Study of the noise sources of an UAV with a two-stroke engine and shrouded propeller

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Abstract. The widespread use of unmanned aerial vehicles poses the task of ensuring their low noise. To solve the problem of designing low-noise unmanned aerial vehicles, it is necessary to have data on the structure of the sound field of various unmanned aerial vehicles and their main noise sources. The results of an acoustic characteristics study of an unmanned aerial vehicle are presented. Its power plant includes a two-stroke piston engine and 4-bladed shrouded pusher propeller. The tests were performed in a wind tunnel at different speeds of the incident flow and different power conditions of the power plant. The dominant source of drone noise is a two-stroke piston engine. The propeller contribution is observed in the second and fourth tones in the radiation spectrum.

1. Introduction

Currently, propeller-driven unmanned aerial vehicles (UAVs) designed for a wide range of military and civil tasks are widely used. Low noise levels are a competitive advantage of civilian UAVs, and the low degree of acoustic signature of military UAVs ensures its survivability [1].

For both military and civilian UAVs, an urgent task is to study the mechanisms of noise generation [2,3], technologies for reducing its intensity [4] and develop methods for the assessment of community noise [5-8]. For propeller aircraft-type UAVs driven by an electric motor [9-12], the dominant community noise source will be the propeller, but the flight time of such devices is currently 1.5-2 hours. The power plant of a UAV with a flight time of about 8 hours includes internal combustion engines (ICEs) of various designs and configurations. Internal combustion engines generate noise during operation which depends on the power conditions of the power plant, the presence of intake and exhaust silencers, as well as sound-proofing engine jacket and other factors, will have a different contribution to the overall community noise level of the UAV in a given direction of the observation [13-16].

When the propeller is positioned in a real configuration on an airplane, additional noise sources may appear due to aerodynamic interference [17-20] of the propeller and airframe elements [21-23], which ultimately significantly changes the acoustic characteristics of the propeller compared to the case of an isolated propeller.
The aim of this work is to study the aeroacoustics characteristics of a UAV with a two-stroke internal combustion engine and a shrouded propeller in a pushing configuration.

2. Methods and calculations
The object of the study is an unmanned aerial vehicle with a take-off weight of ~140 kg. The UAV power plant consists of a two-stroke two-cylinder piston engine without a gearbox and a shrouded propeller of invariable pitch in a pushing configuration. Inside the shroud just behind the propeller, there are elevators and rudders.

Acoustic tests were combined with aerodynamic tests performed under the direction of Ostroukhov Stanislav [24] in Central Aerohydrodynamic Institute named after professor N E Zhukovsky (TsAGI) wind tunnel (T-104). The outcome of wind tunnel testing has been only partially reported here.

When testing the sound pressure measured at 5 points of UAV acoustic field. The diagram of the noise measurement points is shown on figure 1. Measurement points are located in a horizontal plane passing through the longitudinal axis of the UAV on a line parallel to the wind tunnel axis.

![Figure 1. Location of UAV noise measurement points in the wind tunnel.](image)

The ‘PORTABLE’ measuring system was used for recording acoustic signals and subsequent data processing. The main parameters of signal recording on a digital tape recorder are as follows: the signal quantization frequency is 51,200 Hz, the length of recording in one power condition is 14.88 s, and the useful signal was recorded in parallel with 5 measuring channels. Processing of the measured sound pressure included obtaining narrowband spectrum of sound pressure levels with a bandwidth of 2 Hz in the frequency range 0-128,000 Hz, and 1/3-octave spectrum of sound pressure in the frequency range 16-10,000 Hz.

3. Results and discussion
Because the power plant of the UAV is a two-stroke two-cylinder gasoline ICE without gearbox and without exhaust silencer with 2 exhaust pipes and 4-blade propeller, latter being equivalent to 2 two-bladed propellers, the noise spectrum of the power plant of discrete components, and at the odd harmonics of the radiation due to the engine noise, and even noise and the propeller and engine.

Typical narrow-band spectrum of sound pressure levels, measured when the power plant is operating in cruising mode in the presence of an incident flow is shown on figure 2. The graph shows the first 5 tones. As previously noted the odd tones are related, only to the ICE and even composed tones to shrouded propeller and ICE.
3.1. Influence of incident flow velocity

The effect of the incident flow velocity on the measured noise levels is considered on figure 3, where a comparison of narrowband spectrum of sound pressure levels measured at an incoming flow velocity of 30 m/s and 0 m/s is presented. It can be seen that the measured levels of broadband noise up to the second tone in the spectrum significantly depend on the flow velocity in the wind tunnel which indicates that it is impossible to isolate the broadband noise of the internal combustion engine, and the propeller in the UAV noise measured in these tests.

