Preliminary aero-acoustic measurements of free rotating rotor with predefined imbalance

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Abstract. The Rotor noise is known to be highly annoying and intrusive. Therefore, rotor noise will be one of the major design parameters for next-generation quieter rotor-crafts or drones. This will only be possible with a better understanding of rotor aerodynamics and acoustics. The present study tries to use a simplistic rotor driven by an electric motor for the noise generation. A microphone is used to measure the acoustic signals and Fast Fourier Transform is used to find the dominant frequencies or the energy distribution. A differential manometer is used to measure the averaged velocity along the radial direction. The characterization of the flow field in terms of radial velocity variation and acoustic signal characterization provides preliminary information on the physics of aerodynamics and aero-acoustics of rotor systems. The results from the experiments suggest that the predefined imbalance imposed on the rotor increases the noise due to aerodynamics and also due to structural vibrations.

1. Introduction

The study of rotor aerodynamics and aero-acoustics is driven highly by the usage of rotors in wind turbines, helicopters and very recently in drones or Unmanned Aerial Vehicles (UAV). The aerodynamics of rotors are studied for its thrust characteristics and also for its noise characteristics when it is intended to work near or with human beings [1]. When the rotors rotate in open space, the characteristics of acoustics and thrust are different from rotors kept in an enclosure and the same was studied by Truong and Papamoschou [2].

The rotor cross section is usually an aerofoil which can produce lift forces by circulation. The aerofoils produce noise when they are subjected to flow at higher speeds or higher angle of attacks [3]. The noise produced by aerofoils can be reduced by introducing surface modifications especially in the leading edge [4] or trailing edge in the form of serrations or porous medium [5]. The broadband noise could be reduced by using the saw-tooth serrated trailing edge and it does not affect the aerodynamic performance at low Reynolds number [6]. These noises on aerofoils can be also due to boundary layer instabilities [7]. The rotors when used in group has its own new characteristics and there are experimental studies to address the same [8]. There are applications of rotors in wind turbines and the noise characteristics are studied with respect to audible range [9].

The airframe, in bottom mounted configuration, not only produces large periodic turbulent structures which can cause tonal noise, but also causes the smaller turbulent structures to continually impact the rotor which results in broadband noise [10]. The wide range of frequency noise in the skewed rotor is comparatively lower than the unskewed rotor [11]. The reduction in main rotor speed reduces the far field noise [12]. Comparison of sound pressure levels for experimental results and CFD
computations were done at the Kazan National Research Technical University named after A.N. Tupolev (Kazan Aviation Institute), related to helicopter acoustics [13]. A study of the sound produced by multirotor drones operating at static thrust was done by Charles E. Tinney and Jayant Sirohi at University of Texas [14].

All the above mentioned studies from the literature survey are primarily focussed on the flow field characteristics, thrust characteristics or aero-acoustic characteristics of rotors or interacting rotors. Hence, the present study tries to address the aerodynamic effects and aero-acoustic effects of a rotor with a pre-defined imbalance.

2. Experimental Methodology

An experimental methodology for the present preliminary investigation is explained in this section. The rotor setup, blade design and its parameters, the data acquisition, and the data processing are described in detail.

2.1. Rotor setup

The rotor setup (figure 1) used in the present study is a cost effective setup designed by the corresponding author and fabricated by the primary author towards major project work. The setup can be used in the Anechoic Chamber, Aerospace Hangar, Department of Aerospace Engineering at SRM Institute of Science and Technology. The setup consists of a wooden frame with a base to support the motor and the rotor. The wooden frame is kept inside a mesh cage that can sufficiently allow airflow and noise to move out with less disturbance. This cage will prevent the experimentalist from the rotor flying off the motor due to imbalance. The whole setup is sized less than a cubic meter such that it can be kept inside an anechoic chamber for noise experiments. The motor chosen for the study is an electric DC motor and it is powered by a step-down transformer in the form of a DC adapter. The rotors or propellers are connected to the spindle of the motor by mechanically pushing it as it is plug and play type. The fans, air conditioners, and other noise-generating sources are kept in off condition for the entire duration of the experiments. The maximum rotating speed of the motor is restricted to 1000 rpm for this study.

