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Modeling Tunnel Ventilation and Fires

ITA-COSUF Workshop 2014

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Evolution of a tunnel fire emergency

Detection system
Fire and smoke behavior

Signaling
Evacuation strategies
Fire and smoke behavior
Occupation

Fire and smoke behavior

detection

Evacuation

Fire fighting activities

Fire Ignition

Detection

Evacuation complete

Time

Ventilation system

Ventilation system design
Tunnel layout
Weather conditions at the portals

Suppression system

Suppression system design
Fire load characteristics

Evolution of a tunnel fire emergency

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Tunnel layout
Weather conditions at the portals

Suppression system

Suppression system design
Fire load characteristics

Fire dynamics and smoke management

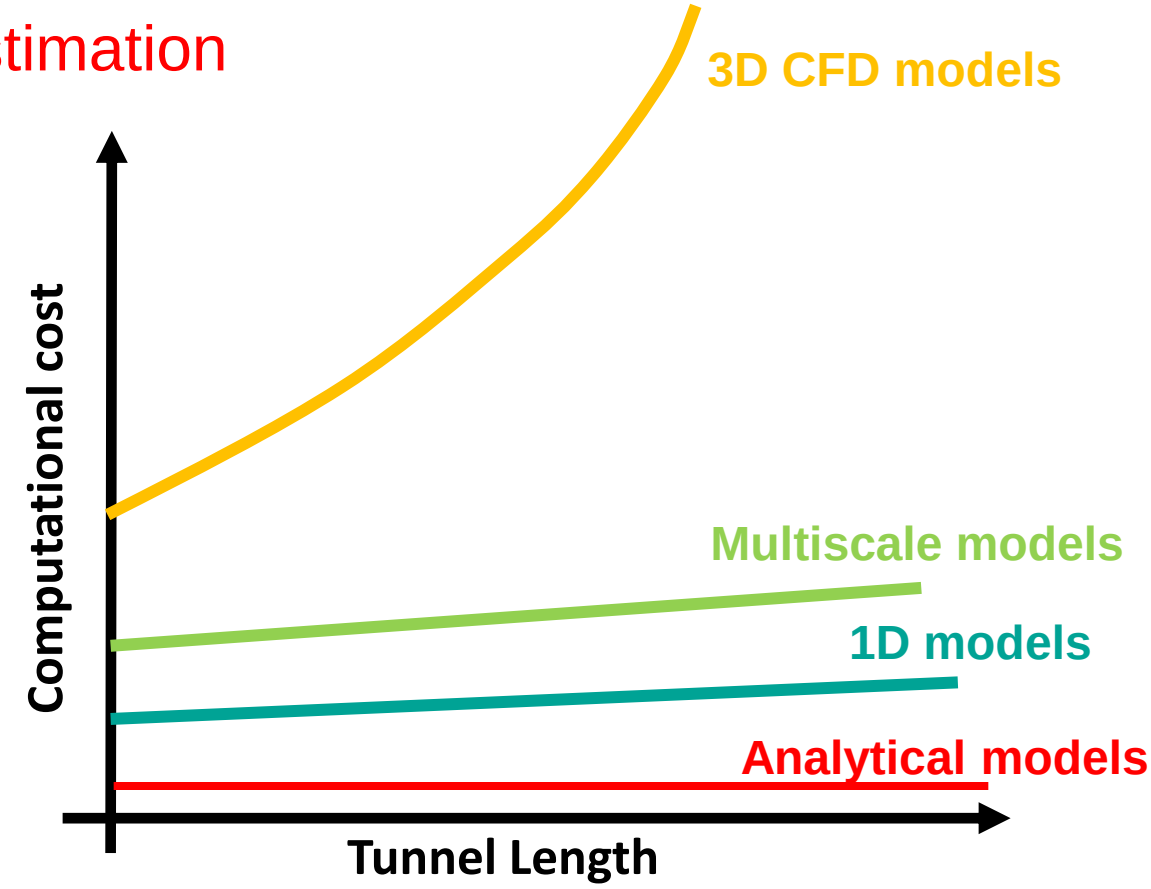
Conditions in tunnels during fire emergencies are dependent on the combined influence of:

- Ventilation system
- Tunnel layout (slopes, junctions)
- Fire size and Location
- Weather conditions at portals and shafts
- Vehicles arrangements

- **The number of possible scenarios is cumbersome**
- **The analysis of the most relevant scenarios must be conducted by using simulation tools**

Modeling tools

- **Analytical models**
  - Semi-empirical correlations for simple geometries
  - Critical velocity estimation
- **1D models**
- **3D CFD models**
- **Multiscale models**

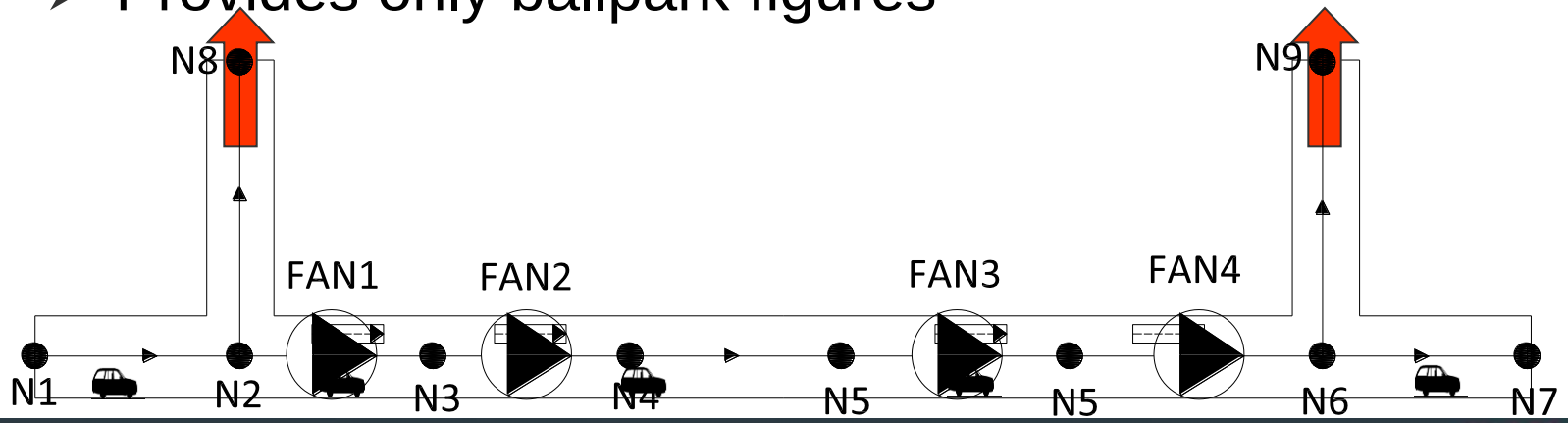


1D models

- Fast simulations (few minutes)
- Straightforward definition of boundary conditions
- Predict the global behaviour of the system
- Well established for design purposes

