DOI: 10.61782/fa.2025.0051

AAVT: A TOOL TO RUN VIRTUAL SURVEYS WITH PASSING AIRCRAFT

Gary Isherwood[1*] **Jonathan Eccles**[2] **Gianluca Memoli**[1]

[1] Department of Informatics, University of Sussex, Brighton, United Kingdom
[2] Metasonixx Ltd, Brighton, United Kingdom

ABSTRACT

Multiple studies have identified the perception of aircraft sounds to be highly multisensorial, making it difficult to predict what the effects of airspace restructuring may be. This is because very few survey methodologies can capture future aircraft-dominated soundscapes, with multisensorial fidelity and in different areas around an airport. In this study, we explore the possibility of creating an immersive environment for soundscape surveys, focused on aircraft sounds and capable of virtually bringing survey participants to different parts of a territory, like virtual tourists. Built within a game engine, our Aviation Acoustics Visualisation Tool (AAVT) combines video recordings of a local community with virtual 3D-modelled passing aircraft. Acoustic emissions within AAVT are based on real audio recordings of single aircraft flyovers at various altitudes. This work describes the technical validation of the tool, including challenges related to audio-visual synchronisation, lens distortion calibration, acoustic level adjustments and system modularity. AAVT provides a foundation for future comparative studies that aim to reproduce multisensory judgements, like the correlation between the visually perceived height of a passing aircraft and the acoustically perceived noise. Future studies will support investigations on community responses and discussions on aircraft noise policies.

Keywords: *Aircraft Noise, Virtual Reality, Non-Acoustic Factors, Soundscape*

**Corresponding author*: *gi53@sussex.ac.uk.*

1. INTRODUCTION

Aircraft noise remains a major source of environmental concern for communities situated near large airports. Although regulatory efforts have contributed to reductions in average sound pressure levels (SPL), public complaints and subjective annoyance persist, often at levels disproportionate to measured acoustic exposure [1, 2]. This suggests that non-acoustic factors—such as visual prominence, perceived height, and contextual expectation can significantly influence how individuals perceive and respond to aircraft noise events [3,4]. The World Health Organization has recognised environmental noise as a public health issue, linking long-term exposure to adverse outcomes including sleep disturbance and cardiovascular disease [5]. In the UK, forecast increases in air traffic have prompted initiatives such as the Civil Aviation Authority's Future Airspace Strategy Implementation – South (FASI-S) - that seeks to restructure national airspace to improve traffic efficiency, reduce emissions, and mitigate noise impacts [6]. However, such initiatives require effective and transparent communication of "change" with affected communities [7], while traditional consultation tools, such as noise contour maps, may not always convey perceptual realities effectively [8].

As an example, previous studies have shown that aircraft judged to be flying lower or appearing visually larger than expected are often rated as more annoying, even when actual SPL remains constant [4]. These perceptual biases complicate predictions of community response and present challenges for perception-focused action plans. The best way to capture complex perceptive judgements would be to bring stakeholders in different parts of the territory, either in person or, with the advent of virtual tourism [9, 10], using immersive environments like Virtual Reality (VR). However, while multisensory effects on noise judgements (often called "non-acoustical factors") have been observed in real-world settings, it is not yet clear whether they can be reliably replicated in controlled virtual environments [11]. To explore this question, we present the Aviation Acoustics Visualisation Tool (AAVT): a modular virtual reality (VR) framework designed to simulate aircraft flyovers using real-world video and audio data (Figure 1). Built within a game engine, AAVT allows control over audio-visual parameters and is intended for use in future perceptual studies. This work describes the design and calibration of AAVT, highlighting possible applications in research and policy context.

Figure 1. Single frame from the user's perspective within VR, showcasing a 3D rendered aircraft flying over a 360deg video recording of the selected location. The aircraft is highlighted with a circle for clarity.

2. BACKGROUND

Immersive technologies have emerged as a promising avenue for both research and communication in acoustics. Georgiou et al. (2022) [12] demonstrated that ambisonic loudspeaker-based virtual environments could replicate stress responses to noise in laboratory conditions. Similarly, Lindquist, Lange, and Kang (2016) [13] showed that visual realism and audio-visual consistency are critical in shaping environmental judgments within 3D simulations. Sahai et al. (2016) [14] extended this by integrating accurate sound rendering with spatially realistic flight paths, reinforcing the need for multisensory coherence in subjective evaluations. Beyond laboratory applications, immersive tools have also found relevance in policy and engagement contexts. For instance, Lugten et al. [15] explored how environmental features, such as water and vegetation can moderate noise perception in VR.

