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# ROAD TUNNEL VENTILATION

# -

# GENERAL

# CONTENT

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1. Traffic Development
2. Tunnel Ventilation Types
3. Design Calculation
4. Summary

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# 1. Traffic Development

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- How Traffic/ Infrastructure develops?
  - More People / Cars
  - More Industrial Activity
  - → More Infrastructure
  - → Limited Space

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- Benefits of Tunnels:
  - Less space (tunnel ⇔ ring road)
  - Direct connections for
    - mountains,
    - rivers / bays,
    - urban / nature areas

    → more competitive (“time is money”)
  - Less Noise
  - More feasible (today’s better know-how)

→ Tunnels will increase

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# 2. Tunnel Types

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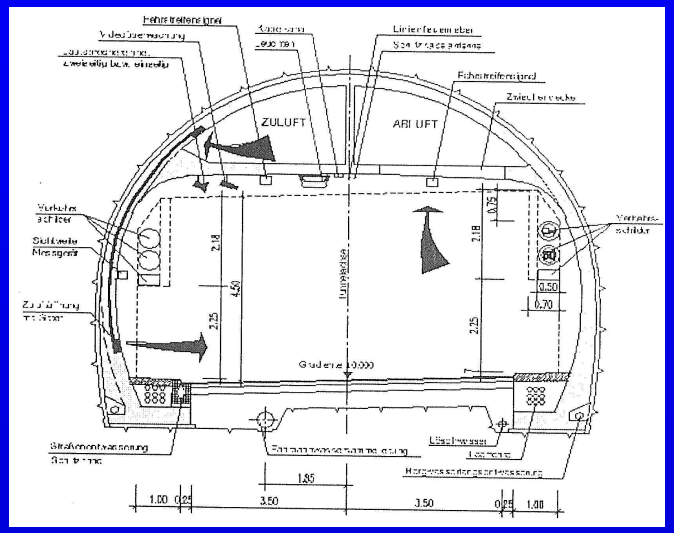
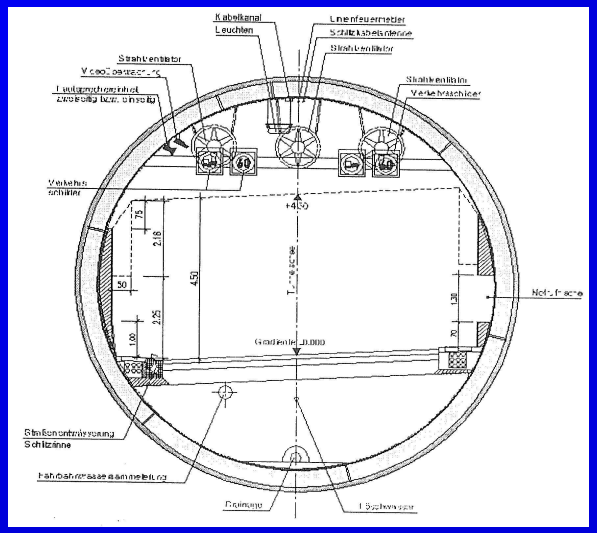
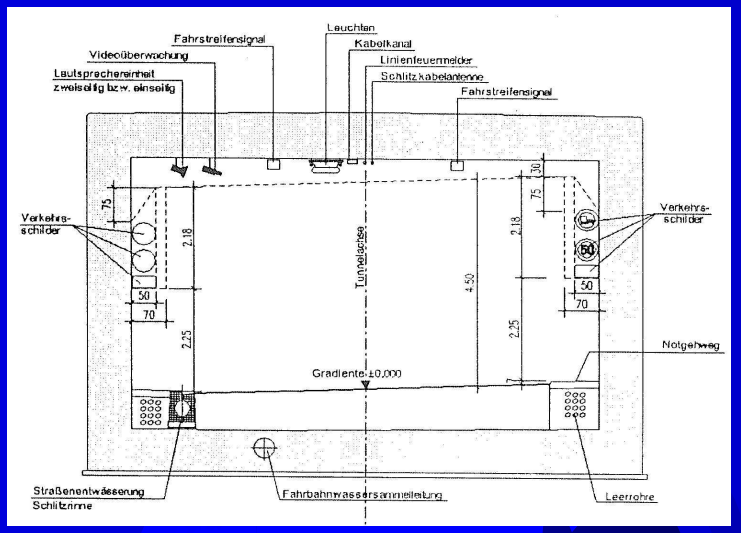
# Common Profiles