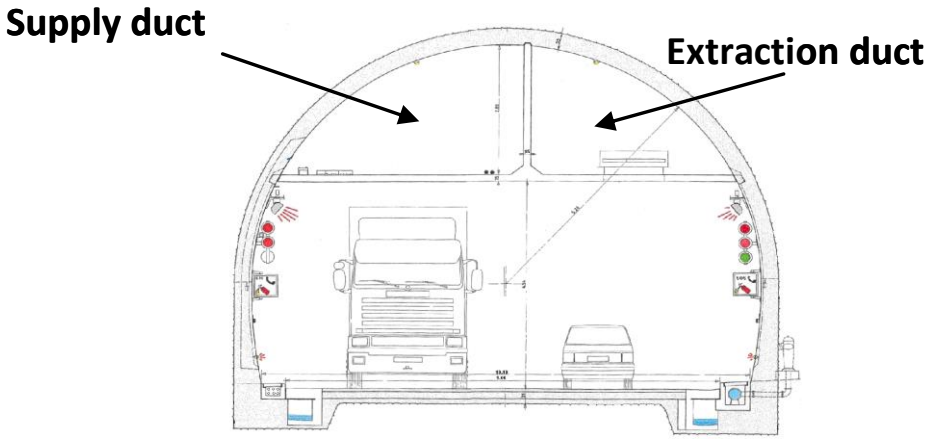
BUT

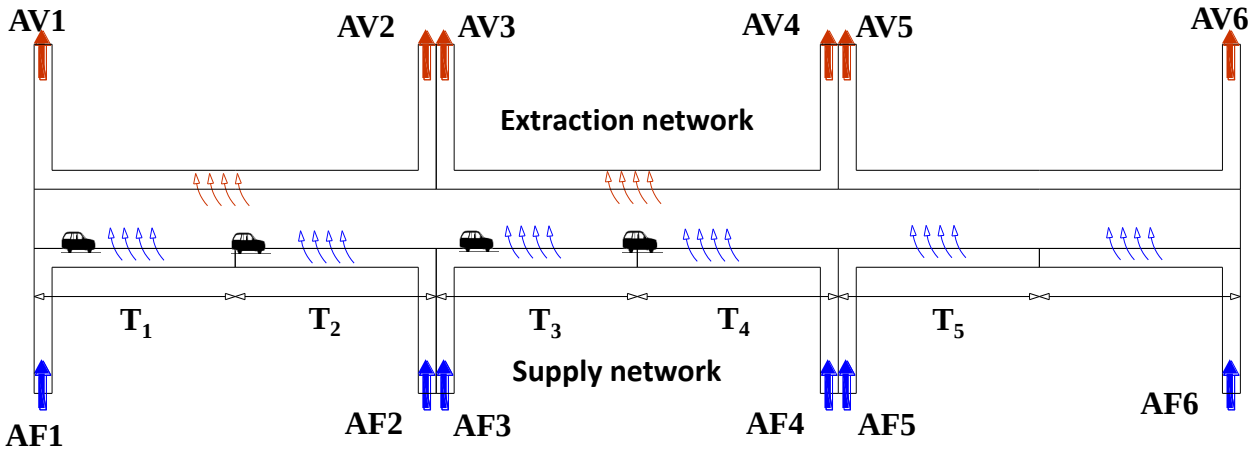
- Need calibration constants to account for 3D effects
- Provides only ballpark figures



Case study: Frejus Tunnel (IT-FR)

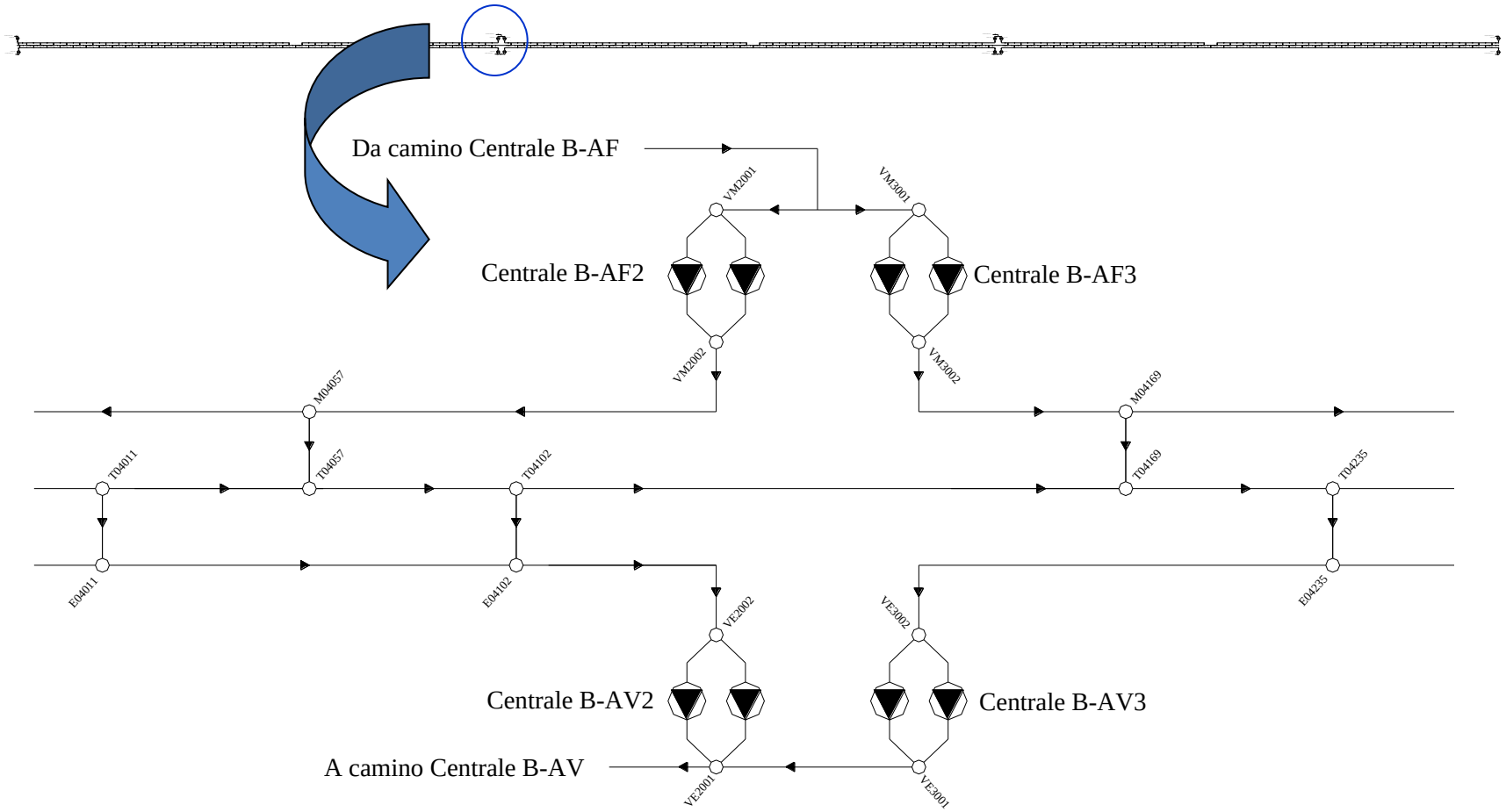
- Two-way tunnel located between Bardonecchia and Modane (IT-FR)
- Fully-transverse
- 12870 m long
- 6 supply & extraction ventilation stations
- Positive France/Italy gradient ≈ 0.6%





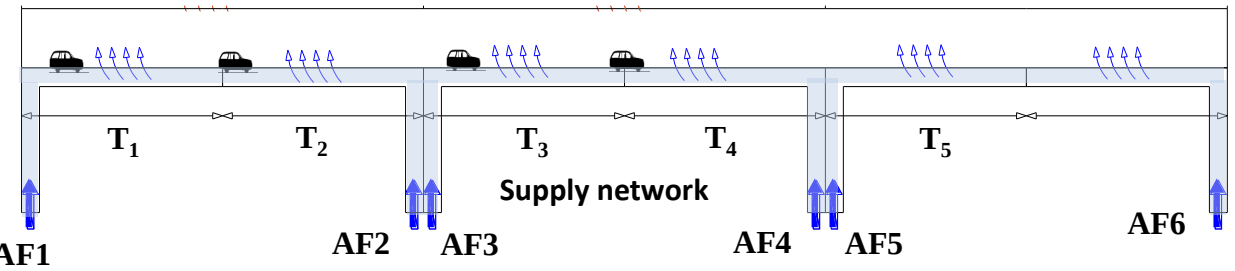
Case study: Frejus Tunnel (IT-FR)

