Japanese and international standards for jet fan ventilation of tunnels

Dr Fathi Tarada

Dr Masahiro Yokota

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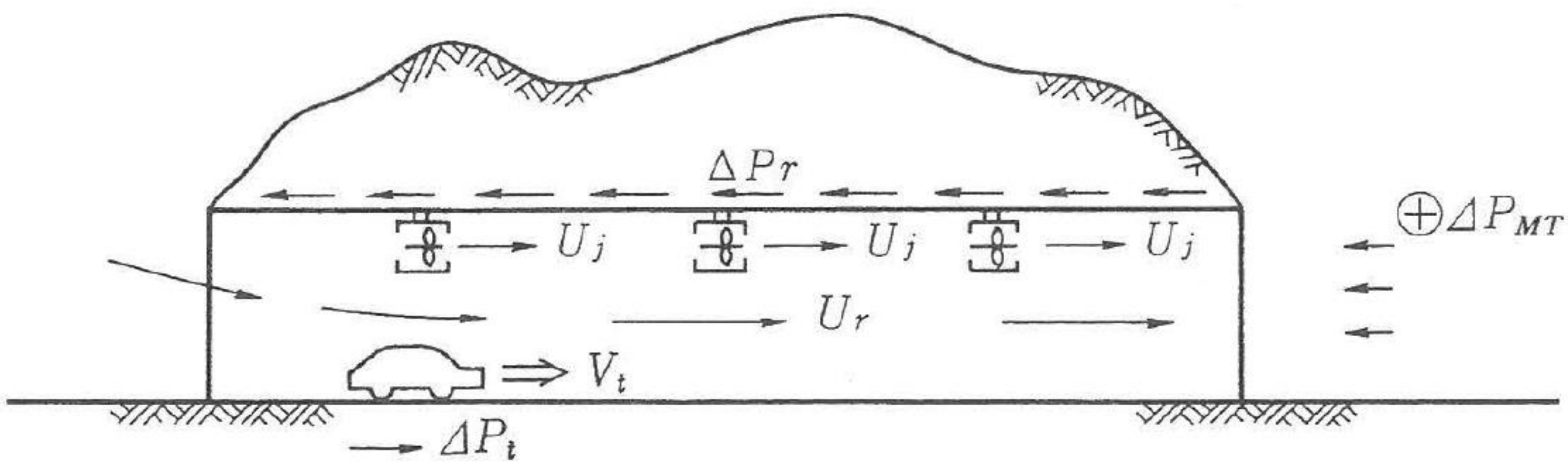
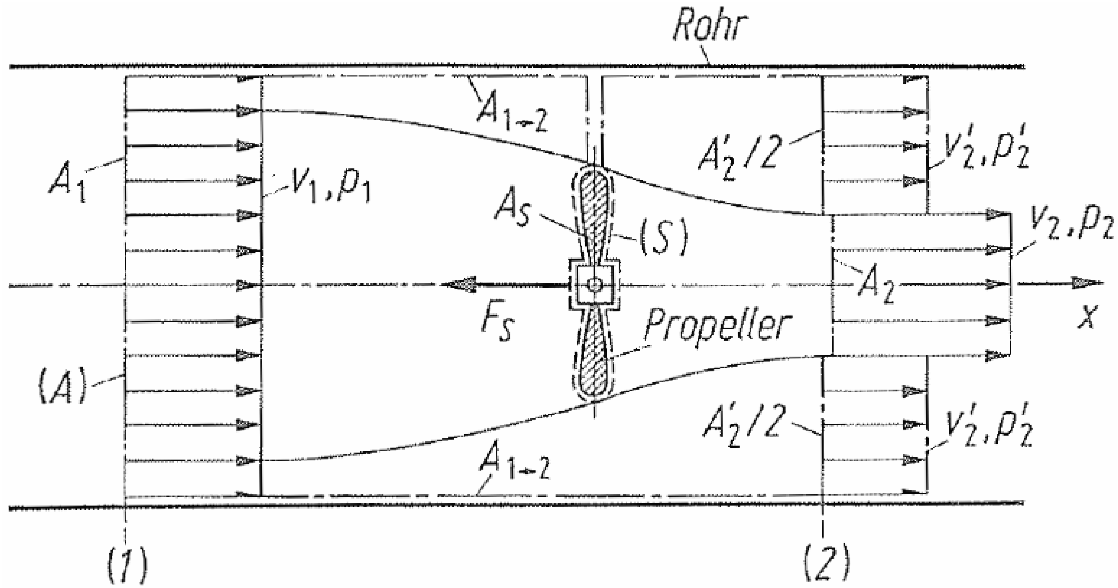
Tunnel ventilation with jet fans



