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Study on the public perception of drone noise

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1. Executive summary

This report documents a study conducted to assess the public perception of drone noise generated by the CAELUS project. The CAELUS project aims to establish the UK's first national drone distribution network for transporting essential medical supplies. Arup's role in the project is to gain an understanding of the public perception of drone noise within the context of this use case in Scotland. To complete this work, a study was undertaken that encompasses several key components:

- **Development and validation of a flexible drone auralisation method:** Arup developed and validated a method for creating realistic drone noise simulations.
- **Incorporation of auralisations into an online listening test:** Participants were invited to evaluate and provide feedback on drone noise perception using an online listening test.
- **Analysis of listening test results:** The response data collected from the test was analysed to gain insights into the public perception of drone noise in the specified context.

In addition to the work described above and following feedback from the CAELUS consortium partners and the wider Future Flight Challenge community, Arup investigated people's perception of drone noise when the use case was not defined ('white label' study). The initial survey was explicit that it related to medical delivery applications. As part of this discreet study, we developed an additional investigation alongside the main body of work. The goal was to explore any difference in response when the use case was not mentioned.

Academic papers related to this work will be published later this year. These papers will provide further technical details on our approach. This document offers an overview of the methodology employed, tailored to the level of detail relevant for consortium members we support.

As well as being beneficial to NHS Scotland and healthcare provision more widely, this body of work significantly contributes to the global effort in addressing the challenges of drone or Uncrewed Aircraft Systems (UAS) and Advanced Air Mobility (AAM) noise. The combination of both the listening tests has provided insights into how the public perceives drone noise in scenarios beyond medical supply delivery.

2. Introduction

Project CAELUS is a UKRI Future Flight Challenge project, part-funded by government, to support NHS Scotland to develop a drone network to transport essential medicines, bloods and other medical supplies throughout Scotland, including to remote communities.

Arup is part of the CAELUS consortium (led by AGS Airports Limited on behalf of NHS Scotland) developing a pilot scale trial of the entire ecosystem required to operate a drone network.

While it is recognized that noise can be a significant barrier to the acceptance of drone networks, the specific response of people to the sound of drones and the effect of people's understanding of the use case remains unclear and is subject to global research (see Lotinga et al., 2023[1] for a recent review). It is acknowledged that an individual's perception of an acoustic environment is closely tied to the context of their experience.

By comparison of two separate studies, one explicitly related to healthcare provision and a second with no use case context provided (the 'white label' study), valuable insights have been derived into the application of drone technologies and the likely public perception of their deployment.

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[1] Lotinga, M. J., Ramos-Romero, C., Green, N., & Torija, A. J. (2023). Noise from Unconventional Aircraft: A Review of Current Measurement Techniques, Psychoacoustics, Metrics and Regulation. *Current Pollution Reports*, *9*(4), 724-745.

Arup's contribution to CAELUS is to use online sound demonstrations to gauge public perception to sound from drones.

This report summarises of the main aspects of the study process and presents the analysis and interpretation of the results.

3. Preliminary engagement and findings

3.1 Literature review

Literature on transportation noise for road, rail and aircraft is well advanced and noise impacts are generally assessed using exposure response relationships. Studies have identified relationships describing the percentage of the population expected to express annoyance above a given threshold for different noise exposure bands. It is well understood that the relationships are dependent on the transportation noise source and a variety of so called 'non-acoustical factors' that typically relate to the context of the listener themselves, their local environment, and their situation. Importantly, there are currently no established relationships to assess the impacts of UAS or AAM noise.

In 2021, the European Union Aviation Safety Agency (EASA) conducted a study[2] on the societal acceptance of Urban Air Mobility (UAM) in Europe. The study identified the potential of noise as a significant barrier to the widespread adoption of advanced air mobility (AAM), ranking second only to safety. The NASA white paper on UAM noise (2020)[3] emphasised the urgent need for the development of metrics and models to accurately predict and assess the human response to AAM noise. As a result, there has been a growing interest in recent years in understanding the impact of drone noise on people.

Key points from the literature review completed are listed below:

- Noise annoyance is a key variable that requires consideration in the effective design of a drone network so that the associated health effects of noise on people in terms of stress response can be mitigated (ISO/TS 15666:2021)
- Drone sounds can elicit a higher annoyance response compared to other transportation sources (Schäffer et. al, 2021)[4]
- The main contributors to annoyance are perceived noise level (PNL) and sharpness (Torija & Self, 2022)[5]
- Further research is needed to better understand the effects of drone noise on existing soundscapes and how ambient noise may mask drone noise (Torija & Self, 2020)[6]

3.2 Industry engagement

Semi-structured interviews were conducted with UK stakeholders from industry, regulating bodies, and academia. The aim of the engagement was to identify and better understand the concerns and issues relating to operational drone noise.

The following main outcomes were identified:

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[2] *EASA. Study on the societal acceptance of Urban Air Mobility in Europe, 2021*

[3] *NASA. Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations, 2020*

[4] Schäffer, B., Pieren, R., Heutschi, K., Wunderli, J. M., & Becker, S. (2021). Drone noise emission characteristics and noise effects on humans—a systematic review. *International journal of environmental research and public health*, *18*(11), 5940.

[5] 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.

[6] Torija, A. J., & Nicholls, R. K. (2022). Investigation of metrics for assessing human response to drone noise. *International Journal of Environmental Research and Public Health*, *19*(6), 3152.

- There is a lack of existing evidence relating to potential effects on health and wellbeing.
- There is a need to capture response data on the unique characteristics of the sound source.
- Background sound and masking, number of events and time of day are expected to have a large effect on the human response.
- There are likely to be differences in attitudinal responses for different use cases – different response for a case with a social benefit compared to commercial or private use.

3.3 Outcomes

The overarching outcomes from the preliminary research exercise can be summarised as:

- There are currently no established exposure response relationships to assess the effects of drone noise in terms of noise annoyance, or other perceptual variables.
- Research is being conducted to understand the perception of drone noise, but there is a lack of knowledge around the response to drones within existing soundscapes.
- There is currently no studies or data on the attitudes to drone noise for different use cases and there is an expectation that the public perception will be different for different use cases.
- There is a need for regulators to gain a better understanding of drone noise and have access to such data to be able to make informed planning decisions and to help incorporate mitigation into operations.
- Annoyance is a subjective response to noise, encompassing feelings of resentment, discomfort, and dissatisfaction when noise interferes with thoughts or activities. It depends not only on the sound itself (such as loudness or pitch) but also on social, psychological, and economic factors. Understanding this interplay is crucial for effective drone network design that incorporates noise management that is capable of assessing risk of increased annoyance and its associated health effects on those potentially affected, that live, work or play in proximity to the networks operations.

