Chapter 32
Global, Regional, and Local Decision Levels to Aircraft Noise Management in Airports

Oleksandr Zaporozhets

Nomenclature

AN	Aircraft Noise
BA	Balanced Approach
ICAO	International Civil Aviation Organization
NAP	Noise Abatement Procedures
NPZ	Noise Protection Zones
WHO	World Health Organization

32.1 Introduction

Aircraft noise (AN) has always been a priority subject in the framework of aviation and the environment (WHO 2018). It primarily affects residential communities close to airports, being a local stressor for the environment in nature (ICAO Resolution A40-17 2019). In a huge number of airports worldwide, this local issue is a limitation for traffic capacity in airports, reducing their operational and economic efficiencies. Combined together, these airport capacity values may produce regional and even global circumstances for the aviation sector as a whole.

Aircraft noise exposes and affects communities within an airport surrounding area, defined by the level of long-term noise exposure or for a specific noisy flyby, especially during a specific interval (during mostly sensitive to noise periods of the day) of observation, taking in mind the influence of temporal duration and number of noise events on total exposure. The AN impacts the population directly and particularly the perceived noise annoyance by communities depends upon the AN exposure, length of the noise event (especially if it is the noisiest contribution to

O. Zaporozhets (✉)
Łukasiewicz Research Network – Institute of Aviation, Warsaw, Poland
e-mail: Oleksandr.Zaporozhets@ilot.lukasiewicz.gov.pl

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overall exposure), and the time of day, when exposure is observed, or dominant human activity performed inside the area of noise exposure (Berglund et al. 1999). Generally, AN exposure varies with the type and size of the aircraft, the power the aircraft is using at the moment, and the altitude or distance of the aircraft to the receptor. A higher distance from the source provides less noise exposure level, this is an essential condition for all noise protection programs.

Between AN exposure and its impact an essential difference exists – a number of factors, including non-acoustical factors, may influence sufficiently on impact values in the condition of the same exposure. The importance of any factor depends essentially on the object of exposure. ICAO BA guidance (ICAO Document 9829 2008) considers only the population as element-at-risk. If acoustical factors may be set into few physical values – aircraft mass and engine type installed, aircraft certificated noise performances, air traffic intensity, distribution of flights among the routes, flight procedures in use, etc., the non-acoustical factors cover a much higher number of human–social, physical, economic, cultural, and environmental issues (Zaporozhets and Blyukher 2019; Vader 2007). Most of them are the subject of human vulnerability assessment to noise exposure. If to consider the current concept for risk assessment, the complicated interdependence exists between exposure, vulnerability, and coping capacity in a noisy environment, so the effect (or damage) of AN on humans may vary considerably. Vulnerability and coping capacity of the population may change between themselves dramatically, so even for the same exposure level, for example, defined by AN exposure footprints for single flybys (Fig. 32.1), the number of the annoyed population inside the exposed area may rise or reduce essentially.

Another variable affecting the overall noise impact is a perceived increase in aircraft noise at sensitive daytime, for example at evening or night when the resting activities are dominant inside the community – when the community is most

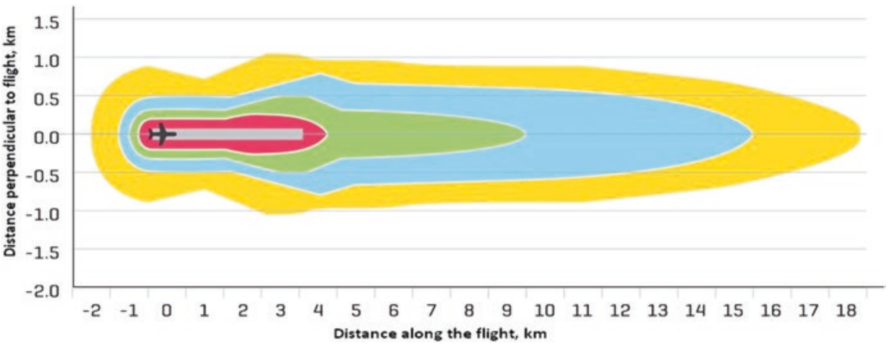

Fig. 32.1 Noise exposure reduction of the aircraft during last 50 years from ICAO Annex 16 Chapter 2 till Chapter 14 certification norms: (**a**) single aircraft departure footprint for *SEL* = 80dBA: in yellow – Chap. 2 model of aircraft, e.g., B737–200; in blue – first-generation Chap. 3 aircraft, e.g., MD80, B737–200 Hush Kit; green – current Chap. 4 aircraft with, e.g., A320, B737–800; red – modern current Chap. 14 (aircraft with geared turbofan engines, e.g., A320neo. (European Aviation Environmental Report 2019)

vulnerable to this hazard issue. The noise limits for these sensitive periods of the day are usually 5–10 dBA stricter (less) and above all they are the limitations for the air transportation activities at airports if fulfilled whole the day. To minimize aircraft noise problems through preventive measures, ICAO policy, primarily, recommends locating the new airports at an appropriate place, such as away from noise-sensitive areas (ICAO Resolution A40-17 2019). Never mind that internationally agreed policy is recognized by the states, each airport requires its own solutions based on its specific characteristics as in noise hazard generation and propagation effects, so as in noise exposure influence on population (or other elements-at-risk) with their vulnerability and coping capacity performances. The circumstances of each airport vary significantly between themselves so an effective operational procedure or even mitigation measure at one airport may not be appropriate (or even feasible) in another.

