Longitudinal Tunnel Ventilation and the Fire Throttling Effect

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AECOM @ Fire & Risk

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Contents

A brief introduction to tunnel ventilation, super critical ventilation velocity and how it relates to the fire throttling effect.

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Acknowledgement

Society of Fire Safety Research Grant 2017

"If I have seen further, it is by standing on the shoulders of giants"

Isaac Newton

Hazelab @ Imperial College London

Our work is to reduce the worldwide burden of accidental fires and protect people, their property, and the environment.

- Research Group headed by Guillermo Rein
- 13 PhD researchers
- 1 Postdoc
- Research in:
  - Forest fires
  - Built Environment
  - Material Flammability

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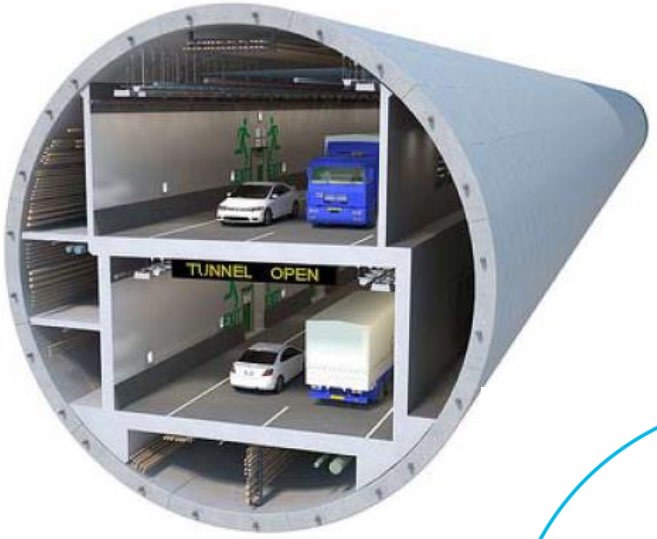
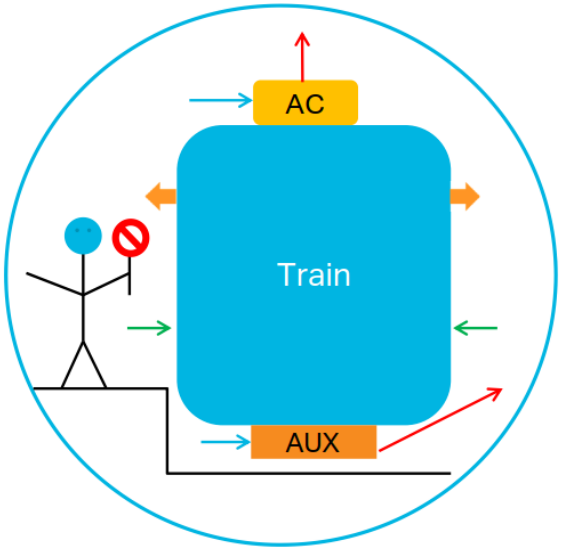
Tunnel Ventilation
An Overview

Tunnel Ventilation: An Overview

- Purpose of ventilation
- Temperature
  - Cooling
  - Auxiliary equipment
- Air Quality
  - CO and fumes
  - Oxygen starvation (petrol / diesel)
- Fire emergencies





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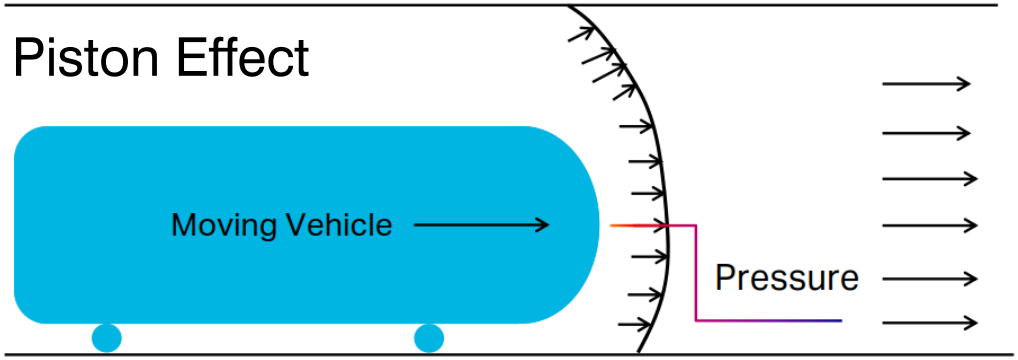
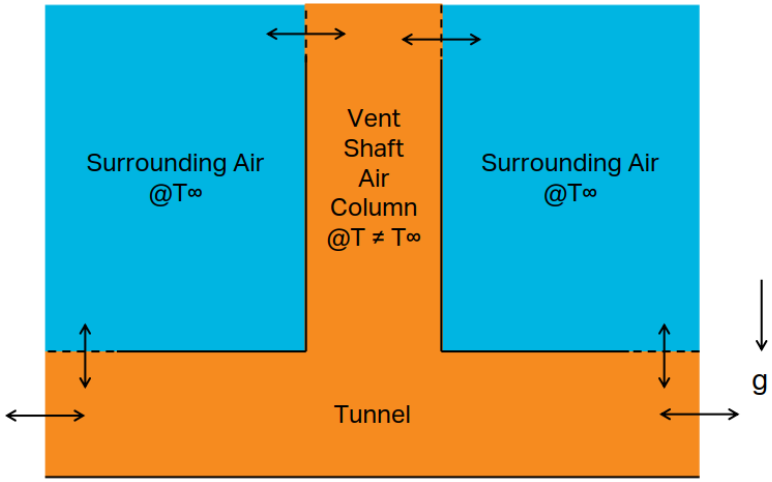
Tunnel Ventilation: An Overview

