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ANALYSIS OF THE AIRCRAFT NOISE IMPACT ON ENVIRONMENT FOR DETERMINE THE RATIONAL WAYS OF ITS REDUCTION

Actuality of the study and the neediest to develop rational ways for aircraft noise reducing is shown. Directions for aviation noise reduction is proposed. Analysis of the problem of aircraft noise has shown that together with increasing cargo-capacity and passenger-capacity of the civil aircraft to increase and aircraft deleterious effect on the environment, including the human health. The structure analysis in general and aircraft noise in particular for determining rational ways of the noise reducing is performed. The following results were obtained: the main characteristics of the aircraft noise spectrum classification, noise characteristics classification, analyzed the main sources of aircraft noise and their noise characteristics are shown. The aircraft noise specifics with depending on the flight stage is given. The main ways to reduce aircraft noise proposed: improving characteristics of engines, as well as improved aerodynamic characteristics of airframe by rational choice of geometrical parameters of particular units.

Keywords: aircraft noise, noise level, noise intensity, noise frequency, noise reduction, protective coverage.

Problem statement. It is important to limit and minimize technogenetics impact on the change of physical environmental factors to preserve the living environment, which is safe for humans. One of these factors is the noise impact of aircraft. Exclude this impact entirely without renouncing of achievements of civilization is impossible and this is unacceptable [1, 2, 3]. Acoustic effects of civil aircraft, the largest in comparison with all other technical sources, unless considered relatively rare launches of spacecraft in sparsely populated areas and conduct of hostilities wartime.

Particularly acute this problem occurs at the airports area. ICAO consistently toughen the aircraft noise level requirements. Thus, objective circumstances and regulatory requirements are forcing designers to modify the approaches to the aircraft designing. But, to successfully complete the task – the noise reduction – is necessary to conduct the detailed analysis of the structure, sources and the impact of aircraft noise. This theme is explored in the proposed paper.

Statement of the problem and its solution. Sound is an undulating propagation of the elastic field particles vibrations. There are two concept of «sound» [4]:

– the biological concept – including acoustic vibrations, which perceived by humans hears, for an average healthy person is a vibration in the frequency range from 16…20 up to $(16...20)\cdot 10^3$ Hz;

– physical concept – combining both audible and inaudible by a human sounds in the nominal range $0...10^{13}$ Hz. The sounds with frequencies equal of permil hertz are found in nature, so the lower limit of the frequency band is practically not limited. The upper limit of frequencies is limited due to the nature of the substance matter atomic-molecular structure: for gases is a 10^9 Hz, and for solid and liquid bodies – $10^{12}…10^{13}$ Hz (figure 1).

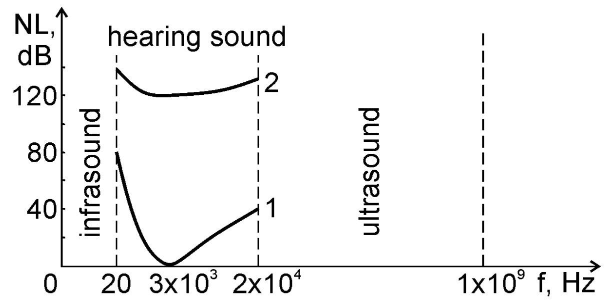

Figure 1 – Range of acoustic oscillations with the humans limitation: 1 – auditory threshold, 2 – threshold of noise pain

To accepted elastic vibrations with frequencies below the audible range of sounds to call infrasound, with frequencies above the top border – ultrasound and in the frequency range from $10^9…10^{13}$ Hz is hypersound. Audible sounds are divided into low frequency (less than 350 Hz), midrange (from 350 to 800 Hz) and high frequency (more than 800 Hz) [5].

The object, which is move in media faster than the sound speed in this media, creates a media shock-wave called a acoustic impact (figure 2) [6].

