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DRONE PASS-BY NOISE PERCEPTION ACROSS VARIOUS URBAN ENVIRONMENTS SETTINGS

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ABSTRACT

Over the past few years, the technical development of Unmanned Aircraft Systems (UAS) for urban monitoring, surveillance, and delivery has increased the possibility of introducing drone mobility in urban settings. This is increasingly attracting scholars to study the effects that introducing drones' urban mobility routes can have on the urban population. Understanding how drone noise interplays with existing road traffic noise is crucial for minimizing the overall acoustic burden on urban populations, and identifying which urban contexts are best suited for drone operations may provide essential insights for noise management. This research investigates how drone noise perception changes in different urban contexts and which conditions are most suitable for implementing drones' urban mobility routes. To this aim, a laboratory experiment was conducted, playing audio recordings of drone flyovers at the building façade in combination with different urban noise levels, including growing road traffic noise, and investigating noise annoyance and perception. Results contribute valuable insights into the relationship between drone noise and human perception across various urban environments and shed light on how different levels of road traffic noise influence individuals' sensitivity to drone flyovers.

Keywords: *uas, road traffic noise, urban context, flyovers, façade.*

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1. INTRODUCTION

In recent years, the integration of drones into urban environments has raised numerous questions regarding their acoustic impact and how noise is perceived by the population. With the expansion of Advanced Air Mobility (AAM) technologies, it is essential to understand how drone-generated noise is perceived in different urban contexts, with particular attention to the influence of background noise on perceived noise annoyance.

Several studies have examined the influence of acoustic characteristics of drone emission and of the surrounding environment on noise perception.

König et al. [1] demonstrated that psychoacoustic metrics such as sharpness, tonality, and roughness significantly influence perceived noise annoyance, highlighting how reducing rotor blade speed can mitigate acoustic impact without compromising the drone's operational performance.

Torija et al. [2] analyzed the effects of a hovering drone on urban soundscape, highlighting that the introduction of drone noise is particularly annoying in quiet environments, whereas in areas with road traffic, its impact is attenuated due to acoustic masking.

This aspect was further explored by Lotinga et al. [3] who, additionally, investigated the role of the different flight operations of drones. Their findings indicate that noise annoyance increases as the drone noise prominence increases and that these effects are more pronounced in quiet areas than in a busy city street situation.

Despite the growing interest of researchers and urban planners in understanding how drone noise in urban contexts can be combined with transportation means noise, with the aim to mitigate the effect of the introduction of this further noise source in future urban scenarios, there are still several unclear correlations among the different variables (drone types, drone maneuvers, source-listening distance,

listening conditions, environmental conditions) involved in this phenomena.
In this paper, we investigated how drone flyovers in urban contexts of Mediterranean countries affect individual noise annoyance.
To this aim, a laboratory listening test, considering various background noise conditions and source-listener distances, with the listener positioned in an indoor environment overlooking the drone flight path with the open window was carried out.

2. METHODOLOGY

A listening test was carried out in the test room of the Sens i-Lab, the multisensory laboratory of the Department of Architecture and Industrial Design of Università degli Studi della Campania "Luigi Vanvitelli". The experiment involved a total of 26 participants (15 males and 11 females).

2.1 Materials

2.1.1 Recordings

Binaural recordings were carried out by using a mobile four-channel recording and playback system (SQobold, Head Acoustics) and binaural headphones (BHS, Head Acoustics).
The background noise was recorded in two measurement points positioned at about 10 m of height in window proximity in the same urban context. The first recording is representative of an acoustic environment characterized by the presence of road traffic noise with a vehicular flow of about 400 veh/h and a speed below 50 km/h. The second is representative of a context with a prevalence of natural sounds. The latter measurement point was also used to record all the drone pass-by. According to European Union Safety Agency guidelines on noise measurement of unmanned aircraft systems [4], pass-by recordings were repeated (at least) six times per each drone-listener distance. Three of these recordings were randomly extracted to be used in the listening test.
A high level of repeatability and accuracy of the position of the drone was ensured by transferring the spatial coordinates of the flight path to the DJI Mavic Mini 2 through the DJI Pilot app. The flight path was described by 6 different waypoints (2 for each path) positioned to create 3 horizontal paths parallel to the façade at 5, 10 and 15 meters distance. This recording perspective was chosen to replicate the acoustic experience of individuals inside buildings overlooking the drone flyover with the open window (Figure 1).

