Evaluation of the Audibility Boundaries of Multirotor Systems of Different Configurations

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Abstract. The paper proposes a method for calculating the limits of audibility of multirotor systems such as quad- and hexacopters. The components of the proposed methodology are data on the noise of the device and the ambient noise, as well as the criterion of the audibility of the device. The acoustic-vortex method is used to simulate the tonal noise of multirotor systems. A trailing edge noise model is used to calculate the broadband noise of propellers.

1 Introduction

The significant development of unmanned aerial systems will inevitably lead to the normalization of the community noise of unmanned aerial vehicles (UAVs) on to minimize the noise impact of such devices on the environment [1]. In the European Union, in 2020, requirements were developed for maximum permissible community noise levels of a multicopter–type UAV for two ranges of take-off weights - up to 900 g and from 900 to 4000 g. At the same time, it is expected to tighten by 2 dBA in 2 years after the entry into force of this regulatory document, and by 4 dBA from 2024. The unit of assessment of community noise in this case is the overall A-weighted sound power level [2]. In the Russian Federation, UAV are subject to mandatory certification, but there are currently no requirements for acoustic certification.

In addition to rationing the noise of multicopters, the task of ensuring their flight without being perceived by an observer is urgent. This work is devoted to this problem.

Within the framework of the presented work, calculated estimates of the hearing limits for multirotor systems such as quadcopter and hexacopter with four and six two-bladed propellers, respectively, were performed.

2 Object of study

The computational study was performed for a two-bladed propeller Parrot Mambo Drone with a diameter of 70 mm and a rotation speed of 12000 rpm. We consider a quadcopter and a hexacopter with four and six two-bladed propellers, respectively, whose propellers operate in hover mode.

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3 Methodology for assessing of audibility boundaries of UAVs

The initial data for the assessment of the audibility boundaries are data on the ambient noise in the flight zone of UAV [3], data on the noise of the multirotor system and the audibility criterion [4]. The structure of the methodology for assessing the audibility boundaries of propeller-driven UAVs is shown in Fig. 1 [5].

To calculate the noise spectrum of a multirotor system, an acoustic-vortex method was used to calculate the tonal components of noise at frequencies multiple of the repetition frequency of the propeller blades. The transfer of vortex disturbances is considered as the main reason for the sound generation by the multicopter propeller at the blade passing frequency. The modeling method is based on the theoretical approach of Blokhintsev, Landau, Crow and Artamonov. The basic equations of the acoustic-vortex method are presented in [6, 7]. This method is implemented in the FlowVision 3.1x software. To calculate the vortex (broadband) noise, the trailing edge noise model is used [8].

The criterion for the audibility of a propeller-driven UAV is the condition.

$$\Delta OASPL = L_{UAV} - L_{background} \geq 3 \text{ dBA} \qquad (1)$$

where $L_{backgound}$ – the overall A-weighted sound pressure levels of ambient noise, L_{UAV} – the overall A-weighted sound pressure levels of UAV.

That is, the UAV becomes audible to the observer when its overall noise level exceeds the overall ambient noise level by 3 dBA.

It is advisable to perform calculated estimates of the audibility boundaries of UAV using specialized software [9–11].

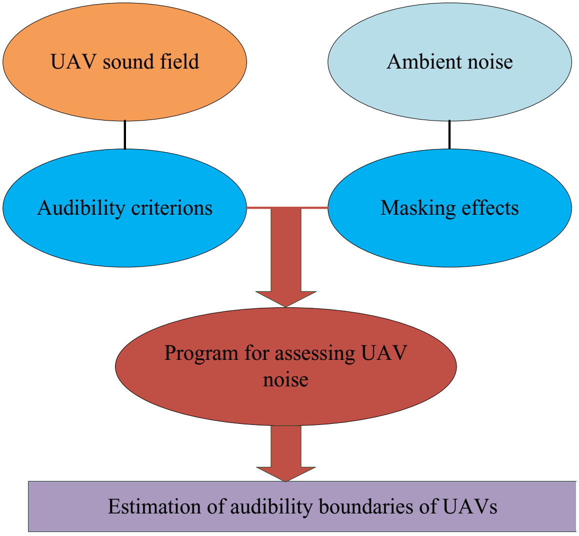


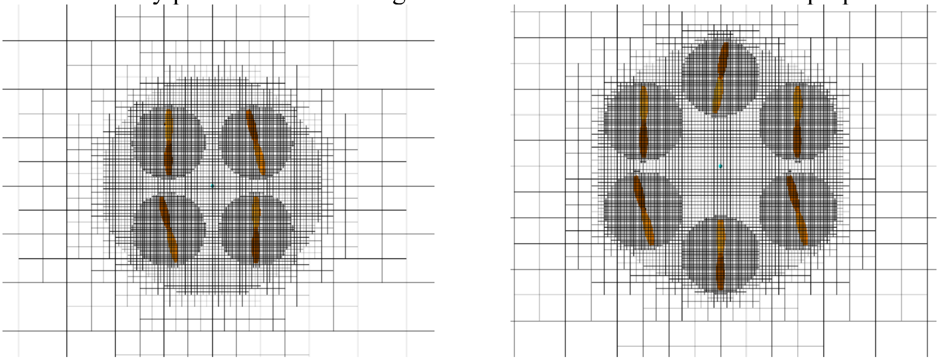
Fig. 1. The structure of the methodology for assessing the audibility boundaries of propeller-driven UAVs.

