

Fire Pattern Research in the US: Current Status and Impact



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Abstract

Fire patterns have been used as a tool to determine the origin of a compartment fire for over 60 years. However, in 1985 the Instructors and Directors of the Fire Investigation Seminar sponsored by the Fire and Safety Engineering Technology Program and the National Association of Fire Investigators asked the question; “What research is available to indicate that using fire patterns to determine the origin of a compartment is valid.” As a result of the original problem statement, the group decided to form the Advanced Fire Patterns Research Project and start to look critically at what data could be developed to assist in the instruction and training of practicing and future fire and explosion investigators.

In 1997, during the “International Conference on Fire Research for Fire Investigation, as a part of the proceedings, identified a number of research initiatives that should be undertaken. Recommendations included; “Validation of pattern analysis – patterns on walls and ceilings and patterns resulting from liquids on floors, Impacts of flashover on fire patterns and other indicators, effects of ventilation on fire growth and origin determination” among others. After that, the National Fire Protection Association through The Research Advisory Council on Post-Fire Analysis issued a White Paper outlining research topics that needed to be addressed. Including “How does one determine when in the course of the fire event a particular pattern was made and how it might relate to a given potential ignition scenario, what are the effects of ventilation and air flow, firefighting activities affect the development of fire patterns.

Fortunately, prior to the call for validation and research the work had already started through the Advanced Fire Patterns Research Project and through recently completed work by the USFA Fire Patterns Study (1997) as well as the Full Scale Room Burn Pattern Study (1997). However at that time, it would have been difficult to predict the research work that would be completed in subsequent years. Fire pattern research since the National Fire Protection Association Research Foundation has in fact followed The Research Advisory Council on Post-Fire Analysis recommendations. Fire Pattern Research has studied single fuel package fire pattern development, full room identically furnished burns have demonstrated that fire development is predictable and the patterns generated early in the growth stage of the fire remain post flashover or full room involvement. While the fire pattern change and grow, but they still remain. The last of the series of tests included the re-creation of an actual fire scene and the test burn confirmed that even with the variables involved in actual fires, similar fire patterns could be formed.

* * *

I. Introduction and Problem Statements

In the 2008 Edition of NFPA-921, “Guide for Fire and Explosion Investigations,”¹ Chapter 17 Origin Determination the following is included:

“17.1.2 Determination of the origin of the fire involves the coordination of information derived from one or more of the following:

- (1) Witness Information. The analysis of observations reported by persons who witnessed the fire or were aware of conditions present at the time of the fire
- (2) Fire Patterns. The analysis of effects and patterns left by the fire (See Chapter 6.)
- (3) Arc Mapping. The analysis of the locations where electrical arcing has caused damage and the documentation of the involved electrical circuits (See Section 8.10.)
- (4) Fire Dynamics. The analysis of the fire dynamics, that is, the physics and chemistry of fire initiation and growth (see Chapter 5), and the interaction between the fire and the building’s systems (See Chapter 7.)”



As indicated, one of the key methodologies included in this section is the analysis of Fire Patterns. Actually, the analysis of fire patterns has been included in all of the editions of NFPA-921 as well as many of the textbooks that have been written concerning fire investigation.

On the surface, this would not appear to be a problem. Since fire patterns and fire pattern analysis has always been a part of origin determination process, it must be correct. The process of validating something because it has been done that way for a long time, is not sufficient to validate the process.

Problem Statement: What research is available to validate the use of the analysis of fire patterns to determine the area of origin.

This question was asked prior to the introduction of NFPA-921 and the most recent fire investigation texts written and as a result in 1985 The Advanced Fire Patterns Research Project was founded by the Directors and Instructors of the Fire Investigation Seminar sponsored by the Fire and Safety Engineering Technology Program (FSE), Eastern Kentucky University (EKU) and the National Association of Fire Investigators (NAFI).

In November 1997 the federal Bureau of Alcohol, Tobacco and Firearms sponsored the *International Conference on Fire Research for Fire Investigation*² that brought together national and international fire researchers and fire investigators to identify the current state of the art and technical gaps in fire investigation. The conference issued Proceedings identifying research and development needs.

Among the cited research and development needs included:

- Fire incident reconstruction -- laboratory methods for testing of ignition source hypotheses
 - Validation of pattern analysis – patterns on walls and ceilings and patterns resulting from liquids on floors
 - Determination of burning rates for different items and development of a burning rate data base
 - Impacts of flashover on fire patterns and other indicators
 - Effects of ventilation on fire growth and origin determination
 - Validation of fire models
 - Fire investigator occupational health and safety
- Training and education needs included:
- Specific training in understanding fire patterns, use of models
 - Protocols for collection of data at the fire scene
 - Training and certification for laboratory personnel
 - Certification programs for investigators
 - Methods and means for training the trainers



A full list of all the identified needs is reported in the conference *Proceedings*.

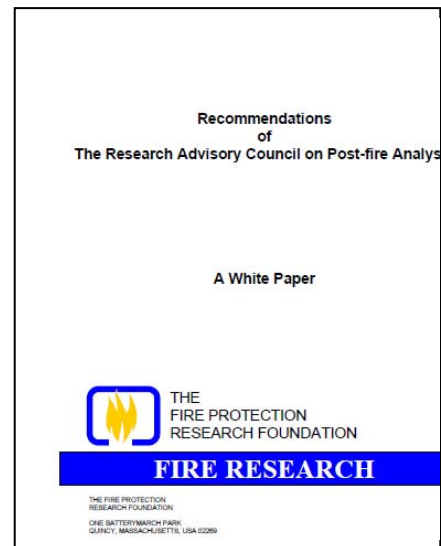
Key in the reported proceedings, are the numerous references to fire patterns and fire pattern persistence post flashover or full room involvement.

