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NOISE IMPACT OF DRONE PARCEL DELIVERY SCENARIO OVER MADRID

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ABSTRACT

To effectively integrate drones into densely populated urban infrastructures, it is crucial to assess their impact on the population's quality of life and mitigate any adverse effects. As noise pollution from drone overflights is a top concern, enhancing our numerical capabilities for predicting VTOL aircraft noise in urban environments is essential.
To achieve this goal, we have developed an integrated toolchain comprising three key components: Flight Mechanics, to accurately model aircraft behavior; Noise Emission at the Source: to quantify the noise generated by the drones and finally Urban Environment Noise Propagation using the open-source tool NoiseModelling.
This comprehensive toolchain enables the creation of detailed noise maps for specific drone scenario definitions.
This paper presents an application of our toolchain in a parcel delivery scenario, featuring DJI Matrice 600 drones operating over a 10 km² sector of Madrid in Spain within a day period, incorporating five distribution centers with varying hourly capacities. The results include a range of informative noise indicators, taking into account noise level, number of flyovers and background noise levels.

Keywords: *drone fleet noise, noise source modeling, urban propagation, parcel delivery, indicators*

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1. INTRODUCTION

Urban Air Mobility (UAM) concepts, particularly those involving Vertical Take-Off and Landing (VTOL) aircraft, are increasingly being explored for applications such as passenger transport, medical logistics, and parcel delivery. As these operations move from theoretical frameworks to real-world implementation, ensuring that they integrate seamlessly into existing urban infrastructures has become a critical research and policy objective. Recent research has proposed a comprehensive U-Space Social and Environmental Performance Framework to assess the broad spectrum of Urban Air Mobility (UAM) impacts on citizens' quality of life, identifying key focus areas such as noise, visual pollution, privacy, equity, emissions, and public safety, and defining corresponding performance indicators for their evaluation [1].
Among the primary concerns associated with drone operations in urban environment and their potential impact on the quality of life of city residents, the focus of this research is on noise pollution. Consequently, the ability to model, predict, and manage noise generated by drones is essential for fostering public acceptance and informing regulation. To address these challenges, we have developed an integrated toolchain that combines three key components: (1) Flight Mechanics, which accurately models aircraft behavior; (2) Noise Emission at the Source, which quantifies noise generated by the drones; and (3) Urban Environment Noise Propagation, using the open-source tool NoiseModelling. This research presents an application of our toolchain in a parcel delivery scenario for the city of Madrid, in Spain, during a single day.
The paper is structured as follows: Chapter 2 describes the noise calculation tool. Chapter 3 defines the parcel delivery scenario. Chapter 4 presents the noise results, while Chapter 5 concludes the paper and outlines future work.

2. NOISE CALCULATION TOOL

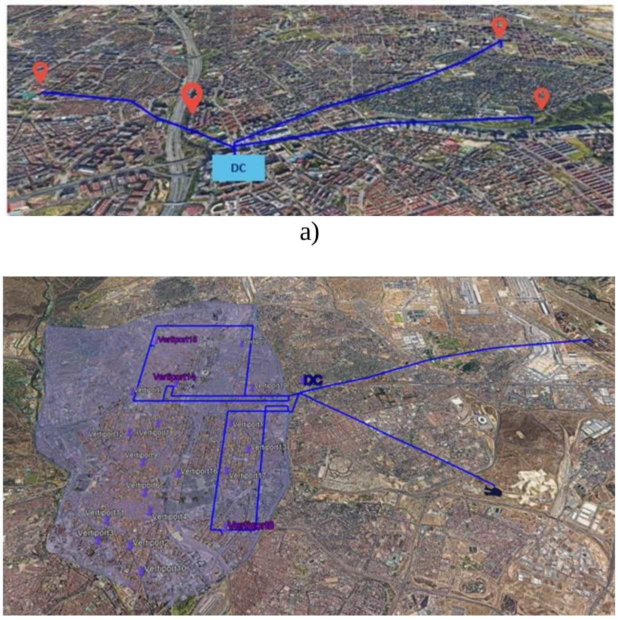
The main structure of the noise calculation chain was presented in [2]. Once a drone fleet scenario is defined (by the consortium partner UPC), the ONERA in-house flight mechanics tool DynaPyVTOL [3] calculates all drone and propeller data that are necessary for the aircraft to comply with the target trajectories and velocities. These data (propeller thrust and RMP, vehicle orientation etc.) are used for the noise emission calculation tool CARMEN [4][5][6] that calculates at each time step along the mission trajectory the main noise sources; in this case propeller noise. Each resulting noise sphere is then combined in a traffic pattern by the UGE NoiseModelling urban propagation tool [7], and the main noise indicators are calculated (see [1]).

