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Research Article

Aircraft Noise Compatibility of the Airports with Progress of Noise Reduction at Source

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Abstract

Creation of noise exposure maps and airport noise compatibility programs are the basic steps in aircraft noise exposure and impact management in/around the airports, both of them are fundamental for aircraft noise zoning procedures. Noise reduction at source is also a strategic element of this management, and efficient implementation of quieter aircraft designs in operation provides closer distances of the boundaries of noise zones prohibited for residences to runway axis. These new conditions oblige the decision-makers, responsible for noise management, to be stricter with procedures for noise zones definition and to include in consideration a number of new acoustic sources inside the aerodrome besides the aircraft in flight operation, which may influence the overall exposure and impact of noise on population living or/and acting around the airport. In other words, current noise exposure maps and airport noise compatibility programs must include these dominant noise sources at specific locations of the airport also, not only the flight noise sources, as it was enough before. Today such essential noise sources for consideration in airport noise management are the aircraft in maintenance and overhaul and the aircraft during the taxing between the runway and stands on apron first of all, especially if their locations are quite far from aircraft flight operation routes and close to the residential areas around the aerodrome. The noise maps are required to be calculated currently, as for aircraft operation, so as for their maintenance and overhaul, but the measurements are evident also for their confidence and accuracy purposes.

Keywords

Aircraft Noise,
Zonning,
Reduction at Source,
Compatibility,
Measurements,
Calculations

Time Scale of Article

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1. Introduction

There are many environmental problems at airports today resulting directly from poor or still non-existent planning for compatible land use. In best cases the national regulation for environment protection requires airports the creation of Noise Exposure Maps (NEMs) and Airport Noise Compatibility Programs and/or Planning (ANCP). For example, in the USA the ANCP was launched by the Aviation Safety and Noise Abatement Act of 1979 (H.R.3547c, 1979) and is currently required by

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US FAA Part 150 (Part 150, 1984) as an obligatory element of the overall airport management. Part 150 is the primary federal regulation directing planning for aviation noise (AN) compatibility on and around the airports. ANCP identifies measures the airport operator has taken or proposes to take to reduce, and/or prevent the introduction of, incompatible land uses in the airport vicinity. Two principle preventions for airports are taken in mind - direct environment protection from the dominant impacting factors and the operational capacity support of the airport at the maximum level.

Noncompatible land use means the use of land that is identified as normally not compatible with the outdoor noise environment. Sanitary norms are the ground for limiting the noise in accordance with activity provided inside the area (at a point) of consideration. Part 150 established the yearly day-night average sound level (DNL or L_{DN}) to be used for AN assessment and defined under Appendix A the appropriate limits for human activities in the vicinity of airports being compatible with them. In general case the ANCP should be addressed on following main activities from the airport with essential contribution of calculated NEMs for assessment of the effect: to reduce existing and forecasted AN levels over existing noise-sensitive land uses; to reduce new noise-sensitive developments near the airport; to mitigate adverse impacts in accordance with federal guidelines (sanitary norms should be used for assessment); to provide mitigation measures that are sensitive to the needs of the community and its stability; and to be consistent with local land use planning and development policies. Feasibility and economic efficiency should be also taken in mind - not only the environmental issues.

Compatibility and consistency of airport activities are defined by AN limits for population health protection in dependence to their activity inside specific AN zones (ANZ) and for defining ANZ boundaries. The boundaries of the ANZ are defined due to calculated NEM, usually in accordance with internationally approved approach/guideline. For AN such an approach is prescribed in the SAE Standard AIR 1845 (SAE AIR1845A, 2012) and in the guideline ICAO Doc 9911 (ICAO Doc 9911, 2018) or its ECAC analogues Doc 29 (ECAC Doc 29, 2016). Calculated L_{DN} = 65 dBA is still identified as the threshold of significant AN exposure as well as incompatible with residential land use. Inside every predefined zone the noise-sensitive land use should be prevented. Any new development inside the ANZ with $L_{DN} \geq 65$ dBA is prohibited, the existent residential and/or administrative areas must be protected if possible, if not – replaced out of the ANZ.

In Europe the recent study of noise exposure level and noise mitigation strategies at six quite different airports (Frankfurt, Heathrow, Zurich, Madrid, Barcelona, and Malaga) during the decade 2003-2013 has been shown by (G.Alonso, A.Benito, L.Boto, 2017). The study provided an overview of the current noise regulations and of noise measures applied by the different airports which main goal to enforce a more stringent noise level limit to ensure that the latest noise reduction technology is incorporated into the aircraft design. According to this study, the average daily noise reduction was possible mainly due to the development of new aircraft technologies focusing on noise reduction at source and consequently on the fleet renewal performed by airlines in the last decades. However, there is still a long way to go as the resident complains have not stopped since the noise pollution is still bothering people mainly at night time.

Aircraft noise exposure calculations need to be highly accurate due to their impact on land-use planning (Meister J., Schalcher S., Wunderli J.-M., Jäger D., Zellmann C., Schäffer B., 2021). Calculation uncertainties strongly depend on the modelling approach, model sophistication, traffic input data, available sound source data and airport peculiarities such as specific aircraft fleet or different flight procedures. In the past, model validations were conducted for different models such as ANCON in the United Kingdom (Rhodes D., Ollerhead J., 2001), and FLULA2 (Buetikofer, R.; Thomann G., 2001) and sonAIR (Jäger D. , Zellmann C., Schlatter F., Wunderli J.-M., 2020) in Switzerland. Studies which compare different noise models together and against measurements are not available. Both, FLULA2 and AEDT, are best practice programs, primarily developed to calculate complex scenarios such as yearly air traffic operations, which include various aircraft types and large numbers of flights. All of them are still not consider as dominant, at least in some locations of the airport, another noise sources except aircraft in flight.

In line with the European Directive 2002/49/EC the Turkish Regulation on Assessment and Management of Environmental Noise (RAMEN) implemented the maximum allowable limit for noise is L_{den} = 63 dB (A) (Akdeniz H., Sogut Z., Turan O. 2021). Due to RAMEN aircraft-induced noise should be evaluated under four main headings including the noise generated during maintenance of the aircraft on the ground. But still the Noise Exposure Mapping at the airport (International Eskisehir Hasan Polatkan Airport, LTBY, was assessed as an example) is realized for flight traffic only – without the contribution of all other dominant noise sources in airport.

In Ukraine the similar system was introduced as it was shown in (Konovalova O., Zaporozhets O., 2021): the rules (SSR-173, 1996) define the ANZ around the airports (aerodromes), the aviation rules (SAAU AR-381, 2019) require to use the DENL (European analogue of the DNL) for ANZ boundaries calculations and proving them by noise measurements in accordance with methodology of

(SAAU Order 585, 2020). The rules (SSR-173, 1996) still consider equivalent sound levels L_{Aeq} and maximum sound levels L_{Amax} as the criteria for noise zoning also (Konovalova O., Zaporozhets O., 2021), which may even confuse the decision-makers, responsible for noise zoning both in airport authority and in urban administration.

ICAO also proposed Balanced Approach to AN management in airports (ICAO Doc 9829, 2004), consisting of 4 main elements – ANZ and compatible land usage is among them. It is of the same strategic importance as a reduction of noise at source by designing the aircraft quieter in accordance with ICAO Standards requirements (ICAO Annex 16, 2019). The evident success during last decades in designing and implementation quieter aircraft provides new circumstances for ANZ and compatible land usage around the airports.

Communities commonly construe aircraft noise regulatory policy as intended to protect airport operations from limitations imposed to reduce community impacts, while airport managements tend to believe that airport noise policy favours consideration of community more than airport interests. AN compatibility of the airport may be considered as broken if the ANZ are defined by calculation of flight AN exposure only. A long-term balance between satisfying public demand for air transportation services on the one hand, and for habitable residential neighborhoods near airports on the other, has proved difficult to achieve. In many cases in EU and around the world in general, intense controversies over increases in AN exposure have delayed or prevented the construction of desired additional airport capacity.

2. Calculation of Aircraft Noise at Kyiv/Zhulyany Airport

Aircraft noise has been an issue in Ukraine at almost every airport over the last four decades. Technology has improved aircraft performance capabilities and reduced its noise. Continued progress in achieving AN and land use compatibility is now focused at the airport specific level.

AN calculations are doing for every airport in Ukraine in accordance with certification rules for the aerodromes, currently these rules are defined by Aviation Rules (SAAU AR-381, 2019), previously by predecessor methods (Zaporozhets O., Tokarev V., 1998, DSTU-N B V.1.1-31, 2013). For example, for the airport Kyiv/Zhulyany first calculations in accordance with guideline (ICAO Doc 9911, 2018) were provided at the beginning of 1990s, when the fleet consisted of USSR aircraft designs completely, mostly certified with Chapter 2 requirements of the ICAO Annex 16 (Fig. 1a). The same flight traffic scenario in the 1990s, but all airplanes in a fleet complying Chapter 2 (ICAO Annex 16, 2019) requirements, have been replaced by airplanes complying with Chapter 3, produce AN exposure as shown on a map in Fig. 1b. The AN contour 65 dBA was reduced 2.5 times by this replacement, which is similar to ICAO decision to phase out the Chapter 2 aircraft in 1997-2002 from international operation.