- Ventilation systems
  - Natural / Passive
  - Mechanical / Active
- Natural / Passive
  - Piston effect
  - Wind
  - Chimney Effect

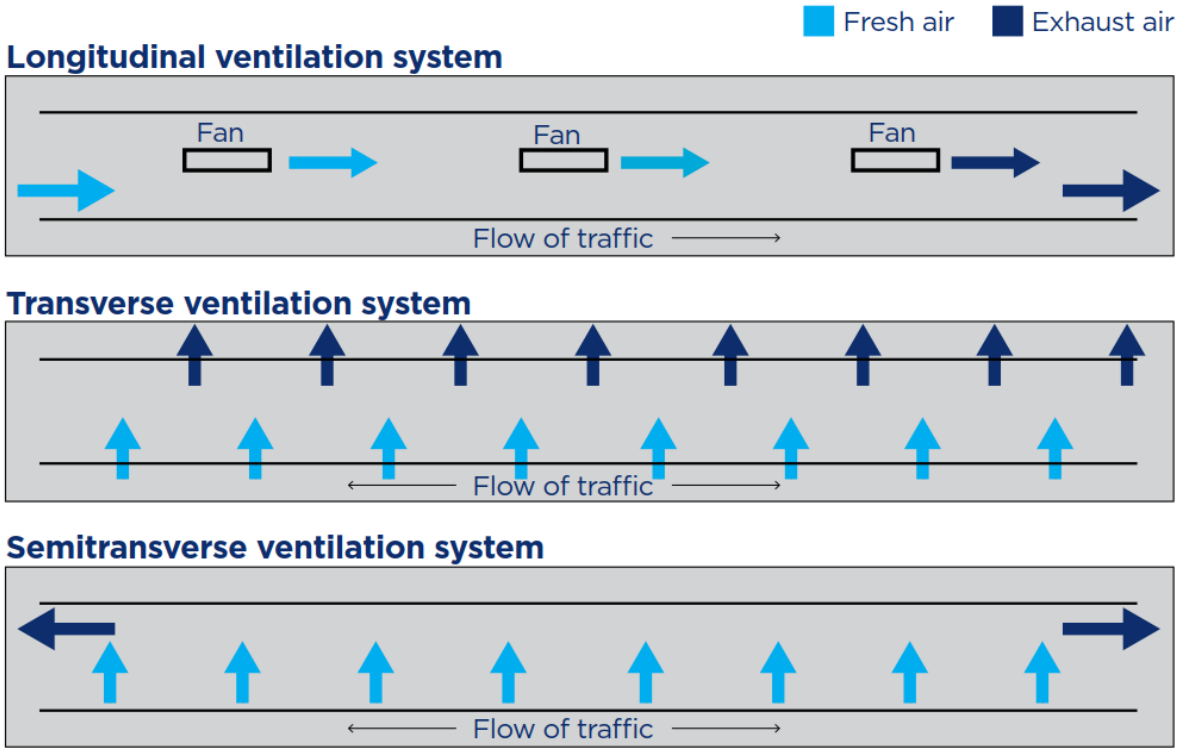




Chimney Effect

Tunnel Ventilation: An Overview

- Ventilation systems
  - Natural / Passive
  - Mechanical / Active
- Mechanical / Active
  - Transverse
  - Semi-transverse
  - Longitudinal

