LARGE FIRE EXPERIMENTS FOR FIRE MODEL EVALUATIONS

by

David D. Evans
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

IN: Interflam '96. 7th International Interflam Conference, March 26-28, 1996, Cambridge, England. Proceedings. Sponsored by Interscience Communications Ltd., National Institute of Standards and Technology; Building Research Establishment; and Society of Fire Protection Engineers; and Swedish National Testing and Research Institute. Interscience Communications Ltd., London, England, Franks, C.A., and Grayson, S., Editors, 329-334 pp., 1996.

LARGE FIRE EXPERIMENTS FOR FIRE MODEL EVALUATIONS

David D. Evans, Fire Safety Engineering Division, National Institute of Standards and Technology, Gaithersburg, Maryland, USA

INTRODUCTION

Recent movement towards performance based evaluation of building safety has placed a premium on demonstrating the accuracy of engineering methods and increased the demand for fire performance data from large scale experiments. Data from large scale experiments are generally the basis for development and evaluation of fire models. Verification of engineering methods for prediction of fire related performance of structures, contents, and fire protection systems has become a priority need to support the development of performance based codes and standards. Generally a great impediment to model verification is the lack of means to quantify the degree of agreement between experiments and predictions or repeated experiments.

Today, the most widely used fire models are based on two-zone predictive methods for fire flow in buildings. These methods along with implementation of engineering correlations developed from large scale fire experiments which include those for prediction of the performance of fire protection systems form the basis of modern fire safety engineering practice. The widespread availability of fast computing power, particularly in the fire research community, has made it possible to model fires in buildings using high resolution field modeling techniques. These are available commercially from engineering software developers and as research tools developed in many of the fire safety laboratories around the world. As an example, NIST has experimented with the capabilities of Large Eddy Simulation technology to predict fire driven flows inside and outside of structures. The results have shown that modeling of building fire flows at a resolution of several centimeters is feasible. The advent of high resolution calculations for use in fire safety analysis has increased the demand for high resolution measurements of fire conditions in buildings.

To meet the demands of the user community, large scale fire testing is increasing in scale, in the number of quantities measured, and in temporal and spacial resolution of the measurements. In addition, means are being developed to readily exchange data among users and research facilities.

NIST LARGE SCALE FIRE TEST FACILITY

The present large scale test facility at the National Institute of Standards and Technology has been in operation since 1974 when fire testing ceased at the National Bureau of Standards site in Washington, DC where testing had been performed since 1914.[1] The test facility supported a broad range of technical activities largely directed at increasing the understanding of fire development in room and corridor geometries characteristic of residential structures. These activities continue today, but there is an increasing need to conduct experiments at larger scale that represent fire scenarios in commercial and industrial facilities. In order to address these needs, it was recognized several years ago that measurement equipment needed to be developed to perform quality measurements of fire phenomena in buildings of opportunity larger than the NIST laboratory. This equipment has seen frequent use in both field experiments and in cooperative studies conducted in national fire research laboratories of other countries.

LARGE FIRE EXPERIMENTS FOR FIRE MODEL EVALUATIONS

David D. Evans, Fire Safety Engineering Division, National Institute of Standards and Technology, Gaithersburg, Maryland, USA

INTRODUCTION

Recent movement towards performance based evaluation of building safety has placed a premium on demonstrating the accuracy of engineering methods and increased the demand for fire performance data from large scale experiments. Data from large scale experiments are generally the basis for development and evaluation of fire models. Verification of engineering methods for prediction of fire related performance of structures, contents, and fire protection systems has become a priority need to support the development of performance based codes and standards. Generally a great impediment to model verification is the lack of means to quantify the degree of agreement between experiments and predictions or repeated experiments.

