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FIRE SPREAD PREDICTION ACROSS FUEL TYPES

Annual project report 2014-2015

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Cover: The 2014 Grampians, Victoria, bushfire.

Photo: Wayne Rigg, CFA.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The rate at which grass fires spread over flat terrain can be predicted with reasonable accuracy. However, estimating the rate of fire-spread through other vegetative types is often more problematic. In wooded areas, say, the localized wind speed is determined in part by ground cover, bushes, tree trunks and the forest canopy. This presents a significant challenge to the development of physical models of bushfires.

At first sight, forests appear to be quite random. However, the geometries of individual trees and forests share a remarkable similarity. Not only are the diameters of the branches of an individual tree distributed in fixed ratios, but the ratios of the tree trunks in a forest share the same distribution. This uniformity has important implications for the modelling of bushfires. For example, in this work, we have generated fractal geometries of trees, and these have been used to estimate the velocity profiles of the wind as it flows through a stand of trees. The self-similarity between individual trees and forests provides an exciting new intellectual framework in which to develop the next generation of bushfire models. Results obtained to date offer considerable promise.

The rate of spread of bushfires can be dominated by embers and firebrands that are conveyed ahead of a fire front. We need to understand how embers are generated and conveyed, and how they ultimately ignite fires. We have designed and constructed an ember generator to help elucidate these mechanisms. A feature of its design is that the firebrands, and the air that conveys them, exit the generator with velocities that are close to being uniform and this helps in our analysis. Results obtained to date clearly demonstrate the uniformity of the air velocity, and methods of measuring the dispersion of embers are underway.

If the rate of ignition of bushfires is to be modeled accurately we need to know the thermo-physical properties of vegetative materials. An extensive battery of experiments aimed at measuring the properties has been developed, and requirements for further testing will be established with end-users.

A conflict exists between modelling the physical details that govern the rate of spread of bushfires and the availability of computing power. As a result, one strand of our research into the next-generation models of bushfires is to develop improved computational methods. One such method has enabled us to model buoyancy-driven flows with great accuracy – it is known as explicit filtering of the discretised Navier-Stokes equation. Having proven the concept, the next stage of our work is to apply it specifically to the rate of spread of bushfires.

Infrastructure must be not only bushfire-resistant, but also aesthetically pleasing and economical to build. To be truly creative, designers benefit from having access to a deep understanding of the mechanisms that determine the rate of heat transfer between a bushfire and structures. Hence, a further strand of our integrated research program aims to develop simple-to-use formulae that will help designers of infrastructure at the urban-bushfire interface.

END USER STATEMENT

Dr Stuart Matthews, *Senior Project Officer, Rural Fire Service, NSW*

This project has made good progress in exploring a variety of important physical processes that govern fire behaviour and impacts. The research team is developing capability in experimental and numerical modelling approaches and has presented some interesting preliminary results in this report. I look forward to further interesting results and integration of the two approaches in the remainder of the project.

As an end user I am pleased with the efforts the research team has made to understand industry needs and with the refinement of the project to target the work to understanding risk to properties. I recognise that this project is doing fundamental research but it is good to see the team have an eye towards eventual application of science outcomes.

INTRODUCTION

Empirical models of the spread of bushfires are inherently limited. One reason is that the data on which they are based cover a limited range of conditions, and we may get results that are dangerously misleading if we extrapolate beyond the ranges of the models. As Andrew Sullivan [1] remarks, empirical models are based on observations, and not on theory. If we are to develop models that accurately predict the rate of spread of bushfires over a wide range of conditions, we must ensure that empiricism contributes to its complement, namely rationalism. For this, we turn to the laws of physics that are the unifying principles that permeate this project.

The laws of physics that govern the rate of spread of bushfires appear to be immutable and universal. They also apply to all of the phenomena that we observe in bushfires. For these reasons, physics-based models are likely to underpin the next generation of bushfire models.

The rate at which fires spread is strongly dependent on the wind speed. The velocity profile of the wind within forests is quite different from that over open ground. An important element of our research program is the accurate prediction of the speed of the wind through a range of types of Australian vegetation. Our new models of bushfires are based, in part, on a unifying feature of nature. Natural organisms in the plant and animal worlds often display regularities in their morphologies or shapes. For example, the diameters of branches of a tree follow a well defined distribution which means that we are able to define the tree's geometry. It can be treated an assemblage of geometrically self-similar components. They are fractal-like except that in our geometrical models of trees we do not consider those elements smaller than a certain size – in other words we represent trees as pre-fractals. This enables us to estimate the drag coefficients, and as a result we have been able to predict the velocity profiles of the wind through some types of vegetation. The results we have obtained are in good agreement with experimental values when the vegetation is dense, and we are refining our analysis to account for sparse vegetation.

The rate of spread of bushfires is often dominated by embers and firebrands being conveyed ahead of the firefront. The research group is harnessing its expertise in aerodynamics to design, construct and operate an ember generator to accurately quantify how embers disperse. Preliminary results have been obtained, and work is progressing on refining the methodology.

The rate at which bushfires spread is strongly dependent on the physical and chemical properties of vegetative materials, such as grasses, woody materials, leaves and so on. Although biological materials are diverse these thermo-physical properties are used in mathematical models that are quite general, and this is a feature of physics-based modelling of bushfires. We have invested in equipment and training in a variety of instruments that is allowing us to measure properties such as thermal conductivity, specific heat, density, heat of pyrolysis, heat of combustion and reaction rate constants.

