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A Comparative Study of Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) for Airflow Measurement

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Abstract**—**Among modern airflow measurement methods, Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV), as visualized and non-instructive measurement techniques, are playing more important role. This paper conducts a comparative experimental study for airflow measurement employing both techniques with the same condition. Velocity vector fields, velocity contour fields, voticity profiles and turbulence profiles are selected as the comparison indexes. The results show that the performance of both PIV and PTV techniques for airflow measurement is satisfied, but some differences between the both techniques are existed, it suggests that selecting the measurement technique should be based on a comprehensive consideration.

Keywords**—**PIV, PTV, airflow measurement.

I. Introduction

EXPERIMENTAL measurement plays an important role for a high-quality airflow study, and also it is dispensable to develop and validate amounts of numerical models with accurate experimental data. However, it is not easy to conduct accurate measurements where the airflow along with high turbulence and unsteady. Sun and Zhang [1] summarized main modern measurement methods for airflow, generally these methods are divided into point-wise technique, such as Hotwire Anemometry (HA), Ultrasonic Anemometry (UA), and global-wise technique, including PIV and PTV. Compared to global-wise technique, the measurements fields employing point-wise technique are small relatively, and their measurement tools may perturb the local airflow, thus point-wise technique is not a smart technique for airflow measurement, especially for large-scale airflow. As global-technique, PIV and PTV techniques have been applied more and more recent years. Sandberg [2] reviewed the applications of PIV and PSV (regarded as the simplest PTV) techniques in ventilated rooms detailed, Cao et al. [3] excellently summarized the typical PIV technology and main applications for indoor airflow study, meanwhile PTV technique has been used as measurement methods in the study on the cabin environment [4], [5] and natural convection [6], [7], all suggest that global-wise technique is becoming a powerful measurement tool for airflow study.

The measurement principles of PIV and PTV have been reviewed in previous excellent scientific literatures [3], [8], [9], thus there is no detailed introduction on this issue. Although PIV and PTV both belongs to global-wise technique, PIV is based on Eulerian measurement principle, which the velocity v is a function of position x and time t, as refers to (1); PTV depends on Lagrangian measurement principle, which each seeded particle could be followed through the time, the velocity is a result of (2).

$$\vec{v} = \frac{d\vec{x}}{dt} \tag{1}$$

$$\vec{v}\left(x(t),t\right) = \frac{d\vec{x}}{dt} \tag{2}$$

This paper presents a comparative study employing both PIV and PTV techniques for airflow measurement under the same experimental conditions, in order to evaluate the advantages and disadvantages of these two measurement methods. For simplicity, the experiment was conducted in isothermal condition, and the only variable is the air inlet velocity. First, the experimental set-up and methodology is described in Section II. In Section III, the measurement results are shown and analyzed. A discussion and conclusions are given in Sections IV and V separately.

II. Experimental Setup and Methodology

A three-dimensional model with 0.4 m x 0.4 m x 0.01m (L x H x D) has been built to perform the measurement experiments employing PIV and PTV technique, the schematic of test section and PIV-PTV measurement system is shown in Fig. 1. Because L and H >> D, thus the model could be regarded as nearly two-dimensional. The airflow inlet and outlet both with the diameter of 10mm are set in the same side of the model, and the centers of the inlet and the outlet are located in the positions of y/L=0.725 and y/L=0.225 separately. In the experiments, the airflow injecting the particle tracers into the test cubic is regarded as the measured airflow; the velocity can be adjusted through the valve on the bubble generator equipment. In order to eliminate the airflow difference during the measurements as soon as possible, PIV measurements and PTV measurements are conducted at the same time. The slot Reynolds number is defined based on the airflow inlet height as Re_{slot}=U0h/υ, with U0 the airflow inlet velocity and υ the kinematic viscosity at room temperature (≈20°C). The z-component of the vorticity is defined as ωz = (∂v/∂x) - (∂u/∂y). Three different inlet velocities

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of the airflow are set; representing the inlet airflow is under the transitional and turbulent conditions separately.

A 2D PIV system produced by LaVision consisting of a Nd:Yag (532mm,100mJ) double laser as the illumination system and a CCD (Charge Couple Device) camera (1024 x 1024 pixel resolution, min. 50 frames/s) for image acquisition is used to conduct the PIV measurements. In this experiment, instead of the laser, conventional light source (halogen lamps) is employed as the illumination system. Because the deep of test cubic is very limited, thus the laser will have strong influence on the flow visualization. Also the PIV camera resolution is relative low, thus Helium-soap bubbles are selected as the tracers based on their appropriate tracking behavior and scatter efficiency.

