Live Fire Training as Simulation:
The Role of Fidelity in Effective Training

Ed Hartin, MS, EFO, MIFireE, CFO

CFBT-US
Not just what and how, but why!™

Fighting fires inside buildings (compartment fires) is a low frequency/high hazard activity for firefighters around the world. Effective training develops the knowledge to make appropriate strategic and tactical decisions as well as proficiency in the skills necessary to mitigate or reduce hazards and provide a safer operating environment. However, the question of what makes fire training effective is often unasked and even more often unanswered.

Understanding & Application

Safe and effective structural firefighting operations require that firefighters and fire officers have a solid understanding of fire dynamics and be skilled in task and tactical activity. However, simply achieving knowledge of fire dynamics and skill in task and tactical activity is not sufficient. Firefighters and fire officers must effectively apply this knowledge on the fireground. Facilitating this transfer from training to operational context is a significant challenge.

Figure 1. Training Transfer to Operational Incidents

It is reasonable to expect that firefighters and fire officers should learn to make critical decisions based on anticipated fire behavior and to work effectively in the fire environment before being called upon to do so under emergency conditions. However, as Aristotle observed; "for the things we have to learn before we can do, we learn by doing" (Aristotle, 1984, p. 1738). Training in a realistic context not only provides an opportunity to develop a practical understanding of fire dynamics and proficiency in firefighting skills, but is also a means for learners to recognize cues and conditions that are critical to effective decision-making.

In emergency operations, firefighters are often faced with limited information about the building, occupants, contents, and fire conditions. This lack of information increases firefighters' risk. However, in the training environment, conditions are controlled to provide a safer environment for the participants.

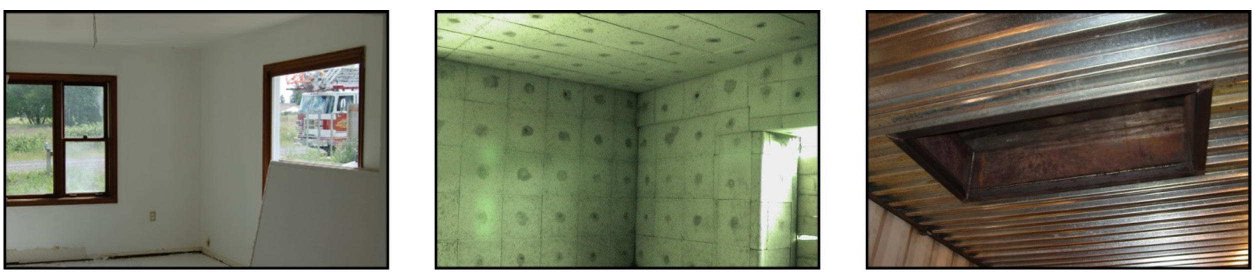
Speaking at the 2009 International Fire Instructors Workshop in Sydney, Australia Dr. Stefan Svensson of the Swedish Civil Contingencies Agency posed the question: "How do we get learners to understand the differences between training fires and 'real fires'". This is an interesting question in that training conducted in a container, burn building, or acquired structure is in fact a "real fire", but has considerably different characteristics than a fire occurring in a house, apartment, or commercial building. Improperly designed training may provide the learner with an inaccurate perspective on the fire environment which can lead to disastrous consequences. The challenge is managing risk while developing a realistic understanding of fire behavior.

What is the Difference?

Compartment fires in the training environment differ from those encountered during emergency operations n the basis of compartment characteristics, fuel, ventilation profile, heat release rate, and time scale. In addition to differences related to fire dynamics, firefighters and fire officers also encounter psychological stress resulting from a sense of urgency and societal expectations of immediate action (particularly in situations where persons are reported to be trapped in the building).

Other than acquired buildings, structures used for fire training are generally designed and built for repetitive use and not for regular human habitation. Structural characteristics that make a durable live fire training facility are considerably different than most if not all other structures in the built environment. Density, thermal conductivity, and specific heat of training structures can be considerably different than a dwelling or commercial structure, which has a significant impact on fire behavior.

Figure 2. Variations in Structural Characteristics Influence Fire Behavior



Note: From left to right, these photos illustrate an acquired structure with gypsum board compartment linings, a purpose built masonry burn building with high temperature ceramic lining, and steel container based prop with corrugated sheet steel lining.

A purpose built prop or burn building is also likely to have significantly different compartmentation and ventilation profile than a typical residential or commercial structure. Live fire training facilities often (but not always) are designed with burn compartments. This speeds fire development and minimizes both initial and ongoing cost. However, fire behavior and the impact of fire control tactics can be considerably different in a large area and/or high ceiling compartment. Many modern structures are designed with open floor plans that are challenging to duplicate in the training environment. Energy efficient structures limit ventilation (air exchange), while training structures are often quite leaky, particularly after extensive use. This can have a significant influence on development of a ventilation controlled burning regime and influence of ventilation on the concentration of gas phase fuel in smoke. Failure of glass windows in ordinary structures should be anticipated, as this changes the ventilation profile and resulting fire behavior. Training structures on the other hand provide a more consistent ventilation profile as durable (e.g., metal) windows do not present the same potential for failure.

While structural characteristics, compartmentation, and ventilation differ between typical structures in the built environment and those used for live fire training, one of the most significant differences lies in the types, quantity, and configuration of fuel. National Fire Protection Association (NFPA) 1403 Standard on Live Fire Training (NFPA, 2007) is fairly explicit regarding fuel characteristics and loading for live fire training evolutions.

NFPA 1403 (2007) Requirements for Fuel Used in Acquired Structures

4.3 Fuel Materials.

4.3.1 The fuels that are utilized in live fire training evolutions shall have known burning characteristics that are as controllable as possible.

