HØGSKOLEN STORD/HAUGESUND

Numerical study of downscaling the Runehamar tunnel fire test

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Assignment text:

In the later years there has been an increase in the number and complexity of tunnels built which is questioning the fire hazard. The ability to use numerical tools in fire risk assessment in tunnels is important due to the expensive, time-consuming and difficult nature of full-scale experimental fire testing.

The motivation for this thesis is to study the feasibility of downscaling tunnels using computational fluid dynamics (CFD). This may give an indication if downscaling is also appropriate in full-scale experimental fire testing. Experimental test data from the Runehamar case study will be compared to numerical simulations using the open source CFD code, Fire dynamics simulator (FDS) version 6.1.

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Numerical study of downscaling the Runehamar tunnel fire test			*(Fylles ikke ut)*
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In Norway, tunnels occupy approximately 800 km of the road. More tunnels are being built every year, and demands for sufficient safety is increasing with it.

A numerical study was conducted. Runehamar fire test tunnel was chosen as the tunnel of interest. Simulations were conducted using the parameters as the experimental data, and scaled with the Froude number. The tunnel was scaled down, 65%, 15% and 5%.

Grid sensitivity was measured by refining the grid and comparing the results. Another method used was, measured turbulence resolution (MTR) using smokeview. The first grid sensitivity test did not reach full convergence, only MTR showed promising results. Despite not reaching convergence, the overall results from the full-scale experiment were in agreement with the experimental test data.

The study suggested that scaling down less than 65% would lead to underestimated results, due to how radiation is scaled.

Preface

This assignment signifies the end of a three years bachelor's degree in fire safety at Høgskolen Stord/Haugesund. Time available was from Januar until May, and amounts to twenty credits, consisting of this report and a product.

Our goal is to develop a better understanding of simulations of tunnels. This means going into areas which has not been a subject in our syllabus. Gaining new knowledge around a subject which is both interesting and relevant for future work, was motivational. Working on this assignment has given us a better understanding of tunnel fire safety and of computational fluid dynamics.

We owe a special thanks to our guidance supervisors: David Rene Ursin Johansen for his endless eagerness in counseling and motivation, without, the assignment would not be possible. And Jon Arild Westlund providing insigth in an engineering point of view and advise surrounding the simulations.

I (Daniel) would like to thank my parents and girlfriend, Oddvin Kinden, Åse Stavland Kinden and Nathalie Bremerthun Hansen for their support and motivation during this study.

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Abstract

An increase in tunnels in Norway, have brought forth a higher demand for safety measures, amongst others, fire safety. Experimental fire safety data from tunnels that contributes to solving engineering problems with low cost and availability is therefore important. Main objective in this assignment is to determine, the possibility of using downscaled tunnels to conduct experimental research in fire safety and conducting a grid-sensitivity analysis, using numerical calculations.

Runehamar fire test tunnel is the comparable object in this study, mainly because of the experimental data available. The data contained measurements of temperature, velocity, heat release rate (HRR) and visibility. The simulations were performed in full-scale, 65%, 15% and 5%-scale.

Previous research done on scaling of a tunnel in simulation, suggest Froude scaling. A technique where HRR, velocity, time, energy and mass is scaled to a dimensionless unit by preserving the Froude number.

Fire Dynamics Simulation (FDS) is an open source software, often used in fire-research. FDS is known all over the world in engineering communities and is a well-validated tool for fire simulation [1]. The tunnel was simplified by making the cross-section rectangular (instead of oval), and shortened until 100 meters upstream from the fire. A fan, with an airflow of 3 m/s, replaced the opening at the 100 meters mark. The domain surrounding the west portal was extended 25 meters with open boundaries. After several tests with different HRR, the chosen fire was a 2,27 m in diameter diesel fire corresponding to 6 MW.

The grid sensitivity criteria was conducted by two different approaches. The first is a method of checking if convergence occur, by refining the grid cell and comparing the results, similarities give convergence. The second is a measure of turbulence resolution (MTR).

Basically by using smokeview, a software that enables the user access to view the simulation, the resolved and unresolved turbulence can be observed. First method of convergence testing gave poor results, unable to reach full convergence. MTR however, gave promising results, resolving over the limit criteria for LES.

Comparison of temperature results in full-scale simulation and experimental data from the Runehamar tunnel test, show good results. However, there are some overestimations in the full-scale simulation. Furthermore, the scaled simulations follow a similar pattern of underestimating the results for every downscaling. Occurring when the tunnel is scaled lower than 65 %, and may be a result of radiation scaling. This study suggests that scaling down more than 65 % leads to underestimated results.

Nomenclature

A	Area of radiation origin	[m]
A_f	Area of pool (fire)	[m^2]
c_p	Thermal capacity	[kJ/K]
D	Diameter of the pool	[m]
D_f	Diameter of the flame	[m]
D*	Characteristic fire diameter	[-]
dx	Grid cell	[-]
dx	Distance	[m]
ϵ	Emissity of the flame	[-]
ϵ_g	Emissivity of the walls	[-]
ϵ_w	Emissivity of the walls	[-]
f	External forces	[N
F_g	View-factor of the gaseous smoke	[-]
F_w	View-factor from the walls	[-]
g	Gravitational acceleration	[m/s^2]
H	Height of tunnel	[m]
$\Delta H_{c,eff}$	Efficient heat of combustion	[kJ/g]
ΔH_c	Heat of combustion	[kJ/g]
H_{eff}	Height from fire source to ceiling	[m]
h	Enthalpy of the fluid	[kJ]
κ	Thermal conductivity	[kW/mK]
$\kappa\beta$	Empirical constant	[-]
L	Length of backlayering	[m]
L_f	Length of flame	[m]
$L_{f,ds}$	Length of downstream flame (high ventilation)	[m]
L_f^*	Dimensionless $L_{f,ds}$	[-]

L_g	Surface temperature of the fire	[K]
m	Mass	[m]
$\dot{m}''$	Mass flux rate	[kg/m^{2}s]
$\dot{m}_{\alpha}'''$	Mass production/destruction of species	[kg/m^{3}s]
η	Mole fraction	[-]
σ	Stefan-Boltzmann constant	[kW/m^{2}K^4]
ρ	Density	[kg/m^3]
∇p	Pressure gradient	[N/m^2]
$\dot{Q}$	Heat Release Rate	[kW]
$\dot{Q}_{max}$	Max Heat Release Rate	[kW]
Q^*	Dimensionless Heat Release Rate	[-]
Q_f^*	Dimensionless Heat Release Rate	[-]
$\dot{q}_x$	Heat flux	[kW/m^2]
$\dot{q}_r$	Radiation (1- dimensional)	[kW]
$\dot{q}''$	Tunnel radiation	[kW/m^2]
$\dot{q}_f''$	Radiation from the flame	[kW/m^2]
$\dot{q}_g''$	Radiation from the gaseous smoke	[kW/m^2]
$\dot{q}_{rr}''$	Radiation from the fuel surface	[kW/m^2]
$\dot{q}_w''$	Radiation from surrounding geometry	[kW/m^2]
$\dot{q}'''$	Volumetric HRR	[kW/m^3]
ΔT	Temperature difference	[K]
T_f	Temperature of the flame tip	[K]
T_0	Initial temperature of the surroundings	[K]
T_∞	Ambient temperature	[K]
T_g	Temperature of the gaseous smoke	[K]
T_w	Temperature of the walls	[K]
τ	Viscous stress tensor	[Pa]
u_0	Longitudinal air velocity	[m/s]
$u_{0,tp}$	Longitudinal velocity at transient point	[m/s]

u_{tp}^{*}	Dimensionless ventilation velocity	[-]
$\dot{V}$	Volumetric air-flow	[m^3/s]
V	Longitudinal velocity	[m/s]
∇	Vector notation	[-]
χ	Combustion efficiency	[-]
Υ_{α}	Mass fractions of gaseous species	[-]

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1 Introduction

According to the Norwegian Public Roads Administration (Statens Vegvesen) there are approximately 1000 tunnels in Norway that covers a distance of 800 km. Daily averaged traffic passing highway tunnels in Norway is 5000 cars [2]. The amount will only increase accordingly as the number of tunnels increase. The tunnels come in different sizes, altitudes and car capacities. They are built up in the mountains and deep under the seabed.

One important factor that has to be considered when building tunnels is fire safety. Several methods of studying fire behaviour in tunnels are available. Real life experiments using a full size tunnel, making a scaled model or conducting a computational simulation.

Tunnels are built with an increase in complexity and length, making it difficult to perform fire tests in an existing tunnel. An example being, Rogfast, the world's longest subsea tunnel (26,7 km) and greatest in depth (390 m), will be built in Norway [3]. A solution to this problem may be Computational Fluid Dynamics (CFD) by simulating fires in tunnels to determine the fire safety. If this can be effectively performed this will lead to cost-efficiency and increase the availability to do tests like this.

1.1 Objective

In Norway, fire safety is important when building tunnels. The reason for this being that tunnel fires have caused and are capable of causing huge incidents, worst case scenario, loss of life. For example, in Oslofjordtunnel (2011) two fires occurred only two months apart, Gudvangatunnel (2013) and Follo (2009) leading to one fatality [4]. Data regarding fire behaviour in tunnels is required to meet these demands. The availability for testing and research in fire safety is limited. There are not many tunnels in Norway that has the possibility for full-scale experiments, and building a full size model tunnel will be problematic, because of high cost and space.

The objective of this study is to try to determine if it is possible to perform fire simulation in a tunnel at full-scale and if they can be downscaled to a more convenient size for testing. By comparing results from several downscaled simulations in FDS and data from the Runehamar Tunnel Fire Tests, the applicability of scaling and full-scale simulations will be studied.

2 Theory

The basics of fire dynamics, including tunnel fire dynamics are described in the following sub-chapters.

2.1 Basic fire dynamics

Fire is defined as a state, process, or instance of combustion in which fuel of other material is ignited and combined with oxygen, giving off light, heat, and flame [5]. In order for a fire to take place; three things are needed: Combustible material, high temperatures, oxygen and a chain reaction between these three components [6].

Fire has three distinct ways to transfer its destructive power figure 1 shows a simple illustration of the three modes of heat transfer. The different modes of heat transfer are: heat-conduction, -convection and -radiation. Conduction that is heat transfer through solids can be explained by the fact that an entire steel rod gets hot even though only the tip is inside the fire. Conduction is the main reason fire spreads through walls. Convection that is heat transfer through fluids is what heats the gases surrounding the fire. Radiation or electromagnetic heat transfer is the reason one cannot hover your hand over a fire for too long without pain. Radiation is what makes a compartment flashover, because the smoke irradiates floors and walls.

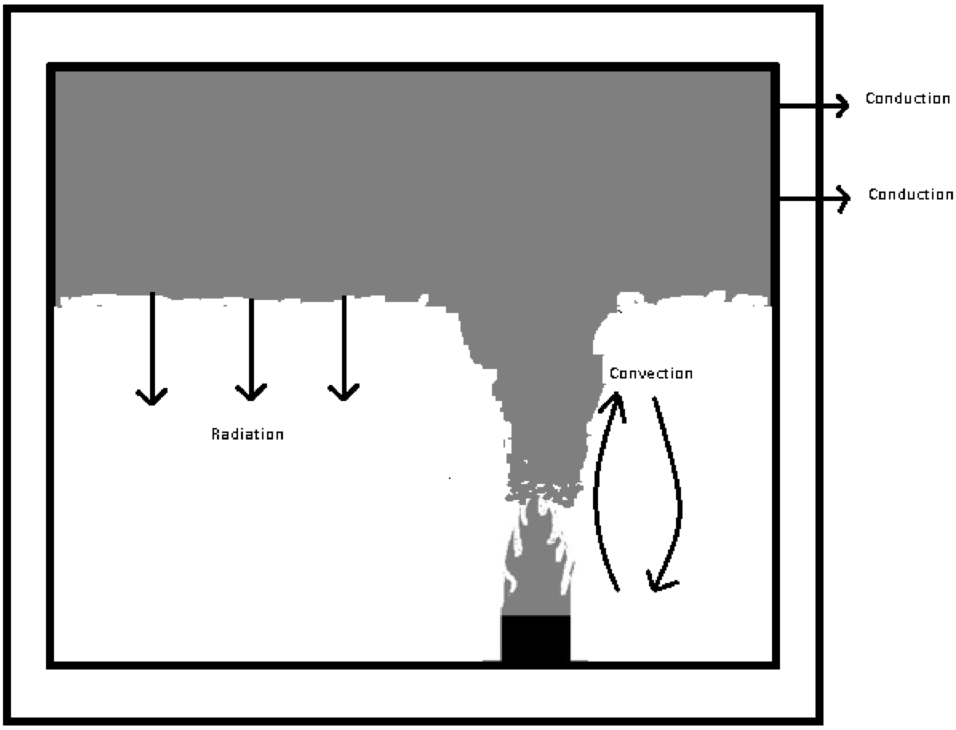


Figure 1 Types of heat transfer

Fires can occur anywhere, in the open, inside houses, in cars and naturally in tunnels. Depending on the environment the fire habituates, it behave in different ways.

2.2 Tunnel fire dynamics

Most of the information in this sub-chapter is acquired from Tunnel Fire Dynamics by Haukur Ingason, Ying Zhen Li and Anders Lönnermark [4].

Tunnel fires are normally fuel-controlled; there are usually no restrictions on air access. Normally there are two openings in tunnels, which act as communicating spaces if no mechanical ventilation is installed. The air-supply to the fire is due to the pressure differences between the fire gases and atmosphere. Studies have also shown that the pressure difference at the portals could have influence over the air-supply [4].

2.2.1 Characteristics of tunnel fires

There is a difference between fires in the open/buildings and fires in tunnels. Two important factors differ when studying fires in tunnels, versus free-burning fires [4]:

- Heat feedback from the surrounding environment
- Effect of natural ventilation on the fire

The determining factor for heat feedback to free-burning fires is the volume of the flame. I.e. only the fire can transmit heat to the fire, since no geometry is enclosing the fire. Fundamentally, this can be explained by the equation for one-dimensional radiation from/to an object:

$$\dot{q}_r = A\epsilon\sigma\mathrm{T}^4 \qquad \textbf{\textit{(1)}}$$

Where:

ϵ is the emissivity of the flame

σ is the Stefan-Boltzmanns constant

A is the area of the object radiation, in this case the fire

ΔT the difference in temperature between object and surroundings

Since equation 1 describes one-dimensional radiative heat transfer, considering three-dimensional heat flux, the volume is taken into account instead of just the area.