During the decade 2001-2010 the air traffic was reduced dramatically in Ukraine for a number of reasons, a fleet consisted of Chapter 3 aircraft dominantly – these conditions provided the reduction of AN exposure up to 10 times (Fig. 1c) in comparison with real scenario 1990s (Fig. 1a). At least, last calculations were made at the end of 2011-2020 decade, traffic increased twice during the decade, so as the AN exposure (Fig. 1d). The calculated areas of the AN contours for all the analysed air traffic scenarios are shown in Tab. 1.

The prohibited for new residential and administrative developments ANZ 65 DNL for all the scenarios are compared between themselves in a Fig. 2. It must be concluded that the accuracy and adequacy of the calculation methodology for AN assessment was changing during this period, mostly in a way of AN contour reduction. For example, the calculated contours for the 1990s scenario includes very specific and very wide segments connected with noise exposure produced at starting points of the aircraft run-offs along the runways, which quickly become narrower along the run-off. This effect of noise radiation assessment in backward direction to aircraft run-off was improved in the SAE Standard AIR 1845 (SAE AIR1845A, 2012) and in the guideline (ICAO Doc 9911, 2018) at the end of 1990s and appropriate AN exposure was reduced essentially. For a number of airports with specific aerodrome layout the improvement of calculation methodology and implementation of quieter aircraft in operation provided the conditions, where and when the flight stages are not responsible for the overall AN exposure around the airports – aircraft taxing, aircraft engine run-ups, other aircraft operation and maintenance on ground surface began to contribute to AN exposure in specific directions and provided higher impact on residential areas than the aircraft in flights.

A similar situation is observed at some airports of Ukraine. For example, at the Kyiv/Zhulyany airport (Fig. 3) the apron with aircraft stands near the both terminals is located at a distance of more than 1 km from the runway axis and the contribution of noise from of aircraft taxiing and services at the stands to the total noise load on residential areas in Kyiv, especially in the North of the airport (on Povitroflotska Street, the nearest building to the aircraft stand on the apron is 400 m away, to the runway - 1500 m). In such and similar cases, projects to assess the sound levels of airport noise should include contribution from the ground stages of the aircraft movement – taxiing and operation/services on stands (in Fig. 3a passenger aircraft stands are close to passenger terminal, business aviation stands and aircraft engine run-ups at MRO). Noise contour for L_{Aeq}=65 dBA in 1990s traffic scenario (Fig. 1a) was ~10 times larger than the same in 2010-2020 decade (Fig. 1d) and covered the area with aircraft stands and taxi ways, so it was not necessary to assess the contribution from these noise sources previously.

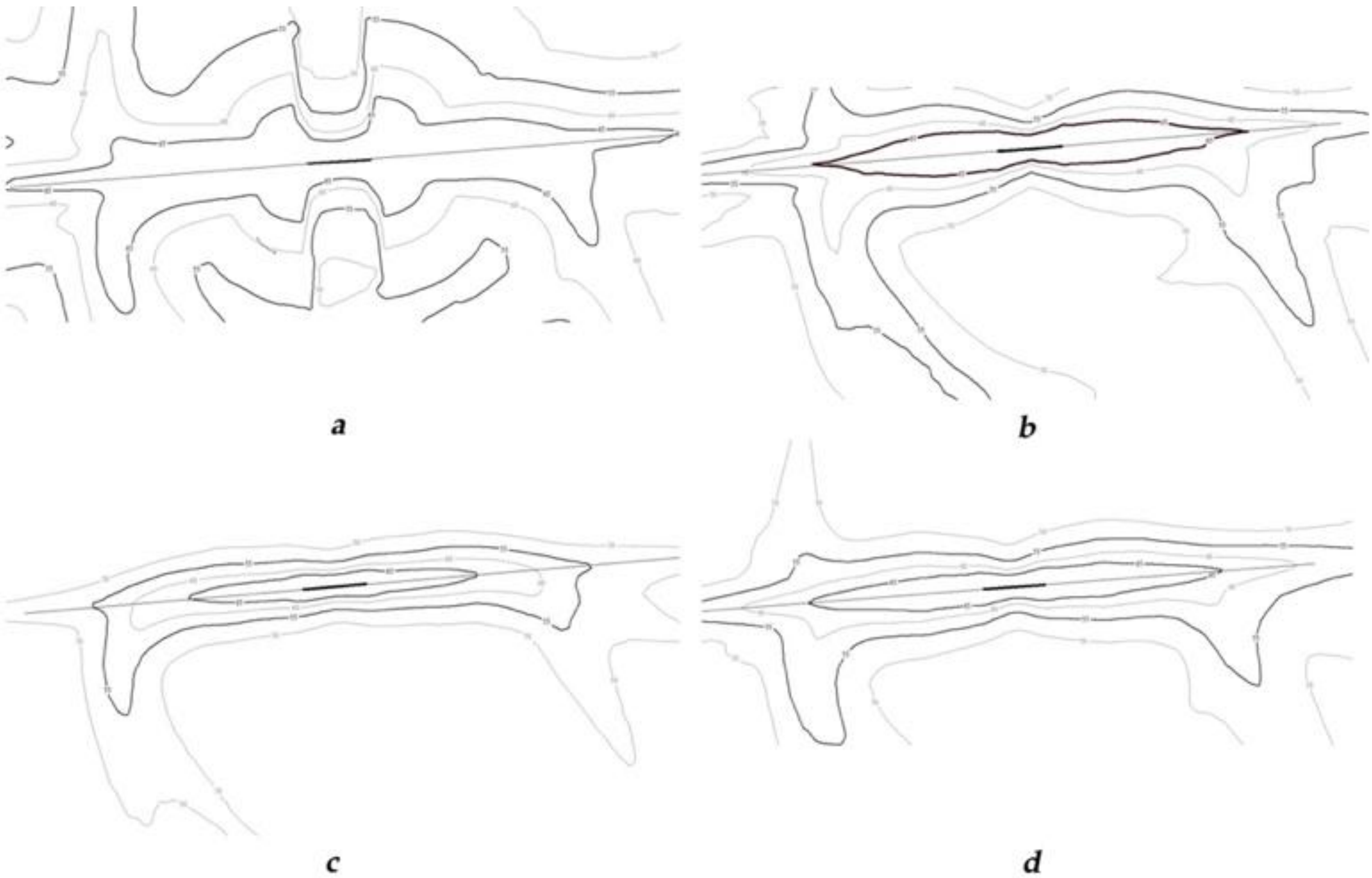


Fig. 1: AN contours for equivalent sound levels LAeq day (internal contour 65 dBA; outer contour 55 dBA) for air traffic scenarios at the airport Kyiv/Zhulyany during the daytime: a) operational scenario for 1990s; b) the same air traffic as in the 1990s, but all airplanes complying with Chapter 2 requirements have been replaced by airplanes complying with Chapter 3; c) air traffic scenario for 2001-2010 decade -- Chapter 2 aircraft are absent in the fleet; d) air traffic scenario for 2011-2020 decade - all airplanes are complying with Chapter 3 and 4 requirements (Annex 16 of ICAO, Volume 1)

Table 1 AN contour areas for equivalent sound levels $L_{Aeq\ day}$, dBA for air traffic scenarios at the airport Kyiv/Zhulyany during the daytime

$L_{Aeq\ day}$, dBA	Contour area, m^2			
	1990s air traffic scenario, Chapter 2 aircraft	**1990s air traffic scenario, Chapter 3 aircraft**	**2001-2010 air traffic scenario**	**2011-2020 air traffic scenario**
50	4.8583E8	1.5477E8	5.2877E7	1.2138E8
55	2.2554E8	5.5186E7	2.0198E7	3.9045E7
60	7.3368E7	2.2976E7	9.6089E6	1.7348E7
65	2.5911E7	1.0265E7	3.7231E6	7.9646E6

