The Effects of Emerging Technology Aviation Noise on Humans

CAP 2962

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Chapter 1
Introduction

1.1 The presence of emerging aviation technologies is an expanding area of aviation and includes vehicles such as Unmanned Aviation Systems (UAS) which are also known as drones[1], and Urban Air Mobility (UAM) aircraft, including air taxis, sometimes referred to as Unmanned Aerial vehicles (UAVs) and electric Vertical Take-Off and Landing vehicles (eVTOLs). This new technology has several potential uses, for example aerial mapping and photography, military surveillance, search and rescue, delivery, and air taxis amongst many others. This presents new challenges for noise legislation and understanding of how these types of noise sources may impact people on the ground. In 2023 the CAA published CAP report 2505, which provided an overview of the current knowledge on the impacts of such emerging technology noise on humans over the past few years to the start of 2023. This CAP report is an update to CAP 2505 and provides an update from the past year on the current knowledge around potential human impacts from noise generated by emerging flight technologies.

1.2 The scope of this report does not cover the effects on humans from spaceflight vehicles, which is covered separately.

[1] Although *UAS* is the regulatory term used by the CAA, there are various other terms in use within the sector for these types of aircraft. This is evident in the range of terminology used by the authors of the papers and studies which are summarised in this report.

Chapter 2

Internoise 2023

2.1 Internoise 2023 was held in Chiba, Toyko and this chapter describes some of the findings pertinent to eVTOL noise impacts that were presented at this meeting.

2.2 **Bauer** presented some initial findings from a realistic Urban Air Mobility (UAM) use-case study on community annoyance at a German vertiport with changing approach and departure paths for UAM aircrafts. The rationale for this study is the novel nature of the noise impacts from UAM. It is not fully understood how noise from these aircrafts will be perceived by local communities and therefore how the human impacts will present. A community in Greater Munich was chosen as the study population and the vertiport was located south of the town centre, inside a business park which includes a suburban railway station. The vertiport will be connected to 5 sites in the neighbourhood which are mainly of relevance for business related travels.

2.3 Two different air taxi types were included in the study: a tilt-wing propeller driven aircraft with higher cruise altitude and longer range, and a multicopter-type for shorter range and lower cruise level. The vertiport is set on top of a building at about 20 metres above the ground. In total, 189 air-taxi movements per day are expected, with about 10% operated during the evening hours (6 p.m. to 10 p.m.) and no flights during the night. Table 1 indicates the details of the flights included in the study.

Table 1: Vertiport connections (flight paths) and main parameters

Vertiport	Distance [km]	Cruise level [m]	Travel time [min]	Air-taxi type	Movements per day
1	63.8	1,500	28.4	tilt-wing	25
2	46.0	1,500	22.4	tilt-wing	40
3	21.8	500	14.4	multicopter	37
4	42.5	1,500	21.3	tilt-wing	58
5	15.4	500	11.2	multicopter	29

2.4 Two different departing and approach paths were studied; firstly a 6° slope for departing and approach to the vertiport, (also a first optimisation, where the flightpaths were adjusted to avoid flight over the town centre) and the second option of a steeper descent and climb procedure, allowing the air-taxi to increase or reduce altitude quickly, and therefore mitigate the noise heard on the ground. This is illustrated in Figure 1:

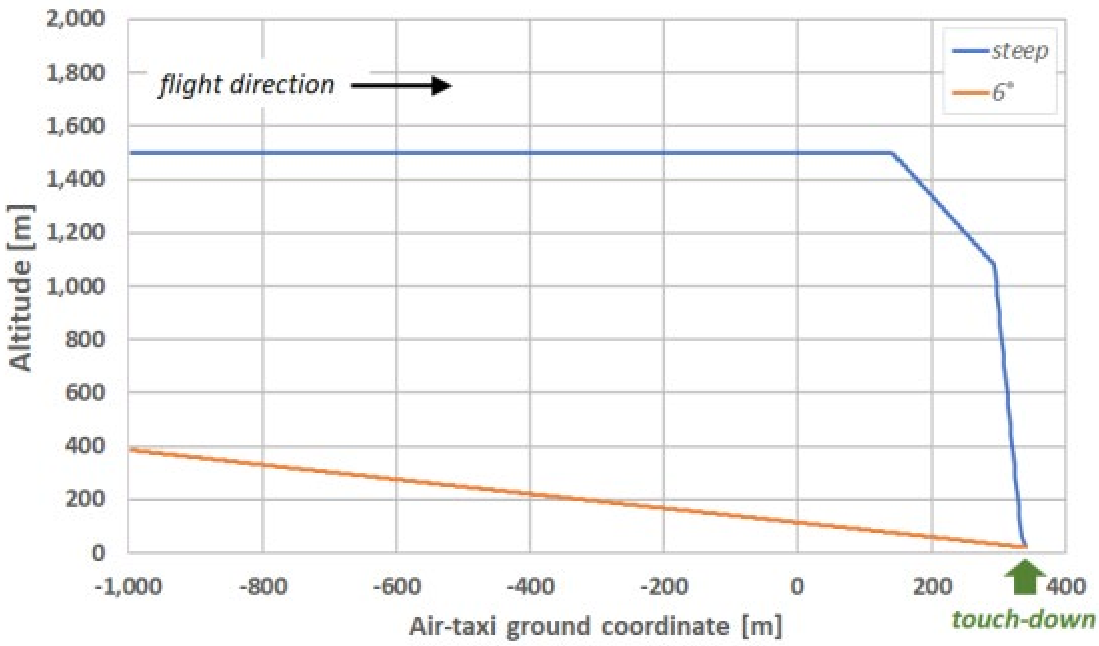

Figure 1: Flat and steep flightpath profiles

2.5 Use-case noise simulations were generated for the various fight routes, air taxi type, noise characteristics and movement numbers for the area of the whole town of Kirchheim, and the resulting noise maps were produced (Figure 2).

Figure 2: A-weighted L_{den} noise maps for the town area, showing the L_{den} for a) the baseline scenario (6° slope), b) the optimised baseline and c) the steep approach and climb.

2.6 The simulations also calculated the estimated community annoyance, based on Community Tolerance Levels (CTL)[2] for aircraft noise, for each of the virtual microphone locations within the town. The authors used a CTL of 50 dB L_{den} for

[2] CTL is defined as the day-night sound level at which 50% of the people in a particular community are predicted to be highly annoyed by noise exposure.

residential areas, and 60 dB L_{den}, for those areas which comprise mainly business and industrial sites within the study area. Table 2 illustrates the percentage of highly annoyed residents in the simulated study area.

Table 2: Percentage of highly annoyed residents in the ratio of computation area (in %)

% highly annoyed	6° slope	6° optimized	steep path
0-10	37.1	47.7	80.6
10-20	43.8	34.7	16.1
20-30	14.4	13.1	2.7
30-40	4.0	3.9	0.5
40-50	0.7	0.7	0.2
highly annoyed residents (total)	13.7	12.5	7.4

2.7 The authors explain that the simulation figures suggest that the change from baseline to an optimised 6° route reduced the annoyance, which is a result of flying over areas with higher CTL. The steep trajectories result in an additional reduction of the number of overall annoyed residents. When calculated over all of the simulated areas, around 1.2% people are less annoyed when experiencing the optimised 6° slope path, but the steep trajectories reduce this by more than 6%, again compared to the 6° baseline.

2.8 The authors conclude by stressing that a change of the flight paths' positioning alone does not reduce the community noise dramatically. Only flying on steeper approach/departure pathways impacts the noise levels to a significant extent, and this is also echoed in the results for annoyance among residents.

2.9 **Kim et al** presented findings from a study into physiological responses to drone noise in a laboratory setting. This Korean study used recorded data from hovering drones. The study aimed to assess the physiological responses from participants when they were exposed to two different types of drone noise with varying frequency characteristics.

2.10 The first was the DJI Spark 2 model weighing 0.3 kg and exhibiting a peak frequency characteristic between 350 to 380 Hz. The second was the DJI M30 model, weighing 3.77kg and a peak frequency at approximately 130 Hz. The sound pressure levels of the test stimuli ranged from 40 dBA to 80 dBA in 10 dB increments. The experiment was conducted in a soundproof booth, and visual information on the drones was provided using an immersive head-mounted display.

2.11 Physiological responses were recorded using a 14-channel electroencephalogram (EEG) device and a wrist-worn device that monitored

Heart Rate (HR), inter-beat interval (IBI) from blood volume pulse (BVP) signals, electrodermal activity (EDA), and skin temperature as well as EEG recordings. The experiment involved two subjects wearing the physiological data collection devices in the auditory test room. They were exposed to drone noise stimuli of 30 seconds in duration. A one-minute relaxation period was provided between each noise presentation for recovery.

2.12 Four participants were studied in this pilot. In terms of EEG (brain activity) results, no significant differences were observed between drone noise levels or types of drone noise presented as background noise. However, the EEG reading at the F4 point in the frontal lobe tended to increase significantly when visual information was presented.

2.13 There were no significant changes observed in response to either the noise or visual information presentation for EDA, HR and IBI. The authors explain that they aim to conduct a larger study to collect meaningful physiological responses to stimuli presented through repeated measurements in future.

2.14 **Jeon et al** presented findings on subjective responses such as annoyance, using the same immersive experience as described in the study above. Five drone noise samples with varying spectral features were gathered through field measurements and presented to subjects through headphones in an auditory test room, adjusting the sound pressure levels and considering the listener's distance from the drone. The weight of the selected drones varied from a minimum of 0.3 kg to 50 kg. The presentation of images and videos of the hovering drones aimed to enhance the immersive experience of the subjects.

