inter·noise 2021
1–5 August | Washington, DC

'ATTACK OF THE DRONES' EXPLORATION OF THE SOUND POWER LEVELS EMITTED AND THE IMPACT DRONE'S COULD HAVE UPON RURAL AREAS

Josephine Nixon[1]
Stephen Dance[2]
School of the Built Environment and Architecture,
London South Bank University
103 Borough Road, London SE1 0AA

ABSTRACT

This study considers the acoustic emission from a DJi Phantom 4 commercial drone using different rotor blades. Measurements were taken from a hovering drone with four commercial product blade configurations. Measurements were taken in accordance with (BS) EN ISO 3745: 2009 *'Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for anechoic rooms and hemi-anechoic rooms'*. The aim of the project was to consider the sound characteristics emitted, specifically tonality and to determine the distance a drone could be heard from, with the different blade configurations, in a rural setting. By considering the different blade configurations within a rural setting, the role drones have within society is considered.

1. INTRODUCTION

The use of drones commercially and recreationally has become increasingly common. A number of studies have been carried out which explore the use of drones on social society, health and security (Cauchard:2015, Clarke *et al*.,:2014, Finn *et al.*,:2012). However, research is limited on the acoustics of drones (Intaretep:2016, Bown:2018). This study considers the sound characteristics produced from a DJi Phantom 4 drone, the propagation of sound from the drone and the impact this could have upon people within a rural UK village. The study aims to identify the noise impact produced from the drone.

2. THE DRONE AND BLADE DESIGN

A DJi Phantom 4 drone was utilised, as it is a popular make and model used for commercial and recreational activities. The drone weighs 1380g and has a diagonal dimension of 350mm and uses four rotator blades each with a 234mm diameter (DJi:2019), see Figure 1. The Phantom 4 drone is usually sold with quick release rotor (propeller) blades.

[1] JN1828@my. bristol.ac.uk

[2] Dances@lsbu.ac.uk

Figure 1 – DJ Phantom IV Drone

A number of manufacturers blades can be fitted to this drone, depending on design the blade varies in face width, shape of tip, and angle of leading and trailing edge, as do the product composite materials.

Noise emission levels of the drone in flight were measured within anechoic chamber of no blades, the quick release blades and carbon fibre blades, see figures 2 and 3 respectively. At all times, an element of sound included the drone's dual, Inertial Measurement Unit (IMU). The IMU system seeks to detect the current rate of acceleration using accelerometers. The IMU detects changes in rotational attributes like pitch, roll and yaw using one or more in-built gyroscopes; and a magnetometer, to assist calibration against orientation drift. Blade guards were also fitted for reasons of safety, see figure 1.

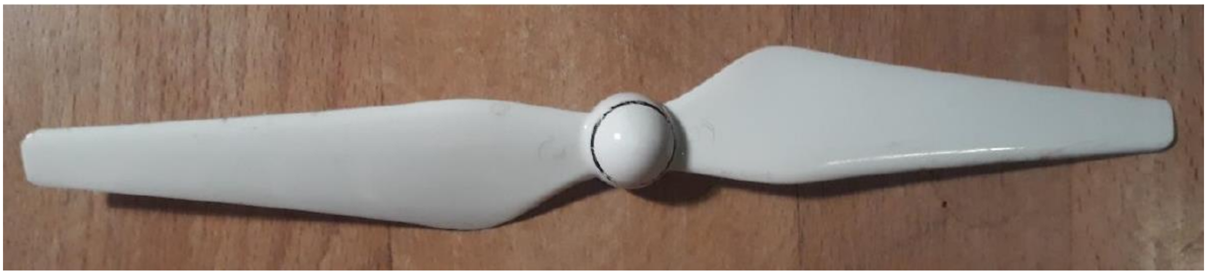

Figure 2 – Photograph of Original Quick-Release Blade

Figure 3 – Photograph of Carbon Fibre Blade

Aerodynamic noise is strongly dependent on airflow speed. It is therefore important to consider the blade passing frequency, which determines any fundamental tones and harmonics from a blade. The blade passing frequency (BPF) is the fundamental frequency, f_0, created by the number of times a blade passes a particular point, equation 1:

$$f_0 = N * RPM/60 \quad \text{(Equation 1)}$$

where N is the number of blades.

