

An experimental study on the shielding performance of buildings exposed to aircraft noise comparing measurements near front and rear facades

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ABSTRACT

This paper explores the shielding properties of buildings exposed to aircraft noise by comparing sound levels near front and rear facades at two locations in the proximity of Amsterdam Schiphol Airport. The focus of the study lies on an experimental approach to measure the shielding capacity of airplanes as fast moving source passes, but primarily on how the urban environment might contribute to noise attenuation from air traffic. The paper therefore builds on studies about shielding effects of buildings seen from an architectural design perspective. In total three pilot studies 45 fly-overs were recorded by microphones in front and behind buildings. One pilot study focuses on ascending airplanes and two on landings. The shielding effect of the building was calculated by subtracting the OASPL (overall A-weighted sound pressure level) graphs of the microphones for the first four seconds of a stabilized sound peak evoked by the passing airplane. A spectral analysis for these time frames is added to study the shielding effects for octave bands between 31.5 and 4000 Hz. The results show that the two buildings have a mean shielding effect of around 11 dB(A) for landings and 14 dB(A) for ascending airplanes, when taking into account the moment sound levels peak at microphone due to a passing airplane. The results show a large variance between results of single flyovers, mainly at the octave bands between 31.5 and 4000 Hz. For instance, for landings the figures show a range between 0 and 7 dB for eight octave bands below 125 Hz while variance stretches between 8 and 14 dB above 125 Hz. For starts these results were respectively around 4 dB for octave bands below 125 Hz and ranges between 8 and 12 dB for bands between 125 and 4000 Hz.

Keywords: aircraft noise, buildings, urban planning, barriers, noise shielding, spectral analysis

1. INTRODUCTION

Aircraft noise is considered as a negative consequence of air traffic and affects communities around airports. Noise mitigation around airports traditionally focusses on muting the source, change operations to keep receivers at distance while establishing noise insulation programs for communities impeded (1-3).

There is growing scientific evidence that sound and perception are not subjective but relate to context and multisensory interplay (4-6). Research suggests that visual quality, supplementary sounds (e.g. water, bird song) or vegetation has an impact on sonic perception of places (4, 7-13). But also the relative difference between exposed (front) and quiet (rear) facades can influence annoyance ratings (14). Literature also show that dimensions of streets canyons have an influence on aircraft and helicopter noise (15, 16). In this light the urban environment can hypothetically provide means to reduce noise annoyance both technically and by thorough and considerate design of (public) space. The first question is however how effective the urban environment can reduce sound from fast moving sources overhead such as aircraft. For design and planning practitioners this may help to understand the effects of design decisions on sound dispersion around buildings. Therefore, from an architectural perspective it is of interest to develop more understanding of the *'urban aircraft acoustics'*. There seems a lack of studies studying the detailed urban ambient aircraft sound as typically noise contours do not make such distinction.

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This paper focuses on the shielding effects of buildings exposed to fast moving sources and is the first step of a PhD-research. The following steps were undertaken:

- Develop a framework for the measurement and analysis of barrier effects for fast moving sources (i.e. airplanes)
- Study the shielding effects of buildings exposed to noise from fast moving sources (i.e. airplanes)

This boils down to the following question forming the main research question of this paper:

Does orientation of facades towards aircraft lead to different sound pressure levels around buildings when exposed to noise from flying aircraft?

In the next chapter the paper first presents the framework for measuring and analysing aircraft noise as fast-moving sound single sources. Secondly, this paper presents results of three pilot studies formed by measurements at two locations near Amsterdam Schiphol Airport (AAS from now on). Finally, the results will be evaluated in the light of urban design and planning and future architectural research in this field.

2. METHOD

2.1 Measurement procedure and equipment

Data from field measurements was collected at two sites during two days. At day 1 (March 31th 2016) sound from 26 landing airplanes was recorded at both sites (11 at site B, 15 at site A), while at day 2 (April 1th 2016) sound by 19 ascending aircraft was recorded at site A only. Sound recorders were placed 1.5 metres in front of the facade oriented towards the flight route (called exposed facade from now on) and 1.5 metres away from the rear facade (called non-exposed facade from now on). For the first day a maximum of three microphones were used at site A and B and placed around the building as shown in Figure 1 and Figure 2 (i.e. for site B all three microphones were used while at site A only 1 and 3). The second day again three microphones were used at site A as shown in Figure 3. The microphones used were B&K type 4189-A-021 connected to a NI USB-4431 processing device placed, microphones were mounted 1.2 metres above the ground surface. At both locations noise emitted by car traffic can be heard, resulting in ambient noise from a nearby motorway for site A in particular.