2.15 The presented Sound Pressure Levels ranged from 40 dBA to 80 dBA in 5 dB increments, randomly presented to the participants. The participants evaluated loudness, noisiness, and annoyance on an 11-point scale.

2.16 The results indicated that both loudness and noisiness showed a proportional relationship with the presented sound pressure level, with correlation coefficients of 0.97 ($p<0.01$) for both measures. The results from the 11-point scale indicated that the average rating for Loudness was 4.94, while the average rating for Noisiness was 5.10. The authors explain that this suggests that the perceived noisiness of drone noise is slightly higher than the perceived loudness of the drone noises.

2.17 The annoyance results indicated a proportional relationship with presented sound level. The average rating of annoyance on the 11-point scale when only auditory information was presented was 5.75. When visual information was presented with the sound, it slightly decreased to 5.54. The percentage of Highly Annoyed was calculated (3 of 11 participants) and logistic regression applied in relation to drone noise with and without the presentation of additional visual information (Figure 3).

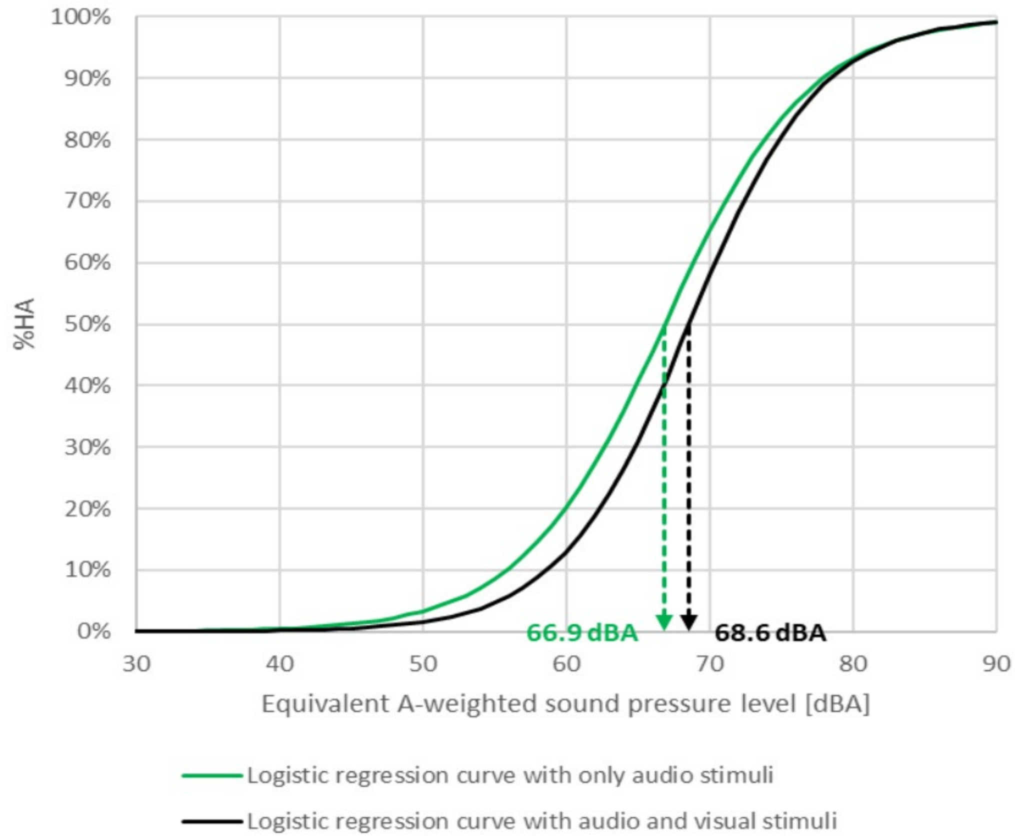

Figure 3: Logistic regression curves of percentage of highly annoyed (%HA) with and without visual stimuli

2.18 The results suggest that the annoyance for drone noise slightly decreases with the addition of visual information. The noise level SPL corresponding to 50% %HA was 66.9 dBA when only auditory information was presented and increased to 68.6 dBA when visual information was provided. This suggests the impact of showing participants a visual representation of the noise source along with the noise level, could be further explored.

2.19 **Thomas et al** presented the methodology for an online listening test study on the public perception of the sound of medical delivery drones in Scotland. This study was led by Arup, London and was part of The Care and Equity Logistics UAS Scotland (CAELUS) project, which aims to establish the United Kingdom's first medical distribution network using drones. The specific goal is to establish a drone network for medical delivery purposes such as blood, medication, test products etc in remote areas of Scotland, and improve delivery between urban and rural areas.

2.20 The authors engaged with various stakeholders when designing the methodology, including the CAA, Defra, academic researchers and policy advisors, The initial discussions with these stakeholders revealed the existing issues surrounding the knowledge on the impacts of such new technology on people. Some of the issues raised included:

- (UAS – unmanned aerial systems) are unknown and new noise sources, with an unknown evidence base on the impacts of UAS noise and health outcomes.
- There may be a need for additional metrics in order to capture the unique sound characteristics of these vehicles.
- Background noise, masking issues, number of events and time of day are expected to have an effect on human responses to noise from UAS.
- Variation of perceptions, but medical use vehicles may have more impact in rural areas.
- There should be different policies for different uses. It is expected that perception will vary with use (more acceptance of medical use versus parcel delivery).
- A requirement for national guidance and regulation on traceability.
- Operational procedures could be used to mitigate noise.

2.21 The design of the experiment allows for examination of altitude or distance variables within the ambient soundscape environment, versus the three dependent variables of interest:

- Audibility: “How audible is the sound of the drone within the existing sound environment?”
- Change to soundscape character: “How much does the sound of the drone change the character of the existing sound environment?”
- Annoyance: “To what extent are you bothered, annoyed or disturbed by the sound of the drone?”

2.22 The paper details the distances used within the study. For the overflights experiment, the drone sound was simulated for pass-bys at three altitudes: 60m, 90m, and 120m. For the take-off experiment, the horizontal distance of the listener from the drone take-off point was simulated at 30m, 60m, and 120m. These altitudes / distances were chosen based on anticipated operating altitudes of drones in various settings. Three different acoustic environments were used to simulate a range of soundscapes likely to be experienced across rural Scotland that could be impacted by the drone operations. These soundscapes are described as:

- Natural / wild - mainly natural sound with little or no anthropogenic sound
- Rural / village - natural sounds mixed with some road traffic noise as experienced in villages that are served by the road network

- Suburban town - dominated by anthropogenic sound that may be experienced in a suburban town setting.

The authors detail the auralisations and visualisations that have been developed for each of these conditions. Participants are asked to rate their responses to each of the drone sounds, with respect to the three dependent variables above. A seven-point scale was used, with 1 being the lowest rating and 7 the highest.

2.23 The virtual microphone signals used in the auralisations have been developed based on an analysis of field recordings conducted on a trial drone similar to those proposed to be used by the CAELUS project. Arup's history of developing visualisations to present to participants alongside the sound recordings resulted in the decision to use a simple animation, synchronised to the drone sound recordings to provide extra information to the listener. The importance of being able to present information that shows the variables being demonstrated (ambient soundscape, altitude of drone pass-by, or distance to take off position) in a way that is not location specific, is easily understood, and has a flexibility that can work with the object-based audio approach adopted for the auralisations was stressed by the authors. The development of such an online protocol for obtaining data allows for a greater reach to participants, particularly in rural areas. The authors explain that the study will be made available to the public and advertised in the areas that the CAELUS trials will occur.

Noise-Con 23

2.24 **Green et al** from the University of Salford presented a paper at Noise-Con 23, on the measurement and human response to noise from unmanned aircraft systems (UAS). The paper describes methodology and data from a field study that measured the noise of several UAS at varying speeds and take-off weights. In addition, a listening test experiment was conducted to investigate the subjective response to several UAS operations when the listener was simulated to be either in an indoor or outdoor position. Analysis of the different metrics used revealed which were the best at predicting 'loudness' and annoyance.

2.25 The measurement aspect of this study is described in depth; for the purpose of this review the results of the listening test are focussed on. Perceived annoyance (PA) and perceived loudness (PL) were assessed for drones performing different operations with the listener positioned outdoors or indoors with a window partially open or closed. The four types of aircraft measured are detailed in Table 3:

Table 3: Specifications of the UAS used within the Listening Experiment

Multirotor Aircraft Models	Number of rotors	UAS Weight (kg)	MTOW* (kg)
Gryphon Dynamics GD28X	8 (4 contra-rotating pairs)	24.9	31.7
DJI M200	4	4.0	6.1
Yuneec Typhoon	6	1.9	2.4

2.26 Four operations were included within this experiment (hovering, fast flyover [15 m/s], take-off and landing). The authors detail the measurements for these operations: *For these field measurements, the microphone was mounted on a tripod at 1.2m above ground. For flyover operations, the microphone was positioned directly underneath the flightpath with the UAS operating at an altitude of 150 feet above the ground (~47.5m). For take-off measurements, the UAS flew to an altitude of 150 feet with a vertical ascent, then proceeded to move away from the measurement position until barely audible, the landing measurements followed the same process but in reverse. For hover measurements, the drone hovered at an altitude of 4 feet (1.2m) above the ground, held the position for 30 seconds and then rotated 90 degrees. For the take-off, landing and hover measurements the distance between the microphone and take-off/landing point was 30 feet (9.1m) from the microphone position.*

2.27 In order to simulate the sound through a building façade, test data from 'NANR116: Sound Insulation Through Ventilated Domestic Windows' was applied to the audio files. It is explained that the measurements presented within NANR116 are laboratory measurements but the receive room was designed to represent a typical residential living room in terms of room dimensions and reverberation time.