Research has investigated the frequency spectrum produced by drone blades Klei et al: 2014, Beall: 2014 and Muller et al: 2014. The noise emission is directly affected by the design of the blade and speed of rotation. The dominating factor is the velocity of the wing tip; the quicker the blade spins, the more turbulence the blade tip would cause. The relation is of the 6th order of the relative velocities, v, of the wing tips, see equation 2.

$$Sound\ Attenuation = -10 log\left(\frac{v^6}{v_0^6}\right)$$

(Equation 2)

3. METHODOLOGY

The free-field method to determine sound power, as prescribed in BS EN ISO 3745: 2012 (*Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precession methods for anechoic rooms and hemi-anechoic rooms*), was utilized to determine the sound power levels emitted by the drone. Some restraints exist when testing the drone, to fly the drone's IMU requires a Compass, GPS Signal or a Signaling Point, which are blocked within the anechoic chamber due to the mass of the laboratories wall construction and amount of steel in the chamber design. Therefore, the drone had to be tethered and partially supported for the measurements to be taken.

Three 1/3 octave band measurements of the drone hovering for 10 seconds were undertaken for each blade type. These values were then logarithmically averaged for each blade type investigated. Five class 1 sound level meters, NTi XL2's, were used to take the simultaneous measurements. Four were located at 1.25m distance at hover height (1.2m high). The remaining sound level meter (SLM) was positioned above the drone using an XLR microphone extension cable. The average sound power was then calculated using the free field method for each 1/3 octave band frequency. Finally, the A-weighted sound power level (Lw_A) was calculated by weighting the sound power spectrum. A Fast Fourier Transform (FFT) measurement was also taken for the carbon fibre blade using the sound level meter directly infront of the drone.

An environmental survey was undertaken between 19:00 – 20:00 hours on the 27th August 2017. The measurements were taken at Roxwell Recreational Park and Playing Fields, Essex, UK. Measurements were undertaken under free-field conditions. The SLM was placed on a tripod located more than 3.5m from any reflective surface and 1.5m above the ground. The noise survey and measurements were conducted, in accordance with BS7445-1:2003 '*Description and measurement of environmental noise. Guide to quantities and procedures'*. Measurements were made generally in accordance with ISO 1996-2:2007 '*Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels*'. Weather conditions throughout the entire noise survey period were noted to be warm (approx. 23° Celsius), dry, with clear skies (<10% cloud cover) and a light wind (<5m/s). These conditions were generally maintained throughout the entire survey period and were considered reasonable for undertaking environmental noise measurements.

4. RESULTS

4.1 Anechoic Chamber Results

Figure 4 illustrates the measured averaged sound pressure level for the different blade types. The amount of sound measured can be seen to change per configuration. The no-blade measurement is significantly quieter as would be expected but it interestingly dips between 63 Hz and 500 Hz, with the exception at 200 Hz.

