A 10 YEAR RETROSPECTIVE AND LOOK AHEAD AT THE USE OF SOUND AND VISUALISATIONS FOR STAKEHOLDER ENGAGEMENT AND UNDERSTANDING PERCEPTIONS OF DISRUPTIVE TECHNOLOGIES

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Abstract

Originally conceived and developed to inform the design of some of the world's best arts and culture venues, over the past 10+ years, Arup SoundLab has also been used to create sound demonstrations that simulate and gauge response to environmental sound. Sound demonstrations combine aural and visual simulations to enable clients, designers, major stakeholders and the general public to experience and better understand sound. They provide robust objective information to support decision making and help shape better outcomes for all.

SoundLab has been used to inform the design of vertiport infrastructure; to assess annoyance and possible health impacts of novel noise sources; to inform local and international policy on noise; and to provide information on the early prototyping of Advanced Air Mobility (AAM) vehicles. These applications are described in the paper, including a recent pilot study for the European Union Aviation Safety Agency (EASA). The EASA study provided insight into people's response to AAM noise impacts, indicating that, in general, annoyance from AAM vehicles could be higher than for other transport modes, which may have implications for planning and legislation for AAM noise**.**

As AAM applications broaden, auralisation and visualisation processes are being developed to facilitate understanding of the multi-faceted AAM planning, permitting and design processes. The immersive experience provides information that is valuable to the various parties involved. These include electric aircraft manufacturers to support understanding of evolving designs; policy makers and planning authorities who may have little knowledge or understanding of these novel noise sources; and airspace designers.

1. INTRODUCTION

One of the challenges facing the establishment of the advanced air mobility (AAM) sector (vehicles, vertiports and operating routes) is the community response to the introduction of these new noise sources in the urban environment. AAM vehicles have different noise profiles from those of traditional aircraft in both noise levels and signature. Key challenges include: (1) health impacts associated with these entirely new sound sources are not widely known: specific noise characteristics such as tonality could potentially increase annoyance; (2) AAM vehicles will fly in the urban environment closer to where people live and work; and (3) the sound will propagate in a complex three-dimensional context, with multiple reflections from buildings and subject to the complexity of a city's microclimate.

The most widely known noise sources that are similar to AAM vehicles are rotorcraft: they operate closer to noise sensitive receptors and fly at lower altitudes than fixed wing aircraft. A recent study[1] summarised the current knowledge about community annoyance of helicopter noise, including acoustic and non-

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acoustic factors. Helicopter noise complaints remain a significant public concern[2],[3].

Additionally, as research continues to develop our understanding of noise impacts on health and quality of life, so the importance of the public acceptability of any new technologies and developments increases. AAM will only thrive if communities understand the implications to their environment and stakeholders are able to engage in fruitful and collaborative discussions. Aircraft manufacturers, airlines, airports, air traffic control services, governments and policy makers are some of the entities involved in the process.

This paper briefly presents a 10-year retrospective of using auralisations and visualisations for stakeholder and community engagement for infrastructure schemes. Through a process of continuous improvement, this approach has proven to be highly successful in conveying complex concepts in an easily accessible way. Sound demonstrations have been used to:

- facilitate dialogue on implications for public health and wellbeing (from a noise perspective);
- increase transparency on how stakeholders could be affected by a proposed development (or novel noise sources);
- ensure proposals are inclusive and accessible;
- support data driven decision making;
- help identify stakeholders' needs and concerns; and
- build trust amongst the entities through impartial advice and integrity.

This paper aims to provide some insight on the impact of the use of sound demonstrations in both traditional and disruptive projects.

2. AURALISATION: A HUMAN CENTRIC APPROACH TO PLANNING AND DESIGN

Originally conceived and developed in 1998 to inform the design of some of the world's best arts and culture venues, Arup SoundLabs around the world (Figure 1) have enabled clients, designers, major stakeholders and the general public to take informed decisions by experiencing sound generation and propagation during planning and design for a much broader range of projects (e.g. airport terminal buildings, infrastructure projects, rotorcraft design). This section outlines projects in which calibrated sound demonstrations supported by verified 3D visualisations have been applied and have proved to be an effective means of conveying environmental impacts. This approach has been developed and successfully used for many new infrastructure schemes to facilitate an understanding of the nature and level of the induced sound.

