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INFLUENCE OF BUILDINGS, FORESTS AND CLIFFS ON AIRCRAFT NOISE EXPOSURE MAPPING - A CASE STUDY

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ABSTRACT

Best practice calculation tools for aircraft noise are currently used for strategic noise mapping and to estimate the noise impact on the population as well as the compliance with legal limit values. A challenging task for these tools is the accurate modelling of sound propagation in complex surroundings such as mountains or densely built-up areas. To date, neither shielding by buildings nor reflections by buildings, forests or cliffs are considered in noise mapping, although they can locally affect the computed sound exposure. In a case study, we investigated a built area in the close vicinity of the runway of the Meiringen military airbase in Switzerland, which is located in a mountain valley with steep cliffs. Aircraft noise simulations, accounting for reflections and shielding by buildings as well as echo by forest and cliffs, were performed with the simulation tool sonAIR and compared with measurements. On this basis, specific situations were identified, where these additional sound propagation effects become relevant. While such refined calculations may yield valuable insights in special situations, it is still recommended to perform standard noise mapping without accounting for these effects.

Keywords: *Noise mapping, sound propagation modelling, aircraft noise, sonAIR*

1. INTRODUCTION

Aircraft noise covers large areas around airfields and airports and is therefore usually determined by means of large-scale grid calculations. Noise contours are then derived from the grid calculations by interpolation. If a building or an area is located within a noise contour that represents the exposure limit value according to relevant legislation, the exposure limit value is considered to be exceeded. Currently, neither shielding from buildings nor reflections from buildings or forest or cliffs are included in such simulations. However, in the case of buildings in the immediate vicinity of a runway of an airport or airfield, shielding of the buildings may strongly reduce the sound exposure on the building side aiming away from the runway, among other effects. The question arises in what situations such effects should be accounted for in simulations.

To shed light on this question, noise mapping using different sound propagation modules of the aircraft noise simulation tool sonAIR are done. The simulations are effectuated in an area close to the runway of the Meiringen military airbase in Switzerland, which is located in a pronounced valley. This allows investigating different sound propagation phenomena, namely, shielding from buildings and reflections from buildings, cliffs and forest. Each sound propagation module is compared individually with the others to get a better understanding of their contribution to the total sound exposure of the area.

2. METHOD

2.1 The simulation tool sonAIR

sonAIR is a scientific tool, namely, a semi-emprical spectral (one-third octave bands within a frequency range of 25

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Hz to 5 kHz) time step aircraft noise calculation program with three-dimensional (longitudinal and lateral) sound emission models [1, 2]. Other notable scientific tools include ANOPP2 [3] or PANAM [4]. These models differ from sonAIR by modelling each sound source (fan blades, spoilers, slats,...) separately. This detailed source descriptions come at the price of requiring very accurate and detailed, but often unavailable input information.

Detailed sound emission models are available in sonAIR for airliners, including separate emission models for engine and airframe noise. The separation of the two models is achieved by a multiple regression approach. In the present case however, the modelling approach is simplified. The F/A-18 Hornet, which is the main aircraft of interest in this study (see section 2.3), is characterized by means of procedural models, which describe the three-dimensional directivity for three defined flight procedures, which are take-off with 100 % power setting, take-off with afterburner, and landing. A simplified modelling approach was chosen for the F/A-18 Hornet due to the lack of flight deck recorder (FDR) data for this jet fighter.

Propagation attenuation is calculated separately from emission with the physically based model sonX (see next section 2.2). Prior to the sound propagation calculation, the Doppler shift is first applied to the moving source directly, affecting the sound emission spectra. The flight effect is then computed according to [5], accounting for the kinematic effect due to the motion of the sound source relative to the propagation medium [6]. The propagation time from source to receiver is calculated using a temperature stratification. Finally, A-weighted levels are calculated at the receiver positions for each time step to derive level-time histories. On that basis A-weighted maximum sound pressure levels $L_{AS,max}$ are derived for each flight and receiver point, along with spectral as well as A-weighted sound exposure level L_{AE}.

2.2 The propagation attenuation model sonX

The propagation calculation was done with the sonX model [7] to establish a sound attenuation database (details see [2]). This model is formulated for point sources. Depending on the scope of the calculation, different sonX modules may be chosen separately or combined, namely:

- BASIC: Direct sound propagation including geometrical divergence, air absorption in a defined (standard) atmosphere, foliage attenuation, ground effect and shielding effect of terrain and/or buildings
- REFLECT: Additional contributions by scattering and coherent reflections at artificial structures such as buildings and noise barriers
- FOREST: Additional contributions by diffuse reflections at forests and cliffs
- METEO: Refinement of BASIC, accounting for meteorological effects, i.e., the influence of a vertically stratified atmosphere on air absorption and barrier effects including acoustical shadow zones. Meteo is not used here and not further discussed.