The National Fire Protection Association’s Fire Protection Research Foundation in a White Paper “Recommendations of The Research Advisory Council on Post-fire Analysis³” issued February 2002,

The White Paper in Section III Recommendations, Origin and Cause Investigation Methods they make the following recommendation

“Research and Development Needs:

Developing the experimental data to resolve these problems can be extremely expensive due to the large number of variables involved and the costs associated with the needed large scale testing. For this reason, very specific research targets need to be identified with potentially high return. In order to accomplish this high cost effort, it will most likely be necessary to share the costs among stakeholders.



Since knowledge of the origin of a fire is, in nearly all cases, essential to determining cause, a high priority should be placed on new or improved methods for identifying the point or area of origin including burn pattern analysis. Such new or improved methods should be developed, peer reviewed and published to meet the challenges of the recent court tests under the Daubert⁴ and Kuhmo⁵ Tire rulings. These rulings have tightened the requirements for both scientific and technical data used as evidence, and the opinion basis of expert testimony. Both these rulings have come into play as tests of the admissibility of evidence and opinions in fire litigation.

Methods for analyzing burn patterns concerning their meaning in the early growth history of the fire are also important. In particular, how does one determine when in the course of the fire event a particular pattern was made and how it might relate to a given potential ignition scenario? One possible approach would be to study from an engineering/combustion perspective the top 10 incendiary ignition scenarios and determine whether there are separate characteristics or groups of characteristics that are unique to a given scenario.

Research also needs to address the effects of ventilation and airflow, either natural or induced by fire fighting activity, on fire patterns. Knowledge of ignition, early fire growth, flame spread and smoke generation as related to the genesis of fire patterns needs to be developed and integrated into the models being used to interpret fire patterns and test origin and cause theories. Methods should be explored that could identify physical or trace evidence specific to the origin of a pattern that could be established by analytical procedures at the fire scene or in the laboratory.”

II. Historical overview of the use of Fire Patterns to determine the origin of structure Fires.

Since the beginning of organized fire investigation, investigators have relied on the examination of building surfaces and the relative damage or change to materials in determining the point of origin of a fire.

Rethoret in his text “Fire Investigations”⁶ written in 1945 explains:

“In which direction is the wood carbonized? Study closely the depth of carbonization at various places. Bear in mind that superheated gases spread upwards. This again will assist you in getting back to the point of origin.” (p 36)

“During the course of a fire, substances undergo changes which show themselves in different manners. These changes are characteristic of these substances and, by themselves, furnish valuable leads to the fire investigator.” (p 36)

“The direction of the flames and gases is governed entirely by air currents. Partly burnt wallpaper, the heavy soot deposits previously mentioned, the position of embers, etc., clearly show to the investigator the direction of the air currents.” (p 70)



(Photograph No. 31)
This picture shows a glaring example of the use of gasoline to accelerate the fire, which, however, due to lack of oxygen, extinguished itself. Note the heavy soot deposits on walls and ceiling, very little carbonizing of wood and only surface blistering from the heat.

Many other references to the observation of fire damage to determine the origin of a fire are included in this very early textbook.

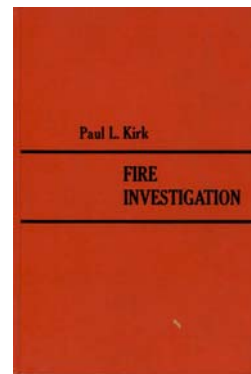
In another early text titled “Fire and Arson Investigation”⁷ written by John A. Kennedy he describes in the Cause and Origin chapter he describes the Arrow or Pointer theory.

“A system of determining the point of origin of a fire by tracing its path back to its source was devised by John Kennedy, the author, and is called the “arrow” or “pointer” theory.” “In fires involving buildings or other structures where wooden joists or studding are exposed and burning, the application of the fire will usually be constant. The sides exposed to the direction from which the fire is coming will be more severely burned studs which serve as pointers or arrows to trace the fire” “The investigator who utilizes the “pointer” or “arrow” system of determining the point of origin of the fire will find himself working backwards” (p 286)



Also, in an early text written by Dr. Paul L. Kirk titled, “Fire Investigation”⁸ published in 1969, in the chapter titled “Fire Patterns of Structural Fires” he describes fire patterns and how they can be used to determine the point of origin of the fire.

“Every fire forms a pattern that is determined chiefly by the configuration of the environment and the availability of combustible material. Because of the upward tendency of every fire, some of the inverted conical shape is characteristic, the apex at the bottom being the point of ignition, with fire rising and spreading. Naturally, this pattern will be altered by the presence of obstructions, or of readily burned fuel in localized areas.” (p 73)



In the section of this chapter that is titled “Tracing the Pattern” he indicates that “A systematic approach to the study of fire pattern is possible and should be followed.” (p 79)

Given the history of using fire spread and fire pattern analysis, it would be reasonable to believe that the system would also be included in the first edition of NFPA-921, “*Guide for Fire and Explosion Investigations*”⁹. Contained in Chapter 11, Origin Determination, the following information is provided concerning the use of fire patterns and heat damage in determining the origin of a fire.

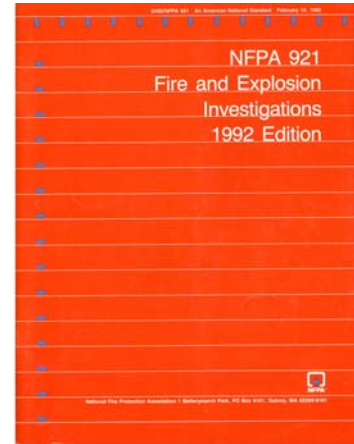
“11-2 Fire Damage Assessment. Investigators will be making assessments of fire spread throughout the examination of the scene. These assessments include recognizing and documenting heat movement and intensity patterns and analyzing the importance and direction of each pattern found.”

