Fire Dynamics

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Section I - Firefighting Fundamentals

The Fundamentals

Scene Size-Up

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Introduction

Why learn fire dynamics? During fire suppression, firefighters can be confronted with a rapidly changing fire environment. And while many firefighters focus their training on the manipulative tasks of suppression, the majority of firefighter injuries and deaths are attributed to the lack of awareness of the fire environment. Furthermore, understanding fire dynamics provides firefighters the tools to anticipate and respond more effectively. With each incident presenting its own unique set of characteristics, our knowledge on the given subject will dictate the appropriate tactic. To put it simply, the better we can understand what the fire wants to do; the more equipped we are to employ the appropriate response. This lays the groundwork for an aggressive culture, which in turn supports the ultimate goal of the fire service: protecting human life.

The following chapter is divided into five phases collectively titled "The Flow of the Call." Each phase is structured and prioritized to replicate the approach of a real-life incident. The five phases are: Learn the Fundamentals, Size-up the Scene, Identify Flow Path, Exterior Water Application, and Interior Water Application. Although structure fires are highly dynamic and complex, our approach to them should stay systematic, as this approach best accomplishes strategic objectives like rescue, fire suppression, and safety.

THE FLOW OF THE CALL

Phase I: The Fundamentals

The goal of this phase is to develop a strong fundamental knowledge for readers to reference as they progress further into the subsequent phases of this chapter. If the fundamentals are not fully understood, the following four phases will fall short. The challenge when conveying content involving fire dynamics is that it can become driven by endless amounts of definitions, theories, and numbers. When delivered with the wrong approach it can become extremely dry for any reader, let alone an entry-level firefighter. To combat this problem, The Fundamentals section is organized to replicate the same sequences a fire follows as it grows from a small flame to a fully involved structure fire. Every step of this event will be explained in greater detail later, but as an initial overview, every structure fire begins as such:

1. The Fire Triangle: A fuel is surrounded by an oxidizer (oxygen), once it is exposed to a form of heat a chemical chain reaction is created, leading to a visible flame.
2. Products of Combustion: Depending on a few variables, whenever a flame is present it will create heat, smoke, and pressure.
3. Heat Transfer: Using the flames and products of combustion as a vessel; heat will transfer itself to its surrounding environment, recruiting additional fuels to heat and pyrolyze, compounding the problem.
4. Stages of Fire: As the fire grows larger, it follows through a sequence of stages with key identifiable indicators. This is where firefighters can make informed decisions that can lead to suppression or rapid-fire spread.
5. Rapid-Fire Development: Fire spread and its heat release rate has reached its peak potential.

The Fire Triangle

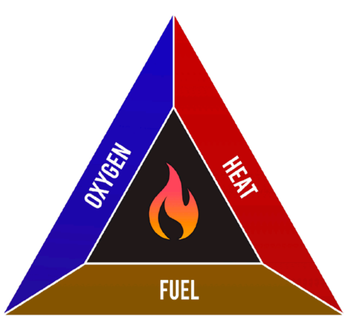


Figure 7-1 Fire Triangle

The Fire Triangle is a visual representation of the three required components that create and sustain fire. Each side of the triangle represents one of the three components Heat, Oxygen, and a Fuel. Why is it so important to understand the fire triangle? A fire is in a constant battle to stabilize all three of its components to sustain combustion. If any one of its components becomes diminished, the fire will smolder and self-extinguish. The better understanding a firefighter has with what stabilizes the triangle, the better the firefighter understands what must be done to deconstruct it.

Heat

The heat component of the fire triangle specifically represents the minimum temperature necessary to ignite a fuel in its atmosphere. To explain further, smoke and gases fill our fires environment, each gas within that atmosphere has its own distinct threshold of temperature that will cause it to ignite, this is referred to as an Auto-ignition Temperature.

How does this information apply to firefighting? During a structure fire, a firefighter will search for the seat of the fire, progressing deeper into the hot, smoke-filled environment. During this path of travel, the firefighter is constantly surrounded with heated gases despite not meeting any visible flames. It's important for the firefighter to identify that while their environment is not currently met with flames, it has the potential to quickly become flammable if we allow the gases to reach their auto-ignition temperatures.

Lastly, while the ignition of gases is our greatest concern, even modest heat without visible flames still presents a substantial threat. Because victims are not afforded the same level of respiratory or skin protection as we are, heat in the form of smoke and gases still subjects victims to lethal outcomes. With this considered, firefighter's must shift their mindset in how water is flown. With the unprotected victims being our greatest priority; water must be applied liberally as an advancement is made, and not just to direct flames but to our compartments smoke and gases as well.

Oxygen

Fires require an oxidizing agent to support the combustion process. Oxygen is the most common naturally occurring oxidizer in air; with a mixture of 21% oxygen, 78% nitrogen, and 1% other elements. In today's modern fire environment, oxygen plays the largest role in the fire's direction of growth. As a fire grows, its supply of oxygen is quickly consumed, requiring a constant supply available to support its progression. However, if oxygen levels drop below 15%, flaming combustion can no longer be supported, resulting in a direction headed towards decay.

How does this information apply to firefighting? If the fire consumes all of its available oxygen or if we tactfully suffocate the fire's supply of oxygen, the end result is suppression. The core issue with structural firefighting is that the fire exists within a compartment. In order to reach and extinguish the fire or perform victim rescues, the firefighter must open up that compartment. This results in an influx of fresh oxygen, further stabilizing the fire triangle. Further in this chapter, we divulge deeper in how a firefighter can transition to interior operations while still restricting the flow of oxygen for fire suppression.

Fuel

A fuel can be any substance that has a fixed shape and volume. Commonly identified fuels include wood, gasoline, and natural gas (methane). What you may notice is that fuels can exist in three different states of matter: solids, liquids, and gases. Though fuels come in three different forms; the most important thing that a firefighter needs to know is that fuels can only burn in one of the three states of matter, which is the gaseous state. In order

Figure 7-2 Solid fuel heated creating pyrolysis gases

for a solid or liquid fuel to burn they must be exposed to a heat source that physically converts them into a gas.

Solid

Solid fuels include woods, plastics, and synthetic building materials. The process of a solid fuel decomposing into a gas is known as pyrolysis. The process of pyrolysis requires sufficient amounts of heat to convert a solid substance into an ignitable gas. A commonly known example of pyrolysis is watching a piece of wood be exposed to an open flame. While it initially does not catch on fire; what can be seen is the wood slowly decomposing to the flame. You begin to see the wood darken and char as white and grey fumes pyrolyze and leave the wood. If you were to look closely, once the wood catches on fire you'd see that the pyrolyzed gases are igniting, not the wood itself. The take-away from this is to change how a firefighter views a smoke-rich environment. Smoke is unburnt fuel; therefore, a smoke-rich environment is one that could combust entirely when it has reached a high enough temperature.

Figure 7-3 Liquid fuel heated creating vaporization of gases

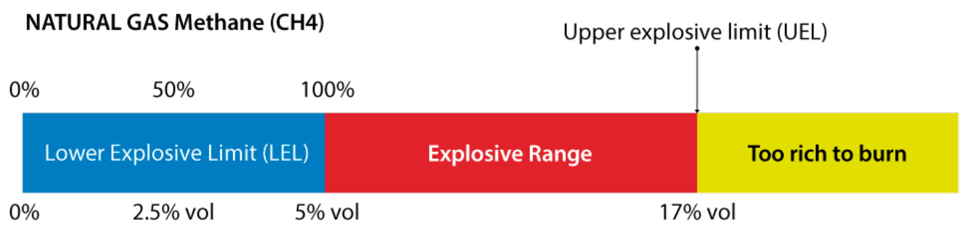
Liquid

An example of liquid fuels includes gasoline, diesel, and cooking oil. Like solids, liquid fuels must first be converted into a gaseous state before they can burn. The process of a liquid turning into a gas is known as vaporization. A commonly known example of vaporization is spilled gasoline on a hot sunny day. Once gasoline is spilled onto the hot asphalt floor, the small puddle quickly disappears into the atmosphere. The heat of the floor transfers to the liquid causing it to reach a temperature in which the liquid vaporizes and converts into a gas. Whether a liquid will convert into a gas depends on temperature.

Gas

Gaseous fuels include propane, methane, and carbon monoxide. For any gas to ignite, it must be within its flammable range. The term flammable range refers to the specific mixture of gas and oxygen that supports combustion. Imagine a kitchen leaking a large amount of methane gas. Initially, there is no chance that the room explodes because the mixture of methane to oxygen is too lean. The kitchen does not have enough methane gas present to support combustion. In other words, the methane is below the Lower Explosive Limit (LEL). On the flip side, if the gas leak continued long enough the methane would eventually displace the room's oxygen. The kitchen would have an excessive amount of methane and not enough oxygen to support combustion. This mixture is considered too rich to explode. In other words, the mixture exceeded methane's Upper Explosive Limit (UEL). The Flammable Range is the spectrum of a gas's concentration that supports combustion.

This concept applies to structural firefighting heavily. As a structure fire progresses, the compartment and its contents off-gas an abundance of superheated gases. This completes two of the three components of the fire triangle (fuel, heat). So why hasn't the room ignited? The concentration of fuel relative to oxygen is too rich (above the UEL). If the firefighter cannot identify the current state of the fire triangle, they don't recognize that any influx of oxygen can cause the gases to fall back within its flammable range and ignite.



