

A Preliminary Examination of the Effectiveness of Hand-Held Extinguishers Against Hidden Fires in the Cabin Overhead Area of Narrow-Body and Wide-Body Transport Aircraft

Timothy R. Marker

July 2007

DOT/FAA/AR-TN04/33

This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.



U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report. This document does not constitute FAA certification policy. Consult your local FAA aircraft certification office as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center's Full-Text Technical Reports page: actlibrary.act.faa.gov in Adobe Acrobat portable document format (PDF).

1. Report No. DOT/FAA/AR-TN04/33		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A PRELIMINARY EXAMINATION OF THE EFFECTIVENESS OF HAND-HELD EXTINGUISHERS AGAINST HIDDEN FIRES IN THE CABIN OVERHEAD AREA OF NARROW-BODY AND WIDE-BODY TRANSPORT AIRCRAFT				5. Report Date July 2007	
				6. Performing Organization Code AJP-6320	
7. Author(s) Timothy R. Marker				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				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591				13. Type of Report and Period Covered Technical Note	
				14. Sponsoring Agency Code ANM-115	
15. Supplementary Notes					
16. Abstract Twenty hand-held extinguisher tests were performed in the overhead space in both narrow- and wide-body aircraft. These tests simulated a typical hidden fire in the inaccessible area above the cabin ceiling by using a number of small, controllable candle lanterns. The purpose of the tests was to determine the performance of the Federal Aviation Administration-required, hand-held Halon 1211 extinguishers against a fire in this area when discharging the agent through a ceiling-mounted port. In an effort to maximize agent performance, the port design was modified as these tests progressed. The tests indicated that individual hand-held extinguishers did not predictably extinguish fires in the large-volume cabin overhead area typical of a wide-body aircraft, regardless of the port design. However, the use of ceiling-mounted discharge ports combined with hand-held extinguishers was more promising against fires in the more confined and smaller-volume overhead area typical of a narrow-body aircraft. Additional work would have to be performed to further develop and optimize this concept.					
17. Key Words Cabin overhead area, Flammability, Halon, Hand-held extinguishers			18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 33	22. Price

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	vii
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	2
Hidden Area Materials Flammability Research	2
Active Fire Protection in Hidden Areas Research	3
Wide-Body Aircraft Hidden Area Test	4
Development of the Fire Source	6
Tests in Crown of Wide-Body Aircraft Cabin Overhead Area	7
Narrow-Body Aircraft Hidden Area Testing	18
Location of Fire Source in the Narrow-Body Aircraft Cabin Overhead Area	19
Narrow-Body Aircraft Air-Conditioning System Configuration	21
Testing in the Narrow-Body Aircraft Cabin Overhead Area	22
SUMMARY	23
CONCLUSIONS	24
REFERENCES	25

LIST OF FIGURES

Figure		Page
1	Wiring Test in a Simulated Cabin Overhead Area	3
2	B-747SP Wide-Body Aircraft	5
3	B-747SP Wide-Body Aircraft Test Section Schematic	5
4	B-747SP Wide-Body Aircraft Aft Cabin Overhead Area	6
5	Candle Lanterns Used in Cabin Overhead Area Tests	7
6	Crown Area Fire Test Configuration	8
7	Ceiling-Mounted Port Extension Tube Mounted in Cabin Ceiling	9
8	Ceiling-Mounted Port Prototype Discharge Head	9
9	Extinguishing Agent Discharged Through the Port in the Wide-Body Aircraft	10
10	Modified Candle Lantern Test Configuration	11
11	Cutaway Schematic of the Modified Candle Lantern Test Configuration	12
12	Modified Candle Lantern Test Configuration in Cabin Overhead Area	13
13	Grill Design Discharge Head	14
14	Feedthrough Design Discharge Head	15
15	Candle Lanterns Located Directly Above Ceiling Panel	16
16	Narrow-Body B-737-200 Aircraft	18
17	Narrow-Body Aircraft Showing Cabin Overhead Area Access	19
18	Narrow-Body Aircraft Test Configuration	20
19	Narrow-Body Aircraft Test Configuration Showing Location of Candle Lanterns	20
20	Narrow-Body Aircraft Test Configuration	21
21	Halon 1211 Discharged Through Ceiling-Mounted Port	22

LIST OF TABLES

Table		Page
1	Number of Candles Extinguished in B-747SP Wide-Body Aircraft Tests	17
2	Number of Candles Extinguished in Narrow-Body Aircraft Tests	23

LIST OF ACRONYMS

E/E	Electronics and electrical
FAA	Federal Aviation Administration
IASFPWG	International Aircraft Systems Fire Protection Working Group
PSU	Passenger service units

EXECUTIVE SUMMARY

In recent years, a number of serious incidents and one fatal accident have occurred involving in-flight fires that originated in inaccessible areas, such as the electronic and electrical bays, the cheek area, behind cabin sidewall panels, and in the cabin overhead area. To prevent this type of fire, the main focus of this research has been to passively reduce the flammability of all materials in hidden areas. A complementary effort is to investigate the efficacy of active fire extinguishment in hidden areas. One initial task of this effort is to assess current hand-held extinguisher capabilities and improve their effectiveness against a typical hidden area fire located in the cabin overhead area.

Twenty hand-held extinguisher tests were performed in the cabin overhead area in both narrow- and wide-body aircraft. These tests simulated a typical hidden fire in the inaccessible area above the cabin ceiling by using a number of small, controllable candle lanterns. The purpose of the tests was to determine the performance of the FAA-required, hand-held Halon 1211 extinguishers against a fire in this area when discharging the agent through a ceiling-mounted port. In an effort to maximize agent performance, the port design was modified as the tests progressed. The results indicated that individual hand-held extinguishers did not extinguish fires in large overhead areas typical of wide-body aircraft, regardless of the port design. The sheer volume of the overhead area in a wide-body aircraft and the relatively small weight of agent limit the effectiveness of hand-held extinguishers. However, the use of ceiling-mounted discharge ports with hand-held extinguishers was more promising against fires in the more confined and smaller-volume cabin overhead area typical of a narrow-body aircraft. During the tests, the discharge port and candle lanterns were located in close proximity to one another. In a more realistic situation, a detection system would probably be required to locate the fire. In addition, a methodology would have to be developed for spacing the discharge ports along the length of the ceiling, which would depend on the specific aircraft overhead configuration, the performance of the available hand-held extinguishers, and the method of locating the hidden fire.