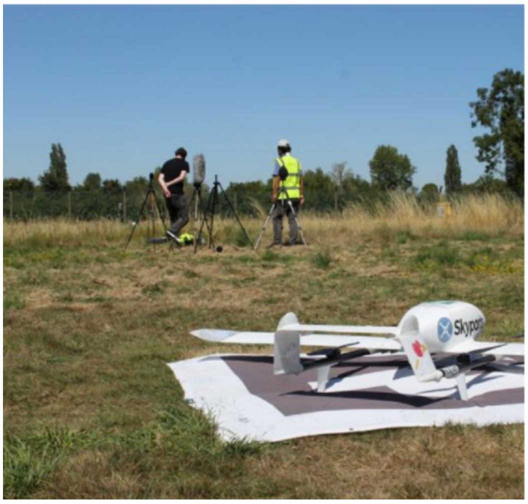
4. Sound demonstration development and validation

To develop the listening experiment a method was required to create flexible auralisations of drone noise at different altitudes and distances; and within different ambient background environments.

There are many different ways to create an auralisation, but to ensure that the listening test is effective, the auralisations must be realistic. To ensure this, the auralisations were calibrated and validated objectively against measured field data and subjectively through critical listening by expert listeners.

4.1 Field survey

A sound survey was conducted on 9 and 10 August 2022 at Westcott Innovation Centre. The aim of the survey was to collect audio recordings and acoustic data for overflights and take-off / landing operations.



Photograph 1: Field survey work

The detail of the survey methodology is not covered in this report. Full technical details will be provided in the QuietDrone papers, but in summary:

- Soundfield microphones, high quality audio microphones, groundplate microphones, and Class 1 sound level meters were positioned at a range of distances from the flight path
- Detailed recordings were made of:
  - Overflights at altitudes of 60m and 100m
  - Take-off / hover / landing operations at altitudes of 10m, 40m, 60m and 100m
  - Overflight drone recordings were made at an operational cruising speed of 55 knots

4.2 Overflight audio processing

4.2.1 Sound sources

The relatively high background sound experienced on site resulted in unsatisfactorily signal to noise levels on the audio recordings. An auralisation method was therefore required to synthesise the overflight operations so they could be aurally presented with different ambient sound environments.

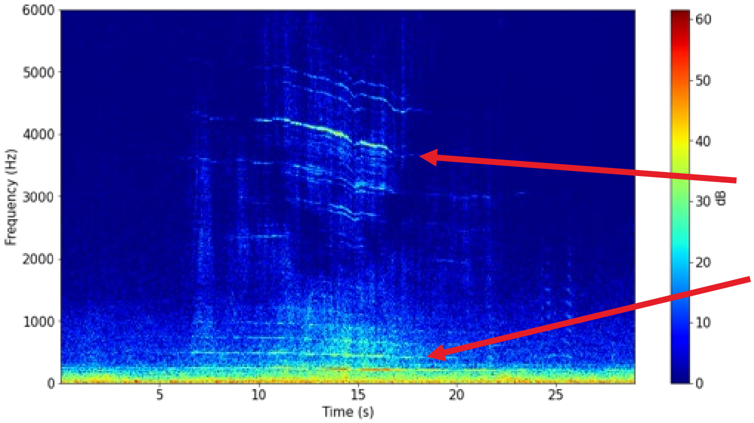


Figure 1: Spectral analysis of drone overflight over time

An analysis of the groundplate microphone data identified the following main components, which informed the synthesis approach:

- High frequency tonal components related to the electric motor
- Harmonic series related to the blade passage frequency (bpf)
- Broadband component related to the airframe

The auralisation method takes into account the acoustic characteristics of these three components, including directivity and variations of the rotor speed over time due to atmospheric turbulence.

4.2.2 Propagation

The sound experienced by the listener will vary depending on the trajectory and speed of the drone. The following time varying propagation effects are accounted for in the method:

- Geometric spreading
- Doppler shift
- Atmospheric attenuation
- Atmospheric turbulence

This allows drones to be aurally synthesised for any trajectory / altitude, to overcome the constraints of the site recordings.

4.2.3 Overflight simulation validation

Objective comparison of the temporal and frequency characteristics of the recorded and synthesised overflight sound demonstrated good objective alignment when plotted (Figure 2).

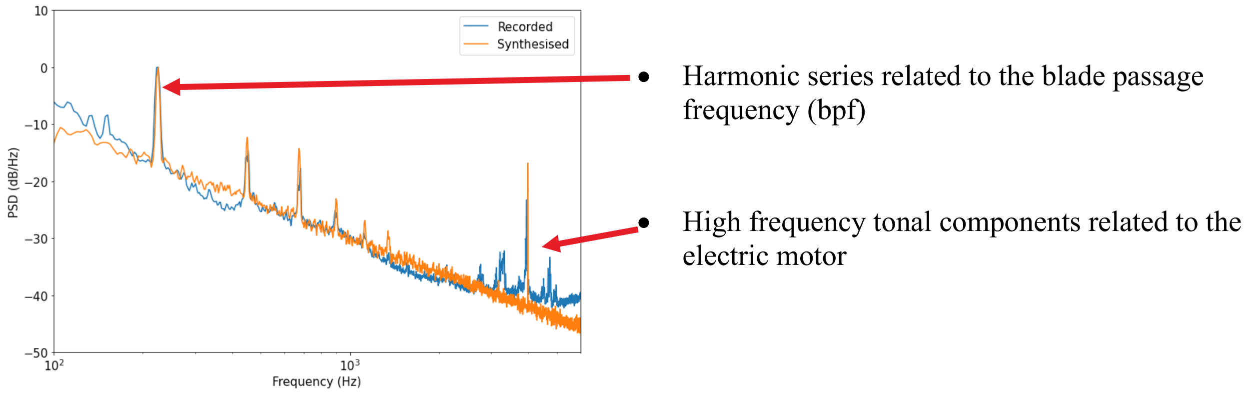


Figure 2: Frequency component analysis of overflight simulation compared against an audio recording

Additionally, a subjective evaluation was completed through conducting a series of critical listening tests with expert listeners in Arup's SoundLab (Figure 3). These confirmed the method produced plausible auralisations.

The outcome was that when auralisations of overflights were played alongside ambient soundscapes used in the listening tests, it was extremely difficult to differentiate between the simulated drone movements and the audio recordings.

Figure 3: An Arup SoundLab facility

4.3 Manoeuvres audio processing

The sound of drone manoeuvres (take offs and landings; Figure 4) have a different sound character to that of overflights. Analysis of the field data showed that take-off and landing operations were dominated by unsteady harmonic components. Options were explored to synthesise these components, but they were judged as sounding too unnatural by the expert listeners, and so discounted for use in the listening test.

