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Open or Closed? An Analysis of Fire Effects and Patterns on Wooden Door Assemblies for the Practitioner

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Open or Closed? An Analysis of Fire Effects and Patterns on Wooden Door Assemblies for the Practitioner

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Open or Closed? An Analysis of Fire Effects and Fire Patterns within the Door Jamb for the Practitioner

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Abstract

The present study investigates if there are any consistent fire effects or patterns that persist on a door assembly after a fire to indicate the position of the door within a fire. There is currently a lack of research on this topic within the field. This causes practitioners to rely on their subjective interpretation of fire patterns within the room. Experiments were conducted with a door assembly 1/6th bench scale model of an ISO standard room. The door assembly was placed in three positions: open, partially open, and closed. Each position was tested ten times, totaling thirty trials. These trials revealed that there are unique damage characteristics to the door jamb and the door face for each door position. As a result, this study lays the foundation to assist in removing subjectivity from the determination of the position of the door during a fire. The findings from these experiments begin to allow practitioners to be able to accurately identify whether the door served as a ventilation opening during the fire event. This understanding of ventilation will assist the investigator and allow them to have a better understanding of the fire dynamics and spread within the compartment.

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Introduction

Fire investigation is a young forensic science that began in the 1940's. In 1980 the National Bureau of Standards, now the National Institute of Standardization and Technology, began the much-needed scientific study of fire patterns (Lentini, 2019). This effort continued to propagate various myths associated with burn patterns by failing to disprove them. But this effort also began the modern study of fire that continues today. The field of fire science is constantly evolving and working towards a systematic and objective methodology that could be used by all investigators. However, the goal of complete objectivity has yet to be reached in how practitioners interpret fire patterns (National Academy of Sciences, 2009). In many instances, the difference between determining a fire to be intentional or accidental comes down to whether a door was left open or closed. An objective technique that interprets the condition of a door post-fire with proven scientific methodology would greatly assist the practitioner. The overall goal of this research is to experimentally determine if any fire effects or patterns within the door jamb area exist post-fire that assist in identifying if the door was open, partially open, or closed.

Door Terminology

There are several identifiable and independently operable parts within the door assembly to create what is commonly referred to as a door, door frame, and hinge assembly. The door frame is what the door panel and locking mechanism sits in (Figure 1). Within the door frame is the door jamb. Specifically, the door jamb is where the door panel intersects with the frame, stopping the door.

Figure 6: Diagram of the components of a door.

The hinge assembly allows the door panel to open and close (Figure 2). Most residential door hinges are butt hinges. Butt hinges have two plates, one that connects to the door and another that connects to the door jamb. Thes two plates are fastened together by a pin (Figure 2).

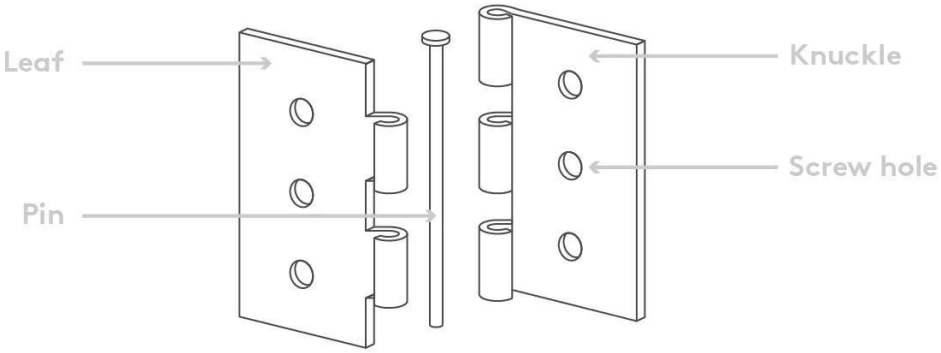


Figure 7: Diagram of the components of a butt hinge.

Purpose

This research aims to provide fire investigators with an objective method to determine the position of a door in a post-fire analysis. Since fire effects and patterns rely on the orientation of the material, it is possible that the positioning of the door will have an observable effect on the development of patterns within the door jamb, and the subsequent determination of whether the door was open or closed.

Literature Review

Limited prior research exists regarding fire patterns within door jambs. Historically, a majority of federally funded research projects have focused on developing an understanding regarding the quality of firefighting operations, with little regard for the forensic examination. In recent years there has been an increase in the number of research projects dedicated to the improvement of fire investigation techniques, with the focus placed on creating a level of objectivity (National Academy of Sciences, 2009).

