Management of Aircraft Noise to Increase Ecological Compatibility of Residential Areas

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Abstract. Development of air transport branch has been inevitably accompanied by environmental pollution. Using international approach, methodology assessing environmental risks from civil aviation, has been permanently enhanced. The purpose of the investigation is to decrease negative environmental effect of aircraft noise on population of the urban areas in the vicinity of airports. Within the balanced approach to management of the aircraft noise, field surveys of noise environment were performed on the residential areas adjacent to the Elizovo International Airport (Petropavlovsk-Kamchatski). Emergence of piston engine aviation has been the main factor of adverse effect on humans and their habitat. Initially the issue was limited by the noise generated by propellers. When reactive era came to the scene, though, and aero-gas dynamic flows within the powerplants, and aerodynamic noise from airframe overflow became the main sources of noise, subsequences of aircraft noise came to be the matter of concern for wide range of specialists. The need to increase capability of aircraft and their speed lead to augmentation of the powerplants thrust, and, as a result, the sound power generated by aircraft rapidly grew. And the severity of the issue has been growing on with the development of aviation, enhancement of international air fleet and flying intensity. As a rule, the airports are located either within cities, or directly in the residential areas which generates extremely unfavourable acoustic conditions for residential population and reduces quality of life. At the present a set of operations to assess noise conditions is carried out in the vicinity of the major airports of the world. It has been established that the localities within a radius of 5-10 km under the aircraft routes are systematically subject to high levels of aircraft wide-band noise with maximal acoustic energy within 63-1,000 Hz. Based on the performed assessment of the noise environment, a foundation was issued to use the most efficient architectural and construction anti-noise actions, in order to obtain maximal ecological benefits.

1. Introduction

Emergence of piston engine aviation has been the main factor of adverse effect on humans and their habitat. Initially the issue was limited by the noise generated by propellers. When reactive era came to the scene, though, and aero gas dynamic flows within the powerplants, and aerodynamic noise from airframe overflow became the main sources of noise, subsequences of aircraft noise came to be the matter of concern for wide range of specialists. The need to increase capability of aircraft and their speed lead to augmentation of the powerplants thrust, and, as a result, the sound power generated by aircraft rapidly grew. And the severity of the issue has been growing on with the development of aviation, enhancement of international air fleet and flying intensity. As a rule, the airports are located either within cities, or directly in the residential areas which generates extremely unfavourable acoustic conditions for residential population and reduces quality of life.

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The environmental requirements for aircraft noise have become the factor determining development of the air transport market, for excess of the allowed noise thresholds is penalized by considerable environmental fines, such limitations as bans of flights at night and prohibition to operate certain types of too noisy aircraft.

Within the federal target-oriented program of Russia ‘Economic and social development of Far East and Transbaikalia for the period until 2018’ [1] a large-scale adaptation of the Elizovo International Airport (Petropavlovsk-Kamchatski, Russia) is being carried out. The updated infrastructure of the airport is rated for long haul civil aircraft and heavy freight carriers such as AN-124, Airbus-330, Boeing-767/777 and others, which will promote optimization and dynamic development of flight connections in the region. The adaptation of the airport was accompanied by research engineering with the purpose of assessment of the acoustic conditions in the residential areas adjacent to the airport and justification of architectural and construction antinoise actions.

2. Aircraft noise as factor of environmental risk

Environmental risk represents negative consequences manifesting themselves as disharmony of natural processes, shifts of ecological balances, disruption of ecological systems, deterioration of humans’ health or living conditions as of environmental performance [2].

According to recent estimates, about 5 million people are subject to aircraft noise with the level $L_{\text{equiv}} > 55$ dB on the territories close to 91 airports in Europe [3]. Reactions of human body to acoustic irritants vary depending on frequency of sound waves, their intensity and duration. Continuous acoustic exposure leads to slow progressive decrement of auditory sensitivity, initially in the high pitch range and later within adjacent frequencies. Decrement of auditive acuity related to discrimination of oral speech can be traced already at the noise level exceeding 75 dB. Those regularly subject to noise level of 90 dB experience not only decrement of hearing, but also attention concentration. Pain sense occurs at the levels of acoustic pressure between 130 dB and 140 dB; at 160 dB eardrum rupture may occur. Chronic noise exposure may lead to acoustic stress not only for auditory system of the body. Noise exposure on involuntary nervous system manifests itself even at the sound of 40-70 dB and does not depend on subjective perception of noise by human. At the sound levels exceeding 85 dB vegetative reactions in the form of disorders of peripheral circulation may be observed. Noise exposure promotes concentration of attention, disorders of physiological functions, weariness appear due to increased metabolic costs and mental stress, speech commutation declines.

