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ANALYSIS OF CRITERIA AND STRATEGIES USED FOR NOISE MONITORING AT AIRPORTS

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Abstract. *The paper gives an overview of international, national and local legislations and policies related to noise monitoring at airports via recommended criteria for measuring of noise levels generated during aircraft operations. The proposed classification of the criteria taking into accounts their characteristics and recommendations for application are described. Analysis of noise monitoring and mitigation strategies that have been identified as "best practice" is presented.*

Keywords: environmental noise criteria; noise monitoring at airports; noise mitigation strategies.

1. Introduction

Environmental noise, aircraft noise in particular, in a wider context is one of the main local environmental problems, because noise exposure is produced close to the source of its radiation. In the European Union (EU) countries about 40 % of the population are exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime and 20 % are exposed to levels exceeding 65 dB(A) [1].

For assessment of the aircraft noise impact on the community near to airports the acoustic calculations and measurements are used.

According the World Health Organization (WHO), noise seriously harms human health and interferes with people's daily activities at school, at work, at home and during leisure time. The main health risks of noise identified by WHO [2] are the following:

– pain and hearing fatigue, Hearing impairment including tinnitus, Annoyance;

– interferences with social behavior (aggressiveness, protest & helplessness);

– interference with speech communication, Sleep disturbance;

– cardiovascular effects (Ischaemic heart disease, Stroke), Hormonal responses & their possible effects on metabolism & immune system, Mental health;

– performance at work and school.

According to most international legal standards, airports are obliged to monitor aircraft noise in their vicinity. Around 85 % of the world's busiest airports have installed systems to measure noise and to control it by the low noise operational and mitigation procedures. Using the results of monitoring, airports may manage their growth by ensuring regulatory compliance and minimizing their environmental footprint.

Obtained measurement results show ~1 dBA for L_{Aeq} coincidence with calculations results and allow preparing correct data base for practical use under ECAC method [3, 4], which completely similar to ICAO recommended method [5]. While results of $L_{A\max}$ estimation still remain under investigations. These requirements are important first of all for aircraft with acoustic performances in accordance with requirements of Chapter 3 of the Annex 16, volume 1 [6]. Their contribution to the aircraft noise impact around the airports is still dominant in countries without directives phase-out for aircraft with poor acoustic performances (noisy aircraft), so their correct input data are still necessary.

2. Problem statement

In particular, usual objectives for monitoring include the following: to determine present conditions; to determine trends; to understand phenomena; to validate and/or calibrate environmental models; to make short-term predictions; to make long-term assessments; to optimize the utility and/or cost-effectiveness of any of the above; and to control. If the control objective is dominant the monitoring system becomes a management subsystem based on observation.

The reasons for aircraft noise monitoring vary depending on the specific characteristics of the airport concerned and can include the following:

– determining and tracking aircraft noise levels in residential areas;

– compliance monitoring if individual aircraft or overall airport noise is subject to limits;

– measuring individual aircraft noise events for the purpose of charging/penalties;

– investigating and responding to noise complaints.

The optimum design of a monitoring system depends greatly on the objectives established for the system, for example following the guidelines shown in Table 1 [7].

Table 1. Strategies for optimizing monitoring system design according to its goals

Goal	Strategy
Environmental factor control	Locate monitors near hotspots
Environmental factor description	Locate monitors over a wide area
Health related studies	Locate monitors at sites representative of noise-sensitive exposure
Trend analysis	Locate monitors in places of largest trends and smallest variability
Environmental factor modeling	Locate monitors according to model considerations

Noise monitoring involves the use of specialized equipment including microphones and computerized/automated logging/recording devices to measure the noise levels from aircraft. It should be mentioned that measurements of noise levels from airport operation are always subject to extremely variable situational and environmental conditions; therefore airports select different strategies in its realization. When the geographical area is to be monitored the preferred sampling strategy depends on: the funds available and the costs of equipping and operating stations; the objectives (e.g. is the goal to estimate the area mean, the long-term trend, or the highest value occurring anywhere in the area?); the required tolerance levels (e.g. is it necessary to estimate the area mean within ±5% with 95% confidence, or will some coarser value be satisfactory?); and the complexity of the field being monitored (gradients, variances, etc.).

