DOT/FAA/AR-06/21

Office of Aviation Research
and Development
Washington, DC 20591

Development of a Standardized Fire Source for Aircraft Cargo Compartment Fire Detection Systems

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May 2006

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-06/21		

4. Title and Subtitle	5. Report Date
DEVELOPMENT OF A STANDARDIZED FIRE SOURCE FOR AIRCRAFT CARGO COMPARTMENT FIRE DETECTION SYSTEMS	May 2006
	6. Performing Organization Code ATO-P R&D
7. Author(s) David Blake	8. Performing Organization Report No.
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Airport and Aircraft Safety Research and Development Division Fire Safety Branch Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research and Development Washington, DC 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ANM-110

15. Supplementary Notes

16. Abstract

This report documents the development and testing of a standardized fire source for cargo compartment fire detection systems. Note that currently, these fire sources cannot be used in actual certification flight tests. The intent of this work was to define a fire source in terms of heat release rate, mass loss rate, and smoke and gas species production rates, and then devise a safe method to simulate whichever aspect of the fire signature that the particular detection system was designed to respond to in the certification tests. This could be done singly or in some combination with smoke generators, heat guns, and the controlled release of actual or surrogate gas species. This report discusses how this fire source is used in a computational fluid dynamics model to predict the transport of smoke, gases, and heat throughout a cargo compartment. The testing concluded that the fire source used in a simulated smoldering fire mode does not produce a fire signature that would be useful in developing multicriteria fire detectors with a better capability to resist false alarms. This report also documents the amount of smoke that would be detectable in various size cargo compartments and the resultant responses of currently in-use aircraft smoke detectors from the simulated smoldering and flaming fires.

17. Key Words	18. Distribution Statement
Smoke detectors, Smoldering fire, Flaming fire	This document is available to the public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F1700.7 (8-72) Reproduction of completed page authorize

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ACRONYMS

CO	Carbon monoxide
CO_2	Carbon dioxide
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
NASA	National Aeronautics and Space Administration
TSO	Technical Standard Order

EXECUTIVE SUMMARY

This report describes the development of a fire source for evaluating the alarm response time of aircraft cargo compartment fire detectors. It also describes how this fire source is used in a computational fluid dynamics (CFD) model for predicting the transport of smoke, heat, and gases throughout an aircraft cargo compartment. The fire source used was a molded plastic resin block with an imbedded nichrome wire heating element. The fire source was used to simulate either a smoldering or a flaming fire. Tests were conducted in both smoldering and flaming modes in several cargo compartments, ranging from a small compartment in a narrow-body fuselage to a well-ventilated main deck compartment in a wide-body fuselage. The compartments were extensively instrumented to measure temperature, heat flux, and smoke and gas species. Validation data were collected to compare the results of the experiments to the predictions of the CFD model. The testing concluded that the simulated smoldering fire source did not produce a fire signature that would be useful for the development of multisensor fire detectors with a better capability to resist false alarms. The flaming fire source did produce a fire signature that could be used for decreasing false fire alarms. The tests also documented that the smoke quantity appropriate for certification tests in smaller compartments was not detectable in the required time in larger, ventilated compartments using detectors that comply with the current Technical Standard Order. The testing also demonstrated that the current light-scattering photoelectric smoke detectors have a more sensitive response to smoldering or artificial smoke than to smoke from a flaming fire. Currently, these fire sources cannot be used in actual certification flight tests. The intent of this work was to define a fire source in terms of heat release rate, mass loss rate, smoke and gas species production rates, and then devise a safe method to simulate whichever aspect of the fire signature that the particular detection system was designed to respond to in the certification tests. This could be done singly or in some combination with smoke generators, heat guns, and the controlled release of actual or surrogate gas species.

1. PURPOSE.

This report describes the development of a realistic and repeatable fire source for the purpose of evaluating the response time of aircraft cargo compartment fire detection systems. It also describes how this fire source is used as a source term for a computational fluid dynamics (CFD) model for predicting the transport of smoke, heat, and gas species throughout a cargo compartment. However, there was never any intent to suggest that these fire sources should be used in actual certification flight tests. The intent was to define a fire source in terms of heat release rate, mass loss rate, smoke and gas species production rates, and then devise a safe method to simulate whichever aspect of the fire signature that the particular detection system was designed to respond to in the certification tests. This could be done singly or in some combination with smoke generators, heat guns, and the controlled release of actual or surrogate gas species.

2. BACKGROUND.

Title 14 Code of Federal Regulations (CFR) 25.857 currently describes four classifications of cargo compartments. With the exception of Class A compartments, they all require a fire detection system that will give a warning to the pilot or flight engineer station. Class A compartments are small compartments adjacent to occupied areas where a fire would be immediately discovered by a crew member.

14 CFR 25.858 requires that:

> "If certification with cargo compartment fire detection provisions is requested, the following must be met for each cargo compartment with those provisions:
>
> (a) The detection system must provide a visual indication to the flight crew within one minute after the start of a fire.
>
> (b) The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased.
>
> (c) There must be means to allow the crew to check in flight, the functioning of each fire detector circuit.
>
> (d) The effectiveness of the detection system must be shown for all approved operating configurations and conditions."

To comply with 14 CFR 25.858(a) and (d), flight tests are required to demonstrate that the detection system will respond to smoke or a smoke simulant in less than 1 minute.

Technical Standard Order (TSO) TSO-C1d, " Cargo Compartment Fire Detection Instruments," applies to cargo compartment fire detectors. This TSO references an additional document, Society of Automotive Engineers Aerospace Standard AS 8036. This standard describes a wide variety of environmental conditions under which fire detector units must function. It also requires that photoelectric and ionization-type fire detectors have an alarm point somewhere between 60% to 96% light transmission per foot. The alarm points of TSO compliant, in-service smoke detectors are typically set near the upper limit of 96% light transmission per foot.

The Federal Aviation Administration (FAA) has also published Advisory Circular (AC) 25-9A, "Smoke Detection, Penetration, and Evacuation Tests and Related Flight Manual Emergency Procedures," that covers certification of cargo compartment fire detection systems. Section 10(a)(2) of AC 25-9A applies to the quantity of smoke to be used in the required flight test and states that:

> "A smoldering fire producing a small amount of smoke in conjunction with the applicable detection time has been selected as a fire or failure condition that could be detected early enough to ensure that the fire and smoke procedures would be effective. Subjective judgment, considering the failure, size of compartment, materials contained in the compartment, and the containment methods and procedures, is needed to assess the significance of a small amount of smoke."

Historically, a wide variety of smoke or simulant sources have been used in fire detection system certification tests. Some examples include bee smokers, tobacco smokers, paper towel burn boxes, theatrical smoke generators (with and without heated chimneys or helium added to increase buoyancy) and FAA Powder. FAA Powder refers to a mixture of lactose and potassium chlorate that was used for some European certification tests. The optical properties and particle sizes of these smokes and simulants varied. In addition, the quantity of smoke or simulant permitted was agreed upon on a case-by-case basis between the applicant requesting certification and the regulatory certification official or designee. The approved quantity was based on subjective judgment and likely allowed different quantities of smoke for different certification projects.

The origin of the FAA powder was an FAA report published in 1966 titled "Characteristics of Fire in Large Cargo Aircraft" [1]. The report mainly described the results of cargo fire tests but also included smoke tests using equal quantities of lactose and potassium chlorate ignited with sparking electrodes in a metal container. Various quantities of these chemicals were used along with two different cargo ventilation rates to document the response of aircraft smoke detectors. The author of the report proposed this method of smoke generation due to the readily available chemicals used and the consistent burning rate, and therefore, smoke generation rate, of the burning mixture. The author also cautioned that the reaction produced high temperatures within the burning container, and the mixture was volatile and easily ignited.

Most of the cargo compartments on passenger-carrying transport aircraft are located below the cabin floor and are inaccessible in flight. The typical procedure in the event of an in-flight warning from the cargo compartment fire detection system is to discharge the fixed fire suppression system into the compartment and divert the aircraft and land at the nearest suitable airport. A study was conducted on the instances of cargo fire detection system alarms for U.S.-registered aircraft for the years 1974-1999 as reported in the FAA Service Difficulty Reporting system [2]. That study concluded that the ratio of false alarms to the detection of actual cargo fires was on the order of hundreds to one. It also noted that during the last few years of the study there were approximately 40 to 60 diversions a year due to false alarms from cargo compartment fire detection systems.

One approach to reducing the current level of false alarms is to employ multisensor fire detectors that would only alarm when exposed to two or more products of combustion. Current aircraft smoke detectors alarm when exposed to airborne particles that could be generated by fires or by other sources. The current advisory material does not address how to certify multisensor fire detectors that, by design, would not alarm at the same level of airborne particles that would cause current fire detectors to alarm without the presence of a secondary confirming signal such as heat or gas species.