4 Finite-difference grid and boundary conditions in numerical simulation of the tonal components of propeller noise

The propellers are placed in the design area in the form of a sphere with a radius of 3 m. The initial grid is formed by rectangular cells with a face size of 0.05 m. This size provides more than six grid cells per wavelength for the first three tones of the blade passing frequency (BPF) of the propeller.

Near the propeller, the adaptation (grinding) of the grid nodes is carried out, while each cell of the initial grid is divided into eight cells, forming a grid of the first level. Further grinding leads to a second-level grid, etc. In this work, grids up to the 5th level of adaptation near the propellers were used. The mesh adjacent to the screw area has a fourth level of adaptation. Fig. 2 shows adapted grids for different configurations of multirotor systems under study.

At the "air" boundary of the sphere, a condition of zero pressure (relative to the "reference" atmospheric pressure) and zero velocity gradients is set. The logarithmic law for the velocity profile with zero roughness is also set on the surface of the propeller.

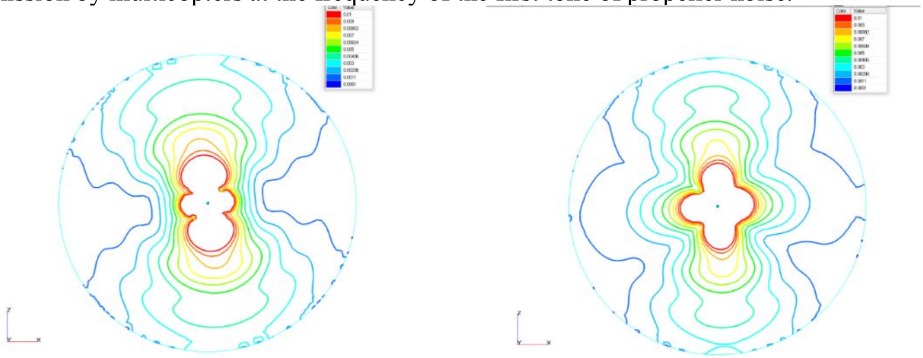


a) quadcopter b) hexacopter

Fig. 2. Adaptation of the grid near the propellers (plan view).

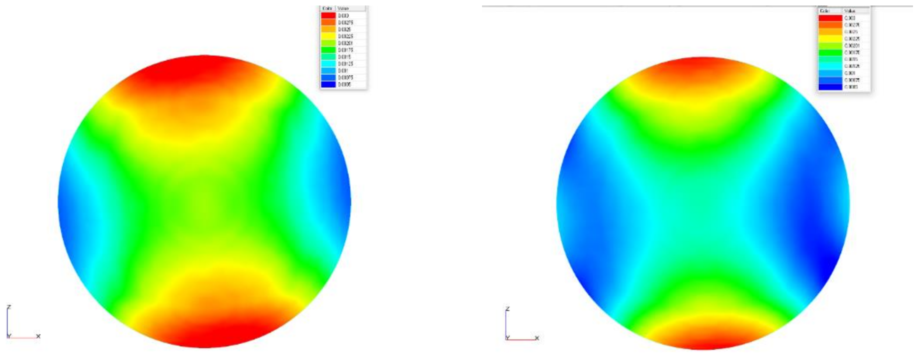
5 Acoustic fields of multirotor systems

The results of calculating the amplitude of the first tone of propeller noise (in Pa) are shown in the plane of rotation for different configurations of multirotor systems are shown in Fig. 3. The amplitude levels of the first harmonic of propeller noise on the surface of the bounding sphere (in Pa) are shown in Fig. 4. You can see the dipole nature of noise emission by multicopters at the frequency of the first tone of propeller noise.



a) quadcopter b) hexacopter

Fig. 3. The amplitude level of the first tone of the propeller noise in the plane of rotation.



a) quadcopter b) hexacopter

Fig. 4. The amplitude level of the first tone of the propeller noise on the surface of the bounding sphere.

6 Results of the assessing of the audibility boundaries of multirotor systems

Within the framework of this section, the results of the evaluation of the hearing boundaries for quadcopter and hexacopter configurations are presented. The results are presented for the hovering mode in the range of elevation angles of 20-160° with a fixed azimuth angle of 0°. The azimuth angle and the seat angle for multirotor systems are shown in Fig. 5.

