Experimental study of interaction of two parallel circular jets

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Abstract. The results of experimental study of interaction in a system of two turbulent circular parallel jets are presented. The studies were conducted using a two-component laser-Doppler anemometer with an adaptive time selection of the velocity vector. The distance between the jet axes in experiments was varied within \( s/D = 1.8-3.0 \) with Reynolds numbers \( Re = 5500 \) and \( 11000 \). Distributions of average and pulsating components of the velocity vector at distances from the nozzle \( H/D = 0-10 \) were obtained. These distributions were analyzed in the region closest to the nozzles and the region of the greatest jet interaction.

1. Introduction

A system of two or more parallel turbulent circular jets is a fairly common configuration in technical applications. In a number of papers, for example [1], it is shown that a system of several jets has advantages over a single jet, such as acceleration of mixing or reduction in the level of generated noise. From the viewpoint of understanding the physics of interaction between individual jets, it is logical to consider the pair interaction.

Despite the fact that a single circular turbulent jet has been studied in detail, for a system of two jets all aspects of jet interaction have not been thoroughly investigated. In [2,3], “interference” of two jets, i.e. suppression of the turbulence level of each of the jets due to inter-jet interaction, is noted. The measurement results on interaction of twin jets at \( Re = 33000-88000 \) and \( s/D = 1.5-1.89 \) are presented in [4]. It is shown that interaction of jets manifests itself in the region adjacent to the nozzles, whereas at large distances the jets merge and behave as one. In this work, it is also noted that interaction of the jets increases with an increase in the Reynolds number and with a decrease in the distance between the jets.

This paper presents experimental data on the flow structure of two parallel circular jets at different Reynolds numbers and distances between the jet axes. At that, the main attention is focused on the near field behind the nozzles, where interaction between the jets is maximal.

2. Experimental setup

In the measurements, we used a setup (Fig. 1, 2), based on a two-component laser Doppler anemometer (LDA) with adaptive time selection and visualization of the velocity vector for precision contactless measurement of the flow velocity vector. The block diagram of the measuring device is made with two-channel acousto-optic channel switching. Increased measurement accuracy is provided by automatic matching of time selection of the velocity vector components with spatial distribution of scattering particles in the flow and improvement of the noise immunity of the electronic signal processing system. An aerosol (particle diameter of 1–1.5 μm), formed at recondensation of glycerol vapors under the...
controlled conditions, was used as light-scattering particles; the aerosol generator was developed by the authors. The ambient room air was almost free of dust. Thus, a gradient of volume concentration of particles was created both along the flow and in the jet cross-sections. When measuring the velocity profile, concentration of particles in the flow could change by two orders of magnitude. A verification comparison with the data of other authors [5] was performed. To move the LDA optical unit, an automatic three-component coordinate device with a minimum displacement step of 0.0125 mm was used. The maximum movement along each axis was 250 mm.

![Figure 1. Scheme of experimental setup. 1 – compressor, 2 – air filter, 3 – reducer, 4 – adjusting valves, 5 – mass flow regulators, 6 – aerosol generator, 7 – experimental section, 8 – laser Doppler velocity meter.](image)

![Figure 2. Photo of experimental setup.](image)

The experimental section was a metal parallelepiped with a hole for one tube, and adjacent holes evenly distributed with a step of $0.5D$ to fix the second tube. Thus, the distance between the jet axes could be discretely varied within $s/D = 1.8-3.0$. The inner diameter of the tube was $D = 10$ mm, the outer diameter was 12 mm. The length of the tubes was 50D, which ensured the stable profiles at the outlet. The flow rate of the supplied air was maintained with the help of Bronkhorst mass flow regulators. The air flow through the tubes was set to provide the required Reynolds number $Re = 5500$ or $11000$. The average and pulsating components of the velocity vector were measured in the range of distances from the nozzle $H/D = 0.5-7.5$. The average number of reliable particles at each point by each measurement component was at least 5000.

3. Results
The average velocity profiles at various distances from the nozzle are shown in Fig. 4. It can be seen that the longitudinal velocity on the axis of each of the jets attenuates along the length, whereas on the
axis of symmetry of a system of two jets, it increases. This growth continues to \(x/D \sim 8\), where it is replaced by a decrease due to jet mixing. We should note that complete merging of jets and transition to the regime, when the flow characteristics are close to a single jet is observed in this case at \(x/D > 15\).

![Figure 3. Scheme of experimental section (system of nozzles).](image)

The profiles of longitudinal velocity pulsations are shown in Fig. 4a. Up to distances from the nozzle \(x/D = 5\), four layers of mixing with maximal pulsations are clearly observed. As the jet moves away from the nozzle and jet interaction increases, distribution of pulsation changes to the form with two maximums, typical of a single jet. Transverse pulsations have qualitatively similar character with longitudinal pulsations (Fig. 4b). Distribution of the average transverse velocity at small distances from the nozzle demonstrates gas entrainment both in the outer mixing layer (negative transverse velocity values) and in the inner layer (positive values). At large distances from the nozzle, ejection in the outer layers of mixing is kept, while the jet mixing leads to its disappearance in the inner region.

![Figure 4. Distribution of average longitudinal velocity and its pulsations (a) and transversal pulsations (b) at different distances from the nozzle. Re=5500, s/D=1.8.](image)
The data for Re=11000 are presented in Fig. 5. Comparison of these graphs with Figures 4 allows analyzing the effect of Reynolds number on the intensity of jet interaction. With an increase in the Reynolds number, the region of jet interaction becomes longer because at x/D = 7.5, an increase in the longitudinal velocity on the axis of symmetry of a two jet system is still observed.

The same trend is observed with increasing distance between the nozzles s (Fig. 6). Comparing this figure with Figs. 4-5, the shift of the above-mentioned characteristic points downstream can also be noted. With a further increase in the distance between the nozzles, s/D = 3.0, the jets do not interact with each other in the studied region (x/D to 10).

![Figure 5](image1.png)

**Figure 5.** Distribution of average longitudinal velocity (a) and its pulsations (b) at different distances from the nozzle. Re=11000, s/D=1.8.

![Figure 6](image2.png)

**Figure 6.** Distribution of average longitudinal velocity (a) and its pulsations (b) at different distances from the nozzle. Re=5500, s/D=2.4.

**Conclusion**

Thus, the paper presents the results of measuring the velocity fields at interaction of two parallel circular turbulent jets using a laser Doppler anemometer. Different distances between jet axes and different Reynolds numbers are considered. It is shown that at the initial stage of flow formation, four mixing layers, where gas is entrained from the ambient space and there are the maxima in turbulent pulsations, are observed. With increasing distance from the nozzle, interaction of jets occurs, which consists in weakening the internal layers of mixing and turbulent pulsations, accordingly. It is also shown that an
increase in the Reynolds number and distance between the jet axes leads to the weakening of interaction and its movement downstream.

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References
[1] Raghunathan S, Reid I M 1981 *AIAA J.* **19** 124–7
[2] Tanaka E 1970 *Bull. JSME* **13** 272–80
[3] Harima T, Fujita S, Osaka H 2005 In: Rodi W, Mulas M (Eds.) *Engineering Turbulence Modelling and Experiments* **6** 501–10
[4] Yin Z 2007 *J. Hydrodynamics, Ser. B* **19** (3) 309–13
[5] Titkov V I, Lukashov V V 2006 *Optoelectronics, Instrumentation and Data Processing* **4** 85–91