Journal of Engineering Physics and Thermophysics, Vol. 74, No. 1, 2001

CHANGE OF THE SIGN OF THE EFFECT WITH INCREASE IN THE INTENSITY OF HIGH-FREQUENCY ACOUSTIC EXCITATION OF A TURBULENT JET

E. V. Vlasov, A. S. Ginevskii, R. K. Karavosov, and T. M. Makarenko

UDC 532.525.2:534.2

Results of an experimental investigation of high-frequency acoustic excitation of turbulent jets for different intensities of the acoustic field are presented. It is shown that upon reaching a certain limiting level of excitation at high frequencies, the sign of the effect changes, i.e., at this level, high-frequency excitation leads to generation of turbulence in the jet rather than its suppression. Hence it follows that the high-frequency acoustic effect that suppresses turbulence is most efficient within an optimum range of frequencies and at an optimum level of excitation.

Earlier it was found [1] that acoustic excitation of a turbulent jet leads to either enhancement of agitation or its weakening. The first effect is reached in low-frequency irradiation (the Strouhal number is $\mathrm{St_s} = f_s d/u_0 = 0.2–0.6$), and the second is reached in high-frequency irradiation (the Strouhal number is $\mathrm{St_s} = 1–5$). These effects depend somewhat on the level of excitation. In low-frequency irradiation, the effect increases with the level of excitation, after which saturation begins, and further increase in the excitation in no way affects the enhancement of agitation. In contrast to low-frequency irradiation, in high-frequency acoustic irradiation with increase in the level of excitation saturation does not occur. Moreover, an increase in the level of excitation beyond a certain value is accompanied by attenuation of the effect, with a tendency for a change of the sign of the effect being observed [1, 2]. The present study is aimed at realizing experimentally a change of the sign of the effect in high-frequency acoustic irradiation of a turbulent jet and for high levels of excitation.

The experiments were conducted on a setup with a diameter of the outlet cross section of the nozzle $d = 20$ mm for a velocity of outflow $u_0 = 10$ and 20 m/sec, which corresponds to the Reynolds numbers $\mathrm{Re} = u_0 d/\nu = 1.4 \cdot 10^4$ and $\mathrm{Re} = 2.8 \cdot 10^4$. The initial turbulence in the flow core at the nozzle cut in the absence of excitation was $\varepsilon_0 = 0.25\%$. The boundary-layer parameters in the outlet cross section of the nozzle were $\delta_0^* = 0.23$ mm and $\theta_0 = 0.11$ mm, and the form parameter was $H = \delta_0^*/\theta_0 = 2.09$, so that the boundary layer was close to laminar. Transverse acoustic excitation of the root part of the jet was achieved by means of a dynamic loudspeaker. The levels of acoustic pressure at the center of the outlet cross section of the nozzle without a flow was varied within the limits $L = 90–135$ dB. Mean and fluctuation velocities were measured by a set of thermoanemometric equipment of the DISA Company. The parameters of acoustic vibrations were specified by means of an audio-frequency generator of a pure tone and a power amplifier. Moreover, the mean velocity was measured by a pneumometric method using a Pitot tube.

Figure 1 presents dependences of the mean velocity u/u_- and the longitudinal fluctuations of the velocity u'/u'_- for the point on the jet axis $x/d = 9.5$ for two velocities of outflow $u_0 = 10$ and 20 m/sec on the Strouhal number $\mathrm{St_s}$ for different levels L. Two facts are noteworthy. For the velocity $u_0 = 20$ m/sec the range of the Strouhal number within which attenuation of agitation is observed ($u/u_- > 1$ and $u'/u'_- < 1$) cor-

State Scientific-Research Center "N. E. Zhukovskii Central Aerohydrodynamic Institute (TsAGI)," Moscow, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 1, pp. 8–9, January–February, 2001. Original article submitted June 23, 2000.

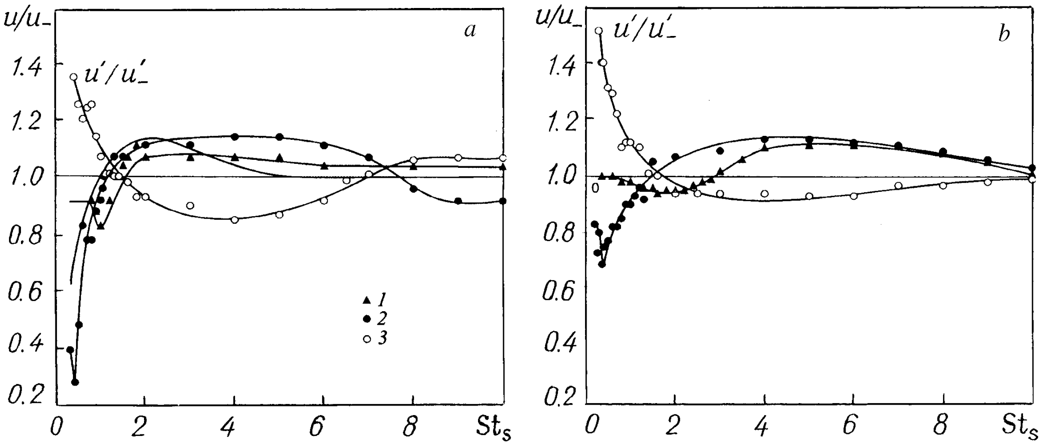

Fig. 1. Dependences of u/u_- (1, 2) and the longitudinal fluctuations of the velocity u'/u'_- (3) on the jet axis at the point x/d = 9.5 on St_s for a velocity of outflow u_0 = 10 m/sec (a) and u_0 = 20 m/sec (b): 1) L = 105 dB; 2, 3) 135.