Airports are usually located within or close to the limits of large urban areas (Fig. 32.2), in better case, a distance to existing noise-sensitive land usage (residential or recreational) may provide human protection from noise exposure and minimize the adverse impacts of their operations. The overlap of urban areas within the noise protection zones (NPZ) around aerodrome (as shown in Fig. 32.2, especially on the East from the runway) may exist and in such a case it indicates that a population inside the zones is exposed and vulnerable and even impacted (at least annoyed) by noise and needs for additional protection (due to noise insulation schemes, etc.).

32.2 General Considerations on Noise Management

The national legal system declares the noise limits (standard values for noise in the environment) usually in practice, which are prohibited for overloading inside the area of any human activity – especially inside residential and rehabilitation areas. The WHO (Berglund et al. 1999) recommends a value of 55 dBA L_{DN} for such a limit (long term), but practically in accordance with national approaches and possibilities (technical and economical) for noise protection, the values 65–75 dBA

Fig. 32.2 Example of Noise Contours for NPZ at Kyiv/Zhulyany International Airport – Kyiv, Ukraine: red contour – 85 dBA L_{Amax}; yellow contour – 80 dBA L_{Amax}; pink boarded zones – residential areas of the Kyiv City

LDN are used to eliminate human activities with the implementation of additional protection from noise. Somewhere, particularly in Ukraine, there are few criteria used for environmental noise assessment and management (Konovalova and Zaporozhets 2021), emphasizing that noise may impact the population in a few ways including the effects during long-term and short-term exposures. Particularly for aviation noise, short-term exposure is important in case of a contribution of the noisiest flight events to overall exposure and especially in conditions of quite small flight traffic, which are observed in regional airports at the first stage of their development. For them, the noise contours for single flight event, defined for sound exposure level *SEL*, or for maximum sound level L_{Amax}, are larger in size (in area also) in comparison with equivalent sound levels L_{Aeq} (for various time intervals and day periods) or noise indices (L_{DN}, L_{DEN}, *WECPNL*, etc.) with normative values (limits).

Of course, a scenario with small air traffic in the particular case of airport operation is not a good reason to define and implement NPZ around the aerodrome. The calculated noise contours for single flight events and for limits in $\mathrm{L}_{\mathrm{Amax}}$ and/or *SEL* may restrain the inconsistency with noise development of the residential and occupational areas around the airport under consideration. That is, for airports with low air traffic, it seems appropriate to assess the boundaries of the zones based on the results of calculating the noise contour for the flight of the loudest aircraft or for the determining type of aircraft at the design stage of the aerodrome (during the design of the runway). This assumption will be valid until the growth of the traffic may reach the intensity of flights providing the more dominant equivalent sound levels L_{Aeq} over the single flight exposure *SEL* (or maximum sound level L_{Amax}) in the definition of the noise zones' boundaries. In any case, the boundaries of the NPZ must not be assessed on the current flight traffic scenario only. It should be done with forecasted scenarios, preferably one of them with the contribution of the most possible undesirable mixture of aircraft in a fleet and their operation during the day.

From another side of the problem, the general plan of land use development around the airport should be considered and it must be consistent with the development of the airport and its noise circumstances. Community engagement in this process becomes definitive, the decision-making by airport authority alone may be mistaken (ICAO Circular 351 2016). A particular challenge was and still is the fact that successful noise impact mitigation interventions by airports often lead to noise contours shrinking size. This usually leads to new developments being approved only – resulting in no net reduction in the number of people exposed to aviation noise, sometimes even to its rise, if this development is inconsistent with shrunk noise contour.

There are few levels of decision-making that exist in a process of aircraft noise management, even in consideration of the problem at a specific airport – the global, regional, and local. The regional or state level is mostly directed on the elimination or reduction of exposed to noise population in the vicinity of the airports. A global approach to the problem solutions is concentrated on manufacturing less noisy aircraft – ICAO international standards for aircraft noise are the examples of such kind of solutions (ICAO Annex 16 2019). The total phase-out of the noisy aircraft (with noise levels under the Chap. 2 requirements) in international air transportation

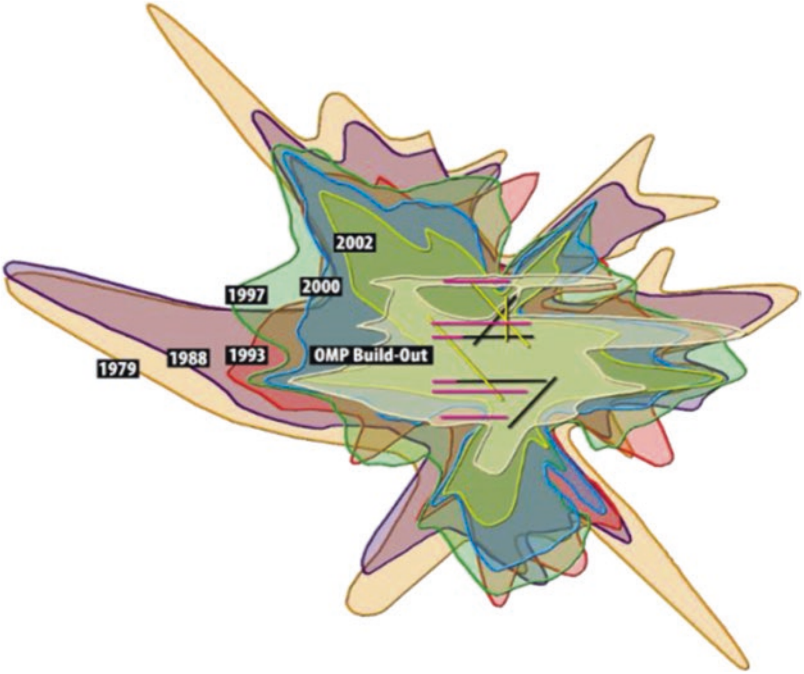

Fig. 32.3 65 dBA L_{DN} noise contour changes at O'Hare Airport (Chicago) due to more stringent standard requirements to aircraft noise and phasing out of noisy types from operation between 1998–2002 despite an increase in flight traffic

