Study on Noise Sources of Multi-rotor Aircraft

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Abstract: *A review of the basic and major sources of noise emanating from a multirotor aircraft is presented in this paper. The noise generated by multirotor aircraft, also known as drones, is a growing concern as their use becomes more widespread. The main sources of noise from a multirotor aircraft are the rotors, the propulsion system, and the airframe. The rotors are the primary source of noise from a multirotor aircraft. The noise is generated by the interaction of the blades with the surrounding air, resulting in a tone that is directly proportional to the rotational speed of the blades. The propulsion system, consisting of the motor and the propeller, is another significant source of noise. The airframe, which includes the body and the landing gear, can also contribute to the overall noise level. Various factors affect the noise level emitted by a multirotor aircraft, including the design and configuration of the rotors and propulsion system, the operating conditions, and the type of flight maneuvers performed. For example, hovering and high-speed flight can generate higher levels of noise compared to cruising flight. Several approaches have been proposed to reduce the noise generated by multirotor aircraft. These include optimizing the design and configuration of the rotors and propulsion system, using noise-absorbing materials, and implementing active noise control techniques.*

Keywords - Noise, Multirotor, UAV, Motor, Vibration, Propellers, Drones, sUAS, UAS, multicopter, noise emission, noise effects, annoyance, perception, motor noise, micro motor, sound visualization, noise source identification, Noise reduction.

1. INTRODUCTION

Multi-rotors or aircraft that generate lift using more than one propeller commonly known as drones are becoming more and more common. Drones are now being introduced into each sector of life. Drones are now widely used in many commercial applications such as photography, inspection, mapping etc. Light weight drones generally contain at most 4 motors and 4 propellers, whereas larger drones generally contain 6 or more motors and propellers. Such aircraft make a loud wining or a high-pitched noise during operation or heavy lifting, this noise creates annoyance and may cause irritation during prolonged hearing. Operation of such aircraft during night can also cause disturbance to sleep of population [1]. Because drone noise has special acoustic characteristics, particularly pure tones and high frequency broadband noise, it is significantly more irritating than road traffic or aircraft noise.

As a general rule, the higher the number of motors and propellers the noise generated will be higher. This study focuses on finding out the major sources that contribute to the generation of noise in a multirotor aircraft. Locating the sources of noise can help us find measures to reduce the noise generated by the aircraft. Reduction in noise is particularly important as aircraft operating near residential areas such as delivery drones might cause a large amount of disturbance by generating noise.

Taking steps to limit the noise impact of multirotor at an early stage is essential, especially since public opinion on drones appears to still be in the formative stages. Accordingly, drone acceptance may evolve in either an advantageous or disadvantageous way, depending on whether benefits or (noise) risks are perceived relative to one another.

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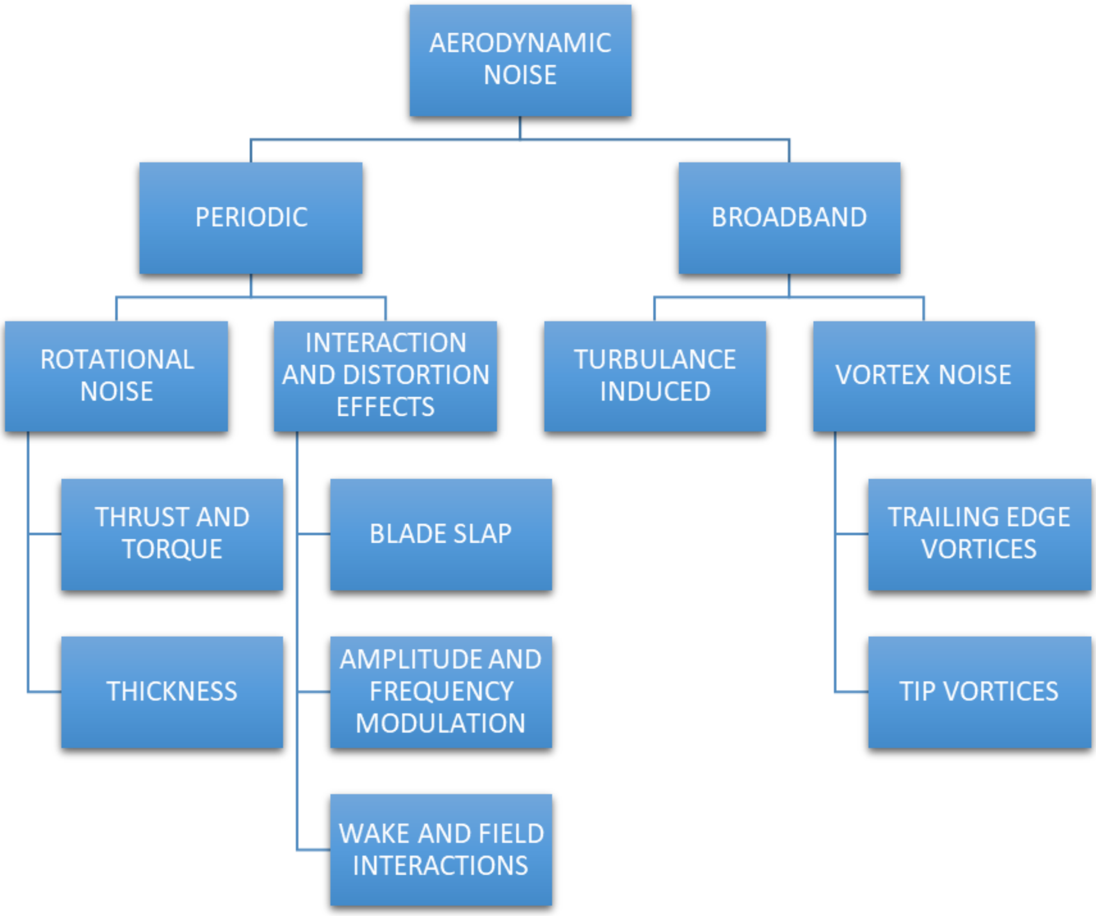

