AIAA'85

AIAA-85-0393
Evaluation of Aircraft Interior Panels Under Full-Scale Cabin Fire Test Conditions

C. P. Sarkos and R. G. Hill,
FAA Technical Center,
Atlantic City Airport, NJ

AIAA 23rd Aerospace Sciences Meeting

January 14-17, 1985/Reno, Nevada

EVALUATION OF AIRCRAFT INTERIOR PANELS UNDER FULL-SCALE CABIN FIRE TEST CONDITIONS

By

Constantine P. Sarkos
Richard G. Hill

Federal Aviation Administration
Technical Center
Atlantic City Airport, NJ 08405

Abstract

Realistic full-scale fire tests demonstrated the potential safety benefits of advanced interior panels in transport aircraft, and displayed the characteristics of cabin fire hazards. The tests were conducted in a C-133 airplane, modified to resemble a wide-body interior, under postcrash and in-flight fire scenarios. The safety benefit of the advanced panel ranged from a 2-minute delay in the onset of flashover when the cabin fire was initiated by a fuel fire adjacent to a fuselage rupture, to the elimination of flashover when the fuel fire was adjacent to a door opening or when an in-flight fire was started from a seat drenched in gasoline. Analysis of the cabin hazards measured during postcrash fire tests indicated that the greatest threat to passenger survival was cabin flashover, and that toxic gases did not reach hazardous levels unless flashover occurred.

Introduction

Objective

The primary objective of this paper is to describe the safety benefits of advanced interior panels under realistic full-scale aircraft cabin fire test conditions. A secondary objective is to characterize and analyze the hazards affecting occupant survivability in cabin fires.

Background

Although the accident record of the airline industry is excellent, on rare occasions accidents do occur with grave consequences. Fire is a major concern because of the large quantities of flammable fuel carried by the airplane and because of the cabin design, which consists of a densely populated enclosure lined and furnished with polymeric materials. For the United States (U.S.) airline industry, an average of 32 fatalities per year are attributable to fire. [1] All of these fatalities have occurred in crash accidents which are usually accompanied by the spillage and ignition of jet fuel. In spite of the intensity and apparent dominance of a jet fuel fire, under certain accident conditions, the survivability of cabin occupants will be established by the hazards of burning interior materials. [2] The Federal Aviation Administration (FAA) is supporting and conducting research, testing, and development to minimize the hazards of burning interior materials in the postcrash fire environment. [3] Also, the in-flight fire problem is now receiving more attention because of this type of accident experience with foreign carriers; e.g., Air Canada DC9 accident in Cincinnati. [4]

Improvements for two important types of cabin interior materials have been investigated — seat cushions and panels. Foremost was the work on seat cushions. Because of the flammable nature of urethane foam cushions, a fire blocking layer concept was developed that provides significant safety benefits for both postcrash and in-flight cabin fires. [5] The FAA has proposed more stringent flammability regulations for seat cushions that would result in the installation of fire blocking layer materials within a 3-year period. [6] The current emphasis by FAA is to develop improved test requirements and materials for interior panels, which constitute the sidewalls, ceiling, stowage bins, and partitions of a contemporary transport cabin interior. The importance of panels during a cabin fire stems from their large surface area and location in the upper cabin (ceiling, stowage bins) where fire temperatures are highest.

Generally, interior panels are composite structures composed of a honeycomb core, resin-impregnated cloth facings and a decorative laminate. Over the past 10 years, the National Aeronautics and Space Administration (NASA) has developed and evaluated improved panel component materials. The main approach has been to increase the anaerobic char yield in order to improve fire performance. [7] Currently, emphasis is on the development of an advanced resin system for lightweight facings, which meets fabrication, mechanical property and service performance requirements, and exhibts superior fire properties compared to in-service materials. [8]

Fire performance of polymeric materials is usually gauged on the basis of small-scale laboratory tests. A large number of fire tests with a variety of end points are available. It is generally recognized that these small-scale test results, a priori, cannot predict the performance of a material in a real fire. Therefore, full-scale fire tests are necessary to determine the potential safety in real fires and to corroborate the trends indicated by small-scale test results. During full-scale tests, important real-world conditions such as fire source, geometry, and scale are reasonably simulated.

