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FAA Proposes New Rules on Cargo Compartment Fire Detection and Suppression

The U.S. Federal Aviation Administration's (FAA's) aircraft systems fire safety program is also conducting research on the feasibility of cabin water-spray systems and on fire safety issues related to a new generation of large transport aircraft.

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On Nov. 14, 1996, the U.S. Federal Aviation Administration (FAA) proposed new requirements for fire-detection and fire-suppression systems in the cargo compartments of all transport-category commercial passenger aircraft. The FAA has also proposed a permanent ban on transporting chemical oxygen generators by commercial passenger aircraft.

A chemical oxygen generator (Figure 1, page 2) is a cylinder about the size of a can of spray paint, with a core containing primarily sodium chlorate. It produces oxygen when a pin is pulled, releasing a spring-loaded firing mechanism that strikes a percussion cap and starts a chemical reaction that produces oxygen — for emergency breathing apparatus used in a sudden, unexpected cabin decompression — and intense heat as a by-product when oxidation occurs in a confined space. The oxygen generator is designed to function safely when properly installed in an aircraft.

[Oxygen generators, transported as cargo, are suspected of causing a fire in the hold of a ValuJet McDonnell Douglas DC-9-32. The May 11, 1996, accident killed all 110 people on board. Flight 592 departed Miami, Florida, U.S., bound for Atlanta, Georgia, U.S. During the climb after takeoff, the flight crew notified air traffic control that there was smoke in the cabin and cockpit. Approximately nine minutes after takeoff, the DC-9 impacted a Florida Everglades swamp.]

Oxygen generators were considered hazardous cargo before the FAA announcement and were subject to strict rules on handling and shipment. But there have been gaps in the hazardous-cargo screening system. The FAA in July said that it planned to hire an additional 130 hazardous-material inspectors as part of a US$14 million plan to increase oversight of hazardous-materials shipments.

The FAA, in its Nov. 14 announcement, said: "In May, the Research and Special Programs Administration (RSPA) imposed an immediate ban on the transportation of chemical oxygen generators by commercial passenger planes and initiated a study to review further appropriate restrictions on similar oxidizing materials."

[The RSPA is a U.S. Department of Transportation agency whose mission is to "make America's transportation systems more integrated, effective and secure" through research and programs that cut across transportation modes.]

In addition, the FAA announced that it would review whether to require fire-detection and fire-suppression systems in class D cargo compartments of commercial airliners, which do not currently carry such equipment. The forward cargo compartment of ValuJet Flight 592, where the fire originated, was class D.

U.S. aviation fire safety regulations are contained in the U.S. Federal Aviation Regulations (FARs) Part 25.851 through Part 25.869. Part 25.857 classifies cargo compartments as class A, B, C or D on passenger airplanes.

A compartment in which a fire "would be easily discovered by a crew member while at [his or her] station" and that is "easily accessible in flight" is categorized as class A.

A class B compartment is one in which a crew member can "effectively reach any part of the compartment with the contents of a hand fire extinguisher"; when the access provisions are used, no hazardous "smoke, flames or extinguishing agent will enter any compartment occupied by the crew or passengers"; and "there is a separate, approved smoke-detector or fire-detector system to give warning at the pilot or flight-engineer station."

A class C compartment does not meet the requirements for class A or B but has "a separate, approved smoke-detector or fire-detector system to give warning at the pilot or flight-engineer station"; has "an approved, built-in fire-extinguishing system controllable from the pilot or flight-engineer stations"; has means to exclude hazardous smoke, flames or extinguishing agent from crew or passenger compartments; and has means to "control ventilation and drafts" inside the compartment so that the extinguishing agent can control any fire in it.

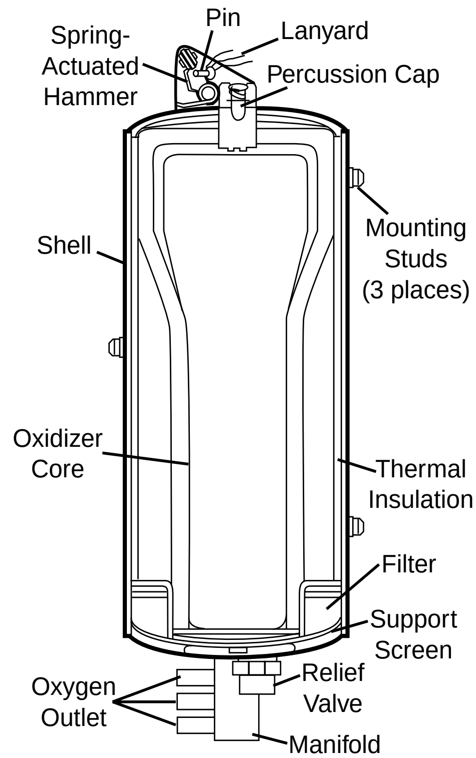
A class D compartment requires no such systems, on the grounds that "a fire occurring in it will be completely confined without endangering the safety of the airplane or its occupants"; that hazardous smoke, flames or other noxious gases cannot penetrate crew or passenger compartments; and that "ventilation and drafts" are controlled so that "any fire likely to occur in the compartment will not progress beyond safe limits."

