2009 BFRL Project Description

Project Title: Gas Velocity Measurement Techniques

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Co-Investigator(s):

BFRL Program: **Reduced Risk of Fire Spread in Buildings**

Objective: Apply state-of-the-art measurement science to fully characterize fire-induced flow and identify the features of the flow that may be exploited to improve conventional flow measurement techniques, develop new measurement techniques, and improve our understanding of fire induced-flows.

Problem:

What is the problem? The members of the FORUM for International Cooperation in Fire Research agree that improved capabilities in fire measurement science including flow measurement techniques are necessary.[1] While there exists a limited amount of experimental data on the fluid dynamics of fires occurring in real structures, a review article[2] warns that more data are needed to ensure the quality of fire research. Prior research has focused on simple configurations such as open fire plumes or wall bounded plumes. Understanding the coupling of fluid dynamics, combustion, radiation, and scalar transport is important for a complete appreciation of the processes occurring in structural fires. The same interactions are present in simple fire configurations but their effects are muted. Quantitative flow measurements are difficult in structural fires due to the complexity and spatial extent of the flows as well as the extreme conditions caused by the fire. One technique has been used almost exclusively to study full-scale fire induced flows, the bi-directional probe. That technique, however, has not been adequately validated, and therefore, neither has the existing fluid dynamic data from full-scale structural fires.

Why is it hard to solve? Flows occurring in structural fires are buoyancy dominated and therefore are easily influenced by the structural geometry and other conditions of the environment. The result is a collection of complex flow patterns which vary significantly over space and time. Flows speeds are low and the environment is harsh. Techniques suited to deliver the most accurate measurements are however difficult to implement or not at all suited for the environment.

How is it solved today, and by whom? The fire community currently relies on bi-directional probes for flow measurement in full-scale fires. The bi-directional probe was

[1] T.J. Ohlemiller et. al. (2000) Measurement Needs for Fire Safety: Proceedings of an International Workshop, NISTIR 6527.
[2] S.R. Tieszen (2001) On the Fluid Mechanics of Fires, Annual Review of Fluid Mechanics, 33:67-92.

designed to be a robust and affordable method of measuring gas velocity in fire experiments. It has been the exclusive measurement technique. The flow measurements inferred from these devices depend on an empirical constant derived from experiments in a uniform and steady flow. Many of the assumptions that guided the development and subsequent use of the probe are not valid for the conditions that the device is applied. The application occurs within buoyancy dominated flows that are inherently non-uniform and unsteady. Therefore the measurement uncertainty of this device has not been well characterized for the application.

Why NIST? The accuracy of bi-directional probe measurements has long been questioned. Comparison studies using an independent measurement technique are not available and this has been partly due to the lack of well established techniques that could be used in the harsh conditions imposed by fire. Having expertise in the application of non-intrusive optical measurements and measurement uncertainty combined with possessing large-scale fire testing facilities, BFRL is best prepared to address the need for improved measurement science in fire-induced flows.

Approach:

What is the new technical idea? Particle Image Velocimetry (PIV) is a laser-based approach to measure gas velocity and visualize flow structure. The technique is not physically intrusive to the flow and offers measurements over a large region with greater spatial resolution and potentially greater accuracy than conventional bi-directional probe measurements which are physically intrusive point measurements. The technique measures the displacement of tracer particles in the flow from digital images of scattered light from the particles. Two high intensity and short duration laser pulses are used to illuminate the particles twice in a single plane (light sheet) of the flow. The laser sheets are coincident in space but separate in time and the time separation is specified based on the flow speed and image magnification. Synchronization of the laser pulses and image frames results in a pair of images from which the velocity field can be inferred from measured displacements and known separation times. Like the bi-directional probe technique which infers flow velocity with a measurement of differential pressure across the probe, PIV infers flow velocity with a measurement of particle velocity within the flow. The techniques are built upon totally independent measurements. The focus is on vent flows, to simplify conduct of the measurements (for example, seeding of the flow), interpretation of the results, and comparison of the results with previous work.