In the following, a DJI Matrice 600 type is used for calculation. The main noise source on this type of aircraft is propeller noise. For the purposes of this case study, the analysis focuses exclusively on tonal noise contributions. This deliberate scope limitation is driven by two key considerations: computational resource constraints and negligible omission error. Indeed, preliminary estimates indicate that omitting broadband noise components would introduce an error of negligible effect on the overall outcome, thus not significantly impacting the study's conclusions. This applies to our specific case study, but cannot, in any case, be generalized.

3. PARCEL DELIVERY SCENARIO

Mainly two types of drone usages were considered: parcel delivery and emergency delivery. Although emergency scenarios are very interesting for featuring access and equity indicators, they constitute only a minor fraction of future daily drone flights. For noise impact considerations the parcel delivery scenarios are much better suited, given that we are at liberty to set up as many distribution centers as we want, located all over the city and furthermore, deliveries are done to individuals all over the city and are not necessarily limited to fixed destinations such as hospitals.
After analyzing habits of already existing delivery hubs and taking into account results of the SESAR Metropolis 2 project [8], the consortium chose to set up five distribution centers, four located around the city center and one within. These distribution centers are configured to handle identical traffic volumes and rates, with two exceptions: one center is situated near a no-fly zone, and another is located in a sparsely populated area, each with adjusted traffic considerations.
A more detailed description of how these choices were made will be presented in further associated publications.

Two types of concepts of operations (ConOps) are considered: free route and constrained airspace. While the free route scenario links delivery hub and destination in the shortest possible way, the constrained airspace uses a free route when outside of the city center but follows a grid based network when inside the city limits (Fig. 1).



a)

b)

Figure 1. Two types of ConOps: a) free route, b) constrained airspace

One main difference between the two ConOps types has a noticeable impact on noise maps. While the free route drone altitude roughly follows the terrain, the constrained airspace presents four layers of flight altitudes. Those are calculated based on the highest point of the mission, leading to locally very important source – receiver distances (see Fig. 2 for one mission example).

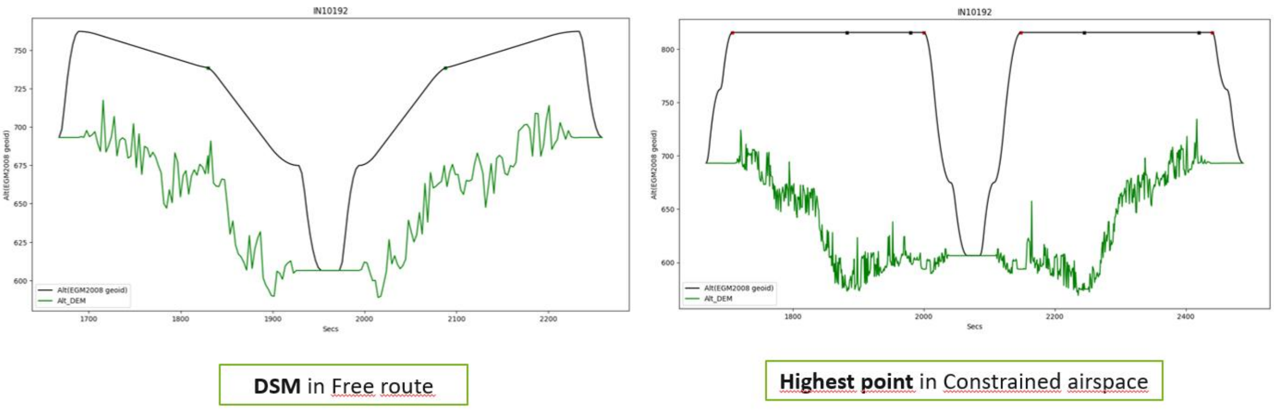


Figure 2. Reference for altitude in two ConOps

Mean height values are around 69 m for free route, and 125 m for constrained airspace, leading to enhanced propagation distances and variable ray paths in the urban environment.
All flight scenarios of the project were calculated by Polytechnic University of Catalonia (UPC) with their tool GEMMA [9].
In the cases presented in this paper, a mean flight frequency of 60 flights per hour (fph) is considered. This number is adapted to time of the day, i.e. one encounters more flights during late afternoon than in the morning for instance (see Fig. 3).