Today, the most widely used fire models are based on two-zone predictive methods for fire flow in buildings. These methods along with implementation of engineering correlations developed from large scale fire experiments which include those for prediction of the performance of fire protection systems form the basis of modern fire safety engineering practice. The widespread availability of fast computing power, particularly in the fire research community, has made it possible to model fires in buildings using high resolution field modeling techniques. These are available commercially from engineering software developers and as research tools developed in many of the fire safety laboratories around the world. As an example, NIST has experimented with the capabilities of Large Eddy Simulation technology to predict fire driven flows inside and outside of structures. The results have shown that modeling of building fire flows at a resolution of several centimeters is feasible. The advent of high resolution calculations for use in fire safety analysis has increased the demand for high resolution measurements of fire conditions in buildings.

To meet the demands of the user community, large scale fire testing is increasing in scale, in the number of quantities measured, and in temporal and spacial resolution of the measurements. In addition, means are being developed to readily exchange data among users and research facilities.

NIST LARGE SCALE FIRE TEST FACILITY

The present large scale test facility at the National Institute of Standards and Technology has been in operation since 1974 when fire testing ceased at the National Bureau of Standards site in Washington, DC where testing had been performed since 1914.[1] The test facility supported a broad range of technical activities largely directed at increasing the understanding of fire development in room and corridor geometries characteristic of residential structures. These activities continue today, but there is an increasing need to conduct experiments at larger scale that represent fire scenarios in commercial and industrial facilities. In order to address these needs, it was recognized several years ago that measurement equipment needed to be developed to perform quality measurements of fire phenomena in buildings of opportunity larger than the NIST laboratory. This equipment has seen frequent use in both field experiments and in cooperative studies conducted in national fire research laboratories of other countries.

FIELD TESTING

Large commercial test facilities and structures for burns of opportunity, frequently in cooperation with local fire service organizations are being utilized to satisfy the need for test results that represent fire scenarios of interest to the fire community. The challenge in the use of structures of opportunity is to build robust instrumentation that can produce nearly the same of quality measurements expected from experiments conducted in on-site large scale test facilities. Of course the use of structures of opportunity provides for increases in experimental space comparable to the actual type facility being studied. As an example, valuable data on fire plume temperatures and the response of fire protection systems was collected during required fire detection system proof of operation testing in a Maryland National Guard helicopter hanger.[2] In this case, a large array of thermocouples was installed in the hanger prior to ignition of 1.8 m x 1.8 m alcohol pan fires. Later measurements of the heat release rate of the test alcohol fire were performed in the NIST Large scale fire test facility to provide the data necessary to analyze the field test data.

NIST has worked cooperatively with Alaska Cleans Seas, an industry funded oil spill cleanup cooperative, to measure smoke plume from large oil pool fire burns, of fires order 100 MW. In order to quantify the emissions of smoke particulate from the burn, specifically developed field instrumentation packages based on measurement techniques developed and tested in the laboratory were used. To measure the total smoke particulate yield (mass of smoke particulate produced per unit mass of fuel burned) by sampling in the smoke plume, analysis equipment was designed to be deployed into a smoke plumes from mini-blimps and helicopters.[3] The measurement of smoke yield from outdoor fires where the entire smoke plume is not collected for analysis illustrated the challenge of large scale fire measurement in the field as compared with more controlled laboratory fire experiments.

In the laboratory, where the entire smoke plume can be collected and measured, three methods of determining the smoke yield have been from liquid hydrocarbon fires have been used: 1) the flux method, 2) the light extinction method, and 3) the carbon balance method.[4] Of these methods only the carbon balance method is suitable for use in field tests. Table 1 shows results of smoke yield measurement for a series of laboratory scale crude oil fires. These data show the good agreement of the carbon balance method with other well established laboratory measurement methods.