Figure 1. Outern (and inner) point of view of the recording position.

2.1.2 Questionnaire

The perceived noise annoyance was assessed according to the ISO/TS 15666 [5]. Each participant, thinking to be at home or in the office, answered the question which asked how much the noise just listened to annoyed him/her. For conditions D5, D10 and D15, which included the drone flyover, it was specified to rate the annoyance due to the drone noise. The rating was expressed on a 5-point verbal scale ("Not at all," "Slightly," "Moderately," "Very," "Extremely") and an 11-point numerical scale (0-to-10).
Additionally, to measure the emotional perception of individuals toward the acoustic environment, the emotional salience questionnaire developed by Masullo et al. [6] to quantify the positive and negative value of the sound environment, was used. The results reported in this paper are, however, limited to the noise annoyance questionnaire on the 0-to-10 numerical scale.

2.2 Experimental Design

This experiment analyzed the noise perception of individuals by combining a four-level factor named *Background noise* and a four-level factor named drone *Distance* (Figure 2). The four levels of *Background noise* derive from the two abovementioned recordings are characterized by: 1) the prevalence of natural sounds (NAT), and 2) the presence of road traffic noise (RTN). In particular, the first recording was set at 40 dB(A) hereinafter named NAT-40, whilst the second recording was used to generate three different road traffic noise conditions at 45, 50 and 55 dB(A) hereinafter names, respectively, RTN-45, RTN-50 and RTN-55.

The four levels of the drone *Distance* factor are obtained considering the measurement at 5, 10 and 15 meters of distance from the façade hereinafter named, respectively, D5, D10 and D15, to which a further condition of "Control", without any drone pass-by, named D∞ was added. A repeated measure full factorial design ensured that each individual experimented with all different 16 listening conditions.

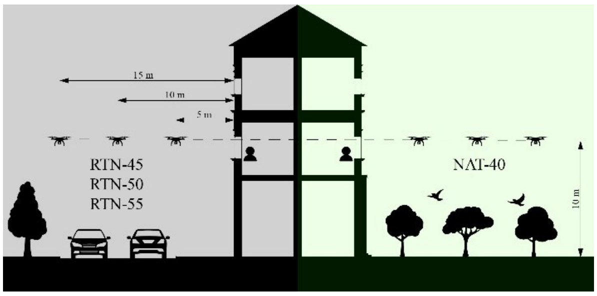

Figure 2. Scheme of experimental conditions.

2.3 Listening test: setup and procedure

The listening test was implemented in the PsychoPy software [7]. One minute-long soundtracks of the background noise were combined with soundtracks, of about 15s, of the flyovers at different distances. To minimize the influence of external factors three different flyover soundtracks were considered per each distance.

The test was administered by a laptop positioned on a table in the centre of the Sens i-Lab test room at the Department of Architecture and Industrial Design of the Università degli Studi della Campania "Luigi Vanvitelli".

The audio playback chain, including the Sennheiser HD-200 Pro headphones that the participants wore to perform the listening test, was calibrated by using an artificial head-shoulder unit HSU III.2 (Head Acoustics).

Participants were instructed to focus solely on the auditory experience and rate their responses per each soundtrack listened to. The choice to exclude visual information was made to limit the possible influence of the visual context on the sound perception ratings.

Initially, participants answered a questionnaire to collect general information about themselves and were trained on how to perform the experiment correctly.

Subsequently, they started listening to the 16 combinations of the *Background noise* x drone *Distance* levels. To prevent the carryover effect, each condition was administered in random order.

During the experiment, participants answered two different questionnaires: on the noise annoyance [] and the acoustic salience [8]. Only the results of the first are presented in this paper.

3. RESULTS

A 4x4 Repeated-Measures ANOVA on the perceived noise annoyance ratings is performed considering the 4 levels of *Background noise* (NAT-40, RTN-45, RTN-50, RTN-55) and the 4 levels of drone *Distance* (D5, D10, D15, D∞).

Results show significant main effects for both factors Background noise $F(3,75)=5.208$, $p<0.003$, $\eta^2_p=0.172$ and drone Distance $F(3,75)=21.118$, $p<0.001$, $\eta^2_p=0.458$.