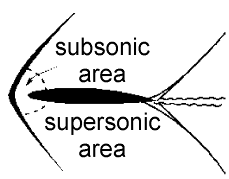

Figure 2 – The nature of the shock-wave at a airfoil for Mach number $M = 1{,}3$

The noise is any undesirable sound or complex of sounds, affecting especially at a human body. Biological affects on other organisms can significantly differ from the typical for humans. So, the upper limit the range of audible sounds for dogs is about $90 \cdot 10^3$ Hz.

Aircraft and their engines create a disturbance in the atmosphere, so it is the zone in which the pressure is decreased and increased about to average pressure of the undisturbed air. These perturbations are moved in the air media at the sound speed and are sensed by the organism as noise.

The objective sound characteristics. Sound waves spring if any force disturbs the media steady state. As a result, the media particles begin to fluctuate about the equilibrium state with the speed, much more than sound waves speed. Sound wave is propagated in media and is carried an energy [7, 8].

For the description of the oscillatory and energy processes in acoustics, it is generally accepted some concepts and their objective (physical) characteristics.

The propagation sound speed a, m/s, is related to the wavelength λ, m, frequency f, Hz = 1/s, and the period of oscillation T, c, by next equation

$$a = \lambda \cdot f = \lambda / T . \quad (1)$$

The sound speed change in air with accordance to its temperature change T, K or t, C is described by the equation

$$a = 20{,}1\sqrt{T} = 332 + 0{,}6t . \quad (2)$$

Sound energy E_s, J – energy, consisting of kinetic energy of oscillating particles and potential energy of media elastic deformation.

The source acoustic power (or sound power) W_s, W – is the total sound energy, emitted from the sound source in all directions of space per unit of time.

Sound pressure p, Pa = N/m^2, is a variable about unperturbed air media pressure, that springs when the sound waves move.

The sound intensity I, in W/m^2 – average flow (volume) of energy W_e, W, at this point of space per unit time through a unit of area F, m^2, which is perpendicular to the sound propagation direction, i.e. $I = W/F$. The sound intensity is a vector, because it is determined depending on the direction of the sound stream. The sound intensity is difficult to measure directly, so in the tests of sound measurements the sound pressure level is determine, and after that carry out the recalculation.

It known, that [8].

$$I = p \cdot V = p^2 / (\rho \cdot a), \quad (3)$$

or,

$$I = f\left(p^2\right), \quad (4)$$

where V is the root-mean-square value of the media particle oscillation velocity at a sound wave, m/s; ρ – media density kg/m^3.

In addition, the product ρ×a is call specific acoustic drag, it is equal 410 [Pa×s/m] for air.

The emanation of acoustic energy by the real sources in environment with different directions is taking place unevenly. For the mathematical description of the features used focus factor

$$\mathrm{F} = I_d / I_{sp} = I_d / W 4\pi r^2 , \quad (5)$$

where I_d – the sound intensity generated by the source at point and at the direction of d, W/m^2; I_{sp} –intensity non-directional (spatial) transducer equivalent power W, in W/m^2; r – the distance from the source to the research point, m.

In practice, there are use: sound pressure p and the sound intensity I, which are different in absolute value 10^8 and 10^{16} times respectively, that is uncomfortable. So in acoustics accepted a certain level of index and its logarithmic value; so, first of all, used sound pressure levels and sound intensity. This way proved to be the more convenient due to the peculiarities of human hearing to respond not to the absolute, but at relative change of power sound.

The level of any index – the result of the comparison of actual values with its predefined (standard) value. Since, in accordance with the equation Weber-Fechner, the person perception different kinds of irritations, in particular sounds or vibration, to proportional to the logarithm of the energy volume, also the level of acoustic index convenient to show as the logarithm of the corresponding relative value.