While airport-related noise levels decrease quickly with distance from an airport, the accuracy of noise measurement also decreases because it is more difficult to distinguish between noise generated during aircraft operations and other noise in the environment, such as road traffic noise or industrial noise.

Noise monitoring at airports is an important process in understanding and dealing with aircraft noise impacts. For achieving a common understanding of the noise problem, data about environmental noise levels should therefore be collected and reported in accordance with comparable criteria. This implies the use of harmonized indicators and evaluation methods, as well as criteria for the modelling of noise-mapping. It is important that when a community noise impact assessment is conducted, the criteria used are valid, justified and comparable.

The monitoring and the noise regulations must properly reflect the true impact of aircraft noise on health, education and quality of life and must reflect best practice.

3. International regulations related to noise monitoring at airports

There are a number of key legislations and policies supporting noise management approaches at airports. International noise regulations establishing criteria for noise monitoring have been provided by the WHO, International Civil Aviation Organization (ICAO), the EU and other international regulatory agencies.

The WHO Guidelines for Community Noise [8] contain general recommendations on measuring of environmental noise. It is recommended that LAeq,T be used to evaluate continuous environmental noise. Where the noise is principally composed of a small number of discrete events, as with aircraft noise, the additional use of outdoor maximum sound pressure level LAmax or sound exposure level SEL is recommended. LAmax and SEL are important laboratory tools to describe instantaneous reactions to noise.

Part III of ICAO’s Annex 16 [6] contains recommendations on noise measurement for monitoring purposes, which are monitoring compliance with noise abatement requirements established for aircraft in flight or on the ground and checking the effectiveness of such noise abatement procedures, first of all noise abatement procedures (NAP). The noise levels measured for certification purposes and decisions concerning the compliance with standards for aircraft noise performances should be approximations to Perceived Noise Levels PNL in PNdB and Effective Perceived Noise Levels *EPNL* in *EPNdB*. To measure all the aircraft noise events in operation at any aerodrome under consideration and to compare the levels with certification data usually not correct due to huge difference between the flight procedures used for noise certification and in usual operation, even including the NAP.

The Policy and Recommended Practices of Airport Council International (ACI) [9] recommend L_{eq}, L_{dn}, L_{den}, *NEF* or *ANEF* as appropriate criteria for determining the level of airport noise impact for land use planning purposes. In some cases it may be appropriate to use the average noise level during specific periods (e.g. night time) or the noise from specific aircraft events (Fig. 1, e.g. assessed with L_{max}, *SEL, EPNL*) to identify the level of airport noise impact and assess land use compatibility. There is no current research to suggest that there is a better metric than L_{dn} and/or L_{den} to relate to annoyance.

A Directive of the European Parliament and of the Council 2002/49/EC [10] applies the noise indicators L_{den} and L_{night} and where appropriate, L_{day} and $L_{evening}$. In addition, existing national noise indicators and related data may be used by EU Member States and should be converted into the indicators mentioned above. The values of L_{den} and L_{night} can be determined either by computation or by measurement (at the assessment position). For predictions only computation is applicable. The END recommends in some cases in addition to L_{den} and L_{night} to use the special noise indicators and related limit values, when the average number of noise events in one or more of the periods is very low (for example, less than one noise event per hour — the noise from a passing aircraft at small regional airports with low intensity of aircraft movements).

4. National criteria for environmental noise measurements used in different countries

There is a wide range of different criteria, some of these criteria are general-purpose and can be applied to almost any type of environmental noise. Other criteria are developed for more specific purposes to be exact for measuring aircraft noise and exactly noise generated during aircraft operations at airports. These noise metrics can be grouped according to whether they measure the sound level of a single event or are cumulative measures of many aircraft operations.

Each country can adopt its own criteria for various noise effect assessment/control, or use international recommendations described above. Basic of them are described here.

The *Noise Exposure Forecast (NEF)* — a complex criterion for predicting future noise impact of airports — has been adopted by the Department of Housing and Urban Development, USA. This is a criterion which takes into account the duration of flyover, the peak noise level, the tonal characteristics and the number of aircraft movements in the daytime and night-time period.