Heat Types

Figure 7-4 Friction generating heat

As you read this, you're currently in an environment surrounded by fuels and a large amount of oxygen. The reason why your environment isn't igniting is because there isn't a source providing sufficient amounts of heat. For any fire to occur, the fuels must be heated sufficiently to convert their current physical state into a gas and then further heated to reach its auto-ignition temperature. The ignition source of a fire is the result of one of the following types of heat: chemical, electrical, or mechanical.

Chemical

For chemical ignition to occur, the oxidation must be rapid enough to reach the fuel's auto-ignition temperature. Rags soaked in linseed oil sitting in an insulated container can heat spontaneously and ignite. This illustrates a form of chemical ignition. Another example of chemical heat is the decomposition of organic matter in a mulch pile.

Electrical

Electricity can generate heat in several ways. When electrical currents flow through a conductor, heat is produced. When the current exceeds its design limits it can overheat and become an ignition source. Electrical arcing caused by a short circuit or loose connection can also produce heat. Electricity can cause a spark, which can also be a source of ignition.

Mechanical

Mechanical heat energy is generated by friction or compression. When two surfaces are rubbed together, friction is present which creates heat. A common example is striking a match. Friction is generated as a match head is rubbed against a coarse striker, creating the heat necessary to ignite the match. Heat of compression is generated when a gas is compressed. Diesel engines employ very high compression ratios that produce sufficient heat to ignite the fuel/air mixture in the cylinders without the use of a spark plug.

Products of Combustion

Heat

Heat from a fire presents two separate problems for structural firefighting. One problem is the heat's temperature and the other is the heat release rate. Let's address both. The temperature of heat presents a multitude of challenges for structural firefighting. The temperature itself pushes our turnout gear to their limits, impairs our physical and mental performance, and elevates all fuels present to reach their auto-ignition temperature. The second challenge is the Heat Release Rate (HRR). This refers to how quickly heat can release itself to affect its surrounding environment. For example: imagine placing a dense wooden dresser against a flame. While it will eventually catch fire and release its heat to its surrounding environment it will take several minutes to do so. Now compare that to a similarly sized plastic dresser which will catch fire in less than a minute. Both items will eventually release roughly the same amount of heat and energy but at drastically different rates. Modern building materials, furniture, and household contents are predominantly made with synthetic materials such as plastics and hydrocarbons as opposed to legacy furniture, which were mostly solid wood. These modern materials drastically accelerate the rate that heat, and fire spread. The more synthetic materials present, the higher the HRR will be; resulting in less time for occupants to egress and less time for firefighters to prevent flashover and search for victims.

Smoke

Smoke is the product of incomplete combustion. As a rule of thumb, the darker the smoke becomes, the more pronounced incomplete combustion is present. Darker smoke from incomplete combustion is typically due to two main variables. If a fire has a limited amount of oxygen present, the combustion process will not be able to consume all the flammable materials present and thus, will result in the remaining products to off-gas in the form of gasses, vapors, and particulates. The second variable causing incomplete combustion is due to the type of fuel that is burning. Plastics, and other hydrocarbon-based products found in modern fuels, produce large amounts of black smoke due to its inability to be fully consumed during combustion. Plastics leave large amounts of micro-fuels left over for further combustion.

The takeaway message is this: as oxygen becomes limited or when the fuel load is primarily hydrocarbons, the products of combustion will be more pronounced in visibility in the form of dark black smoke. Remember, smoke is unburnt fuel. It can and will combust if it finds the right concentration of oxygen and heat.

Gases

Gases are created as the room's contents decompose via Pyrolysis. The most common gasses from pyrolysis are carbon monoxide, carbon dioxide, and methane. These gases are typically referred to as our white, grey, and brown colored smokes ***. As temperatures rise these gases will expand and rise in elevation. Not only are these gases toxic to occupants, they are also highly flammable as well. Combustion can happen instantly if these gases mix with the right concentration of oxygen and heat.

Pressure

One of the most overlooked products of combustion is pressure. Yet pressure is extremely important for a firefighter to understand. Fires produce pressure as gases and smoke rapidly expand. The hotter a fire grows, the higher the pressure builds. Pressure seeks to move from areas of high concentration to low concentration. Once an entire occupancy builds with pressure, the exterior of the home becomes the area of "low concentration" relative to the interior. This would be recognized by pressurized smoke and/or fire forcefully leaving exhaust points such as windows and doors. Because firefighters begin their fire attack starting from the exterior of the home, their initial point of entry can be turned into an exhaust point from which pressure to exit from the structure. As hose streams begin to progress deeper into the structure, they can be met with and overwhelmed by the pressure pushing against them. To combat this, firefighters must win the battle of pressure through the use of their hose streams to push away the products of combustion. With details covered later, firefighters will direct hose streams to the ceiling, creating the greatest amount of gas contraction which in turn, reduces pressure. Once a ventilation point is established, firefighters can then emphasize air entrainment through the movement of their hose streams to push away the products of combustion. Another sign associated with pressure is the heat accompanied with it. The hotter a fire grows, the higher the pressure builds. As you identify high amounts of pressure, from the interior or exterior of the structure, the firefighter must be aware that the fires rate of progression is growing towards flashover.

Heat Transfer

Heat transfer is the transport of heat and energy from an area of high heat to another area of lower heat. For example, consider a Christmas tree on fire in a living room. Heat would travel up and away from the burning tree via a vertical channel until it reached resistance at the ceiling. After hitting the resistance of the ceiling, the heat would channel horizontally seeking cooler areas. Heat transfer has three mechanisms of travel: conduction, convection, and radiation.

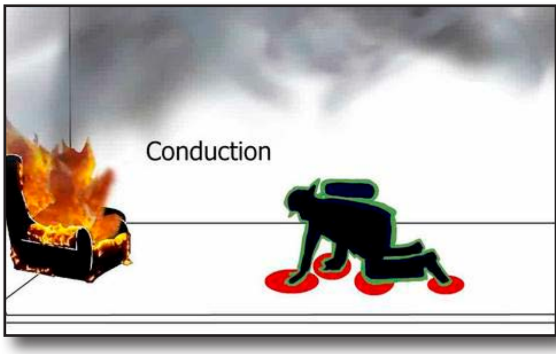


Figure 7-6 Heat Transfer - Conduction

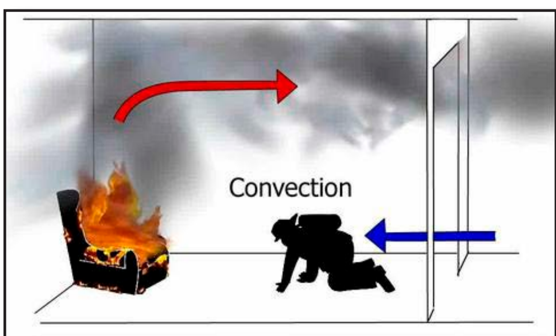


Figure 7-5 Heat Transfer - Convection

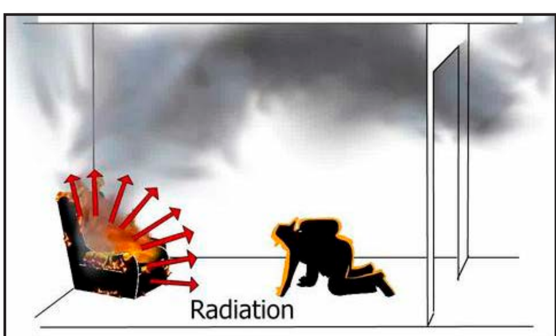


Figure 7-7 Heat Transfer - Radiation

Conduction

Conduction is the transfer of heat when an object is in direct contact with a heat source.. An example of this would be the flame of a lit match placed directly against a curtain. The flame's direct contact with the fabric of the curtain transfers heat via conduction.

Convection

Convection is the transfer of heat through the circulation of heated liquids or gases. In a structure fire, convective heat is heavily present as heated smoke and gases. As the initial room of origin is free burning, the traveling smoke begins to heat and pyrolyze the adjacent contents, compounding the problem. As the volume of smoke increases it begins to lower its level; victims seeking refuge become more susceptible to the impact of its heat. Understanding the transfer of convective heat must shift a firefighter's mindset that smoke, and gases play just as equal of a role as the flame itself in spreading heat within a compartment. If we want to slow heat transfer, disrupt pyrolysis, and better protect victims, we must use water to not just suppress flames but to also cool the heated smoke and gases when temperatures are becoming untenable.

Radiation

Radiation is the transfer of heat energy by electromagnetic waves. Though they are invisible, electromagnetic waves are emitted off all heat sources. If you place your hand a short distance away from a fire, you feel the radiant heat. The larger the heat source, the greater the presence of radiant heat. As the fire grows, radiant heat becomes even more dominant than convective heat. As radiant heat amplifies, the room's overall heat release rate drastically increases.

