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Exit-locating Devices, Aircraft Structural Strengthening and Improved Crew Drills Called "Most Practicable" Accident-survivability Factors

An analysis of survivable accidents found that whether an accident involved fire or ditching was a major determinant of the fatality rate.

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Aviation Writer

Installing improved devices to help passengers find emergency exits, strengthening aircraft seats and floors and improving emergency and evacuation crew drills appear to be the most practicable solutions for making aircraft accidents more survivable, a British study report suggests.

The study, by the firm R.G.W. Cherry & Associates, was designed to assess the most important factors that determine how many aircraft occupants will live through survivable accidents, and to determine the most practicable improvements for making accidents more survivable. The study report, *Analysis of Factors Influencing the Survivability of Passengers in Aircraft Accidents*, also suggested three factors that might improve survivability in future aircraft designs but require further assessment: installing cabin water-spray systems, improving occupant-restraint devices and heightening crew awareness of threats.

The researchers generated a survivable-accidents database and developed software that allowed analysis of specific groups of accidents and mathematical and statistical modeling of survivability factors.

The analysis further indicated that:

- Accidents involving fire, asphyxiation or drowning had different fatality-rate characteristics than other types of accidents (such as impact accidents) in which time was not a survivability factor;

- In 39 accidents analyzed in depth, about one-third of the fatalities were "considered unavoidable, given the particular accident circumstance" (Figure 1, page 2);

- The five-year moving-average fatality rate for all accidents in the database showed a reduction in the fatality rate in the mid-1980s, followed by an increase in the rate at that decade's end. Among the survivable accidents in the database, the average fatality rate varied between 30 percent and 40 percent during the 1983–1993 decade; and,

- The fatality rate was significantly lower for accidents that did not involve fire or ditching (emergency landing in water), with no significant variation during 20 years. With those exceptions, the researchers found no "significant variation of fatality rate" that could be attributed to accident circumstance, aircraft size or aircraft configuration.

The researchers defined a survivable accident as "an accident in which at least one occupant survived or there was potential for occupant survival." The study's computer database used the U.K. Civil Aviation Authority (CAA) *World Airline Accident Summary* as a primary data source. The analysis included a wealth of details about 548 survivable accidents, including 344 fatal accidents, during the period 1973–1993.

After the database was generated, the researchers statistically analyzed the circumstances and characteristics of each accident flight, including parameters such as phase of flight, weather and proximity to the airport. Accident details included information about fire, extent of aircraft damage, occupant injury, fatality rate, exits and evacuation and the status of fuel tanks, cabin, landing gear and slide deployment.

One key measure, the fatality rate, was defined as the number of fatalities divided by the total number of aircraft occupants. The researchers included both crew and passengers as aircraft occupants. Fatalities on the ground who were killed as a result of the accident were not included in the fatality-rate data.

Based on their findings, the researchers suggested that "the fatality rate is not random." Graphing the fatality rates of the 344 fatal accidents in the database, the researchers found a "tri-modal distribution, with relatively high frequencies of occurrence at low, mid-range and high fatality rates" (i.e., the three "peaks" in Figure 2, page 3).

The researchers also derived fatality-rate distributions from the database for survivable accidents that involved specific circumstances. Those included fire; ditching or overrun; and fuel-tank or fuselage rupture. In addition, they analyzed fatality rates for aircraft of different sizes and seating configurations (single- and double-aisle).

Nearly all of the different accident circumstances resulted in a tri-modal distribution pattern similar to that of the whole database. But the researchers noticed that when fatalities in accidents that involved neither fire nor ditching were analyzed, the fatality-rate pattern was different, with no fatality rates recorded in the middle range (between 34 percent and 87 percent). The tentative conclusion was: "Accidents [that] do not involve fire or ditching tend to result in fatality rates at the extremes of the range."

The researchers categorized the cause of death in aircraft-accident fatalities as impact trauma, mechanical asphyxiation [asphyxiation caused by inability to move the diaphragm, which can result from being trapped in wreckage in a restricted space], fire, drowning, asphyxiation or "other" (including cardiac arrest and "loss in flight" [ejection of an occupant following rupture of the pressurized cabin]). Most deaths in the nonfire and nonditching categories of accidents were related directly to impact trauma.

