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THE MODAL ANALYSIS OF A CARBON FIBER HELICOPTER BLADE

Abstract: *The blade and the rotor's components belong to the helicopter's vital parts, parts that if they fail or if they malfunction it will result inevitably in the total destruction of the flying machine. The vibrations are dynamic phenomena usually encountered in the aerospace area, especially for blades and wings in use. The scope of the paper is to determine the characteristic frequencies in order to establish the occurrence possibility of the resonance phenomena. The modal analysis allows for quite a precise investigation of the behavior of a helicopter blade accounting for aspects like specific geometry of the blade, the coupling between the blade and the rotor hub and also for the blade material.*

Key words: *helicopter, blade, vibration, modal analysis, finite element analysis.*

INTRODUCTION

Numerous requirements of the modern aviation made possible the development of numerous other aircrafts, among which quite spread is the helicopter. The development of the computers and experimental layouts allowed the complex approach for the fundamental research and practical matters, on the basis of some mathematical and computational models that became more and more complex in the aviation area.

Using flight phenomena simulation instruments and the component fabrication´s advanced technology, within the aircraft´s structure; the aviation engineers were able to develop and construct components (fuselage, blades, rotors, engines, instruments) with higher performance and increased reliability [1].

Because of its characteristics to go up and down vertically as well as to hover at a fixed point, the helicopter has various uses in different areas. It is a known fact that unlike the airplane, the helicopter is a noisy aircraft, characterized by a high level of vibrations. It is for expected that the rotors, the fuselage and the engines, the gearbox to pose serious vibration issues [2].

It is desirable a reduction of the vibration level for the fuselage for technical issues in the first place to extend the structure´s lifetime by reducing the material´s fatigue effects and to protect the sensitive components (instruments). The vibrations of the fuselage and transmission are less important for these do not affect directly the safety of the flight. The vibrations of the rotor and blade are very important as these are vital equipments; in case of these component´s failures the control of the aircraft can be lost which can lead to the destruction of the helicopter.

Maintaining under control a certain acceptable vibration level is determined by [3]:

- To increase crew efficiency and hence safety of operation;
- Improvement of the passenger´s comfort;
- Improvement for the electronic onboard equipment and the mechanical equipment (rotor, blades);
- Extending the fatigue lifetime for the helicopter´s structural components.

The most important feature of the helicopter blade compared with the airplane wing is that because of the asymmetrical aerodynamic flow the blade´s aerodynamic loads vary continuously and periodically varying according to the helicopter´s flight speed. Moreover, along with the usual elastic and inertial forces that act on a vibrating wing, on the helicopter blade act the following forces: Coriolis, centrifugal forces and axial tension [4].

The practical and theoretical aspects of the helicopter blades were developed as in practice were noticed the following groups of vibratory phenomena [4]:

- Phenomena with dynamic response in which the motion energy of the rotor generated by the engine is being transferred to the blade because of the coincidence between one or more characteristic blade frequencies and a multiple of the blade´s rotational frequency. These phenomena are studied in the classical theory of the linear vibration.
- Aeroelastic instability phenomena, in which an energy transfer takes place from the air current towards the blade under the added effect of the blade´s vibratory distortions and of the aerodynamic force´s cyclic oscillations generated by these vibrations.

The most important aspects in the literature [5, 6] concerning the blade´s aero-elastic and vibratory phenomena are the following: flutter and the classical divergence of the helicopter blade, known as pitch-flap instability, which implies instability caused to the blade´s bending and twisting distortions. These cause a twisting distortion of the blade that leads to the increase of the aerodynamic forces which initially produced the bend of the blade, in this way the distortions grow rapidly until destruction. At the moment when this phenomenon evolves without oscillations it is called divergence and the instability is of static type. On the contrary, the instability is dynamic when it accounts also for the inertial forces so the phenomena are called flutter. The flutter is defined as an instability state of a structure´s oscillatory (periodic) movement, which takes place at a certain speed and with a certain frequency.

In practice, from the helicopter blade´s dynamic stand point results a series of challenges related to the resonance and the dynamic balancing of the blades. A quick methodology to evaluate the possible resonances between the blade´s frequencies and the rotor´s speed is to draw the ω - Ω diagram, having Ω lines constants. The intersection of the Ω lines with a certain frequency indicates the possibility o a resonance, on the condition that the regime speed is not close to such a point.

