"Mathematical Modelling in Fire Science: Current Role and Perspective"

Workshop Report

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The Workshop on "Mathematical Modeling In Fire Science: Current Role And Perspective" was held on 25 of May, 2000. The workshop format has been introduced to the present series of Symposiums for the first time this year, and the intention of the organiser was to use this valuable opportunity for discussion of important topics in Fire Safety Science.

Mathematical modeling was selected as one of these, as the science of fire modeling is at the stage where it is becoming to be absorbed into everyday design practices. However, more consolidated effort is required to assist in the development of integrated fire model which can be applied in reasonable confidence to predict versatile impact of fire.

The workshop was designed to provide modelers working in different areas of fire science with the opportunity of fresh view and broad discussion on the role and most challenging problems in fire modeling.

The ultimate integrated approach to fire impact predictions requires that the interaction between different areas of fire modeling, their current capabilities, limitations and leading trends are well understood. Therefore, the most important technical issues, as well as the ways towards the effective integration of accumulated knowledge, should be subjected to careful consideration.

The most important issues which participants were invited to discuss included identification of the critical issues and priorities in each of key areas.

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The structure of the Workshop included three parts. In the first part, four mini reviews were presented on key areas of mathematical modeling applications in fire science. The mini reviews were presented by:

M. Delichatsios (Fire Technology Laboratory, CSIRO, Australia)	- Fire physics
I. Thomas (Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, Asutralia)	- Risk Assessment studies
K. Harada (Department of Architecture, Kyoto University, Japan)	- Fire and Structures
H. Yoshimura (Department of Architectural Engineering, Osaka University, Japan)	- Human Behaviour

In the second part, three technical papers were presented for discussion. These were given by:

B. Dlugogorski, E. Kennedy (Department of Chemical Engineering, The University of Newcastle, Australia) and R. Wighus (SINTEF, Norway)	- Experimentalist's view on fire modeling
Fan Weicheng and Zhong Maohua (State Key Laboratory of Fire Science, University of Science and Technology of China)	- Review On Modelling Of Fire Physics and Risk Assessment
A. Karpov (Khabarovsk State University of Technology, Khabarovsk, Russia)	- Practical output of simulation: example of massive forest fires

The final part of the Workshop was devoted to general discussion.

I am pleased to point out that the Workshop initiated a lot of interest among the Symposium delegates, and the discussion was lively and productive. The Workshop was held in an informal and inspiring atmosphere, and has accomplished its mission of initiating an important change of ideas in the area of fire modeling.

The range of issues covered during presentations and discussions was very wide, but the main problems facing fire modelers may be briefly summarised as follows.

Two levels of challenges are identifiable. First level include those problems where the physical laws are understood and rigorous mathematical set of equations can be written. This is essentially the case for fire physics where turbulent combustion is the most critical area. Surely, there are still many uncertainties regarding physics, and especially chemical kinetics and radiation. However, the main problem is that the known governing equations can not be solved in a sense that is satisfying from the point of view of practical applications. There are few important consequences of this fact. One is that we still have to rely on experiments and properly designed fire tests in order to get practically meaningful solutions. This is an approach outlined in the presentation by M. Delichatsios. The essence of this approach is a combination of early fire hazard tests with zone or CFD simulations of smoke movement, radiation etc. at later stages of the fire. This seems to be feasible approach since neither experiments nor simulations are sufficient separately at present time. However, some important questions may be raised regarding the validity of early fire hazard tests. Obviously, they are not universally applicable, since a slight change in geometry may result in a dramatic change in fire behavior (recall *trench-effect* !). Another apparent problem is scaling from small experiment scales to real compartments.