In 2009, the National Academy of Sciences published a report that assessed the scientific validity of forensic science in the United States. This committee heard expert testimony and determined that forensic sciences relied too much on expert interpretation of forensic evidence (8). They cite that there is a "notable dearth of peer-reviewed, published studies establishing the scientific bases and validity of many forensic methods" (8). In conjunction with this, the report also notes that forensic sciences rely too much on subjective assessments of patterns. These two specific deficiencies run rampant in the field of fire investigation. As such, it is important to create an environment of scientific objectivity using stringent research regarding methodology and pattern development.

Claflin (2014) argued that the multiple ventilation openings create recognizable patterns within the compartment, which is also supported by the guidance of NFPA 921 (2021). However, Claflin's work indicates ventilation openings aid in fire development by providing a medium for air entrainment to occur and for fuels to mix with oxygen. This assists in the present research because it provides the foundational knowledge that when the door is open there must be an equal entrainment of air into the compartment and dispersion of hot gasses out of the compartment, creating areas of soot deposition and protected areas. Claflin, Carmen, Wolfe, and Gorbett demonstrate that a change in ventilation in a post-flashover compartment will have a substantial impact on the development, and interpretation, of fire patterns.

Soot is defined by the National Fire Protection Association (NFPA) 921: Guide for Fire and Explosion Investigations as, "black particles of carbon produced in a flame" (2021). Mansurov (2005) argues that soot is produced when there is an excess number of carbon molecules when compared to oxygen molecules in the combustion zone. An excess amount of carbon will create incomplete combustion, which is the product of soot in a flame. Lin and Friedlander (1988) argue that soot deposits on material in three ways, diffusion, interception, and impaction. They argue that interception is the most common deposition mechanism since carbon molecules in smoke will coagulate as the smoke plume becomes denser, allowing for fibers and other objects to impede the travel of these solids in the plume. Within this research, interception is likely the mechanism causing a majority of the soot deposition because the door assembly will likely impede the flow of the smoke plume.

Beyond academic research, various textbooks were influential in determining how practitioners interpreted fire patterns on doors and door jambs to determine their position during the fire. Specifically, the works of the NFPA in their publication NFPA 921 (2021), Rethoret

(1945), Lentini (2006), Kennedy (1962), DeHaan (1990), and Icove (2011). Since no scientific testing exists on the topic, the information presented by the authors is based on years of experience. However, a common theme was developed between all others, the elevation of charring indicates the development of the fire (NFPA 921, Rethoret, Lentini, Kennedy, DeHaan, Icove). These textbooks demonstrate that as the upper layer in a fire develops, and moves towards an area of lower pressure, the smoke layer travels through doorways leaving soot deposition and char at high elevations. Although no testing was conducted to validate this claim, the common acknowledgement of this phenomenon since 1945 indicates a strong relationship and evidence that a door was open.

DeHaan and Icove (2011) also postulated that door hinges could be used to determine the position of a door in a post-fire analysis. They offer the concept that hinges with protected areas on the plate indicate that the door was closed. Conversely, they offer that if the plates did not have a protected area, then the door was partially open or open. This hypothesis, based on real world observation, provides another variable to include in the research to validate the common scene exam techniques of practitioners.

The review of these textbooks indicates several effects and patterns that can be identified to determine the position of a door. These include:

- Level of elevation of fire effects, notably charring or soot deposition.
- The position of the hinges, and how soot deposits.
- Whether a line of demarcation within the door jamb is angled or not.
- Soot deposition or discoloration on the plates of a hinge.
- Soot deposition or discoloration on the spine of the hinge.

Methodology

A total of thirty (30) trials were conducted. These trials tested three independent variables, which include the door assembly being open, closed, or opened to a forty-five (45) degree angle. Each position was tested 10 times. Each test began when the door assembly was positioned into the experiment compartment, and smoke was produced from the incomplete combustion of a pool of kerosene. The resulting soot was deposited onto the surrounding material. After the kerosene was fully consumed, or the test had been conducted for ten minutes, the trial was completed. After allowing for the smoke to clear the compartment, a series of systematic photographs of the door assembly were taken, following the data collection protocol.

During each trial, the fuel pan was placed on a scale to record mass loss. The beginning mass and ending mass were recorded. This was used to experimentally derive the necessary volume of fuel to produce enough soot for standardized results.

