URBAN SOUNDSCAPE WITH UAV

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Abstract

The rapid expansion of unmanned aerial vehicles (UAVs) in urban environments introduces a new and distinctive sound source that transforms our soundscapes. This paper explores the characteristics, propagation, and human impacts of UAV noise, and considers how urban planning and design can respond effectively. Compared with conventional urban sounds, UAV noise exhibits unique spectral and temporal features, including tonal components, broadband energy, and dynamic fluctuations linked to flight behaviour. Through a simulation-based case study in Shenzhen, the research shows that UAV noise distributes unevenly across space. Evidence from prior studies suggests that such noise is often perceived as more intrusive and annoying than traditional transportation sounds. Although emerging findings indicate physiological stress responses, results remain inconsistent and require further validation. To address these challenges, the paper advocates for integrating soundscape principles into UAV-related urban planning, with strategies such as optimizing flight paths, increasing operational altitude, adjusting speed profiles, and leveraging existing urban noise for masking.

Keywords: *UAV, Soundscape, Noise, Path Planning*

1. Introduction

Soundscape is defined as 'acoustic environment as perceived or experienced and/or understood by a person or people, in context'[1]. In urban environments, there are multiple sources, from busy traffic corridors and transit hubs, commercial districts with dense human activity, to calmer pockets such as parks, waterfronts, campuses, and residential courtyards—each with different expectations of comfort and appropriateness[2].

UAVs and emerging urban air mobility (UAM) add a distinctive sound source to our environments. The core application scenarios for drones have now shifted comprehensively toward densely built-up urban areas (see Figure 1). They are extensively deployed across all domains of urban operations such as express logistics, medical supply transportation, emergency rescue, urban security patrols, and passenger sightseeing commutes[3]. By July 2025, Shenzhen had launched nearly 300 drone flight routes and completed over 1.7 million cargo flights, becoming a global drone industry hub (www.cls.cn/detail/2055381). Building on this, the city plans to develop over 1,500 low-altitude take-off and landing facilities to support a collaborative operation system under the Shenzhen Low-Altitude Aircraft Landing Facility Layout Plan 2026–2035.

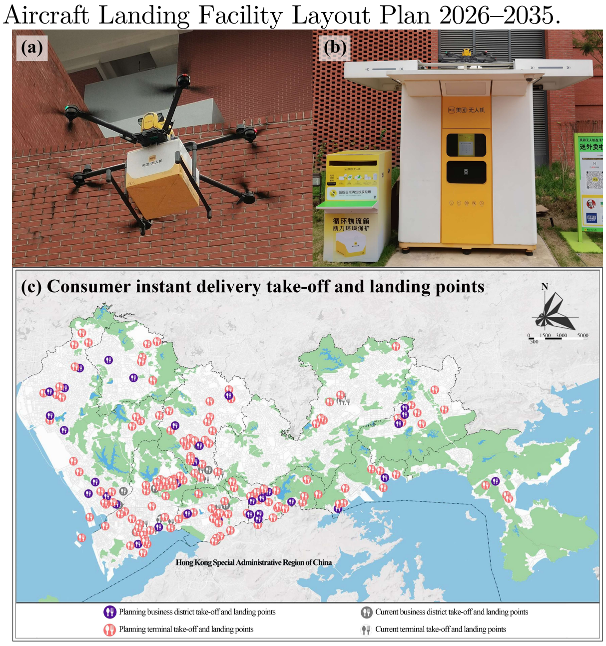

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Figure 1. UAV in Shenzhen, China. (a) A Meituan delivery drone; (b) Meituan drone delivery lockers; (c) Current status and recommended site distribution for low-altitude aircraft of consumer instant delivery takeoff and landing points (adapted from the Shenzhen Low-Altitude Aircraft Landing Facility Layout Plan 2026–2035).

Therefore, it is vital to consider the urban soundscape with UAV. This paper discusses how UAV sounds affect our urban soundscape, in terms of sound source composition, urban sound field, and perception, and consequently, how we would manage the urban soundscape with the sound of UAV integrated.

