Four Firefighters Burned in Residential House Fire - Georgia

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NOTE: This report was originally published on July 6, 2022. During the development of the on-line training program it was noted by that one of the responding units was not included in the timeline. That has been corrected and incorporated into the revised version of this report.

Acknowledgments

This project was supported through a grant from the Department of Homeland Security (DHS) Federal Emergency Management Agency's (FEMA) Assistance to Firefighters Grant Program.

The authors thank Fire Chief John Brant and the LaGrange Fire Department for their willingness to share the information from their incident with others in the fire service so that the safety and effectiveness of the firefighting can improve. Critical to the success of this analysis was the scene documentation and fuel sample collection conducted by Chief David Rhodes (Atlanta Fire Rescue Department, Ret.), BC Brent Hullender (Atlanta Fire Rescue Department), Capt. Dustin Martinez (Cobb County Fire and Emergency Services).

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List of Abbreviations

ALS	Advanced life support
ASTM	American Society for Testing and Materials
DHS	Department of Homeland Security
FDNY	Fire Department of New York
FDS	Fire Dynamics Simulator
FEMA	Federal Emergency Management Agency
FSRI	Fire Safety Research Institute
HRRPUA	Heat release rate per unit area
HRRPUV	Heat release rate per unit volume
ISO	Insurance Services Office
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
PPE	Personal protective equipment
RIT	Rapid Intervention Team
SCBA	Self-contained breathing apparatus
UL	Underwriters Laboratories

1 Executive Summary

On September 3, 2018, two career fire lieutenants and two career firefighters suffered burn injuries as a result of a residential structure fire. The fire occurred in an approximately 752 ft^2 single-story wood frame (Type V) structure built in 1900.

The LaGrange Fire Department invited FSRI to study this incident as part of FSRI's Near-Miss Project which is supported by a DHS/FEMA Assistance to Firefighters Grant. The goal of this project is to enhance the safety and situational awareness of the fire service by applying fire dynamics research results to near-miss or line of duty injury fire incidents. By identifying factors that contributed to the incident, perhaps future incidents may be prevented.

FSRI's analysis of this incident has applied research results and the Fire Dynamic Simulator computational fire model simulations to examine key fire phenomena and tactical outcomes. This report describes the incident, what occurred, why it occurred, and what can be done differently in the future to result in a more favorable outcome.

1.1 Contributing Factors

In reviewing this incident and similar line-of-duty injury incidents, there is a pattern that the root cause of the incident cannot be attributed to a single factor. Rather, these incidents occur due to a combination of factors that act both independently and in conjunction to generate unexpected conditions and outcomes for which the firefighters were not prepared. The review of this incident, including information about the weather, building design and construction, incident narrative, and computational analysis of the fire dynamics, identified six factors that contributed to the ultimate outcome of this incident:

- The combustible exterior finish on the structure and the proximity of the side D kitchen window to side C bedroom window facilitated flame spread from the kitchen to the bedroom along the exterior of the structure.
- Rooms were added to the original structure which resulted in a non-intuitive floor plan and a confusing path of travel for the Fire Control and Search crews between the entry location in the bedroom and the fire in the kitchen.
- The combustible interior wall and ceiling construction enhanced flame spread and fire growth in the kitchen and the bedroom, and was key to initiation of the exterior wall fire and spread through the bedroom window back to the interior of the structure.
- The size-up did not result in recognition of the path of flame spread from the side D kitchen window along the exterior of the residence through the side C bedroom window.

- A back-up line was not positioned to support and protect the Fire Control crew and the initial hoseline.
- Rapidly changing fire conditions within the structure resulted in the burn through of the Fire Control crew's hoseline, blocked egress from the original entry, and left the Fire Control and Search crews trapped in the structure without a means for suppression.

1.2 Key Recommendations

There was a confluence of factors that contributed to the severity of this incident. Some of these factors, including the construction materials and layout of the structure, were unavoidable. As the incident evolved into the Mayday situation, there were also several positive factors that prevented an even worse outcome. The incident commander actively monitored the fire and maintained communication with the Fire Control and Search crews, which provided the crews with a warning that conditions were rapidly changing. Additionally, the Fire Control and Search crews maintained situational awareness which enabled them to locate and use emergency egress options. The Lieutenant of the first arriving fire engine that was part of the Fire Control crew demonstrated this situational awareness by entering the bathroom and closing the bathroom door to shield himself from the fire in the kitchen and hallway so he had time to safely exit through the window. The contributing factors that were identified as avoidable have led to the following recommendations.

Recommendation #1: Size-up should include an assessment of the fire location and the extent of fire spread to determine strategy and tactics.

Discussion: NFPA 1700 *Guide for Structural Fire Fighting* [1] presents strategic considerations for the fire control strategy upon initial arrival:

> **§9.5.2** Initial arrival factors should include considerations of the following:
>
> (7) Fire location, size, extent
> (9) Suspected direction of fire and smoke travel within the structure (flow path)
>
> **§9.7 Assessment of Fire Dynamics to Determine Strategy.** Factors observed from the exterior of the structure should be used for determination of interior conditions.
>
> **§9.7.7 Fire Progression.** Based on the 360-degree survey, identify the fire's suspected direction of travel or potential directions of travel. Consider dynamic events such as changes in ventilation and application of cooling, which may effect the path of travel. What is the current extent of the fire and where is it spreading.
>
> **§9.9.1** The incident commander (IC) should consider the entirety of available information when making a decision with respect to strategy. The IC should continually re-assess the strategy decision based upon changing conditions.

In addition to an assessment of Fire Progression, NFPA 1700 also includes an assessment of Smoke and Fire Conditions (§9.7.1), Fuel Load (§9.7.2), Openings (§9.7.3), Flow Path (§9.7.4), and Fire Control Positioning (§9.7.8). The first responding units conducted a size-up, but there was no recognition of the potential large fuel load on the interior and exterior of the structure or the potential flow path due to the geometry of the structure and the proximity of the flames to the bedroom C side window. Combining the information about the fire with the examination of the building and location of windows and doors can be used to predict how the fire might continue to evolve and move throughout the structure. Had the size-up yielded recognition of the potential evolution of the fire along the exterior of the structure and into the bedroom through the C-side window, different tactics may have been applied that would have prevented the Mayday situation.

Recommendation #2: When the initial size-up reveals fire rapidly spreading on the exterior of the structure, exterior fire control should be applied to limit fire spread.

Discussion: Shortly after the first units arrived and started the size-up, but prior to the initial Fire Control crew entering the structure, extension from the interior fire in the kitchen through the side D kitchen window resulted in an exterior fire along the side D of the kitchen and side C of the bedroom. It has been demonstrated through experimental research that exterior wall fires may easily spread to the interior via penetrations such as air vents, electrical receptacles, plumbing penetrations to faucets and drains, and especially windows [2]. Had the responding firefighters recognized the rapid development and spread of fire along the exterior of the structure and suppressed the exterior fire prior to interior fire control, it is likely that the fire would not have spread beyond the kitchen. Kerber and Zevotek recommended initial fire control or simultaneous fire control of the fire on the exterior of a structure in their report on tactical considerations for attic fires and exterior fire spread hazards [2]. That recommendation and the justification behind it also apply to this incident. Depending on the firefighting resources available, two hoselines could be pulled to simultaneously conduct interior and exterior fire control.

Recommendation #3: A back-up hose line should be in position to support and protect the initial hose line.

Discussion: As defined in NFPA 1410, *Standard on Training for Emergency Scene Operations*, a back-up line is an additional hose line used to reinforce and protect personnel in the event the initial attack proves inadequate [3]. The back-up hoseline serves two main functions: to protect the primary egress path for the initial attack crew and to provide additional water on the fire to support the initial attack crew when needed.

In his book *Engine Company Fireground Operations*, Angulo provides a discussion of timing and placement of the backup line. To summarize that discussion, a back-up line cannot be considered a back-up if it is only stretched after it is needed. A back-up line must be where it is needed, at the time that it is needed to protect and support the initial attack line [4]. In this case, if a back-up line was in position at the entry door, the impact of the fire spreading into the bedroom would have been limited and the primary hose line and the egress path for the Fire Control and Search crews would have been protected.

As the fire spread to and grew in the bedroom to the point of flashover, the hoseline burned through and became unusable. If a back-up line had been in place after entry of the initial line, suppression could have been applied to the fire as it entered the bedroom thus protecting the hose line and the egress path.

There were three ways to stop the fire from spreading from the exterior through the bedroom window and out to the porch:

1. Initial line goes to the CD corner, extinguishes the fire on the exterior, and knocks down the kitchen fire prior to going to the interior.
2. Initial line goes to the interior while the backup line moves into position on the exterior of the CD corner, ready to coordinate control of the exterior fire along with the interior Fire Control team.
3. Initial line moves to the interior while the backup line moves toward their position on the front porch.

The hose movements of options 2 and 3 were called for on the fire ground. However in this case, the combustibility of the asphalt siding, the single pane windows (which failed quickly when exposed to flame), and wood interior walls and ceiling allowed the fire to spread faster than the backup lines could be positioned and put into operation. Once the backup line was in operation from the front porch the fire was effectively and rapidly controlled. Although many of the fire ground decisions were correct, the fire was moving faster than the implementaion of the backup line. This demonstrates the importance of an on-going fire dynamics size-up as a means to stay ahead of the fire spread.

Recommendation #4: Use known information to guide fire ground decisions.

Discussion: The fire extending from the interior of the kitchen to the exterior of the structure was observed. Therefore, the location of the fire was known and the path to advance a hoseline to the fire on the exterior of the house was known. Prior to entry into the house, the path from the front door to the fire was unknown. When the Search crew recognized that the Fire Control crew would need to advance the line through three rooms of the structure prior to getting to the kitchen, that offered another decision opportunity to have a hoseline go to the location of the exterior fire first. In this case, acting on the known information would have improved interior conditions and prevented the spread of the fire, thereby reducing the risk of the unknown conditions that would be encountered as fire operations moved to the interior.

2 Introduction

On September 3, 2018, two career Fire Lieutenants and two career Firefighters suffered burn injuries as a result of a residential structure fire. On September 10, 2018, personnel representing several other fire departments in the area, including a member of the Fire Safety Research Institute (FSRI) Advisory Board visited the fire scene to document the incident and collect material samples from the structure. The narrative and analysis presented in this report rely on the photographs and evidence collected on September 10, 2018, dispatch transcript [5] and videos recorded at the time of the incident, and interviews conducted by a local investigator between September 3, 2018 and September 7, 2018 with fire service personnel involved in the incident and the resident of the structure [6].

The LaGrange Fire Department invited FSRI to study this incident as part of FSRI's Near-Miss Project which is supported by a DHS/FEMA Assistance to Firefighters Grant. The goal of this project is to enhance the safety and situational awareness of the fire service by applying fire dynamics research results to near-miss or line of duty injury fire incidents. By identifying factors that contributed to the incident, perhaps future incidents may be prevented.

FSRI's analysis of this incident will apply research results and utilize fire research tools, such as computer fire models, to examine key fire phenomena and tactical outcomes. This report will explain the incident, what occurred, why it occurred, and what can be done differently in the future to result in a more favorable outcome.

3 Fire Department Overview

LaGrange Fire Department has five stations that house four engine companies and one aerial company. The department has three reserve engines and one reserve aerial apparatus. The department has three deputy Chiefs, 14 lieutenants, 15 sergeants, and 30 firefighters. The department is managed by the Fire Chief with the aid of an administrative assistant. Each of the deputy chiefs is responsible for one of each of the three battalions. Two of the lieutenants are designated as the Fire Training Lieutenant and the EMS Training Lieutenant and lead training in the LaGrange Fire Department Training Center. All units in the department are advanced life support (ALS) units. The department operates a three-battalion shift assignment that consists of 24 consecutive hours on, followed by 48 consecutive hours off. The department responded to 5,355 calls for service in 2019 and holds an Insurance Services Office (ISO) Class 2 rating [7, 8].

3.1 Training and Experience

The LaGrange Fire Department provides medical incident response with an enhanced ALS service. There are personnel within the department licensed as Emergency Medical Technicians at all levels. All personnel are required to complete National Incident Management System (NIMS) Level 100, 200, 700, and 800 training. All officers are certified at NIMS Level 300 and 400. In 2017, the department completed a total of 28,373 hours of training. Over the course of 2018, the year this incident occurred, the department responded to 46 fires.

3.2 Equipment and Personnel

A call for a structure fire was received by Troup County dispatch on September 3, 2018, at 02:50:17 hours [5]. The following apparatus and personnel were dispatched from the LaGrange Fire Department:

Engine 1 (E1)
Lieutenant (E1 Lt)
Sergeant (E1 Sgt)
Firefighter (E1 FF1)
Firefighter (E1 FF2)

Engine 4 (E4)
Lieutenant (E4 Lt)
Sergeant (E4 Sgt)
Firefighter (E4 FF1)

Firefighter (E4 FF2)

Acting Shift Commander
Lieutenant (IC)

Engine 2 (E2)
Sergeant (E2 Sgt)
Firefighter (E2 FF1)
Firefighter (E2 FF2)

Truck 32 (T32)
Sergeant (T32 Sgt)
Firefighter (T32 FF1)
Firefighter (T32 FF2)

A map of the city of LaGrange marked with the structure fire and the locations of the fire stations from which the responding units were dispatched is provided in Figure 3.1.

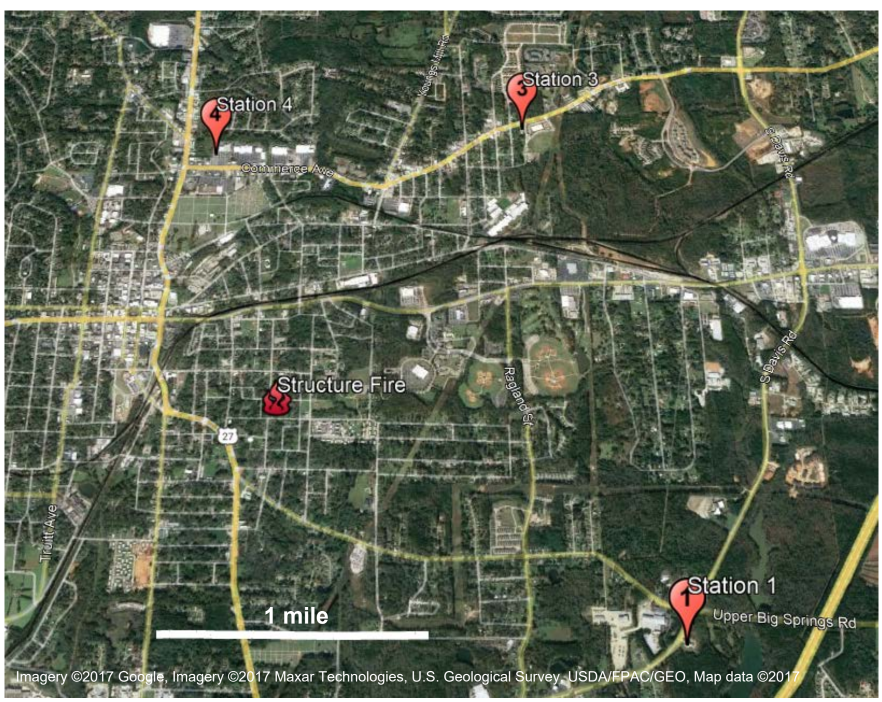


Figure 3.1: Map of structure fire and fire house locations [9].

