STRUCTURAL ANALYSIS OF THE MAIN ROTOR BLADE FOR A LIGHT HELICOPTER - CASE OF HOVERING FLIGHT MODE

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***Abstract*—**The aerospace industry deals from the beginning with structures with special requirements as extreme lightweight and withstanding to a big number of load cases. Aerodynamics constraints lead to supplementary restrictions, the results being the complex shape to sustain the fuselage, the rotor blades or the wings skin. This paper presents a static structural analysis of the main rotor blade for the light helicopter. To simulate the mechanical behavior of the blade, a finite elements method was used. A case of hovering flight mode was considered.

***Keywords* —** finite element method, hovering flight mode, rotor blade, structural analysis.

I. INTRODUCTION

THIS paper presents the mechanical behavior of a helicopter rotor blade, when a hovering flight mode is applied, as the loading conditions.

In order to save the time and money resources, the designer engineers from aerospace industry adopted a designing based structural analysis. A very practical utility of the structural analysis and the stresses and deformations maps is that to help the engineers to design and integrate the Health Monitoring Systems.

According to [5], the first aim of the Structural Health Monitoring systems is to detect and diagnose the occurrence of any structural damage from the incipient phase in order to maintain the aircraft safety.

The structural analysis developed in aerospace area consists in, besides the finite element methods, the strong knowledge of aircraft aerodynamics and aero-elasticity theory.

The results obtained from the structural analysis can help the aerospace industry to optimize the topology of the aircraft components in order to reduce the weight and to maintain the rigidity at an acceptable level (the maximum stress has to be below of the fracture limit of the material).

II. FUNDAMENTALS OF HELICOPTER AERODYNAMICS

The helicopter aerodynamics represents one of the essential tasks for designers.

According to [1] the helicopter is an aircraft that uses rotating wings to produce the lift, propulsion and command forces. The rotor blades rotate around a vertical axis, describing a disk in horizontal plan.

After [7], the aerodynamic forces are developed as a result of relative motion of the blade surface reported to the air.

In [3] it is specified that hovering flight mode is referred to the flight type when the helicopter is maintained at a certain height toward the ground, with no advance.

In order to better understand the helicopter aerodynamics, the main forces that act on the helicopter in its flight are presented in Fig. 1.

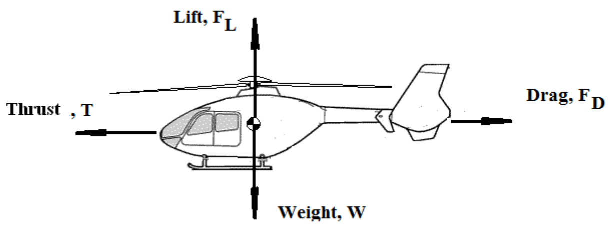

Fig.1. The main aerodynamic forces of the helicopter, adapted from [2].

As it is observed in this image, the aerodynamic forces can be understood as a drag or a thrust of the helicopter in a certain direction.

Weight, *W* is a force oriented down to the centre of the earth. It is directly proportional with the helicopter mass and depends on its loading.

Thrust force, *T* is assured of the propulsion system of the helicopter and it is always oriented to the flight direction.

The drag force, F_D is an aerodynamic force that is opposed to any body, which is moved in a fluid. This force is oriented in opposite side of the flight direction and is concentrated in one point, called the pressure centre.

The lift force, F_L represents the force that keeps the helicopter on the air. This acts on the pressure centre and is oriented perpendicular to the airflow direction. According to [2], the lift force appears as a result of static pressure difference between the two opposite forces of the airfoil.

After [3], an aerodynamic airfoil is the section shape of a blade due to the intersection with a perpendicular plan of the blade surface and parallel with the flight axis.

III. CASE STUDY – FEM ANALYSIS OF A HELICOPTER ROTOR BLADE, IN HOVERING FLIGHT MODE

According to [4] and [6] the structural analysis by finite elements method is based on the structure sharing in individual components called “elements”; its mechanical behavior is already known and understood and it can be easy studied.

For the case of the helicopter blade, the 3D modeling was done with the help of the specialized designing software, CATIA, using the real geometrical data from the technical standards and taking into account the practical recommendations from [2] and [8]. Fig. 2 illustrates the geometry and the main dimensions of the rotor blade.

