Chapter 5

Safety Data Analysis—What Do We Know

Photo credit: Federal Aviation Administration

An FAA inspector observes an airline captain's instrument flying technique.

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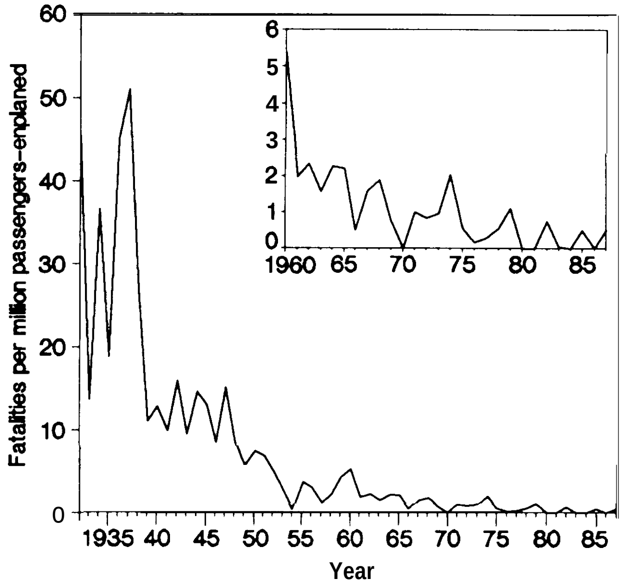
Safety Data Analysis—What Do We Know

Data attest to the safety of commercial aviation; statistics show that over the years the risk of injury or death has steadily declined for airline passengers (see figure 5-l). However, increased traffic congestion and new and different operating patterns have placed unprecedented demands on the aviation system. Measuring recent changes in passenger risk is difficult because accidents are infrequent and data on other safety factors are not systematically collected or maintained (see chapter 4). OTA searched government and industry databases for potential safety indicators, and conducted case studies and surveys of airline management, pilots, and mechanics. The results of these efforts are presented in this chapter. Tasked with assessing commercial aviation safety, OTA focused primarily on Part 121[1] airlines, which carry about 95 percent of the passengers and account for 99 percent of the passenger-miles. However, Part 135 commuter airlines are responsible for the safety of a significant number of people–over 18 million passengers in 1986–and their operations are discussed as well.

[1]Airline operations With airplanes having more than 30 seats or payload capacity greater than 7,500 pounds are certificated under 14 CFR 121. Airlines flying smaller airplanes are governed by 14 CFR 135, or if they choose, the more demanding 14 CFR 121.

Figure 5-1.—Passenger Fatality Rates for Part 121 Scheduled Airlines



SOURCE: Office of Technology Assessment based on data compiled from the Civil Aeronautics Board, Federal Aviation Administration, and National Transportation Safety Board.

ACCIDENT DATA

Accidents and Fatalities

Airline passenger risk is not gauged solely by numbers of fatalities; rather, passenger injury or fatality rates and the rate at which flights end in accidents or crashes are considered the best indicators of past risk. Statistical comparisons for commercial aviation are skewed by differences in aircraft size and in flight distances. For example, since the mid-1970s, Part 121 airline operators have had the fewest fatal accidents; however, because each plane carries many passengers, these operators have had the most passenger fatalities in commercial operations (see table 5-1). To complicate analysis further, over 70 percent of jetliner accidents occur during takeoff, initial climb, final approach, or landing, but these represent only 6 percent of the flight time and even less of the mileage.[2] Therefore, departure information for aircraft and passengers is necessary to estimate risk, and other exposure data do not permit appropriate comparison among the aviation categories. (See chapter 4 for further discussion.)

Although accident data are considered generally accurate and complete, exposure data quality varies with the aviation segment. While most scheduled Part 121 carriers must report extensive traffic data under U.S. Department of Transportation (DOT) requirements, smaller charter, commuter, and air

[2]Boeing Commercial Airplane Co., *Statistical Summary of Commercial Jet Aircraft Accidents: Worldwide Operations 1959&* (Seattle, WA: April 1987).

Table 5-1.–Commerciai Aviation Accident and Fataiity Totals, 1975-87

	Part 121 (scheduled)	Part 121 (nonscheduled)	Part 135 (scheduled)	Part 135 (nonscheduled)
Accidents	269	50	446	1,918
Fatal accidents. . . .	37	11	109	435
Fatalities	1,393	668	431	1,086

SOURCE: Office of Technology Assessment based on National Transportation Safety Board January 198S data.

taxi airlines need report little or none. DOT publishes estimates of all Part 121 and scheduled Part 135 aircraft departures and of all Part 121 passengers carried; these data are used in this chapter. However, OTA had to derive commuter passenger statistics from data collected by the Regional Airline Association (RAA), and estimated air taxi passenger and departure figures from information supplied by the National Air Transportation Association. Due to inherent inaccuracies in these data, the estimates have limited utility for trend analyses, but they are valid approximations of exposure magnitude.

Aircraft departures and passenger enplanements[3] are incorporated into the accident and fatality rates shown in table 5-2. These data show no significant

‘Passenger *departures* would be a better choice here, but the data are not available. Passenger enplanements, or the number of people who board flights, are recorded. Passenger departures equal passenger enplanements on nonstop flights, but are greater on multistop flights.

Fatalities per passenger-carried is one statistical method to normalize the fatality rates among the various industry segments, and offers a sound comparison tool. Fatalities per aircraft-departure, -hour, or -mile would be skewed by aircraft size and range. Since each fatality is not an independent event, these statistics must be used with caution. The three types of risk measurements presented should be considered together.

Tablke 5-2.—Commerciai Aviation Accident and Fatality Rates

Year	Part 121 (scheduled)	Part 121 (nonscheduled)	Part 135[a] (scheduled)	Part 135[b] (nonscheduled)
Accidents per million departures:				
75-77	*4.8*	*53*	*27*	*58*
78-80	*3.7*	*39*	*27*	*54*
81-83	*4.1*	*18*	*12*	*55*
84-86	*2.8*	*22*	*8*	*53*
87	*4.3*	*23*	*14*	*38*
75-87	*3.8*	*30*	*17*	*54*
***Fatal accidents per* million departures:**				
75-77	0.48	10.6	6.3	11
78-80	0.57	6.5	6.5	13
81-83	0.72	2.6	2.6	13
84-86	0.34	8.0	2.1	11
87	0.43	4.6	4.1	12
75-87	0.51	6.5	4.1	12
Fatalities per million passengers-enplaned:[c]				
75-77	*0.34*	*24.2*	*3.4*	*14*
78-80	*0.56*	*0.2*	*4.4*	*13*
81-83	*0.26*	0.1	1.5	11
84-86	0.17	14.7	1.6	9
87	0.41	0.1	2.8	10
75-87	0,33	9.1	2.6	12

[a]Scheduled Part 135 passenger counts estimated by OTA based on Regional Airline Association data.
[b]Nonscheduled Part 135 passenger and departure data estimated by OTA baaed on National Air Transportation Association and other air taxi data.
[c]OTA calculations based on National Transportation Safety Board and Federal Aviation Administration data. All 1987 rates based on estimated passenger-anplanement data.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 19S8, unless otherwise noted.

increase in past passenger risk since the enactment of the Airline Deregulation Act. Indeed, 1984 to 1986 was the safest 3-year period for the large scheduled airlines, and commuter lines improved their safety record substantially, although the downward accident trend faltered in 1987. The inaccuracy of the exposure data limits conclusions regarding safety trends for nonscheduled airlines; however, it appears that air taxi safety remained unchanged.

The relative infrequency of Part 121 charter operations and accidents makes trend analyses for that part of commercial aviation very difficult. Accident rates for scheduled Part 121 and 135 airlines in 198'7 were higher than in recent years,[4] although fatality and accident statistical trends for a single year must be viewed with caution. Since commercial aviation accidents are relatively rare, a single crash of a large jet can skew the statistics.

