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Drone Noise, A New Public Health Challenge?

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Summary

There is a rapidly growing interest in manned and unmanned aerial vehicles of different size from small multi-rotor drones to Urban Air Mobility (UAM) vehicles. With the projected expansion of the sector, for a variety of applications from parcel delivery to transportation of people, it is very likely that urban and rural soundscapes will be altered by drone noise. This can lead to a significant source of community noise annoyance. This is the reason why it is widely accepted that noise is one of the largest limiting factors for public acceptance and adoption of drone technology. Unquestionable, if not tackled appropriately, the noise generated by drone operations might lead to significant tension with exposed communities. This paper aims to introduce the important uncertainty as to how communities will react to a new source of noise. Compared to conventional aircraft, drones generate an unconventional noise signature to which people are completely unfamiliar. Although with important broadband contributions, drone noise is highly tonal and has irritating frequency and amplitude modulations due to varying rotors rotational speeds. They will also flight closer to people and in a bigger number. An important factor to consider is that new communities, not currently affected by aircraft noise, will most likely be affected. Moreover, an overview on challenges and research gaps on noise effects of drones is provided:

(1) It is uncertain whether the current evidence of health effects of aircraft noise will be of application. If not, new evidence will need to be gathered as to health effects of drone noise.

(2) There are neither metrics able to account for the particular characteristics of drone noise nor information about acceptable levels.

(3) There is no understanding on how the deployment of drones will affect the perception of current urban and rural soundscapes.

(4) Community annoyance will be different depending on context, e.g. drone delivering medicines to remote areas vs. drone delivering parcels to your neighbours

(5) For planning purposes, exposure-response functions for drone noise will need to be derived. This introduces the challenge of how to predict long-term effects.

1. Drones: A New Source of Noise

Most drone designs are markedly different from conventional aircraft. The different types and strengths of noise sources in drones compared to fixed wing aircraft and helicopters lead to significantly different noise signatures. Further, the sound produced by drones does not resemble qualitatively the sound generated by contemporary aircraft (Christian and Cabell, 2017).

Cabell et al. (2016) provide a comprehensive description of the basic spectral characteristics of the sound pressure level of a series of small multi-copters. As described by these authors, the sound of small multi-copters is characterised by the presence of multiple complex tones at harmonics of the blade passage frequency (of each rotor). Also, in multi-copter spectra there are significant sound levels at higher harmonics of the blade passage frequency, which seems to be caused by interaction noise from disturbed inflow due to other rotor blades or the fuselage (Magliozzi et al., 1991).

Figure 1 shows typical frequency spectra of an aircraft and a small quadcopter flyover, and a car pass-by. As shown in Figure 1, a typical fixed wing aircraft have a prominent tone at the blade passing frequency (at about 1 kHz in the example shown), with some harmonics at higher frequencies, and a substantial decay in high frequency content due to atmospheric absorption. Compared to a conventional fixed wing aircraft, the frequency spectrum of a small quadcopter contains a significant content in complex tones in the mid-to-high frequency region (between 400 Hz and 1 kHz in the example shown), and high sound level in the high frequency region that might be due to the electric motors (Cabell et al., 2016). This is in agreement with Whelchel et al. (2020) stating that noise of drone propellers is dominated by tonal noise at lower frequencies and broadband noise at higher frequencies. Alexander and Whelchel (2019) also suggested that the important mid-frequency broadband noise might due to trailing edge noise from outer portions of the rotor diameter.

