HELICOPTER NOISE STUDY: TOWARDS A BETTER UNDERSTANDING OF URBAN AIR MOBILITY NOISE

Julien Caillet, Airbus Helicopters, Marignane, France
Pierre Dieumegard, Airbus Helicopters, Marignane, France
Matthieu Sineau, Bruitparif, France
Manuel Hellot, Bruitparif, France
Chrystèle Philipps-Bertin, Université Gustave Eiffel, Lyon, France
Aboud Kourieh, Université Gustave Eiffel, Lyon, France

Abstract

The paper presents the set-up, preparation and results of a helicopter noise annoyance study performed around “Héliport de Paris - Issy-les-Moulineaux – Valérie André” heliport. This study includes acoustic measurements around the heliport, simulations of helicopter noise emissions and their associated noise footprint along the measured trajectories, and the results of a survey carried out on the inhabitants living close to the helicopter routes in the area. This study aims at better understanding helicopter noise annoyance criteria and acceptance of future Urban Air Mobility operations.

1. NOTATION

Symbols

L_{Amax}	Maximum Overall A-weighted Sound Pressure Level
L_{Cmax}	Maximum Overall C-weighted Sound Pressure Level
L_{eq}	Equivalent sound pressure level
DNL	Day-Night Average Sound Level
$L_{Aeq,Source,6h-22h}$	Equivalent A-weighted sound-pressure level, Source considered (Road traffic or Helicopter), average on [6h-22h] time period
L_{den}	Day-evening-Night Sound Pressure Level
SEL_A	Sound Exposure Level, A-weighted
SEL_C	Sound Exposure Level, C-weighted
EmergA	A-weighted helicopter noise emergence
NAxx	Number of events with L_{Amax} above xx dB(A)
NEAyy	Number of events with Emergence above yydB(A)

Acronyms:

HC	Helicopter
AH	Airbus Helicopters
UAM	Urban Air Mobility
ILM	Issy-Les-Moulineaux
Univ. Eiffel	Université Gustave Eiffel
eVTOL	electric Vertical Take Off and Landing
INSEE	Institut National de la Statistique et des Etudes Economiques
HA	Highly Annoyed
OR	Odds Ratio
WHO	World Health Organization

2. INTRODUCTION

Urban Air Mobility (UAM) is gaining momentum as shown by the numerous vehicle concepts unveiled by different manufacturers. However, noise community acceptance remains a major concern for the development of UAM operations. Indeed, some complaints are already raised to helicopter operators and local authorities, especially in urban areas, even though their number of operations is low and negligible compared to that of fixed-wing aircraft (Ref 1, 2).

Previous noise certifications (Ref. 3, 4) and research projects (Ref. 5) show the continuous effort of Airbus Helicopters (AH) to reduce the environmental noise footprint of its aircraft to a minimum thanks to either design changes (Ref. 4,6-8) or the implementation of low-noise procedures (Ref. 9-11).

In order to further reduce operational noise and limit its effect on population overflown, it is important to better understand the factors involved in noise annoyance. There are actually only a few researches on helicopter annoyance compared with commercial aviation, despite this topic is identified at international level. Ref. 2 and Ref. 12 list some previous researches on the topic, which are mainly focusing on short term annoyance. As an example, Ref 13 concludes that dB SEL is a good predictive factor of the latter.

In the frame of the French-funded MOTUS project, a two-fold work package was dedicated to the study of rotorcraft noise acceptance.

On the one hand, laboratory studies were performed with ONERA (Ref. 11, 14) focusing on the short-term annoyance and noticeability of helicopter noise in an urban environment. The effects of both design changes and trajectory modifications on noise perception have been assessed.

On the other hand, activities were conducted in collaboration with Bruitparif and Université Gustave Eiffel (Univ. Eiffel) aiming at understanding long-term annoyance by UAM operations. These researches are the main focus of this paper which presents the completion and results of a comprehensive study of the long-term annoyance due to helicopter noise around “Héliport de Paris - Issy-les-Moulineaux – Valérie André” heliport, referred to as ILM heliport in the following. It includes noise measurements, simulations and the outcome of a survey carried out in the neighborhood of the heliport.

3. STATE OF THE ART and OBJECTIVES

There is little work in literature related to long-term noise annoyance of helicopters. Among this work, a few factors appear to play a non-negligible role in helicopter noise annoyance.

First, helicopters have a variable and very complex acoustic signature due to the presence of multiple noise sources (main and tail rotors, engines…), whose noise emitted strongly depends on the flight condition, as explained in Ref. 11. Such an acoustic signature is all the more variable as helicopters offer specific flight capabilities, such as vertical flight or hovering, which are flight conditions where the noise generating mechanisms are complex and could increase noise annoyance. In our work, we study a wide variety of operations including different types of helicopters and missions in a complex urban environment.

According to Ref. 15 and Ref. 16, vibrations of buildings due to the close passage of helicopters have also been identified as having an impact on noise annoyance. Ref. 17-19 also showed that the number and the frequency of events, as well as the ambient noise in the area could have an impact on the associated noise annoyance. Also, the ambient noise (Ref.19), the signature of helicopter noise and its impulsivity have been reported (Ref.1, 13, 17) to influence the perception of helicopter noise.

All these elements are obviously of interest and shall be taken into account when further investigating helicopter annoyance.

All the acoustic factors mentioned above are measurable. However, Ref. 17,20 show that part of the annoyance is not correlated to noise exposure levels and underline the influence of non-acoustic factors. Those most often cited are safety concerns because helicopters often operate at low altitudes, unpredictability because helicopter trajectories vary considerably due to their very different missions, and the lack of communication from local authorities or heliports. A lot of studies around airport are available and report the importance of these non-acoustic factors (Refs 21, 22), but specificity of rotorcrafts operations is also highlighted (Ref. 17): low flight altitudes, long hover durations, but also the perception of the necessity of the flight operations which encompass a broad range of missions, from medical evacuation and law enforcement to private and commercial touristic operations.

Only a limited number of studies were found in the literature that address long-term annoyance due to helicopter noise (Refs. 17, 19, 20 among recent studies). Despite the extensive list of questions that were addressed in Ref. 17, results were limited by the fact that only a low percentage (7%) of people declared themselves highly annoyed on the 3 selected measurement sites, which considered mainly overflight operations. Moreover, exposure-response relationship was mainly addressed with DNL noise metric, computed with INM. Ref. 20 addressed the situation of noise annoyance around London Heliport, with a concurrent online survey on 1570 persons and both indoor and outdoor measurements. In this case, 84.8% of survey respondent declared to be extremely annoyed by helicopter noise during summer and 57.5% with closed windows. However, measurements were only conducted in 4 test sites, measuring LA_{eq}; LA_{90}, and L_{Amax}. Actual exposure of all participants to the survey was not computed, that did not allow for producing exposure-response relationships.

