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A SUGGESTED PROCEDURE FOR BENCHMARKING FIRE FIELD MODELS

A.J. Grandison, E.R. Galea, M.K. Patel and J. Ewer
Fire Safety Engineering Group, University of Greenwich, London, UK

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ABSTRACT

How does an approval authority determine whether a particular fire field model is appropriate to use in fire engineering applications? Currently, there is no objective procedure that assists the approval authority in making such a judgement. The purpose of this paper is to set out and demonstrate a process for evaluating fire field modelling software. The proposed procedure involves two phases. Phase 1 allowed comparison between different computer codes without the bias of the user or specialist features that may exist in one code and not another. Phase 2 allowed the software developer to perform the test using the best modelling features available in the code to best represent the scenario being modelled. A significant conclusion drawn from this work suggests that an engineer using the basic capabilities of any of the products tested would be likely to draw the same conclusions from the results irrespective of which product was used. From a regulator's point of view, this is an important result as it suggests that the quality of the predictions produced are likely to be independent of the tool used – at least in situations where the basic capabilities of the software are used.

1. INTRODUCTION

The Fire Modelling Standards/Benchmark (FMSB) project is an investigation into the feasibility of establishing a set of standards/benchmarks that can be applied to fire field models. The project was led by the University of Greenwich's Fire Safety Engineering Group (FSEG) and funded by the U.K. Home Office Fire Research and Development Group (FRDG, now part of the U.K. Office of the Deputy Prime Minister). As part of this work, a benchmarking procedure was developed along with a set of example test cases. It must be emphasised that it is not the intent of this work to definitively define the entire range of standards/benchmarks but to suggest and demonstrate the principle behind the proposed procedure and to identify, if appropriate, how the process can be improved. Indeed, if a standards/benchmarking procedure of this type is adopted, it is anticipated that the suite of test cases used would evolve over time as suitable new experimental data are made available or as new theoretical cases are developed. This paper represents a summary of the work performed, a full account [1,2] may be found on the FSEG website [3] along with the detailed specification of the test cases.

The ultimate purpose of a fire field model standard/benchmark is to aid the fire safety approvals authority e.g. fire brigade, local government authority, etc. in assessing the appropriateness of using a particular fire field model as part of a performance based engineered solution for a particular application. Currently there are no objective procedures that assist an approval authority in making such a judgement. The approval authority must simply rely on the reputation of the organisation seeking approval and the reputation of the software being used. In discussing this issue it must be clear that while these efforts are aimed at assisting the approval authorities, there are in fact three groups that are involved, the approvals authority, the general user population and the model developers. Ideally, any proposed standard/benchmark should be of benefit to all three groups. Furthermore, in proposing the standards/benchmark, it is not intended that meeting these requirements should be considered a SUFFICIENT condition in the acceptance process, but rather a NECESSARY condition. Finally, the standards/benchmarks proposed here are aimed at questions associated with the software, not with the competence of the software user.

2. PHILOSOPHY OF THE PROPOSED STANDARDS/BENCHMARKS

It is essential to set standards/benchmarks to assess both the Computational Fluid Dynamics (CFD) engine and the fire model component for each type of code. However, within the fire modelling community, testing of fire field models has usually completely ignored the underlying CFD engine and focused on the fire model. Thus, when numerical fire predictions fail to provide good agreement with the benchmark standard, it is not certain if this is due to some underlying weakness in the basic CFD engine, the fire model or the manner in which the problem was set-up (i.e. questions of user expertise). Furthermore, the case that is being used as the benchmark/standard is usually overly complex or cannot be specified to the precise requirements of the modellers. All of this is often to the benefit of the code developer/user as it allows for a multitude of reasons to explain questionable agreement.

Furthermore, what fire modelling testing that is undertaken is usually done in a non-systematic manner, performed by a single individual or group and is generally based around a single model. Thus it is not generally possible for other interested parties to exactly reproduce the presented results (i.e. verify the results) or to apply the same protocol to other models. This makes verification of the results very difficult if not impossible and the comparison of one model with another virtually impossible.

Previous work on guidelines for accessing fire models [4-6] and CFD codes [7,8] are extensive. A full assessment of any CFD based fire model could cover a range of issues including: 1) scientific content, 2) verification and validation, and 3) practical issues, e.g. usability [9]. It is not the intention of this work to address the entire issue of fire model assessment, but to address specific issues associated with the verification and validation of the fire model capabilities. Here the problem of user bias within the verification and validation phase of any assessment process must be addressed.

User bias can come in many forms and include such issues as; tuning of model performance, modelling expertise of the user and user application expertise. While this issue has been reported for CFD [10] and more specifically for fire modelling [11,12], there appears to be little work on accounting for and eliminating user bias from the evaluation of fire models. Comparisons of fire models conducted in the past have suffered to some degree from user bias [12,13]. User bias has been found to produce ambiguous results from Software Products (SPs) not only in comparison with experiment and between other SPs but also by the same SP operated by different users.

Using blind and a priori testing should remove ‘result tuning’ [11] although it does leave open issues of the user in terms of modelling and application expertise. Allowing the software product vendors to evaluate their own software could result in bias due to the possible usage of undocumented features or by addition of extra coding to improve the results. Independent evaluation could lead to bias due to lack of expertise with that software product. Bias can also be introduced when the assessment procedure is conducted by different people whose judgements and assessments of how the problem should be modelled may differ from one another. Different users may interpret the situation to be modelled differently thereby introducing different assumptions into the numerical solution. Even if the same modelling assumptions are made, different users may use different sub-models, grid refinement levels and levels of convergence which can lead to differing results without any certainty as to why the differences were produced. All of these issues have occurred in one form or another in past benchmarking exercises (see for example [12]).

A procedure to reduce, and hopefully eliminate, user bias from the validation and verification of a CFD based fire model is presented in this paper. Comparisons of fire models in the past have done little in the way of checking the basic CFD capabilities of the fire model. However, the CFD capabilities of a CFD based fire model should also be included in any analysis of the fire model to ensure that the fundamental mathematics is functioning correctly, as intended and as reported.

While maintaining the highest level of safety standards is of general interest to each of the three interest groups associated with fire modelling standards/benchmarks, each interest group has a specific reason for requiring a standard/benchmark. In order to maintain safety standards, the approvals authority must be satisfied that appropriate tools have been employed, the user wants to be assured that he is investing in technology that is suited to the intended task, while the developer would like to have a definable minimum target to achieve.

