THE WPI/FIRE ROOM FIRE COMPUTER MODEL

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ABSTRACT

This paper presents the WPI/Fire computer code. The WPI/Fire computer program is a single room zone-type compartment fire model. It has been used in the analysis of fires and firesafety issues on board surface ships and submarines, subway cars and in buildings.

The computer model is a successor to the Harvard Fire Code, Version 5.0 developed in the early 1980's at Harvard University by Prof. Howard Emmons and the computer code FIRST, an advanced version of the Harvard Code written by researchers at the National Bureau of Standards Center for Fire Research (now the National Institute of Standards and Technology's Building and Fire Research Laboratory).

Like the Harvard Code (and FIRST), the WPI/Fire model is a deterministic, time-dependent, two-layer zone model. It has sophisticated heat transfer routines for the calculation of radiation and convection heat transfer between hot and cold layers, objects and the room boundaries. It calculates flows through multiple door and window vents. Most importantly, it incorporates algorithms for pool fires, gas burners and growing fires as well as fire spread due to target object ignition. The growing fire algorithm accounts for horizontal flame spread growth rates which may be modeled as functions of the incident heat flux to the fuel's surface. Other features include user selected physics subroutines and forced ventilation through doors and windows.

In addition to these features, the WPI/Fire Code incorporates the following major features:

- **Momentum driven flows through ceiling vents,**
- **two different ceiling jet models for use in detector activation,**
- **forced ventilation for ceiling and floor vents, and**
- **an interface to a finite difference computer model for the calculation of boundary surface isotherms and hot spots.**

INTRODUCTION

The WPI/Fire computer program is a single room zone-type compartment fire model. It has been used in the analysis of fires and firesafety issues on board surface ships and submarines, subway cars and in buildings.

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BACKGROUND

There are two basic types of room fire models; field models and zone models. Field models divide the continuum into cells using a fine mesh. Such models then solve the fundamental equations of mass, energy, and momentum transfer for each cell. However, field models are not able to model with a high degree of accuracy, turbulence or combustion processes. Nevertheless, field models do an excellent job at modeling fluid flows and motions between cells. For example, three-dimensional field model can be used to great advantage in the prediction of fire spread from space to space and for detailed investigations of specific phenomena such as ceiling jets.

There are two major difficulties experienced with field models. The first is the tedium required to develop the model input. Even with automatic mesh generation, a substantial effort is necessary to describe the complex geometries found in buildings and rooms, especially with respect to the description of various objects in a room. Second, even with today's fast computers, lengthy computational times are the rule. This often makes sensitivity studies requiring many computer runs prohibitively expensive.

The other common approach used in room fire modeling is the "zone" approach. This approach divides the continuum into a limited number of zones. The most zone subdivisions are those for a hot, upper layer, a colder lower layer, fire plumes and sometimes ceiling jets.

The WPI/Fire Code (WPI-2) is a zone model. WPI-2 has its origins in the Harvard Computer Codes. These codes were originally developed at Harvard University in the 1970's by Prof. Howard Emmons.[1]By 1980 Prof. Emmons and Dr. Mitler released version 5.0 of the Harvard Code. This was the first comprehensive room fire model.[2]

Version 5.0 was followed by version 6.0, a multi-room model, and version 5.3, a more sophisticated single room model. In 1982, Dr. Mitler continued the development of the Harvard Code at the National Bureau of Standards (now known as the National Institute of Standards and technology). The name of the program was changed to FIRST.[3]

At about this time work on a WPI version of Harvard version 5.3 was started. This effort culminated in the development of the WPI/Fire Code, version 1 (WPI-1). This was followed by the release of WPI-2 (the current version of which is WPI/Fire, version 2.1b). WPI-2 incorporates the changes to Harvard 5.3 which were incorporated in WPI-1, many features from FIRST and some additional features.

THE WPI/FIRE CODE

The initial version of the WPI/Fire Code (WPI-1) was developed for use in a specialty application. As a result, the following changes and modifications were made to Harvard 5.3.[4]

1. The input routine was modified to allow screen input or input from a file and a limited on-line help-facility for first time users was added.

2. Additional physical routines were added, including:

   - the ability to model thermally thin walls and objects,
   - buoyancy and momentum driven ceiling vents, and
   - ceiling jet driven heat losses to the ceiling and upper walls.

