
Volume 44
Issue 5
July 2009
ISSN 0379-7112
ELSEVIER
FIRE
SAFETY
JOURNAL
An International journal devoted to research on
Fire Safety Science and Engineering
Editor
D.D. Drysdale
Regional Editors
V. Babrauskas
Y. Hasemi
The official journal of the International Association for Fire Safety Science
Available online at
ScienceDirect
www.sciencedirect.com

Fire Safety Journal 44 (2009) 793–800

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

A comparison of gas velocity measurements in a full-scale enclosure fire

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ARTICLE INFO

Article history:
Received 4 December 2008
Received in revised form
12 March 2009
Accepted 24 March 2009
Available online 25 April 2009

Keywords:
Flow measurement
Fire-induced flow
Particle image velocimetry
Bi-directional probe

ABSTRACT

Gas velocity measurements were conducted in the doorway of an enclosure containing a natural gas fire. Two independent measurement techniques, Stereoscopic Particle Image Velocimetry (SPIV) and bi-directional impact-pressure probes, were utilized for comparison – the first such comparison for a fire-induced flow in a full-scale structural fire. Gas velocities inferred from the bi-directional probe measurements were consistently greater than SPIV measurements in a region of the flow between the floor and the flow interface. The comparison revealed that a measurement bias exists in the bi-directional probe technique. Estimates of the relative magnitude of the bias were inferred from the results.

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1. Introduction

The release of heat due to fire causes the surrounding gases to move due to expansion and buoyancy. The resulting fire-induced flows are of very low speed and they may occur over large spatial regions, especially in the case of full-scale enclosure fires. Accurate measurements to quantify the ventilation in enclosure fires are difficult due to the need to measure small gas velocities for a large area and all while contending with the hazardous conditions of the fire.

Quantifying the ventilation of a burning room in terms of mass flow rate requires measurements of gas velocity and gas density. The flow through vents is countercurrent and three dimensional, therefore a full mapping of the velocity and density fields is required to achieve the best accuracy. Due to the spatial extent of full-scale fire experiments, a complete velocity and density mapping of vent flows was not a feasible option for early investigations. Early efforts to measure the ventilation of room fires employed only a few well placed pressure and temperature measurements and relied on Bernoulli's equation and the assumption of one-dimensional flow [1,2]. Later treatments were improved by making pressure and temperature measurements with vertical arrays of bi-directional probes and bare-bead thermocouples. The vertical arrays were scanned across the vents in order to characterize the three-dimensional nature of the flows [3,4].

1.1. Bi-directional probe

The bi-directional probe is an impact probe similar to the pitot-static probe. The probe obstructs the flow and a pressure differential, ΔP, exists between its front and rear surfaces. The pressure difference is measured using a differential pressure transducer. Using the familiar relation for pitot-static probes, the flow velocity, V, is inferred from the local differential pressure, ΔP, and gas temperature, T, measurements. The molecular weight of the gas, M_{gas}, is assumed to be equal to that of air while the reference pressure, P_{ref}, is standard atmospheric pressure and R_u is the universal gas constant:

$$V = \frac{1}{C}\sqrt{\frac{2R_u}{P_{ref}M_{gas}}\Delta PT} \quad (1)$$

For a well designed pitot-static probe, the probe constant, C, is equal to unity. Because the bi-directional probe is not an ideal Pitot-static probe, its probe constant deviates from unity. McCaffrey and Heskestad [5] determined the probe constant to be 1.08 for flows with Reynolds number greater than 1000. The estimated relative standard uncertainty for this empirical constant is ± 0.10, assuming that the flow direction is within 50° of the probe axis. For flows parallel to the probe axis and with a local Reynolds number greater than 500, the relative standard uncertainty of the constant is ± 0.07.

Since the introduction of the bi-directional probe, it has been the preferred method of measuring flow speed and quantifying the ventilation in fire experiments. The probe is simple to apply and very robust to withstand the harsh environment of the fire. It has been characterized in well conditioned wind tunnel and duct flows [5,6], however these flows only simulated the effect of Reynolds number and not the actual use in complicated flow patterns and under high temperature conditions. The bi-directional probe is a physically intrusive device, therefore the flow responds to the presence of the probe. This interaction of probe and flow creates a local pressure field which is measured by a pressure transducer to infer the local velocity. It is anticipated that

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0379-7112/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.firesaf.2009.03.010

for flow conditions different from the wind tunnel and duct flows of previous investigations, the interactions of probe and flow will be different.

1.2. Particle image velocimetry

Particle image velocimetry (PIV) is an optical imaging technique that measures the displacement of tracer particles in a flow and computes the flow velocity from the measured displacement. A typical PIV setup requires tracer particles to be added to the flow, a light source to illuminate the particles at least twice within a very short interval, and a camera to record the light scattered by the particles. The particle displacement, d, and hence the particle velocity, $d/\Delta t$, is determined through sophisticated post-processing of the recorded images.

