**VULNERABLITY MAPPING OF A HOUSE FROM AN IDEALISED FOREST FIRE**

##### Proposals to the Society of Fire Protection Engineering, October 2021

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# 1. The Research Team

*Chief Investigator* for the project is Professor of Fire Modelling Khalid Moinuddin from Victoria University (VU), Melbourne, Australia. Dr Mahmood Rashid will be *Associate Investigator* and Mr Amila Wickramasinghe will be an engaged PhD student for this project.

This project will draw on specialized wildfire modeling expertise within Victoria University. We are confident we have the expertise and resources to complete the project as specified below within the time scale outlined.

## 1.1 Prior Relevant Experience

Professor Moinuddin has strong relevant track records of international peer-reviewed research publications (<https://scholar.google.com/citations?user=RnXzZ_kAAAAJ&hl=en&oi=ao> ), have attracted significant funds from the Bushfire and Natural Hazard CRC (BNHCRC), Australian Research Council (ARC), Australian defense industry, Australian fire & building regulatory bodies and local industry partners (see Sections 8.1 and 8.2), and successfully managed large and complex research projects. Dr. Rashid has a very good publication record (<https://scholar.google.com/citations?hl=en&user=-9QzmpoAAAAJ> ). He is an extremely capable numerical code developer and has strong expertise in physics-based wildfire modeling.

## 1.2 Personnel Expertise

*Khalid Moinuddin* is a proven leader in fire modelling both building and wildland setting and an editorial board member of the leading fire journal, Fire Safety Journal. So far he attracted AU$2.3 million in external funding (with other researchers). He widened VU's research spectrum from applied only to fundamental as well. His fundamental research works include simulation of gasification of solid fuels and combustion of the gaseous form, turbulent fluid motion using various large eddy simulation (LES) based models, evaporation of the sprinkler/ water mist droplets etc. He is a leading researcher in implementing several submodels in physics-based model Fire Dynamics Simulator (FDS) such as an eddy diffusivity convective heat transfer model [1], an explicitly filtered LES model [2], an improved firebrand drag model [3] and a leaf area density (LAD) configuration [4]. Today VU’s fire research group is in a strong position to conduct research in a wide spectrum from fundamental to applied areas and contribute its fundamental research outcome to applied research and in turn into practical applications. He established three major streams of research: (a) improvement and application of a three-dimensional (3D) physics-based bushfire model (b) fire safety engineering in naval applications and (c) fire properties of building materials and vegetative fuels. He supervised of seven PhD students to completion and currently supervising another three including Mr Wickramasinghe. He will provide the conceptual design and necessary directions for issues arising during the project. He will be accountable for the success of this project and report and communicate the results and findings to the SFPE.

*Mahmood Rashid* is a post-doctoral researcher and received his doctoral degree in Computer Science (Artificial Intelligence), Masters in Computer Science (Data Mining) and Bachelors in Mechanical Engineering. Prior to work at VU, he worked as a post-doctoral researcher at University of Massachusetts, USA. He has excellent programming skill and recently implemented a wind reduction factor (known as wind adjustment factor in USA) in an operational wildland fire propagation model. He is also capable of using FDS. He will be involved in FDS code modification to implement a firebrand generation model and subsequently carry out FDS simulation of dynamic forest fire to determine firebrand and heat flux on a structure.

*Amila Wickramasinghe* is a PhD student and his project involves mapping of firebrand and heat flux on structures in the Wildland-Urban Interface from a static fire of Eucalyptus forest in Australian context. In his study firebrands are manually inputted in FDS modelling.

# 2. Project Approach

Firebrand attack and heat flux on a structure from an approaching wildfire are two primary mechanisms for house loss in wildland-urban-interface (WUI) areas. Therefore various standards (such as [5] ) have been developed for design requirements for houses located at different distance from the forest edge. However, these stadards focus primarily on quantified radiative heat flux. Due to difficulty in modeling firebrands (generation, transport and ignition), vulnerability from firebrand attack has not been quantified. Firebrands play a vital role in the propagation of fire by starting new fires called spotfires, ahead of the fire front during wildfire progression. Firebrands are a harbinger of damage to infrastructure; their effects cause a particularly important threat to people living within the wildland-urban-interface, hampers the suppression of the wildfire or even blocking the evacuation routes for communities and emergency services. Predicting the firebrand generation from a forest fire and trajectory of firebrands and hence the travelling distance plays a vital role in improving the prediction of fire propagation as well as mapping vulnerability of a house in WUI areas.

