FLIGHT SAFETY FOUNDATION

APRIL 2000

FLIGHT SAFETY
D I G E S T

Passenger-mortality Risk Estimates Provide Perspectives About Airline Safety

FLIGHT SAFETY FOUNDATION 1947–2000

Flight Safety Digest

Vol. 19 No. 4 **April 2000**

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Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of aviation safety. Nonprofit and independent, the Foundation was launched officially in 1947 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 830 member organizations in more than 150 countries.

Passenger-mortality Risk Estimates Provide Perspectives About Airline Safety

Aviation accidents generate widespread news coverage, often citing statistics of various kinds that measure air carrier safety and estimate passenger-mortality risk. Another measure, discussed here, shows that a passenger who randomly flew on a U.S. domestic jet every day would go approximately 19,000 years before dying in a fatal accident. Nevertheless, the measure shows a higher mortality risk in some regions of the world for all air carriers that fly there.

Arnold Barnett and Alexander Wang

News media's extensive coverage of air carrier aircraft accidents shows that people give enormous attention to the safety of air transportation. In a 1996 Associated Press survey, U.S. newspaper editors and television news directors said that the Trans World Airlines Flight 800 accident[1] was the "biggest" news story of 1996 and that the ValuJet Flight 592 accident[2] was the fifth biggest story that year.

A 1990 study of page-one newspaper articles regarding fatalities in the United States said that coverage of air carrier accidents in *The New York Times* was 60 times greater than its coverage of AIDS (acquired immune deficiency syndrome), 1,500 times greater than coverage of automobile–related hazards and 6,000 times greater than coverage of cancer.[3]

There is evidence that perceptions among people in the United States about the risks of aviation substantially affect their flying behavior. For example, in the two weeks after the United Airlines Flight 232 accident at Sioux City, Iowa,[4] ticket sales for flights on McDonnell Douglas DC-10 aircraft decreased by 36 percent.[5]

Against these public perceptions, data analysis provides perspective about aviation safety. This article presents the results of a study of data from 1987 through 1996 from around the world (except from the former Soviet Union, where complete data were not available). The study focused on the probability of passenger fatality during flight and built upon two studies of data from earlier periods.[6,7]

Airline Safety Measurements Vary

Traditional methods of measuring air carrier safety and estimating passenger-mortality risk are problematic. Consider, for example, a statement that appeared in *The Wall Street Journal* in 1997:

> [U.S. National Transportation Safety Board] studies show that, from 1993 to 1996, scheduled U.S. carriers averaged only 0.2 fatal accidents per 100,000 flying hours, less than half the fatal accident rate for the four-year period a decade earlier.[8]

The numerator and the denominator in "fatal accidents per 100,000 flying hours" are of questionable value. The term "fatal accidents" includes *all* accidents that cause at least one death and, thus, does not distinguish between an accident that kills one passenger among 300 and an accident that kills everyone aboard. The term gives no credit to safety improvements (fire-retardant materials, for example) that reduce fatalities but do not prevent them.

Safety statistics based on total "flying hours" are questionable because most accidents occur during the takeoff and approach-and-landing phases of flight.[9,10] If the average trip time changes from one period to another, the results of a safety measurement based on flight duration could change for reasons having nothing to do with safety.

Another method of measuring mortality risk was used in 1997 by the Air Travelers Association, based in Washington, D.C., U.S. The association issued safety "report cards" for air carriers around the world. The report cards were based on numerical safety scores calculated for each carrier in 1987–1996 using the following equation (in which S is the safety "score," Z is the number of accidents with passenger fatalities and N is the number of aircraft departures in thousands):

$$S = 100 - \frac{(10{,}000)Z}{N}$$

The safety scores then were converted into letter grades: 90–100 was an A; 80–90 was a B; 70–80 was a C; 60–70 was a D; and any score below 60 was an F. The result, for example, was that a carrier with one fatal accident (or less than one fatal accident) per 1 million departures received a grade of A, and a carrier with more than one fatal accident per 250,000 departures received a grade of F.

Although this method of measuring mortality risk is not based on flight duration and weights all flights equally, it treats all fatal accidents the same, regardless of the *proportion* of passengers killed.

The assigned letter grades are judgments about the meaning of the measurements. Furthermore, the letter grades are unstable, especially for smaller carriers. For example, consider two small air carriers, each of which had 200,000 departures and carried 20 million passengers during the period. One carrier had no fatal accidents; therefore, the S-score is 100, and the carrier receives an A. The other carrier had one fatal accident, in which one passenger was killed; the S-score is 50, and the carrier receives an F. Thus, small differences in actual records can translate into huge differences in letter grades.

Another measure of passenger-mortality risk is "deaths per enplanement" — the ratio of passengers killed to passengers carried. The use of raw numbers of deaths as the numerator is questionable. The report on a 1989 study[7] said:

> When [an aircraft] hits a mountain, killing all passengers, the implications about safety are not three times as grave if there were 150 [passengers] on board rather than 50. And a crash that kills 18 passengers out of 18 should be distinguished from another that kills 18 out of 104. (In the latter case, the high survival rate might reflect excellence in the airline's emergency procedures.) Statistics that weight crashes solely by their numbers of deaths, in other words, are vulnerable to irrelevant fluctuations in the fraction of seats occupied, yet insensitive to salient variations in the fraction of travelers saved.

Q-statistic Shows Mortality Risk per Randomly Chosen Flight

Another method of measuring air carrier safety and estimating passenger-mortality risk is based on the following question: If a passenger chooses a (nonstop) flight completely at random, what is the probability that he or she will be killed during the flight?[11] The probability is called the "Q-statistic."

The Q-statistic is the passenger-mortality risk per randomly chosen flight. To find Q, the probability of selecting a flight that results in passenger fatalities is multiplied by the average proportion of passengers who are killed aboard such flights.[12] The equation is:

$$Q = \frac{V}{N}$$

N is the number of flights conducted during the period. V is the total number of "full-loss equivalents" among the N flights, where the full-loss equivalent for a given flight is the proportion of passengers who do not survive the flight. (For example, if the flight is completed safely, the full-loss equivalent is zero; if the flight results in an accident in which all the passengers are killed, the full-loss equivalent is one; if the flight results in an accident in which 20 percent of the passengers are killed, the full-loss equivalent is 0.2. V is the sum of all full-loss equivalents calculated for all N flights.)

Weighting individual accidents by the proportion of passengers killed in the accidents (as the Q-statistic does) seems more informative than using the number of passengers killed (without reference to how many were on board) and far more informative than reducing the study of flight outcomes to a yes/no answer to the question: "Did any passengers perish?" Furthermore, the Q-statistic ignores the length and the duration of individual flights, is calculated simply and is understood easily.

The Q-statistic, however, cannot circumvent that, given the infrequency of fatal air carrier accidents, the data about the accidents are affected by the statistical volatility that accompanies all rare events. (Statistical volatility means that small changes in data can cause relatively large changes in results. For example, just one accident with no survivors can triple a calculated Q-statistic.)

Choice of Data Requires Deliberation

Some safety assessments of individual air carriers have been based on *all* accidents and incidents that occurred during the study period, rather than just the accidents that resulted in passenger fatalities.

A May 1996 report[13] by the U.S. Federal Aviation Administration (FAA), for example, compared various accident/incident statistics for individual "major" air carriers in the United States.[14] The report made no reference to which of the accidents studied had resulted in fatalities.

The rationale for this type of analysis is that chance is a factor in whether an event becomes a fatal accident. Choosing a data sample that includes nonfatal events also increases "sample sizes" and, thereby, diminishes statistical volatility.

While the idea of analyzing all accidents and incidents, and not just fatal accidents, has some appeal, there are drawbacks. For example, reliable data on incidents and nonfatal accidents are not available in many countries. Moreover, it is an oversimplification to say that chance determines whether an event becomes a fatal accident.

Data analysis does not support the idea that the greater an air carrier's involvement in incidents and nonfatal accidents, the greater its propensity to experience fatal accidents. Between the early 1970s and the mid-1980s, reported incidents and accidents per 100,000 flights doubled for major U.S. domestic air carriers; passenger-mortality risk, however, did not double, but rather decreased by a factor of three.[7]

Data from January 1990 through March 1996 — the same period used in the 1996 FAA report — show the problems of using carrier-specific data on incidents and nonfatal accidents as a proxy for mortality risk.

Table 1
Correlation of Major U.S. Jet Air Carrier[1] Nonfatal Accident/Incident Rates and Passenger-mortality Risk, Jan. 1, 1990–March 31, 1996

Type of Nonfatal Event	Correlation[2]
Incidents Only	–0.10
Incidents and Accidents[3]	–0.21
Accidents Only	–0.29
Serious Accidents Only[4]	–0.34

[1] The U.S. Federal Aviation Administration defines "major air carrier" as an air carrier certified under U.S. Federal Aviation Regulations Part 121 or Part 127 and with annual operating revenues greater than US$1 billion.

[2] Values shown are the coefficients of correlation between the accident/incident rate per 100,000 departures and the mortality risk per randomly chosen nonstop flight (i.e., the Q-statistic).

[3] The U.S. National Transportation Safety Board (NTSB) in 1996 defined "accident" as "an event involving serious injury, loss of life or substantial aircraft damage."

[4] NTSB in 1996 said that accidents in the "serious accident" category "exclude turbulence[-related accidents and] other minor accidents in flight, and gate or ramp accidents."

Sources: Arnold Barnett and Alexander Wang

Table 1 shows correlations of nonfatal accidents/incidents per 100,000 departures for individual major carriers with their passenger-mortality risks, as measured by Q-statistics.

All the correlation coefficients shown in Table 1 are negative, which means that carriers with higher rates of nonfatal accidents/incidents had lower mortality risks. Furthermore, the correlations shown become increasingly negative as the events become more severe — from –0.10 for incidents only to –0.34 for serious accidents only.[15]

Data about all incidents and accidents — whether or not they resulted in fatalities — are important to aviation safety professionals, who must learn whatever they can from every such event to prevent similar events from occurring. Data about nonfatal events, however, are not helpful in measuring current safety performance, because there is no positive correlation between such statistics and passenger-mortality risk.

Thus, this article uses the Q-statistic and fatal accidents in calculating passenger-mortality risks.

U.S. Trunkline Mortality Risk Was 1 in 6.5 Million

U.S. domestic trunklines are air carriers that had national route systems in place when the Airline Deregulation Act of 1978 was implemented in the United States.[16] Sixteen domestic trunklines existed in 1979; mergers, bankruptcies and closures reduced the number to seven by 1996. That year, the trunklines were American Airlines, Continental Airlines, Delta Air Lines, Northwest Airlines, Trans World Airlines (TWA), United Airlines and USAir (now USAirways).

