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EXCERPTS

Fire Dynamics Simulator (Version 5)
Technical Reference Guide
Volume 3: Validation

Volume 3 of the Technical Reference Guide to Version 5 of the Fire Dynamics Simulator (FDS) was released on August 4, 2008. The following are excerpts from Volume 3:

> “*The three volumes of the FDS Technical Reference Guide are based in part on the “Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models,” ASTM E 1355 [2]. ASTM E 1355 defines model evaluation as “the process of quantifying the accuracy of chosen results from a model when applied for a specific use.” The model evaluation process consists of two main components: verification and validation. Verification is a process to check the correctness of the solution of the governing equations.*” (Page *i*)

> “*Verification does not imply that the governing equations are appropriate; only that the equations are being solved correctly. Validation is a process to determine the appropriateness of the governing equations as a mathematical model of the physical phenomena of interest. Typically, validation involves comparing model results with experimental measurement. Differences that cannot be explained in terms of numerical errors in the model or uncertainty in the measurements are attributed to the assumptions and simplifications of the physical model.*” (Page *i*)

> “*Evaluation is critical to establishing both the acceptable uses and limitations of a model. Throughout its development, FDS has undergone various forms of evaluation, both at NIST and beyond. This volume provides a survey of validation work conducted to date to evaluate FDS.*” (Page *i*)

> “*Thanks to Jerry Back, Craig Beyler and Phil DiNenno of Hughes Associates and Pat Tatem of the Naval Research Laboratory for their contribution of experimental data for the “HAI/ NRLWall Fire” series. Thanks also to Craig Beyler for assistance with the data for the “Beyler Hood Experiments.’*” (Page *v*)

“*Validation typically involves (1) comparing model predictions with experimental measurements, (2) quantifying the differences in light of uncertainties in both the measurements and the model inputs, and (3) deciding if the model is appropriate for the given application. This Guide only does (1) and (2). Number (3) is the responsibility of the model user.*” (Page 1)

“*Although the FDS developers continuously perform validation studies, it is ultimately the end user of the model who decides if the model is adequate for the job at hand. Thus, this Guide provides the raw material for a validation study, but it does not and cannot be considered comprehensive.*” (Page 1)

“*The following sections discuss key issues that you must consider when deciding whether or not FDS has been validated. It depends on (a) the scenarios of interest, (b) the predicted quantities, and (c) the desired level of accuracy. Keep in mind that FDS can be used to model most any fire scenario and predict almost any quantity of interest, but the prediction may not be accurate because of limitations in the description of the fire physics, and also because of limited information about the fuels, geometry, and so on.*” (Page 1)

“*When doing a validation study, the first question to ask is, “What is the application?”*” (Page 1)

“*Validation studies of FDS to date have focused more on design applications than reconstructions. The reason is that design applications usually involve specified fires and demand a minimum of thermophysical properties of real materials. Transport of smoke and heat is the primary focus, and measurements can be limited to well-placed thermocouples, a few heat flux gauges, gas samplers, etc. Phenomena of importance in forensic reconstructions, like second item ignition, flame spread, vitiation effects and extinction, are more difficult to model and more difficult to study with well-controlled experiments. Uncertainties in material properties and measurements, as well as simplifying assumptions in the model, often force the comparison between model and measurement to be qualitative at best. Nevertheless, current validation efforts are moving in the direction of these more difficult issues.*” (Page 2)

“*Keep in mind that for any fire experiment, FDS might predict a particular quantity accurately (within the experimental uncertainty bounds, for example), but another quantity less accurately. For example, in the a series of 15 full-scale fire experiments conducted at NIST in 2003, sponsored by the U.S. Nuclear Regulatory Commission, the average hot gas layer (HGL) temperature predictions were within the accuracy of the experiments themselves, yet the smoke concentration predictions differed from the measurements by as much as a factor of 3.*” (Page 2)

"*Model error tends to be reduced by the averaging process, plus most fire models, including FDS, are based on global mass and energy conservation laws that are expressed as spatial averages.*" (Page 2)

"*The desired accuracy for each predicted quantity depends on the technical issues associated with the analysis. You must ask the question: How accurate does the analysis have to be to answer the technical question posed? Returning to the earlier definitions of "design" and "reconstruction," design applications typically are more accurate because the heat release rate is typically specified rather than predicted, and the initial and boundary conditions are better characterized – at least in the analysis. Mathematically, a design calculation is an example of a "well-posed" problem in which the solution of the governing equations is advanced in time starting from a known set of initial conditions and constrained by a known set of boundary conditions. The accuracy of the results is a function of the fidelity of the numerical solution, which is mainly dependent on the size of the computational grid.*" (Page 3)

