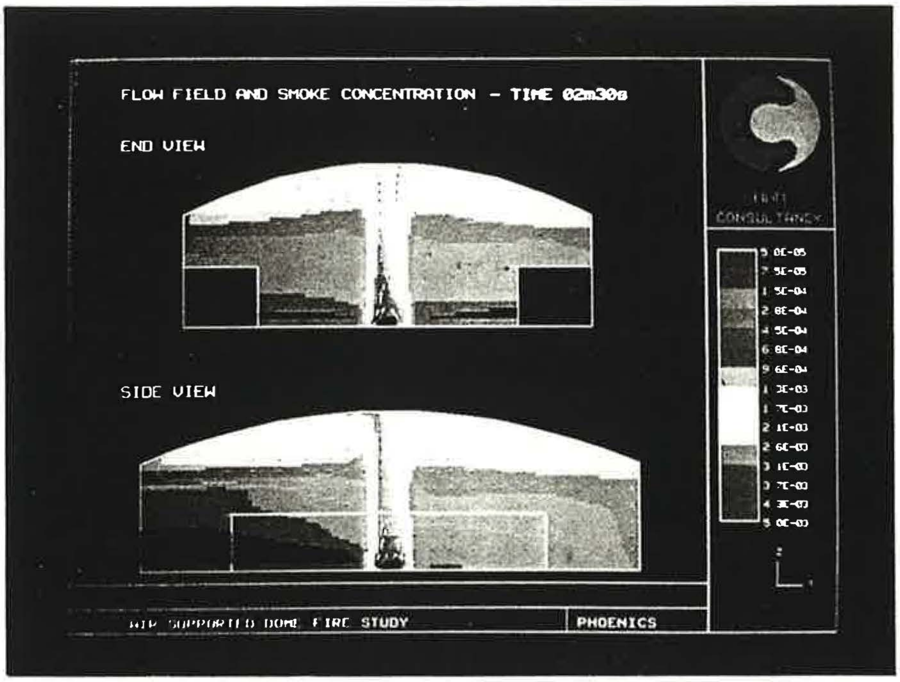
#3772

Rising from the ashes

AIVC

Computational fluid dynamics is a useful tool in the building industry. *Bill Pressdee* reports on Phoenics, a cfd code used for the determination of air movement in and around buildings, temperature distributions, all forms of heat transfer, and the evaluation of the potential spread of fire and smoke.



Left: After 2·5 minutes the fire plume has begun to dominate the flow field. The asymmetrical nature of the flow is due to the initial recirculatory flow induced by the heating and ventilation system.

Below: After 8·5 minutes the fire is burning fiercely, generating a strong buoyancy driven updraught. Air is drawn in at the base of the fire to support the combustion process.

Above and below: 3-D transient simulation of fire in an air-supported stadium showing velocity vectors and smoke concentration contours.

Advances in computer-aided design have been accompanied by a proliferation of applications in solid modelling and structural analysis, many of which have been taken up by various sectors of the building industry. Those for computational fluid dynamics (cfd), however, have moved more slowly. The reason for this is that the expression in mathematics of process relationships is far from simple. This not only includes flow dynamics, heat transfer and chemical reaction effects, but also turbulence, buoyancy-dominated flow, and a variety of other factors.

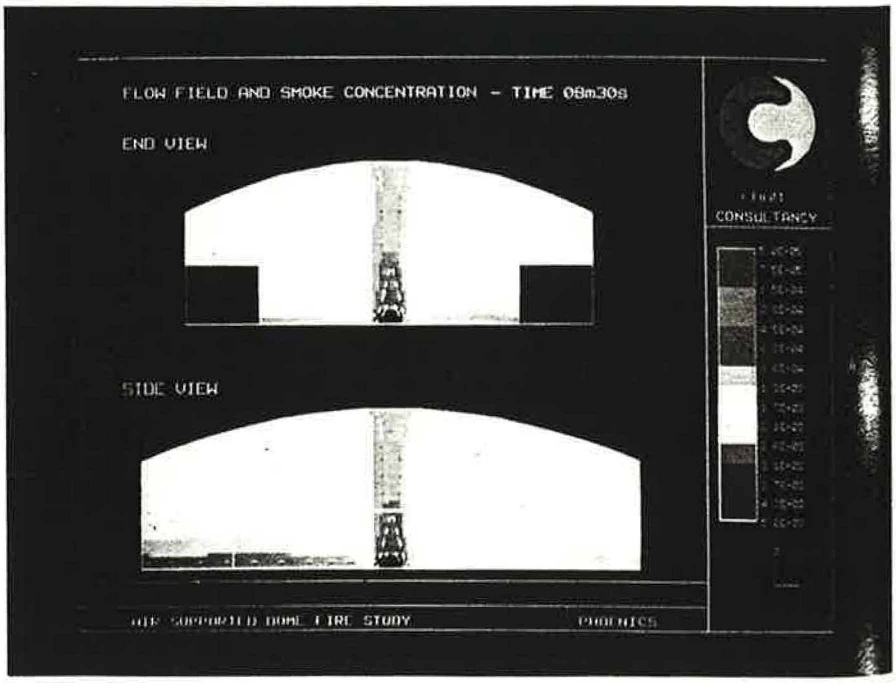
Today, however, cfd codes have grown in complexity while computer costs have decreased dramatically, making cfd modelling a cost-effective alternative to other methods of developing a relevant design and validating it. In many cases the alternatives to cfd would be either physically impossible or prohibitively expensive.

