# THE INFLUENCE OF INITIAL STREAM TURBULENCE ON THE CHARACTERISTICS OF AN AXISYMMETRIC IMMERSED JET

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Results are given of measurement of mean velocity and of velocity fluctuations in an axisymmetric immersed jet at various values of initial turbulence. It is shown that as the initial stream turbulence increases, the length of the entrance section decreases, and that the entrance section practically disappears in a strongly turbulent jet.

Under normal conditions, when a jet discharges from a nozzle with a comparatively uniform initial velocity profile, or discharges from a long tube, with a corresponding nonuniform velocity profile, the turbulence intensity at its initial section does not exceed 1–2%. The results of experimental investigations of plane and axisymmetric jets given in most papers refer precisely to these comparatively low values of initial turbulence of the stream. These initial turbulence values are small in comparison with the greatest turbulence which is generated in a jet.

However, when special turbulence-promoting grids are fitted in a nozzle or a tube, the initial stream turbulence may be very large and reach 20–30%. In this case there is a complete rearrangement of the microstructure of the stream in the initial and transition sections of the jet, not apparent in the characteristics of the mean flow. Investigations carried out up till now of a jet with different initial turbulence levels (we refer, in particular, to the experimental investigation of the mean flow in a plane immersed jet at various values of initial turbulence in [1]) have not as yet given a comprehensive answer to the question of the influence of this parameter.

The present paper gives the results of an experimental investigation of the macro- and microstructure of an axisymmetric immersed turbulent jet with varying initial turbulence. The increased initial turbulence is created by installing turbulence-generating grids, swirl generators, and meshes ahead of the nozzle.

The measurements were made with a constant temperature thermal anemometer, the values of mean velocity and of the mean square value of the longitudinal component of fluctuating velocity being measured. A low-velocity air jet ($u_0 < 100$ m/sec) discharged from a nozzle of $2\delta_0 = 15$ mm diameter. Turbulence-generating grids were fitted at the entrance section of a nozzle of 20-mm diameter. In all cases measures were taken to see that the velocity distribution at the nozzle lip should be practically uniform; this made it possible, in determining the effect of initial jet turbulence on its characteristics, to exclude the effect of initial nonuniformities of the jet.

Figure 1 shows the distribution of mean velocity and of fluctuations of the longitudinal component of velocity $\varepsilon_{u0}$ along the jet axis, for several values of initial turbulence $\varepsilon_0$, while Fig. 2 shows the velocity profiles and the intensity of turbulence in the main part of the jet.

From the data presented the following conclusions may be drawn:

1. As the initial stream turbulence increases, a rearrangement of the flow microstructure in the initial section occurs, the length of the latter decreases, and for $\varepsilon_0 \approx 20\%$ the initial section practically disappears, and a sharp fall in the mean velocity along the axis begins in the immediate vicinity of the nozzle lip. An analogous conclusion may be drawn also from the measurements of a plane immersed jet in [1]. The above phenomena are already in evidence with $\varepsilon_0 \approx$ $\approx 4$–$5\%$.

2. In the main part of the jet the mean velocity profiles are practically universal in the coordinates $\overline{\Delta u}$, $\eta_{1/2}$ for all values of $\varepsilon_0$, and at sufficient distance from the nozzle the profiles of turbulence intensity $\varepsilon_u$ also change very little with change of $\varepsilon_0$ over a wide range (Fig. 2).

3. With increase of initial stream turbulence there is a decrease in the velocity along the jet axis $\overline{\Delta u_m} =$ $= u_m/u_0$ at a fixed distance from the nozzle. This leads to a change in the other characteristics of the jet: the width $\delta$, flow rate Q, and kinetic energy E, since

$$\frac{\delta}{\delta_0} \sim \overline{\Delta u_m}^{-1}, \quad \frac{Q}{Q_0} \sim \overline{\Delta u_m}^{-1}, \ \frac{E}{E_0} \sim \overline{\Delta u_m}.$$

4. At a certain distance from the nozzle the mean square value of longitudinal component of fluctuating velocity $\varepsilon_{u0}$ ceases to depend on the initial stream turbulence, and is practically the same for all values of $\varepsilon_0$; then the location of the maximum dependence of $\varepsilon_{u0}(x)$ with increase of $\varepsilon_0$ is displaced towards the nozzle.