To satisfy the differing requirements of the approvals authority, user and software developer populations, any suite of benchmarks/standards must be both diagnostic and discriminating. Hence, the proposed suite of benchmarks/standards would ideally exercise each of the components of the fire field model i.e. CFD engine and fire model. This means that standards based simply around instrumented room fire tests are insufficient. In addition, benchmarks/standards for simple recirculating flows, buoyant flows, turbulent flows, radiative flows, etc. would also be required.

Ideally, the proposed benchmarks/standards will evolve into a measure of quality, indicating that the fire model has been assessed and deemed to have reached a minimum standard of performance. This does not necessarily mean that the software may be used for any fire application; however it would eliminate from consideration those software products that have not demonstrated that they can attain the standard.

The Software Products (SPs)

Several developers of well known fire field models used in the UK at the time of the study were approached to participate in this project namely, the developers of JASMINE, SOFIE, CFX, PHOENICS and SMARTFIRE (SMF). Three code developers agreed to participate in the first phase. These were the general purpose CFD codes, CFX 4.2 [14] and PHOENICS 3.1 [15] and the specific fire field model, SMARTFIRE v2.01 b389D [16]. Note that since this project was completed, the CFX code's parent organisation changed from AEA to ANSYS. Also, in viewing the results of these benchmark tests it must be emphasised that the tests were performed several years ago using now superseded versions of each of the software products. Since the trials were completed, each product has undergone significant development.

Benchmark Task Group (BTG)

Representatives from the organisations responsible for the identified software products (SP) constitute the Benchmark Task Group (BTG). In addition, the BTG consisted of one independent user of fire field models drawn from the user community (Arup Fire) and a representative from the FRDG. The role of the BTG was to review the proposed benchmarks and specified solution procedures and to review the final results.

3. BENCHMARK PROCEDURES

The benchmarks were divided into two categories, basic CFD and fire. Two types of simulation were performed by each SP being subjected to the benchmarks; these were known as Phase 1 and Phase 2 simulations. There were 10 Phase 1 benchmark simulations, five basic CFD cases and five fire cases (see section 3.1). The nature of the Phase 1 simulations was rigidly defined by FSEG under review by the BTG, this included the mesh specification, time step size, physics to be activated, algorithms to be employed and results to be generated. This was to ensure that the setup for all SPs would be identical or as similar as possible. Where possible, the specification of Phase 1 simulations has been such that all of the SPs participating in the trial were able to achieve the specification.

The case specification was laid out in a detailed pro-forma that gave all the details necessary to model the problem in the rigid manner required for the Phase 1 simulations [1-3]. This was achieved by using the same constants in the turbulence and combustion models for all the SPs. In all the fire cases all the walls were modelled as adiabatic and perfect radiative reflectors, the gases were assumed to have a constant radiation absorption coefficient. All the SPs used identical meshes. The same time step sizes were used and the same differencing schemes were used. It is acknowledged that this process will not necessarily produce optimal results for all of the SPs. This process would also eliminate result tuning/bias as the set up cannot deviate from this rigid specification. In most other benchmarking exercises the users were free to define the model set up which leads to the introduction of user bias.

The Phase 1 simulations were completed before proceeding to the Phase 2 simulations. The Phase 2 simulations were free format in nature, allowing the participants to repeat the simulation using whatever specification they desired. Phase 2 simulations allowed the participants to demonstrate the full capabilities of their SP. However, Phase 2 simulations were only allowed to utilise features that are available within their software product i.e. additional code or external routines were not permitted. All participants had to complete a similar pro-forma that has been supplied for the Phase 1 simulations for their Phase 2 simulations [1-3]. This was necessary, as FSEG would repeat the Phase 2 simulations in order to independently verify the results.

FSEG ran each Phase 1 simulation with each SP. The participants were requested to run at least two of the 10 Phase 1 simulations using their SP. Participants were free to choose which of two simulations to run, however these must have included at least one from the CFD category and one from the fire category. Participants were of course free to run all 10 of the Phase 1 simulations. It was imperative that the participants did not inform FSEG which of the Phase 1 simulation they ran. It should be remembered that the purpose of repeating the simulations was to ensure that FSEG have not fabricated results or incorrectly used a SP.

3.1 The Benchmark Cases

As a first attempt at defining the benchmarks, 10 cases were considered, these involved five simple CFD cases and five fire cases. The cases were defined as follows:

Simple CFD cases:

2000/1/1 – Two dimensional turbulent flow over a backward facing step [17].
2000/1/2 – Turbulent flow along a long duct.
2000/1/3 – Symmetry boundary condition.
2000/1/4 – Turbulent buoyancy flow in a cavity [18].

2000/1/5 – Radiation in a three-dimensional cavity [19].

Fire cases:
2000/2/1 – Steckler's Room (heat source) [20].
2000/2/2 – Steckler's Room (combustion model).
2000/2/3 – Fire in a completely open compartment with lid (heat source).
2000/2/4 – CIB W14 fire (combustion model) [12].
2000/2/5 – LPC007 fire (combustion model) [21].

Full details of these cases can be found in the various reports [1,2] and the detailed specification for the test cases can be found on the FSEG website [3].

4. OVERVIEW OF THE RESULTS

It is not possible to present all the results from all the tests in this paper. This section contains some example results from both the Phase 1 and Phase 2 tests. The full results and full setup details are described by Grandison et al [1,2] and can also be found on the FSEG web site [3].

In studying the results generated in this project, it is important to note the following points:

- The results generated and comments made only refer to the software actually used in the trials. This should not simply be taken to mean the product name but also the release number and version number of the software. Furthermore, the tests were undertaken several years ago and since testing, each product has undergone significant development.
- The Phase 1 results are not intended to represent mesh independent solutions. They are intended to represent converged solutions on "reasonable" meshes. In each test case, the same computational mesh is used by each software product. Phase 2 simulations can be used to explore simulations performed using finer meshes.
- The Phase 1 results do not make use of the most sophisticated physics available in each of the software products. A base line set of characteristics has been set that allow a fair comparison between the codes. Where model predictions are compared with experimental data, these predictions can be improved through the use of more sophisticated physical sub-models. Phase 2 simulations can be used to explore the benefits of using more sophisticated physics.
- Only the SMARTFIRE SP participated in Phase 2. The two other original participants were unable to respond within the timescales required for Phase 2.
- Only three test cases were selected for Phase 2, these were the radiation test case 2000/1/5, the Steckler room fire case 2000/2/1 and the LPC fire case 2000/2/5.
- While the Phase 1 simulations did not make use of the most sophisticated physics models available in each of the SPs, the Phase 2 simulations are intended to explore the benefits of using more sophisticated physics models and finer computational meshes.
- The series of trials undertaken in this project should not be considered to be definitive. They have been selected as a basis for exploring the potential of the benchmarking process. It is intended that additional tests should be added to the suite of test cases.