**Vault**

**blasted rock**

**Round**

**drilled (soft ground)**

**Square**

**enclosure**

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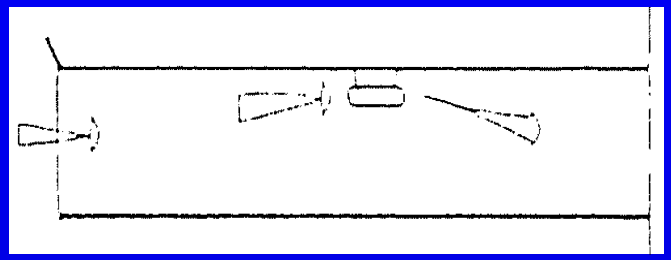
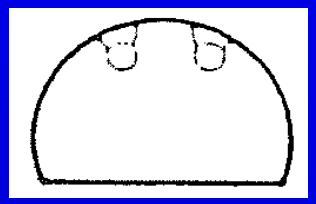
# Tunnel Ventilation Types (VDI 6029)

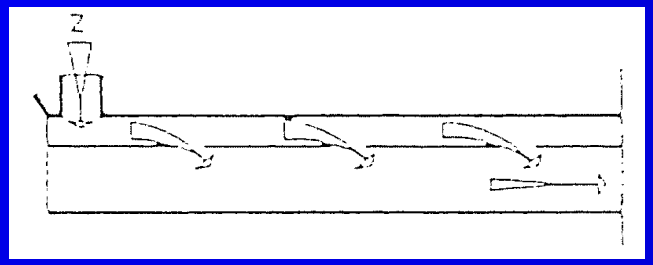
## 1. Longitudinal

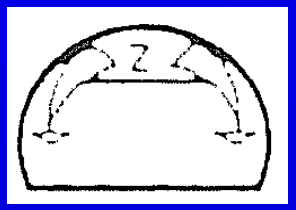




- ⊕ cheap
- ⊖ toxic concentration increases
- ⊖ in fire case smoke extracted towards the tunnel portal

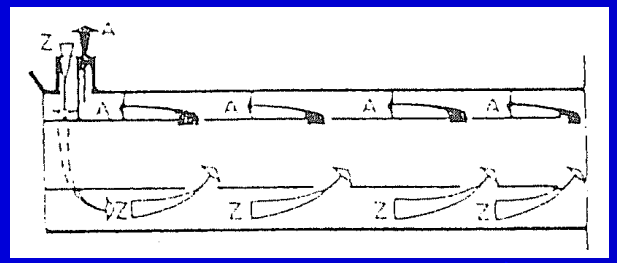
## 2. Semi-transverse

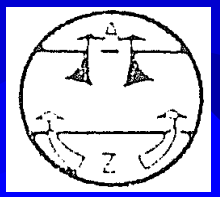



- ⊖ expensive
- ⊕ toxic concentration nearly held constant
- ⊖ in fire case smoke extracted towards the tunnel portal

## 3. Transverse




- ⊖ very expensive
- ⊕ toxic concentration held constant
- ⊖ in fire case smoke exhaust not controllable