1D network consists of 650 branches & 450 nodes

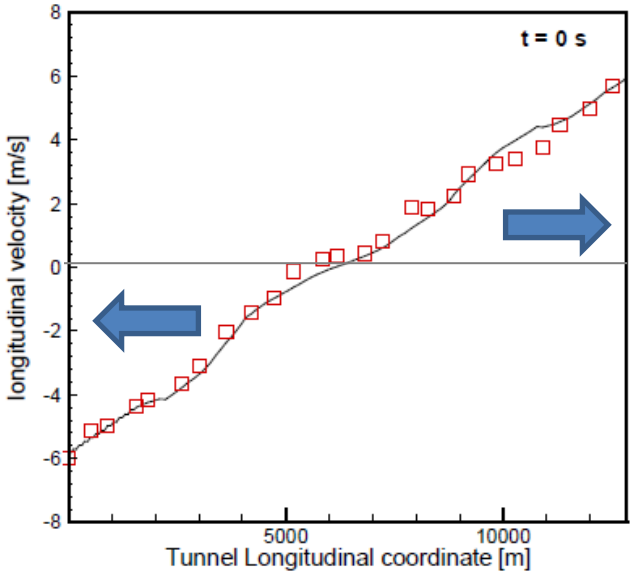


Case study: Frejus Tunnel (IT-FR)

Steady State Ventilation

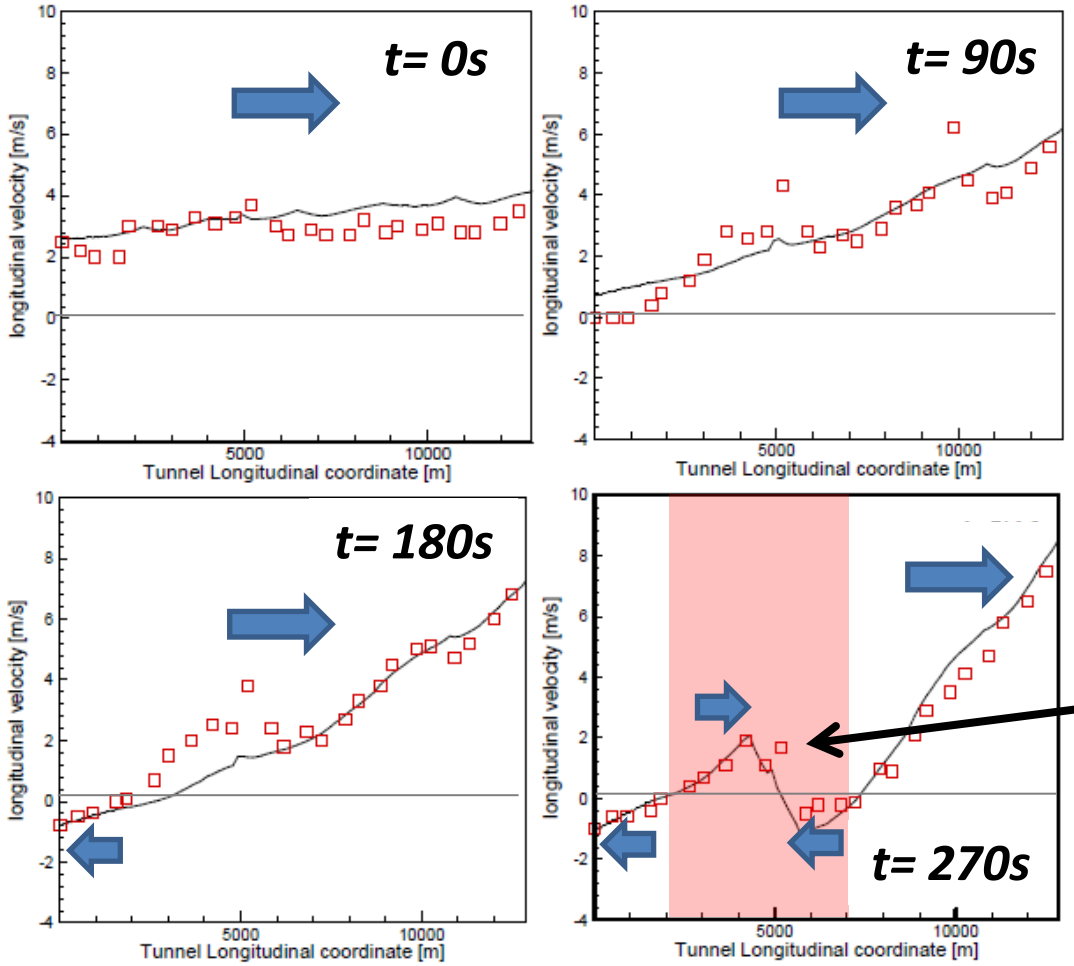


Distributed air supply along the tunnel



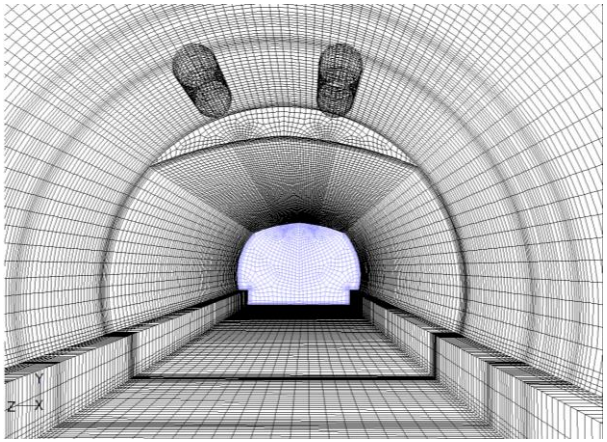
Case study: Frejus Tunnel (IT-FR)

Transient ventilation system response



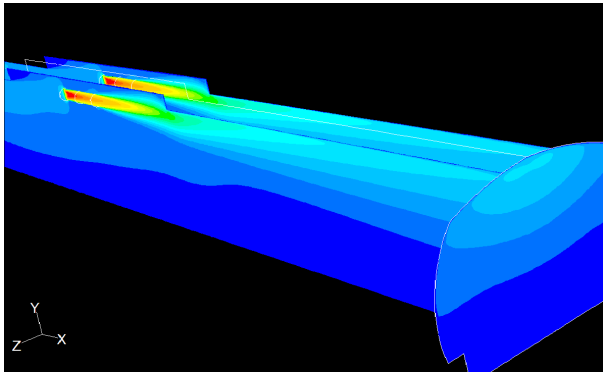
CFD models

- Detailed flow field representation
- Well established for design verification
- Essential for complex geometries:
  - Complex tunnel intersections
  - Metro stations