Mathematics is the handmaiden of science. This epigram continues to hold for our research on physic-based models of bushfires in which we must consider phenomena that occur on length scales of a fraction of a millimeter up to several hundred metres. And herein lies a problem: how can we account for this wide range of length scales? Essentially, we have approached this problem by how the average of the small scale phenomena affect those that occur on a large scale, such as the length and intensity of flames. We have achieved this by filtering out the small scale phenomena from the equations that govern the behaviour of bushfires. The result is the development of a rigorous, accurate and robust model of buoyancy driven flows that shows great promise for the modelling of bushfires. It obviates a serious problem in previous models – that is it provides a true solution of the governing equations.

It is important that infrastructure is resistant to attack by bushfires. To achieve this designers need simple-to-use and accurate design formulae, and this is a further component of our research project in which we have brought mathematics to bear on the problem. This is being achieved in close collaboration with members of the team located at the University of Melbourne. The idea is to be able to accurately describe the flow of bushfire generated wind, say, over infrastructure and to calculate the rate at which the infrastructure heats up. In this way, it will be possible to design structures that are more fire-resistant. The approach is to calculate details of the flow and heat transfer in great detail, and in a way that we believe is very accurate. From these accurate solutions it is planned to extract equations that are much simpler to use.

THE PROJECT - ACHIEVEMENTS

MODELLING AIR FLOW AND THE RATE OF SPREAD OF FIRES THROUGH CANOPIES

The rate of spread of bushfires depends on the speed of the wind. This varies with the height above the ground. We may measure or estimate the wind speed at a height of 10 metres above ground level, say, and we also know that it is zero at ground level. In the case of grass fires in open country, these two values are often sufficient to make a reasonable estimate of the profile of the wind speed close to the ground. However, the situation is more complicated in forested areas. In this case, the wind speed profile is influenced by ground cover, shrubs, tree trunks and the tree canopy. As one might expect, the windspeed in wooded areas is likely to be lower than over open ground.

Essentially a tree canopy exerts a drag force on the wind and reduces its speed. Currently the McArthur model developed in Australia uses a rule-of-thumb based on forest density. The Rothermel model developed in the United States uses a more sophisticated wind adjustment factor that accounts for the effects of surface roughness on the planetary boundary layer wind profile. However, the present models of wind speed reduction do not typically include the variation in drag force with height. Measurements by Moon, Duff and Tolhurst [2] exhibit significant variation in wind speed with height through forest canopies.

The variation in wind speed with height is captured by a simple momentum balance model similar to that introduced by Cionco [3]. The model assumes that the turbulent Reynolds stress is balanced by the drag force of the canopy. The Reynolds stress is then modelled by a classical eddy viscosity approach. Subsequently, the model was extended to include the flow over the canopy and the effect of surface heat flux by Harman and Finnigan [4]. The model requires knowledge of the constant drag coefficient and the area fraction occupied by vegetation (e.g. trunks, branches and leaves) as a function of height through the canopy. The velocity profiles in the canopies in some species, namely spruce, pine, and aspen forest (Amiro [5]) have been measured, and the drag and area fraction parameters have been calculated from the momentum balance model. The drag coefficient and occupied area fraction are unknown. Hence, any attempt to use the momentum balance model with the available data will be somewhat circular.

An underlying mathematical order to forests

Forests appear to be random and chaotic. However, there is an underlying mathematical order within the forest that is described by fractal geometry. For example, if we consider an individual tree we observe that its branches give rise to smaller branches, and these give rise to yet smaller branches. Each branch has a structural geometry that is not only very similar to every other branch, but to the tree itself. The geometry is said to be self-similar.

A most remarkable observation

There is yet another most remarkable unifying geometrical feature of forests: trees in a forest vary in age and this is reflected in the diameters of young trees having smaller diameter trunks than older trees. West, Enquist and Brown [6] have observed that the diameters of individual trees follow a geometrical relationship that is almost identical to that of the branches. This observation opens up the possibility of developing more accurate and general mathematical models of the rate of spread of fires within forests.

Exploiting the fractal nature of trees

In our work, we have used a fractal model of a tree to estimate the drag coefficient of the canopy. As noted above, a fractal model characterises the branching pattern of the tree and the ratios of length and diameter between subsequent generations of branches. A recent technique called ReNormalised Simulation has been developed (Graham and Meneveau, [7]) to compute the drag coefficient of fractal trees. Work until now has focused on flow through a canopy modelled by a simple drag force term, F,

$$F = C_D A(z) u|u|$$

where $A(z)$ is the occupied area of the canopy as a function of canopy height. So far both constant $A(z)$ and $A(z)$ chosen to mimic Amiro's observations have been evaluated. The models are in a domain with $L\_x = 7$, $L\_y = 1$, $L\_z = 2$ with the canopy drag applied in the subdomain $1<x<7$, $0<y<1$ and $0<z<1$. The y-direction is considered unimportant at present for these simulations. There is a small canopy-free region to allow the input profile to develop. The number of discretisation points is currently $N\_x = 96$, $N\_y = 16$, $N\_z = 32$. A u-velocity profile is applied on the plane at $x = 0$. The three forms of the velocity profile chosen are uniform, a power-law and logarithmic. The differences between the logarithmic and power-law input profiles were found to be small over the length of the canopy. We note that it is important to choose an input profile that is consistent with any simple models we attempt to use. Work is currently underway to check the convergence of the mean velocity profile as the computational resolution is increased. We also need to check the effect of the y-width on the mean flow, and the length of the canopy on the overall profile. The overall length of the canopy is important as the observed mean velocity profile decays with distance and has not yet reached a steady state. However, the effect of canopy length will be considered later.