2.28 The experiment and calibration were both conducted within the 'Listening Room' at the University of Salford. 30 participants were included, (73% male) with the majority in the age range 18 – 24 (37%) or 25 – 34 (30%). The interface for the experiments is shown in Figure 4, with the scales for PA and PL shown with values 0 -11.

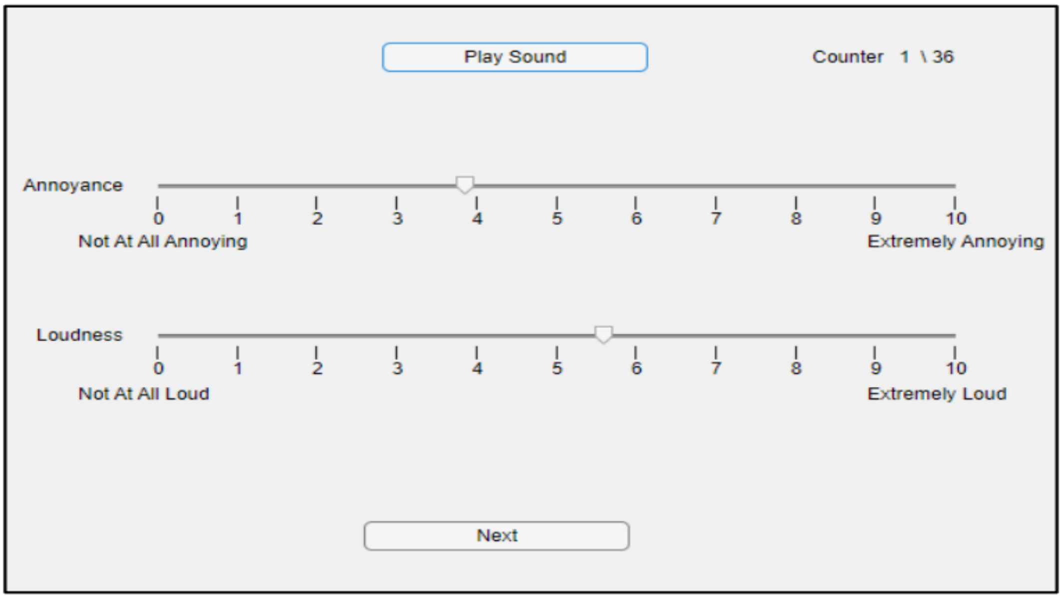

Figure 4: Listening Experiment Interface

2.29 Participants' responses were most annoying and loudest when hearing the noise from an outside location, followed by inside with a partially open window and inside with a closed window producing the lowest responses in each case. Figures 5 and 6 show the annoyance and loudness data when grouped by UAS operation.

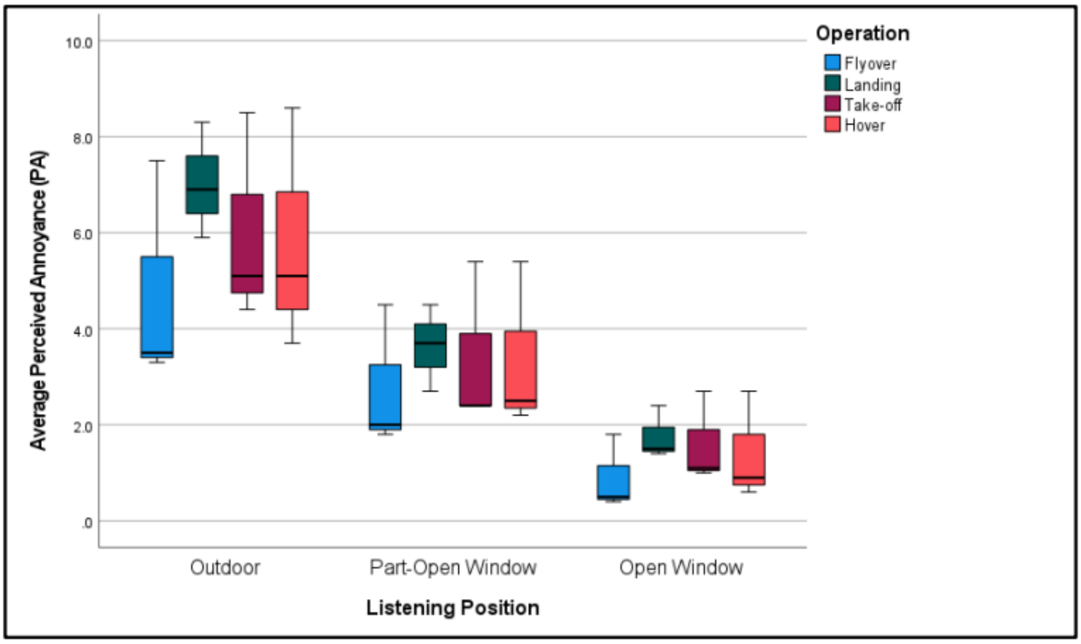

Figure 5: Participant Responses – Annoyance as a function of UAS operation

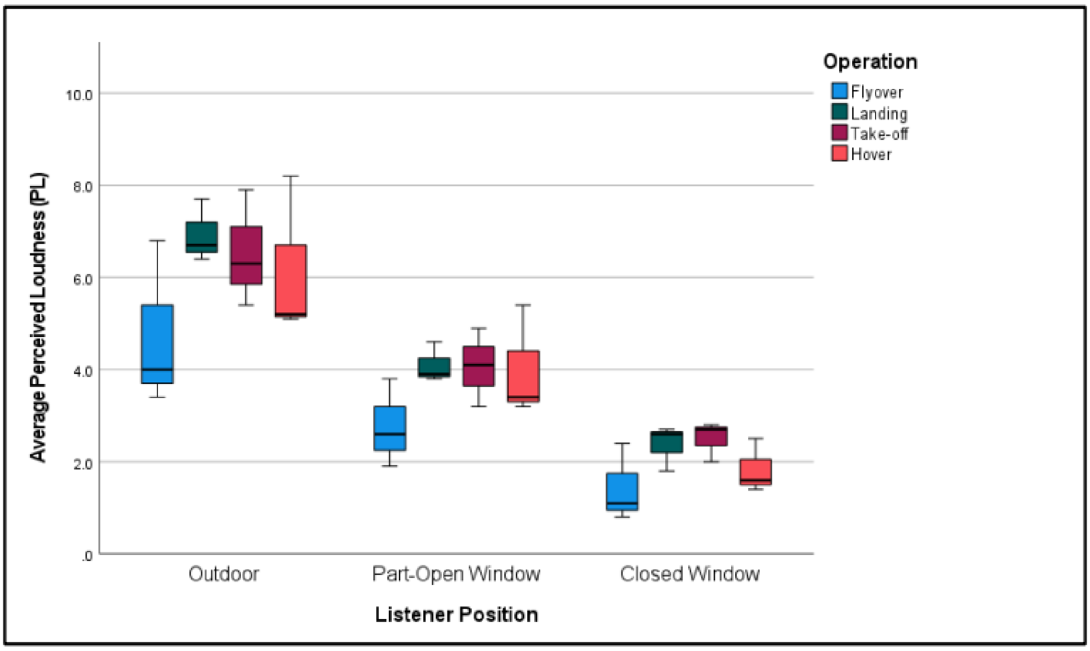

Figure 6: Participant Responses – Loudness as a function of UAS operation

2.30 For PA it is observed that the landing operation is rated as the most annoying for each listener position, and the flyover is the least annoying in each case. Similar responses are seen for PL, but for indoor positions the data is more closely grouped for the landing and take-off positions, with median PL of the take-off operation being perceived as slightly louder.

2.31 In order to understand the metrics that best predict the PA and PL, the authors modelled L_{Aeq}, L_{ASmax} and L_{AE} along with other metrics such as Perceived Noise Level (PNL), Effective Perceived Noise Level (EPNL) and the Sound Quality Metric (SQM) Loudness. The results of regression analysis indicated that the SQM Loudness was the best performing metric for predicting PA with an adjusted R^2 value of 0.96. L_{Aeq} and L_{ASmax} scored marginally lower with adjusted R^2 values of 0.93. For modelling PL, L_{ASMax}, L_{Aeq} and loudness all scored adjusted R^2 values of 0.90. EPNL scored slightly lower with 0.89, PNL with 0.88 and L_{AE} the lowest with 0.80. The authors concluded that based on these results, there appears to be a small benefit to using Loudness over L_{Aeq} or L_{Amax} but all of these three metrics performed well and could be considered good indicators of PA and PL.

Chapter 3
Other Publications

3.1 There have been several other publications on the human impacts of emerging technology aircraft noise over the past twelve months. Many of these focus on the public acceptance of any proposed movements, and the arising considerations around this.

3.2 **Silva et al** published findings on attitudes towards UAM for e-commerce deliveries in three European regions. The aim of the study was to research people's attitudes towards the use of drones for e-commerce deliveries by analysing non-expert opinions of potential users and their online shopping habits. The research also included a survey that investigates links between societal acceptance, technology, and integration of UAM into urban life.

