Aircraft Annual Noise Assessment In The Vicinity Of Airports From Shot-Term Measurements

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Abstract. This article is intended to the specification of the representative time measurement interval in which the annual equivalent level of the aircraft passing-bys may be assessed with a stated accuracy. As a result the definition of representative time duration presented. The adequacy or representativeness of measurements results is based on proposed accuracy criterion. For long-term L_{eq} evaluation procedure under consideration the 'noisiest' events are taking into account. Such events include *SEL's* which are greater than energy mean *SEL* for all aircraft noise events. Based on the standard ISO 20906:2009, for energy mean *SEL* to be statistically representative more than 20 sufficiently noisiest events of aircraft operation must be chosen. The criterion implies that the difference between following equivalent levels: first cover the noisiest events only and second – all events from representative sample, is sufficiently low. This difference practically depends from the proportion of the number of noisiest events to the total number of events in the representative sample. The proposed in article assessment procedure was applied for data sets collected at the point of noise control closely to Vilnius International Airport 4.5 km from end of runway. The statistical distributions of determined SEL's value are presented. Accomplished experimental measurements show that *SEL* average values of aircraft flying-by events during day, evening and night time are the same and equal about 85 dBA. This approach show the possibility for estimation annual results from measurements in only one week representative time interval with 1 dB accuracy of proposed criterion.

1. Introduction

Aircraft noise has a significant impact on environment due to few reasons: close airports location to living areas, relatively large noise levels and repeating of flight noise events, especially during the night time. European Commission report [1] shows that an increase in equivalent sound level at night L_{night} on every 5 dBA may 1.5 times enlarge the percent of sleep disturbances, from 5 % within level L_{night} = 45 dBA (on building façade) up to 12 % within L_{night} = 55 dBA. In accordance with EU directive requirements [1, 2] the calculations of environmental noise descriptors became mandatory, while measurements may be used just for validation of the results [3]. For environmental noise measurements main provision described in international standard ISO 1996-2 [4], which refer to general test method development mainly. As stated in the standard, the sound levels shall be, if possible, determined from the exposure level measurements of individual aircraft flight noise events during representative time period.

In this article a representative time interval is treated as a permanent time interval comprising the set of flight noise events of sufficient number of possible aircraft types operated above considered point of control including possible aircraft flight trajectories and operational conditions. Acoustical data must be collected by permanent long-term measurements with following appropriate data post processing procedures. Determined corresponding long-term statistical assessments of acoustic data of the aircraft noise events (e.g. L_{den}, L_{night}, L_{max}, L_E, etc.) may be extrapolated to much longer time period (e.g. one year). So it is logically clear that if the specific types of aircrafts are operated at considered airport and their operational conditions do not significantly change for a fixed area of the environment, such assumptions for the representative measurement time interval extrapolation (and application of the values of appropriate long-term descriptors) may be acceptable.

The aim of this work is detailed consideration on statistically averaged values [5, 6] of the parameters of aircraft flying-by events inside representative measurement time interval that would permit to extend obtained values to the annual period of their averaging. To estimate the noise impact of the aircraft flying-bys on the living sites the appropriate noise descriptors must be evaluated. The most representative of the noise descriptors is an A-weighted equivalent level estimated for aircraft flying-bys in annual period separately for day, evening and night. So the composite (L_{den}) annual average 12 h day (L_d), 3 h evening (L_e) and 9 h night (L_n) (for the Lithuanian case by Lithuanian noise control law [7]) equivalent A-weighted sound pressure level must be evaluated as follows:

$$L_{\text{den}} = 10\lg\left(0.5\cdot 10^{\frac{L_d}{10}} + 0.395\cdot 10^{\frac{L_e}{10}} + 3.75\cdot 10^{\frac{L_n}{10}}\right) \tag{1}$$

The contribution of night level is most significant and the contributions from day and evening levels are close. In case when mentioned equivalent levels are determined using direct acoustical measurements – this is accomplished using unattended continuous monitoring during the whole year. The one year measurement interval may be considerably reduced applying the statistical estimations of produced by aircrafts flying-bys A-weighted sound exposure levels (SEL).

