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Mean Velocity Distributions under Flow in the Mainstream of a T Pipe Junction

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Experimental studies of mean velocity distributions under flow in the mainstream of a T pipe junction are conducted and the inlet flow keeps a good agreement with the previous research with the Reynolds number about 2.9×10^5 based on the hydraulic diameter and centerline velocity in the main duct inlet. A TSI Constant Temperature Anemometer hot wire system is used to acquire the velocity data in a low speed wind tunnel. The results show that from the suction position, the correlation coefficient and amplitude ratio decrease strongly and recover slowly as the distance far away from the suction. The influence of different inlet velocity in main duct and velocity ratio is analyzed. It could be expected that the correlation coefficient rises again to 1 again, that is to say, the velocity profile would be normal as a typical symmetry at location far enough. The results would be helpful for designing the ventilation and heat transfer equipment used in high speed train.

1. Introduction

High speed railway plays a vital role in economic development and social progress, especially in today's China (Sun et al., 2010). Aerodynamics problems accompanied by the speed-up of train system should be urgently resolved. Ventilation is very important in the train house and the power module. The air exchange can be described as a simplified weak suction (jet) model in a T pipe junction as the velocity of the air in the ventilating device is rather small than the high speed train. The flow characteristic of weak suction (jet) takes significant effects on the drag coefficient, heat transfer efficiency, flow resistance and so on (Raghunathan et al., 2002). For flow in T pipe junction, Liepsch et al. (1982) presented measurements and numerical calculations of laminar flow in a plane 90° bifurcation. The influence of Reynolds number and mass flow ratio on the velocity filed, streamlines, local shear stress and pressure drop were exhibited. Fu et al. (1992) reported a numerical study of the flows in an internal combustion engine inlet manifold. The three-dimensional turbulent flows through a single branched manifold were simulated using the κ-ε model of turbulence.The flow separation in the branch was analysed comprehensively. Neary and Sotiropoulos (1996) presented a numerical study on laminar flows through 90° diversions of rectangular cross-section for various Reynolds numbers, discharge ratios and aspect ratios. The flow topology patterns including zones of recirculation and streamwise vortices were exhibited. Sierra-Espinosa et al. (2000) performed an experimental study on a turbulent flow in 90° pipe junction. The decay of fluctuations upstream the flow bifurcation and separation region with recirculation within the branch were investigated quantitatively. Costa et al. (2006) reported the pressure drop for the flow of a Newtonian fluid in 90° tee junctions with sharp and round corners. It was found that rounding the corners reduced the energy losses by between 10 % and 20 %. Zhdanov et al. (2013) performed an experimental study on the influence of issued jet conditions on mixing of confined flows. The investigations reported that mixing of the developed turbulent jet with the co-flow can be significantly enhanced by rather small vortex generators (tabs). These studies mainly focus on the jet T-junction and the relative small Reynolds number because of the cost for LES with high Reynolds number is very expensive (Piomelli, 2008). Few researches have been devoted to the