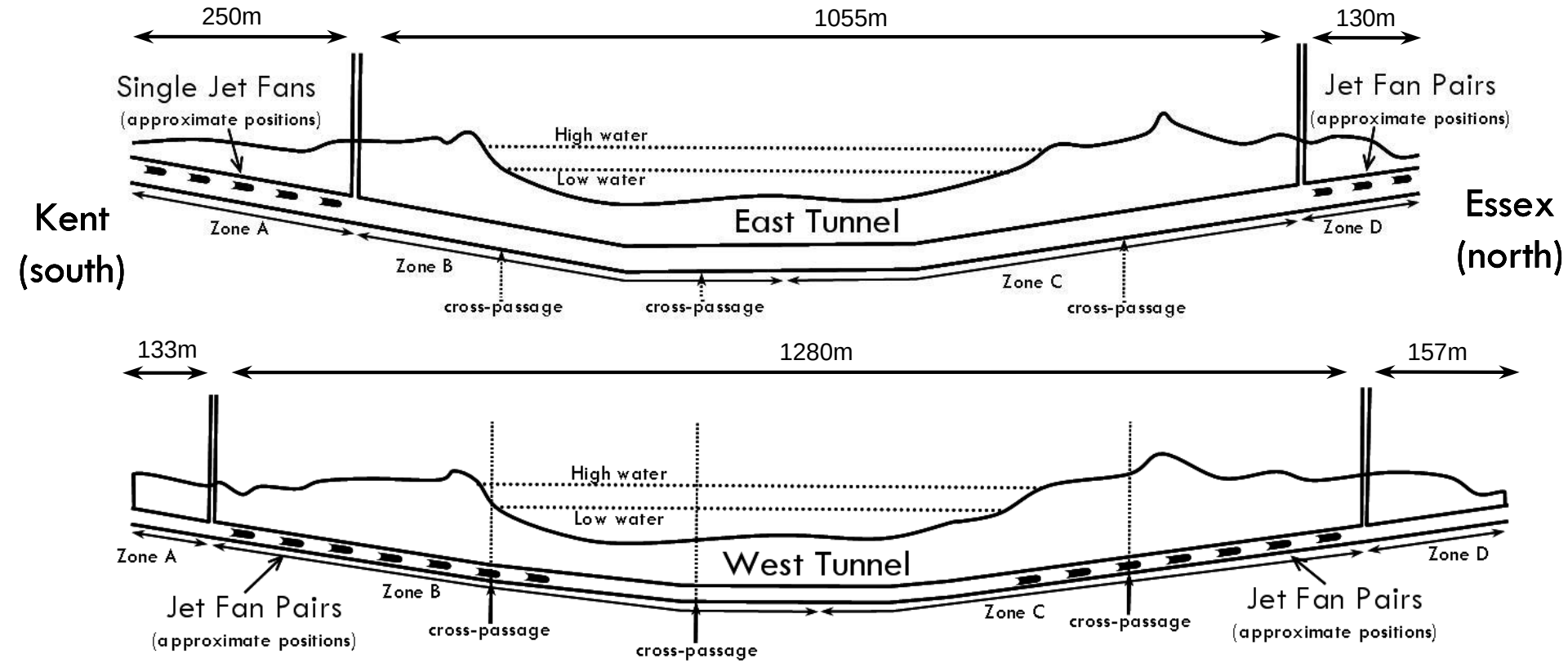


BUT

- Large computational time



Case study: Dartford Tunnels (UK)

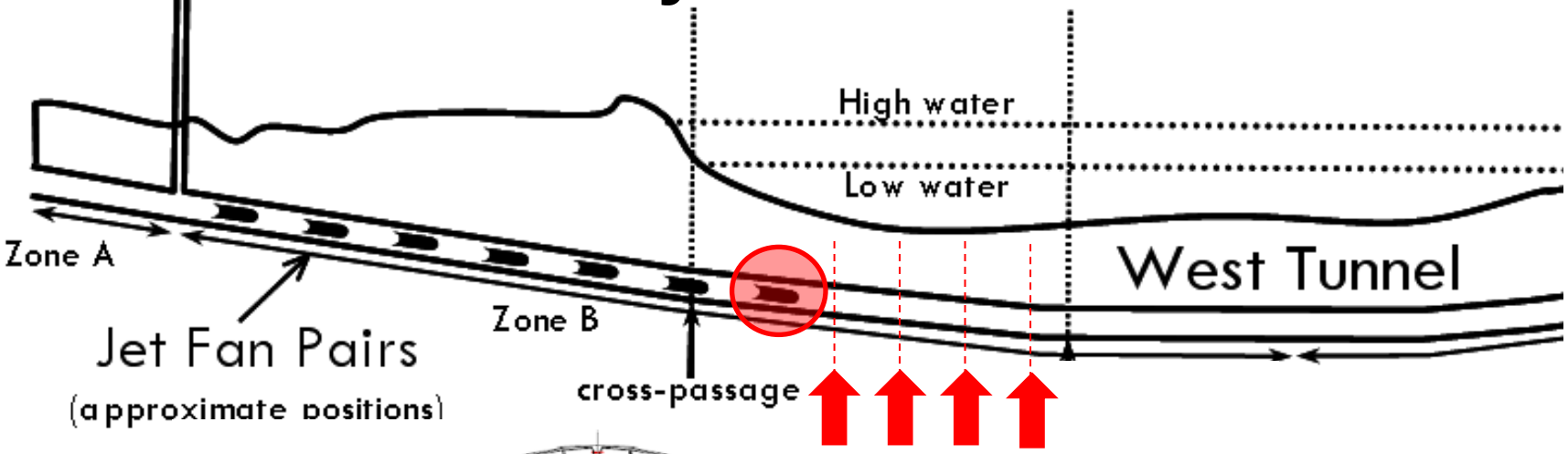


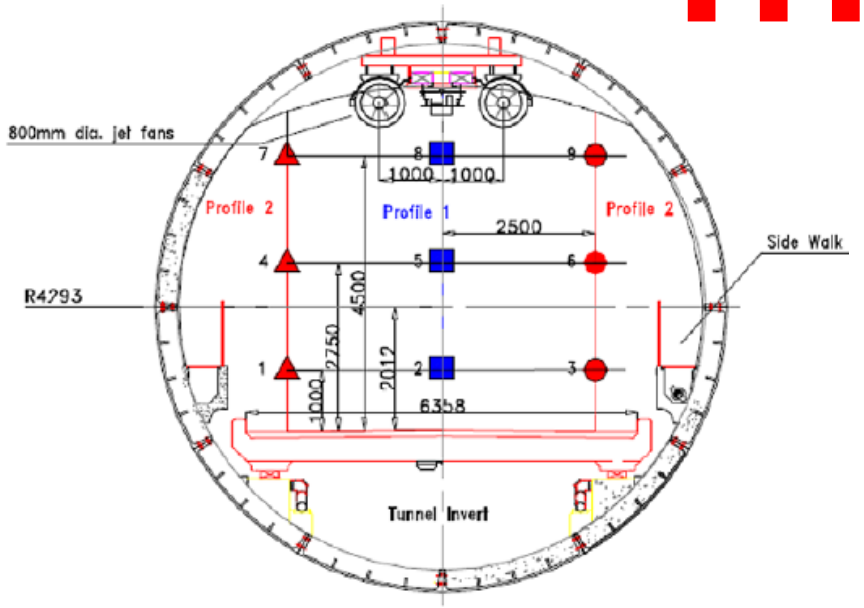
Case study: Dartford Tunnels

Characteristics

- Approx. 1500 m long with hybrid ventilation system
- **East tunnel** diam 9.5 m (1980)
- **West tunnel** diam 8.6 m (1963)
- 2 supply & extraction ventilation stations in the vicinity of the portals
- 28 jet fans in the **West Tunnel**
- 11 reversible jet fans in the **East tunnel**