FDS currently has a Lagrangian particle for solid particle transport. The particles are considered either spherical or cylindrical shape. We have implemented Haider and Levenspiel drag model [6] to account for sphericity of firebrand particles as demonstrated in [3]. FDS also have an ignition model as which can be used to model ignition by firebrand as shown in [7], but rquires a very fine grid resolution around the impact location. The missing part is a firebrand generation model. Currently, a specific rate of firebrands with different shapes, sizes and masses can be ejected from a source location. This rate can be obtained from experimental studies. However, there is a scarcity of such experimental data. Hudson et al. [8, 9] recently at Oregon State University conducted experiments with various vegetation such as Douglas fir, Grand-fir, Western Juniper, and Ponderosa pine. An important aim of Hudson et al. is to determine firebrand landing flux per kg of mass loss (pcs/m2/kg). It was followed by Adusumilli et al. [10] by proposing a linear interpolation method to approximate the firebrands landing number and the number of firebrands generated at the tree source. Douglas fir, Ponderosa Pine, and sagebrush vegetations were subjects of this study. Therefore, an approximate firebrand generation data per kg (pcs/kg) of mass loss for Douglas fir and Ponderosa Pine is available. We aim to modify FDS source in this study, so that from the burning tree approximate number of firebrand is generated as function of tree burning rate. FDS has a well-established model to predict tree burning rate and forest fire propagation [11].

## 2.1 Goals and objectives

Developing a simple and validated firebrand generation submodel in FDS will be a primary output. This is included in FDS roadmap (<https://github.com/firemodels/fds/wiki/FDS-Road-Map>). Once firebrand flux upon structures can be modelled using FDS, physics-based simulations for performance-based design for construction in WUI. Demonstrating the feasibility that fire, firebrand and heat flux from an idealized forest fire impacting on structures can be modelled will be a major outcome of the project towards adopting performance-based design in WUI. Furthermore, prescriptive building standards (such as [5] ) can be improved by quantifying firebrand flux (besides radiative heat flux) using the improved FDS model.

## 2.2 Scope

This study will address the following issues:

1. Implement a firebrand generation submodel in FDS based on fuel mass loss rate
2. Validate the implemented model against a single Douglas tree fire experiment conducted at National Institute of Standard and Technology (NIST) comparing dry fuel mass loss rate and firebrand landing on collecting trays
3. Simulate fire propagations in an idealised forest consisting Douglas trees standing on surface fuel and mapping vulnerability (in terms of firebrand flux and heat flux) on a structure at the end of a forest.

## 2.3 Technical Approach

The following tasks will be undertaken to achieve the project goals:

### 2.3.1 Implementing a firebrand generation submodel in FDS

FDS’ output file *filename\_HRR.csv* gives dry fuel mass loss rate (kg/s). This output quantity will be linked with approximate firebrand generation data per kg (pcs/kg) of mass loss for Douglas fir from [8, 9] [10]. It is recognized that in experimental loss data there are two components: dry mass loss and firebrand loss. As the data of total firebrand number is available, considering their accumulated mass, the amount of total firebrand loss can be estimated. The rest will be dry mass loss. A relationship between dry mass loss and firebrand loss will be established. FDS’ well-established dry fuel mass loss (pyrolysis) model can accurately determine dry mass loss (outputted in *filename\_HRR.csv* file) per timestep and our submodel will generate corresponding number of firebrands. Preliminary estimate shows that firebrand loss is only 2.5 -5% of the total mass loss. Based on experimental data multiple classes (with different shape, size and mass) of firebrands as found in Manzello et al. [12] as well as [8, 9] [10] will be generated. Our preliminary work shows that firebrand generation linking with dry mass loss is feasible.