Large aircraft fatal accidents usually result in either few fatalities or few survivors. From 1975 to 1986, only 17 Part 121 accidents with 10 or more fatalities occurred, and of those accidents, 7 accounted for over 70 percent of the fatalities.

Industry segments have distinctly different accident rates. For example, scheduled Part 121 airlines have significantly better records than other types of air transportation. In contrast, nonscheduled 121 airlines provide less than 3 percent of the Part 121 departures and passengers, but account for 23 percent of the fatal accidents and 32 percent of the fatalities.

Commuter airlines have accident and fatality rates 3 to 10 times above those of the large scheduled airlines. These disparate levels of safety often reflect differences in safety regulations, equipment, and operating environments. For example, commuters may have less advanced technologies or lower training levels than major airlines because they have fewer aircraft in their fleets and fewer passengers per flight to distribute the costs involved. The largest commuter airlines have the best safety records; indeed the 20 largest Part 135 commuters (and Part 121 regionals) have safety records similar to those of jet carriers.[5] Aircraft type and airport characteristics have little influence on the safety record.[6]

Accident Causes and Types

The primary purpose of accident investigations is to determine the probable causes of transportation accidents and to recommend preventive measures. Because most accidents involve a complex congruence of multiple events and causes, aviation accidents do not lend themselves to simple classification or categorizing by type or cause. Moreover, accidents of the same type often require several different preventive measures, although single solutions can sometimes reduce the occurrence rate of a wide range of accidents. For example, ground proximity warning devices reduced markedly the rate of controlled flight into terrain accidents for jetliners (see chapter **7).**

The National Transportation Safety Board (NTSB) currently classifies accidents by a variety of methods, such as causes and factors, sequence of events, and phase of operation. Determining up to five distinct occurrences in the chain of events leading to an accident, NTSB categorizes the accident by the first occurrence. While events such as aircraft component failures and encounters with weather are prominent in first occurrences, human errors are harder to trace from the data.[7]

OTA completed a trend analysis of aircraft component failure as a first occurrence in airline accidents (see figure 5-2). The analysis showed no significant change in the rate for Part 121 carriers and noticeable improvements by the Part 135 commuters during the past decade. Therefore, any recent changes in Part 121 airline maintenance practices appear not to have affected aircraft mechanical reliability in a way that results in more accidents. Data on other common first occurrences, such as encounters with weather or collisions with objects or terrain, cover too broad a range of accident circumstances to provide meaningful trends.

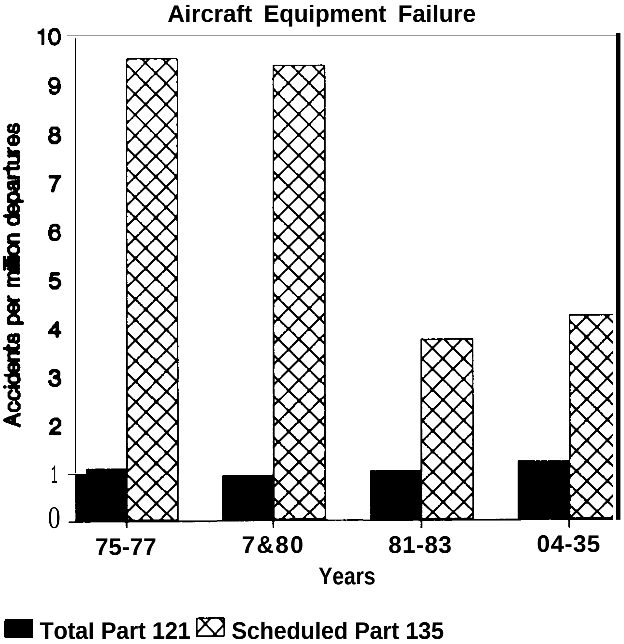
[4]National Transportation Safety Board data released Jan. 13,1988.

[5]Clinton V. Oster, Jr. and C. Kurt Zorn, "Airline Deregulation, Commuter Safety, and Regional Air Transportation," *Growth and Change,* vol. 14, July 1983, pp. 3-11.

[6]Ibid.

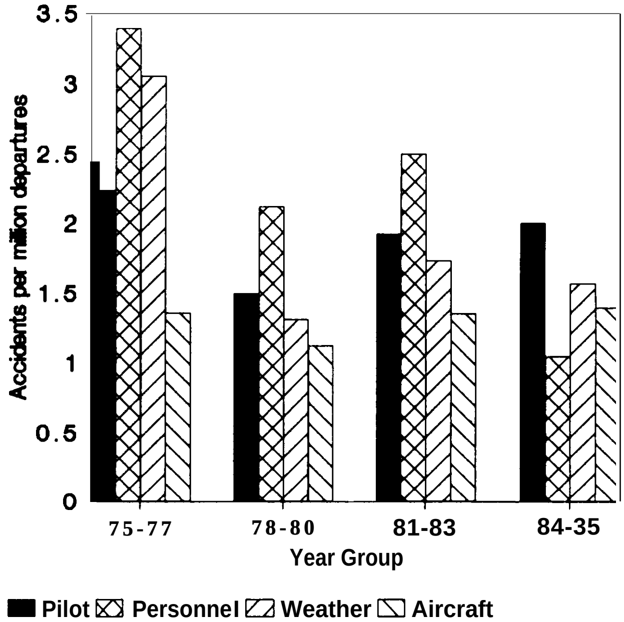
[7]Stan Smith, accident data chief, National Transportation Safety Board, personal communication, May 15, 1987.

Figure 5-2.–Airline Accidents Initiated by Aircraft Equipment Failure



SOURCE: Office of Technology Assessment from National Transportation Safety Board findings of the "first occurrence" in the sequence of events leading to the accidents, 1975-1985.

Figure 5-3.— Part 121 Accident Broad Causes and Factors



SOURCE: Office of Technology Assessment based on National Transportation Safety Board data.

Accident causal data usually imply corrective actions, but since accidents frequently have multiple causes, developing causal categories is difficult. In most cases, each cause is independent of the others, and if one did not exist, the accident might not have occurred. However, analyzing the multiple causes of accidents does highlight the relative prevalence and trends of certain factors. Figure 5-3 shows that while weather- and personnel-related (nonpilot) causal rates for Part 121 accidents diminished prior to deregulation, pilot error and aircraft-related causal rates have changed little.

Boeing, the Flight Safety Foundation, and others have categorized accidents by primary cause. This method gives a clear cross section of accident events and allows accident classification. However, determining which of the multiple causes is the most important is a subjective process. One analysis of major accidents involving large jet transports worldwide found that only 28 percent had a single probable cause,[8] and OTA found that at least 40 percent of Part 121 fatal accidents could not be adequately accounted for by single causes.

Each of these analysis types thus has shortcomings for understanding the complexity of individual accidents. As an alternate method, OTA identified the two most significant sequential causal events in each accident.[9] After reviewing NTSB Part 121 accident briefs, OTA classified all fatal Part 121 accidents from 1975 to 1986 and total Part 121 accidents from 1982 to 1985 according to the classification scheme shown in table 5-3.[10] The relative

[8] Richard L. Sears, "A New Look at Accident Contributors and the Implications of Operational and Training Procedures," *Influence of Training, Operational and Maintenance Practices on Flight Safety,* Proceedings of the Flight Safety Foundation's 38th Annual International Air Safety Seminar (Arlington, VA: Flight Safety Foundation, Nov. 4-7, 1985), pp. 29-51.

[9] For a variation of this method, see Clinton V. Oster, Jr. and C. Kurt Zorn, Transportation Research Center, Indiana University, "Improving Military Charter Safety," unpublished manuscript, November 1987,

[10] Other causal categories are possible, but were not necessary for Part 121 accidents OTA reviewed.