Hence, as highlighted by this state of the art, although several factors have been identified as contributing significantly to the acceptance of helicopter operations, the latter is still not well understood. This can lead to both a significant negative perception of the helicopter by communities and operating restrictions without an objective assessment of helicopter noise impact. This topic has also gained some interest and visibility in the last years due to the potential future Urban Air Mobility (UAM) operations with new electric vehicle architectures (eVTOL), starting to trigger negative reactions in the community even in early demonstration phase (Ref 24).

Therefore, the main objective of the study is to further improve the understanding of helicopter annoyance mechanisms, with an additional target of feeding the understanding of future acceptance of UAM operations. Actually, helicopter operations are already impacted by multiple operating restrictions, decided by local politics as consequence of community complaints. Hence, three main targets are highlighted here. First, supporting Local and National Aviation authorities -e.g DGAC in France- with objective assessment of annoyance. Second, supporting helicopter customers which suffer the consequences of such potential restrictions. And last, but not least, allowing Airbus Helicopters to develop the most efficient noise reduction solutions to reduce annoyance, including low noise design, noise control technologies and low noise operations based on objective targets.

In this study, helicopter noise annoyance is investigated through the preparation, implementation and analysis of a questionnaire survey among the neighborhood community around the urban heliport at ILM (target around 750 surveyed persons), combined with measurements and simulations used to assess noise exposure of the survey participants.

The outcome is the result of a collaboration between Bruitparif, in charge of noise measurements, with recognized expertise in noise issues in the Paris region, Université Gustave Eiffel (Univ. Eiffel) with expertise in conducting surveys related to noise annoyance in communities, and Airbus Helicopters with a proven capability to assess the noise footprint of helicopters on realistic scenarii (Ref. 9, Ref 11).

Noise simulations performed here are an asset to compute community noise exposure, which is a prerequisite for both the preparation of the study and for the computation of individual exposure of the participants to the survey. These simulations are performed with an AH tool coupled with Noise Modelling (Ref. 25) software, which is based on CNOSSOS-EU standard, and which have been adapted so as to take into account the effects of buildings on sound propagation (masking, reflections, refractions…) of aerial sources, such as helicopters. Airbus Helicopters has previously assessed the capability of such a tool chain to take into account complex urban environment effects on noise propagation. It was shown that taking into account buildings (e.g. screening effect) can significantly affect noise levels compared with standard ways of computing aviation noise impacts (Ref 26). This work is the first large scale helicopter annoyance study that intends to include such complex effects in the estimation of survey participants noise exposure.

Among the additional targets, this study aims at deriving exposure-response relationships for a wide variety of acoustic metrics. The latter thus examines multiple indicators, including A- and C-weighted noise levels, energetic or event-based metrics, but also on criteria taking into account emergences to local urban background noise (typically road noise).

4. METHODOLOGY

4.1. SITE SELECTION

The study has been led around ILM heliport for several reasons: it is a heliport located in a highly urbanized environment with many people living nearby. In addition, it hosts a significant number of helicopters movements (9650 in 2019 and 7250 in 2021) and the French Civil Aviation Authority (DGAC) agreed to share the trajectories records of all the helicopter flights in the area during the test period. Last but not least, this heliport faces noise annoyance issues. Strong operating restrictions are already applicable (e.g. training flights are forbidden, 70 movements maximum on weekends and public holidays, and 12000 maximum per year) and the current status of the heliport is at stake to further limit the number of helicopter operations in the area.

In this section, we present the methodology for the selection of the relevant sectors to carry out the survey. First, in order to limit the geographical scope, it was decided to focus the study on the west area of ILM heliport, because it is where the traffic is usually the densest, and also because it concentrates several residential areas. Basic idea was to identify several sectors that would ease an appropriate selection of participants during the survey. One goal was to ensure a good repartition of those surveyed depending on their exposure to both helicopter noise and road traffic noise, considered as ambient noise. Indeed, a second target was to avoid complex multi-exposure cases where participants would be exposed as well to railway noise. In order to carry out the selection, both road and railway noise maps were available based on European Directive 2002/49/CE (Ref. 27) requirements; additionally, L_{den} Helicopter noise map was available from a previous study (Ref. 28). However, it is acknowledged that L_{den} may not be well correlated with helicopter noise annoyance due to their event characteristics, and that this map had to be updated. It was thus decided to make the site selection based on $L_{A,max}$ and emergence noise maps, which have been obtained by numerical simulations, performed with Noise Modelling software, of two average helicopter trajectories: one arrival (QFU24) and one departure (QFU06). The simulations were carried out for the helicopter EC145, whose noise emission model, is available at Airbus Helicopters (Ref. 3). The average (departure/arrival) $L_{A,max}$ noise footprint, illustrated in Fig. 1, is derived from the outputs of the two individual simulations. The helicopter noise emergence, illustrated in Fig. 2, is calculated as the difference:

$$(1)\quad Emergence = L_{A,max,HC} - L_{A,eq,ROAD,6h-22h}$$

where $L_{Aeq,ROAD,6h-22h}$ is the averaged road noise, obtained from strategic noise maps produced in the frame of the European Directive 2002/49/CE, and referred to as background noise.

These simulated noise maps of L_{Amax} and Emergence levels were applied to each building, and people noise exposure was computed based on available population density data from INSEE and BDTOPO 2019.

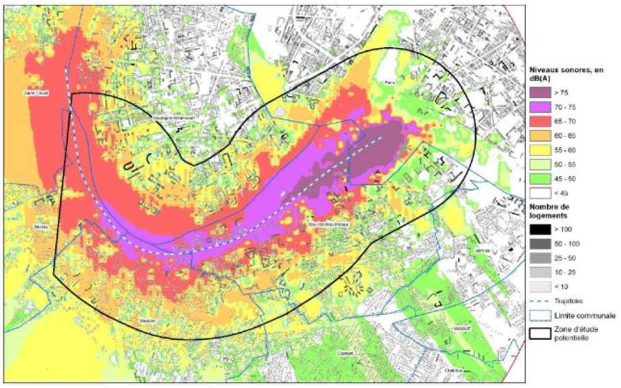


Figure 1. Average helicopter (EC145) noise footprint (L_{Amax}) between departure and approach trajectories

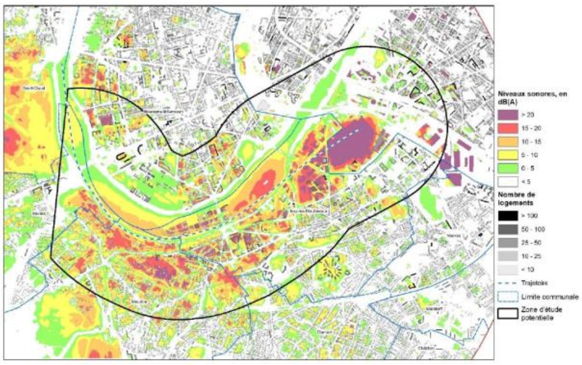


Figure 2. Emergence of helicopter (EC145) noise above background noise ($L_{Aeq,road,6h-22h}$)

8 relevant sectors with different noise exposure were thus defined within an area of 1 km around the average trajectory, so as to get a good repartition of the number of people with high/low exposure to helicopter noise, and high/low helicopter noise emergence to background noise. These sectors, highlighted in yellow in Fig. 3, bring together a potential of 11430 housing units to be approached as part of the survey (See Table 1), which was deemed sufficient enough based on the assumption of 10% of responses to the survey to achieve the target of 750 participants.

