

Introduction to the Special Issue on advanced air mobility noise: Predictions, measurements, and perception^{a)}

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ABSTRACT:

This Special Issue focuses on noise associated with advanced air mobility (AAM), an emerging class of predominantly electric distributed-propulsion aircraft designed for urban and regional transportation. As these vehicles move toward certification and deployment, noise has become a central challenge for regulatory approval and public acceptance, particularly due to operations in densely populated areas and at low altitudes. The 24 contributions in this issue address three key aspects of AAM noise: prediction, measurement, and human perception. Prediction studies span a wide range of modeling fidelities, from high-resolution simulations to improved semi-analytical approaches, and examine complex aeroacoustic mechanisms, including rotor interactions, turbulence ingestion, and broadband noise generation. Measurement studies, largely at model scale, provide new insights into tonal and broadband noise characteristics across configurations and operating conditions, while supporting model validation. Perception-focused contributions investigate annoyance, sound quality metrics, and auralization, emphasizing the role of context and operational factors in shaping human response. Together, these works highlight the interdisciplinary nature of AAM noise research and the need for integrated approaches to enable quieter vehicle design. <https://doi.org/10.1121/10.0044547>

(Received 8 July 2026; accepted 16 July 2026; published online 13 August 2026)

[Editor: James F. Lynch]

Pages: 1427–1435

I. INTRODUCTORY REMARKS

This Special Issue is focused on the topic of advanced air mobility (AAM) noise. While there is no universally accepted definition of AAM at present, the US Congress has defined it as “a transportation system that is comprised of urban air mobility and regional air mobility using manned or unmanned aircraft,” through the Federal Aviation Administration (FAA) Reauthorization Act of 2024.

Stimulated by advances in battery technology and by the rapid introduction of electrification and automation in the transport and mobility sector, the past decade has seen the rapid emergence and evolution of these AAM systems, which have matured from a promising technological concept to one where multiple companies in the US and around the world are in various stages of flight test of their designs in preparations for near-term certifications and subsequent deployment of their vehicles. These vehicles have been designed for passengers, cargo, and public services and

represent a transformative mode of air transportation. Typically based on electric vertical takeoff and landing (eVTOL) concepts, these vehicles offer a convenient means of accessing densely populated urban areas by landing and taking off at vertiports or on rooftops and in so doing alleviate traffic issues in heavily congested metropolitan areas. AAM vehicles also allow for efficient short-range inter-city travel and provide regional connections with rural areas. AAM aircraft can also be used effectively in policing, fire-fighting, and search and rescue operations. As a result, AAM vehicles have garnered much interest from aircraft and car manufacturers, regulators and agencies, research institutions, and academia.

Within the rapidly evolving design space, AAM vehicles can be broadly classified into several representative configuration types, primarily distinguished by their lift-generation mechanisms during forward flight. Some conceptual examples are illustrated in Fig. 1: (i) tilt-rotor eVTOLs, in which all rotors provide lift during vertical flight and transition to thrust generation in forward flight, while wings and other lifting surfaces contribute to lift in cruise; (ii) lift+cruise eVTOLs, where dedicated tilting rotors generate lift during vertical flight and thrust in forward flight, additional lift rotors, typically positioned downstream of the tilting rotors, provide lift in vertical flight but are deactivated under cruise conditions, while wings generate aerodynamic lift during forward flight; (iii) manned multicopter eVTOL

^{a)}Artificial Intelligence (AI) Usage Disclosure: Figure 1 has been created with assistance from Chat-GPT version GPT-5.5. The content has been reviewed by the authors. This is the only use of AI in generating this document.