Figure 1: SoundLab in Manchester, UK

2.1 High Speed Rail

One of the first uses of sound demonstrations for community engagement was in the early stages of inception of the UK High Speed 2 railway, where local action groups were very strongly opposed to the project, with noise being a key issue. One action group played uncalibrated recordings of high-speed trains, to propagate adverse publicity but which also led to a great deal of anxiety in the communities. The issue prompted the railway developer, supported by the UK government, to commission scientifically defensible calibrated audio simulations, supported by visualisations, of how the HS2 route could impact its surroundings. A significant challenge was the need to create defensible sound renderings of technology that did not yet exist.

A peer reviewed approach was developed to model the sound from trains travelling at up to 360km/h. The train models were based on recorded sound from the latest and highest speed trains operating in Europe at the time. The German (Siemens ICE) high speed trains operating in France at between 300 and 320km/h were recorded on a flat and quiet site. The sound levels and frequency spectra were adjusted for the longer higher speeds of HS2 trains, to accord with representative data from an extensive database of sound levels published by the Institute for Sound and Vibration Research, Southampton, UK. The sound demonstrations were also used to help understanding of mitigation methods, such as noise barriers (Figure 2).

The resulting sound demonstrations were a key factor in engaging with the public, helping to alleviate concerns, and ultimately achieving planning consent.

Figure 2 Screenshots of a simulated HS2 train to demonstrate the effect of a noise barrier

2.2 Road Traffic Noise

The A303 is an important and heavily trafficked east-west highway in the south of England, which passes close to the Stonehenge ancient monument, a UNESCO World Heritage Site (Figure 3). This section of the A303 has remained a single carriageway road, which leads to congestion and delays especially during peak times and holiday periods. To alleviate the problems, it is proposed to construct a tunnel to upgrade the road and help restore the ancient landscape and soundscape.

Figure 3 Taking baseline recordings at Stonehenge

For the route optioneering process, sound demonstrations were created for a series of public engagement events to demonstrate the benefits of the proposed scheme options by comparing the current and proposed future scenarios. To simulate the future tunnelled road proposals, a novel audio technique was required to suppress the existing traffic noise sources. The simulations demonstrated the clear benefit of restoring the landscape and improving the acoustic environment and perceived tranquillity of this important site.

2.3 Aviation

Noise intrusion is always a contentious issue for the aviation sector. Sound demonstrations were therefore an important element in London Heathrow Airport's recent consultations on future expansion and airspace change. Building on earlier experience, fully immersive and interactive sound demonstrations were developed that combined verified 3d virtual reality (VR) visualisations with head-tracked audio, so that flights even directly overhead could be simulated (Figure 4). As well as the immersive benefits, introducing VR was aimed at broadening engagement at public events to reach a wider (generally younger) demographic.

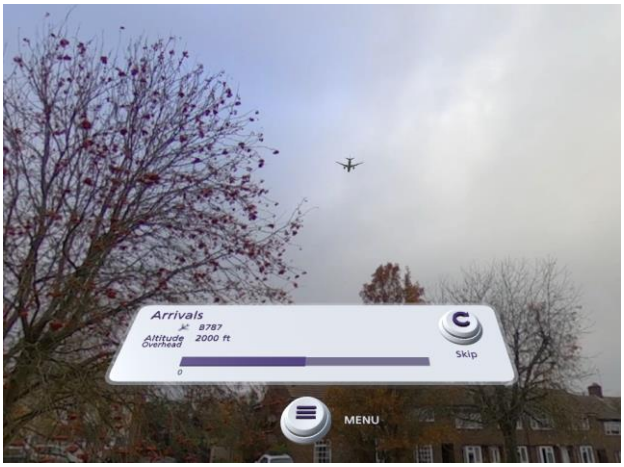

Figure 4: Interactive virtual reality simulation of aircraft passing overhead

3. AURALISATION AND ADVANCED AIR MOBILITY

Current applications of auralisation in the AAM realm include: vertiport infrastructure design; perception studies for annoyance and health impact assessment of novel noise sources; informing noise policy development; and assisting early prototyping of AAM vehicles.

3.1 Simulated AAM Sounds

Through internally funded research, Arup has developed generic acoustic models of AAM aircraft. Once operational conditions such as trajectory, rate of climb, cruise speed and receiver position are defined, sound propagation is modelled using the NASA Auralisation Framework (NAF) software and auralised using Arup SoundLab. This allows the listener to hear the sound of an aircraft that may not

yet exist and can be a useful tool to optimise the aircraft noise signature, for example.

The UAM NASA Acoustics Technical Working Group was established in 2018 to understand the multi-faceted acoustic disruptions posed by AAM. NASA's resulting Urban Air Mobility white paper[4] recognised that metrics used currently for rotorcraft might not be applicable to assessing human response and health and quality of life impacts of AAM flights. Further studies using auralisations were recommended.

