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STRUCTURAL ANALYSIS OF WING IN GROUND CRAFT ROTOR BLADE USING CARBON COMPOUNDS

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ABSTRACT

Structural analysis plays a crucial role in designing safe aerospace vehicles, and this analysis was carryout by the underlying principles of a simplified beam theory known as the “Euler Bernoulli Theory.” Wing in ground craft (WIC) blade material composition was analysed using data from Yang and Ying (2012). From this, mathematical relationships between displacement of a WIC blade and the loading under which it was applied, allowing us to compute factors important for selecting the most suitable material. A factor of safety (FOS) 1.5 was predicted as a benchmark for accepting material composition of rotor blade. Tampered carbon and uniform carbon compounds had safety factor of 5.319 and 7.98 respectively. The results obtained shows that the blade root stress of the individual material ranges from 0.07144 to 0.1072GPa and graphs of axial displacement of Rotor blade were plotted. The speed of 305rpm and blade length of 1.2m, different rotor blade material compositions can be selected by using FOS, stress and axial displacement rotor blade.

Keywords:Wing in Ground Craft; MATLAB; Composite Material;Euler Bernoulli Theory

1.0 Introduction

Wing in ground effect is quite a new concept of designing fast ships, which has vast relevance in numerous areas such as transportation of cargo, tourism, rescue operations, and military functions. WIG craft gives an alternate solution to gain higher speed. The ground effect (GE) is a phenomenon where the lift-to-drag ratio of a body will increase while it is cruising at a very close distance to the surface of water or ground. Volkov and Russetsky (1995) widely discussed useful characteristics of WIG craft. The development of WIG crafts originated from observations made of the landing performance of aircraft in 1920's. Later USA and the USSR became interested in attempting to exploit the potential benefits of ground effect. The USA abandoned efforts to produce ground effect craft in the mid 1960's as they were more interested in surface effect ship development. Germany began work in the late 1960's using the designs of Alexander Lippisch.

Ganguli (2013) depicted the of enhanced design of composites by Khot et al. (1973) as "promising research", the 1980s as "early research", the 1990s as "moving towards design", the 2000s as "the new century" and from 2010 to present as "current research". In revolutionary research period, goals and limitations were associated with strain energy movement, panel buckling, weight, strength, frequency, displacement, epoxy matrices and fibres and ply angles distribution and laminated design (Bert, 1977; Starnes and Haftka, 1979).

The rotor framework offers the lift and land capability. Consistent with standard of WIC procedure, the main load sustaining constituent is the rotor blades (Glaz et al., 2006). To arrive at structural analysis result of rotor blades, VABS and Abaqus are employed. VABS utilizes material properties and complement matches of blade cross-section to ascertain stiffness pattern which at that point can be utilized to gauge material features such as lead-lag torsion, flap torsion couplings and extension torsion. VABS produces Timoshenko stiffness matrix with the asymptotic energy (Kovalovs et al., 2007). So as to enhance the rotor blade functioning, cross-sections of the box beams, which is fabricated out of laminated composite plies, must be reviewed (Williams, 2017). Researchers profited by circumferentially uniform stiffness (CUS) and circumferentially asymmetric stiffness (CAS) composite enabled designs for a slender walled beam (Berdichevsky et al., 1992; Chun et al., 2006; Warminski et al., 2014; Beshay et al., 2015).

Present day rotor blades are fabricated from improved composite material because of greater stiffness/mass ratio, higher fatigue properties as well as capacity of aero-elastic shaping. Improved composite materials have been used in rotor blades commonly because of their high strength to-weight proportion, yet their usual damage tolerance and depletion exhaustion are likewise appealing. Another particularly reassuring piece of composites is their anisotropy, which offers designers ample chances to outline the stiffness properties of structures. At present, rotor blade structures use a unique adaptable fitting of composites to amplify aero-elastic reaction, to lessen vibratory loads, and to prolong exhaustion life (Cesnik and Hodges, 1997).

