Vortex flows from centrifugal fan

by

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ABSTRACT

A comprehensive work has been accomplished for the observation of flow details from a centrifugal fan inside an indoor unit of air conditioners. The present study is finding optimum flow paths in the system that supplies temperature-controlled air into the space human being. Fig. 1 shows the outlet grill of the system (left) and the flow details by PIV system (right) over the grill are objectives of this study. Experiments using PIV system are adopted for velocity measurements. Parallel works with velocity measurements for visualization of out flows illustrates the velocity vectors are good in accuracy. The present experimental rig is PIV system with a high-resolution digital camera. The distribution and patterns of the discharging velocities from the air-conditioner are very useful for design and improvements of the duct in the present unit. Vortex flows of the outlet flows appear in the velocity field of previous system. However, with the improvements referred with the velocity profiles, the efficiency of the system of the modified model increases by about 25%.

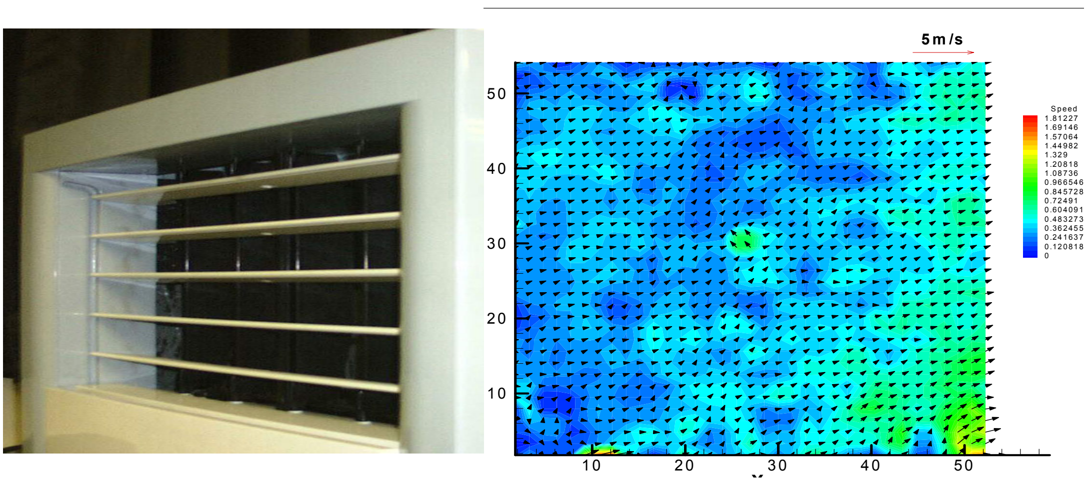

Fig. 1 Photo to show present system (left one) and resultant vectors of out flows

1. INTRODUCTION

The performance of air conditioner means capacity of cooling, efficiency, and noise level. Cooling capacity is basic requirement for that kind of the system and dependent of temperature of air and its flow volume. Flow rate should cover the volume of an interior space for air conditioning. Specially, silent operation of air conditioner is most important issue for decision of products choice. Comprehensive efforts to increase performance of air conditioner are continued to satisfy the demand from customer side (Brownell and Flack, 1984 and Kind, 1997). In addition, separate investigations on each type of fans that are main source of noise of the system, respectively are presented in recent literatures (Kim, 1999 and Myers et al., 1997). However, estimation of performance on whole system involving blower and heat exchanger assembled in a cabinet is not completely reported yet (Matsuki et al., 1988). In this work, evaluation of system performance is presented by using a particle image velocimetry, a wind tunnel, calorimetric chamber and hot-wire anemometer. Main interest lines on measurements and improvements of flows at inlet to a blower and outlet grill of the system. In detail, there are improvements on flow path using velocity vectors obtained by experiments. The adopted method to gauge the velocity is using light scattering particles illuminated by dual pulse laser and the data are validated by parallel measurements of hot wire anemometer. Efficiency on energy is excluded in this work.