worldwide is also an example of a global approach, but it was a single act in aviation history at the beginning of the twenty-first century, as was agreed upon in the 28th ICAO Assembly (in Fig. 32.3 a dramatic change between the AN contours for 1998 and 2002 scenarios), which currently is not recommended by ICAO policy on environment protection. Global phase-out of the aircraft from the operation, especially those that did not reach the final operational resources, means economic damage for airlines and for total air transportation system. Nowadays, the phase-out of the noisiest types of aircraft is considered as a local measure to solve the problem at any particular airport; and only in case if ICAO standards (reduction in the source), noise zoning (reduction of overall noise exposure on population), and operational low-noise procedures are not enough to balance the noise management program.

32.3 Balanced Approach to Aircraft Noise Management

In 2001, the 33rd Session of the ICAO Assembly adopted a new policy for aircraft noise control globally, referred to as the "balanced approach" to noise management. The ICAO BA guidance (ICAO Document 9829 2008) contains the explanation of all elements in general details, namely: reduction of aircraft noise at source – manufacturing quieter aircraft under ICAO standard requirements; noise zoning, land-use planning, and management; noise abatement procedures for aircraft operation; and usually partial restrictions for noisy aircraft operation. The goal is to also identify the noise-related measures that achieve the maximum environmental benefit (minimum environmental risk), using objective and measurable criteria, at any specific airport most cost-effectively. If the main goal in aircraft noise control is to reduce the noise level at the source of its generation, the main goal for noise zoning and land use management is to prevent the people from the noise levels which are detrimental to their health and welfare.

The principle in ICAO BA guidance (ICAO Document 9829 2008) is that a criterion on noise exposure assessment should be day-night noise index L_{DN}, or its analogue in EU – day-evening-night noise index L_{DEN} (European Council 2002). For example, in Ukraine equivalent sound levels L_{Aeq} is used for daytime and nighttime separately, and it is not a direct analog of the day-night noise index. The second principle (not the requirement) – the overall AN exposure and the boundaries of noise zones around an airport under consideration should be defined by calculation. For that, a special method is recommended by ICAO (ICAO Document 9911 2018).

Few levels of aircraft noise assessment exist to be used for decision-making in noise abatement program compilation for the airport. The highest level of strategic solutions needs simple calculations but accurate enough for received solutions. Recommended method (ICAO Document 9911 2018) may be too complicated for that. One of the approaches for simplified calculations is based on a concept of Noise Radius which is similar to the concept of "Noise-Power-Distance" but provides a quick assessment of the exposure and its changes in accordance with considered noise abatement scenario in the airport noise management program (Zaporozhets et al. 2011; Zaporozhets and Tokarev 1998).

The area and sizes of noise zones (Figs. 32.2 and 32.3) is a subject of aircraft noise calculation (ICAO 9829 2008; ICAO 9911 2018); aircraft noise and performance data (from the international ANP database, https://www.aircraftnoisemodel.org/) should be used to derive the noise contours for those specified by the national rules noise levels/indices. To imagine the sizes of noise zones around the aerodrome (or separately for runway) a simple approach may be proposed (Zaporozhets et al. 2011; Zaporozhets and Levchenko 2021) – to consider the noise contours as a result of the intersection of the cylindrical surface of equal sound level (equal to the limit used for noise zoning borders) with the ground surface around the aerodrome and flight paths. It was shown that this simplified contour will be an ellipse, a small radius b which is equal to noise radius R_{N} (or to distance from appropriate "Noise-Power-Distance" relationship from ANP database) and big radius a – to $R_{\mathrm{N}}/\sin\gamma$ for aircraft type under consideration at this flight mode, where γ is an angle of climbing/descending – depending on aircraft type (number of engines in its power plant) and its flight stage (Fig. 32.4).

The main simplification in the concept of Noise Radius R_{N} is that it is considered as constant, at least during the definitive for noise contour assessment flight stages of the aircraft. The results of numerous researches show that R_{N} is varying all the

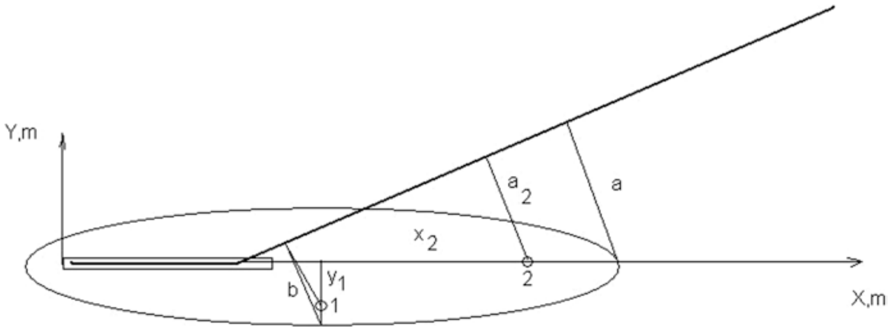

Fig. 32.4 A simplified form of noise footprint having the shape of an ellipse under the takeoff flight path. (Zaporozhets et al. 2011).

time, it is mostly dependent on engine operation mode (engine power) and noise level (type and value) to be considered, but the altitude and speed of flight, meteorological conditions, even type of the ground covering during some specific flight stages are also influencing the value of Noise Radius and its derivatives (Zaporozhets and Levchenko 2021).