2.0 Research Gap

Analyse the structure of a WIC blade is quite challenging relying on Euler Bernoulli beam theory. A central concern during this work was to acquire data to test this theory. Yang and Ying, (2012) was of remarkable assistance with making accessible the data of a WIC. Lekou and Philippid is, (2009) showed the probabilistic design and evaluation of composite rotor blade strength. Kim and Sarigul-Klijn (2001) developed a multidisciplinary enhancement method that strived for minimum load and vibration and most maximum material property of the blade with threshold avoid uncertainty. Soykasap (1999) focused on aero-elastic enhancement for composite tilt rotor blades used in rotor craft. Nowadays, rotorcrafts make use of composite materials to enhance the aero-elastic functioning of rotor blades. Composite rotor blades developed to fabricate helicopter and WIC blades are normally shaped as arched and twisted anisotropic beams from the start. Hodges, (1990) examined the initial phase of modelling procedures for composite rotor blades. The concern of the blade stress rising at a rate that is comparable to blade displacement was deal with by assuming that rotor blade is linear-elastic material. Due to time confinement, constant deformation was not computed at this point rather cross-sectional inelastic body deformation was looked at wherein it was observed that the structure or volume of the cross section static in response to an external load. The inconveniences of examination and construction of fabricated composite forms indicate several unique deficiencies, such as, ply waviness in coated materials, affecting the variability of sectional properties.

Additionally, the maintenance loads of rotor blades are uncertain in actual fact. To balance the risk of uncertainties, a safety factor is fixed in the design process. The problem with the safety factor is that it cannot affirm how secured the piece will be in a certain loading state. This work attempts to develop an efficient and high-fidelity integrated instrument for rotor blade structure. This instrument refreshes inside structure of a blade cross-section. The structural properties of the blade are changed with the use of computerized enhancement techniques to reduce stress and refraction on rotor blades. Blade structure enhancement also integrates manufacturability impediments with the objective that the enhanced design can be adequately fabricated. Furthermore, a designed model based on Euler-Bernoulli beam theory is prescribed to improve the dependability of rotor blades. The consequences of production vulnerability, involving estimations, properties, geometry, and maintenance loads, are looked at in this work. This tool will aid rotorcraft industry to condense model cycle. Using this model, designers will be able to predict the factor of safety of the model in the initial phase and determine the evaluation of a rotor craft. Euler-Bernoulli beam theory will be applied to improve refraction, stress and safety factor.

3.0 Methodology

This study was performed using the Euler-Bernoulli beam theory with WIC principal characteristics as shown in table 1 and 2. The theory converts displacement of material due to loading on a system into a measurement used for determining potential failure during operation. Under this theory, various types of loads can be considered, and several engineering assumptions are made to simplify the calculations. Here, the following assumptions were made:

- The WIC blade was modeled as a cantilever beam (a beam with one fixed end and one free end). This assumption was made because water-craft blades remain fixed to the main rotor at the blade root and free at the blade tip.
- The only load considered in this analysis was axial load, which is applied along the longitudinal axis of the blade. The main focus of this paper was measurement of the axial displacement caused by the rotational movement of the blades.

3.1 Euler-Bernoulli Beam Theory

- The WIC blade was assumed to be made of linear-elastic material. This property means that the stress experienced by the rotor blade increases at the same rate as the blade's displacement (strain). Permanent deformation is not evaluated.
- The cross section of the blade undergoes rigid-body deformation, which means that the cross section does not change in shape or volume in response to an external load. The axial load had a value of

$$F_{axial} = \varrho \Omega_2 x_1 A(x_1) \tag{1}$$

Where ϱ is the material density, Ω is the angular speed of the blade (rad/s), $A(x_1)$ is the cross-sectional area at location x_1 along the span of the blade. Here, x_1 is the root of the blade. For the remaining equations, x (in reference to Figure 1) will be referred to as x_1. The tapered cross section had a blade tip cross-sectional area $A1$ that was half of the blade-root cross-sectional area

$$A_0 = (\text{i.e.}, A_1) = (1/2)A_0 \quad (2)$$

The constant cross section had a cross-sectional area A_0 from blade root to blade tip.

