RELIABILITY OF FIRE TESTS AND COMPUTER MODELING IN FIRE SCENE RECONSTRUCTION – PART I

Introduction

This paper will describe and discuss various kinds of fire tests and computational models (calculations, formulas, and computer-based) that can be useful to fire investigators, and describe applications for each. Since many of these will be familiar, we will focus on their limitations, as well as their abilities. Each of these, before they can be properly presented before a court, must be critically tested and validated. Fire tests have to be shown to be reliable and applicable to the question at hand. The nature of input data needed for models, their proper use, as well as the required skill and knowledge of the user, will be discussed, since those appear to be the major flaws of fire model use today.

Definitions

Fire tests:

Bench scale: Small samples, limited ignition types, field tests, mock-ups (as described in ASTM (American Society for Testing and Materials) D1230, D2859, E1352, D56, NFPA 705, etc.).

Scale models: Reduced scale (typically one quarter life size) mock-ups of compartments and buildings.

Full scale: “Life” size – furniture items, rooms (or partial rooms), cubicles (purpose-built), or multiple rooms. Can include entire buildings.

Mathematical models: Numerical relationships developed from the interpretation of experimental test data (1,2).

Tools needed: Hand calculators (with scientific notation)

To calculate: Smoke filling rates
Flame heights
Virtual origin
Plume temperature
Detector/sprinkler activation

Spreadsheets:

These calculations can also be used to generate spreadsheets to:

Predict impact of fire plumes and ceiling jets, hot gas layers, thermal radiation to targets and critical heat fluxes (3).

Loss histories of actual fires (Fire-Induced Vulnerability Evaluation).

Tables of physical/chemical/thermal properties (FiREDSHEETS) (FDS 2) (4).

Simple computer fire models:

Some calculations are also used in simple computer programs. NIST's FPETOOL includes ASET-BX, (doors, upper layer temp, ventilation limitation, up to flashover) atrium smoke temperature, buoyant gas head, ceiling jet temperature, ceiling plume temperature, egress time, fire/stack forces, plume filling rate, radiant ignition, smoke flow, sprinkler/detector activation, and Thomas flashover correlation (5).

Computer-code models:

Tools: Complex computer programs that use the basic physics of transfer and conservation of mass, momentum and heat to predict features of a compartment fire (sometimes called deterministic models) (6,7).

Zone: CFAST, ASET-B or BX, FIRM (or FIRM-QB), BRANZFIRE. See Table 1 for a summary of some common zone models.

Field (CFD – Computational Fluid Dynamics): FDS, JASMINE, PHOENICS, SOFIE, SMARTFIRE. See Table 2 for a summary of FDS features.

Specialized programs:

Post-flashover: COMPF (time-temp history for energy, mass and species – evaluating structural integrity in fire exposure)

Thermal and structural response: FIRES-T3, TASEF (finite element calculations re: structural fire endurance of a building or particular components using known failure conditions such as loss of tensile strength as a function of temperature)

Fire Protection: DETACT-QS, DETACT-T2, LAVENT (sprinkler and detector response times for specific fires)

Smoke Movement: CONTAM 96, MFIRE (dispersion of smoke and gaseous species)

Egress: EXITT, EXIT 89, EVACNET, SIMULEX (probabilistic (stochastic) modeling of escape of people from fire using predicted smoke conditions, and occupant and egress variables)

Glass breakage: Break 1

Wildland: Behave Plus (8)

Why Do We Bother?

Fire modeling of all kinds helps us understand complex fire processes, such as the relationship of heat release rate to other factors, such as ventilation or heat of vaporization. It can help relate post-fire indicators to fire events and behaviors. It can help analyze unknown factors in fire – ventilation, ignition location, fuel type – and see what effect each has. This is much easier and cheaper than building life-size models and actually burning them. This process is at the heart of the scientific method – creating (or discerning) alternative hypotheses and testing them. This helps satisfy the court's demand for the scientific method. The "error" rates or, at least, the effect of unknown or unknowable variables on estimations of fire processes such as size, rate of growth, and likelihood of flashover can be measured in some terms and relayed on to the court.