Air conditioning system is composed of a heat exchanger and air-handling unit for delivery of temperature-controlled air. Generally, the blower after or ahead of a heat exchanger takes a type of centrifugal fan and its scroll casing. The flows from the blower are discharged through the outlet with guide vanes shown in Fig. 2. The flow has experienced curved flow paths and unequal flow rate at the double inlets of a blower, because control of air-temperature is accomplished by withdrawing heat of inflows. The heat exchange process is attained by direct contact between air and the heat exchanger. Figure 2 shows components in the system and flow path that is complex and anfractuous. The position of the blower is near the wall of the unit and the spatial distance between inlets and the wall is not equal in the two sides (back and front side). Therefore, inflow rate at the two suction regions is different and outflow is pulsating. Most disadvantage condition for the non-uniformity of the inlet flows to the blower is on the unbalance of flow rate of a double suction impellor facing an inclined single heat exchanger of two raw pipeline as shown in Fig. 2. It is obtained that the flow rate of the system is 25CMM (m^3/min.) and noise level of the system is of 62dB(A). Preliminary experiments display the pulsating behaviors of out let flows due to the unequal inflow rate. Furthermore, deviation of magnitude of the outward velocity is noticeable and even there is reverse flow in part. The flow rates should be maintained at lower noise level and the pulsating components of the outlet flows should be removed. The unwanted trend is more pronounced as the unit takes compact design. Information of outlet flows over the outlet grill of an indoor unit of an air-conditioner is very important touchstone of the performance of the system. The aim of this investigation is that operation of the system should be in low noise level and out flows should be spatially uniform. Series of plots of velocity vectors is shown and treatments according to the flow field are made. Consequently, flow path is modified and inlet flow rate is balanced for the double suction rotor by analyzing the information of velocity fields. Sound noise level and uniformity of out flows without change of flow rate confirm the effects of the present improvements. The performance of noise level is reduced by 25% at same flow rate as previous system and pulsating motion of out flows is removed by adjustment of flow path between wall of the cabinet and the blower.

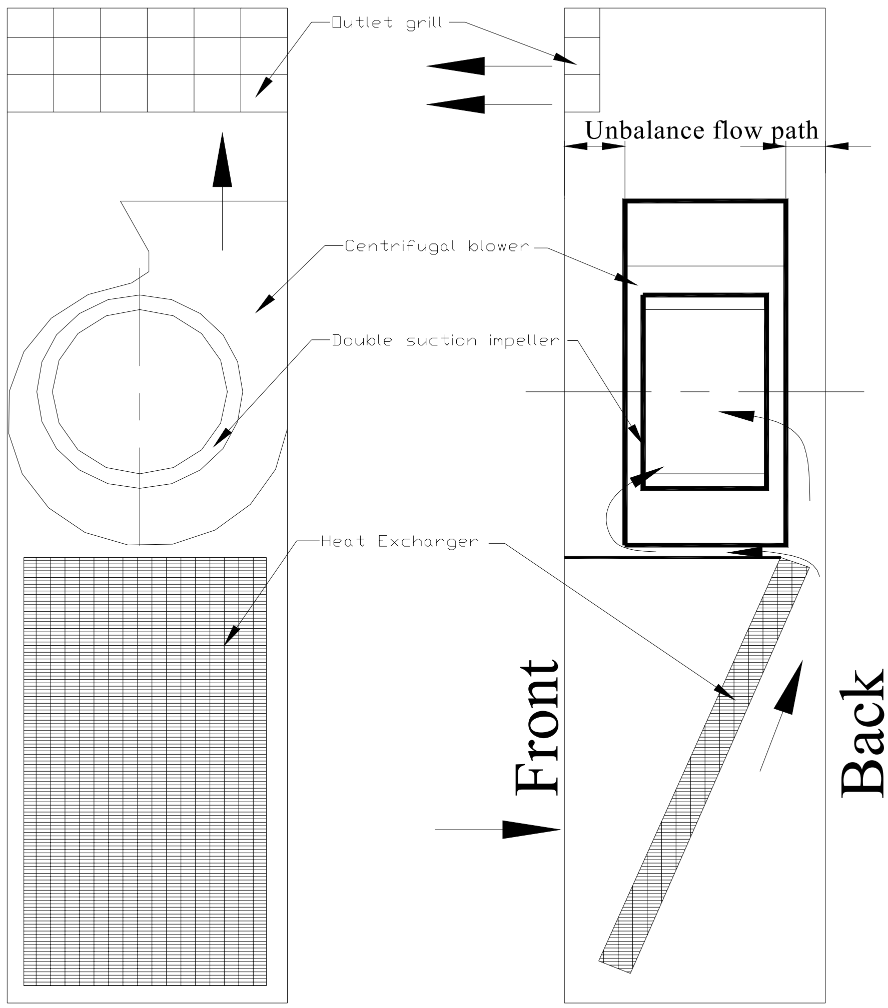

Fig. 2 Flow path around heat exchanger by suction of centrifugal blower

2. EXPERIMENTAL METHOD and PROCEDURE

Purpose of this experimental approach is finding velocity field at outlet of the system and estimating flow rate and noise level of the unit, in order to improve the performance of a present unit. Particle image velocimetry (PIV) measures velocities at outlet and near the blower. Parallel measurements for velocity field with PIV is using hot-wire anemometer for validation of PIV data. In addition to the detail measurements, overall performance of the indoor unit is evaluated, such as flow rate according to static pressure of the flows with a wind tunnel and noise level at different operating conditions in anechoic chamber. The separate rigs for the synthesis investigation are explained below.

