AN EXPERIMENTAL STUDY OF THE STRUCTURAL DAMPING OF THE HELICOPTER MAIN ROTOR BLADE FROM COMPOSITE LAMINATED MATERIALS

Bosko Rasuo - University of Belgrade

ABSTRACT: In this paper experimental results of structural vibratory testing for the light multipurpose helicopter main rotor blade of composite laminated materials are presented. The aim of the main rotor blade vibratory testing was to define the basic aeroelastic properties of the blade. This testing included determination of the natural oscillation modes and natural frequency of the structure in oscillations, as well as defining the blade structural damping. The measurement was performed for three different full-scale models with three different types of cores of the main rotor blade: 1- Rohacell 71 - polyurethane foam, 2- Nomex aramid honeycomb and 3- Nomex phenolic honeycomb, and the results are presented in this paper.

INTRODUCTION

The use of composite laminated materials in many structural applications due to their high specific stiffness and strength has attracted interest in methods for improving the damping performance of these structures. It has been found that the damping structures from composite laminated materials depends on the micromechanical properties of the constituent materials, the lamination schemes and type of cores [1]. The composite damping exhibits an opposing trend to stiffness and strength, being minimum in the direction of fibers and maximum in the transverse and shear directions. Structural damping is also found to be strongly dependent on the structural geometry and deformation modes. Thus there is a need to investigate and analyze of structural components which are capable of describing the global structural response by correlating the damping characteristics of the structural components to the parameters of the basic constituent materials, laminate and core configuration and geometry of the structure [2].

The importance of full-scale testing in the development (and/or redesign) process for composite laminated materials helicopter blades is discussed, and illustrated by means of an example drawn from Aeronautical Department (Faculty of Mechanical Engineering, University of Belgrade) experience in the use of composites in a wide variety of structural applications [3]. The laboratory investigations of the structural damping are conducted at Aeronautical Department on all flight-critical dynamic components in order to determine structural adequacy [4]. In this paper the analysis of behavior by full-scale testing of the structural damping for a main rotor blade for the light multipurpose helicopter propulsion system of composite laminated materials is given (see Figure 1).

A development of the main rotor laminated composite blade for the light multipurpose helicopter propulsion system was conducted. The development was performed in four phases: (1) the blade design on the working station using designing system Howard-Hughes, (2) preparation and cutting of blade components on the Gerber Garment cutting system, (3) blade manufacturing in a two-section die, and (4) final verification testing [5 and 6].

In order to analyze mechanical characteristics and structural damping characteristics three full-scale models of the blade were fabricated. One model of blade (Model 1) with Rohacell 71 polyurethane foam core was structurally identical to the other two models: second one, with Nomex aramid honeycomb core (Model 2) and third one, with phenolic honeycomb core (Model 3).

The verification test program for the main rotor helicopter blade encompassed static and dynamic testing. The static tests of the blade involved experimental evaluation of torsional and flexional blade stiffness and its elastic axis position. Dynamic tests involved testing of vibratory characteristics and testing of blade fatigue characteristic [4, 6 and 7]. All the tests were performed at the Mechanical Faculty of Belgrade University. The essential results of these investigations in this paper are presented. The employed techniques and methods at the testing is the usual practice at all aerospace research centers [8].

