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DECREASE IN THE NOISE OF A SUBSONIC TURBULENT JET EJECTED FROM A RING NOZZLE WITH LONGITUDINAL SLOTS

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The results of investigations of the aerodynamic and acoustic characteristics of a jet ejected from a ring nozzle with longitudinal slots are presented. It is shown that these slots markedly influence the jet mixing and substantially decrease the jet noise generated in a wide frequency range.

The process of noise formation in a jet can be controlled by control of the process of turbulent mixing of the jet with the environment. There are various methods of control of the mixing of submerged jets and wakes for the purpose of decreasing the noise generated by them, e.g., changing the initial inhomogeneity or the initial turbulence of a jet, use of nozzles with different perforated packings deforming the cross section of a jet, acoustic or vibrational excitation of a jet, etc. [1–4]. Recent works carried out in this direction in Russia and abroad concern the possibility of controlling large-scale structures in a jet by different methods, one of which is the formation of vortices for the purpose of destruction of large-scale structures and decreasing the noise. The data presented below are results of such investigations on the noise of a turbulent jet ejected from a ring nozzle with longitudinal slots.

In [5–7], the mixing in a submerged circular turbulent jet ejected from a ring nozzle with perforated conic attachments having longitudinal slots was investigated. It was shown that, in this case, the air flowing through such longitudinal slots with a subsonic velocity forms a system of jets around the main jet. This was supported by measurements of the total-pressure fields in cross sections of the jet and its visual observation. The data obtained indicate that this method of control of a jet allows one to substantially change the jet mixing with losses in the thrust of not larger than 1%.

Since, as was noted above, the process of noise formation in a jet is strongly dependent on its mixing, it may be suggested that the indicated method can be used for decreasing this noise. In this connection, complex investigations of the aerodynamic and acoustic characteristics of jets ejected from conical nozzles perforated with longitudinal slots [5–7] were carried out.

The schematic diagram of the nozzle studied is presented in Fig. 1. Experiments were carried out with model nozzles having a cone angle $\beta = 9^{\text{o}}$, number of slots n = 4, 6, and 8, and a degree of perforation $\Sigma b/\pi D = 1/4$ at $B/D = 0.78$. The input diameter of a conic nozzle was $D = 15$ mm and its output diameter was $d = 12$ mm.

For the purpose of investigating the mixing in a jet ejected from perforated nozzles, we measured the average velocity u/u_0 and the mean-square magnitudes of the longitudinal fluctuations of the velocity u'/u_0 of the flow along the jet axis at an ejection velocity $u_0 = 20$ m/sec, $\text{Re} = 1.6 \cdot 10^4$, and $\text{M} = 0.06$. The measurements were carried out with the use of a set of 55M thermoanemometers of the Disa Company. The dependences of u/u_0 and u'/u_0 on the distance to the nozzle exit section (Fig. 2) show that longitudinal slots in a nozzle markedly influence the process of jet mixing. This agrees qualitatively with the corresponding change in the total pressure along the jet axis [5–7]. In this case, the average velocity of the flow along the jet axis decreases more slowly in the transient and main regions (Fig. 2a) and the magnitude of the longitudinal pulsations of the flow velocity at the jet axis changes (Fig. 2b). When the number of slots increases from $n = 4$ to $n = 8$, these effects are enhanced.

Since, as was noted above, the turbulent-jet mixing is closely associated with the aerodynamic-noise generation, it was interesting to investigate the noise generated by a jet ejected from a nozzle with slots. However, to do this, it is necessary to know the effective ("equivalent") diameter of the nozzle studied because an ordinary conic nozzle and an analogous nozzle with longitudinal slots have different effective cross sections. Determination of the equiva-

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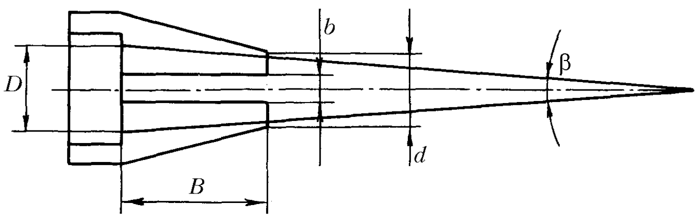

Fig. 1. Diagram of the nozzle studied.