After all trials were conducted, an average mass loss rate was determined based on the length of the trial, the starting mass, and ending mass. This was used to determine an experimental heat release rate using the formula:

$$\dot{Q} = x\, \chi A_f \Delta H_C \dot{m}$$

The experimental heat release rates were then compared to the theoretical heat release rates (calculation-based) which were determined using the formula:

$$\dot{Q} = \chi A_f \Delta H_C \dot{m}_\infty{}''(1 - e^{-kBD})$$

Combustion Efficiency (%)	Experimental HRR door closed(kW)	Experimental HRR door partially open (kW)	Experimental HRR door open (kW)	Theoretical HRR Door Closed (kW)	Theoretical HRR Door open (kW)

20	0.18	0.5	0.5	2.7	2.7
50	0.45	1.2	1.3	6.8	6.8
70	0.63	1.7	1.8	9.5	9.5
100	0.9	2.4	2.6	2.7	13.6

Table 6: Heat release rates of each door assembly position.

When comparing the theoretical heat release rates and the experimental heat release rates of each door position, the importance of ventilation within a compartment becomes increasingly obvious. The theoretical heat release rate calculation assumes a constant source of oxygen, however, each experiment had a small ventilation opening, limiting the growth of the fire evidenced by the mass loss rates of the pool fire.

Materials

An experimental compartment was constructed of 2x4 wood beams and columns with plywood walls. The interior walls were lined with ½-inch gypsum wallboard.

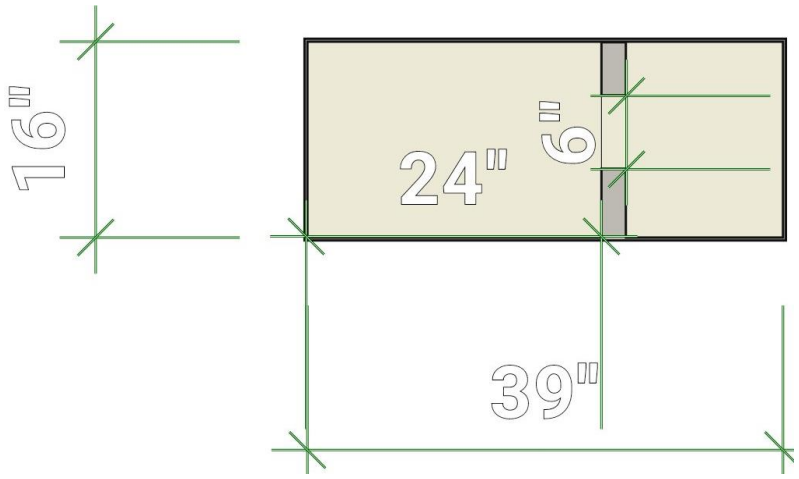


Figure 8: Dimensions of experimental compartment.

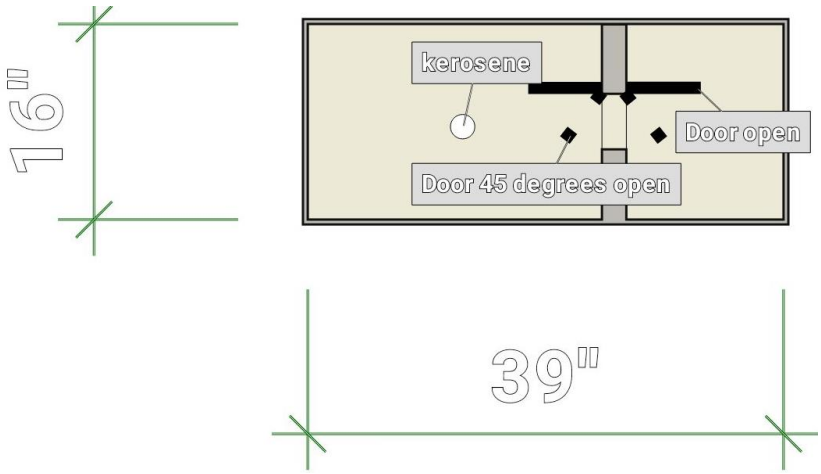


Figure 9: Diagram of door assembly positions and fuel.

The experimental compartment was a 1:6 scale model of an International Organization for Standardization (ISO) 9705 – *Reaction to Fire Test – Room Corner Test for Wall and Ceiling Lining Products (2016).* As such, it was 18 inches wide, 24 inches long, and 18 inches tall. The only openings in the compartment will be the door assembly and where smoke will be applied to the system.