INTRODUCTION

PURPOSE.

The purpose of this technical note is to present the test results obtained during the preliminary evaluation of the effectiveness of hand-held extinguishers discharged to extinguish fires in the cabin overhead area. These tests were also used to determine the improvement in extinguishment capabilities when using ceiling-mounted discharge ports, which have the potential of providing more direct extinguishant application to inaccessible area fires.

BACKGROUND.

In September 1999, a Delta MD-88 made an emergency landing at the Cincinnati/Northern Kentucky International Airport when a fire developed shortly after takeoff. After a strong smell of smoke, the flight attendants noticed a glow coming from the floor grill near the sidewall panel. At least one Halon 1211 extinguisher was discharged through the air return grill in the direction of the glow, which appeared to reduce the intensity of the smoke. A postevent inspection revealed that a shorted wire bundle that powered the right side alternate static port heater located in the cheek area caused a fire that propagated onto the adjacent insulation blanket and spread to involve several other blankets. On January 3, 2000, another Delta MD-88 experienced a static port heater malfunction, causing smoke in the cabin that forced a precautionary landing.

On August 8, 2000, an AirTran DC-9 made an emergency landing in Greensboro, NC, due to dense smoke in the cockpit. After the aircraft landed, the flight crew evacuated and several passengers sustained minor injuries. The investigation revealed that a circuit breaker for the left aft recirculation fan had caught fire, and the fire spread to a wire bundle located behind the main circuit panel in the cockpit bulkhead. The fire intensified and spread upward into the cabin overhead area, where additional materials became involved. The cockpit filled with heavy smoke and made the emergency landing very difficult for the flight crew.

Another AirTran DC-9 experienced an in-flight fire on November 29, 2000, during a scheduled flight from Atlanta, Georgia, to Akron/Canton, Ohio, that originated in the cheek area outboard of the cargo compartment. During the initial climb, the flight crew noted numerous circuit breaker trips and illumination of several indicator lights. The crew declared an emergency with air traffic control and requested a return to the airport. The aircraft landed safely and cleared the runway onto a taxiway. At some point during the landing rollout and taxi, the flight attendants notified the flight crew of smoke in the forward section of the cabin. An emergency evacuation ensued. Examination of the aircraft revealed fire damage to an area of the left fuselage below and aft of the forward passenger entry door and to the adjacent forward cargo and main cabin floor areas. The fire originated in a wire bundle and propagated upward to the area below the cabin floor. Debris, dust, and lint in the cheek area facilitated the propagation of the fire, which eventually involved several cabin floor panels, and also burned wiring, ducts, and hydraulic lines located in this area.

On November 15, 2000, at Copenhagen International Airport, an in-flight fire resulted when a Greenland Air Boeing 757 was hit by lightning that penetrated the fuselage skin in several areas and ignited the insulation blankets above the cabin ceiling. The flight attendants and passengers smelled smoke. Access to the cabin overhead was gained by a standby cockpit crew member using a crash axe. The fire was extinguished using a Halon 1211 extinguisher, which was discharged into the cabin overhead area.

Similarly, on November 29, 2000, an in-flight fire resulted from a lightning strike on an American Airlines MD-80, forcing an emergency landing at Dulles Airport outside of Washington, DC. The lightning strike propagated along a decommissioned antenna and eventually caused ignition of the insulation materials above the cabin ceiling. After smelling smoke, a flight attendant, assisted by a passenger, was able to cut an access hole in the ceiling panel and discharged a Halon 1211 extinguisher in the fire area. The fire was extinguished, but a postincident inspection revealed significant propagation along the insulation material.

The most catastrophic in-flight hidden fire occurred on Swissair Flight 111 on September 2, 1998. During the flight, a fire originated either above the cockpit or in the forward cabin overhead area, where it grew out of control. The fire filled the cockpit with smoke and eventually caused the MD-11 to crash into the ocean off the coast of Peggy's Cove, Nova Scotia. All 229 occupants died as a result of the fire/crash.

DISCUSSION

HIDDEN AREA MATERIALS FLAMMABILITY RESEARCH.

Current Federal Aviation Administration (FAA) research is aimed at the development of more stringent fire test methods for materials located in hidden areas such as the ceiling overhead areas, cheek areas, and electronics and electrical (E/E) bays. This research targets the flammability of materials such as ducts, wires, panel closeouts, clamps, and other hardware located in the hidden and inaccessible areas to upgrade these materials to an equivalent level of fire resistance as recently adopted for thermal acoustic insulation [1]. The objective is to passively reduce the likelihood of an in-flight fire from occurring by substantially improving the fire resistance of materials in hidden areas. The research is coordinated with a subgroup of the International Aircraft Materials Fire Test Working Group, a government/industry group chaired by the FAA. Full-scale tests have been completed in which various types of wiring insulation were evaluated against a realistic fire threat (figure 1) [2].



Figure 1. Wiring Test in a Simulated Cabin Overhead Area

In addition, a parallel research effort is underway to investigate the effectiveness of hand-held extinguishers in these hidden areas and develop fire extinguishing systems, if warranted. The intent of this research is to determine what inaccessible areas of the aircraft could actually benefit from an active detection and extinguishing system, and develop certification criteria. This work is being coordinated through a subgroup of the International Aircraft Systems Fire Protection Working Group (IASFPWG), an industry and government group also chaired by the FAA.

ACTIVE FIRE PROTECTION IN HIDDEN AREAS RESEARCH.

An FAA research proposal was presented at the IASFPWG meeting on March 27 and 28, 2001, in Long Beach, CA. A follow-up subgroup session was convened to discuss the proposed activities in greater detail. The proposed research focused on the E/E bay and, more specifically, to evaluate the range of airflow ventilation rates to determine the feasibility of using a total flood system for fire protection. Since many transport category aircraft currently employ smoke detectors in the E/E bays, a secondary research activity was to determine their effectiveness, given the high level of ventilation in this area of many aircraft. This research proposal was subsequently revised to focus on the cabin overhead area rather than the E/E bays, since a vast majority of the recent incidents involving smoke and fire occurred in these overhead spaces. A common fire event involves a short-circuited wire bundle that ignited contaminated insulation blankets in the cabin overhead area [3].