Another important application of full-scale fire tests, is for the analysis of the hazards affecting survivability during a cabin fire. Usually, the hazards of an enclosure fire, such as a fire inside an aircraft cabin, are grouped into three categories: heat, smoke (visibility), and toxic gases. What is the relative importance of each of these hazards? What are the effects of different types of fire scenarios on the significance of each hazard category? Realistic full-scale tests can provide information which, at the very least, give insight for answering these complex and far-reaching questions.

Discussion

Interior Panel Materials

Figure 1 describes the advanced and in-service panels evaluated in this paper. The test samples were cut from flat sheets made of 1/4-inch thick honeycomb core that were especially fabricated for this study. NASA selected the individual components of the advanced panel design primarily on the basis of optimizing fire performance, and minimal consideration was given to mechanical, service, and processing requirements. The goal was to establish a benchmark for advanced panel fire performance, at this time, irrespective of other practical considerations. The in-service panel contained epoxy/fiberglass facings and represented the type of panel design employed in the earliest wide-body jet interiors.

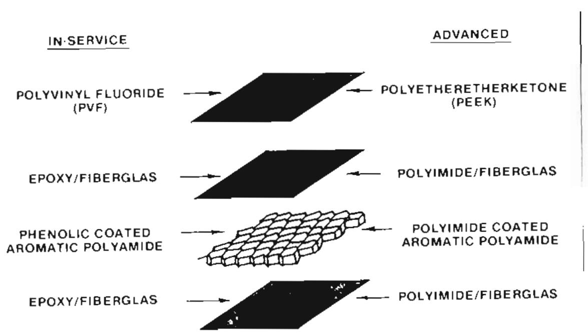

FIGURE 1. COMPOSITION OF COMPOSITE PANELS

Polyimide was selected in the advanced panel design for facing resin and core coating because of its higher degradation temperature and greater anaerobic char yeild compared to epoxy resin. For example, a typical degradation temperature for commercial epoxy and polyimide resin was 500° C and 620° C, respectively. [9] Polyetheretherketone (PEEK) was selected as the decorative film in the advanced panel design, primarily to eliminate the production of hydrogen fluoride during thermal decomposition of the polyvinyl fluoride film commonly used in contemporary panels. The superior thermal stability of the advanced panel was evidenced alone by its cure temperature; viz., 500° F for 16 hours vs. 350° F for approximately 2 hours for the in-service panel.

Small-Scale Test Results

The advanced and in-service panels were initially characterized using standardized small-scale fire tests (table 1). All test methods were American Society of Testing and Materials (ASTM) standards, including the vertical Bunsen burner test method prescribed by FAA under Federal Aviation Regulation (FAR) 25.853. [10] Generally, the advanced panel was better than the in-service panel for all test measurements and gave remarkable results; e.g., no visible smoke, a limiting oxygen index of 69, and a burn length of less than one-inch (FAR 25.853a allows a burn length of six inches). Nevertheless, the results obtained with the in-service panel were excellent by most standards, although consistently inferior to the advanced panel. For example, the limiting oxygen index, which essentially is the minimum concentration of oxygen to allow for ignition by a small pilot flame, was 42 percent for the in-service panel, or double the normal oxygen concentration in air. Similarly, a flame spread index (I_s) of two was well within the design goal of a major airframe manufacturer and was easily compliant with guidelines established for rapid rail vehicles. The test method which provided the greatest discrimination between the advanced and in-service panels was the Ohio State University (OSU) rate of heat release apparatus (a difference in heat output of approximately a factor of 15 was measured). This finding was encouraging in that FAA is currently examining the OSU apparatus as a potential improved fire test method for cabin interior materials. [3]

TABLE 1. SMALL-SCALE TEST RESULTS

TEST METHOD	MEASUREMENT	IN-SERVICE	ADVANCED
VERTICAL BUNSEN BURNER (FAR 25 853A)	BURN LENGTH, IN.	3.0	0.8
	FLAMING TIME, SEC.	3.0	0.0
RADIANT PANEL (ASTM E-162)	I_s	2	<1
NBS SMOKE CHAMBER (ASTM E-662)	D_s AT 90 SEC	20	0.0
	D_s AT 4 MIN.	20	0.0
LIMITING OXYGEN INDEX (ASTM D-2863)	O_2 (%) CONC	42	69
OSU RATE OF HEAT RELEASE* (ASTM E-906)	PEAK HEAT (KW/M^2)	66	4.2
	TOTAL HEAT ($KW\text{-}MIN/M^2$)	116	7.3

*5W/CM², PILOTED

Test Article

The full-scale test article was a C-133 aircraft, modified to resemble a wide-body cabin interior, as shown in figure 2 and reference 2. The cross sectional area is similar to, although slightly smaller than, a wide-body cabin. An interior volume of 13,200 ft^3 is representative of a wide-body jet.

