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COMPOSITE ROTOR BLADES TESTS ESSENTIAL BEFORE MOUNTING ON GYROPLANE

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Abstract

The article presents the course of the composite rotor blades tests. Object of study was designed in Institute of Aviation, new airfoil for gyroplane rotors and technology of manufacturing carbon rotor blades were made. When the test program was developed, we focused for special test to check not only typical rotor blades properties but also composite structures thereby technology of manufacturing. One of the basic rotor blades test is to determine the breaking force, which, taking into account the safety factor, cannot exceed the maximum centrifugal force occurring on the rotor blades during flight. The first step of rotor blades tests was static test, which gave us answer about stiffness in plane of low stiffness and torsional stiffness, it's very important properties related to vibrations. Another mechanical properties measured during tests were centre of gravity and mass moment of inertia in rotor blade. Next step was dynamic test – tracking and balancing verification. After static and dynamics, which has proper results – good balance and no vibration on the entire range of rotational speed – rotor blades can be use on fly object. After getting proper results of static and dynamic test next step was a specially prepared test, which defined the time needed for delamination to take place. During the delamination tests, the rotor blade was subjected to adequate loads that occur in horizontal flight. That kind of test is basis to determine service life of rotor blades.

Keywords: *gyroplane, strength tests, blades properties, composites*

1. Introduction

Gyroplane blades with the rotor hub are the most important elements of the main rotor, before dynamic tests and then to get admission to the flight, blades have to go through a series of tests, which confirm their airworthiness. This article presents tests in case of composite blades. In contrast to blades made of aluminium, composite blades require tests to determine the strength of the composite structure. By performing tests to check the composite structure, the technology of manufacturing the blades, which was created in the Institute of Aviation, can be evaluated. Moreover, this kind of test can determine service life of rotor blades.

Based on the results of research, rotor blades are selected and paired to mount on main rotor. Selected the set of blades which will be admitted to the flight test is a critical step in the design of the rotor. To pair blades all properties of the blade must be known, after that, their cooperation on a special bench can be verified. Testing performed on blades with new laminar profile ILW-LT 11.0 dedicated to work in autorotation, for gyroplane class D, C and B. The new profile has been designed in Institute of Aviation in Warsaw as part of the project "Modern Autorotating Rotor". The new design solution is for-ensure high aerodynamic characteristics, safety and reliability in flight, thereby surpassing the previously used solution [2-4, 7, 9].

2. Test object

The test object is a composite rotor blade, with new laminar profile ILW-LT 11.0, length of blade is 400 mm, and maximum chord is 324 mm. The blade has a variable profile, designed and researched by the Institute of Aviation Aerodynamic Department. Composite consists mainly from carbon fibre made using hand lay-up method. Geometry of blades is shown on the Fig. 1 [5, 6].

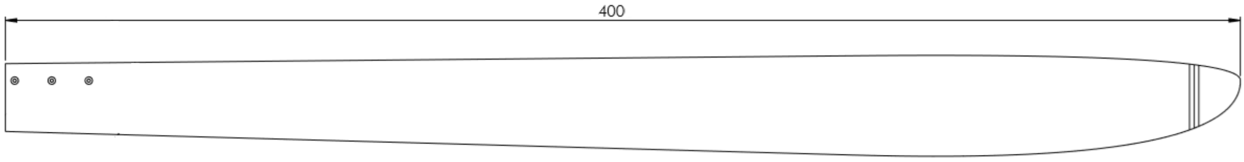

Fig. 1. Geometry of blade with profile ILW-LT 11.0

3. Tests and results

First step of tests was checking the strength of the blade on the strength machine, next static test, then dynamic tests and on the end test, which determine time needed to delamination composite structure.

3.1 Strength test

The aim of the study was to determine the static strength of the fragment of the composite blades structure by static load to its destruction. The test object was a fragment of composite gyroplane blades equipped with elements to introduction load (Fig. 2).

Fig. 2. Strength test object with elements to introduction load

The tests were carried out on the strength machine "Aviata" with the appropriate equipment that allows introduction of required loads for the test sample. Tested fragment of blade was attached to the test stand via placeholders' fasteners. The load occurring in the test was carried out by hydraulic actuator, which is part of Aviata stand. Loads and displacements were registered by "System 5000" – measuring and recording "System 5000" from Vishay MicroMeasurement. For the measurement, force sensor to 450 kN and displacement sensor (measured piston of the actuator displacement) were used. Speed of force applying was 2 mm/min.