3. FIRE SOURCE DEVELOPMENT.

The initial objective of this project was to devise a standardized fire source for both smoldering and flaming fires. The smoldering fire source was desirable because that type of fire had previously been the accepted standard for cargo compartment certification tests. It was decided that a flaming fire source was also needed because not all fires transition through a smoldering state and also because a flaming fire represents a greater threat to the aircraft. Flammable fluids in the presence of an ignition source is an example of a fire that starts immediately with open flames without transitioning through a smoldering state. The standard fire sources were desired to have the following properties:

- Good repeatability and reproducibility.
- Immediate plume of smoke and gases to eliminate any ambiguity about the start time of the fire.
- Ability to generate all the products of combustion that would be expected from actual cargo fires.
- Ability to remotely activate the fire source in an unoccupied compartment.
- Ability to use the fire source in a cone calorimeter to accurately characterize the heat release rate, mass loss rate, and generation rate of the products of combustion.

Standardized fires currently exist and are described in Underwriters Laboratory UL 268 standard and European standard EN-54. While these fires have good repeatability and reproducibility along with good industry acceptance, they do not have many of the other desired properties listed above. A new fire source was developed that consisted of pellets from a variety of plastic resins made of polyvinyl chloride, polystyrene, polyurethane, polybutylene terephthalate, polyethylene, and nylon that were heated and compressed into a 4″ by 4″ by 3/8″ thick block with an imbedded nichrome wire heating element. To simulate a smoldering fire source, voltage is applied to the nichrome wire that heats the resins and produces a plume of light-colored particles. This source is mostly the pyrolysis of the resin pellets and not true smoldering. The nichrome wire heats the resin pellets to the point that they begin to gasify but very little oxygen is consumed in the process. For a flaming fire, 2 ml of heptane is poured on the surface of the resin block and ignited with a spark igniter while voltage is simultaneously applied to the nichrome wire. This produces an immediate flaming fire with black smoke. Figure 1 shows the compressed resin block and imbedded nichrome wire.

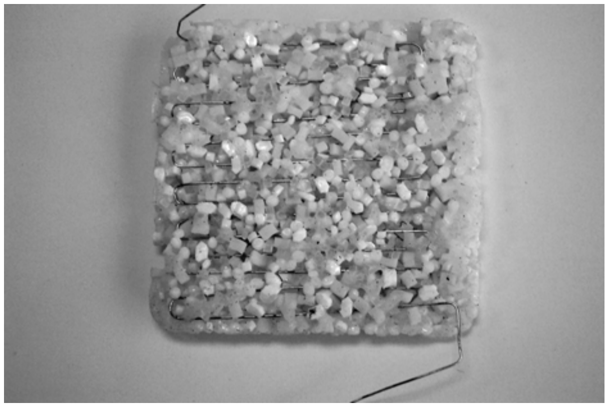


FIGURE 1. COMPRESSED PLASTIC RESIN BLOCK WITH IMBEDDED NICHROME WIRE

The compressed resin block, when used as either a smoldering or flaming fire source, was designed to produce a similar quantity of smoke as was used for certification tests in small cargo compartments. A Rosco model 1600 theatrical smoke generator set at a flow rate of 7.5 ml per minute produced the smoke quantity that was desired to be replicated by the resin block. This smoke generator and setting was reported to be acceptable for use in a certification test on an MD-80 aircraft by the FAA Los Angeles Certification Office.

Initial testing was conducted in the forward cargo compartment of a Boeing 707 aircraft. The compartment volume was 910 cubic feet and was extensively instrumented with thermocouples, smoke meters, and gas analyzer probes. The compartment could be ventilated up to a rate of 17 cubic feet per minute. The thermocouples were 36 gauge, Type K Chromel/Alumel. The smoke meters consisted of a 670-nanometer diode laser and a silicon photovoltaic detector. The laser beam was directed across the full width of the cargo compartment onto the photovoltaic detector. The detector was covered with infrared and bandpass filters to prevent interference from other radiation sources. The measurement units used for smoke in this report are percent light transmission per foot. These units were selected to allow direct comparison with the alarm point units used in TSO C1d and the calibrated alarm points specified on aircraft smoke detectors. These measurements represent the average value per foot over the entire path length. There are undoubtedly areas with more or less smoke densities along different parts of the path length during the tests. The following equation was used to obtain smoke readings in percent light transmission per foot:

$$\%\ Light\ Transmission / ft. = 100 * \left(I / I_o \right)^{1/D} \ [3]$$

where

I = Silicon detector output in smoke
I_o = Silicon detector output in clear air
D = Path length in feet

The gas probes were connected to continuous carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbon, and water vapor analyzers. The cargo compartment had a ventilation system that could allow air to be drawn out of the compartment through a U-shaped duct at a rate of 17 ft^3/min. This ventilation rate and pattern represented a typical leakage rate through cargo compartment door seals. Figure 2 shows the B-707 cargo compartment and instrumentation.

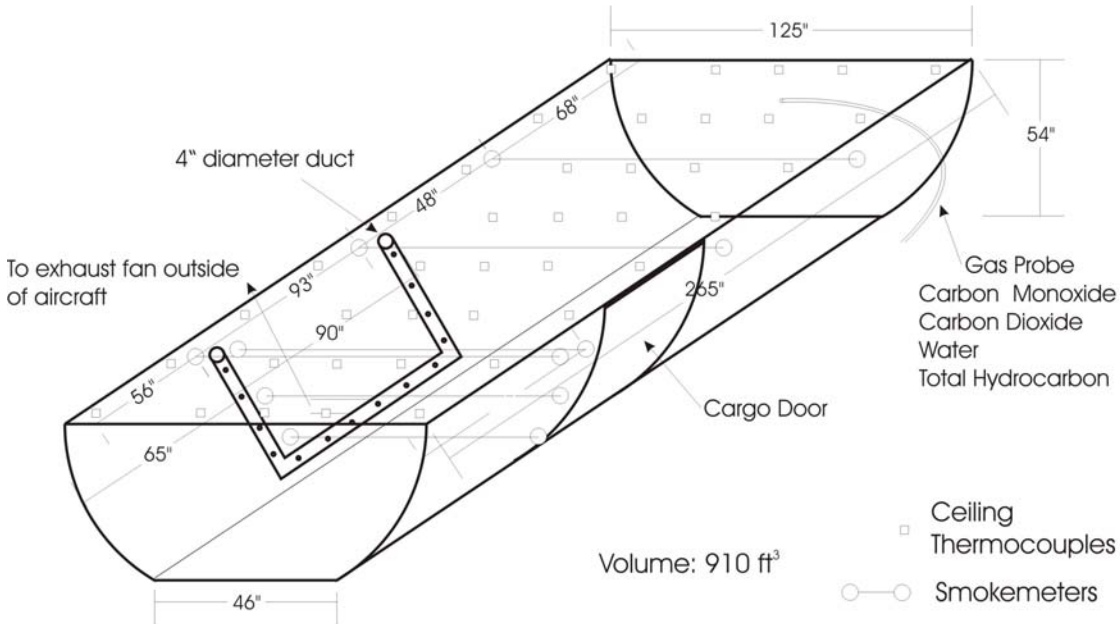


FIGURE 2. B-707 CARGO COMPARTMENT INSTRUMENTATION

The initial testing consisted of a 5-minute test using either the Rosco 1600 smoke generator, a smoldering resin block, or a flaming resin block. Smoke was produced from each source for 1 minute and then the smoke sources were stopped and a mixing fan in the compartment was turned on. Data were collected for an additional 4 minutes. The purpose of the mixing fan was to negate buoyancy effects from the different smoke temperatures. The results of the initial testing are shown in figure 3. The rectangle superimposed over the smoke meter data in figure 3 represents the current requirement of CFR 25.858(a) of 60 seconds for detection along the x axis and the alarm range required by TSO C1d along the y axis. All three smoke sources produced sufficient smoke to fall within the rectangle for this particular cargo compartment volume. After the smoke had been thoroughly mixed, the overall quantity of smoke from the three sources was similar, although not exactly the same.

