MODELING SMOKE FLOW IN CORRIDORS

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INTRODUCTION

The Public Buildings Service (PBS) within the General Services Administration (GSA) is the Federal government's real property manager responsible for the acquisition, design, construction, and operation and management of various types of space for Federal agencies. As part of its responsibility, the GSA must ensure the fire and life safety of the employees and visitors occupying the space under its control, protect Federal real and personal property assets, ensure continuity of the mission of occupant agencies, and provide safeguards to allow emergency forces to accomplish their missions if an incident occurs.

In an effort to accomplish its mission in the most cost effective manner possible, GSA has devoted significant resources to the development of lifesafety alternatives through scientific research. GSA research activities are focused on three major areas: model development and verification, suppression system effectiveness, and protection of mobility impaired persons. Research results have included methodologies for evaluating the response of detection and suppression systems, elevator use for evacuation during fire emergencies[1], and the effectiveness of various strategies for protecting disabled persons[2]. Other projects have addressed issues such as development of a model of sprinkler effectiveness[3], investigation into sprinklered fire exposure on an exit corridor and on spaces adjacent to that corridor[4], expansion of a heat release rate database, and examination of quick response sprinklers in the open landscape office[5]. The development of *FPETool*[6,7] was probably the most significant result of these research activities.

FPETool[6] is a computerized package of relatively simple engineering equations and models. These engineering tools are useful in estimating potential fire hazard and the response of the space and fire protection systems to the developing hazard. *FPETool* utilizes a zone type compartment fire model that predicts the impact on a room environment of a time varying rate of heat release. The room fire model in *FPETool* predicts the impact of fire in a space by tracking the time dependent changes in average upper layer properties including temperature, depth, and concentrations of some gases. Properties of the ceiling jet including temperature and velocity are predicted to allow determination of smoke and heat detector activation times. Using this package of analytical engineering tools, the development and impact of fire in a building can be assessed. GSA has integrated the use of *FPETool* into its design review and facility assessment processes for evaluation of fire risk in GSA controlled space and appropriate resource allocation.

PROTECTION OF THE DISABLED

The United States Congress required, as part of the fiscal year 1989 funding for GSA, that GSA initiate a pilot project to establish "safe areas of refuge from fire for the disabled" in six federal buildings. These "safe areas" or staging areas would be spaces in which people with disabilities could safely wait for evacuation during a fire. The requirement provided for the construction of staging areas on every floor of each building, above or below grade, that was not served by a ramp leading out of the building. There were also specific design requirements for the construction and fire protection features to be used in each staging area.

In 1991, GSA contracted with the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) to evaluate the effectiveness of the staging areas. BFRL evaluated how well the equipment in the staging areas operated, how effective the staging areas were in maintaining a safe environment during fire, and how human behavior affected the successful use of the staging areas[2,8].

An essential step in evaluating the capability of the staging areas and related systems to fulfill the fire safety needs of persons with disabilities was the analysis of the potential fire threat. The BFRL analysis examined the initial fire development, the exposure to occupants while attempting to move to exits or staging areas, the time required for able and disabled persons to travel from a remote location to an exit or staging area, the potential fire exposure to the staging area, and the length of time that the staging area could be expected to remain tenable. The procedures used to estimate fire exposure conditions, occupant egress, and toxic impact included: the models and other evaluation features contained in the fire hazard analysis programs of *FPETool* and the procedures outlined by Steckler for estimating the conditions developed by smoke flow through corridors[9].

CORRIDOR FLOW ANALYSIS

As a result of the staging area analysis, a new module was added to the *FPETool* suite of programs to predict conditions in corridors exposed to room fires[10]. Corridors can serve as conduits for transporting life threatening combustion products from localized fires to other areas of a building. Combustion products from a fire developing in an office often pass through a doorway or other penetration to an adjacent corridor where they establish a buoyancy driven flow beneath the ceiling. A "forward" gravity current of heated gas propagates away from the fire source along the ceiling of the corridor. Since buoyancy drives the flow, any loss of buoyancy due to heat transfer from the hot gas reduces the velocity of the front and also increases its depth. Upon striking the end wall, the flow reverses and forms a "return" current or wave beneath the existing layer. Eventually, the waves disappear, and the layer tends to fill (thicken) uniformly. Figure 1 illustrates the basic features of this flow phenomena.