The floor, walls, and ceiling of the test article are composed of, or lined with, noncombustible materials (all combustible materials in the original cargo aircraft were removed). A CO_2 total flooding system allows for the selective termination of a test. These protective measures have resulted in a durable test article, which has withstood hundreds of tests and requires only periodic repairs in the intense fire areas.

The test article is extensively instrumented to measure the major hazards produced by a cabin fire as a function of time at various cabin locations. The following measurements are routinely taken: temperature, heat flux, smoke density, and concentration of carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), hydrogen chloride (HCl), hydrogen fluoride (HF), and hydrogen cyanide (HCN). Video and photographic coverage document the visual progress of the fire.

The C-133 test article was utilized to compare the performance of the advanced and in-service panels installed in a representative cabin interior layout as sidewalls, stowage bins, ceiling and partitions, under simulated postcrash and in-flight fire conditions. Under the post-crash scenarios, the interior was subjected to an external fuel fire adjacent to an opening (door or fuselage rupture) in the forward part of the fuselage (figure 2). An additional door opening existed in the rear of the fuselage to simulate an opened exit for passenger evacuation. For the in-flight fire scenario, the fuselage openings were covered and a perforated ducting system simulated the ceiling discharge of air into the cabin as occurs with the cabin environmental control system (ECS). A measured cabin air change occurred every 3 minutes. For both types of scenarios, the panels were installed around the fire door (station 140) in a symmetrical manner (see later discussion).

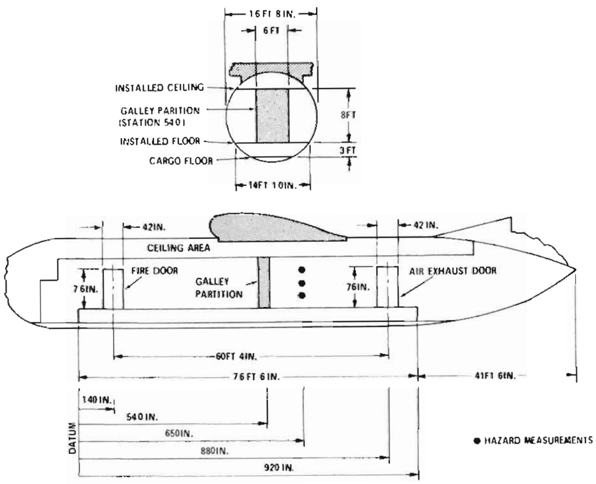

FIGURE 2. SCHEMATIC OF C-133 WIDE-BODY CABIN FIRE TEST ARTICLE

Fire Scenarios

Table 2 outlines the fire scenarios utilized in this study to compare the behavior of the advanced and in-service panels. In general, the postcrash scenarios consisted of an external fuel fire adjacent to a fuselage opening (door or rupture) whereas, the in-flight scenario consisted of a seat fire in a closed fuselage.

TABLE 2 FIRE SCENARIOS

NO.	DESIGNATION	TYPE	IGNITION SOURCE	FUSELAGE CONFIGURATION	VENTILATION
1	FUEL FIRE/ RUPTURE	POSTCRASH	FUEL FIRE	INTACT, TWO OPENINGS: RUPTURE (FIRE) DOOR (AFT)	NATURAL ZERO WIND
2	FUEL FIRE/ OPEN DOOR	POSTCRASH	FUEL FIRE	INTACT, TWO OPENINGS: DOOR (FIRE) DOOR (AFT)	NATURAL ZERO WIND
3	GASOLINE/ SEAT	IN-FLIGHT	SPILLED GASOLINE ON SEAT	CLOSED	CONTROLLED

In the postcrash scenario, previous work had demonstrated that the size of the C-133 external fuel fire produced 80 percent of the radiant heat flux into the interior expected from an infinite fire. [11] Thus, the experimental fuel fire gave a reasonable simulation of a large pool of burning fuel. The tests were conducted inside a large test facility under quiescent (zero wind) conditions. With an unfurnished C-133 interior and zero wind, there is virtually no accumulation of fuel fire hazards (temperature, smoke, and gases) inside the test article. [11] For this reason, the cabin hazards measured with interior materials installed and a zero wind fuel fire are attributed to burning materials, although fuel fire flames are drawn into the interior as the materials begin to ignite and burn. [12] The main role of the fuel fire is to subject the interior materials to intense radiant heat.