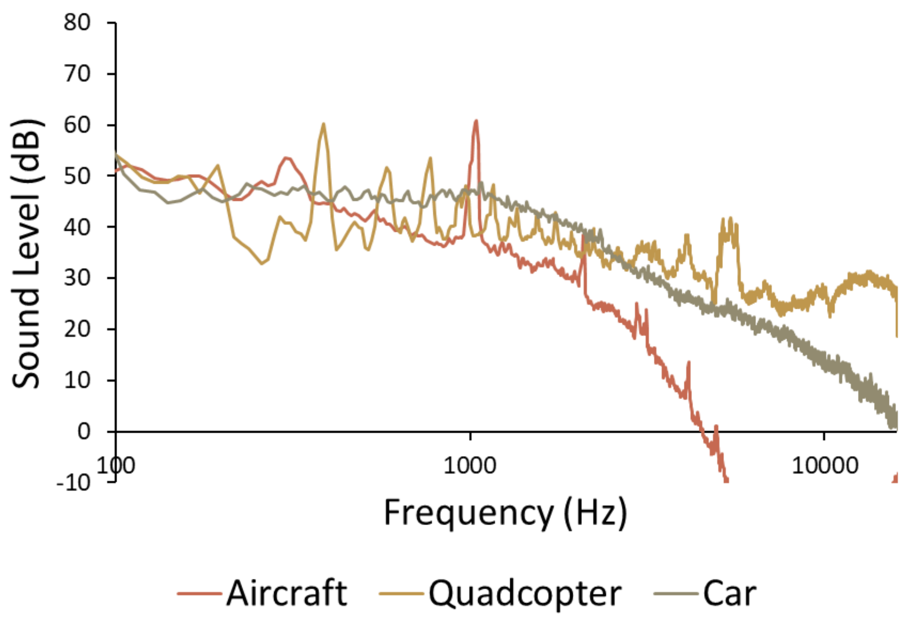

Figure 1. Typical frequency spectrum of an aircraft and a small quadcopter flyover, and a car pass-by, normalised to a L_{Aeq} of 65 dB(A)

Drones have specific noise features that lead to a significant uncertainty in the prediction of the resultant annoyance. For instance, the small tip-to-tip spacing between counter rotating propellers results in a significant source of noise due to blade interaction effects (Alexander et al., 2019; McKay et al., 2019; Torija et al., 2019). Moreover, ambient weather conditions have been found to have a significant impact on sound levels and character of drone noise (Alexander et al., 2019). As shown in Figure 2, tones below 1 kHz significantly differ between static hover and drone hovering outdoors due to varying rotor rotational speeds to maintain vehicle stability. Under typical outdoor conditions, rotors spin at different RPMs to compensate wind influence and ensure the stability of the vehicle. This leads to the maximum amplitudes of the tonal components to become weaker, but also to an increase in the number of tonal components (Alexander and Whelchel, 2019, Torija et al., 2019).

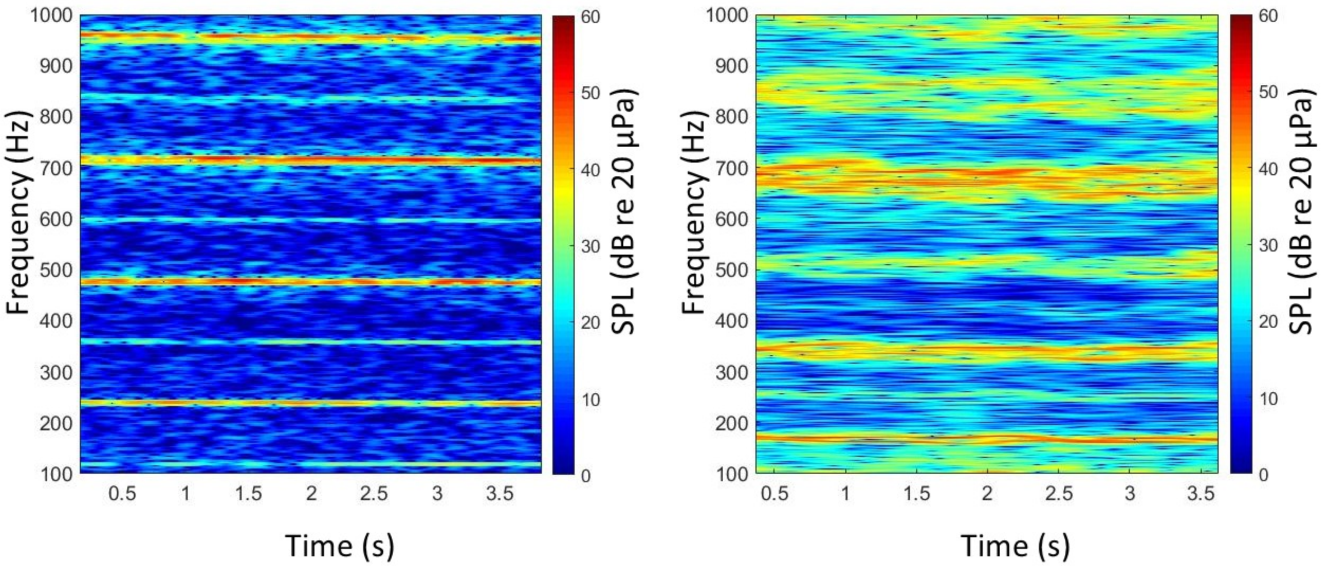

Figure 2. Spectrogram of a quadcopter hover measured in confined anechoic (left) and open environment (right) (Torija et al., 2019)