3. An interface to a three dimensional finite element program was added by Caffrey.[5]

4. A feature in Harvard 5 which allowed user's to pick from a collection of physics subroutines was removed. This was to make it easier for engineers not trained in detailed fire modeling to use the model.

After the release of WPI-1, continuing efforts lead to WPI-2. The current version, 2.3, has had numerous minor bugs removed, documentation written,[6] and the following features added:

1. the ability to choose different physics options which had been removed in WPI-1 was restored,

2. the input routine was improved to improve the user interface,

3. a second ceiling jet model was added, and

4. the ability to model forced ventilation in ceiling and floor vents was added.

The following is a brief description of the improved physics algorithms that have been instituted in the WPI/Fire Code. They are described in depth in the referenced documents.

Thermally thin walls and objects are handled by automatically using thermally lumped models based on a Biot number criterion. The buoyancy and momentum driven ceiling vent algorithms are discussed in detail by Beller [7] The momentum driven vent model is based on an unpublished derivation by Mitler.[8] The assumptions used in the derivation are:

1. The ceiling jet has a constant thickness and a velocity at any point on the ceiling, proportional to the plume's velocity (i.e. only a crude, plume based ceiling jet model is used).

2. Wall and corner effects are negligible and may be ignored.

3. Only one ceiling vent is modeled correctly. Additional vents ignore the change in ceiling jet velocity and thickness caused by flow through the first ceiling vent,

4. Only one burning object is modeled with respect to the ceiling jet and subsequent ceiling vent flow.

5. Puffing and breathing are not accounted for. As a result, floor or wall vents must be open if a ceiling vent is modeled.

The addition of a ceiling jet model per se has been done to account for increased heat transfer to ceilings and walls during the early part of a room fire's development. Two different models are available. The program's user may choose to exclude a ceiling jet model, or to choose one of those offered. They are based on correlations by Cooper [9] and by Motevalli [10]. Cooper's correlation is based on steady-state experiments whereas Motevalli's is based on transient measurements. In Cooper's case the maximum jet velocity and temperature at a given radial distance from the plume's axis are used for calculating the heat flux. If Motevalli's plume is chosen, the correlations for the jet's temperatures at the ceiling are used. Figure 1 illustrates the difference between ceiling jet temperatures using Motevalli's correlation and that using Cooper's correlation. Figure 2 illustrates the reduced hot gas layer temperature predicted using these ceiling jet correlations versus the default case (no ceiling jet).[11]

Caffrey[5] developed an interface with the WPI/Fire code which enables detailed heat transfer calculations in walls and ceilings based on a three-dimensional finite difference model.[12] Results from the use of this program are illustrated in Figure 2 where isotherm calculations for a steel wall are shown.

[12] This finite difference model has not yet been released by WPI

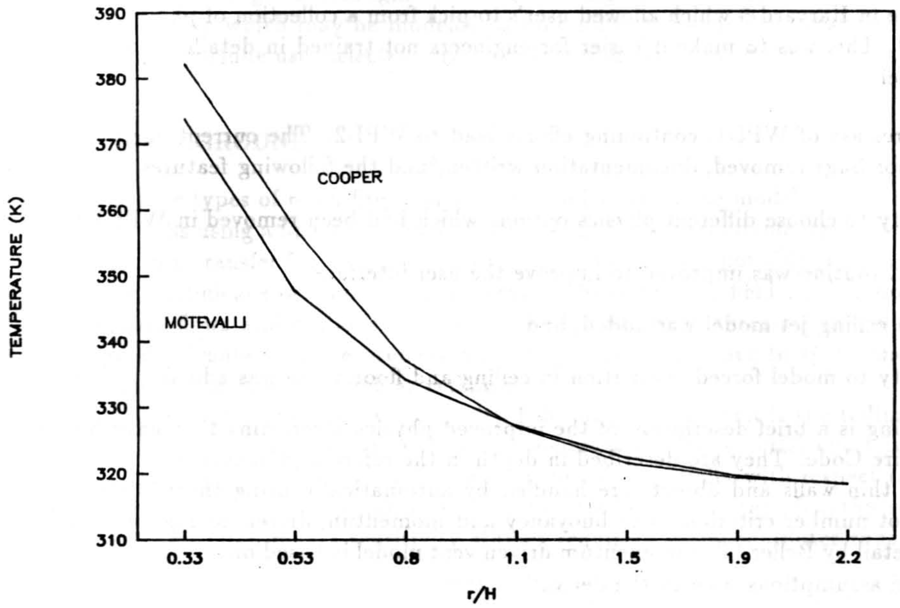

Figure 1: Figure 1 - Ceiling Jet Temperatures Adjacent To The Ceiling, As a Function of the Radial Distance to Ceiling Height Ratio (r/H) as Predicted by Motevalli's and by Cooper's Correlations and Calculated Using the WPI/Fire Code.

