Tunnel Ventilation with Fire Suppression

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Motivation

- Tunnel ventilation design should be treated differently when coupled with fire suppression
- How should designers approach the issue of tunnel ventilation design when fire suppression is applied?

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Agenda

1. Tunnel Ventilation Design Requirements
2. Longitudinal Tunnel Ventilation
3. Tunnel Ventilation with Fire Suppression
4. Design Example
5. Jet Fan Technology
6. Conclusions

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1. Tunnel Ventilation Design Requirements

General Tunnel Ventilation Requirements

- Air quality
  - CO, NOx and visibility measurements
  - Worst-case scenario is congested, slow-moving (or stopped) traffic
- Smoke ventilation
  - Control movement of smoke to permit safe evacuation and fire-fighting
  - Normally the defining design scenario, requiring more ventilation than maintenance of air quality

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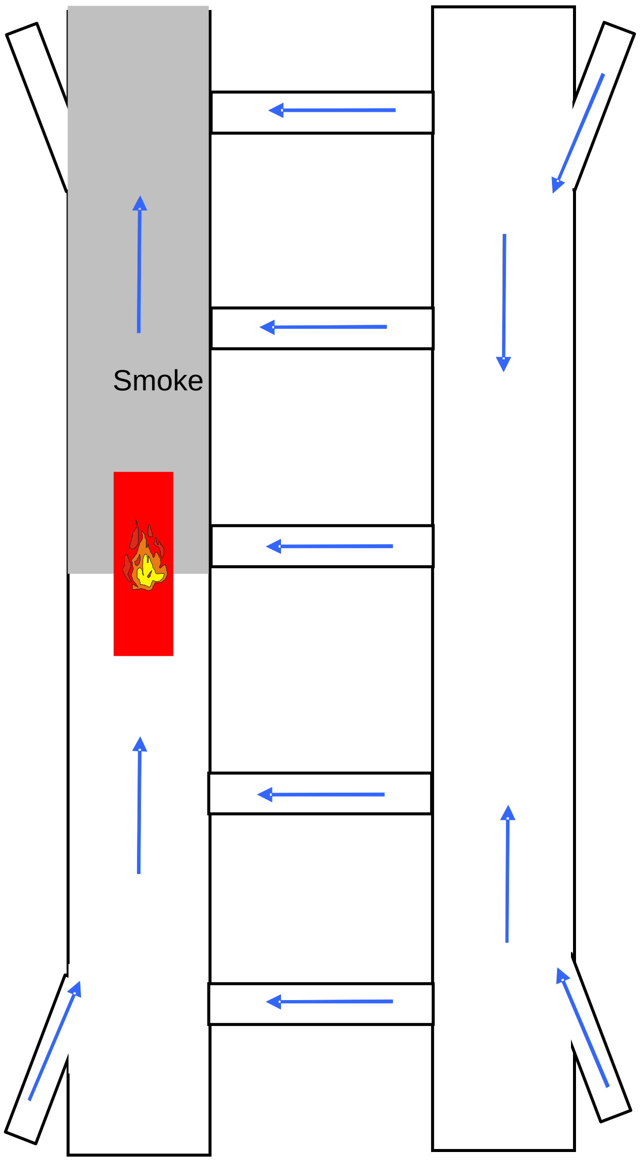
Smoke Ventilation

- Provide clear route for evacuation and fire-fighting: upstream of fire, and through cross-passages
- Pressurise non-incident tunnel bore



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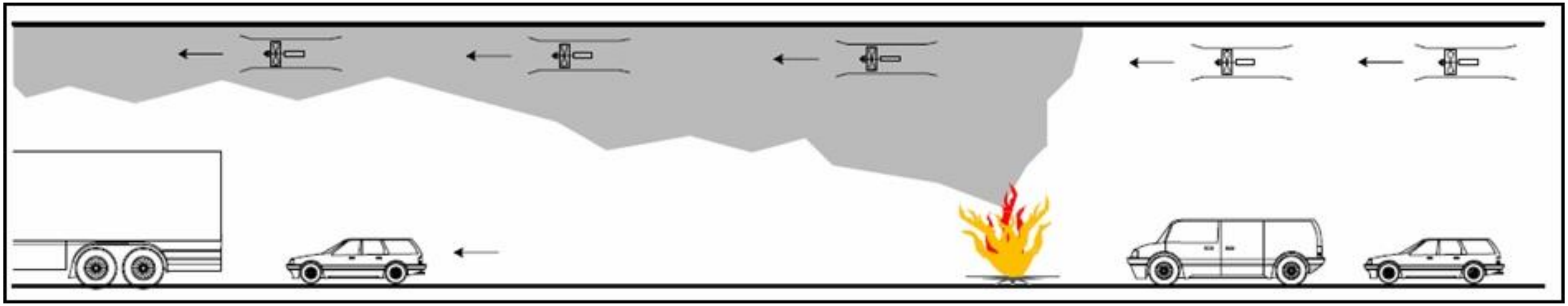
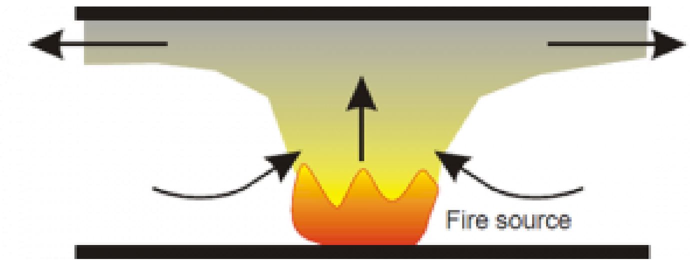
2. Longitudinal Tunnel Ventilation