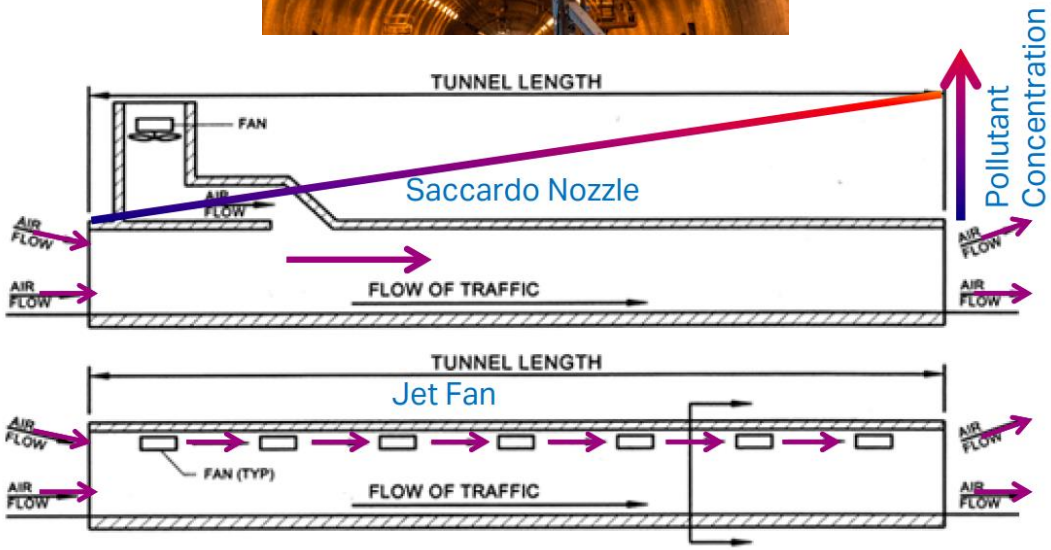


Roads and Maritime Services. *TP04 Road Tunnel ventilation system*, July 2014

Tunnel Ventilation
Longitudinal Ventilation

Tunnel Ventilation: Longitudinal Ventilation

- Longitudinal ventilation
  - Air flow in one direction
  - Single direction traffic
  - Not viable previously; need for large quantities of fresh air
  - Used for the majority of tunnels in Australia last 20 years
  - Easier to construct than transverse systems



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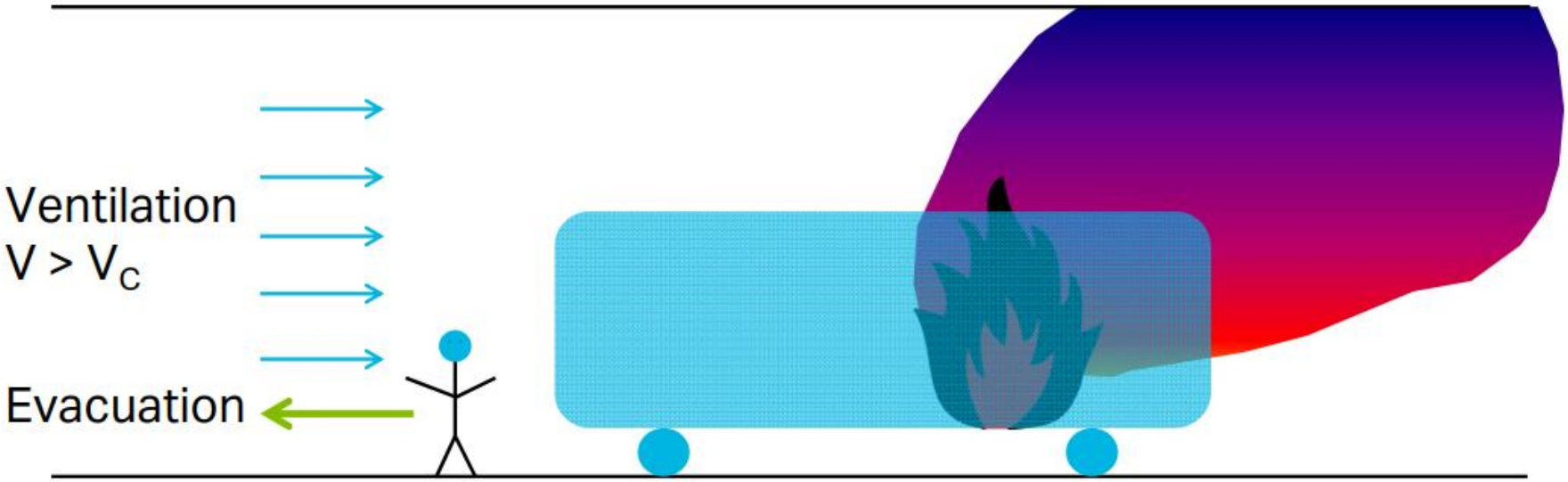
Tunnel Ventilation: Longitudinal Ventilation