Fire testing, whether small-scale or full-scale, can reveal important data on temperatures, flame spread, fuel behavior, effects on target surfaces, smoke production, and ignition mechanisms. Test results, if reliable, can be used to verify hypotheses about a particular fire or a general category of fires, or to create or support mathematical models.

Testing and modeling can also increase the reliability of fire codes by showing what works and what doesn't in limiting fire or smoke movement, or preventing deaths. That, in turn, allows fire codes to be more flexible (performance-based, rather than the sometimes arbitrary and erroneously limiting prescriptive codes) to adapt to new architectural designs or materials.

ASTM Guides

There are a number of guides published by ASTM that are of considerable value to fire investigators interested in fire tests or fire models. These include:

ASTM E603

ASTM E603-01: Standard Guide for Room Fire Experiments – Addresses assembling lists that will be used to evaluate the fire response of materials, assemblies or room contents in real fire situations that cannot be evaluated in small-scale tests. Provisions for measuring the optical density of smoke, temperatures, and heat fluxes in the compartment are described. The documentation and controls necessary are also described (9).

It is particularly important to point out to potential users of fire models that there are existing ASTM guides that deal with critical modeling issues. The most relevant to our discussion here are:

ASTM E1355-97: Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models (10)
ASTM E1591-00: Standard Guide for Obtaining Data for Deterministic Fire Models (11)
ASTM E1895-97: Standard Guide for Determining Uses and Limitations of Deterministic Fire Models (12)
ASTM E1472: Guide for Documenting Computer Software for Fire Models (13)

All of these contain vital information and recommendations for someone contemplating the use of a fire model. As they are published by ASTM (and produced by Committee E-5 on Fire Standards), they represent peer-reviewed guides with which all fire model users should be familiar. They outline the documentation (of both the scene and the model) necessary for demonstrating the reliability of models used. They are intended for evaluation of zone models but are applicable to field models as well.

What Should We Ask About Any Model We Use?

Is it applicable?
Is it the right tool for the job?
Does it give accurate results?
How often does it predict events that do not occur in real fires?
How sensitive is it to changes in input?
What is its error rate?
Has it been used to <u>predict</u> events in real fire tests?
Has it been validated?
Where did it come from?
Where was it published?
What supporting (or contradictory) data has been published?

If we use such models, we quickly realize that the input data they depend on are usually a lot more extensive than we are used to gathering. This paucity of data is more often than not the result of careless or incomplete documentation of the scene. This has been recently addressed by the inclusion of recommended data collection forms in Kirk's, Icove and DeHaan, and NFPA 921 (14,15,16). It is a rare scene that is so completely destroyed that basic dimensions, structural and finish materials, and furnishings (type and placement) cannot be established by careful examination. Even in such instances, interviews, examination of nearby "exemplar" structures, or recovery of pre-fire photos or videos, can often fill in many of the missing pieces.

Assessment

As outlined in E1895, for instance, the user's first step should be to define the scope of the fire assessment and then determine if fire modeling is an appropriate tool (17). Then, the user should determine what models are available and are suitable to run on the available computer hardware considering the size and complexity of the problem. For the models being considered the available documentation should be acquired and evaluated in terms of guidance offered in E1472 (18), Guide for Documenting Computer Software for Fire Models. The limitations of the candidate models must be compared to the problem to be solved – one-room v. multi-room, pre-flashover v. post-flashover.

While it is possible for existing models to be modified to deal with particular problems, any modifications must be made in cooperation with the original model developer and then subjected to suitable validation as outlined in E1355 (19). Other tools, such as small- or large-scale fire tests or mathematical calculations, should be considered as well.

Once a model is selected, the following steps are recommended (20):

1. Verify the known limitations of the model – room dimensions, fire size, or ventilation.
2. Determine the underlying assumptions (two-layer zone or CFD/field model) and assess their impact on the results.
3. Determine the characteristic variables.
4. Determine what input data is required and where it can be obtained.
5. Determine the rigor of the mathematics involved and check to see it will give an answer given the constraints of the problem.
6. Determine extent of validation to establish its appropriateness for the problem. Validation processes are described in E1355.
7. If validation data are not available, sensitivity analysis must be conducted to establish the effect of changing critical variables.
8. Thoroughly document the model "run," including all input data, all assumptions made, and any and all modifications (including validation to support the accuracy of those modifications).