Longitudinal Tunnel Ventilation

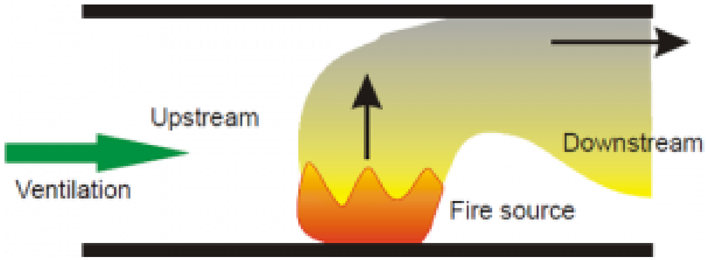


- Types of longitudinal ventilation:
  - Jet fans
  - Saccardo nozzles
  - Push-pull with shafts
- Jet fans are generally the most cost-effective type of ventilation for road tunnels 3 km long or less (although much longer tunnels can also be ventilated that way)

Critical Velocity Requirement



No ventilation applied; smoke travels in both directions (undesirable).



Ventilation applied, greater than critical velocity. Design requirement fulfilled.

- Generate a strong enough longitudinal flow to avoid back-layering
- Applies to main tunnel and also to cross-passages

Tunnel Ventilation Design Process

1. Define design fire
2. Define operational scenarios
3. Establish the required air velocities for smoke control
4. Calculate ‘hot case’ conditions
5. Calculate ‘cold case’ conditions

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‘Hot’ & ‘Cold’ Cases

- ‘Hot’ case: with fire, adverse wind, open cross-passage doors and with no fan redundancy → *check if critical velocity is achieved*
- ‘Cold’ case: without fire, favourable wind, closed cross-passage doors and with full fan redundancy → *check if air velocities exceed 10 m/s*

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Fan Redundancy

- Assumed destruction of fans due to fire

Fire Size (MW)	Distance Upstream of Fire (m)	Distance Downstream of Fire (m)
5	-	-
20	10	40
50	20	80
100	30	120

- Redundancy requirements in case of maintenance (10% or 2 jet fans, whichever is the greater)

Operational Procedures

- Actual performance of the tunnel ventilation system is dependent on operational procedures
- Influenced by uni- or bi-directional traffic flow, traffic control measures, application of fire suppression
- Feedback control of ventilation has a significant effect

World Road Association Guidelines

CASE	TRAFFIC PRIOR TO INCIDENT	PRINCIPLE FOR LONGITUDINAL VENTILATION
A	Unidirectional traffic **without** traffic congestion	Flow velocities in the direction of traffic to prevent or at least minimize backlayering of smoke
B	Unidirectional traffic **with** traffic congestion	Relatively low flow velocities (e.g. 1.2 ± 0.2 m/s) in the direction of traffic in order to minimize flow spread upstream, allow smoke stratification, support dilution of toxic gases and enable people to escape.
C	Bidirectional traffic	Relatively low flow velocities should be maintained, to avoid flow reversal unless circumstances dictate otherwise (for example fires near portals), allow smoke stratification and enable people to escape in both directions.
Note: reference should also be made to National Guidelines, the EU Directive or similar for further advice on the design aspects relating to tunnel length, ventilation objectives and design etc.		

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Differing Country Approaches

- Ventilation control system is considered standard in a number of European countries including Switzerland and Austria, but not in the United Kingdom
- Austria: air velocity in unidirectional traffic between 1.5 m/s to 2 m/s, and for bidirectional traffic between 1 m/s and 1.5 m/s.
- For unidirectional traffic without congestion, German RABT guidelines require a minimum velocity of the air flow exceeding the critical velocity for smoke control.

3. Tunnel Ventilation with Fire Suppression

Main Effects of Fire Suppression

- Critical velocity depends on convective heat release rate
  - Total (chemical) fire heat release rate is reduced via fire suppression
  - Convective proportion of fire heat release is reduced via fire suppression
- Density of air downstream of fire is increased, enhancing jet fan thrust
- Fire-induced fan damage is reduced