Table 1. Principle Dimension of WIC

Item	Value
Scale Factor	1:6
Wingspan	83.4cm
Wing root chord	66.7cm
Middle wingspan	41.4cm
Aspect ratio	1.25
Anhedral angle	13^0
Length of WIG craft	1.2m
Breath of WIG craft	0.13m
Tail wingspan	0.78m
Tail wing chord	0.15m
RPM of rotor Blade	305

Source: Yang and Ying, 2012

Table 2. Material Properties of Blades

Material	*Item*	*Value*
Carbon/Epoxy [4]	Density (*lb/in*3)	$1.423(10^{-4})$
	Young's modulus (*lb/in*3)	$21.5(10^6)$
	Axial Strength (*lb/in*3)	$310(10^3)$
Aluminium 7075-T73 [5]	Density (*lb/in*3)	$2.614(10^{-4})$
	Young's modulus (*lb/in*3)	$10.4(10^6)$
	Axial Strength (*lb/in*3)	$60(10^3)$

3.2 Structural Analysis

The flowchart shown in APP B illustrates the path taken to quantitatively conduct the failure analysis. Starting with the calculations began with the governing equations describing the system.

$$\mathcal{E} = \frac{\Delta \mathrm{L}}{\mathrm{L_{original}}} \quad (3)$$

The displacement u_1 under the axial load P_1 in the x_1-direction is given in Equation 4.

$$\frac{d}{d_x}\left(S\frac{du_1}{dx_1}\right) = -P_1(x_1) \quad (4)$$

Where S is the axial stiffness of the blade material

For a constant Young's modulus E and cross section A, the differential equation characterizing the bladed is placement u_1 in Equation 5.

$$EA\left(\frac{d^2 u_1}{dx^2{}_1}\right) = -\varrho\Omega^2 x^1 A \tag{5}$$

Two boundary conditions were used to solve for the displacement u_1. From these boundary conditions, the displacement for the constant cross-section blade of length L is given in Equation 6

$$u_1(x_1) = \left(\frac{\varrho\Omega^2 L^2}{2E}\right)x_1 - \left(\frac{\varrho\Omega^2}{6E}\right)x_1^3 \tag{6}$$

From a similar analysis, the tapered-cross-section blade was found to have a displacement u_1 given in Equation 7.

$$u_1(x_1) = \left(\frac{\varrho\Omega^2 L^2}{2E}\right)\left(\frac{2}{L}x_1 + \frac{1}{2}\left(\frac{x_1}{L}\right)^2 - \frac{1}{3}\left(\frac{x_1}{L}\right)^3 + 2\ln\left(1 - \frac{x_1}{2L}\right)\right) \tag{7}$$

Now, the governing equations of the problem have been derived.

Since the Euler-Bernoulli beam theory was used, the blade material was assumed to be linearly elastic. Therefore, the following relationship described stress σ1 in terms of axial strain and

Young's modulus E:

$$\sigma_1 = E\epsilon_1 \tag{8}$$

Applying this equation, the stress at the WIC blade root was found to be

$$\sigma_{1\,,root} = E\epsilon_1 \uparrow x_1 = 0 \tag{9}$$

Where "↑" denotes that a parameter is evaluated at a certain value. In this case, ϵ_1 is evaluated at x_1=0. The stresses of the constant- and tapered cross-section blades were found to be

$$\sigma_{1\,,root,constant} = \frac{1}{2}\varrho\Omega^2 L^2 \tag{10}$$

$$\sigma_{1\,,root,taper} = \frac{1}{3}\varrho\Omega^2 L^2 \tag{11}$$

Blade factor of safety indicates that the failure analysis was conducted through comparison of the calculated stresses and the material's critical stress values. For each blade case, the factor of safety (FOS) was computed by relating the calculated stress to the material's yield strength

h in the following way:

$$FOS = (yeild\ Strength)/(Calculated\ Stress) \tag{12}$$

As previously mentioned, aerospace vehicles must have a factor of safety of at least 1.5 in order to gain flight approval, according to FAA requirements. (FAA, 1992)

4.0 Results and Discussion

Rotor blades can be extensively grouped as metallic and composite. Fibre Reinforced plastics (FRP), like glass; carbon and Kevlar-epoxy mixtures are comprehensively harnessed as structural materials in present day rotor blades and hubs. The elementary ideal conditions are their higher great damage resistance, fatigue strength, and weak breakdown modes. Results are obtained using Matlab and Euler-Bernoulli theory as shown in APP A. Carbon and Aluminium compound are used to determine and the outcome the outcome derived in three categories, which are, axial displacement, force of the rotor blade and factor of Safety.

