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# Characterization of Airflows at the Exit of Registers Using Laser Doppler Velocimetry (LDV)

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## ABSTRACT

*This paper reports the results of fluid flow measurements carried out at the exit of sidewall registers. Time-averaged mean velocity and turbulence (local root mean square velocity fluctuation) profiles were measured at the exit plane of two commonly used 8 in. × 4 in. (203 mm × 102 mm) sidewall registers. These data can then be used as an input boundary condition in a computational fluid dynamics (CFD) code to predict the velocity and temperature distribution in an enclosure supplied by the registers.*

*Laser Doppler velocimetry (LDV) was used to measure the axial and vertical components of the velocity vector at various locations across the face of the registers. Measurements at distances removed from the exit plane of the registers, but still within the "near field," show how the complex profile due to the vanes transitions to a jet, and this can provide a partial validation measurement for the CFD results. Measurements were made at two different flow rates, and the evaluation of the results suggests that the velocity field at the exit of both of these registers scales with the flow rate through them. This means that, in the mode of operation in which the supply fan (of an HVAC system) has a "high" and "low" setting, similar velocity scaling would result for these types of registers.*

## INTRODUCTION

Air distribution systems are used to supply conditioned air to a physical enclosure whose environment needs to be regulated within certain limits. A key element of the air distribution system is the air supply outlet, which can be a register, a grille, or a diffuser. Its design determines the manner in which the supply air is distributed within the enclosure (to be simply referred to as a room hereafter) and the resultant mixing of the ambient room air with the supply air. In order to determine the ability of a given register design to produce an acceptable performance, detailed velocity and temperature measurements downstream of the register exit in the entire room must be performed. However, such a task is time intensive and costly. Consequently, the use of computational fluid dynamics (CFD) models to predict the airflow distribution in rooms has become necessary (see, for example, Posner et al. [2003], Sorensen and Nielsen [2003], and Srebric and Chen [2002]). In order to conserve the computational resources, and also because the pertinent choice of turbulence models for simulation of airflow within the register and within the room may be different (Sorenson and Nielsen 2003), the flow within the register is not normally simulated using the CFD (Srebric and Chen 2002). Instead, the flow through the register is simply prescribed as a boundary condition for the CFD model of the room. The prescribed flow through the register is either a simple model (such as the box method) or actual data from measurements. Our goal here is to follow the latter approach—that is, to perform detailed velocity field measurements at the very exit of the register and then use these measurements as the boundary condition for the CFD code to predict the velocity and temperature distribution within the room. The CFD predictions can then be used to determine the register performance parameters, for example, the "throw" as a function of flow rate. Some limited velocity and temperature measurements at selected downstream locations in the room can be performed to test the validity of CFD predictions. Nevertheless, the detailed near-field velocity measurements at the very

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exit of the register are sufficient to characterize[1] the fluid dynamic performance of the register design.

During this investigation, the near-field velocity measurements at the exit of two different commercially available registers were performed. The identity of the registers, designated here simply by the letters A and B, is given in the report by Tutu et al. (2003). Register A (shown on the bottom portion of Figure 3) has an opening of 187 mm × 87 mm. The hydraulic diameter, *D*, of the register opening based upon these dimensions is calculated to be 0.119 m. It was oriented with the longer dimension in the vertical direction. It has a set of 13 flat fixed vanes. The central vane is about 12.5 mm wide and oriented normal to the flow. The top set of six vanes (and the bounding top edge of the register opening) point upward and are oriented at an angle of 30±2 degrees to the horizontal, while the bottom set of six vanes (and the bounding bottom edge of the register opening) point downward and are oriented at an angle of 30±2 degrees to the horizontal. The spacing between the vanes is about 12.2 mm. Register B (shown in Figure 8) has an opening of 189 mm × 87 mm. The hydraulic diameter, *D*, of the register opening based upon these dimensions is calculated to be 0.119 m. It was oriented with the longer dimension in the horizontal direction. It has a set of three curved vanes that can be rotated independently along a horizontal axis parallel to the vane length. The spacing between the vanes is about 25 mm, and the vanes are about 27 mm wide.