2. UAV sound characteristics

Multirotor UAV noise has a distinctive spectro-temporal signature shaped by rotor aerodynamics, control, and propagation. It is typically characterised by blade-passing-frequency (BPF) harmonics within a mixed narrowband–broadband structure, with salient energy often concentrated in the 100–1000 Hz range and around ~2.5–3 kHz, both linked to perceptual salience and annoyance [4]. UAV noise is also strongly time-varying rather than stationary, showing amplitude/frequency modulation, BPF splitting, and level changes across hover, flyover, and transition. Its acoustic character further depends on RPM, flight mode, rotor configuration, and platform scale[5]. Delivery-UAV noise should therefore be treated as a controlled multidimensional variable rather than a generic sound category [6, 7].

The DJI M600 case is used here as a controlled example of a medium-sized multirotor platform relevant to delivery-type UAV operations. Figure 2 illustrates the acoustic characteristics of a DJI M600 flying over the measurement array at a take-off weight of 9.5 kg and a constant speed of 15m/s, measured following ISO 5305:2024 [8]. It can be seen that the UAV noise energy is primarily concentrated in the mid-to-high frequency range, approximately 200–5kHz.

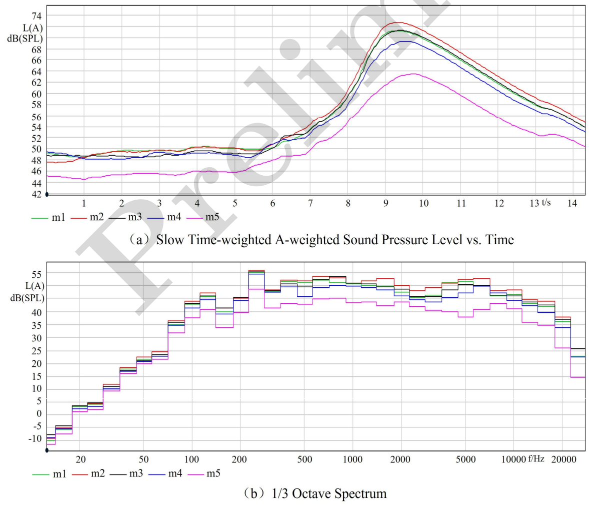

Figure 2. Time and frequency domain characteristics of a UAV.

Figure 3 compares the peak-normalized spectra of UAV noise with human voice, road traffic and birdsong. UAV noise retains more mid- and high-frequency energy than road traffic, whose spectrum is mainly concentrated at low frequencies and declines rapidly above 1 kHz. Human voice is concentrated in the speech-frequency range, while birdsong contains more tonal high-frequency components.

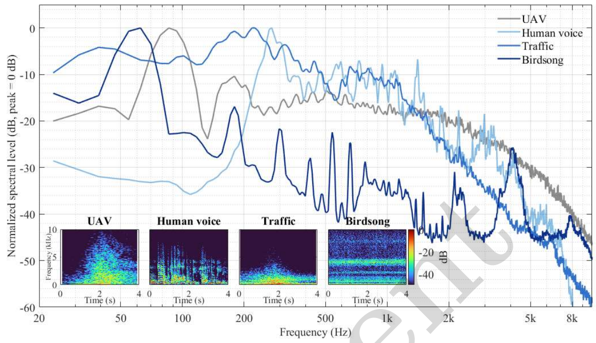

Figure 3. Spectral comparison between UAV sounds and other urban sounds (Source: birdsong [9], UAV [10], traffic [11], human voice [12]).

3. UAV sound propagation

Shenzhen was selected because it is one of China's leading cities in the development of the low-altitude economy; future studies by the authors will extend this simulation framework to major cities around the world for comparative analysis. Taking a drone delivery route at XingHe COCO Park in Futian District, Shenzhen, as an example, a high-precision three-dimensional urban model integrating buildings, roads, and terrain was established for noise mapping (Figure 4). Instead of simulating a single UAV flyover, the delivery corridor was represented as an equivalent continuous line source, with its sound power level specified based on the measured PWL values presented above. This setup represents a future scenario in which frequent UAV operations form a corridor-like traffic flow along a predefined delivery route. The UAVs were assumed to operate at an altitude of 100 m and a speed of 15 m/s. The results show that ground areas beneath and adjacent to the flight corridor can still be exposed to noise levels above 65 dB(A), despite the approximately 100 m vertical separation. This indicates that UAV traffic may remain clearly perceptible at ground level even when operating at relatively high altitudes.