"*If you are embarking on a validation study, you might want to consider the following steps:*

1. *Survey Chapter 2 to learn about past efforts by others to validate the model for applications similar to yours*
2. *Identify in Chapter 3 experimental data sets appropriate for your application*
3. *Read the specific chapters for the quantities of interest*"

(Page 3)

"*More recently, validation efforts have moved beyond just transport issues to consider fire growth, flame spread, suppression, sprinkler/detector activation, and other fire-specific phenomena.*" (Page 6)

"*Formal, rigorous validation exercises are time-consuming and expensive. Most validation exercises are done simply to assess if the model can be used for a very specific purpose. While not comprehensive on their own, these studies collectively constitute a valuable assessment of the model.*" (Page 6)

"*Experiments conducted solely for model validation are somewhat rare. More common are validation studies that use data from past experiments.*" (Page 7)

"*In a follow-up report, Vettori [47] extended his study to include sloped ceilings, with and without obstructions. He found that the difference between predicted and measured sprinkler activation times varied between 4 % and 26 % for all cases studied. He also noted that FDS was able to predict the first activation of a sprinkler twice as far from the fire as another; caused presumably by the re-direction of smoke by the beams on the ceiling.*" (Page 9)

"*Although FDS simulations have been compared to actual and experimental large-scale fires, it is difficult to quantify the accuracy because of the uncertainty associated with material properties. Most quantified validation work associated with flame spread have been for small, laminar flames with length scales ranging from millimeters to a few centimeters.*" (Page 10)

"*For real wood products, it is unlikely that all of the necessary properties can be obtained easily. Thus, grid sensitivity and uncertain material properties make blind predictions of fire growth on real materials beyond the reach of the current version of the model. However, the model can still be used for a qualitative assessment of fire behavior as long as the uncertainty in the flame spread rate is recognized.*" (Page 10)

"*A significant validation effort for sprinkler activation and suppression was a project entitled the International Fire Sprinkler, Smoke and Heat Vent, Draft Curtain Fire Test Project organized by the National Fire Protection Research Foundation [60]. Thirty-nine large scale fire tests were conducted at Underwriters Laboratories in Northbrook, IL. The tests were aimed at evaluating the performance of various fire protection systems in large buildings with flat ceilings, like warehouses and "big box" retail stores.*" (Page 10)

"*However, five experiments were performed with 6 m high racks containing the Factory Mutual Standard Plastic Commodity, or Group A Plastic. To model these fires, bench scale experiments were performed to characterize the burning behavior of the commodity, and larger test fires provided validation data with which to test the model predictions of the burning rate and flame spread behavior [61, 62]. Two to four tier configurations were evaluated. For the period of time prior to application of water, the simulated heat release rate was within 20 % of the experimental heat release rates. It should be noted that the model was very sensitive to the thermal parameters and the numerical grid when used to model the fire growth in the piled commodity tests.*" (Page 10)

"*The scope of the VTT work is considerable. Assessing the accuracy of the model must be done on a case by case basis. In some cases, predictions of the burning rate of the material were based solely on its fundamental properties, as in the heptane pool fire simulations. In other cases, some properties of the material are unknown, as in the spruce timber simulations. Thus, some of the simulations are true predictions, some are calibrations. The intent of the authors was to provide guidance to engineers using the model as to appropriate grid sizes and material properties. In many cases, the numerical grid was made fairly coarse to account for the fact that in practice, FDS is used to model large spaces of which the fuel may only comprise a small fraction.*" (Page 13)

"*The FDS results that best replicated the observed fire behavior indicated that the opening of the basement sliding glass door provided oxygen to a pre-heated, underventilated fire. Flashover was estimated to occur in less than 60 s following the entry of fire fighters into the basement. The resulting fire gases flowed up the basement stairs and moved across the living room ceiling towards the back wall of the townhouse. These hot gases came in direct contact with the fire fighters who were killed. The hot gases traversed the townhouse in less than 2 s, giving the fire fighters little time to respond. The model showed that the oxygen level was too low to support flaming and, therefore, the fire fighters did not have a visual cue of the thermal conditions until it was too late.*" (Page 14)

"*However, in order to assess the accuracy of FDS, there must be some estimate of the combined effect of the uncertainty in the reported input parameters, like the heat release rate of the fire, and the reported measurement of the quantity of interest, like the hot gas layer (HGL) temperature.*" (Page 28)

"*A summary scatter plot of the HGL predictions is given in Fig. 4.1. Most of the predictions fall within the experimental uncertainty bounds. Note, however, that both of these quantities represent spatial averages. At any given point in the compartment, a specific prediction of temperature may not fall within the uncertainty bounds. Point to point comparisons of temperature can be found in the chapters for plumes and ceiling jets.*" (Page 46)