In this line of duty injury incident, the interior Fire Control crew was composed of the lieutenant and a firefighter from E1. The Search crew consisted of the lieutenant and a firefighter from E4. These were the four members that sustained the injuries which required hospitalization in a burn center. E2 served as the rapid intervention team (RIT).

4 Incident Overview

The incident overview provides the information that is needed to conduct the fire dynamics analysis. Much of the information in this section involving time of day, weather, occupancy type, building construction type, fire location, and the extent of fire spread on arrival are data that are typically collected by the first arriving officer to determine the initial strategy and the incident action plan [1].

4.1 Weather

The 911 call for this incident was received at approximately 02:50 hours on September 3, 2018. At that time, weather data collected at Columbus Metropolitan Airport (approximately 36 miles south of the structure involved in the incident) indicated the temperature was 76°F. The dew point was 71°F with a humidity of 85%. The wind speed was 8 miles per hour from the east and there were 0 inches of precipitation over the preceding 24 hours [10]. The house is positioned so the rear side of the house or side C, faces to the North. Based on the videos from the incident, the wind was not a factor in the fire growth or spread.

4.2 Building Construction

The structure involved in the fire was a single-story wood-frame (Type V construction) house built in 1900. The building was originally designed as a duplex dwelling, with symmetrical placement of two entry doors and windows on side A of the structure, but had been converted to a single-family dwelling. The interior floor area of the structure was approximately 752 sq. ft A porch measuring 5 ft wide and 23 ft long was attached to the front of the structure. The front portion of the structure consisted of two rooms of comparable size. These two rooms were furnished as a bedroom (A/D corner) and a living room (A/B corner). The bathroom located in the B/C corner of the structure, and the kitchen on the C/D corner of the structure were additions to the original structure. An unused masonry fireplace separated the living room from the bedroom on side A of the structure. Figure 4.1 shows the layout of the rooms as described above, as well as key furnishing pieces that were in the rooms at the time of the fire.

The foundation of the structure was comprised of masonry pilings that created a crawlspace area beneath the living space. The area between each piling on the perimeter of the structure was filled with concrete blocks. The structural framing consisted of rough sawn lumber. The siding on the exterior walls was 0.5 in thick cedar shiplap siding covered with asphalt siding, as shown in Figure 4.2. The roof structure was comprised of nominally 1 in x 4 in and 1 in x 6 in deck boards laid over the rafters retrofitted with plywood decking laid over the boards. Felt paper and asphalt

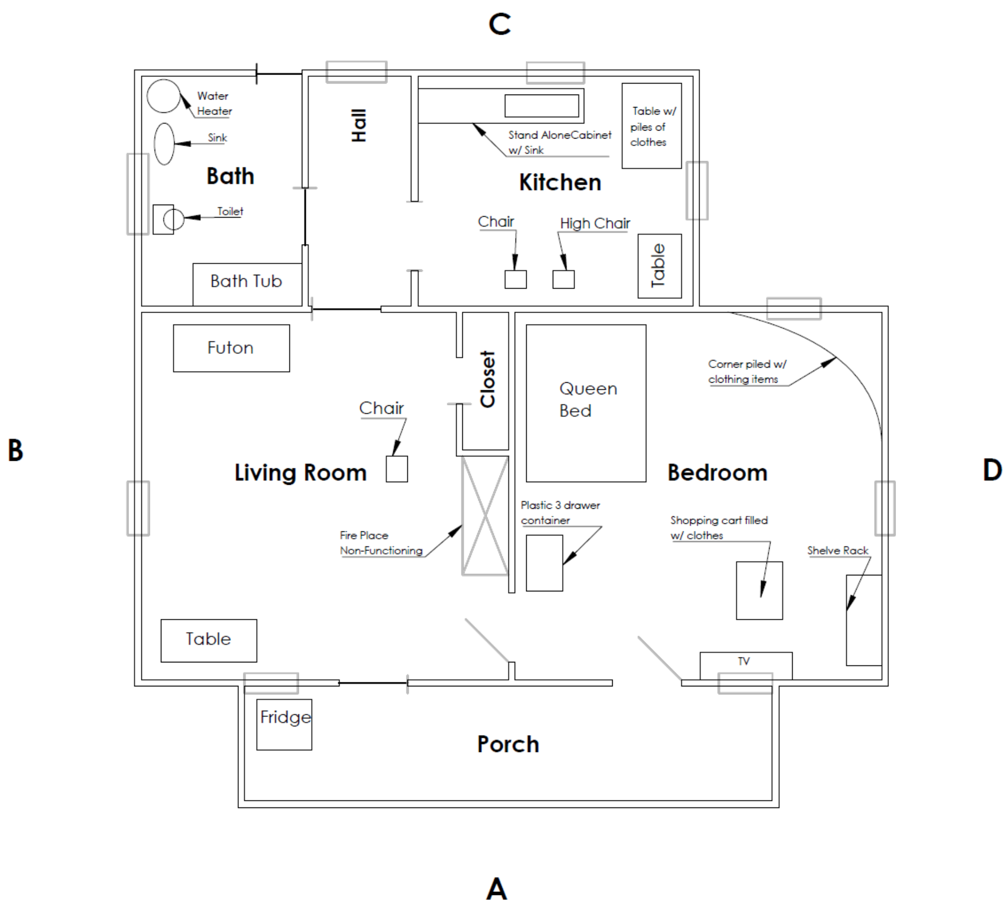


Figure 4.1: Approximate floor plan of the structure with locations of the furnishings at the time of the fire.

shingles were installed on the plywood decking. The interior walls and ceilings were covered with 3 in wide by 0.5 in thick beadboard with many coats of paint. An example of the beadboard construction is shown in Figure 4.3. The void spaces between the wood framing in the walls contained no insulation. The attic space contained cellulosic insulation. The type of construction as well as the doors and windows are visible in the photographs displayed as Figures 4.4 through 4.7, which show the post-fire damage to the exterior of the structure.

Figure 4.2: Photograph of an exterior wall of the structure showing the asphalt siding was installed over the wood siding.

Figure 4.3: Photograph of the interior finish of the walls and ceiling of the structure. This image was taken in the living room but is representative of the bead board that formed the interior surface of the walls and ceiling in the kitchen and bedroom before the fire.

Figure 4.4: Photograph of the A/B corner of the structure.

Figure 4.5: Photograph of the B/C corner of the structure.

Figure 4.6: Photograph of the C/D corner of the structure.

Figure 4.7: Photograph of the A/D corner of the structure.

4.3 Building Contents

The following sections describe the layout of the rooms as well as the contents of each room prior to the incident. All the windows described in these sections were single pane with a bottom sash.

4.3.1 Bedroom

The bedroom was located in the A/D corner of the structure and included an exterior door on side A of the structure, a window on side C of the structure, a window on side D of the structure, and a window on side A of the structure that was adjacent to the kitchen, as shown in Figures 4.6 and 4.7 respectively. The dimensions of the bedroom were approximately 16 ft x 16 ft with a 10 ft ceiling height. The entry door on side A of the structure was a hollow core wood door. Figure 4.8 provides a view from the entry door looking into the bedroom toward the rear of the house. Note that the beadboard on the wall between the bedroom and the kitchen has burned away. The windows had dimensions of 28 in x 66 in with a sill height of 28 in above the floor. An interior doorway, shown in Figure 4.9, connected the bedroom to the living room on side B of the bedroom. The bedroom contained a queen-size mattress and box spring in the B/C corner of the room, a wooden table with a television set on side A of the room next to the exterior door, a wooden shelving unit with miscellaneous items on side D of the room, and a shopping cart full of clothing in the center of the room.

Figure 4.8: Photograph of the bedroom from the entry door looking toward side C.

Figure 4.9: Photograph of the interior doorway from the bedroom leading into the living room.

4.3.2 Living Room

The living room was located in the A/B corner of the structure and included an exterior door on side A of the structure, a window on side A of the structure, and a window on side B of the structure. The dimensions of the bedroom were approximately 16 ft x 16 ft with a 10 ft ceiling height. The entry door on side A of the structure was a hollow core wood door. Both windows had dimensions of 28 in x 66 in with a sill height of 28 in above the floor. The window on the B-side of the structure contained an in-window air conditioning unit at the time of the fire. Refer to Figure 4.4 for the exterior view.

There was an interior doorway on side D of the living room which connected the living room to the bedroom. The photograph in Figure 4.10 was taken from the bedroom doorway. Another interior doorway on side C of the living room connected the living room to a hallway that connected to the bathroom and the kitchen. Figure 4.11 shows the interior door between the living room and the hallway. The door was a solid panel wood door with glass inset in the upper half and plywood panels in the lower half of the door. The door was designed as an exterior door. An inoperable fireplace and chimney were located in the interior wall shared with the bedroom. A closet was located between the fireplace and side C wall in the living room. The living room contained a futon-style sofa on the side C wall, a wooden table with a television set in the A/B corner, a wooden chair on the side D of the room, and miscellaneous items scattered throughout the room.

The closet contained a foam mattress topper. Carpet tiles covered the living room floor.

Figure 4.10: Photograph of the living room from the bedroom looking toward side B.

Figure 4.11: Photograph of the door, which leads to the hallway between the bathroom and the kitchen. Photo taken from the living room looking toward the rear of the structure.

4.3.3 Hallway

The hallway had approximate dimensions of 5 ft x 10 ft with a ceiling that sloped from 6 ft high on side B to 10 ft high on side D. Doors on sides A and B of the hallway connected the hallway to the living room and bathroom, respectively. An open doorway on side D of the hallway connected the hallway to the kitchen. There was a window in the side C wall of the hallway with dimensions of 31 in x 24 in. The walls of the hallway were lined with wood paneling. The sloped ceiling was covered with a thin layer of plywood.

4.3.4 Bathroom

The bathroom was located in the B/C corner of the structure and included an exterior door on side C of the structure and a window on side B of the structure as shown in Figure 4.5. The dimensions of the bathroom were approximately 10 ft x 7 ft with an approximately 6 ft ceiling height. The exterior door had dimensions 24 in x 72 in. The window had dimensions of 42 in x 13 in with an estimated sill height of 48 in above the floor. An interior doorway on side D of the bathroom connected the bathroom to the hallway. The bathroom door was a hollow core wood door with dimensions of 30 in x 72 in, as shown in Figure 4.12. The bathroom contained a bathtub, a toilet, a sink, and the water heater. Figure 4.13 shows the arrangement of the bathroom fixture and window. The walls of the bathroom were lined with wood paneling. The bathroom ceiling was covered with thin plywood panels over gypsum board.

Figure 4.12: Photograph of the bathroom door from the kitchen looking toward side B.

4.3.5 Kitchen

The kitchen was located in the rear of the structure. The dimensions of the kitchen were approximately 10 ft x 12 ft with a 10 ft ceiling height. The kitchen had a window on side C and a window

Figure 4.13: Photograph of the bathroom fixtures and bathroom window as viewed from the hallway looking toward side B.

on side D. The windows had dimensions of 30 in x 45 in with a sill height of 25 in above the floor. An interior doorway on side B of the kitchen connected the kitchen to the hallway. The doorway was 36 in wide and 84 in high. The kitchen contained a standalone counter with a sink fixture made of particle board located at the wall on side C, a table piled with clothing, a high chair, and a small table. A curtain was hanging from side C window and an unknown material was partially covering missing glass panes in side D window. Refer to Figure 4.6 for the exterior view of the kitchen. The remains of the sink cabinet and the kitchen side D wall are shown in Figures 4.14 and 4.15 respectively.

Figure 4.14: Photograph of the sink cabinet below the window on the side C wall.

Figure 4.15: Photograph of the kitchen side D wall. Remains of the window framing for the sill can be seen.

4.3.6 Porch

The porch was located on side A of the structure. The stairway met the center of the porch, such that the two entry doors were equidistant from the stairs. The dimensions of the porch were approximately 23 ft x 5 ft. The porch was made of wood planks with a wooden railing and a roof that completely covered the porch. A refrigerator sat in the B/C corner of the porch in front of the window. A rug was thrown over the railing on the left side of the porch, when looking toward side A. A photograph of the porch viewed from the front yard is presented in Figure 4.16.

Figure 4.16: Photograph of the front porch.

4.4 Timeline

An approximate timeline summarizing the salient events in this incident is listed below. The times are approximate and were obtained from available dispatch channel records, witness statements, and video evidence. This timeline is not intended to be used as, nor should it be used as, a formal record of events. Only those dispatch channel communications related to the fire service personnel actions and the resulting injuries are included.

- **2:50:17**

  Call received for structure fire [5].

- **2:51:11**

  LaGrange Fire Department Engine 1 (E1), Engine 4 (E4), Truck 32 (T32), and Acting Shift Command (IC) dispatched [5]. Troup County Fire Department Rescue 1-1 (R1) dispatched [5].

- **2:56:55**

  E1 arrives at the scene [5].

- **2:57:00**

  Flames observed extending out of kitchen side D window [5].

- **2:57:20**

  E4 arrives at the scene [5].

- **2:57:44**

  IC arrives at the scene [5].

- **2:58:12**

  360 degree size up complete [5]. Flames extending out of kitchen side C window [5].

- **2:58:23**

  T32 arrives at the scene [5].

- **2:58:40**

  IC assumed incident command on A side of structure [5]. E1 Lt and E1 FF1 (Fire Control crew) assigned to offensive strategy with a handline through the entry door on the porch near the A/D corner of the structure [5, 6]. E4 Lt and E4 FF1 (Search crew) assigned to search and rescue with entry through the entry door on the porch near the A/D corner of the structure [5, 6]. E4 and T32 assigned to establish water supply at the hydrant [5, 6].

- **2:58:40–3:02:44**

  Search Crew conducts search in the bedroom and living room [5, 6]. Fire Control crew advances hoseline from the entry door through the bedroom and into the living room. Then they open the door between the living room and the hallway/kitchen, advance into the hall and suppress the fire in kitchen [5, 6]. E2 arrives on scene and is assigned to RIT [5, 6]. R1 arrives on scene and is assigned to "on deck" [5, 6].

- **3:02:44**

  Fire Control crew provides status update,“Standby, we got it knocked down - we’re going to attic now, near front door, we can hear it burning throughout [5].”

- **3:02:54**

  IC responds to Fire Control crew status update,“That’s clear, we still got a lot of exterior fire on the C/D side [5].”

- **3:03:59**

  An exterior line is ordered to be pulled next to side D to suppress fire on side C [5].

- **3:04:13**

  IC updates the interior Fire Control crew,“You’ve got about 30 seconds to get this fire on side A put out or else you’re coming outside [5].”

- **3:04:34**

  E1 Mayday call [5].

