NISTIR 6588

FIFTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY MARCH 1-7, 2000

VOLUME 2

Sheilda L. Bryner, Editor

1901-2001
NIST CENTENNIAL

NIST

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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U. S. Department of Commerce
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Technology Administration
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National Institute of Standards and Technology
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Use of Fire Simulation in Fire Safety Engineering and Fire Investigation

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ABSTRACT

A discussion is presented of recent applications of the Fire Dynamics Simulator software developed at NIST for modeling fires using large eddy simulation technology. Applications and impacts of the model include: prediction of wind-blown smoke plume trajectory and particulate concentration predictions, the interaction of sprinklers, draft curtains and roof vents in warehouse facilities, and fire fighter fatality investigations.

BACKGROUND

One way that the understanding of fire phenomena can be demonstrated is through consistent ability to predict the consequences of fires. The careful study of controlled laboratory experiments provides the foundation for our understanding of fire phenomena. Empirically based predictive methods have formed the basis for the development of many of the tools used in fire safety engineering today. Two of the most frequently used engineering predictive methods for life safety in buildings are ASET-B [1] and DETACT [2]. ASET-B provides time estimates for the onset of hazardous conditions based on smoke layer filling of an enclosure. DETACT provides a time to automatic fire detection by ceiling level devices. ASET-B is based on the experimental correlation of plume entrainment developed by Zukowski [3]. DETACT is based on the experimental correlations of ceiling jet temperature and velocity developed by Alpert [4].

More advanced than the direct applications of experimental-correlation based engineering methods are the often used single-enclosure two-zone fire models. These are capable of representing fire conditions in multiple room geometries of residential and commercial buildings. One of the first of these generalized fire models was the groundbreaking Harvard Computer Fire Code [5], developed under the leadership of Professor Howard Emmons at Harvard University. Today a widely used two-zone fire model is CFAST [6] developed at the National Institute of Standards and Technology (NIST). These models have for a generation served as vehicles for bringing together the best knowledge of fire phenomenon in a form that could be used for engineering purposes. Working from the basic two-cell per room structure of the zone model, many of the sub-grid fire phenomena such as detector actuation and second item ignition have been included as features of the model prediction. Although CFAST at the time of its introduction in 1984 as part of the HAZARD I software package [7], stretched the capabilities of the emerging personal computer resources, this is no longer the case. The core technology of the two-zone fire models is now employed to generate faster-than-real-time fire emergency condition predictions for buildings as a potential part of future technology for fire loss reduction and fire fighter safety. With the onset of faster and cheaper computing, it is now practical at about the same computational time as engineers experienced with the original two-zone fire models to perform simulations containing a million cells. With the capability for high spatial and temporal resolution fire models, comes the possibility of generating technology for visual simulation of fire events. The ability to create accurate visual representations of fire events, whether for product and test method development, fire investigation, training, or simply gaining insight into fire phenomena at scales impractical to test, will forever change the fire safety paradigm. In addition, there will be a need for better fire measurements for model validation and a need for test methods to supply the input for these models. These new fire tests will require measurement of the general fire properties of materials and will move away from relative measurements that are not useful in the physically based models. A new generation of separate empirically based sub-grid fire-phenomena models will be needed that are consistent with the high resolution of the new fire modeling technology and the phenomena that it is capable of predicting.

APPLICATIONS

In 1980 NIST started a competence building project to investigate the application of the large eddy simulation technique to enclosure fire modeling. In 1983 using the CRAY XMP supercomputer at NIST, a 64,000 cell simulation of a fire driven flow in an enclosure was produced, Figure 1 [8]. The large eddy simulation captured the major features of the large-scale turbulence in the fire driven flow, although much larger numbers of cells would be needed for accuracy. Today, with a fine grid of nominally one million cells, flow features over two orders of magnitude in length scale can be captured in enclosure fires.