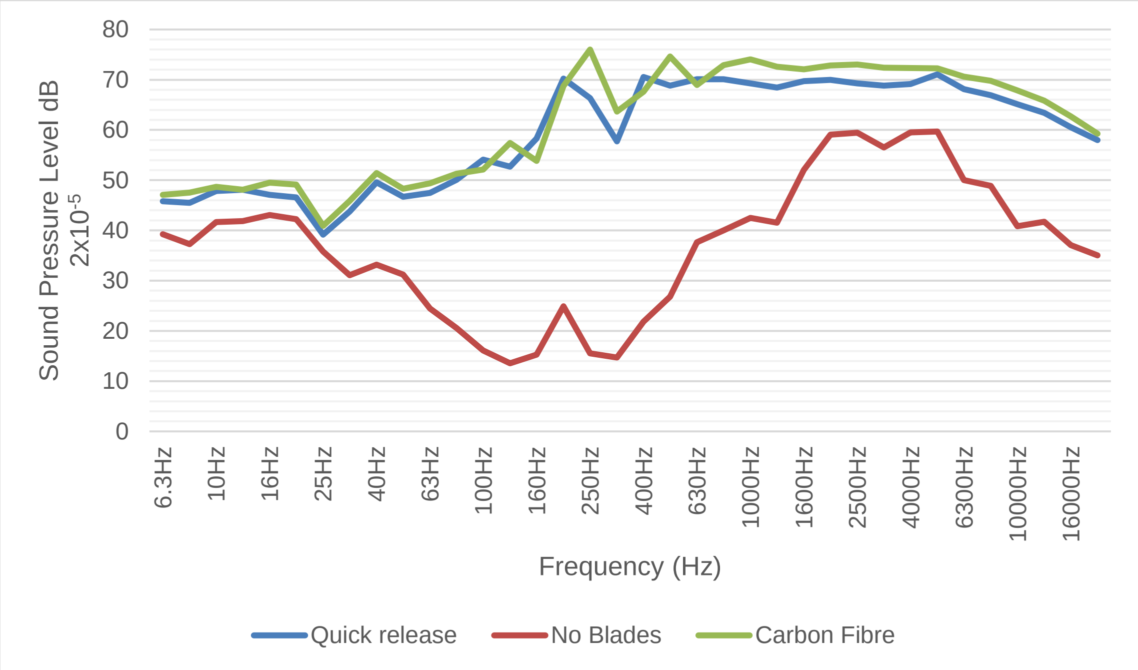

Figure 4 Sound Pressure spectral data of all blade types per 1/3 octave bands, free-field.

The sound power level was determined per blade configuration, see Table 1. The quick-release blade types were found to have the highest values and the carbon fibre blades were found to be the quietest blade type. The drone in operation with no blades was significantly quieter especially in the mid-frequencies, see figure 4. Table 1 provides the overall calculated sound power level (both Z and A-weighted). The A-weighting was calculated as it represents how loud the drone would be perceived by human hearing.

Table 1 Calculated L_W and L_{WA}

Blade Types	**Sound Power (LW)**	**Sound Power (LWA)**
Quick Release	102 dB	100 dB (A)
No Blades	93 dB	93 dB (A)
Carbon Fibre	98 dB	97 dB (A)

4.2 Environmental Survey Results

Table 2 records the results of the environmental baseline survey to determine the $L_{Aeq,1hour}$ and typical $L_{A90,\ 1\ hour}$.

Table 2 Results of the Environmental Survey

Time	$L_{Aeq,\ 1Hour}$	$L_{A90,\ 1Hour}$
27 August 2017 19:00-20:00	42 dB	35 dB

The time history of the environmental survey is shown in figure 5. As seen from the time history the site is relatively quiet and the general background remained relatively level throughout the survey.

