

The flow structure of submerged round jets at low Re numbers

Vadim Lemanov¹, Konstantin Sharov^{1*}, and Vitaly Matyunin^{1,2}

¹ Kutateladze Institute of Thermophysics SB RAS, 630090, 1 Ac. Lavrentiev Ave., Novosibirsk, Russia

²Novosibirsk State University, 630090, 1 Pirogov St., Novosibirsk, Russia

Abstract. An experimental investigation of a laminar-turbulent transition in a round jet flowing from a cylindrical tube with a diameter of 3.2 mm have been carried out. The range of Reynolds numbers in the experiments $Re = Ud / \nu$ were of 700-12000. The measurements have been carried out via the PIV system. The profiles of average velocities and their pulsations in the laminar-turbulent transition zone have been obtained, as well as axial distributions of the longitudinal velocity and longitudinal velocity pulsations. Based on a comparison with the data of other authors, the effect of the initial conditions on the laminar-turbulent transition in a submerged jet has been shown.

1 Introduction

The modern development of MEMS (Micro-Electro-Mechanical-Systems) - technologies stimulated the study of microhydrodynamics of near-wall and jet streams. As a rule, the flow regime in micro-devices is laminar or transient, which contributed to the revival of interest in currents at low Reynolds numbers. It is known that jets are unstable at Reynolds numbers $Re = 10-30$ [1], however, the transition to turbulence occurs at significantly higher values of $Re = 30-2000$ [2, 3]. Basically, gas jets that flow from profiled nozzles and at large Reynolds numbers $Re > 10^4$ are studied. It is known that the initial conditions significantly have a great influence on the dynamics of flow development in the jet. According to different scenarios, a laminar-turbulent transition occurs in the jet flowing from the nozzle and from the cylindrical channel. This is due to the difference in the initial velocity profiles. Works with investigation results of jets that flow from long channels is practically absent in the literature, although such cases are often encountered in practice.

The feature of long channels is that they can also have laminar, turbulent and transient currents, which fundamentally determines the characteristics of the jets that flow from these channels. The effect of these factors, for today remains practically not studied.

* Corresponding author: sharov@itp.nsc.ru

2 Experimental methods and facilities

The submerged jet was formed with a circular channel made of metal, with a diameter $d = 3.2$ mm and a length of $100 d$. Air from the high-pressure line through the reducer and the fine adjustment valve entered the channel. The air flow was measured using Krohne DK 800 rotameters.

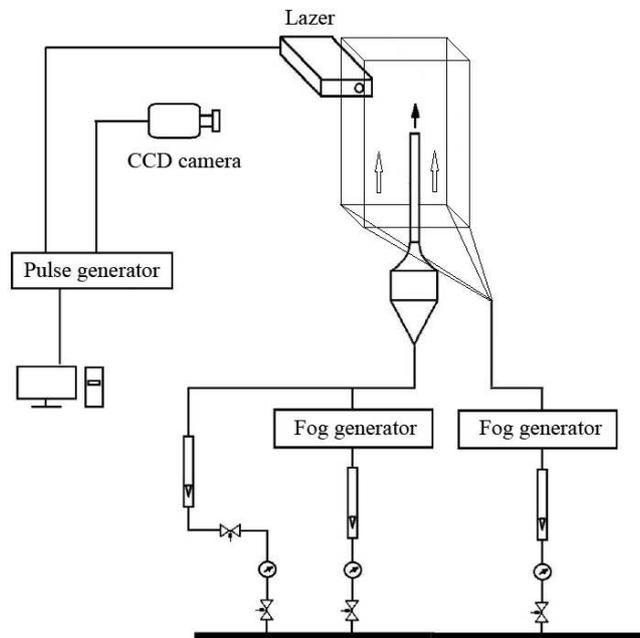


Fig. 1. Experimental set-up.

A stream of air flowed into the flooded air space (a flow chamber of Plexiglas $150 \times 150 \times 400$ mm). To visualize the flow and to measure the velocity fields, an aqueous aerosol with a particle diameter of $1\text{--}2 \mu\text{m}$ was mixed into the flow. The surrounding space in the flow chamber was also filled with a mixture of air and water aerosol.

The experiments have been carried out using a PIV system including: a digital camera, a solid-state pulse laser, a pulse synchronizer and a computer. The resolution of the matrix of the digital camera was 1024×1360 pixels, the laser pulse duration was 5 ns, the radiation energy was 50 mJ, the laser sheet thickness was 0.2 mm, and the minimum time between frames was $20 \mu\text{s}$. In the PIV experiments, the measuring region was 15×20 mm, and the design area had a size of 0.53×0.53 mm.

3 Results

The profiles of mean velocity and pulsations in round jets have been measured by the PIV system. In the experiments, measurements have been made on a section that covered a distance of 4 to 120 mm from the jet beginning. It corresponded to 1.3 and $40 x / d$, where x was the longitudinal coordinate reckoned from the pipe outlet.

Measurements on the channel outlet have shown that the velocity profile was well described by the well-known Poiseuille dependence for flow in cylindrical tubes. This indicated that the flow in the channel was laminar. The profiles of longitudinal mean velocities and pulsation distributions normalized to the average velocity on the axis U_0 at the tube outlet along the laminar-turbulent transition zone are shown in Fig. 2.

