United States General Accounting Office

GAO

Report to the Ranking Democratic Member, Committee on Transportation and Infrastructure, House of Representatives

October 2003

AVIATION SAFETY

Advancements Being Pursued to Improve Airliner Cabin Occupant Safety and Health

GAO

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GAO-04-33

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GAO Accountability•Integrity•Reliability

Highlights

Highlights of GAO-04-33, a report to the Ranking Democratic Member, Committee on Transportation and Infrastructure, House of Representatives

Why GAO Did This Study

Airline travel is one of the safest modes of public transportation in the United States. Furthermore, there are survivors in the majority of airliner crashes, according to the National Transportation Safety Board (NTSB). Additionally, more passengers might have survived if they had been better protected from the impact of the crash, smoke, or fire or better able to evacuate the airliner. As requested, GAO addressed (1) the regulatory actions that the Federal Aviation Administration (FAA) has taken and the technological and operational improvements, called advancements, that are available or are being developed to address common safety and health issues in large commercial airliner cabins and (2) the barriers, if any, that the United States faces in implementing such advancements.

What GAO Recommends

This report contains recommendations to FAA to initiate discussions with NTSB to facilitate the exchange of medical information from accident investigations and to improve the cost and effectiveness data available for setting priorities for research on cabin occupant safety and health. FAA generally agreed with the report's contents and its recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-04-33.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Gerald Dillingham at (202) 512-2834 or dillinghamg@gao.gov.

What GAO Found

FAA has taken a number of regulatory actions over the past several decades to address safety and health issues faced by passengers and flight attendants in large commercial airliner cabins. GAO identified 18 completed actions, including those that require safer seats, cushions with better fire-blocking properties, better floor emergency lighting, and emergency medical kits. GAO also identified 28 advancements that show potential to further improve cabin safety and health. These advancements vary in their readiness for deployment. Fourteen are mature, currently available, and used in some airliners. Among these are inflatable lap seat belts, exit doors over the wings that swing out on hinges instead of requiring manual removal, and photo-luminescent floor lighting. The other 14 advancements are in various stages of research, engineering, and development in the United States, Canada, or Europe.

Several factors have slowed the implementation of airliner cabin safety and health advancements. For example, when advancements are ready for commercial use, factors that may hinder their implementation include the time it takes for (1) FAA to complete the rule-making process, (2) U.S. and foreign aviation authorities to resolve differences between their respective requirements, and (3) the airlines to adopt or install advancements after FAA has approved their use. When advancements are not ready for commercial use because they require further research, FAA's processes for setting research priorities and selecting research projects may not ensure that the limited federal funding for cabin safety and health research is allocated to the most critical and cost-effective projects. In particular, FAA does not obtain autopsy and survivor information from NTSB after it investigates a crash. This information could help FAA identify and target research to the primary causes of death and injury. In addition, FAA does not typically perform detailed analyses of the costs and effectiveness of potential cabin occupant safety and health advancements, which could help it identify and target research to the most cost-effective projects.

A Survivable Large Commercial Airliner Accident

Source: FAA.

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Abbreviations

ACRM	Advanced Crew Resource Management
CAMI	Civil Aerospace Medical Institute
CRM	Crew Resource Management
DGAC	Direction Générale de l'Aviation Civile
DOT	Department of Transportation
DOT IG	Department of Transportation's Inspector General
DVT	deep vein thrombosis
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
JAA	European Joint Aviation Authorities
NASA	National Aeronautics and Space Administration
NIOSH	National Institute of Safety and Health
NTSB	National Transportation Safety Board
OSHA	Occupational Health and Safety Administration
TRL	Technical Readiness Level
TSO	Technical Standing Order

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Accountability * Integrity * Reliability

United States General Accounting Office
Washington, D.C. 20548

October 3, 2003

The Honorable James L. Oberstar
Ranking Democratic Member
Committee on Transportation
and Infrastructure
House of Representatives

Dear Mr. Oberstar:

Airline travel is one of the safest modes of public transportation in the United States, in large part because of the Congress's, Federal Aviation Administration's (FAA), commercial airlines', aircraft manufacturers', and airports' combined efforts to prevent commercial airliner accidents. Furthermore, although a few airliner accidents are catastrophic, there are survivors in a majority of crashes. According to the National Transportation Safety Board (NTSB), passengers survived in 19 of the 26 U.S. large commercial airliner accidents that occurred from 1982 through 2001, and in these 19 accidents, over 76 percent of the passengers (1,523 of 1,988) survived.[1] Additionally, some of the passengers who died in these accidents might have survived if they had been better protected from the impact of the crash or from the effects of smoke and fire and had been better able to evacuate the airliner. This possibility of survival has led federal safety officials to focus their efforts not only on preventing airliner accidents, but also on increasing the chances of surviving them.

Over the past several decades, FAA has been taking regulatory actions to require the implementation of technological and operational improvements in cabin occupant safety and health to help increase passengers' chances of surviving large commercial airliner accidents. In addition, FAA and the aviation community have been conducting research on new technological and operational improvements, which we refer to in this report as advancements, whose implementation could further increase passengers' chances of survival and improve the safety and health of passengers and flight attendants. This report discusses regulatory actions that FAA has taken as well as potential advancements in cabin occupant safety and health that are (1) currently available but not yet implemented or installed, and (2) not yet available and subject to additional research to advance the

[1]Large, or 'transport category' commercial aircraft are defined as those with a capacity of 30 or more passengers or a load of 7,500 pounds or more.

technology or lower costs. For implementation of these advancements to occur, FAA often has to take regulatory action, that is, issuing regulations or airworthiness directives that require the implementation of technological and operational improvements in cabin occupant safety and health. FAA continues to pursue regulatory initiatives as well as conduct research to improve cabin occupant safety and health. The aviation community is also attempting to enhance the safety and health of those traveling and working in airliner cabins through such measures as providing earlier warnings of turbulence and information on the potential to develop blood clots on long-distance flights. Besides increasing cabin occupants' safety and health, these actions and efforts could benefit the airlines by helping to restore passengers' confidence in the safety of flight and thereby increasing the demand for air travel, which fell sharply after September 11, 2001, and still remains below fiscal year 2000 levels.

In response to your request, this report addresses the following questions: (1) What regulatory actions has FAA taken, and what key advancements are available or being developed by FAA and others to address safety and health issues faced by passengers and flight attendants in large commercial airliner cabins? (2) What factors, if any, slow the implementation of advancements in cabin occupant safety and health? In addition, as requested, we identified some factors faced by Canada and Europe in their efforts to improve cabin occupant safety and health (see app. II).

To identify the regulatory actions FAA has taken and the key advancements that are available or being developed to address safety and health issues facing passengers and flight attendants (cabin occupants), we reviewed the relevant literature, interviewed FAA officials, and reviewed FAA's documentation on the regulatory actions it has taken to enhance cabin occupant safety and health. As part of this effort, FAA officials identified key regulatory actions that had been completed in this area. In addition, we interviewed other aviation safety experts in government, industry, and academia from the United States, Canada, and Europe. (See app. I for additional information.) Through our reviews and interviews, we found that FAA's regulatory actions and advancements fell into four broad categories—three related to safety in the event of a crash and one related to general cabin occupant safety and health. The regulatory actions and advancements related to safety in the event of a crash are those actions taken to (1) minimize injuries from the impact of a crash, (2) prevent fire or mitigate its effects, and (3) improve the chances and speed of evacuation. In addition, we discuss the regulatory actions and advancements FAA has taken to address a fourth category—improving the safety and health of cabin occupants. Using the results of our reviews and interviews, we identified and categorized 28 advancements that are currently available or being developed, including 5 impact advancements, 8 fire advancements, 10 evacuation advancements, and 5 cabin occupant safety and health advancements. For each of these advancements, we discuss the background, research, and regulatory status.[2] We also discuss each advancement's technological readiness for use in the existing commercial airliner fleet or in newly produced commercial airplanes. To identify factors that have slowed implementation of airliner cabin occupant safety and health advancements, we interviewed FAA, NTSB, and industry officials. In addition, we analyzed documentation from FAA, NTSB, and aviation safety experts to identify factors relating to key issues within FAA and the aviation community related to prioritizing and funding research, choosing advancements for regulatory implementation, and gaining the aviation community's acceptance of these advancements.

This report does not address cabin air quality because we are doing work in this area for another congressional requester. In addition, given the large scope of this review, the report does not focus on safety and health issues for flight deck crews (pilots and flight engineers) since they face some unique issues not faced by cabin occupants. It also does not address aviation security issues, such as hijackings, sabotage, or terrorist activities.

We conducted our review from January 2002 through September 2003 in accordance with generally accepted government auditing standards.

Results in Brief

FAA has taken a number of key regulatory actions over the past several decades to improve the safety and health of passengers and flight attendants in large commercial airliner cabins. We identified 18 such completed regulatory actions that FAA has taken since 1984. Table 1 shows the number of such actions by category and provides an example for each category of action.

[2]In identifying 28 advancements, we are not suggesting that these are the only advancements being pursued, rather that these advancements have been recognized by aviation safety experts we contacted as offering promise for improving the safety and health of cabin occupants.

Table 1: Regulatory Actions Taken by FAA to Improve Cabin Occupant Safety and Health Since 1984

Category of regulatory action	Example	Number of key actions taken
Minimize injuries from the impact of a crash	Stronger seats	2
Prevent fire or mitigate its effects	Fire-blocking seat cushions	7
Improve the chances and speed of evacuation	Emergency floor lighting	6
Improve the safety and health of cabin occupants	Onboard emergency medical kits	3

Source: GAO.

We also identified 28 advancements that have the potential to increase the chances of surviving a commercial airliner crash and to improve the safety and health of cabin occupants—both passengers and flight attendants. Table 2 shows the number of such advancements by category and provides an example for each.

Table 2: Advancements with Potential to Improve Cabin Occupant Safety and Health

Category of advancement	Example	Number of key advancements
Minimize injuries from the impact of a crash	Lap seat belts with inflatable air bags	5
Prevent fire or mitigate its effects	Reduced fuel tank flammability	8
Improve the chances and speed of evacuation	Improved passenger safety briefings	10
Improve the safety and health of cabin occupants	Advanced warnings of turbulence	5

Source: GAO.

These 28 advancements vary in their readiness for deployment. For example, 14 of the technologies are currently available but not yet implemented or installed. Two of these, preparation for in-flight medical emergencies and improved insulation, were addressed through separate regulations. These regulations require airlines to install additional emergency medical equipment (automatic external defibrillators and enhanced emergency medical kits) by 2004, replace flammable insulation (metalized Mylar®) with improved insulation by 2005, and manufacture new large commercial airliners with improved (thermal acoustic) insulation beginning September 2, 2005. Another currently available advancement is in FAA's rule-making process—retrofitting the entire existing fleet with significantly stronger seats. These seats, commonly referred to as 16g seats, for example, can withstand the force of an impact 16 times a passenger's body weight (16g), rather than 9 times (9g), as currently required primarily for new generation commercial aircraft.[3] For the remaining 11 currently available advancements, while FAA does not require their use, some are being used by selected airlines. For example, some airlines have elected to use inflatable lap seat belts, exit doors over the wings that swing out on hinges instead of requiring manual removal, and photo-luminescent floor lighting.[4] In addition, some of these advancements are available for purchase by the flying public, including smoke hoods and child safety seats certified for use on commercial airliners. The remaining 14 advancements are in various stages of research, engineering, and development in the United States, Canada, or Europe.

Several factors slow the implementation of advancements in cabin occupant safety and health, including those that are currently available, but have not yet been implemented or installed and those that require further research to demonstrate their effectiveness or lower their costs before they are ready for implementation. For those that are ready, and for which design and certification standards have been developed, FAA may undertake the rule-making process to require their implementation. As our prior work has shown, this process can take years. In addition, FAA and its international counterparts attempt to reach agreement on, or harmonize, their requirements for aviation procedures and equipment. The authorities' current harmonization process has resulted in a backlog, which has slowed the implementation of several cabin occupant safety and health advancements. Finally, the airlines must implement the advancements. While some advancements, such as improved safety briefings, can be implemented quickly and economically, others, such as retrofitting commercial aircraft with stronger passenger seats, require time-

[3]A separate rule-making effort in 1988 required that newly manufactured aircraft be equipped with stronger, 16g seats; however, it did not require that the existing U.S. fleet of commercial aircraft be retrofitted with these seats.

[4]FAA officials told us that using photo-luminescent lighting is a different way to meet an existing standard and, therefore, should not be considered an advancement in safety. However, because photo-luminescent floor lighting differs from standard floor lighting in that it works without electricity, some in the aviation community consider it a safety advancement.

consuming, costly changes. FAA may give the airlines several years to retrofit their fleets in order to coordinate the change, when possible, with existing maintenance schedules and allow the airlines to absorb the associated costs. For advancements that require further research before they can be considered for use, FAA's multistep process for identifying potential cabin occupant safety and health research projects and allocating its limited resources to research projects on the advancements is hampered by a lack of autopsy and survivor information and cost and effectiveness data. According to FAA researchers, they have not had adequate access to autopsy reports and certain survivor information that NTSB obtains from autopsy reports and interviews with survivors during its investigations of commercial airliner accidents. This information could help FAA to identify the principal causes of death and injury and the major factors affecting survival, and to target research to advancements addressing these critical causes and factors. NTSB told us that while they provide large amounts of information on the causes of death and injury in information they make publicly available, they would consider making this additional information available to FAA if steps were taken to safeguard the privacy of victims and survivors. FAA's multistep process for selecting research projects on advancements includes consideration of such factors as their potential impact on accident prevention and accident mitigation; however, it does not include developing comparable estimates of cost and effectiveness for competing advancements to allow direct comparisons between them on their potential to reduce injuries and deaths. We developed a cost analysis methodology to illustrate how FAA could develop comparable cost estimates, to enhance its current process. The results of such analyses could be combined with similar estimates of effectiveness using data available from a variety of sources, including industry and academia. Using comparable cost and effectiveness data across the range of advancements could position the agency to choose more effectively between competing advancements, taking into account estimates of the number of injuries and fatalities that each advancement might prevent for the dollars invested. Such cost and effectiveness data would provide a valuable supplement to FAA's current process for setting research priorities and selecting projects for funding.

This report contains a recommendation to the Secretary of Transportation to direct the FAA Administrator to initiate discussions with NTSB to facilitate the exchange of medical information from accident investigations. In addition, the report contains a recommendation to the FAA Administrator to improve the analyses available to decision makers responsible for setting research priorities and selecting projects for improving the safety and health of cabin occupants by (1) developing comparable cost estimates of potential advancements competing for funding and (2) developing or collecting data on the effectiveness of each potential advancement to reduce injuries or fatalities. In commenting on a draft of this report, FAA said that they generally agreed with the report's contents and its recommendations.

Background

The safe travel of U.S. airline passengers is a joint responsibility of FAA and the airlines in accordance with the Federal Aviation Act of 1958, as amended, and the Department of Transportation Act, as amended. To carry out its responsibilities under these acts, FAA supports research and development; certifies that new technologies and procedures are safe; undertakes rule-makings, which when finalized form the basis of federal aviation regulations; issues other guidance, such as Advisory Circulars; and oversees the industry's compliance with standards that aircraft manufacturers and airlines must meet to build and operate commercial aircraft. Aircraft manufacturers are responsible for designing aircraft that meet FAA's safety standards, and air carriers are responsible for operating and maintaining their aircraft in accordance with the standards for safety and maintenance established in FAA's regulations. FAA, in turn, certifies aircraft designs and monitors the industry's compliance with the regulations.

FAA's general process for issuing a regulation, or rule, includes several steps. When the regulation would require the implementation of a technology or operation, FAA first certifies that the technology or operation is safe. Then, FAA publishes a notice of proposed rule-making in the *Federal Register*, which sets forth the terms of the rule and establishes a period for the public to comment on it. Next, FAA reviews the comments by incorporating changes into the rule that it believes are warranted, and, in some instances, it repeats these steps one or more times. Finally, FAA publishes a final rule in the *Federal Register*. The final rule includes the date when it will go into effect and a time line for compliance.

Within FAA, the Aircraft Certification Service is responsible for certifying that technologies are safe, including improvements to cabin occupant safety and health, generally through the issuance of new regulations, a finding certifying an equivalent level of safety, or a special condition when no rule covers the new technology. The Certification Service is also responsible for taking enforcement action to ensure the continued safety of aircraft by prescribing standards for aircraft manufacturers governing the design, production, and airworthiness of aeronautical products, such as cabin interiors. The Flight Standards Service is primarily responsible for certifying an airline's operations (assessing the airline's ability to carry out its operations and maintain the airworthiness of the aircraft) and for monitoring the operations and maintenance of the airline's fleet.

FAA conducts research on cabin occupant safety and health issues in two research facilities, the Mike Monroney Aeronautical Center/Civil Aerospace Medical Institute in Oklahoma City, Oklahoma, and the William J. Hughes Technical Center in Atlantic City, New Jersey. The institute focuses on the impact of flight operations on human health, while the technical center focuses on improvements in aircraft design, operation, and maintenance and inspection to prevent accidents and improve survivability. For the institute or the technical center to conduct research on a project, an internal FAA requester must sponsor the project. For example, FAA's Office of Regulation and Certification sponsors much of the two facilities' work in support of FAA's rule-making activities. FAA also cooperates on cabin safety research with the National Aeronautics and Space Administration (NASA), academic institutions, and private research organizations.

Until recently, NASA conducted research on airplane crashworthiness at its Langley Research Center in Hampton, Virginia. However, because of internal budget reallocations and a decision to devote more of its funds to aviation security, NASA terminated the Langley Center's research on the crashworthiness of commercial aircraft in 2002. NASA continues to conduct fire-related research on cabin safety issues at its Glenn Research Center in Cleveland, Ohio.

NTSB has the authority to investigate civil aviation accidents and collects data on the causes of injuries and death for the victims of commercial airliner accidents. According to NTSB, the majority of fatalities in commercial airliner accidents are attributable to crash impact forces and the effects of fire and smoke. Specifically, 306 (66 percent) of the 465 fatalities in partially survivable U.S. aviation accidents from 1983 through 2000 died from impact forces, 131 (28 percent) died from fire and smoke, and 28 (6 percent) died from other causes.[5]

[5]NTSB, *Survivability of Accidents Involving Part 121 U.S. Air Carrier Operations, 1983 Through 2000*, NTSB/SR-01/01.

Surviving an airplane crash depends on a number of factors. The space surrounding a passenger must remain large enough to prevent the passenger from being crushed. The force of impact must also be reduced to levels that the passenger can withstand, either by spreading the impact over a larger part of the body or by increasing the duration of the impact through an energy-absorbing seat or fuselage. The passenger must be restrained in a seat to avoid striking the interior of the airplane, and the seat must not become detached from the floor. Objects within the airplane, such as debris, overhead luggage bins, luggage, and galley equipment, must not strike the passenger. A fire in the cabin must be prevented, or, if one does start, it must burn slowly enough and produce low enough levels of toxic gases to allow the passenger to escape from the airplane. If there is a fire, the passenger must not have sustained injuries that prevent him or her from escaping quickly. Finally, if the passenger escapes serious injury from impact and fire, he or she must have access to exit doors and slides or other means of evacuation.

Regulatory Actions Have Been Taken and Additional Advancements Are Under Way to Improve Cabin Occupants' Safety and Health

Over the past several decades, FAA has taken a number of regulatory actions designed to improve the safety and health of airline passengers and flight attendants by (1) minimizing injuries from the impact of a crash, (2) preventing fire or mitigating its effects, (3) improving the chances and speed of evacuation, or (4) improving the safety and health of cabin occupants. (See app. III for more information on the regulatory actions FAA has taken to improve cabin occupant safety and health.) Specifically, we identified 18 completed regulatory actions that FAA has taken since 1984. In addition to these past actions, FAA and others in the aviation community are pursuing advancements in these four areas to improve cabin occupant safety and health in the future. We identified and reviewed 28 such advancements—5 to reduce the impact of a crash on occupants, 8 to prevent or mitigate fire and its effects, 10 to facilitate evacuation from aircraft, and 5 to address general cabin occupant safety and health issues.

Minimizing Injuries from the Impact of a Crash

The primary cause of injury and death for cabin occupants in an airliner accident is the impact of the crash itself. We identified two key regulatory actions that FAA has taken to better protect passengers from impact forces. For example, in 1988, FAA required stronger passenger seats for newly manufactured commercial airplanes to improve protection in survivable crashes.[6] These new seats are capable, for example, of withstanding an impact force that is approximately 16 times a passenger's body weight (16g), rather than 9 times (9g), and must be tested dynamically (in multiple directions to simulate crash conditions), rather than statically (e.g., drop testing to assess the damage from the force of the weight alone without motion). In addition, in 1992, FAA issued a requirement for corrective action (airworthiness directive) for designs found not to meet the existing rules for overhead storage bins on certain Boeing aircraft, to improve their crashworthiness after bin failures were observed in the 1989 crash of an airliner in Kegworth, England, and a 1991 crash near Stockholm, Sweden.

We also identified five key advancements that are being pursued to provide cabin occupants with greater impact protection in the future. These advancements are either under development or currently available. Examples include the following:

- *Lap seat belts with inflatable air bags*: Lap seat belts that contain inflatable air bags have been developed by private companies and are currently available to provide passengers with added protection during a crash. About 1,000 of these lap seat belts have been installed on commercial airplanes, primarily in the seats facing wall dividers (bulkheads) to prevent passengers from sustaining head injuries during a crash. (See fig. 1.)

- *Improved seating systems*: Seat safety depends on several interrelated systems operating properly, and, therefore, an airline seat is most accurately discussed as a system. New seating system designs are being developed by manufacturers to incorporate new safety and aesthetic designs as well as meet FAA's 16g seat regulations to better protect passengers from impact forces. These seating systems would help to ensure that the seats themselves perform as expected (i.e., they stay attached to the floor tracks); the space between the seats remains adequate in a crash; and the equipment in the seating area, such as phones and video screens, does not increase the impact hazard.

[6]FAA subsequently proposed, in October 2002, that the 16g seats be put into the entire existing fleet for both passengers and flight attendants within 14 years to better protect passengers from impact forces. We included this proposal in our list of advancements.

- *Child safety seats*: Child safety seats could provide small children with additional protection in the event of an airliner crash. NTSB and others have recommended their use, and FAA has been involved in this issue for at least 15 years. While it has used its rule-making process to consider requiring their use, FAA decided not to require child safety restraints because its analysis found that if passengers were required to pay full fare for children under the age of 2, some parents would choose to travel by automobile and, statistically, the chances would increase that both the children and the adults would be killed. FAA is continuing to consider a child safety seat requirement.

Figure 1: Inflatable Lap Belt Air Bag Inflation Sequence

Source: Amsafe Aviation.

Bulkhead wall seat inflation sequence.

Appendix IV contains additional information on the impact advancements we have identified.

Preventing Fire or Mitigating Its Effect

Fire prevention and mitigation efforts have given passengers additional time to evacuate an airliner following a crash or cabin fire. FAA has taken seven key regulatory actions to improve fire detection, eliminate potential fire hazards, prevent the spread of fires, and better extinguish them. For example, to help prevent the spread of fire and give passengers more time to escape, FAA upgraded fire safety standards to require that seat cushions have fire-blocking layers, which resulted in airlines retrofitting 650,000 seats over a 3-year period. The agency also set new low heat/smoke standards for materials used for large interior surfaces (e.g., sidewalls, ceilings, and overhead bins), which FAA officials told us resulted in a significant improvement in postcrash fire survivability. FAA also required smoke detectors to be placed in lavatories and automatic fire extinguishers in lavatory waste receptacles in 1986 and 1987, respectively. In addition, the agency required airlines to retrofit their fleets with fire detection and suppression systems in cargo compartments, which according to FAA, applied to over 3,700 aircraft at a cost to airlines of $300 million. To better extinguish fires when they do start, FAA also required, in 1985, that commercial airliners carry two Halon fire extinguishers in addition to other required extinguishers because of Halon's superior fire suppression capabilities.

We also identified 8 key advancements that are currently available and awaiting implementation or are under development to provide additional fire protection for cabin occupants in the future. Examples include the following:

- *Reduced flammability of insulation materials*: To eliminate a potential fire hazard, in May 2000, FAA required that air carriers replace insulation blankets covered with a type of insulation known as metalized Mylar® on specific aircraft by 2005, after it was found that the material had ignited and contributed to the crash of Swiss Air Flight 111.[7] Over 700 aircraft were affected by this requirement. In addition, FAA issued a rule in July 2003 requiring that large commercial airplanes manufactured after September 2, 2005, be equipped with thermal acoustic insulation designed to an upgraded fire test standard that will reduce the incidence and intensity of in-flight fires. In addition, after September 2, 2007, newly manufactured aircraft must be equipped with thermal acoustic materials designed to meet a new standard for burn-through resistance, providing passengers more time to escape during a postcrash fire.

- *Reduced fuel tank flammability*: Flammable vapors in aircraft fuel tanks can ignite. However, currently available technology can greatly reduce this hazard by "blanketing" the fuel tank with nonexplosive nitrogen-enriched air to suppress ("inert") the potential for explosion of the tank. The U.S. military has used this technology on selected aircraft for 20 years, but U.S. commercial airlines have not adopted the technology because of its cost and weight. FAA officials told us that the military's technology was also unreliable and designed to meet military rather than civilian airplane design requirements. FAA fire safety experts have developed a lighter-weight inerting system for center fuel tanks, which is simpler than the military system and potentially more

[7] Affected aircraft included Boeing MD-80, MD-88, MD-90, DC-10, and MD-11.

reliable. Reliability of this technology is a major concern for the aviation industry. According to FAA officials, Boeing and Airbus began flight testing this technology in July 2003 and August 2003, respectively.[8] In addition, the Air Transport Association (ATA) noted that inerting is only one prospective component of an ongoing major program for fuel tank safety, and that it has yet to be justified as feasible and cost-effective.

