Wind Impacts on Fire Spread and Structural Failure in a Complex Terrain

Grahame B Douglas[1], Yaping He[1], Kenny C S Kwok[1]

[1]*School of Engineering, University of Western Sydney, Kingswood, Australia, g.douglas@uws.edu.au*

1 INTRODUCTION

Bushfires are a frequent and inevitable aspect of the Australian landscape whose pattern of occurrence is strongly associated with adverse weather conditions [1]. Most bushfires are dealt with and controlled by the various fire services at their early stages of development. Severe fire events that can cause major losses to life, property and the environment are less common, but occur with some regularity. They are erratic in nature and of high intensity, making control difficult [2].

Construction practice, as applied through the Building Code of Australia, has provided some opportunities for improved building resilience in the face of bushfire attack, however, wind loading does not form part of this assessment process [3].

2 NATURE OF WEATHER CONDITIONS ASSOCIATED WITH MAJOR BUSHFIRES IN AUSTRALIA

The role of wind in adverse bushfire conditions is by its very nature, a complex aspect of the fire behaviour phenomenon. Ambient wind conditions are a major driver of fire behaviour in terms of rates of spread, fire intensity, flame characteristics and spotting [4]. Wind also supports the transport of burning embers or brands significant distances to push the fire ahead of the fire front or to vulnerable parts of buildings, thereby increasing building vulnerability to bushfire attack [3].

A measure of potential fire behaviour can be expressed through FFDI or Forest Fire Danger Index. The FFDI generally describes the chances of a fire starting (if ignited), its behaviour and difficulty in suppression. Increased indices occur with smaller changes in reduced humidity and increased wind speed and/or temperature [5]. Increased wind speed gives rise to drier fuels and increased fire behaviour, including rates of fire spread and intensity [1].

3 PAST SURVEYS ON BUSHFIRE ATTACK

It has been generally determined that the majority of losses arising from bushfire events occur within distances of up to 100 metres from the bush [6], [7] when FFDI exceeds 40, although in some cases (notably recent bushfire events in Australian Capital Territory (ACT) and Victoria) these distances have extended to in excess of 250 metres [8], [9]. This is illustrated in Figure 1. Losses that are generally associated solely with ember attack have been noted at distances of up to 700 meters and more [8].

Although house surveys and damage assessments have been undertaken in a range of ways after fire events (e.g. Beaumaris fire in 1944 [10]), it was not until a review of house losses associated with the Ash Wednesday fires in 1983 that the potential role of severe winds was recognized which concluded that winds have "played a role in damaging houses, breaking windows, blowing roofs off … . In some cases the wind did more damage than the fires." [11]. However, a clear framework for the application of wind loadings to construction practice has not been developed [3].

In 2009, after the devastation of the 7 February 2009 bushfires in Victoria, a substantial effort was made to extensively survey 1600 of the over 2000 houses lost or damaged during these fire events. The role of wind was noted as a small contributor to loss/damage although 135 were identified as "Fire and Wind" as a likely cause of house fire [9]. Interestingly, some 33 % were identified as "fire damage, wind unknown" and a small number exhibited wind only effects arising from the fires. This is in strong contrast to reported losses of plantations and properties in 2003 ACT fires [3] and the observed dislodgement of un-burnt roofing elements from burnt out structures in Victoria [9].

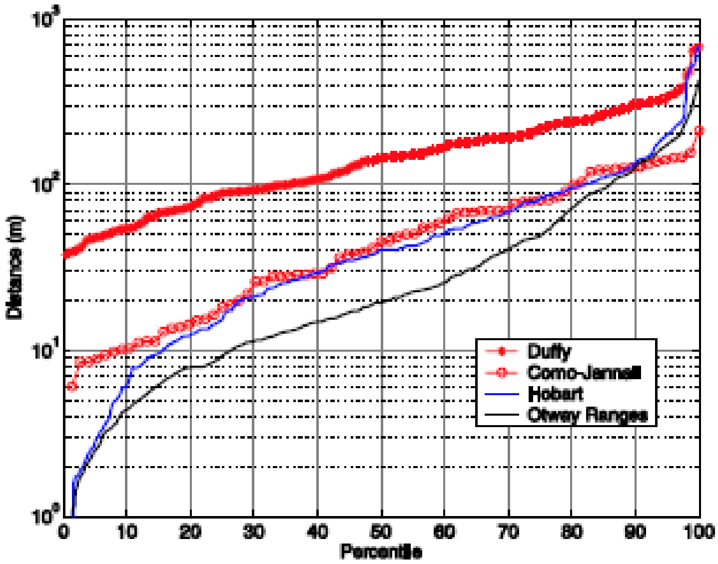

Fig 1 House losses distances from bushland interface [8].

