13th Australasian Fluid Mechanics Conference
Monash University, Melbourne, Australia
13-18 December 1998

REPEATABILITY OF FULL-SCALE EXPERIMENTS ON A TURBULENT PLUME VENTING FROM A BURN ROOM WINDOW

S. Klopovic and Ö.F. Turan‡

Mechanical Engineering-School of the Built Environment
Faculty of Engineering and Science
Victoria University of Technology
P.O. Box 14428 MCMC
Melbourne, Victoria 8001 Australia

ABSTRACT

A simple approach is described to test repeatability of full-scale flashover fire tests with respect to the turbulent plume venting from the burn room window. The fluctuating temperature measurements in the plume are used for this purpose. The results are consistent with expected experimental uncertainty.

INTRODUCTION

Turbulent plumes and ceiling jet flows have been studied extensively especially due to their connection with Fire Safety Engineering and their importance in predicting fire hazards. In fact, the current understanding of fire plumes is based on the work of G.I. Taylor in 1940's (Beyler, 1986). In this study, a series of eight tests have been carried out in a burn room located at the entrance level of a three-storey steel and concrete building. The building, the Experimental Building-Fire Facility, is owned and operated by the Center for Environmental Safety and Risk Engineering of Victoria University of Technology. The fuel load was pre-conditioned real furniture during these tests to simulate flashover fires in a living room. The series of eight tests were designed to cover three ventilation classes, Class 1a, Class 1b and Class 2, in repeat cases of two to three fires each. A summary is given in Table 1 below of all the tests. The ventilation class corresponding to each test is also shown in this table. Further details of the series is given in Klopovic and Turan (1997). The main objective of the present study has been to investigate the external plume. For this purpose, temperature, heat flux, velocity and gas species measurements were taken outside of the burn room window on the external facade. To map the temperature field within the external plume during the series of eight real furniture tests, 140 thermocouples were placed at the nodes of a three-dimensional external grid shown schematically in Figure 1. The grid consisted of four faces parallel to the external facade, seven levels perpendicular to it, and five planes perpendicular to both, as shown in Figure 1. In order to minimize the effect of external wind, the tests were carried out on relatively calm days. This short paper is on the method used to determine repeatability with respect to the external plume of a given class of tests.

DISCUSSION OF RESULTS

To investigate the repeatability of each class of tests, external temperature measurements were used. As an example, the results of Class 1b tests, Burns 5 and 8, are presented here. In Part a of Figures 2 to 4, the dimensionless and time-averaged temperature contours are given during Burns 5 and 8 on Plane 3, Face 1 and Level 4, respectively. In Part b of Figures 2 to 4, the corresponding difference contours are given. Three planes of the three-dimensional external thermocouple grid were chosen for comparison due to the following three reasons. Firstly, Plane 3 is used extensively in the literature to describe fire plumes. Secondly, Face 1 is important in studying the effect of the external plume on the building facade. Thirdly, because Level 4 corresponds to the window above the burn room window, it is important in studying the possibility of a secondary fire in the room above the burn room. For time averaging the fluctuating temperature results, the Consistent External Flaming (CEF) duration of each test was used. The CEF period corresponds to the quasi-steady duration of external flaming. A method was develop to determine the CEF period for each test (Klopovic and Turan, 1997). The difference plots in Part b of Figures 2 to 4 consist of the arithmetic difference between the dimensionless time-averaged temperature contours given in Part a of Burns 5 and 8 at a given point in space.

Plane 3 temperature contours given in Figure 2a of Burns 5 and 8, both show the typical "bellying" of the external plume on its center plane (Turan and Klopovic, 1997) at approximately the same location during the two tests. The hot core on Face 1 is clearly visible in Figure 3a, and it is slightly displaced between the two tests. The temperature contours on Level 4 of Burns 5 and 8 appear to be even more similar than those of Plane 3 and Face 1, as seen in Figure 4a. The difference plots given in Figures 2b, 3b and 4b, show small differences.

In order to quantify the small differences indicated by the difference contours of each ventilation class of tests, the following procedure was developed. As reference, the arithmetic average of the external experimental data of the tests of a given ventilation class was used. As a result, a given group of repeat tests had only one mean difference, standard deviation and maximum difference corresponding to each plane of the three-dimensional external grid. This analysis lead to the results given in Table 2 for each ventilation class.