Fig. 1 Sources of propeller aerodynamic noise

2. LITERATURE

Arthur F. Deming [2] explains the noise produced by a propeller can be divided into two categories: "rotation noise" and "vortex noise." Rotation noise is the most intense and is caused by the pressure wave enveloping the blades and moving with them. Vortex noise, on the other hand, is caused by pressure variations on the blades as a result of changes in circulation. Rotation noise can be further divided into the noise due to torque and thrust, and the noise due to blade thickness. The effect of blade thickness on rotation noise is small, except for higher harmonics at small angles of attack. Vortex noise is influenced by factors such as the angle of attack, velocity, air turbulence, blade chord, and blade shape. The researcher ultimately defines the relation of noise with increasing the tip speed of the propeller.

$$\frac{p_2}{p_1} = \frac{(\gamma+1)}{4}\frac{w^2ax}{c^2}$$

$$= (\gamma+1)\pi^2\frac{a}{\lambda}\frac{x}{\lambda},$$

where $w = 2\pi f$,

a, maximum amplitude at the source, $\xi = a\cos wt$,
x, distance along tube from generator,
λ, wave-length,
γ, ratio of specific heats of air,
c, velocity of sound;

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Vijayanandh R, Ramesh M, Raj Kumar G, Thianesh U K, Venkatesan K, Senthil Kumar M [3], The researchers in this study aimed to design low-noise and efficient propellers for multi-rotor UAVs. They considered important parameters such as blade thickness, tip loss, and blade loading, as well as the effects of the activity factor and advance ratio on propeller performance. After finalizing the design, they studied various noise reduction methods, such as the use of leading-edge combs, trailing-edge tufts, and upper surface porosity. Ultimately, they decided to focus on modifying the leading edges in order to minimize the noise produced by the propellers. These modifications are intended to improve the performance of the UAVs for military applications.

In another study Dubravko Miljković [4] has identified four main reasons for the generation of noise in drones as 1. Propulsion system such as engines and electric motors 2. Exhaust system (only applicable to engines) 3. Propellers 4. Airframe noise. Noise and vibration in an electric motor are caused by several factors. Structural deformation due to electromagnetic forces can produce noise, as can the movement of parts such as gears and bearings. Airflow through the motor can also contribute to noise production. Propeller noise is made up of both tonal and broadband components, with the greatest amount of noise being produced in the plane of the propeller as shown in Fig. 2 the different frequencies that contribute to the noise generation from a propeller. Airframe noise is generally not significant at low speeds and is overshadowed by other sources of noise, such as the propeller and engine.

Through this study it can be understood that there are several ways to reduce the noise produced by piston engines and propellers. One approach is to use absorptive (dissipative) or reactive silencers (mufflers) to dampen the sound. The shape of the blades and airfoil section can also have a small effect on the noise level, with bent-tip (Q-tip) propellers being particularly effective at reducing tip noise. Increasing the number of blades on a propeller can also lower the noise level, although it may decrease efficiency and require more effort to balance. Sound reflectors can be used to redirect noise upwards, and sound-absorbing materials can be applied to the surfaces of the duct to reduce noise. Other methods for reducing propeller noise include the use of synchrophasers, active noise control, and small magnets on the blades that vibrate in the electromagnetic field produced by the propeller frame.