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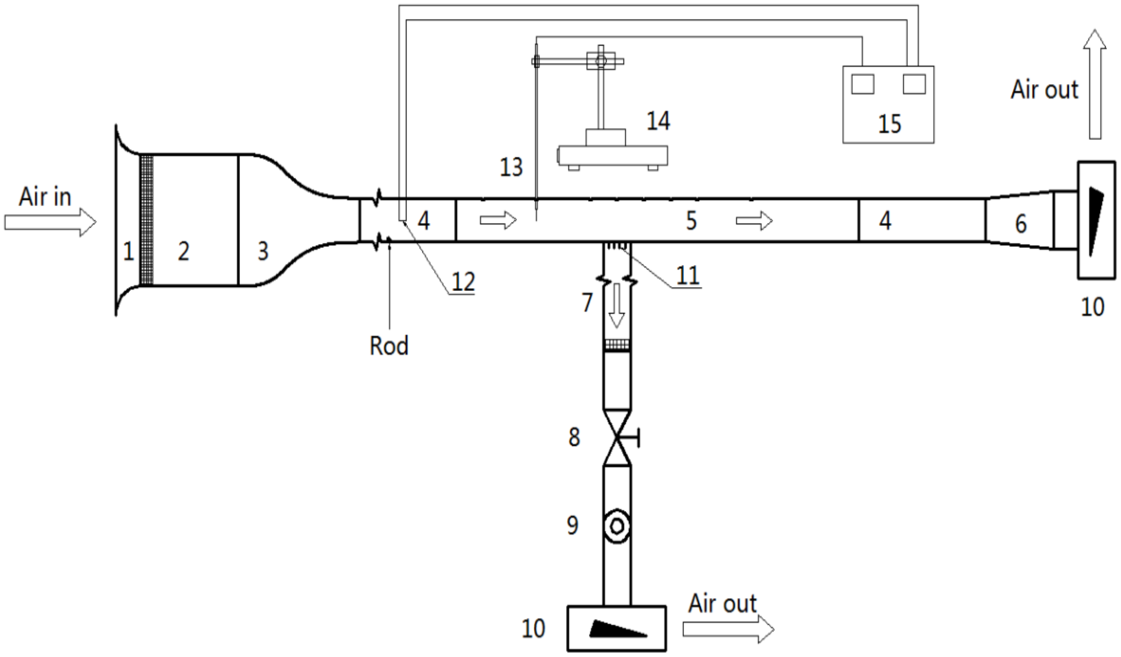
suction T-junction flow with high Reynolds number. The present paper reports on mean velocity distributions under flow in the mainstream of a T pipe junction with the Reynolds number about 2.9×10^5 based on the hydraulic diameter and centreline velocity in the main duct inlet. Two dimensionless parameters, correlation coefficient and amplitude ratio (*AR*), are selected to analyse the velocity characteristics in different position.

2. Experimental system and procedure

The experiments are conducted in an open T-shape wind tunnel with two blowers running at the same time. There are two ducts included in present system, the main duct and the branch. The shape of the cross-section of the main duct and the branch are square and rectangle. Figure 1 shows the schematic diagram of the experiment apparatus, and the three-dimensional geometric model including the details of the vanes, the position and the coordinate of the velocity measurement, are shown in Figure 2, with the origin located in the projection of the branch duct centre on the back side of the main duct. In order to get the velocity distribution along the main duct in different position, eight velocity holes with diameter d_h = 5 mm are arranged on the back surface of the main duct with the name and x-coordinate of p1, p2, p3, p4, p5, p6, p7, p8 and -5d, -3d, -d, 0, d, 2d, 3d, 5d. Here the purpose that we choose d which means the hydraulic diameter of the branch duct with a dimension of 110 mm as the unit of measurement distance is for future research. Another distance parameter l means the width of the main duct, as seen in Figure 2.



1-Entrance; 2-Transition section; 3-Contraction section; 4-Straightening section; 5-Test section of main duct; 6-Expansion section; 7-Branch duct; 8-Valve; 9-Rotor flowmeter; 10-Blower; 11-Vanes; 12-Pitot tube; 13-Hot wire probe; 14-Three-dimensional coordinate frame; 15-Data acquisition system

Figure 1: Schematic diagram of experiment system

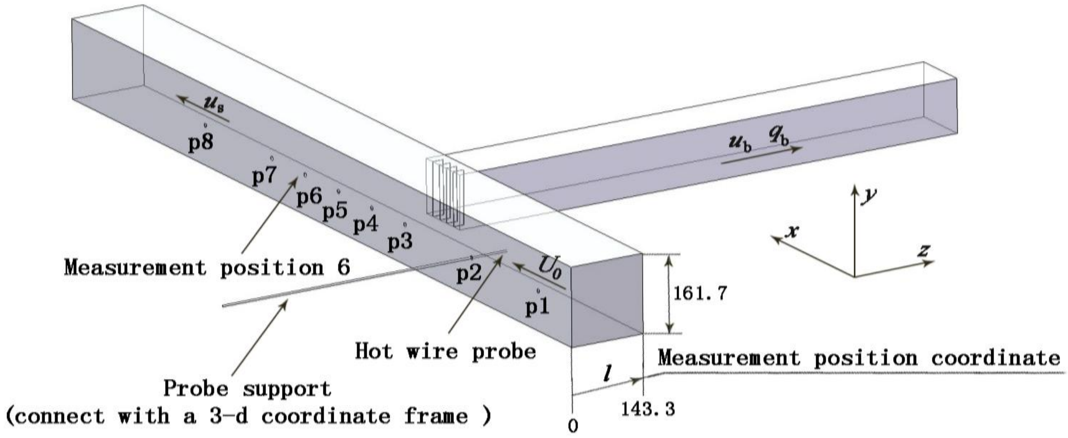


Figure 2: Three-dimensional geometric model

In the experiment process, the air flow from the laboratory room is induced to the main duct and the branch by two frequency modulation blowers running at the same time. The velocity distribution changes with the mean velocity in main duct and the branch. Here, velocity ratio, R, is given as:

$$R = \frac{u_b}{U_0} \tag{1}$$

In Eq(1), u_b and U_0 refer to the bulk mean velocity in the branch duct and the centreline velocity in the main duct inlet, obtained by a rotor flowmeter (80 - 400 m^3/h) with precision of 1.5 % and a Pitot tube mounted near the test section inlet, as shown in Figure 2 and Figure 1. By modulating frequency of the two blowers, eight experiment tests are shown in Table 1. In a single experiment test, mean velocity in eight positions p1-p8, as mentioned before in Figure 4, from 0 to 143.3 mm in a z-direction line controlled by a 3-d coordinate frame with the precision of 1μm are acquired by a hot wire anemometry technique. Unfortunately we have 8 positions only in the first three test cases and the others have 6 because of some bad effects in the 3-d coordinate frame. The hot wire system used in this experiment is a TSI IFA 300 CTA unit with precision of 3 %. An X-probe hot film anemometer is used to measure the two velocity components, x-direction and y-direction. Velocity data is taken at a frequency of 10 kHz for a period of 13.107s.

Table 1: R Values and Related u_b, U_0

U_o (m/s)	30	30	30	40	40	40	50	50
u_b (m/s)	2.4	3.9	5.4	3.2	5.2	7.2	4	6.5
R	0.08	0.13	0.18	0.08	0.13	0.18	0.08	0.13

3. Data reduction

In order to compare the velocity profiles in different positions, correlation analysis is carried out to make a qualitative comparison. The correlation $\rho(X, Y)$ coefficient is defined to scale the similar level of two distributions, X and Y. The formula is shown in the following equation:

$$\rho(X,Y) = \frac{Cov(X,Y)}{\sqrt{D(X)}\sqrt{D(Y)}} \tag{2}$$

Another parameter, amplitude ratio, AR, is calculated between each velocity profile and the standard distribution to describe the change level of amplitude. The amplitude ratio (*AR*) is defined as:

$$AR(X,Y) = \frac{max(Y)}{max(X)} \tag{3}$$

4. Results and discussion

All the measurement instruments had been adjusted to verify the test results and methods before the experiment started to run. Turbulent flow in a square duct experimental study tested by Gessner et al. (1977) is given as a reference for the validation of the present one experiment test in p1 with the approximate Reynolds number in Figure 3. It can be seen that these two results are in good agreement in terms of changing trend and the present experimental study is reliable.

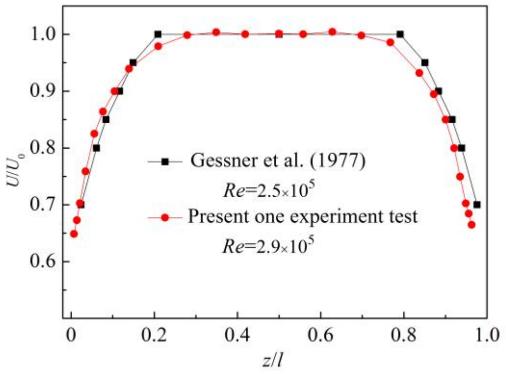


Figure 3: Comparisons between present experimental results and experimental results tested by Gessner et al. (1977)

Figure 4 shows the comparison of the velocity profiles and correlation coefficient in p1 and p2 at $U_0 = 30$ m/s. It can be seen that the two positions have the high similarity and the correlation coefficient approach to 1. So p2 is selected as the standard position uninfluenced by the suction for the analysis of the correlation coefficient and amplitude ratio. Figure 5 depicts that the streamwise velocity profiles, $\rho(n,2)$ and AR at $U_0 = 30$ m/s. It is observed that:

With different R,

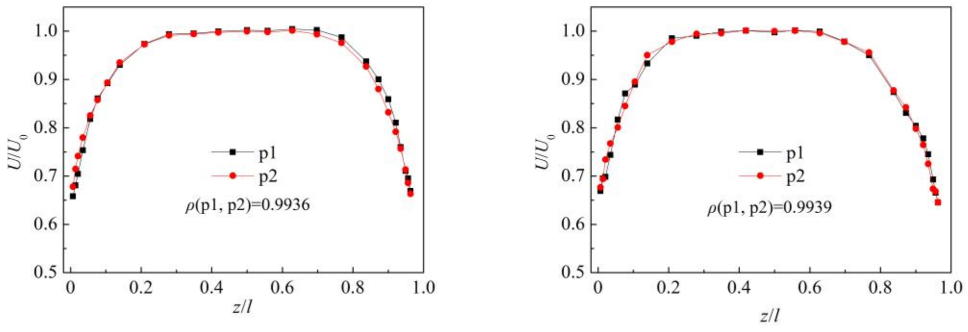
(1) P3 is influenced little and $\rho(3,2)$ remains approximate to 1 except decreases slightly at $R = 0.18$.

(2) P4 which locates at the suction centre have the $\rho(4,2)$ and $AR(4,2)$ decreased strongly with the increase of R. It is obviously that near the 0 mm wall, the velocity increase for the sake of the suction effect.

(3) P5 has lower $AR(5,2)$ than p4 because of the split-flow after the suction area and but higher $\rho(5,2)$. It indicates that the influence of the suction begins to weaken.

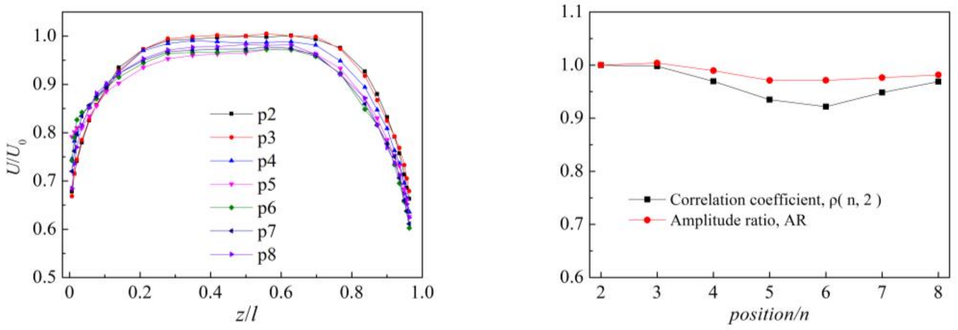
(4) P6 is similar with p5 both $\rho(6,2)$ and AR. But p7 and p8 have the higher correlation coefficient than $\rho(6,2)$. It can be explained that the influence of the suction decreases gradually and the flow begin to recover. It could be expected that the $\rho(n,2)$ rises again to 1 again, that is to say, the velocity profile would be normal as a typical symmetry at location far enough.

With the increase of U_0, the rules keep the same but the suction effects become more seriously and the “recover” turns slow, as seen in Figure 6.