The PTV measurements are conducted employing a 3D PTV system developed by Pascal et al. [10], Different from the 2D PIV system, three CCD cameras (2048 x 2048 pixel resolution, 100 frames/s) as the image recording device in this system to obtain three-dimensional information. Special algorithms are developed and applied for the particle center detection, temporal tracking and 3D reconstruction among PTV measurements.

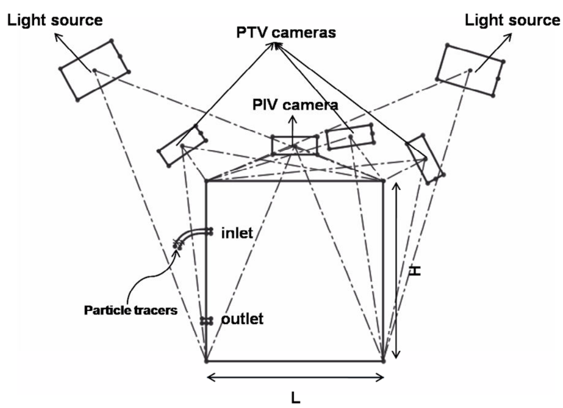

Fig. 1 The schematic of test section and PIV-PTV measurement system

III. Measurement Results

A. Velocity Vector Fields

The measurements are conducted when the airflow is stable, the measured time is 1s. Due to the limitations of processing time of PTV algorithms, the data measured during 0.1s is used to analyze the comparison results. In order to compare with PIV measurement which conducted in Eularian reference frame, the inverse-distance interpolation is applied in PTV measurement to transfer the results in the same Eularian reference frame.

Fig. 2 shows velocity vector fields of PIV and PTV measurements for Re-values of 2700, 4200 and 5500. The large recirculation cell in the test tube, which is driven by the jet, is measured clearly using both techniques. In addition, the smaller recirculation cell in the upper left corner is also detected by two techniques. The flow pattern for these three Re-values measured by PIV and PTV techniques appears to be almost identical. However, Fig. 2 (f) shows a small disordered flow structure in the upper right corner for Re-value of 5500 detected by PTV technique. It shows that when Re-value is high, some distinguished differences between both techniques may occur.

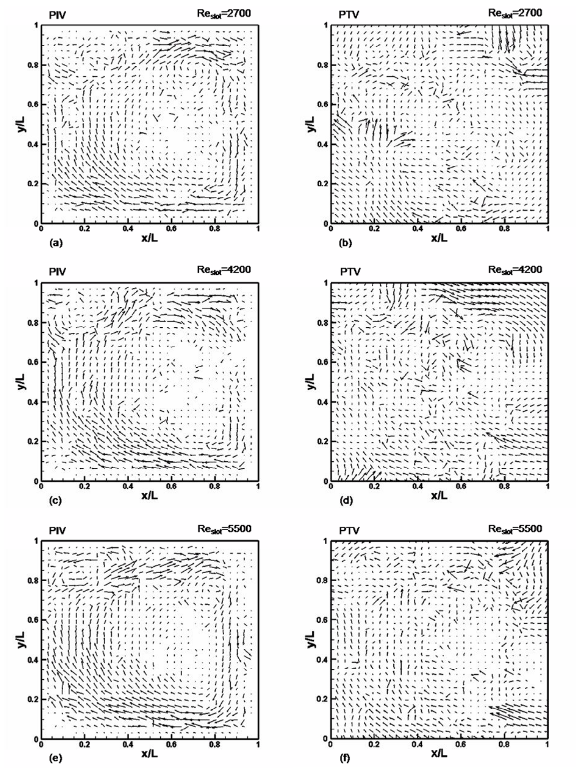

Fig. 2 The velocity vector fields measured with PIV and PTV techniques

B. Velocity Contour Fields

Figs. 3 and 4 separately show x-velocity and y-velocity contour fields for Re-values of 2700, 4200 and 5500. Because the airflow pattern measured by PIV and PTV techniques seems to be same, thus the airflow velocity contour fields also shows the same distributions generally. Fig. 3 shows that the x-velocity with relative large value exists in the upper and lower part of the test cubic for three different Re-values. Fig. 4 shows that the y-velocity with relative large value exists in the left and right part of the test cubic for three different Re-values. Due to the effect of the interpolation, there are more small vortex in the results of PTV measurement.

