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HOMEMADE HELICOPTER DESIGN AND VIBRATIONAL ANALYSIS

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ABSTRACT

In this work, the homemade helicopter aerodynamics is analyzed. The helicopter model is the Sikorsky configuration, in which the main rotor is in perpendicular combination to the tail rotor. The rotors are articulated and their blades are rigid. The main rotor implementation takes into account flap and feather degrees of freedom for each of the equispaced blades as well as their dynamic couplings.Transmitted vibrations due to the rotating rotors blades on the body structure (fuselage) are studied. This work presents an aerodynamic model that allows us to analyse vibrational transmissions on the fuselage (body) of the homemade helicopter. Vibrations in helicopters is a common problem which involves complex interactions between the inertials, structural loads and aerodynamic loads especially in homemade helicopters. The major source of vibrations in helicopters is the main rotor. These vibrations affect the functionality, durability of the engine component parts, increases maintenance frequency (cost) and structural failures. The aerodynamic model has been built up implementing blade element theory. The aerodynamic load creates vibrations on the homemade helicopter and these are analyzed on the fuselage by using short time Fourier transform that brings out the vibrational spectrum. The results of the analyzed serves as a guide to improve the functionality, durability, maintenance frequency and to reduce structural failures of the rotor craft. The results are used as reference characteristics in the construction of rubber engine mount for engine seatings as well as the crew seats, control panel and camera suspensions.

Keywords: Vibrations, Rotor, homemade helicopter, dynamics, aerodynamics.

INTRODUCTION

Helicopter vibration is a common problem which involves complex interactions between the inertial, structural loads and aerodynamic loads. The major source of vibrations in helicopters is the main rotor. In aircraft's design, vibrations have remained one of the major problems affecting helicopter development for years. In fact, the maximum speed and manoeuvring capabilities for most of the modern helicopters are limited by excessive vibration. Vibrations frequencies are either equal to the rotors frequencies or multiple of them. The rotor frequencies are a function of the angular speeds at which they rotate [1]. Vibrations affect the functionality of the engine component parts, increases maintenance frequency and cost, affect comfort, fatigue of passengers and sometimes causes structural failures. High vibration levels experienced by a helicopter could in many cases pose a limitation to the vehicle’s manoeuvring capabilities and forward speed. In addition to this, vibrations affect the helicopter handling qualities, contribute to the fatigue of structural components, reduce the reliability of the main frame design and on board electronic equipment, and influence the precision of equipment such as cameras, measuring devices, etc. [2], [3]. The reduction of helicopter vibrations have always been a difficult task to achieve. Therefore, it is important to study and analyses vibrations in order to identify the predominant frequencies responsible for the for the vibrations. This result can be used to design vibration control schemes for helicopters components and devises [4]. In this work the vibrations generated by the main rotors and transmitted to the fuselage is detected using vibration sensors and an accelerometer. The data collected, which is the displacement in the x and y axis and is process using the matlab software. The result which is a vibration spectrum will enable us to clearly identify the predominant frequencies. These predominant frequencies will be use as specific reference characteristics for the manufacture of rubber engine mount (engine seating) use for the suspusion of some major components in the helicopter especially the engine.

DYNAMIC MODEL

The homemade helicopter is constructed in the Sikorsky configuration i.e., main rotor is in perpendicular combination with the tail rotor. Both systems are mounted on the fuselage. The helicopter model consists of fuselage, main rotor and tail rotor, both articulated, figure 1 below. The main rotor consists of two equally spaced blades joined to a central hub and the tail rotor consists of two equally spaced blades joined to a secondary hub. The blades are rigid in both rotors. The helicopter has six degrees of freedom: three translations along the (X, Y, Z) axes and three rotations around the same axes. The model presented in this paper is based in previous works developed by some authors (see [5], [6], [7], [8],).

Figure 1: The helicopter conceived model

FUSELAGE

The fuselage is the main body section that holds rotorcraft's engine, crew and amongst others. Its degrees of freedom are the lateral and longitudinal translation in the horizontal plane X-Y axis, vertical translation (Z axis) and rotation about these same axes corresponding to pitch, roll and yaw respectively.