In the categories of impact trauma, mechanical asphyxiation and "other" causes of death, time was not a key factor in survival. In contrast, time could have been a major factor in survival that included threats from fire or water, because some aircraft occupants could have escaped fatal injuries if they had had more time. Based on that analysis, the researchers suggested: "Where survival [was] influenced by the time available to escape the threat, then the number of fatalities [tended] to be toward the middle of the fatality-rate band" (the middle "peak" in Figure 2).

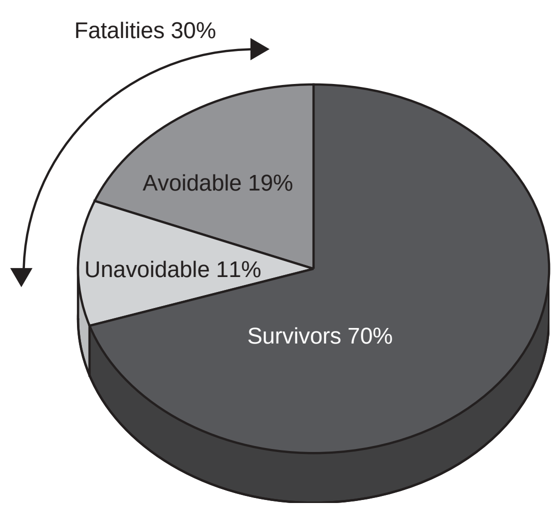
When the researchers analyzed five-year moving-average fatality rates during the 1980s, they found "a relatively low-level fatality rate during the early [and] mid-1980s, which increases toward the end of the decade." Because the analysis included a large number of accidents, the researchers believed that the change was not a random fluctuation.

One possible explanation was that the change might reflect variations in the reporting of fatal accidents during that period. To check that hypothesis, the researchers separately analyzed aircraft accidents during the 1980s in the United States and the United Kingdom, where accidents were most likely to be reported to the database. But they found the same slow rise in fatality rates toward the end of the 1980s.

One factor that the researchers did not investigate, but that could have influenced fatality-rate changes during the 1980s, was the size of passenger loads.

The researchers carried out an in-depth analysis of 39 fatal survivable accidents that were chosen as a "representative sample" of survivable accidents in the database. The fatality rate for those 39 accidents showed a tri-modal distribution similar to that of the entire database, and the average fatality rate for the sample (30 percent) was just slightly less than

Percentage of Fatalities In 39 Survivable Accidents



Source: R.G.W. Cherry & Associates

Figure 1

the fatality rate of the database during the 1983–1993 decade, which varied between 30 percent and 40 percent.

The proportion of accidents by type in the sample roughly approximated the proportion of accidents by type in the entire database. Of the 39 accidents in the sample, 46 percent were fire-related (compared with 42 percent of the entire database); 36 percent were related solely to impact (compared with 46 percent overall); and 18 percent were ditching-related (compared with 12 percent overall).

In the 39 accidents that were studied in depth, 1,055 of the total 3,564 aircraft occupants were fatally injured. The researchers found that "for approximately one-third of the fatalities no survivability-factor improvements were identified [that] would have prevented their deaths." The report said that "those unavoidable fatalities are considered important in the analysis, since they represent the 'floor' at which no improvements to survivability factors may be made that would reduce the number of fatalities."

For the 39 accidents, the researchers identified factors that might influence survivability (Table 1, page 4). Those accidents were analyzed to assess the potential effects of improvements to survivability factors (such as emergency and evacuation crew drills) on the overall chances of survival in an accident.

Because survival conditions tend to vary in different parts of the aircraft, the researchers divided each accident into "scenarios." A scenario was defined as "that area of the aircraft in which the occupants have a similar risk of sustaining fatal or nonfatal injuries."