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4. Design Example

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Rize Tunnel, Turkey

Scope of work

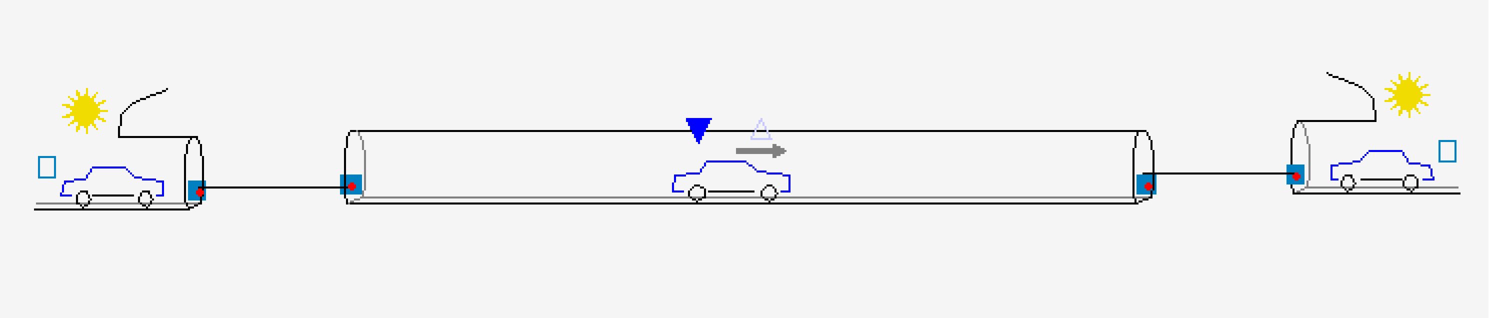
- Estimate the critical velocities for smoke control with a reduced fire intensity due to the activation of TUNPROTEC® fire suppression system
- Estimate the number of jetfans with TUNPROTEC® fire suppression system

Software used

- IDA Road Tunnel Ventilation
- IDA Road Tunnel Ventilation calculates pressure, airflow, temperature as well as CO and NOx concentrations in complex tunnel networks

Case setup

- Tunnel n° 3 modelled (2 bores)
- Details of the geometry (length, slope and fans location) as per design drawings
- Each bore calculated independently
- Traffic stops at fire location, and backs up all the way to the entrance portal



Layout of the system used in the simulation

Conventional Jet Fans

- Aerodynamic thrust provided by each jet fan:

$$T = \eta_i \cdot \rho A_A v_A (v_A - v_\infty)$$

- Where:
- η_i is the installation efficiency
- A_A is the cross section of the jet fan outlet,
- v_A the average fan discharge velocity and
- v_∞ the velocity in the tunnel beyond the direct influence of the jet fan intake and discharge

- Assuming an installation efficiency of 0.71 (conventional jet fan):
  - Jetfan bench thrust should be 1338 N at a discharge velocity of 31.4 m/s and an air density of 1.2 kg/m^3.
  - The power consumption per jet fan was assumed to be 30 kW.

Fire Heat Release Rate

- Unsuppressed fire heat release rate: 100 MW
- Due to activation of suppression system, fire heat release rate drops to 40 MW
- 50% of the suppressed fire heat release rate (20MW) assessed to be convective
- Any fan within 120m downstream or 30m upstream from the fire is considered to be damaged (conservative assumption)
- Fire locations: 7 locations considered, 500m apart from each other

Fire Suppression Cases

Mechanisms of Fire Suppression

- Pyrolysis inhibition through cooling and oxygen deprivation
- Smothering of combustion with liquid and water vapour
- Cooling the hot plume through latent heat of evaporation
- Prevention of fire spread through cooling of neighbouring surfaces