Aircraft noise is a specific acoustic irritant depending on the direction of the runways and aircraft routes, intensity of flights during the day and year, types of the aircraft, etc. severely affecting the noise conditions on the territory in the vicinity of the airports.

The methodology of risk management appeals for quantitative and qualitative assessment of actual and potential hazards and threats for human health. It is noted in the documents of the World Health Organization that management of environmental risks related to effects of transport noises shall ensure absence of unfavourable consequences for health [4].

2.1. International environmental requirements for aircraft noise

The current international requirements for rating of the aircraft noise began to emerge based on the resolution of the Assembly of International Civil Aviation Organisation (ICAO) adopted in 1968, where importance of the aircraft noise near the airports issue was raised for the first time ever. The Appendix 16 of the Convention on International Civil Aviation (1971) contains the information about the rules of description and measurement of aircraft noise, human’s reactions to it, certification of the aircraft for noise parameters, criteria for operational methods decreasing the aircraft noise, control for use of land plots and methods of noise reduction during engines ground run.

Today the ICAO’s mission as of aircraft noise consists of a balanced approach to the aircraft noise management. This approach includes: identification in a given airport of all aspects of noise issue using objective and measurable criteria; analysis of available measures to decrease noise levels; justification of the most economically efficient actions providing maximal environmental advantages [5].

Urgency of the issue is proved by further severization of noise norms recommended by the decisions of the 9th meeting of the Committee on Aviation Environmental Protection (CAEP/9) held in February 2013 in
Montreal: new norms were introduced on December 31, 2017 related to the aircraft of new types with the take-off weight exceeding 55 t; from December 31, 2020 the new norms will be introduced for the aircraft with the takeoff weight less than that specified. Intense search for innovative technical solutions is going on. Russia is the member of ICAO, it is governed by the standards and the practice recommended by this organization, performs environmentally responsible policy for aircraft noise management.

2.2. Aircraft noise management

Within the context of the balanced approach aircraft noise management is implemented via new technologies directly related to research of physical nature of noise generation and studies of acoustic field formation principles.

It is on the stage of the future aircraft concept formation when its environmental parameters are established which will ensure minimal adverse impact on the environment, the passengers and the crew. First of all, this is improvement of the airframe structure and that of the engines, using the latest materials. Decrease of the aircraft noise, however, is not limited only by the engineering and design solutions in the aircraft industry. A set of actions includes organizational, architectural and construction, territorial and planning operations and events, methods to improve flight and ground operation of the aircraft, etc. Implementation of this approach requires detailed elaboration of the aircraft operation scenarios accounting for its place in the transport systems, flights database, areas of adverse impact in the vicinity of the airports, as well as impact of cruise mode on climate.

It should be acknowledged that in practice using operational methods for noise reduction and aeronautical procedures faces limitations provided by strict requirements for flight safety. It is not always possible to form flight schedule balanced during the day, for competitor airlines are undoubtedly eager to offer the best times of arrivals and departures to their passengers but have to account for intensity of take-offs and landings at the airports, especially in peak hours, which requires the need for the night flights. Therefore, sometimes construction and acoustic actions become of the best importance at reduction of acoustic loads on the passengers, airport staff and the people living nearby. It should be mentioned that economic feasibility from the point of financial costs and expediency of implementation is among apparent advantages of some architectural and construction actions.

3. Methods and methodology

According to the current Russian Sanitary Rules and Norms (SanPiN) 2.2.1/2.1.1.1200-03, along the standard flight lanes, in the area of take-off and landing of the aircraft a distance from the source of physical impact is established reducing these impacts to the values of health standards (sanitary breaks). To assess aircraft noise, Russian Federal Consumer Rights Protection and Human Health Control Service (Rospotrebnadzor) (letter No. 01/6084-8-32 dated 09.06.2008) recommends to use GOST 22283-14 – ‘Aircraft noise. Permissible noise levels in residential areas. Methods of measurement’ – establishing maximal permissible levels of aircraft noise in residential areas at take-off, fly-over, landing of the planes and helicopters, as well as during engine run-up operation. During aircraft noise assessment the outlines of the noise are made according to the methodology from ‘Guidelines for establishing limiting zones of residential areas near civil aviation airports according to conditions of aircraft noise’ based on the most unfavourable operating conditions – during peak traffic [6]. Permissible noise levels for population are established by the Sanitary Norms 2.2.4/2.1.8.561-96 – ‘Noise at working places, in the residential and public premises and in the residential area’ [7].

