NOISE PROBLEMS

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Contents

Summary

Actual problems of reduction of a noise of air and ground transport systems are a part of a common struggle for cleanness of our planet, for improvement of conditions of living on the earth. Bases and results of experimental researches of formation, spreading and influence of noise of AJE of aircrafts and of PE of ground transport, that are examined, show, that maximum noise has mainly an aerodynamic origin and arises at operation of transport systems.Trustworthy methods of rated and experimental definition of the level of the noise of engine and its components that form it must be developed. Constructive ways of lowering the noise by influencing the process of sound formation itself and by increasing the intensity of absorption of sound waves as it spreads out should be found. It permits to restrict its limiting values, and also to perfect norms and indexes of level of noise. A creation of airplane and automobiles with small noise level requires an all-embracing solution of the problem that includes works on lowering of a level of a noise of all assemblies and units of airplane or automobile, optimization of operational modes, and trajectories of take-off and landing etc.

1. Physical fundamentals of a noise and sound

1.1. Concepts about noise and sound

Every undesirable sound can have a bad physiological and psychological influence on human organisms and is considered as a noise. Noise is the complex mixture of sounds of various frequencies and tones. All noise can be divided on the basis of its origin to four types: mechanical, aerodynamic, hydraulic and electrical. The reasons of mechanical noise are percussive loads and vibrations. Aerodynamic noises are a consequence of conversion of energy from vortical disturbances to acoustic oscillations by a stream of gas (air) flowing around elements of construction Hydraulic (hydrodynamic) noises are connected, for example, with formation of a cavitation in pumps, hydraulic impact in hydrosystems, and formation of vortexes (turbulence) by the flow of a stream of fluid through the rough internal surfaces of pipes. The electrical noise is the result of oscillations of ferromagnetic masses in electrical machines under the influence of a variable (in space and time) electromagnetic fields. Usually power plants, machines and mechanisms are simultaneously a radiant source of noise of several kinds. However for GTP the aerodynamic noise, that forms, for example, from rotors of compressor and turbine or at mixing of a high-speed exhaust stream of gases, which flows from a jet nozzle of AJE, determines the maximum noise level that must be compared to the values that are established by norms.

Sound represents elastic vibrations that undulatory extend in gases, fluids and solids and are perceptible by a human ear. Human beings can hear a sound with frequencies ranging from 16 up to $2 \cdot 10^4$ Hz. The science of sound is named acoustics. At perception of a sound loudness, pitch and timbre are distinguished. The loudness of a sound is determined by amplitude of vibrations, pitch – by frequency, timbre – by amplitude of vibrations with higher frequencies.

Noise consists of very weak oscillations of pressure, which are spread by air with a local velocity of sound. These oscillations generally vary in a range from $2 \cdot 10^{-5}$ up to 2 Pa at a standard value of atmospheric pressure 101.325 kPa. A human ear balances a constant pressure and reacts only to its oscillations. The velocity of sound is determined by the following expression $a = \sqrt{dp/d\rho} = \sqrt{k \cdot p/\rho} = \sqrt{k \cdot R \cdot T}$, where: k – isentropic index equal to the ratio of the specific heats $k = c_p / c_v$ (for the air $k = 1.4$), R – gas constant, T – absolute temperature. At a temperature of 288 K and normal atmospheric pressure the velocity of sound is equal to 331 $m \cdot s^{-1}$. An essential parameter in the formula for a velocity of sound is the temperature. The presence of temperature gradients in the atmosphere results in bending of sound waves that can have an effect on its spreading. In the exhaust systems of GTE, the temperature of exhaust gases on exit can be 600, …, 800 K, therefore, the local velocity of spreading of sound increases several times. The sound field is an area of space, in which the sound waves are spreaded. In each point of a sound field pressure and velocity of movement of particles of an air vary with time.

1.2. Basic parameters and performances

The length of a sound wave λ is connected to a velocity of sound α and frequency f by the dependence $a = f \cdot \lambda$. The typical lengths of sound waves can vary from 17.2 m at 20 Hz up to 17.2 mm at 20 kHz. The low–frequency waves easily bend round angular areas and barriers, while for a high–frequency sound, zones of acoustic shadow are usually formed. A change of a pressure in a medium due to spreading of sound waves is named sound pressure p, Pa. Taking into account a change of sound pressure with time, the magnitude $\overline{p}^2 = \int_{\tau}^{\tau+t} p^2 d\tau \cdot t^{-1}$, where: t – time of averaging; τ – current time. The resulting sound pressure p_s varies above and below the static pressure of the atmosphere according to the relation $p_s = p_o \, Sin\left[(2\pi f)t\right]$, where: p_o – a constant called the pressure amplitude, t – time in seconds, f – frequency in hetz. In the International System of Units sound pressure is usually in micropascals; abbreviate μPa. Sound pressure is proportional to the velocity of the vibration surface. Such velocity is called the oscillatory velocity. The motion described by a sine wave of a single frequency is called a pure tone. Such simple harmonic motion is important because all sound waves can be shown as composed of one or more simple harmonic waves. A degree of action of a sound on organs of hearing is determined by a quadratic mean value of sound pressure:

$$p_s = \sqrt{\int_{\tau}^{\tau+t} p^2 d\tau \cdot t^{-1}} \quad , \qquad (1)$$

When sound waves have everywhere the same direction of propagation, they are called flat waves. This is caused by the fact that the points of maximum compression form planar surfaces, which are perpendicular to the direction of propagation. Many sound sources emit sound waves in which the points of maximum compression form concentric spheres. Such waves are called spherical waves. In a flat sound wave the ratio of sound pressure to an oscillatory velocity does not depend on oscillation frequency $p/v = \rho \cdot a$. For air at normal atmospheric pressure the density is $\rho = 1.2$ kg·m^{-3}. During spreading of a sound wave transfer of energy takes place. The average stream of an energy at any point of a medium in a unit time, referred to a unit surface area that is normal to the direction of spreading, is named intensity of sound at the given point, $\boldsymbol{I}_s$, W·m^{-2}. The intensity (force) of a sound is equal $\boldsymbol{I} = p_s^2 / (\rho \cdot a)$, where: $\rho \cdot a$ – specific acoustic resistance of a medium and for the air $\rho \cdot C = 413$ (Pa·s·m^{-1}) at temperature 293 К. The given formula for the determination of intensity is correct provided that the direction of a stream of energy is well-defined. In the closed space (for example, in an industrial room) the numerous reflections of sound waves take place and the actual value of the resulting intensity can be insignificant, even if the changes of acoustic pressure are great, and, in this case, the mentioned above dependence $\boldsymbol{I_s} = f(p_s)$ can not be used. The magnitudes of sound pressure (Pa) and force of sound (W·m^{-2}) vary, as shown in a table 1, over a wide range: from the lower value that corresponds to a limit of sensitivity of human ear, up to upper limit of a pain, when the sound is not audible any more ($2.10^{-5} < p_s < 64.5\ Pa$ and $10^{-12} < \boldsymbol{I_s} < 100\ W \cdot m^{-2}$).

Decibels	I, W·m^{-2}	p_s, Pa	Examples of sounds of the indicated force
0	10^{-12}	0,00002	Limit of perceptibility of human ear
10	10^{-11}	0,000065	Rustle of leafs. Weak whisper on a distance 1 m
20	10^{-10}	0,0002	Quiet garden
30	10^{-9}	0,00065	Quiet room. Average level of noise in auditorium. The game of a violin (pianissimo)
40	10^{-8}	0,002	Low music. Noise in a accommodation
50	10^{-7}	0,0065	Weak sound of a wireless receiver. Noise in apartment with opened windows

60	10^{-6}	0,02	Loud wireless receiver. Noise in a shop. Average level of conversational speech on a distance 1 m
70	10^{-5}	0,0645	Noise in cabin of a lorry. Noise inside a tram
80	10^{-4}	0,20	Noisy street. A typewriting bureau
90	10^{-3}	0,645	Automobile horn. Fortissimo of a large symphonic orchestra
100	10^{-2}	2,0	Riveting. Automobile siren
110	10^{-1}	6,45	Pneumatic hammer
129	1	20	Jet engine on a distance 5 m. Strong thunder-claps
130	10	64,5	Pain limit; the sound is not audible already

Table 1. A force of a sound $\boldsymbol{I}$ and sound pressures p_s

In vibroacoustics the logarithmic levels of parameters are used. A generally accepted measure of a level of sound is the decibel, dB. It is caused by the fact that the sensations of the human ear, which arise due to a noise, are proportional to the logarithm of an amount of energy carried by the irritant. As a consequence ,a change of the level of sound, for example, by 5 dB, approximately corresponds to the same change of audibility at any level. At the same time, the change of sound pressure only by 0,01 Pa is equal to a sharp change of perception of a sound at low levels and is hardly distinctive at high levels. The concept of sound level always is meant when a scale expressed in decibels is used.

