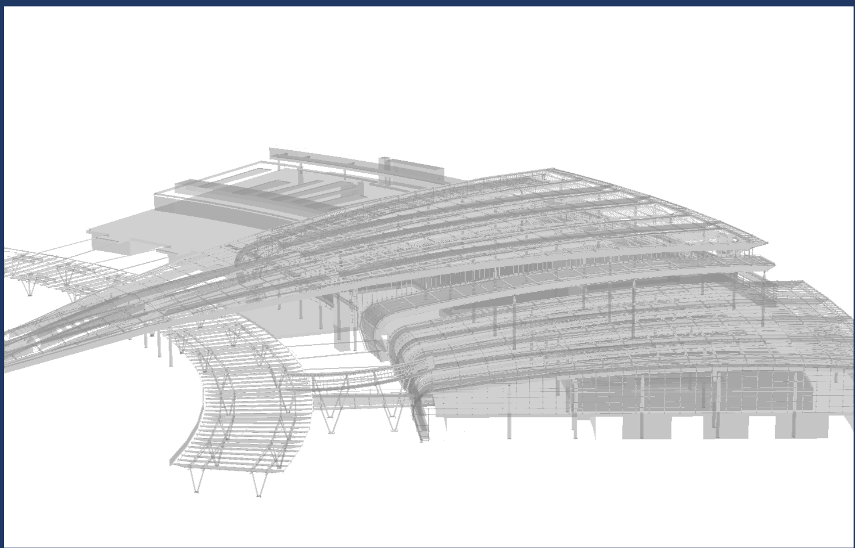
PHOENICS Case Study: Fire
Airport Fire and Smoke Simulation

Sir Seewoosagur Ramgoolam International Airport, the primary airport in Mauritius, was re-designed to cope with increased traffic - experienced and anticipated. As part of the design processes, CHAM was contracted by Gustave Maurel & Fils to simulate fire control measures operating within the main and baggage halls.

The project involved importing a 3D model of the new terminal building and incorporating its major structures, heat sources and ventilation system to investigate heat and smoke dispersion from a hypothetical exhibition car fire in the departure hall on its first floor; an, a luggage fire in the passport control area on level 2.



CAD file imported into PHOENICS

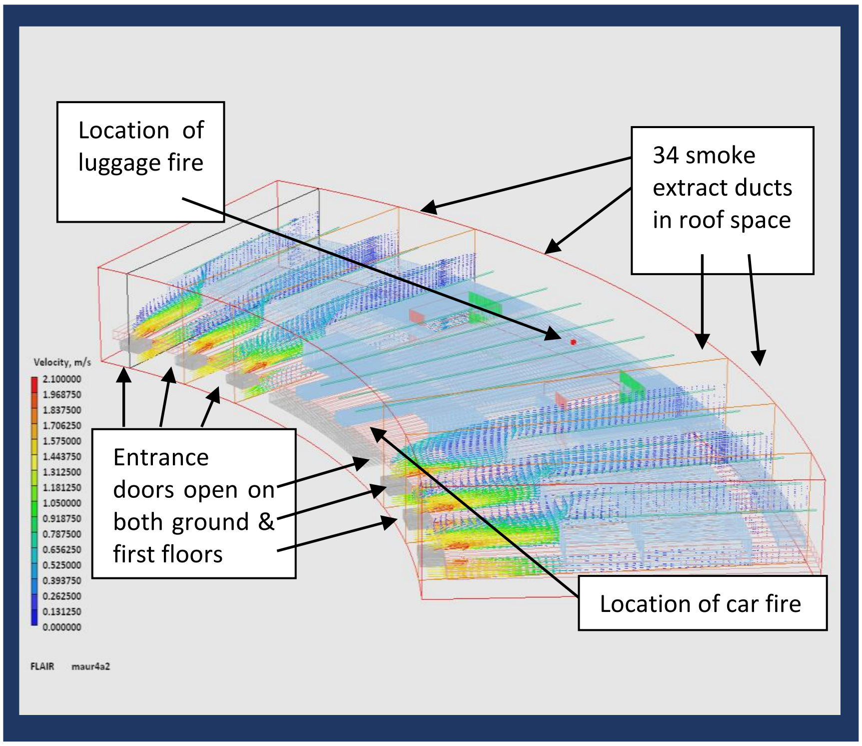
Once a fire starts, the normal ventilation system is de-activated automatically with the airport's twelve primary external access doors, located on the ground floor, being opened fully to permit public egress and provide a source of fresh air.