The documentation for a fire model should include a technical guide or user's manual (as described in E1472) (21). The source code for the model should also be made available to any potential user. Some well-known programs, such as FPETOOL and FDS (Fire Dynamics Simulator) are available for downloading from NIST at no charge. Other programs, such as BRANZFIRE, SIMULEX and ASKFRS, must be purchased as a "user license" for a given period of time. The assumptions used, known numerical and physical limitations, and the physical and mathematical treatments used must also be made available to the user. An excellent source of information is the firemodelsurvey.com website where information about over 150 models is available. A summary of this information was published by Olenick and Carpenter, An Updated International Survey (22).

A good example of a documentation guide for a fire modeling package is FPETOOL: Fire Protection Engineering Tools for Hazard Estimation, by H. E. Nelson (23). That guide describes the main elements of the package, its hardware and software requirements, the fundamental mathematics, underlying assumptions, and comparisons of FPETOOL (Fire Simulator routine) to fire test data. A separate user guide was published as FPETOOL User Guide (24).

The FIRM-QB zone model developed by Marc Janssens has a technical description, program description and user's manual all included in his excellent book, An Introduction to Mathematical Fire Modeling (25). The entire program code and supporting documentation are included in a CD-ROM packaged with the book.

FPETOOL is a collection of analytical tools about fire behavior and properties with simplifications (as assumptions) to make approximations rather than exact predictions using portable or desktop computers. It consists of three main elements:

Fireform (Fire Formulas) – a collection of fire safety calculations.
Makefire – a series of procedures to produce fire input data files for use with Fire Simulator.
Fire Simulator – an integrated set of equations (i.e., a model) designed to allow the user to create a fire case study in a Lotus format with specifications of: room and vent dimensions; fuel characteristics; ceiling, wall and floor materials; input fire to predict layer temperature, flashover, and tenability factors.

According to E1355, the evaluation process consists of four steps:

1. Define the scenarios for which the evaluation is to be conducted.
2. Validate the theoretical basis and assumptions used in the model.
3. Verify the mathematical and numerical robustness of the model.
4. Evaluate/quantify the uncertainty and accuracy (26).

ASTM E1355 offers the following definitions regarding models:

> Evaluation: The process of quantifying the accuracy of chosen results from a model when applied for a specific use.
>
> Validation: The process of determining the correctness of the assumptions and governing equations implemented in a model when applied to the entire class of problems addressed by the model.
>
> Verification: The process of determining the correctness of the solution of a system of governing equations in a model. Verification does not imply the solution of the correct set of governing equations, only that the given set of equations is solved correctly.

These steps are not isolated ones. As Janssens points out: "Step 4 is usually based on a comparison between model output and experimental data and provides an indirect method for validation (Step 2) and verification (Step 3) of a model for scenarios of interest (Step 1). It is generally assumed that the model equations are solved correctly and the terms validation and evaluation are therefore often used interchangeably. It is very rare for anyone but the model's developer to spend the time necessary to carry out steps 2 and 3, although an independent reviewer or researcher may. Portions of the mathematics are sometimes compared to other analytical results. Step 4 can be carried out by comparing a model's predictive results to full-scale tests done specifically for that purpose, tests done by others and published in the literature, results of standard room fire tests done in accordance with ASTM E603, or even against observations or reconstructions of real fires (historical fire data)." (27)

A good example of comparing a compartment fire test against the predictions of mathematical calculations, zone models and a field model was published by Spearpoint, Mowrer and McGrattan in 1999 (28). It showed how accurately calculations and zone models (Fire Simulator, FAST and FIRST) agreed with test data. The full model used was ES3D (a predecessor to FDS). Its predictions (including early fire development) were not as accurate as the calculations and indicated further development was needed.

Model uncertainty is based on repeated runs of similar data and sensitivity analyses to identify critical data. For a complex model with many inputs, it is usually prohibitively costly to run repeated runs with different single inputs. Mathematical techniques have been used to streamline the process.

