Chapter 1

BACKGROUND AND REGULATORY CONTEXT

Background and Regulatory Context

Air travel, for business or pleasure, is an indispensable part of American life. The integrity of the aircraft and air traffic management systems, and the vigilance and skill of those who operate them, are the cornerstones of safe air travel. Should an emergency occur, passenger survival depends on the ability of the aircraft and its contents to withstand impact and the post-crash environment, on the design and effectiveness of escape routes and equipment, and on the crew's ability to help passengers evacuate the aircraft as quickly as possible. Ensuring crashworthiness, prolonging survivable conditions within the cabin, and providing quick egress are major thrusts of Federal safety programs. One of the final measures of an aircraft's readiness for operation is the full-scale evacuation demonstration.

Pursuant to existing Federal aviation regulations, aircraft manufacturers must demonstrate that a new or substantially revised type of aircraft can be completely evacuated under specified conditions in less than 90 seconds. Manufacturers have conducted more than 20 full-scale evacuation demonstrations since 1969, involving over 7,000 volunteers and airline crew personnel.[1] On average, 6 percent of full-scale demonstration participants receive injuries, which typically range from scrapes and bruises to broken bones. In October 1991, a test participant became permanently paralyzed after being injured during a McDonnell Douglas evacuation demonstration test for certification of an MD-11 airplane.[2] This renewed concern on the part of Congress, manufacturers, and passenger, pilot, and flight attendant groups about the safety of the certification process. The air transportation community is striving to find ways to reduce the likelihood of injuries in future tests.[3] At the same time, the community is considering the net benefits of full-scale demonstrations as a requirement for type certification.

The Federal Aviation Administration's (FAA) Aviation Rulemaking Advisory Committee (ARAC) is studying options for the development of performance standards to replace evacuation safety design criteria. Recent congressional Activity includes 991 hearings by the subcommittee on Government Activities and Transportation of the House Committee on Government Operations,[4] and a request for the General Accounting Office (GAO) to assess both the implementation of recent cabin materials regulations and the adequacy of the 90-second evacuation test criterion. GAO's investigation of evacuation demonstration issues is on hold, pending completion of the ARAC Subcommittee's efforts.

In November 1991, the Subcommittee on Government Activities and Transportation of the House Committee on Government Operations requested that the Office of Technology Assessment (OTA) ". . . study the prospects for improving existing methods of evacuation testing in light of the need to balance realism

1 Webster C. Heath, manager, Technical Liaison, Industry Regulatory Affairs, Douglas Aircraft Co., personal communication, Sept. 24, 1992.

2 At the time of the unsuccessful demonstration, the MD-1 1 was certificated to carry 390 passengers. The Douglas Aircraft Company again attempted to certificate the aircraft for 410 passengers on December 11, 1992, employing ramps instead of slides to minimize the potential for injury to test participants. The second, revised demonstration satisfied FAA's requirements for certification. See section on evacuation demonstrations in chapter 2.

3 In 1993, Boeing and Airbus will attempt full-scale demonstrations with their respective B-767 and A-330 aircraft.

4 See Us. Congress, House Committee on Government Operations, "Issues in Aircraft Cabin Safety and Crash Survivability: The USAir-Skywest Accident, " House Report 102-501, Apr. 22, 1992.

5 See U.S. Genera] Accounting Office, *Aviation Safety: Slow Progress in Making Aircraft Cabin Interiors Fireproof*, GAO/RCED-93-37 (Washington, DC: U.S. Government Printing Office, January 1993).

against the safety of test participants."[6] The safety and utility of testing methods are two primary concerns. Investigating the evacuation performance of an aircraft under actual emergency conditions would subject test participants to significant risk of injury. Computer simulation has emerged as a potential tool for evaluating numerous evacuations in changing fire and cabin configurations, trials too hazardous to conduct with human participants.

OTA examined a range of regulatory, research, and technology issues related to passenger safety and evacuation testing, including the scientific validity of the full-scale demonstration as a measure of evacuation capability. While this document describes alternatives to and the relative merits of current full-scale demonstration requirements, it does not provide research or regulatory policy options for Congress. Key issues this background paper does discuss include:

- the current evacuation standards and the role of evacuation testing;
- data collection and analysis to evaluate performance of evacuation systems in actual accidents or incidents;
- potential near-term improvements to demonstration tests that may reduce the likelihood of injury to participants;
- the role of mathematical modeling and/or computer simulations in reducing the need for human participation in the evaluation of evacuation procedures and equipment; and,
- economic concerns.

