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POSSIBILITY OF ACOUSTIC CONTROL OF EXCITED TURBULENT JETS

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The results of experimental investigation of the influence of high-frequency (low-frequency) acoustic action on a turbulent jet preexcited by sound of low (high) frequency are presented. It is shown that the qualitative character of the action remains the same as that for an unexcited jet. However, the quantitative results here are somewhat different; in particular, the possibilities of suppressing turbulence in the jet in its high-frequency excitation are reduced in this case.

It is well known that low-frequency acoustic excitation of turbulent jets (St_s = 0.2–0.6) leads to the intensification of mixing, whereas high-frequency excitation (St_s = 2–6), conversely, leads to its attenuation [1]. Attempts at affecting a jet by several acoustic signals of different frequencies have been made with the aim of improving the efficiency of acoustic excitation of turbulent jets. The acoustic action on a jet at multiple frequencies (at the fundamental frequency and its subharmonic for the corresponding phase shift between them) has been investigated in [2–4]. Such excitation proves efficient as compared to single-frequency excitation at low frequencies and inefficient at high frequencies. However, the problem on double-frequency action for an arbitrary relation of the frequencies has not been considered. At the same time, this is of obvious interest if for no other reason than the possibility of the turbulent jets in actual commercial plants, in particular, in jet engines, being simultaneously exposed to sound at highly diverse frequencies (including the case of simultaneous exposure at high and low frequencies).

The main aim of the present work is to elucidate the possibility of attenuating turbulence in a jet by a high-frequency acoustic action if the jet is preexcited by sound of low frequency. In this connection, we have investigated double-frequency acoustic excitation of the jet under the simultaneous action of low-frequency and high-frequency signals.

The experiments have been performed on a setup with a diameter of the exit cross section of the nozzle of d = 0.02 m for an outflow velocity of u_0 = 20 m/sec, which corresponds to the Reynolds number $\text{Re} = u_0 d/\nu = 2.8 \cdot 10^4$. The initial turbulence in the flow core on the nozzle exit section was $\varepsilon_0 = u'/u_0 = 0.25\%$. The boundary layer was nearly laminar; the shape parameter of the boundary layer was equal to $H = \delta_0^*/\theta_0 = 2.05$. Acoustic excitation was carried out with a loudspeaker whose axis was perpendicular to the jet axis, and the center of the exit cross section of the cone was located in the plane of the nozzle exit section at a distance of 0.1 m from the jet axis. The levels of sound pressure were monitored with a Brule and Kier microphone located in the vicinity of the nozzle exit section. The Strouhal numbers of the acoustic action were equal to St_{s1} = 0.35 and St_{s2} = 3, since the maximum intensification of mixing was observed on this setup for St_s = 0.35 and the maximum suppression of turbulence was observed for St_s = 3.

The measurements were carried out in the following manner. A low-frequency signal (St_{s1} = 0.35) with a certain level was supplied to the loudspeaker. A high-frequency signal (St_{s2} = 3) whose level was successively changed from 100 to 130 dB was additionally supplied to the same loudspeaker from another generator; the ratio of the root-mean-square value of the acoustic vibrational speed in the sound wave to the outflow velocity of the jet $u_s'/u_0 = 20\,(10^{0.05L-6}/\rho a u_0)$ changed from $2.35 \cdot 10^{-4}$ to $7.44 \cdot 10^{-3}$. We measured the values of the average and pulsation velocities at a constant level of the low-frequency signal. Next, we increased the level of the low-frequency signal and carried out a run of measurements again.