4.3.2 Unidentified materials, such as debris found in or around the structure that could burn in unanticipated ways, react violently, or create environmental or health hazards, shall not be used.

4.3.3* Pressure-treated wood, rubber, and plastic, and straw or hay treated with pesticides or harmful chemicals shall not be used.

4.3.4* Fuel materials shall be used only in the amounts necessary to create the desired fire size.

4.3.5 The fuel load shall be limited to avoid conditions that could cause an uncontrolled flashover or backdraft.

4.3.6 Flammable or combustible liquids, as defined in NFPA 30, *Flammable and Combustible Liquids Code*, shall not be used in live fire training evolutions in acquired structures.

4.3.7* The instructor-in-charge shall assess the selected fire room environment for factors that can affect the growth, development, and spread of fire.

4.3.8* The instructor-in-charge shall document fuel loading, including all of the following:

(1) Furnishings

(2) Wall and floor coverings and ceiling materials

(3) Type of construction of the structure, including type of roof and combustible void spaces

(4) Dimensions of the room

NFPA 1403 (2007) also requires removal of low-density combustible fiberboard (4.2.10.5) and storage of combustible materials other than those intended for a given evolution in such a manner to preclude accidental ignition (4.2.17). While the provisions outlined apply to training conducted in acquired structures, the standard contains similar fuel requirements and limitations for non-gas fired, purpose built burn buildings. Most of the fuel specifications outlined in NFPA 1403 can be tied directly to incidents in which participants in live fire training exercises lost their lives. Given the specific requirements and limitations outlined in NFPA 1403, fuel types differ considerably (particularly with regards to synthetic materials) and fuel load in most residential and commercial occupancies is considerably higher than is typically used in live fire training, even in advanced tactical evolutions.

Differences in structural characteristics, ventilation profile, and fuel load provide considerably different fire dynamics between the training and operational environments. How much and in what ways does this impact on the effectiveness of compartment fire behavior training (CFBT)?

Fidelity

As discussed, CFBT, even when conducted in an acquired structure does not completely replicate fire conditions encountered in an operational context. All CFBT involves simulation. The extent to which a simulation reflects reality is referred to as fidelity:

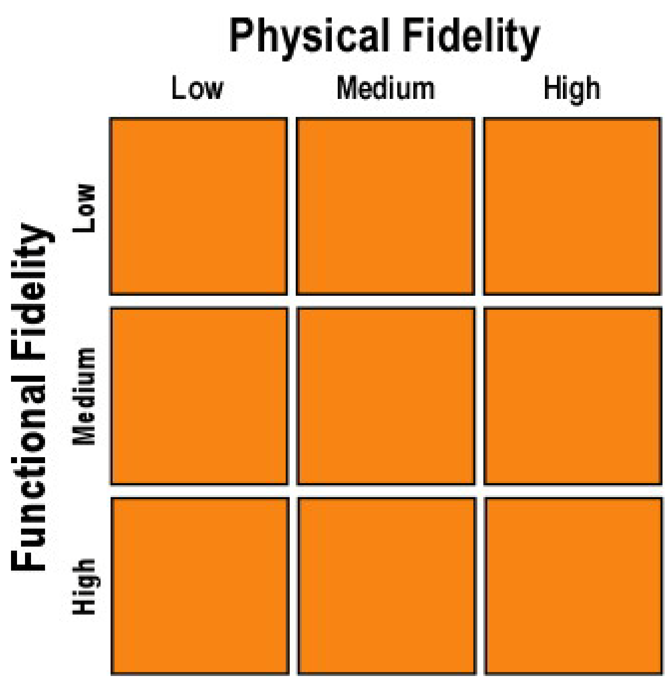
> The degree to which a model or simulation reproduces the state and behavior of a real world object or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation; faithfulness… 2. The methods, metrics, and descriptions of models or simulations used to compare those models or simulations to their real world referents or to other simulations in such terms as accuracy, scope, resolution, level of detail, level of abstraction and repeatability. (Northam, n.d.)

CFBT can involve a wide range of simulations, from the use of photos and video, non-fire exercises, small scale props such as doll's houses, single and multi-compartment props, burn buildings, and acquired structures. Each provides differing degrees of fidelity.

Fidelity can be described in a number of different ways. One fairly simple approach is to examine physical and functional fidelity (see Figure 3). Physical fidelity is the extent to which the simulation looks and feels real. Functional fidelity is based on the extent to which the simulation works and reacts realistically.

Describing fidelity of a simulation as low, moderate, or high, is unlikely to provide adequate clarity. A more useful description of fidelity includes both qualitative and quantitative measures on multiple

Figure 3. Two-Dimensional Fidelity Matrix



Note: Adapted from *Fidelity Versus Cost and its Effect on Modeling & Simulation* (Duncan, 2007) dimensions. But what measures and dimensions? In a compartment firefighting simulation, key elements of physical fidelity will likely include fire behavior indicators such as Building, Smoke, Air Track, Heat, and Flame (B-SAHF). Important aspects of fidelity would include the characteristics of doors and windows (e.g., opening mechanism), hose and nozzles, and influence of tactics such as gas and surface cooling on fire behavior. Replicating conditions encountered during emergency operations using an acquired structure would likely provide the most realistic context and correspondingly the greatest risk to participants.

On the surface it makes sense that increased fidelity would result in increased effectiveness and transfer of knowledge and skill. However, it is important to remember that simulations are a model of reality and "all models are wrong, but some models are useful" (Box & Draper, 1987, p. 424). The importance of the various aspects of fidelity depend on the intended learning outcome of the simulation. In fact, a simulation that focuses on critical contextual elements may be more effective than one that more fully replicates reality.

