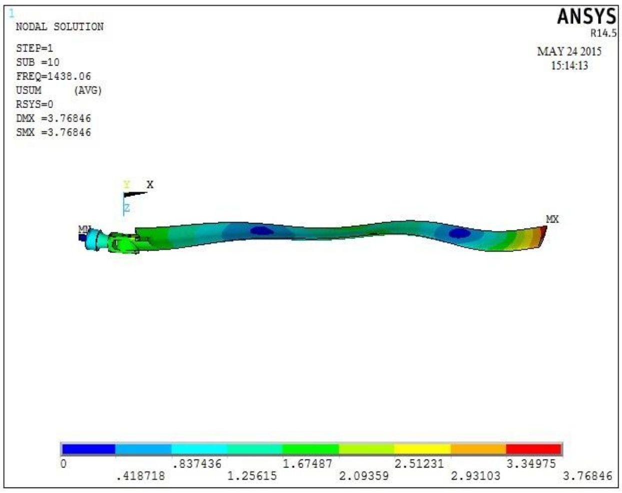

Figure 8: Contour Plot at Step 10 of Aluminum

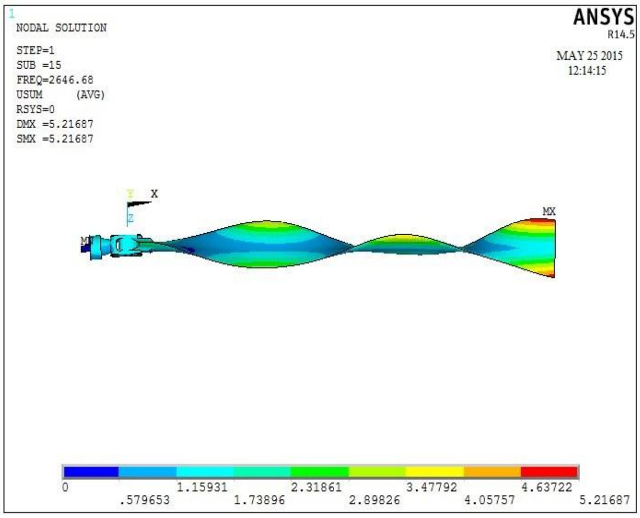

Figure 9: Contour Plot at Step 15 of Aluminum

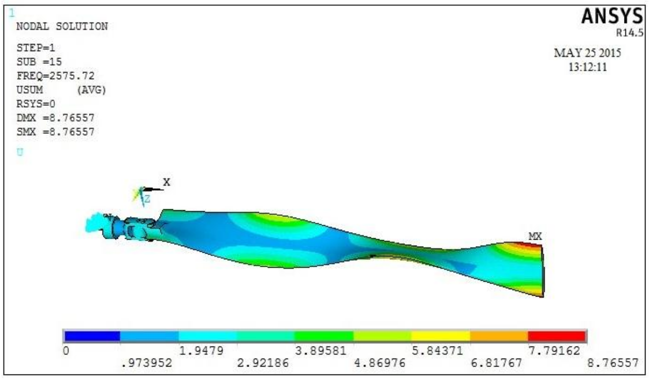

Figure 10: Contour Plot at Step 15 of Steel

Table 3: Frequency between Steel and Aluminum

S.NO	STEEL	ALUMINIUM
1	21.594	21.283
2	25.705	25.368
3	104.342	102.577
4	282.731	277.704
5	439.456	424.4
6	568.3	558.127
7	598.939	588.256
8	956.141	938.513
9	1054.96	1021.27
10	1438.06	1412.14
11	1459.02	1432.86
12	1842.7	1783.45
13	2062.59	2025.72
14	2500.54	2451.82
15	2646.68	2575.72

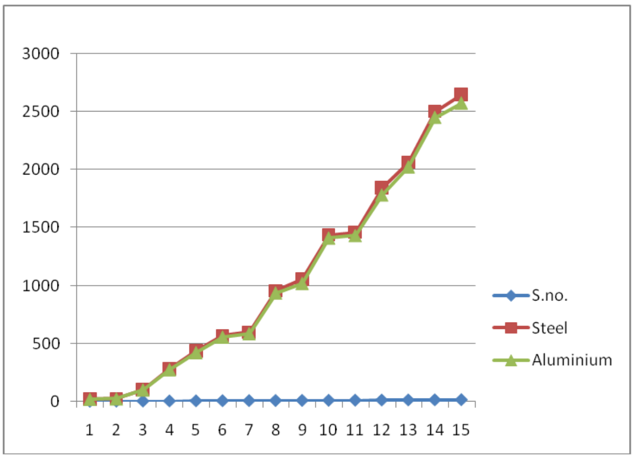

Figure 11: Graph for Steel and Aluminum

6. Conclusion

The helicopter rotor assembly is having four blades and all are symmetry. So one blade or sector model is considered for this study. An analysis is performed with two different materials such as steel and aluminum. The natural frequencies are extracted up to 15 modes. The mode shapes are analyzed for all frequencies and compared both cases. The results are pretty good and well comparable. There is no significant difference in frequencies but at higher modes steel is having higher frequencies. If we compare the weight and effectiveness of modes for both Steel and Aluminum, Aluminum is lighter weight, nearly same stiffness and frequencies. Finally it is concluded from this analysis is that the aluminum is better option as per normal mode analysis prospective.

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