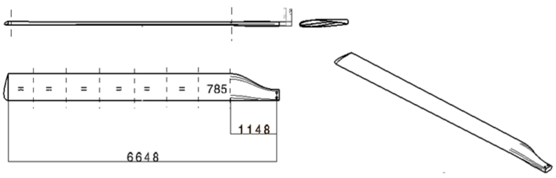

Fig. 2. The geometry and the main dimensions of the blade.

To highlight the mode of loads distribution on the blade, the geometry was divided in 7 segments of the same length, taking into account the variation of the torsion angle from the base to the top.

It is considered that the blade is constructed by three components: longeron, skin and foam that can be observed in Fig. 3.

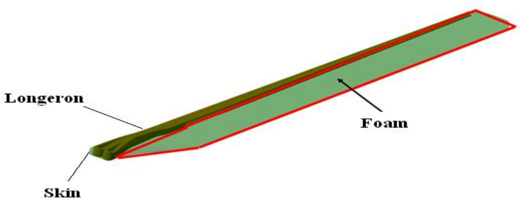

Fig. 3. The main components of the helicopter blade.

For each component, the materials and its properties are selected, as:

- Carbon fiber (CFRP) for skin;
- UD fiber belt for longeron;
- ROHACELL RIMA 51 for the foam;
- Structural steel for the shoulder bushings.

The structural FEM analysis was performed using Hypermesh & Radioss specialized software.

For the meshing it was selected a combination between QUAD (shell) elements, for the skin, HEXA and TETRA (solid) for the longeron and the foam. In the Fig. 4, a) and b), it is presented the meshing of the blade model.

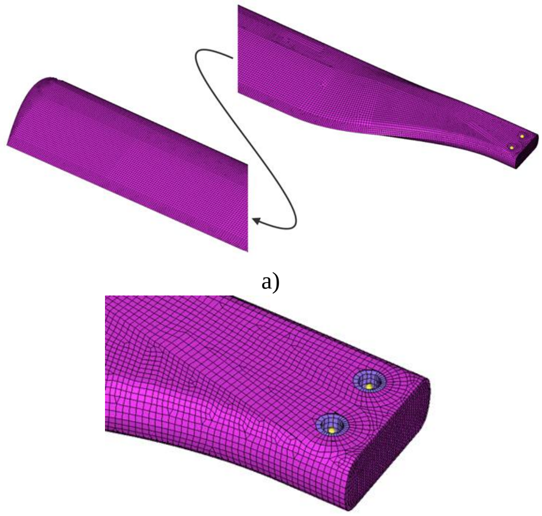

Fig. 4. The meshing of the blade model: a) all the blade surface; b) detail for the shoulder bushings area.

The constraints were introduced in the shoulder bushings area, as in the Fig. 5.

For the two shoulder bushings, it was used the rigid elements type RBE2; the rotation on Ox axis was not constrainted.

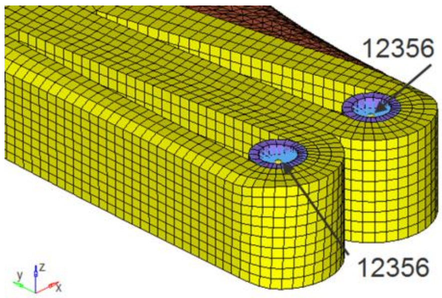

Fig. 5. The constraints in the shoulder bushings area.

The loads acting on the helicopter blade during the flight were computed with the aerodynamic formulas [1], using the real input data.

As to obtain the solution of the static structural analysis, the maximum equilibrium angle of the blade it is computed taking account the centrifugal force components and the lift on each segment. It is obtained a value for the maximum angle of 2.45° that can be observed in Fig. 6.

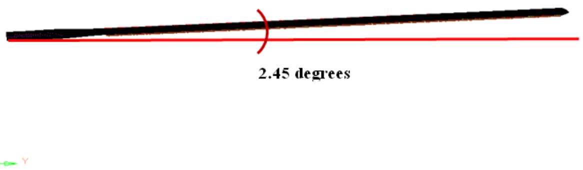

Fig. 6. The equilibrium position of the blade to the horizontal axis.