2. Method

To reduce the measurement interval the criterion for estimation of the accuracy of obtained results in reduced (representative) time interval must be developed. The permanent noise monitoring inside the area affected by noise produced by flight noise events is used for collection of initial data set, large enough (statistically representative) for further analysis. The initial data for investigation were stored as a time history of instantaneous A-weighted sound pressure levels $L_{pA,100ms}$ (registration step is 100 ms). These data are post-processed by a specially developed software to recognise aircraft noise events inside a set and calculate appropriate parameters for i–th event: A-weighted sound exposure level (*SEL*) $L_{AE,i}$. Here the expressions for annual aircraft noise assessment are obtained in following way. Commonly the equivalent sound level $L_{Aeq,T}$ for long-term time interval T, during which the acoustical data for flight noise events are collected, may be calculated as:

$$L_{\text{Aeq},T} = 10\lg\left[\frac{\tau_{\text{ref}}}{T}\sum_{i=1}^{N}\left(10^{L_{\text{AE},i}/10}\right)\right], \tag{2}$$

where $L_{AE,i}$ (i = 1,...,N, N – number of flight noise events inside interval T) – sound exposure level of each noise event; τ_{ref} = 1 s.

For practical usage formula (2) can be presented in other way – separating energy mean sound exposure level and number of flights N inside estimated time interval T:

$$L_{\mathrm{Aeq},T} = \bar{L}_{\mathrm{AE}} + 10\lg\left(\frac{N}{T}\tau_{\mathrm{ref}}\right), \tag{3}$$

where $\bar{L}_{\mathrm{AE}}$ is the energy mean sound exposure level for all of the N flight noise events inside the time interval T under consideration and N/T represents the intensity of flight noise events.

So the equivalent level for long-term interval *T* is directly proportional to the energy mean *SEL* value of flight events inside this interval *T* and logarithmically dependent from flight intensity (*N*/*T*).

Obtained expressions provide useful way for long term interval noise level estimation in case of statistically sufficient number of sound exposure levels collected during the measurements (representative sample) and may serve as a base for the assessment of annual noise level forecast depending on flight intensity. This representative sample must cover as many as possible of aircraft in operation (the full fleet) and their flight trajectories at the point of estimation.

Now, if the obtained *SEL* data in chosen time period *T* is a representative sample for the annual values of *SEL*'s, expression (3) allows to estimate the statistical parameters of flight noise events to achieve the desired noise level in following way. Namely, at what energy average values of *SEL*'s and flight noise events intensities will appropriate (most significant values such as 50 dBA, 55 dBA, etc.) values of long term (annual) noise equivalent level be achieved during different rating time periods (day, evening, night) of the whole day. The appropriate curves are presented in Figure 1.

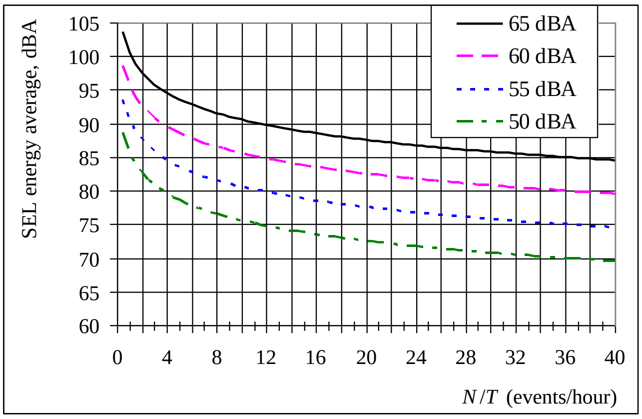

Figure 1. Dependencies for forecasting the long-term equivalent levels from energy mean *SEL* and flight noise events intensity (*N*/*T*).

For example, at night period it is required not to exceed the level of 50 dBA (please, look on low curve on Figure 1), then with intensity 5 flights per hour (high intensity for the night) energy mean *SEL* of flight noise events must not exceed 78.0 dBA, and/or for intensity 2 flights/hour – 83.0 dBA. Thus, these dependencies allow to optimize the value of annual equivalent level in any rating time period at the expense of using quieter aircraft and by decreasing the number of flight noise events.

The annual forecasting of aircraft noise pollution of leaving site with metric based on equivalent level may be achieved using measurements in representative time period, which is significantly shorter of annual period. Representative time period determines the amount of samples (number of registered aircraft noise events) which must be fixed and processed. Standard ISO 20906:2009 [8], for energy mean *SEL* to be statistically representative imply that at least 20 sufficiently noisiest events of aircraft operation must be registered.

To define the most significant (noisiest) set of events, here a way is proposed to include events whose individual *SEL* are greater than energy mean *SEL* for all (total set) aircraft noise events. Such definition takes into account the statistical distribution (histogram) of all events by their energy contribution (*SEL*).