Table 5-3.—Accident Categories

I. Collisions
- A. Controlled flight
  1. Pilot error, then flight path deviation
  2. Pilot error, then aircraft component failure
  3. Personnel error, then flight path deviation
  4. Personnel error, then aircraft component failure
  5. Aircraft component failure
  6. Miscellaneous[a]
- B. Uncontrolled flight
  1. Pilot error, then aircraft component failure
  2. Pilot error, then encounter with weather
  3. Pilot error, then flight path deviation
  4. Personnel error, then aircraft component failure
  5. Personnel error, then weather
  6. Aircraft component failure, then pilot error
  7. Encounter with weather, then aircraft component failure
  8. Aircraft component failure
  9. Encounter with weather
  10. Miscellaneous[a]

II. No collision
- A. Controlled flight
  1. Pilot error
  2. Personnel error
  3. Aircraft component failure
  4. Miscellaneous

[a]OTA classified midair collisions under the miscellaneous category. While a midair could fit possibly into any of the collision categories above, midairs are distinct enough to warrant a separate classification, but are too rare to call for a special category.

SOURCE: Office of Technology Assessment, 1988.

prevalence of accidents according to causal factors is presented in tables 5-4 and 5-5—approximately 60 percent of the fatal accidents by scheduled passenger carriers are initiated by human error, and human error is a causal factor in over 70 percent of these accidents. Aircraft component failure, severe weather, and miscellaneous causes initiated the remaining accidents.

However, when nonfatal accidents are included, the influence of mechanical failure doubles; it is the enabling cause in over 30 percent of all accidents and is involved in almost 50 percent.[11] Additionally, noncollision accidents, which are rarely fatal, result primarily from aircraft component failures. Two fatal noncollision accidents occurred between 1975 and 1986, as compared to 9 nonfatal noncollision accidents between 1982 and 1985; all of these accidents involved aircraft component failures.

[11]The failure of an aircraft component, such as landing gear, may cause substantial damage to the aircraft but not subject the passengers to harm. See “accident” definition, box 4-A, ch. 4.

Table 5-4.–Part 121 Fatal Accidents, 1975-86

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor:						
Pilot	10	1	1	3	15	43
Personnel	3[b]	1[c]	1[d]	0	5	14
Aircraft	4	1	1	3	9	26
Weather	3	0	0	0	3	9
Miscellaneous	2[e]	0	0	1[f]	3	9
All causal factors:[g]						
Pilot	13	2	2	3	20	57
Personnel	3	1	1	0	5	14
Aircraft	6	1	1	4	12	34
Weather	8	0	1	0	9	26
Miscellaneous	2	0	0	1	3	9
Total accidents	22	3	3	7	35	

NOTE: Accidents involving weather turbulence, sabotage, or nonoperational events, such as ramp activities, are not included.
[a]Initiating causal factors may not total 100 percent due to rounding. For all causal factors, numbers do not total 100 percent because most accidents involve multiple causes.
[b]Two accidents involving air traffic control personnel and one involving maintenance personnel.
[c]Accident involved air traffic control personnel.
[d]Ground collision caused by other pilot.
[e]Two midair collisions, including Aeromexico DC-9/PA 28-181 over Cerritos, CA, Aug. 31, 1988.
[f]In-flight collision with parachutist.
[g]All causal factors includes up to two significant causes in the sequence of events leading to the accident.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January *1988.*

Table 5-5.–Part 121 Total Accidents, 1982-85

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor:						
Pilot	14	5	1	3	23	46
Personnel	3[b]	0	0	1[c]	4	8
Aircraft	12	1	2	3	18	36
Weather	2	0	0	0	2	4
Miscellaneous	3[d]	0	0	0	3	6
All causal factors:[e]						
Pilot	16	6	2	3	27	54
Personnel	3	0	0	1	4	8
Aircraft	16	1	2	4	23	46
Weather	8	2	1	0	11	22
Miscellaneous	3	0	0	0	3	6
Total accidents	34	6	3	7	50	

NOTE: Accidents involving weather turbulence, sabotage, or nonoperational events are not included.
[a]For all causal factors, numbers do not total 100 Percent.
[b]Two accidents involving air traffic control personnel and one involving maintenance personnel
[c]Accident involved maintenance personnel.
[d]Two collisions with birds and one collision while taxiing.
[e]All causal factors includes up to two significant causes in the sequence of events leading to the accident.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988.

NONACCIDENT SAFETY DATA

Since aviation accidents are so infrequent, trends observed over 1 or 2 years of accident data may not be meaningful or indicate actual changes in risk. Despite the long-term improvement in aviation safety, recent concern over near midair collisions (NMACs) and airline operations suggests an interest in more timely information on changes in aviation safety. The Federal Aviation Administration (FAA) currently collects many types of nonaccident safety data, such as information on air carrier operations and incidents, but data quality and system limitations prevent analysis of all but a few years of air traffic safety data.

Database validity is the key problem in nonaccident safety data analyses. While aircraft accidents leave permanent evidence, many nonaccident safety events (such as NMACs) are transitory, and some go unrecognized, while others are inaccurately observed. Moreover, even when an event is observed and recognized correctly, it may not be reported for a number of reasons, including misunderstanding of the reporting process, apathy, and fear of repercussions. Current FAA practices present the reporter with many personal risks, including prosecution for Federal Aviation Regulations (FARs) violations, employer sanctions, and time lost for the administrative process.[12]

Nonaccident data analyses have multiple purposes —while isolated reports of safety events can identify the existence of a problem, data must be collected broadly and consistently to estimate reliably the extent of the problem. Moreover, complete and accurate data are required for understanding the causes of problems and for developing countermeasures. Data system management is the final hurdle for nonaccident data utility. Incoming reports must be properly handled and consistently organized, and the resulting databases must be accessible to analysts.

[12]For these reasons, the Federal Aviation Administration grants immunity and guarantees anonymity to reporters who use the Aviation Safety Reporting System, which is administered by the National Aeronautics and Space Administration.

INCIDENT DATA

Every accident begins as an incident, and incidents are reported much more frequently than accidents to National Aeronautics and Space Administration (NASA), NTSB, and FAA databases. Thus aviation incidents, or ‘(near accidents, ” are good substitutes for sparse accident data. Additionally, more information, especially regarding human performance causal factors, is often available from them for safety investigators, since incidents do not result in fatalities or serious damage.

However, incident data are difficult to collect reliably, primarily because of the imprecise definition for aviation incidents. NTSB considers an "incident" to be ". . . an occurrence other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operations."[13] For specific incident types—an in-flight fire, for example—better criteria are used. If collected and analyzed separately, these specifics offer valuable information on safety.

As the ratio of incidents to accidents varies by accident/incident category, trends in total incidents can be misleading. For example, a rise in a widespread, but low-risk incident type and a decrease in an infrequent, but high-risk incident type results in an increase in the total incident rate, although overall risk may be reduced. Analyses by specific accident/incident type avoids this confusion.

Air Traffic Incidents

Air traffic incidents, such as NMACs, runway incursions, and operational errors, reflect aspects of air traffic system[14] safety. For the most part, analyses of these data address aircraft classes, such as air carrier or general aviation (GA), and airspace categories—Terminal Control Areas, for example. Air traffic incidents are defined more clearly than general incidents and are reported primarily by air traffic controllers and pilots.

Near Midair Collisions

An in-flight collision involving a passenger transport is among the most feared of aviation accidents. While such collisions are rare events (see table 5-6), they account for roughly 10 percent of fatalities. Statistics indicate a very low risk with no discernible trends in these accidents, but annual increases in the reported number of NMACs have created concern.

[13]49 CFR 830.2 (Oct. 1, 1987).