The door assembly was constructed of luminal plywood and was held in place by a wood track that has access from the top of the compartment. This track allows the door to be put in place and removed quickly without disturbing the remaining structure. The door assembly has a functional door, hinges, wooden door jamb, and wall extensions that slide into the track. The wall separated the compartment into two compartments, the smoke compartment, and the observation compartment. Inside the observation compartment was a GoPro Hero 4 video camera to document how smoke flowed through the door.

Smoke was produced by the incomplete combustion of kerosene. Kerosene was chosen since it produces a large volume of smoke when burned (Shooto, Dikio, 2012). This was necessary for this experiment since the only fire effect that was being tested was soot deposition.

Controls

As with any research, there are a wide variety of variables that must be considered and controlled. In this instance, since smoke was used, ventilation was controlled. To balance safety and ventilation control, the tests were conducted inside the high bay of the Ashland Fire and Safety Laboratory with the garage door open. Furthermore, the experiment was conducted on days with minimal wind.

Another consideration is the positioning of the door assembly. To ensure the door assembly was in the same position during every experiment, a speed square was used to measure the angle of opening of the door prior to the test beginning. A locking mechanism to ensure the door was held in the same position was not used because it would not be realistic to most fire conditions. Similarly, each experiment was conducted in the same compartment.

To ensure an accurate record of mass loss during the experiment, the scale was tared prior to each test, and was monitored throughout the test to determine when the fuel was fully consumed.

To properly control documentation, a procedure for documenting each trial was developed and is discussed below in the Data Collection Protocols section of this report. A Nikon D5600 Digital SLR camera was used for still photography and a Go Pro Hero 4 was used to video each trial. After the fire self-extinguished, the door assembly was photographed in place, and then transferred to the photographing area. The same photography procedure was done for every trial.

Data Collection

Proper and consistent documentation is of the utmost importance when studying fire patterns and effects. As a result, each experiment was consistently documented through a predetermined data collection protocol. This protocol is discussed in detail below. The door assembly was retained after the tests.

Data Collection Protocols

During each experiment, a GoPro Hero 4 was placed outside the assembly to video how the smoke exited the door assembly. A Nikon D5600 Digital SLR camera was used for still photography of the door setup pre-fire, in place after each trial, and then while placed in a photography station that was specifically built for this experimental series (figure 5). The door was photographed on all sides, documenting how smoke deposited on the door faces and the

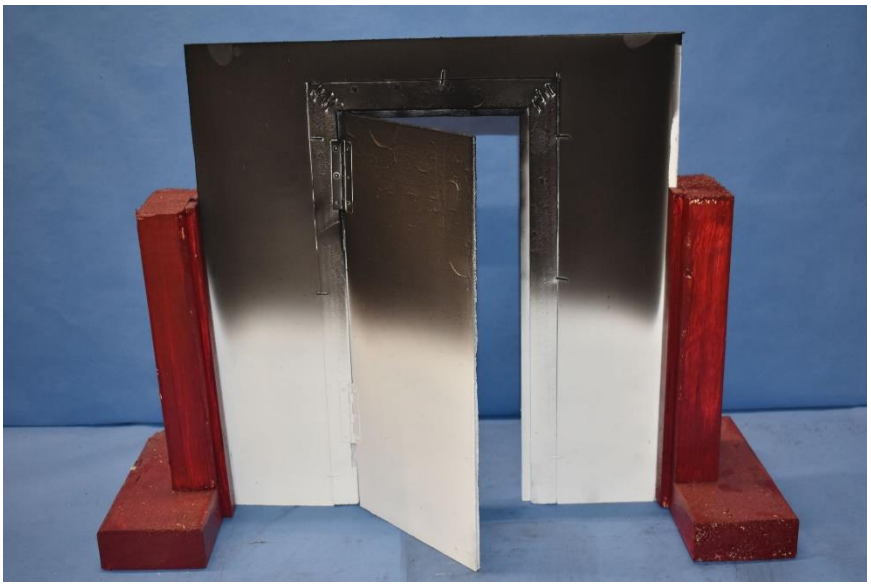


Figure 10: Example of photography station.

jamb. A consistent photography scheme was used throughout the entire experimental series. A measurement scale was added during photography to record measurements and angles of all lines of demarcation.

