APPLICATIONS OF FASTLite

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INTRODUCTION

The use of computer supported fire safety engineering calculations has grown significantly in recent years. One of the early, favorite tools of the fire protection engineer was FIREFORM and later FPEtool, both of which were developed by Bud Nelson[1]. Now NIST has released FASTLite, the successor to these programs.

FASTLite retains the set of simple algebraic equations of FIREFORM, but replaces the single room fire model FIRE SIMULATOR with a (maximum) three room version of CFAST modified to provide the operational features of FIRE SIMULATOR which users have come to depend on. These include simple construction of heat release rate curves, pauses in execution to allow modification of the scenario specification, and automatic output in selectable engineering units; all with the faster-than-real-time execution speeds of the former model.

The platform for these developments is CFAST. By integrating the CFAST zone model into FASTLite prior work on its validation and accuracy assessment is applicable and it is possible to add technical improvements to FASTLite, CFAST, and HAZARD as a single family of models. FASTLite also becomes entirely compatible with the others so that users who begin an analysis with FASTLite can build on the same basic input file by adding additional compartments or features supported in CFAST, such as HVAC modeling.

ENGINEERING APPLICATIONS

Many applications of CFAST to the solution of engineering problems have been published[2]. Where the analysis involves fewer than three rooms the cases can be run in FASTLite with minimal changes. Where more than three rooms are involved, or other non-supported features were utilized some changes to the analytical approach are needed. However, answers produced by FASTLite should be very close (but not necessarily identical) to those produced by CFAST. These differences stem from changes in the input files, and differences in the convergence criteria of the solver introduced to speed execution.

To demonstrate the application of FASTLite to problems of practical interest, two example cases will be presented. One is an alternative design analysis conducted in support of a variance with the code for the Mall of America in Bloomington Minnesota. The second is a fire reconstruction of an incident that took the lives of three firefighters in New York City.

MALL OF AMERICA

In 1989 plans for the largest enclosed shopping mall in the United States were submitted for approval by the Bloomington Minnesota Fire Marshal. This complex provides 390,000 m^2 (4,200,000 ft^2) of space of which just over half is leasable retail space. The remainder of the area is entertainment and support space, including an amusement park called Camp Snoopy. The mall consists of three stories of retail sales area surrounding a central core housing the main entertainment areas. A lower level located below grade houses administrative offices and service areas for the stores and the exit passageway system. A fourth level exists on the east and north sides which contains bars, restaurants and a 15 screen theater complex.

The entire interior is protected by automatic sprinklers. Systems in individual stores are independent from those in the central spaces. Special hazard systems are installed in selected spaces including a deluge system in Lego-Land. Some of the amusement park rides are sprinklered (e.g., an antique wooden carousel), and all cooking operations are protected with dry powder systems. Dry-pipe systems are used in loading dock areas and standpipes are provided for fire department use.

A centrally-monitored alarm system is provided and there is a 24-hour security staff. Point type smoke detectors are provided throughout with linear beam detectors across the atrium space. Smoke control is provided in the central mall by 24 fan units with a total capacity of 1.7M cfm.

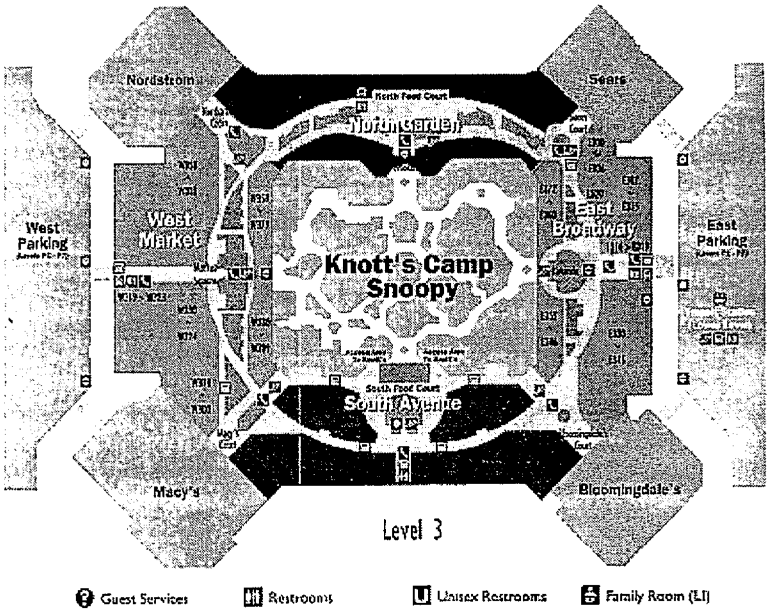

Figure 1 - At Mall of America shops surround a theme park and Assembly occupancies are located on the fourth level

