Noise of small-scale contra rotating rotors

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Abstract. This article presents the results of an experimental study of the noise characteristics of small-scale coaxial counter-rotating rotors. The tests were carried out in an anechoic soundproof chamber for F7/A7 counter-rotating rotors with 11 and 9 blades on the front and rear rotors, respectively. The intensity of noise emission by rotors was compared with the constancy of the thrust of the power units. Acoustic studies have shown the presence of tonal and broadband noise components at low rotation speeds. In addition to the usual noise components, tonal components were also observed for the rotor blade running combinations. The observed noise levels at these frequencies are equal, and in some directions are significantly higher than the noise levels at the frequencies of the blades of the first and second rows. In experiments, it was found that, while maintaining the equality of the rods, with an increase in the diameter, the noise levels at the rotors decrease due to a decrease in peripheral speeds. A decrease in the noise levels of rotors with an increase in the number of blades was established due to a decrease in aerodynamic loads on the blades and peripheral speeds. An important parameter here is the filling factor of the space swept by the blades. With an increase in this coefficient, the rotation noise decreases, but the vortex noise increases significantly.

1. Introduction
Along with insulated main rotor [1, 2], coaxial counter-rotating rotors are also used in aviation. Coaxial aircraft rotor arrangement is a diagram in which a pair of parallel rotors rotate in opposite directions around a common geometric axis. It is used on the An-22, An-70 and Tu-95 aircraft, and is also represented in the open rotor concept [3] offered by Rolls Roys and General Electric.

Coaxial rotors make it possible to obtain the required thrust force with a relatively small diameter of the blade system, since the swept area is effectively used and the rear rotor sucks in additional air from the side. At the same time, it is possible to provide a lower level of vibration and structure-borne noise if the loads from the rotors are opposite in phase. It was assumed that a larger number of blades should also contribute to reducing the noise level.

This work is devoted to an experimental aeroacoustic study of small-scale coaxial rotors.

2. Materials and methods
During acoustic studies with coaxial rotors, to reduce the dimensions of the power unit, it was assumed to use a scheme that would screen the acoustic radiation from the rotors while maintaining traction characteristics.
The tests were carried out on model F7/A7 counter-rotating rotors with 11 and 9 blades on the front and rear rotors, respectively. The design of the rotors was chosen according to [4]. The rotors were 3D-printed from the solid geometry model shown in Figure 1 [5].

![3D model of the rotor](image1)

**Figure 1.** 3D model of the rotor

The power characteristics and the noise generated by the rotors were investigated. The study of the rotor thrust was carried out in a T-5 wind tunnel (Figure 2). The educational aerodynamic unit T-5 of the Department of Aerohydrodynamics of the Kharkov Aviation Institute (Ukraine) is a closed-type tube with an open working part (Figure 3). Table 1 below shows the characteristics of the wind tunnel.

| Parameters                  | T-5               |
|-----------------------------|-------------------|
| Pipe working part diameter  | 0.75 m            |
| Pipe working part length    | 1.2 m             |
| Speed range                 | 10...40 m/s       |
| Initial turbulence degree   | 0.8%              |
| Scales                      | with three components |
| Engine power                | 32 kW             |

![Scheme of a closed-type low-velocity pipe](image2)

**Figure 2.** Scheme of a closed-type low-velocity pipe with an open working part:
1 – collector; 2 – honeycomb; 3 – guide vanes; 4 – fan;
5 – electric motor; 6 – diffuser; 7 – prechamber
The installation diagram of the rotors in the chamber is shown in Figure 4. The rotors were driven by a coaxial brushless electric motor "Himax Contra Rotating Motors" E50-65 610kV.

Figures 3 and 4. T-5 closed-type wind tunnel and Rotors in a wind tunnel

Acoustic tests were carried out in a noise-damped chamber (Figure 5). The characteristics of the chamber are presented in [6].

Figure 5. Investigated rotors in a noise-damped chamber
3. Experimental study of the noise of coaxial rotors
The measurements of the noise characteristics of the unloaded pine brushless electric motor showed an increase in mechanical noise from 34.8 dB at a frequency of 5580 rpm to 42.2 dB at a frequency of 7920 rpm (Figure 6).

Figure 6. Change in the SPL spectrum of the coaxial electric motor with an increase in the number of revolutions ($\alpha = 90^\circ$): a) $n = 5580$ rpm; b) $n = 7920$ rpm
The radiation intensity of the main sources of noise (rotors), was compared with the constancy of the thrust of the power units. The results of noise measurements are shown in Figure 7 (a, b, c). The plots show the acoustic spectrum of F7/A7 rotors (11 + 9 blades) obtained in the experiment. Also the sums of the tones of the blade passing frequency are shown: \( f_{nm} = n \cdot BPF_1 + m \cdot BPF_2 \), where BPF_1, BPF_2 are the blade passing frequency of the front and rear rotor respectively; n, m are integers. From Figure 7 one can conclude that there are tones that may hide in broadband noise, depending on the location of the observer.

Figure 7. SPL spectrum of F7/A7 rotors (11 + 9 blades) recorded (a) upstream – 15º; (b) in the plane of the rotors – 90º; (c) downstream – 150º
As can be noted, the noise spectrum is broadband over a wide frequency range. In addition, the spectrum also contains amplitude-modulated harmonics that are multiples of the blade repetition rate (combination frequencies). That is, in addition to the usual noise components present in the spectra of single-row rotors (rotation noise and its harmonics, broadband noise), tonal components are observed in the running combinations of the rotor blades. The noise levels at these frequencies are equal, and in some directions are much higher than the noise levels at the frequencies of the blades of the first and second rows.

A decrease in the noise levels of rotors with an increase in the number of blades was established due to a decrease in aerodynamic loads on the blades and peripheral speeds. In this case, it is necessary to take into account the influence of the filling factor of the space swept by the blades. With its increase, the rotation noise decreases, but the vortex noise increases significantly.

4. Conclusion
The study of the noise characteristics of the rotors showed the presence of tonal and broadband noise components at low rotor speeds. The high noise of the electric motor itself leads to clearly visible rotor harmonics in the noise spectrum of the rotors.

In the case of the equality of the thrust levels, with an increase in the diameter, the noise levels at the rotors decrease due to the decrease in peripheral speeds.

Consideration of the coaxial (tandem) rotor arrangement showed that, in addition to the traditional noise components, high-level tonal noise at combination frequencies is present in the rotor spectrum.

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