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EXPERIMENTAL INVESTIGATION OF A TURBULENT JET IN TURBULENT CROSS FLOW

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The characteristics of an axisymmetric turbulent jet propagating in a cross flow with a high degree of turbulence are investigated experimentally.

There is a fairly large number of papers devoted to experimental investigations of the development of turbulent round jets in a cross flow [1-6]. These investigations are of interest because a flow of this type is often encountered in technology. The theoretical solution of the problem presently involves great difficulties because of the complex three-dimensional character of the flow in such jets.

The flow structure of a turbulent round jet entering a right-angle cross flow was investigated in detail in [4]; for the most part, the initial, formative section of the jet was investigated. As in all other known experimental work, the transverse flow described in the above paper had a low level of turbulence, 0.3-0.4%. However, in various jet devices where flow of this type occurs, the cross flow is highly turbulent.

The present article provides the results of an experimental investigation of the characteristics of a round turbulent jet propagating in a cross flow whose turbulence level has been increased to 10%. The experiments were performed by means of the experimental device used in [4]. The turbulence level of the cross flow is increased by means of a mechanical turbulator, equipped with a two-row cylinder lattice with the rows moving in opposition. The turbulator is installed at the outlet from the nozzle of a wind tunnel. The description and characteristics of the turbulator are given in [7].

The axis of the jet entering the cross flow at a right angle is located at a distance of 115 mm from the second row of the turbulator lattice. The field of the mean and the pulsating velocities are completely equalized here, while the turbulence intensity in the cross flow is virtually isotropic and approximately equal to 10%. According to L. N. Ukhanova's measurements, the longitudinal integral scale of turbulence was approximately equal to 10 mm at the section of the jet nozzle, while the transverse scale amounted to 5-6.5 mm.

The jet is produced by means of a profiled nozzle with an outlet diameter of 19.5 mm. The cutoff end of the nozzle is mounted flush with the surface of a screen positioned parallel to the flow in the operating section in the wind tunnel below its axis at a distance of 128 mm from it. Drainage of the screen around the jet is provided for investigating the pressure distribution. The thickness of the boundary layer, measured at the screen in front of the nozzle in the absence of the jet at cross flow velocities of 5 and 15 m/sec, was approximately equal to 7 mm.

The air for producing the jet is supplied from a compressor through a receiver. The air discharge was constant in all experiments, while the mean outflow velocity of the jet was equal to $u_0 = 72.5$ m/sec. The Reynolds number, calculated on the basis of this velocity and the outlet diameter of the nozzle, was equal to $0.94 \cdot 10^5$.

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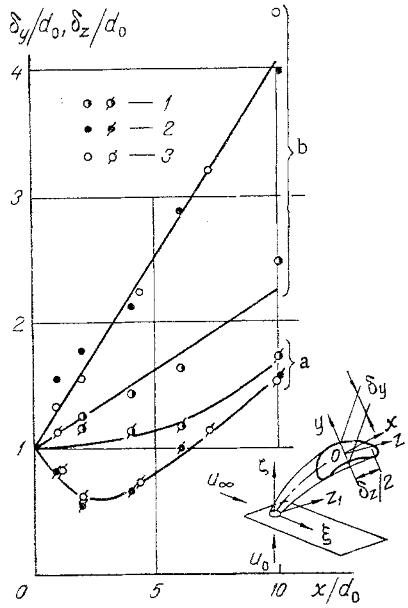

Fig. 1

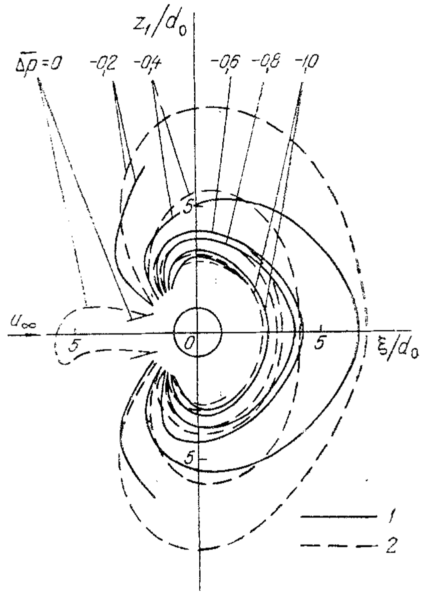

Fig. 2

Fig. 1. Variation of the jet width in the symmetry plane (a) and in the transverse direction (b) with increasing distance from the nozzle cutoff for two ratios of the cross flow velocity m and different turbulence levels in the cross flow ε (%). 1) m = 0.07, ε = 10; 2) 0.2 and 10; 3) 0.2 and 0.3.

