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AMBIENT NOISE: PROBLEM AND STUDY IN THE FRAMEWORK OF UAV AEROACOUSTICS

Petr Moshkov

Moscow Aviation Institute (National Research University), Moscow, Russia, moshkov89@bk.ru

***Abstract**: The role of ambient noise in the problem of community noise of propeller-driven unmanned aerial vehicle is considered. The results of the author's measurements of the spectral characteristics of the background in open terrain, in the mountains, near the sea and the highway are presented. An expression is proposed for calculating the spectrum of background noise in open terrain (wind noise). It is shown that the ambient noise can be an effective noise masker of propeller-driven UAV in the low and medium frequencies.*

***Keywords:** ambient noise, wind noise, background noise, UAV noise, sound scape*

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1. INTRODUCTION

The widespread development of unmanned aircraft systems poses the task of ensuring the highest possible characteristics of these systems at the current stage of the development of science and technology. At the same time, the noise indicators of military propeller-driven (UAVs) are one of the most important and priority at the present time, which is confirmed by numerous studies of the sources of UAV noise [1–3] and, in general, the problems of their audibility [4, 5] and acoustic signature [6, 7]. International standards regulating the maximum permissible community noise levels of civil UAVs are not currently developed, and low noise levels of general-purpose UAVs are, first of all, their competitive advantage.

The problem of determining ambient noise occupies a separate place within the framework of the topic of UAV aeroacoustics. Background noise acts as a masker of a useful signal and the task is to isolate the UAV noise against the ambient noise both by ear [8, 9] and with the help of special measuring systems. This leads to the need to establish objective criteria for assessing the degree of acoustic signature of different types of UAVs when they are used in various natural and weather conditions. The criteria of audibility and acoustic signature are objective noise parameters that allow us to assess the audibility and acoustic signature of various types of propeller-driven UAVs. These criteria generally depend on the spectral characteristics of the UAV sound field and ambient noise. The audibility criteria are also influenced by the peculiarities of human perception of moving sources.

Another aspect of the problem of background noise assessment is the wide application in the near future of aircraft in cities for the delivery of parcels, air taxis, etc. It is expected that by 2030-2035, air transport will be able to partially replace automobile transport, and in another five years, air taxi will be able to transfer to electric power supply schemes and an unmanned control system. The widespread use of UAVs in everyday life will lead to a significant transformation of the soundscape of cities. An important task will be to ensure the flight paths of the aircraft in urban conditions, so that the noise of the device is masked by background noise in the field of application and does not have an additional irritating effect on urban residents.

It should be noted that the transformation of urban soundscapes has already occurred around the world during the COVID-19 pandemic, and a significant number of studies have been devoted to this topic around the world [10–15].

This paper presents the results of ambient noise measurements performed in an open area at a local aerodrome [16]. Background measurements near the sea (surf noise) and in the mountains were carried out close to Gelendzhik (Krasnodar region, Russia) and in the forest near the highway close to Zvenigorod (Moscow region, Russia).

2. METHODOLOGY FOR MEASURING AMBIENT NOISE AND PROCESSING MEASUREMENT RESULTS

To measure the background noise levels, a single-channel measuring system based on a portable noise meter "Ecofizika-110A" was used. The measuring microphone with the installed wind protection was installed on a tripod at a height of 1.2 m relative to the ground surface. The main axis of the microphone was directed upwards. The audio signal was recorded at a sampling rate of 48 kHz. Post-processing of the signal within the framework of the purposes of this paper included obtaining in 5 s increments with exponential averaging of the 1/3-octave spectrum of sound pressure levels in the frequency range of 10–10000 Hz.

3. THE SPECTRAL CHARACTERISTICS OF AMBIENT NOISE

3.1. Open territory

The 1/3-octave spectrum of sound pressure levels measured in an open area with a step of 5 s at a wind speed of 3-6 m/s are shown in Fig. 1. Here and further to the left of the measured spectrum, the pictures show photos of the microphone location.

The spread of the spectrum in the studied frequency range is 20 dB, which is explained by a significant change in the wind speed during measurements. At the same time, three characteristic frequency ranges can be distinguished in the spectrum. The frequency range is 10-315 Hz, where the sound pressure levels decrease with frequency, which indicates the probable dominance of the turbulent atmosphere's self-noise in this frequency domain. The frequency range is 400-2000 Hz, where noise sources are present, apparently unrelated to atmospheric turbulence. The frequency range is 2500-10000 Hz, where noise levels decrease with frequency, but it is worth noting that the recorded background noise levels in this frequency range are commensurate with the natural noise of the measuring system.