Table 1: Preliminary noise exposure statistics.

Emergences [dB(A)]	Lamax,HC [dB(A)]					
	<55	55-60	60-65	65-70	>70	**TOTAL**
<0	541	456	398	81	53	**1529**
0-5	155	535	927	902	110	**2629**
5-10	48	381	1382	575	396	**2782**
10-15	16	118	598	614	324	**1670**
15-20	0	83	735	614	509	**1941**
>20	1	29	27	695	129	**881**
TOTAL	**761**	**1602**	**4067**	**3481**	**1521**	**11432**

For cost and logistic reasons, the noise exposure cannot be measured directly for each participant, and the chosen method to compute survey participants exposure is presented in section 5, based on experimental data. 15 noise measurement stations were thus placed among the 8 selected sectors with the aim of covering these sectors as much as possible despite usual installation constraints (privacy, permissions from properties owners, low background noise target). Hence, the measurements sites have been chosen such that they remain as much as possible away from other noise sources (roads, railways, factories, air-conditioning equipment…) in order to measure events with an emergence of at least 10 dB(A). Additionally, these stations have been placed on the top of buildings (flat surface) in order to avoid corrections due to omplex noise propagation effects, such as masking or reflection on building facades. The sensors' locations are highlighted in red in Fig. 3.

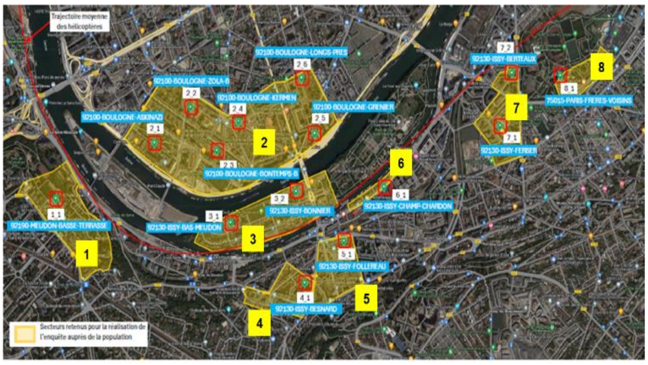


Figure 3. Aerial view of the 8 relevant sectors (yellow areas) & measurement locations (red squares).

4.2. SURVEY PREPARATION

A preliminary survey, based on a literature review of similar studies (see section 3), and on interviews with local helicopter operators, has been carried out with 20 people selected across these sectors. The responses allowed Univ. Eiffel to update and finalize the survey questions.

The questionnaire consisted of a total of 57 closed-ended questions (except for 2 open-ended questions regarding the number of helicopter flyovers per day and per week) and the questions were pre-coded for statistical analysis. Most of the questions included between 4 and 11 items and were presented in the form of frequency or agreement scales (Likert-type scale) and Osgood's semantic differentials scale. The administration of the questionnaire took approximately 45 minutes.

The assessment of long-term annoyance is collected using two standardized scales, one verbal and one numerical (Ref. 29), recommended in studies on noise annoyance. The responses are correlated with various acoustic indicators to establish dose-response relationships and statistically test their validity.

A section of the questionnaire is dedicated to the perception of helicopter flyovers in terms of frequency, number, qualitative aspects and, annoying characteristics, and the different types of operations. The objective here is to determine the acoustic characteristics of helicopter noise that influence the expressed level of annoyance.

Noise annoyance is a multidimensional psychological concept (Ref. 30) introduced to explain the variability of responses observed in transport noise studies under equivalent noise exposure. It integrates into its definition the role of non-acoustic factors (Ref. 31) to explain individuals' reactions to noise considered as an environmental stressor. Questions validated in a study on aircraft noise annoyance (Ref. 32) were adapted to determine the salience of these factors in the specific situation of helicopter flyovers exposure based on the analysis of the preliminary interviews. Thus, the questionnaire address disturbance of daily activities and behavioral coping response, appreciation of the neighborhood and its sound environment, attitudes towards helicopters according to flights 'missions, the perception of control of the noise situation, emotions felt and behavioral reactions to helicopter flyovers, social expectations regarding the environment, as well as sociodemographic and situational factors (type of housing, residential area, etc.).

5. TEST PERFORMANCE AND POST-PROCESSING

5.1. Test Performance

It was decided to conduct the study after the summer break for practical reasons (including avoiding Paris-Le Bourget airshow which generates a significantly increased traffic on the heliport). The survey has been carried out by IPSOS Observer between September, 4th and October 10th, and allowed to collect 768 responses, together with the geolocation of each participant including latitude, longitude, elevation (according to building floor), building type (detached house, terraced house, building…) and building façade orientation. The latter were deemed important, as it was found with preliminary computation that the noise exposure could vary significantly depending on these parameters.

Noise measurement data at each of the 15 noise measurements sites was recorded from September 1st, 2023 to November 14th, 2023 (75 days) with the autonomous Medusa system, developed by Bruitparif and shown in Fig. 4. It is made of four microphones mounted on a 4m-high mast, measuring the noise level (Leq) in dB(A) and dB(C) each 0.1s and allowing to determine the direction of the origin of the sound (azimuth and elevation angles). During the measurement period, data was available in real-time, which ensured monitoring of the proper functioning of the system.

Figure 4. Microphone set-up

From these acoustic measurements, helicopter noise events have been identified based on two criteria:

• "acoustic detection": based on a low-pass Butterworth filtering as shown in Fig. 5. An event is detected if fast smoothing (0.5 Hz, 5th order) curve exceeds slow smoothing (0.01Hz, 1st order) curve by a given threshold and for adjustable parameters on L_{Amax} and duration.

• "aerial event detection": if a minimal proportion (e.g. 60%) of noise elevation angles exceeds a given threshold (e.g. 10°).