As the manoeuvres recordings were made close to the take off/landing location, they have a much higher signal to noise ratio than the overflights meaning it was relatively straightforward to use the high quality recordings obtained on site. Audio processing was used to apply corrections to the recordings to allow for the sound to be simulated at different distances. Corrections to the recordings have been applied to account for geometric spreading and atmospheric attenuation.

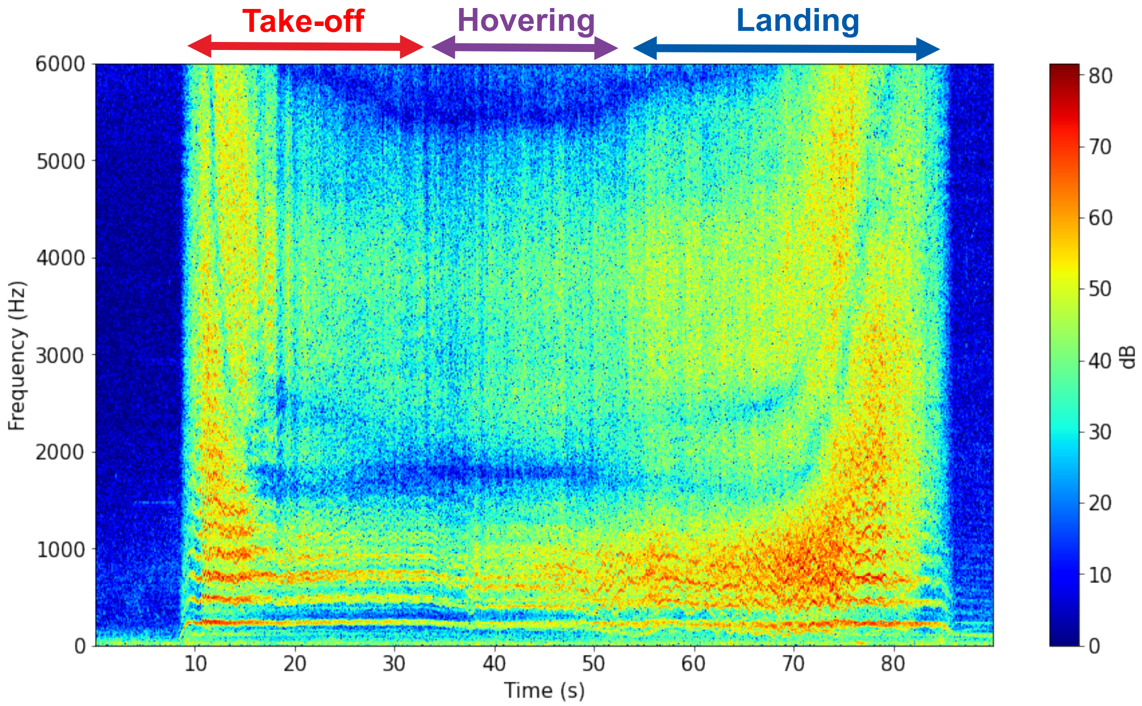


Figure 4: Spectral analysis of a take-off and landing manoeuvre

4.4 Calibration levels

The sound demonstrations of overflights and manoeuvres were calibrated to the sound levels measured on site during the field survey. The measured sound levels from the field survey were used, with adjustments to the sound level made where necessary to account for the varying distances of the simulations based on industry standard practice for sound propagation within ISO 9613-2:1996[7]. Note that since the time of the study, ISO 9613-2 has been withdrawn and replaced with ISO 9613-2:2024[8] although this does not materially affect the study.

4.5 Ambient sound environments

A key question for the study is to understand the public perception of drone overflights and manouvres when they are experienced within different sound environments. Three distinct sound environments were selected to represent typical soundscapes experienced by people across Scotland, where drones may be required to fly. These environments were:

1. **Remote Rural**: This environment is representative of the wilder and more rural areas of Scotland, where nature serves as the dominant source of sound.
2. **Rural Village**: This environment represents a typical village setting, characterized by a mix of sounds from anthropogenic sources (including a small amount of audible road traffic noise) and natural sounds.
3. **Urban**: This environment reflects a more built-up setting, typical of densely populated areas in towns or urban locations, where road traffic becomes the dominant sound.

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[7] ISO 9613-2:1996. *Acoustics - Attenuation of sound during propagation outdoors. Part 2: General method of calculation* .

[8] ISO 9613-2:2024. *Acoustics - Attenuation of sound during propagation outdoors. Part 2: Engineering method for the prediction of sound pressure levels outdoors*

This selection allows the existing sound environment to serve as a discreet variable in the listening test and is considered to provide a fair representation of the range of soundscapes experienced. Recordings were made across various locations in Scotland, with sound level measurements taken simultaneously. The sound levels of the audio samples were then calibrated in Arup's SoundLab to match the levels recorded on site.

4.6 Visual information

The impact of visuals on people's experience of sound in a listening test can be profound. Arup has extensive experience in producing sound demonstrations, and careful consideration is given to the visual stimuli that accompany these demonstrations. For the purpose of the listening test, it was deemed essential that the visuals serve two main purposes:

1. **Provide Information**: Visuals should inform the listener about the position of the drone during its movement relative to the listening position. This clarity ensures that listeners understand where the drone is located during the audio experience.
2. **Avoid Photorealism**: The visuals should not be overly realistic or depict recognizable locations. The aesthetic qualities of such environments (in terms of beauty) could influence participants' perception of the sound and their level of annoyance. Additionally, if video footage were taken from a familiar location, it might bias participants' perception of the noise they experience.

To address these considerations, an infographic approach was adopted, building on the experience of and successful application of this approach for Statutory Consultation for the A66 Northern Transpennine Development Consent Order application in 2021. Generic representations of the environments were used, providing simple visual cues regarding the drone's location in relation to the listening position during the tests.

5. Listening test design and deployment

The aim of the listening experiment was to investigate the human response to drone noise used in the context of medical delivery. The experiment has been designed using established methods from the field of sensory evaluation (c.f. Zacharov 2018)[9]. Specifically, the listening test design followed a single stimulus magnitude rating method with full factorial experimental design. The experiment examined the effect of two independent variables on human perception: altitude/distance and the ambient soundscape environment.

Separate experiments were conducted for overflights and take-off operations. This separation is essential because the sound level and character of these movements differs significantly. Evaluating participants' responses to overflights and take-offs separately allows us to address the unique challenges associated with each scenario. For instance, potential mitigation strategies related to airspace design and take-off/landing positions may require distinct approaches.

5.1 User experience (UX) design

When deploying the listening test, ensuring a fair and unbiased data set is crucial. The test was hosted and deployed through the Commonplace platform; Commonplace is a consortium member of Project CAELUS.