- Longitudinal ventilation in fire mode
  - Keep one side clear of the fire / smoke for evacuation
  - Air flow > critical ventilation velocity, V_c



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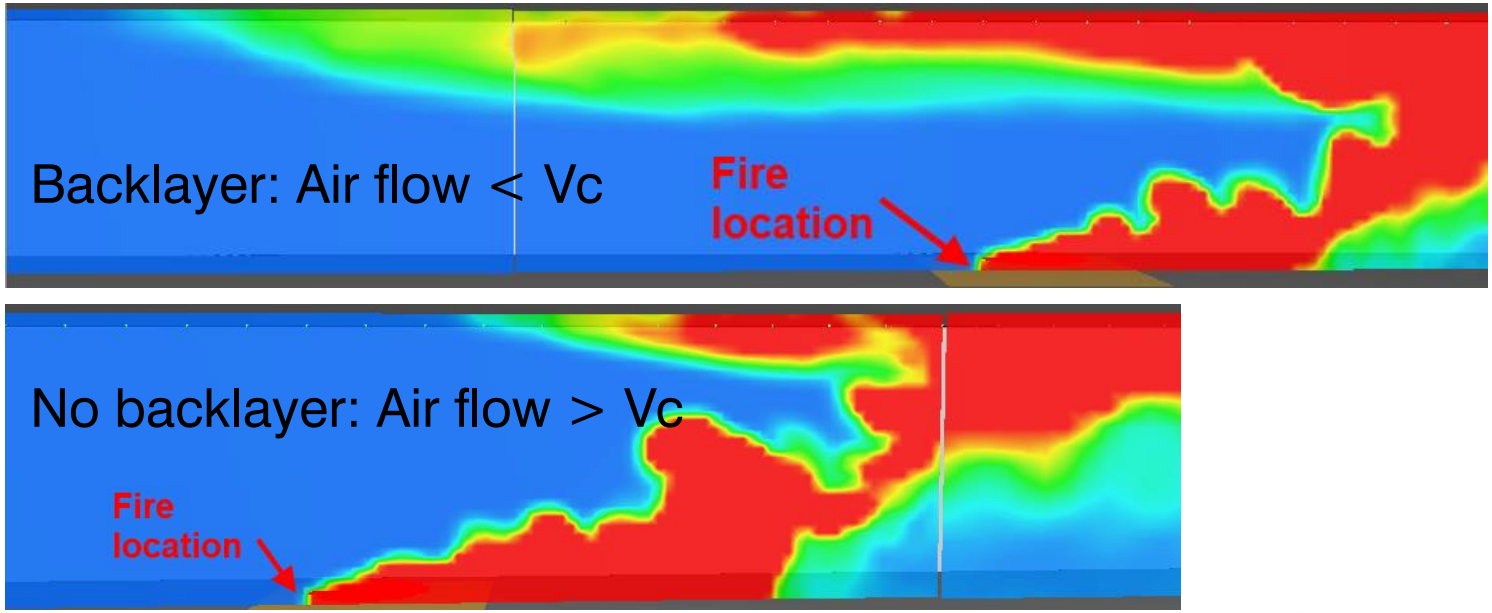

D. Swenson. C*ritical velocity in tunnel fires.* Thunderhead Engineering.

Tunnel Ventilation
Critical Ventilation Velocity

Tunnel Ventilation: Critical Ventilation Velocity

- Velocity needed to prevent backlayering of smoke
- One of the most studied phenomenon
- **1950s:** Origins traced back to Thomas (Fire Research Station, UK)
  - Argued critical velocity governed by the ratio of buoyancy to inertial forces
  - Relationship linked by Froude Number $Fr_m = gH\Delta\theta/(U^2T)$
- **1970s:** Refinements by Heselden
- **1980s:** Refinements by Danziger and Kennedy
  - Related temperature to convective heat release rate
  - Cornerstone of tunnel ventilation design