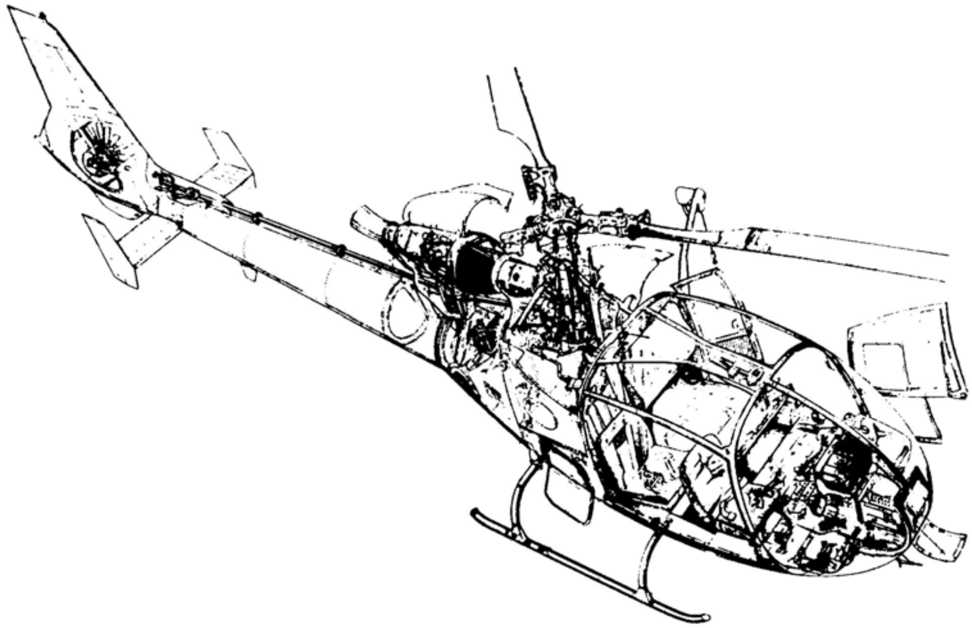

Fig. 1: The light multipurpose helicopter

DESCRIPTION OF MODELS

In the blade manufacture the conventional composite materials with epoxy resin matrix, a fiberglass filament spar, an eighteen-section skin of laminated fabrics, some carbon filament embedded along the trailing edge, a core, leading edge protection strips of polyurethane and stainless steel etc. were used. All the used materials are standard products fabricated at Ciba-Geigy, Interglas GmbH, Torayca and others [1].

Each blade paddle consists of a fiberglass-epoxy spar and a fiberglass blade section which is fastened to the outboard end of the spar. Unidirectional fiberglass-epoxy is used to provide a high modulus in the axial direction and adequate torsional stiffness for full pitch change motion of the blade. Similarly, flapping (out-of-plane) motions are accommodated through elastic bending of the spar. The spar cross section provides the high edgewise (in-plane) stiffness required for an aeroelastically stable rotor.

The inboard or torque tube portion of the blade is not supported by core and is designed to provide high torsional rigidity. The trailing edge contour of the airfoil is formed by a continuous structural pocket which has a Nomex phenolic honeycomb (or Nomex aramid honeycomb or Rohacell 71 polyurethane foam) core and a fiberglass skin. The upper and lower skins are fabricated from woven fiberglass that is laid up with the fibers oriented at $\pm 45°$ and $0°/90°$ to the blade longitudinal axis. On the blades, the inplane blade natural frequency is tuned by stiffening the trailing edge of lower skin with some carbon filaments.

The leading edge contour is formed by a fiberglass leading edge piece which is protected from erosion by a combination of "C" shaped stainless steel and polyurethane erosion strips which are bonded to the blade leading edge. A series of counterweights are bonded to the leading edge of the spar to provide the required chordwise blade balance. The counterweights are molded of elastomer with lead shot embedded in the matrix of fiberglass with lead rod in the laminate. The counterweights fill the area between the leading edge piece and spar (Figure 2).

