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THE CAPABILITIES OF FIRE MODELING: DALMARNOCK FIRE TESTS

By Richard Schulte

An article titled "*Reliability of Computer Models in Fire Safety Design*" authored by Dr. Alan N. Beard appeared in the April 2008 issue of *Industrial Fire Journal*. Excerpts from this article have appeared in a number of articles on this website. Dr. Beard's article makes reference to fire tests conducted in 2006 referred to as the Dalmarnock Fire Tests.

A paper titled "*Round Robin Study of a priori Modelling Predictions of The Dalmarnock Fire Test One*" authored by Guillermo Rein, José L. Torero, Wolfram Jahn, Jamie Stern-Gottfried, Noah L. Ryder, Sylvain Desanghere, Mariano Lázaro, Frederick Mowrer, Andrew Coles, Daniel Joyeux, Daniel Alvear, Jorge A. Capote, Allan Jowsey, Cecilia Abecassis-Empis and Pedro Reszka and published in *Fire Safety Journal* in 2009 provides a summary of a study of fire modeling conducted in conjunction with the fire tests.

The paper includes a number of interesting observations with respect to fire modeling. The following are excerpts from this paper:

> "*Computer fire modelling was first developed as a research tool in the 1970's (Emmons 1978) after the surge of computer resources. It reached its first applications to real fire engineering problems in the late 1980's (Cox et al. 1989, Cox 1998) and now is widely used (Novozhilov 2001, Cox and Kumar 2002) in many aspects of fire science and engineering.*"

> "*Modelling is among the fastest developing areas in fire safety science. However, its ability to reproduce fire phenomena lags experimental understanding by about 10 years (McGrattan 2005). A key aspect where much work is necessary is the proper evaluation of the output from fire modelling.*"

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"The large majority of the studies that have compared simulations to experiments have found them in reasonable agreement. These studies show that current modelling provides good predictions of the average thermal effects of a fire (e.g. hot layer temperature) but do not address the accuracy of the predictions of the fire development (e.g. fire growth and/or the heat released rate) or spatial resolution. . .Of the studies conducted to date, only a few compare modelling results with experimental data from realistic fire scenarios (Reneke et al. 2001, Pope and Bailey 2006), however none of these were conducted a priori or as blind simulations."

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"The validation of fire models is an essential task for the advancement of fire safety engineering. One of the issues that remain to be further explored is the evaluation of the entire process of fire modelling, in which the mathematical model is only a component. The assumptions made by the user, the collection of data for input and the selection of the parameter values (some available in the literature and from experiments, some not) are crucial components leading to the creation of the input file. Furthermore, the interpretation, claimed accuracy and implementation of the model output are key components that further highlight the important roll of the user in the interaction with the model."

"It is reasonable to consider that the current state-of-the-art of fire modelling is reflected not only in the mathematical models' capabilities, but also on how fire dynamics is implemented throughout the different stages of modelling. Thus, in order to assess the strengths and limitations of the process as a whole, all the stages of fire modelling need to be investigated both independently and as a whole. This study looks at the overall process but does not underestimate the value of analysing the individual components."

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"*The objective of this study is to compare the modelling results produced a priori by different teams of modellers of a realistic fire scenario, the Dalmarnock Fire Test One. Test One is part of the Dalmarnock Fire Tests series of fire experiments (Abecassis Empis et al. 2007, Rein et al. 2007), conducted in 2006 in a real high-rise building.*"

"*The objective of this study is to compare the modelling results produced a priori by different teams of modellers of a realistic fire scenario, the Dalmarnock Fire Test One. . .*"

"*A round-robin study involves the analysis of a common scenario by several independent teams and then draws conclusions from the comparison of all results (Beard 2000).*"

"*A round-robin of modelling results typically involves the production of independent predictions of a common event. Conclusions are then drawn from the comparison of the different predictions and the real behaviour. ASTM E 1355 (2005) defines three types of simulation: blind, open and specified. In blind simulations, also called a priori, the modeller is provided only the description of the initial scenario and is responsible for developing the appropriate input from this description, including details of the geometry, material properties, fire development, etc. The modeller has no access to the experimental measurements of the event and thus is providing a forecast. Most fire model validations are open simulations, also called a posteriori, where the modeller is also provided with the results from the experiment. Only a priori simulations are free of the bias that could be introduced by prior knowledge of the development of the event. In specified simulations the modeller is directly given the input file to be run in the model.*"

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"*In fire modelling, only a few round-robins can be found in the literature (Beard 2000, Beard 2005). . . Nevertheless the lack of ample round-robin studies in fire modelling is a pending issue of the discipline.*"

"The present round-robin study involves a pool of participants composed of independent international teams, all working in the field of fire engineering and using fire modelling as part of their professional practice. . .Each team submitted one or more simulations that, in their view, represented the best prediction of the process based on their a priori knowledge."

