Aircraft noise monitoring and temporal measurements in vicinity of airports

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Abstract. Aircraft noise levels are subject of aircraft certification, the aircraft with incorrect levels of noise are illegal to be produced and operated. Permanent or/and temporary noise monitoring to be undertaken usually in local community on assumption that aircraft noise will exceed what is considered 'acceptable' or legally permissible level of noise, and in this connection it is necessary to refer to the legislative control on aircraft noise. The number and location of the terminals in noise monitoring system is important depending upon the specific role they are to play inside this system. The Svantek SV 200 Noise Monitoring Station is a fully integrated solution for unattended noise monitoring applications featuring an internal web server for system configuration, live data streaming, data management and battery powered operation providing true flexibility for both short and long term measurements. Each noise event starts at the time the noise level exceeds a decibel threshold, typically slightly above the background or ambient noise level, and ends at the time the noise level returns to the threshold. The process that correlates noise events to aircraft operations uses defined parameters to match every eligible noise event to specific aircraft operations. Noise events that fall outside these parameters are classified as community noise. Noise monitoring system is very important instrument to assess the efficiency of any noise abatement program in airport under consideration. With time their complexity due to bigger number of monitoring stations is larger, but new communication technologies provide their simplicity in operation and less costs in manufacturing and operation.

1. Introduction
People living around the airports are driven to complain when some nuisance factor (or stressor) in the environment gives rise to annoyance and/or sleep disturbance, especially if this stressor reaches a threshold of tolerance. Noise describes any undesired sound that is perceived as disturbing, annoying and loud. The perception of noise is extremely subjective, meaning that everybody experiences sounds differently: some people enjoy loud music, others find it a disturbance.

From the point of view of physics, aircraft noise is a set of sound pressure levels of differing amount, duration and frequency. Unlike road and rail noise, aircraft noise does not predominantly occur along the complete journey but is rather concentrated on the direct surroundings of the airport in the area of the arrival and departure routes of the aircraft. For example, under § 19a LuftVG (Air traffic Act of Germany), airport operators are required to set up and continuously operate «equipment to measure and record the noise levels of inbound and outbound aircraft at their airports and in surrounding areas». The monitoring points are located mainly close to the publicized approach and departure routes or are near towns and villages affected by the aircraft noise, and must be ideally situated to produce meaningful results for noise impact assessment.

With the amended Air Traffic Noise Act (FluLärmG) which came into force on 31 October 2007 the legislator greatly improved the incorporation of legitimate noise protection interests of people living near airports and fundamentally modernized protection against aircraft noise. The law in particular takes account of current findings regarding the impact of noise and the relevant operating limits. According to § 1 FluLärmG, the purpose of the law is "to ensure there are structural limitations and structural noise protection in the area of airports to protect the general public and neighborhood from danger, major disadvantages and major disturbance caused by aircraft noise".

The noise indicators – day-evening-night noise index L_{DEN} and equivalent L_{ANight} are used as measures of general nuisance and sleep disturbance respectively. The L_{DEN} level reflects emissions averaged over 24 hours and determined according to certain specifications from the equivalent L_{ADay}, $L_{AEvening}$ and L_{ANight} levels for the evaluation times day, evening and night (usually 12, 4 and 8 hours of duration each).

Polish Environmental Protection Law (EPL) treats noise as an environmental pollution also, hence this Act adopts the same general principles, obligations and forms of proceedings in relation to noise, as to other areas of environmental protection. According to art. 179 of the EPL, airports are included in list of objects, whose operation may cause a negative acoustic impact on environment in significant areas, and the manager of such airport is obliged to draw up acoustic maps of the area every 5 years, during which the operation of the airport may exceed permissible noise levels for the environment. Pursuant to EPL, due to existing and circulating aircraft noise, an area of limited use (OOU) is created around the airport. The area of limited use is created by resolutions of the poviat (urban region in Poland) council or voivodeship (administrative person in Poland) regional council, in which the boundaries of this area are defined, restrictions on the use of the area, technical requirements for buildings and the manner of using these areas. As the noise generated by aircraft can spread, the OOU can also be extended analogically. To this end, *environmental noise monitoring* is carried out. For example, the airport "Flughafen München GmbH" currently operates 16 stationary monitoring points which are within a 20-kilometer radius of its location (Figure 1). Measurement results are the basis for the development of acoustic maps that present average values in relation to the year. Noise maps (the European Union Directive 2002/42/EC) are helpful in spatial planning and environmental protection processes and contribute to improving the acoustic climate of the city.