Federal authority for aircraft safety and evacuation standards lies with FAA. The National Transportation Safety Board (NTSB) investigates aviation accidents or incidents and makes recommendations regarding safety improvements, Outside the United States, the Civil Aviation Authority (CAA) of the United Kingdom is most active in improving the evacuation capability of the aircraft and crew under its authority. This section describes the roles of the U.S. agencies and CAA, along with requirements for emergency equipment, cabin safety operations, and crew training.

FEDERAL AVIATION ADMINISTRATION

FAA responsibility for cabin safety encompasses the development and enforcement of the Federal Aviation Regulations (FAR);[7] FAA conducts and sponsors research and development (R&D) programs related to cabin safety to support its rulemaking activities.

Cabin safety certification and compliance authority rests primarily with FAA's Aircraft Certification Service, which manages airworthiness offices throughout the United States and sets airworthiness standards, and the Flight Standards Service, which regulates air carrier operations and crew training and standards. The Certification Service establishes minimum standards for the design and manufacture of all U.S. aircraft and certifies that all aircraft meet these standards prior to introduction into service.[8] Certification authority for large commercial aircraft rests with FAA's Transport Aircraft Directorate in Seattle, Washington.

Under the Executive Director for System Development, the FAA Technical Center in Atlantic City supports regulatory development through in-house and contracted R&D, particularly in the areas of crashworthiness and fire safety. FAA's Civil Aeromedical Institute (CAMI) in Oklahoma City, under the purview of the Office of Aviation Medicine, is another contributor to crashworthiness research and evacuation standards evaluation. CAMI conducts pilot training research and, along with the

6 Barbara Boxer, chair, Subcommittee on Government Activities and Transportation, House Committee on Government Operations, letter to John Gibbons, director, Office of Technology Assessment, November 19, 1991.

7 Title 14, Chapter I Of the Code of Federal Regulations.

8 U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment, OTA-SET-381* (Washington, DC: U.S. Government Printing Office, July 1988), p. 56, available from OTA's Science, Education, and Transportation Program.

Technical Center, supports accident investigation.

To obtain type[9] certification, manufacturers of aircraft having more than 44 passenger seats must conduct emergency evacuation demonstrations that test the following:

- basic aircraft design;
- the efficiency with which passengers can safely be evacuated from the aircraft;
- the emergency evacuation system; and
- the manufacturer's FAA-approved emergency evacuation procedures.[10]

Manufacturers typically elect to conduct the demonstration to serve both the type and operating certification requirements. Figure 1-1 shows the procedure for aircraft type certification, including airframe, seats, and evacuation demonstration.

The number, duties, and location of flight attendants are specified in 14 CFR 121. Flight attendants perform numerous safety-related duties before, during, and after each flight. The individual air carriers provide flight attendants with their initial emergency procedure training, and additional training each year thereafter. Current regulations require 1 flight attendant for every 50 passenger seats.

The description and demonstration of emergency evacuation procedures are integral parts of the operating certificate application procedure.[11] Once all application and demonstration requirements have been satisfied, FAA issues an air carrier operating certificate, specifying the terms, conditions, and limitations of operation.[12]

9 Type, as defined in 14 CFR 1.1, means those aircraft that are similar in design (e.g., DC-10 Series 30 and Series 40, B-747-200 and B-747-400).

10 Federal Aviation Administration, "Evaluate FAR Part 21 Emergency Evacuation/Ditching Procedures/ Demonstration," *Airworthiness Safety Inspectors Handbook, vol. 2* (Washington, DC: November 1988), ch. 77-1.

11 U.S. General Accounting Office, *Aviation Safety: Procedures for Registering and Certifying Air Carriers,* GAO/RCED-87-1 *15FS* (Washington, DC: May 5, 1987), p. 15.

12 Ibid., p. 18.

Recent History

Flight and cabin safety comprises a significant portion of FAA's rulemaking and research duties. In 1979, FAA formed the Special Aviation Fire and Explosion Reduction Advisory Committee to assess related research and regulatory needs. For several years, following the committee's final report in 1980, FAA emphasized the development of improved fire test methods and cabin interior material criteria.[13] Several of the projects and rules related to improving fire safety are identified in table 1-1.