- *Sensor technology*: Sensors are currently being developed to better detect overheated or burning materials. According to FAA and the National Institute of Standards and Technology, many current smoke and fire detectors are not reliable. For example, a recent FAA study reported at least one false alarm per week in cargo compartment fire detection systems. The new detectors are being developed by Airbus and others in private industry to reduce the number of false alarms. In addition, FAA is developing standards that would be used to approve new, reduced false alarm sensors. NASA is also developing new sensors and detectors.

- *Water mist for extinguishing fires*: Technology has been under development for over two decades to dispense water mist during a fire to protect passengers from heat and smoke and prevent the spread of fire in the cabin. The most significant development effort has been made by a European public-private consortium, FIREDETEX, with over 5 million euros of European Community funding and a total project cost of over 10 million euros (over 10 million U.S. dollars). The development of this system was prompted, in part, by the need to replace Halon, when it was determined that this main firefighting agent used in fire extinguishers aboard commercial airliners depletes ozone in the atmosphere.

Appendix V contains additional information on advancements that address fire prevention and mitigation.

Improving the Chances and Speed of Evacuation

Enabling passengers to evacuate more quickly during an emergency has saved lives. Over the past two decades, FAA has completed regulatory action on the following six key requirements to help speed evacuations:

[8]According to FAA, Boeing is flight testing a system similar to the FAA design, and Airbus is flight testing the FAA system in an A320. Boeing announced that it would begin installing inerting systems similar to the FAA design in their 747s in 2005.

- Improve access to certain emergency exits, such as those generally smaller exits above the wing, by providing an unobstructed passageway to the exit.

- Install public address systems that are independently powered and can be used for at least 10 minutes.

- Help to ensure that passengers in the seats next to emergency exits are physically and mentally able to operate the exit doors and assist other passengers in emergency evacuations.

- Limit the distance between emergency exits to 60 feet.

- Install emergency lighting systems that visually identify the emergency escape path and each exit.

- Install fire-resistant emergency evacuation slides.

We also identified 10 advancements that are either currently available but awaiting implementation or require additional research that could lead to improved aircraft evacuation, including the following:

- *Improved passenger safety briefings*: Information is available to the airlines on how to develop more appealing safety briefings and safety briefing cards so that passengers would be more likely to pay attention to the briefings and be better prepared to evacuate successfully during an emergency. Research has found that passengers often ignore the oral briefings and do not familiarize themselves with the safety briefing cards. FAA has requested that air carriers explore different ways to present safety information to passengers, but FAA regulates only the content of briefings. The presentation style of safety briefings is left up to air carriers.

- *Over-wing exit doors*: Exit doors located over the wings of some commercial airliners have been redesigned to “swing out” and away from the aircraft so that cabin occupants can exit more easily during an emergency. Currently, the over-wing exit doors on most U.S. commercial airliners are “self help” doors and must be lifted and stowed by a passenger, which can impede evacuation. (See fig. 2.) The redesigned doors are now used on new-generation B-737 aircraft operated by one U.S. and most European airlines. FAA does not currently require the use of over-wing exit doors that swing out because the exit doors that are removed manually meet the agency's safety standards. However, FAA is working with the Europeans to develop common requirements for the use of this type of exit door.

- *Audio attraction signals*: The United Kingdom's Civil Aviation Authority and the manufacturer are testing audio attraction signals to determine their usefulness to passengers in locating exit doors during an evacuation. These signals would be mounted near exits and activated during an emergency. The signals would help the passengers find the nearest exit even if lighting and exit signs were obscured by smoke.

Figure 2: Manual "Self Help" and "Swing Out" Over-Wing Exits

Source: FAA Civil Aerospace Medical Institute (left), Boeing Company (right).

Appendix VI contains additional information on advancements to improve aircraft emergency evacuations.

Improving the Safety and Health of Cabin Occupants

Passengers and flight attendants can face a range of safety and health effects while aboard commercial airliners. We identified three key actions taken by FAA to help maintain the safety and health of passengers and the cabin crew during normal flight operations.[9] For example, to prevent passengers from being injured during turbulent conditions, FAA initiated the Turbulence Happens campaign in 2000 to increase public awareness of the importance of wearing seatbelts. The agency has advised the airlines to warn passengers to fasten their seatbelts when turbulence is expected, and the airlines generally advise or require passengers to keep their seat belts fastened while seated to help avoid injuries from unexpected turbulence. FAA has also required the airlines to equip their fleets with emergency medical kits since 1986. In addition, Congress banned smoking on most domestic flights in 1990.

We also identified five advancements that are either currently available but awaiting implementation or require additional research that could lead to an improvement in the health of passengers and flight attendants in the future.

- *Automatic external defibrillators*: Automatic external defibrillators are currently available for use on some commercial airliners if a passenger or crew member requires resuscitation. In 1998, the Congress directed FAA to assess the need for the defibrillators on commercial airliners. On the basis of its findings, the agency issued a rule requiring that U.S. airlines equip their aircraft with automatic external defibrillators by 2004. According to ATA, most airlines have already done so.

- *Enhanced emergency medical kits*: In 1998, the Congress directed FAA to collect data for 1 year on the types of in-flight medical emergencies that occurred to determine if existing medical kits should be upgraded. On the basis of the data collected, FAA issued a rule that required the contents of existing emergency medical kits to be expanded to deal with a broader range of emergencies. U.S. commercial airliners are required to carry these enhanced emergency medical kits by 2004. Most U.S. airlines have already completed this upgrade, according to ATA.

- *Advance warning of turbulence*: New airborne weather radar and other technologies are currently being developed and evaluated to improve the detection of turbulence and increase the time available to cabin occupants to avert potential injuries. FAA's July 2003 draft strategic plan established a performance target of reducing injuries to cabin occupants caused by turbulence. To achieve this objective, FAA plans to continue

[9]As noted, actions taken to improve cabin air quality will be discussed in another report.

evaluating new airborne weather radars and other technologies that broadly address weather issues, including turbulence. In addition, the draft strategic plan set a performance target of reducing serious injuries caused by turbulence by 33 percent by fiscal year 2008–using the average for fiscal years 2000 through 2002 of 15 injuries per year as the baseline and reducing this average to no more than 10 per year.

- *Improve awareness of radiation exposure*: Flight attendants and passengers who fly frequently can be exposed to higher levels of radiation on a cumulative basis than the general public. High levels of radiation have been linked to an increased risk of cancer and potential harm to fetuses. To help passengers and crew members estimate their past and future radiation exposure levels, FAA developed a computer model, which is publicly available on its Web site http://www.jag.cami.jccbi.gov/cariprofile.asp. However, the extent to which flight attendants and frequent flyers are aware of cosmic radiation's risks and make use of FAA's computer model is unclear. Agency officials told us that they plan to install a counter capability on its Civil Aerospace Medical Institute Web site to track the number of visits to its aircrew and passenger health and safety Web site. FAA also plans to issue an Advisory Circular by early next year, which incorporates the findings of a just completed FAA report, "What Aircrews Should Know About Their Occupational Exposure to Ionizing Radiation." This Advisory Circular will include recommended actions for aircrews and information on solar flare event notification of aircrews. In contrast, airlines in Europe abide by more stringent requirements for helping to ensure that cabin and flight crew members do not receive excessive doses of radiation from performing their flight duties during a given year. For example, in May 1996, the European Union issued a directive for workers, including air carrier crew members (cabin and flight crews) and the general public, on basic safety and health protections against dangers arising from ionizing radiation. This directive set dose limits and required air carriers to (1) assess and monitor the exposure of all crew members to avoid exceeding exposure limits, (2) work with those individuals at risk of high exposure levels to adjust their work or flight schedules to reduce those levels, and (3) inform crew members of the health risks that their work involves from exposure to radiation. It also required airlines to work with female crew members, when they announce a pregnancy, to avoid exposing the fetus to harmful levels of radiation. This directive was binding for all European Union member states and became effective in May 2000.

- *Improved awareness of potential health effects related to flying*: Air travel may exacerbate some medical conditions. Of particular concern is a condition known as Deep Vein Thrombosis (DVT), or travelers' thrombosis, in which blood clots can develop in the deep veins of the legs from extended periods of inactivity. In a small percentage of cases, the clots can break free and travel to the lungs, with potentially fatal results. Although steps can be taken to avoid or mitigate some travel-related health effects, no formal awareness campaigns have been initiated by FAA to help ensure that this information reaches physicians and the traveling public. The Aerospace Medical Association's Web site http://www.asma.org/publication.html includes guidance for physicians to use in advising passengers with preexisting medical conditions on the potential risks of flying, as well as information for passengers with such conditions to use in assessing their own potential risks.

See appendix VII for additional information on health-related advances.

Advancements Vary in Their Readiness for Deployment

The advancements being pursued to improve the safety and health of cabin occupants vary in their readiness for deployment. For example, of the 28 advancements we reviewed, 14 are mature and currently available. Two of these, preparation for in-flight medical emergencies and the use of new insulation, were addressed through regulations. These regulations require airlines to install additional emergency medical equipment (automatic external defibrillators and enhanced emergency medical kits) by 2004, replace flammable insulation covering (metalized Mylar®) on specific aircraft by 2005, and manufacture new large commercial airliners that use a new type of insulation meeting more stringent flammability test standards after September 2, 2005. Another advancement is currently in the rule-making process—retrofitting the existing fleet with stronger 16g seats. The remaining 11 advancements are available, but are not required by FAA. For example, some airlines have elected to use inflatable lap seat belts and exit doors over the wings that swing out instead of requiring manual removal, and others are using photo-luminescent floor lighting in lieu of or in combination with traditional electrical lighting. Some of these advancements are commercially available to the flying public, including smoke hoods and child safety seats certified for use on commercial airliners. The remaining 14 advancements are in various stages of research, engineering, and development in the United States, Canada, or Europe.

Several Factors Have Slowed the Implementation of Cabin Occupant Safety and Health Advancements

Several factors have slowed the implementation of airliner cabin occupant safety and health advancements in the United States. When advancements are available for commercial use but not yet implemented or installed, their use may be slowed by the time it takes (1) for FAA to complete the rule-making process,[10] which may be required for an advancement to be approved for use but may take many years; (2) for U.S. and foreign aviation authorities to resolve differences between their respective cabin occupant safety and health requirements; and (3) for the airlines to adopt or install advancements after FAA has approved their use, including the time required to schedule an advancement's installation to coincide with major maintenance cycles and thereby minimize the costs associated with taking an airplane out of service. When advancements are not ready for commercial use because they need further research to develop their technologies or reduce their costs, their implementation may be slowed by FAA's multistep process for identifying advancements and allocating its limited resources to research on potential advancements. FAA's multistep process is hampered by a lack of autopsy and survivor information from past accidents and by not having cost and effectiveness data as part of the decision process. As a result, FAA may not be identifying and funding the most critical or cost-effective research projects.

FAA's Rule-making Process to Require Advancements Can Be Lengthy

Once an advancement has been developed, FAA may require its use, but significant time may be required before the rule-making process is complete. One factor that contributes to the length of this process is a requirement for cost-benefit analyses to be completed. Time is particularly important when safety is at stake or when the pace of technological development exceeds the pace of rule-making. As a result, some rules may need to be developed quickly to address safety issues or to guide the use of new technologies. However, rules must also be carefully considered before being finalized because they can have a significant impact on individuals, industries, the economy, and the environment. External pressures—such as political pressure generated by highly publicized accidents, recommendations by NTSB, and congressional mandates—as well as internal pressures, such as changes in management's emphasis, continue to add to and shift the agency's priorities.

[10] ATA noted that, for those technologies that are ready, FAA must develop design and certification standards before undertaking the rule-making process to require their implementation.

The rule-making process can be long and complicated and has delayed the implementation of some technological and operational safety improvements, as we reported in July 2001.[11] In that report, we reviewed 76 significant rules in FAA's workload for fiscal years 1995 through 2000—10 of the 76 were directly related to improving the safety and health of cabin occupants.[12] Table 3 details the status or disposition of these 10 rules. The shortest rule-making action took 1 year, 11 months (for child restraint systems), and the longest took 10 years, 1 month (for the type and number of emergency exits). However, one proposed rule was still pending after 15 years, while three others were terminated or withdrawn after 9 years or more. Of the 76 significant rules we reviewed, FAA completed the rule-making process for 29 of them between fiscal year 1995 and fiscal year 2000, in a median time of about 2 ½ years to proceed from formal initiation of the rule-making process through publication of the final rule; however, FAA took 10 years or more to move from formal initiation of the rule-making process through publication of the final rule for 6 of these 29 rules.

Table 3: Status of 10 Significant FAA Rules Pertaining to Airliner Cabin Occupants' Safety and Health, Fiscal Year 1995 through September of Fiscal Year 2003

Rule title	Initiation date[a]	Time elapsed	Status/disposition
Flight attendant requirements	2/04/86	9 years, 8 months	Terminated/withdrawn 6/06/96
Type and number of passenger emergency exits required in transport category airplanes	10/15/86	10 years, 1 month	Final rule published on 11/08/96
Airworthiness standards; occupant protection standards for commuter category airplanes	5/29/87	11 years, 1 month	Terminated/withdrawn 6/30/98
Retrofit of improved seats in air carrier transport category airplanes	1/26/88	15 years, 6 months	Pending
Child restraint systems	5/30/90	5 years, 9 months	Terminated/withdrawn 2/13/96

[11]U.S. General Accounting Office, *Aviation Rule-making: Further Reform Is Needed to Address Long-standing Problems*, GAO-01-821 (Washington, D.C.: July 9, 2001).

[12]Under Executive Order 12866, federal agencies and the Office of Management and Budget (OMB) categorize proposed and final rules in terms of their potential impact on the economy and the industry affected. The Order defines a regulatory action as "significant" if it, among other things, has an annual impact on the economy of $100 million or more and adversely affects the economy in a material way. To measure the overall impact of the 1998-rule-making reforms, through discussions with FAA officials, we created a database of 76 significant rules. These rules constituted the majority (about 83 percent) of FAA's significant rule workload from fiscal year 1995 through fiscal year 2000.

(Continued From Previous Page)

Rule title	Initiation date[a]	Time elapsed	Status/disposition
Revised access to Type III exits	10/30/92	9 years, 5 months	Withdrawn 5/03/02
Child restraint systems	7/18/94	1 year 11 months	Final rule published on 6/04/96
Child restraint systems	4/07/97	6 years, 3 months	Pending
Emergency medical equipment	10/5/98	2 years, 8 months	Final rule published on 6/12/01
Improved flammability standards for thermal acoustic insulation materials in transport category aircraft	12/04/98	4 years, 7 months	Final rule published on July 31, 2003

Source: GAO analysis of FAA data.

Note: In commenting on a draft of this report, FAA noted that examining the years elapsed from the initiation date of the rule to disposition can be unfair to some actions and that many of the delays were not the fault of FAA.

[a]Initiation dates were identified in FAA's rule-making information system as GAO reported in July 2001. This was the only source for data on the agency's internal milestones, including "initiation date."

Differences in U.S. and Foreign Requirements Can Hamper Adoption of Advancements

FAA and its international counterparts, such as the European Joint Aviation Authorities (JAA), impose a number of requirements to improve safety. At times, these requirements differ, and efforts are needed to reach agreement on procedures and equipment across country borders. In the absence of such agreements, the airlines generally must adopt measures to implement whichever requirement is more stringent. In 1992, FAA and JAA began harmonizing their requirements for (1) the design, manufacture, operation, and maintenance of civil aircraft and related product parts; (2) noise and emissions from aircraft; and (3) flight crew licensing. Harmonizing the U.S. Federal Aviation Regulations with the European Joint Aviation Regulations is viewed by FAA as its most comprehensive long-term rule-making effort and is considered critical to ensuring common safety standards and minimizing the economic burden on the aviation industry that can result from redundant inspection, evaluation, and testing requirements.

According to both FAA and JAA, the process they have used to date to harmonize their requirements for commercial aircraft has not effectively prioritized their joint recommendations for harmonizing U.S. and European aviation requirements, and led to many recommendations going unpublished for years. This includes a backlog of over 130 new rule-making efforts. The slowness of this process led the United States and Europe to develop a new rule-making process to prioritize safety initiatives, focus the aviation industry's and their own limited resources, and establish limitations on rule-making capabilities. Accordingly, in March 2003, FAA and JAA developed a draft joint “priority” rule-making list; collected and considered industry input; and coordinated with FAA’s, JAA’s, and Transport Canada Civil Aviation’s management. This effort has resulted in a rule-making list of 26 priority projects. In June 2003, at the 20th Annual JAA/FAA International Conference, FAA, JAA, and Transport Canada Civil Aviation discussed the need to, among other things, support the joint priority rule-making list and to establish a cycle for updating it—to keep it current and to provide for “pop-up,” or unexpected, rule-making needs. FAA and JAA discussed the need to prioritize rule-making efforts to efficiently achieve aviation safety goals; that they would work from a limited agreed-upon list for future rule-making activities; and that FAA and the European Aviation Safety Agency, which is gradually replacing JAA, should continue with this approach.

In the area of cabin occupant safety and heath, some requirements have been harmonized, while others have not. For example, in 1996, JAA changed its rule on floor lighting to allow reflective, glow-in-the-dark material to be used rather than mandating the electrically powered lighting that FAA required. The agency subsequently permitted the use of this material for floor lighting. In addition, FAA finalized a rule in July 2003 to require a new type of insulation designed to delay fire burning though the fuselage into the cabin during an accident. JAA favors a performance-based standard that would specify a minimum delay in burn-through time, but allow the use of different technologies to achieve the standard. FAA officials said that the agency would consider other technologies besides insulation to achieve burn-through protection but that it would be the responsibility of the applicant to demonstrate that the technology provided performance equivalent to that stipulated in the insulation rule. JAA officials told us that these are examples of the types of issues that must be resolved when they work to harmonize their requirements with FAA’s. These officials added that this process is typically very time consuming and has allowed for harmonizing about five rules per year.

Significant Time May Be Needed to Implement Advancements Once They Are Required, but Some May Enhance Airlines' Competitiveness

After an advancement has been developed, shown to be beneficial, certified, and required by FAA, the airlines or manufacturers need time to implement or install the advancement.[13] FAA generally gives the airlines or manufacturers a window of time to comply with its rules. For example, FAA gave air carriers 5 years to replace metalized Mylar® insulation on specific aircraft with a less flammable insulation type, and FAA's proposed rule-making on 16g seats would give the airlines 14 years to install these seats in all existing commercial airliners. ATA officials told us that this would require replacement of 496,000 seats.

The airline industry's recent financial hardships may also delay the adoption of advancements. Recently, two major U.S. carriers filed for bankruptcy,[14] and events such as the war in Iraq have reduced passenger demand and airline revenues below levels already diminished by the events of September 11, 2001, and the economic downturn. Current U.S. demand for air travel remains below fiscal year 2000 levels. As a result, airlines may ask for exemptions from some requirements or extensions of time to install advancements.

While implementing new safety and health advancements can be costly for the airlines, making these changes could improve the public's confidence in the overall safety of air travel. In addition, some aviation experts in Europe told us that health-related cabin improvements, particularly improvements in air quality, are of high interest to Europeans and would likely be used in the near future by some European air carriers to set themselves apart from their competitors.

[13]According to ATA, even if a technology is available in the marketplace, it may not be adopted by the airlines until it has been certified by FAA--ensuring that "improvements" do not inadvertently compromise overall safety of the aircraft.

[14]One of these U.S. carriers is no longer in bankruptcy.

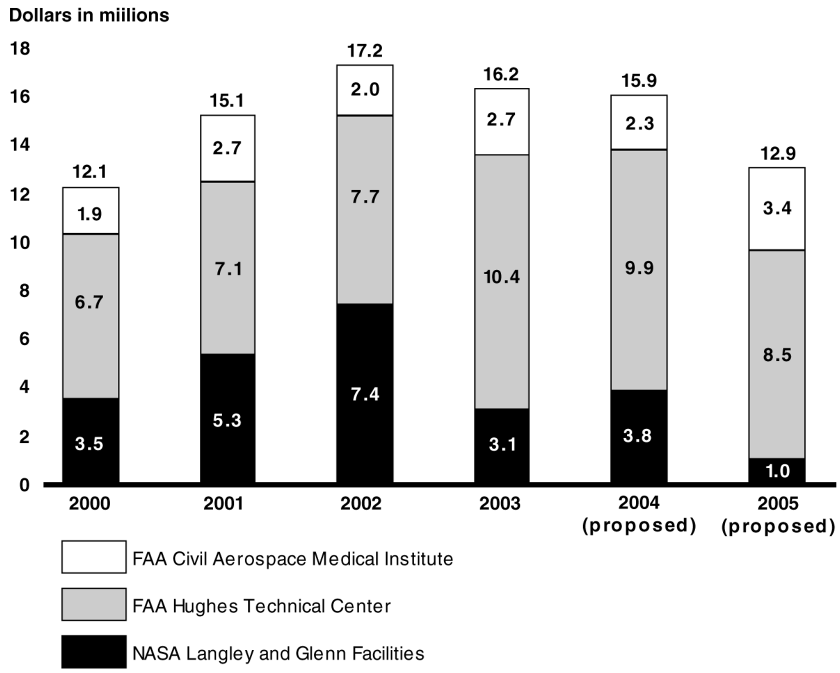
FAA's Multistep Process for Allocating Limited Resources to Research Projects Is Hampered by Lack of Autopsy and Survivor Information and Cost and Effectiveness Data

For fiscal year 2003, FAA and NASA allocated about $16.2 million to cabin occupant safety and health research. FAA's share of this research represented $13.1 million, or about 9 percent of the agency's Research, Engineering, and Development budget of $148 million for fiscal year 2003. Given the level of funding allocated to this research effort, it is important to ensure that the best research projects are selected. However, FAA's processes for setting research priorities and selecting projects for further research are hampered by data limitations. In particular, FAA lacks certain autopsy and survivor information from aircraft crashes that could help it identify and target research to the most important causes of death and injury in an airliner crash. In addition, for the proposed research projects, the agency does not (1) develop comparable cost data for potential advancements or (2) assess their potential effectiveness in minimizing injuries or saving lives. Such cost and effectiveness data would provide a valuable supplement to FAA's current process for setting research priorities and selecting projects for funding.

Federal Research on Aircraft Cabin Occupant Safety and Health Issues

Both FAA and NASA conduct research on aircraft cabin occupant safety and health issues. The Civil Aeromedical Institute (CAMI) and the Hughes Technical Center are FAA's primary facilities for conducting research in this area. In addition, two facilities at NASA, the Langley and Glenn research centers, have also conducted research in this area. As figure 3 shows, federal funding for this research since fiscal year 2000, reached a high in fiscal year 2002, at about $17 million, and fell to about $16.2 million in fiscal year 2003. The administration's proposal for fiscal year 2004 calls for a further reduction to $15.9 million. This funding covers the expenses of researchers at these facilities and of the contracts they may have with others to conduct research. In addition, NASA recently decided to end its crash research at Langley and to close a drop test facility that it operates in Hampton, Virginia.

Figure 3: Funding for Federal Research on Cabin Occupant Safety and Health Issues, by Facility, Fiscal Years 2000-2005

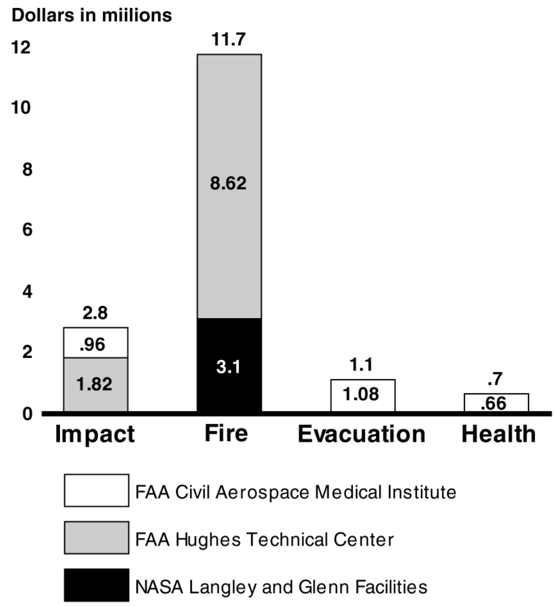


Source: FAA and NASA.

Note: FAA Hughes Technical Center data includes work in fire-safe fuels, fuel-tank inerting, arc fault circuit breakers, and airport rescue and fire-fighting operations.

In fiscal year 2003, FAA and NASA both supported research projects, including aircraft impact, fire, evacuation, and health. As figure 4 shows, most of the funding for cabin occupant safety and health research has gone to fire-related projects.

Figure 4: Allocation of Federal Funding for Aircraft Cabin Occupant Safety and Health Research, Fiscal Year 2003



Source: FAA and NASA.

Note: Sum of bars exceeds $16.2 million due to rounding. FAA Technical Center data includes work in fire-safe fuels, fuel-tank inerting, arc fault circuit breakers, and airport rescue and fire-fighting operations

FAA Research Selection Process Hampered by Lack of Autopsy and Survivor Information and Cost and Effectiveness Analyses

To establish research priorities and select projects to fund, FAA uses a multistep process. First, within each budget cycle, a number of Technical Community Representative Group subcommittees from within FAA generate research ideas. Various subcommittees have responsibility for identifying potential safety and health projects, including subcommittees on crash dynamics, fire safety, structural integrity, passenger evacuation, aeromedical, and fuel safety. Each subcommittee proposes research projects to review committees, which prioritize the projects. The projects are considered and weighted according to the extent to which they address (1) accident prevention, (2) accident survival, (3) external requests for research, (4) internal requests for research, and (5) technology research needs. In addition, the cost of the proposed research is considered before arriving at a final list of projects. The prioritized list is then considered by the Program Planning Team, which reviews the projects from a policy perspective.

Although the primary causes of death and injury in commercial airliner crashes are known to be impact, fire, and impediments to evacuation, FAA does not have as detailed an understanding as it would like of the critical factors affecting survival in a crash. According to FAA officials, obtaining a more detailed understanding of these factors would assist them in setting research priorities and in evaluating the relative importance of competing research proposals. To obtain a more detailed understanding of the critical factors affecting survival, FAA believes that it needs additional information from passenger autopsies and from passengers who survived. With this information, FAA could then regulate safety more effectively, airplane and equipment designers could build safer aircraft, including cabin interiors, and more passengers could survive future accidents as equipment became safer.

