Experimental studies of single rotors noise of small scale

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Abstract. The work experimentally investigated the characteristics of the noise of large-scale isolated rotors on small-scale models. The experimental rotor model was based on the F7 / A7 design developed by General Electric. The small diameter rotors were 3D printed and powered by brushless DC motors. The studies were implemented at a speed of up to 8500 rpm. Far-field acoustic measurements were performed in a noise-damped anechoic chamber. The noise characteristics of the brushless motors used in the experiments were investigated separately. For brushless motors, the main component is mechanical noise at the speeds of the motor shaft and its harmonics. For a uniaxial electric motor, the mechanical noise at the shaft speed increases with an increase in the rotational speed, while the noise at its higher harmonics decreases. The study of the coaxial electric motor showed an increase in mechanical noise at the higher harmonics of rotation. In experiments with insulated rotors, the tonal and broadband noise content was recorded. The study showed that with an increase in the rotational speed of a single rotor, the noise level rises from 65 to 80 dB. In this case, the maximum sound pressure shifts towards higher frequencies.

1. Introduction
One of the main directions of development of the world aircraft construction is the design of aircraft equipped with engines with an open rotor, which increases fuel efficiency [1 - 4]. The rotors of modern aircraft engines, especially the rotors of an open rotor, represent a complex object in terms of the technological process and quality requirements. The development of rotors is associated with aerodynamics and dynamics, design and manufacturing technology, and control. While the propulsive efficiency advantage of a counter-rotating open rotor over a conventional turbofan engine is undeniable, open rotors have not found commercial use due to installation problems and noise. Perhaps the most annoying issue is the interaction noise caused by the rich tonal content of the counter-rotating rotors.

Experimental tests of rotors are limited by specific parameters: the complexity and high cost of modern experimental equipment and the complexity of the production of rotors. With the creation of equipment and the development of three-dimensional printing methods, it became possible to manufacture complex, small-scale objects with high resolution. This result leads to a reduction in the production costs of experimental rotor models.

This paper presents an experience of experimental investigation of small-scale rotor noise.
2. Materials and methods

2.1. Making rotors

For the experimental study, a rotor was used, information about which is presented in the open press [5, 6]. The rotor creation process is presented in [7].

2.2. Equipment

Noise measurement studies were carried out in a noise-damped chamber (Figure 1) of the National Aerospace University named after N.E. Zhukovsky "KhAI", Kharkov [8]. Main characteristics of the camera:

- volume after muffling – 62 m³ (chamber with the absorbing floor);
- operating frequency range of 1/3 octave frequency bands, Hz – 160 ... 10,000 Hz;
- plugging– wedges PPU EL2240;
- deviations from free field conditions = 1.5 dB.

The rotor is driven by a power plant, which includes:

- Brushless brushless motor – Motor A30-12 XLV4 "Hacker": power supply 14.5 V; current 47 A; power 681 W; \( n_{\text{max}} = 8500 \) rpm;
- speed regulator – Controller X55-SB-Pro.

Measuring equipment RFT (Germany) is built into the ceiling of the chamber and includes:

- narrow-band filter – 01020;
- microphone 1/4 "MK 202;
- level recorder – 02013;
- coordinate device based on a rotary table RFT 02012. Measurement radius 1.6 m.

During the research, the control of the operating modes of the power plant was carried out:

- digital tachometer "Hangar 9 Micro Digital Tachometer" with LCD display, which measures the speed of 2, 3, and 4-blade rotors in the range up to 32000 rpm.
- laser tachometer for measuring the number of revolutions of the multi-blade rotor.
The control equipment includes speed controllers (ESC) and speed controllers – servo tester. Figure 2 shows the position of the test piece and measuring equipment.

![Figure 2. Position of the test piece in the anechoic chamber](image)

3. Noise research

3.1. Examining the noise of brushless motors
The noise of the TURNIGY G25870kV brushless electric motor and the Himax Contra Rotating Motors E50-65 610kV coaxial brushless electric motor was investigated. The noise generated by a brushless electric motor is divided into three categories: magnetic, mechanical, and aerodynamic.

Measurements of the noise characteristics of the TURNIGY G25 870kV uniaxial brushless electric motor with one support (bearing) were carried out on an unloaded electric motor. The main component is mechanical noise at the speeds of the motor shaft and its harmonics. Measurements have shown that the magnetic and aerodynamic noise is weak at a shaft rotation frequency of \( n = 168 \, \text{rpm} \). With an increase in the rotational speed, the mechanical noise at the rotational speed of the shaft increases, while the noise at its higher harmonics decreases (Fig. 3).

Comparison of the spectra of the TURNIGY G25 870kV motors and the coaxial brushless electric motor Himax Contra Rotating Motors E50-65 610kV showed an increase in mechanical noise at the higher harmonics of rotation in the coaxial brushless electric motor (Fig. 4). This result is a consequence of the addition of two additional journal bearings.
Figure 3. Changes in the spectral components of motor noise with increasing shaft speed: brushless electric motor G250 "Turnigy", $\alpha = 90^\circ$ $n_1 = 168$ rpm, $n_{10} = 1680$ rpm, $n_{20} = 3360$ rpm

Figure 4. Comparison of the noise spectra of brushless motors running without load.

3.2. Investigation of the noise of single rotors

The rotor speed range in the experiments was 3000-8500 rpm. The measurement range of the frequency spectrum is 0-20000 Hz. An increase in the rotor rotation speed increased the sound pressure level from 65 to 80 dB (Fig. 5). In this case, the maximum sound pressure shifted towards high frequencies (Fig. 6), which is apparently associated with increased flow turbulence.
Figure 5. Sound pressure level (SPL) versus rotor speed

Figure 6. Dependence of the frequency at which the maximum sound pressure is reached, on the rotor speed

In the frequency range up to 500 Hz, harmonics associated with rotation noise are observed. Broadband noise is observed in the frequency range above 500 Hz. Broadband noise is formed due to pulsations of aerodynamic pressure on the surface of the blade and turbulent pulsations of the speed of the flow running on the rotor disk and flow in the vortex sheet behind the rotor blades. At the same time, up to a rotor speed of the order of $n = 5500$ rpm, clear peaks are observed in the broadband noise region (Fig. 7), and with an increase in the rotational speed, the broadband noise has a continuous spectrum (Fig. 8).
For the rotor noise both at a frequency of $n = 3048$ rpm and $n = 7320$ rpm, the first rotor harmonics are visible (3 first rotor harmonics for 3048 rpm and the first two for 7320 rpm). This data is associated with the high noise of the engine itself at these frequencies.

The amplification of the broadband component of the rotor noise can be caused by the fact that with an increase in revolutions at a constant angle of installation of the blades, the local angles of attack of the incoming flow on the blade become large causes the flow to stall. This situation corresponds to the flow around a bluff body since the cross-sectional profile was set in the form of a flat plate. This flow can lead to significant amplification of broadband noise.
4. Conclusion

Studies of the noise characteristics of single rotors have shown the presence of tonal and broadband noise components at low rotor speeds. The portability of the results to real geometry requires research at rotor speeds of the order of 50,000 rpm. Tensile testing of experimental models showed that these samples do not withstand such rotational speeds. An increase in the strength of samples requires a different manufacturing technology, as, for example, in [9].

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