Wind Blown Smoke Plumes

The first major application of this new technology by NIST was in the area of smoke plume dispersal from large fires. The oil spill response community needed to develop the technology that would allow safe use of in-situ burning of spills as a response method. One of the immediate concerns was the trajectory and ground area impacted significantly by the smoke plume produced by the burning. To be successful, the computational domain had to be moved from the room-scale of meters to the scale of kilometers. Fortunately the scale of the important mixing phenomena also increased with the size of the fire source now representative of a major fuel spill, so that an approximate large eddy simulation technology was practical with an equivalent 500,000 cell simulation. Figure 2 shows an early 1990's simulation where the transition from the existing simulation of the fire in an enclosure to the wind blown smoke plume simulation is demonstrated [9].

The new calculations that considered the dynamics of a strong fire source in a crosswind flow provided predictions that were great improvements over the existing Gaussian models for dispersion of pollutants. Calculations for the State of Alaska [10], showed that under even severe conditions, the downwind area effected by high concentrations of smoke particulate extended only a few kilometers from the fire. As a result of the calculations, guidelines were established under which spill burning could be approved for areas beyond 5 km distance from populated areas with site specific analysis. With suitable computations for specific incidents, this distance might be reduced to 1 km.

To facilitate the use of this technology in spill and other hazardous fire conditions, a portable computer version of the model was developed by NIST for free distribution. This software works with information that would readily be available visually to responders to produce the needed input for the simulation. Of course, measured information, if available, may be entered to improve the accuracy of the predictions for a specific incident. This software A Large Outdoor Fire plume Trajectory model - Flat Terrain (ALOFT-FT) [11] is available for downloading from the web site http://fire.nist.gov. In 1999, the visual simulations of smoke plume trajectories performed by NIST in Gaithersburg using this software provided the information needed for Oregon authorities to approve the intentional burning of fuel aboard the grounded freighter *New Carissa,* Figure 3. Burning before the break-up of the ship significantly reduced the pollution from the incident. This software has also been used in the planning of large-scale oil pool fire experiments conduced by the Japan National Oil Company at Tomakomai.

Warehouse fires

Fire driven flows dominate the spread of fires in box arrays typical of industrial storage facilities. Options for the protection of these facilities include fire sprinklers, heat and smoke vents, and draft curtains that are barriers to horizontal spread of smoke under ceilings in large area facilities. Even though these three systems are often installed together, the interactions during a fire have not been fully quantified. With suitable development of sub-grid phenomena models for fire growth, fire suppression with water sprays, and the response of heat activated devices, such as sprinklers and roof vents, it was felt that the large eddy simulation modeling could provide valuable insight into the performance of these systems. The use of modeling as both a planning and analysis tool was likely to yield an understanding of the interactions of sprinklers, vents and draft curtains that had not been gained from many years of limited large-scale testing.

Warehouse-size fire tests are expensive. They are also complex and variable. Figure 4 shows the geometry of the fire test used to evaluate the interactions of fire sprinklers, roof vents and draft curtains at Underwriters Laboratories in Northbrook, Illinois. In order to make a meaningful prediction, both the fire growth and the suppression of the array of boxed plastic commodity must be predicted from modeling with a cell size of 15 cm length. The ability to predict burning rates and suppression is the fundamental advancing step in fire modeling that needs to be addressed before simulations of fire are possible that would provide benefit comparable to large-scale testing. In this first effort considerable small-scale testing with the fuel packages and parts of the array were performed so that the initial behavior of the fire growth in the array and the suppression with water could be duplicated with the large eddy simulation model. This allowed the larger issues of the interactions between the fire protection systems and their effects on the overall fire to be studied and compared to large-scale tests. Reliable predictions of large-scale tests provided a basis for exploring conditions that were not directly tested. This enhancement of the experimental results through the use of modeling both increased the value of the modeling to the study and also increased confidence in the results. Figure 5 shows predicted near-ceiling temperatures and the predicted results for sprinkler actuation for one of the fire tests [12]. The results show that major features of the test, such as the number and locations of sprinklers activated, are predicted well. Even with the large amount of effort expended in this study, the details of time of activation of each sprinkler is not dependably predicted particularly near the edge of the area of activation. In order to do better, there must be improvements in both the predictions and the measurements of the heat sensitive hardware devices like sprinklers. With the normal variations that occur in large-scale testing, it may be beneficial to understand the uncertainties of the tests themselves to properly gauge the accuracy of the models.