The accuracy with which FDS predicts temperatures and heat release rates has been validated by large-scale fire tests. Testing has shown that FDS temperature predictions were within 15% of the measured temperatures, and heat release rates were within 20% of measured values (29). Results, however, are often presented as ranges to account for some uncertainty. FDS is the primary fire-modeling tool used by NIST and has been used in major fire investigations involving large losses and death (30,31,32).

When model results are compared to a full-scale test fire, it is usually assumed that the real-fire data is the gold standard. The complexities of the room fire environment and the variable of turbulence make it impossible, however, to get exactly the same measurements when the real fire is repeated. Estimates of the uncertainties inherent in some measurements can be as high as ±30% (33).

Testing Simple Mathematical Calculations

To illustrate these processes, let us take a simple mathematical calculation and insert various values.

Temperature at ceiling:

$T_o - T_\infty = 25\,(Q_c^{2/5} / Z - Z_o)^{5/3}$ (Heskestad), where Q = total heat release rate
Q_c = convective heat release rate

$T_o - T_\infty = 21.6\,Q^{2/3}\,Z^{-5/2}$ (McCaffrey) Z or H = height at which measurement is desired (or ceiling)

$T_o - T_\infty = 16.9\,Q^{2/3} / H^{5/3}$ (Alpert) T_o = temperature (ºC)
`
T_∞ = ambient temperature (ºC)

By plugging in values for Q, Q_c, and Z (or H), we can see what effect the variable of height has on temperature. Putting these calculated values into a spreadsheet allows us to see what effect variables (and different formulas) have. We note that all three are based on $Q^{2/3}$ power, which tells us that the fundamental physics of all three models are in agreement. Q_c in the Heskestad formula adds a value for estimating the effect of unusually high (or low) radiant heat losses as Q_c is the heat released in the convective plume. Most fires have a Q_c of ~60% Q, but very smoky fires like oil wells or very “clean” flames like alcohol will have higher Q_c values. The Heskestad formula also includes a correction for virtual origin (Z_o) when the source is very energetic (high HRR) or very weak.

Ceiling Temperature Calculation Spreadsheet:

Q	$Q^{2/3}$	Q_c (60%)	$Q_c^{2/5}$	Z or H	$Z^{5/2}$	$H^{5/3}$	$T_{o(McC)}$	$T_{o(H)}$ (if Z_o = 0)	$T_{o(A)}$
500	68.12	300	9.79	1	1	1	1363 + 25	1121 + 25	1067 + 25
				2	5.65	3.17	241 + 25	352 + 25	336 + 25
				3	15.58	6.26	87 + 25	179 + 25	170 + 25
				4	32	10.08	43 + 25	111 + 25	105 + 25

Let's use another mathematical model:

Z_c (height of continuous flame plume) = 0.08 $Q^{2/5}$
Z_i (intermittent plume) = 0.20 $Q^{2/5}$
$Z_t = Z_c + Z_i$

If Q = 500 $Q^{2/5}$ = 12.01 Z_c = 0.96m per McCaffrey formula
Z_t = 2.4m

so our flame temperature calculated above at 1m would be measured at just above the tip of the continuous flame, the measured maxima we know from experimental observations to be about 800-900˚C. Note that all three give about the same temperatures for plume temperatures above the continuous flame (with McCaffrey being more conservative). If we look at data, such as Fig. 1 (37), we can see that for plume temperatures above the continuous flame there is a direct relationship between $Z/Q^{2/5}$ and temperature. The "flame" zone data tells us that these formulas will not give accurate results for points in the continuous flame zone (since those are continuous in the 800-900ºC range).

[Figure 1 here.]

The Heskestad formula for estimating visible flame heights from non-point-source fires is $Z - Z_o = 0.23\ Q^{2/5} - 1.02D$. This is applicable when the fire is not near any walls.

What about the effects of walls, corners, and combustible wall coverings? What happens to flame height v. Q against a non-combustible wall, or in a corner? Re-radiation from nearby walls increases the efficiency and creates higher temperatures in the flame plume. Because the entrainment of cooling air into the plume is reduced, the flame plume retains its heat and buoyancy longer and a different formula applies ($Z = 0.174\ (kQ)^{2/5}$) that fits better to observed data (where K = 1 for unconstrained, K = 2 for 1 wall, K = 4 for corner) (38). If the wall covering is combustible, a major variable is introduced that invalidates a simple flame height calculation.