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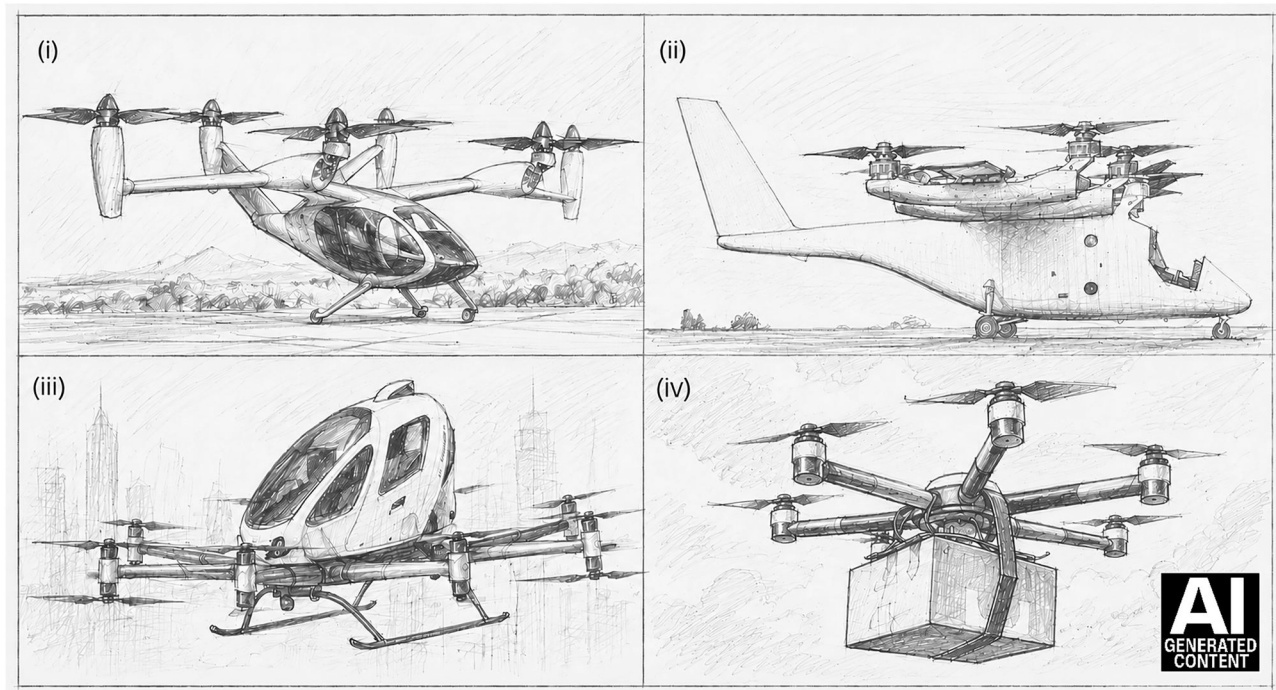


FIG. 1. Representative AAM vehicle configurations.

systems, in which lift is produced exclusively by distributed rotors; and (iv) unmanned multicopter systems [unmanned aerial systems (UASs)].

Although this classification is necessarily simplified, it captures the fundamental architectural distinctions across AAM concepts and provides a useful framework for understanding their underlying design trade-offs. In particular, it highlights how different lift-generation and propulsion strategies lead to strongly coupled multidisciplinary interactions that govern overall system performance. These include interactional aerodynamics and aeroacoustics arising from rotor–rotor and rotor–airframe interactions, installation effects associated with the integration of propulsion units and lifting surfaces, flight dynamics influenced by configuration-dependent stability characteristics, and aero-mechanical constraints linked to actuation mechanisms, structural loads, and transition phases between flight regimes. Collectively, these aspects underline the inherently coupled nature of AAM vehicle design, where aerodynamic, acoustic, structural, and control considerations cannot be treated in isolation.

Certification, community acceptance, and the subsequent at-scale deployment of these vehicles are likely going to be challenged by their noise levels and perceived negative impact by the public. Exposure to excessive noise levels has been well-documented by numerous studies to lead not only to hearing damage but also other health-related issues, such as sleep disturbance, cardiovascular diseases, and degraded cognitive performance among children (World Health Organization Regional Office for Europe, 2018). Indeed, recent studies on societal acceptance of urban air mobility

(UAM) by the European Union Aviation Safety Agency (EASA) found that noise was the second greatest public concern about the introduction of UAM across Europe (EASA, 2021). Currently, the acceptable community noise level resulting from conventional fixed-wing and rotary-wing aircraft operations, which is largely restricted to the vicinity of airports and heliports, is set by various regulatory bodies (e.g., FAA and EASA). The noise concern due to AAM operations is projected to pose an acute issue, as these aircraft are expected to operate in or near densely populated urban areas at much higher landing and takeoff frequency and lower altitude than conventional aircraft.

Predicting, measuring, and mitigating AAM noise, both at source and in the far field as perceived by an observer, is a challenging endeavor. At the component level, the common design trend of distributing thrust over multiple, smaller, rotors/propellers leads to lower tip speeds and thus lower steady-loading tonal noise levels. However, the reduced Reynolds number can result in transitional boundary layer phenomena, such as the occurrence of laminar separation bubbles, which are difficult to characterize both numerically and experimentally, besides their capability to increase significantly the high-frequency broadband noise levels.

Aeroacoustic experiments for rotors in confined environments, even isolated ones at smaller scale, face effects associated with test-chamber recirculation and reverberation, as well as significant challenges in measuring blade surface level quantities, such as unsteady pressure and skin friction. In addition, these AAM rotors must operate under axial, hover, and edgewise flight conditions. These different

modes of operation give rise to drastically different noise generation mechanisms. The elevated relative importance of broadband noise due to the use of smaller rotors and its unsteady modulation, especially in AAM vehicles employing multiple rotors, also strongly affect how rotor noise is perceived by an observer on the ground. Typically, rotor broadband noise is only captured via high-fidelity turbulence-resolving simulations, which are computationally intensive and intractable for many-query design optimization or parametric study purposes. On the other hand, computationally inexpensive semi-empirical and semi-analytical noise models frequently used in the early design phase of rotors are not robust or accurate enough to model noise generated by the complex three-dimensional transitional flow around rotor blades.