The trunklines in 1987–1996 collectively conducted 44.7 million flights. ("Flight" hereafter will mean nonstop flight or departure.) Passenger fatalities occurred in 15 accidents. The proportions of passengers killed in the accidents ranged from 1 percent to 100 percent. The total number of full-loss equivalents (V) the trunklines experienced was 6.63 (Table 2, page 4). Their overall Q-statistic was 6.63/44.7 million, or 1 in 6.5 million (all Q-statistics shown are rounded to the nearest half million for numbers greater than 1 million or to the nearest 100,000 for numbers less than 1 million).

This Q-statistic means that a passenger who selected one trunkline flight every day would go, on average, approximately 18,000 years before dying in a fatal accident. This statistic shows not only that the mortality risk is infinitesimal on individual flights, but also that even frequent fliers face negligible cumulative risk.

Table 2 (page 4) shows that passenger-mortality risks for flights during the period differed among the individual trunklines. Two carriers (American and TWA) had Q-statistics of zero. Continental's Q-statistic was 0.32/4.5 million or 1 in 14 million. Delta's Q-statistic was 0.16/8.5 million or 1 in 53 million. Northwest's Q-statistic was 1.21/4.9 million or 1 in 4 million.

Table 2
Mortality Risk for U.S. Domestic Trunklines,[1] 1987–1996

Airline	Number of Full-loss Equivalents[2]	Number of Flights (millions)	Mortality Risk per Flight[3]
American	0	7.2	0
Continental	0.32	4.5	1 in 14 million
Delta	0.16	8.5	1 in 53 million
Northwest	1.21	4.9	1 in 4 million
TWA	0	2.7	0
United	1.40	6.5	1 in 4.5 million
USAir	3.53	8.6	1 in 2.5 million
Others[4]	0.01	1.8	1 in 180 million
Total	**6.63**	**44.7**	**1 in 6.5 million**

[1] U.S. domestic trunklines are air carriers that had national route systems in place when the Airline Deregulation Act of 1978 was implemented in the United States. The data include wholly owned subsidiaries of the trunklines that subsequently were absorbed into the trunklines.

[2] The "full-loss equivalent" for a given flight is the proportion of passengers who did not survive the flight. The numbers shown in this column are the total numbers of full-loss equivalents experienced during the study period.

[3] Mortality-risk estimates (Q-statistics) were derived from the formula Q = V/N, in which N is the number of flights conducted during the period and V is the total number of full-loss equivalents among the N flights. In mortality-risk estimates shown, numbers are rounded to the nearest half million.

[4] Include Braniff, Eastern and Pan Am, all of which ceased operations during the period.

Sources: Arnold Barnett and Alexander Wang

United's Q-statistic was 1.4/6.5 million or 1 in 4.5 million. USAir's Q-statistic was 3.53/8.6 million or 1 in 2.5 million.

Before conclusions are made regarding the comparative safety of the individual air carriers, however, consider the following example: Suppose that 100 people are given fair coins (that is, coins not biased toward heads or tails) and that they are asked to toss the coins 20 times. The laws of chance suggest that someone will get 16 heads of 20 tosses and that someone else will get only four heads of 20 tosses. To attribute great meaning to these results would be farfetched; there was no genuine difference in the coins, and if the experiment were repeated, a particular person's results on the first toss would have no value in predicting that person's results on the second toss.

Similarly, we should consider the possibility that the differences shown in Table 2 can be attributed to chance. An *equal-safety hypothesis* would posit that, if all the trunklines were equally effective in avoiding passenger fatalities, the probability that a particular trunkline would have experienced any given one of the 15 fatal trunkline accidents in 1987–1996 would be equal to its proportion of trunkline flights.

For example, a trunkline that conducted 12 percent of the flights in 1987–1996 would have a 12 percent chance of experiencing a given fatal accident. By considering the probability of different outcomes in such a distribution of accidents, we can assess how much disparity in observed records among the trunklines reasonably could be attributed to chance.

Calculations reveal that the probability is about 1 in 9 (11 percent) that, in a random distribution of the 1987–1996 trunkline accidents, the carrier that received the largest share of full-loss equivalents would have had as large a share as USAir had during the period.[17]

Under the usual statistical (and legal) standards applied in testing a hypothesis, the hypothesis would be rejected only if the evidence seems to contradict the hypothesis and the chance of such a "hostile" result is less than 5 percent. As stated above, the chance is 11 percent under an equal-safety hypothesis (that is, under a random distribution of accidents) of getting observed differences across carriers as large as those shown in Table 2. The data, therefore, do not provide a basis for rejecting the equal-safety hypothesis.

In other words, we have no *statistically significant* evidence that USAir was operating less safely than other trunklines in 1987–1996. USAir's relatively high number of full-loss equivalents plausibly can be ascribed to chance. Moreover, Table 2 provides no statistically significant evidence of any real difference in mortality risk among the seven trunklines.

Of interest is that USAir's Q-statistic, which was a factor of five higher than that for other trunklines in 1987–1996 (3.53/8.6 million vs. 3.1/36.1 million), was roughly a factor of five *lower* than the collective Q-statistic for the other trunklines in 1977–1986. Such a reversal is more consistent with random variability than with a continuing systemic difference.

Data Vary Among Domestic Jet Operations

In addition to trunklines, two other categories of U.S. air carriers conducted scheduled jet operations: established regional carriers and "new-entrant" carriers. The established regional carriers, which provided jet service in particular regions of the United States prior to deregulation, included Alaska Airlines, Hawaiian Airlines and Southwest Airlines. New-entrant carriers, which provided virtually no scheduled domestic jet flights before deregulation but took advantage of deregulation to begin such flights, included Air South, People Express, Tower Air and Western Pacific.

Table 3 shows mortality risk for the trunklines, established regional carriers and new-entrant carriers for 1977–1986, 1987–1996 and 1977–1996. The data show that the trunkline Q-statistic for 1987–1996 was 60 percent higher than the trunkline Q-statistic for 1977–1986 (1 in 6.5 million [or 3.2 in 21 million] vs. 1 in 10.5 million [or 2 in 21 million]). The data also show a higher Q-statistic for the new entrants than for the other two air carrier groups in 1977–1996.

Before accepting these data at face value, however, their statistical significance should be determined.

Even if the probability of passenger fatality was the same for every flight over the 20-year period, chance might be involved in some difference in Q-statistics between 1977–1986 and 1987–1996 (much as a fair coin tossed 10 times on Tuesday might yield more heads than the same coin tossed 10 times on Monday). Statistical tests show that the pattern of data in Table 3 is very much within the limits of random variation.[18] Thus, there is no clear evidence that U.S. jet-carrier safety either improved or became worse in 1987–1996, compared with 1977–1986.

Further scrutiny of the data reveals the tenuousness of apparent time-trend evidence in Table 3. Almost 25 percent of trunkline full-loss equivalents for 1977–1996 resulted from accidents that occurred in one year (1987). Thus, if the data were presented for two different time periods, 1977–1987 and 1988–1996 (instead of 1977–1986 and 1987–1996), the trunkline Q-statistic for the first period would be higher than for the second period (1 in 7 million vs. 1 in 10 million) and the apparent evidence of an adverse time trend would be reversed.

Moreover, while Table 3 suggests that the safety of the established regional carriers improved substantially over time, they actually had one fatal accident in 1977–1986 and no fatal accidents in 1987–1996. One accident does not indicate a trend.

Data Fail to Show Significant Differences Among U.S. Jet Airlines

The key question when comparing air carriers is whether the new entrants performed significantly worse than the established carriers (the trunklines and the established regionals). Briefly stated, a statistical test would answer "no." This does not prove that there were no differences in mortality risk among the air carriers; it means that data for the few accidents recorded cannot be cited convincingly as proof of differences among the carriers.

In 1987–1996, the new entrants had 3 million flights and one fatal accident. Based on the fatal-accident pattern for the established air carriers, the probability of having at least one fatal accident in 3 million flights is greater than 25 percent. (The established carriers had 15 fatal accidents in more than 52 million flights.) Because 25 percent is above the 5 percent threshold for determining statistical significance, the difference between the new entrants and the established carriers is not statistically significant.

Table 3
Mortality Risk for Three Categories of Scheduled U.S. Jet Air Carriers, 1977–1996

	Mortality Risk per Flight[1]		
Category	**1977–1986**	**1987–1996**	**1977-1996**
Trunklines[2]	1 in 10.5 million	1 in 6.5 million	1 in 8 million
Established Regionals[3]	1 in 3 million	0	1 in 10 million
New Entrants[4]	1 in 1 million	1 in 3 million	1 in 1.5 million

[1] Mortality-risk estimates (Q-statistics) were derived from the formula Q = V/N, in which N is the number of flights conducted during the period and V is the total number of "full-loss equivalents" among the N flights. A full-loss equivalent for a given flight is the proportion of passengers who did not survive the flight. In mortality-risk estimates shown, numbers are rounded to the nearest half million.

[2] U.S. domestic trunklines are air carriers that had national route systems in place when the Airline Deregulation Act of 1978 was implemented in the United States. The data include wholly owned subsidiaries of the trunklines that subsequently were absorbed into the trunklines.

[3] Established regional air carriers are those that provided jet service in particular regions of the United States before the Airline Deregulation Act of 1978 was implemented.

[4] New-entrant air carriers provided virtually no scheduled domestic jet flights before the Airline Deregulation Act of 1978 was implemented but took advantage of deregulation to begin such flights.

Sources: Arnold Barnett and Alexander Wang

In summary, there is no compelling statistical evidence from 1987–1996 suggesting that U.S. jet carriers differ with respect to passenger-mortality risk. The Q-statistic for scheduled domestic jet carriers (trunklines, regionals and new entrants) was 1 in 7 million (see Table 4, page 7). At this rate, a passenger who selected one flight on these carriers every day would go, on average, approximately 19,000 years before dying in a fatal accident.

Nonjet Commuter Mortality Risk Was 1 in 2 Million

Short-haul commuter flights conducted by nonjet aircraft (that is, reciprocating-engine aircraft and turboprop aircraft) were an important part of the U.S. domestic air system in 1987–1996. In that period, there were 60 percent as many nonjet commuter flights as domestic jet flights. (Most commuter operations were conducted by air carriers either affiliated with or owned by established trunklines.)

In 1987–1996, U.S. commuter operators conducted approximately 35 million nonjet flights and had 19.08 full-loss equivalents, which yield a Q-statistic of 1 in 2 million (19.08/35 million). Thus, nonjet commuter flights generated more than twice as many full-loss equivalents as the jet-carrier flights (19.08 vs.7.63) even though the nonjet commuter flights were slightly over half as numerous as the jet-carrier flights. Under an equal-safety hypothesis for the two categories of carriers, the probability is 1 percent that chance would cause the commuter airlines to have as disproportionate a share of full-loss equivalents as they did.

Because the observed difference is less than 5 percent, it is statistically significant. Nevertheless, whether such a difference reflects an intrinsic difference in safety for an air carrier category, rather than differences in flying conditions, is not clear. One commuter accident during the period, for example, was a collision on a runway at an uncontrolled, rural airport where no commercial jets operated.