4.1 Axial Displacement of Rotor Blade

Tampered and Carbon epoxy compound is used and for each blade case, the axial displacement was calculated and plotted against normalized length as shown in Fig 1 Normalized length is used, rather than the actual blade length, to generalize these calculations to all possible blade lengths. Fig 1 and 2 shows the different material axial displacement of the blade increases from blade root to blade tip. Fig 3 shows that the axial displacement of the combined material composition of the blade which increases from blade root to blade tip.

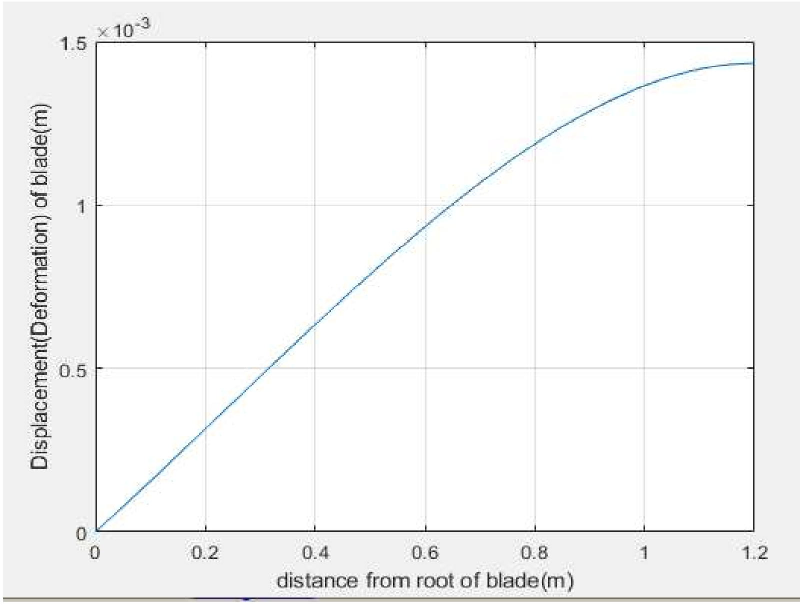

Fig 1: Tampared Carbon epoxy axial displacement against length

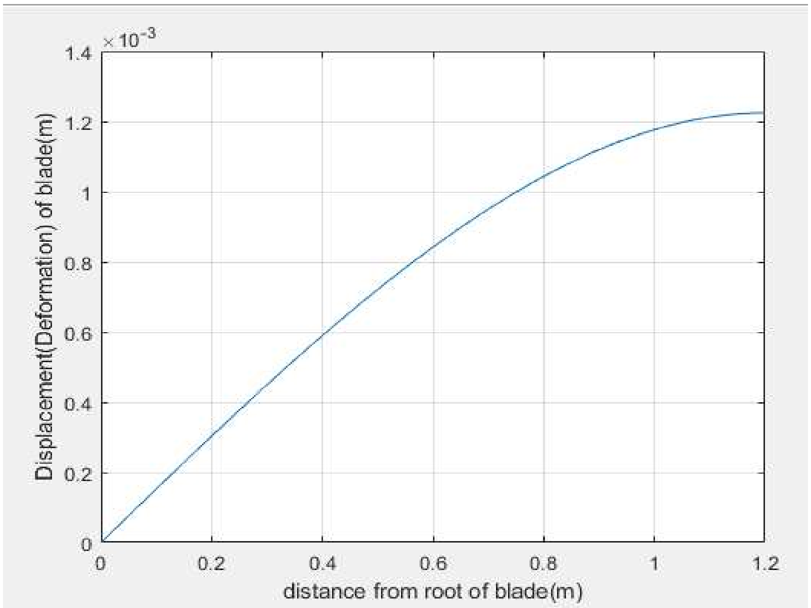

Fig 2: Uniform Carbon epoxy axial displacement against length

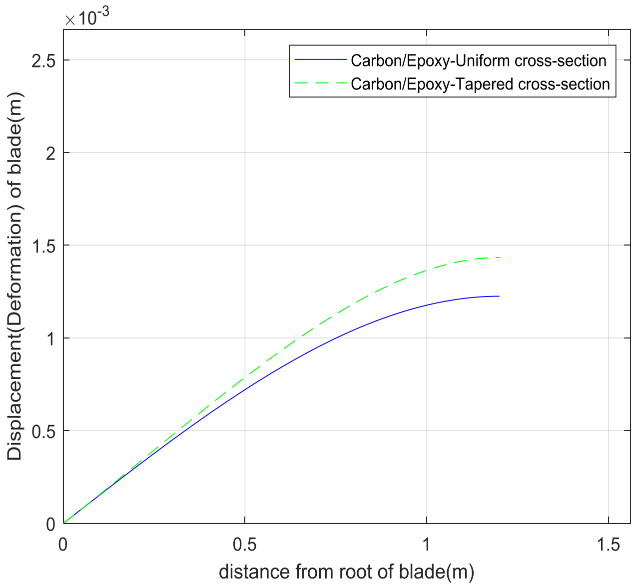

Fig 3 Combine uniform material axial displacement against length

In addition, the tampered carbon-cross-section blade displays the largest displacement between the cases. The carbon/epoxy constant and tapered-cross-section blade shows a significant difference in displacement.

Based on this figure, uniform carbon epoxy blades displace less than tampered carbon blades under the same operating condition.

4.2 Axial Force of Rotor Blade

Axial force was of interest because it reflects the stress experienced by the system due to the applied load. If the system undergoes greater stress, the likelihood of failure increases. The carbon/epoxy and tapered-cross-section blade undergoes the axial force shown in table 3. As mentioned, the tapered blade carries less weight than the constant blade, which implies that the tapered blade experiences less stress at the blade root for a given load.

Table 3: Root Stress of Rotor Blade

Material	Cross-section	Blade-root stress (GPa)
Carbon/Epoxy	Constant	0.1072
Carbon/Epoxy	Tapered	0.07144

5.0 Conclusion