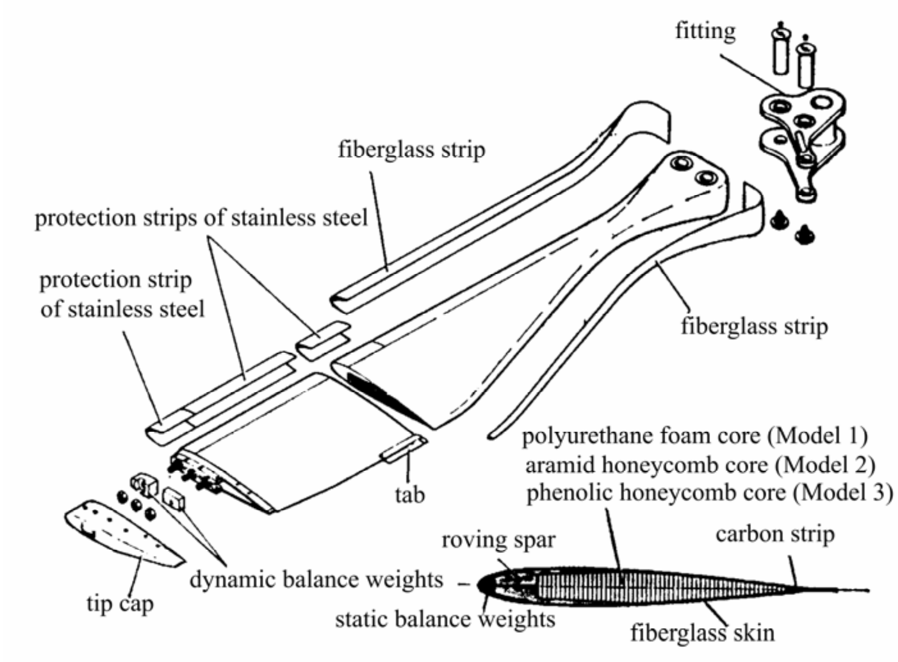

Fig. 2: The helicopter main rotor blade made of composite laminated materials

EXPERIMENTAL PROCEDURE AND RESULTS

The purpose of the static tests was to evaluate experimentally torsional and flexional stiffness and elastic axis position of all the three blade models. To determine the blade torsional stiffness one needs to define the required torsional moment in the ruling cross-section which would cause a torsion of one radian relative to the blade root cross-section. The results for all the three investigated blade models for the cross-section 12 (Figure 3) are presented in Table 1 [5 and 6].

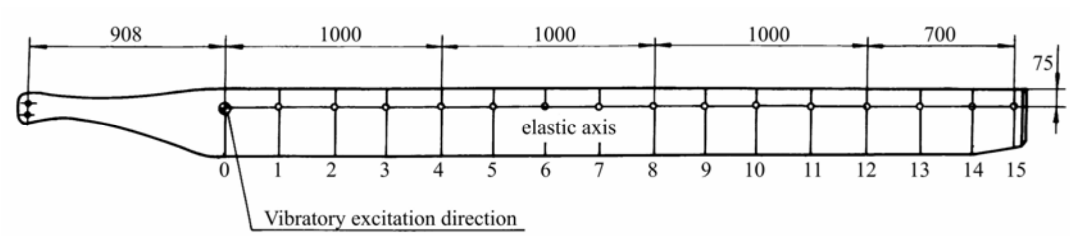

Fig. 3: Measurement points in vibratory testing

The calculated values of the elastic axis deflections were utilized for calculation of the flexional stiffness for all the three blades. The results with averages of the flexional stiffness for the selected cross-section 12 for all models are presented in Table 1 [5 and 6].

The aim of the main rotor blade vibratory testing was to define the basic aeroelastic properties of the blade. This testing included determination of the natural oscillation modes and natural frequency of the structure in oscillations, as well as defining the blade structural damping.

A very robust facility frame made of steel *U* and *L*-profiles tied together with screws was used in the course of the main rotor blade attachment vibratory testing program.

Several control measurements were performed with the aim to check the rigidity of the frame and its eventual interference in the course of the experiment itself. At the beginning the model frame frequency characteristics were measured, and then a new load of about 500 kg was added to the frame and new measurements were carried out. The results in both measurements coincided which meant that the rigidity of the frame was absolutely satisfactory, proving that its influence on the measurement could be neglected.

All the elements used in these tests are shown in the flow-chart diagram, Figure 4. There it can be clearly seen that all the elements were divided into two functional sections. The first one was composed of excitation apparatus while the second one was made of response-detection equipment. Measuring points were placed along the elastic axes of the blade in the same order as shown in Figure 3.