The following relations determine magnitudes of levels of sound pressure, in decibels (dB):

1. Sound Pressure Level (SPL)

   $$L_p = 10\log\left(p_{eff}^2 \Big/ p_s^2\right) = 20\log\left[\overline{p}_{\Delta f} \Big/ \left(2.10^{-5}\right)^{-1}\right],$$

   Where $\overline{p}_{\Delta f}$ – mean quadratic pressure in frequency band Δf ; $p_s = 2.10^{-5}$ Pa – threshold value of sound pressure;

2. Intensity of a Sound, L_I

$L_I = 10\log\left(\boldsymbol{I}_{\Delta f}/\boldsymbol{I}_0\right)$,

where $\boldsymbol{I}_{\Delta f}$ – intensity of a sound in frequency band Δf, Io – the reference sound intensity, $\boldsymbol{I}_0 = 10^{-12}$, in W·m^{-2} (the numerical values of L_p and L_I differ only about 0.16 dB)**;** thus, for example, for a difference of sound intensity of ten times ($\left(I_{01} = 2\bullet10^{-4}W\bullet m^{-2}, I_{02} = 2\bullet10^{-5}W\bullet m^{-2}\right)$ the equivalent difference in sound intensity level is 12 per cent, because accordingly $\left(L_1\right)_1 = 83$ dB and $\left(L_1\right)_2 = 73$ dB.

3. Sound Power Level, L_W

$L_W = 10\log\left(W/W_o\right)$,

where W – full sound power of a radiant, in W ($W_0 = 10^{-12}$ – the lowest magnitude of a sound power).

If the noise is received from several sources, the resulting intensity can be calculated from:

$\boldsymbol{I}_\Sigma = \boldsymbol{I}_1 + \boldsymbol{I}_2 + \ldots + \boldsymbol{I}_n$,

where $\boldsymbol{I}_1$, $\boldsymbol{I}_2$, $\boldsymbol{I}_n$ – intensity of separate radiants.

If we divide this expression by $\boldsymbol{I}_0$ and obtain the logarithm of it, we get:

$$L_\Sigma = 10\ \log\left(\boldsymbol{I}_\Sigma/\boldsymbol{I}_0\right) = 10\ \log\left(\boldsymbol{I}_1/\boldsymbol{I}_0 + \boldsymbol{I}_2/\boldsymbol{I}_0 + \ldots + \boldsymbol{I}_n/\boldsymbol{I}_0\right)$$
$$= 10\ \log\left(10^{0{,}1L_1} + 10^{0{,}1L_2} + \ldots 10^{0{,}1L_n}\right) = 10\ \log\sum_{i=1}^{n}10^{0{,}1L_i},$$

where $L_1, L_2 ... L_n$ – levels of intensity (of sound pressure), created for a point by every power plant taken separately. If on a flight vehicle (or in a machine hall) we installed several (n) identical engines each giving a level of sound pressure L, then

$L_\Sigma = L + 10\ \log n = L + \Delta L$.

For example, at $n = 2, 3\ldots10$, the level L_Σ**,** by comparison with its value for one engine L_1, varies by magnitude $\Delta L = L_\Sigma - L_1 = 3;\ 4;\ 7\ldots10$ dB. The spreading of a sound in a distant sound field, where influence of finite sizes and forms of an emitter of a sound on performances of a sound field are insignificant, is determined by a relation $L_{r_i} = L_{r_0} - 20\lg\left(r_0/r_i\right) - B$. Magnitude L_{r_0} determines a known level of sound pressure on a datum distance r_0; r_i – distance, on which the magnitude L_{r_i} is estimated; B – additional slackening of a sound in atmosphere at an absorption of a sound by an air, fog, rain, vegetation, walls etc. For an ideal medium, when $B=0$, the level of intensity of a sound at doubling of a distance decreases approximately by 6 dB. Basic performance of a noise is the spectra of levels of mean quadratic sound pressure and level of its intensity, i.e. distribution of these parameters on frequency. Spectrum of a noise of AJE is shown in Figure 1. As it is visible, there is a continuous background noise - wide-band, or so-called "white" noise. Peaks of intensity, designated on figure by digit 2, are laid on this background noise, which are disposed in a field of midband frequencies that are connected with work of inducer vanes of AJE.