Weather data for Schiphol airport reports an average temperature of 7.8°C, wind speed 3 - 4 Bft NE direction (38°) and relative humidity of 78% for 31 March, and average temperature of 8,2°C, wind speed 2-3 Bft SE direction (126°) and relative humidity of 68% for April 1th (17).

2.2 Measurement locations

Site A is situated nearby 700 metres horizontally from the flight path to the Kaagbaan, one of AAS's six runways. The five-storey-building focussed on is part of an office park and has a height of around 18 metres (18). Site B is located at a distance of approximately 300 metres horizontally to the dominant descending path towards the Aalsmeerbaan (see Figure 2). Similar to site A, the two-storey-building is located at a logistic park and has a height of around 8 metres. Both buildings have flat bitumen-covered roofs.

2.3 Flight paths and height

Average flight heights for landings at the point airplanes are orthogonally positioned to the first microphone (Figure 3) is between 50 and 100 metres for site A and B. For starts (only applicable to site A) the average altitude lays between 125 and 250 metres, based on open-source radar data published by AAS (19). The dates and times retrieved from these databases are those referred to in this paper (i.e. March 31th and April 1th 2016). This data provides rough estimations of flight paths and tracks, at the moment of writing a request to use detailed databases supervised by Air Traffic Control the Netherlands (LVNL from now on) is pending.

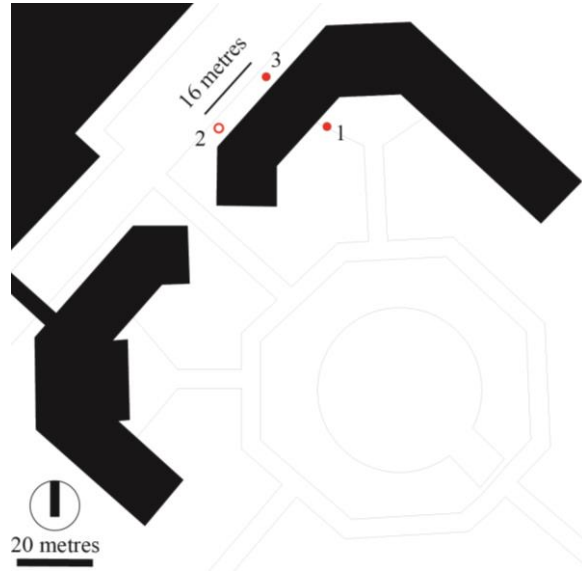


Figure 1 Aerial picture (google earth pro 2013) for site A (red box)

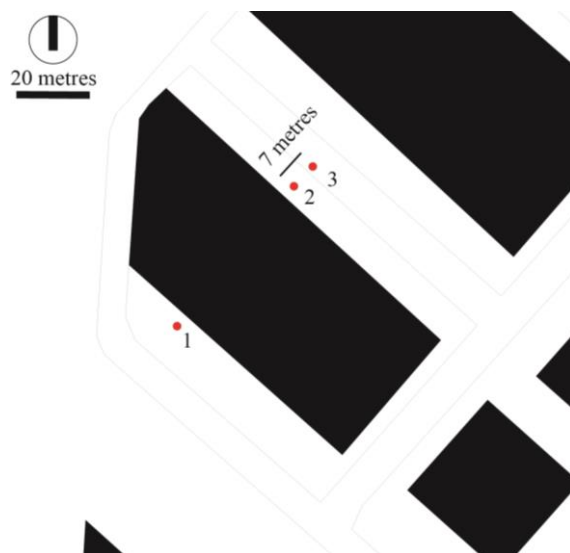


Figure 2 Aerial picture (google earth pro 2013) for site B (red box)