What appears therefore is some confusion about the role of wind in the destruction of houses and inconsistency in evaluation. This may be partly attributed to the inconsistencies in the survey format and in the skills of data collectors. Survey forms changed a number of times over the years and in more recent fires information was collected only in electronic format. The surveyors had mixed skills and recorded information after the fires, with little data collected by fire fighters at the scene [9].

4 FIRE GENERATED WIND GIVING RISE TO HOUSE LOSS OR DAMAGE DURING BUSHFIRE

During the Victorian bushfires, ambient average wind speeds measured at stations some distance from the fires (e.g. Kilmore Gap AWS) only rarely exceeded 60 kph [12]. Such wind velocities can not of itself be associated with wind damage to structures. Wind gusts, although larger, were also unlikely to be a major mechanism for building damage. Wind speeds in excess of 100 kph are required for significant building damage and this is in stark contrast to views that local wind speeds ranged from 40 kph to 50 kph during the ACT fires of 2003 [13].

It is often observed in discussion with operational fire fighters and from film footages that significantly stronger winds can be associated with the passage of the fire. Three key elements in the development of major fires especially that associated with fire events at the extreme to catastrophic levels have been identified [14], [15] and [1]. The three key elements are: terrain, weather and fuel. These key elements can give rise to dramatic pyro-convection plume driven fires as seen during the 2003 ACT and 2009 Victoria fires. In fact the ACT fires were said to move 10 km in 45 minutes, indicating a significant wind strength which impacted on Canberra suburbs with a resultant loss of 4 lives and some 500 houses plus other businesses and buildings [1].

Terrain can be divided into three categories: flat (mostly grassland), undulating (with woodland vegetation) and rugged (usually forested). The role of terrain appears crucial in establishing the conditions associated with such large fires. Altitude of the terrain may also be a contributor particularly during periods of instability. Terrain gives rise to leeward disintegration of high altitude air streams and subsequent mixing with the onset of unstable conditions between the fire front and upper airstream. Lee slope channeling and coupled flow atmosphere events giving rise to a plume driven feedback. In addition, spotting may cause new fires ahead of the fire front and burning up the lee side slope increasing the influence of converging fire fronts with resultant increased fire activity. The resultant plume is a violent pyro-convection dominant event and damage has been rated at an equivalence of F-2 on the Fujita Tornado Intensity Scale, with wind speeds of between 51 to 70 m/s (180 – 250 kph) [15].

The weather patterns preceding major bushfire events have been described earlier, however a number of pre-conditioning events may contribute to fire weather. For example, air at high altitudes can be associated with the dramatic and rapid loss of moisture arising from cooling and ice formation, effectively reducing overnight humidity. Such conditions may stream down from higher altitudes to lower altitudes aiding in the conditioning of fuels and contrary to the traditional diurnal cycle of day/night moisture gradients that operate in normal conditions. In some areas, Foehn-like conditions may also play a role in pre-conditioning lower altitudes [16].

Weather is a key driver in the development of bushfires. During major bushfires of FFDIs of >50, severe to extreme fire weather in unstable conditions in conjunction with sufficient fuel aid plume development. Plumes have been reported as rising 10 km in the air [14]. Such conditions can be seen in the development of pyro-cumulonimbus clouds in relation to the ACT fires in 2003. This was replicated during the 2009 Victoria bushfires where fire-induced winds were estimated as exceeding 120 kph [2].

Importantly, the most severe winds occur on the lee slope and in rugged terrain, wind direction is not dictated by ambient wind alone. Winds may travel along topographical distortions such as gullies and saddles, increasing localized wind speeds in complex terrain [14], [15].

5 CONCLUSION

Bushfires under extreme conditions of weather and fuel and under the influence of rugged terrain, gives rise to increased fire behaviour out of proportion with the ambient conditions normally associated with bushfire events. This can give rise to the development of a violent pyro-convection dominant event and associated increased winds [17].

A preliminary wind strength risk framework based on fuel, topographical context and distance can be developed for the purposes of protection of buildings from the effects of elevated wind velocities associated with thermal expansion, buoyancy and streaming of high altitude winds under exaggerated bushfire behaviour. Table 1 provides a preliminary framework from which further work can be undertaken.