2. Is the Current Evidence of Health Effects of Aircraft Noise of Application to Drone Noise?

Aircraft noise is one of the most adverse environmental effects of aviation. There is substantial evidence of a strong relation between aircraft noise and annoyance (Basner et al., 2017). Based on current state of scientific knowledge, Basner et al. (2017) also found that there is sufficient evidence for marked negative effects of aircraft noise exposure in terms of cognitive impairment in children and sleep disturbance; and also that "*there is a good biological plausibility by which noise may affect health*." In a recent paper, Clark et al. (2020) state that "*there is low quality evidence for a harmful effect of road traffic noise, aircraft noise, and railway noise on some cancer outcomes.*" The World Health Organization (WHO) suggest good evidence in the relation between aircraft noise and cardiovascular disease, sleep disturbance, annoyance and cognitive impairment. The WHO guidelines for protecting human health from exposure to aircraft noise:

- strongly recommends avoid exposure to more than 45 dB L_{den}, as "*this level is associated with adverse health effects*," and

- Strongly recommends avoid night-time exposure to more than 40 dB L_{night}, as "*this level is associated with adverse effects on sleep*" (WHO, 2018).

Compared to conventional fixed wing aircraft and rotorcraft, small drones are expected to be quieter (Theodore, 2018). However, with the significant business opportunities, the expectation is that a substantial number of drones might inundate the skies of cities across the globe. Just in the UK, PWC[1] estimate that by 2030 there will be 76.233 drones flying in operation (Heathrow airport in London has 1,303 daily average flights). Further, drones will fly at relatively low altitudes over populated areas that have not normally been exposed to aircraft noise. With drones operating at low flight levels, and therefore a reduced atmospheric absorption, high frequency noise is likely to be an important an important factor for annoyance. Regarding UAM vehicles, increasing size will mean an increase in loudness. Notwithstanding the uncertainty about specific designs, it is expected that the sound generated by UAM vehicles, with dominance of complex tones, will be of similar character of drone sounds.

It is well known that non-acoustic factors such as fear, perceived control, trust in authorities and previous experience with or future expectations regarding noise have a strong contribution to individual annoyance reactions (Basner, et al., 2017; Sparrow et al., 2019). For the specific case of drones, a recent report[2] suggests safety, privacy and security, in addition to noise and visual pollution, as the main concerns with regards to the used of drones. Sparrow et al. (2019) conclude that "*There is preliminary evidence that the public may be concerned with these new noise sources intended for transportation and package delivery.*" For all the above, it seems unlikely that the current evidence of health effects of aircraft noise can be of application to drone noise. Further research is needed to understand the effects of this new source of noise on public health and wellbeing.

3. What are the Metrics and Acceptable Levels for Drone Noise?

Hitherto, there is no regulation establishing the necessary noise metrics for the certification and regulatory frameworks for the industry and governing bodies. A recent publication (Senzig and Marsan, 2018) suggests that current noise certification methods for fixed- and rotary-wing aircraft may not be suitable for certificating Unmanned Aerial Vehicles (UAVs). These authors also describe the main limitations of noise metrics to account for the specific characteristics of UAVs. For instance, current aircraft noise metrics assume a relatively constant noise source, and therefore might not be able to account for the perceptual effect of unstable noise (due to vehicle control system) during typical UAV manoeuvring operations. Torija et al. (2019a), found that the current metric for aircraft noise certification, i.e. Effective Perceived Noise Level (EPNL), is not able to account for the subjective response to aircraft noise with high number of tonal components evenly distributed along the frequency spectra.

Christian and Cabell (2017) investigated the performance of four noise metrics to account for the noise annoyance due to a series of UAVs and road vehicles: A-weighted Sound Exposure Level (SEL_A), C-weighted Sound Exposure Level (SEL_C), EPNL, and Loudness exceeded 5% of the time (L5). They found that none of the four metrics tested was able to capture the subjective difference between the UAV and road vehicle sounds. This is in line with a research carried out by Torija et al. (2020) to investigate the noise perception of a hovering UAV in a series of urban scenarios. These authors found the participants' responses on perceived annoyance highly influenced by acoustics factors particularly characteristic of small quadcopter noise or non-acoustic factors such as visual scene and expectation. Christian and Cabell (2017) suggest that a loitering correction (accounting for the time of exposure to UAV noise) and the addition of psychoacoustic measures as tonality can lead to a better performance in predicting noise annoyance of UAVs. However, qualitative characteristics of UAV sounds might also be relevant

[1] https://www.pwc.co.uk/intelligent-digital/drones/Drones-impact-on-the-UK-economy-FINAL.pdf
[2] https://media.nesta.org.uk/documents/Flying-High-full-report-and-appendices.pdf

for understanding the intrinsic annoyance of these vehicles, and also the perceptual differences with traditional transportation noise sources.