Some preliminary results for mean velocity profile over the length of the canopy are shown in Figures 1 and 2.

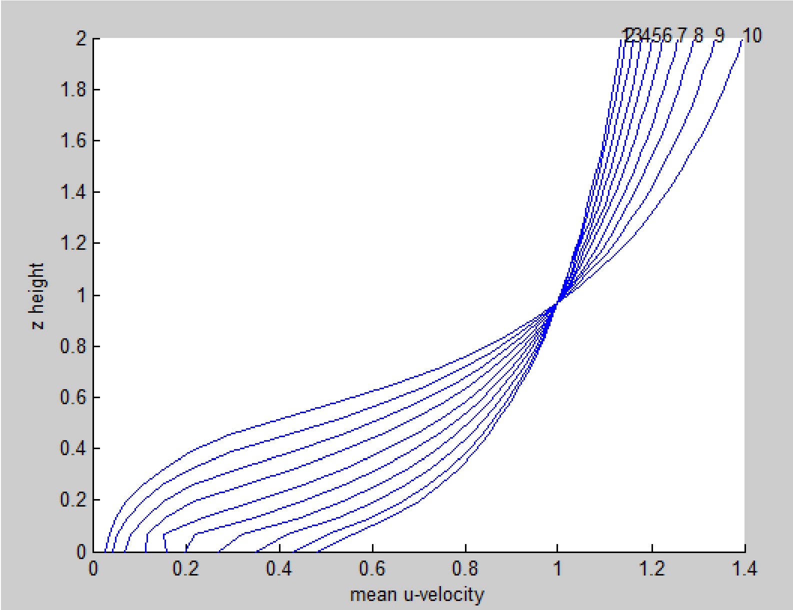

Figure 1: Mean centreline *u*-velocity profile over the canopy for a logarithmic input profile. (1) is in the canopy-free region, and (10) is at the end of the canopy. Note the velocity profile has been normalised by the velocity at the top of the canopy, and these results are preliminary.

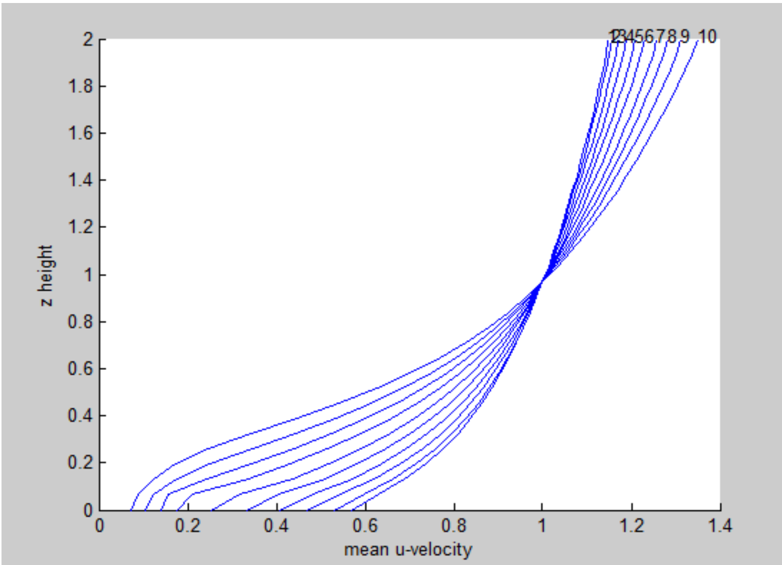

Figure 2: Mean centreline *u*-velocity profile over the canopy for a 1/7-power law input profile. (1) is in the canopy-free region, and (10) is at the end of the canopy. Note the velocity profile has been normalised by the velocity at the top of the canopy, and the results is preliminary.

Fractal trees

An estimate of the occupied area of the canopy as a function of height may be obtained from a truncated (i.e. finite) fractal tree model. We firstly consider modelling the tree simply as a fractal as shown in figure 3, however this leads to discrete steps in *A(z).* We attempt to smooth the tree by firstly applying a Gaussian blurring filter and then by smoothing the *A(z)* with a moving average, as shown in figure 4. The occupied and cumulative area functions from the fractal tree are found to be at least qualitatively correct. More work is required to obtain qualitative agreement for Amiro's data.

We have evaluated the applicability of the momentum balance model of wind velocity through a tree canopy for calculating the wind speed reduction factor. Firstly, we attempt to simulate the experimental measurements of Amiro using a Large Eddy Simulation approach with the measured drag coefficient and area fraction profile. We then compute the area fraction from a fractal model and compare the modelled data with the simulated wind profile. Finally, we obtained both the drag coefficient and the area fraction from ReNormalised Simulation and compare the simulated wind speed profile with the measurements of Amiro (1990).

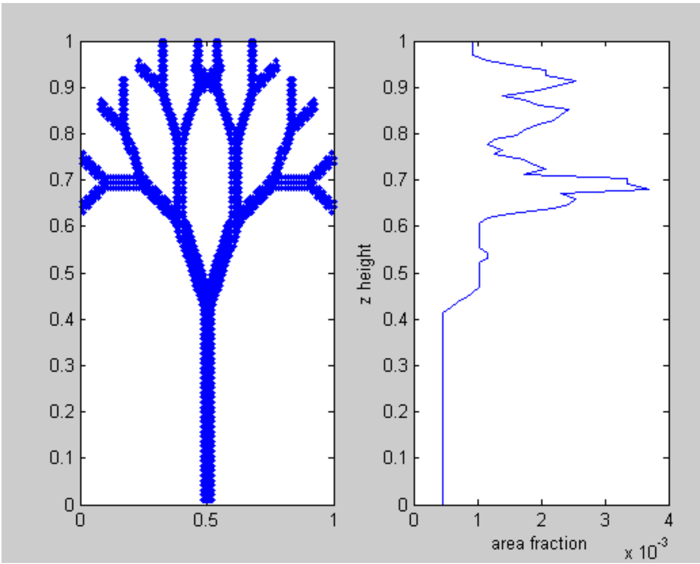

Figure 3: An example fractal tree and corresponding *A*(*z*).