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[9] *Zacharov, N. (Ed.). (2018). Sensory evaluation of sound. CRC Press*

Leveraging Commonplace's expertise in deploying online engagement, the user experience (UX) design of the listening test deployment was carefully considered. The experiment also underwent refinement based on internal user testing.

5.2 User setup

Online sound demonstrations have a limitation in terms of accurately calibrating absolute sound levels experienced by remote listeners. This limitation arises from the listeners' control over the volume of playback on their individual systems. Arup has previously conducted internal research, demonstrating that relative differences can be reliably compared in online sound demonstrations.

To ensure a comparable playback experience in terms of volume, participants were instructed to take the following steps before completing the experiment:

1. Reduce any sources of noise in their environment (e.g. close windows and doors).
2. Adjust the volume of their playback device until a recording of a provided audio signal of human speech sounds natural to them.

Participants are then asked to maintain that playback level throughout the duration of the experiment. This methodology, successfully deployed by Arup during the A66 public consultation, as noted above in Section 4.6, ensures a fair and comparative listening experience for a reasonably diverse set of listeners.

5.3 Independent variables

The study was designed to investigate the following independent variables:

- Overflight altitude {60m; 90m; 120m}
- Distance from the take-off point {30m; 60m; 120m}
- Ambient background environment {remote rural; village; urban}

These variables were identified based on the prior literature review and engagement. Participants were required to provide rating for nine sound demonstrations for both the overflights and take-off sections of the experiment.

5.4 Data capture

The experiment focused on collecting data from participants on the audibility, sound character and annoyance of the drone noise they experience during the listening test.

5.4.1 Quantitative data capture

Participants were requested to respond to the following questions, providing a dataset for each of the related response variables. Answers were provided on a seven-point scale, yielding a quantitative dataset corresponding to each of the independent variables.

Response variable	Listening test question
Audibility	How audible is the sound of the drone within the existing sound environment?
Character	How much does the sound of the drone change the character of the existing sound environment?
Annoyance	To what extent are you personally bothered, annoyed or disturbed by the sound of the drone?

5.4.2 Qualitative data capture

In addition to the quantitative data, provisions were made for participants to openly respond, providing further qualitative data regarding their perceptions of drone noise during the survey. The following questions were used to capture these views.

- Which particular characteristics of the drone sounds determined your responses?
- Do you believe the purpose/application for which the drones are used would influence your response to the sound?
- Which of the following best describes the area in which you live (rural hamlet or isolated dwelling / rural village / rural town / urban town or city)?
- Do you have any other general comments or feedback for the listening test that you have just completed?

5.5 Industrial feedback and supplementary study

A webinar was hosted by Arup to capture views from the drone industry on the study and the listening test design. This was conducted as an online webinar and views where captured that helped to further shape and refine the listening test documented above.

A significant request that came out of this webinar was the need for information on the public perception of drone noise from drones that have other use cases. In response to this, a supplementary study of drone noise was undertaken, in which the same listening test was used but without any reference to the use case (the 'white label' study).

6. Results

The variables of distance (where sound attenuates with greater distance from the source) and soundscape (the background sound environment that drone overflights and manouvres are experienced within), where analysed through the assessment of the quantitative data from the listening tests. This provided information on the listeners annoyance against these variables.

Context was explored to understand how different factors influence annoyance by comparing quantitative data of people's reactions based on whether or not they knew the drones' application. To do this, two different groups were assessed:

- Main Study Group: They were informed at the start of the test that the drones were used for medical delivery.
- White Label Study Group: They were not informed about the drone's application.

The listening test survey received in total 911 participant response which is broken down as follows:

- CAELUS Main study – overflight: 93
- White label study - Overflight : 482
- CAELUS Main study – Manoeuvres: 93
- White label study - Manoeuvres: 243

Subsequent statistical analysis of the quantitative data using repeated measures analysis of variance (ANOVA) revealed statistically significant relationships between annoyance and all the independent variables included in the study (altitude/distance, soundscape type, and context). These findings show that that annoyance varies as a function of drone-listener distance (altitude for overflight operations and distance from the take-off point for take-off operations), the character of the existing soundscape, and the use of the drone.

The below section summarises the quantitative data results and provides a summary of the most pertinent qualitative results observed. It is noted that the qualitative data is quite rich, and further learnings could be achieved through further analyses.

6.1 Overflight operations

Overflight operations relate to the drone passing overhead, at varying altitudes and experienced in different soundscapes.

6.1.1 Distance and soundscape

Figure 5 shows the results for overflight operations that relate to distance and soundscape. The bars show the mean annoyance rating over all participants and the error bars represent the 95% confidence interval.

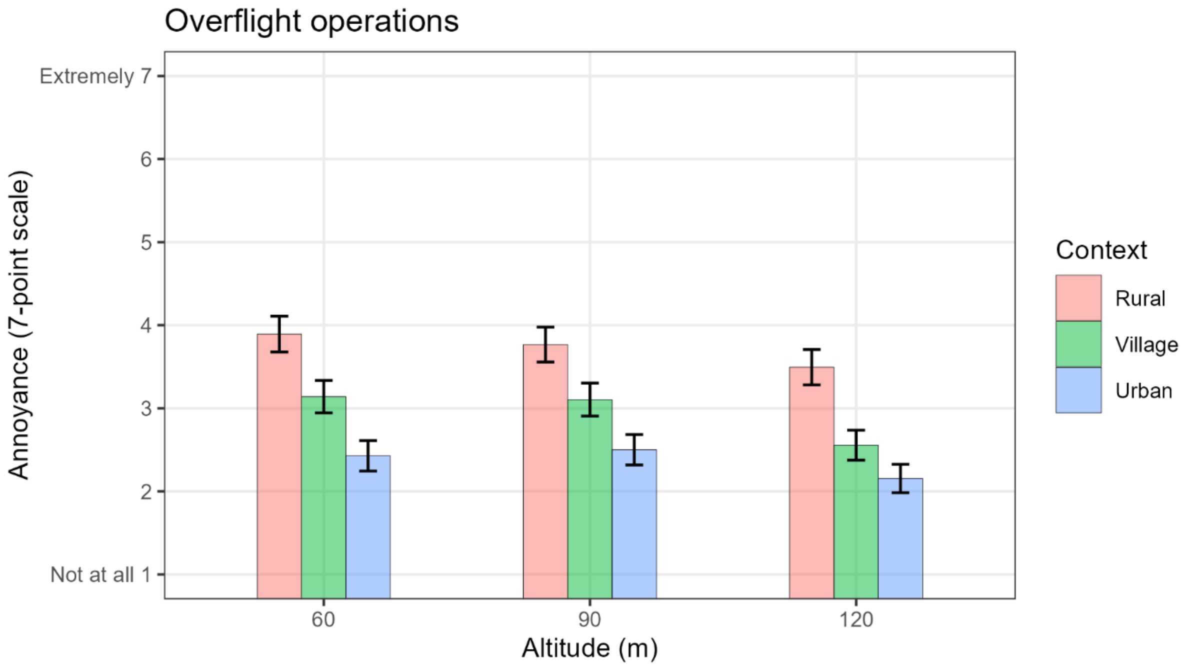

Figure 5: Noise annoyance results for distance and soundscape variables for drone overflights

