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Wind-blown pool fire, Part I: Experimental characterization of the thermal field

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ABSTRACT

Experiments were conducted to investigate the macroscopic thermal behaviour of 2 m diameter Jet A fires in crosswinds of 3–10 m/s. This scenario simulated an outdoor transportation accident with the fire representing a burning pool of aviation fuel. To date, the limited number of experiments that have been conducted to examine wind effects on fire behaviour have generally been performed at small scale, which does not fully simulate the physics of large fires, or in outdoor facilities, with poorly controlled wind conditions. This paper presents the first systematic characterization of the thermal environment in a large, turbulent, pool fire under controlled wind conditions. Three parameters describing flame geometry – flame tilt, flame length and flame drag – were measured using temperature contour plots and video images. The temperature-based method of estimating flame geometry provided considerable improvement over visually based methods, particularly when significant smoke blockage of the luminous flame envelope occurred. At low wind speeds, significant plume curvature was observed, hindering description of flame tilt by a single angle. As the wind speed increased up to 10 m/s, extremely high levels of flame tilt, flame drag and flame length occurred.

1. Introduction

One of the motivations for research into fire behaviour is to improve the ability to predict hazards from a fire in a given accident scenario [1–3]. In order to analyse a given scenario, one must first determine (either by modelling or by direct observation) how large the fire is and how intensely it is burning, requiring knowledge of such characteristics as flame geometry, flame temperature and heat release rate. Once the size and intensity of the fire are established, heat transfer models can be used to predict hazard levels to the fire surroundings [2,4]. Collection of quality experimental data is critical to verifying the accuracy of such predictions, and model validation is indeed an important part of fire model development [3]. Therefore, experimental simulation of realistic, yet controlled, accidental fire scenarios is necessary for improvement of existing fire models and development of new models.

To date, most of the experimental research into fire behaviour has been conducted on fires in quiescent atmospheres, with smaller fires typically studied in controlled laboratory environments [5–8] and larger fires studied outdoors under calm or very low (<2 m/s) wind conditions [7,9–12]. The ability to simulate real-life accident scenarios has been limited, however, because tests with small-scale fires do not fully simulate the physics of large-scale fires and outdoor tests with larger fires are subject to poorly controlled ambient conditions. This has severely restricted the quantity and quality of the data that have been acquired. Some research into wind-blown pool fires has been conducted, focussing initially on flame geometry [13–21]. In most cases, photographic or video images were used to characterize the shape of the fire, yet visual methods have limited effectiveness in large, sooty fires. Differences in the methods used to define and measure flame geometry have also contributed to significant scatter in the results. Recently, fuel burning rate and heat feedback to the fuel surface have been more closely examined in wind-blown fires, with some studies showing approximately linear increase in burning rate with increasing wind speed [21–25] and others indicating more complex, non-monotonic changes in burning rate as the wind speed increased [26,27]. These findings are in contrast to earlier studies that reported decreasing trends in burning rate with increasing wind speed [28,29]. Such conflicting trends demonstrate the need to better understand the physics affecting wind-blown pool fires across a wide range of fire size, wind speed and fuel type.

The present study builds upon the above research through a series of controlled, large-scale experiments to investigate the thermal environment encountered in an accident scenario with a pool fire in crosswind. Through characterization of the

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Nomenclature

θ	flame tilt angle (deg)
D	diameter of fuel pool (m)
D'	length of elongated flame base when flame drag is present (m)
L	flame length (m)
T_{init}	temperature measured immediately prior to test (°C)
T_{ss}	average temperature measured during period of steady burning (°C)
x	coordinate specifying distance from fuel pan centre in direction of wind; see Fig. 4 (m)
y	coordinate specifying distance from fuel pan centre perpendicular to direction of wind; see Fig. 4 (m)
z	coordinate specifying height above floor; see Fig. 3 (m)

Fig. 1. University of Waterloo Live Fire Research Facility.

temperature field in the fire plume, the overall geometry of the fire could be described in greater detail than by looking at video images alone. In Part I of this two-part paper, the experimental methods and main experimental results are presented. In Part II, the measured parameters of flame geometry are compared to values predicted by empirical correlations available in the literature.

2. Experimental setup

2.1. Test enclosure

All experiments were performed in the University of Waterloo Live Fire Research Facility. The test enclosure was designed to allow repeatable experiments involving large fires in controlled and fully characterized crosswinds. The enclosure had a floor area of 19.5 m by 15.4 m and was surrounded by corrugated steel walls and a corrugated steel, gable roof (Figs. 1 and 2). The height of the enclosure was 7.6 m at the walls and 12.8 m at the longitudinal midplane. For the present experiments, the furniture calorimeter area at the southeast corner of the test enclosure (Fig. 2) was blocked off with a large piece of tarp in order to minimize its effect on the flow field inside the test enclosure.

A wind generation system was located at the west end of the test enclosure. This system was composed of six vane axial fans (Model 78-26 Series 1000) manufactured by Howden Buffalo Inc. of Camden, SC. Each fan was 2.0 m in diameter and had a specified maximum flow rate and rotational speed of 78.7 m^3/s and 1185 rpm, respectively. Variable frequency drives on the fan motors permitted operation at lower flow rates. The fans were arranged in a bank of two rows with three fans each, one stacked on top of the other (Fig. 1). The flow from the fans first passed through a plenum of 8.2 m by 5.9 m cross-sectional area and 8.3 m length (Fig. 2). An array of square ducts (seven across by five tall, with the same total cross-sectional area as the plenum) was located at the exit of the plenum. Each duct had a cross-sectional area of 1.2 m by 1.2 m and a length of 1.8 m. The ducts, along with two vertical screens located roughly halfway down the plenum, provided a basic level of conditioning to the crosswind flow before it entered the test enclosure. After passing through the test enclosure, the flow exited through a 7.9 m by 7.9 m overhead door, which was kept fully open whenever the fans were in operation.

Characterization studies of the flow field inside the test enclosure indicated relatively uniform wind speed in the main core region of the flow [30]. Time-averaged, cold-flow measurements taken with bi-directional velocity probes at a distance of 2 m downwind of the plenum exit indicated local spatial variations (1σ) in wind speed of $\pm 13\%$ within the core region. Turbulence intensity levels of approximately 11% were also measured in the core region using a sonic anemometer positioned 1.25 m downwind of the plenum exit on the longitudinal midplane of the test enclosure. As distance downwind of the plenum increased, the prominence of the local spatial variations in velocity diminished due to effects of mixing within the flow, while levels of turbulence intensity measured on the longitudinal midplane did not change significantly. Additional details of the wind characterization study are available in Best [30].

2.2. Burner

The burner was a fixed quantity, stainless steel pan with a mean inside diameter of 1.97 m and depth of 0.18 m.[1] The pan was

[1] For simplicity, the pan diameter will hereafter be referred to by its nominal value, 2 m.