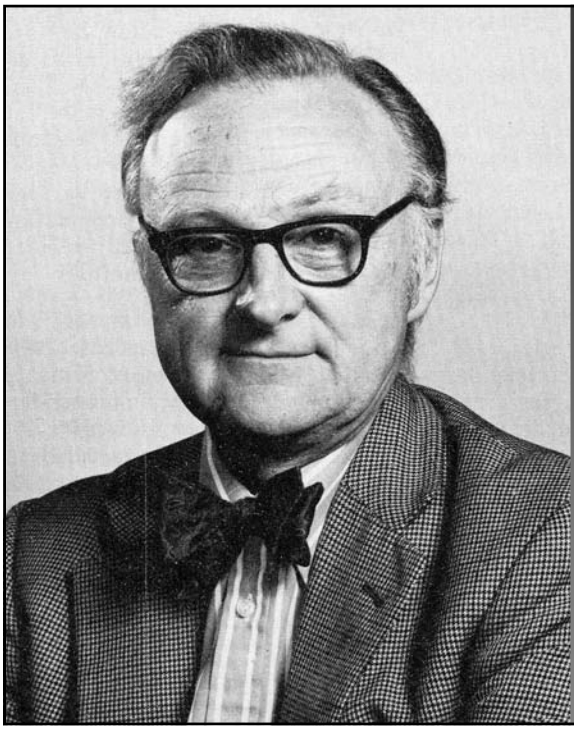
The Role of Fire Science

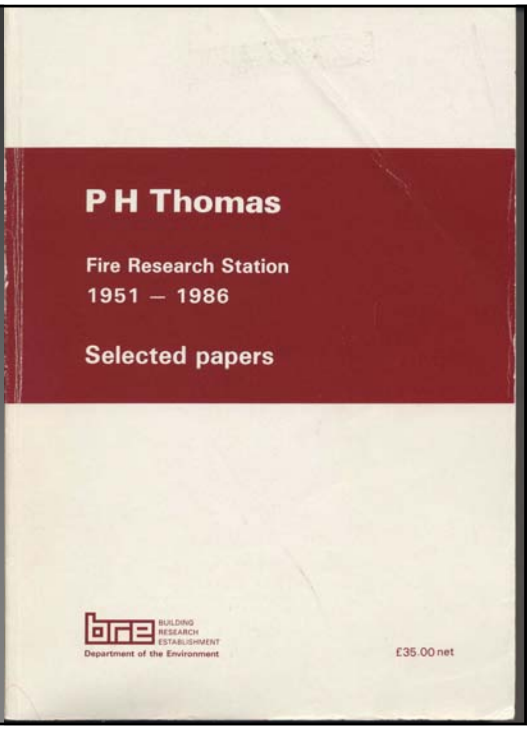
2008 Philip Thomas Lecture



- Coordinator CIB W14, 1974-1994
- Chairman ISO TC92, 1976-1995
- First Chair IAFSS, 1985-1991

Seminal contributions to so many areas of the science of fire

- self-heating
- thermal explosion
- ignition and extinction
- water sprays
- flame size
- air entrainment
- enclosure fire dynamics
- flashover
- flame spread
- smoke venting
- forest fires
- etc, etc



P H Thomas

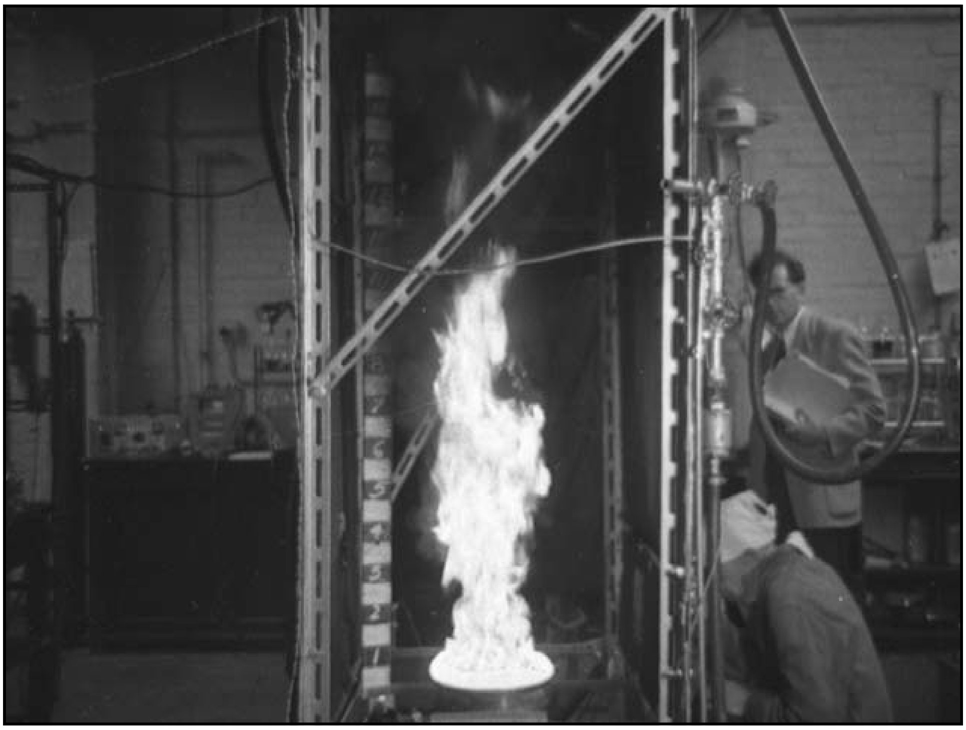
Fire Research Station
1951 — 1986

Selected papers

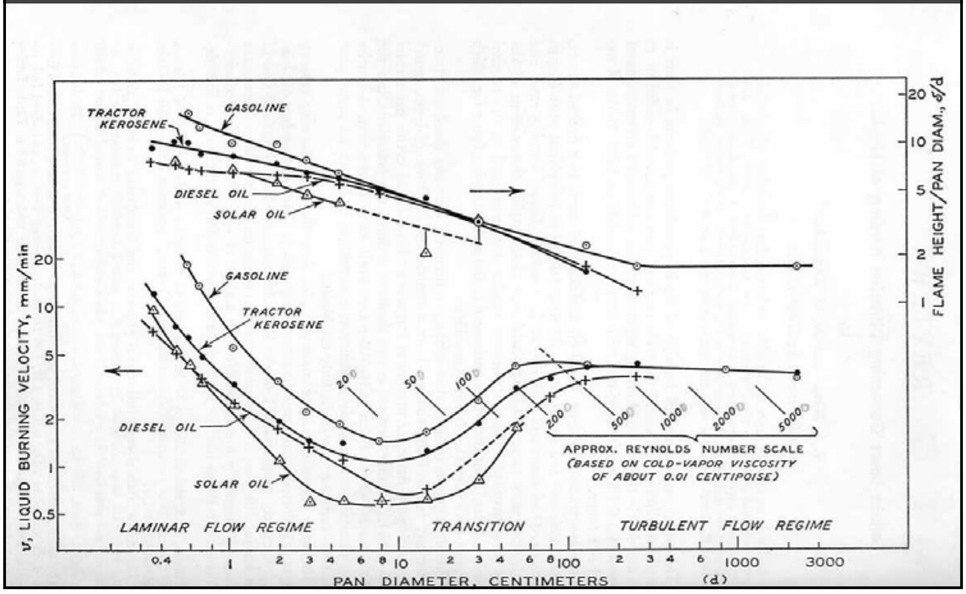
BUILDING
RESEARCH
ESTABLISHMENT
Department of the Environment

£35.00 net

Buoyant Diffusion Flames



Blinov & Khudiakov’s data (as presented by Hottel, 1958)



Flame height-dimensional analysis

- Dimensional arguments suggest flame length:

$$\frac{L}{D} \propto f\left(\frac{Q^2}{gD^5}\right)$$

if average air velocity

$$\propto L^{1/2}$$

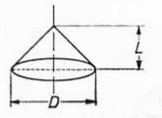
f determined from entraining surface area, then

$$\frac{L}{D} \propto \left(\frac{Q^2}{D^5}\right)^{\frac{1}{2p+1}}$$

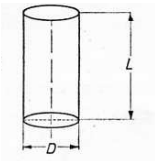
Flame height-dimensional analysis

- where p is a shape factor, varying from 0 to 2 with increasing L/D
- $\frac{L}{D} \propto \left(\frac{Q^2}{D^5}\right)$; $\frac{L}{D} \propto \left(\frac{Q^2}{D^5}\right)^{\frac{1}{3}}$; $\frac{L}{D} \propto \left(\frac{Q^2}{D^5}\right)^{\frac{1}{5}}$