In a study by Zawodny et al. [5], it was found that the noise produced by the motor was a significant contributor to the tonal noise of a UAV in the 300 Hz band around 1 kHz. This suggests that the motor is a significant source of noise in UAVs and should be considered when designing ways to reduce the overall noise level of the vehicle. Small rotor and propeller-powered vehicles, such as small unmanned aerial vehicles, produce noise that needs to be further studied. While a CFD-based method was able to capture some of the more complex noise generation mechanisms that a simpler blade-element prediction method could not, the computational complexity of the CFD method makes it difficult to use in the early stages of design. Psychoacoustic testing also showed that existing loudness metrics do not accurately capture the increased annoyance caused by sUAS compared to ground vehicles. More work is needed to understand the acoustic characteristics that contribute to this annoyance and to develop a computable annoyance metric that takes those characteristics into account.

One potential approach to reducing motor noise in sUAVs is to use passive noise reduction methods, which involve the use of materials or structures that absorb or reflect sound to reduce its intensity. In a study on passive noise reduction methods for sUAV motors, Yujie Qian [6] proposed using a composite noise reduction construction that wraps around the motor with a 5 mm gap for heat dissipation. This construction would include materials that absorb sound, such as micro-perforated panels (MPPs), as well as materials that provide sound insulation, such as soundproof fiber and sound insulation felt. The combination of sound absorption and insulation would help to reduce the overall noise level of the motor.

The researchers noted that the noise reduction performance of the composite construction would depend mainly on its ability to absorb sound, as the materials used are too thin to provide significant sound insulation.

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However, by including both sound absorption and insulation materials in the construction, it would be possible to achieve a better overall noise reduction performance.

The use of lightweight and flexible materials in the composite construction would also be important, as sUAVs are typically designed to be as lightweight and agile as possible. Soundproof fiber and sound insulation felt are suitable choices for this purpose, as they are both lightweight and flexible, while also providing good sound absorption and insulation properties. In conclusion, the use of a composite noise reduction construction that combines sound absorption and insulation materials could be an effective approach to reducing motor noise in sUAVs. By carefully selecting materials that are lightweight and flexible, while also providing good noise reduction performance, it would be possible to design sUAVs that are both efficient and quiet. In a study by Matthew B. Galles[7], The aim of the researchers in this study was to develop a method for reducing the noise impact of unmanned aerial systems (UAS) operating near residential communities. To do this, they incorporated a new acoustic metric for flight control of an unmanned aerial vehicle (UAV). This involved creating a source noise model based on Gutin's work, and using an acoustic controller to reduce propeller noise by modifying the flight speed.

To incorporate a new acoustic metric for flight control, the researchers needed to develop both a source noise model and an acoustic controller. The noise model was based on Gutin's work, which estimates propeller noise based on the speed and geometry of the propellers. The acoustic controller then used this information to control the flight speed of the UAV in order to reduce propeller noise. The control approach used in this study focused on modifying the flight speed only, without perturbing the trajectory of the UAV. This allowed the UAV to maintain its desired flight path while reducing propeller noise. Multiple flight simulations were performed to test the effectiveness of this approach, and the results showed that it was possible to integrate a new acoustic metric for flight control of a UAS in this way.

Overall, this study demonstrates the potential for using an acoustic metric to reduce the noise impact of UAS in residential areas. By incorporating this metric into the flight control system, the researchers were able to control the flight speed of the UAV in order to reduce propeller noise. This approach could be useful for developing more effective methods for mitigating the negative effects of UAS noise on communities near areas where these systems are used. Beat Schäffer's [1] study on drone noise emission characteristics highlights the factors that influence the emission strength of drones. The study found that the emission strength depends on the drone model, payload, and operating state or flight maneuver. Drones also exhibit a pronounced vertical angular emission directivity, with a uniform radiation expected in the horizontal plane due to symmetry. Figure 3 shows the fundamental frequencies and their impact intensities as a function of power spectral density on a wide band of frequencies of a DJI MAVIC 2 pro drone. The study also suggests that there may be a correlation between operating condition and rotor speeds. This could potentially be used to develop a rotational speed-dependent emission model that could estimate the emission for a given operating condition. However, this approach is hindered by the fact that in horizontal flight, different rotational speeds of the front and rear rotors are required for forward motion. Additionally, the interaction between the rotors also plays a role in sound generation, making it difficult to estimate emissions from a speed emission model that is typically obtained for hovering. As figure 4 demonstrates, the sound signature of a multirotor is generally higher than an aircraft or a car in normalized environment. Overall, the study provides important insights into the acoustic characteristics of drones and how they can be used as sources of noise. Understanding these characteristics is important for developing effective methods for mitigating the negative effects of drone noise on residential communities. Further research is needed to develop more accurate models and control approaches that can be used to reduce the noise impact of drones.