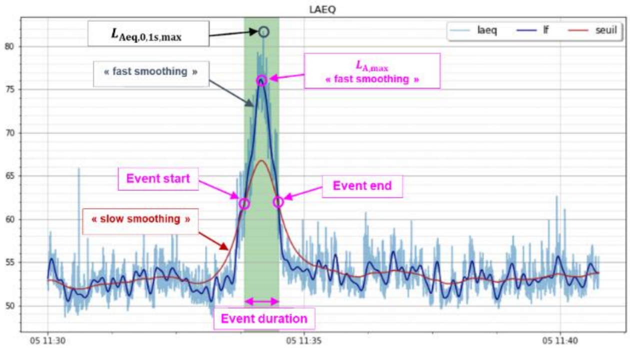


Figure 5. Example of an event detection. Time evolution of LAeq,0.1s and smoothed curved.

In total, 15329 helicopter events were detected on the 15 sensors. These events were compared with Radar data, showing a good correlation and emphasizing a good quality of the detected movements.

For each of these events, various indicators such as event time, duration, L_{Amax}, L_{Cmax}, SEL_A, SEL_C were gathered. As expected, sectors 7, 8 and also sector 1 (see Fig 3.) are associated with a higher number of events due to the fact that some helicopter operations in the east of the heliport or west of Paris may impact these sectors while not impacting sectors 2 to 6.

Bruitparif also updated the computed road noise exposure at the façade of each participant considering its precise location (latitude, longitude, building floor) from strategic noise maps produced in the frame of the European directive 2002/49/CE with the assumptions of the 4th expiry (Fig. 6). These values were considered more representative than the ambient noise values measured by the Medusa, because measured background noise data on building roofs are not relevant when considering road noise.

Additionally, helicopter traffic data was provided by DGAC for the test period September-October 2023 (H/C types, movement information, detailed trajectories) as well as movement statistics on a full year period preceding our test period (from August 2022 to July 2023).

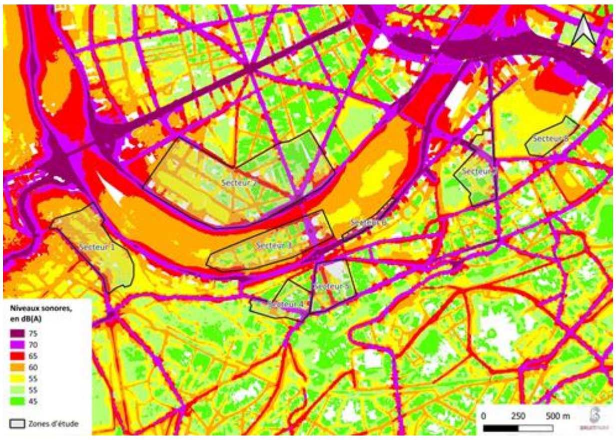


Figure 6. Lden_Road noise map.

These statistics were also used to assess the variability of helicopter movements along the year, and the representativity of the measurement period on the yearly exposure. 934 movements/ month were identified on the measurement period while the yearly average is very similar (943), despite important variation along the year ([400-1600]). The measurement period was deemed very representative of the yearly exposure and was directly used to compute noise exposure statistics.

It is also noted that out of the total number of movements controlled by the local air traffic management, one third are transit, and approximately 50% are on the west side -our area of study- of the heliport.

Additionally, approximately 37 helicopter type designs (some of them were grouped due to lack of precision in the raw data) flew on the heliport in this period, from old type designs such as SA318 Alouette II to lasted H160, with both single and twin engine (73%) helicopters. By order of number of movements, EC135, EC145, AS355 A109 and AW139 and R44 are the most represented. Additional data regarding mission type are available for some of these movements.

5.2. Post-processing

In order to analyze the responses to the survey, we need to estimate the noise exposure for each of the 768 participants based on the events recorded by the 15 noise measurement stations. To do this, complementary numerical simulations have been carried out to compute transfer functions between measured locations and surveyed sites. As mentioned earlier, these simulations have been performed with Noise Modelling software which was specifically adapted to helicopter noise sources, and for a given helicopter type (EC145). Detailed information about the movements (H/C type, mission and trajectory) collected for September 2023, were used to crosscheck helicopter noise simulations quality.

The methodology to compute the transfer functions is detailed hereafter. In a first step, detailed analysis of the helicopter traffic data in September 2023 (radar data provided by DGAC) enabled to classify the trajectories in various clusters (high vs. low altitude, mean/north/south trajectories, low speed/high speed flights), and to check if these parameters could significantly influence the transfer functions. The relative average error, computed for a given helicopter type on these various clustered trajectories, was deemed acceptable to consider a unique transfer function per participant based on a standard trajectory. Transfer functions take the form of with corrections both in dB(A) and dB(C), between the noise levels at each microphone and each participant.

Then, each participant is associated with three noise measurement sites base on a Delaunay triangulation, as shown in Fig. 6. For any participant lying outside the triangulation, the nearest noise measurement site is selected.

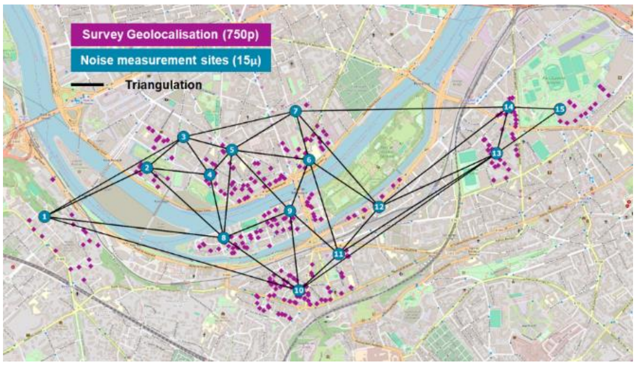


Figure 6. Geolocation of participants (violet) and noise measurement sites (blue).

Finally, the noise exposure (for each measured event on the measuring stations) for each participant i is computed as follows:

$$(2) L_i = \sum_{k=1}^{3} \alpha_{i,k} * (L_{j_{i,k}}^{\text{meas}} + \Delta_{j_{i,k}}),$$

where $\alpha_{i,k}$ is the weighting coefficient of the Delaunay triangulation, $L_{j_{i,k}}^{\text{meas}}$ is the noise level measured at the associated measurement site $j_{i,k}$ and $\Delta_{j_{i,k}}$ is the transfer function between the participant i and the noise measurement site $j_{i,k}$. The computation process is schematized in Fig. 7.

From these estimations of helicopter noise at each participant location and for each detected event, the aggregated noise exposure along the measured period was computed for each participant, including A- and C-weighted Leq, Lmax, SEL, NA, and emergences noise levels.