These peaks of intensity 2 (discrete components of continuous background noise) form tonal noise (tone is a sound that has certain pitch). As is well known, the elementary sound wave is characterized by amplitude, which periodically changes in time, $A=f(t)$ and period T, where: t – time, for which the signal was observed, T – period of change of amplitude A, f – frequency, $f=1/T$. Actually in real conditions the acoustic signals are not repeated and contain all possible frequencies in a given range, as it is shown in Figure 1. If we filter out one arbitrary frequency, it appears that oscillation frequency corresponding to this frequency changes in time by chance. The only way of description of a frequency structure of such signal is reduced to resolution of common frequency band into a series of additive ranges and to the definition of a level of a signal in each range. At the definition of a spectrum of a noise of engine all frequency band is arranged on separate bands appropriate to an octave. The more detailed conception about a noise can be received with the help of spectra in 1/3 – octave frequency band. The octave is called an interval between frequencies, which differ in two times, $f_2=2f_1$. At any acoustic research as initial is taken the frequency of 1000 Hz that is a central frequency octave of a band 1000 Hz. For $1/3$ of octaves the relation between final frequency of a band and initial will be $f_2=\sqrt[3]{2}\cdot f_1 \cong 1,26 f_1$ (see Table 2).

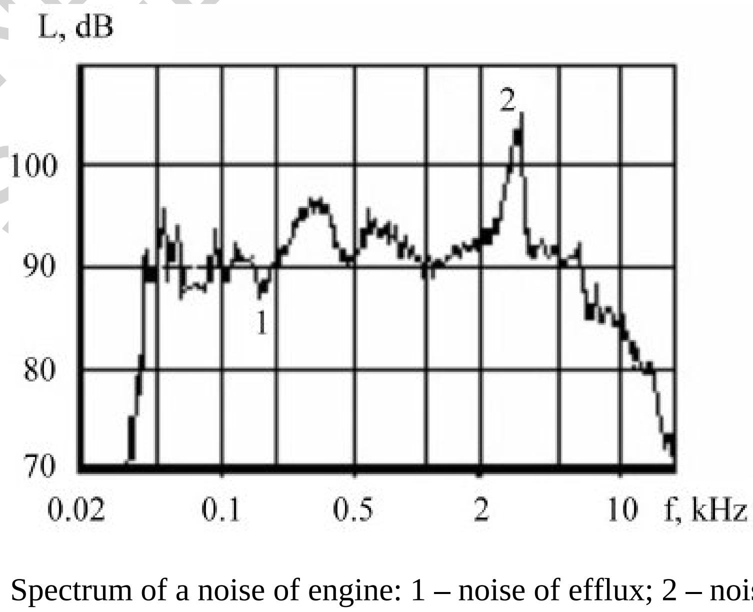

Figure 1. Spectrum of a noise of engine: 1 – noise of efflux; 2 – noise of a fan

Lower boundary frequency, Hz	Preferable central frequency, Hz	Upper boundary frequency, Hz
22,4*	25	28,2
28,2	31,5*	35,5
35,5	40	44,7*
44,7*	50	56,2
56,2	63*	70,8
70,8	80	89,1*
89,1*	100	112,2
112,2	125*	141,3
141,3	160	177,8*
177,8*	200	223,9
223,9	250*	281,8
281,8	315	354,8*
354,8*	400	446,7
446,7	500*	562,3
562,3	630	707,9*
707,9*	800	891,3
891,3	1000*	1122
1122	1250	1413*
1413*	1600	1778
1778	2000*	2239
2239	2500	2818*
2818*	3150	3548
3548	4000*	4467
4467	5000	5623*
5623*	6300	7079
7079	8000*	8913
8913	10 000	11 220*
11 220*	12 500	14 125
14 125	16 000*	17 783
17 783	20 000	22 387*

Table 2. Central and boundary frequencies in octaves* and $1/3$ – octave bands.

For aviation engines, as a rule, the $1/3$– octave spectrum in a range of midband frequencies $f_{mid} = 50...10,000$ Hz is used. This includes 24 frequency bands. The average levels of sound pressure in dB are measured in each separate frequency band, refering to them as central frequencies. As a result, a spectrum of a noise is obtained; an example of which is shown in Figure 1.

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Biographical Sketch

Valeri G. Nesterenko was born in 1939, graduated from Moscow Aviation Institute in 1963. He is the author of more than 70 printed works, including: album "Aircraft modular gas turbine engines"; atlas of schemes and constructions of assemblies of AJE (1991); "Design and calculation of basic supports and shafts of AJE" (1999); "Design and calculation of connections of elements of rotor of GTE" and other. Valeri G. Nesterenko is senior lecturer of Moscow Aviation Institute (MAI) on chair of construction and design of engines of aircrafts with 1992. In MAI he does teaching work and gives courses of lectures on a number of educational disciplines of speciality "Design of construction of AJE": "Construction and design of AJE", "Power plants of aircraft AJE", "Reliability of AJE". In the present he is the technical adviser of Designer Bureau IACI.