PREDICTING FIRE GROWTH INVOLVING INTERIOR FINISH MATERIALS INCLUDING THE EFFECTS OF LATERAL FLAME SPREAD AND LAYER HEATING

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INTRODUCTION

A fire growth model has been developed to predict the flame spread and total heat release rate of a fire in the corner of a combustible lined room. Input data for the combustible lining was developed using small-scale test data from the ASTM E1354 cone calorimeter [1] and ASTM E1321 LIFT [2]. The fire growth model includes a flame spread model [3,4] linked with a two zone compartment fire model, CFAST Version 3.1.2 [5]. The model was validated against large-scale Navy and USCG ISO 9705 room test data [6,7] and large-scale open corner test data on a variety of combustible materials [4]. Using this model, the effects of layer heating and lateral flame spread on fire growth in a corner configuration were explored. Lateral flame spread was found to be an important consideration in large spaces (i.e., open corner) where layer heating was not significant. In smaller compartments (i.e., ISO 9705), the effects of layer heating are significant and lateral flame spread is less important.

FIRE GROWTH MODEL DESCRIPTION

The fire growth model is capable of predicting fire conditions that develop during the pre-flashover stages of a compartment fire. The fire growth model consists of two linked programs: a flame spread program and a compartment fire model. The flame spread program is the Navy flame spread model developed by Beyler*, et al.* [3] and Lattimer *et al*. [4]. This model is used to calculate the contribution of wall linings to the growth of a fire inside a compartment. The compartment fire model is the two-layer, multi-compartment smoke spread model CFAST 3.1.2, which was developed by researchers at National Institute of Standards and Technology [5]. The two models were linked together so that the models can exchange information at a user selected time interval. Using the upper-layer gas temperature from CFAST, the flame spread model determines the cumulative burning area inside the compartment and the total heat release rate of the fire. CFAST uses this total heat release rate from the flame spread model to calculate the gas temperature, smoke levels, and combustion product concentrations throughout the area being analyzed over the next time interval.

Flame Spread Model Description

The flame spread program within the fire growth model is a non-symmetric model capable of predicting two-dimensional flame spread and heat contribution from combustible walls and ceilings. The current version of this model is capable of predicting fire growth inside compartments lined with multiple combustible and noncombustible wall linings with the fire in different locations. The model accounts for the effects of compartment thermal conditions on the flame spread along lining materials. Flame spread input data for the combustible boundary materials were developed from small-scale test data in the ASTM E1354 cone calorimeter and ASTM E1321 LIFT. The model has been previously validated against fire test data for flame spread over a vertical wall [3].

The flame spread model divides the combustible surfaces being considered in the analysis into a user selected number of square, uniform size cells. During the fire each cell is considered to be in one of three stages : pre-heat, burning, or burnout. During the pre-heat stage, a heat transfer algorithm was used to predict the temperature rise of each cell with time [3]. The heat transfer algorithm was based on theory developed from assuming the material behaves as a semi-infinite solid with a cubic temperature profile through the material and a time varying heat flux boundary condition. The heat flux boundary condition is equal to the net heat flux into the material, which is determined from the heat flux correlations for the fire, hot gas layer heating, and reradiation losses. A cell is predicted to ignite when the surface temperature reaches the material ignition temperature or when lateral flame spread calculations determine that the cell has ignited. In the burning stage, the heat release rate of a cell is dependent on the net heat flux into the material and the fire properties of the cell material. The total heat release rate is determined by adding the heat released from all burning cells with the heat release rate of the initiating source fire. A cell is predicted to burnout when the total potential heat release has been expended.

A fire in a corner configuration results in a three-dimensional flame spread problem. To model this, the corner configuration was divided into three regions: the lower portion of the corner walls ($z<0.8H$ where z is the elevation and H is the ceiling height), the top portion of the walls near the ceiling ($0.8H<z<H$), and the ceiling. To determine the heat flux boundary conditions for each region, correlations to predict the heat flux from the fire were required for each direction of flame spread. Both the lower and top portion of the walls have two-dimensional flame spread. Therefore, several heat flux correlations were required to predict both the vertical and horizontal

distribution in heat flux within these regions. On the ceiling, the flame spread was assumed to be one-dimensional radially out from the corner; therefore, heat flux correlations were required to predict the radial distribution in heat flux along the ceiling.

Many of the heat flux correlations and the flame length correlation were based on data from the study conducted by Lattimer *et al*. [4]. In this study, fire tests were conducted in a 2.44 m high, 2.1 m wide non-combustible corner with a ceiling. Flame lengths, heat fluxes to the corner boundaries, and gas temperatures were measured with area sources in the corner and in separate tests with L-shaped line burners in the corner. L-shaped line burner tests were conducted to simulate conditions produced by burning boundaries. Area source fires were square sand burners 0.17 – 0.50 m on a single side, while L-shaped line burners were 0.17 – 0.50 m on a single side. All fires were produced using propane gas with heat release rates ranging from 25 – 300 kW. Flame length and heat flux measurements were also made in three large-scale tests with a 0.17 m square burner (100 kW for 600 seconds and 300 kW for 600 seconds) in corner lined with a different combustible material in each test.