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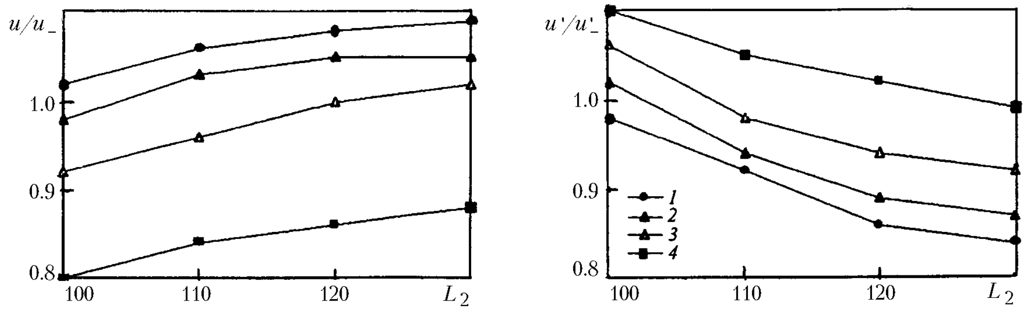

Fig. 1. Values of $u/u\_$ and $u'/u'\_$ in the case of single-frequency and double-frequency acoustic actions vs. level of excitation at high frequencies: 1) single-frequency excitation (St_{s1} = 0.35); 2–4) double-frequency excitation (St_{s1} = 0.35 and St_{s2} = 3); 2) L_1 = 110; 3) 120; 4) 130 dB.

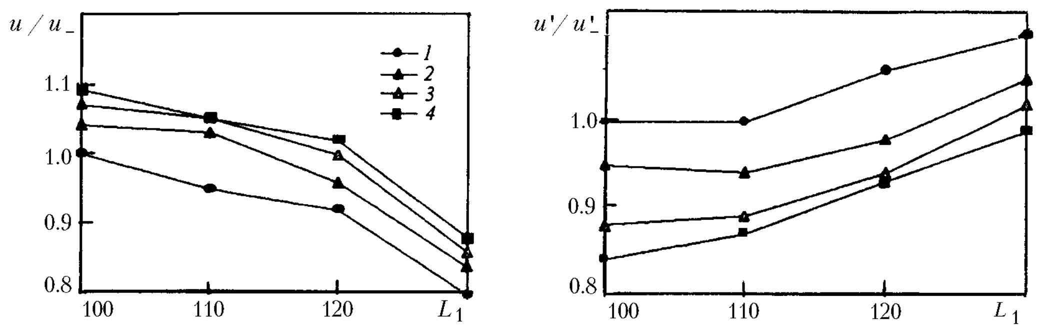

Fig. 2. Values of $u/u\_$ and $u'/u'\_$ in the case of single-frequency and double-frequency acoustic actions vs. level of excitation at low frequencies: 1) single-frequency excitation (St_{s2} = 3); 2–4) double-frequency excitation (St_{s1} = 0.35 and St_{s2} = 3); 2) L_2 = 110; 3) 120; 4) 130 dB.

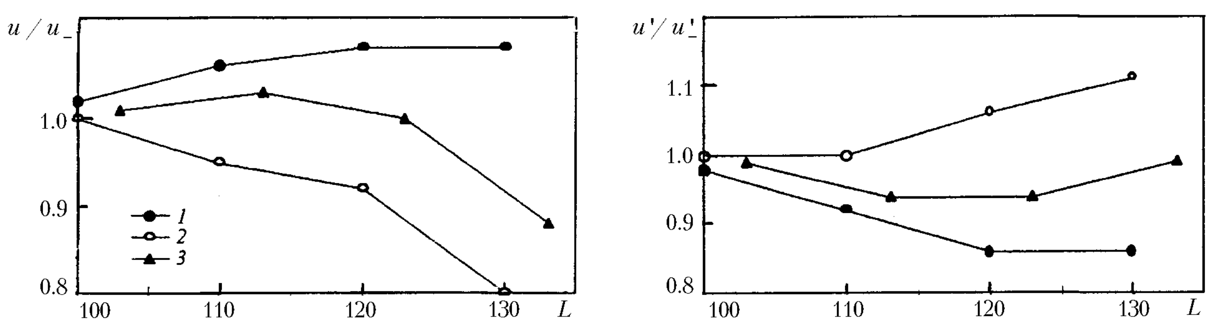

Fig. 3. Values of $u/u\_$ and $u'/u'\_$ in the case of single-frequency and double-frequency acoustic actions at different excitation levels: 1) St_s = 3; 2) 0.35; 3) double-frequency excitation (St_{s1} = 0.35 and St_{s2} = 3).