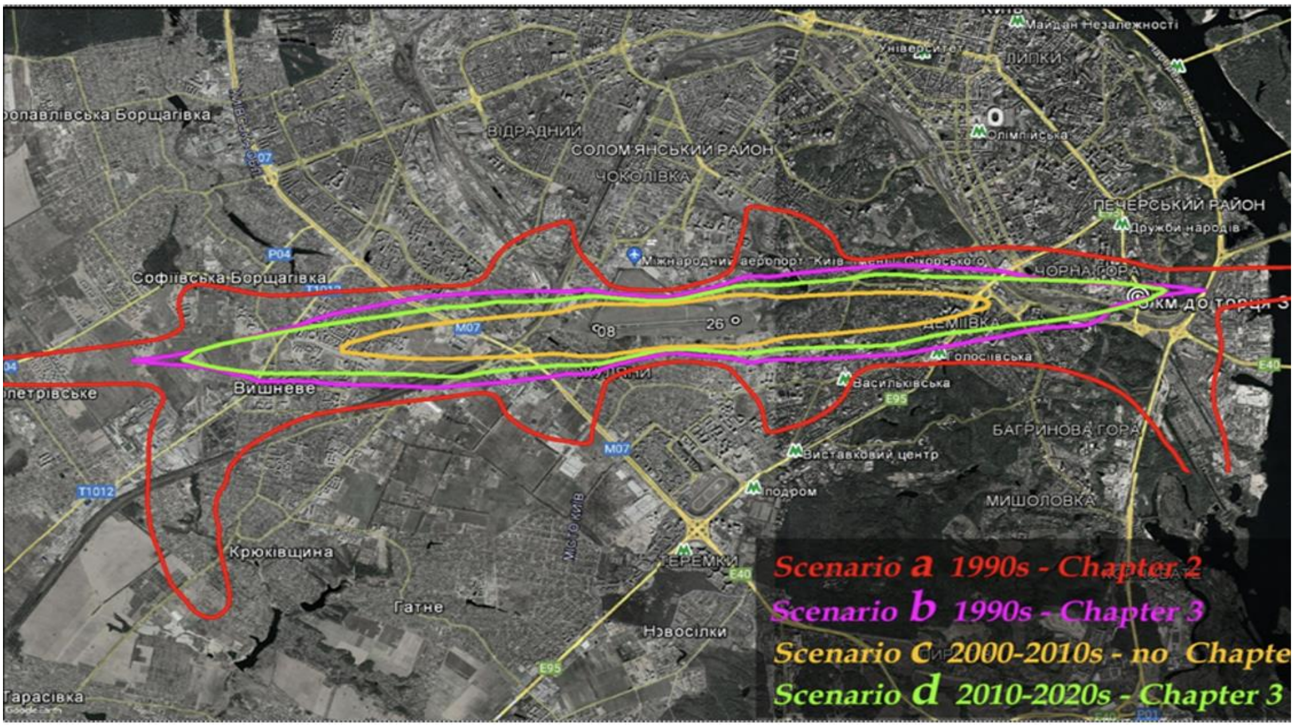
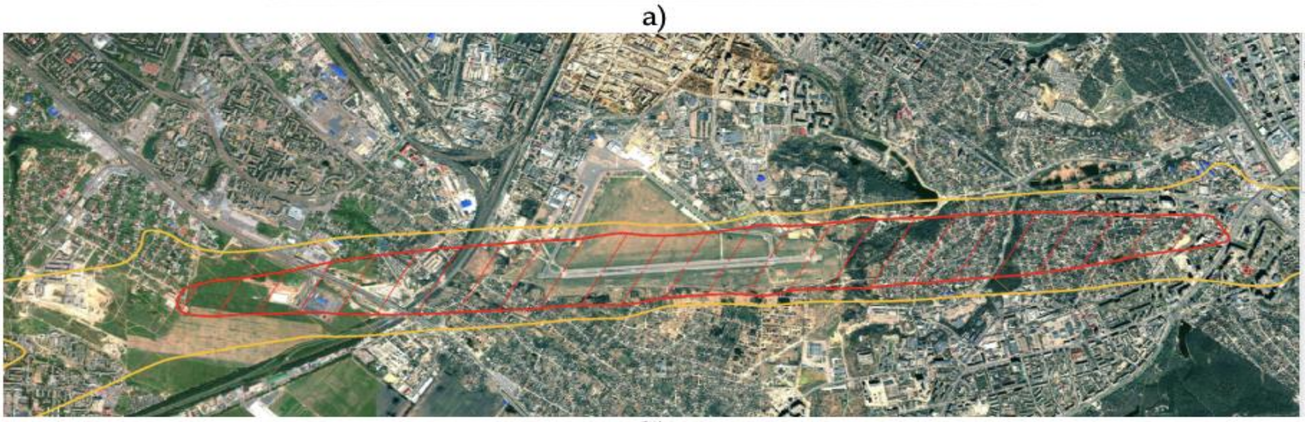


Fig. 2: Comparison of AN contours for equivalent sound levels $L_{Aeq\,day}$ = 65 dBA for the air traffic scenarios, shown in Fig. 1 between themselves

a)



b)

Fig. 3: Airport Kyiv/Zhulyany: a) the apron with aircraft stands near the terminal is located at a distance of more than 1 km from the runway axis; b) noise zones for 2010-2020 air traffic scenario – red contour is for Leq day=65 dBA

3. ICAO Standard Requirements to Aircraft Noise and Management of Noise Exposure Around the Airports

Today's civilian aircraft are quieter than at any time in the history of jet-powered flight. The new ICAO AN standard requirements (Annex 16 of ICAO, 2019) do not force manufactures to develop new technology. However, as new noise reduction technologies emerge, they do ensure that new aircraft continue to meet increasingly quieter standards within the bounds of what is technologically feasible and economically reasonable. As a result, for many years there was a steady decline in the number of people exposed to significant noise in communities located near airports. In recent years, however, as aviation industry growth has led to an increase in operations in many areas, the number of people and the size of the areas experiencing significant aircraft noise has started to show a gradual expansion.

The single most influential factor in that decline was the phased transition to quieter aircraft, which effectively reduced the size of the areas around airports experiencing significant noise levels. A more significant impact on AN assessment should be expected from a further reduction in noise levels at the source, when the sound levels at the control (certification) points and for the noise contours with the normative value of the sound level (eg 75 dBA $L_{Amax\ night}$) will not be displayed on the airport noise map. As can be seen from **Fig. 4** the AN contour for take-off/climbing of the aeroplane with Chapter 14 noise performances (ICAO Annex 16, 2019) is already within the runway size. The character aircraft type for each ICAO Chapter group is shown in **Tab. 2**. For the shown spectral classes the class 101 includes dominance of jet noise in low frequency bands if to compare with classes 103 and 104. Therefore, further expected more stringent requirements for AN levels at three points of noise control (take-off, climbing and descending before landing) will create conditions where the noise contours for single departure and arrival events will be indeterminate for exposure assessments with essential noise levels (correspondent to environmental noise limits) and decision-making in the airport noise control program.

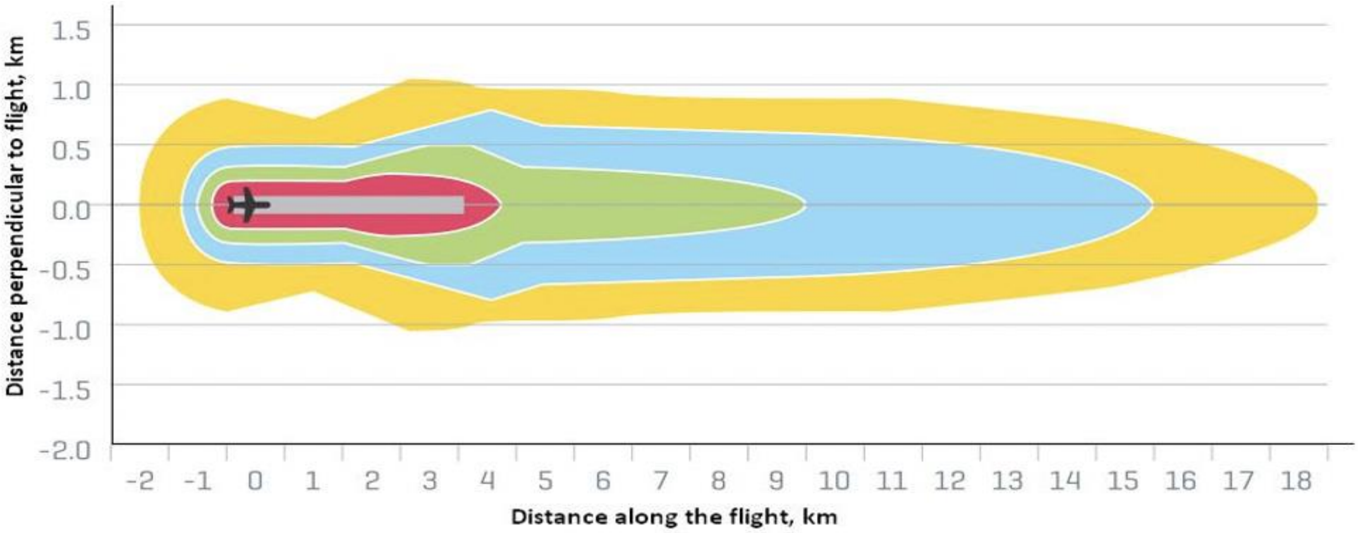


Fig. 4: An footprint (single aircraft departure contour for SEL=80dBA) reduction during last 50 years from ICAO Annex 16 Chapter 2 till Chapter 14 certification norms: in yellow – Chapter 2; in blue – Chapter 3, aircraft Hush Kit; green – Chapter 4; red - current Chapter 14 (European Aviation Environmental Report, 2019)