On August 22, 1985, as a Boeing B-737 attempted to take off from Manchester International Airport (England), its left engine disintegrated, causing a fuel spill and a subsequent fuel-fed cabin fire. Of the aircraft's 137 occupants, 55 died aboard the burning aircraft. Most were later found to have been incapacitated from smoke and toxic gas inhalation. Accident analysis indicated that limited access to overwing exits and competition among passengers delayed evacuation of the plane.

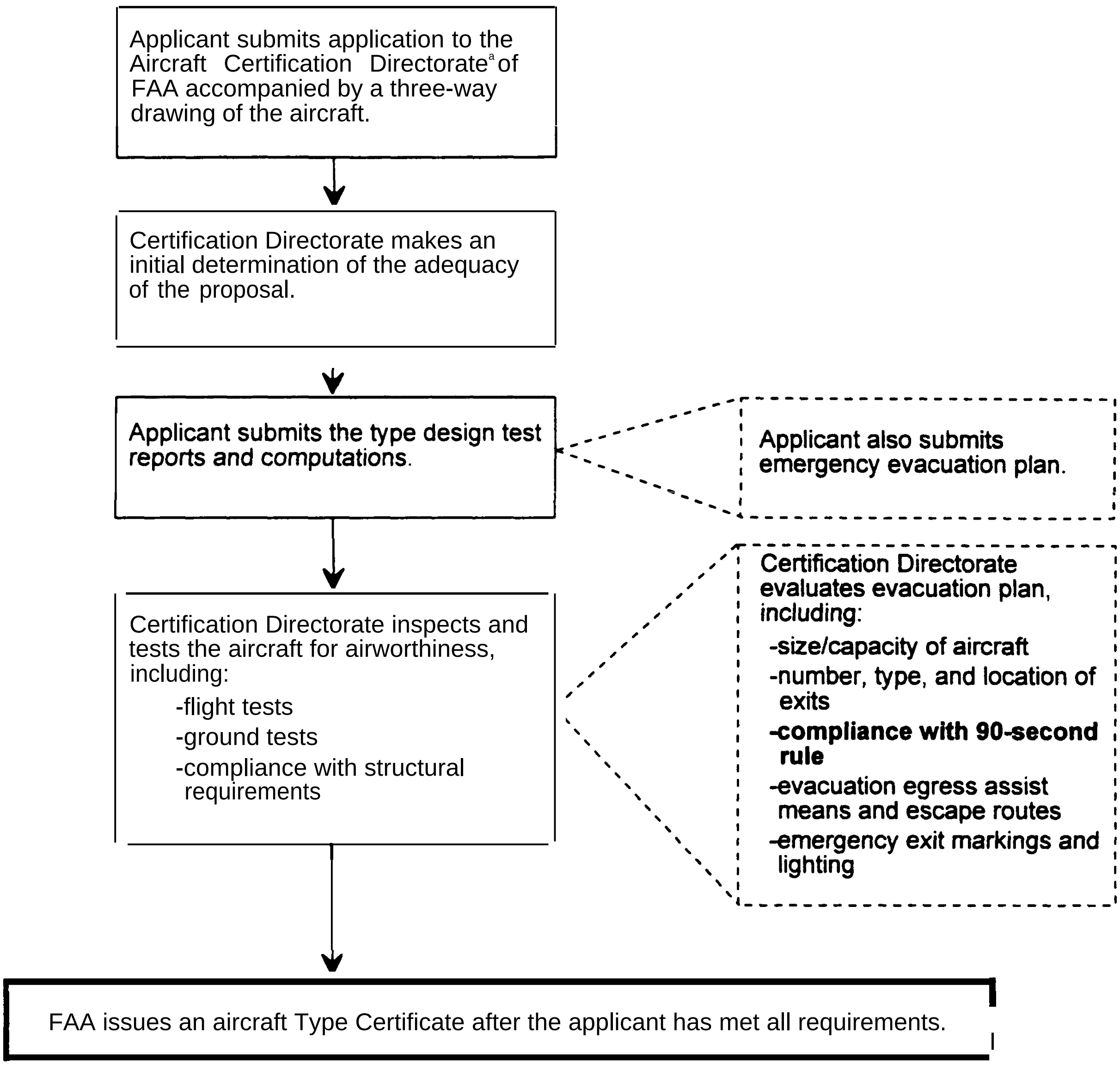
In September 1985, FAA convened a public technical conference related to emergency evacuation from transport aircraft.[14] Discussion centered on emergency exits and slides, full-scale evacuation demonstrations, and crew training. FAA formed an Emergency Evacuation Task Force to coordinate activities of three working groups established during the conference--Design and Certification, Training and Operations, and Maintenance and Reliability.[15] In 1986, FAA agreed to develop and issue rulemaking and/or advisory material on

