



WHITE PAPER

Tuning the Skies: Next-Generation Psychoacoustic Metrics for Urban Air Mobility

07.01.2026
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Executive Summary

The implementation of Urban Air Mobility (UAM), driven by electric Vertical Takeoff and Landing (eVTOL) aircraft and Unmanned Aircraft Systems (UAS), will be heavily influenced by public acceptance. While significant engineering efforts focus on safety and efficiency, the acoustic signature of these new aircraft represents a critical, and possibly unrecognised, barrier to widespread adoption.

Current noise certification standards are largely adapted from traditional aviation and are only partially effective as they focus primarily on sound pressure level (decibels). This historic approach overlooks the unique and complex acoustic characteristics of eVTOLs, which may be perceived as highly detectable or annoying, even at lower decibel levels.

Without refinement that accurately reflects public acceptance, Urban Air Mobility will likely face continued debate and resistance as a viable method of commercial or personal air transportation.

This paper introduces a new consideration for certification that integrates psychoacoustic metrics to create a sound profile that is not only compliant but also community accepted. This approach supports the delicate balance between the need for safe detectability and the requirement of minimal noise pollution.

1. Introduction: The Future Soundscape of Electrified Aircraft

The advent of Urban Air Mobility (UAM) is set to revolutionise aerial transport, offering a new dimension for delivery logistics, personal travel, and other applications. As with many areas of acoustic study, the foundation of this analysis lies in preventing auditory damage, minimising community noise impact, and reducing public annoyance.

While governing bodies are working diligently to develop regulations, the current framework is generally an adaption of standards from traditional aircraft noise testing (for example, ICAO Annex 16, FAA Part 36, ISO 5305, ISO 3744, and EASA standards). By focusing primarily on decibel-based compliance, manufacturers may develop aircraft that meet legal requirements but fail the crucial test of public perception.

Metrics such as Effective Perceived Noise Level (EPNL) incorporate weighting for duration and tonal noise but should be expanded to better reflect the complex acoustic signature of such aircraft. Without a holistic understanding of all noise sources and their psychoacoustic impact, the industry risks creating a future that is legally compliant but publicly unacceptable.

2. The Delicate Balance: Detectability vs. Annoyance

While ongoing development and improvements are critical, a complete absence of sound is not ideal. A certain level of detectability should be considered a safety feature, especially for low-altitude UAS like delivery drones that may interact with humans. The automotive industry faced a similar challenge, leading to the implementation of standards such as FMVSS 141, which mandates minimum noise thresholds for otherwise silent battery electric vehicles to ensure pedestrian safety.

This highlights the central challenge for UAM acoustics: defining the delicate balance between necessary detectability and publicly acceptable sound. Aircraft must be audible enough to be detected, but not so intrusive that it becomes a source of constant complaint. Achieving this balance is impossible using decibel measurements alone; it requires a deeper understanding of how humans perceive sound.

Regardless of the purpose of an electrified aircraft, its acoustic output is a complex combination of multiple noise sources and frequencies.



Public acceptance of eVTOL and UAS aircraft will depend not only on safety and efficiency, but also on how their acoustic signature is perceived by communities.

3. The Complex Acoustic Signature of Electrified Aircraft

The noise produced by electrified aircraft is fundamentally different from that of both conventional aircraft and automobiles, presenting a unique acoustic challenge. The presence of multiple noise sources across a very broad frequency range makes the resulting sound profile particularly complex.

UAS and eVTOL aircraft often use multiple motor/propellers, which creates an additional challenge. If identical frequencies are present from multiple sources, the noise may be amplified significantly. However, if two or more sources operate at slightly different frequencies – due to mechanical variations or parasitic losses in the system – the tones begin to interact.

This interaction can create a “beating” or “pulsing” effect, which may be more detectable or more annoying than a singular frequency at a higher amplitude.

This challenge is also addressed in traditional aircraft with multiple engines or propellers, using techniques such as speed synchronisation, blade synchrophasing, or active noise and vibration control. However, these solutions may not always be feasible or considered for smaller electrified aircraft.



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4. Integrating Psychoacoustics into Certification

To address this challenge, certification standards must evolve beyond simple decibel metrics. Whether incorporated directly into regulations or applied in parallel during product development, engineers should recognise the importance of this approach and the tools required to design well-balanced aerial products.

The solution lies in combining simulation with subjective analysis (jury testing) to identify and prioritise dominant noise sources based on their perceived characteristics. HBK’s Sound & Vibration Engineering Services team brings both the tools and extensive experience required to design and execute effective jury studies, taking into account the nuances of subjective evaluations.