This paper evaluated the structural integrity of constant- and tapered-cross-section WIC blades made with carbon/epoxy compounds. The Euler-Bernoulli beam theory was used to analyze the displacements, axial forces, engineering strain, and stresses experienced by the WIC blades. In conclusion, the factors of safety for all blade cases were more prominent than 1.5. The safety factor of the constant cross-section blades was seen to be lower (7.978-5.319).The tapered cross-section was computed to have the best values.

Therefore, the carbon/epoxy blades appeared to perform more safely under the working conditions. Finally, the blade stress for the constant cross-section blades was observed to be lower (0.1072-0.07144) for the tampered carbon. As a result, the carbon/epoxy blades were shown to perform more safely under the operating conditions of the WIC blade.

5.1 Recommendations

Based on the results obtained from this project the following recommendations are hereby made.

- Structural analysis can be further improved by accounting for multiple loads, including lift and drag.
- Finite Difference Method can be used to analyse the structural analysis of rotor blade
- Bending and Torsional load can be analysed to improve the structure of rotor blade.

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Appendix A. Matlab Code

```
% A Rotor Blade Structural Analysis
clc
w=305; L=1.2;
disp('1. DESIGN FOR ONE GIVEN CHOICE OF MATERIAL')
disp('2. ONLY DISPLAY DISPLACEMENT-POSITION GRAPHS ON SAME AXES')
s0=input('Specify option: ');
disp(' ')
if s0==1
  FOS1=input('Specify the design FACTOR OF SAFETY (FOS): ');
fprintf('Select MATERIAL TYPE for blade\n')
disp('1. CARBON/EPOXY')
disp('2. ALUMINIUM')
  s=input('Specify option: ');
disp(' ')
if s==1 % CARBON/EPOXY
rho=1600;
    E=70*10^9;
Axial_critS=570*10^6;
fprintf('Select GEOMETRIC TYPE for blade\n')
disp('1. Contact gpdwise@gmail.com)
disp('2. Contact gpdwise@gmail.com)
ss=input('Specify option: ');
disp(' ')
```

```
ss==1 % CARBON/EPOXY with UNIFORM CROSS-SECTION
Aroot=9.641;
 A=Aroot;
CalStress=0.5*rho*w^2*L^2;
 FOS=Axial_critS/CalStress;
  x=linspace(0,L,100);
 U=(rho*(w^2)*(L^2)/(2*E)).*x-(rho*w^2/(6*E)).*(x.^3);
plot(x,U)
```

Appendix B. Flow Chart