Table 2 AN contour areas for equivalent sound levels $L_{Aeq\ day}$, dBA for air traffic scenarios at the airport Kyiv/Zhulyany during the daytime

	Chapter 2	Chapter 3	Chapter 4	Chapter 14
Correspondent Stage of the US FAR 36	Stage 2	Stage 3	Stage 4	Stage 5
Character aircraft type	B737-200	B737-200 Hush Kit	B737-800, A320	B737MAX, A320neo
Spectral class in ANP database	101	102	104	103

For investigations of noise footprints corresponding to a single flight path, the coordinates of the boundaries and areas of noise contours are defined simply by the intersection of cylinder surfaces with predefined sound exposure level around the axially-symmetric noise source – an aircraft in flight, with the earth's surface of AN calculation (Zaporozhets O., Tokarev V., 1998; Zaporozhets O, Tokarev V, Attenborough K, 2011). In other words, the central axis of these cylinders is coincident with the flight path axis and the radius of a particular cylinder surface is defined as *the noise radius* R_n for a given noise level. The aircraft maybe represented as a moving point noise with constant velocity v. At the point of interest under the flight path:

$$L_A(t) = \underline{L_{Amax}} + 10 \lg [R_n^2 / (R_n^2 + v^2 t^2)], \quad (1)$$

where L_{Amax} is the maximum value of $L_A(t)$ for a given noise event. For the simplified case, if noise source is considered without any directivity of sound radiation and sound absorption maybe neglected, it occurs when the aircraft is directly above the point of interest

$$LAmax = LAmax – 20 \lg Rn,$$

where $\underline{L_{Amax}}$ is defined by the flight mode (engine mode, flight velocity and aerodynamic configuration). If the further simplification of zero sound absorption is made, a formula (1) can be written for sound exposure level *SEL* in the following form:

$$SEL = LAmax + CR - 10 \lg (Rnv) \quad (2)$$

where C_R is the function of sound absorption along the distance between the trajectory and the point of interest and of the reference time duration T_0 (for *SEL* it is equal to 1 s).

In general case the whole flight path may be divided into separate sections, in each of which the flight parameters remain approximately constant, calculations are performed in each section k and the results are summed. If presume the overall flight path under consideration with flight parameters (engine thrust T, flight velocity v, and flight path angle γ) being quasi-constant and for the particular case of zero rotations of each segment of the path, it transforms to the equation for an ellipse (**Fig. 5**):

$$z2\sin2\gamma + x2 = Rn2. \quad (3)$$

If to assume that flight performances are the same between the ICAO Chapter 2 and Chapter 14 aircraft (or between Stage 2 and 5 for the US FAR 36, thus only noise characteristics were changed with time) – the flight path angle γ and thrust T maybe considered equal between them – the reduction of noise radius and area of the simplified noise footprint (ellipse) during the AN certification era is looking like at **Fig. 6**. Reached reduction for current NEO (MAX) aircraft on around 80% of the AN footprint and on 60 % the noise radius is looking similar with more strict calculations of the footprints shown at Fig. 4.

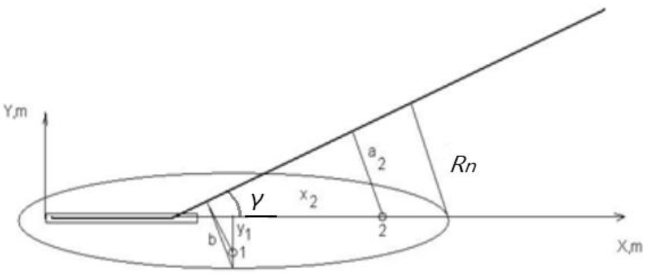


Fig. 5: A simplified form of noise footprint having the shape of an ellipse under the take-off flight path

The difference between the certified noise level at climbing flyover point (L_2) and the level corresponding to the final point on the contour L along the departure flight (or arrival noise contour in dependence to noise level at ICAO standard point No 3) axis may be written (Powell CA, 2003; Zaporozhets O, Tokarev V, Attenborough K, 2011):

$$L_2 – L = C\lg(R_n/a_2), \quad (4)$$

where the constant C defines the attenuation rate, for cylinder spreading its value is near to 10 (formula (2)) and for spherical spreading - near to 20 (formula (1)), a_2 is the minimum distance from the taking off path to the certification point № 2 (for departure).

Similar view is possible on the difference between the certified noise level at take-off (L_1) and the level corresponding to the final point on the contour L aside the flight – ICAO noise control point No 1 in **Fig. 5**. The area S of noise contour at aircraft take-off and climbing is proportional with quite high correlation to the product of L_2 and L_1:

$$\lg(S) = (L_2 + L_1) / C + D, \quad (5)$$

where constants C and *D* are different for various types of the sound levels L, L_1 L_2, and for different groups/types of the aeroplanes (Zaporozhets O, Tokarev V, 1998; Powell CA, 2003; Zaporozhets O, Tokarev V, Attenborough K, 2011). Better correlation between the footprint area and the levels was found for sound exposure levels like *SEL* and *EPNL*. For implementing the approach for strategic analysis of any air traffic and AN load scenario the correlations between the exposure SEL and maximum L_{Amax} sound levels may be used like:

$$SEL = A + B\, L_{Amax}. \quad (6)$$

Attention should be taken in mind in using such correlations like formula (6) (if the higher accuracy of the assessment should be considered), because the constants A,B are different not only for the types (groups) of the aircraft due to their different ANP spectral class (explained in ANP database), but they are different for approach and departure flight stages, and even are dependent from the distance to flight axis (**Fig. 7**) also. It means that constants C and D in (2) may vary with the value of L, which is dependent to distance of noise source from the point of noise control. By-the-way, the difference between the sound exposure levels like *SEL* and *EPNL* is not so big and evident, *EPNL* is usually higher on 2-3 dB over the *SEL* (**Fig. 8**). Strictly talking not only the engine operation mode (thrust) at taking-off/climbing may influence the form of resulting contour for departure flight.

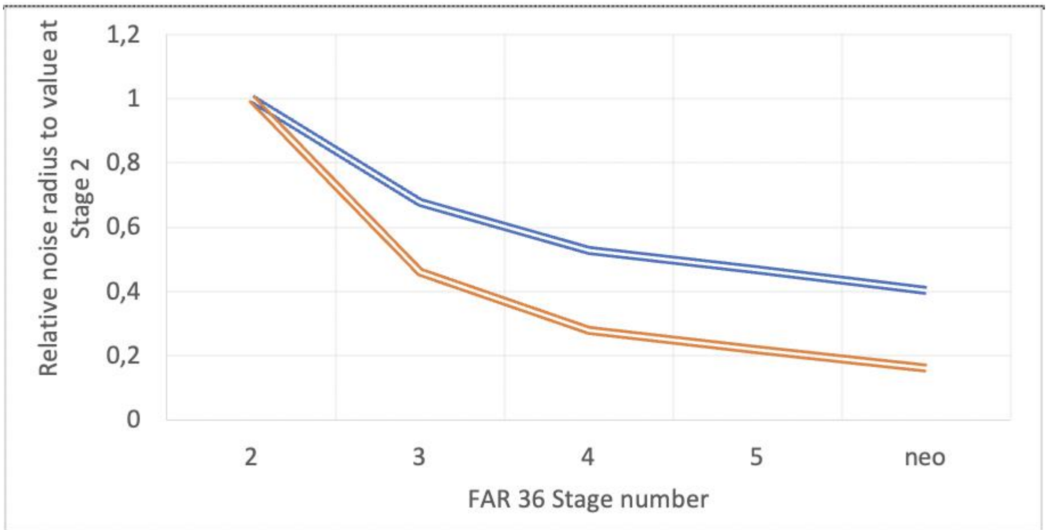


Fig. 6: Noise radius reduction with improvement of noise performances (due to FAR 36 standard stringency) relatively to FAR Stage 2 requirements: blue – relative noise radius; red – relative footprint (ellipse) area