Category	Source	Acoustic Characteristics
1. Aerodynamic Noise (most prevalent)	Propeller/Rotor System	Tonal Noise: The distinct “loading noise” found at the blade-pass frequency (BPF) and its harmonics. With typical motor speeds of 1500 – 4500 RPM, this creates fundamental operating frequency (first rotational order) from 25 – 75 Hz. Annoying tones due to blade-pass frequency might be found in the 200 – 600 Hz range (depending on the rotor design). Broadband Noise: Turbulent airflow from the blade’s edge and tip creates a high frequency “hissing” sound.
2. Motor and Drivetrain Noise	Electromagnetic Noise	A high-frequency whine from rotor/stator interaction. This is impacted by the motor’s control strategy, design, and assembly. Operating frequencies are often in the range of 2 kHz – 4 kHz, which coincides with peak sensitivity of human hearing.
	Mechanical Noise	Noise from gearboxes, bearings, and other moving parts. Frequencies vary depending on the design variables of each component.
	Ancillary Noise	Sounds from essential support systems like cooling fans and hydraulics. These can create noises and associated harmonics across a broad range of frequencies.
3. Interaction Noise	Airflow Turbulence	Complex and often unpredictable noise caused by the aerodynamic interaction between components, such as rotor-to-rotor or rotor-to-wing interactions.

Table 1: Principal Noise Sources of Electrified Aircraft

In this process, sounds should be recorded using a Head and Torso Simulator (HATS), such as the HBK's High-frequency HATS Type 5128, to ensure the highest fidelity playback. Binaural reproduction of these sounds is critical, given their nature and influence on detectability.

This transducer is capable of recordings from 20 Hz to 20 kHz, covering the full range of human hearing.



HBK High-frequency HATS Type 5128 enables binaural recordings that accurately capture how electrified aircraft are perceived by listeners.

Recordings are prepared for inclusion in a jury test by trimming audio files to a common length and removing any extraneous noises to avoid subconscious bias. Baseline recordings from real products should be presented, but these are by no means the limit of valuable possibilities.

Sounds may also be generated by Computer Aided Engineering (CAE) tools or modified using Finite Impulse Response (FIR) filters to assess juror reactions to specific features. For example, the blade pass frequency of a rotor can be reduced or amplified by a distinguishable amount.

When baseline and modified versions of the same sound are presented, jurors can determine whether the change is detectable, and relevant. This provides engineers with valuable information into product performance and helps identify where to focus further development efforts.

An acoustic playback system such as VI-grade's Jury Evaluation & Analysis is ideal for collecting subjective feedback in a controlled setting. This system manages sound playback, collects juror votes, and uses statistical models to identify the psychoacoustic metrics that best correlate with juror subjective preferences.



Acoustic jury evaluation used to correlate listener preferences with psychoacoustic metrics.

A combination of subjective testing methods, such as paired comparison and semantic differential, can be used to identify optimal sound signatures and to decouple critical psychoacoustic attributes such as “detectable”, “annoying”, and “obtrusive”.

This enables engineers to understand, for example, that a high-frequency noise at a given amplitude may be perceived as far more annoying than a lower-frequency noise at the same, or even a higher, decibel level.

From this analysis, a new set of certification metrics should be established. These metrics will quantify the character of sound, including:

- Loudness: The perceived intensity of the sound, based on human hearing sensitivity and other parameters
- Sharpness: The presence of high frequency components
- Tonality: The strength of discrete tones
- Fluctuation Strength and Roughness: The degree of modulation in the sound, resulting from multiple harmonics, which can be highly detectable and annoying

Several algorithms can be used to quantify these characteristics. Together, they form the foundation of psychoacoustics – the scientific study of how humans perceive sound. This is not a question of how quiet or loud something is, but instead, how acceptable it is to listeners.

5. Conclusion and Recommendation

The foundational work of standards like ICAO Annex 16, including corrections for tone and duration, is a step in the right direction. However, it is not sufficient to address the multi-source, broad-frequency acoustic nature of electrified aircraft. While future standards continue to evolve, engineers and designers should consider not only noise and vibration amplitude, but also the frequency characteristics of their sources, and their psychoacoustic impact.

It is imperative that industry and regulatory bodies collaborate to develop a new noise certification standard for eVTOL and UAS applications. This standard must be built on a foundation of psychoacoustics, moving beyond a single-number decibel rating. By adopting metrics such as loudness, sharpness, and roughness, engineers can design aircraft that are not only compliant but also optimised for community acceptance. This will help ensure the long-term success and sustainability of the Urban Air Mobility revolution.



Future noise certification standards should consider psychoacoustic metrics alongside traditional decibel-based assessments to support community acceptance of Urban Air Mobility.