AN EXPERIMENTAL TECHNIQUE FOR VERIFICATION FATIGUE CHARACTERISTICS OF LAMINATED CONSTRUCTIONS FROM COMPOSITE MATERIALS: FULL-SCALE TESTING OF THE HELICOPTER ROTOR BLADES

Bosko Rasuo
University of Belgrade, Faculty of Mechanical Engineering, Aeronautical Department, 11120 Belgrade 35, Serbia

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Abstract

The importance of full-scale testing in the development process for composite laminated materials helicopter blades is discussed, and illustrated by means of two examples drawn from Aeronautical Department, Faculty of Mechanical Engineering experience in the use of composites in a wide variety of structural applications. Laboratory fatigue testing is conducted at Aeronautical Department on all flight-critical dynamic components in order to determine structural adequacy.

In this paper the analysis of behavior by fatigue testing for a main rotor blade for a light multipurpose helicopter propulsion system and a heavy transport helicopter tail rotor blade of composite laminated materials are given.

1 Introduction

Fatigue testing of the helicopter blades was accomplished in a special test facility designed to simulate the in-flight loading. The applied test loads include simulated steady centrifugal, vibratory cordwise bending, vibratory flapwise bending, and vibratory torsional pitch motion.

The fatigue analysis of these composite laminated structures was performed after fatigue test cycles for detection of laminate separation, tolerance and distortion of structure crossections. All the tests were performed at the Aeronautical Department of the Faculty of Mechanical Engineering of Belgrade University. The essential results of these investigations in this paper are presented.

The development and qualification of aircraft components and systems includes a heavy emphasis on a full-scale test approach independent from the design process. In the case of fatigue-loaded flight-critical components, a laboratory fatigue program is conducted.

The component full-scale fatigue program is conducted with few compromises in mounting interfaces, flight load simulation, assembly procedures and inspection methods. Test methods and fatigue mechanisms for the following components are discussed: a main rotor blade for a light multipurpose helicopter propulsion system and a heavy transport helicopter tail rotor blade.

2 Model Description

A development of a main rotor laminated composite blade for a light multipurpose helicopter propulsion system (Figure 1) and a heavy transport helicopter tail rotor blade were conducted. The development was performed in four phases: (1) the blades design on the working Syber-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 [1,2].

The verification test program for the main rotor helicopter blade encompassed static and