Stages of Fire

There are several distinct stages of fire: Incipient, Growth, Ventilation-Limited, Fully Developed, and Decay. The varying stages evolve as the fire grows and decays in volume, displaying their own identifiable characteristics. **The main objective for this section is to help you identify the fire's crucial transition between the Growth stage and the Fully Developed staged.** This key transition is where flashover occurs. One of the leading causes of firefighter deaths is being caught in a flashover environment. The better we can recognize this crucial transition, the quicker we can adjust both our tactics and our position within the fiery compartment. Another important aspect to emphasize is that the stages of fire will not exist singularly. Structure fires involve multiple compartments within that structure that are all developing at different rates. Where one compartment may be in its incipient stage, another may be on the brink of flashover.

Incipient Stage

This is the beginning stage of a fire. The fire triangle is established with a flame localized to its initial fuel package. The heated products of combustion form a thin plume of smoke and gasses that quickly rise upward. This rise is rapidly dispersed horizontally in a shallow layer at the ceiling. This is referred to as the ceiling jet. Convection is the primary source of heat transfer during the incipient phase. A unique benchmark characteristic of the incipient stage is that; the overall environment in the room is not influenced by the fire. In other words, despite the fact that a hot fire consumes the initial fuel package, the overall temperature and oxygen levels in the room remain unchanged.

Figure 7-8 Incipient Stage

Growth Stage

The growth stage begins as the room's environment becomes impacted by the fire; the oxygen level decreases, and the temperature rises. The increasing temperature recruits more items to pyrolysize and burn. The primary mode of heat transfer transitions from convection to radiation. This is important to note as it marks the point when turnout gear begins to saturate with radiant heat. As the growth stage progresses, oxygen will rapidly be consumed and the fire's need for more oxygen will depend on a new opening for ventilation. Whether or not ventilation can be found will dictate the fires transition in one of two directions, to a Fully Developed fire or to a Ventilation-Limited state. The Growth Stage has some specific indicators

Figure 7-9 Neutral plane continues to lower in level as Growth Stage matures

that experienced firefighters can use to predict which direction the fire will progress. Read on below for a description of these indicators.

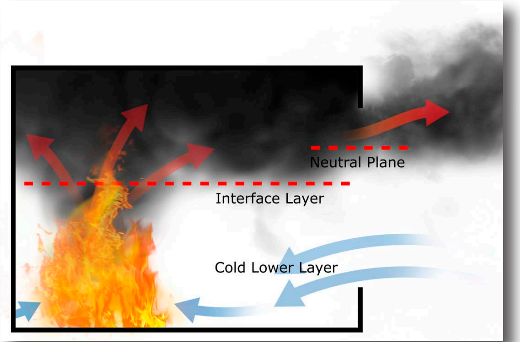


Figure 7-10 Neutral Plane

Neutral Plane

As the production of smoke increases during the growth phase, the smoke's volume will grow so large that it slowly accumulates downward from the ceiling toward the floor of the compartment. This creates a visual point of connection where the layer of smoke meets the underlying layer of fresh air, this is called the neutral plane. Firefighters must identify where the neutral plane exists relative to the compartment ceiling's height. The lower the neutral plane drops in elevation, the closer the compartment is to flashover. Also, when dealing with tall compartments, firefighters must carefully assess their environment as the neutral planes level can be deceptively high and still reach flashover.

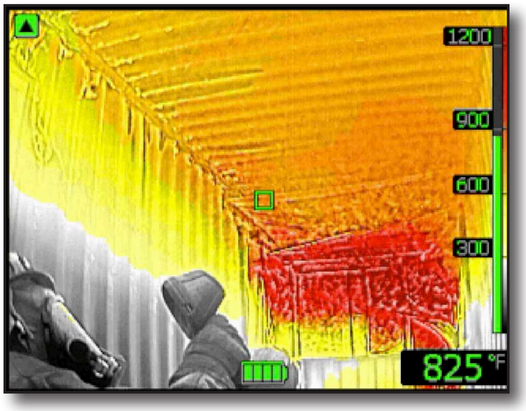


Figure 7-11 Thermal Layering through a Thermal Imaging Camera (TIC)

Thermal Layering

As heat filled gases grow in volume within a compartment, the gases will gradually layer themselves from top to bottom based on their temperatures. The hottest of gases stay at the top while the lower temperature gases drop towards the bottom. The further the fire progresses; the greater the temperatures increase at all layers until the rooms gases and contents collectively reach their ignition temperature and form a flashover. When met with extremely high temperatures at the compartment's lower levels, firefighters must identify that flashover conditions are rapidly approaching.

Rollover

Rollover is a late sign of impending flashover. Rollover can be seen at the highest part of the compartment where the hottest layers of the atmosphere exist. Smoke and gasses at that level have reached their autoignition temperatures causing them to combust and form a "roll" of flames that travel across the ceiling. Rollover is a significant indicator of impending flashover that firefighters must identify for their safety.

Figure 7-12 Rollover

Vent-Point Ignition

Vent-point ignition is a visual indication of pre-flashover conditions that can be identified from the outside of a structure. Imagine hot pressurized smoke rapidly leaving an opening. Suddenly you begin to see the smoke ignite and sustain a flame a bit farther from the exhaust point where the smoke is less dense. Let's apply the fire triangle to these conditions. The internal environment of the compartment is filled with gasses and smoke that are both rich in temperature and fuel but cannot combust into flame due to the missing oxygen.Once the smoke expels outside the compartment, it meets the external environment's oxygen and immediately turns into flames.

Ventilation-Limited

As mentioned earlier, a fire can progress through the Growth Phase in two directions: to a Ventilation-Limited or Fully Developed fire. A Ventilation-Limited fire is in a transitory state of decay in which all available oxygen has been consumed. Open flames are less prevalent or non-existent, but the extreme heat continues to pyrolyze the fuels. This creates an environment that is rich in both fuel and heat but lacks a source of oxygen. A Ventilation-Limited fire, as its name states, is limited only by its source of ventilation. Once firefighters open the compartment, the missing component of oxygen becomes re-established. Therefore, it is critical openings remained limited with an emphasis towards aggressive water application. If the fire triangle becomes re-established during a ventilation-limited state, fire growth will quickly transition to the fully developed state.

Figure 7-13 Hot gases reach exterior oxygen and ignite. Vent-Point Ignition

Fully Developed Stage

The fully developed stage begins once rapid-fire development occurs, either by Flashover, Backdraft, or Smoke Explosion. The fire triangle has become fully stabilized with the heat release rate reaching its peak potential. When met with this environment, firefighters must keep suppression efforts high while evaluating their proximity to this volatile environment. Withtemperatures reaching 1,100 degrees, PPE will reach failure with little to no reaction time. The National Institute of Standards and Technology (NIST) shows that an SCBA face mask, the weakest piece of PPE, will reach failure when exposed to temperatures of only 450° F. Additionally, SDFD personnel are currently outfitted with Lions V Force turnout gear; providing flashover protection for an average of only 20 seconds before personnel sustain 2nd degree burns. This further emphasizes the importance to maintain situational awareness. With multiple compartments existing within one structure, firefighters can quickly transition from one compartment in its infancy stage to another that is fully engulfed.

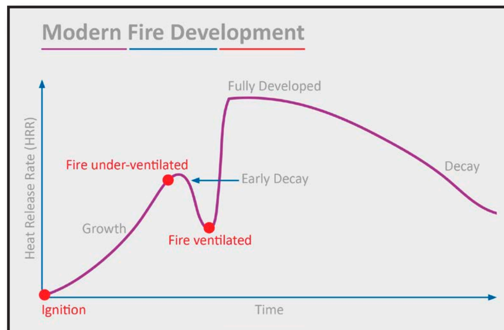


Figure 7-14 Modern fire development growth curve

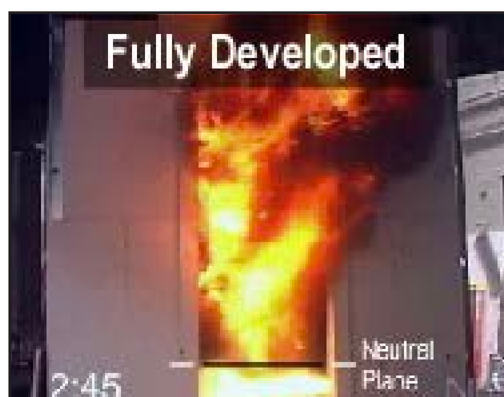


Figure 7-15 Fully Developed Stage

Rapid-Fire Development

Flashover

Flashover occurs when the compartments radiant heat pre-heats all solid fuels sufficiently to off-gas and reach their auto-ignition temperatures simultaneously. Applying the fire triangle to this environment; just prior to flashover, the fire triangle is stable in both its heat and oxygen but is lacking in its fuel. It's not until all of the compartment's fuels have pyrolyzed to the appropriate concentration that they burn simultaneously, creating this occurrence. Because of this, the best way to prevent flashover is the recognition of the signs previously stated in the growth stage. If the fire cannot be knocked down, halting further pyrolysis, firefighters must create a safe distance between themselves and the fire and cool from a safer location. Fire triangle analysis: Flashover has heat and oxygen but lacks sufficient fuel.