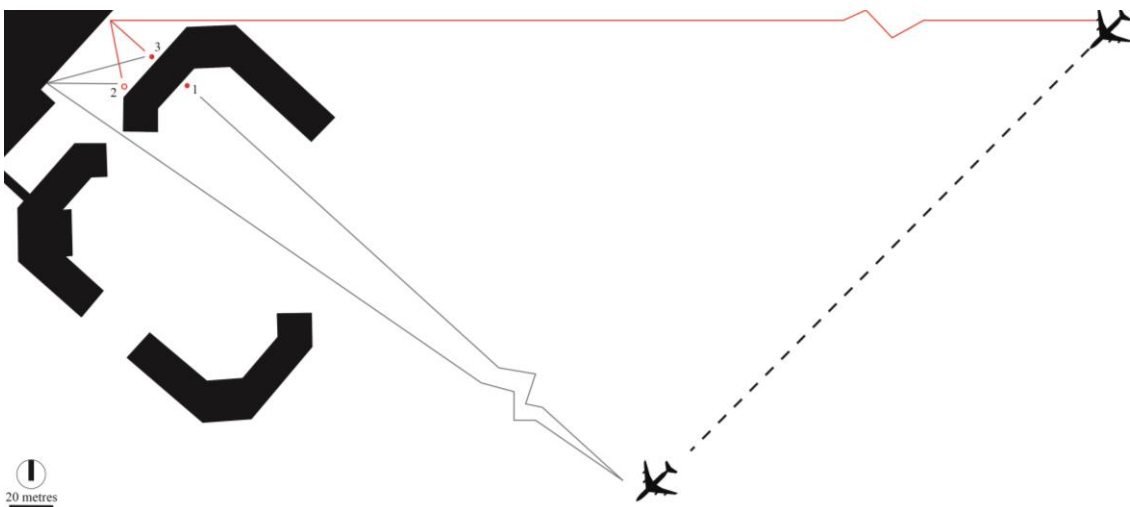


Figure 3 Diagrammatic snapshots of sound rays dispersion towards the microphones for two positions of an aircraft (horizontal difference between source and microphones are not drawn to scale).

2.4 Data processing

During the experiment local CET (central European time) was registered at the moment airplanes passed. Time registration will be used to link FANOMOS (Flight track and Aircraft Noise Monitoring System) EHAM (Amsterdam) radar data to trace height and aircraft type once access to this database is given. Data from the microphones was processed using in house NLR² MATLAB codes transferring records to OASPL³-, WAV files and spectrograms. A second NLR code, based on fft (fast fourier transform), was used to draw spectral diagrams (for octave bands between 31.5 and 4000 Hz) from the data sets. The WAV files enable to listen back in case of ambiguity about sound profiles displayed on graphs and spectrograms.

2.5 Data analysis of a-weighted maximum sound levels (OASPL diagrams)

First, sound levels during the first four seconds of the first sound peak at microphone 1 (non-exposed facade) were compared. The reason to follow this procedure is that microphones 2 and 3 are exposed similar to microphone 1 just prior or after the sound peak at microphone 1 (caused by the relative high speed of the source). In other words, the position of the source in relation to the building and microphones changes fast (because of the speed of aeroplanes), within seconds all microphones are exposed equally. Therefore the assumption is that the OASPL graphs only capture building's shielding capacity during the first peak registered at microphone 1. Moreover, interference and reflections between surrounding buildings may amplify or negate sound levels from place to place and thereby might obscure results. In order to evaluate the effect of the building it is therefore suggested as more effective to focus on the moment source and microphone 1 are positioned orthogonally (which is about the moment the sound level increases and stabilises, see Figure 4 and Figure 5). The average sound level (LAEQ) over these four seconds per microphone is subtracted from each other. This results in calculated difference of maximum a-weighted sound levels between microphones for each flight. The results are combined for each location and presented in whisker boxplots⁴.

2.6 Data analysis of spectral composition

Second, the results from the samples representing the four seconds of the peak at microphone 1 were analysed by looking at spectral composition for all microphones. Again, the differences between microphones were calculated over 4 seconds, but now per octave band. This provides more refined information about the shielding effects of buildings. As location A was also exposed to noise from the A4-motorway nearby, a spectral analysis for one sound sample (duration 30 seconds) without aircraft noise is also presented. In contrast to the other spectral analyses, the sample of the motorway is analysed by looking at differences per second (i.e. as there is only one file of 30 seconds, the sound fluctuations without the sample are compared).