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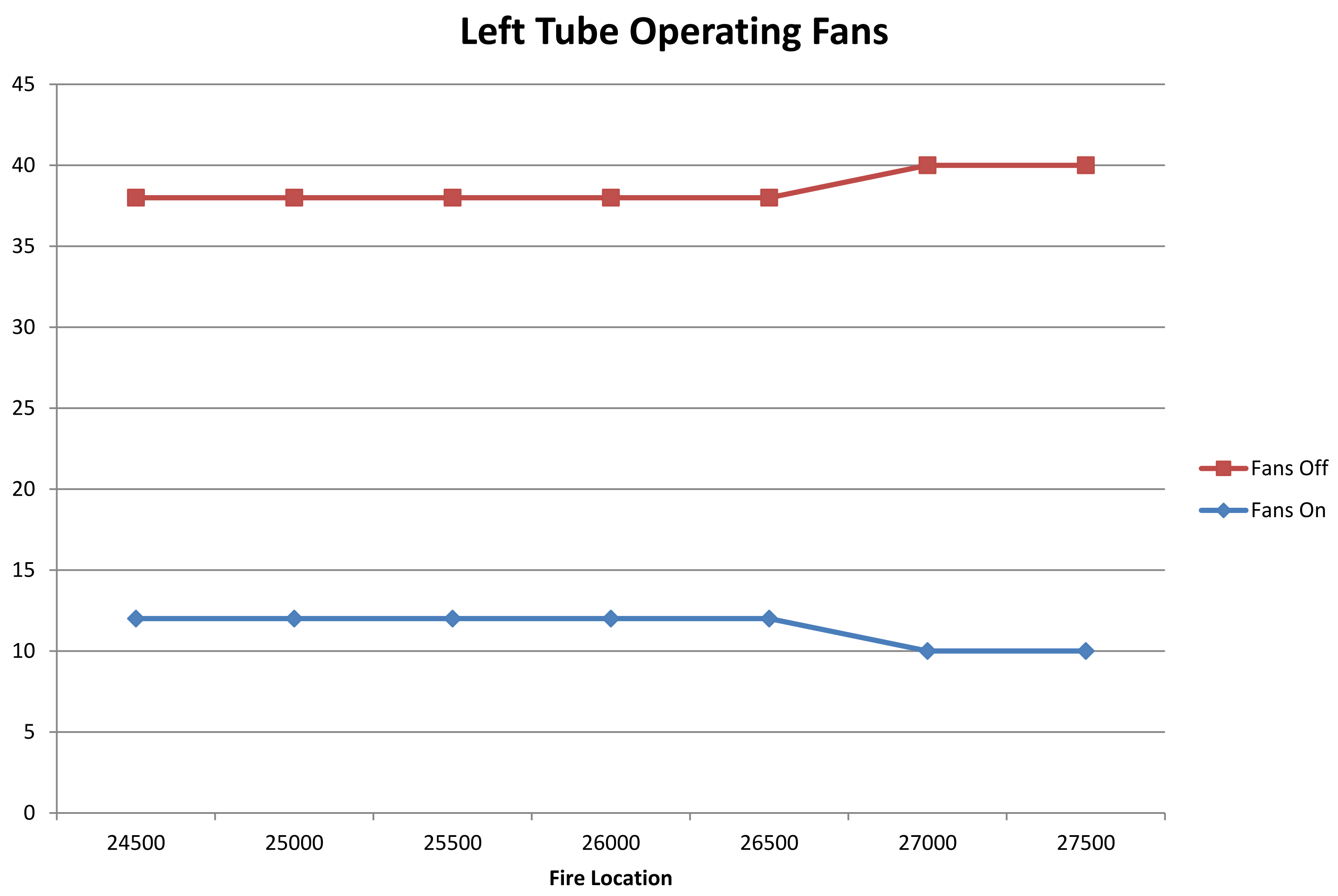
Left Tube Operating Fans
45
40
35
30
25
20
15
10
5
0
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26000
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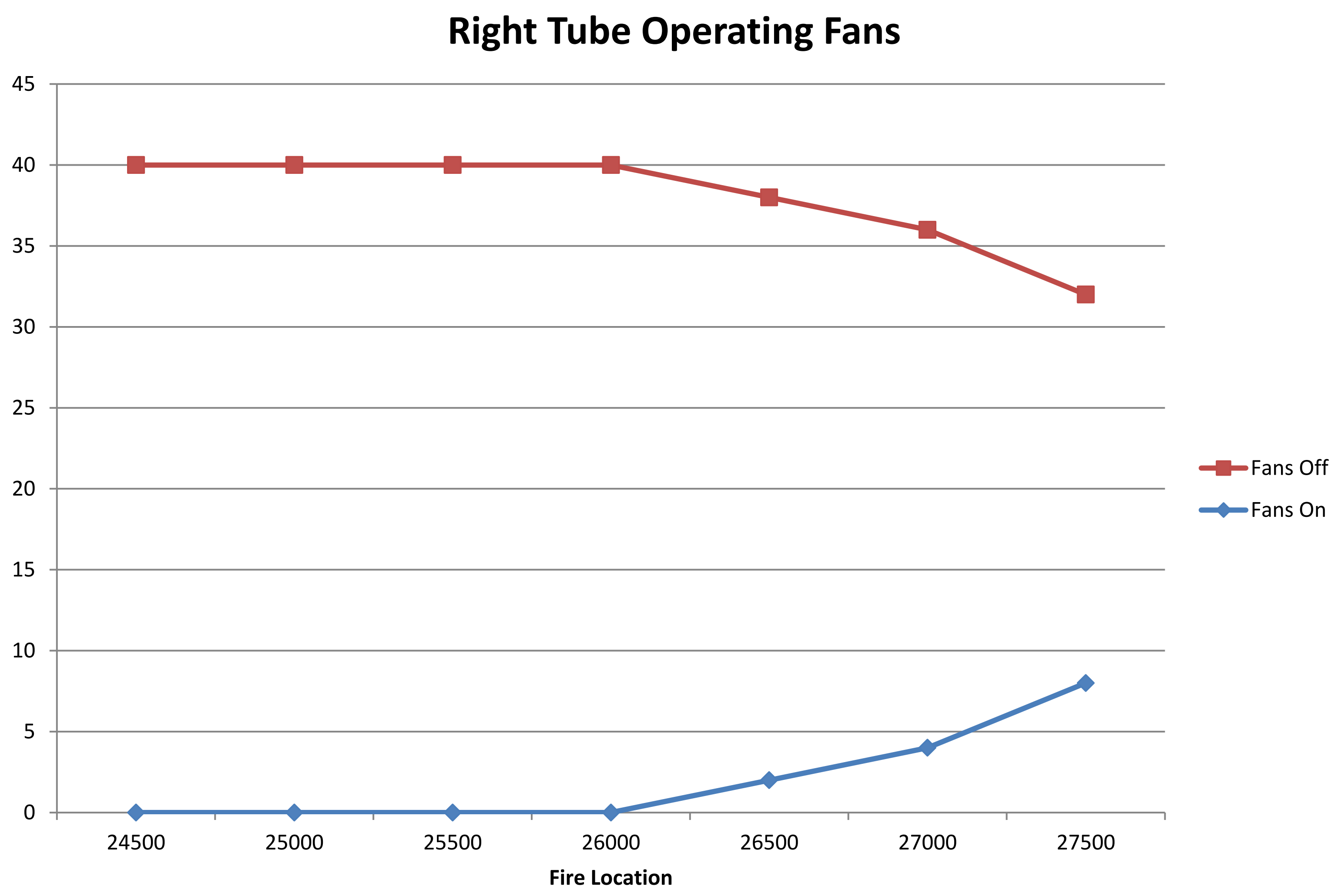
27000
27500
Fire Location
Fans Off
Fans On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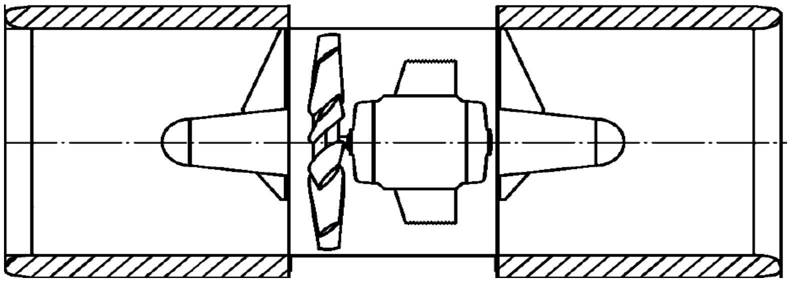
25500
26000
26500
27000
27500
Fire Location
Fans Off
Fans On