The most obvious difference between the SPs is that PHOENICS uses a staggered velocity mesh whereas SMARTFIRE and CFX use a co-located velocity mesh by means of Rhie and Chow interpolation [22] and while SMARTFIRE and PHOENICS make use of a six-flux radiation model [15,16], CFX uses a discrete transfer radiation model [14,23].

4.1 The CFD Benchmark Results

In studying the outcome of the Phase 1 test cases, it is clear that when identical physics is activated, identical computational meshes used and similar convergence criteria applied, all of the software products tested are capable of generating similar results. This is an important observation and suggests – that within the limitations of the tests undertaken – that these three codes have a similar basic capability and are capable of achieving a similar basic predictive standard.

The results from the CFD test cases are consistent with the view that the basic underlying physics implemented within the codes are similar and are capable of producing similar representations of the physical phenomena modelled (e.g. see Fig. 1). In addition, where experimental results or theoretical solutions are available, the software products have produced reasonable agreement with these results [1], the vast majority of the results differed by less than 10%. It can be seen from Fig. 1 that the local maxima/minima predicted by all the models were within 15% of the experimental value. No doubt, it could be argued that improved agreement could be achieved if the spatial mesh and time stepping are improved. This potentially could have been demonstrated in the Phase 2 simulations.

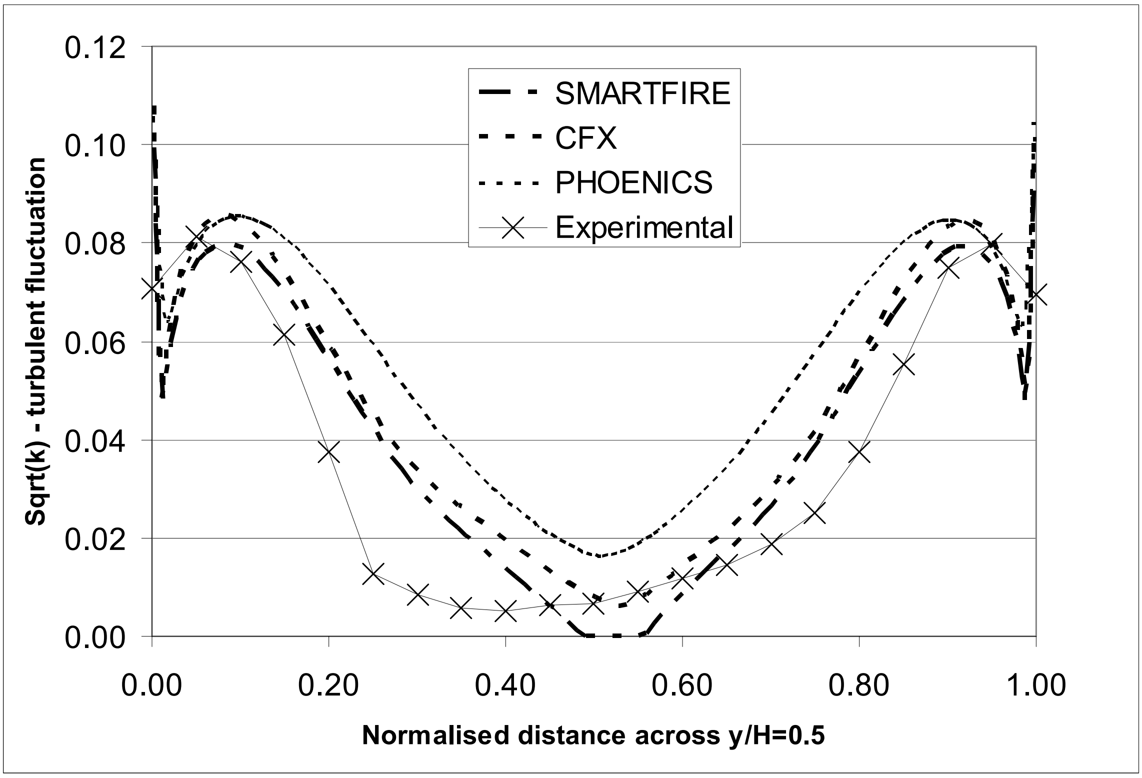

Fig. 1: Result from Phase 1 for case 2000/1/4, turbulent fluctuations vs displacement

The one area that showed relatively poor agreement with theoretical results concerned the radiation model performance (i.e. case 2000/1/5). The six-flux radiation model used by SMARTFIRE [16] and PHOENICS [15] produced very similar results however, they displayed significant differences to the theoretical zone results (e.g. see Fig. 2) [19]. While the six-flux model appears capable of representing the average trends within the compartment, it does not produce an accurate representation of local conditions. The CFX radiation model when used with a single ray (the closest approximation to the six-flux model possible but not mathematically equivalent) displays a more significant weakness and severely under-predicts the emissive power in the cavity. It should however be noted that the producers of CFX do not recommend that the discrete transfer radiation model be used with so few rays. The radiation model used by CFX is inherently a more sophisticated model than the six-flux model and is capable of utilising significantly more rays.

It should be recalled that the purpose of the Phase 1 test cases was to compare the performance of the various codes when similar physics capabilities were utilised in all three codes. It should however be noted here that when 12 rays are used in the CFX radiation model, it produces very good agreement with the theoretical results. It is clear from these results that users should be aware of the limitations of the six-flux model when performing fire simulations. The six-flux radiation model while capable of representing the average trends within the compartment does not produce an accurate representation of local conditions. Situations that are strongly radiation driven, such as the prediction of flame spread over solid surfaces and structural response to fire should be treated with care. When using the six-flux model, it is possible that target fuel surfaces would not be preheated by radiation or would receive more radiation than expected and therefore leads to great inaccuracy in a flame spread process.