In tunnels, the lining of the walls, cross-sectional area and ventilation needs to be taken into consideration as well. It is not satisfactory to consider just the flame, as the surrounding geometry and smoke contributes heat feedback to the fire as well. The following equation and figure 2, shows what to take into consideration when determining the heat feedback from a tunnel fire:

$$\dot{q}'' = \left(\dot{q}_f'' + \dot{q}_g'' + \dot{q}_w'' - \dot{q}_{rr}''\right) \cdot \frac{\Delta H_{c,eff}}{L_g} \qquad \textbf{\textit{(2)}}$$

Where:

$\dot{q}_f''$ is the radiation from the flame

$\dot{q}_g''$ is the radiation from the hot smoke gasses

$\dot{q}_w''$ is the radiation from the surrounding geometry

$\dot{q}_{rr}''$ Backwards radiation from the fuel surface

$\Delta H_{c,eff}$ Is the efficient heat of combustion

L_g Is the surface temperature of the fire

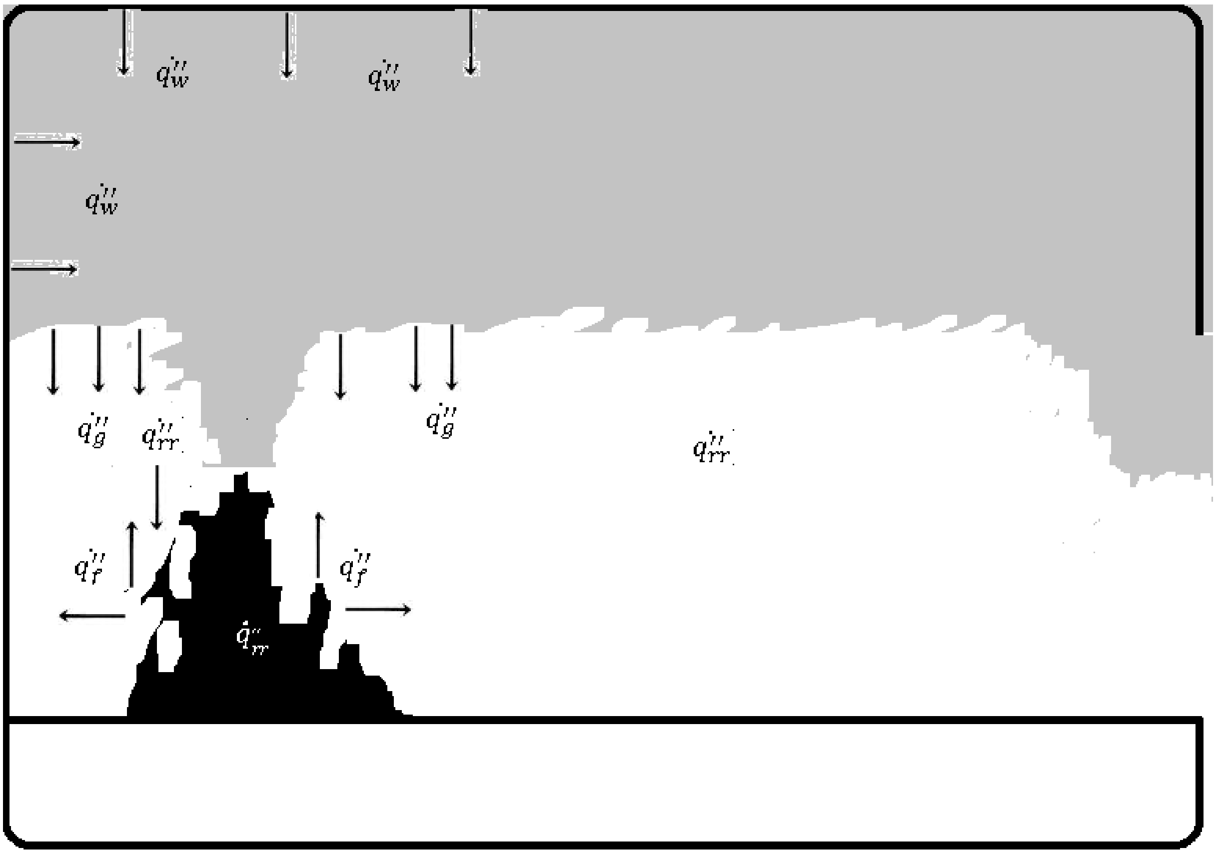


Figure 2 Balance of radiation heat transfer

Radiation from the hot smoke gasses illustrated in figure 2, can be found using the following equation:

$$\dot{q}_g'' = F_g \epsilon_g \sigma T_g^4 \tag{3}$$

And from/to the surrounding geometry:

$$\dot{q}_w'' = F_w \epsilon_w \sigma T_w^4 \tag{4}$$

Where:

ϵ is the emissivity of the flame

σ is the Stefan-Boltzmanns constant

F is the view-factor

ΔT the difference in temperature between object and surroundings

The subscripts w and g stands for walls and gas respectively.

Equations 2, 3 and 4 describes radiation, but there will be some heat loss to the surrounding geometry caused by conduction through the walls. Fourier's law, the law of heat conduction, is a simple equation describing the amount of heat transferred by conduction:

$$q_x = -\kappa \frac{dT}{dx} \tag{5}$$

Where:

q_x is the heat flux

κ is the thermal conductivity

$\frac{dT}{dx}$ is the temperature gradient

From equation 5 it is discernible that κ is an important variable in this equation. Thermal conductivity describes a materials ability to transfer heat through itself [7].

Table 1 Examples of thermal conductivity

Material	Thermal conductivity [W/m,K]
Concrete	0.8
Glass	0.8
Steel	50.2
Wood	0.12-0.04 (Depending on the humidity)

Table 1 gives examples of thermal conductivity, in order to provide some perspective of how this value differs in materials. By using materials with higher thermal conductivity, the heat transfer increases. Concrete, which is close to the material found in tunnels, has a higher value than wood, which is commonly used in buildings. Higher values of κ, results in more heat being transferred through the corresponding material. There is data available on the thermal conductivity on different kinds of rocks, as this the major component in a tunnel, to determine the κ the geological composition of the tunnel section has to be studied. Most tunnel linings are composed of concrete [8].

The effects of ventilation on fire in tunnels compared to free burning fires are important to note. Ventilation is a crucial factor determining whether a fire is fuel-controlled or ventilation-controlled, as both can occur in a tunnel. Fuel controlled, means that there is enough air supply to sustain the fire through the entire combustion process. Ventilation controlled fires occur when there is a lack of air.

If the volumetric airflow rate is too low, compared to the HRR of the fire, the fire becomes ventilation controlled. On the other hand, if the volumetric flow rate is proportionally higher than the HRR, the fire is fuel controlled. The following equation can predict the max HRR possible, to maintain a fuel controlled fire:

$$\dot{Q}_{max} = \dot{V}\eta\rho\Delta\mathrm{H_c} \qquad \textbf{\textit{(6)}}$$

Where:

$\dot{V}$ Is volumetric airflow per second

η Mole fraction of oxygen in the air

ρ Is the density of the oxygen

ΔH_c Is the combustion efficiency of oxygen

Using regular values for air, this can be written as:

$$\dot{Q}_{max} = 2{,}73V \qquad \textbf{\textit{(7)}}$$

A fire developed in a tunnel will interact with the surrounding walls and the ventilation airflow already present creating complicated airflow patterns and turbulence around the fire. A sloped tunnel will create buoyancy forces along the tunnel that may lead to changes in the flow pattern for the entire tunnel. Given a ventilation velocity of small proportions, the energy contained within the smoke gasses can begin to continuously push the ventilated air backwards creating backlayering. Backlayering is usually avoided by using ventilation to increase the air velocity to 3-3.5 m/s, this results in sufficient force to prevent the smoke gasses from pushing the air backwards [4].

In the case of compartment fires versus tunnel fires, these differ in three important ways [4]:

- The effects of the ventilation factor
- The flashover conditions
- The stratification development

The maximum HRR in a compartment fire is limited by the amount of air being supplied to the fire. Opening areas and the heights of the openings in the compartment determine HRR. In tunnels, HRR is determined differently. Placement of the fire, slope, the cross-sectional area, length and type of tunnel lining material, as well as weather conditions at the openings has to be considered when determining the HRR in tunnels. The amount of air available inside a tunnel is considerably higher than in normal compartments. Mechanical ventilation is very common in longer tunnels, and this creates forced ventilation, which is very uncommon in compartments. Consequences of mechanical ventilation are seen in HRR, combustion efficiency and spread of heat and smoke.

In both tunnels and compartment fires, the possibility of flashover is present. The term flashover is defined as “The rapid transition to a state such that all the surfaces of the combustible materials within a compartment are involved in the combustion [4].” Fires in compartments usually reach flashover within a few minutes. Flashover does not usually occur without the confines of a compartment. This does not, however, seem to be the case with tunnels. The main reason for this is the large heat losses to the surrounding materials, lack of fuel and containment of gasses. In tunnels however, an under-ventilated fire is very much possible in tunnels, and should be given special notice. If a ventilation system is activated during an under-ventilated fire it may affect the fire giving it a sudden increase in size and length, as flammable gasses not yet combusted would suddenly be ignited in the presence of freshly supplied air.

2.2.2 HRR

Fires in tunnels usually start in motorized vehicles, and if the size and type of vehicle is known, it is possible to predict the HRR from statistical values in literature. Typical HRRs for five door cars is between 2 – 6 MW. A bus has a typical HRR between 30 – 35 MW, and for HGVs the HRR can vary from very low, up to as high as 200 MWs depending on what the HGV is carrying. [4]

Given a pool fire in a tunnel, because of a leak from a fuel tank for example, one can determine the HRR using the following equation established by Babrauskas:

$$\dot{q}'' = \dot{m}''\left(1 - e^{-\kappa\beta D}\right)\chi\Delta H_c A_f \tag{8}$$

Where:

$\dot{m}''$ is the maximum value for mass burning rate

$\kappa\beta$ is an empirical constant

χ is the combustion efficiency

ΔH_c is the heat of combustion

A_f is the area of the pool

D is the diameter of the pool.

2.2.3 Tunnel fire ventilation

The European Union's tunnel safety directive describes what shall be taken into account when designing the ventilation system:

- Controlling pollution from road vehicle under normal and peak traffic flow,
- Controlling pollution during an incident of accident,
- Controlling heat and smoke in the event of a fire. [9]

There are three different kinds of ventilation in tunnels: Longitudinal ventilation, transverse ventilation and semi-transverse ventilation.

Longitudinal ventilation

In longitudinal ventilation, the air is forced through the tunnel using jet fans or normal fans. Jet fans are often used in tunnels due to cost efficiency and easy usage compared to making shafts and ventilation tubes. Ventilation of this type consists of groups of jet fans situated along the ceiling, usually two or three fans.

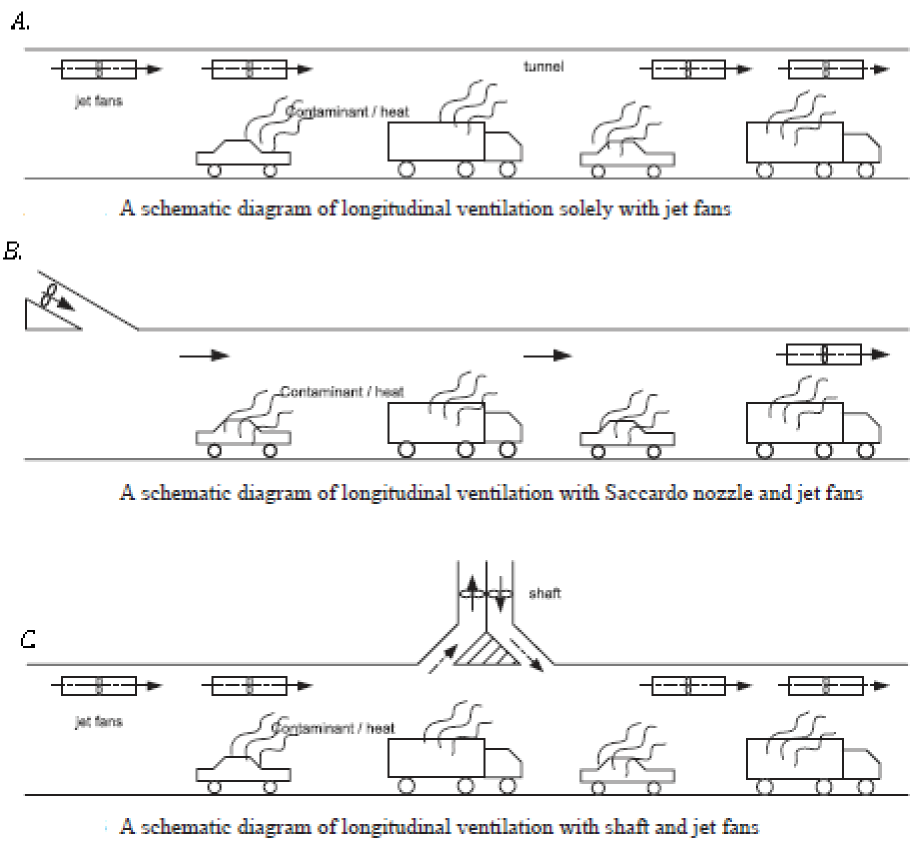


Figure 3 Different schematics showing the types of longitudinal ventilation, adapted from Tunnel Fire Dynamics. [4]

Figure 3 – A shows the most common type of ventilation in tunnels. The air and contaminants are pushed towards the exit longitudinally. This does not eliminate the contaminants, but increases the concentration of contaminants as the flow moves along the tunnel. Heat acts in a very similar way as the contaminants, resulting in a build-up of energy at the end of the tunnel. This means that in case of a very long tunnel, longitudinal ventilation may not be satisfactory. [4]

Transverse ventilation

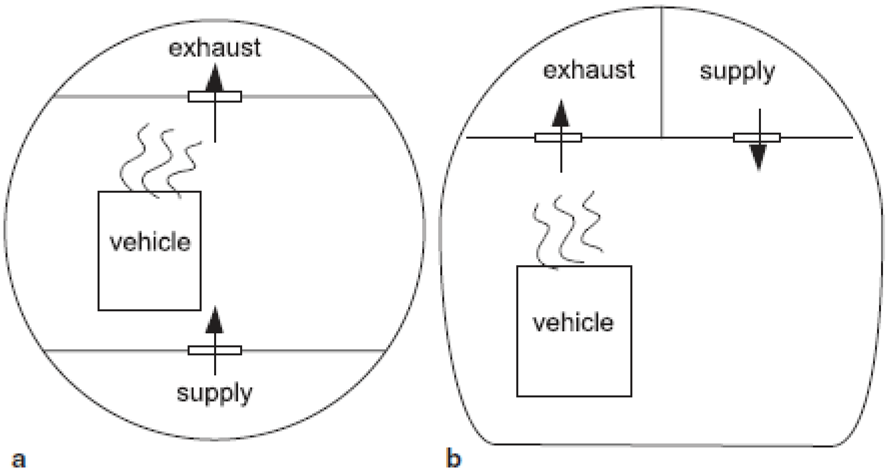


Figure 4 A schematic diagram of transverse ventilation [4]

In a transverse ventilation system, as shown in figure 4, the air remains uncontaminated using exhaust and supply vents along the tunnel, where fresh air is supplied from and contaminated air is exhausted. Ducts along the tunnel ceiling are used to exhaust and supply fresh air into the tunnel.

Semi-transverse ventilation

In a semi-transverse ventilation, as shown in figure 5 , fresh air is supplied to the tunnel or contaminated air is exhausted out depending on what is necessary.