Design Results

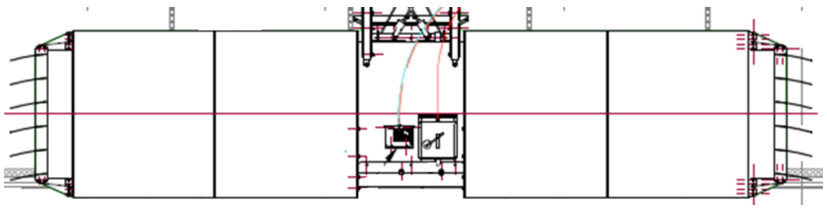
- After installation of TUNPROTEC® fire suppression system:
- North bore: the total number of fans to be installed in this bore can be reduced from 50 down to 16 (12 operating fans plus an allowance of 4 for maintenance and fire damage)
- South bore: the total number of fans to be installed in this bore can be reduced from 40 down to 12 (8 operating fans plus an allowance for maintenance and fire damage)
- Consideration should be given to the probability of delay in activation of the fire suppression system, or a failure in its operation

5. Jet Fan Technology

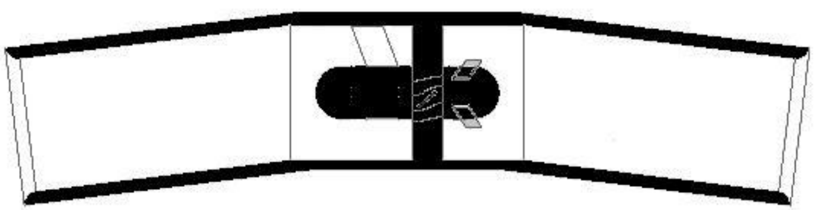
Jet Fan Technologies