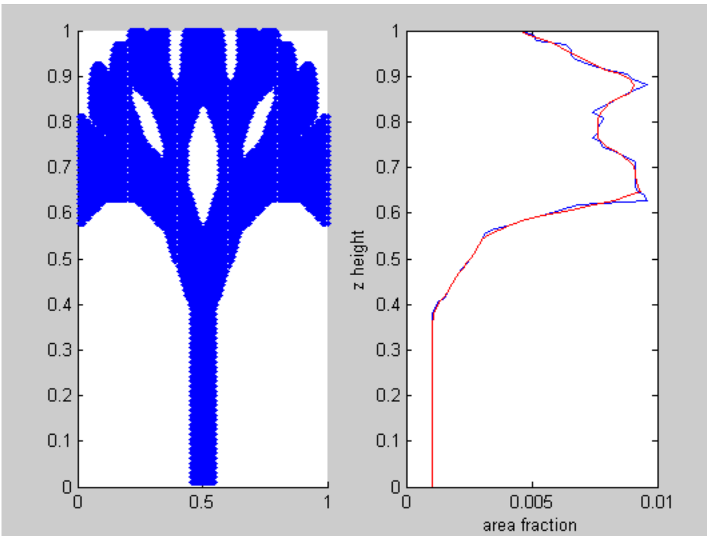

Figure 4: The same example fractal tree as in figure 3, but blurred by a Gaussian filter, and corresponding *A*(*z*) (blue) and smoothed *A*(*z*) (red).

THE SPREAD AND DISTRIBUTION OF FIREBRANDS

Devastating bushfires are often associated with windy conditions. High winds cause firebrands or embers to be conveyed downwind, and in high intensity bushfires they are lofted in buoyancy-driven updrafts. As a result, firebrands often play a critical role in controlling the rate of spread of bushfires. This component of the project is motivated by the need to devise comprehensive models of the dispersion of embers and firebrands, and their propensity to ignite vegetation. This is achieved by characterizing key physical and chemical properties of fire brands and embers generated by a range of Australian flora, and determining their aerodynamic properties.

Thermo-physical properties of Australian flora

Initial experimental investigations of thermo-physical properties such as thermal conductivity, thermal diffusivity, and heat capacity using a hot disk analyzer, have been completed. The preliminary work formed part of a training and calibration exercise. Data have been obtained on cotton, wool, PMMA, pine and pine char and reaction kinetics of cardboard. The next step is to obtain samples of materials that are important in the context of Australian bushfires. This will be carried out in close consultation with end-users.

The design and construction of a firebrand generator

To be credible, computer-generated models must be validated against experimental data. Hence, a firebrand generator has been designed and constructed so that the distribution of firebrands can be modelled and measured. NIST has developed a firebrand generator, dubbed a 'fire dragon', to study the interaction of firebrands with buildings, but the NIST model suffers a serious deficiency. The problem is this: the outlet from which the fiery embers disgorge resembles that of a dragon's mouth set atop of a long vertical neck. As a result, the embers are conveyed around a 90° bend immediately before they are cast out horizontally. Hence, the distributions of the embers and air velocity at the dragon's mouth are highly non-uniform.

General principles are often elucidated by carrying out experiments under somewhat idealized conditions. To this end, the BNHCRC research group at Victoria University is developing an ember generator from which the embers are discharged uniformly. The design process exploits the power of FDS 6.1.2, an open source computational fluid dynamics package widely used in fire engineering. The simulations indicate that to ensure that the velocity profile of the air leaving the generator is uniform, the generator must exceed a defined length. If this critical length is not exceeded the velocity profile is markedly doughnut shaped. Figure 5 shows a design that satisfies the requirement that the velocity profile is well developed and approaching uniformity.

The effectiveness of this design has been evaluated by measuring the velocity profiles of air exiting the mouth of two models of our ember generator. One of the prototypes was 1 metre longer than the first, and the effect of this extension on the uniformity of the velocity profile was measured. A pitot tube was used to measure the velocities of the air leaving the generator and the signal from a pressure transducer was recorded by means of a Keyinsight Technologies Multimeter 34972A. An inherent feature of the design is that the velocity profile is likely to be asymmetrical. The pitot traverses were therefore carried out in two orthogonal directions – in our case horizontal and vertical.

When solids are introduced into the air stream momentum is transferred from the air to the solids. The ember generator was used to convey cubes of pine with sides of length 1 cm, and photography and videography were used to measure their velocities at the exit of the generator. It was observed that the prototypal embers had exit velocities of about 12 m/s.

Very preliminary results of the scattering of embers is shown in figure 6, and it is planned to carry our comprehensive tests. It is clear that the embers do not land in a random pattern, but they are influenced by the texture of the material used to capture them. This is an area for further development.

Figure 7. Results from a very preliminary experiments on the distribution of embers emanating from a prototype firebrand generator.