The specific research task was to assess the level of protection in the cabin overhead areas by measuring the effectiveness of the existing hand-held Halon 1211 extinguishers. Since the actual volume of the cabin overhead area can vary greatly, depending on the type of aircraft, it is quite possible that the effectiveness of existing extinguishers will depend on the size of the aircraft.

One main problem associated with fire suppression in the cabin overhead area is accessibility. In several of the recent incidents, access to the cabin overhead area was gained forcibly (i.e., using some type of tool or device to cut through the ceiling panel). Once access is gained and the fire source is located, the threat is greatly reduced, since the extinguishing agent can be applied directly to the fire. Fires in inaccessible areas may initially be very small and of little threat, but the difficulty in accessing them allows sufficient time for growth, leading to a much more dangerous and difficult situation. This being the case, it would be beneficial to devise a method of allowing easy cabin overhead area access to quickly locate and extinguish fires in these areas. Based on their examination of hidden fire incidents, the National Transportation Safety Board has recommended that the FAA examine methods of accessing hidden fires.

One approach to a more effective extinguishing agent application is the use of panel-mounted ports that would allow insertion of the extinguisher nozzle, thereby eliminating the need to forcibly gain access to this area. Originally designed to allow the extinguishing agent to discharge into a circuit breaker panel, these devices have recently been adapted for use in the ceiling. Although the extinguishing agent can be applied more readily, determining the appropriate point of discharge is still the challenge. This problem can be magnified by significant ventilation in the cabin overhead areas, making it difficult to accurately predict the location of the fire source. An accurate method of detecting the fire location would greatly compliment the port system approach [4].

To better evaluate the effectiveness of hand-held extinguishers in the cabin overhead area, initial tests were conducted in a wide-body aircraft outfitted with ceiling-mounted ports to allow agent dispersion above the cabin ceiling. The ports were designed and manufactured by Logo Tech Manufacturing Corp of East Islip, New York.

WIDE-BODY AIRCRAFT HIDDEN AREA TEST.

The initial evaluation of the hand-held fire extinguisher effectiveness in cabin overhead areas was conducted in a B-747SP aircraft (figure 2). A schematic of the test section is shown in figure 3.

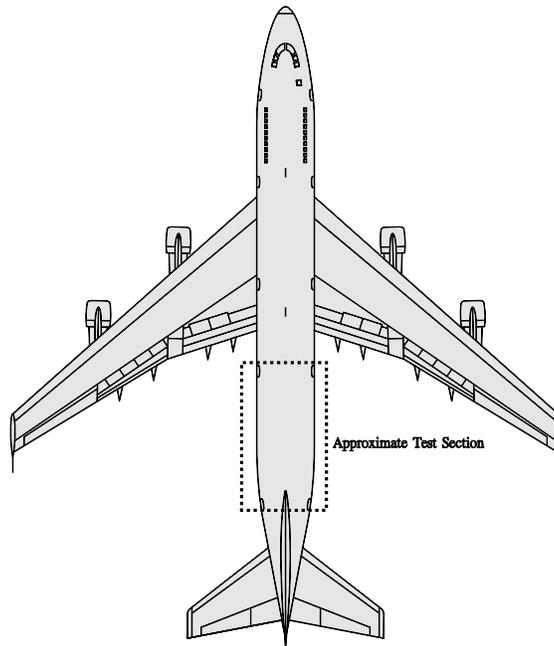


Figure 2. B-747SP Wide-Body Aircraft

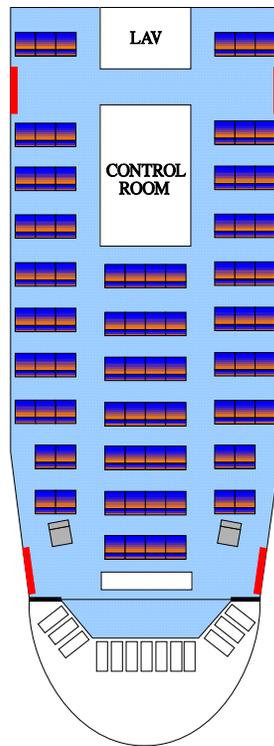


Figure 3. B-747SP Wide-Body Aircraft Test Section Schematic

Although a majority of the cabin overhead volume is devoid of combustible materials, the periphery contains insulation blankets and adjacent wire bundles. There are also several wire bundles that run along the centerline, just above the ceiling panels. The aft overhead section of the B-747SP wide-body aircraft is shown in figure 4.



Figure 4. B-747SP Wide-Body Aircraft Aft Cabin Overhead Area

DEVELOPMENT OF THE FIRE SOURCE.

Since the B-747SP was an operational test aircraft, as opposed to a true fire test article, care had to be taken not to cause damage to the interior during live fire tests. To create a realistic yet safe fire scenario, small candle lanterns were incorporated to measure the range and volume of fire extinguishant. The candles were paraffin-based discs, enclosed in a protective metal shroud to prevent wax spillage and ignition in the event that the candle tips over (figure 5). The candle lanterns were equipped with glass cylinders that shrouded the flames, making it somewhat difficult to extinguish them. For this reason, the glass shrouds were removed for all tests performed in the cabin overhead area. Once lit, the candle lanterns could burn continuously for 4 hours, making them ideal for this type of hidden space test.



Figure 5. Candle Lanterns Used in Cabin Overhead Area Tests

TESTS IN CROWN OF WIDE-BODY AIRCRAFT CABIN OVERHEAD AREA.

Since the combustible materials (insulation and wiring) were located at the periphery of the fuselage, the initial test configuration placed the lit candle lanterns at the uppermost section, known as the crown. Six candle lanterns were placed along the fuselage centerline, spaced 30 inches apart (figure 6). Because the cabin overhead area extinguisher tests were also intended to evaluate hand-held extinguisher performance during in-flight conditions, the cabin overhead area recirculation fan was activated for all tests.