Fig. 1 is a simple illustration of a typical SPIV setup. A laser(s) delivers two laser pulses that are coincident in space but separated in time by a precisely known delay, $\Delta t=(t_2-t_1)$. The laser beams are expanded into light sheets and illuminate the tracer particles in the flow field of interest. The particles are assumed to fully follow the flow. Light is scattered from the particles and recorded on two separate frames (one for each laser pulse) of a Charge Coupled Device (CCD) camera. Post-processing of the images involves dividing the images up into smaller interrogation regions and computing the average displacement vector, (d_x, d_y), of the tracer particles for each interrogation region [7]. A standard PIV system employs a single CCD camera which can only measure the displacements in the plane of the laser sheet. By introducing the second camera to view the same area as the first camera but from a different angle, a stereo configuration is achieved which allows the out of plane displacement of the particles to be determined. The result is the full displacement vector (d_x, d_y, d_z). After the displacement vectors are computed, the velocity vectors (v_x, v_y, v_z), are computed by dividing the displacement vectors by the time interval between consecutive laser pulses.

Because SPIV measures the displacement of tracer particles, it is completely independent of the bi-directional probe method of measuring gas velocity. It is a non-intrusive optical measurement, therefore providing an interrogation of an undisturbed flow. The technique is capable of performing thousands of measurements over large planar regions and with good spatial resolution. SPIV can be used to characterize flows in great detail and therefore allow for a better interpretation of the process under observation.

The following sections will describe an effort to compare flow velocity measurements from bi-directional probes with those from SPIV, under the conditions of an actual fire-induced flow. Using the ISO 9705 room and a natural gas burner to generate conditions similar to the developing stages of an enclosure fire, SPIV and bi-directional probes were applied to measure the velocity of the air moving into a room through a single vertical opening, the doorway.

2. Experimental setup

The fire experiments were performed using the ISO 9705 Room. This is a full-scale room used to evaluate wall surface products for their contribution to fire growth. Fabrication of the room followed the specifications stated in the standard [8]. The interior dimensions of the room were measured using a flexible tape measure and determined to be $3.60\,m \times 2.40\,m \times 2.40\,m$ (length $\times$ width $\times$ height). The interior walls of the enclosure were lined with both drywall (lower half of the vertical walls and the floor) and calcium silicate panels (upper half of the vertical walls and the ceiling). Both materials were applied as two sheets and the resulting wall thickness was 2.5 cm. The estimated standard

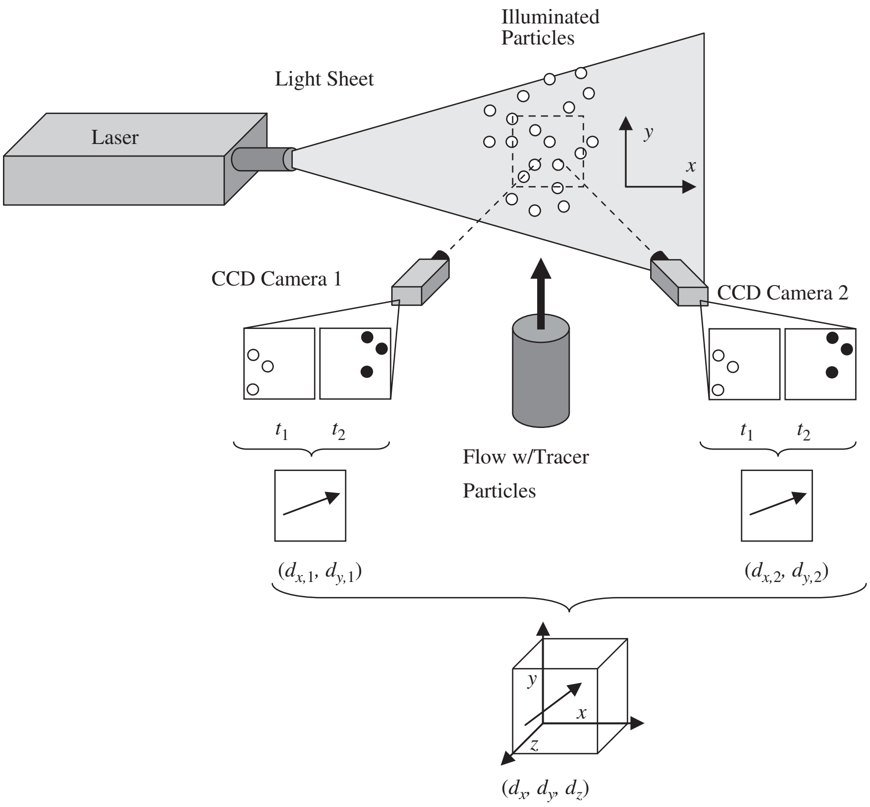

Fig. 1. Typical SPIV experimental setup.