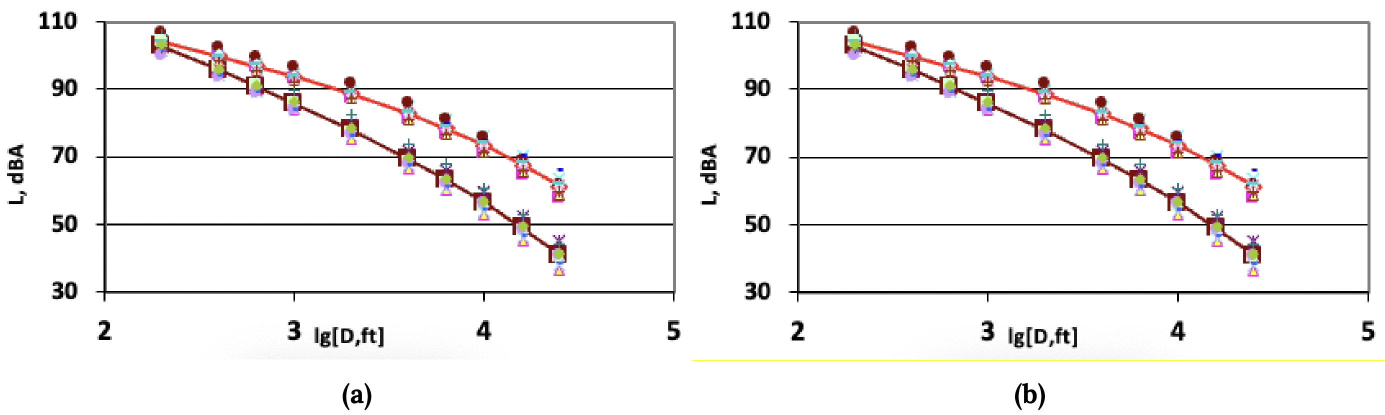


Fig. 7: Dependence (a) between SEL (red rhombuses) and LAmax (brown squares) and the difference (b) between them for the distance to flight axis for the aeroplane group A-320 and B-737

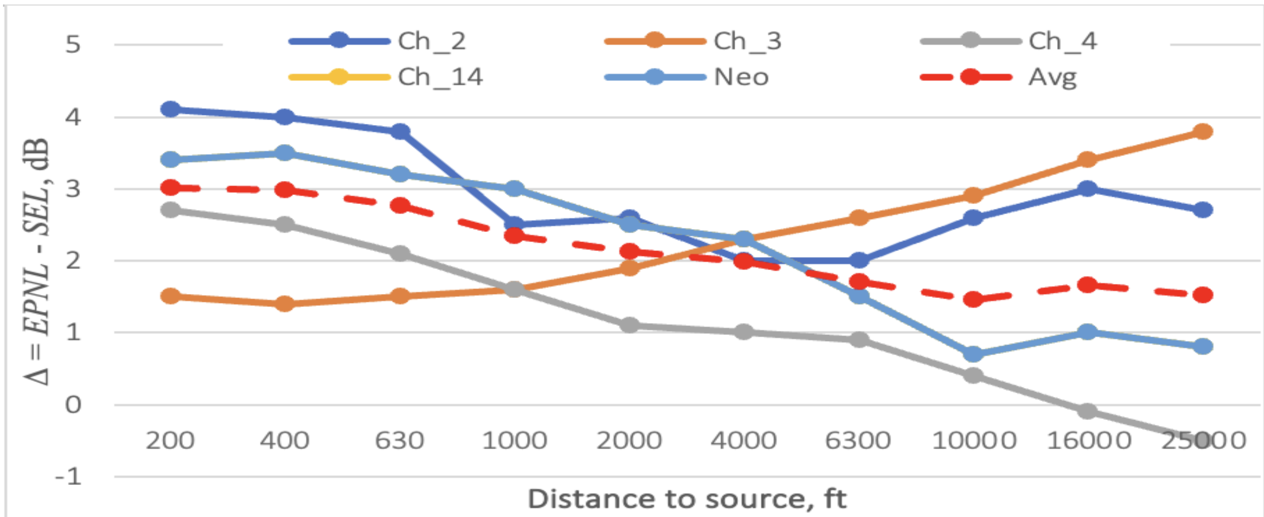


Fig. 8: Difference Δ between *EPNL* and *SEL* with distance for the aeroplane group A-320 and B-737 and different

AN stringency requirements

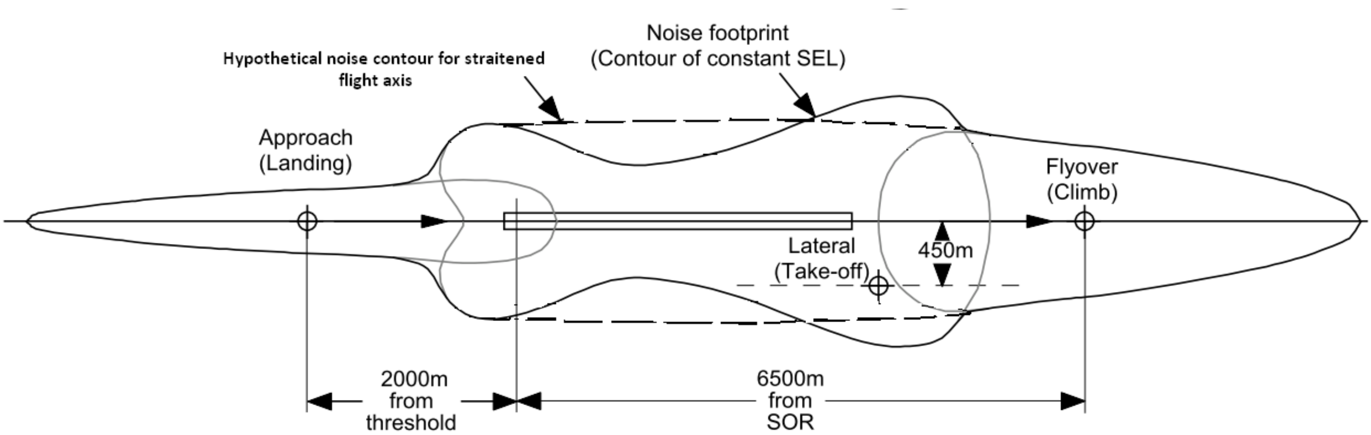


Fig. 9: Hypothetical noise contour for straitened flight during departure and excluded ground effect for sound propagation close to runway

Close to runway the flight altitudes are small and distances to contour line are quite big, so lateral effect is changing the line sufficiently, mostly for the flight path segments along taking-off (**Fig.** 9). If to use the concept of hypothetical contour, defined by equal noise exposure cylinder intersection with surface plane discussed above (**Fig. 5**) and the exposure level on cylinder surface is defined by character noise level for climbing flight stage (dashed line in F**ig. 9**) the changes in contour line and area are covered between themselves and the values are very close one to another for various models – simplified and in accordance with ICAO (ICAO 9911, 2018) requirements (**Fig. 10).**

The dependence for relative area $S=S_{StageK}/S_{Stage2}$ of noise contour at take-off and climbing (S_{TO+CL} in **Fig. 10**) from the acoustics performances (defined by FAR-36 requirements from the Stage 1 till Stage 5) is quite similar with contour area change in **Fig. 1** and **Tab. 1**, as it is shown in **Fig. 11,** and very similar with noise radius and simple footprint area reduction due to improvement of noise performances in **Fig. 6** (shown as FAR 36 standard stringency).

Particularly for the airplanes with noise performances in accordance to requirements of FAR 36 Stages 3-5, which are currently in operation, – the dimensions/areas of the simplified contours for departure flight are within 10% of the accuracy of INM contour data.

Bigger differences between the dimensions and areas of the simplified and INM contours for airplanes of Stage 1 and 2 performances may be described by a number of reasons – main of them that the method of assessment during AN certification procedures for these stages was different from existing ones and their data are normalized/harmonized with current method requirements not correctly always, even in ANP database (the same with INM database, which is very similar with ANP database). The results for FAR Stage 5 (equal to ICAO Chapter 14) performances are so small that the character contour for L_{Amax} night may lie closely to the runway, somewhere inside the territory of the aerodrome as shown in **Fig. 4**.

This ~60% reduction of the noise radius and ~80% reduction of the footprint area provides the similar shortening of the distance from runway to ANZ boarder with AN limit 65 DNL (residential development is prohibited). Once again returning to equivalent sound levels L_{Aeq} and/or noise indices L_{DN}, first of all because of their much higher correlation with noise impact assessment, one should consider the difference between them and single flight event value like *SEL* is as follows:

$$LAeq = SEL - 10 \lg T + 10 \lg n, \quad (7)$$

where *T* is a temporal interval of L_{Aeq} definition to be assessed, *n* – number of single events with sound exposure *SEL*. Here in formula (7) the value of *SEL* is defined for determining type of the aircraft in scenario under consideration, as it was discussed before.

