Chapter 4

FINDINGS AND CONCLUSIONS

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An aircraft's evacuation capability is one of many safety issues the Federal Aviation Administration (FAA) reviews before the aircraft is permitted to enter service. Evacuation equipment is one of a long line of measures intended to improve passenger safety in the event an emergency occurs aboard an aircraft. However, technology alone does not ensure that a passenger escapes the cabin under adverse circumstances. The abilities and actions of flight attendants and the passengers themselves factor greatly into the success of an evacuation.

BENEFITS AND LIMITATIONS OF EVACUATION DEMONSTRATIONS

- **Full-scale demonstrations are costly and expose participants to significant hazards.** The cost of conducting full-scale demonstrations can exceed $1 million each. For example, the cost for the first attempt to certificate the MD-1 1 aircraft with 410 passenger seats was approximately $1.3 million.[1] On average, approximately 6 percent of participants are injured during full-scale tests. Participant injuries were the basis for the 1978 rule change allowing analysis and partial/component tests to replace full-scale demonstrations when conditions warranted. While most injuries have been minor, broken bones and paralysis have occurred. Less severe injuries than expected for traditional demonstration formats occurred in the FAA-approved December 1992 MD-11 certification test in which slides were replaced with ramps and the exterior of the aircraft was lighted.
- **A full-scale demonstration simulates evacuation for only a narrow, optimistic range of emergency conditions.** The certification requirements represent an aborted takeoff at night (i.e., no structural damage, cabin fire, or smoke) with a distinct subset of potential passengers (i.e., no children, persons with disabilities, or non-English speaking passengers).

There are major weaknesses with using FAA full-scale demonstrations as measures of evacuation performance: 1) only one data point is provided for a measurement that could have a broad probability distribution; 2) the selection criteria for test "passengers" do not reflect actual passenger demographics; and 3) tests do not encompass many of the conditions in actual accidents.

- **Successful evacuation in an actual emergency depends on more than the flow rates demonstrated for certification.** Factors in the outcome of a real emergency evacuation include: cabin and flight crew capabilities; aircraft integrity and seating technologies; passenger and baggage characteristics; and actual accident conditions, such as fire and smoke.

Adding "realism" (e.g., smoke and fire) to full-scale demonstrations as they are currently configured increases the risk of injury to test participants without guaranteeing reduced risk of injury to the flying public. The variability of actual accident conditions cannot be represented with only a few approximations of emergency settings.

The Performance Standards Working Group of FAA's Aviation Rulemaking Advisory Committee, charged with developing revised emergency evacuation requirements and compliance methods for reducing the risk of injury to full-scale demonstration participants, was not able to reach consensus on its proposal to modify the certification test to rely more heavily on analysis. Recommendations and a final report were submitted in January 1993. The working group has since begun to consider whether design standards for emergency evacuation can and should be converted to performance standards.

1 Webster C. Heath, manager, Technical Liaison, Industry Regulatory Affairs, Douglas Aircraft Co., personal communication, July 8, 1992.

- **FAA acknowledges that demonstrations provide only a benchmark for consistent evaluation of various seating and exit configurations; the** requirement to demonstrate complete evacuation within 90 seconds is not an adequate performance standard for measuring evacuation capabilities.[2] Nor is the one-time demonstration useful for system optimization; it provides manufacturers a single opportunity to observe flaws and take corrective actions. After a second attempt to attain certification, one cannot be confident that differences in test results are statistically significant.

Because compliance with some of the test conditions is subjectively determined, variability in the test conditions can occur. During the October 1991 certification test for the MD-11 aircraft, the simulated "dark of night" and crew mix requirements were thought to be more rigorous than for prior tests.

- **Present evacuation certification rules do not encourage development of new technology for extending the period of survivability in postcrash fires.** FAA has emphasized the development of technologies that can speed evacuation rates and reduce total evacuation time (e.g., faster deploying slides, floor-level path lighting). But FAA rules give no credit for technologies that, in real life, could extend the period of survivability within the cabin.

MODELS AND SIMULATIONS FOR EVACUATION CERTIFICATION

- At present, neither certification by fill-scale demonstration nor by purely analytical methods is acceptable to all segments of the aviation community. Manufacturers feel existing data from prior evacuation certification tests have validated their mathematical models such that full-scale demonstrations can often be replaced by combinations of component/system tests and analysis, but statistical analysis of data and model sensitivity have not been explored. Passenger, flight attendant, and pilot groups have expressed concern with reliance on analysis to demonstrate compliance with evacuation standards.

- **The aircraft certification process will likely continue to rely on human test subjects in the foreseeable future.** However, a combination of analysis and partial demonstrations or component tests can be developed to minimize the risk of injury and provide more comprehensive data on aircraft performance than fill-scale demonstrations.

- **Human behavior in certification tests may be empirically modeled using data from prior demonstrations, but cannot yet be reliably "simulated."** Estimates for average reaction times and egress rates are known for evacuation during controlled conditions. Because few reliable data exist on human behavior during accidents, the variations in human judgment and decisionmaking that might be expected for changing hazardous conditions cannot be predicted. These data cannot be obtained from current demonstration requirements, which do not address motivational effects or other behavioral factors that often exist in a real emergency. Manufacturers' mathematical models are insensitive to age, sex, and other characteristics of demonstration participants.