The in-flight fire scenario consisted of the ignition of a passenger seat doused with one quart of gasoline. It probably represented the most intense in-flight fire that is likely to occur out in the open (in contrast to a fire in a concealed area). The use of forced ventilation in a closed fuselage for the in-flight scenario was expected to affect the fire characteristics, compared to the postcrash case with fuselage openings and natural ventilation.

Test Results and Analysis

General Approach

The general approach was to compare the test results between the advanced and in-service panels for each of the three types of fire scenarios. A total of six full-scale tests were conducted, consisting of a single test with each type of panel for each fire scenario.

Postcrash Fuel Fire and Fuselage Rupture Scenario

The arrangement of materials with the post-crash fire scenario with a fuselage rupture adjacent to the fuel fire is shown in figure 3. Basically, a small area of the interior in the vicinity of the fuselage rupture was lined with the panels being examined and furnished with seats and carpet. The same type of seats and carpet were used for all the tests. The seats were surplus aircraft passenger seats protected with cushion fire blocking layers and the carpet was new, aircraft grade wool/nylon carpet. The quantity of materials employed was more than adequate to produce non-survivable conditions in the event of ignition and adequate fire growth. By using seats and carpet in addition to the panels being evaluated, the effect of panel flammability on the ignition and burning of other cabin materials used in large quantities, and vice-versa, was taken into consideration.

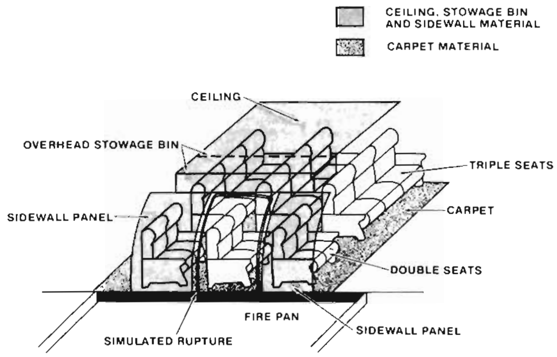

FIGURE 3. POSTCRASH FUEL FIRE/RUPTURE SCENARIO

The postcrash fuel fire scenario with a fuselage rupture was the most severe fire condition used, primarily because a seat was centered in the rupture and exposed to high levels of radiant heat. When that seat started to burn, it caused additional radiant heat to impinge upon the other interior materials. A flashover — defined in this paper as the sudden and rapid uncontrolled growth of the fire from an area in the immediate vicinity of the fuel fire to the remaining materials — occurred with both types of panels. However, the time to flashover was much earlier in the test with in-service panels than in the test with advanced panels. As shown in figure 4, the difference in flashover time, from the rapid rise of temperature measured by a thermocouple mounted 12 inches below the ceiling and near the fire door, was approximately 140 seconds. Since the occurrence of flashover is the event in a postcrash cabin fire that creates non-survivable conditions, as discussed later in this paper and in an earlier study (reference 2), the advanced panels also resulted in 140 seconds of additional time available for evacuation, or 150 percent more available evacuation time than with the in-service panels. This difference in available evacuation time was clearly a significant benefit to be gained from the advanced panels.

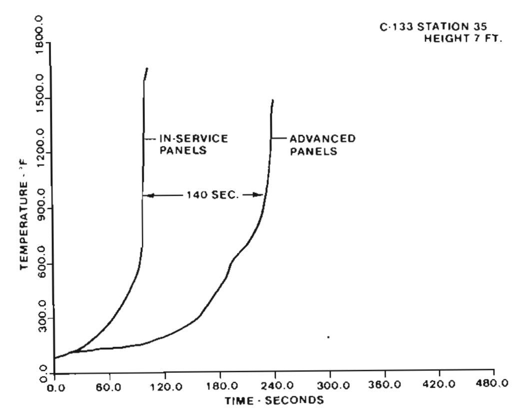

FIGURE 4. BENEFIT OF ADVANCED COMPOSITE PANELS-EXTERNAL FUEL FIRE/FUSELAGE RUPTURE SCENARIO

Postcrash Fuel Fire and Open Door Scenario

The arrangement of materials with the postcrash fire scenario with an opened door adjacent to the fuel fire is shown in figure 5. Materials placement was similar to the fuselage rupture scenario except that the center row of seats was eliminated and a box-like structure representing a galley was installed. The resultant fire condition was less severe than with the fuselage rupture scenario because of the removal of the passenger seat next to the opening.