When the equivalent level metric for noise pollution assessment is used, it is possible to relate the number of events in representative sample Nrepr with number of noisiest events Nmax. This allows to forecast the amount of representative sample and to determine the possible measurement time interval. So it may help planning the procedure of representative measurements in case when it's necessary to check noise level at several environmental points for one year period (e.g. by applying the mobile monitoring system). For this purpose, let's introduce the energy mean SEL of the noisiest events only – and consider the difference between following equivalent levels: first cover the noisiest events only and second – all events from representative sample with appropriate energy mean SEL, $\bar{L}_{AE,repr}$. Applying formula (3) this difference □Lrepr can be expressed in following form:

$$\Delta L_{repr} = 10\lg\left(1+\frac{N_{max}}{N_{repr}}\right) + 10\lg\left(\frac{1}{1+\frac{N_{max}}{N_{repr}}} + \frac{1}{1+\frac{N_{repr}}{N_{max}}}10^{\left(\bar{L}_{AE,max}-\bar{L}_{AE,repr}\right)/10}\right). \qquad (4)$$

As the representative sample should replace true (annual) sample of flight noise events, this difference practically determines the accuracy of annual equivalent level assessment in case when only noisiest events are taken into account and as seen from formula (4), it depends from the proportion of number of noisiest events to the total number of events in the representative sample, N_{max}/N_{repr} and from difference between average SEL values for mentioned numbers of events, $\bar{L}_{AE,max} - \bar{L}_{AE,repr}$. The last difference, as will be shown later, is narrowly changing for various conditions (samples for day, night and evening periods and for different flights intensities) and practically it varies between 3 – 5 dB. So the value of difference □Lrepr (measure of accuracy) may be expressed graphically in dependence with proportion N_{max}/N_{repr} as shown in Figure 2.

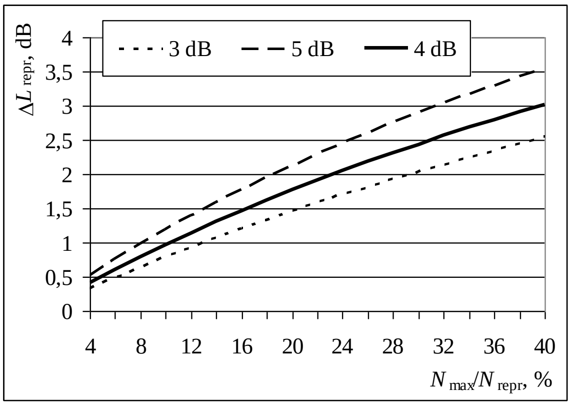

Figure 2. Dependence of annual equivalent level assessment accuracy from relative number of noisiest events N_{max}/N_{repr}, when the difference between the average *SEL* values of noisiest and representative set of events is equal to 3, 4 and 5 dB.

Obtained formula and graphical dependencies allow to determine the amount of representative sample N_{repr}, so that in the worst case (when only a number of noisiest events N_{max} in succession are taken into account) the determined long-term equivalent sound level would have a controllable accuracy. So the amount of representative sample (number of events) is related with the accuracy of long term equivalent level determination. For example, accuracy of 1 dB in average should correspond to about 11 % of the noisiest flight noise events (please see Figure 2 middle curve) and if $N_{max} = 20$, the amount of representative sample would not be less than 182 registered events.

Note, that as the noise pollution estimation based on equivalent levels metric includes assessments separately for day, evening and night rating periods and at night the number of flights is limited (is smallest), so it's enough to determinate the amount of representative sample for night period only (for other periods the amount of representative sample will automatically exceeded).

3. Experimental results

For the method under development, a case study was carried out in the vicinity of Vilnius (low intensity of flights) International Airport. The location of selected point is shown in Figure 3.

Figure 3. Location of point **1** for noise control in vicinity of Vilnius International Airport.

The point 1 of noise monitoring was selected just within the borders of L_{den} = 55 dBA noise zone. It is located 50 m from city arterial road, where traffic noise provides a similar L_{den} as an aircraft noise. The time interval for analysis was chosen large enough to be representative for flight noise events and is equal to one month. Other character parameters for noise measurement point are presented in Table 1.