From the considerations before, the value of R_N is not the same for the definitions of semi-minor *b* and semi-major *a* axises of the equivalent ellipse for the noise contour under consideration. Because the maximum operation mode is used for engines at takeoff, the nominal – at climbing; but for quieter types of aircraft this difference is lesser (Fig. 32.1).

The most sensitive violation of the simplification of the concepts of constant noise radius and ellipse for the noise contour occurs at the point of intersection of the segments of the flight path of the altitude, which changes the mode of operation of engines (in Fig. 32.1 it corresponds to a distance of ~4 km). But generally, the error (inaccuracy) of these changes does not seem significant in strategic assessments and decisions.

32.3.1 ICAO Standard Requirements to Aircraft Noise and Management of Noise Exposure around the Airports

A more significant impact on the 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 (e.g., 75 dBA $L_{\text{Amax night}}$) will not be displayed on the airport noise map. As can be seen from Fig. 32.1, the noise contour for takeoff/climbing of the airplane with Chap. 14 noise performances (ICAO Annex 16 2019) is already within the runway size. Therefore, further expected more stringent requirements for aircraft noise levels at three points of noise control (takeoff, 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.

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 2003; Zaporozhets et al. 2011):

$$L_2 - L = C\lg\left(a / a_2\right), \tag{32.1}$$

where the constant C defines the attenuation rate, for cylinder spreading its value is near to 10 and for spherical spreading – near to 20, a is the minimum distance from the flight path to the final point on the contour (Fig. 32.4), a_2 is the minimum distance from the taking off path to the certification point No 2 (for departure). Similar view is possible on the difference between the certified noise level at takeoff (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. 32.4. The area S of noise contour at takeoff and climbing is proportional with quite high correlation to the product of L_2 and L_1:

$$\lg\left(S\right) = \left(L_2 + L_1\right) / C + D, \tag{32.2}$$

which is the same as Eq. (32.1). Constants C and D are different for various types of the sound levels L, L_1 L_2, and for different groups of airplanes (Zaporozhets and Tokarev 1998; Powell 2003; Zaporozhets et al. 2011). Better correlation was found for sound exposure levels such as *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 as follows:

$$\mathrm{SEL} = A + BL_{\mathrm{Amax}} \tag{32.3}$$

Attention should be made in using correlations such as the above formula (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 spectral class (explained in ANP database), but they are different in approach and departure flight stages, and are even different in their distances to flight axis (Fig. 32.5). 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.

Strictly speaking, not only the engine operation mode (thrust) at taking off/climbing may influence the form of resulting contour for departure flight. 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. 32.6). If to use the concept of hypothetical contour, defined by equal noise exposure cylinder intersection with surface plane discussed above

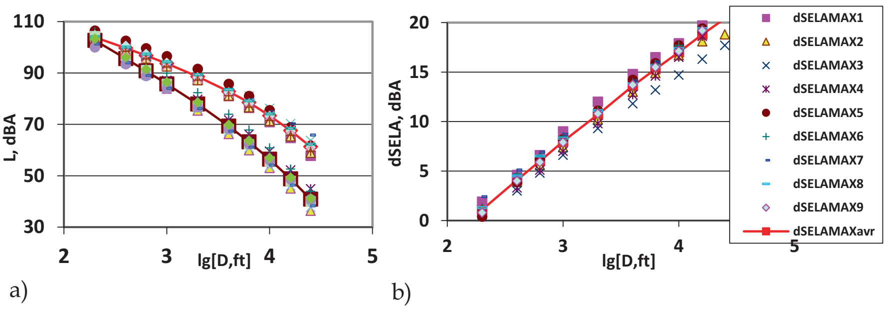

Fig. 32.5 Dependence (**a**) between SEL (red rhombuses) and L_{Amax} (brown squares) and the difference (**b**) between them for the distance to flight axis for the airplane group A-320 and B-737

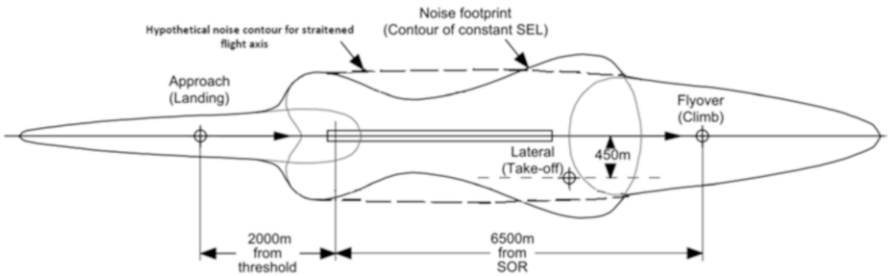

Fig. 32.6 Hypothetical noise contour for straitened flight during departure and excluded ground effect for sound propagation close to runway

(Fig. 32.4) and the exposure level on cylinder surface is defined by character noise level for climbing flight stage (dashed line in Fig. 32.6), 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. 32.7).