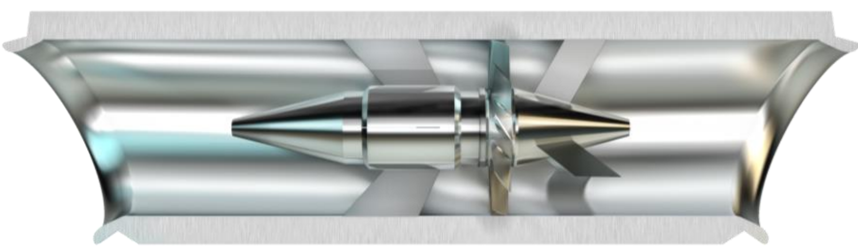
Conventional jet fan



Jet fan with deflectors

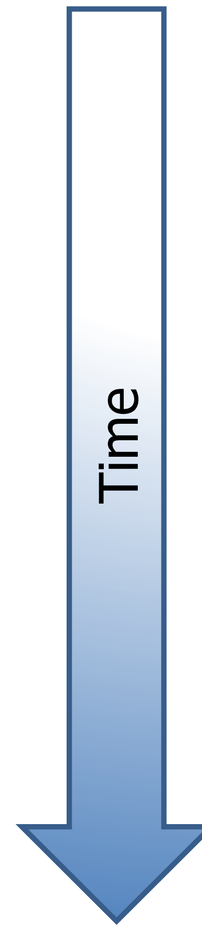


Slanted silencers



MoJet

Oldest



Most recent

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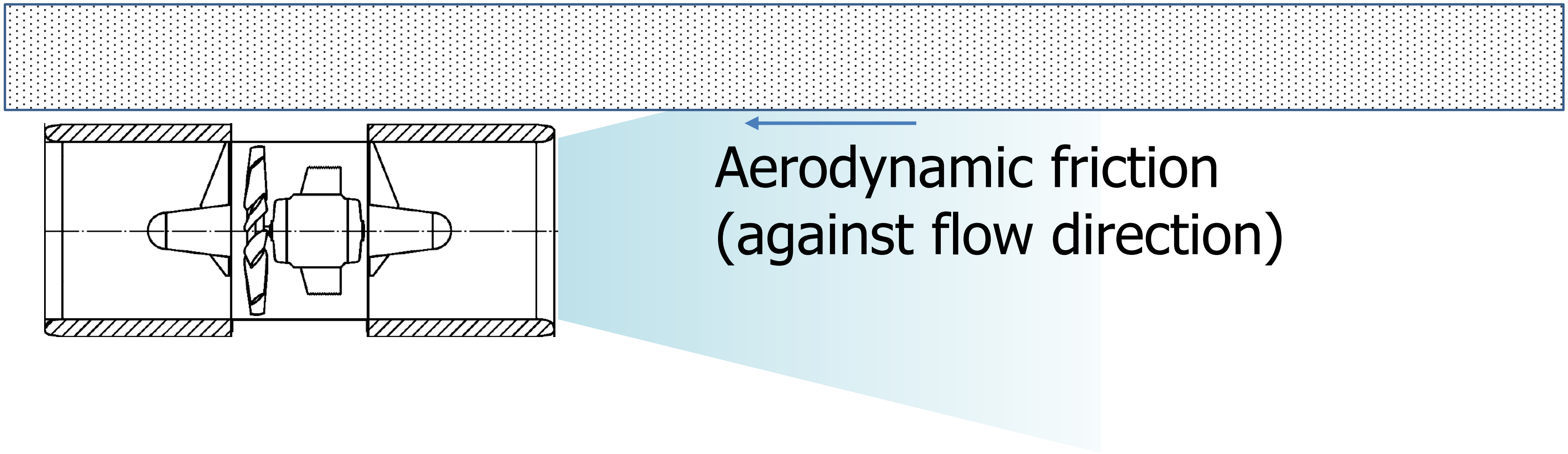
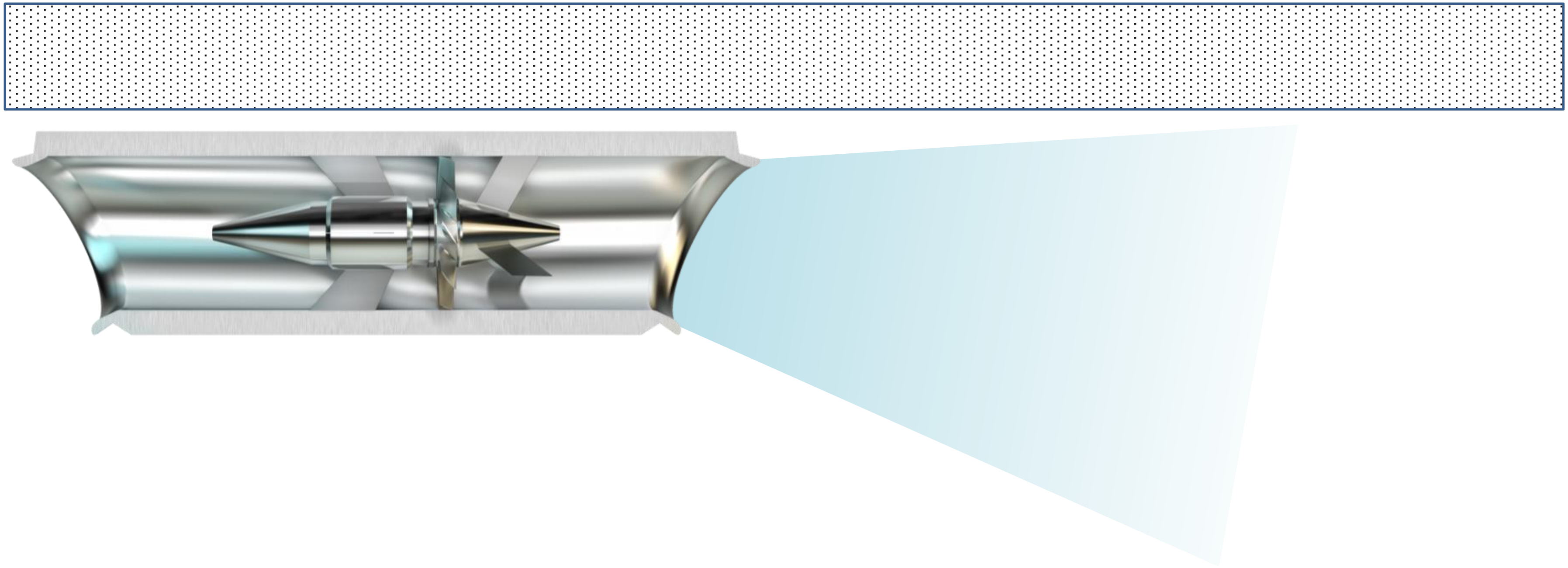
The Coanda Effect



- Discharged jet tends to stick to tunnel soffit and walls
- Typically 30% to 50% of thrust lost via aerodynamic friction

Solution



- Deflect the discharged jet to reduce aerodynamic friction
- In-tunnel thrust increased by up to 100%

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How to select the right technology?

