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# A SCALE MODEL APPROACH TO SIMULATE AIRCRAFT NOISE IN STREET CANYONS: A COMPARISON BETWEEN IN-SITU AND LABORATORY MEASUREMENTS

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## ABSTRACT

Previous studies showed that the design of the urban and architectural context affects local sound levels. Due to surface reflections and edge diffraction, sound levels are reduced or amplified, depending on building geometry and surface materials. Compared to other traffic sources in cities, aircraft noise is currently not integrated in (urban) sound prediction models, while the accuracy of models integrating aircraft noise is uncertain. To examine (aircraft) noise attenuation related to building design, a full-scale test-site for experiments was built in Amsterdam. In the experiment, sound and weather data is collected and used to identify the influence of building geometry and cladding on the propagation of aircraft noise. A subset of the measurements collected on days without wind was used to validate a method for measurements with scale models in an an-echoic room. Based on a series of discrete monopole source positions, three flight paths were simulated. Measurements in the anechoic room were compared with measurements in the full-scale field lab. This paper presents the results of the experiment and sets out a method for scale model experiments focusing on the prediction of sound in urban canyons for overhead sound sources at great distance from receivers.

**Keywords:** *aircraft noise, urban design, architecture, noise attenuation, scale models, in-situ measurements*

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## 1. INTRODUCTION

Aircraft noise is a major environmental stressor for people living near airports, leading to severe annoyance and stress-related health complaints[1]. To protect residents against severe noise levels, most countries prohibit developers from building in areas deemed too noisy, based on set threshold levels[2]. In the EU, the way the acoustic footprint of air traffic is calculated is standardized and defined by ECAC's doc.29. Like other calculation protocols, doc.29 combines tabulated footprints of individual flyovers during a specified period to compose Lden values for specific points on a grid[3]. The underlying assumption is that buildings and (small) vertical obstacles can be omitted, only including landscape morphology and (horizontal) surface materials. Previous studies have shown that the built context around a receiver can locally amplify or reduce airplane noise due to surface reflections, edge diffraction around objects, and absorption[4, 5]. A handful of studies have investigated the influence of building geometry on aircraft noise in street canyons[4, 6, 7]. In most cases (geometrical acoustical, GA from now on) computational models are used, with mixed results. GA models generally compute valid results for sound sources located close to a receiver, for wavelengths longer than the dimensions and properties of the obstacle or structure placed in the domain between a source and receiver[8]. Close to flight paths, aircraft noise is generally characterized by its rumbling sound. This is partially due to the great distance between source and receiver, which induces a greater absorption of mid and high frequency in the atmosphere. An alternative for computational models are scale models, in which sound levels are measured in a (semi-) controlled environment. Scale models do not compromise or approach the wave phenomena of the sound field itself, therefore rendering a realistic simulation of the interaction between sound waves and obstacles, at least in theory. Scale models are rarely used to simulate aircraft noise in streets, and only at close distance from the source, and dating back to the 1970s[9]. In general, it is uncertain if scale models provide a realistic impression of the behaviour of aircraft in urban settings, due to e.g. scaling factors, atmospheric effects, and speaker and microphone settings. This paper presents the preliminary results of measurements comparing sound levels in a real and simulated street canyon exposed to aircraft noise, using a 1:50 scale model, at a relatively far distance. The aim of the study was twofold, namely, to:

- Test a scale model method to predict local variances in sound levels inside street canyons exposed to noise emitted by airplanes flying at a great distance.
- Identify under which circumstances and for which geometries such a scale model approach can be used to compare urban design variants.

## 2. METHOD

### 2.1 Case description

For the study, data collected in two full scale mock-up streets was used. The mock-up streets are part of a field lab built near Amsterdam Schiphol airport in which the influence of building and street design on the propagation of aircraft noise is studied[5]. The field lab consists of three (on both ends enclosed) streets/ courtyards, each with a different geometry. The surroundings buildings are made from stacked shipping containers placed on concrete floor slabs. In total ten microphones are fixed to the facades, either facing towards or away from the nearby flight path. For the study presented in this article, data from eight microphones were used. The field lab is located near a flight path commonly used for departures in south-western direction.