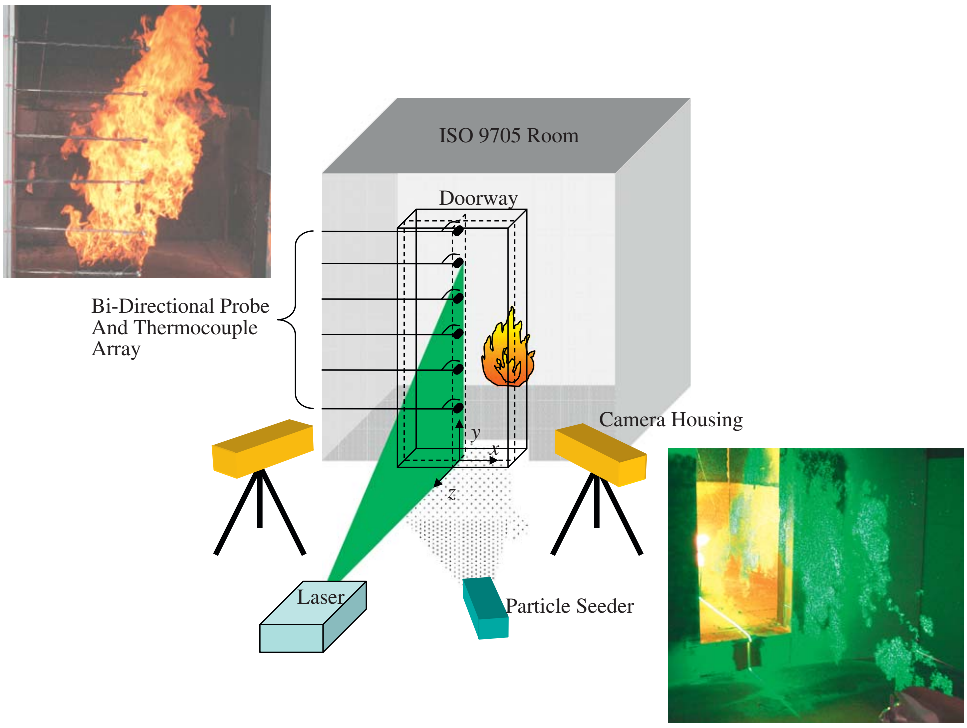

Fig. 2. Schematic illustration of the ISO 9705 room and instrumentation along with photos of the bi-directional probe array and the laser scatter from the seed particles.

uncertainty of the interior dimensions is ± 0.04 m. A doorway served as the only vent for the enclosure. It was located on the center of one of the $2.4\,\text{m} \times 2.4\,\text{m}$ walls, and had internal dimensions of $0.79\,\text{m} \times 1.96\,\text{m}$ ($W \times H$). The depth of the doorway was larger than usual due to the requirement of a window mounted on one side of the doorway to pass the laser sheet across the doorway for additional PIV measurements. The depth of the doorway or jamb depth, D, was 0.30 m, resulting in a doorjamb that extended beyond the exterior framework of the enclosure. The estimated standard uncertainty of the doorway dimensions is ± 0.01 m. A rectangular coordinate system (x,y,z), was adopted for dimensions and measurement locations. Its origin (0,0,0) was located at the floor of the doorway and at the geometric center of the plane defined by the width of doorway and the depth of the doorjamb, Fig. 2.

Measurements of differential pressure through the doorway were acquired with a vertical array of 14 bi-directional probes placed on the centerline of the doorway as shown in Fig. 2. Each probe had a dedicated differential capacitance manometer; each with a measurement range of 0–133 Pa and relative standard uncertainty of ± 0.0007. The probe dimensions used for the present investigation are displayed in Fig. 3. The probe array began at coordinates (0,14,0) cm (14 cm above the floor of the ISO 9705 room) and the vertical spacing between each probe was 14 cm, with the exception of a spacing of 12.5 cm between the topmost probe and its adjacent probe.

Temperature measurements from bare-bead thermocouples were used to estimate the vertical profile of gas temperature, T, in the doorway. The thermocouples were Type K and were placed adjacent to each bi-directional probe to provide an estimate of the local gas temperature. Thermocouples located at elevations of 1.4 m and below were constructed with 0.255 mm diameter wire (30 gauge) and had an average bead diameter of $0.6\,\text{mm} \pm 0.1$ mm. Thermocouples located above an elevation of 1.4 m (the 4 topmost thermocouples) were anticipated to be exposed to the high temperature gas flowing out of the room and were constructed of 0.511 mm diameter wire (24 gauge). The average bead diameter for these thermocouples was $1.0\,\text{mm} \pm 0.1$ mm.

In the present experimental setup, diagrammed in Fig. 2, the SPIV system consisted of a double pulsed Nd:YAG laser, two double-framed CCD cameras, and a desktop computer for image acquisition, time synchronization, and vector processing. The laser delivered two beams with average pulse energy of 200 mJ/pulse at 532 nm. A sheet forming optics assembly expanded the beams to a height of approximately 1.8 m at the doorway and a sheet thickness of approximately 1.2 cm. Positioning of the laser sheet at the doorway was performed by a 90° mirror attached to a translation stage.