IMPROVED COMPUTATIONAL METHODS FOR MODELLING BUSHFIRES

Commercial versus public domain software for modelling bushfires

Scientists and engineers who develop physics-based models of the rate of spread of fires are confronted with a choice. They can base their models on commercially available software, or they can modify open source computer codes. Commercially available software offers several advantages. For example, it offers valuable features such as ease of operation, sophisticated graphical outputs, excellent documentation and technical support. Physics-based models of bushfires typically solve many millions of equations, and commercial software often incorporates highly optimised equation solvers. However, from the point of view of research, commercial software has the disadvantage that its inner workings are proprietary, hence it is presented to users as a 'black box'. Furthermore, small fire-engineering consultancies may consider some commercial software inordinately expensive. Open source software is an alternative to commercial software. In many ways, it is the antithesis of commercial software, but it has the advantages of being free and the source code is available for users to modify. The development of open source software often provides a focal point for communities of scholars and researchers.

In CESARE we have adopted Fire Dynamics Simulator (FDS), open source software developed by McGrattan et al. [8]. The Navier-Stokes equation governs the transport of air and the products of combustion generated by the fire, and herein lurks a problem. The physical size of a fire front may be on the order of hundreds of meters or more, yet the phenomena that ultimately determine how fires behave have spatial scales of a fraction of a millimetre. Hence, it is far beyond present day computing power to resolve all of these scales. An offshoot of FDS, the Wildland-Urban Interface Fire Dynamics Simulator (WFDS) goes some way to dealing with this problem by using a mathematical procedure known as Large Eddy Simulation in which the small scale eddies are not resolved. Instead, their effects are modelled by means of empirically based equations. In other words, we do not know the physical features of any of the small scale eddies, but we attempt to quantify the effect they have collectively on the flow.

A fortuitous inevitability - implicit filtering of the Navier-Stokes equations

The smallest eddies that occur in air flows associated with bushfires ultimately dissipate and lose their form because the randomness of molecular motion eventually overcomes the small eddies' structure. However, the ordered kinetic energy associated with the small scales is preserved because the molecules of the fluid attain a higher average velocity – the energy has been dissipated and it appears as an increase in the temperature of the fluid. It so happens that when the Navier-Stokes equation is expressed in a form that is suitable for its solution on a computer the dissipation is implicitly accounted for. In one sense that the mathematical formulae implicitly account for the dissipation is a stroke of luck, although it could be regarded as a mathematical necessity. Such approaches to the modeling large eddies are known eponymously as 'implicit' filtering; here filtering suggests that the small scale eddies have been filtered out from the solution and only large scale eddies remain. Hence, the term large eddy simulation.

A more refined approach to filtering out small scale eddies that cannot be simulated in detail

Implicit filtering is not always accurate. One reason is that when we solve the Navier-Stokes equation we are able to calculate variables, such as the local velocity and temperature, of the air at a finite number of points. To ensure that the modelling of bushfires is accurate we need to consider a large number of points, but this can result in increased errors in our modelling of the smallest resolved eddies. A way around this is to smooth out the errors by averaging the velocities, temperatures and so on over a number of finite points – this can be done explicitly just like we might find the average of the age of schoolchildren in a class. This results in more accurate modelling.

Explicit filtering works like this: The idea is to solve the governing mathematical equations with values of variable such as a gas concentration or velocity averaged over some volume in space. Figure 8 shows a filter of width Δ that comprises three cells, each of width dx. Values of the variables, Φ_i, are associated with the i^{th} cell. If we use the implicit method the mean values of the variables within the three cells that comprise the grouping shown would be Φ_i. However, when we use explicit filtering the mean value would instead be $0.25\Phi_{i-1} + 0.5\Phi_i + 0.25\Phi_{i+1}$.

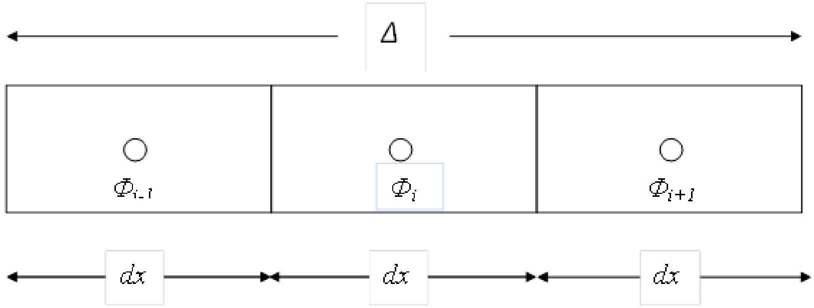

Figure 8. Three adjacent cells

Validation of our approach to explicit filtering

Although our work is strongly motivated by the need to model the rate of spread of bushfires, it is essential that we evaluate the proposed explicit schemes on well-defined systems. One such system involves a flow driven by temperature differences, a characteristic of bushfires. The system consists of an enclosure that is 2.5m high, four sides of which are well insulated and they are treated as adiabatic, as shown in Figure 9. Of the remaining two walls one is maintained at a uniform temperature of 77.2°C and the other at 31.4°C.

The experimental data obtained by Cheesewright *et al.* were used as a benchmark against which our mathematical models of buoyancy driven turbulent flows were evaluated. The widths of the filters used in the calculations are based on the thickness of the boundary layers that are typically about 1 cm. Figures 10 and 11 show the computed and measured velocity and temperature distributions at the mid-height of the cavity for two filter widths, Δ, and two grid sizes, dx. In the figures Case 14 corresponds to a filter width, Δ, of 0.2δ and dx is 0.0625Δ in which δ is the thickness of the boundary layer, and the corresponding values for Case 23 are 0.1δ and 0.125Δ.