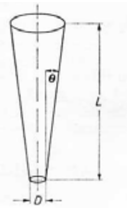
p=0

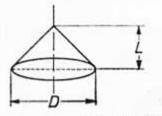


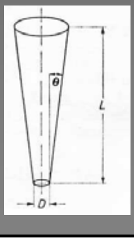
p=1



p=2







Flame height data

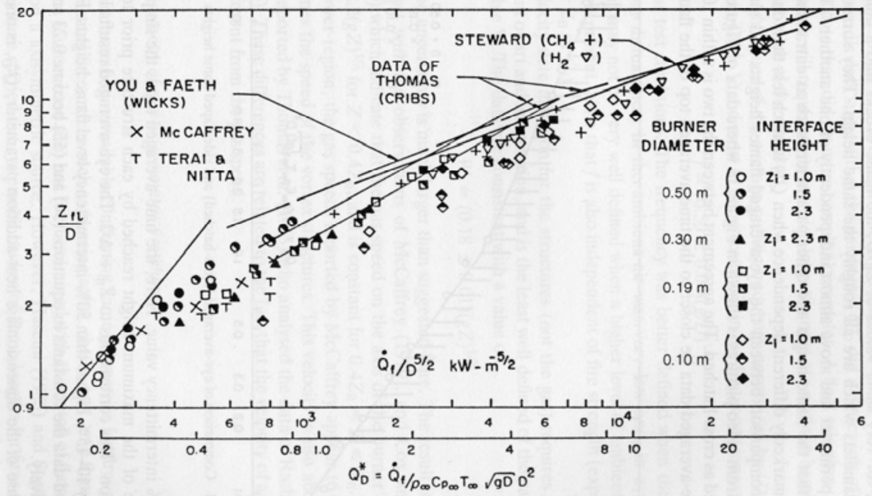
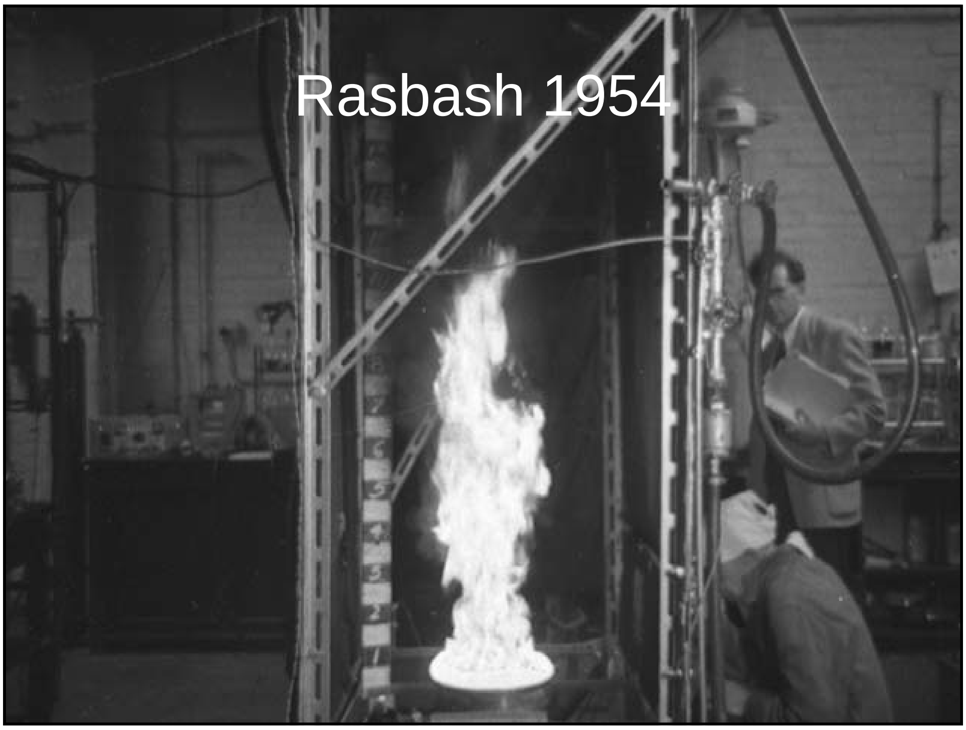


Figure 17 Eye-averaged flame-height data correlation.

Rasbash 1954



Model for flame velocity

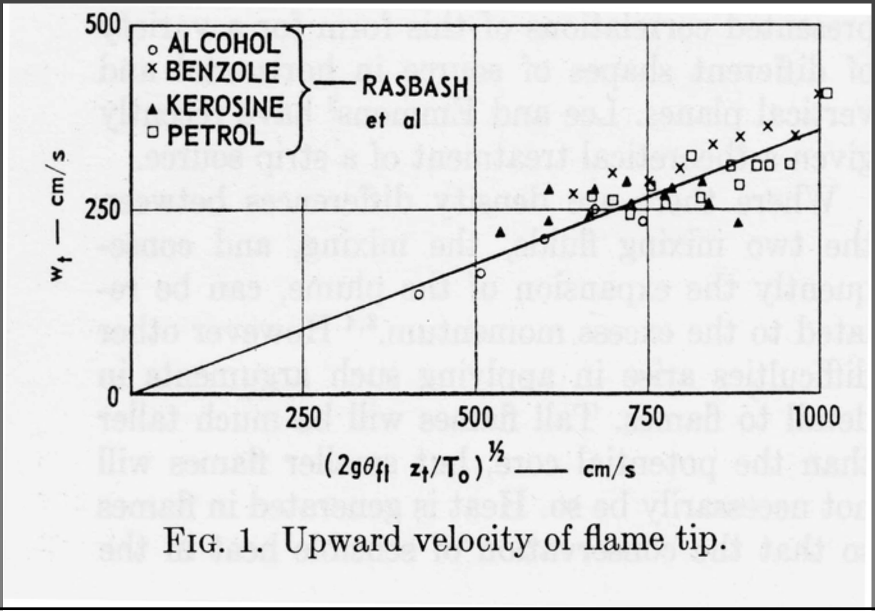
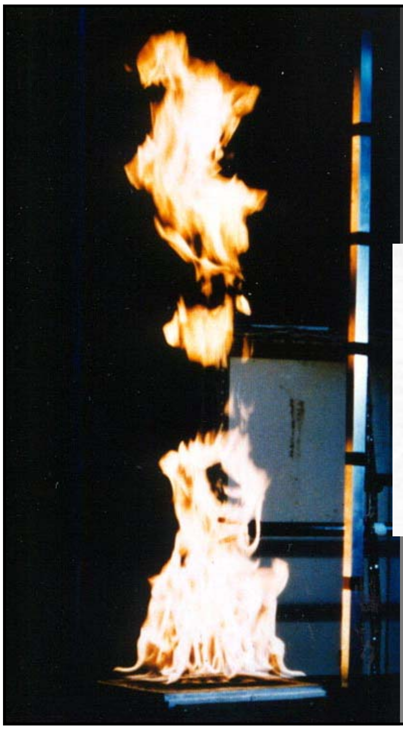
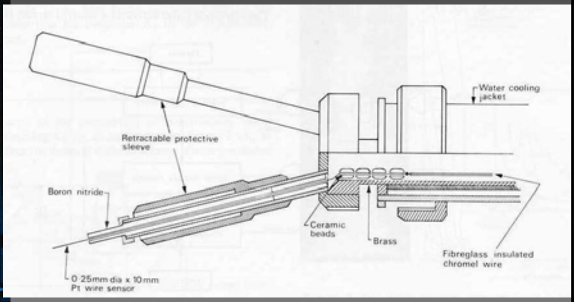


FIG. 1. Upward velocity of flame tip.

Transit time of natural fluctuations





Fluctuations in temperature and flame ionization

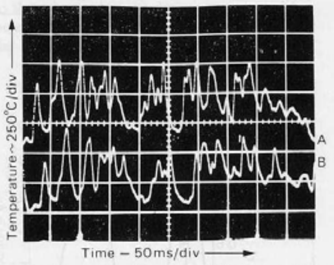


FIG. 2 - Temperature fluctuations obtained at two points A and B in fire.

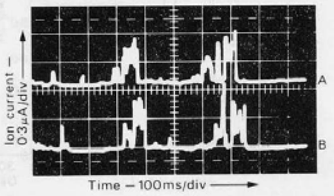
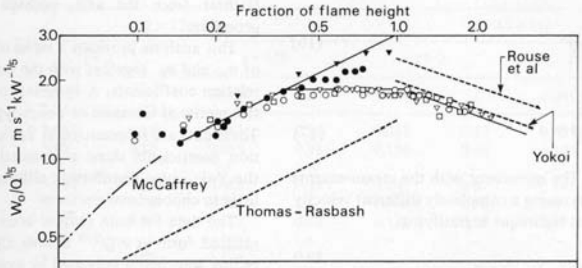
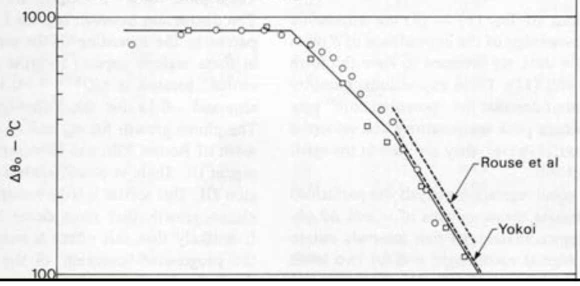


FIG. 3 - Ion current fluctuations at points A and B in fire.