The following can be concluded from the quantitative data relating to distance and soundscape:

1. There is stronger annoyance when the drones are experienced in quieter, more rural settings that have higher proportions of natural sound, than busier environments with higher levels of road traffic noise.
2. Noise annoyance is lower in more urban environments, where road traffic noise has more presence in the ambient soundscape. This suggests that the higher background noise level, and the noise masking that it provides, increases the tolerance of drone overflights.
3. There is a general trend that annoyance decreases with overflight altitude in each environment, although the decrease in annoyance between 60m and 90m altitude is quite small, and a stronger decrease occurs moving to 120m overflight altitudes, particularly for the rural and village soundscapes.

These findings are supported by the detailed statistical analysis presented in Woodcock et al. (2024)[10].

[10] Woodcock, J., Thomas, A., McLeod, L., Lampkin, G., Sharp, C., Maldonado, A.L., Hiller, D. (2024*) Influence of operational and contextual factors on the human response to drone sound*. In the proceedings of QuietDrones2024.

6.1.2 Context

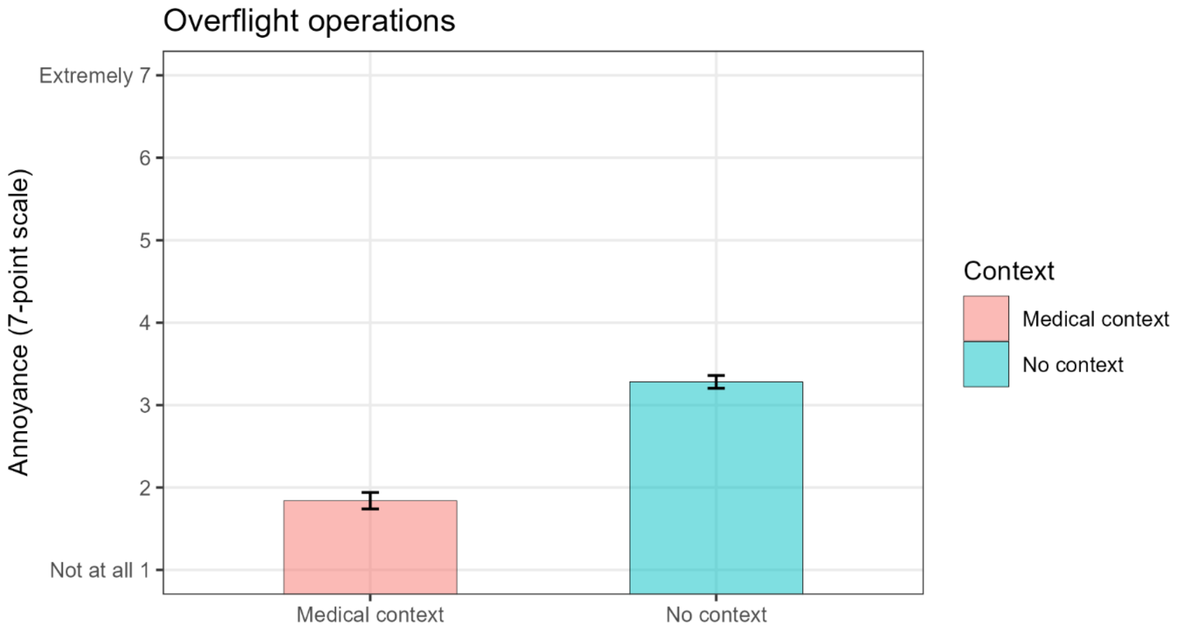

Figure 6: Difference in noise annoyance for overflight operations when the medical delivery context is provided or not

There is a clear reduction in the annoyance result when the use case is understood to be associated with medical delivery than being unknown.

6.2 Take off operations

The sound during take off operations has a different character and level to the overflight sound. Vertical take-off and landing sound was subjectively quite similar in terms of sound character and level and hence, to limit the number of different tests in the study, only take off operations have been used.

6.2.1 Distance and soundscape

Figure 7 shows the relationships between annoyance for take-off operations that relate to distance and soundscape.

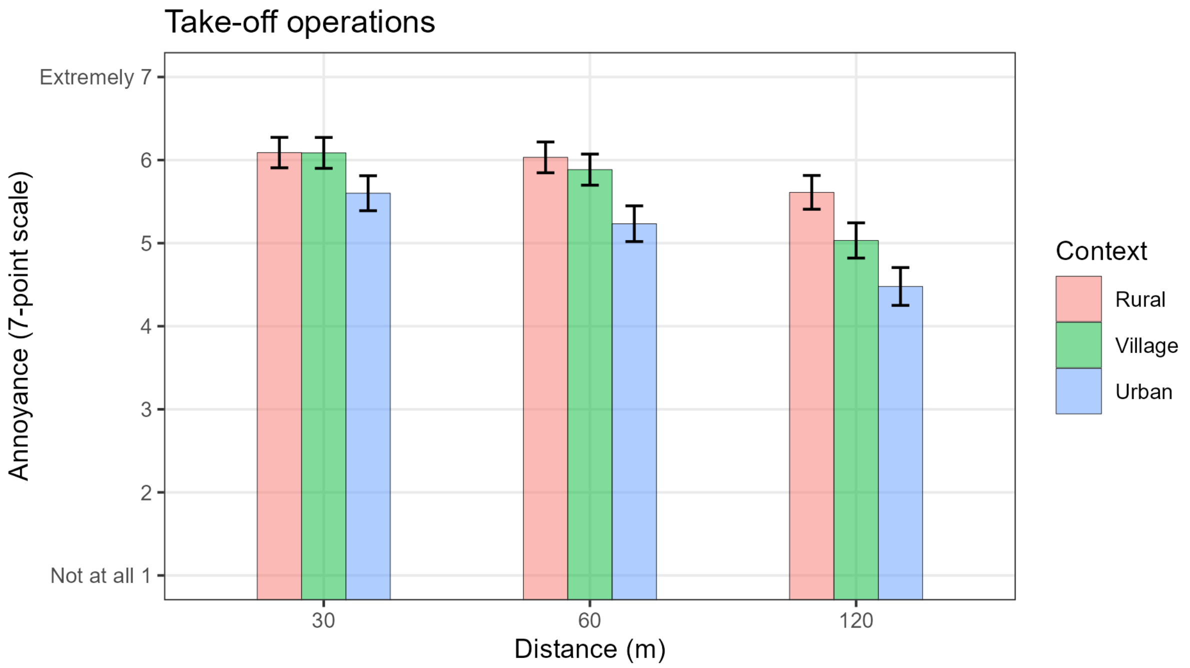

Figure 7: Noise annoyance results for distance and soundscape variables for drone take off manouvres

Some conclusions relating to the quantitative data relating to distance and soundscape:

1. The annoyance rating for take-off operations is much higher than that attributed to overflight operations in all soundscapes (Figure 5).
2. Annoyance is higher when experienced in rural and village soundscapes, and slightly reduced for suburban, suggesting that broad band road traffic noise could be providing some beneficial noise masking.
3. For rural and village soundscapes, there is little change in noise annoyance between the distances of 30 and 60m, and an increase to 120m is required to have any real effect in reducing noise annoyance for rural and village soundscapes.
4. There is a slightly more linear reduction in annoyance relating to distance for urban soundscape settings.