2.1 Velocity measurements

Flow details inside a unit are very necessary data for increasing the efficiency of the fan system and reduction of fan noise from turbulent flows (Adrian, 1991). Experimental tool for velocity measurements are various ways involving laser Doppler Velocimetry used in popular, nowadays. In this work, particle image velocimetry is adopted for obtaining instantaneous flow field near the interesting region. The light source is Nd-Yag laser of 50mJ in power and 15Hz in minimum exposure frequency. Light scattering particles are liquid drops of oil provided from a six-jets atomizer that controls the size of the liquid-drops. The particles flow neutrally. The size of the drop is approximately 0.5μm ~ 2.0μm and the particles are found almost 30,000 in an image frame. Figure 3 displays typical primary image of light-scattering drops neutrally following fluid flows.

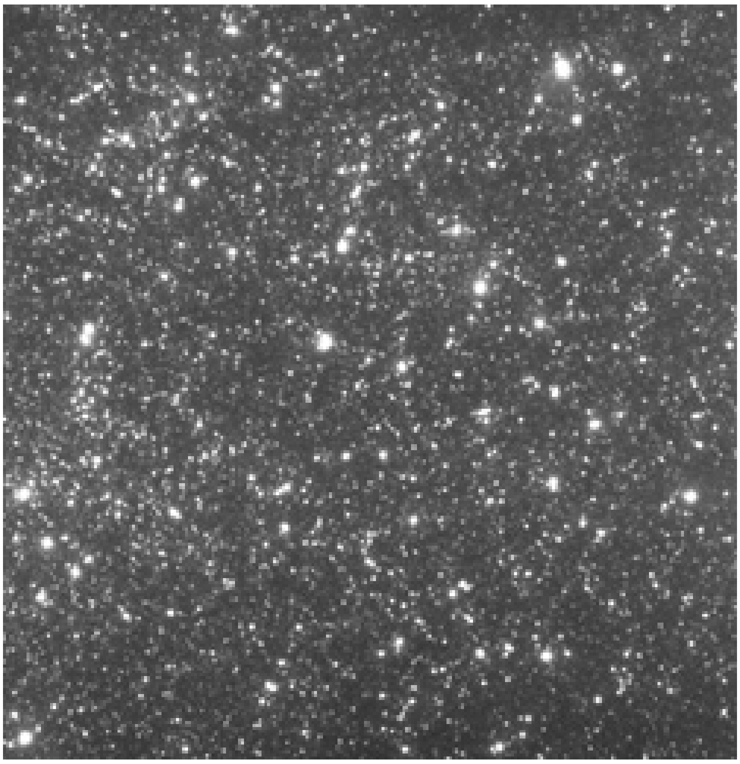

Fig. 3 Typical image to show light scattering particles

The accessory of a blower and other structures inside the case are made of transparent materials for image capturing. The light sheet stands a digital camera in perpendicular direction. Digital closed circuit camera captures crude image in resolution of 1killo byte by 1killo byte in two-dimensional plane. A programmable controller synchronizes the instant of camera exposure and laser lighting. A main computer automatically controls all the process of image acquirement including tracking and identification of particles in a series of images. Time duration between two sequence images is 25 μs and laser light opens for 10ns at each exposure. One image frame has two sequence pictures for this double exposure system with time interval of 129μs. Physical dimension on an image comes from direct measurement of known length in a frame. In this work, precision ruler is imposed on an image for identification of real distance between pixels.

Velocity measurements with images have a precedent condition of particle-identification on an image frame. There are many algorithms for the procedure. Among them, effective methods against memory saving of a processing computer are applied for this experiments (Adrian, 1991). The algorithm for instantaneous velocity is based on FFT and the other for velocity gradient for some special ranges uses concepts released by Hart (1998). These two algorithms show successive results in published articles (Hart, 1998 and Adrian, 1999).

Velocity vectors obtained by PIV is validated parallel experiments using hot-wire anemometer of IFA 300, Tsi. The comparison between the two results is made at the center position of the outlet grill of the unit. Two different measurements illustrate in Fig. 4. Measurements for the comparison are kept at a prefixed location during 20 second at every two-second. The validation procedure depicts the difference of two data is within 1.7% range. Velocities by PIV is little lower than the data by hot-wire anemometer, because the light scattering particles are affected with controlled temperature from air conditioner, object of this research. Transient difference between the two data is caused by the pulsating flows mentioned above. However, the measurements of the present PIV are approved within proper error bound.