The double-framed CCD cameras had sensors of 2048×2048 pixels with pixel dimensions of 7.4 μm on a side. Image frame rates achieved during the experiments were on the order of 1 frame per second due to the data transfer limits of the desktop computer. Wide angle 20 mm focal length lenses were used in order to keep the cameras close to the doorway and capture as much of the doorway as possible in the images. Each camera was placed in a housing that was purged with air in order to protect it from the heat and the seed particles. Laser line filters (532 nm) were placed in front of each camera to reduce the amount of background light collected from the ambient lighting and from the fire.

The seed particles were gas filled hollow plastic spheres, commonly referred to as microspheres. The particles had a weight averaged diameter ranging from 100 to 140 μm and a density of 30 kg/m^3. A paint sprayer was used to inject a fine cloud of seed particles into the area outside of the ISO room. Particle injection was remotely applied; a trigger pulse engaged a pneumatic actuator only during PIV image acquisitions. Details on the PIV setup and vector processing are discussed in a separate article [9].

The coordinates for each measurement technique are listed in Table 1. Positioning of the probes and laser sheet with respect to the coordinate origin was performed manually and confirmed using a flexible tape measure. The estimated standard uncertainty

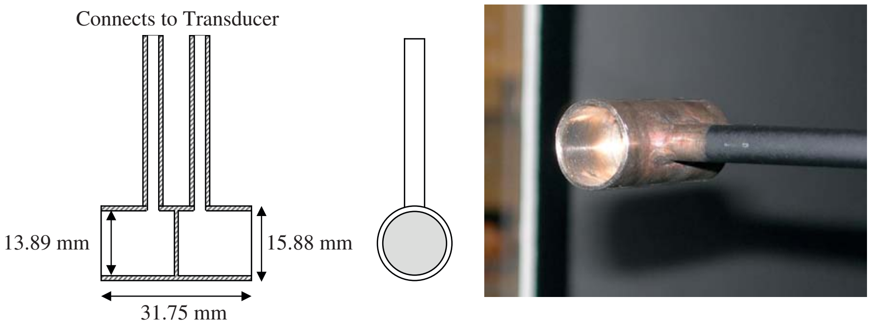

Fig. 3. Dimensional illustration and photo of the bi-directional probe used in the present study.

Table 1
Physical probe and SPIV measurement locations.

Technique	Measurement	*x*, m	*y*, m	*z*, m
Bi-directional probe and thermocouple	Differential pressure and temperature	0.00	0.14–1.82 (spacing = 0.14), 1.95	0.00
SPIV	Particle displacement	0.00	0.00–1.45 (spacing = 0.02)	−0.68 to 0.85 (spacing = 0.02)

of their position is $\pm$0.01 m. The bi-directional probe and thermocouple measurements were conducted with a simple vertical array located in the geometric center of the doorway. Stereoscopic PIV measurements were conducted on a vertical plane intersecting the line of probes at the center of the doorway. The laser sheet propagated through the doorway into the ISO room and was perpendicular to the front wall of the ISO room. In this configuration, the bulk flow of the fluid was parallel to the plane of the laser sheet; therefore, the evolution of the flow as it moved from outside the doorway to inside the room was characterized.

Fires were generated using a natural gas burner (30.5 cm $\times$ 30.5 cm) placed in the center of the ISO room, with the top of the burner being 30 cm above the room floor. The volume flow rate of natural gas was measured by a rotary displacement meter upstream of the burner. Assuming complete combustion of the natural gas, the real-time heat output of the burner was computed using the measured volume flow rate corrected for local conditions and the heat of combustion of natural gas, 33710 kJ/m^3. The burner supplied fires ranging from 34 to 511 kW; all fires were over-ventilated for the room and doorway dimensions. The relative expanded (coverage factor of 2 for an estimated 95% confidence interval) uncertainty of the computed energy supplied by the flow of natural gas to the burner exit was estimated to be $\pm$0.02 [10].

A complete experiment started with achieving quasi-steady-state conditions inside the room for the minimum fire size, acquiring measurements, increasing the natural gas flow to reach the next fire size, and repeating the process until the final fire size was attained. Quasi-steady-state was defined by a relatively constant temperature reading from an aspirated thermocouple located in the upper layer inside the room, $(x,y,z) = (0.81,1.95,-0.62)$ m. Upon reaching this steady-state, tracer particles were injected into the flow and SPIV measurements were taken. At least 200 SPIV measurements were recorded at a rate of 1 Hz for each fire size. Temperature and differential pressure measurements at the bi-directional probe array were performed continuously, and the readings were recorded at a rate of 1 Hz.