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"The large-scale Dalmarnock Fire Tests (Abecassis Empis et al. 2007, Rein et al. 2007) consist of three tests conducted in a 23-storey reinforced concrete building in Glasgow (UK), July 2006. The two tests of main interest here (henceforth referred to as Test One and Test Two) were those conducted in two identical flats, whereas the third test involved only smoke management in a stairwell and will not be further discussed. The Dalmarnock Tests were set up to recreate a realistic fire scenario involving multiple fuel packages arranged in an ordinary fashion, consistent with real dwellings. Arrangements of this type invariably result in fire growth that is not readily obvious and thus prediction of fire development can be a challenge. Nevertheless, the Dalmarnock compartment test was designed to maximise its repeatability. Ignition procedures and fuel distribution were defined in a manner such that potential variations could be kept to a minimum. Furthermore, the comparison of the results from Dalmarnock Fire Test One and Test Two confirms that the repeatability of the tests was high (Rein et al. 2007, Chp 4). This study considers only Test One for comparison against fire modelling, however Test Two is briefly discussed."

> *"It is a common conception that fire experiments could significantly differ from each other when run under the same conditions, and therefore many repeats are necessary to achieve validation data. Given the cost and complexity of large-scale fire tests, it is evident that the number of repeats that will establish statistical validity for the data will never be achieved. . ."*

"*It is a common conception that fire experiments could significantly differ from each other when run under the same conditions, and therefore many repeats are necessary to achieve validation data. Given the cost and complexity of large-scale fire tests, it is evident that the number of repeats that will establish statistical validity for the data will never be achieved. This feature distinctive to fire is associated to its inherent complexity and has always cast a shadow of uncertainty upon any modelling validation exercise. Experimental data used for comparison with modelling results can never be considered as robust as it could be in other fields, such as small flames.*"

"*. . .Given the cost and complexity of large-scale fire tests, it is evident that the number of repeats that will establish statistical validity for the data will never be achieved. This feature distinctive to fire is associated to its inherent complexity and has always cast a shadow of uncertainty upon any modelling validation exercise. . .*"

"*The two main processes that can lead to drastic differences in fire development are the ignition of individual items before flashover and the windows breaking and falling out. The ignition issue was addressed by defining an ignition protocol for the first item and by placing it in close proximity to a large quantity of fuel arranged vertically, in the form of a bookshelf. This provided an ISO room corner test type of configuration where it is guaranteed that flashover will be attained soon after the ignition of the secondary item. The potential bounds of variability of the data were thus established by using very different ventilation and ignition conditions for both tests.*"

"*. . .This provided an ISO room corner test type of configuration where it is guaranteed that flashover will be attained soon after the ignition of the secondary item. . .*"

"*The aim of the study was the forecast of fire dynamics for the set scenario. The teams were asked to forecast the test results as accurately as possible, and to avoid an engineering analysis with conservative assumptions or safety factors, as is common for use in fire safety design. All teams were given access to a common pool of information about the test experimental setup and initial conditions.*"

"*The teams were given all the details available up to ignition of the fire and a general overview related to the aftermath. This included: the geometry and dimensions of the flat; a detailed and measured layout of the room furniture; 50 photographs of the whole compartment final set-up, windows, fuel packages and instrumentation; and individual descriptions, material, dimensions and photographs of each furniture item. A replica of the sofa, the wastepaper basket and the ignition protocol was tested separately, under laboratory conditions, and the initial heat release rate of the ensemble was measured in the furniture calorimeter. This experiment was allowed to burn until one third of the sofa mass was consumed and then the fire was then extinguished. This heat release rate measurement was also provided to the teams. Information on the ventilation conditions included size, photographs and status of the windows and doors. One of the main compartment window panes was externally forced to break at 800 s after ignition, and this information was also provided to the teams. Meteorological data from two nearby weather stations were also available. . .It is important to note that the extent of this information by far exceeds the typical set of data available for a user when attempting to simulate a fire of this nature.*"