Figure 4. Door Entry Drill

For example, teaching the mechanics and sequence of door entry procedures (see Figure 4) might be more effectively accomplished using a standard door without smoke and flame than under more realistic live fire conditions. On the other hand, reading fire behavior indicators at the door and effectively predicting interior conditions is likely to require substantively different elements of context. However, at this point, we simply have unsupported opinion and in some cases anecdotal evidence of the effectiveness or lack of effectiveness of current training practices. The key to this puzzle is to clearly define the intended learning outcomes and identify the critical elements of context that are required.

The Questions

Some firefighters and fire officers subscribe to the belief that use of acquired structures with realistic fuel loading is the only way to develop the necessary competence and skills to operate safely and effectively on the fireground. However, current standards such as *National Fire Protection Association (NFPA) 1403 Standard on Live Fire Training* (2007) place specific constraints on fuel types and loading. Some departments are faced with environmental constraints that preclude burning Class A fuel for structural live fire training and consequently use gas fired structures (or don't conduct live fire training at all). Most departments who have access to purpose built structures and props for structural live fire training are limited to a single type of facility (due to economic constraints). This gives rise to an interesting set of questions:

- What degree of simulation fidelity is necessary to develop the knowledge and skills necessary for safe and effective operation on the fireground?
- What are the key elements of fidelity for various learning outcomes such as 1) developing understanding of fire development in a compartment, 2) dynamic risk assessment, inclusive of recognizing critical fire behavior indicators, 3) selecting appropriate fire control techniques, 4) developing competence and confidence when operating in a hazardous environment, 5) developing skill in nozzle operation and technique, 6) evaluating the effect of tactical operations.
- Is live fire training the only or most effective simulation method for achieving these learning outcomes? If so, what type of simulation will safely provide the required degree of fidelity? If not, what other simulation method may be used in place of, or in addition to live fire training to provide the required degree of fidelity?

Effective performance under stressful conditions such as those encountered during firefighting operations requires substantial training in a realistic context. However, effective training in this context presents considerable challenges.

> Training effective task performance in stressful situations requires that the following conditions be met: (a) Trainees should be exposed to and familiarized with stressors characteristic of the criterion situation; such stressors should be introduced into the training process in a manner that (b) prevents the build-up of anxiety and (c) minimizes interference with acquisition of skills that the training is designed to promote (Friedland & Keinan, 1992, 157)

Examining the various dimensions of fidelity provides a starting point for a more substantive discussion of live fire training as simulation and critical elements of context for safe and effective fire training programs.

Dimensions of Fidelity

As discussed previously fidelity may be examined on the basis of the physical and functional characteristics of the simulation (see Figure 3). However, this simple model provides limited guidance when examining live fire training. Here it is necessary to identify the key elements of physical and functional fidelity to support the specific learning outcomes intended from a given training evolution.

In *A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research*, Rehmann (1995) describes three purposes of aircraft flight simulation: 1) provide practice on specific skills, 2) reinforce acquisition and use of job-relevant knowledge, or 3) to evaluate a system or new concept. The fidelity requirements for each of these three purposes may be quite different. In addition, fidelity applies to the simulator itself, the participants, and related or events external to the simulator. In a flight simulator, each subsystem of the simulator (e.g., cockpit layout, audio, motion) has specific fidelity characteristics that must be considered as illustrated in Figure 5.

Figure 5. Flight Simulator Subsystem Fidelity Characteristics

Cockpit/Crew Station

None
Simulated Generic Type Instruments
Partially Simulated Cockpit
Full Crew Station

Audio

None
Significant Cockpit Sounds
Incidental Sounds
Realistic

Control System

No Force Feel
Constant Force
Partial Duplication
Complete Duplication

Mathematical Model [fluid dynamics and flight characteristics of the aircraft]

Simple
Complex

Environment

Clean Air
Discrete Wind Gusts
Varied Turbulence

Ground Handling

No Gear
Rigid Gear
Simplified Gear
Comprehensive

Mission Equipment

Communication Only
Communication/Navigation
Complete

System Latency

Non-Real-Time
Significant Delay
Minimal Delay
Real-Time

Visual

Day
Night
Limited Field of View
Full Field of View

Note: Adapted from *A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research*, Report Number DOT/FAA/CT-TN95/46p. 12, Albert Rehmann, 1995, United States Department of Transportation, Federal Aviation Administration.

While flight simulation is considerably different than simulating a compartment fire, both are complex and multi-dimensional. In addition, use of flight simulation has been studied extensively as a component of pilot training. These studies, while not directly applicable to fire training, may provide a starting point for examination of live fire training as simulation of firefighting operations and identification of potential dimensions of fidelity.

Interesting Puzzle

As previously defined physical fidelity is the extent to which the simulation looks and feels real and functional fidelity is the extent to which the simulation works and reacts realistically. Recently Roy Reyes of the Swedish Civil Contingencies Agency provided me with an interesting puzzle from a fire behavior instructor course that he had conducted in Valencia, Spain. Look at the photo in Figure 6 and consider the following questions, one quite general and the other very specific:

1. What do you see in the photo?
2. Why are the flames in the hot gas layer in the center, and not across the entire width of the compartment?

