HELICOPTER NOISE IN URBAN FLIGHT

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Abstract

The present paper deals with a test campaign carried out in order to investigate the interaction between sound waves emitted by an helicopter and a model of an idealized urban contest. Test campaign was performed in Politecnico di Milano anechoic room, in order to analyze data produced by only helicopter noise. Set up consisted in a two blade main rotor helicopter model and a rectangular prism in aluminium as the landing building model. Ground observers perception was recorded by means of a surface microphone and a realistic landing trajectory was approximated as a succession of fixed point measurements. Collected data have been analyzed through acoustic spectra and sound maps. Spectra were used to comprehend physical phenomena, such as reflection, diffraction and shielding, and to analyze the different components of helicopter noise. Sound maps analysis enabled to get a global perspective of involved phenomena and to understand how much people close to building are stressed by an helicopter approaching an elevated urban helipad.

1 INTRODUCTION

Uncomfortable noise related to helicopter traffic over metropolitan areas is particularly critical in the phase of approaching and landing on helipads on buildings roof. A good knowledge of the physics involved in related phenomena could lead to define better flight procedures and also to improve building design from this point of view. Also, a deeper comprehension of interaction phenomena would help in improving existing computational codes thought for aeroacoustic simulations [1][2]. Indeed, urban traffic of VTOL aircraft is expected to grow rapidly in next years, so that it will impact city planning criteria too. In this frame, an experimental activity was planned at Politecnico di Milano aimed to perform acoustic measurements in an anechoic room on a test case reproducing a helicopter approaching an elevated helipad by using a small rotor model and a simple geometry building model. This setup did not included a tail rotor so that a non negligible noise contribution was missing. Nevertheless the main rotor remains the main noise source in reality [3] so that this simple rig allowed for a clear identification of the main effects. Moreover, such a test rig makes possible to get experimental data which are usually collectable only by means of full scale experiments, which are far more demanding in terms of costs and test facilities [4].

2 EXPERIMENTAL ACTIVITY

2.1 Test rig

The experimental activity was performed in the anechoic chamber of Politecnico di Milano - Dipartimento di Energia, in semi-anechoic configuration, i.e. with reflecting floor. The layout of the tests set up is shown in Fig. 2. The small rotor model used for the experimental activity with diameter $D = 0.15$ m, see Fig. 3, was the same developed for GARTEUR AG24 (Helicopter Fuselage Scattering Effects for Exterior/Interior Noise Reduction) [5].

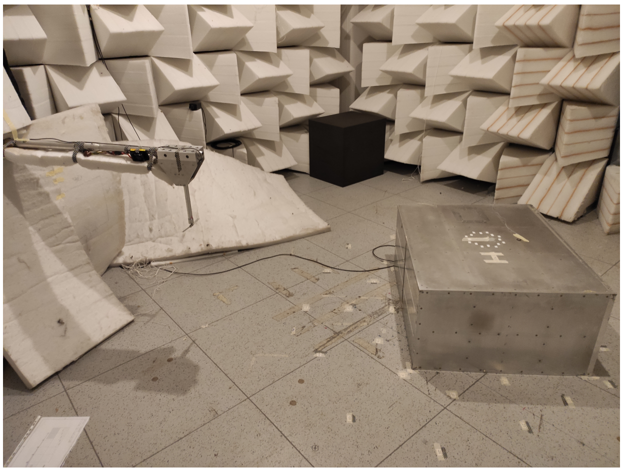

Figure 1: Set up with rotor at 1.5m from landing point.

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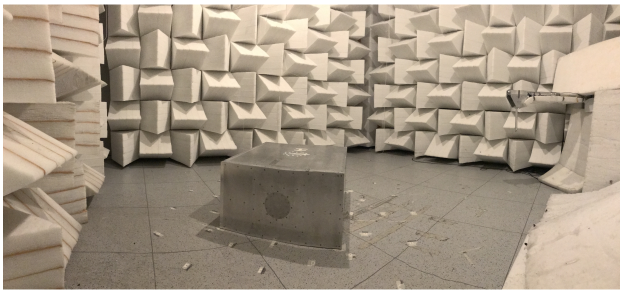


Figure 2: Experimental set up in the Politecnico di Milano anechoic chamber.