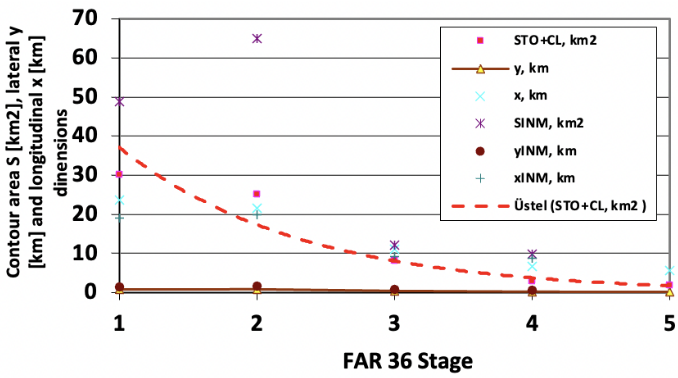


Fig. 10: Comparison between the dimensions and area for noise contour 75 dBA LAmax defined by simplified model and INM for Boeing-737 at departure with noise performances in accordance with FAR-36 requirements (from B737-100 for Stage 1 till Boeing-737MAX for Stage 5)

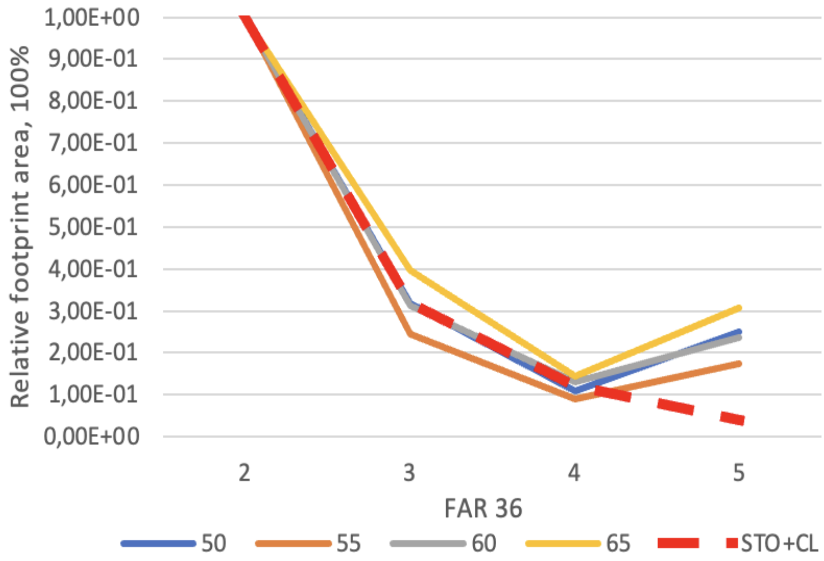


Fig. 11: Comparison between the relative areas for noise contour 75 dBA LAmax defined by simplified model and INM for Boeing-737 at departure (from Fig. 8, red dashed line) with noise contour areas LAeq day for Kyiv/Zhulyany airport in Tab. 1): 65 dBA – yellow line; 60 dBA – gray line; 55 dBA – light braun line; 50 dBA – blue line

This simplified formula (7) allows defining that the contour for night-time limit L_{Aeq} = 55 dBA (as defined by the Ukrainian rules for noise zoning (Konovalova O, Zaporozhets O, 2021)) the number of aircraft flight events n similar to determining type in the scenario should be ~10 if it is equal to ICAO Chapter 2 noise performances, rising till ~30 if the noise performances will be equal to ICAO Chapter 14 requirements. For daytime noise limit L_{Aeq} = 65 dBA the same assessment is showing the change in a number of events n between ~140 for ICAO Chapter 2 and >500 flybys for ICAO Chapter 14 aircraft flybys.

So, with quieter determining aircraft in a fleet of the scenario under consideration the dominance of the single noise exposure contour may not be diminished by noise equivalent contour. It may be a new principle condition for aircraft noise zoning determination in the future AN scenarios. Second principle result of last decade – human annoyance to AN became stricter, if the Shultz Curve has defined ~30% of annoyed population at L_{DN} = 65 dBA few decades ago, now the studies in EU and US airports define the same amount at 50-55 dBA. One of the reasons may be explained with big shortening of the distance for residential development close to airport. AN loading on the population of the air traffic is the same, but the visual impression of the departing and approaching aircraft may be bigger, so the current Annoyance Curve for aircraft noise is much closer to the Annoyance Curve for wind farm noise (which is most annoying at the moment among the environmental noise sources).

Aircraft produced today are 75% quieter than the first civilian jets that appeared in operation 50 years ago (**Fig. 4**). The newly manufactured aircraft typically produce around half the noise of the aircraft they are replacing, so with this advance the air traffic movements can double without increasing the total noise exposure output (ICAO Document 10127, 2019). During the 50 years of aircraft noise standardization from ICAO (1st Edition of Annex 16 – Aircraft Noise was published in 1969) and continuous strengthening of the requirements from ICAO Chapter 2 till current 14 (ICAO Annex 16, 2019) the cumulative reduction was gained up to ~35 dB, close to this value is necessary to be reached till the ACARE noise goal at 2050 (Flightpath 2050, 2011). The next strengthening of noise requirements for the aircraft may provide the conditions of disappearing the single event contours (footprints) with sufficient for analysis and management levels (L_{Amax} 75 dBA for the night and 85 dBA for the day), as they are used in Fig. 4, 6 and 8, from consideration in population exposure tasks.

3.1. Ground AN assessment

Tremendous reduction of the flight AN contours in airports during last decade provided new situation in AN assessment for the airports – contribution from the ground aircraft movements in AN exposure must be included in NEM and at further steps - in ANCP to manage the AN exposure and its impact on population. Previous AN exposure, defined by flight events, covered the contributions from ground events, as anybody may look from the **Fig. 2**, - AN contour for 1990s scenario cover completely the taxiways and apron with stands, which were not changes during last decades.

Enhanced modelling of aircraft taxiway noise, as it is discussed in (Page, J., et al., 2009; Page, J., Hobbs, C. and Gliebe, P., 2013), is a subject of inclusion in current methodology of AN assessment (SAE AIR1845A, 2012; ICAO Doc 9911, 2018). The same approach is explained in (Zaporozhets O., Levchenko L., 2018) for AN from aircraft taxing, and for aircraft engine run-up noise (Zaporozhets O., Karpenko S., Levchenko L., 2021). Current NEM for airports should include these AN sources for effective realization of the ANCP also.

4. Measurement of Aircraft Noise at Kyiv/Zhulyany Airport

Quieter aircraft and more accurate calculation models produce conditions that residential areas are much closer today to airport territory then 4 decades ago (AN contours used for defining the ANZ boarder are much smaller). Accuracy of calculation methods currently are higher, it is quite similar with accuracy of the noise measurements.

It is necessary to mention that the new Ukrainian legislation allows airports to provide a systemic program to measure noise exposure in their vicinity (SAAU Order 585, 2020), taking into account both European and world best practice (Konovalova O., Zaporozhets O., 2021). First of all, there is very important because most of Ukrainian airport can be considered as city airports – they are surrounded by residential areas in all directions from runways. Second point of attention, there is a need to check the calculated quite short distances from the runways to the boundaries of the ANZ with prohibited human activities due to over-limit noise exposure. The airport on its own cannot minimise noise impacts – the AN exposure only, current circumstances provide new more strict requirements on AN exposure assessment. They are essential in order for the airport to maintain current operations and enable potential sustainable growth.

4.1. Measurements of aircraft taxing noise

Instrumental studies of air pollution and noise within the aerodrome "MA Kyiv/Zhulyany" are performed since 2018 (Synylo K., Ulianova K., Zaporozhets O., 2021). The location of the monitoring station for air pollution and noise was determined for research during the landing of the aircraft, the run along the runway, taxiing to the parking lot, taking into account the direction of the wind. In particular, the location of the measuring station was oriented to the prevailing (South Western, 190-210^o) wind direction in the airport area. The monitoring station was located at a distance of 15 m from the edge of TaxiWay 2: 50.24.278 '030.27.739' (Fig. 10).

The results of the measurements allow us to validate noise and pollution models in the vicinity of the airport IsoBella (analogue INM, FAA, USA) and PolEmiCa (analogue of Emission Dispersion Modelling System EMDS, FAA, USA). The comparison of measured and modelled noise levels and concentrations of pollutants has shown that correlation coefficients are rather high (0.9…0.99) (**Fig. 11**).

The results of the measurements allowed us to gain the next targets: clarification of the emission factors of engines and aircraft noise levels in operational conditions; description of the noise and emission interdependencies during real flight operation, particularly for taking-off and landing modes. Measured data allow us to assess noise and emission interdependencies during taxing and takeoff run stages and confirm the linear dependence between noise levels, operational modes and emission indexes and possibility of the applying of Linear Interpolation to the ICAO Engine Emission Data.

Measurement results are important to prove the results of calculation, which are used for ANZ and for environmental capacity assessment of the airport, predefined by AN and LAQ calculations and limits. If the environmental capacity of the airport is smaller than operational – the optimization task is recommended to solved (Tokarev V., Kazhan K., 2014).

AN compatibility of the airport may be considered as broken if the ANZ are defined by calculation only, and the measurement results for AN are definitely higher at their borders. If the ANZ distances from the runway axis are smaller due to quieter aircraft implemented in operation such situation is looking obvious, so the calculations of AN contours, which are used for ANZ border defining, should be confirmed by AN measurements. Accuracy of AN measurements and calculations must be equalized if it is possible in reality (Zaporozhets, O. and Levchenko, L., 2021).

4.2. Comparison of flight noise measurement results with calculated and certification noise levels

The results of noise measurement in the vicinity of Kyiv/Zhulyany and Kyiv/Gostomel aerodromes were analysed from several points of view:

- comparison with normative values of environmental noise in accordance with the requirements of national norms and rules;
- comparison with the results of noise certification of types of aircraft operated at the aerodrome;
- comparison with the results of the calculation of the sound levels of the AN, performed to justify the boundaries of the zones of residential building restriction from noise conditions.