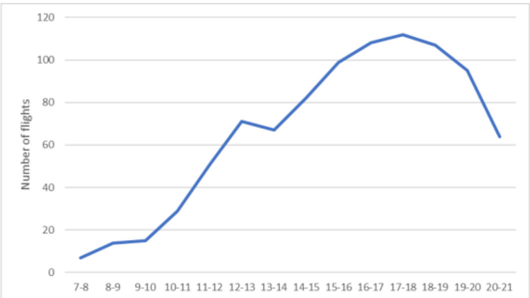


Figure 3. Operations per hour across the day in the area of interest

Lower flight frequencies have been evaluated as well, but are not presented here.
In order to assess the Performance Framework indicators (see [1]), we choose a specific of area of interest, covering a 5.9 km*1.7 km area in Madrid, that includes key elements such as residential areas, recreational zones, restricted locations (e.g., the Royal Palace in purple), and hospitals (see Fig. 4).

Several drone types are considered, which are most suitable for delivery and emergency operations. As explained in chapter 2, only one type is used in the parcel delivery scenarios that serve for noise indicator assessment: a DJI Matrice 600 that has a maximum take-off weight of 15.5 kg and 6 propellers equipped with 2 blades of approximately 0.5 m diameter.

4. NOISE RESULTS

Noise maps were calculated over the whole day for two ConOps (free route and constrained airspace) with varying flight numbers (60/40 fph). For visualization purposes only small time extracts are shown in this paper. Future analyses, scheduled for the upcoming months, will delve deeper into daily patterns and pinpoint locations yielding unforeseen results, providing a more comprehensive understanding.
In the following, two periods of day are considered: 9:00 – 9:15 am and 5:00 - 5:15 pm. These intervals are chosen for their variety in flight numbers (see Fig. 3 and Fig. 4). The only vertiport located inside the area of interest is in the upper part, centered.

Several noise metrics were calculated, including L_{Aeq}, L_{Amax}, ASEL, TA, NA and others.

Figure 5 shows L_{Aeq} noise maps integrated over a 15 minutes period for a morning and an afternoon period for a free route scenario, translating directly into a noise map the trajectory representation of Fig. 4. Noise levels depend on the number of drones, globally leading to a higher impact for the citizen on the afternoon. However, at a finer level of detail the precise flight altitude, urban architecture and the terrain have a non-negligible influence on the noise maps. A quantification of each parameter's impact on noise levels on the ground needs to be done.

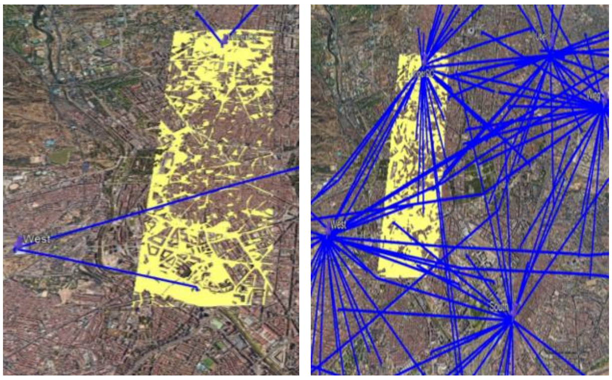


Figure 4. Drone traffic over 15 minutes: morning period (left), afternoon period (right)

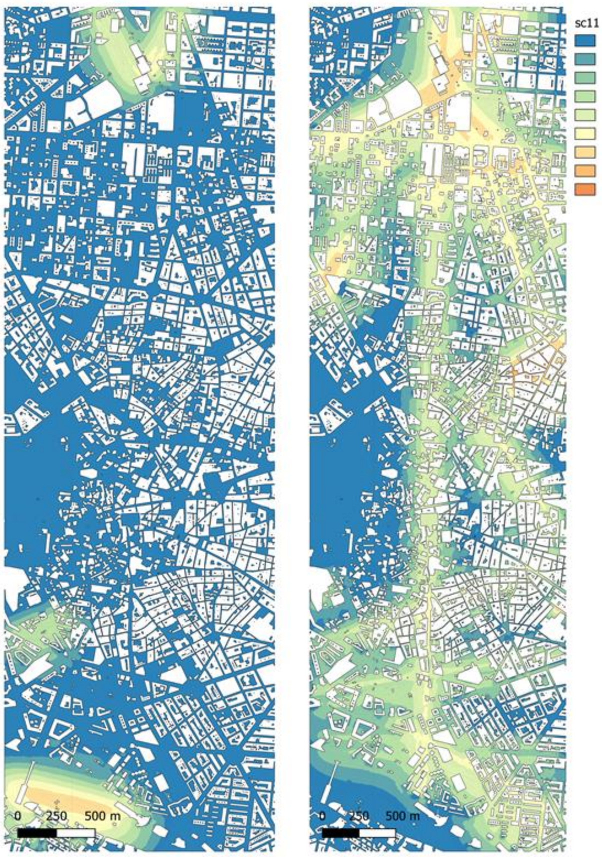


Figure 5. $L_{Aeq,15\ min}$ [dBA], free route : morning period (left), afternoon period (right)

Absolute noise levels are not shown for several reasons. Noise levels depend greatly on drone type and their flight configuration. In this test case the DJI Matrice 600 is equipped with propeller that have only 2 blades and rotate with relatively low rotation frequencies. This leads to extremely low frequency tonal noise content, to which the human ear is not well adapted and hence cannot hear very well. This is well translated by A-weighting filters. This configuration can be considered fortunate for the population since first psychoacoustic studies show that sharpness might be an important contributor to noise annoyance [10][11], and in general low frequencies are better masked by broadband urban background noise.