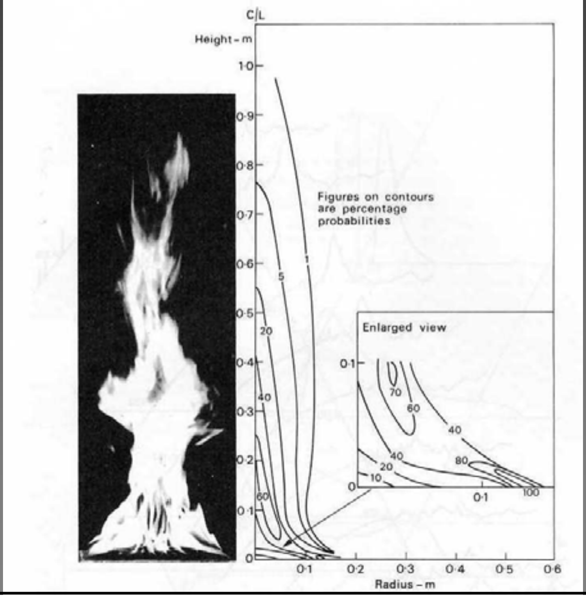
Centreline velocity & Temperature



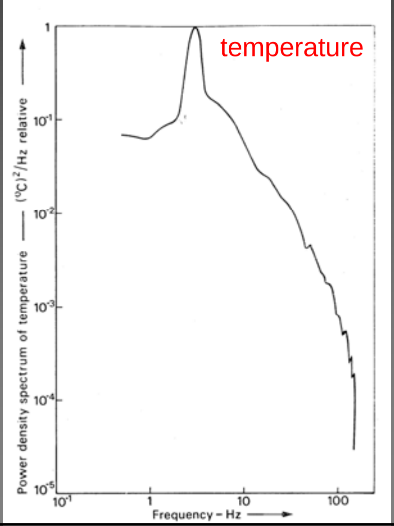
(a) Normalised velocity with height

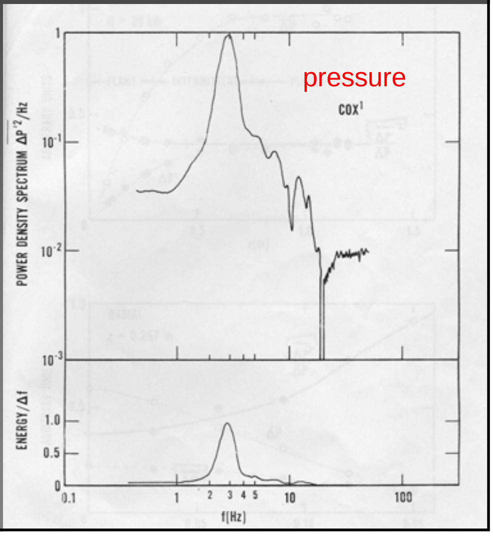


Intermittency



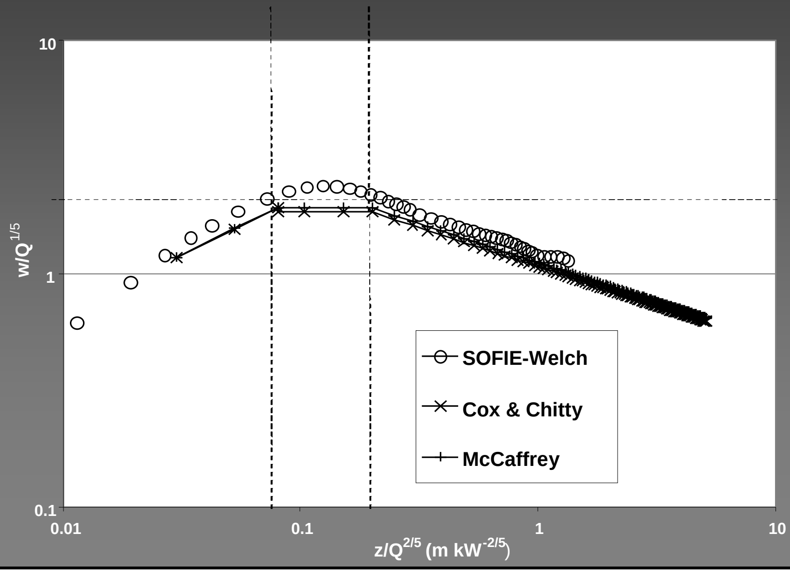
Spectra of gas temperature and pressure difference



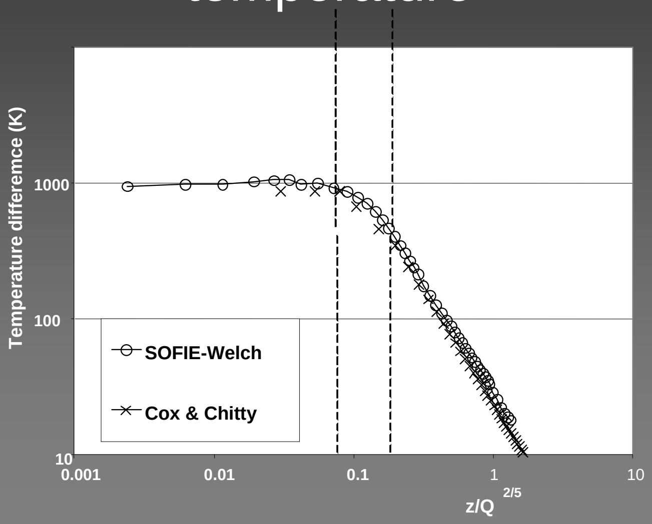


Fire Modelling

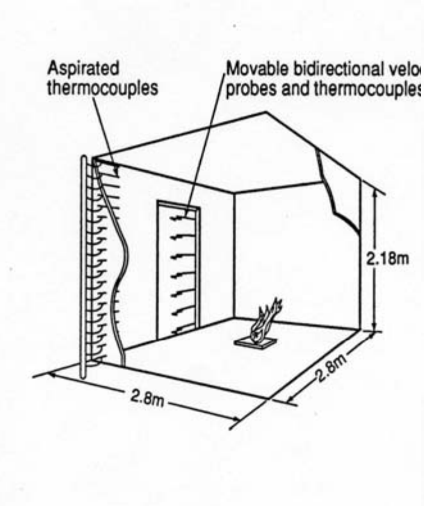
RANS CFD centreline velocity

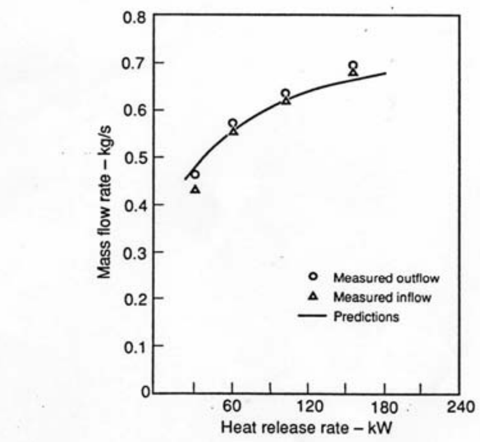


RANS CFD Centreline temperature

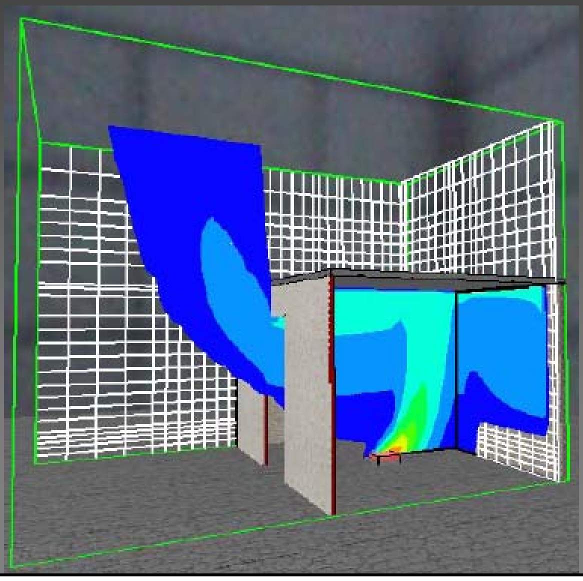


Early JASMINE RANS prediction (1983)





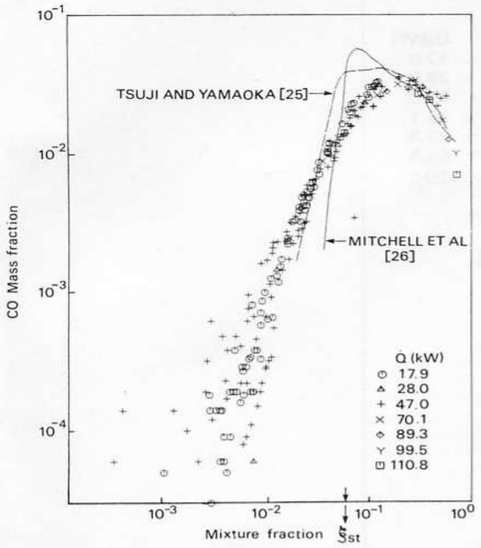
Plume deflection as predicted by CFD

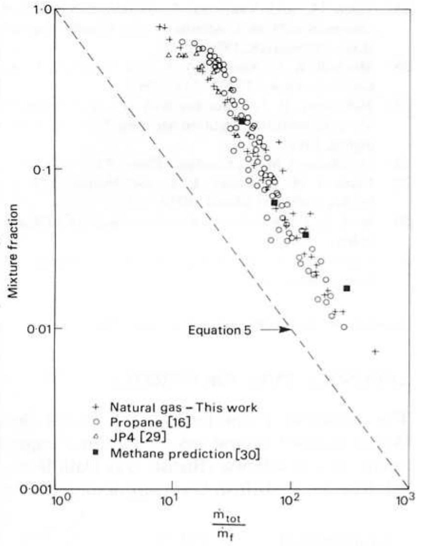


Development of “sub-models”

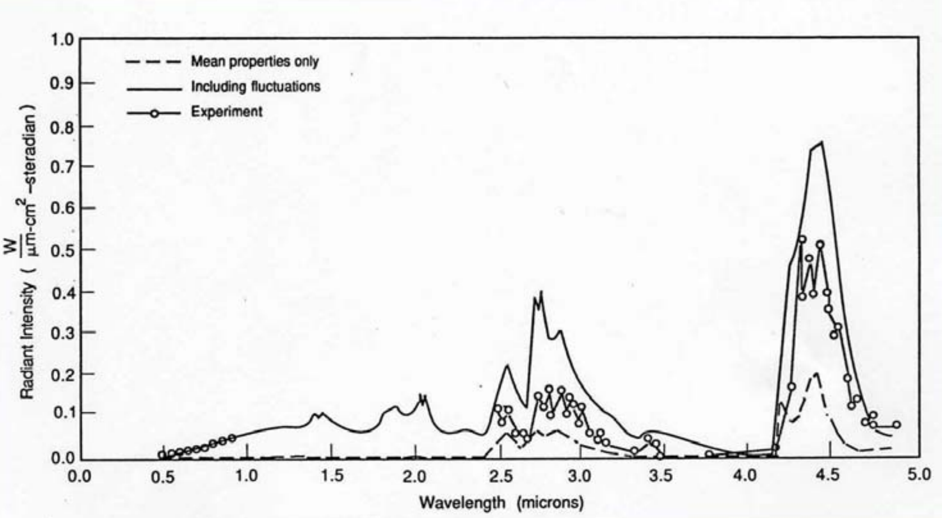
- Turbulence-chemistry interactions
- Turbulence-radiation
- Two phase flow (sprinkler droplets, fibre/particulate dispersion)
- Gas-solid interactions

Non-equilibrium species





Predicted spectral distribution using laminar flamelet model (Syed et al)



0.5 and 1.0mm droplet trajectories over 400kW fire (Ayres)