MAIN ROTOR

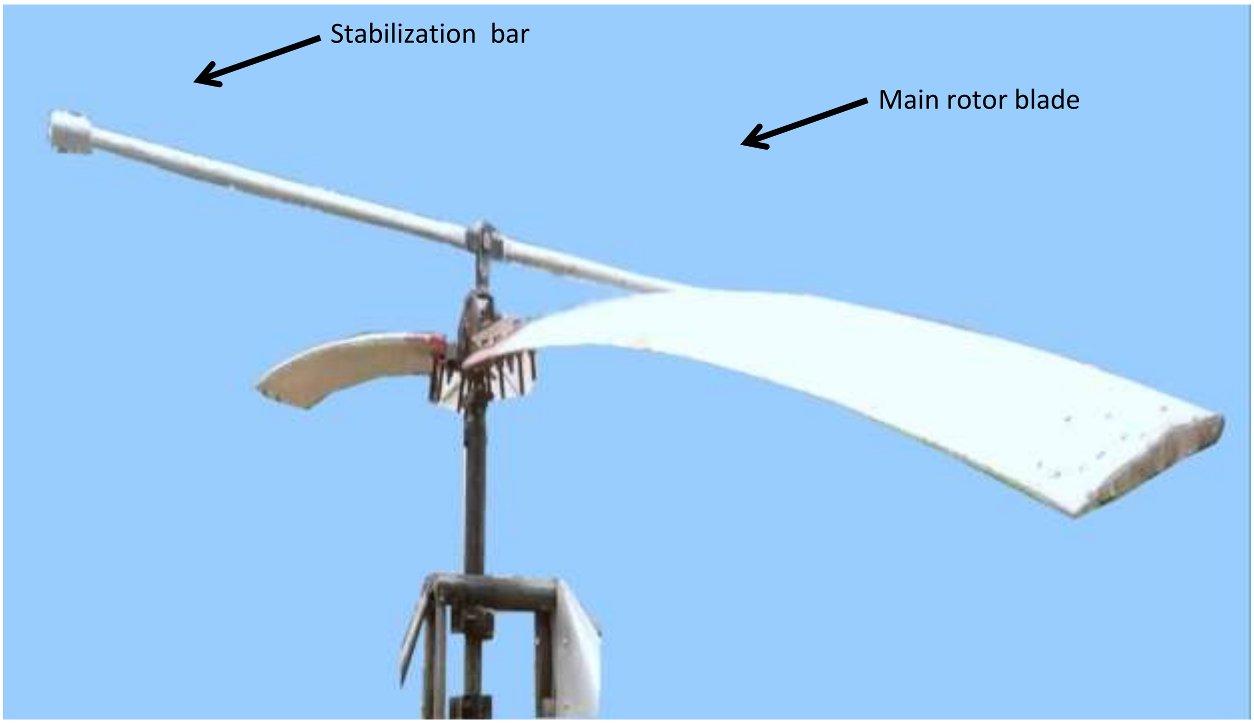


Figure 2: Realized and mounted main rotor blades.

The role of the main rotor is to generate the lift force that carries the aircraft's weight, figure 2 above. It enables the helicopter to be suspended in the air and provides the control that allows to follow a prescribed trajectory in the various spatial directions by changing altitude and executing turns. It transfers prevailingly aerodynamic forces and moments from the rotating blades to the non-rotating frame (fuselage). The blades are kept in uniform rotational motion (constant speed), by a shaft torque from the engine. A common design solution adopted in the development of the helicopter is to use hinges at the blades roots that allow free motion of the blade normal to and in the plane of the disc. The most common of these hinges is the flap hinge which allows the blade to flap, this is, to move in a plane containing the blade and the shaft. The flap hinge is more frequently designed to be a short distance from the centre line. This is termed an "offset" (eR), and it offers the designer a number of important advantages. A blade which is free to flap, experiences large Coriolis moments in the plane of rotation and a further hinge (called lag) is provided to relieve these moments. This degree of freedom produces blade motion on the same plane as the disc. In the presence of aerodynamic loads the degree of freedom generates the blade’s drag force. A blade can also feather around an axis parallel to the blade span. Blade feather motions are necessary to control the aerodynamic lift developed and, in forward motion of the helicopter, to allow the advancing blade to have a lower angle of incidence than the retreating blade and therefore balancing the lift across the craft. In order to be able climb, the feather angle needs to be increased. On the other hand, in order to descend, the blade's feather angle is decreased. Because all blades are acting simultaneously in this case, or collectively this is known as collective feather and allows the rotorcraft to rise/fall vertically [9]. Equally for this control, to achieve forward, backward and sideways flight, changes of feather angle is required. The feather angle on each individual blade is varied at the same selected point on its circular pathway. This is known as cyclic feather or cyclic control. Blade feather control is achieved through a linkage of the blade to a swashplate, figure 3 below.