These findings are supported by the detailed statistical analysis presented in Woodcock et al. (2024)[11].

6.2.2 Context

Figure 8 compares the annoyance results for take off manoeuvres for the medical application and white label study.

[11] Woodcock, J., Thomas, A., McLeod, L., Lampkin, G., Sharp, C., Maldonado, A.L., Hiller, D. (2024*) Influence of operational and contextual factors on the human response to drone sound*. In the proceedings of QuietDrones2024.

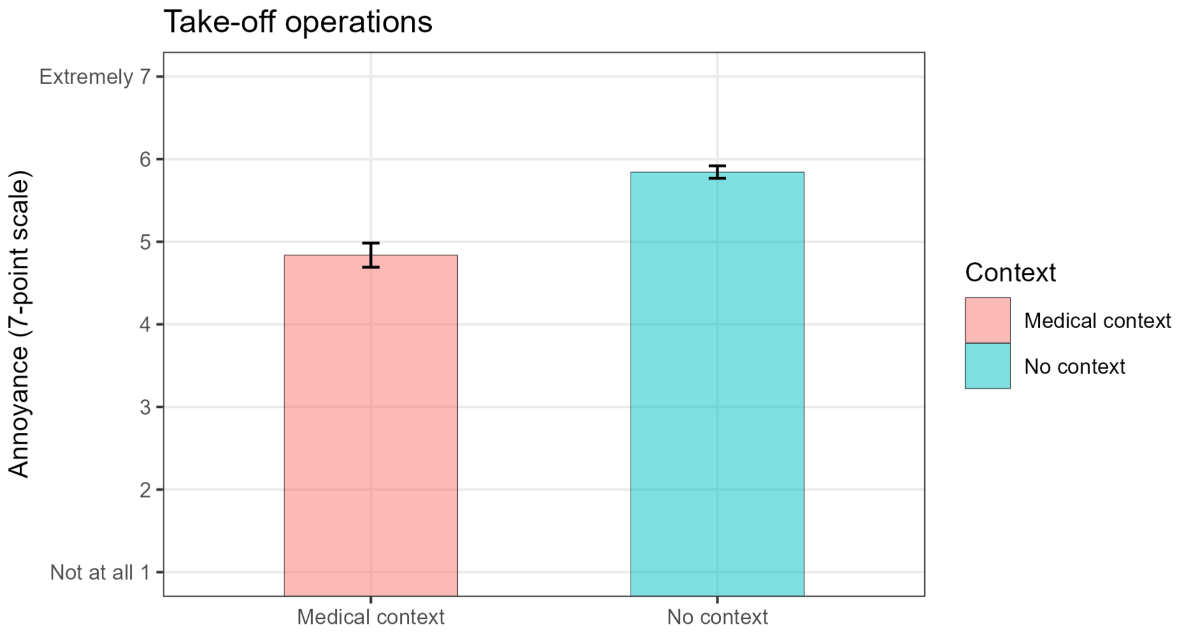

Figure 8: Difference in noise annoyance for take-off manoeuvre operations when the medical delivery context is provided or not

Similar to the overflight operations there is lower level or annoyance for medical applications than when the use case is not understood.

There is a marked increase in the annoyance of drone noise in both contexts compared with the overflight operations, as expected due to the different sound character and level.

6.3 Qualitative analysis

At the end of the test, participants were asked to answer a series of open text questions. Two areas were studied in more detail to derive deeper meaning from the results through qualitative analysis of the responses received from participants. The two questions were:

- What characteristics of the drone sound influenced your responses?
- Do you believe the purpose/application for which the drones are used would influence your response to the sound? Please explain your reasoning.

For the first question, a count of the words for characteristics was made for both tests to determine descriptors for the drone noise.

For the second question, analysis was made on the white label study only (where the context was not presented) to determine which contexts were considered more acceptable and therefore more tolerant of the sound and the contexts which were considered less acceptable and therefore less tolerant of the sound. For both questions, a high-level sorting of words was carried out to remove stop words such as “and”, “it” etc. Words were not grouped as part of this process.

6.3.1 Use cases

Figure 9 and Figure 10 show the use cases for which drone noise was deemed to be most and least acceptable / tolerable. Use cases were not provided to the participants, so they were free to suggest acceptable / unacceptable contexts without bias. The top use cases for acceptable / more tolerable context were emergency and medical which gives favour to the CAELUS project.

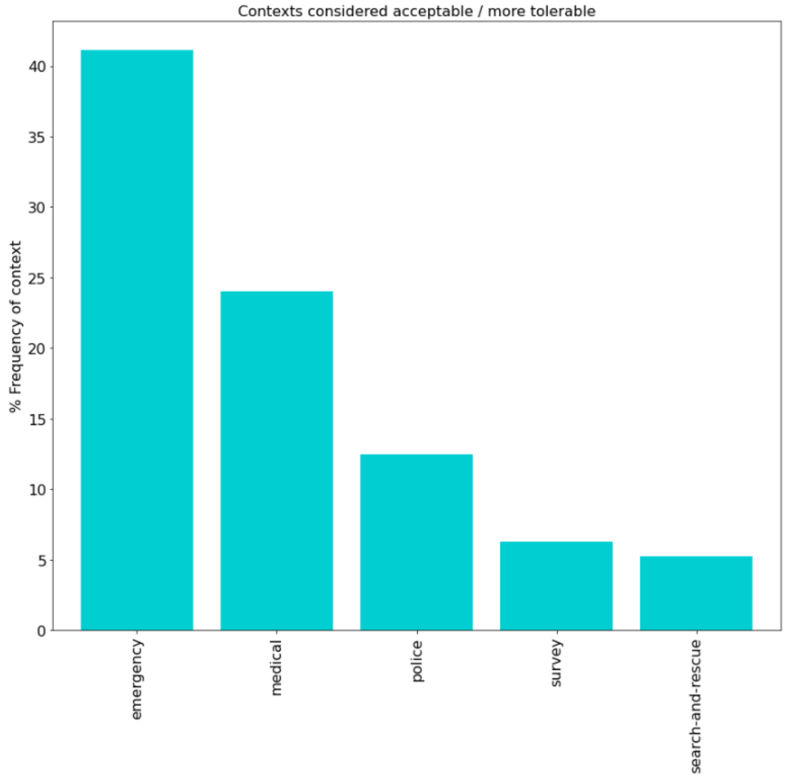

Figure 9: Use cases for which the noise was considered to be most acceptable / tolerable