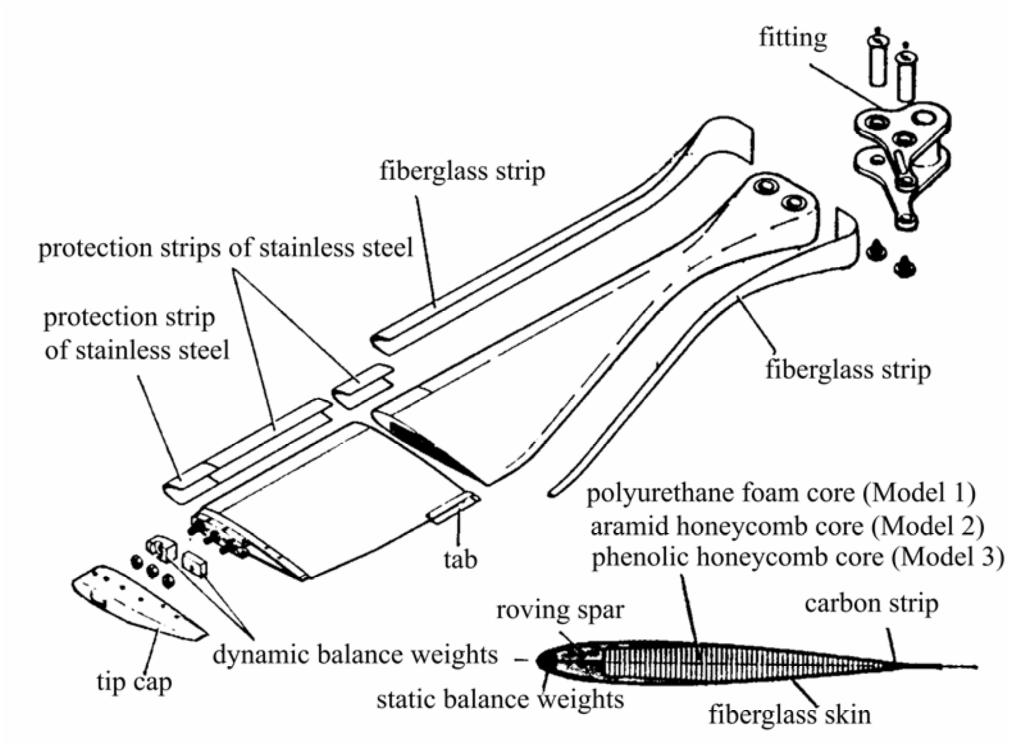

Fig. 1: The helicopter main rotor blade made of composite laminated materials.

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 [3-6].

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 (see Figure 1).

All the used materials are standard products fabricated at Ciba-Geigy, Interglas GmbH, Torayca and others.

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 [1].

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 [6].

The upper and lower skins are fabricated from woven fiberglass that is laid up with the fibers oriented at ±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

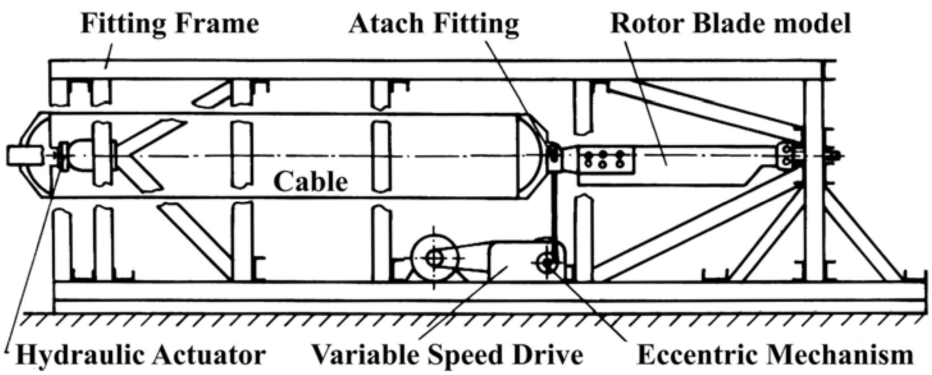

Fig. 2: Main and tail rotor blade fatigue test facility.

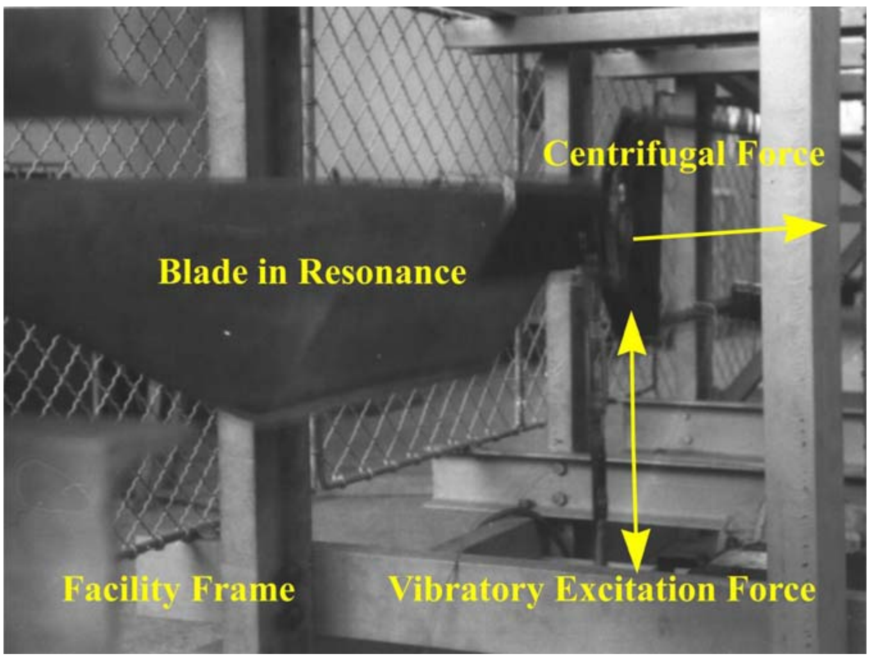

Fig. 3: The main rotor blade in fatigue testing.

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.

