A COMBINED FIELD-ZONE MODEL FOR COMPARTMENT FIRE

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ABSTRACT

A new model (F-Z model) is proposed for compartment fire modeling, which is a combination of field model and zone model being currently available. The main idea of the F-Z model is to use field model for rooms (in which the two-layer assumption of zone model is inadequate.) of fire origin, with strong ventilation or the rooms in which a detail simulation is required, and to use zone model for other spaces in the compartment. The general structure and the way to deal with interface between field and zone models within the framework of F-Z model are described and demonstrated by performing two- and three -dimensional F-Z modeling for a two-room compartment fire. Also, the case is experimentally studied. Predictions by the F- Z model are in qualitative agreement with experimental data, which shows that the F-Z model is promising in compartment fire modeling.

INTRODUCTION

Computer modeling has drawn much attention from engineers and scientists in fire research[1]. There are mainly two kinds of models available at present for compartment fires. They are zone model and field model. The zone model is active, being widely developed, which is based on two-layer assumption [2] in a compartment fire. The zone model produces a fairly reasonable simulation in many cases[3]. However, the two-layer phenomenon does not generally exist in some special cases, such as in a room of fire origin or with strong ventilation. Also, current zone model is limited in its simulation of fluid flow, heat transfer and flame spread, which are of importance to many applications (detection, sprinkler activation, complex geometries, etc.). The field model[4] can in principle give the distributions of gas velocity, temperature, concentration of various species and their variation with time in a compartment fire by solving a set of partial differential equations. However, the field model needs a large amount of storage and run time of a computer. It is still impossible for applying the field model to a high rise building in the foreseeable future.

It is advisable to develop a new model, which retain the advantage of both field and zone models. The new model presented here is a combination of field and zone models, and so called as the Field-Zone model (F-Z model in short) . The main idea of the F-Z model is to use field for rooms of fire origin, with

strong ventilation or rooms in which a detail simulation is needed, and to use zone model for the others connected with the rooms mentioned above. By the F-Z model compartment fire will be able to be predicted well under the capability of present computer. The main difficulty in construction of the F-Z model is to explore a way to treat an interface, of which on both sides the field model and zone model are performed respectively.
Within a framework of the F-Z model either one-, two- or three- dimensional field modeling can be adopted for predictions of fire behavior in those specially-interested rooms. Accordingly, they can be called respectively as one-, two- or three-dimensional (1-, 2- or 3-D in short) F-Z model. In the present paper two cases have been studied in different ways. First, both 2- D F-Z model and Zone model are carried out for prediction of smoke movement in a two-room compartment, and the predictions obtained by the two models are compared. Secondly, the 3-D F-Z model is used in a small-scale system, which is experimentally studied as well. Comparisons are made of predictions and experimental data.

F-Z MODEL AND EXPERIMENT

The F-Z model consists of three parts. They are field model, zone model, and the interface treatment.

1. FIELD MODEL

Fire is a complex phenomenon. It consists of fluid flow, heat and mass transfer, chemical reactions and their interactions. Most of real fire are turbulent processes. Models are usually needed to describe the processes of turbulence transport, turbulent combustion, heat radiation, vaporization of liquid fuel or pyrolysis of solid fuel, soot formation and consumption, etc. Models are various with different generality, reliability, flexibility and economy. Therefore compromise must be made according to the requirements in study, when people choose a model.
In the present study the governing equations of continuity, momentum, energy and chemical species are constructed and solved together with the buoyancy-modified k- ε turbulence model, which can be cast into a general form given on Table 1. [5] [6]

2. ZONE MODEL

Various zone models are available in literature. A moderate- level zone model[7] is adapted for the present study.

3. INTERFACE TREATMENT

Boundary conditions must be given in the interface, which are needed for solving the governing equations in field modeling. Zero gradient condition is adaptable for all dependent variables except for the velocity component perpendicular to the interface, which is determined by an assumption of mass conservation in the grids adjacent to the interface. Variation of pressure with height of the interface should be taken into account, which is given by a formula,

$$P_N = P_O - \sum_{i=1}^{N} \rho_i g h_i$$

where the subscript O denotes a value on the ground, and N is index of a grid being referred to.

To perform zone modeling in the connected room, the flow rates of mass and energy cross the interface and their variation with time are required, which are obtainable from appropriate summation of the predictions of velocity, temperature, concentration of species and density in the interface by field modeling. Taking calculation of energy flow rate, $\bar{E}$, as an example,

$$\bar{E} = \sum_{i=1}^{N} C_{pi} \rho_i T_i u_i a_i$$

where i refers to the index of a grid in the interface; N the total number of grid in the interface; C_{pi}, T_i, ρ_i, u_i, and a_i stands for specific heat, temperature, density, velocity of the gas, and the area of the grid boundary respectively.