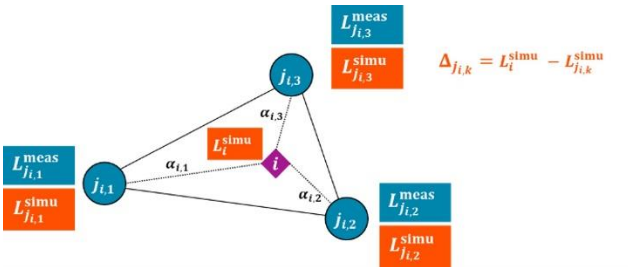
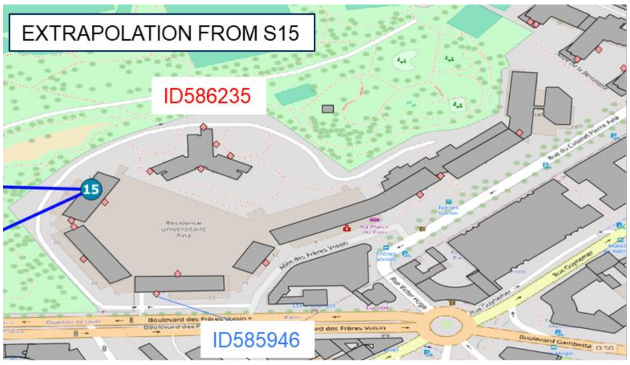


Figure 7. Synthesis of the computation process of the noise exposure for each participant

An example of the resulting noise exposure is given hereafter for two surveyed positions (ID586235 and ID 585946) located in sector 8, near the heliport. As shown in Fig. 8, ID586235 is exposed to the north (facing the heliport), quite far from the main road in the south. On the contrary, ID585946 is located on the opposite side of the buildings block, facing south and much more exposed to road noise.



POSITION	ID586235	ID585946
Amb Lden	43,2	62,1
Lden H/C	49,7	39,5
LAeq6h-22h	49,1	38,8
MoyLAmax	70,4	60,2
EmergA	34,8	6
NA50	26,6	26,6

Figure 8. Individual Noise Exposure Example

Noise exposure results which are based on similar noise measurement data (sensor n°15 located on top of the left building) show a significant impact of the orientation of the main façade exposed to noise, with approximately 10dB higher values (L_{Amax}, or integrated metrics such as L_{Aeq}, or L_{den}) for ID586235. Besides, On the contrary, ID585946 is exposed to a $L_{den,road}$ 19dB higher due to the proximity of the road. The resulting emergence of helicopter noise is significantly different, (6dB vs 34.8dB). One can also notice that both persons are exposed to the same number of events (26.6 daily average movements) as quantified through NA50 (Number Above 50dBA).

6. RESULTS AND DISCUSSION

In this section, the results of noise exposure from the combination of measurements and simulations, basic survey analyses, and finally correlations of annoyance versus noise exposure are discussed.

6.1. Noise Exposure

As discussed in previous section, various aggregated metrics were computed for each participant, among with A- and C-weighted Leq, Lmax, SEL, NA, and emergences noise levels. Some illustrations of these metrics are presented and commented hereafter.

Noise exposure shows an average number among the participants between 10 and 16 helicopter events per day (between 8 and 13 on the daily period [6h-18h], between 1 and 3 on the evening period [18h-22h] and less than 1 event on the nigh period). Some participants located close to the heliport may see a few more events (between 20 and 24 events per day, likely from operations east of the heliport).

Global statistics of noise levels in various metrics are shown on Fig. 9 under boxplot format. Ambient L_{den} (from road traffic), Helicopter L_{den}, but also AvgL_{Amax} (the average L_{Amax} value on all H/C events), EmergA (the average value on all events of emergence of H/C noise compared with ambient L_{Aeq} in the period -day, evening, night- of occurrence of the event), NA65 (Number Above L_{Amax} value of 65dBA), and NEA15 (Number of Events with an emergence Above 15dBA) are provided as examples.

Classically, this representation shows the median value (red central mark), the box edges are the 25th and 75th percentiles, the whiskers extend to the most extreme points that are not considered as outliers, and the outliers are plotted individually (red marks).

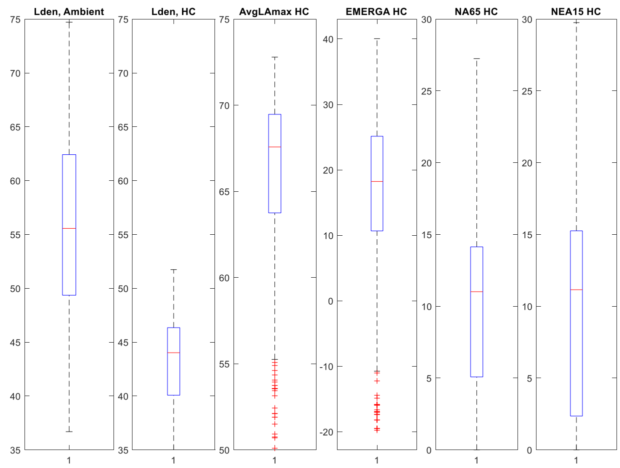


Figure 9. Statistics on various noise exposure metrics

It can be seen that helicopter L_{den} (median L_{den}=44dB, max=51dB) is far below the ambient noise (median L_{den}=55.6dB, max=74.7dB), and well below the regulatory limits as per European Directive 2002/49/CE for air transportation. Additionally, these values are also mainly below the noise quality recommendations of WHO for air transportation (Ref. 33). These references correspond to a context which is different from the one of heliport operations but remain the main ones for air transportation.

It is to be noted (not shown on the graph) that the extremely low number of night events lead in night average noise levels (Ln) well below the associated references. Additionally, there are no noticeable differences between noise exposure during week and week-end periods (slightly more events in the evening and night during week-end, likely due to rugby world cup that occurred during the measurement period).

Nevertheless, average L_{Amax} noise levels as seen by survey participants are rather high (median L_{Amax}=67.6dBA) which is well above ambient noise levels and result in relatively high emergence noise levels (median emergence = 18.2dBA).

On a typical day, a median value of 11 events above 65dBA is experienced by the participant, with a similar number of events with an emergence above 15dBA. One can states that most people living in the study area would ear helicopter operations outside their housing.

Fig. 10 to Fig.12 hereafter show the spatial repartition of these noise levels for each survey participants around the heliport.