"*Nevertheless, temperature measurements near the ceiling can be used to evaluate the model's ability to predict the flow of hot gases across a relatively flat ceiling.*" (Page 57)

> “*The thermocouple nearest the ceiling in Tree 7, located towards the back of the compartment, has been chosen as a surrogate for the ceiling jet temperature. Curiously, the difference between measured and predicted temperatures is noticeably greater for the open door tests. Certainly, the open door changes the flow pattern of the exhaust gases. However, the predicted HGL heights for the open door tests, shown in the previous section, do not show a noticeable difference from their closed door counterparts. The predicted HGL temperatures are only slightly less than those measured in the open door tests, due in large part to the contribution of Tree 7 in the layer reduction calculation.*” (Page 57)

Test No.	Burner Pos.	Vent Operation	First Act. (s)		Total Acts.		Draft Curtains	Heat Release Rate MW @ s
			Exp.	FDS	Exp.	FDS		
I-1	B	Closed	65	53	11	11	Yes	4.4 @ 50
I-2	B	Manual (0:40)	66	53	12	9	Yes	4.4 @ 50
I-3	B	Manual (1:30)	64	53	12	9	Yes	4.4 @ 50
I-4	C	Closed	60	52	10	11	Yes	4.4 @ 50
I-5	C	Manual (0:40)	72	52	9	8	Yes	4.4 @ 50
I-6	C	Manual (1:30)	62	52	8	8	Yes	4.4 @ 50
I-7	C	74°C link (DNO)	70	52	10	11	Yes	4.4 @ 50
I-8	B	74°C link (9:26)	60	53	11	11	Yes	4.4 @ 50
I-9	D	74°C link (DNO)	70	55	12	16	Yes	4.4 @ 50
I-10	D	Manual (0:40)	72	55	13	14	Yes	4.4 @ 50
I-11	D	74°C link (4:48)	N/A	N/A	N/A	N/A	Yes	4.4 @ 50
I-12	A	Closed	68	58	14	13	Yes	4.4 @ 50
I-13	A	74°C link (1:04)	69	59	5	11	Yes	6.0 @ 60
I-14	A	Manual (0:40)	74	127	7	7	Yes	5.8 @ 60
I-15	A	Manual (1:30)	64	59	5	13	Yes	5.8 @ 60
I-16	A	74°C link (1:46)	106	99	4	6	Yes	5.0 @ 110
I-17	B	100°C link (DNO)	58	54	4	6	No	4.6 @ 50
I-18	C	100°C link (DNO)	58	58	4	4	No	3.7 @ 50
I-19	A	100°C link (10:00)	56	60	10	4	No	4.6 @ 50
I-20	A	74°C link (1:20)	54	64	4	4	No	4.2 @ 50
I-21	C	74°C link (7:00)	58	52	10	4	No	4.6 @ 50
I-22	D	100°C link (DNO)	60	54	6	5	No	4.6 @ 50

> “***Table 6.1:*** *Results of the UL/NFPRF Experiments. Note that DNO means “Did Not Open”. Also note, the fires grew at a rate proportional to the square of the time until a certain flow rate of fuel was achieved at which time the flow rate was held steady. Thus, the “Heat Release Rate” was the size of the fire at the time when the fuel supply was leveled off.*”

(Page 63)

“*Figure 6.2 displays graphically the difference between predicted and measured sprinkler activation times as a function of burner position. Note that there are no experimental uncertainty bounds on the plot because it is difficult to estimate the combined uncertainty related to the various parameters that are input into the model. For example, changing the median volumetric droplet size from 1000* µm *to 750* µm *led to a reduction of approximately 50 % in the number of predicted sprinkler activations due to the increased cooling of the smaller droplets. Consequently, three replicate experiments are compared to show how much variation one can expect in sprinkler activation times in repeat experiments.*” (Page 63)

“*FDS treats smoke like all other combustion products, basically a tracer gas whose mass fraction is a function of the mixture fraction. To model smoke movement, the user need only prescribe the smoke yield, that is, the fraction of the fuel mass that is converted to smoke particulate. For the simulations of the NIST/NRC tests, the smoke yield is specified as one of the test parameters. Figure and Figure contain comparisons of measured and predicted smoke concentration at one measuring station in the upper layer. There are two obvious trends in the figures: first, the predicted concentrations are about 50 % higher than the measured in the open door tests. Second, the predicted concentrations are roughly three times the measured concentrations in the closed door tests.*” (Page 73)

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