Very similar criteria are still in use in Canada and Australia for airport noise zoning. Transport Canada uses a *Noise Exposure Forecast (NEF)* system to provide a measurement of the actual and forecasted aircraft noise in the vicinity of airports. The *Australian Noise Exposure Forecast (ANEF)* System was developed through a major socio-acoustic survey carried out in the vicinity of a number of Australian airports in 1980. The *ANEF* system incorporated a weighting for the period 7 p.m. to 7 a.m. (as opposed to the 10 p.m. to 7 a.m. period under the *NEF* system) as the study showed that this gave the best correlation between noise dose and community reaction. The *ANEF* is an equal energy noise index similar to the L_{dn} and L_{eq}.

Weighted Equivalent Continuous Perceived Noise Level (WECPNL) is used for environmental regulations in Japan, but simplified in comparison to the same criteria proposed by ICAO. It is a measure to assess the continuous exposure to long-term noise of multiple aircraft.

The *Single Event Noise Exposure Level (SENEL)* metric — the level of a continuous one-second sound which contains the same amount of energy as the complete noise event — used in California is virtually identical to the *Sound Exposure Level (SEL)* metric used by the US Federal Aviation Administration and other federal agencies.

N70 is a metric which originated from Australia and it describes the number of noise events (*N*) exceeding an outdoor maximum noise level (*Lmax*) of 70 dBA. The 70 dBA outdoor level was chosen because it corresponds to the Australian standard for the onset of indoor speech interference of 60 dBA (10 dB attenuation by the building fabric with open windows is allowed for)

5. Characteristics of criteria for environmental noise measurements

Airport-related noise can be measured/calculated from single events — such as an individual aircraft's takeoff or landing (aircraft operation) — or as the cumulative average level of noise from all aircraft operations at airports over time.

Description of a noise from a single event (aircraft fly over)

The noise level generated during an individual aircraft flying nearby can be described as:

– starting increasing above some appointed background noise at some moment of time when the exceeding sound can be distinguished;

– increasing until reaching a peak value;

– decreasing until again reaching and becoming lower than a level of a threshold or ambient sound level.

Description of continuous or multiple noise events

In order to provide a description of continuous or multiple noise events there is necessary to process it by way of weighted average measurement of the noise over an extended period of time.

With the aim of comparison of different strategies for noise monitoring and selection of the best practice among them it is proposed to divide all indicators into three classes taking into account their characteristics (Table 2):

I class — Simple criteria — criteria for environmental noise measurements which can be described as simply physical effects of noise.

II class — Integrate criteria — derived from the simple physical noise criteria by weighting them over time (day/evening/night weightings) or averaging over longer time periods.

III class — Complex criteria — combined physical characteristics of noise with its impact on the population taking into account impact on human organism (annoyance, sleep disturbance etc.).

Table 2. Characteristics of criteria for environmental noise measurements

Criteria		Characteristics
L_{Aeq},T	Equivalent Sound Level	Quantifies the noise environment as a single value of sound level for any desired duration of the noise event (fly over). This descriptor correlates well with the effects of noise on people.
SEL	Sound Exposure Level	Description of the physical effect of a single noise event (fly over).
$L_{A\max}$	A-weighted Maximum Noise level	Description of the physical effect of a single noise event (fly over).
PNL	Perceived Noise Level	An active band analysis that measures noise in one octave intervals. Measures sound in each octave and compensates for discrete tones that are annoying but not necessarily loud. A measure proposed by ICAO to assess the continuous exposure to long-term noise of multiple aircraft.
EPNL	Effective Perceived Noise Level	This descriptor is derived from *PNL* and accounts for pure tones and duration effect. Similar to *PNL* but measures noises in one-third octaves. A complex rating used to certify aircraft types for flyover noise. This includes corrections for pure tones and for the duration of the noise.
L_{dn} *(DNL)*	Day-night Average Sound Level	Description of noise exposure events (fly over) over a 24-hour period. This noise is weighted to take into account the decrease in community background noise of 10 dB during night.
L_{den}		The annual average 24-hour L_{eq}, with weightings of 5 dB for evening (19:00-23:00) and 10 dB for night-time (23:00-07:00).
L_{Aday}		Description of approximation of day-time disturbance. The annual average 12-hour L_{eq} for daytime (07:00-19:00).
L_{Anight}		Description of approximation of night-time disturbance with about 10dB correction added to L_{Aday}. the annual average 8-hour L_{eq} for night-time (23:00-07:00).
$L_{Aevening}$		Description of approximation of night-time disturbance with about 5dB correction added to L_{Aday}. The annual average 4-hour L_{eq} for the evening period (19:00-23:00).
NEF	Noise Exposure Forecast	A complex criterion for predicting future noise impact of airports. The computation considers Effective Perceived Noise Level of each type of aircraft, flight profile, number of flights, time of

Criteria		Characteristics
		day, etc. Generally used in plots of equal *NEF* contours for zoning control around airports.
ANEF	Australian Noise Exposure Forecast	An equal energy noise index similar to the L_{dn} and L_{eq}.

