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New Guidance for the Spill Plume in Smoke Control Design

Dr Roger Harrison
BRE Global
BRE Fire Research Conference
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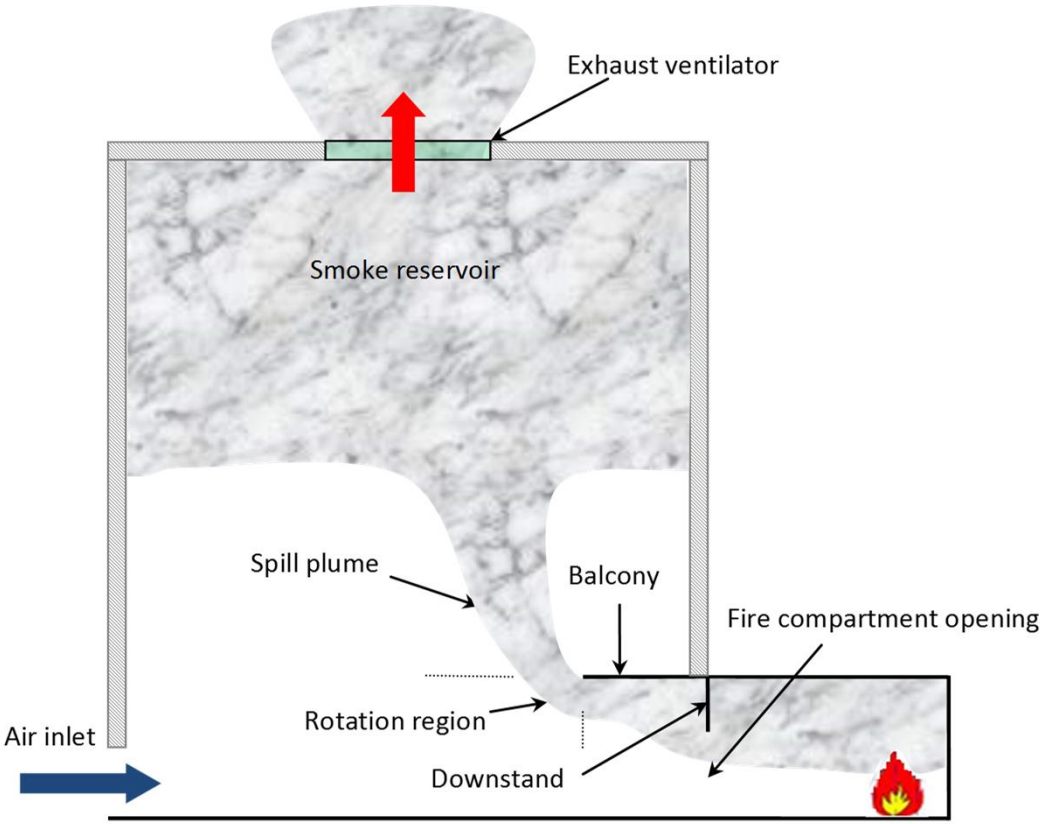
Smoke Control Objectives

Smoke control systems may have several objectives, such as:

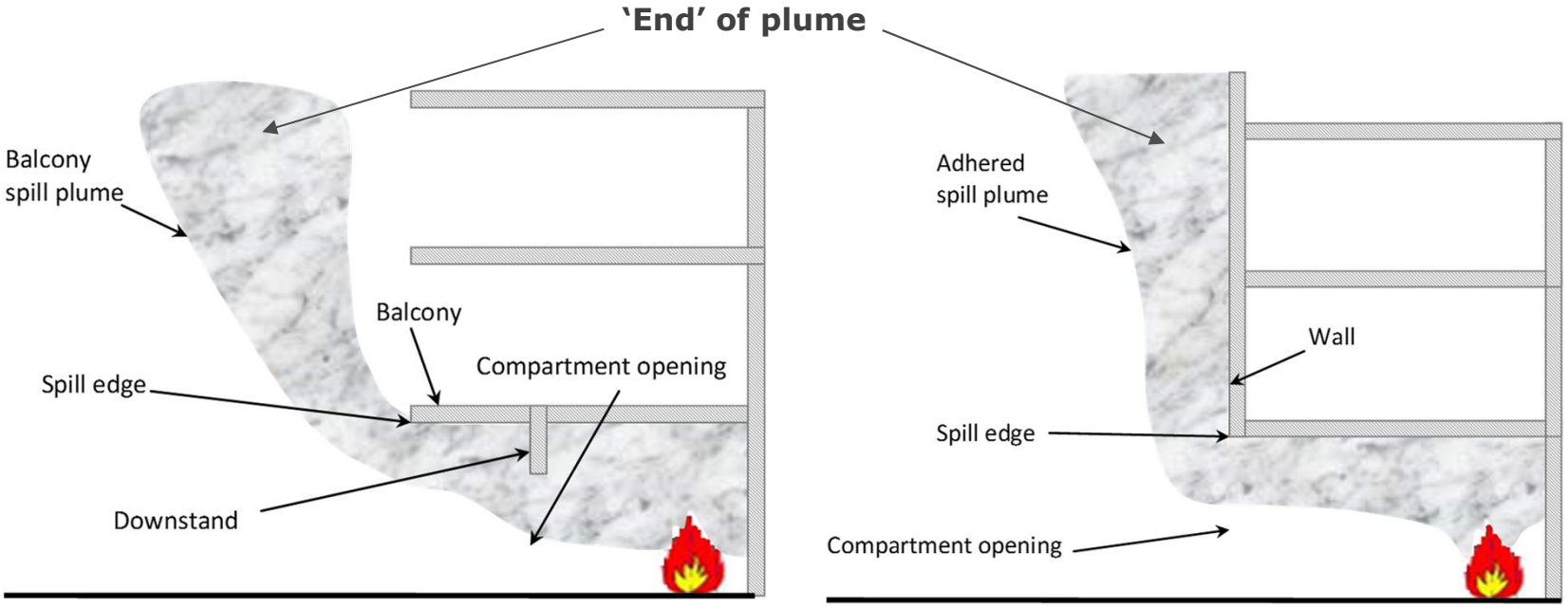
- Removing smoke from the building for means of escape
- Maintaining tenable conditions in the area of fire origin or areas adjoining the fire for means of escape
- Removing smoke during or post fire-fighting operations
- Minimising the risk of smoke spread to adjoining parts of the building

The Thermal Spill Plume



- Determine mass flow rate of gases produced
- Dependent on entrainment of air into plume

Terminology



– 2-D plumes do not include end entrainment

– 3-D plumes include end entrainment

Calculation Methods

- Simple spill plume formulae (based on empirical correlations)
  - Commonly used (e.g. CIBSE Guide E,PD 7974-2, NFPA 92)
  - Useful in early design stages to inform more complex methods
- Analytical methods or theories (utilises empirical data)
  - The BRE spill plume method [BR 368],etc.
- Computational Fluid Dynamics (CFD) modelling
  - More versatile, can be used for novel designs
- Uncertainties and limitations in some calculation methods
  - Supporting experimental data has been sparse
  - Can be large differences predicted smoke production rates
  - Scenarios where design guidance does not exist

