HAZARD II, Implementation for Fire Safety Engineering

Richard W. Bukowski, P.E. and Walter W. Jones
NIST Building and Fire Research Laboratory
Gaithersburg, MD 20899-0001 USA

For presentation at the Open International Symposium on: Fire Safety Design of Buildings and Fire Safety Engineering, 19-20 August, 1996, Oslo, Norway

Introduction

Much of the world is engaged in the transition from prescriptive codes to performance-based codes for the regulation of safety in the built environment. The motivation for these changes is the concept that sensible regulations lead to improved flexibility of design and lower costs for no reduction in safety. In such a construction climate it is easier to attract international business development with its attendant jobs and growth of the tax base, especially in these times of the global marketplace.

The fact that these changes are happening now is testament to recent improvements in the scientific basis for engineering; specifically the ability to predict (quantitatively) the performance of buildings with an uncertainty which can be covered by reasonable factors of safety. A key factor in the transfer of this scientific knowledge into engineering practice was the development of computer models and software applications like HAZARD I for personal computers -- and the rapid increase of computer power and decrease in cost of this hardware.

By placing powerful predictive tools which are grounded in proper science into the hands of the practicing engineer, exploitation of existing "equivalency clauses" in U.S. codes soon followed. Widespread use of the models brought requests for additional features, a simpler user interface, and better access to the myriad of data required for input. It was quickly recognized that the ability to make an impressive presentation of results; to the client, the code official, or to a jury, resulted in many requests for improved graphical presentation tools.

These requests from our customers have shaped our continued investment in the development of HAZARD II.

Background

The first release of the methodology was Hazard I, version 1.0, in the Summer of 1989. Hazard I version 1.1 was released in the spring of 1992. Version 1.2 was published in the spring of 1994. Many improvements have been made in the documentation which accompanies the software. These improvements are a result of the experiences fire protection engineers and others have had in using the methodology.

Fire Safety Design of Buildings and Fire Safety Engineering. Conference Compendium. Proceedings. Session 3: Fire Safety Engineering Tools. August 19-20, 1996. 1-7 pp, 1996.

The centerpiece underlying all of Hazard I is a zone model of fire growth and smoke transport. The Hazard Methodology surrounds this with models of egress and tenability, auxiliary computer codes, databases and tables to enable efficient use of the model. Over the past decade the Building and Fire Research Laboratory (formerly the Center for Fire Research) has developed computer based models as a predictive tool for estimating the environment which results in a building when a fire is present. In the beginning, there were three of these models: FAST, FIRST and ASET. Originally there was supposed to be a benchmark fire code, with all algorithms of fire phenomena available for experimentation. A change in direction was made in 1986 and it (code name CCFM) was subsequently developed as a prototype of a well structured model. In 1989, another decision was made that development of many computer programs was not the best possible course. The modeling program evolved to two programs from that decision. The one underpinning HAZARD is CFAST. The other is FPETool, which will be discussed later.

CFAST is intended to operate on many platforms, be as error free as is humanly possible, be simple to run for simple problems, yet allow complexity where needed. The code is extremely fast. It is faster than any code of comparable completeness and complexity. It works on laptop personal computers, Unix workstations and supercomputers. It provides for extensive graphics for analysis with pre- and post-processing modules. It is extremely fast on single compartment cases, and with the data editor, there is tremendous flexibility for parameter studies, "what if" testing and so on. It is intended to be a complete, yet very fast, computer code for calculating the effects of fire on the environment of a building. It is particularly well suited for doing parameter studies of changes, both subtle and large, within a single compartment.

Overview of recent changes

This section discusses the changes which have occurred in the various modules which constitute the HAZARD package. The discussion is focussed on those who use the components of the package individually, but everything that is stated applies to the combined HAZARD package.