The European Commission has issued the Implementing Regulation (EU) 2019/945 "to provide citizens with high level of environmental protection, it is necessary to limit the noise emissions to the greatest possible extent." The Annex Part 15 to this document states a maximum allowable sound power level of 85 dB for UAVs in the 'open' category. However, the sound power level is unable to account for all the typical acoustic features of UAVs (e.g. tonality, high frequency noise, etc) and the proposed maximum value does not seem related to public reaction. Therefore, more research is required to understand and predict the perception of UAV noise. Building upon this research, metrics optimised to UAV noise can be developed and acceptable levels can be proposed.

4. What will be the Influence of Drone Operations on Soundscape Perception?

Torija et al. (2020) investigated the effects of a hovering small quadcopter on the perception of a series of urban soundscapes. They found that in soundscapes with reduced road traffic noise, the participants taking part in their study reported a significantly higher perceived loudness and annoyance than in soundscapes highly impacted by road traffic noise, although the sound level of the quadcopter was held constant at 65 dBA across all scenarios. These results suggest that "*the concentration of drone operations along flight paths through busy roads might aid in the mitigation of the overall community noise impact caused by drones."* However, these results also suggest that *as traffic varies over the day there will be times with low traffic volume when local residents experience the loudness and annoyance of drones much more"* (Eißfeldt, 2020). Torija et al. (2020) found that the reported annoyance with UAV noise is up to 6.4 times higher than without UAV noise, in locations with low road traffic volumes.

Therefore, public acceptance of drone operations will be primarily driven by the characteristics of the local soundscape, and the expectations of exposed communities. In other words, the noise impact generated by drones will be a function of the change in acoustic experience over the typical ambient sound at a particular time of day. Uber will consider background noise to plan routes and skyport locations, so Uber Air operations do not increase the ambient equivalent continuous sound level (L_{Aeq}) by more than 1.5 dBA[3].

Further research is required to simulate different manoeuvring operations of drones in realistic audio-visual scenes (i.e. ecologically valid perceptual stimuli) to understand how the public will react to the introduction of these novel vehicles in their local soundscape. This research will aid regulators to define operating requirements for drones based on annoyance and acceptance.

5. How can Long-Term Effects of Drone Noise be Predicted?

The effects of transportation noise on individuals or a population is traditionally assessed using noise exposure-response relationships. These are empirically derived functions relating exposure metrics (e.g. Day-Night Level – DNL) and effects of noise exposure (e.g. percentage of highly annoyed persons). Well-established exposure-response relationships for transportation noise and annoyance (e.g. Miedema and Vos, 1998) have provided evidence for the development of noise regulation[4] and definition of recommended noise exposure levels[5]. Exposure-response relationships have been derived for a series of auditory and non-auditory effects of noise on health (Basner et al., 2014).

[3] https://evtol.com/news/uber-elevate-community-engagement/

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN

[5] https://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf

As said above, it is highly unlikely that that there will be enough evidence to derive exposure-response relationships for drone noise before wider communities are actually exposed to the noise of these vehicles. There have been some laboratory studies comparing noise perception of UAVs and other conventional transportation vehicles (Christian and Cabell, 2017; Torija et al., 2020). However, it is uncertain whether the findings of laboratory studies could be extrapolated to real scenarios. An alternative approach could be to apply 'annoyance bonus' or 'annoyance penalties', observed at laboratory when comparing drone noise with other sources of transportation noise, to standard transportation noise exposure relationships, in order to derive exposure-response functions for drones. However, still these derived drone noise exposure-response functions will need to be validated with field studies.

Therefore, innovative approaches are needed to derive exposure-response functions aiding regulators with the prediction of long-term exposure to drone noise.

6. Conclusions

This paper introduces and discusses the main challenges and research gaps on noise effects of drones. The paper outlines the main noise characteristics of drones, and states the need for further research to

i. understand the effects of drone noise on public health and wellbeing,
ii. develop metrics to assess community noise impact of drones,
iii. define acceptable levels for drone noise,
iv. inform best operational practices for drones with regard to noise profiles, and
v. innovate in the approaches to predict long-term noise effects when drones operate at scale.