### 2.2 In-situ measurements

#### *2.2.1 Setup*

Sound levels are recorded around the probes continuously, which are matched with radar data from the airport, and meteorological data from a weather mast at the airport, which is managed by the Dutch Met Office (KNMI). Based on various criteria, as discussed in [5], sound events which matches aircraft flyovers are cut from the dataset, and saved as separate flight peaks. Based on time stamps, the acoustic data is linked to the position of an airplane, giving the x,y,z-coordinates of the airplane per second.

#### *2.2.2 Equipment*

In the field lab, sound levels were measured by eight microphones, all placed near facades facing either towards, or away from, the nearest flight route. The position of the microphones is shown in Figure 1. The microphones are placed 20 centimetres away from the facades, each 1.5 meter above the ground surface, except for microphone 2 and 6 which sit each 3.9 meter above the ground surface. This height corresponds to the position of a window on first storey of a building. Class II microphones were used (NP2 series), provided by Munisense, equipped with a porous water repellent wind screen. Microphones are kept in thermoplastic waterproof boxes, and connected to the electricity grid. The microphones also have a built-in battery, which can provide electricity in case of power cuts. Acoustic data is stored as WAV files on a flash drive on site, and remotely on a cloud server through 4G. Sound pressure levels (SPL) in third octave bands are recorded every 0.125 seconds and uploaded on the cloud server. The acoustic data is matched with a time stamp, linked to a clock at the server.

#### *2.2.3 Analyses*

For the analysis of the in-situ measurements, only recordings at moments without wind (hourly wind speeds equal to 0 m/s) were selected for further analysis. This led to a subset of 32 flyovers which flew past the test site between November 2021 and March 2023. Each flyover contains information about the altitude (z) and geo-position (x,y) of the airplane at the moment the maximum sound pressure level was measured. Based on the distribution of the position and altitude of the 32 flyovers, three flights were taken from the subset, matching closest with the mean (M), first (Q1) and third (Q3) quartile positions (x,y) in the dataset. For these three benchmark flights, Figure 2 show the SPL for eight microphone positions. The graphs show a clear difference between the microphones placed near facades that face towards, and away from, the flight paths. For each flight, four random ‘stills’ were defined during the flight events, which position in seconds on the x-axes are marked with black dotted lines. The stills correspond to x,y,z, positions on the three flight paths, which were

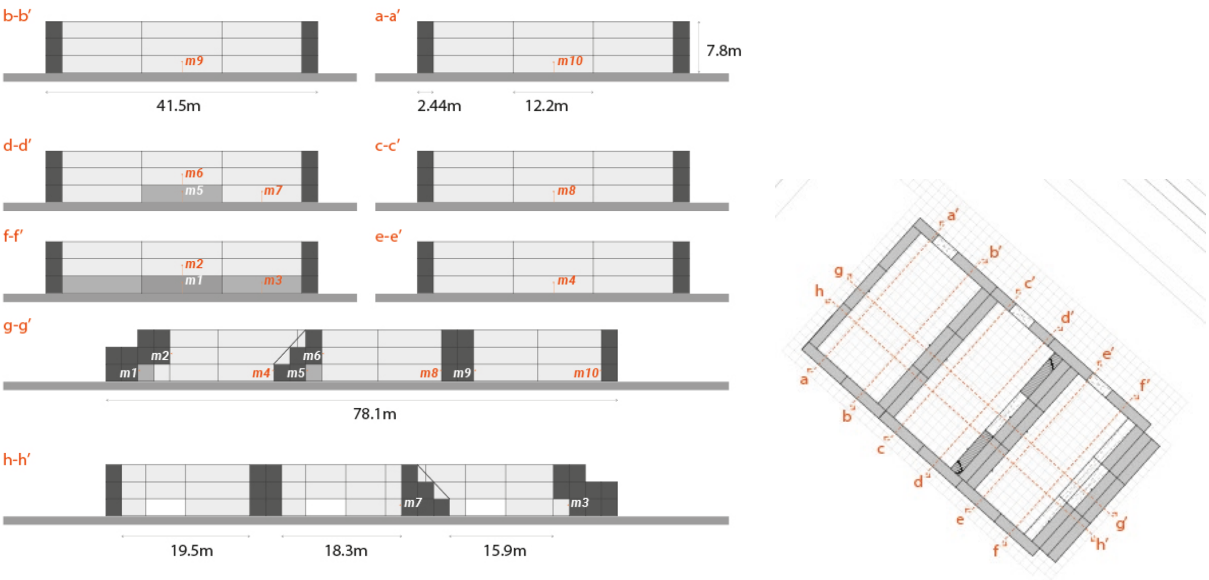


**Figure 1** (left) sections and (right) top view of the field lab near Amsterdam Schiphol Airport (the Netherlands), m = microphone. For this article only results for microphones 1-8 were used.