The first auralisations of synthesised electric aircraft were presented at the Farnborough International Exhibition and Conference Centre for the Global Urban Air Summit (GUAS) in September 2019, at a time when AAM vehicle recordings were not available or published. The generic AAM vehicle model is shown in Figure 5. Two flightpath scenarios (shown in Figure 6) were modelled, including existing urban soundscape recordings, to demonstrate the impacts of AAM vehicle noise on the urban environment and to evaluate public perception. The outcomes were well received by the GUAS participants. The presentation of these sound demonstrations was undertaken in partnership with Six Miles Across London Limited (S.M.A.L.L.), who will also design and build the first operational vertiport in the world, Air-One®, later this year in Coventry, UK.

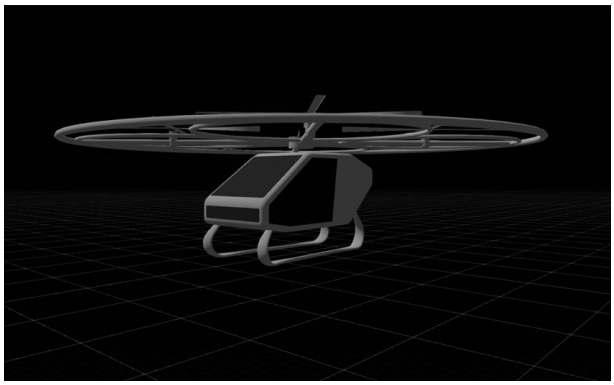

Figure 5: Generic model

In preparation for AAM operation in the city airspace, Los Angeles Department of Transportation and the City of Los Angeles began to outline future noise policy in 2020. To inform the potential acoustic impacts of AAM flights and help shape the city's policy making, sound demonstrations were developed and created[5]. Urban soundscapes at three locations across the city were recorded and the pass-by sound of a helicopter, a generic AAM vehicle and a generic drone using the same flight path were overlayed.

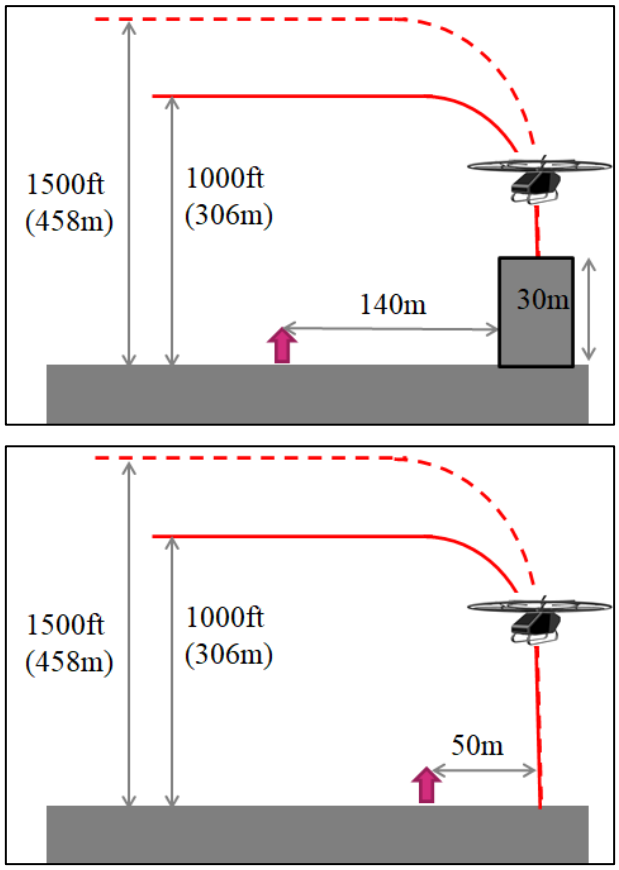

Figure 6: Scenarios modelled for understanding AAM sound perception

3.2 AAM Airspace Planning

Noise contours are often used to visualise the impacts of aviation noise. Typically, these contours are produced using specialist noise modelling software such as the FAA's Aviation Environmental Design Tool (AEDT) or the CAA's ANCON model. Through internally funded research, Arup has developed a web-based tool to enable operators and stakeholders to carry out their own preliminary exploration of the noise impacts of fixed wing and rotorcraft vehicles. Using this tool, initial optioneering of routes can be undertaken quickly and efficiently without the need for specialist noise modelling software.