3 Experimental Approach

The inboard and root section of the rotor blades are usually tested as a simple cantilever beams. Simulated centrifugal load is applied and an eccentric and crank arm is used to apply bending loads.

The blades are oriented at an angle to the plane of motion of the eccentric arm so that combined flatwise and chordwise bending loads are simultaneously applied.

The program and the way in which these investigations were carried out on both rotor blades represent a standard practice followed by majority of scientific and research aeronautical institutions.

In the course of the rotor blades attachment fatigue testing program, a very robust facility frame made of steel *U* and *L*-profiles tied together with screws was used (Figure 2).

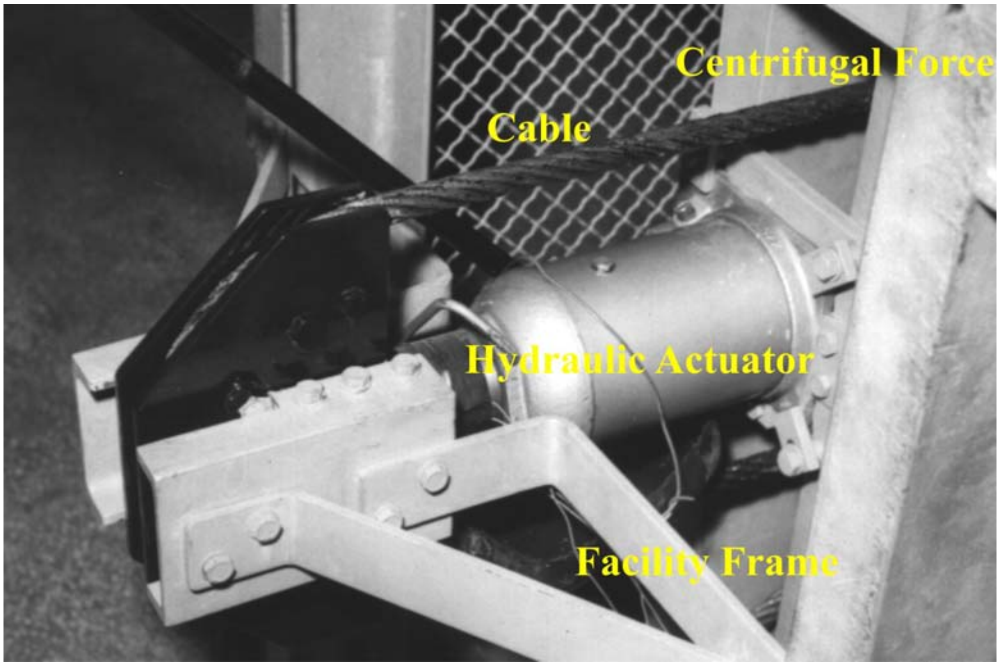

Fig. 4: The module for the centrifugal force simulation.

Fatigue testing of the root part of the blade spar is one of the most important investigations of the helicopter blades made of composite laminated materials in respect to their load carrying ability and survivability check-ups. These tests are carried out with an aim to define eventual delamination of the composite laminated structure, changes of shape of the root part of the blade and the loss of its load carrying ability after having been exposed to a certain cycle of alternating variable loads which, on their part, are a consequence of the in-flight combined load influence.

The applied test loads include simulated steady centrifugal, vibratory chordwise bending, vibratory flapwise bending, and vibratory torsional pitch motion.

The cyclic load consists of flapping and lagging loads with simultaneous application of centrifugal force (Figures 3 and 4).

4 Conclusion

The fatigue test results demonstrate that the designed solution, laminate blade structure from composite materials, have met the fatigue requirements given in standards and guidelines. The post-test performed checking showed no delamination, no permanent deformation or any other form of the helicopter blade destruction.

Full-scale testing of fatigue-loaded composite aircraft components designed for low-weight, flight-critical applications are required to verify structural adequacy and/or to provide data for redesign. The failure observed in full-scale testing were generally not predicted by design analysis and were related to design details such as ply endings, holes, curved sections, bonded joints, and bolted joints.

Well-designed composite laminated structures can provide 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 give constructions with exceptionally high level of survivability so important in both military and civil aviation.

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Contact Author Email Address

The contact author email address:
brasuo@mas.bg.ac.rs

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