Figure 6. Participants Conducting a Fire Behavior Demonstration

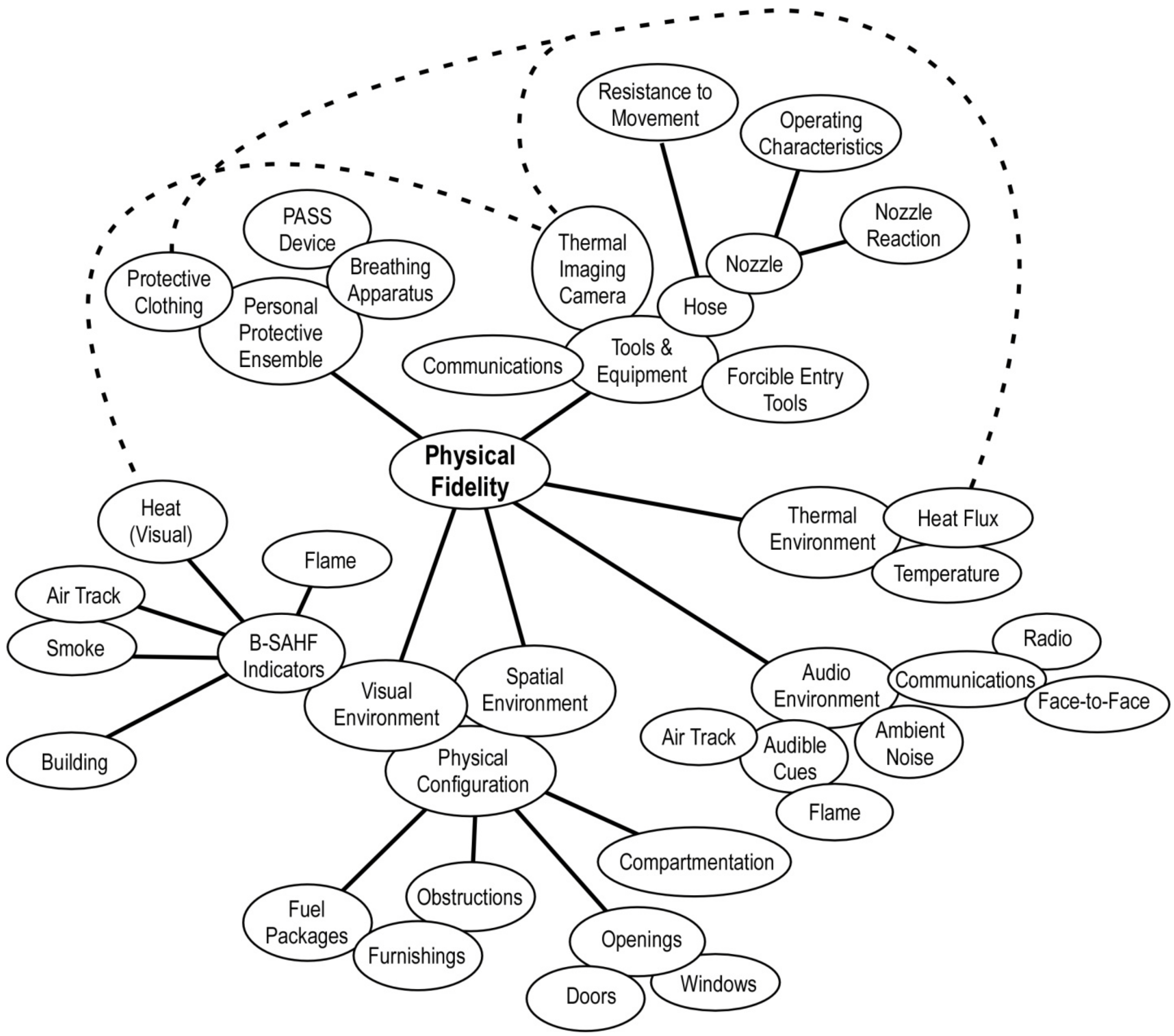
Physical and functional fidelity are potentially quite important in developing firefighters' understanding of fire behavior and skill in application of fire control techniques. The two questions that Roy posed are important. However, two more fundamental questions could be asked: 1) To what extent is the fire behavior in this container based prop reflective of conditions that would be encountered in a "real" fire? 2) Does it matter (given the learning outcomes intended for this training session)?

Physical Fidelity

Physical fidelity is important in providing visual, audible, and tactile cues that are essential to developing and maintaining situational awareness. In addition, physical fidelity is a key component in firefighters' perception of the realism of the simulation.

The concept of physical fidelity is simple. However, when you consider the compartment fire environment, it quickly becomes more complex.. Physical fidelity may include the firefighters' personal protective ensemble, tools, and equipment as well as visual, audio, and thermal aspects of the environment. As illustrated in Figure 7, a number of these elements of physical fidelity are interrelated.

Figure 7. Physical Fidelity Concept Map



This concept map is a simple and preliminary look at the elements of physical fidelity. Each of the concepts illustrated can be further refined and elaborated on to provide a richer picture of physical fidelity in live fire training.

Personal Protective Equipment

The toxic and thermal hazards in the live fire environment necessitate the use of personal protective equipment. Of necessity, firefighters must have a high level of proficiency in the use of personal protective equipment under a variety of conditions. Wearing the same personal protective ensemble as used in the operational environment provides an element of realistic context. Personal protective clothing and self-contained breathing apparatus also modify perception of visual and thermal cues (which may be a grey area between physical and functional fidelity). In addition, following normal breathing apparatus control and accountability procedures reinforces the importance of these procedures in the operational environment and make the requisite skills and practices second nature.

Tools and Equipment

Some CFBT evolutions do not require the use of firefighting tools and equipment other than a hose and nozzle. However, it is important to remember that not all that is learned is taught. What habits might be developed if learners do not become comfortable in deployment and use of hoselines while carrying the tools normally required during firefighting operations? Integration of the use of firefighting tools and equipment with CFBT may or may not have a significant impact on fire behavior learning outcomes, but is likely to positively influence firefighters' ability to work effectively in the fire environment.

