Multi-scale Fire Modelling Method in Longitudinally Ventilated Tunnels for FDS6.1

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Contents

Introduction - Team

- Work carried out in 2014
- Led by Edmund Ang (Imperial College London), with collaborators:
  - Guillermo Rein (Imperial College London)
  - Joaquin Peiro (Imperial College London)
  - Roger Harrison (AECOM UK)
  - Izabella Vermesi (Imperial College London)
- Special thanks to software support from Thunderhead Engineering

Introduction - Multi-scale Modelling

- Multi-scale modelling based on Colella *et al* [1]
- Previous work based on commercial CFD package and Reynolds Averaged Navier Stokes
- Multi-scale modelling using FDS6:
  - Not attempted before
  - Enabled by the FDS HVAC feature
  - Proof of concept by Vermesi *et al* [2]
  - Constant flow specified at boundary
  - No coupling of jet fans to the fire behaviour

Multi-scale Modelling - What and Why

- Increasingly denser and taller buildings
  - Scarcity of land resources
  - High rise buildings
  - Options for above ground rail or utility network limited
- Tunnel is often the more practical solution
- Tunnels can be used for rail, roads or utilities

Multi-scale Modelling - What and Why

- Ventilation is needed to most tunnels
  - Life safety (fumes or CO from fire)
  - Regulating temperature (train operation)
- Three main types of ventilation system
  - Longitudinal (jet fans)
  - Transverse (ducted supply and extract)
  - Semi-transverse (hybrid of ducted and non-ducted)

Multi-scale Modelling - What and Why

Figure 1. ECRL Rail Tunnel, Australia

Multi-scale Modelling - What and Why

- Design of tunnel ventilation system
- 1D / Subway Environment Simulation (SES)
  - Early stages of design
  - Fast computation
  - Provides global averaged prediction
  - Limitations on gas species or high resolution calculations

Multi-scale Modelling - What and Why

- 3D / Full CFD simulation
  - To validate the design carried out at the earlier stages
  - Time consuming
  - Provides high resolution predictions, e.g. gas species and combustion
  - Tunnel section models often shorten to reduce computational time
- Is there a best of both world?

Multi-scale Modelling - What and Why

- Multi-scale modelling method
- Using 1D for far field tunnel sections
- Full CFD for near field, or tunnel section of interest
- Significantly reduce the computational time
- Off-set computational time for longer tunnel section

Multi-scale Modelling - What and Why

- Multi-scale modelling method
- Direct and indirect coupling methods
- FDS6.1 is based on indirect coupling method
- Implemented using HVAC feature
    - Acknowledge this is not the intended use of HVAC

Multi-scale Modelling - Implementation

- Model is based on Dartford Tunnel West
- Cold flow field measurement data available [1]
- Dartford Tunnel West properties:
  - 1.5 km long
  - 14 jet fans pairs (JFP) with 8.3 m^3/s per fan
- Key of multi-scale model
  - Interface between 1D and full CFD sections
  - Flow need to be fully developed