3.3 The authors explain that although there have been previous studies on UAM acceptance, their literature review highlighted the need for further studies to overcome the issues related to negative public perception by engaging the prospective users in the co-creation of UAM-enabled services. Previous findings have indicated that attitudes vary from one region to another due to economic, lifestyle, and cultural differences. This study used an online questionnaire with three parts:

- Socio-demographic characterisation
- Attitudes towards online shopping and home delivery services
- Acceptance of UAM technology and UAM delivery services.

3.4 Data was collected in Portugal (N = 300), Poland (N = 500) and Italy (N = 125). The Portugal study population comprised 72% from some of the most populated areas of the country (Porto, Aveiro, Braga, and Coimbra). The results indicated significant differences between Portugal, Poland, and Italy. Portuguese and Polish respondents displayed the least knowledge about drone delivery services, whereas a majority of Italians were quite aware of drone deliveries (83%). Portuguese and Polish respondents are willing to pay more if the solution is more flexible than other delivery modes. In general, regardless of the acceptance of drone delivery services, the authors found a positive attitude towards drone use in the city centres, especially among the Portuguese respondents, with the most significant expected benefits being lower congestion and pollution levels. Italians are the most supportive of public investment in these services and more open to have their home overflown by drones.

3.5 The authors also used cluster analysis[3] to further examine the data from Portugal and Poland in terms of participants' classification of drones according to shopping habits and potential acceptance. The cluster analysis in these two of the three regions revealed an evident low-acceptance group and an evident high-acceptance group, with a third group positioned in the middle. This group presented serious concerns, but at the same time was open-minded. Low-acceptance clusters were characterised in both cases by females and people who do not typically shop online, while high-acceptance clusters were frequent online shoppers. The Polish respondents were more extreme in their attitudes (more negative and more positive) than the Portuguese sample. Figure 7 shows clusters in relation to the willingness-to-pay an additional fee for drone delivery and the openness to public investment in UAM infrastructure.

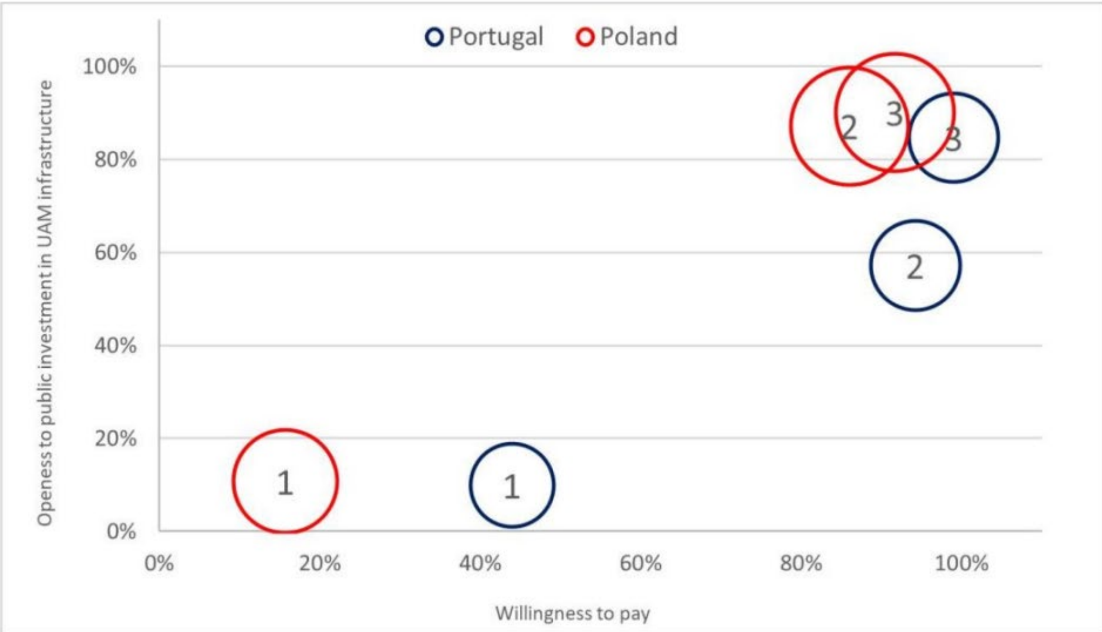

Figure 7: Willingness to pay versus openness to public investment.

3.6 The authors explain that the results indicate that in both regions, cluster 1 (low acceptance) shares similar views on public investment, but the willingness-to-pay is much higher in Portuguese respondents. The Polish cluster representing potential acceptance is more open to public investment than its Portuguese counterpart (cluster 2).

3.7 The high-acceptance clusters (cluster 3) are more similar in both regions in relation to the chosen variables, as can be seen by the overlap between both

[3] Cluster analysis is used in research to group a set of objects or observations into subsets called clusters. The goal of cluster analysis is to identify inherent patterns, similarities, or relationships within the data, by organising the objects in a way that objects within the same cluster are more similar to each other than to those in other clusters.

clusters 3. Additionally, in the Polish sample, the potential-acceptance cluster is similar to the high-acceptance one, which makes it also very close to the high-acceptance Portuguese cluster regarding public investment and willingness-to-pay.

3.8 The authors suggest that studies of this type are useful for planning the implementation of drone use and that individuals in the low acceptance clusters can be targeted specifically in terms of marketing and design features. In addition, policymakers must address their specific concerns and objections and aim to mitigate the negative impacts of UAM. It is suggested that future research can examine the safety perceptions of people on the ground, and the perceptions towards medical usage drones which tend to evoke higher acceptance rates.

3.9 **Boucher et al** published research from the Langley NASA research centre on a psychoacoustic test for UAM vehicle sound quality. The aim of the study was to investigate what people may find annoying about the type of sound produced by UAM vehicles. It is explained that this study seeks to address some technical challenges such as:

- in the absence of a database of recordings, how can UAM noise stimuli be generated for use in a psychoacoustic test?
- how can these stimuli be designed to span a significant range of sound quality?
- how can a psychoacoustic test be conducted to test sound quality factors that may contribute to annoyance?

3.10 The authors describe how such challenges are approached in this study, and the aims of the research which focused on how sound quality of UAM vehicle noise affects perceived annoyance, assuming that loudness is the dominant factor. Specific research questions were:

1. What is the relative difference between effects of loudness alone and effects due to a combination of other sound quality characteristics?
2. In terms of sound quality other than loudness, what are some of the important factors influencing annoyance responses to UAM noise?

3.11 Forty participants were exposed to 136 unique UAM rotor noise stimuli, each lasting 4.6 seconds. These simulations allowed for changes to rotor noise parameters such as the blade passage frequency, the relative level of broadband noise, and the relative level of tonal motor noise. The loudness level was kept at a constant, so the sound quality parameters could be altered, and the responses measured.

3.12 In addition, a subset of the UAM noise stimuli were compared to a reference sound that varied in loudness. From these responses, the relative effect of changes in loudness or changes in other sound quality metrics on annoyance was evaluated by the authors. The test was divided into two parts to measure subjective annoyance to UAM noise:

- annoyance ratings on an 11-point scale to 136 unique UAM noise stimuli of equal loudness and
- annoyance comparisons between a subset of UAM noise stimuli of equal loudness and a reference sound that varied in loudness.

3.13 The authors found that the equal annoyance point between the reference sound and the UAM noise stimuli occurred when the reference was 3.3 sones (approximately 6.3 dB) higher than the UAM noise stimuli. The reference sound had some temporal variations removed, which suggested that some annoying aspects of UAM noise were missing in the bland reference sound and that loudness is not the only sound quality that is important for the subjective rating of UAM noise.

3.14 Further examination revealed the importance of sharpness, tonality and impulsiveness in the perception of UAM sound. Sharpness is a measure of spectral balance; it increases if acoustic energy is concentrated at higher frequencies. Tonality is a measure of sound quality that correlates to how humans perceive the tonal components of sound. Impulsiveness is the perceptual effect resulting from sudden changes in sound intensity. High tonality and impulsiveness both resulted in higher annoyance responses. Conversely, high sharpness levels reduced annoyance, which was unexpected. The authors explain the significant interactions between these variables. When impulsiveness and tonality both increased, annoyance responses also increased. For low impulsiveness, the annoyance responses increased significantly when tonality is high. Again, higher sharpness was perceived to be less annoying. This is illustrated in Figure 8. The authors concluded that there is a need for psychoacoustic models that account for tonality and impulsiveness in research into annoyance responses from UAM vehicles, to enable these characteristics of noise and how they interact with annoyance to be further understood in this context.

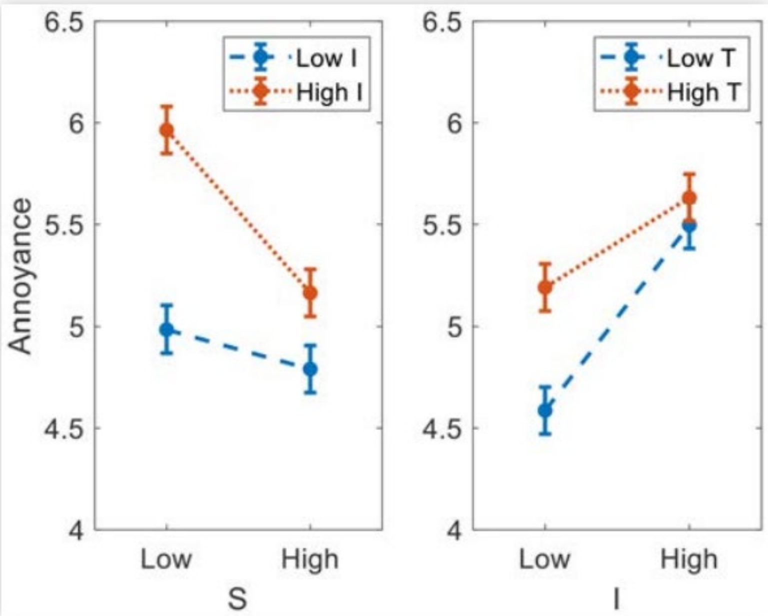

Figure 8: Significant interaction effects contributing to annoyance when considering sharpness (S), tonality (T), impulsiveness (I) and fluctuation strength (F) (not significant).