In summary, while these studies provide a foundation for virtual frameworks such as the AAVT, which aim to bridge the gap between objective acoustic data and experiential perception, the question of their "verisimilarity" remains open. Virtual Reality environments can capture perceptual and contextual factors such as visual impressions, spatial audio, and individual attitudes that influence noise annoyance beyond what traditional metrics explain, but factors such as the technological substrate and the duration of the exposure may be crucial to evaluate long-term judgements [16]. The AAVT builds upon this by creating a modular platform for future perceptual studies and participatory investigations focused on aircraft infrastructures.

3. METHODOLOGY

Figure 2 summarises the role this work on the path towards the first user study with the Aviation Acoustics Visualisation Tool (AAVT). This work does not present a user study, but covers the technical aspects of audio-visual synchronisation, system modularity, user experience, and visual realism. Perceptual testing and survey-based evaluation will be conducted in future studies.

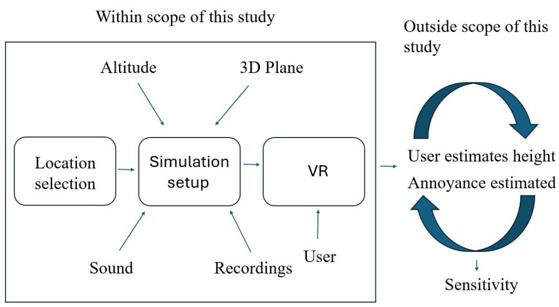

Figure 2. flowchart illustrating the complete sequence from simulation configuration and VR system setup to participant interaction and survey completion.

Table 1. Comparison between original experiment and planned virtual ones.

Original experiment	AAVT
Participants were recruited among residents in local areas around Gatwick airport.	Participants will be virtually transported in local areas around Gatwick airport, not necessarily where they live.
Semi-structured interviews would happen in local green areas, interrupting the flow for each identifiable aircraft.	A 3D-rendered aircraft will pass through the scene on a pre-defined flight path with corresponding audio playback. After each flight event, participants will remove the headset to complete a paper-based survey.
Participants were asked to express perceptive judgements on distance, height and noise for up to four passing aircraft, within a 15-minute, semi-structured interview.	Participants would be asked to express perceptive judgments on 4 passing aircraft, at different distances and heights.

3.1 From the final experiment to tool requirements

The version of AAVT presented in this work has been optimised to run a user study that replicates the experiments described by [17] (see right side of Figure 2). A comparison between the original requirement and the planned experiment can be found in Table 1. AAVT was designed to make this experiment possible.

3.2 Selected location

Once the technical requirements had been identified, the first step in Figure 2 was selecting a location. For this version of the AAVT, we selected Penshurt Place: a historic building near Penshurst, Kent, 32 miles (51 km) South East of London (see Figure 3). This site was selected due to its proximity to Gatwick's noise monitoring terminal in Chiddingstone and for the availability of the survey data from [17]. Gatwick flight tracking data [18] indicates a mean overflight altitude of approximately 6,335 feet (SD = 2,698 feet), highlighting the broad variation in aircraft height. 42% of aircraft travel between 3,000 and 6,000 feet - AAVT was then required to reproduce these conditions.

Figure 3. 3D-rendered aircraft flying over the Penshurst Place building, within the VR environment. The aircraft is circled for clarity.

3.3 Aircraft Modelling and Visual Parameters

Given its prevalence in Gatwick's flight operations [19], the Airbus A320-Neo was selected as the reference aircraft. A 3D model was created in Blender 4.1 [20] using manufacturer specifications [21], with a fuselage length of 37.57 m and wingspan of 34.10 m. This model was imported into Unreal Engine 5.2.1 [22], which operates on a 1 cm = 1 Unreal unit scale. The pitch angle was adjusted to reflect a standard 3° glide slope [23], while the roll angle remained level for azimuthal consistency. Contrails and other high-altitude visual cues were deliberately excluded, as they typically occur well above the altitudes simulated in this scenario [24].

3.4 Audio Acquisition and Playback

As shown in Figure 5, our class I sound level meter (Bruel & Kjaer, model 2270) was mounted on a 1.5-meter-high tripod positioned on soft grass. Acquisition was set in 1/3rd octaves and no corrections for ground reflections were applied, in accordance with ISO 1996-2:2017 [25]. Real-time SLM recordings were used to calibrate the readings made by the permanent meter operated by Gatwick airport, situated approximately 2 km North-West of the selected location [26].