Particularly for airplanes with noise performances in accordance with the 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 – first is 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 to ANP database). In fact, the results for FAR Stage 5 (equal to ICAO Chap. 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. 32.1.

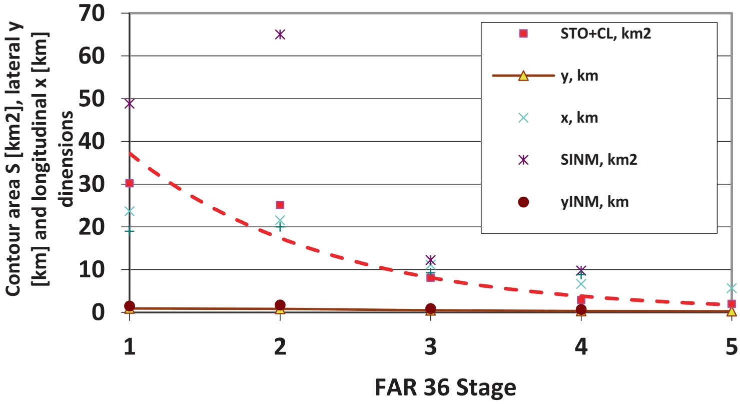

Fig. 32.7 Comparison between the dimensions and area for noise contour 75 dBA L_{Amax} defined by simplified model and INM for Boeing-737 at departure with noise performances in accordance with FAR-36 requirements (from B737–100 for Stage 1 till Boeing-737MAX for Stage 5)

Again returning to equivalent sound levels L_{Aeq} and/or noise indices L_{DN}, first because of their much higher correlation with noise impact assessment, one should consider the difference between them and single flight event value such as *SEL* as follows:

$$L_{Aeq} = \mathrm{SEL} - 10\lg T + 10\lg n, \tag{32.4}$$

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 (32.4) the value of *SEL* is defined for determining type of the aircraft in scenario under consideration, as it was discussed before.

This simplified formula (32.4) allows to define the contour for night-time limit L_{Aeq} = 55 dBA (as defined by the Ukrainian rules for noise zoning (Konovalova and Zaporozhets 2021)), the number of aircraft flight events *n* similar to determining type in the scenario should be ~10 if it is equal to ICAO Chap. 2 noise performances, rising up to ~30 if the noise performances will be equal to ICAO Chap. 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 Chap. 2 and > 500 flybys for ICAO Chap. 14 aircraft flybys. Thus, 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 principal condition for noise zoning determination in the future AN scenarios.

Aircraft produced today are 75% quieter than the first civilian jets that appeared in operation 50 years ago (Fig. 32.1). The newly manufactured aircraft typically produce around half the noise of the aircraft they are replacing, so with this innovation, 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 (first Edition of Annex 16 – Aircraft Noise was published in 1969) and continuous strengthening of the requirements from ICAO Chap. 2 up to the current Chap. 14 (ICAO Annex 16 2019), the cumulative reduction was gained up to ~35 dB, close to this value is necessary to be reached until the ACARE noise goal at 2050 (Flightpath 2050 2011). The next strengthening of noise requirements for the aircraft may provide the conditions of eliminating the single event contours sufficient for analysis and management levels (L_{Amax} 75 dBA for the night and 85 dBA for the day) from consideration in population exposure tasks.

32.3.2 Land-Use Planning

The need for land-use planning in the vicinity of an airport was recognized in the early history of civil aviation and focused on the use and control of the land. Manual (ICAO Document 9184 2018) is focused on land use and environmental management on and around an airport. Airport operators can reduce the environmental impacts – noise, air emission/pollution, safety issues of their operations by incorporating environmental management plans and procedures with land-use compatibility planning with a broad appreciation of their relative sensitivity of the population to the aircraft operational safety, local third-party risk, and noise exposure. Among land-use planning measures, the noise zoning around airports is the primary, main, and most effective to be protected from noise exposure; they should be implemented as soon as noise problems are foreseen (Fig. 32.8). But compatible land-use planning and management should be based on appropriate forecasted aircraft noise contours, rather than current contours, which must prevent encroachment of residential development at airports where future aircraft noise levels are projected to increase.

It is still recommended that the assessment of environmental noise continue to be an integral element in identifying and solving land use planning problems and of noise management overall. Inside the zone of noise management, it is necessary to organize a set of plans (a program for noise protection) that govern urban planning and management with respect to airport activities. The principles of zoning of

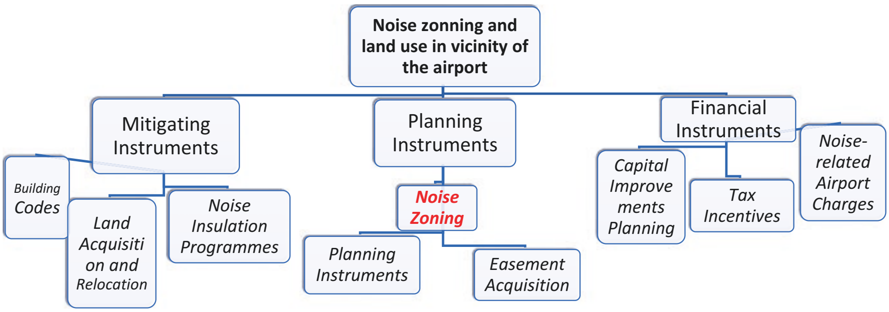

Fig. 32.8 Noise zoning and land usage instruments in airport environment

territory around the aerodrome in conjunction with the aerodrome (heliport, permanent runway) and land use are substantiated accounting on the quantity and quality of lands of any state is proved in Novakovska et al. (2020). In reality, each airport is different in its operational, social, economic and political situation, as well as in the type of land use in its vicinity. That is why the airport noise protection program should include a land-use control system to assure that all the prescribed measures not only comply with the airport development plan but also with the plan of urban development and the goals of the communities involved.