- Jet fans deliver a longitudinal thrust to the tunnel air
- Flow is induced from the inlet tunnel portal, and is discharged at the exit tunnel portal
- The jet fan thrust is designed to overcome aerodynamic pressure drops into, along and out of the tunnel

Jet fan calculation methodologies

Calculation Methodologies - 1

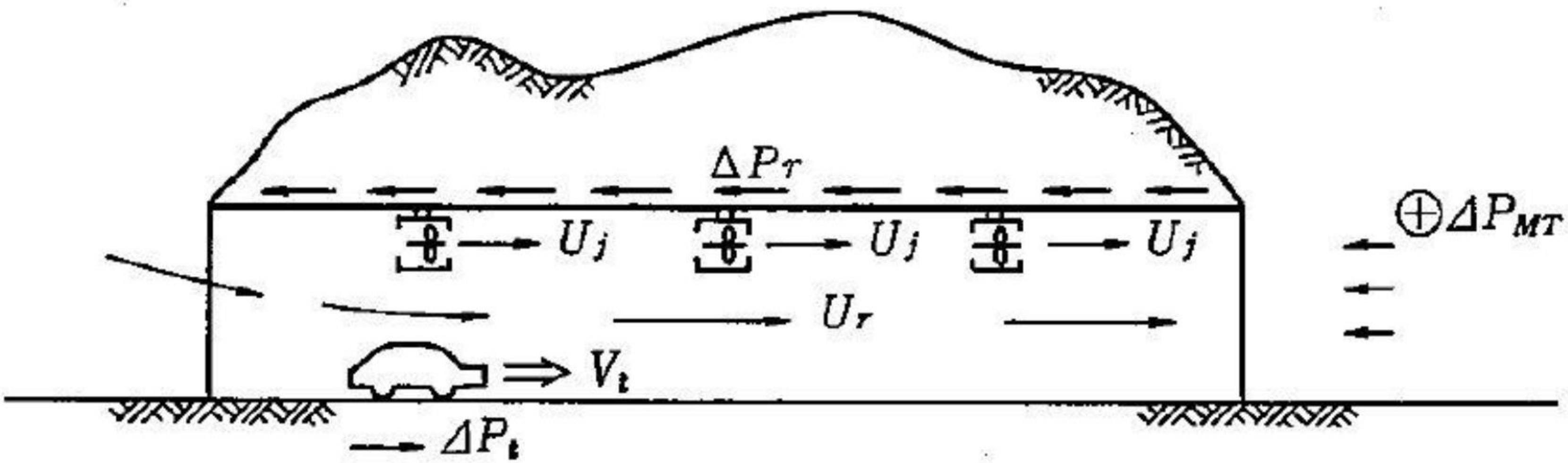


Truckenbrodt (1980)

$$T_{\max} = \frac{\rho}{2} \frac{A_1 A_2}{(A_1 - A_2)^2} \left[(2A_1 - 3A_2) v_2^2 - 2(A_1 - 2A_2) v_1 v_2 - A_2 v_1^2 \right]$$

Calculation Methodologies - 2

Meidinger (1964)



$$\Delta P_j = \frac{1}{2}\rho \cdot U_j^2 \cdot \phi \cdot \frac{1-\psi}{(1-\phi)^2}(2-3\phi+\phi\psi)$$