The rotational speed of the rotor during the tests was 23400 rpm, equivalent to a tip Mach number of the blade $M_{tip} = 0.54$. The building model (courtesy of DLR) was the same used for AG-22 (Forces on Obstacles in Rotor Wake) [6] and consists of a parallelepiped aluminium alloy box $0.45m$ high with $1m \times 0.8m$ base. Considering both the rotor and building dimensions, a scale factor $\lambda = 1/100$ was assumed for the test case with respect to a real urban environment, where a medium weight full scale helicopter with rotor diameter of $15m$ is approaching the roof of a building 45 m high. The definition of the scale factor was particularly considered in order to scale the measured frequency and particularly for the A-Weighting of noise [7]. During the tests, the rotor model was positioned at five different points along an approaching path by means of two orthogonal motorized sliding guides.

Figure 3: The rotor model.

The noise transmitted at soil was measured by means of a flat microphone sequentially located at different positions on the floor for each rotor position. Due to low speeds that characterise helicopter approaching phase, noise analysis performed at fixed rotor positions can be considered sufficiently adequate for phenomenon description. The helicopter descent path reproduced during the tests is shown in Figure 4, where the furthest point of the rotor is positioned at a distance of 2 m before the landing point on the building rooftop, corresponding to 200 m at full scale.

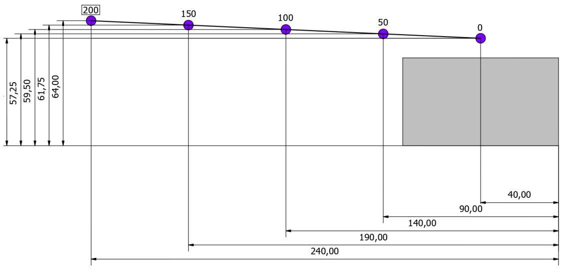


Figure 4: Rotor descent trajectory, dimensions in cm.

Figure 5 shows observers pattern chosen for microphone measurements around the building model. Their distribution was thought in order to guarantee enough resolution around the building and to analyze different effects caused by interactions between sound waves and building walls. Nearest observers were placed at a distance of 5 cm from the building model, while the furthest were positioned at a distance of 50 cm, i.e 50 m at full scale.

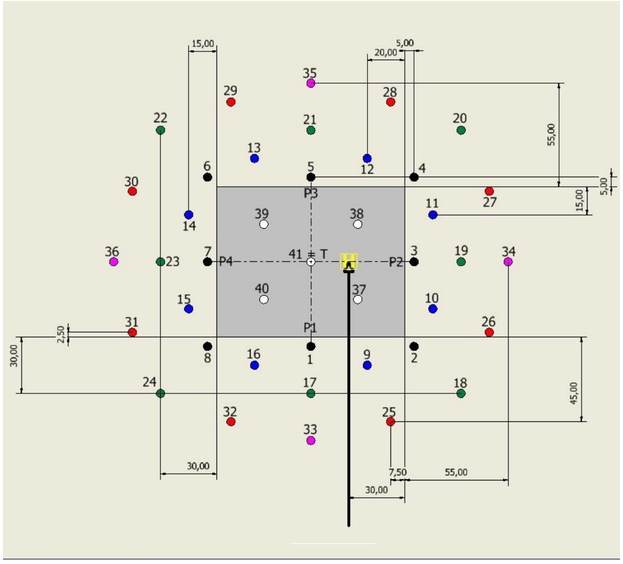


Figure 5: Measurements points distribution on the floor.

2.2 Test campaign

The tests allowed to design a map of the noise at ground level in terms of Sound Pressure Level (SPL) and to provide comparison between noise spectra obtained at different ground locations. A constant monitoring over environmental conditions and rotor use state was performed during the tests to assure a high degree of homogeneity and provide an accurate comparison of the data collected during different trials. Table 1 reports the average and standard deviation values of absolute pressure, temperature and relative humidity recorded in test chamber during the measurements. In particular, standard deviation values clearly shows no remarkable variations of environmental conditions during the tests as they were kept almost constant all along the campaign. The repeatability of measurements was checked over a specific microphone location far away from building, rotor and anechoic chamber walls. Figure 6 shows a comparison between two spectra collected in the same reference position. This observer, number 48, is placed 2 m away from the frontal wall, rotor side, and 2 m far from the rotor, such that neither interactions with building nor direct exposure to rotor wake could affect its recordings. No remarkable difference between their average broadband noise levels and the position of rotor harmonics is appreciable, thus showing a high level or repeatability of the microphone measurements.

