Lecture

CHAM

Fire Modelling

Fire Modelling

Fire modelling enables one to:

- Check smoke ventilation is adequate
- Predict development of smoke layer with time
- Predict visibility distance (sight length) through smoke
- Predict how much time will be available for escape
- Predict how hot surfaces will get

Fire Modelling

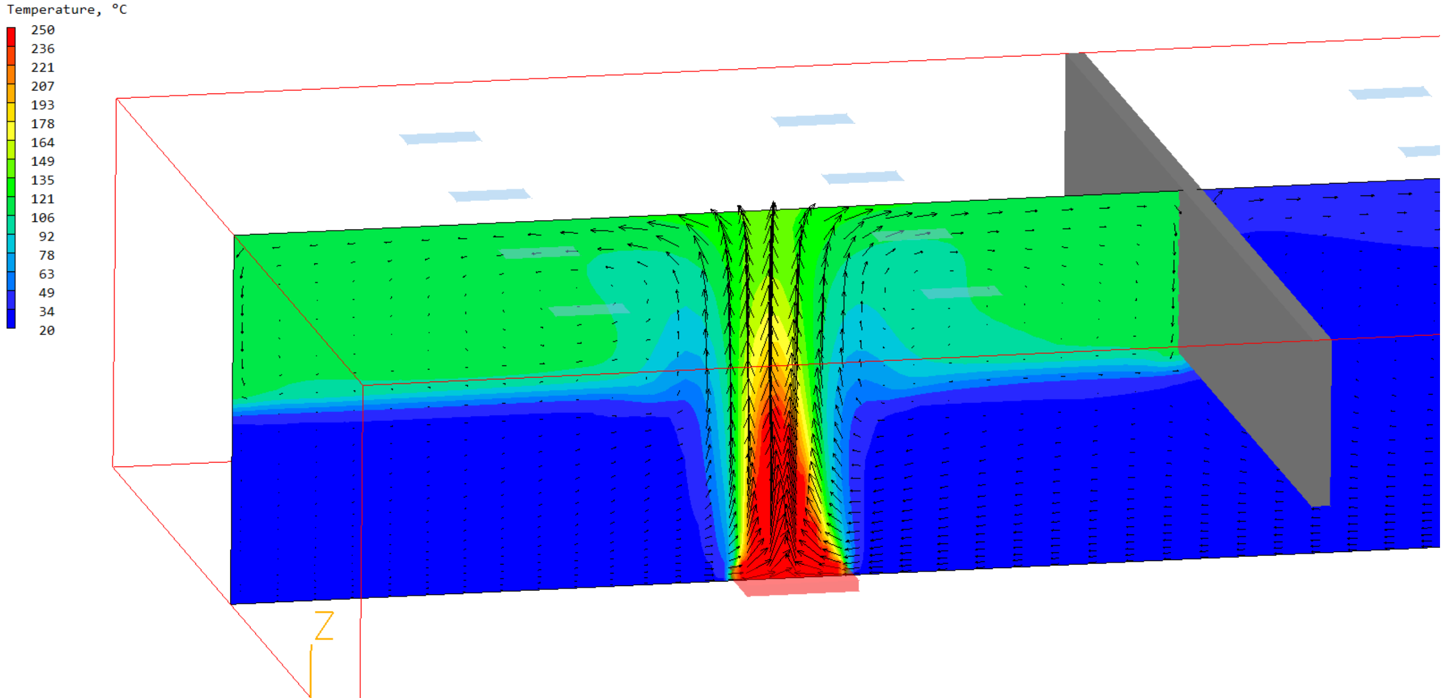
- Two approaches to fire modelling with CFD:

- Specified heat source within a specified region (the “Fire object” in VR)
- Use a simple combustion model (e.g. “mixed is burnt”)

- In effect, the latter predicts the shape and size of the burning region – the former specifies them
- Using a combustion model is more complex and would require “core” PHOENICS rather than FLAIR
- Here we will focus on specifying the heat source using the Fire object in VR

Example

- Fire in a large hall with smoke vents in the ceiling and a smoke dam
- Note fire plume and temperature stratification
- Red region shows temperature > 250 C

