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THE INFLUENCE OF THE BLADES LEADING EDGE ANTI-EROSION PROTECTION ON MAIN ROTOR PERFORMANCES

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Abstract

This article presents the influence of rotor blade airfoil shape on main rotor performances. In this case, we analysed the influence of anti-erosion tape, which is applied to the leading edge of the blade to protect the blades from environmental conditions. In Gyro-Tech Innovation an Aviation Company and Institute of Aviation the independent tests of helicopter and gyroplane main rotors were performed. Research includes: bench tests, on the test stand for dynamic testing of insulated rotors and tests on two flying constructions, gyroplane Cavalon produced by AutoGyro GmbH Company and ultralight helicopter Dynali H3. On the test bench, a two-blade rotor, used in ultralight and unmanned helicopters, was tested. In article, the authors present importance of the proper selection and application of anti-erosion coatings on rotor blades. Discuss the behaviour of the above-mentioned constructions with main rotor blades leading edge covered anti-erosion tape, during flight tests. The results of bench tests, including the comparison of polar curves of the main rotor with anti-erosion coating and without were also presented and discussed.

In the summary of this article among others the solution of technological pocked introduced in the rotor blade, corresponding to the thickness of the anti-erosion tapes, in such way that after tape is applied it does not change the contour of the blade airfoil were presented.

Keywords: *airfoil, rotor blades, flight tests, light and ultra-light rotorcrafts*

1. Introduction

The aim of this article is to show influence of the variation of the rotor blade airfoil shape on main rotor performances. Rotor blades are complex structures designed to balance a number of competing requirements. The structure is generally defined to maximize aerodynamic performance, carry flight loads, and ensure aeroelastic stability. Advanced, lightweight rotor blades are manufactured of a fibreglass composite or carbon composite structure. The blade airfoil shape changes may result from heating, mechanical damage e.g. foreign object damage (FOD), abrasion damage, weather conditions like icing or even lightning strikes. These phenomena' consequently cause changes in the blade airfoil, that leads to a reduction in the aircraft's performances [2].

The work focuses mainly on changes in blade aerodynamic profile surface caused by the use of anti-erosion coating on the blade leading edge. In fact, anti-erosion protection is used on blades leading edge to prevent most of damage mentioned above; including resistance to fluids (e.g. rain drops). The use of this type of anti-erosion coatings (Fig. 1) on the blade leading edge can significantly reduce maintenance, repair, overhaul costs, and extend service life [1, 4, 7]. The article presents research conducted on a test stand, as well as flight tests. The research was conducted to show that even a small change in the rotor blades aerodynamic profile might have dire consequences, especially for light and ultra-light aircraft structures.

2. Bench tests

At the Institute of Aviation tests of the innovative main rotor, performances were carried out. Research was conducted on test bench for testing isolated rotors. The stand is dedicated for testing rotors of light helicopters and gyroplanes [3, 6]. The bench test allows real-time measurement of rotor properties, such as rotor thrust, rotational speed, or power absorbed by the rotor, on that basis of which polar characteristics of the tested object can be obtained.

Tests were carried out on two different main rotors. The research was conducted in such a way to compare the performances of these two rotors.

Fig. 1. Example of anti-erosion tape (Polyurethane Protective Tape) on left ILX – 27 blades coating with tape on right tape used by Gyro-Tech Company

2.1. Test object

The test object was two-blade teetering rotor designed in the technical division of the Institute of Aviation – Centre for Composite Technologies. The rotor blades with new airfoil were made in prepregs technology (shown in Fig. 2). The blades chord length varies along the span, and twisted tip. The diameter of the tested rotor was 7.11 m. To the rotor blades was applied anti-erosion tape with a thickness of 0.7 mm.

Fig. 2. New rotor blades

The new rotor blades were designed for an unmanned helicopter (ILX-27) to replace the previous one to improve the performance of the helicopter.