- Jet deflection
- Compactness
- Jet throw extension
- Noise regeneration
- Deflector metal fatigue risk
- Additional power consumption
- Loss of bench thrust
- Risk of bearing damage

Jet Fan Technology Comparison

Technology	Deflect Jet	Compact	No jet throw extension	No noise regeneration	No deflector metal fatigue risk	No additional power	No loss of bench thrust	No risk of bearing damage
Conventional	✗	✓	✓	✓	✓	✓	✓	✓
Deflectors	✓	✓	✗	✗	✗	✗	✗	✓
Slanted silencers	✓	✗	✓	✓	✓	✗	✗	✗
MoJet	✓	✓	✓	✓	✓	✓	✓	✓

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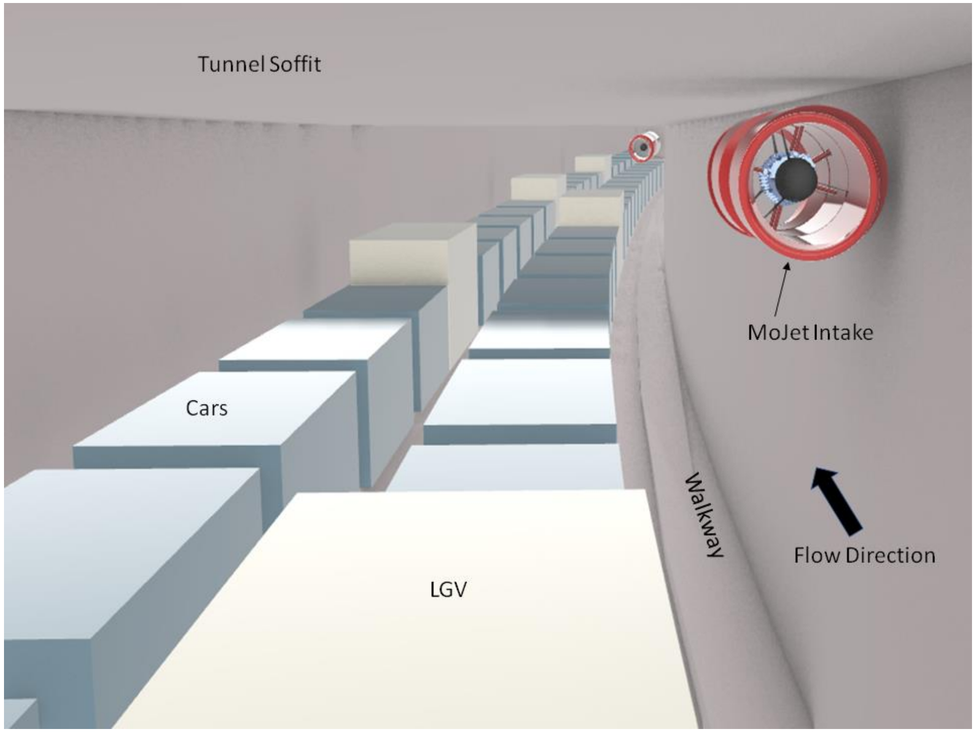
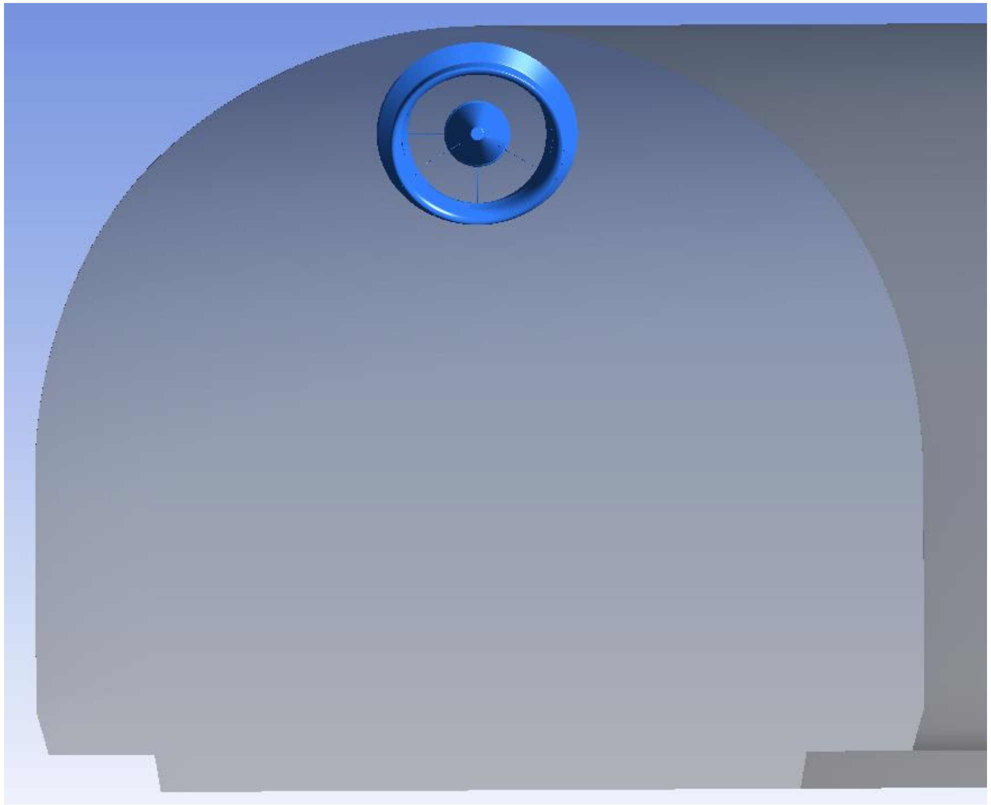
Corner-Mounted MoJets