In general, we note that background noise in an open area can be an effective marker of UAV noise in the frequency range up to 100 Hz for both the observer and the measuring microphone.

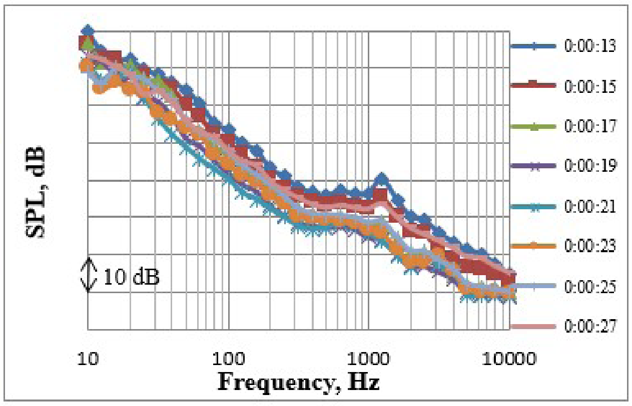


Fig. 1: 1/3-octave spectrums of ambient noise in open terrain conditions at a wind speed of 3–6 m/s

The influence of wind speed on the measured ambient noise levels is considered in Fig. 2. An increase in the wind speed by 2 m/s leads to an increase in the measured sound pressure levels in the entire studied frequency range by up to ~12 dB. At the same time, the A-weighted overall sound pressure level increases by 6 dBA. The increase in noise levels in the frequency range of 10–250 Hz is most likely due to an increase in the intrinsic noise of the turbulent atmosphere with an increase in wind speed. Since a change in wind speed also leads to an increase in noise levels in the range of 315-10000 Hz (Fig. 1, 2), therefore, it is most likely that the source of radiation in this frequency range is the noise of the flow around the grass cover. This hypothesis is confirmed by the expected size of the characteristic source, which, taking into account the maximum of vortex noise at a frequency of 1250 Hz at a wind speed of 6 m/s and the Strouhal number taken into account in the calculation of 0.2, is equal to 0.96 mm.

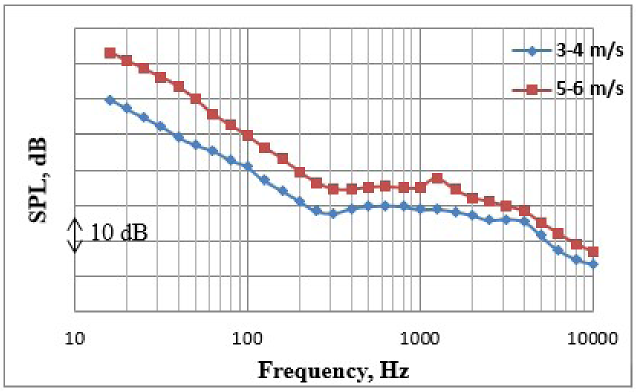


Fig. 2: Influence of wind speed on ambient noise levels in open terrain

In the spectral representation of atmospheric turbulence, it is customary to distinguish three characteristic intervals: energy, inertia and dissipation. The shape of the turbulence spectrum at the inertial interval, as a rule, agrees with the known Kolmogorov energy spectrum , where f – frequency in Hz [17].

The shape of the background noise spectrum with a frequency-decreasing intensity in the spectrum can be described by a functional dependence:

$$E(f) \propto f^{-\frac{5}{3}}$$

where
f – frequency in Hz [17].

Kraichnan [18, 19] suggested that two-dimensional turbulence can exhibit two types of inertial range: the range of energy transfer, for which the exponent is -5/3, and the range of entropy transfer, for which the exponent is -3.

The shape of the background noise spectrum with a frequency-decreasing intensity in the spectrum can be described by a functional dependence:

$$I(f) = c_1 f^{-\alpha} \quad (1)$$

where

c_1 – empirical proportionality coefficient that depends on the wind speed and other parameters that determine the ambient noise levels of a turbulent atmosphere,

α – indicator of the decline in spectral intensity.