3.15 As part of their paper questioning whether UAM can become a reality, **Pak et al** included a discussion on public acceptance. The aim of the paper was to provide an overview of selected key research topics related to UAM and how the German Aerospace Center (DLR) contributed to this research in the project "HorizonUAM - Urban Air Mobility Research at the German Aerospace Centre (DLR)"

3.16 The paper provides a section on the potential benefits of UAM, how vertiports may be designed and potential use-cases. In terms of societal acceptance, the design and comparison of cost-benefits are cited as important factors. Figure 9 displays how systematically comparing benefits and costs, the efficiency, sustainability, and societal impact of different configurations of system components can be evaluated.

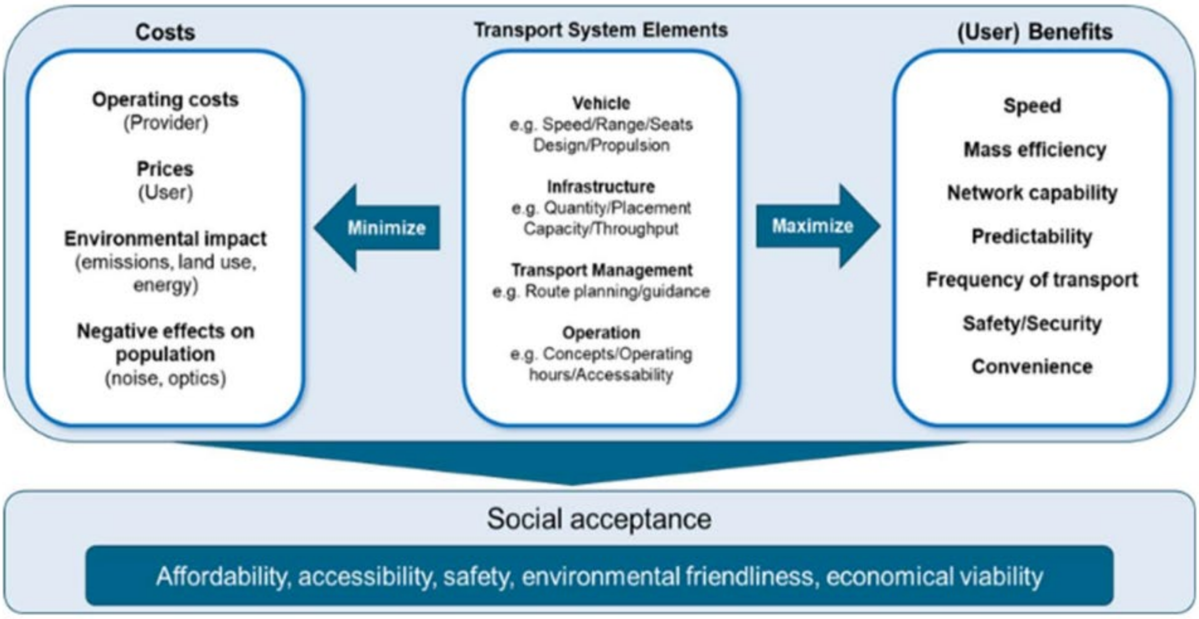

Figure 9: Social acceptance resulting from balancing the costs and benefits of a transportation system.

3.17 The paper cites that there are three aspects of social acceptance as previously stated by Wüstenhagen (2007). They are socio-political acceptance, community acceptance, and market acceptance. Socio-political acceptance refers to the social acceptance of technologies and policies by the public, key stakeholders, and policy makers at the broadest and most general level. The specific acceptance by local stakeholders, such as potential users, non-users and local authorities, is referred to as community acceptance. The third aspect is market acceptance, which is shown by the adoption of new products by consumers and investors' acceptance.

3.18 As part of the HorizonUAM study, to examine the risks and benefits of UAM, a large-scale telephone survey was conducted in 2002 and included 1001 participants to determine current opinions of the German population on civilian drones and air taxis. The results suggested that civil drones tended to be regarded in quite a positive manner, but this was not the case for air taxis in the survey. Answers regarding the attitude towards air taxis ranged from very negative to very positive. The majority of German residents were concerned about the potential misuse of civil drones for criminal purposes as well as the violation of privacy. Willingness to use air taxis in the future was highest for use cases involving rural areas.

3.19 The paper concluded that social acceptance and in particular community acceptance are essential for the implementation of UAM in many societies. The concerns around noise, safety, energy consumption, visual pollution and land use will need to be addressed. The authors also stressed the importance of community engagement and tailoring the information to all audiences for transparency. Real, live demonstrations are recommended to increase the familiarity with UAM in the general public.

3.20 The results from the telephone survey in this study were explained in more detail in a paper by **End et al**. In terms of civilian drones, the highest level of agreement was found for civil protection (e.g., monitoring flood spread), followed by rescue operations (e.g., police, fire brigade), and research (e.g., nature observation). The lowest level of agreement was found for parcel delivery, leisure and hobbies, and taking photos and videos for advertising purposes. 75% of the respondents fully (32%) or somewhat (43%) agreed that civilian drones should be allowed to fly over their homes for the purposes they agreed on. Regulations or restrictions were rated as most important for night-time and residential areas.

3.21 When asked the question: “Please tell me to what extent you are personally concerned about the following aspects. (Very concerned/ rather concerned/ rather not concerned/ not concerned at all; %)The potential for misuse for criminal purposes and violation of privacy were most common among given answers regarding concerns, while noise concerns were least common. This is shown in Figure 10.

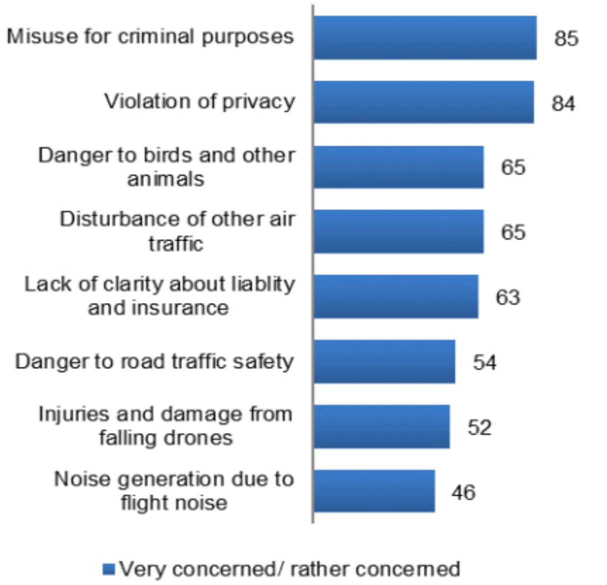

Figure 10: Concerns about civilian drones

3.22 In terms of air taxis, attitudes were relatively balanced, with more very negative than very positive responses. The extent to which respondents expected air taxis to bring benefits for the population was relatively balanced (18% great benefit, 33% some benefit, 27% little benefit, 21% no benefit at all). However, most respondents anticipated air taxis to bring at least some risk for the population. Willingness to use an air taxi was most widespread for use cases within a rural area and between a rural area and a big city.

3.23 The statistical analysis for urban drones revealed the youngest generation Z (18-26 years) had a significantly more positive attitude towards civilian drones than generation Y (27 to 42 years) and the generation 59-77 years. Women had a significantly less positive attitude towards civilian drones compared to men. For income, people who rated their income to be more than needed had a significantly more positive attitude towards drones than those who rated their income to be approximately as needed. People who had active experience with drones (had flown a drone) had a significantly more positive attitude towards civilian drones than those with passive or no experience of drones. Participants who were more informed had a significantly more positive attitude towards civilian drones, than those who weren't.

3.24 For noise sensitivity, participants with a higher sensitivity had a significantly less positive attitude towards drones compared to those with a lower sensitivity, and for annoyance, the more people felt annoyed by noise in general the less positive their attitude towards civilian drones was.

3.25 For air taxis, as with civilian drones, women were more negative in their attitudes compared to men. For age, participants aged 18-26 years displayed significantly more positive attitude towards air taxis than 78+ years, and generation 27 to 42 years had a significantly more positive attitude towards air taxis than the 78+ year generation and the 59-77 years group. With regard to income, the participants who rated their income to be more than needed had a significantly more positive attitude towards air taxis than those who rated their income to be approximately as needed. The same results for experience and knowledge with civilian drones was found for air taxis; participants who had active experience with civilian drones (had flown a drone) had a significantly more positive attitude towards air taxis than those with passive or no experience. People with higher noise sensitivity had a significantly more negative attitude compared to people with lower noise sensitivity. Participants who responded they were not annoyed at all had a significantly more positive attitude towards air taxis than people who felt somewhat annoyed by noise in general. People with a strong interest in environmental protection had a significantly more negative attitude compared to those who were not strongly interested. The authors found that the presence of dense road or railway traffic at the residential location, nor the presence of audible aircraft traffic in daily life were shown to have a significant influence on the attitudes towards civilian drones or air taxis in the current study.