Backdraft

Figure 7-16 Backdraft

Backdraft is another form of rapid-fire development, occurring when a heat and fuel rich environment receives a rapid influx of oxygen. During a ventilation-limited fire, the oxygen levels drop to no longer support flaming combustion, however, heat is still heavily present. Because of this, solid fuels continue to smolder and pyrolyze, creating an over-pressurized compartment filled with fuels heated beyond their ignition temperature. When oxygen is suddenly introduced, an explosion follows. Fire triangle analysis: backdraft has sufficient fuel and heat but lacks oxygen.

Backdrafts are rare, yet dangerous. Fortunately, backdrafts have identifiable warning signs, visible from outside the involved compartment. Indicators of backdraft include black smoke with a yellow tinge, windows with heavy smoke staining, and crevices around doors/windows sucking air in.

*** If signs are present, crews must make coordination the priority while staying out of the path of travel for any doors or windows that can possibly fail. Vertical ventilation is of importance as this will allow smoke and heat to expel from the structure in a vertical channel, a path out and away from fire personnel. Once the compartment can de-pressurize and release its components, crews can carefully cool from a distance to remove the compartments heat and halt further pyrolysis.

Figure 7-17 Truck 11 experiences a smoke explosion after vertical ventilation in Barrio Logan

Smoke Explosion

A smoke explosion occurs when a large volume of smoke migrates from its origin and finds an outside source of ignition or conditions to accelerate its heat, creating an explosion. Let's analyze a smoke explosion using the fire triangle. The hot voluminous smoke is itself a flammable fuel. The smoke has migrated outside to an oxygen rich environment, creating a mixture of fuel/oxygen, the only question left is if its within its flammable range. The only thing missing is heat or an ignition source. Large dense volumes of smoke exiting a structure should be avoided and/or encountered with caution.

Overview

Our most vital tool is our understanding of fire dynamics. With this knowledge, firefighters can identify and anticipate rapid fire development.

Here is a quick overview of rapid-fire development:

- **Flashover - is stable with its heat and oxygen but is missing its fuel.**
- **Backdraft - is stable in its heat and fuel but is missing its oxygen.**
- **Smoke explosion - is stable in its oxygen and fuel but is missing its heat.**

Our mitigating tools are our hose lines and ventilation tactics. Heat and fuel will de-stabilize once hose streams can create a heat absorption rate that outpaces the fires heat release rate. Oxygen will de-stabilize through ventilation restriction and coordination. The missing piece involving the marriage of these two is the timing and coordination. If ventilation tactics are performed without simultaneous water application, uncontrolled volumes of oxygen will drive the fires heat release rate. If water is being applied without proper ventilation, flow path and the products of combustion can make advancement and search efforts difficult. When both can be achieved in coordination, victim rescue, fire suppression, and firefighter safety will net a positive outcome.

Phase II: Scene Size-Up

The initial size-up to an incident is one of the most important actions to be undertaken. This initial interpretation of conditions dictates our strategic and tactical decisions, setting both the tone and tempo for operations. A poor evaluation and thus, a poor response to conditions, often yields a negative outcome for the entire operation as a whole and can be difficult to recover from. While the first-arriving officer bears the responsibility for the initial size-up and action plan, each firefighter must size-up an incident with their own individual contributing function in mind.

The following phase is divided into both pre-arrival and post-arrival considerations; a set of indicators intended to assist a firefighter in their assessment of fire behavior.

Pre-Arrival Considerations

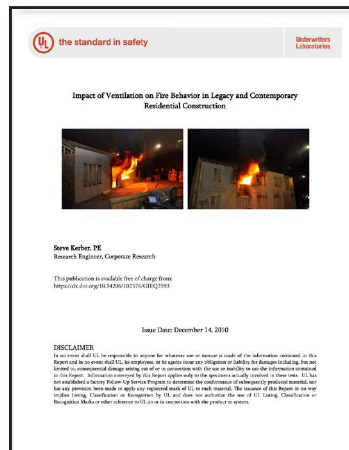
When does a size-up begin? Does it begin by reading the dispatch notes en route? Does it only begin upon arrival at scene? While each component leading to your arrival has importance; there's an equally important component to evaluate before the incident ever begins. If a structure fire involves the burning of a room's contents, the structure itself, or both. Firefighters can take a proactive approach to assess these same components prior to a fire's inception. During routine medical aids or travel time, firefighters should evaluate their surrounding district. This provides the opportunity to assess the components that will affect fire behavior; the buildings design and the contents within them.

Contents: Modern vs Legacy Fuels

Over the past several decades, fuel loads within a structure have changed drastically due to the modern integration of the plastic industry. In the 1970's, the average American home was furnished with either a wood, cotton, or silk-based material. These are referred to as our Legacy fuels. Legacy fuels are predominantly denser in size and are resourced from organic based materials. As a result, legacy fuels pyrolysize slower, creating a less hostile and slower paced fire growth. As a result, the allotment of time for occupancy egress, victim rescue, and fire suppression were substantial. However, finding these furnishings have become far and few between in the typical 21st-century home. Instead of legacy fuels, today's homes are filled with Modern Fuels. Modern Fuels are petroleum-based fuels, furniture made of plastic, rubber, Styrofoam, particle board, etc. The material and lack of density in these synthetic fuels have impacted fire behavior, and thus, firefighting tactics substantially.

UL Study

Underwriters Laboratory conducted a study titled "Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction." The study involved flashover experiments in two side-by-side rooms that were of equal size, fuel load, and time of ignition. The difference was that one room was furnished with legacy fuels and the other with modern fuels. The legacy-based room burned slower while producing less energy and smoke. The modern-based room reached flashover conditions significantly faster and produced far more energy and toxic byproducts. For a comparison, legacy fueled rooms experienced flashover in 29 minutes and 30 seconds. In contrast, the modern fueled room reached flashover in as little as 4 minutes and 57 seconds. Showing to burn with a faster heat release rate and consumption of oxygen, the study confirms that firefighters have inherited conditions that drastically shorten our window of opportunity for both rescues and flashover prevention.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Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction

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Research Engineer, Corporate Research

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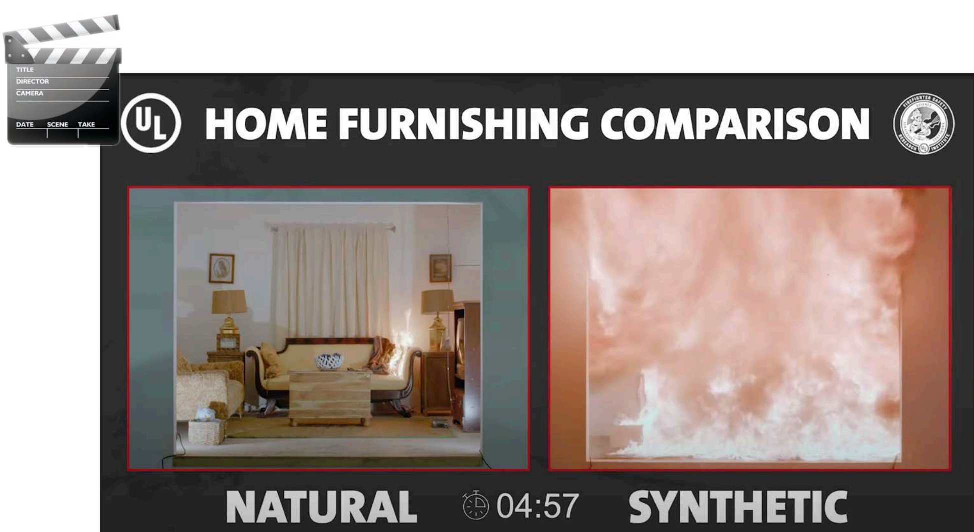
Link 7-1 UL Study- "Impact of Ventilation on Fire Behavior"



Building Design

Below Grade / Descending Hillside Structures

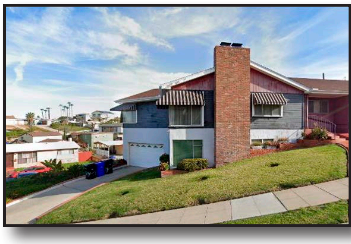


Figure 7-18 Residential home with a below grade garage

A below grade structure is a building that has one or more floor levels below the alpha side point of entry. These below grade levels can be basements, garages, or living spaces intended for normal occupancy. The threat with these designs is when the fire involvement exists at the lower levels. The reason why this is a problem resorts back to the previous phase covering The Products of Combustion. As a review, heat, smoke, and gases rise as the temperature goes up. The other product of combustion, pressure, wants to expand and travel from areas of high concentration to areas of low concentration. With a standard single- or two-story home, extinguishment is much more attainable due to the products of combustion travelling up and away from crews as they advance into a structure. More specifically, the products of combustion move towards the ceilings, upper floors, and/or a vertical exhaust point. Now contrast this to a building design with a fire that is below the crews making entry. The street side entry point now becomes the highest exhaust point of the structure. As the front door opens, all products of combustion will travel toward fire crews, making the front door the focal exhaust point. Oftentimes, crews are entering a losing battle, hose streams lack the adequate stream distance and pressure front to reach the seat of the fire while physically absorbing the products of combustion until they're overwhelmed. With below grade structures, crews must perform a 360° size-up, identify alternative entry points, and perform a coordinated ventilation plan for an effective fire attack.