However for methodology demonstrations, levels are very limited. Other drone types with other propellers would have led to higher noise levels (either due to higher noise emission or higher, and hence less filtered, frequency content).

Another point is that, notably, the 15-minute integration period stands in contrast to commercial aviation norms (being relatively short) and drone flyover durations (being comparatively long), warranting further discussion on its applicability.

This "long" time integration also flattens out a lot L_{Aeq} values when only few drones overfly the receivers during the given time period.

Figure 6 shows a comparison of the two ConOps during the afternoon period. Changing the route type from free route to grid based necessarily implies that different sectors will be overflown. This will have consequences on the number of people exposed, when combining noise and population density. For noise considerations alone, the main impact will come from the difference in flight height as seen in the example of Fig. 2. Since mean flight heights are much higher for the grid based scenario, noise levels could be expected to be lower at receiver positions, since drone-receiver distances increase. However, the area of interest comprises densely built areas; the sound rays therefore encounter many buildings and are partially masked to the receivers. At higher altitudes rays propagate freely, without obstacles, towards the receivers. Contour maps for the grid based scenario are hence often more widespread than for the free route scenario where drones fly lower and are masked by the buildings (see Fig. 6).

In general, more detailed analyses are necessary for assessing what is the exact cause of increased or decreased noise levels: drone number, change in route, presence of buildings, flight height etc.

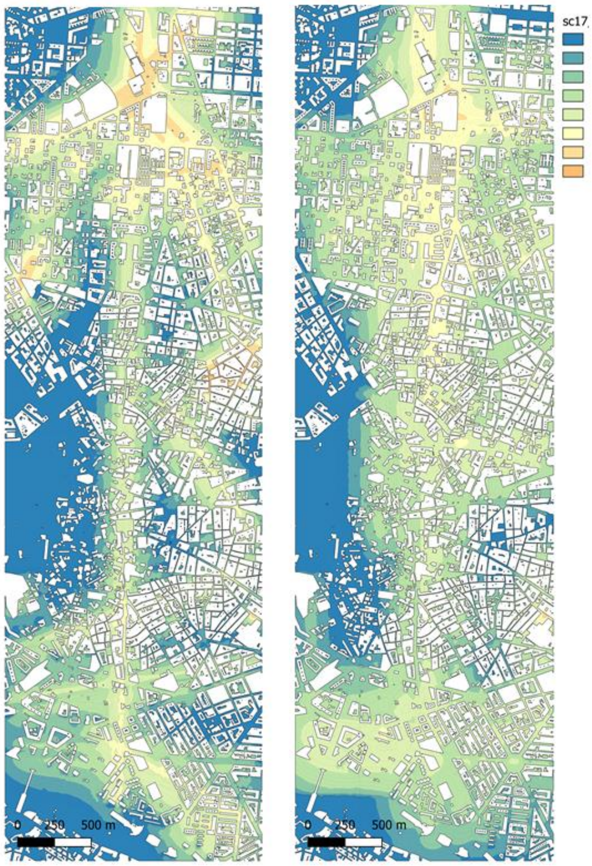


Figure 6. $L_{Aeq,15\ min}$ [dBA], afternoon : free route (left), grid based (right)

5. CONCLUSION

In the MUSE project, we enhanced a noise calculation toolchain to account for drone fleet scenarios, applying it to a parcel delivery case study in a Madrid area, Spain. Scenario types varied in route pattern, flight altitude, flight number etc. In this paper some results are shown for fleets composed of DJI Matrice 600 drones in different configurations, leading to interesting analyses with regard to flight height impact, importance of background noise and choice of drone type.
This work will be developed further in upcoming publications, with more detailed investigations of the impact of flight number per hour (20 / 40 fph) and impact of the considered hour of the day and hence varying number of flights and number of exposed people. Additionally, a more thorough discussion about the employed metrics and indicators will be led. These studies will refine our understanding of drone operations' noise effects, informing strategic decisions in aerospace.

6. ACKNOWLEDGMENTS

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