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FIRE COALESCENCE AND MASS SPOT FIRE DYNAMICS: EXPERIMENTATION, MODELLING AND SIMULATION

Annual project report 2015-2016

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Version	Release history	Date
1.0	Initial release of document	05/09/2016

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

Publisher:
Bushfire and Natural Hazards CRC

August 2016

Citation: Sharples, J.J., Hilton, J.E., Sullivan, A.L. (2016) Fire coalescence and mass spot fire dynamics: experimentation, modelling and simulation Annual project report 2015-2016. Bushfire and Natural Hazards CRC.

Cover: The Mt Bolton – Laverys Road fire in Victoria, February 2016. Photo by: Wayne Rigg, CFA

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EXECUTIVE SUMMARY

This report outlines the progress of the *Fire Coalescence and Mass Spot Fire Dynamics* project, which is one of the projects within the Next Generation Fire Modelling cluster.

The project has now been running for approximately 15 months. The Science Plan has been finalized and the Advisory Committee has been settled. The experimental program is now up and running after a few initial delays caused by issues with sourcing adequate fuel and with development of experimental apparatus. The modelling and simulation aspects of the project have made a number of significant fire spread modelling developments and have made strong contributions to our understanding of the processes driving fire coalescence and dynamic fire spread more generally.

In particular, the research has addressed the role that fire line geometry (especially curvature) plays in the dynamic propagation of wildfires. The project team has demonstrated that fire propagation models incorporating curvature dependence can out-perform quasi-steady (first-order) models when applied to simple wind-driven fires at both laboratory and field scales.

In addition, the research has produced a number of fundamental insights into how the shape of the fire line can affect the pyroconvective interactions between different parts of a fire. These insights have mostly been gained by targeted simulations using a coupled fire-atmosphere model.

At this stage the project has published two conference papers (one peer reviewed), and two conference posters. There are currently three journal papers submitted to international peer-reviewed journals with another one in the final stages of preparation. In addition, the project team has delivered thirteen presentations and posters to stakeholders and researchers

After providing some background information on the project's aims and methodology, this report provides details on the progress of the project to date. In particular this includes:

- Update on milestone delivery;
- New research developments;
- Details on presentations that have been delivered by members of the project team;
- Details on publications and publications in preparation;
- Progress of the PhD scholar.

At the time of writing, the project is on schedule. The project team is confident that all milestones will be successfully delivered along with a number of unscheduled, yet significant research outputs.

A/Prof. Jason Sharples
Project Leader
School of Physical, Environmental and Mathematical Sciences,
UNSW Australia

END USER STATEMENT

Simon Heemstra, *New South Wales Rural Fire Service, NSW*

The project is making good headway using an innovative multi-streamed approach including laboratory experiments, coupled fire-atmosphere physical modelling and simplified analogue modelling. I expect that the results of the research will lead to operationally applicable tools that will improve our ability to predict fire spread. I am very pleased with the level of end user engagement from the project team, which will be key to technology transfer later in the project. The number and quality of research publications coming out of the project is excellent.

INTRODUCTION

Fire behaviour in dry eucalypt forests in Australia (and in many other vegetation types to a lesser extent) is characterised by the occurrence of spotfires—new fires ignited by the transport of burning debris such as bark ahead of an existing fire. Under most burning conditions, spotfires generally play a minor role in the overall propagation of a fire, except perhaps when spread is impeded by breaks in fuel or topography which spotfires enable the fire to overcome. However, under conditions of severe and extreme bushfire behaviour, spotfire occurrence can be so prevalent that spotting becomes the dominant propagation mechanism and the fire spreads as a cascade of spotfires forming a 'pseudo' front (McArthur 1967).

It has long been recognised that the presence of multiple individual fires affects the behaviour and spread of all fires present. The convergence of separate individual fires into larger fires is called coalescence and can lead to rapid increases in fire intensity and spread rate, often in directions at odds with the prevailing wind. This coalescence effect is frequently utilised in prescribed burning via multiple point ignitions to rapidly burn out large areas.

The zone between two coalescing fires is known as the convergence or junction zone and can be a very dangerous place to be for firefighters and may lead to highly erratic fire behaviour as witnessed during the 2003 Canberra fires. Fire behaviour under such conditions may be dominated by dynamic feedback processes between the energy released by each fire and the coupling of that energy with the atmosphere.

All existing operational fire behaviour models assume that a fire will burn at an approximately constant (quasi-steady) rate of spread for a given set of environmental conditions. While recent work showed that an individual fire starting from a point accelerates to this steady state, little research has been undertaken into the behaviour of multiple simultaneous adjacent ignitions under wildfire conditions or the effects of the dynamic feedbacks involved. No operational fire spread models currently account for the dynamical aspects of fire spread, particularly fire-fire interactions. This inability to accurately predict the behaviour of mass spotting events and the interactions of multiple adjacent fires places firefighters at risk and the general public in danger. With the projected climate change impacts expected to produce more extreme bushfires and a prevalence of mass fire behaviour, this deficiency in our understanding and operational systems represents a considerable knowledge gap.