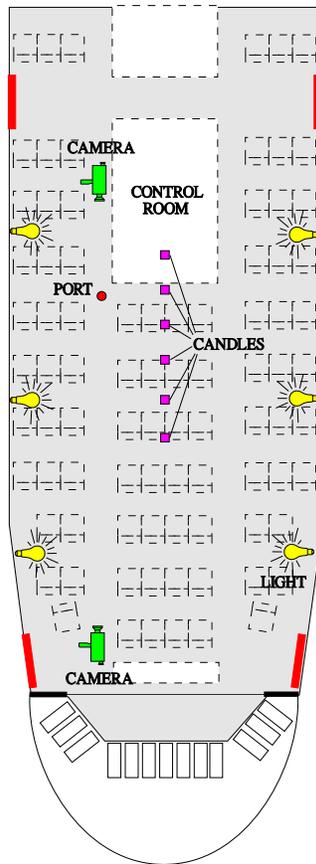


Figure 6. Crown Area Fire Test Configuration

To use the available extinguishing agent most efficiently, the initial ceiling-mounted port was designed to extend above the cabin ceiling to promote extinguishing agent transport to the combustible materials near the crown of the aircraft. The port and discharge head contained a series of threaded extension tubes, each measuring approximately 6 inches long. When five extension tubes were used in conjunction with the head, the discharge point was situated 30 inches above the cabin ceiling. The discharge head was designed to propel the agent radially (figures 7 and 8).



Figure 7. Ceiling-Mounted Port Extension Tube Mounted in Cabin Ceiling



Figure 8. Ceiling-Mounted Port Prototype Discharge Head

The ceiling-mounted port and associated tubes and head were centered over the left aisle, just aft of the crew rest area, which was converted into a control room for these tests. Cameras were mounted in the cabin overhead area to capture the sequence of events during extinguishing agent discharge. One important note was that all extinguishers incorporated a flexible discharge hose, allowing the extinguisher to remain perfectly upright during discharge. This enabled full expulsion of the extinguisher contents, which would not be possible otherwise, since the extinguisher would need to be held horizontally to engage the ceiling-mounted port. Also of note was the requirement that the person discharging the extinguishing agent needed to stand on the armrests of the seats to reach the ceiling-mounted port (figure 9).



Figure 9. Extinguishing Agent Discharged Through the Port in the Wide-Body Aircraft

During test 1, a 2.5-lb Halon 1211 extinguisher was discharged through the ceiling-mounted port; however, none of the six candles were extinguished. This result indicated that 2.5 lbs of Halon 1211 was incapable of providing the required extinguishment concentration in this large cabin overhead area. For this reason, a more conservative, modified candle configuration was devised to better determine the extinguishing capability of this amount of Halon 1211 (figure 10).

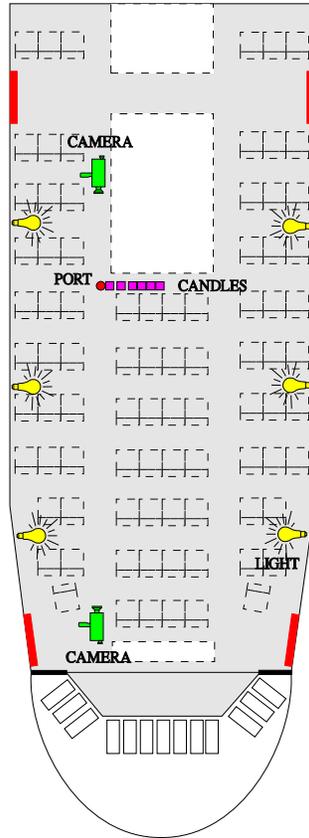


Figure 10. Modified Candle Lantern Test Configuration

Using this arrangement, the candles were hung closer to the discharge head, perpendicular to the axis of the aircraft (figures 11 and 12). The distance from the first candle situated directly over the port to the last candle was approximately 42 inches.

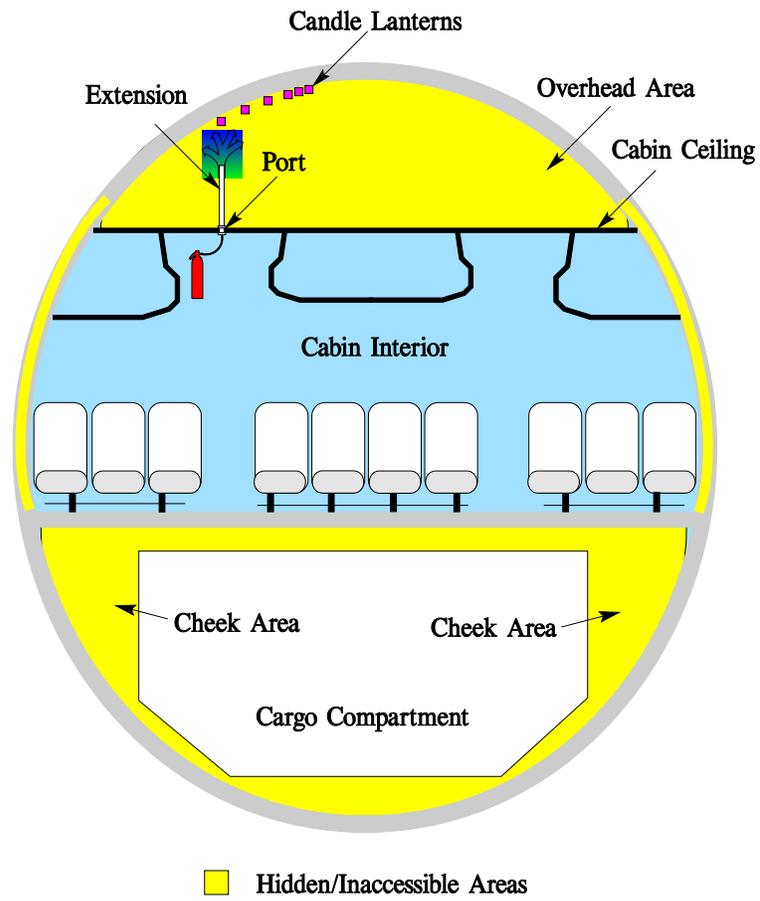


Figure 11. Cutaway Schematic of the Modified Candle Lantern Test Configuration



Figure 12. Modified Candle Lantern Test Configuration in Cabin Overhead Area

During test 2, the ceiling-mounted port and associated hardware were identical to test 1, extending above the ceiling approximately 30 inches. After the modified candle configuration in test 2, only one of the six candles was extinguished, again indicative of minimal protection in a large volume with only one 2.5-lb extinguisher.

