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RECONNAISSANCE DRONE NOISE REVIEW

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Abstract. *The paper analyzes the sound of drones, both as environmental noise and as a parameter for their detection. The reasons for the psychoacoustic character of the noise and the conditions for effective acoustic detection are examined. Comparative results of sound measurements are provided for three types of reconnaissance drones individually, while hovering at different altitudes.*

Key words: *drone, anti-drone, reconnaissance drone, noise, psychoacoustic, detection*

1. INTRODUCTION

Although drones are a symbol of innovative freedom and technical power in the airspace, in terms of noiselessness, they have not surpassed birds, as their operation is always accompanied by sound. In the world of drones, acoustics is found in two areas: the noise of drones in the environment and the sound detection of drones.

Unmanned aerial vehicles (UAVs – Unmanned Aerial Vehicles), or drones, are a synthesis of aerodynamics, electrical engineering, computing, and new materials. Thanks to their unmanned operation, whether remotely controlled or autonomously programmed, and their three-axis movement, drones enable wide, cost-effective, and easy applications, dependent only on creativity and needs.

Drones are easily accessible in their basic design and, with optimal performance, are increasingly integrated into our daily lives (for: filming, entertainment, journalism, delivery,

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research, surveillance and security, agriculture, real estate, construction, logistics, etc.). They are classified by weight, operational range, and risk (open-category drones can fly within visual range), and can also be divided into: fast (racing) drones and slow (hovering cameras or cargo drones).

Civil aviation authorities in some technologically advanced countries have allowed the production of drones for transporting people, passenger UAVs (unmanned aerial vehicle-UAV) or some eVTOL (electric vertical take-off and landing-eVTOL). Technological platforms for urban air mobility involve vertical takeoff and landing, three-axis operationality controlled from the ground or autonomously via routing protocols. Certainly, safety requirements are the most important for this air mobility sector. Due to traffic in populated areas, environmental pollution and noise emission requirements are also important.

Electronic commerce is rapidly growing and engaging consumer drones that fly at low altitudes to deliver packages to customers, which can significantly increase the noise in populated areas (above the thresholds of 45 dBA at night and 55 dBA during the day, according to Regulation about noise in the Republic of Serbia (Official Gazette of RS 75/2010, Directive EC 49/2002 and ISO 1996).

Mostly used unmanned aerial vehicles are based on electric motors (with or without brushes, which are quieter but shorter-lived), batteries (lithium-ion 3.7 V or lithium-polymer 3.6 V), composite materials, and other sophisticated components (GPS systems, controllers, voltage regulators, cameras, sensors (accelerometers, gyroscopes, magnetometers, barometers, etc.)), which make them intelligent and powerful.

Hardware-wise, drones are multirotors, whose movement in all directions is achieved by changing the speed of the propellers (the kinetic energy of rotation generates thrust). On the commercial market, quadcopters are the most common, with four rotors, that is, four motors connected to two pairs of propellers that rotate in opposite directions to achieve movement (as rotating in the same direction would cause them to spin around their axis). Propellers, through fast rotation, generate force that lifts, lowers, and moves the drone through the air, causing vibrations and sound.

Drone noise mostly depends on the propellers (shape, number, size, and material), followed by: the propulsion system (motor power and type – brushless motors are quieter), aerodynamics, volume, and payload, as well as environmental noise and wind speed.

The type of drone can be recognized by its sound: higher-speed drones usually have smaller propellers with a higher pitch and are noisier, while slower drones (mostly used for cargo, filming, etc.) have larger propellers with a lower pitch.

Lower noise is achieved through design and an optimal relationship between the diameter of the blades and the rotor. To achieve good aerodynamics characteristics, and reduce energy consumption and noise, the propeller blades are individually balanced with precision. Larger diameter, smooth, and light propellers will overcome air resistance with fewer revolutions and produce less noise.

There is also an attempt to manufacture an ultra-quiet drone without propellers, for cargo transport and delivery, based on space technology and ion propulsion (the generated ion cloud creates thrust).