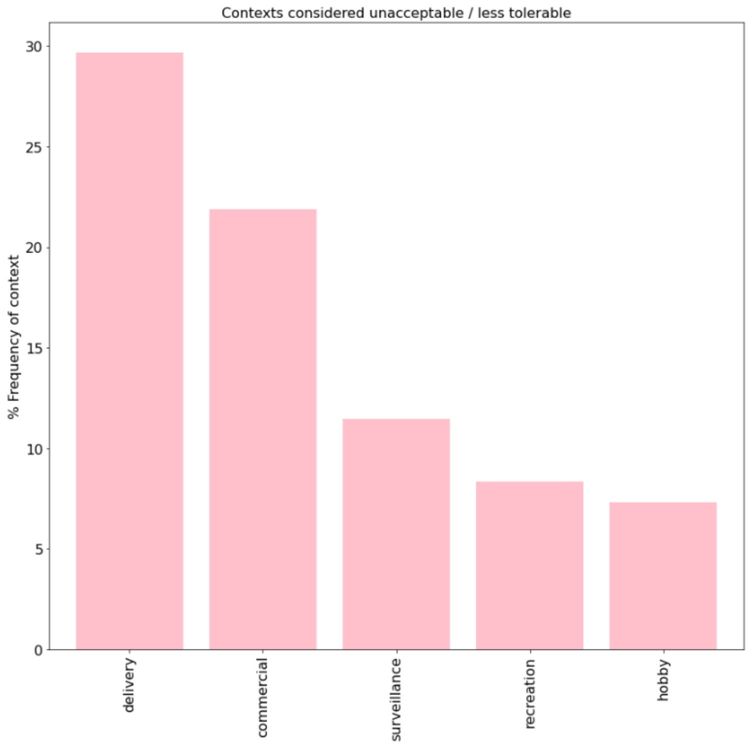

Figure 10: Use cases for which the noise was considered to be least acceptable / tolerable

6.3.2 Sound character

Participants were also asked to provide an answer to the question:

"*What characteristics of the drone sound influenced your* responses?"

This has provided a qualitative set of words used to describe the drone noise, which are summarized in Figure 11 and Figure 12.

The most common words for both manouvres and overflights were loud, harsh, buzz and annoying. Comparing the frequency of use of these words, loud and harsh were used more frequently for the take-off sounds than for the overflights.