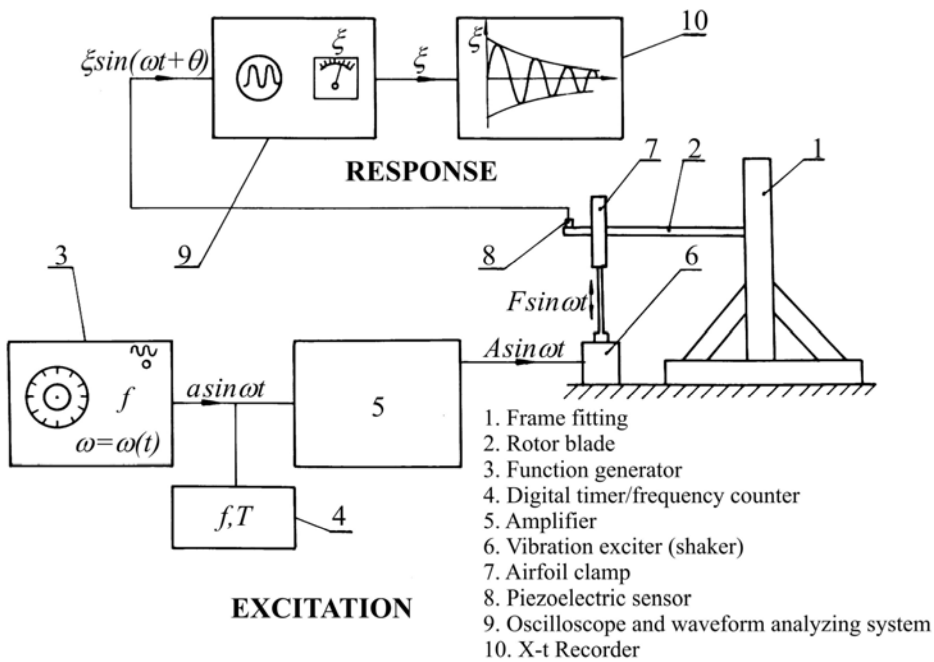

Fig. 4: Employed equipment in vibratory testing

The excitation apparatus consisted of a pulse generator, a signal amplifier, a digital timer/frequency counter, a vibration exciter (shaker) and an airfoil clamp; while the response detection group was made of: piezoelectric accelerometers, oscilloscope with voltmeters and a multichannel *X-t* recorder.

A pulse generator with a sinusoidal excitation function and with a precise adjusting of frequency set-point value in a range from 0.01-10 000 *Hz* was used in this experiment. A digital frequency counter was used for precise read-out of excitation frequency. The vibration exciter was an electrodynamic one which is also considered to be the most suitable for harmonic analysis and this type of experiment.

The link between the vibration exciter and the rotor blade was formed of a rigidly tied aluminum alloy pipe with adjustable length and by use of a panel airfoil clamp which was shaped so as to fit the rotor blade cross-section at the location of application of excitation. For displacement measurement in these investigations piezoelectric accelerometers were used and they measured displacements at selected points on the blade as shown in Figure 3. A special kind of cement was used to provide a close link between the pick-up and the blade in the course of measurement.

In these investigations, as a first step, a harmonic analysis for all the three types of blades was performed. Having determined the frequencies for the first-four harmonic's natural (resonant) modes of oscillations, displacement vectors for the first-four oscillation modes were measured. Some results are shown in Figures 5-10 and Table 1.

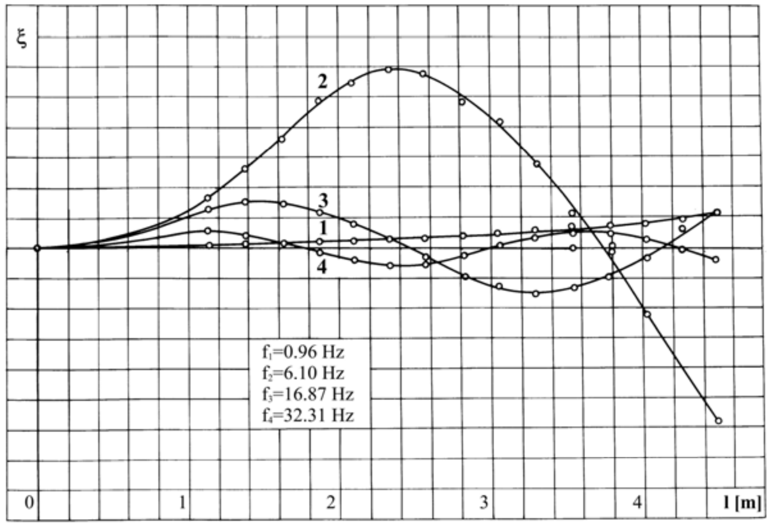

Fig. 5: Natural modes of oscillation for the blade with Rohacell polyurethane foam core (Model 1)

Figure 5 shows the results of the harmonic analysis of the first-four oscillation harmonics for the blade model with foam Rohacell 71 polyurethane core (Model 1). A comparative presentation of the first, second, third and fourth oscillation modes for all the three blade types are shown in Figures 6-9.