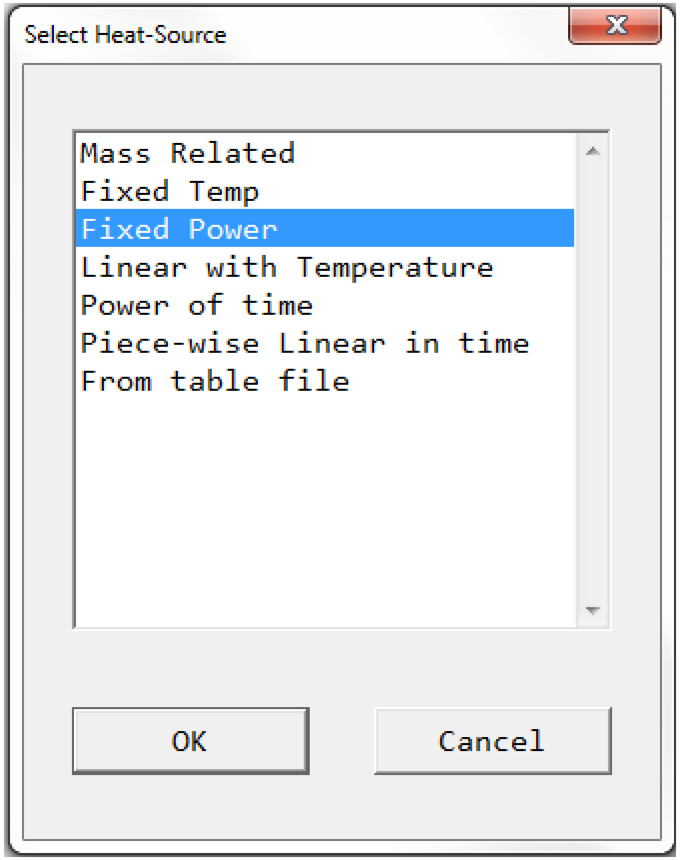


The Fire Object

- Fire object enables details of the fire to be specified
- Typically, a rectangular box with specified size (no particular benefit from being e.g. “car-shaped”)
- Need to specify:
  - > heat source as function of time
  - > mass source (i.e. mass of gas vaporised from burning materials)
  - > scalar source (i.e. source of smoke concentration)
- Typically:
  - > heat source will be specified in watts
  - > mass source defined as “heat related”
  - > scalar (smoke) source defined as “mass related”
- Plus various numerical data, to be mentioned later

Heat Source Options

- Clicking the Heat Source button offers the following possibilities.



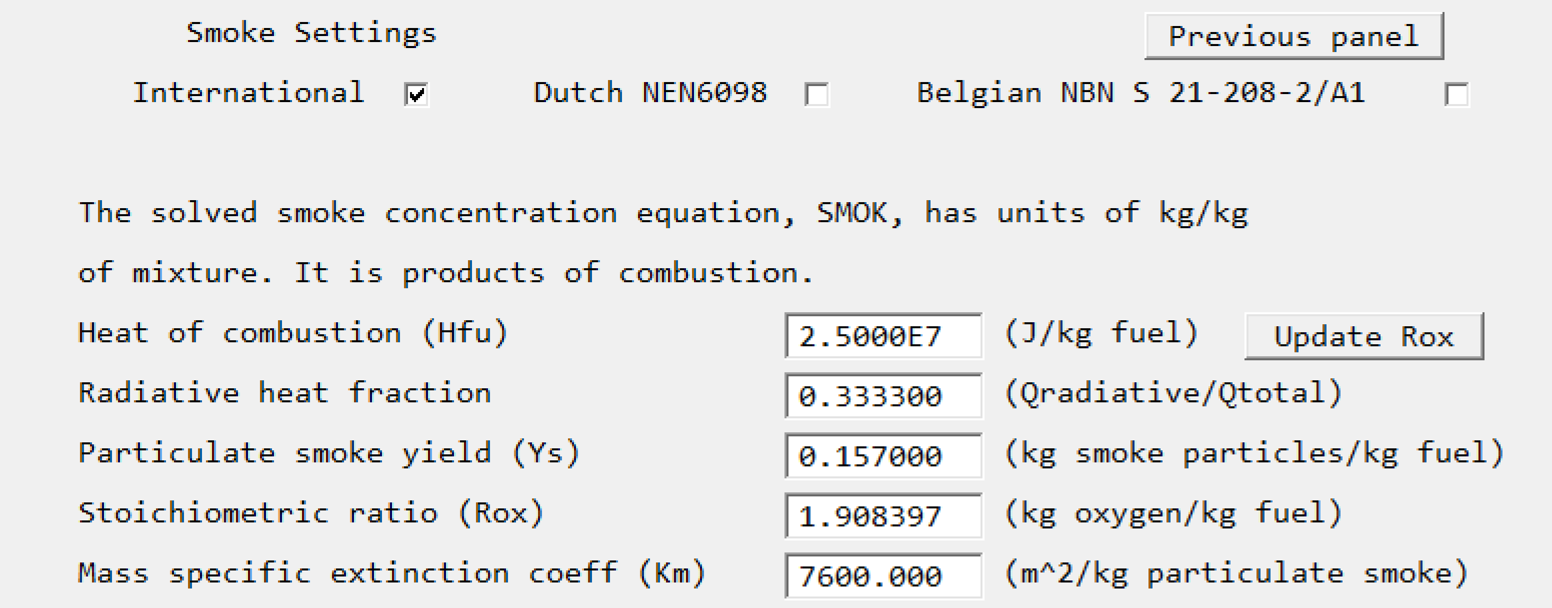
To utilise an empirically-derived heat release curve, the final two options may be helpful – piecewise linear, with the data derived either from a menu panel or from a table file.