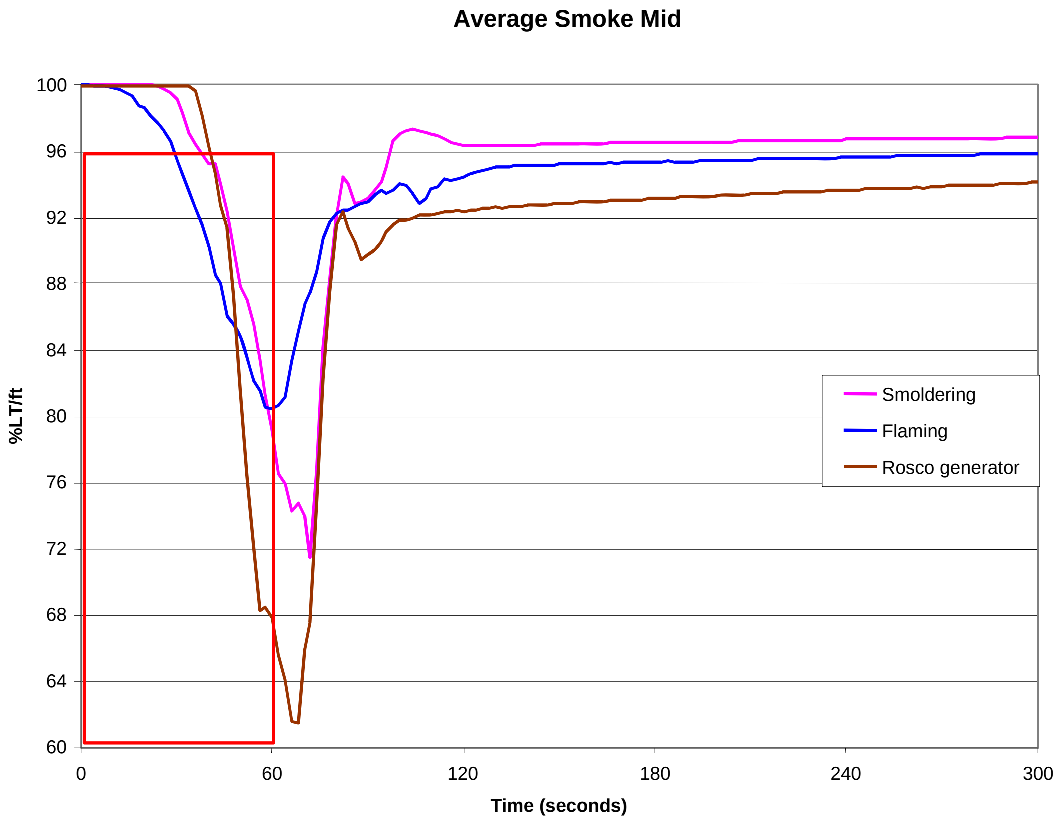
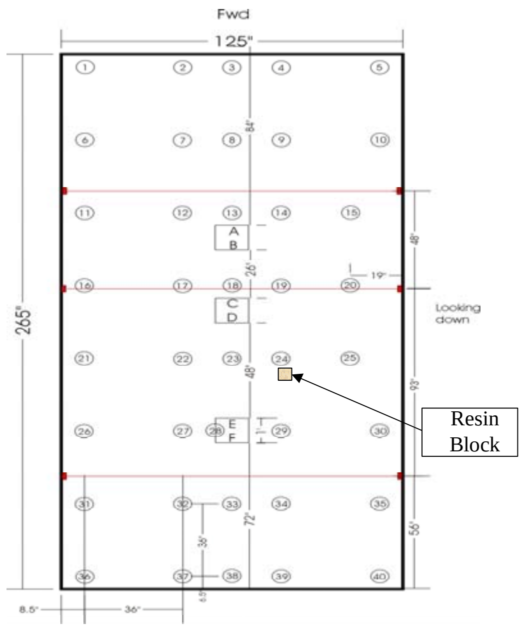


FIGURE 3. SMOKE OUTPUT FROM THREE FIRE SOURCES

As a further check of the quantity of smoke produced by the resin blocks, the tests were repeated with aircraft-type smoke detectors installed. Although ionization detectors have been used in cargo compartments by some manufacturers, most airplanes use light-scattering photoelectric detectors. These detectors consist of a light beam directed across a chamber. A light-sensing photodiode was mounted in the chamber in an area where the light beam would not normally strike. The detector alarms when particles enter the chamber and cause the light beam to reflect onto the photodiode. Two light-scattering photoelectric detectors from three different manufacturers were installed in each of three recessed pans in the ceiling of the cargo compartment. The alarm point for the detectors ranged from 91% to 96% light transmission per foot. Figures 4 through 7 show the location of the resin block, the combustion mode, and the alarm times for all six smoke detectors. A mixing fan was not used for these tests. The test procedure for these and all subsequent tests, unless otherwise stated, was to supply power to the embedded nichrome wire for 3 minutes, remove power, and continue to collect data for an additional 2 minutes, resulting in a 5-minute total duration test.



Smoldering Resin

Alarm Times (Seconds)

Detector A: 69

Detector B: 66

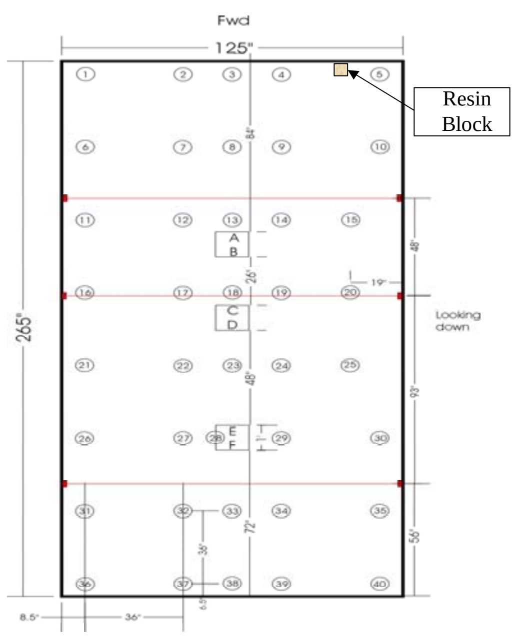
Detector C: 33

Detector D: 36

Detector E: 30

Detector F: 36

FIGURE 4. SMOLDERING RESIN BLOCK NEAR THE CENTER OF B-707 CARGO COMPARTMENT



Smoldering Resin

Alarm Times (Seconds)

Detector A: 101

Detector B: 69

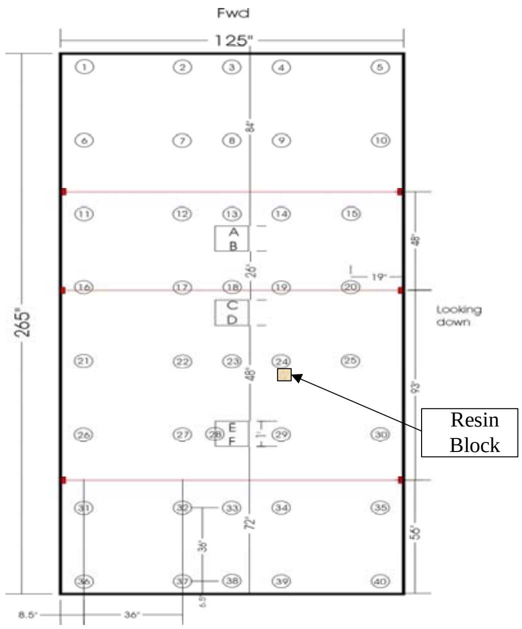
Detector C: 64

Detector D: 85

Detector E: No alarm

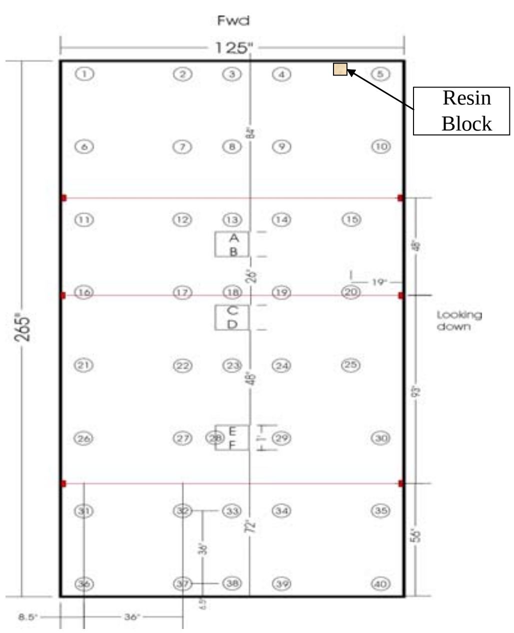
Detector F: 119

FIGURE 5. SMOLDERING RESIN BLOCK IN THE FORWARD CORNER OF B-707 CARGO COMPARTMENT



Flaming Resin
Alarm Times (Seconds)
Detector A: 56
Detector B: 150
Detector C: 39
Detector D: 45
Detector E: 32
Detector F: 36

FIGURE 6. FLAMING RESIN BLOCK NEAR THE CENTER OF B-707 CARGO COMPARTMENT



Flaming Resin
Alarm Times (Seconds)
Detector A: 70
Detector B: 61
Detector C: 52
Detector D: 65
Detector E: 81
Detector F: 100

FIGURE 7. FLAMING RESIN BLOCK IN THE FORWARD CORNER OF B-707 CARGO COMPARTMENT

In three of the four cases, at least one detector alarmed in less than 60 seconds. The earliest detector alarm in the case of the smoldering resin block in the forward corner was 64 seconds. The results of these trials gave confidence that the smoke quantity from the resin blocks were similar to what had previously been approved for certification tests in small cargo compartments.