Class D compartments have less than 28 cubic meters (1,000 cubic feet), considerably smaller than class C compartments, and have a prescribed minimum air leakage rate. Class C compartments have no restriction on the air leakage rate, but air leakage must not diminish the effectiveness of the Halon fire-suppression system.

Class C compartments are generally found on larger aircraft, such as Boeing 747s, 757s and 767s; class D compartments are on smaller, older aircraft such as Boeing 737s and McDonnell Douglas DC-9s. All class C and class D compartments are below the main deck.

Both class B and class C compartments "must have a liner, and the liner must be separate from (but may be attached to) the airplane structure," under Part 25.855. The liner must meet standards based on a test method described in Appendix F, Part III, of Part 25. Among the criteria for a material to pass the test are the following: "There must be no flame penetration of any specimen within five minutes after application of the flame source [which is also specified in detail], and the peak temperature measured at [10.2 centimeters (four inches)] above the upper surface of the horizontal test sample must not exceed [204.4 degrees C (400 degrees F)]."

Chemical Oxygen Generator, Cut-away View



Source: U.S. National Transportation Safety Board

Figure 1

The Nov. 14 FAA announcement continued: "A first rulemaking, to be issued shortly, would propose banning oxidizing materials from commercial passenger aircraft cargo compartments. A second rulemaking would propose requiring the retrofit of fire-detection and [fire-]suppression equipment on approximately 2,800 older transport aircraft.

"Currently, most long-range passenger planes include the detection and suppression systems in the cargo compartments. On older planes, these [class D] compartments have been required to be virtually airtight and lined with fire containment materials. However, while numerous complex issues remain outstanding, newly concluded analysis has determined that such systems could be extended to all passenger aircraft cargo compartments." The proposals will be presented as a Notice of Proposed Rulemaking (NPRM), and the rulemaking process includes a period for public review and comment.

The FAA action is a reversal of its previous position on cargo hold fire-detection and fire-suppression systems. The U.S.

National Transportation Safety Board (NTSB) has urged the FAA to order the systems on commercial aircraft since 1988, following an in-flight fire involving an American Airlines DC-9-83 en route from Dallas/Fort Worth (Texas, U.S.) International Airport to Nashville (Tennessee, U.S.) Metropolitan Airport.

[The flight carried as cargo a drum of chemicals for textile processing. Because of a shipper's ignorance of hazardous-cargo regulations, the drum included hydrogen peroxide solution (an oxidizer) and a sodium orthosilicate-based mixture. The solution leaked during the flight, causing a chemical reaction with the orthosilicate-based mixture, and a fire resulted. Near the end of the flight, cabin crew members reported to the captain that there was smoke in the passenger cabin and that the floor above the midcargo compartment was hot and soft.

[The captain was skeptical about the report because a malfunctioning auxiliary power unit (APU) had generated fumes on an earlier flight and did not declare an emergency. Following a normal landing, the occupants were safely evacuated at the destination.]

As a result of the accident, the NTSB, in its September 1988 investigation report, urged the FAA to require fire- or smoke-detection systems for all class D cargo compartments; to require a fire-extinguishing system for all class D cargo compartments; and to consider the effects of authorized hazardous-materials cargo in fires for all types of cargo compartments and require appropriate safety systems to protect the aircraft and occupants.[1]

Several major aircraft accidents judged to be survivable have included extensive loss of life because of the effects of fire.

On Aug. 10, 1993, the FAA stated that fire- or smoke-detection systems were too costly and did not provide a significant degree of protection to occupants of airplanes and terminated its rulemaking process for requiring such systems.

The most recent cargo compartment proposals are, however, part of an ongoing FAA effort to reduce the number of aircraft passengers killed by fire and smoke in cabins in otherwise survivable aircraft accidents.

FAA Civil Aeromedical Institute (CAMI) researchers have reported that "although cabin occupants may survive the initial forces of such crashes, they are frequently unable to escape from the fire environment because of performance impairment from the smoke-caused toxicity," as well as the visibility reduction caused by the smoke.[2]

The researchers noted that smoke has many components, of varying toxicity. For example:

- Carbon monoxide and hydrogen cyanide, both of which tend to be present when fires produce substantial amounts of smoke, can cause death if present in high enough concentrations. Exposure to nonlethal concentrations of the two compounds can make smoke victims dizzy or confused;

- Irritants present in smoke can cause pain, induce tears or make smoke victims disoriented; and,

- Other "reactive" molecules in smoke sometimes are toxic or pathological, although the effects can be delayed.[3]

A CAMI data base shows that between 1967 and 1993, 360 fire-related fatalities of 134 civil aircraft accidents in the United States appeared to have resulted at least partly from smoke or toxic fumes, which had impaired the victims' ability to escape from the aircraft. The conclusion was based on CAMI analysis of postmortem examination of blood samples.[4]

Fire has been the most important factor in pilot fatalities following accidents to commuter aircraft and air taxis.[5]

Several major aircraft accidents judged to be survivable have included extensive loss of life because of the effects of fire.