The tool provides a simple web-based interface that allows the user to draw flight paths and assign different numbers and types of vehicle to each flight path. The tool calculates noise contours for each flight path and implements GIS processing to calculate metrics including the area and total population within each contour. The calculation procedure is currently based on the ECAC Doc 29[6] method for modelling noise from fixed wing aircraft and the FAA's Heliport Noise Model[7] (HNM) and has been adapted to AAM vehicles based on published information and internal research.

Example noise contours produced by the tool for an eVTOL vehicle are shown in Figure 7.

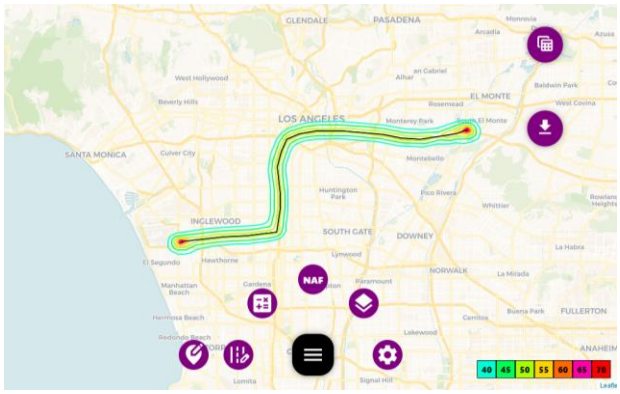

Figure 7: Noise contours calculated by Arup's Airspace Optioneering Tool for an eVTOL vehicle.

4. PILOT STUDY OF AAM NOISE PERCEPTION

The European Union is preparing a framework to support the introduction of AAM and support Europe to become a world leader in this sector. It is expected that AAM may be a reality in Europe by 2024-25[8].

EASA conducted a survey-based assessment of public acceptance of AAM in the EU[9], with the participation of 3,690 citizens across six European cities. Qualitative and quantitative surveys identified noise as one of the major concerns for societal acceptance of AAM. This prompted further investigation of the issues around response to AAM noise response.

A pilot study was then undertaken using SoundLab to gain initial insight into people's response to AAM noise signatures, which differ from those of traditional rotorcraft. Characteristics of the noise signature such as tonality could potentially result in a different dose / response profile when compared to existing aircraft sources. Legislation, planning for vertiport infrastructure and routes and the design of electric aircraft will be highly influenced by how noise is perceived by communities. AAM operations pose another layer of complexity since, compared with other types of aircraft, their flight paths are likely to be closer to where people live and work.

The pilot study aimed to: (1) investigate whether sound demonstrations would be an appropriate way to engage with and understand people's responses to UAM sound; (2) test and develop approaches to undertake the tests, with a view to carrying out a larger study; and (3) gain initial insight into people's perceptions of UAM sound, noting that the sample would be too small to yield statistically reliable results.

4.1 Method

Due to travel restrictions during the Covid-19 pandemic, the study was carried out using a transportable facility (m|Lab) installed in Arup's office in Amsterdam. As in SoundLab, m|Lab uses 3D ambisonic sound, focused at the listener's head height, from an array of loudspeakers, at floor level, head height and overhead (plus bass loudspeakers). Walls are treated with sound absorbing material. The setup is shown in Figure 8.