3. Results

3.1 Differences around buildings (A-weighted maximum sound levels)

Figure 4 and Figure 5 show the results for the combined OASPL diagrams of microphones 1,2 and 3. The graphs highlight the frames in which the peak evoked by an aircraft flyover stabilizes. The average sound pressure levels for the four seconds lying within these boxes is calculated for all microphones and compared (i.e. subtracted). Figure 5 depicts how sound levels first increase behind the building due to noise ingress from aside (while microphone 1 is still shielded by a flank of the building) after which sound levels drop and again increase once the aircraft has passed the building. A similar pattern can be observed in Figure 4 as sound levels decrease at microphone 1 while remain peaking at microphone 2 and 3. This can be explained by the motion of the airplane and noise shielding from the building once the aircraft touches the runway. Figure 3 displays diagrammatic snapshots for two positions along the flight path illustrating sound (ray) dispersion between source and microphones.

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³ Diagrams displaying maximum a-weighted sound levels

⁴ Whisker boxplots presents the data in four quartiles, between the absolute minimum, maximum and the mean of a data set

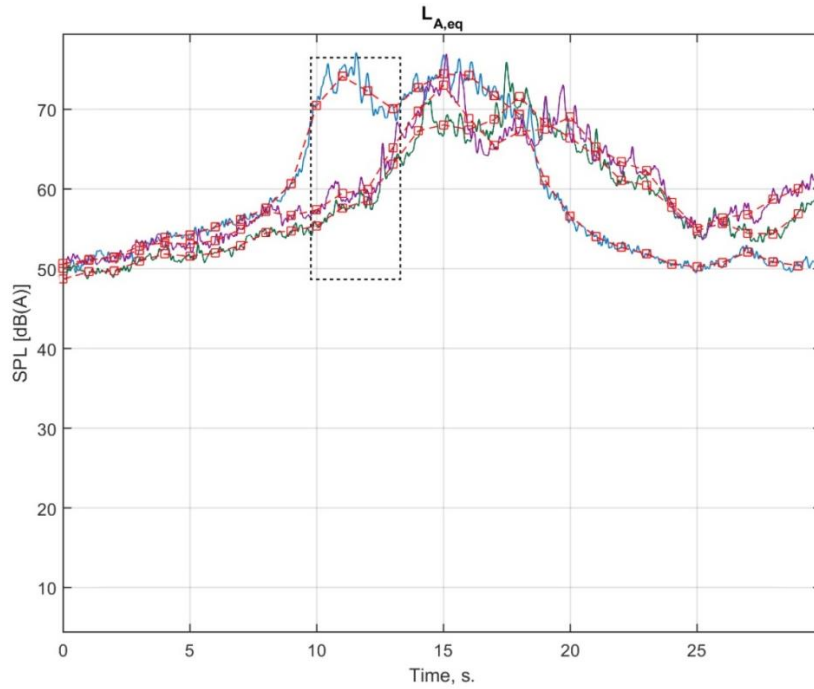


Figure 4 Results for airplane 1 around 18:03:23 at site B, blue: microphone 1, purple: microphone 2, green: microphone 3, dashed lines indicate the position of the first peak. Differences between microphones are based on LAEQ values calculated over the four seconds lying within the dashed frame.