	Mean Value	σ
Pressure $[10^4 Pa]$	9.9138	0.0057
Temperature $[K]$	291.93	0.31
Relative Humidity $[\%RH]$	39.5	1.2

Table 1: Environmental conditions during the tests.

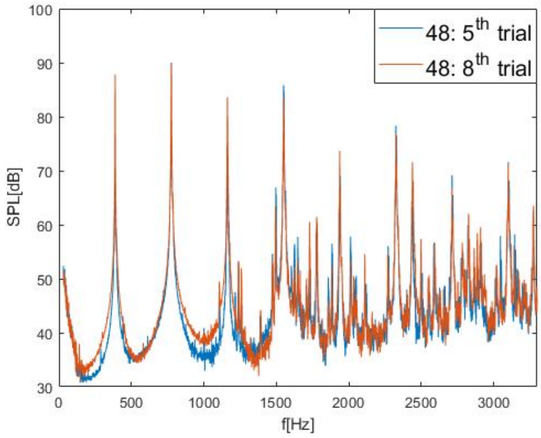


Figure 6: Repeatability check of microphone measurements: spectra comparison of signals acquired at same reference point. Observer 48

Each measurement was performed with an observation time $T_s = 10$ s. Spectra were obtained by post-processing using a moving mean process over smaller time intervals of $T_w = 1$ s. This process enabled to reduce random noise that could affect data. A typical spectrum of a signal recorded during the test campaign, see Fig. 7, shows mainly three components of noise:

- Loading Noise: Related to pressure variation caused by rotor blades, and so to lift forces generated by blades. Represented by even rotor harmonics $2n\Omega$ with first rotor harmonic presenting the highest peak value;
- Odd Harmonics Noise: Partly related to possible small asymmetries in rotor blades and partly to vibrations caused by aerodynamic loads and motor operating. It is represented by odd motor harmonics $(2n+1)\Omega$;
- Broadband Noise: Generally related to turbulence and interaction with fuselage, but contains contributions by other minor phenomena. Without obstacles in proximity of the helicopter it behaves as a plateau nearly constant throughout the spectrum.

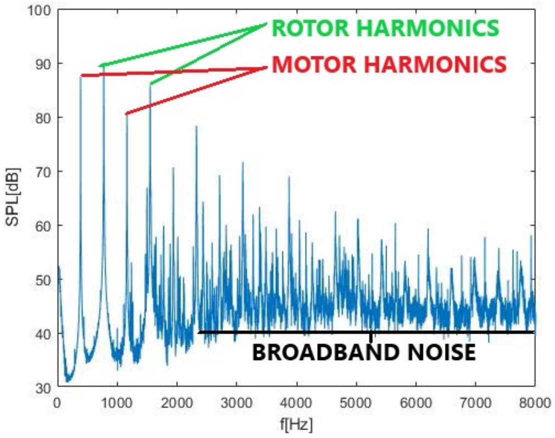
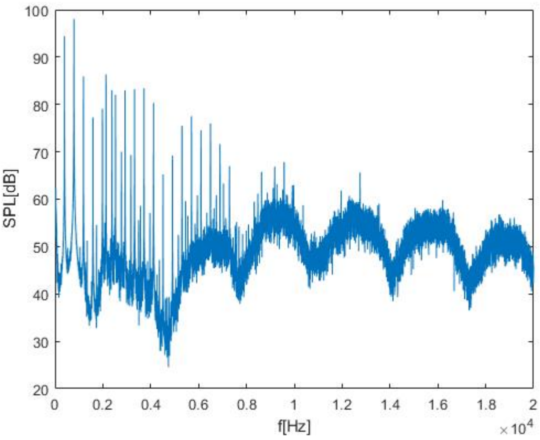