Expression (1) can be used to estimate background noise with a similar spectrum with a frequency-decreasing intensity in the presence of experimental constants α and c_1. According to the results of the author's research in an open area, the indicator of the decline curve α is 3. In accordance with the works of Kraichnan [18, 19], it can be concluded that the empirical constant corresponds to the range of entropy transfer in the inertial range of two-dimensional turbulence.

As an example, a comparison of the calculated and measured 1/3-octave spectrum of sound pressure levels at a wind speed of 5–6 m/s are shown in Fig. 3. One can see a good agreement between the calculated and experimental data up to the frequency of 315 Hz, where the ambient noise levels are determined by the self-noise of the turbulent atmosphere.

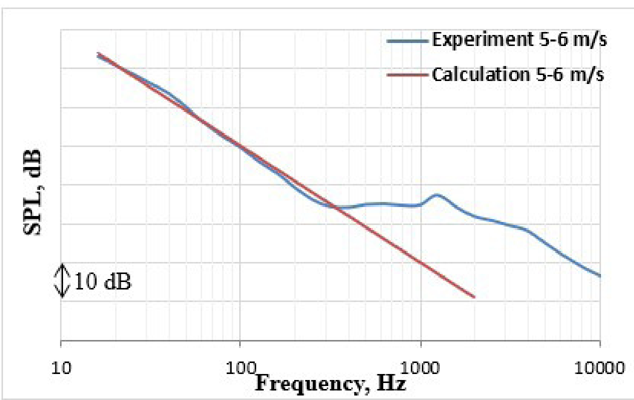


Fig. 3: Comparison of calculated and measured 1/3-octave spectrum of sound pressure levels

3.2. Near the sea

The 1/3-octave spectrum of sound pressure levels measured near the sea at low wind speed are shown in Fig. 4. The maximum levels are observed in the 1/3-octave bands with central frequencies of 50 and 400 Hz. The spread of the spectrum (up to ~20 dB) is most likely due to the different height and speed of the incoming waves. It can be seen that in this case, the ambient noise can be an effective masker of UAV noise in the range of ~250–2000 Hz, as well as tonal noise in the 50 Hz band.

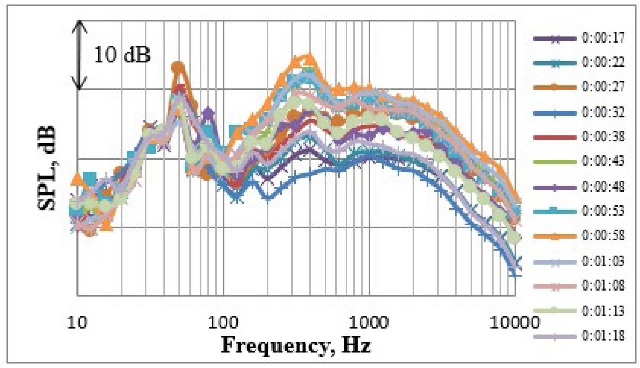
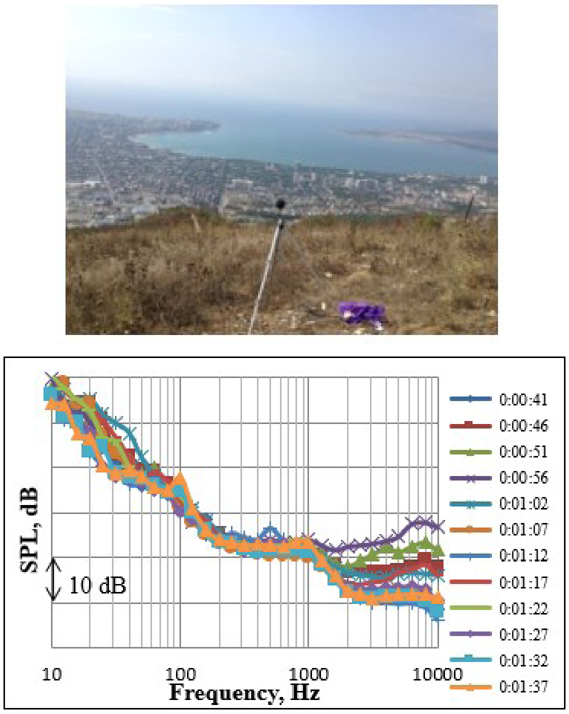


Fig. 4: 1/3-octave spectrum of sound pressure levels measured in 5 s increments near the sea (surf noise) at a wind speed of 0.5 m/s