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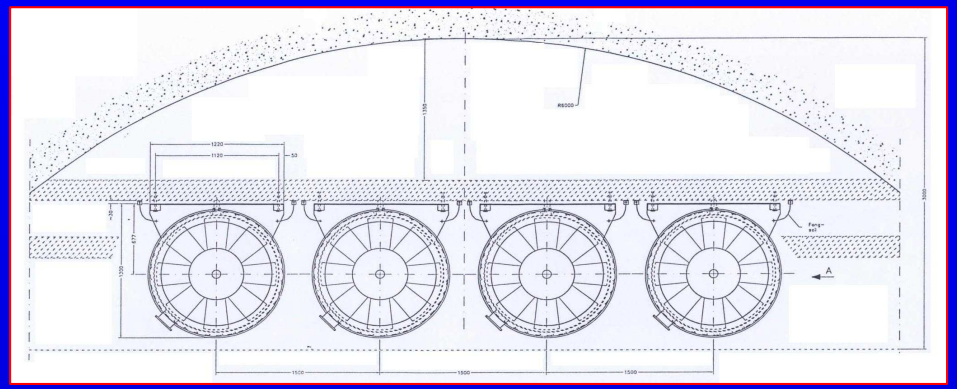
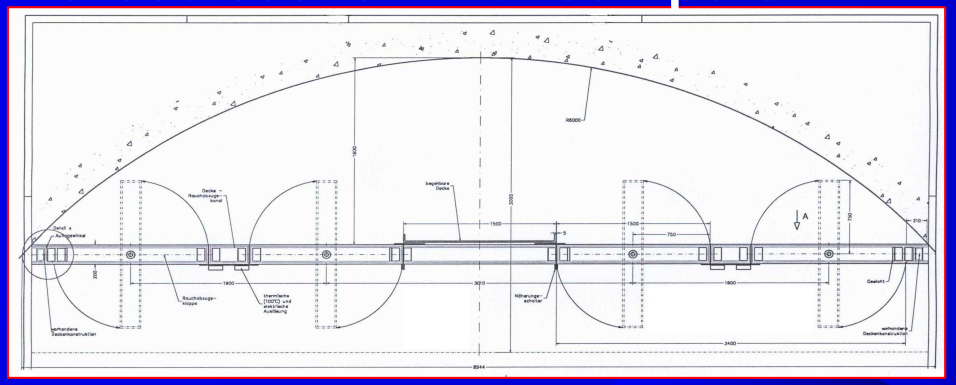
# 4. Combined Longitudinal Ventilation with Spot Extraction (Elbtunnel design by WITT & SOHN)

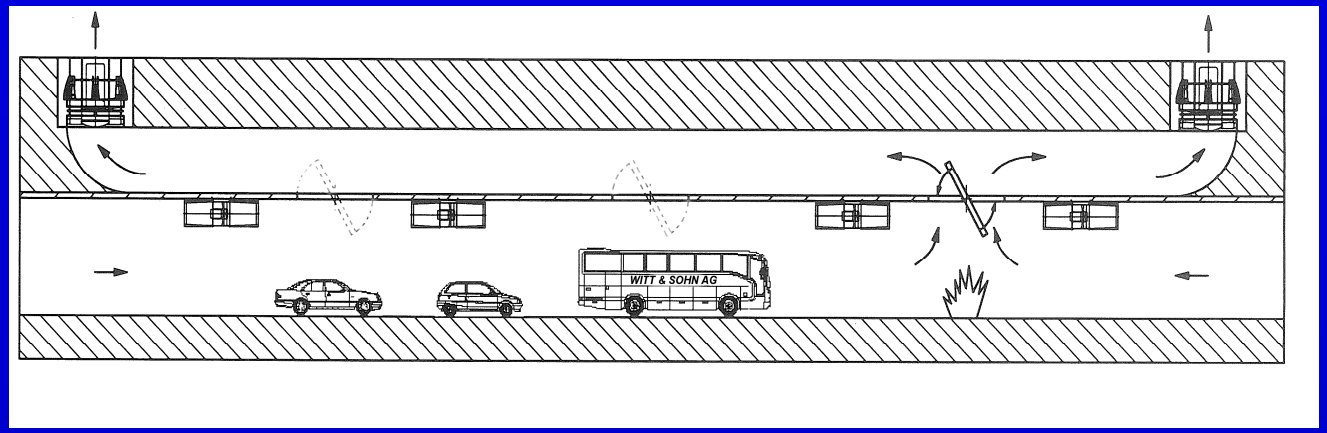
**Cross-section with jet fans**



**Cross-section with dampers**



**Longitudinal section**




- ⊖ **expensive**
- ⊕ **toxic concentration held constant**
- ⊕ **in fire case smoke is been extracted at spot of fire**