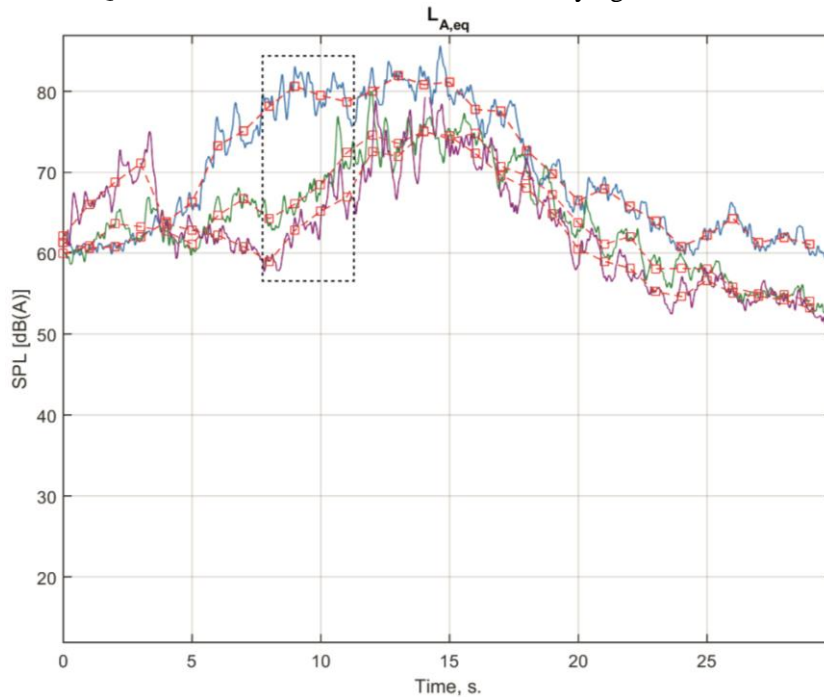


Figure 5 Results for airplane 12 around 14:12:35 at site A (April 1th), blue: microphone 1, purple: microphone 2, green: microphone 3, dashed lines indicate the position of the first peak. Differences between microphones are based on L_{AEQ} values calculated over the four seconds lying within the dashed frame.

	1	2	3	4	5	6	7	8	9	10	11
CET- sound file	18:03:23	18:05:53	18:07:53	18:10:53	18:24:03	18:25:03	18:27:03	18:29:33	18:32:03	18:35:33	18:43:52
Microphone 1	72	72	76	74	74	84	87	72	76	73	71
Microphone 3	62	67	65	62	69	71	78	64	67	62	66
Microphone 2	60	64	62	61	66	68	74	61	66	59	63
Δ Micr. 1 - 3	12	8	14	13	8	16	13	11	10	14	8
Δ Micr. 1 - 2	10	5	11	12	5	13	9	8	9	11	5
Δ Micr. 2 - 3	2	3	3	1	3	3	4	3	1	3	3

Table 1 Average results (dB(A)) during first peak at microphone 1 for landings crossing site B, March 31th 2016

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CET sound file	13:31:31	13:34:01	13:35:31	13:40:01	13:42:01	13:43:31	13:45:31	13:50:31	13:52:31	13:55:02	13:57:01	14:04:01	14:08:31	14:10:31	14:13:01
Mic. 1	62	59	64	61	62	63	66	64	72	63	65	65	64	64	68
Mic. 3	53	53	54	54	54	54	55	54	56	54	55	55	55	55	57
Δ Micr. 1- 3	9	6	10	7	8	9	11	10	16	9	10	10	9	9	11

Table 2 Average results (dB(A)) during first peak at microphone 1 for landings crossing site A, March 31th 2016

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
CET-sound file	13:48:05	13:49:35	13:51:05	13:55:35	13:57:35	13:59:35	14:04:35	14:06:05	14:07:35	14:10:05	14:11:05	14:12:35	14:13:35	14:23:03	14:25:03	14:30:33	14:32:33	14:34:03	14:35:33
Mic. 1	83	85	84	77	70	77	77	75	86	76	76	79	80	69	79	75	75	75	81
Mic. 2	72	75	74	66	59	65	67	65	75	66	66	68	71	59	66	65	63	65	72
Mic. 3	69	72	71	62	59	61	61	60	70	63	64	64	67	59	63	65	59	61	69
Δ Micr. 1- 3	14	13	13	15	11	16	16	15	16	13	12	15	13	10	16	10	16	14	12
Δ Micr. 1- 2	11	10	10	11	11	12	10	10	11	10	10	11	9	10	13	10	12	10	9
Δ Micr. 2- 3	3	3	3	4	0	4	6	5	5	3	2	4	4	0	3	0	4	4	3

Table 3 Average results (dB(A)) during first peak at microphone 1 for landings crossing site A, April 1th 2016

Table 1 shows the results at site B for landings. Based on these figures the average difference between microphone 1 and 3 (exposed versus non-exposed facade) is 12 dB(A) with a median of 13 dB(A). All values lay between 8 dB(A) and 16 dB(A) and most (6/11) between 11 dB(A) and 14 dB(A). The difference between microphone 1 and 2 (exposed facade versus the microphone placed halfway the street) is 9 dB(A) with a median of 10 dB(A). Here all values lay between 5 dB(A) and 14 dB(A) of which most (6/11) between 9 dB(A) and 12 dB(A). This suggests that although both position 2 and 3 are partly shielded by the building, the closer to the building the higher the effect.

Table 2 also presents results for landing aircraft but now for site A (and thus a higher building). In this case only two microphones were used, one 1.5 metres before the exposed facade and one 1.5 metres away from the non-exposed facade (1 and 3, Figure 1). The average difference between both facades is 10 dB(A) with a median of 10 dB(A). All values are between 6 dB(A) and 16 dB(A) of which the latter can be perceived as outlier as most results (12/15) lay between 8 and 11 dB(A).