The module BASIC accounts for all the requirements given by the guideline for official aircraft noise calculations in Switzerland [8]. Atmospheric absorption is calculated according to ISO 9613-1 [9], ground reflections use an analytical solution for spherical waves, and barrier effects are taken into account using a solution based on Maekawa [10].

The model REFLECT for reflections is based on two analytical solutions of the reflection problem, one for coherent reflections and one for scattering (used here) [11]. To increase performance, REFLECT is implemented in a simplified way. Instead of calculating diffraction, only a visibility check is performed. Energy exchanges up to the third order are taken into account by considering reflections between sources and reflectors, reflectors between each other and reflectors and receptor. In addition, the terrain is assumed to be fully reflecting and it is also used in the determination of the visibility checks.

The FOREST reflection model [12] relies on the idea that the reflection of an individual tree can be represented by two reflections, namely, one at the trunk and one at the crown. The reflection of an entire forest is then modeled as the superposition of the contributions of a set of representative trees per area.

In terms of computational time, the different modules have a strong impact on the overall computational cost of a simulation. In the case of the present simulations and using a standard workstation (Intel Core i7 and 32 GB RAM), the propagation calculation of a single flight takes a few minutes when using only the BASIC module with or without buildings. When building reflections are added, this time increases by about 10-20 minutes. Finally, when the FOREST module is added, the calculation time is about two hours with the settings used in this project.

2.3 Calculation scenario

In the present study, the calculation of the aircraft noise impact of propeller-driven aircraft (propeller-driven aircraft and helicopters) is omitted, since their contribution to the total annual calculation of the military airbase considered here is negligible, as previous calculations confirmed. Thus only the noise generated from the fighter jet aircraft are taken into account. The two jet fighter aircraft currently operated in Switzerland are the F/A-18 Hornet and F-5 Tiger. As no sonAIR model of the F-5 Tiger exists since it is soon to be withdrawn from active duty, it is simulated using the F/A-18 Hornet as proxy. To account for the different noise emission levels, the number of movement is adjusted accordingly (methodological approach proposed by ECAC Doc 29 Vol.1 in section 6.4 [13]).

2.4 The metric of interest: rating sound level Lr

To assess the effect of the different sound propagation modules, the so-called rating sound level Lr according to the Swiss Noise Abatement Ordinance NAO [14] is used. It corresponds to the A-weighted equivalent continuous sound pressure level L_{Aeq}, representing the annual air operations for jet fighter aircraft within a reference daytime period of 12 hours, to which different corrections are applied: First, the L_{Aeq} is extrapolated to the average peak operation (six busiest months), and second, the Lr is obtained after application of two level corrections, one if yearly air operations exceed 15'000 (not applicable here) and another set to -8 dB for military aviation (for details see [14]). In the Results section, where differences between the calculation modules are discussed, the level corrections, which are the same for all modules, cancel each other out, so that the differences correspond to differences in the L_{Aeq}.

3. RESULTS

Figure 1 shows the study area (or calculation area) used for this study, along with the runway to the north and an exemplary trajectory of an F/A-18 departure towards west on runway 28. The area was selected because it is close to the runway, so that strong effects of buildings on the annual noise exposure are expected. In other areas, for example where the aircraft are already high in the air and/or which are directly overflown by the aircraft, much smaller effects will occur.

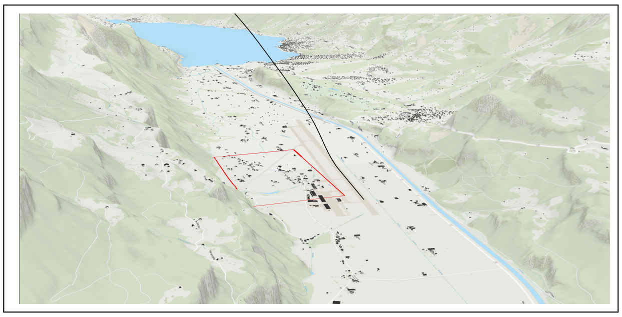

Figure 1. Calculation area (red square) next to the runway of the military airbase Meiringen, which is located in the middle of a valley, with steep cliffs rising directly to the north and south of it. In black, an exemplary F/A-18 Hornet departure trajectory is shown. Map: © OpenStreet Map contributors, and the GIS User Community.

The differences in the annual rating sound level Lr depending on the applied sonX modules revealed that the barrier effect of buildings has the most pronounced (reducing) effect on the calculated noise exposure. This results in large-scale level reductions of more than 2 dB, and up to 12 dB directly on the building facades averted from the runway. Building reflections on facades, in contrast, only increase the Lr locally, close to the facades, by up to 3-4 dB on the buildings' sides facing the runway. The effect would be particularly pronounced in shielded situations without direct sound incidence, where reflections strongly increase the low sound exposure level. In the present case, however, with relatively low buildings and less dense development, this effect is rather weak. These findings agree well with exemplary first calculations of Empa for single flights in [15] and prove the transferability to annual operation scenarios.