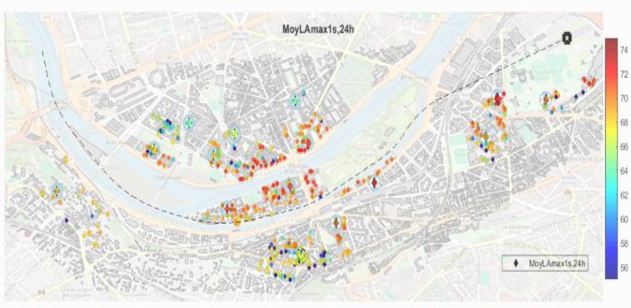


Figure 10. L_{Amax} (Average) mapping of all survey participants

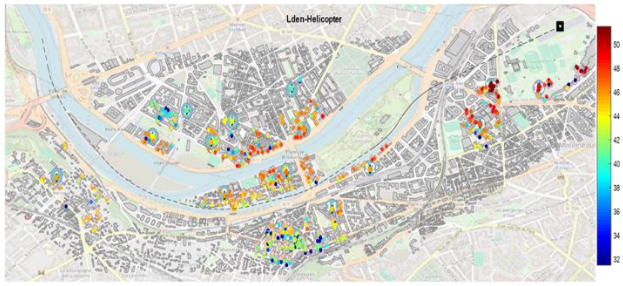


Figure 11. L_{den_HC} mapping of all survey participants

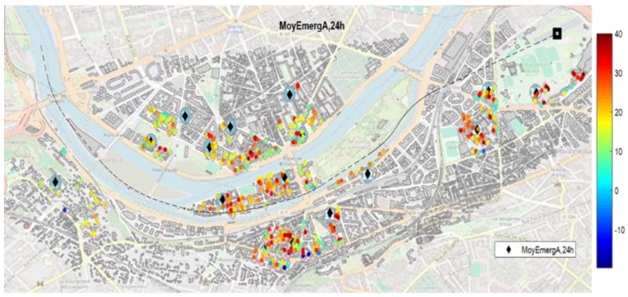


Figure 12. Average Emergence mapping of all survey participants (no emergence for measurement sensors)

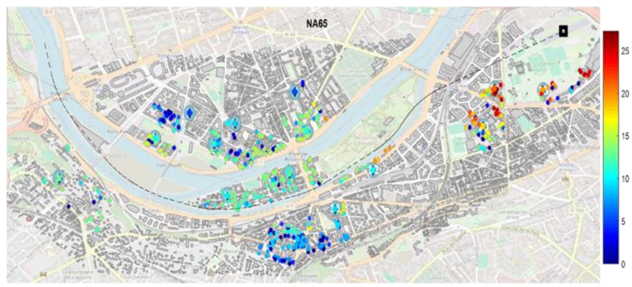


Figure 13. NA65 mapping of all survey participants

Obviously, analysis of these noise exposure maps shows that most of these acoustic metrics are well correlated, since all participants would see a similar number of events. It is also shown that even though some sites are logically more exposed than others (e.g sites 6, 7 and 8, see Fig.3), close proximity of the participants to helicopter trajectories but different building facades orientations explain that both people exposed to noise levels above 65dBA (for example) and other with much lower exposure could be encountered on any of the 8 sites.

6.2. Annoyance

The 5-point verbal scale (Ref. 29) was used to assess participants' annoyance levels, with five possible responses: extremely, very, moderately, slightly, or not at all. In this paper, severe annoyance (HA / non-HA) is used as an outcome in all statistical analyses where HA is defined as the number of participants who reported being either very or extremely annoyed.

Perceptive variables were used to create a primary multivariate model to explore the relationship with severe annoyance as follows:

a. The frequency of hearing helicopter noise indoors with windows open: in two categories (Never, rarely, or sometimes / Often or always), where participants were asked to describe the frequency at which they hear, even faintly, helicopter noise when they are at home indoors with windows open.

b. The most annoying aspect is the number of helicopter passages: in two categories (Uncited / Cited), where participants were asked: "When you think about helicopter flyovers that you hear when you are at home, what is the most annoying for you among this list of options ? And chose to cite or not the option: The intensity of the noise when a helicopter passes."

c. The most annoying aspect is the intensity of the noise: derived from the same question as in b, participants were also asked to choose whether "the intensity of the noise when a helicopter passes" was the most annoying aspect. Responses were also categorized as (Uncited / Cited).

d. Noisy neighbourhood: in two categories (Not at all, slightly, or moderately noisy/ Very or extremely noisy), where participants were asked: “Overall, would you say that your neighbourhood is".

The questionnaire included many additional questions, as described in section 4.2. Results associated with these perceptive variables are partly discussed in next section. Statistical analyses are being conducted to further study the influence of these different factors relative to noise exposure on long-term annoyance.

The distribution of participants' responses on the 5-point verbal annoyance scale across all sectors of the study was calculated, along with the mean responses on the 11-point numeric annoyance scale.

Subsequently, univariate logistic regression models were used to assess the association between severe annoyance and various helicopter noise indicators, which were introduced here into the models as categorical variables.

Then, univariate logistic regression models were rerun separately for each noise indicator introduced here as a continuous variable, per 1dB(A), 1dB(C), or one event increase to explore the exposure–response relationship between noise exposure and severe annoyance. These models predicted the probability of participants being highly annoyed at corresponding indicator levels and were used to generate exposure–response curves.

Finally, a preliminary multivariable logistic model was created to study the association between severe annoyance and a selected number of perceptive non-acoustic variables that describe perceptions of noise.

The results of logistic regressions are later presented as odds ratios with their corresponding confidence intervals (Table. 2).

Among the 768 participants that were enrolled in the study, 140 (18%) reported being highly annoyed (HA) by helicopter noise. Looking more in details, Fig.12 shows that among the study population, 12% indicated being very annoyed and 6% reported being extremely annoyed, Conversely, 35% reported not being annoyed at all by helicopter noise. It can be seen, with a good similarity with noise exposure results shown in previous section, that sectors 6, 7 and 8 reports the highest percentage of highly annoyed (and the highest mean of numeric annoyance (see Ref. 29), together with sector 1. The latter is located much further from the heliport, but this is a residential area with suburban housings. Results from these sectors should nevertheless be interpreted with care, since the latter include a limited number of participants.

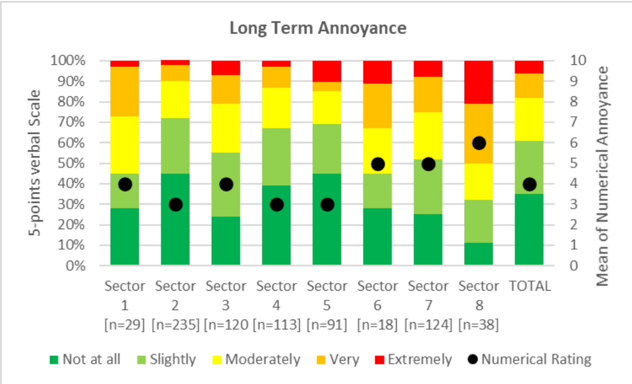


Figure 12. Distribution of participants responses on the verbal and numerical annoyance scales related to helicopter noise

Overall, highly annoyed people are located on all sectors, which can be seen more in detailed on Fig. 13 below.

Figure 13. Location of highly annoyed participants on various test sites.