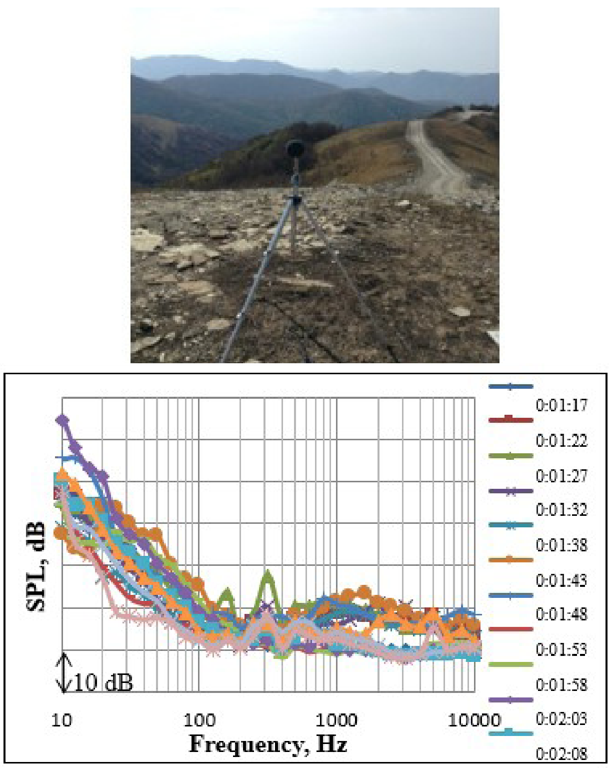
3.3. In the mountains

The 1/3-octave spectra of sound pressure levels measured in the mountains at different control points at different wind speeds are shown in Fig. 5. You can see the decrease in the intensity of ambient noise with frequency, as well as when measuring the background in open terrain. At the same time, at a wind speed of 3.5–4.5 m/s (Fig. 5a), the spread of the measured sound pressure levels in the frequency range of 10–100 Hz is up to 10 dB, while in the frequency range of 100–100 Hz, the spread of sound pressure levels does not exceed 5 dB. The greatest spread of levels in the spectrum is observed at frequencies above 1000 Hz (up to 20 dB), which indicates that at high frequencies there are additional sources of noise of natural origin that are not associated with atmospheric turbulence.

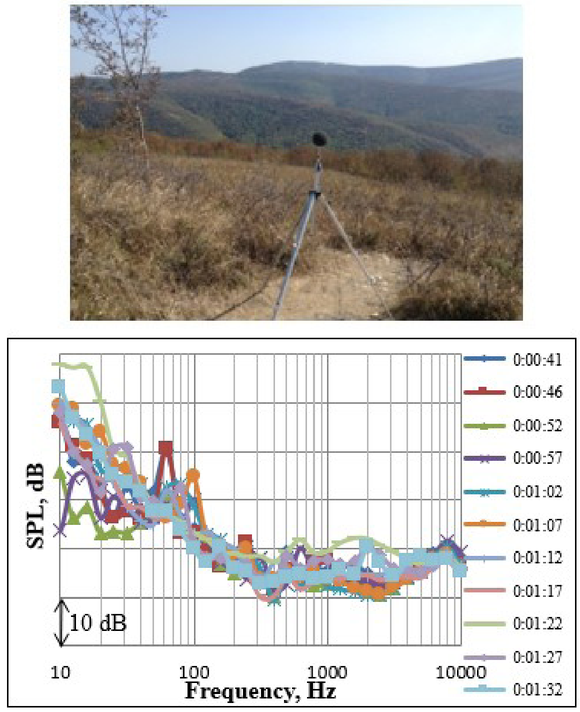
At low wind speeds up to 1.5 m/s (Fig. 5b, c), the spread of the measured background levels reaches 35 dB in the low frequency range up to 100 Hz. At higher frequencies, the measured background levels are very low.



(a)



(b)



(c)

Fig. 5: 1/3-octave spectrum of sound pressure levels measured in 5 s increments at different control points in the mountains at different wind speeds

3.4. In a field

The 1/3-octave spectrum of sound pressure levels measured in a field near the city of Gelendzhik at a wind speed of 1 m/s are presented in Fig. 6. It can be seen that ambient noise levels in the frequency range of 200-1000 Hz are not related to the natural noise of the turbulent atmosphere. The measured levels above 2000 Hz are most likely related to the self-noise of the measuring system.