Board-Up Structures

Figure 7-39 Residential home as a Board-Up Structure

Board-up structures present another issue for fire personnel. A board-up structure is a place of occupancy that has been condemned. Oftentimes, sheets of plywood will cover all exterior openings with an attempt to make the occupancy uninhabitable. In a typical occupancy, as heat, smoke, and pressure grow in volume; the building will naturally self-ventilate via a failed door or window. The reinforced openings of board-up structures cannot self-ventilate, creating an oven-like effect to the inside of the building. When fire crews finally create the first opening, all of the pressurized products of combustion will advance against interior operations. With these conditions, crews must perform an effective 360° size-up, fire attack, and coordinated ventilation plan to create an alternative exhaust point, away from the path of personnel.

Post-Arrival Considerations:

Reading Smoke

When approaching an incident, firefighters should take the opportunity to assess smoke conditions exiting the structure. This, is a practice referred to as "reading smoke." Typically, initial reports categorize smoke as either "light" or "heavy." While this is fine as an initial report, it falls short when trying to understand and anticipate interior conditions. Reading smoke has five characteristics that must be analyzed with two steps to follow when putting this information together. The five characteristics are: Volume, Velocity, Density, Color, and Location. The two steps to follow are: one, assess these characteristics collectively at each individual opening, the second step is to then compare and contrast the various openings as a whole. The first step is to understand the conditions in that individual compartment, whereas the second is to anticipate conditions for thestructure as a whole.

Figure 7-19 Reading Smoke - Volume

Volume

Smoke volume is an indicator for the amount of fuels "off-gassing" within a given space. It's important to note that when assessing a smoke's volume, it must be relative to the size of its compartment. For example, it doesn't take much of a fire event to fill a small single-family household with smoke. In contrast, it would take a serious fire event to produce enough volume to show even a small amount of smoke leaving a large warehouse. When dealing with residential structures, keep in perspective the district that you serve. Districts can vary widely in what's considered a "typical" sized single-family dwelling.

Figure 7-20 Reading Smoke - Velocity of smoke exits at different rates throughout the different openings

Velocity

Smoke velocity is a direct indicator for the heat inside the structure. As combustion ensues, energy is released in the form of heat and pressure. Heat causes the dilation and rapid expansion of surrounding gases, which pressurizes smoke to exit the structure. As the fire grows larger, this cascade of events continues until the compartment becomes over-pressurized. The greater the gases expand, the faster they want to exit the structure. As the temperature rises, visual changes in the smoke's velocity follows. In the incipient and growth stages, smoke forms a smooth, wispy, and steady release. This smooth and steady release of smoke is referred to as laminar flow. As the growth stage matures and transitions to a fully developed fire, a more violent, boil-like appearance flows, mimicking the look of active flames occurs, this is referred to as turbulent flow. So how do we put this all together? When examining velocity, compare the various openings. Openings closest to the seat of the fire will have the greatest smoke velocity. Be advised, excessively rapid and turbulent smoke may indicate an impending hostile fire event.

Density

Smoke density is an indicator of the interior condition's volatility. Either through combustion or incomplete combustion; solid fuels break down and leave behind unburnt fuel in the form of gasses and smoke. As the fire continues, the smoke begins to thicken. So how do we put this all together? We know that smoke is fuel, right? The greater the density, the richer the smoke. The richer the smoke, the greater the propensity for a hostile fire event to occur.

Figure 7-21 Reading Smoke - Density

Color

Smoke color indicates the type of material burning. In typical residential and commercial structure fires, it is rare that a single fuel source is emitting smoke. Virtually all solid materials will initially emit a white smoke when first heated. This white smoke is predominantly the release of moisture from the fuel. Once the material dries out, the smoke's color will begin to change, indicating the true source of fuel. Natural materials such as wood and structural members emit brown smoke, whereas hydrocarbons emit black smoke. Gray smoke is a mixture of moisture (white) and hydrocarbons (black).

Figure 7-22 Reading Smoke - Location & Color - Indicating an attic fire with structural members

Location

The location of the smoke is a characteristic that is easy to observe but also easy to overlook. Furthermore, the exact exhaust location can be obscured by large quantities of smoke. Firefighters must take the time to locate the smoke's origin. It is always best to conduct a 360° size-up. With a 360° size-up, firefighters can make key determinations. For example, to determine whether the smoke is exiting from a sub-floor, a bedroom window, or from the eaves, etc.

Overview

Time is a firefighter's most critical challenge when responding to structure fires. Both the time for the fire to develop, and the time the fire has to create new hazards for firefighters. Consider the time available for a fire to develop. Time elapses before 911 is activated. Time elapses before a response is dispatched. Time elapses donning PPE, traveling to the scene, initiating fireground operations, etc. Then we must factor in how modern materials have shortened our time window even further. All this is to say, firefighters should anticipate arriving on-scene to an environment that has already reached pre-flashover or flashover conditions. To adjust, firefighters must sharpen their pre- and post-arrival tactics to increase their ability to recognize and anticipate the effect of time on fire conditions.

	Definition	Time Objective
Preburn Time	From ignition until the fire is reported to the public safety answering point (PSAP)	Unknown variable No time objective
Dispatch Time	From public call until fire units are notified	64 seconds to 106 seconds (NFPA 1221, 2019)
Turnout Time	From when fire units are notified until apparatus leaves the station	80 seconds (NFPA 1710, 2020)
Travel Time	From when first engine leaves the station until they arrive at the scene	240 seconds; this is for first-arriving engine (NFPA 1710, 2020)
Setup Time	From when fire units arrive at the scene until fire units take effective action	2 minutes (NFPA 1720, 2020)

Figure 7-23 NFPA Statistics Elapsement of time from preburn to an effective action

Phase III: Identifying Flow Path

The following phase is a continuation to the firefighter's size-up, however, with the topic of flow path being of such great importance, it is a topic all in itself. To start, what is a flow path? Flow path is a term used to identify the direction in which oxygen, heat, and smoke travel once a compartment is opened. Why should we understand flow path? To start, dealing with a flow path is inevitable. Structural firefighting requires a compartment to be opened, and every opened compartment will have a flow path. Whether it be through a door, a window, or a roof, a flow path and its effects will be present and must be handled appropriately. The objective of this phase is to understand the effects of flow path and how to control them.

Types of Flow Path's

Bi-Directional

When a structure fire has a single opening, it will have a bi-directional flow path. A bi-directional flow path occurs when the interior and exterior atmospheres compete to travel through the same opening simultaneously. From the exterior, oxygen is drawn into the compartment, occupying the bottom half of the opening because of its cooler temperature. Simultaneously, heated byproducts of combustion exit from the interior, occupying the opening's top half. Visually, this creates a neutral plane, separating the two environments at the openings mid-point. The hazard with a bi-directional flow path occurs when the flow path occupies the same opening that personnel must enter. As personnel enter and advance, they are met head-on with the flow paths exhaust point, subjecting crews to high temperatures and volatile gasses. If the exhaust is excessively hot and violent, crews must emphasize a slow pace of advancement with aggressive water application. By placing a fixed stream towards the compartment's highest levels, gas contraction will take place, removing both heat and pressure until ventilation tactics are ready. For example, coordinated vertical ventilation in a situation like this would create a unidirectional flow path that would greatly improve conditions for advancement.

Figure 7-24 Bidirectional Flow Path- E17 Firefighter approaches the alpha side door of a structure fire

Unidirectional

A unidirectional flow path occurs whenever a compartment has two or more openings. Now having multiple openings, the separate atmospheres no longer compete to travel through the same opening, allowing the intake and exhaust points of the structure exist at separate locations. Visually, unidirectional flow paths are easy to identify. If you see an opening that is roughly 100% inlet or 100% exhaust, there is a corresponding opening elsewhere to pair with. Conceptually, unidirectional flow paths become fairly predictable to identify as well. Because heat and gasses rise, exhaust points will typically be dictated by height, causing the high-leveled opening to be the exhaust while the lower-leveled opening becomes the inlet. When dealing with openings of similar height, pressure, not height, dictates their locations. The closer an opening is to the seat of the fire, the higher amount of heat and pressure it is subjected to, forcingit to become an exhaust and thus, leaving the further opening to become the intake.