- In a June 2, 1983, accident, an in-flight fire was discovered in the lavatory of an Air Canada McDonnell Douglas DC-9-32 that was en route from Dallas, Texas, U.S., to Montréal, Québec, Canada. The flight crew made an emergency landing at Greater Cincinnati International Airport, Covington, Kentucky, U.S. All five crew members escaped, as did 18 passengers, but another 23 passengers were killed when a "flash fire" destroyed the aircraft, 60 seconds to 90 seconds after cabin crew members had opened the forward cabin doors and three overwing exits.[6]

  The accident investigation report noted that "although fatalities occurred, this accident must be considered survivable because none of the survivability factors were violated."

  No deceleration forces that were transmitted to the occupants exceeded human tolerance, nor was the aircraft structure damaged in a way that made survival impossible, the report said. But it appeared that "those who succumbed either made no attempt to move toward an exit or started too late and were overcome as they attempted to move toward an exit. ... It is also possible that some of the passengers were incapacitated because of exposure to toxic gases and smoke during the descent and landing."[6]

- On Aug. 19, 1980, a fire — whose origin was never discovered — occurred aboard a Saudi Arabian Air

Lockheed L-1011 about 12 minutes after takeoff. The L-1011 was flown back to the airport at Riyadh, Saudi Arabia, and landed safely.

The airplane turned off the runway after the rollout, and came to a stop two minutes and 40 seconds after touchdown. After conversations between the tower and the flight crew, and between the tower and fire fighters, the engines were shut down three minutes and 15 seconds after the airplane had stopped on the taxiway.

" ... We are trying to evacuate now," was the last transmission received from the flight crew, but no doors on the L-1011 were opened. "Attempts by the crash/fire/rescue (CFR) personnel to enter the aircraft and open the doors were unsuccessful until the no. 2 door on the right side of the aircraft was opened ... about 23 minutes after all the engines had been shut down," the Saudi Arabian accident investigation report said.

All 301 occupants were killed. "Postmortem examinations and toxicological findings revealed that the deaths in this accident were attributable to the inhalation of toxic gases and/or exposure to the effects of the fire, heat and lack of oxygen," the accident investigation report said. "There were no unusual forces transmitted to the aircraft occupants, as the landing and subsequent rollout were normal."[7]

- On Nov. 11, 1965, a United Airlines Boeing 727 landed short of the runway at Salt Lake City Municipal Airport, Salt Lake City, Utah, U.S. The airplane's main gear collapsed, and the B-727 caught fire as it slid more than 0.8 kilometer (one-half mile) on the nose gear and fuselage underside.

The official accident investigation report said: "This was a survivable accident. There were 91 persons aboard the aircraft and 50 were successful in evacuating ... . The remaining 41 occupants were overcome by dense smoke, intense heat and flames, or a combination of these factors, before they were able to escape. There were no traumatic injuries which would [have prevented] their escape."[8]

Fire Safety Research Focuses on Cabin Interiors

To develop ways of avoiding such fire-related accidents and fatalities, the FAA operates an ongoing Aircraft Systems Fire Safety (ASFS) program. The program has traditionally focused on transport-aircraft interiors, including the cabin and cargo compartments, to develop fire safety improvements.

Accidents influence the direction and level of support for the ASFS research and development (R&D) program. Scarce financial resources are often devoted to a problem that has been highlighted by an accident. The direction of R&D is also influenced by fire safety concerns associated with new aircraft designs or new technology and past regulatory activities and interior-design changes.

Rather than being dedicated to basic research, the ASFS program has near-term goals — improvements with the potential for immediate application. (Long-range research related to aircraft fire safety is conducted separately under the FAA Fire Research program, where the primary emphasis is on developing ultra-fire-resistant interior materials. The Propulsion and Fuel Systems program is responsible for improving postaccident fuel containment on transport aircraft.)[9]

The ASFS first identifies fire-related problems. For example, seat cushions, particularly those made of urethane foam, and large surface-area panels (sidewalls, ceiling, stowage bins and partitions) have been identified as the major postaccident fire hazards among interior materials.

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Improvements are then developed at the FAA Technical Center, Atlantic City, New Jersey, U.S., in the fire-test facilities. Projects can often be completed relatively quickly because of the availability of dedicated facilities and in-house expertise. The results of this research are used by FAA certification officials as the bases for regulatory decisions or advisory material aimed at improving aircraft fire safety.