The conclusions given above were obtained mainly on the basis of an analysis of the distribution of the mean and fluctuating velocities along the jet axis. It is therefore of interest to measure these parameters in transverse sections of the jet, especially within the initial and transition sections. Measurements of this kind were made for two values of initial turbulence, $\varepsilon_0 \approx 1.3\%$ and $\varepsilon_0 \approx 8.3\%$. The corresponding results are shown in Fig. 3 and confirm the above conclusion regarding the effect of initial turbulence on the length of the initial section.

We shall now determine the dependence of the experimental constant $\varkappa$ appearing in the semi-empirical formula for turbulent friction on initial stream turbulence. For this purpose we shall use the formula

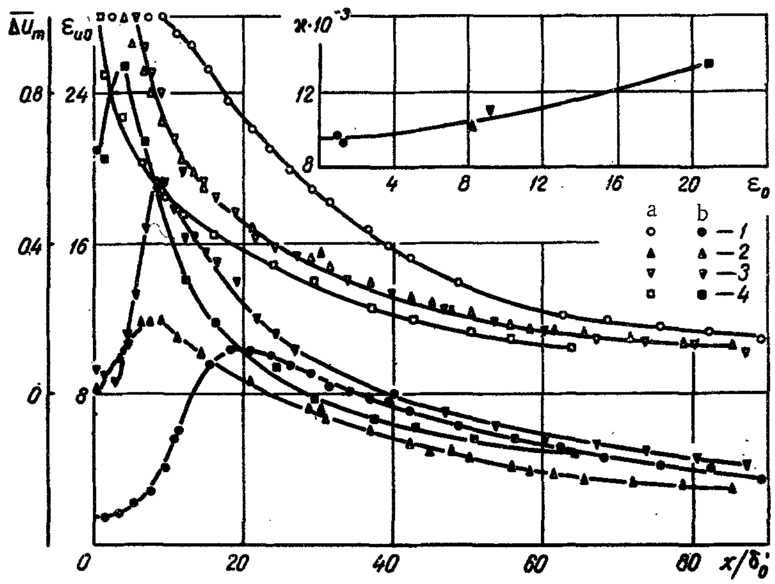


Fig. 1. Effect of initial stream turbulence on the variation along the jet axis of the mean velocity and of fluctuations in longitudinal velocity component. The upper right corner shows the empirical "constant" $\varkappa$ as a function of initial stream turbulence: a—for $\overline{\Delta u}_m(\bar{x})$; b—$\varepsilon_{u0}(\bar{x})$; 1—with $\varepsilon_0 = 1.5\%$; 2—8.3; 3—9.3; 4—20.9.

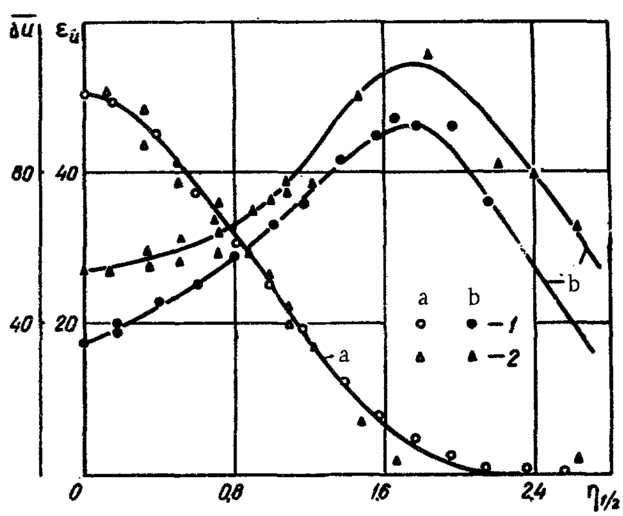


Fig. 2. Dimensionless profile of mean velocity and turbulence intensity profile in the main section of the jet ($\bar{x} = 40$) for various values of initial turbulence: a—for $\overline{\Delta u}(\eta_{1/2})$; b—$\varepsilon_u(\eta_{1/2})$; 1—with $\varepsilon_0 = 2.1\%$; 2—20.9.