It can be seen that both of the proposed schemes result in velocity and temperature profiles that accurately match the experimental values, and this implies that the solutions are converging with the continuous, as opposed to discretised, solutions.

It is important to appreciate that the explicit filtering scheme described above was implemented in FDS (Fire Dynamics Simulator). Having established that explicit filtering is capable of capturing details of buoyancy-driven turbulent flows, the next stage of the work is to apply the method to modelling bushfires.

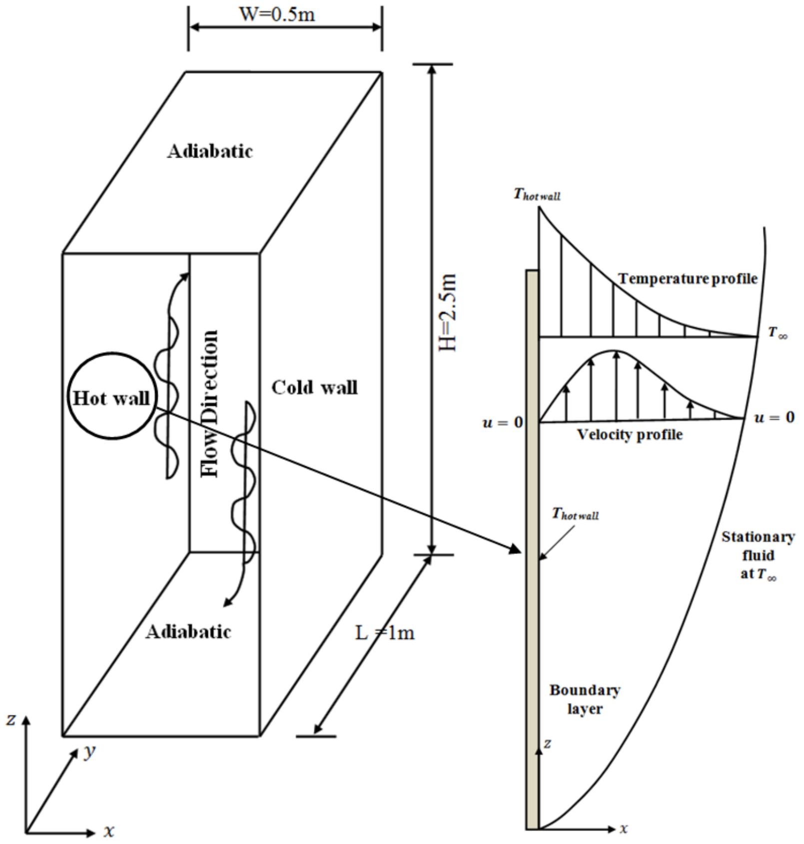

Figure 9. A schematic of the differentially heated cavity used by Cheesewright *et al*. to measure the distribution of temperature and velocity. It can be seen that velocity and temperature boundary layers form adjacent to the hot wall. The no-slip velocity boundary condition prevails at the wall, whilst the temperature is highest at the heated wall and it assumes the average temperature in the core of the cavity. An approximately antisymmetric condition prevails on the cool wall. This work lays the groundwork for developing reliable models of buoyancy driven flows that arise in bushfires.

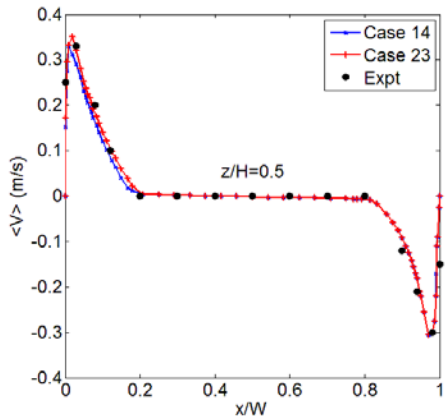

Figure 10. Computed and measured velocity profiles at the mid-height of a differentially heated cavity.

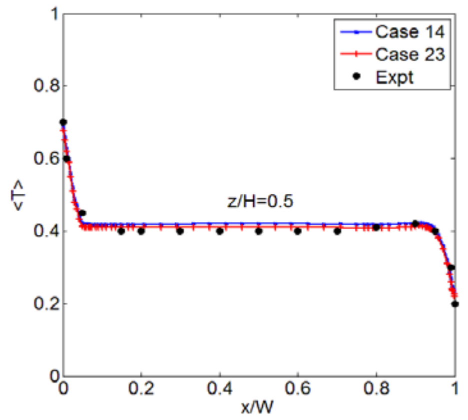

Figure 10. A Computed and measured temperature profiles at the mid-height of a differentially heated cavity.

AIR FLOW OVER AND AROUND BUILDINGS AT THE BUSHFIRE-URBAN INTERFACE

Infrastructure located in bushfire prone areas must be designed so that it is fire resistant. This entails not only choosing suitable materials of construction, but also incorporating design features that ameliorate the effects of fire. These can include well-known features such as gutters in which debris does not accumulate, protective screens for windows and doors, modifying the surrounding landscape and so on. This component of the project aims to bring the principles of engineering science to design fire-proof structures and calculate airflows around buildings.

Mixed forced and natural convection over horizontal surface

To meet our aim we need to quantify the behaviour of airflow and heat transfer adjacent to surfaces. The logarithmic law of the wall is typically used to describe the mean velocity of the flow in the near wall region where the production of turbulence due to a shear flow is much larger than the production of turbulence due to buoyant effects. The law of the wall allows the shear stress to be specified as a boundary condition and allows the boundary layer velocity profile to be modelled in Large Eddy Simulations.