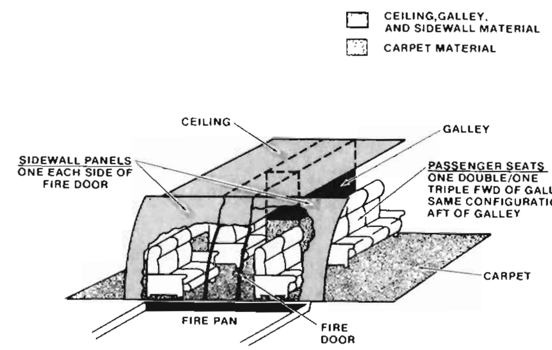

FIGURE 5. POSTCRASH FUEL FIRE/OPEN DOOR SCENARIO

The superior fire performance of the advanced panels was even more evident with the fuel fire/open door scenario. Under this scenario, the usage of advanced panels eliminated flashover. This result is demonstrated in figure 5, which compares the temperature history inside the test article for both types of panels. With in-service panels, flashover occurred in aproximately 2 1/2 minutes; however, with advanced panels, flashover did not occur over the 7-minute test duration. A comparison of the results with both types of postcrash scenarios (see figures 4 and 6) demonstrates the consistency of the data and illustrates that the rate of development of a cabin fire is largely dependent on fire scenario.

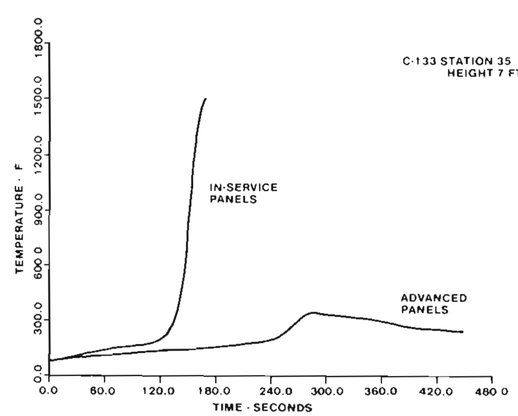

FIGURE 6. BENEFIT OF ADVANCED COMPOSITE PANELS - EXTERNAL FUEL FIRE/OPEN DOOR SCENARIO

An analysis of the cabin hazards measured in the fuel fire/open door test with in-service panels revealed the importance of flashover in dictating survivability during a postcrash cabin fire. This data is shown in figure 7, which contains the hazard histories measured approximately 40 feet aft of the fire door at an elevation of 5 feet 6 inches. The methods of analysis are described in reference 13. Before the flashover which occurred at approximately 150 seconds, the cabin environment was clearly survivable; after flashover, the conditions very suddenly deteriorated to such a degree that survival would have been highly unlikely. The suddeness of flashover, and perhaps the fact that it occurs without any apparent warning, may make passengers unaware of the imminent dangers that they face during a cabin fire. For example, within 30 seconds, as shown in figure 7, visibility decreased from about 30 feet to 3 feet, temperature measured from slightly above ambient to over 400° F, CO increased from zero to over 2500 ppm, and oxygen decreased from ambient to 16 percent. Therefore, it was concluded tha. improvements in postcrash cabin fire safety, when burning interior materials are the dominant factor, can be best attained by delaying the onset of flashover. If material selection is on the basis of state-of-the-art small-scale fire tests, then the use of an appropriate flammability test would seem to be far more beneficial than the use of either smoke or toxicity tests.

