SUPPRESSION OF SELF-EXCITED OSCILLATIONS IN WIND TUNNELS WITH AN OPEN WORKING PART BY MEANS OF PERIODIC INJECTION-SUCTION IN THE BOUNDARY LAYER OF THE NOZZLE

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The effect of high-frequency periodic injection-suction in the boundary layer of the nozzle near its output section on the attenuation of coherent structures and, as a consequence of this, on the suppression of self-excited oscillations in wind tunnels of the closed type with an open working part was studied experimentally.

It is well known [1] that for certain flow velocities self-excited oscillations appear in wind tunnels of the closed type with an open working part. These oscillations are caused by the interaction of the periodic oscillations of the flow in the free jet (ring vortices in the mixing layer) and acoustic oscillations in the return-flow channel (standing sound waves). The traditional methods for damping the self-excited oscillations in wind tunnels (attenuation of vortex formations in the mixing layer by generating a circular nonuniformity of the flow at the nozzle cutoff or making openings in the walls of the diffuser in order to attenuate the standing sound waves in the return-flow channel of the tunnel) are not always completely effective.

The discovery of the possibility of controlling coherent structures of the free jet by irradiating it with acoustic radiation [2, 3] was employed to develop acoustic methods for controlling the pulsations of the flow in wind tunnels [4, 5]. In these methods the flow in the channel of the wind tunnel is irradiated with a monochromatic wave whose frequency corresponds to the Strouhal number Sh_S = 2-5, and in addition the source of the acoustic disturbances — an electrodynamic loud speaker — is placed in the return-flow channel of the tunnel.

Acoustic methods for controlling pulsations of the flow were found to be very effective. They have made it possible to suppress completely the self-excited oscillations in wind tunnels of different sizes (with diameter of the working part from d = 0.15 to d = 2.2 m) and to reduce the longitudinal pulsations of the flow in the self-excited regimes by a factor of 3-12 and in the non-self-excited regimes by approximately a factor of 1.5-2.

Together with its effective suppression of self-excited oscillations the acoustic method indicated above also has certain drawbacks. First, since the return-flow channel of the wind tunnel is an acoustic resonator with a set of resonance frequencies, at which the acoustic signal is amplified, this method of suppressing self-excited oscillations in the tunnel is connected with the sharp selectivity of the system with respect to the perturbing frequency depending on the flow velocity in the working part of the tunnel. Second, significant pressure pulsations at the frequency of acoustic irradiation are separated in the spectrum of the pressure pulsations in the working part of the tunnel.

In this work we attempted to realize a method of suppressing self-excited oscillations in a wind tunnel that is free of these drawbacks. To this end the mixing layer in the working part of the tunnel was excited by means of periodic injection-suction in the boundary layer of the nozzle near the output section through a narrow slit connected with the closed toroidal cavity, which in turn was connected to the sound radiator. Periodic pulsations of the pressure in the cavity led to periodic ejection of air through the narrow slit or sucking of air into the cavity.

This method for exciting the mixing layer of the jet has two potential advantages over the method described above. First, to attenuate the coherent structures in the mixing layer, only a thin boundary layer near the nozzle cutoff and not the entire volume of the return-flow channel of the tunnel and the core of the flow in the working part is excited. Second,

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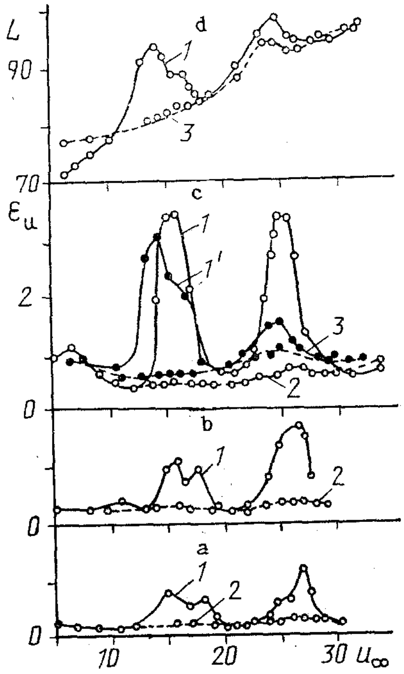