Aircraft audio was recorded using a consumer-grade Insta360 X4 dual-lens 360° camera [27] featuring four integrated microphones. Audio was encoded in AAC at 48 kHz and 16-bit resolution and exported as stereo through Insta360 Studio. Extracted .wav files were processed using FFmpeg [28] and imported into Unreal as non-spatialised audio sources. These were mapped to the aircraft blueprint and anchored at the origin (X=0, Y=0, Z=0) to maintain alignment with the visual model.

3.5 Sound Pressure Level Calibration

The task of creating aircraft in different positions relative to the user requires to change the volume and the phase of the stereo recordings according to the moving position of the passing sources attached to the aircraft e.g. according to the CNOSSOS model [29]. Calibrating playback levels in Unreal Engine, however, requires a calibration of its normalised floating-point Volume Multiplier (0.1–4.0). The Meta Quest 3 headset [30] adds further uncertainty due to its HRTF spatial rendering and limited published output data. To calibrate the output in terms of real-world sound pressure levels, pink noise was played via a UE5 Sound Cue and measured with a calibrated sound level meter outside the headset. A near-field reading was taken 1.5 cm from the right speaker to approximate the in-headset experience. To verify the response curve, three readings per volume level were taken at 30 cm. The Meta Quest system volume was fixed at 12/15. A second-degree polynomial regression was fitted to the data in Figure 4.

A Python script was used to reverse this curve and calculate the required Unreal multiplier for a given SPL, based on 1.5 cm measurements (Fig. 4). Aircraft sound levels were estimated at three positions: 4km before, directly overhead, and 4km beyond using data from Gatwick's NTK noise terminals. Visual distances were calculated from ground distance and altitude using FlightTrack. These values were used to create a lookup table linking visual distance to SPL, from which Unreal multipliers were derived using the polynomial fit.

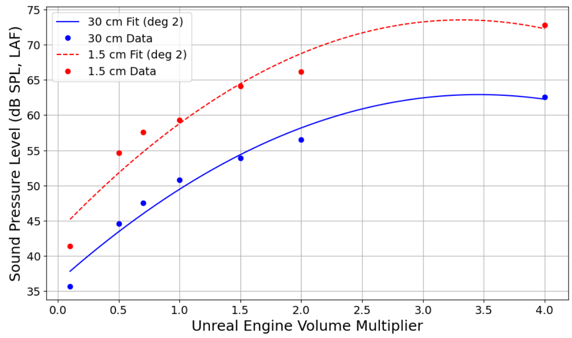

Figure 4. SPL vs. UE Volume Multiplier for Meta Quest 3 measured using pink noise playback

3.6 Configuration and Modularity

A key design goal of AAVT is its modularity, so that user-study participants can experience different locations in the same experiment, without reconfiguring the full system. Unreal Engine allows rapid substitution of video backgrounds and aircraft geometry via a blueprint system supporting standard .obj models. Aircraft paths and orientation parameters can be adjusted through the Details panel, which also provides amplitude weighting control.

Figure 5. Camera and sound level meter setup at the Penshurst location

4. SYSTEM SETUP AND VALIDATION

This section outlines the calibration and configuration steps carried out during the current phase of AAVT development, including aircraft motion modelling, lens distortion analysis, audio playback calibration, and system adaptability across different scenarios.

4.1 Lens Distortion and Camera Calibration

The Insta360 X4 camera uses two wide-angle lenses and automatically stitches the images together to produce a full 360° view. However, this process introduces some visual distortion, particularly around the edges, that may affect how planes are visually perceived.

To measure these distortions and understand the camera's optical behaviour, we performed a calibration using a standard checkerboard pattern. This pattern provides a known reference: each square is the same size, and the corners form a perfect grid. Multiple photos of the checkerboard were taken from different angles. The Open CV [31] calibration software then compares where the corners appear in the image (what the camera sees) with where they should be in real life (the known geometry of the checkerboard). From this, two sets of values are calculated as shown in Fig (1)

$$\mathbf{K} = \begin{bmatrix} 1335 & 0 & 1901 \\ 0 & 1325 & 1081 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The camera matrix $\mathbf{K}$ contains the camera's calibration settings. The values 1335 and 1325 (in the top-left and middle of the diagonal) represent the focal length in pixels along the horizontal and vertical axes, relating to how "zoomed in" the camera is. No correction gets applied if these two numbers are similar within 3%. The values 1901 and 1081 (in the top-right and middle-right of the matrix) indicate the optical centre (also called the principal point), the location in the image where the lens is focused, typically near the centre of the frame (the theoretical centre should be at coordinates 1920,1080 for a 4k resolution, so the correction due is negligible). The bottom row is a standard placeholder used in computer vision to maintain mathematical consistency.

$$\mathbf{D} = \begin{bmatrix} -0.0200, & 0.305, & 0.00382, & -0.00671, & -0.780 \end{bmatrix} \quad (2)$$

The distortion coefficients $\mathbf{D}$ in Fig (2) how the camera lens bends the image, especially near the edges. The first three values (–0.0200, 0.305, 0.00382) account for radial distortion, which causes straight lines to bow outward or inward. The last two (–0.00671, –0.780) correct tangential distortion, which occurs if the lens is slightly misaligned, shifting parts of the image sideways. Since the values of $\mathbf{D}$ were much smaller than 1, even in this case the correction to apply was negligible.