where

Φ = Aj/Ar, Ψ = Ur/Uj

Simplified Method

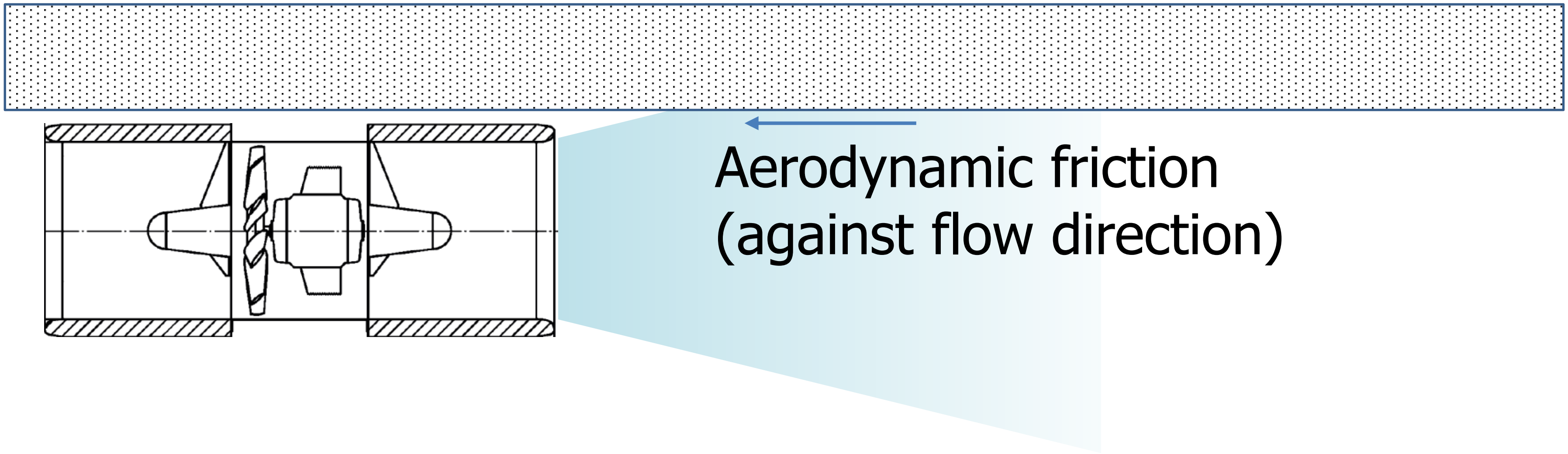
- Applicable where the jet fan cross-sectional area is much smaller than the tunnel cross-sectional area (almost always the case)
- Delivers conservative estimates of thrust, typically 2 to 3 % lower than those of the more accurate methods

$$T_{\max} = \rho A_A v_A (v_A - v_\infty)$$

Reductions in Jet Fan Thrust

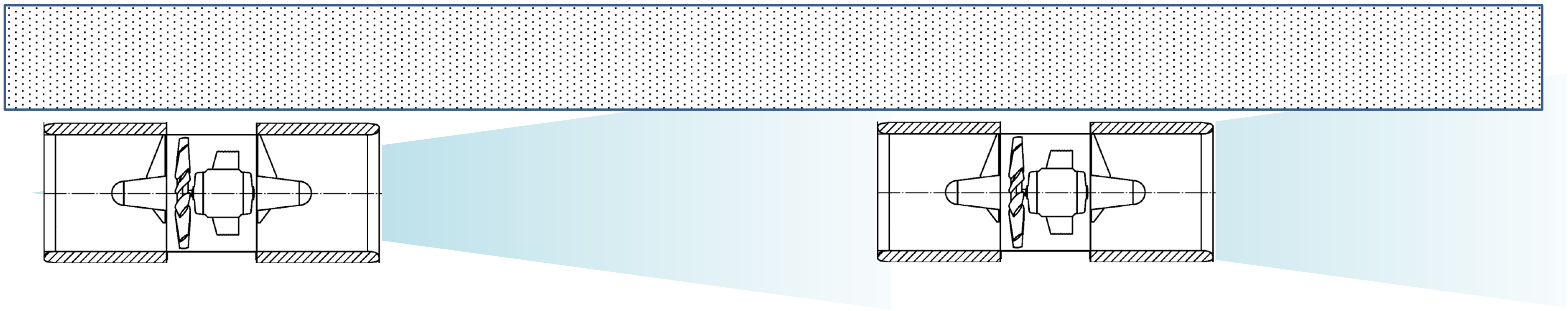
- Aerodynamic friction between the jet and neighbouring tunnel surfaces (Coanda effect)
- Jet interaction effects for downstream jet fans (jet fan spacing effect)
- Interaction effects between adjacent jet fans in a single bank (jet interference)