The Phase 2 predictions for the radiation test case (2000/1/5) using the SMARTFIRE multi-ray radiation model [24,25] with 24 rays, showed considerable improvement over the results generated in Phase 1 (see Fig. 3). The results from this simulation indicate the greater inherent accuracy that the multi-ray radiation model has over the simpler six-flux model. It is important to note that the greater degree of accuracy offered by the multi-ray model may not manifest itself in producing more accurate fire predictions. Whether or not the multi-ray radiation model will make a significant difference in a fire simulation depends on the nature of the case being examined.

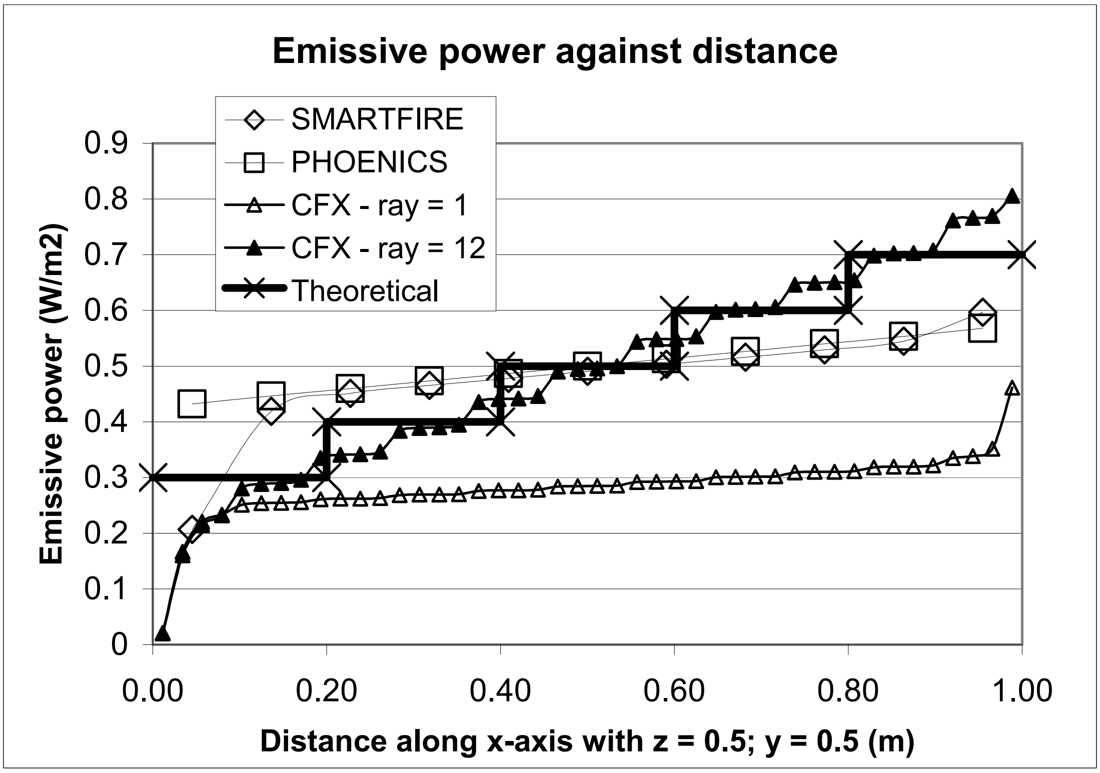

Fig. 2: Results from Phase 1 for 2000/1/5 showing radiative emissive power against distance

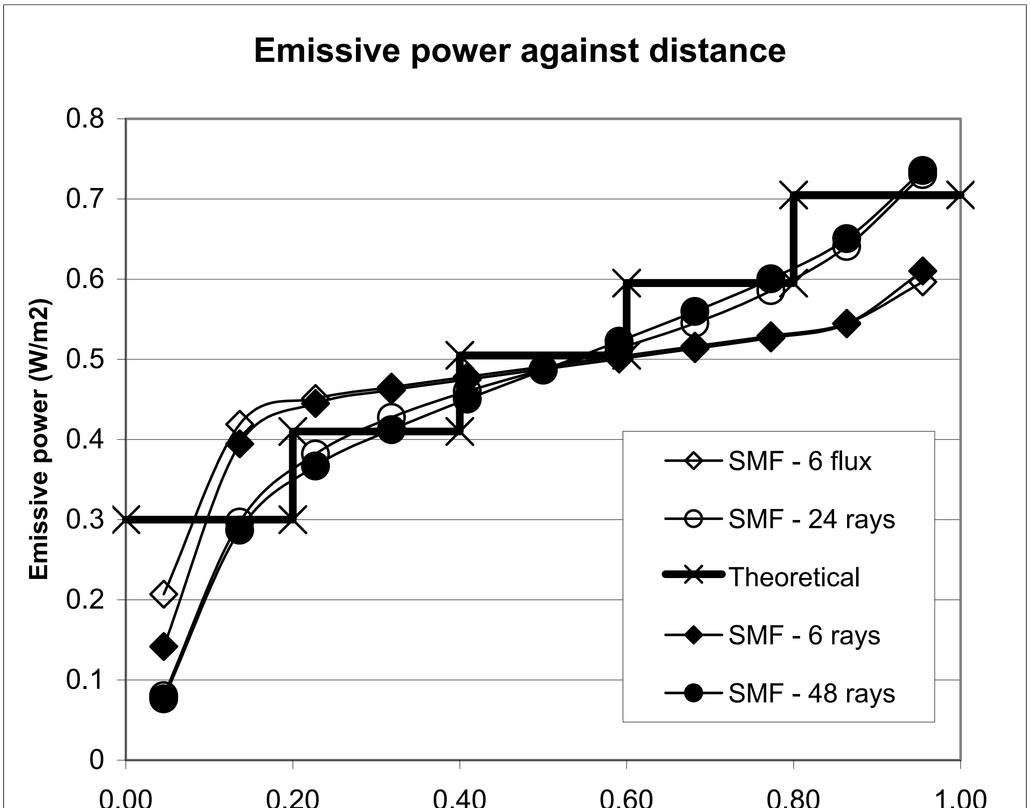

Fig. 3: Results from Phase 2 for 2000/1/5 showing emissive power against distance

4.2 The Fire Benchmark Results

The fire cases were intended to provide a more challenging series of tests. Unlike the simple CFD test cases, the fire cases make use of a range of CFD capability. Furthermore, they focus attention on the software's capability within the specific domain of interest i.e. fire modelling.

