Simulation of the piston effect of a train entering or leaving an underground station

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Aim & Objectives of the study

Why? What for? How?
Air management inside train stations

WHY MODELLING AIR FLOW INSIDE TRAIN STATIONS?
> Pollutant dispersion
> Pedestrian comfort
> Thermal management

WHAT IS DRIVING AIR MOVEMENT INSIDE THE STATION?
> Wind blowing outside
> HVAC systems
> Train movement

WHAT WE ARE FOCUSING ON HERE?
> Subway train, low speed, max 70kph
> Compressibility neglected: we are not modeling the pressure wave propagation of high speed trains inside the tunnels
> Not interested into the aerodynamic of the train itself (slipstream)

> To be able to quantify the amount of air movement inside/outside the station due to the train displacement
Developing a Design Tool

USING OPENFOAM AS A SIMULATION TOOL TO DESIGN TRAIN STATIONS

> Easy to setup
> Easy to transpose to different train station geometries
> Easy to run: industrial grade solution
> Part of a wider simulation tool to model air flow management inside train stations
Methodology

A Simplified Train Station
> Very simple geometry to setup the methodology

- 6 shafts connected to surface
- Atmosphere: Fixed pressure 0Pa
- Underground connection: fixed pressure +0.2Pa

- Length station: 150m
- Width station: 28m
- Length tunnel: 8m
- Width train: 3m
- Height tunnel: 6m
- Height train: 3m
Methodology

The main trick: DynamicMesh + Moving Wall + ACMI

ACMI + DYNAMIC MESH

> Arbitrary Cyclic Mesh Interface
> Moving mesh: both train and tunnel are moving inside the fixed station
Methodology
About boundary conditions

ON THE WALLS?
> On the train: moving wall, velocity equal to domain displacement
> On the tunnel: fixed zero velocity

→ Works just fine!

WHICH BC AT THE END OF TUNNEL?
> Wall  ➔ neither realistic nor stable
> Cyclic ➔ works OK but increases the flow rate in the tunnel
> Fixed pressure ➔ works fine, realistic (there must be a ventilation shaft somewhere)
> Solver: pimpleDyM Foam (Openfoam 3.0.1)
> Turbulence: k-eps Realizable
Methodology

Results

**COMPLEX BEHAVIOR**

- Wind speeds look realistic
- Transient behavior into the shafts is interesting to analyze

> Air flow velocity in the shafts

- Train enters the station
- Train stops
Methodology

Analysis
Application to a real train station
The train station

HIGHLY DETAILED BIM MODEL
> Open IFC format
> All the tunnels to surface and the connections to underground network are modelled

MEASUREMENTS
> Sonic anemometers
> Dozen of points in the station
> Difficult to identify an isolated event (arrival/departure)
> Volume extraction from the BIM model
> First simplification

> Moving mesh requires further simplification:
  ➔ To straighten the curb
  ➔ To keep the tunnel height constant
> Small volumes at each exit to model the pressure loss of the flow expansion into the atmosphere

> Connection to underground network: fixed pressure calculated from the measurements (1m/s in the tunnel)
Investigated Scenarios

**ARRIVAL**

- **t=0s**
- **t=14.5s**
- **t=38s**

**DEPARTURE**

- **Time: 0.5s**
- **Time: 23.5s**
- **Time: 40.0s**

**TRACK A**

**TRACK B**

**acceleration speed distance**

60kph

-0.7m²/s²

+0.7m²/s²
Time: 5.5s
Simulations
Simulations

Arrival track A

Train enters the station

Train stops

Arrival track B

Train enters the station

Train stops
Comparison to measurements

> Comparison to measurements difficult to achieve (sensor position, train direction, combination arrival/departure)
> Order of magnitude is good, both in time and velocity
Comparison to measurements

> Comparison to measurements difficult to achieve (sensor position, train direction, combination arrival/departure)

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A designing tool

Prediction of the impact of modifications in the train station
> Modification of 7 windows ➔ what impact on the air velocity inside the station?
A designing tool

> A lot of air seems to go back and forth through those windows

Time: 19.0s
Impact of the openings

Windows opened
Windows closed

Arrival track B
Arrival track A

> Major impact for the exit located close from the windows
Impact of the openings

> Smaller impact for the exit located far from the windows
Conclusions
Conclusions

> A simulation tool based on OpenFOAM to design train stations

> Allow to investigate the piston effect of trains entering and leaving the station

> Comparisons to measurements quite difficult to achieve but they show that the orders of magnitude are OK

> Application to a real train station in order to predict the impact of closing some windows.

> A designing tool: part of AREP wider simulation suite for air management inside train station.