Multi-scale Modelling - Implementation Diagram

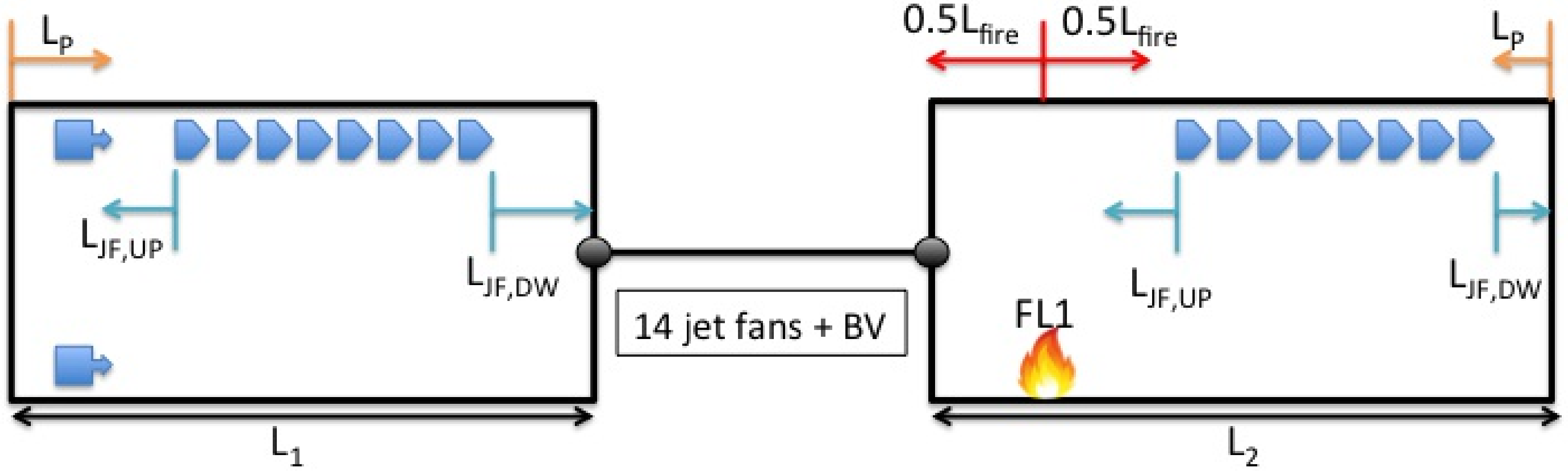

Figure 2. Representation of multi-scale model

Multi-scale Modelling - Implementation Details

- L_p is length of portal = 50 m
- $L_{JF,UP}$ and $L_{JF,DW}$ are length up and downstream of jet fans = 35 m and 130 m respectively
- L_{fire} is length each side of fire = 170 m
- Calibrated from running multiple models

Cold Flow Modelling Results

- Cold flow modelling results presented separately in Tunnelling and Underground Space Technology [3]
- Good correlation from 80 m downwind of the jet fans
- Poorer correlation nearer to jet fans:
  - Lack of detailed information of installed jet fans
  - Difficulty to accurately model the jet fans
  - No accurate measurement of tunnel walls' surface roughness

Cold Flow Modelling Results

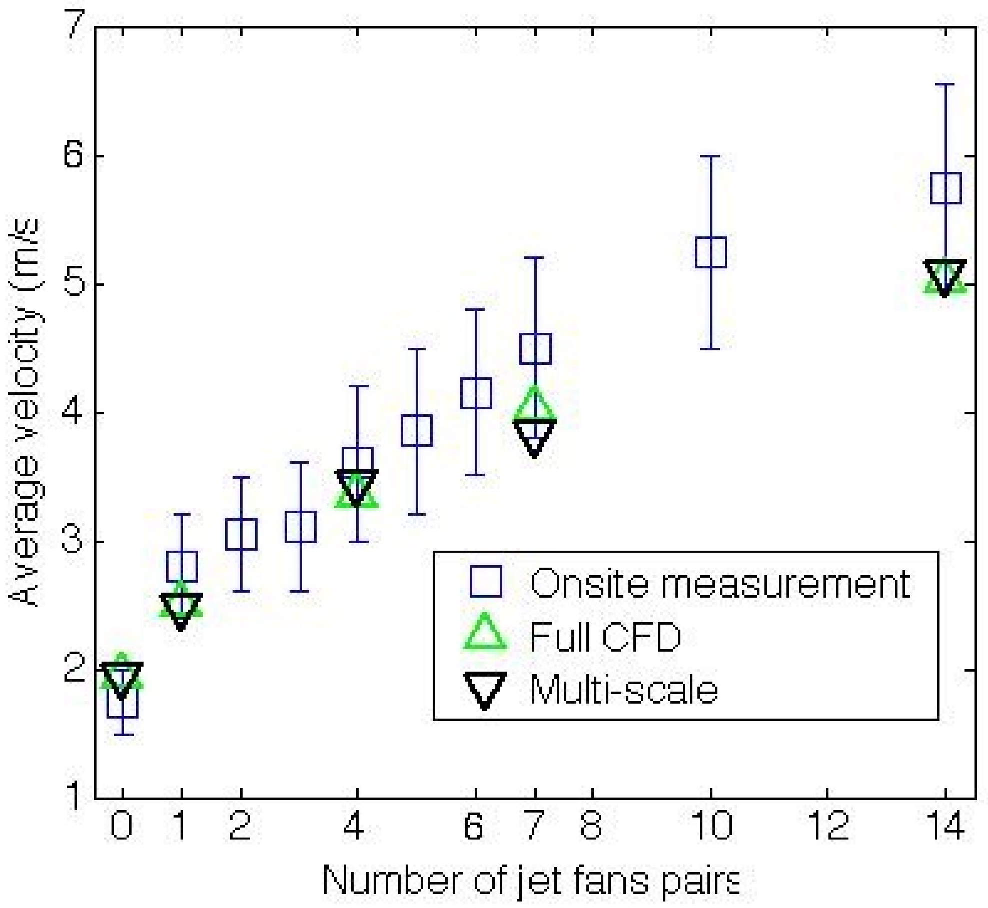

Figure 3. Average velocities measured in the tunnel [3]