**Figure 4** Close-up of a model scale 1:50 for courtyard 2 and the microphone connected to a movable rail. system (top). Scale model and the anechoic room used for the experiments (bottom).

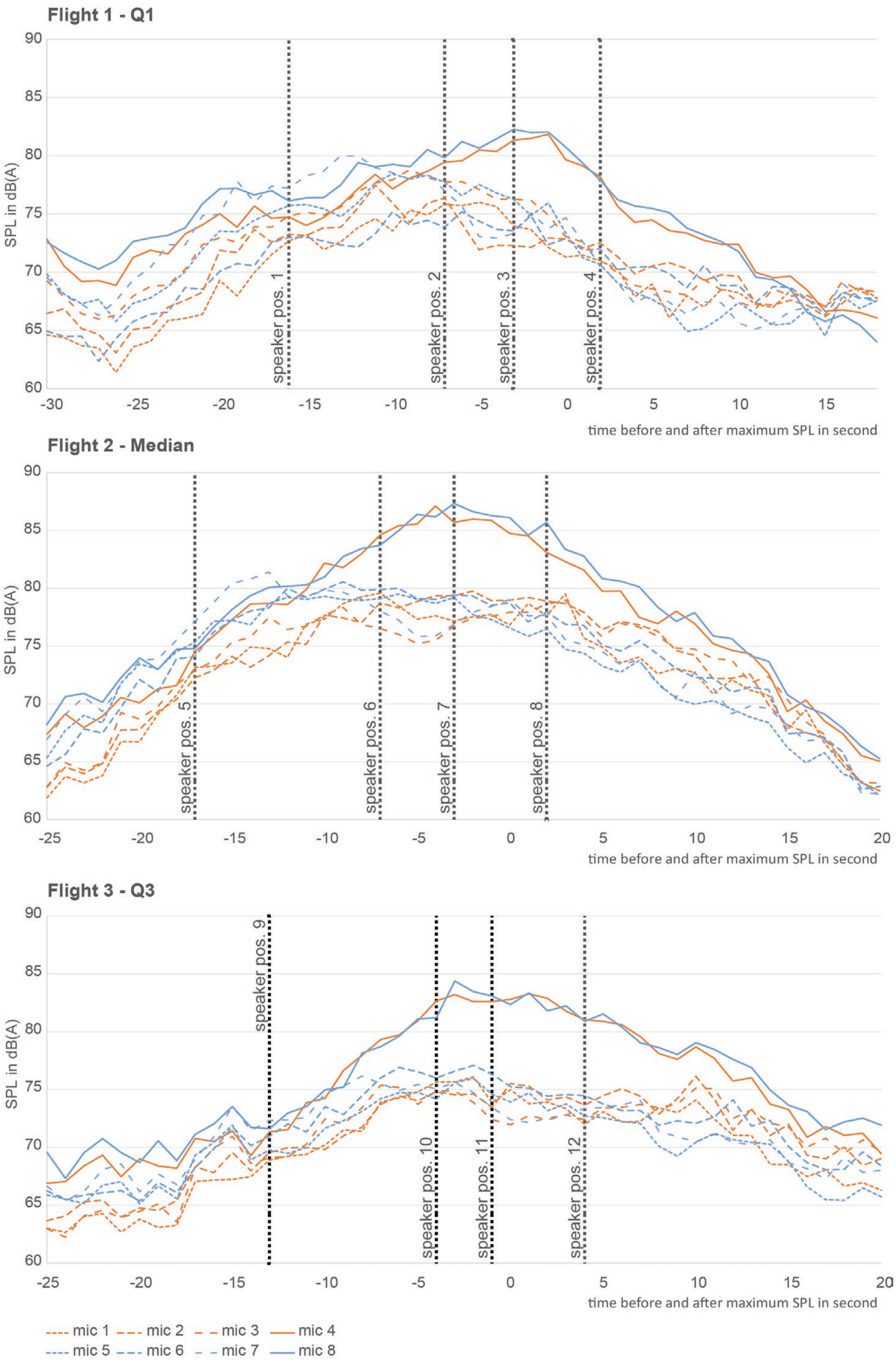


**Figure 2** Sound pressure levels for eight microphones and speaker positions / stills.

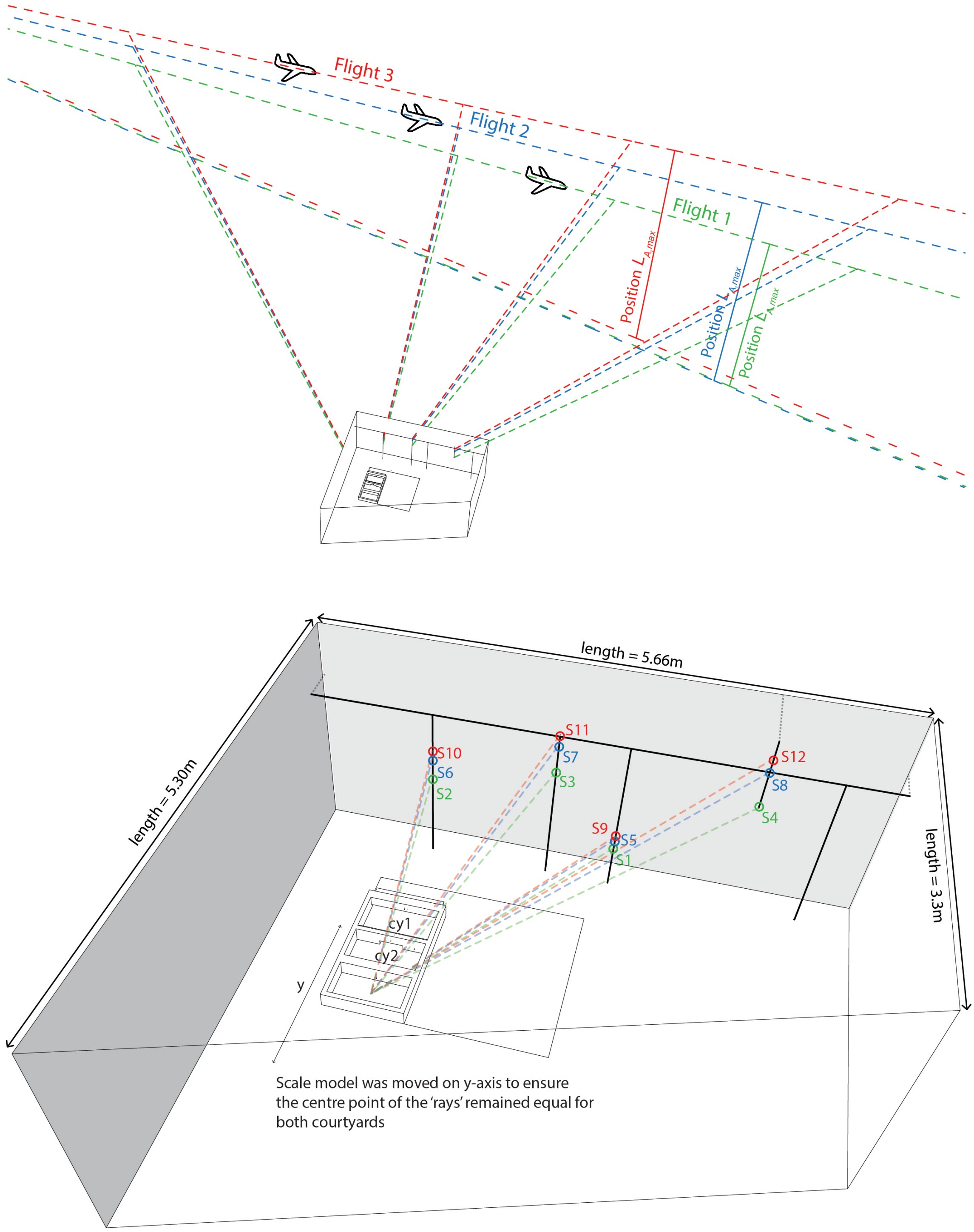


**Figure 3** (top) Flight paths relative to the field lab, the dotted lines are straight rays between the centre of the third courtyard and the x,y,z position of the stills in **Figure 2**. (bottom) Position of the speakers inside the anechoic room, cy = courtyard.

simulated as discrete speaker positions in a scale model experiment in an anechoic room, see Figure 3.

