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The influence of the jets configuration on the intensity of their mixing

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Abstract. Experimental study results of two parallel turbulent jets and a set of discrete jets evenly distributed over a circle are presented. Distributions of averaged velocities and their pulsations were obtained and analysed. It was shown that in the case of a discrete annular jet, the flow structure changes significantly, and the distribution of average velocities indicates the presence of the large-scale vortex structure on the jet axis.

1. Introduction

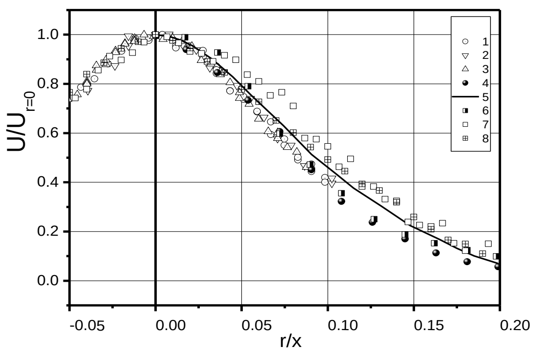
The study of turbulent jets and their interaction is topical in terms of improving the efficiency of numerous devices having the widest technical application: ejectors, fuel supply systems, jet cooling devices, etc. Large-scale turbulent structures play an important role in jet flows, which has been confirmed by a number of experimental studies [1-3].

The present experimental study aims at studying the interaction of the system of parallel turbulent jets in order to identify the features of their structure. The problem also has an important fundamental component, lying in the field of physics of turbulent jet interference. Assuming the presence of vortex structure, their detailed study will enable the control over the jets mixing and heat transfer at different configurations of jets.

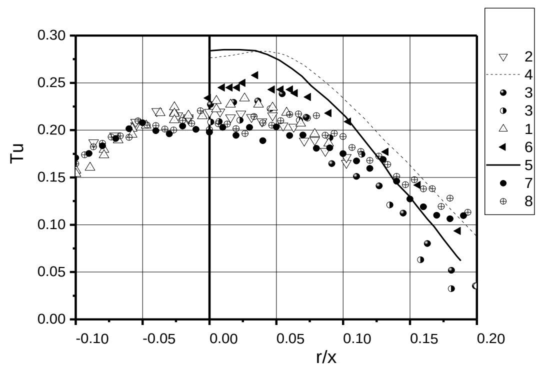
Figure 1. Experimental stand for the study of aerodynamic parameters of flows using a two-component LDA

2. Experimental setup

To solve the above-mentioned problems, an experimental stand is used (Figure 1). It is based on a two-component laser Doppler anemometer (LDA) with adaptive time selection and visualization of the velocity vector for precision non-contact measurement of the flow velocity vector. The structural configuration of the measuring device includes a two-channel acousto-optic circuit switching. Increased measurement accuracy is provided by automatic matching of time selection of the velocity vector components with the spatial distribution of scattering particles in the flow and by improving the noise resistance of the electronic signal processing system. The used light-scattering particles were formed by spraying the mixture of glycerol and water (50%/50%) using the aerosol generator TSI 9306. Air in the room was almost dust-free. Thus, a gradient of the volume concentration of particles was formed both streamwise and in the cross sections of the jets. In velocity profile measurement, the concentration of particles in the flow could change by two orders of magnitude. Verification comparison with data of other authors [4] was carried out (Figure 2a, b).



(a)



(b)

Figure 2. Average velocity distribution in submerged turbulent jet(a), distribution of turbulence intensity (b). Points and lines: data [9] Re=8500 and (1) x/D=10 (2)x/D=15 (3)x/D=20; data [5] x/D=25 (4) Re=16000 (5) Re=5500;data [6] (6). Present work Re=8300 (7) x/D=11.6 (8)x/D=16.8.