There are a number of additional phenomena which have been to version 2.0. For example, we have implemented a ceiling jet algorithm[1] which takes into account heat loss from a fire placed in an arbitrary position within a compartment. The algorithm describes the theory and implementation of the algorithm which accounts for the off-center placement of the fire and its effect on heat transfer to the room surfaces. This allows us to include the 3D location of a fire in a room. The natural continuation of this work would be to include smoke and heat detectors in the model so that such studies can be conducted in a systematic manner, both for detection within a compartment, as well as remote detection, that is for detector siting in adjacent compartments. A flame spread model now exists in CFAST. At present it is for vertical spread only, but the extension to horizontal (surface and lateral) is being studied. Finally, a general radiation model is now utilized. This is a ten wall model for the four upper wall segments, four lower wall segments, ceiling and floor. Numerically it is simplified to four segments, based on symmetry of the rectangular parallelepiped used in our zone model[2]. It is just slightly slower than the earlier extended ceiling algorithm, but the improvement in accuracy is significant.

The routines for predicting egress of people and the effect of the fire on human behavior have been combined into a single entity called Survival. The main difference in Survival is that incapacitation or death will prevent further movement of a person. The original thrust of Exitt and Tenab, revealing the relative effects of toxic insults, has been incorporated into Survival.

Enhancement Philosophy

As we continue to improve the hazard methodology, there are four avenues to follow: increase the number and improve the capability of the phenomena which are modeled, Improve the usability of the package, provide derivative applications, and expand the scope of the use of the methodology.

As the concept of fire safe structures develops, the question will arise of how much does some improvement cost, how much will it save, and what are the likely actions of those involved in a fire. One area we have not discussed explicitly is the valuation of a building or system subject to a fire, and what the worst or most probable fire and associated dollar loss would be. Risk management is tool of choice for the future, and cost is the best metric for that risk.

HAZARD is now published with some sample cases. It would be beneficial to enhance its use by providing a set of cases from start to finish with a data file and a video of the actual case being burned in a large scale testing facility. We could have a presentation of fire and its consequences. This might include (computer) video and associated data sets for simulation.

The concept of general building/people/fire interactions needs to be included. There are three aspects which we need to address. The first is the people/building interaction. The second is an integrated model for high-rise and residential. The third is an editor for people movement rules. The fire model is sufficiently fast that the run time graphics is almost irrelevant. It should be possible to develop Survival so that the people interact with the fire by having Survival call the CFAST kernel.

The front end graphical user interface (GUI) for CFAST/Hazard v2.0 will be a vast improvement over the text based interface we currently utilize. We intend to extend this to all aspects, including the use of the FPETool (FireForm) idea as a utility within HAZARD. Our concept of a GUI will be embodied first in FASTLite and the CFAST shell. In the first instance, we will have a simple single file editing session. The long range plan is to allow editing of multiple sessions and concurrent execution of the model. In some ways this goes beyond our original goal of providing a simple filter to prevent data entry errors, but it will allow us to make the databases much more versatile without encumbering those using the methodology too much. We will extend the editor to include the graphics output as well as the people placement and specification of those items which affect the behavior of people. The new GUI's will present a graphical, two dimensional representation of a building. Also under development are computer aided design (CAD) based input and output displays. These improvements should aid in encouraging the use of these models by architecture firms and others not familiar with fire problems, but intimately concerned with buildings.

An important extension of the hazard methodology is the concept of automated parameter variation, which includes incorporating probability of actual events to determine the relative effect of particular scenarios. This capability will increase the usefulness of our models manyfold. As part of this work, we will develop a mechanism to ascertain the sensitivity of the outcome to the parameters themselves (fine variation) as well as their variation (gross variation). A critical point will be to decide upon a reasonable extent of variation. For example, if we consider a door that will be open or closed, should we consider it to be absolutely closed, with leakage, a crack ⅛, ¼, ½ and fully open, or some other combination?