Fig. 2. Equal-static pressure lines at the screen around the jet for a ratio of the cross flow velocity to the jet velocity of 0.2 and different turbulence levels in the cross flow (%). 1) 10; 2) 0.3.

The mean velocity and the turbulence intensity were uniformly distributed over the outlet section of the submerged jet. The deviation of the velocity from its mean value was equal to less than 1%, while the turbulence intensity at the jet core amounted to 0.9%. The investigations were performed by using a five-channel air pressure receiver with a maximum spacing of 1.6 mm between orifices for two ratios of the cross flow velocity to the jet velocity, m = 0.07 and m = 0.2.

The jet axis as the line of maximum velocities in the symmetry plane was determined first for each set of operating conditions. According to measurement data, the turbulence of the cross flow did not affect the shape of the jet axis. The coordinate system used in our work is shown in Fig. 1.

We subsequently measured the velocity vector and the dynamic and static pressures along the two axes, y and z, in sections perpendicular to the x axis at distances of 1, 2, 4, 6, and 10 nozzle diameters, measured along the jet axis.

It was of interest to determine the manner of jet expansion in the cross flow with an increase in the turbulence level. For this, we determined the jet boundaries as the lines where the gauge dynamic pressure was equal to 0.2 of the maximum gauge dynamic pressure in a given perpendicular plane ($\bar{\Delta}p_0 = (p_0 - p_{0\infty})/(p_{0max} - p_{0\infty}) = 0.2$).

Figure 1 shows the variation of the jet width in two planes: the symmetry plane x0y and the transverse plane x0z. Similar characteristics of a jet propagating in a nonturbulent cross flow ($\varepsilon_\infty \approx 0.3\%$), borrowed from [4], are given for m = 0.2. It is evident that the jet width remains virtually unaffected as the turbulence of the cross flow increases to 10%. This was not unexpected, since the turbulence level in such a jet is extremely high, especially in its rear part [6].

In both a turbulent and a nonturbulent cross flow, the jet characteristics differ qualitatively for a "weak" and a "strong" jet. For a weak jet (m = 0.2), expansion across the flow is considerably more intensive than along the flow. This difference in behavior is also observed in the case of a strong jet, but to a lesser extent. In the symmetry plane, for m = 0.07, the jet expands slightly near the nozzle, while, for m = 0.2, the jet contracts over a section of up to 2.5 diameters.

The static pressure distribution at the screen around the jet also indicates the weak effect of the degree of turbulence in the cross flow on jet propagation. Figure 2 shows the equal-pressure curves $\overline{\Delta p} = 2(p - p_\infty)/\rho u_\infty^2$, which indicate that the cross flow turbulence does not affect qualitatively the static pressure distribution. Turbulence attenuation occurs more slowly only beyond the jet (in the wake region).

Thus, the turbulence level of the cross flow does not exert any appreciable influence on the jet in the cross flow.

NOTATION

u_0, mean jet outflow velocity; d_0, diameter of the outlet cross section of the nozzle; u_∞, cross flow velocity; m, ratio of the cross flow velocity to the jet velocity; x, y, z, coordinate axes; ε_∞, intensity of the cross flow turbulence; p_0, dynamic pressure at the measuring point; $p_{0\infty}$, dynamic pressure in the cross flow; p_{0max}, maximum dynamic pressure in the plane perpendicular to the jet axis; Δp_0, relative gauge dynamic pressure; $\overline{\Delta p}$, relative gauge static pressure at the screen; p, static pressure at the measuring point; p_∞, static pressure in the cross flow; ρ, density.

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