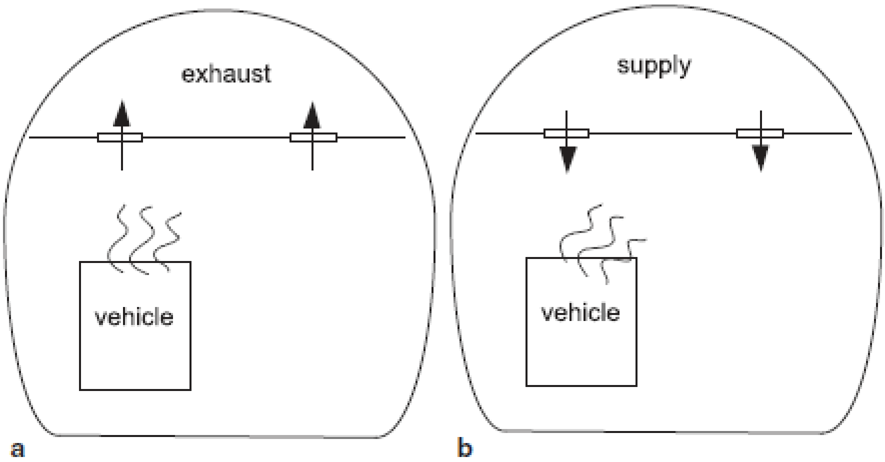


Figure 5 A schematic diagram of semi-transverse ventilation [4]

2.2.4 Backlayering

Backlayering is an effect where smoke spreads in the opposite direction of the air velocity as shown in figure 6, denoted as L_b. This happens because the kinetic energy in the smoke is larger than the counter directional airflow. As a result, some of the smoke travels in the opposite direction of the airflow. Since new smoke is being produced with its own kinetic energy, the smoke continues to push the counter directional airflow until the energy from the smoke and air respectively, cancels each other out. Given that new smoke is being produced with roughly the same amount of energy, the area where the energy difference is zero is where the backlayering settles.

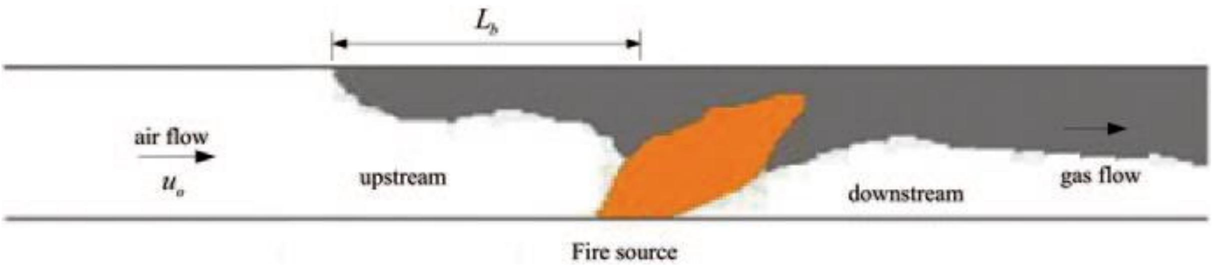


Figure 6 A schematic diagram of back-layering in a tunnel fire [4]

The length of backlayering can be expressed as [10]:

$$\frac{L}{H} = f(Q^*, \frac{V^2}{gH}) \quad (9)$$

Where:

L is the backlayering length

H is the height of the tunnel

V is the longitudinal velocity

Q^* is the dimensionless HRR

g is the gravitational acceleration.

The smoke spread in tunnels is dependent on the magnitude of the air velocity caused by the ventilation system, especially near the fire. The amount of backlayering can be described using three velocity ranges [4]:

- Low air velocity (0-1 m/s), can give backlayering 25 times the tunnel height.
- Moderate air velocity (1-3 m/s), can give backlayering from 0 to 25 times the tunnel height.
- Critical velocity (< 3 m/s), usually no back layering.

2.2.5 Gas temperature

The ability to predict gas temperatures in a tunnel fire is important. This information can be used to calculate heat exposure, fire detection time, fire spread and dimensioning of ventilation systems. The integrity of the tunnel structure is highly dependent on the gas temperature, and by using standardized time-temperature curves one can determine the prolonged temperature resistance of different materials.

The maximum ceiling gas temperature can be calculated using:

$$\Delta T_{max} = \begin{cases} 17.5\frac{\dot{Q}^{\frac{2}{3}}}{H_{ef}^{\frac{5}{3}}}, & V' \leq 0.19 \\ \frac{\dot{Q}}{u_0 b_{fo}^{\frac{1}{3}} H_{ef}^{\frac{5}{3}}}, & V' > 0.19 \end{cases} \quad (10)$$

And:

$$V' = \frac{u_0}{w^*} \tag{11}$$

Where:

$$w^* = \frac{g\dot{Q}}{b_{fo}\rho_0 c_p T_o} \tag{12}$$

Where:

V' is the dimensionless ventilation velocity

w^* is the characteristic plume velocity

b_{fo} is the radius of the fire

H_{ef} is the effective height from the fire to the ceiling

2.2.6 **Flame length**

There are different ways to define the flame length, depending on the size of the fire.

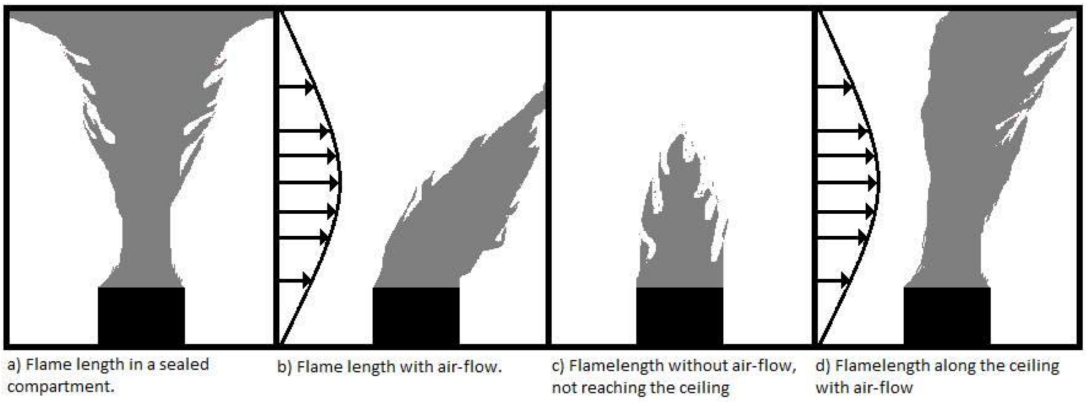


Figure 7 Different types of flame lengths

The flame length for buoyancy driven flames can be estimated using Heskestad's correlation for flame height [11]:

$$L_f = 0.235\dot{Q}^{\frac{2}{5}} - 1.02D_f \qquad \textbf{(13)}$$

Equation 13 can be used to calculate the height of the flame, when no ventilation is present as in figure 7 (a,c). The extension under the ceiling is not considered.

An equation for flame lengths in tunnels was established using data from HGV-EU-REKA-tests. In this equation the flame length was defined as the distance between the 600°C contour to the center of the object burning, or from the rear. The flame length from the rear of the object is represented by the following equation [4]:

Flame length in tunnel fires:

$$L_f = 0.02\left(\frac{\dot{Q}}{120}\right)\left(\frac{u_0}{10}\right)^{-0.4} \qquad \textbf{(14)}$$

Where:

$\dot{Q}$ is the HRR

u_0 is the longitudinal velocity.

Using data from the Runehamar tests and Memorial tests another equation was proposed, expressed as follows [12]:

$$L_f = \frac{1370\dot{Q}^{0.8}u_0^{-0.4}}{(T_f - T_0)^{\frac{3}{2}}H^{\frac{3}{2}}} \tag{15}$$

Where:

T_f is the temperature of the flame-tip

T_0 is the surrounding temperature

H is the height of the tunnel

The difference between equations 14 and 15 is that equation 14 is a conservative fit to data from HGV-EUREKA 499 tests, and only valid for this particular tunnel. Equation 15 is based on more data but is only suitable for ceiling jets under unconfined ceilings. The equation can only be used on flames that does not impinge on the ceiling. Equation 14 and 15 imply small effect of the longitudinal velocity on the flame length compared to the HRR.

Given a longitudinal velocity lower than the critical velocity, the flame will impinge on the ceiling and spread bi-directionally upstream and downstream of the fire. The total flame length, meaning the distance between the flame tips in each direction longitudinally, is dependent on the velocity of the ventilation. Experiments have shown that if the dimensionless ventilation velocity is above 0.3 there are only flames downstream of the fire [4]. Below 0.3 there are two parts of horizontal flame regions, upstream region and downstream region. This transition point is defined by equation 16 [4]:

$$u_{tp}^* = \frac{u_{0,tp}}{\sqrt{gH}} \tag{16}$$

Where:

$u_{0,tp}$ is the longitudinal velocity.

The length of the downstream flame during high ventilation rate can be expressed as:

$$L_{f,ds} \propto \frac{\dot{Q}H}{AH_{eff}^{\frac{1}{2}}} \tag{17}$$

Where:

H_{eff} is the height from the fire source to the ceiling.

This equation requires some knowledge of proportionality constant, which is difficult to determine. As such, a new size has to be defined, a dimensionless flamelength. By using this size one can determine the flamelength by simplifying the equation:

$$L_f^* = \frac{L_f}{H} \tag{18}$$

Where:

L_f^* is the dimensionless flamelength

L_f is the flamelength

H is the height of the tunnel.

The dimensionless flame length is defined, using correlations from test data, as:

$$L_f^* = 5.5Q_f^* \tag{19}$$

Where:

Q_f^* is the dimensionless HRR.

The dimensionless HRR is defined as:

$$Q_f^* = \frac{\dot{Q}}{\rho_0 c_p T_0 g^{\frac{1}{2}} AH_{eff}^{\frac{1}{2}}} \tag{20}$$

Where:

c_p is the thermal capacity for air

By using equation 18, one can determine the length of which the flame extends under the ceiling. This is only valid for fires with flames that impinges on the ceiling as in figure 7 (a,d), usually above 20 MW [4].

2.3 Computational Fluid Dynamics (CFD)

The information below is gathered from Computational Fluid Dynamics: Principles and Applications, J. Blazek [13].

In the early 1970's, Computational Fluid Dynamics (CFD) became an abbreviation for the use of numerical mathematics, physics and computer science. Computer science has been an increasing factor over the years, because of its evolution in processing power. At the beginning of the 80's, Euler's equations made it feasible to perform simulations in 3-D. Since computers have evolved, there was a demand for more complex simulations.

Together with the super computers and techniques like multigrid, it is possible to do simulations even with inviscid flows. Multigrid method is a group of algorithms that solves differential equations using hierarchy of discretization. Incorporating the Navier-Stokes equations gave the user the opportunity to conduct simulations of an even more demanding nature, with viscous flows.

CFD solves a set of governing equations numerically, since it is impossible to solve them analytically. Geometry in a simulation is therefore divided into rectangular grid-cells where the equations are contained within each cell. They are further solved for each cell involved with the simulation. Today's computers possess great processing power, which makes simulations capable of containing a great number of cells. As the number of grid cells increase, so does the accuracy and details of the simulation, but only to a certain point. It is not unlikely to have simulations that contain several million grid-cells. This number affect the computational time consumption, since it has to solve for every cell over the time and area given.

2.3.1 Governing equations

Governing equations are the pillar for any CFD modelling. They consist of the conservation of mass, momentum and energy. In this section, the equations are presented only at their derived form.

The general form of equation (21) the conservation of mass, states that mass only changes, it does not deteriorate nor is it created [14].

$$\frac{\partial \rho}{\partial t} + \nabla\, \rho u = 0 \tag{21}$$

What fire simulations have in difference with other types, is that it contains several gaseous species. To be capable of incorporating this into the equation, each gaseous species is explicitly accounted for in a set of transportation equations [14].

$$\frac{\partial(\rho \Upsilon_\alpha)}{\partial t} + \nabla \cdot (\rho \Upsilon_\alpha u) = \nabla \rho \mathrm{D}_\alpha \nabla \Upsilon_\alpha + \dot{m}_\alpha''' \tag{22}$$

For conservation of momentum the total force on the fluid element equals the total momentum on the fluid element. The conservation equation is as follows:

$$\frac{\partial(\rho u)}{\partial t} + \nabla(\rho u u) = -\nabla \mathrm{p} + \mathrm{f} + \nabla \tau \tag{23}$$

The essentials of the equation above is Force = Mass x Acceleration, i.e Newton's Second law of motion. Here, $\nabla \mathrm{p}$ is the pressure gradient, $\nabla \tau$ is viscous flows and f is external forces, that is driving the fluid [14].

The conservation of energy equation have been incorporated with source terms related to combustion, heat release rate, conduction, radiation, pressure and kinetic energy in the right hand side of equation 19. The conservation of energy is given as.

$$\frac{\partial(\rho h)}{\partial t} + \nabla(\rho h u) = \frac{Dp}{Dt} + \dot{q}''' - \nabla \cdot \mathrm{q} + \varepsilon \tag{24}$$

As mentioned, no analytical solution to the governing equations exists, i.e they must be solved numerically [14].

2.3.2 Turbulence modeling

Flows can be distinguished in two different ways: Laminar and turbulent. A laminar flow signifies that a fluid is stable. For example a candlelight burning have a very small heat release rate and have a close to none influence by the surroundings. In contrast, a turbulent flow is an unstable fluid. What mainly determines if a flow is laminar or turbulent is the Reynold's number.

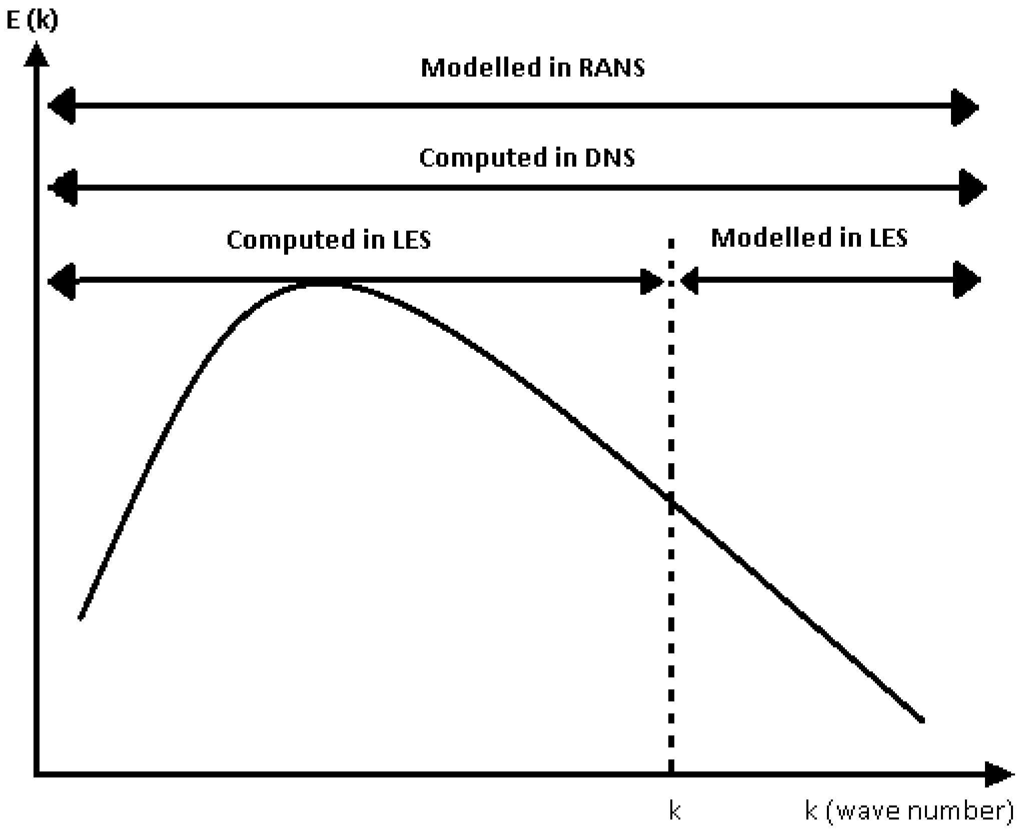


Figure 8 Turbulence modelling

There are three different approaches of treating turbulence:

The first approach is Reynold's average Navier-stokes (RANS). This was created over a century ago, Osborne Reynold introduced a way of treating the turbulence by solving the conservation equations in a statistically time averaged form. Enthalpy, velocity and species mass fractions are decomposed into a fluctuating and a time-averaged component [14].