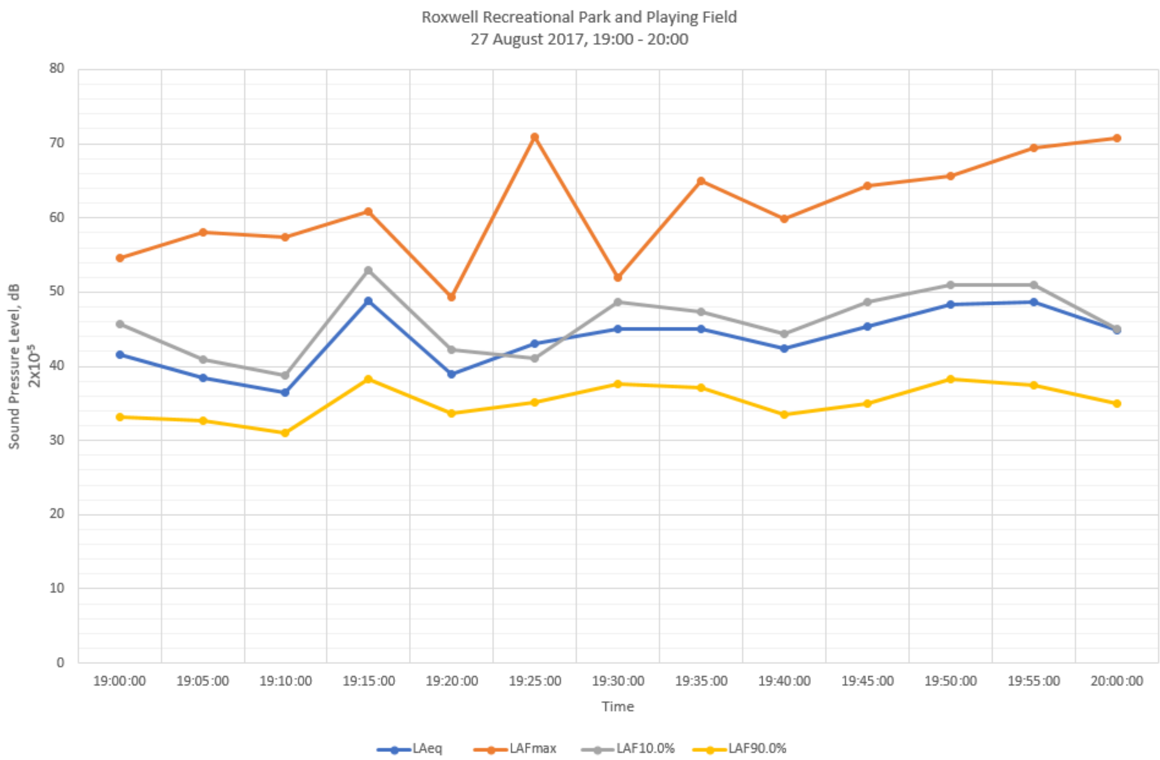

Figure 5 – Time History of the Environmental Survey

5. DISCUSSION

The results show that the rotational blades increase the emitted sound power level, see table 1, as the quietest measurement is with no blades. Research needs to be consider blade design to help reduce noise pollution, which is a point argued strongly by Leslie *et al.*, (2008, 2010) and Wong (2010) amongst others, as drones are becoming increasing common. An increase in energy in the higher frequencies can be identified in the spectral data for no blades (figure 4), increasing after 400 Hz and substantially after 1600 Hz therefore we can infer that for a DJi Phantom IV drone, that rotor self-noise is a dominant part of the system for high frequencies which supports Intaratep *et al.,*:2016, finding when testing DJi Phantom II drones.

A difference between the sound power levels of the different blade types is identified. This supports Intaratep's *et al.,:*2016 findings on the variations seen depending on different blade types. This study found when testing within the anechoic chamber that the carbon fibre blades measured the quietest. The main difference in the blades is the material and weight.

5.1 Tonality

Tonality can be identified within the mid-frequency 1/3 octave 200Hz bands for the no blade test and quick-release blades. This is defined in BS4142:2014 as a greater than 5 dB increase in any 1/3 octave band than adjacent 1/3 octave bands. Tonality was found in the 250Hz band for the carbon fibre blades. Harmonic tonality can also be seen within the 500Hz octave band. Therefore, although the carbon fibre blades are quieter, they are also more tonal. The increase in tonality, could mean people find the carbon-fibre blades more 'annoying'. The findings suggest that characteristics of tonality could alter depending on the drone and blade types.

A FFT was undertaken of the carbon fibre blades, as subjectively this was heard to be tonal. Figure 6 shows a scatter graph of the FFR and EQ levels of the carbon fibre blades, taken as a 10 second measurement within the London South Bank University Anechoic Chamber.