New phenomena needed: There are many new phenomena which we need to incorporate. Those under active consideration include

Compartment to compartment heat transfer via conduction,
Flow within compartments (hybrid),
Burning at corners (furniture, adjoining walls),
Structural effects (barriers to smoke and fire spread as well as load bearing capability)
Improved pyrolysis model (based on more fundamental physical aspects of materials)
Construction design files (databases used for building and ship design)
Self consistent fire - both a flame spread model and a pyrolysis model
Improved understanding of species generation such as CO/CO_2 and its source,
Two directional heat transfer in walls (non-congruent thermocline)
Better detector and other sensor activation (include new detectors)
Deposition and agglomeration of smoke and other species
Suppression - include fire size, drop size and distance effects, geometry of the fire, evaporation/cooling
Modifications to all modules to utilize FDMS[3],[4] databases
Corrosion - add on for HCl - important for semiconductor industry and warehouses.
Smoke movement in tall shafts, stairways and atria

Limitations: There are phenomena which can be done better.

- *General* - Pyrolysis (and flame spread) models still depend on test methods, no heating/cooling in HVAC ducts, and reverse flow in fans is not allowed

- *Entrainment* – fire plume and doorway jet entrainment are based on the same experimental correlations. The fire plume (for large spaces) and the doorway jet (in general) are often used outside the normal range of validity of these correlations.

- *User specification* – the level of agreement is critically dependent upon careful choice of the input data for the model. A better understanding of typical fire induced leakage in buildings would facilitate more accurate description of the building environment.

- *Statistical treatment of the data* – presentation of the differences between model predictions and experimental data in are intentionally simple. With a significant base of data to study, appropriate statistical techniques to provide a true measure of the "goodness of fit" should be investigated.

- *Experimental measurements* – measurement of leakage rates, room pressure, or profiles of gas concentration are atypical in experimental data. These measurements are critical to assessing the accuracy of the underlying physics of the models or of the models ability to predict toxic gas hazard.

An important part of our work is developing into providing various types of databases. This is an important underpinning of the cooperative venture. Companies will be able to make decisions on products or building assemblies. At present we are redoing the FDMS concept. There are two reasons: 1) it is very difficult to add new types of tables. This has resulted in many people abandoning its use; and 2) for the fire modeling work we need a consistent and well defined database structure for data which is used for validation, the various data sets we use within the models, and so on. We are developing the new structure and modules with the caveat in mind that previous work should fit into and be usable.

Extensions to the methodology

There are several possible extensions to this work. For real time fire fighting, a portable computer (hand held) would allow one to walk through a building (before or after a fire) and catalog the contents of a building. This could be brought back to the office and used directly as input to the model for geometric specification and data initialization. As the Cellular Digital Packet Data standard becomes more prevalent, onsite inspections will allow such hand held computers to interact directly with desk bound servers for maintaining databases and assessing code compliance. As the model codes become more sophisticated, and their complexity increases, researchers, code officials, and everyone else will be aided by on such capabilities. There simply is not enough time to bother with all of the details. This is the arena which should allow us to pursue the goal of a better qualitative understanding of fires, as well as doing more of it faster.

All large buildings have annunciator panels for various alarms. Indeed, some fire departments can display floor plans of buildings in the command center at a fire. It is a logical next step to incorporate fire models into the alarm system to display both the current status of a building and a prediction of conditions in the next five minutes.

Another area is that of risk. Risk is the next step up from a hazard calculation, and requires a much more general understanding of the parameters which affect the outcome of a fire and its impact on humans and structures. This application would require an automated application of the model over types of fires, day and night scenarios, position of the fire and so on. The number of such calculations can become enormous. Some means of doing this in an acceptable time frame will need to be found. Also, in order to provide performance evaluation tools, it is necessary to know how often something does not happen, as well as what to do when a catastrophe occurs. As part of this work, we are developing a mechanism to assess the sensitivity of the outcome to the parameters themselves (fine variation) as well as their variation (gross variation). A critical point will be to decide upon a reasonable extent of variation.