For the structural analysis, the lift, the drag and the centrifugal forces were applied as distributed forces on the nodes on each blade segment, both on the upper side and the soffit.

The aerodynamic moment was divided in a couple of forces and it is applied in the same nodes that for the other loads.

For the final calculus the combination of all loads (the lift + the centrifugal force + the aerodynamic moment) case was considered, as in the Fig. 7.

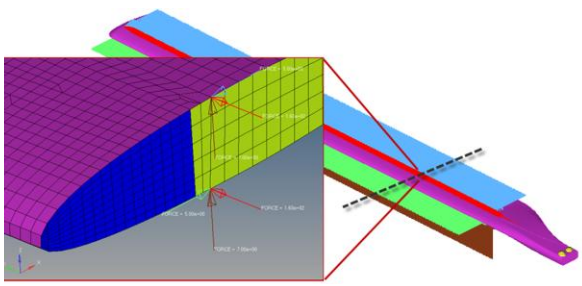

Fig. 7. The loads introduced in the blade structure.

The case of hovering flight mode supposes the displacement of the free end of the blade, in the vertical plan, as illustrated in the Fig. 8, a and b.

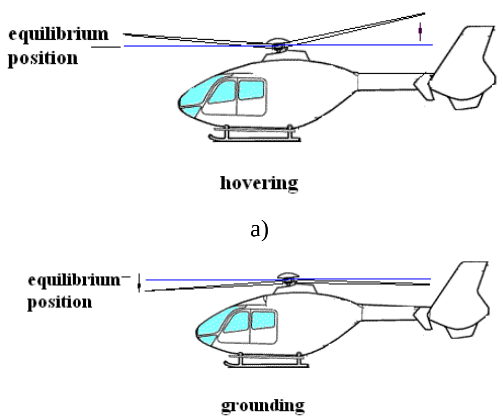

Fig. 8. The blades position in the two cases: a) hovering; b) grounding, adapted from [2].

For the hovering flight mode, two cases of loading are considered:

- hovering, when the free end of the blades is moved up to the equilibrium position;
- grounding, when the free end of the blades is moved down, below the equilibrium axis.

It is to note that in the hovering flight mode case, the blades have no rotating motion.

IV. RESULTS

Applying the limit load case, for the mechanical behavior simulation, in conditions of the hovering flight mode, it is obtained a set of results that are presented in what follows.

In Fig. 9, the distribution of the total maximum displacement values along the blade skin is illustrated. One can observe that the critical values, of 226 mm are located on the free end of the blade.

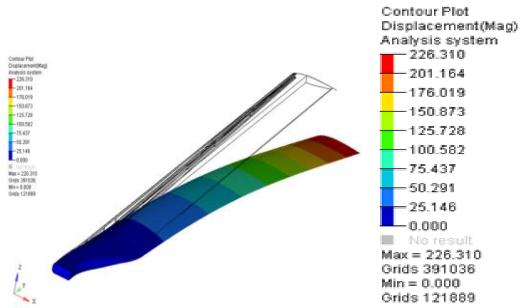

Fig. 9. The total maximum displacement (scaled displacement).

The maximum displacement on Oz axis is presented in Fig. 10. According to the image, one can see that the maximum values, of 169 mm, are placed on the free end of the blade.

Fig. 10. The maximum Oz displacement.

Fig. 11 illustrates the local deformations distribution on the longeron. In the case of hovering flight maneuvers, the longeron is one of the components that are loaded with to the highest deformations. As it can be observed that the critical area appears on the lateral inner side of the fitting area.

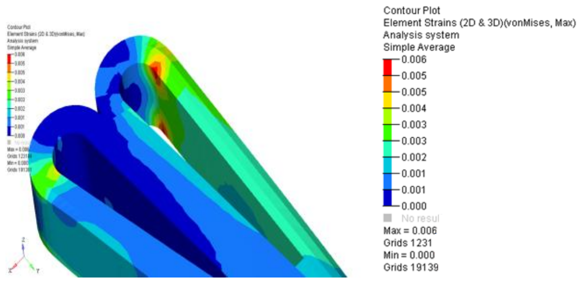

Fig. 11. The local deformation on the longeron.

The von Mises stresses map is showed in Fig. 12. It is observed that the high stress area is developed on the inner edge of the longeron, in the fitting zone. Its value of 78 N/mm^2 emphasizes that the blade structure has a high rigidity.