Applications of this model are limited. We cannot easily change the fuel or the suppressant in the simulation. A simple change in the box container material, the sprinkler, or the spacing in the array would introduce changes that at this time could not be handled without input from extensive experimentation to generate sub-grid models.

The high temporal and spatial resolution of the large eddy simulation technology provide a basis for visual simulation of fire scenarios that can be adapted to real-time animations for viewing on a computer monitor or for recording on video tape. Of course these animations are visualizations of the quantitative information from the fire models. The animations provide the easiest way to transmit information about the fire performance for use of decision makers who may not be technically trained in fire engineering. These animations will also be useful for training purposes. Figure 4 shows one image from an animation of the sprinkler-draft curtain-vent test. Colors for the flame surface and smoke particulate are based on imaging parameters set to visually represent the scalar temperature and composition properties of the predicted flows.

Fire Fighter Fatality Investigations

In the United States about a hundred line-of-duty deaths of fire fighters occur annually. Many of these occur when fire fighters are caught in situations where the behavior of the fire is unexpected. The emerging ability to simulate the dynamics of fire in buildings with the large eddy simulation technology and display the computed results using a visual animation with quantifiable features is providing new insight to the dynamics events leading to fire fighter deaths and injuries. This technology can provide a basis for training future fire fighters to avoid the mistakes of the past.

NIST has provided advice on several fire fighter fatality incidents based on its use of large eddy simulation to recreate as closely as possible fire events that have been recorded from witnesses. As information on the fuels involved and on the initial time line is generally unavailable, greater uncertainty is associated with these predictions than those of controlled laboratory tests. We have succeeded in demonstrating the major fire phenomena that played a role in the tragedies. For example, in New York City in 1998, three fire fighters died in the hallway outside of a tenth floor apartment. In that case, calculations with the large eddy simulation model showed that gusting winds outside of the building provided puffs of fresh air at high velocity into the room of fire origin. The high velocity fresh air flow allowed increased burning of the accumulated combustion products. Hot combustion products were forced continually into the hallway and out of the building through the open windows of an apartment on the downwind side. The hot gases moving at high velocities in the corridor subjected the fire fighters to conditions that exceeded the capacity of their protective garments to protect them, see Figure 6.

Many fire fighters who have viewed the animations of the high-rise apartment fire incident were unaware of the fire dynamic hazard generated by gusting wind loads on buildings when the fire can vent through openings on both the upwind and downwind sides of the building. Lessons learned though this analysis may help to save lives of fire fighters in the future.

Personal computer versions of the large eddy simulation fire model named Fire Dynamics Simulator (FDS) and the companion software SMOKEVIEW for visualization of results are available for downloading free of charge from the web site, http://fire.nist.gov.

CONCLUDING REMARKS

Fire simulation provides an opportunity for the benefits of fire science research to be showcased in engineering applications that allow fire events to be understood more readily by the diverse audience of professionals involved in fire safety. Each one of the applications presented provided new insight for the users into the fire phenomena and fire effects that are important to their needs. This technology is only beginning to be practical for application to engineering problems. A great amount of research remains to be done to support the continued development of the underlying sub-grid models and the verification of predictions in a variety of applications. High quality fire modeling combined with effective visualization of results will provide the foundation for fire safety decisions of the future.

