Noise and Visual perception of Urban Air Mobility vehicles

Roalt Aalmoes[1], Naomi Sieben[2]

[1] Environmental & Policy Support Department, Royal Netherlands Aerospace Centre NLR
[2] Faculty of Psychology, University of Utrecht
Roalt.Aalmoes@nlr.nl

Abstract

Urban Air Mobility (UAM) is a new popular concept for air vehicles, such as parcel delivery drones and air taxis, in an urban environment. Despite many positive aspects of this implementation, there are also negative sides, such as noise pollution. Little is known about the impact of drone noise and other types of UAM vehicles, but what research has shown is that annoyance rates towards drone noise is generally higher than that of existing conventional aircraft noise. To further investigate the noise impact of drones, a subjective experiment is proposed to measure the perception of UAM noise, with or without their visual appearance. The fly-over of a drone is presented using the Visual Community Noise Simulator (VCNS), where a busy urban area and a more ambient urban area in Amsterdam are simulated using a controlled Virtual Reality environment. Drones and similar sounding vehicles and appliances are compared in two city environments with distinctive ambient background sound levels. The influence of visual perception is also examined by comparing the reaction to noise stimuli with or without visual appearance of a drone. Following, four hypotheses are composed, where it is first of all expected that drones are perceived less annoying, when there is a visually presentation as well. It is also expected that drones are perceived less annoying in a louder urban environment than a more ambient urban environment. Third, familiar sounds are expected to be as annoying as drones if they are represented with a drone visualisation. Fourth, the attitude towards drones and the sound sensitivity is related to the annoyance of drones. With a limited number of participants, the experiment set up proves to be successful and more participants will be invited as well. Results are expected Spring 2021.

1 Introduction

In recent years, the aerospace industry has an increasing interest for the concept of Urban Air Mobility (UAM): a new research branch has emerged on the implementation of these new air traffic vehicles, such as parcel delivery drones and the generally larger Personal Air Vehicles (PAVs), also known as air taxis. Research shows that the use of these vehicles could prove to be a safer, more reliable, and more environmental alternative, with a reduction of pollution from fossil-fuel emissions, to current transportation networks [1][2] [3]. A big obstacle that could prevent the successful implementation of Urban Air Mobility is public acceptance [4][5]. One major aspect of public acceptance is noise exposure, but research related to the noise impact of these category of vehicles is still in its infancy compared to other well-known noise sources.

The impact of noise emission is however important, as it is associated with depression and anxiety [6]. Noise annoyance has also been estimated to be the second major health effect of environmental noise after sleep disturbance by the World Health Organization [7]. The influence of noise emission has been researched extensively in other domains, such as with conventional aircraft. One of the earliest and most robust finding is from Miedema and Vos [8]. Here, they computed response curves for percentage of highly annoyed (%HA) people to day-night average sound level (L_{den}) of aircraft, road and railroad traffic. These curves show that at the same level of L_{den}, aircraft noise elicit a higher percentage of annoyed people, followed by road traffic noise and railroad traffic noise. This is but one of many studies that show a higher annoyance rate towards aircraft, compared to other types of transportation, such as rail and road traffic [9][10][11].

Even though noise annoyance of aircraft has been studied extensively, relatively little research has been done about the noise impact of UAMs on people. What has been shown, however, is greater annoyance rates towards UAM vehicles compared to aircraft noise [12] and also towards road traffic, specifically the drive-by of a car or van [13].

Therefore, it is important to further investigate the noise impact of these small unmanned vehicles on people. When solely focussed on noise emission of drones, Christian & Cabell [13] as well as Gawk et al. [12] have shown a high level of annoyance but without taking the visual perception into account. It is, however, interesting that the study of Gwak et al. [12] found a significant higher level of annoyance towards medium and large drones when compared to aircraft, but smaller drones showed an actual decrease in annoyance compared to aircraft at the same level of loudness. An explanation for the high level of annoyance for drones could be due to the sharp characteristic of the produced sound [12]. On the other hand, the smaller drone had a similar sharp sound but lower annoyance rates. This might be explained by the tonality of the sound, since the authors did not take this psychoacoustic characteristic into account. Therefore, tonality of a signal may need to be considered for measuring annoyance, aside from the loudness and sharpness of drone noise [14].