Also, contained in the first edition of NFPA 921 in Chapter 4, Fire Patterns the following information is provided.

“4-1 Introduction. One of the major objectives of a fire scene examination is the recognition, identification, and analysis of fire patterns. The analysis of the fire patterns is performed in an attempt to trace fire spread, identify areas and points of origin, and identify the fuels involved.”

Similar discussions are contained in all of the subsequent editions of NFPA 921.

Again, given the emphasis on Fire Patterns and Fire Pattern Analysis in the literature where is the research that supports the validity of fire pattern analysis as a tool to determine the origin of a fire?



Initially, as previously indicated, this question was asked and the Advanced Fire Patterns Analysis Project was formed.

Advanced Fire Pattern Research Project (AFPRP)

The AFPRP was founded by the Directors and Instructors of the 1985 Annual Fire Investigation seminar that was being conducted at ECU, and sponsored by NAFI and ECU. Since the formation of the project, considerable work has been undertaken to study fire growth and spread in both full scale and ¼ scale test burns. Much of the data generated has been utilized to supplement instruction in the area of Fire Pattern Analysis. To date, more than seventy full-scale, half-scale, and quarter-scale burn tests have been completed at ECU as a result of the seminars sponsored by ECU, NAFI and later also co-sponsored by the National Fire Protection Association (NFPA). The research burns have enhanced the knowledge base of the fire investigation community.



Separate from the work done by the AFPRP, the National Institute of Standards and Technology, Center for Fire Research obtained funding from the United States Fire Administration to conduct full scale fire tests to study Burn Patterns. This research began in November 1994 with the final report “USFA Fire Burn Pattern Tests”¹⁰ issued in 1997. Included in the summary of results is the confirmation that “many of the concepts, investigative systems, dynamics of pattern production, and patterns analysis concepts put forward in the current, peer reviewed, standard text for fire pattern analysis in the profession, NFPA 921-1995, *The Guide for Fire and Explosion Investigations* were confirmed by the program’s testing.”

Abstract

Fire patterns are the visible or measurable physical effects that remain after a fire. These include thermal effects on materials, such as charring, oxidation, consumption of combustibles, smoke and soot deposits, distortion, melting, color changes, changes in character of materials, structural collapse, and other effects.

The first scientifically controlled and recorded research into the formation, growth, nature, and investigative analysis of post-fire patterns was conducted in 1994-1995, by the United States Fire Administration under the direction of a specially appointed research committee of fire investigation experts. To provide data for the research, the United States National Institute of Science and Technology, Building and Fire Research Laboratory (NIST- BFRL) facilitated ten full-scale room fire tests. The purpose of the testing was to provide basic research into the true nature of fire patterns used by fire investigators to make determinations of fire origins and fuels.



The results indicated that generally, fire patterns provide definitive data useful for the determination of the origin of fires. It was found that fire patterns are influenced by a number of variables. The most notable of these from this research, was ventilation and flashover. In some particular cases ventilation was shown to be able to change or move patterns to such an extent that the correct interpretation of the pattern was made more difficult. The room fire phenomena of flashover was observed in a majority of the test fires. It was found that flashover was able to obscure some patterns present on room surfaces prior to flashover, including patterns from ignitable liquids used as an accelerant.

Results and conclusions were also reached in the areas of floor patterns, truncated cone patterns, floor jets, trailers, burning under furniture items, low level burning, depth of gypsum wallboard dehydration, water spray patterns, color of smoke, and the detection of ignitable liquids.

Summary of Results

Many of the concepts, investigative systems, dynamics of pattern production, and patterns analysis concepts put forward in the current, peer reviewed, standard text for fire pattern analysis in the profession, NFPA 921-1995, *The Guide for Fire and Explosion Investigations*, [1] were confirmed by the program's testing. These various confirmed fire patterns concepts include the following;

- Formation dynamics of truncated cone patterns
- Intensity patterns
- Movement patterns
- Calcination (dehydration) of gypsum wallboard
- Pattern persistence through flashover
- Depth of char
- "V" patterns
- "U" Patterns
- Pointer/Arrow patterns
- Hourglass patterns
- Saddle burns
- Clean burn
- Heat shadowing
- Protected areas
- Beading of electrical conductors
- "Pulled" light bulbs
- Melting of materials
- Truncated cone patterns

Several of the "old wives' tales" and fire investigation misconceptions which are repudiated in NFPA 921 were also shown to be unsubstantiated by the program testing. Some of these theories include the following:

- Wide "Vs" vs. narrow "Vs"
- Crazeing of window glass
- Nature of charring
- Window sooting/staining
- Color of smoke and flame.

Whether patterns are persistent through the room flashover transition is a commonly questioned issue. It had been opined by some, without appropriate testing or research, that flashover would destroy the patterns produced by early plume development. In the program testing, in every case in which the test rooms transited through flashover, the truncated cone (plume and upper layer) produced patterns persisted and were readily identifiable on the wall and ceiling surfaces of the post-flashover compartment.