Fig. 1

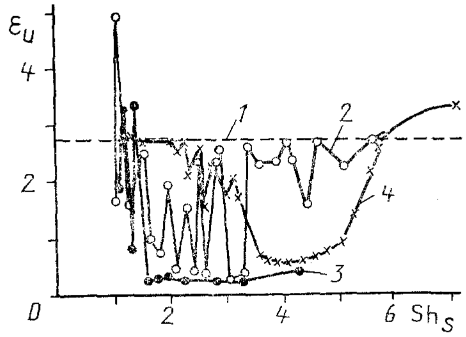

Fig. 2

Fig. 1. The longitudinal pulsations of the velocity in the working part of the tunnel ε_u, %, and the noise level outside the tunnel L, dB, as a function of the flow velocity u_∞, m/sec; 1, 1') in the absence of acoustic excitation; 2) with periodic injection-suction with frequency f_S = 358 Hz (the electric power of the radiator is equal to 50 W); 3) same with a 3-W radiator; a, b, c) the dependences $\varepsilon_u(u_\infty)$ on the axis of the working part with x/d = 0, 0.5, and 1.0; d) the dependence $L(u_\infty)$ at the point x/d = 0, r/d = 1.3.

Fig. 2. The velocity pulsations on the axis of the working part at x/d = 1 in the self-oscillatory regime (u_∞ = 15 m/sec) as a function of the excitation frequency: 1) starting value of ε_u; 2) with the jet excited by a radiator placed in the return channel (the electric power of the radiator is equal to 5 W); 3) with periodic injection-suction through a slit in the wall of the nozzle (the electric power of the radiator is equal to 50 W); 4) same with a 3-W radiator.

since the narrow slit is an inefficient sound radiator there is hope that for this method of suppressing self-excited oscillations in the working part no significant pressure pulsations will appear.

The object of study was a wind tunnel with an open working part 0.3 m long and with a nozzle diameter d = 0.15 m. Periodic injection-suction was realized by creating a pulsating pressure in a ring-shaped chamber placed at the nozzle cutoff. The pressure pulsations in the chamber were generated by a dynamic loudspeaker with an electric power of 50 W, connected with the chamber by means of four rubberized canvas hoses, or a dynamic loudspeaker with a power of 3 W connected directly to the ring-shaped chamber. The chamber had a 0.3 mm wide slit 7 mm from the end of the nozzle.

The acoustic oscillations were generated by a pure-tone generator. The velocity pulsations were measured with the help of a constant temperature hot-wire anemometer and the pressure pulsations in the working part of the tunnel were measured with a capacitor microphone 12.7 mm in diameter equipped with a windbreak cap, while pressure pulsations outside the tunnel were measured with a microphone 25.4 mm in diameter.

The results of the measurements were compared with analogous measurements in the same tunnel [4], when an electrodynamic sound radiator with an electric power of 5 W was installed in the return channel in order to suppress self-excited oscillations.

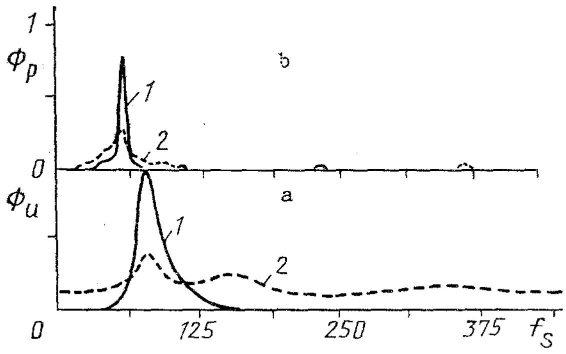

Fig. 3. The change in the spectra of velocity and pressure pulsations at the point x/d = 1, r/d = 0 with suppression of the self-excited oscillations: 1) no acoustic excitation; 2) with periodic injection-suction with frequency f_s = 358 Hz; a) spectrum of pulsations of the longitudinal velocity with u_∞ = 25 m/sec (the electric power of the radiator is equal to 50 W); b) the spectrum of pressure pulsations with u_∞ = 15 m/sec (3-W radiator). f_s, Hz.