### 2.3.2 Validate submodel

The submodel of firebrand generation will be validated against Manzello et al. [12]’s single Douglas tree fire experiment. FDS’ pyrolysis submodel has already been validated against this experiment [11]. The focus of this proposed study is firebrand generation submodel and hence its validation is necessary. The modelling configuration and firebrand collencting tray arrangement is given in Figure 1.

|  |
| --- |
| C:\Users\s4620106\OneDrive\dgl_results analysis\results\To milestone report\new images\layoutDimensions.JPGC:\Users\s4620106\OneDrive\dgl_results analysis\results\To milestone report\domain.JPG   1. (b)   **Fig. 1.** (a) is a Smokeview illustration of model tree (at 0 second time). The plan view of firebrand collection tray arrangement is shown in (b). Each tray is numbered 1 to 26 and the tree base is at the middle of 3-4 and 9-10 trays. A, B are the parallel branches of the tray arrangement. |

Based on experimentally collected firebrand data, 30 mass classes of firebrands will be generated throughout the volume of the tree as a function of mass loss. The validation will be carried out by comparing firebrands collected by trays. Unfortunately, specific number of firebrand collected by each tray data is not available. However, total number of firebrand collected is known (70 pieces). Validation will be conducted against this value.

### 2.3.3 Forest fire modeling for vulnerability mapping on a structure

After conducting validation with a single tree, we will conduct a set of simulations of forest fires and compute firebrand and heat flux on a nearby house structure. The forest will be comprised of Douglas fir trees, 20 m tall on a surface of pine needles. A representative image of simulation configuration is shown in Figure 2. It is to be noted that the role of surface fuel (pine needles) is to provide continuous energy to the crown fire. This is referred to as a supported crown fire [13] and our previuos study shows that such support is necessary [14]. If the needles are unable to provide necessary energy, surface fuel will relaced by grass whose validated property exists [15]. The main aim is to simulate propagating crown fire and mapping firebrand and heat flux on the nearby house.

The forested area will be 50 m long and starts 50 m from the domain inlet. The trees will be regularly spaced in a staggered fashion in a number of columns. The trees will be equally spaced; alternating between columns of trees. The tree will be modelled as a cylindrical trunk and the crowns will be modelled in a conical shape. The overall domain is 150 m long, 25 m wide, and 200 m tall. 200 mm grid resolution will be used around the forested region including the house and the rest of the domain will have 400 mm resolution. 200 mm grid resolution was shown to be sufficient to ensure numerically converged heat release rate results [14] which are free of errors caused by under resolving the simulations. The inlet is a power law (1/7) model of the atmospheric boundary layer (ABL) with various wind speed (3, 6 and 10 m/s) at 2 m above the ground. The second parameter to be varied is fuel moisture content (associate relative humidity of air): three FMC will be selected. Therefore a total of nine simulations will be conducted. The house structure will be relatively small: 10 m long, 8 m wide, and 4.5 m tall.

The house configuration will be made with a third-party tool Pyrosim to mimick actual house designs. Devices to measure firebrand flux, radiative heat flux, convective heat flux and surface temperatures at various strategic locations of the house.

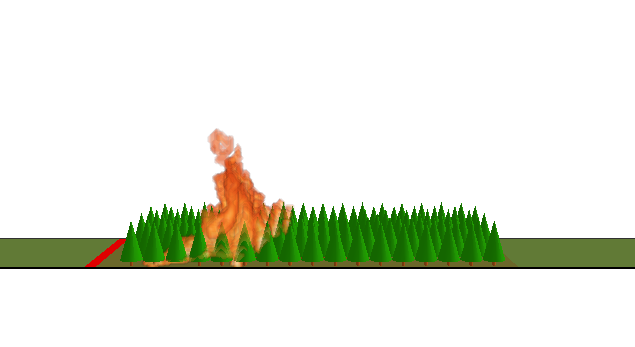




Fig 2. : A prepresentive image of a forest fire approaching a house. The trees are rendered as green cones and the flames as orange. The red line indicates a modelled rectangular ignition line. Not to scale.

