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INNOVATIVE COMPOSITE GYROPLANE ROTOR BLADES – FATIGUE TESTS

Małgorzata Wojtas, Agnieszka Sobieszek, Tomasz Szczepanik

Institute of Aviation
Department of Transport and Energy Conversion Division
Krakowska Av. 110/114, 02-256 Warsaw, Poland
tel.: +48 22 8460011, ext. 224, 711
e-mail: malgorzata.wojtas@ilot.edu.pl, agnieszka.sobieszek@ilot.edu.pl
tomasz.szczepanik@ilot.edu.pl

Abstract

The paper presents test bench method for verifying the fatigue life of the rotor blades, working in operating conditions in a position steady flight (autorotation), on the aviation construction called the gyroplane. One of the critical elements of this design is the main rotor, which in its modern versions takes the form of advanced composite structures subjected to loads in flight complex variable, the nature of which differs from the well-known operating conditions of helicopter rotors. The article includes a description of the test object, which are composite rotor blades designed specifically to work in autorotation, the specificity of loads of autorotation rotor, and method of implementation of the gyroplane rotor work cycles in the test bench. The main aim of this research is to evaluate the sustainability of the composite blades under the gyroplane operating loads with the goal to allow the rotor to operate in the air. The tests were carried out for 100 hours of gyroplane flight at loads do not exceed the maximum operating loads, and for several hours under a load higher than operating. During test for the evaluation of composite structure, the infrared camera with dedicated software IRNDT was used. The reached showed structural integrity in critical mounting section of the blade.

Keywords: *rotor blades, fatigue tests, NDT, composite*

1. Introduction

The aim of tests was verification of durability of composite rotor blade on trailing edge. Rotor blade was verified by variable loads corresponding to the operating conditions at cruising speed. Cruising speed takes 85% of gyroplane operating time [1-3]. Trailing edge of rotor blades, mainly in critical section near root, it is exposed to the greatest deformation thereby is the weakest point of the composite structure. Upper and lower halves of rotor blades on trailing edge is bonded and does not contain a reinforcing structure, which increases composite structures endurance 10 times. Therefore, the most important stage in durability test of new blades is to investigate in long-term tests delamination in a critical section.

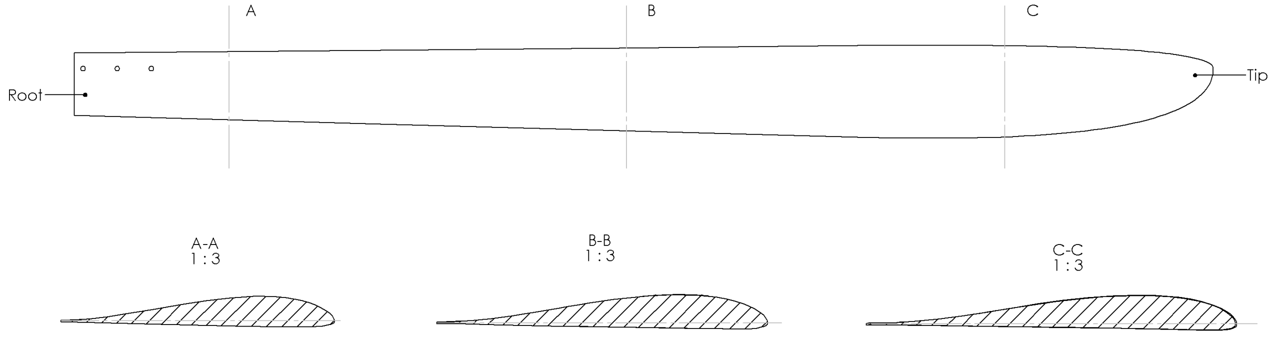

Fig. 1. Rotor blade main section

2. Research object

Carbon composite rotor blades referred to in this article, are advanced solution dedicated to work in autorotation. Blades designed for a new Class of gyroplanes (Class A) have to provide higher performance, increase the flight speed of gyroplane and ensure high safety and comfort of the flight.

New airfoil ILW-LT-11.0 of relative thickness 11% of airfoil chord was designed in Aerodynamic Department of Institute of Aviation. The starting point for the airfoil design was airfoil NACA 9H12 MOD which was a slightly modified version of the airfoil NACA 9H12 commonly used for design of gyroplane-rotor blades since forties (40s) of the last century.