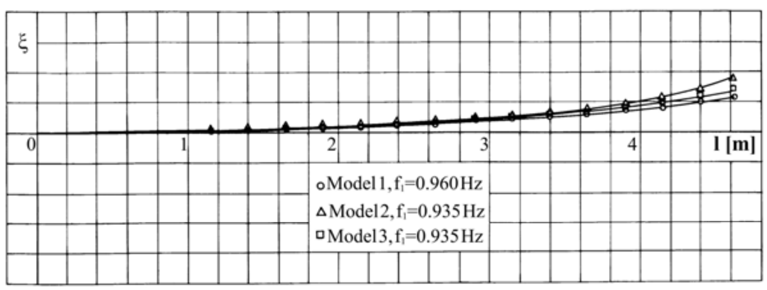

Fig. 6: Comparative results for the first oscillation mode

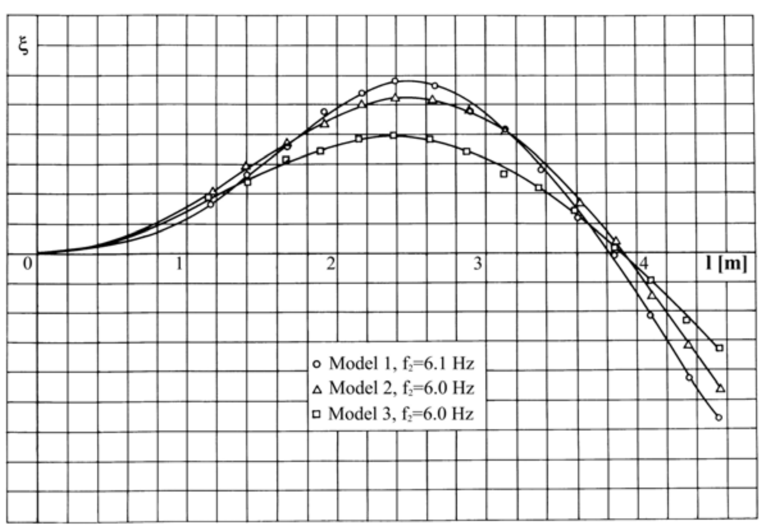

Fig. 7: Comparative results for the second oscillation mode

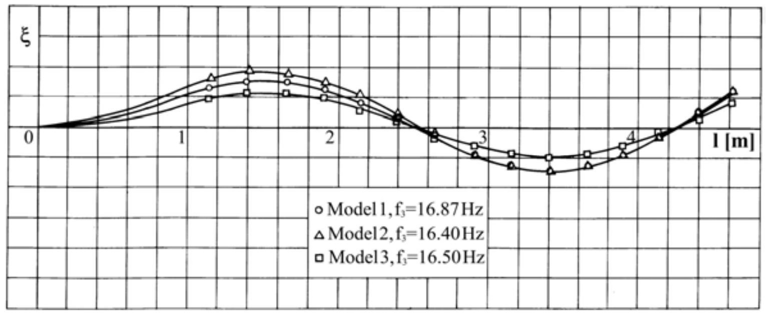

Fig. 8: Comparative results for the third oscillation mode

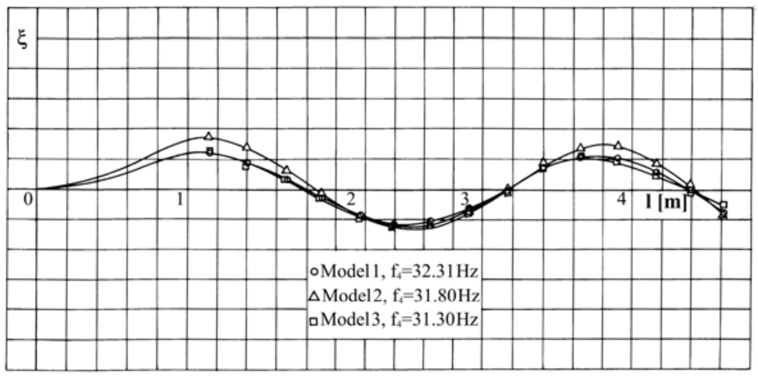

Fig. 9: Comparative results for the fourth oscillation mode

Rotor blade structural damping was determined from amplitude reduction of free vibration. The blades were excited to vibrate with the first (resonant) oscillation mode with continuously decreasing amplitude due to damping effects. The original records obtained from these tests for the third blade model at the cross-section 10 with time base 5 s/cm is shown in Figure 10.