Testing Simple Computer Models

Testing FPETOOL

FPETOOL contains the following subroutines in FireForm (Fire Formulas) as DOS menus:

ASET-BX
Atrium smoke temperature
Buoyant gas read

Ceiling jet temperature
Ceiling plume temperature
Egress time
Fire/stack forces
Plume filling rate
Radiant ignition
Smoke flow
Sprinkler/detector activation
Thomas' flashover correlation
Ventilation limit
Upper layer temperature

Select: Thomas' flashover from FPETOOL menu.
Intent: Equation for estimating amount of energy in a room to raise temperature to a point likely to produce flashover. Formula developed on a combination of theory and empirical data.
Needed input data: Length, width, height of space; height and width of opening.
Limitations: one vent or all vents combined.
Assumptions: one vent; enough air; all walls equal in thermal properties.

Output example – Thomas' Flashover Correlation (English units used here – FPETOOL will also do all calculations in SI (metric) units):

Room	Door	Total kW	Door Loss	Wall Loss
20 x 12 x 8	6.7' x 3'	1865	1097	768
20 x 12 x 8	6.7' x 2.9'	1829	1060	769
20 x 12 x 8	8' x 2.9'	2149	1383	766
19 x 12 x 8	6.7' x 3'	1833	1097	737
16 x 12 x 8	6.7' x 3'	1739	1097	642
16 x 12 x 8	6.7' x 0'	658	0	658
16 x 12 x 8	6.7' x 0.4'	802	146	656

Sensitivity analysis:

Note amount of changes on required HRR resulting from modest changes in room or door dimensions.

Select: Ventilation limit from FPETOOL menu.

Output: estimates the maximum burning rate that can take place in a room with an opening of given size.
Input: combustion efficiency, room opening height and width.

Assumptions:

100% combustion efficiency (can be changed)

If rate of mass loss (burning) is less than ventilation limit, fire is free burning.

If rate of mass loss (burning) is greater than ventilation limit, excess fuel will flow out opening to burn as flame there.

Each opening adds uniformly to ventilation limit.

Sill and soffit height have no impact.

No interference occurs between exhaust gases and incoming air.

Sensitivity:

6.7' x 3' permits 4021.4 kW fire inside room at 100% combustion efficiency
6.7' x 2' permits 2680.9 kW fire inside room at 100% combustion efficiency
6.9' x 3' permits 4202.8 kW fire inside room
7' x 3' permits 4294.5 kW fire inside room
6.7' x 2.5' permits 3351.2 kW fire inside room

Observe that uncertainty in door measurement (± 3") makes very little difference in the HRR. All calculated values are typically considered reliable to ± 10%.

Select: Plume filling rate from FPETOOL menu.

Output: Volume flow of smoke at a point above a fire (unconstrained).

Input: Fire size (HRR) and vertical distance above fuel.

Default values: radiant fraction: .35 (convective fraction: .05, additional loss: .15)

Calculations:

500 kW fire: 5354 cfm 8' above fire

500 kW fire: 6960 cfm 10' above fire (as room air is entrained into rising plume)

Assumptions: unconstrained flow, not filling a room layer, density of smoke equal to room air at normal temperature.

<u>Testing ASET-BX</u>

Output: Mathematical model for estimating rise in temperature and descent of fire-produced hot gas layer.

Limits:

Only predicts onset of flashover (layer temperature)
No vents to allow smoke to exit room
One room

Assumptions:

There is one floor level vent to prevent buildup of pressure due to thermal expansion.

T_{amb} = 70˚F (23˚C)

Input:

Heat loss fraction (default = 0.9)
Height at base of flames (default = 0, on floor)
Ceiling height
Floor area
Printout interval
Max. sim time = 600 s.
Input fire – choice of slow, moderate, fast, ultra-fast, t^2, formula or user specified
Warns when smoke level descends to flame (possible hole vitiation)
Warns when T approaches 1150˚F (600˚C) (flashover condition)

Sample calculations:

240 ft^2, 8 ft ceiling, fast t^2 fire:
Layer to floor at 151 s. – 557-678˚C, 2465 kW fire. Estimates flashover at 230-240 s.

