Simplified method for longitudinal ventilation system design in fire situations

Del Rey, Fernandez, Fraile, Espinosa
Dimensioning of longitudinal ventilation systems

1. The most usual case (two tubes unidirectional tunnels)
2. A very well known problem (at least for single tube)
3. Easy to formulate (one-dimensional approach)

Consequently …

Different designers should come up with very similar solutions (number of jet fans)
Simplified method for longitudinal ventilation system design in fire situations

Or not
What regulations in Spain say (RD635/2006):

2.11.4 Los sistemas de ventilación deberán poder extraer el humo para un incendio tipo con potencia mínima de 30 MW y caudal mínimo de humos de 120 m$^3$/s.

Ventilation systems should be able to control the smoke according to a minimum design fire of 30 MW and minimum air flow rate of 120 m$^3$/s.
What can construction companies and designers do?

- Ask the fan supplier to provide calculations
- Apply methodologies from other countries

RVS 09.02.31 (Austria)
Dossier Pilote du ventilation (CETU)
ASTRA 13 001 (Switzerland)

Systems and equipments for fire and smoke control (PIARC)
The general criteria are clearly defined

- (Prescriptive) target velocity
  (typically 3 m/s but 4 m/s in France for DG fires)

- Balance equation for pressure differences
  (selection of worst case scenarios)

\[
\Delta P_{\text{fans}} \geq \Delta P_{\text{vehicles}} + \Delta P_{\text{losses}} + \Delta P_{\text{chimney}} + \Delta P_{\text{meteor}} + \Delta P_{\text{blockage}}
\]

AND…

Simplified method for longitudinal ventilation system design in fire situations
Influence of temperature

- Through the chimney effect induced by the slope
- on the jet fans reliability and efficiency

Source: Systems & equipments for fire and smoke control
PIARC 2007
Calculation of pressure losses due to the fire:

Fire loads and their influence on ventilation design:
A simple model for use in regulations

P Sturm, M Bacher, M Beyer
Graz University of Technology,
Institute for Internal Combustion Engines and Thermodynamics, Austria

B Höpperger, J Croll
ILF Consulting Engineers, Austria

The aerodynamic calculations to be carried out for longitudinal ventilation systems comprise the items mentioned in the last section and the calculation of flow losses in the tunnel taking into consideration specific structural characteristics and installed elements (such as traffic signs, niches, portals, surface roughness, etc.).

In addition, it must be taken into account that in the presence of smoke the effective thrust of jet fans decreases due to the increase in temperature. The jet fans must be arranged in such a way that they do not influence each other. If this cannot be pre-
Influence of temperature on effective thrust of jet fans

\[ F_j = \Delta p_j \cdot A_T = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \rho_0 \cdot Q_j \cdot \left( \frac{T_0}{T} \right) \left( u_j - u_0 \right) \]

Source: Systems & equipments
PIARC 2007

Thrust Reduction

Temperature rise (K)

- \( V = 0 \, \text{m/s} \)
- \( V = 1 \, \text{m/s} \)
- \( V = 2 \, \text{m/s} \)
- \( V = 3 \, \text{m/s} \)
- \( V = 4 \, \text{m/s} \)
Inter-ministry circular 2000-63. Appendix 2

A reduction in fan performance when operating in hot air must be taken into account, as also loss of the fans which will be destroyed by heat (see section 4.4.2.a). In tunnels more than 800 m long dimensioning will be based on calculation of these two effects. In tunnels less than 800 m long it is not generally possible to comply strictly with the condition above. These two effects can then be taken into account by increasing the thrust deriving from the abovementioned paragraphs by a figure of 30% in tunnels less than 500 m long and by 50% in other circumstances.

Dossier Pilote du ventilation du CETU

- Detailed description of methodology (different fire locations)
  - By verification (of effective thrust is enough)
  - By calculation of the air velocity achieved

- Simplified criteria:
  - L<500 meters: total thrust increased by 30%
  - 500<L<800 meters: total thrust increased by 50%
  - L>800 meters: detailed calculations
Verification for each fire location.

\[
\sum_{n=1}^{\text{num jetfans}} \Delta P_n \geq \Delta P_{\text{losses}} + \Delta P_{\text{vehicles}} + \Delta P_{\text{chimney}} + \Delta P_{\text{meteorol}} + \Delta P_{\text{fireblockage}}
\]

\[
\Delta P_n = \frac{\eta_{\text{inst}} \cdot F_{\text{nom}}}{S_{\text{fan}}} \left(1 - \frac{V_{\text{crit}}}{V_{\text{jet}}} \cdot \frac{T(x)}{T_{\text{amb}}} \cdot \frac{T_{\text{amb}}}{T(x)}\right)
\]

Simplified method for longitudinal ventilation system design in fire situations
Calculation of the air velocity achieved

![Graph showing air velocity over time]
What ‘big fires’ are?
Example of the influence of the DESIGN FIRE LOAD

- 200 MW – 4m/s
- 200 MW – 3m/s
- 100 MW – 4m/s
- 100 MW – 3m/s
- 30 MW – 3m/s

Simplified method for longitudinal ventilation system design in fire situations
Design fire selection.