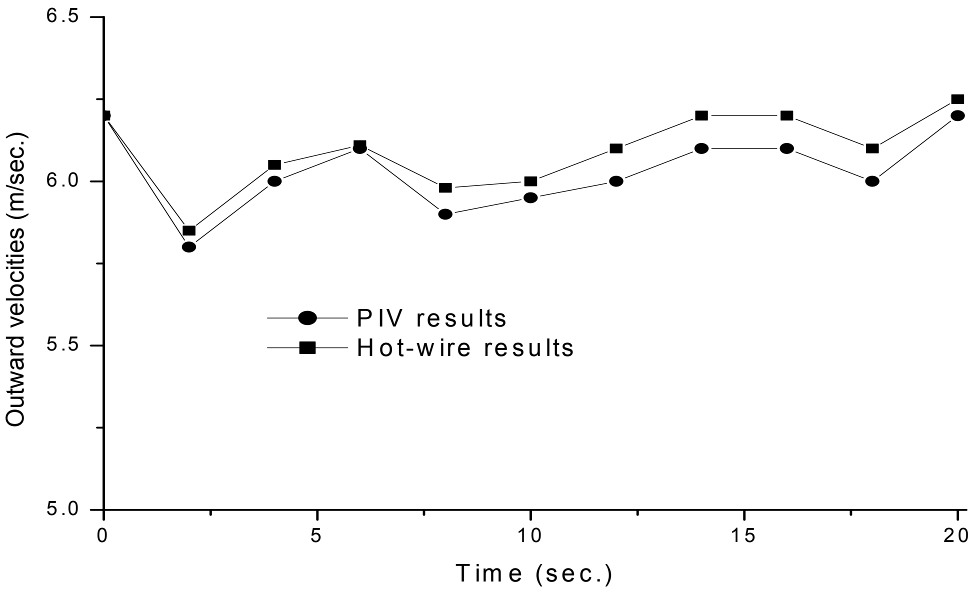

Fig. 4 Comparisons of PIV results with hot-wire anemometer for outward velocity at center of duct

2.2 Performance evaluation

In order to evaluate the performance of the present system, well-constructed wind tunnel is used. The experimental rig involves sensors for measurements and data acquisition unit connected to personal computer. The present wind tunnel follows ASHRAE standards (ASHRAE, 1985) for accuracy of obtained data and can measure static pressure in front of the system and flow rates by manipulating of nozzles of the fan tester. Wind tunnel system for capacity of flow rate and static pressure is composed of discharging blower with a butterfly valve for adjustments of flow rate in the tester and rectangular duct. Schematic diagram of the wind tunnel and fan system is shown in Figure 5. In the apparatus, static pressure is measured at four points in peripheral direction and averaged. Pressure difference before and after the nozzles is also found for calculating the flow rates. The range for flow rate covers up to 80 CMM (Cubic Meter per Minute). Driving motor for the test fan is connected with torque meter for estimation of total efficiency of the fan. In addition, the entrance of the wind tunnel is connected to a full anechoic chamber for measurements of noise level of the unit. With this combined system, it is able to estimate the aerodynamic performance and noise level of the unit, simultaneously.

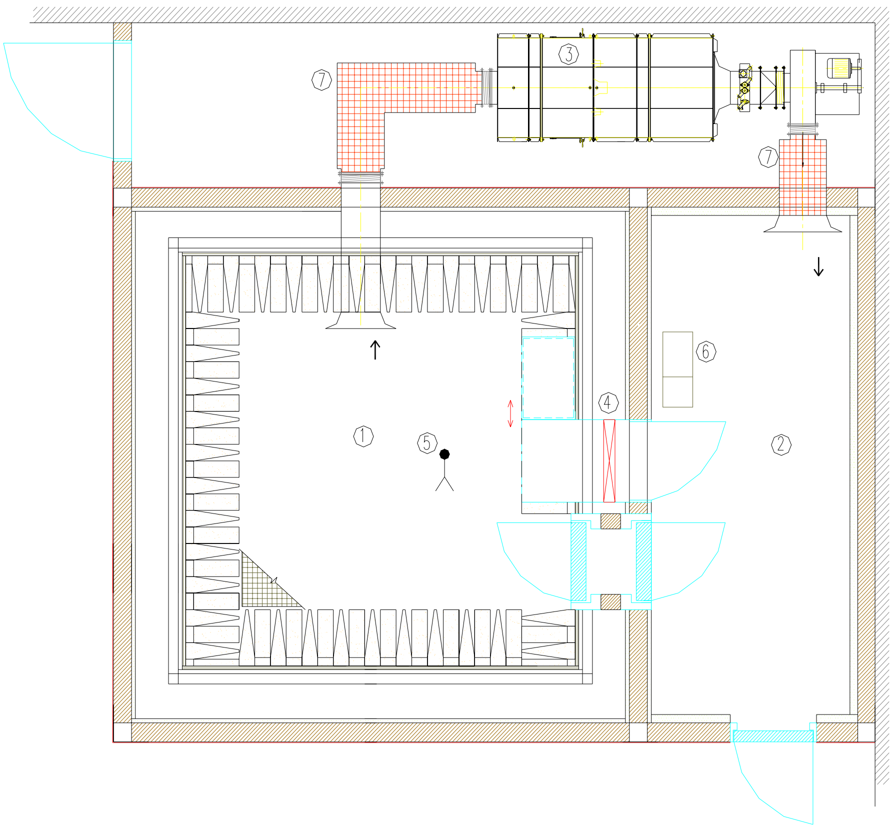

Fig. 5 Wind tunnel (○,3) connected to anechoic chamber (○,1) with microphone (○,5), silence (○,7) and test unit (○,4)

Performance test of a fan is looking for an optimal operation and design point of it. The present works on fan-capacity exhibit operation condition of the considered fan. Fluid dynamic performance is displayed in terms of flow rate and static pressure rise due to the action of the fan. In general, pressure behind a rotating fan is approximately equal to atmospheric one. The pressure rise is obtained by just measuring pressure in front of the fan. In order to evaluate the pressure rise according to flow rate, an automatic controlled motor system is adopter for adjustment of damper valve.