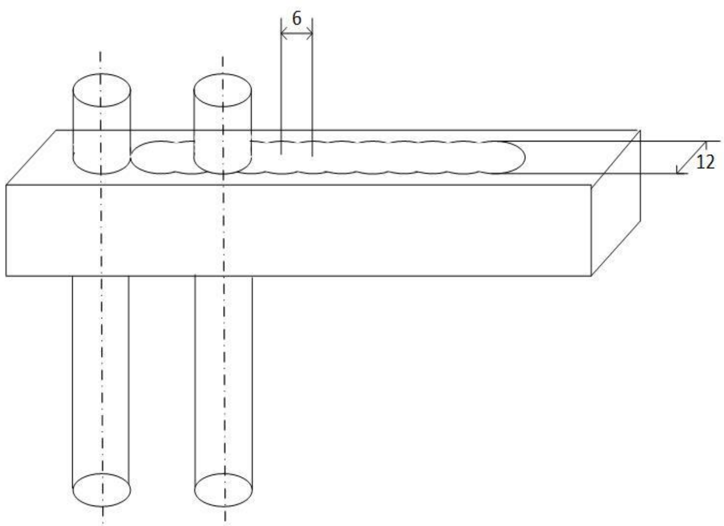


Figure 3. Scheme of the experimental section.

3. Experimental results

At the first stage of the research, the features of the interaction of two parallel free jets were studied. The experimental section consisted of two round tubes (inner diameter D=10mm, outer 12mm, and L= 500mm) arranged in parallel (Figure 3). The section design allowed discretely changing the distance between the tubes with a step of 0.5 D. Let us consider two jets with a nozzle diameter of 10 mm at a distance of 1.2D from each other. Data on mean and pulsation characteristics of the flow were obtained for various geometric parameters and Reynolds numbers.

At a distance of 5mm and 15mm from the nozzle outlet, the distributions of axial and radial velocity and their pulsations were measured for two separate parallel jets (Figure 4a, b, c, d). From figure 4a it is seen that the distribution of the axial velocity up to H=15 mm is almost unchanged, as are the corresponding pulsations (Figure4c). The situation is the same for the radial component of the velocity and its pulsations (Figure 4 d). This suggests non-mixing of the jets; and a slight change in their structure is due to the resistance of the ambient air.

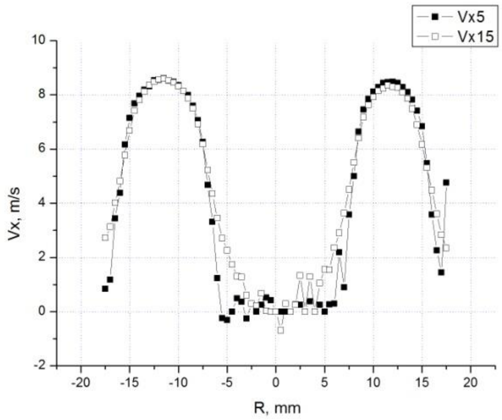


Figure 4a. Axial velocity at H = 5, 15 mm. Re = 5500

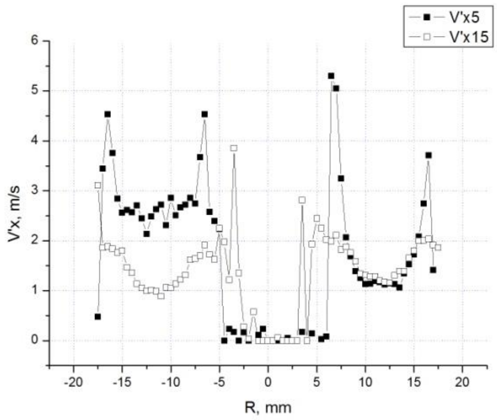


Figure 4c. Axial velocity pulsations at H = 5, 15 mm. Re = 5500.

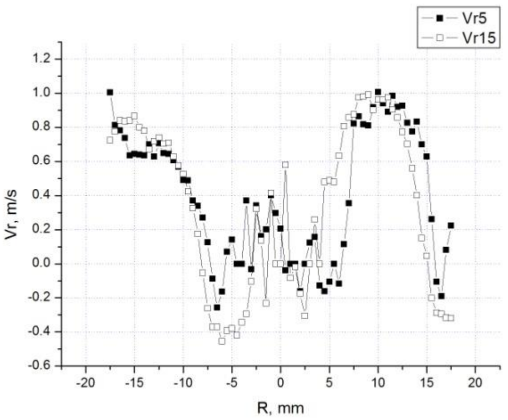


Figure 4b. Radial velocity at H = 5, 15 mm. Re = 5500

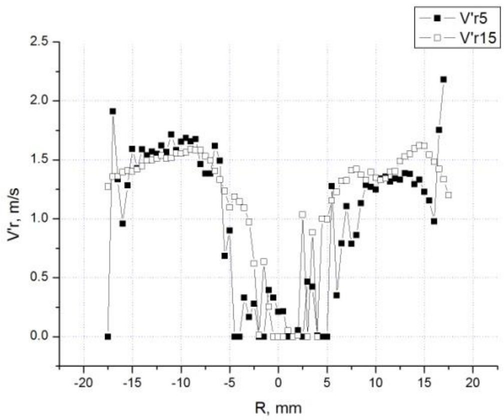


Figure 4d. Radial velocity pulsations at H=5, 15 mm, Re = 5500.