The second approach is Large Eddy Simulation (LES), which computes the large turbulent structures (eddies) and models the smallest. Eddies are the reason for the combustion products and gaseous fuel to mix with the air in the area of the fire. This model takes in mind that the largest of eddies are the ones who are responsible for the major part of the mixing. As shown in figure 8, the computed area of LES contain eddies that have an adequate size to be computed, and give a reasonable accuracy and saves time in the simulations. What this technique does, is simplifying the prediction of thermal gas flow and smoke with sufficient accuracy to make it solvable [15].

The final approach is Direct Numerical Simulation (DNS). In DNS all turbulent motions are captured on the grid. Hence viscosity, material diffusivity and thermal conductivity has no representing models. Using direct numerical simulation means it needs a very fine grid. Because it is limited to a very fine resolution, only turbulent jets and small laminar flames can be simulated. Due to the computational expenses generated from this approach, DNS is not applicable for industrial flows [14].

2.3.3 FDS

All of the information below that deals with the FDS software, is found in the FDS technical reference guide [15].

In this study the CFD software used, was Fire Dynamics Simulations (FDS). The development of FDS and Smokeview (a visualization program) is a result of cooperation internationally and led by the National Institute of Standards and Technology (NIST) and VTT Technical Research Centre of Finland.

The software is appropriate for fire induced fluid-flows and utilized LES for its turbulence modelling. The governing equations in general take into account for a great amount of physical processes. With a simulation of a fire scenario, it is the fire and its physical processes that are of importance. Therefore, the equations are simplified were only the important aspects are being solved, which are important for a fire induced fluid-flow. These simplified equations were developed by Ronald G. Rehm and Howard R. Baum [15], and is widely incorporated into the research community of combustion. They are known as the "low mach number" equations for combustion, valid for flows with speed lower than 0.3 Ma.

A gas which has been put into a low speed motion, by buoyancy forces and chemical heat release, are described by these equations. Combustion in a fire is a relatively in-efficient process and involves fuel gases that contain more than hydrogen and carbon atoms. If a simulation were to be as real as possible, the number of species of gas that needs to be kept track of would be limitless. Normally, the numbers of fuels are limited to one, and reactions to one or two steps to make the book keeping easier. In combustion, there are at least six gas species that needs to be hold track of, fuel, oxygen, carbon- mono/dioxide, water vapor and nitrogen. Assuming single step reaction only two transport equations need to be solved, fuel and products [15].

Pressure that is resolved temporally and spatially is decomposed into background pressure and perturbation. The equation used for pressure solving is called Poisson equation, which is an elliptic partial differential equation. The divergence of the momentum equation is the way to procure it.

Prior to the calculations the geometry, boundary conditions and properties surrounding the fire had to be set up first. The simulation setup consists of codes, which are sorted into namelist groups. Each namelist group describes a function in the simulation [16].

2.4 Scaling

Scaling is widely used in the fire safety community, as it can be applied to almost any aspect of fire research. It has contributed to a wider understanding of fire dynamics, through the work of Heskestad, Quintiere etc [17] [18]. These individuals reviewed scaling techniques such as pressure modelling and Froude modelling, and applied these to ceiling jets, burning rate, flame spread and enclosure fires.

Scaling is often applied to study fire safety in tunnels, due to the high costs associated with full-scale tests.

2.4.1 Froude Scaling

Froude number

The Froude number is defined as:

"Froude number (Fr), in hydrology and fluid mechanics, dimensionless quantity used to indicate the influence of gravity on fluid motion." [19]

When scaling the Froude number the ratio of inertial force and buoyancy force is governed. Because smoke flow is driven by buoyancy, Froude scaling works by preserving the Froude number. The Reynolds number is not preserved, but the fluid mode is kept the same. Other dimensionless groups are preserved implicitly and have been proved to be reasonably scaled [4].

Scaling correlations

Table 2 Table showing the different scaling correlations

Type of unit	Scaling
Heat release rate [kW]	$\frac{Q_m}{Q_f} = \left(\frac{L_m}{L_f}\right)^{\frac{5}{2}}$
Velocity [m/s]	$\frac{V_m}{V_f} = \left(\frac{L_m}{L_f}\right)^{\frac{1}{2}}$
Time [s]	$\frac{t_m}{t_f} = \left(\frac{L_m}{L_f}\right)^{\frac{1}{2}}$
Energy [k]	$\frac{E_m}{E_f} = \left(\frac{Lm}{L_f}\right)^{3}$
Mass [kg]	$\frac{m_m}{m_f} = \left(\frac{L_m}{L_f}\right)^{3}$
Temperature [K]	$\frac{T_f}{T_m} = 1$

More about this scaling technique can be read in [4] Tunnel Fire Dynamics, here the method of finding these correlations are described in detail.

2.4.2 Pressure scaling

Pressure scaling preserves both Froude number and Reynold number by adjusting the environmental pressure in the test bed; this also indicates the preservation of the Grashof number. Because of this, both buoyancy force and fluid field can be scaled appropriately. Pressure scaling is very difficult, because the pressure has to be increased to very high levels in a model scale, which limits its use in fire modeling. The benefits of preserving the Reynold number are limited because of its lesser importance compared to the Froude number. [4]

2.4.3 Scaling and heat transfer

In this subsection, the information is gathered from the Tunnel Fire Dynamics (2015) book by Haukur Ingason, Ying Zhen Li and Anders Lönnermark [4].

Convective heat transfer scales well if the relative roughness is kept constant in the different scales, and the flow is turbulent. The reason for this is that at high Reynolds numbers the relative roughness remains more or less constant. The Reynolds number is what determines whether a flow is turbulent or not.

The convective heat transfer to the walls is expressed as follows:

$$\dot{Q}_c = h_c A_w (T_g - T_w) \tag{25}$$

Where:

h_c is the convective heat transfer coefficient

The subscript w refers to the walls.

Temperature and geometry scales well already, and the convective heat transfer coefficient scales as:

$$h_c \propto l^{\frac{1}{2}} \tag{26}$$

In radiative heat transfer more factors have to be considered, as this is highly dependent on the geometry, amount of smoke, soot, view-factors etc. The radiative heat transfer is simplified as:

$$\dot{Q}_r = h_r A_w (T_g - T_w) \tag{27}$$

Where:

h_r is the radiative heat transfer coefficient

This coefficient could be written as:

$$h_r = \epsilon\sigma(T_g^2 + T_w^2)(T_g + T_w) \tag{28}$$

Where:

ϵ is the emissivity of the walls

And the emissivity is:

$$\epsilon = 1 - e^{-k_m L_m} \tag{29}$$

Where:

k_m and $L_m$is the mean absorption coefficient and mean beam length of the flame and smoke flow respectively.

Equation 29 shows that the emissivity is highly dependent on the length scale, and becomes difficult to estimate. Because of this the heat absorbed by the geometry surrounding the fire may be wrongly estimated; as such, the radiative heat transfer is not reliable when scaled.

In enclosure fires or tunnel fires, the soot is what determines the absorption of radiation, and the properties of the soot remains constant if the fuel is not changed. The absorption coefficient is not changing when models are scaled, which may lead to an underestimation on the local heat absorbed and outgoing radiation. Due to this the gas temperature can decrease in model scales.

3 Runehamar tunnel fire tests

The study undertaken in this report is based on the Runehamar Tunnel Fire Tests.
The location of the test tunnel is 5 km from Åndalsnes town centre, and 40 km from Molde, Norway. There are three tunnels in the area, all of which are closed for ordinary traffic. Two of them are used as test sites for fire research and the third is used as a storage area. The shape and length of the tunnel make it ideal to conduct research and the development of new tunnel safety technology. In the Norwegian tunnel Runehamar, five large-scale fire tests were performed to gather test data on fires in tunnels. This includes HRR, fire spread, gas production, wall temperatures, visibility, backlayering, fire growth rate, gas temperature, flame length, ventilation and pulsation. These tests were performed by SP Technical Research Institute of Sweden, TNO in Netherlands and SINTEF of Norway. [12]

3.1 Geometry of the tunnel

The Runehamar tunnel is a 1650 meters long, 9 meter wide and 6 meter high tunnel. The tunnel is oval in shape and has virtually no considerable slope. The tunnel has mountains on one side and a fjord on the other.

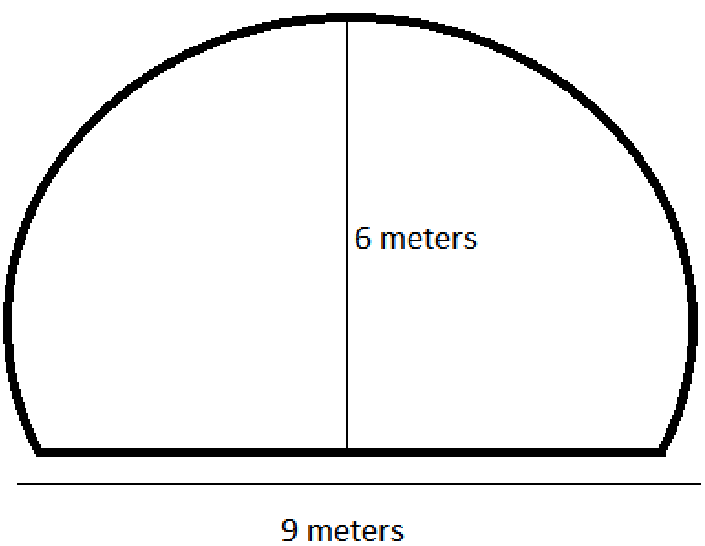


Figure 9 Simple illustration of tunnel opening

3.2 *Experimental procedure*

In the following sub sections the overview of the experimental procedure will be introduced, this procedure was followed when setting up the simulations.

3.2.1 Mobile fan units

The longitudinal airflow was made using two mobile fan units. These were placed 12 m outside the eastside of the tunnel and 50 – 60 m inside the eastside of the tunnel. The fans had a diameter of 1.25 m and an engine power of 75 kW giving approximately 2600 N thrust at 2000 RPM. Airflow rate of the fans was 47.2 m^3/s [12]. This gave an air velocity of 2.9 – 3.4 m/s 50 meters upstream of the fire [12]. After ignition and at the peak of the fire, this velocity decreased to 2.4 – 2.5 m/s due to thermal resistance from the fire [12]. Average velocity at the measurement station was 3 m/s.

3.2.2 Test overview

5 tests were performed in the Runehamar tunnel fire tests; this rapport will use test t0 [12], a 200 L diesel pool with a diameter of 2.27 m and a maximum HRR of 6 MW. The diesel was in a pan 1 m above the floor.

3.2.3 Measurements

Temperatures were measured along the tunnel, from -100 m upstream of the fire to 458 m downstream of the fire at a measurement station.

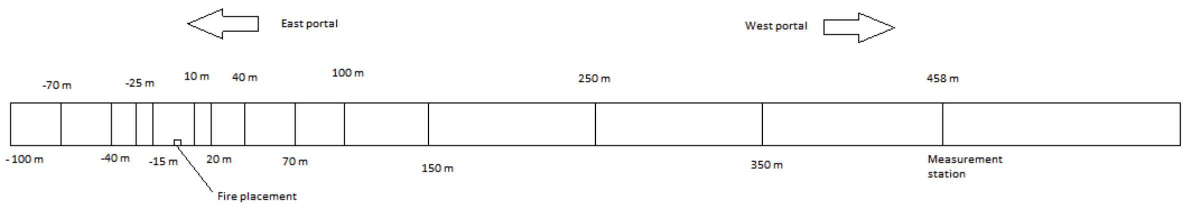


Figure 10 Overview of thermocouple placement

The temperatures were measured using unsheathed thermocouples, except near the fire sheathed thermocouples were used. At the measurement station, temperatures were measured at 5 different heights; 0.7 m, 1.8 m, 2.9 m, 4.1 m, 5.1 m.

Bi-directional probes were place at the measurement station, as well as one at -50 m and 3 m above the road surface. The velocity of the gas was measured using these pressure difference probes. [12]

The visibility was measured at the measurement station downstream of the fire and 2.9 m above the floor. All data was recorded every 1 seconds. [12]

4 Simulation of the Runehamar tunnel fire tests

The sub sections in this chapter describe the simulation setup, grid sensitivity analysis and the results from the simulations done in this study.

4.1 Simulation setup

This section will explain what parameters were used when setting up the simulation.

4.1.1 Combustion and fire model

In the experiment, there were five different maximum heat release rates. Three HRRs were chosen of interest 120 MW, 60 MW and 6 MW. 120 and 60 MW were chosen for the first test runs, severe pulsations of the flame gave an unstable solution. Fires of such a high HRR causes problems in FDS. Dozens of pressure iterations needs to be solved, increasing the computational cost. Hence, further testing with higher HRR was unnecessary. Instead, 6 MW was found to give a stable numerical solution, and a cost efficient simulation time.

Combustion setup consisted of a diesel fire, burning in a steel burner 1 meter up from the floor. This correlates with the experiment in the Runehamar tunnel. The diesel pool had an area of about 4m^2, corresponding to a HRR per unit area of 1500kW/m^2. As in the experiment, the fire was located in the centre of the tunnel (in y-direction), 1 meter up (in the z-direction) and 1037 meters from the east opening (in x-direction). Table 3 show the input parameters for the fire used in the simulation.

Table 3 Input parameters for the combustion model

Input parameters for the combustion model	
Fuel	Diesel
Soot yield	0.1
Heat of combustion	39.7 MJ/kg
Fire diameter	2.7 m
HRRPUA	1502.7 kW

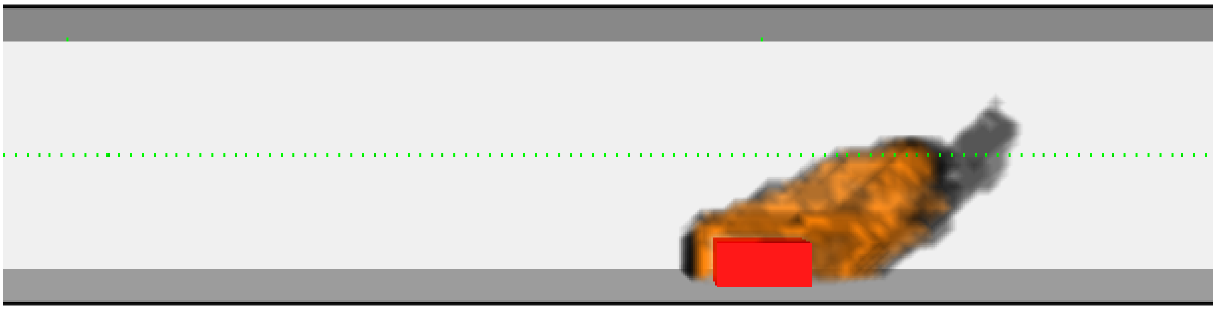


Figure 11 Illustration of the fire in smokeview

4.1.2 Calculation domain

Simulation containing the whole length of the tunnel, was proven challenging (explained in chapter 4.2.5). The duration of the simulation time surpassed the time given in this project. Because of ventilation challenges and reduction in time, the tunnel was cut 100 meter upstream from the fire, and instead of an opening, a vent was put in its place. The size of the tunnel, after it was edited, was 700 meters in length, 6 meters in height and 9 meters in width. Figure 12 show an approximation of the tunnel before and after it was cut.