Thermal Environment

The thermal environment is a likely critical element of physical context. Elevated temperature and changes (particularly increases) in temperature are critical cues in the fire environment. With use of a thermal imaging camera (TIC), some aspects of the thermal environment are translated to visual indicators. However, it is critical that firefighters not solely focus on technological means for perception of the thermal environment.

Audio Environment

Audible fire behavior indicators tend to be subtle (e.g., crackling of burning wood or sound resulting from high velocity air track). However, depending on the specific learning outcomes intended for a given training activity, these may be significant. Other elements of the audio environment may include ambient noise (e.g., apparatus, blowers (fans), and other power equipment) as well as sound from breathing apparatus and normal radio communication. Each of these audio elements provides a realistic context that may or may not have an influence on learner perception of critical cues and learning outcomes.

Spatial Environment

Compartment configuration has a major influence on functional fidelity, but also impacts firefighters' perception of the realism of training activity. For example, a single compartment, container based prop has limited similarity to a multi-compartment, residential structure. This is of little concern when conducting initial training in fire development and nozzle technique, but presents a challenge if this is the only facility available for tactical training.

Visual Environment

Many of the Building, Smoke, Air Track, Heat, and Flame (B-SAHF) fire behavior indicators are assessed visually. Developing learners' ability to read the fire and predict likely fire behavior is dependent on realistic appearance of these cues.

Functional Fidelity

While physical fidelity is important, functional fidelity; realistic functioning of the simulation, is likely even more important. Development of critical skills and the ability to read the impact of tactical action is dependent on adequate functional fidelity. As with physical fidelity, the concept is straight forward, the simulation should function in a realistic manner. However, this is likely to be even more complex than simply looking realistic. Roy Reyes's questions regarding behavior of flames during the fire behavior demonstration (as illustrated in Figure 6) provides an interesting starting point to think about the nature and importance of functional fidelity.

The first question asked, what do you see in the photo? Firefighters are engaged in a training session in a container based CFBT cell with a fire located in the front on the right side. A well defined hot gas layer has developed with flames extending through the hot gas layer at the center of the compartment.

The second question is more significant. Why are the flames extending in the hot gas layer in the center of the compartment and not across the full width of the compartment? There could be a number of possible explanations, but it is likely that the metal walls of the container are acting as thermal ballast. Energy used to increase the temperature of the metal compartment walls (which have excellent thermal conductivity) is not being used in the combustion process (preventing flaming combustion next to the walls). The same phenomenon can be demonstrated by placing a coil of copper wire into a candle flame. This causes a reduction in flaming combustion, and in many cases the wire absorbs sufficient energy to extinguish the flame.

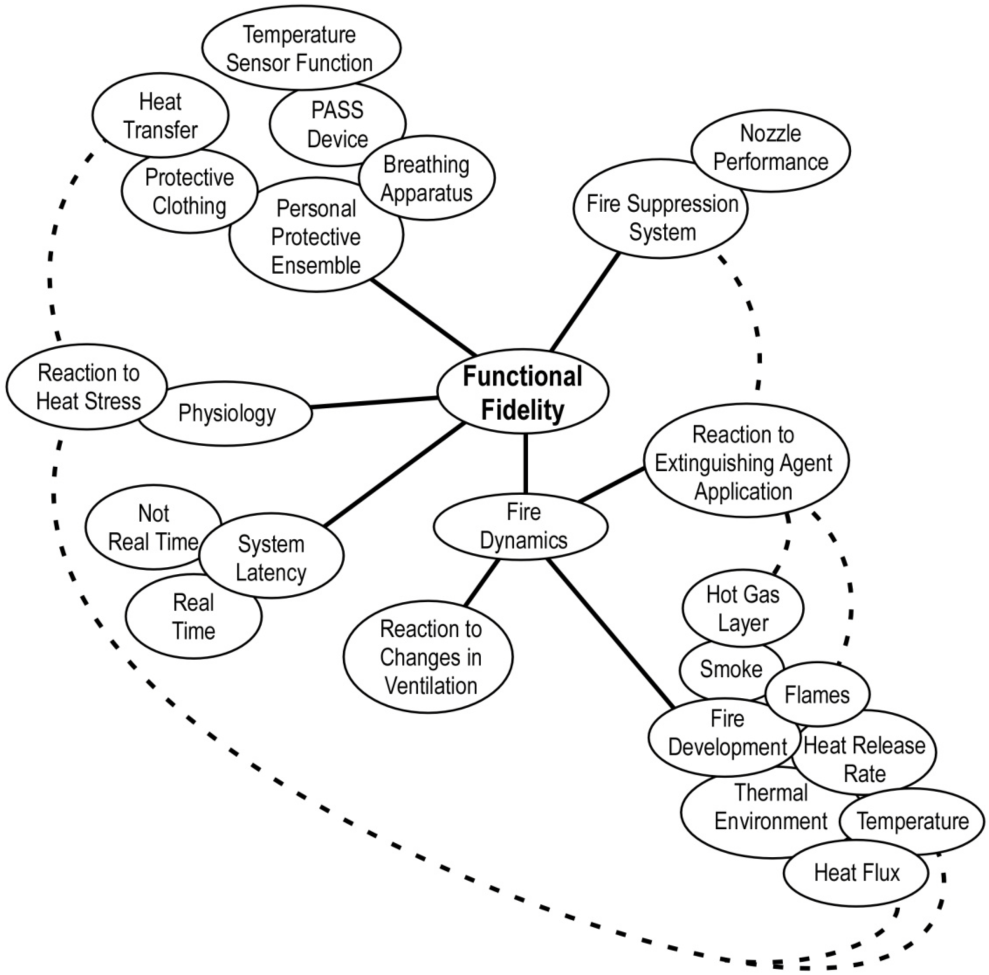
So, the thermal conductivity of the container walls can at times influence the behavior of flaming combustion in CFBT cells. Does this present a problem or is it simply an opportunity to present the puzzle to the learners and engage in discussions about heat transfer and the concept of thermal ballast?