ACKNOWLEDGMENT

This paper is presented as part of a symposium to honor Professor Howard Emmons as part of the UJNR Technical meeting. The author had the opportunity during his formal engineering education to be a student of Professor Howard Emmons. During those years of the Home Fire Project at Harvard, full-scale bedroom fire experiments were conducted to measure and observe fire phenomena from ignition to extinction. The metric for success then and now is the ability to accurately predict building fire phenomena. We

continue to build on the foundations established for us by the fire research pioneered by Howard Emmons. The more work that I do to help advance fire safety, the more I appreciate the magnitude of his accomplishments.

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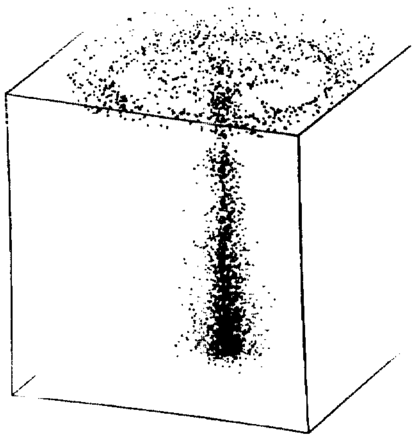

Figure 1 64,000 cell simulation of an enclosure fire, 1983 [8]

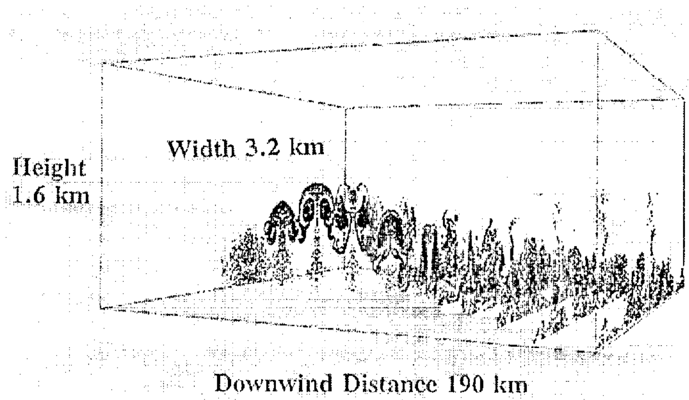

Figure 2 Simulation of wind blown smoke plume, 1993 [9]

