SCHULTE & ASSOCIATES
Building Code Consultants
880D Forest Avenue
Evanston, IL 60202
fpeschulte@aol.com
847/866-7479

POLITICAL SCIENCE: NIST'S WORLD TRADE CENTER INVESTIGATIONS

By Richard Schulte

An article titled "*The NIST WTC 7 investigation report: A critique*" which appeared in the February and March 2009 issues of Plumbing Engineer magazine noted several serious flaws in Federal government's investigation into the collapse of the WTC 7 Building. Interestingly enough, a presentation made by Dr. Kevin McGrattan of the Building and Fire Research Laboratory at NIST titled "*Fire Modeling: Where Are We? Where Are We Going?*" within weeks after the release of the NIST's final investigation report on the collapse of the towers in September 2005 also appears to have exposed serious flaws in NIST's investigation work on the collapse of the WTC towers.

Dr. McGrattan's presentation made to the Eighth Fire Safety Science Symposium sponsored by the International Association for Fire Safety Science includes the following excerpts:

> "*Indeed, current generation zone and field (computational fluid dynamics or CFD) models address transport phenomena reasonably well, making them useful for many engineering applications. For example, FDS did successfully replicate many of the phenomena associated with the Rhode Island nightclub fire. However, it has not yet reached the point of reliably predicting, for large scale applications, such important phenomena as flame spread, extinction, suppression, and CO and smoke production, all of which demand more detailed chemistry and physics than are currently incorporated in the model.*"

> "*For various reasons, those who actually write the computer programs too often cannot or will not explain which algorithms work, which do not, and which have no effect at all on the results. This communication gap leads to unwarranted claims by end users who believe the models are predicting more than they actually are.*"

"*One broad conclusion has been that for simple geometries, all the models do a fairly good job in describing the bulk mass and energy transport. That is, upper and lower layer temperatures are predicted well enough for design purposes. CFD models have an advantage when the geometry is complex, and the simpler models have an advantage when a quick answer is needed, or hundreds of quick answers are needed for a probabilistic analysis. But some might say that this is where we were 10 years ago. Perhaps, but some changes have been made over the past decade to move us forward. Computers are faster and the models have become more robust and easier to use, and some progress has been made in modeling under-ventilated compartments and the burning of complicated targets, like power cables. However, the NRC study clearly identified these subjects as worthy of further development.*"

"For various reasons, those who actually write the computer programs too often cannot or will not explain which algorithms work, which do not . . . This communication gap leads to unwarranted claims by end users who believe the models are predicting more than they actually are."

"*At this point, three different CFD techniques have emerged for modeling fire: Direct Numerical Simulation (DNS), Large Eddy Simulation (LES), and Reynolds-Averaged Navier-Stokes (RANS). . . .DNS is still not practical for large-scale fire simulations. LES and RANS employ models of the unresolved sub-grid dissipative processes. These "turbulence models" vary in scope, with LES attempting to compute as much of the "resolvable" length and time scales (the "large eddies") as possible (Fig. 1), whereas RANS averages over significantly larger spatial and temporal scales than those that are characteristic of the given numerical grid or the fundamental frequency of the fire.*"

"*While the model developers continue to argue the merits of each technique, the model users should decide for themselves which is more appropriate for their particular applications.*"

"While the model developers continue to argue the merits of each technique, the model users should decide for themselves which is more appropriate for their particular applications."

"*Regardless of model type – zone, RANS, LES – we have fairly high confidence in our ability to model transport phenomena. In other words, if we are given the fire's heat release rate and the yields of the various exhaust products, we can predict compartment temperatures to within 20% at worst, and at best to within experimental accuracy. Which merely means that we can solve the mass, momentum and energy conservation equations reliably if we are given the source terms and boundary conditions. . . .However, the next step to take us beyond our simple combustion models appears to be a sizable leap into the unknown.*"

"*Currently, our models cannot predict the outcome of these experiments, except in certain circumstances. Note the emphasis on the word predict. We can track soot and CO reasonably well, and we often use empirical rules relating the global equivalence ratio and CO/soot generation, but we still can't make reliable predictions in large-scale, under-ventilated compartment fire simulations.*"

"". . .if we are given the fire's heat release rate and the yields of the various exhaust products, we can predict compartment temperatures to within 20% at worst, and at best to within experimental accuracy."

"*Combustion researchers are busily studying counterflow flames, and fire modelers are busily burning houses down, but who is bridging the gap*?"

"*Many in the combustion community maintain that we can predict detailed combustion phenomena now. . . The question remains, however, about the quality of the information that a CFD model can provide locally, relative to the detail inherent in the sub-grid model. No matter how good the flamelet library, the weak link is the information being passed from the resolvable scales.*"

"Fire models serve a fairly small community and have been developed and maintained by literally a few dozen individuals. Many more may have contributed in some way, but relatively few people actually write the programs. There simply aren't enough resources to support more."

