2009 BFRL Project Description

Project Title: Underventilated Compartment Fire Measurements to Support FDS Development

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Principal Investigator: Andrew Lock

Co-Investigator(s): Matthew Bundy, Erik Johnsson, Paul Fuss

BFRL Program: Reduced Risk of Fire Spread in Buildings

Objective:

Provide a database of experimental measurements to enable fire modelers to validate predictions of under-ventilated fires in enclosed spaces and to improve the fundamental understanding of the physics, chemistry, and structure of these fires.

Problem:

What is the problem? Fire protection engineers, fire researchers, regulatory authorities, fire service and law enforcement personnel all rely on fire models (such as the NIST Fire Dynamics Simulator, FDS) for design and analysis of fire safety features in buildings and for post-fire reconstruction and forensic applications. FDS and other field models lack the ability to accurately and reliably predict the thermal conditions and chemical species in compartment fires, especially in under-ventilated conditions[1]. Inaccurate predictions of incomplete burning and soot levels impact calculations of radiative heat transfer, burning rates, and estimates of human tenability. High-quality (relatively low, quantified uncertainty) measurements of fire gas species, temperature, and soot from the interior of underventilated compartment fires are needed to guide the development and validation of FDS and other field models.

Why is it hard to solve? Detailed measurements of a full scale enclosure (FSE) are challenging due to the transient nature of the evolving fire and the extremely harsh measurement environment. Very high amounts of soot and water and extremely high temperatures (greater than 1200 °C) require the development of advanced measurement techniques. Furthermore, underventilated fires, of the type being investigated here, can create unique safety hazards due to the high temperatures, a highly oxidizing environment, and dangerous concentrations of toxic gas species. Previous experimental investigations were limited to global measurements of heat release rate, temperature, and CO production because of this environment.[2] Therefore,

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[1] Floyd, J. and McGrattan, K., "Validation of A CFD Fire Model Using Two Step Combustion Chemistry Using the NIST Reduced-Scale Ventilation-Limited Compartment Data", *Proceedings of the 9th International Association of Fire Safety Science (IAFSS)*, (2008) accepted April 2008.

[2] Bryner, N. P.; Johnson, E. L.; Pitts, W. M. "*Carbon Monoxide Production in Compartment Fires - Reduced-Scale Enclosure Test Facility*;" National Institute of Standards and Technology, NIST IR 5568: 1994.

specialized measurement equipment and probes are needed to conduct the FSE experiments. Further, the compartment endures extreme abuse from the FSE experiments requiring innovative and sustainable construction of the enclosure to facilitate extended duration steady state measurements as well as multiple repetitions of transient cases.

How is it solved today, and by whom? This measurement science problem is not being addressed elsewhere. Previous work on this problem, conducted at NIST[2,3] and Virginia Tech[4] in the 1990s, examined the global characteristics of underventilated fires burning in a reduced scale ISO 9705 enclosure (RSE) and full scale ISO 9705 enclosure (FSE), but did not address local conditions. The previous work showed the limitations of using the Global Equivalence Ratio to predict carbon monoxide (CO) formation. Although the previous investigations made measurements of the temperatures, gas species, soot concentrations, and velocities, they were not sufficiently accurate or complete to satisfy current fire model development needs. We have attended recent international workshops on compartment fires[5] and surveyed the recent scientific literature, including the premier international symposium on fire safety[6], and found no documentation of RSE or FSE fire measurements that approach the scope of the experimental investigation proposed here.

Why NIST? The study of underventilated compartment fires is directly related to the BFRL mission of meeting the measurement science needs of the U.S. fire safety industries because engineers rely on validated data and models to enable fire protection design and analysis. NIST has the facilities, personnel, and expertise to foster a strong relationship with modelers and provide experimental data that addresses their specific needs.

Approach:

What is the new technical idea? Comprehensive and innovative measurements will be conducted that track all of the carbon mass at a number of locations in a series of underventilated FSE fires. Detailed measurements accounting for carbon in every possible form, i.e. fuel, soot, intermediate, and complete products of combustion, will be performed. Comprehensive data sets of this type have not been previously reported for FSE fires. The chemical data will be augmented by temperature and velocity data to provide a complete picture of the physics and chemical structure of the environment within the fire enclosure. Measurements will be completed for a variety of fuel types and configurations and a fully annotated database will be made publically available.

Why can we succeed now? Experienced gained during the FY06 and FY07 Reduced Scale Enclosure (RSE) fire test series and recent upgrades to the facilities and measurement equipment available within BFRL make it possible for the measurement needs to be fulfilled. An innovative soot measurement probe (SMP) was developed during FY08 as part of this project, allowing for

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[3] Pitts, W. M.; Johnsson, E. L.; Bryner, N. P., (1994) Carbon Monoxide Formation in Fires By High-Temperature Anaerobic Wood Pyrolysis, Twenty-Fifth Symposium (International) on Combustion: 1445-1462.
[4] Gottuk, D. T.; Roby, R. J.; Beyler, C. L., (1995) The role of temperature on carbon monoxide production in compartment fires, Fire Safety Journal 24, (4): 315-331.
[5] Workshop on fires in enclosures, The Institute of Fire Safety Engineering Research and Technology (FireSERT), University of Ulster, Northern Ireland, 30-31st May 2006
[6] Proceedings of the 9th International Association of Fire Safety Science (IAFSS), Karlsruhe, Germany, 21-26th September 2008

the first time, a time dependent measurement of soot. A novel robust FSE design was used in FY08 as part of this project, allowing multiple full-scale enclosure fire experiments without requiring constant re-building of the compartment. An advanced species sampling system was designed and fabricated as part of this project, which allows multiple location gas sampling and storage for subsequent gas chromatographic analysis. The availability of a multi-probe translation stage developed as part of the Velocity Project will facilitate the doorway sampling measurements.