![Figure 1. a) Full rotor setup.](image1)

![Figure 1. b) Rotor fixed to motor](image2)
2.2. Rotor design, definitions, and parameters

The rotor used in the present study is a two-bladed propeller type with a flat blade surface (figure 2). The rotor naming convention follows B2CXY (B-Blade, 2 for 2 blades, CX for length discarded in cm and Y for position of microphone, where E-top side of rotor plane, F-front side of rotor plane).

![Figure 2. Various rotors used in the present study with predefined discarded lengths.](image)

2.3. Data acquisition system

The data acquisition consists of a differential manometer to measure the flow velocity and a microphone from Samsung A50 for acoustic data acquisition. The microphone is kept at the top of the grid to avoid damage from rotor (Refer to figure 1 a). The measured data is logged as a comma-separated variable file for plotting purposes.

2.4. Data processing

The acoustic data is acquired via OpeNoise application for the Fast Fourier Transformation and the resulting spectrum is shown in figure 3. Figure 3 shows the noise from the ambiance and the full rotor.
3. Results and Discussion

In this section, the results/data obtained from the aerodynamic and aero-acoustic experiments (performed outside the anechoic chamber). The results after processing are discussed in detail via sub-sections like aerodynamics of rotors, aero-acoustic characteristics via spectrum and noise characteristics of rotor imbalance.

3.1. Aerodynamics of rotors

The measurements of axial velocity was carried out for plotting radial profiles. This is due to the faster decay of axial components in the flow axis which is not measurable by the present manometer. Figure 4 shows the variation of axial velocity on the radial locations away from the axis of the rotor. The cases considered are consisting of a full rotor and three rotors with discarded lengths of 1cm, 3cm and 5cm. It is to be noted that the cases chosen are to show the trend clearly. The increase in cut length results in reduced peak axial velocity in the radial direction. Also, the profile width shows that the effect of cut length results in profile becoming wider and the increase in magnitude is seen towards the axis of the rotor.
Figure 4. The axial velocity profile along the radial direction.

3.2. Aero-acoustics of rotor and its imbalance

The acoustic data in the form of pressure fluctuations are recorded by the device containing the microphone via OpeNoise application and the post-processed data is seen as a graph. The post-processing of acoustic data was done by employing Fast Fourier Transformation (FFT). The spectrum of acoustic data along with the amplitude is shown by the graph in figures 3 and 5. The rotor noise is measured in the plane on the top side and front side which shows the difference in amplitude in the low-frequency regime. There are also variations in the high-frequency regime which might be due to the non-flat response of microphone used in the present study. The dominant frequencies are found in certain cases with higher discarded lengths are due to the structural vibrations induced by the rotor imbalance. In case of measurements from top side of rotor plane the Sound Pressure level increases gradually from 37.5dB for 1cm discarded length to 45.3dB for 6cm discarded length. A gradual increment from 46dB for 1cm discarded length to 49.2dB for 6cm discarded length is observed.
3.3. Effect of rotor imbalance on noise characteristics

The noise developed by the rotor is due to its aerodynamics and the vibration due to the rotary motion. The Over All Sound Pressure Level (OASPL) in dB is plotted for various discarded propeller lengths as shown in figure 6. The plot shows that the amplitudes of sound pressure levels measured from the top side of the rotor plane is lesser than the amplitudes of the sound pressure level measured in front of the rotor. Also, the sound levels increase with an increase in the discarded length of the propeller. This increase in sound levels with increased imbalance is due to the rotor aerodynamics and the vibration caused by the imbalance. The increase in noise levels is higher for the in-plane measurements than the measurements made in front of the rotor plane. It should be noted that the rotor stand is not fixed to the ground for all the cases considered in this study. The isolation of vibration-induced acoustics will provide pure information of aerodynamically generated noise.

Figure 5. Spectrum of acoustic data for various cases.

![Figure 5](image-url)
4. Conclusions
The present study was about aerodynamics and rotor noise due to a rotating propeller. A microphone was used to measure the acoustic pressure data and Fast Fourier Transform is used to find the spectral characteristics revealing the dominant frequencies or the energy distribution. The increase in noise levels is higher for the measurements made in front side of the rotor than the measurements made in top side of the rotor plane. A differential manometer is used to measure the averaged velocity to provide the radial variation. The increase in cut length results in reduced peak axial velocity in the radial direction. The results from the experiments suggest that the predefined imbalance imposed on the rotor increases the noise due to aerodynamics and also due to structural vibrations. The usage of vibration dampeners will reduce the structural noise and pure aerodynamically generated acoustics can be studied.

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