For Class 1b results, the mean difference, standard deviation and maximum difference for Plane 3 were 0.035, 0.021 and 0.10, respectively. Therefore, the external temperature results of Burns 5 and 8 differed

---

‡ Please address all correspondence to this author.
E-mail address: ofturan@dingo.vut.edu.au

from their reference on the average by 0.035±0.021. The maximum average difference of 10% is within about three standard deviations of the mean, making it a rare occurrence. Similarly for Face 1 and Level 4, respectively, the results of Burns 5 and 8 are different by 0.051±0.036 and 0.024±0.019 from the reference. The maximum differences of 0.14 and 0.68 are about 2.5 to 34.5 standard deviations of the corresponding mean values. These numerical results indicate that Level 4 temperature contours were more repeatable than the other planes for Class 1b results. As indicated by the numerical values presented in Table 2 for the other two ventilation classes, Level 4 results in general were better repeated than Plane 3 and Face 1 results. In forming Table 2, the results of Burns 3 and 6 are not used. In the case of Burn 3, unexceptably high wind during the test caused increased air entrainment, resulting in lower external temperatures. Burn 6 did not develop to flashover due to the activation of the air handling system of the building.

CONCLUSIONS

A simple method is used to determine the repeatability of full-scale flashover fire tests with respect to the temperature field within the external plume. The arithmetic average of a given set of repeat tests is used as the reference to define the mean difference, standard deviation and maximum difference on each plane of the external plume for a given ventilation class of tests. This approach has given a means to show that Level 4 results were more repeatable than Plane 3 and Face 1 results. Considering that the temperatures were below 600°C on Level 4, this conclusion is expected, since radiative errors in thermocouple readings become negligible for temperatures less than 600°C (Luo and Beck, 1996).

REFERENCES

BEYLER. C.L. "Fire plume and ceiling jets", Fire Safety Journal, **11**, 53-75, 1986.

LUO, M. AND BECK, V. "Effects of air-handling system on fire spread in a full scale building", 6th Australian Heat and Mass Transfer Conference, December 9-12, 1996 .

KLOPOVIC, S. AND TURAN, Ö.F. "Externally venting flames: Two sample ventilation cases". ASME Proceedings of the 32nd National Heat Transfer Conference, **3** (HTD-Vol. 341): Fire and Combustion. Ed. by L. Gritzo and J.P. Delplanque, 71-90, Baltimore, MD, USA, 1997. Also to appear in Fire Safety Journal (1998).

Table 1. Summary of the series of eight real furniture burns. WLC refers to window lowering criterion. WLC#1: Burn room window lowered when either the glass temperature reached 250°C, or the burn room gas temperature reached 450°C; WLC#2: Burn room window lowered when the mass loss rate in the room reached 0.1 kg/min.

Test	Wood Equivalent Fuel Load (kg/m²)	Burn Room Door (D1)	Stairwell Door (D9)	Additional Factors
BURN 1	26.36	Open	Closed	Burn room window opened, Class 1a
BURN 2	28.05	Open	Closed	WLC#1, Class 1a
BURN 3	27.65	Closed	Closed	WLC#2 , Class 2
BURN 4	28.32	Closed	Closed	WLC#2, Class 2
BURN 5	28.21	Open	Open	Window failed, Class 1b
BURN 6	27.90	Open	Open	WLC#1, Smoke Management System on, no flashover, Class 1b
BURN 7	27.95	Closed	Closed	WLC#1, Smoke Management System on, flashover occurred, Class 2
BURN 8	28.48	Open	Open	WLC#1, combustible linings in corridor, Class 1b

Table 2. Statistical analysis of experimental data of external temperature contours to determine repeatability. Mean difference (MEAN), standard deviation (STD) and maximum difference (MAX) between the reference and corresponding pairs of tests on Plane 3, Face 1 and Level 4.