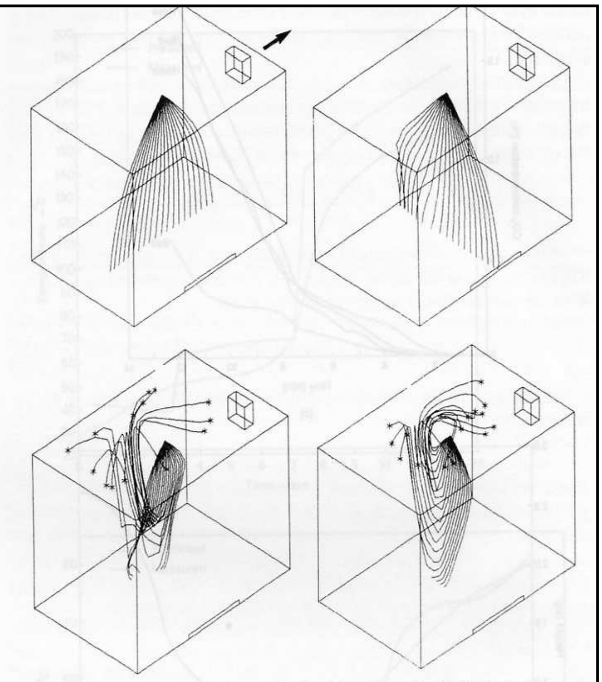
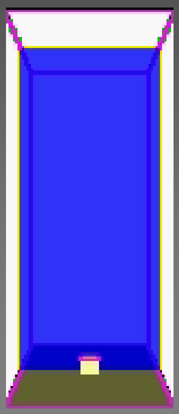


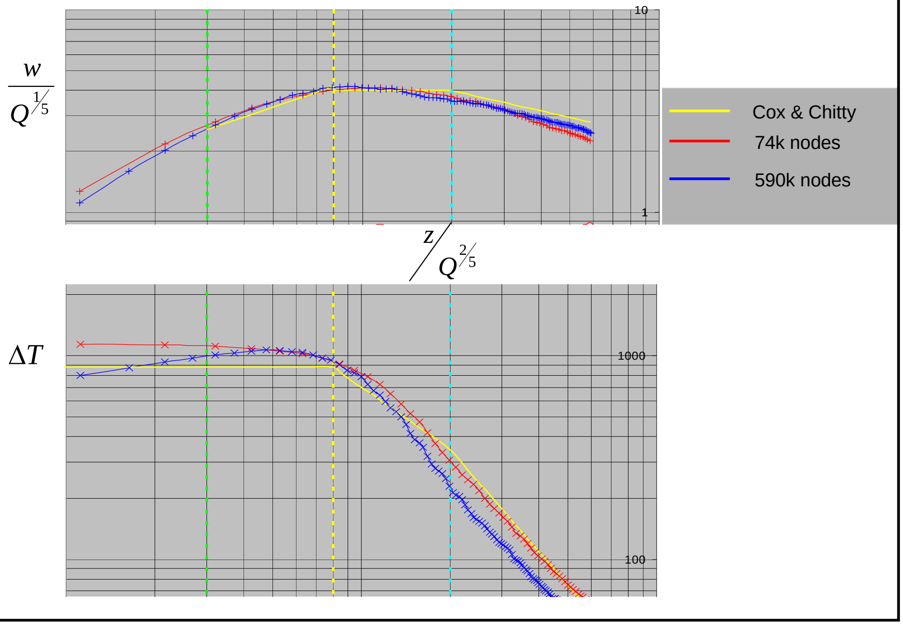
Figure 24 Predicted trajectories of water droplets injected over the 400 kW fire in the Lawrence Livermore fire test cell (see Figure 22).

Large Eddy CFD

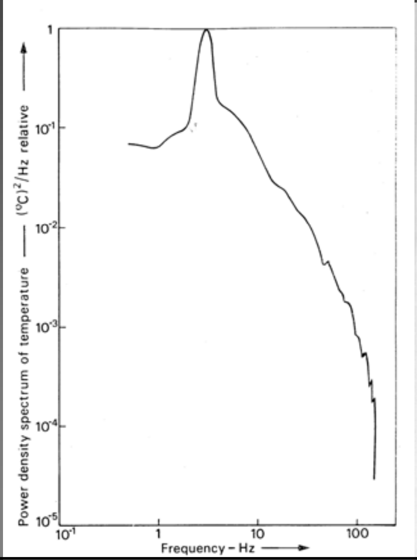
NIST FDS model

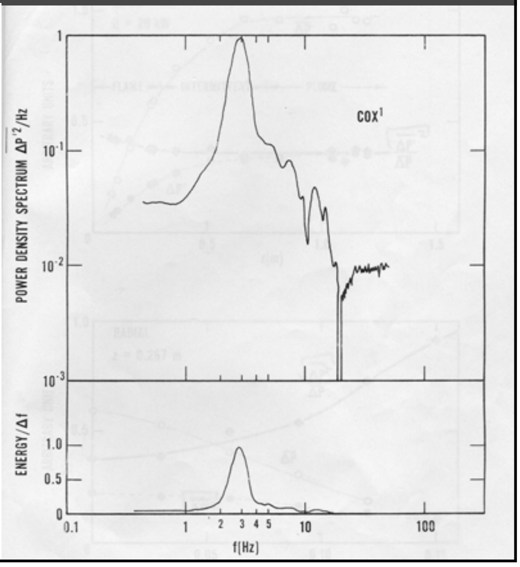


LES CFD predictions (FDS-Welch)

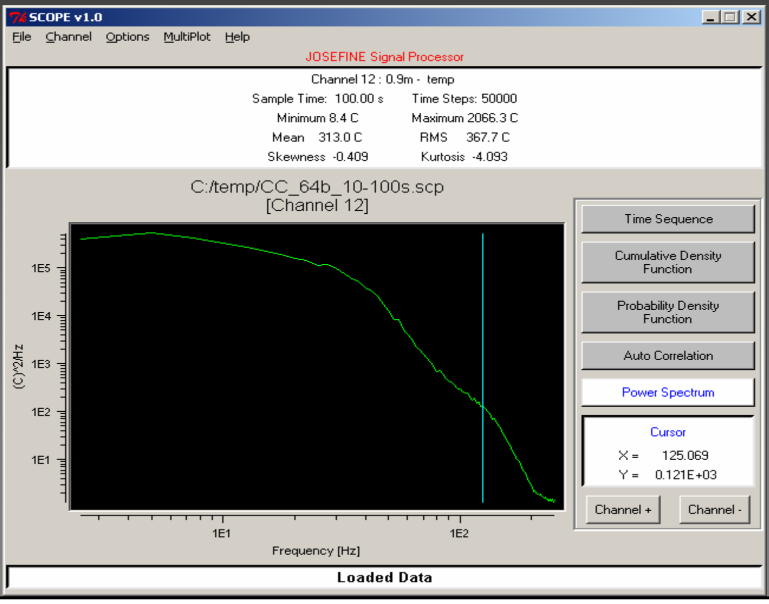


Spectra of gas temperature and pressure difference





Gas temperature spectrum from FDS



Channel 12 : 0.9m - temp

Sample Time: 100.00 s   Time Steps: 50000

Minimum 8.4 C   Maximum 2066.3 C

Mean 313.0 C   RMS 367.7 C

Skewness -0.409   Kurtosis -4.093

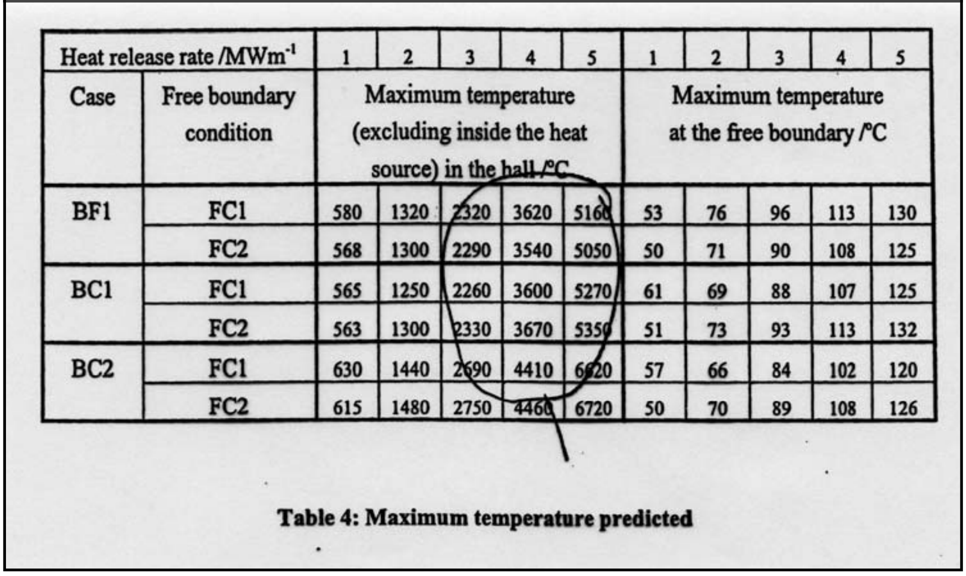
Research needs

- While CFD models capture the broad behaviour more research is needed to understand laminar-turbulent transition above source
- Rayleigh-Taylor instability causing toroidal vortex engulfment of air?
- Understanding turbulence-chemistry (CO formation) and turbulence-radiation interactions; boundary layer flow

FSE

- Developing maturity of fire engineering came at a time when political trend was favouring performance-based regulatory reform
- However it is not yet mature and practitioners need to be very cautious
- They need to understand the tools available and to know their limitations

An example of mis-use of RANS CFD



Heat release rate /MWm^{-1}		1	2	3	4	5	1	2	3	4	5
Case	Free boundary condition	Maximum temperature (excluding inside the heat source) in the hall /°C					Maximum temperature at the free boundary /°C				
BF1	FC1	580	1320	2320	3620	5160	53	76	96	113	130
	FC2	568	1300	2290	3540	5050	50	71	90	108	125
BC1	FC1	565	1250	2260	3600	5270	61	69	88	107	125
	FC2	563	1300	2330	3670	5350	51	73	93	113	132
BC2	FC1	630	1440	2690	4410	6620	57	66	84	102	120
	FC2	615	1480	2750	4460	6720	50	70	89	108	126