While FAA has independent authority to investigate commercial airliner crashes, NTSB generally controls access to the accident investigation site in pursuit of its primary mission of determining the cause of the crash. When NTSB concludes its investigation, it returns the airplane to its owner and keeps the records of the investigation, including the autopsy reports and the information from survivors that NTSB obtains from medical authorities and through interviews or questionnaires. NTSB makes summary information on the crashes publicly available on its Web site, but according to the FAA researchers, this information is not detailed enough for their needs. For example, the researchers would like to develop a complete autopsy database that would allow them to look for common trends in accidents, among other things. In addition, the researchers would like to know where survivors sat on the airplane, what routes they took to exit, what problems they encountered, and what injuries they sustained. This information would help the researchers analyze factors that might have an impact on survival. According to the NTSB's Chief of the Survival Factors Division in the Office of Aviation Safety, NTSB provides information on the causes of death and a description of injuries in the information they make publicly available. In addition, although medical records and autopsy reports are not made public, interviews with and questionnaires from survivors are available from the public docket.

NTSB's Medical Officer was unaware of any formal requests from the FAA for the NTSB to provide them with copies of this type of information, although the FAA had previously been invited to review such information at NTSB headquarters. He added that the Board would likely consider a formal request from FAA for copies of autopsy reports and certain survivor records, but that it was also likely that the FAA would have to assure NTSB that the information would be appropriately safeguarded. According to FAA officials, close cooperation between the NTSB and the FAA is needed for continued progress in aviation safety.

Besides lacking detailed information on the causes of death and injury, FAA does not develop data on the cost to implement advancements that are comparable for each, nor does it assess the potential effectiveness of each advancement in reducing injuries and saving lives. Specifically, FAA does not conduct cost-benefit analyses as part of its multistep process for setting research priorities. Making cost estimates of competing advancements would allow direct comparisons across alternatives, which, when combined with comparable estimates of effectiveness, would provide valuable supplemental information to decision makers when setting research priorities. FAA considers its current process to be appropriate and sufficient. In commenting on a draft of this report, FAA noted that it is very difficult to develop realistic cost data for advancements during the earliest stages of research. The agency cautioned that if too much emphasis is placed on cost/benefit analyses, potentially valuable research may not be undertaken. Recognizing that it is less difficult to develop cost and effectiveness information as research progresses, we are recommending that FAA develop and use cost and effectiveness analyses to supplement its current process. At later stages in the development process, we found that this information can be developed fairly easily through cost and effectiveness analyses using currently available data. For example, we performed an analysis of the cost to implement inflatable lap seat belts using a cost analysis methodology we developed (see app. VIII). This analysis allowed us to estimate how much this advancement would cost per airplane and per passenger trip. Such cost analyses could be combined with similar analyses of effectiveness to identify the most cost-effective projects, based on their potential to minimize injuries and reduce fatalities. Potential sources of effectiveness data include FAA, academia, industry, and other aviation authorities.

Conclusions

Although FAA and the aviation community are pursuing a number of advancements to enhance commercial airliners' cabin occupant safety and health, several factors have slowed their implementation. For example, for advancements that are currently available but are not yet implemented or installed, progress is slowed by the length of time it takes for FAA to complete its rule-making process, for the U.S and foreign countries to agree on the same requirements, and for the airlines to actually install the advancements after FAA has required them. In addition, FAA's multistep process for identifying potential cabin occupant safety and health research projects and allocating its limited research funding is hampered by the lack of autopsy and survivor information from airliner crashes and by the lack of cost and effectiveness analysis. Given the level of funding allocated to cabin occupant safety and health research, it is important for FAA to ensure that this funding is targeting the advancements that address the most critical needs and show the most promise for improving the safety and health of cabin occupants. However, because FAA lacks detailed autopsy and survivor information, it is hampered in its ability to identify the principal causes of death and survival in commercial airliner crashes. Without an agreement with the National Transportation Safety Board (NTSB) to receive detailed autopsy and survivor information, FAA lacks information that could be helpful in understanding the factors that contribute to surviving a crash. Furthermore, because FAA does not develop comparable estimates of cost and effectiveness of competing research projects, it cannot ensure that it is funding those technologies with the most promise of saving lives and reducing injuries. Such cost and effectiveness data would provide a valuable supplement to FAA's current process for setting research priorities and selecting projects for funding. To facilitate FAA's development of comparable cost data across advancements, we developed a cost analysis methodology that could be combined with a similar analysis of effectiveness to identify the most cost-effective projects. Using comparable cost and effectiveness data across the range of advancements would position the agency to choose more effectively between competing advancements, taking into account estimates of the number of injuries and fatalities that each advancement might prevent for the dollars invested. In turn, FAA would have more assurance that the level of funding allocated to this effort maximizes the safety and health of the traveling public and the cabin crew members who serve them.

Recommendations for Executive Action

To provide FAA decision makers with additional data for use in setting priorities for research on cabin occupant safety and health and in selecting competing research projects for funding, we recommend that the Secretary of Transportation direct the FAA Administrator to

- initiate discussions with the National Transportation Safety Board in an effort to obtain the autopsy and survivor information needed to more fully understand the factors affecting survival in a commercial airliner crash and

- supplement its current process by developing and using comparable estimates of cost and effectiveness for each cabin occupant safety and health advancement under consideration for research funding.

Agency Comments and Our Evaluation

We provided copies of a draft of this report to the Department of Transportation for its review and comment. FAA generally agreed with the report's contents and its recommendations. The agency provided us with oral comments, primarily technical clarifications, which we have incorporated as appropriate.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 10 days after the date of this letter. At that time, we will send copies to the appropriate congressional committees; the Secretary of Transportation; the Administrator, FAA; and the Chairman, NTSB. We will also make copies available to others upon request. In addition, this report is also available at no charge on GAO's Web site at http://www.gao.gov.

Contacts and staff acknowledgements for this report are included in appendix IX. If you or your staff have any questions, please contact me or Glen Trochelman at (202) 512-2834

Sincerely yours,

Gerald L. Dillingham

Gerald L. Dillingham
Director, Physical Infrastructure Issues

Objectives, Scope, and Methodology

As requested by the Ranking Democratic Member, House Committee on Transportation and Infrastructure, we addressed the following questions: (1) What regulatory actions has the Federal Aviation Administration (FAA) taken, and what key advancements are available or being developed by FAA and others to address safety and health issues faced by passengers and flight attendants in large commercial airliner cabins? (2) What factors, if any, slow the implementation of advancements in cabin occupant safety and health? In addition, as requested, we identified some factors affecting efforts by Canada and Europe to improve cabin occupant safety and health.

The scope of our report includes the cabins of large commercial aircraft (those that carry 30 or more passengers) operated by U.S. domestic commercial airlines and addresses the safety and health of passengers and flight attendants from the time they board the airliner until they disembark under normal operational conditions or emergency situations. This report identifies cabin occupant safety and health advancements (technological or operational improvements) that could be implemented, primarily through FAA's rule-making process. Such improvements include technological changes designed to increase the overall safety of commercial aviation as well as changes to enhance operational safety. The report does not include information on the flight decks of large commercial airliners or safety and health issues affecting flight deck crews (pilots and flight engineers), because they face some issues not faced by cabin occupants. It also does not address general aviation and corporate aircraft or aviation security issues, such as hijackings, sabotage, or terrorist activities.

To identify regulatory actions that FAA has taken to address safety and health issues faced by passengers and flight attendants in large commercial airliner cabins, we interviewed and collected documentation from U.S. federal agency officials on major safety and health efforts completed by FAA. The information we obtained included key dates and efforts related to cabin occupant safety and health, such as rule-makings, airworthiness directives, and Advisory Circulars.

To identify key advancements that are available or are being developed by FAA and others to address safety and health issues faced by passengers and flight attendants in large commercial airliner cabins, we consulted experts (1) to help ensure that we had included the advancements holding the most promise for improving safety and health; and (2) to help us structure an evaluation of selected advancements (i.e., confirm that we had included the critical benefits and drawbacks of the potential advancements) and develop a descriptive analysis for them, where appropriate, including their benefits, costs, technology readiness levels, and regulatory status. In addition, we interviewed and obtained documentation from federal agency officials and other aviation safety experts at the Federal Aviation Administration (including its headquarters in Washington, D.C.; Transport Airplane Directorate in Renton, Washington; William J. Hughes Technical Center in Atlantic City, New Jersey; and Mike Monroney Aeronautical Center/Civil Aerospace Medical Institute in Oklahoma City, Oklahoma); National Transportation Safety Board; National Aeronautics and Space Administration (NASA); Air Transport Association; Regional Airline Association; International Air Transport Association; Aerospace Industries Association; Aerospace Medical Association; Flight Safety Foundation, Association of Flight Attendants; Boeing Commercial Airplane Group; Airbus; Cranfield University, United Kingdom; University of Greenwich, United Kingdom; National Aerospace Laboratory, Netherlands; Joint Aviation Authorities, Netherlands; Civil Aviation, Netherlands; Civil Aviation Authority, United Kingdom; RGW Cherry and Associates; Air Accidents Investigations Branch, United Kingdom; Syndicat National du Personnel Navigant Commercial (French cabin crew union) and ITF Cabin Crew Committee, France; BEA (comparable to the U.S. NTSB), France; and the Direction Générale de l'Aviation Civile (DGAC), FAA's French counterpart.

To describe the status of key advancements that are available or under development, we used NASA's technology readiness levels (TRL). These levels form a system for ranking the maturity of particular technologies and are as follows:

- TRL 1: Basic principles observed and reported
- TRL 2: Technology concept and/or application formulated
- TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept developed
- TRL 4: Component validation in laboratory environment
- TRL 5: Component and/or validation in relevant environment
- TRL 6: System or subsystem model or prototype demonstrated in a relevant environment
- TRL 7: System prototype demonstrated in a space environment

- TRL 8: Actual system completed and “flight qualified” through test and demonstration

- TRL 9: Actual system “flight proven” through successful mission operations

To determine what factors, if any, slow the implementation of advancements in cabin occupant safety and health, we reviewed the relevant literature and interviewed and analyzed documentation from the U.S. federal officials cited above for the 18 key regulatory actions FAA has taken since 1984 to improve the safety and health of cabin occupants. We used this same approach to assess the regulatory status of the 28 advancements we reviewed that are either currently available, but not yet implemented or installed, or require further research to demonstrate their effectiveness or lower their costs. In identifying 28 advancements, GAO is not suggesting that these are the only advancements being pursued; rather, these advancements have been recognized by aviation safety experts we contacted as offering promise for improving the safety and health of cabin occupants. To determine how long it generally takes for FAA to issue new rules, in addition to speaking with FAA officials, we relied on past GAO work and updated it, as necessary. In order to examine the effect of FAA and European efforts to harmonize their aviation safety requirements, we interviewed and analyzed documentation from aviation safety officials and other experts in the United States, Canada, and Europe. Furthermore, to examine the factors affecting airlines’ ability to implement or install advancements after FAA requires them, we interviewed and analyzed documentation from aircraft manufacturers, ATA, and FAA officials.

In addition, to determine what factors slow implementation we examined FAA’s processes for selecting research projects to improve cabin occupant safety and health. In examining whether FAA has sufficient data upon which to base its research priorities, we interviewed FAA and National Transportation Safety Board (NTSB) officials about autopsy and survivor information from commercial airliner accidents. We also examined the use of cost and effectiveness data in FAA’s research selection process for cabin occupant safety and health projects. To facilitate FAA’s development of such cost estimates, we developed a cost analysis methodology to illustrate how the agency could do this. Specifically, we developed a cost analysis for inflatable lap belts to show how data on key cost variables could be obtained from a variety of sources. We selected lap belts because they were being used in limited situations and appeared to offer some measure of improved safety. Information on installation price, annual maintenance and refurbishment costs, and added weight of these belts was obtained from belt manufacturers. We obtained information from FAA and the Department of Transportation's (DOT) Bureau of Transportation Statistics on a number of cost variables, including historical jet fuel prices, the impact on jet fuel consumption of carrying additional weight, the average number of hours flown per year, the average number of seats per airplane, the number of airplanes in the U.S. fleet, and the number of passenger tickets issued per year. To account for variation in the values of these cost variables, we performed a Monte Carlo simulation.[1] In this simulation, values were randomly drawn 10,000 times from probability distributions characterizing possible values for the number of seat belts per airplane, seat installation price, jet fuel price, number of passenger tickets, number of airplanes, and hours flown. This simulation resulted in forecasts of the life-cycle cost per airplane, the annualized cost per airplane, and the cost per ticket. There is uncertainty in estimating the number of lives potentially saved and their value because accidents occur infrequently and unpredictably. Such estimates could be higher or lower, depending on the number and severity of accidents during a given analysis period and the value placed on a human life.

To identify factors affecting efforts by Canada and Europe to improve cabin occupant safety and health we interviewed and collected documentation from aviation safety experts in the United States, Canada, and Europe.

We provided segments of a draft of this report to selected external experts to help ensure its accuracy and completeness. These included the Air Transport Association, National Transportation Safety Board, Boeing, Airbus, and aviation authorities in the United Kingdom, France, Canada and the European Union. We incorporated their comments, as appropriate. The European Union did not provide comments.

We conducted our review from January 2002 through September 2003 in accordance with generally accepted government auditing standards.

[1]A Monte Carlo simulation is a widely used computational method for generating probability distributions of variables that depend on other variables or parameters represented as probability distributions.

Canada and Europe Cabin Occupant Safety and Health Responsibilities

The United States, Canada, and members of the European Community are parties to the International Civil Aviation Organization (ICAO), established under the Chicago Convention of 1944, which sets minimum standards and recommended practices for civil aviation. In turn, individual nations implement aviation standards, including those for aviation safety. While ICAO's standards and practices are intended to keep aircraft, crews, and passengers safe, some also address environmental conditions in aircraft cabins that could affect the health of passengers and crews. For example, ICAO has standards for preventing the spread of disease and for spraying aircraft cabins with pesticides to remove disease-carrying insects.

Canada

In Canada, FAA's counterpart for aviation regulations and oversight is Transport Canada Civil Aviation, which sets standards and regulations for the safe manufacture, operation, and maintenance of aircraft in Canada. In addition, Transport Canada Civil Aviation administers, enforces, and promotes the Aviation Occupational Health and Safety Program to help ensure the safety and health of crewmembers on board aircraft.[1] The department also sets the training and licensing standards for aviation professionals in Canada, including air traffic controllers, pilots, and aircraft maintenance engineers. Transport Canada Civil Aviation has more than 800 inspectors working with Canadian airline operators, aircraft manufacturers, airport operators, and air navigation service providers to maintain the safety of Canada's aviation system. These inspectors monitor, inspect, and audit Canadian aviation companies to verify their compliance with Transport Canada's aviation regulations and standards for pilot licensing, aircraft certification, and aircraft operation.

To assess and recommend potential changes to Canada's aviation regulations and standards, the Canadian Aviation Regulation Advisory Council was established. This Council is a joint initiative between government and the aviation community. The Council supports regulatory meetings and technical working groups, which members of the aviation community can attend. A number of nongovernmental organizations—including airline operators, aviation labor organizations, manufacturers, industry associations, and groups representing the public—are members.

[1]The Headquarters Division of Transport Canada provides guidance and assistance to Regional Civil Aviation Safety Inspectors – Occupational Health and Safety who conduct inspections, investigations, and promotional visits to ensure that airline operators are committed to the safety and health of their employees.

The Transportation Safety Board (TSB) of Canada is similar to NTSB in the United States. TSB is a federal agency that operates independently of Transport Canada Civil Aviation. Its mandate is to advance safety in the areas of marine, pipeline, rail, and aviation transportation by

- conducting independent investigations, including public inquiries when necessary, into selected transportation occurrences in order to make findings as to their causes and contributing factors;
- identifying safety deficiencies, as evidenced by transportation occurrences;
- making recommendations designed to reduce or eliminate any such deficiencies; and
- reporting publicly on their investigations and findings.

Under its mandate to conduct investigations, TSB conducts safety-issue-related investigations and studies. It also maintains a mandatory incident-reporting system for all modes of transportation. TSB and Transport Canada Civil Aviation use the statistics derived from this information to track potential safety concerns in Canada's transportation system.

TSB investigates aircraft accidents that occur in Canada or involve aircraft built there. Like NTSB, the Transportation Safety Board can recommend air safety improvements to Transport Canada Civil Aviation.

Europe

Europe supplements the ICAO framework with the European Civil Aviation Conference, an informal forum through which 38 European countries formulate policy on civil aviation issues, including safety, but do not explicitly address passenger health issues. In addition, the European Union issues legislation concerning aviation safety, certification, and licensing requirements but has not adopted legislation specifically related to passenger health. One European directive requires that all member states assess and limit crewmembers' exposure to radiation from their flight duties and provide them with information on the effects of such radiation exposure. The European Commission[2] is also providing flight crewmembers and other mobile workers with free health assessments prior to employment, with follow-up health assessments at regular intervals.

Another European supplement to the ICAO framework is the Joint Aviation Authorities (JAA), which represents the civil aviation regulatory authorities of a number of European states[3] that have agreed to cooperate in developing and implementing common safety regulatory standards and procedures. JAA uses staff of these authorities to carry out its responsibilities for making, standardizing, and harmonizing aviation rules, including those for aviation safety, and for consolidating common standards among member counties. In addition, JAA is to cooperate with other regional organizations or national European state authorities to reach at least JAA's safety level and to foster the worldwide implementation of harmonized safety standards and requirements through the conclusion of international arrangements.

Membership in JAA is open to members of the European Civil Aviation Conference, which currently consists of 41 member countries. Currently, 37 countries are members or candidate members of JAA. JAA is funded by national contributions; income from the sale of publications and training; and income from other sources, such as user charges and European Union grants. National contributions are based on indexes related to the size of each country's aviation industry. The "largest" countries (France, Germany, and the United Kingdom) each pay around 16 percent and the smallest around 0.6 percent of the total contribution income. For 2003, JAA's total budget was about 6.6 million euros.

In early 1998, JAA launched the Safety Strategy Initiative to develop a focused safety agenda to support the "continuous improvement of its effective safety system" and further reduce the annual number of accidents and fatalities regardless of the growth of air traffic. Two approaches are being used to develop the agenda:

[2]The European Union, previously known as the European Community, is an institutional framework for the construction of a united Europe. The European Commission is a governing body that proposes policies and legislation.

[3]JAA currently has 26 full members and 11 candidate members.

- The “historic approach” is based on analyses of past accidents and has led to the identification of seven initial focus areas—controlled flight into terrain, approach and landing, loss of control, design related, weather, occupant safety and survivability, and runway safety.

- The “predictive approach” or “future hazards approach” is based on an identification of changes in the aviation system.

JAA is cooperating in this effort with FAA and other regulatory bodies to develop a worldwide safety agenda and avoid duplication of effort. FAA has taken the lead in the historic approach, and JAA has taken the lead in the future hazards approach.

JAA officials told us that they use a consensus-based process to develop rules for aviation safety, including cabin occupant safety and health-related issues. Reaching consensus among member states is time consuming, but the officials said the time invested was worthwhile. Besides making aviation-related decisions, JAA identifies and resolves differences in word meanings and subtleties across languages—an effort that is critical to reaching consensus. JAA does not have regulatory rule-making authority. Once the member states are in agreement, each member state’s legislative authority must adopt the new requirements. Harmonizing new requirements with U.S. and other international aviation authorities further adds to the time required to implement new requirements.

According to JAA officials, they use expert judgment to identify and prioritize research and development efforts for aviation safety, including airliner cabin occupant safety and health issues, but JAA plans to move toward a more data-driven approach.[4] While JAA has no funding of its own for research and development, it recommends research priorities to its member states. However, JAA officials told us that member states’ research and development efforts are often driven by recent airliner accidents in the member states, rather than by JAA’s priorities. The planned shift from expert judgment to a more data-driven approach will require more coordination of aviation research and development across Europe. For example, in January 2001, a stakeholder group formed by the European Commissioner for Research issued a planning document entitled *European*

[4]According to officials from the United Kingdom’s Civil Aviation Authority, a JAA member, a limited benefit analysis has been developed to provide guidance, but this document has not yet been published.

Aeronautics: A Vision for 2020, which, among other things, characterized European aeronautics as a cross-border industry, whose research strategy is shaped within national borders, leading to fragmentation rather than coherence. The document called for better decision-making and more efficient and effective research by the European Union, its member states, and aeronautics stakeholders. JAA officials concurred with this characterization of European aviation research and development.

Changes lie ahead for JAA and aviation safety in Europe. The European Union recently created a European Aviation Safety Agency, which will gradually assume responsibility for rule-making, certification, and standardization of the application of rules by the national aviation authorities. This organization will eventually absorb all of JAA's functions and activities. The full transition from JAA to the safety agency will take several years--per the regulation,[5] the European Aviation Safety Agency must begin operations by September 28, 2003, and transition to full operations by March 2007.

[5]On July 15, 2002, the European Parliament and the Council of the European Union (E.U.) adopted Regulation (EC) No 1592/2002 establishing common rules for the E.U. in the field of civil aviation and establishing a new European Aviation Safety Agency.

Summary of Key Actions FAA Has Taken to Improve Airliner Cabin Safety and Health Since 1984

Key improvement areas	Action taken	Purpose	Status
Impact			
Stronger (16g) passenger seats	FAA required that seats for newly developed aircraft be subjected to more rigorous testing than was previously required. The tests subject seats to the forward, downward, and other directional movements that can occur in an accident. Likely injuries under various conditions are estimated by using instrumented crash test dummies.	To improve the crashworthiness of airplane seats and their ability to prevent or reduce the severity of head, back, and femur injuries.	This rule was published on May 17, 1988, and became effective June 16, 1988. However, only the newest generation of airplanes is required to have fully tested and certificated 16g seats. FAA proposed a retrofit rule on October 4, 2002, to phase in 16g seats fleetwide within 14 years after adoption of the final rule.
Overhead bins	FAA issued an airworthiness directive requiring corrective action for overhead bin designs found not to meet the existing rules.	To improve the crashworthiness of some bins after failures were observed in a 1989 crash in Kegworth, England.	The airworthiness directive to improve bin connectors became effective November 20, 1992, and applied to Boeing 737 and 757 aircraft.
Fire			
More stringent flammability standards for interior materials	In 1986, FAA upgraded the fire safety standards for cabin interior materials in transport airplanes, establishing a new test method to determine the heat release from materials exposed to radiant heat and set allowable criteria for heat release rates.	To give airliner cabin occupants more time to evacuate a burning airplane by limiting heat releases and smoke emissions when cabin interior materials are exposed to fire.	FAA required that all commercial aircraft produced after August 20, 1988, have panels that exhibit reduced heat releases and smoke emissions to delay the onset of flashover. Although there was no retrofit of the existing fleet, FAA is requiring that these improved materials be used whenever the cabin is substantially refurbished.
“Fire-blocking” seat cushions	In 1984, FAA issued a regulation that enhanced flammability requirements for seat cushions.	To retard burning of cabin materials to increase evacuation time.	This rule applies to transport category aircraft after November 26, 1987.
Halon fire extinguishers	In March 1985, FAA issued a rule requiring at least two Halon fire extinguishers on all commercial airliners, in addition to other required extinguishers	To extinguish in-flight fires.	This rule became effective April 29, 1985, and required compliance by April 29, 1986.
Smoke detectors in lavatories	In March 1985, FAA issued a rule requiring air carriers to install smoke detectors in lavatories within 18 months.	To identify and extinguish in-flight fires.	This rule became effective on April 29, 1985, and required compliance by October 29, 1986.
Fire extinguishers built in to lavatory waste receptacles	In March 1985, FAA required air carriers to install automatic fire extinguishers in the waste paper bins in all aircraft lavatories.	To identify and extinguish prevent in-flight fires.	This rule became effective on April 29, 1985. This rule required compliance by April 29, 1987.

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Key improvement areas	Action taken	Purpose	Status
Cargo compartment protection	In 1986, FAA upgraded the airworthiness standards for ceiling and sidewall liner panels used in cargo compartments of transport category airplanes.	To improve fire safety in the cargo and baggage compartment of certain transport airplanes.[a]	This rule required compliance on March 20, 1998.
Cargo compartment fire detection and suppression	In 1998, FAA required air carriers to retrofit the U.S. passenger airliner fleet with fire detection and suppression systems in certain cargo compartments. This rule applied to over 3,400 airplanes in service and all newly manufactured airplanes.	To improve fire safety in the cargo and baggage compartment of certain transport airplanes.[a]	This rule became effective March 19, 1998, requiring compliance on March 20, 2001.
Evacuation			
Access to exits: Type III exits	This rule requires improved access to the Type III emergency exits (typically smaller, overwing exits) by providing an unobstructed passageway to the exit. Transport aircraft with 60 or more passenger seats were required to comply with the new standards	To help ensure that passengers have an unobstructed passageway to exits during an emergency.	This rule became effective June 3, 1992, requiring changes to be made by December 3, 1992.
Public address system: independent power source	This rule requires that the public address system be independently powered for at least 10 minutes and that at least 5 minutes of that time is during announcements.	To eliminate reliance on engine or auxiliary-power-unit operation for emergency announcements.	This rule became effective November 27, 1989, for air carrier and air taxi airplanes manufactured on or after November 27, 1990.
Exit row seating	This rule requires that persons seated next to emergency exits be physically and mentally capable of operating the exit and assisting other passengers in emergency evacuations.	To improve passenger evacuation in an emergency.	This rule became effective April 5, 1990, requiring compliance by October 5, 1990.
Location of passenger emergency exits	Rule issued to limit the distance between adjacent emergency exits on transport airplanes to 60 feet.	To improve passenger evacuation in an emergency.	This rule became effective July 24, 1989, imposing requirements on airplanes manufactured after October 16, 1987.
Floor proximity emergency escape path marking	Airplane emergency lighting systems must visually identify the emergency escape path and identify each exit from the escape path.	To improve passenger evacuation when smoke obscures overhead lighting.	This rule became effective November 26, 1984, requiring implementation for large transport airplanes by November 26, 1986.
Fire-resistant evacuation slides	Emergency evacuation slides manufactured after December 3, 1984, must be fire resistant and comply with new radiant heat testing procedures.[b]	To improve passenger evacuation.	This technical standard became effective for all evacuation slides manufactured after December 3, 1984.
General safety and health			
Preparation for in-flight emergencies	In 1986, FAA issued a rule requiring commercial airlines to carry emergency medical kits.	To improve air carriers' preparation for in-flight emergencies.	This rule became effective August 1, 1986, requiring compliance as of that date.