The emergency smoke extraction systems located in the airport's roof structure are activated.

Concentration, Heat and Momentum Limited (CHAM)
Bakery House, 40 High Street, Wimbledon Village, London, SW19 5AU, England
Tel: +44 (0)20 8947 7651 Email: phoenics@cham.co.uk Web: www.cham.co.uk

Model construction

The CFD model was constructed using a polar coordinate meshing system suited to the airport's design layout. The work scope included constructing a CFD model incorporating provision of smoke extraction grilles from supplied drawings and extraction rates based upon operational specification.



Both transient and steady-state simulations were undertaken. Steady-state case results showed the overall flow regimes including major heat and smoke product sources, air inlet and smoke extraction. Steady-state results reflect a "worse-case" scenario of a continuous fire with constant heat and smoke release; and fail to reflect the effectiveness of smoke-extraction units over a specified period of time.

Transient calculations were needed to show the accumulation and dissipation of smoke product, its layering and expected visibility at head height, throughout the progression of each fire simulated. As before, the CFD model incorporated operation of the smoke extraction system whilst assuming that the normal ventilation system is inactive, but with the addition of a representative fire curve over time.

Fire specification

The heat and product output of both luggage and car fires were in accordance with CIBSE guidelines. In transient mode, the luggage fire was set to grow and dissipate over 10 minutes, and the car fire over a 20-minute period, to simulate development of the smoke plume and layer. In this example, the heat release increases linearly for 300s, remains constant to 600s, and then declines linearly after 1200s total.

For the car fire the smoke production was based on a heat of combustion of 2.5×10^7 J/kg, and a particulate smoke yield of 0.157kg_smoke/kg fuel; for the luggage fire the corresponding figures were 5.7×10^6 J/kg and 0.16kg_smoke/kg fuel. These values are typical for polystyrene and PVC respectively. It was also assumed that the stoichiometric ratio was 1.908kg_O2/kg fuel for the car fire and 0.435kg_O2/kg fuel for the luggage fire.

Sight Length

The variable "sight length" or "visibility" (SLEN) is been used in this study to display variations of smoke concentration. This measure of how far one can see through the smoke, is inversely proportional to the smoke particulate density (and proportional to the brightness of the object being looked at). Following CIBSE Guide E this quantity is defined as:

$$SLEN = \min (D_{max}, A/(K_m * C_{s,p}))$$

Where Km is the mass-specific extinction coefficient in m2/kg-particulate-smoke, $C_{s,p}$ is the particulate smoke concentration in kg/m^3 of mixture, and A is an empirical coefficient with the value A=3 for light-reflecting objects. In the literature it has been established, empirically, that the value of K_m can be considered a constant of the order of 7000 to 8000 m^2/kg particulate smoke. CIBSE Guide E, and other sources, suggest a value of 7600 m^2/kg for the flaming combustion of wood or plastics as has been used in the model.

Visibility coefficient D_{max} is defaulted to 30m; this provides an effective maximum for SLEN, and ensures that visibility has a finite rather than infinite value in smoke-free regions.

The particulate smoke concentration $C_{s,p}$ is derived from the solved-for combustion-products mass-fraction C_s via the expression:

$C_{s,p} = r * Y_s * C_s /(1+R_{ox})$

Where r is the mixture density (kg-product/kg-mixture), Y_s is the particulate smoke yield (kg-particulate-smoke/kg-fuel), and R_{ox} is the stoichiometric ratio (kg-oxygen/kg-fuel). CIBSE Guide, E suggests that, for the purposes of escape, visibility should be at least 8m.

Mathematical Representation

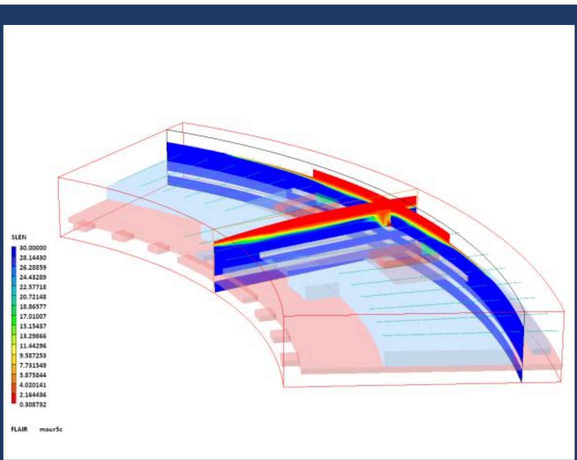
Partial differential equations for steady flow were solved, representing conservation of mass and three components of momentum, these being the familiar Navier-Stokes equations which govern fluid flow. Conservation equations of this form have been solved for: three components of momentum, thermal energy, two turbulence variables (k and epsilon - see below), and smoke concentration. The mass continuity equation is also solved and is expressed in the form of a pressure-correction equation, from which the pressure field is determined.