The results for the sound levels in Fig. 12, 13 (departure) and 14, 15 (arrival) indicate a wide range of deviations of the measured values from the averages, which necessitates the analysis of samples for each type of the aircraft and the flight stage separately. Sound levels, in particular maximum sound levels, at a distance of 6-8 km along the take-off axis from the starting point on the runway dominate essentially over regulatory values of the rules (SSR-173, 1996) as for night ($L_{A\,max}$ =75 dBA) so as for day ($L_{A\,max}$ =85 dBA) time periods.

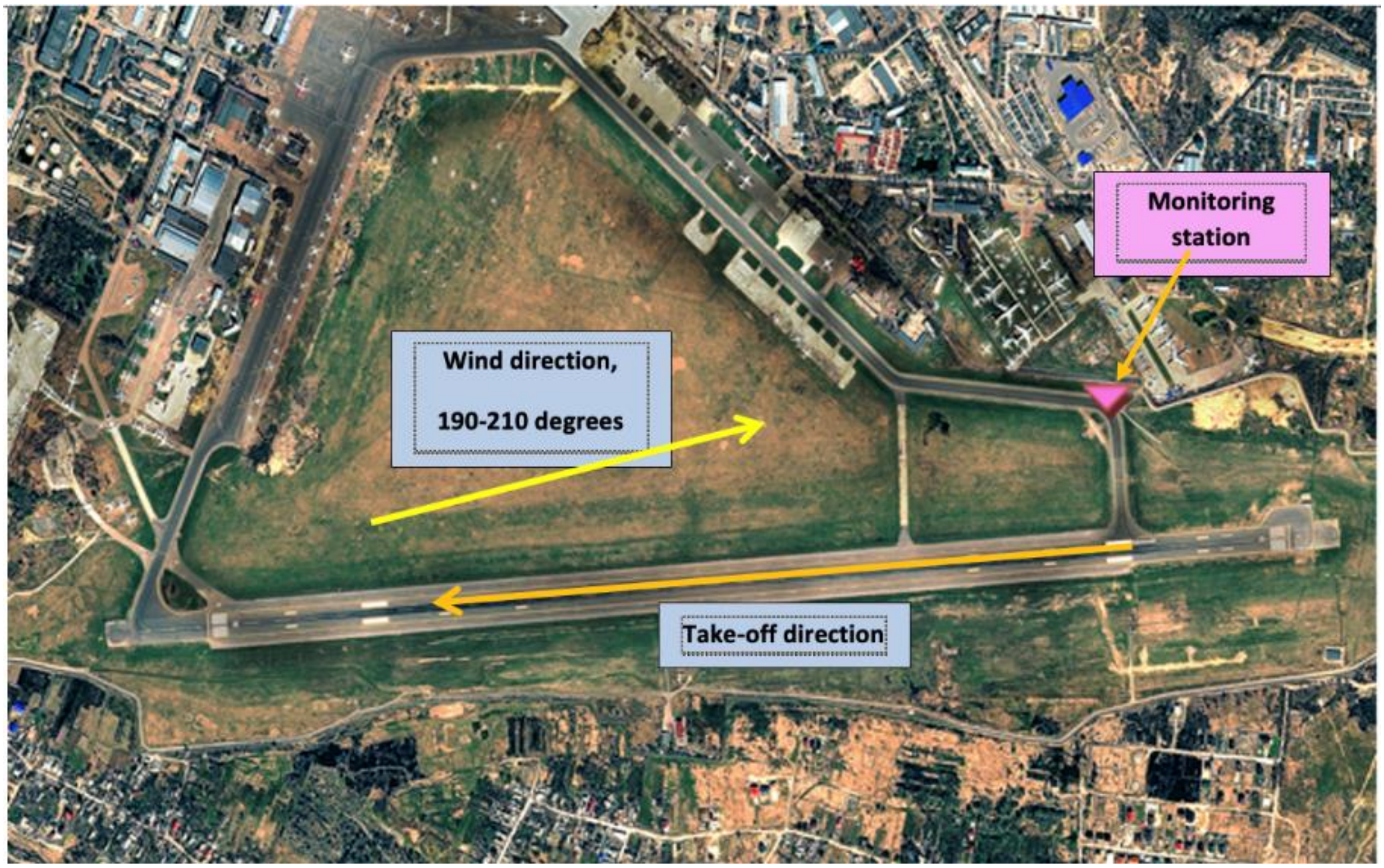


Fig. 10: Location of the noise and air pollution monitoring station during taxiing along the main Taxiway, turn on the Taxiway №2, take-off along the runway in Western direction

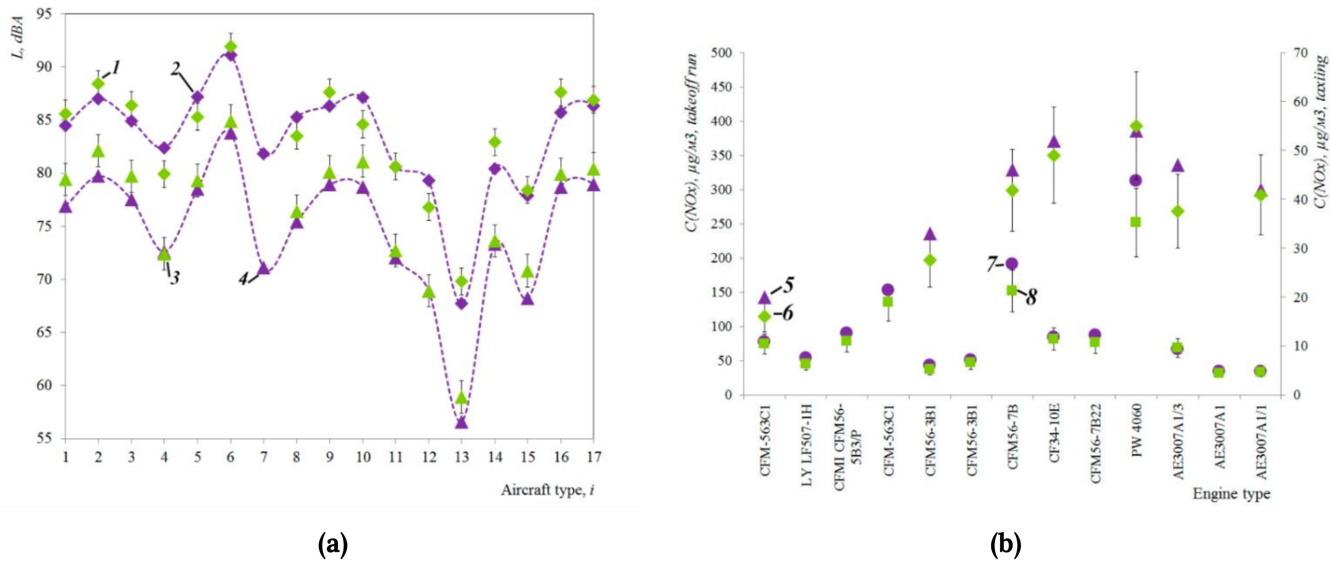


Fig. 11: Comparison of measured and modelled noise levels (a) and concentrations (b) of the pollutants: 1 – calculated SEL, dBA; 2 – measured SEL, dBA; 3 – calculated LAmax, dBA; 4 – measured LAmax, dBA; 5 – calculated NOx concentration during taxiing C(NOx), µg/m3; 6 – measured NOx concentration during taxiing, µg/m3; 7 – calculated NOx concentration during take-off run C(NOx), µg/m3; 8 – measured NOx concentration during take-off run C(NOx), µg/m3

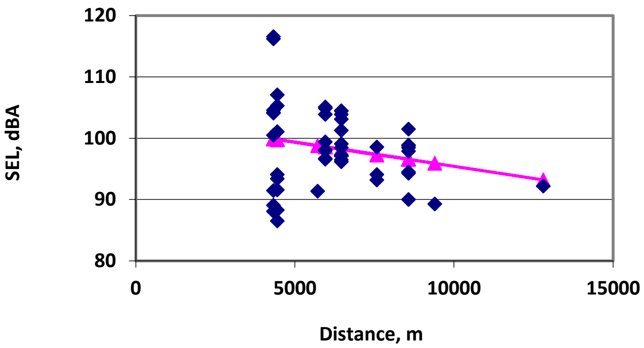


Fig. 12. Dependence of sound exposure levels L_{AE} from the distance to the point of aircraft start on runway during the aircraft departure (blue rhombus - measured values, pink triangle - linear approximation for the set)