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Key improvement areas	Action taken	Purpose	Status
Ban on smoking for majority of domestic commercial flights	In 1988 and 1989, the Congress passed legislation banning smoking on domestic flights of varying durations.	To limit the impact of poor cabin air quality on occupants' health	These laws became effective in 1988, and 1990, respectively.
Prevention of in-flight injuries	In June 1995, following two serious events involving turbulence, FAA issued a public advisory to airlines urging the use of seat belts at all times when passengers are seated but concluded that existing rules did not require strengthening. In May 2000, FAA instituted the Turbulence Happens public awareness campaign.	To prevent passenger injuries from turbulence by increasing public awareness of the importance of wearing seatbelts.	Information is currently posted on FAA's Web site.

Source: GAO presentation of FAA information.

[a]Technical Class C category cargo compartments are required to have built-in extinguishing systems to control fire in lieu of crewmember accessibility. Class D category cargo compartments are required to completely contain a fire without endangering the safety of the airplane occupants.

[b]Standard Order (TSO)–C69B ("Emergency Evacuation Slides, Ramps, Ramp/Slides, and Slide/Rafts") prescribes minimum performance standards for emergency evacuation slides, ramps, ramp/slides, and slide/rafts, including standards for resistance to radiant heat sources.

Summaries of Potential Impact Safety Advancements

This appendix presents information on the background and status of potential advancements in impact safety that we identified, including the following:

- retrofitting all commercial aircraft with more advanced seats,
- improving the ability of airplane floors to hold seats in an accident,
- preventing overhead luggage bins from becoming detached or opening,
- requiring child safety restraints for children under 40 pounds, and
- installing lap belts with self-contained inflatable air bags.[1]

Retrofitting All Commercial Aircraft with More Advanced Seats

Background

In commercial transport airplanes, the ability of a seat to protect a passenger from the forces of impact in an accident depends on reducing the forces of impact to levels that a person can withstand, either by spreading the impact over a larger part of the person's body or by decreasing the duration of the impact through the use of energy-absorbing seats, an energy-absorbing fuselage and floors, or restraints such as seat belts or inflatable seat belt air bags adapted from automobile technology. In a 1996 study by R.G.W Cherry & Associates, enhancing occupant restraint was ranked as the second most important of 33 potential ways to improve air crash survivability.[2] Boeing officials noted that the industry generally

[1]Officials with the United Kingdom's Civil Aviation Authority commented that inflatable airbags are but one solution for providing upper torso restraint. These officials cited a European Union funded "Going Safe" seat, which through an energy-absorbing device enables a lap and diagonal belt system to be fitted to an unmodified seat rail.

[2]R.G.W. Cherry & Associates, *Analysis of Structural Factors Influencing the Survivability of Occupants in Aeroplane Accidents*, Civil Aviation Authority, Paper 96011 (London: December 1996).

agrees with this view but that FAA and the industry are at odds over the means of implementing these changes.

According to an aviation safety expert, seats and restraints should be considered as a system that involves

- the seats themselves,
- seat restraints such as seat belts,
- seat connections to the floor,
- the spacing between seats, and
- furnishings in the cabin area that occupants could strike in an accident.

To protect the occupant, a seat must not only absorb energy well but also stay attached to the floor of the aircraft. In other words, the "tie-down" chain must remain intact. Although aircraft seat systems are designed to withstand about 9 to 16 times the force of gravity, the limits of human tolerance to impact substantially exceed the aircraft and seat design limits. A number of seat and restraint devices have been shown in testing to improve survivability in aviation accidents. Several options are to retrofit the entire current fleet with fully tested 16g seats, use rearward-facing seats, require three-point auto-style seat belts with shoulder harnesses, and install auto-style air bags.

FAA regulations require seats for newly certified airplane designs to pass more extensive tests than were previously required to protect occupants from impact forces of up to 16 times the force of normal gravity in the forward direction; seat certification standards include specific requirements to protect against head, spine, and leg injuries (see fig. 5).[3] FAA first required 16g seats and tests for newly designed, certificated

[3]The 1988 seat dynamic performance standards changed seat standards and testing. The new standards expanded seat testing to include potential injuries caused by head strikes on the back of seats and on stationary bulkheads, as well as criteria limiting lumbar and femur loads. These limits, if exceeded, could cause injuries that could prevent evacuation. Seats must be tested for forces in several directions to account for forward, downward, and other directional movements such as may occur in an accident. Previous FAA regulations required seats to be tested in only one primary direction at 9gs of force. The 16g level was adopted rather than a higher standard because the floor tracks of many of the airplanes in use in 1988 would break away upon an impact of more than 16gs.

airplanes in 1988; new versions of existing designs were not required to carry 16g seats.[4] Since 1988, however, in anticipation of a fleetwide retrofit rule, manufacturers have increasingly equipped new airplanes with "16g-compatible" seats that have some of the characteristics of fully certified 16g seats.[5] Certifying a narrow-body airplane type to full 16g seat certification standards can cost $250,000.[6,7]

Figure 5: Coach Seating and Impact Position in Coach Seating

Source: Weber Aircraft.

Coach seating (16g certified seats).

Post-crash test impact position of coach seating.

[4]The initial proposed rule, *Retrofit of Improved Seats in Air Carrier Transport-Category Airplanes*, 53 Fed. Reg. 17650 (1988) proposed requiring compliance with improved crashworthiness standards for all seats of transport-category airplanes used under part 121 and part 135 and prohibiting the operation of these airplanes unless all seats met the crashworthiness performance standards required by *Improved Seat Safety Standards*, 53 Fed. Reg. 17640 (1988).

[5]In general, most 16g-compatible seats meet the structural requirements of the 16g seat rule but do not need to meet the head injury criteria.

[6]Each aircraft type typically has 8 to 10 different types of seats, each of which must be certified; a typical economy class seat costs about $1,800. For marketing reasons, airlines usually choose their own distinctive seats, which must be certified for each type of airplane they fly.

[7]According to a Boeing Official, one cost estimate compiled by ATA and the Aerospace Industries Association in response to NPRM 88-8 presented in December 1988 showed the recurring per program cost [was listed] at $440,000.

In 1998 FAA estimated that 16g seats would avoid between about 210 to 410 fatalities and 220 to 240 serious injuries over the 20-year period from 1999 through 2018. A 2000 study funded by FAA and the British Civil Aviation Authority estimated that if 16g seats had been installed in all airplanes that crashed from 1984 through 1998, between 23 to 51 fewer U.S. fatalities and 18 to 54 fewer U.S. serious injuries would have occurred over the period. A number of accidents analyzed in that study showed no benefit from 16g seats because it was assumed that 16g seats would have detached from the floor, offering no additional benefits compared with older seats.[8] Worldwide, the study estimated, about 333 fewer fatalities and 354 fewer serious injuries would have occurred during the period had the improved seats been installed. Moreover, if fire risks had been reduced, the estimated benefits of 16g seats might have increased dramatically, as more occupants who were assumed to survive the impact but die in the ensuing fire would then have survived both the impact and fire.[9]

Status

Seats that meet the 16g certification requirements are currently available and have been required on newly certificated aircraft designs since 1988. However, newly manufactured airplanes of older certification, such as Boeing 737s, 757s, or 767s, were not required to be equipped with 16g certified seats. Recently, FAA has negotiated with manufacturers to install full 16g seats on new versions of older designs, such as all newly produced 737s.[10] In October 2002, FAA published a new proposal to create a timetable for all airplanes to carry fully certified 16g seats within 14 years.[11] The comment period for the currently proposed rule ended in March 2003.

[8]R.G.W. Cherry & Associates, *Benefit Analysis for Aircraft 16-g Dynamic Seats*, DOT/FAA/AR-00/13 (Washington, D.C.: April 2000). This study examined 25 large commercial airplane accidents that occurred from 1984 and through 1998 and possibly involved seat-related fatalities or injuries.

[9]In commenting on the proposed 16g seat retrofit rule, Boeing noted that there were fundamental, fatal flaws in both the analysis of benefits and the analysis of costs of implementing this rule.

[10]Until recently, FAA generally did not require a manufacturer to meet new, higher safety standards that are put in place after the date the manufacturer applies for a type certificate unless FAA can demonstrate that an unsafe condition exists. FAA's changed product rule requires manufacturers to comply with the latest airworthiness standards when significant design changes are proposed for a derivative aircraft that will be certificated under an amended or supplemental type certificate. 65 Fed. Reg. 36244 (2002).

[11]*Improved Seats in Air Carrier Transport Category Airplanes*, 67 Fed. Reg. 62294 (2002).

Under this proposal, airframe manufacturers would have 4 years to begin installing 16g seats in newly manufactured aircraft only, and all airplanes would have to be equipped with full 16g seats within 14 years or when scheduled for normal seat replacement. FAA estimated that upgrading passenger and flight attendant seats to meet full 16g requirements would avert approximately 114 fatalities and 133 serious injuries over 20 years following the effective date of the rule. This includes 36 deaths that would be prevented by improvements to flight attendant seats that would permit attendants to survive the impact and to assist more passengers in an evacuation.

FAA estimated the costs to avert 114 fatalities and 133 serious injuries at $245 million in present-value terms, or $519 million in overall costs, which, according to FAA's analysis, would approximate the monetary benefits from the seats.[12] FAA estimated that about 7.5 percent of airplane seats would have to be replaced before they would ordinarily be scheduled for replacement. FAA's October 2002 proposal divides seats into three classes according to their approximate performance level. Although FAA does not know how many seats of each type seat are in service, it estimates that about 44 percent of commercial-service aircraft are equipped with full 16g seats, 55 percent have 16g-compatible seats, and about 1 percent have 9g seats. The 16g-compatible or partial 16g seats span a wide range of capabilities; some are nearly identical to full 16g seats but have been labeled as 16g-compatible to avoid more costly certification, and other partial 16g seats offer only minor improvements over the older generation of 9g seats. To determine whether these seats have the same performance characteristics as full 16g seats, it may be sufficient, in some cases, to review the company's certification paperwork; in other cases, however, full crash testing of actual 16g seats may be necessary to determine the level of protection provided.

FAA is currently considering the comments it received on its October 2002 proposal. Industry comments raised concerns about general costs, the costs of retrofitting flight attendant seats, and the possibility that older airplanes designed for 9g seats might require structural changes to accommodate full 16g seats. One comment expressed the desire to give some credit for and "grandfather" in at least some partial 16g seats.

[12]FAA assumed benefits of $3 million for an averted fatality and $0.5 million for an averted serious injury.

Improving the Ability of Airplane Floors to Hold Seats in an Accident

Background

In an accident, a passenger's chances of survival depend on how well the passenger cabin maintains "living space" and the passenger is "tied down" within that space. Many experts and reports have noted floor retention—the ability of the aircraft cabin floor to remain intact and hold the passenger's seat and restraint system during a crash—as critical to increasing the passenger's chances of survival. Floor design concepts developed during the late 1940s and 1950s form the basis for the cabin floors found in today's modern airplanes.

Accident investigations have documented failures of the floor system in crashes.[13] New 16g seat requirements were developed in the 1980s. 16g seats were intended to be retrofitted on aircraft with traditional 9g floors and were designed to maximize the capabilities of existing floor strength. While 16g seats might be strong, they could also be inflexible and thus fail if the floor deformed in a crash. Under the current 16g requirement, the seats must remain attached to a deformed seat track and floor structure representative of that used in the airplane.[14] To meet these requirements, the seat was expected to permanently deform to absorb and limit impact forces even if the 16g test conditions were exceeded during a crash.

A major accident related to floor deformation occurred at Kegworth, England, in 1989. A Boeing 737-400 airplane flew into an embankment on approach to landing. In total, only 21 of the 52 triple seats—all "16g-compatible" —remained fully attached to the cabin floor; 14 of those that remained attached were in the area where the wing passes through the

[13]A study of survivable accidents that took place from 1970 through 1978 indicated that floor deformation during a crash was a primary cause of seat failure in 60 percent of the accidents. (Chandler, et al., DOT/FAA/CT-82-118)

[14]In the dynamic 16g seat test with a deformed floor, one floor track must be pitched 10 degrees (up or down) relative to the other floor track, which must in turn be rolled 10 degrees.

cabin and the area is stronger than other areas to support the wing.[15] In this section of the airplane, the occupants generally survived, even though they were exposed to an estimated peak level of 26gs. The front part of the airplane was destroyed, including the floor; most of these seats separated from the airplane, killing or seriously injuring the occupants. An FAA expert noted that the impact was too severe for the airplane to maintain its structural integrity and that 16g seats were not designed for an accident of that severity. The British Air Accidents Investigation Branch noted that fewer injuries occurred in the accident than would probably have been the case with earlier-generation seats. However, the Branch also noted that “relatively minor engineering changes could significantly improve the resilience and toughness of cabin floors . . . and take fuller advantage of the improved passenger seats.” The Branch reported that where failures occurred, it was generally the seat track along the floor that failed, and not the seat, and that the rear attachments generally remained engaged with the floor, “at least partially due to the articulated joint built into the rear attachment, an innovation largely stemming from the FAA dynamic test requirements.” The Branch concluded that “seats designed to these dynamic requirements will certainly increase survivability” but “do not necessarily represent an optimum for the long term . . . if matched with cabin floors of improved strength and toughness.”[16]

Status

Several reports have recommended structural improvements to floors. A case study of 11 major accidents for which detailed information was available found floor issues to be a major cause of injury or fatalities in 4 accidents and a minor cause in 1 accident. Another study estimated the past benefits of 16g seats in U.S. accidents between 1984 and 1998 and found no hypothetical benefit from 16g seats in a number of accidents because the floor was extensively disrupted during impact.[17] In other

[15]Some 16g-compatible seats were manufactured to meet 16g dynamic testing standards but did not complete FAA’s certification process for floor deformation on representative floors and seat tracks and technically met only the 9g seat certification requirements.

[16]Report on the accident to Boeing 737-400 G-OBME near Kegworth, Leicestershire, on 8 January 1989, Aircraft Accident Report 4/90, AAIB, DOT, London, HMSO; “Recommendations for Injury Prevention in Transport Aviation Accidents,” prepared for NASA, Langley Research Center, by Simula Technologies, Inc., February 2, 2000, TR-99112, S97324.

[17] “Benefit Analysis for Aircraft 16-g Dynamic Seats,” Final Report, U.S. Department of Transportation (DOT/FAA/AR-00/13) and U.K Civil Aviation Authority (CAA Paper 99003).

words, unless the accidents had been less severe or the floor and seat tracks had been improved beyond the 9g standard on both new and old jets, newer 16g seats would not have offered additional benefits compared with the older seats that were actually on the airplane during the accidents under study.

A research program on seat and floor strength was recently conducted by the French civil aviation authority, the Direction Générale de l'Aviation Civile. Initial findings of the research program on seat-floor attachments have not shown dramatic results and showed no rupture or plastic deformation of any cabin floor parts during a 16g test. However, French officials noted that they plan to perform additional tests with more rigid seats. Because many factors are involved it is difficult to identify the interrelated issues and interactions between seats and floors. A possible area for future research, according to French officials, is to examine dynamic floor warping during a crash to improve impact performance.

FAA officials said they have no plans to change floor strength requirements. FAA regulations require floors to meet impact forces likely to occur in "emergency landing conditions," or generally about 9gs of longitudinal static force. According to several experts, stronger floors could improve the performance of 16g seats. In addition, further improvement in seats beyond the 16g standard would likely require improved floors.

Preventing Overhead Storage Bin Detachment to Protect Passengers in an Accident

Background

In an airplane crash, overhead luggage bins in the cabin sometimes detach from their mountings along the ceiling and sidewalls and can fall completely or allow pieces of luggage to fall on passengers' heads (See fig. 6.). While only a few cases have been reported in which the impact from dislodged overhead bins was the direct cause of a crash fatality or injury, a study for the British Civil Aviation Authority that attempted to identify the specific characteristics of each fatality in 42 fatal accidents estimated that the integrity of overhead bin stowage was the 17th most important of 32 factors used to predict passenger survivability.[18] Maintaining the integrity of bins may also help speed evacuation after a crash.

Safer bins have been designed since bin problems were observed in a Boeing 737 accident in Kegworth, England, in 1989, when nearly all the bins failed and fell on passengers. FAA tested bins in response to that accident. The Kegworth bins were certified to the current FAA 9g longitudinal static loading standards, among others. When FAA subsequently conducted longitudinal dynamic loading tests on the types of Boeing bins involved, the bins failed. Several FAA experts said that the overhead bins on 737s had a design flaw. FAA then issued an airworthiness directive that called for modifying all bins on Boeing 737 and 757 aircraft. The connectors for the bins were strengthened in accordance with the airworthiness directive, and the new bins passed FAA's tests.

The British Air Accidents Investigation Branch recommended in 1990 that the performance of both bins and latches be tested more rigorously, including the performance of bins "when subjected to dynamic crash pulses substantially beyond the static load factors currently required." NTSB has made similar recommendations.

Turbulence reportedly injures at least 15 U.S. cabin occupants a year, and possibly over 100. Most of these injuries are to flight attendants who are unrestrained. Some injuries are caused by luggage falling from bins that open in severe turbulence. Estimates of total U.S. airline injuries from bin-related falling luggage range from 1,200 to 4,500 annually, most of which occur during cruising rather than during boarding or disembarking.[19]

The study for the British Civil Aviation Authority noted above found that as many as 70 percent of impact-related accidents involve overhead bins that become detached. However, according to the report, bin detachment does not appear to be a major factor in occupants' survival and data are insufficient to support a specific determination about the mechanism of

[18] R.G.W. Cherry & Associates, *Analysis of Structural Factors Influencing the Survivability of Occupants in Aeroplane Accidents*, Civil Aviation Authority, Paper 96011 (London: December 1996).

[19] Flight Safety Foundation, "Increased Amount and Types of Carry-On Baggage Bring New Industry Responses," November-December 1997, Vol. 32, No. 6, p. 6.

failure. FAA has conducted several longitudinal and drop tests since the Kegworth accident, including drops of airplane fuselage sections with overhead storage bins installed. A 1993 dynamic vertical drop test showed some varying bin performance problems at about 36gs of downward force. An FAA longitudinal test in 1999 tested two types of bins at 6g, at the 9g FAA certification requirement, and at the 16g level; in the 16g longitudinal test, one of the two bins broke free from its support mountings.

Status

In addition to the requirement that they withstand forward (longitudinal) loads of slightly more than 9gs, luggage bins must meet other directional loading requirements.[20] Bin standards are part of the general certification requirements for all onboard objects of mass. FAA officials said that overhead bins no longer present a problem, appear to function as designed, and meet standards. An FAA official told us that problems such as those identified at Kegworth have not appeared in later crashes. Another FAA official said that while Boeing has had some record of bin problems, the problems are occasional and quickly rectified through design changes. Boeing officials told us that the evidence that bins currently have latch problems is anecdotal.

Suggestions for making bins safer in an accident include adding features to absorb impact forces and keep bins attached and closed during structural deformation; using dynamic 16g longitudinal impact testing standards similar to those for seats; and storing baggage in alternative compartments in the main cabin, elsewhere in the aircraft, or under seats raised for that purpose.

Child Safety Seats

Background

Using a correctly-designed child safety seat that is strapped in an airplane seat offers protection to a child in an accident or turbulence (see fig. 6). By contrast, according to many experts, holding a child under two years old on an adult's lap, which is permitted, is unsafe for both the child and for other

[20] Bins are required to withstand 9g forward (longitudinal), 3g upward, 6g downward, and other load requirements.

occupants who could be struck by the child in an accident. Requiring child safety seats for infants and small children on airplanes is one of NTSB's "most wanted" transportation safety improvements. The British Air Accidents Investigation Branch made similar recommendations, as did a 1997 White House Commission report on aviation.

Figure 6: Examples of Child Safety Seats

Source: Transport Canada.

Aft-facing seat developed for children under 20 pounds by Transport Canada.

An FAA analysis of survivable accidents from 1978 through 1994 found that 9 deaths, 4 major injuries, and 8 minor injuries to children occurred. The analysis also found that the use of child safety seats would have prevented 5 deaths, all the major injuries, and 4 to 6 of the minor injuries. Child safety advocates have pointed to several survivable accidents in which children died—a 1994 Charlotte, North Carolina, crash; a 1990 Cove Neck, New York, accident; and a 1987 Denver, Colorado, accident—as evidence of the need for regulation.

A 1992 FAA rule required airlines to allow child restraint systems, but FAA has opposed mandatory child safety seats on the basis of studies showing that requiring adults to pay for children's seats would induce more car travel, which the study said was more dangerous for children than airplane travel. One study published in 1995 by DOT estimated that if families were charged full fares for children's seats, 20 percent would choose other modes of transportation, resulting in a net increase of 82 deaths among children and adults over 10 years.

If child safety seats are required, airlines may require adults wishing to use child safety seats to purchase an extra seat for the child's safety seat. FAA officials told us that they could not require that the seat next to a parent be kept open for a nonpaying child. However, NTSB has testified that the scenarios for passengers taking other modes of transportation are flawed because FAA assumed that airlines would charge full fares for infants currently traveling free. NTSB noted in 1996 that airlines would offer various discounts and free seats for infants in order to retain $6 billion in revenue that would otherwise be lost to auto travel. Airlines have already responded to parents who choose to use child restraint systems with scheduling flexibility, and many major airlines offer a 50 percent discount off any fare for a child under 2 to travel in an approved child safety seat. The 1995 DOT study, however, estimated that even if a child's seat on an airplane were discounted 75 percent, some families would still choose car travel and that the choice by those families to drive instead of fly would result in a net increase of 17 child and adult deaths over 10 years.

In FAA tests, some but not all commercially available automobile child restraint systems have provided adequate protection in tests simulating airplane accidents. Prices range from less than $100 for a child safety seat marketed for use in both automobiles and airplanes to as much as $1,300 for a child safety seat developed specifically for use in airplanes.

A drawback to having parents, rather than airlines, provide child safety seats for air travel is that some models may be more difficult to fit into airplane seat belts, making a proper fit more challenging. While the performance of standardized airline-provided seats may be better than that of varied FAA-certified auto-airplane seats, one airline said that providing seats could present logistical problems for them. However, Virgin Atlantic Airlines supplies its own specially developed seats and prohibits parents from using their own child seats. Because turbulence can be a more frequent danger to unrestrained children than accidents, one expert told us that a compromise solution might include allowing some type of alternative in-flight restraint.

Status

Child safety seats are currently available for use on aircraft. The technical issues involved in designing and manufacturing safe seats for children to use in both cars and airplanes have largely been solved, according to FAA policy officials and FAA researchers. Federal regulations establish requirements for child safety seats designed for use in both highway vehicles and aircraft by children weighing up to 50 pounds. FAA officials explained that regulations requiring child safety seats have been delayed, in part, because of public policy concerns that parents would drive rather than fly if they were required to buy seats for their children. On February 18, 1998, FAA asked for comments on an advanced notice of proposed rule-making to require the use of child safety seats for children under the age of 2. FAA sponsored a conference in December 1999 to examine child restraint systems. At that conference, the FAA Administrator said the agency would mandate child safety seats in aircraft and provide children with the same level of safety as adults. FAA officials told us that they are still considering requiring the use of child safety seats but have not made a final decision to do so. If FAA does decide to provide "one level of safety" for adults and children, as NTSB advocates, parents may opt to drive to their destinations to avoid higher travel costs, thereby statistically exposing themselves and their children to more danger. In addition, FAA will have to decide whether the parents or airlines will provide the seats.

If FAA decides to require child safety seats, it will need to harmonize its requirements with those of other countries where requirements differ, as the regulations on child restraint systems vary. In Canada, as in the United States, child safety seats are not mandatory on registered aircraft. In Europe, the regulations vary from country to country, but no country requires their use. Australia's policy permits belly belts but discourages their use. An Australian official said in 1999 that Australia was waiting for the United States to develop a policy in this area and would probably follow that policy.

Inflatable Lap Belt Air Bags

Background

Lap belts with inflatable air bags are designed to reduce the injuries or death that may result when a passenger's head strikes the airplane interior. These inflatable seat belts adapt advanced automobile air bag technology to airplane seats in the form of seat belts with embedded air bags. If a passenger loses consciousness because of a head injury in an accident, even a minor, nonfatal concussion can cause death if the airplane is burning and the passenger cannot evacuate quickly. Slowing the duration of the impact with an air bag lessens its lethality. According to a manufacturer's tests using airplane seats on crash sleds, lap belts with air bags can likely reduce some impact injuries to survivable levels.[21]

FAA does not require seats to be tested in sled tests for head impact protection when there would be "no impact" with another seat row or bulkhead wall, such as when spacing is increased to 42 inches from the more typical 35 inches. While more closely spaced economy class seat rows can provide head impact protection through energy-absorbing seat backs, seats in no impact positions have tested poorly in head injury experiments, resulting in severe head strikes against the occupants' legs or the floor, according to the manufacturer. This no impact exemption from FAA's head injury criteria can include exit rows, business class seats, and seats behind bulkhead walls and could permit as many as 30 percent of seats in some airplanes to be exempt from the head impact safety criteria that row-to-row seats must meet.