The Coanda Effect



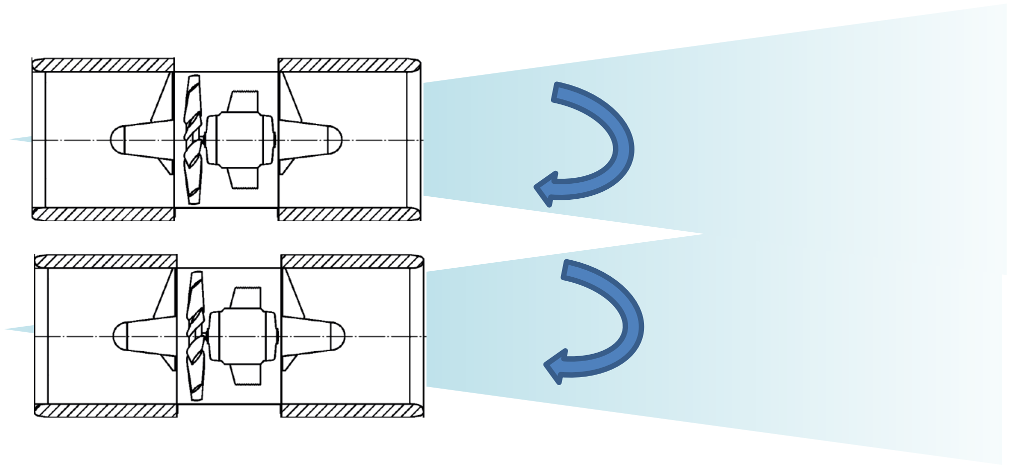
- Discharged jet tends to stick to tunnel soffit and walls
- Typically 30% to 50% of thrust lost via aerodynamic friction
- Additional losses due to jet interaction and flow impingement

Downstream Jet Interaction Effects



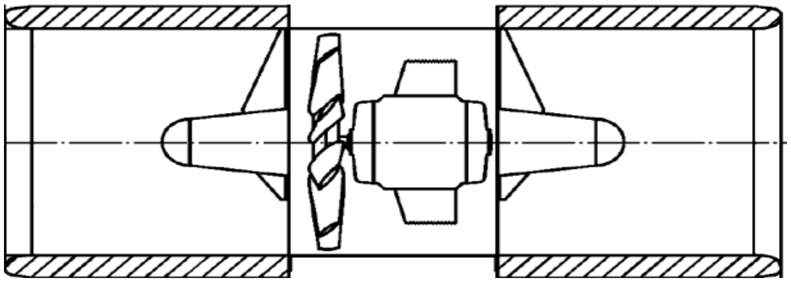
- Downstream jet fan ingests high-velocity jet, reducing its thrust
- Additional form drag due to high-velocity jet flowing over downstream jet fan

Interactions between Jets within a Bank

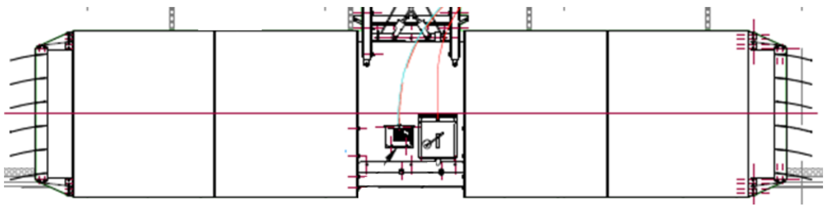


- Potential clash between the swirling jets on discharge
- Additional turbulence and shear causes loss of thrust

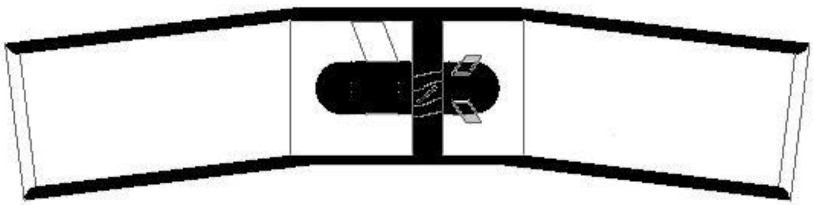
Jet Fan Technologies



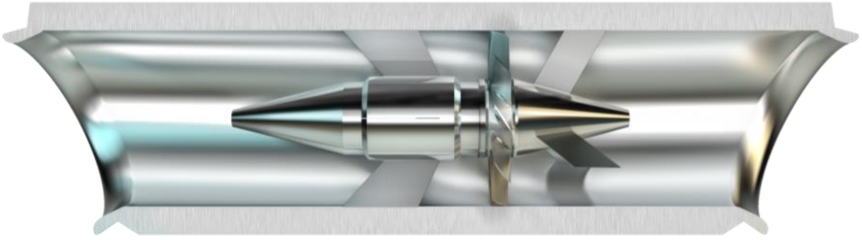
Conventional jet fan



Jet fan with deflectors

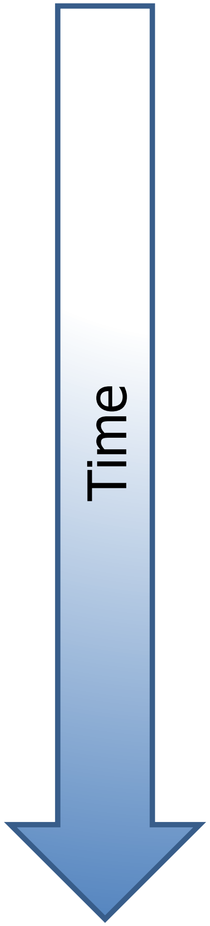


Slanted silencers



MoJet

Oldest



Most recent

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Effect of Jet Fan Technology