Additionally, 26% people declared to be highly annoyed during spring-summer season, in contrast with only 9% during autumn-winter. Similarly, 34% declared to be highly annoyed outside, 27% inside their housing with open doors, and 10.5% inside with closed windows.

6.3. Correlations and discussion

Noise exposure data and survey results were combined by Univ. Eiffel to study long-term annoyance due to helicopters flyovers.

A correlation between noise exposure and annoyance was found, as shown by a trend of increased prevalence of highly annoyed participants with higher levels of noise or number of events (for all the metrics presented earlier). This trend is visible on the exposure-response relationships between helicopter noise as continuous variables and severe annoyance due to helicopter noise using predicted probabilities derived from the logistic regression models, as shown for examples in Figs 14-16. Models were separately run for each indicator, treating the latter as a continuous variable with an increase of 1dB or 1 event. All these models demonstrate a statistically significant association between severe annoyance and helicopter noise exposure.

Fig. 14 shows the exposure-response relationship for energetic A-weighted metrics, including L_{den}, L_{Aeq_24h}, and $L_{Aeq\_6h\text{-}22h}$ that exhibit very similar shapes. Note that, as there are only a few helicopter movements during the night but a few more during the evening, L_{Aeq_24h} values are globally lower than L_{den} and $L_{Aeq,6h\text{-}22h}$ for a given participant. As a consequence, similar proportions of severe annoyance are obtained at lower values of L_{Aeq_24h} compared with the two other metrics.

Fig.15 also show a similar relationship for A-weighted and C-weighted curves which is shifted to higher noise levels (due to the higher C-weighted noise exposure values). A similar conclusion had been drawn in Ref. 17 showing a strong correlation between A-weighted and C-weighted SELs around 2 US heliport sites.

Fig. 16 presents the exposure-response relationship for event-based indicators (NA55, NA60, NA62, NA65 and NA70) which clearly show a trend of increased severe annoyance for higher number of events above a certain threshold, but also a gap in this severe annoyance when increasing number of events at high intensity of noise (L_{Amax}>70dB(A) or L_{Amax}>65dB(A)), while the response remains quite constant for lower noise levels and low number of events.

One outcome of the study is that all the metrics chosen to measure participants exposure to noise are highly correlated between each other, which can be explained by the fact that all helicopter trajectories flown in the vicinity of the heliport remain very similar, so that, statistically, increasing the number of helicopter movements logically increasing helicopter average daily exposure on energy-based metrics in the same proportion for all survey participants. It is thus not obvious that one or the other of these metrics is more correlated to severe annoyance.

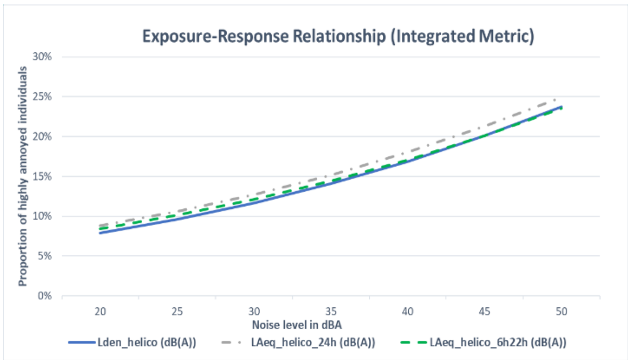


Figure 14. Exposure-response relationship for energetic A-weighted metrics, including L_{den}, $L_{Aeq\ \_24h}$, and $L_{Aeq\_6h\text{-}22h}$

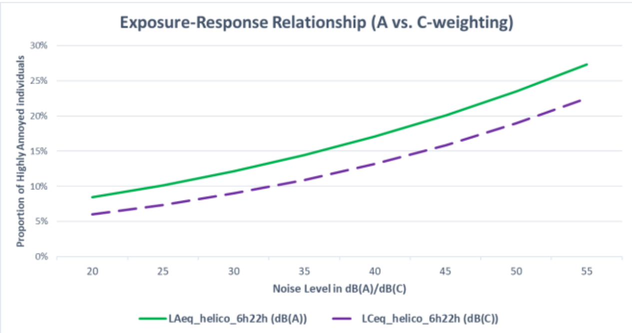


Figure 15. exposure-response relationship for energetic A and C-weighted metrics

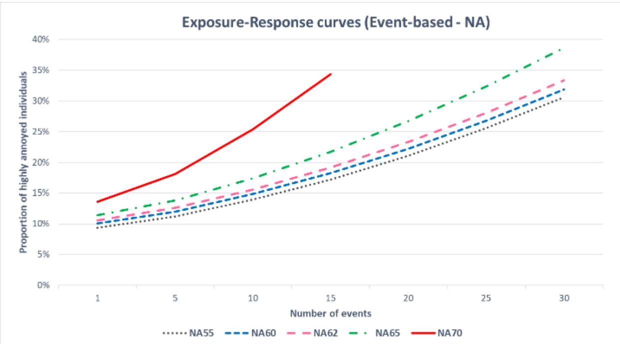


Figure 16. exposure-response relationship for event-based (Number Above) A-weighted metrics

Table 2 presents the odds ratios, results of the univariate logistic regression models studying the association between severe annoyance and helicopter noise exposure. The vast majority of the models demonstrate a statistically significant association.

Table 2: Crude Estimates for the Association Between Severe Annoyance and helicopter Noise Exposure (energetic & event-based indicators).

Indicator	Level/Nb	OR	Pvalue	R2
Lden_HC [dB(A)]			**0.03**	0.02
	< 35	Ref	-	
	35-39	0.85	0,67	
	40-44	1.35	0,32	
	≥45	**2.02**	**0,02**	
LAeq_HC_6h22h [dB(A)]			**0.05**	0.02
	<35	Ref	-	
	35-39	1.14	0.76	
	40-44	1.23	0.53	
	≥45	1.93	0.04	
LCeq_HC_6h22h [dB(C)]			**0.01**	0.03
	<40	Ref	-	
	40-45	1.20	0.69	
	46-50	1.03	0.94	
	≥51	**2.09**	**0.02**	
NA62			**<0.01**	0.05
	0-4	Ref	-	
	5-9	0.80	0.62	
	10-14	0.99	0.97	
	15-19	1.24	0.50	
	20-24	**3.07**	**<0.01**	
	25-30	**2.87**	**0.01**	
NA65			**<0.01**	0.04
	0-4	Ref	-	
	5-9	1.18	0.59	
	10-14	1.34	0.28	
	15-19	**1.97**	**0.05**	
	20-24	**4.28**	**<0.01**	
	25-27	**2.94**	**0.02**	
NEA15			**<0.01**	0.04
	0-4	Ref	-	
	5-9	1.02	0.96	
	10-14	1.14	0.62	
	15-19	1.00	0.99	
	20-24	2.66	**<0.01**	
	25-30	3.14	**<0.01**	

Results of Univariate Logistic Regression Models.
Bold indicates statistical significance.

