Aircraft noise calculations for relevant periods of day using a complete set of radar data

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Introduction

Aircraft noise contours are usually determined with model calculations. As the noise contours have important consequences for land use planning and payments of compensation, the model calculations need to be highly accurate.

Where available, the aircraft noise simulation program FLULA2 developed at Empa [1, 2] uses the radar data provided by the airports for the definition of flight paths. In the standard way of operation, a subset of flight paths is randomly selected out of all available radar data of one year. This selection ignores the time of day the corresponding flights took place. However, flight geometries may strongly fluctuate over the 24 h of a day, e.g. because heavy airplanes usually start at the beginning of the night for intercontinental flights. The hypothesis of this study was that taking into account the changes in flight geometries over the 24 h of a day as determined from one year’s radar dataset enhances the accuracy of the model results. To test this hypothesis, FLULA2 was extended to perform separate calculations for relevant periods of day, using all available flight paths of one year. Exemplarily for Zurich Airport, Switzerland, in the year 2006, modelling results of this new approach were compared with results of the standard FLULA2 approach.

Materials and Methods

The FLULA2 simulation program

Details on the model may be found in [1, 2]. In short, FLULA2 considers (i) the topography, (ii) the statistics of movements per aircraft type, air route and period of day, (iii) the sound directivity patterns of individual aircraft, and (iv) the flight paths, determined from radar data where possible. Based on these input data, FLULA2 calculates the aircraft noise for receiver locations at specified points of a grid. At the final stage of the calculations, noise contours are estimated from the grid-points. Aircraft noise is calculated for relevant periods of day, i.e. for time intervals within the 24 h of a day, as defined e.g. by legislation.

There are several ways to account for the vertical and horizontal dispersion of flight paths for a given aircraft type and air route. One common approach is to reduce the radar data to a main and a few side tracks and a mean flight profile to calculate the aircraft noise. In contrast, FLULA2 considers the dispersion by calculating the aircraft noise from a set of single flights defined by radar data where possible. In the standard way of operation, FLULA2 randomly selects a sample of up to 100 flight paths per aircraft type and air route, irrespective of the time of day the corresponding flights occurred. For each of these flights, FLULA2 calculates the sound exposure level ($L_{AE}$). All resulting $L_{AE}$ from the single flights are then energetically averaged and scaled to one movement. The resulting specific $L_{AE}$ (i.e. per aircraft type and air route) are denoted as ‘footprints’ in the following, and their determination as ‘footprint-calculation’. The footprints obtained with the standard way of operation represent the yearly average of the $L_{AE}$ over the 24 h of a day. The footprints are weighted with the statistics of movements, separately for relevant periods of day, and energetically summed up to obtain time-of-day-specific noise contours. Thus, operational fluctuations over the 24 h of a day on a yearly average are considered by means of weighting the footprints. This standard way of operation is denoted as ‘statistical choice calculation (SCC)’.

In this study, we extended the model as follows. Firstly, separate footprint-calculations are performed for relevant periods of day. Secondly, all available flight paths of one year’s flight operation are used in the footprint-calculations, i.e. by selecting all flight paths belonging to the respective period of day. As a result, one obtains time-of-day-specific footprints for every simulated period of day. As radar data of only ~95% of all flights are usually available, the footprints are still scaled to one movement. As for SCC, the footprints are weighted and summed up to obtain time-of-day-specific noise contours. Thus, average operational changes over the 24 h of a day are considered in the footprint-calculations (time-of-day-specific flight geometries) as well as by means of weighting the footprints. This extended approach is denoted as ‘complete time-of-day-specific calculation (CTC)’.

The question to answer is: Are there differences between CTC and SCC? That is, are there differences in the dispersion of flight paths between different periods of day, which may have e.g. an influence on specific noise contours at night?