The methods used for the most precise characteristic of the noise mode in the residential area use the values of the equivalent levels of sound \( L_{\text{equiv}} \). This value \( L_{\text{equiv}} \) accounts for maximal levels of noise during fly-overs of certain planes, duration of the higher 10 dB and intensity of flights during the day; it also enables to perform energetic summing-up of acoustic energy affecting humans during the day. Studies of the noise mode near the airports of various classes enabled to establish the picture of ear pollution and conditions of noise propagation in the residential areas in the radius of 6 km. The equivalent level of sound at 24 h intensive operation during the daytime may be 80 dB (A); 78 dB (A) – at night.

If a residential area is located under the takeoff route at the distance 1 km from the end of the landing strip, \( L_{\text{equiv}} \) reaches 80 dB (A); at the 4 km distance from the end of the landing strip the equivalent levels of sound are decreased down to 70...77 dB in the daytime and 70...75 dB at night depending on the class of the airport. Within the residential area at the distance of 2...3 km perpendicularly to the landing strip axis the equivalent
levels of sound are considerably lower: 64...61 dB (A) in the daytime and 59...55 dB at night. Within 4 ... 6 km from the landing strip where there are take-off and landing lines, holding area, the aircraft traffic most intensively affects the noise environment of the area [8].

According to the Federal State Unitary Enterprise State Scientific-Research Institute for Civil Aviation, half-width of the outline of the maximal level of sound \( L_{A_{\text{max}}} = 85 \text{ dB (A)} \) (daytime operation) during taxiing of an aircraft of the 2nd noise group (type IL-96, Tu-154, Tu-134) is 250 m, and during taxiing of the aircraft such as IL-76, A-319/320/321, B-757/737 and others of the 3rd and 4th noise groups – 180 m.

The order of noise measurements and their subsequent assessment was performed in the same way according to the sanitary requirements of Methodical Instructions 4.3.2194-07 – ‘Control of noise level in the residential area, in the residential and public premises’. To perform measurements of acoustic pressure levels, 12 benchmarks were selected at the border of the residential area. During measurements of the aircraft noise the following equipment was used: noise level meter Testo-816; spectrum analysing noise level meter Oktava101A; noise level meter-vibrometer Algoritm-03. During measurements the following limitations were accounted for: no measurements during precipitations, at the wind speed more than 5 m/s, negative air temperatures and at unfavourable combinations of temperature and relative humidity of ambient air.

Simultaneously with the noise levels measurements subjective reaction of people to aircraft noise was studied by polling the people living near the airports.

4. Characteristic of ear pollution from Elizovo International Airport (Petropavlovsk-Kamchatski, Russia)

According to the current Russian classification of the civil aviation airports (Operational Stability of Airports USSR), the Elizovo International Airport is related to class ‘A’ and corresponds to the code ‘4E’ by the ICAO standard. The airport is suitable for operation of aircraft both of Russian manufacture (IL-62, Tu-154, IL-86, Tu-134, Yak-40, IL-96-300, IL-76, An-124-100, Tu-204, Tu-214), and B-777, B-767, A-320 and other types of the aircraft of classes 3 and 4, helicopters of all types. The location of the airport is shown in Figure 1 obtained using the online-maps resource. At present there are two parallel landing strips with artificial coating at the axial distance 210 m between them:

- Artificial Landing Strip (ALS)-1 with magnetic direction landing 163R/343L (ALS-1 16R/34L);
- ALS-2 with magnetic direction landing 163L/343R (ALS-2 16L/34R);
- network of taxi strips (TS I-II);
- ramp and long-range aircraft of civil sector;
- ALS-1 16R/34L, length – 2,500 m, width – 60 m, commissioned in 1958 and after the ALS-2 16L/34R was built in 1978 decommissioned due to coating wear;
- ALS-2 16L/34R, length – 3,400 m, width – 60 m, commissioned in 1978.

The main sources of noise at the airport are the operated aircraft generating high levels of acoustic pressure during engines operation on the ground, at takeoff and landing and during fly-overs on the route at the heights up to 2,000 m. At present in Elizovo the civil aviation aircraft are operated: Boeing-777, A-320, Boeing-767, Sukhoi SJ, Tu-204, Boeing-737, L-410, Yak-40, An-28, helicopters Mi-8.