For designing a variable-chord blade for gyroplane main rotor was necessary to design additional base airfoils, thinner than ILW-LT-11.0. To meet this requirement, the following additional gyroplane airfoils have been designed and optimized: ILW-LT-10.0 of relative thickness 10% of airfoil chord, and ILW-LT-09.0 of relative thickness 9% of airfoil chord. The sub-family of gyroplane airfoils intended for the variable-chord blade is presented in Fig. 2 [5-9].

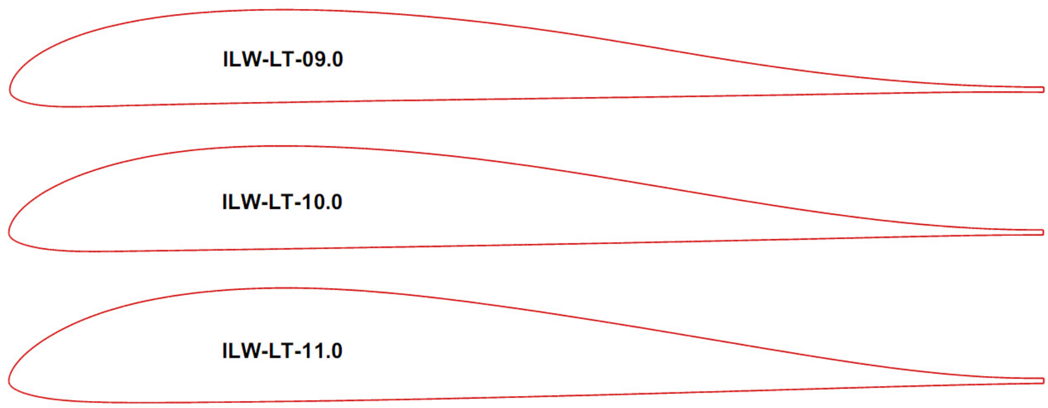

Fig. 2. Sub-family of airfoils designed for a variable-chord blade of gyroplane main rotor [6]

In addition, the tip of the blade has been optimized in such a way as to reduce the drag and noise of the gyroplane rotor. Fig. 3 shows the geometry of the blade with variable chord.

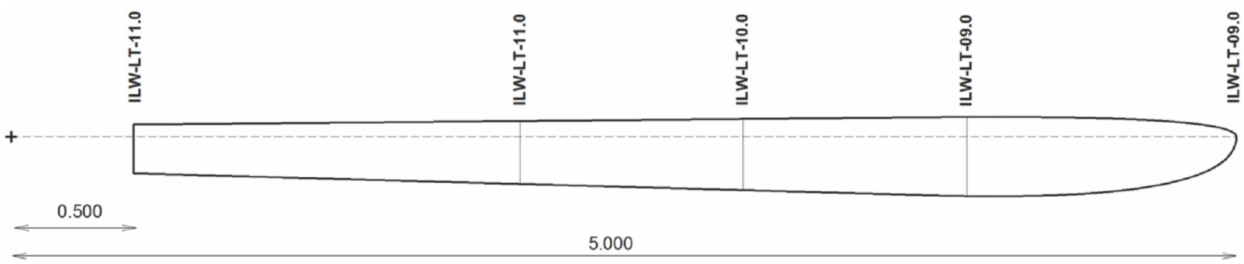

Fig. 3. Geometry of the variable-chord blade of the gyroplane main rotor – ILW.11/10/09.D10.0 [6]

Final composite blades designed for bench and flight tests were made 50 cm shorter than assumed in the project. First blades examples were tested on gyroplanes class B, which are smaller and do not require such long blades.

3. Gyroplane main rotor loads

During the durability tests rotor blade was loaded by forces corresponding to the operating conditions in level flight of gyroplane. Tab. 1 shows the assumed basic properties of gyroplane level flight accepted for calculations and tests.

Tab. 1. Flight gyroplane conditions

Rotor pitch angle, °	Radius of rotor, m	Rotor Speed, rpm	Gyroplane weight, kg
5.00	4.20	377.00	450.00

Calculated average values of blade loads during gyroplane flight are shown in Tab. 2, while types of bending force (T_g) and torsional moment (M_s) shown in Fig. 4.