In an effort to determine the capability of the 2.5 lbs of Halon 1211 without the aid of any hardware, the ceiling-mounted port system was removed, and test 3 was conducted with the extinguisher simply discharged through the resulting hole in the ceiling. This exercise could be considered a simulation of the two actual incidents (Greenland Air B-757 and American Airlines MD-80) in which the aircrafts had been struck by lightning and direct access to the ceiling was gained using a tool. Surprisingly, all six candle lanterns were extinguished during this test. This indicated that the extension tube and prototype discharge head were choking off much of the 2.5-lb Halon 1211's thrust, thereby inhibiting performance. A further indication that the extinguishing agent was being restricted when using this port system was the formation of liquid Halon 1211 at the port intake. During discharge, the liquid Halon 1211 began dripping from the interface between the port and the extinguisher nozzle, and continued until the discharge was complete. Although the discharge durations (with and without the port) were not measured with a timer, the formation of the liquid drops when using the port was a clear indication that the discharge was being restricted.

As a result, a second discharge head was designed and fitted to the ceiling-mounted port. The new discharge head featured a grill design and was much less restrictive than the previous discharge head with holes (figure 13).



Figure 13. Grill Design Discharge Head

Using the identical perpendicularly placed candle lantern test configuration, a 2.5-lb Halon 1211 extinguisher was discharged through the ceiling-mounted port containing the grill design discharge head with no additional extension tubes (test 4). This resulted in five of the six candle lanterns being extinguished. Interestingly, the lantern directly above the ceiling-mounted port location was not extinguished, indicating the upward thrust of agent was still somewhat inhibited.

To substantiate this theory, in test 5, a feedthrough design discharge head was attached to the end of the ceiling-mounted port (figure 14). This, again, resulted in five of the six candle lanterns being extinguished. In this case, the nonextinguished lantern was farthest from the discharge location, indicating good upward thrust, but slightly reduced radial range.

During test 6, the feedthrough discharge head was replaced by the grill design discharge head, with the addition of one 6-inch extension. This configuration was aimed at maintaining the optimal radial coverage, but also to better suppress the candle lantern directly above the ceiling-mounted port location. The test resulted in the same five candle lanterns being extinguished.



Figure 14. Feedthrough Design Discharge Head

The last test in this series (test 7) used the feedthrough discharge head in conjunction with one 6-inch extension. This resulted in extinguishing all six candle lanterns. Although this result was promising, it was important to consider that the actual location of a fire may not be precisely known, and that optimization based on a specific fire location may yield misleading results. It is entirely possible that a fire could also occur directly on the top surface of the ceiling panels, either directly as the result of a wire bundle fire in this area or indirectly from a wire bundle fire above that had produced flaming drips to the ceiling surface below. For this reason, an additional candle lantern test scenario was devised in which the lanterns were placed just slightly above the ceiling panel (figure 15).

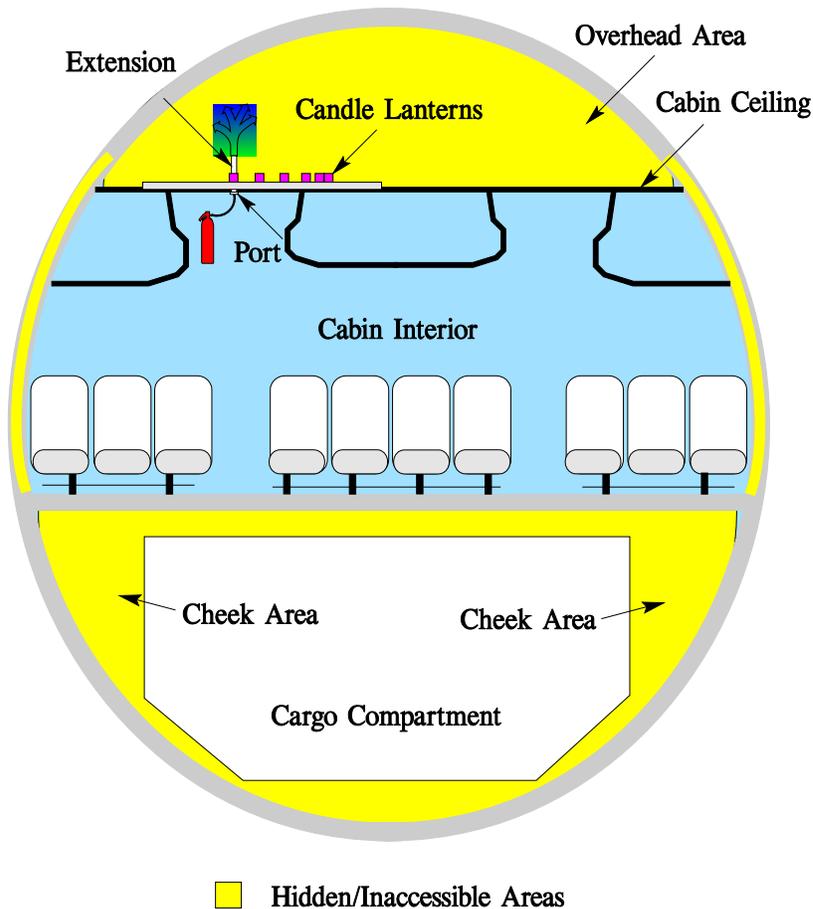


Figure 15. Candle Lanterns Located Directly Above Ceiling Panel

For this configuration, the six candle lanterns were placed on top of a section of aluminum frame, directly underneath the previous positions near the crown. The candle lanterns were placed on top of the aluminum frame, approximately 4 inches above the ceiling panel.

During test 8, the feedthrough discharge head was used with one short extension. This, again, resulted in all six candle lanterns being extinguished, as occurred when the candles were located near the crown in test 7. During test 9, the feedthrough discharge head was replaced by the grilled discharge head, resulting in only four of the six candles being extinguished. Additional tests were run using the feedthrough discharge head with no extension (test 10) and the grilled discharge head with no extension (test 11), resulting in three of the six candles being extinguished in each case.

To determine the baseline extinguisher capability without the aid of a ceiling-mounted port, the extinguisher was discharged through the hole in the ceiling from the removed port. None of the six candles were extinguished (test 12). This was a distinct difference to the previous candle configuration in which all six candles were extinguished without the aid of the ceiling-mounted

port system. This highlighted the vast difference in extinguishing capabilities, depending on the location of the fire.

