

CHAPTER 7

Zone Computer Fire Models for Enclosures

William D. Walton

Introduction

Computer programs are used in many areas of fire protection design, including suppression system design, smoke control system design, and egress analysis. The emphasis in this chapter is on zone computer fire models for enclosures. Zone fire models are computer programs designed to predict the conditions resulting from a fire in an enclosure. These models solve the equations based on the zone assumptions describing the fire-induced conditions within an enclosure.

Computer fire models can provide a faster and more accurate estimate of the impact of a fire and the measures used to prevent or control the fire than many of the methods previously used. While manual calculation methods provide good estimates of specific fire effects (e.g., prediction of time to flashover), they are not well suited for comprehensive analyses involving the time-dependent interactions of multiple physical and chemical processes present in developing fires.

The state of the art in computer fire modeling is changing rapidly. Understanding of the processes involved in fire growth is improving, and, thus, the technical basis for the models is improving. The capabilities, documentation, and support for a given model can change dramatically over a short period of time. In addition, computer technology itself (both hardware and software) is advancing rapidly. A few years ago, a large mainframe computer was required to use most of the computer fire models. Today, all of the zone fire models can be run on personal computers. Therefore, rather than provide an exhaustive review of rapidly changing state-of-the-art available computer models, the following discussion will focus on a representative selection. The reader is guided to References 1 and 2 for a comprehensive review of computer fire models.

Mr. William D. Walton is a research fire protection engineer with the Building and Fire Research Laboratory, National Institute of Standards and Technology.

Enclosure Fire Models

There are two major classes of computer models for analyzing enclosure fire development. *Stochastic or probabilistic models* generally treat fire growth as a series of sequential events or states. These models are sometimes referred to as *states transition models*. Mathematical rules are established to govern the transition from one event to another (e.g., from ignition to established burning). Probabilities are assigned to each transfer point based on analysis of relevant experimental data, historical fire incident data, and computer model results. For a complete discussion of stochastic models, see Section 3, Chapter 16.

In contrast, *deterministic models* represent the processes encountered in a compartment fire by interrelated mathematical expressions based on physics and chemistry. These models may also be referred to as *room fire models*, *computer fire models*, or *mathematical fire models*. Ideally, such models represent the ultimate capability: discrete changes in any physical parameter could be evaluated in terms of the effect on fire hazard. While the state of the art in understanding fire processes will not yet support the *ultimate model*, a number of computer models are available that provide reasonable estimates of selected fire effects.

The newest type of deterministic fire model is the *field model*. This type of model solves the fundamental equations of mass, momentum, and energy for each element in an enclosure space that has been divided into a grid of smaller units. A complete discussion of field modeling can be found in Section 3, Chapter 8. Although field model technology and use have advanced rapidly in recent years, it should be noted that field models require substantial computer resources and are relatively complex to use.

The most common type of physically based fire model is the *zone or control volume model*, which solves the conservation equations for distinct and relatively large regions (control volumes). A complete discussion of the fundamental principles behind the zone fire model formulation can be found in Section 3, Chapter 5. A number of

zone models exist, varying to some degree in the detailed treatment of the fire phenomena. The dominant characteristic of this type of model is that it divides the room(s) into a hot, upper layer and a cooler, lower layer. (See Figure 3-7.1.) The model calculations provide estimates of key conditions for each of the layers as a function of time. Zone modeling has proved to be a practical method for providing estimates of fire processes in enclosures.

The beginnings of pre-flashover zone fire modeling can be traced to the mid-1970s with the publication of a description of the fundamental equations by Quintiere.³ Based on these equations, the first zone fire model published was RFIRES by Pape and Waterman,⁴ followed shortly by the HARVARD model by Emmons and Mitler.⁵ The development of zone fire models was facilitated both by the advancement in the understanding of the basic physics of fire growth in a compartment and advances in, and the availability of, mainframe computers. Following the publication of these two models a number of zone fire models for mainframe computers were introduced. In 1985 the first zone model, ASET-B, written specifically for the newly available IBM-compatible personal computers, was introduced by Walton.⁶ Since that time additional models have been introduced, and most of the models written for mainframe computers have been converted for use in personal computers.