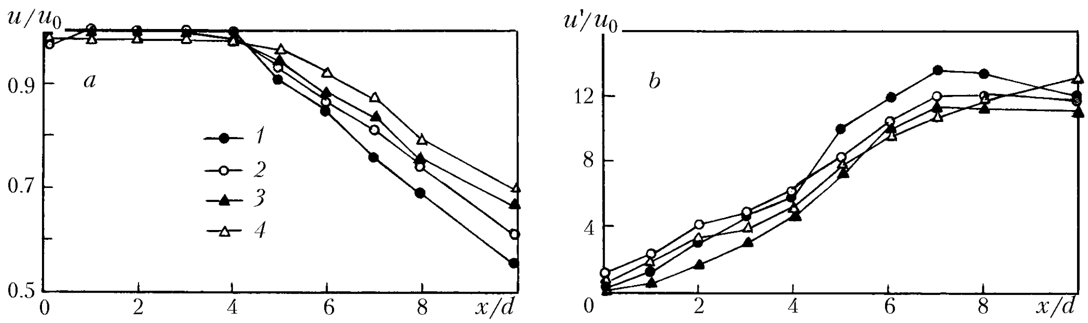

Fig. 2. Distribution of the average (a) and fluctuating (b) velocities along the axis of a jet: 1) circular jet; n = 4 (2), 6 (3), and 8 (4).

lent diameter is of great importance for investigating the acoustic characteristics of a jet because, according to the known Lighthill formula, the total acoustic power of a jet is proportional to the square of the diameter of a nozzle [2]; therefore, the results of acoustic measurements were brought to dimensionless form with the use of the equivalent diameter d_e. This diameter was determined by the following method. Experiments on jet noise were conducted at a constant total pressure in a settling chamber positioned upstream of a nozzle p; in this case, the rate of air flow through the nozzle $Q = \rho_0 u_0 F$ was measured with the use of a flowmeter positioned in a supply pipeline. The velocity and density of a jet ejected from the nozzle at $\pi = p/p_a$ were determined from tables of gas-dynamic functions, and then d_e was determined.

The noise of jets was measured in an anechoic chamber [2]. As sound detectors, we used 4135-type microphones from the Brüel & Kjaer Company, the signal from which was fed through cathode followers onto a Brüel & Kjaer 2032-type, two-channel, real-time analyzer. The digitized signal from the analyzer was fed into a computer, with the use of which, the spectra of pressure fluctuations were obtained in the 1/3-octave frequency bands in the range 200–20,000 Hz. In accordance with the ratings of the electroacoustic apparatus used, the accuracy of acoustic measurements was ±0.5 dB.

The measuring microphones were installed in the horizontal plane passing through the axis of a jet on a circular arc of radius 1 m at an angle of 30–90^o to the axis of the jet. The nozzle studied was connected to the plenum chamber, into which air was supplied from high-pressure gas-holders through a system of silencers. The jet-ejection regime was controlled by the total pressure in the plenum chamber. Experiments were conducted at differential pressures in the plenum chamber: π = 1.4 and 1.8, which corresponds to an ejection velocity of u_0 = 230 and 302 m/sec; in this case, Re was equal to $2.1 \cdot 10^5$ and $2.75 \cdot 10^5$ and M was 0.68 and 0.83.