3.26 **Bretin et al** published a paper on proximity, stress and discomfort in human-drone interaction in real and virtual environments. This study was focussed on social drones rather than UAM vehicles or drones used for medical assistance, or deliveries, and explored the effect of proximity to people on wellbeing. The study also examined the use of virtual reality (VR) and whether the use of VR altered the results of human-drone proxemic experiments. Proxemics is the study of personal space and the degree of separation that individuals maintain between each other in social situations. Participants' perceived stress between a resting baseline and different flying conditions (static far, approach, and static close) for two drone speed conditions (1 m/s, 0.25m/s) were compared. Participants perceived threat level was also assessed after each speed condition. This method allowed for the authors to identify whether a flying drone induces any perceived stress and if its state (approaching, static), proximity (close, far), and speed can modulate it. It also allowed for investigation of the association between the stress induced by the drone and its threat level.

3.27 The participants were also asked to rate their level of discomfort and how ideal the current drone position was for different locations (from 40 cm to 450 cm from the participant). This allowed for investigation and understanding of participants' proxemic preferences and the ability to map how discomfort varied with the distance of the drone. Participants (N = 42) were split into two groups; one experiencing VR and one in a real-world setting.

3.28 The authors found that a drone's state and location can induce significant stress among participants, and that these factors also correlate with the drone's perceived level of threat. No significant effect of the drone's speed or the environment (VR versus real-world) was found on participants' stress, discomfort, and distance ratings.

3.29 While participants reported the drone's speed as an important factor for the threat assessment, it had no significant effect on stress, threat perception, or discomfort. Less than 50% of them noticed the drone going 4 times faster or slower between the conditions, although the resting period between the presentation of each condition may have had an effect. The proximity of the drone was associated with increased stress and discomfort.

3.30 The authors concluded that these findings can be related to the real-world use of drones, such as search and rescue or police operations. Such situations may already be stressful for the people involved, and they may feel anxious, distressed or threatened. The results from this study confirm that it is important to prevent potential drone interactions from causing further discomfort or distress.

3.31 **Thomas et al** investigated the quantification of visual pollution from UAM. The authors developed a quantitative measure that can calculate the visual pollution from one or multiple Urban Air Vehicles (UAVs). An image-based questionnaire was also used to investigate relationships between the factors relating to visual pollution. The results indicated that visual pollution increases with the number of UAVs and when the distance to the UAV decreases, and that respondents are more likely to accept a higher level of visual pollution from UAVs used in emergency situations. People seemed to be more accepting of visual pollution in an urban environment rather than a rural one, and respondents with a negative opinion about UAVs gave higher visual pollution scores.

3.32 The authors suggest that future research could include investigation of how visual pollution and noise interact and how the UAV moves through the air can affect visual pollution.

3.33 **Brents et al** published findings from a study on the intention to complain about UAS. The goal of the research was to identify factors that influence, and how they influence, intention to complain about UAS noise. The Theory of Planned Behaviour[4] (TPB) and the Technology Acceptance Model[5] (TAM) were used to obtain eight factors relating to the intention to complain about UAS noise within a cross-sectional survey. Five factors were found to significantly influence the intention to complain about UAS noise: attitude, subjective norms, perceived usefulness, perceptions of risk to safety, and familiarity. The results indicated that attitude and subjective norms were the most influential factors, and the authors suggest this highlights the need for UAS stakeholders to engage with the public regarding issues around the use of UAS in order to minimise complaints.

3.34 **Stoltz et al** used a mixed method approach to investigate public perceptions of drones. Mixed method approaches combine qualitative and quantitative methods to examine complex topics. Twenty participants were included in the study, which consisted of a virtual simulation to investigate the visual perception of drone flights in an urban setting (quantitatively measured). The qualitative element to the study involved a team task with participants asked to give their thoughts on controlling and co-ordinating drone traffic in a socially acceptable way. The participants also discussed their attitudes, perceived risks, and benefits of different drone use cases such as civil protection, parcel delivery, and air taxis.

3.35 The paper discusses the TAM as a means of predicting the acceptance and use of new technologies. It is explained that although this model incorporates the willingness to use, in the case of drones most people will not be the actual operators, but more likely will be overflown. Therefore, in addition to TAM, the authors suggest that a model developed by Chamata and Winterton may be a more appropriate model of drone acceptability. They adapted the TAM with respect to the risk assessment of drone operations (Left part of Figure 11). The also added a transparency factor, with the phrase ‘technology acceptance’ included in the model.

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[4] TPB maintains that three core components, namely, attitude, subjective norms, and perceived behavioural control, together shape an individual's behavioural intentions.

[5] TAM is an information systems theory that models how users come to accept and use a technology.

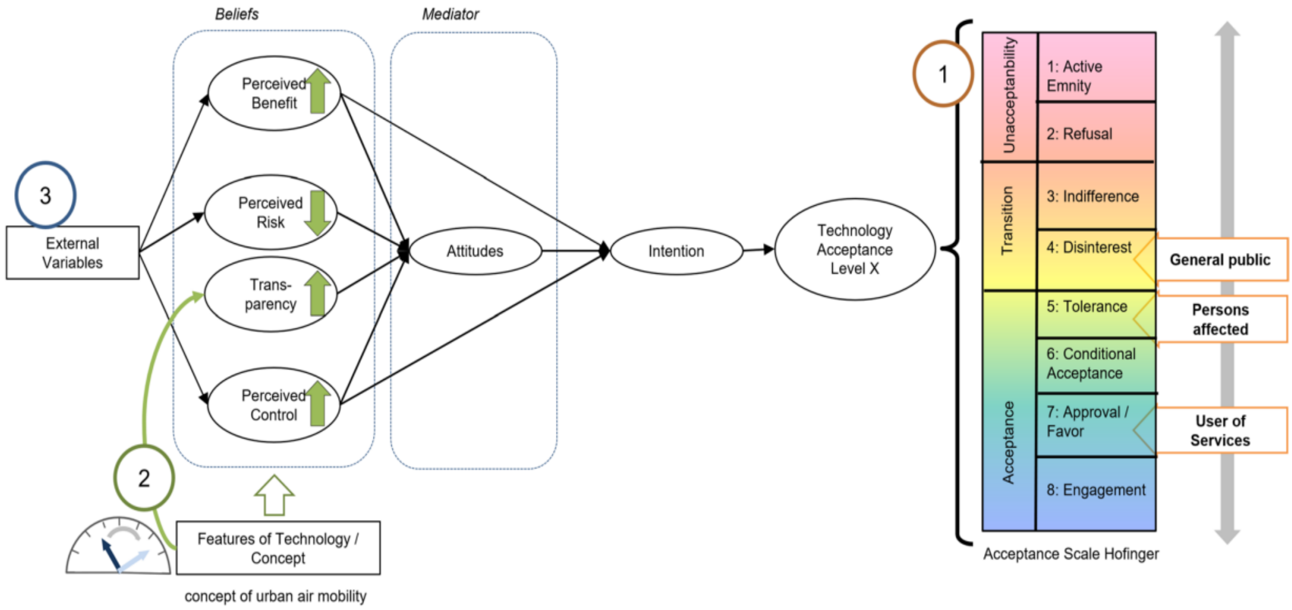

Figure 11: Proposal for acceptance in developing a traffic management concept for urban drone traffic.

3.36 The right-hand side of Figure 11 illustrates the Unacceptability–Acceptance Scale, developed by Hofinger in 2001, with eight categories that describe acceptance based on behaviour. The authors provide an overview of the various levels and explanations of how people would behave at certain acceptance levels concerning drones is listed in the following:

1. *Active enmity*: Usually, enmity appears through actions. Regarding drones, this might be, e.g., individual active campaigns, stopping drones, or taking legal action against them.
2. *Refusal*: Verbal comments are used to express refusal. When acceptance reaches this level, people criticise drones and refuse to use them.
3. *Indiference:* Neither acceptance nor non-acceptance can be attributed to this level. A reference to drones is made here with both positive and bad connotations.
4. *Disinterest:* People's attitudes toward drones are indifferent; they don't raise any subjective concerns. Again, neither acceptance nor rejection can be assigned in this case. Drones are not a topic of discussion or curiosity among people.
5. *Tolerance:* Acceptance is shallow at this level and results from power initiatives. This might indicate that people are reluctant to use drones despite being required to do so, such as in a professional setting.

6. *Conditional acceptance:* This level denotes a low level of rationally motivated acceptance connected to situations. People would prefer to view the usage of drones as beneficial under specific circumstances.
7. *Approval/favour*: This level equates to a high level of acceptance when the acceptor genuinely believes that the acceptance object is beneficial. Regarding drones, the benefits of the technology exceed the drawbacks. Here, people perceive drones as valuable, and they are very willing to employ them voluntarily.
8. *Engagement:* This level equates to high acceptance, shown by behaviour motivated by internal conviction. People are firmly convinced of the value of drones and actively participate in technology development.

3.37 For the visual simulation part of the experiment, each participant experienced seven scenarios, including the reference scenario, and each three scenarios of the factors of fight altitude and visual density. The sequence was randomised, and participants did not know which scenario they were watching. Each scenario lasted one minute. After each scenario, they were asked to answer the post-run questionnaire.