The corridor module in *FPETool* is a first order model which approximates the initial flow conditions from a steady state fire condition such as usually occurs following flashover. It predicts the initial flow of a wave front generated by a fire either in the corridor or in a room adjacent to the corridor. The routine predicts the rate of travel, the position of the wave front at any time, the depth of the wave front, and the longitudinal temperature profile of the hot gas behind the wave front.

As part of the development process, the corridor flow module was compared to available experimental data[10]. These comparisons indicated reasonable agreement (about 30%) between experimental data and calculation results. However, most of the full scale tests were not conducted for use in verifying a corridor flow model. Therefore, the availability of required input data was limited and a number of assumptions were required to complete the comparisons. In addition, the tests covered a very limited number of possible scenarios.

A project now underway to further enhance and validate the *FPETool* corridor flow module. As part of the project, the appropriateness of the existing corridor model for different room - corridor arrangements and corridor lengths is being assessed, and modifications will be made as necessary. This corridor module was developed and verified using relatively small steady state fires (about 500 kW). The range of validity of the model is being examined for various fire sizes and growth rates. Full scale fire tests and computational fluid dynamics (field) models are being used to conduct the analysis.

Full Scale Experiments

The United States Coast Guard (USCG) has a 37.5 m long corridor fire test facility on their test vessel, the Mayo Lykes (Figure 2). This vessel is located at the USCG's Fire and Safety Test Detachment in Mobile, Alabama. A series of full scale fire tests were conducted, using a range of fire sizes (heat release rates) and fuel sources, to ascertain the speed(s) at which smoke propagates along the length of the corridor. Two fire compartments were utilized during this test series. Fire Room "A" was located at approximately midway along the length of the corridor. This compartment was used when the test scenario called for the smoke flow to be bi-directional within the corridor. Fire Room "B" (see Figure 2) is located at the aft end of the corridor. This compartment was used when the test scenario called for smoke flow in the corridor to be in a single direction only. The two fire rooms and the corridor were instrumented to gather data concerning the fire parameters, temperatures, gas flows out of the fire compartments and within the corridor, and the relative density of the smoke.

Field Modeling Analysis

The application of field modeling or computational fluid dynamics to the solution of fire protection problems is relatively new. However, these techniques have been used successfully to model fire and smoke movement[11]. Field modeling provides significantly more detail than the typical two layer zone model. The use of field modeling technology will become more widespread as the benefits of these models are recognized and the required computer hardware decreases in price.

Using the flow and temperature data from selected tests, a field model[12] was calibrated to predict the smoke movement within the Mayo Lykes' test corridor. The corridor flow phenomena, as predicted by the field model, is illustrated in Figure 3. Using a temperature range of 50 °C, Figure 3 shows the flow at three time intervals. At 25 seconds, the flow has reached approximately half way down the corridor. The flow reaches the end of the corridor at 36 seconds. At 50 seconds, the flow has hit the end of the corridor and a return wave is moving back toward the burn room. Once the return wave reaches the end of the corridor, the corridor will begin to fill in a manner similar to that predicted by a zone type fire model.

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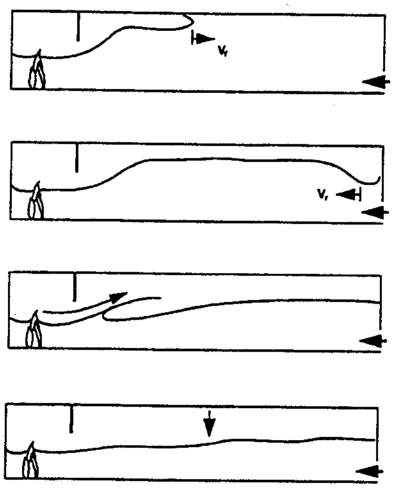

Figure 1. Diagram of corridor flow phenomena.