2.2. Tests results and analyses

The purpose of the new rotor's tests was to determine its performances. During tests, polar curves of the main rotor were determined. Test results were compared with the test results of the previous rotor and with the rotors theoretical characteristics, as shown in Fig. 3.

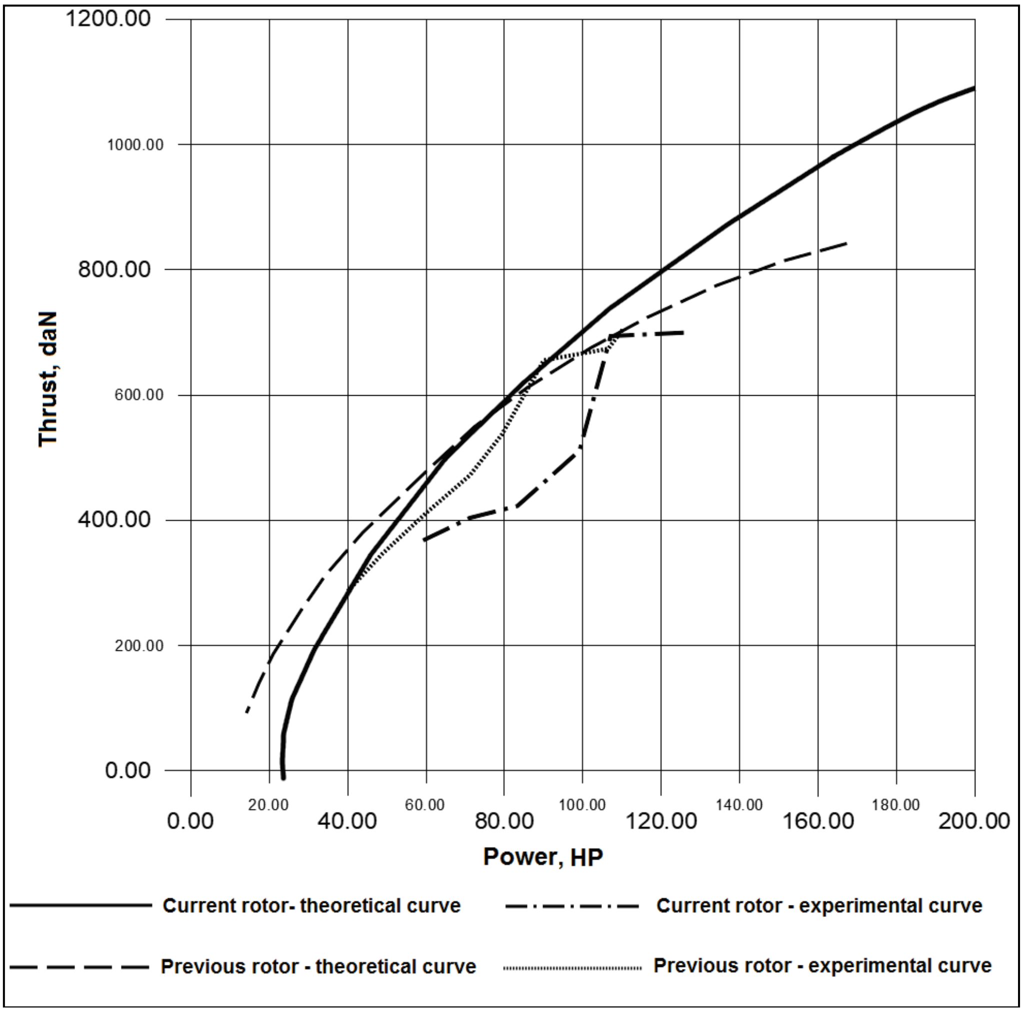

Fig. 3. Comparison of experimental results with computational results for rotor rotational speeds of 430 rpm

In the chart above (Fig. 3), we can see significant differences in energy consumption between tested rotors and in relation to the calculated data. The new rotor has a much higher power consumption than the previous rotor. However, the theoretical analysis assumed that the new rotor would have about 5-10% better performance. After the analysis of tests results and reviewing the available literature, it was found that observed discrepancies in the energy consumption may has a source in an anti-erosion tape glued on the leading edge of the blade and protruding beyond the outline of the profile by 0.3-0.7 mm.