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# 3. Design Calculation

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- Tunnel Design Procedure:
  a) Determination of Volume Flow
     - Normal/ Congestion Case (→ PIARC)
     - Fire Case (→ Fire Size + FROUD)
     → Maximum Air Speed
  b) Determination of Total Tunnel
     - Pressure Drop and
     - Thrust
  c) Determination of Jet Fan Thrust and Quantity

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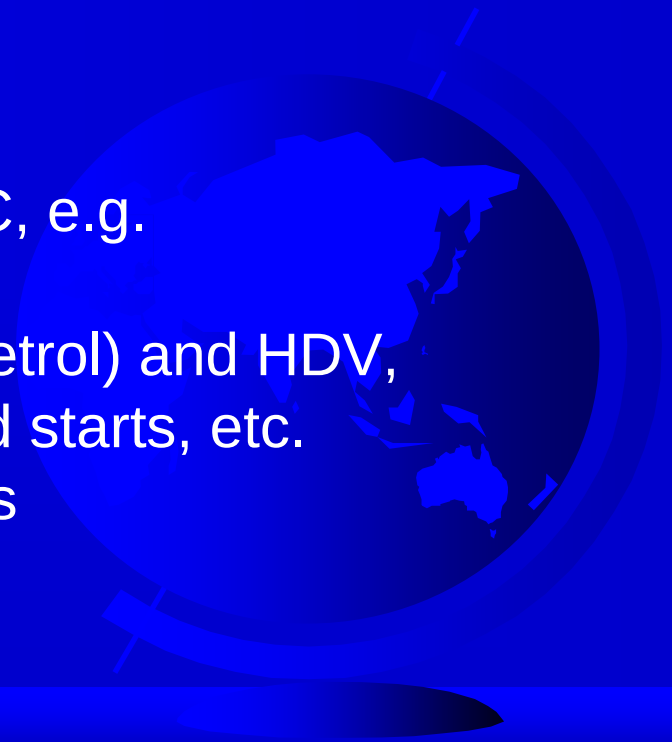
# a) Volume Flow acc. to PIARC

(Permanent International Association of Road Congresses)

$$Q_{PIARC,\ required} = \frac{M \cdot L}{V} \cdot q(v,i,h,t) \cdot \frac{1}{C_{adm} - C_{amb}}$$

M := traffic flow
L := length of tunnel
V := speed of cars
q → please refer to various tables in PIARC, e.g.
- traffic load and composition
- toxic gas emission of PCU (Diesel/ Petrol) and HDV,
- factors for aging, tunnel gradient, cold starts, etc.

$C_{adm}$ := admissible concentration of toxic gases
$C_{amb}$ := ambient concentration of toxic gases



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# PIARC (sample tables)

Table 2.2

| | | Average peak traffic density (pcu/km) or traffic flow (pcu/h) per lane | | | |
|---|---|---|---|---|---|
| | | RURAL TUNNEL | | | |
| | | uni-directional traffic | | bi-directional traffic | |
| | V [km/h] | pcu/km | pcu/h | pcu/km | pcu/h |
| fluid traffic | 60 | 30 | 1 800 | 23 | 1 400 |
| congested traffic | 10 | 70 | 700 | 60 | 600 |
| stoppage | 0 | 150 | 0 | 150 | 0 |
| | | URBAN TRAFFIC | | | |
| | | uni-directional traffic | | bi-directional traffic | |
| | V [km/h] | pcu/km | pcu/h | pcu/km | pcu/h |
| fluid traffic | 60 | 33 | 2 000 | 25 | 1 500 |
| congested traffic | 10 | 100 | 1 000 | 85 | 850 |
| stoppage | 0 | 165 | - | 165 | - |

table 1:

Passenger Car Units per lane, km and hour

| Traffic situation | CO-concentration | | Visibility | |
|---|---|---|---|---|
| | Design year dimensionnement | | Extinction coefficient K | Transmission s (beam length: 100 m) |
| | 1995 | 2010 | | |
| | ppm | ppm | 10-3 . m ' | % |
| Fluid peak traffic 50 - 100 km/h | 100 | 70 | 5 | 60 |
| Daily congested traffic, standstill on all lanes | 100 | 70 | 7 | 50 |
| Exceptional congested traffic, standstill on all lanes | 150 | 100 | 9 | 40 |
| Planned maintenance work in a tunnel under traffic | 30 | 20 | 3 | 75 |
| Closing of the tunnel | 250 | 200 | 12 | 30 |

table 2:

concentration limits for CO, smoke and $NO_x$

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a) Volume Flow acc. to FROUD

(dimensionless key number)

Estimation based on:

- Fire Size
- Tunnel Geometrie
- FROUD Number

→ Max. required Volume Flow:
PIARC ⇔ FROUD

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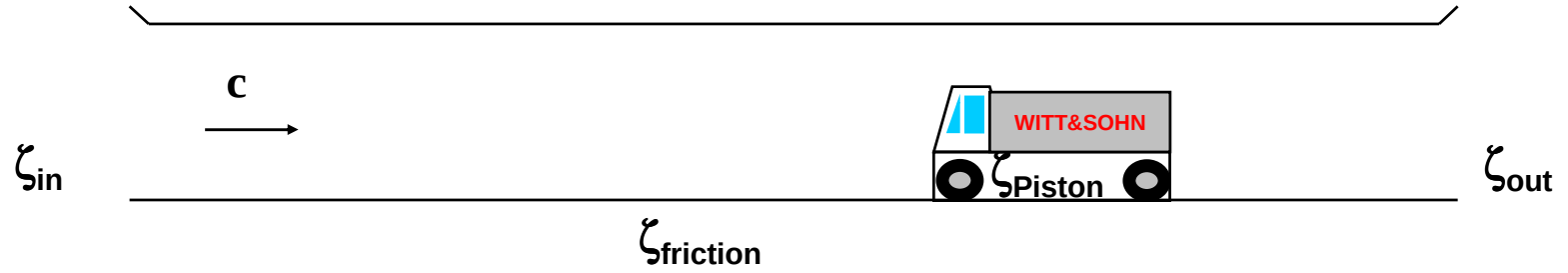
# b) Total Tunnel Pressure Drop + Thrust:




$$\Delta p_{total} = (\zeta_{in} + \zeta_{friction} + \zeta_{piston} + \zeta_{out}) \cdot \Delta p_{dyn}$$

$$= \left( 0.3 + \frac{k \cdot l}{d_h} + f\left( n_{cars} ; \frac{PCU}{HDV} \right) + 1.0 \right) \cdot \Delta p_{dyn}$$

with $$\Delta p_{dyn} = \frac{\rho}{2} \cdot c^2 = \frac{\rho}{2} \cdot \left( \frac{Q_{PIARC\ /\ FROUD}}{A_{Tunnel}} \right)^2$$

$$T_{total,\,tunnel} = \Delta p_{total} \cdot A_{tunnel} \cdot (1 + \nu_{Kempf} + \nu_{back})$$

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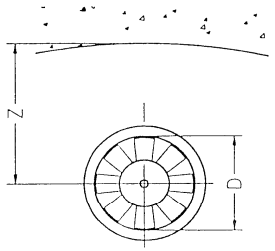
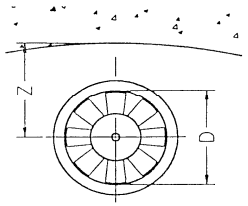
# Kempf (**survey values**)