Table 1. Parameters of the measurement point for noise assessment from aircraft flight noise events

Measurement time interval	Distance from end of runway	Detected intensity per whole-day (evening)	Environment type	Total L_{den} dBA
one month	4.5 km	29.5 (4.7)	Urban	about 60

The energy average SEL for the whole representative sample – $\overline{L}_{AE,repr}$ and for the group of noisiest events – $\overline{L}_{AE,max}$ were determined and appropriately presented in Table 2.

Table 2. Energy mean and maximum *SEL* (dBA), calculated from long-term recorded aircraft noise data set at point 1 during day (07:00 – 19:00), evening (19:00 – 22:00) and night (22:00 – 07:00) periods

Rating period	Descriptors			
	$\overline{L}_{AE,repr}$ dBA	$\overline{L}_{AE,max}$ dBA	$\overline{L}_{Amax,S}$ dBA	$\overline{L}_{Amax,F}$ dBA
night	84.7	87.4	75.7	77.2
day	84.7	87.6	75.6	77.0
evening	84.9	87.8	75.5	77.0

As follows from Table 2 the difference between the average SEL values of noisiest and representative set of events $\overline{L}_{\mathrm{AE,max}} - \overline{L}_{\mathrm{AE,repr}}$ is about 3 dB. So the upper curve in the Figure 2 must be applied for assessment of average SEL determination. Also Table 2 shows that the values of the average SEL, $\overline{L}_{\mathrm{AE,repr}}$ that are the estimations of the true SEL, $\overline{L}_{\mathrm{AE}}$ in formula (3) practically are the same during the whole-day. The last mean that $\overline{L}_{\mathrm{AE,repr}}$ may be determined during the whole-day period and that obtained value of average SEL is suitable for day, evening and night time periods. That situation is arose due to the fact that aircraft types, their flight-by trajectories and operation modes do not changed during the whole-day in respect to the receiver point 1. So the measurement time interval for desired value of the average SEL may be considerably reduced (instead of statistics of aircraft flying-bys for night period the statistics in whole-day may be applied). The amount of 885 aircraft flying-by events (532 in 12h day, 140 in 3h evening and 219 in 9h night) were processed during the one month measurements. So the average intensities are following 29.5 for whole-day; 17.7 for 12h day; 4.7 for evening and 7.3 for nigh periods. In Figure 4 presented the distribution histogram for measured SEL values during the whole-day periods in the receiver point 1.

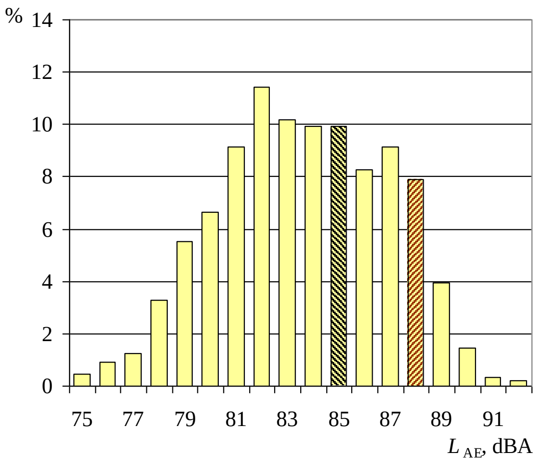

Figure 4. *SEL* distribution histogram for whole-day periods (one month): the hatched columns present the SEL average for the representative sample (84.8 dBA) and for the set of noisiest events (87.7 dBA).

Typical records for flight noise events registered in day and night periods are shown in Figure 5. Residual sound allows to estimate the background noise level, which is used as initial for the event's starting point. The comparison between the character parameters of the events are presented in Table 3, which shows the similarity in SEL and MAX values. The differences are observed for the residual sound levels and as a result in duration of the events.

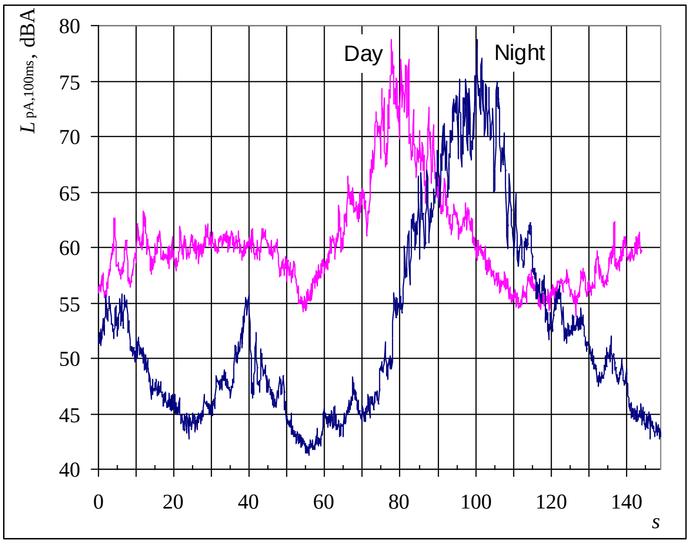

Figure 5. Typical aircraft events in night/evening and day (12h) periods

Table 3. Character parameters of the typical events (shown in Figure 5) for day and night/evening periods

