CFD – Colour For real thing?

There is increasing debate in the field of Fire Engineering as to whether predictions calculated using Computational Fluid Dynamics (CFD) are reliable. Some experts declare that the tools are well advanced and ready for mainstream use while others express a preference for them to be locked away in the research institutions that developed them!

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In fact, what is most important is that they are used <u>and checked</u> by people who understand them. In this article we look, in layman's terms, at how easily CFD tools can be used <u>and</u> abused, particularly in relation to the complexities of predicting the operation of an Aspirating Smoke Detector (ASD). The examples given provide an insight into how CFD is a powerful tool for the professional fire engineer but with the increasing ease of use and accessibility can allow novice users to generate colourful but misleading simulations which appear very impressive. Ultimately, the article concludes that, as with early motorcars, there is still a need for the man-with-a-red-flag.

A tongue-in-cheek comment from one well respected fire consultant illustrates one aspect of the challenge. He said simply, "I like CFD as, in the hands of an expert, it will give me any incompetent" person – assuming the former is not totally unscrupulous!

Fortunately, as the science is not new there are now guidelines and standards on how a Fire Engineered solution should be conducted and presented. BS7974:2001 – "Application of Fire Safety Engineering Principles to the design of buildings" is an excellent example of how "good practise" can be realised. For example, Section 5 provides recommendations on the content and structure of the final report which, if followed, make it relatively easy for an independent expert to review the validity of any CFD models used to justify a particular design; the pertinent information being presented in a logical and consistent fashion.

As CFD tools develop further, they will inevitably get easier to use and become more robust – not just in terms of the accuracy of the

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answer I want!". Whilst alarming, this is not as disturbing as the availability of simple tools which feed assumptions into downloadable CFD packages and enable people with zero experience in Fire Engineering to generate convincing smoke and heat simulations. In the first case, we have a professional using the tool with a full understanding of the factors that can influence the results, while in the second case, huge assumptions can be overlooked unintentionally. A "consciously competent" person is arguably somewhat safer than an "unconsciously

models, size of meshes and computational complexities but also in terms of restricting the inputs, the variables and user interfaces. Eventually it will be possible for CFD tools to be driven safely by relatively inexperienced users – rather like the fact that cars can now be driven by normal people, without any knowledge of what is going on under the bonnet! However, widespread car use is only possible because of the standardised positions for controls and all the automatic adjustments such as electronic ignition, automatic choke, ABS, EPS etc. So, it

Directors or the

can be assumed that when CFD models have equivalent solutions/protections for "normal driving" conditions then there *is* scope for them to be driven *unsupervised* by a wider population of users – without being preceded by a man-with-a-red-flag! Of course, in the case of Fire Engineering, the "man-with-the-red-flag" is essentially a respectable independent reviewer of the work/design. Fortunately, there are increasing numbers of experts with CFD experience so the costs for such an independent review are inevitably falling.

density (using CFD) and comparing it with the claimed sensitivity of the particular detector – whether that detector is a conventional or addressable point detector or a single *independent* sampling hole of an aspirating detector. For point detectors this is because they respond very differently according to their design, operation and the particular characteristics of the smoke and airflow surrounding the detector.

Clearly, for an ASD system which uses a centralised detector sampling from many points