Drone noise is irritating, with psychoacoustic impact, resembling the fluctuating buzz of a large insect or a swarm of insects. Compared to other sources, drone noise is equally unpleasant as that of vehicles (though drone noise levels are about 6 dBA lower) and traditional aircraft (at 100m distance a helicopter noise is about 95 dBA and a large quadcopter about 55 dBA), due to prominent tones in the spectrum (motor hum and whistling during rotor rotation). The irritability of the noise depends on the axial distance between the rotors and can be reduced through optimal design, and spacing between opposing rotating propeller pairs. Although propellers should rotate at the same speed, sometimes a prominent tone is heard because two close frequencies (from the two pairs of opposing rotors) create a third virtual frequency (from their difference), producing a periodic loud sound.

Considering the environment noise criteria, the question arises as to what altitude a drone should fly to be discreet. The greatest challenge and coverage is a silent and unobtrusive drone in rural areas, where ambient noise is minimal.

The application of drones for surveillance and security is a priority, as they quickly provide precise data and images from large areas that the human eye cannot detect. In order to have good-resolution data while remaining unnoticed, drones must be silent and fly at optimal heights, which should be predicted considering that ambient noise varies by area and time of day. Noise levels decrease by 6 dB at double the distance, so its spreading can be roughly predicted.

The flight control system sends commands to the motors via radio transceiver signals and transmits data that microcontrollers process and execute algorithms for stabilization and navigation. Most drones use radio frequencies of 2.4 GHz or 5.8 GHz, with a range from several hundred meters to several tens of kilometers. With higher frequency, the transmission of radio data increases but the signal range decreases. Data from the camera is compressed and sent via the radio transmitter to the receiver, which decompresses it and displays it on the screen.

In a short time, the „celebratory" use of drones has evolved into military applications. Unmanned aerial vehicles (UAVs) with integrated weapons, such as suicide drones, are becoming a significant part of warfare, supported by intelligence gathered through reconnaissance. Military drones conduct delivery, observation, and reconnaissance of enemy positions, and "guided munitions" attacks, reducing human losses.

Prototypes are tested in real combat conditions, so development is rapid, and the market is quickly supplied not only with cheap, mass-produced but also expensive, precise flying weapons.

The military drone industry is simultaneously developing and producing anti-drone systems, which involve tracking drones.

Active tracking for counter-drone operations includes the processes of detection, classification with identification, and localization with countermeasures, integrating sensors: radar, radio frequency analyzers, cameras, and microphones.

Individually, these systems are not always successful:

- Radar ignores small flying objects such as small drones and birds.
- Radio frequency analyzers have a relatively short range, lower effectiveness in areas with multiple radio signal sources, and cannot detect autonomous drones that do not maintain contact with a controller.
- Optical and infrared (IR) cameras do not work well in fog and darkness and, when operating alone, can mistakenly identify birds as drones.
- Acoustic detectors (systems of microphones) have a short range, up to 500 m due to noise and environmental interference, and may be useless if the aircraft shuts down its engines in the final phase when dropping payload or performing a kamikaze mission.

An audio detector system on an active drone records the sound of the motor and propellers of the drone it tracks and compares it with an acoustic profile from the database. Through triangulation, it accurately locates the object and distinguishes between: aircraft sizes, drones from birds, and fixed-wing aircraft from multirotor ones. It does not depend on radio signals, so it can detect: autonomous drones, those in areas with multiple signals, those changing radio frequencies, and so on. It also detects small drones (small for radar) and those that do not emit heat (without infrared, made of composite materials).

2. Methodology

Small commercial drones are often modified for reconnaissance and target location, and it is desirable for them to be quiet and barely noticeable (with high-resolution cameras in three axes to transmit live footage and thermal cameras for nighttime conditions). They usually fly above 50 meters to remain visually inconspicuous when combined with the terrain.

Laboratory-controlled measurements (in an anechoic chamber) ensure repeatability of results, unaffected by the environment, which is why the drone's acoustic model is recorded under these conditions depending on motor power and propeller rotation speed. Wind tunnel testing allows for a more realistic (and expensive) two-dimensional assessment of noise emissions.

Field-based, realistic measurements include environmental influences (ambient noise, ground absorption, reflection from obstacles, wind, humidity, temperature, etc.). Under these conditions, the drone’s acoustic model is treated as a point source of sound, where noise emission must be synchronized with the geometry and coordinates of the position.

The drone’s acoustic model has four operational states: hovering, horizontal forward/ backward flight, climbing, and descending.

In horizontal flight (moving forward/backward with different rotor speeds), noise emission is similar to that of hovering (with a difference of 0 ÷ 3 dB), as long as the number of revolutions remains constant.