Tab. 2. Calculated blade loads

Centrifugal Force, N	Torsional moment M_s, Nm	Bending Force T_g, N
45159.00	from -75.80 to 0.00	from -529.00 to +269.00

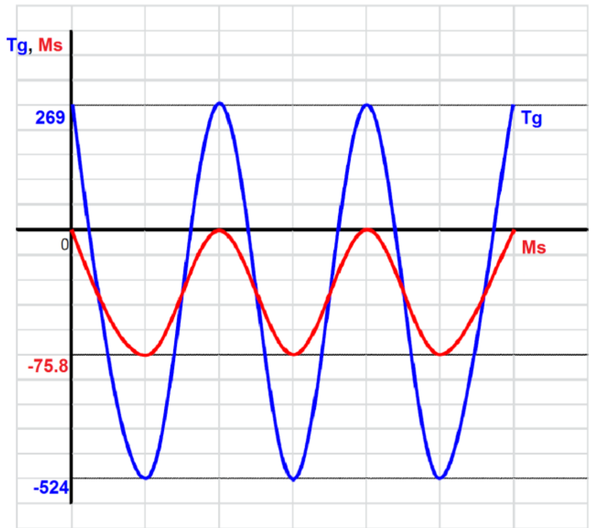

Fig. 4. Types of bending force (Tg) and torsional moment (Ms)

For tests the centrifugal force was assumed as a constant, while the torsional moment and bending moment variables in the given range. The directions and orientations of the forces and moments acting on the blade are shown in Fig. 5. The frequency of the blade's working cycle is 6.28 Hz.

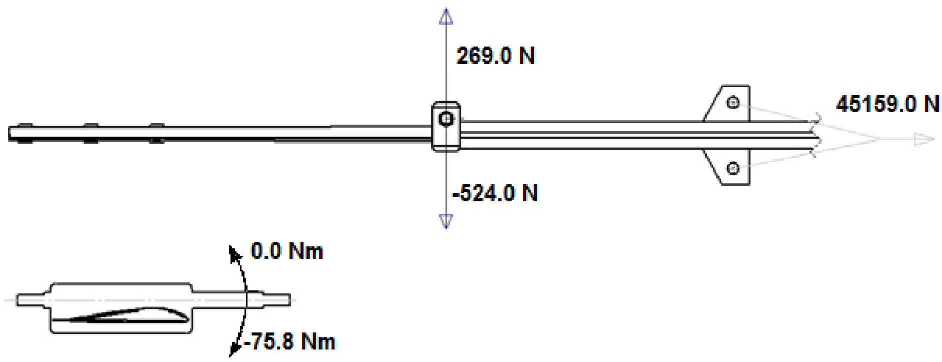

Fig. 5. Directions and orientations of the forces and moments acting on the blade

4. Tests methodology

The tests were carried out on a specially designed test stand equipped with appropriate accessories enabling the loads introduction on rotor blade. Load presented in Section 3 was carried out using electrohydraulic research system (as shown in Fig 6) and MTS Aero 90 – control system.