Rating period	Parameter					
	$L_{AE,1}$ dBA	$L_{AS,max}$ dBA	$L_{AF,max}$ dBA	$L_{Aeq,1}$ dBA	L_{res} dBA	Δt (L_{res}+3 dB) s
night/ evening	84.9	75.5	78.7	66.2	44-48	60
day 12h	84.9	76.6	78.7	68.0	58-60	35

The representativeness of obtained results in measurements may be checked using Figure 3. As seen from the histogram in Figure 4 and from results presented in Table 3 the difference $\overline{L}_{AE,max} - \overline{L}_{AE,repr}$ is 3 dB.

Duration of representative measurements depends on the lowest flight intensity, what happens during evening rating time period, and is equal to 4.7 events per evening (Table 1). Then from Figure 3 using the lower curve for specific accuracy of ΔL_{repr} and e.g. for the number of noisiest events fixed on level of 20 events the duration of representative measurement time interval may be determined. The results of corresponding calculations for ΔL_{repr} accuracy of 1 and 2 dB are listed in Table 4 below.

Table 4. Results of duration determination of representative measurement time interval (whole-days) for number of noisiest events N_{max} = 20, when the flight intensity per evenings is 4.7 and per whole-days – 29.5 (see Table 1).

Accuracy, ΔL_{repr}	2 dB	1 dB
N_{max}/N_{repr} %, (Figure 3)	29	13
Number of N_{repr}	69	154
Whole days (N_{repr} /4.7)	15	33
Whole days (N_{repr} /29.5)	3	6

Thus, the annual equivalent levels for rating time intervals (day, evening, night) comprised in L_{den} descriptor may be estimated using formula (3) and data from Table 2 for sound exposure values of representative flight noise events.

Note that the average SEL values obtained from the measurements are practically the same throughout the whole-day periods and such situation is typical for airports with low flight intensity. This can significantly reduce the representative time interval because the whole-day intensity is 29.5 flying-bys that is pointed in the last line of Table 4.

Conclusions

Obtained results show that the time interval for determining correctly the annual equivalent sound levels may be reduced, and at the same moment they should be used for better understanding the noise impact in the vicinity of airports. The relationship of flight intensity with the equivalent level is used to estimate the aircraft noise impact.

It is shown that intensity of aircraft noise events influences the equivalent sound level greatly: the long-term equivalent sound level is directly proportional to the energy mean $\bar{L}_{AE}$ of flight events during the interval *T* and logarithmically – to the number of flights. Thus noise impact descriptors for aircraft flight noise events based on equivalent level metric (e.g. L_{den}) will be defined by flights intensity only in case, where the types of operated aircraft and their flight trajectories at point of estimation from year to year are changed slightly (in this way $\bar{L}_{AE}$ varied insignificantly). As shown, this also opens a way to predict the annual value of descriptors based on equivalent sound level for aircraft noise assessment near airports with different flights intensity by measurements during shorter time duration– so called, representative time interval.

For determination of the representative time interval, which is necessary to define the most significant (noisiest) set of events, it is proposed to take into account the events with *SEL* greater than energy mean *SEL* for all aircraft noise events in observation. The analytical and graphical relationships are suggested between the amount of representative sample of flight noise events (that determines duration of the representative measurement time interval) and the number of significant events, based on the measure of accuracy, when the annual equivalent level will be estimated by taking into account the noisiest events only.

Using the measurements during representative time interval only for annual noise assessment allows to change or to reduce the fixed monitoring stations with restricted number of mobile noise monitoring stations and/or to extent the number of points for noise monitoring.

The accomplished experimental measurements at sites for living near (4.5 km from the take-off point) Vilnius International Airport show the possibility for prediction of annual results by measurements in representative (one week) time interval with 1 dB accuracy of proposed criterion.

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