A "turbulence model" represented the effects of turbulent mixing. The standard "k-epsilon" model was employed; this requires the solution of two additional equations, for turbulence kinetic energy (k) and dissipation rate (epsilon). It was not considered necessary to solve for radiative heat fluxes.

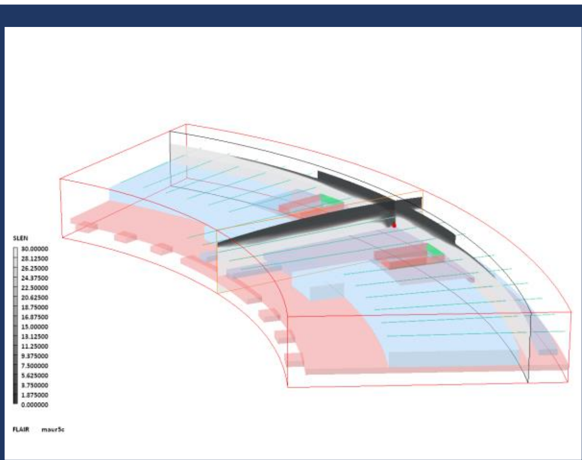
Numerical Solution

Numerical grids of between 1.2 million and 1.4 million cells were used for the solution, representing an appropriate balance between the competing demands of computer run time, accuracy and available budget.

Results - Luggage Fire Results – level 2



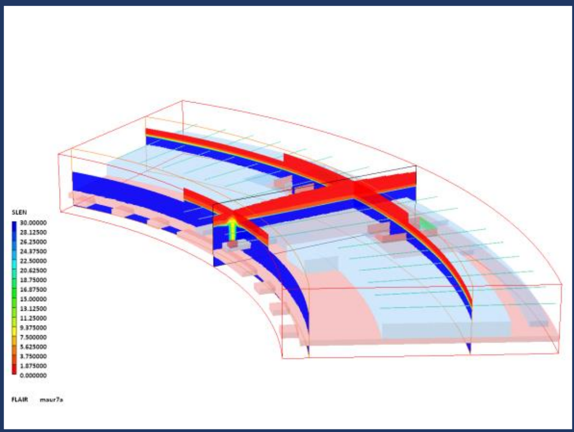
Sight Length after 20 minutes
Blue/Green/Yellow acceptable – Orange/Red unacceptable



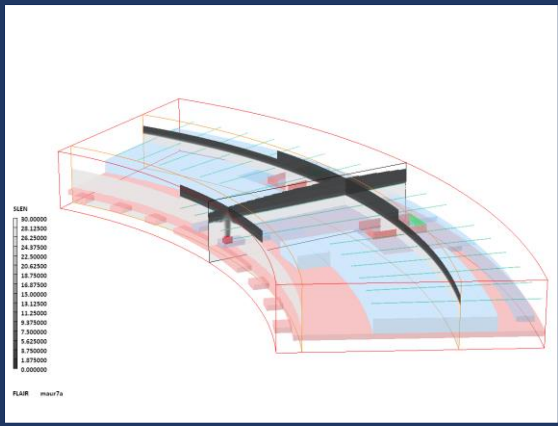
Sight Length after 20 minutes – Grey Scale

Car Fire Results – level 1

The results show that the fire generates both heat and smoke product in the form of a plume that rises towards the smoke extraction grilles. Any smoke that passes the extraction grilles accumulates in the roof structure but does not impede visibility at lower levels. With the exception of the immediate vicinity of the fires, the visibility (sight length) at 2m above floor level remains good throughout the airport and above the 8m minimum suggested by CIBSE. *Click [here]() and [here]() for animations.*



Sight Length after 20 minutes: Blue/Green/Yellow acceptable – Orange/Red unacceptable



Sight Length after 20 minutes – Grey Scale