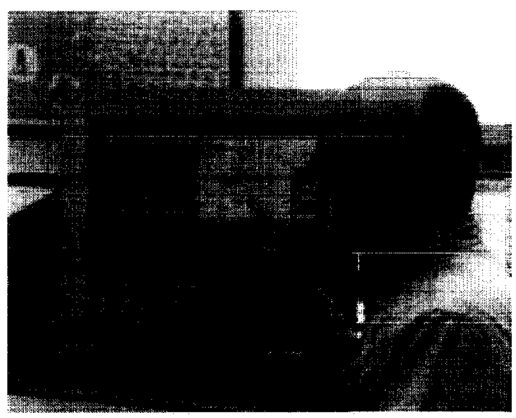

Figure 3 ALOFT-FT aids oil spill response, 1999

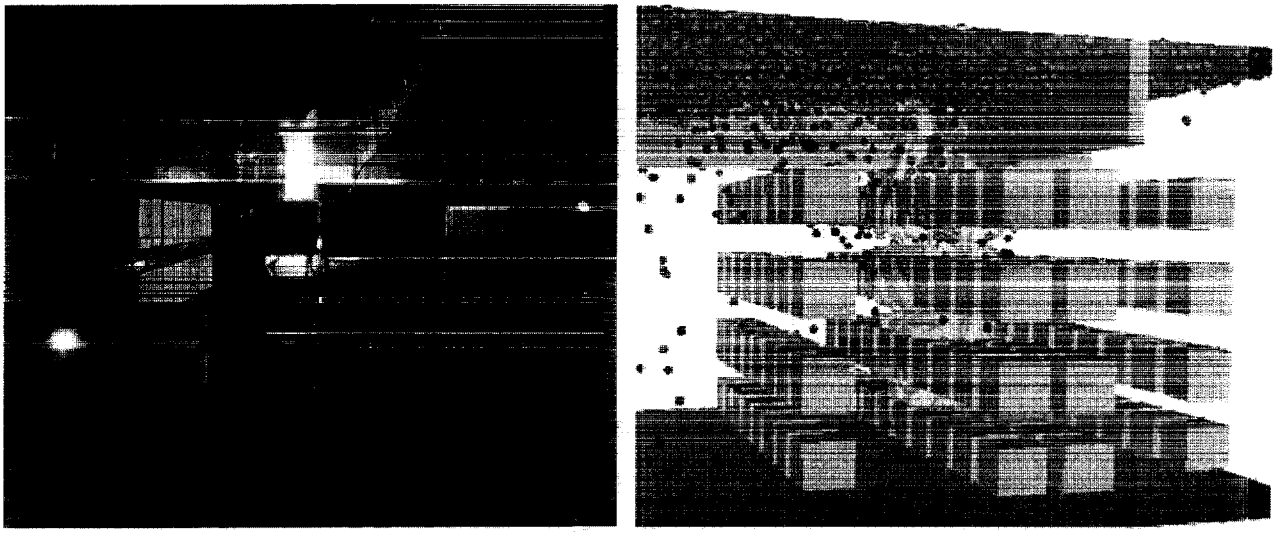

Figure 4 Geometry for sprinkler, roof vent and draft curtain experiments and simulation

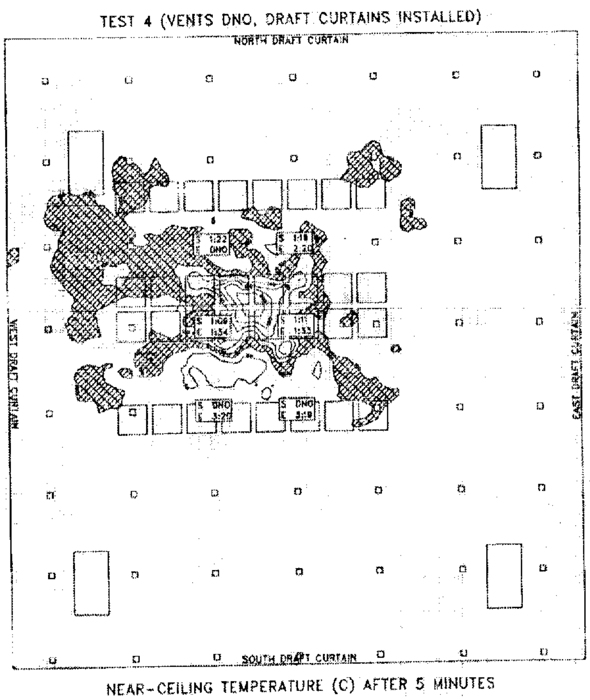

Figure 5 Fire Dynamics Simulator predictions of sprinkler response

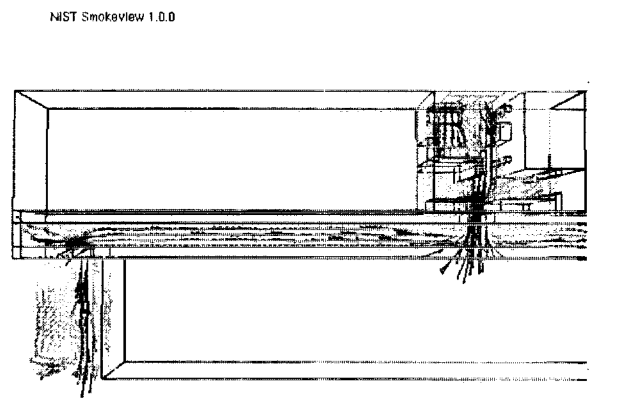

Figure 6 Apartment building fire simulation