An enduring "wives' tale" about "V" patterns has been that the angle of the line, of demarcation forming the legs of the "V" patterns were in some way indicative of the rate of burning of the fuel. The adage was that "*Wide 'Vs' indicate slow fires, narrow 'Vs' indicate fast fires.*" Because this concept of analysis of "V" angles flies in the face of conventional fire science logic, the program directly addressed this issue, in an attempt to put this point to rest. This was done by testing fuel packages with widely different rates of heat release on exactly the same test rooms and producing similarly angled "V" patterns. Other than those aspects which deal with the total plume length and therefore the production of ceiling jets, rates of heat release have little bearing on the angled shape of the patterns produced. In that regard, it could even be argued that the larger the size of the ceiling jets, the more downward radiation exists to widen the top of the plume. From this argument it would appear more logical that the "faster" the fire, the wider the "V," but this reversal of the "wives' tale" theory was not displayed in the test results either.

The width of the angles of lines of demarcation of a pattern is largely a function of the rate of heat release and the total time of burning.

As a supplementary part of the testing, the production and persistence through flashover of ignitable liquid patterns on floors were explored. Though burned "liquid pour" patterns were evident on floor coverings pre-flashover, the persistence of such patterns through the flashover environment was much less identifiable. A need for more research is indicated in this area.

Throughout the ten test burns, it became apparent that one factor of fire pattern development, the effect of ventilation, was the least understood. In the first four tests, which were conducted in the full-scale burn facility of NIST₁, all exhaust gases were mechanically exhausted and collected for species analysis. This provided for a supply of fresh air into the bottom of the test room doorways and prevented the vitiation of the fire. The remaining tests were conducted in actual dwellings where the concentration of oxygen in the air supply to the fire was significantly reduced because of the smoke which accumulated in adjacent compartments. Consequently the fire's entrained make-up air

became more and more contaminated with products of combustion, and vitiation of the fire occurred.

In addition, the path of travel of relatively "clean," oxygen-rich air also affected the production of patterns. Except in the cases when the fire originated in the corner itself, the corners of the test rooms acted like small dead-airspaces, where the patterns indicated that less burning was-present. Placement of the furniture within the test rooms also had an effect upon the production of the "dead air" spaces. It became clear that the effects of ventilation on fire patterns was an additional factor which also needs more research.

Another series of full scale fire tests were conducted as a result of funding provided by the National Institute of Justice, with a report "Full Scale Room Burn Pattern Study"¹¹, released in December 1997.

Abstract

One method fire investigators use to determine the cause and origin of a fire is the study of patterns or "indicators left on building components or building contents by the fire. Previous studies have shown that some traditionally used indicators have little or no technically defensible basis. In order to study the patterns or "indicators" produced by fires, full scale experiments were conducted using test rooms furnished as residential bedrooms. Temperatures and heat fluxes at various locations in the room were measured. In some cases, the concentration of oxygen, carbon monoxide, and carbon dioxide were measured. This report describes the experimental setup, measurement results, and the post fire inspections of the rooms.

Discussion and Conclusions

The results of the measurements during the experiments showed good agreement between experiments with the same method of ignition. In addition, the times to events such as window breakage and transition to flashover were also similar. A limited number of point measurements, however, cannot be expected to accurately portray localized conditions throughout the burn room. This is especially true for the measurement of gas concentrations, where it would be useful to know the concentrations of oxygen, and fire gases in the lower layer of the room, near the fuel packages. Differences in the measurements between experiments of the same type included maximum temperature and the neutral plane height in doorways. These differences could be attributed to ventilation effects. The ability to compare measurements from the gasoline ignited experiments, however, was limited due to the power failure during experiment.



FIGURE 29. Photograph of the chair as viewed through doorway, Experiment 1.

Comparisons of the conditions of the rooms and furnishings after the experiments resulted in the determination of several similarities, as well as many differences, between experiments with the same method of ignition. Examples of similarities include sagging of bed springs (gasoline ignition) and bed frames, protection of room surfaces by furniture, the presence of deformed light bulbs, more severe burning of floor surfaces near the center of rooms as compared to near the edges of rooms,

and the presence of areas burned clean of soot. Areas with differing levels of soot deposition, and areas burned clean of soot formed patterns corresponding to indicators defined in NFPA 921 such as clean burns and “V” patterns. Similarities are summarized in Table 10, where the presence of a condition in an experiment is indicated by "Y" for yes, the condition was present; or "N" for no, the condition was not present. Dashes in the table indicate that the experiment could not be compared to the other experiments in a comprehensive manner due to the limitations of the data or photographs.

Table 10. Experiment Similarities

Experiment Condition	1	2	3	4
Doorway Char Indicator	N	Y	-	-
Clean Burn on the wall above and behind the chair	Y	Y	Y	Y
Furniture outline	Y	Y	-	-
Protection behind and/or below furnishings	Y	Y	-	-
Mattress spring sag	N	Y	Y	Y
Bed frame sag	N	N	Y	Y
Pulled Bulbs	Y	Y	-	-
Heavy charring in center of floor	-	-	Y	Y
Pattern behind door	-	-	Y	N
Clean Burn	Y	Y	Y	Y
“V” Patterns	Y	Y	Y	Y
Window Breakage	N	Y	Y	Y

One similarity of interest found in the gasoline experiments was the heavier burning found near the center of the rooms. While this is the same area where the gasoline was poured, the cause of the heavier burning in these experiments was not conclusively demonstrated. Other possible explanations are ventilation effects from the door, and radiant heat transfer view factors between the floor and the hot gases in the upper layer. The formation of flammable liquid burn patterns is a potential topic for further study.

Significant differences in the condition and appearance of the burn rooms and furnishings were present between experiments with the same method of ignition. The differences consisted of the severity of burning, the locations of patterns, and the types of patterns present. Overall, there was a lack of pattern consistency. As mentioned previously, ventilation effects are the likely cause of the pattern inconsistencies, and should be tightly controlled in future experiments. Characterization of the ventilation conditions present would be aided by the instrumentation of openings for the measurement of flow velocity. Only if ventilation effects are minimized will it be possible to fully gauge the effects of ignition scenarios on pattern formation.