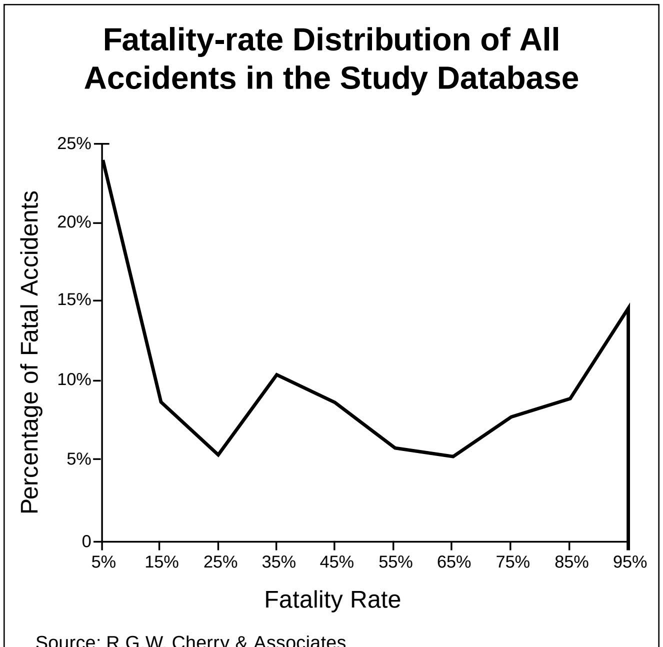


Figure 2

The mathematical model used for the analysis included the concept of a "survivability chain," which was based on the premise that the aircraft occupants could be subjected to a series of independent threats (such as impact, fire and drowning). The chain was used to assess the likely number of fatalities for each scenario when subjected to the separate threats, such as impact and asphyxiation, experienced in the accident.

"In most cases, the [survivability] factors would have a positive effect in reducing the number of fatalities," the report said, "but in some instances, improvements to increase survivability for a particular accident circumstance might have an adverse effect on another." For example, in a scenario where occupants had an opportunity to survive by evacuating the aircraft, additional flight attendants might enhance the evacuation efficiency and so reduce the number of fatalities. But in a nonsurvivable scenario, the additional flight attendants would be killed, and the number of fatalities would be greater than it would have been without the survivability-factor "improvement."

Statistical and mathematical models were used to determine a median reduction in the number of fatalities that would be achieved by improvements in each survivability factor.

Because those assessments were based on aircraft standards at the time of each accident, the researchers also reanalyzed each accident to consider the (usually improved) fatality rates if the aircraft had been configured under the latest standards. Although the mathematical models could not perfectly represent the accidents, the researchers believed that the models "[provided] a better assessment of the likely effect of improvements to survivability factors than would otherwise be derived from a simple estimate of the resultant change in the number of survivors."

One way to assess the accuracy of the analysis was to compare its results with those of previous research into two survivability factors: smoke hoods and cabin water-spray systems. In both, the prior independent estimates correlated well with the fatality-rate predictions in the study:

Smoke hoods. Research by the U.S. Federal Aviation Administration (FAA)[1] and the U.K. CAA[2] indicated that the use of smoke hoods would result in a fatality-rate reduction of 1.1 percent if every aircraft occupant used the hoods without delay, and a reduction of 0.7 percent if it was assumed that some passengers would not use the hoods. Those FAA and CAA estimates were based on studies of 20 fire-related accidents involving 3,058 persons. In all, they predicted that 100 percent usage of smoke hoods would have saved about 80 lives in those accidents.

Those results correlated well with the Cherry & Associates researchers' predictions, the report said. The Cherry & Associates analysis ranked smoke hoods in the category of factors that seemed "unlikely to be practicable." Nevertheless,

Table 1
Survivability Factors Analyzed for Accident-fatality Rate Reduction Practicability