For horizontal surfaces, when buoyant production of turbulence becomes significant (relative to the shear production) the Moin-Obukhov similarity theorem expresses the non-dimensional mean velocity and temperature fluxes in terms of so-called universal functions of non-dimensional length. These functions must be determined empirically, or from numerical simulations of fluid flow. The accepted form of the universal function for momentum gives the logarithmic law of the wall mean velocity profile with a linear correction for the buoyancy production.

Flows over vertical and inclined surfaces when buoyancy forces combine with wind-driven flows

When there are no buoyant forces, the logarithmic law of the wall is independent of the orientation of the wall and can be applied to model the mean fluid velocity over vertical (or inclined) surfaces. Indeed the log law of the wall is widely used to simulate fluid flows in many engineering applications. However, in fire situations universal functions for mixed and forced convection flow over vertical surfaces have not been determined and the Moin-Obukhov correction to the log law is not immediately applicable to such flows.

There are many examples of fluid flow over heated vertical (and inclined) surfaces, particularly in bushfire scenarios. For example, accurate predictions are required of the behaviour of fires as they interact with buildings and structures at the bushfire-urban interface. To approach this problem we consider an idealised flow: a channel which is periodic in the streamwise and spanwise directions, and has vertical solid walls.

If we are to design infrastructure that is more fire-resistant we must have a detailed understanding of heat transfer between air that has been heated by a bushfire, say, and a wall. The main quantities of interest are the velocity and temperature fields of the flow. The general behaviour of the flow may be characterised by several dimensionless quantities. The Grashof number is the ratio of buoyant forces to the viscous forces, the Prandtl number is the ratio of viscous diffusivity to the thermal diffusivity, the Rayleigh number is the product of the Grashof number and the Prandl number, and the (bulk) Reynolds number of the flow, which is the ratio of inertial forces to viscous forces.

The problem of natural convection with no shear flow through a vertical channel has been studied by a number of authors, see for example Batchelor [9]. Our work on improved computational methods for modeling bushfires, discussed above, is a special case of this situation. In the case considered by Batchelor [9] the (steady or long time) mean velocity profile is approximately cubic and the mean temperature profile is approximately linear. In a bushfire how air is likely to strike a vertical surface of a building, say, in which case mixed convection flow purely buoyancy driven flow will be modified by the shear flow. Three important particular cases exist based on the direction of the shear flow relative to the buoyant force. The shear flow may be parallel to buoyant force, called assisting flow. This situation arises when cooler air flows adjacent to a surface that has been heated by thermal radiation from a bushfire, say. Alternatively, the shear may be antiparallel to the buoyant force, called opposing flow. This occurs when air that has been heated in a bushfire strikes a cool wall – the air is likely to flow up a wall, but as the air cools its density increases and buoyancy forces oppose the forced convection. Finally, the shear flow may be mutually orthogonal to the buoyant force and the vector normal to the wall. Since we consider a channel domain, we ignore the possibilities of imposed mean velocities in directions normal to the wall.

Previously, Kasagi and Nishimura [10] simulated mixed convection flow in a vertical channel. They found that the aiding and opposing effects on turbulent statistics and quasi-coherent structures are similar to the effects of injection and suction at the walls.

The aim of this study is to identify the effect of buoyancy on shear stress and hence the logarithmic law of the wall for the momentum and heat exchange near a vertical surface using direct numerical simulation in a channel with aiding, opposing, and cross shear flows. The idea is that it this will ultimately lead to more accurate models of flows over surfaces heated in a bushfire.

THE PROJECT - EVENTS

RECRUITMENT

Dr Duncan Sutherland

Postdoctoral Fellows provide key inputs to research projects. They are independent researchers and they are dedicated to their projects. In seeking a Postdoctoral Fellow to join our team we initiated a global search and as a result we received 45 applications. Shortlisted candidates were interviewed.

Duncan Sutherland was an outstanding candidate and he took up his position in early September. Duncan holds a first class honours degree and a PhD in applied mathematics from the University of Sydney. He has carried out research on energy dissipating structures in fluid flows, an area of relevance to modelling bushfires in which turbulent energy is both produced and dissipated. His interests also extend to parallel computing and high Reynolds number flows. Duncan has also given a presentation on the aerodynamics of cyclists, and he speculates on the effect of their hairstyles on their performance.

Postdoctoral Fellow, Dr Duncan Sutherland

Mr Rahul Wadhwani

Postgraduate students often do a lot of the heavy lifting in research projects. Again we initiated a global search for a PhD student, and Rahul Wadhwani, has been selected. Rahul has a degree in chemical engineering with a specialisation in hydrocarbon engineering from the Indian Institute of Technology, Roorkee. As an undergraduate he carried out computational fluid dynamics studies on the design of chemical reactors. Rahul's PhD studies will concentrate on developing mathematical models of pyrolysis (gasification) of Australian vegetation and the dispersion of embers. The resulting data will form an essential component of our strategy to develop a platform on which to build the next generation of bushfire models. Furthermore, data on the physical and combustion characteristics of embers and firebrands produced by Australian vegetation will be collected. All these data will be used as input parameters to a computer model.