- **3:05:24**

  An additional hoseline is ordered to be pulled to side A [5].

- **3:06:23**

  All fire visible from the exterior had been suppressed from side A by E2 [11].

- **3:06:37**

  E4 Mayday call [5].

- **3:06:51**

  Firefighter observed exiting through living room window on side A [5].

- **3:07:21**

  Firefighter observed exiting through bathroom window on side B [5].

- **3:08:09**

  Two firefighters observed exiting through side B living room window [5].

4.5 Detailed Incident Narrative

A resident of the home woke up in the bedroom at approximately midnight on September 3, 2018 to prepare food for one of her young children. She went to the kitchen, lit a tea candle to provide light, and rested the candle on the back part of the sink in the kitchen. The resident believes she left the candle lit and returned back to her bed. Later in the night she woke up to the smell of smoke in the house and discovered a fire in the kitchen. She and the other residents evacuated the structure and called 911. Then she attempted to suppress the flames extending from the side D kitchen window with water flowing from a garden hose.

E1, E4, E2, and T32 as well as the Acting Shift Commander (IC) from the LaGrange Fire Department were dispatched to the scene. E1 was the first unit to arrive at the scene and E1 Lt set up command and accountability on the street in front of side A. The entry door to the bedroom was open when E1 arrived and it was noted there were small flames on side C of the structure and heavy smoke on side A of the structure. E4 arrived at the scene at approximately the same time as IC. IC conducted a 360-degree size-up and noted fire venting out of the kitchen side D window. Figure 4.17 shows an image recorded with a LaGrange police officer body camera that provides an idea of the extent of the flame extending from the kitchen window at 02:57:40, approximately the time IC arrived on the scene. IC took over incident command on the street of side A.

Figure 4.17: Flames extending out of the side D kitchen window at 02:57:40. E1 has been on scene for almost 1 minute [11]

The E4 Search crew entered the structure at approximately 02:58:40 via the entry door to the bedroom and started conducting a right-hand search. During the search of the bedroom, visibility was sufficient such that the E4 Search crew members could see their feet while in a high squat position. The Search crew concluded their search of the bedroom stating that the room was clear. After clearing the room, E4 Lt returned to the entry door and told E1 Fire Control crew that the fire was in the back of the structure and that they would need to immediately go to the left after entering the structure. The Search crew stayed at the entry door and allowed the Fire Control crew to enter the structure and proceed into the living room.

The Fire Control crew moved into the living room with the nozzle and observed there was not much heat in the room. The Search crew followed after the Fire Control crew and conducted a left-hand search of the living room and stopped when they reached a window on side B of the room. The Fire Control crew moved to the closed door that led to the hallway and the kitchen. It was noticed that paint on the door was starting to bubble due to heat from the hallway. The Fire Control crew opened the door to the hallway and noted a glow to the right of them and flames rolling over the ceiling in the kitchen. The Fire Control crew entered the hallway and flowed water for 10 to 15 seconds to suppress the fire in the kitchen. E1 FF1 noted crackling sounds which led him to believe there was extensive fire in the attic. E1 Lt told E1 FF1 that he saw more fire and told E1 FF1 to hand him the nozzle. E1 FF1 handed the nozzle to E1 Lt. and additional water was flowed into the kitchen.

After providing an update to IC about the fire being knocked down, at 03:02:44, the Fire Control crew remained in the hallway. Ten seconds later, IC noted that there was still significant fire on the exterior of the structure, particularly on side C of the structure and side D of the kitchen. The images in Figures 4.18 and 4.19 were recorded at 02:59:50 and 03:01:53, while the Fire Control and Search crews were operating inside the structure.

Figure 4.18: Flames extending out of the C/D corner of the structure, 02:59:50 [11].

Shortly after relaying the status of the fire on the exterior of the C/D corner of structure to the Fire Control crew, IC ordered a back-up line to be pulled along side D of the structure to suppress the fire at the exterior C/D corner. Evidence and observations indicate this line was never completely pulled or put into service at the C/D corner. IC noted significant fire on side A of the structure; flames exiting the entry doorway and extending under the porch roof. IC relayed this observation to the crews on the interior. At 03:04:13, IC gave the Fire Control crew 30 seconds to suppress the fire on side A of the structure before ordering the interior crews out of the structure. During this time period, the fire spread back into the kitchen. The image displayed in Figure 4.20 shows flames extending out of the bedroom entry door. That image was recorded at 03:03:51, a little more than a minute after the Fire Control crew had suppressed the fire in the kitchen.

Approximately 21 seconds after IC gave the Fire Control crew 30 seconds to suppress the fire, the Fire Control crew called Mayday. Both members of the Fire Control crew were in the hallway that connected the living room and the kitchen when they made the Mayday call. After the incident, it

Figure 4.19: Flames continuing to extend out of the C/D corner of the structure, 03:01:53 [11]

Figure 4.20: Flames extending out of the bedroom on side A, 03:03:51 [11]

was discovered that the hoseline that passed through the bedroom and the living room had burned through near the bedroom entry door, so the Fire Control crew no longer had appropriate pressure at the nozzle when the fire spread back into the kitchen and the bedroom reached flashover conditions. Figure 4.21 provides a sense of the volume of fire that was visible on the porch from the neighbor's house at 03:04:38, about 4 seconds after the the first Mayday call.

The fire continued to increase in size while IC directed E2 to bring a hoseline to side A. A view from the next door neighbor's front yard, Figure 4.22, shows the size of the fires at both the A/D and C/D corners of the house. All four firefighters were still in the structure at this time, however they were in areas on the opposite side of the house.

Figure 4.21: Flames extending out of the bedroom on side A at the time of the first Mayday, 03:04:38, as viewed from the neighbor's porch on side D [11]

Figure 4.22: Flame spread at the A/D and C/D corners of the structure 40 seconds after the first Mayday, 03:05:14, as viewed from side D [11]

Based on the body camera footage from the LaGrange police, by 03:06:23 most of the fire in and on the structure has been suppressed by E2 [11]. However both the E1 and E4 crews are still in the structure.

At the time of the initial Mayday call, 03:04:34, E1 FF1 moved into the living room toward the front of the structure. E1 FF1 located the living room window on side A and exited the structure through the window. Complicating the exit was a refrigerator that was sitting on the porch directly in front of the window. He was observed exiting the living room window onto the porch at 03:06:51.

At the Mayday call, E1 Lt moved into the bathroom adjacent to the hallway and closed the door behind him to protect himself from the increasing temperature and severe thermal conditions. E1 Lt searched for an exit out of the bathroom. He found a narrow window on side B of the structure. E1 Lt could not fit through the window with his self-contained breathing apparatus (SCBA) air tank, so he removed it to climb out through the window. He was seen coming through the bathroom window at 03:07:21. At this point both members of the E1 Fire Control crew were out of the structure.

Two minutes and three seconds after the Fire Control crew made their Mayday Call, the E4 Search crew also called Mayday (03:06:37). Leading up to the second Mayday call, the E4 crew was moving through the bedroom searching for emergency egress in high temperature and low visibility condtions. The E4 Mayday call occurred 10 to 20 seconds after the majority of the fire was suppressed. Both members of the E4 Search crew located the living room window on side B of the structure. The lower portion of the window contained an air conditioner unit. The crew was able to remove the air conditioner unit and exit the structure through that window. They were observed exiting the structure at approximately 03:08:09. They had been in the structure for approximately 9 minutes. About 2 minutes of that time they were in the living room adjacent to the flashed-over bedroom.

5 Analysis

5.1 Fire Dynamics Modeling

The Fire Dynamics Simulator (FDS) developed by the National Institute of Standards and Technology (NIST) and the Technical Research Centre of Finland (VTT) is a computational fluid dynamics (CFD) fire model that allows practitioners to simulate the evolution of fires and predict flame spread rates, heat release rates, temperatures, velocities of the corresponding buoyant gas flows, and other quantities of interest [12]. FDS has undergone extensive verification [13] and validation [14]. FDS was used in this near miss investigation to aid in the understanding of how the fire spread from the kitchen to the bedroom and to estimate the temperatures the firefighters experienced leading up to and during the mayday situation.

5.1.1 Model Development

The model geometry and materials were defined to emulate the actual geometry and materials in the residence as closely as possible while adhering to the underlying rectilinear grid requirement. The computational domain for the simulations was 31.5 ft x 39.4 ft x 16.4 ft and centered on the structure. The domain was meshed with a uniform grid with elements that were 4 in (0.1 m) on each side. Views of the FDS geometry from the A/D corner and from the C/D corner are displayed in Figure 5.1.

A plan view of the modeled structure is shown in Figure 5.2 with each color corresponding to a specific material. The sides and top of the computational domain were defined as open boundaries which allowed for both inflow and outflow. The ambient temperature was defined as 76°F (24°C). To make the model consistent with the narrative presented by the homeowner, the wood products in the kitchen (two chairs, two tables, and cabinetry) were defined to immediately release heat as if they had achieved steady-state burning at the beginning of the simulation. The total heat release rate (HRR) of these furniture items was approximately 5 MW. These wood products and the walls on sides C and D of the kitchen were defined to be removed from the computational domain as mass was lost during the simulated burning to adhere to the conservation of mass. To ensure consistency with the timeline presented by the Fire Control crew, several nozzles were placed throughout the kitchen to simulate approximately 25 seconds of water applied inside the structure during firefighter intervention 6.5 minutes after the simulation began. The cooling effect of the water on the burning surfaces was modeled as described later in this section.

To represent an open bottom sash for side A window and side D window in the bedroom, the windows were defined such that the bottom 16 in (0.4 m) was open and the rest of the glass was intact. Several windows and the door between the living room and the hallway to the kitchen changed from closed to open during the incident to represent actions taken by the firefighters. The timing

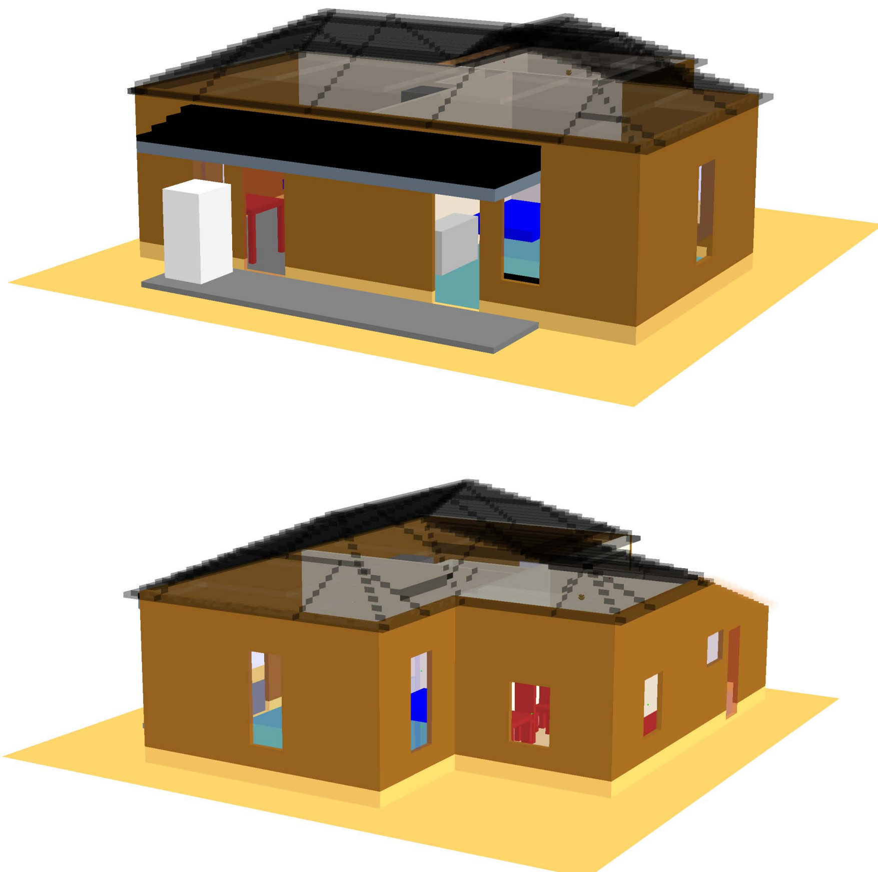


Figure 5.1: Images of Stucture Modeled in FDS

of these changes and the explanation for each event are provided in Table 5.1. The simulation was started with an initial fire size of 60 kW and allowed to spread throughout the kitchen because the initial ignition and incipient stages of the fire were not important to fire department intervention and actions and the simulation defined as described here yielded conditions which matched fire department personnel observations.

Table 5.1: Window and Door Opening Events

Event	Simulation Time [s]	Approx. Time	Explanation
Beginning of simulation	0	2:56:30	Begining of simulation
Firefighter entry	180	2:59:30	Search and Fire Control crews enter the structure
Bedroom C side window open	330	3:02:00	Glass breaking due to exposure to exterior fire
Hallway door open	390	3:03:00	Fire Control crew open hallway door
Suppression in hallway and kitchen starts	390	3:03:00	Fire Control crew start suppression in hallway and kitchen
Suppression in hallway and kitchen ends	415	3:03:25	Fire Control crew stops flowing water
First Mayday call	480	3:04:30	Search Crew Mayday call
Second Mayday call	620	3:06:50	Fire Control Crew Mayday call
Living room A side window open	660	3:07:30	E1 FF1 exits through living room A side window
Living room B side window open	740	3:08:50	E4 Lt and E4 FF1 exit through living room B side window
Bathroom B side window open	740	3:08:50	E1 Lt exits through bathroom B side window

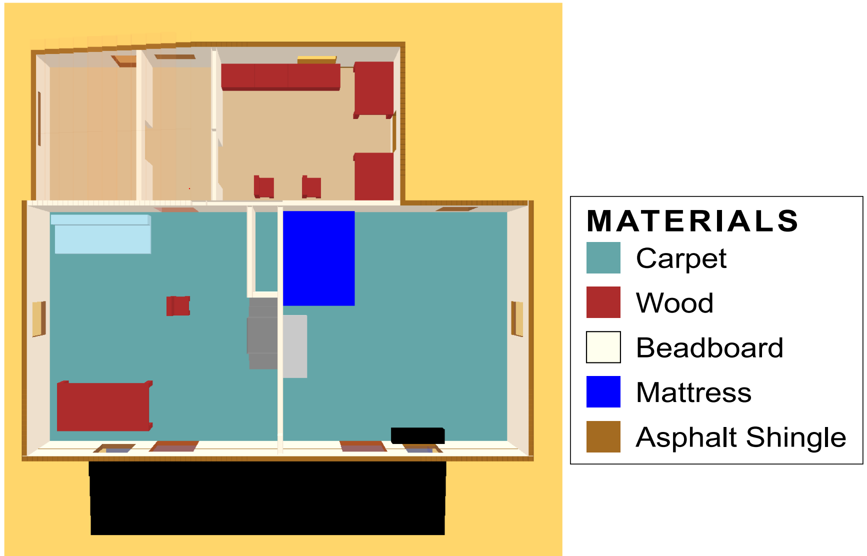


Figure 5.2: FDS model geometry with materials color coded

The time at which the window on side C of the bedroom broke was not directly observed during the incident, but has been defined at a simulation time of 330 s (150 s after firefighter entry). The window was intact at the time the Search crew entered and started the search of the bedroom (2:58:40), but the video evidence indicated flame extension from the A side bedroom window five minutes later at 3:03:51. The accounts from the firefighters and observers indicate the bedroom was fully involved a minute or so prior to the observation of flame extension. Mowrer conducted experiments in which windows were exposed to specific radiant heat fluxes to determine the time to breakage and the temperature at breakage with each given exposure [15]. Results showed that single pane, wood frame windows exposed to a heat flux of 14.5 kW/m^2 showed breakage 55 s to 85 s after initial exposure at temperatures that ranged from 302°F (150°C) to 356°F (180°C). Heat fluxes in excess of 100 kW/m^2 would be expected due to direct flame impingement on the window glass, and considering the significantly higher heat fluxes than those studied by Mowrer, it is reasonable to assume the glass would have broken a few seconds after flame impingement. The side C bedroom window was removed from the simulation 150 s after firefighter entry to simulate breakage.

