Effects of the Acoustic Field Generated by a Single-Axial Rotor

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The purpose of this study was to understand the sources of noise generated by small-scale rotors, specifically to reduce this noise in unmanned aerial vehicles (UAVs) or drones. Drones are utilized to serve a variety of different purposes. However, the noise generated by their rotor blades creates limitations for their adaptation to both private and public utilization settings [1]. Therefore, a study was conducted on the sources of this noise and how to reduce it.

The sources of sound produced from a single-axial rotor can be allocated into three categories, monopole, dipole, and quadrupole. Monopole noise, or thickness and high-speed impulsive noise, is radiated in all directions. Dipole noise is characterized as loading noise, which is caused by the changes in blade loading due to a change in rotor thrust. There is also quadrupole loading or blade-vortex interaction noise due to the aerodynamic interactions occurring between the blades in the aerodynamic field [3].

In this study, two microphones were used to measure the acoustic field on a small 15-centimeter diameter rotor. For initial testing, the rotor was clamped to the table with one microphone placed level and the second microphone placed slightly below the rotor. Further testing will include placing the rotor on a stand to attain a more accurate reading. The microphones are connected to data acquisition for both a numerical and visual representation of the acoustic field generated by the rotor. The rotor was operable at different speeds, and the blades on the rotor were interchangeable for experimentation.

Experiments were conducted under unique conditions to attain the most accurate representation of the generated acoustic field. First, the rotor was operated at three different rotor speeds, 1980, 2970, and 3990 RPM. The varying rotor speeds represent a better understanding of the acoustic field changes. Second, the distance between the rotor center and the microphone was varied, with an experiment conducted at 1, 2, and 5 rotor diameter distances. This was done to study the drone acoustic noise propagation. The data was sampled at a frequency of 25,000 Hz.

To analyze the results, the data collected was interpreted through a series of MATLAB codes. This allowed for the calculation of the overall sound pressure level (OASPL) at each unique testing condition. The equation for this calculation is in Eq. (1).

$$OASPL = 10 \times \log\left(\int_{20}^{20000} \frac{PSD(f)df}{P_{ref}^2}\right) \quad (1)$$

It was observed that the OASPL increased in all incidences where the rotor RPM was increased. This result was expected due to the increase of dipole noise produced by a greater thrust. Also, it was observed that the OASPL decreased as measurements were taken at further distances from the rotor center. This observation was also expected due to the dissipation of monopole noise into the surrounding environment. These results can be seen below in Fig. 1.

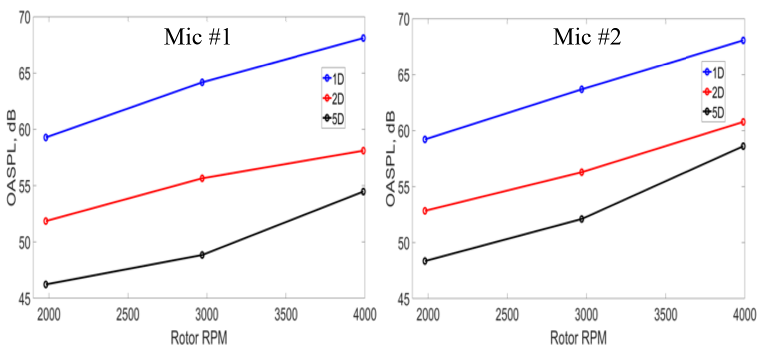

Fig. 1. OASPL measurements for microphones 1 & 2.

A frequency spectrum was required for analyzing the sound pressure level at different frequencies. A fast fourier transform was used to transform the data from the time domain to the frequency domain. This conversion is done

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using Eq. (2). The sound pressure level (SPL) is analyzed across the audible frequency range.

$$SPL = 20 \times \log\left(\frac{P_{rms}}{P_{ref}}\right);\ P_{ref} = 2 \times 10^{-5} \qquad (2)$$

It was observed that lower frequency sound levels were higher when measured closer to the rotor and lowered as measurements were taken further away. The monopole and dipole sound sources can be accounted for this phenomenon. It was also observed, however, that high-frequency sound levels showed similar characteristics across all distances from the rotor center. These higher frequency sounds are of concern due to the irritation and damage they can cause to human ears. This is due to the quadrupole sound source. These results can be seen in Fig. 2.

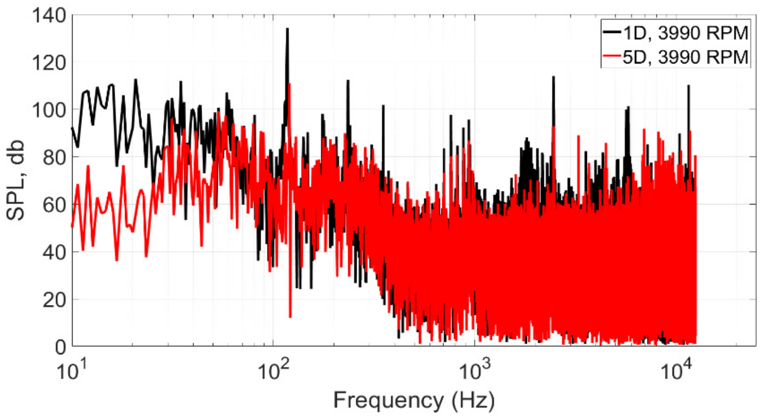

Fig. 2. SPL measurements in frequency domain at 1 & 5 diameter distances.

Previous studies have shown to reduce this noise, and modifications can be made to the blade design. A common way to reduce this noise is to incorporate trailing edge serrations on each blade [2]. Although there is a consensus that this will reduce the noise generated, the fluid dynamics remain unknown. To explore this solution, experiments will be conducted using both smooth trailing edge and serrated trailing edge blades to measure their effects on the acoustic field generated by the rotor. The accuracy of this data will be improved upon by including data collected from eight microphones to attain a more complete reading of the acoustic field, and by utilizing strain gauge loadcells in the rotor stand to quantify whether the rotor is performing appropriately.

Statement of Research Advisor

With the increasing rate of adoption of drones in civilian and military applications, the noise produced by the rotors will be a significant shortcoming to their widespread adoption. This study is a starting point to identify the physical aeroacoustic sources of the noise produced by small-scale rotors. In the future, the plans are to optimize the wing planform to reduce the magnitude of noise produced.

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Authors Biography

Emily Wilson is a junior-year student pursuing a B.S. degree in Aerospace Engineering at Auburn University. She has worked in the Applied Fluids Research Group for two years with responsibilities for the development of experimental testing designs.

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