At the vehicle level, aerodynamic interactions and installation effects introduce additional, and often dominant, noise sources. These arise from several mechanisms: (i) rotor wake and slipstream impinging on downstream wing or fuselage surfaces, or, more critically, (ii) being ingested by downstream rotors; (iii) wake generated by an airframe component and subsequently ingested by a rotor and (iv) the presence of structural elements in close downstream proximity to a rotor, such as a motor-supporting arm, which distort the inflow through potential effects, leading to unsteady rotor loading and increased tonal noise; and (v) rotor-rotor interaction in side-by-side rotor installations with small tip-gap distances. In addition to these aerodynamic installation noise sources, tightly integrated rotor-airframe designs characteristic of most AAM aircraft also give rise to strong acoustic installation effects due to scattering and shielding by vehicle surfaces, which can significantly alter both the level and directivity of far-field noise. Acoustic scattering effects involving rotating broadband noise sources are challenging to model numerically, and, to date, no dedicated experiments have been performed to quantify the acoustic scattering effect of multirotor AAM vehicles.

In the specific context of UAM noise, the UAM Noise Working Group (UNWG) was formed by NASA with an assembly of acoustics experts from academia, industry, and government agencies. Divided into the following four subgroups, UNWG has promoted dialogues aimed at identifying and addressing the following areas: Tool Development and Experimental Validation, Ground and Flight Testing, Human Response and Metrics, and Regulation and Policy. These activities culminated in the first white paper on UAM noise, published in 2020, which evaluated current practices, identified technological gaps, and provided recommendations for future research (Rizzi *et al.*, 2020). The UNWG has compiled a revised white paper, which includes updated research goals, a new assessment of current practices, and an identification of gaps and recommendations to reach the updated goals (Rizzi *et al.*, 2026).

With a total of 24 articles, this Special Issue of the *Journal of the Acoustical Society of America* (JASA) addresses three key aspects of AAM noise research, namely prediction, measurement, and human perception, corresponding to the first

three of the four UNWG subgroups. While the fourth subgroup, Regulation and Policy, is not explicitly represented, it is expected to become increasingly important as AAM vehicles advance toward certification and entry into service, bringing noise certification requirements, regulatory considerations, and community acceptance to the forefront.

On the prediction side, the issue presents a diverse set of numerical studies spanning a wide range of fidelity, from scale-resolving lattice-Boltzmann simulations to mid-fidelity Reynolds-averaged Navier-Stokes (RANS)-based approaches, as well as enhancements to semi-empirical and semi-analytical models, including Brooks, Pope, and Marcolini (BPM)- and Amiet-based formulations.

On the measurement side, the contributions include small-scale experimental investigations of isolated rotors, multirotor configurations, and complete vehicle setups, providing valuable insight into dominant noise generation mechanisms and the characteristics of radiated AAM noise.

Human perception is also a critical factor for public acceptance of AAM. Contributions in this area address topics such as auralization, annoyance, and sound quality metrics. Several studies quantify annoyance through subjective listening tests based on synthesized or recorded AAM noise.

In addition, a number of articles explore noise reduction and control strategies, including shape optimization, multirotor synchrophasing to exploit acoustic interference, the use of passive treatments, such as acoustic metamaterials, and trajectory optimization. However, other important aspects remain relatively underexplored, including full-scale/vehicle operational noise measurements, acoustic shielding and scattering effects, sound propagation in urban environments, wake-building interactions, and atmospheric influences on sound propagation. This reflects the emerging nature of AAM research and highlights the need for continued investigation and future Special Issues to more comprehensively address these topics.

II. PREDICTIONS

The papers collected in this Special Issue address AAM noise through three tightly coupled perspectives: the primary scientific or engineering objective pursued, the modeling fidelity adopted for noise prediction, and the physical mechanisms responsible for sound generation. Together, they provide a structured yet complementary view of how aeroacoustic challenges in AAM can be understood, predicted, optimized, and mitigated across a wide range of configurations and scales.

From the standpoint of scientific objectives, several contributions emphasize noise prediction and physical interpretation as a prerequisite for robust design. High-fidelity numerical simulations are used to elucidate the mechanisms governing tonal noise directivity in distributed propulsion systems, showing how aerodynamic interaction and acoustic interference between closely spaced rotors lead to strong phase-dependent variations in radiated sound (Zarri *et al.*, 2025). A similar

emphasis on physical understanding underpins investigations of turbulence ingestion in forward flight, where numerical simulations reveal how coherent inflow disturbances interact with rotating blades to generate both enhanced broadband noise and additional tonal components (Trascinelli *et al.*, 2025). The analysis of rotor–structure interaction in small drones further demonstrates how unsteady aerodynamic loading induced by nearby structural elements can dominate tonal radiation and produce complex three-dimensional directivity patterns (Rendón-Arredondo *et al.*, 2025). Complementing these aerodynamic studies, the contribution focusing on electric motor noise highlights that non-aerodynamic sources may also contribute significantly to the overall acoustic footprint of AAM vehicles, particularly in the high-frequency range (Hakansson *et al.*, 2025).