			MEAN	STD	MAX
PLANE 3	**Class 1a**	**BURN 1/BURN 2**	0.080	0.068	0.23
	Class 1b	**BURN 5/BURN 8**	0.035	0.021	0.10
	Class 2	**BURN 4/BURN 7**	0.020	0.015	0.11
FACE 1	**Class 1a**	**BURN 1/BURN 2**	0.050	0.037	0.16
	Class 1b	**BURN 5/BURN 8**	0.051	0.036	0.14
	Class 2	**BURN 4/BURN 7**	0.061	0.050	0.25
LEVEL 4	**Class 1a**	**BURN 1/BURN 2**	0.025	0.027	0.11
	Class 1b	**BURN 5/BURN 8**	0.024	0.019	0.68
	Class 2	**BURN 4/BURN 7**	0.027	0.023	0.17

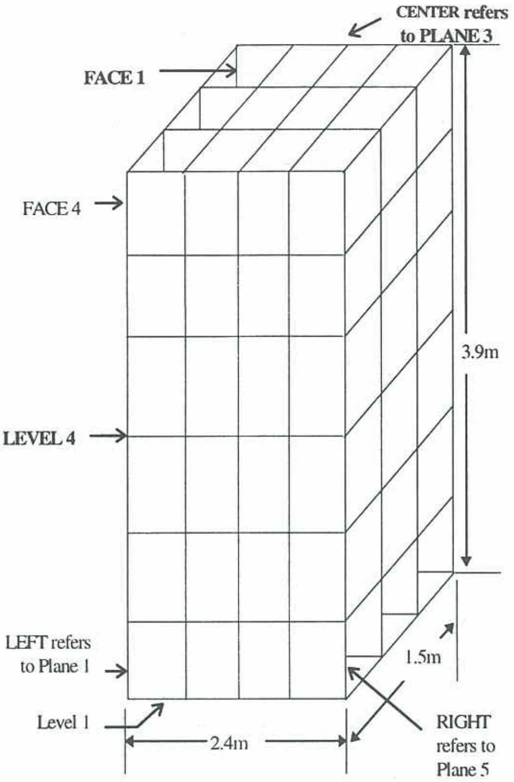
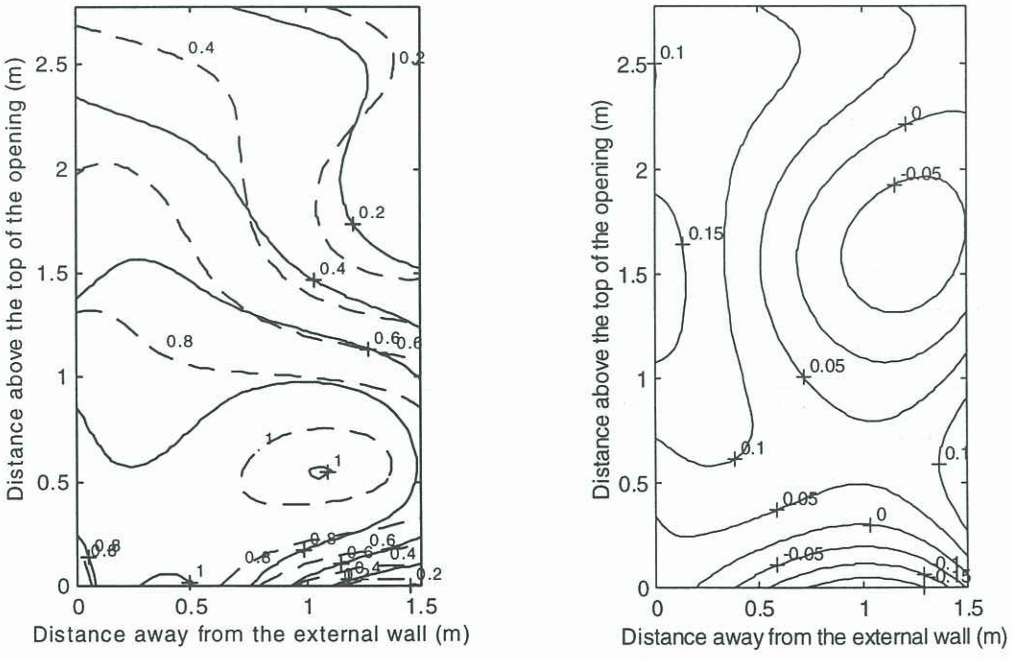