No zone fire model is *best* for all applications. The selection of a zone fire model for a particular application depends on a number of factors. While most of the zone fire models are based on the same fundamental principles, there is significant variation in features among the different models. The decision to use a model should be based on an understanding of the assumptions and limitations for the particular model. In general the more detailed the model outputs, the more extensive the model inputs, and the greater the computer execution time required. When using any computer fire model, it is always a good idea to test the sensitivity of the model outputs to changes in model inputs. If small changes in model inputs result in large changes in model outputs, the user must exercise great care in selecting the input values.

A key issue in selecting a model is model validation. Comparison of model results with experimental data is valuable for determining the applicability of a model to a

particular situation. Comparisons of model results with experimental data are limited, and the number of comparisons varies widely among the models. The model user should carefully examine model validation comparisons before selecting a model. Frequently, experienced model users will use more than one model to evaluate a particular situation. If several models provide similar results this can increase the confidence in the results. Similar results do not, however, guarantee that the results accurately represent the physical conditions being modeled, since most of the zone fire models are based on the same basic assumptions.

Overview of Representative Zone Fire Models

ASET Computer Program

ASET (available safe egress time) is a program for calculating the temperature and position of the hot upper smoke layer in a single room with closed doors and windows. ASET can be used to determine the time to the onset of hazardous conditions for both people and property. The required program inputs are the heat-loss fractions, the height of the fuel above the floor, criteria for hazard and detection, the room ceiling height, the room floor area, a heat release rate, and (optional) species generation rate of the fire. The program outputs are the temperature, thickness, and (optional) species concentration of the hot upper smoke layer as a function of time, and the time to hazard and detection. ASET can examine multiple cases in a single run. ASET was written in FORTRAN by Cooper and Stroup.⁶

ASET-B Computer Program

ASET-B is a program for calculating the temperature and position of the hot upper smoke layer in a single room with closed doors and windows. ASET-B is a compact version of ASET, designed to run on personal computers. The required program inputs are a heat-loss fraction, the height of the fire, the room ceiling height, the room floor area, the maximum time for the simulation, and the rate of heat release of the fire. The program outputs are the temperature and thickness of the hot upper smoke layer as a function of time. Species concentrations and time to hazard and detection, calculated by ASET, are not calculated in the compact ASET-B version. ASET-B was written in BASIC by Walton.⁶

COMPBRN III Computer Program

COMPBRN III is primarily used in conjunction with probabilistic analysis for the assessment of risk in the nuclear power industry. The model is based on the assumption of a relatively small fire in a large space, or a fire involving large fuel loads early during the pre-flashover fire growth period. The model's strengths are (1) emphasis on the thermal response of elements within the enclosure to a fire within the enclosure, and (2) model simplicity. The temperature profile within each element is computed,

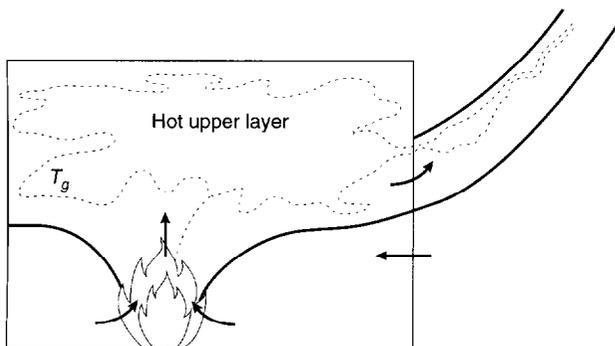


Figure 3-7.1. Two-layer model with no exchange between layers except the plume.

and an element is considered ignited or damaged when its surface temperature exceeds the user-specified ignition or damage temperature. The model outputs include the total heat release rate of the fire, the temperature and depth of the hot gas layer, the mass burning rate for individual fuel elements, the surface temperatures, and the heat flux at user-specified locations. COMPBRN III was written by Siu et al.⁷

COMPF2 Computer Program

COMPF2 is a computer program for calculating the characteristics of a post-flashover fire in a single building compartment, based on fire-induced ventilation through a single door or window. It is intended both for performing design calculations and for the analysis of experimental burn data. Wood, thermoplastics, and liquid fuels can be evaluated. A comprehensive output format is provided that gives gas temperatures, heat-flow terms, and flow variables. The documentation includes input instructions, sample problems, and a listing of the program. The program was written in FORTRAN by Babrauskas.⁸