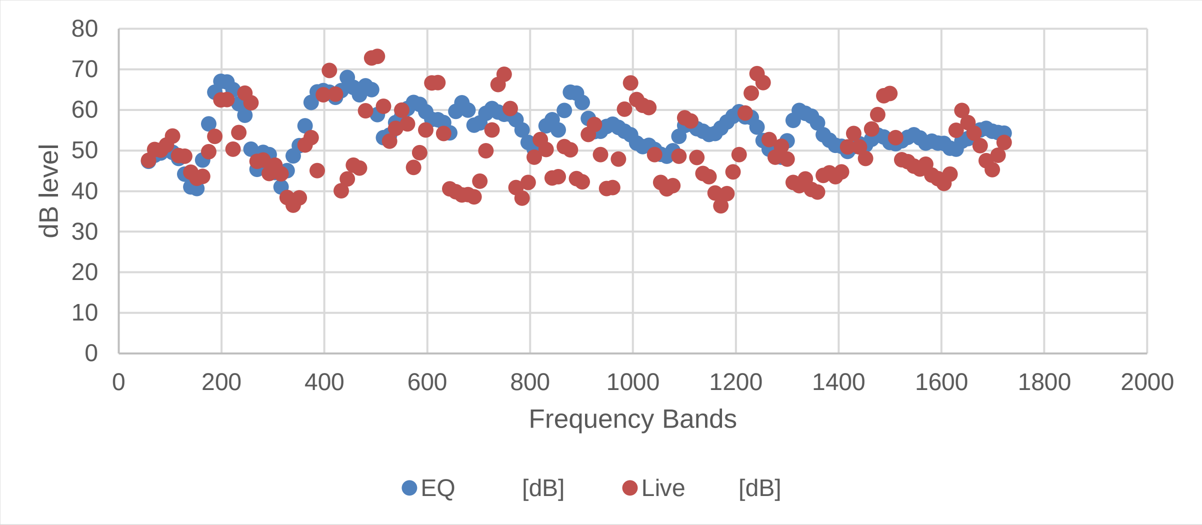

Figure 6 Scatter Graph of FFT and Carbon Fibre Blades.

The actual live pressure compared to the accumulated pressure differs, as seen in Figure 6. When averaged out the sound pressure level, EQ (blue dots), becomes more of a constant flatter line across the octave bands, especially at mid-frequencies. The live level (red dot) however is more sporadic and fluctuates. Therefore, tonality is seen in very specific frequencies. The blue EQ dots, are arguably similar to the measurement's seen in the 1/3 octave band analysis with where tonality was noted, see Figure 4. The red live dots, show more definite peaks, however, assuming fundamentals and harmonics at certain frequencies, e.g. 250Hz 500Hz.

5.2 Equal Loudness Curves

In order to determine if the tonality would impact upon a receptor the sound pressure level of the different blade types is considered in relation to the equal loudness curves, as shown in Figure 7 and in Table 3. The Equal Loudness Contours are "a standardised set of curves which show how the loudness of pure tone sounds varies with frequency at various sound pressure levels." (Peters *et al.,:*2011, p341).

Table 3 Overall Noise Rating Level based on the Equal Loudness Curves

Type of Blades	**Noise Rating Level**
Quick Release	79
No Blades	68
Carbon Fibre	81