In the vertical direction, as altitude is gained and the air becomes thinner, the noise becomes more pronounced. During descent, due to airflow and maneuvers with changing rotor speeds, the sound pressure and noise level increase. Descent is slower with more time spent at lower altitudes, thus amplifying the environmental impact of the noise.

According to the test plan for the demonstration of three types of smaller reconnaissance unmanned aerial vehicles (UAVs) at the test site, in a free sound field, in the vertical plane, individual noise measurements of drones, and quadcopters, were conducted while hovering at different altitudes.

The microphone measurement point was located at a height of 1.2 meters from the ground and in the vertical plane beneath the drone (while hovering) at altitudes of 50 m, 100 m, 200 m, or 300 m.

The measurement (at a sampling rate of 51.2 kHz) was performed with a G.R.A.S Pressure Microphone 40AD and a noise and vibration measurement amplifier system NetDB.

3. Results

The measurement results are presented in Tab. 1 and in the time signal graphs (equivalent level L_{eq} expressed in dB(A)fast) and their 1/3 octave spectra.

The fundamental harmonic at 125 Hz is from electric motors, while the next ones are from rotating propellers.

Table 1 Results of noise measurement in the vertical plane, under the drone, quadcopter

Hover height drone (m)	Drone noise level, L_{eq}, (dB(A)fast)			Ambient noise, L_{eq} (dB(A))
	MATRICE 300 (higher, 9 kg)	MATRICE 30 T (medium, 4 kg)	MAVIC 3E (small, 1 kg)	
50	56.3	57.4	49.7	42.8
100	53.1	50.8	53.2	
200	54.6	49.3	55.5	
300	48.3	50.2	54.0	

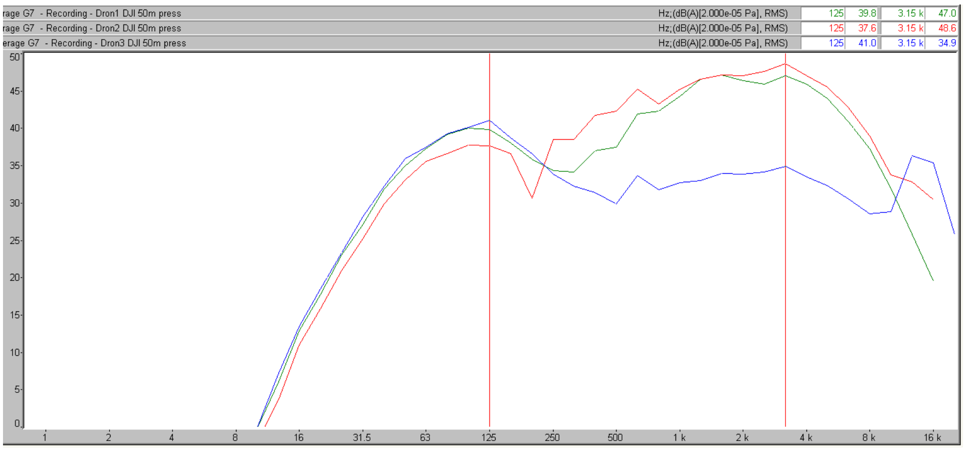

Fig. 1 The 1/3 noise spectrum of a large, medium and small drone in the vertical plane, at a height of 50 m

Figure 1 shows noise spectrum from the engine of large (Matrice 300), medium (Matrice 30T) and small (Mavic 3E) drones measured at a height of 50 m at a frequency of 125 Hz. The propeller frequency is around 3.15 KHz. The data are given in different colors for Figs. 1 and 2:

- Green color – large drone data (Matrice 300).
- Red color – medium drone data (Matrice 30T).
- Blue color – small drone data (Mavic 3E).

The smallest noise level is from a small drone, which is also visible in the data given in Tab. 1. The data in Tab. 1 also shows that small drone noise is higher at higher heights, because of the need to compensate for thin air and increase in height. That is why it is prescribed for small drones to fly at heights lower than 100 m.

Figure 2 shows, similar to Fig. 1, the noise spectrum from engines of large (Matrice 300), medium (Matrice 30T) and small (Mavic 3) drones measured at a height of 100 m at a frequency of 125 Hz. The propeller frequency is around 125 KHz. The similar conclusions we can make here like given in Fig. 1, for a height of 50 m.