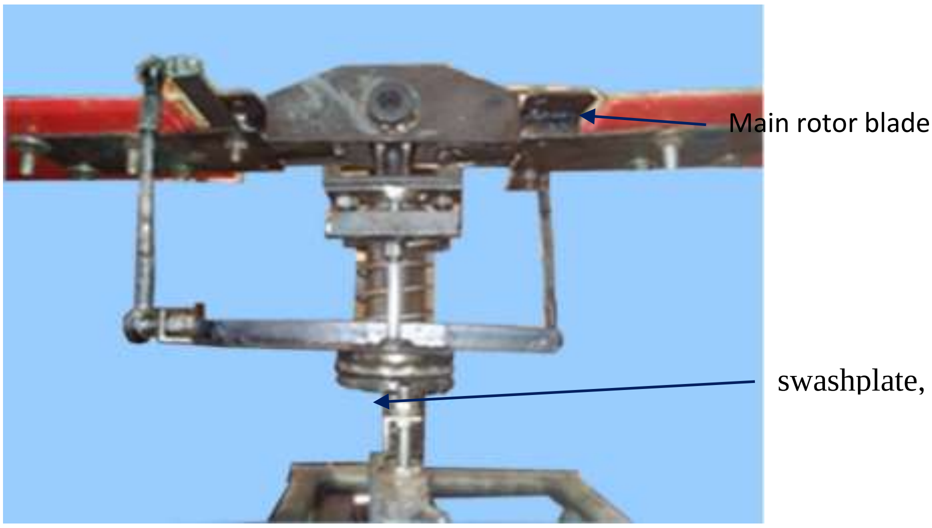


Figure 3: Construction and installation of the swashplate.

TAIL ROTOR

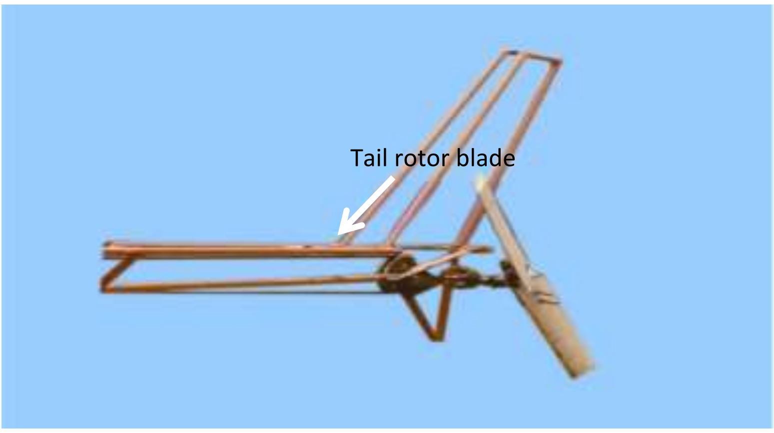


Figure 4: Realized tail rotor

The tail rotor is mounted perpendicularly to the main rotor figure 4. It counteracts the torque and the yaw motion naturally produced by the main rotor blades. In accordance to Newton's third law of action and reaction, the fuselage tends to rotate on the opposite direction to the main rotor's blades as a reaction of the torque that appears (see Figure 5).

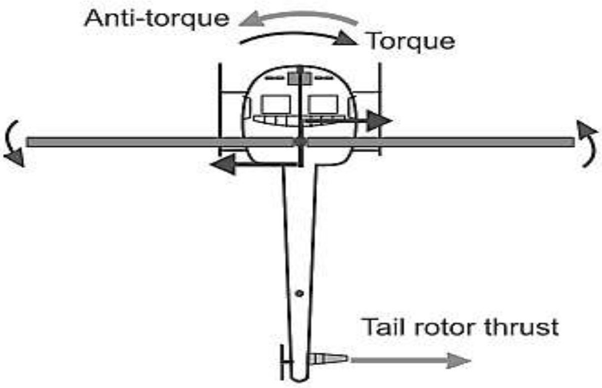


Figure 5: The anti-torque(tail) rotor produces the thrust required to oppose the torque

This torque must be counteracted and/or controlled before any type of flight is possible. Two anti-torque pedals allow the pilot to compensate for torque variance by providing a means of changing pitch (angle of attack) of the tail rotor blades. This provides heading and horizontal directional control during flight. Driven by the main rotor at a constant ratio, the tail rotor produces thrust in a horizontal plane opposite to the torque reaction developed by the main rotor. Since the main rotor torque varies during flight when power changes are made, it is necessary to vary the thrust of the tail rotor equally. Part of the engine power is required to drive the tail rotor, especially during operations when maximum power is used. Any change in engine power output produces a corresponding change in the torque effect.