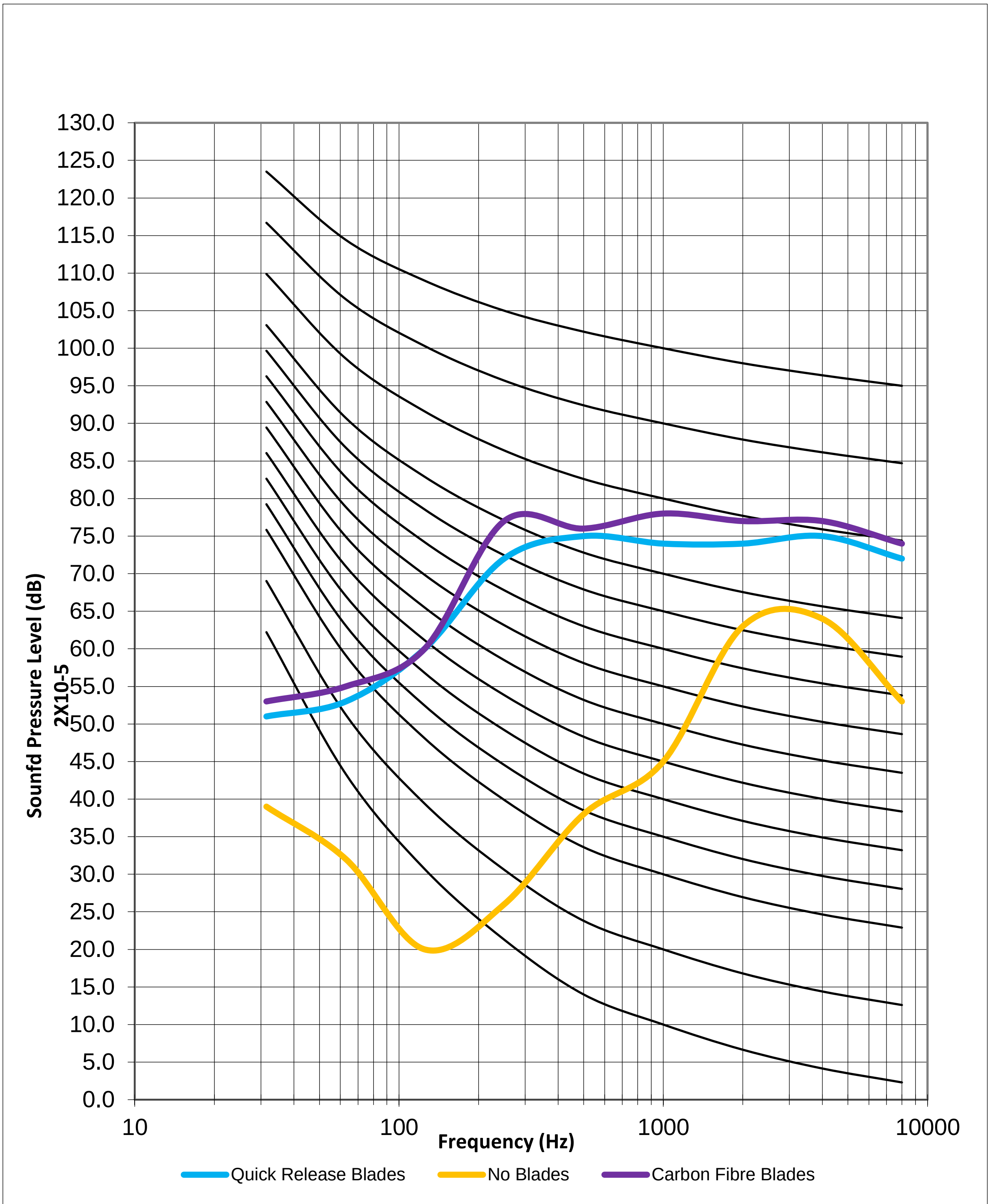

Figure 7 Equal Loudness Curves and their Noise Rating

The tonality seen in the carbon-fibre blades are more in-line with human hearing as seen from the equal loudness curves (see figure 7) as they have the highest noise rating level. It is therefore likely, that this would negatively impact receptors. Table 3 supports this, as it provides the overall noise rating level based on the Equal Loudness Curves.

5.3 Exploration of the impact of a Phantom 4 drone on a Rural Environment.

If we consider the sound pressure levels measured within the anechoic chamber and compare these to the background levels of a recreational park, then sound propagation can be predicted. Emission levels from the quick-release blades are predominantly used to explore sound propagation in a rural setting, as these DJi manufactured blades are supplied with the drone. The rural site chosen to conduct the background manual measurements was a recreational playing field. This site is on the edge of rural village, Roxwell, which was surrounded by residential properties to the south and agricultural fields to the north, east and west.

In order to determine the distance a drone could be heard from in a rural setting, the drone was considered as a free-field point source. The sound was assumed to propagate spherically from the drone. Air attenuation was also considered due to the large distances and high frequencies (Peters et al.,:2011, p44).

The drone with quick release blades, is predicted to be highly perceptible at a distance up to 650m and clearly perceptible at a distance of 1100m, when considering air absorption and point source distance propagation. In the case of the carbon fibre blades; the distance a drone would still be clearly perceptible is 180m, a significant reduction, 470m, than the quick release blades. However subjectively it may be more annoying to the receptor, due to the presence of tonality.