TABLE I. PARTIAL DIFFERENTIAL EQUATIONS

$$\frac{\partial(\rho\Phi)}{\partial t} + \frac{\partial}{\partial X_i}(\rho u_i \Phi) = \frac{\partial}{\partial x_i}\left(\Gamma_\Phi \frac{\partial \Phi}{\partial x_i}\right) + S_\Phi$$

EQUATIONS	Φ	Γ_Φ	S_Φ
CONTINUITY	1	0	0
u	u	μ_{eff}	$-\frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial w}{\partial x}\right) + \rho g$
v	v	μ_{eff}	$-\frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial w}{\partial y}\right)$
w	w	μ_{eff}	$-\frac{\partial P}{\partial z} + \frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial z}\right) + \frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial v}{\partial z}\right) + \frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial w}{\partial z}\right)$
k	κ	Γ_k	$G_B + G - \rho\varepsilon$
ε	ε	Γ_ε	$\varepsilon/\kappa[C_1(G+G_B)(1+C_3R_f) - C_2\rho\varepsilon]$
H	H	Γ_h	S_h

4. EXPERIMENT

The experimental set- up is sketched in Fig 1. A electric heat source withcontrolled power is centrally located in room A. 24 thermocouples are placed in room A and B , and linked with a 24-CH THERMALS A/D and a computer for temperature measurement and data processing.

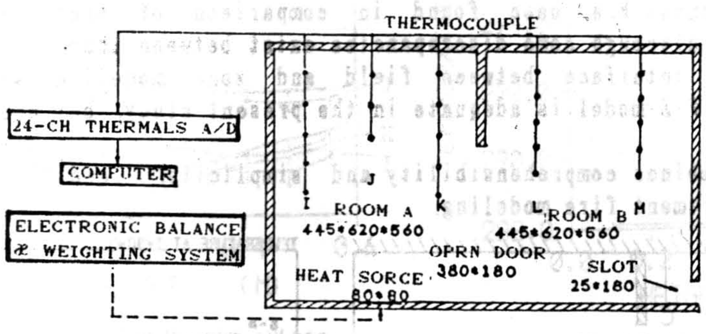

Fig 1. SKETCH MAP OF THE EXPERIMENT

RESULTS AND DISCUSSIONS

Two cases have been studied with the F-Z model.
The first is to predicted the smoke movement in a two-room compartment by the 2-D F-Z model and the zone model respectively. The geometry and the size of the compartment are shown in Fig. 2 The predictions of temperature distributions in three sections of the fire-origin room are given in Fig. 3. A typical saddle-shape cure shown in Fig. 3 is due to entrainment of surrounding air by the fire plume. Fig. 4 shows the hot-layer development in the room next to the room of fire origin by the F-Z model and zone model respectively They give qualitatively-agreed results. The second study is to compare the results of hot -gas movement in a small-scale compartment (see Fig. 1) , which are obtained by 3-D F-Z modeling and experiment. The prediction of velocity distribution in a typical section is given in Fig. 5, which shows the flow field in detail.
Fig. 6 gives the results in room A. It can be seen that the tendency of predictions and experiment is siminar, although systematic over predictions are shown. Temperature distributions in the room B are given in Fig. 7. The layering phenomenon can be seen from the experiment data.
It can be seen from the experiments (Fig. 7) that gas layering phenomenon is not clear in a room with a heat source, whereas the two-layer assumption is close to experiment in the connected room.
Predictions by F-Z model are in qualitative agreement with experiment. However, the temperature is over predicted, which may be attributed to the assumptions of walls being adiabatic, and to neglect of thermal capacity of walls and the isolator of the electrical heater.

Here we may draw the following conclusions.

Two-dimensioned F-Z modeling and zone modeling have been performed for prediction of the smoke movement in a two-room compartment. The F-Z model can give the flow field, heat and mass transfer in detail, but needs larger computer capacity(storage and run time).

Three-dimensional F-Z modeling as well as experimental measurement have been made to study the hot gas movement in a small-scale two-room system. Qualitative agreement has been found in comparison of predictions with experiment data, although some discrepancies exist between them.

The treatment of interface between field and zone modeling within the framework of the F-Z model is adequate in the present study, but needs to be further verified.

The F-Z model combines comprehensibility and simplicity, and is full of promise in compartment fire modeling.