Noise annoyance elicited from drones may not only be influenced by the sound perception, but also by the visual perception. A way to test visual perception of drones, without the physical presence of a drone is by using Virtual Reality (VR). Torija et al. [15] found an increase in perceived pleasantness and decrease in perceived annoyance and loudness of drones when these vehicles were visually present in a louder urban environment. This outcome could prove to be beneficial, considering drones would be flying in an urban area, where road traffic is already present and the background noise is higher. This is one of the only studies where the subjective measurement of drones was conducted in this controlled environment, while also taking visual perception into account. However, only the perception of a hovering drone, (the small quadcopter DJI Phantom 3 Standard) was measured here, without looking at other models or at the effects of the drone actually flying over as they would in a real-life setting.

This study aims to investigate the subjective ratings of an overflying drone in a loud and quieter urban environment. The visual aspect of this subjective evaluation will be generated with NLR's Virtual Community Noise Simulator (VCNS). Here, a virtual environment will be simulated using VR glasses and noise cancelling headphones, in which a hovering or an overflying drone will be presented. This study also aims to see whether similar, but more familiar helicopter and lawnmower sounds elicit comparable annoyance rates as drone noise. Accordingly, the following research question is composed; How does the addition of visual perception change the annoyance rates towards drones, compared to only sound perception in a loud versus quieter urban environment? It is hypothesized that:

I. Drones will be perceived as less annoying, when they are presented visually with the corresponding sound, compared to when only the sound of the drone is presented.

II. Drones will be perceived as less annoying in a louder urban environment, compared to a more ambient urban environment

III. More familiar helicopter and lawn mower sounds that resemble drone sounds will be considered equally annoying as drones if their visual appearance is the same

IV. Apart from age, gender and highest finished education as control variables, attitudes towards drones and noise sensitivity will be measured as well. As follows, the next two hypotheses are composed as the outcome of these measurements.

a. People who have a negative attitude towards drones will perceive these drones as more annoying than people with more positive attitudes.

b. People who are sensitive to sound will perceive these drones as more annoying than people that are less sensitive to noise.

2 Simulation of Urban Air Mobility concepts

To objectively evaluate noise impact from Urban Air Mobility vehicles, such as drones or PAVs, a research facility is needed that can mimic the same circumstances for each test subject. Having test subjects experiencing real test flights with these vehicles can be considered most realistic, but it has a number of disadvantages. First, these tests require actual vehicles and certified operations to be allowed to take place and can be expensive. Second, the foreseen environment, an urban environment, may prove to vary per test subject: the weather may be different and/or the ambient noise levels may vary as well. A facility such as the VCNS where audio and visual stimuli are constant for each test subject is therefore chosen for this experiment.

Since 2007, the NLR acquired their first version of the noise simulator [16]. Purpose of the simulator is to demonstrate future changes around airports that impact the noise experience for communities. This simulator has been improved by NLR to make use of the latest VR hardware and audio hardware has been replaced by a software equivalent [17]. The simulator presents participants an audio-visual experience of a simulated aircraft fly-over. Main capabilities of the simulator for this research are:

- A representative binaural audio replay of an aircraft fly-over or other sound sources,
- binaural ambient audio replay,
- a represented visualization of the aircraft, and
- a 360 degrees visualization of the location, and
- a questionnaire overlay in VR that can be used by the test subject using a handheld remote controller.