Alongside these predictive and interpretative efforts, several papers explicitly target design-oriented objectives. The use of RANS simulations combined with semi-analytical noise models enables systematic evaluation of design sensitivities for rotor trailing-edge noise, clarifying the relative influence of airfoil choice, blade geometry, and rotational speed (Won *et al.*, 2025). A more direct optimization perspective is adopted through the coupling of steady RANS simulations with the Ffowcs Williams–Hawkings formulation and a discrete adjoint solver, enabling gradient-based reduction of tonal noise while maintaining thrust requirements (Abergo *et al.*, 2025). Noise reduction is also pursued through non-aerodynamic means, with a comprehensive filtering framework proposed to identify optimal passive acoustic metamaterials for specific eVTOL applications, including ducted fans and cabin noise control (Dogu *et al.*, 2025). In parallel, source-level noise reduction strategies are explored by exploiting rotor phase synchronization, which is shown to enable directional attenuation of tonal noise through controlled acoustic interference (Zarri *et al.*, 2025).

These diverse objectives are supported by a broad spectrum of modeling fidelities. Scale-resolving lattice-Boltzmann simulations are central to studies addressing complex flow–acoustic interactions, including distributed propeller synchronization (Zarri *et al.*, 2025), turbulence ingestion in forward flight (Trascinelli *et al.*, 2025), and rotor-wake/beam interaction noise (Rendón-Arredondo *et al.*, 2025). These approaches provide access to detailed unsteady flow fields and enable source decomposition analyses that would be difficult to obtain experimentally. Middle-fidelity computational fluid dynamics (CFD) formulations are employed where computational efficiency is required, particularly for design exploration and optimization. RANS-based simulations are used to extract boundary-layer quantities for trailing-edge noise prediction (Won *et al.*, 2025), and steady rotating-reference-frame simulations form the backbone of adjoint-based tonal noise optimization (Abergo *et al.*, 2025). Reduced-order and semi-analytical models further extend predictive capabilities, with Amiet-based formulations adapted for turbulence ingestion using pointwise inflow measurements (Piccolo *et al.*, 2025) and BPM-based

self-noise models enhanced with noncompactness corrections to improve high-frequency broadband noise prediction for small rotors (Mukherjee *et al.*, 2025). Analytical and numerical modeling is also applied to non-aerodynamic noise sources, enabling the assessment of electric motor noise within an integrated vehicle context (Hakansson *et al.*, 2025), while experimental–numerical characterization supports the classification and selection of acoustic metamaterials for passive noise control (Dogu *et al.*, 2025).

Across all modeling approaches, the contributions address a range of physical sound generation mechanisms relevant to AAM vehicles. Tonal noise emerges as a dominant concern in multiple studies, whether arising from blade-passing harmonics and their modification through rotor–rotor interaction (Zarri *et al.*, 2025), from blade–structure interaction leading to unsteady loading (Rendón-Arredondo *et al.*, 2025), from steady thickness and loading noise targeted through adjoint-based optimization (Abergo *et al.*, 2025), or from electromagnetic and mechanical excitations in electric propulsion systems (Hakansson *et al.*, 2025). Broadband noise associated with turbulent boundary layers is treated in detail through CFD-informed trailing-edge noise modeling (Won *et al.*, 2025) and through improved BPM-based formulations accounting for noncompactness effects (Mukherjee *et al.*, 2025). Leading-edge interaction noise is shown to play a critical role in turbulence-ingestion scenarios, where large-scale inflow disturbances dominate tonal and low-to-mid-frequency broadband radiation (Trascinelli *et al.*, 2025) and where Amiet-based models are extended to handle complex and partially characterized inflow conditions (Piccolo *et al.*, 2025). Finally, interaction noise, whether between rotors, between blades and structural components, or between aerodynamic and non-aerodynamic subsystems, is shown to be a defining feature of compact AAM configurations (Hakansson *et al.*, 2025; Rendón-Arredondo *et al.*, 2025; Zarri *et al.*, 2025).

Overall, the Special Issue demonstrates that addressing AAM noise requires a structured integration of objectives, modeling approaches, and physical mechanisms. By combining high-fidelity simulations for physical insight, middle-fidelity and adjoint-based methods for efficient optimization, and enhanced semi-analytical and passive approaches for system-level prediction and mitigation, the collected papers collectively advance the methodological and conceptual foundations needed to support the design of quieter AAM vehicles.

III. MEASUREMENTS

Experimental measurements relevant to the noise of AAM aircraft are the focus of several articles collected in this Special Issue. As AAM vehicles are not yet in widespread operation, their acoustic characteristics are not yet well understood. Since there is a dearth of acoustic data for full-scale AAM aircraft, this Special Issue contains several articles describing smaller-scale experiments intended to provide new insights into the acoustics of this new class of

vehicles. With the appropriate analysis, these measurements provide new insights into the physical mechanisms of noise generation and the characteristics of the radiated noise. As evident from several of the previously mentioned articles on noise prediction (Hakansson *et al.*, 2025; Mukherjee *et al.*, 2025), such experimental data are also essential for the validation of aeroacoustic prediction tools and to characterize phenomena that are not fully understood.