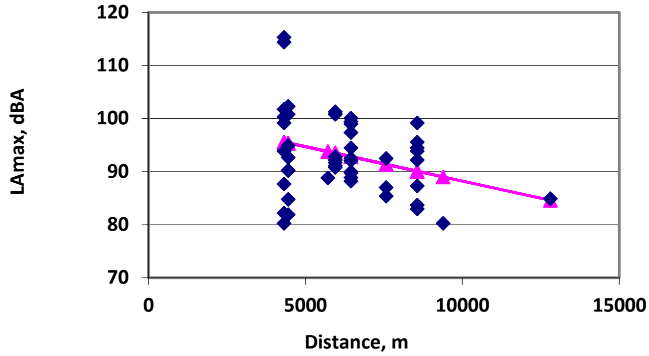


Fig. 13. Dependence of the maximum sound levels LA max from the distance to the point of aircraft start on runway during the aircraft departure

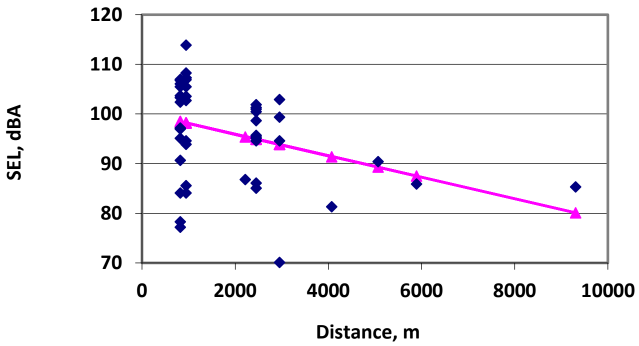


Fig. 14. Dependence of sound exposure levels L_{AE} from the distance to the runway end during the aircraft arrival

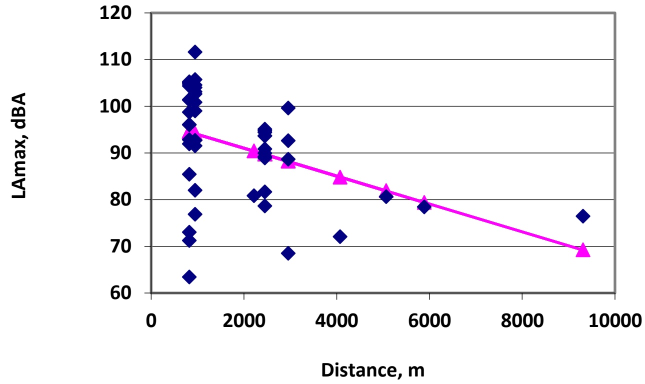
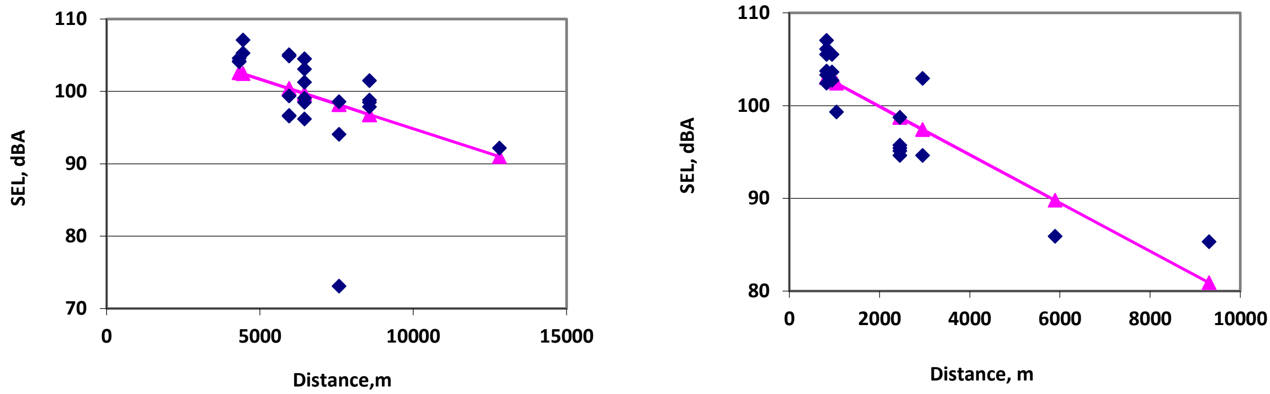


Fig. 15. Dependence of the maximum sound levels $L_{A\,max}$ from the distance to the runway end during the aircraft arrival



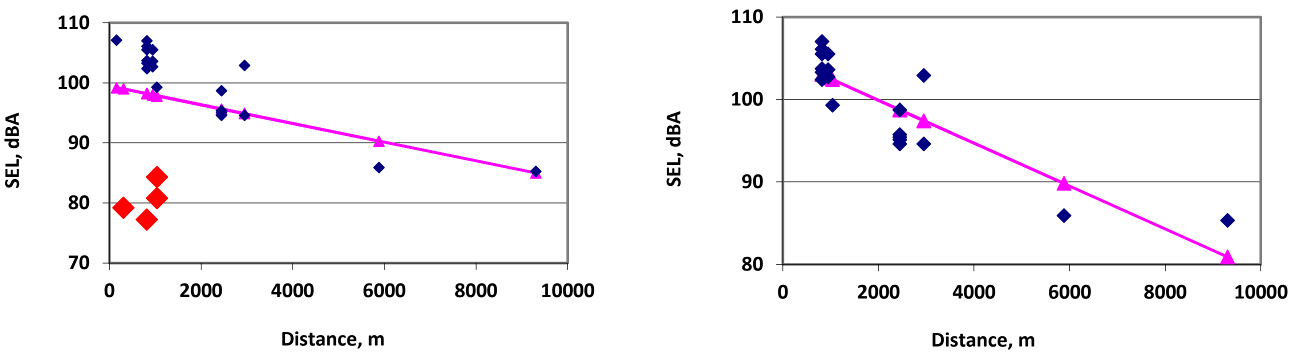
(a) (b)

Fig. 16. Dependence of sound exposure levels LAE for An-124 departure from the distance to the point of aircraft start on runway: a) full set data; b) a set with excluded highly deviated data; blue rhombus - measured data, pink triangle - linear approximation for the set

The largest data set at Kyiv/Gostomel studies was obtained for AN events for the An-124 aircraft (sound levels for the departure in Fig. 16 and for the arrival in Fig. 17). The approximation for a complete data set indicates unsatisfactory statistical values (for arrivals the correlation coefficient = -0.330 and coefficients of linear approximation B0 = 99.4, B1 = -0.00155, etc.), so in each of the sets, in particular for arrivals (Fig. 17), the measured data with significant deviations from the approximation line (marked in red rhombus in the corresponding figures) were excluded from further statistical analysis. The results for observation sets with the removed deviated data are much more correlated between themselves (standard deviations for a limited sample are 2-3 times smaller than the deviations for the full data set, correlation coefficient = -0.873 and coefficients of linear approximation B0 = 105.1, B1= -0.0026, etc). These highly deviated data were excluded from comparison with the noise certification data for the aircraft also. Comparison of the results of sound level measurements with calculations (Fig. 12-17) indicate minor differences (1-2 dBA) between them, especially with excluded highly deviated data, the assessment of which leads to the conclusion of sufficient accuracy of the calculations, in particular for aircraft An-124 (Fig. 16, 17), which determines the main noise load on the environment in airport Kyiv/Gostomel.

5. Conclusions

Aircraft activities and their AN exposure evaluation by measurement studies and modelling techniques may provide more accurate representation of its contribution to total noise exposure inside airport area and the improvement for: estimation of aircraft noise performances for actual operation conditions and precise exposure calculation from the aircraft at any stage of their operation; initial information for control of sanitary-hygienic requirements to aircraft noise of the airport; scientific grounding for ANZ around the airport; practical recommendations for instrumental monitoring of aircraft noise; improving of aircraft noise modelling system; estimation of aircraft contribution during different ground and flight stages to noise inside and outside the airport.



(a) (b)

Fig.17. Dependence of sound exposure levels LAE for An-124 arrival from the distance to the runway end: a) full set data; b) a set with excluded highly deviated data; blue rhombus - measured data, pink triangle - linear approximation for the set; red rhombus - data with significant deviations from the approximation.

A significant reduction in noise emissions at the source and the creation of relatively quiet aircraft have led to the approach of noise contours with levels equal to the established limits for public health protection to the borders of the airport territory. In turn, this allows to bring the activities of the population, including their residence, closer to the airport. But the requirements for determining noise contours and corresponding zones remain unchanged, computational methods are still decisive for them.

AN compatibility of the airport may be considered as broken if the ANZ are defined by calculation of flight AN exposure only, and the measurement results for AN are definitely higher at their borders. If the ANZ distances from the runway axis are smaller due to quieter aircraft implemented in operation such situation is looking obvious, so the calculations of AN contours, which are used for ANZ border defining, should be confirmed by AN level measurements. Accuracy of AN measurements and calculations must be equalized if it is possible in reality because of their simultaneous importance. Current NEM for airports should include the contribution from ground surface AN sources for effective ANCP also, their absence in compatibility planning may provide the conditions for its inefficiency.

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