Design Fires

Experience in shopping malls in the U.S. has shown that the sprinklered stores do not represent an exposure threat to the mall. Thus, the design fires selected for evaluation represented scenarios involving the amusement park and eating establishments located in the central core[3]. Many of the park rides utilize molded acrylic cars and all use hydraulic systems with their combustible fluids. Eating areas are subject to the accumulation of paper trash including boxes in which supplies are delivered and wrappers, plates, and utensils from the food itself.

Based on these considerations, eight scenarios were developed:

A. Base of fire at 2nd floor retail, east of 3rd floor opening, two foot draft curtain at second floor.
B. Base of fire at 3rd floor retail adjacent to food court, two foot draft curtain between retail and food court.
C. Base of fire at 1st floor retail, fill to1.8 m (6 ft) above 4th floor theater lobby.
D. Base of fire at 3rd floor food court, draft curtain at walkways none at theater sign.
E. Same as D but draft curtain at sign.
F. Base of fire at 3rd floor food court inside draft curtain, fill to draft curtain at theater sign.
G. Same as F except 5.2 m (17 ft) draft curtain at sign.
H. Same as G but fill to1.8 m (6 ft) above 4th level theater lobby.

For each scenario the fire growth rate was a "semi-universal fire" -- a composite of t^2 curves originally proposed as representative of mixed fuels (figure 2). Peak rates of heat release of 5 MW were used to represent worst case conditions for a fire in a sprinklered retail space. This is consistent with the value used by U.K. researchers in similar studies of shopping malls. For fires in the atrium area, the high ceilings will result in significantly larger fires before sprinkler activation. There, peak rates of heat release of 25 MW were used. Smoke filling times neglected the effect of the smoke exhaust system to be conservative.

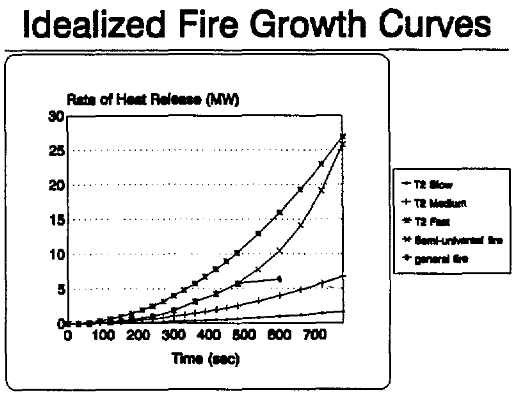

Figure 2 - Comparison of assumed fire growth rates with standard fire curves

Recently some concerns have been expressed about the growing use of kiosks in shopping malls and airports. These represent small concentrations of fuel located in central spaces which often have high ceilings where the ceiling mounted sprinklers may not provide adequate protection for a fire in the kiosk. These have generally not been considered in fire scenarios for shopping malls which have been published, and they were not included in the Mall of America design. NIST has recently conducted experiments to measure burning rates for such kiosks[4].