DYNAMIC MODEL DESCRIPTION

The parameters used for the design carried out in this work are shown in table 1. For the purpose of dynamic designing, the action of external forces are not considered, for example: gravity. An unbalance of masses is considered on the main and the tail rotors blades in order to analyse a source of vibrations in the helicopter with an amplitude to be detected in the spectrum figure 6

Figure 6: Helicopter realized model

Table 1: Main and tail rotor masses

Parameters	**Symbol**	**Value**
Helicopter Mass	H_m	157.54kg
Main Blade one mass	MR_{m1}	3.67kg
Main Blade two mass	MR_{m2}	3.61kg
Tail Blade one mass	TR_{m1}	0.51g
Tail Blade two mass	TR_{m2}	0.52g
Tail Rotor Speed	TR_s	632rpm
Main Rotor Speed	MR_s	451rpm

AERODYNAMIC MODEL AIR DENSITY

For every flight condition, the air density changes with the height (h), for the lower atmosphere where helicopters fly below 6000 m, the standard value of air density can be approximated as:

$$\rho = \rho_0 e^{-0.0296h/305.6} \qquad (1)$$

Where h is expressed in meters and ρ_0 is 1.225kg/m^3
(air density at sea level)[10]

INDUCED VELOCITY

During hover flight, the induced velocity can be obtained as $v_i = v_{io}$, v_{io} is the hover induced velocity, which can be considered constant in hover, the traction force, T, becomes equal to the disc loading (weight of the helicopter), see Figure 6 [10]:

$$v_{io} = \sqrt{\frac{T}{2\rho R^2}} \qquad (2)$$

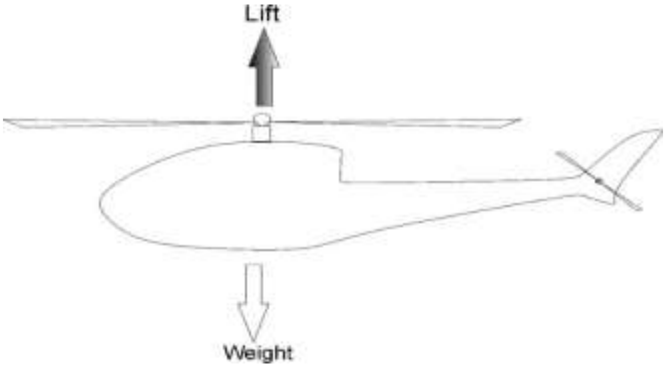


Figure 7: Main forces acting on the helicopter

BLADE ELEMENT ANALYSIS

Blade element theory forms the basis of most modern analyses in helicopter rotor aerodynamics as it estimates the radial and azimuthal distributions of blade aerodynamic forces (and moments). In addition to this, the rotor performance can be obtained by integrating the sectional airloads at each blade's elements over the length of the blade and averaging the result over a rotor revolution [9]. Figure 8 is a plan view of the rotor disc, viewed from above. The blade radius is R and the tip speed is given by ΩR. An elementary blade section is considered at radius y, of chord length c and spanwise width dy.

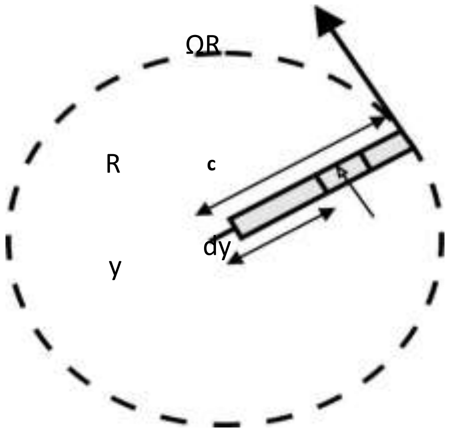


Figure 8: Main rotor disc viewed from above

The velocity components on the blade's section are shown in Figure 4. The flow seen by the section has velocity components Ωy in the disc plane and $(v_i + v_c)$, v_i is the induced velocity and v_c is the upward velocity) perpendicular to it [11].The resultant local flow velocity at any blade element at a radial distance y from the rotational axis has an out of plane component. Figure 9.

U_P= $(v_i + v_c)$ normal to the rotor plane as a result of climb and induced inflow and in plane component U_T= Ωy parallel to the rotor due to blade rotation, relative to the disc plane. The resultant velocity at the blade element is therefore the composition of both [9]:

$$U = \sqrt{U_P^2 + U_T^2} = [(v_i + v_c)^2 + (\Omega y)^2]^{1/2} \qquad (3)$$

The blade's feather angle θ, is imposed by the pilot's collective control input. The angle between the flow direction and the plane of rotation, known as the inflow angle ϕ , is therefore [11]:

$$\tan\phi = \frac{\left((v_i + v_c)\right)}{\Omega y}$$

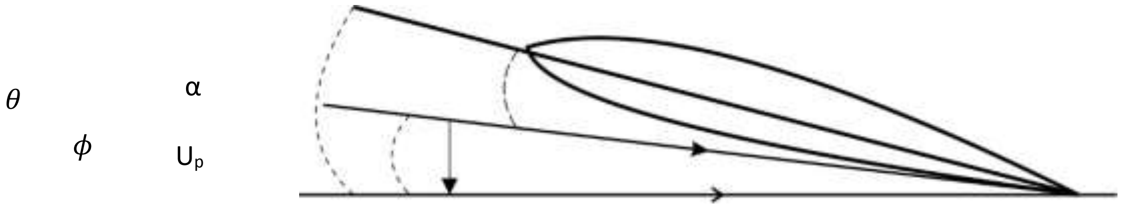


Figure 9: Velocity components $\boldsymbol{U_T}$ and $\boldsymbol{U_P}$

If the feather angle at the blade element is θ, then the aerodynamic or effective angle of attack is:

$$\alpha = \theta - \phi \qquad (4)$$

The resultant incremental lift, dL, and drag dD per unit span on a blade element are:

$$dL = \frac{1}{2}\rho U^2 c C_l dy \qquad (5)$$

$$dD = \frac{1}{2}\rho U^2 c C_d dy \qquad (6)$$

Where ρ is the air density, C_l and C_d are the lift and drag coefficients, c is the local blade chord. The lift dL and drag dD act perpendicular and parallel respectively to the resultant flow velocity.

THRUST COEFFICIENT

The thrust coefficient approximation for hover flight is written as

$$C_T = \frac{1}{2}\sigma\alpha\left[\frac{1}{3}\theta - \frac{1}{2}\lambda\right] \qquad (7)$$

θ is the feathering angle, α is the lift slop, $\lambda = \frac{v_{ih}}{\Omega R}$, v_{ih} is the induced hover velocity, R is the rotor radius and σ is the solidity factor, which for a constant blade chord is given by

$$\sigma = \frac{Nc}{\pi R}$$

N is the number of main rotor blades and c is the blade chord [11].

KINEMATIC DRIVE DIAGRAM OF THE HELICOPTER

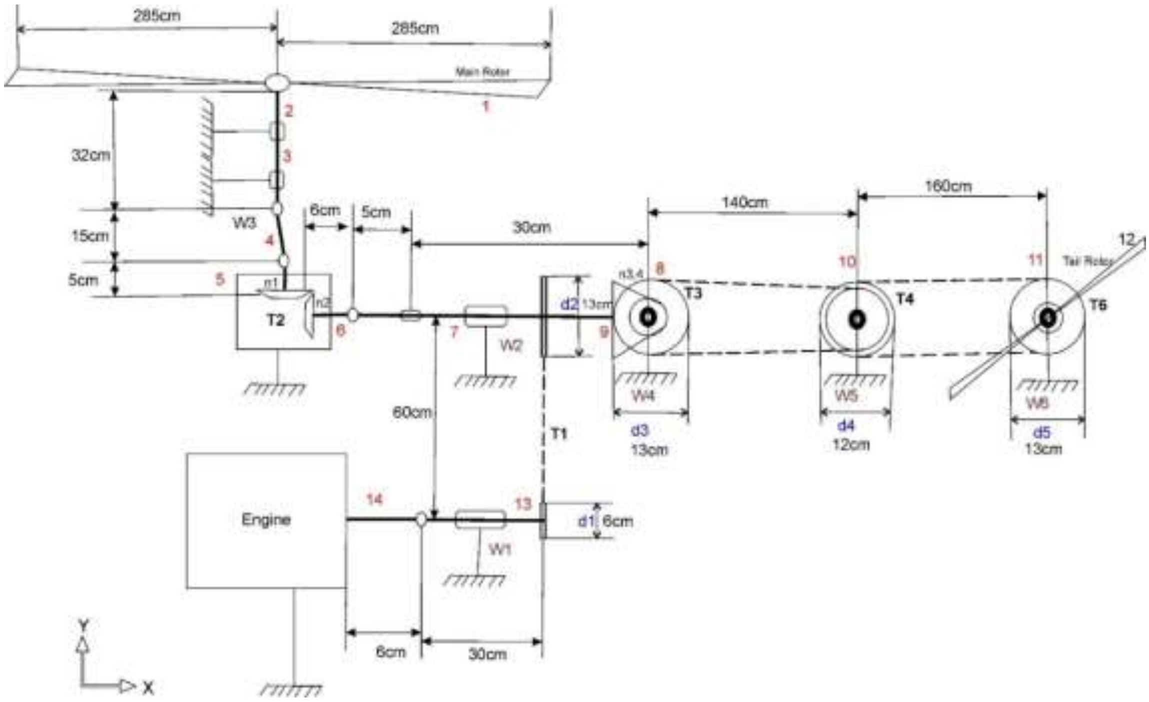


Figure 10: Kinematic diagram of the helicopter.

Data collected: d3= d5 =13cm, d4= 12cm, n1=, n2= 15 teeths, n3= n4= 10 teeths, the numbers in red indicate the connections of the helicopter system. We notice therefore 15 links (couplings). Motion transmissions are represented by Ti, where i =1, 2,3,4,5.