Moreover, major changes in 1995 in the operating requirements for small commuter airplanes (in an effort to establish "one level of safety" for air carrier operations) might make data prior to that year less relevant in assessing present-day risk.

There are few routes on which jet carriers and nonjet commuters compete. Compared with jet carriers, automobiles provide more competition with commuter aircraft.[19] Researchers have estimated that the types of automobile drivers who might use commuter flights — sober, seat-belted, more than 40 years old and in heavier-than-average automobiles — have a mortality risk that varies linearly with distance traveled and is approximately 1 in 6 million on an intercity trip of 200 miles.[20] That risk estimate is a factor of three lower than the Q-statistic for nonjet commuter planes.

Data Fail to Support Reputation of U.S. Carriers as the Safest

For the purposes of this article, international operations include international flights conducted by three categories of air carriers:

- "U.S. carriers," with home offices in the United States, an "advanced-world" country (see below);
- "Advanced-world carriers," with home offices outside the United States but in other economically advanced, technologically advanced and politically democratic countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland and the United Kingdom); and,
- "Developing-world carriers," with home offices in countries other than those categorized as the advanced world.

The disorder of data available for carriers with home offices in the former Soviet Union precluded their use.

Table 4 shows 1977–1986 Q-statistics for U.S. air carriers and other advanced-world carriers.

The Q-statistics for U.S. carriers are especially interesting, because U.S. carriers often are perceived as the world's safest carriers. Table 4 shows that, in both domestic operations and international jet operations in 1987–1996, U.S. carriers had higher mortality risks than their counterparts elsewhere in the advanced world. (Data for a 10-year period that ended Feb. 29, 2000, show the same result; see "What the Recent Record Shows About Mortality Risk," page 11.)

The differences in Table 4, however, simply might reflect the statistical volatility of data about rare events. For example, if there had been one additional non-U.S. domestic jet accident without survivors during the period, the Q-statistic for non-U.S. carriers would have been 2.65/18 million, or 1 in 7 million; thus, there would have been no difference between the U.S. carriers and the non-U.S. carriers.

Therefore, one cannot assert that, in terms of safety, U.S. jet carriers have fallen behind other advanced-world airlines. Nevertheless, the Q-statistics similarly do not support the perception that U.S. carriers are significantly safer than other advanced-world carriers. Rather, the data seem to show that — as with automobile safety, railroad safety, industrial safety and overall life expectancy — the safety of U.S. carriers meets the norms of the advanced world.

Data Show Higher Mortality Risk for Developing-world Carriers

Table 5 (page 7) shows statistics about the collective 1987–1996 record of air carriers with home offices in the developing world.

Table 4
Mortality Risk for Advanced-world[1] Scheduled Jet Operations, 1987–1996

	Full-loss Equivalents[2]	Number of Flights (millions)[3]	Mortality Risk per Flight[4]
Domestic Flights			
U.S. Carriers[5]	7.63	55	1 in 7 million
Other Advanced-world Carriers	1.65	18	1 in 11 million
All Advanced-world Carriers	9.28	73	1 in 8 million
International Flights			
U.S. Carriers	3.00	4	1 in 1.5 million
Other Advanced-world Carriers	4.06	16	1 in 4 million
All Advanced-world Carriers	7.06	20	1 in 3 million

[1] Advanced-world carriers have home offices in economically advanced, technologically advanced and politically democratic countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, the United States and the United Kingdom).

[2] The "full-loss equivalent" for a given flight is the proportion of passengers who did not survive the flight. The numbers shown in this column are the total numbers of full-loss equivalents experienced during the study period.

[3] Statistics about numbers of flights conducted by non-U.S. carriers involved approximations. Flight numbers were rounded to the nearest million.

[4] Mortality-risk estimates (Q-statistics) were derived from the formula Q = V/N, in which N is the number of flights conducted during the period and V is the total number of full-loss equivalents among the N flights. In mortality-risk estimates shown, numbers are rounded to the nearest half million.

[5] U.S. carriers include trunklines and established regional air carriers (as of 1978 deregulation) and new-entrant carriers (after deregulation). Trunklines are air carriers that had national route systems before deregulation.

Sources: Arnold Barnett and Alexander Wang

Table 5
Mortality Risk for Developing-world[1] Scheduled Jet Operations, 1987–1996

	Full-loss Equivalents[2]	Estimated Number of Flights (millions)[3]	Mortality Risk per Flight[4]
Domestic Flights	25.6	12	1 in 500,000
International Flights	21.3	8.5	1 in 400,000

[1] Developing-world carriers have home offices in countries other than those countries categorized for the purposes of this study as economically advanced, technologically advanced and politically democratic.

[2] The "full-loss equivalent" for a given flight is the proportion of passengers who did not survive the flight. The numbers shown in this column are the total numbers of full-loss equivalents experienced during the study period.

[3] Various approximations were used to derive these estimates.

[4] Mortality-risk estimates (Q-statistics) were derived from the formula Q = V/N, in which N is the number of flights conducted during the period and V is the total number of full-loss equivalents among the N flights. In mortality-risk estimates shown, numbers are rounded to the nearest 100,000.

Sources: Arnold Barnett and Alexander Wang

The mortality-risk estimates are factors of 16 and seven higher than, respectively, the corresponding domestic and international statistics in Table 4 for advanced-world air carriers.

Safety records vary among developing-world air carriers; many carriers had no fatal accidents in the period. Developing-world carriers generally are so small for statistical purposes, however, that, even under an equal-safety hypothesis, many Q-statistics of zero would be expected.

One way to explore possible differences is to perform separate calculations for air carriers in those developing nations in which recent political and/or economic changes may have moved them closer to being categorized as advanced-world countries. These nations include a group of Asian countries (Hong Kong, Malaysia, Singapore, South Korea, Taiwan and Thailand) and the former Soviet satellites in Eastern Europe (Bulgaria, Czech Republic/Slovakia, Hungary, Poland and Romania; Albania has no jet carriers, and air service in the former Yugoslavia was curtailed by conflicts during the study period).

If developing-world air carriers differ in mortality risk, the difference might manifest itself in appreciably lower Q-statistics for air carriers in the Asian countries and in the

Table 6
Mortality Risk for Scheduled Airlines in Selected Asian Countries[1] and in Former Soviet Satellites in Eastern Europe,[2] 1987–1996

Air Carrier Origin	Full-loss Equivalents[3]	Number of Flights (millions)	Mortality Risk per Flight[4]
Asian Countries	5.94	4.2	1 in 700,000
Eastern Europe	1.68	0.7	1 in 400,000

Note: Statistics are based on domestic flights and international flights.

[1] Hong Kong, Malaysia, Singapore, South Korea, Taiwan and Thailand were selected for the study as rapidly developing Asian countries that have had economic growth and substantial increases in per capita income.

[2] Includes Bulgaria, Czech Republic/Slovakia, Hungary, Poland and Romania (Albania has no jet carriers, and air service in the former Yugoslavia was curtailed by conflicts during the period).

[3] The "full-loss equivalent" for a given flight is the proportion of passengers who did not survive the flight. The numbers shown in this column are the total numbers of full-loss equivalents experienced during the study period.

[4] Mortality-risk estimates (Q-statistics) were derived from the formula $Q = V/N$, in which N is the number of flights conducted during the period and V is the total number of full-loss equivalents among the N flights. In mortality-risk estimates shown, numbers are rounded to the nearest 100,000.

Sources: Arnold Barnett and Alexander Wang

Table 7
Mortality Risk for Scheduled Jet Flights Between Cities in the Advanced World[1] And the Developing World,[2] 1987–1996

Air Carrier Origin	Full-loss Equivalents[3]	Estimated Number of Flights (millions)[4]	Mortality Risk per Flight[5]
Advanced World	4.03	2.5	1 in 600,000
Developing World	4.98	3	1 in 600,000

[1] Advanced-world air carriers have home offices in economically advanced, technologically advanced and politically democratic countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, the United States and the United Kingdom).

[2] Developing-world air carriers have home offices in countries other than those countries categorized for the purposes of this study as economically advanced, technologically advanced and politically democratic.

[3] The "full-loss equivalent" for a given flight is the proportion of passengers who did not survive the flight. The numbers shown in this column are the total numbers of full-loss equivalents experienced during the study period.

[4] The estimated numbers of flights were subject to sampling errors.

[5] Mortality-risk estimates (Q-statistics) were derived from the formula $Q = V/N$, in which N is the number of flights conducted during the period and V is the total number of full-loss equivalents among the N flights. In mortality-risk estimates shown, numbers are rounded to the nearest 100,000.

Sources: Arnold Barnett and Alexander

former Eastern European Soviet-satellite countries than for other carriers in the developing world. Table 6, however, does not clearly suggest such a difference. This outcome (and a more general review of developing-world air carrier data) suggest that, while it may be implausible that the hundreds of developing-world carriers are identical in safety, there is no rule of thumb based on national characteristics to distinguish less-safe carriers from more-safe carriers.

Developing-world Air Carriers Match Advanced-world Carriers on Comparable Routes

The overall Q-statistics are significantly lower for advanced-world air carriers than for developing-world carriers, but an assumption cannot be made that this difference prevails on routes flown by both groups of carriers. These routes connect cities in the advanced-world countries with cities in the developing-world countries (for example, routes between Paris, France, and Karachi, Pakistan; Tokyo, Japan, and Delhi, India; or Miami, Florida, U.S., and Caracas, Venezuela).

Table 7 shows relevant Q-statistics for routes between advanced-world cities and developing-world cities. (The estimated numbers of flights are subject to sampling error; see "How Mortality-risk Estimates Were Derived," page 12.) The data show that there was no advanced-world safety advantage on these routes in 1987–1996 and that the mortality risks of advanced-world carriers on these routes were much closer to the norms for developing-world carriers than to those for their home countries.

While some accidents had no apparent relation to the advanced world/developing world categorization, Table 7 suggests that the relatively difficult flying environments in developing-world countries may pose hazards to all carriers that fly there, regardless of their national origins.

Overall Mortality Risks Are Low

Table 8 combines the results shown in other tables and helps summarize the key findings.

Table 8
Mortality Risk for Several Types of Scheduled Service, 1987–1996

Type of Service	Mortality Risk per Flight[1]
Advanced-world[2] Domestic Jet	1 in 8 million
U.S. Commuter[3]	1 in 2 million
Developing-world[4] Domestic Jet	1 in 500,000
International Jet Within Advanced World	1 in 5 million
International Jet Between Advanced World and Developing World	1 in 600,000
International Jet Within Developing World	1 in 400,000

[1] Mortality-risk estimates (Q-statistics) were derived from the formula $Q = V/N$, in which N is the number of flights conducted during the period and V is the total number of "full-loss equivalents" among the N flights. A full-loss equivalent for a given flight is the proportion of passengers who did not survive the flight. Mortality-risk estimates shown are rounded to the nearest half million for numbers greater than 1 million or to the nearest 100,000 for numbers less than 1 million.

[2] Advanced-world air carriers have home offices in economically advanced, technologically advanced and politically democratic countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, the United States and the United Kingdom).