So today in Europe there is a number of legal issues define the requirements for noise zoning and noise monitoring inside and around the airports, they are strategic elements of aircraft noise exposure and impact management in particular [1].

2. Legal requirements for noise monitoring in Ukraine

Section X "Protection of the environment" of the Air Code of Ukraine consider in art. 84 the requirements for protection of the population from harmful impact of aircraft emissions and airport local air pollution, noise, electromagnetic radiation, third party risk during aircraft operation and maintenance (http://zakon0.rada.gov.ua/laws/show/3393-17). The noise levels during aircraft operation must not exceed the maximum permissible level established by the aviation and, first of all, by sanitary rules of Ukraine.

The ICAO Balanced Approach to aircraft noise management (EC Directive 2002/30/EC) was transposed into Air Code of Ukraine though the article 84 in Chapter X "Protection of the Environment". This article establishes the ICAO procedures with regard to the introduction of noise-related operating restrictions at Ukrainian airports. These include:

- taking into account costs and benefits of new measures (art. 84.5)
- being non-discriminatory on grounds of nationality or identity of air carrier or aircraft manufacturer and being no more restrictive than necessary in order to achieve the environmental objectives for a specific airport (art. 84.4)
- ensuring any performance-based operating restrictions are based on the noise performance of the aircraft as determined by ICAO certification procedures (art. 84.3).

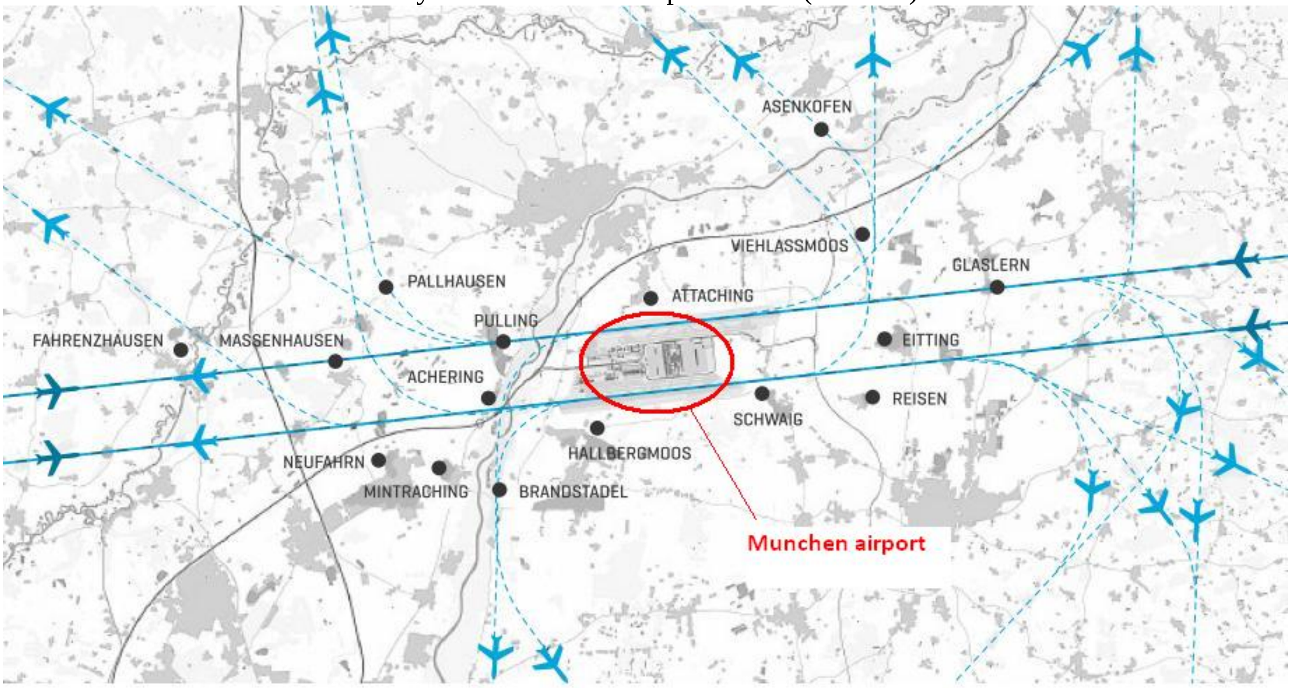


Figure 1. Aircraft noise monitoring – sites of the Flughafen München GmbH stationary monitoring points

Unfortunately Air Code of Ukraine requires nothing about obligations for noise monitoring around airports, so as the Law of Ukraine “On Ensuring Sanitary and Epidemic Safety of the Population”, which is mostly connected to noise impact assessment and control in Ukraine.