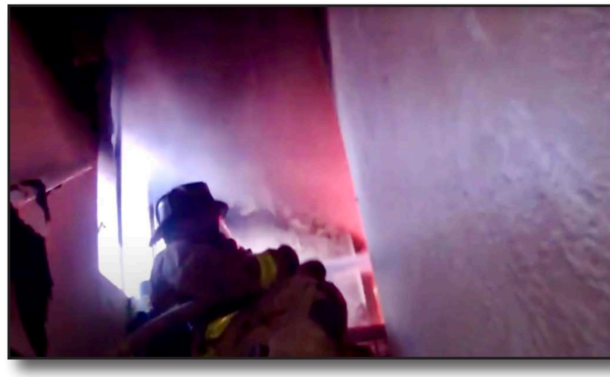


Figure 7-25 Undirectional Intake - E12 Firefighter extinguishes from the interior next to a window acting as an intake

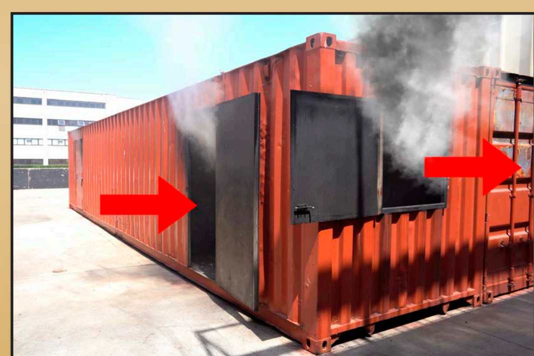
Figure 7-26 Undirectional Exhaust - Same incident - Corresponding window acting as the exhaust on the charlie side

Flow Path

A single ventilation opening is established, creating a bi-directional flow path

A second opening is created, slowly transitioning the flow path

With two ventilation openings present, a uni-directional flow path is created



Smoke and fire production increases due to the increased supply of oxygen

Wind Driven

Working against a wind driven fire is a worst-case scenario. A wind-driven flow path occurs when accelerated wind activity both controls the flow path and dramatically increases its oxygen supply. In San Diego, wind direction is fairly predictable. Winds blow from west to east during the day, and east to west during the night. Buildings adjacent to canyon rims and slopes are also more susceptible to increases in wind conditions. Situational awareness must be utilized to identify the hazards of your district and the current weather conditions. Utilizing a 360° size-up is the best practice to mitigate these hazards. If met head-on with wind driven activity, an alternative route of entry must be found, even if that means the back side of the structure.

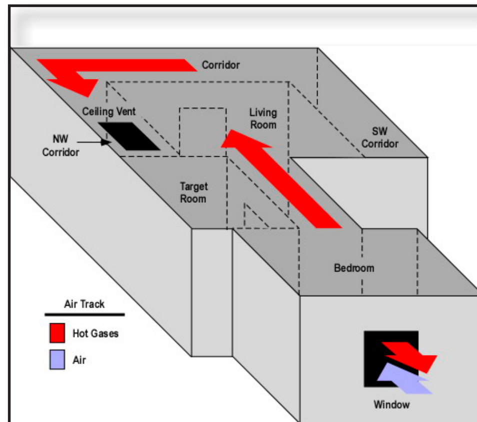


Figure 7-28 Wind driven fire

Creating Flow Path's

Now that the different forms of flow path have been identified, the next step is to understand how some of our most common tactics create them. Personnel should make it second nature to think about current and expected flow paths whenever performing these tactics.

Forcible Entry

Forcible entry immediately creates a flow path. Fortunately, most methods of forcible entry leave the breached opening intact, allowing the flexibility to close the opening and create a controlled flow path. Because of its timing on-scene, the opportunity for forcible entry typically arises prior to hose lines being ready. If so, forcible entry should still be achieved, however, with an emphasis towards the entryway staying closed until hose lines are in place.

Door Control

The most reliable way to manage the flow path is with good door control. Simply put, door control means limiting the size of an opening by closing doors as much as possible and whenever possible. However, balancing the need for door control and hose advancement can be difficult when personnel are limited. This is where fireground discipline must be exercised. Ideally, the first-in engine company should be relieved from door control as soon as support arrives, by doing so, hose advancement can remain aggressive while still limiting the environments oxygen. However, when support is limited, door control should remain the focus until hose

Figure 7-29 Vertical Ventilation - T12 Firefighter creating a unidirectional flow path

advancement requires further assistance. At no point should door control take priority over water application.

Vertical Ventilation

The most important aspect of vertical ventilation is good coordination with the interior suppression crew(s). If vertical ventilation is done prematurely, a flow path is created, accelerating fire conditions prior to personnel going interior. To make matters worse, what separates vertical ventilation from other tactics is its inability to be closed once created, this is referred to as an uncontrolled flow path. That is why coordination is so important. Vertical ventilation is only effective if it is achieved simultaneously with meaningful water application. If done correctly and properly coordinated, the unidirectional flow path relieves the products of combustion while hose streams combat the heat. If vertical ventilation is applied without water application, fire behavior will always increase and drastically worsen interior conditions.

Vent-Enter-Isolate-Search (VEIS)

VEIS provides firefighters an alternative means to access and rescue victims. This targeted search tactic should be considered when reports on-scene indicate a high likelihood of a victim's location. However, this tactic does not come without its own set of risks that must be addressed. Statistically, studies show that remote locations, such as a bedroom, are where victims seek shelter. When fire behavior does not afford us the time to anchor a search at the front door, firefighters can go straight to the source, outside the bedroom window (Window Initiated Search). However, once the window is breached, firefighters create a flow path. Regardless if its bi-directional or uni-directional; fire and its products of combustion will be drawn towards the bedroom, creating an exhaust point where rescue efforts are initiated. To prevent this from happening, personnel must immediately locate and close the bedrooms door, thereby isolating the area of rescue from the rest of the structure and controlling the flow path.

Hydraulic Ventilation

Figure 7-30 J Street Incident - Reports of victims trapped in bedroom. E12 Firefighter performs a targetted search (VEIS)

Hydraulic ventilation is a tactic that should be applied immediately once the fire has been knocked down. To begin, firefighters should find an exhaust point and position their nozzle 3-6 feet away from it. Once the hose line is opened, a straight stream can exit the opening and slowly turn into a 60° fog pattern without fully encompassing it. By doing so, the 60° fog pattern creates air entrainment, a component to our hose stream that uses nozzle pressure to physically pull the interior environment out the exhaust point, aiding in visibility for the primary search. What makes this option superior to other forms of ventilation is that the nozzle is already in the hands of interior personnel, making the transition of knockdown to ventilation seamless. Bypassing the time for communication and coordination, crews can immediately exhaust the toxic gases, making the environment more tenable for victims awaiting a rescue.

Hydraulic Ventilation

After knockdown, a straight stream is flown through an opening

Minimal entrainment of air exits thewindow

Firefighter adjusts the nozzle to a fog pattern

Firefighter fully encompasses the opening, blocking its ability to exhaust.

Fog pattern is flown through the opening, leaving the bordering spaces unblocked.

Maximum entrainment of air exiting the window

Applying Flow Path

Learning the topic of flow path can be a difficult task, understanding how to apply that knowledge in real-time is an even taller task to accomplish. Understanding how to do so is this phases intention. Despite all its different forms and subtle nuances, the entire danger of flow path really boils down to two key principles: avoiding the exhaust point and limiting the fire's oxygen. Allowing the opportunity for a reader to move past this phase without identifying this, would be a mistake. So long that these two principles are handled properly, flow paths will heavily contribute to a successful fire attack.

Avoid the Exhaust Point

Regardless of the reason, whether it be below grade, wind driven, or simply choosing the wrong entry; avoid the flow paths exhaust point. Whenever we are met with a well-developed exhaust point, the chance to be over-run with fire behavior drastically increases. If the exhaust point cannot be redirected, communicate your findings, and perform a 360° size-up to find an alternative means of entry. If no other entry point is available, a risk-assessment must be performed. If entry at the exhaust point must happen, then the pace of advancement must be slowed down with a heavy emphasis towards door control and water application.

Limit the Oxygen

With a well-developed fire, the best way to avoid an exhaust point is to create a uni-directional flow path, up and away from personnel. However, doing so comes at the cost of your inlet growing, increasing the supply of oxygen. This is the next issue to address. If the increased oxygen is left uncontrolled, fire growth will quickly escalate. This is the next objective to address, and the solution falls back to the fire triangle. The triangles component of oxygen is strengthening, which in turn, strengthens heat. We combat this issue by de-stabilizing both oxygen and heat simultaneously. As a flow path becomes unidirectional, address the component of oxygen via door control while combating the component of heat through aggressive water application.

Phase IV: Exterior Water Application

Modern fuel loads have created an environment more volatile than ever before. As previously mentioned, the volatility of today's fires doesn't come from them burning hotter, it comes from their heat release rate, which allows temperatures to accelerate faster than ever before. This only further highlights the importance of applying water as quickly as possible. Firefighters can accomplish this by the use of exterior water streams, employing a transitional attack.

Transitional Attack

There are a lot of misconceptions to what a transitional attack is. To start, this tactic does not replace an interior attack, nor does it relegate personnel exclusively to exterior operations. Transitional Attack is an offensive fire attack made from the exterior of a structure. With an emphasis towards early water application, the transitional attack's sole objective is to improve interior conditions prior to entering. By doing so, crews can begin cooling the environment as soon as possible; contracting the super-heated gasses and "resetting the clock" for flashover. As crews knock back the fire, the hose lines repositioning is then prepared to support a seamless transition, concluding this tactic with an interior advancement to achieve a full knockdown.

Applying Transitional Attack

As with all tactics, the application and context of the tactic can often be more important than the tactic itself. That is why it's important to understand when a transitional attack is appropriate. The opportunity to employ a transitional attack comes down to two scenarios; categorized as either an action of need or an action of opportunity.

Action of Need

When interior conditions are unsafe to enter, an action of need is presented. As we analyze our buildings and conduct a size-up; we may see conditions on the verge of a hostile fire event. Whether it be the direct point of entry or from a distant window, firefighters can take this opportunity to cool their environment as opposed to entering and facing these conditions head-on. Another action of need is when a rescue is being performed. While rescue efforts are conducted, exterior crews can flow water into or around the area of rescue. By doing so, conditions will drastically improve, resulting in gas contraction, lowered temperatures, and a more tenable environment for victims awaiting extraction.