Why can we succeed now? PIV is a well established flow measurement technique that has been applied with great success in small flow regions of laboratory scale experiments, but only recently have measurements of large-scale flow fields been attempted. Advances in imaging and optical technology have made it possible extend the size of measurements to interrogate large regions of flow in full-scale structural fires. The increase in power-to-size ratio of lasers has also made it easier to transfer the technique from well controlled laboratories to the field. Stereoscopic PIV (SPIV), an extended capability of PIV, has matured therefore making it possible to measure the full velocity vector instead of only two vector components. This capability has greatly increased the versatility of PIV to provide a richer set of data from a single measurement location.

What is the research plan? SPIV will be applied to completely map the fire-induced flow field across the doorway of an enclosure fire. The doorway is chosen because such vent flows are essential to computing mass and energy balances to confirm experiments and simulations and the bi-directional probe was designed specifically for vent flow measurements.

A digital database composed of two fire conditions, representing the early and final stages of a developing fire, will be created from the velocity field data and made available to the fire research community. In addition to the SPIV measurements, simultaneous measurements using the conventional technique of the bi-directional probe to infer flow velocity will be conducted to provide an application specific *in-situ* comparison of the two techniques. Laboratory scale experiments will be used to confirm the results of the in-situ comparison. Finally, a characterization of the performance of the bi-directional probe in doorway flows will be communicated with recommendations on improving its use.

The complete mapping of the flow across the doorway using SPIV will be the first quantitative characterization of a full-scale fire-induced vent flow using a non-intrusive technique. Since SPIV is a well established technique with well documented accuracy the measurements will provide a new benchmark for velocity measurements in doorway flows. This benchmark will be used to judge the accuracy of conventional techniques and newly developed techniques that have practical usefulness for frequent fire testing. Such data are valuable to experimentalists because it stretches the potential for fire measurement science beyond the exclusive use of the bi-directional probe and provides independent evidence for comparison and confirmation of experimental results. It also provides evidence of flow characteristics that can be exploited for the development of other improved measurement techniques.

The spatial extent and spatial resolution of the SPIV measurements will result in a very information rich database of doorway gas velocity. The spatial extent and resolution of the data will be comparable to that generated by computational fluid dynamics models. Developers of these models will have access to a new source of high-quality experimental data to increase the strength of model validation efforts.

Recent Results:

- Two sets of PIV measurements conducted in the ISO 9705 room with full-scale fires: (1) FY2006 Completed the mapping of the velocity field for air flowing into the lower half of the doorway; (2) FY2008 Completed the mapping of the velocity field for gases flowing out of the upper half of the doorway. Comparison measurements with bi-directional probes were conducted for each set.
- ***Output:*** One journal article[3] and 3 conference presentations (one published proceedings[4], one invited[5]).

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[3] R. A. Bryant, The Application of Stereoscopic Particle Image Velocimetry to Measure the Flow of Air into an Enclosure Containing a Fire, (Submitted to Experiments in Fluids - 2008).
[4] R. A. Bryant, A New Approach to Ventilation Measurements in Enclosure Fires, Proceedings of the 11th International Conference on Fire Science and Engineering, London, UK, (2007).
[5] R. A. Bryant, Large-Scale PIV Measurements in Fire Research, International Colloquium on Fire Science and Technology, Chung Ang University, Seoul, South Korea (2007).

Outcomes

- PIV measurements in the doorway of the ISO 9705 room provide the first ever comparison of the bi-directional probe with a totally independent velocity measurement technique in an actual fire-induced flow. The measurements exposed some of the limitations of the bi-directional probe when used to measure vent flows.
- The PIV measurements represent the most comprehensive characterization of the vent flow velocity field since the measurements of Steckler[6] and colleagues, which have been the benchmark for such measurements for over 20 years.

Impact

- Fire research community adoption of NIST measurement science tools to assess the accuracy of conventional measurement techniques characterizing the fluid dynamics of fire.

Standards and Codes: None

[6] K. Steckler, J. G. Quintiere, W. J. Rinkinen, Flow Induced by Fire in a Compartment, NBSIR 82-2520, National Bureau of Standards, Gaithersburg, MD, (1982).