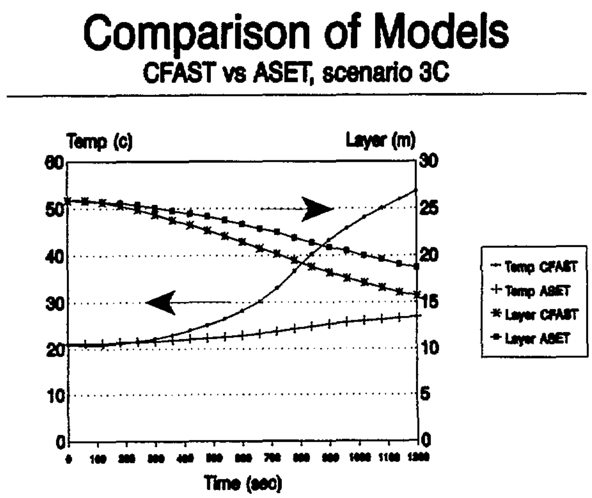

Figure 3 - Limits on entrainment affect filling rates in tall spaces

Filling Times

Smoke filling times were estimated with ASET[5], and sprinkler activation times with DETACT QS[6]. Since the ceiling height in the central core is 26 m (85 ft), most plume models will overpredict entrainment in tall plumes because no constraints are placed on the entrainment. This will result in lower temperatures and faster layer descent rates (figure 3). CFAST and FASTLite limit entrainment in tall plumes and produces better predictions of conditions in such spaces.

Evacuation Times

Egress calculations were performed with FPEtool and hand calculated using values from Fruin[7] of 17 persons per minute per foot of effective exit width, and were found to be in general agreement. Egress times, smoke filling times, and sprinkler activation times for the eight scenarios are tabulated below:

Scenario	Egress Time (s)	Smoke Fill Time (s)	Sprinkler Activation(s)
A	4:18	5:00	5:12
B	4:18	6:00	5:12
C	4:10	21:00	12:49
D	4:10	7:30	8:19
E	4:10	7:00	8:19
F	4:10	1:05	8:19
G	4:10	2:05	8:19
H	4:10	10:30	8:19

Some variations of draft curtain depths were examined to establish optimum conditions (e.g., F and G). In addition, several time delays were incorporated in the calculations. These included 120 s for smoke detector activation, 60 s for security investigation prior to sounding the evacuation signal, 80 s for exhaust fans to reach full flow, and 30 s start delay for occupants.

In spite of the huge numbers of people who may occupy this mall at any given time, much smaller numbers would be directly involved in an evacuation of the core area because individual stores, and especially the restaurants and theaters on the fourth level have direct access to the exit stairs. Thus, the assumed exiting population from the theater area was 850 (10% of the theater patrons are assumed to exit via the way they came in plus the number of persons estimated to be in ticket lines or at the concession stands). The number of patrons of the major restaurants were assumed to be 4700, of whom 2200 would exit through the mall area.

Subsequent to the acceptance of the analysis by the regulatory authorities the engineering firm had the opportunity to re-run the evacuation calculations with AEA Technology's EGRESS model. Similar times were obtained for all scenarios.

MODELING A BACKDRAFT: THE 62 WATTS ST. FIRE[2]

The Building

The fire occurred in a three story, multiple brick dwelling of ordinary construction approximately 6.1 m (20 ft) wide by 14 m (46 ft) deep, and 3½ stories tall. The building contained four apartments, one on each story, with the basement apartment half below grade. While the basement apartment had its own entrance, access to the others was by an enclosed stairway running up the side of the building. The building was attached to an identical building (64 Watts St.) that was not involved.

The buildings were built in the late 1800's and had undergone many alterations over the years. Recent renovations included replacement of the plaster/lathe with drywall on wood studs, lowering the ceilings to 2.5 m (8.25 ft), new windows and doors, heavy thermal insulation, sealing and calking to minimize air infiltration (the building was described as very tight.). Built before central heat, the apartments had numerous fireplaces, most of which had been sealed. The apartment of fire origin had 2 fireplaces, but only the one in the living room was operable. All apartments had thick plank wood floors.

The apartments had similar floorplans; the differences resulting from the stairway. There was a living room in the front, kitchen and bathroom in the center, and a bedroom in the rear. Not found in the other apartments, the first floor apartment had an office within the bedroom which was not significant in the fire. The roof had a scuttle for access and a wired glass skylight located over the stairway.

The Incident

On March 28, 1994 at 7:36pm, the New York City Fire Department received a telephone report of heavy smoke and sparks coming from a chimney at 62 Watts St., Manhattan. The initial response was 3 engines, 2 ladders, and a battalion chief. On arrival they saw the smoke from the chimney but no other signs of fire. The engine companies were assigned to ventilate the roof above the stairs by opening the scuttle and skylight, and two three-person hose teams advanced lines through the main entrance to the first- and second-floor apartment doors.