Figure 1 shows that, as rotor speed increases, the excitation harmonics fan out. The resonant frequencies of the blades also change with rotor frequency because of the effect of centrifugal stiffening. Figure 1 shows how flapping, ωf, and lagging, ωl, resonant frequencies may change with rotor speed [3].

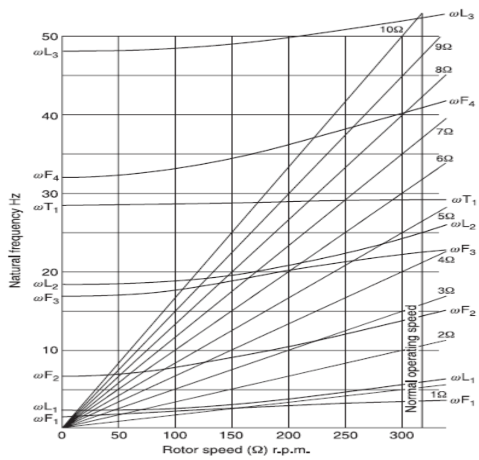

Fig. 1 Diagram of the natural frequencies and the rotor speed of helicopter [3]

These vibration phenomena characteristic to helicopters were studied and there are considerable efforts in finding solutions to dampen these vibrations. The most important dampening systems are:

- DAVI or dynamic anti-resonant vibration isolator. This works using a mechanical impedance convertor to raise the moving mass artificially. Between the transmission and the hull is a lever carrying a bob weight [3,6];
- The french helicopter constructors introduced the system for reducing the vibrations like supple platinum. Supple platinum is made of a titanium alloy and is placed between the inferior part of the main transmission box and the mechanical board at the helicopter. Supple platinum is a vital part and has the role to reduce the vertical vibrations produced by the main rotor's blade [7].

2. HELICOPTER BLADE`S DESIGN DETAILS

The continuous improvement of the helicopter rotor determined mostly significant progress concerning the flight performance and quality. The most important developments are related to: rotor type, blade profile, the blade´s shape and twisting mode, the tip of the blade, the materials from which is made and the noise level.

From the need to unload the blades from the cyclical bending stresses and to avoid transmitting through the rotor hub to the helicopter´s structure the cyclical roll and pitching torques and the oscillations in the blade´s rotational plane, the blades are designed with the three degrees of freedom in rotation: flapping, feathering, lagging (figure 2).

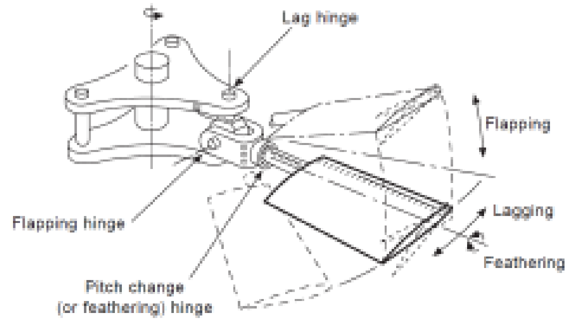

Fig. 2 The main movements of the blade [3]

The blade represents any rotor´s active and vital element and is flushed or hinged at one end in the rotor hub. The classification of the blades according to their shape is described in figure 3.

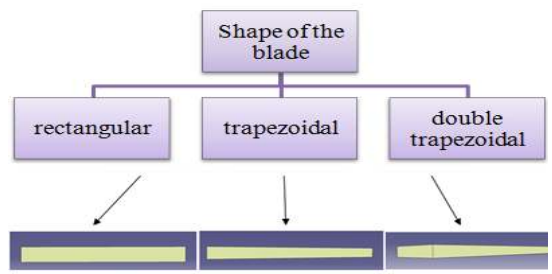

Fig. 3 The geometrical shape of the helicopter blades

The helicopter blade needs to meet the following general design principles [2]:

- Mechanical strength;
- Dimensional profile precision;
- Resistance to humidity and corrosion
- Static and dynamic balancing
- Rigidity in relation to the three possible movements of the blade (flapping, feathering, lagging)

In figure 4 it is described the internal structure of a helicopter blade having the following components: the fiberglass and carbon fiber skin, foam, the honeycomb structure.