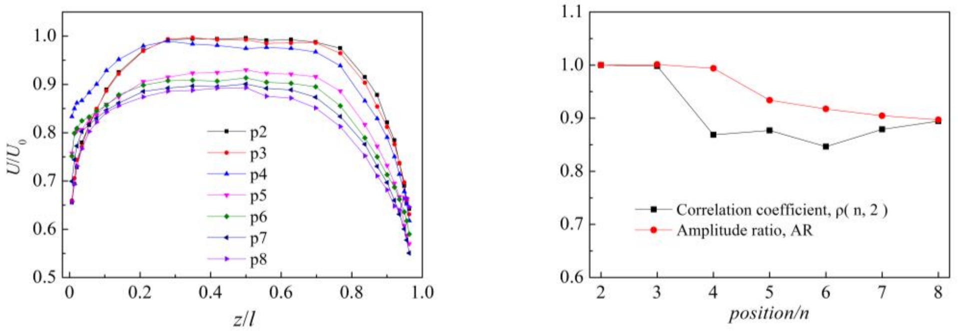


(a) R = 0.08 *(b) R = 0.18*

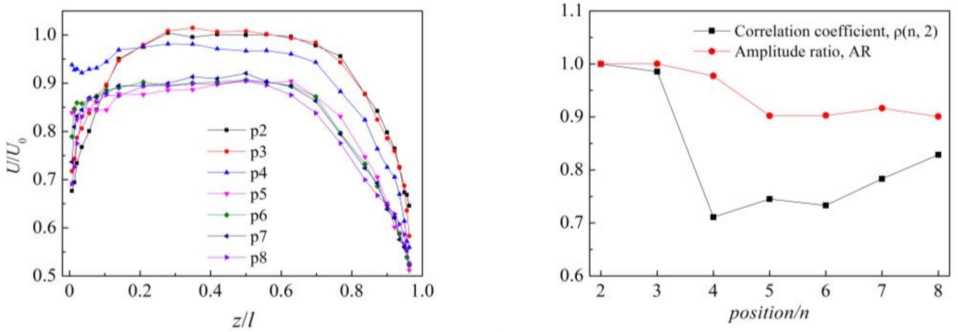
Figure 4: Velocity profiles in p1 and p2 at $U_0 = 30$ m/s



(a) R=0.08



(b) R=0.13



(c) R=0.18

Figure 5: Streamwise velocity profiles, ρ(n,2) and AR at $U_0 = 30$ m/s

5. Conclusions

Experimental studies of mean velocity distributions under flow in the mainstream of a T pipe junction are conducted and the inlet flow keeps a good agreement with the previous research. The velocity profiles in p1 and p2 keep the same unaffected distribution. The suction influence starts at p4 and the correlation coefficient and amplitude ratio decrease strongly but recover slowly as the distance far away from the suction. With the increase of U_0, the rules keep the same but the suction effects become more seriously and the “recover” turns slow It could be expected that the correlation coefficient rises again to 1 again, that is to say, the velocity profile would be normal as a typical symmetry at location far enough.

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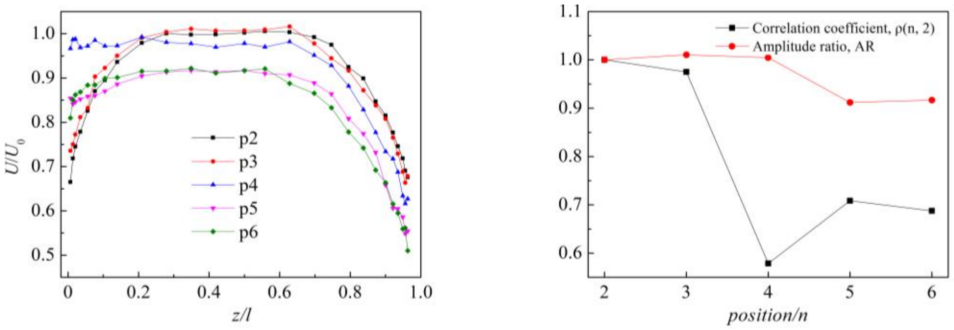
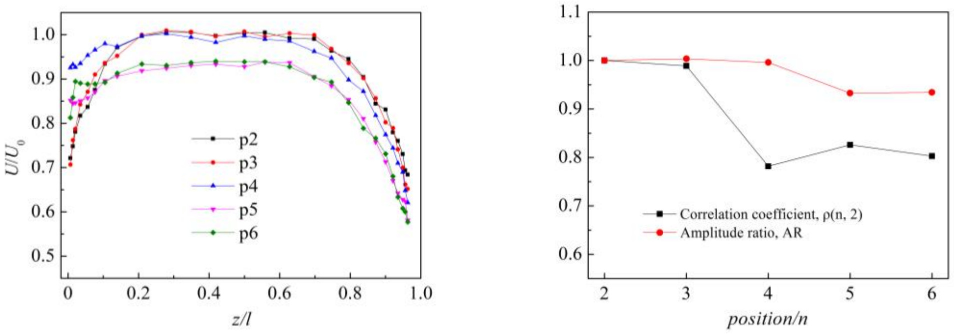


(a)U_0 = 40 m/s, R = 0.18



(b)U_0 = 50 m/s, R = 0.13

Figure 6: Streamwise velocity profiles, ρ(n,2) and AR

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