Figure 3 presents the dependences of the sound pressure L on the Strouhal number St = fd_e/u_0, obtained in the case where a microphone was positioned at an angle α = 30^o to the axis of a jet. The results presented indicate that longitudinal slots in a nozzle actually decrease the jet noise by a large value (to 2–4 dB) in a wide frequency range. As was expected [4], a decrease in the turbulence along the axis of a jet leads to a decrease in the jet noise. Therefore, the acoustic efficiency of the apparatus studied increases with increase in the number of slots from n = 4 to n = 8. An increase in the ejection velocity of a jet from 230 to 302 m/sec leads to a small increase in the acoustic efficiency of the nozzle considered.

Thus, it has been established that the perforation of a nozzle with longitudinal slots can be fairly successfully used, along with such methods as installation of shavers or other means at the nozzle edge, to decrease the noise of a jet stream. It should be noted that in the case where the nozzles studied were used, the losses in the thrust did not

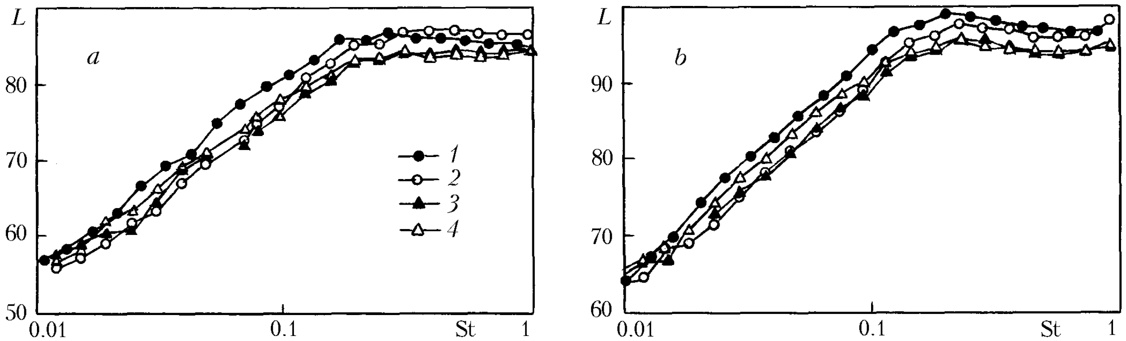

Fig. 3. Dimensional spectra of the pressure fluctuations in the far field of jets ($\alpha = 30^{\circ}$) ejected from nozzles with slots (u_0 = 230 (a) and 302 m/sec (b)): 1) circular jet; n = 4 (2), 6 (3), and 8 (4).

exceed, according to the data of [5–7], 1%, which is appropriate for silencers of turbulent-jet noise (providing a decrease in the noise by 2–4 dB). The perforated nozzles considered can have a large number of variable parameters influencing the mixing of a submerged turbulent jet. Therefore, the results presented do not determine the best geometric parameters of the nozzles studied; they only indicate that longitudinal slots in conic nozzles allow one to effectively control the aerodynamic and acoustic characteristics of turbulent jets.

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NOTATION

B, length of the slots, m; b, width of the longitudinal slots, m; c, velocity of sound, m/sec; d, output diameter of a conic nozzle, m; D, input diameter of a conic nozzle, m; d_e, equivalent diameter, m; f, frequency, Hz; F, effective area, m^2; L, sound-pressure level, dB; $M = u_0/c$, Mach number; n, number of slots; p, total pressure upstream of the nozzle, Pa; p_a, ambient pressure, Pa; Q, initial flow rate of a jet, kg/sec; $Re = u_0 d/\nu$, Reynolds number; St, Strouhal number; u_0, ejection velocity of a jet, m/sec; u, average velocity of the flow at the axis of a jet, m/sec; u', mean-square magnitude of the longitudinal velocity fluctuations, m/sec; x, longitudinal coordinate, m; α, angle between the measurement direction and the axis of a jet, deg; β, cone angle of a nozzle, deg; ν, kinematic viscosity coefficient of air, m^2/sec; π, pressure drop in the nozzle exit section; ρ_0, density of the air in a jet, kg/m^3. Subscripts: a, atmospheric; e, equivalent; 0, initial value.

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