CSTBZ1 Computer Program

CSTBZ1 is a computer program for post-flashover fires, based on similar basic assumptions as those of COMPF2. The equations of mass and energy conservation are written without neglecting the fuel source term, and several vertical openings in a room can be considered. The equation of heat diffusion into the walls is solved either by a classical explicit finite difference method, or by a new modal approach that offers the capability of storing in a file a few numbers characterizing a given wall, leading to a rapid calculation of the superficial wall temperatures. A sophisticated numerical algorithm was used to solve the equations through uncoupling. The program was written by Curtat and Bodart.⁹

CFAST Computer Program

The CFAST (consolidated model of fire growth and smoke transport) is an upgrade of the FAST program¹⁰ and incorporates numerical solution techniques originally implemented in CCFM program.¹¹ FAST is now the graphical user interface program for CFAST. CFAST is a multi-room model that predicts within a structure resulting from a user-specified fire. CFAST version 4.0.1 can accommodate up to 30 compartments with multiple openings between compartments and to the outside. The required program inputs are the geometrical data describing the compartments and connections; the thermophysical properties of the ceiling, walls, and floors; the fire as a rate of mass loss; and the generation rates of the products of combustion. The programs outputs are the temperature and thickness of, and species concentrations in, the hot, upper layer and the cooler, lower layer in each compartment. Also given are the surface temperatures and heat transfer and mass flow rates. CFAST also includes mechanical ventilation, a ceiling jet algorithm, capability of multiple fires (up to 30), heat transfer to targets, detection and suppression systems, and a flame spread model. CFAST was written in FORTRAN by Jones, et al.^{12,13}

BRANZFIRE Computer Program

BRANZFIRE is a zone fire model for predicting the fire environment in an enclosure, resulting from a room-corner fire involving walls and ceilings. The zone fire model uses conservation equations based on those found in CFAST.¹² BRANZFIRE predicts ignition, flame spread, and the resultant heat released by the wall and ceiling lining material subjected to a burner fire. The model considers upward flame spread on the walls and beneath the ceiling, lateral flame spread on the walls, and downward flame spread from the ceiling jet. Wall and ceiling flame spread properties are computed from cone calorimeter data. Program outputs include layer height, species concentrations, gas temperatures, visibility, wall temperatures, and heat release rate. BRANZFIRE was written in Visual Basic by C. Wade.^{14,15,16}

JET Computer Program

JET is a two-zone single compartment model where the compartment is enclosed by a combination of draft curtains and walls. The ceiling may contain fusible links and vents where the vents operate in response to the fusing of the links. The ceiling vents remove hot, upper layer gas from the compartment. The fire is characterized by a time-dependent heat release rate, a time-dependent radiative fraction, and either a constant or variable fire diameter, which is determined using a heat release rate per unit area for the burning material. Inputs also include the thermal properties of the ceiling. Program outputs include the ceiling jet temperature and velocity, link temperature, and activation times. JET was written in FORTRAN by W. D. Davis.¹⁷

FIRST Computer Program

FIRST is the direct descendant of the HARVARD V⁵ program developed by Emmons and Mitler. The program predicts the development of a fire and the resulting conditions within a room given a user-specified fire or user-specified ignition. It predicts the heating and possible ignition of up to three targets. The required program inputs are the geometrical data describing the rooms and openings, and the thermophysical properties of the ceiling, walls, burning fuel, and targets. The generation rate of soot must be specified, and the generation rates of other species may be specified. The fire may be entered either as a mass loss rate or in terms of fundamental properties of the fuel. Among the program outputs are the temperature and thickness of, and species concentrations in, the hot, upper layer and the cooler, lower layer in each compartment. Also given are surface temperatures and heat transfer and mass flow rates. The FIRST program was written in FORTRAN by Mitler and Rockett.¹⁸