### 2.3.4 Analysing the results and documentation

The results of the project will be analysed and a detailed report of the project and conclusions will be submitted. In light of the results, we will offer some comments on the possibility of performance-based design in WUI using physics-based simulation results. We will also endeavor to present a correlation between firebrand flux and heat flux.

# 3 Proposed timeline

The proposed timeline for the project completion is given in the below table:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Milestones | Months | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Initial project launch meeting |  |  |  |  |  |  |  |  |
| Implementing firebrand generation submodel in FDS |  |  |  |  |  |  |  |  |
| Model validation against single tree experiment |  |  |  |  |  |  |  |  |
| Forest fire modelling for vulnerability mapping on a house |  |  |  |  |  |  |  |  |
| Data analysis and final report |  |  |  |  |  |  |  |  |

# 4 Amount Requested and Justification

**Requested Budget from SFPE:** Complete Project: US$29,977

We are seeking US$29,977 from the SFPE to complete the proposed budget. Of these,

* US$23650 will be used for 0.4FTE of Dr Mahmood Rashid’s time. He will be developing the firebrand generation submodel within FDS, conduct model validation and carry out the necessary fire simulations.
* US$4237 will Mr Amila Wickramasinghe’s involvement as 0.5 a day (on average) throughout the project. He will collate literature data to develop a function for firebrand generation rate per kg dry fuel consumed as function of vegetation species, wind velocity and FMC
* US$2090 will be used for 175 KSU supercomputing time.

Victoria University will cover 0.1 FTE of Prof Khalid Moinuddin’s time which is equivalent to US$12,300 (~30% of the total budget).

We believe the project will be an excellent value for money for the SFPE.

# 5 Project Impact

a. How does the proposed work align with SFPE Foundation’s mission to “enhance

the scientific understanding of fire and its interaction with the natural and built

environment?” (150 words max)

b. If executed as planned, how will this project help SFPE Foundation deliver on its

Strategic Goals (including student engagement and education)? (Please refer to

the 2019-2021 SFPE Foundation Strategic Plan.) (250 words max)

c. What kind of impact do you expect the proposed project to have? (250 words max)

d. How will your approach to this project contribute to increasing diversity, equity,

and inclusion throughout the research process, as well as enhance the potential

positive impact of the project deliverables for underrepresented, marginalized, or

historically excluded or disadvantaged communities globally? (250 words max)

# 6 Potential Conflict / Restrictions

# 7. List of Research Funding (last five years only) (Australian dollars)

Optimising fire alarm notification for high risk groups. Bruck D. & Thomas, I. R., US Fire Protection Research Foundation, 2006. $324,100.

Waking to a fire: Optimising the smoke alarm signal. Bruck D. & Thomas I. R. ARC Linkage Project Grant 2006-2007 $65,389 from ARC, $65,400 from industry partners.

Domestic Smoke Alarm Literature Study. Thomas I. R., 2006 Bushfire CRC Ltd. $28,500

Optimising the smoke signal for the aged. Bruck D. & Thomas, I. R., US National Fire Protection Foundation, 2005-2006. $98,000.

Fire Risk Modelling – Phase 2, Class 2 Buildings. Thomas I. R. 2005 Australian Building Codes Board. $58,000

Fire Risk Evaluations of Commercial Buildings. Bennetts I. D. & Thomas I. R. ARC Linkage Grant 2005-2006. $242,800.

Facility for analysis of Thermal Decomposition of Solid Materials at High Pressures. ARC Linkage LIEF 2004. Dlugogorski B. Z., Burford R., Masri A., Creelman, R., Thomas I. R. $289,900

Fire Protection of School Buildings. Thomas I. R. 2004-2006 Department of Education (All Australian States). $156,000.