To record the ambient environment, a camera rig containing 10 GoPro Hero 4 cameras is used. In combination with camera stitching software, these recordings are used to create a spherical video that can be replayed in the VCNS. Ambient sound recording is done with a Zoom H3-VR to make first-order ambisonics recordings. A Rion nl-52 Sound Level Meter is also used to measure ambient sound levels. Sounds and visual are later synchronized by aligning the GoPro audio recording with the recording from the Zoom and the Sound Level Meter.

Sound-only presentation							
Louder street	Hovering drone A	Fly-over drone A	Hovering drone B	Fly-over drone B	Fly-over helicopter	Hovering lawnmower	Lawnmower on ground
Quieter street	Hovering drone A	Fly-over drone A	Hovering drone B	Fly-over drone B	Fly-over helicopter	Hovering lawnmower	Lawnmower on ground

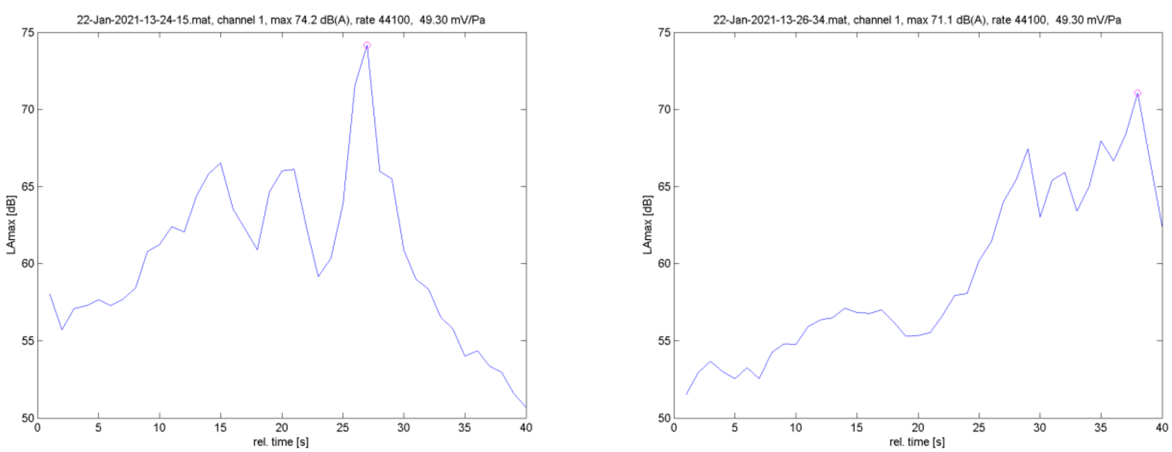
Visual model + sound presentation						
Louder street	Hovering drone A + visualization of small drone	Fly-over drone A + visualization of small drone	Hovering drone B + visualization of large drone	Fly-over drone B + visualization of large drone	Fly-over helicopter + visualization of helicopter	Hovering lawnmower + visualization of small drone
Quieter street	Hovering drone A + visualization of small drone	Fly-over drone A + visualization of small drone	Hovering drone B + visualization of large drone	Fly-over drone B + visualization of large drone	Fly-over helicopter + visualization of helicopter	Hovering lawnmower + visualization of small drone

Table 1: combinations of the 26 different conditions presented in the virtual environment, where the vehicles are either presented in the louder virtual street, or the quieter virtual street.

In the VR experiment, 28 trials, also consisting of 2 practice trials are presented in two different virtual environments, a louder urban street and a quieter urban street, See Table 1. In the louder environment, a number of cars, a truck, and a motorcycle pass by, while in the quieter environment, only two cars pass by at the end of the presented video clip. In both areas, some pedestrians and bicycles pass by as well. Both recordings were taken in the city of Amsterdam, The Netherlands, see Figure 1. The sound levels LA_{max} (slow, 1s) of the louder and quieter urban area presented in Figure 2. In these two environments, sounds of a smaller (type A) and larger (type B) drone, helicopter, and lawnmower are simulated.