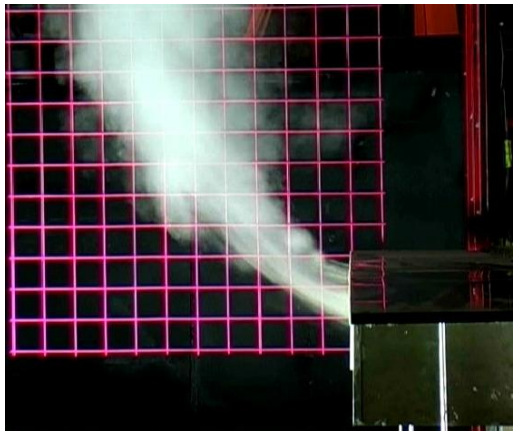
Aims and Objectives

- Provide a better understanding of spill plume entrainment

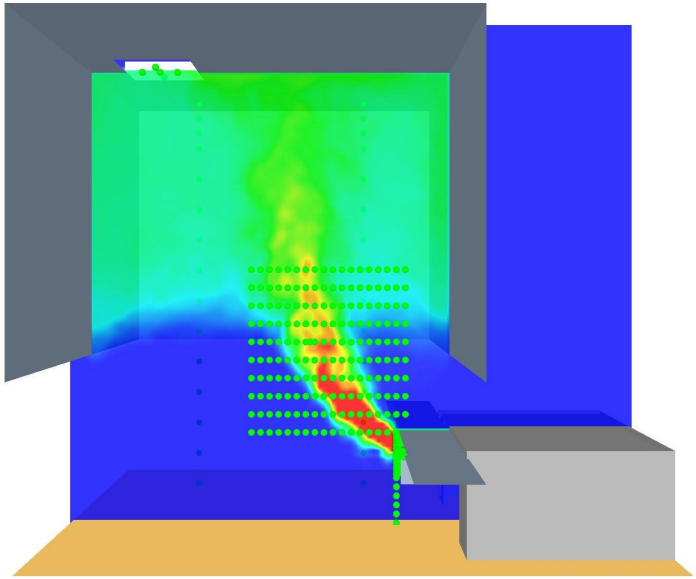
- Produce new data to provide options to Fire Engineers for design purposes in the form of:
  - A range of new and improved simplified design formulae for a variety of spill plume scenarios
  - Improvements to the existing analytical methods (i.e. the empirical elements)
  - An initial assessment of CFD modelling with recommendations for appropriate use (e.g. grid size)

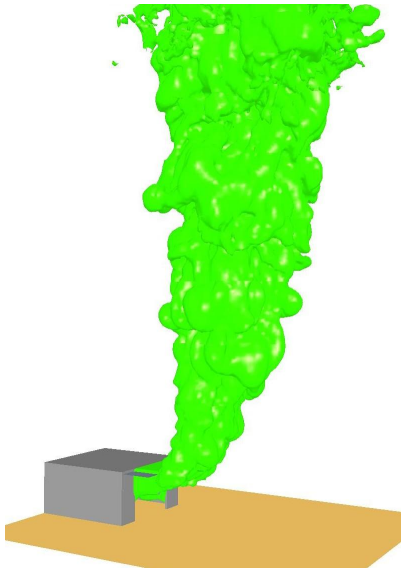
Physical Scale Modelling

- Alcohol fires in a 1/10th physical scale model
- Designed to satisfy the scaling laws (i.e. turbulent flow on full and model scale)
- Measure temperature, velocity, mass flow, etc
- Over 300 experiments carried out



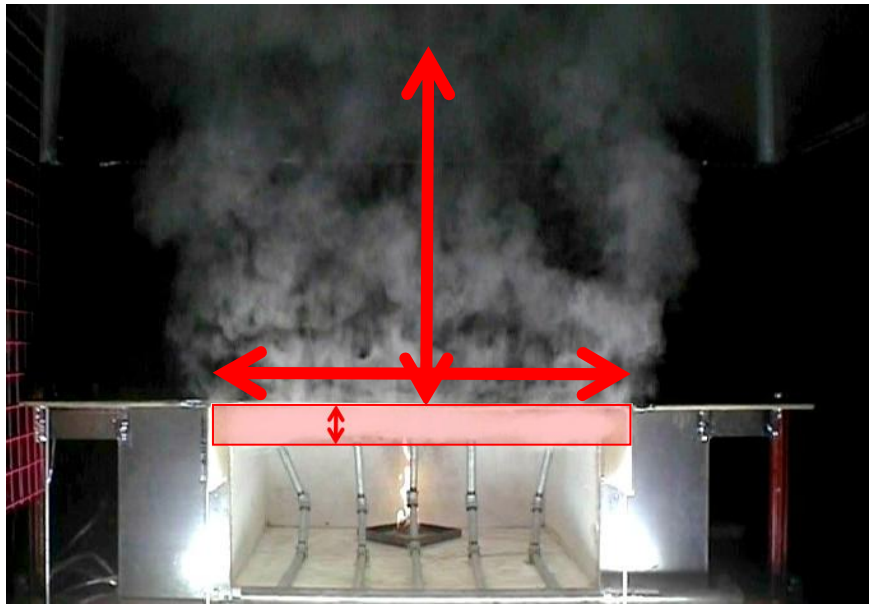
Numerical Modelling





- CFD used to model the experiment for validation
- Examine plumes at high heights of rise
- Fire Dynamics Simulator (FDS 5) mainly used

Terminology



W_s = width of plume at the spill edge (m)

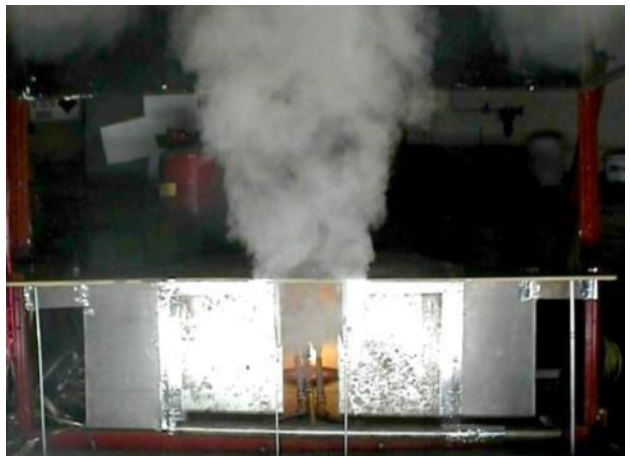
d_s = depth of the layer below the spill edge (m)

z_s = height of rise of plume above the spill edge (m)