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"*In total, ten simulations were submitted: eight CFD simulations using FDS4 (McGrattan and Forney 2006), and two simulations using zone model CFAST (Peacock et al. 2000).*"

"*The process of converting the data from CFD model-type to zone model-type information and the assumptions inherent to the process were the responsibility of each team and considered as part of the round-robin study.*"

"*It is important to keep in mind while analyzing the results that all simulations were forecast conducted a priori, and beckoning the words attributed to Sir Winston Churchill (circa 1945) that: "I always avoid prophesying beforehand because it is much better to prophesy after the event has already taken place".*"

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"*The predicted times to flashover varied approximately between a 180 % overprediction down to a 100 % under-prediction and fell into two main groups, those predicted at 800 ± 80 s (~13 min) – very close to the time for forced window breakage at 800 s – and those that predicted flashover before 180 s ± 80 s (~3 min). One simulation predicted that no flashover would occur. Similarly, the predicted maximum average temperatures in the compartment varied approximately between a 50 % over-prediction down to a 70 % underprediction.*"

"**Table 2: Comparison of simulated time to flashover and maximum average temperature in the smoke layer of the main compartment with experimental data.**"

Simulation	Time to Flashover [s]	Maximum Average Smoke Layer Temperature [°C]
A1	850	790
A2	290	500
B	840	690
C	No flashover	200
D1	200	720
D2	80	1150
E1	180	900
E2	180	610
F1	720	590
F2	850	720
Experimental	**300**	**750**

"*The simulations show a wide scatter of predicted fire behaviours. One simulation (D2) over-predicts the HRR by 100 %, another (E1) provides a reasonably good prediction and all other simulations under-predicted the HRR in the range of 30 % to 90 %. . .Other teams deemed the measured sofa HRR to be deficient or too slow for the fire growth stage. The best average results and lowest scatter are obtained after the forced window breakage (at 800 s), as the teams were informed of the timing of this event.*"

"*Most simulations underpredicted the hot layer temperature. Four simulations fell within a 10 % to 40 % underprediction range and the others were above the 50% range of over- and under-predictions. The very wide range of behaviours predicted reflects the influence of the user's assumptions when converting field results to zone results, as well as the difference in overall assumptions used for the input.*"

“*The simulation that predicts the HRR within 10 % (E1) of the experimental measurements, over-predicts local temperatures up to 200% during the growth phase but post-flashover, the disparity is reduced to an average 25 % difference.*”

> “*The results indicate large scatter and considerable disparity, both amongst the predicted fires and between the predicted fires and the experimental data.*”

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> “*It is important to emphasise that none of the predictions accurately predicted the time to flashover.*”

“*Although not the intent of the paper, the results show that out of the ten simulations; one provided good results; four provided acceptable results in some sense; and five did poorly. It is important to emphasise that none of the predictions accurately predicted the time to flashover. One simulation predicted HRR development and wall heat fluxes adequately, but diverged from experimental data on other local quantities. Thus, one conclusion is that in complex modelling scenarios, such as Dalmarnock, good results at the global compartment scale do not necessarily correlate to good results at the local scale.*”

“*. . .Since most participants used the same fire model, FDS4, it is reasonable to think that the wide range of predicted behaviour is mostly the result of the uncertainty associated with the definition of the input data (assumptions and parameter values). The large number of degrees of freedom (i.e. apparent possible assumptions, uncertainty in the parameter values and sensitivity of the model, among others) and the broad variability of the material properties available in the literature lead to large variability in the results. This variability needs to be considered when fire modelling is used to predict fire growth in complex scenarios. These conclusions are expected to be applicable to the full suite of fire models currently available, and not uniquely to the two models used in this study.*”

“*The study is an assessment of the state-of-the-art of fire modelling in a non-trivial, realistic scenario and evaluates the process of fire modelling as a whole, including the prediction of the heat release rate and the effect of different assumptions, input parameter values, computational approaches and user interactions with the model.*”