The effects of dynamic processes on fire spread cannot be calculated using tables, spreadsheets or simple calculators. To comprehensively account for the effects of dynamic fire spread it is necessary to model the phenomenon using a physics-based model that incorporates complete descriptions of the key processes, including interactions between the fire, the fuel, topography and the surrounding atmosphere (e.g. WFDS (Mell et al 2007), FIRETEC (Linn et al 2002)). Unfortunately, such a modelling approach is computationally intensive and expensive, with associated model run-times that prohibit operational application (Sullivan 2009).

This project addresses these issues by investigating the processes involved in the coalescence of free-burning fires under experimentally controlled conditions, quantifying the physical mechanisms involved in these, and investigating the potential of geometric drivers of fire line propagation (e.g. fire line curvature) with the aim of developing a physically simplified proxy for some of the more complicated dynamical effects. This approach enables development of models that are able to effectively emulate the dynamics of fire spread without the need to explicitly model fire-atmosphere or fire-fire interactions in a computationally costly manner.

PROJECT BACKGROUND

To enhance our knowledge of the effects of intrinsic fire dynamics on fire spread this project employs sophisticated mathematical modelling techniques in combination with fire experiments spanning laboratory and landscape scales. In particular, the project will develop computationally efficient fire spread models which include physically simplified proxies for complicated dynamical effects.

The overarching analytical approach adopted in this project is to treat fire as an evolving interface. This is not new – many researchers have treated fire in such a way, but the methods they have used have often been confounded due to the changes in topology that can be encountered when fire lines merge or when pockets of unburnt fuel develop (Bose et al. 2009). Such occurrences are rife when spot fires coalesce (see Figure 1), and so employing a methodology that is able to successfully deal with these types of behaviours is crucial to effectively and efficiently model spot fire development. We therefore employ a level set approach, which is well known to be able to deal with such complexities (Sethian, 1999).

In addition to its ability to deal with topological changes, the level set method also allows for the easy inclusion of variables such as fire line curvature, which we aim to include as a two-dimensional proxy for more complicated three-dimensional effects.

This project builds on initial work by members of the project team, who have investigated the use of curvature-based models to simulate instances of dynamic fire propagation such as fire line merging (Sharples et al. 2013; Hilton, 2014).

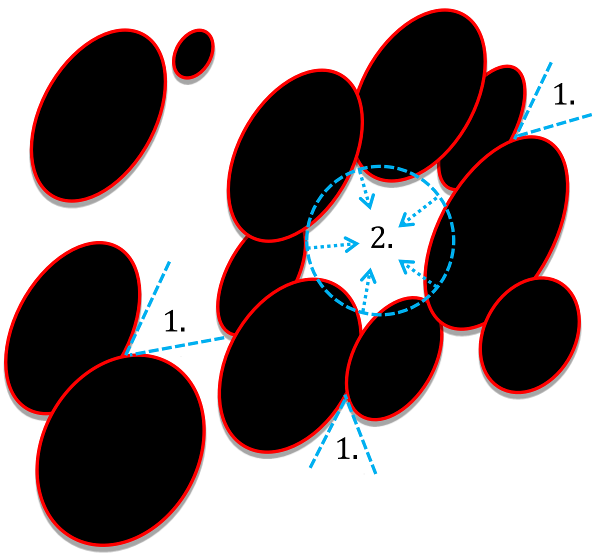


Figure 1: Schematic representation of coalescing spot fires. Examples of fire line merging are marked with a 1, while an example of perimeter collapse is marked with a 2. Both phenomena involve changes in topology.

To complement model development the project will also include a targeted experimental program. This will involve analysis of experimental fires burning under controlled laboratory conditions as well as analysis of field experiments.

LEVEL SET METHODS FOR INTERFACE MODELLING

Level set methods provide a feasible method for dealing with the types of behaviours encountered when spot fires coalesce. Figure 1 shows a schematic representation of coalescing spot fires and the types of topological issues that can arise due to the discontiguous nature of spot fires.

Dynamic behaviour and curvature dependence

Viegas et al. (2012) noted that when two obliquely intersecting fire lines merge, their point of intersection will advance more rapidly than what would normally be expected. This is due to dynamic interactions that enhance radiative and convective heat transfer in a way that causes the fires to burn faster in regions surrounded by fire. Such regions can be characterized as having negative fire line curvature. Sharples et al. (2013) showed how using a curvature dependent rate of spread can successfully emulate the types of behaviour observed by Viegas et al. (2012). This approach allows for the effect to be modelled in two-dimensions despite the complicated three-dimensional processes that are actually driving it.

The level set method employed is formulated as follows:

$$\frac{\partial \varphi}{\partial t} + \alpha \nabla^2 \varphi + N(\varphi) = 0, \qquad (1)$$

where

$$N(\varphi) = \alpha \frac{\nabla \varphi}{|\nabla \varphi|} \cdot \nabla(|\nabla \varphi|) + \beta |\nabla \varphi|. \qquad (2)$$

In this model a simple affine dependence of rate of spread on fire line curvature has been assumed; that is,

$$R = \alpha \kappa + \beta,$$

where R is the rate of spread (normal speed), κ is the fire line curvature and α and β are model parameters.