As the standard value, used for comparison when the sound level determining, are accepted the minimum values of the sound intensity and sound pressure, which human hears with frequency sound of 1000 Hz. This is I_0 = 10^{-12} W/m^2 and p_0 = $2 \cdot 10^{-5}$ Pa. They got the name of thresholds of audibility.

Thus, the level of sound intensity (sound power level)

$$L = 10\, lg\left(I / I_0\right). \quad (6)$$

From equation (6), taking into account the dependence (5), the sound pressure level

$$L = 10\, lg\left(p^2 / p_0^2\right) = 10\, lg\left(p / p_0\right)^2 = 20\, lg\left(p / p_0\right). \quad (7)$$

Acoustic power level

$$L = 10\, lg\left(W / W_0\right) \text{ at } W_0 = 10 - 12W . \quad (8)$$

For the sounds (noise) analysis in the total range of frequencies it divided into separate lanes. In music and technical acoustics it most often divided into octaves –

frequency bands in which the upper limit frequency f_u at twice time higher then lower limit f_1, i.e. $f_u = 2f_1$.

The sound pressure levels are used for acoustic measurement, the levels of sound intensity – for acoustic calculations.

Noise spectrum is a components complex of the sound pressure levels, which received by frequency analysis. Noise spectrum is an impotent characteristic, it is the base for planning the technical ways to noise reduce. General noise level L_Σ, dB, is the value, that corresponding to the full intensity of the spectral components of an audio signal L_i in all its frequency range, divided into n lanes:

$$L_\Sigma = 10\lg \sum_{i=1}^{n} 10^{0,1L_i} . \qquad (9)$$

Subjective characteristics of the sound. In general, the subjective perception of sound is determined by the indexes, which are comparable with objective acoustic characteristics. The main differences relate to the following features of psycho-physiological humans responses [9, 10].

Hearing aid man reacts at same moment to all: frequency sounds (pitch of tone), their intensity and tone structure, depending on the relative intensity of additional oscillation of higher level than the base frequency, which determines by the pitch of tone.

In figure 1 shown how a person with normal hearing changing perception of sounds having minimum intensity with changing frequency, i.e. «hearing threshold curve» in the audible frequencies range.

The upper curve in figure 1 corresponds to the pain sensations threshold that present at sound level 120…130 dB, with little dependent on frequency. With more stronger sound these are possible rupture eardrums, contusion, and at levels above 160 dB the death [10].

The extent of the noise deleterious effects vastly depends also on how it differs from the usual noise and individual attitude to it. Noise during evening and night time with ceteris paribus has significantly more irritation. The absence of normal silence, especially at night, leading to premature fatigue and illness.

It is taken to use special correction (figure 3) for account for the man perceptual the different frequencies sounds. So in standard sound level meter, in accordance with the requirements of GOST 17187-87, provides several scales of frequency correction: A, B, C, and D.

Measuring with frequency correction scale B, C and D are rare, in specific cases, whereas the measurement by the scale A of the standard sound level meter is often as much as possible. They have specific name "sound levels scale A" and have specific designation – L_A, as well as a special unit of measurement – the decibel (dBA). When applying scale D it gets the audio levels by the scale of D – L_D in decibels (dBD).

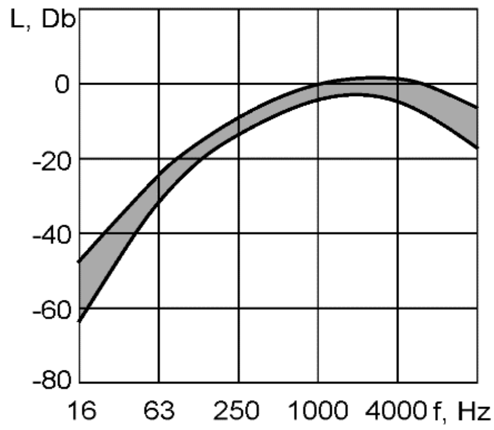

Figure 3 – Frequency response scale A of the standard sound level meter

Characteristics of aircraft noise. The aircraft noise has some differences from the stationary sources noise. The main of them are: the inconstancy of noise in time; frequent repeatability of noise; specific spectrum of sounds; available in the spectrum characteristic of discrete components [9, 10, 11, 12].