The first two fire cases consisted of the small non-spreading fire within the small ventilated compartment modelled using either a heat source or a gaseous combustion model (i.e. cases 2000/2/1 and 2000/2/2). For these cases, all the software products appear to produce a good representation of the measured temperature distribution within the compartment and velocity profile within the doorway. Furthermore, there are insignificant differences between the temperatures predicted by heat source model (unfilled symbols in Fig. 4) and gaseous combustion model (filled symbols in Fig. 4 with –C added to SP name). However, all the software products appear to over-predict the hot layer temperature (see Fig. 4). This over-prediction was due to the simple specification of the conditions required in Phase 1 which included the use of adiabatic walls.

The SMARTFIRE Phase 2 simulations, see Fig. 5, for this case consisted of the following cases:

1) Phase 1 results for 2000/2/1 (using a simple volumetric heat release rate model) – identified as SMF – phase - 1 in Fig. 5.
2) As (1) with improved physical properties and improved boundary conditions – identified as SMF – (2) in Fig. 5. The radiation absorption coefficient is now a more accurate function of temperature. The thermal properties; heat capacity, density, and thermal conductivity of the wall are included in the calculation. The wall emissivity is assumed to be 0.8.
3) As (2) with the multi-ray radiation model with 24 rays replacing the six-flux radiation model – identified as SMF – (3) in Fig. 5.
4) As (2) with refined mesh and taking advantage of symmetry – identified as SMF – (4) in Fig. 5.

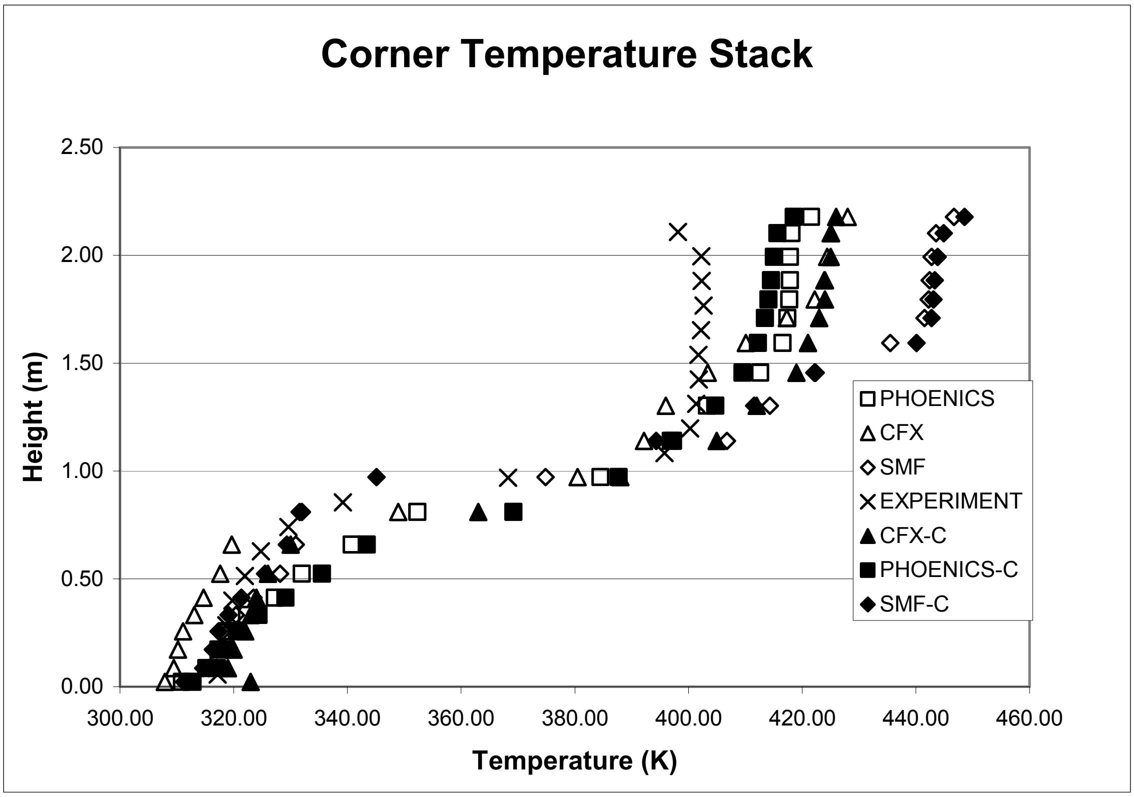

Fig. 4: Results from Phase 2 for 2000/2/1-2 showing corner stack temperatures within compartment