[3] Includes service by reciprocating-engine aircraft and turboprop aircraft.

[4] Developing-world air carriers have home offices in countries other than those categorized for the purposes of this study as economically advanced, technologically advanced and politically democratic.

Sources: Arnold Barnett and Alexander Wang

Although the mortality-risk estimates vary by factors of up to 20, all are low in absolute terms. Even in the riskiest setting — international jet flights within the developing world — a passenger who took one flight every day would travel more than 1,000 years on average before being involved in a fatal accident.

Many of the risk differences in Table 8 are statistically significant (that is, they are too large to be treated as temporary or random fluctuations in data), but there are no statistically significant differences among flights in a given category. Thus, if these data offer a guide, 1 in 8 million flights is a plausible mortality-risk estimate for the following:

- All advanced-world domestic jet flights; and,
- Jet flights within the United States.

For international flights between countries in the advanced world and the developing world, 1 in 600,000 flights is a plausible mortality-risk estimate for flights on air carriers from either "world."

The mortality risk is several times higher for both domestic jet flights and international jet flights within the developing world than the mortality risk for corresponding flights within the advanced world. No such disparity exists, however, for flights between the developing world and the advanced world.

Thus, when two air carriers serve a particular route nonstop, there is no reason related to Q-statistics to prefer one air carrier over the other air carrier.

These results show that air carrier identity might be less useful as an "explanatory variable" for safety differences than are the relative hazards of different flying environments. And, much as a rising tide lifts all boats, efforts to improve the less-safe environments might bring equal benefits to all air carriers that fly through them.♦

[Editorial note: This article was based on a study supported by a grant from FAA to the National Center of Excellence in Aviation Operations Research. The authors acknowledge the input of Carolyn Edwards, Christopher Hart and Jack Wojciech of the FAA Office of System Safety; Todd Curtis of The Boeing Co.; and Amedeo Odoni of the Massachusetts Institute of Technology. The viewpoints in this article are the exclusive responsibility of the authors and do not represent official policies or positions of FAA.]

References and Notes

1. Trans World Airlines Flight 800, a Boeing 747-131, struck the Atlantic Ocean near East Moriches, New York, U.S., July 17, 1996, after departing from Kennedy International Airport, New York, New York, for a scheduled flight to Paris, France. All 320 occupants were killed. As of April 10, 2000, the U.S. National Transportation Safety Board (NTSB) had not published a final report on the accident.

2. ValuJet Airlines Flight 592, a Douglas DC-9-32, struck terrain May 11, 1996, approximately 10 minutes after departing from Miami (Florida, U.S.) International Airport. NTSB said, in its final report, that the accident resulted from a fire in the aircraft's Class D cargo compartment that was initiated by the actuation of one or more oxygen generators being carried improperly as cargo.

The report said that the probable causes of the accident were: "the failure of SabreTech [a maintenance subcontractor to ValuJet] to properly prepare, package and identify unexpended chemical oxygen generators before presenting them to ValuJet for carriage; the failure of ValuJet to properly oversee its contract maintenance program to ensure compliance with maintenance, maintenance training and hazardous-materials requirements and practices; and the failure of the [U.S.] Federal Aviation Administration (FAA) to require smoke-detection [systems] and fire-suppression systems in Class D cargo compartments." (See "Chemical Oxygen Generator Activates in Cargo Compartment of DC-9, Causes Intense Fire and Results in Collision with Terrain," *Accident Prevention* Volume 54, November 1997.)

3. Barnett, A. "Air Safety: End of the Golden Age?" *Chance*, Volume 3 (February 1990).

4. United Airlines Flight 232, a McDonnell Douglas DC-10-10, experienced a catastrophic failure of the no. 2 engine during cruise flight July 19, 1989. Debris from the no. 2 engine disabled the three hydraulic systems that powered the aircraft's flight controls. The aircraft struck terrain on approach to Sioux Gateway Airport, Sioux City, Iowa, U.S. Of the 296 occupants, 111 occupants were killed. NTSB said, in its final report, that the probable causes of the accident were "the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility, which resulted in the failure to detect a fatigue crack originating from a previous undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines; the subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls." (See "United 232: Coping With the 'One-in-a-Billion' Loss of All Flight Controls," *Accident Prevention* Volume 48, June 1991.)

5. Barnett, A.; Menhigetti, J.; Prete, M. "The Market Response to the Sioux City DC-10 Crash." *Risk Analysis*, Volume 12 (March 1992).

6. Barnett, A.; Abraham, M.; Schimmel, V. "Airline Safety: Some Empirical Findings." *Management Science*, Volume 25 (November 1979).

7. Barnett, A.; Higgins, M.K. "Airline Safety: The Last Decade." *Management Science*, Volume 35 (January 1989).

8. "Final Approach: Landing Procedures are Tied to Air Crashes," *The Wall Street Journal*, Aug. 11, 1997: Section A1.

9. Matthews, Stuart. "Safety and Statistics: What the Numbers Tell Us About Aviation Safety at the End of the 20th Century." *Flight Safety Digest* Volume 16 (December 1997): 1–10.

10. Boeing Commercial Airplane Group. *Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959–1997*, June 1998.

11. "Completely at random" means that if the number of flights to choose from were N, the chance is 1/N that the passenger would select any particular flight.

12. Suppose, for example, that of 10 million flights during a certain period, four flights resulted in passenger fatalities with an average fatality rate of 60 percent (and, thus, an average survival rate of 40 percent). The chance of randomly selecting an ill-fated flight would be 4 in 10 million, or (dividing numerator and denominator by four) 1 in 2.5 million; and the chance of perishing on such a flight would be 60 percent (0.6). Thus, the overall risk of death is 0.6 times 1 in 2.5 million, or (dividing numerator and denominator by 0.6) 1 in 4.2 million.

13. U.S. Federal Aviation Administration (FAA). *Safety Issue Analysis: Low-Cost Air Carrier Safety Record.*

14. FAA defines "major air carrier" as an air carrier certified under U.S. Federal Aviation Regulations Part 121 or Part 127 and with annual operating revenues greater than US$1 billion.

15. NTSB in 1996 defined "accident" as "an event involving serious injury, loss of life or substantial aircraft damage" and said that accidents in the "serious accident" category "exclude turbulence[-related accidents and] other minor accidents in flight, and gate or ramp accidents."

16. The Airline Deregulation Act of 1978 phased out the U.S. government's control over fares and service, relying instead on market forces to decide the price and quality of domestic air service.

17. The calculations involved such concepts as order statistics and p-values; details are available on request to abarnett@mit.edu.

18. The statistical tests are available on request to abarnett@mit.edu.

19. Trains and buses also compete with commuter airlines, but to a lesser extent than automobiles.

20. Evans, L.; Frick, M.; Schwing, R. "Is It Safer to Fly or Drive?" *Risk Analysis* Volume 10, 1990. For discussion of the authors' belief that the mortality risk of 1 in 6 million is too high for these automobile drivers, see: Barnett, A. "It's Safer to Fly." *Risk Analysis* Volume 11 (January 1991).

About the Authors

Arnold Barnett, Ph.D., is George Eastman Professor of Management Science at the Massachusetts Institute of Technology (MIT) Sloan School of Management. His specialty is applied mathematical modeling on issues of policy importance. The results of his research on aviation safety have appeared in publications including The New York Times, The Wall Street Journal, Scientific American, The Economist and Newsweek. *He has extensive consulting experience in aviation. He has worked for 10 airlines, three airports and the U.S. Federal Aviation Administration. He received the 1996 President's Award from the Institute for Operations Research and the Management Sciences for "outstanding contributions to the betterment of society." He is a principal investigator of a 1999 Sloan Foundation grant to MIT for study of the global aviation industry. Barnett holds a doctorate in applied mathematics.*

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Appendix A
What the Recent Record Shows About Mortality Risk

Events since the end of the study period (Dec. 31, 1996) are consistent with the study's broad conclusions. Although accurate data about recent numbers of flights are not available, the following general observations can be made from available data from Jan. 1, 1997, to Feb. 29, 2000:

- One conclusion from the study of 1987–1996 data was that mortality-risk differences among U.S. domestic jet air carriers might be the result of short-term statistical fluctuations of no predictive value. Subsequent data are consistent with this conclusion: In 1997 through February 2000, no fatalities occurred during flights conducted by the carriers (USAir and the new-entrant carriers) that had comparatively high mortality risks (Q-statistics) in 1987–1996; but the largest carrier that had no fatal accidents during domestic operations in 1987–1996 (American Airlines) had one fatal accident;

- Another conclusion was that the increase in the trunkline mortality risk from 1977–1986 to 1987–1996 (from 1 in 10.5 million to 1 in 7 million) might be a short-term fluctuation. The trunkline mortality risk for the decade ending in February 2000 was approximately 1 in 12 million;

- As in 1987–1996, the mortality risks for domestic flights and international flights conducted by U.S. jet carriers in 1997 through February 2000 were slightly higher than those for other advanced-world jet carriers. Nevertheless, this difference might be a short-term fluctuation;

- The mortality risk for developing-world air carrier flights continued to be higher than the risks for advanced-world carrier flights;

- Nevertheless, advanced-world carriers and developing-world carriers continued to have comparable records on routes between the "worlds." Three fatal accidents on such routes in 1997 through February 2000 involved the deaths of all or almost all of the passengers aboard the airplanes, and two of the accidents involved developing-world carriers.♦

— Arnold Barnett and Alexander Wang

Appendix B
How Mortality-risk Estimates Were Derived

In the calculations of passenger-mortality risk for randomly selected nonstop flights (the Q-statistic) — using the equation Q = V/N, where V is the number of full-loss equivalents[1] and N is the number of flights — the various estimates of V were based on annual aviation safety data summaries presented in *Flight International* magazine and records from various Internet web pages. Boeing's Product Safety Office provided additional data.[2]

Even if an air carrier's Q-statistic is stable over a long term, the carrier's Q-statistic will fluctuate periodically from the long-term average. The number of full-loss equivalents (V) experienced by a carrier is statistically volatile. For example, a carrier that averages one fatal accident per decade has approximately a 37 percent chance of having no fatal accidents in a given 10-year period, a 37 percent chance of having one fatal accident and a 26 percent chance of having more than one fatal accident. Thus, even if the precise number of flights conducted by the air carrier (N) is known for every period, the volatility in V will induce considerable volatility in the mortality-risk calculation (Q).

Published data provided accurate numbers of flights conducted by scheduled U.S. jet operations (domestic and international), but published data were not available for some other flight operations. For example, there were no published data on the number of nonstop jet flights conducted by advanced-world air carriers between cities in the advanced world and cities in the developing world.