The first-floor hose team forced the apartment door and reported:

- a momentary rush of air into the apartment, followed by
- a warm (but not hot) exhaust, followed by
- a large flame issuing from the upper part of the door and extending up the stairway.

The first-floor team was able to duck down under the flame and retreat down the stairs, but the three men at the second-floor level were engulfed by the flame which now filled the stairway. An amateur video was being taken from across the street and became an important source of information when later reviewed by the fire department. This showed the flame filling the stairway and venting out the open scuttle and skylight, extending well above the roof of the building. Further, the video showed that the flame persisted at least 6½ minutes (the tape had several pauses of unknown duration, but there was 6½ minutes of tape showing the flame).

Damage to the apartment of origin was limited to the living room, kitchen and hall -- closed doors prevented fire spread to the bedroom, bath, office, and closets. There was no fire extension to the other apartments and no structural damage. The wired glass in the skylight was melted in long "icicles" and the wooden stairs were mostly consumed. The description provided by the surviving hose team was of a classic backdraft; but these usually persist only seconds before exhausting their fuel supply. Where did the fuel come from to feed this flame for so long?

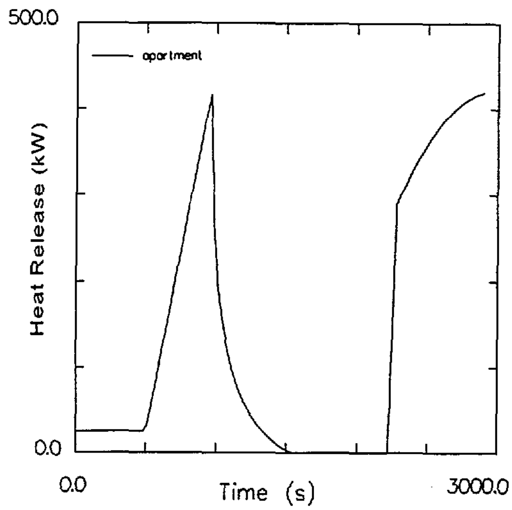

Figure 4 - HRR in apartment

Cause and Origin

The subsequent investigation revealed that the first-floor occupant went out at 6:25pm, leaving a plastic trash bag atop the (gas) kitchen range which he was sure was turned off. It is reasonable that the pilot light ignited the bag, which then involved several bottles of high alcohol content liquor on the counter, and spread the fire to the wood floor and other contents. The occupant confirmed that all doors and windows were closed, so that the only source of combustion air was the fireplace flue in the living room from which the smoke and sparks were seen to emerge.

Theory

Clearly, the fire burned for nearly an hour under severely vitiated conditions. The open flue initially provided expansion relief and later vented smoke as the ceiling layer dropped below the level of the opening. Such vitiated combustion results in the production of large quantities of unburned fuel and high CO/CO_2 ratios. As shown in studies of the backdraft phenomenon[8], when a door is opened under such conditions, warm air flowing out is replaced by ambient air which carries oxygen to the fuel. When this combustible mixture ignites, a large flame extends from the door. To determine whether enough fuel could collect within the apartment to feed the flame for the period of time observed, the CFAST model[9] was used to recreate the incident. The file for this case was subsequently converted to a FASTLite file by modeling the fireplace as an opening producing an equivalent flow, and is included with the distribution files[10] as an example.