FAA fire safety regulations, based on research conducted by the ASFS program,[10] were implemented between 1984 and 1991 by aircraft manufacturers and airlines. They included the following:

- A regulation requiring that urethane foam in aircraft seat cushions meet a stringent flammability test that simulates a postaccident fire. About 650,000 seats have been protected with fire-blocking layers at a cost to U.S. airlines of US$75 million;

- A stringent heat-release test for large surface-area panels. Airframe manufacturers were required to develop new material designs to comply with the standard. Airlines and airframe manufacturers have invested more than US$100 million in low heat- and smoke-release panels. [Further incremental improvements in seat-cushion or panel fire-test performance would offer only minimal benefits in postaccident fire safety. Long-term FAA R&D is aimed at developing ultra-fire-resistant (practically fireproof) interior materials];

Photo: AP Wide World Photos

All crew members and passengers successfully evacuated ValuJet Flight 597, a DC-9 that was destroyed by fire after an engine failure during takeoff roll, June 8, 1995.

- A rule requiring airplane emergency lighting systems to define the escape path (aisle) and identify each exit when smoke accumulates in the upper cabin and obscures overhead lights;

- A revised technical standard order (TSO) including a new test requirement that measures the heat resistance of pressurized escape-slide material; and,

- A rule requiring a stringent burn-through test for ceiling and sidewall cargo liners in inaccessible cargo compartments.

More recently, an airworthiness directive (AD) was issued April 20, 1993, to ensure adequate fire protection (upgrading class B cargo compartments to class C standards) in “combi” aircraft [those that carry both freight and passengers on the same deck]. The AD resulted from a Nov. 27, 1987, accident to a South African Airways B-747 “combi” aircraft en route from Taipei, Taiwan, to Mauritius. [About 46 minutes before the estimated time of arrival at Mauritius, the flight crew informed approach control that there was smoke in the airplane. The airplane plunged into the ocean, killing all 159 persons aboard. An official accident investigation determined that the accident followed an uncontrolled fire in the main deck cargo compartment, resulting in loss of control.]

Nevertheless, stricter FAA cabin flammability standards for large surface-area materials have generally affected only aircraft manufactured after the regulations took effect on Aug. 20, 1990.

For aircraft already in service at that time, the retrofitting of upgraded standards for cabin furnishings of older aircraft has been slow. According to a 1993 report by the U.S. General Accounting Office (GAO), “[U.S.] airlines have to comply with the new standards only when they undertake a substantially complete replacement of cabin interior components. ...

“[But] airlines infrequently replace entire cabin interiors. ... Airline officials told GAO that the components not meeting the standards are usually refurbished and reinstalled, rather than [being] replaced with components that meet the standards. Industry practice is to replace a worn-out component with one that meets the standards if it is necessary to purchase a new component. ... This piecemeal replacement of individual components will likely not significantly reduce the hazards posed by a postcrash fire.”

The GAO report concluded that “under the current practice of replacing aircraft, the entire [U.S.] fleet is not expected to comply with the stricter flammability standards until 2019.”[11]

In its accident investigation report on a 1995 ValuJet DC-9-32 uncontained engine failure leading to a cabin fire that destroyed the airplane, the NTSB noted that the regulation establishing new flammability criteria for materials used in the interiors of transport-category airplanes required compliance only at the first “general retrofit” of older airplanes.

[The accident occurred on June 8, 1995, during the DC-9’s takeoff roll at Hartsfield Atlanta (Georgia, U.S.) International