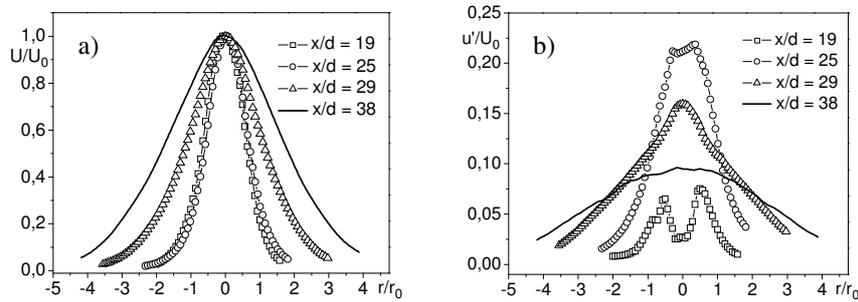


Fig. 2. The profiles of longitudinal mean velocities (a) and pulsation distributions (b) along the laminar-turbulent transition zone at the Reynolds number $Re = 1700$.

The data presented in the figure were obtained with the Reynolds number $Re = 1700$, which was determined from the bulk velocity. Here, the distance $x / d = 25$ corresponds to the maximum value of turbulent pulsations at the axis of the jet in the laminar-turbulent transition zone. This maximum usually characterizes the coordinate of the transition point. The distributions of the average velocities (Figure 2 a) tend to significant expand in radial direction after $x/d = 25$. This is explained by an increase in the expansion angle of the jet during the transition to turbulent flow.

In the pulsation distributions (Fig. 2b), it can be seen that in the laminar flow regime, the turbulence maxima are located along the edges of the jet, in the mixing layers. On the axis of the jet, the degree of turbulence is not great and amounts to a few percents. In the laminar-turbulent transition, the pulsations on the axis intensively increase, reach a maximum, then there are a small decrease and at the same time the profile of the pulsations become more crowded. Longitudinal and transverse pulsations behave similarly.

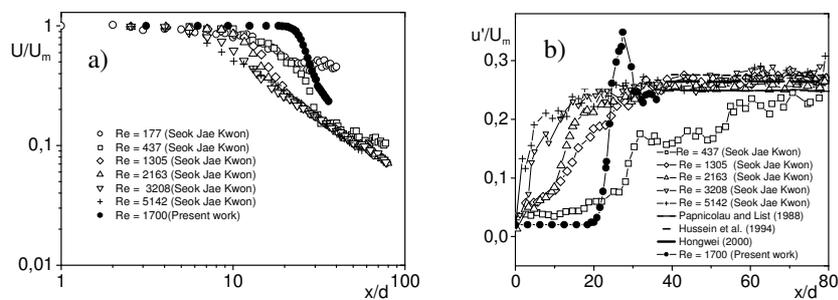


Fig. 2. The distribution of mean values (a) and intensity of turbulent fluctuations (b) of the longitudinal velocity along the axial line of the jet. Comparison of present work experimental data with the data of other authors.

Fig. 3 shows a comparison of our experimental data with the data of other authors, which are given in the article S. J. Kwon et. al. [2]. The figure shows the distribution of mean values and intensity of turbulent fluctuations of the longitudinal velocity along the

axial line of the jet. The data are normalized to the average velocity on the axis of the jet U_m in the current section. The graph shows that the jet studied in this work has a much more extended laminar part than the works listed for comparison. This is indicated by a section from 0 to $\sim 20 x / d$ in the graph of Fig. 3 a, b, where the average velocity and intensity of pulsations practically do not change. At a distance of $x / d = 20$, a laminar-turbulent transition begins, the average velocity begins to decrease (Fig. 3a), pulsations then increase sharply (Fig. 3b). At $x / d = 25$, the pulsations have a maximum, after which the pulsation intensity decreases to values corresponding to the developed turbulent flow.

Comparing our experimental data with the data of S. J. Kwon et. al. [2] and other authors cited in his work, one can see that the behaviour of the pulsation intensity differs markedly from that obtained in our work. The growth of pulsations occurs at much shorter distances, and does not occur as intensively as in our case. This can be explained by the fact that in the experiments of S.J. Kwon et. al. [2], the nozzle was used and the initial velocity profile was top-hat. This also explains the longer laminar zone in our experiments (Figure 3 a), which exceeds the analogous jet parameter in the experiments of S.J. Kwon et. al. [2], even at the lowest Reynolds numbers ($Re = 177$).

Conclusion

A study was made of the air jet structure when it outflows from a cylindrical channel of great length at low Reynolds numbers. Distributions of axial mean velocities and pulsations along the jet length in a wide range of Reynolds numbers ($Re = 700-12000$) are obtained. Profiles of mean velocity, as well as profiles of longitudinal pulsations in the zone of laminar-turbulent transition in the jet, are obtained. Based on a comparison with the data of other authors, the effect of the initial conditions on the laminar-turbulent transition in a submerged jet is demonstrated.

The work was partially supported by the Russian Foundation for Basic Research (grant 17-08-00958).

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