DEGREES OF FREEDOM

The degree of freedom of the system is the number of independent variables required to define the motion or orientation of the rigid body in space (the number of directions or coordinates a body can move). It is used in kinematics to calculate the dynamics of a body.

According to the kinematic diagram of the helicopter as shown in fig 10, we noted 13 couplings, 9 lower pairs, and 2 upper pairs. (Gandhi, 2011) [12]

The total number of degrees of freedom is expressed by the formula,

According to Grubler's Rule

$$F = 3(n - 1) - 2L - h \qquad (8)$$

Where

n = Number of coupling (links);

L = Number of lower turning point (revolute joints) (one degree of freedom).

h = Number of upper turning point (half joints) (two degree of freedom).

n=15 L=9 h=6

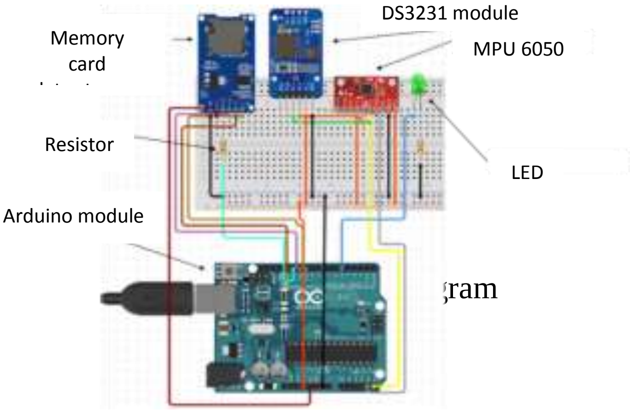
$F = 3*(15 - 1) - 2*9 - 6 = 18$

Therefore, since F ≥ 1, the system is a mechanism.

VIBRATIONS ANALYSIS

The vibrations generated by the main rotors blades are transferred to the body structure of the homemade helicopter.

Circuit diagram: The design and simulation of the circuit was done using the Proteus software.



ram

Analysis of the vibration for the helicopter is a difficult task due to the complexity of the structure, but some accuracy is achievable with modern techniques. This work is carried out by estimating the vibrations transmitted on the fuselage when the aerodynamic model has been implemented as well as a comparison to dynamic vibrations generated, Figure 11. In order to develop the analysis, the following steps : a) detection of vibration signals on the fuselage as a consequence of the aerodynamic load using a vibration sensor and an accelerometer in which the displacement in the x and y axis was measured as a function of time and with unbalance of masses of the rotors were determined using electronic suspending mass scales, b) analysis of the vibrations in the x and y axis with time generated spectrogram with matlab software for identification of the predominant frequencies.

VIBRATIONAL TRANSMISSION

Vibrations appearing on the fuselage's axes X (roll), Y (pitch) and Z (yaw) are studied. Only two of the axes are analyzed and examine, X and Y as in [7], figure 12 below. The aerodynamic model satisfies the following structural characteristics.

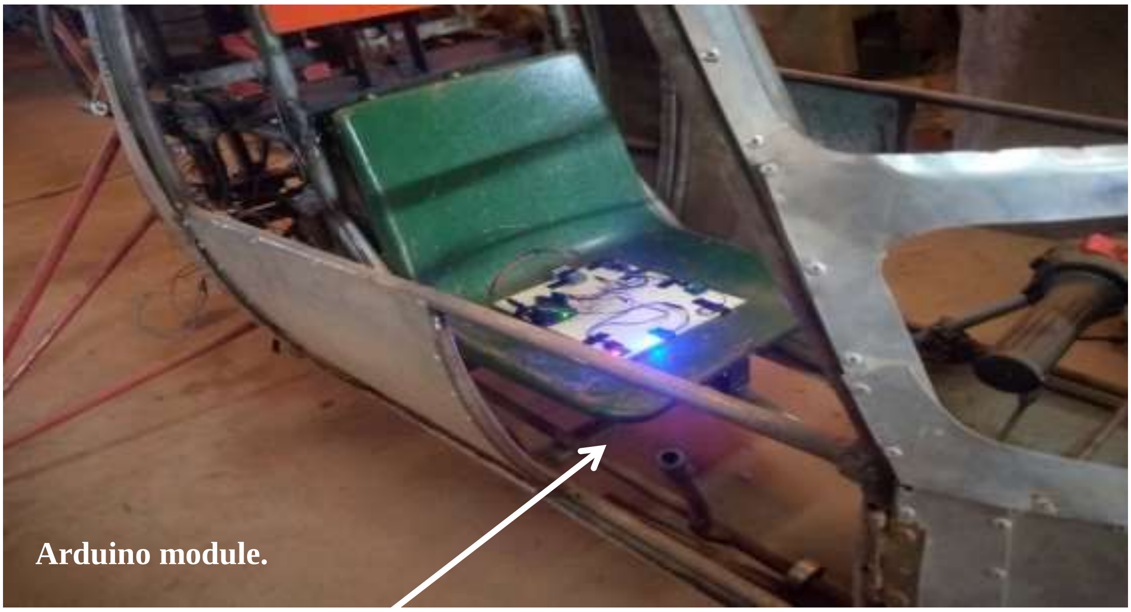


Figure 12: Vibration detection Arduino module.