The project aims to extend these initial investigations to consider more appropriate mathematical formulations of geometric dependence and also the inclusion of extrinsic factors such as wind and slope.

EXPERIMENTAL PROGRAM

The modelling techniques outlined above will be complemented by a series of laboratory experiments using the CSIRO Pyrotron facility (Sullivan et al. 2013). In addition the research will also draw upon available data from field-based experiments. Empirical information will be complemented with information gained from targeted numerical experiments using a coupled fire-atmosphere model. The use of such modelling enables a deeper insight into the physical mechanisms driving the observed dynamic behaviours.

Laboratory experiments

A series of experiments using the CSIRO Pyrotron facility will be conducted. These experiments will be broken down into four categories:

- Parallel fire line experiments
- V-shaped fire experiments
- Ring fire experiments
- Multiple spot fire experiments

The specifics of this experimental program are provided in detail in the Project Science Plan.

Field experiments

In addition, the project will analyse data collected as part of the CSIRO-led Project Aquarius (1983-1985), which examined the behaviour of a number of point ignitions set in close proximity to each other. Again, the Science Plan provides more detail.

Also, if and when opportunities arise, data arising through other collaborative research will be used to help inform the project research. For example, the collaborative arrangement between UNSW and the University of Coimbra, Portugal, which is further supported through the MOU between the Bushfire and Natural Hazards CRC, has already produced experimental data of relevance.

Numerical experiments

A number of numerical simulations will be carried out in order to better understand the physical mechanisms driving spot fire coalescence, to provide information of the scale dependence of the effects under consideration, and to provide additional information for two-dimensional model development.

Moreover, the numerical simulations will also provide information relating to ember trajectories that are being driven by an evolving heat source. As such they will provide information that will be used as part of the development of an end-to-end model for spot fire development.

These simulations will make use of the WRF-Fire coupled fire-atmosphere model, which will be run on the supercomputer at the NCI National Facility at the ANU.

WHAT THE PROJECT HAS BEEN UP TO

MILESTONE DELIVERY

At the time of writing the project has completed all milestones to date. In particular this has included delivery of the finalised Science Plan and submission of two papers to the International Journal of Wildland Fire. Moreover, a short video has been developed to communicate the project's background and aims at a non-technical level .

A number of issues were encountered that delayed progress on some milestones. Specifically, there were delays related to software availability issues (which have since been resolved), and due to a combination of sourcing fuel of sufficient quantity, quality and consistency and experimental apparatus problems. The experimental program outlined in the Science Plan involves a very large number of experiments, and so requires a substantial amount of fuel to facilitate them. The ability to source such a large quantity of fuel of similar characteristics (species, composition, etc.) has been problematic. As a solution, the experimental design has been adapted so that alternate fuel (such as straw) can be effectively utilised if necessary.

The second issue holding up the experimental program involved development of a circular (metal) trench to ignite ring-shaped fires in the Pyrotron. Unfortunately, such a configuration is prone to warping, especially under duress of heat, and this warping would lead to uneven ignition patterns. This issue has now been resolved – we have taken delivery of ring fire ignition trenches and the experimental program is back on track.

Looking ahead, production of one scheduled paper has been held up due to data availability issues – it has taken longer than anticipated to collate the Project Aquarius data. Alternate options have been considered; for example, we have made initial enquiries about using the data set derived from field experiments conducted by researchers from the University of Coimbra.

Some technical issues have also with spin-up of the WRF atmospheric model. Problems with energy leakage from the model domain have meant that we have been unable to establish the stable turbulent boundary layer required to model the effects of a fire on ember fall distributions. This issue has been addressed by seeking expert advice from the National Centre for Atmospheric Research (NCAR) in the United States. The received advice is now being implemented. Overall, however, it is expected that these issues will only delay delivery by by up to six months. An extension of the due date of delivery will likely be sought in these two cases, with commensurate adjustment of the due dates of other contingent deliverables.

RESEARCH DEVELOPMENT

The research has been developed along three main lines of focus:

- Development of the level set model to incorporate dependence on environmental variables such as wind and slope;
- Investigation of intrinsic fire dynamics caused by pyroconvective interactions;
- Experimental observations of dynamic fire propagation in the CSIRO Pyrotron.

In the first case, the model given above by equations (1) and (2) was extended by modifying the nonlinear term in (2) to one of the form given in equation (3):

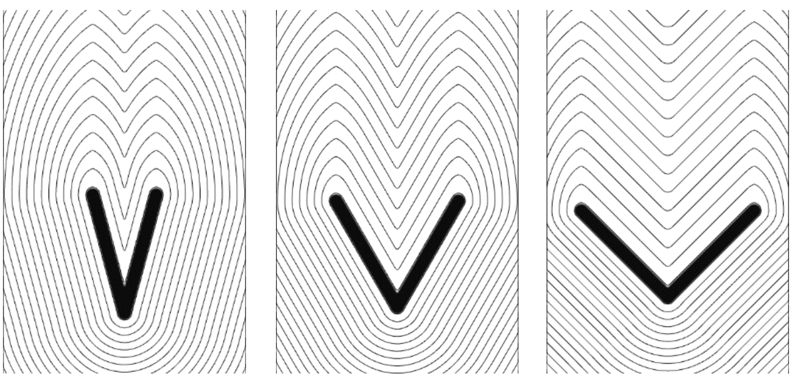
$$N(\varphi) = \alpha \frac{\nabla\varphi}{|\nabla\varphi|} \cdot \nabla(|\nabla\varphi|) + \beta|\nabla\varphi| + \boldsymbol{u}(\gamma) \cdot \nabla\varphi. \tag{3}$$