Ⓐ Friction loss



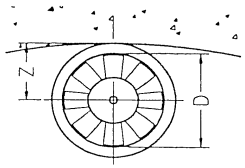

$\frac{Z}{D} = 1.5$

$T_{net} \cong T_{jet} \times 0.91$




$\frac{Z}{D} = 1.0$

$T_{net} \cong T_{jet} \times 0.87$




$\frac{Z}{D} = 0.7$

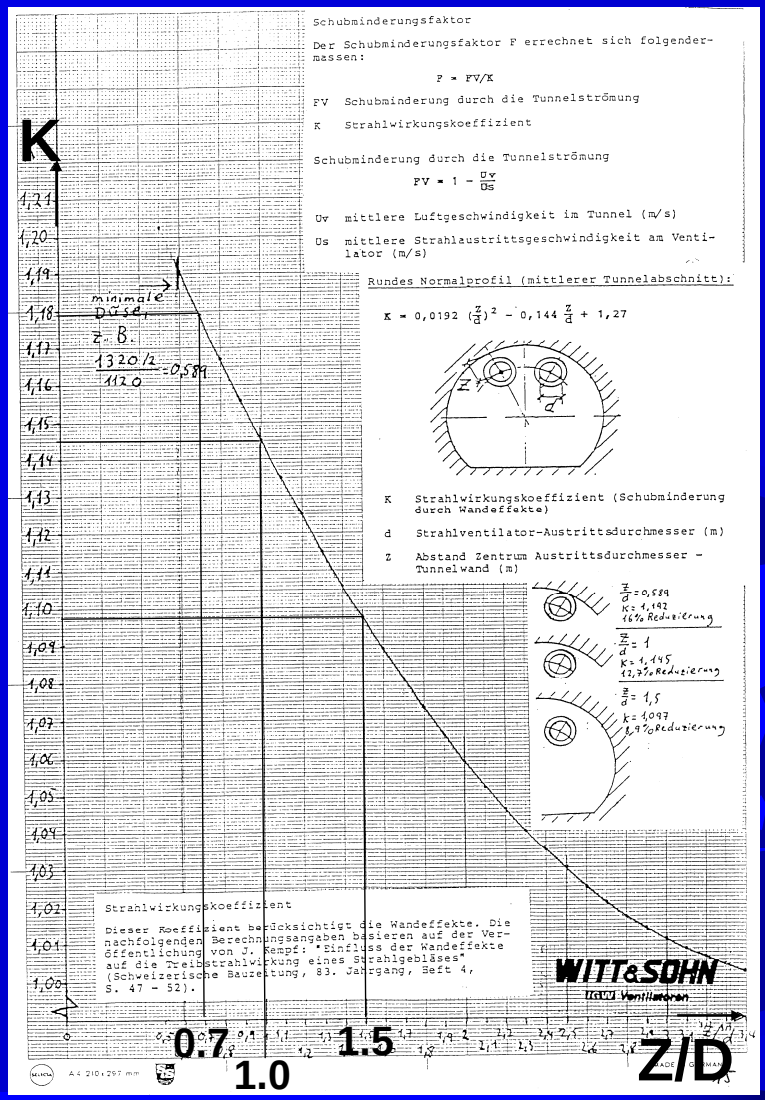
$T_{net} \cong T_{jet} \times 0.85$

Wall friction diagram ⇒

$$T_{net} \cong T_{jet} \cdot \nu_k$$

$$\nu_k = \frac{1}{K}$$

$$K = f\left(\frac{Z}{D}\right)$$ ⇒



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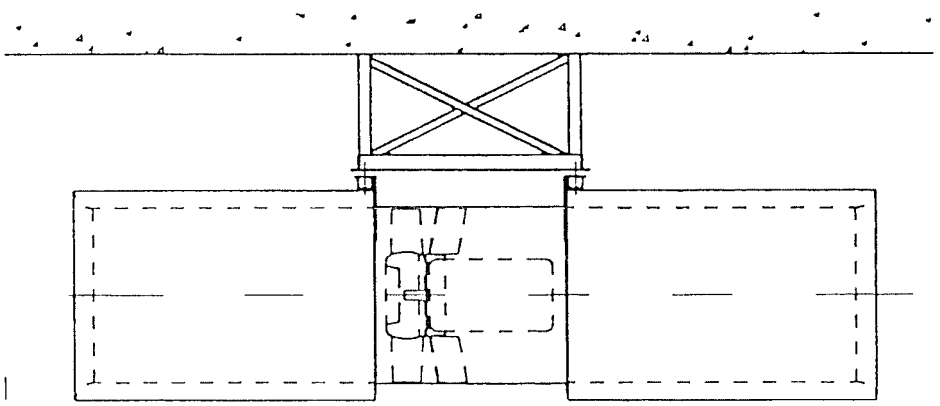
# Background velocity