- Half the number of active conventional jet fans required, plus an allowance for maintenance and fire damage
- Spacing between MoJets reduced from about 100m to 40m, with less cabling required.

Soffit-Mounted MoJets

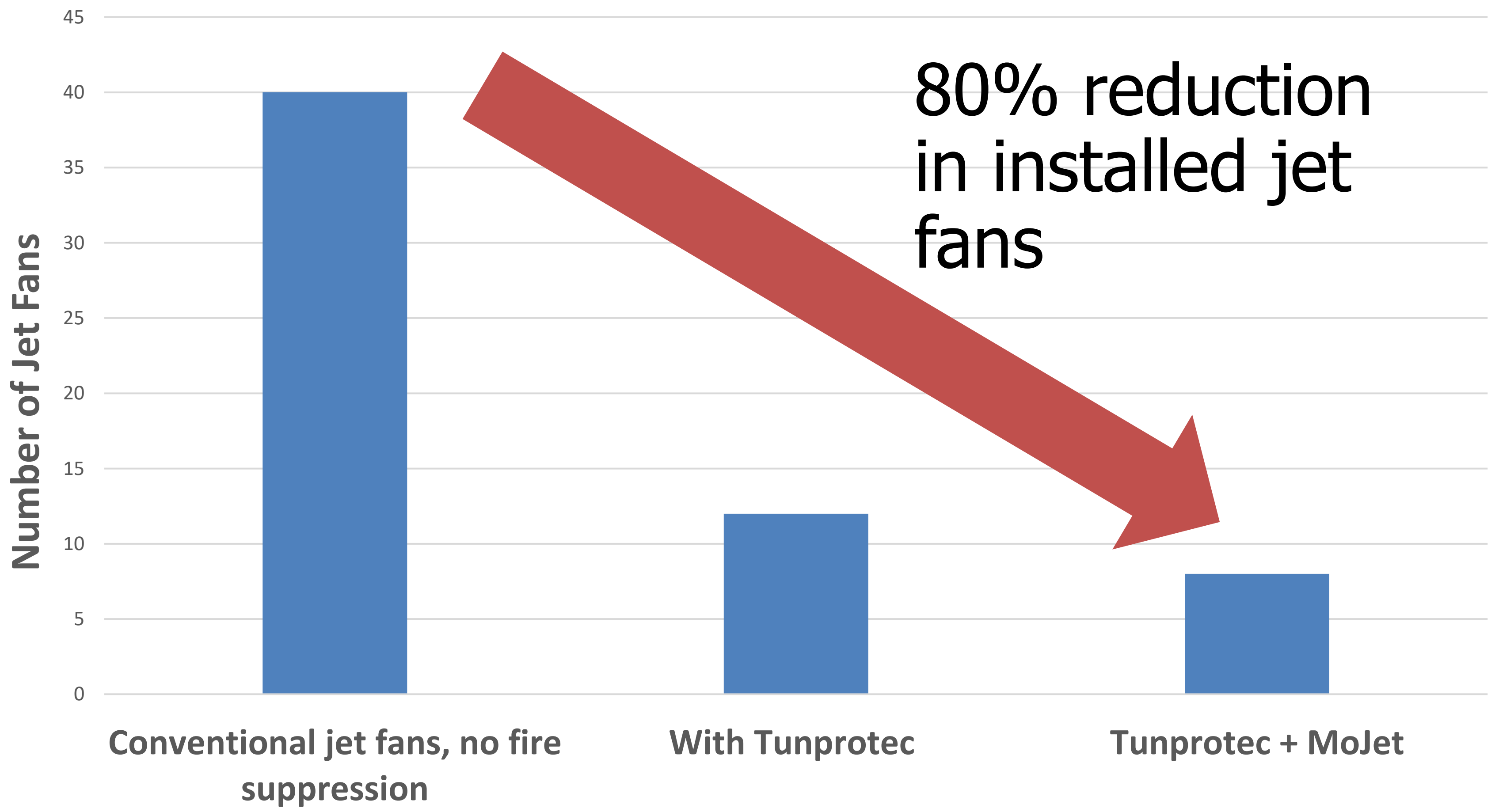


- 25% fewer active MoJets required, compared to conventional jet fans.

Combination of fire suppression and MoJets

- Required number of fans for smoke ventilation is reduced by at least 50%
- Still require an allowance for damage due to fire, but arguably only for one bank of fans (not two)
- Allowance for fans under maintenance
- Check ventilation for air quality during traffic congestion

Rize Tunnel, South Bore



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Any Questions?