Table 1. Laboratory measurements of smoke yield from crude oil fires

		Crude Oil Fuel Type	Flux Method	Light Extinction Method	Carbon Balance Method
NIST Cone Calorimeter D=0.085 m	1	Murban	0.053	0.053	0.053
	2	Murban	0.052	0.049	0.052
	3	Murban	0.057	0.054	0.057
	4	Murban	0.054	0.052	0.056
	5	Louisiana	0.063	0.060	0.067
	6	Louisiana	0.058	0.061	0.062
	7	Louisiana	0.063	0.062	0.068
NIST Large Calorimeter D=0.6 m	1	Murban	0.093	0.067	0.080
	2	Murban	0.093	0.082	0.077
	3	Murban	0.090	0.063	0.082
FRI*, Japan D=2.0 m	1	Murban	0.134	0.149	0.139
	2	Murban	0.128	0.150	0.137

* Fire Research Institute

Three assumptions are made in the use of the carbon balance method in field tests. The first is that the smoke particulate is predominately carbon. The second assumption is that samples are collected over a suitable time period to average out natural fluctuations in the fire and plume. The third assumption is that no preferential separation of smoke particulate and combustion gases occur in the smoke plume up to the point where the sample is taken. In all field measurements the smoke yield measurement is made close to the source where the smoke and gaseous combustion products move in a well formed smoke plume.

The expression for smoke yield[3] in terms of the measured quantities is,

$$Y_S = \frac{m_P \; (m_{C,Fuel}/m_F)}{m_P \; + \; 12 \; n \; (\Delta \chi_{CO_2} \; + \; \Delta \chi_{CO})} \tag{1}$$

where:
- Y_S = smoke yield
- $m_{C,Fuel}$ = mass of carbon in the fuel burned
- m_F = mass of fuel burned
- m_P = mass of smoke particulate
- n = moles of gas
- $\Delta \chi_{CO_2}$ = difference between the volume fraction of CO_2 in the sample and the background
- $\Delta \chi_{CO}$ = difference between the volume fraction of CO in the sample and the background

The ratio $m_{C,Fuel}/m_F$ is evaluated by determining the elemental carbon mass fraction in the fuel. From the elemental analysis of the fuel, this value is 0.848 for the Murban crude oil and 0.862 for the Louisiana crude oil.[4]

This method has been applied to the field measurement of smoke particulate in at sea burns of crude oil directed by Environment Canada off the coast of Newfoundland near St. John's in 1993. In these tests crude oil was burned in a fire resistant containment boom with nominal effective burn diameters of 11 m to 14 m. Measurements of smoke yield from the fires were made by suspending a sampling package below a mini-blimp tethered to a boat stationed under the plume immediately downrange of the burn area as shown in figure 1. Six measurements of smoke yield were made during two off shore burns of Alberta Sweet Blend Mix crude oil. The results showed very good agreement ranging from 14.8% to 15.5%.[3]

Smoke production from large fires and potential downwind exposure of the population to combustion products are a safety concern. In order to help assess and advise local authorities on the expected exposure in downwind areas to smoke particulate from large fires, NIST developed a large eddy simulation (LES) model for large fire smoke plume trajectories in the atmosphere. This model is used by the State of Alaska as part of the approval process for intentional burns of accidental oil spills. Although many calculations have been performed to provide information to authorities,[5] there has been little opportunity to obtain verification data. In 1994, Alaska Clean Seas (ACS) conducted controlled pool burns of Prudhoe Bay crude oil in facilities on the North Slope of Alaska to evaluate the performance of fire resistant boom. These nominal 9 m diameter crude oil burns were used by NIST as an opportunity to measure ground concentration of smoke particulate in order to verify the large eddy simulation (LES) computational models of fire plume trajectories and particulate deposition. Figure 2 shows the results of these tests in which sparse one hour average ground level particulate concentrations at selected locations over a 6 km x 2 km area downwind of the fire are compare to LES model predicted concentration contours.[6] In figure 3 the location and one hour average particulate concentration (μg/m³) measured by the collection stations are indicated by numbers. Predicted results are shown as shaded gray scale contours. Visual inspection of figure 3 shows "good" agreement between predicted and measured results for all but the one position -- 85 (μg/m³). This measurement may have been influenced by dust or emissions from vehicles.

Figure 1. Smoke plume sampling at offshore crude oil burns.

Figure 2. Smoke plume from Alaska North Slope Burn used for LES model verification.