FPETOOL Computer Program

FPETOOL is the descendent of the FIREFORM program.¹⁹ It contains a computerized selection of relatively simple engineering equations and models useful in estimating the potential fire hazard in buildings. The calculations in FPETOOL are based on established engineering

relationships. The FPETOOL package addresses problems related to fire development in buildings and the resulting conditions and response of fire protection systems. The subjects covered include smoke filling in a room, sprinkler/detector activation, smoke flow through (small) openings, temperatures and pressures developed by fires, flashover and fire severity predictions, fire propagation (in special cases), and simple egress estimation. The largest element in FPETOOL is a zone fire model called FIRE SIMULATOR. FIRE SIMULATOR is designed to estimate conditions in both pre- and post-flashover enclosure fires. The inputs include the geometry and material of the enclosure, a description of the initiating fire, and the parameters for sprinklers and detectors being tracked. The outputs include the temperature and volume of the hot smoke layer; the flow of smoke from openings; the response of heat-actuated detection devices, sprinklers, and smoke detectors; oxygen, carbon monoxide, and carbon dioxide concentrations in the smoke; and the effects of available oxygen on combustion. FPETOOL was written in BASIC by Nelson.²⁰

LAVENT Computer Program

LAVENT is a program developed to simulate the environment and the response of sprinkler elements in compartment fires with draft curtains and fusible-link-actuated ceiling vents. The zone model used to calculate the heating of the fusible links includes the effects of the ceiling jet and the upper layer of hot gases beneath the ceiling. The required program inputs are the geometrical data describing the compartment, the thermophysical properties of the ceiling, the fire elevation, the time-dependent heat release rate of the fire, the fire diameter or the heat release rate per unit area of the fire, the ceiling vent area, the fusible-link response time index (RTI) and activation temperature, the fusible-link positions along the ceiling, the link assignment to each vent, and the ambient temperature. A maximum of 5 ceiling vents and 10 fusible links are permitted in the compartment. The program outputs are the temperature and height of the hot layer, the temperature of each link, the ceiling jet temperature and velocity at each link, the radial temperature distribution along the interior surface of the ceiling, the activation time of each link, and the area opened. LAVENT was written in FORTRAN.²¹

WPI/FIRE Computer Program

WPI/FIRE is a direct descendant of the HARVARD V⁵ and FIRST¹⁸ programs. It includes all of the features of the HARVARD program version 5.3 and many of the features of the FIRST program. WPI/FIRE also includes the following additional features: improved input routine, 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. The WPI/FIRE program was written in FORTRAN by Satterfield and Barnett,²² and additions to the program continue

to be developed by graduate students at the Center for Fire Safety Studies, Worcester Polytechnic Institute.