Cold Flow Modelling Results

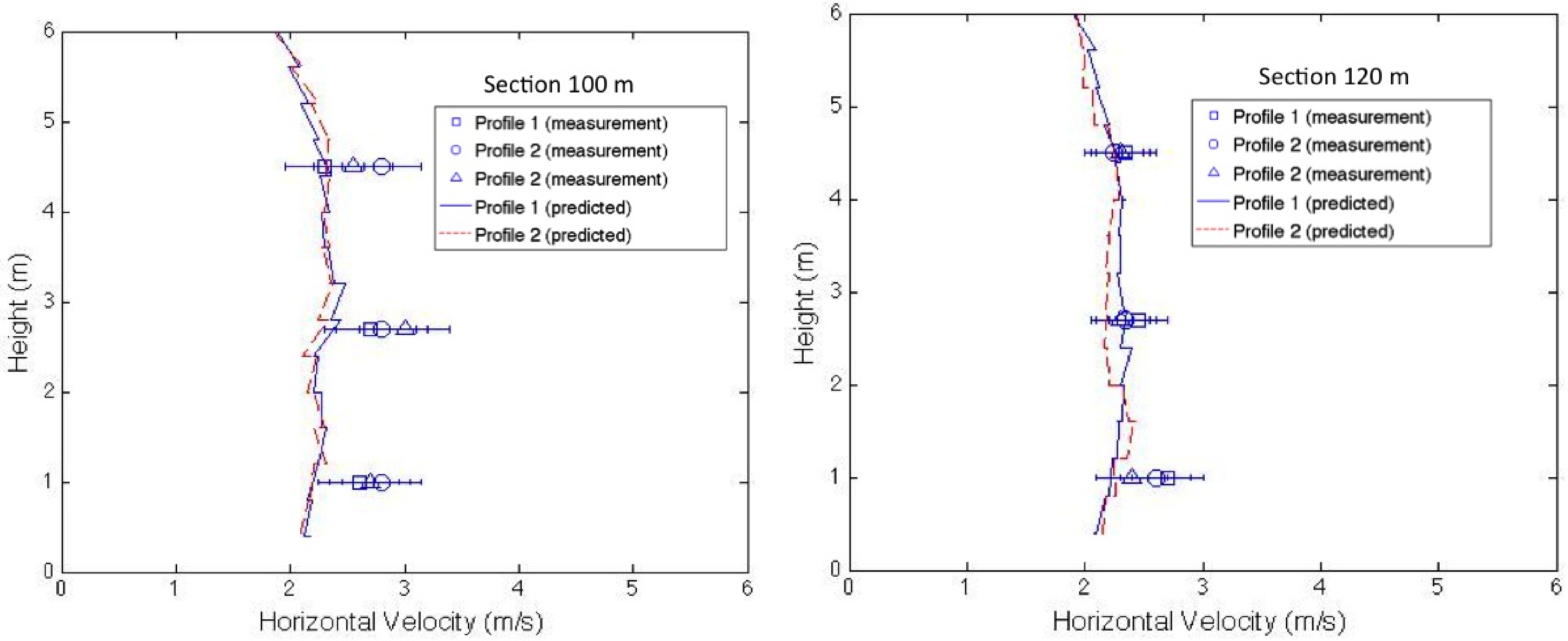

Figure 4. Multi-scale model velocity profile downwind of jet fans [3]