Same room with moderate t^2 fire:

Layer to floor @ 220 s.
Flashover at 370 – 380 s. (Layer T = 584 – 662˚C)
1602 kW fire

If ceiling 9', moderate t^2 fire:

Layer to floor in 340 s.
Flashover at 390 s.

Per Thomas correlation: with normal door (6.7' x 3'), HRR_{FO} = 1865 kW w/ 8' ceiling and 1916 w/ 9' ceiling.

Testing Complex Computer Models

One of the major differences between zone and field models is that field models often include routines that calculate the growing fire based on first principles of thermal response, heat flux and flame spread. Of course, this requires that the initial fuels be identified and their physical and thermal properties carefully defined as input data.

The limitations of this text are such that detailed descriptions of complex fire models cannot be included here. The reader is referred to the reference list included here or to the firemodelsurvey.com website. Some case examples in the references will be offered in Part II of this paper to illustrate the principles.

The following questions should be answered:

Appropriateness – is the model's output useful and applicable?
Limitations (time, ventilation, output)
Resources – computer speed and capacity needed (see Table 1)
Experience needed
Input data needed – what default conditions apply if input data is incomplete?

Sensitivity – what happens to output when input data is changed?

Accuracy:
- Are the results/outputs realistic? Would they occur that way in a real fire?
- Has the model been used to predict the outcome of a test burn – such as tenability, temperatures, or time to flashover? How accurately did it predict the actual fire results?
- Was the model "fine-tuned" to make its predictions more accurate? (Was the program run multiple times with different data to slightly "tweak" the result?)
- How was the data collected in the test burn? Direct observation, thermocouple measurements, radiometers?
- Where were the measurement/observation point(s)?
- (The fire environment can be so complex that temperature or radiometric data collected in one location may not be representative of the entire room, leading to possible variations of as much as ± 30%.)

Reproducibility:
- If the program is run with the same data by the same person, does it give the same answer?
- If the program is run with the same data by a different person, does it give the same answer?

Robustness:
- Is the program applicable to different situations? Has it been tested and demonstrated to give accurate results if starting conditions are very different?
- Has it been shown to give reliable results for:
  - Small fire in a big room v. large fire in a small room?
  - Adequate ventilation v. underventilated?
  - "Ultra-fast" t^2 fire v. "medium" t^2 fire?
- (Is the testing done "game playing" or thorough testing of alternative hypotheses?)

Analysis:

What features of fuel, starting conditions, initial fire size are input data and what assumptions have been made by the analyst based on personal judgment or “bias”?

The “Other Side”

When one is presented with computer fire model results in an adversarial (court) context, the following points may be useful.

<u>Accuracy</u> – The accuracy of input data – initial fire HRR, growth rate – is <u>critical</u> to accuracy of final result. “Garbage in – gospel out” is the risk with computer models. Are data arbitrary? Are they correct for the scenario in question?

<u>Assumptions</u> – What assumptions were made by the user to fill the gaps? Incompleteness of data from the scene is the major reason for most failed computer model attempts. What default values does the model insert if data is not available? Will those default values make a difference (i.e., what is the model’s sensitivity to those values)?

<u>Impression</u> – How is the data presented? Is it in the form of reviewable printed output or a single dramatic action cartoon? SMOKEVIEW will show “movement” of flames and smoke that is a stop-action representation of a “temperature” surface or smoke concentration. Other models (or users) refrain from showing smoke or flame movement because it is, to some extent, too complex, and too random to show accurately.

<u>Correctness</u> – Is it the right model for the job? What is the question the investigator wants to answer? What is the question the model was <u>intended</u> to answer (temperature, smoke filling, species concentration)? What are the limitations of the model – number of rooms, fire growth, size of fire, ventilation, time? Will this model address those issues correctly in the problem at hand? Is information about conditions in a specific location at a specific time needed? If so, a zone model may not be able to give an appropriate answer.

<u>Evaluation/Validation</u> – Was the model created and validated for a particular scenario (small fire in a big room) and was it being used here for a very different scenario without proper (published) evaluation?