As stated earlier, functional fidelity is the extent to which the simulation works and reacts realistically. Figure 8 identifies five subsystems related to functional fidelity of live fire simulation: 1) firefighter physiology, 2) personal protective equipment, 3) the fire suppression system (e.g., hose, nozzle), 4) system latency (i.e., time lag between action and response), and 5) fire dynamics. This concept map is a simple and preliminary look at the elements of functional fidelity. Each of the concepts illustrated can be further refined and elaborated on to provide a clearer picture of physical fidelity in live fire training.

Physiology & Personal Protective Ensemble

Live fire simulation places the participant in a hostile environment requiring the use of personal protective clothing and self-contained breathing apparatus. Functional fidelity in these subsystems and their interaction with the thermal environment may or may not be a critical element of context, depending on the intended learning outcomes of the simulation. However, insulation of firefighters from the thermal environment encountered in structural firefighting delays, modifies, and may limit perception of critical thermal cues (e.g., high temperature, changes in temperature). Overcoming this challenge requires training in a realistic thermal context.

Figure 8. Functional Fidelity Concept Map



Fire Suppression System

One of the most critical elements in functional fidelity of the fire suppression system involves interaction with fire dynamics: Does the fire and fire environment (e.g., hot gas layer) react appropriately to extinguishing agent application? In some respects there may be a conflict between the desire for physical fidelity of the fire suppression system and functional fidelity of the interaction between extinguishing agent application and fire dynamics. For example, it may be desirable for participants to use the same flow rate (providing realistic nozzle reaction) in simulations as will be used in the structural firefighting environment. However, the limited fuel load typically used to provide a safe training environment do not result in the same required flow rate for fire control as fire in a typical residential or commercial compartment. Does use of a high flow handline in live fire simulation with limited fuel load create an unrealistic expectation of the performance under actual incident conditions? Which is more effective, realistic flow rate with a limited fuel load or matching of flow rate and fuel load to provide a realistic interaction between the fire and fire attack? This question remains to be answered.

The type of nozzle used presents a simpler issue related to functional fidelity in live fire simulation. Most combination nozzles have similar operational controls for controlling the flow of water (i.e. on and off) and pattern adjustment. However, there are subtle differences such as the extent of movement needed to adjust from straight stream to wide angle fog. Flow control mechanisms vary more widely from fixed flow rate, to variable flow and automatic nozzles. Firefighters must be able to select pattern and flow as necessary based on conditions encountered in the fire environment and intended method of water application. Use of a substantively different nozzle in training than during incident operations is likely to result in less than optimal performance. However, as with the question of flow rate, the extent to which this is a concern is unknown.

System Latency

In general, live fire training simulations are conducted in real time. However, time lag due to system limitations in Class B (gas) fired props or delay in instructor or operator perception of changing conditions in either Class A or B fueled props can influence system latency, resulting in faster or slower than normal interaction between fire dynamics and fire control subsystems.

Fire Dynamics

Likely the greatest concerns with regards to functional fidelity are in the area of fire dynamics. If firefighters are to learn how fires develop and the impact of changes to ventilation profile and application of extinguishing agents, the fire must behave as it would under actual incident conditions (or as close to this ideal as can be safely and practically accomplished).

Most fuels encountered in structure fires are solids (e.g., furniture, interior finish, structural materials). Class A fuel used in live fire training, often has a lower heat of combustion and heat release rate than typical fuel in the built environment, but is similar in that it must undergo pyrolysis in order to burn; providing similar (but not identical) combustion performance. Combustion of Class A fuel also results in generation of significant smoke, another similarity to typical fuels in the built environment. Class B (gas) fuel used in structure fire simulations has a high heat of combustion with heat release rate controlled through engineering and design of the burner system. However, this fuel generally burns cleanly, necessitating introduction of artificial smoke to provide higher fidelity. Flaming combustion and smoke production must be mechanically controlled by a computerized system, a human operator, or both. The nature of the fuel and design of the combustion system also impact on the fires reaction to changes in ventilation and application of extinguishing agents such as water.

Changes to ventilation will not substantively influence fire behavior if the fire is fuel controlled. However, if the fire is ventilation controlled, changes in ventilation can have a significant impact on fire behavior (which may or may not be desirable, depending on the intended learning outcomes).

With Class A fuel, water applied to cool the hot gas layer or to fuel packages has a similar impact as it would in actual structural firefighting operations. The degree of similarity is dependent on the design of the compartment in which the training is being conducted as well as fuel factors and ventilation profile. With Class B fuel, temperature sensors, computerized controls, and a human operator all must interact to ensure that water application results in appropriate changes to combustion.

Maintaining the Balance

One important factor to consider in live fire training simulation is that despite the fact that it is a training exercise, the fire is real. While I too use the terms training fire and real fire, the combustion processes and fire dynamics in live fire training are the same as encountered in a structure fire. What is different is the type, amount, and geometry of the fuel used and the ventilation profile. Providing complete functional fidelity (as well as physical fidelity) simply requires that structural environment, fuel loading, and ventilation be the same as would be encountered in an actual incident. However, this substantially increases variability of outcome and the risk to participants.