A laser Doppler velocimeter (LDV) was used to measure two components of the velocity vector at the exit of two registers at various locations across the face of the registers. Details of the experimental facility and instrumentation are presented in the next section. This is followed by the measurements for the registers A and B. It is emphasized here that the intent of these measurements is not to evaluate the register performance directly in a typical home setting (where the register is likely to be located close to the floor or ceiling) but to provide detailed near-field measurements at the register exit for use in a CFD simulation.

## EXPERIMENTAL SETUP AND MEASUREMENT TECHNIQUE

### Description

In order to ensure a well-characterized flow without any anomalies into the register, a flow conditioning system was designed and constructed. Although the duct systems used in most American homes and small businesses may not have uniform and symmetric incoming flow, it is nevertheless important to ensure that the airflow entering into the register-boot combination is relatively uniform and symmetric. Otherwise, any unanticipated or interesting observations will always be suspected as having been probably caused by the peculiarities of the flow delivery system. For this reason, this flow field (spatial velocity profile at the entrance to boot) must be shown to be symmetric and without anomalies by measurement prior to testing of the registers. A schematic of the flow conditioning system and the experimental apparatus is shown in Figure 1. A variable speed 254-mm-diameter duct blaster was used as a source for the air delivery. As shown in Figure 1, it delivers air to the flow conditioning system, which consists of a "diffuser," followed sequentially by a 1.2-m-long and 457-mm-diameter settling chamber, a contraction, and a 1.5-m-long, 178-mm-diameter duct. The "settling chamber" has a "flow straightener" (denoted by EC in Figure 1), which consists of 152-mm-deep and 25.4-mm-square openings with

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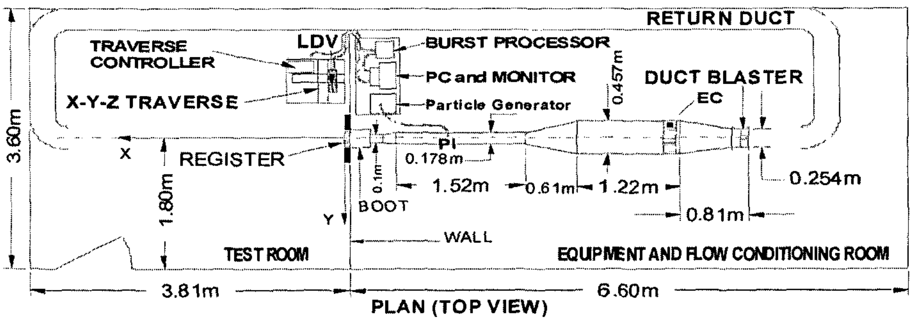
[1] As discussed later, the velocity field at the exit of the register is influenced by the design of the "boot"—the transition piece between the register and the supply duct. Thus, for practical applications the boot and the register should be considered as an integrated system.



PI: PARTICLE INJECTION. (6.35mm ID Metal tube injects particles along the centerline of pipe)
EC: 152mm Deep "Egg Crate" with 25.4mm x 25.4mm openings and a screen on either side
The Center Line of the flow system is at an elevation of 1.5m above the floor of the Test Room
Height of the Test Room: 2.59m.

***Figure 1*** *A schematic of the experimental facility for the study of velocity profiles at the exit of HVAC registers. X and Y are the axial and lateral coordinates, respectively.*

a screen on either end. The purpose of the flow straightener is to remove any swirling components of velocity from the airflow, and also to dampen any flow nonuniformities.

Since the laser Doppler technique uses the scattered light from particles in the flow to measure the flow velocities, particles need to be injected into the flow. A commercial "fluidized bed particle generator" was used for this purpose to inject titanium dioxide particles in the airstream. The particles were injected along the centerline of the 178-mm-diameter duct via a 6.35 mm internal diameter tube. The particle injection location is shown in Figure 1. The nominal mean diameter of these particles is 3 microns. The LDV system consists of the following components:

a. Laser, detector, and optics module (designated in the text by "LDV probe")
b. Digital burst processor