Table 4: Maximum temperature predicted

Modelling-Problems
eg RANS

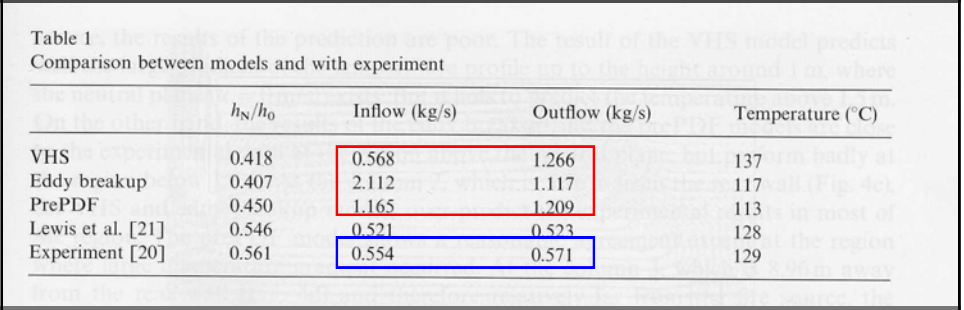


Table 1
Comparison between models and with experiment

	h_N/h_0	Inflow (kg/s)	Outflow (kg/s)	Temperature (°C)
VHS	0.418	0.568	1.266	137
Eddy breakup	0.407	2.112	1.117	117
PrePDF	0.450	1.165	1.209	113
Lewis et al. [21]	0.546	0.521	0.523	128
Experiment [20]	0.561	0.554	0.571	129

Serious risk of CFD mis-use

- SFPE Handbook, Chapter on CFD, 2002
- HSE (Guidance for HSE Inspectors: Assessment of CFD), 2002
- ODPM-Computer Model Performance Assessment Scheme (CoMPAS), 2004

But determinism can only go so far….

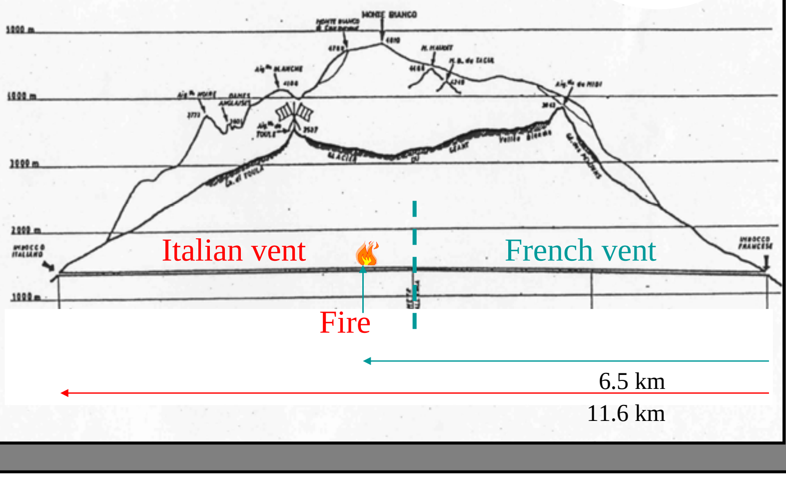
An illustration

Mont Blanc Tunnel Fire

39 fatalities; March 1999

Tribunal Administratif de Grenoble
Dossier n° 9901079-5

Mont Blanc Section



Italian vent

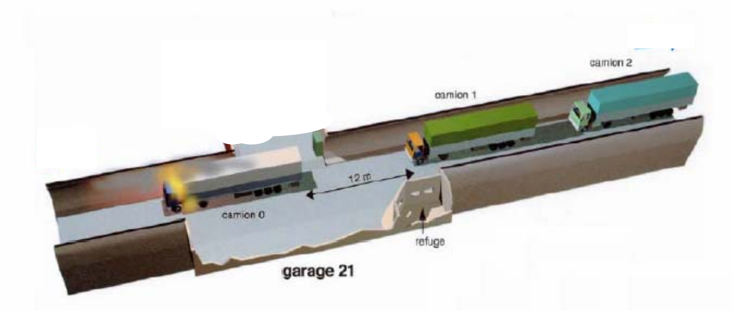
French vent

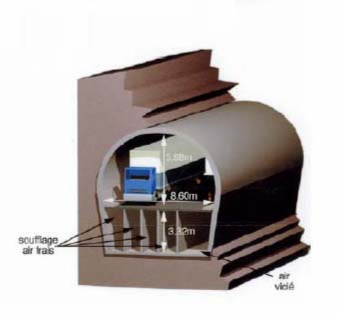
Fire

6.5 km

11.6 km

Tunnel Section





The Mont Blanc Tunnel Fire

- all deceased were on French side of the truck, 38 within 1km of fire-most still in their vehicles
- decisions on smoke ventilation were critical; responsibilities divided between two separate control rooms at French & Italian ends of tunnel
- French half extracted at roof apex; Italian side supplied air at roof apex

Tribunal 2005

We were asked to conduct:

CFD simulations of the gas phase conditions in the tunnel coupled with tenability and escape simulations for the occupants:

for

- the conditions of the tragedy
- and for possible alternative ventilation choices particularly the “Cas Consignes”

Modelling Philosophy

- there are things we know (dimensions; gradients of tunnel, construction materials used, dimensions location, contents of truck, ventilation settings)
- there are things we don't (fire "size" & growth rate, external pressure difference between ends of tunnel
- assumptions/approx necessary

Modelling (CFD & Human Factors)

BRE JASMINE model

- transient calculations of whole length of tunnel modelled
- three gradients of tunnel included
- rate of fire growth estimated from truck fire load & available opacity meter data
- Smoke visibility & CO/HCN concentrations from engineering correlations

CFD simulations coupled to Human Factor modelling (FED & people movement)

Initial condition is simulation of cold flow before the fire

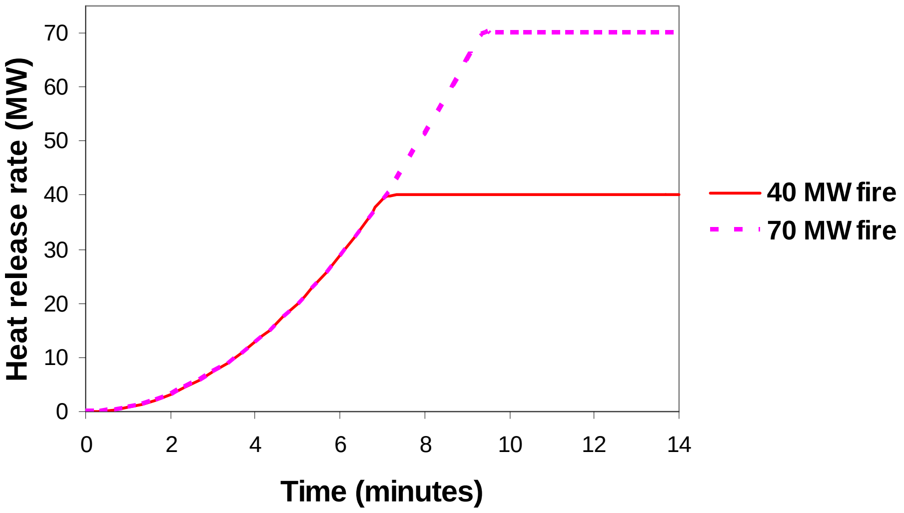
- steady-state “cold flow” modelled first; compared to anemometers in tunnel
- external pressure difference between tunnel ends based on the meteorological data
- transient fire source then added

Fire Modelling

Modelling detail of fire propagation
through complex geometries of an assortment
of different “fuels” is not possible
(margarine, flour, tyres, kerosene,
polyurethane sandwich board etc)

so assumptions/approximations need to be made

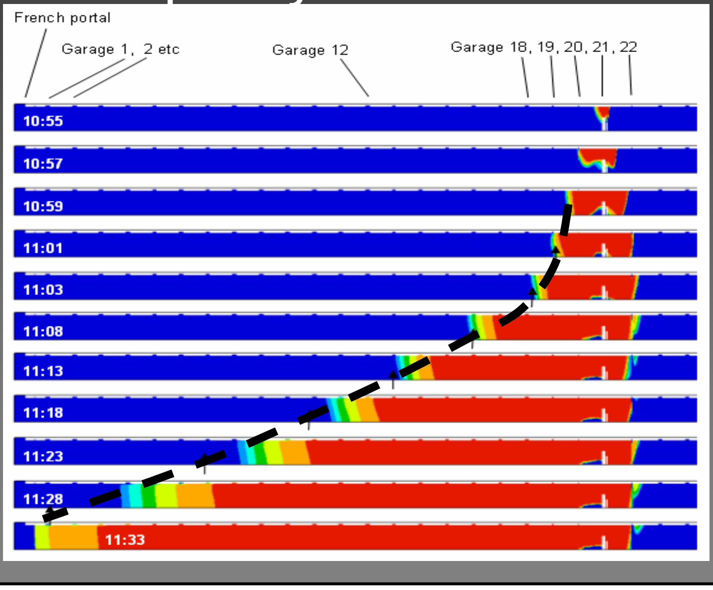
Assumed fire sources



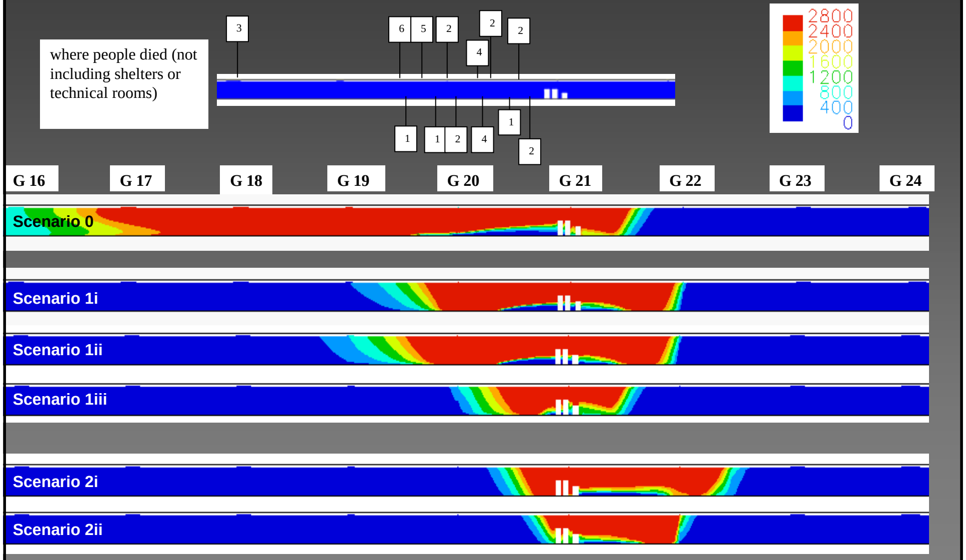
The Fire-assumptions for fuel

- mass release rate of fuel determined from the heat release rate curve
- heptane chemistry used as a “surrogate” fuel
- smoke yield of the actual materials was represented by rigid polyurethane, a typical “smokey” fuel