State sanitary rules No 173, 1996 in art. 5.21 [2] require the location of the aerodromes (helicopters) under construction should be transferred outside urban and rural settlements in accordance with the requirements of DBN 360-92* "Urban planning. Planning and building of urban and rural settlements" [3], particularly to requirements of art 7.18: in 30 - 40-minute transport accessibility from the city center (distance 20 - 30 km). Air flight routes (tracks) should not cross the urban and rural settlements. The distance from the boundary of the airfield (including helicopter airfield), the radio and meteorological stations, the testing stations of aircraft engines and other aerodrome objects, the routes of aircraft flight to the boundary of existing or prospective construction and mass recreation areas should provide sanitary norms inside these areas, noise in accordance with State standard GOST 22283-88 "Aviation noise. Acceptable levels of noise in residential buildings and methods for its measuring" [4], "State sanitary norms of permissible noise in the premises of residential and public buildings and on the territory of residential areas" № 463 (February 22, 2019) [5], as well as the maximum permissible levels of electromagnetic radiation.

Sanitary norms N 463-2019 require that assessment of non-constant noise for compliance with the permissible levels should be carried out simultaneously for the equivalent $L_{A\ екв}$ and maximum L_{Amax} sound levels, dBA. The L_{Amax} is the peak noise event in decibels, the L_{Aeq} is the average sound level for the event in decibels, and the SEL is the average sound level for the event in decibels accounting for both intensity and duration, Fig. 2. SEL takes all of the energy under the line in a sound pressure level versus time graph and compresses it to a 1 second value. For example, for territories adjacent to residential buildings the equivalent sound level should not exceed 55 and 45, dBA. Acceptable values of the equivalent and maximum sound levels on the territory of the building around airports should be taken according to the Table 1.

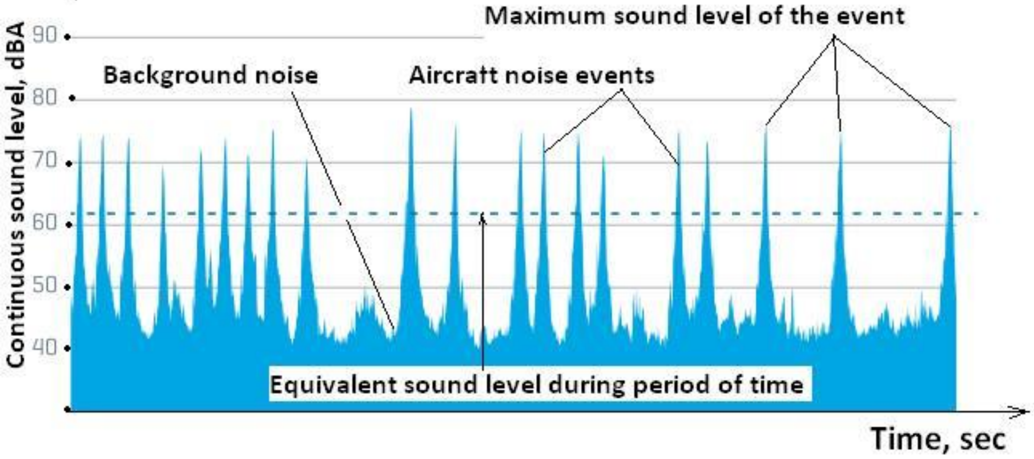


Figure 2. Equivalent $L_{A\ екв}$ and maximum L_{Amax} sound levels of the aircraft noise events during the period of observation

Table 1. Noise protection zones around the airports (State sanitary rules No 173, 1996)

Day time	A	B	C	D
Day	$L_{Aeq}\leq60$	$61\leq L_{Aeq}\leq65$	$61\leq L_{Aeq}\leq65$	$L_{Aeq}>65$
	$L_{AMax}\leq80$	$81\leq L_{AMax}\leq85$	$61\leq L_{AMax}\leq85$	$L_{AMax}>85$
Night	$L_{Aeq}\leq50$	$51\leq L_{Aeq}\leq55$	$56\leq L_{Aeq}\leq60$	$L_{Aeq}>60$
	$L_{AMax}\leq70$	$71\leq L_{AMax}\leq75$	$76\leq L_{AMax}\leq80$	$L_{AMax}>80$

The results show that for airports with low intensity of flights the long term equivalent sound level is heavily changing in relation with the long term maximum sound level, but for high intensity flight traffic this interrelation is quite stable. In the vicinity of airports with low flight intensity the maximum sound level as a noise impact metric is more sensitive than the equivalent level.