Cold Flow Modelling Results

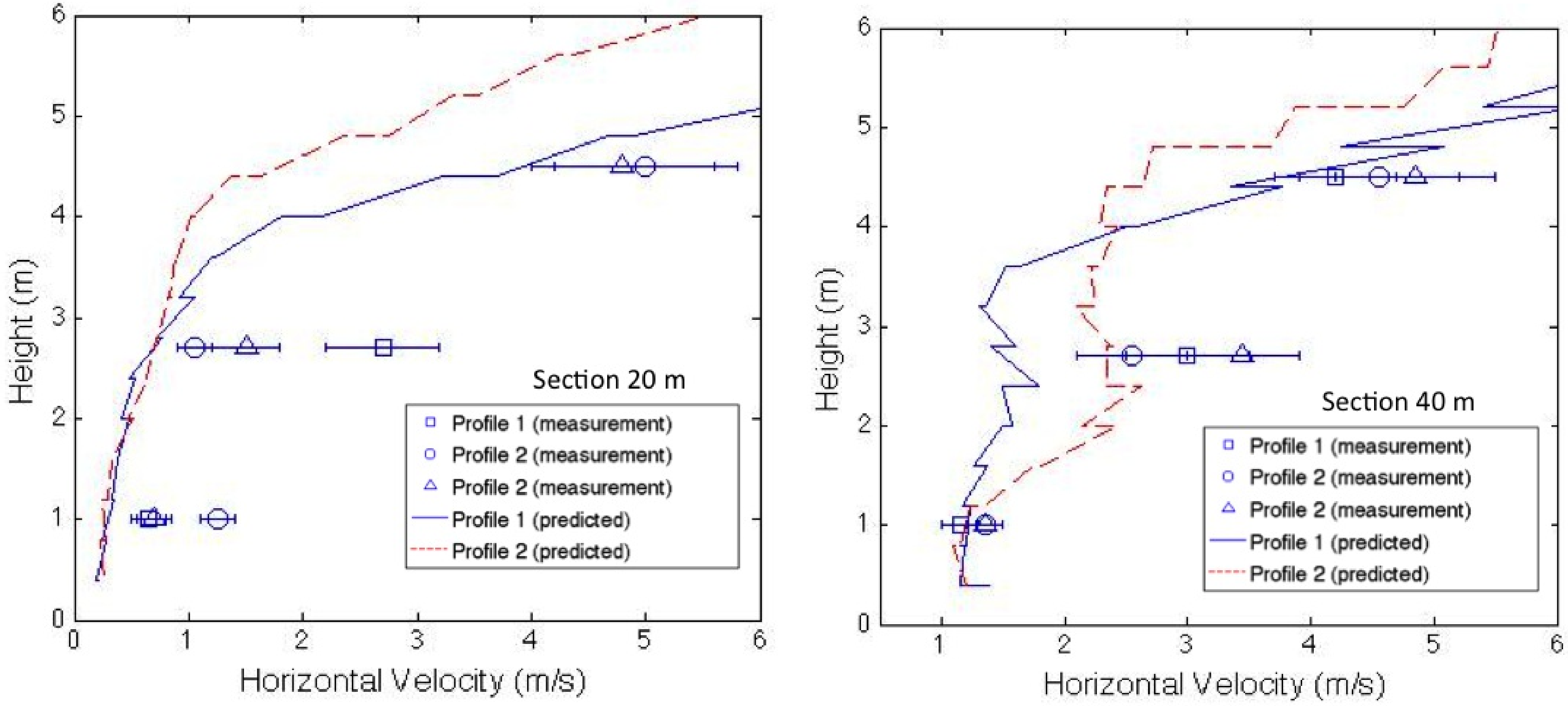

Figure 5. Multi-scale model velocity profile downwind of jet fans [3]