The rated aggregate outline of noise generated at taxiing of the aircraft at the Elizovo airport was created by the criterion of maximal level of sound at night \( L_{A_{\text{max}}} = 75 \text{ dB (A)} \) and daytime \( L_{A_{\text{max}}} = 85 \text{ dB (A)} \) for the most ‘noisy’ aircraft (IL-96).

The nature of subjective perception of noise by humans varies depending on duration of the noise load, type of activity and rest at various periods of day. The dwellers of the houses located near the Elizovo airport note that during the period of the most intensive traffic (summer season of mass vacations) they experience changes of their emotional state to the extent of stresses: nervousness, irritation increase, headaches and insomnia become more frequent, weariness comes faster, it is more difficult to concentrate on work, memory deteriorates. Children complain for alarm and fear, loss of appetite, pain in ears; the dwellers of the houses located close to the take-off and landing lines and to the sites of engine run-up complain for vibration of the houses themselves and houseware. Pensioners and the people suffering diseases of nervous system and CVS, e.g., hypertensive, suffer the greatest discomfort.
After processing of the data obtained during polling the local dwellers permanently living near the airport at a radius of 10 km the following results were derived: the sound levels of 65-75 dB do not considerably affect the population, and complaints are not many – 13-15%. With increase of the maximal noise level up to 80...85 dB the number of complaints increases up to 25-38%, and the levels of 95-100 dB cause negative reaction of 63-94% of the population. Irritation induced by noise especially increases in older age groups. The persons of up to 40 years old present 50% of complaints, 41-50 years old – 74%, older than 51 years – 91% [8]. Such dynamics is explainable, for the last group mainly consists of the persons spending the most of their spare time at home.

5. Results and discussions

The analysis of the field study results allows to reveal locations of dominating effect of the aircraft noise sources and to quantitatively assess the levels of ear pollution from the considered airport only in the area of civil aviation. It is impossible to obtain and take into account the data of operation and take-offs and landings of the military aircraft.

In general, after adaptation of the Elizovo airport the situation with noise impact on sanitary and epidemiologic welfare of the population living in the vicinity of the airport is satisfactory. At the same time, by the results of the sanitary break areas construction by the ‘aircraft noise’ factor during night operation of the aircraft of L-410 type and daytime operation of the aircraft of IL-96 type many localities in the direct vicinity from Elizovo airport turn out to be in the area of adverse impact: settlements Zarechny, Dvurechye, Krasny, Nagorny, Krutoberegovy. The location of these settlements as of the airport is shown in Figure 1.

![Figure 1. Location of Elizovo airport](image)

In the Zarechny, Dvurechye, Nagorny settlements excess of the rated value of maximal sound level according to GOST 22283-14 (Table 1) was \( \Delta L_{A_{\text{max}}} = 9.6 \) dB; by SN 2.2.4/2.1.8.562-96 (Table 2); for daytime excess of \( \Delta L_{A_{\text{max}}} = 14.6 \) dB, for night \( \Delta L_{A_{\text{max}}} = 24.6 \) dB.

| Time of day        | Equivalent sound level \( L_{A\text{equiv}}, \text{dB (A)} \) | Maximal sound level at single exposure \( L_{A_{\text{max}}}, \text{dB (A)} \) |
|-------------------|------------------------------------------------------------|------------------------------------------------|
| Daytime (from 7:00 am to) | 65                                                         | 85                                                         |
| Night (from 11:00 pm to 7:00) | 55                                                         | 75                                                         |

Table 1. Permissible values of sound levels in the residential area according to GOST 22283-14
Table 2. Permissible values of sound levels in the residential area according to SN 2.2.4/2.1.8.561-96

| Time of day            | Equivalent sound level $L_{A\text{equiv}}$, dB (A) | Maximal sound level at single exposure $L_{A\text{max}}$, dB (A) |
|-----------------------|----------------------------------------------------|---------------------------------------------------------------|
| Daytime (from 7:00 am to | 55                                                | 70                                                            |
| Night (from 11:00 pm to 7:00) | 45                                                | 60                                                            |

It is worth mentioning that at present in many countries the requirements to limit residential construction and the option of functional use of the area subject to aircraft noise are legally implemented. For instance, in Germany, according to the Act for Protection against Aircraft Noise permissible levels of aircraft noise have been established [9]; in the UK the values of equivalent levels of aircraft noise are established which govern issue of permits for residential construction. In France the Civil Aviation Department prepares ‘Noise exposure charts’ being the mandatory document for urban development aimed at restriction of construction close to the airports and the air routes. In Denmark aircraft noise is determined in $L_{dn}$ calculated for three months a year with the biggest number of operations with the allowance $+5$ dB in the evenings and $+10$ dB at night. In the U.S.A. delimitation of the territory near the airports by the types of functional use and establishment of compatibility of land use types with the sound levels $L_{dn}$ (dwelling in the areas of aircraft noise exposure is limited at $L_{dn} > 65$ dB) is performed according to part 150 of the Federal Aviation Rules (FAR Part 150) [9,10].