### 2.3 Scale model experiment

#### *2.3.1 Setup*

For the scale model experiment, a 1:50 model was built, made from MDF. The model was placed in an anechoic room cladded with noise absorbent material on the walls (Easyfoam Nop Premium, 5 centimetres thick), at the Applied Physics department at the technical university in Delft, the Netherlands (TU Delft), see Figure 4. Based on the coordinates of the 'stills', twelve speaker positions were defined. As the scaled positions of the airplane did not fit inside the room, the aircraft positions were moved on an imaginary straight line which was drawn between the centre of the scale model and the scaled position of the airplane, see Figure 3. To perform this step, the room, flight paths and scale model were simulated in a 3D model (SketchUp Pro 2022).

### 2.4 Equipment

In previous computational studies, airplane flyovers were modelled as either line or point sources. Aircraft noise is a composite of sound emitted by individual vibrating components and air columns. However, at great distance, the differences become less apparent, and the overall directivity of sound is more of less equally distributed in all directions[3]. For the experiment, the following equipment was used: a 1/4″ microphone, type 4136 592785 from Brüel & Kjær, two amplifiers for the microphone ARIZ77 No. 81.690267 and Brüel & Kjær type 2804, a Dell OptiPlex 790 computer with Matlab version R2011b, a noise source from Tymphany, type XT25SC90-04, an amplifier for the noise source, mono 60W type E60. The microphone was connected to a aluminium stick attached to a movable rail system. The rail system allows the microphone to move to a fixed position, which x,y,z coordinates are controlled by an interface on the computer. The frequency range of the combination of speaker and microphone lies between 12.5Hz – 40kHz, which corresponds to 25Hz-800Hz in a full-scale environment. However, as the range of the microphones in the field runs from 50Hz, only data between 50Hz-800Hz was analysed for this experiment. The directivity of the speaker depends on the frequency but remains equal across all frequencies for the normal of the speaker's front. To avoid speaker-induced differences across frequencies, the direction of the speaker was kept perpendicular to the midpoint of the scale model for all twelve speaker positions. This was done by placing the speaker in 3D-printed holders which were fixed on U-profiles.

#### *2.4.1 Analyses*

To exclude reflections from the room's ceiling and walls, the sound signal was first recorded and analysed in an empty chamber to determine first and second order reflections. Based on the results, it was decided to only use the first 0.02 seconds of the sweep signal for further analysis. To correct for Doppler, a post-processing script was written in MATLAB 2018b, based the sound signal for each microphone, and the position of the speaker and microphone relative to flight direction and speed. Data was also corrected for frequency dependent air absorption, based on (air) humidity, pressure, and temperature, which was recorded every hour during the experiments in the anechoic room.

### 2.5 Comparison protocol in-situ and scale model measurements

In an ideal setting, the sound power level, directivity, and energy distribution are identical across frequencies for 'real' and 'simulated' sources alike. This is unfortunately not feasible, partly because e.g. source power levels and pilot settings are unknown, and more generally, very difficult to obtain or measure. Despite these challenges, results collected under different conditions can still be compared, e.g. by focusing on the relative differences between microphones inside of courtyards. The level of agreement between the measurements in the anechoic room and field lab were determined by comparing the relative differences between the microphones in the courtyards. In this study, in both courtyards the microphones with a direct line of sight (LOS from now on) towards the flight paths were taken as the reference microphone, microphone 4 and 8 respectively.

$$dL_{field\ lab} = L_{mic\ n} - L_{ref\ mic} \quad \text{(eq. 1)}$$

$$dL_{anechoic\ room} = L_{mic\ n} - L_{ref\ mic} \quad \text{(eq. 2)}$$

$$dL_{courtyard\ n,\ mic\ n} = dL_{field\ lab} - dL_{anechoic\ room} \quad \text{(eq. 3)}$$

Results for each 'shielded' microphone were subtracted from the reference microphone, for each of the twelve speaker positions, following equations 1 and 2. Overall differences between measurements in the field lab and scale model were calculated based on equation 3. The procedure automatically means that the energy distribution across frequencies as for the 'real' and source is no longer