Bringing these research gaps is crucial to appropriately tackle noise issues associated with drones, and therefore protect quality of life and health of exposed communities.

References

Alexander, W.N., and Whelchel, J., 2019, "Flyover Noise of Multi-Rotor sUAS." In Proceedings of InterNoise 2019, Madrid, Spain.

Alexander, W.N., Whelchel, J., Intaratep, N., and Trani, A. 2019. "Predicting community noise of sUAS." In: Proceedings of 25th AIAA/CEAS Aeroacoustics Conference (AIAA 2019-2686). Delft, The Netherlands.

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., Stansfeld, S. 2014. "Auditory and non-auditory effects of noise on health." Lancet, 383(9925): 1325–1332.

Basner, M., Clark, C., Hansell, A., Hileman, J.I., Janssen, S., Shepherd, K., Sparrow, V. 2017. "Aviation noise impacts: State of the science." Noise Health, 19(87), 41-50.

Cabell, R., Grosveld, F., and McSwain, R. 2016. "Measured noise from small unmanned aerial vehicles." In: Proceedings of NOISE-CON 2016, Vol. 252, Institute of Noise Control Engineering, Providence, RI, USA.

Christian, A. and Cabell, R. 2017. "Initial investigation into the psychoacoustic properties of small unmanned aerial system noise." In: Proceedings of the 17th AIAA Aviation Technology, Integration, and Operations Conference (AVIATION 2017), Denver, CO, USA.

Clark, C., Crumpler, C., Notley, H. 2020. "Evidence for environmental noise effects on health for the United Kingdom policy context: A systematic review of the effects of environmental noise on mental health, wellbeing, quality of life, cancer, dementia, birth, reproductive outcomes, and cognition." International Journal of Environmental Research and Public Health, 17(2), 393.

Eißfeldt, H. 2020. “Sustainable Urban Air Mobility supported with participatory noise sensing.” Sustainability, 12(8), 3320.

Magliozzi, B., Hanson, D.B., and Amiet, R.K. Propeller and propfan noise. In Harvey H. Hubbard, editor, Aeroacoustics of Flight Vehicles: Theory and Practice: Volume 1: Noise Sources, number NASA RP-1258, pages 1–64, 1991.

McKay, R.S., Kingan, M.J., and Go, R. 2019. “Experimental investigation of contra-rotating multi-rotor UAV propeller noise.” In: Proceedings of Acoustics 2019, Cape Schanck, Victoria, Australia.

Miedema, H.M.E., and Vos, H. 1998. “Exposure-response relationships for transportation noise.” Journal of the Acoustical Society of America, 104, 3432.

Senzig, D.A., and Marsan M. 2018. “UAS Noise Certification,” In proceedings of Inter-Noise 2018, paper in18_1855, Chicago, United States.

Sparrow, V., Gjestland, T., Guski, R., Richard, I., Basner, M. et al. Aviation Noise Impacts White Paper. In: ICAO 2019 Environment report Chapter 2 Aircraft noise 2019.

Theodore, C.R. 2018. “A summary of the NASA Design Environment for Novel Vertical Lift Vehicles (DELIVER) project.” In: Proceedings of the AHS International Technical Conference on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, USA.

Torija, A.J., Roberts, S., Woodward, R., Flindell, I.H., McKenzie, A.R., and Self, R.H. 2019a. “On the assessment of subjective response to tonal content of contemporary aircraft noise.” Applied Acoustics, 146, 190-203.

Torija, A.J., Self, R.H., and Lawrence, J.L.T. 2019b. “Psychoacoustic characterisation of a small fixed-pitch quadcopter.” In: Proceedings of InterNoise 2019, Madrid, Spain.

Torija, A.J., Li, Zhengguang, Self, R.H. 2020. “Effects of a hovering unmanned aerial vehicle on urban soundscapes perception.” Transportation Research Part D: Transport and Environment, 78, 102195.

World Health Organization. Environmental Noise Guidelines for the European Region. WHO Regional office for Europe, Copenhagen. 2018

Whelchel, J., Alexander, W.N., and Intaratep, N. 2020. “Propeller noise in confined anechoic and open environments.” In: Proceedings of AIAA Scitech 2020 Forum, Orlando, FL, USA.