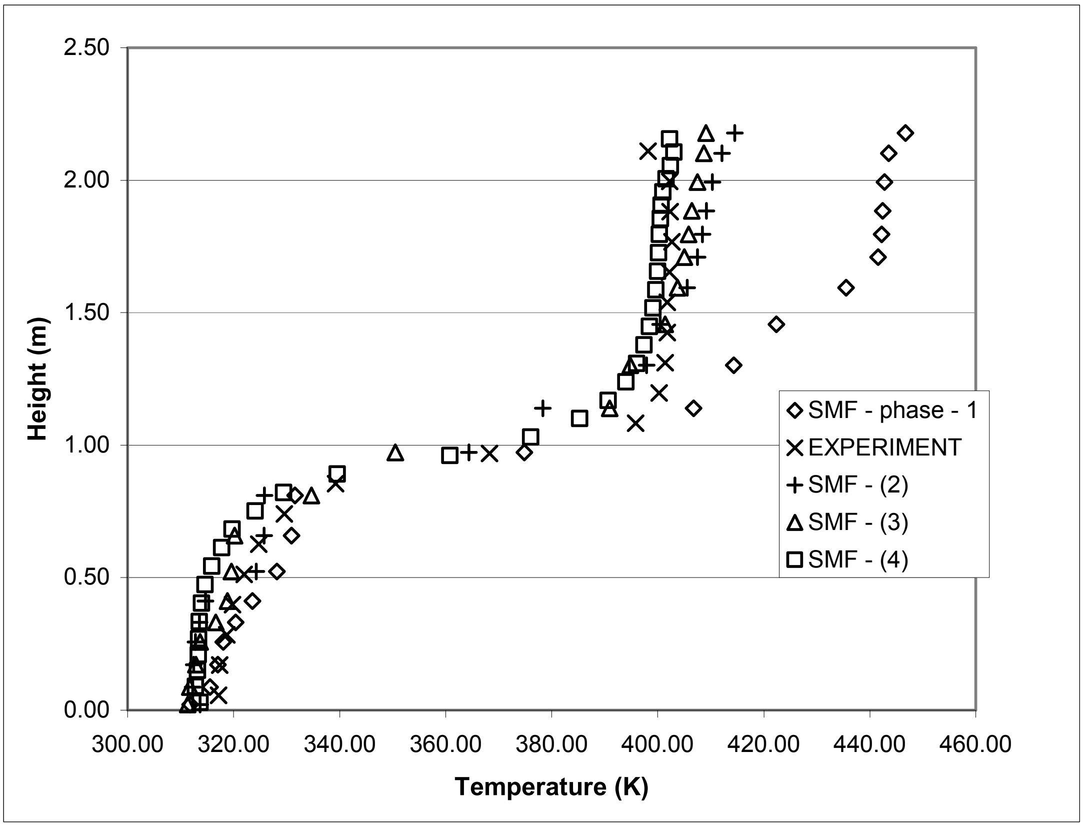

Fig. 5: Results for SMARTFIRE (SMF) from Phase 2 for 2000/2/1 showing corner stack temperatures produced using improved physics representation and refined mesh

All the cases were run for 200 seconds of simulated time using 200 time steps of 1 second at which point steady state conditions are achieved. In cases (1), (2) and (3), the same computational mesh is used as that in the Phase 1 calculations (i.e. 13,020 (31 × 20 × 21) cells). In case (4), the computational mesh was refined to consist of 49,980 (49 × 34 × 30) cells; it must also be remembered that only half the domain is modelled as symmetry is used which produces an equivalent cell budget of 99,960 (49 × 43 × 60) cells.

The results for Phase 2 [2] showed that considerable improvement could be achieved by a more sophisticated treatment of the wall boundary conditions and more accurately representing the material properties. While further improvement could be achieved through the use of the multi-ray model and mesh refinement, these were insignificant in comparison (see Fig. 5).

Examining the hot layer temperature shows considerable improvement over the phase 1 predictions, SMF-1, for the phase 2 predictions as shown in Table 1 below.

The third fire case (i.e. case 2000/2/3) consisted of a fire – represented by a prescribed heat release rate – centrally located in a completely open compartment (i.e. without confining walls but with a ceiling). While there were no experimental results for comparison purposes, it was clear that all three software products produced near identical results for Phase 1 testing. The maximum difference in peak temperature was less than 8%.

Table 1: Hot Layer temperatures for Phase 2 SMARTFIRE (SMF) testing

	Experiment	SMF-1	SMF-2	SMF-3	SMF-4
Temperature	401	442	408	406	400
%diff with experiment	n/a	42%	7%	5%	1%

The fourth fire case (i.e. case 2000/2/4) consisted of a large fire in a medium sized compartment which was well ventilated. The fire was modelled using a prescribed mass release rate in conjunction with a gaseous combustion model. Here again all three software products produced good agreement when compared with each other. However, towards the end of the simulation period, there was a significant difference between the predicted and measured temperatures. This is thought to be due to problems with the experimentally determined heat release rates. Had time permitted, it would have been interesting to continue the numerical predictions for a longer period of time to compare the maximum temperatures produced by the various codes.

The fifth fire case (i.e. case 2000/2/5) consisted of a large fire in a small sized compartment which was under ventilated. The fire was modelled using a gaseous combustion model. Here again all three software products produced good agreement when compared with each other in the early phases of the fire development. However, towards the end of the simulation period, there was a significant difference between the predicted and measured temperatures and between the predictions produced by the various software products (see Fig. 6). The suffix –H in Fig. 6 indicates a high thermocouple location, 3.0 m above the floor, and the suffix –L indicates a low thermocouple location, 1.5 m above the floor. These thermocouples were located in the corner of the compartment away from the fire. The differences between the predictions and the measured values were thought to be primarily due to the simplicity of the boundary conditions imposed on the calculations resulting in very high temperatures being generated within the compartment.

It is also worth noting that all the simulations had to be prematurely stopped due to convergence difficulties. Although there is little value in displaying these results in terms of experimental comparison, it was important to carry through the procedure for all the SPs to see if any performed significantly differently to the other SPs. In the Phase 2 simulations, the wall boundary conditions were more accurately modelled, better physical properties were used and the SMARTFIRE multi-ray radiation model was used. In total two additional simulations were performed. The mesh used for the Phase 2 cases was identical to that used in Phase 1. The Phase 2 simulations were run using 180 x 5-second time steps to give an overall simulation time of 900 s.

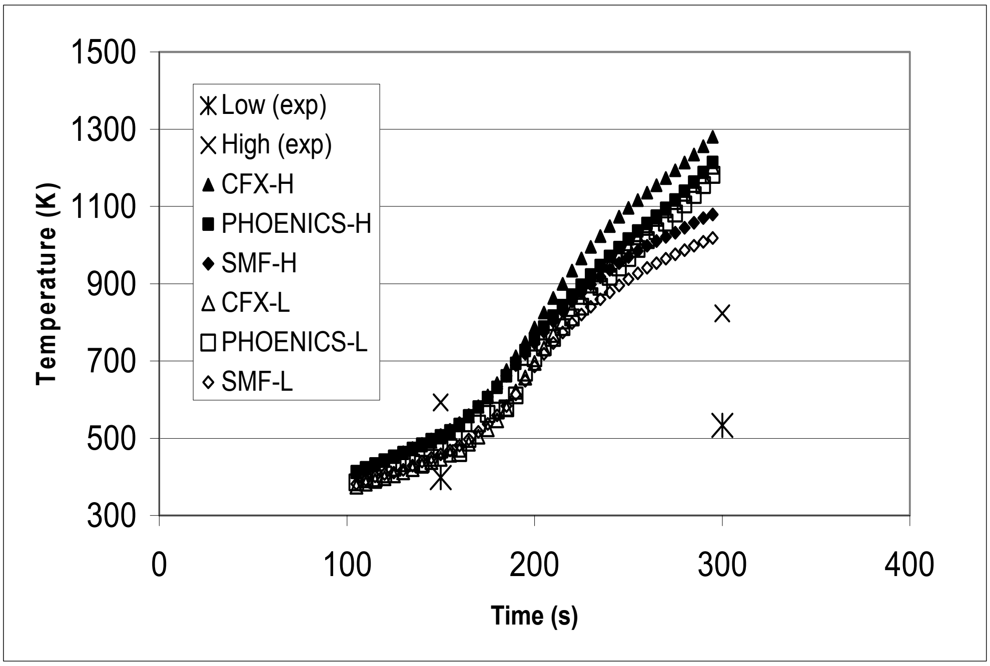

Fig. 6: Results from Phase 1 for 2000/2/5 showing corner stack temperatures produced using the various SPs and the experimental results (exp) at the High and Low measuring locations