C. Velocity Profiles at Three Locations

Figs. 5-7 show vertical profiles of x-velocity obtained from the measurements using PIV and PTV techniques for three different Re-values at the location of x/L=0.226,x/L=0.516 as well as x/L=0.806 separately. The measured velocities using both techniques show the same varying trends at every Re-value and location.

All figures indicate that there are large differences of the measured value by both techniques in the part of between y/L=0.7 and y/L=1. This phenomenon may result from the fact that the particle tracers attach to the glass of the cube, thus the

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number and lifetime of tracers is limited. Fig. 6 shows that when x/L=0.516, which is the near middle of L, a relative large difference of the measured value occurs. The reason is that the number of particle tracers traced is very limited in this part, which can be certificated in Fig. 2. Another large difference of measured value exists when Re-value is 5500, which are shown in Figs. 6 (c) and 7 (c), it suggests that when conducting the airflow measurement with high Re-values, PTV technique and PIV technique may have different behaviors.

D. Vorticity Profiles at Three Locations

Figs. 7-9 show vertical profiles of z-vorticity obtained from the measurements using PIV and PTV techniques for three different Re-values at the location of x/L=0.226,x/L=0.516 as well as x/L=0.806 separately. For PTV measurements, the value of ω_z is more disordered, which results from the small vortexes created by inverse-distance interpolation.

E. Turbulence Profiles at Three Locations

Vertical distributions of the longitudinal turbulence intensities u_{rms}/u_{in} and vertical turbulence intensities v_{rms}/u_{in} obtained from PIV measurements at x/L=0.226, x/L=0.516 and x/L=0.806 for three Re-values of 2700, 4200 and 5500 are shown in Figs. 10-12. The vertical distributions of turbulence intensities of PTV measurements doesn't be provided, because their final results derive from all particle trajectories tracked during the measured time based on inverse-distance interpolation method.