3. RESULTS and DISCUSSION

Much effort to improve the unit performance is made in this work. The process of this work is schematically presented in Fig. 6. As shown in Fig. 6, the sequence of this project strongly depends the analysis of the velocity distribution over the outlet-grill and double inlets of the impellor. Improvements according to the analysis of the velocity field for considering region are tried and then the effects are validated by using performance test equipment.

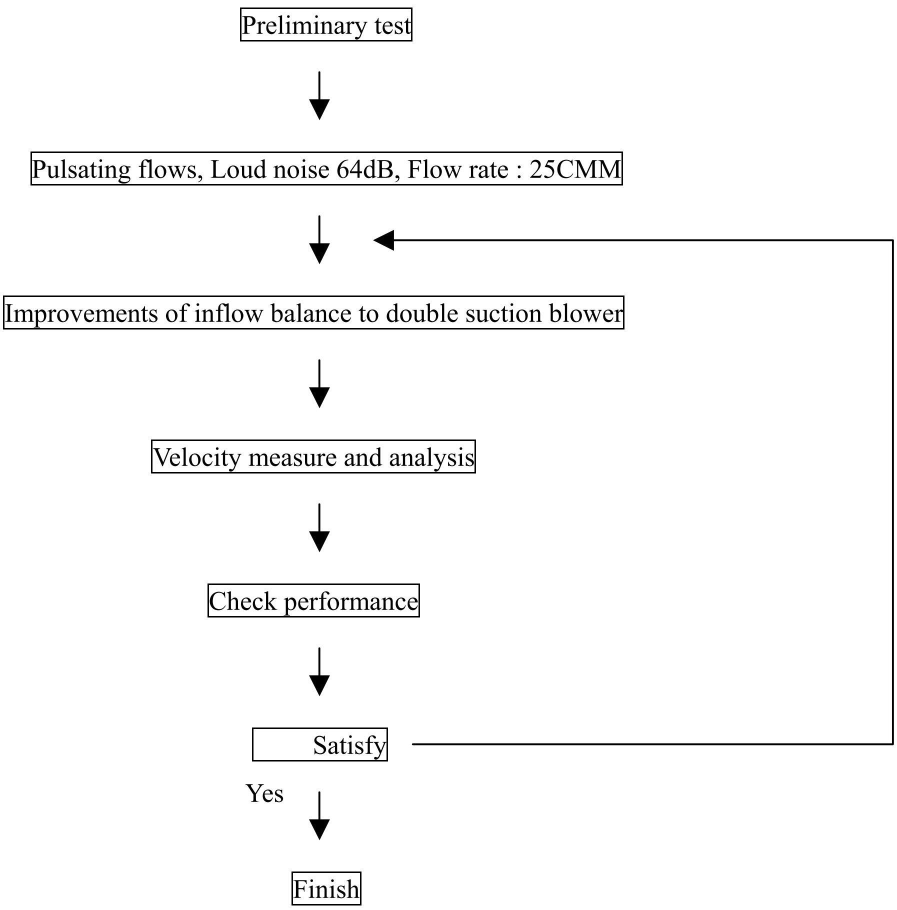

Fig. 6 Flow chart for research process

3.1 Preliminary results

In order to understand the present status of the unit, aerodynamic and aero-acoustic performance are evaluated by using an anechoic chamber with wind tunnel. Figure 7(a) shows the flow rate according to