Case study: Dartford Tunnels





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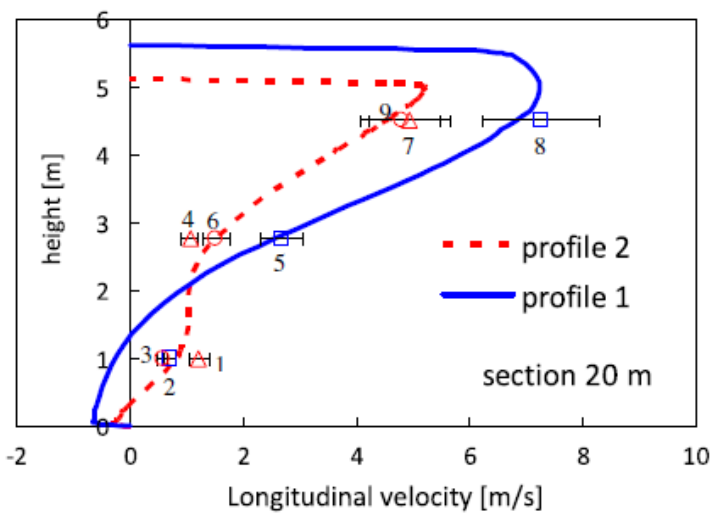

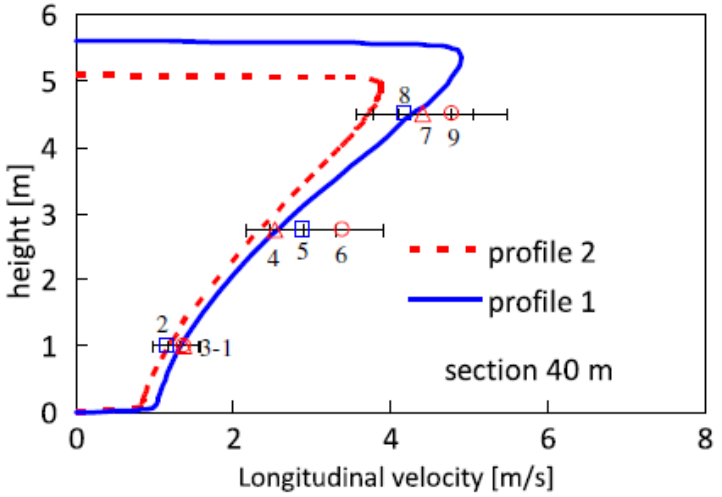

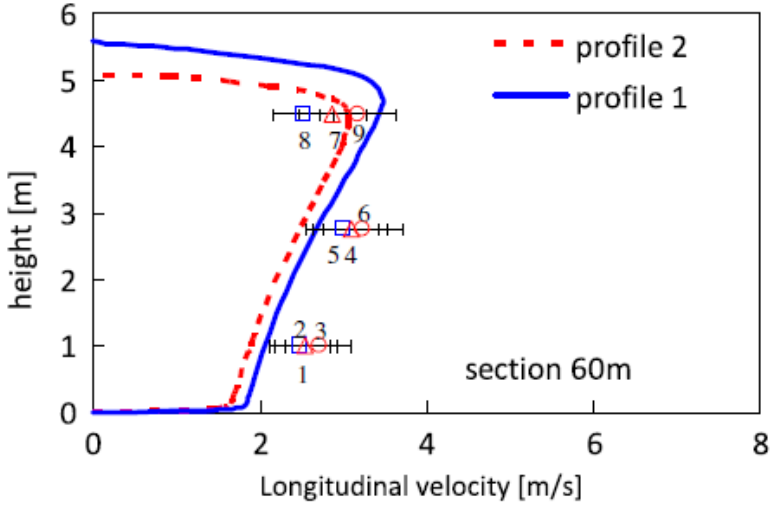

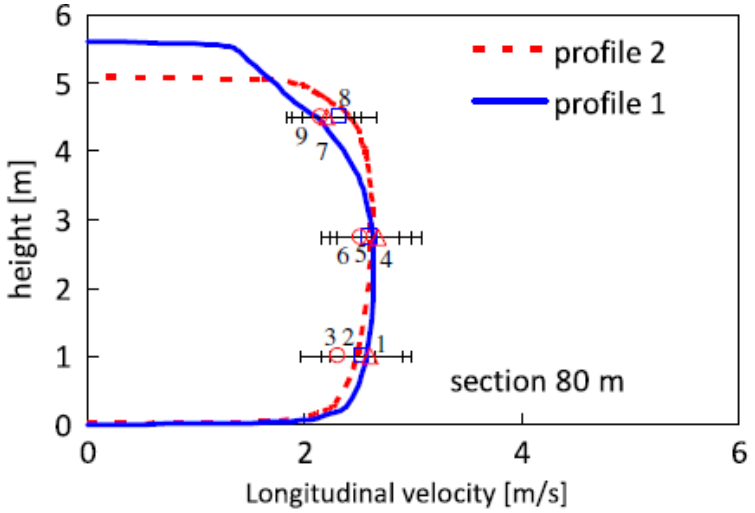

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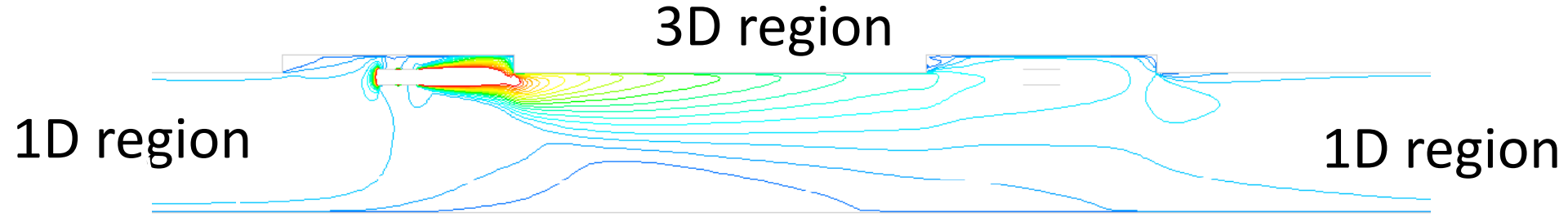
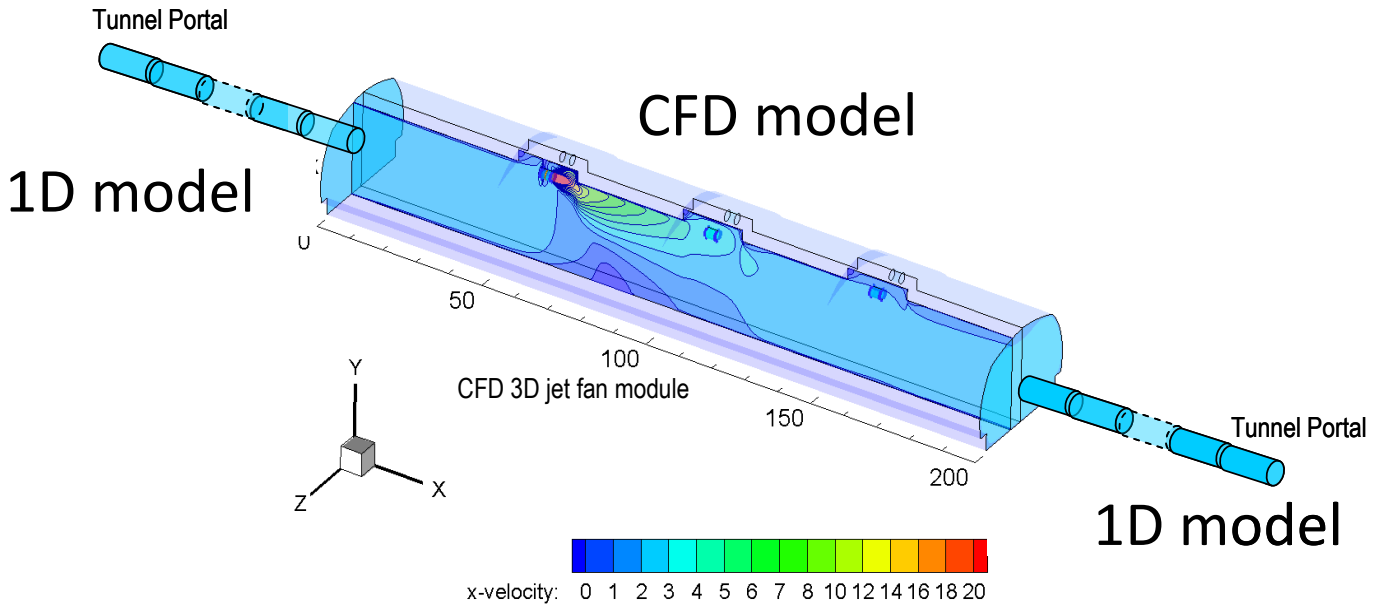
Multiscale models