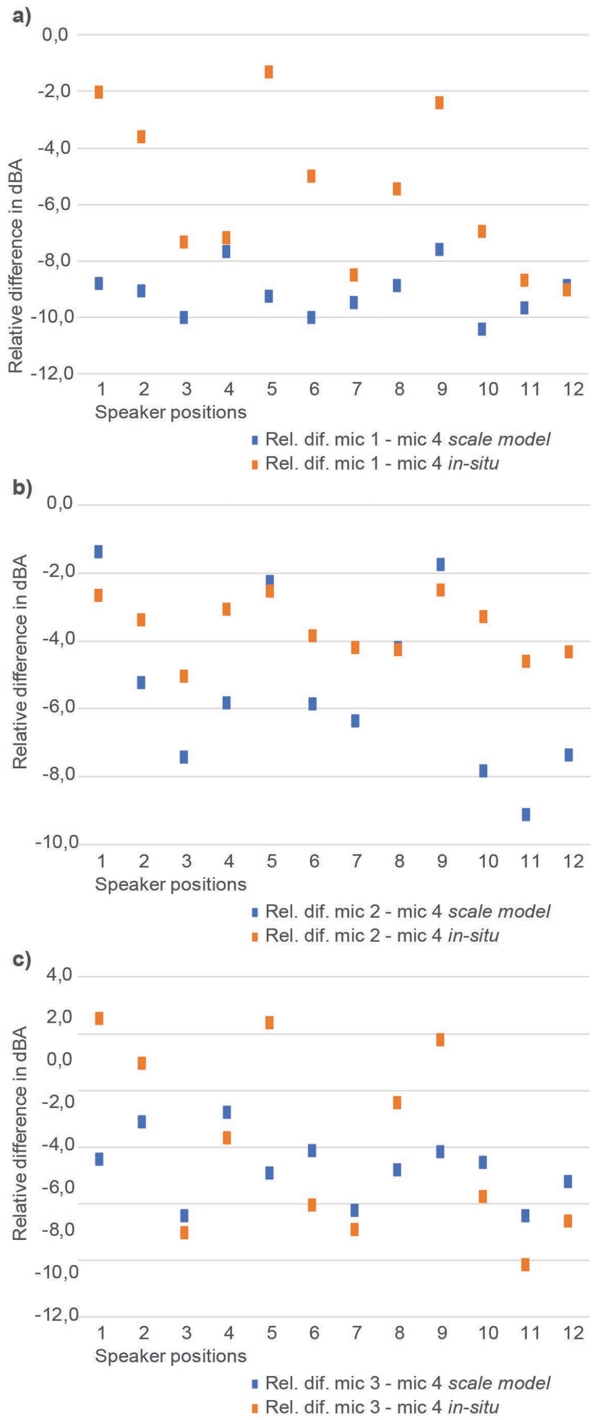


**Figure 5** Relative differences between exposed and shielded microphones for courtyard 1.

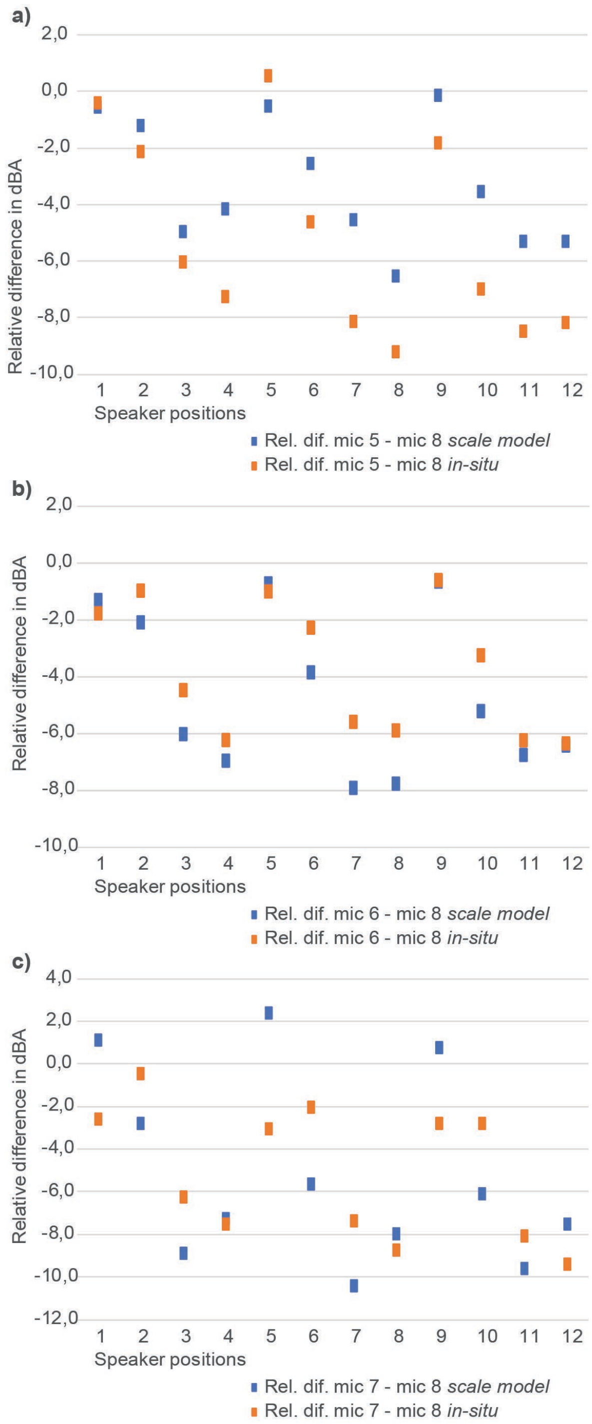


**Figure 6** Relative differences between exposed and shielded microphones for courtyard 2.

relevant, and a generic broadband source can be used for all simulations.

## 3. RESULTS

Figure 5 shows the relative differences between a) microphone 1 versus 4, b) microphone 2 versus 4, and c) microphone 3 versus 4, for both the in situ and scale model measurements in courtyard 1. Compared to in-situ measurements, differences between microphone 1 and 4, and microphone 2 and 4, were on average 4,2dBA ($\sigma$ = 2,6dBA) greater in the anechoic room. By comparison, differences between in situ measurements and the scale model were smaller for microphone 3 and 4, i.e. 1,9dBA ($\sigma$ = 1,9dBA) on average. Figure 6 shows the relative differences between a) microphone 5 versus 8, b) microphone 6 versus 8, and c) microphone 7 versus 8, for both the in situ and scale model measurements in courtyard 1. Compared to courtyard 1, measurements in the field lab and anechoic room show smaller differences for courtyard 2. On average, the sound levels for in-situ measurements are 0,5dBA ($\sigma$ = 1,9dBA) greater compared to the anechoic room, varying between 1,4dBA ($\sigma$ = 2,2dBA) for Figure 6.a, -0,6dBA ($\sigma$ = 2,3dBA) for Figure 6.b, and -0,6dBA ($\sigma$ = 2,3dBA) for Figure 6.c.

## 4. DISCUSSION AND CONCLUSIONS

In this article, preliminary results were presented for a study in which a method was tested to simulate sound in street canyons from airplanes flying at far distance, using a scale model.