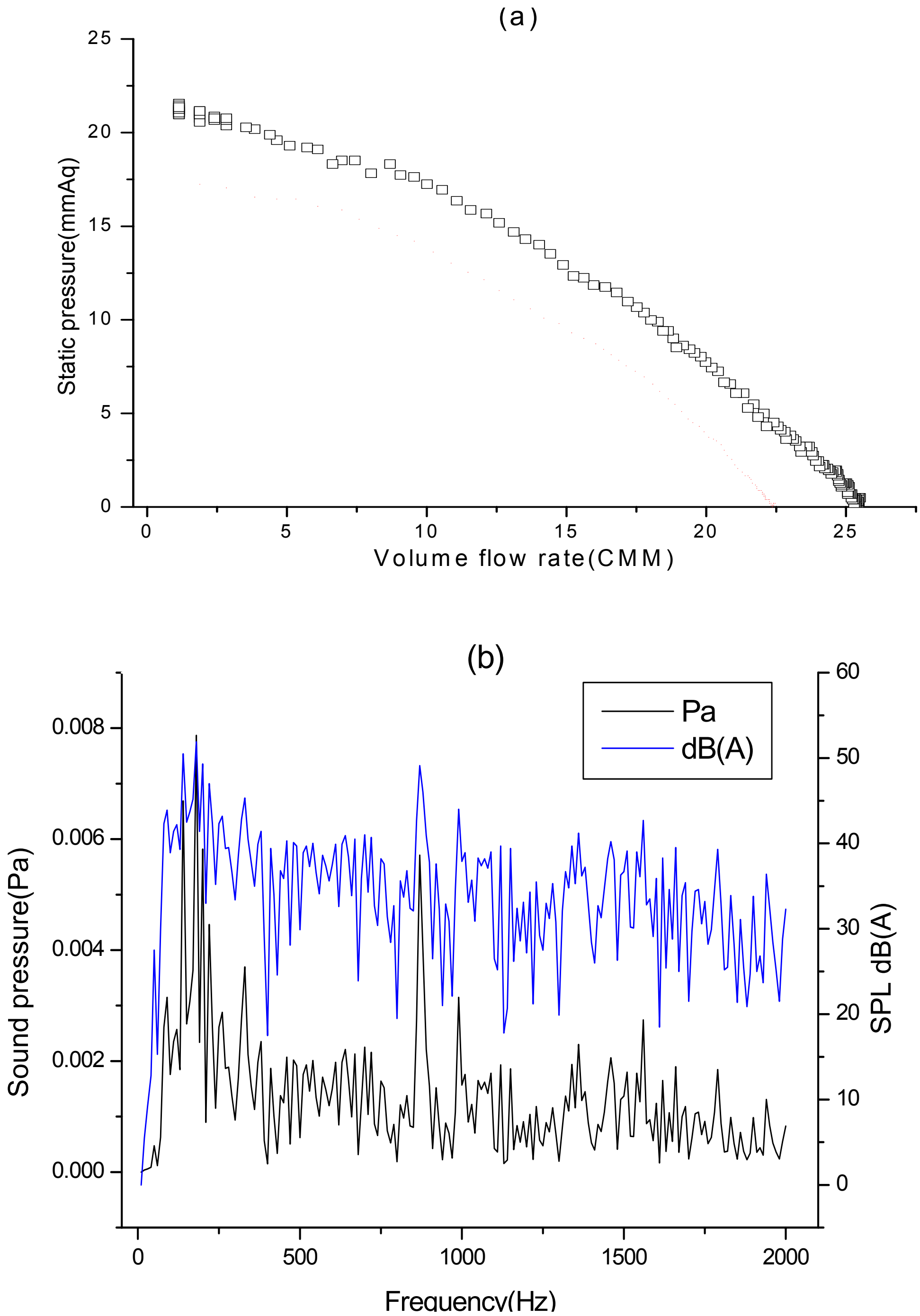

Fig. 7 Aerodynamic (a) and aero acoustic (b) performance for model before improvements

static pressure and noise level and Fig. 7(b) for noise level. Flow rate according to static pressure raise is reverse proportional patterns and maximum flow rate is found at the atmospheric pressure. In case of noise distribution on frequency domain is not simple and peak values appears in a characteristic frequency of 250 Hz and 800Hz. The noise test means that the noise depends on structure bone noise. This preliminary experiment confirms the performance and noise level.

Another characteristics of this unit are pulsating flow of outward velocity at the outlet and non-uniform distribution of spatial velocities on the outlet. The trend is measured by PIV and plotted in Figs. 8 and 9. The time interval for the pulsating flows is 7/30 sec. Due to the unbalance of inlet flow to double-suction impellor, the pulsating flows appear in magnitude of outward velocity. Non-uniform flows are also unwanted phenomena. Fig. 9 illustrates the non-uniform patterns of flows in spatial. The two characteristics of flows field should be removed by treatments of optimization of flow path and equal flow rate at the two inlets. The vortex flow at the corner region of the outlet grill is measured by PIV and presented in Fig. 10. The vortex pattern shows flow instability and reverse outward flow in part shown in the vectors toward right direction in the plot. This vortices motion should be reduced.