Use of a purpose built structure allows control of variability and provides the ability for repetitive and ongoing training. Purpose-built structures are often designed to use either solid Class A fuel or gaseous Class B fuel. Facility design and selection of fuel type should be based on a wide range of factors including provision of adequate fidelity for the type of training to be conducted, environmental issues, health and safety of participants, anticipated duty cycle (i.e., frequency and duration of training activity) and life-cycle cost (e.g., initial purchase price, ongoing maintenance costs).

Figure 9. Live Fire Simulation with Class B/Gas (left) and Class A/Carbonaceous Fuel (right)

As illustrated in Figure 9, there can be obvious and substantial differences in physical fidelity when gas fired props are used to simulate a typical compartment fire. Depending on the purpose of the simulation these physical differences can be important. However, differences in functional fidelity may be even more important.

Training Facilities and Systems

While CFBT may incorporate a wide range of simulation that does not involve live fire (e.g., photo or video based exercises, two-dimensional computer based simulation, immersive virtual reality),at present live fire training remains the only means to provide near full context training in fire behavior and firefighting tactical operations. There are a wide range of props and facilities used for live fire training, each of which has different performance characteristics and capabilities.

What types of live fire training facilities are most appropriate? The answer to this question is at once simple and complex! The simple answer is that it depends on your intended learning outcomes. The more complex answer requires fire service trainers to balance the fidelity required to achieve intended learning outcomes with environmental concerns and economic limitations.

Realistic Live Fire Training

Kriss Garcia and Reinhard Kauffman authored an article titled Realistic Live Burn Training You Can Afford which was published in *Fire Engineering* magazine in May of 2009. In this article, they extolled the advantages of constructing a panelized wood frame structure lined with several layers of 5/8" sheetrock (see Figure 10) as an alternative to other types of structural live fire training props and facilities. While this prop is designed for temporary and limited use, it replicates some important characteristics of typical wood frame, residential structures in the United States. This raises an interesting question. To what extent does a fire training prop or facility need to replicate the characteristics of the type of structure it is intended to simulate? Focusing this question more specifically, what specific characteristics are most important (e.g., configuration and compartmentation, thermal performance, ventilation profile)?

Figure 10. Build and Burn Single Family Dwelling

Photo provided by Kriss Garcia (positivepressureattack.com)

The most important factor to consider in design, selection, and use of live fire training props and facilities is that all live fire training is a simulation. The fire is real, but the fuel load and conditions are managed to create a specific effect (unlike in the "real world"). This does not necessarily mean that the training is ineffective, simply that each evolution is intended to provide the participants with a specific opportunity to learn and develop skills.

Kriss and Reinhard (2009) are particularly critical of props constructed from steel containers. They state that these type of props do not provide a realistic context for showing fire development or honing fire tactical skills. I respectfully disagree with several caveats. 1) A single compartment prop (such as a demonstration or attack cell) is not designed or intended for tactical training. This type of prop is designed to provide a safe and effective environment to demonstrate fundamental fire development in a compartment and the opportunity for learners to practice nozzle technique. 2) Multi-compartment container-based props do provide a reasonable context for tactical training with interior doors, obstructions, potential for varied fire location, etc. However, as with all other types of prop using Class A fuel (including the build and burn structure), the fuel load and configuration is considerably different than in an actual dwelling or commercial structure. Kriss also points to the severe fire conditions and damage to both equipment and participants when working in container based props. This is the result of inappropriate use, not a defect in the type of prop used. Conditions are set and controlled by the instructors.

I have greater agreement with Kriss's and Reinhard's (2009) observations on high-tech gas fired props in that they often fail to replicate key fire behavior indicators and may not respond appropriately to ventilation and application of water, providing poor feedback to the learners on their performance.

I also agree with many of Kriss's and Reinhard's (2009) observations on acquired structures. However, their example illustrating "unpredictable fire behavior" due to medium density fiberboard that had been plastered over, resulting in ignition of pyrolysis products behind the attack crew is inaccurate. This fire behavior was entirely predictable, but unanticipated (the big difference here is that unanticipated fire behavior is simply the result of a lack of information on the part of the instructors, not by random action by the fire). Kriss states that when working with acquired structures, you need to strictly adhere to the requirements of NFPA 1403. This may be a bit misleading in that this standard applies to all live fire training (including use of the build and burn structure).

Kriss and Reinhard (2009) make a good case for the ideal live fire training structure. However, it is critical to also give some thought to the intended purpose of the building or prop. Single compartment props (regardless of what they are constructed out of) may be a tremendous tool for practicing door entry and nozzle technique much like a putting green or driving range when practicing golf. The putting green and driving range are useful tools in developing specific skills, but they are not the game of golf. The ideal live fire training prop is designed to provide a means to safely, effectively, and efficiently achieve specified learning outcomes. Much the same as there is no single tactic that will solve all problems presented on the fireground, there is no single type of live fire training prop that provides the ideal context for all types of live fire training evolutions. Again, it is critical to remember that all live fire training is a simulation. The key is to provide an adequate degree of physical and functional fidelity (look real enough and behaves real enough) to achieve the intended learning outcomes.

Intended Use and Learning Outcomes

Pilots in the United States Air Force follow an exacting course of study which includes classroom instruction, simulation, and flight instruction in trainer aircraft such as theT6 and T38 before progression to more advanced aircraft such as the F22 Raptor. Each simulator and aircraft used in this progression is intended to provide the pilot with a specific learning context. After transition to high performance aircraft, pilots continue to use simulators to practice skills that may be too high risk to perform in flight.