"*Fire models serve a fairly small community and have been developed and maintained by literally a few dozen individuals. Many more may have contributed in some way, but relatively few people actually write the programs. There simply aren't enough resources to support more. As a result, those who write the programs find themselves in a peculiar position. They have tremendous influence over the day to day practice of fire protection engineering, but in a strange way are also isolated from it because all of their time is consumed by the never-ending minutiae of making the thing actually work. Few step inside the laboratory except for an occasional tour; most never see real buildings burn except on the evening news. So there is a widening gap between the people who write the programs, the people who run the programs, and the people who are influenced by the results. Everyone involved in the process wants to claim success. That's natural. The modeler is hesitant to express doubts about the increasingly elaborate sub-models demanded by the practitioners who are in fierce competition for projects that inevitably push the model just a bit further than for which it was designed – certainly further than for which it was validated.*"

"While I am gratified to see others working with the model, I am mortified that I cannot understand what they have done."

"*I must confess that I do not understand most of the papers I read on the subject, and I have a doctorate in mathematics and have spent the last 14 years writing and applying CFD models! The equation in Fig. 3 was copied from a paper (which I won't cite) that described the implementation of a turbulent combustion algorithm in FDS. While I am gratified to see others working with the model, I am mortified that I cannot understand what they have done.*"

"*Those reviewing papers, attending conferences, or using CFD models ought to demand this type of explanation. It's not enough for the author or speaker to merely cite someone else, who in turn cites someone else, and so on.*"

"*As with flamelets, it's difficult to know exactly what information is being generated directly from the equations being solved, or even what those equations are. The number of empirical parameters continue to grow, as do the number of new, largely unphysical terms in the equations. To borrow a term invented by the US military to indicate when it has overstepped its original mission, we face in our models equation "creep.*"

"*Fire modeling has a wider user community outside of academia than other fields of CFD. The benefit of this trend is that the fire models have always been bandied about more, tested, tweaked, cursed. That's how the models have developed as quickly as they have. That's how computers moved from mainframes to "handhelds" in about 20 years. But like computer viruses, there's a price to pay. How do we stop bad fire modeling? Better communication. As I said above, the model developers have to tell the truth about how the models work, and how well they work. But the practitioners have to listen, no matter how dull the discussion about stoichiometry, extinction coefficients, and, yes, turbulence. Too often, model users simply say that they don't have the necessary background to understand the models. That's understandable for the more sophisticated numerical techniques, but not for the physical models. If a paper under review does not explain the model well, the reviewer ought to send it back and get an explanation. Badly written papers should no longer slide through the system because everyone is afraid to admit that they do not understand them.*"

"How do we stop bad fire modeling?"

"*I am comfortable applying a new feature if I make it clear to my sponsor that 90% of what I'm doing is fairly routine and I've got loads of validation work to back it up. But I'll also explain the new idea, what the issues are, that it has never been validated, etc. Usually it's not critical to the outcome, but if it is, I'll just run a couple of simulations to bound the possible range of answers. Validation will come eventually, but in the meantime, we exercise the model because it takes time for new algorithms to shake out. Robust, efficient code evolves.*"

"I can point to validation work performed by myself and others, but the most important validation work is that which is done by the user, not the developer. There are several reasons. First, model developers are hesitant to show bad results. Rarely do I read a paper about an inaccurate model, unless it is someone else's model."

"*Finally, a few words about validation. I am often asked, "Is your model validated?" Rather than answer with a long explanation of verification, validation, model sensitivity, and so on, I simply answer the question with a question: "Is it?" I can point to validation work performed by myself and others, but the most important validation work is that which is done by the user, not the developer. There are several reasons. First, model developers are hesitant to show bad results. Rarely do I read a paper about an inaccurate model, unless it is someone else's model. Second, model developers know how best to run the model to perform well in a given situation. Thus, as a service to both the model developer and to the fire community alike, the user ought to do a modest amount of model validation, both to assure himself that he can properly run the code, and also to assess the accuracy of the model for the given application.*"

". . . .the user ought to do a modest amount of model validation, both to assure himself that he can properly run the code, and also to assess the accuracy of the model for the given application."

"*Papers on CFD fire modeling should be evaluated in terms of clarity, transparency, and practicality. Just because a paper is incomprehensible does not mean that it must be brilliant work and published. We will not make progress unless the modelers are forced to explain themselves better, and the person best suited for explaining how a model really works is not necessarily the one who's name is tagged to it, but rather the one working behind the scenes to ensure that it actually runs.*"

"*. . . .who is going to maintain these enormous computer codes? To most it is a minor consideration; it is just assumed that someone will. However, as the models move from "research" to "practice," we should think more about it, because the improvement of the models is more and more influenced by our ability to keep the codes running as computers change, students graduate, and peoples' minds get soft.*"

". . . .who is going to maintain these enormous computer codes?"