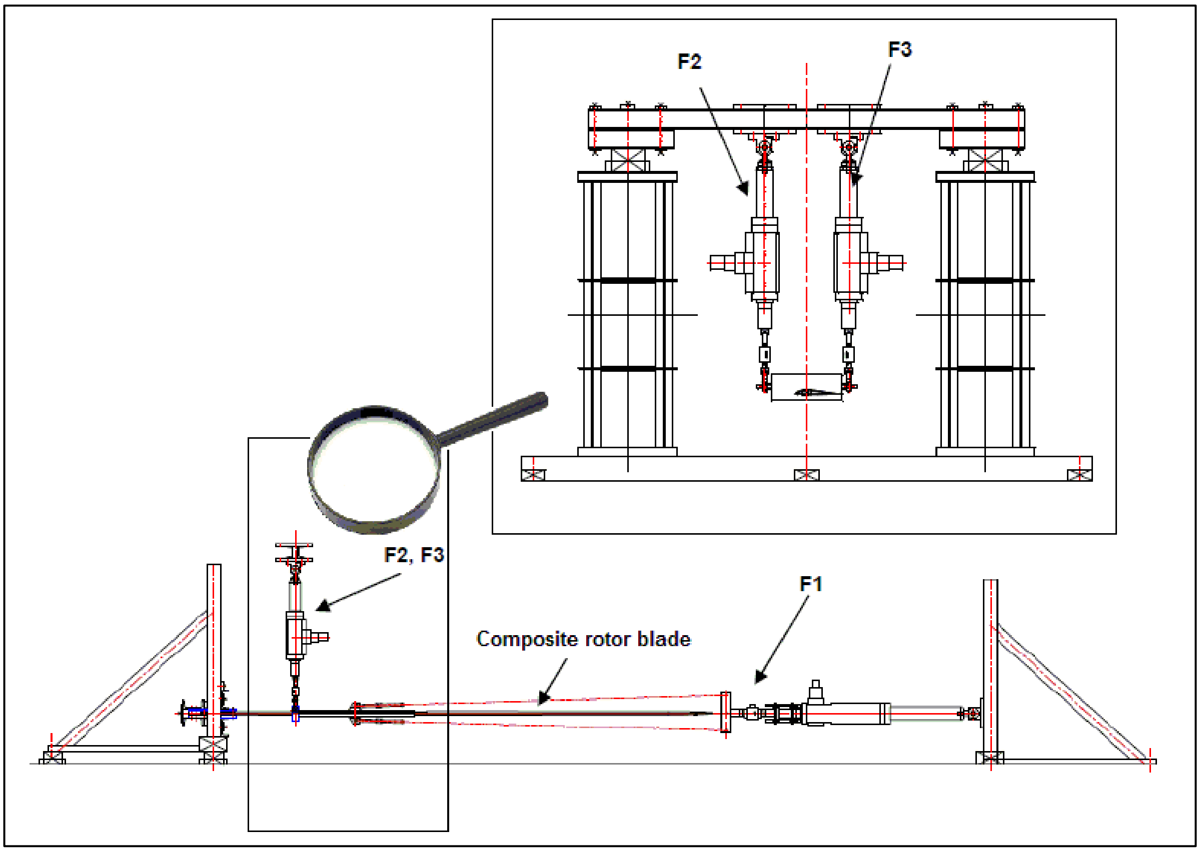

Fig. 6. The method of carrying out loads on the test stand

Forces and moments realized due to the manner of their introduction have been replaced by forces: F1 – centrifugal force (as planned) and force F2 – force realizing the torsional moment, and force F3 – force realizing the bending moment (as shown in Tab. 3 and Fig. 7).

Tab. 3. Loads carried out by the actuators system

Centrifugal Force F1, N	F2, N	F3, N
45159.00	from 134.50 to -440.40	from 134.50 to -83.60

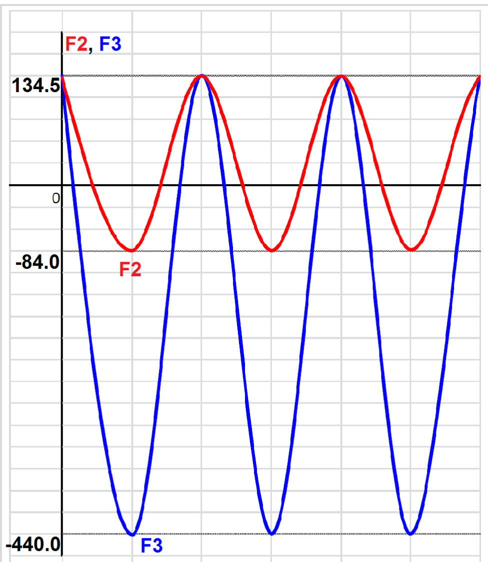

Fig. 7. Loads performed in the test

In order to correctly set the moments F2 (bending force) and F3 (torsional moment) to the rotor blade, the rod was mounted along chords of blade. The rod was doped in a proper place by glass fabric installed with a wet lamination method. The ends of the rod were the mounting point for the actuators. To set F1 – centrifugal force – prepared special handle, mounted on the blade with the same method as rod (as shown Fig. 8).

Fig. 8. Test stand

The tests of rotor blade with variable-chord were performed according to the tests program. The loads were carried out with blocks of 22 608 cycles representing 1 hour of flight. In order to control and evaluation of defects that could occurred in the internal structures of the blades between the selected blocks the blades were verified by non-destructive method – thermography (IRNDT) [4]. Research was divided into two stages. In the first stage, tests for 100 hours of gyroplane flight were carried out. Tab. 4 shows the course first stage of research. In second tests stage loads F2 and F3 (blending and torsional moments) were increased every 50% of maximum loads from first stage of tests, F1 (centrifugal force) was not changed. After each IRNDT test, decision to continue the test and the number of cycles was made. The aim of the second stage of test was to damage the composite structure. A total of 173528 cycles of destructive loads were carried out (over 100% of the loads assumed in the tests). The maximum load used in the tests was 600% of permissible load. To sum it up, during tests 2 434 328 cycles, i.e. 107 h 41 min of gyroplane flight were carried out.