The combustible materials of interest were defined in the FDS model with thermo-physical properties and ignition temperatures estimated from the literature and heat release rate per unit area (HRRPUA) defined according to cone calorimeter tests conducted on materials collected from the structure. The density of the materials collected from the structure was measured directly. The model accounted for heat transfer through the solid phase and thermal equilibrium between the solid surface and the gas phase to predict the surface temperature of the solid material given the thermal conditions and convective and radiative heat fluxes from the surroundings. When the sample surface achieved the ignition temperature, the mass loss and heat release rate of the solid material was defined to produce the HRRPUA that was measured in the cone calorimeter experiments, as described in Appendix A. The surfaces and materials were defined such that mass was conserved as the solid mass was converted into gas. The set of properties for each combustible material as defined in the model is displayed in Table 5.2.

Table 5.2: Properties of Materials Defined in FDS Model

Property	**Wood**	**Carpet Tile**	**Asphalt Siding**	**Mattress**
Thermal Conductivity [W/mK]	0.14*	0.3*	0.75*	0.04*
Specific Heat Capacity [kJ/kgK]	2.4*	3.2*	0.83*	1.8*
Density [kg/m^3]	460	820	1120	125
Emissivity	0.85*	0.9*	0.92*	0.9#
Ignition Temperature [°F] (°C)	608* (320)	572* (300)	536# (280)	734* (390)
HRRPUA [kW/m^2]	See Figure A.4	90	325	See Figure A.5

* Sourced from the *Handbook of Fire Protection Engineering* [16]
\# Estimated

Samples of several materials from the structure were collected to facilitate testing to inform the FDS model. The samples that were tested to define burning materials in the models included the painted beadboard, asphalt siding, and carpet tile. The data collected in these experiments as well as a discussion providing justification for the HRRPUA values that appear in Table 5.2 are provided in Appendix A.

Suppression applied from within the structure was simulated by introducing water droplets to the computational domain and decreasing the HRRPUA of the surfaces wetted by the water droplets. Observations from the Fire Control crew are consistent with the fire in the kitchen and hallway being visibly knocked down after approximately 25 seconds of water flow directed from the doorway to the hall and kitchen. The direction of water flow and the total flow rate applied over time during the incident are unknown, so the simulation was defined to match the oservations of the Fire Control crew. The water was introduced at several nozzles positioned throughout the hallway and kitchen. The positions of the nozzles defined in the computational domain are shown in Figure 5.3.

The simulated nozzles at the hallway door directed flow toward side C of the structure, while the nozzles defined in the hallway directed water flow toward and away from the door. The simulated nozzle at the kitchen door directed flow into the kitchen toward side D of the structure. The simulated nozzles at the center of the kitchen at the floor level were directed at 45° above the horizontal toward the A, B, C, and D sides of the structure. The simulated nozzles at the center of the kitchen at the middle elevation were directed at parallel to the horizontal toward the A, B, C, and D sides of the structure. The simulated nozzles at the center of the kitchen at the ceiling elevation were directed 45° below the horizontal toward the A, B, C, and D sides of the structure. Each nozzle was defined to flow water with a total flow rate of approximately 10.5 gpm (40 LPM). A total of 22 nozzles were defined for a total flow rate of approximately 230 gpm (870 LPM). Although this total flow rate is higher than typical for a 1-3/4 in hose, it produced conditions consistent with the observations without affecting fire progression elsewhere in the structure.

The simulated water droplets were ejected from each of the nozzles with a velocity of 22.4 MPH (10 m/s) over a 120° cone. The droplets were defined with a residence time of 15 s such that the droplets did not have a lasting effect beyond the immediate suppression activities, which is consistent with fire spreading back into the kitchen after suppression activities were terminated. The

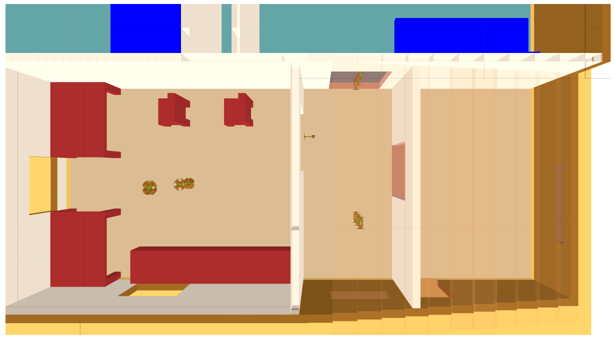


Figure 5.3: Locations of nozzles defined to simulate suppression in FDS model

droplets introduced to the computational domain had a diameter of 1 mm. An ‘`E_COEFFICIENT`’ was defined to reduced the HRRPUA of the burning surfaces according to the mass of water wetting the burning surface. The functional form of the reduction in HRRPUA with an `E_COEFFICIENT` defined may be found in the literature [12]. The `E_COEFFICIENT` defined for all burning surfaces in this work was chosen through trial and error as 4 m^2/(kg-s) to suppress the burning surfaces over a few seconds of water application.

5.1.2 Interpretation of Model Results

The following sections contain figures that present the conditions generated by the model based on the aforementioned boundary conditions and material definitions. Contours of gas temperatures and isosurfaces of volumetric heat release rate (HRRPUV), which represent the locations of the visible flame, are presented. These temperatures and isosurfaces may be compared to observations and data from the scene. While most of the temperature contours are presented with a rainbow colorbar, several figures present the modeled gas temperature contours in terms of thermal operating classes to help with interpretation of the simulation results.

Estimated Firefighter Thermal Exposure

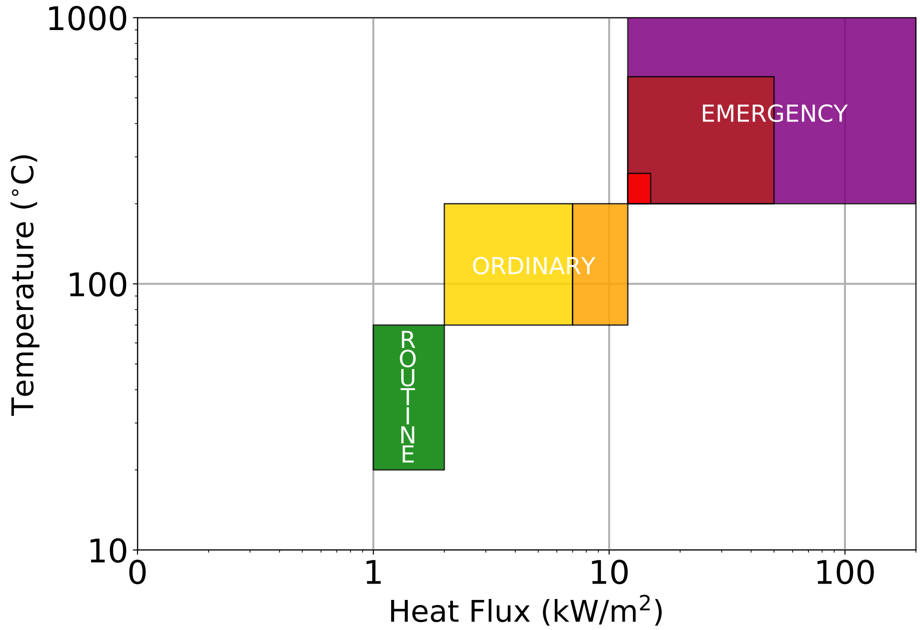
Temperature and heat flux determined in different locations in the structure can be used to approximate the thermal exposure to firefighters during search and rescue operations. This analysis is advantageous independent of the toxic or thermal exposure to occupants, as it gives an approximation of the time that the areas of the structure would fall into ranges of relative hazard for firefighters conducting a search or fire control operations.

The thermal insult to firefighters can be approximated using thermal operating classes originally defined by Utech. In 1973, Utech suggested a combination of the local air temperature and the incident heat flux to estimate the components of radiative and convective heat transfer, respectively, to a firefighter. He used these two quantities to define three ranges of firefighters’ operational thermal conditions: routine, ordinary, and emergency [17]. Routine conditions were defined as those with a surrounding temperature between 20 °C (70 °F) and 72 °C (162 °F) and an incident heat flux between 1 kW/m^2 and 2 kW/m^2. The thermal environment crosses into the Ordinary operating range with temperatures between 72 °C (162 °F) and 200 °C (392 °F) and heat fluxes between 2 kW/m^2 and 12 kW/m^2. Emergency operating conditions are present when heat flux exceeds 12 kW/m^2 and temperature is in excess of 200 °C (392 °F).

In 2017, Madrzykowski [18] compiled previous research efforts to characterize the thermal operating environment of firefighters. Recent literature highlighted that evaluating the operating environment of firefighters by pairing temperature and heat flux may not appropriately reflect the entire range of conditions encountered by firefighters. Additionally, the thermal conditions within a structure can rapidly change from environments where firefighters would be safe, to conditions where firefighters would be in immediate danger. More sophisticated characterization of heat transfer through firefighter turnout gear and appropriate exposure thresholds for firefighter turnout gear are an area of ongoing research.

Leveraging recent fire environment and PPE research, Utech's original operating classes have been modified in FSRI studies to better describe the thermal hazards to which firefighters may be exposed [19]. The Routine operating class remains unchanged. The Routine operating class corresponds to conditions that would be experienced in ambient environments or during the overhaul phase of a fire. Ordinary operating conditions include thermal environments that might be encountered next to a post-flashover room. The Ordinary operating class has been split into two levels based on heat flux exposures. Provided firefighters were not previously operating under higher thermal exposure conditions, they are still likely able to function under Ordinary operating conditions from 10 min to 20 min at a time. To better characterize the upper limits of exposure, the emergency operating class has been split into three regions. The top bound of Emergency I is set to be at the thermal conditions for which many firefighter PPE components are evaluated [20]. Emergency II is defined as the region where the thermal conditions are representative of localized burning/flaming combustion, and Emergency III would be equivalent to a post-flashover exposure. The emergency classes represent exposures at which a firefighter may be able to safely operate on the order of tens of seconds (Emergency I) to beyond the limits of PPE (Emergency II and III). The modified thermal classes and corresponding temperature and heat flux ranges are presented in Figure 5.4.

For the analysis presented here, the thermal classes defined only by gas temperatures are considered, and as a result there is only one Ordinary operating class in the figures that show temperature contours colored according to the thermal operating classes.



Operating Class	Temperature Range [°F]	Temperature Range [°C]	Heat Flux Range [kW/m²]
Routine	68 – 162	20 – 72	1 – 2
Ordinary I	162 – 392	72 – 200	2 – 7
Ordinary II	162 – 392	72 – 200	7 – 12
Emergency I	392 – 500	200 – 260	12 – 15
Emergency II	500 – 1112	260 – 600	15 – 50
Emergency III	> 1112	> 600	> 50

Figure 5.4: Modified thermal operating classes

Figure 5.5 displays a plan view of the isosurfaces of a HRRPUV of 200 kW/m^3 at the approximate time the Search and Fire Control crews entered the structure. This isosurface may be interpreted as the approximate flame progression when the firefighters entered the structure. Figure 5.5 shows that the flames were confined to the interior of the kitchen, the exterior C and D sides of the kitchen, and the exterior C side of the bedroom at the time the firefighters made entry which is consistent with the model definition and the observations of the firefighters.

Figure 5.6 shows temperature contours of the residence at the approximate time of firefighter entry at an elevation of 35 in (0.9 m). This is the approximate height of a crawling firefighter. It is evident with the door between the living room and the hallway to the kitchen closed that the gas temperatures in the living room and bedroom were only slightly above ambient temperature while the temperatures in the kitchen, hallway, and bathroom were significantly elevated. These temperatures are consistent with firefighter observations of visibility to their feet in a standing position and the feeling of little heat within the bedroom and living room.

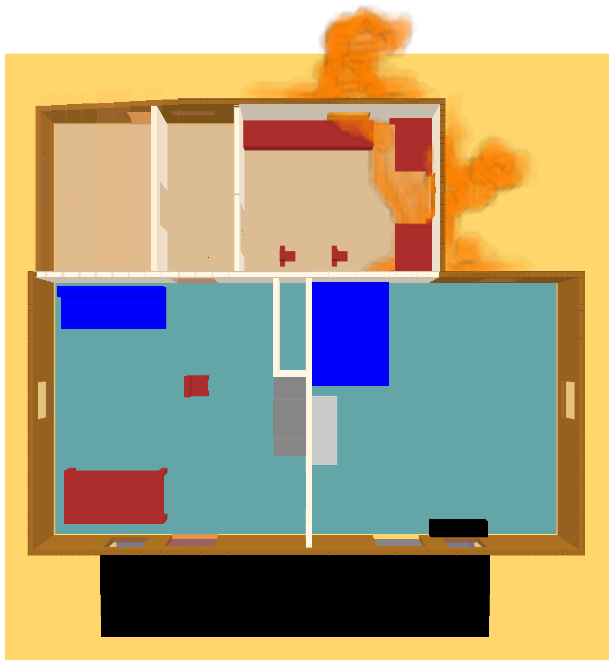


Figure 5.5: Approximate flame progression at firefighter entry

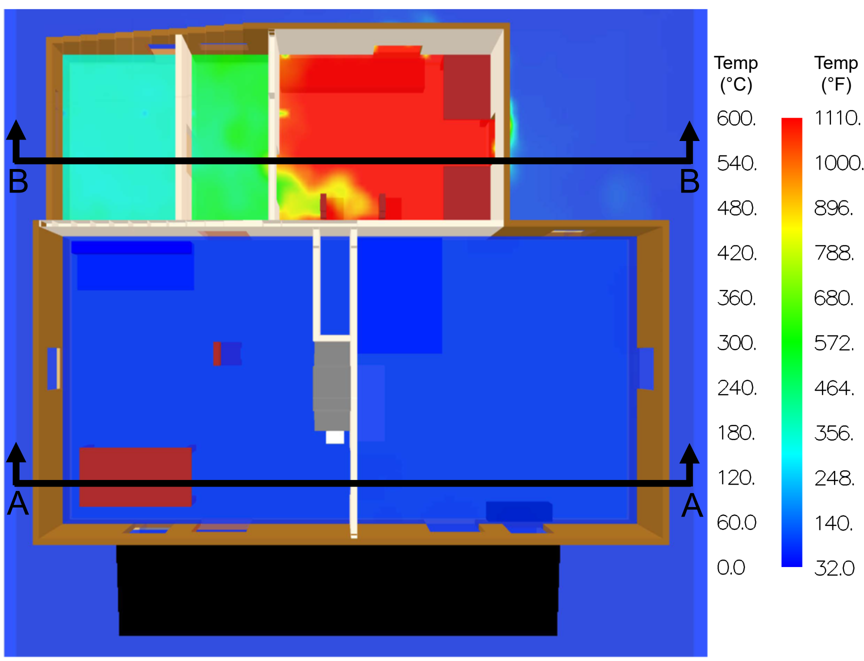


Figure 5.6: Gas temperatures at the time of firefighter entry at an elevation of 35 in (0.9 m). Solid black lines indicate locations of cross-sections.