Cold Flow Modelling Results

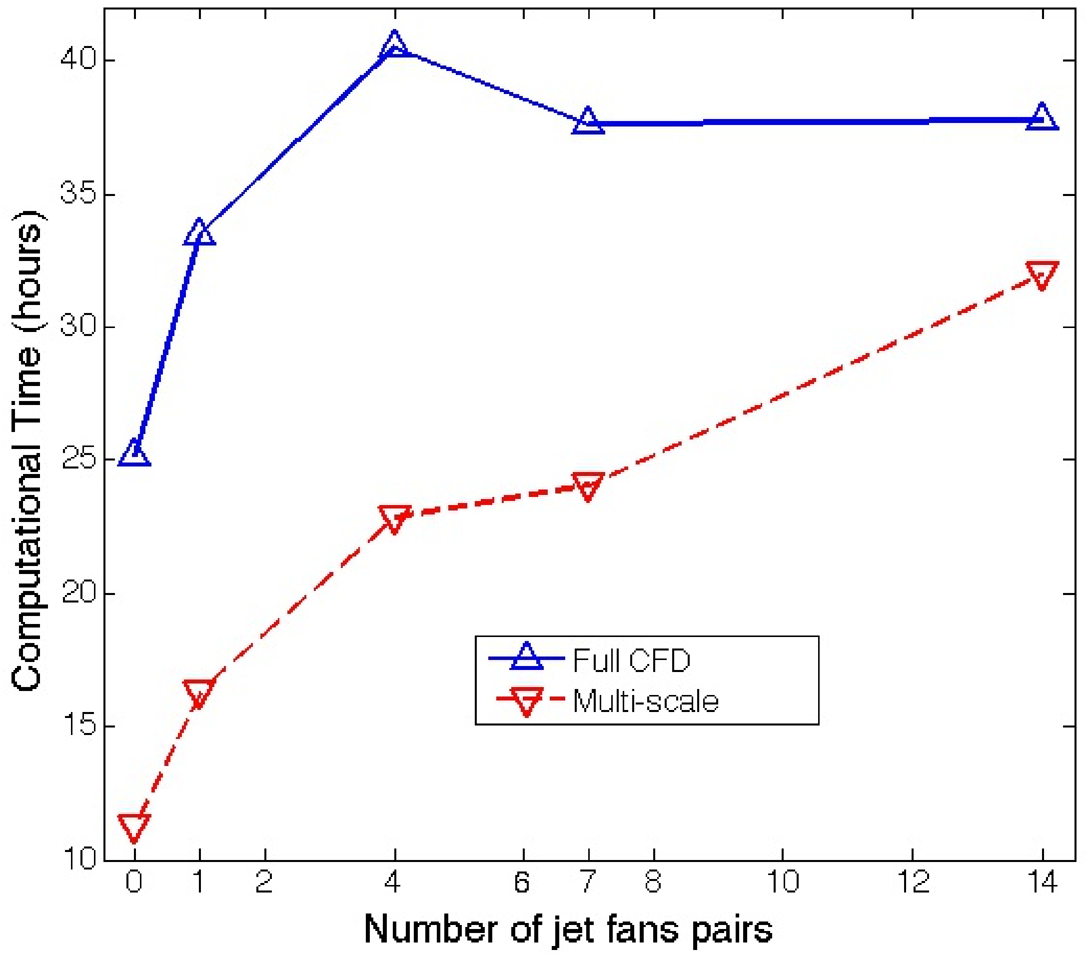

Figure 6. Reduction in computational time for the multi-scale model

Multi-scale Fire Modelling Results

- Adapted from the same cold flow multi-scale model
- Introduction of a fire in the middle of the tunnel
- Three fire sizes considered, 35 MW, 55 MW and 75 MW
- Validation study conducted (Arup Tunnel case)
- Mass flow rate is the measured variable
- Interesting behaviour observed in the multi-scale model

Multi-scale Fire Modelling Results

- Oscillatory mass flow observed
- Mass flow rates in multi-scale models do not stabilise compared to the full CFD model
- It is yet to be determined if the oscillation is numerical
- Similar oscillation for velocity and temperature observed by Vermesi *et al* [2]