- Corrections to the calculated jet fan thrust depend on the jet deflection technology
- Focus of this presentation is on conventional jet fans

Effect of Installation Details

Installation details have a significant effect on the jet fan installation factor:

- below a soffit
- within a niche
- distances to nearest tunnel surfaces
- presence of downstream impingement surfaces, e.g. tunnel headwalls and signs

Thrust Calculation accounting for Inefficiencies

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

where

η_i = jet fan installation factor or "boosting coefficient) (< 1) to account for inefficiencies including

- Coanda effect
- Downstream jet interaction
- Sideways jet interaction

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Jet fan installation factors

Installation Factor Estimation - Europe

- Europe: correlations based on measurements by Kempf (1965) and Woods / South Bank University (1997) are widely used.
- Based upon model-scale experiments, hence Reynolds numbers are much lower than in real tunnels.
- These correlations have been shown to be too optimistic by more recent researchers, e.g. from Graz University (2016).

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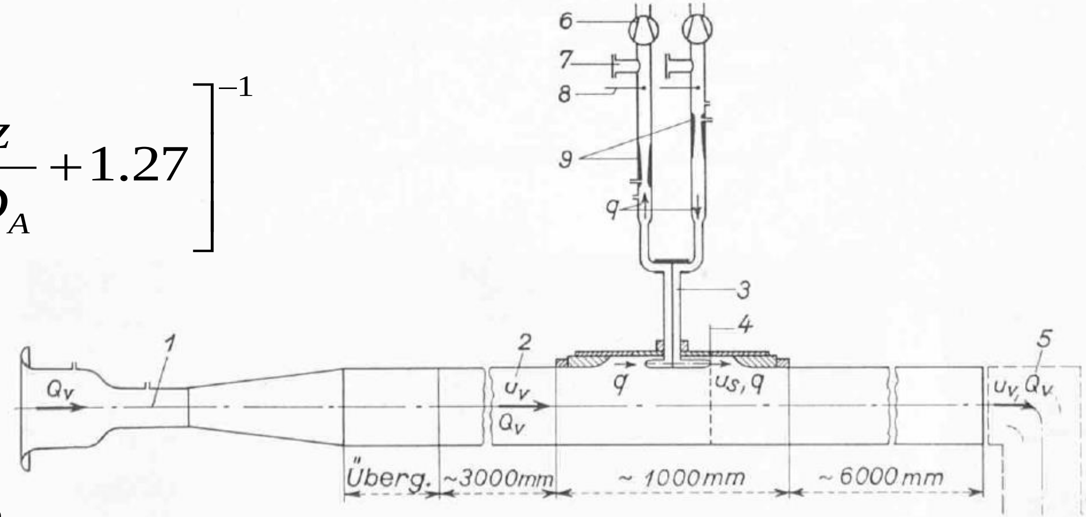
Kempf Measurements (1965)

$$\eta_i = \left[0.0192 \left(\frac{z}{D_A} \right)^2 - 0.144 \frac{z}{D_A} + 1.27 \right]^{-1}$$



D_A = outlet diameter of the jetfan
z = distance between the centre axis of the jet at the outlet and the tunnel wall

- Based on 1:60 scale measurements
- Reynolds number approximately 50 time smaller than reality
- Jet had no swirl, hence expanded slowly and was less likely to attach to the tunnel wall
- No jet interaction / interference effects investigated
- Measurements and correlation cannot be relied upon