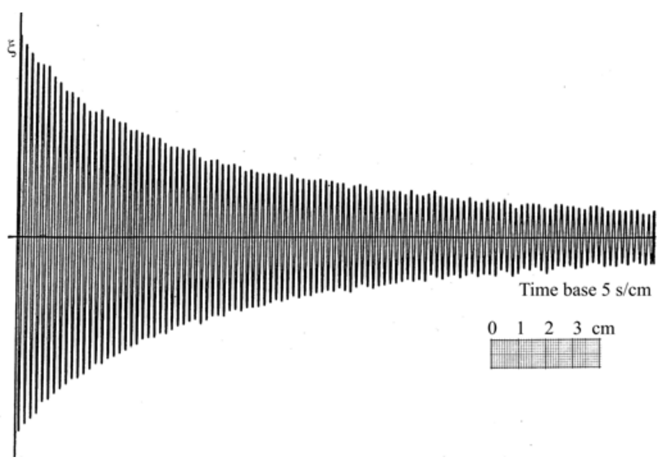

Fig. 10: Structural damping for the blade with Nomex phenolic honeycomb core (Model 3)

The logarithmic decrement of the free vibrations was utilized to characterize the structural damping diagram (Figure 10). Its value was determined as:

$$\delta = \frac{1}{n} \ln \frac{x_k}{x_{k+n}} \qquad (1)$$

where n=10 is the number of observed oscillations, x_k is observed initial amplitude in the time interval, whereas the correspondent average value of amplitude is:

$$x_m = \frac{1}{2}(x_k + x_{k+n}) \quad (2)$$

Q-factor is also usually used to define the structural damping and gives relative energy (E) reduction in successive oscillations. Q-factor is defined as:

$$Q = \frac{E_1}{E_1 - E_2} \approx \frac{1}{2\delta} \quad (3)$$

The comparative presentation of the results of the structural damping for all types of blades, expressed by the logarithmic decrement and the Q-factor are given in Figures 11 and 12 and Table 1.