Destructive force must be higher than the maximum centrifugal force occurring on the blades during the flight gyroplane. In this case, damage force is 321.10 kN (Fig. 3) and centrifugal force occurred on rotor blades during flight is 45.16 kN. Damage took place on the one of mounting hole.

3.2. Static tests

Static tests are fundamental for pairing blades in sets for mounting on main rotor. Before dynamic test stiffness, mass, centre of gravity and mass moment of inertia have to be checked. If mentioned properties are similar in both blades, which will be mount on rotor or we can change them by additional balancing weight to make them as similar as its possible then we can go to the next step – rotor tests. Firstly, we need to know mass and mechanical properties. After weighing blades next test will be measurement of stiffness - stiffness in plane of low stiffness and torsional stiffness.

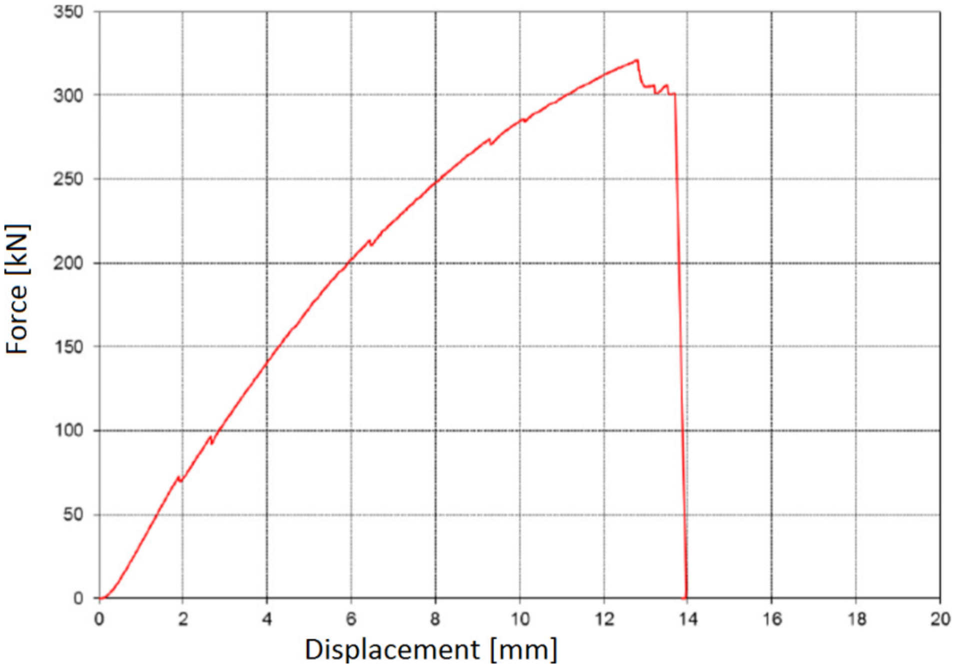

Fig. 3. Graph of force versus displacement during test strength

Stiffness is an important parameter, which allows for verification the computational level of vibration that may occur during the dynamic test. Measurements carried out globally – measure the deflection and global angle of torsion and locally, i.e. is measure stiffness in selected points along the blade length. During stiffness, test blades have to be mounted on test stand in such a way that the plane of high stiffness is vertically and a leading edge is facing upwards. Ensure adequate mounting blades to the position of measurement that the test is not flowed to the results of stiffness. Additional it must be ensured proper blades mounting, which will not flowed to the results of blade stiffness. To determine the stiffness was used specially made measuring devices equipped with a dial indicator. The measurement is carried out by reading from the sensor displacement values for each blade segments during test object loading. The leading edge of the blade is a base for measuring instrument. The loads system must provide the introduction of pure bending moment, in case of bending stiffness, and pure torque, in the case of torsional stiffness.