MODEL VALIDATION

The fire growth model was validated against large-scale ISO 9705 room/corner tests on eight different materials [6] and large-scale open corner tests on three different materials [4]. The validation consisted of comparing model results with measured heat release rate, smoke production rate, and flame front propagation.

Some of the ISO 9705 validation results are provided in Figure 1. The model provided a reasonable prediction of the heat release rate and smoke production rate. Similar results were predicted whether or not the lateral flame spread using LIFT small-scale data was considered in the fire growth simulation. This was determined to be due to hot gas layer in the room preheating unignited material which then in turn accelerated the flame spread across the surface. Lateral spread on the walls was predicted to change by less than 1% when the lateral flame spread was included in the calculations, indicating that the fire growth in the small room is dominated by wind-aided flame spread. These results also demonstrate that the fire growth model can adequately predict conditions during the ISO 9705 room/corner test using small-scale test data from the only the ASTM E1354 cone calorimeter.

The fire growth model was also validated against large-scale open corner tests where no hot gas layer was allowed to develop. In these tests, the total heat release rate, flame length, and the flame front propagation were measured. A comparison of the plywood lined corner data and the model predictions are provided in Figures 2 and 3. The solid line in Figures 2 and 3 corresponds to simulations with lateral flame spread using LIFT results while the dot-dash line corresponds to simulations without lateral flame spread using LIFT results. For simulations with LIFT lateral flame spread, the model was able to predict the heat release rate to within 30% (see Figure 2), and provided a conservative estimate of the flame front on the lower part of the walls (see Figure 3). In simulations without LIFT lateral flame spread, the flame front location decreased by nearly 60% (see Figure 3) and the heat release rate decreased by 25-30%. Based on these results, predictions of fire growth in large rooms should include lateral spread using data from ASTM E1321 LIFT in addition to the ASTM E1354 cone calorimeter ignition and heat release rate data.

With the model validated against data with and without hot gas layer effects, simulations were conducted to demonstrate the effect of the hot gas layer on the heat release rate of the fire. Figure 4 shows the predicted heat release rate for a material inside an ISO 9705 room and for the same material lining an infinitely large room with a 2.4 m high ceiling where no hot gas layer develops. In simulations with the hot gas layer (i.e., ISO 9705), when the gas temperature reaches close to the ignition temperature of the lining material, the flame spread across the material accelerates and soon after the room reaches flashover. However, with no hot gas layer, the model predicts that the heat release rate will increase to a certain point and then decreases as material begins to burn out.

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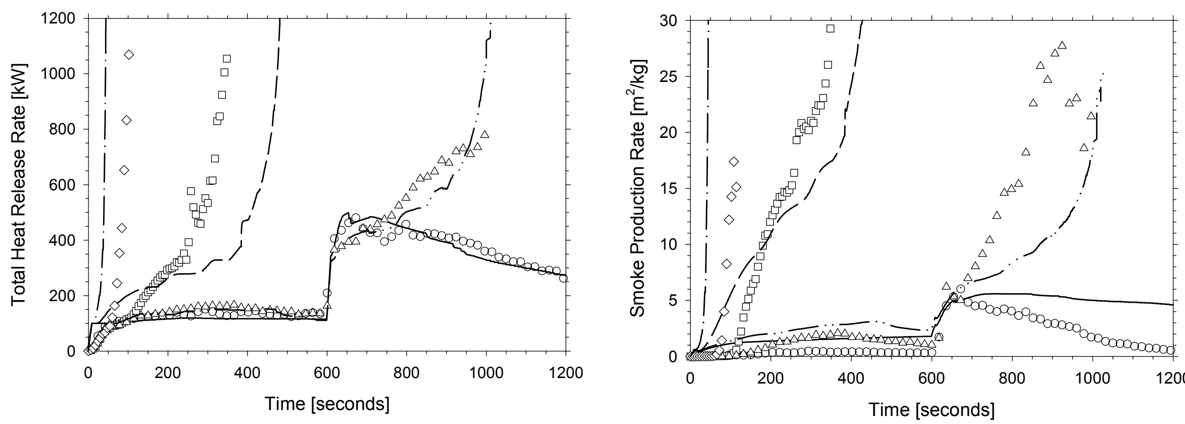

Figure 1. Measured and predicted total heat release rate and smoke production rate in ISO 9705 tests on different materials. Material No. 1 [○ (data), — (model)], Material No. 3 [□ (data), – – (model)], Material No. 5 [△(data), –· · – (model)], Material No. 7 [◇(data), –·– (model)]. Data from Reference [6].