Status

According to the manufacturer, 13 airlines have installed about 1,000 of the devices in commercial airliners, mainly at bulkhead seats; about 200 of

[21]One manufacturer's testing shows that the inflatable lap belts can reduce head injury criteria scores from about 2,000 to 200-300 in a 16g impact. A score of 1,000 implies a skull fracture, possible loss of consciousness, and a 16 percent risk of life-threatening brain injury.

these are installed in the U.S. fleet. All of the orders and installations so far have been done to meet FAA's seat safety regulations rather than for marketing reasons, according to the manufacturer.

The airlines would appear to benefit from using the devices in bulkhead seats if that would allow them to install additional rows of seats. While the amount of additional revenue would depend on the airplane design and class of seating, two additional seats may produce more net revenue per year than the cost for the devices to be installed throughout an aircraft.[22] Economic constraints are acquisition costs, maintenance costs, and increased fuel costs due to weight. The units currently weigh about 3 pounds per seat, or 2 pounds more than current seat belts. According to the manufacturer, the air bag lap belts currently cost $950 to $1,100, including maintenance. The manufacturer estimated that if 5 percent of all U.S. seat positions were equipped with the devices (about 50,000 seats per year), the cost would drop to about $300 to $600 per seat, including installation.[23]

Lap belt air bags have been commercially available for only a few years. FAA's Civil Aerospace Medical Institute assisted the developers of the devices; manufacturers for both passenger and military use (primarily helicopter) are conducting ongoing research. FAA and other regulatory bodies have no plans to require their installation, but airlines are allowed to use them. The extent to which these devices are installed will depend on each airline's analysis of the cost and benefits.

[22]At an annual life-cycle cost of approximately $12,000 to outfit an average airliner with lap belt air bags on all seats of the U.S. fleet, assuming an installation cost of $450 per seat position not including maintenance and replacement costs. A GAO analysis of the 2002 Annual Report of Southwest Airlines, which has relatively low passenger revenue per available seat mile compared with other airlines, found that each seat produced an annual net revenue of about $10,000. See appendix VIII for our analysis of the costs associated with lap belts.

[23]According to the manufacturer, the installation of the most common design requires maintenance of one minute per seat position for a diagnostic test every 1,900 flight hours, and the devices must be refurbished about once every 7 years at about a third of the initial price.

Summaries of Potential Fire Safety Advancements

This appendix presents information on the background and status of potential advancements in fire safety that we identified, including the following:

- preventing fuel tank explosions with fuel tank inerting;
- preventing in-flight fires with arc fault circuit breakers;
- identifying in-flight fires with multisensor fire and smoke detectors;
- suppressing in-flight and postcrash fires by using water mist fire suppression systems;
- mitigating postcrash damage and injury by using less flammable fuels;
- mitigating in-flight and postcrash fires by using fire-resistant thermal acoustic insulation;
- mitigating fire-related deaths and injuries by using ultra-fire-resistant polymers; and
- mitigating fire deaths and injuries with sufficient airport rescue and fire fighting.

Fuel Tank Inerting

Background

Fuel tank inerting involves pumping nitrogen-enriched air into an airliner's fuel tanks to reduce the concentration of oxygen to a level that will not support combustion. Nitrogen gas makes a fuel tank safer by serving as a fire suppressant. The process can be performed with both ground-based and onboard systems, and it significantly reduces the flammability of the center wing tanks, thereby lowering the likelihood of a fuel tank explosion.

Following the crash of TWA Flight 800 in 1996, in which 230 people died, NTSB determined that the probable cause of the accident was an explosion in the center wing fuel tank. The explosion resulted from the ignition of flammable fuel vapors in this tank, which is located in the fuselage in the space between the wing junctions. NTSB subsequently placed the improvement of fuel tank design on its list of "Most Wanted Safety

Improvements" and recommended that fuel tank inerting be considered an option to eliminate the likelihood of fuel tank explosions.

FAA issued Special Federal Aviation Regulation 88[1] to eliminate or minimize the likelihood of ignition sources by revisiting the fuel tank's design. Issued in 2001, the regulation consists of a series of FAA regulatory actions aimed at preventing the failure of fuel pumps and pump motors, fuel gauges, and electrical power wires inside these fuel tanks. In late 2002, FAA amended the regulation to allow for an "equivalent level of safety" and the use of inerting as part of an alternate means of compliance.

In a 2001 report, an Aviation Rule-making Advisory Committee tasked with evaluating the benefits of inerting the center wing fuel tank estimated these benefits in terms of lives saved. After projecting possible in-flight and ground fuel tank explosions and postcrash fires from 2005 through 2020, the committee estimated that 132 lives might be saved from a ground-based system and 253 lives might be saved from an onboard system.[2]

Status

Neither of the two major types of fuel tank inerting—ground-based and onboard—is currently available for use on commercial airliners because additional development is needed.[3] Both types offer benefits and drawbacks.

- A ground-based system sends a small amount of nitrogen into the center wing tank before departure. Its benefits include that (1) it requires no new technology development for installation, (2) the tank can be inerted in 20 minutes, and (3) it carries a lesser weight penalty. Its drawbacks include that it is unable to inert for descent, landing, and taxiing to the

[1]ATA noted that more than 80 fuel tank Airworthiness Directives have been adopted since the crash of TWA Flight 800 and that a similar number of directives are currently under development.

[2]The committee also estimated, on the basis of data on nitrogen exposure from the Occupational Safety and Health Administration and the National Institute of Occupational Safety and Health, that from 24 to 81 lives could be lost over the same period, depending on the degree of oxygen depletion. The report did not specifically indicate whether this forecast was for a ground-based, onboard, hybrid, or any other inerting system.

[3]By using more general terminology, this terminology excludes hybrid and liquid nitrogen inerting systems, also considered by the Aviation Rule-making Advisory Committees for their 1998 and 2001 reports.

destination gate, and nitrogen supply systems are needed at each terminal gate and remote parking area at every airport.

- An onboard system generates nitrogen by transferring some of the engine bleed air – air extracted from the jet engines to supply the cabin pressurization system in normal flight—through a module that separates air into oxygen and nitrogen and discharges the nitrogen enriched air into the fuel tank. Its benefits include that (1) it is self-reliant and (2) it significantly reduces an airplane's vulnerability to lightning, static electricity, and incendiary projectiles throughout the flight's duration.[4] Its drawbacks include that it (1) weighs more, (2) increases the aircraft's operating costs, and (3) may decrease the aircraft's reliability.[5]

According to FAA, its fire safety experts' efforts to develop a lighter-weight system for center wing tank inerting have significantly increased the industry's involvement. Boeing and Airbus are working on programs to test inerting systems in flight. For example, Boeing has recently completed a flight test program with a prototype system on a 747.

None of the U.S. commercial fleet is equipped with either ground-based or onboard inerting systems, though onboard systems are in use in U.S. and European military aircraft. Companies working in this field are focused on developing new inerting technologies or modifying existing ones. A European consortium is developing a system that combines onboard center wing fuel tank inerting with sensors and a water-mist-plus-nitrogen fire suppression system for commercial airplanes.

In late 2002, FAA researchers successfully ground-tested a prototype onboard inerting system using current technology on a Boeing 747SP. New research also enabled the agency to ease a design requirement, making the inerting technology more cost-effective. This new research showed that

[4]According to an FAA safety expert, FAA is addressing only the center wing tank because of its significantly higher flammability exposure and the low risk of an explosion in the wing tanks.

[5]A current controversial issue is whether inerting technology will be considered flight-critical hardware—and therefore will be required to function properly for the aircraft to fly. If it is deemed flight critical, its reliability may affect the dispatch rate of the aircraft. For example, if the technology experiences operational problems, the aircraft may be allowed to fly only 25 times a week, even if it is scheduled to fly 30 times a week. This problem reduces revenue to the airline and is a greater concern for civilian than for military aviation, because there are usually replacements for military aircraft.

reducing the oxygen level in the fuel tank to 12 percent—rather than 9 percent, as was previously thought—is sufficient to prevent fuel tank explosions in civilian aircraft.[6] FAA also developed a system that did not need the compressors that some had considered necessary. Together, these findings allowed for reductions in the size and power demands of the system.

FAA plans to focus further development on the more practical and cost-effective onboard fuel tank inerting systems. For example, to further improve their cost-effectiveness, the systems could be designed both to suppress in-flight cargo fires, thereby allowing them to replace Halon extinguishing agents, and to generate oxygen for emergency depressurizations, thereby allowing them to replace stored oxygen or chemical oxygen generators.

NASA is also conducting longer-term research on advanced technology onboard inert gas-generating systems and onboard oxygen-generating systems. Its research is intended (1) to develop the technology to improve its efficiency, weight, and reliability and (2) to make the technology practical for commercial air transport. NASA will fund the development of emerging technologies for ground-based technology demonstration in fiscal year 2004. NASA is also considering the extension of civilian transport inerting technology to all fuel tanks to help protect airplanes against terrorist acts during approaches and departures.

The cost of the system, its corresponding weight, and its unknown reliability are the most significant factors affecting the potential use of center wing fuel tank inerting. New cost and weight estimates are anticipated in 2003.

[6]FAA fuel tank safety experts conducted tests under high temperatures and found that a tank with an oxygen level of 12 percent was inert against internal threats, such as sparks and hot surfaces. According to one FAA expert, the system provides a "below 12 percent" inert tank under all conditions except for a brief time during descent when local pockets in the tank may approach 16 percent oxygen. The expert said that at this time, the tank is generally cool enough to be nonflammable even with normal air (21 percent oxygen) in the tank. If the tank is cool enough, internal threats will not ignite the fuel air mixture. He said the probability of explosions is very low in the wing tanks because they are not heated by other airplane systems.

- In 2001, FAA estimated total costs to equip the worldwide fleet at $9.9 billion for ground-based, and $20.8 billion for onboard, inerting systems.[7]

- In 2002, FAA officials developed an onboard system for B-747 flight-testing. The estimated cost was $460,000. The officials estimated that each system after that would cost about $200,000. The weight of the FAA prototype system is 160 pounds.[8] A year earlier, NASA estimated the weight for a B-777 system with technology in use in military aircraft at about 550 pounds.[9]

Arc Fault Circuit Breaker

Background

Arcing faults in wiring may provide an ignition source that can start fires. Electrical wiring that is sufficiently damaged might cause arcing or direct shorting resulting in smoking, overheating, or ignition of neighboring materials. A review of data produced by FAA, the Airline Pilots Association, and Boeing showed that electrical systems have been a factor in approximately 50 percent of all aircraft occurrences involving smoke or fire and that wiring has been implicated in about 10 percent of those occurrences. In addition, faulty or malfunctioning wiring has been a factor in at least 15 accidents or incidents investigated by NTSB since 1983. Properly selecting, routing, clamping, tying, replacing, marking, separating, and cleaning around wiring areas and proper maintenance all help mitigate the potential for wire system failures, such as arcing, that could lead to smoke, fire and loss of function. Chemical degradation, age induced cracking, and damage due to maintenance may all create a scenario which

[7]These estimates included the costs for modifying aircraft that are currently in service, in production, and being designed, and they assumed a predicted reduction in the accident rate of 75 percent.

[8]This system does not have the capability to inert the cargo compartment, bay, and wheel well, and it dumps oxygen as effluent rather than using it for an emergency passenger oxygen system.

[9]A 2001 NASA study indicated that two liquid nitrogen systems were the only ones that appeared capable of inerting all fuel tanks of a commercial aircraft full time.

could lead to arcing. Arcing can occur between a wire and structure or between different wire types. Wire chafing is a sign of degradation; chafing happens when the insulation around one wire rubs against a component tougher than itself (such as structure or control cable) exposing the wire conductor. This condition can lead to arcing. When arcing wires are too close to flammable materials or are flammable themselves, fires can occur.

In general, wiring and wiring insulation degrade for a variety of reasons, including age, inadequate maintenance, chemical contamination, improper installation or repair, and mechanical damage. Vibration, moisture, and heat can contribute to and accelerate degradation. Consequences of wire systems failures include loss of function, smoke, and fire. Since most wiring is bundled and located in hidden or inaccessible areas, it is difficult to monitor the health of an aircraft's wiring system during scheduled maintenance using existing equipment and procedures. Failure occurrences have been documented in wiring running to the fuel tank, in the electronics equipment compartment, in the cockpit, in the ceiling of the cabin, and in other locations.

To address the concerns with arcing, arc fault circuit breakers for aircraft use are being developed. The arc fault circuit breaker cuts power off as it senses a wire beginning to arc. It is intended to prevent significant damage before a failure develops into a full-blown arc, which can produce extremely localized heat, char insulation, and generally create problems in the wire bundles. Arc fault circuit protection devices would mitigate arcing events, but will not identify the wire breaches and degradation that typically lead up to these events.

Status

FAA, the Navy, and the Air Force are jointly developing arc fault circuit breaker technology. Boeing is also developing a monitoring system to detect the status of and changes in wiring; and power shuts down when arcing is detected. This system may be able to protect wiring against both electrical overheating and arcing and is considered more advanced than the government's circuit breaker technology.

FAA developed a plan called the Enhanced Airworthiness Program for Airplane Systems to address wiring problems, which includes development of arc fault circuit breaker technology and installation guidance along with proposals of new regulations. The plan provides means for enhancing safety in the areas of wire system design, certification, maintenance, research and development, reporting, and information sharing and outreach. FAA also tasked an Aging Transport Systems Rule-making Advisory Committee to provide data, recommendations, and evaluation specifically on aging wiring systems. The new regulations being considered are entitled the Enhanced Airworthiness Program for Airplane Systems Rule and are expected by late-2005. Under this rule-making package, inspections would evaluate the health of wiring and all of its components for operation, such as connectors and clamps. Part of the system includes visual inspections of all wiring within arm's reach, enhanced by the use of hand-held mirrors. This improvement is expected to catch more wiring flaws than current visual inspection practices. Where visual inspections can not be assumed to detect damage, detailed inspections will be required. The logic process to establish proper inspections is called the Enhanced Zonal Analysis Procedure, which will be issued as an Advisory Circular. This procedure is specifically directed towards enhancing the maintenance programs for aircraft whose current program does not include tasks derived from a process that specifically considers wiring in all zones as the potential source of ignition of a fire.

Additional development and testing will be required before advanced arc fault circuit breakers will be available for use on aircraft. The FAA currently is in the midst of a prototype program where arc fault circuit breakers are installed in an anticollision light system on a major air carrier's Boeing 737. The FAA and the Navy are currently analyzing tests of the circuit breakers to assess their reliability. The Society of Automotive Engineers is in the final stages of developing a Minimum Operating Performance Specification for the arc fault circuit breaker.

Multisensor Detectors

Background

Multisensor detectors, or "electronic noses," could combine one or more standard smoke detector technologies; a variety of sensors for detecting such gases as carbon monoxide, carbon dioxide, or hydrocarbon; and a thermal sensor to more accurately detect and locate overheated or burning materials. The sensors could improve existing fire detection by discovering and locating potential or actual fires sooner and reducing the incidence of false alarms. These "smart" sensors would ignore the "nuisance sources" such as dirt, dust, and condensation that are often responsible for triggering false alarms in existing systems.[10]

According to studies by FAA and the National Institute of Standards and Technology, many current smoke and fire detection systems are not reliable. A 2000 FAA study indicated that cargo compartment detection systems, for example, resulted in at least one false alarm per week from 1988 through 1990 and a 200:1 ratio of false alarms to actual fires in the cargo compartment from 1995 through 1999. [11] FAA has since estimated a 100:1 cargo compartment false alarm ratio, partly because reported actual incidents have increased According to FAA's Service Difficulty Report database,[12] about 990 actual smoke and fire events were reported for 2001.[13]

Multisensor detectors could be wired or wireless and linked to a suppression system. One or several sensor signals or indicators could cause the crew to activate fire extinguishers in a small area or zone, a larger area, or an entire compartment, resulting in a more appropriate and accurate use of the fire suppressant. For example, in areas such as the avionics compartment, materials that can burn are relatively well-defined. Multisensor detectors the size of a postage stamp could be designed to detect smoldering fires in cables or insulation or in overheated equipment in that area. Placing the detectors elsewhere in the airplane could improve the crew's ability to respond to smoke or fire, including occurrences in hidden or inaccessible areas.

Improved sensor detection technologies would both enhance safety by increasing crews' confidence in the reliability of alarms and reduce costs by avoiding the need to divert aircraft in response to false alarms. One

[10]One type of smart sensor would analyze the light-scattering properties of the particles in the air to differentiate between smoke particles and nuisance sources.

[11]*Aircraft Cargo Compartment Smoke Detector Alarm Incidents on U.S.-Registered Aircraft, 1974-1999*, DOT/FAA/AR-TN00/29 (Washington, D.C.: June 2000). The study indicated a generally increasing number of false alarms as the size of the fleet grew.

[12]Operating requirements for all aircraft have been amended by a 2000 final rule, whose deadline was recently extended for the third time, to report the occurrence or detection of failures, malfunctions, or defects concerning fire warning systems and false warnings of fire or smoke in the entire U.S. fleet.

[13]According to FAA fire safety experts, most of these are contaminated air or smoke events in the cabin, detected by people, not by detectors.

study estimated the average cost of a diversion at $50,000 for a wide-body airplane and $30,000 for a narrow-body airplane. A diversion can also present safety concerns because of the possible increased risk of an accident and injuries to passengers and crew if there is (1) an emergency evacuation, (2) a landing at an unfamiliar airport, (3) a change to air traffic patterns, (4) a shorter runway, (5) inferior fire-fighting capability, (6) a loss of cargo load, or (7) inferior navigation aids. In 2002, 258 unscheduled landings due to smoke, fire, or fumes occurred. In addition, 342 flights were interrupted; some of these flights had to return to the gate or abort a takeoff.

FAA established basic detector performance requirements in 1965 and 1980. Detectors were to be made and installed in a manner that ensured their ability to resist, without failure, all vibration, inertia, and other loads to which they might normally be subjected; they also had to be unaffected by exposure to fumes, oil, water, or other fluids. Regulations in 1986 and 1998 further defined basic location and performance requirements for detectors in different areas of the cargo compartment. In 1998, FAA issued a requirement for detection and extinguishment systems for one class of cargo compartments, which relied on oxygen starvation to control fires. This requirement significantly increased the number of detectors in use.

Status

Multisenor detectors are not currently available because additional research is needed. Although they have been demonstrated in the laboratory and on the ground, they have not been flight-tested. FAA and NASA have multisensor detector research and development efforts under way and are working to develop “smart” sensors and criteria for their approval. FAA will also finish revising an Advisory Circular that establishes test criteria for detection systems, designed to ensure that they respond to fires, but not to nonfire sources. In addition, several companies currently market “smart” detectors, mostly for nonaviation applications. For example, thermal detection systems sense and count certain particles that initially boil off the surface of smoldering or burning material.

A European consortium has been developing a system, FIREDETEX, that combines the use of multisensor detectors, onboard fuel tank inerting, and water-mist-plus-nitrogen fire suppression systems for commercial airplanes. This program and associated studies are still ongoing and flight testing is planned for the last quarter of calendar year 2003. The results of tests on this system are expected to be made public in early 2004, and will help to clarify the possible costs, benefits, and drawbacks of the combined system.

Additional research, development, and testing will be required before multisensor technology is ready for use in commercial aviation. NASA, FAA, and private companies are pursuing various approaches. Some experts believe that some forms of multisensor technology could be in use in 5 years. When these units become available, questions may arise about where their use will be required. For example, the Canadian Transportation Safety Board has recommended that some areas in addition to those currently designated as fire zones may need to be equipped with detectors.[14] These include the electronics and equipment bay (typically below the floor beneath the cockpit and in front of the passenger cabin), areas behind interior wall panels in the cockpit and cabin areas, and areas behind circuit breaker and other electronic panels.

Water Mist Fire Suppression

Background

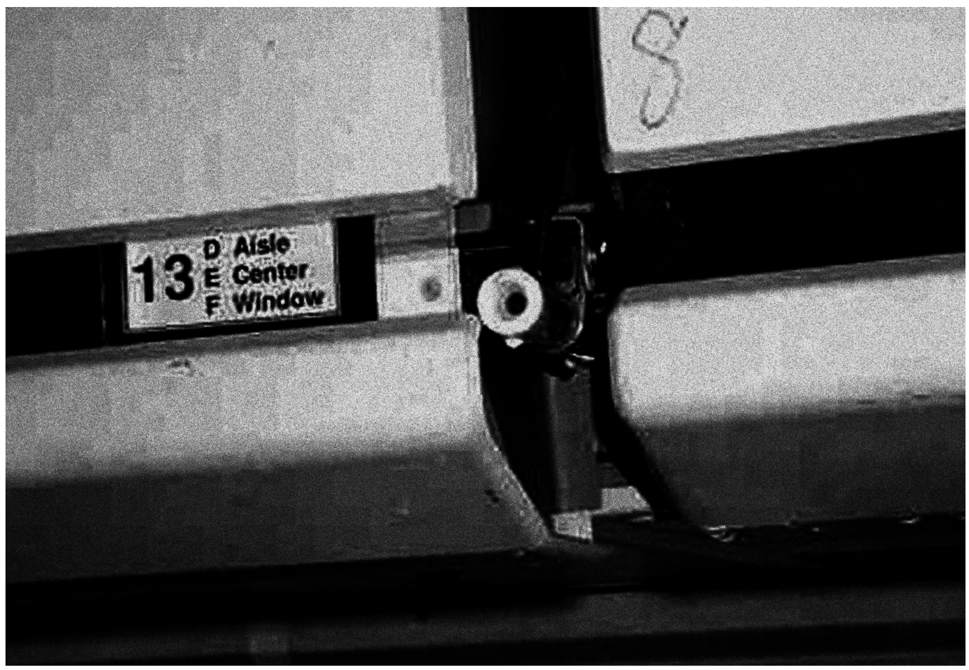
For over two decades, the aviation industry has evaluated the use of systems that spray water mist to suppress fires in airliner cabins, cargo compartments, and engine casings (see fig. 7). This effort was prompted, in part, by a need to identify an alternative to Halon, the primary chemical used to extinguish fires aboard airliners. With few exceptions, Halon is the sole fire suppressant installed in today's aircraft fire suppression systems. However, the production of Halon was banned under the 1987 *Montreal Protocol on Substances that Deplete the Ozone Layer*, and its use in many noncritical sectors has been phased out. Significant reserves of Halon remain, and its use is still allowed in certain "critical use" applications, such as aerospace,[15] because no immediate viable replacement agent

[14]This recommendation was one of several resulting from the Canadian Transportation Safety Board's investigation of the Swissair Flight 111 crash.

[15]A use is considered "critical" when a need exists to protect against fire or explosion risks in areas that would result in a serious threat to essential services or pose an unacceptable threat to life, the environment, or national security. Typical critical users are aerospace, certain petrochemical production processors, certain marine applications, and national defense.

exists. To enable the testing and further development of suitable alternatives to and substitutes for Halon, FAA has drafted detailed standards for replacements in the cargo and engine compartments. These standards typically require replacement systems to provide the same level of safety as the currently used Halon extinguishing system.

Figure 7: Water Mist Nozzle and Possible Placement



Source: FAA.

According to FAA and others in the aviation industry, successful water mist systems could provide benefits against an in-flight or postcrash fire, including

- cooling the passengers, cabin surfaces, furnishings and overall cabin temperatures;
- decreasing toxic smoke and irritant gases; and

- delaying or preventing "flashover" fires from occurring.[16]

In addition, a 1996 study prepared for the British Civil Aviation Authority examined 42 accidents and 32 survivability factors and found that cabin water spray was the factor that showed the greatest potential for reducing fatality and injury rates.[17] In the early 1990s, a joint FAA and Civil Aviation Authority study found that cabin water mist systems would be highly effective in improving survivability during a postcrash fire.[18] However, the cost of using these systems outweighed the benefits, largely because of the weight of the water that airliners would be required to carry to operate them. In the mid- and late-1990s, FAA and others began examining water mist systems in airliner cargo compartments to help offset the cost of a cabin water mist system because the water could be used or shared by both the cargo compartment and the cabin. European and U.S. researchers also designed systems that required much less water because they targeted specific zones within an aircraft to suppress fires rather than spraying water throughout the cabin or the cargo compartment.

In 2000, Navy researchers found a twin-fluid system to be highly reliable and maintenance-free.[19] Moreover, this system's delivery nozzles could be installed without otherwise changing cabin interiors. The Navy researchers' report recommended that FAA and NTSB perform follow-up testing leading to the final design and certification of an interior water mist fire suppression system for all passenger and cargo transport aircraft. Also in 2000, a European consortium began a collaborative research project

[16]Flashover can occur in an airplane cabin fire when all exposed combustible surfaces reach ignition temperature more or less simultaneously. It is characterized by rapid increases in temperature, with smoke, toxic gases, and oxygen depletion creating a largely nonsurvivable environment.

[17]R.G.W. Cherry & Associates, *Analysis of Structural Factors Influencing the Survivability of Occupants in Aeroplane Accidents*, Civil Aviation Authority, Paper 96011 (London: December 1996).

[18]*Increasing the Survival Rate in Aircraft Accidents: Impact Protection, Fire Survivability, and Evacuation*, European Transport Safety Council (December 1996).

[19]Twin-fluid systems use air, nitrogen, or another gas in combination with water. They require lower water supply pressure and bigger nozzle orifices.

called FIREDETEX, which combines multisensor fire detectors, water mist, and onboard fuel tank inerting into one fire detection and suppression system.[20]

In 2001 and 2002, FAA tested experimental mist systems to determine what could meet its preliminary minimum performance standards for cargo compartment suppression systems. A system that combines water mist with nitrogen met these minimum standards. In this system, water and nitrogen “knock down” the initial fire, and nitrogen suppresses any deep-seated residual fire by inerting the entire compartment.[21] In cargo compartment testing, this system maintained cooler temperatures than had either a plain water mist system or a Halon-based system.

Status

Additional research and testing are needed before water mist technology can be considered for commercial aircraft. For example, the weight and relative effectiveness of any water mist system would need to be considered and evaluated. In addition, before it could be used in aircraft, the consequences of using water will need to be further evaluated. For example, Boeing officials noted that using a water mist fire suppression system in the cabin in a post crash fire might actually reduce passenger safety if the mist or fog creates confusion among the passengers, leading to longer evacuation times. Further, of concern is the possible shorting of electrical wiring and equipment and damage to aircraft interiors (e.g., seats, entertainment equipment, and insulation). Water cleanup could also be difficult and require special drying equipment.