At the modern time the following approach (it based at the noise level scales A and D) uses for the indicative estimation of aircraft noise.

Inconstant in time noise, i.e. such whose sound pressure levels in time are changed more than 5 dB, characterized by energy equivalent sound level

$$\mathrm{L}_{\mathrm{Aeq}} = 10\lg\left[\frac{1}{T}\sum_{i=1}^{n}\left(t_i 10^{0,1L_{Ai}}\right)\right], \qquad (10)$$

where T – the total period of observation, i.e. the total time of noise effect, with various levels of sound L_{Ai}; n – the bands number that split the analyzed audio frequency range; i – the band index; t_i – time sound effects i-bands; L_{Ai} – the average sound level of the i-band with taking into account the features of his human perception.

In the world for estimation and further rule-making of aircraft noise by the recommendation of ICAO has developed and uses the following special criteria:

– *perceived noise level PNL*, measurement is in specific units PNdB. This criterion focuses on frequency contents of aircraft noise;

– *perceived noise level with accordance of the discrete components of the PNL,* measurement is in specific units TPNdB;

– *effective perceived noise EPNL*, measurement is in EPNdB. The criterion of EPNL takes into account not only frequency contents, but also the discrete components in the spectrum and the noise duration in accordance with the equation

$$EPNL = PNLM + C + D \qquad (11)$$

where $PNLM$ – the maximum value of the perceived noise level, PNdB; C – correction, taking into account the discrete components in aircraft noise, PNdB; D – correction, taking into account the duration of noise.

Methods for calculating perceived noise levels with according to the measurements, corrections C and D, as well as effective perceived noise levels are given in GOST 17229-85. For engineering calculations with the real measurements data, performed by the sound level meter with standard filters at the scales A or D, is used the simplified method with empirical dependencies for acoustic characteristics calculation. For example, when high precision is not required, for aircraft with turbojet engines used the approximate equation

$$PNL \text{ (or } PNLT) = L_A + 13 = L_D + 7 ,$$

or airplanes with turbofan engines

$$PNL = L_A + 15 = L_D + 9 .$$

Sources of aircraft noise. The noises are divided into mechanical, hydraulic, electromagnetic and aerodynamic. Aviation noise is the aerodynamic type, it is one of the most significant sound level. They are the result of air flow around various bodies. The reason for the aerodynamic noise: vortex processes in the airflow; gas ripple caused by the rotation of the blades of fans, turbines; fluctuations related with the inhomogeneity and ripple of the stream [13–18].

Noise sources from modern civil subsonic aircraft are: aircraft engines, auxiliary power units (APU) and external parts of airframe. On the ground at the time of the engine idling the primary source of noise is the APU. At takeoff, climbing and cruise flight the noises from main engines higher, then other sources, but also airframe specific structural elements create a part of this noise. At time of the descent and approach the large part of the noise the airframe produce.

In the engine noise sources are divided at internal and external groups. For subsonic passenger airplanes and helicopters widely use turbofan and turboprop engines. In them, the internal sources are: fan, compressor, combustor, turbine and exhaust section, and external sources are: stream jet and turboprop engine propeller.

The fan (compressor) noise spectrum consists of broadband and tonal (discrete) noise (figure 4). Discrete components are correspond to the main band from blades turning. For example, in the case shown in figure 4, they are the frequencies of 4,7 and 9,6 kHz. Broadband components of this noise occur due to vortexes, generated from airflow about blades and vane ring. At modern engine fans are present supersonic tip speed, that creates the shock waves and very uneven field pressure at turning blades, as the result, the noise from blades turning and general fan noise rough increases.