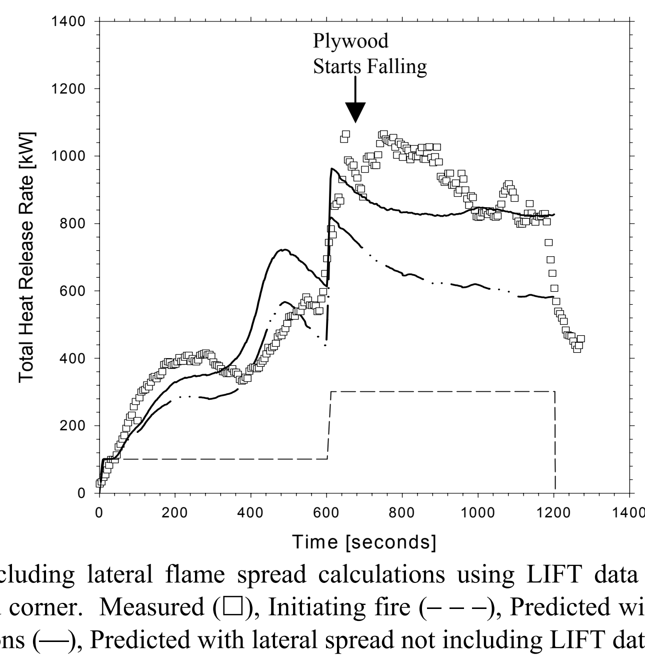

Figure 2. Effects of including lateral flame spread calculations using LIFT data on the heat release rate in the plywood lined corner. Measured (□), Initiating fire (– – –), Predicted with lateral spread including LIFT data calculations (—), Predicted with lateral spread not including LIFT data calculations (–··–).

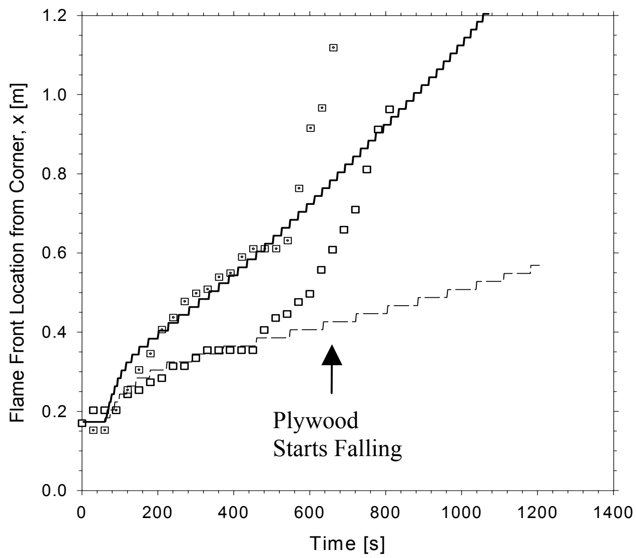

Figure 3. Effects of including lateral flame spread calculations using LIFT data on the lateral spread on the walls in the plywood lined corner. Measured 0.90 m above the burner (□), Measured 1.50 m above the burner (▣), Predicted with lateral spread including LIFT data calculations (—), Predicted with lateral spread not including LIFT data calculations (–··–).

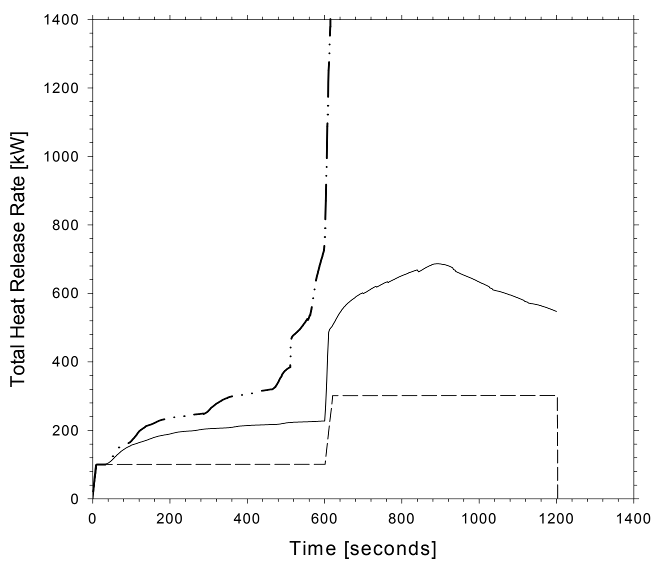

Figure 4. Effects of a hot gas layer that can develop in an ISO 9705 room on the heat release rate. E-Glass FR vinyl ester lining an open corner (—) and lining an ISO 9705 room (— · · —). Initiating fire (– – –).