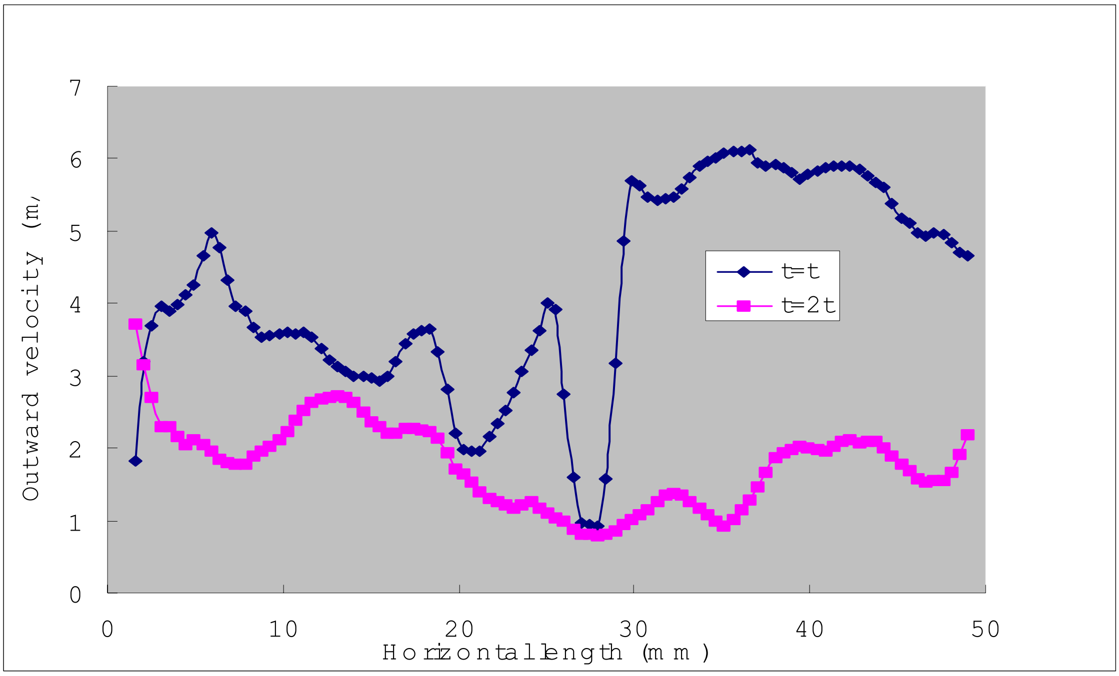

Fig. 8 Time dependent flows at center of outlet during 7/30 sec.

Emphasis lies on the improvements of flow path, specially the distance between blower and solid wall of the cabinet. The spatial location of blower inside the unit is main parameters for the improvements. The distance between outlet and blower is elongated by 12mm and the distance between blower and solid wall at the back panel is enlarged by 25mm. The specific distance is found by parametric studies for several conditions. This effort improves the performances of the unit and removes the pulsating characteristics of outward flows. The improved results are discussed next section.

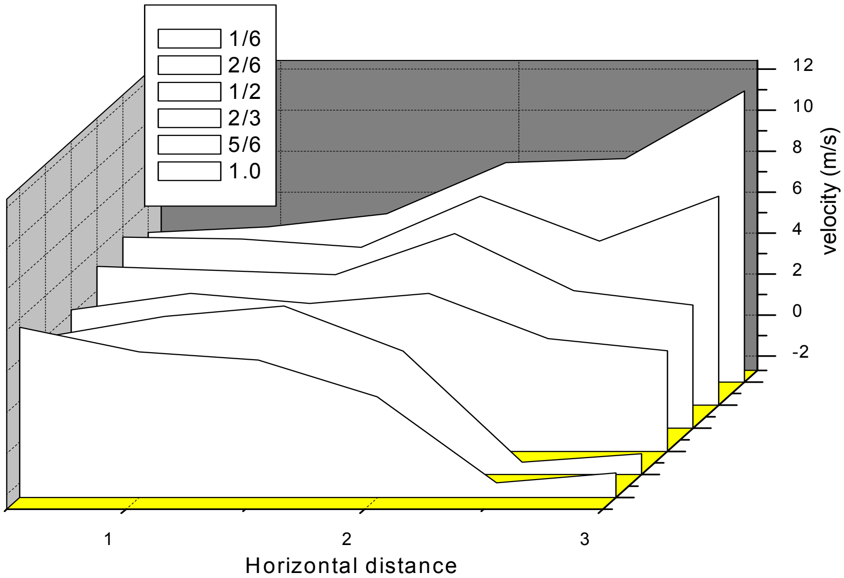

Fig. 9 Horizontal variations of outward velocities at different position on outlet