Local airport rules can include noise limits, curfews, and penalties on excessive noise levels. These measures are considered mostly as constraints, they may limit the operational capacity of airports (for example, by restrictions for flights during the night) and they may affect the economics of air transportation by limiting the takeoff weight, payload and consequently reducing the economic benefit of a specific flight.

Where the opportunity still exists to minimize aircraft noise problems through preventive measures, the main efforts should be prioritized as follows: locate new airports at an appropriate place, such as away from noise-sensitive areas; take the appropriate measures so that land-use planning is considered fully at the initial stage of any new airport or of development at an existing airport; define zones around airports associated with different noise levels considering population levels and growth as well as forecasts of traffic growth and establish criteria for the appropriate use of such land, taking account of ICAO guidance (ICAO Document 9829 2008); enact legislation, establish guidance or other appropriate means to achieve compliance with those criteria for land use; and ensure that reader-friendly information on aircraft operations and their environmental effects are available to communities near airports, etc.

Among the alternatives to regulate land developments inside the surrounding area affected by the airport, a number of modification or restriction of land uses exists to achieve greater consistency between aviation and human activities, or in other words – to reach compatibility between the airport and its environs. These control measures may be divided into three categories, as follows: Planning Instruments, Mitigating Instruments, and Financial Instruments. Some examples of these instruments are listed in Fig. 32.8.

Noise zoning is a core regulation in noise exposure/impact management on population (Fig. 32.8) realized through Planning Instruments and should specify land development depending on the level of noise exposure and use restrictions, based on certain noise levels – the limits, which are incompatible with human activities inside the zones. The limits and a list of zones around the airport are defined by the state rules, usually similar to all airports of the state. These regulations should protect both – the airport and the residents in their mutual developments. Noise exposure is not the only factor to be considered in land-use management in the vicinity of airports. It is recognized that economic factors are involved in land-use choices. Ideally, land-use decisions around airports would try to find a compatible balance between the interests in the land and the aeronautical use of the airport.

It is quite a difficult subject because the communities are striving to be closer to the airport due to the desire for better conditions in a number of businesses connected to airport activities. Land-use planning must account for existing development and ensure that future planned development is also consistent between the aviation sector and communities, and compatible with their various goals including the changes in aviation noise exposure due to changes in aircraft fleet and air traffic in airports. Easements should restrict the use of land to that which is compatible with aircraft noise levels.

Some of the airports due to their specific place in the air transportation system of the state (or inside the region) may use/implement different rules from the state rules noise limits, which may or mitigate or allow a specific land usage inside the zone. An appropriate sound insulation program should be provided to control interior noise levels inside the buildings that are impossible to be removed out of areas exposed to noise. A necessary budget for the insulation program is usually gathered by implementing the noise-related airport charges – main financial investments to any noise protection program in the airport under consideration. Noise monitoring systems – continuous or permanent – are the instrument for objective noise exposure assessment of the air traffic inside the specific zone (where a noise monitor is installed) or to be used for assessing the efficiency of any implemented noise protection measure.

The strategic routing of aircraft through navigable airspace to minimize noise impact for both sensitive land uses as well as populated areas are essential in the airport planning process. The protection of the residents is understood as a dynamic process, meaning that the evaluation criteria must be repeatedly tested and – if necessary – adapted to new scientific findings (Chyla et al. 2020). Compared with traditional ICAO balanced approach elements, which are defined by physical effects of sound generation and propagation, involving non-acoustical factors must now be included to reduce the annoyance. Up to now, annoyance was mainly explained through acoustical factors such as sound intensity, peak levels, duration of time in-between sound events, and number of events. The non-acoustical factors ("moderators" and/or "modifiers" of the effect) have still received empirical attention but without a deep theoretical approach, despite the fact that various comparative studies reveal that they play a major role in defining the impact on people.

32.3.3 Noise Abatement Procedures

Operational procedures are intended for use by aircraft of the existing fleet and have the potential to make an immediate improvement in the environmental impact of aviation, as a rule locally emphasized at airports where the noise zoning and land use procedures are realized with omissions (ICAO Document 8168 2020; ICAO Document 9888 2007). The methodology and the decision-making algorithms for environmental control needs with NAPs were given in Tokarev et al. (Tokarev and

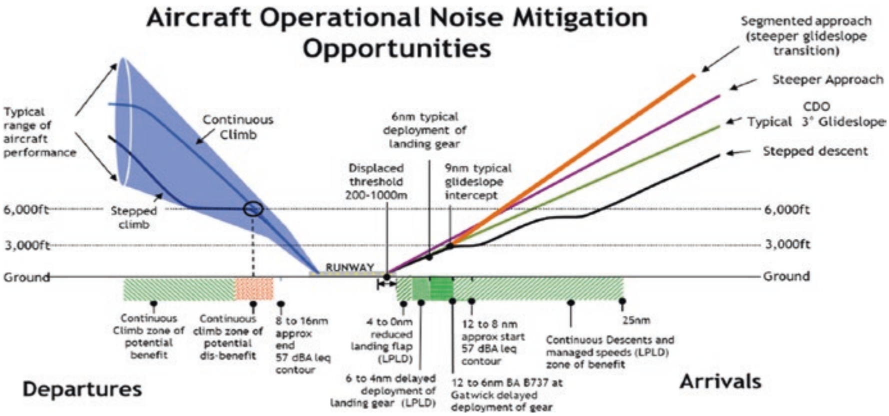

Fig. 32.9 Aircraft operational noise mitigation opportunities – illustrative, not to scale (Sustainable Aviation Noise Road-Map 2018)