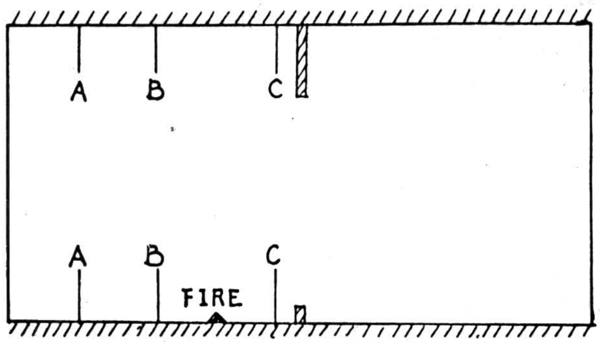

FIG 2.. GEOMETRY OF THE COMPARTMENT

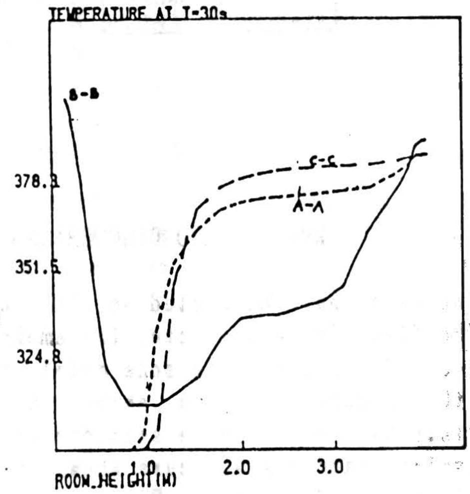

FIG 3. VARIATION OF TEMP WITH HEIGHT

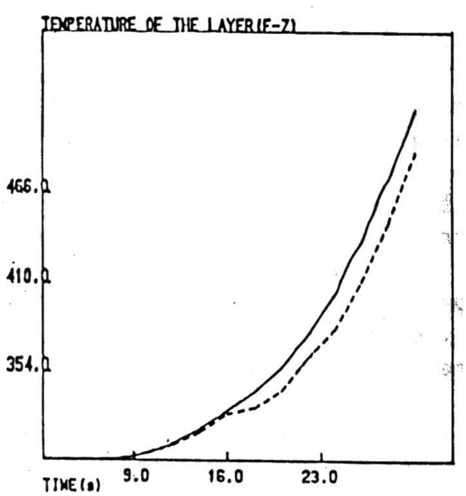

FIG 4. VARIATION OF TEMP WITH TIME

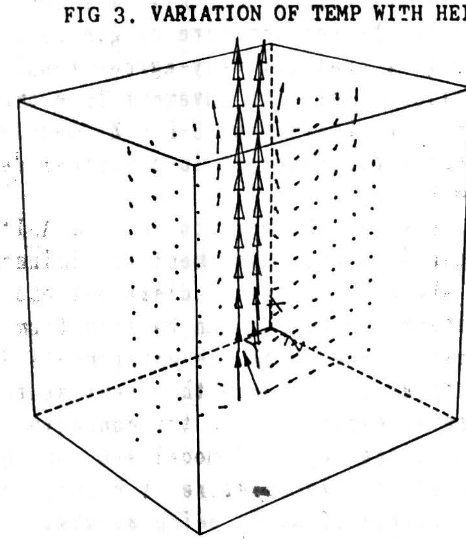

FIG 5.Z PLANE'S VELOCITY DISTRIBUTION (T=1.0S)

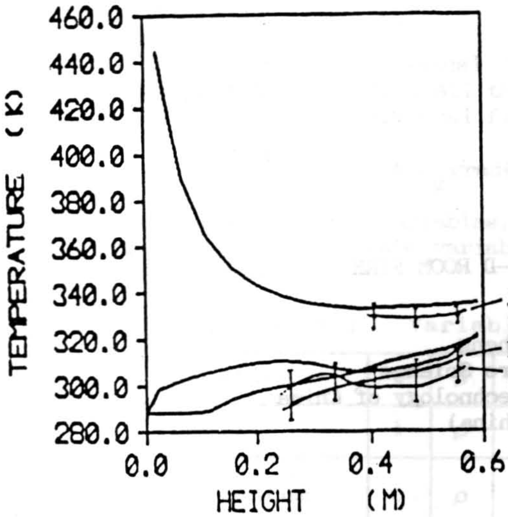

FIG 6. CURVE OF TEMP-HEIGHT IN ROOM A

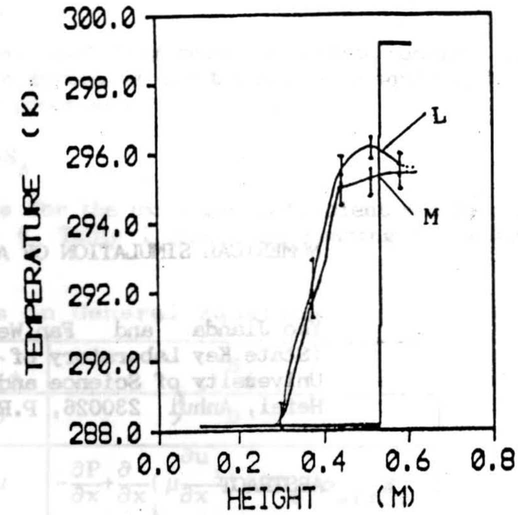

FIG 7.CURVE OF TEMP-HEIGHT IN ROOM B

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