Smoke

- To predict smoke generation you must click “Solve smoke fraction” to ON
- This is done in the “Models” menu
- Smoke is solved as a mass fraction, i.e. kg_smoke per kg_(air+smoke)
- The “Settings” button allows one to set a number of important constants – see next panel

“Smoke Settings” panel

- Important constants that should be set:



Smoke Settings

International ☑ Dutch NEN6098 ☐ Belgian NBN S 21-208-2/A1 ☐

The solved smoke concentration equation, SMOK, has units of kg/kg of mixture. It is products of combustion.

Heat of combustion (Hfu)	2.5000E7	(J/kg fuel)
Radiative heat fraction	0.333300	(Qradiative/Qtotal)
Particulate smoke yield (Ys)	0.157000	(kg smoke particles/kg fuel)
Stoichiometric ratio (Rox)	1.908397	(kg oxygen/kg fuel)
Mass specific extinction coeff (Km)	7600.000	(m^2/kg particulate smoke)

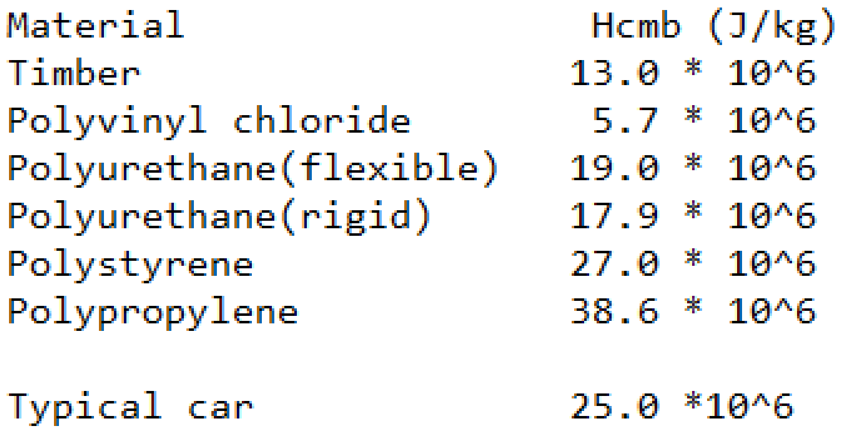
- These values are for the “International” setting, which is the default in FLAIR
- The user should consider whether these values are suitable or should be changed

Heat of Combustion

- The heat of combustion and the stoichiometric ratio are not really “smoke settings”, they are fundamental parameters controlling the fire
- They also appear in the Fire object attributes panel
- However, they are best set here in the Smoke Settings panel
- Some typical values are given in the next panels