Simulated scenario

Exemplarily for the year 2006, we determined the noise contours around Zurich Airport with SCC (~27000 flights used in the footprint-calculations) and CTC (~235000 flights). For SCC, one footprint-calculation was performed (see above), while for CTC, separate footprint-calculations were performed for the four periods of day according to Swiss legislation (Noise Abatement Ordinance, NAO [3]), namely day ($d$, 06–22 h), and first ($n_1$, 22–23 h), second ($n_2$, 23–06 h), and third ($n_3$, 06–22 h) period of day.
23–24 h) and last hour of the night (n3, 05–06 h). There is a flight ban from 00–05 h. Calculations were done for large aircraft (>8'618 kg according to NAO [3]).

Based on the footprints obtained by CTC and SCC, the sound rating levels ($L_{r}$) were calculated as prescribed by NAO [3]. Here, we present the following $L_{r}$:

- $L_{r_{d}}$: Noise of the traffic of large aircraft for $d$, corresponding to the A-weighted equivalent-continuous sound pressure level ($L_{Aeq}$) from 06–22 h on a yearly average.
- $L_{r_{n1}}$: Noise of the traffic of large aircraft for $n1$, corresponding to the $L_{Aeq}$ from 22–23 h on a yearly average.
- $L_{r_{n2}}$: Noise of the traffic of large aircraft for $n2$, corresponding to the $L_{Aeq}$ from 23–24 h on a yearly average.

**Comparisons of the modelling approaches**

**Flight paths**

We compared the flight paths used for the footprint-calculations with CTC and SCC exemplarily for the starts of Avro RJ100 on a selected air route. We present the flight paths as flight tracks, i.e. as projections to the horizontal plane.

All other input data (topography, statistics of movements, and sound directivity patterns) are identical for CTC and SCC, and are therefore not discussed in the following.

**Noise contours**

We compared the sound rating levels $L_{r_{d}}$, $L_{r_{n1}}$, and $L_{r_{n2}}$ obtained by CTC and SCC cartographically, qualitatively by overlapping the noise contours as well as quantitatively as differences in the $L_{r}$.

In addition, we calculated the mean differences in $L_{r_{d}}$, $L_{r_{n1}}$, and $L_{r_{n2}}$ between CTC and SCC at grid points as a function of the sound level in steps of 1 dB (i.e. for classes of 1 dB width). The results correspond to the mean differences between CTC and SCC at grid points in areas exposed to the respective sound levels.

**Areas and persons above exposure limits**

Based on the sound rating levels $L_{r}$ obtained by CTC and SCC, we determined the size of the areas and the number of persons living in areas above the exposure limits according to NAO [3], i.e. where planning values, impact thresholds and alarm values are exceeded. Calculations were done separately for the relevant individual $L_{r}$ according to NAO (see [3] for details) as well as for the envelopes, i.e. the set union of these $L_{r}$. Here we present the results of the envelopes only, as they quantify the relevant legal consequences.

The population numbers around the airport used for the calculations are based on the census of the year 2000. (Note that using these population numbers allowed for a realistic estimation of consequences of aircraft noise. However, the results do not have any legal meaning. For the latter purpose, data of the year 2006 would have been necessary.)

**Comparison with monitoring data**

Finally, we compared the resulting time-of-day-specific $L_{Aeq}$ (i.e. $L_{r_{d}}$, $L_{r_{n1}}$ and $L_{r_{n2}}$) obtained by CTC and SCC with monitoring data measured by several monitoring stations in the vicinity of the airport to determine which method represents measurements more precisely.