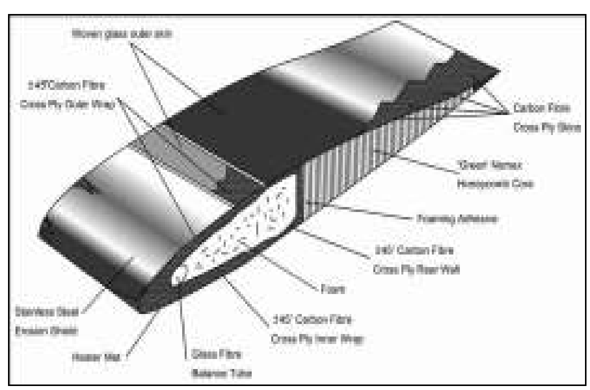

Fig. 4 Cross section view of a composite blade [8]

3. MODAL ANALYSIS OF HELICOPTER BLADE USING ANSYS WORKBENCH

The modal analysis is the method through which the modal parameters of a structure are determined (frequency, dampening and modal form), for all the associated modes within the interest area.

The natural frequencies and the vibration modes are important parameters for the design stage because it gives information about the analyzed structure´s dynamic regime behavior. The modal analysis is a mandatory computational stage for the spectral analysis and the transitory or harmonic analysis through effects overlapping. The modal analysis is considered a linear analysis although the problem with vectors and associated values that needs to be solved implies numerical iterative methods. The main stages that are necessary for the blade´s specific vibratory phenomena (rotor flutter, flap-feather instability, pitch-feather instability, nonlinear aeroelastic phenomena - stall flutter) are (figure 5):

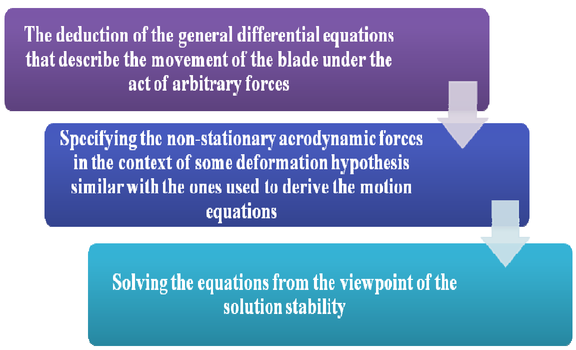

Fig. 5 The stages of a vibration blade analysis

The difficulty degree for the three stages presented before (figure 5) vary from case to case and depends on the complexity of the mathematical model chosen and of the way in which the description of the stability solution is to be described. For this reason the recent studies in the helicopter blade´s vibration phenomena grew significantly, pushed by the new possibilities in regard to the graphic unit´s performances and by the new specific software that facilitates the access to faster results since the development stage of the product.

The most important programmes for finite element analysis and specifically modal analysis are: Ansys, Nastran, Abaqus, Ansa, Hypermesh. It is to be observed that for each of these programmes there is a special interface that accounts for all the software´s specific elements.

The modal analysis of the helicopter blade achieved in this paper with the help of ANSYS 15 is a linear analysis. Any non-linearity like plasticity and the contact elements are ignored even though it is defined. A modal solution is achieved after a modal analysis which covers the following stages (figure 6): design of the model in a CAD software or in the finite element analysis software (for simpler models); applying the loadings and getting the solution through structural analysis; the expansion of the modes; view of the results.

Fig. 6 The main stages of a modal analysis achieved with a finite element software

To realize the 3D model of the helicopter blade the SIKORSKY SC1095 (figure 7) profile was used, which has the following characteristics: particular to helicopter blades; maximum thickness 9.5% at 26.9% chord; maximum camber 0.8% at 26.9% chord.

Fig. 7 SIKORSKY SC1095 airfoil

The main characteristics of the blade used for modal analysis in Ansys 15 software: chord 600 mm; shape: rectangular; length: 6.25 m; skin thickness: 0.6 mm.

The main mechanical characteristics of the carbon fiber used for the studied blade are described in table 1.

Table 1

Mechanical characteristics of the carbon fiber

Characteristics	Units	Carbon Fiber
Young’s Modulus 0°	GPa	70
Young’s Modulus 90°	GPa	70
In-plane Shear Modulus	GPa	5
Poisson’s Ratio		0.10
Ult. Tensile Strength 0°	MPa	600
Ult. Comp. Strength 0°	MPa	570
Ult. Tensile Strain 0°	%	0.85
Ult. Comp. Strain 0°	%	0.80
Density	g/cm^3	1.60

In figure 8 it is described the discreet model of the helicopter blade which contains 12400 nodes, 12300 quad 4 elements.