References Cited

1. R. Friedman, *An International Survey of Computer Models for Fire and Smoke*, 2nd ed. (Dec. 1991). Available from Library, Factory Mutual Research Corporation, 1151 Boston-Providence Turnpike, Norwood, MA 02062.
2. R. Friedman, "An International Survey of Computer Models for Fire and Smoke," *Jour. of Fire Prot. Engr.*, 4, 3, pp. 83-92 (1992).
3. J. Quintiere, "Growth of Fires in Building Compartments," ASTM STP 614, American Society for Testing and Materials, Philadelphia, PA (1977).
4. R. Pape, T.F. Waterman, and T.V. Eichler, "Development of a Fire in a Room from Ignition to Full Room Involvement—RFIRES," *NBS-GCR-81-301*, National Bureau of Standards, Washington (1981).
5. H.E. Mitler, "The Harvard Fire Model," *F. Safety J.*, 9, pp. 7-16 (1985).
6. W.D. Walton, "ASET-B A Room Fire Program for Personal Computers," *NBSIR 85-3144*, National Bureau of Standards, Washington, DC (1985).
7. V. Ho, N. Siu, and Apostolakis, "COMPBRN III—A Fire Hazard Model for Risk Analysis," *Fire Safety J.*, 13, 2-3, pp. 137-154 (1988).
8. V. Babrauskas, "COMPF2—A Program for Calculating Post-Flashover Fire Temperatures," *NBS TN 991*, National Bureau of Standards, Washington, DC (1979).
9. M.R. Curtat and X.E. Bodart, *1st Symposium International Association for Fire Safety Science*, Hemisphere Publications, Gaithersburg, MD, p. 637 (1986).
10. W.W. Jones, "A Multicompartment Model for the Spread of Fire, Smoke and Toxic Gases," *F. Safety J.*, 9, pp. 55-79 (1985).
11. G.P. Forney and L.Y. Cooper, "The Consolidated Compartment Fire Model (CCFM) Computer Application. VENTS, Parts I, II, III, IV," *NISTIR*, National Institute of Standards and Technology, Gaithersburg, MD (1990).
12. W.W. Jones, G.P. Forney, R.D. Peacock, and P.A. Reneke, "A Technical Reference for CFAST: An Engineering for Estimating Fire and Smoke Transport," *TN-1431*, National Institute of Standards and Technology, Gaithersburg, MD (2000).
13. R.D. Peacock, P.A. Reneke, W.W. Jones, R.W. Bukowski, and G.P. Forney, "A User's Guide for FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport," *SP-921*, 2000 Edition, National Institute of Standards and Technology, Gaithersburg, MD (2000).
14. C.A. Wade, D. LeBlanc, J. Ierardi, and J.R. Barnett, "A Room-Corner Fire Growth & Zone Model for Lining Materials," *Second International Conference on Fire Research and Engineering (ICFRE2)*, National Institute of Standards and Technology and Society of Fire Protection Engineers, Gaithersburg, MD, pp. 106-117 (1998).
15. C. Wade and J. Barnett, "A Room-Corner Fire Model Including Fire Growth on Linings and Enclosure Smoke-Filling," *J. of Fire Prot. Engr.*, 8(4), pp. 183-193 (1997).
16. C. Wade, "Branzfire-Engineering Software for Evaluating Hazard of Room Lining Materials," in *Conference Proceedings on the Eight International Interflam Conference*, Interscience Communications Limited, London, pp. 1147-1152 (1999).
17. W.D. Davis, "The Zone Fire Model Jet: A Model for the Prediction of Detector Activation and Gas Temperature in the

Presence of a Smoke Layer," *NISTIR 6324*, National Institute of Standards and Technology, Gaithersburg, MD (1999).

18. H.E. Mitler and J.A. Rockett, "User's Guide to FIRST, A Comprehensive Single-Room Fire Model," *CIB W14/88/22*, National Bureau of Standards, Gaithersburg, MD (1987).
19. H.E. Nelson, "FIREFORM—A Computerized Collection of Convenient Fire Safety Computations," *NBSIR 86-3308*, National Bureau of Standards, Gaithersburg, MD (1986).
20. H.E. Nelson, "FPETOOL: Fire Protection Engineering Tools for Hazard Estimation," *NISTIR 4380*, National Institute of Standards and Technology, Gaithersburg, MD (1990).
21. Y.L. Cooper, "Estimating the Environment and the Response of Sprinkler Links in Compartment Fires with Draft Curtains and Fusible-Link-Actuated Ceiling Vents Theory," *F. Safety J.*, 16, pp. 137-163 (1990).
22. D.B. Satterfield and J.R. Barnett, "User's Guide to WPI-FIRE Version 2 (WPI-2)—A Compartment Fire Model," Worcester Polytechnic Institute, Center for Fire Safety Studies, Worcester, MA (Aug. 1990).

Additional Readings

- L.Y. Cooper and D.W. Stroup, "ASET—A Computer Program for Calculating Available Safe Egress Time," *F. Safety J.*, 9, pp. 29-45 (1985).
- B. Hagglund, "A Room Fire Simulation Model," *FOA C 20501-D6*, National Defense Research Institute, Sweden (June 1983).
- B. Hagglund, "Simulating the Smoke Filling in Single Enclosures," *FOA C 20513-D6*, National Defense Research Institute, Sweden (October 1983).
- J.A. Swartz et al., *Final Technical Report on Building Fire Simulation Model*, Vols. I and II, National Fire Protection Association, Quincy (1983).
- T. Tanaka, "A Model of Multiroom Fire Spread," *NBSIR 83-2718*, National Bureau of Standards, Washington (1983).
- E.E. Zukoski and T. Kubota, "Two-Layer Modeling of Smoke Movement in Building Fires," *F. and Matls.*, 4, 1, p. 17 (1980).