While they are not discussed in detail in this report, there are consistent differences between the results of the chair ignition and the gasoline ignition fires. An example is present in the aforementioned Table 10, where the bed frame was deformed during the gasoline ignited fires (experiments 3 and 4), but were not deformed during the chair ignition fires (experiments I and 2). Due to the small number of experiments conducted, as well as the other variables in the experiments such as ventilation conditions, the results are not conclusive. Further experimental study, with the

goal of understanding the conditions present in the fire rooms, are necessary before conclusions can be drawn as to the impact of the fire ignition method on indicator formation.

While on the surface, the reader could discount the research based on the discussion and conclusion. But, upon careful review of the photographs provided and the discussion there are similarities even though they may be subtle. Also, in the discussion concerning the effects of ventilation, which were good, especially, for future research projects and when evaluating fire patterns during the determination of an origin.

III. Overview of Recent Fire Pattern Research Completed.

A. Depth of Calcination Measurement in Fire Origin Analysis¹². Presented during the Fire and Materials conference 2003, San Francisco, CA the following is an abstract of that research project and report.

This is a report on a research project into the practical use of measurements of depth of calcination of room fire exposed gypsum wallboard, under actual fire scene investigation conditions, to discover and illustrate movement and intensity fire patterns for fire origin determination. The work builds on the previously published research of Posey and Posey, 1983; McGraw and Mowrer, 1999; Mowrer, 2000; and Schroeder and Williamson, 2000 and the procedures outlined in NFPA National Fire Codes component document NFPA 921-2001, *Guide for Fire and Explosion Investigations*, sections 4.12 through 4.12.4.

This research project was performed in conjunction with the 2002 National Advanced Fire, Explosion, and Arson Investigation Training Program cosponsored by the National Association of Fire Investigators (NAFI), the Eastern Kentucky University Fire and Safety Engineering Technology Program (EKU), and the National Fire Protection Association (NFPA).

The research was designed to illustrate and, if appropriate, support the system for measuring depth of calcination on fire exposed vertical gypsum wallboard and used in fire patterns analysis as recommended in NFPA 921. The tests and data collection were conducted in March 2002 full-scale room fire evolutions, using ten fire investigators of widely varying experience, from novices to full time professionals, to make and record depth of calcinations measurements with no previous knowledge of the actual origins of the test fires.

Additional supplemental laboratory bench testing was conducted as background research into the loss of density of gypsum wallboard from heat exposure at the Forensic Fire Science and Technology Laboratories of John A. Kennedy and Associates.

Research test results were good, providing accurate and reproducible fire movement analysis and supporting the calcination measurement techniques, systems, and tools advocated by NFPA 921. Collected data was comparable among participants with widely varied fire investigation experience and after only minimal instruction and practice in the calcination depth measurement techniques and tools.

B. “Full Scale Room Burn Pattern Study”¹³. Presented during International Symposium on Fire Investigation Science and Technology (IFSI) 2006 conference and was based on three series of two fire tests conducted during the National Advanced Fire, Arson, and Explosion Investigation Science and Technology Program™, March and November 2005 and March 2006. An abstract of the report is provided.

Full-scale research burns into the nature of patterns in compartment fires were conducted at the new fire research facility of Eastern Kentucky University. Key questions to be addressed by the research burns were:

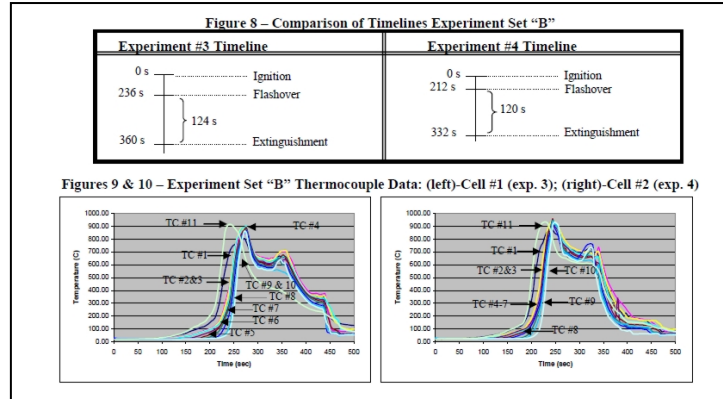
- (a) patterns persistence through flashover and full room involvement
- (b) reproducibility of patterns geometry in minimal variable testing methods
- (c) reaffirmation of standard patterns analysis methodologies, such as heat and flamevector analysis, depth of calcination measurement, and truncated cone patterns formation and analysis.

As an added value these research burns were designed to test the validity of content of the National Fire Code© component document, *NFPA 921 – Guide for Fire and Explosion Investigations* chapters on Fire Patterns, and Origin Determination.

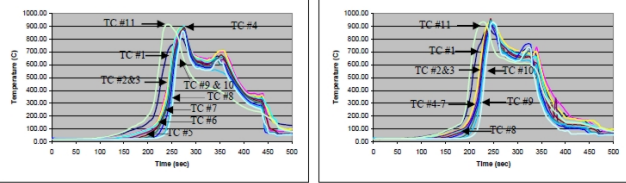
These tests demonstrate a remarkable resemblance of patterns in minimal variable testing methods. Patterns persistence through flashover and full room involvement was observed, as well as the reproducibility of specific fire patterns, heat and flame vector analysis results, and depth of calcinations measurements. In addition, several ancillary fire effects, fire patterns, and post-fire analysis issues were successfully examined.