Now compare the profiles of velocities and pulsations of the jets at a distance H=50 and 100 mm (Figure 5a, b, c, d). It is clear that at H=50 mm the jets "contact" each other by their edges; subsequently at a distance of 50-100 mm their mixing into one jet occurs. Mixing occurs due to pulsations, the radial component of which is equal to a quarter of the axial velocity. The distance at which the mixing occurs 4 times exceeds the distance between the jets. In addition, in figures (Figure 5a, b, c, d) it is shown that at a distance *H*=50 mm from the section, the jets begin to stick together with a small shift to the right, and at a distance *H*=100 mm the left jet as if "jumps" on the right one. A similar pattern is observed for the radial distribution of velocities, but the pulsations of both axial and radial velocities remain symmetrical. That is, the" jumping" of the jet is not due to the measurement error.

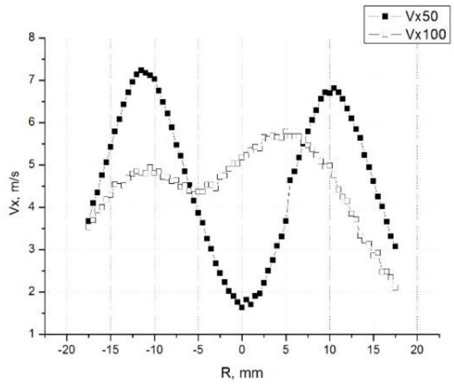


Figure 5a. Axial velocity at *H* = 50, 100 mm. Re = 5500.

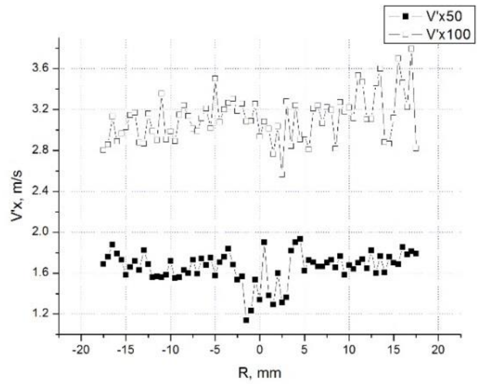


Figure 5c. Pulsations of axial velocity at *H* = 50, 100 mm. Re = 5500.

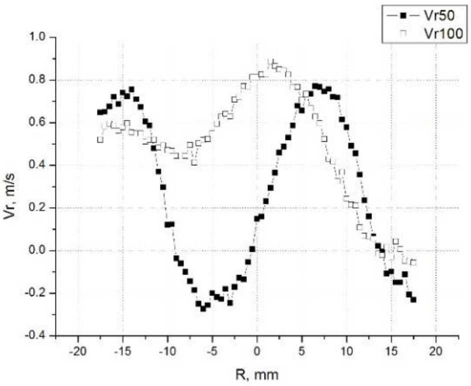


Figure 5b. Radial velocity at *H* = 50, 100 mm. Re = 5500.

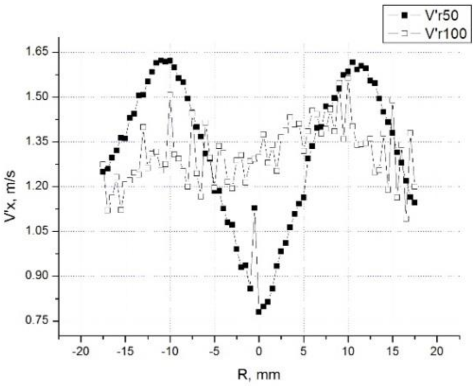


Figure 5d. Pulsations of radial velocity at *H* = 50, 100 mm, Re = 5500.