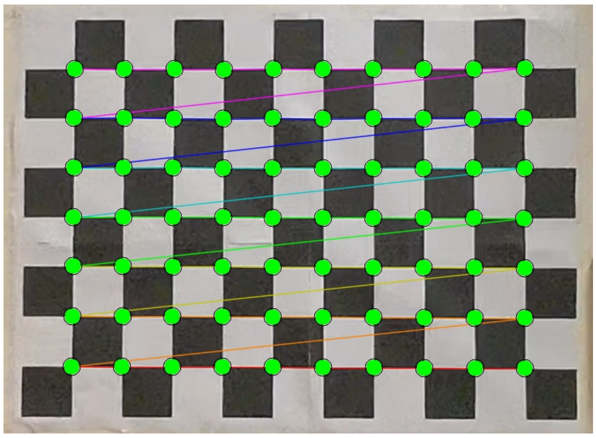

Figure 6. Checkerboard image used to measure camera lens distortion. The green dots show where the software detected the inner corners of the squares, and the lines help confirm that the grid pattern is accurately aligned.

5. CONCLUSION

This work detailed the development and technical validation of the Aviation Acoustics Visualisation Tool (AAVT), a virtual reality-based system for simulating aircraft flyovers with controlled audio and visual parameters. The platform integrates real aircraft audio recordings and 3D rendered aircraft models to allow flexible configuration of flight paths, aircraft types, and environmental settings. Calibration methods addressed lens distortion and playback amplitude. The challenges of reproducing audio and video accurately in VR were discussed, including challenges in spatialisation and synchronisation.

As described in Figure 2, this stage of the project focused on system setup and validation. Future work will evaluate perceptual responses to aircraft overflights in VR, exploring the effects of visual prominence and contextual cues on annoyance ratings. Future versions of AAVT will embed better spatialisation (e.g. Ambisonic) and a more detailed acoustic modelling of the aircraft source, being AAVT closer to its intended use in both experimental studies and consultation settings. Its design supports future deployment in stakeholder engagement processes, including noise impact communication as required under the UK Civil Aviation Authority's Noise Action Plan framework [7].

6. ACKNOWLEDGMENTS

The author gratefully acknowledges support from the Engineering and Physical Sciences Research Council (EPSRC) and Metasonixx through a collaborative PhD Studentship at the University of Sussex.

7. REFERENCES

[1] D. Schreckenberg, B. Griefahn, and M. Meis, "The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance," *Noise and Health*, vol. 12, no. 46, pp. 7–16, 2010.

[2] J. M. Fields, "Effect of personal and situational variables on noise annoyance in residential areas," *The Journal of the Acoustical Society of America*, vol. 93, no. 5, pp. 2753–2763, 1993. Retrieved from https://ntrs.nasa.gov/citations/19930012128.

[3] H. M. Miedema and H. Vos, "Noise sensitivity and reactions to noise and other environmental conditions," *Journal of the Acoustical Society of America*, vol. 113, no. 3, pp. 1492–1504, 2003.

[4] G. Memoli, G. Hamilton-Fletcher, and S. Mitchell, "Soundscape assessment of aircraft height and size," *Frontiers in Psychology*, vol. 9, p. 2492, 12 2018.

[5] World Health Organization, *Environmental Noise Guidelines for the European Region*. Copenhagen, Denmark: WHO Regional Office for Europe, 2018. `https://www.who.int/europe/publications/i/item/9789289053563`.

[6] UK Civil Aviation Authority, "Future airspace strategy implementation – south (fasi-s)." `https://www.caa.co.uk`, 2021.

[7] UK Civil Aviation Authority, "Noise action plans review," 2024. Accessed: April 6, 2025.

[8] R. Guski, D. Schreckenberg, and R. Schuemer, "Who environmental noise guidelines for the european region: A systematic review on environmental noise and annoyance," *International Journal of Environmental Research and Public Health*, vol. 14, no. 12, p. 1539, 2017.