The addition of the advection term $\boldsymbol{u}(\gamma) \cdot \nabla\varphi$ permits incorporation of the extrinsic effects of wind and slope; however at this stage of the research only the effects of wind have been incorporated. It is worth noting that incorporating wind in this way differs with the way wind is incorporated in existing fire spread models. For example, in PHOENIX Rapid Fire and the newly developed ACCESS-Fire coupled fire-atmosphere model the effect of wind is built into the normal speed of the fire line. In the model proposed here, the effect of wind is treated as bulk advection, which can be tuned (through the model parameter γ) independently of other variables affecting the rate of spread of the fire.

In particular, the advective effect of wind is modelled as follows:

$$\boldsymbol{u}(\gamma) = \begin{cases} \gamma(\hat{w} \cdot \hat{n})\hat{w} & \text{if } \hat{w} \cdot \hat{n} > 0, \\ 0 & \text{if } \hat{w} \cdot \hat{n} \leq 0. \end{cases}$$

Here $\hat{w}$ and $\hat{n}$ are the unit vectors pointing in the direction of the wind and normal to the interface, respectively. The model defined by (1) and (3) has been applied to experimental fires at both laboratory and field scales and was found to accurately reproduce the observed fire propagation in both cases. Moreover, for fires with negatively curved perimeters, the model incorporating curvature (i.e. with $\alpha \neq 0$) was found to produce results that better resembled the observed fire propagation, than results obtained from models with no curvature dependence. This finding suggests that curvature is a useful proxy for dynamic fire propagation in some scenarios.



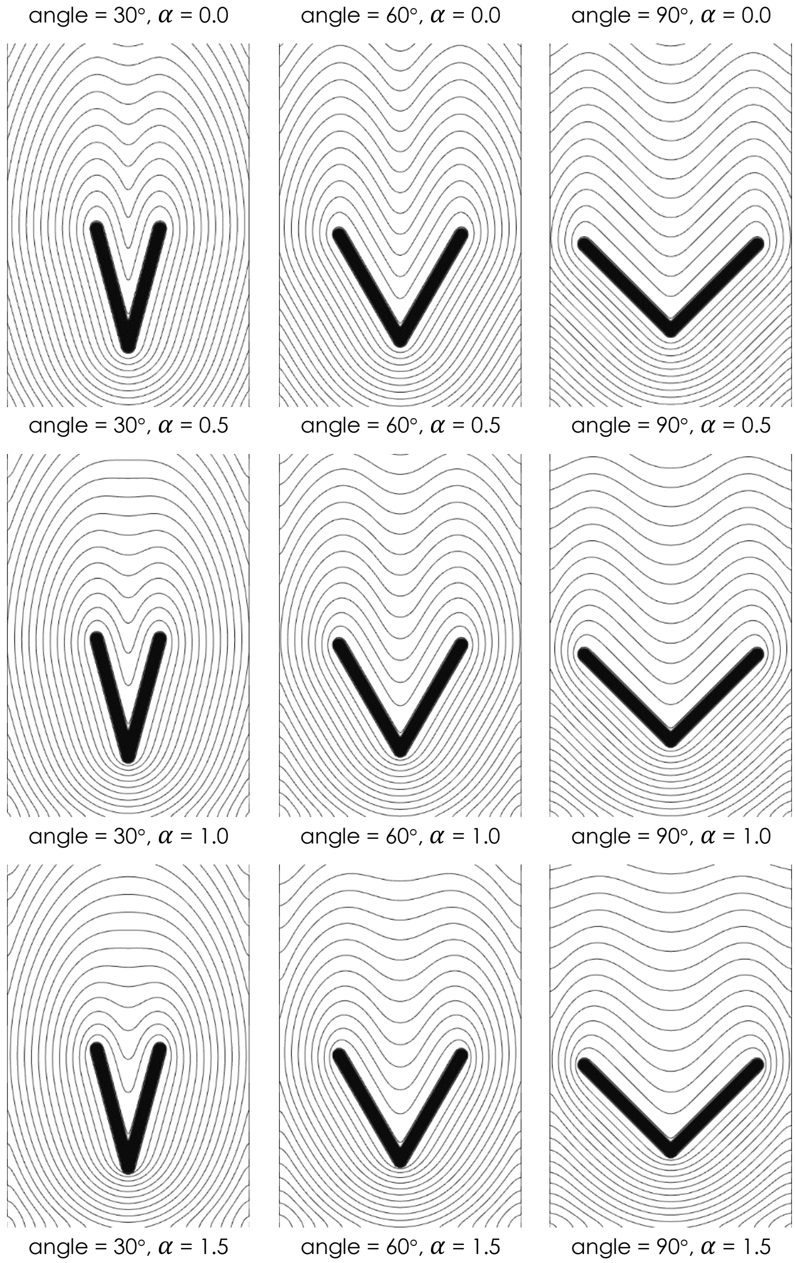


Figure 2: Computational simulations of 'V-shaped' fire isochrones for a range of interior angles and strengths of curvature dependence (described by parameter α). The other model parameters are fixed: $\beta = 0.2$ and $\gamma = 0.3$.