C. Advanced Fire Pattern Research Project¹⁴: Single Fuel Package Fire Pattern Study. Also presented during International Symposium on Fire Investigation Science and Technology (ISFI) 2006 conference this research project focused on the reproducibility of Triangular, Columnar, and Conical fire patterns using scaled compartments and wood cribs. An abstract of the report is provided.

Several studies have been completed in the creation of and documentation of various fire patterns. However, no study had sought to prove the reproducibility of the fire patterns used for fire scene investigations. Although some of these studies have been subjected to peer review, the purpose of this research was to quantify the reproducibility of fire patterns used by investigators in the determination of origin and cause, and to provide support for the contents of *NFPA 921-Guide for Fire & Explosion Investigation*. This study focused on the development of three recognized pattern formations: Triangular (Inverted cone), Columnar, and Conical. Specifically, this study researched the development of these pattern formations on standardized witness surfaces (drywall panels) during the combustion process of a standardized fuel package (wood cribs). This study showed that although the time to reach the pattern differed, the amount of mass consumed and heat produced by the fire, along with the ignitability of the witness surface and the heat energy imparted on the receiving surface were the decisive factors in reproducing a consistent, similar pattern. This study



Figures 9 & 10 – Experiment Set “B” Thermocouple Data: (left)-Cell #1 (exp. 3); (right)-Cell #2 (exp. 4)



was intended to place a foothold below an existing study titled Full Scale Room Burn Pattern Study, which was also seeking to validate the reproducibility of fire patterns. This current study illustrates that similar fuel packages will reproduce a similar pattern in a controlled environment.



D. Fire Pattern Persistence and Predictability on Interior Finish and Construction Materials During Pre and Post Flashover Compartment Fires¹⁵. Presented during the Fire and Materials conference 2007, San Francisco, CA the following is an abstract of that research project and report. This paper reported on a total of four (4) series of two burn tests conducted March and Fall of 2005 and 2006.

Fire Patterns, as defined by NFPA-921 are the visible or measurable physical effects that remain after a fire. Fire Pattern analysis has been a key factor in the determination of the origin and cause of fires for the past 50 years. In 1985 the Advanced Fire Patterns Project was formed between the National Association of Fire Investigators (NAFI) and the Fire and Safety Engineering Technology Program, Eastern Kentucky University to complete research into the development of fire patterns on exposed surfaces. Since the formation of the project, considerable work has been undertaken to study fire growth and spread in both full scale and ¼ scale test burns. Much of the data generated has been utilized to supplement instruction in the area of Fire Pattern Analysis.

The purpose of this paper is to describe the results of the most recent full scale test burns that were conducted at Eastern Kentucky University and sponsored by the Advanced Fire Pattern Project. For the past 2 years a series of eight full scale tests were conducted in identically constructed, finished and furnished compartments. In each of the tests with one exception all fires progressed to full room involvement. Additionally, a full scale test was completed on a specially constructed and furnished room to assist in studying fire growth and spread and the resulting pattern formation in comparison to the fire patterns that were witnessed in a compartment of an actual compartment fire in which there had been a fatality.

These full scale test burns provided a considerable amount of data concerning fire pattern development and evolution during fire growth and spread. Specifically, these test burns demonstrated fire pattern persistence and predictability during pre and post full room involvement fires. The full scale tests demonstrated that the fire patterns described in current literature are correct and when used properly can assist in the determination of the origin of a fire.



E. Fire Pattern Persistence and Predictability in Pre and Post Flashover Compartment Fires¹⁶. Presented during International Symposium on Fire Investigation Science and Technology (ISFI) 2008 conference, this report finalized the last of the test fires that were to be completed from 2005 to 2007. The total number of identical test burns over the three year period was 10 and one additional test was conducted based on an actual fire. An abstract of the report is provided.

Fire Patterns, as defined by NFPA-921 are the visible or measurable physical effects that remain after a fire. Fire Pattern analysis has been a key factor in the determination of the origin and cause of fires for the past 50 years. In 1985 the Advanced Fire Patterns Project was formed between the National Association of Fire Investigators (NAFI) and the Fire and Safety Engineering Technology Program, Eastern Kentucky University to complete research into the development of fire patterns on exposed surfaces. Since the formation of the project, considerable work has been undertaken to study fire growth and spread in both full scale and 1/4 scale test burns. Much of the data generated has been utilized to supplement instruction in the area of Fire Pattern Analysis.

The purpose of this paper is to describe the results of the most recent full scale test burns that were conducted at Eastern Kentucky University and sponsored by the Advanced Fire Pattern Project. For the past 3 years a series of ten full scale tests were conducted in identically constructed, finished and furnished compartments. In each of the tests with one exception all fires progressed to full room involvement. Additionally, a full scale test was completed on a specially constructed and furnished room to assist in studying fire growth and spread and the resulting pattern formation in comparison to the fire patterns that were witnessed in a compartment of an actual compartment fire in which there had been a fatality.

These full scale test burns provided a considerable amount of data concerning fire pattern development and evolution during fire growth and spread. Specifically, these test burns demonstrated fire pattern persistence and predictability during pre and post full room involvement fires. The full scale tests demonstrated that the fire patterns described in current literature are correct and when used properly can assist in the determination of the origin of a fire.



F. Full-Scale Single Fuel Package Fire Pattern Study¹⁷. Presented during International Symposium on Fire Investigation Science and Technology (ISFI) 2008 conference, this research project focused on a single fuel package (chair) in a scaled room. A copy of the report abstract is provided.