Kazhan 2014), where the efficient numerical optimization was realized using the Lagrange multipliers method. Operational NAPs in use today can be categorized into three broad components: noise abatement flight procedures; spatial management; and ground movement management. Figure 32.9 schematically shows the operational opportunities of the NAPs. It also gives an indication of the areas (distances to the runway at departure and arrival) benefiting from some of any procedures outlined.

Given the above, the following guiding principles should be adopted when considering operational opportunities to reduce noise: safety must not be negatively affected; operational procedures should be developed in accordance with relevant ICAO provisions or regulatory guidance while allowing for the implementation of new procedures as that guidance evolves; changes to operational procedures must consider aircraft and operator capabilities and limitations with appropriate approval by the regulator; appropriate assessment tools and metrics to support decision-making and post-implementation review of conformance should be maintained; interdependencies should be considered between other environmental and non-environmental impacts and disproportionate trade-offs should be avoided. Of course, any progress in designing low noise aircraft would therefore lead to relaxing the stringency of the NAP to be used (Zaporozhets and Blyukher 2019).

In Fig. 32.10, it is shown that for ICAO Chap. 4 aircraft, the AN reduction ability via throttling the engines during the departure is more than twice less in comparison with Chap. 2 aircraft. Further improvements in noise generation at source (more balanced between the main acoustic sources of the aircraft) will provide much less ability for noise reduction by NAPs and the importance of the NAPs for AN management will be much limited.

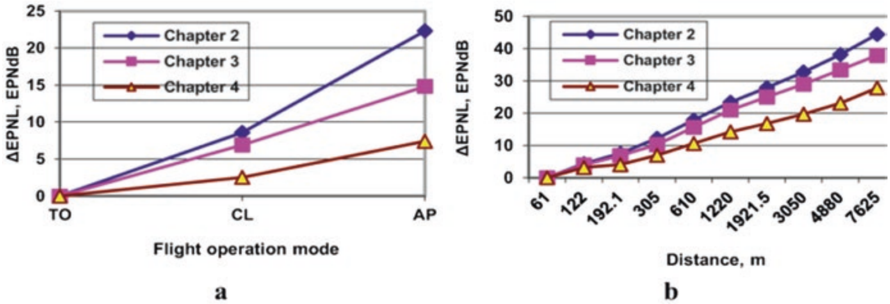

Fig. 32.10 Aircraft noise standard stringency influence on NAP ability to reduce noise level: (**a**) at point of noise control; (**b**) along with flight path distance

32.3.4 Aircraft Operating Restrictions to Reduce Noise Exposure

An operating restriction is defined in ICAO BA guidance (ICAO Document 9829, 2004), as "any noise-related action that limits or reduces an aircraft's access to an airport." The guidance recommends avoiding their application as a first measure to eliminate noise exposure in the airport vicinity, even in any specific point of noise control. Only in cases of insufficiency of the first three in reducing noise exposure levels at any location that operating restrictions may be implemented (EU Regulation 598 2014).

The decisions of the 40th Session of the ICAO Assembly on operating restrictions are contained in Assembly Resolution A40–17 (ICAO Resolution A40-17 2019), Appendix E "Local noise-related operating restrictions at airports." As stated above, it is limiting the operational and economic efficiency of the airport work. If the benefits from the first three BA elements are limited to fulfil the environmental requirements to noise at any location, operating restrictions should be considered and implemented in the following way: be based on the acoustic performance of the aircraft, which should be determined as the noise certification results, consistent with procedures of Annex 16, Volume I (ICAO Annex 16 2019); be fitted to solving the noise problem of the airport concerned in accordance with the balanced approach principles; be mostly of a partial nature, not the complete withdrawal of operations at an airport; consider the consequences for air transport services, especially if the suitable alternatives are absent (for example, long-haul flights); conditions of competitiveness should not be violated (for example, exemptions may be granted for carriers of developing countries); be introduced stepwise, considering the possible economic burden for operators and, if reasonable, give operators advance notice and time for preparations.

Operational constraints can immediately provide a significant reduction in the impact of aircraft noise around airports, but they can increase the financial burden for both airport operators and airlines. Today, hundreds of airports worldwide are