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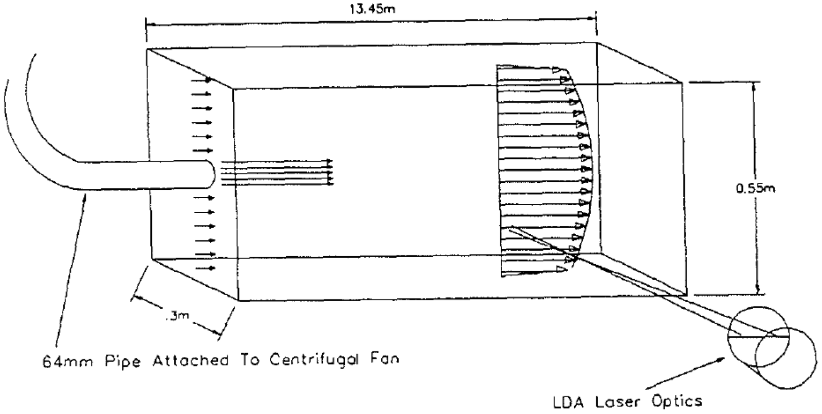
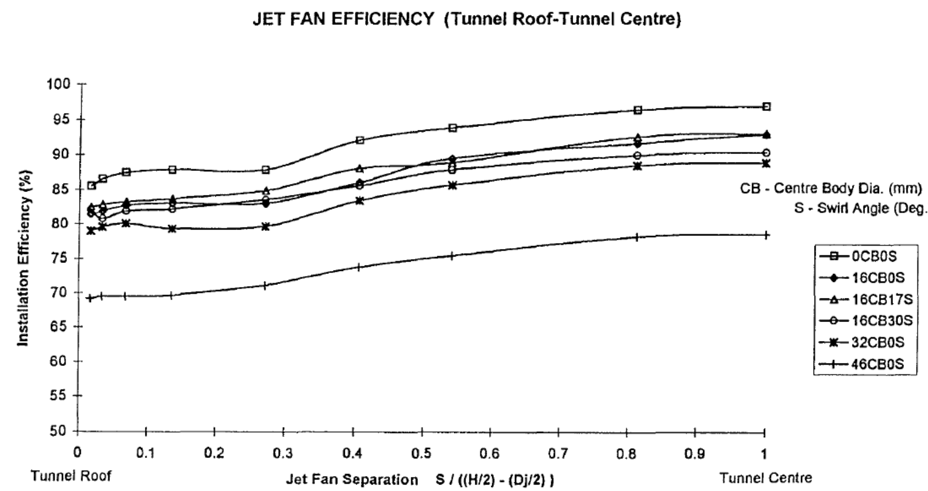
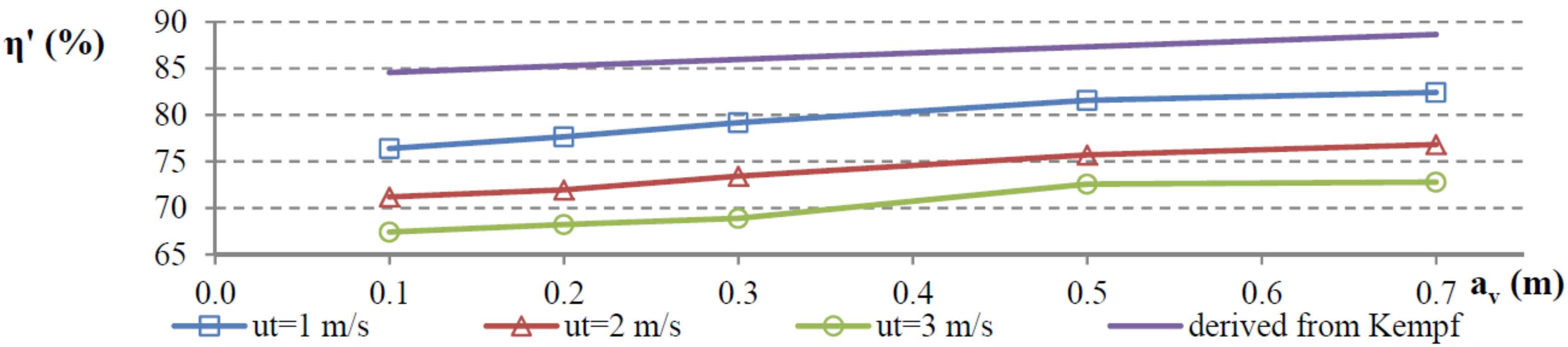
Woods / South Bank University Measurements (1997)





- 1:15 scale model
- Reynolds numbers approximately 15 times lower than reality
- No jet interaction / interference effects investigated
- Not a good basis for tunnel ventilation design

Graz University (2016)



- 3D CFD calculations validated against measurements for two tunnels, using jet fans with deflection vanes
- Installation factors reported based on 3D CFD - significantly lower installation factors than Kempf reported
- Installation factors reduce with increasing tunnel air velocity, and increase with increasing jet fan diameter
- No discharge swirl modelled – hence results are questionable for conventional jet fans (i.e. without deflection vanes)

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Installation Factor Estimation - Japan

- Guidance generally towards setting unity for the installation factor
- Measurements carried out in Japanese road tunnels in 2000 indicated a range of installation factors from 0.7 to 1.07, depending on the tunnel air velocity and the distance between jet fans