[14]The "air traffic system" includes all flight operations, not only those under air traffic control.

Table 5-6.—Commercial Aircraft Midair Collisions

	Part 121 (total)	Part 135 (scheduled)	Part 135 (nonscheduled)
1975-1977	0	2	4
1978-1980	1	0	9
1981-1983	0	2	8
1984-1986	0[a]	1	2
1987	0	1	2

[a]A midair collision between an Aeromexico DC-9 and a private PA 2&181 occurred over Cerritos, CA on Aug. 31, 1988.

SOURCE: Office of Technology Assessment based on National Transportation Safety Board data as of January 1988

FAA and NASA collect data on NMACs independently, but both agencies rely on voluntary reports. FAA investigates each report and can impose penalties if regulations were violated. In contrast, NASA maintains the anonymity of the reporter and FAA guarantees immunity from potential penalties that could result from the event. FAA has cited its own mismanagement of NMAC report paperwork, as well as changes in public perception and awareness, as reasons for not using the FAA NMAC database for trend analysis. FAA corrected its report processing problems in 1985,[15] and claims that recent increases in NMAC rates more closely reflect reality.[16]

OTA finds that substantial evidence points to analytically valid subsets of NMAC data. FAA recovered many missing 1983 and 1984 NMAC reports, and FAA and NASA databases show similar trends from 1981 to the present; moreover, NASA data were not subject to management problems during this period. However, this does not preclude changes in pilot (the primary reporters of NMACs) perception from influencing both sets of data.

Air carrier pilots are a relatively homogeneous group who are very aware of incident reporting procedures and may thus be more likely than GA pilots to report an observed NMAC. Moreover, air carrier pilots fly primarily under instrument flight rules (IFR) and, if involved in an NMAC, would

[15]Burt Solomon, "FAA Runs Into Some Heavy Turbulence in Aviation's Worst Year for Fatalities, " *National Journal*, Oct. 12, 1986, pp. 2313-2316.

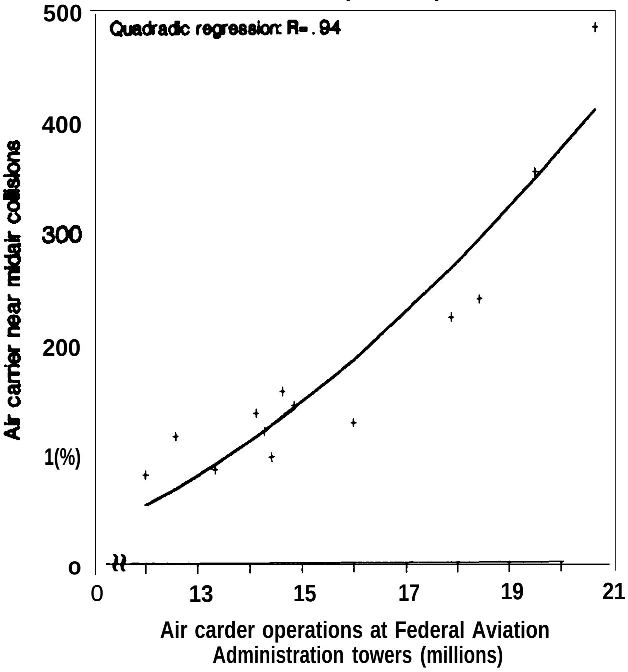
[16]Donald Engen, administrator, Federal Aviation Administration, "Aviation Safety (Near Midair Collisions and Runway Incursions)," testimony before U.S. Congress, House Committee on Public Works and Transportation, Subcommittee on Investigations and Oversight, Apr. 9, 1987, p. 66.

be in communication with air traffic control (ATC). For reporting purposes, aircraft involved in NMACs are grouped into three categories: air carrier (Part 121 or 135 operators), GA, and military. Air carrier and GA aircraft are involved in over 95 percent of the reported NMACs.[17]

The FAA Office of Aviation Safety found that less than 20 percent of air carrier/GA and military/GA incidents are reported by the GA operators involved.[18] In a comparative analysis of FAA and NASA NMAC reports, OTA found that about 18 percent of the air carrier-involved NMAC reports in the FAA database show up in the NASA data, as contrasted to less than 10 percent of all FAA NMAC reports. Air carrier NMAC data are more consistent than the other subsets of the data, including the total.

Theoretically, the NMAC rate (and the actual collision rate) is proportional to traffic density raised to some power.[19] Since traffic density data are not readily available, OTA used aircraft operations (takeoffs and landings) at towered airports as a substitute. OTA found that the annual number of air carrier operations and the annual number of reported air carrier-involved NMACs fit a nonlinear model well, as shown in figure 5-4. Despite the implication that increases in air carrier traffic will result in higher numbers of air carrier NMACs, accident data do not bear out a correlation between increasing frequency of reported NMACs and increasing risk of collision. The sparseness of the collision data prohibit determining valid trends; we simply cannot tell with current information.[20]

Figure 5=4.—Air Carrier Near Midair Collisions (1975-87)



SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

Runway Incursions

A collision between two airliners on a runway can be just as devastating as a collision in the air; the greatest loss of life in aviation resulted from such an accident involving two B-747s in Tenerife in 1977. Near collisions on the ground raise many of the same concerns as near collisions in the air.

Currently, runway incursions (see definition in chapter 4) as well as other ground incidents caused by an air traffic controller's actions are reported as "operational errors," and when the pilot is at fault, the event is reported as a "pilot deviation." Additionally, some runway incursion reports end up in the NMAC database.[21] Because FAA has not systematically collected data or published analyses on runway incursions and does not maintain a separate runway incursion database (although it plans to establish one),[22] information on runway incursions must be extracted from these other databases, which have been maintained in their current form only since 1985.

[17]U.S. Department of Transportation, Federal Aviation Administration, "Selected Statistics Concerning Pilot Reported Near Mid-Air Collisions (1983 -85)," June 1986, p. A2-1.

[18]Ibid, p. 8

[19]The near midair collision risk is proportional to the number of potential conflict pairs of aircraft (approximately the number squared) per area for a two dimensional, random flight path model. See Walton Graham, Questek, Inc., "Technology Requirements as Derived From Accident Rate Analysis," AIAA-80-0918 (Washington, DC: American Institute of Aeronautics and Astronautics, May 1980).

[20]The Federal Aviation Administration's Office of Aviation Safety's Safety Analysis Division has several studies underway of near midair collisions by airport and airspace location.

[21]Brian Poole, Federal Aviation Administration, Office of Aviation Safety, personal communication, Jan. 21, 1988.

[22]Ken Chin, Federal Aviation Administration, Office of Aviation Safety, personal communication, Nov. 3, 1987.

While most runway incursions are probably observed by the controllers or pilots involved, an NTSB special investigation found that the data are not complete and are difficult to use effectively .2] NTSB uncovered several runway incursions, classified as operational errors or pilot deviations, that controllers did not formally report.[24] FAA's Air Traffic Evaluations and Analysis Division reviews all operational error reports and has established a task group to study surface incidents, and the Office of Aviation Safety tracks statistics regarding surface deviations by pilots.

NASA collects runway "transgression" data through Aviation Safety Reporting System (ASRS) reports. Runway transgressions are defined as any erroneous occupation of a runway at a controlled airport by an aircraft or other controlled vehicle. Traffic growth resulting in more reported NMACs may have a similar influence on surface problems; indeed, runway transgressions show similar trends to those of NASA and FAA NMAC reports. However, while transgressions have been increasing, the conflicts (or near collisions) resulting from them have not increased since 1984, according to ASRS data.

Operational Errors and Deviations

Since 1985, FAA has maintained an automated database of operational errors and operational deviations. Simply phrased, these incidents are occurrences attributed to ATC operations that result in improper separation between an aircraft and another aircraft, terrain, or obstacles (operational error) or infringement upon protected airspace by an aircraft (operational deviation). (See chapter 4 for complete definitions.)