$$V_c = \left(\frac{gH\dot{Q}_c}{\rho C_p A T_f Fr_m} \right)^{1/3}$$

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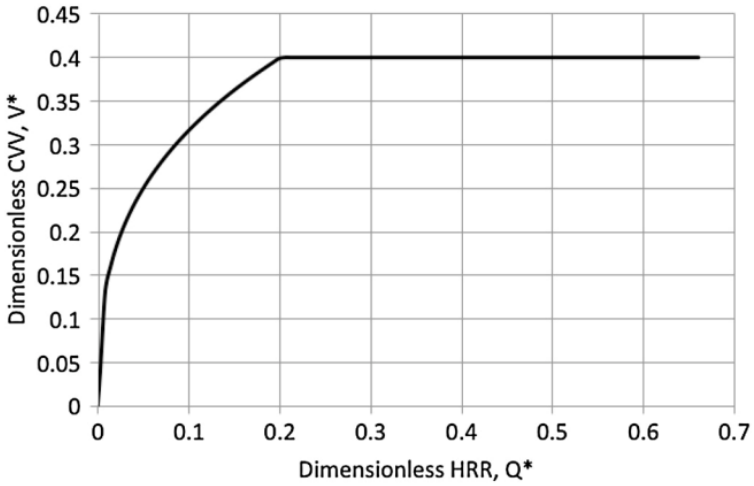
Tunnel Ventilation: Super Critical Ventilation Velocity

- **1995:** Oka and Atkinson defined ‘super critical’ ventilation velocity
- So what is the super critical ventilation velocity?
- Fire size and critical velocity
  - Relationship up to a limit
  - No increase in velocity needed beyond
  - Typically ~ 3 to 4 m/s for road tunnels



A. Vaitkevicious and R. Carvel. *Investigating the throttling effect in tunnel fires.* Fire Technology, June 2015

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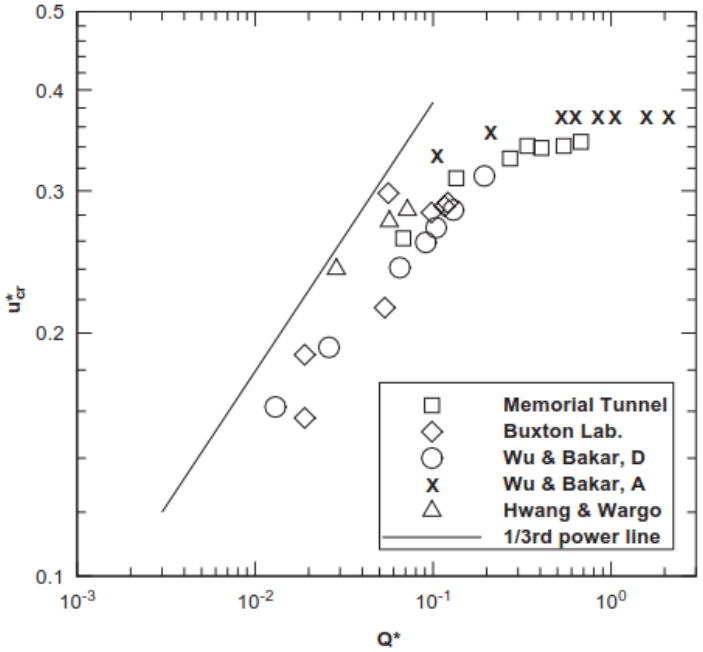
Tunnel Ventilation: Super Critical Ventilation Velocity

- **2000:** Further refinements by Wu and Bakar
- Further experiments showing this
- Foundation of other researches
  - Tunnel dimensions
  - Relationship between velocity and fire growth
  - Slope in tunnels
  - Blockages in tunnels
  - Critical velocity near portals
- Modified equation used today
  - NFPA 502 etc