Multi-scale Fire Modelling Results

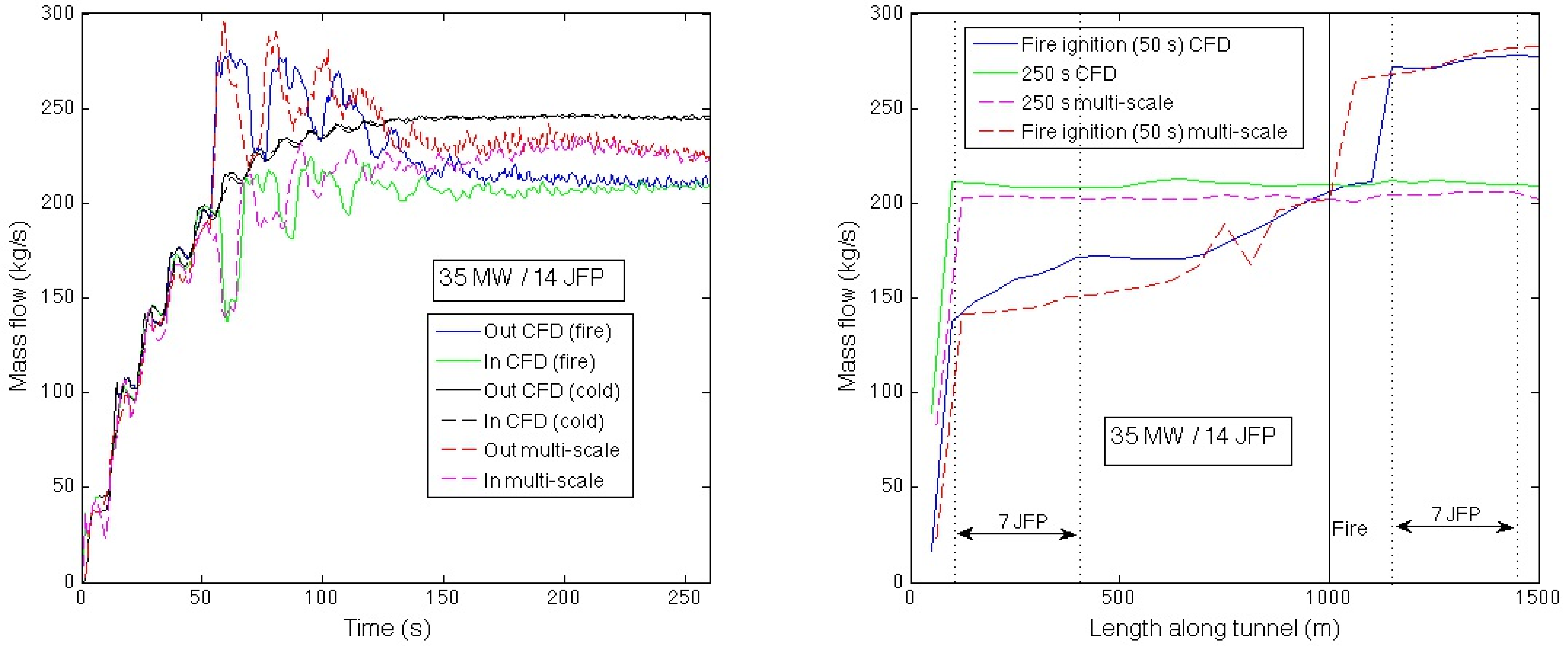

Figure 7. Mass flow rates (35 MW) in the tunnel. Left: Mass flow in and out. Right: Mass flow along the tunnel.