Six experiments were conducted to repeat the conditions of the enclosure fire with the exception of the maximum fire size, 511 kW, for which only two repeat experiments were conducted, one for each technique. Bi-directional probe measurements were conducted for three experiments. In order to conduct SPIV measurements at the locations occupied by the bi-directional probes, the probes were removed for the remaining experiments. A plot of the upper layer thermocouple measurement with respect to the ideal heat release rate computed from the natural gas volume flow rate measurement, Fig. 4, demonstrates a very tight grouping of the two measurements at each fire condition. The standard deviation of the repeat upper layer thermocouple measurements was less than 1.0% of the mean of the repeats for all fire conditions. The standard deviation of the heat release rate was less than 1.0% of the mean of the repeats for all but one condition, which was 1.5% of the mean. This very low relative standard deviation in both measurements demonstrates an excellent repeatability of the conditions inside the room. Since the geometry of the doorway (or the room) did not change between experiments, except for the removal of the bi-directional probes, it was assumed that the experimental conditions at the doorway would remain consistent and the two techniques to measure doorway flow velocity could therefore be compared.

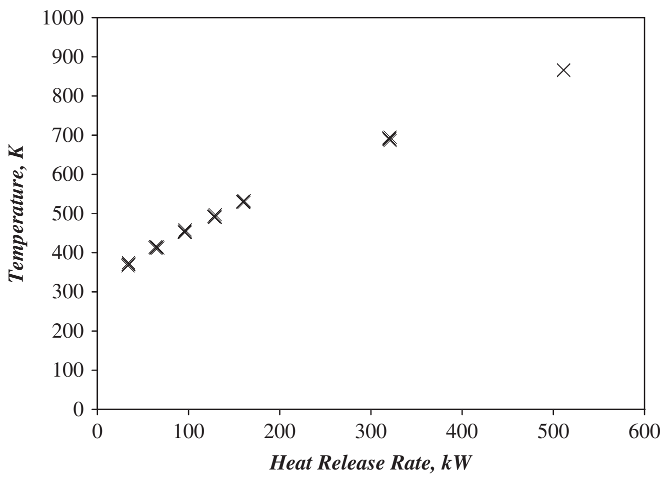

Fig. 4. Repeat measurements from the upper layer thermocouple and the ideal heat release at the burner.

3. Results and discussion

Stereoscopic PIV was applied to measure the velocity field due to the air flowing into the ISO room. Fig. 5 demonstrates the vector fields measured when SPIV was applied along a vertical slice at the center of the doorway. The vectors represent the velocity components within the plane of the laser sheet, v_z and v_y, while the color contours represent the flow speed with the directional information of the bulk flow, $Vsign(v_z)$ ($sign(v_z) = -1$ for $v_z < 0$, $sign(v_z) = 1$ for $v_z > 0$). The velocity component normal to the laser sheet, v_x, is small at the centerline, ranging from -0.25 to 0.2 m/s, and is therefore not shown. Each vector represents the average flow velocity over an area of 4 cm × 4 cm, the spatial resolution of the measurement. A 50% overlap of the image interrogation regions during processing produced a final measurement spacing of 2 cm in each direction. Fewer vectors are presented here for clarity. Fresh air flowing into the room is presented as blue contours while the hot air and products leaving the room are presented as the yellow to red contours. The green band between the inflow and outflow represents the region where V approaches zero. Note that with the exception of the region very close to the floor, most of the region of air flowing into the room was captured by the SPIV measurements. Only the lower portion of the flow out of the room was captured. Poor particle seeding and poor image quality at the vertical extremes of the measurement region prevented the computation of valid vectors in these regions. he survival of tracer particles in the hotter regions of the flow also limited the measurement. The estimated relative expanded (coverage factor of 2 for an estimated 95% confidence interval) uncertainty of the SPIV measurements is ± 0.06. This estimate includes the uncertainty due to the particle displacement measurement and the estimated settling velocity of the particles [9].

The intersection of the centerline slice measurements and the bi-directional probe array occurs along a vertical line at $x = 0$ cm and $z = 0$ cm. This is represented by the white squares in Fig. 5. Since the physical probe measurements and the SPIV measurements could not occur simultaneously at the same locations, the bi-directional probes had to be removed during the SPIV measurements. In the region defined by the thickness of the door jamb (region between the two vertical dashed lines) in Fig. 5, the change in color contours and the change in vector length along the horizontal direction demonstrate that the change in flow speed is significant as the flow moves from the outside to inside the room. This is true also as the flow moves from inside the room to the outside. The flow gradients along z are not as dramatic as along y, but the SPIV data demonstrates that it is important to compare data at identical spatial locations and not assume flow uniformity in any one direction. The bi-directional probe measurements were therefore compared to the SPIV centerline slice measurements at the same locations but from repeated experiments.