Except for the second tone in the radiation spectrum, tonal noise levels are higher without an incident flow than in the presence of an incident flow. This fact can be explained as follows. Despite the equality of engine speeds, the engine operates according to different partially high-speed characteristics. In the presence of incident flow, the engine is less loaded, since the thrust of the propeller in the presence of incident flow is less than when the propeller is operating without an
incoming flow. Therefore, the noise levels of the first 9 harmonics in the spectrum (figure 3) in static conditions. The second tone level in the spectrum radiation, caused by the engine and propeller increases, in the presence of incident flow increases due to the increased characteristic propeller velocity and blade-wake interaction noise.

3.2. Influence of engine speed
The effect of the engine speed at a constant incident flow velocity is considered on figure 4 where a comparison of narrowband spectrums of sound pressure levels measured at an incident flow velocity of 20 m/s at different engine speed is presented. Noise levels up to the frequency of the first tone in the spectrum do not depend on the operating mode of the power plant and are associated with background noise in the wind tunnel. Increasing the frequency of crankshaft rotation leads to a shift in the frequency of tones components the positive levels in the spectrum (with the exception of the third and fifth engine tones) which is peak with an increase in engine power, thrust and circumferential tip velocity are increased of the shrouded propeller in accordance.

Figure 4. Effect of engine speed on narrowband sound pressure levels (incident flow velocity 20 m/s, reference point T2).

3.3. Energy characteristics of the UAV sound field
Due to the impossibility of separating broadband components in the noise spectrum due to vortex propeller noise and ICE broadband noise, and wind tunnel background noise, the energy analysis of the UAV sound field was performed only for the tonal components of the spectrum. The results of acoustic measurements were processed to obtain the sound power levels of the first 15 tones and the overall sound power level of the first 15 harmonics.

In this work, the sound power level or power watt level \( PWL \), was calculated using the following equation (1) which takes into account the tunnel or freestream Mach number effect [25]:

\[
PWL = \frac{2 \pi d^2}{P_0 c_0} \int_0^\pi \left(1 - M_0 \cos \theta_g \right)^2 \frac{\bar{p}^2(d, \theta_g)}{\sin \theta_g} d\theta_g,
\]

where \( d \) – sideline distance from model centerline, \( \rho_0 \) – ambient air density, \( c_0 \) – speed of sound, \( M_0 \) – tunnel or freestream Mach number, \( \theta_g \) – geometric (measurement) angle, \( \theta_e = \theta_g - \sin^{-1}(M_0 \sin \theta_g) \) – acoustic or emission angle, \( \bar{p}^2(d, \theta_g) \) – time-averaged sideline mean-squared pressure at measurement
angle. The intensity was assumed to be symmetric about the axis of the model and integrated over the portion of the spherical surface spanned by the sideline measurement angles.

The influence of the engine power condition on the overall sound power level is shown on figure 5. You can see the instability of the measurement results, which can be caused by:
- Presence of turbulent flows in the test portion of the wind tunnel.
- Impossibility to maintain a constant propeller and engine speed due to the use of an invariable pitch propeller.

Based on the data shown on figure 4 the overall sound power of the power plant is proportional to the engine speed to the degree of 5.3.

The most common characteristic of an aerodynamic type acoustic radiation source is acoustic efficiency. Acoustic efficiency is a relative measure of the amount of mechanical energy of a power plant radiated as acoustic energy. The acoustic efficiency of the power plant is from 0.21% to 0.91% depending on the power conditions.

4. Conclusion
A study of the noise sources of a UAV with a piston engine and shrouded propeller in a pushing configuration is performed. The influence of the incident flow velocity and the engine speed on the spectral characteristics of the sound field is considered. The energy dependences of the sound power of the overall tonal radiation on the engine speed are obtained. It is shown that in the absence of an exhaust silencer the dominant noise source is the two-stroke internal combustion engine. The contribution of the propeller is observed at the first even harmonics in the radiation spectrum. The overall sound power of the power plant is proportional to the engine speed to the degree of 5.3. The acoustic efficiency of the power plant is from 0.21% to 0.91% depending on the power conditions.

Further steps in the development of this topic can be studies of UAVs whose power plants include four-stroke engines, engines with mufflers for intake and exhaust noise, as well as engines enclosed in the hood. It is necessary to generalize information about the acoustic characteristics of different UAVs in order to develop in the future a method for selecting a power plant, taking into account the requirements for community noise.

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