2009 BFRL Project Description

Project Title: Predictive Model Development

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BFRL Program: Reduced Risk of Fire Spread in Buildings

Objective: To support the public release of the NIST/BFRL fire models, CFAST and FDS, and to continue development of FDS and the visualization tool, Smokeview, that is used by both models so that the model can be used to predict fire spread and growth in a furnished room.

Problem:

What is the problem? Fire protection engineers, regulatory authorities, fire service personnel, and fire researchers all rely on fire models for design and analysis of fire safety features in a building and for post-fire reconstruction and forensic applications. Performance-based design of buildings requires validated fire modeling tools to justify equivalent safety when compared to prescriptive code requirements. For example, performance-based standards like NFPA 805 (Fire Protection for Light-Water Reactor Electric Generating Plants) require that fire models be *verified* and *validated* according to guidelines set forth in standard guides like ASTM E 1355, *Evaluating the Predictive Capability of Deterministic Fire Models*.

Why is it hard to solve? The challenge is three-fold. First, we must develop state of the art physics-based sub-models to describe turbulent fluid flow, combustion, radiative heat transfer, and other fire-related phenomena for length-scales that vary many orders of magnitude (from cm to 10^2 km) . Second, we have to demonstrate the models' accuracy using large-scale measurements and document the results according to standard protocols. Third, we have to still provide robust, easy-to-use software to the fire protection engineering community with a focus on run-time and computational efficiency. All three challenges are significant and will require coordination of many tasks to succeed.

How is it solved today, and by whom? An article in the *Journal of Fire Protection Engineering* (Olenick and Carpenter, Vol.13, May 2003) lists nearly 50 zone models and 20 computational fluid dynamic (CFD) models of fire. Most of these models were developed between 1980 and 2000, and few are actively maintained. Those that are currently maintained are either for special applications, are proprietary, or are used for research only. Few of the models are publicly available. Almost none of these have been carefully validated.

Why NIST? CFAST and FDS are the two most widely-used validated fire models in the world, because no other single organization has the will or resources to develop and maintain them. Commercial software vendors consider fire protection engineering too small of a market to invest in research specifically aimed at fire. Universities cannot maintain the models indefinitely without a steady source of funding. Professional societies, like the Society of Fire Protection Engineers (SFPE), typically do not have enough resources from its membership fees. Private fire protection engineering firms, who constitute the majority of the user community, do not have the resources to do it, and would not share the models with competitors even if they did. However, we have been successful in developing and maintaining the models because we have created a collaborative development framework that involves consulting firms like Hughes Associates, Schirmer Engineering and ArupFire; professional societies like the SFPE and NFPA Research Foundation; government labs like VTT Finland and SP Sweden; testing labs like Underwriters Laboratories and Southwest Research; universities like Worcester Polytechnic University (US), Edinburgh (UK), Victoria (Australia), Canterbury (New Zealand), and software developers like Thunderhead Engineering who have developed a commercially viable graphical user interface (GUI) for FDS, and Reaction Engineering, who are currently developing a GUI for both FDS and CFAST.

Approach:

What is the new technical idea? There are three components of our modeling activities – algorithm development, verification and validation, and user support. We want to focus on the first, and automate as much as we can the second and third. the new technical idea in algorithm development needs to be explained: (Sample: The idea is to improve and expand the predictive capability of current fire models using sub-models that better describe critical physical and chemical processes in fires and can be validated using advanced fire measurement techniques. New data generated through on solid-phase and gas-phase phenomena will guide the development of sub-models on material burning and soot emission.

The automation of the maintenance is new to fire modeling because the field is moving into maturity and few have considered what must be done long-term to maintain this technology. We are developing a system now that will allow interested stakeholders outside of NIST to help maintain the models permanently. Before that can happen, we must have a system, often referred to as a *Configuration Management Plan*, that allows dozens of individuals to access and modify the source code and documentation according to an established set of guidelines.

Why can we succeed now? Performance-based design in fire protection engineering is still relatively new, and as it continues to grow there will be increasing demand for validated numerical models. We have the right team to meet this growing demand. In BFRL, McGrattan and McDermott will focus on gas phase flow issues, Prasad will focus on the solid phase, Forney will continue improving Smokeview, Klein will handle IT issues, and Peacock will be in charge of CFAST. In addition, there are two grants starting in FY 08 that directly support FDS development; one to Jason Floyd at Hughes to improve the combustion algorithm (soot production) and one to WPI/SwRI/SFPE to develop a standard guide for model input, especially solid phase/pyrolysis property data. Our partnership with VTT Finland is still strong, and they are focusing on continued development of the pyrolysis routines, evacuation, and mist suppression. New data generated through complementary projects in the Reduced Risk of Fire

Spread in Buildings Program on solid-phase (material burning) and gas-phase phenomena (underventilated enclosure fires) led by Linteris and Bundy, respectively, will be used to guide and validate model development. Coordination of pyrolysis and material burning research in the Fire Research Division will enhance progress in our understanding of fire spread on real materials.