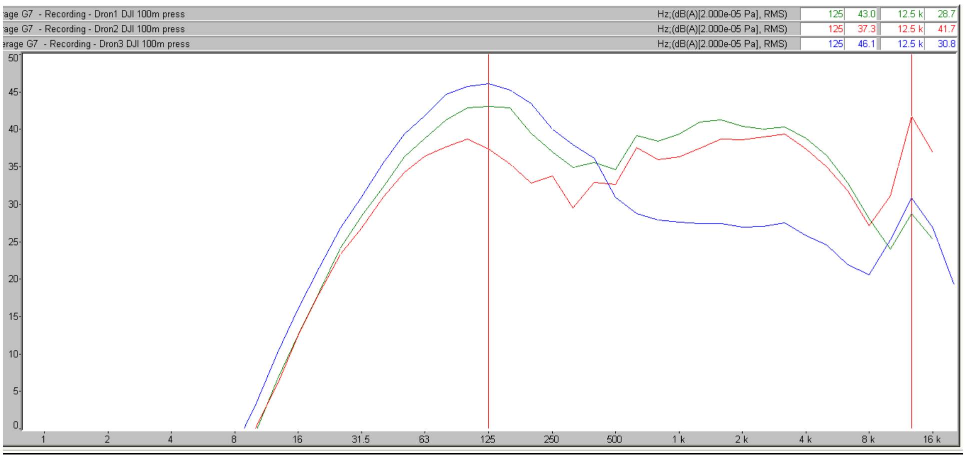

Fig. 2 The noise spectrum of a large, medium and small drone in the vertical plane, at a height of 100 m

Figure 3 gives the data for a small drone at heights of 50 m (green color), 100 m (red color), 200 m (blue color) and 300 m (purple color), where it can be seen that the small drone noise amplitude is getting lower with increase of height.

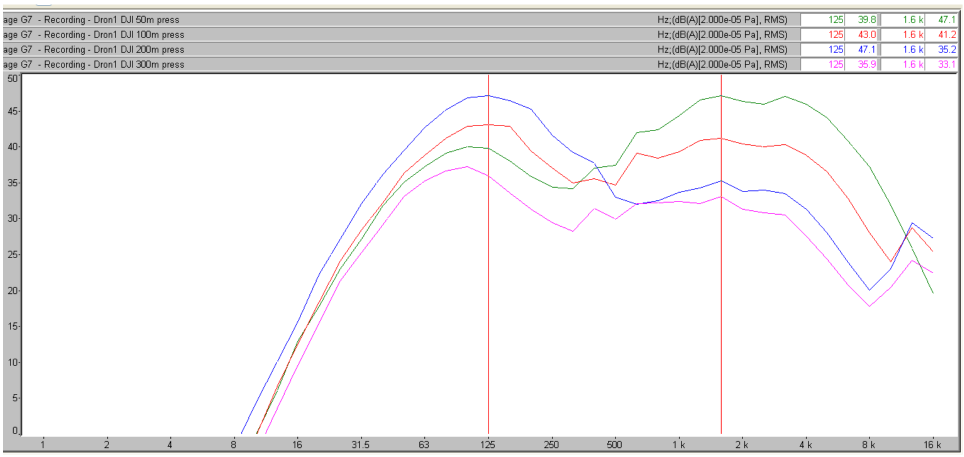

Fig. 3 The noise spectrum of a small drone in the vertical plane, at heights of 50 m, 100 m, 200 m and 300 m

Figure 4 gives the data for a medium drone at heights of 50 m (green color), 100 m (red color), 200 m (blue color) and 300 m (purple color), where it can be seen that a medium drone noise amplitude is getting lower with increase of height.

Figure 5 gives the data for a large drone at heights of 50 m (green color), 100 m (red color), 200 m (blue color) and 300 m (purple color), where it can be seen that the noise from engine of a drone is higher than the noise from propellers, because it is much easier for him to stay in the air.