The repeatability of the conditions inside the ISO room was demonstrated by the interior temperature measurements, Fig. 4. To evaluate the repeatability of the measurements at the doorway the standard deviation for the repeat velocity measurements was computed. SPIV and bi-directional probe measurements at each bi-directional probe location in the region $0.14 \leqslant y \leqslant 0.7$ were used. This region was chosen because it was far enough removed from the intermittency of the flow interface for all fire conditions. The ratio of the standard deviation and the mean measurement value for the three repeat measurements over all fire conditions, with the exception of the 511 kW fire, is listed in Table 2. Only a single measurement for each technique was conducted for the 511 kW fire. The standard deviation of the repeat bi-directional probe measurements was approximately 5% of the mean. The ratio improved to approximately 3% for the repeat SPIV measurements and is consistent with the larger set of SPIV measurements discussed in a separate article [9]. The results demonstrate good repeatability for such a small number of repeat measurements,

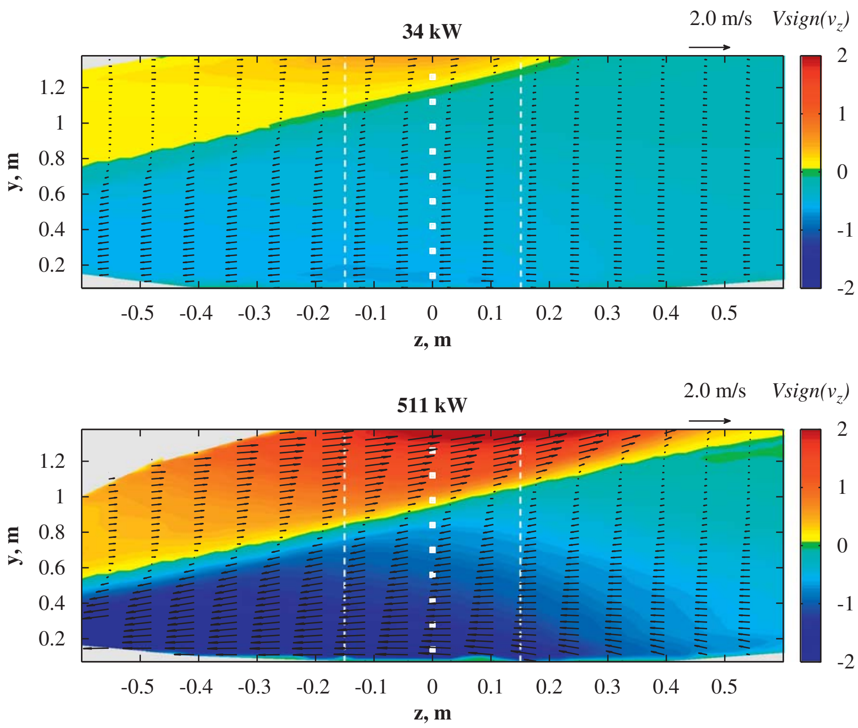

Fig. 5. Centerline slice of velocity vector field for 34 and 511 kW fires; contours represents flow speed and include directional information ($sign(v_z) = -1$ for $v_z < 0$, $sign(v_z) = 1$ for $v_z > 0$); white squares represent locations of bi-directional probes, dashed lines represent the extent of the door jamb.

Table 2
Ratio of standard deviation and mean for three repeat experiments computed from velocity measurements.

Measurement	Standard deviation/mean		
	Avg	Min	Max
V_{BDP}	0.048	0.005	0.302
V_{PIV}	0.032	0.001	0.143

Statistics are computed for the combined repeat data from each bi-directional probe location in the region $0.14 \leqslant y \leqslant 0.7$ and for all fires up to and including 320 kW.

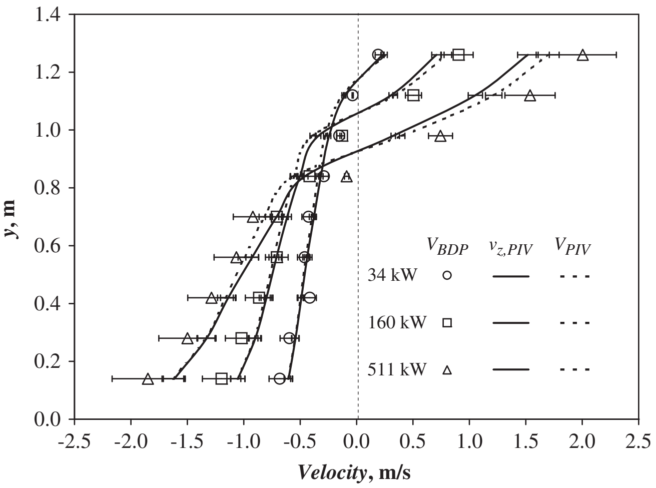

Fig. 6. Vertical profiles of velocity measured with the bi-directional probes, V_{BDP}, and SPIV measurements of v_z and V on the doorway centerline.

therefore the mean of the repeat measurements between the two methods can be compared.

The vertical profiles of the velocity measurements from the bi-directional probes and SPIV, at $x = 0.0$ and $z = 0.0$, are plotted in Fig. 6. Profiles for three of the seven fire sizes are shown for clarity. The velocity results for the bi-directional probe measurements were computed using Eq. (1), with $C = 1.08$, and assuming the molecular weight of the gas to be equal to that of air. It is estimated that the relative discrepancy between the molecular weight of the gas flowing out of the room and the molecular weight of air will be less than 0.01.