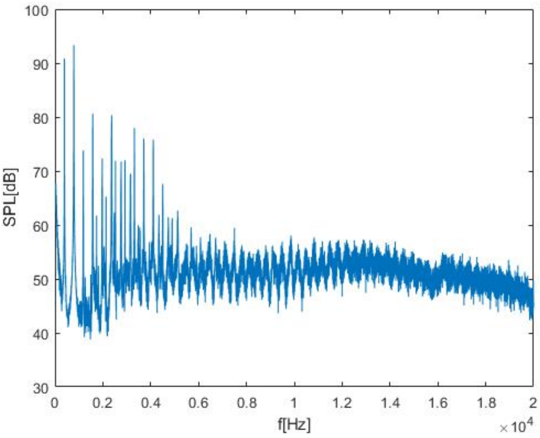
Figure 7: Typical spectrum recorded by reference observer. Observer 48

2.3 Results: Spectral Analysis

Experimental results will be presented in terms of sound spectra and noise diffusion maps. The spectra allow to identify the main physical phenomena caused by the interaction between the acoustic waves produced by the rotor and the building, i.e. shielding, diffraction and reflection. Then, the diffusion maps show the noise intensity perceived by an observer placed at the ground level. This approach allows a more immediate visualization of these phenomena together with an accurate numerical indication on noise perceived by ground observers. Starting from landing side observers' analysis, it is noteworthy that spectra are characterized by high levels of broadband noise (around $40 \sim 50 dB$) and high peak values which reach $110dB$. Spectra analysis shows that in this area the main phenomenon caused by interaction of sound waves with building is reflection. This effect can be observed in the spectrum by the pattern created by the alternation of constructive and destructive interference, caused by phase displacement between direct and reflected sound waves. Indeed, in Fig. 8a showing the spectrum of the signal acquired in correspondence of the closest observer to frontal wall with the helicopter in the furthest position from the building, at multiples of the frequency related to difference of covered distance by direct and reflected waves δ, constructive interference are found. On the other hand, phase opposition interference happens at multiples of the frequency related to half of δ. In this case $\delta = 0.196m$, and considering the sound speed characterising this trial $c = 342.6\frac{m}{s}$, the frequency related to the first phase opposition results to be $f \simeq 1.7kHz$, which matches the one showed by Fig. 8a.



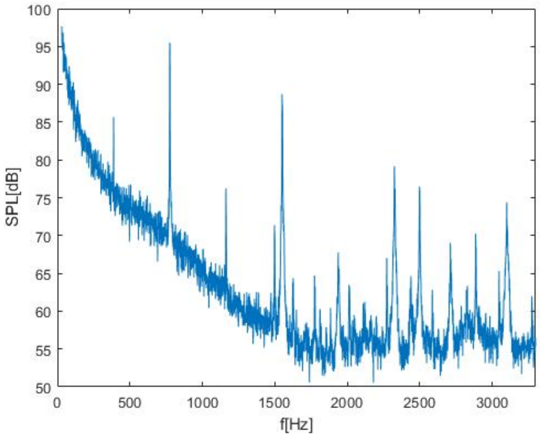
(a) Observer 1



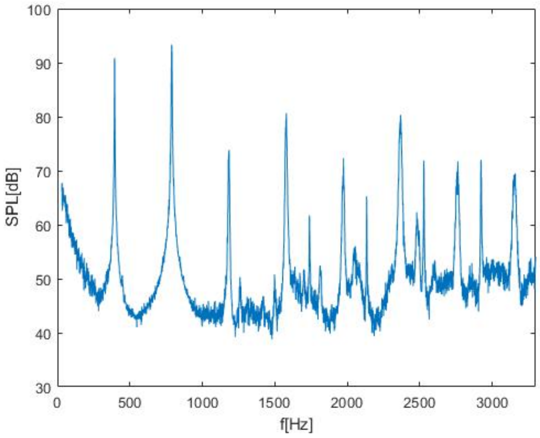
(b) Observer 33

Figure 8: Spectra comparison showing reflection phenomenon, rotor at 2 m from landing point.

By comparing Fig. 8a and Fig. 8b, which shows a spectra recorded by an observer at 50 cm (i.e. 50 m at full scale) away from the wall, the rate of interference peaks due to reflection increases with the distance of observers from building. Physically, it is possible to relate this observation to the variation of the difference of covered distance between direct and reflected waves. As an observer gets away from the building wall, the difference δ of covered lengths increases. This fact causes the frequency related to the first interaction decrease and the rate of wave interference in frequency to increase. Together with a change in pattern rate, a decrease in the strength of this phenomenon is found to happen as the observers get away from building front wall. It is possible to notice that the difference in amplitude between constructive and destructive interference passes form about $20dB$ in Fig. 8a to $\sim 10dB$ in Fig. 8b. This effect makes nearly negligible the effect of reflection at a distance which is the same as the height of the building model.