Phoenics is the computer code used for this purpose and has been developed by the British company Cham based in Wimbledon.

Using Phoenics, 2-D and 3-D models can be developed which show airflow and temperature distributions throughout domestic dwellings under various internal conditions, and the effects of varying heat sources or ventilation can be shown.

Using such models, the effective employment of various materials in the construction can be explored and optimised, and the size of equipment to provide the necessary degree of heating and ventilation throughout the house can be calculated. The effect of the external environment on the models can then be studied over a full seasonal range of weather conditons. Heat losses to the outside environment can be determined and all hot spots and cold spots can be identified and remedied.

In Sweden, such studies have taken a step further and various Phoenics studies have been undertaken by the Swedish Metereological and Hydrological Institute to examine the pressure of the wind around a small-scale house and to identify areas of weakness during gale-force winds. Such simulations have shown good correlation with wind tunnel experiments carried out by the Swedish Institute of Building Research. The useful data derived from studies on a single house have prompted further work on the more complicated flows around individual houses in a housing complex. Similar studies are being undertaken in Australia and other parts of the world.



Air flows in large buildings

CFD has been used to model auditoria and other large, complex spaces to ensure that the air circulation and temperature gradients provide comfort under all conditions. The number, size position, pressure and temperature of the sources of air flow can be optimised and, similarly, the arrangements for exhausting it.

Generally the study of airflow in large buildings is combined with prediction of the spread of fire and smoke. This is a matter of considerable interest to the building contractor, as such studies can enable preventative measures to be taken. Liability for damage caused by fire can thereby be rebutted by clear evidence that the possible hazards had been assessed and the necessary precautions taken.

A wide range of studies have been undertaken by various international bodies. The Fire Research Station of the DoE which uses a version of Phoenics (called Jasmine) offers a consultancy service with Cham to provide the benefit of their experience and expertise.

The practical alternatives to simulation studies for determining the spread of fire and smoke in buildings are limited. Even the lighting of controlled fires in completed buildings will require extensive and costly instrumentation and tests to produce useful data, much of which are prone to inaccuracy. Such tests can only address a limited number of environmental conditions, and they will stop short of reaching a state where the fire temperatures and spread constitutes a danger to the building.

Any modifications to the building as a result will be retrospective and will cost money.

On the other hand cfd studies, which are relatively low-cost, can be carried out at any time, before or during the construction, and they can be as comprehensive as required. They can even be used to test the building to destruction.

Such studies may be limited to showing the optimum positions for fire doors, smoke detectors and sprinkler outlets, but they will probably indicate in addition the safest escape routes and how fire safety can be generally improved. Various studies to this end have been completed on shopping malls, stores, air terminal buildings, power stations,etc.