There is a consequence of the use of a rotating frame of reference that affects vibrational frequencies created on the rotor and transmitted to the fuselage. The frequencies generated by the rotor may contain the rotational frequency of the rotor and the external perturbation frequencies [15]. An arduino module for vibration detection is mounted on the seat of the homemade helicopter to detect and save vibrations reaching the helicopter framework, figure 12 above.In order to analyze the vibrations appearing on the fuselage, the Short Time Fourier Transform (STFT) is used.

$$S_X(t,\omega) = \int_{-\infty}^{\infty} x(\tau)h(\tau - t)e^{-j\omega}\, d\tau \qquad (9)$$

X (t) is the corresponding signal understudy, and h (t) is a finite support window function. The properties of the window function h (t) have a significant effect on the STFT display and should be carefully chosen. Matlab simulations are carried out for 50 seconds, although the results plotted in figures 11 and 13 show the first 5 seconds only, for clarity of the view. The height is h = 250 m and the main rotor's collective feather angle is 0.195 rad and tail rotor's collective feather angle is also 0.195 rad. Figure 11, shows the fuselage's oscillations (vibrations) on the X axis for 5 seconds. Figure 13, shows the corresponding spectrogram obtained for this simulation in the y-axis. Various predominant frequencies which come from the main rotor loads (approximately 14.4Hz) can be seen on the spectrogram in figures 12 and 14. There is a second predominant frequency (approximately 30.1 Hz) which is twice the flap frequency and a third predominant frequency is found at around 78.5 Hz.

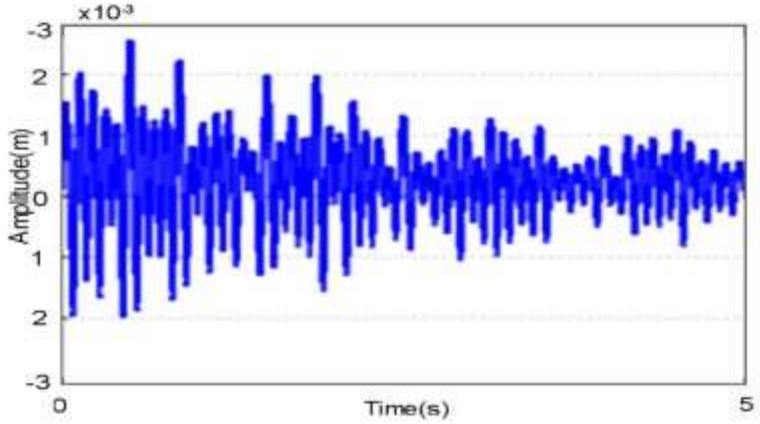


Figure 13: Vibrations on the fuselage x-axis

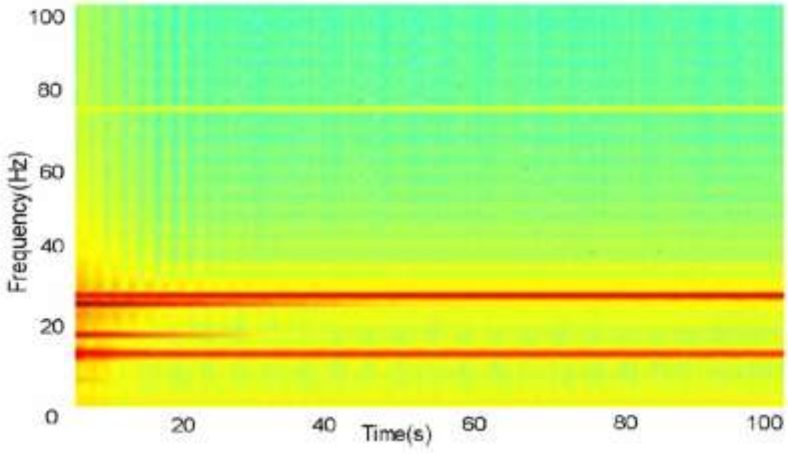


Figure 14: Spectrum on the fuselage x-axis

Similar analysis is carried out for the oscillations appearing on the fuselage's Y axis (see Figure 14).The three predominant frequencies of these vibrations appear in the spectrogram in Figure 14. These are approximately 14.4 Hz which are caused by the main rotor blades’ flap, the second frequency is approximately 30.1 Hz, this value is twice the main rotor flap frequency and the third frequency is around 78.5 Hz.