Therefore, sampling procedures were devised to estimate many of the N-values. Data from the mid-month listings of nonstop flights in the June 1992 issue of the *Official Airline Guide* (*OAG*) were used to approximate the average weekly rate for the decade. (June 1992 is just past the middle of the period 1987–1996, and mid-June is neither a peak-travel period nor the depth of an off-season period.) The following examples show how the data were used:

- To begin estimating the number of domestic jet flights in Spain in 1987–1996, the weekly number of nonstop domestic jet flights from Madrid in mid-June 1992 was doubled (to take account of flights into Madrid). The process was repeated for Barcelona, with the exception that all nonstop flights between Barcelona and Madrid were excluded. The process was repeated for Seville, excluding nonstop flights between Seville and Madrid, and between Seville and Barcelona. The process then was repeated for all other Spanish cities that had nonstop jet service. The total number of weekly nonstop flights between the cities was multiplied by 50 to approximate an annual number. The annual number then was multiplied by 10 to approximate the number of domestic jet flights in the 10-year period. The primary sampling error in this calculation was the extent to which mid-June 1992 flight frequencies differed from the full-period mean for 1987–1996. A secondary source of error was the difference between published schedules and actual operations.

- For flights between cities in the advanced world and cities in the developing world, every fifth page in the *OAG* (beginning with page 5) was examined, and every nonstop-flight listing during a week in mid-June 1992 was counted. (Data were derived from 248 such pages.) Page 1195, for example, showed that advanced-world air carriers conducted 14 nonstop flights per week from Manila to Tokyo, while developing-world carriers conducted 11 such flights. The numbers in each category were multiplied first by five (to reflect the full *OAG* listings rather than a 20 percent sample) and then by 50 and 10 to extrapolate from the one week studied to the full decade. The sampling error in this calculation was the use of data from 20 percent of the pages in the *OAG*.

These sampling errors could have been avoided by using *OAG* data for all 120 months of the study period. Such an effort, however, would have been labor-intensive and would have done nothing to reduce the high random component in observed V-values that is by far the dominant source of volatility in the Q-statistics.♦

— Arnold Barnett and Alexander Wang

Notes

1. The full-loss equivalent for a given flight is the proportion of passengers who do not survive the flight. V is the sum of all full-loss equivalents calculated for all N flights.

2. A full listing of the events used in calculating V-values is available on request to abarnett@mit.edu.

1999 Data Show Decrease in Accidents in Russian Commercial Aviation

No fatal accidents were recorded involving operations of regular passenger airplanes, charter airplanes or business airplanes.

FSF Editorial Staff

Data compiled by Flight Safety Foundation-Commonwealth of Independent States (CIS) showed that no fatal accidents occurred in 1999 in Russia's regular passenger-airplane operations, charter-airplane operations or business-airplane operations.

Seven fatal accidents were recorded in 1999, compared with nine fatal accidents in 1998. All seven fatal accidents in 1999 involved commercial helicopter operations, the data showed (Figure 1, page 14). The seven fatal accidents in 1999 resulted in 43 fatalities, compared with 37 fatalities the previous year (Figure 2, page 14).

A total of 21 accidents, including the seven fatal helicopter accidents, occurred in 1999 among all types of aircraft used in commercial aviation in Russia — a decrease from 33 accidents in 1998, the data showed.

The overall 1999 fatal accident rate for the civil aviation fleet was 0.49 accidents per 100,000 flight hours (Figure 3, page 15), and the number of fatalities per 1 million passengers was 2.0 (Figure 4, page 15).

Data showed that the fatality rate per 1 million passengers on scheduled passenger flights was zero in 1999 for the third consecutive year (Figure 5, page 16).

In helicopter operations, the accident rate was 6.16 accidents per 100,000 flight hours (Figure 6, page 16).

Of the 21 accidents in 1999, 13 were attributed to violations of formal flight regulations by crewmembers (Figure 7, page 17). Five other accidents were attributed to piloting mistakes and erroneous decisions by flight crewmembers, two were attributed to operational mistakes by aircrews, and one was attributed to an "in-flight aviation failure."

FSF-CIS, based in Moscow, Russia, pursues aviation safety activities in the CIS and is one of several regional organizations worldwide that cooperates with Flight Safety Foundation to help improve aviation safety.