In literature [2], the influence changing the shape of blade airfoil on the rotors performances is presented. Overlay (anti-erosion tape in our case) with a thickness of 0.125 mm, in of the rotor model with blades of a chord of 85.00 mm resulted losses by about 8%. For the investigated rotors with 200 mm chords, the scaled thickness of the overlay (tape), appropriate for comparison, is 0.3 mm thickness. Therefore, theoretically, it can be assumed that the power losses with a 0.7 mm overlay would be about 19%. What means that at power range 50-80 kW, the power losses would be respectively from 4.00-6.40 to 15.00 kW (5.40-9.00 to 20.00 HP).

After removing the anti-erosion tape from the leading edge of tested blades, further tests were carried out. The results are presented below in Fig. 4.

Chart above (Fig. 7) gives an overview of the three different polar characteristic of main rotors. Two curves represent the polar characteristic of rotor, for blades with anti–erosion tape and without anti – erosion tape. As can be seen for rotor blades with tape in comparison with blades without tape for the same power, the rotor thrust is lower by about 0.8 kN, so the power loss is about 12% for rotor blades with anti – erosion tape on blades leading edge [5].

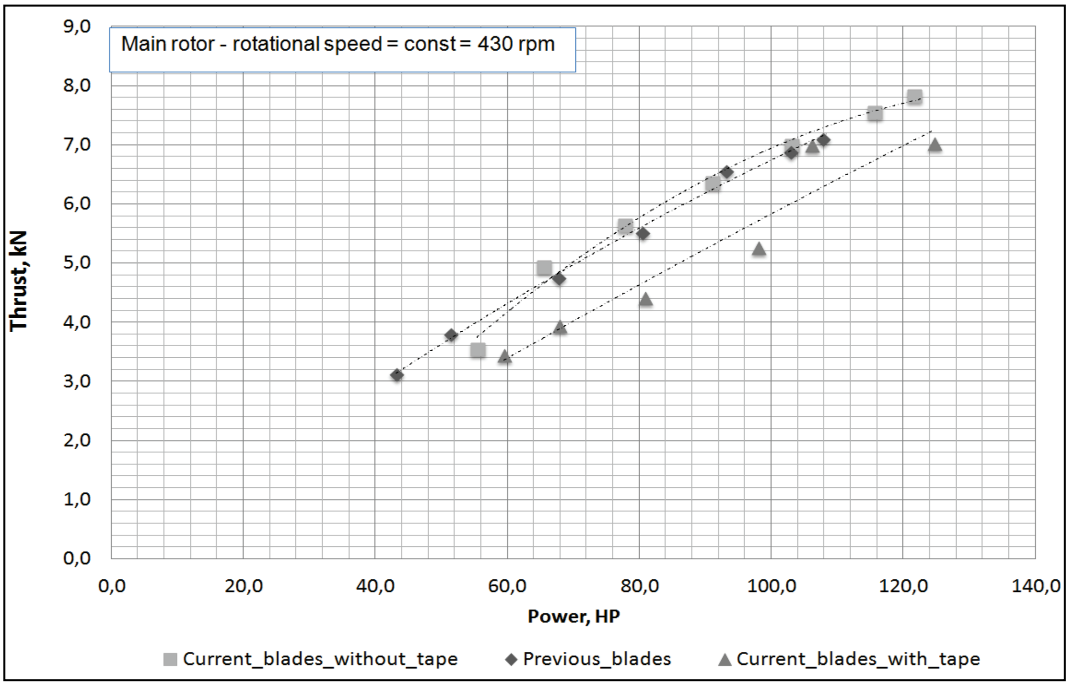

Fig. 4. Comparison of experimental results for rotor rotational speeds of 430 rpm

3. Flight tests

First flight tests were conducted on the gyrocopter Cavalon (SP-XTBL with registration marks), produced by the German company Auto-Gyro GmbH, shown in Fig. 5. The original 8.40 m diameter aluminum main rotor was changed to modern composite rotor made by Gyro-Tech Company with a diameter of 8.60 m.