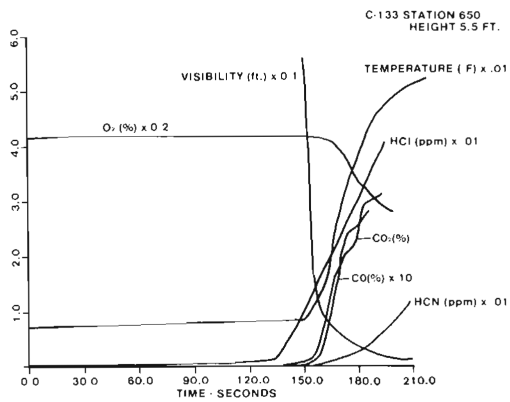

FIGURE 7. HAZARD TIME PROFILES WITH IN-SERVICE COMPOSITE PANEL - EXTERNAL FUEL FIRE/ OPEN DOOR SCENARIO

Why were the hazards measured 40 feet aft of the fire door at an elevation of 5 feet 6 inches virtually zero for over 2 minutes in the fuel fire/open door test with in-service panels? There are two likely reasons for this result. First, the small mass burning rate before flashover and the large cabin volume (13,200 cubic feet) made dilution and wall loss effects (heat transfer, adsorption) dominant. Secondly, the hazards that are produced before flashover are largely contained in the hot "smoke layer" which clings to the ceiling, above the measurement location and probably above the head of most passengers. Previous C-133 tests, [2], and the photographic/ video coverage from the tests described in this paper, document the significant stratification during a postcrash cabin fire with natural ventilation; i.e., with no forced ventilation.

Figure 8 also demonstrates that the hazards over this 7-minute test were clearly survivable. At 7 minutes, the temperature had only increased by 20° F over ambient, the concentration of CO_2 was 2000 ppm, the concentration of O_2 remained at ambient, and visibility had decreased to 50 feet. The toxic gases CO, HCl, HCN, and HF were not detected. This data also supports the conclusion that in a postcrash cabin fire, the hazards effecting survival are created by a flashover. Also, smoke and toxic gas hazards affecting survivability did not materialize as a consequence of flashover being prevented.

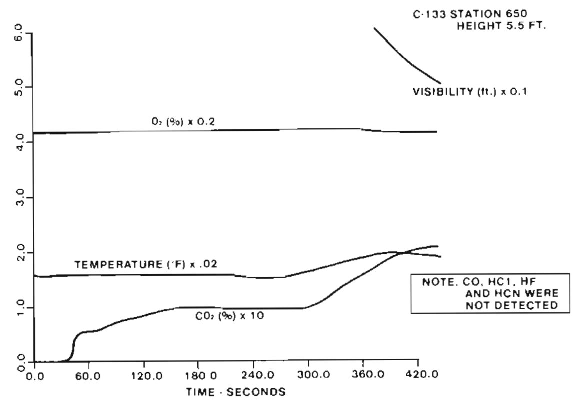

FIGURE 8. HAZARD TIME PROFILES WITH ADVANCED COMPOSITE PANELS EXTERNAL FUEL FIRE/ OPEN DOOR SCENARIO

In-Flight Fire Scenario

Figure 9 shows the arrangement of materials for the in-flight scenario. The placement of panels was identical to the fuel fire/rupture test, and two rows of double seats with cushion fire blocking layers were used. The fuselage openings were covered and a perforated duct simulated air discharge from the cabin ECS. The seat next to the covered door, doused with one quart of gasoline, served as the fire source. This type of seat fire will burn for 2 mnutes, with a peak burning rate at 40 seconds before self-extinguishing because of the fire blocking layer. [13]

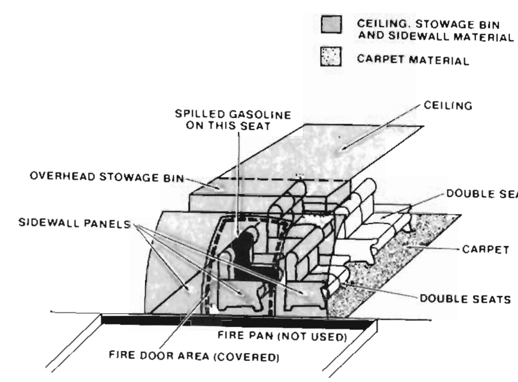

FIGURE 9. IN-FLIGHT GASOLINE/SEAT SCENARIO

The in-flight fire scenario was the least severe of the three scenarios studied. Figure 10 compares the temperature history near the fire source for the in-service and advanced panels. As in the fuel fire/open door test, flashover did not occur with the advanced panels. The fire resistance of the more flammable in-service panels was also sufficient to delay the onset of flashover until 8 minutes. From a practical viewpoint, an in-flight fire of this kind with in-service panels would, under most circumstances, have been extinguished by crewmembers utilizing hand-held extinguishers before the fire became out of control.