$\dot{Q}_c$ = convective heat flow of the layer below the spill edge (kW)

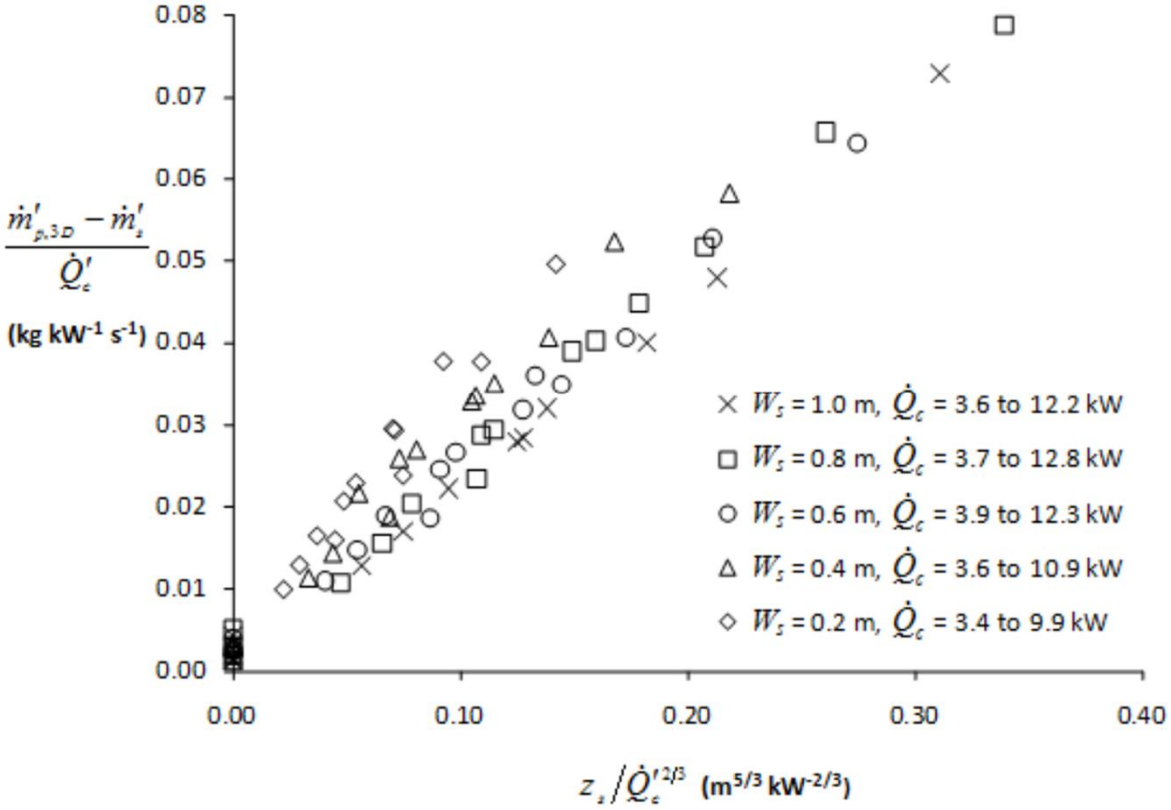
$\dot{m}_s$ = mass flow rate of the layer below the spill edge (kg/s)

Experiments

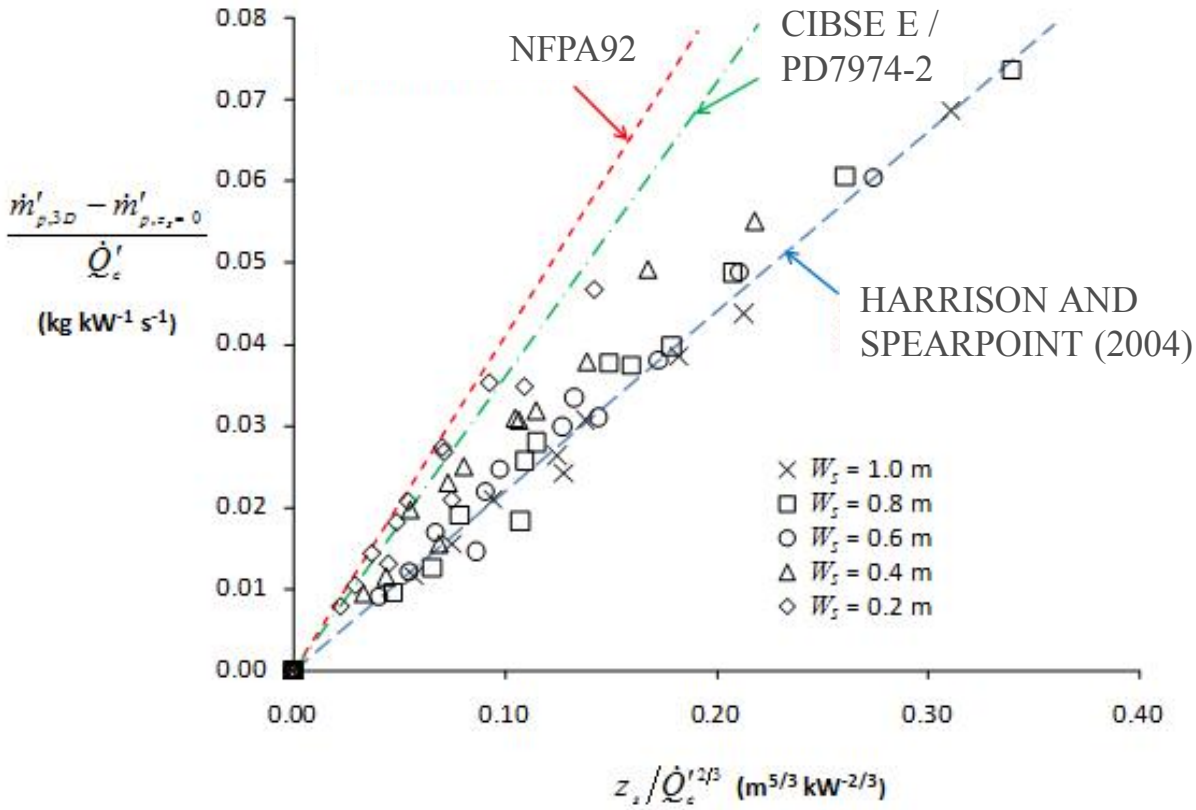


- Parameter variation
  - Fire size, compartment opening width and height of rise of plume varied
  - 2-D and 3-D plumes
  - Balcony and adhered plumes