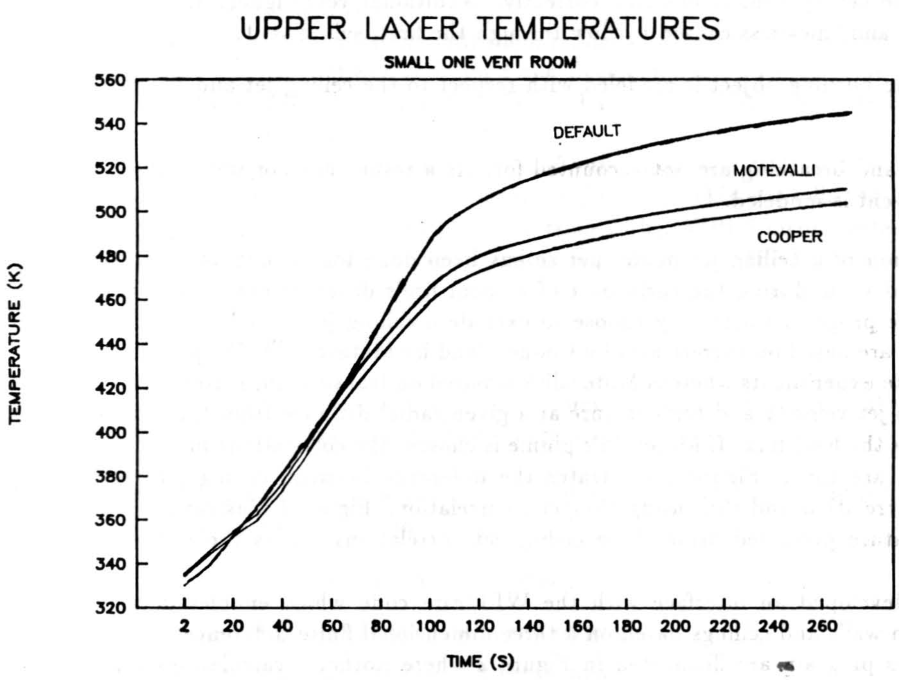

Figure 2: Figure 2 - Upper Layer Temperature as Predicted Using the WPI/Fire Code and no Ceiling Jet Model (Default), Cooper's Ceiling Jet Model and Motevalli's Ceiling Jet.

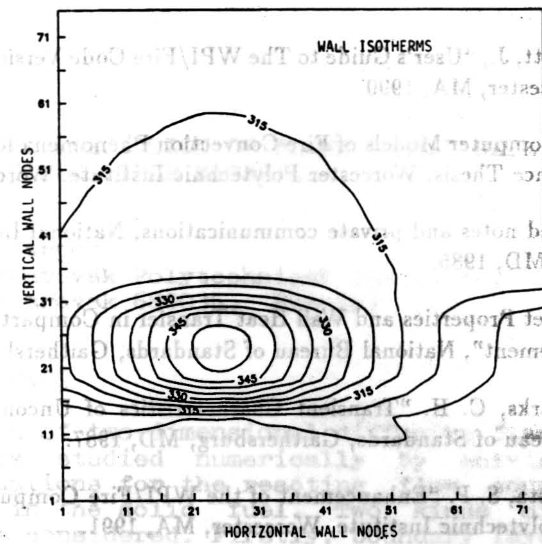

Figure 3: Wall Temperatures Predicted Using Results from the WPI/Fire Code and Caffrey's Computer Model

FUTURE DEVELOPMENTS

The WPI/Fire Code is constantly being improved. Currently, versions for UNIX platforms as well as the PC[13] are available. Work in progress includes an enhancement to the online help facility, an improved method for utilizing furniture calorimeter data for use in the growing fire algorithm, the prediction of ignition of the hot gas layer and the prediction of time to sprinkler activation. Lastly, a graphics-based user interface (GUI) for post-process analysis of the computer results is under development. This GUI will operate only in an X-Windows environment, but will enable users to graph various variables, as well as view 'movies' of the fire development in a simple, easy to use manner.

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