Bonferroni *post-hoc* pair comparisons show that the noise annoyance rating is higher in NAT-40 than RTN-45 ($M_{NAT\text{-}40\text{-}RTN\text{-}45}=-0.555$, $p=0.037$). At the same time, they result higher in D5 conditions than D10 ($M_{D5\text{-}D10}=1.139$, $p<0.001$), D15 ($M_{D5\text{-}D15}=2.230$, $p<0.001$), and D∞ ($M_{D5\text{-}D\infty}=1.893$, $p<0.001$), while no statistical differences emerged between D10 and D15 with D∞.

Significative differences emerge also in the interactions *Background noise* x drone *Distance,* $F(9,225)=15.674$, $p<0.001$. In particular, Bonferroni *post-hoc* pair comparisons show that, in NAT-40, the noise annoyance ratings significantly decreases along *Distance* ($M_{NAT\text{-}40(D5\text{-}D10)}=1.058$, $p=0.022$; $M_{NAT\text{-}40(D5\text{-}D15)}=2.315$, $p<0.001$; $M_{NAT\text{-}40(D5\text{-}D\infty)}=3.958$, $p<0.001$; $M_{NAT\text{-}40(D10\text{-}D15)}=1.258$, $p=0.005$, $M_{NAT\text{-}40(D10\text{-}D\infty)}=2.900$, $p<0.001$), while this not occurs for the RTN conditions (Figure 3).

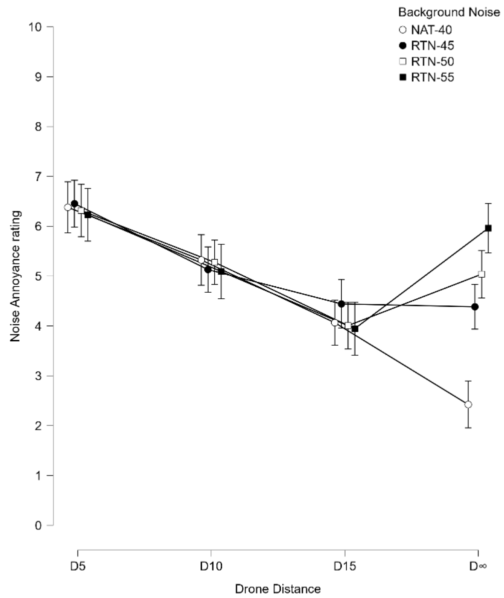

Figure 3. Noise Annoyance average ratings standard error in different experimental conditions.

4. DISCUSSION

The data analyses collected in the experiment show how allowing drone flyovers in urban contexts can significantly affect the inhabitants' noise annoyance levels.
In particular, the perceived noise annoyance depends on both the characteristics of the acoustic environment where it occurs and of the drone's flypath distance from the façade where is the listener.
Even though, in general, the drone noise can alter the background noise annoyance, in the case of road traffic background noise of 50 and 55 dB(A), the increase in annoyance is not evident. This suggests that beyond a certain threshold, drone noise does not further contribute to modulating background noise perception.
With the drone introduction in the existing background noise, the noise annoyance increases notably compared to conditions without the drone. Moreover, as the distance increases (10 and 15 meters), the noise annoyance decreases, indicating that proximity plays a crucial role in raising the noise annoyance level. This effect can be explained by the fact that, at short distances, the drone's noise is louder and more distinct, whereas at greater distances not.
In quieter contexts, such as the NAT-40, the presence of the drone has a significantly greater impact compared to the loudest urban backgrounds.
In fact, in the absence of a dominant background noise, the drone's sound emerges more clearly, making it more intrusive and disturbing. Conversely, in backgrounds with heavier traffic noise, the drone's effect is partially masked and its effect on perceived noise annoyance is reduced.

5. CONCLUSIONS

This study provides some insights into the noise annoyance caused by drone flyovers in different urban sound contexts.
The results show that background noise type and drone distance are crucial variables in shaping the perception of drone noise.
Findings suggest some important practical implications. If the goal is to reduce drone pass-by-related annoyance, operating at distances greater than 10 meters could be beneficial, especially in natural or low-noise settings. Additionally, in urban environments with high noise levels, the drone's effect may be less significant, indicating that drone usage in such contexts could be more accepted by the public.
It is worth mentioning that, as the drone used in this study belongs to the small category (C0 <250g) typically employed for survey and inspection purposes, it impact could be significantly lower than that caused by the drones that will be used in the next years for logistics transport. Therefore, future research should explore the noise annoyance caused by heavier drones, whose noise signatures and operational profiles may pose greater challenges to public acceptance.

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