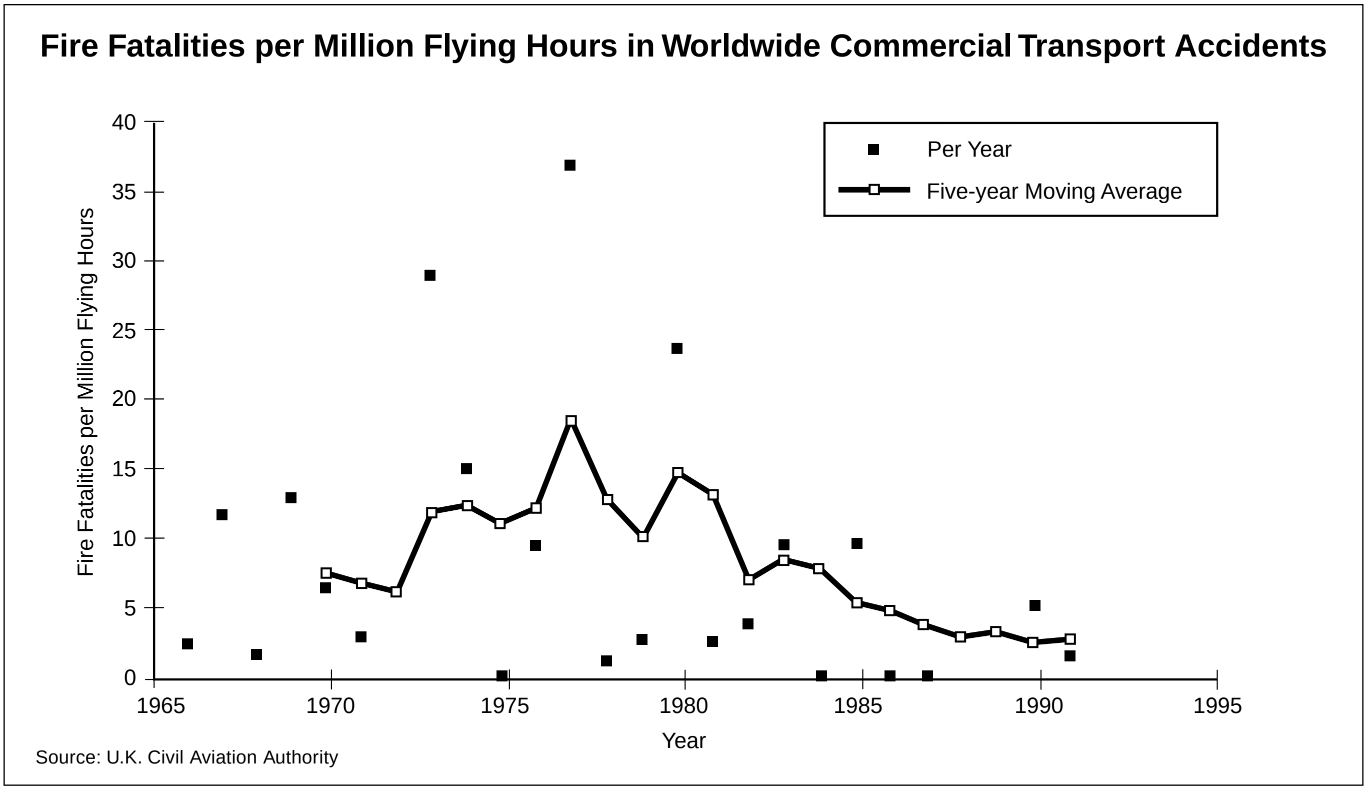

Figure 2

Airport. Shrapnel from the rupture of a right-engine compressor disk penetrated the fuselage and the right-engine main fuel line, resulting in a fire that spread through the cabin. The takeoff was rejected and an emergency evacuation ordered. One flight attendant experienced serious puncture and burn wounds, and five passengers had minor injuries from the evacuation.]

The NTSB report on the 1995 ValuJet accident concluded that "it is reasonable to expect that if an air carrier applied this regulation, as written, an airplane [could be] in service for 20 or more years [and] never be subjected to a 'general retrofit.'"[12]

The NTSB report also noted that it had asked the FAA to "prohibit the use ... of cabin materials in all transport-category airplanes that do not comply with the improved fire safety standards contained in [FARs Part] 25.853," following a 1991 runway collision at Los Angeles (California, U.S.) International Airport. [A USAir B-737 collided with a Skywest Fairchild Metroliner while the B-737 was landing on Runway 24 left. The Metroliner was positioned on the same runway awaiting takeoff clearance. All 10 passengers and crew members aboard the Metroliner and 20 passengers and two crew members aboard the B-737 were killed in the accident.]

The NTSB determined that the B-737 had been manufactured before the effective date of the FAA standards and was not required to be, nor was it, equipped with upgraded fire-retardant cabin furnishings. "Of the 22 killed on board the B-737," the NTSB said, "20 succumbed as a result of the inhalation of toxic smoke that was generated by the burning cabin furnishings."[13]

[The NTSB's recommendation for fleetwide implementation of the Part 25.853 standards was not adopted by the FAA. In March 1992, the FAA responded that it had evaluated the issue and had determined that in the Los Angeles runway incursion accident, it was unlikely that improved materials would have fostered survivability. The FAA letter also declared that such a requirement would not be economically feasible.[13]]

The ASFS program is working on future developments, including new fire-protection requirements for accessible cargo compartments in small airplanes and a TSO for flight recorders that will include new fire-test criteria aimed at ensuring greater recorder survivability in postaccident fires.

The number of people killed by fire in aircraft accidents has declined, with the record far better now than it was 15 years to 20 years ago (Figure 2).[14] The improving trend seems to coincide with the FAA-mandated fire safety improvements implemented from 1984 to 1991. But the same data might also suggest that fire safety improvements have reached a point of diminishing returns and that fire fatalities will increase as world airline traffic increases.

Future Actions Aim at Specific Targets

Future directions for the ASFS program will focus on three major areas: materials, fire management and systems.

Materials research will seek to develop improved or new fire-test methods and criteria for aircraft materials.

Fuselage burn-through. In approximately 50 percent of survivable postaccident fire accidents, the fuselage remains intact, and the cabin is ignited by fire from external fuel tanks burning through the fuselage. An example is the B-737 accident in Manchester, England.

[On Aug. 22, 1985, a British Airtours B-737-236 suffered an uncontained left-engine failure during a takeoff roll. The failure punctured a wing fuel-tank access panel, and fuel leaking from the wing ignited, producing a large fire plume trailing the engine. The pilots rejected the takeoff, brought the aircraft to a halt and ordered an evacuation. Wind directed the fire onto the fuselage.]