13 Constantine Sarkos, Federal Aviation Administration, "Full Scale Test Results and Status of FAA's Cabin Safety Program," *Proceedings of the Flight Safety Foundation/ Federal Aviation Administration International Aircraft occupant Safety Conference and Workshop, DOT/FAA/OV-89-2* (Washington, DC: U.S. Department of Transportation, August 1989), p. 179.

14 50 *Federal* Register 32087 (Aug. 8, 1985).

15 For further description of the conference and its working groups, see U.S, Department of Transportation, Federal Aviation Administration, *Task Force Report on Emergency Evacuation of Transport Airplanes, vol. 1, Summary Report,* DOT/FAA/VS-86/1,I (Washington, DC: July 1986).

Figure I-I--Federal Aviation Administration Procedures for Issuing an Aircraft Type Certificate



[a]The FAA office responsible for evaluating compliance with certification requirements for a given class of aircraft.

SOURCE: Office of Technology Assessment, 1993.

Table 1-1—Federal Aviation Administration Fire Safety Program

	Project/subject	Action	Issued (compliance)
1.	Seat cushion fire blocking 14 CFR Part 135 extension	Final Rule Final Rule	10/26/84 (11/26/87) 11/25/87 (12/1/88)
2.	Floor proximity lighting	Final Rule	10/26/84 (11/26/86)
3.	Lavatory smoke detectors	Final Rule	3/26/85 (10/29/86)
4.	Lavatory automatic fire extinguisher	Final Rule	3/26/85 (4/29/87)
5.	Halon fire extinguishers	Final Rule	3/26/85 (4/29/86)
6.	Class E cargo compartment fire extinguishers	Final Rule	3/26/85 (10/29/85)
7.	Class C & D cargo or baggage compartments	Final Rule	5/16/86 (6/16/86)
8.	Improved cargo liners	NPRM	10/28/87 (2 years)
9.	Crew member PBE for flight attendants	Final Rule	5/26/87 (7/6/89)
10.	Heat release-interior materials	Final Rule	7/21/86 (8/20/88 and 8/20/90)
11.	Smoke density-interior materials	Final Rule	8/19/88 (8/20/90)
12.	Fuel system crash resistance	NPRM	4/26/89
13.	Small airplane crash resistant fuel systems	NPRM	2/14/90
14.	Passenger PBE	Rulemaking dropped	
15.	Cabin water spray system	R&D	
16.	Class C & D cargo compartments	R&D	

KEY: NPRM = Notice of Proposed Rulemaking; PBE=protective breathing equipment.

SOURCE: John J. Petrakis, “FAA Occupant Protection and Cabin Safety Overview,” *Proceedings of the Flight Safety Foundation/Federal Aviation Administration International Aircraft Occupant Safety Conference and* Workshop, DOT/FAA/OV-89-2 (Washington, DC: U.S. Department of Transportation, August 1989), p. 56; and Office of Technology Assessment, 1993.

29 specific proposals recommended by the working groups. All but 2 of the 29 recommendations resulted in FAA action by the beginning of 1992.[16]

Of the numerous elements of an aircraft's emergency evacuation system, exit and slide design, flight attendant training, and full-scale evacuation demonstrations required for type certification have engendered the most attention and public debate. The key design and training requirements and related areas of contention are discussed below; full-scale demonstrations are described in a subsequent section.

Exits

Since 1967, FAA has regulated the location of emergency exits on airplanes with the following requirements:

- Specific types and numbers of exits must be provided for given numbers of passengers;
- Exits must be located to provide the most effective means of passenger evacuation; and
- Exits must be distributed as uniformly as practical with respect to passenger seating.

Exit arrangement, deployment, and marking, and emergency lighting must meet specific criteria.[17] See box 1-A for a description of various types of aircraft exits.