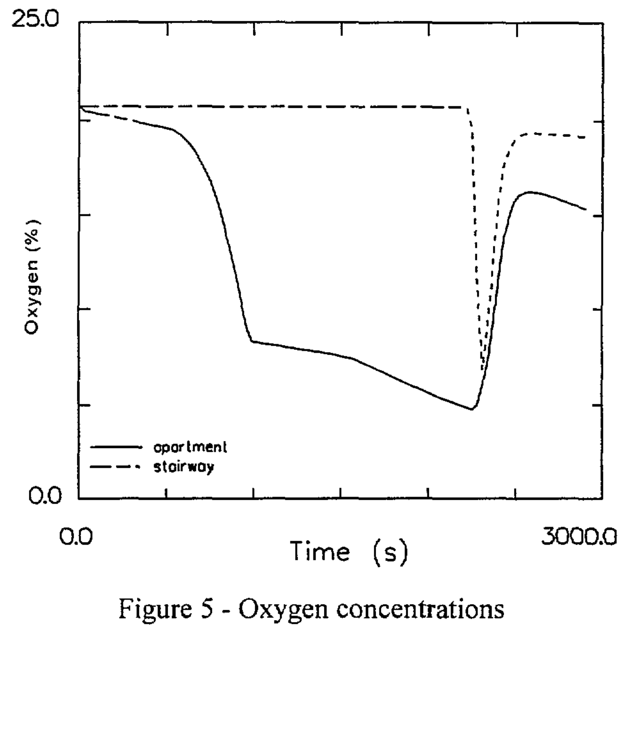

Figure 5 - Oxygen concentrations

Computer Analysis

The apartment of origin was modeled as a single room with dimensions of 6.1 m (20 ft) by 14 m

(46 ft) by 2.5m (8.25 ft). The stairway was modeled as a second room 1.2 m (4 ft) by 3 m (10 ft) by 9.1 m (30 ft) connected to the apartment by a closed door and having a roof vent of 0.84 m^2 (9 ft^2) area. The fireplace flue was modeled as a 10 m (33 ft) high vertical duct with a cross section of 0.14 m^2 (1.5 ft^2). All these dimensions were provided by the fire department from measurements taken at the scene.

The initial fire was assumed to be a constant heat release rate (HRR) of 25 kW from actual data on burning trash bags[11]. This fire then transitioned into a "medium t^2" fire with a peak heat release rate of 1MW (fig 4); however this was never reached due to limited oxygen. Such "medium t^2" fires are characteristic of most common items of residential contents[12].

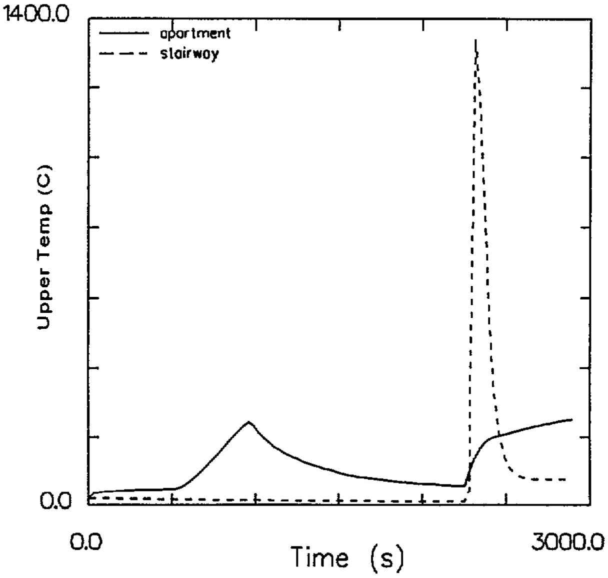

Figure 6 - Upper temperatures

Results

Compiling and entering the data into CFAST required approximately two hours and the model required only a few seconds to perform the calculations. The fire grew to about 500 kW over 5 minutes of simulation time, then rapidly throttled back as the oxygen concentration dropped below 10% (fig. 5). Temperatures in the apartment peaked briefly at about 300 °C (570 °F) at the time of peak burning, then rapidly dropped below 100 °C (200 °F) as the burning rate fell (fig. 6). The concentration of carbon monoxide (CO) rose to about 3000 ppm and unburned fuel accumulated within the apartment volume during this stage of vitiated combustion.

The front door was opened at 2250 seconds into the simulation as an estimate of when the first floor team made entry. Immediately, there was an outflow of warm (100 °C) air from the upper part of the doorway, followed by an inrush of ambient air in the lower part of the doorway, followed by the emergence of a large door flame -- exactly as reported by the firefighters. This door flame grew within a few seconds to a peak burning rate of nearly 5 MW (fig. 7), raising the temperature in the stairway to over 1200 °C (2200 °F) (fig. 5) -- sufficient to melt the glass in the skylight, as observed. Most importantly, the quantity of unburned fuel accumulated in the apartment caused the door flame to persist for more than 7 minutes (fig. 7).

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