Typical velocity contours in the proximity of a jet fan

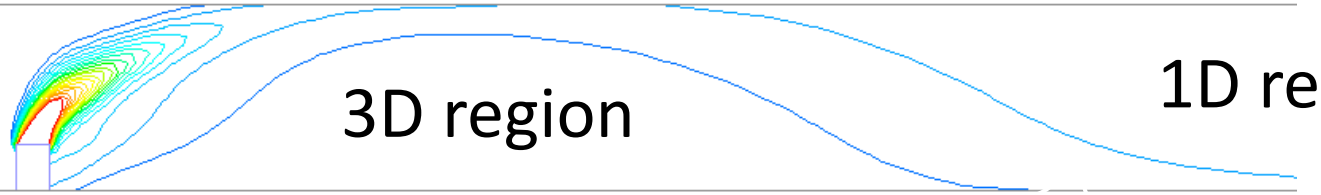




Multiscale models

Typical velocity contours in the proximity of a fire

1D region

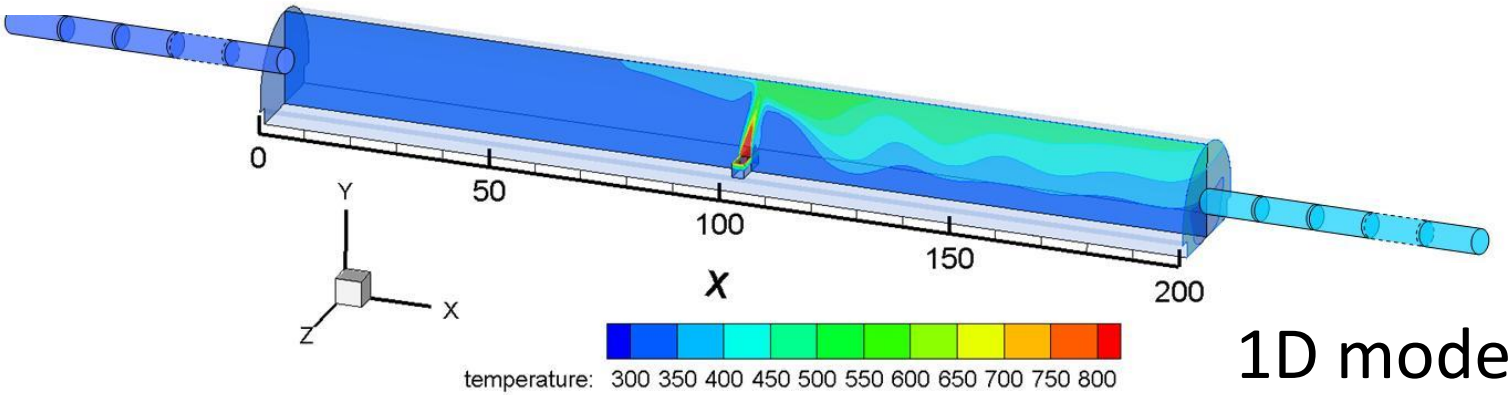


3D region

1D region

1D model

CFD model



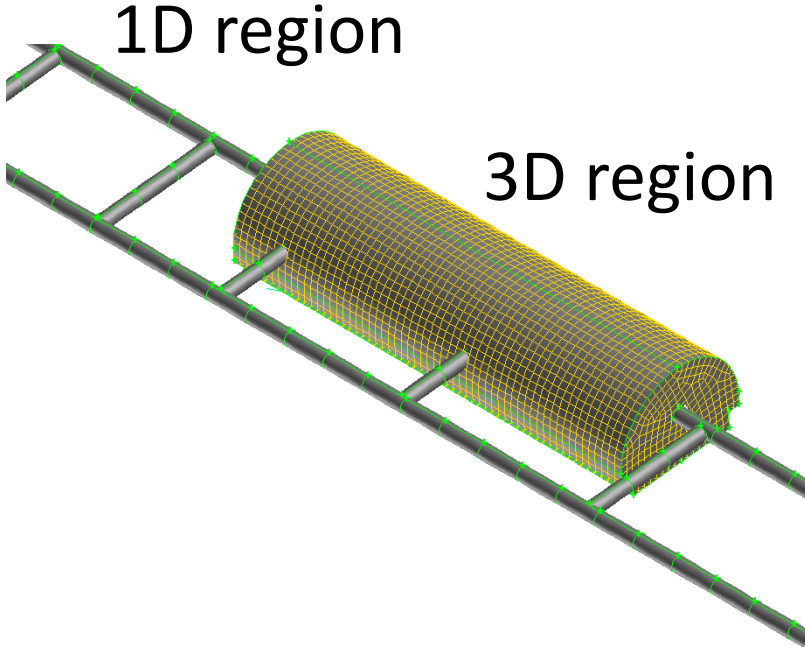
1D model

Multiscale models

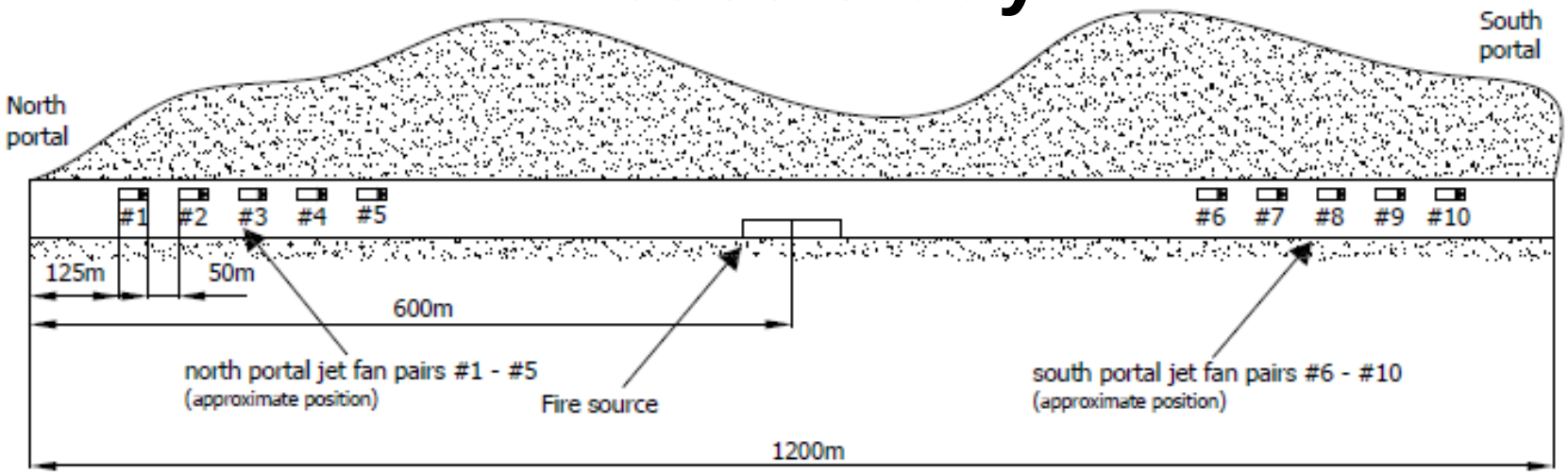
- Reduction of the computational time (up to 2 orders of magnitude)
- As accurate as CFD
- Applicable for parametric studies, sensitivity analyses, etc.