In 1986, after analysis of the Manchester accident indicated congestion at the overwing exit contributed to slow evacuation, CAA issued an airworthiness notice for alternate minimum requirements for seating next to overwing exits.[18] FAA, in turn, authorized CAMI to evaluate the proposed changes under conditions that would enable comparison with the minimum requirements delineated in the FAR.[19] CAMI conducted the evacuation tests in 1986 and 1991. In May 1992, FAA issued a final rule requiring transport aircraft having 60 or more passenger seats[20] to make Type III overwing exits more accessible (e.g., provide wider passageways between seats or remove the seat adjacent to the exit).[21] With compliance required by December 1992, the rule also mandated that all aircraft with Type III exits display placards that describe how to open and stow the exit, and state the exit door's weight.

Slides

To prevent injury to passengers and crew escaping through floor-level exits located more than 6 feet above the ground, assist devices (e.g., slides or slide-rafts) are required. The rapid deployment, inflation, and stability of evacuation slides are critical elements of the evacuation system. Slide design and performance requirements are contained in technical standard orders, while general slide requirements are found in 14 CFR 25. In 1983, FAA revised the requirements to specify criteria for resistance to water penetration and adsorption,

16 U.S. Department of Transportation, Federal Aviation Administration, *Task Force Report on Emergency Evacuation of Transport Airplanes, vol. 3, Final Report*, FAA/AIR-92-01 (Washington, DC: Jan. 23, 1992), p. 11.

17 14 CFR 25.807, Amendment 25-15, 32 *Federal Register 13263* (Sept. *20, 1967).*

18 Civil Aviation Authority, United Kingdom, "Access to and Opening of Type III and Type IV Emergency Exits," Airworthiness Notice No. 79, 1986.

19 Paul G. Rasmussen and Charles B. Chittum, *The Influence of Adjacent Seating Configurations on Egress Through a Type III Emergency Exit, Final Report, DOT/FAA/AM-89/14* (Washington, DC: December 1989). Although the final report was not released until 1989, the tests were authorized in 1986. Additional tests were conducted in 1991; see Garnet A. McLean et al., Civil Aeromedical Institute, *Effects of Seating Configuration and Number of Type III Exits on Emergency Aircraft Evacuation*, Final *Report*, DOT/FAA/AM-92/27 (Washington, DC: U.S. Department of Transportation, August 1992).

20 FAA considers that a minimum of 60 passenger seats, which typically requires at least 15 rows, enables operators to provide the additional access through seat row adjustment without a loss of revenue. 57 *Federal Register 19239* (May 4, 1992).

21 57 *Federal Register* 19220 (May 4, 1992).

Box 1-A--Description of Passenger Emergency Exits

Type A[a] Rectangular opening at least 42 inches wide by 72 inches high, with specified dimensions for passageways to main and cross aisles. Floor-level Type A exits must be equipped with dual-lane emergency slide. Overwing Type A exits with step-downs[b] outside the airplane typically have automatically deployed and erected means of reaching the wing and ground.

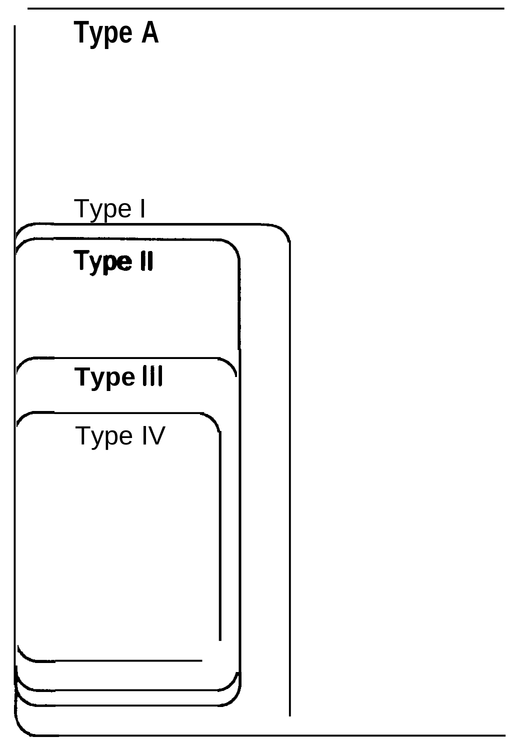
Type I[a] Floor level exit at least 24 inches wide by 48 inches high.