(a) Rotor at 0.1m from Observer 33



(b) Rotor at 1.1m from Observer 33

Figure 9: Spectra comparison showing effect of rotor wake on the first 8 harmonics.

Another physical effect which characterizes observers placed in the frontal area is the exposure to rotor wake. By focusing on the band from $30Hz$

to 3.5kHz of spectra recorded by the same observer with helicopter in two different positions, an effect on broadband noise could be noted. In particular, due to rotor wake turbulence, a remarkable increase in amplitude is found at low frequencies when the rotor is just over the observer (see Fig. 9a) with respect to the case when the rotor is further (see Fig. 9b).

Measurements on the rear of the building highlighted two other physical phenomena that influence observers in this area, i.e. shielding and diffraction. The former is provided by the presence of the building that causes a general decrease of broadband noise sound levels as can be observed from the spectrum shown in Fig. 10, bringing the average values to about $20 \sim 35dB$, which are far less than the ones found during frontward observers analysis. Rotor harmonics also result to be affected by shielding and their peak values do not overcome $80dB$. The effect of shielding is particularly intense at high frequency, see Fig. 10, where broadband noise suffers from a constant decrease with frequency increasing. Indeed, due to the presence of the obstacle, while sound waves with greater length waves, i.e. two or three times the height of the building, can pass the obstacle and get to the observer, high frequency waves are more shielded by the building edge.

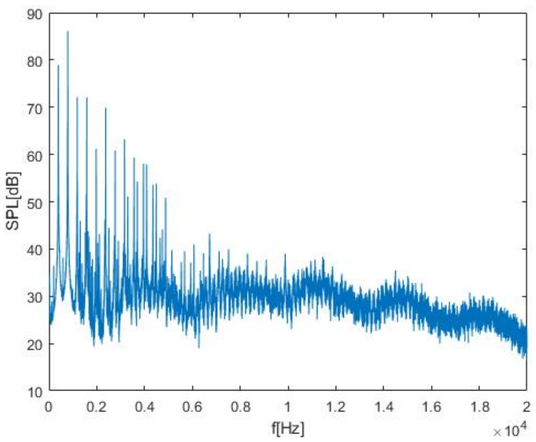


Figure 10: Spectrum on the rear of the building subject to shielding. Observer 28

The second phenomenon is diffraction that shows the typical behaviour caused by wave interference. This effect is caused by the interaction between building edge and sound waves produced by the helicopter. When waves arrive at the rear edge, each point of it turns into a new orthotropic sound source. So an observer is hearing numerous sound waves, which have covered different distances, and are then affected by phase displacement. This difference in phase causes interferences, which are clearly visible in Fig. 11, representing the spectrum perceived by Observer 28 on the rear of the building. Similarly to what observed due to reflection, a pattern of destructive and constructive interactions is present.

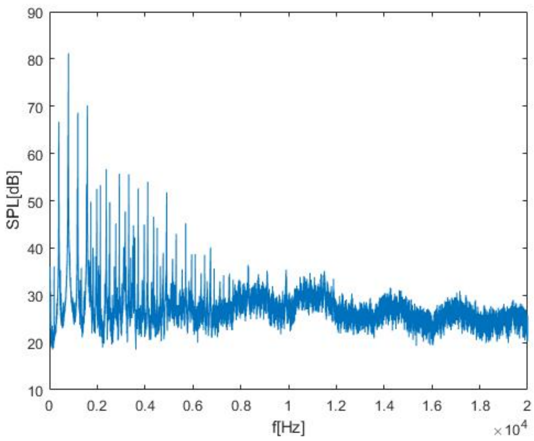


Figure 11: Spectrum on the rear of the building subject to strong diffraction. Observer 13

2.4 Results: Sound Maps

In order to show human perceived sound as the helicopter is approaching SPL maps are presented and discussed in the following. To draw the maps spectra are scaled to real frequencies, by means of scaling ratio $\lambda = 1/100$, in order to shows results for real dimensions. Indeed, as the model tip Mach number can be considered in the order of a real one, the frequency are reduced to full scale simply dividing by 100. Then, in order to get human perceived spectra, it was chosen to A-Weight dB values at each real frequency, in order to weight sound levels according to dynamic response of human ear [7]. By summing the average amplitudes at each third of octave, total perceived sound has been computed. Since human ear is much more sensible at high frequency with respect to lowest ones, rotor harmonics give a minor contribution since the loudest ones are found at low frequencies. Following maps are oriented as Fig. 5, so model rotor is approaching the building from the lower part of the map.