Fig. 5. Test object – gyroplane Cavalon

Technical flight tests showed that the rotor operates in a normal speed range, achieved approximately 370 rpm, with a load of about 100 kg (around two people). Then, as requested by the receiver, the leading edge was secured with a professional, used on helicopters, anti-erosion tape with a thickness of 0.2 mm, shown on Fig. 6. Flight tests have shown drastic decrease in rotor rotational speed to around 290 rpm – 300 rpm, as a result, a stall might have occurred.

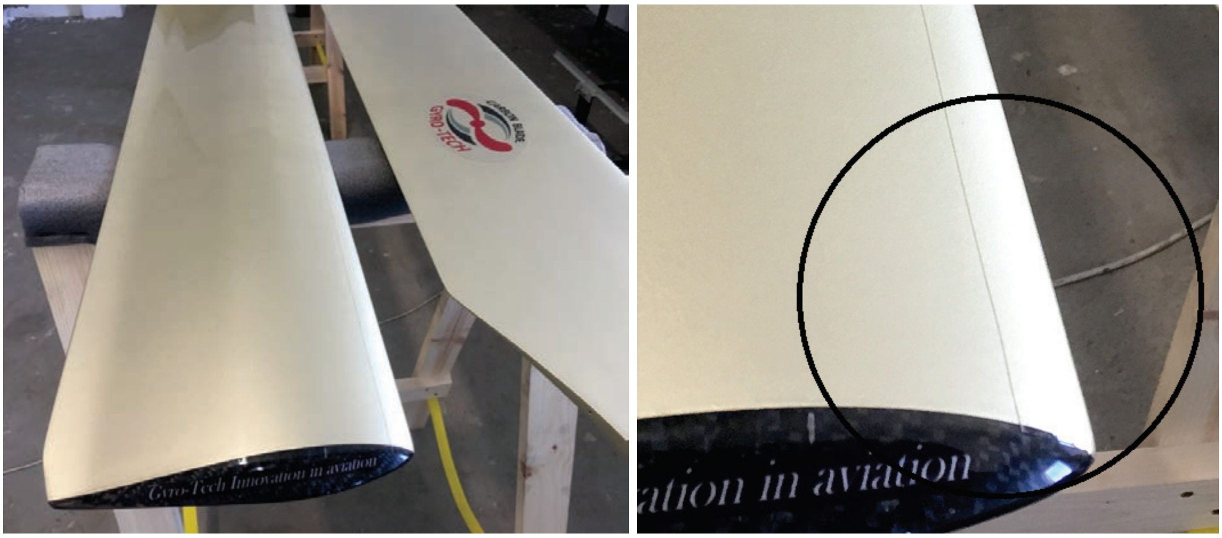

Fig. 6. Test object – blades with anti-erosion tape (0.2 mm thickness)

Several actions have been taken to improve the performance of the gyroplane. In the first place, the pitch angle of the rotors has been reduced from 2 degree to 1.4 degree. This change increased the rotor speed by about 10-15 rpm, but it was still not acceptable value.

The second possible solution was to change the length of the blade connector. The length of the blade connector was decreased about 10 cm, which reduced the rotor diameter to 8.5 m. This change allowed increasing the speed of the gyroplane rotor by another 10-15 rpm, which was still insufficient for the fully safe gyroplane flight.