5. Tests results and analysis

Thermography is a quantitative method, not a qualitative one and thermograms comparison is possible despite different scales and environmental conditions. Differences in the selected temperature scales for thermograms result depend of tests conditions. Due to the duration of the tests and long breaks between each NDT tests condition were different:

Tab. 4. Schedule of 100 hours gyroplane flight test

No.	Description	No. of completed cycles		No. of completed cycles since the beginning		Comments
		Flight hours	Cycles	Flight hours	Cycles	
1	Review „0”	0	0	0	0	IRNDT
2	Start of the test	0	0	0	0	–
3	1 hour flight	1	22608	1	22608	–
4	Review	–	–	–	–	IRNDT
5	2 hours flight	2	45216	3	67824	–
6	Review	–	–	–	–	IRNDT
7	3 hours flight	3	67824	6	135648	–
8	Review	–	–	–	–	IRNDT
9	3 hours flight	3	67824	9	203472	–
10	Review	–	–	–	–	IRNDT
11	4 hours flight	4	90432	13	293904	–
12	Review	–	–	–	–	IRNDT
13	4 hours flight	4	90432	17	384336	–
14	Review	–	–	–	–	IRNDT
15	37 hours flight	37	836496	54	1220832	–
16	Review	–	–	–	–	IRNDT
17	46 hours flight	46	1039968	100	2260800	–
18	Review	–	–	–	–	IRNDT

- ambient temperature,
- sunlight affecting the increase of the quantity and intensity of the reflections,
- the wires heating level which were the background for the blade.

Size and location of the research stand made it impossible to standardize the conditions of the study.

Figure 9 shows changes in the composite structure of the blade are visible in thermograms made after 2 434 328 cycles. The defect is located in a rectangular area. Thermogram No. 1 was made before the fatigue tests, after blade was mounted on test stand. Thermogram No. 2 was made after 2260800 cycles (i.e. after 100 hours of gyroplane flight). Thermogram No. 3 and 4 with visible change in composite blade construction was made after 2 434 228 and 2 434 328 cycles, the maximum loads were 550% and 600% of permissible load.

6. Conclusion

The research approach presented in the article is innovative. Tests required for certification focus on testing the static strength of the blade root. Tests carried out at the Institute of Aviation were aimed at evaluation of new composite blade structure in particular on trailing edge of rotor blades. The tests were prepared and made before the first flight test of the blades on the autogyro. As the authors discussed in the previous paragraph damage in blade structure was observed after applying 550% permissible loads.