BUT

- The location where the model transitions from 1D regions to 3D regions must be carefully selected.

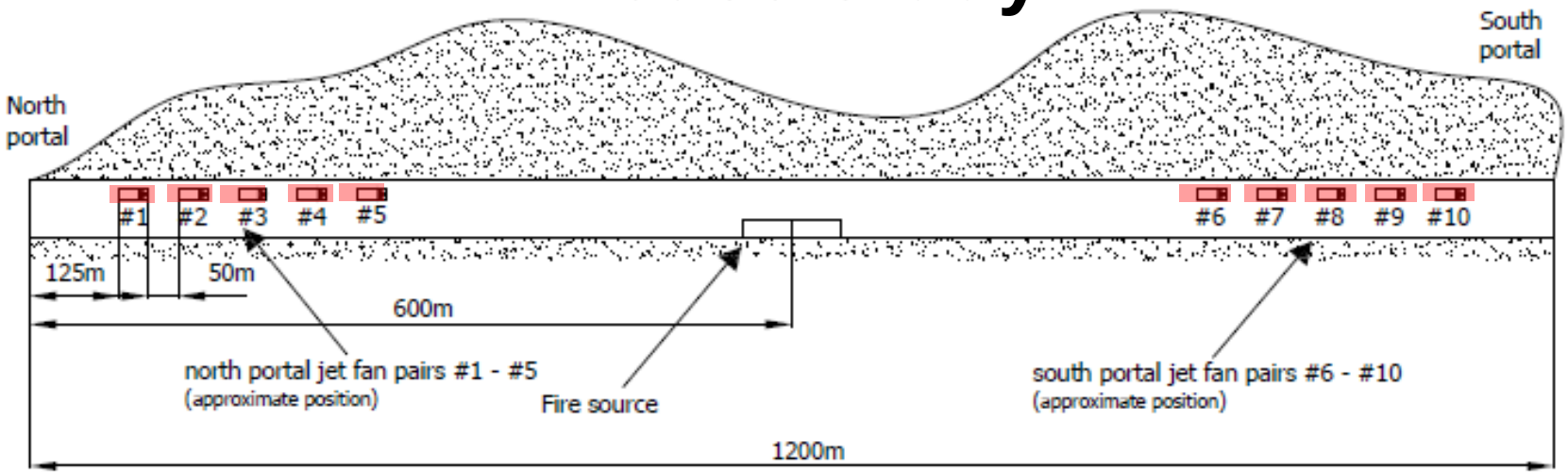


Case Study



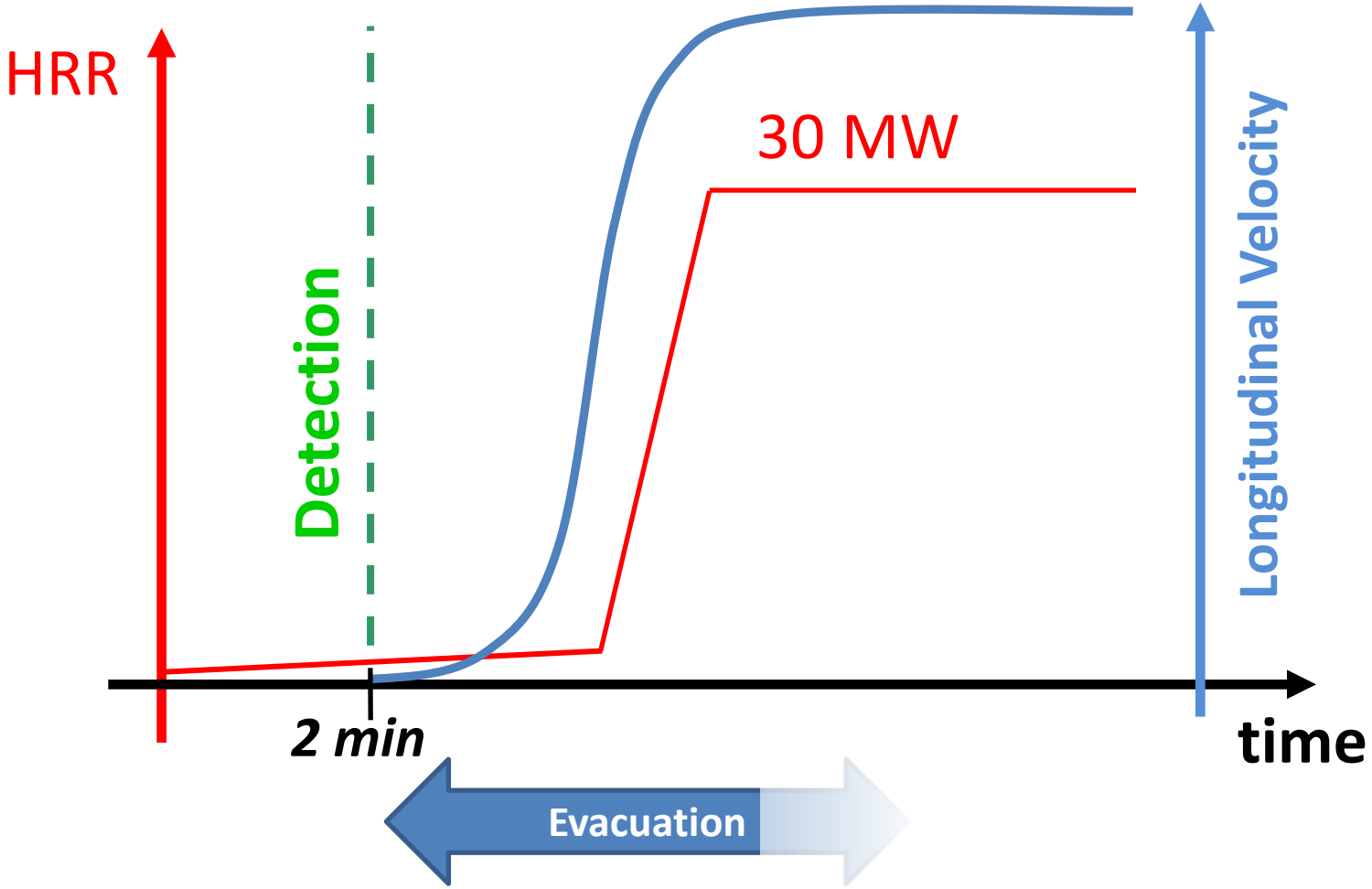
- 1200 m long longitudinally ventilated
- 10 pairs of jet fans
- Fire located in the centre of the tunnel
- Fire max HRR: 30 MW