Type II Floor level exit at least 20 inches wide and 44 inches high. May also be located over the wing, with step-up inside the airplane of no more than 10 inches and step-down outside the airplane not exceeding 27 inches.

Type III[a] Rectangular opening at least 20 by 36 inches with step-up not to exceed 20 inches. Most often placed over the wing, having stepdown not exceeding 36 inches.

Type IV[c] Over-the-wing exit no less than 19 by 36 inches, with step-up of no more than 29 inches and step-down no greater than 36 inches.

Tail[a] Similar to the Type I exit in size, a *ventral* exit is a passage from the passenger compartment through the plane's fuselage down a set of stairs to the ground. Tail *cone* exits lead directly out of the airplane's tail onto an escape slide.



[a] Exit types most commonly used in large transport aircraft.
[b] *Step-down* is the actual distance between the bottom of the required opening and a usable foothold, extending out from the fuselage, that is large enough to be effective without searching by sight or feel. *Step-up* is the height from the floor of the cabin to the lower sill of the exit.
[c] Used in aircraft having fewer than 10 passenger seats.

SOURCE: Office of Technology Assessment, 1993, based on 14 CFR 25.807; Daniel A. Johnson, *Just in Case: A Passenger's Guide to Airplane Safety and Survival*, (New York, NY: Plenum Press, 1984), p. 148; and Mary Edwards and Elwyn Edwards, *The Aircraft Cabin: Managing the Human Factors* (Hants, England: Gover Technical Publishing Co., 1990), p. 140.

puncture strength, radiant heat resistance, and deployment as flotation platforms after ditching.[22]

Training and Operations

FAA requires operating certificate holders (airlines) to establish and maintain training programs for each crew member. FAA also regulates cockpit crew hours but not flight attendants' duty time. Activities required of flight attendants prior to takeoff include verifying that passengers' seat belts are fastened, briefing passengers on emergency equipment use, and ensuring all galley items and carry-on luggage are securely stowed. Flight attendants also administer first aid and cope with other in-flight emergencies.

During flight attendant *initial training,* required instruction topics include passenger handling, cabin and galley equipment use, airplane characteristics pertinent to in-flight emergency procedures, appropriate provisions of the FAR, and extensive emergency training. *Recurrent training* includes a review of the crew member's state of knowledge of the airplane and their duties, provides new instruction as necessary in subjects required for initial ground training, and requires a competence check in assigned duties and responsibilities.[23] Cabin crew members receive recurrent training every 12 months.[24]

Along with instruction in procedures and equipment use, the emergency training must provide at least one firefighting drill and at least one emergency evacuation drill.[25] During initial training and once each 24 months during recurrent training, crew members must perform and observe additional emergency drills, In general, this is accomplished using cabin mockups, in which flight attendants and other crew members operate exits and simulate the deployment, inflation, and use of slides. Hands-on training with the slides is provided only in initial training.[26]

NATIONAL TRANSPORTATION SAFETY BOARD

Created in 1966 under the U.S. Department of Transportation, NTSB became an independent executive branch agency in 1975. It investigates accidents[27] for all transportation *modes,* including general aviation, selected public-use aircraft, and commercial transports; conducts safety studies; and issues recommendations for changes in regulations and procedures. FAA is not bound to accept NTSB regulatory change suggestions.[28]

Aircraft operators must immediately notify NTSB whenever an accident occurs or an aircraft evacuation involves use of an emergency egress system.[29] The information provided to NTSB must include the number of persons aboard the aircraft, and the number killed or

22 John J. Petrakis, Federal Aviation Administration, "FAA Occupant Protection and Cabin Safety Overview," *Proceedings of the Flight Safety Foundation/Federal Aviation Administration International Aircraft Occupant Safety Conference and Workshop,* DOT/FAA/OV-89-2 (Washington, DC: U.S. Department of Transportation, August 1989), p. 47. See also Federal Aviation Administration, "Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations," TSO C-69B, unpublished report Aug. 17, 1988.

23 14 CFR 121.427; 35 *Federal Register* 90 (Jan. 3, 1970).

24 Flight deck crew training requirements are contained in 14 CFR 121, Subpart N.

25 The realism of the evacuation drills is of concern; e.g., United Airlines uses darkness in its flight attendant training. William Hathaway, U.S. Department of Transportation/Research and Special Programs Administration, Volpe National Transportation Systems Center, personal communication, Jan. 15, 1993.