Similarly to building reflections, forest and rock reflections only affect the Lr locally, again especially in shielded areas and close to the reflectors (rocks, forest) situated in the southern part of the noise map, and thus only have a limited effect on the noise levels.

Figure 2 summarizes the before-mentioned integral differences by showing the difference in Lr between the simulation with all sonX modules combined (i.e., shielding and reflections from buildings, reflections from forests and cliffs) and only the BASIC one (no buildings; no reflections from forests and cliffs). Shielding by buildings has clearly the strongest reducing effect on the Lr (wide areas coloured in blue). Lr increases due to building reflections, as can be seen in front of buildings close to the runway especially (limited red areas). Finally, Lr increases due to forest and cliff reflections, with the latter being relatively close to the south-east of the study area.

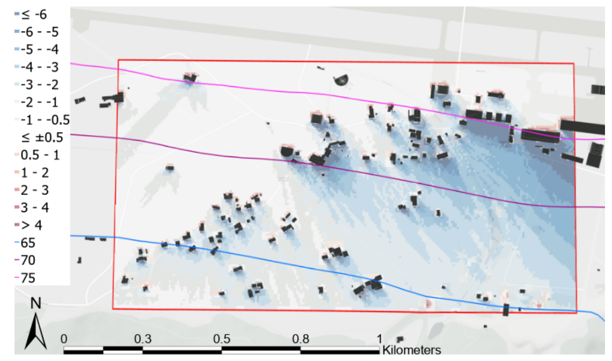

Figure 2. Difference in Lr between the simulation accounting for reflections and shielding by buildings and reflections by forests and cliffs, and the BASIC module without these effects. For orientation of the absolute Lr, relevant contours according to Swiss legislation (60, 65, 70 dB [14]) are shown. Map: © OpenStreet Map contributors, and the GIS User Community.

The dominant level reduction due to shielding from buildings for exposure classes with $Lr < 74$ dB becomes also obvious in the statistical evaluation of the level differences depicted in Figure 3 as boxplots per level class for all receiver points of the calculation area in Figure 2. For high noise exposure classes ($Lr > 74$ dB), the differences between the calculations (and thus the effect of the shielding/reflection modules on noise exposure) are negligible, since this area is located close to or on the airport site, which is flat and free from buildings. Direct sound propagation dominates there; the small level increases are caused by building reflections.

4. DISCUSSION

In this study, the influence of reflections and shielding by buildings, and of reflections from forest and cliffs on the resulting noise exposure was quantified for the first time for a larger area and for annual air operation (rating sound level Lr), at the example of a jet fighter aircraft on a military airfield in a mountain area in Switzerland. The results show that the aircraft noise exposure calculations with sonAIR accounting for the above effects provide meaningful results and are applicable for noise mapping.

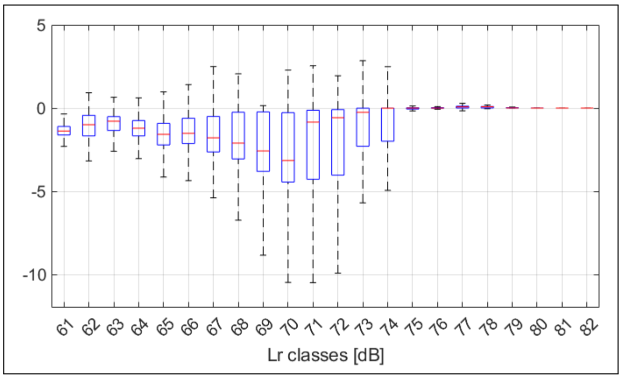

Figure 3. Boxplots of the differences in Lr between the simulation accounting for reflections and shielding by buildings and reflections by forests and cliffs, and the BASIC module without these effects.

Although buildings and terrain can strongly affect the noise exposure locally, their consideration for noise mapping purposes is questionable. First, and in particular, the consideration of buildings results in highly variable (i.e., non-smooth) noise contours, which is rather unsuitable for noise mapping to obtain an overview on the exposure situation. Second, the present findings apply to a situation in a mountain region with a valley with steep flanks. For less extreme situations, the contribution of reflections from forests and cliffs to the noise exposure will usually be negligible. Third, the findings apply to an area directly adjacent to a runway, where building effects are particularly pronounced. In areas further away from airfields or airports and especially under air routes, the studied building, forest and cliff effects are negligible for annual noise exposure. And finally, the calculations were carried out in a very small area compared to calculations covering the whole exposure range defined by legal noise exposure limits. With the currently available computational power, it is hardly possible to account for the building, forest and cliff effects for large-scale mapping purposes with justifiable effort. In conclusion, the FOREST and REFLECT modules provide important information and insights for the investigation of specific questions restricted to limited areas. For large-scale noise mapping, however, this level of detail in the calculation is not recommended.

5. ACKNOWLEDGMENTS

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