The first of the Phase 2 cases involved the following configuration. The boundary conditions were modelled more accurately using heat-conducting walls that took into account the physical properties of the wall (asbestos). The properties of the floor (concrete) and the steel obstruction were also taken into account. The wall emissivity was assumed to be 0.8. The model made use of turbulent (log-law) momentum and heat transfer at the walls (See [16] for details). The second Phase 2 simulation was identical to the first with the exception that the SMARTFIRE multi-ray model with 24 rays (identified as SMF-MR in Fig. 7) replaced the six-flux radiation model.

In the Phase 2 simulations, it was possible to generate converged solutions for the entire duration of the experiment. While differences between the numerical predictions and measured values persisted, the numerical predictions were able to reproduce most of the observed trends in the experimental results (see Fig. 7).

Both of the Phase 2 cases over-predict the experimental values with the results generated using the multi-ray model being slightly closer to the measured results. Differences between the multi-ray model and the experimental results for the high measuring location are as high as 30%, while for the low measuring location, the error is as high as 63% (see Fig. 8). For the six-flux model, the maximum errors are 31% and 71% respectively. The experimental trends in the upper temperatures are reproduced well by the numerical predictions. These temperatures tend to increase until about 300 seconds into the fire and then remain approximately constant. The numerical predictions follow this trend but the peak is reached at approximately 425 seconds. The experimental trends in the lower temperatures show a continual increase over the entire duration of the experiment. However, the numerical predictions for the lower temperatures follow those of the upper temperatures.

The noted over-prediction could be due to inaccuracies in the experimental data and deficiencies in the model assumptions such as assuming a constant wall emissivity of 0.8.

The results from all the fire cases support the conclusions drawn from the CFD test cases. While there are minor differences between the results produced by each of the software products; on the whole they produce – for practical engineering considerations – identical results.

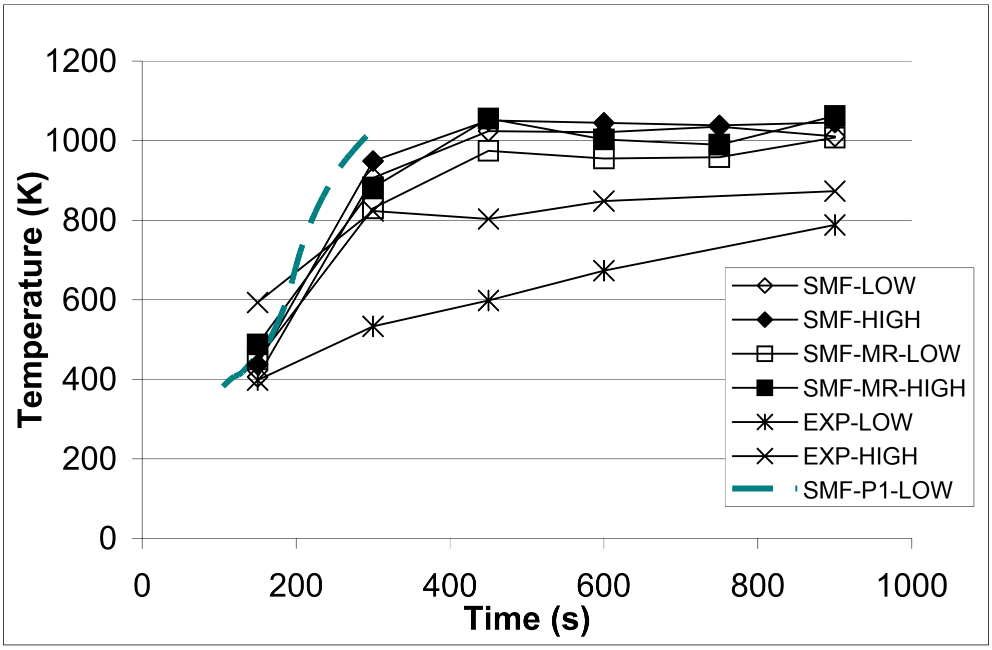

Fig. 7: Results from Phase 2 for 2000/2/5 showing corner stack temperatures produced using the two SMARTFIRE configurations and the experimental results (exp) at the High and Low measuring locations