Code	Survivability Factors
U	Rearward-facing Seats
F	Occupant Restraint
P	Seat/Floor Strength
U	Infant Seats
U	Strength of Overhead Stowage
U	Structural Strength of Cabins (Ditching/Impact Resistance)
U	Adequacy of Flotation Equipment
U	Exit Operability
U	Flight Attendant External Visibility*
U	Number of Flight Attendants
U	Adequacy of Airfield Emergency Services
U	Exit-route Accessibility (Floor-level Exits)
U	Toxicity of Materials
U	Flammability of Materials
U	Head-strike Adequacy**
P	Passenger Awareness of Exit Routes
P	Emergency and Evacuation Crew Drills
U	Slide Operability (including Slide/Raft)
F	Crew Awareness of Threat
U	Flight Crew–Cabin Crew Communication
U	Cabin Crew–Passenger Communication
U	Burn-through of Cabin
U	Smoke Drills
U	Number of Exits
U	Ease of Access to Flotation Equipment
U	Smoke Hoods
F	Cabin Water-spray Systems
U	Exit-route Accessibility (Non-floor-level Exits)
U	Floor Exit-route Lighting
U	Toilet Smoke Detectors
U	Systems (Oxygen, Hydraulics, etc.) Crashworthiness

P = Preferred Solution
F = Requires Further Assessment
U = Unlikely to Be Practicable

* = Flight attendants' abilities to view external hazards from inside the aircraft, giving them more information on which to base judgments such as whether using a particular exit would constitute a fire hazard in an emergency evacuation

** = The potential for injury caused by occupants' heads striking seats or bulkheads during impact

Source: R.G.W. Cherry & Associates

in the light of further research, reassessment may be warranted, the report said.

Cabin water-spray systems. The U.K. CAA analysis of 95 fire-related accidents involving 9,723 aircraft occupants suggested that the use of cabin water-spray systems might have saved 3,705 lives.[3] When considering all accidents (both fire-related and other accidents), the reduction in fatality rates from the cabin water-spray systems was found to be 1.6 percent. "This assessment [correlated] well with the fatality-rate improvements predicted for cabin [water-spray systems] based on the work" done by the Cherry & Associates researchers, the report said.

After estimating the likely change in fatality rates from improvements in each survivability factor, the researchers compared that change to the difficulty of implementing the improvements. A group of engineers experienced in the design, certification and operation of civil aircraft assessed the difficulty and cost of researching and developing solutions, the cost of implementation and the effect on aircraft operating costs. This assessment was completed for in-service aircraft and for future designs. The result was a ranking of factors that would be the most effective in reducing aircraft-accident fatalities.

With those rankings and their mathematical analyses, the researchers divided the survivability factors into three categories:

Preferred solutions. The factors judged to have the best chance of improving survivability (coded P in Table 1) were increasing passenger awareness of exit locations; increasing the strength of aircraft seats and floors; and improving emergency and evacuation crew drills. The analysis of each of those factors showed that "the improvement in fatality rate is likely to be favorable, compared to the difficulty in developing and implementing solutions," the report said.

Factors requiring further assessment. The factors that the researchers deemed to require further assessment (coded F in Table 1) were: increasing crew awareness of threat; improving occupant-restraint systems (seat belts, air bags, shoulder harnesses, etc.); and installing cabin water-spray systems. Those factors fell in the middle category, "where further detailed analysis would be required to determine whether improvements to this survivability factor warrant prioritization for research and development activities," the report said.

Factors unlikely to be practicable. The remaining factors analyzed by the researchers — which included smoke hoods, infant seats and flotation devices — were classified as "solutions unlikely to be practicable" (coded U in Table 1). Analysis of those factors showed that they were in the lowest category, in which "the improvement in fatality rate is not likely to be favorable compared to the difficulty in developing and implementing solutions," the report said.

Some of the factors in this category were absent in many of the accidents in the database, and likely would have reduced the fatality rate in those accidents, but have since been instituted in newer aircraft designs. Because further improvements in those factors would probably have less significance for fatality-rate improvement than other possible changes, they were included among those “unlikely to be practicable.”

The researchers explained their assessment of the three factors that they found to be most practicable for improving aircraft-accident survivability:

Passenger awareness of exit routes. The report said that this factor is worthy of future research because “its life-saving potential is likely to be favorable compared to the difficulty in developing and implementing solutions for both in-service aircraft and new designs.”

Although the introduction of escape-path markings represents an improvement, the report suggested that the markings “may not be readily visible to passengers in certain accident scenarios, and they do not necessarily lead the passenger to an available exit. The use of [audible] devices at the exits activated on door opening could [solve] both of those problems.”