Ⓑ Background velocity loss



Air speed inside tunnel ( $v_{tunnel}$ )

Thrust ( $T_{jet}$ )
Outlet velocity ( $v_{jet}$ )

$$T_{net} = T_{jet} \times \left(1 - \frac{v_{tunnel}}{v_{jet}}\right)$$

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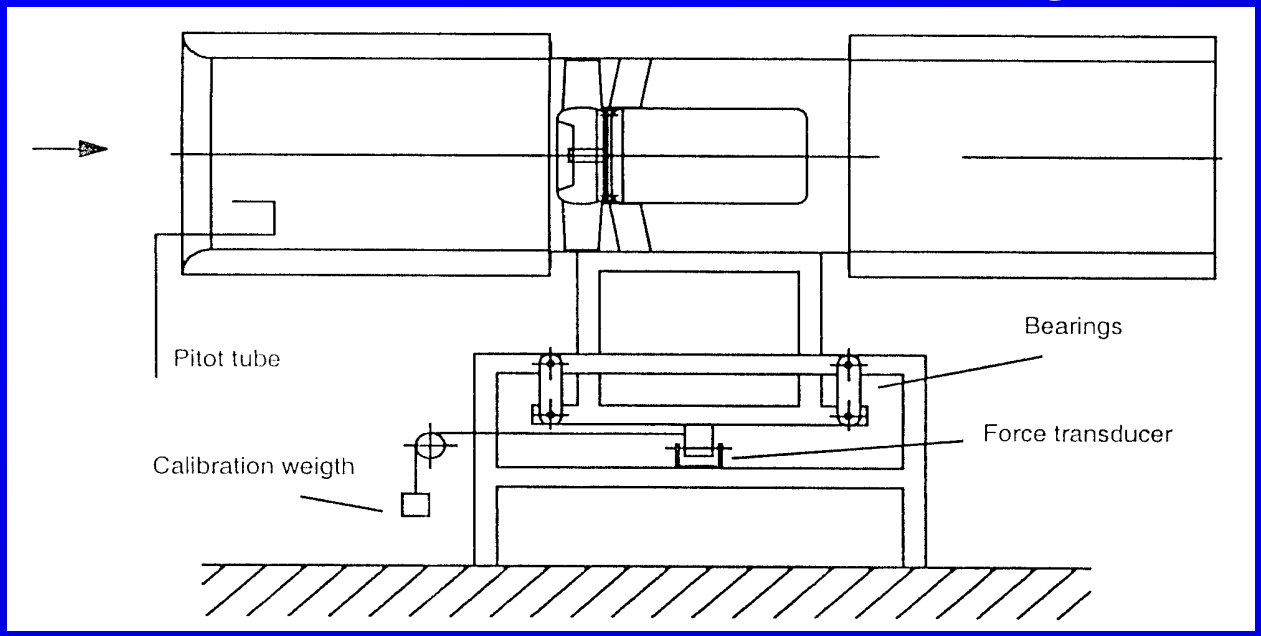
# c) Jet Fan Thrust and Quantity




Test Rig:

→ $T_{static}$

→ Jet-Selection databased

Quantity of Jet Fans required :

$$n_{jet\ fans} = \frac{T_{total,tunnel}}{T_{static}} \cdot f_{Safety} \qquad \Rightarrow f_{Safety} = 1.05..1.15$$

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# 4. Summary

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- Tunnels increasing worldwide
- 4 Tunnel Ventilation Types
  - (Longitudinal, (Semi-) Transverse, Elbtunnel)
- Calculation of
  - required Tunnel Volume Flow → PIARC
  - Tunnel Pressure Drop and
  - Total Tunnel Thrust
- Determination of required Quantity of Jets

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# Innovation in Fan Technology