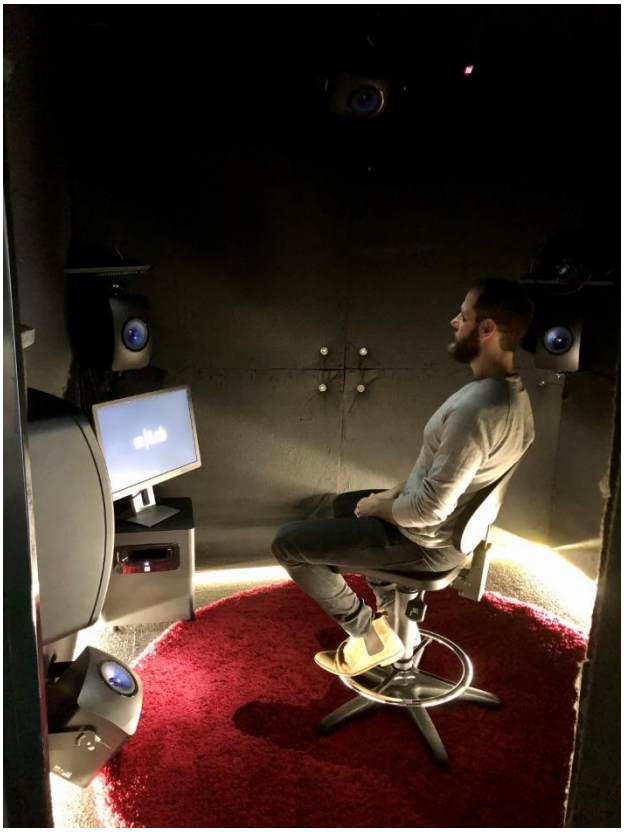

Figure 8: Noise auralisation setup in Arup m|Lab in Amsterdam

Sounds were calibrated to a level of 80dB$L_{Amax,F}$ from jet aircraft, helicopter, bus, motorbike, large multicopter drone, smaller multicopter drone, recorded air taxi and synthesised air taxi. Additionally, the air taxi sound was reproduced at two lower sound levels (60 and 70dB$L_{Amax,F}$).

The listeners were asked to rank each sound according to "how much the sound would bother, annoy or disturb them" on a scale of 0 (not at all) to 10 (extremely) as Figure 9 shows. They were also asked to provide comments on what aspects of the sound had contributed to their rating.

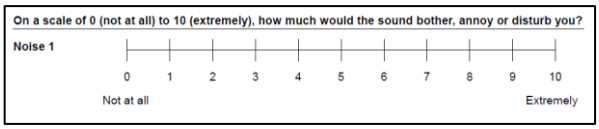

Figure 9:Scale to measure level of annoyance and disturbing

A total of 20 listeners took part, with one listener at a time. This was an initial study and a larger scale study would be required to be statistically representative. However, the results provide some indication of the possible risks and can support the design of further and more detailed studies.

4.2 Pilot Study Results

Preliminary results are summarised in Figure 10, showing the mean annoyance rating and 95% confidence intervals for each source. Further details are given in the EASA report.

4.2.1 Familiarity

When sounds at similar levels were compared, participants reported a generally higher level of annoyance for the unfamiliar sounds, as shown in Figure 10. The difference was particularly marked when comparing AAM sounds with road transport sources. This may indicate that the level of annoyance will decrease as citizens become familiar with sounds of AAM vehicles.

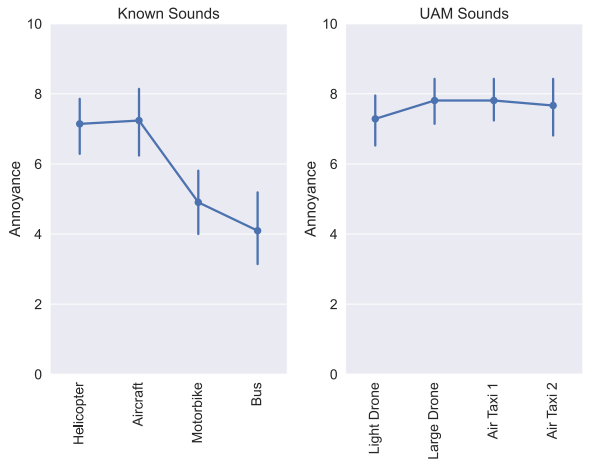

Figure 10: Results separated into familiar and unfamiliar sounds, error bars show bootstrapped 95% confidence intervals

As described on the EASA report: *"most comments featured recognition of or familiarity with the sounds being linked to lower (relative) annoyance scores".*

The air taxi and large drone scored the highest mean average annoyance result. The synthesised air taxi at 80dBL$_{Amax,F}$ (Air Taxi 2) scored only slightly lower. This could lead to the conclusion that *unfamiliar* sounds, in this case AAM sounds, are perceived more negatively or that the sound *characteristics* of these aircraft lead to a more negative rating at the same maximum sound level, compared to the other sounds to which the participants were exposed.

The synthesised (rather than actual recording of a vehicle) air taxi model (Air Taxi 2) had a very similar reported annoyance rating to the actual air taxi recording, evidencing the robustness of the model for perception testing.

4.2.2 Relationship between annoyance and sound pressure level

Figure 11 illustrates the results of the tests undertaken with the same sound source (Air Taxi 2) at three different sound levels. As expected, the annoyance increases with sound level.