Heat of Combustion

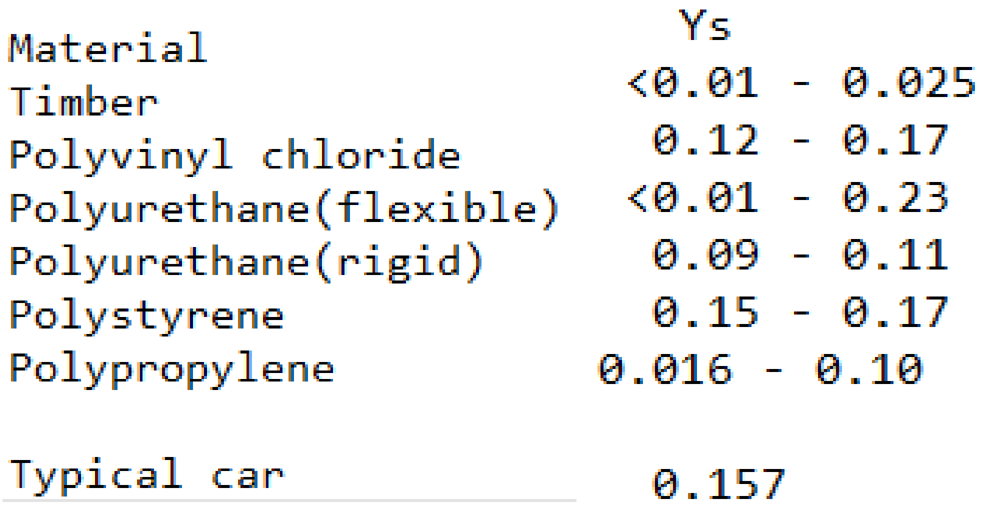
- The heat of combustion (J/kg) is the heat released when 1 kg of fuel burns
- This 1 kg of fuel reacts with Rox kg (say) of oxygen; Rox is known as the stoichiometric ratio
- Some typical values for the heat of combustion:
- (from CIBSE Guide E, table 10.7):



Material	Hcmb (J/kg)
Timber	13.0 * 10^6
Polyvinyl chloride	5.7 * 10^6
Polyurethane(flexible)	19.0 * 10^6
Polyurethane(rigid)	17.9 * 10^6
Polystyrene	27.0 * 10^6
Polypropylene	38.6 * 10^6
Typical car	25.0 *10^6

Particulate Smoke Yield

- Some typical values for the particulate smoke yield, units kg/kg-fuel:
- (from CIBSE Guide E, table 10.7)



Material	Ys
Timber	<0.01 - 0.025
Polyvinyl chloride	0.12 - 0.17
Polyurethane(flexible)	<0.01 - 0.23
Polyurethane(rigid)	0.09 - 0.11
Polystyrene	0.15 - 0.17
Polypropylene	0.016 - 0.10
Typical car	0.157

Models for Car Fires

- The “Dutch” or “Belgian” fire models (see previous slide) are intended for modelling car fires, e.g. in underground or multi-storey car parks
- These models are not discussed here. But in brief:
- When these are selected, options appear in the Attributes panel for the Fire object to select from a number of appropriate heat-release curves
- The Dutch model also has its own formula for visibility distance (to be mentioned later)
- Full details are given in the description of the Fire object in the FLAIR User Guide TR313, in POLIS

- http://www.cham.co.uk/phoenics/d_polis/d_docs/tr313/tr313.htm#Fire

Radiation

- In a fire, the heat output is both convective (i.e. direct heat transfer to the air) and radiative
- Typically, about 2/3 convective and 1/3 radiative (the "radiative fraction")

- Two approaches to fire modelling:
- (1) The radiative part can be modelled using a radiation model
- OR (2) assume the radiation has no local effect – do not include it in the model, and reduce heat release by the amount of the radiative fraction

Radiation

- PHOENICS has the capability of modelling the radiation, using the IMMERSOL model

- User must decide whether or not to use IMMERSOL
- For example, it is required if heating of nearby surfaces is to be predicted
- If radiation is modelled, the radiative fraction must be set to zero – as the full heat release must now be modelled

Radiation

- Modelling radiation adds considerably to the complexity of the model
- and adds computer time!
- So – only model radiation from fire if this is really required

Steady or Transient?