This research project is a continuation of a previous study (Hicks, et al., 2006), which analyzed fire patterns produced from wood cribs. The current study continued this fire patterns research by burning ten commercially available polyurethane (PU) foam chairs and documenting the fire patterns. The reproducibility of fire patterns was analyzed to compare one PU foam chair test to the next, as well as in association to those produced by burning wood cribs. Two aspects of fire pattern production were examined. The first aspect focuses on the reproducibility of a conical shaped fire pattern formed on standard gypsum wallboard surfaces. Second, this study analyzed the effects of the upper layer and its role in the production of a conical shaped fire pattern. This study showed that although the time to reach the fire pattern differed, a duplicate fire pattern was reproduced from a similar loss of mass. The results of this study illustrates that similar fuel packages will reproduce a similar conical shaped fire pattern. Additionally, lowering of the upper layer was found to affect the resulting conical shaped fire pattern. A subsequent aspect of this research is the implication that these patterns can be utilized by fire investigators in determining an area of origin.



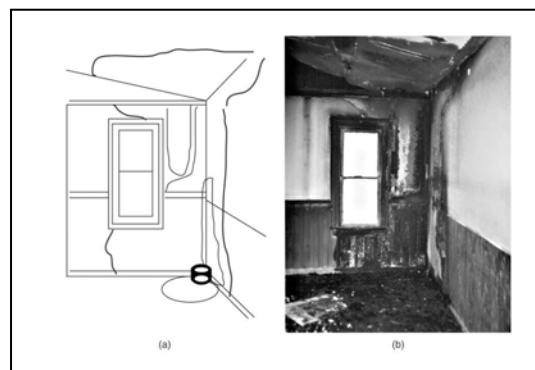
G. “Hourglass” Burn Patterns: A Scientific Explanation for Their Formation¹⁸. Presented during International Symposium on Fire Investigation Science and Technology (ISFI) 2008 conference, this research project focused on an explanation of the formation of Hourglass burn patterns. A copy of the report abstract is provided.

Abstract

The science of interpreting burn patterns is considered important by fire investigators when establishing a fire’s area of origin. When a fire occurs in a room adjacent to a wall or corner, the fire plume often creates damage called “V” patterns. In certain cases, this pattern appears in the shape of an “hourglass” burn pattern. The identification and vector analysis of this specific burn pattern is included in several treatises in the field, including *Kirk’s Fire Investigation*¹⁹, *Forensic Fire Scene Reconstruction*²⁰, and the National Fire Protection Association’s *NFPA 921 – Guide for Fire and Explosion Investigation*²¹. The purpose of this paper is to scientifically explain the formation of “hourglass” burn patterns. Both fire testing and mathematical analysis by the authors show that the formation of “hourglass” burn patterns is a direct function of the fire plume’s virtual origin, which is mathematically tied to the heat release rate and surface area of the fuel package. Several examples are provided along with engineering calculations.

Conclusions

Fire pattern damage analysis is a vital investigative technique for fire scene reconstruction. The visual interpretation of damage created by fire plumes can isolate and accurately identify the area of fire origin. Locating and identifying the first fuel package ignited is a critical step in the accurate reconstruction of any fire incident. Careful analysis of fire patterns can significantly aid the scene investigator in this effort. Because effects like charring, melting, ignition, and protection are predictable, their location and distribution offer a sound basis for locating fuel packages, which can be confirmed by interviews or pre-fire photos.



Systematic steps relying upon the placement of the fire plume and the calculation of its virtual origin can be used by fire investigators to support and document thermal damage patterns, identify the fire’s direction and intensity, confirm significant witness observations, and verify the results of fire modeling. These systematic steps should invoke the scientific method to test and evaluate various hypotheses of the fire’s origin and spread.

From these observations, the authors conclude the following:

- Formation of patterns on walls follows well-established heat transfer laws.
- The areas and lines of demarcation within the V pattern can reveal the temperature distribution within the plume to help confirm the location and source of the fuel package.
- The presence of an hourglass pattern typically represents a high energy fire with a small effective diameter and strong entrainment near its base – this may be a pattern from a fuel package such as a urethane foam cushion or an ignitable liquid pool.

- An inverted V pattern (sometimes termed an ‘A-pattern’) indicates a lower energy fuel package with a wider effective diameter.
- Fire hazard analysis tools, such as the NRC’s Fire Dynamics Tools, can be effective in evaluating the various properties of fire plumes, including virtual origin, flame height, estimated heat release rates, and duration.

H. Other Research Projects that were Conducted During the Burn Tests

1. Computer Fire Models for Fire Investigation and Reconstruction²¹. Presented during International Symposium on Fire Investigation Science and Technology (ISFI) 2008 conference. This research project focused on the use of fire models for fire pattern prediction and the validity of fire models to test a fire origin hypothesis. An abstract of the report is provided.

Fire modeling can be separated into two broad categories, physical and mathematical fire modeling. Physical fire modeling has been around since the dawn of man and consists of burning objects to evaluate their effects. Study of fire phenomena by utilizing mathematics began in the early 1940’s. Mathematical fire modeling can further be arranged into three categories based on the types of calculations performed, including: hand calculations, zone models, and computational fluid dynamics models. A general discussion of each type of modeling is presented in this paper. Computer fire modeling has been used to design and analyze fire protection systems (i.e. sprinkler systems, detection systems), evaluate the effects of fire on people and property, estimate fire risks, and assess post fire reconstruction. This paper focuses on the use of computer fire models for fire investigation purposes and provides a detailed discussion on the input data needed for fire modeling, available education and training, and its application in analyzing fire dynamics. Specifically, the use of computer fire models in validating or refuting an origin hypothesis by comparison of fire patterns was studied.