Investigators concluded that the fuel fire penetrated the fuselage in about 60 seconds. Although passengers suffered no impact trauma, 55 people died from the effects of the cabin fire. The U.K. Aircraft Accidents Investigation Branch (AAIB) recommended "increased effort directed towards fire hardening of the hull [and] the limitation of fire transmission through the structure."[15]

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The FAA has conducted full-scale fuselage burn-though fire tests. It appears that the area below the main cabin floor is most vulnerable to burn-through because the thermal insulation is not as thick in this area as it is in other areas. Fire and smoke penetration into the cabin first occurs through air-return grilles and sidewall-panel edging.

A cooperative program between the FAA and the U.K. Civil Aviation Authority (CAA) is evaluating new materials and concepts aimed at hardening fuselages against burn-through. Researchers are looking at the insulation properties of thermal-acoustical insulation, at the installation and fastening features of the insulation and whether intumescent paints or mechanical gates will prevent flame entry through air-return grilles. [Intumescent paints swell and char when exposed to heat, forming a fire-retardant barrier between the flame and the coated material.] Success could lead to new design guidelines.

Composite-materials research. The planned use of composite material for fuselages in high-speed civil transports (HSCTs), the next generation of supersonic transport aircraft, is another concern. Conventional aluminum skin conducts heat away and melts quickly when exposed to a fuel fire, but a composite skin chars and is probably an effective barrier against fuel fires originating outside the fuselage, e.g., from a wing tank. On the other hand, there is concern that smoke and toxic or combustible gases can percolate through the composite, filling the cabin. This issue must be resolved at an early stage of the HSCT design.

Hidden in-flight fires. In-flight fires that originate in hidden or inaccessible areas pose a special threat. Upgraded seat-cushion and panel fire-test standards to enhance postaccident fire survivability did not address the in-flight hidden-fire scenario. Hidden fires often involve materials such as thermal-acoustical insulation, wiring and cable installed behind the cabin sidewall, above the ceiling and beneath the floor.

Contamination plays an important role in the problem. Full-scale tests have shown that new and uncontaminated thermal-acoustical insulation will not propagate a fire initiated by a small ignition source.[16] But investigation of a number of hidden fires that occurred in flight and on the ground, and which destroyed some aircraft, revealed extensive contamination (thick, greasy dust on cables) in hidden areas.

Electrically generated fires. Most aircraft in-flight fires are electrical and are usually controlled before they threaten flight safety. Electrical fires can cause high cockpit-smoke levels, but wiring selection in civil transports is not based on smoke-emission standards. Electrical faults from frayed wires have occurred because of failed or improper securing of wiring and cable. More comprehensive test methods are needed for electrical wiring, as are improved methods for securing and protecting cable and wiring.

Fire management research will focus on the rapid and reliable detection of aircraft fires and effective fire extinguishing or suppression.

Risk of fire is posed also by fuel, freight and luggage in cargo compartments, passenger carry-on luggage, hydraulic fluid and emergency-oxygen systems. Fire management employs active systems to counter these fire hazards.

Halon replacement. For 35 years, Halon 1301 was the agent of choice in aircraft fire-extinguishing systems. A later rule, based in part on ASFS program research, requires at least two Halon 1211 hand-held extinguishers in every transport airplane. The requirement is based on the demonstrated superior fire knockdown capabilities and low toxicity of Halon 1211. But on Dec. 31, 1993, the manufacture of Halon ceased because of an international agreement based on evidence that Halon contributed to the depletion of the ozone layer of the Earth's atmosphere.

Because Halon might become unavailable for aircraft fire-extinguishing systems, finding Halon replacements has become the highest priority of the ASFS R&D program.

The FAA is working closely with the aviation industry to evaluate promising new agents under full-scale fire-test conditions and to develop the basis for demonstrating potential substitutes' equivalent fire protection to Halon for aircraft applications, including cargo compartments, engine nacelles, hand-held extinguishers and lavatory trash receptacles.[17]

Cabin water-spray systems. Cabin water-spray systems have been considered as a way to increase postaccident fire survivability against all fire sources, including burning jet fuel. The FAA has worked with the U.K. CAA and Transport Canada to test and develop a cabin water-spray system. The system tested, which was developed in the United Kingdom, continuously sprayed water throughout the cabin for about three minutes.

In numerous full-scale fire tests involving a range of fire scenarios and employing wide-body, standard-body and commuter-aircraft test platforms, it was shown that water spray increased survival time by two minutes to three minutes in all but the most severe fire conditions. In addition, a zoned system was developed that provided more protection than the original system but used only 10 percent as much water.

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Cabin water-spray systems were criticized on the grounds that the water contacting the fire would create large quantities of steam, which could cause respiratory-tract injuries and might heat parts of the cabin to such a degree that the risk of thermal injury to passengers would be greater. But a study undertaken by the FAA CAMI concluded that the hazard of steam injury was relatively low because of the localized nature of the systems being tested.