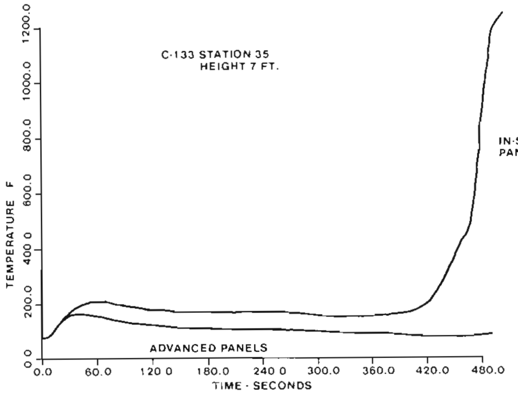

FIGURE 10. BENEFIT OF ADVANCED COMPOSITE PANELS - IN-FLIGHT FIRE SCENARIO

The controlled ventilation in the in-flight scenario tended to distribute the seat fire hazards throughout the airplane. Figure 11 presents the measured hazard histories, at a station located 40 feet aft the fire source at an elevation of 5 feet 6 inches, for the in-service panel test. Each of the measured hazards was detected before the onset of flashover, apparently because of the mixing action associated with the controlled ventilation. In contrast, for the postcrash tests where the cabin was ventilated naturally through fuselage openings, the hazards were primarily contained in the ceiling smoke layer, and remained virtually undetected at the 5-foot 6-inch sampling height until the cabin flashover (e.g., see figure 7). For the in-flight test, however, each measured hazard before flashover was well below its estimated incapacitation level. For example, at 8 minutes the calculated dose of CO was approximately 4000 ppm-minutes, which is significantly below the estimated human escape impairment dose of 30,000-40,000 ppm-minutes.[14] Also, the measured concentration of HCl, which was less than 100 ppm, would have been easily tolerated by passengers, based on recent primate studies.[14] The main peril before flashover was the dramatic loss in visibility due to smoke (calculated visibility was less than 10 feet at 30 seconds). Smoke obscuration may lead to panic and may impede fire control measures by the crew, especially if the smoke persists, as evidended by figure 11. It is interesting to note that significant smoke obscuration can occur without hazardous levels of toxic gases or elevated temperatures.

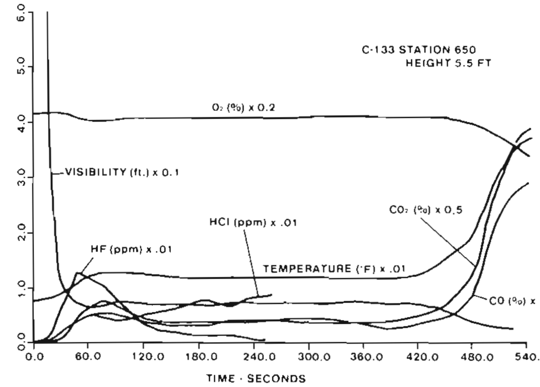

FIGURE 11. HAZARD TIME PROFILES WITH IN-SERVICE COMPOSITE PANELS - IN-FLIGHT FIRE SCENARIO

Figure 12 compares the calculated visibility for the advanced and in-service panel tests. With the advanced panel, smoke obscuration increased until the seat fire began to self extinguish and decreased thereafter as the smoke was exhausted by the controlled ventilation system. Smoke obscuration persisted throughout the in-service panel test because the seat fire spread to other cabin materials and eventually resulted in a flashover. Therefore, during an in-flight cabin fire the environmental control system can alleviate smoke conditions, provided that the concentrations are not excessive or the fire is brought under control.