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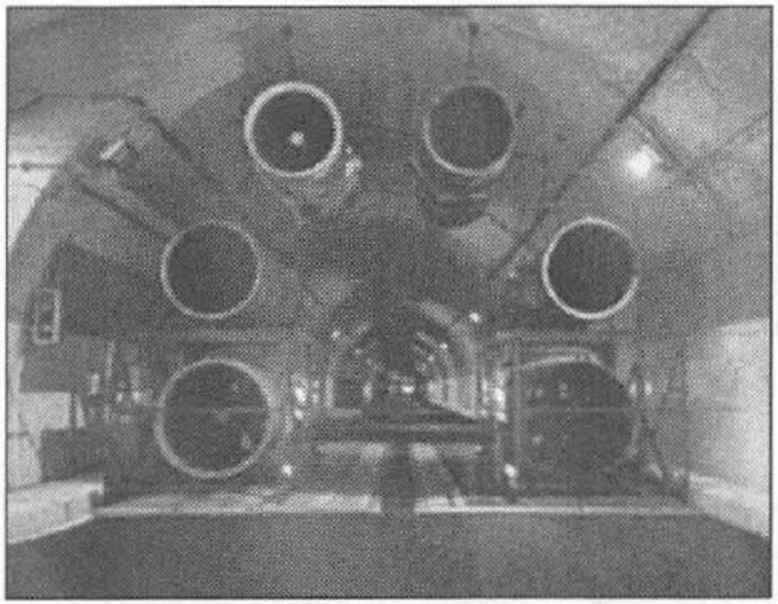
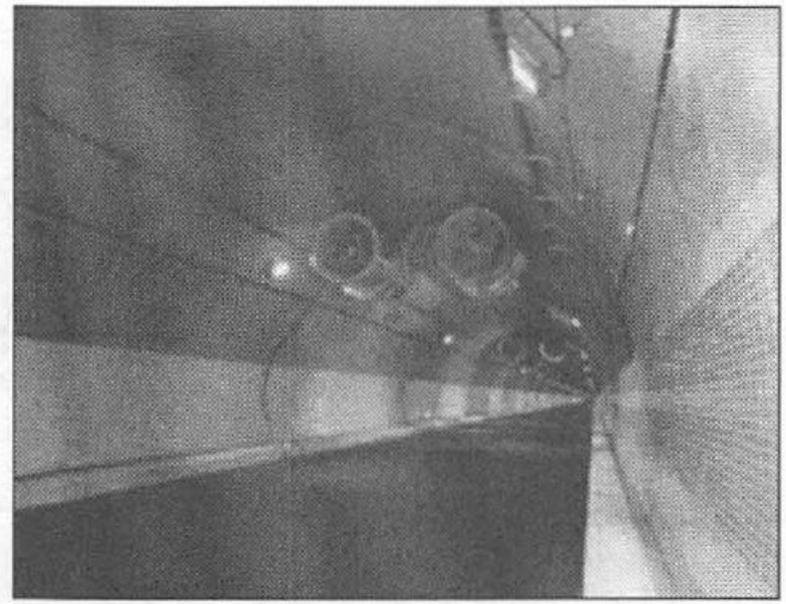
Japanese Road Tunnel Measurements (2000)



Photograph 1
High Air Speed Generation Equipment



Photograph 2.
Installation Interval of 40 m

Jet fans were mounted at a significant distance from the tunnel soffit (distance was not reported).

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Japanese Standards and Guidelines

Japanese Tunnel Ventilation Standards and Guidance

Category	Publisher	Name
Standard	Japan Road Association	Road Tunnel Technical Standards (Ventilation) and Commentary
Guideline	East Nippon Expressway Company Central Nippon Expressway Company West Nippon Expressway Company	Design Guidelines, Vol. 7, Mechanical Facilities (Chapter 2, Tunnel Ventilation)
Guideline	Metropolitan Expressway	061 Mechanical Equipment Design Guidelines (Tunnel Ventilation Equipment)
Guideline	Hanshin Expressway	3050 Tunnel Ventilation Guidelines

Japan Road Association – Road Tunnel Technical Standard

- Meidinger equation (full and simplified versions) proposed to calculate the pressure rise across a jet fan – but without any installation factor.
- In the text: a "booster coefficient" should be used to account for friction or for losses due to the mixing of the jet with the surrounding air.
- No guidance provided in that standard as to what the value of that "booster coefficient" should be.
- Implication appears to be that the full jet fan thrust, without any reduction, can be assumed.