Measured thermocouple temperatures were not corrected for radiation but were applied directly as estimates of gas temperature. For the flow into the room, the measured temperatures were typically less than 306 K. The exception was the case of the largest fire, 511 kW, where the maximum temperature below the flow interface was 324 K. The air flowing into the room should be at the same temperature as the ambient air, so the difference in the thermocouple temperature and the temperature of the local ambient air is the most conservative estimate of the uncertainty of the gas temperature for the flow into the room. This standard relative uncertainty was typically below ± 0.03, with the exception of the largest fire where it ranged from ± 0.04 to ± 0.09. The thermocouples above the flow interface were exposed to the hot gases flowing out of the room. Again the measurements estimate the gas temperature and the difference in the measurement and the gas temperature is applied as the uncertainty of the gas temperature measurement. This difference was estimated using the energy balance on a bare-bead thermocouple in a cross flow described by Blevins and Pitts [11]. The relative difference, and therefore the relative standard uncertainty, ranged from ± 0.01 to ± 0.07 for the measurements of gas temperature in the flow out of the room.

The relative uncertainty of the gas velocity measurement using the bi-directional probe was estimated by combining the relative standard uncertainty of each parameter in Eq. (1), with the exception of R_u and P_{ref} which are well known constants and assumed to have negligible uncertainty. The differential pressure and gas temperature measurements are the only dynamic variables in Eq. (1). The relative uncertainty of the differential pressure measurement is constant for each reading while the relative uncertainty of the temperature measurements depends on the conditions. Error bars in Fig. 6 represent the estimated expanded (coverage factor of 2 for an estimated 95% confidence interval) uncertainty of the gas velocity measurement using the bi-directional probe and using SPIV. The relative expanded uncertainty of the bi-directional probe measurements ranged from ± 0.14 to ± 0.22. The uncertainty of the bi-directional probe measurements is much larger than the SPIV measurements due to the large relative standard uncertainty in the empirical probe constant, C, estimated at ± 0.07 for this study. When the fire size increases above 320 kW the uncertainty due to the gas temperature measurement also begins to contribute more to the combined uncertainty.

Fig. 6 shows that there is a discrepancy between the velocities measured with the two techniques. However the error bars for the bi-directional probe measurements are larger than the discrepancy for most of the measurements below the flow interface. This suggests good agreement within the bounds of uncertainty between the two techniques but the discrepancy deserves further study because within a specific region of the flow a consistent trend was observed for the different fire conditions.

The relative magnitude of the discrepancy changes with elevation or position within the flow field. Velocity measured with the bi-directional probes was usually greater than that measured with SPIV. The exception was the region of flow into the room but very close to the interface of the inflow and outflow. The bi-directional probe was designed to reduce the occurrence of clogging by soot and particles and to be less sensitive to flow angle. Therefore it has large openings for accumulating fluid to measure the fluid pressure, see Fig. 3. The large openings also collect the flow from a large angle and therefore average the induced pressure differential over the collection angle. Each component of the velocity vector contributes to the probe's response. The vertical components of the vectors of Fig. 5 and the discrepancy between v_z and V profiles of Fig. 6 demonstrate that the flow through the doorway is not entirely horizontal, especially in the flow out of the room where the discrepancy between v_z and flow speed is the greatest.

The ratio of the velocity inferred from the bi-directional probe measurement and the v_z component of velocity inferred from the SPIV measurements is plotted with respect to v_z in Fig. 7. Negative v_z represents the flow into the room and each bi-directional probe in the lower portion of the doorway had companion SPIV measurements for comparison. Near the flow interface, where v_z and V approach zero, the discrepancy between the bi-directional probe and SPIV results was large (see Fig. 6). In this region the probe results were consistently lower than the SPIV results. Fig. 7 demonstrates an increasing ratio which passes through unity as the magnitude of v_z increases.

For any given fire size and for the flow into the room or below the flow interface, the flow speed increases with increasing vertical distance from the flow interface. The exception will be in the boundary layer region near the door sill where the no-slip condition holds at the rigid boundary. Further away from the flow interface the data suggest that the discrepancy between the bi-directional probe and SPIV results approaches a limiting value.

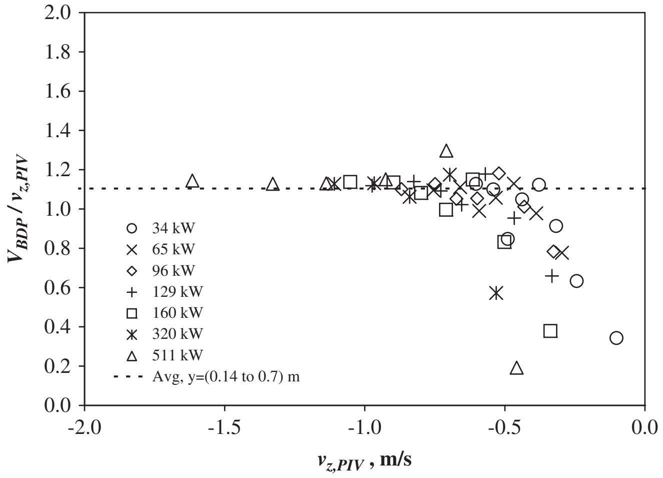

Fig. 7. Direct comparison of bi-directional probe velocity measurements, V_{BDP}, and v_z from SPIV measurements. Negative v_z represents flow into the room.