Table 3, other than the previous two, presents results for ascending aircraft which means that average flight levels are much higher compared to descending airplanes. In this case three microphones were used of which one was placed near one the building's edges. The average difference between exposed and non-exposed facade (microphone 1 and 3) was 14 dB(A) with a median of 16 dB(A). All values lay between 12 and 16 dB(A) of which a vast majority (17/19) between 13 dB(A) and 16 dB(A). When looking at the difference between sound levels recorded near the edge and the directly exposed facade an average of 11 dB(A) was found with a median of 10 dB(A). Here all values lay in a bandwidth between 9 and 13 dB(A) of which most (16/19) between 10 dB(A) and 12 dB(A).

3.2 Differences around buildings per octave band

Figure 7 and Figure 8 illustrate that when looking at the composition of the sound spectrum the output is much wider spread than suggested in Table 1, Table 2 and Table 3. Moreover, generally speaking there is a difference between the results in the 31.5 Hz octave band and the others. Minima in Figure 7 are just lower than 0 (no difference) and only remain equal in the 31.5 and 63 octave bands, for the higher octave bands these outliers do not fall further than 4 or 5 dB. Figure 8 suggests negative outliers (up to -9 dB in the 63 dB octave band) in the first two spectral bands but suggest a similar trend as in Figure 7 for all bands beyond 125 Hz.

The sound spectrums per microphone displayed in Figure 6 shows that there is a difference between the exposed and non-exposed sides for all octave bands (except for 63 Hz in the first graph). Figure 7 confirms this trend, although Figure 8 depicts negative results for the first two octave bands. This suggests that sound levels are higher at the non-exposed sides compared to the directly exposed facade of the building. This can be explained by Figure 9 which shows that for a situation with only noise from the motorway at location A, there is a strong negative difference between microphone 1 and 3 for the first two octave bands. There is an adjacent facade (+- 8 meters) behind the building and microphone 2, and the distance between both facades is around 20 meters. Looking at the wave lengths of the first two octave bands, a similar phenomenon as described for low frequency noise near one of AAS's runways might lead to standing waves between these two buildings increasing sound levels near microphone 2 (20). As a wide variety of airplane types passed by, sound spectrums of single descending flyovers were probably not powerful enough to level out effects of road traffic in this part of the spectrum. This might also explain why this effect is vacant in Figure 7a for starts; normally the engines have a higher thrust leading to higher levels of mainly low frequency noise (21). The drop in the 63 Hz octave band in Figure 6b might be related to either impact of road traffic noise, but more likely, to the bespoke sound profile of the airplane- and engine type (i.e. as the figure concerns a landing procedure the engines have a lower thrust than during e.g. start procedures as showed in Figure 6a).

The figures suggest that shielding increases when the flight height goes up (based on Figure 7a seen against Figure 7b). Based on literature and the barrier model (22), the opposite would be expected. When looking at sound levels from landing aircraft and ambient sound levels, this (small) difference can be explained by the fact that the full shielding effect is obscured by ambient sound levels from other traffic modalities (at least near site A). It is therefore assumed that in fact shielding is higher when airplanes are flying lower but that the real shielding effect is not accurately captured due to other

sounds sources in the background.

The height of the building seems to have a negative effect on sound reduction for the 31.5 and 63 Hz octave bands as can be observed in Figure 7 and Figure 8. In both graphs it can be seen that site A scores significantly lower than site B for these bands. As said, this might be due to impeding effects of the motorway near location A leading to interference between two facades.