The first position considered in the discussion is the one in which the helicopter is in the furthest point from the building at $200m$ from the landing point. Fig. 12 clearly highlights some of the effects previously discussed. Indeed, a huge decrease in the sound perceived by the observers is found at rear of the building due to shielding phenomenon. In this area the minimum value is indeed $20dB$ while the values in the front part of the building are a bit less than $50dB$. Diffraction phenomenon then causes the presence of local peaks in this area and a local minimum. Shielding effect results to be very strong. Indeed, a difference of about $30dB$ is found between most stressed observers and least ones. This is caused by the effect at high frequencies, which are the most perceived by human ear, but at the same time, are the most filtered by shielding effect caused by the rear edge. The shaded area is then clearly visible, and it has a very defined border with non-shielded area. On the other hand, as can be expected, the highest values of dBA perceived are found in the front part of the building. Although the peak values are found near the rotor's position, it is possible to notice other local peak values with a minor intensity caused by the reflection of the sound waves on the wall of the building. This effect becomes stronger and therefore more visible when the rotor is closer to the landing position, as discussed in the following.

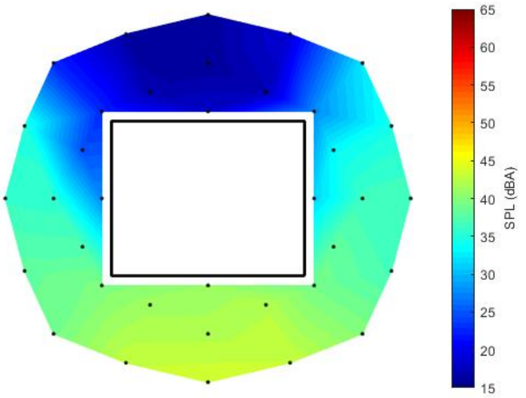


Figure 12: Sound diffusion map when the rotor is located at 200*m* from the landing point

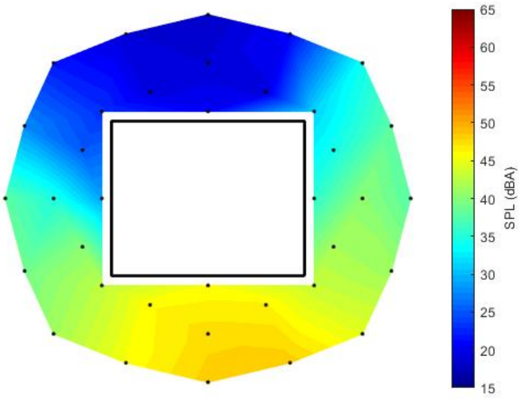


Figure 13: Sound diffusion map when the rotor is located at 150*m* from the landing point

The map shown in Figure 13 obtained from measurements with rotor at 150 m from the landing point, allows to see how much the reflection effect increases while the helicopter approaches the helipad. Indeed, in this case the highest values of *dBA* are found near the walls of the building due to wave interference. Also the shielding effect becomes clearer accentuating what was already seen in the previous case and influencing also a region on the left side of the building. Then, diffraction phenomenon can be seen through the changes in the pattern of local minima and maxima in the rear of the building.

Fig. 14 showing the map obtained when the rotor is at 100 m from the landing point, shows that the SPL perception appears to be more homogeneous at least in the front part of the building. This is due to the effect of rotor wake turbulence in this area, strongly exposed to rotor jet. The maximum detected frequency in *dBA* is found around $150Hz$ in correspondence of a phase constructing interference. Therefore, due to the presence of the rotor, which is very close to observers, the most perceived frequencies are no longer rotor harmonics but the random noise produced by the turbulent structures made by the rotor jet. Thus, turbulence not only widely increases SPL at very low frequency, but also heightens the average sound level of the broadband at frequencies where human hear is more sensitive. Moreover, due to shielding effect, an increase in the sound perceived by the observer who is the farthest from the wall in the rear of the building is found. This observer is, indeed, the first among all the backward observers which is going to be directly hit by sound waves as soon as the rotor approaches to the building.