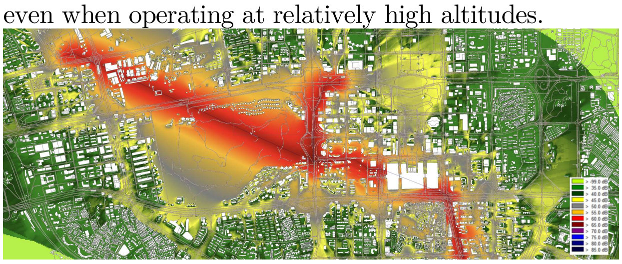

Figure 4. Drone noise distribution map in Shenzhen (Receiver height set at 1.6 m).

Figure 5 compares the sound maps of UAVs with those of road traffic, birdsong, and square dancing. Unlike road traffic, which is mainly constrained to line-like movement on the ground plane, square dancing, which acts more like an area source, and birdsong, which is typically distributed as scattered point sources, UAVs behave as mobile point sources in three-dimensional space. They can hover while continuing to emit noise and move flexibly in all directions, producing a more spatially dynamic sound pattern that can also affect upper floors of high-rise buildings.

Figure 5. Comparison of sound maps among UAV, road traffic, birdsongs, and square dance, in a typical urban area in Shenzhen.

4. Psychological and physiological effects of UAV sound

4.1 Psychological effect

It is indicated by existing research that, driven by psychoacoustic characteristics such as high sharpness, pronounced tonality, and strong fluctuation strength, UAV noise induces higher subjective annoyance than traditional transportation noise, such as road vehicles or commercial aircraft, even at equivalent objective sound pressure levels[13]. Consequently, it frequently triggers public complaints and could have negative impacts on mental health[14].

In this study, extensive Weibo (a popular social media in China) texts in Shenzhen have been analysed, with data preprocessing and text classification being conducted via Python and the Jieba library. Following the fine-tuning of a Chinese Large Language Model (LLMs), supervised machine learning methods are applied to filter UAV noise-related data. The initial dataset contained a total of 2,423,660 records. Using a keyword filtering strategy, records relevant to the topic were initially extracted, yielding 84,247 data points. Subsequently, a large language model was utilised to perform semantic classification and filtering of the text content, identifying 10,824 records relating to urban sounds and 1,037 records relating to noise. Building on this, the geolocation data was further refined to exclude records with vague or invalid locations, such as those simply labelled 'Shenzhen'. This process ultimately yielded 682 valid samples with precise geolocation data, including two records of drone noise. The results reveal a consistent concentration of UAV noise complaints in open green spaces (e.g., Bijiashan Park) and expansive plazas. A possible reason is that UAV noise is rendered more audibly intrusive in such environments due to the lack of background sound masking and physical barriers (e.g., vegetation or buildings) required for attenuation, whereby psychological resistance and annoyance are exacerbated.

4.2 Physiological effect

Current evidence suggests that UAV noise can trigger stress-related physiological responses, but the pattern is still mixed and depends on sound characteristics, exposure history, and context. EEG-based Kansei-analyzer studies found that louder UAV/UAM-related sounds produced stronger stress responses, and unsteady or rotor-like sounds were more stress-provoking than steadier sounds with similar frequency bands. Short-term habituation reduced some reactions, but did not remove them completely[15]. A follow-up study using industrial drone sound at four loudness levels further showed a carryover effect: once participants had heard a loud event, their EEG-derived stress remained elevated even when the volume was later reduced, suggesting that prior high-level exposure may prolong physiological arousal[16].

However, direct multimodal laboratory evidence remains limited. In a pilot study using two drone noises, immersive visual presentation, no significant effects of drone type or level were found for EEG, EDA, HR, or IBI. The main tendency was that adding visual drone information increased frontal EEG activity at F4[17].

5. Designing a soundscape with a UAV

5.1 Mitigating UAV noise and planning route

There is a range of ways to mitigate UAV noise in urban areas, as shown in Figure 6, such as reducing rotor RPM, route planning, and taking advantage of vegetation and water bodies. Perception studies show that take-off and landing are usually the most annoying phases. While slower take-offs may reduce annoyance but slower flybys may worsen it because of longer exposure[18].