- With CFD in general, modelling a transient is generally thought of as more complex than steady-state
- But for fires, the opposite is often true – a transient run is often easier to converge than a steady run
- You could model steady if:

  > heat release is constant
  > heat release is not large
  > you are interested in long-term effects such as height of the smoke layer
  > you are not interested in time available for escape
  > you are not interested in rate of heat-up of nearby surfaces

- Otherwise, model transient

Modelling a Transient Fire

- Need to consider the time step carefully
- Small step (e.g. 1 second) will probably give good convergence
- Unfortunately may also imply long run time!
- Large step (e.g. 10 seconds) makes time requirement more manageable
- But convergence likely to be more difficult – may need more sweeps, which rather defeats the benefit of the large step
- We advise some experimenting and careful consideration in choosing the time step
- To monitor the progress of the fire and smoke it is important to dump frequently (“Output” / “Write flow field”)

Visibility Distance

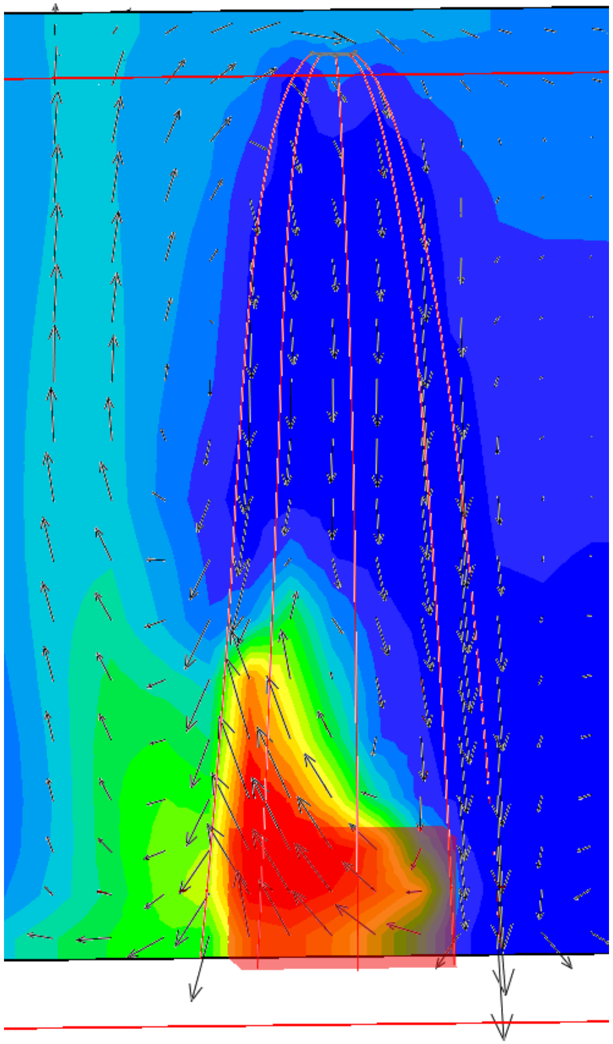
- Visibility distance is an important parameter when considering fire safety in a smoky environment
- SLEN – how far you can see <u>objects</u> through smoke
- SLN2 – how far you can see <u>lights</u> through the smoke
- Activated in the Smoke Settings panel (“Models” menu)
- These parameters relate to the smoke concentration at the observer’s location
- They do not take into account variations in smoke concentration along the line of sight
- The latter can be handled using the “Light intensity reduction” feature (expensive in run time) – see TR313

Visibility Distance

- A maximum value (default 30m) is prescribed for the visibility distances – greater values than this are not of practical interest
- SLEN = 30m is therefore deemed to be good visibility
- People are reluctant to proceed through smoke if the visibility is less than 8m (CIBSE fire-engineering guide)
- So for the purposes of escape, the visibility should be greater than 8m
- Easily assessed by plotting SLEN contours in the Viewer
- Smoke concentration plots are often better presented using SLEN rather than SMOK

