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# The Fire Hazard Assessment Methodology

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## *Introduction*

The United States alone spends about $850B per year on new and renovated construction[1]. About 1/5 of this is to assure safety from unwanted fires. This presents a major opportunity for the introduction of new fire safe products to the building and transportation industries and new products such as advanced detectors and suppression systems and fire fighting equipment for the fire safety industry. These industries need measures of performance for their products and mechanisms to show that these products can be safely and quickly introduced. In order to derive this benefit it is necessary to have tools to evaluate building systems performance which then provide a metric for the effectiveness of design and material use. The Fire Hazard Assessment Methodology provides the first component of a performance evaluation system.

Hazard I is a prototype of a general purpose fire hazard assessment method. The scope of this prototype, its data base and the example cases are focussed on single family residential occupancies. The product helps to make the results of fire research available in a usable way. The hope is that the tedium associated with applying a multiplicity of formulae to solve a problem will be alleviated to some extent.

The methodology consists of a set of procedures combining expert judgment and calculations to estimate the consequences of a specified fire. These procedures involve four steps: 1) defining the context, 2) defining the scenario, 3) calculating the hazard, and 4) evaluating the consequences. Steps 1, 2, and 4 are largely judgmental and depend on the expertise of the user. Step 3, which involves use of the extensive HAZARD I software, requires considerable expertise in fire safety practice. The core of HAZARD I is a sequence of procedures implemented in computer software to calculate the development of hazardous conditions over time, calculate the time needed by building occupants to escape under those conditions, and estimate the resulting loss of life based on assumed occupant behavior and tenability criteria. These calculations are performed for specified buildings and fire scenarios of concern.

## *History*

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.

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 to the HAZARD software package:***

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[2] 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[3]. 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 salient difference in Survival is that incapacitation or death will prevent further movement of a person. The original thrust of Exitt (sic) and Tenab, which allows one to see relative effects of toxic insults, has been incorporated into Survival.

***A View of the Evolution of Fire Modeling:***

As we continue to improve the 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 calculating fire safe structures takes hold, the question will arise of how much does some improvement in safety cost, how much will it save? 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 concomitant dollar loss would be. Such a capability would be on top of that for estimating the effect of fire.

The concept of general building/people/fire interactions could be included. There are three aspects which we would need to be addressed. The first is the people/building interaction. The second is an integrated model for highrise 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) is a vast improvement over the text based interface currently in use. We intend to extend this to all aspects of modeling, including the use of the FireForm tools as a utility within HAZARD. Our concept of a GUI will be embodied first in FASTLite and the CFAST shell. The CFAST shell embodies a more holistic view of the interaction of a fire with the building environment and FASTLite is the continuation of FPETool in a windowing mode. In some ways this goes beyond our original goal of providing a simple filter to prevent egregious mistakes. However, there are several databases associated with fire modeling: thermophysical properties, fire curves, validation data and so on. It allows us to make these databases much more versatile and accessible without encumbering the user of the system too much. By extending the GUI concept to include the graphics output as well as the people placement and specification of those items which affect the behavior of people, it will be possible to provide a uniform basis (look and feel) for all of our modeling effort. This would, in turn, provide a general framework for cooperation in fire research. For example, our post processing tools are being extended by us and others for use with CFD models.

***New phenomena:*** There are many new phenomena which could be incorporated. 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), 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, 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[4],[5] databases, Corrosion - add on for HCl - important for semiconductor industry and warehouses. Smoke movement in tall shafts, stairways and atria.

***Limitations***: There are phenomena for which the algorithms are adequate, but could be more accurate:

• *General* - Pyrolysis (and flame spread) models still depend on test methods. No heating/cooling in HVAC ducts, and reverse flow in fans 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 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 because the flow characteristics of the model depend critically on the structure being modeled.

An important part of our work is developing <<b>>various types of databases. This is an important underpinning of the US Japan Panel on Natural Resources cooperative program (UJNR). 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 becomes more prevalent, onsite inspections will allow such hand held computers to interact directly with desk bound servers for maintaining databases and ascertaining 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 stratagems. 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 plug these display into the alarm system to see the current status of a building and then make a prediction of 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 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.

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 aspec, 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 Focus***

**Data and sample runs:** We now deliver HAZARD with some sample cases. It would be useful to provide a set of cases from start to finish with a test case, a video of the actual case being burned in a facility such as the BFRL Large Scale Fire Test Facility, and the accompanying data.

**Survival and the kernel:** The concept of general building/people/fire interactions needs to be included. This would allow realistic evacuation scenarios to be studied. There are three aspects which we need to address. The first is the people/building interaction. The second is an integrated model for highrise and residential. The third is an editor for people movement rules. It should be possible to develop Survival so that the people interact with the fire by having Survival call the CFAST kernel.

**Parameter variation and estimation of probabilities:** One of the most important extensions of HAZARD I would be the concept of automated parameter variation, which include incorporating probability of actual events to ascertain the relative effect of particular scenarios. This capability would increase the usefulness of our models many fold. As part of this work it is necessary to 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?

### *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 meeting performance standards.

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