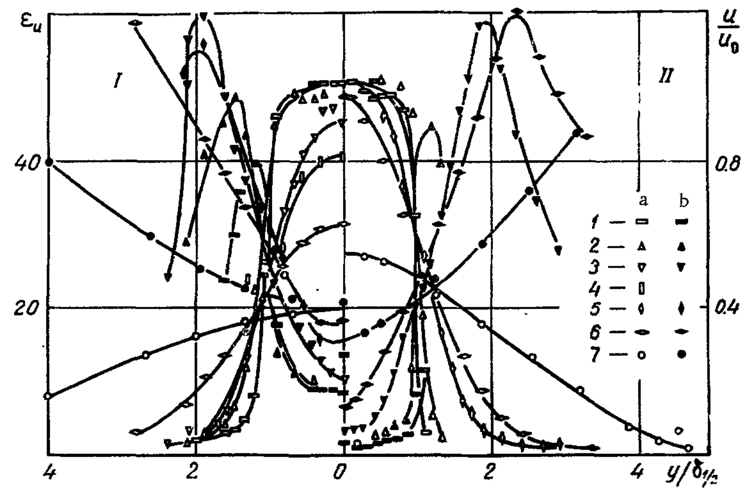


Fig. 3. Profiles of mean velocity and of turbulence intensity in the initial and transition sections of the jet, for two values of initial turbulence, $\varepsilon_0 = 8.3\%$ (I) and 1.3% (II): a—for $u < u_0$; b—$\varepsilon_u$; 1—with $\bar{x} = 0.5$; 2—2; 3—4; 4—6; 5—8; 6—12; 7—30.

$$\overline{\Delta u}_m = \left[1 + 24\sqrt{2b_2}\,\varkappa\,(\bar{x} - \bar{x}_0)\right]^{-1}$$

of [2], where $b_2 = 11/210$; $\bar{x} = x/\delta_0$ and $x_0$ is the length of the initial section of the jet. In conformity with the latter formula, the data of Fig. 1 were redrawn in the form of straight lines, in the coordinates $\overline{\Delta u}_m^{-1} - 1$, $\bar{x}$, which permits us to determine, from their slopes, the dependence of $\gamma$ on the initial degree of turbulence (Fig. 1, upper right corner). The nature of the dependence of $\gamma(\varepsilon_0)$ observed is in good agreement with the analogous dependence cited by Abramovich [3] for an initial flow nonuniformity.

In conclusion it should be noted that the characteristics of the mean flow in an immersed turbulent jet are affected by the initial scale of turbulence as well as by the initial turbulence, especially when the scale is commensurate with the transverse dimension of the nozzle. To investigate the effect of the initial scale for small scale values, we made measurements of the jet parameters along the axis with meshes installed at the nozzle lip. The initial turbulence was then practically unchanged, only the initial scale being changed (mesh size was 0.5, 1, and 1.5 mm). No measurable influence of initial scale was observed here.

Thus, by changing the initial stream turbulence, we may to some extent change the characteristics of the mean flow in a turbulent jet. In any case the substantial curtailment of the initial section of the jet observed above as the initial turbulence is increased may be used when there is a need to intensify turbulent mixing, i.e., to exclude the region of comparatively high velocity as being a source of hydraulic loss, increased noise, and so on.

## NOTATION

x, y are the cylindrical coordinates with origin at the center of the nozzle exit section; u, $u_m$ are the longitudinal component of mean velocity in the jet and its value on the jet axis; $u_0$ is the mean velocity at the nozzle lip; $\varepsilon_0$ is the initial turbulence of the flow at the nozzle lip; $\varepsilon_u$, $\varepsilon_{u0}$ is the intensity of turbulence referred to the local value of mean velocity or to the initial value at the nozzle lip, ($\varepsilon_u = \sqrt{\overline{u'^2}}/u$, $\varepsilon_{u0} = \sqrt{\overline{u'^2}}/u_0$); $\delta_0$, $\delta$, $\delta_{1/2}$ are the radii of the nozzle exit section, of the transverse section of the jet, and the half-width corresponding to $\overline{\Delta u} = 0.5$; $\eta_{1/2} = y/\delta_{1/2}$; $\overline{\Delta u} = u/u_m$; $\overline{\Delta u}_m = u_m/u_0$.

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