[20]Inerting involves reducing flammability in fuel tanks, which is discussed separately in this report.

[21]Boeing commented that this more recent system would not pass the original cargo minimum performance standard, and Boeing disagrees with FAA’s relaxing of the original standard.

Fire-Safe Fuels

Background

Burning fuel typically dominates and often overwhelms postcrash fire scenarios and causes even the most fire-resistant materials to burn.[22] Fuel spilled from tanks ruptured upon crash impact often forms an easily ignitable fuel-air mixture. A more frequent fuel-related problem is the fuel tank explosion, in which a volatile fuel-air mixture inside the fuel tank is ignited, often by an unknown source. For example, it is believed that fuel tank explosions destroyed a Philippines Air 737 in 1990, TWA Flight 800 in 1996, and a Thai Air 737 in 2001. Therefore, reducing the flammability of fuel could improve survivability in postcrash fires as well as reduce the occurrence of fuel tank explosions.

Reducing fuel flammability involves limiting the volatility[23] of fuel and the rate at which it vaporizes.[24] Liquid fuel can burn only when enough fuel vapor is mixed with air. If the fuel cannot vaporize, a fire cannot occur. This principle is behind the development of higher-flashpoint fuel, whose use can decrease the likelihood of a fuel tank explosion. The flash point is the lowest temperature at which a liquid fuel produces enough vapor to ignite in the presence of a source of ignition—the lower the flash point, the greater the risk of fire. If the fuel is volatile enough, however, and air is sucked into the fuel tank area upon crash impact, limiting the fuel's vaporization can prevent a burnable mixture from forming. This principle supports the use of additives that modify the viscosity of fuel to limit postcrash fires; for example, antimisting kerosene contains such additives.

[22]An average widebody aircraft carries 50,000 gallons of aviation fuel at takeoff.

[23]Fuels function by releasing combustible gases. Indicators of volatility include a fuel's boiling point (the higher the boiling point, the less volatile the fuel) and vapor pressure (the higher the vapor pressure, the more volatile the fuel). Therefore, raising the temperature can increase volatility. A highly volatile fuel is more likely to form a flammable or explosive mixture with air than a nonvolatile fuel. By definition, gases are volatile. Liquid fuels either are sufficiently volatile at room temperature to produce combustible vapor (ethanol, petrol) or they produce sufficient combustible vapors when heated (kerosene).

[24]The fuel vaporization rate is the minimum temperature to which the pure liquid fuel must be heated so that the vapor pressure is high enough for an explosive mixture to be formed with air--then the liquid is allowed to evaporate and is brought into contact with a flame, spark, or hot filament. Flash points are lower than ignition temperatures.

According to FAA and NASA, however, these additives do nothing to prevent fuel tank explosions.

From the early 1960s to the mid-1980s, FAA conducted research on fuel safety. The Aviation Safety Act of 1988 required that FAA undertake research on low-flammability aircraft fuels, and, in 1993, FAA developed plans for fuel safety research. In 1996, a National Research Council experts' workshop on aviation fuel summarized existing fuel safety research efforts. The participants concluded that although postcrash fuel-fed aircraft fires had been researched, limited progress had been achieved and little work had been published.

As part of FAA's research, fuels have been modified with thickening polymer additives to slow down vaporization in crashes. Participants in the 1996 National Research Council workshop identified several long-term research goals for consideration in developing modified fuels and fuel additives to improve fire safety. They also agreed that a combination of effective fire-safe fuel additives could probably be either selected or designed, provided that fuel performance requirements were identified in advance. In addition, they agreed that existing aircraft designs that reduce the chance of fuel igniting do not present major barriers to the implementation of a fire-safe fuel.

A 1996 European Transport Safety Council report suggested that antimisting kerosene be at least partially tested on regular military transport flights (e.g., in one tank, feeding one engine) to demonstrate its operational compatibility. The report also recommended the consideration of a study comparing the costs of the current principal commercial fuel and the special, higher-flashpoint fuel used by the Navy. According to NASA and FAA fire-safe fuels experts, military fuel is much harder to burn in storage or to ignite in a pan because of its lower volatility; however, it is just as flammable as aviation fuel when it is sprayed into an engine combustor.

Status

Fire-safe fuels are not currently available and are in the early stages of research and development. In January 2002, NASA opened a fire-safe fuels research branch at its Glenn Research Center in Ohio. NASA-Glenn is conducting aviation fuel research that evaluates fuel vapor flammability in conjunction with FAA's fuel tank inerting program, including the measurement of fuel "flash points." NASA is examining the effects of surfactants, gelling agents, and chemical composition changes on the vaporization and pressure characteristics of jet fuel.[25]

In addition to FAA's and NASA's research, some university and industry researchers have made progress in developing fire-safe fuels. Many use advanced analytical, computational modeling technologies to inform their research. A council of producers and users of fuels is also coordinating research on ways to use such fuels. NASA fuel experts remain optimistic that small changes in fuel technologies can have a big impact on fuel safety.

Developing fire-safe fuels will require much more research and testing. There are significant technical difficulties associated with creating a fuel that meets aviation requirements while meaningfully decreasing the flammability of the fuel.

Thermal Acoustic Insulation Materials

Background

To keep an airplane quieter and warmer, a layer of thermal acoustic insulation material is connected to paneling and walls throughout the aircraft. This insulation, if properly designed, can also prevent or limit the spread of an in-flight fire. In addition, thermal acoustic insulation provides a barrier against a fire burning through the cabin from outside the airplane's fuselage (See fig. 8.). Such a fire, often called a postcrash fire, may occur when fuel is spilled on the ground after a crash or an impact.

[25]A surfactant, or surface-active agent, is a soluble compound that reduces the surface tension of liquids, or reduces interfacial tension between two liquids or a liquid and a solid. A gelling agent is a fuel "thickener."

Figure 8: Fire Insulation Blankets

Source: FAA.

Aircraft insulation flammability test.

While this thermal acoustic insulation material could help prevent the spread of fire, some of the insulation materials that have been used in the past have contributed to fires. For example, FAA indicated that an insulation material, called metallized Mylar®, contributed to at least six in-flight fires. Airlines have stopped using this material and are removing it from existing aircraft.

FAA's two main efforts in this area are directed toward preventing fatal in-flight fire and improving postcrash fire survivability.

- Since 1998, FAA has been developing test standards for preventing in-flight fires in response to findings that fire spread on some thermal acoustic insulation blanket materials. In 2000, FAA issued a notice of proposed rule-making that outlined new flammability test criteria for in-flight fires. FAA's in-flight test standards require thermal acoustic insulation materials to protect passengers. According to the standards, insulation materials installed in airplanes will not propagate a fire if ignition occurs.

- FAA is also developing more stringent burnthrough test standards for postcrash fires. FAA has been studying the penetration of the fuselage by an external fire—known as fuselage burnthrough—since the late 1980s and believes that improving the fire resistance of thermal acoustic insulation could delay fuselage burnthrough. In laboratory tests conducted from 1999 through 2002, an FAA-led working group determined that insulation is the most potentially effective and practical means of delaying the spread of fire or creating a barrier to burnthrough. In 2002, FAA completed draft burnthrough standards outlining a proposed methodology for testing thermal acoustic insulation. The burnthrough standards would protect passengers and crews by extending by at least 4 minutes the time available for evacuation in a postcrash fire.

Various studies have estimated the potential benefits from both test standards:

- A 1999 study of worldwide aviation accidents from 1966 through 1993 estimated that about 10 lives per year would have been saved if protection had provided an additional 4 minutes for occupants to exit the airplane.

- A 2000 FAA study estimated that about 37 U.S. fatalities would be avoided between 2000 and 2019 through the implementation of both proposed standards.[26]

- A 2002 study by the British Civil Aviation Authority of worldwide aviation accidents from 1991 through 2000 estimated that at least 34 lives per year would have been saved if insulation had met both proposed standards.

[26]FAA's benefit estimate, based on $2.7 million per life saved, ranges from $37.7 million to $231.5 million, discounted to present value, based partially on 37.2 deaths avoided from its 2000 study. FAA could not quantify benefits from flame propagation requirements, but indicated that avoiding an accident with 169 passenger fatalities would avert a $231.5 million loss (not including the cost of the plane).

Status

Insulation designed to replace metallized Mylar® is currently available. A 2000 FAA airworthiness directive gave the airlines 5 years to remove and replace metallized Mylar® insulation in 719 affected airplanes. Replacement insulation is required to meet the in-flight standard and will be installed in these airplanes by mid-2005. In that airworthiness directive, FAA indicated that it did not consider other currently installed insulation to constitute an unsafe condition.

Thermal acoustic insulation is currently available for installation on commercial airliners. This insulation has been demonstrated to reduce the chance of fatal in-flight fires and to improve postcrash fire survivability. On July 31, 2003, FAA issued a final rule requiring that after September 2, 2005, all newly manufactured airplanes having a seating capacity of more than 20 passengers or over 6,000 pounds must use thermal acoustic insulation that meets more stringent standards for how quickly flames can spread.[27] In addition, for aircraft of this size manufactured before September 2, 2003, replacement insulation in the fuselage must also meet the new, higher standard.

Research is continuing to develop thermal acoustic insulation that provides better in-flight and burnthrough protection. Even when this material is available, the high cost of retrofitting airplanes may limit its use to newly manufactured aircraft. For example, FAA estimates that the metallized Mylar® retrofit alone will cost a total of $368.4 million, discounted to present value terms, for the 719 affected airplanes. Because thermal acoustic insulation is installed throughout the pressurized section of the airplane for the life of its service, retrofitting the entire fleet would cost several billion dollars.

Ultra-Fire-Resistant Polymers

Background

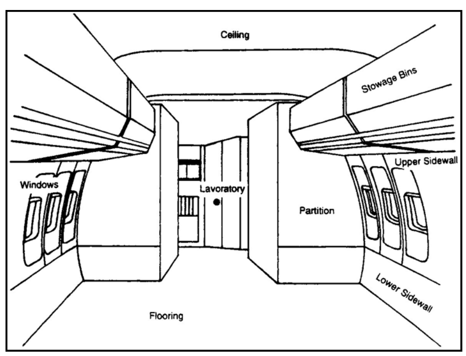
Polymers are used in aircraft in the form of lightweight plastics and composites and are selected on the basis of their estimated installed cost,

[27]Improved Flammability Standards for Thermal/Acoustic Insulation Materials Used in Transport Category Airplanes; Final Rule, FAA/DOT (14 C.F.R. parts 25, 91, et al.).

weight, strength, and durability. Most of the aircraft cabin is made of polymeric material. In the event of an in-flight or a postcrash fire, the use of polymeric materials with reduced flammability could give passengers and crew more time to evacuate by delaying the rate at which the fire spreads through the cabin.

FAA researchers are developing better techniques to measure the flammability of polymers and to make polymers that are ultra fire resistant. Developing these materials is the long-term goal of FAA's Fire Research Program, which, if successful, will "eliminate burning cabin materials as a cause of death in aircraft accidents." Materials being improved include composite and adhesive resins, textile fibers, rubber for seat cushions, and plastics for molded parts used in seats and passenger electronics. (See fig. 9.)

Figure 9: Flammable Cabin Materials and Small-scale Material Test Device



Source: FAA.

Flammable plastic (polymeric) cabin materials.

Flammability tester for samples of materials.

Adding flame-retardant substances to existing materials is one way to decrease their flammability. For example, some manufacturers add substances that release water when they reach a high temperature. When a material, such as wiring insulation, is heated or burns, the water acts to absorb the heat and cools down the fire. Other materials are designed to become surface-scorched on exposure to fire, causing a layer of char to protect the rest of the material from burning. Lastly, adding a type of clay can have a flame-retardant effect. In general, these fire-retardant polymers are formulated to pass an ignition test but do not meet FAA's criterion for ultra fire resistance, which is a 90 percent reduction in the rate at which the untreated material would burn. To meet this strict requirement, FAA is developing new "smart" polymers that are typical plastics under normal conditions but convert to ultra-fire-resistant materials when exposed to an ignition source or fire.

FAA has adopted a number of flammability standards over the last 30 years. In 1984, FAA passed a retrofit rule that replaced 650,000 seat cushions with flame-retardant seat cushions at a total cost of about $75 million. The replacement seat cushions were found to delay cabin flashover by 40 to 60 seconds. Fire-retardant seat cushions can also prevent ramp and in-flight fires that originate at a seat and would otherwise burn out of control if left unattended. In 1986 and 1988, FAA set maximum allowable levels of heat and smoke from burning interior materials to decrease the amount of smoke that they would release in a postcrash fire. These standards affected paneling in all newly manufactured aircraft. Airlines and airframe manufacturers invested several hundred million dollars to develop these new panels.

Status

Ultra-fireresistant polymers are not currently available for use on commercial airliners. These polymers are still in the early stages of research and development. To reduce the cost and simplify the testing of new materials, FAA is employing a new technique to characterize the flammability and thermal decomposition of new products; this technique requires only a milligram of sample material. The result has been the discovery of several new compositions of matter (including "smart" polymers). The test identifies key thermal and combustion properties that allow rapid screening of new materials.[28] From these materials, FAA plans to select the most promising and work with industry to make enough of the new polymers to fabricate full-scale cabin components like sidewalls and stowage bins for fire testing.

FAA's phased research program includes the selection in 2003 of a small number of resins, plastics, rubbers, and fibers on the basis of their functionality, cost, and potential to meet fire performance guidelines. In 2005, FAA plans to fabricate decorative panels, molded parts, seat cushions, and textiles for testing from 2007 through 2010. Full-scale testing

[28]These methods test the heat release rate, total heat of combustion of the volatiles, thermal stability, char yield, decomposition process, and rate of decomposition.

is scheduled for 2011 but is contingent upon the availability of program funds and commercial interest from the private sector.

Research continues on ultra-fire-resistant polymers that will increase protection against in-flight fires and cabin burnthrough. According to an FAA fire research expert, issues facing this research include (1) the current high cost of ultra-fire-resistant polymers; (2) difficulties in producing ultra-fire-resistant polymers with low to moderate processing temperatures, good strength and toughness, and colorability and colorfastness; and (3) gaps in understanding the relationship between material properties and fire performance and between chemical composition and fire performance, scaling relationships, and fundamental fire-resistance mechanisms. In addition, once the materials are developed and tested, getting them produced economically and installed in aircraft will become an issue. It is expected that such new materials with ultra fire resistance would be more expensive to produce and that the market for such materials would be uncertain.

Airport Rescue and Fire-Fighting Operations

Background

Because of the fire danger following a commercial airplane crash, having airport rescue and fire-fighting operations available can improve the chances of survival for the people involved. Most airplane accidents occur during takeoff or landing at the airport or in the surrounding community. A fire outside the airplane, with its tremendous heat, may take only a few minutes to burn through the airplane's outside shell. According to FAA, firefighters are responsible for creating an escape path by spraying water and chemicals on the fire to allow the passengers and crew to evacuate the airplane. Firefighters use one or more trucks to extinguish external fires, often at great personal risk, and use hand-held attack lines when attempting to put out fires within the airplane fuselage. (See fig. 10). Fires within the fuselage are considered difficult to control with existing equipment and procedures because they involve complex conditions, such as smoke-laden toxic gases and high temperatures in the passenger cabin. FAA has taken actions to control both internal and external postcrash fires, including requiring major airports to have airport rescue and fire-fighting operations.

Figure 10: Airport Rescue and Fire Training

Source: FAA (left), Oshkosh Truck Corporation (right).

In 1972, FAA first proposed regulations to ensure that major airports have a minimal level of airport rescue and fire-fighting operations. Some changes to these regulations were made in 1988. The regulations establish, among other things, equipment standards, annual testing requirements for response times, and operating procedures. The requirements depend on both the size of the airport and the resources the locality has agreed to make available as needed.

In 1997, FAA compared airport rescue and fire-fighting missions and standards for civilian airports with DOD's for defense installations and reported that DOD's requirements were not applicable to civilian airports. In 1988, and again in 1998, Transport Canada Civil Aviation also studied its rescue and fire-fighting operations and concluded that the expenditure of resources for such unlikely occurrences was difficult to justify from a benefit-cost perspective. This conclusion highlighted the conflict between safety and cost in attempting to define rescue and fire-fighting requirements.

A coalition of union organizations and others concerned about aviation safety released a report critical of FAA's standards and operational regulations in 1999. According to the report, FAA's airport rescue and fire-fighting regulations were outdated and inadequate.

Status

In 2002, FAA incorporated measures recommended by NTSB into FAA's *Aeronautical Information Manual Official Guide to Basic Flight Information and Air Traffic Control Procedures*.[29] These measures (1) designate a radio frequency at most major airports to allow direct communication between airport rescue and fire-fighting personnel and flight crewmembers in the event of an emergency and (2) specify a universal set of hand signals for use when radio communication is lost.

In March 2001, FAA responded to the reports criticizing its airport rescue and fire-fighting standards by tasking its Aviation Regulatory Advisory Committee to review the agency's rescue and fire-fighting requirements to identify measures that could be added, modified, or deleted. In 2003, the committee is expected to propose requirements for the number of trucks, the amount of fire extinguishing agent, vehicle response times, and staffing at airports and to publish its findings in a notice of proposed rule-making. Depending on the results of this FAA review, additional resources may be needed at some airports. The overall cost of improving airport rescue and fire-fighting response capabilities could be a significant barrier to the further development of regulations. For example, some in the aviation industry are concerned about the costs of extending requirements to smaller airports and of appropriately equipping all airports with resources. According to FAA, extending federal safety requirements to some smaller airports would cost at least $2 million at each airport initially and $1 million annually thereafter.

[29]This manual is designed to provide the aviation community with basic flight information and air traffic control procedures for use in the National Airspace System of the United States.

Summaries of Potential Improved Evacuation Safety Advancements

This appendix presents information on the background and status of potential advancements in evacuation safety that we identified, including the following:

- improved passenger safety briefings;
- exit seat briefings;
- photo-luminescent floor track marking;
- crewmember safety and evacuation training;
- acoustic attraction signals;
- smoke hoods;
- exit slide testing;
- overwing exit doors;
- evacuation procedures for very large transport aircraft; and
- personal flotation devices.

Passenger Safety Briefings

Background

Federal regulations require that passengers receive an oral briefing prior to takeoff on safety aspects of the upcoming flight. FAA also requires that oral briefings be supplemented with printed safety briefing cards that pertain only to that make and model of airplane and are consistent with the air carrier's procedures. These two safety measures must include information on smoking, the location and operation of emergency exits, seat belts, compliance with signs, and the location and use of flotation devices. In addition, if the flight operates above 25,000 feet mean sea level, the briefing and cards must include information on the emergency use of oxygen.

FAA published an Advisory Circular in March 1991 to guide air carriers' development of oral safety briefings and cards. Primarily, the circular defines the material that must be covered and suggests material that FAA believes should be covered. The circular also discusses the difficulty in motivating passengers to attend to the safety information and suggests making the oral briefing and safety cards as attractive and interesting as possible to increase passengers' attention. The Advisory Circular suggests, for example, that flight attendants be animated, speak clearly and slowly, and maintain eye contact with the passengers. Multicolored safety cards with pictures and drawings should be used over black and white cards. Finally, the circular suggests the use of a recorded videotape briefing because it ensures a complete briefing with good diction and allows for additional visual information to be presented to the passengers. (See fig. 11.)

Figure 11: Airline Briefing to Passengers on Safety Briefing Cards

Source: Association of Flight Attendants.

Status

Despite efforts to improve passengers' attention to safety information, a large percentage of passengers continue to ignore preflight safety briefings and safety cards, according to a study NTSB conducted in 1999. Of 457 passengers polled, 54 percent (247) reported that they had not watched the entire briefing because they had seen it before. An additional 70 passengers indicated that the briefing provided common knowledge and therefore there was no need to watch it. Of 431 passengers who answered a question about whether they had read the safety card, 68 percent (293) indicated that they had not, many of them stating that they had read safety cards on previous flights.

Safety briefings and cards serve an important safety purpose for both passengers and crew. They are intended to prepare passengers for an emergency by providing them with information about the location and operation of exits and emergency equipment that they may have to operate—and whose location and operation may differ from one airplane to the next. Well-briefed passengers will be better prepared in an emergency, thereby increasing their chances of surviving and lessening their dependence on the crew for assistance.

In its emergency evacuation study, NTSB recommended that FAA instruct airlines to "conduct research and explore creative and effective methods that use state-of-the-art technology to convey safety information to passengers."[1] NTSB further recommended "the presented information include a demonstration of all emergency evacuation procedures, such as how to open the emergency exits and exit the aircraft, including how to use the slides." That research found that passengers often view safety briefings and cards as uninteresting and the information as intuitive. FAA has requested that commercial carriers explore different ways to present the materials to their passengers, adding that more should be done to educate passengers about what to do after an accident has occurred.

Exit Seat Briefing

Background

Passengers seated in an exit row may be called on to assist in an evacuation. Upon a crewmember's command or a personal assessment of danger, these passengers must decide if their exit is safe to use and then open their exit hatch or door for use during an evacuation. In October 1990,

[1]NTSB, *Safety Study: Emergency Evacuation of Commercial Airlines*, [A-00-86] (Washington, D.C.: 2001).

FAA required airlines to actively screen passengers occupying exit seats for "suitability" and to administer one-on-one briefings on their responsibilities. This rule does not require specific training for exit seat occupants, but it does require that the occupants be duly informed of their distinct obligations.

Status

According to NTSB, preflight briefings of passengers in exit rows could contribute positively to a passenger evacuation. In a 1999 study, NTSB found that the individual briefings given to passengers who occupy exit seats have a positive effect on the outcome of an aircraft evacuation. The studies also found that as a result of the individualized briefings, flight attendants were better able to assess the suitability of the passengers seated in the exit seats.

According to FAA's *Flight Standards Handbook Bulletin for Air Transportation*, several U.S. airlines have identified specific cabin crewmembers to perform "structured personal conversations or briefings," designed to equip and prepare passengers in exit seats beyond the general passenger briefing. Also, the majority of air carriers have procedures to assist crewmembers with screening passengers seated in exit rows.

FAA's 1990 rule requires that passengers seated in exit rows be provided with information cards that detail the actions to be taken in the case of an emergency. However, individual exit row briefings, such as those recommended by NTSB, are not required. Also included on the information cards are provisions for a passenger who does not wish to be seated in the exit row to be reseated. Additionally, carriers are required to assess the exit row passenger's ability to carry out the required functions. The extent of discussion with exit row passengers depends on each airline's policy.

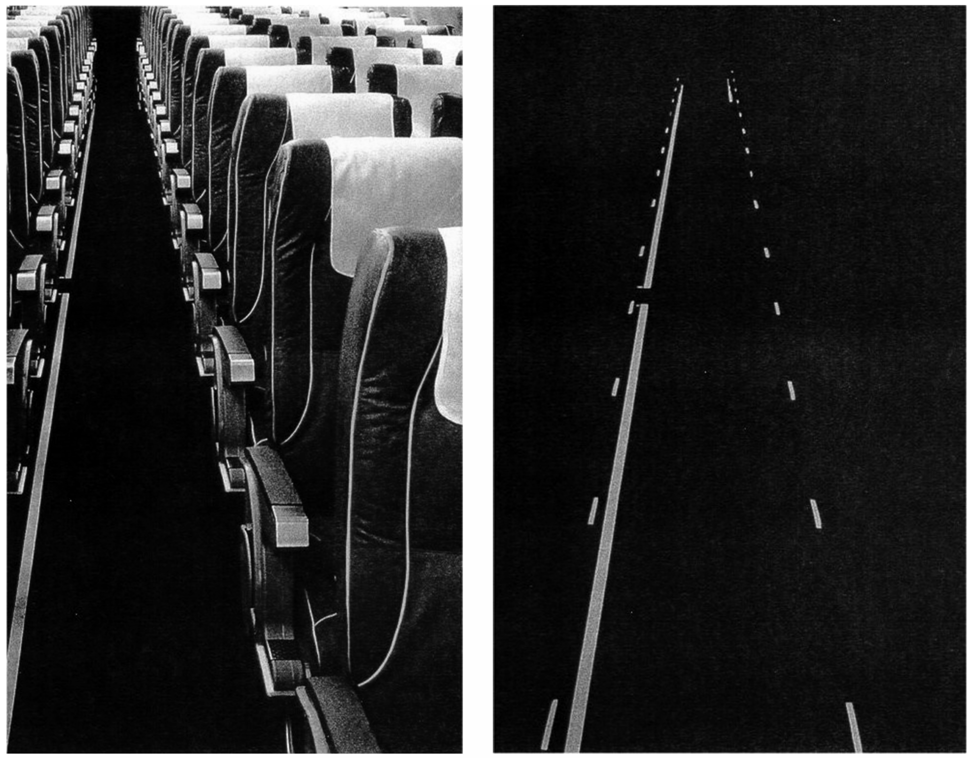
Photo-luminescent Floor Track Marking

Background

In June 1983, an Air Canada DC-9 flight from Dallas to Toronto was cruising at 33,000 feet when the crew reported a lavatory fire. An emergency was declared, and the aircraft made a successful emergency landing at the Cincinnati Northern Kentucky International Airport. The crew initiated an evacuation, but only half of the 46 persons aboard were able to escape before becoming overcome by smoke and fire. In its investigation of this accident, NTSB learned that many of the 23 passengers who died might have benefited from floor tracking lighting. As a result, NTSB recommended that airlines be equipped with floor-level escape markings. FAA determined that floor lighting could improve the evacuation rate by 20 percent under certain conditions, and FAA now requires all airliners to have a row of lights along the floor to guide passengers to the exit should visibility be reduced by smoke.