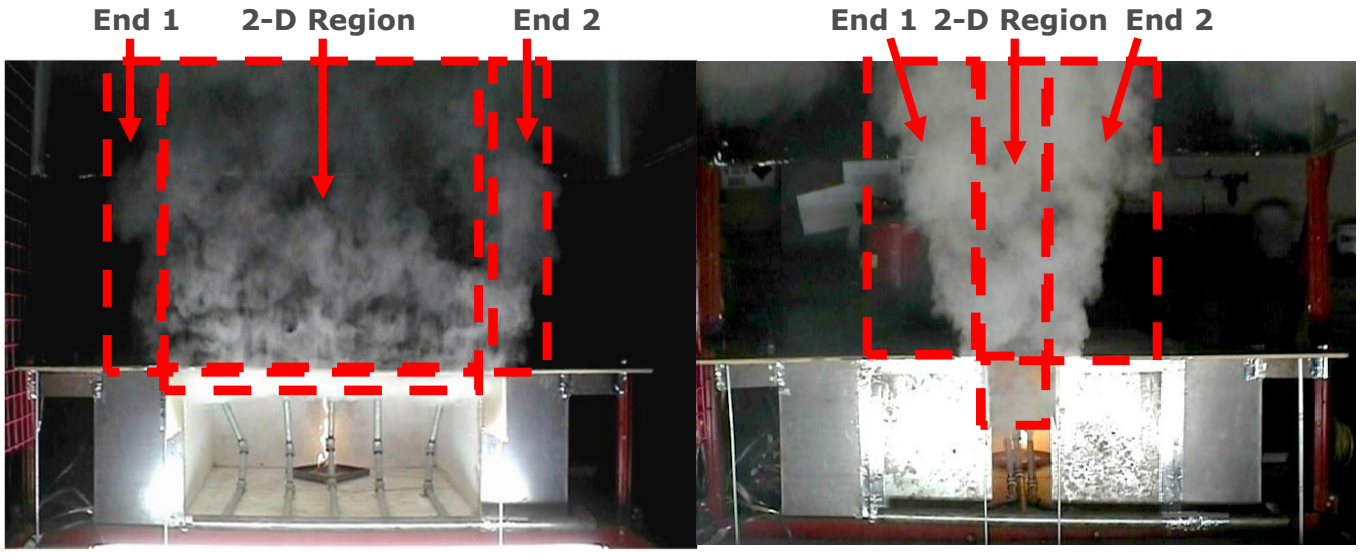
3-D Balcony Spill Plume



3-D Balcony Spill Plume



3-D Balcony Spill Plume



- General expression developed by decoupling and characterising key entrainment regions
- Experimental data collapse to a single general relationship

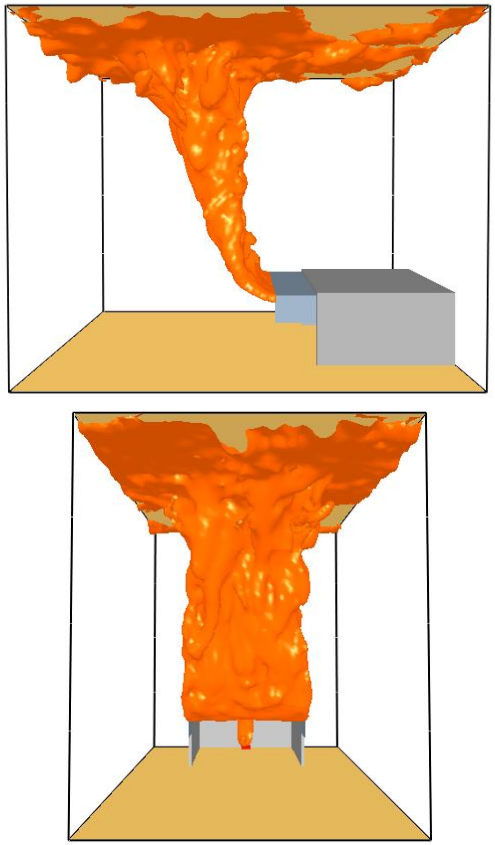
Balcony Spill Plume Formulae

Sum of entrainment into the decoupled flows

$$\dot{m}_{p,2D} = 0.16\dot{Q}_c^{1/3} W_s^{2/3} z_s + 1.34\dot{m}_s$$

$$\dot{m}_{p,3D} = 0.16\dot{Q}_c^{1/3}\left(W_s^{2/3} + 1.56 d_s^{2/3}\right) z_s + 1.34\dot{m}_s$$

FDS Modelling



- Grid sensitivity analysis carried out using the scale model data
- Guidance on appropriate grid for design purposes
- FDS5 provided a very good prediction of plume behaviour and entrainment
- FDS5 then used extrapolate the analysis (i.e. higher heights of rise)

3-D Balcony Plume to Axisymmetric

- New empirical design formula exhibits linearity
- The spill plume will eventually behave like an axisymmetric plume at high heights of rise (a power law)
- By matching the new design formula with an axisymmetric plume formula

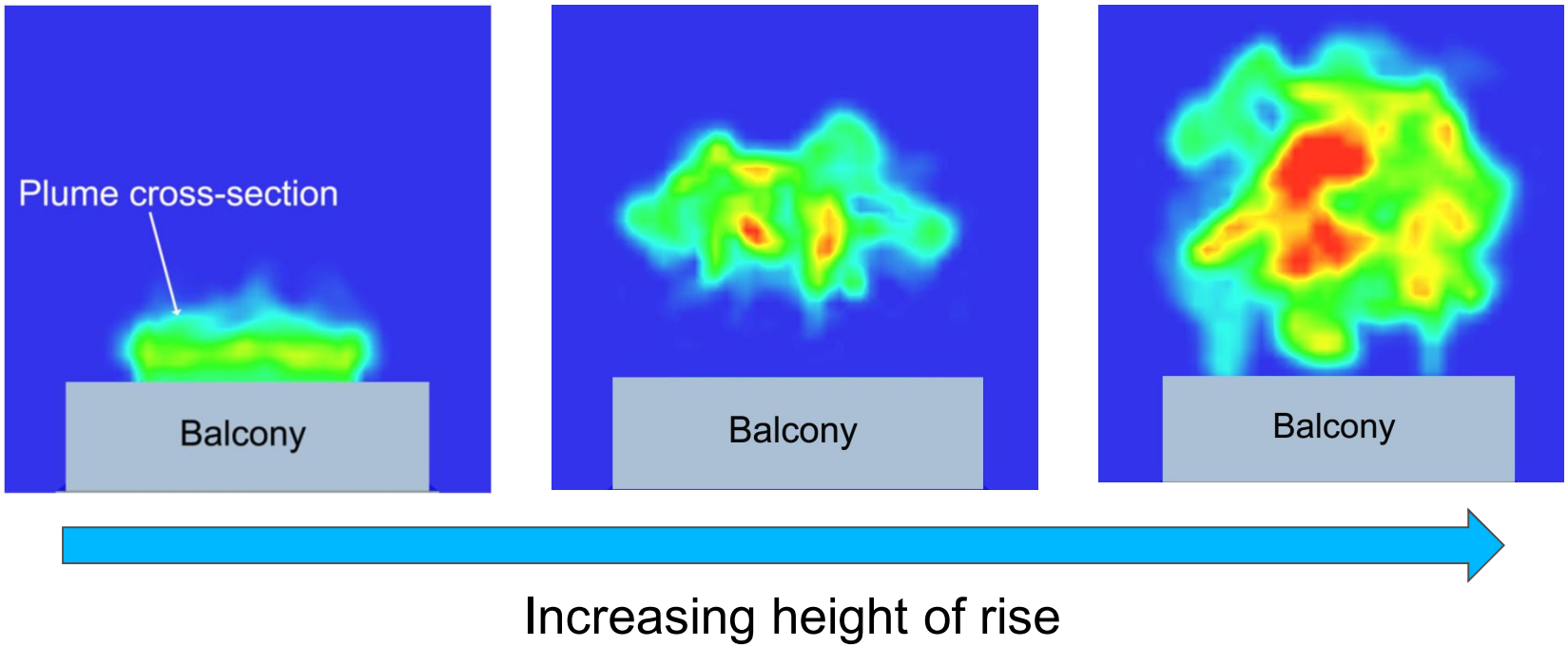
$$z_{trans} = 3.4\left(W_s^{2/3} + 1.56 d_s^{2/3}\right)^{3/2}$$