Multi-scale Fire Modelling Results

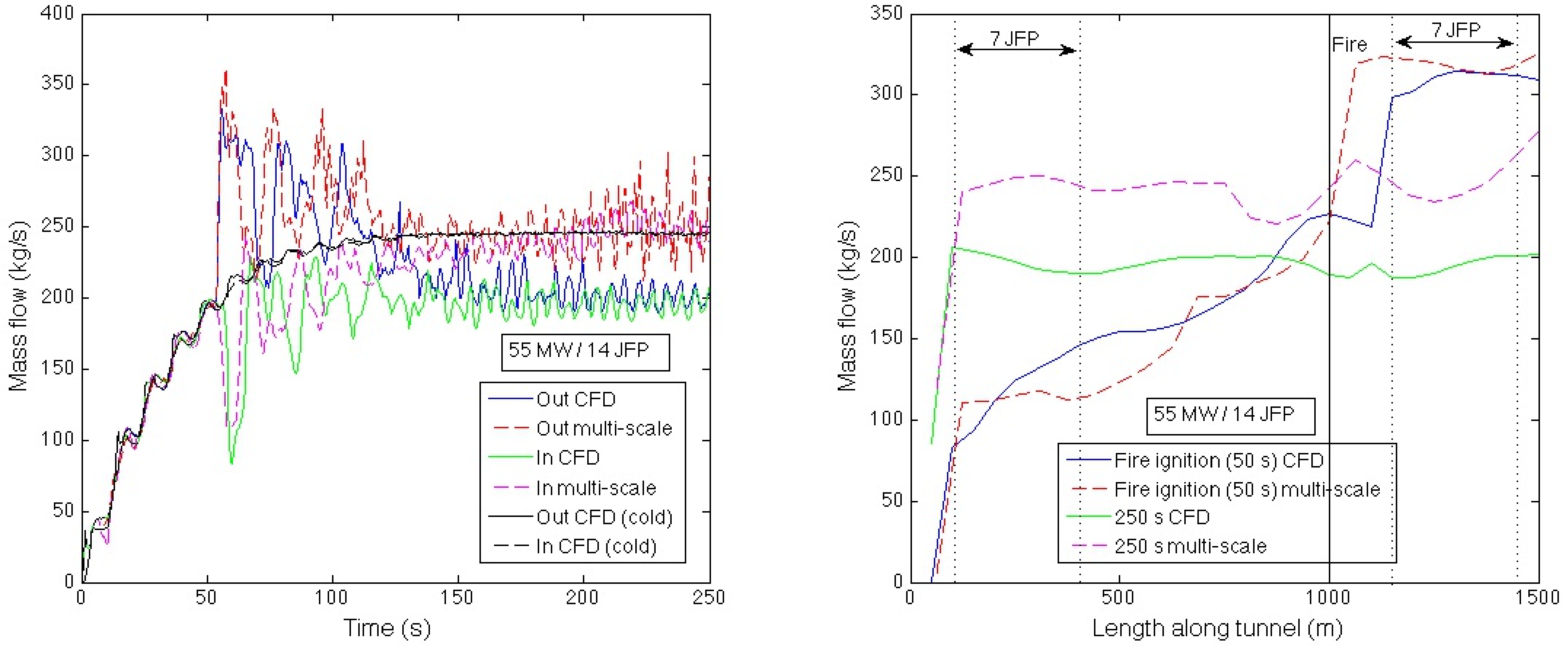

Figure 8. Mass flow rates (55 MW) in the tunnel. Left: Mass flow in and out. Right: Mass flow along the tunnel.

Multi-scale Fire Modelling Results

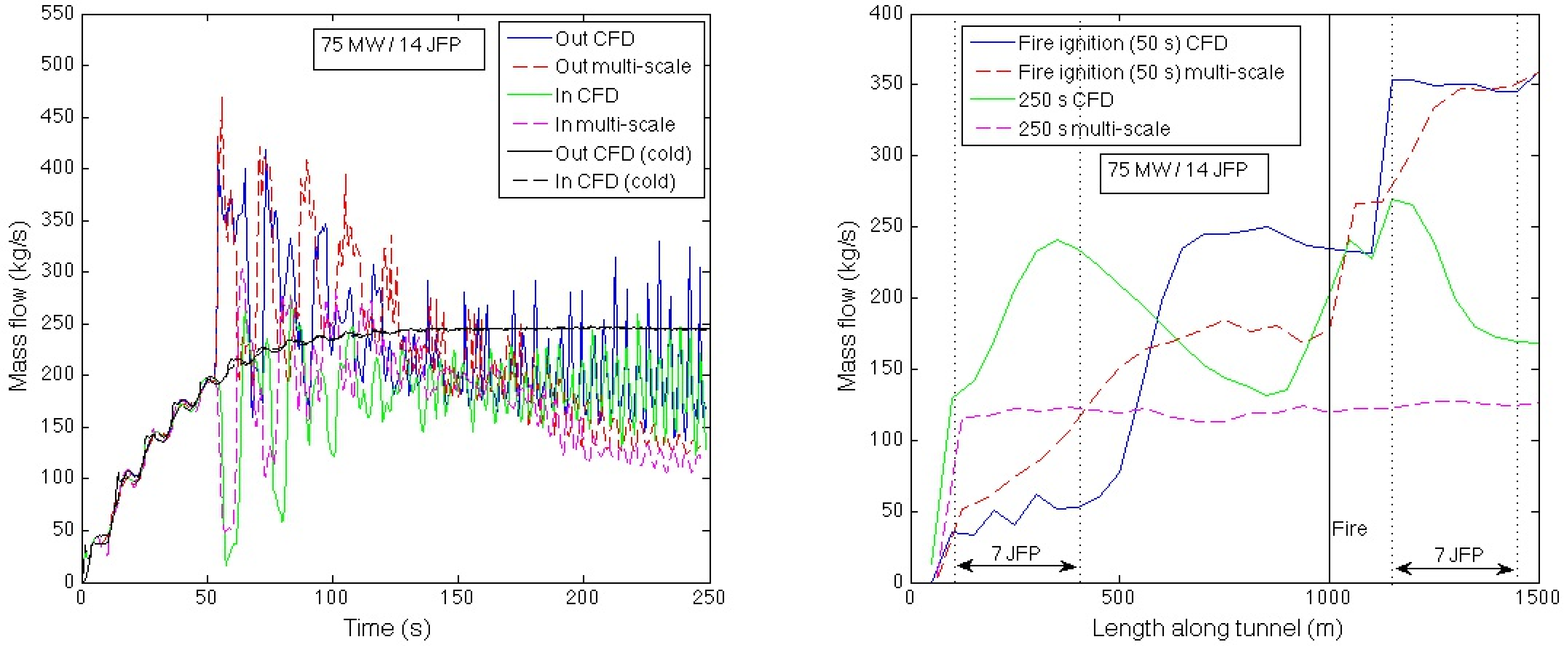

Figure 9. Mass flow rates (75 MW) in the tunnel. Left: Mass flow in and out. Right: Mass flow along the tunnel.