Action of Opportunity

Imagine being the first in nozzle firefighter at a fully involved single family residence. Near the front door, smoke and fire are spewing out of a compromised window. You are masked up, nozzle in hand, hose line charged, ready to go. But there is a delay. Maybe a delay with forcible entry? Maybe your partner had an issue masking up? Regardless, you are ready. You should now make an Action of Opportunity. You have the opportunity to flow water into the structure and improve the conditions until the delay is resolved, at which point you'd immediately go interior to aggressively attack the fire.

Transitional Attack Technique

Due to the nature of exterior water streams, a firefighter's ability to assess their technique comes from behind the nozzle, from a distance, with conditions obstructing their visibility. It is also common for firefighters to perform a transitional attack from a lowered angle, physically limiting their ability to see their stream's effectiveness. Because of this, Underwriters Laboratory (UL) conducted a study titled "Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival." The study was broken down into two components: Water Mapping, and Air Entrainment. These two components finally answered the question, what is the most effective way to perform a transitional attack?

Exterior Water Application

Improper vs Proper Technique

Improper - Firefighter flows water into a window with a shallow angle

Improper - Shallow angle causes the stream to only make contact with backside of the compartment

Improper - Rapid stream movement pressurizes the compartment, pushing heat and gases further into the structure

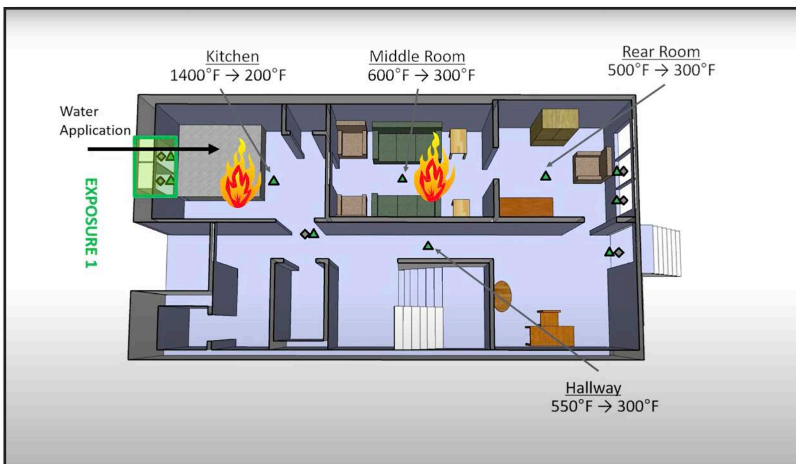
Proper - Close proximity

Proper - The steep angle allows the stream to make contact immediately, dispersing water along the entire compartment

Proper - Nozzle movement stays fixed, minimizing air entrainment, and allowing window to self-exhaust

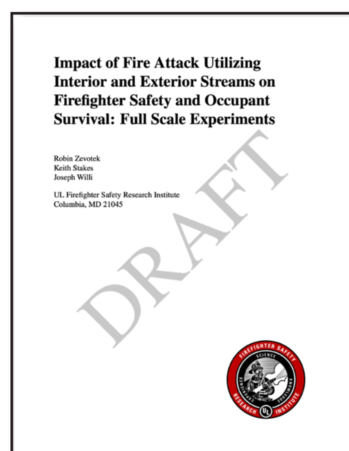
Water Mapping

The water mapping study was conducted to determine the most effective form of water distribution. The study began by identifying the most effective angle for our water stream to be positioned. Personnel positioned themselves as close as possible to the affected opening. Then, water streams were directed with a steep angle towards the ceiling, just clearing the openings header. As the water's pressure contacted the ceiling, it continued to slide along its path until it collided with the corresponding walls, creating a sprinkler-like effect, and providing the greatest amount of surface area coverage. When the angle was decreased, the hose stream would coat a significantly lower amount of surface area. This was consistent regardless of the nozzle type or pattern. The study illustrated that when water is applied effectively, interior conditions improve drastically not just for the initial compartment but for the structure as a whole, allowing the quick onset of gas contraction to cascade and cool the adjacent rooms.



Air Entrainment

The next phase of the study was to see how air entrainment affected a transitional attack. The study found that as air entrainment increased, negative consequences would follow. This was due to two components: blocking the opening's ability to exhaust, and pressurizing oxygen into the compartment. When our hose streams cover the opening, either by fog pattern or by rapidly moving a straight stream, the compartment is unable to exhaust. The hose stream is not only sealing off the opening, it is in fact pushing the heat and pyrolyzed gasses to the adjacent rooms, creating conditions for volatile events to occur. The study illustrates that we should use a straight stream in a fixed position when outside the window. If hose streams must be moved, firefighters must make an emphasis towards keeping the exhaust opening clear.


Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Full Scale Experiments

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Link 7-2 UL Study: Impact of Fire Streams on FF Safety and Occupant Survival

Phase V: Interior Water Application

The final phase takes a deeper look into the interior component of Underwriters Laboratory's (UL) study titled "Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival." Before we begin, it's important to identify what our objective is when making an interior attack. While the obvious answer is extinguishment, the underlying objective is to protect any survivable spaces where victims may be finding refuge. Because victims are not afforded respiratory or heat protection like we are, fire personnel must utilize their hose line with a more deliberate application. Choosing to not just extinguish the fire, but to aggressively create a more tenable atmosphere for victims, until a rescue is performed. The following phase emphasizes how to accomplish this.

The Problem – Heat, Pressure, Re-Growth

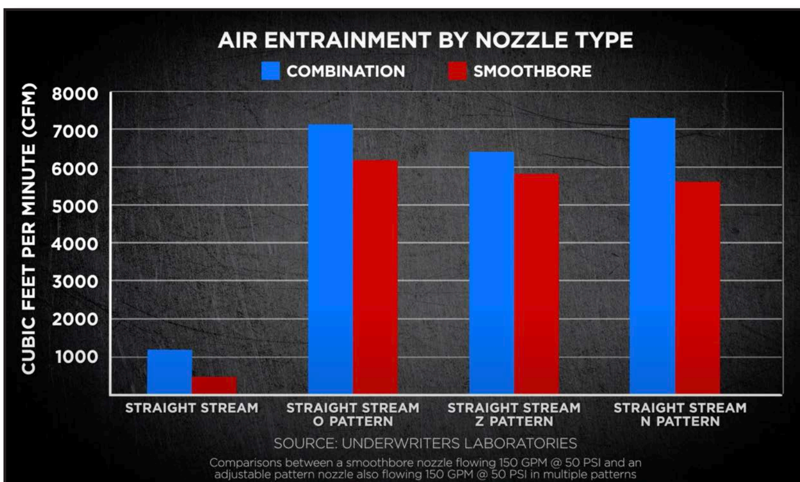
Anytime we can present and frame the problem we are facing in a clear and well-defined manner, the chances to identify its solution becomes substantially easier. So, when it comes to interior operations, the question then arises "what exactly is impeding our ability to extinguish the fire and protect survivable space?" The answer is the heat release rate (HRR), pressure, and re-growth. Pyrolyzation drives the HRR. Combusting or not, pyrolyzation occurs across all surfaces during a structure fire, providing a constant supply of gases to expand and ignite, increasing the HRR. As the heat transfers to adjacent surfaces, the cycle repeats itself, creating the problem where the rate of release outpaces our rate of absorption. The next problem we face is pressure. As pressure expands to a large enough volume, it starts to control the environments circulation. This creates a problem, as the products of combustion move freely throughout the structure, surfaces, victims, and personnel become saturated with its contents. The last problem we face is re-growth. During the advanced stages of fire, interruptions in water flow can allow the HRR to re-establish itself. This creates a problem, as breaks in water flow become prolonged and frequent, the seat of the fire is allowed the time to pyrolyze, creating a rebounding effect that prolongs extinguishment. As long as these three components exist freely, **the fire is dictating the outcome.**

The Solution – Cooling, Entrainment, Advancement

If heat, pressure, and re-growth are the problems, then our methods of cooling, air entrainment, and advancement are the solutions. However, results can be inconsistent when personnel are simply "putting the wet stuff on the red stuff" and flow without purpose. Instead, personnel must utilize their hose line to its greatest efficiency. To combat the HRR, personnel must apply water rapidly in a slow and methodical manner. Creating the rapid contraction of gases, breaking the cycle of pyrolysis, and creating a pace where we can absorb heat at a faster rate than it is generated. Aiding in the battle against pressure, personnel must use air entrainment to control their environment, directing the products of combustion out and away from themselves. To combat re-growth, personnel must advance their hoseline with a relentless pace of water application, preventing any chance for the fire to re-establish itself. When these components are applied, **were now dictating the outcome.**

Air Entrainment

What is air entrainment and how is it used? When we open our nozzle, highly pressurized water flows out. As the water flows outward, it pulls air along with it- a lot of air. This is called air entrainment and the quantity we generate can be increased and/or limited depending on how we operate the nozzle. When we create rapid movement with our hose stream or widen our nozzle pattern, entrainment is increased significantly, creating up to 12,000 cfm, surpassing the cfm of a gas-powered ram-fan. Comparatively, when a straight stream is flowing in a fixed position, entrainment is severely limited, generating as little as 500 cfm. This is an important concept to understand. It highlights the nozzles capacity to act as both a fan and water stream simultaneously.