Some example fire propagation simulations produced by the curvature-dependent level set model can be seen in Figure 2. The figure illustrates the effect that the curvature parameter α has on the propagation of the fire – regions of high fire line curvature spread more rapidly when $\alpha \neq 0$.

However, there are some particular fire spread scenarios for which fire line curvature will not be able to properly account for observed dynamic fire propagation. Figure 3 illustrates one such example, in which two straight, parallel fire lines burn towards each other. Even though there is zero fire line curvature the two fire lines interact in a distinctly dynamic fashion.

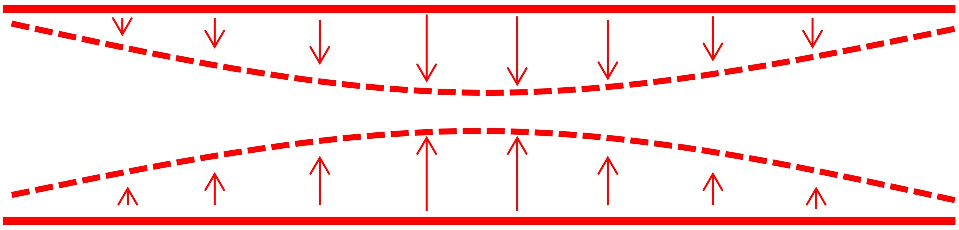


Figure 3: Schematic representation of two straight, parallel fire lines (solid lines) burning towards each other. The dashed lines indicate the fire lines at some subsequent time and portray the effect of the dynamic interaction between the two fire lines. The arrows represent the relative rates of spread of different parts of the fire lines.

Similar conclusions can be drawn from numerical simulations conducted using a coupled fire-atmosphere model. This work considered the propagation of circular arc fires of varying angular extent. Despite the fact that the curvature of each of the fire lines (arcs) was identical, the behaviour of each varied markedly depending on the angular extent of the fire lines. This is illustrated in Figure 4.

The results shown in Figure 4 effectively prove that fire line curvature is not a good predictor of dynamic fire propagation in general, although Hilton et al. (2016) demonstrate its utility in certain cases. Taken together, these findings suggest that there is likely a more general approach to modelling dynamic fire propagation, which amounts to a ‘curvature effect’ in certain special cases. This issue is now being addressed by the research team through further investigation of the physical mechanism behind the ‘curvature effect’ and the innovative use of potential flow based methods.

As part of the second line of research focus, coupled fire-atmosphere modelling was also used to investigate the pyroconvective dynamics that arise when two fire lines merge at an oblique angle. In particular, the simulations emulated the configurations considered by Viegas et al. (2012), albeit at a much larger scale. This work has been detailed by Thomas et al. (2016), who demonstrate the effect that pyroconvective interaction between the fire lines has on the propagation of merging fire lines.

Indeed, Thomas et al. (2016) show that when pyroconvective interaction between the fire lines is removed, the two fire lines spread in a quasi-steady manner. Moreover, they found that when the pyroconvective interaction is included the resulting fire behaviour is qualitatively similar to that observed by Viegas et al. (2012); that is, the point of intersection of the two fire lines initially spreads very rapidly and subsequently decelerates. Results from couple fire-atmosphere simulations illustrating this effect are shown in Figure 5.

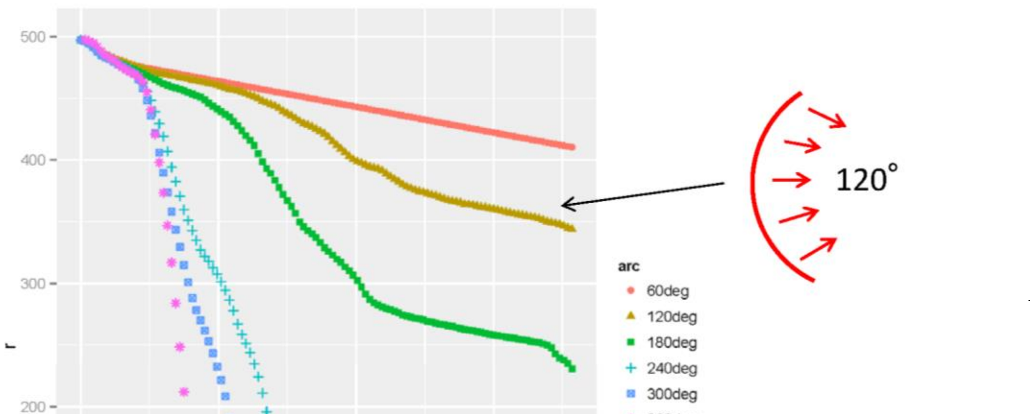


Figure 4: Rate of spread curves for circular arc fires. The schematics on the right indicate the initial fire line configurations for the 120° and 240° cases.