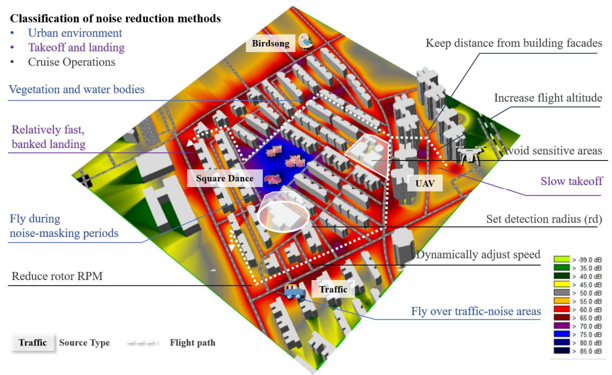

Figure 6. Noise mitigation strategies for urban UAV noise.

UAV path-planning studies usually address noise in three ways. First, spatial-constraint approaches treat sensitive land uses, such as hospitals, schools, and dense housing, as restricted or penalised areas, allowing simple geometric avoidance but often missing finer exposure differences [19, 20]. Second, spatially discretised methods assign noise or sensitivity costs to grid or voxel cells and sum them along routes, making it easier to balance noise with energy, privacy, and risk, although results depend heavily on spatial resolution [21, 22]. Third, time-step-based methods calculate noise along the evolving trajectory, better capturing changes across altitude, speed, and flight phase, but with much higher computational demand[21, 22]. It is noted that drone routes are not only an operational issue but also a matter of spatial planning and governance. Dedicated low-altitude planning, supported by urban spatial analysis, noise monitoring, dynamic route adjustment, data transparency, and community engagement, is needed to reduce impacts and improve public acceptance. Figure 7 maps the spatial structure of Meituan's drone delivery network in Shenzhen, towards route optimization, where a limited number of launch sites are concentrated around major commercial districts, each serving multiple landing points distributed across parks, waterfront areas and public facilities within nearby catchments.

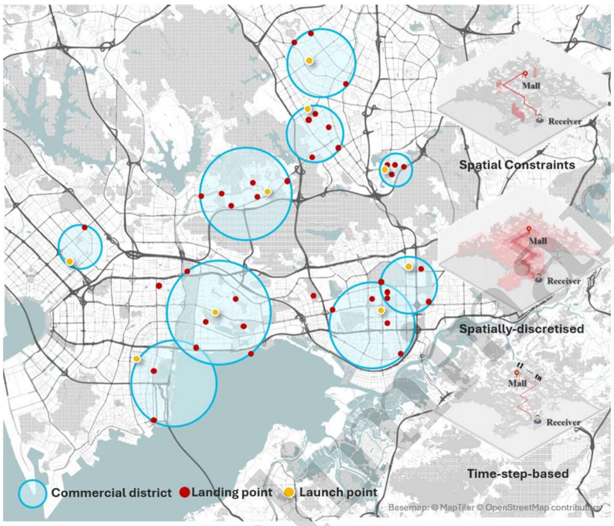

Figure 7. Spatial distribution of Meituan drone delivery sites in Shenzhen towards route optimization, where the site locations are based on social media information for demonstration purposes.

5.2 Masking and multi-sensory interactions

Traffic-dominated environments around 70 dBA can substantially mask UAV noise, raising annoyance by only 1.3×. However, this should not be interpreted as a mitigation strategy, because high traffic-noise exposure is itself harmful and undesirable. In quieter park settings around 55 dBA, where masking is weaker, annoyance may increase by up to 6.4× and pleasantness declines markedly[23]. Masking by positive urban sounds, including natural sounds such as water features and birdsong, as well as human sounds, should also be considered[24]. Beyond energetic masking, attentional masking is also important, particularly in audio-visual interactions[25]. In natural settings, seeing a drone may reduce perceptual comfort, whereas this effect may be weaker in noisy urban environments. Other multisensory effects, such as sound-smell interactions, should likewise be considered[26].

6. Conclusions

UAV is a distinctive urban sound source with strong tonal and temporal characteristics, increasing soundscape complexity. Its distribution depends on altitude, urban form, and weather. Current evidence shows higher annoyance and possible stress-related physiological responses, though physiological evidence remains limited. Future work should combine acoustic simulation, real route data, and stronger perceptual and physiological experiments to support adaptive and acceptable low-altitude planning within a multisensory soundscape framework.

7. Acknowledgments

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