The increasing use of drones in an "ever increasing variety of roles that are in close proximity to populated areas" (Leslie et al.,:2008, p1) could therefore have a far bigger noise impact than previously considered. This study has identified that more needs to be considered in ways to quieten drones in rural areas, as there are generally lower background noise levels to mask drone noise and they can be heard from a large distance. An example of which is to increase the lift area of the blades and hence lower the rotation speed necessary to fly the drone. However, this may affect the efficiency of the drone in terms of flight duration and range (Nixon: 2017).

4. CONCLUSIONS

This study aimed to identify the aeroacoustic noise emitted from DJi Phantom IV drone blades and identifies the aeroacoustics performance of two different blade types. This study proves that blade types can have an impact on the emitted sound power levels and especially upon tonality. The distance a drone can be heard within a rural location is substantial. It is clearly audible (a Phantom IV drone with quick release blades installed) at a distance of 650m. The equal loudness curves and investigation identifies that drones could be considered as annoying. The optional carbon fibre blades had a reduced sound power output, 4 dB or 3 dBA, compared to the original quick releasee blades; however, they had greater tonal elements. This tonality, is arguably, part of the 'annoyance' factor felt and the distance they can be heard in a rural location gives eminence for increasing legislation and further research into making drones quieter.

5. REFERENCES

1. BS EN ISO 3745 (2009 supersedes by 2012) Acoustics – Determination of Sound Power Levels and Sound Energy Levels of Noise Sources Using Sound Pressure – Precision Methods for Anechoic Rooms and Hemi-Anechoic Rooms, BSI Standards Publications, UK, ISBN 978 0 580 53881 0,
2. Cauchard J. R., Jane L. E., Zhai K. Y., and Landay J. A., (2015) Drone & Me: An Exploration Into Natural Human-Drone Interaction, UBICOMP 15 September 7-11, Osaka Japan, ACM
3. Clarke R., (2014) Understanding the Drone Epidemic, Computer Law and Security Review, issue 30 pages 230 – 246, Elsevier Ltd,
4. Clarke R., (2014) The Regulation of Civilian Drones' Impact on Behavioural Privacy, Computer Law and Security Review, issue 30 pages 286 – 305, Elsevier Ltd,
5. Finn, Rachel L., and Wright, David (2012), Unmanned Aircraft Systems: Surveillance, Ethics and Privacy in Civil Application, Computer Law and Security Review 28 (2012) p184 – 194.

6. Intaratep N., Alexander W. N., Devenport W. J., Grace A. M., and Dropkin A., (2016) Experimental Study of Quadcopter Acoustics and Performance at Static Thrust Conditions, American Institute of Aeronautics and Astronautics, Aeroacoustics Conferences (22nd AIAA/CEAS) 30 May – 1 June 2016, Cross Mark AIAA 2016-2873 Lyon, France
7. Bown, Jessica (2018),Why your pizza may never be delivered by drone, Technology of Business Reporter, BBC news https://www.bbc.co.uk/news/business-46483178, published 14/12/2018 accessed 27/01/2019
8. BS7445-1:2003 '*Description and measurement of environmental noise. Guide to quantities and procedures'*. Measurements were made generally in accordance with ISO 1996-2:2007 '*Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels*'
9. Leslie A., Wong K. C., and Auld D., (2008)., Broadband Noise Reduction from a Mini-UAV Propeller through Boundary Layer Tripping, Acoustics and Sustainability: How Should Acoustics Adapt to Meet Future Demands? AAS 2008, 24-26 November, Geelong Australia
10. Leslie A., Wong K. C., and Auld D., (2010), Experimental Analysis of the Radiated Noise from a Small Propeller, Proceedings of 20th International Congress on Acoustics, ICA 2010, 23-27 August 2010 Sydney, Australia
11. Wong K. C., and Auld D., (2010), Experimental Analysis of the Radiated Noise from a Small Propeller, Proceedings of 20th International Congress on Acoustics, ICA 2010, 23-27 August 2010 Sydney, Australia
12. Peters R. J., Smith B. J., and Hollins M., (2011) Acoustics and Noise Control, Third Edition Routledge UK
13. Nixon J (2017) 'Attack of the Drones! Noise Impact from Recreational Drone Use in a Rural Area, Roxwell', London South Bank University, Diploma Thesis