Therefore, there is no doubt that further development of CFD (alternatively called *field*) models is required. This development will require a lot of interaction with experimental investigations. The presentation by B. Dlugogorski, E. Kennedy and R. Wighus was particularly interesting as it gave an experimentalist's perspective on the problem. The authors analysed the possibility of CFD application to the design of fire suppression (particularly water mist systems) and concluded that at present stage it is not feasible, except in some special cases of very quick (virtually instantaneous) extinguishment. These arguments, concerned with the general CFD prediction problems, initiated a very hot and interesting discussion. Some of participants pointed out that the answer should not be formulated in "yes" or "no" terms, and more differentiated approach should be taken to understand current capabilities and limitations of field models. Some types of fire suppression (by conventional water sprinklers) is more easily and successfully analysed by CFD methods, which gives a hope that more complicated cases (such as water mist systems) can also be predicted, provided a sufficient effort has been made.

Problems of similar nature exist with the models development for fire impact on structures. The problems that need to be addressed here include localised fire behavior in complex geometries, fire propagation processes and fire behavior in large compartments. It also apparent that the need still exists for further data collection. Such data should be organised in the format of databases (both at normal and high temperatures).

Probably of a more serious concern for fire modeling is the another level of problems, which are hardly susceptible to exact mathematical formulation. In this category Risk Assessment and Human Behaviour may be included. These areas are much less formalized, although definitely some very good progress has been made in quantifying these important effects. For example, similarity between human crowd behavior and that of liquid medium has been extremely helpful. In general, people reaction to fire is very hard, if possible at all, to quantify, and this represents a real obstacle in construction of any realistic, integrated model of fire impact. A manifestation of this is the fact that current occupant behavior modeling grossly over-estimates fatalities, as it has been pointed out in the review by Ian Thomas. There may be a need for some conceptually new mathematical approaches in this area (*fuzzy logic?*).

Integrated models of fire (for example, *FIRECAM*) do currently exist, being able to consider the dynamic (time-dependent) interaction among fire growth, fire spread, smoke movement, human behavior and fire department response. However the reliability of their application is very far from being certain. A large number of different submodels, which are not always sufficiently verified themselves makes it difficult to obtain reliable predictions.

There are currently a large number of very interesting and important approaches to fire predictions, which have been reviewed by Fan Weicheng and Zhong Maohua. Their paper also contains a very valuable list of references, which surely will be of help for researches involved in fire modeling. However, it appears that no one can point out at least one reliably working model, ready for practical applications.

Apart from compartment fires, other important applications have also been considered at the Workshop. A brief talk on forest fires was given by Dr. Karpov from Khabarovsk State University of Technology, Russia. The topic of this presentation was the same as the invited lecture by the same author (see present Proceedings), but initiated a more informal discussion, which helped audience with better understanding of large-scale fire phenomena.

Overall, more consolidated and consistent effort is required for future fire models development. There are a number of general issues which needs to be addressed more closely.

The two essential requirements for development of any mathematical fire models are computer-code verification and model validation. The first refer to the internal model features, such as treatment of descretisation errors, numerical consistency and solution convergence issues. The latter refers to the quality of various physical submodels, and also includes the issues of sensitivity to uncertain inputs. Unfortunately, these problems are not being always properly addressed in fire modeling studies. The standards of results reporting (performance, convergence, sensitivity studies and related matters) should be improved throughout the literature.

Another critical area is extensive validation studies and intelligent use of available experimental data. In this regard, the following problems seem to be important:

- Identification of reliable sources of experimental data and more effective ways of their exposure and utilisation (databases, websites, and other arrangements)

- Systematisation of experimental data and coordinated validation effort

It is worth noting that some non-published data start to become publicly available, and may be used by various research groups. The examples are a Database of Turbulence and Heat Transfer and Particle Tracking Velocimetry Database, available from the Turbulence and Heat Transfer Laboratory, Department of Mechanical Engineering, The University of Tokyo

(*//www.thtlab.t.u-tokyo.ac.jp/*). It is hoped that such data-sharing practices will be gradually developing to allow a more effective use of experimental data to be made.

In summary, some of the major problems facing fire modelers at present may be identified as follows:

- Fundamental physical problems (turbulence, turbulence-chemistry interactions, radiation)
- Numerical problems (code verification, convergence, lack of resolution, etc.)
- Lack of measured properties / parameters in the areas where formalized mathematical approach is possible
- Difficulty in formalizing and quantification of human behavior and risk assessment in fires
- Lack of general methodology in combining formal mathematical and informal (heuristic and empirical procedures)
- Effective validation procedures and interactions between experimentalists and fire modelers are urgently needed.