<u>Fine-Tuning</u> – When a comparison to a test fire is offered, the number of model runs should be evaluated. Was the model run with changes in input data to get the model to “match” the real fire?

<u>User qualified</u>? – Did the user have the correct documentation (user’s guides, technical manuals)? How much experience did the user have with this model? Were other models

considered or used? What steps did the user take the make sure the model was correct and correctly used (e.g., reviewing published evaluations)?

When fire test results are offered, many of the same issues arise. While there are some ASTM and NFPA guidelines for fire tests, there are many valid tests that cannot follow a specific guide due to the variables present or issues to be tested. The questions should be:

- What was the issue to be tested – what was the objective of the test?
- Was this a test in which particular variables were changed while others were held constant?
- Was this a demonstration rather than a controlled test?
- How was data collected, assembled, analyzed and reported?
- How do the "test" conditions vary from the actual (or purported) fire conditions?
- Were all important variables controlled and documented?
- If this were a reduced-scale model, what corrections were applied for factors that were not scalable by linear reduction (ventilation, velocity, radiant heat/distance, and material response, for instance)?

Conclusions

Appropriate uses for computer models:
- Testing hypotheses, not proving causation
- Validating or explaining post-fire indicators
- Estimating timelines
- Evaluating human factors and fire/smoke conditions

Precision of fire calculations or fire models:
- <u>Not</u> to second decimal point!
- Best results: predictions accurate (duplicative of real world results) to ±30%

For fire tests:
- What was the intent of the test or demonstration?
- Were important variables identified and controlled?
- Was the collection and analysis of data done correctly?

Judicial consideration:
- Does probative value outweigh potential bias or misunderstanding (the "I saw it on TV, therefore it must be true" logic)?

Does any model pass the major tests:
- Sensitivity
- Accuracy
- Published

Tested (validated)
Used by qualified expert

Was sufficient and correct input data gathered and entered?
What assumptions were made about the pre-fire conditions, ignition, initial fire?
What default decisions were made?
Is this a fair and impartial analysis?
The most common flaw today in the use of fire models is the lack of data and documentation of the original scene.

Pre-fire conditions such as: the type and placement of fuel packages; floor, wall and ceiling materials and coverings; dimensions of rooms; and sizes, sill and soffit heights of all vents are essential to any accurate model. The more estimates that have to be made, the less reliable the results will be. Without critical dimensions any modeling is fancy guesswork, and such guesswork should play no role in scientific fire investigations.

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Table 1: Some Common Zone Models

Model	Limitations	Input Required	Use/Output
ASET	• Single room • No openings • Input fire required	• Room size: area and height • Radiative loss fraction • Conductive loss fraction • Detection criteria: layer temperature, rate of rise temperature, concentration of combustion product • Hazard criteria: layer temperatures, concentration of combustion product • Fire- exponential growth curve or digital file Q v. time to maximum temperature	Calculates layer depth and temperature and concentration of two products of combustion. Gives the time at which these exceed a user-specified threshold
FPETOOL: ASET-BX ASET-B	• Single room • One inlet • Leakage flow • No openings (vents) • Cannot be used to predict post-flashover conditions • Input fire	• Room size: L, W & H • Fire height (above floor) • Fire details: existing heat release curve or 100 data points of Q v. time • Convective heat loss • Maximum time	• Calculates smoke layer, depth and temperature with time • Temperature of layer used to predict flashover • Heat output with time

Model	Limitations	Input Required	Use/Output
FPETOOL Fire Simulator	• Single room • One door (or equivalent) • Input fire	• Heat of combustion (one fuel) • Optical extinction coefficient • Flashover temperature • Minimum O_2 concentration for combustion in smoke layer @ 21°C • Minimum O_2 concentration for combustion in smoke layer @ 600°C • Freeburning CO/CO_2 molar ratio • Vitiated CO/CO_2 molar ratio • Radiant heat transfer fraction • Maximum heat transfer loss • Sprinkler or heat detector: distance, RTI, location • Smoke detector – location	To simulate a fire – pre- or post-flashover: • Layer temperature with time • Layer depth with time • Gas concentration (CO, CO_2, O_2) • Time to flashover
FASTlite	• Input fire required • Up to three interconnected rooms with vents • Fire growth model is a stripped-down version of the CFAST zone model	• Room dimensions • Locations and dimensions of windows/doors. Ceiling, floor and wall materials • Position of fire • HRR of fire • Product (smoke & toxic gases) generation rates for fire	• Upper layer temperature in each room • Upper layer depth in each room • Temperature of ceilings, walls and floors • Gas concentrations in both layers • Heat radiation to floor