"Although a potential hazard from steam and hot water vapor–saturated air does exist, exposure to these conditions for more than a second or two is highly unlikely and could theoretically be avoided by maintaining the correct posture and quickly evacuating the aircraft," the study report said. It added that the overall heat in a cabin during a fire would be "significantly higher" *without* the cabin water-spray system.[18]

Nevertheless, two drawbacks to such systems stand in the way of their practical application: a high weight penalty and high cost of installation. Those factors, combined with the relatively small number of fire fatalities in recent years, seem likely to delay or prohibit cabin water-spray systems from being required.

The FAA is now evaluating the effectiveness of cabin water-spray systems against cargo fires as a potential Halon alternative. Cabin water-spray systems will also be evaluated for future aircraft designs, where the cost-benefit ratio may be more favorable than it is in present designs.

Fire detection. Reliable and rapid detection of fire and smoke is critical to effective intervention systems and procedures. It has been estimated that 90 percent of cargo compartment smoke-detector activations are false alarms. Although Part 25.858 states that a cargo compartment fire-detection system "must provide a visual indication to the flight crew within one minute after the start of a fire," there are currently no standardized test procedures to demonstrate compliance with this regulation.

Responsiveness to actual fires may vary for different FAA-approved smoke-detection systems. For example, FAA fire tests have demonstrated that artificial smoke, used to certify smoke detectors, produced a more rapid response time than real smoke in detector systems employing vacuum-sampling lines.[19] Thus, a need exists for more reliable smoke-detection systems and standardized test procedures for the certification of aircraft smoke detectors.

Lavatory fire protection. Lavatories have been the source of several fatal in-flight fires, including the 1983 Air Canada accident, which caused a total of 146 fire-related fatalities. Since then, the FAA has made important improvements in lavatory fire protection. Smoking has been banned and Halon fire extinguishers placed in lavatories, and lavatory trash receptacles have been fire-hardened. FARs Part 25.854, which went into effect in May 1991, mandates that for airplanes with a passenger capacity of 20 or more:

- "Each lavatory must be equipped with a smoke-detector system or equivalent that provides a warning light in the cockpit, or provides a warning light or audible warning in the passenger cabin that would be readily detected by a flight attendant; [and,]

- "Each lavatory must be equipped with a built-in fire extinguisher for each disposal receptacle for towels, paper or waste located within the lavatory. The extinguisher must be designed to discharge automatically into each disposal receptacle upon occurrence of a fire in that receptacle."

Nevertheless, serious lavatory fires continue to occur. On Sept. 5, 1993, an in-flight fire occurred about 20 minutes after takeoff in the aft lavatory of a Dominicana de Aviacion B-727 en route from San Jose, Costa Rica, to Santo Domingo, Dominican Republic. The flight crew made a safe landing and all of the aircraft's occupants escaped, but the fire destroyed the aircraft. The accident also highlighted deficient crew procedures in locating and extinguishing in-flight fires.

Hand-held extinguishers, for example, were readied but never discharged.

On March 17, 1995, an Intercontinental Airlines DC-9 was gutted by fire while parked on a ramp in Barranquilla, Colombia. Investigators noted similarities between this unattended ramp fire and the 1983 Air Canada in-flight fire.

These fires raise concern about the adequacy of lavatory fire protection. Potential ignition sources include flushing motors, water heaters, lighting ballasts, electrical outlets, improper passenger activity (detector tampering, smoking, etc.) and certain design features, such as high ventilation rates, that may circumvent early fire detection. All point to the need for R&D to enhance fire protection design and crew fire-fighting procedures in aircraft lavatories.

Aerosol cans. Aerosol cans carried in passenger luggage are a relatively unrecognized fire safety hazard. Since 1979, aerosol cans have employed flammable hydrocarbon propellants including propane, butane and isobutane to replace ozone-depleting chlorofluorocarbons (CFCs). The remnants of discharged aerosol cans have been found in burned-out aircraft, although it has been difficult to establish what roles, if any, the aerosol cans played causing in the fires.

Full-scale fire tests have shown that bursting aerosol cans release their hydrocarbon propellants and increase the fire growth rate. They may also become projectiles that dislodge or penetrate cargo liners, allowing a fire to spread to other areas of the airplane.[20] The behavior of aerosol cans in cargo compartment fire tests has parallels elsewhere; bursting cans have broken through car trunks and windshields after being overheated by the sun.

A safer aerosol can design has been developed under an FAA-funded Small Business Innovative Research (SBIR) study. The improved can withstands higher operating pressures and provides a mechanism for the controlled release of the can's contents at elevated pressure.[21] Additional research is necessary to determine the benefit of improved aerosol cans and to develop the design concept into a viable product.

