Modeling and Analysis of a Helicopter Rotor Blade

K. Simhachalam Naidu¹, M. Sriram², B. Shishira Nayana³

Associate Professor, Department of Aerospace Engineering, PG Scholar, MLR Institute of Technology, Hyderabad, India

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 ‘HELI OPTER’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 using the finite element method. 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.

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'Amécourt's linguistic contribution would be to eventually describe the vertical flight he had envisioned. In 1906, two French brothers, Jacques and Louis Breguet, began experimenting with airfoils for helicopters.

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 \( C_{\text{lmax}} \) 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 0012 symmetric series can be approximated by the equation

\[
C_{d0} \approx 0.007 + (t/c)
\]

Where \( t/c \) is the thickness-to-chord ratio.

The result is valid in the range \( 0.06 \leq t/c \leq 0.24 \). 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

\[
C_{p0}=\frac{1}{2}\sigma \int_{0}^{1} \frac{c}{d0}r^3 dr=\frac{1}{2}\sigma \int_{0}^{1} (0.01-0.001r) r^3 dr.
\]

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](image1)

### 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

\[
y_1 = T/0.2(a_0x^{0.5}+a_1x^2+a_2x^3+a_3x^4)
\]

\[
a_0 = 0.2969
\]

\[
a_1 = -0.126
\]

\[
a_2 = 0.2843
\]

\[
a_3 = -0.105 (or) -0.1036
\]

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.

![Figure 2: NACA0012 sectional shape](image2)
### Table 1: Aerodynamic Characteristics

<table>
<thead>
<tr>
<th>Air Density, ( \rho ) (slug/ft(^3))</th>
<th>No. of Blades in Main Rotor, ( N_b )</th>
<th>Helicopter Gross Weight(s), ( W ) (lb)</th>
<th>Main Rotor Blade Radius, ( R ) (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( .00223789(\rho_{SL}) )</td>
<td>4</td>
<td>4500, 4086</td>
<td>17.5</td>
</tr>
</tbody>
</table>

### Table 2: Material Properties

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>STEEL</th>
<th>Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus N/mm(^2)</td>
<td>( 2.080\times10^5 )</td>
<td>( 68.3\times10^3 )</td>
</tr>
<tr>
<td>Poission’s Ratio</td>
<td>0.3</td>
<td>0.34</td>
</tr>
<tr>
<td>Density Kg/mm(^3)</td>
<td>( 7.84\times10^{-5} )</td>
<td>( 2.67\times10^{-5} )</td>
</tr>
</tbody>
</table>

### 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 DassaultSystèmes. 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's Mirage 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.

#### 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.

### 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.
Table 3: Frequency between Steel and Aluminum

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

References


Author Profile

M.Sriram pursuing Master’s degree in Aerospace engineering from M.L.R college of Engineering and Technology (2013-2015). he received Bachelor’s degree in Aeronautical Engineering from MNR College of Engineering and Technology, JNTU Hyderabad in 2013. Interested in Aerodynamic analysis and under gone the internship program in CFD with ALTAIR Acu-slove in 2013.