Taking the results of $L_{Aeq\_HC\_6h22h}$ (dB(A)) as an energetic indicator, it is observed that the probability of being highly annoyed by helicopter noise is significantly higher among those exposed to levels ≥45 dB(A) compared to those exposed to levels < 35 dB(A), with an odds ratio (OR) of 1.93

Regarding event-based indicators, the result in this table indicates that individuals exposed to 20-24 events of helicopter noise exceeding 62dB (NA62) are 3.07 times more likely to report being highly annoyed compared to those exposed to 0-4 events. This trend of a significantly higher probability of being highly annoyed when compared to the reference group emerges earlier at lower event thresholds for higher noise levels, beginning at 15-19 events for NA65 and 10-17 events for NA70 (not shown in the table).

The latter may suggest a stronger relationship with intensity of noise compared with the number of events, as soon as the intensity of noise is above a certain threshold (e.g 70dB(A)). This result nevertheless should be taken with care since only a few people exposed to high number above 70dB(A) are present in the participant's panel.

An initial multivariable logistic regression model that includes only perceptive factors was fitted to study the association between severe annoyance and variables describing the perception of noise (Table 3). A statistically significant positive association was found between severe annoyance and all perceptive variables in the model. For example, participants who cited that the most annoying aspect is the intensity of the noise are more than 6 times more likely to report being highly annoyed (HA) compared to those who did not cite this option, with an adjusted Odd Ratio of 6.78 (95% CI: 2.79-16.46). One can note that this adjusted Odd Ratio is lower (2.34) when considering the participants who cited that the most annoying aspect is the number of helicopter movements.

Table 3: Adjusted estimates for the association between severe annoyance and perceptive factors describing the perception of noise

Variable	OR	(95% CI)	P value	R2
frequency of hearing helicopter noise indoors with windows open				
Never. rarely or sometimes	Ref	-	-	
Often or always	**7.12**	**(4.55; 11.12)**	**<0.01**	
The most annoying aspect is the number of helicopter passages				
Uncited	**Ref**	-	-	
Cited	**2.34**	**(1.52; 3.7)**	**<0.01**	0.41
The most annoying aspect is the intensity of the noise				
Uncited	**Ref**	-	-	
Cited	**6.78**	**(2.79; 16.46)**	**<0.01**	
Noisy neighborhood				
Not at all, slightly, or moderately	**Ref**	-	-	
Very or extremely	**3.83**	**(2.45; 5.99)**	**<0.01**	

Results of an Adjusted Logistic Regression Model: All variables were simultaneously included in the model.
Bold indicates statistical significance.

Note that a consistently higher Odds Ratios (ORs) for noise intensity compared to the number of passages were observed in the adjusted models even when only those two variables were included in a logistic regression model. This suggests that the perceived intensity of noise has a stronger association with severe annoyance than the frequency of helicopter movements.

In this analysis of the association between perceptive factors describing the perception of noise and severe annoyance, one can also note that participants who consider that their living environment is noisy are more prone to be highly annoyed (OR 3.83) that people who don't, while the perception of a noisy neighborhood was mainly correlated to road traffic noise. This may indicate that adding VTOL noise to an already noisy environment may be even more detrimental and cause more annoyance in the population.

In addition, Figures 14-16 also show that even at very low values for all noise metrics, the percentage of highly annoyed people takes values above 10%, which indicates that many participants have declared being highly annoyed even for very low exposure. Hence, annoyance is probably explained by factors other than noise exposure as depicted by classical noise metrics, including non-acoustic factors.

Moreover, the Nagelkerke R^2 values for all logistic regressions ranging from 0.02 to 0.05 across all models (see Table 2), indicates that the variation in severe annoyance explained by helicopter noise indicators is relatively low. Despite this, statistically significant associations were observed, suggesting that these variables have some explanatory power and that helicopter noise indicators play a role in predicting severe annoyance. While these models provide valuable insights into the relationship between noise exposure and annoyance, their predictive capacity is limited and conclusions should be drawn cautiously, taking in consideration other non-acoustic variables not included in the models.

The effect of these non-acoustic variables will be further investigated in next steps of this study. At a first glance, and among these factors, it is identified that the attitude of participants significantly differs depending on the reason for the helicopter flight. A significant difference is observed among the participants: on the one hand, emergency medical services (EMS) and parapublic missions (e.g., surveillance) were viewed positively; on the other hand, private flights are perceived negatively. It is also noted that participants who think that there are a lot of private flights in the area are likely to be more annoyed than the others.

7. CONCLUSIONS AND PERSPECTIVES

This paper presents the targets, methodology and results of a large-scale annoyance study for helicopter noise around “Héliport de Paris - Issy-les-Moulineaux – Valérie André” heliport. The analysis of both measurements and simulations of noise exposure was presented, as well as annoyance description and correlation with exposure to noise. These results for an urban heliport are of primary interest for a better understanding of community perception of helicopter noise, and may serve also as a basis for Urban Air Mobility operations acceptance.

The methodology which has been set-up, involving advanced microphone measurements on building roofs, computation of helicopter noise exposure of all individual participants based on trajectories analyses and advanced numerical noise simulations, and a large survey on 768 persons in the west of the heliport, allows to study the associations between annoyance response of these participants and their exposure to noise as described through many different metrics, energy or event-based.

In this paper, the annoyance due to helicopter noise is identified as not negligible in the vicinity of the heliport (18% highly annoyed), despite noise exposure levels that remain well below the regulatory limits as per European Directive 2002/49/CE for air transportation (not defined for such context), and well below exposure from road traffic. A statistically significant association between noise exposure and severe annoyance is established, that indicate the explanatory power of various helicopter metrics in predicting severe annoyance. Interesting results are also found in the correlation between Number Above (NA65, NA70) based regression models and the latter. Perceptive factors analysis also suggests that the perceived intensity of noise has a stronger association with severe annoyance than the frequency of helicopter movements. Also, noticeable features correlating the annoyance and the perception of the noise in their neighborhood are highlighted.

Additionally, a rather high proportion of highly annoyed people was identified, even at very low noise exposure. Moreover, the limited predictive capacity of the models to explain variability of annoyance also suggests that other variables such as non-acoustic factors may also significantly contribute to annoyance perception. Perspectives of this paper include complementary analyses of the survey that will be used to investigate the effects of these non-acoustic factors.

Finally, more than 15000 helicopter noise events were measured and may be later used to further analyze good and bad practices of local operations, but also to further validate numerical simulation models available at Airbus Helicopters. This dataset may additionally be used to corelate helicopter noise certification levels with observed operational noise levels. This will also allow to derive further design and operational recommendations to reduce VTOL annoyance.

8. ACKNOWLEDGMENTS

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