The quality of operational error/deviation data varies by subset. Operational error/deviation data are categorized by type of ATC facilities—terminals[25] and en route centers. For centers, operational errors and deviations are tracked automatically by the Operational Error Detection Program, while error information at terminals comes primarily from reports initiated by the personnel directly involved in the incident. (At en route centers, 57 percent of errors and deviations are reported by automatic systems, as compared to 10 percent at terminals. Not surprisingly, the reported error/deviation rate at centers was nearly four times greater than at terminals, yet terminals handle about twice the number of aircraft.)[26] Consequently, many aspects of operational errors/deviations can be more accurately analyzed when the data are grouped by ATC facility.

Without the aid of significant technological developments (see chapter 7), air traffic controllers faced increasing workloads throughout the past decade. The average number of flight operations handled by each controller[27] in recent years is higher than for any period except the one immediately following the controller's strike in August 1981,[28] as illustrated in figure 5-5. (Actual workloads vary considerably at individual centers and terminals.)[29]

The FAA Office of Aviation Safety has analyzed in detail the 1985 and 1986 data. The precise relationship between growing traffic levels and error rates is not clear. Overall traffic and controller workload have increased since 1985, and reported controller errors declined from 1985 to 1986, and then increased at half the rate of the traffic growth in 1987. FAA investigated error/deviation rates for a given year at facilities with varying traffic loads. For center data (the most reliable), there are no well-defined relationships between error/deviation rates and the average annual workload per controller or the number of operations at the regional or individual facility level.[30] For terminal data, no correlation was found at the individual facilit y level, though some was observed on a regional basis. Higher error/deviation rates occurred for terminals in regions with the lower controller workloads.[31]

'~ National Transportation Safety Board, *Special Investigation Report-Runwa y Incursions at Controlled Airports in the United Stares,* NTSB/SIR-86/01 (Washington, DC: May 6, 1986).

[24] Ibid.

[25] Terminals are the facilities, such as towers and approach controls, that provide air traffic control services at airports.

[26] Ibid, p. 3-7.

*'For this analysis, a "controller" is a Federal Aviation Administration employee who directs air traffic. Full performance level controllers, qualified on all air traffic control positions in a tower or center, and developmental controllers, qualified on at least one position, are included.

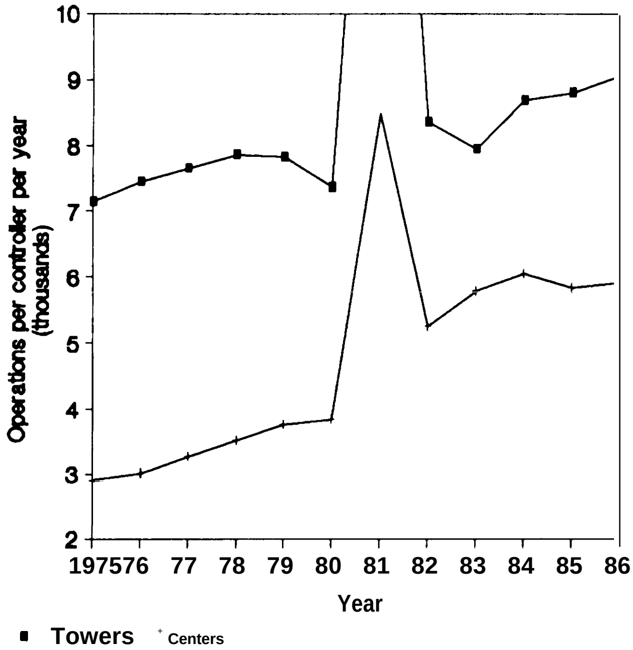
[28] For the latter half of 1981 and much of 1982, some military air traffic controllers were assigned to centers and towers.

[29] U.S. Department of Transportation, Federal Aviation Administration, *Profile of Operational Errors and Deviations in the U.S. Air Traffic System, Calendar Year 1985* (Washington, DC: May 1986), pp. 3-55 and 3-58.

[30] Ibid, p. 3-53.

[31] Ibid, p. 3-53.

Figure 5-5.—Operations Per Controller at Towers and Centers



NOTE: 1981 rates are distorted due to the walkout and subsequent dismissal of controllers.

SOURCE: Office of Technology Assessment based on Federal Aviation Administration data.

The causal categories for operational errors and deviations are human error, equipment problem, and faulty procedure;[32] human error was involved 98 percent of the time. FAA examined controller experience as a factor in the human error-caused incidents, and found that center controllers with 6 to 8 years of full performance level experience had by far the highest error/deviation rate in 1985, more than seven times greater than other controllers. (Similar data are not available for terminals.)[33] FAA has not conducted a similar analysis of 1986 or 1987 data.

In summary, the only conclusion that can be drawn from current operational error/deviation data is that no drastic deterioration in ATC safety has occurred. Consistent data over a longer timeframe and additional analysis could shed light on the correlation among incident rates, traffic levels, and controller workload.

[32]Ibid, p. 3-68.
[33]Ibid, p. 3-100.

General Incidents

Although FAA has improved its collection and analyses of ATC incidents since 1985, the agency gives scant attention to other air carrier and GA incidents. Aviation Standards manages the reporting process for these incidents, and maintains them in its Accident/Incident Data System (AIDS). However, AIDS has limited analytical capabilities, and the data, as currently processed, have little value as accident data surrogates.

AIDS was established primarily for administrative purposes; FAA cannot ensure easily that airlines report incidents accurately and consistently, and does not make certain that its investigators process the information properly. OTA compared the distribution of incident reports by FAA region to the accidents that occurred in each for the period 1980 to 1985. For this analysis, OTA assumed that geography did not substantially influence the distribution of incident types (the ratio of incidents to accidents depends upon incident type). For the separate categories of air taxis, commuters, and Part 121 carriers, OTA found large regional biases for the ratio of total incidents to total accidents, varying from 78 to 1 to less than 1 to 2. For example, 7 percent of the Part 121 accidents and only 1 percent of the incidents occurred in the Alaska Region, while in the Great Lakes Region, 18 percent of the accidents and 33 percent of the incidents happened.

Most of OTA's sources, inside and outside of FAA, familiar with this incident database believed that it is not valid for analytical purposes. OTA's review of the database and data system confirm that the data should not be used for measuring changes in aviation safety. However, DOT's annual report to Congress pursuant to the Airline Deregulation Act,[34] as well as some journalists, have used AIDS incident trends in published analyses.

The Aviation Safety Reporting System offers an alternate source of incident information. Since reports are made voluntarily, and many pilots do not know of the existence of ASRS, it is difficult to determine the validity of trends in the data over time, although ASRS can provide insight into the

[34]U.S. Department of Transportation, *Annual Report on the Effect of the Airline Deregulation Act on the Level of Air Safety* (Washington, DC: February 1987).

underlying causes of incidents, especially the role of human factors. Consequently, while ASRS analyses can recommend preventive measures for certain classes of incidents, they cannot conclusively determine the rate of incident occurrences. However, ASRS offers supplemental information to other databases on trends and distribution of incidents such as NMACs and runway incursions. Moreover, unlike AIDS, the ASRS reporting format is designed to facilitate computer entry and analysis, the data are reviewed and encoded by experienced analysts, and numerous quality control procedures are used to ensure proper data processing.