The photography sequence specifically accounted for those damage characteristics identified in previous fire investigation literature, which include:

- Level of elevation of fire effects, notably charring or soot deposition.
- Whether a line of demarcation within the door jamb is angled or not.
- Soot deposition or discoloration on the plates of a hinge, if opened.
- Soot deposition or discoloration on the spine of the hinge, if closed.

Data Analysis

Data analysis included conducting a visual examination of the fire effects and patterns of each trial, determining an average mass loss rate, calculating, and estimating heat release rates, and taking measurements of the angle to the lines of demarcation. This analysis revealed distinct damage characteristics unique to each door position, that were replicable.

Analysis of the damage on closed doors revealed three damage characteristics that are identified in Table 1. These were determined by examining all the photographs of the closed-door trials and evaluating any characteristics that persisted through all ten trials. For the closed door, soot deposited on both hinges and the door face in every trial (10/10 = 100%). However, there was a lower elevation of soot deposition on the ‘lock side’ of the door in seven of nine trials (77.8%). A single trial was excluded as an outlier due to the soot production was not sufficient to produce soot deposition anywhere on the door jamb. Table 1 indicates the damage characteristics that were only found on closed doors and their frequency.

Damage Characteristics	Damage	Frequency

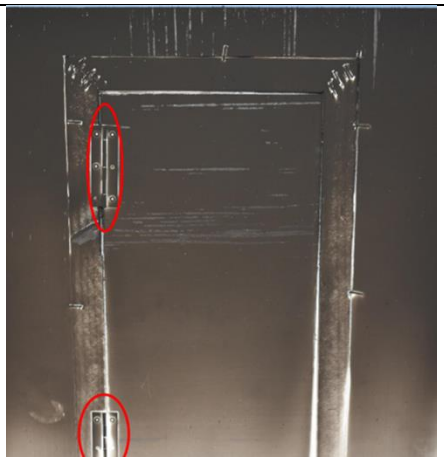
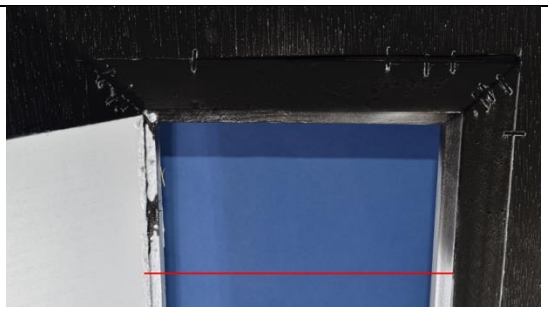
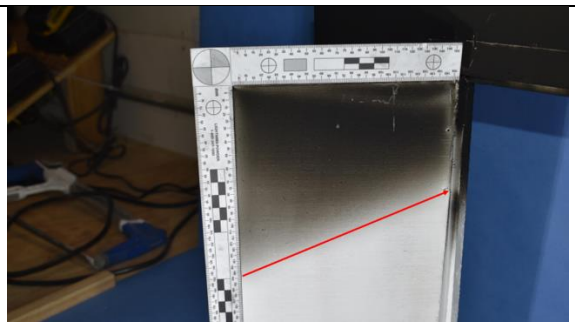
Soot deposition on the door face inside the compartment		100%
Soot deposition on all hinges		100%
Lower elevation of soot deposition on the 'lock side of the door'		77%

Table 7: Damage characteristics of a closed door.

Analysis of the damage of partially open doors (45-degree opening) revealed four damage characteristics (Table 2). These characteristics were determined by examining all photographs of the partially open trials and evaluating any characteristics that persisted through all trials. These characteristics include soot deposition on a single hinge, an angled line of demarcation on the outside door face, a level line of demarcation on the inside door face, and

lower elevation of damage on the hinge side of the door jamb. Each damage characteristic was present in every test, indicating that they were repeatable findings.