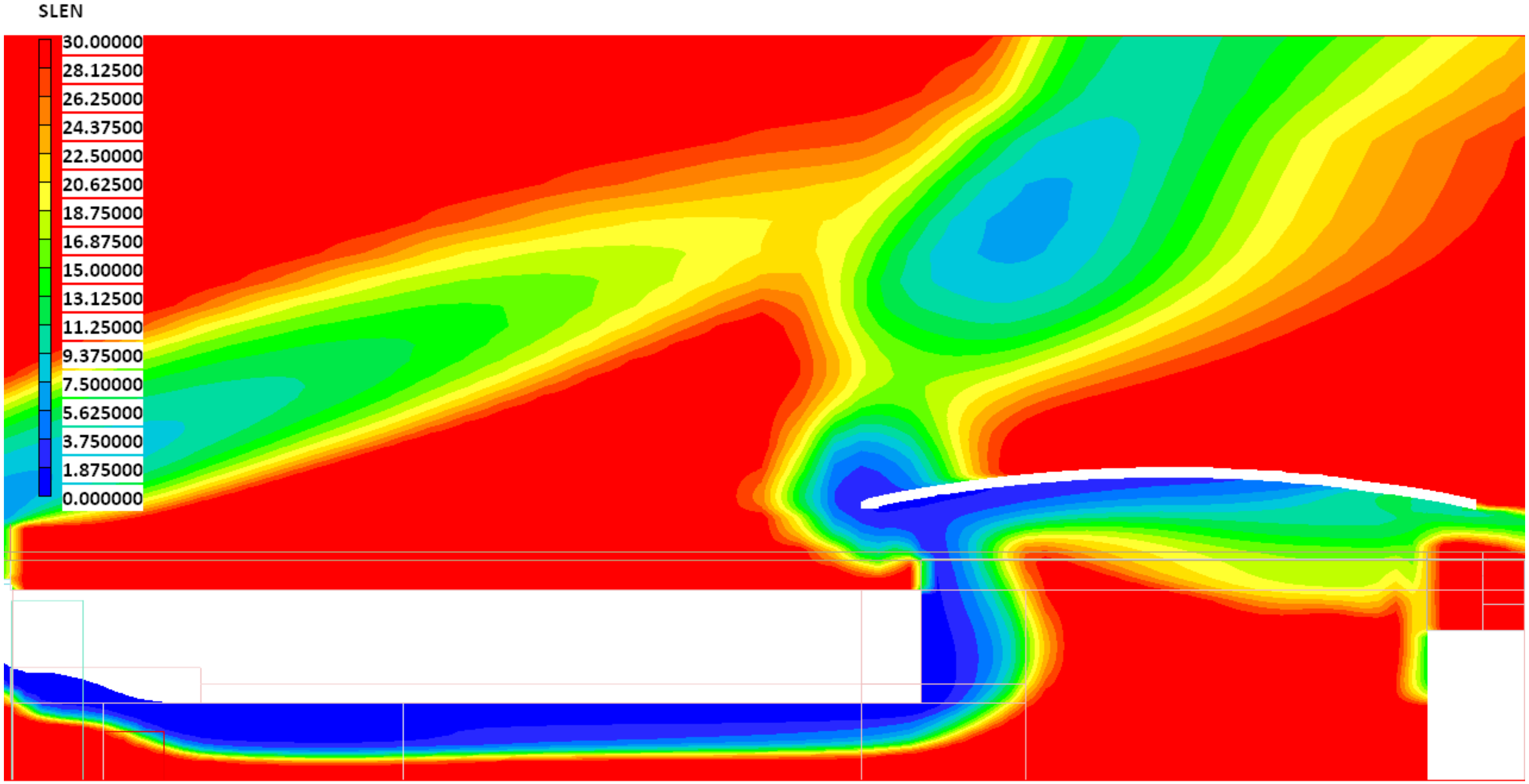
Modelling Sprinklers

- “Sprayhead” object in FLAIR
- Droplets tracked using Lagrangian GENTRA module
- Can set droplet size, volume flow rate, spray angle, etc
- The droplets evaporate, providing a cooling effect