What is the research plan? The development of FDS will proceed along two major fronts – the gas phase and the solid phase.[1] For the gas phase, we plan to make FDS run in parallel on hundreds of individual processors to resolve, for example, fire spread in the wildland-urban interface over areas that are roughly 100 km^2 or fire spread in buildings whose volumes are comparable to 10 floors of the World Trade Center (WTC), but with much finer resolution than that used previously for such a large-scale calculation (10 cm instead of 50 cm). These calculations will involve hundreds of millions of grid cells, and there is considerable work to be done to the basic hydrodynamic model to make this happen – streamlined transport algorithms, improved scalability on parallel computers, more stable turbulent combustion models.

The increased resolution in the gas phase will lead to more accurate prediction of the heat flux to solid surfaces. To exploit this, work will be done in conjunction with a three year grant to WPI/Southwest Research/SFPE whose objective is to develop standard methods of obtaining material properties for fire models. Much of our validation work has focused on the gas phase – it is time to get serious about validation work for flame spread. Up to now, part of the problem with flame spread validation has been the lack of material properties. As we begin to measure these properties, we will need to validate the current solid phase algorithms within FDS.

Finally, the tremendous increase in the size of the calculations will require Smokeview to be overhauled so that it can handle gigabytes of data, rather than megabytes. This means shifting from a 32 bit to a 64 bit operating system to overcome the current limitation in the size of calculations that can be viewed in Smokeview.

Recent Results:

Output:

- Validation experiments on a two-story structure conducted at the U.S. ATF Fire Research Laboratory. Technical report in preparation.
- FDS and CFAST Validation Guides released in the Spring of 2008 utilizing automated data processing of a suite of verification and validation examples
- "Extending the Mixture Fraction Concept to Address Under-Ventilated Fires," by Jason Floyd (grantee) and Kevin McGrattan accepted for publication in *Fire Safety Journal*, 2008.
- "Validation of a CFD Fire Model Using Two Step Combustion Chemistry Using the NIST Reduced-Scale Ventilation-Limited Compartment Data," by Floyd and McGrattan, accepted

[1] A comprehensive road-map on FDS development is presented on the FDS website (http://code.google.com/p/fds-smv/wiki/FDS_Road_Map) and addresses technical details for improved gas phase combustion, pyrolysis and the sold phase, droplets, particles and the dispersed second phase, active fire protection systems, radiation, the flow solver, and IT and user support issues.

for publication in the Proceedings of the Ninth International Symposium on Fire Safety Science, 2008.

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- Floyd, J. E.; McGrattan, K. B., Multiple Parameter Mixture Fraction With Two-Step Combustion Chemistry for Large Eddy Simulation, Volume 2;Interflam 2007. (Interflam '07). International Interflam Conference, 11th Proceedings. Volume 2. September 3-5, 2007, London, England, 907-918 pp, 2007.
- Duthinh, D.; McGrattan, K. B.; Khashkia, A., Recent Advances in Fire: Structure Analysis, Fire Safety Journal, Vol. 43, No. 2, 161-167, February 2008.

Outcomes:

- Collaborative development system set up for CFAST to mimic that of FDS (source code revision management, on-line user discussion forum, bug tracking, mailing lists)
- Pressure correction algorithm implemented successfully in FDS.
- Massively parallel processing successfully executed on more than 100 individual processors, enabling the ability to execute FDS with relatively high spatial resolution.
- FDS version 5 released in October 2007; over 22,000 downloads over a five month period from January 2008 through May 2008.

Standards and Codes: The (NFPA) Fire Protection Research Foundation has recently highlighted the use of FDS in six major studies that it has sponsored with industry including, Smoke Detector Performance for Ceilings with Deep Beam Pockets, Citing Requirements for Hydrogen Supplies, Modeling of Fire Spread in Roadway Tunnels, Smoke Detection of Incipient Fires, Smoke Detector Spacing for Sloped Ceilings, and Smoke Detector Spacing for Corridors with Deep Beams. All of these studies were motivated by technical issues associated with various NFPA standards.

Impact:

In addition to the standards and code impact, the models are being used daily by the majority of fire protection firms worldwide. The number of users is estimated to be somewhere between 1000 and 2000. Letters from users and our daily on-line discussion forums provide anecdotal information about the types of applications. In general, the models are an integral part of the shift from prescriptive to performance-based building/fire code enforcement. This means that engineers use the models to demonstrate alternative fire protection design strategies that reduce costs without compromising life safety.[2]

[2] Assessing the total impact on society is challenging, if not impossible. The challenge is two-fold – economic and cultural. The impact is multifaceted and complex. For example, if, as a result of an FDS calculation, a building

owner receives a variance from the local building code and does not install a sprinkler system, the sprinkler manufacturer loses while the building owner gains. Furthermore, the number of fires, and fire deaths, in that type of occupancy per year might be so low that assessing whether the lack of a sprinkler system in that particular building and others like it led to an increased number of fire deaths would likely be statistically dubious.