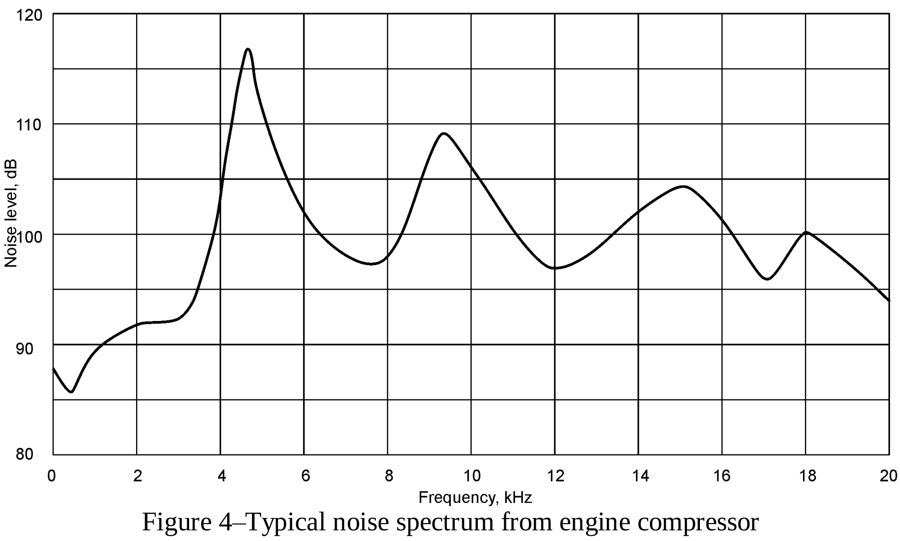

Figure 4–Typical noise spectrum from engine compressor

At the high-bypass ratio engines internal noise of the hot part consists of noise combustion chambers, turbines and exhaust section.

Combustion noise – low frequency broadband. Its intensity strongly depends on the shape and size of the chamber. Can-annular combustion chambers produce noise more than annular combustor.

The turbines noise has the same reasons that and fan, but it has the following feature. The stream, exiting from the combustion chamber, has increased irregularity and fluctuations (random deflections, oscillations), so all the noise components the rough increased. Discrete components are present at the range of high and most disagreeable medium frequencies (last are present at slow-turning turbines fans).

Noise exhaust channel is relate of its high speed, high turbulence and inhomogeneity for stream after the turbine. It consists of rectifier parts flow noise and other obstacles, turbulent noise, noise of interaction with the channel border.

Internal sources noise is emitted in the rear hemisphere with the high angle (60...70° for maximum emission). This increases aircraft noise at climbing and landing.

The turbulent pulsations in zone of jet mixing with the external airflow is a main reason of the jet noise. The jet noise acoustic power is proportional to the area of the output nozzle and eighth degree specific exhaust velocity. While the largest part of the sound energy emitted at the initial part of the jet, and beyond 10…15 diameters of the nozzle the jet is silent.

With increasing jet stream diameter and gas temperature the noise spectrum is shifted toward lower frequencies, with increasing jet velocity – in the direction of high frequencies. Therefore, the low-frequency and medium-frequency noise are typical for the modern gas-turbine engines

For turbojet engines is characteristically that jet noise is significantly higher than the internal engine noise. The overall level of the acoustic power in the wide frequency range can be approximately estimated by the equation

$$L = 80 \cdot \lg V_n + 20 \cdot \lg \rho_n + 10 \cdot \lg F_n - K, \quad (12)$$

where V_n – jet velocity from the nozzles; ρ_n – jet gas density in the nozzle exhaust cross-section; F_n – nozzles cross-section area; K – jet temperature-dependent variable value, $K = 57$ dB for cold jet, $K = 44$ dB for hot jet.