$$z_s > z_{trans}$$

$$\dot{m}_{p,3D} = 0.071 \dot{Q}_c^{1/3} z_s^{5/3}$$

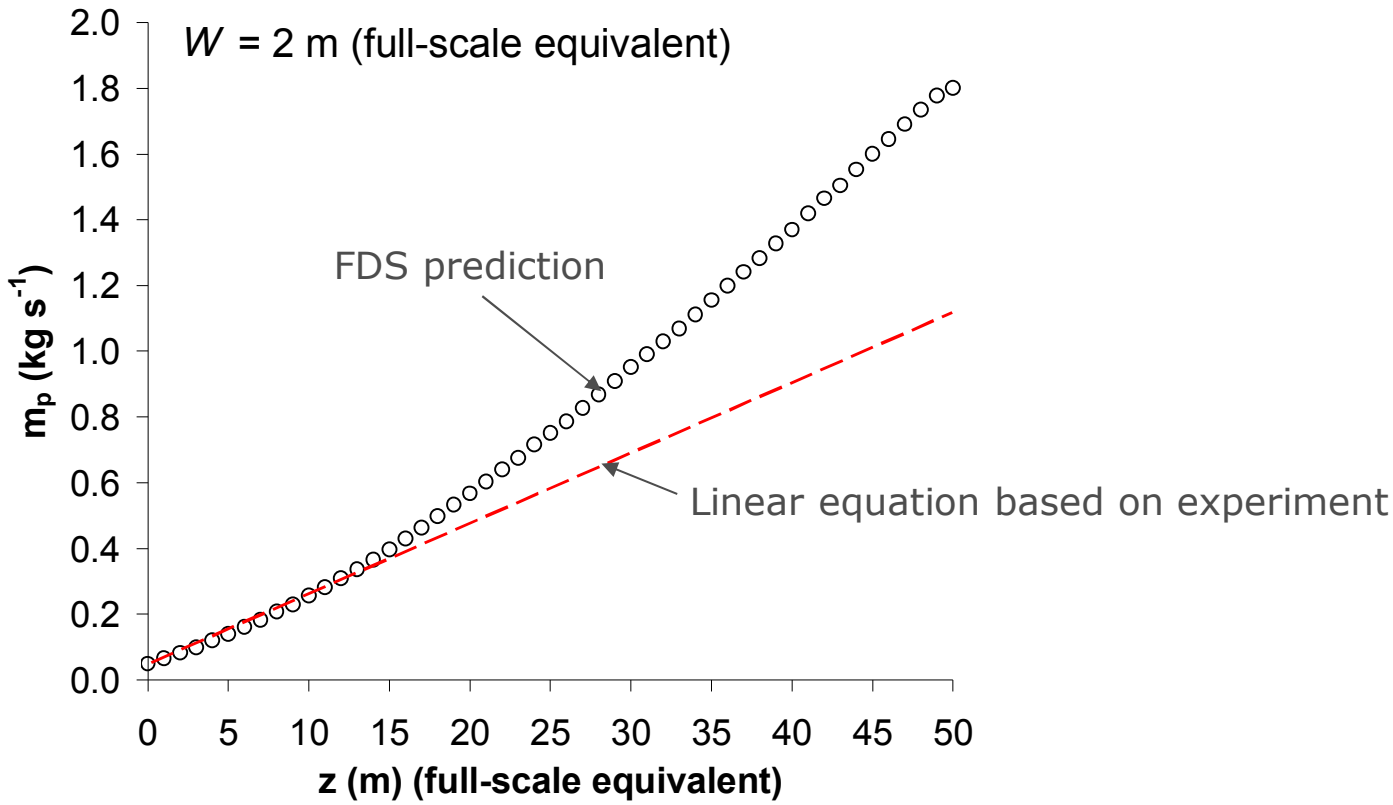
3-D Balcony Plume to Axisymmetric

FDS modelling at higher plume heights than in experiments

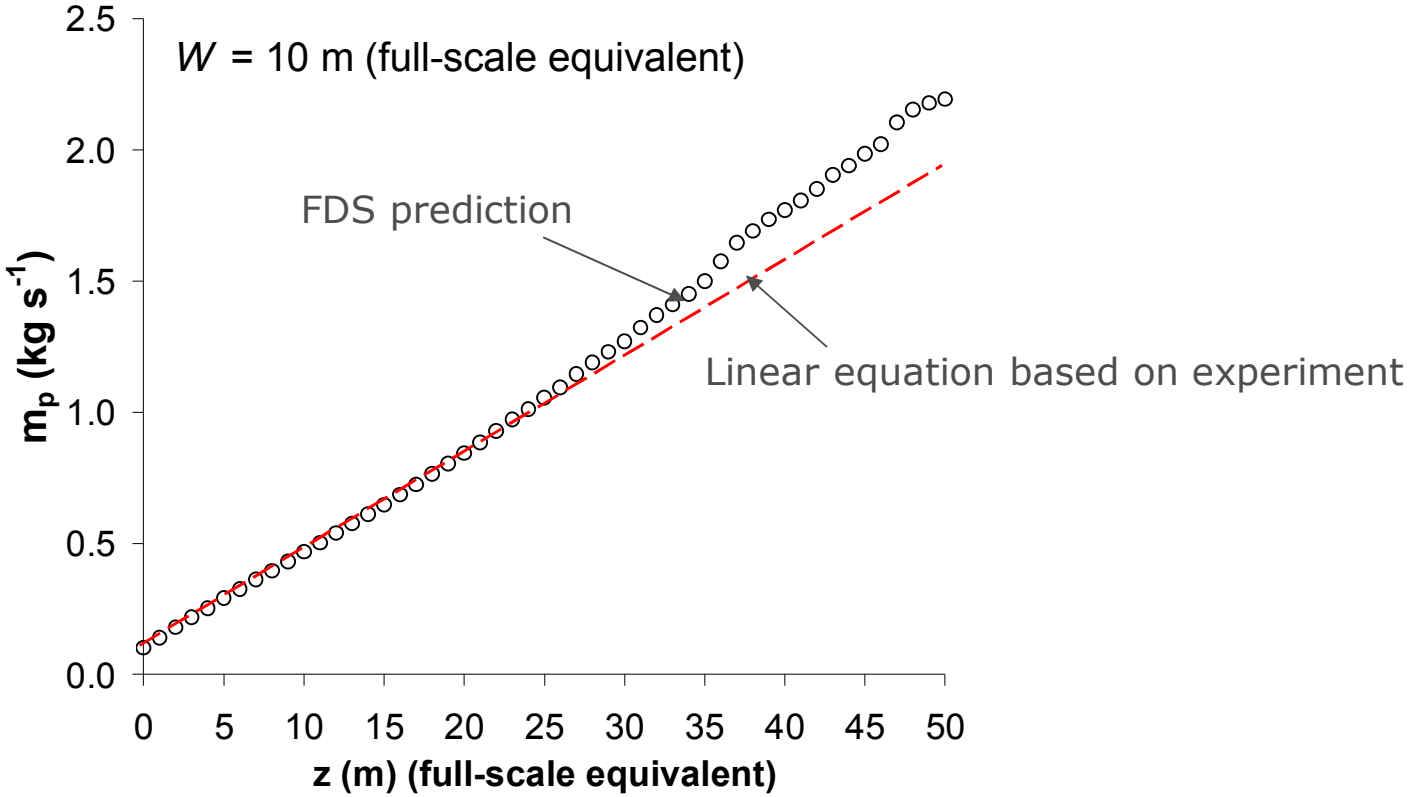


Increasing height of rise

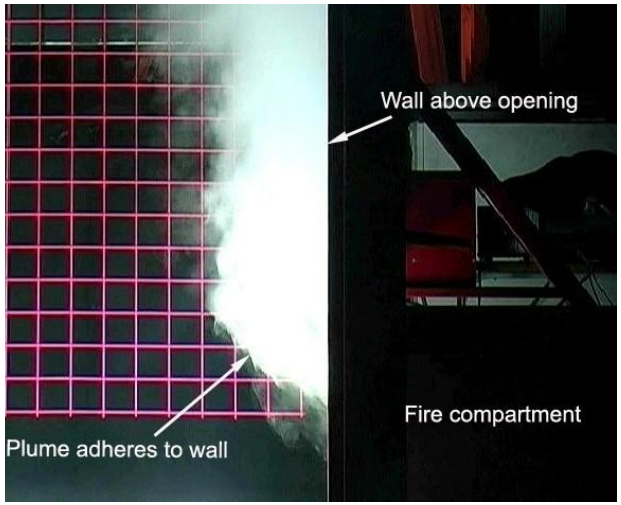