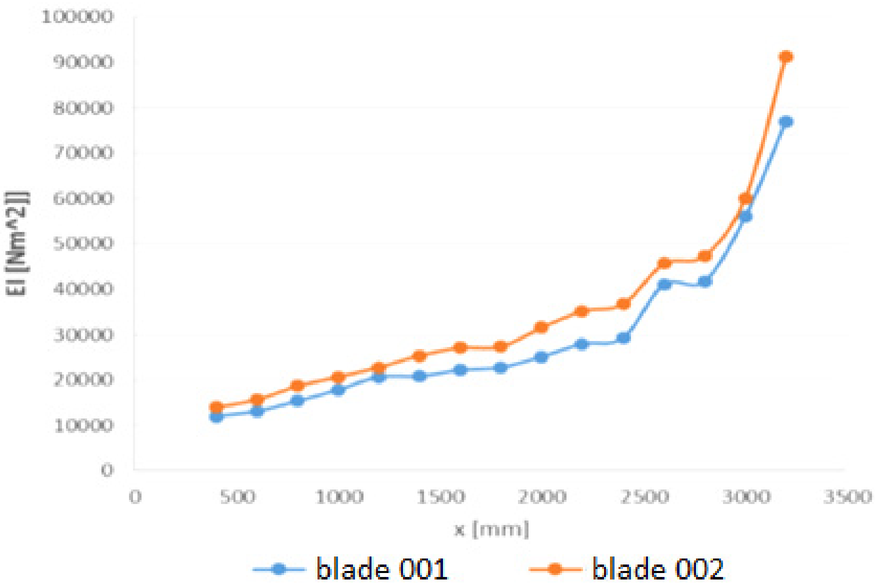

Fig. 4. Comparison of flexural stiffness in plane of small stiffness for the blades 001 and 002

After stiffness test and weighting next step was checking the balance pair of blades with most similar results in previous tests. Test stand of balance operates on a swing and allows for assessment height difference of blades settings by U-tube (liquid column gauge mounted next to blades tip. A lighter blade, which set higher on test stand, requires a balance by adding lead balls into the balancer chamber. After estimating the amount of balancing lead balls necessary to balance the configuration, they are placed in a chamber and then the tip of the blade is mounted; and checks the blades alignment. If the blades reached new optimal positioning, substitute mass balancing should be prepared and placed in the balancing chamber. The tips of blades have to be glued with paying particular attention to the even distribution of the same amount of adhesive.

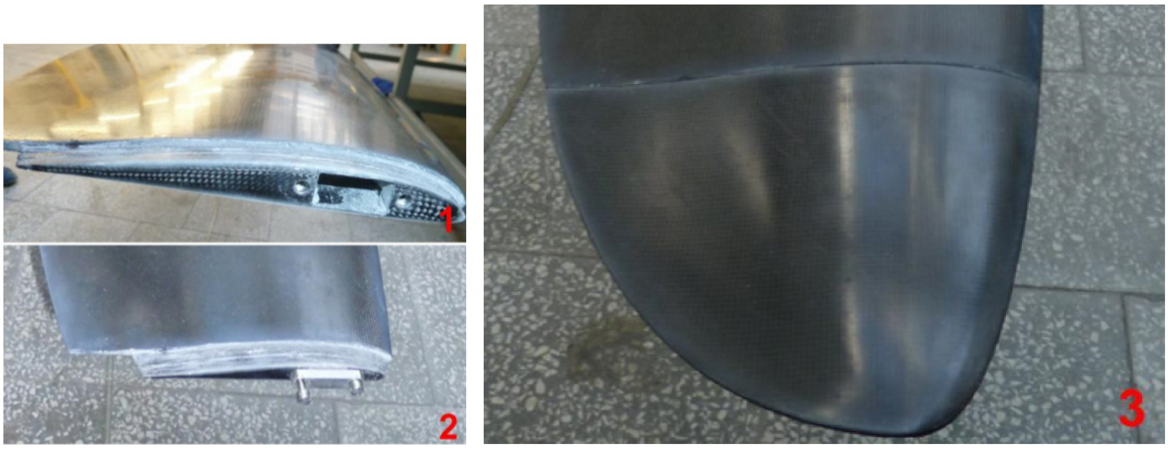

Fig. 5. Important elements of blades tip (1) for fixing the insert hole for balancing chamber, (2) balancing chamber placed into blade (3) the composite tip of the blade

Verifications balancing are centres of gravity checking. Centre of gravity must be verified in two planes along the length span of a blade and in the plane of the chord. Measurement of reaction at selected points allows for the calculation centres of gravity. The schemes of the measurement stands are shown in the Fig. 6 and 7. To determine the value of reactions is required laboratory scale and two prisms, which will be a force point.