26 Noreene Koan, chairperson, National Air Safety Committee, Association of Flight Attendants, personal communication, Dec. 12, 1992.

27 An aircraft accident is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. *incident* means an occurrence other than an accident, associated with the operation of an aircraft, that affects or could affect the safety of operations. 49 CFR 830.2.

28 Office of Technology Assessment, op. cit., footnote 8, p. 53.

29 49 CFR 830.5.

seriously injured.[30] NTSB then assesses the accident or incident and determines probable cause. However, NTSB is not required to keep track of the nature of passenger injuries (i.e., whether the injuries occurred as a result of a collision or during evacuation from the aircrafit.[31] Because existing accident/incident databases do not support assessment of the performance of evacuation systems during actual emergency conditions, this information must be painstakingly gleaned from investigator reports.

Accident/Incident Reports

FAA's Aviation Standards National Field Office maintains a database of accidents and incidents officially reported to NTSB and reports filed by FAA field inspectors.[32] NTSB admits it does not collect all relevant data because reporting requirements omit some types of evacuations (i. e., those in which no serious injuries occurred). According to NTSB staff, a significant number of occurrences are not monitored because of a shortage of personnel, variability in reporting efforts, and an emphasis on fatal accidents.[33]

The performance of evacuation systems has not been the focus of accident investigations. Reporting has improved over the years, according to Boeing staff, as investigators have begun to pay more attention to crashworthiness as well as airworthiness issues.[34] A Boeing paper presented at FAA's 1985 technical workshop on evacuation safety cited a total of 583 known inservice incidents in which aircraft were evacuated. FAA neither maintains nor requires manufacturers to maintain records of evacuation-related injuries. According to safety interest groups, the manufacturers share this safety data among themselves, but choose not to release it to the public.[35] Because the information is proprietary, Boeing admits a reluctance to share certification documents with pilot and flight attendant groups at the time FAA views them.[36]

UNITED KINGDOM CIVIL AVIATION AUTHORITY

Among other activities, CAA supports R&D related to cabin safety and evacuation. CAA's projects in the area of aircraft and safety regulation cover operational problems and airworthiness, including passenger survivability, and human factors in general.[37]

Currently, CAA efforts include:

- determine the feasibility of developing computer models to assess seating configuration in relation to the number of exits for both new aircraft and for aircraft operating without the full complement of exits available;
- develop models for predicting the behavior of fires in different aircraft cabin configurations; and
- assess the potential of cabin water spray systems (CWSS) to extend evacuation

30 *Serious injury* is defined as any injury: 1) requiring hospitalization for more than 48 hours, commencing within 7 days of receipt of the injury; 2) resulting in fracture of any bone (except simple fractures of nose, fingers, or toes); 3) causing severe hemorrhages, nerve, muscle, or tendon damage; 4) involving any internal organ; and 5) involving any second- or third-degree bums, or bums affecting more than 5 percent of the body surface.

31 Matthew McCormick, chief, Survival Factors Division, and Stan Smith, chief, Data and Analysis Division, National Transportation Safety Board, personal communication, Dec. 17, 1991.

32 U.S. Congress, Office of Technology Assessment, *Transportation of Hazardous Materials, OTA-SET-304* (Washington, DC: U.S. Government Printing Office, July 1986), p. 71, available from OTA's Science, Education, and Transportation Program.

33 Nora Marshall, senior accident investigator, National Transportation Safety Board, personal communication, Jan. 8, 1992.

34 George Veryioglou, senior manager, 747/767 Payload Systems, Boeing Commercial Airplane Group, personal communication, Jan. 25, 1993.

35 Matthew Finucane, director, Air Safety and Health, Association of Flight Attendants, personal communication, Dec. 18, 1991.

36 Veryioglou, op. cit., footnote 34.

37 Civil Aviation Research and Development Programme Board, *Programme of Research and Development for Civil Aviation Operations and National Air Traffic Services,* Issue 23 (Cheltenham, England: Civil Aviation Authority, April 1992), p. iii.

time and save lives, and to study the feasibility of CWSS implementation on transport aircraft.[38]

The United Kingdom's Accident Investigation Board assumes many of the same responsibilities and investigation activities as NTSB.

[38] *Ibid., pp. 15-18.*