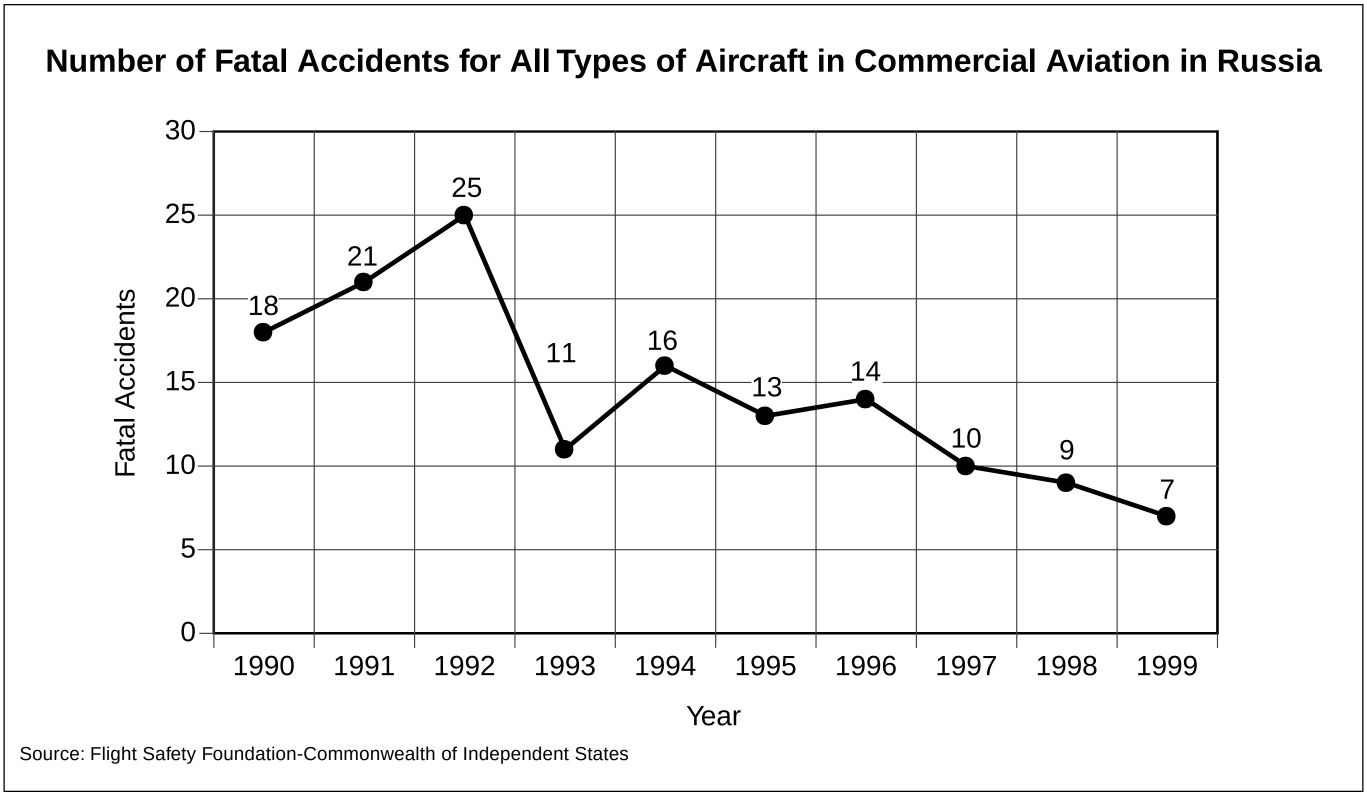

Figure 1

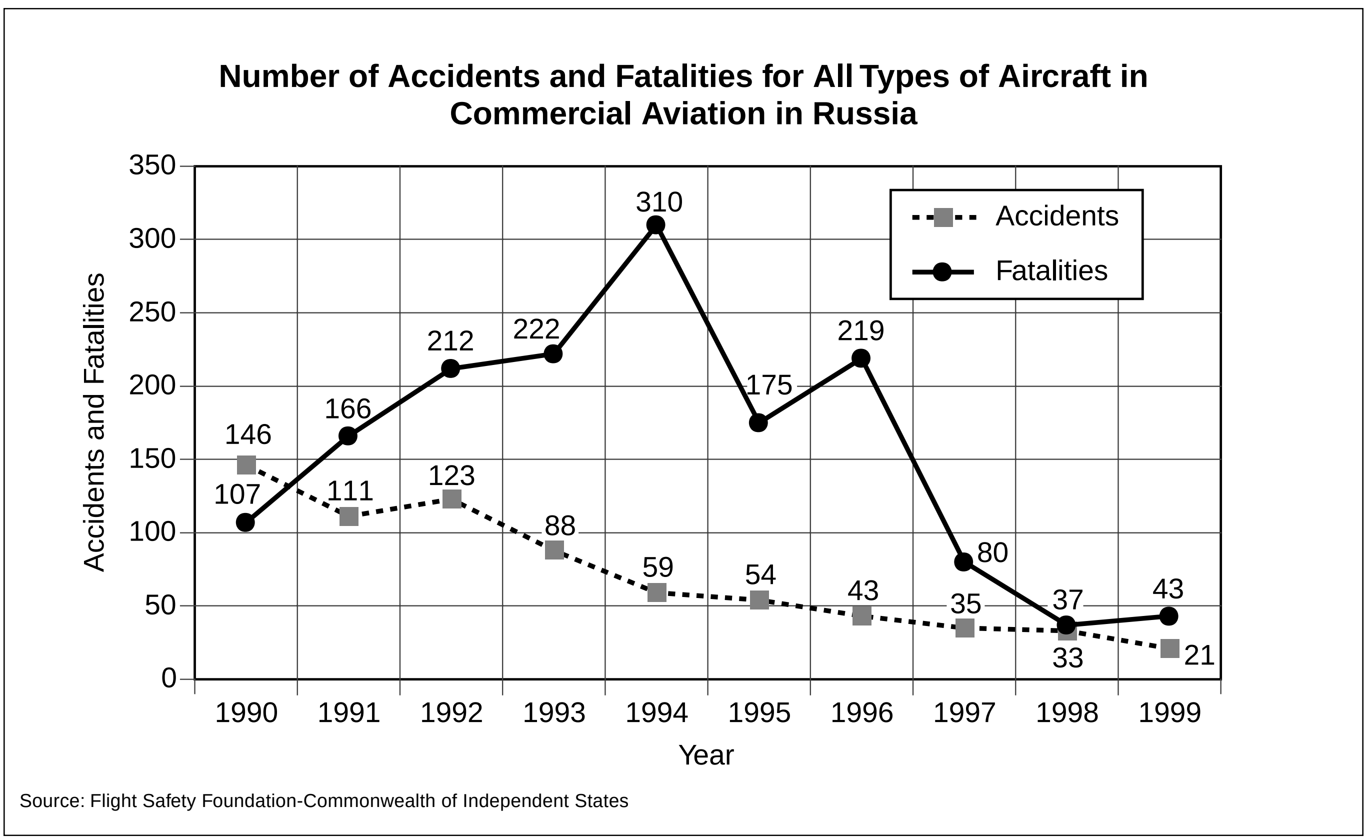

Figure 2

Figure 3

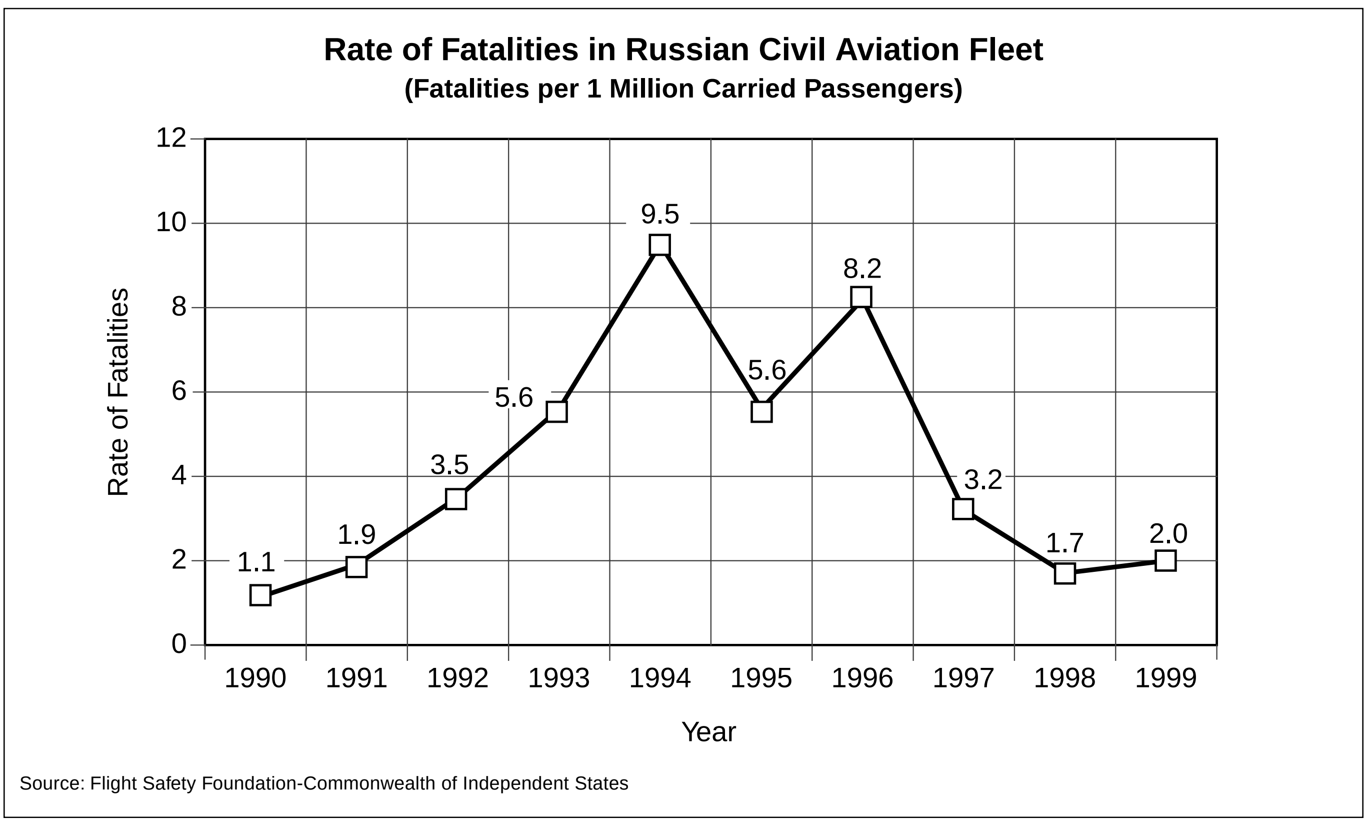

Figure 4

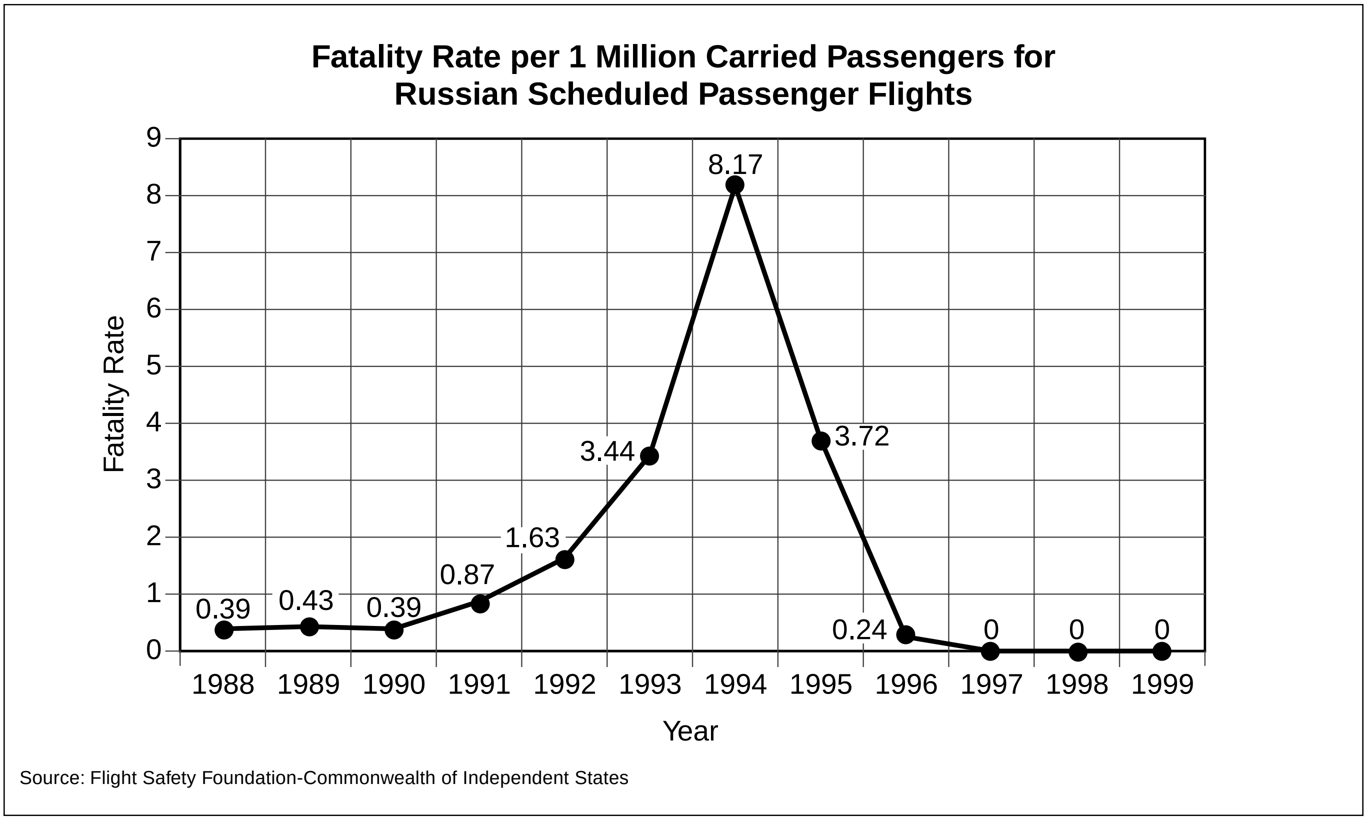

Figure 5

Figure 6

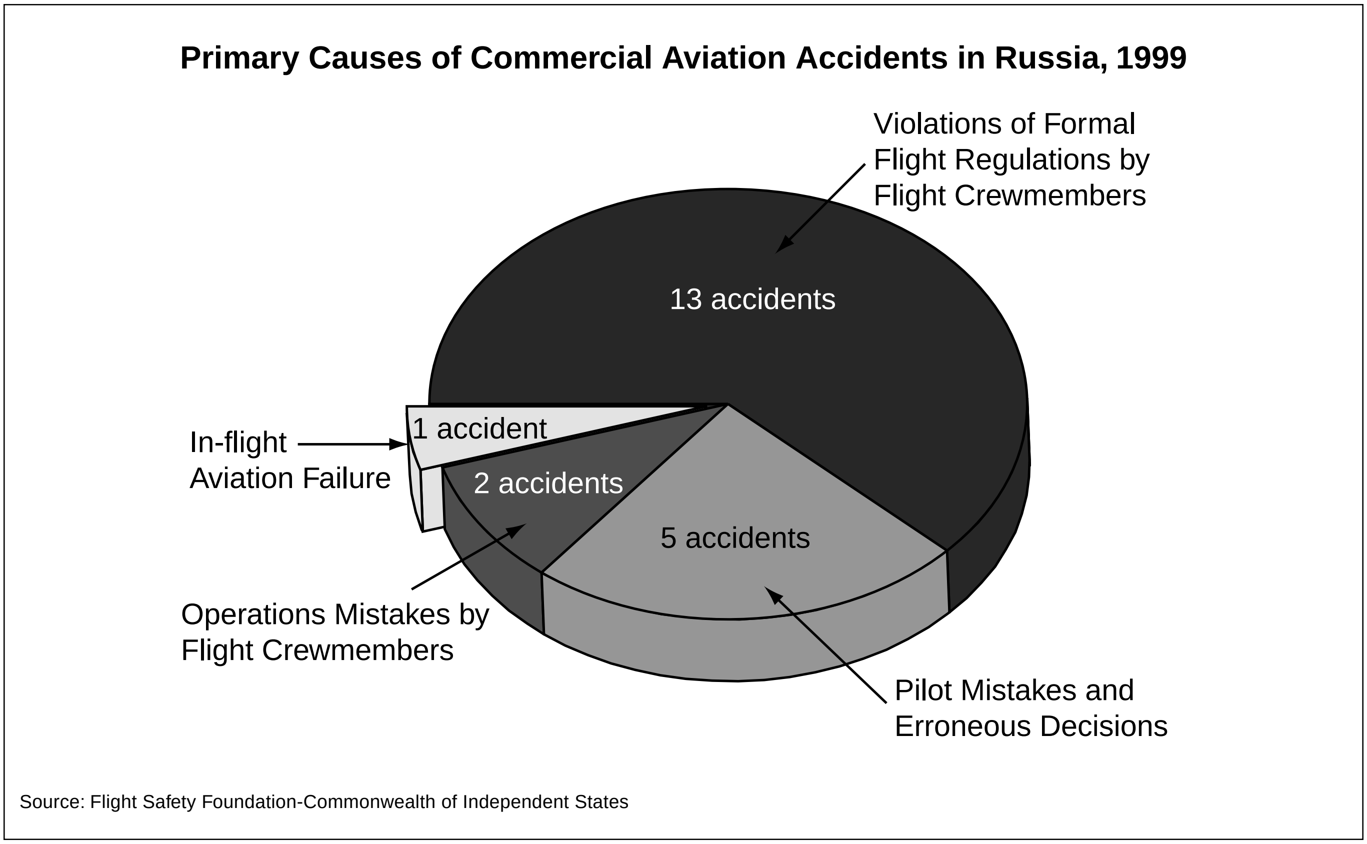
Primary Causes of Commercial Aviation Accidents in Russia, 1999
Violations of Formal Flight Regulations by Flight Crewmembers
13 accidents
1 accident
In-flight Aviation Failure
2 accidents
5 accidents
Operations Mistakes by Flight Crewmembers
Pilot Mistakes and Erroneous Decisions
Source: Flight Safety Foundation-Commonwealth of Independent States

Figure 7

Publications Received at FSF Jerry Lederer Aviation Safety Library

FAA Publishes Guidelines for Turbine-engine Operations in Extreme Rain, Hail

Advisory circular, based on a study that found potential flight safety risks, recommends methods of showing compliance with FAA requirements.