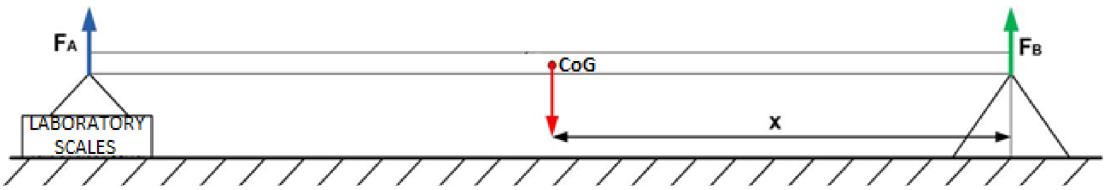

Fig. 6. Scheme of test stand to measure centre of gravity in span of blade length

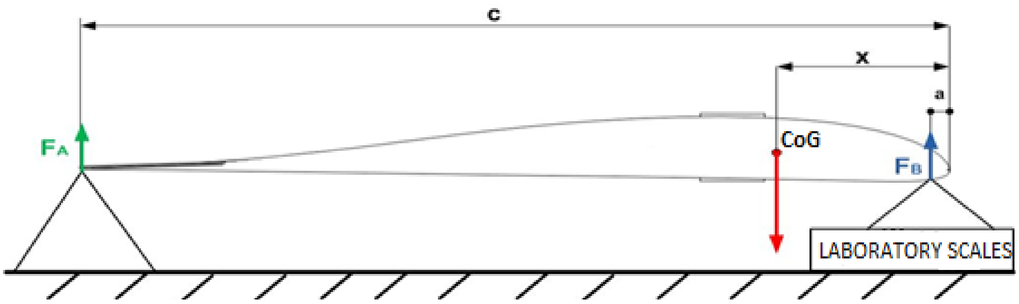

Fig. 7. Scheme of test stand to measure centre of gravity in chord plane

The calculated values of the centres of gravity are shown in Tab. 1. Based on the analysis of the results concludes that the blades can be approved to the dynamic tests.

Tab. 1. The values of centre of gravity

CoG	BLADE 001		BLADE 002		
	mm	%	mm	%	
along span of blade lenght	2028.04	52.8	2021.43	52.6	**0.2 %**
in chord plane	53.10	17.7	58.04	19.3	**1.6 %**

3.3. Gyroplane rotor dynamic testing

Before proceeding to flight tests, it is necessary to carry out a series of functional and dynamic tests. Tests of rotating object i.e. propellers or rotors are performed in an especially dedicated place for such tests called 'Rotunda'. 'Rotunda' consists of two parts, a cage in the form of a cylinder with a diameter of 22 m made of two layers of steel mesh stretched on pylons and control room located outside the cage with two-layer reinforced glass. This provides full security for the research personnel during the rotating object tests [1, 8].

The gyroplane composite rotor blades test was carried out on a special test bench for testing isolated rotors (Fig. 8). Test bench specially designed and constructed for gyroplanes rotors tests is equipped with three-axis acceleration sensor to control the vibration of the rotor, four force sensors to measure thrust, reflective optical sensor, which measures the speed of the rotor and potentiometric sensor in the actuator to measure the angle of attack of the blades. A rotor mounted on the position was powered by engine through shaft, one-way clutch, gearbox and rubber clutch protecting the rotor against temporary overload propelling torque.