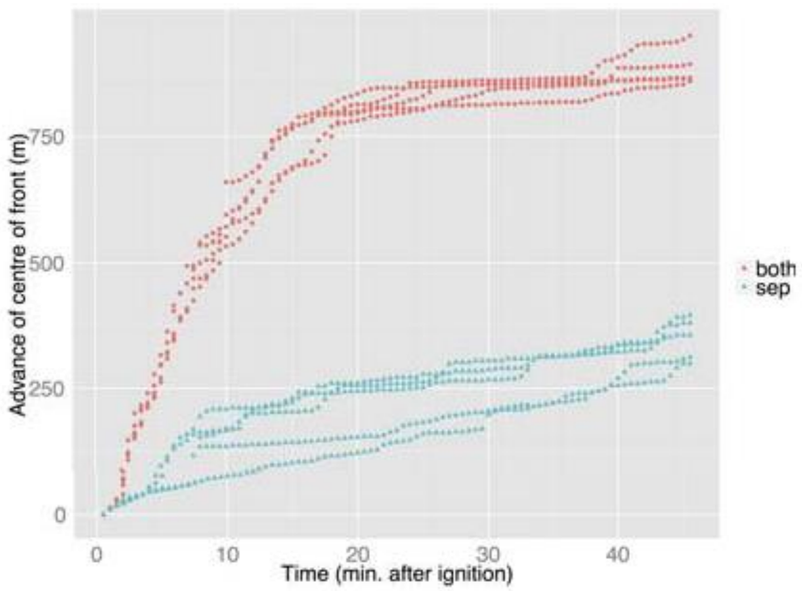


Figure 5: Fire front advance over time for a V-shaped fire with fire lines meeting at 30°. The figure shows the results for various ensemble members. Red points represent spread when both arms of the 'V'-configuration are ignited simultaneously. Blue points indicate spread when each arm is ignited individually (representing the decoupled case). Figure adapted from Thomas et al. (2016).

The findings of Thomas et al. (2016) address an unresolved question concerning the merging of two oblique fire lines: is the dynamic fire spread observed in such cases primarily driven by radiative or convective effects; or is it perhaps a combination of the two? The results of Thomas et al. (2016) strongly indicate that the answer to this fundamental question is that the dynamic fire behaviour is driven primarily by convection and in particular, by pyroconvective interaction between the two fire lines.

The third line of research focus is the experimental fire program being conducted in the CSIRO Pyrotron, with Phase 1 currently being completed. This phase of investigation concentrated on the study of the effect of 'V-shaped' ignitions of various lengths and angles and separation, with the express outcome of being able to ascertain the effect of fire line geometry on the behaviour and spread of small fires from ignition. The experimental design identified 4 main treatments (angles of 15°, 30°, 45° and 60° from centre—total angle of inflection is thus twice this value) of line ignitions of two lengths (800 mm and 1500 mm). The hypothesis being tested is that the effect of the angled ignition increases the rate of forward spread of the apex of the 'V'. The experimental control in this instance is determined as the rate of spread of a straight ignition line with no inflection.