The measurements described in this Special Issue cover a range of configurations, including isolated rotors (Gautam *et al.*, 2025; Tinney and Valdez, 2026), multiple interacting rotors (Gan *et al.*, 2025; Turhan *et al.*, 2025; Wang *et al.*, 2026), coaxial co-rotating rotors (Beni *et al.*, 2026), and complete vehicles in free flight (Gan *et al.*, 2025; Meister *et al.*, 2026; Zamponi *et al.*, 2025). Most measurements were made in anechoic chambers, some focusing on hover or static thrust operating conditions (Beni *et al.*, 2026; Gan *et al.*, 2025; Tinney and Valdez, 2026; Wang *et al.*, 2026), while others used aeroacoustic wind tunnels to characterize the noise during forward flight (Gautam *et al.*, 2025; Turhan *et al.*, 2025). Zamponi *et al.* (2025) measured the noise from a free-flying drone in a reverberant environment, using signal processing techniques to transform the measured signals into free-field equivalent measurements. Meister *et al.* (2026) measured the noise of a free-flying drone in an outdoor environment using microphones mounted to the aircraft itself. While all experiments were conducted at small scale, the authors generally designed the test configurations and operating conditions so that the data could be related to full-scale AAM aircraft.

One major theme across these measurements is the relative contributions of tonal and broadband noise to the overall acoustic characteristics of AAM aircraft. For example, Tinney and Valdez (2026) conducted measurements on a 35% scale model of a notional eVTOL rotor in hover. The blade counts, tip speeds, and collective pitch angles were varied. Simultaneous measurements of performance and acoustics were conducted. Increasing the blade count increased the aerodynamic efficiency of the rotor at high collective pitch settings, where the rotor thrust is the highest, but reduced the efficiency at the low collective pitch setting due to the increase in profile drag. To account for the human response to noise, Helmholtz scaling was applied to transform the measured spectra to a full-scale equivalent, and A-weighted sound pressure levels were computed. The measured acoustic spectra were decomposed into tonal and broadband components. The relative importance of the tonal and broadband components was found to vary by operating condition. At low collective pitch settings, the broadband noise component was found to dominate the scaled A-weighted noise levels. Additionally, two distinct peaks were observed in the broadband frequency spectrum. As the collective pitch was increased, the higher-frequency broadband noise peak was observed to reduce in amplitude. Conversely, the tonal noise increased with increasing collective pitch, contributing as much to the A-weighted noise levels as the broadband components at the highest collective

pitch settings tested. The tonal and broadband components both appear to have a similar dipole-like directivity, with the noise levels reaching a minimum for observers near the plane of the rotor. These measurements were complemented with laser light sheet visualizations of the rotor wake, which may be useful in evaluating competing theories for the observed broadband noise trends. While prior studies of AAM noise have emphasized the importance of broadband noise for low-tip-speed rotors, Tinney and Valdez (2026) concludes that tonal noise may be equally important for some configurations and operating conditions.

Measurements conducted by Gautam *et al.* (2025) result in similar conclusions. The authors conducted an experimental study to investigate the effects of tip speed variation on a fixed-pitched propeller in edgewise flight. At low forward flight speeds, the in-plane noise radiation was found to scale with the sixth power of the tip Mach number when it is greater than 0.3. At tip Mach numbers lower than 0.3, the in-plane noise was observed to scale with the Mach number at a lower exponent. Out-of-plane noise measurements revealed similar trends, but with noise scaling at a greater exponent of the tip Mach number. As the forward flight speed increases, the scaling trends become much more complex, with the overall sound pressure level scaling between the second and eighth powers of the tip Mach number, depending on the radiation direction. Tonal noise was identified as the dominant contributor to the noise at low forward flight speeds, while broadband noise became more significant at higher flight speeds. This behavior may explain the relatively complex scaling at higher flight speeds.

Other experiments focused on the noise generation trends of multiple interacting rotors. Turhan *et al.* (2025) conducted an aeroacoustic wind tunnel experiment of overlapping propellers in axial flight. The lateral and axial separation distances between a pair of propellers were varied. Tonal noise levels were found to be particularly sensitive to the lateral spacing, with an overlap of 40% of the propeller diameter resulting in an increase in the overall sound pressure level by 14–18 dB relative to the nonoverlapping case. Weaker aeroacoustic interactions were observed even when the propellers were not overlapping. For example, the tonal noise decreased by 2–4 dB when the lateral spacing between the propellers increased from zero between the tips to a separation of 5% of the propeller diameter. While the tonal noise levels changed markedly with lateral spacing, no distinct differences in the broadband noise levels were observed across the cases studied, in contrast to the previously described hover experiments.