Figure 11. T6, T38, & F22 Aircraft

The same concept can be applied to live fire training. Observing fire development and the effect of water application may require a somewhat different context than evolutions involving door entry procedures and integration of fire control and tactical ventilation. In an ideal world, fire service agencies would have access to various types of live fire training props, each suited to providing the best context for specific levels of training and learning outcomes.

Container based props and burn buildings may be simple or complex dependent on their intended purpose and learning outcomes that they are designed to support (see Figures 12-16).

Figure 12. Split Level Cell, Palm Beach County Fire Rescue

Figure 13. Single Level Demo/Attack Cell, Gresham (OR) Fire & Emergency Services

Figure 14. Large Volume Container, Swedish Civil Contingencies Agency, Sandö, Sweden

Figure 15. Small Masonry Burn Building, Fairfax (VA) Fire & Rescue

Figure 16. Large Masonry Burn Building, British Fire Service College

Each of these structures has significantly different characteristics and is most appropriate to support different learning outcomes (but can, and are often of necessity used for varied purposes). Fire departments faced with limited fiscal resources are often limited in their options for live fire training. If they are fortunate, they have or have access to a purpose built structure that provides a safe and effective environment for a variety of types of live fire training. Each of these types of structures has limitations. The major problem encountered is when instructors and learners believe that the purpose built structure is intended to fully replicate a realistic fire environment as encountered during emergency incidents. It cannot, much the same as a flight simulator cannot fully replicate flying a high performance aircraft. However, it can replicate critical elements of context that help develop knowledge, skill, and a high level of proficiency.

Instructors must 1) identify the intended learning outcomes and critical elements of context necessary to develop learner proficiency to ensure participant safety and 2) recognize both the capabilities and limitations of the props and facilities available.

Other Considerations

Fire departments often face a more difficult challenge than determining what type of prop or facility is most effective or how to best use available facilities. The cost of live fire training is a major concern and unfortunately is often a major determining factor in the availability and type of live fire training conducted. The initial cost for purpose built props and facilities can be a large hurdle with simple commercially built props and structures costing from $40,000 to hundreds of thousands of dollars (or even more for a large burn building as illustrated in Figure16). However, initial cost of the prop or facility is the tip of the iceberg. Ongoing costs include fuel, maintenance, as well as instructor and student costs.

In addition to operational characteristics and cost, environmental considerations and restrictions can also have a significant impact on both design and operation of live fire training facilities and can also have a impact on initial and ongoing cost of operation.

The Way Forward

In general, there has not been a concerted and scientifically based effort to determine the critical elements of context required for live fire training. Live fire training must look real enough (physical fidelity) and react realistically to tactical operations (functional fidelity). However, we have not defined to what extent this is necessary to develop critical skills.

The variety of props, structures, and facilities available for live fire training is substantial, as is the difference in initial, ongoing, and life-cycle cost. While some work has been done comparing these various options, it is often left to individual departments to sort this out without a consistent framework or methodology.

Questions Remain

In their 2009 meeting in Sydney, Australia, the IFE Compartment Firefighting SIG identified the need for a greater emphasis on fire behavior training at all levels (e.g., entry level firefighters, incumbent firefighters, and fire officer) as well as ongoing professional development and skills maintenance. However, a number of interesting questions remain, including:

- What are the most effective methods of developing firefighters' understanding of compartment fire behavior?
- What is necessary to effectively facilitate transfer of this knowledge from training to the operational context?
- What level of fidelity is necessary in live fire training do develop and maintain critical skills?
- How can technological simulation (computer or video based) be used to augment live fire training to maintain proficiency?
- To what extent might non-live fire simulation (e.g., two dimensional or immersive virtual reality computer based simulation) be used to develop compartment firefighting competencies?

Professor David Morgan of Portland State University observes that "A successful research project requires two things: Meaningful research questions and appropriate means to answer those questions" (Morgan, 2005, p. 1-2). One of the greatest potential benefits resulting from collaboration between members of the IFE Compartment Firefighting SIG is the integration of the skills of academics and practitioners, scientists and firefighters. During the 2009 workshop, SIG member Steve Kerber from Underwriters Laboratory (formerly with the National Institute for Standards and Technology) emphasized the importance of scientists and engineers doing research *with*, not simply for the fire service. This has the potential to not only identify meaningful questions, but also to provide the knowledge and skills necessary to answer them.

At present, live fire training simulation using Class A fuel provides the highest (physical and functional) fidelity. However, there is no reason why other systems such as those using Class B (gas) fuel could not be designed in such a way to provide higher fidelity. However, this would likely increase both complexity and cost. In addition, there is tremendous potential for use of computer based (non-live-fire) fire training systems to develop some (but likely not all) of the skills necessary to safely operate in the structural firefighting environment.

Closing Thoughts

Commercial and military pilots follow an exacting course of study which includes classroom instruction, simulation, and flight instruction in trainer aircraft before progression to more advanced aircraft. Each simulator and aircraft used in this progression is intended to provide the pilot with a specific learning context. After transition to high performance aircraft, pilots continue to use simulators to practice skills that may be too high risk to perform in flight. The same concept can be applied to live fire training.

All live fire training is a simulation. However, it must have adequate physical and functional fidelity (i.e., it must look, work, and react with sufficient realism) if it is to be effective. Live fire training must replicate critical elements of context necessary to develop knowledge, skill, and a high level of proficiency based on the intended learning outcomes. However, it is important to recognize that not all that is learned is taught. Missing elements of critical context can have unintended, and potentially hazardous consequences.

Effective performance under stressful conditions requires substantial training in a realistic context. However, the exact degree and specific nature of fidelity to develop the knowledge and skill required for safe and effective fireground operation is unknown. This presentation will examine live fire training as a simulation of the operational environment and key elements of fidelity that potentially impact learning outcomes.

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