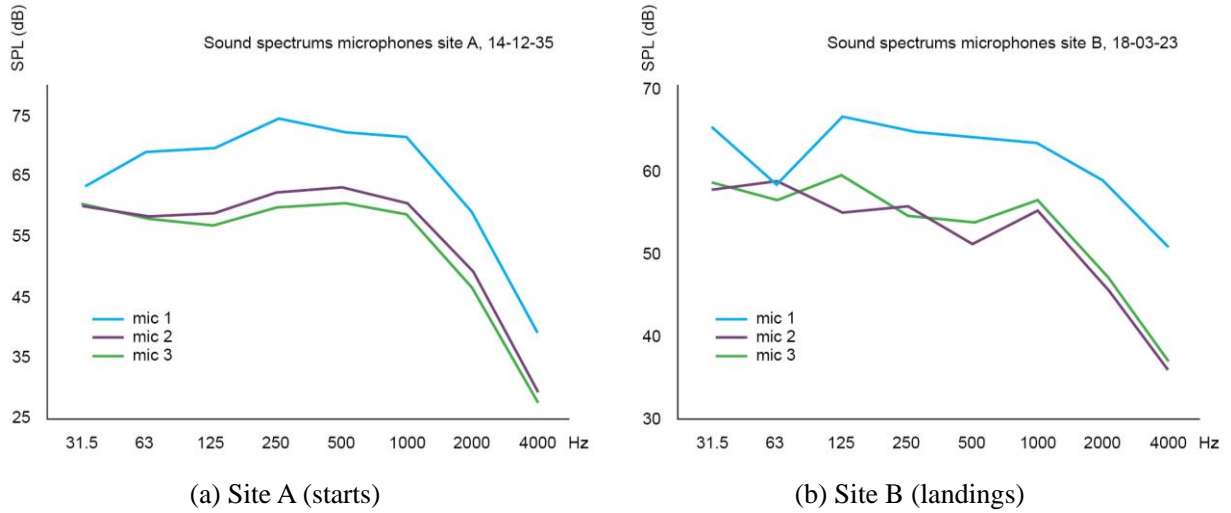


Figure 6 Sound spectrums for the flights displayed in Figure 4 and 5 over the four seconds representing the first peak at microphone 1

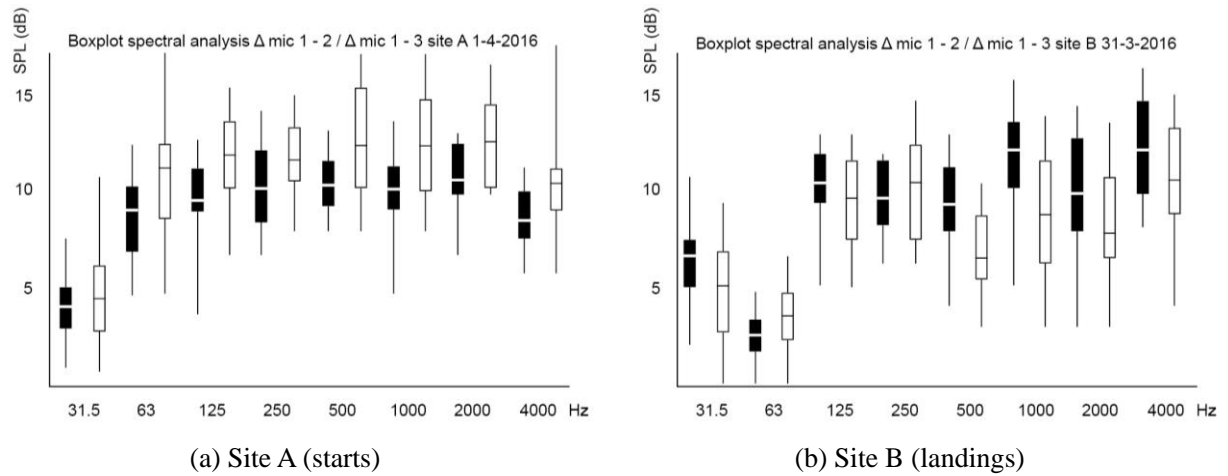


Figure 7 whisker-boxplots displaying differences between microphones 1-2 and 1-3 per octave band. The black boxes are the results for Δ mic. 1-2, the white boxes show the results for Δ mic. 1-3

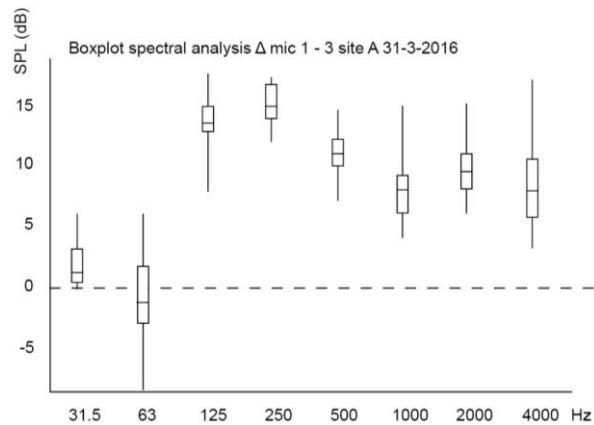


Figure 8 whisker-boxplot displaying differences between microphones 1-3 per octave band