Figure 1: Two screenshot of the spherical video used for the ambient environment. On top, the louder environment of the Abbennesstraat. The bottom is the quieter environment of the Aalsmeerplein.

The sound-only conditions, where only the sounds of the vehicles are presented and not the visual model, consists of seven simulations. Here, the sounds of overflying and hovering drone types A and B are presented, as well as an overflying helicopter sound and a hovering / ground-stationed lawnmower sound is simulated. All these conditions are presented in the louder and the quieter environment, resulting 14 total sound-only trials. As for the visual conditions, the drones and helicopters are presented in the same fashion as in the sound only conditions, with the



(a) (b)

Figure 2: Ambient sound levels in LAmax of the louder urban environment (a) and the quieter urban environment (b).

corresponding visual presentation. For drone A, a smaller drone is presented and for drone B a larger one. In the visual conditions, only a lawnmower sound is heard with the same visual presentation as drone A. These visual-only conditions consist out of 6 simulations, in the louder and quieter area, resulting in a total of 12 trials. All the simulated clips are (pseudo)randomly presented, where the participants viewed a different sequence of vehicles. This also counts for the background simulation, which has been counterbalanced, resulting in half the participants viewing the louder street first and the other half receiving the quieter street first.

The drone sound samples and trajectory files were provided by the European Union Aviation Safety Agency (EASA). For the type A (smaller) drone, a MK Quadro XL was used with a Maximum Take-off Weight (MTOW) of 2.5 kg. For the type B (larger) drone, a Gryphon GD-40X was used with 40 kg MTOW. A (light) helicopter sound with a 1100 kg MTOW was also used in the simulation as reference sound for a known flying sound source. The recording of the lawnmower sound, an electric-powered Bosch ART 27+ string trimmer, was made for this study with the Rion nl-52 recorder at a distance of 10 meters. The hovering and flyover audio stimuli are normalized to a similar Sound Exposure Level (SEL) value, to prevent bias of annoyance due to varying noise levels.

Visual models of a PAV, a small drone (See Figure 3), and a helicopter were used and augmented over the recorded spherical video, according to their trajectory. The VCNS uses a mask to indicate which parts of the spherical video is foreground and would block the sight of the presented vehicle. The audio sources of the vehicles were not adjusted for any reflection or shielding of buildings.

Figure 3: The visual of the two drones in the quieter urban environment. The top figure shows a small quadcopter visualisation, the bottom figure a PAV-type visualisation.

3 Method

3.1 Questionnaires

During the VR part of the experiment, participants answer five questions after each condition. Rated on a 10-point Likert scale, participants report their sense of annoyance, feeling threatened, loudness, squeakiness, and distinguishable tones of the sound. These characteristics of sounds are considered to assess their overall annoyance and in the way the sound distinguish drone noise from aircraft noise [10] [12] [18]. Participants answer these questions, which pop up in the virtual environment, using the joystick in their left hand.

The rest of the questionnaires consists of personal information, including gender, age and highest finished education, noise sensitivity and attitudes towards drones. For the noise sensitivity questionnaire, the shortened version of the Weinstein Noise Sensitivity Scale (WNSS) [19] is used. The questionnaire regarding attitudes towards drones consists of six questions on either a 10-point Likert scale or dichotomous questions with a yes/no answer.

3.2 Experimental setup

Thirty people are approached to enter in this experiment, through word of mouth and from personal circles. The participant is sitting in front of a table in a room where only the researcher and participant are present without further distractions. The participant stays seated during the complete time of the experiment, which lasts around 45 minutes. The experiment is done in accordance with the NLR COVID'19 protocol (due to the pandemic), tailored for the VCNS facility.