A multirotor’s acoustic emission is composed of low and mid frequency tonal and harmonic components that are correlated with the rotor speed, as well as broadband noise at high frequencies with a weak decrease in power density.

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NIET Journal of Engineering & Technology (NIETJET)
Volume 13, Issue Winter / Summer 2025 ISSN: 2229-5828 (Print)

3. GAPS

As mentioned by Dubravko Miljković [4] the main sources of noise emission on drone are motor, propellers, exhaust systems and airframe. Several studies have been found to confirm these findings and have provided multiple solutions to mitigate this issue. The main focus of researchers over the years have been to reduce the noise generated propellers as it is considered the most significant source of noise emissions. Very slight work has been performed in the field reducing noise generated due to rotation of motors. Since, recent small unmanned aircrafts are mostly electrically driven thus exhaust noise in least of the issue but measures are available to reduce noise from exhaust using mufflers.

It must be noted that the study on reducing the noise while optimizing the airframe is very scarce and most of the study regarding the airframe is based on the structural soundness. There has been finding where the difference in propeller tips have been found the prime reason for noise emission. Since, todays small unmanned aircraft use gyroscope data mounted on the drone itself as feedback to constantly make slight adjustments to keep the drone level and to maneuver accurately these slight changes need to be attained by adjusting the rotor speed, these changes in speed change the tip speed of propellers contributing to the prime source of generation of noise in drones. Larger drone avoids this small adjustment by mounting dampers with the gyroscopic sensor but that is not a suitable solution for small light weight drones due to the size constraints and weight constraints. Thus, a study method is needed to be devised to study the noise sources of a small light weight drones in hover and forward flight conditions.

4. FIGURES AND TABLES

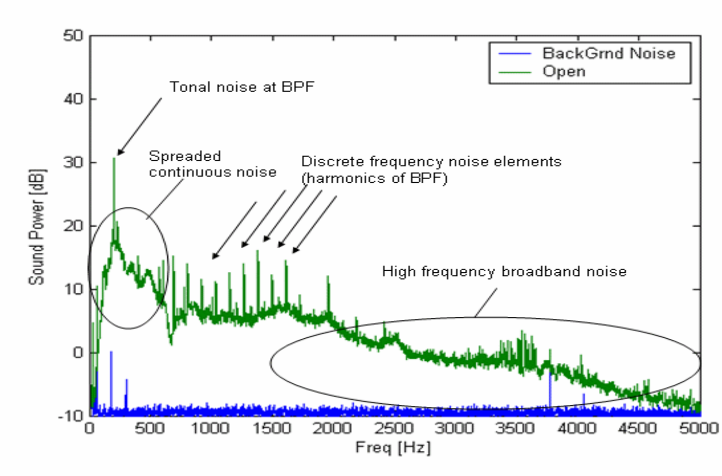

Fig. 2 Noise spectrum of a propeller [9]