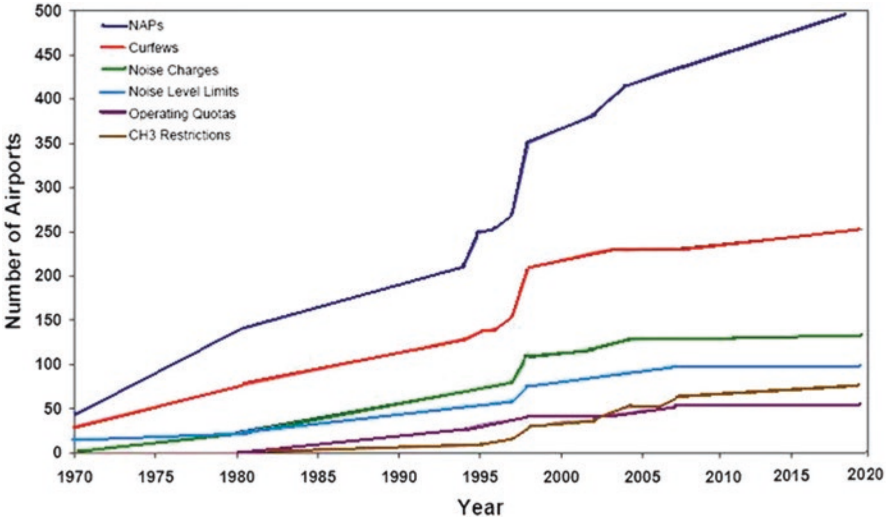

Fig. 32.11 Growth in aircraft noise restrictions at airports worldwide; data from "Airport Noise and Emissions Regulations" (Boeing 2021)

implementing aircraft operating restrictions for noise management purposes on a case-by-case basis, whilst limiting capacity, but improving the noise climate around airports (Fig. 32.11). The figure is built on data from Boeing's database "Airport Noise and Emissions Regulations" (Boeing 2021).

Aircraft operating restrictions for noise management may include as follows: restriction rules; noise quota or budget; non-addition rules; nature of flights; night-time restrictions; curfews; charges, etc. Any of them may fall into one or more of the four of the below-described categories, depending on how they are applied: Global (restrictions adopted worldwide – ICAO and EU decisions on Chap. 2 aircraft phase-out from the operation are the examples); Local (restrictions adopted by airport authority or by the state to eliminate the operation of noisy aircraft types, for example, Chap. 3 aircraft, another way the environmental constraints in a specific airport may reduce its efficient work); Aircraft-specific (restrictions applied to a specific type based on individual aircraft noise performance, usually at the specific route of departure or arrival at the airport); and Partial (restrictions applied for specific flight directions or/and for certain runways at the airport, during noise-sensitive time periods of the day, on specific days of the week).

32.4 Results and Discussion

Until now, all the existing BA elements have been assessed by changes in the noise exposure, mostly via noise contour modeling, and in some cases via monitoring. This allows for the evaluation of noise control measures to determine the most cost-effective and beneficial for environmental protection (Zaporozhets et al. 2011). In the best cases, the process is performed with public notification and consultation procedures, supplemented with mechanisms for dealing with disputes and complaints. It requires developing noise action plans with obligatory participation of the public, especially if their residential/rehabilitation area or substantive environmental aspects are impacted by aircraft noise.

A brief analysis of all the elements of ICAO BA shows that ICAO noise standards accompanied with technological improvements of aircraft noise performances provide a reduction of aircraft noise exposure globally, at least for international air transportation. The second BA element – noise zoning and land usage – is mostly a subject of regional/national noise exposure management, predefined by regional (such as Directives inside the EU) or/and national rules.

Numerous violations of noise limits may be observed inside the zones in the vicinity of the airport, for their control a third element is included – the NAPs. Airport and airline authorities must find the best solution to what kind of the NAP will be most efficient in any specific case. This is a subject for local consideration.

Flight restrictions are mostly the subjects of local decisions and only in cases of the insufficiency of the first three BA elements. There are a number of regional and global restrictions that also exist – they are effective for all airports if implemented for the whole (national, regional, or global) system at the same time.

Besides the technical elements, which are completely based on noise intensity metrics, the noise annoyance (and other types of outcomes of aircraft noise exposure to neighbouring residents) must now be addressed. This evolution may lead to a new vision of the balanced approach to aircraft noise control in the very near future (Zaporozhets and Blyukher 2019).

Addressing such human-centric concerns, encompassing fear, negative health effects, and other environmental issues may lead to adding a fifth element to the ICAO BA to aircraft noise management around the airports. Strategies that reduce noise annoyance, as opposed to noise, may be more effective in terms of protecting public health from the adverse impacts of noise and its interdependence with other environmental, operational, economic and organizational issues of airport, and airlines operation and maintenance (Zaporozhets and Blyukher 2019).

32.5 Conclusion

It is important to differentiate between noise exposure and the resulting noise nuisance (primarily annoyance) in different communities and to manage each appropriately. The protection of the residents from aircraft noise exposure is understood as a dynamic process, meaning that the evaluation criteria (both for exposure and nuisance) must be repeatedly tested and – if necessary – adapted to new scientific findings (Chyla et al. 2020). Compared with the traditional ICAO BA elements, which are defined by physical phenomena of sound generation and propagation, non-acoustical factors must now be included to reduce the annoyance. Up to now, annoyance was mainly explained through acoustical factors such as sound intensity, peak levels, duration of time in-between sound events, number of events (Janssen et al. 2011). The non-acoustical factors ("moderators" and/or "modifiers" of the effect) have still received empirical attention but without a deep theoretical approach, despite the fact that various comparative studies reveal that they play a major role in defining the impact on people (Job 1988).

ICAO BA continues to be developed in a few ways. Strategic solutions and decision-making procedures need simplified but quite accurate assessment tools of noise exposure and further – noise impact calculations. Second point – the global reduction of AN exposure at sources through technology improvements and new stringent standards implementation will continue to eliminate the NAPs and aircraft operating restrictions (as obviously shown in Fig. 32.11), at least as all of them are used today. More attention will be done to the management of non-acoustical factors, but the principles of their management are looking quite different from the current ICAO BA.

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