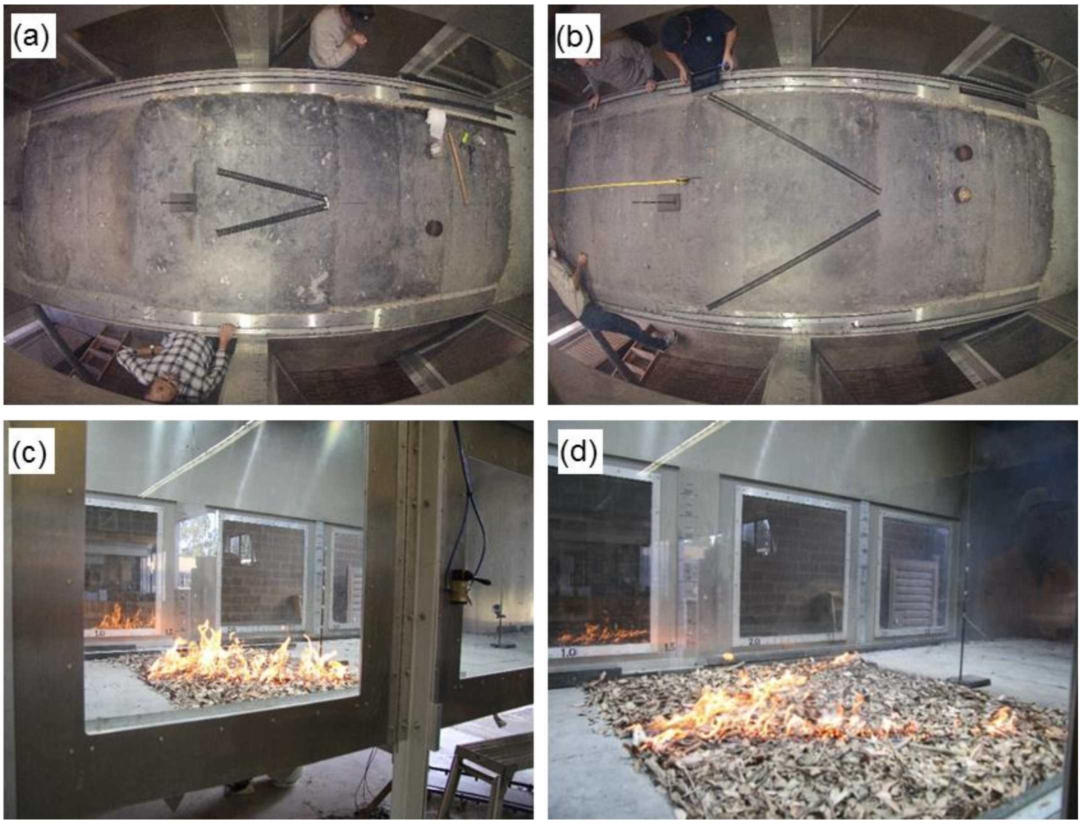


Figure 6: Photographs of experimental set up and experimental fires conducted in the CSIRO Pyrotron as part of the experimental program. Panel (a) shows the ignition pattern for the 800 mm, 15° inflection and zero separation case, while panel (b) shows the same for the 1500 mm, 30° inflection and 150 mm separation case. Panel (c) shows the 800 mm, 30° inflection, no wind experiment underway, while panel (d) shows the 1500 mm, 30°, 1 m s^{-1} wind experiment underway.

The fuel bed consisted of local dry eucalypt forest litter (dead leaf, bark and twigs) < 3 mm in diameter. Fuels were dried in a large walk-in oven to ensure fuel moisture contents were between 3 and 6% oven-dry weight (typical of wildfire conditions). Two wind speed regimes were investigated: 1 m s^{-1} (equivalent to about 11 km h^{-1} in the open above a typical dry eucalypt forest) and zero wind. Example photographs of the experimental set up and of actual experiments can be seen in Figure 6.

A total of 4 replicates of each treatment for each length (where feasible) were undertaken. Additional experiments were undertaken with the same level of replication to investigate the effect of separation of the ignition lines at the apex. This amounted to a total of 64 experiments.

Analysis of the data will commence soon. Primary importance will be rectification of video footage and auto-mapping of fire perimeter to enable direct comparison with simulation results.

PRESENTATIONS

The project has delivered the following presentations and posters:

1. **DYNAMIC MODELLING OF FIRE COALESCENCE: Spot fire project.** Bushfire and Natural Hazards CRC Research Advisory Forum, QUT Brisbane, November 2015. Delivered by J. Sharples.
2. **PYROCONVECTIVE INTERACTION OF TWO MERGED FIRE LINES: Curvature effects and dynamic fire spread.** 21st International Congress on Modelling and Simulation, Gold Coast, December 2015. Delivered by C. Thomas
3. **EXTREME AND DYNAMIC FIRE BEHAVIOUR.** Victorian Country Fire Authority - Fire Behaviour Analyst Pre-season Workshop, December 2015. Delivered by J. Sharples.
4. **AN OVERVIEW OF EXTREME FIRE BEHAVIOUR.** Laharum Brigade Information Day, July 2015. Delivered by J. Sharples.
5. **UNDERSTANDING EXTREME FIRE BEHAVIOUR.** ACT Rural Fire Service Advanced Firefighter Principle Course, July 2015. Delivered by J. Sharples.
6. **EXTREME AND DYNAMIC FIRE BEHAVIOUR: Strange things that can happen in and around the high-country and rugged terrain.** ACT Rural Fire Service Crew Leaders Development Workshop, August 2015. Delivered by J. Sharples.
7. **EXTREME AND DYNAMIC FIRE BEHAVIOUR.** NSW Rural Fire Service Southern Districts Information Day, October 2015. Delivered by J. Sharples.
8. **DYNAMIC FIRE BEHAVIOUR AND FIRE LINE GEOMETRY**. Australia and New Zealand Industrial and Applied Mathematics (ANZIAM) Conference 2016, Canberra, February 2016. Delivered by C. Thomas.
9. **UNDERSTANDING EXTREME BUSHFIRE DEVELOPMENT.** Joint University of New South Wales and New South Wales Rural Fire Service Workshop, Homebush NSW, February 2016. Delivered by J. Sharples.
10. **UNDERSTANDING FIRE LINE DYNAMICS USING A COUPLED FIRE-ATMOSPHERE MODEL**. Joint University of New South Wales and New South Wales Rural Fire Service Workshop, Homebush NSW, February 2016. Delivered by C. Thomas.
11. **DYNAMIC FIRE SPREAD AND FIRE LINE GEOMETRY**. 5th International Fire Behaviour and Fuels Conference, Melbourne, April 2016. Delivered by J. Sharples.
12. **NATURE ABHORS CURVATURE – FIRES INCLUDED: Modelling spot fire coalescence.** Poster presentation at the 2015 AFAC and Bushfire and Natural Hazards Conference, Adelaide, September 2015. Presented by J. Sharples.
13. **DYNAMIC FIRE BEHAVIOUR AND FIRE LINE GEOMETRY.** Poster presentation at the 5th International Fire Behaviour and Fuels Conference, Melbourne, April 2016. Presented by C. Thomas.