Air Entrainment Techniques

Fixed stream is flown, creating minimal air entrainment

Opposite side ventilation opening shows no movement of smoke

Option 1: Inverted U
Nozzle moves from left to right

Nozzle movement continues from right to left and repeats itself

Option 2: O-Pattern
Nozzle moves in a rapid circular motion

Both options create air entrainment. Pressurized smoke exits the opposite side ventilation opening

Create a Pressure Front

Due to the environments pressure directing heat and toxic gases towards firefighters; it is incumbent on personnel to use air entrainment as a means to redirect and control their environment. Because fog patterns dramatically limit the streams distance and penetration, a rapidly moving straight stream is the option of choice. This is best achieved by moving the nozzle in an "O" or "Inverted U" pattern with a straight stream. This creates a pressure-front that "seals off" the entire span of the compartment and directs the products of combustion away from victims and personnel, towards the exhaust point. Not only does this action improve visibility but the products of combustion become less rich as they exhaust, decreasing the atmospheres volatility. Normally, this tactic could be achieved by use of a fan, however, the coordination between increased ventilation and water application would have to be precise to avoid the possibility of pressurized oxygen feeding the fire without water application. Because these two components are married through our hose line; the environment is ventilated and cooled simultaneously.

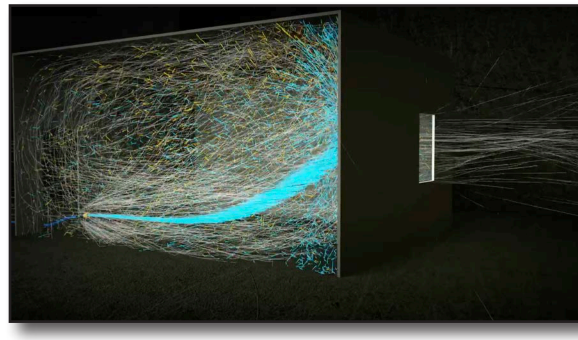


Figure 7-34 Nozzle movement creating air entrainment with an opposite side ventilation opening

Nozzle Movement

After identifying the structures state of ventilation, personnel must choose the appropriate way to operate their nozzle. With the options to apply water with a fixed stream or with nozzle movement, personnel can apply water in a methodical manner to control their environment.

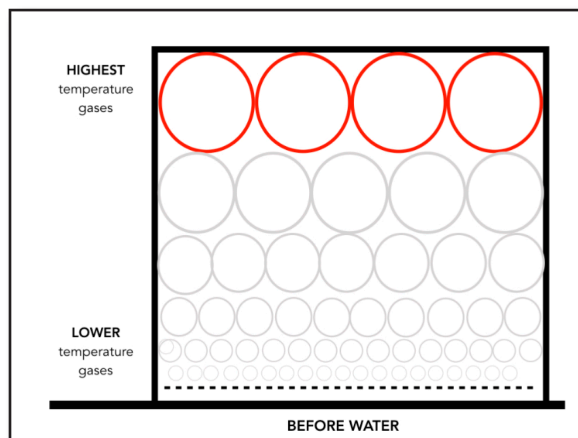


Figure 7-35 Thermal layering of gases prior to water application

Ventilation Openings

When opening the nozzle, firefighters must identify if a ventilation opening is present, as this will dictate how the hose stream should be flown. Because a moving hose stream creates air entrainment, the thermal layering, as well as the products of combustion, will pressurize and travel away from the interior crew. Whether it be a window, door, or hole in the roof, a ventilation opening must be established to allow the products of combustion to exhaust from the area of high concentration (the interior) to the area of low concentration (the exterior). However, if a ventilation opening is not present, the resulting pressure will have no outlet to escape. This leads to a back-pressured event that will disrupt the thermal layering, causing high-temperature gases to bank down towards personnel, or worse, travel to the structures uninvolved areas. When met in this situation, a nozzle flowing in a fixed position is the option of choice.

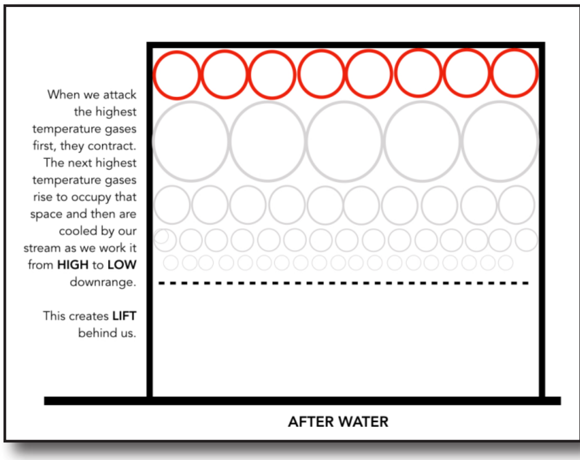


Figure 7-36 Thermal layering absorbed after water application, creating a "lift"

Water Application - Fixed

When conditions warrant a fixed stream, the emphasis must be on our hose streams angle. Since we cannot incorporate air entrainment, the battle of pressure must be controlled through gas contraction. This is accomplished by applying water towards the highest point of the compartment. By doing so, were addressing the area where the hottest gases exist and have the greatest potential to combust. As water coats the ceiling, it contracts and absorbs the hot gases, leaving its space unoccupied. This allows the next layer of gases to rise and once again occupy the ceiling space for our hose stream to absorb. As this process repeats itself, the absorption of each layer creates a visible "lift" in smoke. This lift supports a firefighter's visibility to observe the layout of the structure and locate the source of the fire.

Water Application - Movement

When conditions warrant a moving hose stream, firefighters have the option of either an "O" or "Inverted U" pattern. By doing so, not only are we creating a pressure front but were also cooling the environment in an efficient and systematic manner. Both options start with opening the nozzle towards the ceiling, addressing the super-heated gases for both contraction and absorption. However, the compartments other surfaces are still pyrolyzing and must be addressed. This is where the rest of our stream's application has its effect. With either pattern you choose, the stream moves back-and-forth from the ceiling to the walls in a methodical manner. This allows the water to coat all other surfaces, absorbing heat and halting pyrolysis.

Hose Advancement

Regarding hose advancement, multiple techniques can be found across the country. However, regardless of the technique, their principals of advancement fall into one of two categories, a "Shutdown and Move" or a "Flow and Move". This is important to understand, as choosing the proper method will differ in how the environment is effected around and ahead of the suppression crew.

Shutdown and Move

A "Shutdown and Move" involves shutting down the hoseline to facilitate the advancing crew's movement. When encountering the earlier stages of fire, such as the incipient and early moments of the growth stage, a shutdown and move is appropriate. However, if applied inappropriately, such as the advanced stages of fire, interior conditions can become difficult to extinguish. This is due to the hose stream being shut down for a prolonged period of time, allowing temperatures to rebound to their original state. UL studies were conducted to examine the effects of this method applied inappropriately. The study found that when the nozzle was shutdown periodically re-growth occurred. To make matters worse, conditions often developed with interior crews unable to notice its development. Studies further showed that the early stages of re-growth were often over the head of the advancing crew and because of their structural protective gear, crews were unable to feel any changes in their environment until re-growth reached a more pronounced state.

Flow and Move

When met with extreme conditions, the emphasis must be made to keep an open hose line during advancement. As long as the hose line is flowing, the environment is reacting to our tactics, creating a constant cycle of cooling and contraction. When interruptions occur, requiring the hose line to be shut down, gasses are afforded the time to rebound and expand. This allows the fire to take back control, creating an environment where we are now the ones having to react. Every second that water is flowing stops that, creating conditions where our rate of water flow smothers the heat release rate (HRR). The Underwriters Laboratory (UL) study (Page 134, Figure 6.8.2) proved that relentless and methodical water application towards the room of origin dropped temperatures from 1,200° to 200° within 15 seconds.

Closing Statement

The number one priority of the fire service is savings lives. If a victim cannot exit a building, we are counting on them to seek a survival space for shelter, waiting for a rescue to be performed. Those victims are counting on us to protect that survivable space. How we intend to protect that space is with the fire services most reliable tool, the hose line. As our only mitigating resource, a successful fire attack starts and stops with a well-trained firefighter operating the nozzle with purpose. Our training and knowledge with fire dynamics provides us the knowledge to assess, identify, and predict our fire's environment. This chapter is intended to support that.

Media & Links Index

1. Air Entrainment
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12. Pyrolysis: Turning Solid Fuels to Smoke - Episode 2
13. Flashpoint, Flame Point, and Autoignition
14. Complete Combustion vs Incomplete Combustion
15. Flammability Range

References

1. UL Study: Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction, Steve Kerber, PE, December 14, 2010
2. UL Study: Impact of Fire Attack Utilizing Interior and Exterior Streams on Firefighter Safety and Occupant Survival: Full Scale Experiments, UL Firefighter Safety Research Institute, January 25, 2018
3. Principles of Fire, Chapter 7, SDFD Drill Manual 2009 version
4. IFSTA Essentials of Firefighting, 7th Edition

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Revisions/Updates

Date	***Revision/Update Description***
December 2023	A significant re-write of this chapter (formerly titled Principles of Fire) was completed