Multi-scale Fire Modelling Results

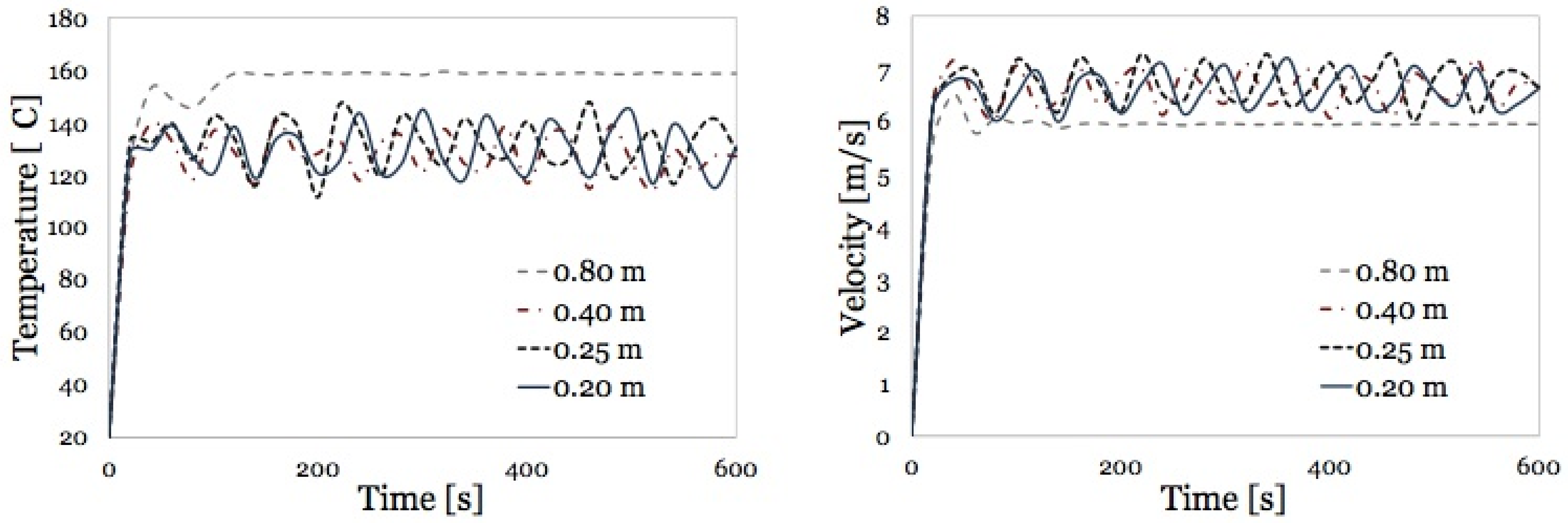

Figure 10. Oscillating temperature and velocity in a tunnel fire [3]

Conclusion

- Multi-scale modelling using FDS6.1 + HVAC is feasible
- Can be used for cold flow multi-scale modelling
- Fire modelling using the multi-scale model:
  - Oscillating mass flow
  - Mass flow rates do not stabilise compared to the full CFD model
  - Should not be used until the above two questions can be answered

Reference

[1] F. Collela, G. Rein, and J. L. Torero. "A Novel Multiscale Methodology for Simulating Tunnel Ventilation Flows During Fires." *Fire Technology* 47 (January): 221–253. Jan. 2011.

[2] I. Vermesi, G. Rein, F. Colella, M. Valkvist, and G. Jomaas. "Reducing the Computational Requirements for Simulating Tunnel Fires by Combining Multiscale Modelling and Multiple Processor Calculation." *Tunnelling and Underground Space Technology*. 2016.

[3] C.D.E. Ang, G. Rein, J. Peiro, and R. Harrison. "Simulating Longitudinal Ventilation Flows in Long Tunnels: Comparison of Full CFD and Multi-Scale Modelling Approaches in FDS6." *Tunnelling and Underground Space Technology* 52 (February): 119–126. Feb. 2016.