"*CFD fire models have been around since the early 1990's; zone models since the early 1980's. Each group of models are less than a generation old, but already are showing signs of age. At NIST, Walter Jones, the developer of CFAST, a commonly used zone fire model, has retired. Only two people remain who are familiar with the source code. FDS is maintained by myself with some support from over-worked colleagues and several former post-docs, guest researchers and, for lack of a better term, enthusiasts, who are familiar enough with the source code to make meaningful improvements and nurse it into middle age. Smokeview, the visualization companion of FDS, is maintained by only one person, Glenn Forney. The program currently exceeds 50,000 lines of instructions. What will become of it?*"

"CFD fire models have been around since the early 1990's; zone models since the early 1980's. Each group of models are less than a generation old, but already are showing signs of age."

"One way to foster the collective maintenance idea is to make the source codes available."

"*One way to foster the collective maintenance idea is to make the source codes available. Of course, this is heresy to software vendors, but consider that most scientific software was publicly funded in one way or another. This is certainly true of most of the popular fire models. Making the source codes available means that there will always be a critical mass of people supporting the program and double-checking the algorithms.*"

"*As for money, it appears that no one today is getting rich selling fire models. But there clearly is a thriving community of model users who make money selling their expertise. The model developers can support themselves by exploiting their advanced knowledge of the numerics, and hopefully use this income to further the technology.*"

"*As CFD modeling of fire becomes more and more routine, more people will become interested in the inner workings of the codes and take the next steps if and only if the algorithms are explained better, the source codes are made available, funding is directed towards methods that work, and publishing clear and concise papers and manuals is encouraged. The very limited set of developers currently maintaining the fire model stockpile cannot move us forward alone. There are very talented individuals throughout the fire community – at universities, at private companies, at the various labs – who are willing to contribute to the effort, and we must foster this co-operative spirit in any way we can.*"

Analysis

By now you're probably thinking: what do the excerpts from Dr. McGrattan's presentation in September 2005 have to do with NIST's World Trade Center towers collapse investigation? The investigation was not even mentioned in these excerpts. The answer to this question is "absolutely nothing" when only McGrattan's presentation is considered, but when considered along with comments regarding the melding of structural engineering and fire modeling made by others, everything.

> The answer to this question is "absolutely nothing" when only McGrattan's presentation is considered . . .

Dr. McGrattan's presentation is clearly a candid view of the capabilities of fire models in use at the time of NIST's investigation into the collapse of the World Trade Center towers. Couple Dr. McGrattan's commentary on fire modeling in September 2005 with Richard Bukowski's paper titled "*Prediction of the Structural Fire Performance of Buildings*" from 2003 and the Hughes Associates' research report titled "*The Technical Basis of a Fire Resistance Test for Performance-Based Fire Design of Buildings*" dated June 2007 and there is even stronger evidence that NIST's "cutting-edge" melding of structural engineering and fire modeling in the WTC towers collapse investigation exceeded the actual capabilities of the models used by NIST in the investigation.

Clearly, Dr. McGrattan's commentary on fire models indicates that the capabilities of the models are limited and that substantial work on the models still lies ahead in order to improve and perfect them. In other words, the fire models in use in 2005 and today were, and still are, a "work in progress" and that the work on improving and expanding the capabilities of the models, as well as "validating" the models, will need to continue for the foreseeable future.

> In other words, users of a fire model should not simply assume that the model will produce accurate results because the model was developed by NIST.

In particular, Dr. McGrattan's comments regarding model "validation" are of interest, considered both by themselves and in the context of the NIST WTC investigations. McGrattan indicates that "*the user ought to do a modest amount of model validation, both to assure himself that he can properly run the code, and also to assess the accuracy of the model for the given application*". In other words, users of a fire model should not simply assume that a model will produce accurate results because the model was developed by NIST.

In the context of the NIST World Trade Center towers investigation, NIST was not only the developer of the fire model used, but also the user of multiple models.

In the context of the NIST World Trade Center towers investigation, NIST was not only the developer of the fire model used, but also the user of multiple models. Hence, per Dr. McGrattan's comments, NIST should have conducted "validation" experiments to verify that the models which were utilized in the investigation were actually capable of providing accurate output . There is no doubt that NIST conducted experiments to develop input for their models and utilized available video footage of the WTC incidents in an attempt to verify that the fire models were able to predict the fire spread. However, these forms of "validation" of the models do not necessarily mean that the temperatures predicted in the modeling were necessarily precise enough to accurately predict the structural response to the fire.