Modelling human arousal behaviour in fire; influence of gender, alcohol, cue type and cue presentation on response parameters. 2003 Victoria University New Discovery grant $25,000

An Integrated Systems Analysis: Fire Growth and Severity in Enclosures. 2003 ARC Linkage Grant & Industry Partners Thomas I. R., Bennetts I. D. & Clancy, P. $186,951

FIRE-RISK Modelling. Thomas, I. R. 2003 Australian Building Codes Board $89,000

Low Rise Class 3 Timber Buildings. Thomas, I. R. 2002 Australian Building Codes Board. $21,450

Large Scale Experimental Building – 2001 Fire Facility (Collaborative Systemic Infrastructure Initiative) Department of Education, Training and Youth Affairs. Thomas I. R. and Industry Partners – Scientific Services Laboratory (SSL), Australian Government Analytical Laboratories, BHP Billiton Ltd and OneSteel Ltd. - $3,000,000

# 8. References

[1] K. Moinuddin and J.-d. Li, "A new convective heat transfer model for fire dynamics simulator," in *Proceedings: 13th Asian Congress of Fluid Mechanics (13 ACFM)*, 2010, pp. 819-822: Bangladesh Society of Mechanical Engineers.

[2] M. Sarwar, M. J. Cleary, K. A. M. Moinuddin, and G. Thorpe, "On linking the filter width to the boundary layer thickness in explicitly filtered large eddy simulations of wall bounded flows," *International Journal of Heat and Fluid Flow,* vol. 65, pp. 73-89, 2017.

[3] R. Wadhwani, D. Sutherland, G. Thorpe, and K. Moinuddin, "Improvement of drag model for non-burning firebrand transport in Fire Dynamics Simulator (accepted)," in *24th International Congress on Modelling and Simulation (MODSIM2021)*, Sydney, Australia, 2021.

[4] D. Sutherland, J. Philip, A. Ooi, and K. Moinuddin, "Large Eddy Simulation of Flow Over Streamwise Heterogeneous Canopies: Quadrant Analysis," in *Proceedings of the 21st Australasian Fluid Mechanics Conference*, 2018: Australasian Fluid Mechanics Society.

[5] S. A. Sydney, "AS 3959-2009: Construction of buildings in bushfire prone areas, Standards Australia: Sydney," ed, 2009.

[6] A. Haider and O. Levenspiel, "Drag coefficient and terminal velocity of spherical and nonspherical particles," *Powder technology,* vol. 58, no. 1, pp. 63-70, 1989.

[7] R. Wadhwani, "Physics-based simulation of short-range spotting in wildfires," PhD Thesis, College of Engineering and Sciences, Victoria University, Melbourne, 2019.

[8] T. R. Hudson, R. B. Bray, D. L. Blunck, W. Page, and B. Butler, "Effects of fuel morphology on ember generation characteristics at the tree scale," *International Journal of Wildland Fire,* vol. 29, no. 11, pp. 1042-1051, 2020.

[9] S. Adusumilli, T. Hudson, N. Gardner, and D. L. Blunck, "Quantifying production of hot firebrands using a fire-resistant fabric," *International Journal of Wildland Fire,* vol. 30, no. 2, pp. 154-159, 2020.

[10] S. Adusumilli, J. E. Chaplen, and D. L. Blunck, "Firebrand generation rates at the source for trees and a shrub," *Frontiers in Mechanical Engineering,* p. 35, 2021.

[11] K. Moinuddin and D. Sutherland, "Modelling of tree fires and fires transitioning from the forest floor to the canopy with a physics-based model," *Mathematics and Computers in Simulation,* 2019.

[12] S. L. Manzello, A. Maranghides, and W. E. Mell, "Firebrand generation from burning vegetation," *International Journal of Wildland Fire,* vol. 16, no. 4, pp. 458-462, 2007.

[13] J.-L. Dupuy and D. Morvan, "Numerical study of a crown fire spreading toward a fuel break using a multiphase physical model," *International Journal of Wildland Fire,* vol. 14, no. 2, pp. 141-151, 2005.

[14] K. Moinuddin and D. Sutherland, "Modelling of tree fires and fires transitioning from the forest floor to the canopy with a physics-based model," *Mathematics and Computers in Simulation,* vol. 175, pp. 81-95, 2020.

[15] K. A. M. Moinuddin, D. Sutherland, and R. Mell, "Simulation study of grass fire using a physics-based model: striving towards numerical rigour and the effect of grass height on the rate-of-spread," *International Journal of Wildland Fire,* vol. 27, no. 12, pp. 800-814, 2018.