Wang *et al.* (2026) studied the aeroacoustics of a heavy-lift drone with four fixed-pitch coaxial propellers. Although the experiment was conducted in an aeroacoustic wind tunnel, the focus of the article is on hover or static thrust operating conditions. Therefore, the tunnel speed was set to zero, with the flow collector used to extract the downwash generated by the vehicle. The vehicle was configured with the coaxial propeller systems operating in both co-rotating and counter-rotating configurations without any

phase synchronization. The co-rotating configuration was found to be significantly quieter, as measured on an A-weighted basis, than the counter-rotating configuration at all thrust levels. Broadband noise was found to be a significant contributor to the A-weighted noise levels. The noise levels of the co-rotating configuration did not vary much across the range of thrust levels measured. Conversely, the counter-rotating configuration had a much larger variation in noise levels across the operating conditions tested. Both tonal noise and broadband noise were prominent for the counter-rotating configuration, with “haystacking” around the propeller tones, suggesting that the increased noise may be caused by the aft propellers ingesting the wake of the upstream propellers. In addition to varying the thrust of the vehicle by uniformly varying the revolutions per minute (RPM) of the fore and aft propellers, some conditions were run with the fore and aft coaxial propeller pairs operating at different RPM. For both co- and counter-rotating configurations, the noise increased when the forward propeller operated at a higher RPM than the aft propeller. Likewise, the noise reduced for the same thrust when the aft propeller was operated at a higher RPM than the fore propeller. Although noisier, the counter-rotating configuration was observed to be slightly more efficient than the co-rotating configuration, possibly due to aerodynamic swirl recovery.

Zamponi *et al.* (2025) also conducted acoustic measurements of a multicopter drone, focusing on the variations in noise due to maneuvering flight. Since large anechoic test facilities are not readily available, the measurements were conducted in a large reverberant space. Acoustic phased array processing with a tailored Green’s function was used to “dereverberate” the measured signals, with the aim of generating a free-field equivalent measurement. The effect of reverberation on the signal was shown to be on the order of 5 dB. Time-frequency analysis was then conducted on the dereverberated signals for the drone conducting various maneuvers within the test hall. The tonal noise varied significantly as the rotor RPM were varied throughout the maneuvers. The vehicle noise was also shown to have significant directionality during maneuvers, with up to 15 dB variation across the range of directions measured.

Meister *et al.* (2026) conducted an outdoor noise measurement of two different commercial quadcopter drones, which differed in size and weight. Both drones were instrumented with a compact data acquisition “backpack,” which connected to lightweight microphones that were extended to in-plane and out-of-plane locations away from the vehicle body using carbon reinforced polymer booms. The primary focus of the article is comparing the differences in the measured noise between hovering flight and forward flight at various speeds. Measured noise levels increased with increasing forward flight speed. Both vehicles experienced a rapid increase in the equivalent noise level over a short transition interval of airspeeds. The authors suggest that over this transition range, stronger aerodynamic interactions begin to occur between the front and rear rotors as the vehicle pitches nose-down at increasing forward flight speeds.

This is supported by an analysis of the spectral data, showing that both the tonal and broadband components of the noise increase over this interval. The authors also observed that psychoacoustic measures of loudness and roughness show a marked change between the hover and forward flight conditions.

Beni *et al.* (2026) performed experimental measurements of aerodynamic thrust, torque, and acoustic emissions of a coaxial, co-rotating drone rotor under hover conditions in an anechoic chamber. Data were collected for 116 combinations of axial spacing and phase offset angle between two two-bladed rotors, at a constant rotational speed corresponding to a tip Mach number of approximately 0.3. The results indicate that, within a phase offset range of approximately -40° to 0° , thrust, power, and tonal noise attain their maximum values, while broadband noise is minimized. Overall, the observed variations are on the order of 10% for the power coefficient and about 2 dB for noise levels. In addition to corroborating trends previously reported in the literature, the acoustic measurements highlight the persistent difficulty of avoiding contamination from flow recirculation within the test chamber, a limitation widely acknowledged in prior studies.

Finally, Gan *et al.* (2025) conducted a study on the modulation of broadband noise on multicopter aircraft. Experimental measurements included both a large hexacopter drone in free flight at an outdoor test site and a smaller hexacopter drone mounted in an anechoic chamber. Analyses of the data were conducted using both the sound pressure level computed over a sliding window, in addition to more advanced cyclostationary methods. During normal operations outdoors, the broadband noise levels were found to modulate by 5–9 dB. The modulation depth for the small hexacopter mounted in the anechoic chamber was smaller, approximately 3 dB at a modulation frequency of 2 Hz, when normal RPM control was used. However, the small hexacopter was also equipped with an electronic phase control system. While designed to control the tonal noise of the aircraft, in this article, the potential of synchrophasing to control modulation of the broadband noise was also explored. The modulation could be nearly eliminated or increased, demonstrating the ability to control the modulation depth by up to 5 dB. The modulation depth and frequency were shown to impact sound quality metrics, such as the fluctuation strength and roughness. Since modulation depth may be significant for human perception, the article concludes that synchrophasing may have some utility in controlling broadband, as well as tonal, sources of noise.