On the right jet, there were initially larger pulsations of axial velocity compared with the left jet (Figure 4c). In this regard, the axial velocity in the right jet decreased faster than in the left jet, so there was an uneven velocity distribution. For turbulent jets, such a difference in distributions is acceptable. Pulsations of axial velocity at *H*=50 mm (Figure 5c) were distributed in the cross section uniformly. For *H*=100 mm, the pulsations of the axial velocity were also uniform, but their level is 2 times higher than at *H*=50 mm, which indicates a high turbulence of the flow. The radial velocity pulsations were flattened at *H*=100 mm.

The second stage was to study the flow characteristics in a set of discrete jets evenly distributed over a circle (Figure 6). The experimental section in Figure 6 consisted of the housing and the inner channel with grooves, located over the radius and forming the system of annular discrete jets. In addition it was possible to supply an axial jet. The outer diameter of the ring *D*=22 mm, the inner diameter D_1=16 mm, the diameter of the axial opening D_0=10 mm, the length of the slot was equal to the distance between them and equaled 5 mm.

Figure 6. Experimental section, annular discrete jet.

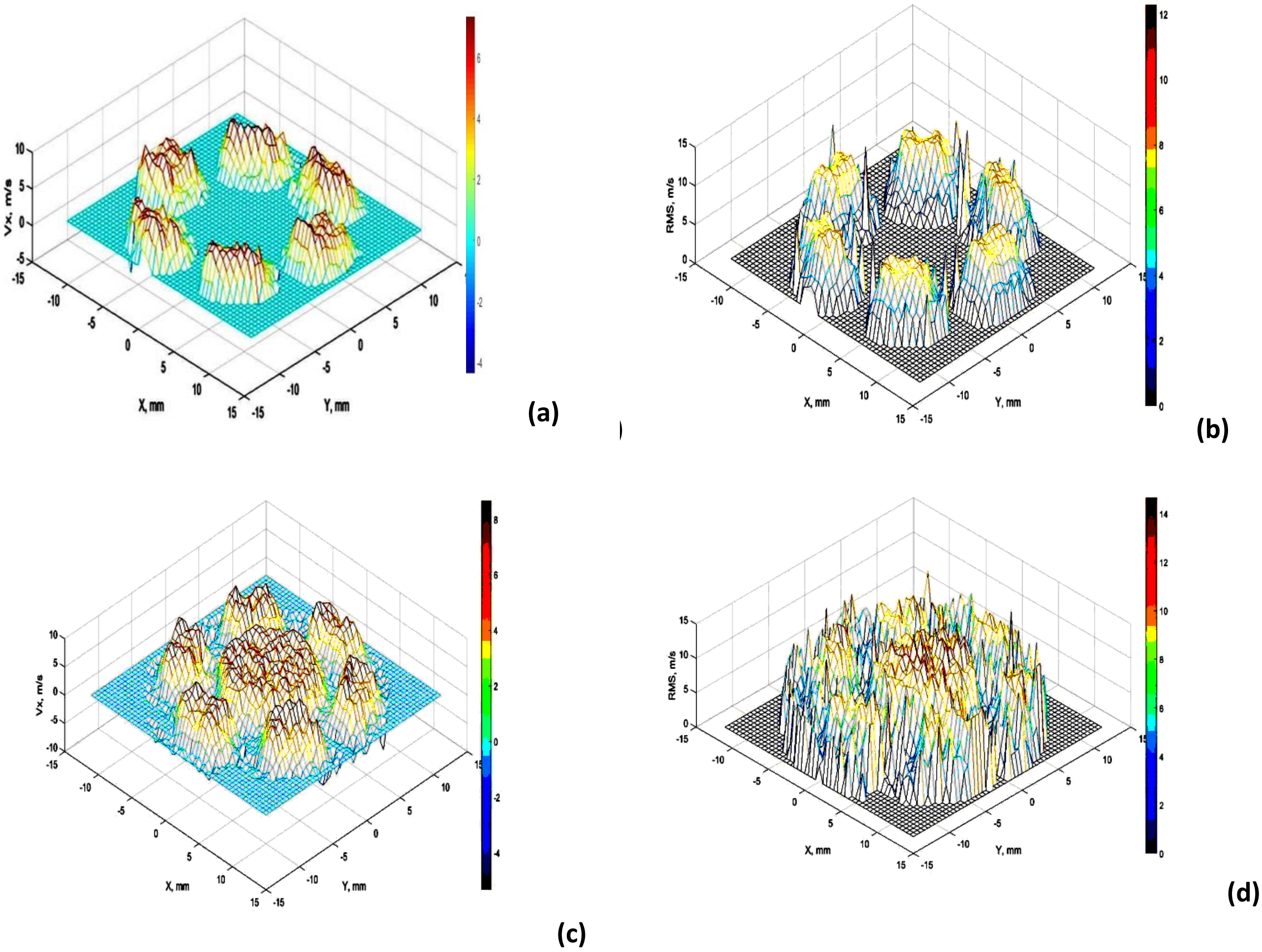


Figure 7. The axial velocity profile at 5 mm from the nozzle outlet (a), the profile of axial velocity pulsations at 5 mm from the nozzle outlet (b), the axial velocity profile at 5 mm from the nozzle outlet (with axis) (c), profile of axial velocity pulsations at 5 mm from the nozzle outlet (at axis) (d).

For the annular set consisting of 6 discrete jets, the axial velocity distribution and that of the corresponding pulsations at *Z*=5 mm from the nozzle outlet, as well as the streamlines passing through 2 velocity maxima on the plane over the *Z* axis and over the radius were measured.