Visibility predictions and opacity meter data

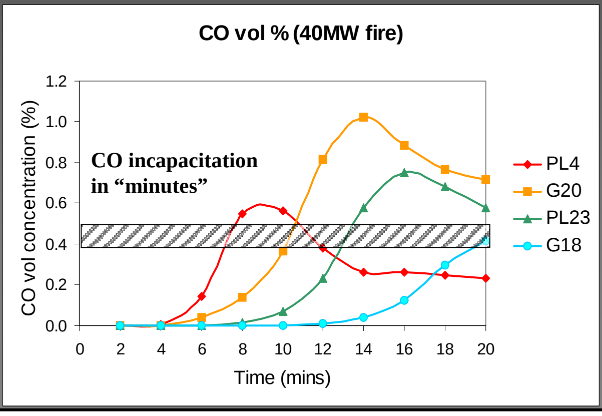


Carbon monoxide contours at 11:13 am

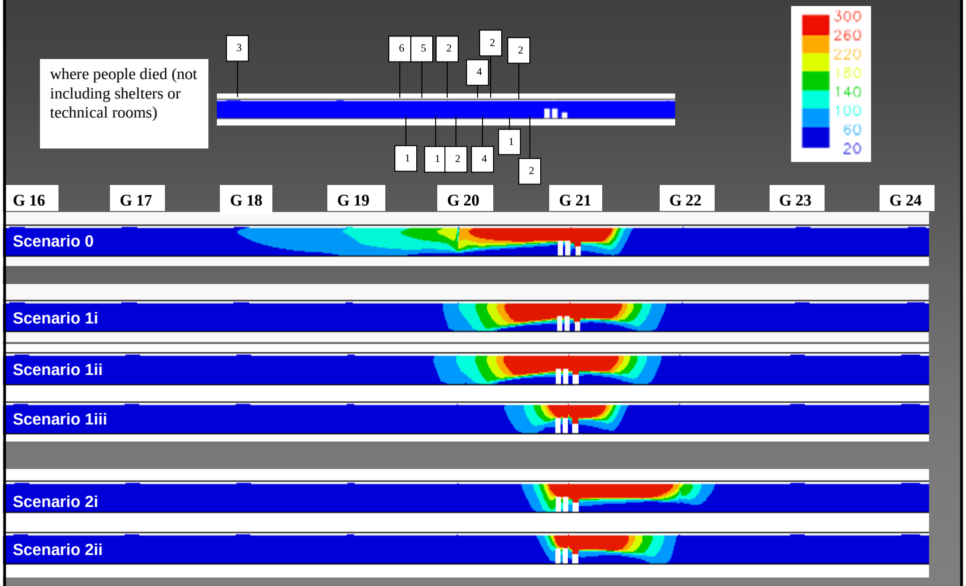


CO concentration at “head height”

- 2m above road surface



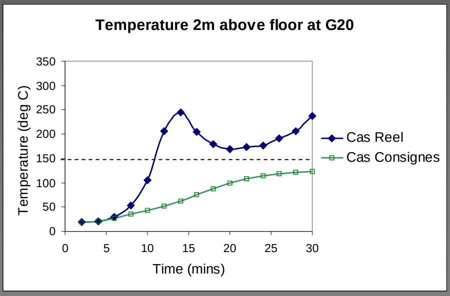
Gas temperature contours at 11:13 am

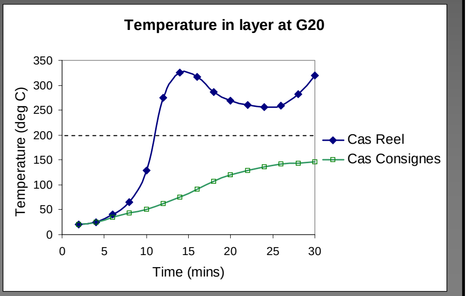


Gas temperature Garage 20, Scenarios 0 and 1(i)

150°C immersion temperature tolerate for “minutes”

200°C ≅ 2.5kW/m^2; pain on bare skin-1min





Model conclusions

- toxic gas hazards spread quickly to G18 (900m) by about 11.13 (20 minutes)-38 people died within 932 m of Truck, PL0
- thermal hazard develops rapidly spreading to G20 (300m) by about 11.04 (11 minutes)-19 people died within 303 m of PL0
- the detailed gas-phase conditions used as inputs for human tenability and egress modelling for victims

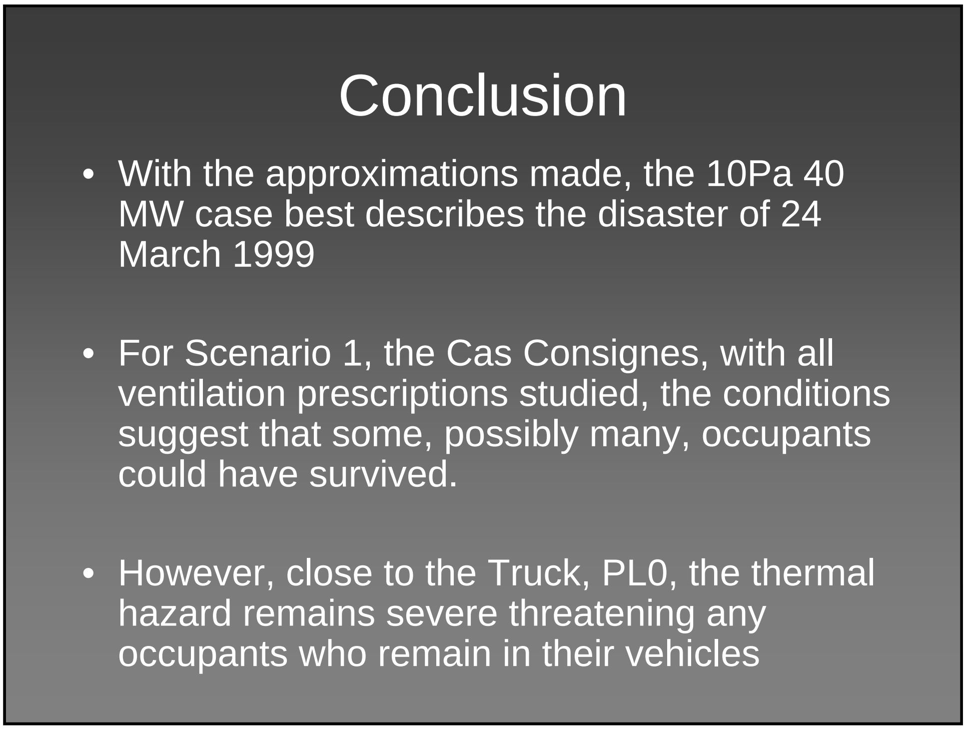
How robust are these conclusions?

To ensure that our conclusions are robust and prudent, we considered further how sensitive they are to different assumptions for

- maximum fire size
- larger external pressure difference from Italy to France

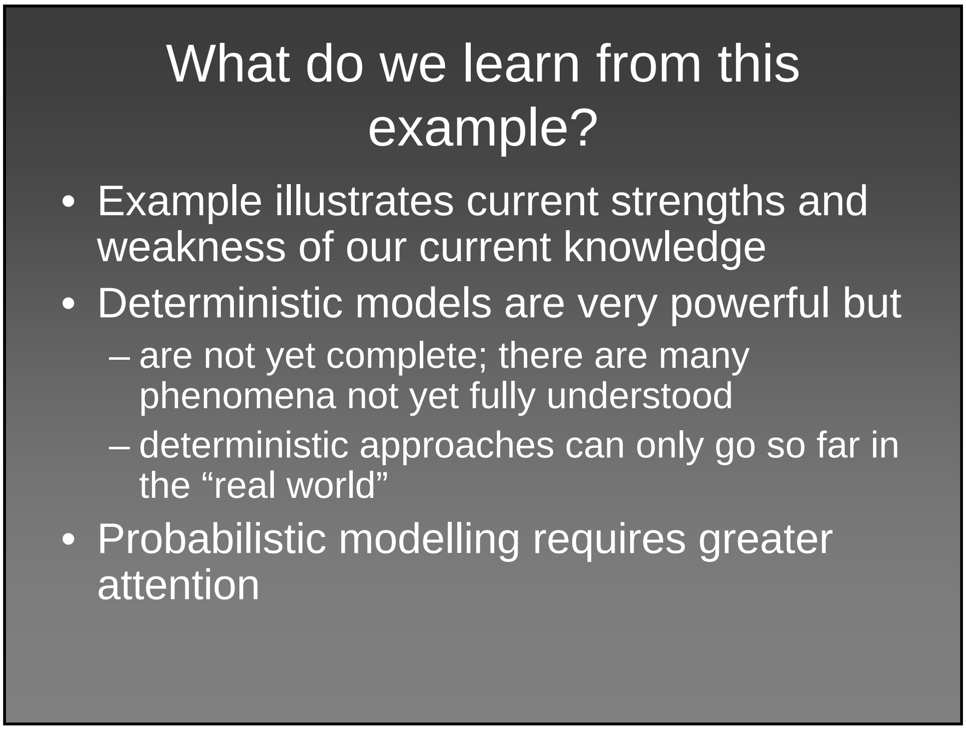
"A Worst Case"

- Tenability analysis of survivability for an assumed more severe case of 40 Pa, 70 MW fire concludes that
    - —the occupants of VL20 (407 m from Truck, PL0) would have died at 540 m from PL0 rather than 932 m, where they were actually found
- Thus this "worst case" possibility is less compatible with the known facts on the day of the incident



Conclusion

- With the approximations made, the 10Pa 40 MW case best describes the disaster of 24 March 1999
- For Scenario 1, the Cas Consignes, with all ventilation prescriptions studied, the conditions suggest that some, possibly many, occupants could have survived.
- However, close to the Truck, PL0, the thermal hazard remains severe threatening any occupants who remain in their vehicles



What do we learn from this example?