The black lines in Figure 5.6 indicate the locations of two cross-sections. The cross-section through the bedroom and living room (A-A) is displayed in Figure 5.7. The cross-section through the kitchen, the hallway, and the bathroom (B-B) is displayed in Figure 5.8. The temperatures from floor to ceiling in the bedroom and living room at the time of firefighter entry were in the range of 32°F (0°C) to 140°F (60°C). These temperatures are consistent with the observations from the Search crew. At the same time, the temperatures throughout the kitchen were above 1112°F (600°C) as shown in Figure 5.8. As a result of flow through open doorways from the kitchen into the hallway and from the hallway into the bathroom, the temperature in the bathroom was in the range of 248°F (120°C) to 356°F (180°C).

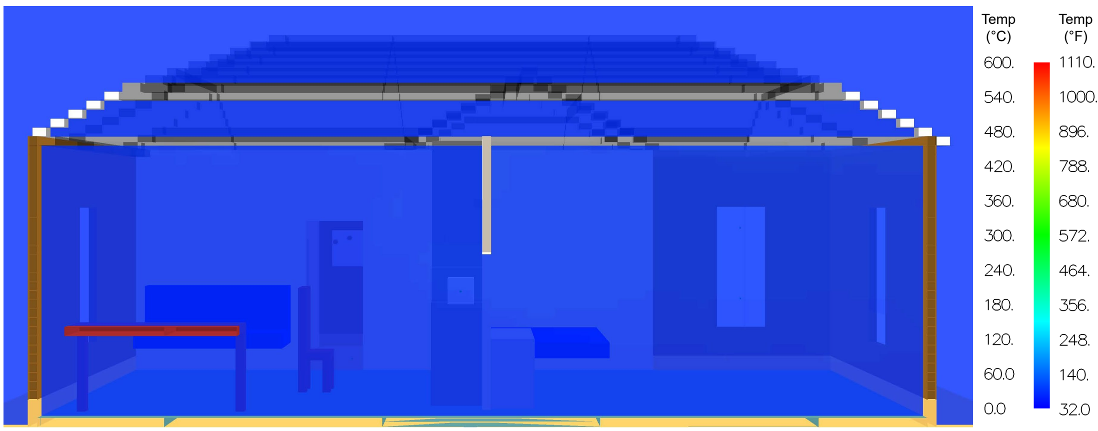


Figure 5.7: Gas temperatures in the bedroom and living room at the time of firefighter entry

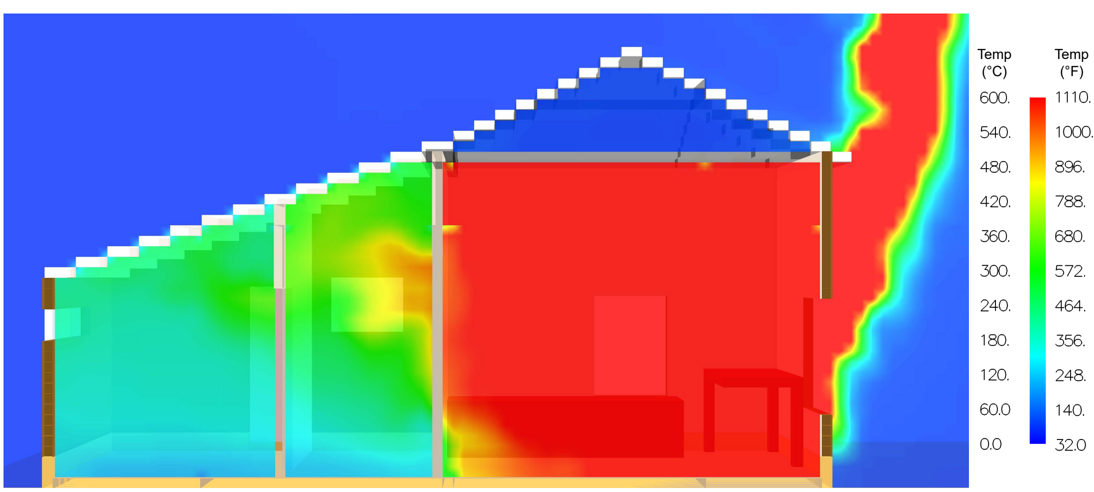


Figure 5.8: Gas temperatures in the bathroom and kitchen at the time of firefighter entry

Figure 5.9 displays a plan view of the structure with temperature contours at an elevation of 35 in (0.9 m) colored according to the previously defined thermal operating classes at the approximate time the Search and Fire Control crews entered the structure. Consistent with the accounts by the Search and Fire Control crews, the bedroom and living room were in Routine thermal operating class. The kitchen had reached flashover conditions and was in the Emergency III and Emergency II class, while the hallway was in the Emergency I and Emergency II classes, and the bathroom was in the Ordinary class.

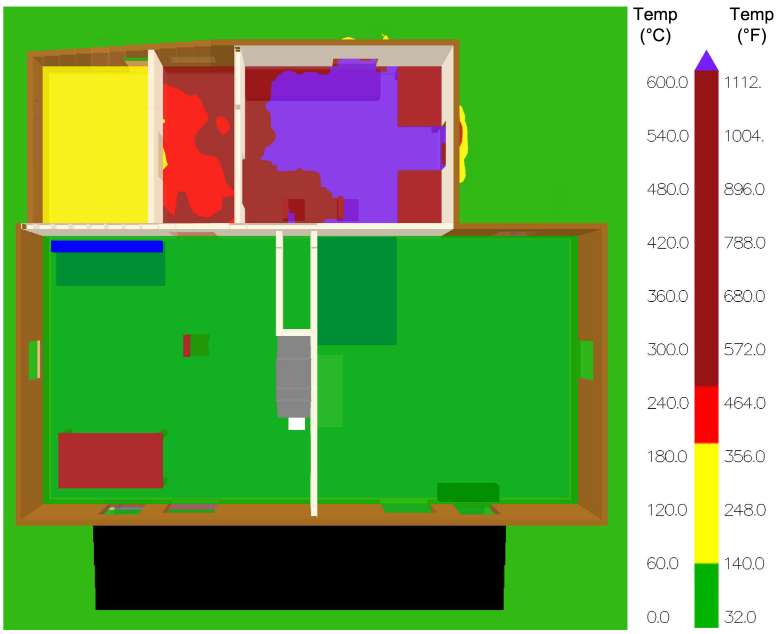


Figure 5.9: Gas temperatures colored according to thermal operating classes at the time of firefighter entry

Figure 5.10 displays the plan view of the residence with isosurfaces of HRRPUA generated when the bedroom was completely involved in the fire after flame spread from the exterior of side C of the bedroom into the bedroom through the window opening. The image is from the approximate time of the first Mayday call.

Figure 5.10: Approximate flame progression at the time of the Mayday call

Figure 5.11 displays temperature contours from throughout the structure at the approximate time of the first Mayday call at an elevation of 35 in (0.9 m). At this elevation, temperatures throughout the bedroom exceeded 896°F (480°C), temperatures in the living room were in the range of approximately 356°F (180°C) to 464°F (240°C), and the temperatures in the bathroom were in the range of 464°F (240°C) to 572°F (300°C). The accounts from involved firefighters include that E1 Lt entered the bathroom after the hose burned through and closed the door behind him. The post-fire walk through revealed large portions of the upper half of the door had burned away, but it is unclear when in the timeline that occurred. The closed bathroom door was represented in the simulations but burning away of the door was not explicitly represented, and the temperatures indicated in the figures may be lower than those that E1 Lt actually experienced in the bathroom.

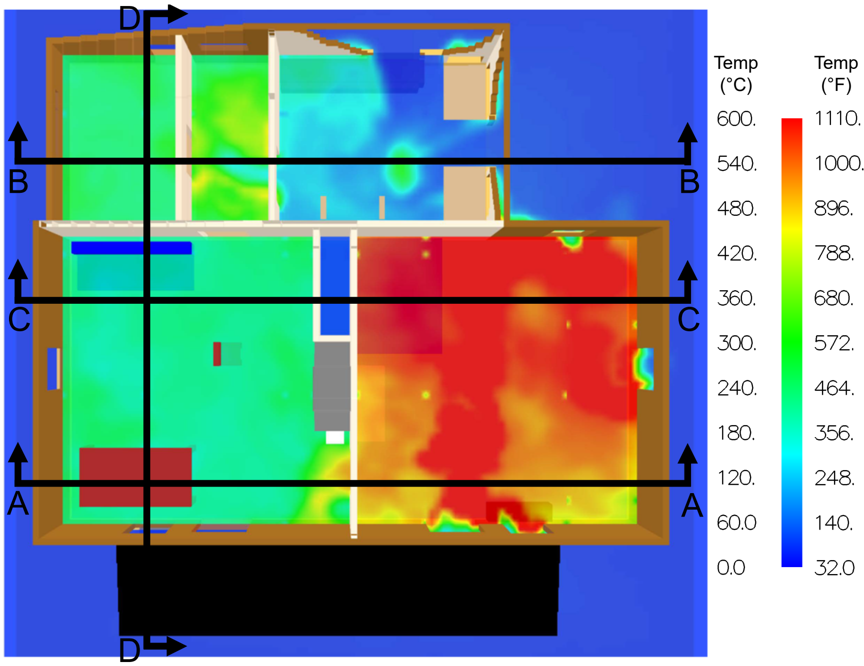


Figure 5.11: Gas temperatures at the time of the first Mayday call at an elevation of 35 in (0.9 m). Solid black lines indicate locations of cross-sections.

The cross-sections indicated in Figure 5.11 are displayed in the following figures. The cross-section through the bedroom and living room (A-A) is displayed in Figure 5.12. The cross-section through the kitchen, the hallway, and the bathroom (B-B) is displayed in Figure 5.13. The temperatures throughout the bedroom at the first Mayday call were above 480°C (896°F). Temperatures at elevations below approximately 47 in (1.2 m) in the living room and the bathroom were less than 240°C (464°F) and below approximately 35 in (0.9 m) were less than 180°C (356°F) at the time of the first Mayday call. 47 in (1.2 m) typically corresponds to a low squat position which E1 Lt may have been in while searching for egress from the bathroom.

The accounts from the Search crew place them in the BC corner of the living room at the time they made the Mayday call. Figure 5.14 displays the temperature contours at side C of the living room and bedroom (C-C in Figure 5.11) and Figure 5.15 displays temperature contours through the bathroom and living room (D-D in Figure 5.11) at the time of the first Mayday call. At the approximate location of the Search crew when the first Mayday call was made, the gas temperatures were consistent with those in the front of the living room. The temperatures at 47 in (1.2 m) elevation were approximately 464°F (240°C) and less than 356°F (180°C) below 35 in (0.9 m) elevation. The temperatures were slightly lower at the same elevation moving closer to the front of the living room (to the right in Figure 5.15). Based on the condition of the turnout gear, it does not appear that the gear was exposed to temperatures in excess of 500°F (260°C) for long periods of time, so these temperatures are consistent with the available information.

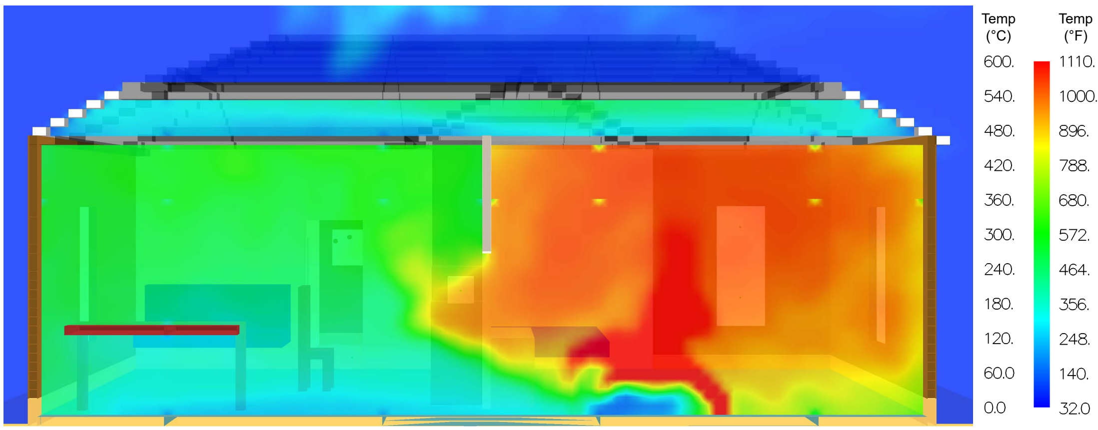


Figure 5.12: Gas temperatures in the bedroom and living room at the time of the first Mayday call

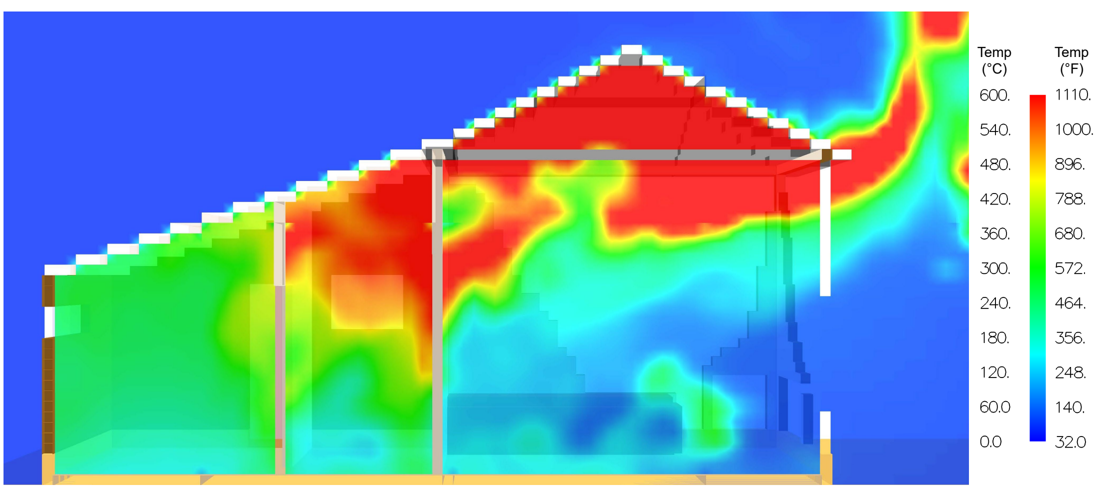


Figure 5.13: Gas temperatures in the bathroom and kitchen at the time of the first Mayday call

