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ACOUSTIC EXCITATION OF NONCIRCULAR TURBULENT JETS

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Results of experimental investigation of turbulent mixing in jets flowing out of nozzles with different cross sections in the case of low- and high-frequency acoustic excitation of the jets are presented. The influence of the shape of the cross section of a nozzle on the acoustic-excitation sensitivity of a jet flowing out of it is analyzed.

Control of the aerodynamic and acoustic characteristics of turbulent jets by exciting them acoustically has been investigated mainly for submerged circular and plane jets [1]. Experimental data on acoustic excitation of jets flowing out of nozzles with a noncircular cross section are much more scanty. The most interesting results on low-frequency acoustic excitation of such jets have been obtained for an elliptic cross section of the nozzle as applied to the initial laminar and turbulent boundary layers on the nozzle cut [2, 3]. The low-frequency acoustic excitation of turbulent jets flowing out of nozzles with a complex cross section (equilateral and isosceles triangles, etc.) makes it possible to enhance the relative role of small-scale mixing [4, 5]. As the characteristic linear dimension of such jets one usually uses the equivalent diameter d_e of a circular nozzle the discharge area F of whose cross section is equal to the area of a noncircular nozzle $F = \pi d_e^2/4$.

There have also been attempts at investigating experimentally the acoustic excitation of a turbulent jet flowing out of a rectangular nozzle at low and high frequencies [6].

In the present work, we give results of experimental investigation of the aerodynamic characteristics of turbulent jets flowing out of nozzles with different cross sections (circular, triangular, six-lobe, and other cross sections) in transverse low- and high-frequency acoustic excitation. The experimental setup has been described in [7] as applied to a nozzle with a circular cross section.

The first part of the experiment was performed for circular and triangular nozzles (equilateral triangle, d_e = 20 mm) for an efflux velocity of u_0 = 20 m/sec. The boundary layer in the outlet cross section of the nozzle was laminar, the degree of turbulence on the cut of the nozzle at its center was $\varepsilon_0 = u'/u_0$ = 0.25%, and the level of sound pressure near the nozzle's edge was L = 125 dB. The Reynolds number was $\text{Re} = u_0 d_e/\nu = 2.8 \cdot 10^4$.

In the course of the experiment, we measured the fields of the average velocity and of longitudinal velocity pulsations in a wide range of acoustic-irradiation frequencies. Figure 1 shows the dependences $u/u_{-} = F_1(\text{St}_s)$ and $u'/u'_{-} = F_2(\text{St}_s)$ illustrating a change in the average velocity and the longitudinal velocity pulsations on the axis of the jet in the cross section x/d_e = 8 at different values of the Strouhal number $\text{St}_s = f_s d_e/u_0$ for the circular and triangular nozzles. This yields the known result for a circular jet according to which, at low frequencies ($\text{St}_s < 1$), the mixing becomes intensified (the average velocity decreases by approximately 25%, and the longitudinal velocity pulsations increase by 10%) while at high frequencies (St_s = 1.5–8) the effect is the reverse (the average velocity increases by approximately 15%, and the velocity pulsations decrease by 20%). For the jet flowing out of the triangular nozzle the situation is different: at a low frequency (St_s = 0.25), the velocity on the jet axis decreases by 40%, whereas at high frequencies the increase in the average velocity and the corresponding decrease in the velocity pulsations here are less pronounced.

Figure 2 shows changes in the average velocity and the longitudinal velocity pulsations along the jet axis at St_s = 0.3 and 5.0 for the circular and triangular nozzles. These dependences, similarly to the curves given in Fig. 1,