FSF Library Staff

Advisory Circulars

Turbine Engine Power-Loss and Instability in Extreme Conditions of Rain and Hail. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) No. 33.78-1. Feb. 8, 2000. 19 pp. Available through GPO.*

This advisory circular (AC) incorporates standards developed after a study initiated in 1988 by the Aerospace Industries Association working with The European Association of Aerospace Industries. The study concluded that there was a potential flight safety risk for turbine engines on airplanes operating in conditions of extreme rain or hail. The AC provides guidance and acceptable methods that may be used to demonstrate compliance with requirements contained in two sections of U.S. Federal Aviation Regulations (FARs) Part 33. FARs Part 33.78(a)(2) pertains to the operation of turbine engines in extreme rain and hail, and Part 33.78(c) pertains to engines installed on supersonic airplanes. [Adapted from AC.]

Reports

The Human Factors Analysis and Classification System — HFACS. Shappell, Scott A.; Wiegmann, Douglas A. U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. Report No. DOT/FAA/AM-00/7. February 2000. 18 pp. Available through NTIS.**

Keywords:
1. Aviation
2. Human Error
3. Accident Investigation
4. Database Analysis

Although human error is a factor in 70 percent to 80 percent of aviation accidents, most accident-reporting systems are not designed according to any theoretical framework of human error. Because of this, most accident databases are not suitable for a traditional human error analysis, making the identification of intervention strategies difficult. This report discusses the need for a general human error framework for the development of new investigative methods and the restructuring of accident databases. The recently developed human factors analysis and classification system (HFACS) is described. The HFACS framework has been used in military aviation, commercial aviation and general aviation to examine systematically underlying human causal factors to improve aviation accident investigations. [Adapted from Introduction and Conclusion.]

The Effects of Napping on Night Shift Performance. Della Rocco, Pamela S.; Comperatore, Carlos; Caldwell, Lynn; Cruz, Crystal. U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. Report No. DOT/FAA/AM-00/10. February 2000. 36 pp. Available through NTIS.**

Keywords:
1. Air Traffic Control Specialists
2. Naps

3. Shift Work
4. Night Shift
5. Performance
6. Vigilance
7. Sleepiness
8. Sleep Quality
9. Mood

This report is the result of a collaborative effort between the U.S. Federal Aviation Administration's Civil Aeromedical Institute and the U.S. Army Aeromedical Research Laboratory to study the effects of napping on the midnight shift as a potential countermeasure to sleepiness during the shift. This paper examines the effects of naps taken during a night shift on sleepiness and performance after awakening and throughout the duty hours following the nap. Sixty air traffic control (ATC) specialists were randomly assigned to one of three midnight-shift napping conditions: a long nap of two hours, a short nap of 45 minutes, and no nap. ATC specialists completed four days of tests during which they worked three early morning shifts, followed by a rapid rotation to the midnight shift. Participants completed three 1.5-hour test sessions during the midnight shift and participated in two computer-based tests. One session was administered before the nap, and two were administered after the nap. Results indicated that naps taken during the midnight shift could be beneficial as a countermeasure to sleepiness and decreases in performance on the midnight shift. [Adapted from Introduction and Conclusion.]

Books

Coping with Computers in the Cockpit. Dekker, Sidney; Hollnagel, Erik, editors. Brookfield, Vermont, U.S.: Ashgate Publishing, 1999. 247 pp.

Increased cockpit automation in commercial aircraft fleets means that pilots must be skilled managers of both human resources and automated resources. Changes have occurred in operational requirements and training requirements that have caused a shift in the potential for human error and system breakdown. This book examines how the aviation industry is coping with cockpit automation. The text covers current initiatives by the aviation industry, practical and scientific approaches to problems with flight deck automation, and recent developments in automation and human factors.

Contains a Bibliography and Index. [Adapted from Preface and inside front cover.]

Human Performance in General Aviation. O'Hare, David, editor. Brookfield, Vermont, U.S.: Ashgate Publishing, 1999. 326 pp.

Although most pilots and flights involve general aviation, the available literature on human performance deals mainly with commercial aviation. Yet the effects on general aviation of changes in areas such as flight instruction, navigation, and aircraft design and instrumentation are just as dramatic. This book provides an overview of current human factors knowledge that applies to general aviation and also of likely future developments. Each chapter is written by a specialist familiar with the operational background of general aviation. Among the topics discussed are strategies for flight instruction, the development of computer-based training, skill development and the involvement of general aviation pilots in incidents and accidents. Contains an Index. [Adapted from inside front cover.]♦

Sources

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Updated U.S. Federal Aviation Administration (FAA) Regulations and Reference Materials

Advisory Circulars

AC No.	Date	Title
91-58A	Feb. 10, 2000	*Use of Pyrotechnic Visual Distress Signaling Devices in Aviation*. (Cancels AC 91-58, *Use of Pyrotechnic Visual Distress Signaling Devices in Aviation*, dated May 27, 1982.)
70/7460.2K	March 1, 2000	*Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace.* (Cancels AC 70/7460-2J, *Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*, dated Nov. 29, 1995.)

Accident/Incident Briefs

Vibration, Banging Noises Prompt Landing at Departure Airport

Inspectors trace Boeing 757's problem to engine surge during acceleration.

FSF Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Passengers Report Flames Coming From Left Engine

Boeing 757. Minor damage. No injuries.

The airplane had just departed from an airport in Spain when the flight crew heard three loud bangs and felt vibrations. The left exhaust gas temperature (EGT) indication exceeded the redline.

The flight crew leveled the airplane at 3,000 feet and reduced left-engine thrust to idle. Passengers reported flames coming from the left engine, and the crew declared an urgency, shut down the left engine and conducted a precautionary landing at the departure airport. (The International Civil Aviation Organization has said that "urgency" means "a condition concerning the safety of an aircraft or other vehicle, or of some person on board or within sight, but which does not require immediate assistance.")

Inspection of the bleed valve control unit (BVCU) and transient pressure unit (TPU) indicated that there had been an engine surge. Maintenance technicians replaced the fuel flow governor, the BVCU and the TPU. Examination of data from the digital flight data recorder confirmed that the engine had surged. The engine manufacturer said that the surge probably was a result of loss or damage of the high-pressure compressor rotor-path lining, a problem sometimes associated with high-time engines. The engine was removed for further examination and refurbishment.

Computer Problem Blamed for Faulty EICAS Warnings

Boeing 767. No damage. No injuries.

The captain reported a normal takeoff roll in visual meteorological conditions at an airport in Portugal, followed by normal rotation. As the airplane's nose pitched up 10 degrees to 12 degrees, the stick shaker activated for two seconds to three seconds. The captain observed several messages from the engine indication and crew alert system (EICAS), including "FWD CARGO DOOR."

"I looked back to confirm attitude, etc., and in that time, everything returned to normal," said the captain.

The captain said that the EICAS "RECALL" function showed no abnormal indications.

Earlier, during turnaround at the airport in Portugal, the configuration warning had sounded for 10 seconds to 15 seconds while the engines were not operating, and EICAS messages appeared for "FLAPS" and "PARKING BRAKE."

Examination of the airplane revealed that the no. 9 slat-position sensor had failed, causing activation of the stick shaker. The sensor was replaced, and all proximity switches were tested. There were no reports of a recurrence of the cargo door message.

The airline's flight safety officer said that modification of EICAS computer variants resulted in occasional false indications while engines were not operating and that this situation can result in configuration warnings when the flaps are retracted and the parking brake is on; the indication disappears when the engines are started. The computers were being returned to the manufacturer for further modification.

Collision With Sea Gulls Disables Engine

Airbus A340. Minor damage. No injuries.

An airplane en route from Turkey to South Africa was flown back to the departure airport after colliding with a flock of sea gulls shortly after takeoff. The collision caused the pilots to shut down one of the airplane's two engines. The airplane's radar antenna also was damaged.

The panel had separated from the airplane just above the lower edge, which remained fastened to the airplane. The panel was not recovered. Inspection revealed that two anchor nuts for the leading-edge fasteners were cross-threaded but that the other nuts were serviceable.

The operator determined that the panel had separated along the forward edge and that the top and rear side attachments had failed because of overload. The panel had been checked for security two months before the incident occurred.

Wing Panel Separates on Takeoff

Boeing 757. Minor damage. No injuries.

The aircraft was departing from an airport in England when a passenger told flight attendants that he had heard a "thud" from the right side of the airplane. Aircraft handling and aircraft systems were normal, and rain and darkness prevented crewmembers from visually inspecting the airplane.

After the airplane was landed at another airport in England, an examination by maintenance technicians showed no defect; the "thud" was assumed to have been the sound of shifting baggage. The first officer conducted a walk-around inspection of the airplane and found no defect.

After passengers boarded the airplane, a maintenance technician, who had not participated in the postlanding examination of the airplane, observed that a three-foot-square (0.9-meter-square) panel was missing from the overwing fairing area.

The panel had separated from the airplane just above the lower edge, which remained fastened to the airplane. The panel was not recovered. Inspection revealed that two anchor nuts for the leading-edge fasteners were cross-threaded but that the other nuts were serviceable.

The operator determined that the panel had separated along the forward edge and that the top and rear side attachments had failed because of overload. The panel had been checked for security two months before the incident occurred.

Air Taxi Commuter

Smoke Near Engine Prompts Evacuation of Airplane

Saab 340B. No damage. No injuries.

Night instrument meteorological conditions prevailed for the scheduled flight from an airport in the United States. The flight crew taxied the airplane to the departure runway with the right engine operating and the left engine not operating.

As they taxied, the crew attempted twice to start the left engine, and when their attempts failed, the captain decided to return to the gate.

When the right engine was shut down, the flight attendant observed what appeared to be smoke near the left engine. She notified the captain, who ordered an evacuation from the right side of the airplane. When the flight attendant opened the right-side door, in front of the right-engine propeller, the propeller was still rotating. By then, there was no smoke near the left engine; the left-side door was opened, and passengers and crew disembarked.

Cylinder Separates From Engine Before Takeoff

Britten-Norman Islander. Minor damage. No injuries.