A good indication of variety of problems that needs to be resolved could be drawn from general discussion. At the end of this discussion, Michael Delichatsios invited participants to identify areas, which in their view require priority attention. I think it is worthwhile to reproduce the answers here. The answers given were as follows:

1. Fire safety of older (heritage) buildings
2. Quality of Risk Assessment
3. Chemistry / fluid dynamics interaction in fires
4. Correlation between small- and large-scale fires
5. Human behavior, gender / social imbalances in fire casualties
6. Global aspects of fires (e.g. environmental)
7. Active fire protection
8. Education / research personnel.

It is easily seen how wide the answers are spread. This fact certainly reflects the existence of a range of very important problems to be resolved, as well as different opinions which exist among fire science experts.

Conclusions

- Mathematical modeling is becoming increasingly important area of Fire Safety Science. However, at present stage neither fire modeling, nor fire tests alone are giving the complete ability to predict fire behavior.
- The lack of adequate techniques for treatment of fundamental physics / chemistry problems in fires still hinders further progress.
- Quality of interaction and information exchange between modeling and experimental studies should be dramatically improved.
- There are still a large number of unresolved fundamental issues in application of mathematical techniques to fire dynamics and fire safety issues. A number of important problems in the areas of Human Behavior and Risk Analysis lacks formalization. In order to achieve effective application of fire models in modern flexible fire regulations, a

methodology development is required to combine formal mathematical and informal empirical procedures.

- Conference Organisers should be praised for their efforts to introduce workshop format to the present series of Symposiums. Informal discussions have proved to be very important, and feedback received on Workshop from Conference delegates seems to be quite positive. It is desirable that workshop structure is preserved at the following Symposiums with other topics of common interest open for discussion.

Finally, I would like to thank Conference Organisers for providing an opportunity for this informal discussion, Workshop speakers for their invaluable efforts and all participants for their enthusiastic input into discussion.

I hope we would be able to continue our discussions at the next Symposium in Australia.

Human Behavior

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Human behavior in fire is dependent on complexity of egress routes, familiarity with built-environment, spaciousness/closedness, fire and smoke spread, light, alarm signals, fire detector activation time, legibility of way guidance signs, etc. This paper presents a mini-review on human behavior and its modeling, mainly focusing on Japan.

1. Surveys and experiments on human behavior in fire

For fire safety planning of buildings it is essential to clarify human behavior in fire. In 1932 a fire broke out at Shirakiya Department Store in Tokyo, resulting in 14 victims. Architects and building engineers were very surprised at this fire because they believed reinforced concrete buildings would not burn up. Within a month after the fire the first scientific survey was made on the salesclerks inquiring their escape behavior during fire [1]. The findings were that most of them made for staircases they habitually used, and that some occupants who were driven into a corner by smoke and heat courageously or recklessly climbed down tied ropes, connected cloths, chimney, flagpole, down pipe, etc. Since this fire, human behavior in fire has been scientifically surveyed and analyzed by many fire scientists and environmental psychologists.

In order to supplement the weak point of questionnaire surveys and interviews, various experiments on human behavior have been made. In Japan the first experiments on human behavior in fire date back to 1970s. Dr. Jin made successful experiments on walking speed in very dense and irritant smoke environment and in complete darkness [2]. Recent experiments use computer graphics and virtual reality simulator [3] [4] [5].

2. Findings on human behavior in fire

Through various observations, surveys and experiments, considerable part of human behavior in fire is already clarified. The findings are as follows.
1) They use familiar doorways, corridors and stairs.
2) When they face danger, they trace back their own routes to familiar area.
3) They make for light, or brighter, more spacious side.
4) They instinctively avoid and elude irritant environment or danger such as smoke and fire.
5) They follow other evacuees when they lose their judgement.