Figure 8 shows the streamlines and the projection of velocities *Vx* and *Vr*. The formation of a vortex structure in the near-axis zone is apparent. From the graph of pulsations it may be inferred (Figure 7b) that weak vortex structures are formed and exist for a short period of time. The area between the jets is equal to the area of the jet itself, but the mixing of the discrete jets is 250% faster than the mixing of two separate jets. This is precisely due to the appearance of weak vortex structure inside the ring. Figure 7c shows that the component of the axial velocity around the jets is negative; hence, a vortex structure is formed around each jet, which is confirmed by low values of pulsations in the vortex zones (Figure 7d).

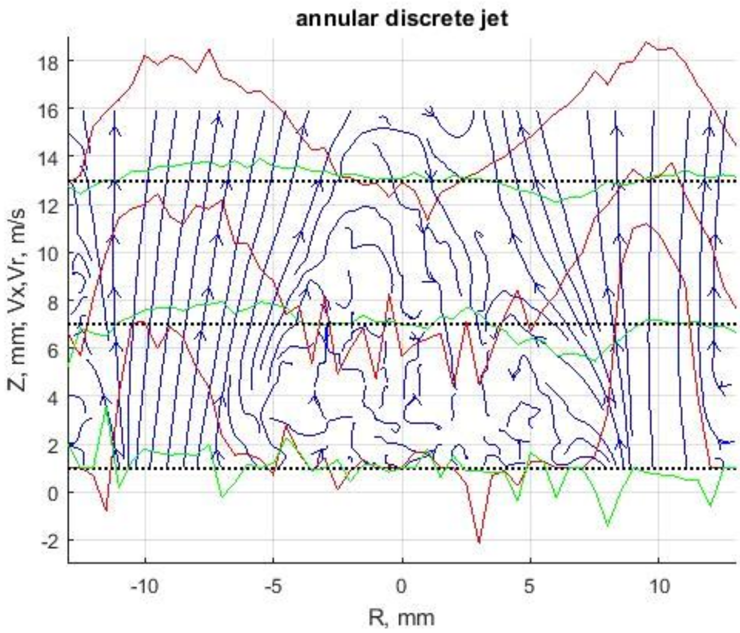


Figure 8. Streamlines and profiles of axial and radial velocity at a distance of 1, 7, and 13 mm from the nozzle outlet (blue – streamlines; green – radial, red – axial velocity).

4. Conclusions

Two jets interact at long distances, and with the appearance of additional jets, the structure of the flow changes (the case with 6 discrete jets in the ring). That is, the interaction between the jets is determined not only by the distance between the jets, but also by their number. In particular, in the case of a discrete annular jet, the flow structure changes significantly, and the distribution of average velocities indicates the presence of the large-scale vortex structure on the jet axis. This suggests the inapplicability of the two-jet approximation approach for the calculation of problems with a large number of jets. Moreover, due to the vortex structure formation, the mixing efficiency increases that is significant for many practical problems. By changing the jet velocities and their number, the mixing of the jets can be controlled.

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