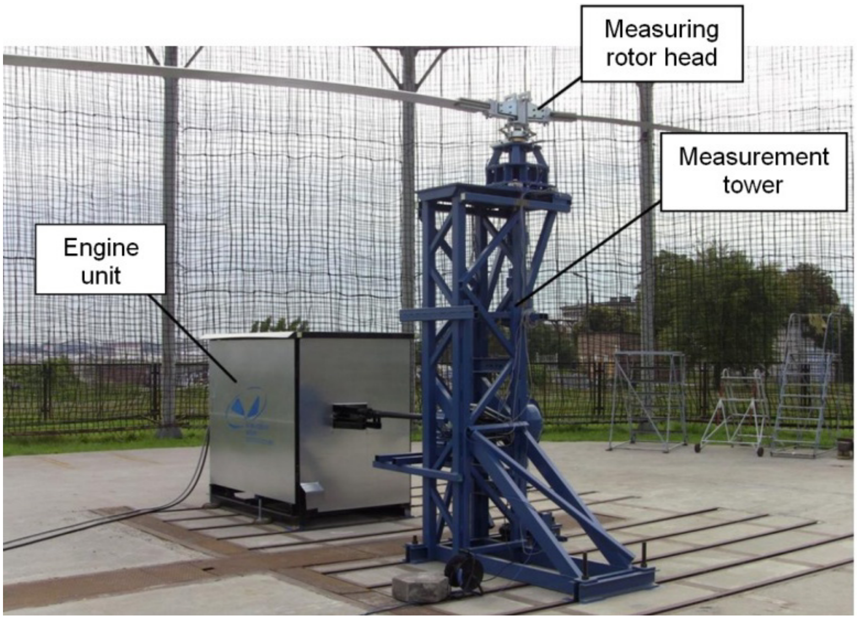

Fig. 8. Test bench for isolated rotors tests, located in 'Rotunda'

Within the preparation for the dynamic test, it is necessary to perform rotor static balance and check the correctness of its assembly. Next step is verification of strength and vibration of the rotor. This involves rotating the rotor to approximately 100 rpm maintaining that speed for about 10 minutes, and then progressively increasing the rotor speed to about 300 rpm, which is expected speed of the rotor during gyroplane flight. During tests parameters i.e. rotor rotational speed and vibrations, vibrations of the test bench and parameters of the engine unit are controlled. After test, proper assembly of test object on the test bench is checked, order to be able proceed with next test.

Second step was rotor blades tracking. This is a dynamic balancing of the whole rotor, to verify the blades are moving in the one track. Tracking were performed for rotor rotational speed of 250 rpm and the blades angle 0.8°. Fig. 2 shows the results of blade tracking carried out using high-speed camera. The image with high-speed camera analysed using applications created in LabView. As shown in Fig. 9 blade trace deviation is about 20 mm what is an acceptable result.

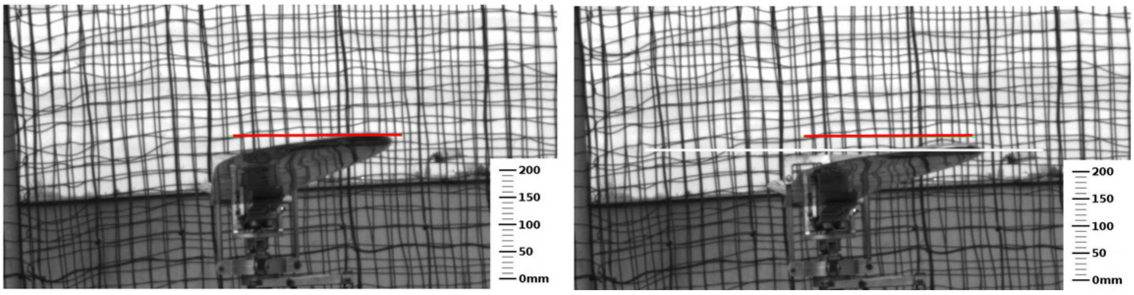

Fig. 9. Rotor blade tracking at a rotational speed of 250 rpm, blade angle 0.8°

Also examined the thrust of the rotor according to rotational speed and angle of attack of the rotor blades. The tests was carried out for the three angles of rotor blade, i.e. 0.8°, 2.8°, 3.9° and rotational speed 280 rpm (Fig. 10).