The following Tab. 3 presents distribution of the criteria for environmental noise measurement among the chosen classes.

Table 3. Proposed classification of criteria for environmental noise measurement

Class	Criteria	
I	L_{Aeq}, T	Equivalent Sound Level
I	*SEL*	Sound Exposure Level
I	$L_{A\max}$	A-weighted Maximum Noise level
I	*PNL*	Perceived Noise Level
I	*EPNL*	Effective Perceived Noise Level
II	L_{dn} (*DNL*)	Day-night Average Sound Level
II	L_{den}	
II	L_{Aday}	
II	L_{Anight}	
II	$L_{Aevening}$	
III	*NEF*	Noise Exposure Forecast
III	*ANEF*	Australian Noise Exposure Forecast

SEL and L_{Amax} are quite good correlated describing one aircraft event (fly-bys) at a time. L_{Amax} is often used by airport authorities for assessing complaints or evaluating instant noise situation, e.g. assessing noise from an aircraft type individually. Common provision for aircraft noise in situ measurements are described in the standard ISO 1996-2 [11], which become as a guideline referred to general test method development. As stated in the standard the sound levels shall, if possible, be determined from *SEL* measurements of individual aircraft fly-bys.

L_{dn} and L_{den} allow analyzing relationships to the annoyance effects using 10 and 5dB as night and evening corrections respectively.

Consequently, the analysis of the above mentioned, but not only, recommended practices indicate that the equal energy principle is substantial for measuring of noise from airport operations due to its characteristics and that a L_{Aeq}, T criteria will represent the noise effects quite full. And, when there are distinct events to the noise need to be evaluated, the *A-weighted maximum level* ($L_{A\max}$) is a better indicator of the disturbance to sleep and other activities. In most cases, however, the *A-weighted sound exposure level* (*SEL*) provides a more consistent measure of single-noise events because it is based on integration over the complete noise event. In combining day and night L_{Aeq}, T values, night-time weightings are often added. Night-time weightings are intended to reflect the expected increased sensitivity to annoyance at night due to the lower levels of background noise and demand for quite environment for rest and sleep.

Usually measurements required for control of external noise the broad band analysis. For more detailed analysis it is necessary to provide data in discrete frequency bands: usually one-third octave bands. Frequency analysis is relatively new in airport noise control systems and where measurements are used for validating noise models.

6. Noise monitoring strategies

Noise monitoring involves the use of specialized equipment including microphones and computerized/automated logging/recording devices to measure the noise levels from aircraft. The basic components of the noise monitoring system are:

– Aircraft noise monitoring terminals;
– Aircraft noise server;
– Noise monitoring software
– Aircraft noise database;
– Interfaces to ATC and radar data.

According to a special ICAO CAEP Work Program, an airport noise monitoring effort should:

(a) Compile data on methods used to describe aircraft noise exposure and applications of the data,

(b) Determine the contribution (general and/or specific by type, route, airlines, etc.) of aircraft to the overall noise exposure;

(c) Collect data on the characteristics of airports with noise and/or flight path monitoring systems;

(d) Collect details of airport noise monitoring systems such as capabilities, data stored, technical support;

(e) Compare calculated and monitored noise levels for a suitable sample of airports;

(f) Compare measured noise levels with certificated noise levels for a range of aircraft types and operating conditions;

(g) Examine changes in measured noise exposure over a representative time period; and

(h) Update advisory documents on methodologies and applications of noise contouring and monitoring, supplemented, for environmental noise management, by the elements of expert and decision-making systems.