We employed a set of Disa 55M hot-wire anemometry equipment for measurements of the average and pulsation velocities. The sensor of the hot-wire anemometer was installed in the cross section x/d = 8 on the jet axis.

Figure 1 compares the values of $u/u\_$ and $u'/u'\_$ in the case of single-frequency (St_{s1} = 0.35, curve 1) and double-frequency (St_{s1} = 0.35 and St_{s2} = 2, curves 2–4) acoustic action for different relations of the levels of the signals supplied. The subscript "–" corresponds to the values of the average and pulsation velocities in an unexcited jet. The values of the high-frequency excitation level are plotted on the abscissa axis. Each curve corresponds to a certain value of the low-frequency signal. The plots presented show a strong dependence of the results obtained on the relation between the levels of low-frequency and high-frequency excitation. Curves 2 and 3 are equidistant, in practice, to curve 1, i.e., as the level of the high-frequency signal increases, the suppression of turbulence is enhanced even in the

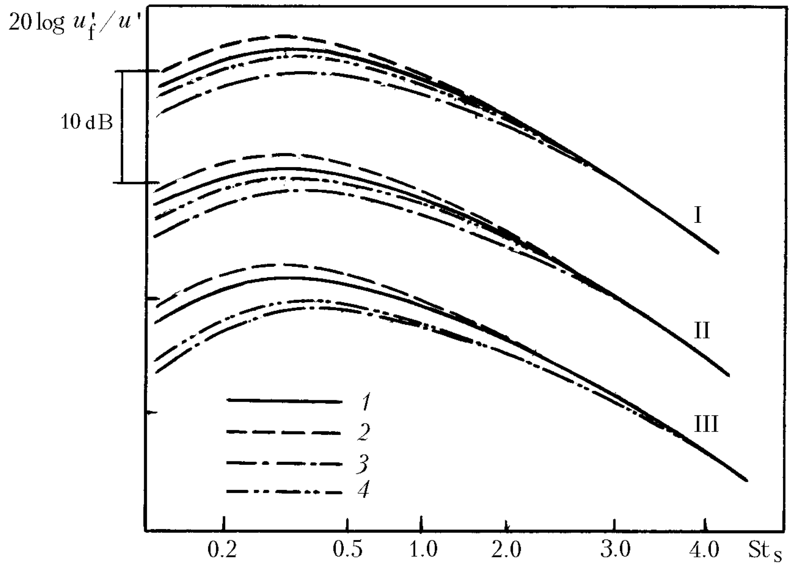

Fig. 4. Spectra of velocity pulsations in the case of single-frequency and double-frequency actions at the point x/d = 8 on the jet axis: 1) the jet without excitation; 2) St_{s1} = 0.35; 3) St_{s2} = 3; 4) double-frequency excitation (St_{s1} = 0.35 and St_{s2} = 3); I) L_1 = 110 and L_2 = 110; II) 110 and 120; III) 110 dB and 130 dB.