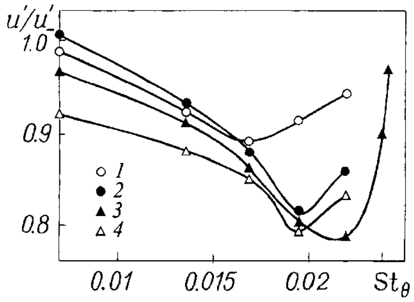

Fig. 2. Dependences of u'/u'_- on St_θ for a mixing layer in the cross section x/θ_0 = 200 for different amplitudes of acoustic excitation: 1) u'_s/u_0 = 0.5%; 2) 2.5; 3) 3.5; 4) 4.5.

responds to St_s = 2–10; for $St_s > 10$ there is a clearly defined tendency for disappearance of the effect. For the velocity of outflow u_0 = 10 m/sec, we observe a change of the sign of the effect, i.e., at L = 135 dB and $St_s > 8$ we have $u/u_- < 1$ and $u'/u'_- > 1$.

In order to characterize the intensity of acoustic excitation, the parameter u'_s/u_0 is sometimes introduced. This ratio can be calculated by the formula

$$u'_s/u_0 = 20\,(10^{0.05L-6}/\rho a u_0)\,.$$

According to Fig. 1, for u_0 = 10 m/sec a change of the sign of the effect occurs when $u'_s/u_0 \approx 2.8\%$, and for u_0 = 20 m/sec it occurs when $u'_s/u_0 \approx 1.4\%$.

The results presented above for a turbulent jet are in agreement with a similar study for mixing layers [3]. In the indicated work, the effect of the amplitude of high-frequency excitation on suppression of turbulence in the mixing layer of a round jet of diameter d = 270 mm that was irradiated through a narrow slot in the radial direction at the nozzle cut was studied. The initial boundary layer was laminar (θ_0 = 0.374 mm, u_0 = 15 m/sec, the Strouhal number was $St_\theta = f_s\theta_0/u_0$ = 0.006–0.025, and the amplitudes were u'_s/u_0 = 0.5, 2.5, 3.5, and 4.5%). As the characteristic of suppression of turbulence in the mixing layer we used the ratio u'/u'_- (here u' and u'_- are the minimum root-mean-square values of the longitudinal pulsation of the velocity with and without excitation, respectively, in the cross section x/θ_0 = 200, where the suppression was maximum). It turned out (Fig. 2) that for the lowest studied level of excitation u'_s/u_0 = 0.5% maximum suppression occurs for the Strouhal number St_θ = 0.017, which corresponds to the maximum spatial increase in the disturbances in full conformity with the linear theory of stability. As the level of excitation increases from 0.5 to 4.5%, the maximum suppression of turbulence in the mixing layer shifts toward higher values of St_θ, from St_θ = 0.017 to 0.022.

The conclusions drawn from our experiments are in agreement with this result: as a level of high-frequency excitation increases, the range of frequencies at which the mixing in the jet attenuates changes. As follows from Fig. 2, when $St_\theta \geq 0.025$, a change of the sign of the effect is possible, i.e., it may turn out that $u'/u'_{-} > 1$.

The work was carried out with financial support from the Russian Fund for Fundamental Research, grant 00-01-00152.

NOTATION

x, longitudinal coordinate; d, diameter of the outlet cross section of the nozzle, m; u_0, velocity of jet outflow, m/sec; u, mean velocity on the jet axis, m/sec; u_{-}, mean velocity on the jet axis without acoustic excitation, m/sec; u', root-mean-square value of the velocity fluctuations, m/sec; u'_{-}, root-mean-square value of the velocity fluctuations without acoustic excitation, m/sec; $\varepsilon_0 = u'/u_0$, intensity of the velocity fluctuations, %; f_s, frequency of the acoustic excitation, Hz; L, level of the acoustic pressure, dB; δ_0^*, displacement thickness, m; θ_0, momentum loss thickness in the boundary layer of the nozzle, m; H, form parameter of the boundary layer; u'_s, intensity of the velocity fluctuations in the sound wave without a flow in the direction of its propagation near the nozzle edge, %; a, velocity of sound, m/sec; ρ, density of the outflowing gas; $St_s = f_s d/u_0$; $St_\theta = f_s \theta_0/u_0$; $Re = u_0 d/\nu$; ν, kinematic viscosity.

REFERENCES

1. E. V. Vlasov and A. S. Ginevskii, *Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza*, No. 6, 37–43 (1973).
2. E. V. Vlasov, A. S. Ginevskii, R. K. Karavosov, and T. M. Makarenko, *Inzh.-Fiz. Zh.*, **71**, No. 1, 81–85 (1998).
3. M. Nallasamy and A. K. M. F. Hussain, *Trans. ASME, J. Fluid Eng.*, **111**, 102–104 (1989).