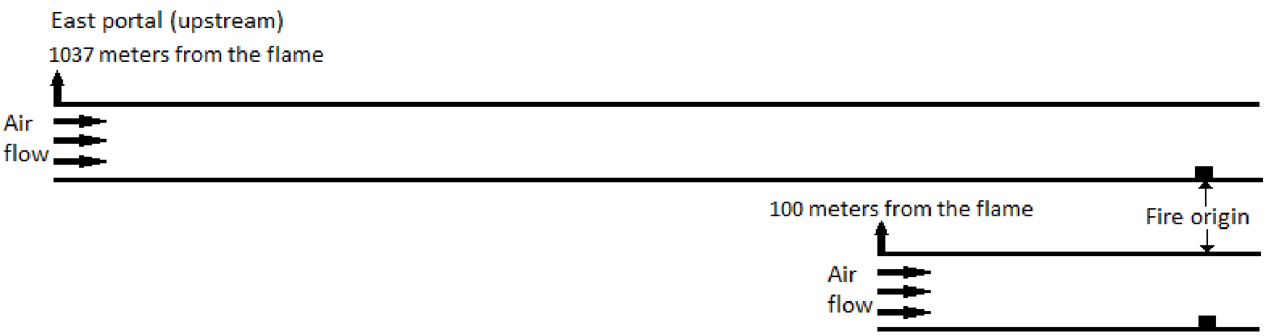


Figure 12 illustrates the tunnel before and after the cut

4.1.3 Geometry

At first the simulations were intended to include the whole length of the tunnel which proved to be difficult. In order to simulate such a vast area with a reasonable amount of grid-cells, results in increased simulation time.

Since the measurement station farthest from the fire upstream was 100 meters, the tunnel was cut at this location. Cross-section of the tunnel were simplified, from an oval shape to a rectangular shape, keeping the height and width of the tunnel.

4.1.4 Boundary conditions

In order to avoid any pressure build up in the tunnel, an extension of the tunnel was included. An open boundary extended from the portal, where the smoke from the fire could escape the tunnel. The portal of the tunnel is defined as a hydraulic diameter. And the hydraulic diameter gives a perspective of the length the open boundaries are supposed to be. It is defined as [4]:

$$D = \frac{4A}{P} \tag{30}$$

Where D is the hydraulic diameter, A is the cross section of the portal and P is the perimeter. There exist different criteria in literature for enclosure and free burning fires. However, there are no criteria for tunnels. For safety measures in this simulation, a numerical study of the tunnel with coarse grid gave a picture in smokeview of how far the smoke travelled. With a small margin, the length of the open domain became 25 meters.

Table 4 Input parameters for materials

Input parameters for materials	
Walls	
Material	Light concrete
Density	1200 kg/m^3
Conductivity	1.0 W/m K
Specific heat	0.88 kJ/kg K
Burner	
Material	Steel
Emissivity	0,5
Density	7850 kg/m^3
Conductivity	45.8 W/m K
Specific heat	0.46 kJ/kg K

4.1.5 Ventilation

Because of the experimental data, two fans were placed near the opening of the eastside portal, one inside the tunnel and one outside. These fans had a velocity of 2.9 m/s – 3.4 m/s, and contributed with air flow throughout the length of the tunnel. The air flow produced by the fans, need to reach the fire and stabilize in order to give comparable results. Figure 12 show the difference in distance from the portal to fire in the uncut and cut version. In this assignment a velocity of 3 m/s was chosen as the default air flow, since it is the average velocity contributed from the fans. 3 m/s air flow would result in needing approximately 300 seconds to travel the 1037 meters until reaching the fire. By cutting the tunnel at 100 meters from the fire, and placing a fan at this location, the time changed to approximately 30 seconds, and solved the problem.

4.1.6 Measurements

The experiment focused on recording measurements of gas temperature in the ceiling, heat release rate, flame length and fire spread. Because this report studies the possibility of scaling, it had to take into account that it was possible in some way to re-calculate them into their full-scale equivalent. Hence, the focus in this project was in measuring gas-temperature, heat release rate and velocity.

Temperature was measured using a thermocouple in both the simulation and in the experiment. This gave comparable results, and a way of measuring backlayering. By using matlab it became possible to create devices for HRR measurement from -50 m until +100 m, with a width equal to the grid cell size (figure 13). The reason for this is simply to enable the use of HRR to calculate the flame length and HRR directly over the fire, also by using matlab. In addition to the thermocouples, the simulation contained slice files across the whole length of the tunnel, enabling the possibility to withdraw information concerning the velocity at the point of interest.

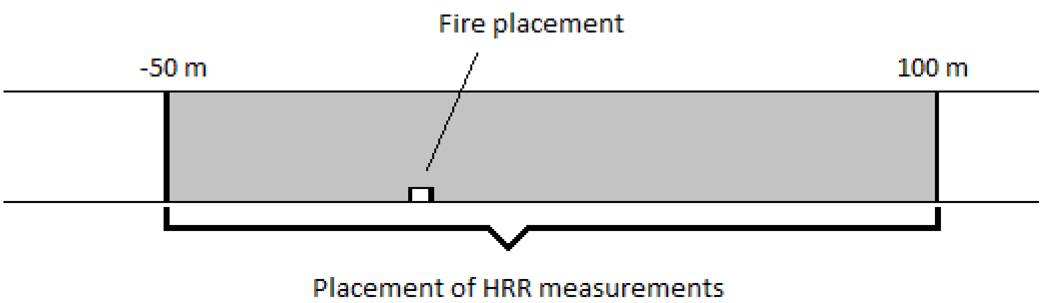


Figure 13 Illustration of the HRR measurements

4.2 Grid sensitivity analysis

Finding the correct grid cell size is always a challenge. There are some guidelines in the FDS user-guide, specifically describing at the dimensionless diameter of the fire. The grid spacing is dependent on the variables of interest. Smaller fires may require more grid cells than larger fires. If the simulation involves a buoyant plume the non-dimensional expression *D*/dx* can be used, where *dx* is the grid cell size and *D** is the dimensionless diameter, expressed as:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}} \tag{31}$$

It's recommended to use values of D*/dx between 4 and 16.

Using regular values for air, *D** in this simulation was 1.98, the corresponding *D*/dx was 7.95.*

According to Li et al, a cell size of 0.075D* gave a reasonable value for simulation of fires in a tunnel. This would have given a cell size of about 0.15, which would have resulted in too long simulation time and the criteria of *D*/dx* between 4 and 16 was used. In order to determine whether a solution has reached convergence and the correct grid resolution, a grid sensitivity analysis has to be performed.

There are several ways to do this, and not all methods are equally good. This study will use two of these methods:

The first method is to study the resolved turbulence on the grid-points, specifically the measure of turbulence resolution. Measure of turbulence resolution is defined as:

$$MTR(x,t) = \frac{k_{sgs}}{k_{res}+k_{sgs}} \tag{32}$$

Where:

$$k_{res} = \frac{1}{2}\tilde{u}_i\tilde{u}_i$$

$$k_{sgs} = \frac{1}{2}(\tilde{u}_i - \bar{u}_i)(\tilde{u}_i - \bar{u}_i)$$

Where:

$\tilde{u}_i$ is the resolved LES velocity, which means FDS managed to calculate the velocity.

$\bar{u}_i$ is the test filtered velocity, which means FDS had to model the velocity because of the grid cell size.

A large amount of unresolved velocity,k_{sgs}, results in an unresolved simulation. It is desirable that most of the turbulence is calculated, figure 8 illustrates this. The results of the MTR-study come in a range of 0-1, with zero being totally resolved and vice versa. This method is an approximation of the Pope criterion, by time averaging the MTR in a plane one can approximate this number. Pope defined LES with MTR < 0.2; **LES** requires at least a resolution of 80 %. This may not be sufficient for engineering problems, but has shown to give satisfactory results [16].

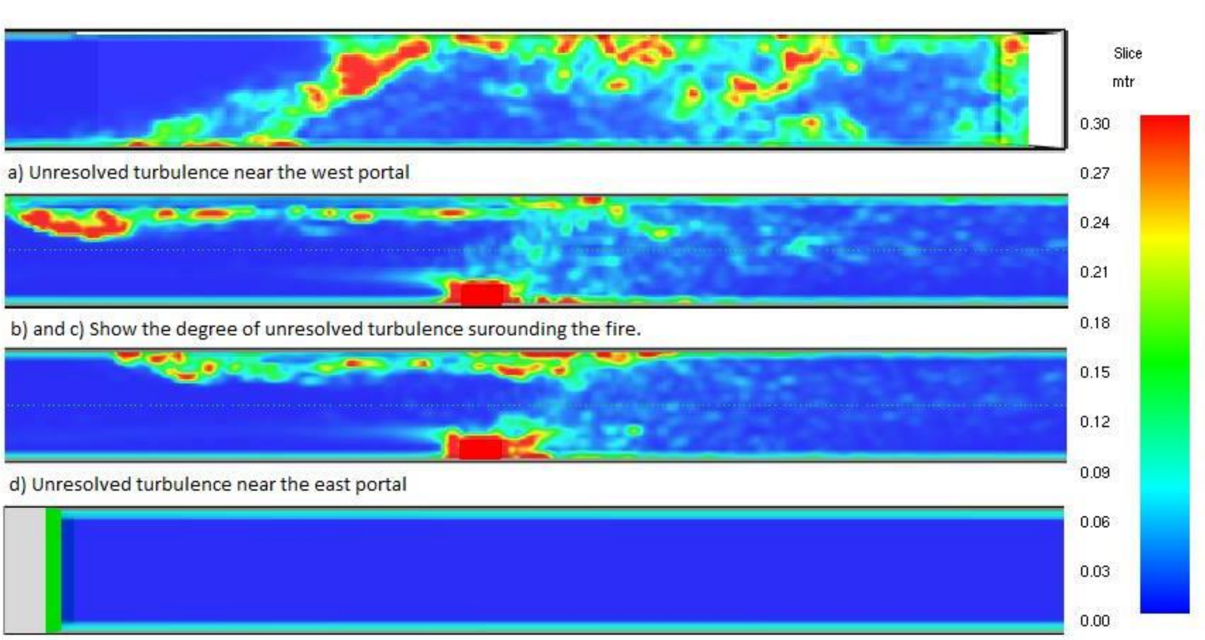


Figure 14 MTR slices of the simulation with dx = 25 cm

Based on the visual representation of MTR in figure 14 at the east portal (d), where the longitudinal ventilation has its origins, it is clear that the turbulence is completely resolved.

Studying the area surrounding the fire (b & c), more unresolved turbulence appears. However, most of the turbulence appear to be resolved or at least come below Pope's criteria for LES (80%), the modelled part in figure 8 should be 20 % [16]. Directly in the fire and in the vicinity, there are peaks of unresolved MTR up to 30 %, this is not important because there is no practical application to study how the flame itself behaves. The outlet of the tunnel (a) shows the same trend as around the fire.

The second way to determine if the results have converged is by refining the grid cell size and comparing the results. In this case, cell sizes of 30 cm, 25 cm and 20 cm were used. By comparing results and locating where the changes in results are small when refining the grid cell size, it is possible to determine if the simulation has reached convergence. Unfortunately, the simulation with the smallest grid cells encountered numerical instability, and lack of time made it impossible to restart this simulation. The results drawn from this simulation are uncertain at best, but will still be presented. The reason this simulation encountered numerical instability was because of the pressure iterations and velocity correlations were too high. There is a possibility to increase these factors, but this increases the simulation time.

Table 5 Overview of simulation times during grid sensitivity analysis

Simulation no.	Grid cell size	Number of cells	Simulation time
1	30 cm	1 440 000	2.7 days
2	25 cm	2 419 200	6.2 days
3	20 cm	4 725 000	21 days on 60 % of the simulation
Li et al	15 cm	11 200 000	Minimum 100% increase from 20 cm, Ca. 88 days.

Table 6 shows quite the difference in simulation time, when going from dx = 25 cm to dx = 20 cm. Following Li et al’s suggestion would have taken too long time with the computational power available in this study.

4.2.1 Backlayering length

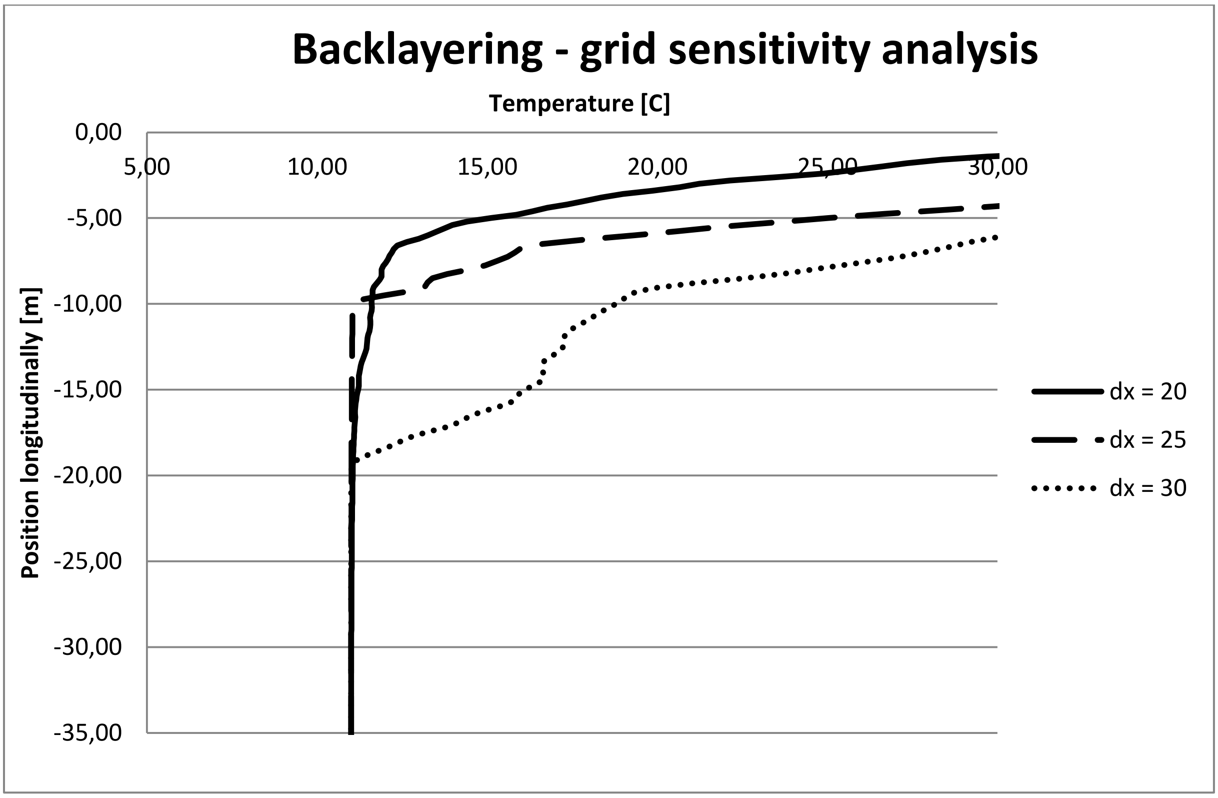


Figure 15 Backlayering length with different cell sizes

Criteria for backlayering was chosen to be where the temperature of the smoke gasses increased by 1-2 degrees Celsius upstream of the fire. The temperature was time averaged along the ceiling from the fire, up to 20 meters upstream of the fire. When the temperature starts increasing, backlayering has occurred.