Case Study



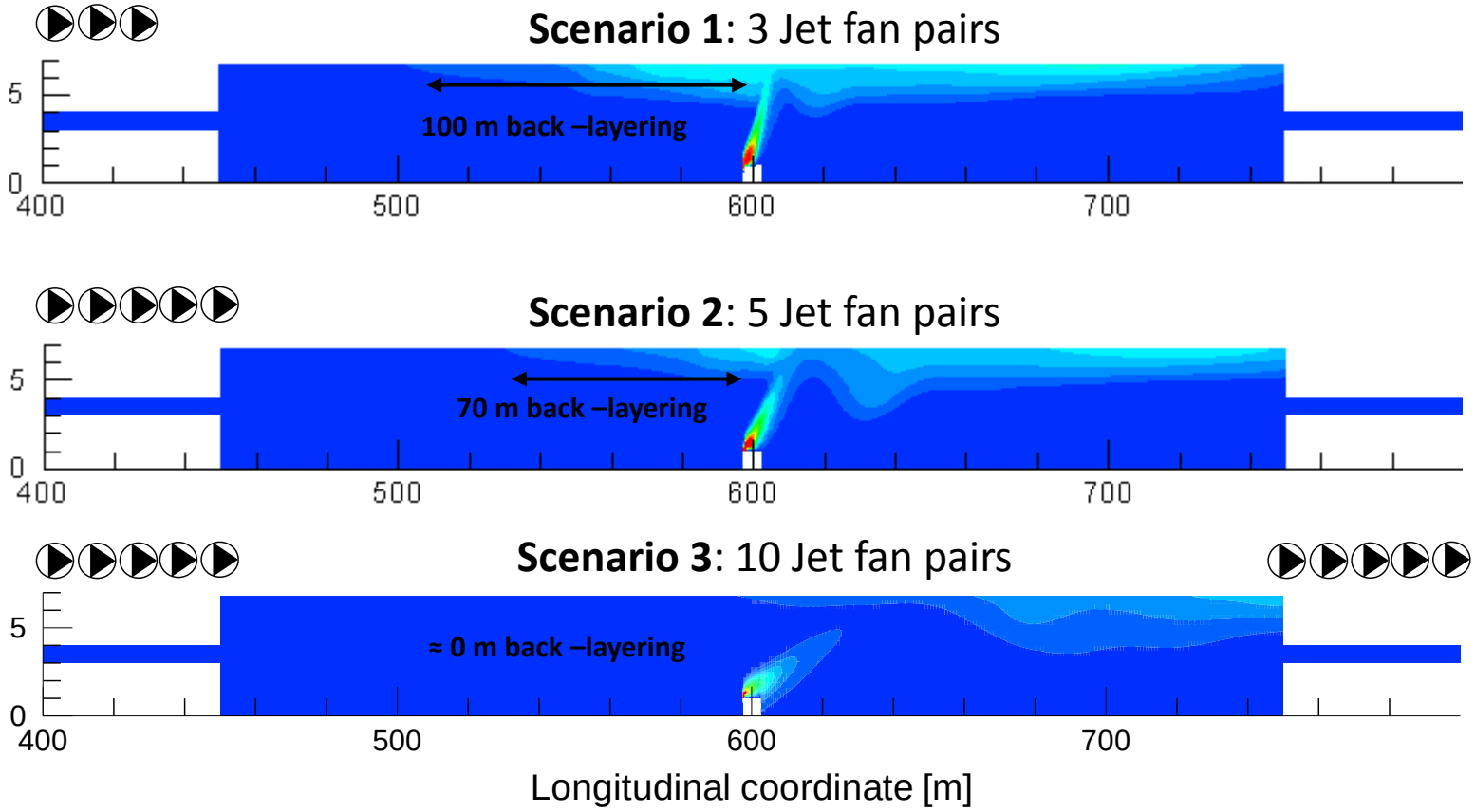
- **Ventilation scenarios**
  - Scenario 1: 3 jet fan pairs
  - Scenario 2: 5 jet fan pairs
  - Scenario 3: 10 jet fan pairs

Case Study


HRR
30 MW
Longitudinal Velocity
Detection
2 min
time
Evacuation

Case Study

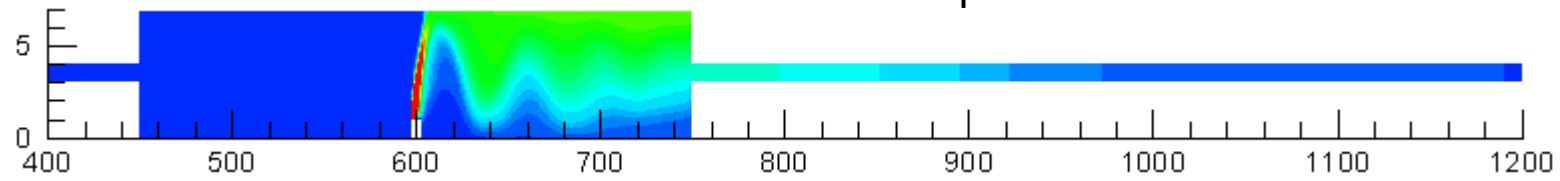
Multiscale results: 3 minutes after ignition



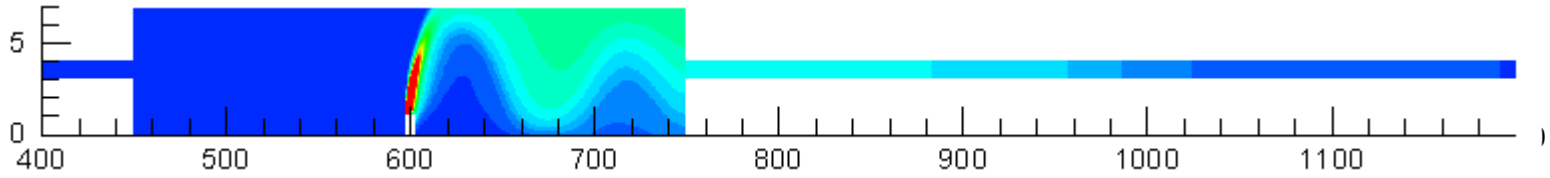
Case Study

Multiscale results: 5 minutes after ignition

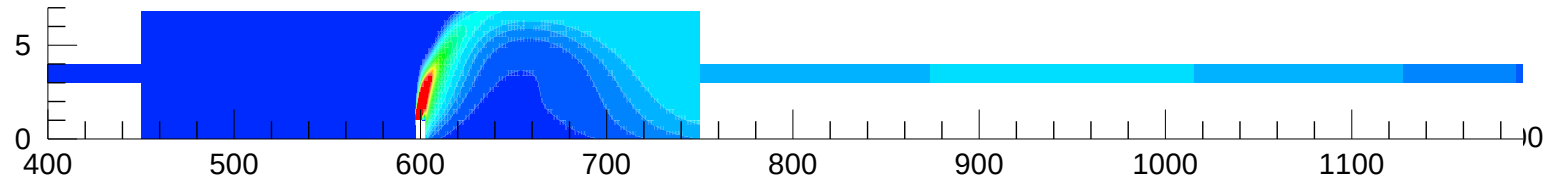
Scenario 1: 3 Jet fan pairs



Scenario 2: 5 Jet fan pairs



Scenario 3: 10 Jet fan pairs



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Conclusions

Management of fire emergency scenarios in tunnels or subways systems requires understanding of the interaction between fire, ventilation system and evacuation process.

- Accurate description of the fire near field (stratification, smoke spread, tenability conditions)
- Accurate description of the far field (the effect of remote ventilation stations, jet fans, ambient conditions).

- Several modelling approaches can be used:
  - Analytical models
  - 1D models
  - CFD models
  - Multiscale models

Conclusions

Multiscale models retain most of the advantages of CFD and 1D models and are well suited for:

- Characterization of ventilation system response.
- Detection and smoke propagation analysis.
- Optimization of tunnel ventilation system design and emergency ventilation strategies
- Combined optimization of cost/safety in the tunnel

Any questions?

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