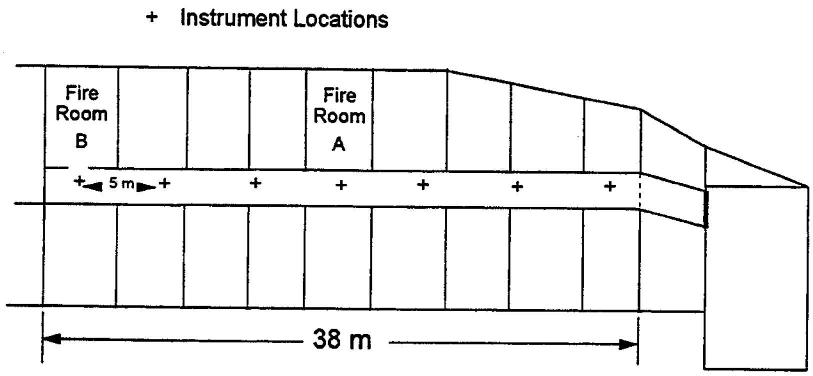

Figure 2. Plan view of Mayo Lykes Test Vessel

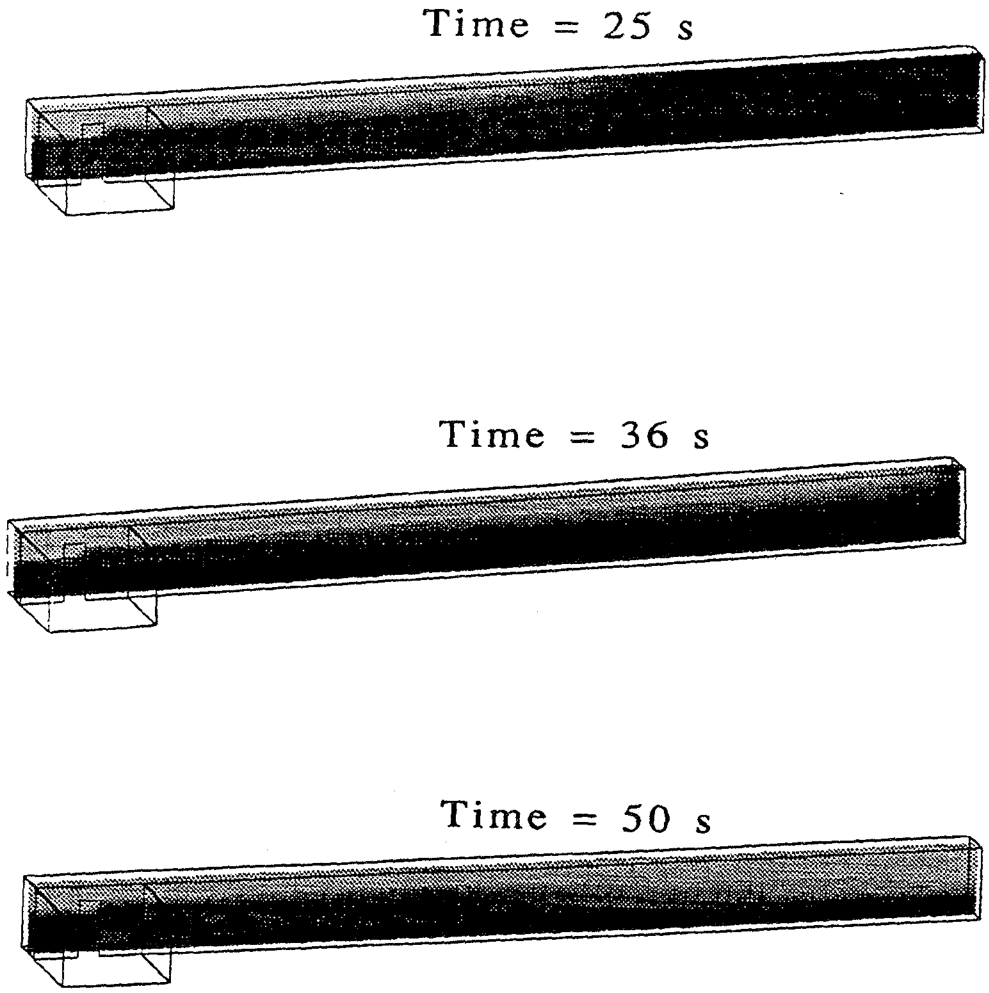

Figure 3. Temperature contours from field model calculations depicting flow in corridor for three simulation times.