A PowerPoint presentation with additional information about the procedure and questions asked during the experiment is viewed before the start of the experiment on a laptop in front of the participant. In the PowerPoint slides examples of sounds are provided for the five questions asked after each condition. The VCNS makes use of the Oculus Quest VR headset, connected using the Oculus Link to an Alienware m17 laptop with NVIDIA RTX 2080 Super graphics card. Instead of the supplied headphone, a Bose QuietComfort 25 headset is used with noise-cancellation disabled. The left motion controller of the Oculus is used for the test subject to provide answers during the test. Furthermore, the VR glasses and headphones can be adjusted to the comfortability of the participant. Questionnaires outside of the VR environment are filled in on paper.

3.3 Procedure

Before the start of the experiment, participants read and sign the informed consent and view the PowerPoint presentation with the additional information about the procedure and questions during the experiment. After the initial briefing of the experiment, half of the participants receive the sound-only conditions first, where only the sounds of the vehicles are presented without visual stimuli and the other half receives the visual condition first, where the vehicle is visually presented. Consequently, participants are told that after the two practice trials they have to look around to find the source of the sound, or they will only hear the sound.

After 14 or 16 trials, depending on which condition the participant is in, a break is provided where participants can take off the headset. After the break, the conditions are changed, where participants who received the sound-only condition first, will now receive the visual condition and vice versa. This is also explained to the participants during the break, meaning that if in the start of the experiment they were told to look around to find the source of the sound (visual condition), then they are told in the break of the experiment that the vehicles would not be visually presented anymore. After completing the VR part of the experiment, which takes around 30 minutes, participants fill in the three questionnaires about attitudes towards drones, noise sensitivity and personal information.

4 Initial results

The experiment has started, and the moment of writing, 11 test subjects of a total of 30 have participated. The test set up proved to be successful as all participants finished the test without problems, requesting intermediate help, or simulation problems.

5 Conclusion

An experiment has been set up to evaluate the auditory and visual perception of drones in an UAM setting. For this purpose, a quieter urban environment and a louder urban environment are recorded. Using augmented and Virtual Reality technology, audio with and without visual stimuli are presented to test subjects. The participants are split in two test groups, where one group first only evaluates auditory stimuli, while the other group evaluates auditory stimuli in combination with a visual representation of the sound. To compare and objectively evaluate drone sounds, these sounds are mixed with other similar sounds, such as helicopters and lawnmowers. And in some stimuli, lawn mowers and helicopters are represented by, respectively, a (visual) drone model and a helicopter model as well. With a limited number of participants, the experiment set up proves to be successful and more participants will be invited as well. Currently, 11 participants have been tested, with overall positive responses and strong feelings of immersion into the virtual environment. Comments made by these participants include easy use of the joysticks, well audible sounds and good duration, where the experiment is short enough to keep the attention span active, especially since the sounds are quite repetitive. Final tested are expected to be finished early March and results will be available Spring 2021. The experiment also provides the means for follow-up research on the topic of Urban Air Mobility, noise annoyance, and public acceptance.

Acknowledgments

The authors would like to thank the EASA for providing the sound samples that were used in this research from project SC03 of the Framework contract EASA.2016.FC21.

References

[1] Poulton, G. (n.d.). *Rethinking Urban Air Mobility. Airbus*. Retrieved June 17, 2017, from https://www.airbus.com/newsroom/stories/rethinking-urban-air-mobility.html

[2] Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. *Transportation Research Part A: Policy and Practice*, *132*, 696–712. https://doi.org/10.1016/j.tra.2019.12.020

[3] Eißfeldt, H. (2020). Sustainable Urban Air Mobility Supported with Participatory Noise Sensing. *Sustainability*, *12*(8), 3320. https://doi.org/10.3390/su12083320

[4] Booz, Allen, Hamilton, Urban Air Mobility (UAM) Market Study, Final Report, https://ntrs.nasa.gov/api/citations/20190001472/downloads/20190001472.pdf (Retrieved 14 February 2021), NASA 2018.