Aviation rules of Ukraine No 381-2019 "Requirements for the aerodrome operator regarding the spatial zoning of the area around the airport from the conditions of aviation noise exposure" establish legal procedures for spatial noise zoning of the area around the airport, taking into account the conditions of exposure to aviation noise, preparing of noise maps and conditions for determining aviation noise at and near the airport during takeoff, flight, landing, launch and testing of aircraft engines. When applying an ICAO balanced approach to aircraft noise management, the combined daily equivalent noise level L_{den} is used to determine the boundaries of the area of impact of aviation noise in vicinity of the aerodrome/airport simultaneously with the normative criteria L_{Aeq} and L_{Amax}. Systematic control of aviation noise levels should be performed using stationary (permanent) and mobile (portable) aircraft noise monitoring systems (ANOMS). The need to install ANOMS at the aerodrome area is determined by the operator of the airport (aerodrome).

Aviation noise monitoring data is an information base for summarizing statistical information on the characteristics of aviation noise at the airport (at the aerodrome) and in the vicinity, informing the public, relevant government agencies and local governments about the characteristics of noise, clarifying the actual areas of aviation noise in the vicinity of the airport (aerodrome) to take into account the prospects for the development of settlements. The accumulated database of the results of long-term systematic measurements of aviation noise characteristics is the basis for the development and implementation of both an individual airport (aerodrome) and the aviation industry as a whole to reduce the negative impact of aviation noise on environment (population). The aerodrome operator shall implement measures to reduce the harmful effects of aviation noise using an ICAO balanced approach to noise management.

To evaluate the effect of the protection measures implemented, a comprehensive set of surveys to evaluate the short- and long-term effects should be undertaken. A number of the previous studies indicate that when changes in noise exposure are achieved by source-related measures (quieter aircraft and/or low noise flight procedures implemented, air traffic reduced, etc.), the responses could be higher than those predicted from the exposure-response relationships established from a more stable condition. In studies where the changes include noise screens or insulation efforts, the change may be smaller than predicted. A review of different theoretical approaches explaining such differences can be found elsewhere.

Airport noise monitoring is generally used to evaluate noise abatement programs and to develop aircraft departure and arrival procedures that minimize the impact of aircraft noise based upon altitude, flight path, and time of day.

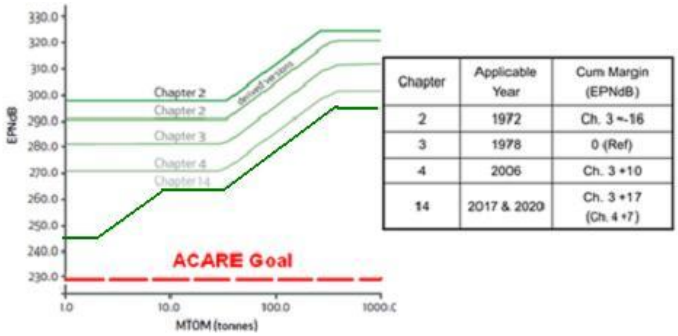
Permanent or/and temporary (portable) noise monitoring to be undertaken usually in local community on assumption that aircraft noise will exceed what is considered ‘acceptable’ or legally permissible level of noise, and in this connection it is necessary to refer to the legislative control on aircraft noise. The number and location of the terminals in noise monitoring system is important depending upon the specific role they are to play inside this system. The portable noise monitors allow the operator of the airport or other independent organization responsible for supervising the noise exposure in environment to provide homeowners with specific information about aircraft noise levels at a specific home during a sample two-week monitoring period. For example, in USA practice this data is for their information only. Due to strict US Federal Aviation Administration (FAA) guidelines, the data collected by the portable noise monitors will not be used to determine eligibility for the Residential Sound Insulation Program around the airports.