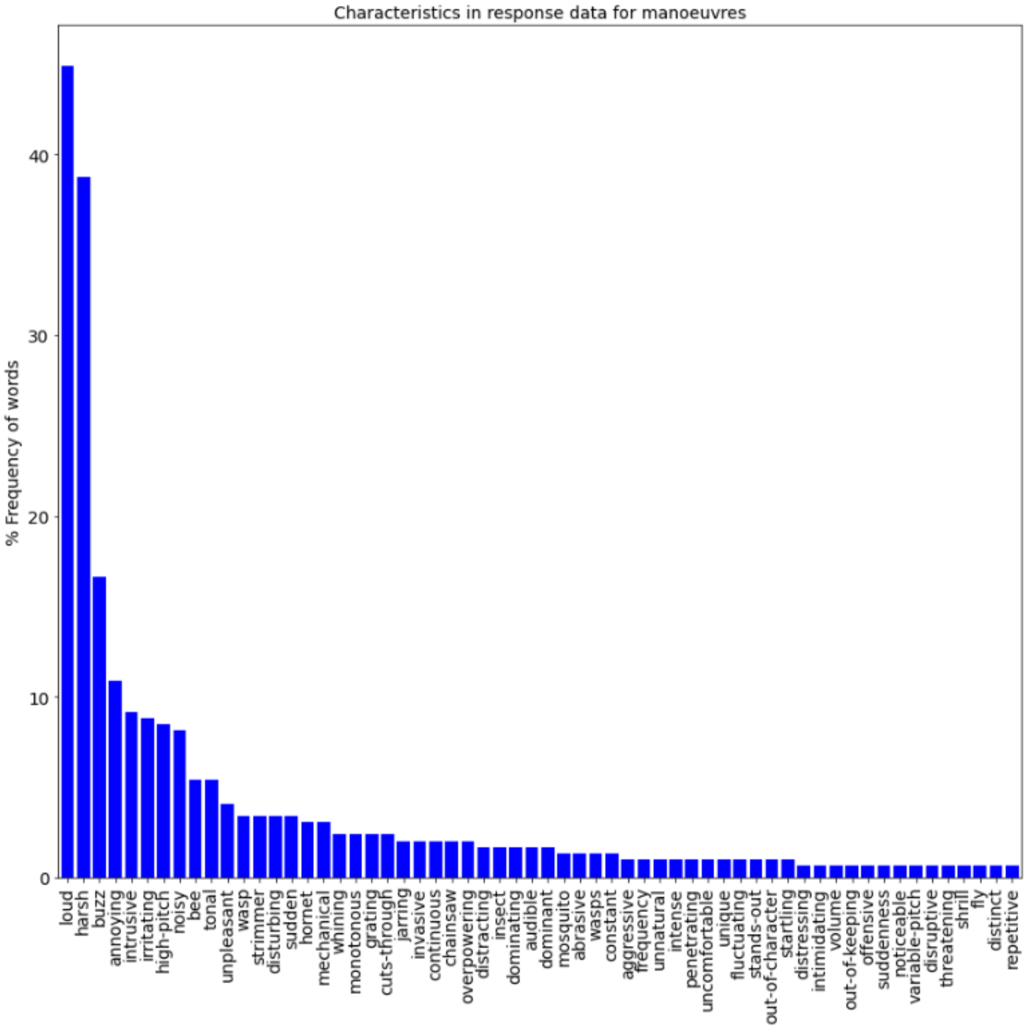

Figure 11: Sound characteristic words most used to describe manouvres

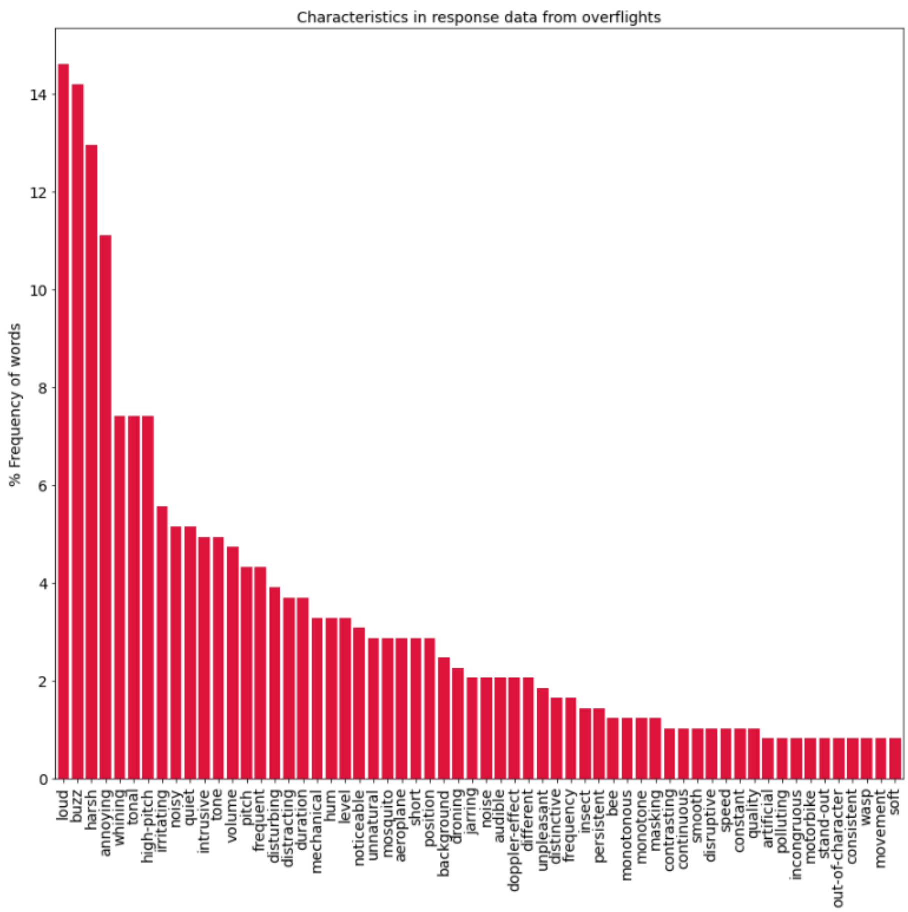

Figure 12: : Sound characteristic words most used to describe overflights

7. Conclusions

7.1 Contextual understanding and annoyance reduction

When people recognize that drones are serving medical purposes, there is a noticeable reduction in annoyance. Understanding the context—specifically, that these drones are facilitating medical deliveries—can alleviate negative sentiments associated with their presence.

A potential risk associated with more general use of drones (and by extension AAM) is that, if drones become introduced widely without proper understanding of the noise impacts, there is a greater risk of noise annoyance and associated health effects occurring. Related to this health outcome, a strong individual and community opposition would be expected. The results indicate that socially valuable applications are less likely to be annoying, and therefore more likely to be acceptable to individuals and communities potentially effected providing the context of their operations is understood.

7.2 Soundscape perspective

The results clearly show that soundscapes impact perception of and response to drone noise. Understanding the existing soundscapes and strategically planning drone routes, including take off and landing locations, can help enhance public acceptance and minimize annoyance.

The results indicate that noise masking, where certain broad band sounds (e.g. traffic noise) decrease the perceptual elements of the drone noise sound character, can provide mitigation to annoyance levels for some drone operations and altitudes.

Additionally, there are higher levels of annoyance when drone noise is experienced in quieter and more natural soundscape environments.

7.3 Distance and altitude

Whilst a decrease in noise annoyance is shown for increased distance from the drone, the distances measured for take-off operations of 30 and 60m show very little change in the annoyance. This indicates that larger distances and/or other noise mitigation methods should be considered to provide any perceptual mitigation benefit in terms of noise annoyance.

There is a clear relationship with the altitude of drone overflights and reduced annoyance, but this relationship is not necessarily linear, and the local relationship of the terrain, as well as the soundscape, should be considered.

7.4 Recommendations

7.4.1 Drone identification

To enhance public acceptance and minimise annoyance to medical and other socially useful applications, drone delivery networks should make their nature of the service being provided easily identifiable:

- **Symbolic Markings**: the network should consider using a universally recognized symbol, such as a red cross, prominently displayed on medical delivery drones. This visual cue immediately communicates their purpose and fosters positive associations.
- **Drone Tracking Web Platforms:** Similar to existing plane tracking platforms, a specialized web platform could allow individuals to identify drones within the network. Real-time tracking data would empower people to distinguish between medical drones and other types, reducing uncertainty and stress.

For services requiring permanent or frequently used landing/take-off points, public acceptance is likely to be greater if the local population is engaged with before operations commence. This should focus on the community benefits of the provision but also make clear that the drones will be audible for the short periods of take-off and landing.

7.4.2 Flight path design and noise interaction

Flight path planning should consider noise annoyance as a primary airspace design principle. The process should:

- **Recognise and make use of the benefit from noise masking:** flight path design should consider that drone noise will be less perceptible and annoying when experienced against existing broadband and consistent environmental noise. (e.g., road traffic noise), and account for proximity to other consistent sound sources in its design holistically, with consideration of the nearest noise sensitive receptors.
- **Use distance attenuation** from the nearest noise sensitive receptors, but also recognise other potential mitigation such as screening and the directivity of noise from drone overflights and manoeuvres and use this to minimise noise exposure further.

7.4.3 Take-off / landing locations and soundscape design

The data shows a marked increase in noise annoyance for take-off (and so likely to be the same for landing) operations compared with overflights. This is as expected and is likely to be due to the differences in sound levels and character. Noise impacts should be considered when selecting locations for take-offs and landings, especially for locations that are likely to have frequent use.

Vertiport locations within NHS estates should be carefully considered in terms of its operations, proximity to noise sensitive receptors and the existing ambient soundscape. For example, it may be possible to position vertiports to maximize natural barrier effects or reduce annoyance through noise masking. Masking might be provided by existing road traffic or by careful soundscape design to suit the local context.

7.4.4 Wider implications

The study has further demonstrated the need for urgent development of evidence based noise impact assessment criteria that can be applied to planning applications for UAS and AAM use. This would support planning and policy decision makers and support manufacturers in developing their designs.

The character and level of sound from drones should be considered when procuring drone use, particularly where they will be used in sensitive areas. Inclusion of noise in the assessment criteria may help to incentivise manufacturers and suppliers to strive for quieter drone designs. This approach is already well established by some major airports that incentivise use of quieter aircraft through landing charges.