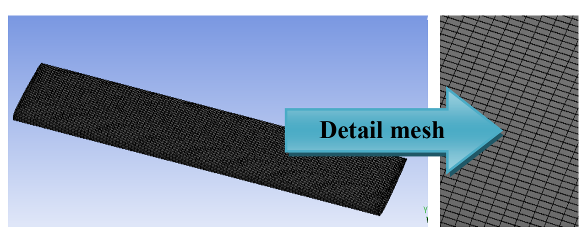

Fig. 8 Meshing of the blade model – detail

To estimate the behavior of the blade (fixed in rotor) at vibrations, it shall have done a modal analysis in Ansys 15 software for determining the frequencies (table 2) and the 6 modes of vibration (figures 9 - 14).

Table 2

Determined Modal Frequencies of blade

Mode number	Frequencies [Hz]
1	1.9453
2	8.5202
3	11.33
4	11.745
5	11.766
6	13.03

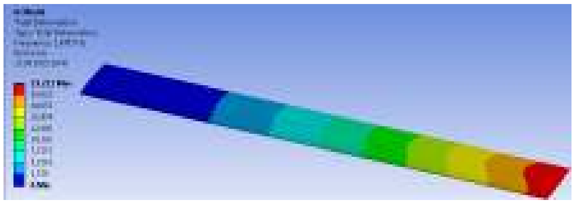

Fig. 9 Mode shape 1

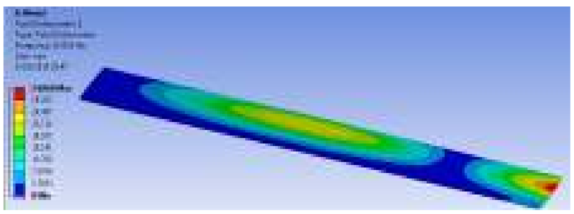

Fig. 10 Mode shape 2

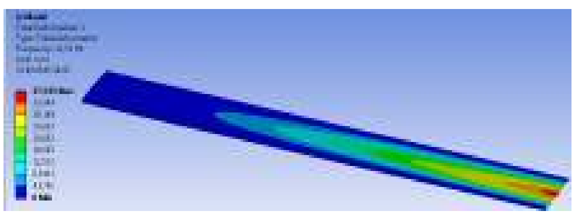

Fig. 11 Mode shape 3

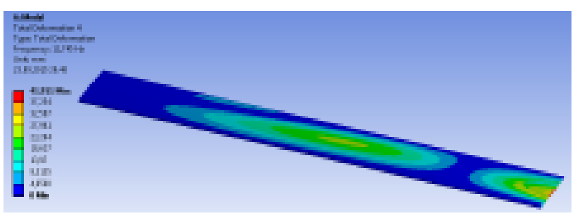

Fig. 12 Mode shape 4

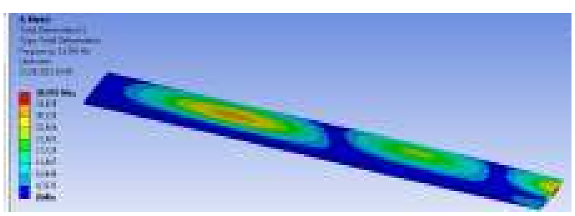

Fig. 13 Mode shape 5

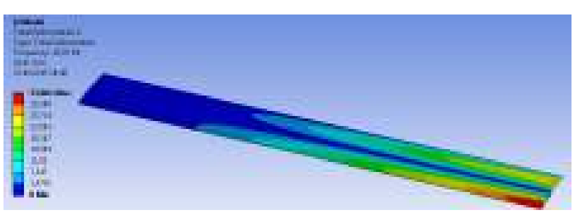

Fig. 14 Mode shape 6

4. CONCLUSIONS

As a way of transport the helicopter was extensively developed in the last years. It has to be accounted that by its design the helicopter is subjected continuously to cyclical loads so it has to withstand to a high number of fatigue cycles and vibration. The most susceptible elements of the helicopter to these stresses are the rotor assemblies, the main rotor and the tail rotor or anti-torque rotor, within which a main place is taken by the blades. Within this paper were presented the results of the modal analysis of a carbon fiber blade which is outfitted on helicopters. The blade´s characteristic frequency domain for the blade analyzed in this paper is from 2 Hz to 13 Hz. The results obtained from the modal analysis of the carbon fiber blade demonstrated that its frequencies are superior to those functional of a blade so that there shall be no problems with its use.

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