3-D Balcony Plume to Axisymmetric



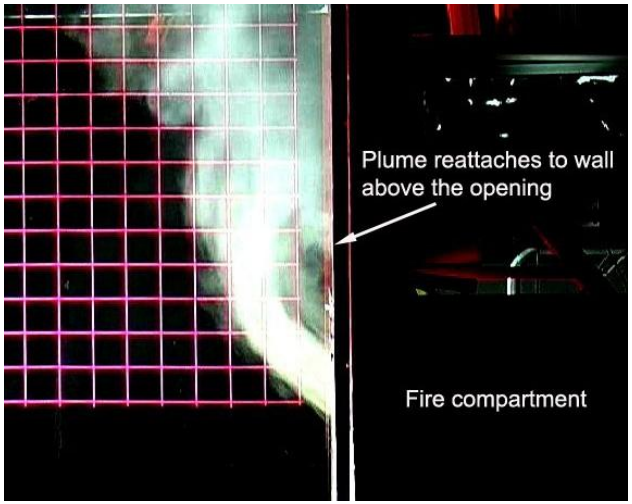
3-D Balcony Plume to Axisymmetric



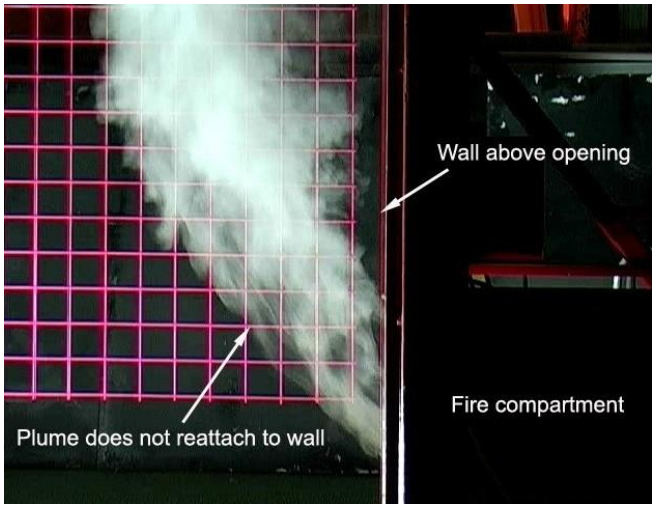
3-D Adhered Plume



Wide opening

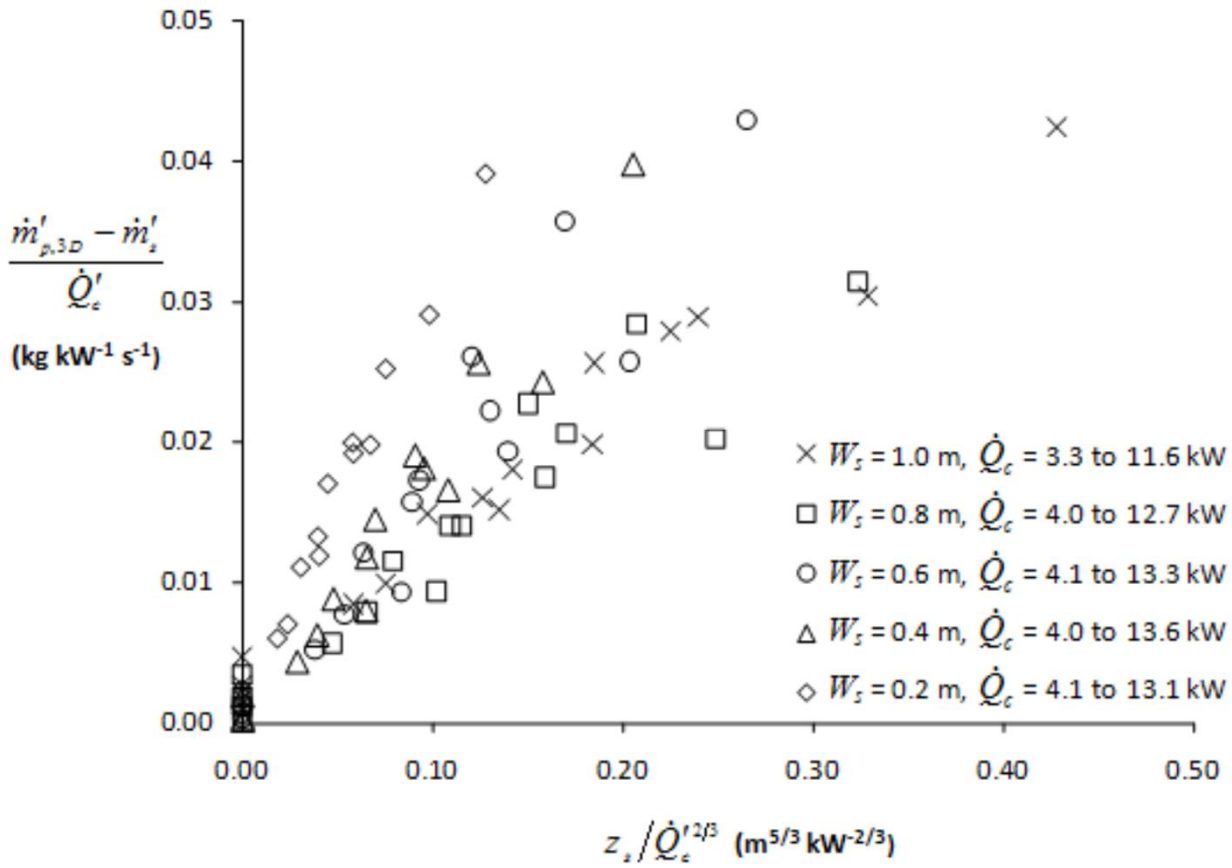


Intermediate opening



Narrow opening

3-D Adhered Plume