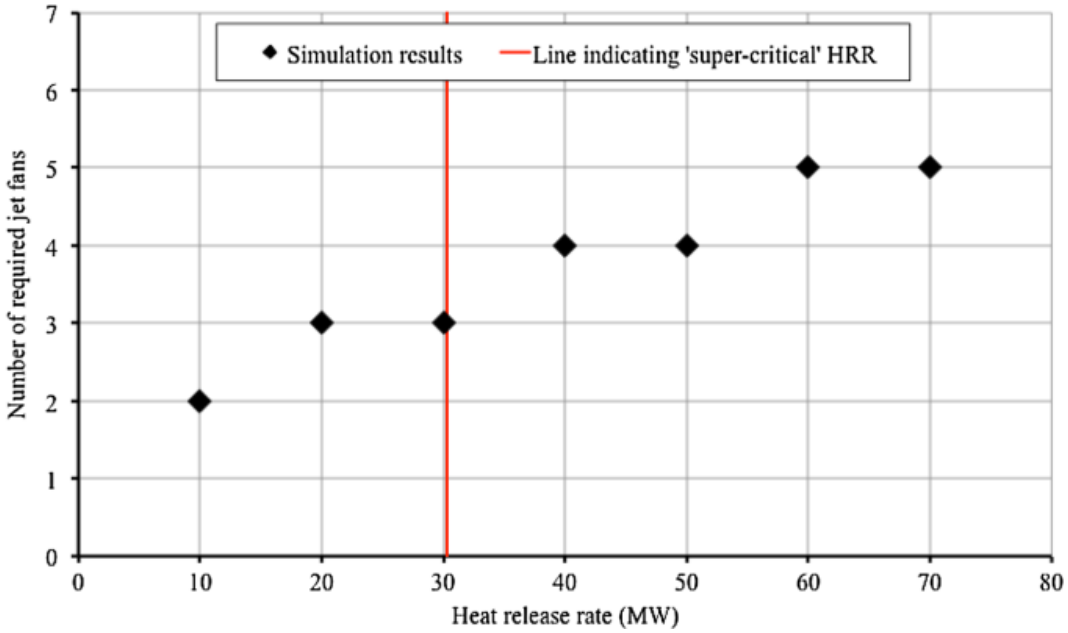


C.C. Hwang and J.C. Edwards. *The critical ventilation in tunnel fires .* Fire Safety Journal, 2002.

Fire Throttling Effect
So how does it all relate?

Tunnel Ventilation: Fire Throttling Effect

- So what is the fire throttling effect?
- An observed phenomenon where a fire increases the flow resistance
- Pressure drop / flow resistance due to fires



A. Vaitkevicious and R. Carvel.
Investigating the throttling effect in tunnel fires.
Fire Technology, June 2015

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Tunnel Ventilation: Fire Throttling Effect

- **1973:** First discussed for mining tunnels by Greuer
- **1979:** Experimental observations by Lee
- **A forgotten and overlooked period**
- **2014:** Rediscovered by Colella *et al* whilst working on the novel multi-scale modelling approach for long tunnels
- PIARC *Jet Fan Calculation Procedure*
  - A recognised phenomenon
  - To be verified in a CFD study

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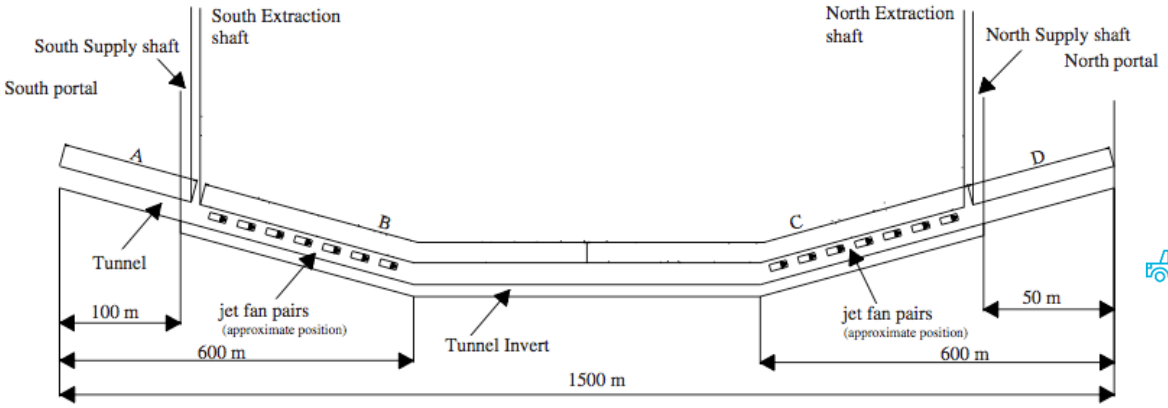
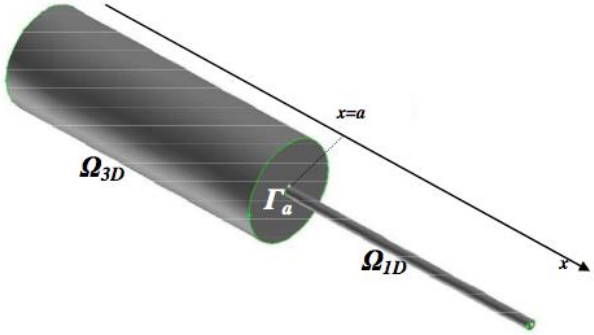
Tunnel Ventilation: Fire Throttling Effect