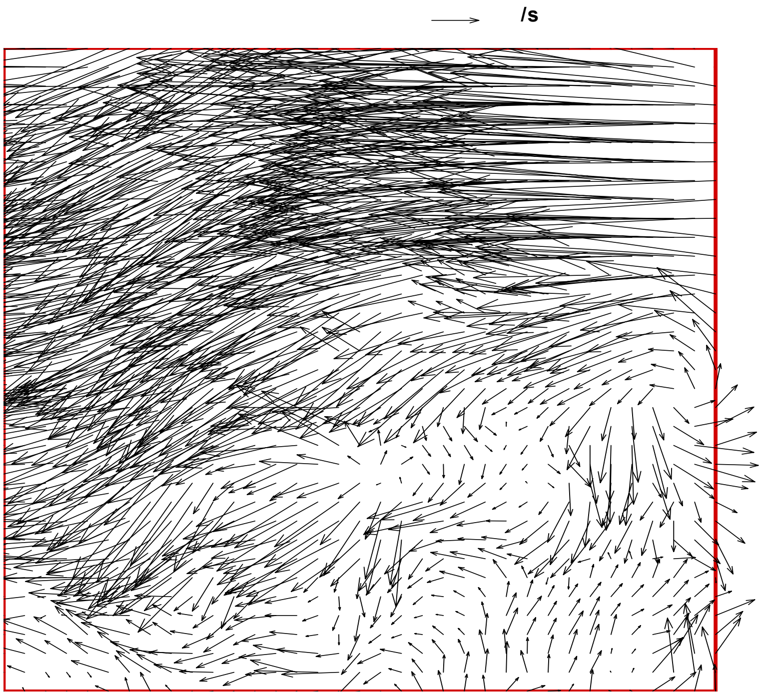

Fig. 10 Plots of velocity vector of outflows at right-bottom corner of duct

3.2 Improved results

As stated early, improvements are concerned with the location of blower inside the unit and adjustments of inlet flows to an impeller. The effects are noticeable and the pulsating motion is removed. The resulting flows are plotted in Fig. 11. In comparison with Fig. 10 for previous unit, flow magnitude is enhanced as several times and reverse flows are not found in flow field. Flow is straight near the guide vanes and circulating flows are found in central region. This flow patter shows the present improvements are effective for removing the unwanted reverse flows and pulsating flows. It is also kept for flow rate to meet the previous performance and reduce the noise level. Measurements after improvements of the unit are carried out for the noise levels flow rate and pulsating motions. Fig. 11 proves the removed pulsating motions. In addition, flow rate is same as previous model of 25CMM and noise level is decreased by 8 dB(A). The rearrangement on the flow balance at the inlet of the blower causes this positive result concerned with performance and flow noise.

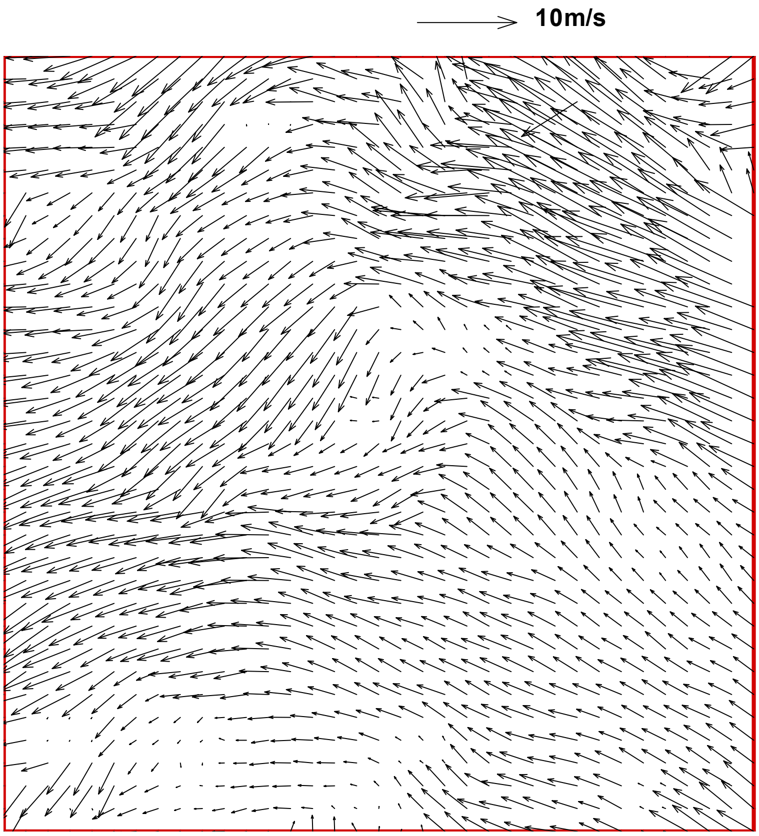

Fig. 11 Plots of velocity vectors for improved model

4. SUMMARY

Engineering problems concerned with indoor unit of air conditioner are solved in the work to adopt experimental methodologies such as PIV and anechoic room connected to a wind tunnel. Experimental data explain the status of the present system and effects of the improved treatments on it. Improvements are to find optimal position of the blower inside the unit that is a noise source and cause pulsating out flows due to unequal flow rate between the double inlets. Vertical distance from the roof of the unit to the blower is not optimized. Consequently, the optimum position of the blower is closely concerned with the all distance from the sidewalls and the ceiling. Trial efforts are made and optimum position of blower among them is selected. The procedure of finding the location uses the velocity data from PIV and the validation of each improvement is carried out by tests of wind tunnel with a full anechoic chamber. Obtaining the velocity information is most important because velocity vector illustrates the reverse flow and pulsating flows. In summary, the performance of the unit is increased in noise level and uniformity of out flows.

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