On transport category aircraft, these escape markings, called floor proximity marking systems, typically consist primarily of small electric lights spaced at intervals on the floor or mounted on the seat assemblies, along the aisle. The requirement for electricity to power these systems has made them vulnerable to a variety of problems, including battery and wiring failures, burned-out light bulbs, and physical disruption caused by vibration, passenger traffic, galley cart strikes, and hull breakage in accidents. Attempts to overcome these problems have led to the proposal that nonelectric, photo-luminescent (glow-in-the-dark) materials be used in the construction of floor proximity marking systems. The elements of these new systems are “charged” by the normal airplane passenger cabin lighting, including the sunlight that enters the cabin when the window shades are open during daylight hours. (See fig. 12.)

Figure 12: Floor Track Marking Using Photo-luminescent Materials



Source: Nemoto and Company.

Normal marking conditions. Dark.

Status

Floor track marking using photo-luminescent materials is currently available but not required for U.S. commercial airliners. Performance demonstrations of photo-luminescent technology have found that strontium aluminate photo-luminescent marking systems can be effective in providing the guidance for egress that floor proximity marking systems are intended to achieve. According to industry and government officials, such photo-luminescent marking systems are also cheaper to install than electric light systems and require little to no maintenance. Moreover, photo-luminescent technology weighs about 15 to 20 pounds less than electric light systems and, unlike the electric systems, illuminates both sides of the aisle, creating a pathway to the exits.

Photo-luminescent floor track marking technology is mature and is currently being used by a small number of operators, mostly in Europe. In the United States, Southwest Airlines has equipped its entire fleet with the photo-luminescent system. However, the light emitted from photo-luminescent materials is not as bright as the light from electrically operated systems. Additionally, the photo-luminescent materials are not as effective when they have not been exposed to light for an extended period of time, as after a long overseas nighttime flight. The estimated retail price of an entire system, not including the installation costs, is $5,000 per airplane.

Crewmember Safety and Evacuation Training

Background

FAA requires crewmembers to attend annual training to demonstrate their competency in emergency procedures. They have to be knowledgeable and efficient while exercising good judgment. Crewmembers must know their own duties and responsibilities during an evacuation and be familiar with those of their fellow workers so that they can take over for others if necessary.

The requirements for emergency evacuation training and demonstrations were first established in 1965. Operators were required to conduct full-scale evacuation demonstrations, include crewmembers in the demonstrations, and complete the demonstrations in 2 minutes using 50 percent of the exits. The purpose of the demonstrations was to test the crewmembers' ability to execute established emergency evacuation procedures and to ensure the realistic assignment of functions to the crew. A full-scale demonstration was required for each type and model of airplane when it first started passenger-carrying operations, increased its passenger seating capacity by 5 percent or more, or underwent a major change in the cabin interior that would affect an emergency evacuation. Subsequently, the time allowed to evacuate the cabin during these tests was reduced to 90 seconds.

The aviation community took steps in the 1990s to develop a program called Crew Resource Management that focuses on overall improvements in crewmembers' performance and flight safety strategies, including those for evacuation. FAA officials told us that they plan to emphasize the importance of effective communication between crewmembers and are considering updating a related Advisory Circular. Effective communication between cockpit and cabin crew are particularly important with the added security precautions being taken after September 11, 2001, including the locking the cockpit door during flight.

Status

The traditional training initiative now has an advanced curriculum, Advanced Crew Resource Management. According to FAA, this comprehensive implementation package includes crew resource management procedures, training for instructors and evaluators, training for crewmembers, a standardized assessment of the crew's performance, and an ongoing implementation process. This advanced training was designed and developed through a collaborative effort between the airline and research communities. FAA considers training to be an ongoing development process that provides airlines with unique crew resource management solutions tailored to their operational demands. The design of crew resource management procedures is based on principles that require an emphasis on the airline's specific operational environment. The procedures were developed to emphasize these crew resource management elements by incorporating them into standard operating procedures for normal as well as abnormal and emergency flight situations.

Because commercial airliner accidents are rare, crewmembers must rely on their initial and recurrent training to guide their actions during an emergency. Even in light of advances and initiatives in evacuation technology, such as slides and slide life rafts, crewmembers must still assume a critical role in ensuring the safe evacuation of their passengers. Airline operators have indicated that it is very costly for them to pull large numbers of crewmembers off-line to participate in training sessions.

FAA officials told us that improving flight and cabin crew communication holds promise for ensuring the evacuation of passengers during an emergency. To improve this communication and coordination between flight and cabin crew, FAA plans to update the related Advisory Circular, oversee training, and charge FAA inspectors with monitoring air carriers during flights to see that improvements are being implemented. In addition, FAA is enhancing its guidance to air carriers on preflight briefings for flight crews to sharpen their responses to emergency situations and mitigate passengers' confusion. FAA expects this guidance to bolster the use and quality of preflight briefings between pilots and flight attendants on security, communication, and emergency procedures. According to FAA, these briefings have been shown to greatly improve the flight crew's safety mind-set and to enhance communication.

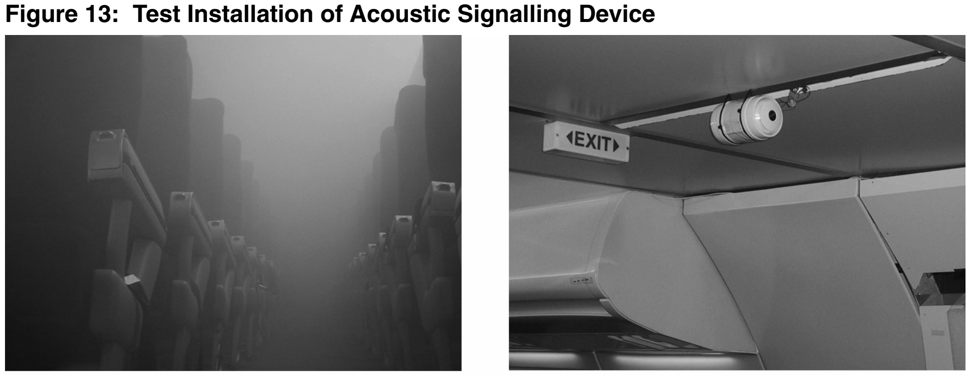
Acoustic Attraction Signals

Background

Acoustic attraction signals make sounds to help people locate the doors in smoke, darkness, or when lights and exit signs are obscured. When activated, the devices are intended to help people to determine the direction and approximate distance of the sound—and of the door. Examples of audio attraction signals include recorded speech sounds, broadband multifrequency sounds ("white noise"), or alarm bells.

Research to determine if acoustic attraction signals can be useful in aircraft evacuation has included, for example, FAA's Civil Aeromedical Institute testing of recorded speech sounds in varying pitches, using phrases such as "This way out," "This way," and "Exit here." Researchers at the University of Leeds developed Localizer Directional Sound beacons, which combine broadband, multifrequency "white noise" of between 40Hz and 20kHz with an alerting sound of at least one other frequency, according to the inventor (see fig. 13).

Figure 13: Test Installation of Acoustic Signalling Device



Source: SoundAlert Company.

Cabin simulation of reduced visibility (left) and aircraft test of accoustic signaling device (right).

Note: Acoustic signaling device is of the type used near building exits.

The FAA study noted above of acoustic attraction signals found that in the absence of recorded speech signals, the majority of participants evacuating a low-light-level, vision-obscured cabin will head for the front exit or will follow their neighbors. In contrast, participants exposed to recorded speech sounds will select additional exits, even those in the rear of the airplane. During aircraft trials conducted by Cranfield University and University of Greenwich researchers, tests of directional sound beacons found that under cabin smoke conditions, exits were used most efficiently when the cabin crew gave directions and the directional sound beacons were activated. With this combination, the distribution of passengers to the available exits was better than with cabin crew directions alone, sound beacons alone, no cabin crew directions, or no sound beacons. Researchers found that passengers were able to identify and move toward the closest sound source inside the airplane cabin and to distinguish between two closely spaced loudspeakers. However, in 2001, Airbus conducted several evacuation test trials of audio attraction signals using an A340 aircraft. According to Airbus, the acoustic attraction signals did not enhance passengers' orientation, and, overall, did not contribute to passengers' safety.

Status

While acoustic attraction signals are currently available, further research is needed to determine if their use is warranted on commercial airliners. FAA, Transport Canada Civil Aviation, and the British Civilian Aviation Authority do not currently mandate the use of acoustic attraction signals. The United Kingdom's Air Accidents Investigation Branch made a recommendation after the fatal Boeing 737 accident at Manchester International Airport in 1985 that research be undertaken to assess the viability of audio attraction signals and other evacuation techniques to assist passengers impaired by smoke and toxic or irritant gases. The Civilian Aviation Authority accepted the recommendation and sponsored research at Cranfield University; however, it concluded from the research results that the likely benefit of the technology would be so small that no further action should be taken, and the recommendation was closed in 1992.

The French Direction Generale de l'Aviation Civile funded aircraft evacuation trials using directional sound beacons in November 2002, with oversight by the European Joint Aviation Authorities. The trials were conducted at Cranfield University's evacuation simulator with British Airways cabin crew and examined eight trial evacuations by two groups of 'passengers.' The study surveyed the participants' views on various aspects of their evacuation experience and measured the overall time to evacuate.

The speed of evacuation was found to be biased by the knowledge passengers' gained in the four successive trials, and by variations in the number of passengers participating on the 2 days (155 and 181). The four trials by each of the two groups of passengers also involved different combinations of crew and sound in each. The study concluded that the insufficient number of test sessions further contributed to bias in the results, and that further research would be needed to determine whether the devices help to speed overall evacuation.

Further research and testing are needed before acoustic attraction signals can be considered for widespread airline use. The signals may have drawbacks that would need to be addressed. For example, the Civil Aviation Authority found that placing an audio signal in the bulkhead might disorient or confuse the first few passengers who have to pass and then move away from the sound source to reach the exit. Such hesitation slowed passengers' evacuation during testing. The researchers at Cranfield University trials in 1990 concluded that an acoustic sound signal did not improve evacuation times by a statistically significant amount, suggesting that the device might not be cost-effective.

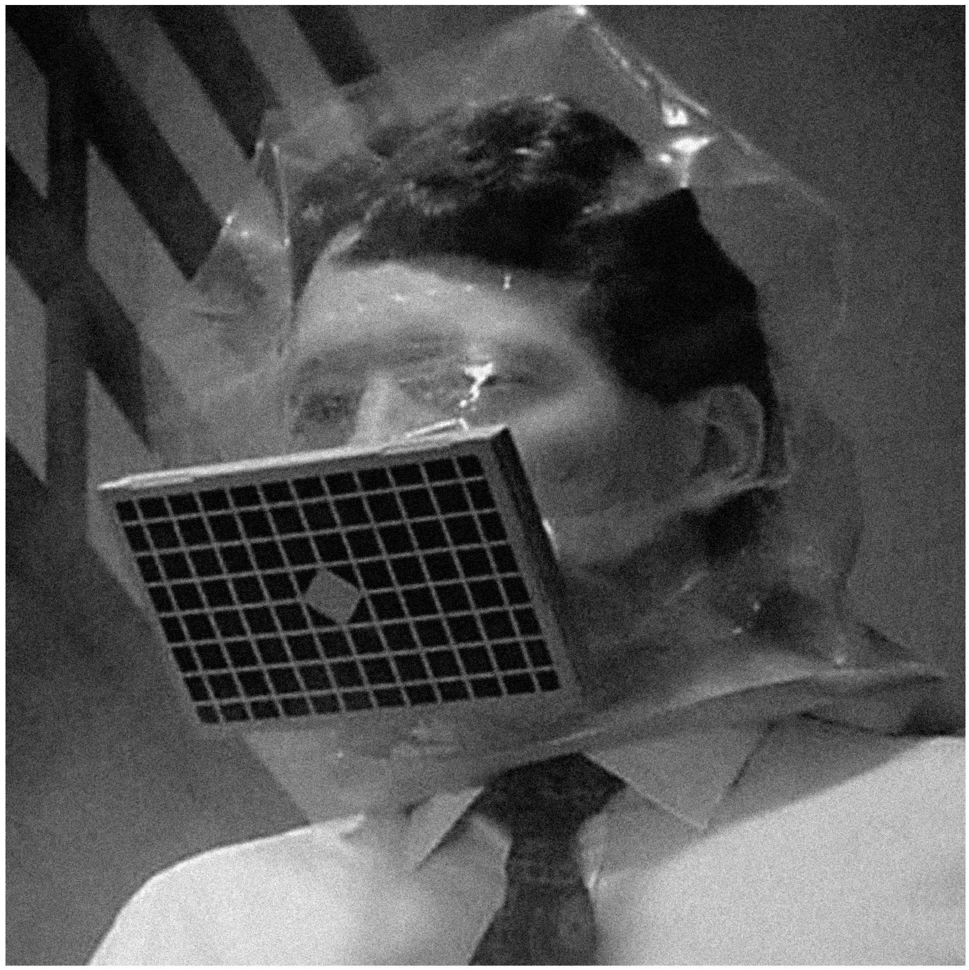
Smoke Hoods

Background

Smoke hoods are designed to provide the user with breathable, filtered air in an environment of smoke and toxic gases that would otherwise be incapacitating. More people die from smoke and toxic gases than from fire after an air crash. Because only a few breaths of the dense, toxic smoke typically found in aircraft fires can render passengers unconscious and prevent their evacuation, the wider use of smoke hoods has been investigated as a means of preventing passengers from being overcome by smoke and of giving them enough breathable air to evacuate. However, some studies have found that smoke hoods are only effective in certain types of fires and in some cases may slow the evacuation of cabin occupants.

As shown in figure 14, a filter smoke hood can be a transparent bag worn over the head that fits snugly at the neck and is coated with fire-retardant material; it has a filter but no independent oxygen source and can provide breathable air by removing some toxic contaminants from the air for a period ranging from several minutes to 15 minutes, depending on the severity and type of air contamination. The hood has a filter to remove carbon monoxide—a main direct cause of death in fire-related commercial airplane accidents, as well as hydrogen cyanide—another common cause of death, sometimes from incapacitation that can prevent evacuation. Hoods also filter carbon dioxide, chlorine, ammonia, acid gases such as hydrogen chloride and hydrogen sulfide, and various hydrocarbons, alcohols, and other solvents. Some hoods also include a filter to block particulate matter. One challenge is where to place the hoods in a highly accessible location near each seat.

Figure 14: An Example of a Commercially Available Smoke Hood



Source: Essex Company.

Certain smoke hoods have been shown to filter out many contaminants typically found in smoke from an airplane cabin fire and to provide some temporary head protection from the heat of fire. In a full-scale FAA test of cabin burnthrough, toxic gases became the driving factor determining survivability in the forward cabin, reaching lethal levels minutes before the smoke and temperature rose to unsurvivable levels.

A collaborative effort to estimate the potential benefits of smoke hoods was undertaken in 1986 by the British Civil Aviation Authority (CAA), the

Federal Aviation Administration, the Direction Générale de l'Aviation Civile (France) and Transport Canada Civil Aviation. The resulting 1987 study examined the 20 accidents where sufficient data was available out of 74 fire-related accidents worldwide from 1966 to 1985. The results were sensitive to assumptions regarding extent of use and delays due to putting on smoke hoods. The study concluded that smoke hoods could significantly extend the time available to evacuate an aircraft and would have saved approximately 179 lives in the 20 accidents studied, assuming no delay in donning smoke hoods. Assuming a 10 percent reduction in the evacuation rate due to smoke hood use would have resulted in an estimated 145 lives saved in the 20 accidents with adequate data. A 15 second delay in donning the hoods would have saved an estimated 97 lives in the 20 accidents.[2] When the likelihood of use of smoke hoods was included in the analysis for each accident, the total net benefit was estimated at 134 lives saved in the 20 accidents. The study also estimated that an additional 228 lives would have been saved in the 54 accidents where less data was available, assuming no delay in evacuation.[3]

The U.S. Air Force and a major manufacturer are developing a drop-down smoke hood with oxygen. Because current oxygen masks in airplanes are not airtight around the mouth, they provide little protection from toxic gases and smoke in an in-flight fire. To provide protection from these hazards, as well as from decompression and postcrash fire and smoke, the Air Force's drop-down smoke hood with oxygen uses the airplane's existing oxygen system and can fit into the overhead bin of a commercial airliner where the oxygen mask is normally stowed. This smoke hood is intended to replace current oxygen masks but also be potentially separated from the oxygen source in a crash to provide time to evacuate.

Status

Smoke hoods are currently available and produced by several manufacturers; however, not all smoke hoods filter carbon monoxide. They are in use on many military and private aircraft, as well as in buildings. An

[2]These estimates assume 100 percent smoke hood use. The net 97 lives saved with a 15 second delay assumes that smoke hoods would have saved lives in six accidents and cost lives in four; the net 145 lives saved with a 10 percent reduction in the evacuation rate assumes that smoke hoods would have saved lives in six accidents and cost lives in two.

[3] "Smoke Hoods: Net Safety Benefit Analysis," a collaborative effort by the Civil Aviation Authority, Federal Aviation Administration, Direction Générale de l'Aviation Civile, and Transport Canada, London, November 1987, CAA Paper 87017.

individually-purchased filter smoke hood costs about $70 or more, but according to one manufacturer bulk order costs have declined to about $40 per hood. In addition, they estimated that hoods cost about $2 a year to install and $5 a year to maintain. They weigh about a pound or less and have to be replaced about every 5 years. Furthermore, airlines could incur additional replacement costs due to theft if smoke hoods were placed near passenger seats in commercial aircraft.

Neither the British CAA, the FAA, the DGAC, nor Transport Canada Civil Aviation has chosen to require smoke hoods. The British Air Accident Investigations Branch recommended that smoke hoods be considered for aircraft after the 1985 Manchester accident, in which 48 of 55 passengers died on a runway from an engine fire before takeoff, mainly from smoke inhalation and the effects of hydrogen cyanide. Additionally, a U.K. parliamentary committee recommended research into smoke hoods in 1999, and the European Transport Safety Council, an international nongovernmental organization whose mission is to provide impartial advice on transportation safety to the European Commission and Parliaments, recommended in 1997 that smoke hoods be provided in all commercial aircraft. Canada's Transportation Safety Board has taken no official position on smoke hoods, but has noted a deficiency in cabin safety in this area and recommended further evaluation of voluntary passenger use.

Although smoke hoods are currently available, they remain controversial. Passengers are allowed to bring filter type smoke hoods on an airplane, but FAA is not considering requiring airlines to provide smoke hoods for passengers. The debate over whether smoke hoods should be installed in aircraft revolves mainly around regulatory concerns that passengers will not be able to put smoke hoods on quickly in an emergency; that hoods might hinder visibility, and that any delay in putting on smoke hoods would slow down an evacuation. FAA's and CAA's evacuation experiments—to determine how long it takes for passengers to unpack and don smoke hoods and whether an evacuation would be slowed by their use—have reached opposite conclusions about the effects of smoke hoods on evacuation rates. The CAA has noted that delays in putting on smoke hoods by only one or two people could jeopardize the whole evacuation. An opposite view by some experts is that the gas and smoke-induced incapacitation of one or two passengers could also delay an evacuation.

FAA believes that an evacuation might be hampered by passengers' inability to quickly and effectively access and don smoke hoods, by competitive passenger behavior, and by a lack of passenger attentiveness during pre-flight safety briefings. FAA noted that smoke hoods can be difficult to access and use even by trained individuals. However, other experts have noted that smoke hoods might reduce panic and help make evacuations more orderly, that competitive behavior already occurs in seeking access to exits in a fire, and that passengers could learn smoke hood safety procedures in the pre-flight safety briefings in the same way they learn to use drop-down oxygen masks or flotation devices.

The usefulness of smoke hoods varies across fire scenarios depending on assumptions about how fast hoods could be put on and how much time would be available to evacuate. One expert told us that the time needed to put on a smoke hood might not be important in several fire scenarios, such as an in-flight fire in which passengers are seeking temporary protection from smoke until the airplane lands and an evacuation can begin. In other scenarios—a ground evacuation or postcrash evacuation — some experts argue that passengers in back rows or far from an exit may have their exit path temporarily blocked as other passengers exit and, because of the delay in their evacuation, may have a greater need and more time available to don smoke hoods than passengers seated near usable exits.

Exit Slide Testing

Background

Exit slide systems are rarely used during their operational life span. However, when such a system is used, it may be under adverse crash conditions that make it important for the system to work as designed. To prevent injury to passengers and crew escaping through floor-level exits located more than 6 feet above the ground, assist devices (i.e., slides or slide-raft systems) are used. (See fig. 15.)

Figure 15: Drawing of Possible Emergency Slide Testing of FAA's 747 Test Aircraft

Source: FAA.

The rapid deployment, inflation, and stability of evacuation slides are important to the effectiveness of an aircraft's evacuation system, as was illustrated in the fatal ground collision of a Northwest Airlines DC-9 and a Northwest Airlines 727 in Romulus, Michigan, in December 1990. As a result of the collision, the DC-9 caught fire, but there were several slide problems that slowed the evacuation. For example, NTSB later found that the internal tailcone exit release handle was broken, thereby preventing the tailcone from releasing and the slide from deploying.

Because of concerns about the operability of exit slides, NTSB recommended in 1974 that FAA improve its maintenance checks of exit slide operations. In 1983, FAA revised its exit slide requirements to specify criteria for resistance to water penetration and absorption, puncture strength, radiant heat resistance, and deployment as flotation platforms after ditching.

Status

All U.S. air carriers have an FAA-approved maintenance program for each type of airplane that they operate. These programs require that the components of an airplane's emergency evacuation system, which includes the exit slides, be periodically inspected and serviced. An FAA principal maintenance inspector approves the air carrier's maintenance program. According to NTSB, although most air carriers' maintenance programs require that a percentage of emergency evacuation slides or slide rafts be tested for deployment, the percentage of required on-airplane deployments is generally very small. For example, NTSB found that American Airlines' FAA-approved maintenance program for the A300 requires an on-airplane operational check of four slides or slide rafts per year. Delta Air Lines' FAA-approved maintenance program for the L-1011 requires that Delta activate a full set of emergency exits and evacuation slides or slide rafts every 24 months. Under an FAA-approved waiver for its maintenance program, United is not required to deploy any slide on its 737 airplanes.

NTSB also found that FAA allows American Airlines to include inadvertent and emergency evacuation deployments toward the accomplishment of its maintenance program; therefore, it is possible that American would not purposely deploy any slides or slide rafts on an A300 to comply with the deployment requirement during any given year. In addition, NTSB found that FAA also allows Delta Air Lines to include inadvertent and emergency evacuation deployments toward the accomplishment of its maintenance program.

NTSB holds that because inadvertent and emergency deployments do not occur in a controlled environment, problems with, or failures in, the system may be more difficult to identify and record, and personnel qualified to detect such failures may not be present. For example, in an inadvertent or emergency slide or slide raft deployment, observations on the amount of time it takes to inflate the slide or slide raft, and the pressure level of the slide or slide raft are not likely to be documented. For these reasons, a 1999 NTSB report said that FAA's allowing these practices could potentially leave out significant details about the interaction of the slide or slide raft with the door or how well the crew follows its training mock-up procedures. Accordingly, in 1999, NTSB recommended that FAA stop allowing air carriers to count inadvertent and emergency deployments toward meeting their maintenance program requirement because conditions are not controlled and important information (on, for example, the interface between the airplane and the evacuation slide system, timing, durability, and stability) is not collected. The recommendation continues to be open at the NTSB. NTSB officials said they would be meeting to discuss this recommendation with FAA in the near future.

Additionally, NTSB recommended that FAA, for a 12-month period, require that all operators of transport-category aircraft demonstrate the on-airplane operation of all emergency evacuation systems (including the door-opening assist mechanisms and slide or slide raft deployment) on 10 percent of each type of airplane (at least one airplane per type) in their fleets. NTSB said that these demonstrations should be conducted on an airplane in a controlled environment so that qualified personnel can properly evaluate the entire evacuation system. NTSB indicated that the results of the demonstrations (including an explanation of the reasons for any failures) should be documented for each component of the system and should be reported to FAA.[4]

Overwing Exit Doors

Background

Prompted by a tragedy in which 57 of the 137 people on board a British Airtours B-737 were killed because passengers found exit doors difficult to access and operate, the British Civil Aviation Authority initiated a research program to explore changes to the design of the overwing exit (Type III) door.

Trained crewmembers are expected to operate most of the emergency equipment on an airplane, including most floor-level exit doors. But overwing exit doors, termed "self-help exits," are expected to be and will primarily be opened by passengers without formal training.[5] NTSB reported that even when flight attendants are responsible for opening the overwing exit doors, passengers are likely to make the first attempt to open the overwing exit hatches because the flight attendants are not physically located near the overwing exits.

There are now two basic types of overwing exit doors—the "self-help" doors that are manually removed inward and then stowed and the newer "swing out" doors that open outward on a hinge.

According to NTSB, passengers continue to have problems removing the inward-opening exit door and stowing it properly. The manner in which the overwing exit is opened and how and where the hatch should be stowed is not intuitively obvious to passengers, nor is it easily or consistently depicted graphically. NTSB recently recommended to FAA that Type III overwing exits on newly manufactured aircraft be easy and intuitive to

[4]NTSB, *Emergency Evacuation of Commercial Airplanes*, 2001, [A-00-76] (Washington, D.C.:2000).

[5]The overwing exit hatch can weigh as much as 65 pounds and be 20 inches wide and 36 inches high.

open and have automatic stowage out of the egress path.[6] NTSB has indicated that the semiautomatic, fast-opening, Type III overwing exit hatch could give passengers additional evacuation time.

Status

Over-wing exit doors that "swing out" on hinges rather than requiring manual removal are currently available. The European Joint Aviation Authorities (JAA) has approved the installation of these outward-opening hinged doors on new-production aircraft in Europe. In addition, Boeing has redesigned the overwing exit door for its next-generation 737 series. This redesigned, hinged door has pressurized springs so that it essentially pops up and outward, out of the way, once its lever is pulled. The exit door handle was also redesigned and tested to ensure that anyone could operate the door using either single or double handgrips. Approximately 200 people who were unfamiliar with the new design and had never operated an overwing exit tested the outward-opening exit door. These tests found that the average adult could operate the door in an emergency. The design eliminates the problem of where to stow the exit hatch because the door moves up and out of the egress route.