Aircraft noise continues to be a concern for neighborhoods in a region of airport location and across the state. An increase in complaints at any airport has been attributed to community and media awareness of airline schedule changes to accommodate early morning and late-night travel demand, resulting first of all in more consolidated flight corridors over some neighborhoods (usually controlled by flight tracking subsystem of the overall aircraft noise monitoring system - ANOMS), noise abatement flight procedures (usually controlled by noise monitors of the ANOMS) and/or even by flight restrictions along specific flight routes close to the neighborhoods. Usually a key strategy for limiting aircraft noise exposure to population over the broader region is to maximize aircraft movements over the non-residential area (for example over the forest or water) and minimize movements over communities.

3. Balanced approach to noise management and monitoring

Noise management or protection program in airport usually based on ICAO Balanced approach to noise management: noise reduction at source and noise certification of the aircraft; noise zoning and appropriate land-use in airport vicinity; noise abatement flight procedures; flight restrictions (usually last element, if the first three are not effective in solution of any noise problem). Balanced approach considers the management of noise exposure over area of noise control. Noise monitoring in this case is the main instrument to assess the efficiency of these noise management program in airport or of any its element separately.

Noise reduction at source and noise certification of the aircraft is a strategic element, which defines a noise approval for the aircraft, granted according to a standardized procedure in which the noise emissions of the aircraft are measured at three defined monitoring points during a flyover – taking off, climbing and descending before the landing – the mostly laud flight stages. Continuous reduction of aircraft noise in source by implementation of newish technologies to engine and airframe design provides a fundament for more stringent noise levels (figure 3.a) and noise footprint (Figure 3b) of the aircraft – changes due to noise reduction technologies are dramatically large, aircraft produced today are 75% quieter than those of 50 years ago.



a)

b)

Figure 3. Noise exposure reduction of the aircraft during last 50 years from ICAO Annex 16 Chapter 2 till Chapter 14 certification norms: a) certification norms from the ICAO Annex 16, vol. 1 Aircraft noise; b) footprint in yellow – Chapter 2 model of aircraft, e.g.: B737–200; in blue – first generation Chapter 3 aircraft, e.g.: MD80, B737–200 Hush Kit; green – current Chapter 4 aircraft with, e.g.: A320, B737–800; red - modern current Chapter 14 aircraft with geared turbofan engines, e.g.: A320neo

As a result a modelled overall 65 L_{DN} noise contour at airport has shrunk in size consistently since 1970-ies (Fig.4) despite an increase in total aircraft operations because of the replacement of ICAO Chapter 1 and 2 aircraft with Chapter 3 and 4 aircraft, further implementation of Chapter 14 aircraft in operation will reduce them much more.

Higher noise exposure means higher population annoyance to noise – a number of complaints will arise. Day-Night Average Sound Level L_{DN} (or DNL index) is a 24-hour equivalent sound level similar with L_{DEN} used in Europe. L_{DN} is expressed as an average noise level on the basis of annual aircraft operations for a calendar year. To calculate the L_{DN} at a specific location, sound exposure levels (SELs) (the total sound energy of a single sound event) for that particular location are determined for each aircraft operation (landing or takeoff).

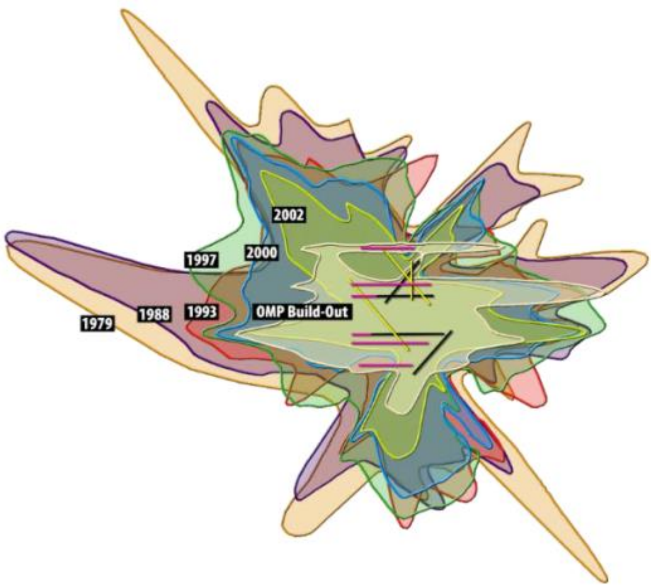


Figure 4. 65 L_{DN} noise contour changes at airport O'Hare (Chicago) due to more stringent standard requirements to aircraft noise despite an increase in flight traffic

The SEL for each operation is then adjusted to reflect the duration of the operation and arrive at a "partial" L_{DN} for the operation. The partial L_{DN} are then added logarithmically — with the appropriate penalty for those operations occurring during the nighttime hours — to determine total noise exposure levels for the average day of the year.