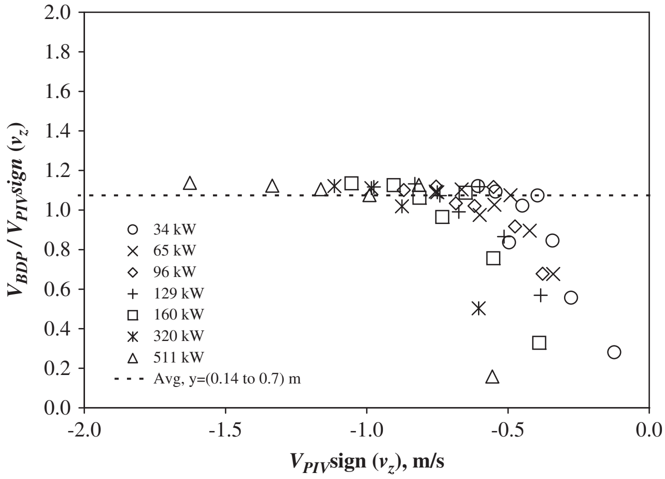

Fig. 8. Direct comparison of bi-directional probe velocity measurements, V_{BDP}, and V from SPIV measurements.

The average value of the ratio is 1.10 for the region $0.14\,\text{m} \leqslant y \leqslant 0.7$ m. Therefore the velocity inferred from the bi-directional probe measurements was an average of 10% greater than that determined from SPIV.

The flow speed, V, was computed from the SPIV measurements since the full velocity vector was resolved. Fig. 8 presents the ratio of the velocity inferred from the bi-directional probe measurement and the V inferred from the SPIV measurements. Since the flow speed is dominated by v_z, there is a similar wide range of discrepancy with a limiting value observed when comparing the velocity data from the bi-directional probes and V. In the case of comparing flow speed, the average value of the ratio is 1.07 for the region $0.14\,\text{m} \leqslant y \leqslant 0.7\,\text{m}$. The discrepancy decreases when comparing flow speed because the bi-directional probe was designed to be less sensitive to flow angle and includes the contribution of each velocity component. Therefore, its response is more representative of flow speed.

The consistent trends observed for the measurement discrepancy between the two techniques imply that a measurement bias exists. Despite the good agreement within the bounds of uncertainty between the two independent measurements there is room for improvement of the bi-directional probe technique to reduce its uncertainty by identifying and reducing the measurement bias.

Similar trends were observed for the flow out of the room, positive v_z, however these trends are not conclusive due to a very limited amount of data. Companion SPIV measurements were not possible for each bi-directional probe measurement in the flow out of the room due to the challenges of conducting PIV in this region of the flow.

4. Summary and conclusions

Stereoscopic PIV has been applied to measure the velocity of air flowing into the doorway of an enclosure and induced by a full-scale fire within the enclosure. The ISO 9705 room with standard dimensions served as the enclosure and a natural gas burner served as the fire source. SPIV is a new approach to quantifying the ventilation in enclosure fires. It is a non-intrusive technique that infers flow velocity from the measured displacement of seed particles which is completely independent of the temperature and differential pressure measurements typically applied in fire testing to infer flow velocity. Conventional measurements of flow velocity were also performed in the doorway using bi-directional probes and compared to the SPIV measurements-the first such comparison for a fire-induced flow in a full-scale structural fire.

The details of the velocity field provided by SPIV confirm that flow uniformity should not be assumed in any one direction for a fire-induced flow through a doorway. Therefore, when comparing measurement data, it is essential to compare measurements at identical spatial locations. The comparison of SPIV and bi-directional probe measurements was performed for the flow of air into the room and resulted in a wide range of discrepancy between the velocity data. The discrepancy was the greatest in the region near the flow interface where the flow speed is low. Away from the flow interface where the flow speed increased, the discrepancy appeared to approach a limiting value. In this region the discrepancy was more consistent; the velocity inferred from the bi-directional probe measurements was on average 10% and 7% greater than SPIV measurements of v_z and V, respectfully. The lower discrepancy when comparing flow speed, V, confirms that the bi-directional probe measurement is more representative of flow speed.

The comparison of the bi-directional probe measurement with an independent measurement technique, SPIV, demonstrated that there is a region of the flow where the bi-directional probe measurement consistently over estimates flow velocity. This implies that a measurement bias exists in the bi-directional probe technique. However, with an estimate of the bias, the bi-directional probe measurement can still be applied with confidence in this region. Further investigation is required to determine the source of the bias, to suggest means to reduce the bias, and to ultimately reduce the uncertainty of the bi-directional probe measurement when applied in a fire-induced doorway flow.

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