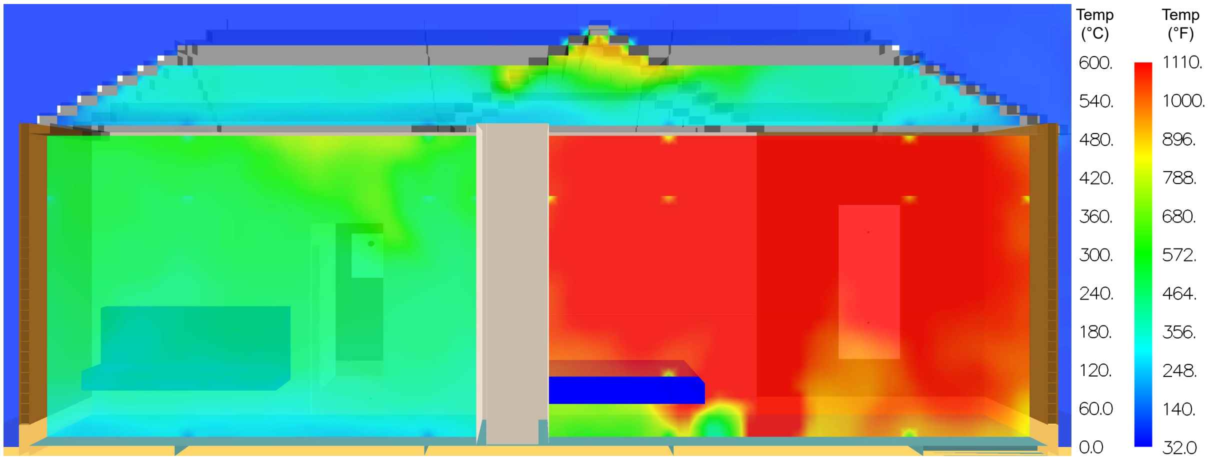


Figure 5.14: Gas temperatures on side C of the bedroom and living room at the time of the first Mayday call

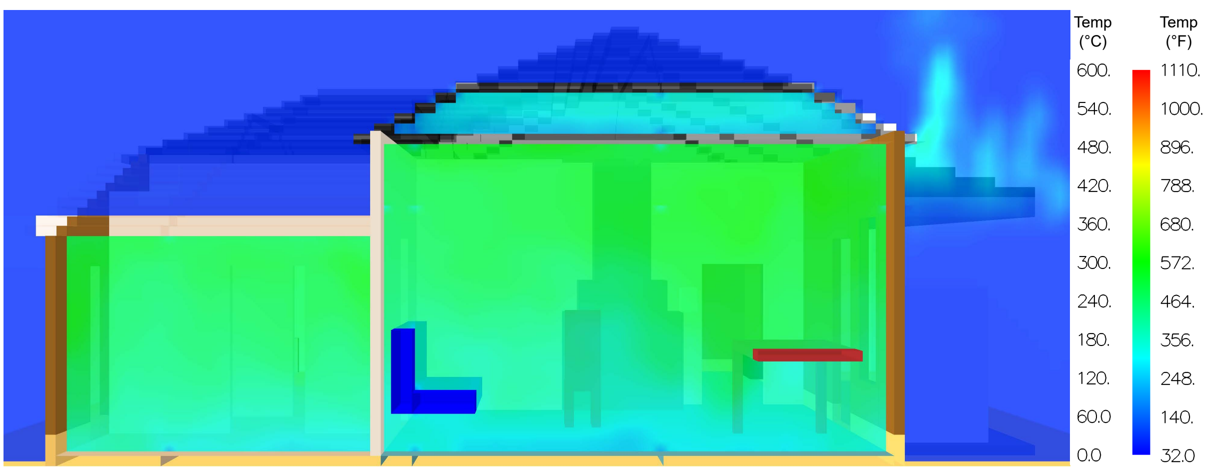


Figure 5.15: Gas temperatures on side B of the bathroom and living room at the time of the first Mayday call

Figure 5.16 displays a plan view of the structure with temperature contours at an elevation of 35 in (0.9 m) colored according to the thermal operating classes at the time of the first Mayday call. The bedroom had reached post-flashover conditions and fire had spread back to the kitchen prior to the first Mayday call. According to the analysis, much of the living room was in the Emergency I operating class with some areas in the Ordinary operating class at an elevation consistent with the firefighters squating or kneeling. This indicates that there were local areas within the hallway and living room where gas temperatures were above those for which the PPE was designed and explains why the Fire Control crew was approaching a point where the heat was intolerable and why they were searching for an exit.

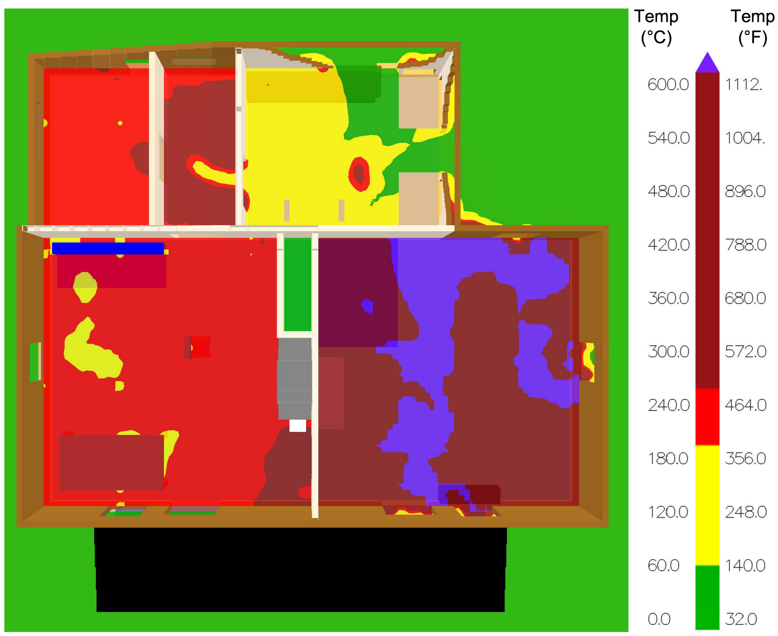


Figure 5.16: Gas temperatures colored according to thermal operating classes at the time of the first Mayday call

After the first Mayday call, temperatures throughout the residence continued to increase and resulted in the Search crew making a Mayday call approximately two minutes after the first Mayday call. Figure 5.17 shows a plan view of the residence with temperature contours at an elevation of 35 in (0.9 m). Exterior fire attack had commenced between the first Mayday call and the second Mayday call, so temperatures displayed in the living room and bedroom in the figure are likely higher than those that were observed during the actual Mayday situation.

The state of the bathroom door in the simulation changed from opened to closed between the first and second Mayday calls to maintain consistency with the accounts from the involved firefighters, and this is evident in Figure 5.17. The cross-section shown in Figure 5.17 is displayed in Figure 5.18. The temperatures from floor to ceiling in the bathroom in the simulation when the door was closed were in the range of 212°F (100°C) to 248°F (120°C). These temperatures indicate the door provided some safety from the thermal conditions in the burning areas of the residence until the door started to burn through.

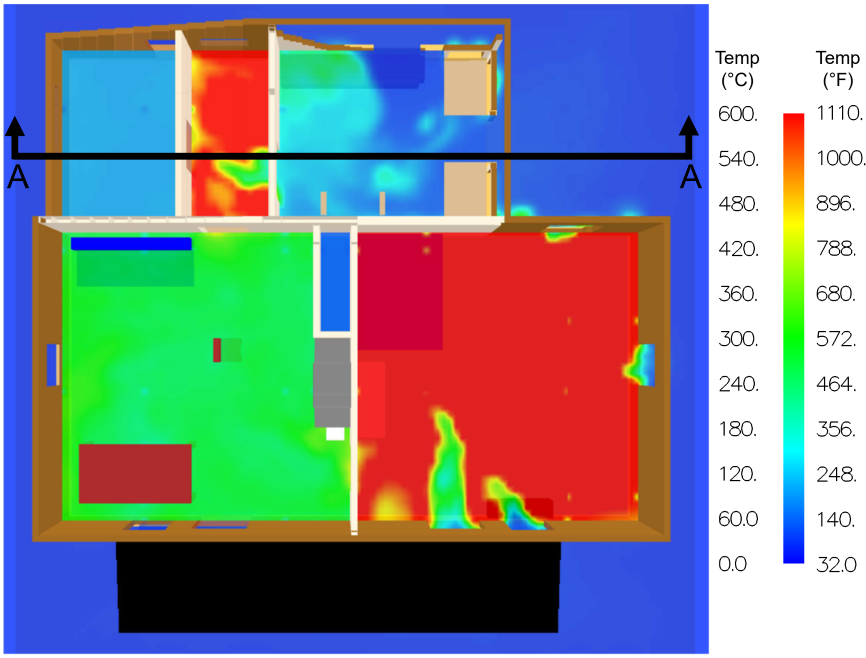


Figure 5.17: Gas temperatures at the time of the second Mayday call at an elevation of 35 in (0.9 m). Solid black lines indicate locations of cross-sections.

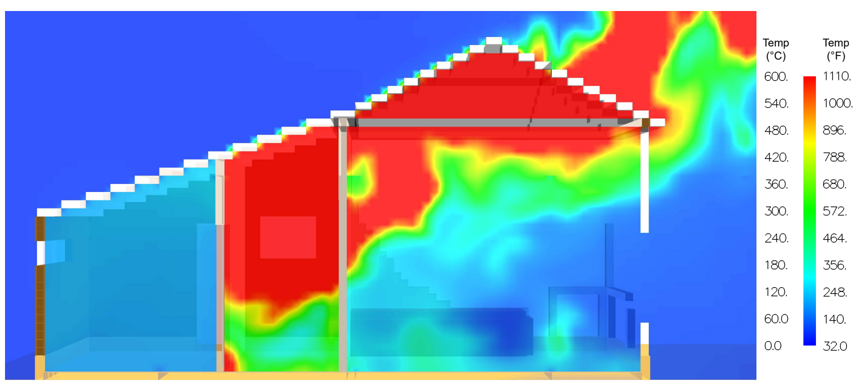


Figure 5.18: Gas temperatures at the time of the second Mayday call at an elevation of 35 in (0.9 m)

Figure 5.19 displays a plan view of the structure with temperature contours at an elevation of 35 in (0.9 m) colored according to the thermal operating classes at the time of the second Mayday call. Flashover conditions and the corresponding Emergency III operating class were evident in the bedroom and the hallway, which led to the second Mayday call. Between the first and second Mayday calls, higher temperature conditions developed in the living room, exemplified by Emergency I and Emergency II class conditions throughout the living room, and created a situation where evacuation was necessary to preserve the lives of the firefighters.

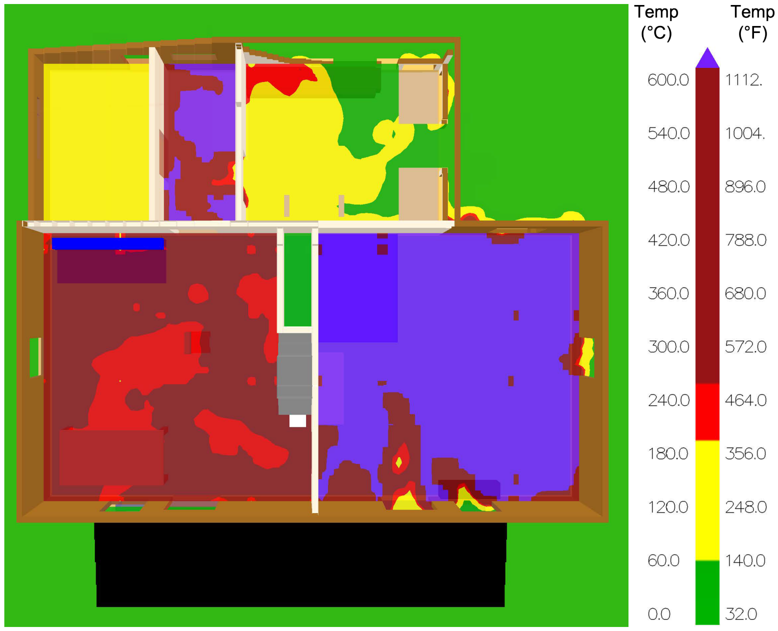


Figure 5.19: Gas temperatures colored according to thermal operating classes at the time of the second Mayday call

5.2 Exposure Analysis

There was no fire in the bedroom when the Search crew conducted their search. At some time between 2:58:40, when the Search crew started the search of the bedroom, and 3:04:34, the time of the Fire Control crew's Mayday call, the conditions in the bedroom developed such that the hose used by the Fire Control crew burned through at two points. The state of the hose when the fire investigators arrived at the scene is shown in the photographs presented in Figure 5.20.

The hose used by the Fire Control crew was designed and tested to comply with UL 19 ***Standard for Safety*** *Lined Fire Hose and Hose Assemblies* [21]. UL 19 defines a Hydrostatic Strength Test (§13), Heat-Resistance Test (§17), and a Conductive Heat Test (§38). The Hydrostatic Strength Test (§13) involves charging a hose curved around a surface with a radius of 27 inches with water to three times the marked service test pressure without leakage, rupturing, or breaking. The Heat Resistance Test involves placing a steel block heated to 500°F (260°C) in contact with the surface of a hose filled with static water for 60 seconds. The Heat Resistance Test requires a Hydrostatic Strength Test to be conducted after the block is removed from the surface of the hose. The Conductive Heat Test involves placing a steel block heated to 752°F (400°C) in contact with the surface of a hose charged with water to 300 psi for 15 minutes or until the hose suffers a 20 psi pressure loss. After the exposure in the Conductive Heat Test, the leakage rate is determined.

Because thermal conditions change rapidly in structure fires, particularly when transitioning to flashover, the parameters in the UL test method may be used as guidelines for the conditions and duration at which hoses may remain intact and effective. FSRI and the Fire Department City of New York (FDNY) conducted live fire tests with charged hoses in a flashover simulator training

Figure 5.20: Photographs of the hose used by the Fire Control crew

prop to assess the degradation of fire hose performance when the hose was exposed to realistic fire conditions [22]. The average temperature at which leakage occurred for the tested hoses with similar construction to the hose that burned through in this incident was 478°F (248°C), and the average heat flux at leakage was 33 kW/m^2, but the lowest heat flux at which leakage was observed was 25 kW/m^2. One definition that is commonly used for the onset of flashover is a heat flux of 20 kW/m^2 from the hot upper gas layer to the floor of a room [23]. Weinschenk et al. measured the heat flux to the floor near a vent opening in a post-flashover compartment fire as ranging up to peak values of 140 kW/m^2 [24].