Considering the gap in backlayering length from dx = 30 cm and dx = 25 cm, its quite clear that 30 cm is not accurate enough. However when looking at the difference between 25 cm and 20 cm, this is a much closer correlation. The difference in backlayering length here, is about 1-2 meters.

4.2.2 Flame length

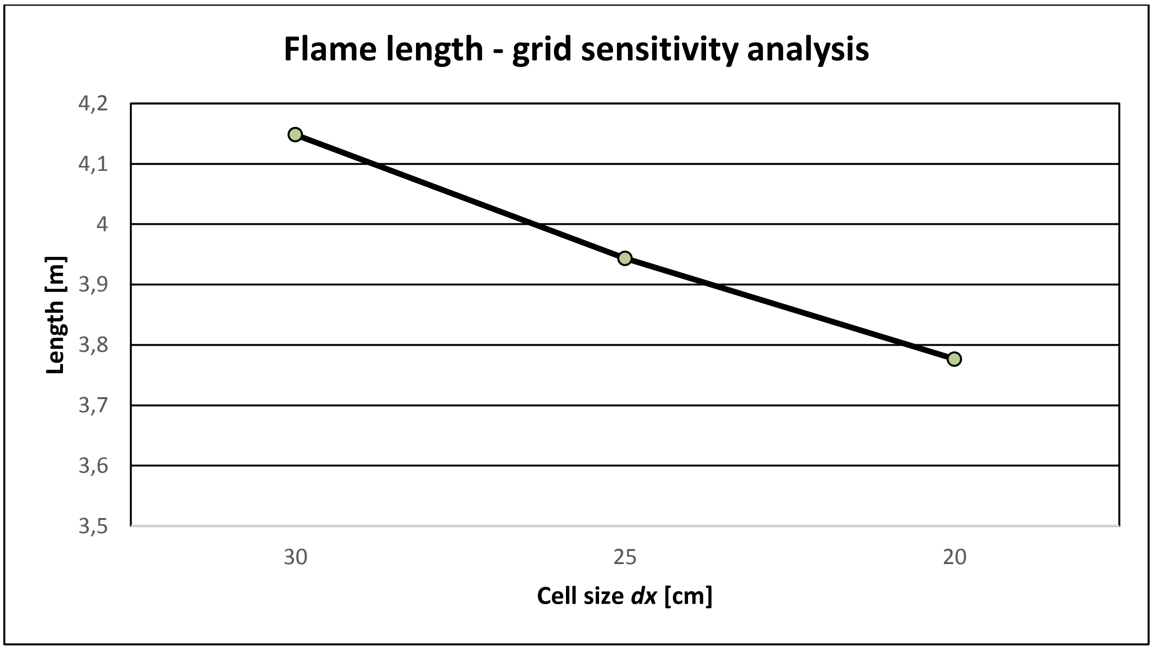


Figure 16 Flame length for grid sensitivity analysis

The flame length was, as mentioned in the previous chapter, calculated using HRR measurements from – 50 m upstream to 100 m downstream of the fire. The location of the flame tip had to be where only a small amount of HRR was taking place, the area where only 1% HRR was released got defined as the flame tip illustrated in figure 17.

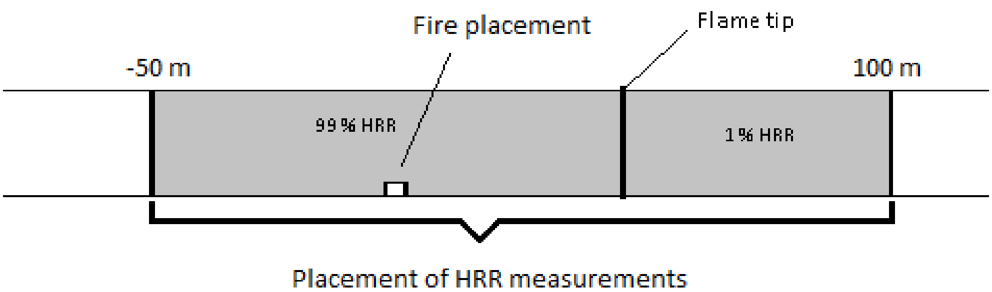


Figure 17 Flame length criteria [15]

In this case, the change from 25 cm to 20 cm is only a bit smaller than that of 30 cm to 25 cm. The difference is only 15-20 cm, which is considered to be relatively low. It is important to consider that only 100 seconds of the finest simulation was used when gathering the HRR data because of the numerical instability, which means the flame may not have reached steady state yet.

Taking into consideration; the simulation time, computer requirements, difference in backlayering lengths and flame lengths.

As previously presented in equation 9, the backlayering is mostly dependent on the dimensionless HRR and the longitudinal velocity. In all cases the dimensionless HRR and velocity remain as constants, and may explain why there is a clear convergence in the backlayering and not in flame length. The flame length is dependent on the measured HRR, which differs when the grid-cells become smaller, because more of the combustion zone is calculated.

4.2.3 Velocity

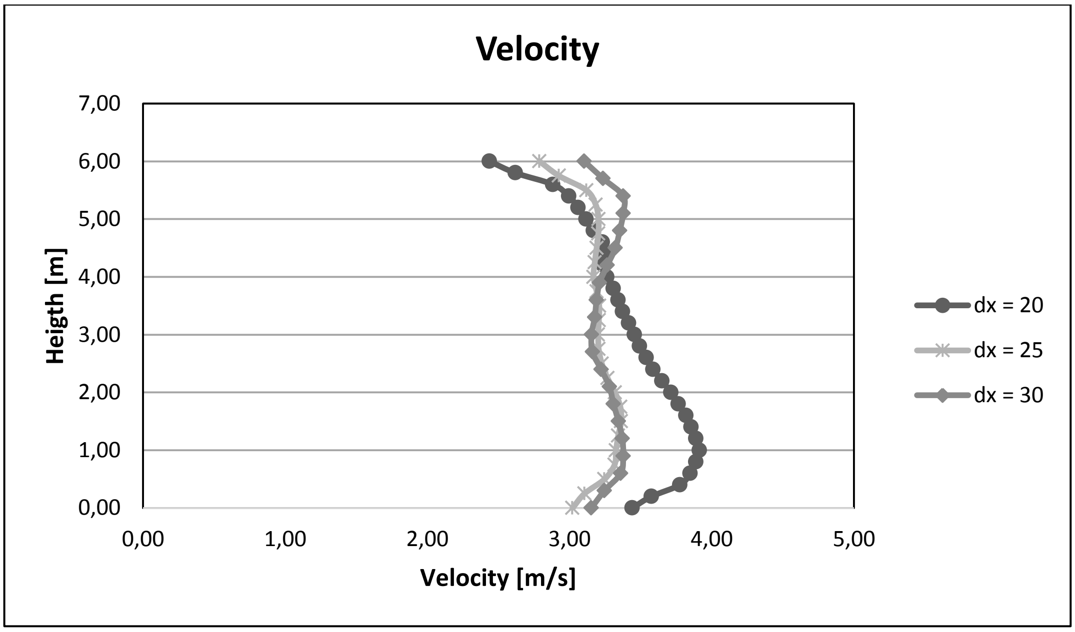


Figure 18 Velocity for sensitivity analysis

In figure 18 and 19 the finer simulation, dx = 20, is not converging with dx = 25. The simulations with dx = 25 and dx = 30 respectively, is more similar. This may be the result of the numerical instability in the simulation with dx = 20, or that the simulation has not reached convergence. The data is time-averaged from 50-100 seconds, and gather 50 m upstream of the fire.

4.2.4 Temperature

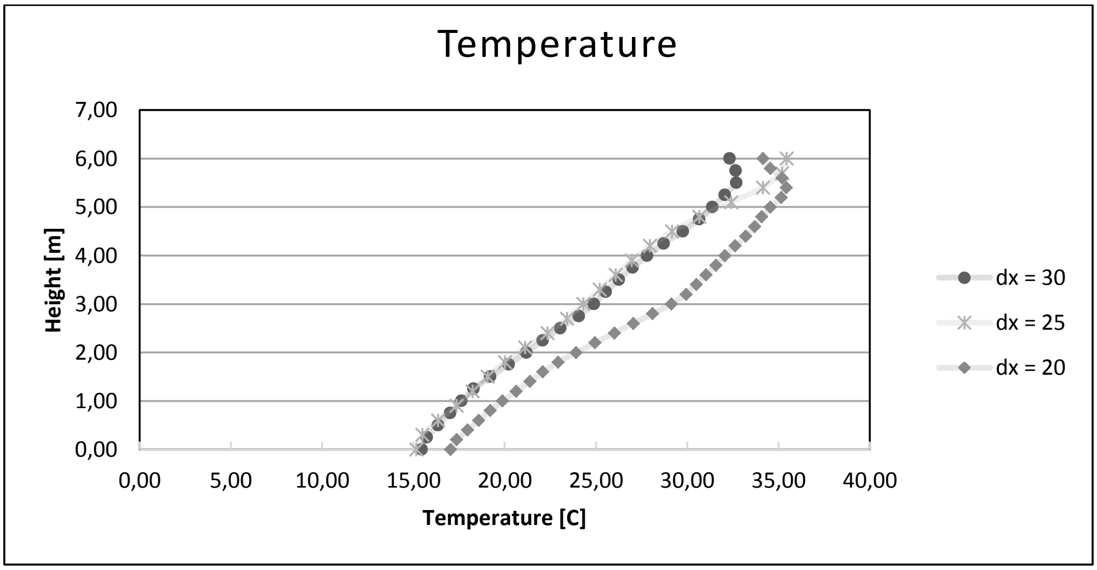


Figure 19 Temperature for sensitivity analysis

A grid cell size of 25 cm was deemed appropriate for further simulations as well as the downscaling.

4.3 *Results from the simulations*

A comparison of the results from the Runehamar test and the results from the simulations will be presented in the following sub-sections.

4.3.1 Ceiling gas temperature

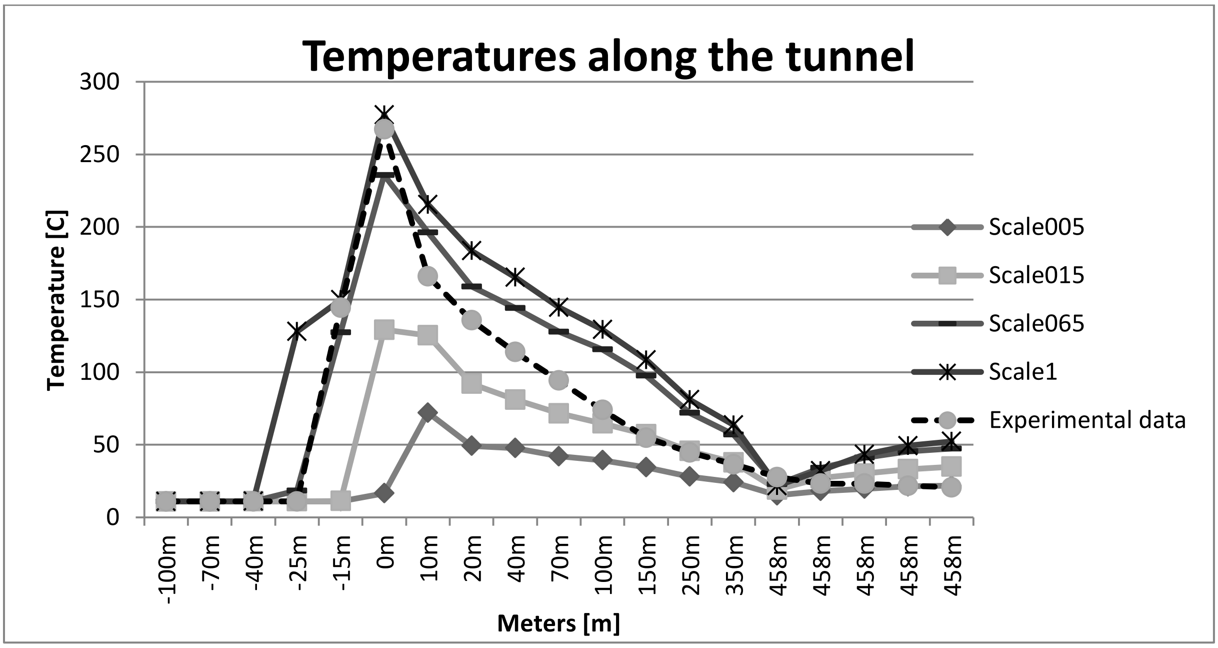


Figure 20 Temperature measured along the tunnel

The agreement between the experimental data and the full scale simulation is good, however there is some overestimation at -40, -25 m, as well as at the measurement station (458 m). Figure 20 shows a maximum temperature of about 270 °C, using equation 10, 11 and 12 it is possible to determine what the maximum ceiling temperature will be. Using these empirical correlations a temperature of 240.9 °C was found, the complete calculation can be found in annex A. This coincides with both the simulation and experiment.

There are some outliers among the different scale models, most of them are underestimated like scale015 and scale005. The immediate trend is that the temperature decreases when downscaling. The full-scale model agrees fairly well with the experimental data, the same with scale065, except for a small underestimation. With the smallest scale-models the same trend applies, here the temperature is even more underestimated. Keeping in mind the correlation between temperature and heat transfer in form of radiation, the fact that radiation is highly dependent on the length scale may be the reason for the underestimations. Figure 25 shows that the radiation loss to the boundaries decreases as the models are down scaled. If the radiation loss to the boundaries decreases, the radiation from the smoke and fire may decrease as well, resulting in a decrease in temperature. Some of the radiation from the total HRR in FDS is underestimated, leading to a decrease in the total HRR in the model scales.

4.3.2 Flame length

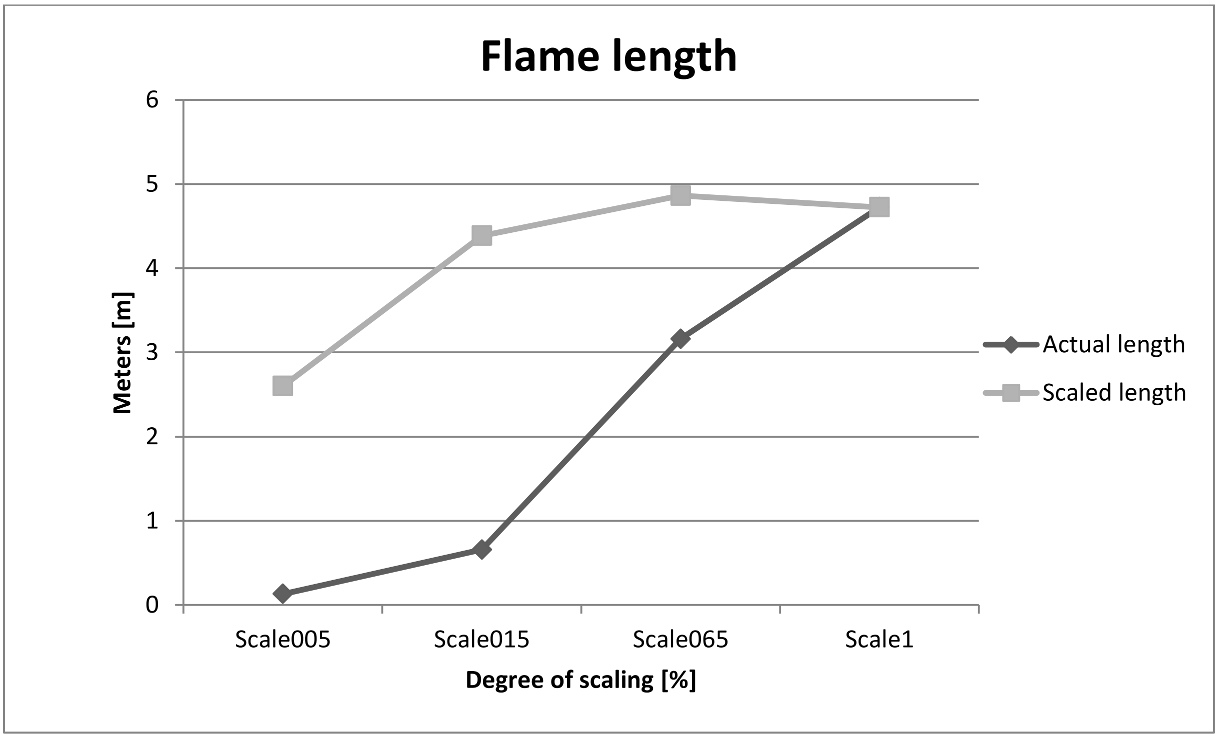


Figure 21 Flame length for the different scaling's

It is important to note that the flames in these simulations do not impinge on the ceiling, but bends horizontally because of the longitudinal airflow.