END USER ENGAGEMENT

Members of the project team engaged with various end users a number of times throughout the year. The main user engagement activities are represented in the list of presentations provided above. Specifically these activities included:

- The 5th International Fire Behaviour and Fuels Conference
- The 2015 AFAC/Bushfire and Natural Hazards CRC conference
- The 2015 Bushfire and Natural Hazards CRC Research Advisory Forum
- The 2015 MODSIM Congress (NSW RFS members in attendance)
- The UNSW - NSW Rural Fire Service Information Day, which involved a number of presentations and discussions between end users and researchers
- Laharum Brigade (CFA) Information Day
- Southern Districts NSW Rural Fire Service Association Information Day
- Victorian Fire Behaviour Analyst Pre-Season Workshop, which included end users from the Country Fire Authority and DELWP.
- The ACT Rural Fire Service Advanced Firefighter Principles Course and the Crew Leader Development Course.

PUBLICATIONS IN PREPARATION

A number of publications are in preparation - see the publications list.

PROGRESS OF THE PHD SCHOLAR

The PhD scholar (Chris Thomas) has been making steady progress and his research has produced a number of significant insights, particularly via his innovative use of WRF-Fire to investigate idealized dynamic fire spread scenarios. Chris was successfully confirmed into the PhD program at UNSW after his annual review in October 2015. So far Chris has published a peer-reviewed conference paper and a conference poster. He currently has a paper under review with the International Journal of Wildland Fire and another journal paper in preparation. Chris is well on-track to successfully complete his PhD research and submit his thesis within scheduled timeframes.

PUBLICATIONS LIST

Sharples, J.J., Hilton, J.E., Sullivan, A.L., Miller, C., Thomas, C.M. (2016) Using fire line geometry to model dynamic fire spread. In: Proceedings of the 5th International Fire Behaviour and Fuels Conference April 11-15, 2016, Melbourne, Australia. Published by the International Association of Wildland Fire, Missoula, Montana, USA

Raposo, J.R., Viegas, D.X., Xie, X., Almeida, M., Figueiredo, A.R., Porto, L., Sharples, J.J. (2016) Analysis of the physical processes associated to junction fires at laboratory and field scales. *International Journal of Wildland Fire* (under review).

Hilton, J.E., Miller, C. Sharples, J.J., Sullivan, A.L. (2016) Curvature effects in the dynamic propagation of wildfires. *International Journal of Wildland Fire* (under review).

Thomas, C., Sharples, J.J., Evans, J.P. (2016) Modelling the dynamic behaviour of junction fires with a coupled atmosphere-fire model. *International Journal of Wildland Fire* (under review).

Sharples, J.J., Hilton, J.E., Sullivan, A.L. (2016) On the interaction of two oblique fire fronts. In preparation. To be submitted to the International Journal of Wildland Fire.

Thomas, C., Sharples, J.J., Evans, J.P. (2015) Pyroconvective interaction of two merged fire lines: Curvature effects and dynamic fire spread. In Weber, T., McPhee, M.J. and Anderssen, R.S. (eds) MODSIM2015, 21st International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2015.

Thomas, C., Sharples, J.J., Evans, J.P. (2016) Modelling the dynamic behaviour of junction fires with a coupled atmosphere-fire model. Poster presentation at the 5th International Fire Behaviour and Fuels Conference April 11-15, 2016, Melbourne, Australia.

Sharples, J.J., Hilton, J.E., Miller, C., Sullivan, A.L. (2015) Nature abhors curvature – fires included! Poster presentation at AFAC/Bushfire and Natural Hazards CRC Conference.

CURRENT TEAM MEMBERS

The research team is currently made up as follows:

A/Prof. Jason Sharples, UNSW

Dr James Hilton, CSIRO

Dr Andrew Sullivan, CSIRO

End-user/Advisory Committee – lead by Drs Simon Heemstra and Stuart Matthews, NSW Rural Fire Service.

ADDITIONAL TEAM MEMBERS

Mr Christopher Thomas, UNSW

Chris is a PhD scholar in Mathematics at UNSW under the supervision of A/Prof Sharples, and is the recipient of a BNHCRC top-up scholarship. Chris' project has been aligned with the spotfire coalescence project and he is now an integral part of the project team.

Mr Richard Hurley, CSIRO

Richard is a technical officer working at the CSIRO Pyrotron facility with Dr Sullivan. Richard is extensively involved in conducting the experimental program and as such is a crucial member of the project team.

Ms Claire Miller, CSIRO

Claire was a graduate research officer working at CSIRO with Dr Hilton. Claire was involved in implementing the level set models and has contributed significantly to publications. She has now left CSIRO to pursue a PhD at the University of Melbourne, and is only contributing to the project on an ad hoc basis.

Additional assistance for experimental work in Phase 1 was provided by Dr Matt Plucinski, Mr Will Swedosh, and Mr Vijay Koul.

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