While the new swing-out doors are available, it will take some time for them to be widely used. Because of structural difficulties and cost, the new doors are not being considered for the existing fleet. For new-production airplanes, their use is mixed because JAA requires them in Europe for some newer Boeing 737s, but FAA does not require them in the United States. However, FAA will allow their use. As a result, some airlines are including the new doors on their new aircraft, while others are not. For example, Southwest Airlines has the new doors on its Boeing 737s. The extent to which other airlines and aircraft models will have the new doors installed remains to be seen and will likely depend on the cost of installation, the European market for the aircraft, and any additional costs to train flight attendants in its use.

[6]NTSB, *Emergency Evacuation of Commercial Airplanes*, [A-00-76] (Washington, D.C., 2000).

Next Generation Evacuation Equipment and Procedures

Background

Airbus, a leading aircraft manufacturer, has begun building a family of A380 aircraft, also called Large Transport Aircraft (see fig. 16). Early versions of the A380, which is scheduled to begin flight tests in 2005 and enter commercial service in 2006, will have 482 to 524 seats. The A380-800 standard layout references 555 seats. Later larger configurations could accommodate up to 850 passengers. The A380 is designed to have 16 emergency doors and require 16 escape slides, compared with the 747, which requires 12. Later models of the A380 could have 18 emergency exits and escape slides.

Figure 16: Airbus' Planned Double Deck Aircraft

Source: Airbus.

Status

The advent of this type of Large Transport Aircraft is raising questions about how passengers will exit the aircraft in an emergency. The upper deck doorsill of the A380 will be approximately 30 feet above the ground, depending on the position (attitude) of the aircraft. According to an Airbus official responsible for exit slide design and operations, evacuation slides have to reach the ground at a safe angle even if the aircraft is tipped up; however, extra slide length is undesirable if the sill height is normal.

Previously, regulations would have required slides only to touch the ground in the tip-up case, even if that meant introduction of relatively steep sliding surfaces. However, because of the sill height, passengers may hesitate before jumping and their hesitation may extend the total evacuation time. Because some passengers may be reluctant to leap onto the slide when they can see how far it is to the ground, the design concept of the A380 evacuation slides includes blinder walls at the exit and a curve in the slide to mask the distance to the ground.

A next-generation evacuation system developed by Airbus and Goodrich called the “intelligent slide” is a possible solution to the problem of the Large Transport Aircraft’s slide length. The technology is not a part of the slide, but is connected to the slide through what is called a door management system composed of sensors. The “brains” of the technology will be located inside the forward exit door of the cabin, and the technology is designed to adjust the length of the slide according to the fuselage’s tipping angle to the ground. The longest upper-deck slide for an A380 could exceed 50 feet.

The A380 slides are made of a nylon-based fabric that is coated with urethane or neoprene, and they are 10 percent lighter than most other slides on the market. They have to be packed tightly into small bundles at the foot of emergency exit doors and are required to be fully inflated in 6 seconds. Officials at Airbus noted that the slides are designed to withstand the radiant heat of a postimpact fire for 180 seconds, compared with the 90 seconds required by regulators.

According to a Goodrich official, FAA will require Goodrich to conduct between 2,000 and 2,500 tests on the A380 slides to make sure they can accommodate a large number of passengers quickly and withstand wind, rain, and other weather conditions. The upper-level slides, which are wide enough for two people, have to enable the evacuation of 140 people per minute, according to Airbus officials. An issue to be resolved is whether a full-scale demonstration test will be required or whether a partial test using a certain number of passengers, supplemented by a computer simulation of an evacuation of 555 passengers, can effectively demonstrate an evacuation from this type of aircraft. Airbus officials told us that a full-scale demonstration could result in undesirable injuries to the participants and is therefore not the preferred choice.

Officials at the Association of Flight Attendants have expressed concern that there has not been a full-scale evacuation demonstration involving the

A380. They are concerned that computer modeling might not really match the human experience of jumping onto a slide from that height. In addition, they are concerned that other systems involved in emergency exiting, such as the communication systems, need to be tested under controlled conditions. As a result, they believe a full-scale demonstration under the current 90-second standard is necessary.

Personal Flotation Devices

Background

All commercial aircraft that fly over water more than 50 nautical miles from the nearest shore are required to be equipped with flotation devices for each occupant of the airplane. According to FAA, 44 of the 50 busiest U.S. airports are located within 5 miles of a significant body of water. In addition, life vests, seat cushions, life rafts, and exit slides may be used as flotation devices for water emergencies.

FAA policies dictate that if personal flotation devices are installed beneath the passenger seats of an aircraft, the devices must be easily retrievable. Determinations of compliance with this requirement are based on the judgment of FAA as the certifying authority.

Status

FAA is conducting research and testing on the location and types of flotation devices used in aircraft. When it has completed this work, it is likely to provide additional guidance to ensure that the devices are easily retrievable and usable. FAA's research is designed to analyze human performance factors, such as how much time passengers need to retrieve their vests, whether and how the cabin environment physically interferes with their efforts, and how physically capable passengers are of reaching their vests while seated and belted. FAA is reviewing four different life vest installation methods and has conducted tests on 137 human subjects. According to an early analysis of the data, certain physical installation features significantly affect both the ability of a typical passenger to retrieve an underseat life vest and the ease of retrieval. This work may lead to additonal guidance on the location of personal flotation devices.

FAA's research may also indicate a need for additional guidance on the use of personal flotation devices. In a 1998 report on ditching aircraft and water survival, FAA found that airlines differed in their instructions to passengers on how to use personal flotation devices.[7] For example, some airlines advise that passengers hold the cushions in front of their bodies, rest their chins on the cushions, wrap their arms around the cushions with their hands grasping the outside loops, and float vertically in the water. Other airlines suggest that passengers lie forward on the cushions, grasp and hold the loops beneath them, and float horizontally. FAA also reported that airlines' flight attendant training programs differed in their instructions on how to don life vests and when to inflate them.

[7]LB & M Associates, Inc., and Garnet A. McLean, *Analysis of Ditching and Water Survival Training Programs of Major Airframe Manufacturers and Airlines*, CAMI [DOT/FAA/AM-98/19], (Washington, D.C.).

Summaries of General Cabin Occupant Safety and Health Advancements

This appendix presents information on the background and status of potential advancements in general cabin occupant safety and health that we identified, including the following:

- advanced warnings of turbulence;
- preparations for in-flight medical emergencies;
- reductions in health risks to passengers with certain medical conditions, including deep vein thrombosis; and
- improved awareness of radiation exposure.

This appendix also discusses occupational safety and health standards for the flight attendant workforce.

Advanced Warnings of Turbulence

Background

According to FAA, the leading cause of in-flight injuries for cabin occupants is turbulence. In June 1995, following two serious events involving turbulence, FAA issued a public advisory to airlines urging the use of seat belts at all times when passengers are seated, but concluded that the existing rules did not require strengthening. In May 2000, FAA instituted a public awareness campaign, called Turbulence Happens, to stress the importance of wearing safety belts to the flying public.

Because of the potential for injury from unexpected turbulence, ongoing research is attempting to find ways to better identify areas of turbulence so that pilots can take corrective action to avoid it. In addition, FAA's July 2003 draft strategic plan targets a 33 percent reduction in the number of turbulence injuries to cabin occupants by 2008—from an annual average of 15 injuries per year for fiscal years 2000 through 2002 to no more than 10 injuries per year.

Status

FAA is currently evaluating new airborne weather radar and other technologies to improve the timeliness of warnings to passengers and flight attendants about impending turbulence. For example, the Turbulence Product Development Team, within FAA's Aviation Weather Research Program, has developed a system to measure turbulence and downlink the information in real time from commercial air carriers. The International Civil Aviation Organization has approved this system as an international standard. Ongoing research includes (1) detecting turbulence in flight and reporting its intensity to augment pilots' reports, (2) detecting turbulence remotely from the ground or in the air using radar, (3) detecting turbulence remotely using LIDAR[1] or the Global Positioning System's constellation of satellites, and (4) forecasting the likelihood of turbulence over the continental United States during the next 12 hours. Prototypes of the in-flight detection system have been installed on 100 737-300s operated by United Airlines, and two other domestic air carriers have expressed an interest in using the prototype. FAA also plans to improve (1) training on standard operating procedures to reduce injuries from turbulence, (2) the dissemination of pilots' reports of turbulence, and (3) the timeliness of weather forecasts to identify turbulent areas. Furthermore, FAA encourages and some airlines require passengers to keep their seatbelts fastened when seated to help avoid injuries from unexpected turbulence.

Currently, pilots rely primarily on other pilots to report when and where (e.g., specific altitudes and routes) they have encountered turbulent conditions en route to their destinations; however, these reports do not accurately identify the location, time, and intensity of the turbulence. Further research and testing will be required to develop technology to accurately identify turbulence and to make the technology affordable to the airlines, which would ultimately bear the cost of upgrading their aircraft fleets.

Preparations for In-flight Medical Emergencies

[1]LIDAR (LIght Detection And Ranging) is a technology that can measure the distance, speed, rotation, and chemical composition and concentration of a remote target, such as turbulence.

Background

The Aviation Medical Assistance Act of 1998 directed FAA to determine whether the current minimum requirements for air carriers' emergency medical equipment and crewmember emergency medical training should be modified. In accordance with the act, FAA collected data for a year on in-flight deaths and near deaths and concluded that enhancements to medical kits and a requirement for airlines to carry automatic external defibrillators were warranted. Specifically, the agency found that these improvements would allow cabin crewmembers to deal with a broader range of in-flight emergencies.

Status

On April 12, 2001, FAA issued a final rule requiring air carriers to equip their aircraft with enhanced emergency medical kits and automatic external defibrillators by May 12, 2004. Most U.S. airlines have installed this equipment in advance of the deadline.

In the future, new larger aircraft may require additional improvements to meet passengers' medical needs. For example, new large transport aircraft, such as the Airbus A-380, will have the capacity to carry about 555 people on long-distance flights. Some aviation safety experts are concerned that with the large number of passengers on these aircraft, the number of in-flight medical emergencies will increase and additional precautions for in-flight medical emergencies (e.g., dedicating an area for passengers who experience medical emergencies in flight) should be considered. Airbus has proposed a medical room in the cabin of its A-380 as an option for its customers.

Reducing Health Risks to Passengers with Certain Medical Conditions

Background

Passengers with certain medical conditions (e.g., heart and lung diseases) can be at higher risk of health-related complications from air travel than the general population. For example, passengers who have limited heart or lung function or have recently had surgery or a leg injury can be at greater risk of developing a condition known as deep vein thrombosis (DVT) or travelers' thrombosis, in which blood clots can develop in the deep veins of the legs from extended periods of inactivity. Air travel has not been linked definitively to the development of DVT, but remaining seated for extended periods of time, whether in one's home or on a long-distance flight, can cause blood to pool in the legs and increase the chances of developing DVT. In a small percentage of cases, the clots can break free and travel to the lungs, with fatal results.

In addition, the reduced levels of oxygen available to passengers in-flight can have detrimental health effects on passengers with heart, circulatory, and respiratory disorders because lower levels of oxygen in the air produce lower levels of oxygen in the body—a condition known as hypoxia. Furthermore, changes in cabin pressure (primarily when the aircraft ascends and descends) can negatively affect ear, nose, and throat conditions and pose problems for those flying after certain types of surgery (e.g., abdominal, cardiac, and eye surgery).

Status

Information on the potential effects of air travel on passengers with certain medical conditions is available; however, additional research, such as on the potential relationship between DVT and air travel, is ongoing. The National Research Council, in a 2001 report on airliner cabin air quality, recommended, among other things, that FAA increase efforts to provide information on health issues related to air travel to crewmembers, passengers, and health professionals. According to FAA's Federal Air Surgeon, since this recommendation was received, the agency has redoubled its efforts to make information and recommendations on air travel and medical issues available through its Web site www.cami.jccbi.gov/aam-400/PassengerHandS.htm. This site also includes links to the Web sites of other organizations with safety and health information for air travelers, such as the Aerospace Medical Association, the American Family Physician (Medical Advice for Commercial Air Travelers), and the Sinus Care Center (Ears, Altitude, and Airplane Travel), and videos on safety and health issues for pilots and air travelers. The Aerospace Medical Association's Web site, http://www.asma.org/publication.html, includes guidance for physicians to use in advising passengers about the potential risks of flying based on their medical conditions, as well as information for passengers to use in determining whether air travel is advisable given their medical conditions. Furthermore, some airlines currently encourage passengers to do exercises while seated, to get up and walk around during long flights, or to do both to improve blood circulation; however, walking around the airplane can also put passengers at risk of injuries from unexpected turbulence. In addition, a prototype of a seat has been designed with imbedded sensors, which record the movement of a passenger and send this information to the cabin crew for monitoring. The crew would then be able to track passengers seated for a long time and could suggest that these passengers exercise in their seats or walk in the cabin aisles to enhance circulation.

While FAA's Web site on passenger and pilot safety and health provides links to related Web sites and videos (e.g., cabin occupant safety and health issues), historically, the agency has not tracked who uses its Web site or how frequently it is used to monitor the traveling public's awareness and use of this site. Agency officials told us that they plan to install a counter capability on its Civil Aerospace Medical Institute Web site by the end of August 2003 to track the number of visits to its aircrew and passenger health and safety Web site. The World Health Organization has initiated a study to help determine if a linkage exists between DVT and air travel. Further, FAA developed a brochure on DVT that has been distributed to aviation medical examiners and cited in the Federal Air Surgeon's Bulletin. The brochure is aimed at passengers rather than airlines and suggests exercises that can be done to promote circulation.

Improved Awareness of Radiation Exposure

Background

Pilots, flight attendants, and passengers who fly frequently are exposed to cosmic radiation at higher levels (on a cumulative basis) than the average airline passenger and the general public living at or near sea level. This is because they routinely fly at high altitudes, which places them closer to outer space, which is the primary source of this radiation. High levels of radiation have been linked to an increased risk of cancer and potential harm to fetuses. The amount of radiation that flight attendants and frequent fliers are exposed to—referred to as the dose—depends on four primary factors: (1) the amount of time spent in flight; (2) the latitude of the flight—exposure increases at higher latitudes; for example, at the same altitude, radiation levels at the poles are about twice those at the equator; (3) the altitude of the flight—exposure is greater at high altitudes because the layer of protective atmosphere becomes thinner; and (4) solar activity—exposure is higher when solar activity increases, as it does every 11 years or so. Peak periods of solar activity, which can increase exposure to radiation by 10 to 20 times, are sometimes called solar storms or solar flares.

Status

FAA's Web site currently makes available guidance on radiation exposure levels and risks for flight and cabin crewmembers, as well as a system for calculating radiation doses from flying specific routes and specific altitudes. To increase crewmembers' awareness of in-flight radiation exposure, FAA issued two Advisory Circulars for crewmembers. The first Advisory Circular, issued in 1990, provided information on (1) cosmic radiation and air shipments of radioactive material as sources of radiation exposure during air travel; (2) guidelines for exposure to radiation; (3) estimates of the amounts of radiation received on air carriers' flights on various routes to and from, or within, the contiguous United States; and (4) examples of calculations for estimating health risks from exposure to radiation. The second Advisory Circular, issued in 1994, recommended training for crewmembers to inform them about in-flight radiation exposure and known associated health risks and to assist them in making informed decisions about their work on commercial air carriers. The circular provided a possible outline of courses, but left it to air carriers to gather the subject matter materials. To facilitate the monitoring of radiation exposure levels by airliner crewmembers and the public (e.g., frequent fliers), FAA has developed a computer model, which is publicly available via the agency's Web site. This Web site also provides guidance and recommendations on limiting radiation exposure. However, it is unclear to what extent flight attendants, flight crews, and frequent fliers are aware of and use FAA's Web site to track the radiation exposure levels they accrue from flying. Agency officials told us that they plan to install a counter capability its Civil Aerospace Medical Institute Web site by the end of August 2003, to track the number of visits to its aircrew and passenger health and safety Web site. FAA also plans to issue an Advisory Circular by early next year, which incorporates the findings of a just completed FAA report, "What Aircrews Should Know About Their Occupational Exposure to Ionizing Radiation." This Advisory Circular will include recommended actions for aircrew and information on solar flare event notification of aircrew. While FAA provides guidance and recommendations on limiting the levels of cosmic radiation that flight attendants and pilots are exposed to, it has not developed any regulations.

In contrast, the European Union issued a directive for workers in May 1996, including air carrier crewmembers (cabin and flight crews) and the general public, on basic safety and health protections against dangers arising from ionizing radiation. This directive set dose limits and required air carriers to (1) assess and monitor the exposure of all crewmembers to avoid exceeding exposure limits, (2) work with those individuals at risk of high exposure levels to adjust their work or flight schedules to reduce those levels, and (3) inform crewmembers of the health risks that their work involves from exposure to radiation. It also required airlines to work with female crewmembers, when they announce a pregnancy, to avoid exposing the fetus to harmful levels of radiation. This directive was binding for all European Union member states and became effective in May 2000. According to European safety officials, pregnant crewmembers are often given the option of an alternative job with the airline on the ground to avoid radiation exposure to their fetuses. Furthermore, when flight attendants and pilots reach recommended exposure limits, European air carriers work with crewmembers to limits or change their subsequent flights and destinations to minimize exposure levels for the balance of the year. Some air carriers ground crewmembers when they reach annual exposure limits or change their subsequent flights and destinations to minimize exposure levels for the balance of the year.

Occupational Safety and Health Standards for Flight Attendants

Background

In 1975, FAA assumed responsibility from the Occupational Health and Safety Administration (OSHA) for establishing safety and health standards for flight attendants. However, FAA has only recently begun to take action to provide this workforce with OSHA-like protections. For example, in August 2000, FAA and OSHA entered into a memorandum of understanding and issued a joint report in December 2000, which identified safety and health concerns for the flight attendant workforce and the extent to which OSHA-type standards could be used without compromising aviation safety. On September 29, 2001, the DOT Office of the Inspector General (DOT IG) reported that FAA had made little progress toward providing flight attendants with workplace protections and urged FAA to address the recommendations in the December 2000 report and move forward with setting safety and health standards for the flight attendant workforce. In April 2002, the DOT IG reported that FAA and OSHA had made no progress since it issued its report in September 2001. According to FAA officials, the joint FAA and OSHA effort was put on hold because of other priorities that arose in response to the events of September 11, 2001.

Status

FAA has not yet established occupational safety and health standards to protect the flight attendant workforce. FAA is conducting research and collecting data on flight attendants' injuries and illnesses.

On March 4, 2003, FAA announced the creation of a voluntary program for air carriers, called the Aviation Safety and Health Partnership Program. Through this program, the agency intends to enter into partnership agreements with participating air carriers, which will, at a minimum, make data on their employees' injuries and illnesses available to FAA for collection and analysis. FAA will then establish an Aviation Safety and Health Program Aviation Rule-Making Committee to provide advice and recommendations to

- develop the scope and core elements of the partnership program agreement;
- review and analyze the data on employees' injuries and illnesses;
- identify the scope and extent of systematic trends in employees' injuries and illnesses;
- recommend remedies to FAA that use all current FAA protocols, including rule-making activities if warranted, to abate hazards to employees; and
- create any other advisory and oversight functions that FAA deems necessary.

FAA plans to select members to provide a balance of viewpoints, interests, and expertise. The program preserves FAA's complete and exclusive responsibility for determining whether proposed abatements of safety and health hazards would compromise or negatively affect aviation safety.

FAA is also funding research through the National Institute for Occupational Safety and Health (NIOSH) to, among other things, determine the effects of flying on the reproductive health of flight attendants, much of which has been completed.[2] FAA plans to monitor cabin air quality on a selected number of flights, which will help it set standards for the flight attendant workforce.

The Association of Flight Attendants has collected a large body of data on flight attendants' injuries and illnesses, which it considers sufficient for use in establishing safety and health standards for its workforce. Officials from the association do not believe that FAA needs to collect additional data before starting the standard-setting process.

The European Union has occupational safety and health standards in place to protect flight attendants, including standards for monitoring their levels of radiation exposure. An official from an international association of flight attendants told us that while flight attendants in Europe have concerns similar to those of flight attendants in the United States (e.g., concerns about air quality in airliner cabins), the European Union places a heavier emphasis on worker safety and health, including safety and health protections for flight attendants.

[2]NIOSH is also conducting research on airliner cabin environmental quality, respiratory symptoms of flight attendants, and disease transmission.

Application of a Cost Analysis Methodology to Inflatable Lap Belts

The following illustrates how a cost analysis might be conducted on each of the potential advancements discussed in this report. Costs estimated through this analysis could then be weighed against the potential lives saved and injuries avoided from implementing the advancements. This methodology would allow advancements to be compared using comparable cost data that when combined with similar analyses of effectiveness to help decisionmakers determine which advancements would be most effective in saving lives and avoiding injuries, taking into account their costs. The methodology provides for developing a cost estimate despite significant uncertainties by making use of historical data (e.g, historical variations in fuel prices) and best engineering judgments (e.g., how much weight an advancement will add and how much it will cost to install, operate, and maintain). The methodology formally takes into account the major sources of uncertainty and from that information develops a range of cost estimates, including a most likely cost estimate. Through a common approach for analyzing costs, the methodology facilitates the development of comparable estimates. This methodology can be applied to advancements in various stages of development.

Inflatable Lap Belts

Inflatable lap belts are designed to protect passengers from a fatal impact with the interior of the airplane, the most common cause of death in survivable accidents. Inflatable seat belts adapt advanced automobile technology to airplane seats in the form of seat belts with air bags embedded in them. Several hundred of these seatbelt airbags have been installed in commercial airliners in bulkhead rows.

Summary of Results

We calculated that requiring these belts on an average-sized airplane in the U.S. passenger fleet would be likely to cost from $98,000 to $198,000 and to average about $140,000 over the life of the airplane. On an annual basis, the cost would be likely to range from $8,000 to $17,000 and to average $12,000.

We considered several factors to explain this range of possible costs. The installation price of these belts is subject to uncertainty because of their limited production to date. In addition, these belts add weight to an aircraft, resulting in additional fuel costs. Fuel costs depend on the price of jet fuel and on how many hours the average airplane operates, both subject to uncertainty. Table 5 lists the results of our cost analysis for an average-sized airplane in the U.S. fleet.

Table 4: Costs to Equip an Average-sized Airplane in the U.S. Fleet with Inflatable Lap Seat Belts, Estimated under Alternative Scenarios (In 2002 discounted dollars)

	Cost scenario			
Cost	Low	Average	High	95 percentile[a]
Life-cycle	$98,000	$140,000	$198,000	$186,000
Annualized	$8,000	$12,000	$17,000	$16,000
Per ticket[b]	$0.08	$0.13	$0.19	$0.18

Source: GAO analysis.

[a]For example, a 95 percentile estimate means that there is a 95 percent probability that the total life-cycle costs per airplane will be $186,000 or less.

[b]Cost rounded to the nearest cent.

According to our analysis, the life-cycle and annualized cost estimates in table 5 are influenced most by variations in jet fuel prices, followed by the average number of hours flown per year and the installation price of the belts. The cost per ticket is influenced most by variations in jet fuel prices, followed by the average number of hours flown per year, the number of aircraft in the U.S. fleet, and the number of passenger tickets issued.

Methodology

To analyze the cost of inflatable lap belts, we collected data on key cost variables from a variety of sources. Information on the belts' installation price, annual maintenance and refurbishment costs, and added weight was obtained from belt manufacturers. Historical information on jet fuel prices, extra gallons of jet fuel consumed by a heavier airplane, average hours flown per year, average number of seats per airplane, number of airplanes in the U.S. fleet, and number of passenger tickets issued per year was obtained from FAA and DOT's Office of Aviation Statistics.

To account for variation in the values of these cost variables, we performed a Monte Carlo simulation.[1] In this simulation, values were randomly drawn 10,000 times from probability distributions characterizing possible values

[1]"Monte Carlo simulation is a widely used computational method for generating probability distributions of variables that depend on other variables or parameters represented as probability distributions. Monte Carlo methods are to be contrasted with the deterministic methods used to generate specific single number or point estimates." Susan Poulter, "Monte Carlo Simulation in Environmental Risk Assessment - Science, Policy And Legal Issues," 9 *Risk: Health, Safety & Environment* 7 [Winter 1998].

for the number of seat belts per airplane, seat belt installation price, jet fuel price, number of passenger tickets, number of airplanes, and hours flown.[2] This simulation resulted in forecasts of the life-cycle cost per airplane, the annualized cost per airplane, and the cost per ticket.

Major assumptions in the cost analysis are described by probability distributions selected for these cost variables. For jet fuel prices, average number of hours flown per year, and average number of seats per airplane, historical data were matched against possible probability distributions.[3] Mathematical tests were performed to find the best fit between each probability distribution and the data set's distribution. For the installation price, number of passenger tickets, and number of airplanes, less information was available.[4] For these variables, we selected probability distributions that are widely used by researchers. Table 6 lists the type of probability distribution and the relevant parameters of each distribution for the cost variables.

Table 5: Key Assumptions

Cost variable	Type of distribution	Mean or average	Standard deviation	Minimum	Maximum	Likeliest	Mode	Scale
Fuel price	lognormal	$0.93	$0.33					
Seats	lognormal	161	8					
Installation price	triangular			$300	$600	$450		
Hours	extreme value	2,353					2,643	539
Airplanes	normal	4,438	399					
Tickets	normal	419	35					

Source: GAO analysis.

[2]A probability distribution is a set of all possible events and their associated probabilities. Probability refers to the likelihood of an event.

[3]Historical data from 1975 through 2001 were available for the number of seats per plane, and from 1977 through 2002 for jet fuel prices. Aircraft utilization data for 2001 were available for annual hours per aircraft.

[4]Historical data from 1995 through 2001 were available for the number of planes and tickets.

GAO Contacts and Staff Acknowledgments

GAO Contacts

Gerald L. Dillingham (202) 512-2834
Glen Trochelman (202) 512-2834
Beverly Norwood (202) 512-2834

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