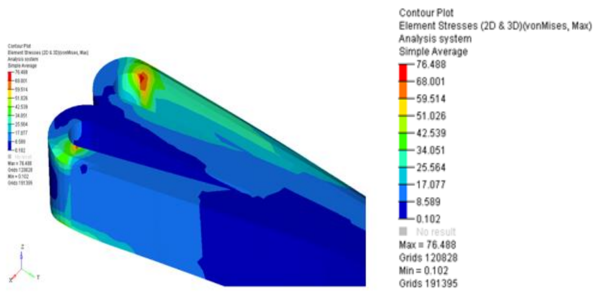

Fig. 12. The maximum von Mises stresses on the longeron.

In figure 13, the variation of the equivalent stress along the blade skin is illustrated.

For the case of the loading conditions (hovering flight mode), it can be observed that the critical stresses are located on the skin, near the fitting area, on the lateral edge.

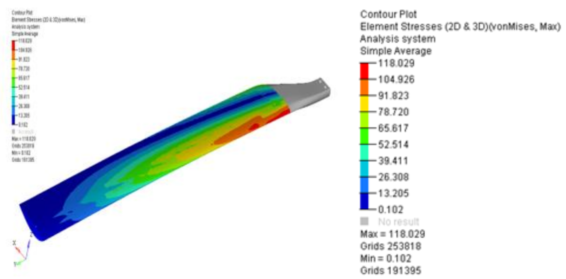

Fig. 13. The variation of the equivalent stress along the blade skin.

V. CONCLUSIONS

The hovering flight mode consists in maintaining the helicopter at a certain height to the ground. In this case, the blades have no rotating motion.

For the case of the helicopter blade model, after the finite elements analysis, some conclusions related to the modeling and the structure behavior, for the selected loading conditions are identified:

- the model of the rotor blade has the advantage of a lightweight structure due to the introduction of the foam in the place of the ribs that exists at other helicopters blades models;
- due to the up – down motion of the free end of the blade, in the shoulder bushings area, on the longeron, some critical deformations (0.006 %) appear;
- the value of the maximum displacement of the blade (226 mm) can be considered as being acceptable, for the selected loading conditions and the geometrical dimensions of the blade;
- the maximum stress on the longeron (78 N/mm^2) means that the blade structure has a good rigidity;
- for the case of the selected loading conditions, some critical equivalent stresses appear on the lateral inner surface of the blade skin.

As future research directions, studies of topological optimization in order to reduce the structure weight and to maintain the rigidity at an acceptable level are considered.

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REFERENCES

[1] A. Postelnicu, Gh. Deliu, R. Udroiu, *Theory, Performances and Construction of the Helicopters (Teoria, performantele si constructia elicopterelor).* Cluj Napoca: Ed. Albastra, 2001, ISBN 973 – 650 – 008 - X.

[2] Y. C. M. Niu, *Airframe Structural Design. Practical Design Information Data on the Aircraft Structures.* California: Canmilit Press Ltd., 1998, ISBN 962 – 7128 – 04 - X.

[3] D. Crocker, *Dictionary of Aviation.* London: A & C Black Publishers Ltd., 2007, eISBN – 13: 978 – 1 – 4081 - 8.

[4] O. C. Zinkiewicz, R. L. Taylor, *The Finite Element Method. The Basis*. Ed. Butterworth – Heinemann, 2000, ISBN: 0 – 7506 – 50494.

[5] D. Cazangiu, M. Bulmaga, *Aspects regarding to the Design of the Feature Extraction Algorithms used at Structural Health Monitoring Systems*. Research and Science Today, Nr. 1 (7), Targu Jiu, 2014, ISSN –e: 2285 – 9632.

[6] Y. Liu, Lecture Notes: *Introduction to Finite Element Method*. University of Cincinnatti, 1998.

[7] L. J. Clancy, *Aerodynamics*. Pitman Publishing Ltd., 1975, ISBN 0 – 273 – 01120 – 0.

[8] E. F. Bruhn, *Analysis and Design of Flight Vehicle Structures*. Tri - State Offset Company, 1973.

[9] * * *, Hypermesh 8.0. User's Manual. Altair Engineering Inc., 2008