There was never any intent to suggest that these fire sources should be used in actual certification flight tests. The intent was to (1) define a fire source in terms of heat release rate, mass loss rate, and smoke and gas species production rates and (2) devise a safe method to simulate whichever aspect of the fire signature that the particular detection system was designed to respond to in the certification tests. This could be done singly or in some combination with smoke generators, heat guns, and/or the controlled release of actual or surrogate gas species.

4. TEST SERIES.

The next phase of the testing was conducted in a cone calorimeter with Fourier Transform Infrared mass spectroscopy gas species measurement capability. A series of tests of both the simulated smoldering and flaming modes were conducted. The resultant data proved to be very repeatable and characterized the heat release rate, mass loss rate, and smoke and gas species production rate for both modes of combustion. Because the simulated smoldering mode was mostly pyrolysis, it produced very little fire signature in terms of heat release rate or gas species production. The flaming resin block mode produced a strong fire signature in all of the measured parameters. Figure 8 shows the difference in carbon monoxide production between smoldering and flaming modes as well as the repeatability of the data.

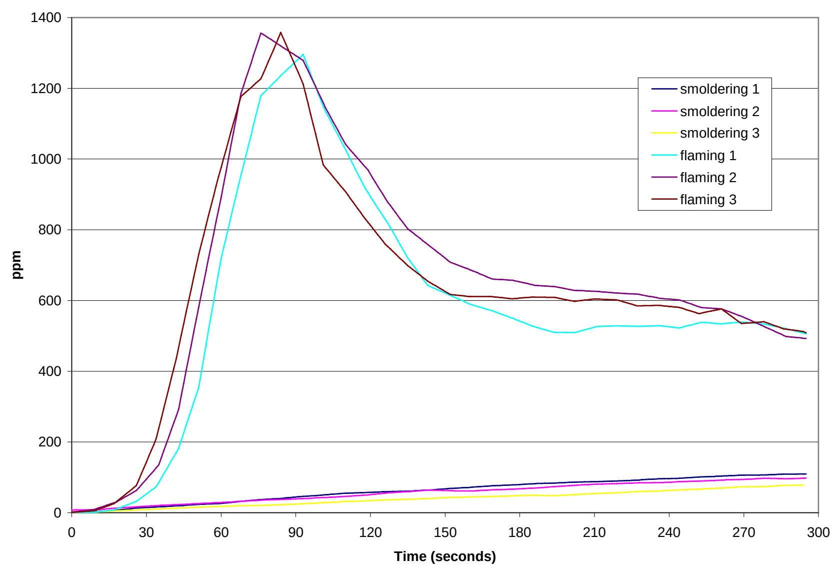


FIGURE 8. CARBON MONOXIDE FROM SMOLDERING AND FLAMING RESIN BLOCK

Additional testing was conducted in the B-707 cargo compartment using both the smoldering and flaming resin blocks. The smoke quantity from both modes of combustion was previously documented so the objective of this series of tests was to characterize the measured levels of temperature and gas species. A gas probe was installed on the ceiling of the cargo compartment near the center. Sample air was drawn out of the compartment through the probe and passed through continuous gas analyzers that measured carbon dioxide, carbon monoxide, total hydrocarbons, and water vapor. The resin blocks were located on the compartment floor near the center of the compartment and in the forward right hand corner. Three tests were conducted at each location for both the smoldering and flaming mode. Figures 9, 10, and 11 show the rise in the measured levels of CO, CO_2, and ceiling temperature, respectively, for the smoldering and flaming resin blocks near the center of the compartment. The plotted values are the average readings from the three tests and were normalized by subtracting the values at time zero from all subsequent values. The levels of total hydrocarbon and water vapor showed similar tendencies.

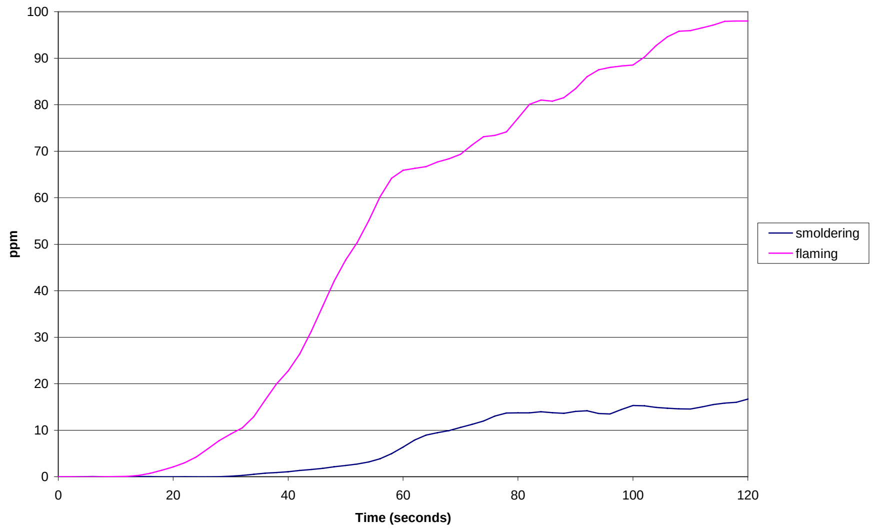


FIGURE 9. SMOLDERING AND FLAMING RESIN BLOCK CO LEVEL NEAR THE CENTER OF COMPARTMENT

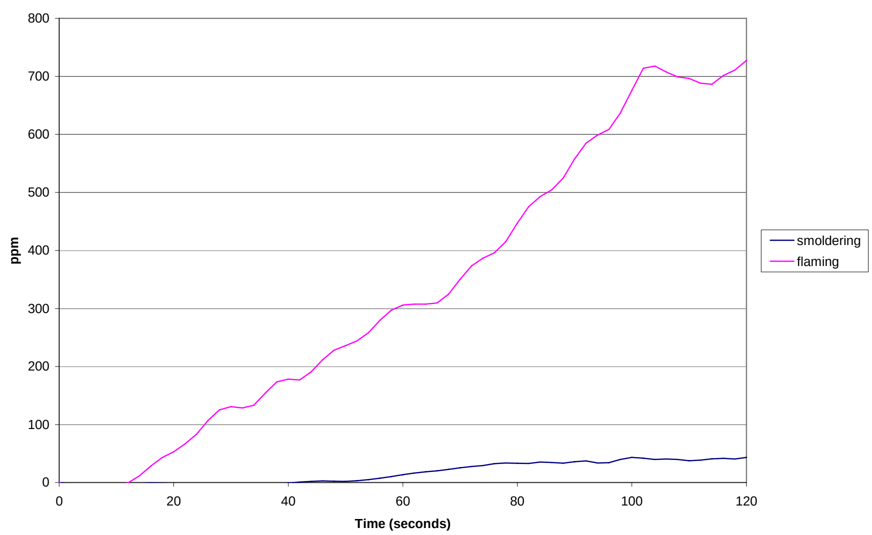


FIGURE 10. SMOLDERING AND FLAMING RESIN BLOCK CO_2 LEVELS NEAR THE CENTER OF COMPARTMENT

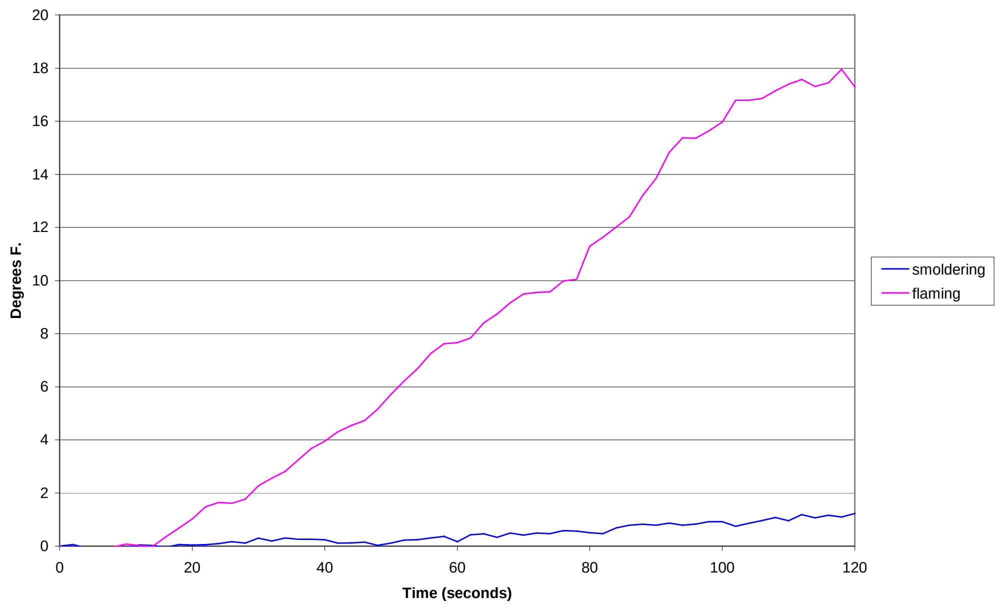


FIGURE 11. SMOLDERING AND FLAMING RESIN BLOCK CEILING TEMPERATURE RISE NEAR THE CENTER OF COMPARTMENT

The fire signature generated from the resin block in the simulated smoldering mode for heat release rate, mass loss rate, and gas species production rate were extremely low. The levels were well below the background environmental levels that would be expected in a cargo compartment with an open door in the presence of cargo handlers and airport ramp vehicles. The only fire signature from the smoldering resin block that reached detectable levels was from smoke.