**Results**

**Flight paths**

![Figure 1: Flight paths of the starts of Avro RJ100 on air route N32 of Zurich Airport (presented as flight tracks) used for CTC (1 footprint-calculation per period of day, choice of all available flight paths) and SCC (1 footprint-calculation for the 24 h of a day, statistical choice of flight paths), and resulting footprints ($L_{Aeq}$, scaled to one movement) (inlet figure) for the day ($d$, 06–22 h, top) and the second hour of the night ($n2$, 23–24 h, bottom).](image)

As Figure 1 exemplarily shows for starts of Avro RJ100 during $d$, the random selection of flight paths with SCC adequately represents the horizontal dispersion of the flight paths of the day, and the resulting footprints of CTC and SCC are very similar. The same holds true for those hours of the night where the flight geometries are similar to those of the day. In contrast, where the flight geometries differ from those of the day, or where only few flight paths exist, the random choice of flight paths may not represent the horizontal dispersion of the flight paths adequately, and the resulting footprints of CTC and SCC will differ. The latter situation is
shown exemplarily in Figure 1 for starts of Avro RJ100 during n2. The fact that Avro RJ100 did not turn east during n2 cannot be taken into account with SCC, and the resulting footprint is inaccurate (although in areas only which are of minor importance for the resulting noise contours).

The same as for the flight tracks similarly holds true also for the vertical dispersion of the flight paths, i.e. for the flight profiles (altitude and speed in function of the flown distance, not shown). Large differences are observed e.g. for those hours of the night during which heavy aircraft start for intercontinental flights, having substantially smaller angles of climb than during the day, which may only be accounted for by CTC.

Thus, one may expect increasing differences in the resulting noise contours determined with CTC and SCC in the course of the time of day (see below).

### Noise contours

Figure 2 shows the contours of the sound rating levels \( L_{rg} \), \( L_{rn1} \) and \( L_{rn2} \) for the day (06–22 h), and for the first (22–23 h) and second hour of the night (23–24 h).

By trend, \( L_{rg} \), \( L_{rn1} \) and \( L_{rn2} \) of CTC are higher than those of SCC for noise levels relevant for NAO [3], i.e. for \( L_{rg} \geq 53 \) dB, \( L_{rn1} \geq 43 \) dB and \( L_{rn2} \geq 43 \) dB, and accordingly, the mean differences between the \( L_r \) calculated with CTC and SCC (CTC minus SCC) per dB-class are mostly positive. This might be due to the fact that using all available flight paths results in a larger horizontal and vertical dispersion of the flight paths used in the footprint-calculation (cf. Figure 1 for the day), which may in turn cause higher noise levels. However, this hypothesis still needs to be verified.

For the day, the noise contours obtained with CTC and SCC are almost identical (Figure 2), and accordingly, the mean differences per dB-class range from −0.01 to +0.02 dB only for \( L_{rg} \geq 53 \) dB. However, the differences between CTC and SCC increase in the course of the time of day (\( d < n1 < n2 \)). While for \( n1 \), differences range from 0 to +0.13 dB for \( L_{rn1} \geq 43 \) dB, the differences get as large as −0.25 to +0.24 dB for \( L_{rn2} \geq 43 \) dB (Figure 2). These differences are all very small compared to the uncertainties of calculated aircraft noise of ±0.5 dB (\( d \)) and ±1.0 dB (\( n1, n2 \)) [4].

### Areas and persons above exposure limits

As CTC results in somewhat higher sound levels than SCC (see above), all resulting areas above the exposure limits [3] of the relevant individual \( L_r \) are larger for CTC than for SCC, and the differences between CTC and SCC increase in the course of the time of day (\( d < n1 < n2 \), not shown). The areas of the resulting envelopes determined with CTC are 58.7 km\(^2\) (alarm values), 407.2 km\(^2\) (impact thresholds) and 571.9 km\(^2\) (planning values), which differ by +0.4%, +0.7% and −0.4% from the areas obtained with SCC. (The negative difference for the areas above planning values is due to a larger intersection area of the individual \( L_r \) of CTC used to calculate the envelope, compared to the intersection area of SCC.)