The report suggested that although more study is needed before specific recommendations can be made, specialists should consider fitting such audible devices on emergency exits so that the audible device is activated when an exit is opened. “The method of operation on exits having the same method of opening in normal and emergency modes requires further consideration,” the report said, because “automatic operation of such a device may be difficult to achieve, and if such devices were fitted they [would be] likely to require manual initiation.”

Aircraft seat and floor strength. Although stricter standards for the strength of aircraft seats and floors already have been introduced, the report suggested that further strengthening of seats and floors would be “likely to result in worthwhile improvements in survivability when applied to future aircraft designs.” The researchers’ model did not include nonfatal injuries and the possible effect of stronger seats/floors on reducing the number of fatalities among passengers whose injuries prevent escape from fire or drowning. For that reason, the researchers said, “the reduction in fatalities resulting from improvements in this survivability factor are likely to be greater than suggested” in the report. “[Determining] the practicability of making these improvements on in-service aircraft would require a further study; however, for new aircraft the cost/benefit analysis is likely to result in a positive conclusion for this survivability factor,” the report said.

Emergency and evacuation crew drills. One advantage of improving emergency and evacuation crew drills is that the drills can be implemented the same way in new and in-service aircraft. The report suggested that “an evaluation of flight and cabin-crew procedures would yield beneficial improvements in survivability. Such an evaluation would [include] the lessons to be [learned] from previous accidents to provide improved drills on all transport-category airplanes. Improvements in this survivability factor are only likely to be fully effective if changes to emergency and evacuation drills are complemented by enhanced crew-training procedures.”

Three other survivability factors require further analysis before they can be determined to be practicable, the researchers said:

Crew awareness of threat. Installing video cameras that would enable flight crews to monitor the aircraft and areas around it to detect hazards has been suggested. [Although not cited in the report, one accident in which video cameras might have improved survivability was the Aug. 22, 1985, British Airtours Boeing 737 accident at Manchester, England, following an uncontained engine failure during the takeoff roll. The failure punctured a wing fuel-tank access panel, and leaking fuel ignited. The flight crew could not see the fire, and, unaware of its severity, rejected the takeoff but failed to order an immediate evacuation. Wind directed the fire onto the fuselage, and 55 people died when the fuselage was engulfed in fire and smoke.]

According to the researchers, “further research would be required before any firm conclusions could be reached. However, changes of this kind are considered more suited to new designs [than to] in-service aircraft.”

Occupant restraint. The researchers said that “it is feasible that improvements in this survivability factor may show a positive result from the cost-benefit analysis for future aircraft designs.” As in the analysis of the seat- and floor-strength factor, the researchers’ model for the occupant-restraint factor did not include the possibility of further reductions in fatalities if some passengers escaped death by fire or drowning because they had better restraints and, thus, were uninjured. “No attempt has been made to be definitive about the methods that may be used to improve occupant restraint,” the report said, because “it is considered that research in this subject should not be confined to any particular area, but all means [should be] evaluated for their [effectiveness].”

Cabin water-spray systems. The researchers said that adding cabin water-spray systems is “unlikely to be practicable on in-service aircraft.” But the analysis indicated that “ worthwhile benefits might be achieved on future designs.”

The researchers suggested three ways to make their predictions more accurate:

- Expand the database to include more accidents;
- Improve mathematical models by including “passenger immobility [caused by] sustaining injuries as a result of impact”; and,

- Make a more detailed assessment "of the difficulty of developing and implementing the solutions" that would increase survivability.

Nevertheless, the report said, the database analysis appeared "to give a reasonable indication of the survivability factors that are most likely to yield cost-beneficial results" in improving cabin safety. ♦

Editorial note: This article was adapted from *Analysis of Factors Influencing the Survivability of Passengers in Aircraft Accidents*, a report by R.G.W. Cherry & Associates Ltd., Tooke House, Bull Plain, Hertfordshire, England, that was commissioned by the European Communities Commission and was published in the proceedings of the International Conference on Cabin Safety Research, held Nov. 14–16, 1995, in Atlantic City, New Jersey, U.S. The 30-page report, dated March 1996, includes 11 figures.

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