Metropolitan Expressway - Guideline

- Distance between a jet fan and a tunnel wall can affect the installation factor, and there are some experimental measurements of this effect.
- In the Metropolitan Expressway, there are various tunnel cross-sections, and no overall classification has been made.
- An installation factor of unity is proposed, if that value is not obtained from experiments or elsewhere.

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Hanshin Expressway - Guideline

- This guideline suggests a default value of unity for the jet fan installation factor.
- It acknowledges that there are many factors that can interfere with the pressure boosting power of a jet fan, such as changes in the cross-section of the tunnel (internal clear height), the presence of a branching or merging section, the presence of obstructions such as signs, etc.
- The issue of aerodynamic friction between the jet and tunnel surfaces is not addressed in this guideline.

East/West/Central Nippon Expressway Guideline

Table 7-4-1, “Wind speed and boost coefficient Kj in the roadway”

車道内風速	JF設置間隔	昇圧係数 K_j
4m/s以下	100m	0.99
4m/s超　8m/s以下	120m	0.92
8m/s超　12m/s以下	140m	0.90

- Very high values for the jet fan installation factor, with no allowance for the physical installation arrangements, i.e. distance of the jet fan to the nearest soffit or wall, whether the jet fan is installed in a niche or close to a physical obstruction etc.
- No allowance for jet interference effects (within bank and between banks of jet fans)
- Trend of reducing installation factor with increasing tunnel air velocity is consistent with the findings of other researchers

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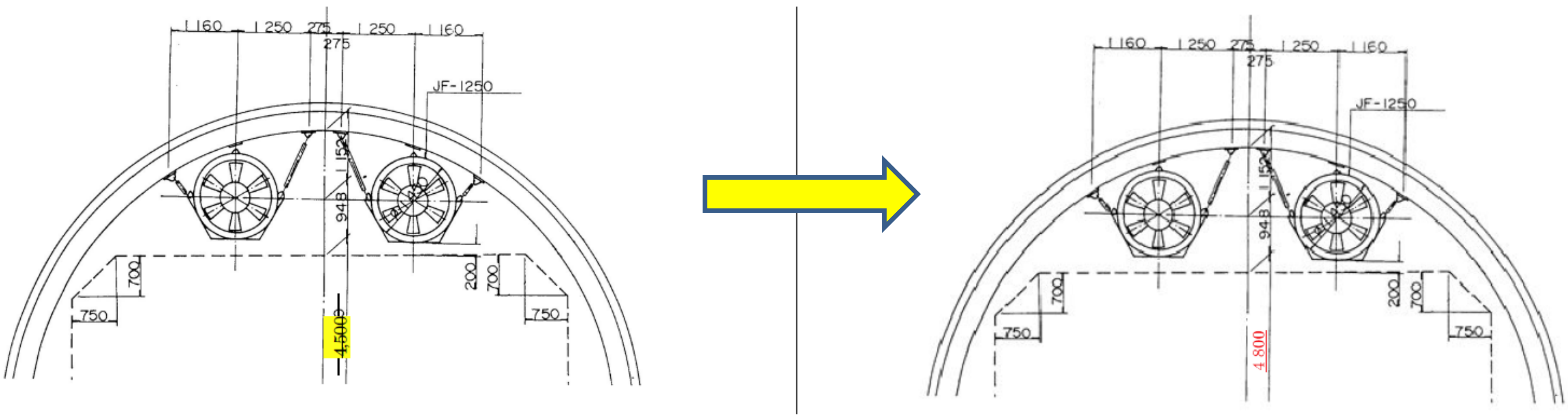
Future Trends

New Road Structure Ordinance

- Road Structure Ordinance in Japan has recently been revised, and the height limit (traffic gauge) inside the tunnel has been increased from 4.5m to 4.8m.
- This is to allow additional headroom for HGVs along important logistics roads.
- Less room for jet fans in existing road tunnels.



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Refurbishment of Existing Tunnels

- Some existing tunnels in Japan require refurbishment of tunnel ventilation systems
- Smaller diameter jet fans, close to soffit or to soffit/wall corners
- Fundamental physics cannot be ignored – installation factors for such installations are much less than unity

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Conclusions

- Original jet fan installations in Japan comprised large-diameter fans, installed far from the soffit, and at generous distances between fan banks → installation factors close to unity.
- Changing regulations and refurbishment requirements for ventilation are a challenge for designers
- Improved consideration of installation factors, and better jet fan technology, should be considered.

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