The next series of tests were conducted in a 3500-cubic-foot cargo compartment below the floor of a DC-10. The compartment had two methods of ventilation, a U-shaped duct to simulate leakage through cargo door seals, and two ceiling air inlets to simulate a forced ventilation system typically found in larger compartments. The leakage system could extract air at a rate of 87 ft^3/min, and the ceiling vents could provide inlet air at a rate of 400 ft^3/min. Testing was conducted using either the leakage system in low-flow ventilation conditions or using the ceiling air inlets in high-flow ventilation conditions. The DC-10 compartment was instrumented in a similar matter as the B-707 and is shown in figure 12.

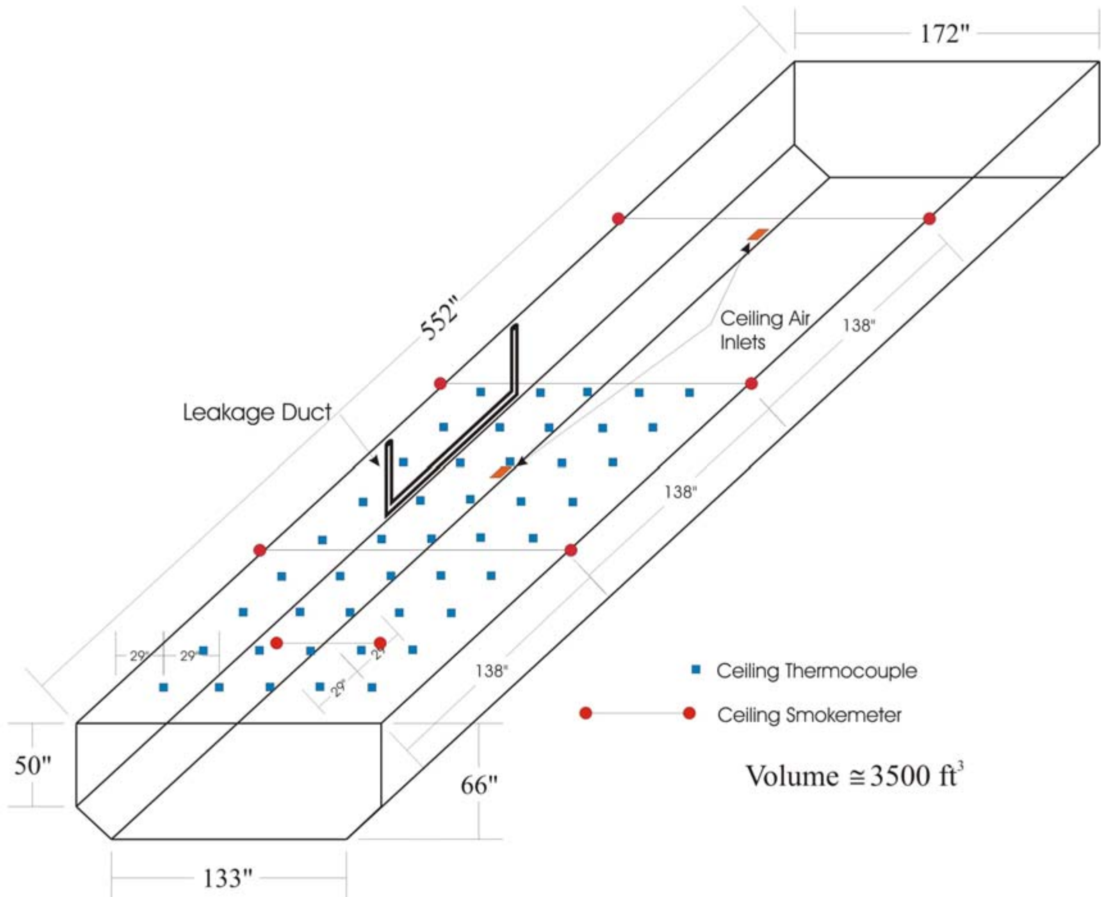


FIGURE 12. DC-10 CARGO COMPARTMENT

The first series of tests conducted in the DC-10 was with four aircraft-type smoke detectors located in recessed pans in the compartment ceiling. The detectors were similar to the ones used in the B-707 cargo compartment. The tests used resin blocks in both the smoldering and flaming mode located near the center of the instrumented section of the compartment and in the forward right hand corner. The high-flow ventilation system using the ceiling air inlets was used for these tests. Each location and combustion mode was repeated twice. Figures 13 through 16 show the average smoke detector activation times for these 5-minute duration tests.

Detector	Alarm Time
A	1:40
B	1:12
C	No Detection
D	No Detection

Alarm time is the average of 2 tests.

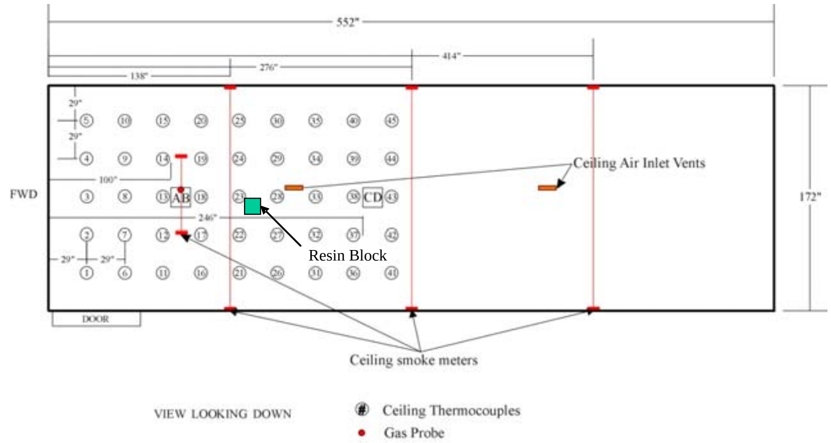


FIGURE 13. FLAMING RESIN NEAR THE CENTER OF DC-10 CARGO COMPARTMENT

Detector	Alarm Time
A	1:07
B	0:56
C	No Detection
D	No Detection

Alarm time is the average of 2 tests.

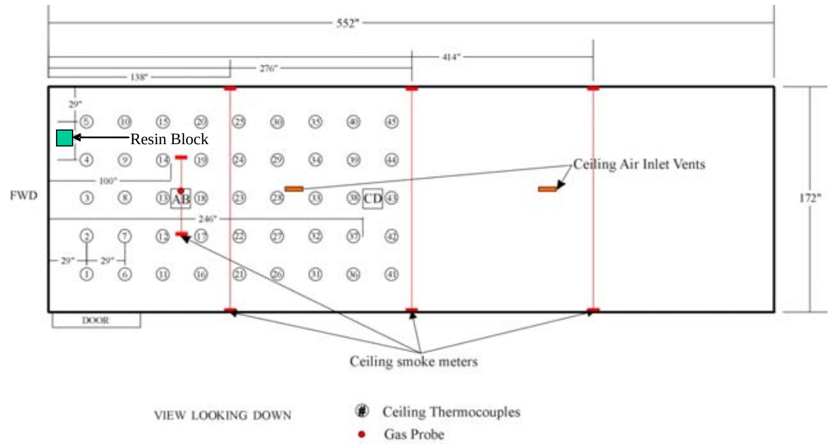


FIGURE 14. FLAMING RESIN IN THE FORWARD CORNER OF DC-10 CARGO COMPARTMENT

Detector	Alarm Time
A	2:26
B	1:50
C	No Detection
D	No Detection

Alarm time is the average of 2 tests.