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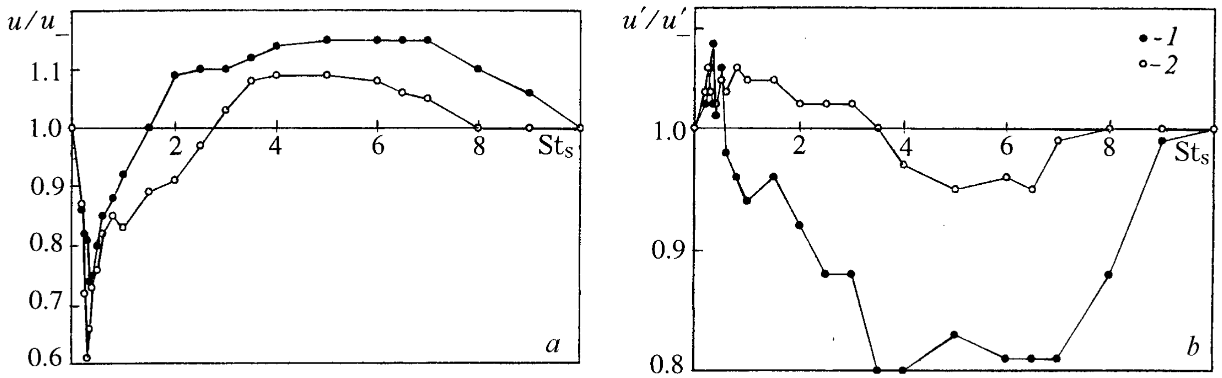

Fig. 1. Dependences of the average (a) and longitudinal pulsation velocities (b) on the jet axis at x/d_e = 8 on the Strouhal number of acoustic excitation for circular (1) and triangular (2) nozzles.

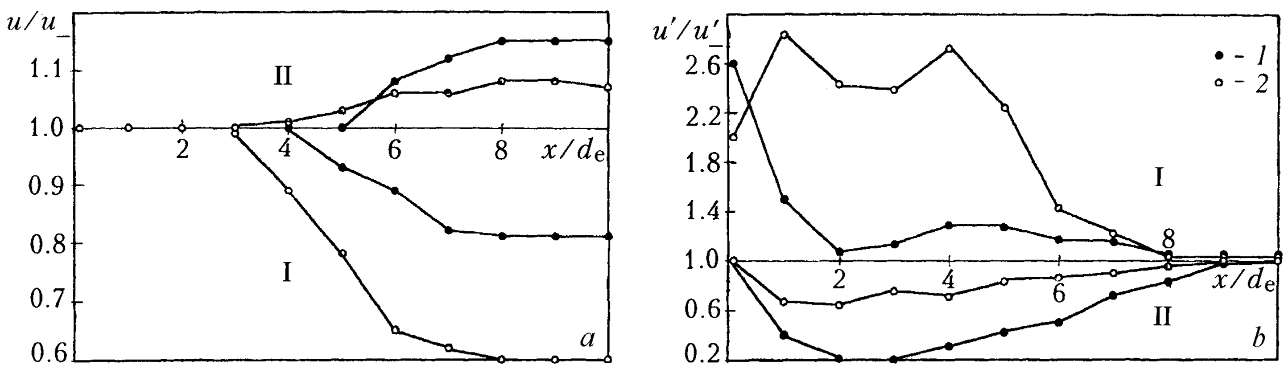

Fig. 2. Change in the average (a) and longitudinal (b) velocities along the jet axis at St_s = 0.3 (I) and St_s = 5.0 (II) for circular (1) and triangular (2) nozzles.