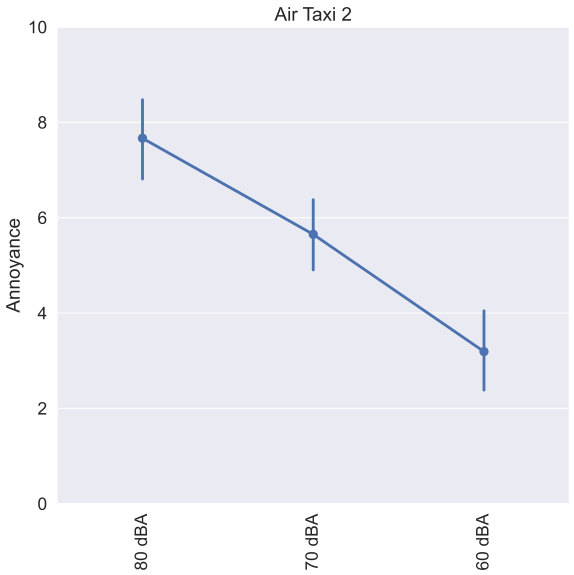

Figure 11: Reported annoyance as a function of sound level, error bars show bootstrapped 95% confidence intervals

4.2.3 Sound character and response

Spectrograms for each sound source are presented in Figure 12. These show how the frequency content and sound level change with time for four of the sources tested. The x-axis corresponds to the time and the y-axis corresponds to the frequency. The colours indicate the sound pressure level: blues are the lower levels, with increasing levels being magenta, red and white.

For most AAM vehicles there was generally a clear tonal component at around 3kHz, which corresponds to frequencies where humans are most sensitive. The tonality is much more distinct with the air taxis tested than with the drones.

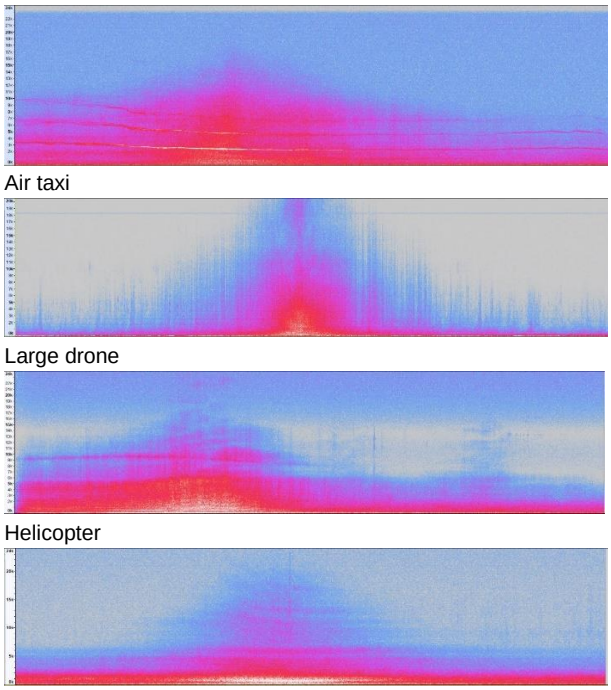

Figure 12: Sound signatures of four test sources

5. CONCLUSION AND NEXT STEPS

Arup is continuing to develop methods using sound to facilitate dialogue and understanding of the environmental impacts and societal response to noise exposure from existing and innovative transport systems. In parallel with the development of AAM technology, models for this new technology are being constantly developed and refined. Models of generic AAM vehicles have been created that represent the three main vehicle types: multicopter; lift and cruise; and vector thrust. For each, dominant sources of tonal and broadband noise are modelled and combined.

It is already possible to model different urban scenarios and evaluate the combined effect of the sound signature of a certain aircraft type with different ambient sound environments. These can be used for perceptual testing to develop better understanding, to drive policy and to inform the design of new vehicles.

The pilot study for EASA provided valuable initial insight into people's response to AAM sound and the signatures that differ from those of traditional aircraft. However, the small study sample means that the results are not sufficiently statistically significant to reach definitive conclusions: the AAM community would benefit from a larger scale study, learning from the pilot study.

As AAM applications broaden, auralisation and visualisation processes can continue to develop to facilitate understanding of the multi-faceted AAM design processes. The immersive experience enables the best possible understanding of evolving designs, enabling a focus on where and how improvements can be made, before beginning construction. This applies not only to the vehicles but also to the vertiports and other infrastructure required for their successful introduction and expansion.

Working with electric aircraft manufacturers enables these tools to be applied to three design development streams: (1) internal stakeholder engagement, using auralisation to facilitate the dialogue between the technical team and corporate members; (2) external stakeholder engagement; and (3) early prototyping for noise.

Looking more widely at the AAM sector, a combined approach to assessing the impact of noise and carbon emissions is also under development, using similar technologies and methods.

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