4. Noise monitoring instrumentations

A noise monitor is an electronic instrument that measures sound pressure levels. Each noise monitor (other words – station or terminal) uses a Class 1 noise meter approved to International Electrotechnical Commission (IEC) 61672 Electroacoustics standards and can record multiple octave or 1/3-octave bands and threshold exceedance levels. An operator of the noise monitoring system must routinely checks the calibration and performs annual preventative maintenance for every noise monitor in the ANOMS. Noise monitors are sited in consultation with community representatives and based primarily on the criteria outlined in “Criteria for the Permanent Noise Monitors” technical document for ANOMS.

For example, a Svantek noise monitoring system is based on SV 200/SV 200A top-of-the range stations (accuracy Class 1 IEC 61672-1: 2013 type approved in EU). Their measurement capabilities of the SV200/SV 200A are optimized for noise monitoring applications. They measure and store results suitable for automatic reports, detailed information for advanced post-processing analysis and streams live data stream for real time noise monitoring. Standard measurement functionality includes multi-profile data logging, real time 1/1 and 1/3-octave logging, audio event recording and statistical analysis. Measuring capabilities can be extended with real time audio streaming and weather condition monitoring. SV 200/200A can be used for both and 0° and 90° reference direction, typically used for aircraft and environmental noise. The reference direction is user selectable in the instrument configuration.

The weatherproof housing protects SV 200 noise monitoring station against extreme weather conditions while fulfilling class 1 accuracy. Special attention was given to the highly efficient windscreen which reduces noise, even at high wind speeds. Internal heating and rugged a dual layer housing enables the SV 200 to operate from -30°C up to +60°C and humidity up to 100% RH.

The Svantek SV 200 Noise Monitoring Station is a fully integrated solution for unattended noise monitoring applications featuring an internal web server for system configuration, live data streaming, data management and battery powered operation providing true flexibility for both short and long term measurements. ‘All in one’ design for portable, mobile and permanent noise monitoring installations of the Svantek SV 200 provides:

- Real-time 1/1 or 1/3 octave analysis;
- Audio events recording;
- Rugged housing protecting the system against harsh environmental conditions (IP66);
- Integrated electrostatic actuator for full system verification;
- Class 1 according to IEC 61672;
- Integrated high speed 3G or Wi-Fi modem;
- Automatic time synchronization;
- Large windscreen against high-speed wind;
- Intelligent heater protecting microphone against humidity;
- Live audio & data streaming capabilities;
- Low power consumption, integrated Li-Ion battery and direct connection for solar panels;
- Highly reliable and secure data push and configuration pull communication protocol;
- Both, server and web based system configuration;
- Community & airport characteristics available simultaneously.

A model SV 200A differ from SV 200 with built-in 4 microphones for noise directivity detection. This revolutionary solution enables identification of dominant noise sources providing information about their location both in vertical and horizontal directions. In practice, the measurement of directionality gives the opportunity to indicate the dominant source of noise in the area of measurement or to exclude unwanted events. Real-time frequency analysis in 1/1 and 1/3 octave bands and audio signal (a specific file in wave format) for listening and recalculation allow to provide the detailed analysis of the detected noise signal for further recognition of the noise source in acoustic environment. The files with their results may be saved as time-history data.

The SV 307 is a new noise monitoring terminal (NMT) dedicated for permanent noise monitoring, now with a high speed 4G modem. The SV 307 integrates Class 1 sound level meter with a modem in the removable waterproof housing. The SV 307 is equipped with a patented MEMS microphone with a life-time warranty. The measurement data is stored on the microSD card. The SV 307 is designed for permanent noise monitoring, it has been equipped with a patented double self-system check: an inbuilt reference sound source producing 100dB at 1 kHz plus real-time check based on reference microphone. The waterproof housing of SV307 can be removed to get an access to the user interface with a colour display and keypad. The SV 307 has an internal Li-Ion battery and interface for connecting solar panels. A waterproof mains adapter for charging the battery and powering the station is also included.