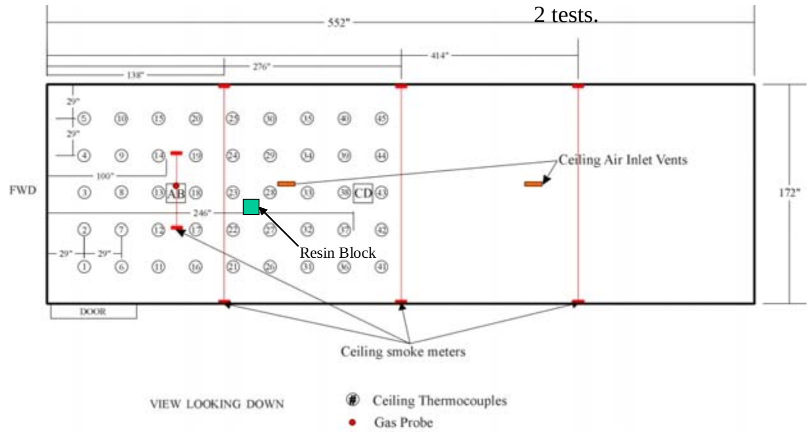
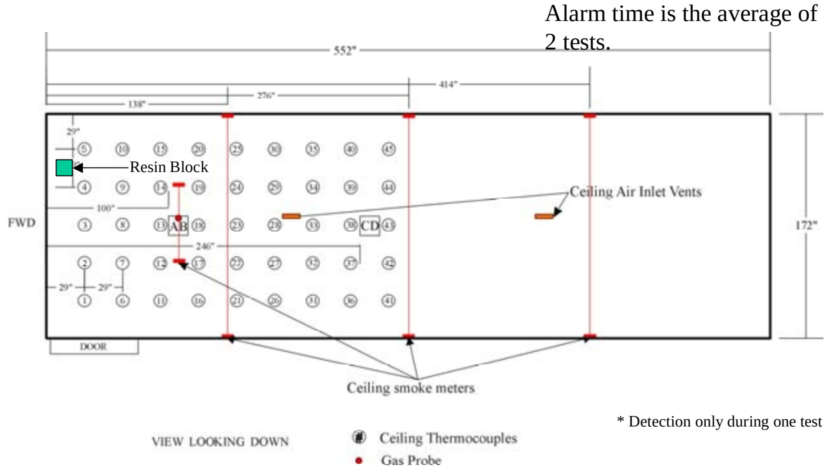


FIGURE 15. SMOLDERING RESIN NEAR THE CENTER OF DC-10 CARGO COMPARTMENT

Detector	Alarm Time
A	1:22
B	1:01
C	2:53*
D	No Detection

Alarm time is the average of 2 tests.



* Detection only during one test

FIGURE 16. SMOLDERING RESIN IN THE FORWARD CORNER OF DC-10 CARGO COMPARTMENT

Only one of the flaming and smoldering resin block tests produced sufficient smoke to activate the detectors in less than 1 minute. The smoke quantity needed to achieve detection in less than 1 minute with detectors meeting the TSO C1d alarm point criteria for a compartment of this size and ventilation rate would be greater than the quantity appropriate for a B-707 sized cargo compartment. This leads to the practice of allowing more smoke for certification tests in larger, ventilated compartments. CO and CO_2 gas levels were also monitored during these tests. As expected, the gas levels from the smoldering resin block were even lower than the tests in the smaller B-707 cargo compartment and were well below the background levels that would be expected in an airport environment.

A final series of tests were conducted in a main deck DC-10 cargo compartment. The compartment volume was 6400 ft^3 and was ventilated at a rate of approximately 1 air change every 4 minutes. The ventilation was supplied to the main deck through two 10″ diameter ducts with two parallel series of 1″ diameter holes in each duct. The holes were positioned to direct the flow of air exiting the ducts inboard and downward into the main deck. The compartment was instrumented with a ceiling mounted smoke meter and a gas probe as shown in figure 17.

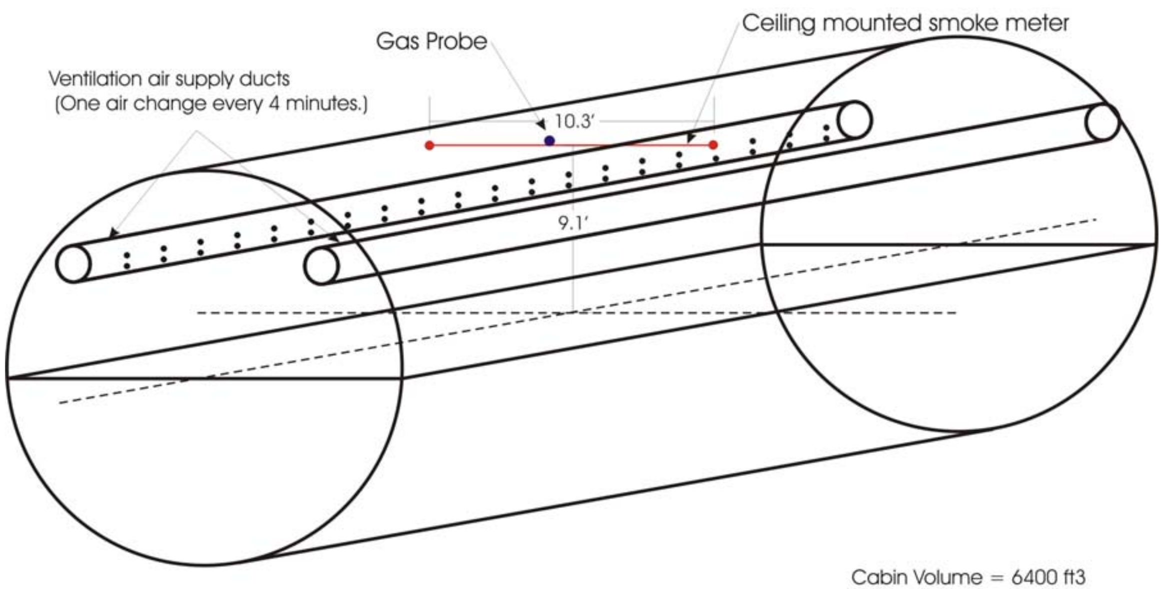


FIGURE 17. MAIN DECK CARGO COMPARTMENT

The first tests in this series consisted of a single flaming resin block on the centerline of the compartment floor, starting directly under the smoke meter and then moving away at 5-foot increments until the resin was 15 feet from the smoke meter. One additional test was conducted with the resin block 5 feet from the smoke meter with the ventilation system turned off. Figure 18 shows the results of the tests relative to the 1-minute detection time and TSO C1d alarm point requirements.

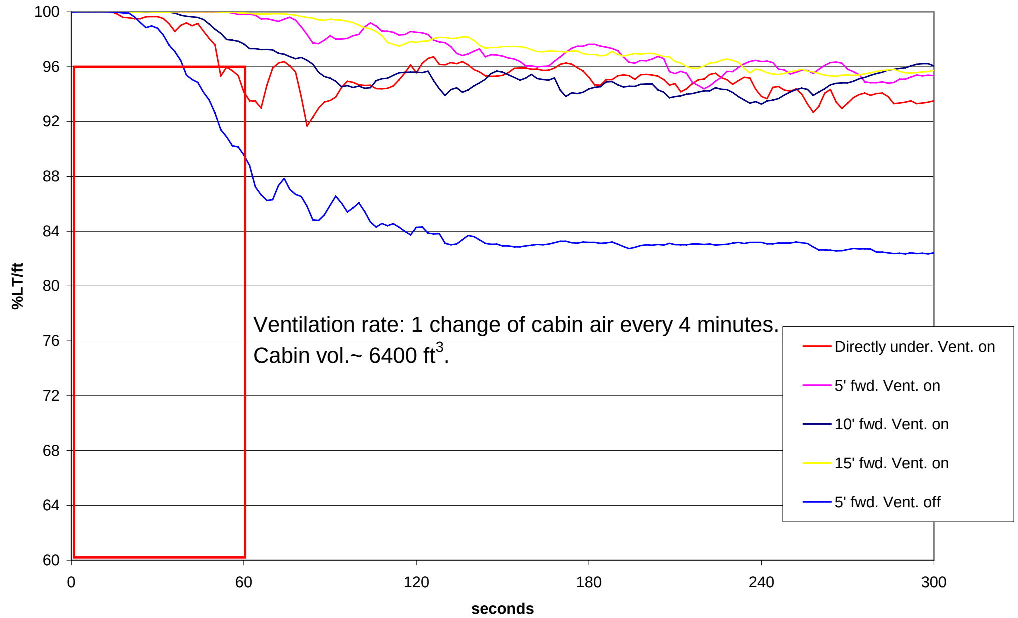


FIGURE 18. DC-10 MAIN DECK CABIN SMOKE

Test measurements of CO and CO_2 were taken using a flaming resin block directly under the ceiling smoke meter and gas probe with the ventilation system on. The data were normalized by subtracting the value at time zero from all subsequent values. An upward trend in both CO and CO_2 is evident, but the magnitude of the measurements was extremely low due to the large air volume and high ventilation rate. Figures 19 and 20 show the CO and CO_2 levels respectively and the average value for the three tests conducted.