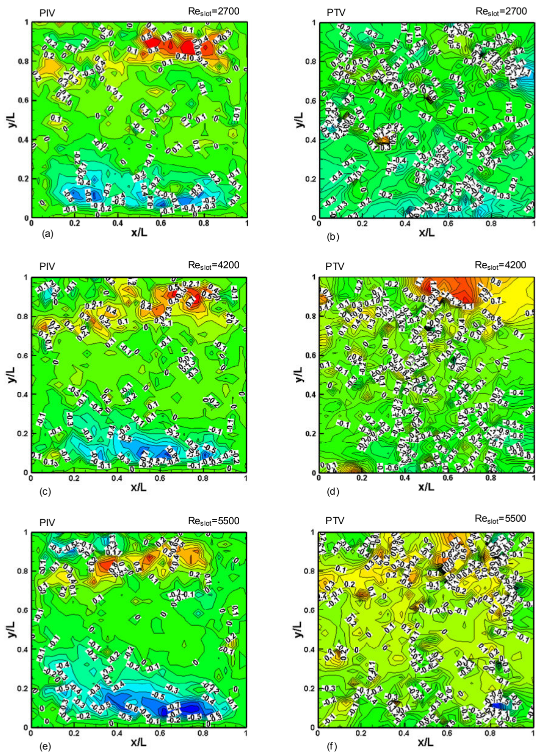

Fig. 3 The x-velocity contour fields measured with PIV and PTV techniques

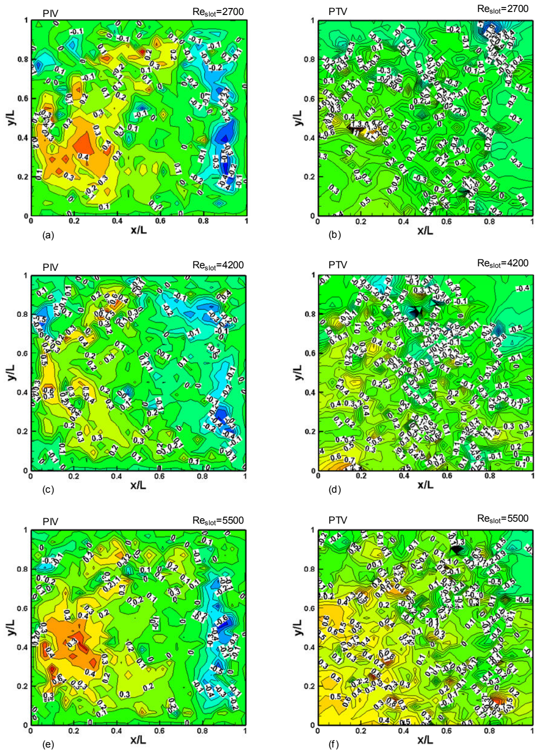

Fig. 4 The y-velocity contour fields measured with PIV and PTV techniques

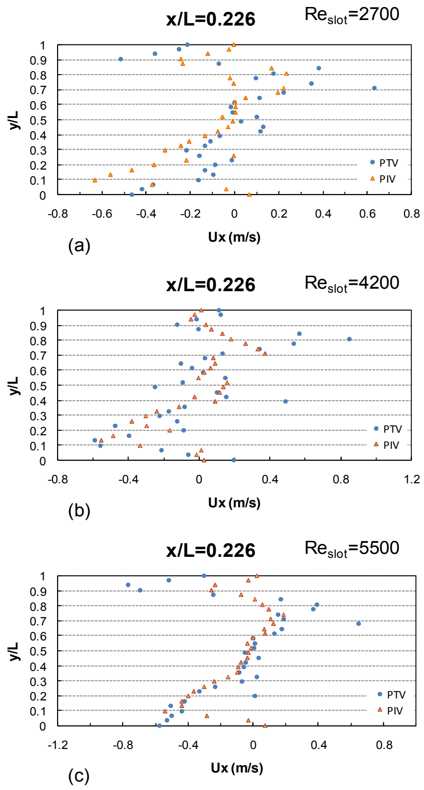

Fig. 5 Vertical profiles of x-velocity at X/L=0.226

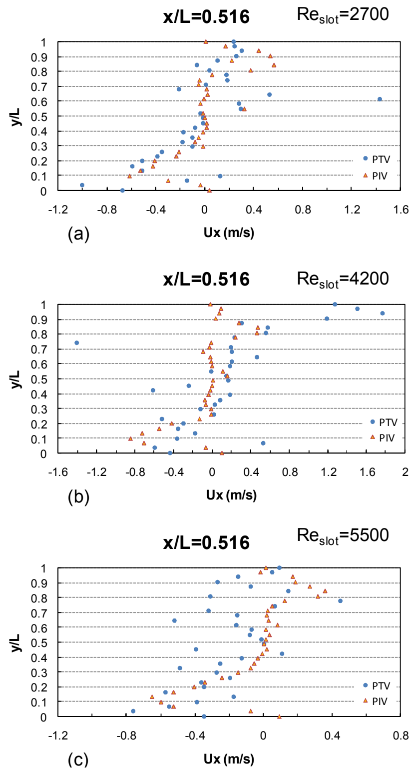

Fig. 6 Vertical profiles of x-velocity at X/L=0.516

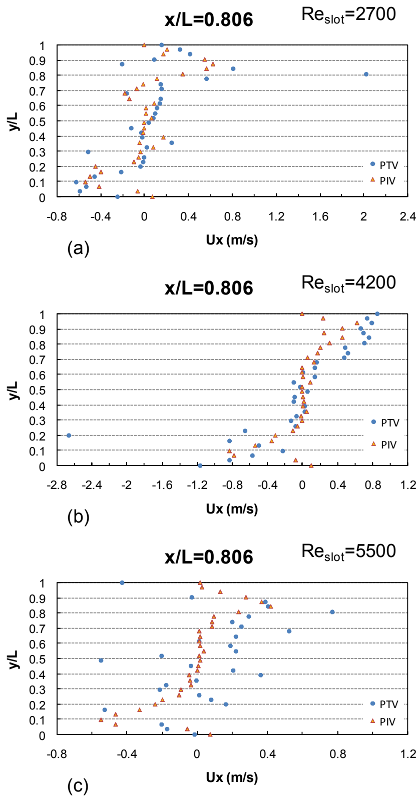

Fig. 7 Vertical profiles of x-velocity at X/L=0.806

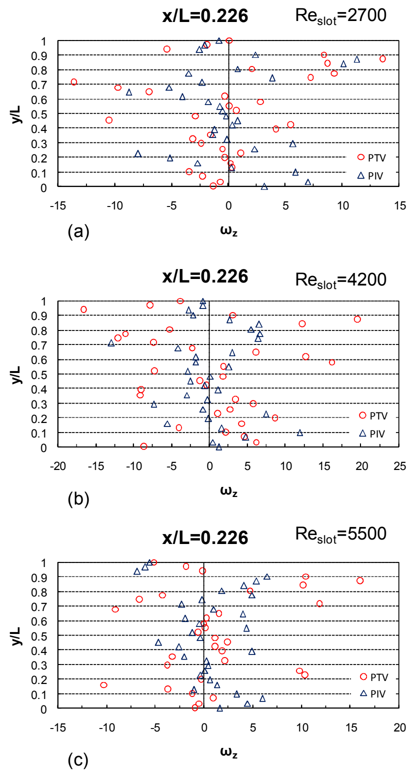

Fig. 8 Z-vorticity profiles at X/L=0.226

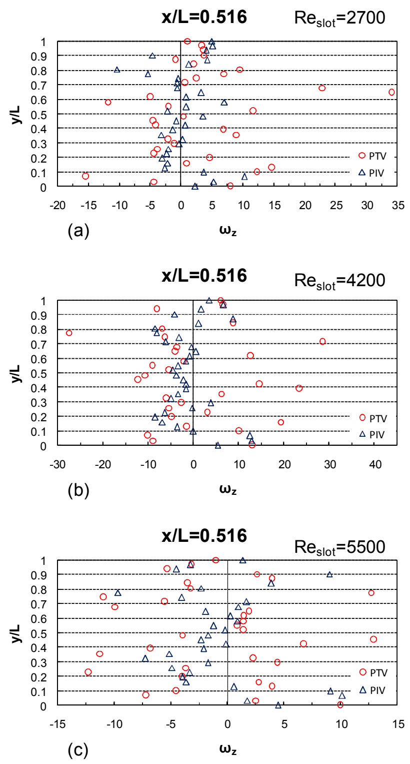

Fig. 9 Z-vorticity profiles at X/L=0.516

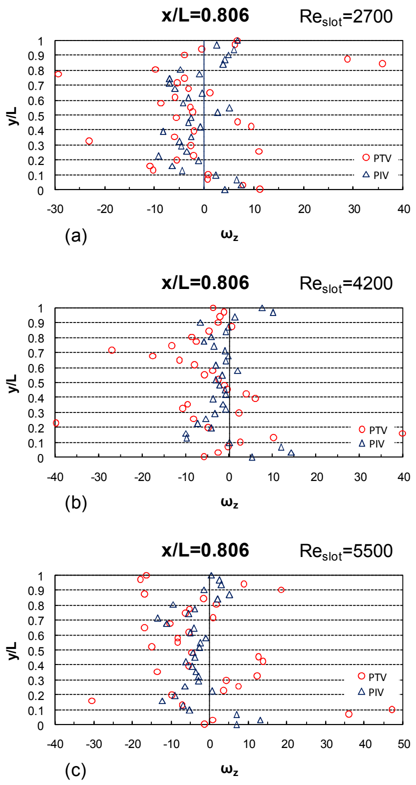

Fig. 10 Z-vorticity profiles at X/L=0.806

IV. Discussion

A comparative experimental results regarding with PIV and PTV technique for airflow measurement have been presented in this paper. A nearly two-dimensional cubic was used to perform flow visualizations and measurements.

To the knowledge of the authors, experimental work as presented in this paper is quite limited. Although previous research indicated the importance and difficulties in modeling turbulent flow very well, the vast majority of experiments on room airflow were conducted employing the PIV technique, usually obtaining two-dimensional information well. Consequently, there is a lack of three-dimensional experimental data on room airflow to validate numerical models. PTV technique is the technique which provides the three-dimensional and two-dimensional information, and thus it should be adopted as the measurement method more in the future. However, there are some limitations concerning the experimental work described in this paper.

For PIV technique, the number of particle tracers which satisfy the tracking behavior and scattering efficiency is a key factor to obtain a better measurement result. In the experiments this paper presented, HFSBs are used as the tracers combined with the needs of PTV measurement and the resolution of PIV camera. Thus there are not sufficient particle tracers in some regions when conducting PIV measurement, so that the velocity vector fields in these regions are rare, such as the part of between y/L=0.2 and y/L=0.6. In addition, the reflections of the light on the glass of the test section make it difficult to obtain better results in this area of the cube. The lifetime of particle tracers is also a significant factor that affecting the measurement result, long lifetime means that the long trajectories could be tracked; it is helpful to analyze the airflow characteristics.