As we extend the capability of the zone models, we are encountering the inherent limitations of these types of models. The general concept of a zone or control volume model uses a volume as one of the variables. Inherently there is no spatial information available. The first deviation from this viewpoint was the necessity of including height *vs.* width information in order to calculate flow through a normal vent, such as a door. The second came when flow through a ceiling/floor opening and mechanical ventilation were included. We have extended the concept for the position of the fire. The next step would be to define the spatial component of a compartment so that we could include more sophisticated interactions. This latter is important, for example, in dealing with detection and suppression problems.

The automatic transfer of information from one set of calculations to another is important to avoid unnecessary errors and repetitive data entry. The quest is to provide a tool which will aid rather than hinder. This is not an attempt to make the application of such methods trivial, but rather to provide a mechanism to allow researchers, fire protection engineers, code officials and others, access to the most current understanding of the behavior of fires.

Finally, we have the human factors aspect, that is, how much does fire really cost? Since our knowledge of a situation is not perfect, what range of results might one expect given a most likely scenario. This is the "human factors and cost."

The ability to provide these and other improvements to the hazard assessment technology will depend on the reception and support given to this effort. User feedback is crucial to the process of identifying the most needed. Through this process, research priorities can be established to address the needs of the community in the most efficient manner. In addition, we challenge the fire safety community to review and comment on this effort. The gaps in knowledge identified herein can then help guide our work toward resolving these issues. As we continue to plumb the depths of this problem, both the direction and scope of the methodology will be influenced by what users say is needed as well as the results which evolve naturally from the BFRL's research efforts.

New Technology

Technologies which we should address and embrace include the diversity of computer platforms which are evolving, networks and multiprocessor systems, and new hardware such as CDROM.

CDROM: The first technology we intend to address is our distribution medium. Multimedia is on the rise and the prediction for CDROM sales is 2-3 million in 1993 alone. As sales grow, the per unit cost comes down, and is now only about three times that of a standard floppy but with almost 500 times the capacity. Using the CDROM as a medium allows us to include the databases which will be necessary to utilize the new generation of fire models. In addition, we can include video sequences of some of the sample and test cases. We need to run actual fires of some of the samples files which we distribute with HAZARD and include the video with the distribution.

Networks: At present there are over 100 million microcomputers in use. This number, including high end workstations, is likely to continue to increase. Manufacturers are beginning to develop small-scale parallel systems, and the cost of adding a processor board is only about 20% of the cost of a new system. The implication is that 2 to 10 processor systems are likely to become the norm for computer systems. Also, office systems are being networked. It is especially those people we are trying to reach. We should be able to take advantage of these hardware configurations. This utilization will become more important as the models become more complex and there is an associated increase in the computing time. We will begin developing a method to utilize parallel processing to greatly increase speed.

Conclusions

The intent is to provide tools which will help improve the understanding of fires. This is an attempt to provide a mechanism to allow researchers, fire protection engineers, and others access to the most current understanding of the behavior of fires. These engineering tools could then be the basis for demonstrating compliance with performance objectives.

References

1. Cooper, L. Y., Fire-Plume Generated Ceiling Jet Characteristics and Convective Heat Transfer to Ceiling and Wall Surfaces in a Two-Layer Zone-Type Fire Environment: Uniform Temperature Ceiling and Walls, National Institute of Standards and Technology (USA) Internal Report 4705 (1991).

2. Forney, G.P., Computing Radiative Heat Transfer Occurring in a Zone Fire Model, National Institute of Standards and Technology (USA) Internal Report 4709 (1992).

3. Portier, R., A Programmer's Reference Guide to FDMS File Formats, National Institute of Standards and Technology Internal Report 5162 (1993).

4. Portier, R., Fire Data Management System, FDMS 2.0, Technical Documentation, National Institute of Standards and Technology Technical Note 1407 (1994).