It is likely that a new hose tested to UL 19 would be capable of withstanding a contact temperature of at least 500°F (260°C) and should be able to withstand environments with higher gas temperatures. Since the history of the hose that burned through is unknown, it is a conservative to assume the gas temperatures exceeded 500°F (260°C) at the floor level of the bedroom for the hose to burn through. Conditions in the bedroom between 2:58:40 and 3:04:34 developed from relatively little heat and slightly elevated temperatures to flashover with temperatures in the upper gas layer that exceeded 1112°F (600°C). The results of the FDS simulation indicated that the gas temperature at the floor level in the doorway between the living room and the bedroom after flashover conditions developed in the bedroom but before the first Mayday call was consistently approximately 464°F (240°C). This temperature was slightly lower than the average at which hose burnthrough occurred in the FDNY study and lower than the temperatures to which the hose is required to be subjected per UL 19. Because the temperature at the floor level was approximately the same as the average for hose failure in the FDNY study, the FDS results appear to be consistent with the situation the firefighters faced during the incident.

The development of flashover conditions in the bedroom occurred shortly before or shortly after suppression in the kitchen. The fire on the exterior of the structure created thermal conditions in the vicinity of the window on side C of the bedroom sufficient to cause the window to break. Figure 5.21 displays a photograph taken after the incident that shows the exterior of the structure surrounding the side C bedroom window. The flames that extended from the side D kitchen window caused the fire to spread along the exterior of side C of the bedroom and the photographs show the asphalt siding completely burned away, revealing charred wood lap siding that was beneath the composite asphalt. The results of the FDS model and the photographic evidence show this is a plausible explanation of the evolution of the fire.

Fire damage indicated that the fire likely ignited the window frame, the flames caused the window to break, and the fire passed through the window opening. Because the entire structure was preheated from the fire in the kitchen that burned for a minimum of ten minutes prior to fire service intervention as well as the hot gases that permeated the entire structure, the interior wood beadboard in the bedroom likely ignited shortly after the window frame ignited. Because the ceiling and walls were covered in the same painted wood beadboard, the flame rapidly spread across the walls and ceiling and the room transitioned to flashover relatively quickly. At this point, the room lining materials, the carpet, and all the contents were burning simultaneously. The results of the fire dynamics modeling support this conclusion.

It is noteworthy that, despite the suppression activities conducted by the Fire Control crew, the wall separating the bedroom from the kitchen was completely burned through with only charred studs remaining after the incident. The fact that suppression was applied to the kitchen by the Fire Control crew but the suppression did not affect the growing fire in the bedroom indicates the wall was likely intact at the time suppression was applied to the kitchen. This supports the conclusion that fire passed through the side C bedroom window and ignited the room lining materials and the contents of the bedroom prior to burn-through of the wall between the bedroom and the kitchen.

With the conclusion that the fire progressed from the kitchen to the exterior of the structure and subsequently through the side C bedroom window, it is evident that the uncontrolled exterior fire likely caused the bedroom to rapidly transition to flashover. This rapid transition prevented the Fire Control crew and the Search crew to exit the structure along the same path they took when they entered. As temperatures in the bedroom, the hallway, and the living room increased, none of the firefighters were able to access or operate the entry door in the bedroom or the bathroom of the structure, and they were forced to find paths of egress through the windows.

Figure 5.21: Photograph of the exterior of side C of the bedroom

6 Contributing Factors

In reviewing this incident and similar line-of-duty injury incidents, there is a pattern that the root cause of the incident cannot be attributed to a single factor. Rather, these incidents occur due to a combination of factors that act both independently and in conjunction to generate unexpected conditions and outcomes for which the firefighters were not prepared. The review of this incident, including information about the weather, building design and construction, incident narrative, and computational analysis of the fire dynamics, identified six factors that contributed to the ultimate outcome of this incident:

- The combustible exterior finish on the structure and the proximity of the side D kitchen window to side C bedroom window facilitated flame spread from the kitchen to the bedroom along the exterior of the structure.
- Rooms were added to the original structure which resulted in a non-intuitive floor plan and a confusing path of travel for the Fire Control and Search crews between the entry location in the bedroom and the fire in the kitchen.
- The combustible interior wall and ceiling construction enhanced flame spread and fire growth in the kitchen and the bedroom, and was key to initiation of the exterior wall fire and spread through the bedroom window back to the interior of the structure.
- The size-up did not result in recognition of the path of flame spread from the side D kitchen window along the exterior of the residence through the side C bedroom window.
- A back-up line was not positioned to support and protect the Fire Control crew and the initial hoseline.
- Rapidly changing fire conditions within the structure resulted in the burn through of the Fire Control crew's hoseline, blocked egress from the original entry, and left the Fire Control and Search crews trapped in the structure without a means for suppression.

6.1 Key Recommendations

There was a confluence of factors that contributed to the severity of this incident. Some of these factors, including the construction materials and layout of the structure, were unavoidable. As the incident evolved into the Mayday situation, there were also several positive factors that prevented an even worse outcome. The incident commander actively monitored the fire and maintained communication with the Fire Control and Search crews, which provided the crews with a warning that conditions were rapidly changing. Additionally, the Fire Control and Search crews maintained situational awareness which enabled them to locate and use emergency egress options. The Lieutenant of the first arriving fire engine that was part of the Fire Control crew demonstrated this situational awareness by entering the bathroom and closing the bathroom door to shield himself from the fire in the kitchen and hallway so he had time to safely exit through the window. The contributing factors that were identified as avoidable have led to the following recommendations.

Recommendation #1: Size-up should include an assessment of the fire location and the extent of fire spread to determine strategy and tactics.

Discussion: NFPA 1700 *Guide for Structural Fire Fighting* [1] presents strategic considerations for the fire control strategy upon initial arrival:

> **§9.5.2** Initial arrival factors should include considerations of the following:
>
> (7) Fire location, size, extent
> (9) Suspected direction of fire and smoke travel within the structure (flow path)
>
> **§9.7 Assessment of Fire Dynamics to Determine Strategy.** Factors observed from the exterior of the structure should be used for determination of interior conditions.
>
> **§9.7.7 Fire Progression.** Based on the 360-degree survey, identify the fire's suspected direction of travel or potential directions of travel. Consider dynamic events such as changes in ventilation and application of cooling, which may effect the path of travel. What is the current extent of the fire and where is it spreading.
>
> **§9.9.1** The incident commander (IC) should consider the entirety of available information when making a decision with respect to strategy. The IC should continually re-assess the strategy decision based upon changing conditions.

In addition to an assessment of Fire Progression, NFPA 1700 also includes an assessment of Smoke and Fire Conditions (§9.7.1), Fuel Load (§9.7.2), Openings (§9.7.3), Flow Path (§9.7.4), and Fire Control Positioning (§9.7.8). The first responding units conducted a size-up, but there was no recognition of the potential large fuel load on the interior and exterior of the structure or the potential flow path due to the geometry of the structure and the proximity of the flames to the bedroom C side window. Combining the information about the fire with the examination of the building and location of windows and doors can be used to predict how the fire might continue to evolve and move throughout the structure. Had the size-up yielded recognition of the potential evolution of the fire along the exterior of the structure and into the bedroom through the C-side window, different tactics may have been applied that would have prevented the Mayday situation.

Recommendation #2: When the initial size-up reveals fire rapidly spreading on the exterior of the structure, exterior fire control should be applied to limit fire spread.

Discussion: Shortly after the first units arrived and started the size-up, but prior to the initial Fire Control crew entering the structure, extension from the interior fire in the kitchen through the side D kitchen window resulted in an exterior fire along the side D of the kitchen and side

C of the bedroom. It has been demonstrated through experimental research that exterior wall fires may easily spread to the interior via penetrations such as air vents, electrical receptacles, plumbing penetrations to faucets and drains, and especially windows [2]. Had the responding firefighters recognized the rapid development and spread of fire along the exterior of the structure and suppressed the exterior fire prior to interior fire control, it is likely that the fire would not have spread beyond the kitchen. Kerber and Zevotek recommended initial fire control or simultaneous fire control of the fire on the exterior of a structure in their report on tactical considerations for attic fires and exterior fire spread hazards [2]. That recommendation and the justification behind it also apply to this incident. Depending on the firefighting resources available, two hoselines could be pulled to simultaneously conduct interior and exterior fire control.

Recommendation #3: A back-up hose line should be in position to support and protect the initial hose line.

Discussion: As defined in NFPA 1410, *Standard on Training for Emergency Scene Operations*, a back-up line is an additional hose line used to reinforce and protect personnel in the event the initial attack proves inadequate [3]. The back-up hoseline serves two main functions: to protect the primary egress path for the initial attack crew and to provide additional water on the fire to support the initial attack crew when needed.

In his book *Engine Company Fireground Operations*, Angulo provides a discussion of timing and placement of the backup line. To summarize that discussion, a back-up line cannot be considered a back-up if it is only stretched after it is needed. A back-up line must be where it is needed, at the time that it is needed to protect and support the initial attack line [4]. In this case, if a back-up line was in position at the entry door, the impact of the fire spreading into the bedroom would have been limited and the primary hose line and the egress path for the Fire Control and Search crews would have been protected.

As the fire spread to and grew in the bedroom to the point of flashover, the hoseline burned through and became unusable. If a back-up line had been in place after entry of the initial line, suppression could have been applied to the fire as it entered the bedroom thus protecting the hose line and the egress path.

There were three ways to stop the fire from spreading from the exterior through the bedroom window and out to the porch:

1. Initial line goes to the CD corner, extinguishes the fire on the exterior, and knocks down the kitchen fire prior to going to the interior.
2. Initial line goes to the interior while the backup line moves into position on the exterior of the CD corner, ready to coordinate control of the exterior fire along with the interior Fire Control team.
3. Initial line moves to the interior while the backup line moves toward their position on the front porch.

The hose movements of Option 2 and, subsequently, Option 3 were ordered on the fire ground during this incident. However in this case, the combustibility of the asphalt siding, the single pane windows (which failed quickly when exposed to flame), and wood interior walls and ceiling allowed the fire to spread faster than the backup lines could be positioned and put into operation. Once the backup line was in operation from the front porch the fire was effectively and rapidly controlled. Although many of the fire ground decisions were correct, the fire was moving faster than the implementation of the backup line. This demonstrates the importance of an on-going fire dynamics size-up as a means to stay ahead of the fire spread.

Recommendation #4: Use known information to guide fire ground decisions.

Discussion: The fire extending from the interior of the kitchen to the exterior of the structure was observed. Therefore, the location of the fire was known and the path to advance a hoseline to the fire on the exterior of the house was known. Prior to entry into the house, the path from the front door to the fire was unknown. When the Search crew recognized that the Fire Control crew would need to advance the line through three rooms of the structure prior to getting to the kitchen, that offered another decision opportunity to have a hoseline go to the location of the exterior fire first. In this case, acting on the known information would have improved interior conditions and prevented the spread of the fire, thereby reducing the risk of the unknown conditions that would be encountered as fire operations moved to the interior.

7 Summary

FSRI in collaboration with the LaGrange Fire Department conducted a review of a near-miss incident that resulted in burn injuries of four members of the department. This effort was supported by a DHS/FEMA Assistance to Firefighters Grant. FSRI's analysis of this incident has applied research results and the Fire Dynamic Simulator computational fire model simulations to examine key fire phenomena and tactical outcomes. This report describes the incident, discusses the contributing factors, and provides recommendations which could result in a more favorable outcome. In this case, the fire spread from the interior of the structure to the exterior of the structure. While the firefighters were inside the structure extinguishing the fire in the kitchen (area of fire origin), the fire on the exterior of the structure spread into and flashed over the room where the firefighters had entered the structure. This resulted in a burn through of the fire hose and the firefighters ability to egress by following the line out of the structure was compromised. The increased fire hazard in the structure resulted in the firefighters being exposed to increased convected and radiant heat which resulted in the four members receiving burn injuries.

Four key recommendations resulted from this analysis: 1) size-up should include an assessment of the fire location and the extent of fire spread to determine strategy and tactics, 2) when the initial size-up reveals fire rapidly spreading on the exterior of the structure, exterior fire control should be applied to limit fire spread, 3) a back-up hose line should be in position to support and protect the initial hose line, and 4) use known information to guide fire ground decisions.

References

[1] National Fire Protection Association, Quincy, Massachusetts. *NFPA 1700, Guide for Structural Fire Fighting*, 2021.

[2] S. Kerber and R. Zevotek. Fire Service Summary Report: Study of Residential Attic Fire Mitigation Tactics and Exterior Fire Spread Hazards on Firefighter Safety. UL Firefighter Safety Research Institute, Columbia, Maryland, November 2014. doi:https://dx.doi.org/10.54206/102376/LIHB1439.

[3] National Fire Protection Association, Quincy, Massachusetts. *NFPA 1410, Standard on Training for Emergency Scene Operations*, 2020.

[4] R.A. Angulo. *Engine Company Fire Ground Operations*. Jones & Bartlett Learning, Burlington, MA, 2021.

[5] Troup County 911. Dispatch History for Call Number:2018069565. Transcript from September 3, 2018.

[6] Investigator Rob Vael. Case Summation for Case No. 2018-000-3226.

[7] LaGrange Departments of Public Safety. LaGrange Departments of Public Safety 2017 Annual Report. Available at http://www.lagrangefire.org/Content/Templates/documents/2017%20LFD%20Annual%20Report.pdf. (Accessed November 15, 2021).

[8] LaGrange Fire Department. LaGrange Fire Department Annual Report. Available at http://www.lagrangefire.org/Content/Templates/documents/LFD%20Annual%20Report.pdf. (Accessed November 15, 2021).

[9] Google Maps. Satellite Imagery from LaGrange, GA. 3/31/2017: U.S. Geological Survey. Available at https://www.google.com/maps/@33.0324613,-85.0213139,116m/data=!3m1!1e3. (Accessed November 15, 2021).

[10] Weather Underground. Weather history for Columbus Metropolitan Airport, September 3, 2018. Columbus, GA: The Weather Channel Interactive, Inc. Available at https://www.wunderground.com/history/daily/us/ga/columbus/KCSG/date/2018-9-3. (Accessed November 15, 2021).

[11] LaGrange Police Department. Body Camera Footage File 2018090281.

[12] K. McGrattan, S. Hostikka, J. Floyd, R. McDermott, and M. Vanella. *Fire Dynamics Simulator, User's Guide*. National Institute of Standards and Technology, Gaithersburg, Maryland, USA, and VTT Technical Research Centre of Finland, Espoo, Finland, sixth edition, November 2021. doi:http://dx.doi.org/10.6028/NIST.SP.1019.

[13] K. McGrattan, S. Hostikka, J. Floyd, R. McDermott, and M. Vanella. *Fire Dynamics Simulator, Technical Reference Guide Volume 2: Verification*. National Institute of Standards and Technology, Gaithersburg, Maryland, USA, sixth edition, November 2021. doi:http://dx.doi.org/10.6028/NIST.SP.1018.