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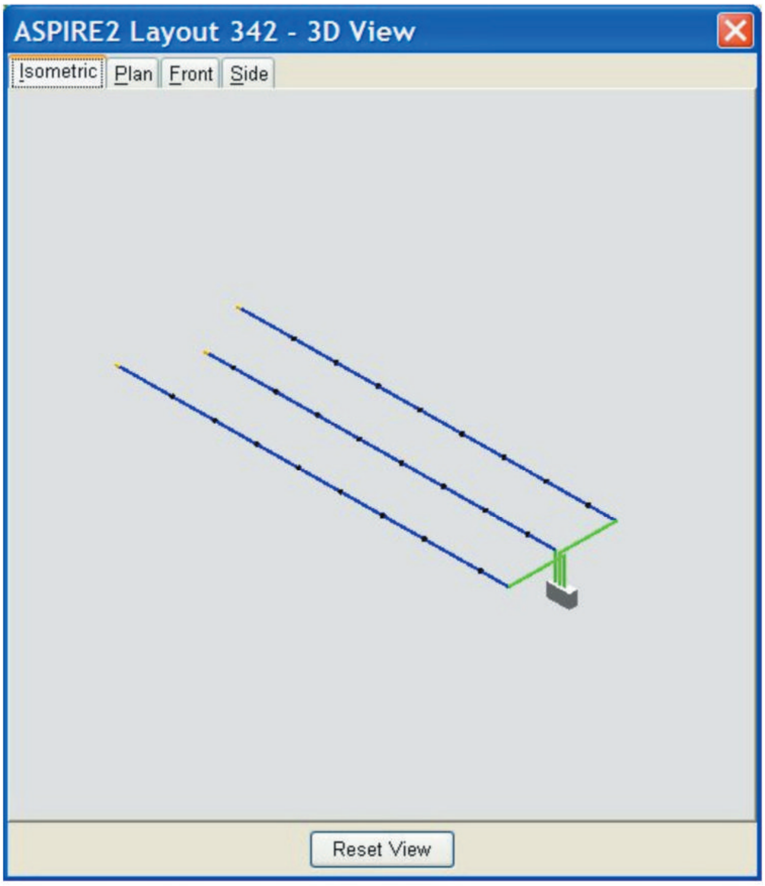
Regardless of who constructs, drives and reviews the CFD model it is imperative that the model is operated within its limits/assumptions and that those limits/assumptions have been properly defined and verified. For example, the Application Engineering Group (AEG) at Xtralis have generated numerous CFD models to predict the response of VESDA detectors:

– In a wide range of enclosure geometries (i.e. high ceilings, large areas, irregular shapes, etc), ceiling types (flat, beam pockets, waffle-type), enclosure types (material type, density), etc.
– In a wide range of environmental conditions such as natural/mechanical ventilation, different ambient temperatures, varying air stratification levels etc.
– For a wide range of fuel types and fire sizes such as varying heat release rates (HRR) for example T^2 and steady state growth profiles, varying soot yield, etc.

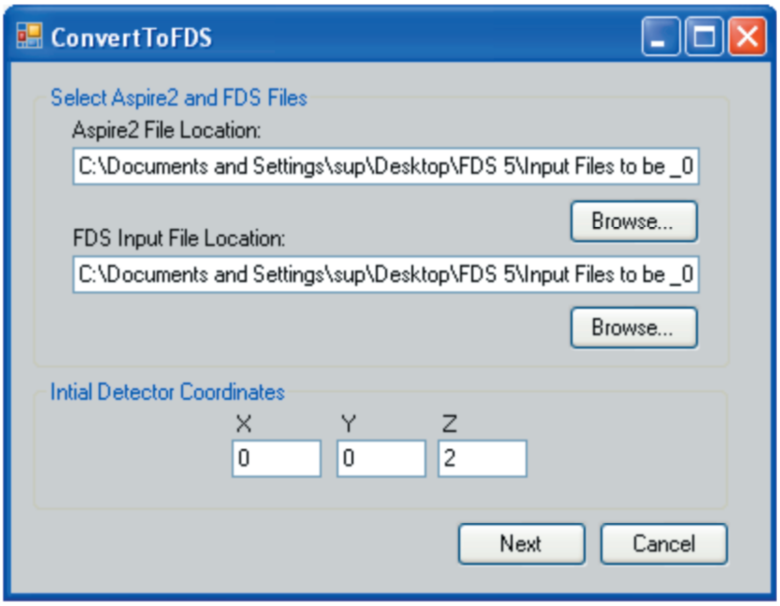
These simulations have been supported and developed in association with numerous fire experiments which test and validate the CFD models and as such they are being used successfully to campaign for changes in the prescriptive codes. Most importantly, the research has been reviewed and supported by independent experts within the Fire Engineering community.