PhD student Rahul Wadhwani

ESTABLISING WORKING RELATIONSHIPS WITH RESEARCHERS IN FRANCE

During July 2014 Graham Thorpe visited leading bushfire laboratories in France. Researchers at the Institut National de la Recherche Agronomique (INRA) at Avignon work closely with the developers of FIRETEC located at the Los Alamos National Laboratory. The team at INRA contributes to specifying the geometrical structure of vegetation and its effect on the interaction with the atmosphere and estimating radiation through vegetation. They also carry out research on strategies for reducing the rate of propagation of bushfires. His host at INRA was Dr François Pimont whose doctorate was supervised by Professor Dominique Morvan at the Université de la Méditerranée, Marseille, whom he also visited. As one might expect, there is some synergy between the two groups. Professor Morvan has recently produced a detailed study on the aerodynamics of the interaction of the atmosphere and vegetative canopies, work that could play an important role in the development of next generation physics-based models of bushfires. Nancy, in the North East corner of France, is not renowned for being subject to large bushfires. It is, however, renowned for its Laboratoire d'Energétique et de Mécanique Théorique et Appliquée (LEMTA) at the Université de Lorraine. Graham Thorpe was welcomed by Professor Pascal Boulet who outlined his laboratory's research on detailed measurements on the spectral properties and pyrolysis of vegetative materials. The laboratory also works on modelling bushfires and it has recently installed a 6m long wind tunnel along with a particle image velocimeter for studying the rate of spread of bushfires over undulating terrain. LEMTA researchers also work on the suppression of fires using water mists and the re-design of firefighters' uniforms.

Outcome of the visits

The visits have resulted in a significant outcome, namely one of our PhD students, Rachael Aganetti, is presently working in Professor Morvan's group on the spontaneous combustion of biosolids. This project shares many features with the modeling of bushfires. A follow up visit will be made in late 2015 with a view to developing long term links specifically to work on bushfires.

INTERACTION WITH END-USERS

Meeting with Drs Simon Heemstra and Stuart Matthews

A meeting between Drs Heemstra, Matthews and the project team was held at Werribee on 30 January 2015 to discuss the future outcomes of the present and subsequent projects. The most immediate upshot of the meeting was that Duncan Sutherland should attend the Fire Behaviour Analyst course run sponsored by the Rural Fire Service (RFS), NSW and described in detail above. A further important outcome concerned the uncertainty of the development of the wind velocity profile in a copse of trees or in a region of forest in proximity to a clearing. This affects the rate of spread of fires and it is worthy of further research. This view is reinforced in notes on the Fire Behaviour Analysts course.

Fire Behaviour Analysts course

The RFS hosted a course for fire behaviour analysts in March taught by Kevin Tolhurst, Andrew Sullivan, and others. The so-called FBAN course covers material relevant to the operational use of empirical fire-spread forecasting models such as the McArthur model and Vesta model, as well as detailed physical description of many wild fire phenomena. In order to broaden the knowledge of the VU research group postdoctoral fellow Duncan Sutherland was selected to attend the course, which was funded by the lead end users at the RFS.

The course introduces the operation models used by fire-fighting agencies across the country and applies them to real fire case studies in a series of fire prediction exercises. The theory behind the various models, for forest fuels, grasslands, heathland, and shrub type fuels, is discussed including the background of the experiments, results, and limitations of the models. Since the overall weather patterns are also very significant to fire behavior prediction, several lectures and exercises were dedicated to meteorological theory and applied weather prediction. Fuel models and fuel moisture models were also discussed. Factors such as long term moisture content are not at present captured by physics based models. Over the course of the day, as the humidity and ambient temperature change, plant material absorbs and desorbs moisture from the atmosphere. Typically, only the drying process of the combusting or pyrolysing fuel of known initial moisture content is considered in Wildland-urban Fire Dynamics Simulator. Importantly, the course highlighted the requirements of the end users and the relevance of physics based modelling to overall fire behaviour prediction. Physics based models should be used to gain deep insight into the behaviour of fires in idealised common situations where experimentation is not always practical.

The course also highlighted a number of areas, such as modelling the wind flow over terrain and canopies, modelling the convective heating of canopies, short distance ember transport, ignition of spot fires, and capturing large scale features such as the convective columns of the fire, where physics based models can be applied to gain insights which are of practical importance to the end users.

TEAM DEVELOPMENT ACTIVITIES

Duncan Sutherland of VU works closely with Professor Ooi and Dr Daniel Chung of The University of Melbourne on developing very accurate models of the roughness of surfaces that mimic those of tree canopies. The idea is to be able to model the effects of trees on the wind profile in within forests and in proximity of other types of vegetation. The models may also account for buildings at the peri-urban interface. The collaboration is very productive and it is resulting in the joint development of codes, joint publication of the research in high impact journals, and it neatly complements the highly applied nature of our research.

CURRENT TEAM MEMBERS

Research team

Dr Daniel Chung, University of Melbourne
Associate Professor Khalid Moinuddin, Victoria University
Professor Andrew Ooi, University of Melbourne
Dr Duncan Sutherland, Victoria University
Professor Graham Thorpe, Victoria University

End users

Dr Simon Heemstra, Manager Community Planning, NSW Rural Fire Service
Andrew Stark, Chief Officer, ACT Rural Fire Service
Lawrence McCoy, Senior Fire Behaviour Analyst, NSW Rural Fire Service
Ralph Smith, Branch Manager, DFES, WA
Chris Wyborn, Senior Technical Officer, Fire Protection Association of Australia
Mike Wouters, Senior Fire Ecologist, DENS, South Australia
Paul Fletcher, Assistant Chief Fire Officer, SAMFS
Andrew Sturgess, Fire behaviour Analyst, Queensland Fire and Emergency Services
Rochelle Richards, Tasmania Fire Service

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