Damage Characteristic	Damage	Frequency
Soot deposition on only the top hinge		100%
Level line of demarcation on the inside door face that is level with the wall		100%
Angled line of demarcation on outside door face		100%

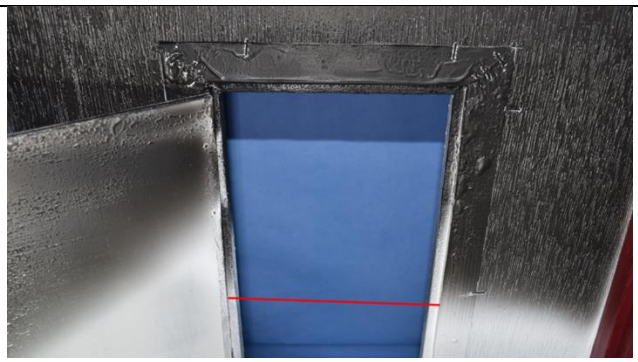
Lower elevation of damage on the hinge side of the door		100%

Table 8: Damage Characteristics of Partially Open Doors

All the same characteristics identified for the partially open door were also repeated with the fully open door (90 degree), except with one difference: the damage characteristic to the face exterior door face. When examined, there was a horizontal line of demarcation on the open door, while the partially opened door had an angled line of demarcation. This damage characteristic occurred during every trial, making the difference between determining if the door was open or partially open objectively possible.

Damage Characteristic	Damage	Frequency
Soot deposition on only the top hinge		100%

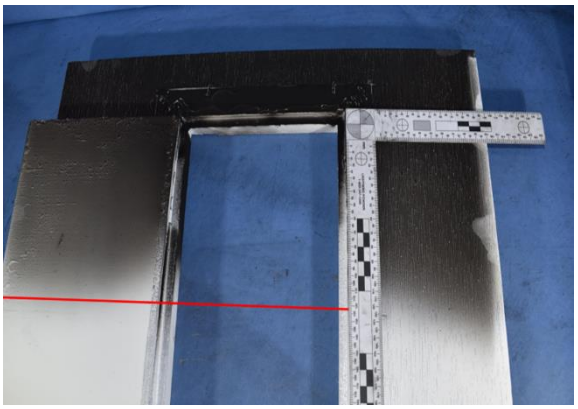
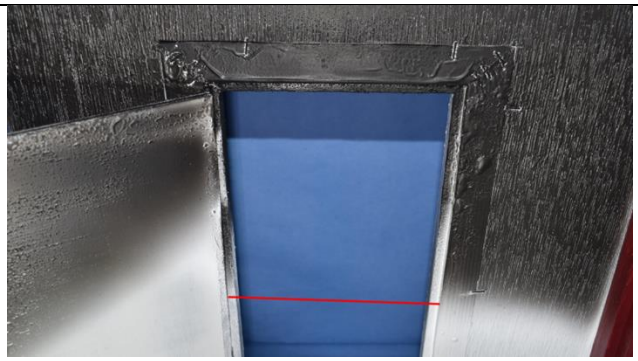
Level line of demarcation on the inside door face that is level with the wall		100%
Horizontal line of demarcation on outside door face		100%
Lower elevation of damage on the hinge side of the door		100%

Table 9: Damage characteristics of an open door.

Conclusions

Ventilation is not only a key aspect of fire growth and development, but it can also severely impact the development of fire patterns within a compartment. As a result, it is necessary for the investigator to be able to objectively determine if the door was open or not during the fire. No research was identified that assisted an investigator in objectively determining the position of a door post-fire. The experimental series performed in this work determined that there are specific damage characteristics associated with door positions. These include:

Open	**Closed (90-degrees)**	**Partially open (45-degrees)**
Soot deposition on the door face inside the compartment	Soot deposition on only the top hinge	Soot deposition on only the top hinge
Soot deposition on all hinges	Level line of demarcation on the inside door face that is level with the wall	Level line of demarcation on the inside door face that is level with the wall
Lower elevation of soot deposition on the ‘lock side of the door’	Horizontal line of demarcation on outside door face	Angled line of demarcation on outside door face
	Lower elevation of damage on the hinge side of the door	Lower elevation of damage on the hinge side of the door

Table 10: Damage characteristic summary.

As a result, the practitioner can observe damage within the door jamb and on the face of the door to assist in determining the door position. Furthermore, by understanding the position of the door the investigator can better understand the influence of ventilation and the size of the fire.

Discussion

The partially open door had an angled line of demarcation on the exterior door face. When the line of demarcation between the partially open and the fully open door is compared, it is evident that the angle of the door is related to the formation of the angled line of demarcation on the door face. As a result, further research should be conducted to determine how the angle at which doors are positioned changes the angle at which the line of demarcation forms. This research may assist the practitioner in potentially knowing the exact angle of the door opening and how much ventilation to the room existed during the fire, which may assist the investigators in better understanding the fire dynamics.

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