Predicting when an Aspirating Smoke Detector operates – or indeed when any smoke detector operates – is not a simple matter and depends critically on the smoke entry characteristics. It is NOT valid to assume that you can predict the moment of detection by calculating the optical within a space, each sampling point has a particular flow and transport delay which contributes to the smoke analysis and alarm reporting performed by the centralised detector. Fortunately, this "smoke entry" characteristic is largely independent of the airflows in the locality of the sampling hole and can be predicted reasonably reliably. The same is not true for a normal point detector whose "smoke entry" response can be significantly affected by the localised airflows – whether resulting from the thermal affects of the fire or from inherent airflow present in the protected space. So, it is a gross assumption to simply presume that an alarm will be signalled when the optical density of smoke predicted by the CFD model exceeds the "sensitivity" of the detector – particularly when the "sensitivity" is simply taken as the number quoted by the manufacturer (whether in dB/m or %obscuration/m).

Predicting the smoke entry characteristic of an ASD actually uses a form of CFD – i.e. various pipe flow models. While predicting pipe flows generally is widely researched and understood, predicting the flow of air into a pipe with numerous holes in it is not trivial because each hole changes the flow characteristic at each sampling point. However, Xtralis (and other ASD manufacturers) have developed software packages (see ASPIRE2 figure) which predict the flow of air into each hole and the resultant transport time to the detector. These models have been refined over many years and, while some are more accurate than others, they provide useful information which can be integrated with CFD fire models.



The Application Engineering Group (AEG) at Xtralis have, over the last 5 years, pioneered the use of CFD models to predict the performance of ASD systems and have influenced many projects and several standards groups with their work. As already mentioned, much of this work has been validated against fire tests. Most recently, AEG has been reviewing the *latest* release by the US National Institute of Standards and Testing (NIST) of Fire Dynamic Simulator (release 5.1.0) which now claims to provide routines for calculating the response of a multi-hole ASD system. This is an important step forward and Xtralis have made available a converter to translate the design data of ASD system, contained within an ASPIRE2 pipe design (see figure), into data for input to FDS5.



It is important to appreciate that the validation work and, moreover, the fixed alarm thresholds, on which the reputation of VESDA is founded, is fundamental to the validity of this integration of ASPIRE2 and FDS5. Without fixed alarm thresholds it becomes *extremely* complex to predict the response of an ASD because the sensitivity of an adaptive system depends on the smoke and background conditions during the hours *before* the fire, and consequently before the CFD model starts.

The ASPIRE2 to FDS5 converter is only available to experienced users of FDS who undertake training on ASPIRE2 and the converter. Most importantly the converter makes no assumptions about the building fabric, the background airflows, the temperature conditions, the fire size, position or combustion characteristics, nor does it make any assumptions about the mesh or setting needed to actually run a fire model using FDS5. Such information is the remit and responsibility of the Fire Engineer running the programme. **In stark contrast, a similar pipe-model-to-FDS4 converter is available on the internet which makes assumptions that are sufficient to quickly generate a simple FDS model.** The results from this model can be used to generate 3D visualisations of the smoke spread which, while being very convincing, is based on many unrecorded assumptions and could be lethal if used as a basis for a Performance Based Design for the protection of a building.