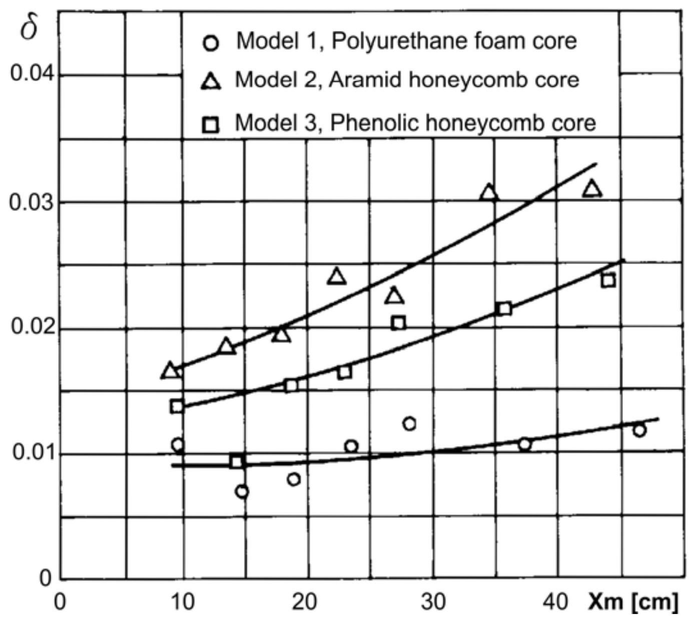

Fig. 11: Logarithmic decrement of blade free vibration

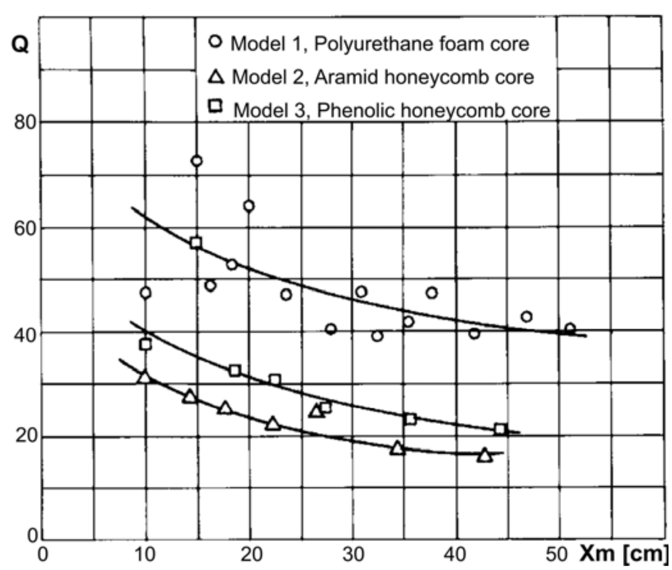

Fig. 12: Q-factor of blade vibration for all three types of models

Table 1: Tested models comparative results

Type of model	1	2	3
Type of core	polyurethane foam	Aramid honeycomb	Phenolic honeycomb
Elastic axis position, *x/c*	0.25	0.25	0.25
Average values of torsional stiffness $m_{\Theta m}$ [*daN m/rad*]	194.06	171.58	165.11
Average values of flexional stiffness $m_{\delta m}$ [*daN m/rad*]	1026.37	931.00	920.75
first mode f_1 [*Hz*]	0.96	0.935	0.935
second mode f_2 [*Hz*]	6.1	6.0	6.0
third mode f_3 [*Hz*]	16.87	16.4	16.5
fourth mode f_4 [*Hz*]	32.31	31.8	31.3
δ (x_m=30 *cm*)	0.010	0.026	0.019
Q-factor (x_m =30 *cm*)	46	19	26

CONCLUSION

The static tests results for all investigated composite blade models show that the blade with the Rohacell 71 polyurethane foam core, designated as Model 1, performed best as far as the torsional and flexional characteristics are considered. In all three cases the elastic axis position was practically the same, i.e. at 25 % of cross-section's airfoil cord (Table 1).

The results from the blade frequency analysis show an exceptional conformity of the basic modes as well as their oscillation frequencies for all three types of blades. The obtained differences in frequencies and displacement vectors for some basic types of oscillation modes were within the range 1.6-5.6 %. The structural damping tests indicate, that the blade with Rohacell 71 polyurethane foam core has the least structural damping, more then two times less than the blades with Nomex aramid honeycomb core (see Table 1).

Well-designed composite laminated structures can provide a satisfactory level of damping, a high degree of damage tolerance and in practice it is still very difficult to utilize the full fiber strength potential of composite structures. The composite laminated materials with adequate core give constructions with exceptionally high level of the structural damping so important in aircraft application.

REFERENCES

[1] Baker, A. A. Kelly, D. and Kelly, D. (Editors), (2004). Composite Materials for Aircraft Structures, 2nd Edition, AIAA, New York.

[2] Lakes, R. S. (2002). High Damping Composite Materials: Effect of Structural Hierarchy, *Journal of Composite Materials*, 36: 287-297.

[3] Guyett, R. P. and Cardrick, A. W. (1980). The Certification of Composite Airframe Structures, *Aeronautical Journal*, 84, 188-203.

[4] Rasuo, B. (1999). Verification Testing of Aeronautical Constructions from Composite Laminated Materials in Designing Process, *Journal of Aerospace*, V-107-1, SAE International, Warrendale, USA. 1714-1719.

[5] Rasuo,B. (2001). Design, Fabrication and Testing of the Helicopter Tail Rotor Blade from Composite Laminated Materials, 13th International Conference on Composite Materials, Proc. of the 13th Int. Conf. on Composite Materials, ICCM-13, Beijing, China, (CD-ROM).

[6] Rasuo, B. (2007). An experimental methodology for evaluating survivability of an aeronautical construction from composite materials: An overview, *International Journal of Crashworthiness*, **12**: 9-15.

[7] Pai, F. (2007). Highly Flexible Structures: Modeling, Computation, and Experimentation, AIAA, New York.

[8] Crocker, M. J. (Editor) (2007). Handbook of Noise and Vibration Control, John Wiley & Sons Inc., Hoboken, New Jersey.