3.38 The results on altitude indicated that participants did not feel restricted in their behaviour, and they disagreed with the statements relating to feeling watched by drones or feeling disturbed. The authors concluded that the responses to all scenarios did not suggest that participants felt negatively about drones at any time. Regarding visual density, the responses tended to be more negative the more drones were flying in the scenario, but again, the findings indicated that the participants never really felt unpleasant in any of the scenarios.

3.39 The team task and group discussion reveal that all participants voted to use drones for civil protection and research. The feedback on drone use for taking pictures and films, as a hobby, and as an air taxi was neutral or positive. There were about equal numbers of attitudes for positive and negative responses to delivery drones. This data is shown in Figure 12:

3.40 The authors described the findings regarding the acceptance level of different drone applications and found that most of the use cases would require a higher acceptance level on the Hofinger scale. Only civil protection and research scored 7 or above on the scale, with photo and video, air taxis and parcel delivery all scoring 6, with hobby and leisure uses scoring 2-3 indicating refusal, and indifference. The detailed discussion within the focus groups about parcel delivery and passenger transport revealed that acceptance depends on how these services will be implemented and whether society perceives them as beneficial.

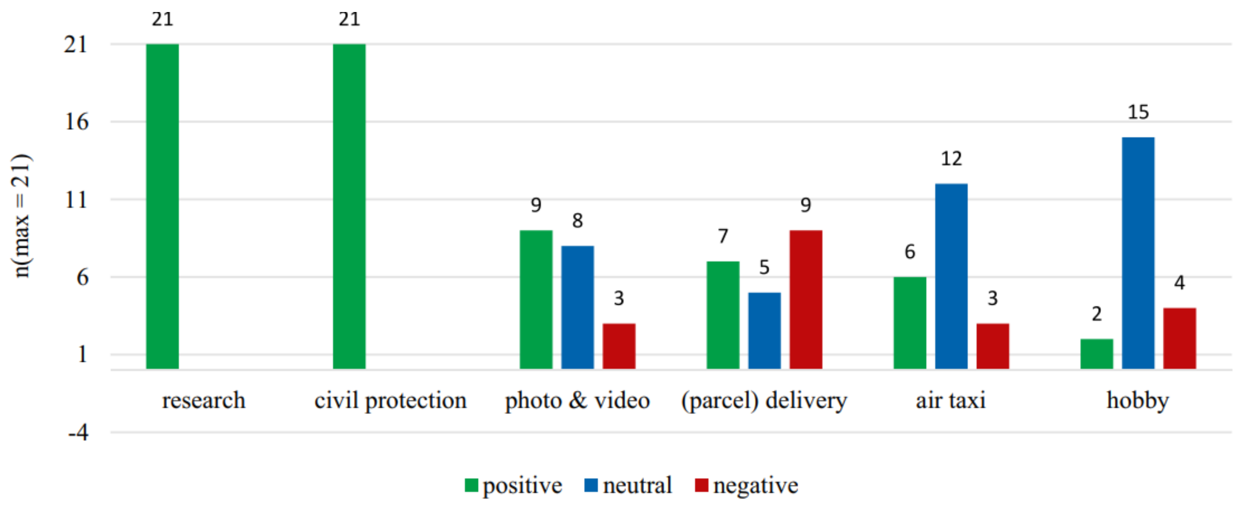

Figure 12: Bar chart with absolute frequencies of positive, neutral, and negative votes related to drone applications, n=21

3.41 The authors concluded that this study provides evidence that this mixed methodology is appropriate for use in drone research in future, and they suggest a preliminary classification of drone use on this scale. Future work requires larger sample sizes and improved simulation design.

3.42 **Sieben et al** presented findings on the psychoacoustic characterisation of drone noise. The study examined drones, helicopters and lawnmowers as previous research has suggested that people find drones more annoying than helicopters, but less annoying than lawnmowers. The aim of this study was to investigate the subjective psychoacoustic elements to these sounds, in order to gain further understanding of the difference in annoyance scores.

3.43 A virtual reality laboratory study with 30 participants examined these noise sources and subsequent annoyance ratings, loudness, threatening, squeakiness and tonality scores on an 11-point scale. Two types of drones, a larger Gryphon GD-40X (140cm motor to motor) drone and a smaller MK Quadro XL (56cm motor to motor) drone, a helicopter, and a lawnmower were presented. The helicopter and both drones were presented as an overhead flyover and normalised to a SEL of 75 dBA. Two urban environments were used, and participants were presented both where the visual model was visible, and others where the visual model was not made visible, resulting in a combination of 26 different conditions.

3.44 The results indicated that for all vehicles, loudness was a strong predictor of annoyance scores. For helicopters and drones, perceived threatening was also a significant contributor to annoyance, while tonality contributed significantly to lawnmower annoyance scores. The visualisation element of the study contributes to the understanding of perceived safety of different drone models, as larger hovering drones were perceived as more threatening than smaller hovering drones, but only when the visual model was presented.

3.45 Perceived squeakiness showed a similar pattern as the annoyance towards the vehicles, where the lawnmower was considered to be most squeaky, followed by the drones and lastly by the helicopter, and squeakiness was not a significant predictor of annoyance scores. The author concluded that noise annoyance research should also include investigation of visual aspects that may subjectively change people's perceived safety. They stress the other aspects of noise such as perceived tonality and safety concerns are important factors in studying the acceptability of emerging technologies such as drones and air taxis.

3.46 **Miron et al** published findings on public drone perception of drone use for emergency service response (police, fire brigade, ambulance service) in a civilian context, whilst capturing how exposure to drone operations may influence and alter perception. The study was located in Isleworth, UK, where two surveys were conducted before and after flight operations (pre-and post-treatment).

3.47 Participants were recruited either through letter with a QR code for people to follow, a Facebook advert which then took them to the online survey, or by filling in the paper survey and posting it back. 239 responses were received (both digitally and via mail) in the first part of the study (April, 2021).

3.48 The survey included15 questions on demographics, risk, security, privacy perceptions, technology acceptance, and perceptions of drones used to support emergency response. All perceptions were measured using a 5-point Likert scale. The take-off and Landing (TOL) site was located approximately 7 km to the east of the eastern end of the southern runway at London Heathrow Airport (LHR).

3.49 The findings indicated that there was no difference in perceptions of using drones for emergencies between the pre- and post-treatment groups. Acceptance of technology and privacy concerns were significant predictors in both groups. Those participants who were less concerned about privacy who already share personal information with public and private actors perceived drones positively for emergency response. The authors also found open-mindedness about new technology positively impacted public perception of drones. In the post-treatment group, three additional statistically significant predictors were found: age category, education level, and exposure to drones.

3.50 The authors address the limitations of the study, being conducted at a time when restrictions due to Covid-19 were in place suggests that a larger scale study is required in a different location without such restrictions, and with the addition of a control group and a larger sample size.

3.51 **Wang et al** conducted a literature review on the societal acceptance of drones between 2010 and 2022. The aim of the review was to identify the acceptance factors associated with urban drones, and areas that have been the focus of attention within the current body of knowledge and those areas which have not been focussed on as much and may be given more consideration in future.

3.52 The final set of 96 articles included in the review consisted of journal articles (75 %), conference papers (22 %), and other types of publications (3 %), such as a data brief, a book chapter, and a technical report. There was a general increase of articles published since 2015, with a higher number in 2022 (nearly 21 %). There was a strong quantitative focus in studying public perceptions, amounting to 52 % of the total set of articles. In terms of research methodology, over 53 % of the studies were quantitative, followed with qualitative methodology (nearly 21 %) and mixed methods (nearly 18 %), as well as literature reviews (over 7 %).

3.53 The authors found the review contained eight categories of drone use purpose:

- Emergency: including natural disaster, search and rescue missions, firefighting.
- Public health: including routine medical delivery, pandemic outbreak control, public health surveillance.
- Public safety and security: including public infrastructure inspection, boarder control surveillance, crime monitoring, law enforcement.
- Agriculture: including precision farming, pesticide spread, crop monitoring, etc., in peri-urban areas.
- Industry and services: including construction or warehouse inspection, consumer goods delivery, transportation of goods or humans.
- Research: including environmental monitoring, earth observation, wildlife management, ecological measurement.
- Journalism: including filmmaking, media production of events, sports and exhibitions, artistic performance of drone light shows.
- Recreation: including hobbies, outdoor explorations, companionship.

3.54 The authors found that noise was a significant concern within the studies in this review, with at least 13 of the studies containing data on annoyance due to drone noise. They stated that a general lack of regulation effectively governing drone noise was observed within this review, whereby the exiting certification measures were perceived as not reflecting the complexity of noise emission of drones. The review highlighted key themes in the acceptance of drone use and the most important topics discussed in the articles concerning societal acceptance of urban drones are shown in Table 4:

Table 3: Thematic classification of societal acceptance factors associated with urban drones.

Cluster	Theme
Technical Factors	Levels of Autonomy
	Technical Risk
	Noise
	Aerodynamics & Design
Operational Factors	Application Type, Purpose & Location
	Dual-use & Mis-use
	Trust, Accountability, Integrity & Transparency
Regulatory Factors	Privacy
	Safety & Security
	Aviation
Economic Factors	Technical Performance & Usefulness
	Intention to Adopt the Technology
	Related Infrastructure & Services
Impact Factors	Environmental Impacts
	Health Impacts
	Quality of Life Impacts
Personal Factors	Socio-Economic Status (SES)
	Emotional & Psychological Readiness
	Technical Knowledge & Competency
External Factors	Media Appropriation & Public Communication
	Peer & Social Group Influence
	Information Source & Influence
	Technical Terminology

3.55 The review discusses each of these factors in detail. It is concluded that the review has highlighted key areas of concerns where most consensus across the literature existed, such as the technical, operational, and regulatory factors. The authors explain that personal and external factors lack scientific research, and therefore would benefit from further work in future.