In most of the simulations, the flame length was approximately 4-5 meters. Equation 15 for flame lengths gave a flame length of 4.43 m. Equation 15 is used because the equation is created from experiments in Runehamar Tunnel Fire Tests. The complete calculation can be found in Annex A. There is no data on the flame lengths from the fire test. This does show the same trend for underestimations as the simulations were scaled down. The flame length produced in figure 21 comes from the HRR-method described in chapter 2.2.6. Figure 26 shows that the total HRR decreases as the models are scaled down; this will naturally affect the flame length.

4.3.3 Velocity at measurement station

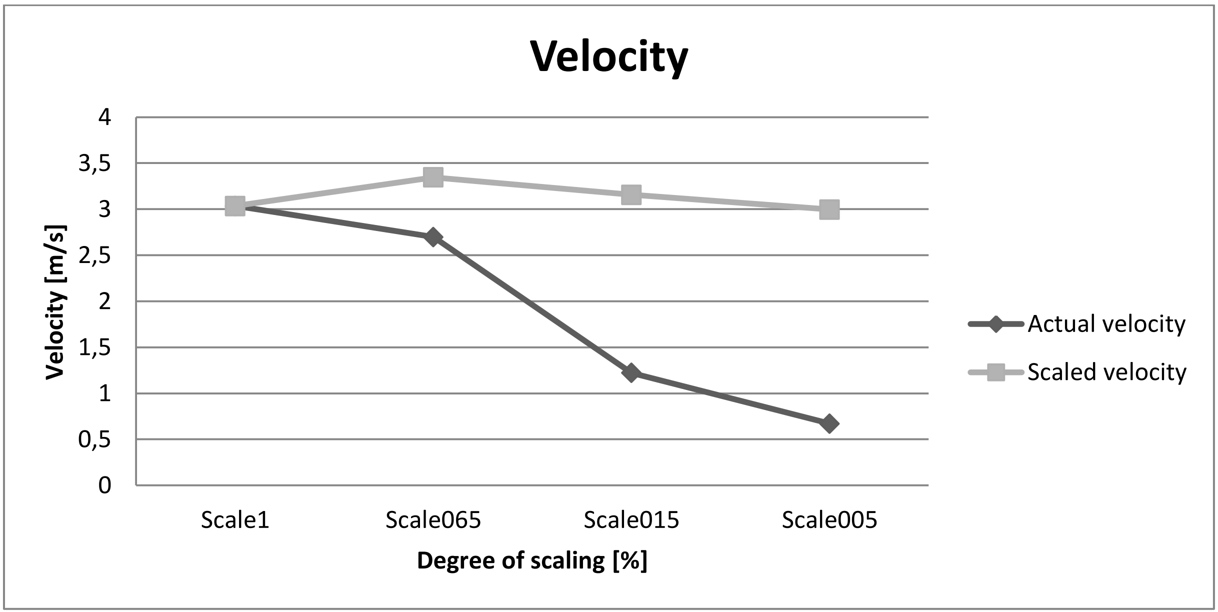


Figure 22 Velocity at measurement station

In the experiments, the velocity was measured to approximately 3 m/s at the measurement station. The same applies for the full-scale model. Most of the scale models gave about 3 m/s as well, with approximately $\pm$ 10 % difference. The underestimations seen in the previous results is not present here, the reason for this may be that the velocity is not overly dependent on HRR and radiation.

4.3.4 Temperature at the measurement station

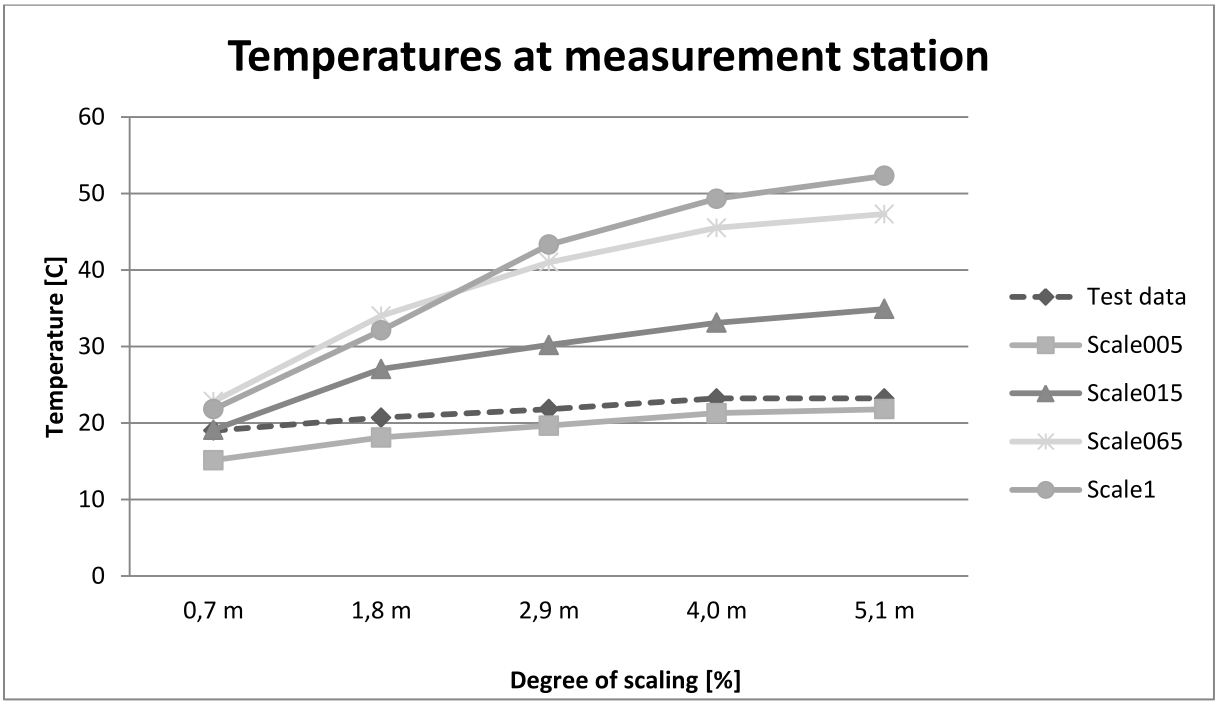


Figure 23 Showing temperatures at the measurement station for each of the scaling's

The temperatures at the measurement station do not agree at all. In the test the temperatures remained steady at about 20 degrees Celsius in all the vertical measurement-points. In the full scale simulation the temperatures are overestimated. The reason for this may be that the smoke does not lose as much energy towards the measurement station as it did in the experiment. The experiment had ventilation at the inlet of the tunnel approximately 1000 meters upstream of the fire, and the simulations had ventilation only 100 meters upstream of the fire. The airflow velocity in figure 22, shows a small overestimation on velocity in the model scales, compared to the experimental data. Given that the velocity has been averaged, the overestimation on the actual values that has been averaged may be higher, figure 24 from smokeview shows velocities around the measurement station of 3.9 m/s. This may have resulted in a shorter travel time for the smoke, and subsequently a shorter time for energy to dissipate from the smoke and higher temperatures at the measurement station.

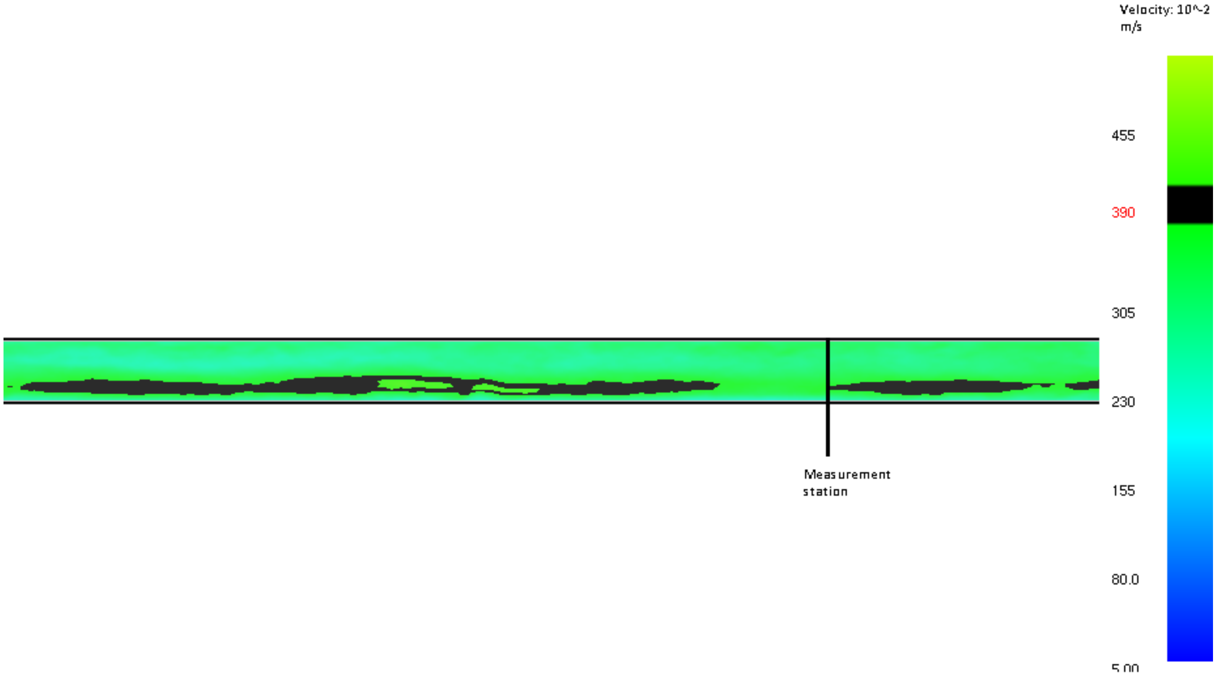
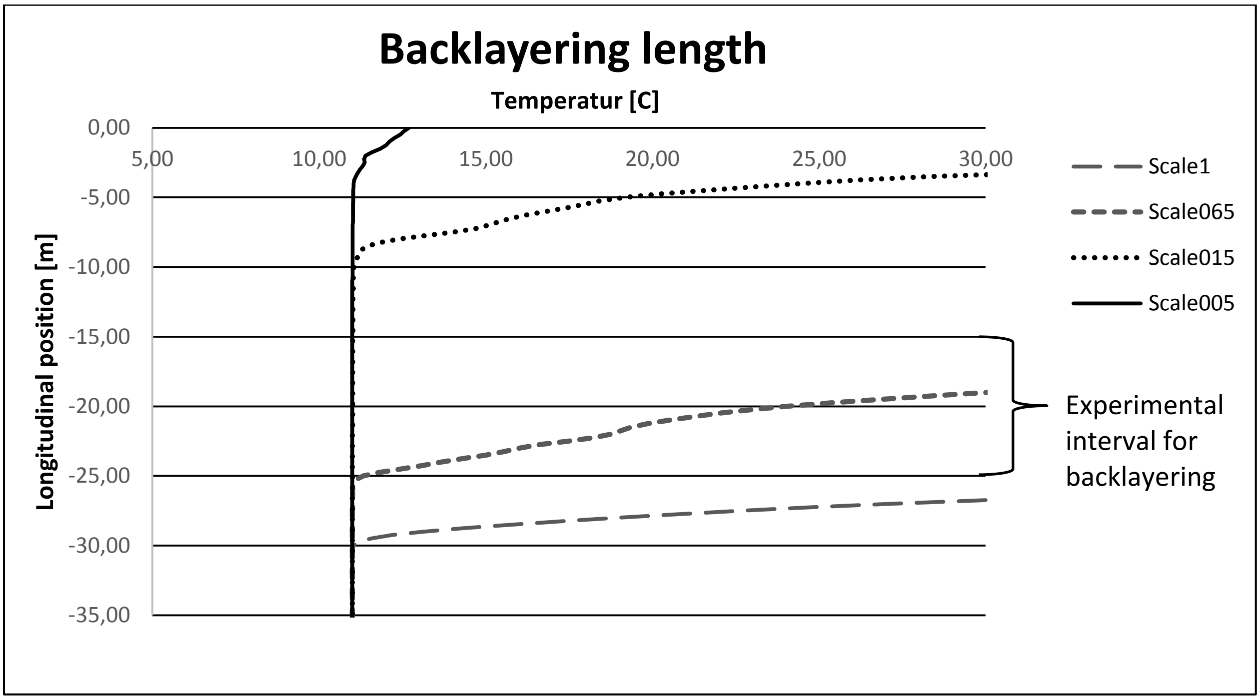


Figure 24 Example of velocity at measurement station

4.3.5 Backlayering length



In the Runehamar Fire Tests, the backlayering length was observed to be between 15 and 25 meter. This is slightly overestimated in Scale1, the full-scale model. The same trend for underestimations from previous results is observed as the models were scaled down. The criteria for backlayering are described in chapter 2.2.4. Using this criterion, backlayering in the full-scale simulation happened around the 30 meter mark.