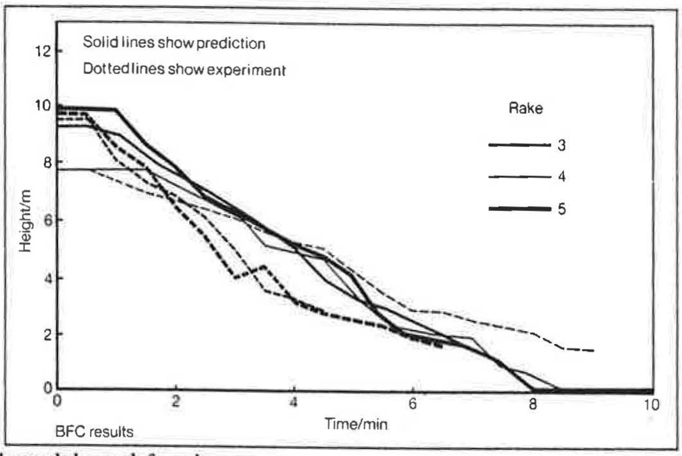
Modelling stadia

An interesting study carried out by DoE in conjunction with the Cham Consultancy Group concerned a large building in Tokyo. A Japanese company, Shimizu Construction, is developing a design for an oval sports stadium, capable of holding a capacity crowd of 60 000 under an air-supported domed roof. The glassfibre dome is to be held aloft by 25 mm (water gauge) overpressure, supplied by two compressors via a computer-controlled air conditioning system. The air is fed in via four independent quadrants around the periphery of the stadium.

The fact that a large number of people would be under cover in the stadium and in close proximity to each other made an examination of its design for fire hazards of paramount importance. To this end the company constructed a 1/6th scale model of the stadium, (11·6 m to the dome apex, and 34 m by 28 m in plan), fitted with extensive instrumentation. 19 tests were conducted with methanol fire sources placed in various locations, the combustion providing a fire duration of up to 11 minutes with an estimated peak heat release rate of 2·2 MW. One of the tests was selected for comparison with a cfd model in order to prove to the efficacy of the cfd approach.

The air system was configured to provide an air supply generated from two opposing quadrants at different temperatures to induce recirculation. A complex recirculating flow field had therefore to be modelled from the start of the test.

In addition to measurements taken on vertical arrays of thermocouples and velocity probes mounted around the stadium, smoke was released into the clean-burning, methanol plume so the smoke spread and growth of the fire plume could be recorded on video cameras. Step-by-step diagrams were developed of temperature contours and velocities during the fire and post-fire stages. The smoke plume was shown to reach the ceiling after 14 s, and subsequently the flow field changed from a lateral flow to a radial impact jet. After 70 s smoke from the central fire reached the stadium wall.



Above: The height above ground level at which the temperature has risen 10°C. As the hot gas layer thickens the isotherm descends to ground. The graph shows the excellent agreement of the simulation with the test results.

The equations of the mathematical model used for the simulation were solved using either a polar cylindrical, or a body-fitted coordinate grid. The agreement between the experimental test data and that of the simulation was shown to be excellent, except in the immediate vicinity of the fire where it was obscured by the relative coarseness of the grid. The use of a finer grid for this area should easily clarify this matter. The fact that such good agreement was obtained signifies these cfd techniques as an extremely useful modern design approach for architects, building service designers and planners.

Coding

The computer code Phoenics developed by Cham is designed to be used interactively by engineers. After more than ten years of development it has reached a high degree of complexity and user-friendliness. It can be used on a wide range of computers and workstations from the level of an IBM PC, to the largest vector-processing supercomputers.

A user can prepare a data file on the pre-processor which completely describes the problem using a menu-driven facility, using the just released Phoenics 1·5. This facility enables the fluid involved to be simply specified, whereupon parameters such as viscosity, density and specific heat are automatically set by selection from a library of common fluids, such as air or water. Difficult definitions which present problems to new users such as buoyancy forces, turbulence intensities, surface friction forces and fluid compressibility are also now covered by menu options. Additional help is given by a large library of test cases and a guidance program.

The computational grid and location of boundary conditions such as doors, windows, heaters, partitions and walls, can be displayed during set-up to ensure the problem is addressed correctly. At the conclusion of the problem set-up, a fully annotated input language command file is created which enables rapid progress to the command input mode – a boon for novices or sporadic users.

The main processor assembles and solves the relevant Navier-Stokes and additional governing equations, producing result files for vdu inspection or for printing. A post-processor is available to display 2-D or 3-D plots consisting of vectors or contours of all variables, grids and geometries, graphical relationships, as well as full on-line help facilities.

The system is flexible, allowing users to introduce their own mathematical models or replace solvers with ones devised by themselves. Phoenics can also be interfaced with other cad codes such as those used for constructional engineering, or landscape contouring. It is supplied to clients on an annual or perpetual licence, the fee depending on the facilities required and the type of computer system used. An introductory scheme enables interested organisations to try the system on their own machines over a sample period to assess its usefulness to them.