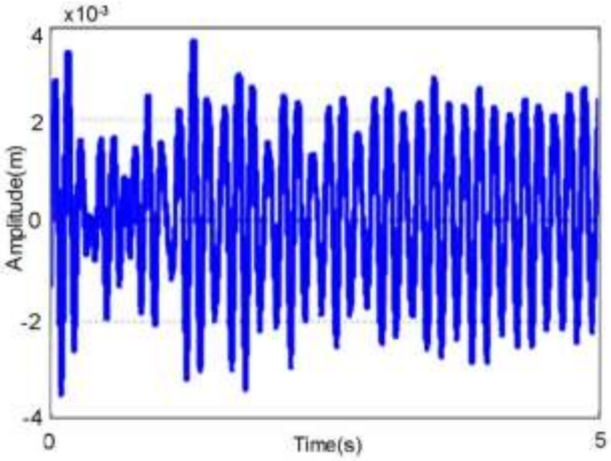


Figure 15: Vibrations on the fuselage y-axis

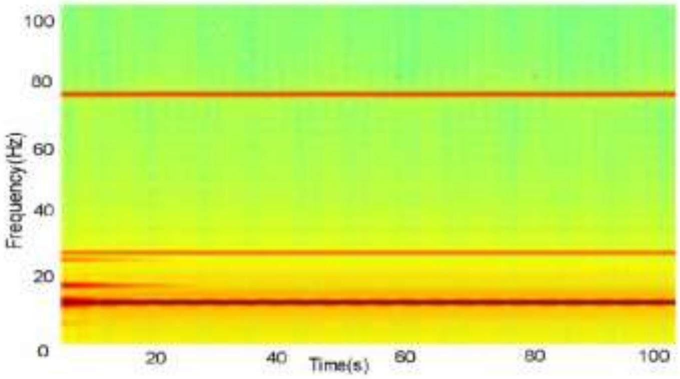


Figure 16: Spectrum on the fuselage y-axis

DISCUSSION AND CONCLUSION

DISCUSSION

Many of the homemade helicopters realized in Africa were constructed not respecting the basic principles of aerodynamics, where by in our work we made an effort to respect basic aerodynamic principles. Our model realized is one of the best homemade helicopter in Africa conforming to standard norms.

Most of the homemade helicopter studied suffers from serious vibrations of the framework due to unbalanced main rotor blades, whereby we have scrupulously balanced our main rotor blades. Balancing of the main rotor blades drastically reduced vibrations transmitted to the body framework therefore giving more stability of the body framework.

For most of the homemade helicopters studied, the cause of excessive vibrations was not studied whereby we have studied and analyzed the vibrations transmitted to fuselage in order to established measures to reduce the vibration on the framework.

The predominant vibrations frequencies determined in our analysis 14.4Hz, 30.1Hz and 78.5Hz were relatively higher as compared to similar analyses carried out by some authors in the review of literature. These discrepancies in frequencies were appreciable because similar analysis carried out in literature review were done with single seat modern helicopter meanwhile our analysis was done with a homemade helicopter in Africa. With respect to this our research contribute to the advancement of aeronautics knowledge in Africa, breaking the vicious cycle of aeronautics research in Africa and Cameroon in particular.

Realizing this work was relatively challenging and we were satisfied to have taken the challenge to produce these results. There is still much work to be done especially in constructing a more sustainable swarhplates, Rotor blades, and a control system.

CONCLUSIONS

The homemade helicopter model under study is on Sikorsky configuration, the model reproduces the dynamic behaviour of a helicopter, which is capable of transmitting perturbations from the main rotor to the fuselage in form of vibrations. The model has been implemented with used of matlab software for analysis. This work has presented a helicopter aerodynamic model in which the blade element theory has been used for the analysis. This is important in order to study and analyze the vibrations appearing in the fuselage as a consequence of aerodynamic load .Various tests under the action of these conditions were carried out in order to study vibrations appearing on the fuselage roll and pitch axes. The fuselage vibrations spectrograms were obtained and analyzed using short time Fourier transform process with matlab software, and various cases were considered when the aerodynamic load were included in the dynamic helicopter model, the obtained results match those predicted by theoretical approaches. As a consequence, the spectrograms were also studied and showed a reasonable discrepancy according to the expected behaviour introduced by the aerodynamic model. Spectrograms analysis on the fuselage’s roll and pitch axes capturing transmitted vibrations as a consequence of the aerodynamic load were obtained. The results obtained enables the identification of some predominant frequencies used as references characteristics for the manufacture of rubber engine mount used for the engine seatings as well as crew seats, measuring devices suspension stabilization .As a result of this the homemade helicopter design and vibrational analysis have been satisfactory. These results are still on an early stage and the authors expect to develop further analogies with experimental results in future work.

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