The laser has a wavelength of 685 nm and a power of 50 mW (25 mW for each of the two beams). The burst processor contains the electronics to process the signals from the LDV probe. It is controlled from a desktop personal computer (PC) via proprietary LDV software, and the processed data are transferred to the PC. A 350-mm focal-length lens is connected to the front end of the LDV probe. It outputs two laser beams that are 50 mm apart at the exit of the lens. To enable the measurement of the direction of the velocity component, the frequency of one of the beams is shifted by 40 MHz by the Bragg cell in its path. The measurement volume (the location at which the instantaneous velocity is measured) formed by the region of intersection of the two laser beams is an elongated ellipsoid that is 3.8 mm in length, with minor axes of 0.3 and 0.1 mm. For all the measurements performed here, the 3.8-mm-long major axis was always aligned parallel to the lateral *Y*-coordinate direction. The velocity data from a given location consist of a series of instantaneous values: $U_1$, $U_2$, $U_3$...$U_N$, which are recorded at discrete times $t_1$, $t_2$, $t_3$... $t_N$. These data can then be used to calculate such items as the time-averaged mean velocity and the root mean square velocity fluctuation. During the experiments, the LDV software was set up to collect 1500 velocity samples for a maximum duration of 90 seconds at each measurement location. Toward the edges of the flow field, where the particle concentration and the flow velocities are low, the total number of data points collected during the 90-second interval was much less than 1500. For the instrument settings used during these experiments, the uncertainty in the measurement of instantaneous velocity of individual data points, $U_i$, is estimated to be 0.006[2] m/s. The uncertainty (standard deviation) in the computed temporal mean velocity component due to the finite sample size ($N = 1500$) is given by ($u'/\sqrt{N}$), where $u'$ is the root mean square fluctuation in the velocity component being measured. Thus, for a location where $u' = 1$ m/s, the total uncertainty (standard deviation) in the measured temporal mean velocity component is estimated to be 0.03 m/s.

The LDV probe was mounted on a motor-controlled three-axis traversing mechanism. The traverse has a total travel of 245 mm in each of the two horizontal directions, and a travel of 375 mm in the vertical direction. The position of the LDV probe is indicated on the front panel display of the traverse controller with a resolution of 0.005 mm. This position is also transferred to the PC and recorded along with the velocity data. By installing a 90-degree bracket on the vertical traversing axis of the traversing mechanism, the LDV probe can be rotated 90 degrees, which effectively rotates the plane formed by the two laser beams leaving the LDV probe. Since the LDV measures the component of velocity along the plane of the laser beams and normal to a line that bisects the angle between the two beams, two orthogonal velocity components could be measured by rotating the LDV probe by 90 degrees. During these experiments, the axial (*U*) and the vertical (*W*) velocity components were measured. Although all the three velocity components are needed for the complete characterization of the velocity field, only two components of the velocity vector were measured. However, the chosen register designs were such that the velocity vectors at the exit of these registers have only two dominant velocity components. Excluding the outer edges of the flow, the temporal mean value of the third velocity component (which was not measured) is expected to be very much smaller than the axial component. Therefore, and also because of time constraints, the third velocity component was not measured.

## Velocity Profiles at the Exit of the Flow Conditioning System

The registers to be tested were 203 mm × 102 mm in cross section. These are typically screwed onto a 203 mm × 102 mm boot. The boot, in turn, is connected to the air delivery system via a 102-mm-diameter duct. As shown in Figure 1, a short length of 102 mm (4 in.) diameter sheet metal duct was connected to the end of the flow conditioning system. The flow conditioning system was then moved until the end of this duct was flush with the location where the register would be located during the tests. The LDV instrumentation was then set up to measure velocity profiles at the exit of this duct.

Measurements of the axial velocity component across the duct exit along diameters at four different angles relative to the horizontal and at a distance of 20 mm from the duct exit were performed. Both the temporal mean and the turbulence level in the axial velocity were computed. These are plotted in Figure 2. As can be seen, the velocity profile is reasonably uniform and symmetric. Furthermore, the turbulence level is low. These measurements show no anomalies and demonstrate that the flow conditioning system is working as designed. The nominal flow rate during these measurements was 0.0387 $m^3/s$

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[2] The laser Doppler velocimeter computes the instantaneous velocity $U$ from the relation $U = d_f F$, where $d_f$ is the fringe spacing in the measurement volume (provided via calibration by the manufacturer) and $F$ is the measured doppler frequency. Since the uncertainties in $d_f$ and $F$ are statistically independent and are known from the instrument specifications, the uncertainty in $U$ is easily calculated.