Processing of the acoustic signals in the terminals and at the central station (server) of a noise monitoring system results in evaluating noise by way of different indices according to the goals of monitoring:

– monitoring and evaluating of single noise events (aircraft fly over) by way of maximum noise levels and analogous indexes (L_{Amax}, *PNLM* etc);

– monitoring and evaluating of single noise events (aircraft fly over) by way of effective noise levels (*SEL*, *EPNL* etc.);

– assessing of noise situation during prescribed time period by way of equivalent noise levels and similar indices (L_{Aeq}, *ECPNL* etc.);

– determination of noise levels which exceed limits during prescribed time periods by way of percentile noise levels (*L10*, *L50* and *L90*).

When locating a permanent or temporary monitoring site, consideration should be given to background or ambient noise sources such as roads, trains, weather, animals, and to security issues and access for regular calibration and maintenance. If a monitor is located too far from the airport, aircraft noise levels may not be sufficiently high above ambient noise conditions to register as clear, separate noise events. The system must be able to distinguish between aircraft events and other noise events.

Stationary monitoring installations should be with weatherproof microphones and calibrated sound level meters. The monitoring site devices allow data capturing, audio recording and storage. Each measuring station should be connected to the airport with a telephone/data line or an internet connection. Meteorological devices can be added which allow the taking of weather data into account.

Automated systems should to be linked to radar or other aircraft identification systems to ensure that recorded noise events are aircraft movements and that a sufficient and representative proportion of all movements are captured. Installation of webcams which are automatically activated by predefined noise events helps to prove that all noise events captured by monitoring system are really aircraft flies over. With a connection to flight information systems (e.g. air traffic control system or radar data) the noise data is correlated with the corresponding flights.

The following noise monitoring strategy including a complex of monitoring and tracking systems has been identified as "best practice". The complex of monitoring and tracking systems contains of:

– *Complaint Management System* maintaining a noise complaint system that provides a substantive and timely response to all noise complaints;

– *Flight Tracking System* that provides an accurate history of aircraft flight tracks;

– *Noise Monitoring System* providing accurate history of noise environment around the airport.

The efficiency of such complex approach depends not only from airport operator, but, to a greater extent, from aircraft operator compliance with noise abatement procedures. To make progress in efficiency airport should establish incentive-based techniques to encourage all operators to comply with all noise abatement measures

7. Conclusions

1. The general disadvantage of the 1st class criteria (Simple criteria) is that it is quite hard to assess long term effects of noise. They represent very good physical effects of generated noise and allow short term assessment.

2. 2nd class criteria (Integrated criteria) are intended for assessment of a noise situation which occurs over a long period of time by adding physical effects of noise events. They allow long-term effects assessment with relationship to annoyance and for sleep disturbance.

3. 3rd class criteria — Complex criteria — can be used for impact assessment and for noise mapping in noise action plans.

4. The advanced research will embrace case study approach analysis of the efficiency of noise monitoring systems with regard to their key features and noise management strategies at airports

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О. В. Коновалова. Аналіз критеріїв та стратегій, що використовуються для моніторингу шуму в аеропортах

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У статті представлено огляд міжнародного, національного та локального законодавства та політики стосовно моніторингу шуму в аеропортах за допомогою критеріїв вимірювання рівнів шуму, що генерується при експлуатації літаків. Описано запропоновану класифікацію критеріїв з урахуванням їх характеристик та рекомендації щодо використання. Представлено аналіз стратегій моніторингу та обмеження шуму, що визначені як «найкраща практика».

Ключові слова: критерії оцінки шуму навколишнього середовища; моніторинг шуму в аеропортах; стратегії обмеження шуму; екологічний моніторинг; засоби захисту довкілля.

Е. В. Коновалова. Анализ критериев и стратегий, которые используются для мониторинга и ограничения шума в аэропортах

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В статье представлен обзор международного, национального и локального законодательства и политики касательно мониторинга шума в аэропортах с помощью критериев измерения уровней шума, который генерируется при эксплуатации самолетов. Описаны предложенная классификация критериев с учетом их характеристик и рекомендации по их использованию. Представлен анализ стратегий мониторинга и ограничения шума , которые являются «наилучшим практическим опытом».

Ключевые слова: критерии оценки шума окружающей среды; мониторинг шума в аэропортах; стратегии ограничения шума; средства защиты окружающей среды; экологический мониторинг.

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