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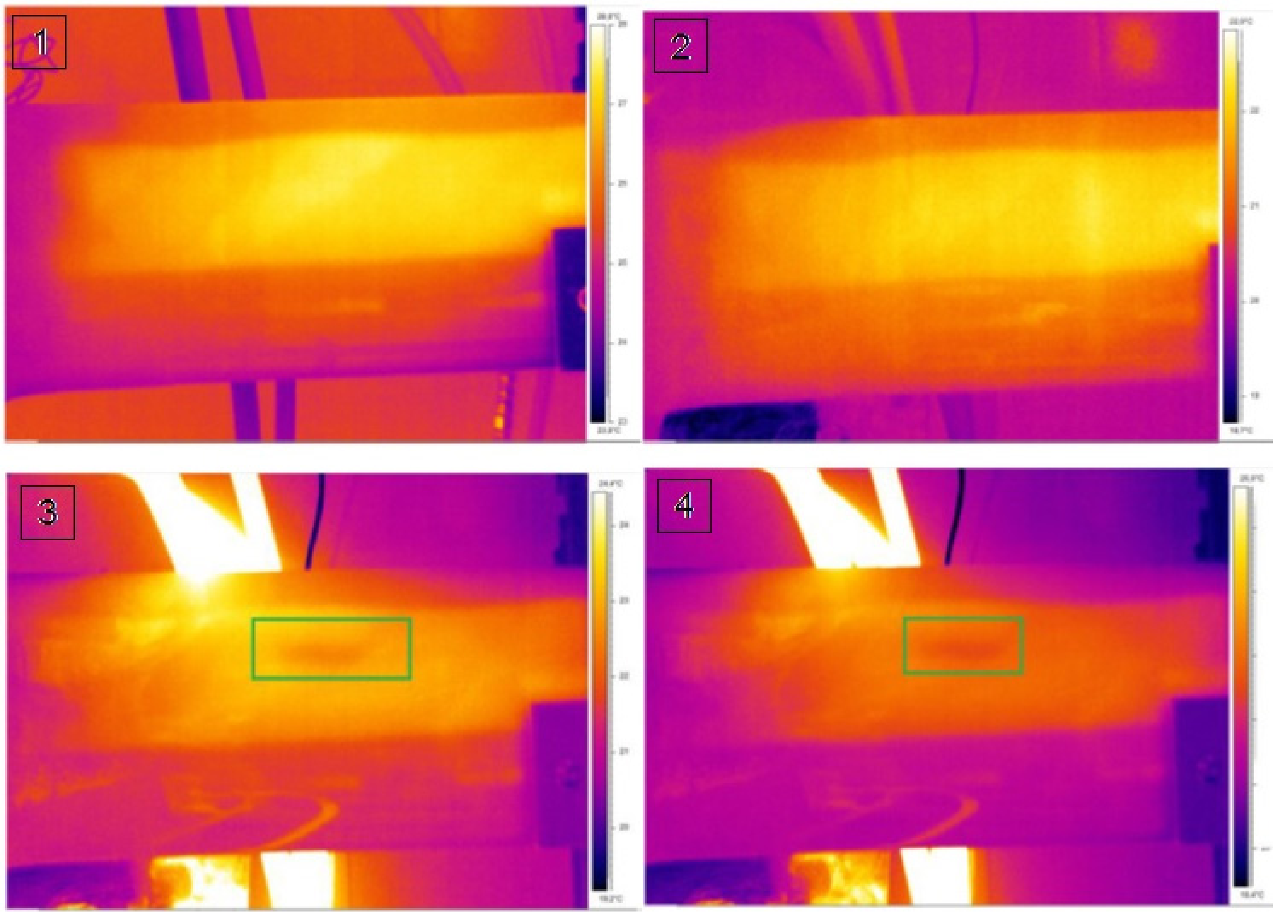

Fig. 9. Thermogram of rotor blade critical section. In the thermogram 3 and 4 structure defect is visible (area with green edges)

References

[1] Czyż, Z., Łusiak, T., Czyż, D., Kasperek, D., *Analysis of the pre-rotation engine loads in the autogyro*, Advances in Science and Technology, Vol. 10, No. 31, pp. 169-176, 2016.

[2] Duda, H., Pruter, I., *Flight performance of lightweight gyroplanes*, 28th International Congress of the Aeronautical Sciences, Brisbane, Australia 2012.

[3] Niemi Jr., E. E., Raghu Gowda, B. V., *Gyroplane rotor aerodynamics revisited – blade flapping and RPM variation in zero-g flight*, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida 2011.

[4] Sobieszek, A., *Assessment of feasibility the use of infrared techniques in aviation – testing structures and aviation part*, Journal of KONES, Vol. 23, No. 4, pp. 479-485, 2016.

[5] Sobieszek, A., Wojtas, M., *Composite rotor blades tests essential before mounting on gyroplane*, Journal of KONES, , Vol. 23, No. 4, pp. 487-494, 2016.

[6] Stalewski, W., *Aerodynamic design of modern gyroplane main rotors*, Transactions of the Institute of Aviation, No. 1 (242), pp. 80-93, Warsaw 2016.

[7] Stalewski, W., Zalewski, W., *Analysis of selected states of gyroplane flight based on computational aerodynamic characteristics of its components*, Transactions of the Institute of Aviation, No. 219, pp. 280-288, Warsaw 2011.

[8] Stalewski, W., Dziubiński, A., *Projektowanie aerodynamiczne wirnika autorotacyjnego*, XI Międzyuczelniane Inżynierskie Warsztaty Lotnicze, Bezmiechowa 2014.

[9] www.wirnikautorotacyjny.pl.

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