- Example illustrates current strengths and weakness of our current knowledge
- Deterministic models are very powerful but
  - are not yet complete; there are many phenomena not yet fully understood
  - deterministic approaches can only go so far in the “real world”
- Probabilistic modelling requires greater attention

Probabilistic modelling in FIREGRID (Koo et al, 2008)

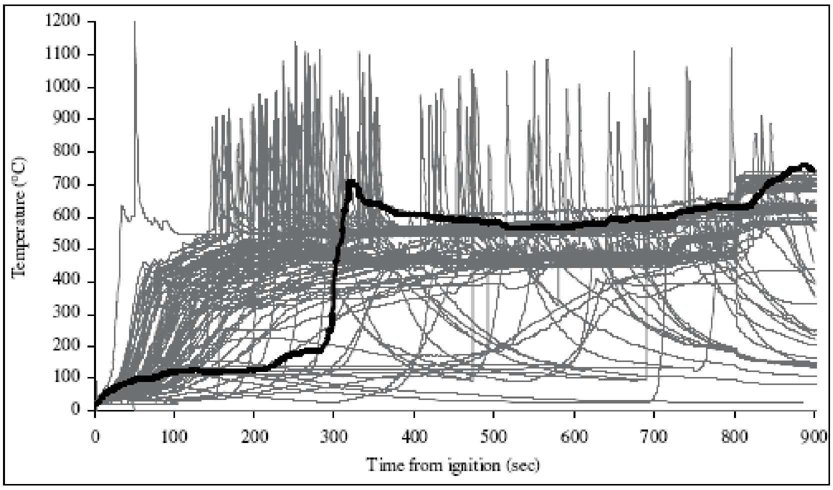
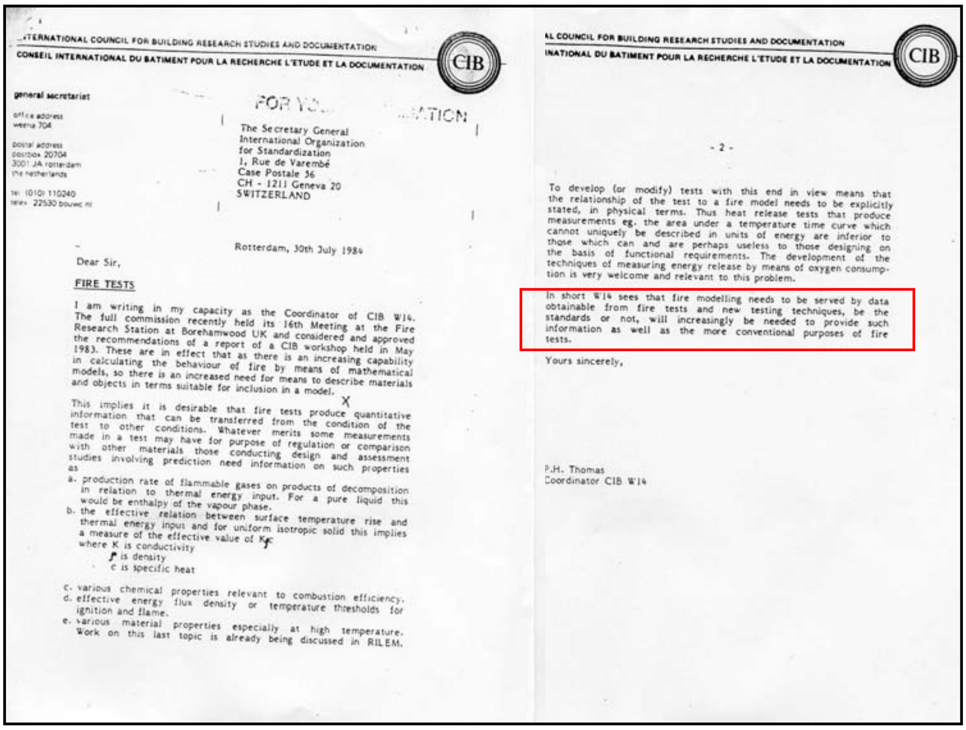


Fig. 5. 100 CRISP outputs among 2000 simulations.

Fire Testing & International Standards

Prof Kunio Kawagoe

"The purpose of fire research is to do away with the fire resistance test"



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CH - 1211 Geneva 20
SWITZERLAND

Rotterdam, 30th July 1984

Dear Sir,

FIRE TESTS

I am writing in my capacity as the Coordinator of CIB W14. The full commission recently held its 16th Meeting at the Fire Research Station at Borehamwood UK and considered and approved the recommendations of a report of a CIB workshop held in May 1983. These are in effect that as there is an increasing capability in calculating the behaviour of fire by means of mathematical models, so there is an increased need for means to describe materials and objects in terms suitable for inclusion in a model.

X

This implies it is desirable that fire tests produce quantitative information that can be transferred from the condition of the test to other conditions. Whatever merits some measurements made in a test may have for purpose of regulation or comparison with other materials those conducting design and assessment studies involving prediction need information on such properties as

a. production rate of flammable gases on products of decomposition in relation to thermal energy input. For a pure liquid this would be enthalpy of the vapour phase.
b. the effective relation between surface temperature rise and thermal energy input and for uniform isotropic solid this implies a measure of the effective value of $K\rho c$
   where K is conductivity
   ρ is density
   c is specific heat
c. various chemical properties relevant to combustion efficiency.
d. effective energy flux density or temperature thresholds for ignition and flame.
e. various material properties especially at high temperature. Work on this last topic is already being discussed in RILEM.

To develop (or modify) tests with this end in view means that the relationship of the test to a fire model needs to be explicitly stated, in physical terms. Thus heat release tests that produce measurements eg. the area under a temperature time curve which cannot uniquely be described in units of energy are inferior to those which can and are perhaps useless to those designing on the basis of functional requirements. The development of the techniques of measuring energy release by means of oxygen consumption is very welcome and relevant to this problem.

In short W14 sees that fire modelling needs to be served by data obtainable from fire tests and new testing techniques, be the standards or not, will increasingly be needed to provide such information as well as the more conventional purposes of fire tests.

Yours sincerely,

P.H. Thomas
Coordinator CIB W14

ISO TC92 new responsibility,1995

“Fire Tests on Building Materials, Components and Structures”

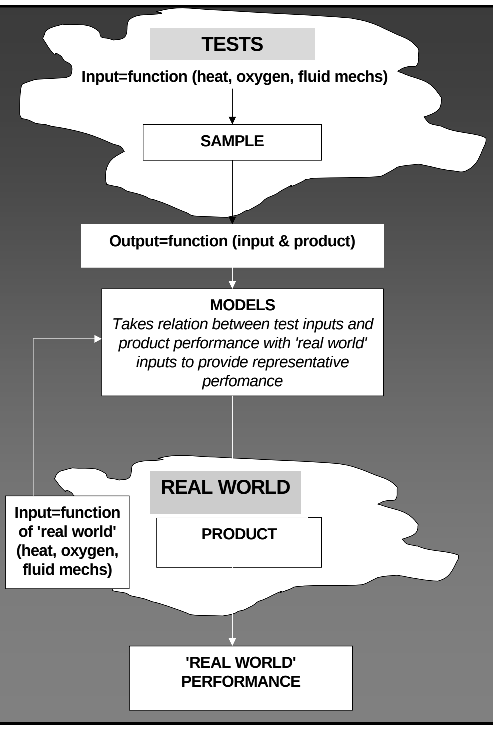
to

“Fire Safety”

ISO Fire Tests for FSE

- that 'product' performance in the test is provided in quantitative terms
- that exposure conditions must be provided in quantitative form
- that processes in the test are sufficiently well prescribed that they can be modelled
- that performance from the particular conditions of the test must be translatable by predictive methods to the design environment

ISO TC92 “Fire Safety” future framework document



TESTS

Input=function (heat, oxygen, fluid mechs)

SAMPLE

Output=function (input & product)

MODELS

Takes relation between test inputs and product performance with 'real world' inputs to provide representative perfomance

REAL WORLD

Input=function of 'real world' (heat, oxygen, fluid mechs)

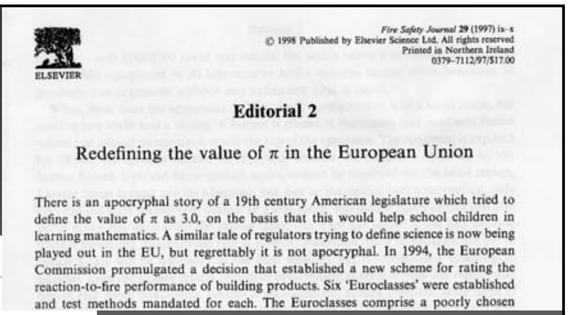
PRODUCT

'REAL WORLD' PERFORMANCE

“Unfortunate” political influences

- Single Burning Item test
- Privatisation of many national labs
- Lack of strategic research policy; reduction in funding for research

SBI Test



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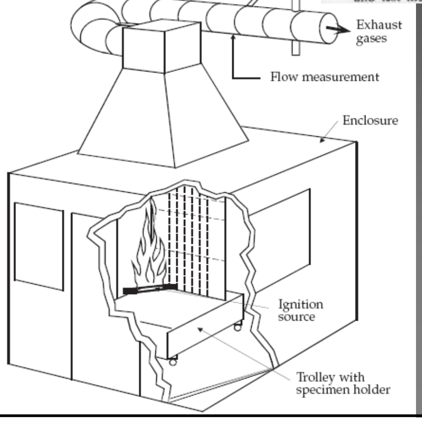
ELSEVIER