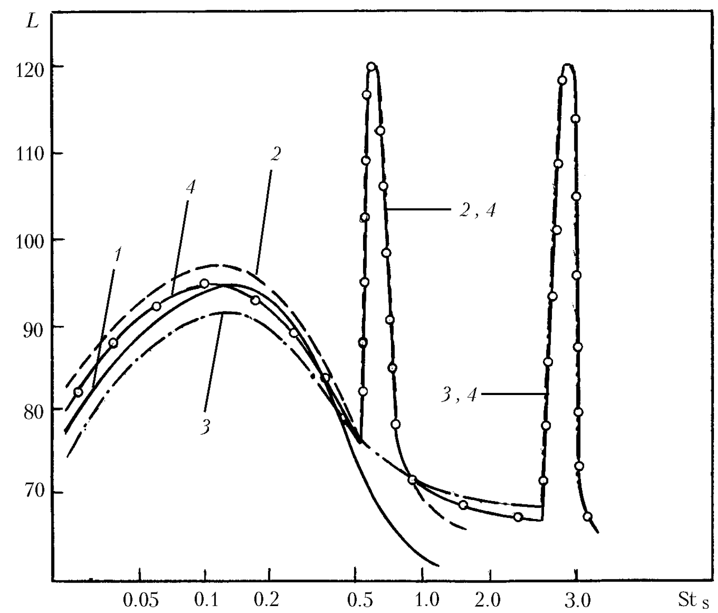

Fig. 5. Spectra of pressure pulsations in the near field of the jet at the point x/d = 5, y/d = 2; 1) the jet without irradiation; 2) St_s = 0.35; 3) St_s = 3; 4) double-frequency action (St_{s1} = 0.35 and St_{s2} = 3).

presence of low-frequency excitation of the jet. However, it should be noted that with increase in the level of the low-frequency signal one must also increase the level of the high-frequency audio signal so as to attain a pronounced effect of suppression of turbulence.

Figure 2 gives analogous results but depending on the level of low-frequency excitation. Here each curve corresponds to a certain level of the high-frequency signal.

Figure 3 compares the values of $u/u\_$ and $u'/u'\_$ in the case of single-frequency (1, 2) and double-frequency (3) acoustic action at different levels of excitation. Here the levels of high-frequency and low-frequency signals are the same in the case of double-frequency acoustic action. It has been found that at the excitation level L = 130 dB, the low-frequency component of the double-frequency signal becomes dominant as it were and we observe intensification of turbulent mixing, although it is weaker than that in the case of just a low-frequency action of the same level.

The plots (see Figs. 1–3) show that the effect of suppression of turbulence due to the high-frequency acoustic action on a turbulent jet excited by sound of low frequency proves less pronounced than that for an unexcited jet at the same levels of the acting high-frequency sound. This conclusion is confirmed by the results of spectral measurements of velocity pulsations in third-octave frequency bands, which are presented in Fig. 4, where L_1 corresponds to the level of low-frequency excitation and L_2 corresponds to the level of high-frequency excitation.

It is well known that the turbulent characteristics of a jet are closely related to the noise radiated by the jet. In this connection, we conducted an experiment on measuring pressure pulsations in the near acoustic field of a turbulent jet (x/d = 5, y/d = 2, d = 0.04 m, and u_0 = 100 m/sec). Results analogous to those presented above have been obtained: in the case of simultaneous action of sound of high and low frequencies on the jet at L = 125 dB we have a certain rise of the spectrum in the region of low and average frequencies for third-octave noise spectra, which, however, is weaker than that in the case of just a low-frequency action (Fig. 5).

Thus, the qualitative character of the action of a high-frequency signal on the jet preexcited by sound of low frequency remains the same as that for an unexcited jet. However, the quantitative results here are somewhat different and the possibilities of suppressing turbulence in the jet are reduced in this case.

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NOTATION

a, velocity of sound, m/sec; d, diameter of the exit cross section of the nozzle, m; f, frequency of acoustic disturbances, Hz; H, shape parameter of the boundary layer; L, level of sound pressure, dB; Re, Reynolds number; $\mathrm{St_s}$, $\mathrm{St_{s1}}$, and $\mathrm{St_{s2}}$, Strouhal numbers; u_0, velocity of outflow of the jet, m/sec; u and u', average velocity and root-mean-square values of velocity pulsations on the jet axis, m/sec; $u\_$ and $u'\_$, the same in the absence of acoustic excitation, m/sec; u'_f, root-mean-square values of velocity pulsations in 1/3rd-octave frequency bands; u'_s, root-mean-square value of the acoustic vibrational speed in the sound wave, m/sec; x and y, longitudinal and transverse coordinates; δ_0^*, displacement thickness in the boundary layer on the nozzle exit section, m; ε_0, intensity of velocity pulsations, %; ν, kinematic coefficient of viscosity of the gas, m^2/sec; θ_0, momentum thickness in the boundary layer on the nozzle exit section, m; ρ, density of the outflowing gas, kg/m^3. Subscripts: f, frequency; s, sound; s1, low-frequency excitation; s2, high-frequency excitation; 0, parameters of the jet on the nozzle exit section.

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