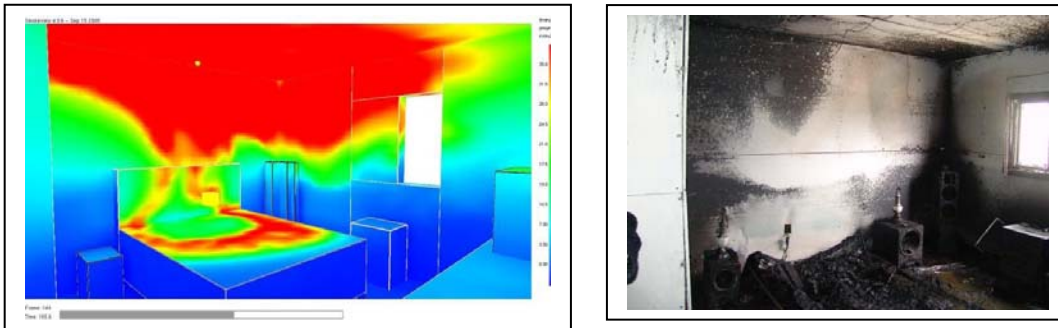


Figure 7: Analyzing Fire Patterns with Computer Fire Modeling Compared to Post-Fire Patterns

2. Arc Fault Mapping Test. During the March 2006 and 2007 Test Burns conducted for the National Advanced Fire, Arson, and Explosion Investigation Science and Technology Program™ and for the Advanced Fire Pattern Research Project that has been referenced previously in this paper. A series of four Arc Mapping Tests were conducted, however at this time the tests have not been reported.

The methodology used for these tests was to install a grid wire under the drywall and connect each of the grids to a separate energized circuit. The order in which the circuits tripped was noted and the wire harvested from the burn rooms to be examined off site. Currently, the conductors are being analyzed and a report will be generated and published.

IV. Conclusions.

Unlike laboratory bench-top tests (i.e. flash point tests) where variables can be easily controlled, a full-scale room fire test has a wide variety of uncontrollable variables, mostly linked to ventilation. It is rare that full-scale tests can be completely reproducible. The experimental research results reviewed in this paper show fire pattern reproducibility well within the parameters that can reasonably be expected. Regardless of the thousands of variables that can affect both fire growth and subsequent pattern formation, similarities in pattern formation between the experiment sets were observed and measured. The most important finding from these tests is that fire patterns provide substantial evidence for the accurate identification of the correct area of origin. The only fire pattern that generally did not show persistence in post flashover or full room involvement were those that were formed as a result of the use of ignitable liquids as reported by Tony Putorti in his four full scale test burns and the USFA tests.

These tests reaffirmed that fire patterns persist during post flashover conditions, as well as provide evidence of the evolution of these fire patterns. This research revealed that the initial plume patterns are not lost, in fact, the experiments presented here have shown that the demarcation lines or initial fire patterns formed by the plume persist after flashover. The research shows that these patterns do begin to evolve from the sharp distinct demarcation lines into more subtle demarcation lines due to the descending upper layer and its resulting damage. However, the initial plume patterns are still present and have been reliably shown to assist in determining an area of origin.

Concerning issues with ventilation. Ventilation has and will be a factor that needs to be considered during the use of fire patterns for the determination of a fire's origin and the development of the compartment fire. While not a comprehensive list of issues to be considered, it is a start.

1. Forced ventilation (positive and negative) or natural ventilation as a result of firefighting operations, may very well cause a fire pattern to be changed or altered. Additionally, ventilation may cause the fire to develop or spread in a direction that is not consistent with what the investigator would consider normal.

2. Recycling of air within the compartment and limited fresh air intake into the compartment may result in vitiation or a slower development. Conversely, an unlimited supply of fresh air, especially in the early stages of development may also affect the rate of fire growth as a result of cooling the space.

3. In compartments that have transitioned through flashover or to full room involvement, conditions throughout the compartment are fairly consistent except at ventilation openings where the combustion process is more efficient and results in higher temperatures. The more efficient combustion will also cause the formation of “clean burn” fire patterns while in the remaining portions of the compartment “clean burn” fire patterns are a result of a fuel package.

Additional research is needed to better predict the effects of ventilation.

V. Anticipated Future Research.

Additional research is needed and as of this time, the Advanced Fire Pattern Research Project does have plans to expand the scope of the current research. Changes will include moving the origin, analysis of the persistence of fire patterns well after flashover, continuation of analyzing the patterns that remain after igniting a small fuel next to a large fuel and analyzing whether a reliable origin can be determined; the use of FDS/Smokeview in analyzing fire patterns, and the addition of ignitable liquids to the ignition scenario.

Two items for consideration for future research projects of this nature. First, care should be taken to establish the photography protocols so that photographs can be taken at the same location for each test using the same camera, flash, lens, and amount of zoom. A photo diagram or log would assist. Second, the development of wall elevation diagrams and each of the fire patterns observed transferred to the diagram and the subsequent heat and flame vector diagram.

There are a number of fire pattern research projects that are currently in progress and some that are pending approval and funding. This listing of future fire pattern research projects is limited to those that provided the information.

Bill Hicks and Greg Gorbett with the Fire and Safety Engineering Technology Program, ECU have obtained funding for a series of full scale burn tests in addition to those that are conducted as a part of the normal fire investigation courses.

NIST is also continuing to study fire patterns and persistence and hopefully other full scale tests that are completed for other projects, fire pattern analysis can be included.

University of Tennessee, with David Icove have applied for funding as a part of the fire grant program.

End Notes

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Copies of all of the papers and materials referenced in this report on Fire Pattern Research in the U.S.: Current Status and Impact can be obtained from the TRACE Fire Protection and Safety website. www.TRACEfireandsafety.com

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