3.56 **Lotinga et al** published a review of current measurement techniques, psychoacoustics, metrics and regulation in relation to noise from unconventional aircraft. The review aimed to assess the current developments in UAS and UAM in terms of measurement and assessment of noise. The review describes the methodologies for measurement of UAM and UAS vehicles in the laboratory and in the field settings. The authors describe the differences in measurement techniques, including types of microphones and their positions within the studies. In terms of annoyance measurement, the applied measurement techniques are often applied in steady flight. The authors stress that the change between phases could significantly impact annoyance due to changes in tonal characteristics during these phases.

3.57 The review discussed the human response to noise from advanced air mobility (AAM) including UAM and UAS. Loudness was found to be the most important predictor of annoyance from the 15 studies reviewed. Figure 13 shows the exposure-response functions for % Highly Annoyed (HA) people at a given sound level L_{AE}.[6]

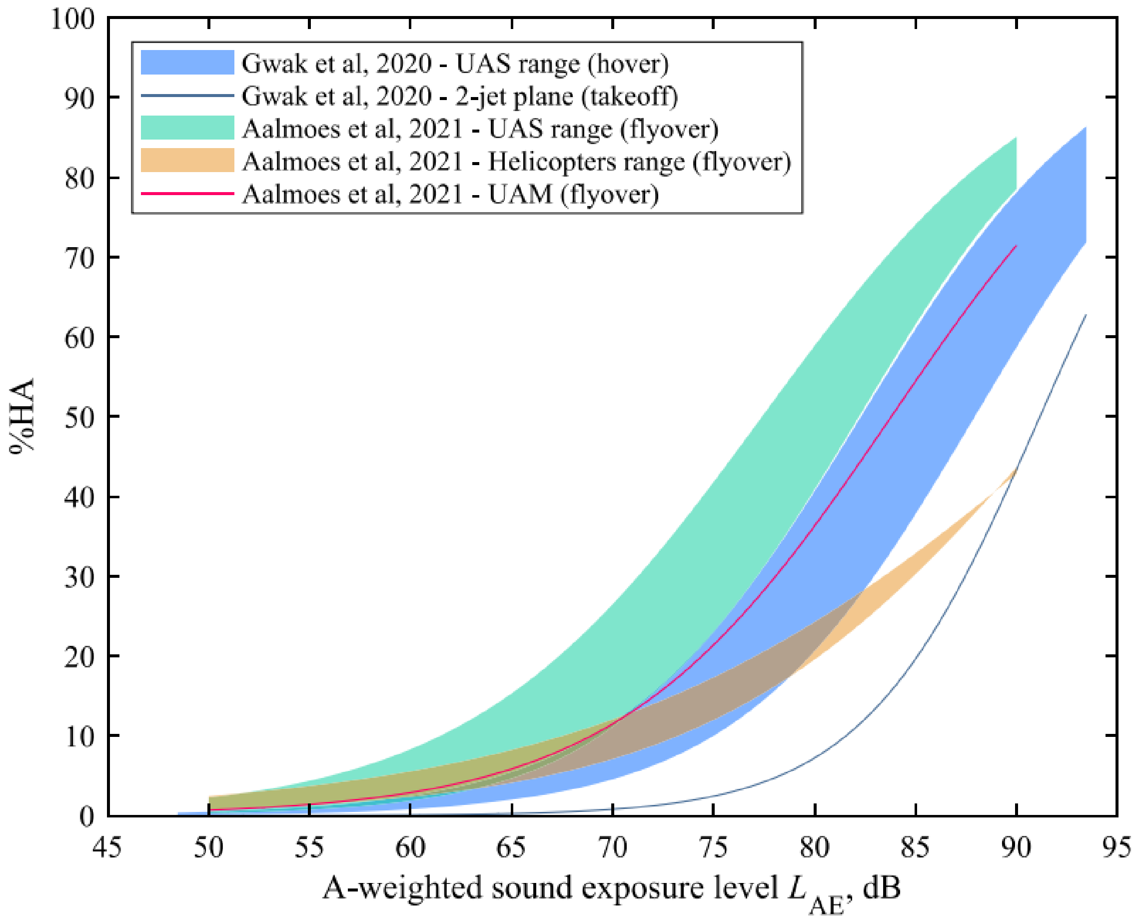

Figure 13: Exposure-response functions for % highly annoyed persons at given sound level; experimental data from Gwak et al. and Aalmoes et al.

3.58 The authors conclude that the likelihood of the use of AAM, UAM and UAS is quickly increasing. Psychoacoustic experiments have demonstrated that the particular acoustic features of UAS sound have the potential to increase noise annoyance responses compared with those associated with existing transportation modes. The authors stress that it will therefore be important to consider sound quality parameters alongside traditional metrics. They argue that it is not yet known whether relying on the approaches to human response from conventional transportation noise sources such as aircraft noise will be sufficient in terms of noise management approach, due to the acoustic profiles being

[6] LAE represents the overall (A-weighted) acoustic energy within a single event by summing the energy between the maximum level and the ±10 dB points of the event.

different. Elements such as sharpness, roughness and tonality all contribute to noise from these new technologies exhibiting potential for different annoyance responses and, ultimately, health effects such as those observed with aircraft noise.

3.59 The authors also identified research gaps for the areas of acoustic measurements, human detection, noticeability, perception and response, and sound exposure metrics and noise regulation. Gaps in the human response area, included:

- Models and metrics could be improved by incorporating sound quality components, which can more accurately represent the perception of the distinctive acoustic characteristics of AAM sound emissions.
- Only a small number of experimental studies have investigated the effects of personal and contextual factors on responses, and the available evidence indicates these could have considerable influence, which should be accounted for.
- The existing human response studies generally consider the sound of an individual AAM vehicle. The complex psychoacoustics from vertiports and flight paths with multiple vehicles has not yet been considered.
- Further experimental research could be used to develop indicative exposure-response functions for annoyance.
- There is a lack of data on the impact of noise from these vehicles on sleep and physiological responses.
- it is important to investigate the potential for sound and noise to affect wildlife in addition to humans.

Chapter 4

Drones and wildlife

4.1 In addition to the impact of emerging aviation technology noise on humans, there have been some publications that aim to address the impacts of noise from these types of vehicles on wildlife.

4.2 The first of two papers is by **Jackman et al,** which is a policy intervention brief that examines the use of drones in conservation settings and explores the possible negative impacts on wildlife. One of the questions posed by the researchers was “How might conservation drone use be facilitated while limiting potential harms to humans and wildlife in their midst?”

4.3 A group of academic researchers formed and worked together over a year to develop a policy briefing on responsible drone use, in relation to conservation practitioners. The interdisciplinary group identified four areas for consideration, which were discussed at workshops, plenaries and roundtable discussions:

- Technicalities (what drones can do in forest/wildlife conservation);
- Rights and communities (how drones could be used to support the rights of communities);
- Drones and green securitisation (where and when monitoring becomes surveillance); and
- Ethics and protocols (discussion and sharing of best practices for drone use fostering environmental justice.

4.4 The resulting policy briefing[7] on responsible drone use for conservation practitioners provides guidelines for best practice for the use of drones as part of biodiversity conservation and/or efforts to defend rights to land. Risks that drones can pose to local communities and wildlife and propose mitigating strategies for minimising these risks are also outlined.

4.5 **Colombelli-Négrel et al** published a paper on the response of koalas to drones, with the rationale that drones used for conservation may expose koalas to noise and visual pollution from drones. Drones are sometimes used as a method for monitoring koala populations in Australia and the authors were interested in assessing whether there were any behavioural or physiological responses to drones in this setting.

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[7] Responsible drone use in biodiversity conservation: Guidelines for environmental and conservation organisations who use drones - CIFOR Knowledge (cifor-icraf.org)

4.6 Fitbits were used to measure heart rate, alongside vigilance behaviour assessment and physiological responses (heart rate and breathing rate) in captive koalas. Drones were flown at 15 metres above their head, which resulted in a short-term increase in vigilance but no effects on heart rate or breathing rates were found. The authors suggest that drones may not have long-term detrimental effects on koalas' fitness or energy demands and therefore this may be a suitable practice for conservation and monitoring of the species.

Chapter 5

Summary

5.1 This report has provided an overview of the research between 2022-2023 into the potential effects of emerging aviation technology noise on people. The main findings presented at the Internoise conference have been summarised, and findings which have been published in the literature over this twelve-month period have been described.

5.2 It is clear that this is a rapidly growing area of research, particularly with respect to investigations into public acceptance of these emerging technologies. The noise impacts on people are important considerations and play a significant role in the acceptance of such technologies. Concerns regarding impacts on wildlife and the natural world are also raised. The noise profile characteristics produced by emerging technology aviation vehicles are being more clearly understood in terms of the impact on annoyance. The impact on sleep disturbance will need to be understood more clearly, as well as the role non-acoustic factors will play with this type of noise exposure and response.

5.3 Quiet Drones 2024 is being held in Manchester. It is expected that findings presented at this meeting, and from more studies published in this growing area of research over the next year will prove to be important for developing noise policy and legislation for these kinds of aircraft, and for the protection of the people exposed to noise from them.

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