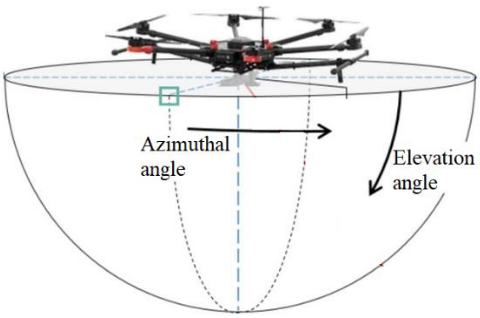


Fig. 5. Azimuthal and elevation angles.

The calculated estimate is made for two distances of 10 and 20 m for different angles of the place and the results are presented for the quadcopter and hexacopter configurations in Fig. 6 and 7, respectively. To determine the audibility boundaries, the graphs show the criteria for the audibility of the UAV for ambient noise in an open area at wind speeds of 3-4 m/s and 5-6 m/s. The effects of noise masking were not taken into account in the calculation.

It can be seen that for the configuration of a quadcopter at a distance of 10 m at a wind speed of 3-4 m/s, the device is audible in the entire range of angles of the place under consideration (Fig. 6). At the ambient noise level at a wind speed of 5-6 m/s, the device is audible in the range of angles of 20-50° and 140-160°. At a distance of 20 m with a wind speed of 3-4 m / s, the device is audible in the range of angles of 20-50 ° and 140-160 °, and at a wind speed of 5-6 m / s we do not hear in the entire range of elevation angles.

For the hexacopter configuration at a distance of 10 m at a wind speed of 3-4 m/s, the device is audible throughout the considered range of angles of the place (Fig.7). At the ambient noise level at a wind speed of 5-6 m / s, the device is not audible in the entire range of angles of the place. At a distance of 20 m at both wind speeds, the device is not audible in the entire range of elevation angles.

The data in Fig. 6 and 7 also indicate that the hexacopter configuration is somewhat quieter than the quadcopter configuration, which is also consistent with the data presented in Fig. 4.

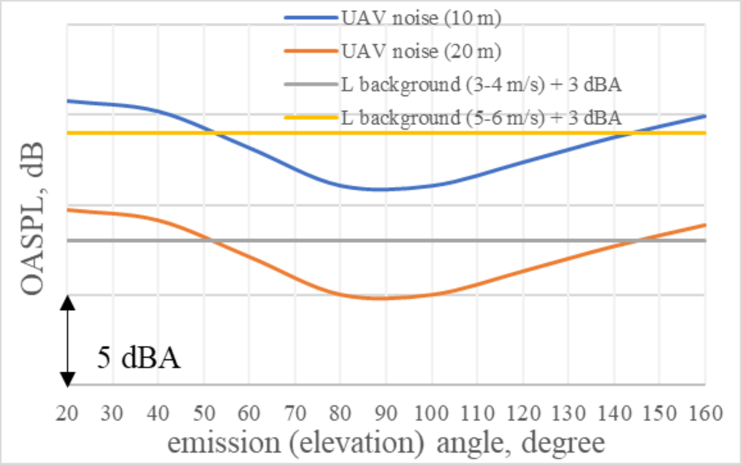


Fig. 6. Assessing of the audibility boundaries for quadcopter.

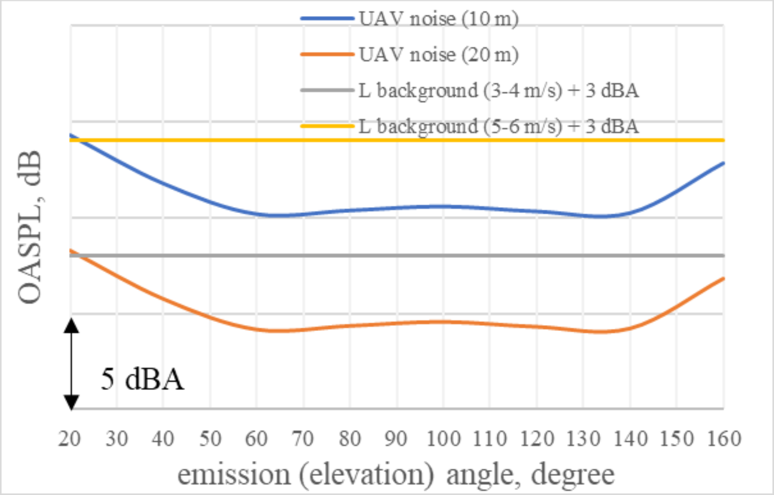


Fig. 7. Assessing of the audibility boundaries for hexacopter.

7 Conclusion

A methodology for calculating the of audibility boundaries of multirotor systems is proposed and tested. The main elements of the methodology are data on the UAV noise and ambient noise in the area of application of the device, as well as the criterion of UAV audibility. The results of calculating the audibility boundaries of devices such as quadcopter and hexacopter are presented.

It is of interest to further investigate and propose low-noise configurations of multirotor systems, taking into account the degree of their audibility.

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