Altogether, the measurements described in this Special Issue provide some insight into the acoustic characteristics of AAM aircraft and may also prove useful for future validation of prediction methods. The acoustic trends are complex, with both tonal noise and broadband noise being dominant features of the noise radiation under different operating conditions. Aerodynamic interactions can be the dominant noise generation mechanism, especially in forward flight. These interactions can also occur in hover for counter-rotating

coaxial rotor configurations. Maneuvering flight can further increase the noise generation of multirotor aircraft. The aerodynamic and acoustic interactions between rotors strongly affect the radiated noise; however, their sensitivity to the operating condition of the aircraft also reveals an opportunity for advanced flight control systems to reduce the noise generation and improve the sound quality of AAM aircraft.

IV. PERCEPTION

In addition to noise predictions and measurements, human perception is an extremely important factor to consider for AAM to reach its potential. AAM missions span from urban to rural, may include a higher number of operations than conventional aircraft, and may operate at lower altitudes in closer proximity to people. These unique circumstances highlight the importance of studying how people react to this new noise source. Contributors to this Special Issue assess these topics and more, underlining that noise from AAM vehicles must be acceptable to the public for communities to benefit the most from this new transportation technology.

Due to the diverse set of AAM missions envisioned, a large range of vehicle configurations are considered in this Special Issue. These vehicles vary in takeoff weight, whether they are intended for small package delivery or for moving people, number of rotors, etc. Noise is synthesized from hover recordings of UASs ranging from 0.25 to 29 kg and having four or six rotors (Ramos-Romero *et al.*, 2025). Human perception is also studied for UAS vehicles with takeoff mass in the range of 2–60 kg (Lotinga *et al.*, 2025). Landing procedures are investigated for distributed electric propulsion vehicles of different scales, including an unmanned aerial vehicle of 1.5 kg and a UAM one-passenger vehicle of 584 kg (Ko *et al.*, 2024). Low-broadband and low-tonal fan designs are evaluated for distributions of 26 low-speed ducted fans for a four-passenger aircraft, which exhibit complex directivity patterns showing strong dependence on axial and lateral angles (Schade *et al.*, 2025). Although AAM vehicles are often VTOL aircraft, conventional takeoff and landing (CTOL) vehicles may also play a role in satisfying AAM missions, specifically a short-range battery-powered electric CTOL aircraft, which was the subject of a laboratory perceptual study on cabin noise (Knuth *et al.*, 2025).

With such a large range of vehicle configurations and diverse set of noise characteristics, data on human perception are still comparatively sparse. Therefore, researchers collect subjective responses to AAM noise by conducting listening tests. Perception in terms of annoyance or pleasantness is quantified in laboratories through forced choice A/B comparisons as well as by asking test participants to rate examples of AAM noise on an 11-point numerical scale (Knuth *et al.*, 2025; Lotinga *et al.*, 2025). Beyond the laboratory, a type of field test called a soundwalk provides a “more holistic approach that considers the interaction of the

(AAM) noise with the existing acoustic environment,” an example of the soundscape approach (Green *et al.*, 2025). With this approach, responses on semantic differential scales for pleasantness, eventfulness, appropriateness, comfort, and calmness are collected. Socio-acoustic surveys, also known as community noise tests, may be done in the future once AAM noise is more prevalent, enabling the types of observational studies that have traditionally been conducted with other sources of transportation noise.

After listening tests yield subjective responses, researchers evaluate which noise metrics best correlate with human perception. This starts with conventional A-weighted sound pressure level (Tinney and Valdez, 2026) but also includes more advanced noise metrics, such as loudness, and other sound quality metrics, such as sharpness, tonality, fluctuation strength, and impulsiveness (Green *et al.*, 2025; Knuth *et al.*, 2025). Psychoacoustic annoyance models (i.e., non-linear combinations of loudness and other sound qualities) are also assessed (Knuth *et al.*, 2025; Ko *et al.*, 2024). New models are built, and how well they predict human perceptual response is tested with statistical rigor. An interesting two-stage approach to this problem consisted of a machine learning algorithm to first identify important noise metrics, followed by traditional regression techniques to determine model coefficients (Lotinga *et al.*, 2025). Although predictive models of human perception to AAM noise are informative and very useful, especially for comparative evaluation of similar noise samples, cross-validation on a wide range of AAM noise is still needed before predictive models significantly offset the need for listening tests. For future community noise tests on AAM noise, the distinction between subject-specific regression models and population average models, as discussed in Lotinga *et al.* (2025), will be very important.