Very large commercial transports. R&D is also focusing on future aircraft designs, such as upper-deck vulnerability in double-deck very large commercial transports (VLCTs) that will carry between 800 passengers and 1,000 passengers. Carrying out an emergency evacuation from high elevations would become even more life-threatening if a chimney-like effect created a fire on the upper deck.

Industry and government officials agree that the VLCT must be designed to higher fire safety standards than present-day transport aircraft. In a parallel past situation, more stringent fire-safety and emergency-evacuation design criteria were imposed on wide-body jets when they were introduced into service in the early 1970s.

Enhanced fire protection of the VLCT upper deck would likely involve three elements:

- Developing fire stops and barriers to prevent fire from spreading upward from the lower deck. All potential fire paths such as open stairways and elevators would require protective measures to prevent upward flame spread;

- Protecting the upper-deck floor from the effects of a fire from below. The strength of flooring and floor beams, especially those of composite construction, must be adequate during evacuation to prevent floor collapse; and,

- Enhancing fire protection of the upper-cabin interior will likely raise the relative effectiveness of improved fire-resistant materials above that of an on-board cabin water-spray system.

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Research will explore the protection of vital aircraft systems from the effects of fire or prevention of the malfunction of these systems from causing or accelerating the spread of a fire.

Past accidents and full-scale tests indicate that improvements in oxygen and hydraulic systems could improve both postaccident and in-flight fire safety.

Oxygen systems. A large amount of "pure" oxygen is carried on commercial airliners. Oxygen systems include oxygen generators for passenger use in the event of depressurization, oxygen for the flight crew, medical oxygen and crew breathing-protection devices for in-flight fire. Prevention of fires caused by oxygen-system malfunctions during servicing and maintenance will prevent hull losses.

In its initial investigation of the May 1996 ValuJet Flight 592 accident, the NTSB estimated that more than 150 chemical oxygen generators were shipped as cargo on the accident aircraft.

The oxygen generators in the cargo compartment of Flight 592, which were capable of producing intense heat during oxygenation, lacked the shipping caps needed to shield the oxygen generators against accidental discharge, the NTSB said. The cargo compartment had no fire- or smoke-detection system to alert the pilots to the fire.

[The NTSB urgently recommended, among other things, that FAA permanently prohibit carrying oxygen generators aboard passenger or cargo aircraft unless the oxygen generators' chemical cores have been discharged. The FAA's Nov. 14 announcement in effect accepted the recommendation.]

Oxygen generators have been the cause of several other transport aircraft fires. Inadvertent activation of an oxygen-supply canister caused a fire that gutted a DC-10 in Chicago, Illinois, U.S., on Aug. 10, 1986. [The American Trans Air charter flight had landed and discharged its passengers normally, with no indication of fire. A company maintenance worker, examining damaged passenger seat backs incorporating chemical oxygen generators that had been carried as cargo aboard the aircraft, accidentally triggered the oxygen-generation reaction in one canister. Nearby seat covers were ignited, and the fire burned through the cabin floor and eventually consumed the cabin.]

In an Oct. 11, 1989, accident in Salt Lake City, replacement of an oxygen bottle during preboarding of a B-727 caused an extremely intense fire that rapidly spread throughout the cabin. There were few occupants on board, and they were able to escape the fire as it reached untenable conditions within 45 seconds.

In addition, many of the postaccident fire fatalities in the 1991 runway incursion accident in Los Angeles were attributed to the severed crew emergency-oxygen system.

FAA fire tests demonstrated a three-minute loss of survival potential because of the release of oxygen into a postaccident cabin fire.[22] Ways to reduce the quantity of oxygen accidentally released, such as flow restrictors, fuses or solid-oxygen generators, should be explored. The ultimate answer may be an oxygen-generation system using gas separation–membrane technology, which would require a long-term R&D program.

Hydraulic systems. Aircraft hydraulic fluid has been the source of both in-flight and postaccident fires. An America West B-737 experienced a short circuit of a wire in a "B" hydraulic pump, which punctured an "A" hydraulic system line. A fire erupted and burned through to the electrical wires to the standby hydraulic pump. The flight crew maintained manual control and touched down safely, but the aircraft slid 1,160 meters (3,803 feet) past the runway end. There were no injuries in the Dec. 30, 1989, accident at Tucson, Arizona, U.S. FAA tests indicated that hydraulic-fluid spray contained in an enclosure, such as a wheel well, can burn intensely if ignited.

On Nov. 19, 1980, a Boeing 747 experienced a fire following a hard landing at Seoul, Korea, when sparks ignited hydraulic fluid released by damaged struts. Fifteen people died in the postaccident fire, which did not involve jet-fuel spillage.

There is a misconception that fire-resistant aviation hydraulic fluid is noncombustible. Near-term R&D is necessary to determine what improvements are feasible to prevent or further minimize hydraulic-fluid fires.[23]

Because of large R&D fund reductions by the U.S. Congress and increasing competition among FAA safety programs, it is difficult to set a timetable for future fire-safety research. It is likely that more research projects will not be funded than will be funded during the next five years.♦

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