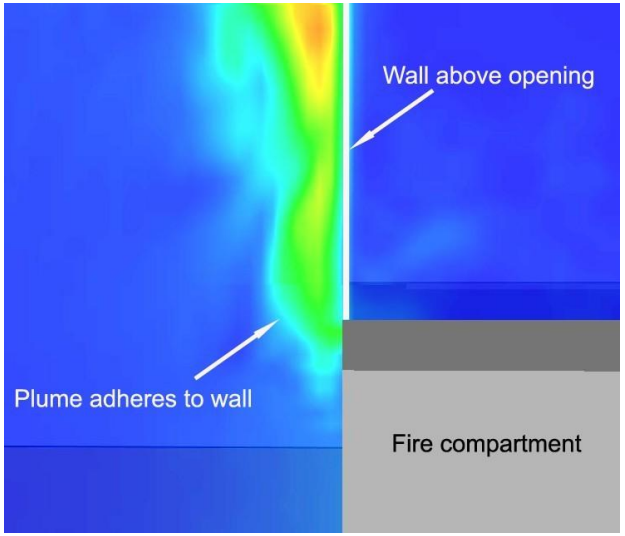
Adhered Spill Plume Formulae

- General expression developed by decoupling and characterising key entrainment regions
- Experimental data collapse to a single relationship

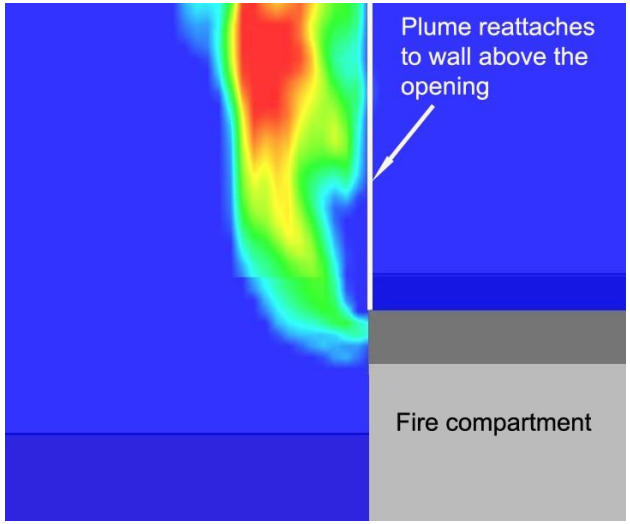
$$\dot{m}_{p,2D} = 0.08\dot{Q}_c^{1/3} W_s^{2/3} z_s + 1.34\dot{m}_s$$