A first observation is that for some microphones the relative differences are greater in the 'real' environment' while for others the opposite effect is visible. This means that the results cannot tell whether results from the scale model under- of overpredicts the relative difference between microphones compared to a 'real' environment. However, the observed ambiguity depends mostly on the variation in the in-situ measurements, which variance is much greater compared to data collected in the controlled setting of the anechoic room. Despite the fact that for this experiment only flights were selected without wind, cloud coverage and temperature gradients will likely refract incident sound waves, which could still lead to e.g. spectral broadening. This not only means that the sound waves' normal changes direction, but it could also affect the energy distribution across frequencies.

A second observation is that the level of agreement between measurements in 'real' and 'scaled' courtyards seem to depend on the geometry of the courtyards. For example, microphone 1 is furthest pushed back from the building line underneath a roof overhang. Results from measurements in the anechoic room show that the speaker position has no clear effect on the relative shielding for this microphone (see Figure 5.a). In the anechoic room, the microphone is fixed on a moveable stick, which also partially shields the microphone itself. For most microphones in the scale model, the variance in sound levels related to speaker positions follows a similar trend as those in the 'real' environment. This is best illustrated for microphone positions with 'space' around the probes, especially those in courtyard 2. This means that the method can be used to compare how individual building shapes influence aircraft noise in streets.

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