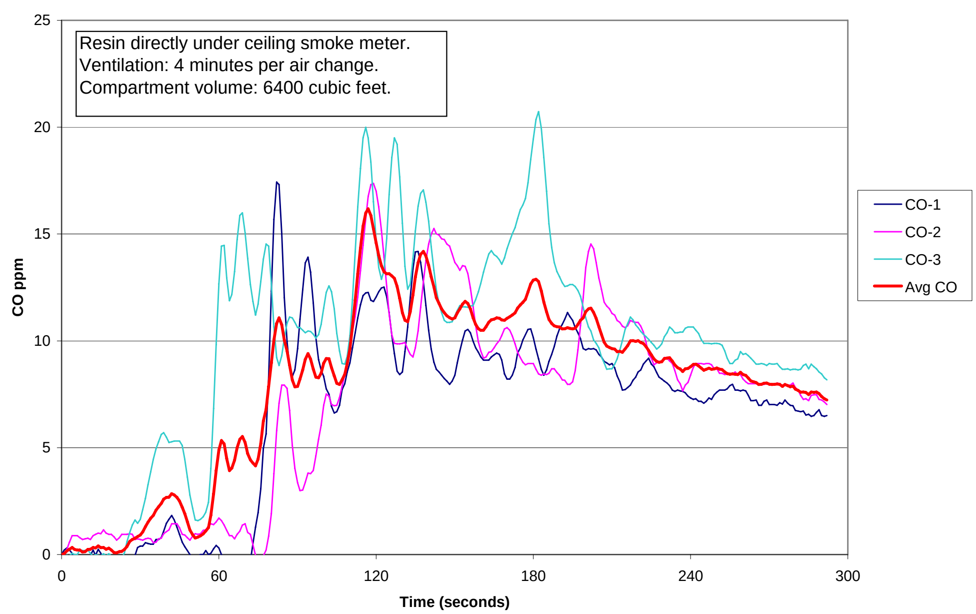


FIGURE 19. CO LEVELS IN THE DC-10 MAIN DECK COMPARTMENT

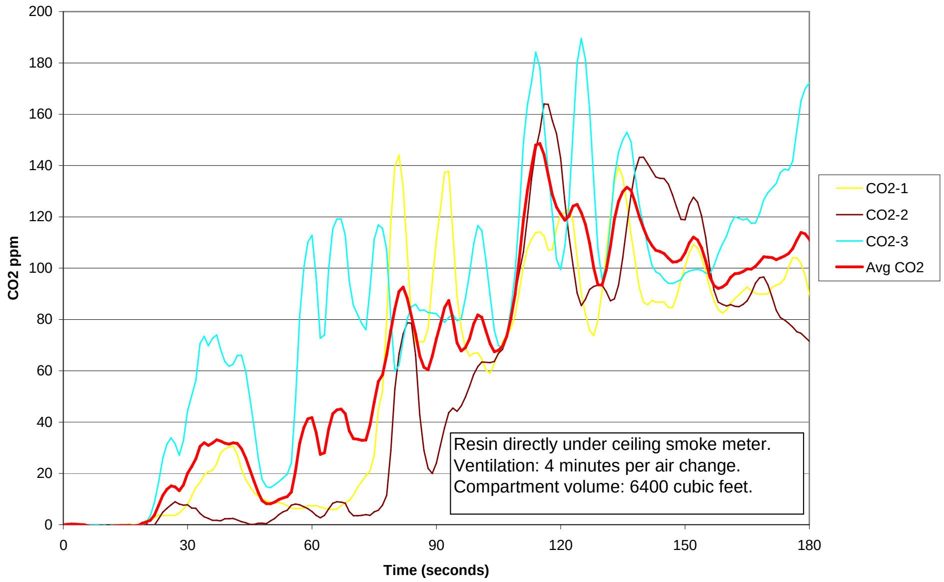


FIGURE 20. CO_2 LEVELS IN THE DC-10 MAIN DECK COMPARTMENT

Testing in the main deck of the DC-10 continued to determine if multiple flaming resin blocks ignited simultaneously would produce enough smoke to be detected in less than 1 minute. Two tests were conducted using two flaming resin blocks ignited simultaneously and a third test was conducted using three resin blocks. The resin blocks were on the floor of the compartment near the centerline and 5 feet aft of the ceiling smoke meter. None of the three tests produced enough smoke to fall within the TSO C1d alarm requirements in less than 1 minute. Figure 21 shows the smoke measurements for these tests.

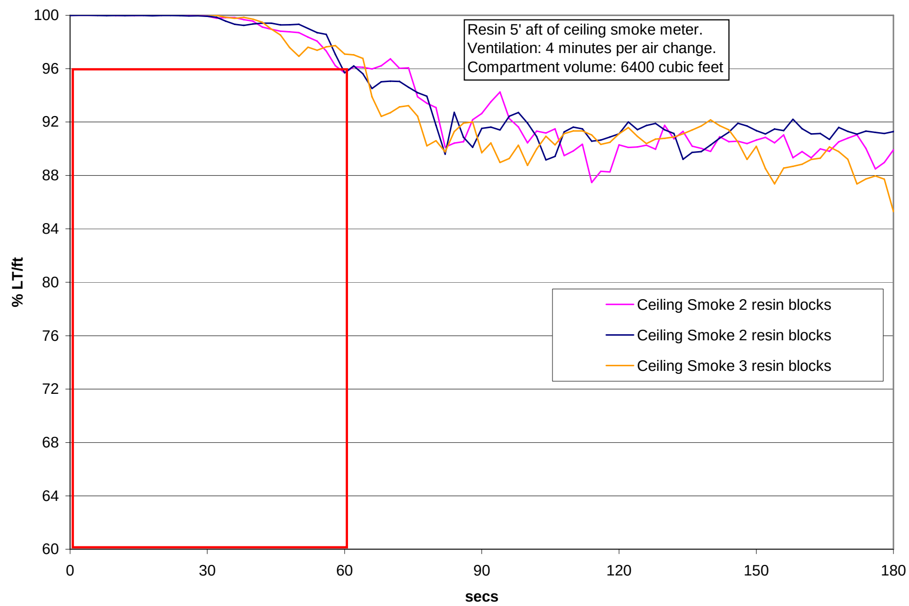


FIGURE 21. CEILING SMOKE LEVELS FROM MULTIPLE FLAMING RESIN BLOCKS IN THE DC-10 MAIN DECK COMPARTMENT

As explained in section 3, the smoke meter values are the average percent light transmission per foot over the full 10.3′ path length of the laser light. The smoke density in the area of the laser path directly above the fire location would likely be much denser. Additional tests were conducted to determine if the smoke density in that area was sufficient to cause the activation of aircraft smoke detectors. Three flow through type smoke detectors were installed in the DC-10 test article with the air sampling points located at the same height as the smoke meter. The longitudinal locations of the probes were directly above the fire source, 5 and 10 feet forward of the fire source. Tests were conducted with the simultaneous ignition of two and then three flaming resin blocks with the ventilation system on. None of the smoke detectors alarmed during the tests.

5. COMPUTATIONAL FLUID DYNAMICS MODEL DEVELOPMENT.

While these tests were being conducted, a parallel effort was underway by Sandia National Laboratories to develop a CFD model to predict the transport of smoke, heat, and gases throughout an aircraft cargo compartment. Sandia received funding for the CFD project from the National Aeronautics and Space Administration (NASA) Glenn Research Center through the NASA Aviation Safety Program. This program identified research projects that could lead to improvements in aviation safety and provided funding for those projects. The reduction of cargo compartment false alarms was selected as one of those projects and led to the decision to fund Sandia for their contribution to that goal. The CFD model was designed to predict the transport of products of combustion and does not attempt to model the actual combustion process. The data generated from the cone calorimeter resin block tests was used as the source term that was input into the CFD model. It is envisioned that the CFD model can be used during cargo fire detection certification efforts by running simulations to explore the effect of fire location, detector location, alarm set points, and algorithms on detector response times. At this time, the CFD model has undergone a preliminary validation using data from tests in the B-707 cargo compartment with no ventilation airflow. The results of the initial validation effort and a description of the code mathematical approach are contained in reference 4. Additional validation is currently underway using data from experiments in the below floor, 3500 ft^3 ventilated DC-10 cargo compartment. The results of that validation effort will be published when available.