A final test (test 13) was run in which two extension tubes were connected to the ceiling-mounted port with no discharge head. This configuration resulted in four of the six candle lanterns being extinguished. The results of this test series, in which the candles were located just above the ceiling, did not appear to follow as predictable a pattern as when the candles were placed near the crown (table 1). For example, in test 8, all six candles were extinguished using a feedthrough discharge head in which, presumably, the agent is propelled mainly in an upward fashion away from the candles located near the ceiling. However, when using the grilled design discharge head during test 9, only four of the six candles were extinguished. It was anticipated that the grilled design discharge head would provide equal or better results under these conditions, but this was not the result. Furthermore, it is difficult to explain the difference in results between tests 8 and 10, even though the only difference was the use of a short extension in test 8. Since the candles were located at (test 10) or below (test 8) the discharge point in both instances, it was surprising that twice as many candles were extinguished in one test compared to the other.

Table 1. Number of Candles Extinguished in B-747SP Wide-Body Aircraft Tests

Port Candle	Hole in Ceiling	Prototype With Five Extensions	Grill Design With No Extension	Feedthrough Design With No Extension	Grill Design With One Extension	Feedthrough Design With One Extension	Two Extensions With No Head
		Test 1					
6 Along Crown (axial)	X	0	X	X	X	X	X
	Test 3	Test 2	Test 4	Test 5	Test 6	Test 7	
6 Near Crown (perp)	6	1	5 ^a	5 ^b	5 ^c	6	X
	Test 12		Test 11	Test 10	Test 9	Test 8	Test 13
6 on Top of Ceiling Panel	0	X	3	3	4	6	4

^a Candle directly above discharge NOT extinguished

^b Candle farthest from discharge NOT extinguished

^c 4th candle from discharge NOT extinguished

X Not tested

It is possible that when the discharge point is above the candles, the extinguishing capabilities depend on the amount of agent mixing. Similarly, the amount of agent mixing is likely dependent on the fuselage geometry, and slight differences in the discharge point can equate to slightly better or worse mixing and, hence, extinguishing capability. The test results are also limited by the lack of statistical data, since only one test was run for each specific case.

NARROW-BODY AIRCRAFT HIDDEN AREA TESTING.

Tests conducted in the wide-body aircraft indicated the use of hand-held extinguishers in conjunction with ceiling-mounted ports was largely ineffective against cabin overhead area hidden fires. It appeared that the substantial volume above the cabin ceiling was the reason for this result, and the effectiveness of the ceiling-mounted ports was not predictable. The small amount of extinguishing agent discharge was simply inadequate to safely protect this large volume, resulting in sporadic success. It follows that the use of hand-held extinguishers in conjunction with ceiling-mounted ports could be more effective in a narrow-body aircraft configuration. For this reason, additional tests were carried out in a B-737-200 narrow-body aircraft (figure 16).

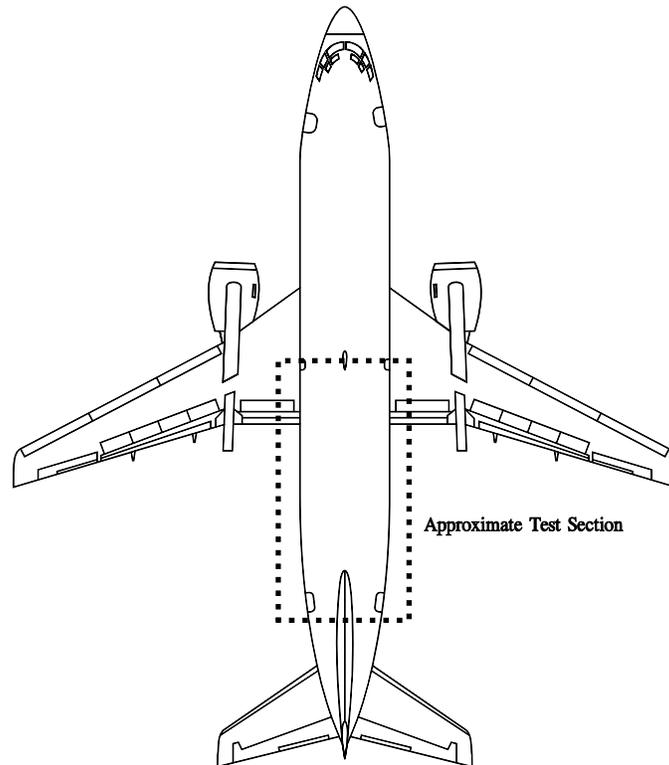


Figure 16. Narrow-Body B-737-200 Aircraft

During the pretest inspection of the narrow-body aircraft, it was determined that the cabin overhead panels could be unfastened and rotated downward, giving nearly unlimited access to the cabin overhead area (figure 17). Although the locking mechanism for the panels was hidden in the overhead stowage bins and was somewhat difficult to activate, it became much easier to perform once the operator became familiar with it. This was a significant finding in that, given the proper training, a fire in the hidden overhead area of this type of aircraft with this particular panel attachment scheme could easily be accessed and extinguished. This was not true for the wide-body aircraft, in which the ceiling height was much greater and the ceiling panels were significantly larger.



Figure 17. Narrow-Body Aircraft Showing Cabin Overhead Area Access

LOCATION OF FIRE SOURCE IN THE NARROW-BODY AIRCRAFT CABIN OVERHEAD AREA.

Since the cabin overhead area of the narrow-body aircraft was relatively small and cluttered in comparison with the wide-body aircraft, there were only a few possibilities in terms of the location of the candle lantern fire sources. As such, the lanterns were hung from a hydraulic line that was mounted to the fuselage formers in the cabin overhead area (figure 18). This resulted in the lanterns being very close to a large wire bundle that ran forward to aft, which was a realistic simulation in terms of fire location (figure 19). The ceiling-mounted port was installed 15 inches from the centerline of the aircraft, which was approximately aligned with the candle lanterns.