[5] Torija, A.J.; Clark, C. A, Psychoacoustic Approach to Building, Knowledge about Human Response, to Noise of Unmanned Aerial Vehicles. Int. J. Environ. Res. Public Health 2021, 18, 682. https://doi.org/10.3390/ijerph18020682

[6] Beutel, M. E., Jünger, C., Klein, E. M., Wild, P., Lackner, K., Blettner, M., Binder, H., Michal, M., Wiltink, J., Brähler, E., & Münzel, T. (2016). Noise Annoyance Is Associated with Depression and Anxiety in the General Population- The Contribution of Aircraft Noise. *PLOS ONE*, *11*(5), e0155357. https://doi.org/10.1371/journal.pone.0155357

[7] World Health Organization. Regional Office for Europe. (2011). Burden of disease from environmental noise: quantification of healthy life years lost in Europe. *World Health Organization. Regional Office for Europe*, pp 106. https://apps.who.int/iris/handle/10665/326424

[8] Miedema, H.M.E. & Vos, H. (1998) Exposure-response relationships for transportation noise. *The Journal of the Acoustical Society of America*, *104*, 3432–3445. https://doi.org/10.1121/1.423927

[9] Brink, M., Schäffer, B., Vienneau, D., Foraster, M., Pieren, R., Eze, I. C., Cajochen, C., Probst-Hensch, N., Röösli, M., & Wunderli, J. (2019). A survey on exposure-response relationships for road, rail, and aircraft noise annoyance: Differences between continuous and intermittent noise. *Environment International*, *125*, 277–290. https://doi.org/10.1016/j.envint.2019.01.043

[10] Guski, R., Schreckenberg, D., & Schuemer, R. (2017). WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance. *International Journal of Environmental Research and Public Health*, *14*(12), 1539. https://doi.org/10.3390/ijerph14121539

[11] Wothge, J., Belke, C., Möhler, U., Guski, R., & Schreckenberg, D. (2017). The Combined Effects of Aircraft and Road Traffic Noise and Aircraft and Railway Noise on Noise Annoyance—An Analysis in the Context

of the Joint Research Initiative NORAH. *International Journal of Environmental Research and Public Health*, *14*(8), 871. https://doi.org/10.3390/ijerph14080871

[12] Gwak, D. Y., Han, D., & Lee, S. (2020). Sound quality factors influencing annoyance from hovering UAV. *Journal of Sound and Vibration*, 115651. https://doi.org/10.1016/j.jsv.2020.115651

[13] Christian, A. W., & Cabell, R. (2017, June 2). Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noise. *23rd AIAA/CEAS Aeroacoustics Conference*, 4051. https://doi.org/10.2514/6.2017-4051

[14] Torija, A.J., Self, R.H. & Lawrence, J.L. (June 2019). Psychoacoustic characterisation of a small fixed-pitch quadcopter. *Proceedings of Inter-noise 2019*, Madrid, Spain, pp. 16-19

[15] Torija, A. J., Li, Z., & Self, R. H. (2020). Effects of a hovering unmanned aerial vehicle on urban soundscapes perception. *Transportation Research Part D: Transport and Environment*, *78*, 102195. https://doi.org/10.1016/j.trd.2019.11.024

[16] Michael Arntzen, Aircraft noise calculation and synthesis in a non-standard atmosphere, Proefschrift, ISBN-978-94-6259-464-7, 2014

[17] Aalmoes, den Boer, Veerbeek, Virtual Reality Aircraft Noise Simulation for Community Engagement, *INTERNOISE 18*, Chicago, IL, pages 994 - 1998, pp. 1559-1566(8), 2018.

[18] Fastl, H.,Zwicker, E., Psycho-acoustics, facts and models, third edition, *Springer series*, 2007.

[19] Weinstein, N. D. (1978). Individual differences in reactions to noise: A longitudinal study in a college dormitory. *Journal of Applied Psychology*, *63*(4), 458–466. https://doi.org/10.1037/0021-9010.63.4.458