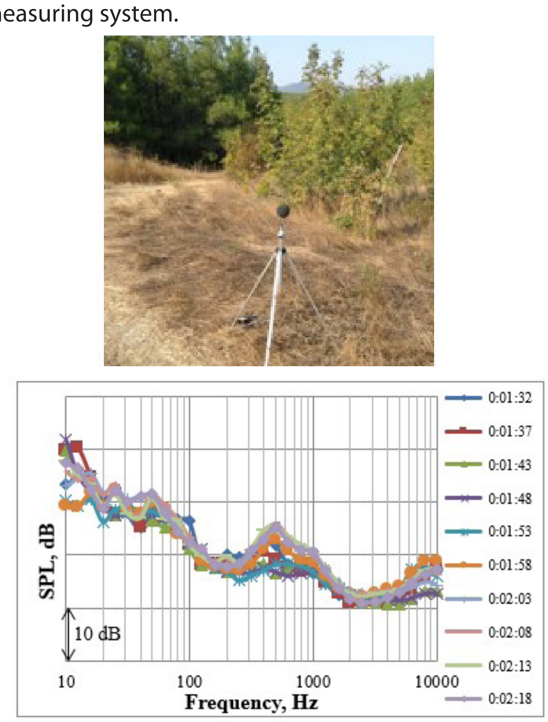


Fig. 6: 1/3-octave spectrum of sound pressure levels, measured in increments of 5 s, in the field at a wind speed of 1 m/s

3.5. In the forest near the highway

The 1/3-octave spectrum of the sound pressure levels of ambient noise measured in the forest at low wind speed with the audible noise of vehicles from the road are shown in Fig. 7. The greatest variation in the measured levels is observed in the frequency range 2000-10000 Hz, which, apparently, is due to the different power of car engines and their weight. In the frequency range of 10–2000 Hz, the spread of the measured sound pressure levels does not exceed 5 dB. Moreover, in the frequency range of 10-100 Hz, noise levels are almost constant, and some reduction in noise levels is observed at a frequency of 160 Hz. It can be seen that in this case, the noise of vehicles can be an effective masker of UAV noise in the frequency range of 10-1600 Hz. It should also be noted that in general, the noise level of the flow of vehicles is affected by many factors, such as traffic intensity, speed, the ratio between trucks and cars, road surface (type and condition), etc.

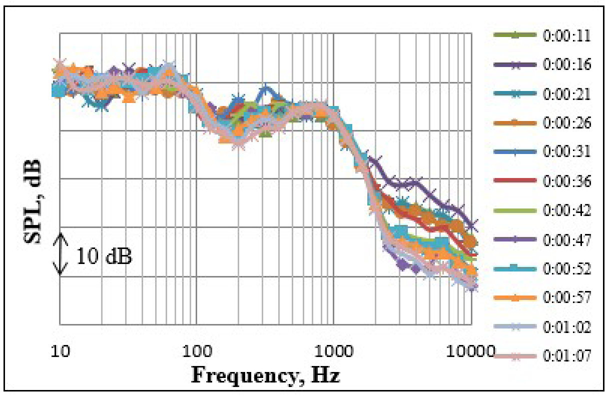


Fig.7: 1/3-octave spectrum of sound pressure levels measured in the forest near the highway at a wind speed of less than 1 m/s

4. CONCLUSION

The problem of ambient noise is considered in the context of the community noise problem of propeller-driven UAVs. The results of measurements of background noise in an open territory, near the sea, in the mountains and in the forest near the highway are presented. In the conditions of open terrain and in the mountains in the frequency range of 10-315 Hz in 1/3-octave frequency bands, the source of background noise is the self-noise of the turbulent atmosphere. It is shown that the ambient noise can be an effective masker of the UAV noise for both the observer and the measuring microphone. An expression for estimating the spectral characteristics of background noise in an open area is presented. The presented results of the author's studies of the spectral characteristics of ambient noise are consistent with the publications of other authors [20–26].

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Petr Moshkov *is Ph.D. of Engineering Science, Leading engineer of the Moscow aviation institute (national research university) (Moscow, Russia).*
Petr Moshkov is a specialist in aeroacoustics. Petr Moshkov is the author of over 45 scientific papers. He presented the main results of scientific research at the international conferences in Moscow, Gelendzhik, Svetlogorsk, Delfts.