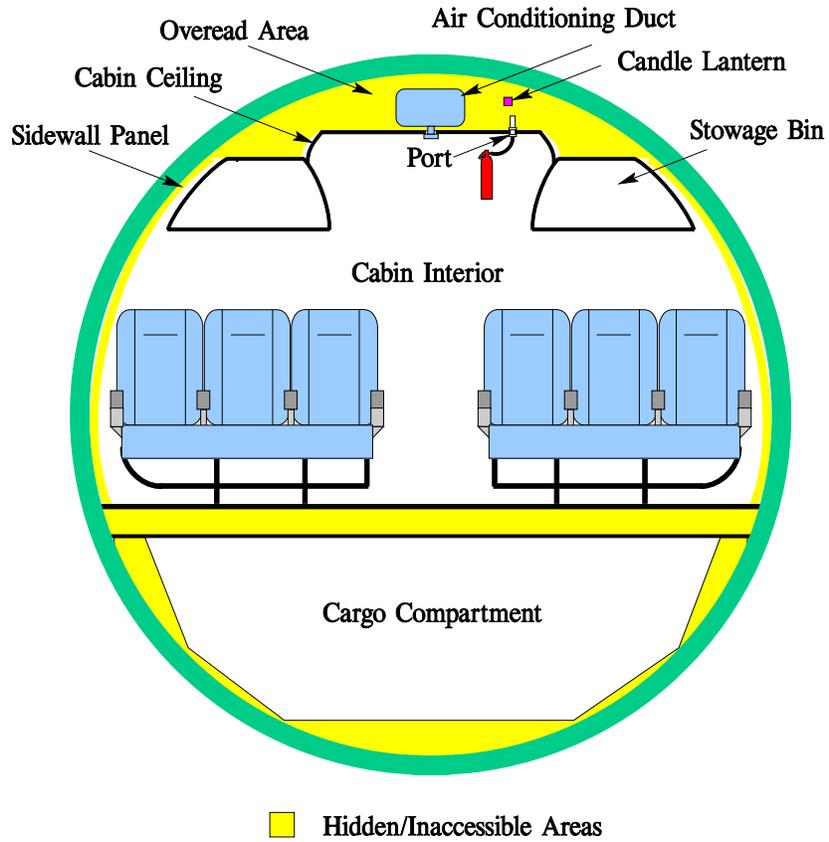


Figure 18. Narrow-Body Aircraft Test Configuration



Figure 19. Narrow-Body Aircraft Test Configuration Showing Location of Candle Lanterns

During the initial tests, six candle lanterns were suspended from the hydraulic line along the port side of the aircraft and spaced 12 inches apart (figure 20). As a result of this spacing, the farthest candle was located approximately 66 inches from the discharge port.

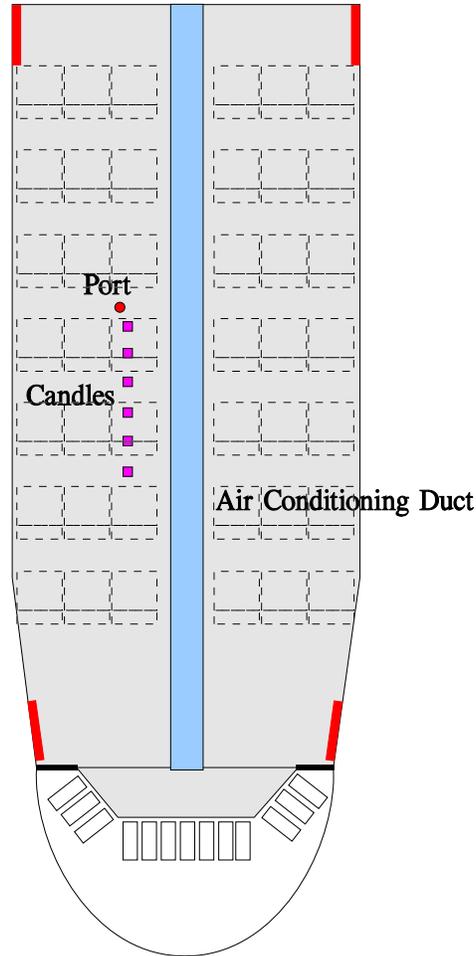


Figure 20. Narrow-Body Test Configuration

NARROW-BODY AIRCRAFT AIR-CONDITIONING SYSTEM CONFIGURATION.

Since the overhead area extinguisher tests were designed to evaluate hand-held extinguisher performance during in-flight conditions, the air-conditioning packs were activated for all tests in the narrow-body test aircraft. Although the B-737-200 air-conditioning system did not have an overhead recirculation fan like the wide-body aircraft, the main air distribution duct was in close proximity to the extinguishing agent discharge area and, therefore, could have possibly played a minor role in the dispersion of the extinguishing agent. Similarly, the gasper system was activated, resulting in air feed to the passenger service units (PSUs) located above each group of seats.

TESTING IN THE NARROW-BODY AIRCRAFT CABIN OVERHEAD AREA.

After lighting all six candle lanterns, the ceiling panels were quickly reinstalled to their proper position. The 2.5-lb Halon 1211 extinguisher was then fully discharged through the ceiling-mounted port, followed by a brief 1-minute settling period to allow the extinguishing agent to fully disperse in the cabin overhead area (figure 21). The ceiling panels were then unfastened to allow inspection of the candle lanterns. This procedure was followed for all tests.



Figure 21. Halon 1211 Discharged Through Ceiling-Mounted Port

During test 1, only the ceiling-mounted port was installed, with no extension or discharge head. This resulted in only the first two candles being extinguished. This outcome was expected, since the bulk of the discharge was straight upward into the fuselage with minimal radial dispersion.

Test 2 was run using the prototype discharge head (figure 8) attached to the end of the ceiling-mounted port. This configuration provided extinguishment of four of the six candles, a much better result than test 1. Although the overall thrust of the extinguisher was restricted with this design, it did convey the extinguishing agent far enough radially to give this outcome.

During test 3, the prototype discharge head was replaced with the grilled design discharge head (figure 13). In earlier wide-body aircraft tests, this grill discharge head proved to be less restrictive, giving a slight advantage in performance over the prototype discharge head. However, the wide-body aircraft tests were run with the candle lanterns mostly vertical in relation to the discharge head, whereas the narrow-body aircraft tests were run with the candles nearly horizontal to the discharge head. Following full discharge, only three of the six candles were extinguished. Although the grill discharge head was less restrictive, it appeared slightly vertically biased, allowing more vertical discharge than radial. Given this characteristic, the

result was not surprising, since a majority of the extinguishing agent was sent vertically, and only a percentage of it was conveyed radially where the candles were located.