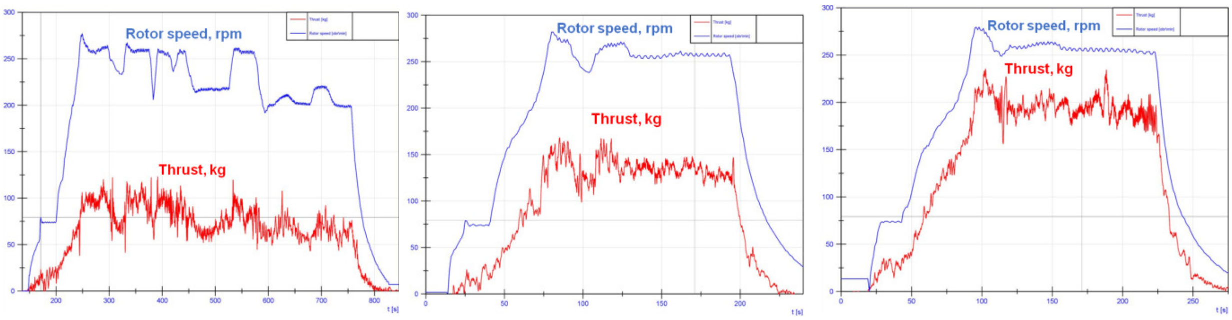

Fig. 10. Dependence within the rotor thrust and blades angle of attack at a constant rotor rotational speed 280 rpm; (left) blade angle of attack set at 0.8°, (centre) blade angle of attack set at 2.8°, (right) blade angle of attack set at 3.9°

Gyroplanes generally fly with blade angle of attack at about 2.5°. Angles about 4° are called high angles of attack. Depending on the gyroplane type, its weight, as well as the blade length and form, the blade attack angle can be different.

3.4. Study of blade delamination

In case of new composite product uses in aviation, study of delamination gives a lot of important information about service life and structure quality. During test, which defined the time needed to take place delamination blade, was loaded by adequate loads to that occur in horizontal flight. It was also opportunity to check technology of manufacturing blades. The aim of the study was to test the durability of adhesive layer applied, the top and bottom halves on the trailing edge of the blade of the composite under the action of variable loads, corresponding to the working conditions of the blades at cruising speed, which is 85% of the life of the gyroplane. The trailing edge of the blade, especially in the critical area in the basal part, is exposed to biggest deformation and is the weakest point of the composite structure.

Studies were carried out on a test stand shown in Fig. 11. Centrifugal force inflicted will be actuator with a maximum range of 50 kN. Torque and bending will be implemented by two actuators with a maximum range of up to 10 kN. The actuators are equipped with tensome-ances sensors measure the force. Moreover to inspection rotor blade structure infrared camera equipped to perform non-destructive testing was using.

Fig. 11. Test stand of delamination study

The loads occurring during gyroplane flight are shown in Tab. 2. The force of the centrifugal assume as constant , the torque and bending force change in the specified range. The frequency of the duty cycle of the blade is 6.28 Hz.

Tab. 2. The loads occurring during gyroplane flight

Centrifugal force, N	Torque, Nm	Bending force, N
45159	Min: –75.8 Max: 0	Min: –524 Max: 269

Studies of the composite blade were carried out in two stages. In the first stage of tests were carried out for the maximum loads occurring during level flight gyroplane. This phase consisted of 100 hours of flight gyroplane. In the course of the trials were carried out blades inspections with non-destructive methods – thermography. Second stage was achievement the force which damage composite structure, in this case it was 600% force used in first stage of tests.

Thermographic studies performed each after reaching the appropriate number of cycles. By cycle is understood to mean step of the task following loads: torque: (–75.8 Nm) – (0 Nm) – (–75.8 Nm), the bending moment (–524 Nm) – (269 Nm) – (–524 Nm) with a constant centrifugal force equal to 45159 N.

4. Conclusion

The article presents the most important studies in the process of admission blades for flight. Performed tests can be divided into:

- strength tests – that evaluate if the blade stand the force occurring during the gyroplane flight,
- static tests – which allow for pairing blades to the dynamic test on the basis of their mass and mechanical properties,
- dynamic tests – kind of static tests control, a key element that can verify the behaviour blades on the object flying,
- test of blade delamination – pre-verify blades service life, they provide verification for the composite structure.

Admission blades for the flight a multistage and long-term process. Each of the stages of research plays an important role and is complementary to the previous step of the research.

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