Figure 2: Noise contours of the complete air traffic of one year obtained with CTC (bold solid lines; 1 footprint-calculation per period of day, choice of all available flight paths) and SCC (bold dotted lines; 1 footprint-calculation for the 24 h of a day, statistical choice of flight paths) for the sound rating levels \( L_{rg} \) (top, 06–22 h), \( L_{rn1} \) (middle, 22–23 h) and \( L_{rn2} \) (bottom, 23–24 h), and differences (thin solid lines; CTC minus SCC). Dark grey: absolute differences > 1.0 dB; light grey: 1.0 dB ≥ absolute differences > 0.5 dB.
The resulting number of persons living in areas of the envelopes above the exposure limits are larger for CTC than for SCC. With CTC, one obtains 2'622, 31'203 and 78'640 persons, respectively, above the alarm values, impact thresholds and planning values, which exceed the corresponding numbers obtained with SCC by +1.6%, +2.0% and +0.9%. Compared to the uncertainties in the quantifications of areas (10% for \(d\) and 20% for \(n1\) and \(n2\)) and numbers of persons above the exposure limits (15% for \(d\) and 30% for \(n1\) and \(n2\)), the differences between CTC and SCC are small.

**Comparison with monitoring data**

For all periods of day (\(d\), \(n1\) and \(n2\)), the differences between calculated (CTC and SCC) and measured \(L_{\text{eq}}\) are quite small (not shown) and not significant, considering the uncertainties of calculated and measured aircraft noise [4]. The differences are almost identical for CTC and SCC (not shown). Therefore, the two methods are equivalent with regard to their potential to represent monitoring measurements in the vicinity of airports. With that respect, none of the two methods may be preferred.

**Discussion**

The SCC method accounts for operational changes over the 24 h of a day only by means of weighting the footprints (yearly average of \(L_{\text{eq}}\) over the 24 h of a day) to calculate time-of-day-specific noise contours, while CTC also considers possible time-of-day-specific differences in flight geometries with separate footprint-calculations, besides weighting the footprints.

For the day, CTC and SCC yield very similar results. The \(L_{\text{r}}\) obtained by CTC and SCC are almost identical. In the course of the time of day, however, the differences in the sound rating levels obtained with CTC and SCC increase in the order \(d < n1 < n2\), which is due to the more and more unrepresentative selection of flight paths used for SCC. While the differences between CTC and SCC are small compared to the uncertainties of calculated aircraft noise, CTC results in somewhat higher sound levels than SCC and, accordingly, also in somewhat larger areas and number of persons living in areas above exposure limits. However, with regards to legal requirements, SCC is sufficiently accurate in accounting for operational time-of-day-specific changes.

The two methods are equivalent with respect to their potential to represent monitoring measurements in the vicinity of airports. However, in remote areas, we expect CTC to be more accurate than SCC, as with increasing distances from the airport, the fanning out of the flight paths gets less accurately accounted for by SCC (cf. Figure 1).

**Conclusions**

For the simulated scenario (air traffic of Zurich airport in 2006, calculations of time-of-day-specific \(L_{\text{r}}\) according to NAO [3]), CTC and SCC gave similar results, which, however, differ more and more in the course of the time of day. Nevertheless, SCC describes time-of-day-specific operational changes with sufficient accuracy. Also the comparison with monitoring measurements does not allow preferring one or the other method. Nevertheless, CTC has several advantages to SCC, namely that (i) CTC allows the consideration of changes in flight geometries over the 24 h of a day, (ii) CTC might be more accurate in remote areas than SCC, and (iii) CTC considers every single flight of one year’s flight operation, which will increase the acceptance in the population and will thus be politically important.

As FLULA2 uses radar data in calculations wherever possible, the step from a random selection of a subset of flight paths (SCC) to the use of a complete data set (CTC) is small, and the extra effort (mostly longer computational time) is manageable. Thus, calculations based on all available flight paths of one year’s radar data set can be performed with reasonable expenditure of time, and they allow for a very detailed consideration of the average operational fluctuations over the 24 h of a day. In conclusion, taking into account the changes in flight geometries in different periods of day enhances the accuracy of the model results.

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**References**