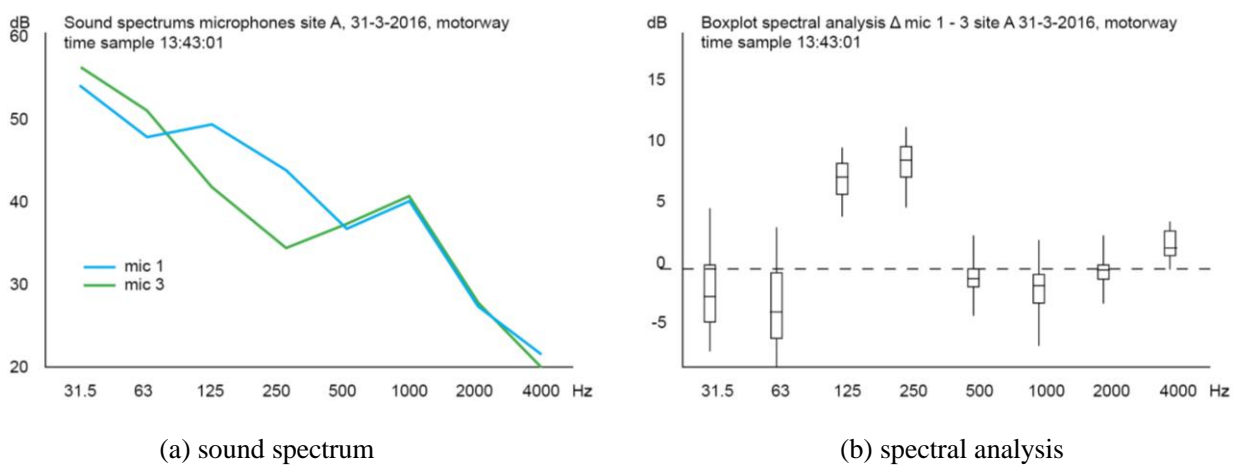


Figure 9 (a) Sound spectrums of sound sample noise motorway at 13-43-01 for mic 1 and 3, (b) whisker boxplot showing results of differences between mic 1 and 3 based on the results per second⁵

4. CONCLUSIONS

The data analysed in this study suggest orientation of facades, seen as the difference between exposed and non-exposed sides, clearly affects sound levels around buildings when exposed to aircraft noise. The biggest effects, with means around 14 dB(A), were found for situations in which the aircraft was ascending and flight height is higher than for landings. For landings, when aircraft have an estimated height between 50 and 100 metres when positioned orthogonally towards the first microphone, the mean difference between front and rear sides was around 10/12 dB(A). Data from landings also showed more distribution compared to starts and contained more outliers, either above or below the calculated means.

The results of the spectral analysis were more spread and show a difference between frequencies below and above 125 Hz (i.e. the 125 Hz octave band). In most cases, even for frequencies below 125 Hz orientation of facades results in sound reduction although significantly less than for mid- and high frequencies. The results suggest that noise from nearby motorways might lead to higher sound levels near shielded facades. These findings stresses that more research is needed to understand the interplay between sounds from different modalities, but also possible effects of interference between buildings when exposed to either fast-moving point or constant line sources.

The method deployed in these pilot studies suggest that shielding effects can be determined by

⁵ The duration of the sample was 30 seconds, for this analysis the results per second are analysed and presented in the graph

taking snapshots from larger sound samples. This implies that sound levels around buildings in the proximity of flight paths, when infinitely long and parallel to the flight track, can lead to differences as suggested in the pilot studies. The question is if this is correct. Reflections between, or diffraction over facades might slightly reduce shielding effects just after the time frames included in the snapshots, although effects of interference in canyons are probably low (because the source is moving). The same goes for effects of atmospheric turbulence and wind. However, the results strongly hint that buildings may have serious shielding properties for fast moving single sources, at least under calm climatic situations. The pilot studies therefore encourage further research on the interface of buildings and aircraft noise, either architecturally (e.g. shape and orientation) and methodologically (e.g. measuring / simulating fast moving sound sources). The aim is to continue the discussion about balancing both fields during Internoise this summer.

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