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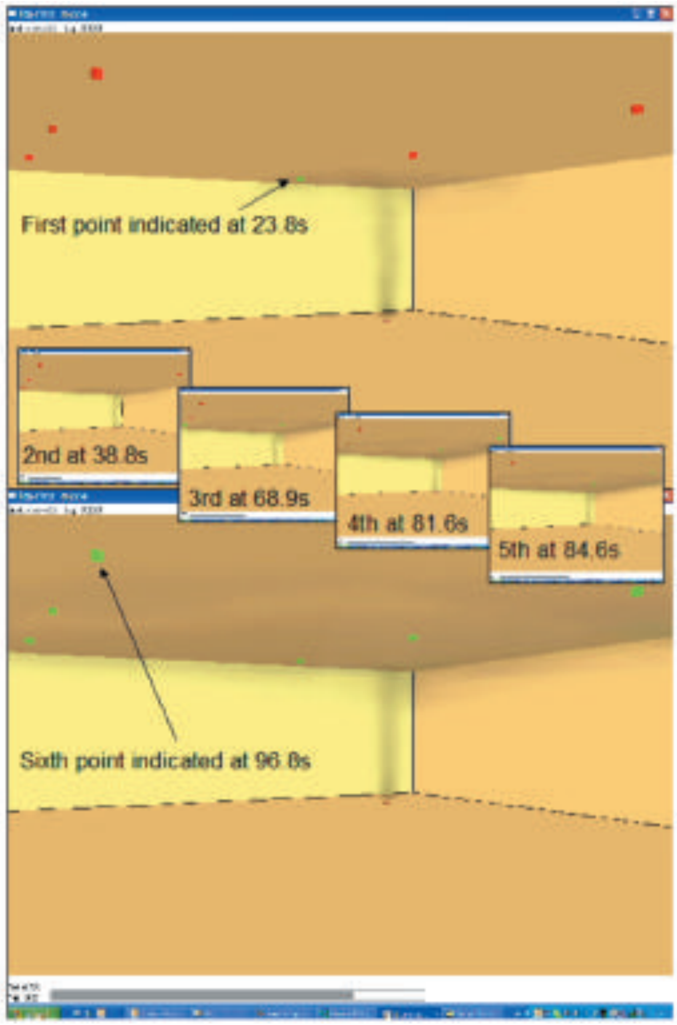

The simulation shown in the figure above was generated by a novice after only 3 hours minimal effort using free software downloaded from the internet. Behind the convincing graphics, the solution indicates is that the ASD detector protecting the warehouse will signal an alarm after 23.8 seconds.

What is remarkable about the results from the downloaded software model is that the alarm times predicted are based on the theoretical sensitivity of individual sampling holes on a detector that continually adjusts its sensitivity to the background.

However, huge assumptions (and some errors) are made to get this result and the novice user was completely unaware of them. For example:

- while the fire size was specified as $100kW/m^2$ over $1m^2$ (i.e. a 100kW fire) the results shows it over 0.1x0.1m (i.e. only 1kW)
- the fire type – a constant heat release polystyrene fire – was a hidden key assumption.
- while the building dimensions were specified the fact that the surfaces were assumed to be brick was unknown.
- initial temperature conditions were unspecified, no openings were modelled, no airflows were considered (from air handling units etc),
- No objects, additional fire load or fire spread was included in the model. Just an open space with an idealised constant 100kW polystyrene fire with constant soot yield.

Regardless of these model limitations in addition to these assumptions in the fire model, the results generated as presented take no account of the transport time or the cumulative effect which are fundamental to ASD technology. While it is relatively simple to add the transport time to the reported response time of each hole (as recommended), calculating the cumulative effect is more challenging. Fortunately, the most recent release of FDS now includes routines to do this – however, to date they have not been independently tested and verified. What is remarkable about the results from the downloaded software model is that the alarm times predicted are based on the theoretical sensitivity of individual sampling holes on a detector that continually adjusts its sensitivity to the background.

This serves as a good example of how powerful tools in the hands of the unskilled, "unconscious incompetent" is highly undesirable.

Currently, the majority of us in the Fire Industry are still learners in the use of CFD for Fire Engineering so having a driving instructor (or respectable peer) to review any Fire Engineered solution remains imperative. Exactly who is qualified to take the role of the man-with-a-red-flag is not absolutely certain but whoever they are and whatever their qualification, there is no doubt that they have an important role to play to ensure that the unquestionable power of CFD is not abused – intentionally or otherwise. IFP