What is the research plan? A full-scale ISO 9705 enclosure (FSE) has been constructed with consideration of durability, low maintenance cost, realistic properties, and well defined boundary conditions. Initial experiments focused on well-controlled fires involving a burner using natural gas, ethanol, heptane and toluene placed inside the enclosure. Experiments explored the effects of fuel type and distribution, using realistic fuels (such as wood or plastic). Further experiments will supplement the previous work, continuing to build the database of results. Liquid and gaseous fuels will be accurately metered to enable calculation of mass burning rate. Some liquid and all solid fuels will have their mass loss measured during burning in order to determine the combustion efficiency. When possible, experiments will be run to near-steady conditions or in well controlled transients. Experiments will be designed to track the distribution of carbon in the enclosure. Gas measurements will include O_2, CO, CO_2, H_2 and H_2O. Other carbon containing species including hydrocarbons up to C_8 will be measured using gas chromatography. Average soot measurements will be performed using gravimetric sampling techniques. Additionally, further development of an extractive optical soot measurement probe (SMP) will continue and will provide time resolved measurements of local soot concentration. Surface temperatures, heat fluxes, and velocities will also be measured. The flux of mass and enthalpy at the doorway will be measured, facilitating assessment of the experimental uncertainty through consideration of the conservation rules. Measurements in the doorway will allow determination of the relative amounts of internal and external burning. Mapping of the internal area and doorway will be accomplished by the use of long (2m) linear stages to provide precise positioning of gas species, velocity, and temperature probes. The database will focus on realistic scenarios that involve fuels burning with the physical complexities of furnishings including heat feedback to the fuel and induced air entrainment into the room which are not independently controlled.

Recent Results:

Output:

- Two peer-reviewed journal articles [7,8]
- Two conference proceedings [9,10]

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[7] Kim, S.C., and Hamins, A., "On the Temperature Measurement Bias and Time Response of an Aspirated Thermocouple in a Fire Environment," *J. Measurement Sci. Tech.*, 2007, accepted April 2008.
[8] Ko, G.H., Hamins, A., Bundy, M., Johnsson, E., A Mixture Fraction Analysis of Combustion Products in the Upper Layer of Reduced-Scaled Compartment Fires, Combust. Flame, accepted for publication, September 2008.
[9] Lock, A., Ko, G.H., Bundy, M., Johnsson, E., Hamins, A., "Measurements in Standard Room Scale Fires," *Proceedings of the 9th International Association of Fire Safety Science (IAFSS)*, accepted April 2008.

- Two NIST Technical Notes [11,12]

Outcomes:

- Developed innovative real time extractive soot measurement probe (SMP) to be used in underventilated FSE fire experiments.
- Data used to guide and validate the predictive capability of the FDS fire model.[13]
- Database of RSE fire experiments available to modelers through the BFRL website: http://www.fire.nist.gov/bfrlpubs/NIST_TN_1483.pdf

Anticipated Outputs

- Several archival journal publications are planned based on the FY08 work.
- FSE fire experiments including compartment mapping are planned for FY09.
- A new technical note reporting on the FY09 FSE experimental work is planned.

Anticipated Outcomes

- Database of full-scale enclosure (FSE) fire experiments including distributed fuels and different fuel types available on-line.
- The innovative real time extractive SMP will be further refined enabling complete tracking of carbon in the FSE.
- Realistic and detailed mapping results will be provided to fire modelers to help them validate and further develop their numerical models.
- More robust and cost effective heat flux measurements will be made possible by comparison of various technologies in real fire scenarios.

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[10] Johnsson, E. L., Bundy, M., Hamins, A., "Reduced-Scale Enclosure Fires - Heat and Combustion Products Measurements", International Interflam Conference, 11th Proceedings. Volume 1. September 3-5, 2007, London, England, 415-426 pp, 2007.

[11] Bundy, M., Hamins, A., Johnsson, E. L., Kim, S.C., Ko, G.H., Lenhert, D.B., "Measurements of Heat and Combustion Products in Reduced-Scale Ventilation-Limited Compartment Fires", National Institute of Standards and Technology, NIST TN 1483. July 2007.

[12] Lock, A., Bundy, M., Johnsson, E., Hamins, A., Ko, GH., Hwang, C., Fuss, P., Harris, R., "Measurements of Full-Scale Underventilated Compartment Fire Experiments Utilizing Various Phase Fuels in Multiple Distributions", National Institute of Standards and Technology, NIST TN XXXX, (*Expected September, 2008*).

[13] Floyd and McGrattan, to appear in the Proceedings of the 9th IAFSS Symposium, 2008.