OTA examined the relative prevalence of categories of ASRS incidents and compared them to accident data. NASA categorizes incidents by "primary problem, " a classification quite similar to the "primary cause factor" used by Boeing in accident groupings. ASRS data indicate that from 1981 through 1986, the flight crew was the source of the primary problem in 69 percent of the air carrier incidents. Boeing's summary of worldwide commercial jet accidents from 1976 to 1986 also shows flight crew error as the primary cause in about 65 percent of the accidents.[35] Other categories do not match quite as well. ASRS data cite the aircraft and ATC/airports as the problem in about 6 percent and 22 percent of the reports respectively, while Boeing's analyses indicate that the aircraft accounts for 18 percent of the accidents and ATC/airports cause less than 5 percent. Such differences illustrate the errors that can be made in using the ***number*** or *percent* of incident reports to prove a point; nonetheless the incident reports are valuable analytic tools.

[35]The National Transportation Safety Board's broad statistics cannot be used here as easily. Since *multiple* causes and factors are published instead of a ***single*** primary cause for each accident, Aviation Safety Reporting System and National Transportation Safety Board data cannot be compared by percentage.

ACCIDENT/INCIDENT CAUSAL FACTORS

The primary causal factors (see chapter 4) of accidents and incidents are aircraft capabilities, personnel capabilities, traffic environment, weather, and random events. However, all of these factors are not amenable to trend analyses. For example, while weather is a key factor in aviation safety, weather-related accidents usually stem from insufficient weather information or errors in human judgment. Most would agree that a serious degradation of aircraft, personnel, or traffic system capabilities would likely result in a decrease in safety and a need to develop countermeasures. Therefore, changes in these three causal areas offer early warnings for Federal and industry safety attention.

Aircraft Capabilities

Commercial aircraft[36] are designed and maintained to extraordinary standards, with multiple redundancies and wide operating margins. Although their components occasionally fail, few of the failures become serious accidents, and most component failures, even some that result in accidents, have a small direct impact on passenger safety. Indeed, most component failure accidents involve no collisions or crashes, and few fatalities. Aircraft component failure initiates 35 percent of the total accidents by Part 121 scheduled passenger carriers, but just 18 percent of the fatal accidents. Moreover, of the passenger airline fatal accidents initiated by component failures between 1975 and 1986, only one involved an airplane that had become unflyable.[37] Flight crew capabilities played a major role in the other accidents. On the other hand, each component failure indirectly affects safety—from distracting the flight crew to limiting the airworthiness of the aircraft.

FAA, airlines, and manufacturers collect detailed data on the mechanical reliability of commercial aircraft, and the databases show many improving, and few adverse, trends in aircraft reliability. Because of close monitoring of aircraft performance, and the economic incentive to the airlines and manufacturers, aircraft component reliability problems are solved quickly,

[36]Transport category airplanes (see 14 CFR 25), such as the jetliners common to the major air carriers, are the only ones explicitly considered in this section. Aircraft certificated under 14 CFR 23, SFAR 23, and SFAR 41, such as those used by commuter and regional airlines, were not addressed.

[37]DC-10 accident, Chicago, IL, May 25, 1979.

Engine Shutdown and Failure Rates

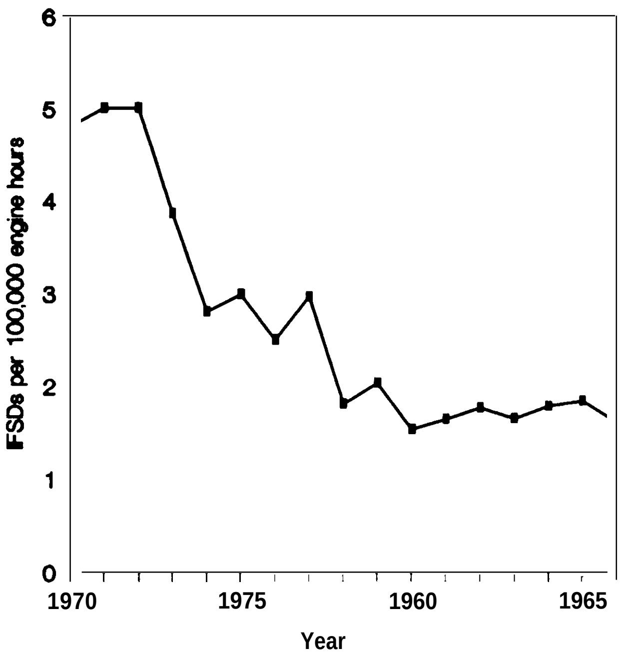
Modern jetliners are capable of operating safely, even in the unusual event of an engine failure in any phase of flight; indeed, engines are sometimes shutdown in flight as a precautionary measure if a problem is detected or suspected. All in-flight engine shutdowns must be reported to FAA; the airframe and engine manufacturers also keep close tabs on these data.

The engine shutdown rate declined for U.S. jet fleets during the past decade, with the current engine shutdown rate for the familiar B-727s, B-7375, and DC-95, falling to about half the rate of the mid-1970s.[38] (See figure 5-6.) A more critical subset of these events, engine noncontainments[39] for a specific aircraft type, occur fewer than 10 times per year worldwide. These are broad statistics; specific engine model series, as well as individual air carrier maintenance practices, should be considered in engine reliability analyses. However, these data show that overall, engine reliability is not a problem.

[38] Federal Aviation Administration Air Carrier Aircraft Utilization and Propulsion Reliability Reports and Boeing Commercial Airplane Co. data.

[39] A noncontainment occurs when an engine component fails and penetrates the outer casing of the engine.

Figure 5-6.–Basic In-flight Shutdown (IFSD) Rate, (domestic operators only) B727/JT8D Engines



SOURCE: Office of Technology Assessment based on Boeing Commercial Airplane Co. data.

Safety Reliability of Other Components

The airframe manufacturers collect data on the failure rates of other aircraft parts, such as hydraulic, pressurization, and electrical systems. OTA obtained data for worldwide fleets only,[40] but they showed that these events also occur infrequently. In-flight pressurization loss and single system electrical power loss happen about 5 times each in a million flight-hours. The trends over time for these events are shallow, and depending on the aircraft type, increase or decrease. Single system hydraulic power loss occurs more frequently (about 60 events per million flight-hours in 1986), but the rates have consistently declined for all the Boeing models.

Airlines are required[41] to report certain aircraft failures, defects, or malfunctions to FAA. This information, along with reports from independent maintenance and repair facilities, are entered into FAA's Service Difficulty Reporting System (SDRS). The large volume of SDRS data-enables FAA to identify aircraft mechanical problems that could otherwise go unnoticed. However, FAA does not enforce the reporting requirements or verify the accuracy of the data. While SDRS data trends are useful as problem alerts, they do not constitute sound measurements of aircraft component reliability changes.

Unscheduled Landings

Due to the cost involved[42] and the inconvenience to the passengers, an airline will divert a flight to an airport other than the final destination only if a serious event occurs. While some unscheduled landings, resulting from weather-related airport closures or passenger medical emergencies, are beyond the control of the airline, maintenance or operating practices may cause mechanical-related flight diversions. If the criteria for deciding on whether to divert remain consistent, trends in

[40] Boeing data.

[41] 14 CFR 121.703 and 121,705 (Jan. 1, 1987).

[42] For example, the average direct operating expense for Boeing 727-200s in air carrier service is over $2,100 per hour.

mechanical-related unscheduled landings will give one indication of changes in the reliability of critical aircraft components. FAA requires that airlines report all unscheduled landings due to mechanical difficulties or malfunctions. However, since these reports are part of SDRS, the problems with database validity discussed above apply.

OTA examined unscheduled landing data from the SDRS database. A comparison of the unscheduled landing rates (reported events per departure) for the major carriers revealed differences as great as a factor of 12 among them.[43] OTA obtained some data, which are assumed to be accurate, directly from a few airlines. The FAA data on unscheduled landings ranged from more than 80 percent below the airline records in one case to 12 percent above in another. OTA concludes that this subset of SDRS data, as currently kept, cannot be used for trend analysis or comparisons among airlines.