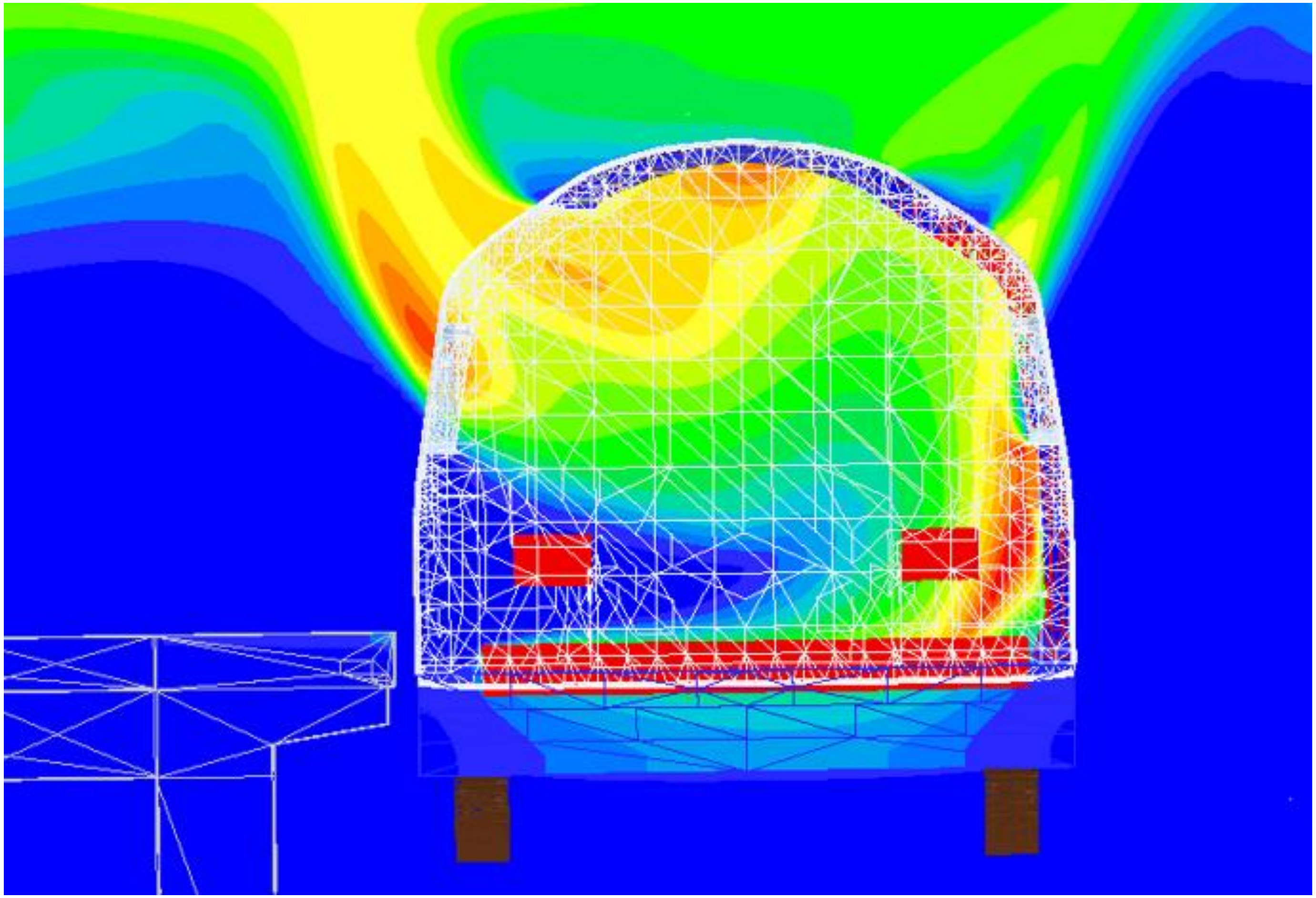
Example – Fire in a Mall

- Fire in a shopping mall
- Wind blows smoke (blue) along mall from left to right
- Reaching atrium, smoke rises to curved roof, then out



Example – Fire in a Tube Train

- Temperature contours



Luggage Fire in Air Terminal

- Plot of visibility length – colours reversed, smoke is red
- High smoke concentrations near ceiling only
- Green lines show the smoke extracts (at bottom of smoke layer)
- Design validated