Editorial 2

Redefining the value of π in the European Union

There is an apocryphal story of a 19th century American legislature which tried to define the value of π as 3.0, on the basis that this would help school children in learning mathematics. A similar tale of regulators trying to define science is now being played out in the EU, but regrettably it is not apocryphal. In 1994, the European Commission promulgated a decision that established a new scheme for rating the reaction-to-fire performance of building products. Six 'Euroclasses' were established and test methods mandated for each. The Euroclasses comprise a poorly chosen



Privatisation of National Labs

- *"………..as these national labs become privatized/commercialized, the focus of their work will be more on income-producing activities, such as standardized testing, and less on true research.*
- *The net result has a dual negative effect: the further erosion of badly needed fundamental research programs and the spread of standardized testing of questionable value for certification"*

Croce, Interflam 2001

Fire Engineering - Summary

- Growing maturity of fire science and engineering coincided with world-wide trend towards deregulation
- Flexible, performance based design when done properly offers enormous benefits
- But there are areas that are not yet robust
- Research is essential for the safe implementation of performance based codes

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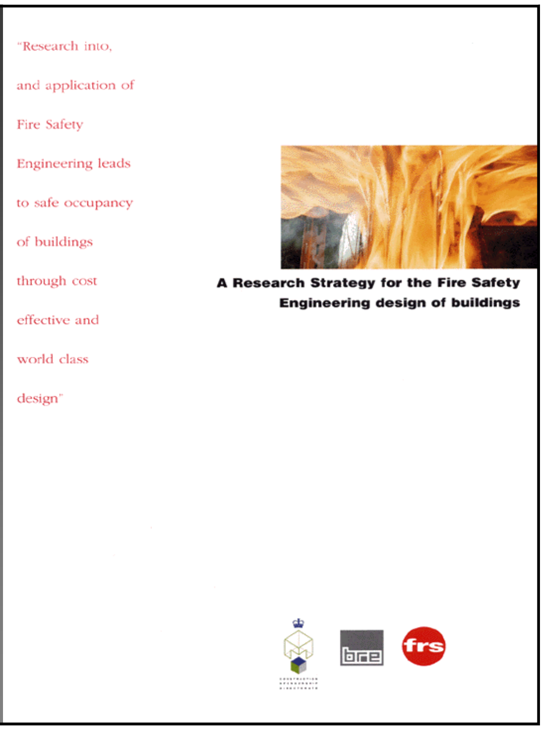
Scientific research needs



"Research into,
and application of
Fire Safety
Engineering leads
to safe occupancy
of buildings
through cost
effective and
world class
design"

A Research Strategy for the Fire Safety Engineering design of buildings

10 year research strategy

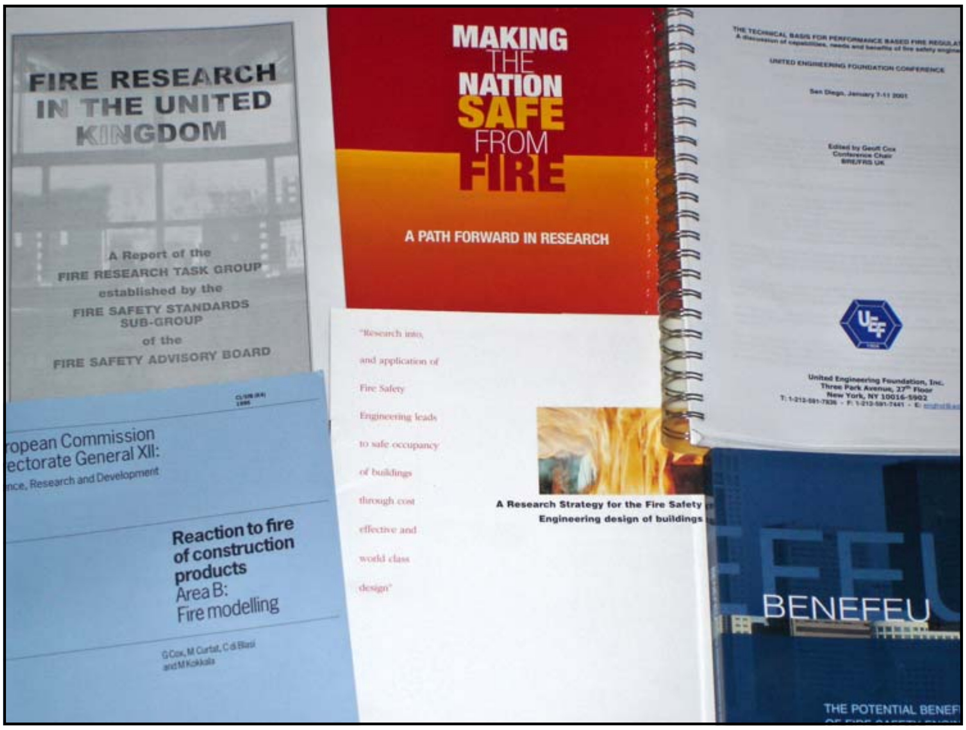
- *Department of the Environment (DoE) published “A Research Strategy for the Fire Safety Engineering Design of Buildings” 1995*
- *“……achieve by the year 2005 a scientifically based and fully developed Fire Safety Engineering package (methodology furnished with appropriate calculation methods and data) that can be applied in a cost-effective way to the design and management of buildings………”*
- WHERE IS IT????

Research for FSE

- Fire initiation & development
- Combustion products & smoke movement
- Passive protection
- Detection
- Active protection
- Evacuation
- Characteristic data
- Fire Statistics
- Risk assessment

Some topics

- Flame spread over solids
- under-ventilated fires
- Model development, RANS, LES, DNS models
- Turbulence/chemistry; Turbulence/radiation; boundary layers
- CFD model ‘validation’/blind simulation challenges
- Application of advanced diagnostics for fires
- fire suppression ‘science’
- development of ‘smart’ materials based on our knowledge of fire science



Research Requirements

- EC DG X11, Norbert Peters review on Reaction to Fire of Construction Products, 1996
- Intergovernmental Fire Research Group, 2001
- ODPM FSAB, 2003
- EU Benefeu, 2002
- US United Engineering Foundation, 2001
- US National Research Council, 2003
- SFPE “A Research Agenda for Fire Protection Engineering”, 2000

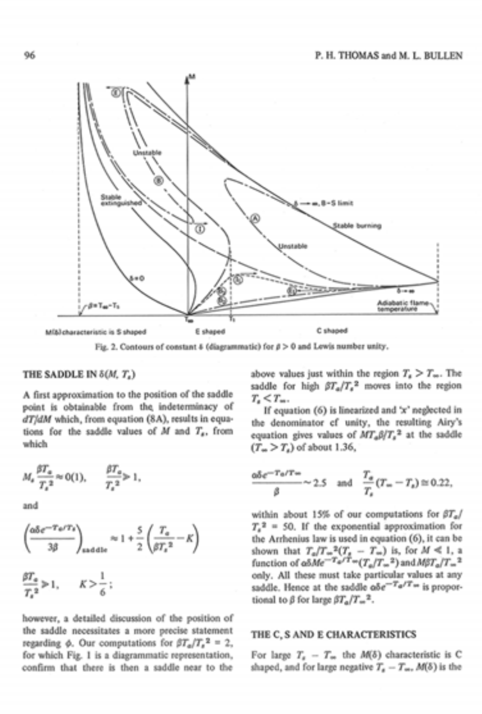


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Fig. 2. Contours of constant δ (diagrammatic) for $\beta > 0$ and Lewis number unity.

THE SADDLE IN $\delta(M, T_s)$

A first approximation to the position of the saddle point is obtainable from the indeterminacy of dT/dM which, from equation (8A), results in equations for the saddle values of M and T_s, from which

$$M_s \frac{\beta T_a}{T_s^2} \approx 0(1), \qquad \frac{\beta T_a}{T_s^2} \gg 1,$$

and

$$\left(\frac{\alpha\delta e^{-T_a/T_s}}{3\beta}\right)_{\text{saddle}} \approx 1 + \frac{5}{2}\left(\frac{T_a}{\beta T_s^2} - K\right)$$

$$\frac{\beta T_a}{T_s^2} \gg 1, \qquad K > \frac{1}{6};$$

however, a detailed discussion of the position of the saddle necessitates a more precise statement regarding ϕ. Our computations for $\beta T_a/T_s^2 = 2$, for which Fig. 1 is a diagrammatic representation, confirm that there is then a saddle near to the above values just within the region $T_s > T_\infty$. The saddle for high $\beta T_a/T_s^2$ moves into the region $T_s < T_\infty$.

If equation (6) is linearized and 'x' neglected in the denominator cf unity, the resulting Airy's equation gives values of $MT_a\beta/T_s^2$ at the saddle $(T_\infty > T_s)$ of about 1.36,

$$\frac{\alpha\delta e^{-T_a/T_\infty}}{\beta} \sim 2.5 \quad \text{and} \quad \frac{T_a}{T_s}(T_\infty - T_s) \simeq 0.22,$$

within about 15% of our computations for $\beta T_a/T_s^2 = 50$. If the exponential approximation for the Arrhenius law is used in equation (6), it can be shown that $T_a/T_\infty^2(T_s - T_\infty)$ is, for $M \ll 1$, a function of $\alpha\delta M e^{-T_a/T_\infty}(T_a/T_\infty^2)$ and $M\beta T_a/T_\infty^2$ only. All these must take particular values at any saddle. Hence at the saddle $\alpha\delta e^{-T_a/T_\infty}$ is proportional to β for large $\beta T_a/T_\infty^2$.

THE C, S AND E CHARACTERISTICS

For large $T_s - T_\infty$ the $M(\delta)$ characteristic is C shaped, and for large negative $T_s - T_\infty$, $M(\delta)$ is the

Charles Babbage 1852

“Propose to any Englishman any principle or any instrument, however admirable, and you will observe that the whole effort of the English mind is directed to find a difficulty, a defect, or an impossibility in it.

If you speak to him of a machine for peeling a potato, he will pronounce it impossible; if you peel a potato with it before his eyes, he will declare it useless because it will not slice a pineapple.”

End