An outgrowth of the Sandia model development was an analysis of the optical properties of smoke from the flaming resin block, the smoldering resin block, and theatrical smoke generators previously used in certification tests [5]. One of the conclusion of the study was that the individual primary particle size of smoke from flaming fires was between 3 and 750 times smaller than the primary particle size of simulated smoke. Another of the conclusions was that the reduction in light transmission from the smoldering resin block and the theatrical smoke generators was due entirely to scattering of the light beam while only 20%-30% of the reduction in light transmission from the flaming resin block was due to scattering with the remainder due to absorption. As stated earlier, the most common aircraft smoke detectors are the light scattering photoelectric type. Based on the conclusion of the Sandia work described above, it would be expected that these types of smoke detectors would respond more rapidly to artificial or smoldering fire smoke due to the significantly greater light scattering that they produce.

Figure 22 shows the output of a ceiling smoke meter with a 5-foot path length in the below floor DC-10 cargo compartment. The data is from two flaming and two smoldering tests with the resin block located on the floor near the center of the cargo compartment. The light transmission graphs are annotated with the time that the first smoke detector alarmed for each test. In each case, the smoke detector that alarmed first was in the recessed pan just above the path of the smoke meter light beam. The expected results discussed in the previous paragraph was confirmed by these data. There was more smoke in the compartment at the time of smoke detection of the flaming fire than there was at the time of smoke detection of the smoldering fire.

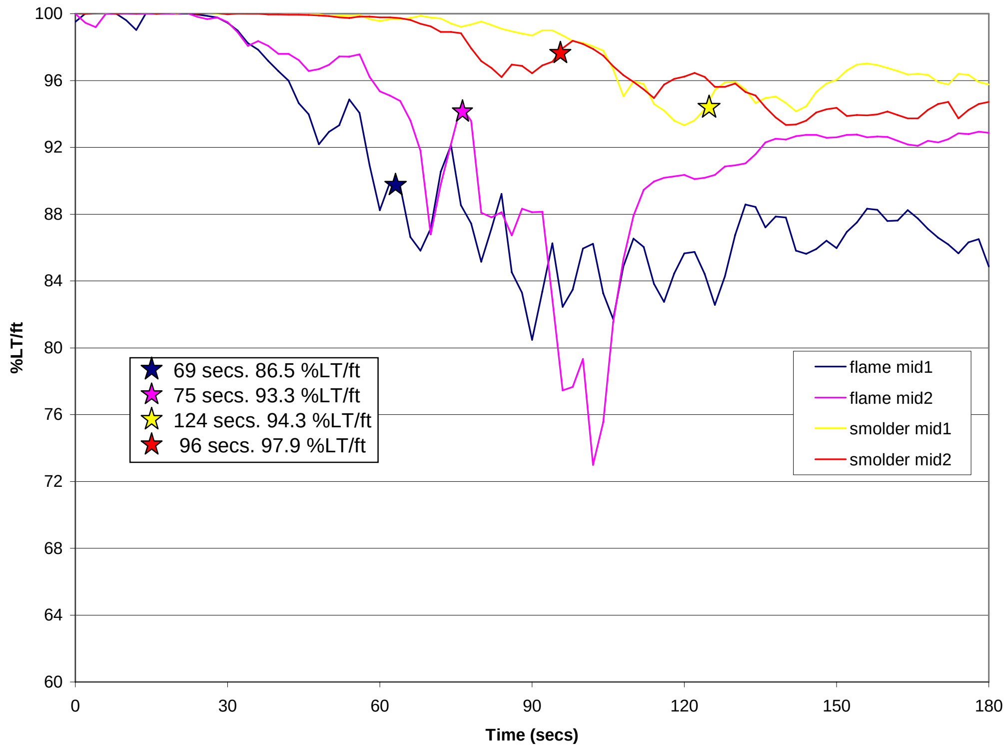


FIGURE 22. SMOKE LEVELS AT DETECTOR ALARM TIME FOR FLAMING AND SMOLDERING FIRES NEAR THE MIDDLE OF THE DC-10 COMPARTMENT

Figure 23 shows the data from the continuation of this test series with the resin blocks located on the floor in the forward corner of the compartment. The trend of detector alarm occurrences with less smoldering smoke than flaming smoke was again evident.

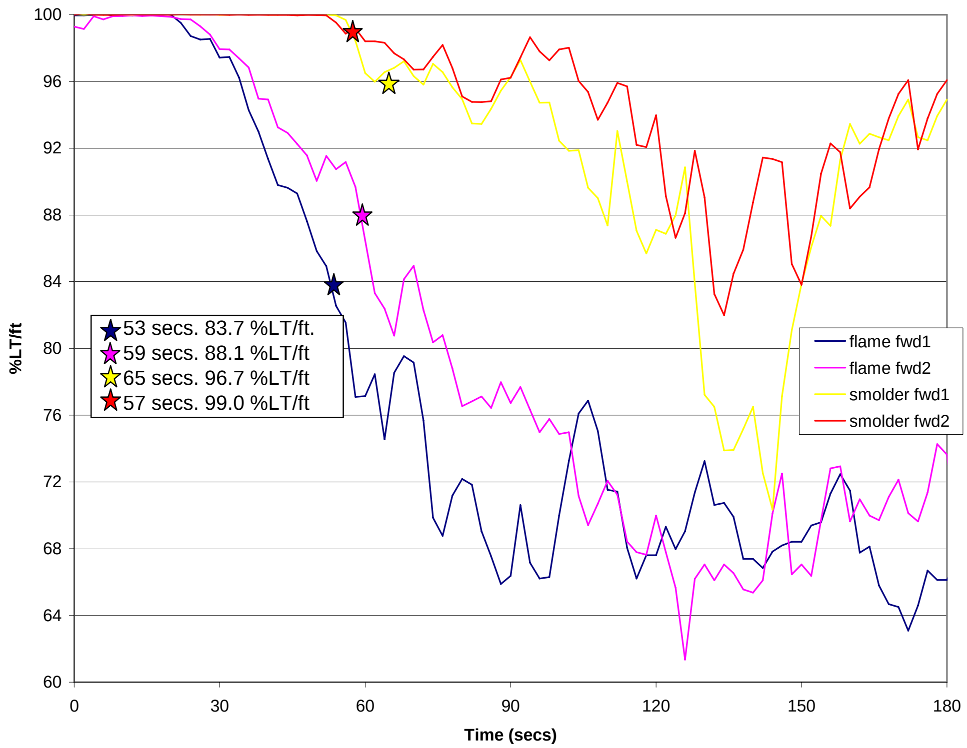


FIGURE 23. SMOKE LEVELS AT DETECTOR ALARM TIME FOR FLAMING AND SMOLDERING FIRES IN THE FORWARD CORNER OF THE DC-10 COMPARTMENT

6. CONCLUSIONS.

- Fires that produce smoke quantities similar to what has been used in previous certification tests in small cargo compartments do not produce sufficient smoke to be detected in less than 1 minute in larger, ventilated cargo compartments with smoke detectors meeting the alarm point requirements of Technical Standard Order C1d.

- The simulated smoldering fire source developed during this project and theatrical smoke generators do not produce a fire signature that could be used by multisensor fire detectors to discriminate between actual fires and nuisance alarm sources.

- The flaming fire source developed during this project did produce a fire signature that could be used to discriminate between actual fires and false alarm sources in smaller cargo compartments.

- Less smoke is required to cause current light scattering, photoelectric aircraft smoke detectors to alarm if the smoke source is from a smoldering fire or a smoke generator than is required if the fire source is a flaming fire. This is due to the difference in the light scattering properties of the different types of smoke.

7. REFERENCES.

1. Gassmann, Jules J., “Characteristics of Fire in Large Cargo Aircraft,” FAA-ADS-73, March 1966.

2. Blake, David, “Aircraft Cargo Compartment Smoke Detector Alarm Incidents on U.S.-Registered Aircraft, 1974-1999,” FAA report DOT/FAA/AR-TN00/29, June 2000.

3. Underwriters Laboratories Inc., UL 217, “Single and Multiple Station Smoke Alarms,” Fifth Edition, February 21, 1997.

4. Suo-Anttila, Jill, Gill, Walt, Callegos, Carlos, and Nelson, James, “Computational Fluid Dynamics Code for Smoke Transport During an Aircraft Cargo Compartment Fire: Transport Solver, Graphical User Interface, and Preliminary Baseline Validation,” FAA report DOT/FAA/AR-03/49, October 2003.

5. Suo-Anttila, Jill, Gill, Walt, and Gritzo, Lou, “Comparison of Actual and Simulated Smoke for the Certification of Smoke Detectors in Aircraft Cargo Compartments,” FAA report DOT/FAA/AR-03/34, November 2003.