[9] F. Hruby, "The sound of being there: Audiovisual cartography with immersive virtual environments," *Journal of Cartography and Geographic Information*, vol. 69, pp. 19 – 28, 2019.

[10] R. Yung and C. Khoo-Lattimore, "New realities: a systematic literature review on virtual reality and augmented reality in tourism research," *Current Issues in Tourism*, vol. 22, no. 17, pp. 2056–2081, 2019.

[11] G. Brambilla and L. Maffei, "Perspective of the soundscape approach as a tool for urban space design," *Noise Control Engineering Journal*, vol. 58, no. 5, pp. 532–539, 2010.

[12] F. Georgiou, C. Kawai, and R. Pieren, "Laboratory setup for assessing physiological stress buildup and recovery associated with noise annoyance using virtual reality and ambisonic loudspeaker reproduction," in *Proc. of the 24th International Congress on Acoustics*, (Gyeongju, Korea), 2022.

[13] M. Lindquist, E. Lange, and J. Kang, "From 3d landscape visualization to environmental simulation: The contribution of sound to the perception of virtual environments," *Landscape and Urban Planning*, vol. 148, pp. 216–231, 2016.

[14] A. Sahai, F. Wefers, S. Pick, E. Stumpf, M. Vorländer, and T. Kuhlen, "Interactive simulation of aircraft noise in aural and visual virtual environments," *Applied Acoustics*, vol. 101, pp. 24–38, 2016.

[15] M. Lugten, M. Karacaoglu, and K. White, "A vr experiment testing the effects of fountain sound and visible vegetation on soundscape quality in areas exposed to aircraft noise," in *Proceedings of Internoise 2017*, 08 2017.

[16] E. Brambilla, E. Petersen, K. Stendal, V. Sundling, T. E. MacIntyre, and G. Calogiuri, "Effects of immersive virtual nature on nature connectedness: A systematic review and meta-analysis," *DIGITAL HEALTH*, vol. 10, p. 20552076241234639, 2024.

[17] G. Memoli, G. Hamilton-Fletcher, and S. Mitchell, "Soundscape assessment of aircraft height and size," *Frontiers in Psychology*, vol. 9, p. 2492, 2018.

[18] Gatwick Airport Limited, "How high are flights in my area?," 2020. Accessed April 2025.

[19] Gatwick Airport Limited, "Noise action plan 2024–2028," 2024. Accessed April 2025, see p. 89.

[20] B. Foundation, “Blender 4.1 [computer software].” https://www.blender.org, 2024.

[21] Airbus, “A320 family specifications.” https://aircraft.airbus.com/en/aircraft/a320-family/a320ceo, 2023.

[22] E. Games, “Unreal engine 5.2.1 [computer software].” https://www.unrealengine.com, 2023.

[23] International Civil Aviation Organization (ICAO), *Annex 14 to the Convention on International Civil Aviation, Volume I – Aerodrome Design and Operations*. Montreal, Canada: ICAO, 6th ed., 2013. Retrieved from https://www.warningspheres.com/pdf/icao-annex-14-2013.pdf (see p. 46 for standard 3° glide path).

[24] National Aeronautics and Space Administration (NASA), “On the trail of contrails.” https://www.earthdata.nasa.gov/news/feature-articles/trail-contrails, 2013. Accessed April 2025.

[25] “ISO 1996-2:2017 acoustics – description, measurement and assessment of environmental noise – part 2: Determination of environmental noise levels.” International Organization for Standardization, 2017.

[26] Gatwick Airport Limited, “Community noise monitoring at bidborough – final report,” 2015. Accessed April 6, 2025.

[27] Insta360, “Insta360 x4 action camera specifications.” https://www.insta360.com/product/insta360-x4, 2024. Accessed April 2025.

[28] FFmpeg Developers, “Ffmpeg: A complete, cross-platform solution to record, convert and stream audio and video.” https://ffmpeg.org, 2024. Version used: 6.1; Accessed April 2025.

[29] S. Kephalopoulos, M. Paviotti, F. Anfosso-Lédée, D. Van Maercke, S. Shilton, and N. Jones, “Advances in the development of common noise assessment methods in europe: The cnossos-eu framework for strategic environmental noise mapping,” *Science of The Total Environment*, vol. 482-483, pp. 400–410, 2014.

[30] Meta Platforms Inc., “Meta quest 3 mixed reality headset.” https://www.meta.com/quest/quest-3, 2023. Accessed April 2025.

[31] OpenCV Team, “Opencv (version 4.11.0) [computer software].” https://opencv.org, 2023. Used for camera calibration; accessed April 2025.