Whether as part of a listening test or for noise metric analysis, auralization is a useful tool to experience and subjectively evaluate noise from AAM vehicles and their operations. Auralization, starting from either aeroacoustic noise predictions or from field measurements, can be particularly useful for perceptual assessments in the early design phase of new aircraft (Knuth *et al.*, 2025; Ko *et al.*, 2024; Ramos-Romero *et al.*, 2025; Schade *et al.*, 2025). While flight test campaigns can be time-consuming and expensive, an approach to auralize a wider range of operations without a complete set of field measurements was demonstrated by Ramos-Romero *et al.* (2025). They show that auralizations of flyover events from hover recordings successfully reproduce realistic stimuli of small multirotor aircraft.

There are several aspects of AAM operations that are important for human perception, including the high expected number of flyover events as well as the close proximity to people during takeoffs and landings. Landing procedures also require comprehensive noise analysis, because interaction of rear rotors with blade wakes caused by front rotors leads to large variations in noise (Ko *et al.*, 2024). Sound quality metric values are generally higher for takeoff and landing operations than for flyover operations, resulting in

higher annoyance (Lotinga *et al.*, 2025) and greater impact (Green *et al.*, 2025) for takeoff/landing operations than for flyovers. This can be mitigated through noise reduction of landing procedures, which has been demonstrated using reinforcement learning (Ko *et al.*, 2024). In addition to the importance of takeoff and landing procedures, en-route noise is also of concern, because the larger number of UAS events increases annoyance (Lotinga *et al.*, 2025). Optimized trajectories in an urban environment show reductions in both sound exposure level and the maximum sound level when compared to a route that only minimizes flight time (Kim *et al.*, 2025).

Perception of AAM vehicle noise depends on context, especially the background noise level. It was shown that annoyance to UAS noise is higher in a calm urban park with low background noise levels than it is near a busy city street with high background noise levels (Lotinga *et al.*, 2025). Similarly, UAS noise is more impactful in terms of perceptual changes in pleasantness and eventfulness in a green space than it is in a city traffic zone (Green *et al.*, 2025). In addition, detectability of UAS source noise in the presence of background noise was highly correlated with UAS noticeability and with the mean change in annoyance rating (Lotinga *et al.*, 2025).

Noise propagation in urban environments is necessary to accurately predict noise impact of AAM vehicles that operate in densely populated areas. While this can be a computationally expensive endeavor due to the influence of multiple reflections from buildings and diffraction around structures, a noise propagation prediction algorithm based on deep learning was used that was efficient enough to be used in a trajectory optimization framework of a one-passenger UAM vehicle (Kim *et al.*, 2025). Although this propagation algorithm was not used to produce auralizations, noise propagation in urban environments may increase realism and help to evaluate human perception of AAM vehicles operating in urban environments.

Finally, researchers recognize that human perception may need to be balanced with other complex factors. For example, economic factors, such as energy consumption and duration of landing procedures, will need to be balanced with sustainability and carbon neutral goals for air travel (Knuth *et al.*, 2025; Ko *et al.*, 2024).

V. CONCLUDING REMARKS AND OUTLOOK

AAM is rapidly transitioning from concept to operational reality, bringing with it a fundamentally new aeroacoustic landscape shaped by distributed propulsion, low-altitude operations, and close proximity to communities. The contributions in this Special Issue demonstrate clear progress in understanding, predicting, and assessing AAM noise, spanning advances in high- and mid-fidelity modeling, targeted experimental campaigns, and increasingly sophisticated approaches to human perception. At the same time, they collectively underscore that AAM noise is governed by tightly coupled aerodynamic, acoustic, operational, and

perceptual factors, requiring integrated and interdisciplinary solutions.

Several important gaps remain. Most notably, there is a lack of full-scale and operational noise measurements, which are essential for validating models and establishing reliable noise certification frameworks. Installation effects, both aerodynamic and acoustic, including shielding and scattering in complex multirotor configurations, require further dedicated investigation. Sound propagation in realistic urban environments, including interactions with buildings, atmospheric effects, and wake-structure coupling, remains insufficiently understood. In addition, robust, generalizable models linking physical noise metrics to human perception are still in their infancy and require broader validation across vehicle types and operating scenarios.

Addressing these challenges will require coordinated efforts across experiments, simulations, flight testing, and socio-acoustic studies, alongside continued collaboration between academia, industry, and regulatory bodies. Such efforts are essential to enable the design, certification, and public acceptance of quieter AAM systems.

ACKNOWLEDGMENTS

The guest editors of this Special Issue would like to thank Stephen A. Rizzi and Siddhartha Krishnamurthy for early conceptualization of this Special Issue, Aaron Vaughn for serving as co-chair of the special session on advanced air mobility noise at the 186th Meeting of the Acoustical Society of America, and members of the NASA Urban Air Mobility Noise Working Group for advancing the state-of-the-art and for creating a network of experts in this emerging field. Special thanks are also extended to the many reviewers who provided critical and valuable feedback on the papers that were submitted and to the JASA staff for their assistance with this Special Issue.

AUTHOR DECLARATIONS

Conflict of Interest

The authors declare no conflicts of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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