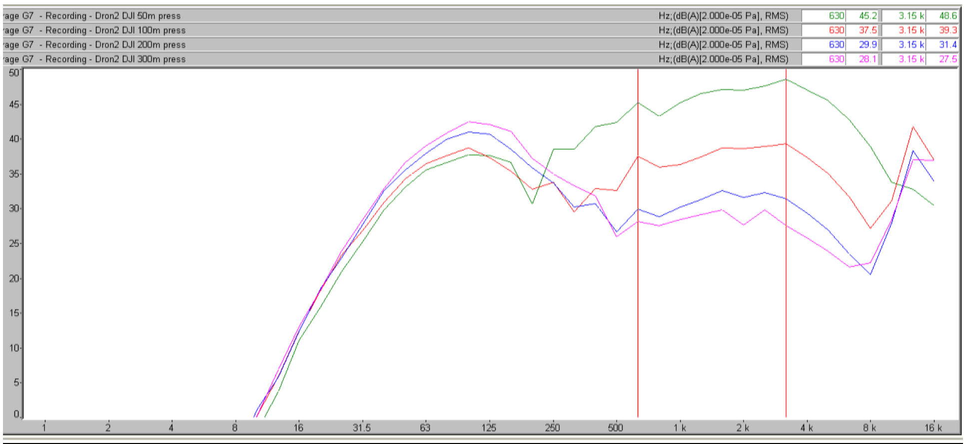

Fig. 4 The noise spectrum of a medium drone in the vertical plane, at heights of 50 m, 100 m, 200 m and 300 m

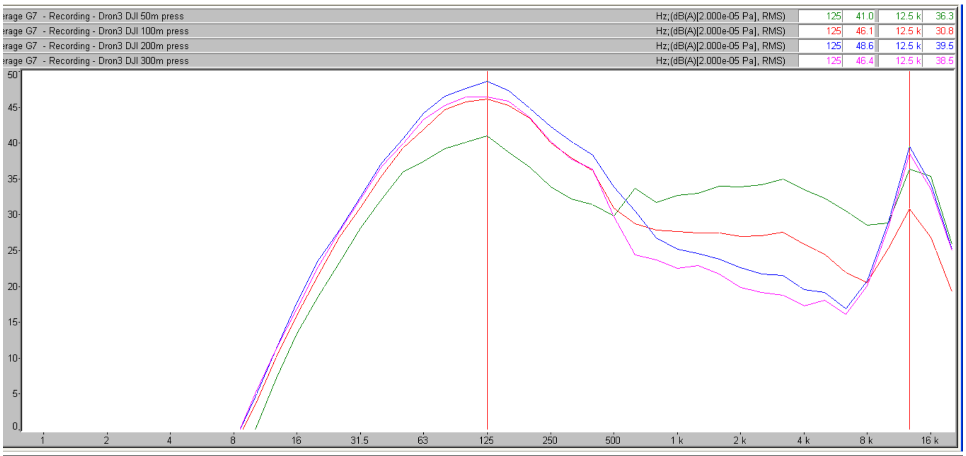

Fig. 5 The noise spectrum of a larger drone in the vertical plane, at heights of 50 m, 100 m, 200 m and 300 m

4. CONCLUSIONS

The application of drones in all areas of life is for the benefit of humans (for an easier, (un)healthier life), but it is accompanied by noise emissions as a new, additional environmental pollutant.

Depending on the hardware design, payload, and operational function, drones emit irritating noise that is more unpleasant in terms of their character and spectral content than their level. Measuring noise levels quantifies the sound, while psychoacoustics analyzes the tonality and other characteristics to which people strongly react (loudness, sharpness, roughness, fluctuation, etc.). Theoretically, noise decreases with altitude, but the allowable flying height is legally limited depending on the drone's designated category.

The results of measurements on reconnaissance drones show that the smallest drone with a pair of ”quiet” propellers (made of carbon fibers, which have high aerodynamic efficiency, lower noise, and reduced energy consumption) above (50 / 100) meters is no longer quiet, as it struggles in the increasingly thin air by increasing the propeller speed. At the same time, in order to be a reconnaissance drone and remain visually inconspicuous, it is desirable for it to fly above 50 m.

A drone's flight is always accompanied by sound, and thus each drone has its own audio profile, which serves as a reliable parameter for detecting them.

To determine the sound profile of an aerial vehicle, both laboratory and field testing should be applied.

Acoustic detectors, made up of a series of microphones, record the sound of the drone they are tracking and compare it with the audio profile stored in the server database.

Detecting small reconnaissance drones is complex because they do not emit heat (no infrared signature, due to the plastic body and electric motors), and intentionally change radio frequencies, which is why acoustic detection is significant. For nighttime conditions, combined audio-IR visual detection is preferable.

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