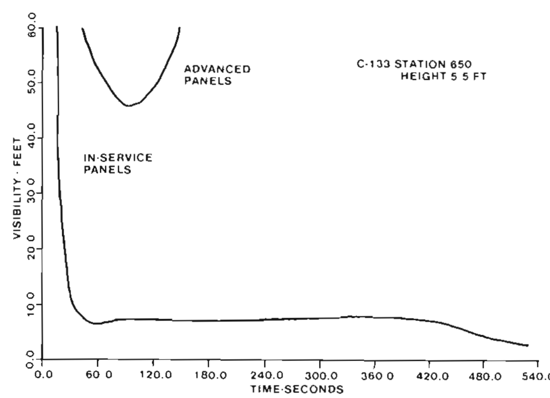

FIGURE 12. SMOKE VISIBILITY COMPARISON OF ADVANCED AND IN-SERVICE COMPOSITE PANELS - IN-FLIGHT FIRE SCENARIO

Summary of Significant Findings

Based on the realistic, full-scale cabin fire tests and analysis described in this paper, and on the composite panel materials evaluated and the types of fire scenarios employed, the following are the significant findings:

(1) Advanced interior panels can provide a significant safety improvement during postcrash and in-flight cabin fires.

(2) The greatest threat to passenger survival during postcrash cabin fires dominated by burning interior materials, is cabin flashover.

(3) Toxic gases produced during postcrash cabin fires consisting of a fuel fire adjacent to a fuselage opening or in-flight fires initiated by a gasoline-drenched seat fire do not reach hazardous levels unless flashover occurs.

(4) During an in-flight fire, the cabin environmental control system has a major effect on the distribution and dissipation of hazards.

References

1. Final Report of the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee, Federal Aviation Administration, Volume I, Report FAA-ASF-80-4, June 26, 1980.

2. Sarkos, C. P., Hill, R. G., and Howell, W. D., The Development and Application of a Full-Scale Wide-Body Test Article to Study the Behavior of Interior Materials During a Postcrash Fuel Fire, AGARD Lecture Series No. 123 on Aircraft Fire Safety, AGARD-LS-123, June 1982.

3. Engineering and Development Program Plan Aircraft Cabin Fire Safety, Federal Aviation Administration, Report FAA-ED-18-7, revised February 1983.

4. Aircraft Accident Report: Air Canada Flight 797, McDonell-Douglas DC-9-32, C-FTLU, Greater Cincinnati International Airport, Covington, KY, June 2, 1983, National Transportation Safety Board, Report NTSB/AAR-84/09, August 8, 1984

5. Sarkos, C. P., and Hill, R. G., Effectiveness of Seat Cushion Blocking Layer Materials Against Cabin Fires, SAE Technical Paper No. 821484, presentd at Aerospace Congress and Exposition, October 25-28, 1982.

6. Flammability Requirements for Aircraft Seat Cushions; Notice of Proposed Rulemaking, DOT/FAA, Federal Register, Volume 48, No. 197, p. 46251, October 11, 1983.

7. Parker, J. A., and Kourtides, D. A., Fire-worthiness of Transport Aircraft Interior Systems, AGARD Lecture Series No. 123 on Aircraft Fire Safety, AGARD-LS-123, June 1982.

8. Parker, J. A., and Kourtides, D. A., New Fireworthy Composites for use in Transportation Vehicles, Journal of Fire Sciences, Vol. 1, No. 6, pp 432-458, November/December 1983.

9. Eklund, T. I., Quasi-Steady Analysis of Aircraft Panel Flammability, Federal Aviation Administration, Report DOT/FAA/CT-84/14, June 1984.

10. Airworthiness Standards; Transport Category Airplanes, DOT/FAA, Federal Aviation Regulations, Volume III, Part 25, Trasmittal 10, effective May 1, 1972.

11. Hill, R. G., Johnson, G. R., and Sarkos, C. P., Postcrash Fuel Fire Hazard Measurements in a Wide-Body Aircraft Cabin, Federal Aviation Administration, Report FAA-NA-79-42, December 1979.

12. Quintiere, J. G., and Tanaka, T., An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program, Part 5: Some Analyses of the Postcrash Fire Scenario, National Bureau of Standards, Report NBSIR 82-2537, July 1982.

13. Hill, R. G., Brown, L. J., Speitel, L., Johnson, G. R., and Sarkos, C. P., Aircraft Seat Fire Blocking Layers: Effectiveness and Benefits Under Various Scenarios, Federal Aviation Administration, Report DOT/FAA/CT-83/43, February 1984.

14. Kaplan, H. L., Grand, A. F., Rogers, W. R., Switzer, W. G., and Hartzell, G. E., A Research Study of the Assessment of Escape Impairment by Irritant Combustion Gases in Postcrash Aircraft Fires, Federal Aviation Administration, Report DOT/FAA/CT-84/16, September 1984.