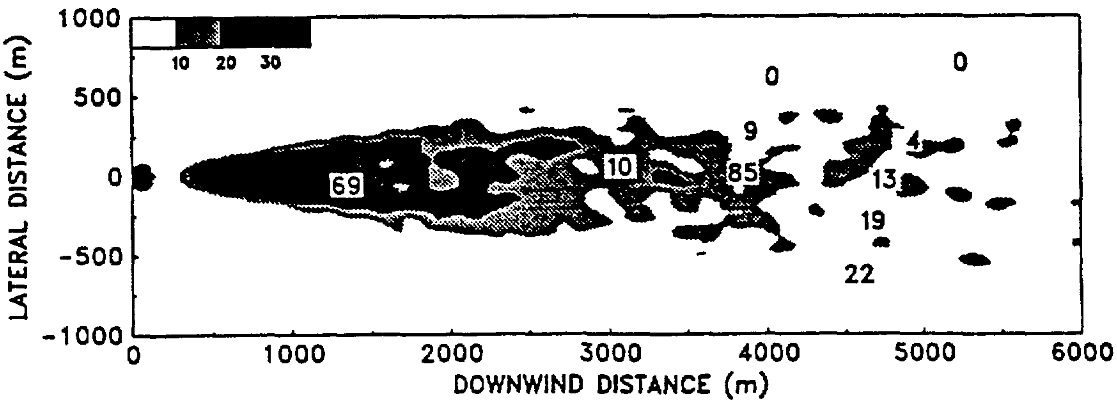

Figure 3. Predicted and measured ground level particulate concentrations from ACS burn 1.

At the present time, we are at a loss for techniques to quantify the "goodness" of the agreement between the experiments and the predictions. This is a problem that is common to many areas of fire modeling and experimentation where it is not possible to quantify comparisions of multi-dimension predictions with experiments. The same problem arises when trying to compare time dependent predictions. As an example, figure 4 shows the predicted and measured mass flow out of a doorway of full scale furnished room fire test. Predictions are based on current zone fire model technology.[7]

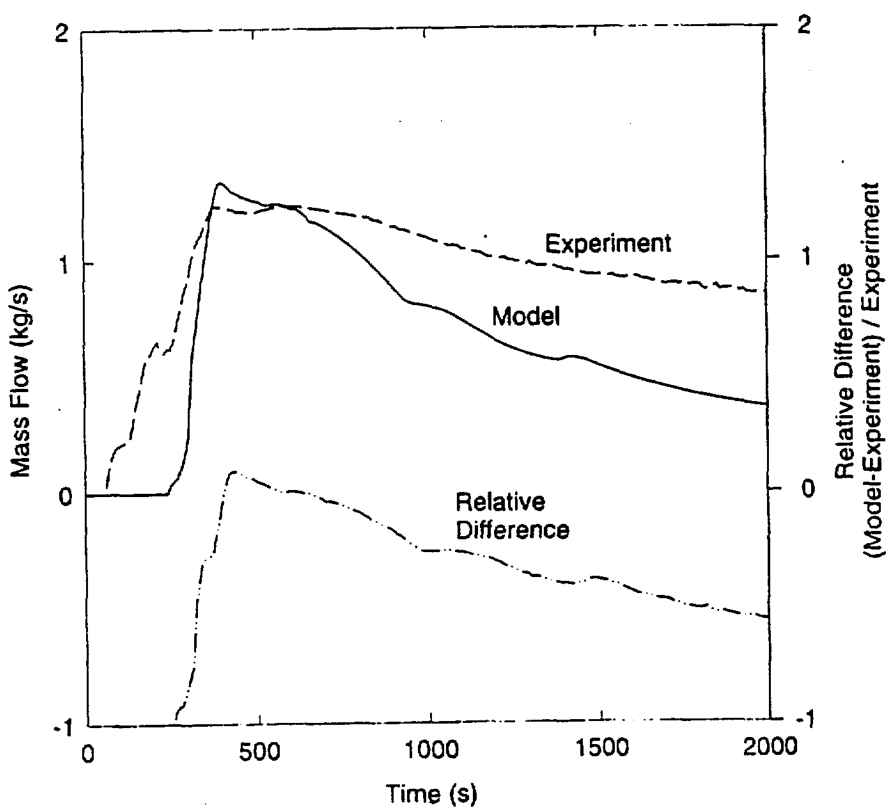

Figure 4. Comparision of measured and predicted mass flow from a furnished room fire.