During test 4, the feedthrough design discharge head was installed. Only one of the six candles was extinguished using this configuration. As was the case with the grill discharge head, during the feedthrough test, a majority of the extinguishing agent is thrust vertically and, thus, reliant on the geometry of the cabin overhead area to assist in the radial dispersion. As mentioned above, this grill discharge head was much more effective during the wide-body aircraft tests, when the fire source was mostly vertical with respect to the discharge point.

A final test (test 5) was run in which the entire ceiling-mounted port was removed. This exercise was also performed during the wide-body aircraft test with surprisingly good results. During the narrow-body aircraft test, the extinguisher hose was inserted into the hole in the ceiling panel and directed slightly towards the candle lanterns. All six candles were extinguished. Given the confined space above the ceiling in which the candle lanterns were located, this result was not surprising, since there was no extinguishing agent restriction and the discharge was directed towards the fire source. Although this test pointed out the effectiveness of the Halon 1211 under certain conditions, it is unlikely that it could be duplicated during an actual event when the exact position of the fire would be difficult to ascertain.

These initial five tests were repeated to confirm their results. During replicate tests, all results were identical with the exception of test 8 in which only two of the candles were extinguished, as opposed to three during test 3 (table 2).

Table 2. Number of Candles Extinguished in Narrow-Body Aircraft Tests

Port Candle	Ceiling-Mounted Fitting Only	Prototype Head	Grill Design Head	Feedthrough Design Head	Hole in Ceiling*
	Test 1	Test 2	Test 3	Test 4	Test 5
6 Along Crown (axial)	2	4	3	1	6
	Test 6	Test 7	Test 8	Test 9	Test 10
6 Along Crown (axial)	2	4	2	1	6

*Extinguisher aimed toward candles.

SUMMARY

Tests conducted in the wide-body aircraft cabin overhead area have highlighted the limitations of small, hand-held extinguishers at protecting large, expansive areas from fire. Unless the exact location of the fire can be determined and, more importantly, the extinguishing agent applied at or near the fire, it appears unfeasible to safely protect the cabin overhead area with hand-held extinguishers and ceiling-mounted ports. However, similar tests carried out in a narrow-body aircraft have shown a marked increase in extinguisher effectiveness against cabin overhead area fires when the agent is applied via ceiling-mounted ports. Since the area above the ceiling in

narrow-body aircraft is much more confined, hand-held extinguishers are more likely to be effective. This finding may not be evident by simply comparing the number of candles extinguished in both types of tests (comparison of tables 1 and 2). This is because the candles encompass a larger area in the narrow-body aircraft tests, with the farthest candle placed approximately 66 inches from the discharge port. By comparison, the farthest candle in the wide-body aircraft tests was placed only 42 inches from the discharge port. When taking this into account, it is clear that a 2.5-lb hand-held extinguisher provides more protection in the narrow-body aircraft.

One significant finding borne out of the tests was that if ceiling panels could be lowered or removed and the overhead volume directly accessed, a significant increase in firefighting capabilities could be achieved. Although the particular locking mechanism for the narrow-body aircraft used in the tests was initially difficult to operate, it became routine after several practice simulations. It is not known, however, whether ceiling panels on other narrow-body airplanes (e.g., Airbus, Bombardier, Embraer) can be lowered as easily as on the research airplane. Additionally, there may be future requirements from the Transportation Safety Administration to make it more difficult to access areas behind ceiling and sidewall panels as part of the effort to combat terrorism.

Another finding was that the combination of ceiling-mounted ports and hand-held extinguishers are most effective if the extinguisher is equipped with a flexible discharge hose. Many aircraft extinguishers are not so equipped, making it necessary to position the extinguisher horizontally. When this occurs, only 50% of the agent will be available, significantly reducing the firefighting effectiveness of hand-held extinguishers.

CONCLUSIONS

The cabin overhead area presents a number of impediments to fire suppression. Since the cabin overhead area can be considered continuous, the location of the fire source may be difficult to determine. In wide-body aircraft, recirculation fans in the cabin overhead area have a tendency to transport and mix the smoke, making it even more challenging to pinpoint the location of the fire.

In a narrow-body aircraft, the use of hand-held extinguishers is more applicable, since the cabin overhead area is much more confined, greatly reducing the quantity of agent required. However, an array of multisensor type detectors located in the cabin overhead area would be required to help pinpoint the fire and allow the cabin crew to discharge hand-held extinguishers through ceiling-mounted ports in the vicinity of the activated detectors. In addition, the spacing of the ports would be dependent upon the specific aircraft overhead area design, the types of available hand-held extinguishers, and the layout of the detection system. A distribution manifold could be attached to each ceiling-mounted port to allow a more even application of the extinguishing agent in the threat area.

Another aspect of fire protection in narrow-body aircraft that needs emphasis is the ability to quickly remove the ceiling panels, exposing the otherwise hidden overhead area. It may be

possible to effectively train the cabin crew on overhead panel removal to access a fire without the use of detectors, automatic suppression systems, or ceiling-mounted ports. This does not appear to be the case with wide-body aircraft, because the ceiling panels are generally larger and more difficult to reach without taking drastic measures. Also, as noted in the Summary, lowering of ceiling panels on airplanes other than the research airplane, may not be as easy and there is the potential for the Transportation Safety Administration to require restricting access to areas behind ceiling and sidewall panels.

REFERENCES

1. Marker, T.R., "Development of Improved Flammability Criteria for Aircraft Thermal Acoustic Insulation," FAA report DOT/FAA/AR-99/44, September 2000.
2. Cahill, P., "An Evaluation of the Flammability of Aircraft Wiring," FAA report DOT/FAA/AR-TN04/32, December 2004.
3. Cahill, P., "Flammability of Aircraft Insulation Blankets Subjected to Electrical Arc Ignition Sources," FAA report DOT/FAA/AR-TN00/20, April 2000.
4. Suo-Anttila, J., Gill, W., and Gritzko, L., "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.
5. Advisory Circular AC 120-80 on fighting In-Flight Fires, January 2004.