[14] K. McGrattan, S. Hostikka, J. Floyd, R. McDermott, and M. Vanella. *Fire Dynamics Simulator, Technical Reference Guide Volume 3: Validation*. National Institute of Standards and Technology, Gaithersburg, Maryland, USA, sixth edition, November 2021. doi:http://dx.doi.org/10.6028/NIST.SP.1018.

[15] F. Mowrer. Window Breakage Induced by Exterior Fires. Technical Report NIST-GCR-98-751, Gaitherburg, MD, 1998.

[16] M. Hurley, D. Gottuk, J.R. Hall, K. Harada, E. Kugliowski, M. Puchovsky, J. Torero, J.M. Watts, and C. Wieczorek, editors. *SFPE Handbook of Fire Protection Engineering*. Springer, Bethesda, MD, 5th ed. edition, 2016.

[17] H. Utech. Status report on research programs for firefighters protective clothing. In *Proceedings of the Fire Department Instructor's Conference*, Indianapolis, IN, 1973.

[18] D. Madrzykowski. Fire Fighter Equipment Operational Environment: Evaluation of Thermal Conditions. PRF-2017-05, NFPA Fire Protection Research Foundation, Quincy, Massachussets, August 2017.

[19] C. Weinschenk and K. Stakes. Analysis of Search and Rescue Tactics in Single-Story Single-Family Homes Part III: Tactical Considerations. Technical report, UL Fire Safety Research Institute, Columbia, Maryland, May 2022. doi:https://dx.doi.org/10.54206/102376/XSLA7995.

[20] National Fire Protection Association, Quincy, Massachusetts. *NFPA 1971, Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, 2018.

[21] UL 19. Standard for Lined Fire Hose and Hose Assemblies. Standard, Northbrook, IL, 2018.

[22] Daniel Madrzykowski, Craig Weinschenk, Joseph Willi, and Brian Fink. Exposing Fire Service Hose in a Flashover Chamber: Report of Test.

[23] James R. Lawson. Fire Facts. Nist special publication 1102, Gaithersburg, MD, 2009.

[24] C. Weinschenk, D. Madrzykowski, and P. Courtney. Impact of Flashover Fire Conditions on Exposed Energized Electrical Cords/Cables. *Fire Technology*, 56:959–991, 2020. doi:10.1007/s10694-019-00915-8.

[25] American Society for Testing and Materials, West Conshohocken, Pennsylvania. *ASTM E 1354-17, Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Combustion Calorimeter*, 2017.

[26] Bjorn Sundstrom, editor. *Combustion Behaviour of Upholstered Furniture: fire safety of upholstered furniture: the final report on the CBUF research programme*. Interscience Communication, London, 1996.

Appendix A

Fire Dynamics Simulator Model Input Parameter Justification

Cone calorimeter experiments were conducted on approximately 4 in x 4 in square samples of each material at heat fluxes of 35 kW/m^2 and 70 kW/m^2 in general accordance with ASTM E 1354 *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter* [25]. The heat release rate data normalized by the surface area of the sample material (HRRPUA) measured in these experiments are displayed in the following figures. The time scale for these figures is displayed after ignition because such an interpretation of the data is most useful for defining a burning material in FDS.

Figure A.1 shows the heat release rate data measured for the asphalt siding. The mean time to ignition for the asphalt siding when exposed to a total heat flux of 35 kW/m^2 was approximately 154 s and the mean time to ignition when exposed to a total heat flux of 70 kW/m^2 was approximately 27 s. Heat fluxes in excess of 70 kW/m^2 are consistent with direct impingement of flames on a material surface or complete immersion of an object in a fire. The asphalt siding on side D of the kitchen and in the vicinity of the side C bedroom window experienced flame impingement and it is reasonable to assume the incident heat flux to these surfaces exceeded 70 kW/m^2.

As is evident in the HRRPUA data measured with the cone calorimeter with an incident heat flux of 70 kW/m^2, the heat release rate increased over approximately 50 s to a steady mean value of approximately 325 kW/m^2. The HRRPUA remained relatively steady for 70 s and gradually decreased over the next 300 s. To represent this behavior as closely as possible in the model, the material was defined with a steady HRRPUA of 325 kW/m^2 after the ignition temperature was achieved. The ignition temperature could not be directly inferred from the cone calorimeter data, so the ignition temperature was assumed as a relatively low value to ensure flame spread within the model that was consistent with the observations at the scene. It is expected that a heat flux higher than 70 kW/m^2 incident to the asphalt siding was possible due to flame impingement, although no data were available on the HRRPUA measured in higher incident heat flux experiments. The relatively low ignition temperature defined in the model was intended to compensate for the potential higher HRRPUA that would be expected from the asphalt siding exposed to higher incident heat fluxes. The density of the asphalt siding was directly measured and the thermal conductivity, heat capacity, and emissivity were assigned values from the *Handbook of Fire Protection Engineering* [16].

Figure A.2 shows the heat release rate data measured for the carpet tile. The mean time to ignition for the carpet tiles when exposed to a total heat flux of 35 kW/m^2 was approximately 95 s and the mean time to ignition when exposed to a total heat flux of 70 kW/m^2 was approximately 13 s. The carpet acted as a target for ignition and contributed to late-stage growth of the fire. The heat flux incident from the hot gas layer to the floor at the onset of flashover is typically approximated as a minimum of 20 kW/m^2. The density of the carpet samples collected from the scene was

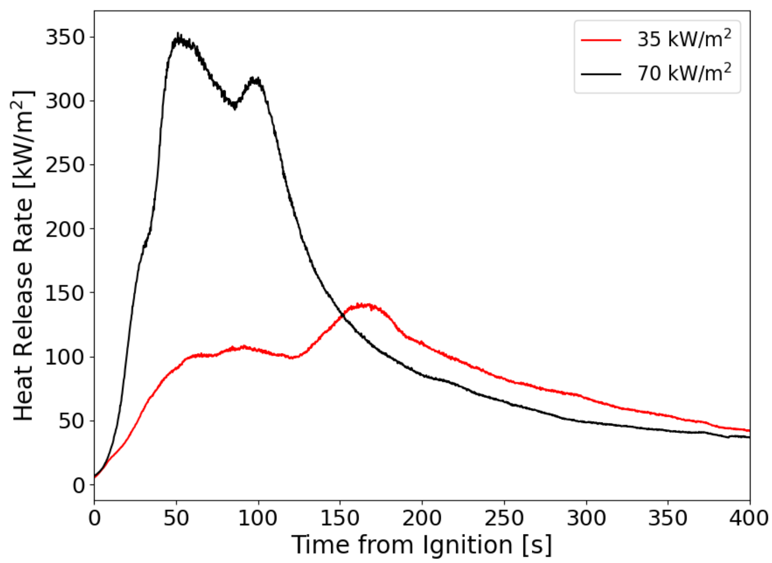


Figure A.1: Heat release rate data collected from asphalt siding in cone calorimeter tests

directly measured. The HRRPUA of the carpet was defined as 90 kW/m^2, which was the mean HRRPUA over the duration of the cone calorimeter tests conducted with an incident heat flux of 35 kW/m^2. The ignition temperature, thermal conductivity, heat capacity, and emissivity were defined according to values in the *Handbook of Fire Protection Engineering* [16] for similar carpet products.

Figure A.3 shows the heat release rate data measured for the painted beadboard. The mean time to ignition for the beadboard when exposed to a total heat flux of 35 kW/m^2 was approximately 60 s and the mean time to ignition when exposed to a total heat flux of 70 kW/m^2 was approximately 7 s. The beadboard and other wood products in the structure were some of the first items ignited as well as targets in later stages of the fire. The density of the beadboard was measured directly from the samples collected at the scene. The thermal conductivity, heat capacity, emissivity, and ignition temperature were defined according to values for various painted and unpainted wood samples presented in the *Handbook of Fire Protection Engineering* [16]. The properties for the wood beadboard were assigned to all wood products defined in the model because the minor variations between wood species and products was assumed to be inconsequential.

The ceiling and walls were lined with the painted beadboard and so it is likely that the beadboard experienced a wide range of incident heat fluxes and charred during the fire. Charring would change the thermal properties of the bulk material and result in an overall decrease in the HRRPUA of the material. The HRRPUA in the model was defined to be similar to the data collected in the cone calorimeter with an incident heat flux of 35 kW/m^2. The HRRPUA as defined in the model is plotted in Figure A.4.

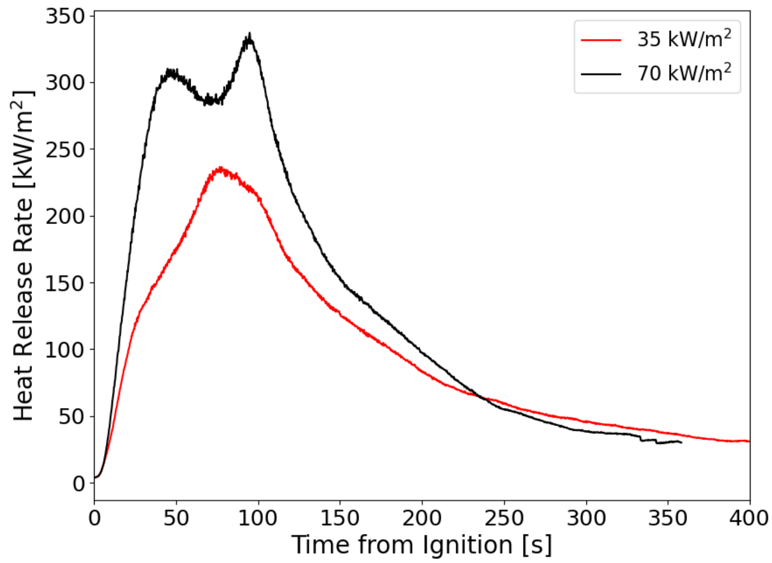


Figure A.2: Heat release rate data collected from carpet tiles in cone calorimeter tests

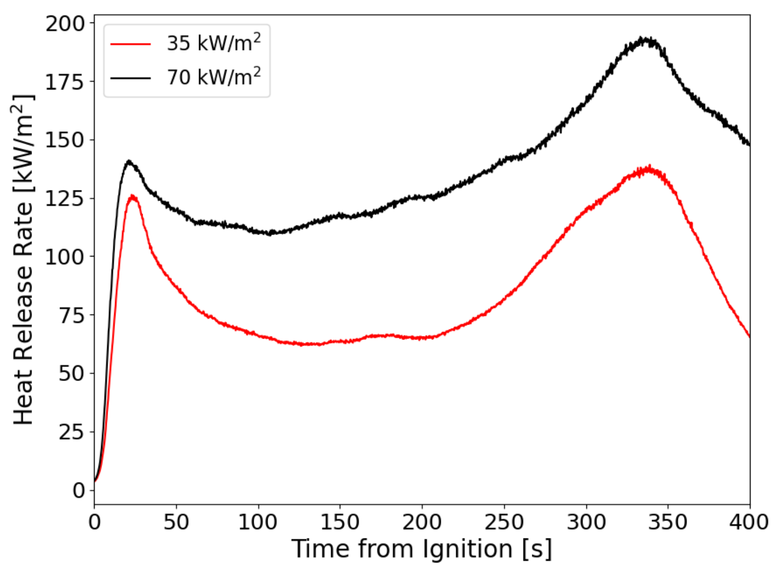


Figure A.3: Heat release rate data collected from beadboard in cone calorimeter tests

The mattress was defined in the FDS model as an obstruction with thermo-physical properties and the ignition temperature of polyurethane foam found in the *Handbook of Fire Protection Engineering* [16]. The HRRPUA of the mattress was defined such that the total HRR of a similar

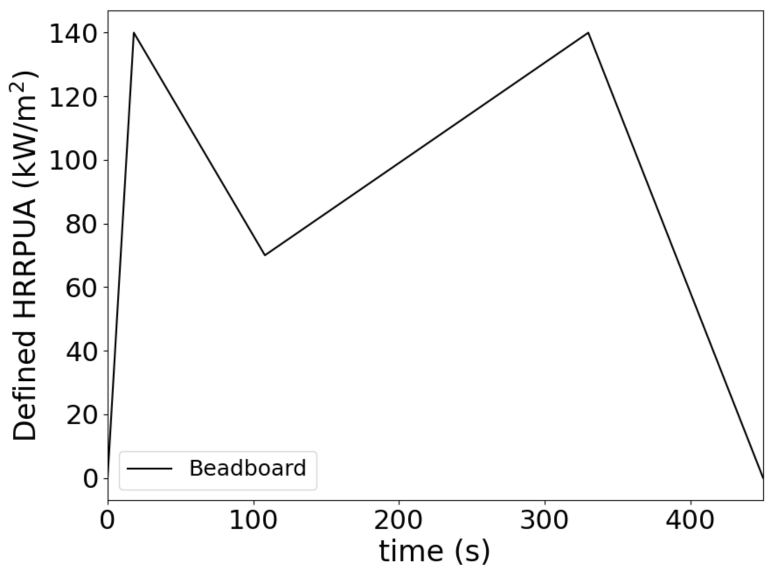


Figure A.4: Model heat release rate definition for painted beadboard

inner-spring mattress tested to assess the combustion behavior of upholstered furniture [26]. The defined HRRPUA as a function of time is plotted in Figure A.5.

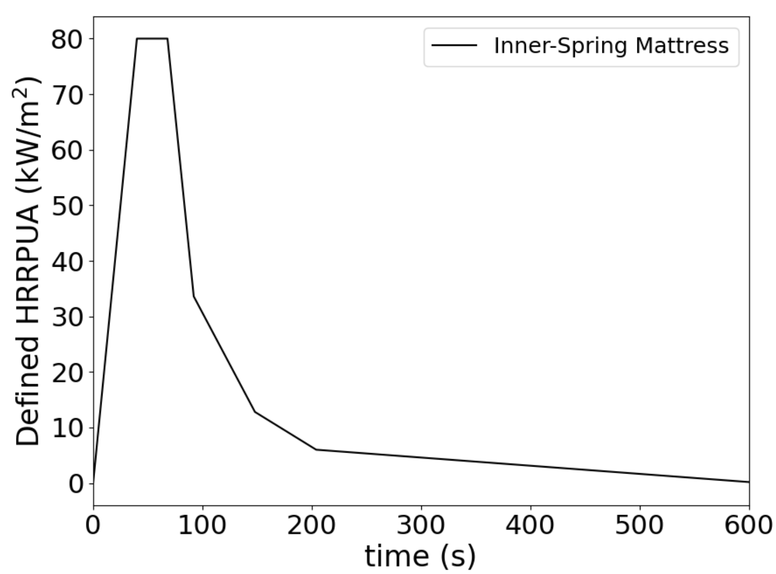


Figure A.5: Defined HRRPUA for the mattress

Photographs taken of the structure after the incident indicate that the ceiling of the kitchen burned away. To represent this change in the structure and the associated change in fire dynamics, the ceiling of the kitchen was defined to be removed when the surface temperature at the center of the exposed side of the ceiling exceeded 1112°F (600°C).