Model	Limitations	Input Required	Use/Output
FIRM-QB	• Single room • Input fire • Single vent in wall • Fire in center of compartment	• Room dimensions (area and height) • Vent width, sill and soffit height • Fire base height • Radiative heat loss fraction • Total heat loss (to room) fraction • Maximum simulation time • Heat release rate Q (existing data file fire or input Q v. time data)	• Predicts consequences of a user-specified fire in a compartment • Temperature and height of upper layer • Mass flow through vent • Time to reach untenable conditions

Model	Limitations	Input Required	Use/Output
HAZARD I (Suite) includes FAST, EXIIT, DETACT, TENAB	• Up to six compartments - rectangular • Input fire – detailed profile required • Limit of connections	• Ambient conditions • Compartment sizes • Vent openings (sizes, sill and soffit heights) • Thermal properties for each compartment (ceiling, floor, and walls) • Fire: ▪ Heat of combustion of each fuel ▪ O_2 limit ▪ Position of fire in each room ▪ Type of fire (pool, furniture, etc.) ▪ Time intervals ▪ Mass loss (per interval) ▪ Heat release (per interval) ▪ Height (per interval) ▪ Area (per interval) ▪ H/C (soot) (per interval) ▪ CO/CO_2 (per interval) ▪ C/CO_2 (per interval) ▪ HCN (per interval) ▪ HCl (per interval) (from FIREdata or tests)	(For each compartment at specified time interval): • Upper and lower layer temperature • Upper layer volume and depth • Ceiling and upper wall temperature • Floor and lower wall temperature • Flow of combustion products to layer • Vent flows • Radiation to target • N_2, O_2, CO & CO_2 content of upper layer • HCl and HCN content of layer • Optical density in upper and lower layers • N_2, O_2, CO & CO_2 content in lower layer • Pressures

Model	Limitations	Input Required	Use/Output
EXITT	Uses FAST results (above)	Uses FAST model files on occupants and evacuation mode distances	Determine evacuation procedure of occupants
TENAB	Uses FAST results (above)	Uses FAST model files plus EXITT and tenability info.	Calculates the FEDs (fractional equivalent dose) of toxic products and any subsequent times to incapacitation and death of occupants
CFAST (v. 3.1.7)	• Input (initial) fire • 86,400 s. max • 30 compartments • 30 object fires • Can overpredict hot layer temps. • Treats all fires as point sources	• Room dimensions • HVAC details • Ceiling, wall, & floor materials & coverings • Vent sizes, soffit & sill heights • Fuel packages • Initial fire	• Production of heat and mass by burning objects • Flows through horizontal and vertical vents • Temperatures, optical densities, species concentration in multiple compartments
All Zone Models	Assumptions that upper and lower layers do not mix and are each uniform in temp, conc. and density throughout the compartment. Only one source of fire, pumping all energy into one localized plume. Results are only approximate.		

Table 2: FDS Field Model

Model	Limitations	Input Required	Use/Output
FDS (NIST)	• Multiple rooms increase running time of FDS • Requires high-speed workstations and lengthy execution times • Multiple runs are time-consuming • Limited validation? (more published each year)	• Room dimensions • Location and dimensions of openings (windows, doors, vents) • Floor, wall, and ceiling finishes • Position of fire(s), HRR, properties • Properties of fuel packages • Grid (cell) size • Location and properties of heat detectors, thermocouples, and sprinkler heads • Define outputs to be displayed (slice, boundary, isosurface temps, radiative visibility, heat flux, CO, CO_2, and O_2 content levels) • Proprietary software to input CAD drawings	• To simulate a multi-room fire during all phases of development • Smokeview produces 3-D display of defined outputs (e.g., temps, radiative heat flux, etc.) • Sprinkler suppression (under-active research) • Simulate initial growth • Compare witness statements with fire growth