Evacuation models developed for buildings include some human behavioral factors but are not fully transferable to aircraft. For example, there are many configurational differences. The psychological data used in these models are limited to that obtained in interviews of building fire survivors.

Computer simulations, creating repeated and varied evacuation trials, may be more valid as measures of an aircraft's evacuation performance than a single full-scale demonstration would be. At the very least, the simulations can suggest a range of outcomes for given test conditions. Recent computer simulation efforts may provide the technology base for an improved simulation capability. The additional psychological data

2 54 *Federal Register* 26692 (June 23, 1989).

required for validating behavioral assumptions will be difficult to attain.

- **Evacuation rates for existing aircraft components are predictable.** The results of industry analyses typically correlate well with observed rates through doors, aisles, slides, and other components under consistent test conditions. What is not known or predictable is the performance of the emergency evacuation system in an actual emergency (i.e., how many doors/slides will be inoperable or blocked by fire/smoke, how quickly will smoke or flames enter the cabin if a postcrash fire occurs, what interactions will take place between passengers to speed or slow the evacuation?). OTA notes that evacuation trials with human test subjects measure none of these events. Factors that greatly affect the outcome of a real emergency evacuation include: cabin and flight crew capabilities; the integrity of the aircraft and cabin furnishings; passenger and baggage characteristics; and hazardous conditions.

DATA ISSUES

- Additional experimental data are required to validate models/simulations. Earlier industry simulation efforts stalled due to the lack of human factors data. The data collection phase of a current simulation development project has been delayed for lack of funding. Although FAA's present test fuselage is adequate for studying issues related to single-aisle, narrow-body airliners, there is no facility, worldwide, that can be used to analyze egress from double-aisle, wide-body transports.

- Data on injuries related to evacuation testing are not readily available, nor are they classified by severity. Neither FAA nor the National Transportation Safety Board (NTSB) collect information on precautionary[3] evacuations. Data from actual emergency evacuations are unevenly collected and analyzed. With current database structures, evacuation performance data must be painstakingly gleaned from accident reports.

- Recommended changes to FAA fire safety test objectives in the 1980s helped FAA to develop improved test procedures and obtain more comprehensive data for rulemaking. The National Institute of Standards and Technology and the United Kingdom's Civil Aviation Authority are two excellent sources for complementary evacuation and fire data.

AIRCRAFT EVACUATION PERFORMANCE AND SAFETY

- **Survivability in commercial air transports is improving,** largely through the introduction of technologies that mitigate impact forces and delay incapacitation from smoke, heat, and toxic gases.[4] Though still a significant threat, fire has become less of a risk in survivable accidents. In the early 1980s, FAA attributed 40 percent of fatalities in survivable accidents to fire effects. A review of U.S. airline accidents that occurred between 1985 and 1991 showed that approximately 10 percent of fatalities were related to fire. Two central elements of evacuation systems are heat-resistant slides that inflate and deploy automatically and floor-level path lighting.

- **Crew training and passenger actions are as crucial to successful evacuations as are the aircraft's design and equipment.** According to NTSB, as the crashworthiness of aircraft improves, flight attendants assume a more critical role in ensuring passenger safety. Flight attendant training, done in cabin mockups without passengers, may not provide crew members with sufficient skills for motivating passengers to evacuate more efficiently and assessing flow control problems. Because simulation could rapidly show the potential results of different commands and crew actions on the outcomes of emergency evacuations, simulation technologies could

3 Evacuations in cases where the threat of fire or harm later disappeared.

4 By delaying the onset of smoke, the presence of fire retardant materials augments passenger vision as well as improves the potential for survival.

enhance training in passenger management and use of emergency equipment.

- There is wide variation in the mobility, strength, and perceptive capabilities of aircraft passengers. Under existing aviation regulations, airline operators restrict seating in exit rows to those persons willing and able to read, hear, and understand emergency instructions and to operate evacuation equipment.[5]
- Another factor is the presence and type of carry-on baggage. Some increase in cabin safety could be expected from further restrictions on carry-on baggage, which in an accident can impede passenger movement from seat to aisle and aisle to exit. In addition, passengers often stop to retrieve carry-on items, which flight attendants must remove before the passengers use the slides.
- **Technology efforts to suppress or mitigate thermo-toxic conditions will likely aid passenger survivability more than efforts to further speed evacuations.** Changing demographics suggest passenger evacuation rates will be, on average, slower in the future. To achieve significant reductions in evacuation times from typical seating configurations would require more doors (which add weight and reduce seating capacity, resulting in revenue losses) or fewer passengers (more lost revenue). Speeding evacuation through small changes in technology would be difficult. British analysis of fire deaths in international accidents during the 1980s indicated that new technologies intended to delay deadly heat and toxicity levels after a crash are likely to save many more lives than would efforts to further speed evacuation.[6]

5 *55 Federal Register 8072* (Mar. 6, 1990).

6 Ronald Ashford, "Air Safety Regulation and Its Commercial Impact," *Aeronautical Journal, vol. 95, No. 943*, March 1991, p. 85.