The captain had just applied full power for an early afternoon takeoff from an airport in England when the airplane yawed to the right and the right-engine rpm decreased. The captain rejected the takeoff and shut down the right engine.

Examination of the engine revealed that the no. 3 cylinder had become detached from the engine. The piston crown was within the cylinder, and the gudgeon-pin lugs and the piston skirt were broken.

The engine, the no. 3 cylinder and some metallic debris were returned to the company that had overhauled the engine about 220 flight hours before the incident. An examination revealed that all eight cylinder-attachment studs had failed. The examination also revealed that cadmium plating was undamaged on parts of two cylinder hold-down nuts and detached portions of the cylinder-attachment studs, indicating that they had not been torque-tightened onto the cylinder flanges.

The company that overhauled the engine said that its final inspection involved checking the accessible cylinder hold-down nuts to ensure that the nuts were not loose.

"The inspection records indicated that this had been done, although it appeared at odds with the evidence of the undamaged cadmium on the nut faces," the report said.

Tail Skid Damaged During Landing in Gusty Winds

Fokker F27 Mk 500. Substantial damage. No injuries.

Surface winds were reported from 240 degrees at 27 knots, with gusts to 33 knots, as the airplane approached an airport in England for a landing just before midnight. Because of turbulence, the captain added five knots to the approach speed.

As the airplane was flown across the runway threshold, the captain observed a 10-knot decrease in indicated airspeed. Power was reduced, and the sink rate was checked with the elevator just before the touchdown, which the captain described as firm.

After the engines were shut down, a maintenance technician informed the captain of damage to the airplane that had been caused when the airplane's tail scraped the ground after landing. The tail skid and the area to the rear of the pressure bulkhead were damaged, there was a hole one foot (0.3 meter) long in the fuselage skin, and a section of under-fuselage skin in front of the bulkhead was scraped.

The flight operations manager said that, under normal conditions, pilots close the throttles just before touchdown, but in gusty crosswinds, closing the throttles can result in an immediate loss of lift and an increase in the descent rate that cannot be stopped by increasing pitch attitude.

Corporate Business

Electrical Wire Cited in Engine Fire

Gulfstream IV. Minor damage. No injuries.

The airplane was cruising at Flight Level 410 on an afternoon repositioning flight in visual meteorological conditions in the United States when flight crewmembers observed a low fuel-flow and a low exhaust gas temperature for the left engine, as well as rising indications on the oil temperature gauge and the fuel temperature gauge for the left engine.

The captain asked air traffic control (ATC) for clearance to descend, and when he reduced power, the fire-warning light for the left engine illuminated. The pilot pulled the left fire T-handle, and the fire-warning light was extinguished. Crewmembers secured the engine and asked ATC to request that emergency equipment be available when the airplane landed. The landing was uneventful.

Maintenance personnel said that their examination of the airplane revealed that the lower forward area of the left engine nacelle had been damaged by fire and that an electrical wire coming from an alternator in the engine had chafed against the no. 4 fuel line.

Separated Hinge Freezes Aileron Movement

Learjet 24B. Minor damage. No injuries.

Visual meteorological conditions prevailed when, shortly after departure from an airport in the United States, the pilots retracted the landing gear and the wing flaps and then heard the landing-gear warning horn.

The pilot said that he observed that the airplane was in a steep right bank and that the first officer was having trouble controlling the airplane. The captain took the controls and discovered that, even when he held "extreme forces on the control wheel in [an] attempt to roll the aircraft back to the left, the aircraft continued to roll to the right."

The captain reduced power from the left engine and increased power from the right engine, decreasing the amount of right bank angle. The flight crew reported the problem to air traffic control and continued turning right for a landing at the departure airport.

Examination of the airplane revealed that the right wing-flap inboard hinge had separated from the wing flap, causing the wing flap to shift so that the outboard edge of the flap contacted the inboard edge of the right aileron and forced the aileron upward.

Other General Aviation

Safety Harnesses Fail During Forced Landing

De Havilland Tiger Moth. Substantial damage. One serious injury; one minor injury.

The airplane was being flown at about 1,100 feet when the engine lost power and sounded rough. As the pilot positioned the airplane for a forced landing on a golf course in England, the engine appeared to resume normal operation. The pilot then completed a 360-degree turn, and the engine lost power again. The pilot landed the airplane in the wooded area next to the golf course. During the landing, both Sutton-type harnesses failed, and both of the airplane's occupants were injured.

The temperature at a nearby airport at the time of the accident was 12 degrees Celsius (54 degrees Fahrenheit) and the dew point was 6 degrees Celsius (43 degrees Fahrenheit), conditions that are considered favorable for formation of carburetor ice at cruise power.

After the accident, the U.K. Air Accidents Investigation Branch noted an earlier order, issued in August 1998 by the U.K. Civil Aviation Authority (CAA), in which the CAA said that it would require the issuance of service bulletins to require the installation of either life-limited Sutton harnesses or improved modern harnesses for de Havilland aircraft equipped with replacement harnesses made from synthetic materials.

Pilot Lands Airplane in Field After Failure to Climb

Piper Arrow IV. Substantial damage. Three minor injuries.

Visual meteorological conditions prevailed for the early afternoon takeoff from an airport in England on Runway 06, and the pilot said that surface winds were from 260 degrees at 20 knots.

The private pilot, who had 114 hours total flight time, including two hours in Arrow IVs, said that, as the airplane became airborne, he retracted the landing gear.

The airplane gained little altitude, and the stall-warning horn sounded. When the pilot lowered the nose to gain airspeed, the landing gear automatically extended. The airplane then struck a power cable and yawed to the left. The pilot tried to retract the landing gear again, but the left-main gear remained down. The airplane was landed in a field, where it went through a hedge and came to a stop next to a railway embankment and a tree. The pilot and two passengers exited through the cabin door.

The pilot said that the engine might have lost power.

Weight-and-balance calculations indicated that the airplane was operating near the maximum allowable takeoff weight of 2,750 pounds (1,247 kilograms). Takeoff performance data in the airplane's flight manual/pilot's operating handbook indicated that, with no wind and no flaps, the takeoff distance from a paved, level, dry runway to an altitude of 50 feet was 670 meters (2,200 feet), with an estimated ground roll of 536 meters (1,760 feet). Runway 06 has a usable length of 400 meters (1,312 feet), with a 200-meter (656-foot) overrun at each end.

Propeller Separates During Flight

Ercoupe 415-C. Substantial damage. No injuries.

Visual meteorological conditions prevailed for the late afternoon flight from an airport in the United States. The pilot said that the airplane was in cruise flight at 4,500 feet and approaching rising terrain when he increased power to gain altitude.

The engine then began to vibrate. The pilot said that he heard a noise and saw a flash to his left, then heard a bang on the left wing. He observed that the upper leading edge of the left wing was dented. Then he heard a whining noise and observed that the propeller had separated.

The pilot landed the airplane in a field, and the nose landing gear collapsed after landing.

Examination of the engine revealed that the crankshaft had separated forward of the oil-slinger flange.

"The fracture spiraled around the crankshaft and suffered a large amount of mechanical damage," the report said. "The laboratory's factual report noted that a fatigue region intersected this damaged area."

The outer surface of the crankshaft was marked by scattered pits of corrosion on the fractured end and a region of fretting that was near a keyway used to secure the propeller to the hub. The report said that the fatigue-initiation area corresponded to the location and depth of the edge of the keyway slot.

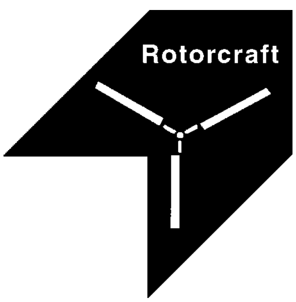
Engine Failure Prompts Hillside Landing

Pitts Special. Substantial damage. One serious injury.

The pilot was flying the airplane back to an airport in Northern Ireland after an aerobatics practice session. When he reduced power to 1,500 rpm to begin a descent, the engine failed.

The pilot chose a site on a hill for an emergency landing and reduced speed to 68 knots for final approach. The airplane stalled, and the right wing struck a hedge. The fuel tank ruptured when the airplane struck the ground. The pilot was covered with fuel, but he crawled out of the cockpit and away from the airplane.

Subsequent inspection revealed no evident cause of the engine failure. The report said that the airplane's Bendix Pressure Carburetor model PSH-BBD had been overhauled in 1977 and that the engine manufacturer's recommended maximum time between engine — and carburetor — overhauls is 2,000 hours or 12 years.



Skid Strikes Terrain as Helicopter Hovers in Mountainous Area

Hughes 269A. Substantial damage. Two minor injuries.

The helicopter was transporting a service technician to a remote radio-repeater site in a mountainous area of the United States. Visual meteorological conditions prevailed for the flight, and winds were reported at 10 knots, with gusts to 15 knots.

The pilot said that, as he flew the helicopter near the intended landing site, he increased collective pitch and slowed approach airspeed, and the rotor revolutions per minute (rpm) began to decrease. The pilot hovered the helicopter over uneven terrain, about 30 feet (nine meters) downhill from the intended landing site.

"I was able to keep the toes of the skids on the uphill slope while trying to get my rpm back up," the pilot said. "I rolled the throttle on and lowered the collective as much as I dared."

The pilot said that, while trying to reposition the helicopter, he increased collective pitch and left-pedal input. The left skid struck terrain, and the helicopter rolled over.

The pilot said that there were no pre-accident mechanical problems with the helicopter. The accident damaged the rotor system, fuselage and tail boom.

Tie-down Strap Damages Helicopter During Attempted Takeoff

Bell 206B. Minor damage. No injuries.

Passengers had just boarded the helicopter for a midday flight in visual meteorological conditions from a remote biological-survey site in the United States. The pilot attempted to start the engine, but a main-rotor-blade tie-down strap was attached to a rotor blade. As the rotor blades began to turn, the tie-down strap struck the helicopter's vertical stabilizer. The stabilizer and the tail boom were damaged. The three passengers and the pilot were not injured.

Helicopter Rolls After Being Landed on Uneven Terrain

Robinson R22B. Minor damage. One minor injury.

The helicopter was on a flight from an airport in England with an occupant who intended to photograph a protest march. Visual meteorological conditions prevailed and winds were calm.

The pilot could not locate the marchers, so he decided to land to inquire about the exact location of the march. He selected a green area, hovered to check the site's suitability and then attempted to land. As the helicopter settled, the pilot felt it move rearward and downward. The pilot applied power and tried to fly the helicopter off the site, but the helicopter began to spin. The low-rotor-warning horn sounded and the low-rotor-warning light illuminated.

The pilot said that he realized that he could not control the helicopter, so he put it back on the ground. Then the helicopter rolled to the right and came to rest. Neither the pilot nor the passenger could get out of the helicopter until bystanders cut the passenger's seat belt and helped both occupants exit through the left-side door.

The pilot attributed the accident to his selection of a landing site with uneven terrain.♦

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