Large-Scale Particle Image Velocimetry Measurements of a Fire-Induced Doorway Flow

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Introduction

Quantifying the ventilation available to a room fire is an important step to understanding fire behavior. The fresh air that moves into an enclosure provides the oxygen necessary to support the combustion while also serving to moderate the temperature of the compartment. The hot fire gases that move out of an enclosure transfer heat and combustion products from the localized point of the fire to remote locations within a built structure. Mass flow rate is the parameter typically used to quantify the ventilation for a fire within a room. Due to the three dimensional nature of flow through vents, a full mapping of the velocity and density fields is necessary to determine the mass flow rate. Early treatments quantifying fire induced flow through vents relied on Bernoulli's equation and a hydraulics-orifice approach [1,2,3], therefore only a few well placed pressure and temperature measurements were required. Later treatments were improved by adding vertical arrays of pressure and temperature measurements and scanning them across the vents in order to address the three dimensional nature of the flows. [4,5]

In order to perform a more complete characterization of the fire-induced velocity field in a vent, non-intrusive and planar measurement techniques such as Particle Image Velocimetry (PIV) may be applied to measure the velocity vector field across the plane of a doorway. The dimensional scale of the flow field in a full-scale doorway of a room presents many challenges for PIV measurements. Challenges such as optical signal and particle selection were addressed for a reduced-scale experiment. [6] Following the lessons learned from the reduced-scale experiment, large-scale PIV measurements of a fire-induced doorway flow were successfully demonstrated in a full-scale fire experiment. Stereoscopic PIV measurements were conducted in the doorway of an ISO 9705 room to measure the flow into the room. Simultaneous temperature and differential pressure measurements were conducted on the vertical centerline using the types of thermocouples and pressure probes typical of fire tests. The independent measurements of the velocity field will be compared.

Experiment

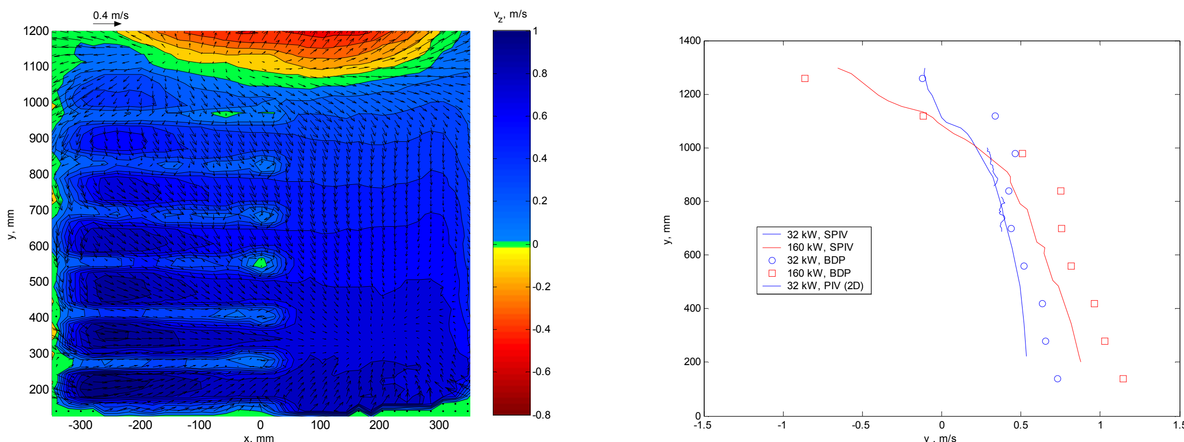
The room employed in this experiment was constructed to meet the requirements of the ISO 9705 fire test to evaluate surface products for their contribution to fire growth. [7] The interior dimensions of the room were 3.6 m x 2.4 m x 2.4 m (L x W x H) with a doorway of dimensions 0.8 m x 2.0 m (W x H) located in the center of one of the 2.4 m x 2.4 m walls. A natural gas fire was supplied from a square burner with dimensions of 30.5 cm on a side. The burner stood 30 cm above the room floor and was located in the center of the room. The heat input was controlled and steady state conditions were established at specified set points which ranged from 32 kW to 160 kW.

A vertical profile of temperature and differential pressure measurements were conducted on the centerline of the doorway. Temperature measurements were conducted with Type K bare bead thermocouples. Local measurements of differential pressure were conducted using bi-directional pressure probes. This device is similar to a Pitot-Static probe and is typically applied in fire test flow measurements due to its ruggedness. [8] The vertical array of thermocouples and bi-directional probes was located at the center of the door jamb which had a depth of 0.3 m. Local gas density and gas velocity were inferred from the temperature and differential pressure measurements.

An independent and simultaneous measurement of local gas velocity was conducted using Stereoscopic PIV. A double pulsed Nd:YAG laser illuminated the measurement region which included the entire width of the doorway and the lower 1.2 m of the doorway height. Expanded polymer microspheres served as the seeding particles for the PIV measurements. They were introduced into the quiescent flow outside of the ISO room and followed the flow through the doorway.

Results

Figure 1a displays the velocity vector field for a planar slice across doorway of the room. The imaged region covers the lower half of the doorway where the flow is predominantly into the room. The v_z velocity component is normal to the doorway plane (normal to the page) and is represented by the color contours. The blue contours represent the flow of ambient air into the room. The measurement included a small region of the hot gas and combustion products flowing out of the room, which is represented by the orange-red color contours. At the interface of the counter current flows v_z is zero. This is identified by the u-shaped green band near the top of Figure 1a. Stereoscopic PIV reveals such flow characteristics which are not apparent from the velocity data from traditional bi-directional probes. Also captured by the PIV measurement is the intrusive effect of the probes. This is displayed on the left hand side of Figure 1a.



a) b)

Figure 1 a) Velocity vector field for the 160 kW fire. b) Comparison of centerline profiles of measurements from bi-directional probes, Stereoscopic PIV (SPIV), and traditional PIV (2D).

A comparison of the probe and PIV data is presented in Figure 1b. The centerline profile demonstrates that the velocity measured by the bi-directional probes is consistently greater than the velocity measured with the PIV technique. Part of the contribution to this discrepancy may be the acceleration of the flow through the depth of the door jamb. In order to conduct simultaneous PIV and probe measurements the laser sheet was placed just directly in front of the bi-directional probe array. Therefore the PIV measurements were acquired slightly upstream of the bi-directional probes. Two dimensional PIV measurements performed in a slice perpendicular to the doorway confirm the Stereoscopic PIV measurements. These measurements also demonstrate that the velocity increases with increasing z position in the vicinity of the door jamb. PIV measurements reveal a much greater detail of the spatial dependence of fire-induced flow in a doorway. This information will serve to improve the design of flow velocity measurements in full scale enclosure fire tests.

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