4.3.6 Radiation loss to boundaries and total HRR

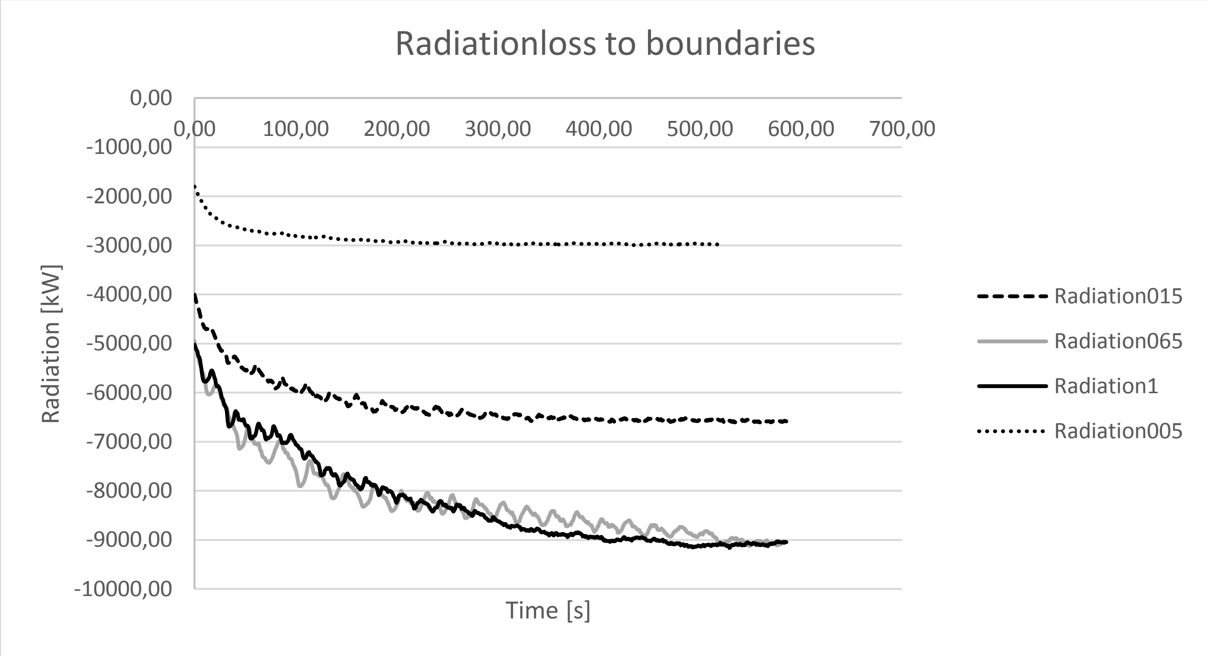


Figure 25 Radiation loss to boundaries

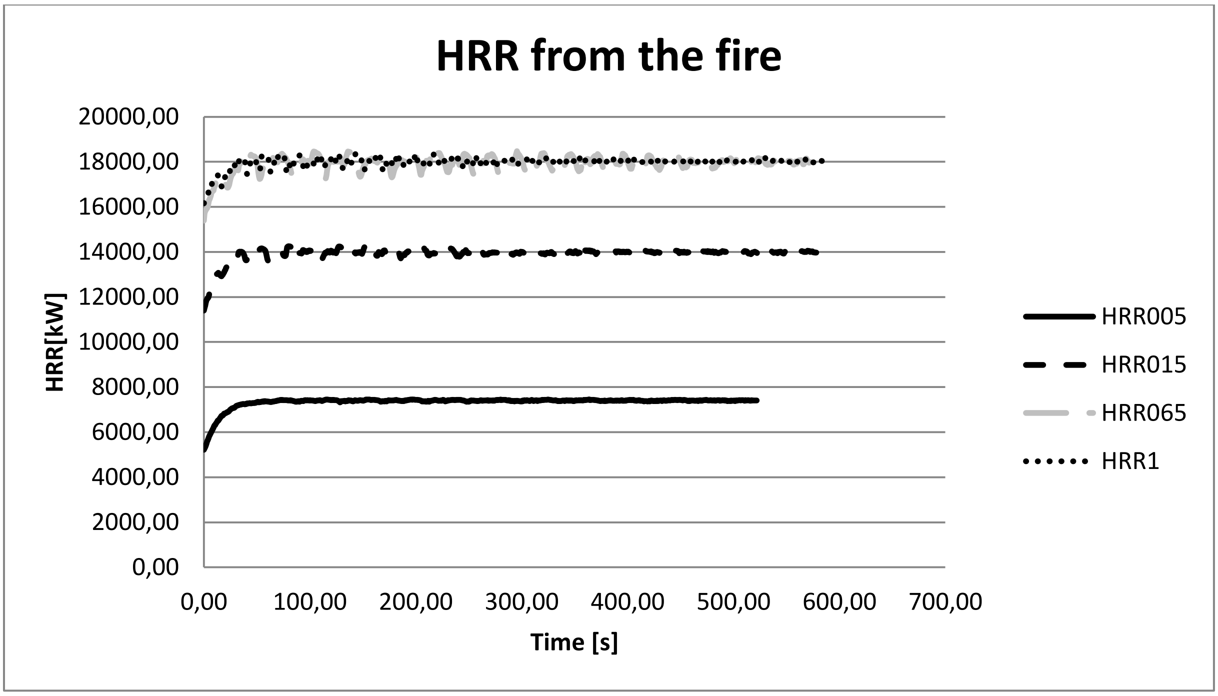


Figure 26 Total HRR from the fire

The radiation loss to the boundaries and HRR in the simulations appears to not scale well. As described in the theory, chapter 2.4.3, the radiation is dependent on the length scale and this may cause some of the radiation to be underestimated when the models are scaled down. Another reason for this underestimation is that the local absorption coefficient is not scaled well, as presented in chapter 2.4.3 [4].

4.4 Results overall

There seem to be good agreement between the full scale simulations and the experimental data. Temperature measurements, velocity and backlayering seem to coincide with the results from the experiments. The full scale model flame length and maximum ceiling temperature is very close to the empirical calculation.

From the results presented in the previous sub sections, scaling is acceptable up to a certain point, specifically 65 %. As the scale models decreased in size, the underestimations of the results became larger. The reason for this may be found in the scaling capabilities of radiative heat transfer and the effect this has on the total HRR. There is good agreement between 65 % and the full-scale model, this may indicate where the limit on down scaling is.

5 Conclusion

The grid sensitivity analysis did not show a clear convergence. This may be caused by the numerical instability encountered. The time-cost of using the finest grid (dx = 20 cm) was too high for this study, and may generally be too high for engineering problems, as well. The study of MTR showed acceptable resolution in the chosen grid cell size. There was poor resolution directly around the fire, however the region of interest, down and upstream of the fire showed acceptable resolution. This was concluded to be reasonable for this study and further simulations were done using a grid cell size of 25 cm.

An attempt was made to simulate fires with higher maximum HRR, over 60 MW in this study. HRR above 60 MW lead to pulsations in FDS and subsequently many pressure iterations and high velocity error. Maximum pressure iterations of 10 eventually lead to numerical instability.

The results from the full-scale experiments compared to the simulations were in reasonable agreement. Temperature measurements, velocity and backlayering coincided with the results from the experiments, despite the lack of convergence. The temperatures measured along the ceiling in the experiment were in good agreement with the predictions of the full-scale simulation. With the scale models the temperatures showed increased underestimations as the models became smaller, especially below 65%.

The velocity was in good agreement with the experiment in every model except the 5% scale model, which leads to the conclusion that cutting the tunnel and using a vent as a boundary condition may be acceptable. There existed no data on the flame length of the chosen experimental test, however the equation derived from the Runehamar tests gave approximately the same result as the simulations predicted.

This study has shown that it may be possible to perform simulations on tunnels in full-scale with the simplifications made in this study. In general, test data from the different scale models showed a decrease in agreement as the models were scaled down. According to the results from this study, at less than 65% full-scale the results became underestimated. The underestimations in the results were caused by the scaling of radiation, as this affected the total HRR from the fire.

In order to simulate tunnels with recommended resolution, higher-quality equipment and time is necessary. Using grid cell criteria recommended in the FDS user guide [16] and Tunnel Fire Dynamics by Haukur and Ingasson [4] caused the simulations to have a low time-cost efficiency. With high-end computers and limitless time, it is possible to use FDS for full-scale tunnel fires according to the findings in this study.

6 Further Work

- Finding a correlation for the extension outside the tunnel

The boundary extension of open air outside the fire domain is an important part of any simulation, and achieving zero pressure difference over the boundary is important. For enclosure and free-burning fires there exists a criteria for the minimum extension required, this was not found for tunnels during this study. Given the importance of this criterion, a correlation for tunnels should be established.

- Perform a study on the actual effect that down scaling has on the radiation solver in FDS

This study showed a gross underestimation of the radiation as the down-scaling increased. Most likely it follows some sort of pattern. Being able to determine this pattern may help to counteract this effect in FDS and possibly in experimental scale models.

- Executing a full grid-sensitivity study of tunnel fires

The criteria given in the FDS user guide and Tunnel Fire Dynamics by Haukar and Ingasson created time-consuming simulations, and according to the findings in this study this criteria may be too demanding and possibly unnecessary for engineering-problems. However a complete study on grid-sensitivity should be done with engineering-problems in mind.

7 References

[1] K. McGrattan, S. Hostikka, R. McDermott, J. Floyd, C. Winschenk and K. Overholt, “Fire Dynamics Simulator Technical Reference Guide Volume 3: Validation,” National Institute of Standards and Technology, 2016.

[2] A. Kveen and M. Lindstrøm, “Tunneler,” Statens Vegvesen, 17 04 2015. [Online]. Available: http://www.vegvesen.no/fag/Teknologi/Tunneler. [Accessed 04 2016].

[3] S. Vegvesen, “e39rogfast,” Statens Vegvesen, [Online]. Available: http://www.vegvesen.no/Europaveg/e39rogfast. [Accessed 04 2016].

[4] Haukur and Ingasson, Tunnel fire dynamics, New York, NY: Springer, 2015.

[5] Dictionary.com, “Dictionary.com,” [Online]. Available: www.dictionary.com/browse/fire. [Accessed 11 4 2016].

[6] Firesure, “Firesure,” [Online]. Available: http://www.firesure.ie/fire_safety_guidance/theory_of_fire.html. [Accessed 11 4 2016].

[7] NDT resource center, “NDT resource center,” [Online]. Available: https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Physical_Chemical/ThermalConductivity.htm. [Accessed 17 4 2016].

[8] British Tunnelling Society, Thomas Telford, Tunnel Lining Design Guide, 2004.

[9] The european parliament and the council of the european union, “EUR-lex,” 29 April 2004. [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32004L0054. [Accessed 17 4 2016].

[10] L. Ying Zhen, L. Bo and H. Ingason, “Study of critical velocity and backlayering lenght in longitudinally ventilated tunnel fires,” SP Technical Research Institute of Sweden, Sweden, 2010.

[11] G. Heskestad, “Fire Plume,” SFPE Handbook of Fire Protection Engineering, Quincy, 1995.

[12] I. Haukur , L. Ying Zhen and A. Lönnermark, “Runehamar tunnel fire tests,” SP Technical Research Institute of Sweden, Sweden, 2014.

[13] J. Blazek, COMPUTATIONAL FLUID DYNAMICS Principles and Applications, Elsevier, 2015.

[14] K. McGrattan and S. Miles, “Modeling Enclosure Fires Using Computational Fluid Dynamics (CFD),” in *SFPE handbook of fire protection engineering*, Quincy, Mass, National Fire Protection Association, 2002, pp. 230-232.

[15] K. McGrattan, S. Hostikka, R. McDermott, J. Floyd , C. Winschenk and K. Overholt, “Fire Dynamics Simulator Technical Reference Guide Volume 1: Mathematical Model,” NIST, National Institute of Standards and Technology, 2013.

[16 K. McGrattan, S. Hostikka, R. McDermott, J. Floyd, C. Weinschenk and K. Overholt, “Fire

] Dynamics Simulator User's Guide," National Institute of Standards and Technology, 2013.

[17] G. Heskestad, "Scaling the interaction of water sprays and flames," Fire Safety Journal, 2002.

[18] Q. JG, "Scaling Applications in Fire Research," Fire Safety Journal, 1989.

[19] Encyclopedia Britannica, "Global Britannica," [Online]. Available: http://global.britannica.com/science/Froude-number. [Accessed 6 4 2016].

[20] H. Ingasson and L. Ying Zhen , "Model scale tunnel fire tests with longitudinal ventilation," SP technical research institute of sweden, Boras, 2010.

[21] K. M. a. S. Miles, "Modelling Enclosure Fires Using Computational Fluid Dynamics," in *SFPE handbook of fire protection engineering*, National Fire Protection Association, 2002, pp. 230-232.

[22] D. J. Phillip, SFPE handbook of fire protection engineering, Massachusets: National Fire Protection Association, 2002.

8 Annex A

8.1 Maximum ceiling gas temperature

Used to compared empirical and experimental ceiling temperatures

$$\Delta T_{max} = \begin{cases} 17.5\frac{\dot{Q}^{\frac{2}{3}}}{H_{ef}^{\frac{5}{3}}}, & V' \leq 0.19 \\ \frac{\dot{Q}}{u_0 b_{fo}^{\frac{1}{3}} H_{ef}^{\frac{5}{3}}}, & V' > 0.19 \end{cases} \tag{33}$$

And:

$$V' = \frac{u_0}{w^*} \tag{34}$$

Where:

$$w^* = \frac{g\dot{Q}}{b_{fo}\rho_0 c_p T_o} = \frac{9.81 \cdot 6000}{2.27 \cdot 1.205 \cdot 1.005 \cdot 284} = 75.4$$

$$V' = \frac{u_0}{w^*} = \frac{3.0}{75.4} = 0{,}04$$

$$\Delta T_{max} = 17.5\frac{\dot{Q}^{\frac{2}{3}}}{H_{ef}^{\frac{5}{3}}} = 17.5 \cdot \frac{6000^{\frac{2}{5}}}{3^{\frac{5}{3}}} = 229{,}9 \rightarrow T_{max} = 240{,}9\ C$$

8.2 Flame length

Used to calculate the flame length and then comparing it with the models.

$$L_f = \frac{1370\dot{Q}^{0.8}u_0^{-0.4}}{(T_f - T_0)^{\frac{3}{2}}H^{\frac{3}{2}}}$$

$$L_f = \frac{1370 \cdot 6000^{0.8} \cdot 3^{-0.4}}{(600-11)^{\frac{3}{2}} \cdot 6^{\frac{3}{2}}}$$

$$L_f = 4.43\ m$$

9 Annex B: Tabled results

Table 7 shows the same results as figure 23, only presented as a table.

Table 6 Temperatures at the measurment station

	Position				
	0.7 m	1.8 m	2.9 m	4.0 m	5.1 m
	Gas temperature (^{o}C)				
Scale1	21.8	32.1	43.3	49.3	52.3
Scale065	22.8	34	41	45.5	47.3
Scale04	11.1	12.8	16.8	20.3	21.3
Scale015	19.1	27.06	30.2	33.1	34.9
Scale005	11.1	11.3	11.6	12.3	12.7
Test data	19	20.7	21.8	23.2	23.2

10 Annex C: FDS input file

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&TIME T_END= 600, /

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/Mescellancous Parameters/
/SURF_DEFAULT='CONCRETE'/
&MISC TMPA=11/
/U0=8/
/RESTART=.FALSE./

&MISC SURF_DEFAULT='WALL'/

/*******************  COMPUTATIONAL GRID
**********************************************

&MESH ID='Tunnel', IJK=2800,36,24, XB=-100, 600, 0.0, 9.0, 0.0, 6.0 /

/********************* Passive ventilations openings MESH 1:
*******************************************
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HØGSKOLEN STORD/HAUGESUND

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/Data hentet fra FDS 5.2 user guide

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/********************** Output ****************************************
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/*********************** MATERIAL & SURFACE
********************************************



&MATL ID             = 'LIGHT-CONCRETE'
     DENSITY          = 1200.
     CONDUCTIVITY      = 1.0
     SPECIFIC_HEAT     = 0.88 /

&MATL ID             = 'STEEL'
     EMISSIVITY       = 0.5
     DENSITY          = 7850.
     CONDUCTIVITY      = 45.8
     SPECIFIC_HEAT     = 0.46 /

&SURF ID             = 'WALL'
     RGB            = 170,170,170
     MATL_ID          = 'LIGHT-CONCRETE'
     THICKNESS        = 0.1 /

&SURF ID             = 'BURNER'
     COLOR           = 'BLACK'
     MATL_ID          = 'STEEL'
     THICKNESS        = 0.005 /



&TAIL /
/*********************** End ******************************************
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