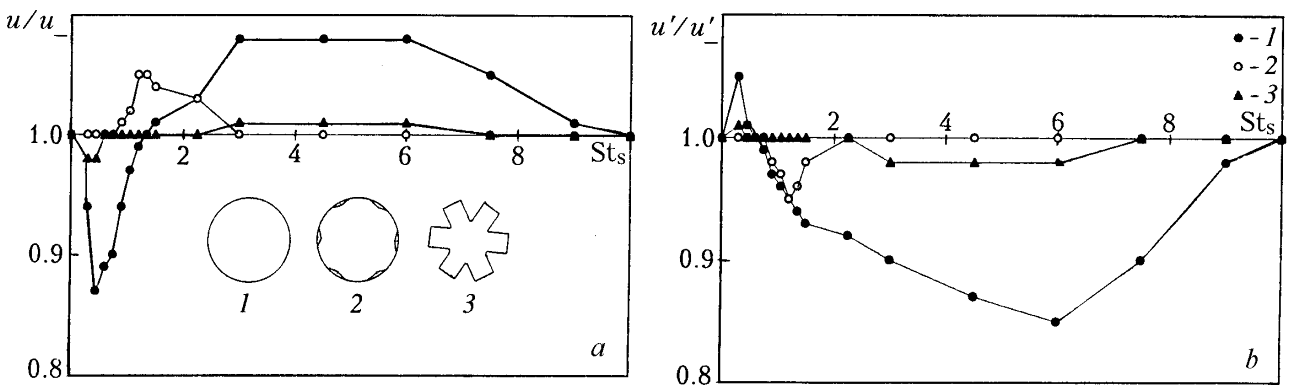

Fig. 3. Dependences of the average (a) and pulsation (b) velocities on the jet axis at x/d_e = 8 on the Strouhal number of acoustic excitation St_s for a circular nozzle (1), a circular nozzle with six generators of longitudinal vortices (2), and a six-lobe nozzle (3) when Re = $4.2 \cdot 10^4$.

show that the jet flowing out of the triangular nozzle is more sensitive to low-frequency excitation (St_s = 0.3) and less sensitive to high-frequency excitation (St_s = 5.0) than the circular jet.

The second part of the experiment was performed for jets flowing out of a circular nozzle (d = 30 mm), a circular nozzle with six generators of longitudinal vortices, and a six-lobe nozzle. The corresponding dependences of the relative change in the velocity u/u_{-} and the longitudinal velocity pulsations u'/u'_{-} on the Strouhal number St_s at the point on the jet axis $x/d_e = 8$ are given in Fig. 3, whence, in particular, it follows that the jets flowing out of shaped nozzles (2 and 3 in Fig. 3) are insensitive, in practice, to both low- and high-frequency acoustic excitations. The result obtained is consistent with the conclusions of [8], where the acoustic characteristics of jets flowing out of nozzles with different configurations have been investigated.

Thus, the disruption of the azimuthal uniformity of flow on the initial portion of a jet flowing out of a nozzle with a complex cross section leads to a weakening of coherent structures and hence decreases the dependence of the jet on acoustic excitation.

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NOTATION

x, longitudinal coordinate; d, diameter of the outlet cross section of the circular nozzle, m; d_e, equivalent diameter of the noncircular nozzle, m; u_0, efflux velocity of the jet, m/sec; u and u', average velocity and root-mean-square values of the velocity pulsations on the axis, m/sec; u_- and u'_-, the same, in the absence of acoustic excitation, m/sec; f_s, acoustic-excitation frequency, Hz; L, level of sound pressure, dB; ν, kinematic coefficient of viscosity of the gas, m^2/sec. Subscripts: e, equivalent; s, sound.

REFERENCES

1. A. S. Ginevskii, E. V. Vlasov and R. K. Karavosov, *Acoustic Control of Turbulent Jets* [in Russian], Moscow (2001).
2. H. S. Hussain and A. K. M. F. Hussain, Excited Elliptic Jets, *AIAA Paper*, No. 544 (1985).
3. F. Hussain and H. S. Hussain, *J. Fluid Mech.*, **208**, 257–320 (1989).
4. E. Gutmark, K. C. Schadow, D. M. Parr, C. K. Harris, and K. J. Wilson, The Mean and Turbulent Structure of Noncircular Jets, *AIAA Paper*, No. 543 (1985).
5. E. Gutmark, K. C. Schadow, K. J. Wilson, and D. M. Parr, Small-Scale Mixing Enhancement on Acoustically Excited Jets, *AIAA Paper*, No. 1985 (1986).
6. L. N. Ukhanova and L. N. Voitovich, *Inzh.-Fiz. Zh.*, **67**, No. 4, 537–543 (1984).
7. E. V. Vlasov, A. S. Ginevskii, R. K. Karavosov, and T. M. Makarenko, *Inzh.-Fiz. Zh.*, **74**, No. 1, 8–9 (2001).
8. C. J. Moore and D. H. Brierley, in: *Proc. Joint Symp. Mech. Sound Gener. Flows*, Berlin (1979), pp. 48–54.