Table 1: (Preliminary) Relative risk of pyrocumulous generated fire behaviour.

Terrain/Vegetation conditions.	**Fire Weather (FFDI 50) Wind speeds < 30 kph**	**Fire Weather (FFDI 50-75) Wind speeds 30-45 kph**	**Fire Weather (FFDI 75+) Wind speeds >45 kph**
Flat ground Grass – heath, woodland. Short fire run. Windward slopes.	Low risk	Low risk	Moderate risk
Undulating topography, low forest – woodland. Moderate fire run. Windward slopes.	Low risk	Moderate risk	High Risk
Rugged terrain Heavily timbered Plateau or leeward slopes. Long fire run.	Moderate risk	High Risk	Extreme risk

6 REFERENCES

1. Webb R., Davis C.J. and Lellyett S. 2003. Meteorological aspects of the ACT Bushfires of January 2003. *Submission to the Inquiry into the Operational Response to the January 2003 Bushfires.* (McLeod Inquiry website).
2. Tolhurst K. 2009 Report on the Physical Nature of the Victorian Fires occurring on 7th February 2009.
3. Blanchi, R. and Leonard, J. 2005. *Investigation of Bushfire Attack Mechanisms Resulting in House Loss in the ACT Bushfire 2003*. Report for Bushfire CRC. CSIRO Manufacturing and Infrastructure Technology.
4. Gould, J.S.; McCaw, W.L.; Cheney, N.P.; Ellis, P.F.; Knight, I.K. and Sullivan, A.L. 2007a *Project Vesta. Fire in dry eucalypt forest: fuel structure, fuel dynamics and fire behaviour*. Ensis-CSIRO, Canberra, and WA Department of Environment and Conservation, Perth.
5. Noble I.R.; Bary G.A.V. and Gill A.M. 1980. McArthur's fire-danger meters expressed as equations. *Australian journal of ecology* **5**, 201-203.
6. Ahern A. and Chladil M. 1999. How far do bushfires penetrate urban areas? Paper presented at the *1999 Australian Disaster Conference*, Emergency Management Australia, Canberra, ACT.
7. Douglas G.; Tan Z.; Midgley S. and Short L. 2009. Bushfire Building Damage - A NSW Perspective. *Proceedings of the Royal Society of Queensland*, Vol 115, pp. 161-169.
8. McAneney J.; Chen K.; Crompton R. and Pitman A.J. 2007. Australian Bushfire Losses: past, present and future. *Wildfire 2007,* Seville, Spain.
9. Bushfire Cooperative Research Centre (2009) *Victorian 2009 Bushfires Research Response: Final Report*.
10. Barrow G.J. 1945 A Survey of Houses Affected in the Beaumaris Fire, January 14, 1944 *Journal of the Council for Scientific and Industrial Research,* Vol. 18, No. 1.
11. Ramsay G.C., McArthur N.A. and Dowling V. 1987. Preliminary results from an examination of house survival in the 16 February 1983 bushfires in Australia. *Fire and Materials*, vol.11, 1987: pp. 49-51.
12. Bureau of Meteorology 2009. *Appendix 6*: forming part of the Submission to the Victorian Bushfire Royal Commission.
13. Wang H. 2006 Ember Attack: Its Role in the Destruction of Houses during ACT Bushfire in 2003. *Life in A Fire-Prone Environment: Translating Science into Practice* Bushfire Conference 2006 - Brisbane, 6–9 June 2006.
14. Sharples, J.J. 2009. An overview of mountain meteorological effects relevant to fire behaviour and bushfire risk. *Int.J. of Wildland Fire*, 18, 737–754.
15. McRae R. 2009 *Submission to the Victorian Bushfire Royal Commission*. (SUBM.002.052.0325_R)
16. Sharples J.J., Mills G.A., McRae R.H.D. & Weber R.O. (2009). “Fire danger anomalies associated with Foehn-like winds in southeastern Australia”, *Proc 18th World IMAC/MODSIM Congress*, 13-17 Jul., Cairns, Australia,.http://mssanz.org.au/modsim09.
17. Dold, J.W., Weber, R.O., Gill, M., McRae, R., Cooper, N., 2005, Unusual phenomena in an extreme bushfire, *5th Asia-Pacific Conference on Combustion*, The University of Adelaide, Adelaide, Australia, 17-20 July 2005.