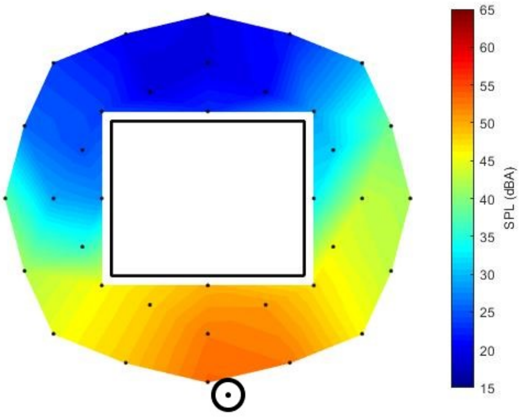


Figure 14: Sound diffusion map when the rotor is located at 100*m* from the landing point

The map obtained from measurements with rotor at 50 m from landing point is shown in Fig. 15. Although some measurements points are missing in this map, a quantitative analysis of this condition can be nevertheless made. The effect of reflection and turbulence in the front of the building is very strong, reaching a perceived level of $60dB$. Being the rotor very close to the building, the shielding effect extents over the side wall observers, leaving only frontward observers very exposed to rotor noise. Then, it is possible to notice a general increase of the mean value of noise, since even in the rear part of the building it does not go under $25 \sim 30dB$.

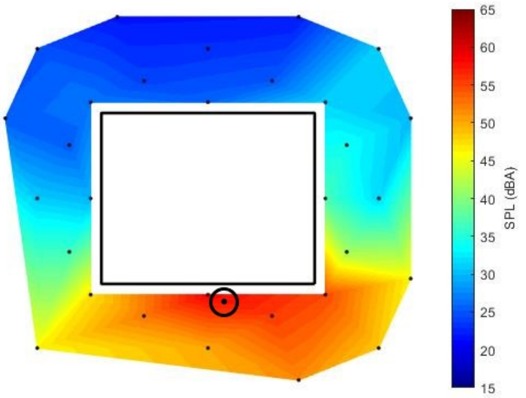


Figure 15: Sound diffusion map when the rotor is located at $50m$ from the landing point

3 CONCLUSIONS

An experimental campaign was performed at anechoic test chamber of Politecnico di Milano to investigate the noise effects related to an helicopter approaching an helipad on the roof of a building. Thanks to a relatively simple setup, the main phenomena related of the noise transmitted by the helicopter to the soil during this approaching manoeuvre have been highlighted, producing a general picture of the problem. The obtained database provides quantitative information publicly available for acoustic codes validations. Further developments of the activity will include experiments reproducing different approaching paths and/or different buildings models to allow for sensibility tests.

4 ACKNOWLEDGMENTS

Copyright Statement

REFERENCES

[1] Tomasz Lusiak, Adam Ziubiński, and Kazimierz Szumanski. Interference between helicopter and its surroundings, experimental and numerical analysis. Task Quarterly, 13(4):379–392, 2009.

[2] Stavros Vouros, Ioannis Goulos, and Vassilios Pachidis. Integrated methodology for the prediction of helicopter rotor noise at mission level. Aerospace Science and Technology, 89:136–149, 2019.

[3] A. Chyla and M. Bukala. The analysis of hospital helicopter landing sites location in terms of their vibroacoustic impact. Transaction On Aerospace Research, 3:43–56, 2019.

[4] David A. Hilton and Robert J. Pegg. The noise environment of a school classroom due to the operation of utility helicopters. NASA Technical Memorandum, NASA TM X-71957, 1974.

[5] J. Yin, A. Zanotti, G. Gibertini, L. Vigevano, and K.S. Rossignol. Design of a generic rotor noise source for helicopter fuselage scattering tests. In Proceedings of the 44th European Rotorcraft Forum (ERF 2018), pages 11–20, 2018.

[6] G. Gibertini, D. Grassi, C. Parolini, D. Zagaglia, and A. Zanotti. Experimental investigationon of the aerodynamic interaction between a helicopter and ground obstacles. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, 229:1395–1406, 2015.

[7] J.P. Cowan. Handbook of Environmental Acoustics. John Wiley and Sons, 1994.