Turning back to Russian reality it should be mentioned that a system of requirements to the areas and antinoise actions was practiced before; it provided the 4-zone gradation of the territory. As a rule, the area prohibited for urban development was allocated, and recommendations were proposed as of the facilities protection level against noise. This system was valid according to ‘Recommendations to allocate areas limited for urban development near civil aviation airports according to aircraft noise conditions’ [11].

To use aerodrome environs, at present the Russian Department of Transportation is preparing amendments to Article 47 – ‘Location of various facilities near airports’ – of the Air Laws Regulations of Russia [12] and supplements to Articles 31, 32 and 40 of the Town-Planning Code of Russia [13]. Practical implementation of such amendments will be directly related to the need of rating the aircraft noise in the appropriate areas.

The analysis of the aircraft noise measurements in the established area of the Elizovo airport demonstrated the need to install acoustic insulation windows in the residential areas (as architectural-planning action) to reduce impact of the aircraft noise. With the current $L_{A\text{max}} = 84.6$ dB for the daytime, the acoustic insulation windows with the acoustic insulation factor $R_A = 30 - 40$ dB is necessary.

The main element of the window opening (multiple glass pane) is the structure consisting of two or more tightly interconnected glass panes. Connection is achieved using special spacer frame filled with absorbing powder. As a rule, double-chamber glass pane is equipped with internal and external sealer. This excludes formation of condensate within. Closed cavities are filled with dry air or rare gas. Mounting of the multiple glass panes of such design demonstrates perfect parameters of acoustic- and heat insulation.

Additional functional properties of single/double-chamber glass pane are achieved by covering the external glass with coatings of various types. Based on the glass of various types and design features, the double/single-chamber glass panes may demonstrate the following special features: sunlight protection, sound insulation or shockproof. The multiple glass panes may be double-chamber and single-chamber. As a rule, the double-chamber is more reliable and durable. The following parameters are indicated on the multiple glass panes: glass thickness and type, width of spacer frames, type of gas (dry air, by default).
Table 3. Main features of multiple glass panes

| Glass pane type | Glass pane design | Glass pane thickness, mm | Acoustic insulation factor $R_A$, dB |
|-----------------|-------------------|--------------------------|-------------------------------------|
| Single-chamber  | 4-12-4            | 20                       | 25                                  |
| Single-chamber  | 4-16-4            | 24                       | 25-27                               |
| Double-chamber  | 4-8-4-10-4        | 30                       | 38-40                               |
| Double-chamber  | 4-8-4-8-4         | 28                       | 37-39                               |
| Double-chamber  | 4-10-4-10-4       | 32                       | 37-39                               |
| Double-chamber  | 4-12-4-12-4       | 36                       | 37-39                               |
| Double-chamber  | 4-12-4-6-4        | 30                       | 27-30                               |
| Double-chamber  | 6-10-4-6-4        | 30                       | 32-34                               |

The example of such windows is ‘KBE Expert’ – 5-chamber glass pane system of 70 mm width. The windows made of ‘KBE Expert’ profile combine functionality, absolute safety and environmental friendliness of the ‘greenline’ formula. The ‘KBE Expert’ profile features enhanced heat- and acoustic properties, ideal geometry, reliability.

6. Conclusions

Development of air transport market is accompanied with unfavourable environmental impact of the aircraft noise on the population of urban areas located near the airport.

According to balanced approach to the aircraft noise management field studies of aircraft noises were performed in the residential areas adjacent to the Elizovo International Airport (Petropavlovsk-Kamchatski, Russia). The analysis of the results showed feasibility of taking architectural-construction anti-noise actions. The need to install acoustic-insulated windows with the acoustic insulation factor of at least 40 dB in the residential areas has been justified.

Adaptation of the normative acts in the area of regulation and assessment of the civil aviation impact on the environment will allow optimization of the land-use procedures during development and agreement of the sanitary-protected areas of the airports.

Conflict of interests

The authors confirm that the data represented in this article do not form conflict of interests.

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