Figures 1a, b, and c show the longitudinal component of the velocity pulsations ε_u on the axis of the working part at distances from the end of the nozzle x/d = 0, 0.5, and 1.0 as a function of the flow velocity u_∞ in the absence of and in the presence of (f_s = 358 Hz) an acoustic excitation. The distinct maxima of the velocity pulsations, which become more intense downstream and are caused by the development of self-excited oscillations, are observed at velocities u_∞ = 15 and 25 m/sec. The slight difference between the curves 1 and 1' is caused by the insignificant (of the order of 50 μm) radial shift of the edges of the ring-shaped slit when the experimental apparatus was remounted.

It follows from Figs. 1a, b, and c that with periodic injection-suction with frequency f_s = 358 Hz the self-excited regimes in the working part virtually disappear; the corresponding Strouhal numbers Sh_s = 1.6-5.4.

Figure 1d shows the dependence of the pressure pulsations at the point x/d = 0, r/d = 1.3, on the flow velocity with and without periodic injection-suction. It follows from here that suppression of self-excited oscillations in the tunnel is accompanied by a significant drop in the noise level in the near acoustic field of the jet.

To compare the two methods for suppressing self-excited oscillations in the tunnel — by means of acoustic irradiation of the flow with a dynamic loudspeaker placed in the return-flow channel and by periodic injection-suction through a narrow slit near the end of the nozzle — Fig. 2 shows the dependence of the intensity of the pulsations ε_u on the Strouhal number of the acoustic action on one of the self-excited regimes (u_∞ = 15 m/sec) at the point x/d = 1, r/d = 0. We can see that in the case of the periodic injection-suction for Strouhal numbers in the range Sh_s = 1.6-5 stable suppression of the self-excited oscillations occurs; this advantageously distinguishes this method for controlling self-excited oscillations from the previous method [4, 5], in which owing to the resonance properties of the return-flow channel the efficiency of the suppression changes in a jump-like fashion as a function of the Strouhal number.

The spectra of the pulsations of the flow velocity and the pressure pulsations on the axis of the working part (for x/d = 1), presented in Fig. 3, illustrate the effectiveness of the suppression of self-excited oscillations with periodic injection-suction. It is obvious that here the peaks in the spectra in the case of periodic excitation of the mixing layer are substantially lowered, and the pressure pulsations at the frequency of acoustic irradiation increase very insignificantly.

So, the method proposed for suppressing self-excited oscillations in wind tunnels with an open working part has been found to be quite effective and makes it possible to expand substantially the range of working regimes of the tunnel, to reduce pulsations of the velocity and pressure in the working part, and to reduce the noise in the working enclosure of the tunnel. The power consumption in this method is very low: for a driving power of the tunnel of about 1 kW the electric power of the dynamic loudspeaker is equal to 3 W. For a radiator efficiency of the order of 1-2%, required for suppressing self-excited oscillations, the acoustic power does not exceed 0.01% of the power required to drive the tunnel.

NOTATION

x and r, coordinates in a cylindrical coordinate system whose origin lies at the center of the output section of the nozzle; d, diameter of the output section of the nozzle; u_∞, velocity of the incoming flow; u', pulsations of the longitudinal velocity; $\varepsilon_u = \sqrt{\langle u'^2 \rangle}/u_\infty$, intensity of the pulsations of the longitudinal velocity; f_s, frequency of the external action; L, level of the sound pressure; $Sh_s = f_s d/u_\infty$, Strouhal number; Φ_u and Φ_p, spectral densities of the pulsations of the longitudinal velocity and the pressure, which are measured, respectively, in a three-octave and narrow (Δf = 2.5 Hz) frequency bands.

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