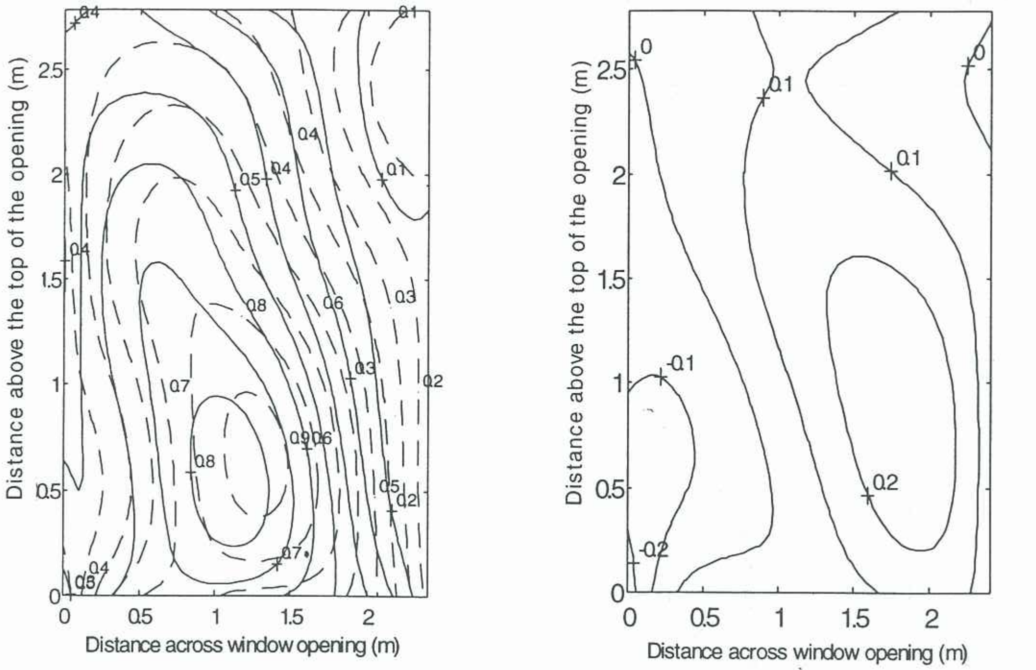
Figure 1. External three-dimensional thermocouple grid. A thermocouple was attached 5 cm away from each node of the grid



a) Burn 5 (dashed) & Burn 8 (solid).

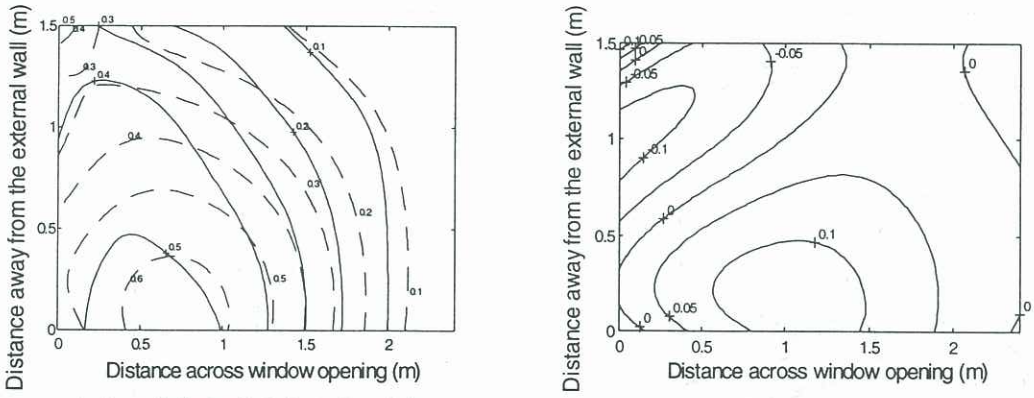
b) Difference between Burn 5 and Burn 8.

Figure 2. Class 1b (Burns 5 and 8) Plane 3 **(a)** dimensionless and time-averaged temperature contours; and **(b)** the corresponding difference contours.



a) Burn 5 (dashed) & Burn 8 (solid). b) Difference between Burn 5 and Burn 8.

Figure 3. Class 1b (Burns 5 and 8) Face 1 (**a**) dimensionless and time-averaged temperature contours; and (**b**) the corresponding difference contours.



a) Burn 5 (dashed) & Burn 8 (solid).

b) Difference between Burn 5 and Burn 8.

Figure 4. Class 1b (Burns 5 and 8) Level 4 (**a**) dimensionless and time-averaged temperature contours; and (**b**) the corresponding difference contours.