Boeing also keeps unscheduled landing data, but the data for U.S. operators was limited. The unscheduled landing rate for the B-747 (the only type with available data) steadily declined since its introduction, falling by half since the mid-1970s.

Personnel Capabilities

Theoretically, human performance reliability could be measured in a similar manner, but data collection on these capabilities is difficult, especially in the operating environment. Human capabilities such as motor skills, alertness, and cognitive skills (for example, decisionmaking and judgment) are believed to play major roles in human error-caused aircraft accidents. Selection, training, experience, and working conditions, as well as physiological, psychological, and sociological status, affect the capabilities of the aviation system work force. However, the magnitude and direction of the interrelationships between and among these factors is poorly understood. Current data on the underlying human failure causes that culminate in accident-causing errors are studied by only a few experts. Consequently, identifying, developing, and implementing countermeasures is hampered by limited understanding of effective ways to modify human behavior and attitudes.

Since human error is involved in the majority of commercial aviation accidents, better collection and analysis of data on human capabilities and failures is the cornerstone of future gains in aviation safety. Additionally, research and data collection to identify innovative and effective human error countermeasures is essential.

Traffic Environment

About 20 percent of the Part 121 fatal accidents, and less than 5 percent of total accidents, result from traffic environment factors.[44] Traffic environment factors include the reliability of the ATC system and airport and airway facilities, along with air traffic levels and mixes. Any one, or several of these variables may be involved in any given accident. However, the traffic environment accidents that fall into specific categories, such as midair collisions or those caused by ATC errors, are so rare that trends cannot be determined.

[43] These differences usually go unnoticed, since Federal Aviation Administration inspectors review data from their respective carriers only.

[44] OTA analysis of National Transportation Safety Board accident briefs.

MANAGEMENT PRACTICES

Managerial practices, from corporate policy-setting to pilot decisionmaking, affect airline safety. The selection and training of employees and the maintenance and operation of vehicles and equipment are major components of the performance capabilities of the aviation system. While FAA sets standards and conditions for these practices, individual airline procedures to meet these guidelines vary widely. This section describes changes in industry-wide practices since deregulation, and highlights significant differences among carriers.

Currently, FAA evaluates management practices through inspections, such as the on-site audits. Ideally, the FAA inspector becomes familiar with the details of an airline's operations and is knowledgeable about practices at other carriers. FAA uses inspections primarily for coaching and disciplining airlines, rather than analysis, and has kept few historical records of inspections.[45] Consequently, FAA has no systemwide qualitative data on airline management practices or changes in them. Moreover, many of the results or effects of management practices are not investigated or are unmeasurable, and the complex interactions of management processes leave few clear cause-and-effect trails.

Seeking supplementary sources for information about changes in management practices over the past decade, OTA examined economic data reported by the airlines, such as flight schedules and maintenance expenses. Additionally, OTA solicited answers to a confidential survey from airline pilots, mechanics, and company officers, and through a contractor, conducted case studies supplemented by on-site interviews with four airlines.

Maintenance

As controlling operating costs became increasingly important, attention focused on whether economic pressures would force carriers to cut corners on maintenance. OTA found that maintenance expenditure data for the major carriers show no evidence that airlines unduly cut costs. Moreover, the

[45] U.S. Congress, General Accounting Office, *Aviation Safety: Needed Improvements in FAA's Airline Inspection Program Are Underway,* GAO/RCED 87-62 (Washington, DC: May 1987), pp. 24-38.

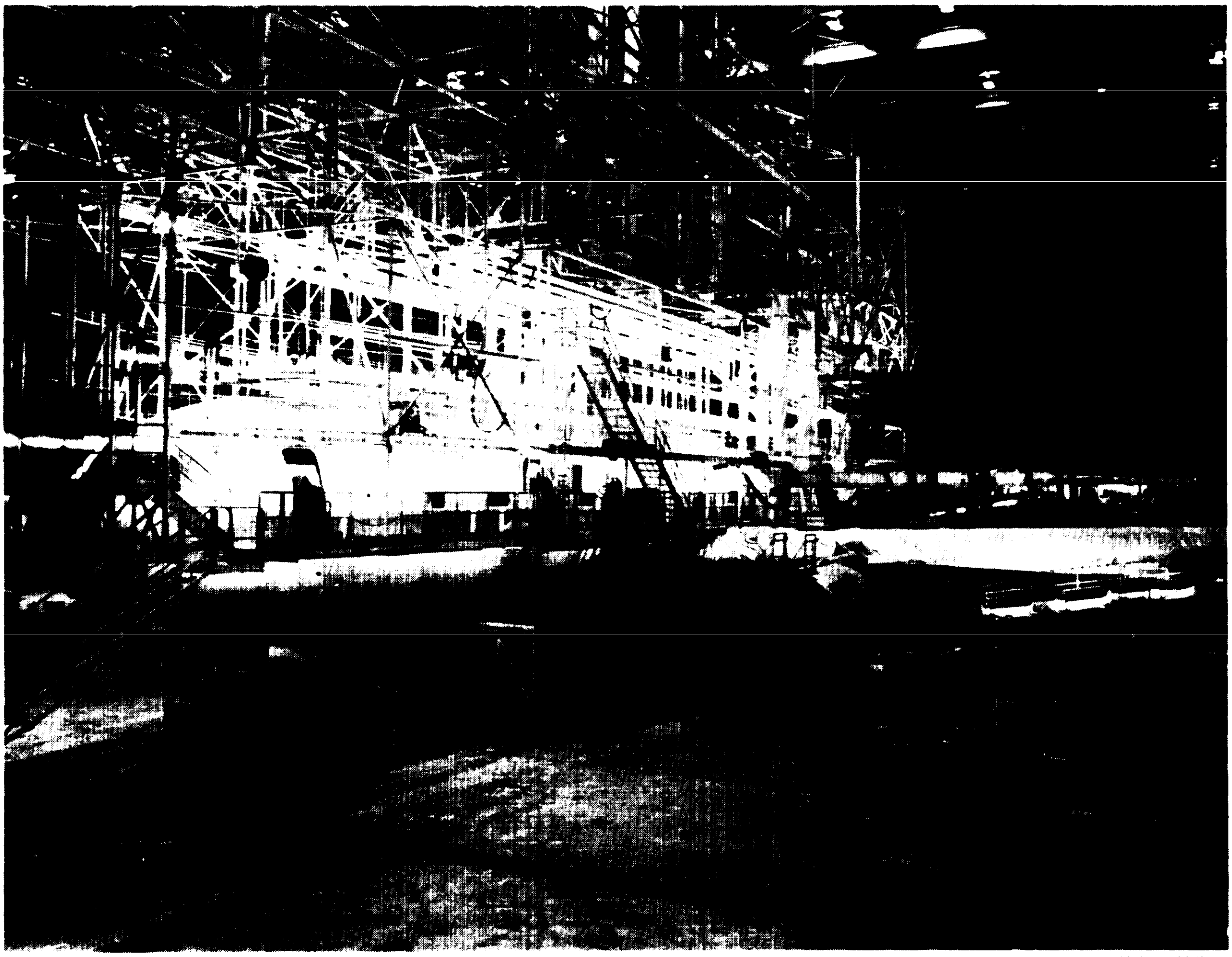


Photo credit: United Airlines

Commercial transport aircraft undergo extensive periodic maintenance.

accident record for the large airlines and data on aircraft mechanical reliability reflect no increase in aircraft system failures, as might be expected if maintenance quality had deteriorated.