$$\dot{m}_{p,3D} = 0.3\dot{Q}_c^{1/3} W_s^{1/6} d_s^{1/2} z_s + 1.34\dot{m}_s$$

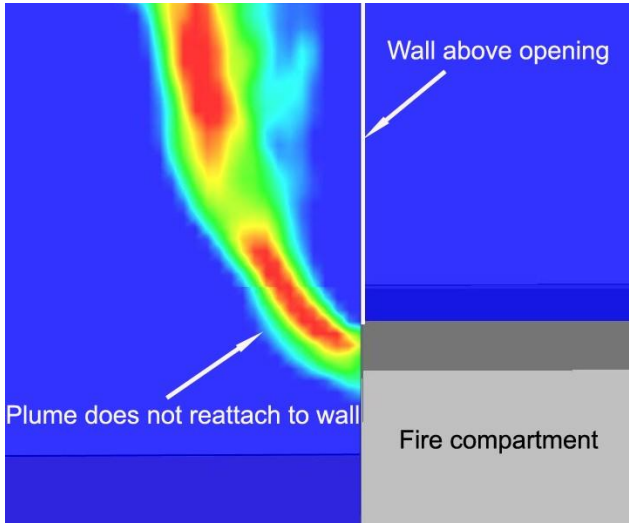
3-D Adhered Plume



Wide opening



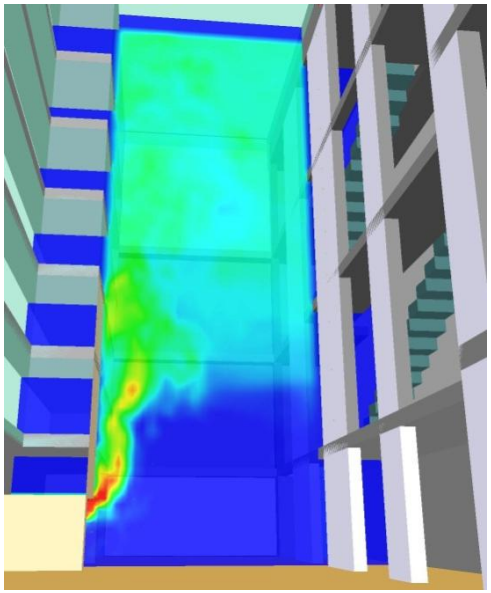
Intermediate opening

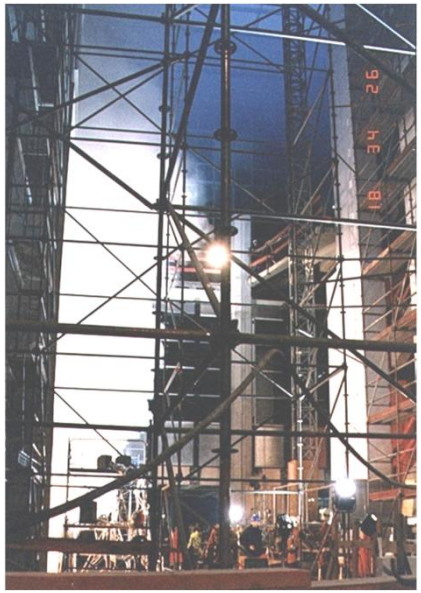


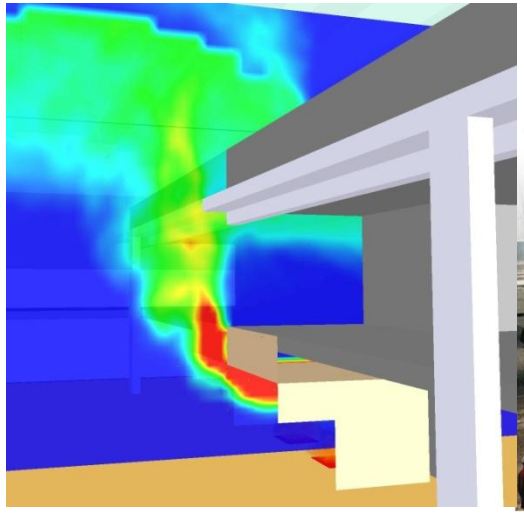
Narrow opening

Case Studies – Full Scale

To assess guidance with full scale 'Hot Smoke Test' data







Implementation

- CIBSE Guide E (Fire Engineering)
  - Included in next revision, late 2018
- PD 7974 Part 2 (Application of fire safety engineering principles to the design of buildings - Spread of smoke and toxic gases within and beyond the enclosure of origin)
  - Full revision of this standard
  - Late 2018
- BS EN 12101 (Guidelines on functional recommendations and calculation methods for smoke and heat exhaust ventilation systems)
  - Ongoing

Implementation - B-RISK

Forms the spill plume entrainment model in B-RISK, a next generation version of the BRANZFIRE fire zone model

BRANZ

STUDY REPORT

SR 282 (2013)

B-RISK User Guide and Technical Manual

C. Wade, G. Baker, K. Frank, A. Robbins, R. Harrison, M. Spearpoint and C. Fleischmann

Fire Technology
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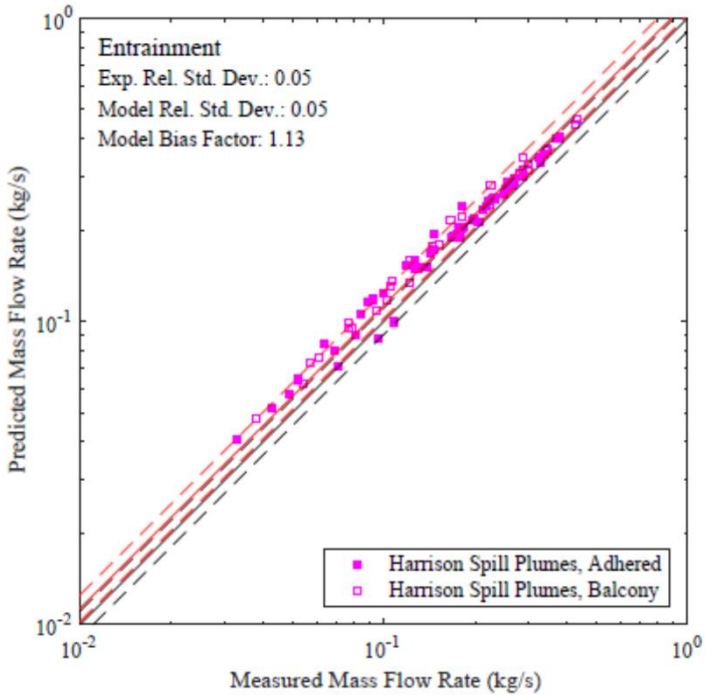
Predicting Spill Plumes with the Fire Risk Zone Model B-RISK

Roger Harrison, AECOM Fire and Risk Engineering, St Albans, UK*
Colleen Wade, BRANZ Ltd, Porirua City, New Zealand
Michael Spearpoint, Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

Implementation - FDS6

Experimental data used for FDS6 validation guide:



Further Reading

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- Harrison R and Spearpoint M. The Horizontal Flow of Gases below the Spill Edge of a Balcony and an Adhered Thermal Spill Plume. International Journal of Heat and Mass Transfer, Vol. 53, No. 25-26, pp 5792-5805, December 2010.
- Harrison R and Spearpoint M. A simple approximation to predict the transition from a balcony spill plume to an axisymmetric plume. Journal of Fire Protection Engineering, Vol. 20, No. 4, pp 273-289, November 2010.
- Harrison R and Spearpoint M. A comparison of channelled and unchannelled balcony spill plumes. Journal of Building Services Engineering Research and Technology, Vol. 31, No.3, pp 265-277, August 2010.

Further Reading

- Harrison R, Spearpoint M and Fleischmann C. Numerical modelling of balcony and adhered spill plume entrainment using FDS5. Journal of Applied Fire Science. Vol. 17, No. 4, pp 337 - 366, 2007-2008, July 2010.
- Tan F, Harrison R and Spearpoint M J. Physical scale modelling of smoke contamination in upper balconies by a channelled balcony spill plume in an atrium. Journal of Fire Sciences, Vol. 28, No. 4, pp 313-336, July 2010.
- Harrison R and Spearpoint M. Physical scale modelling of adhered spill plume entrainment. Fire Safety Journal. Vol. 45, No. 3, pp 149 - 158, April 2010.
- Harrison R. Entrainment of air into thermal spill plumes. Doctor of Philosophy Thesis, University of Canterbury, New Zealand, October 2009.
- Harrison R and Spearpoint M. Characterisation of balcony spill plume entrainment using physical scale modelling. Proceedings of the 9th Symposium of the International Association of Fire Safety Science, Karlsruhe, Germany, pp 727-738, September 2008.

Summary

- New guidance has been developed in the form of:
  - A range of new simplified design formulae for balcony and adhered plumes that apply more generally than existing methods
  - A simplified formula for when a balcony plume becomes an axisymmetric plume
  - An assessment on the use of numerical modelling
  - Being implemented into standards and models

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Thank you

BRE Group
Watford, UK
WD25 9XX
+44 (0)333 321 88 11
enquiries@bre.co.uk
www.bregroup.com