Visual inspection of figure 4 shows that the peak flow was predicted well, but predictions later in time are a well below those measured. Whether or not these results are considered "good" enough for application is a matter that must be addressed with full knowledge of the interceded application. The point here is to consider means to quantify the agreement of model prediction and data from the experiment to facilitate discussion of the "goodness" of the results. Figure 4 also shows the relative difference between predicted and experimental results. The initial relative difference is -1 at the start of the test. It diminishes to 0 near the peak rate. Then increases in magnitute to -0.55 at the end of the comparision. These variations over the course of the test suggests that while an overall assessment of performance may be done, applications may need to consider placing different weightings on different times during the fire. As an example, in evacuation calculation, accuracy predictions of fire conditions early in the fire development are much more important than later in the fire event. Of course, there also has to be general recognition that the measured results from large scale experiments are themselves subject to some uncertainity and are generally difficult to repeat and replicate. Thus, that the metric for the comparision has its own generally unquantified uncertainity.

CONCLUSION

There is an increasing need for large scale fire measurements in laboratory facilities and in the field to verify the accuracy of the predictive methods that are available and under development to provide the underpinnings for performanced based codes and standards. The development of high resolution models, has presented an additional challenge to develop experimental methods to provide data for verification. Standard means are needed to quantitative the accuracy of the methods and experiments in order to facilitate discussion among the many groups involved in the application of performance based methods.

REFERENCES

1. D. Gross, Fire Research at NBS: The First 75 Years, Fire Safety Science -- Proceedings of the Third International Symposium, Edinburgh, Scotland, July 8-12, 1991. Elsevier Applied Science, London, UK.

2. W.D. Walton, K.A. Notarianni, A comparison of Ceiling jet Temperatures Measured in an Aircraft Hanger Test Fire With Temperatures Predicted by Detact-QS and LAVENT Computer Models, NISTIR 4947, January , 1993. National Institute of Standrads and Technology, Gaithersburg, MD, USA

3. W.D. Walton, J. McElroy, W.H. Twilley, and R.R. Hiltabrand, Smoke Measurement Using a Helicopter Transported Sampling Package, Proceedings of the Seventeenth Arctic and Marine OilSpill Program (AMOP) Technical Seminar, June 8-10, 1994: Vancouver, British Columbia. Environment Canada, Ottawa, Canada.

4. D.D. Evans, W.D. Walton, H.R. Baum, K.A. Notarianni, J.R. Lawson, H.C. Tang, K.R. Keydel, R.G. Rehm, D. Madrzykowski, R.H. Zile, H.Koseki, E.J.Tennyson, In-Situ Burning of Oil Spills: Mesoscale Experiments, Proceedings of the Fifteenth Arctic and Marine OilSpill Program Technical Seminar, June 10-12, 1992: Edmonton, Alberta. Environment Canada, Ottawa, Canada.

5. K. B. McGrattan, A.D. Purtorti, W.H. Twilley, D.D. Evans, Smoke Plume Trajectory from In Situ burning of Crude Oil in Alaska, NISTIR 5273, October 1993, National Institute of Standrads and Technology, Gaithersburg, MD, USA.

6. K.B. McGrattan, W.D. Walton, A.D. Putorti, W.H. Twilley, J.McElroy, and D.D. Evans, Smoke Plume Trajectory from In Situ Burning of Crude Oil in Alaska -- Field Experiments, Proceedings of the Eighteenth Arctic and Marine OilSpill Program (AMOP) Technical Seminar, June 14-16, 1995: Edmonton, Alberta. Environment Canada, Ottawa, Canada.

7. R.D. Peacock, W.W. Jones, and R.W. Bukowski, Verification of a Model of Fire and Smoke Transport, Fire Safety Journal, Vol 21, 1993, pp.89-129.