This study is a first step in a more extensive research on the comparison of two techniques. In the future work, the test cube with a non-reflective paint will be used in order to obtain the measurement results near the glass of the cube. A new particle tracer's generator with the ability of generating more particles with longer lifetime will be built. In addition, simulated particles, Hot-Wire Anemometry and CFD simulations will be conducted as complementary information in order to define the advantages and disadvantages of PIV and PTV techniques more precisely.

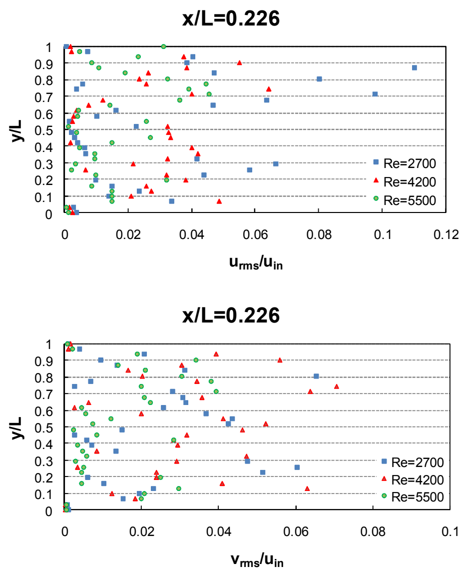

Fig. 11 Turbulence profiles at x/L=0.226

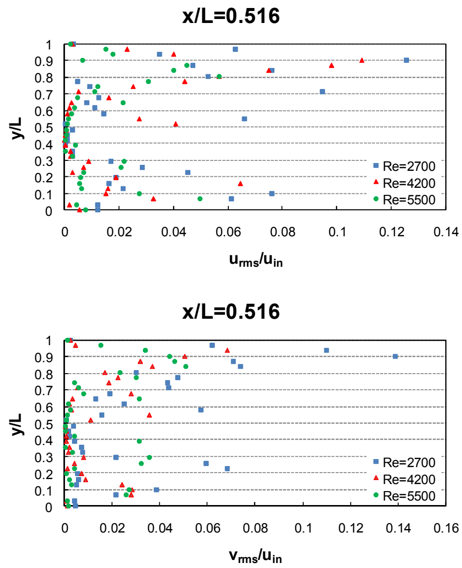

Fig. 12 Turbulence profiles at x/L=0.516

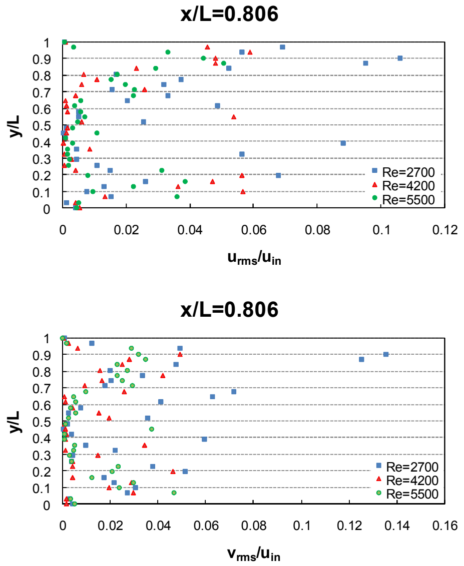

Fig. 13 Turbulence profiles at x/L=0.806

V. Conclusion

This paper presents a comparative experimental measurement for airflow using PIV and PTV techniques. An experimental set-up has been designed to conduct this research regarding with measurement methods. The measurements are conducted when the inlet airflow with Re-values of 2700, 4200 and 5500. The velocities, vorticity and the turbulence intensities are presented in this paper and used to compare both techniques.

The following conclusions can be made: (1) Both PIV and PTV techniques can detect the velocity vector fields well; (2) In the upper part of the cube (between y/L=0.7 and y/L=1), the difference of the measured values by both techniques is relative larger; (3) As the Re-value increases, a distinguished difference of the measured values exists by both techniques.

Because the inverse-distance interpolation is applied in PTV measurement, it seems that PIV technique provides better information. However, it doesn't suggest that PIV technique is better than PTV technique. It is noticed that the limitations mentioned in the previous section have influences on the final measurement results, when these limitations are overcome, more details will be shown to decide the advantages and disadvantages of PIV and PTV technique. Researchers should select appropriate measurement methods based on the needs. If the measured view is small and focuses on a plane, PIV technique can be employed. When the measurement occurs in a big whole domain, it is better to choose PTV technique as the measurement tool. In addition, when conducting the measurement for the area near the airflow inlet, point-wise techniques such as HA may be adopted to get right results.

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