If a number has to be thrown out on design fire heat release rate of road tunnel ventilation systems, what is it (in MW) or the closest?

- 5
- 10
- 20
- 40
- 50 or higher

Votar
Dimensioning of longitudinal ventilation systems

1. The most usual case (two tubes unidirectional tunnels)
2. A very well known problem (at least for single tube)
3. Easy to formulate (one-dimensional approach)

However…

Again to decide on the value of HRR to be considered
(and even more other parameters as heat transfer coefficient)

Sophisticated methodologies are available but:
- ‘Black box’ feeling to the results given by designers
- Require more expertise in ventilation
Interest of a simplified method:

- Unnecessary to use transient 1D models
- Large but simple arithmetic formula
- Easy to use for parametric studies
- Use of coefficients depending on relevant parameters (HRR, Tunnel Length and/or position of fire)

Some assumptions are inherent: Uniform spacing between jet fans (but the coefficients could be reformulated for other arrangements)
Simplified method for longitudinal ventilation system design in fire situations

IGNACIO
DEL REY

Parametric study for different scenarios + numerical fitting

Coefficients as functions of HRR, Tunnel Length, and Fire location (%)

\[
coef_1 = \frac{1}{L} \left[ \int_0^{x_{inc}} \frac{T_x}{T_0} \, dx + \int_{x_{inc}}^{L} \frac{T_x}{T_0} \, dx \right] 
\Rightarrow
coef_1 = \left[ L + \frac{K}{B} (1 - e^{B(x_{inc}-L)}) \right] \cdot \frac{1}{L}
\]

\[
coef_1 = 1 + 5.67 e^{-0.03} (\dot{Q}) - 1.63 e^{-0.06} (\dot{Q} \cdot L) - 5.07 e^{-0.03} (\dot{Q} \cdot X_{inc}) + 2.79 e^{-0.06} (\dot{Q} \cdot L \cdot X_{inc})
+ 1.58 e^{-0.10} (\dot{Q} \cdot L^2) - 6.13 e^{-0.04} (\dot{Q} \cdot X_{inc}^2) - 3.24 e^{-0.10} \cdot (\dot{Q} \cdot L^2 \cdot X_{inc})
- 1.11 e^{-0.06} (\dot{Q} \cdot L \cdot X_{inc}^2) + 1.64 e^{-0.10} (\dot{Q}^2 \cdot L^2 \cdot X_{inc}^2)
\]
Reasonable good approximation against the complete method

75600 cases
- Cross section
  (65-100 m²)
- Tunnel length
  (500-300 m)
- Tunnel slope
  (-3, +3%)
- Air velocities
  (3-6 m/s)
- HRR
  (5-200 MW)
- 50 Fire positions
(First) Conclusions:

A simplified method for dimensioning of longitudinal ventilation for unidirectional tunnels is presented, which could be of help for:

• Estimation of installed power
• Preliminary calculations

And last but not least…

The use of this simplified methodology ‘opens the door’ to more sophisticated approached: probabilistic methods
Definition of relevant criteria as random variables
Definition of relevant parameters as random variables

Simplified method for longitudinal ventilation system design in fire situations
Definition of safe regions (i.e. safety margin, $F(X) > 0$)

$$F(x) = \Delta P_{\text{fans}} - (\Delta P_{\text{vehicles}} + \Delta P_{\text{losses}} + \Delta P_{\text{chimney}} + \Delta P_{\text{meteor}} + \Delta P_{\text{blockage}})$$

![Graph showing the relationship between fire position and differential pressure.](image)
Under a deterministic approach, the number of jet fans to be installed should be able to provide in the worst case $F(x) > 0$ ($P_f=0$).
Under a probabilistic approach, the cumulative distribution function for the Safety margin can be obtained for different number of fans installed.
Then, probability of failure can be used as a criteria which helps to avoid over-dimensioning of the ventilation system.
Final conclusions:

- The selection of the Design Fire seems to be an issue already unsolved even for “easy” longitudinal ventilation systems.
- Adopted solutions are strongly dependant of designer hypothesis.
- The utilization of probabilistic approaches could help to avoid the over-dimensioning of the ventilation systems (worst fire size, meteorological conditions, fire location, etc).
Simplified method for longitudinal ventilation system design in fire situations