- The impact of the fire throttling effect has been observed
- No analytical or empirical model describing this
- But a numerical glimpse in the FDS Multi-scale fire modelling work
- Dartford Tunnel in London



C.D.E. Ang, G. Rein, J. Peiro and R. Harrison
Simulating longitudinal ventilation flows in long tunnels CFD and Multi-scale modelling
Tunnellling and Underground Space Technology, February 2016



F. Collela, R. Borchiellini, V. Verda, and G. Rein.
Multiscale Modelling of Tunnel Ventilation Flows and Fires.
[Online] https://www.era.lib.ed.ac.uk/handle/ 1842/3528, May 2010.

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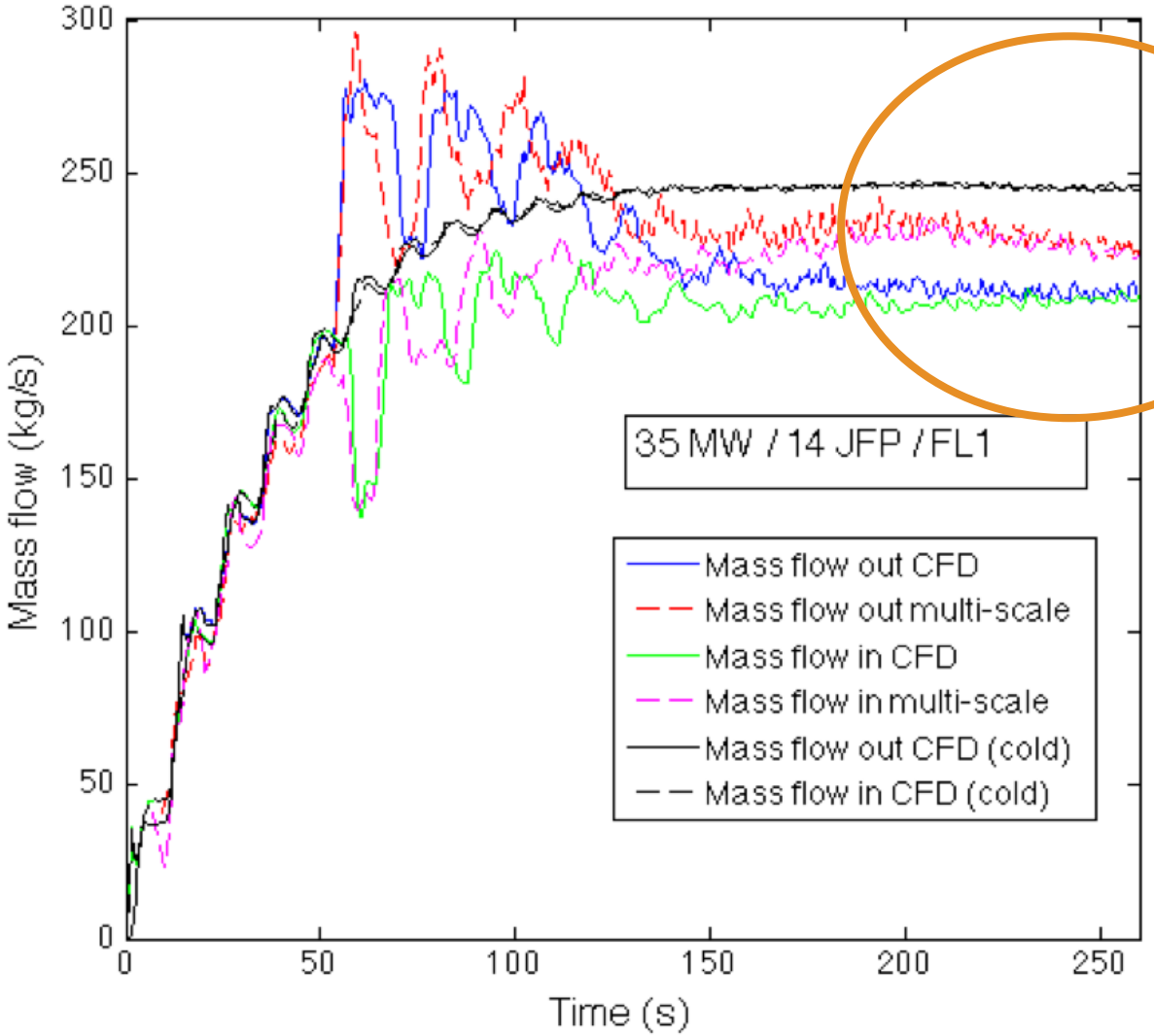
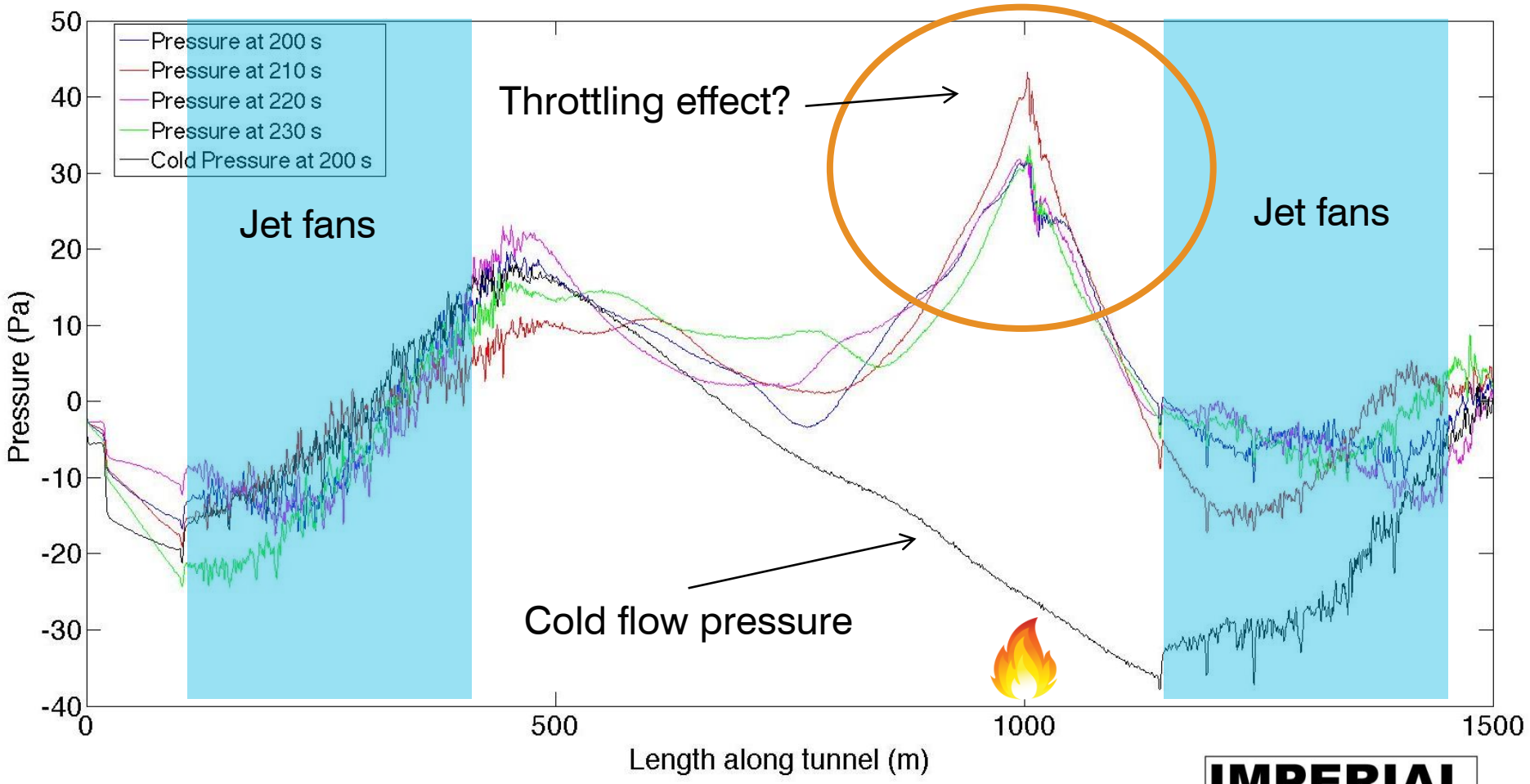
Tunnel Ventilation: Fire Throttling Effect



Reduction in mass flow

Tunnel Ventilation: Fire Throttling Effect



Conclusion

- Longitudinal tunnel ventilation will continue to be a popular means to ventilate a tunnel
- Fire throttling effect is an important consideration
- For a larger fire, the number of fans needed to achieve the critical velocity increases (the critical velocity remains unchanged)
- We do not have an analytical or empirical description of this yet
- Only through ‘black box’ CFD modelling – how accurate?
- **We are working on this – My PhD research!**

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Thank You

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