After exhausting all possibilities of main rotor configuration, blades were returned to the original version with 8.6 m diameter of main rotor without anti-erosion tape on the leading edge. The rotation speed of the main rotor was within the range of about 350 rpm (one person – pilot) and about 370 rpm for the flight of two persons (pilot and passenger).

Identical tests were carried out for Gyro-Tech main rotors on the Belgian Dynali H3 helicopter. Direct application of the anti-erosion tape to the blades leading edge resulted in a significant increase in the power necessary for the flight and performance deterioration.

Based on that experience, a technological pocket was introduced in the swage to offset the airfoil leading edge so that the anti-erosion tape fits in it without affecting the blade airfoil shape (Fig. 7).

The flight tests of gyroplane with main rotor (diameter 8.6 m) with technological pocket in blades, where the anti-erosion tape was bonded, were carried out. Tests have shown that the rotor operates in the same rotational speed range (about 370 rpm) as in tests without a tape.

Currently, in the Gyro-Tech blades manufactured among others for Dynali helicopters, is used a delimitation of the contour on the leading edge of blade where an anti-erosion tape with a thickness of 0.5 mm is glued. This ensures that the surface of the blade airfoil is unchanged.

4. Conclusion

The purpose of applying anti-erosion coatings on critical elements of aircraft constructions, such as rotor blades, is to protect them against environmental conditions or other mechanical damage, as well as to ensure safe and comfortable flight. However, it should be noted that incorrectly adjusted thickness of anti-erosion tape and bad application on the blade leading edge could have a significant effect on the performance of the rotorcraft. This is particularly dangerous for ultra-light and light constructions that may result in a stall and as a consequence dangerous aviation accident.

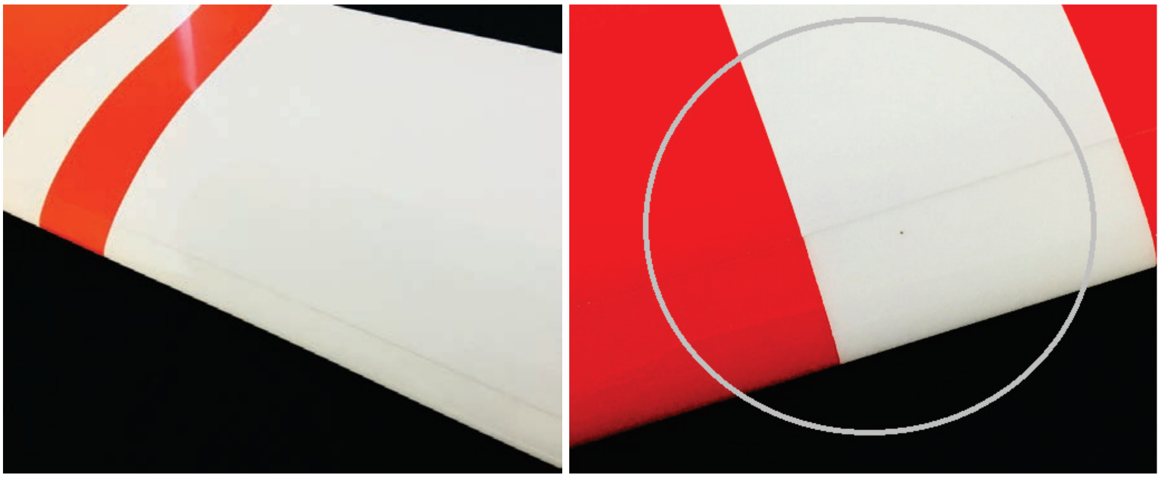

Fig. 7. Test object – blades for light helicopters with anti-erosion tape (0.5 mm thickness) glued in delimitation of the contour on the leading edge of blade

Omitting the flight safety issues the correct application of an anti-erosion tape influences power consumption of the main rotor. As the article shows in the described example the power consumption can be even 12% higher, when we apply a poorly matched anti erosion tape. That fact affects the flight economy increasing fuel consumption per kilometre of flight.

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