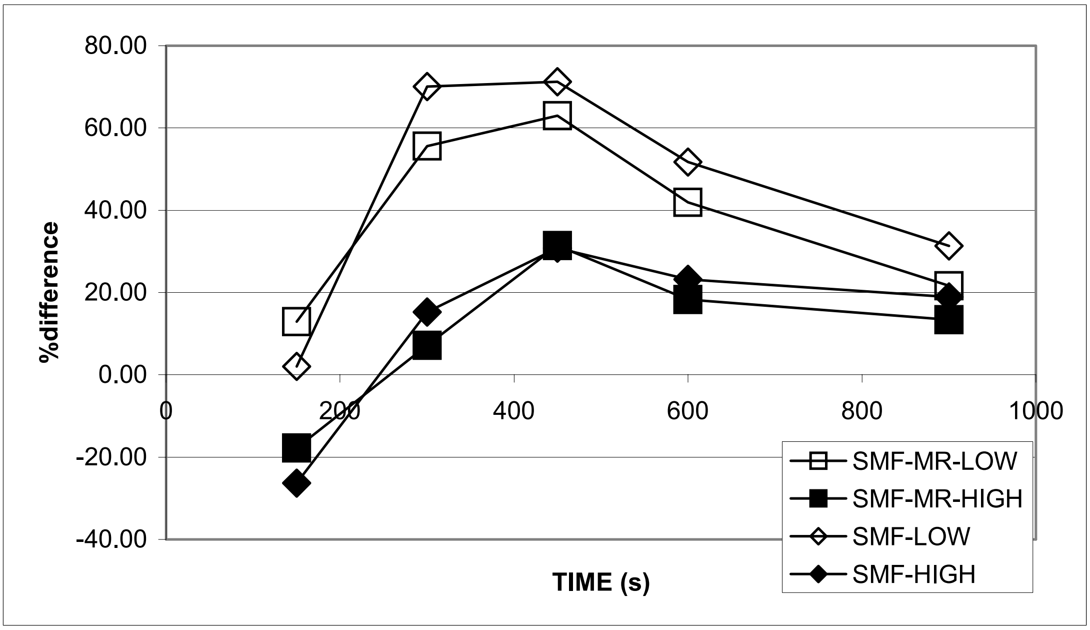

Fig. 8: Difference with experimental results (%) in the SMARTFIRE predictions using the six-flux model for the corner stack in test case 2000/2/5

4.3 Findings Concerning the Proposed Methodology

This work has highlighted several areas in which improvements can be made to both the procedures used and the test cases examined. A modification to the testing procedures is suggested that would reduce the burden and cost of performing the testing by the test organisation or BTG. While all of the test cases using all of the codes were run by a single organisation – in this case FSEG – the code developers also were requested to run an independent selection of the test cases as specified.

This was necessary to verify that the results produced in this exercise are a true and fair representation of the capabilities of the various software products under the specified test conditions. This has proven to be quite useful as it brings the developers into the benchmarking process and it eliminates issues concerning fairness and biased reporting of results. However, if this process is to become a standard requirement, the testing organisation will have a considerable amount of work to do if it is to run every software product and its various upgrades through each of the test cases. In order to reduce the cost of testing, it is suggested that the roles of the BTG and model developers should be reversed, with the BTG performing the random testing and the software developers running and submitting all of the test cases. As part of this process, it is intended that the test cases would still be specified at a high level by the BTG however, the test case input files should then be set up and eventually run by each of the participating SP developers. Each of the input files should also be checked by the BTG to ensure that they conform to the standards of the benchmark. While this process places pressure on the participating software producer to generate the input files and run the cases, if the benchmarking procedure becomes an accepted standard, code vendors will be prepared to participate at this level.

With regard to the benchmark cases utilised in the current procedure, several improvements can be suggested for the fire cases. Fire case 2000/2/4 was run for 10 minutes of simulation time. Although all the SPs exhibit the same growing trend and similar temperatures, it would be useful to run the case for a longer time period. This could be compared with the experimental results in order to determine the differences between maximum predicted and maximum measured temperatures. Fire case 2000/2/5 proved difficult to obtain converged predictions due to the artificial nature of the boundary conditions utilised in Phase 1. This case is also complicated as flashover occurs and the fire becomes ventilation controlled. While it is necessary in Phase 1 to select a set of “simple” boundary conditions that can be represented by most SPs, another choice of boundary conditions would be appropriate. For example, it is possible to run this case with a fixed wall temperature with unit emissivity. It must however be noted that these boundary conditions are just as unrealistic as the adiabatic boundary conditions used in Phase 1.

However, this would have the effect of artificially removing a large amount of heat from the compartment and may allow the simulation to run for longer.

There is also the obvious need for additional test cases to further benchmark the SPs. This need must be balanced against the work that would be involved in carrying out these exercises. In particular, additional fire cases based on well defined experiments are needed. One possible candidate case by Isaksson et al. [26] gives experimental data and simulation data from JASMINE and SOFIE for a fire in a room with a perforated suspended ceiling. Another possible source of good experimental data concerns a room fire trial conducted by Neilson [27].

In addition, once a version of a SP is entered into the benchmarking process, all the test cases must be run with that version of the software. If another release version of the SP is produced, this will need to go through the benchmark process in its entirety. Therefore, a mix and match process in which different versions of a code are used in order to improve the level of agreement should not be permitted.

5. CONCLUDING COMMENTS

In studying the outcome of the benchmark test cases, it is clear that when identical physics is activated, identical computational meshes used and similar convergence criteria applied, all of the SPs tested are capable of generating similar results. This is an important observation and suggests, that within the limitations of the tests undertaken, that these three codes have a similar basic capability and are capable of achieving a similar basic standard.

The results from the CFD test cases are consistent with the view that the basic underlying physics implemented within the codes tested are similar and provide a good representation of reality. This should come as no surprise as all three software products purport to model fluid dynamics processes using similar techniques. However, from a regulatory viewpoint, it is reassuring to have an independent verification of this similarity. In addition, where experimental results or theoretical solutions are available, the software products have produced reasonable agreement with these results. No doubt, it could be argued that improved agreement could be achieved if the spatial mesh and time stepping are improved. This was indeed demonstrated in the Phase 2 simulations. While this may seem an intuitively obvious result, it is a necessary demonstration of the capability of the fire modelling tool that this can be done in a measurable and reproducible manner.

The results from the fire cases support the conclusions drawn from the CFD test cases. While there are differences between the results produced by each of the software products; on the whole they produce, for practical engineering considerations, identical results.

A significant, and somewhat reassuring, conclusion to draw from these results is that an engineer using the basic capabilities of any of the three software products tested would be likely to draw the same conclusions from the results generated irrespective of which product was used. From a regulators view, this is an important result as it suggests that the quality of the predictions produced are likely to be independent of the tool used, at least in situations where the basic capabilities of the software are used. A second significant conclusion is that within the limits of the test cases examined and taking into consideration experimental inconsistencies and errors, all three software products are capable of producing reasonable engineering approximations to the experimental data, both for the simple CFD and fire cases.

The concept of the testing protocols has been shown to be a useful tool in providing a verifiable method of benchmarking and gauging both the basic and advanced capabilities of CFD based fire models on a level playing field. To further improve the capabilities of the approach, it is recommended that additional test cases in the two categories be developed, several of the fire cases be refined and that the benchmarking process be adapted to place the main emphasis on the SP developer.

Finally, in viewing the results of these benchmark tests it must be emphasised that the tests were performed several years ago using now superseded versions of each of the software products. Since each product was tested, each product has undergone significant development.

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