SvanNET cloud service monitors the wireless communication, powering and access to the SV 307 data. The scope of the basic SvanNET can be extended with multipoint project management that offers data storage in the cloud, data sharing, advanced alarming and reporting features. SvanNET is an on-line solution which means it doesn’t require software installation and is accessible through a web browser. The responsive design enables use of SvanNET on various devices such as smartphones or tablets. SvanNET data storage is a quick access to the measurement data due to an unlimited download speed. In the case of long term measurements, the stored data can be conveniently browsed and downloaded by the time range.

The SvanPC++ Environmental Measurements feature is designed for post processing of data recorded by the SV 307 system. It offers a powerful calculator and an automated noise event finder for noise source identification. The option for 1/3 octave real-time analysis allows measurement of the noise frequency contents and is used for verification of noise sources in the environment. Plus time domain signal recording to wave-format works during measurement and is logged in parallel to a time history. Once downloaded to PC it can be played back.

V 277 PRO is a portable monitoring system housed in a waterproof case dedicated for periodic outdoor measurements. The station is based on the SVAN 977 which can be easily removed from the case and used as a hand-held sound level meter. Class 1 noise measurements are performed over a very wide dynamic range over 110 dB from 10 Hz up to 20 kHz. The time-history of results such as L_{eq}, L_{Max}, L_{Min} and L_{Peak} with two simultaneous logging steps is saved on 8 GB microSD card (upgradeable up to 128 GB). The station can perform real-time frequency analysis in 1/1 octave bands and save it as time-history data.

The modern ANOMS (every its monitor) records noise events based on threshold exceedance. Each noise event starts at the time the noise level exceeds a decibel threshold, typically slightly above the background or ambient noise level, and ends at the time the noise level returns to the threshold. Noise monitoring and analysis is complicated by the fact that aircraft are not the only source of noise. A number of tools are used for identifying noise events which are not caused by aircraft. Some of the systems system achieves an accuracy of 0.970 (if trained on big number of previous events) manually labeled noise events.

The single event noise data may be uploaded to the webpage on a daily or weekly basis. Each file contains: the monitor Site ID, the start date and time of the event, the date and time of the peak noise for the event, the duration in seconds of the event, and the L_{Amax}, the L_{Aeq}, and the SEL of the noise event in decibels.

Once the noise events are collected and downloaded to the ANOMS, they are correlated to actual aircraft operations. The process that correlates noise events to aircraft operations uses defined parameters to match every eligible noise event to specific aircraft operations. Noise events that fall outside these parameters are classified as community noise.

The criteria provided below are established to guide the airport authority and the community in their decision-making regarding requests for additional noise monitors and decisions related to decommissioning. This criteria is consistent with and expands upon the criteria in the fact sheet of ANOMS document:

- Main purpose for installing a permanent noise monitor
  - Report aircraft noise levels as a matter of public interest
  - Monitor trends in aircraft noise
  - Validate the approved noise contours
- Criteria for Selecting a Location for a Permanent Noise Monitor
  - Location in relation to arrival/departure flight paths based on air traffic conditions (airspace availability and utilization), airfield conditions and weather conditions
  - Distance from the 65 DNL noise contour
  - Need not already being met by existing monitor locations (currently 36 sites)
  - Ambient (background) noise levels---residential areas vs. industrial areas
  - Access to utilities (electric power and telecommunications)
  - Cost/Benefit of data associated with an additional monitor
  - Input from the local communities
- Criteria for Decommissioning a Permanent Noise Monitor
  - Location in relation to arrival/departure flight paths based on air traffic conditions (airspace availability and utilization), airfield conditions and weather conditions
  - Significant decreases in actual aircraft noise levels
  - Consistent increases in actual ambient noise levels
  - No major negative impacts on long-term trend analysis
  - Inability to renew lease agreement or request from property owner after coordination
  - with community to locate a replacement location
  - Costs associated with the relocation

Conclusions

Noise monitoring system is very important instrument to assess the efficiency of any noise abatement program in airport under consideration. With time their complexity due to bigger number of monitoring stations is larger, but new communication technologies provide their simplicity in operation and less costs in manufacturing and operation. Newish ANOMS are looking more available even to airports with small air traffic – they are looking beneficial even in such cases. So in Ukraine the expectation of their installation are much realistic than few decades before.

Acknowledgement

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