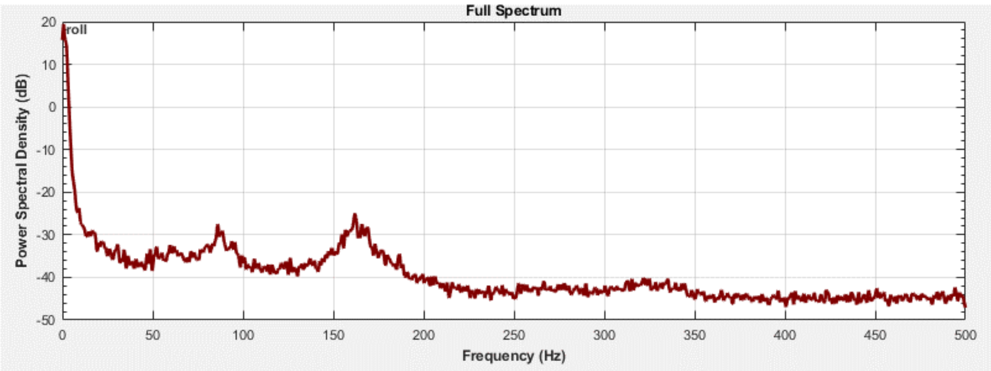

Fig. 3 Narrowband spectrum of a hovering multirotor measured in the laboratory

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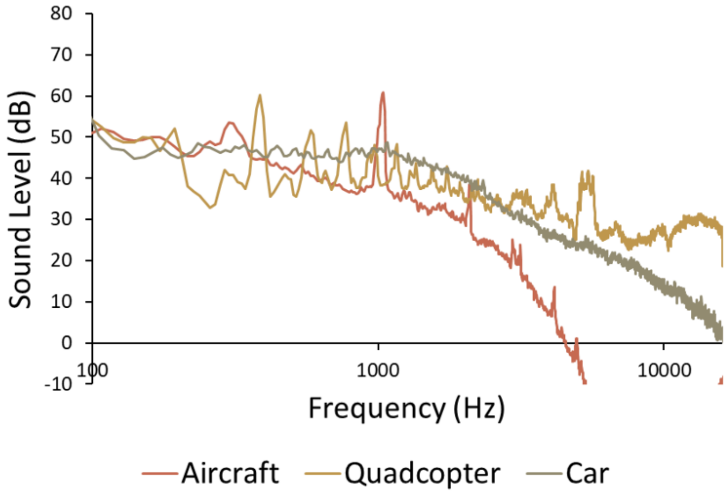

Fig. 4 Typical frequency spectrum of an aircraft and a small quadcopter flyover, and a car pass-by, normalized to a LAeq of 65 dB(A).

5. CONCLUSION

In conclusion, the noise generated by drones is a significant issue that needs to be addressed. Researchers have identified the motor, propellers, exhaust system, and airframe as the main sources of noise emissions from drones. Various methods have been proposed for reducing propeller noise, including the use of mufflers, bent-tip propellers, and sound-absorbing materials. The motor is also a significant source of noise, particularly in the 300 Hz band around 1 kHz. To reduce the overall noise impact of drones, researchers have proposed incorporating a new acoustic metric for flight control. This involves developing a source noise model and an acoustic controller to reduce propeller noise by modifying the flight speed. Multiple flight simulations have shown that this approach is effective, and it could potentially be used to mitigate the negative effects of drone noise on residential communities. However, further research is needed to develop more accurate and effective methods for reducing the noise impact of drones. This could involve studying the effects of different propeller designs, blade thickness, and airfoil sections on noise emissions, as well as the use of synchrophasers, active noise control, airframe optimization and other techniques. Psychoacoustic testing can also be used to evaluate the perceived loudness of drone noise and help develop more effective noise reduction strategies.

REFERENCES

[1]. B. Schäffer, R. Pieren, K. Heutschi, J. M. Wunderli, and S. Becker, Drone noise emission characteristics and noise effects on humans-A systematic review, *International Journal of Environmental Research and Public Health*, 18(11), 2021, 5940.

[2]. A. F. Deming, Propeller rotation noise due to torque and thrust, *The Journal of the Acoustical Society of America*, 12(1), 1940, 173–182.

[3]. R. Vijayanandh, M. Ramesh, G. Raj Kumar, U. K. Thianesh, K. Venkatesan, M. Senthil Kumar, Research of noise in the unmanned aerial vehicle’s propeller using CFD, *International Journal of Engineering and Advanced Technology*, 8(6S), 2019, 145–150.

[4]. D. Miljkovic, Methods for attenuation of unmanned aerial vehicle noise, *41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 2018.

[5]. S Nikolas Zawodny, Randolph Cabell, A summary of NASA research exploring the acoustics of small unmanned aerial systems, *AHS specialists’ conference on aeromechanics design for transformative vertical flight*, 2018.

[6]. Y. Qian, Y. Wei, D. Kong, and H. Xu, Experimental investigation on motor noise reduction of Unmanned Aerial Vehicles, *Applied Acoustics*, 176(107873), 2021, 107873.

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19, Knowledge Park-II, Institutional Area, Greater Noida (UP), India.

[7]. M. B. Galles, N. H. Schiller, K. A. Ackerman and B. A. Newman, Feedback control of flight speed to reduce unmanned aerial system noise, *AIAA/CEAS Aeroacoustics Conference*, 2018.
[8]. Engineering Acoustics/Noise from cooling fans, Wikibooksm https://en.wikibooks.org/wiki/Engineering_Acoustics/Noise_from_cooling_fans#Rotor-Casing_interaction [1 March 2018]

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