In my view, "validation" of the capability of a model to predict temperatures in a room, or a series of rooms, which would be considered to be relatively small when compared to floors in the World Trade Center towers (approximately 40,000 square feet), is simply not sufficient to consider the model "validated" for use in analyzing the structural response of the WTC towers to the large fires burning simultaneously on multiple floors in each tower. Obviously, the number of potential variables increases as the size of the fire compartment increases. Minor variations in the physical characteristics of the structural members, including the connection welds and bolts, as well as the structural fire protection, could potentially have a significant impact on the structural response to fire. These real-world variations simply cannot be modeled.

Obviously, the number of potential variables increases as the size of the fire compartment increases. Minor variations in the physical characteristics of the structural members, including the connection welds and bolts, as well as the structural fire protection, could potentially have a significant impact on the structural response to fire.

Conclusions

NIST's recommendations for the improvement of the safety of buildings, specifically high rise buildings, included in the WTC towers collapse investigation report included a recommendation that structural engineering and fire modeling be melded together and that tall buildings be designed for "total burnout" (i.e. assuming failure of the sprinkler protection required to be provided for the building). Based upon statements included in Dr. McGrattan's presentation, it would appear that the melding of the structural engineering and fire modeling is "still not ready for prime time". Despite the fact that fire has been with us since ancient times, our understanding of this phenomena is still rather rudimentary. If this is indeed the case, then attempting to design building structural systems utilizing fire as a "design load" would essentially have to be considered to be more fiction, than non-fiction, at least at the present time.

Imagine waiting years for computers to perform a calculation and then finding out that the calculations are largely fictional exercises.

Although the concept of melding structural engineering and fire modeling sounds relatively simple, as a practical matter, the complexity of implementing this concept is probably beyond our present ability to perform the calculations for a tall building even with today's sophisticated and powerful computers. The number of potential variables in a severe fire in a tall building is extremely large and, hence, calculations which include the effects of all of the potential variables could take years to perform. Imagine waiting years for computers to perform a calculation and then finding out that the calculations are largely fictional exercises.

Perhaps it's time for a more realistic assessment of our capabilities regarding the combination of structural engineering and fire modeling and, if NIST's World Trade Center towers and WTC 7 investigation work is more fiction that fact, perhaps it's time for NIST to let the American public know that too.

. . . if NIST's World Trade Center towers and WTC 7 investigation work is more fiction that fact, perhaps it's time for NIST to let the American public know that too.

As an engineer who was taught how to use a slide rule to perform engineering calculations as a freshman in college, there are two old adages which I learned in my younger days which are still applicable today-the first is "show me" and the second is "keep it simple sweetheart (KISS)".

The primary means of providing fire protection for high rise buildings in the United States has been sprinkler protection since the middle 1970's. With 35 years of experience using sprinklers to provide protection for high rise buildings, there has yet to be a failure of this protection (other than on September 11th). In effect, sprinkler protection has made major fires in high rise buildings obsolete.

In effect, sprinkler protection has made major fires in high rise buildings obsolete.

The backup means of providing fire protection for high rise buildings is manual suppression. The fires at the First Interstate Bank Building in Los Angeles in 1988 and the One Meridian Plaza Building in Philadelphia in 1991 clearly demonstrated that floor-to-floor fire spread can be prevented by sending fire fighters to floors above the fire. Given this, the probability that a "total burn out" in a high rise building will occur is, for all practical purposes, zero.

Despite the fact that the probability of "total burn out" is essentially zero, building codes in use in the United States still require that the structural elements of high rise buildings be protected with substantial structural fire protection, in addition to the sprinkler protection and manual fire fighting equipment (a standpipe system) mandated. Although fire spread to multiple floors in the fires at the First Interstate Bank Building and the One Meridian Plaza Building, both of these buildings remained structurally stable throughout the fires (although there was concern about the stability of the One Meridian Plaza Building during the fire and this building eventually had to be demolished). Hence, it can be concluded that the structural fire protection presently mandated is adequate even in the event of sprinkler system failure and the spread of fire to multiple floors.

Given that the present protection mandated for high rise buildings has successfully provided protection for high rise buildings in the United States for the last 35 years (i.e. a demonstration of both the "show me" adage and the "KISS concept"), should even more fire protection be mandated for tall buildings simply because of the events which occurred on September 11th? The engineers and research scientists at the BFRL at NIST apparently think so, but these same engineers and scientists produced two flawed investigations of the building collapses which occurred in Lower Manhattan on September 11th.

Perhaps NIST's recommendations included in the two investigation reports are also flawed. . . .

Perhaps NIST's recommendations included in the two investigation reports are also flawed- at least its something worth pondering.

* * * * *