"*The aim of the round robin exercise was to forecast the test results as accurately as possible, and not to provide an engineering analysis with conservative assumptions or safety factors. Design for fire safety was not the objective of the exercise. The issue of how to use reliably fire modelling for safety and engineering design is a very important issue that currently under research by many institutions and firms.*"

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"*Fire modelling is not yet able to predict the HRR and more research efforts need to be tailored towards this issue. However, fire environments can still be calculated if the HRR is part of the input data to the modelling process. This is because current modelling tools provide good predictions of the effects of a fire (e.g. temperature field) once the HRR is provided.*"

"*Nevertheless, the general behaviour captured by several simulations provides fire features that may be good enough to be applied towards some engineering problems if a robust and conservative methodology is defined. A prerequisite for this methodology is that it can use predictions with crude levels of accuracy and that it applies appropriate safety factors.*"

> "*Nevertheless, the general behaviour captured by several simulations provides fire features that may be good enough to be applied towards some engineering problems if a robust and conservative methodology is defined.*"

"*Our gratitude to the Building and Fire Research Laboratory at NIST for developing and the computer fire models used in this study and for making them freely available. We regret that users of different fire models withdrew from the study or declined our invitation to participate.*"

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Discussion

What else can you say about the above, other than to say: interesting, very interesting?

> This reminds me of the models used to predict the track of hurricanes-eighteen different models and eighteen different hurricane tracks.

Basically, what the above means is that using fire modeling for forensic purposes is essentially no better than using a listed fire safety dart board or a listed deck of fire safety tarot cards for purposes of prognostication. This reminds me of the models used to predict the track of hurricanes-eighteen different models and eighteen different hurricane tracks. Obviously, at least one of the models will correctly predict the track of the hurricane at least occasionally. All we need is another model which tells us which model is correct at a given time-that's the hard part.

Few, if any forensic uses of fire modeling will have as good of information as was available in the test described above, yet 10 attempts at modeling the fire failed to predict the time that flashover would occur, although one of the models came within 10 seconds of predicting the flashover time. Ten seconds is probably an acceptable result, however, the problem is to figure out which modeling effort will actually provide an accurate prediction. Perhaps, like the hurricane models, all we need is another model to tell us which modeling result is correct.

> Based upon the above, it appears that either a dart board or a deck of tarot cards should be able to predict the results of a fire as accurately as the models.

Hopefully, the next time the models are put to the test, a fire safety dart board and a fire safety deck of tarot cards can also be included in the trial. Based upon the above, it appears that either a dart board or a deck of tarot cards should be able to predict the results of a fire as accurately as the models.

It seems quite obvious why the Dalmarnock Fire Tests have been ignored by the profession. Even if the models are constructed perfectly, the input into the model must be correct in order to achieve accurate results. In other words, the adage "garbage in, garbage out" applies and therein lies the weakness of the models.

How does one know if the input to the model is correct? The Dalmarnock Fire Tests clearly illustrated that even “fire modeling experts” do not agree on the correct input for the model. If the “experts” can’t get it right, then how can it be expected that someone who isn’t an “expert” will get it right? It would seem that the results of the Dalmarnock Fire Tests fire model trials demonstrated clearly that there are no “experts”.

How does one know if the input to the model is correct?

The results of the Dalmarnock Fire Tests do not necessarily mean that fire modeling is “*worthless*”, but the tests do indicate that fire modeling is pretty much close to “*worthless*”, *i.e.*, junk science, at least at present.

It would seem that the results of the Dalmarnock Fire Tests fire model trials demonstrated clearly that there are no “experts”.

Perhaps in twenty or thirty years, fire modeling techniques will be perfected so that modeling can be used with some degree of confidence that the prediction results are meaningful. Until then, don’t throw away that dart board.

Actually, good building fire protection design isn’t all that difficult to achieve based upon experience. Good building fire protection design consists of some combination of active fire protection, passive fire protection and egress facilities. The NFPA “decision tree” developed in the late 1970's serves as a basis for determining what good building fire protection actually is and you can’t get a whole lot simpler than the NFPA “decision tree”.

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Fire modeling is just an attempt to quantify what experience already tells us about how to design “safe” buildings. Unfortunately, at present, the level of confidence in the modeling results is questionable at best. Of course, a computerized result is impressive, particularly to non-engineers. If a computer did it, the results must be correct.

Fire modeling-“making the simple complex”.

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