Propeller noise is the main for turboprop engines. It is the result of blades force impact on the air, in which there are: displacement air, the turbulent layer generation on the blades surface and in wash. Additional noise is the result of shock waves and local seals. They are present at subsonic and supersonic speeds of the blades tips. The main characteristics of the propellers, which influence on the noise: propeller diameter; blades number; specific blades tip speed (Mach number).

Conclusions. International requirements for the aircraft noise level continue to toughen up and airports are preparing to control of their execute. So, in Europe bigger part of airports already are equipped with remote control of aircraft noise.

Acoustic improvement of civil aircraft depends on the action plan to reduce noise generated by airplanes and helicopters. Since the problem of aircraft noise is complex, then the noise proof requires the solution solving at many interrelated tasks [4]:

– creation of low-noise engines;

– development and using new passive noise-proof equipment (coverage);

– development and using active noise-proof equipment (noise against noise);

– improving flight performances of aircraft;

– analysis of rational engines arrangement;

– decreasing aerodynamic noise from airframe, landing gear, etc.

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АНАЛІЗ ВПЛИВУ АВІАЦІЙНОГО ШУМУ НА НАВКОЛИШНЄ СЕРЕДОВИЩЕ З МЕТОЮ ВИЗНАЧЕННЯ РАЦІОНАЛЬНИХ ШЛЯХІВ ЙОГО ЗМЕНШЕННЯ

Показані актуальність дослідження та необхідність розробки раціональних шляхів зі зниження авіаційних шумів. Запропоновано напрями щодо зниження шуму авіаційної техніки (АТ). Аналіз стану проблеми авіаційного шуму показав, що з ростом вантажопідйомності й пасажироємності повітряних суден цивільної авіації збільшується шкідливий вплив авіаційної техніки на довкілля, в тому числі на здоров'я людини. Для визначення раціональних шляхів зниження шуму був виконаний аналіз структури шумів взагалі й авіаційних шумів зокрема. Отримані наступні результати: виявлено основні характеристики спектра авіаційного шуму, наведено класифікацію характеристик шумів, проаналізовано основні джерела шуму літаків, показані характеристики відповідних шумів. Надана коротка характеристика шуму АТ в залежності від стадії польоту. Запропоновані основні напрямки щодо зниження авіаційного шуму: поліпшення характеристик двигунів, а також вдосконалення аеродинамічних характеристик літаків шляхом раціонального вибору геометричних параметрів окремих агрегатів.

Ключові слова: авіаційний шум, рівень шуму, інтенсивність шуму, частота шуму, шляхи зниження шуму, захисні покриття.

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АНАЛИЗ ВЛИЯНИЯ АВИАЦИОННОГО ШУМА НА ОКРУЖАЮЩУЮ СРЕДУ С ЦЕЛЬЮ ОПРЕДЕЛЕНИЯ РАЦИОНАЛЬНЫХ ПУТЕЙ ЕГО УМЕНЬШЕНИЯ

Показаны актуальность исследования и необходимость разработки рациональных путей по снижению авиационных шумов. Предложены направления по снижению шума авиационной техники (АТ). Анализ состояния проблемы авиационного шума показал, что с ростом грузоподъемности и пассажироемкости воздушных судов гражданской авиации увеличивается и вредное влияние АТ на окружающую среду, в том числе и на здоровье человека. Для определения рациональных путей снижения шума был выполнен анализ структуры шумов вообще и авиационных шумов в частности. Получены следующие результаты: выявлены основные характеристики спектра авиационного шума, приведена классификация характеристик шумов, проанализированы основные источники шума самолетов и показаны характеристики соответствующих шумов. Дана краткая характеристика шума АТ в зависимости от стадии полета. Предложены основные направления по снижению авиационного шума: улучшение характеристик двигателей, а также совершенствование аэродинамических характеристик самолетов путем рационального выбора геометрических параметров отдельных агрегатов.

Ключевые слова: авиационный шум, уровень шума, интенсивность шума, частота шума, пути снижения шума, защитные покрытия.