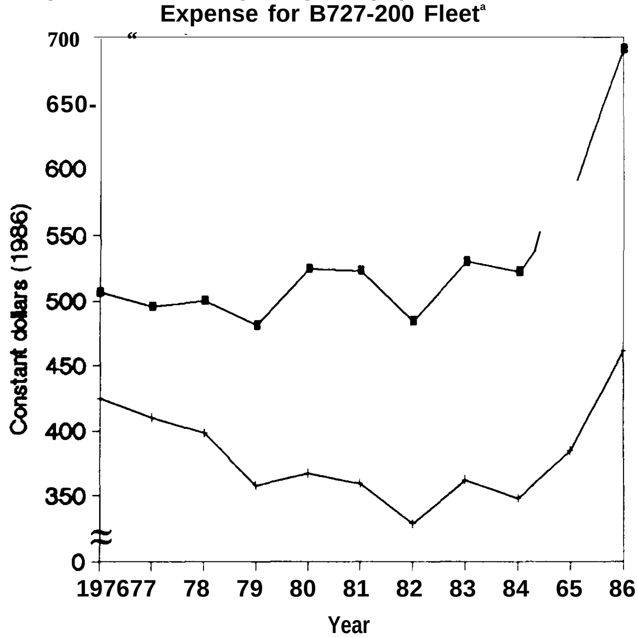
Declines in maintenance expense as a percentage of total operating expense are not good measures of changes in the quality of airline maintenance. Technological advances and efficiencies from modern maintenance inspection devices and inventory management systems affect maintenance expense, while fuel costs and nonmaintenance labor are large and widely fluctuating contributors to operating costs. Maintenance expense trends for specific aircraft types and models are more meaningful. Additionally, since maintenance requirements depend on the amount of aircraft use, expense data should be normalized by flight hours or departures.

Industry-wide on average, flight equipment maintenance expenses (in constant dollars) for specific aircraft models have increased since the early 1980s (see figure 5-7). Due to differences in accounting methods, route structure, and fleet size and age, maintenance expenditure comparisons among individual airlines must be viewed cautiously. OTA examined data for the eight major air carriers that operated the Boeing 727-200 during the past decade (1976 to 1986), since the B727-200 was the most common aircraft model over that period. For each airline, the trends in maintenance costs per flight-hour and per departure have increased since 1982 and reached the highest levels of the decade in either 1985 or 1986.[46]

OTA identified three broad maintenance-related changes within the airline industry that warrant future attention. The quality of maintenance is affected by more contract maintenance, more aircraft leasing instead of owning, and more flight operations and tighter schedules.

Major carriers have consistently contracted with outside companies for about 11 percent (based on dollars spent) of their maintenance needs, while the smaller national carriers contract for about 40 per-cent. The rapid growth of the national carrier segment of the industry (over 250 percent in flight-hours in 10 years v. 21 percent for the majors) caused

Figure 5-7.—Average Flight Equipment Maintenance Expense for B727-200 Fleet[a]



[a]Major carriers only.

SOURCE: Office of Technology Assessment based on Research and Special Programs Administration data.

the total contract maintenance use for the industry to increase from 12.5 percent in 1983 to 16 percent in 1986. While contract maintenance should not be any less safe than in-house maintenance, it places an important aspect of a carrier's safety network in another company's hands. Airlines, by regulation, must provide their own inspectors to monitor contractors' work, as the responsibility for airworthiness rests with the operator-of the aircraft. Contract maintenance, by its nature, is not as easy as in-house work to monitor and manage.

The number and value of aircraft in scheduled and charter services that are not owned by the carriers operating them has grown significantly. OTA estimates that over half of all aircraft transactions for new and used planes in the United States since 1984 involved leases. In 1986, leasing companies bought 10 percent of the total output of Boeing and Douglas; orders were expected to grow to 14 percent in 1987. Since the aircraft's long-term value is not theirs to preserve, some operating carriers changed some aspects of their maintenance programs. For aircraft nearing the end of their leases:

[46]One airline had its highest expense levels with respect to departures only and not to flight-hours.

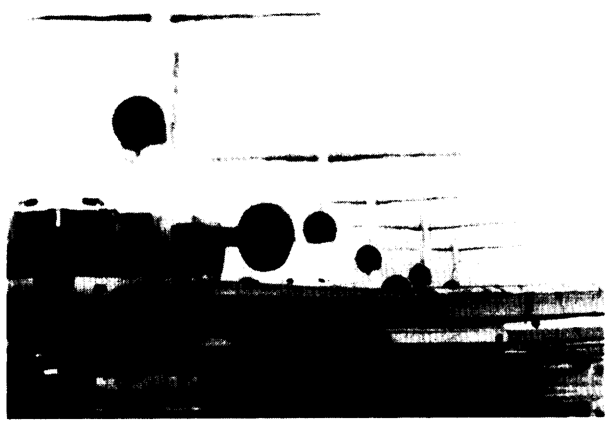
- periodic inspections are used in lieu of permanent fixes for complying with airworthiness directives when possible;
- engines, airframes, landing gear, and other life-limited components (replaced after a fixed number of hours or landings) are near the ends of their estimated lives; and
- corrosion is treated only to the degree required.[47]

Cost reductions such as these affect economic maintenance primarily, as opposed to airworthiness maintenance. For example, an aircraft that has been flown up to a major overhaul requirement can be worth as much as 65 percent less than one that is progressively and currently maintained.[48] While leased aircraft meet airworthiness standards, the question remains open as to whether operator-owned aircraft that may receive more extensive maintenance are safer. No industry-wide data are currently available that compare the safety impact of operator-owned aircraft maintenance to leased aircraft maintenance.

Precise flight schedules are required for efficient operation of hub and spoke systems. OTA research corroborated press reports that pilots and mechanics feel pressure, implicit and, in some cases explicit, to overlook mechanical problems to prevent delays. In addition, special FAA maintenance surveillance conducted in 1987 found that a few airlines improperly deferred maintenance regarding minimum equipment lists, a problem FAA addressed in spring 1988 by tightening required procedures. Finally, OTA research indicates that several airlines do occasionally postpone maintenance, and many choose lower levels of maintenance when cash flow is a problem or when using leased aircraft.

Operations

The major operating changes in commercial aviation over the past decade were the expansion of hub and spoke systems and the record growth in flights by the major, national, regional, and commuter airlines. The primary impacts are that airports have reached their traffic capacity limits, and airline



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schedules have increased demands on the air traffic system equipment, facilities, and personnel, creating traffic congestion and delays (see chapter 7). Additionally, operating practices affect the number of flight-hours and departures experienced by each airline's pilots and aircraft.

Since the early 1980s, the airlines, on average, have increased the number of flight-hours and departures per aircraft per day, although current utilization rates are generally below 1979 levels for aircraft types in existence before deregulation. Since maintenance requirements are primarily flight-hour or cycle dependent, increased utilization necessitates more frequent maintenance on a calendar basis. Additionally, the major airlines have increased the productivity of their mechanic work forces. Seven of the 10 major carriers in existence at the end of 1986 operated more flight-hours per mechanic recently (1983-86) than they did prior to deregulation.

Of greater concern is the effect of increased hours and departures per day on pilot performance. While FARs set limits on flight-hours over various time periods, they do not address duty-hours or departures, both of which affect pilot fatigue and are covered in the aviation regulations of other countries. (See chapter 6.) Few airlines keep track of pilot duty

[47] Simat, Hellieson, and Eichner, "Safety of the Air Transportation System in a Deregulated Environment," OTA contractor report, October 1987.
[48] Ibid.

time; the pilots from five out of eight large airlines responding to OTA's survey indicated that duty time has increased or become more inconvenient since deregulation. On the other hand, pilot flight-hours have not changed much, since they have remained close to the upper limits established either by labor contracts or Federal regulations. Other environmental factors, such as operational complexity and traffic density, also affect pilot fatigue. However, recent considerable gains in the understanding of fatigue have not been transferred to the operating setting.[49]

Hub and spoke systems require finely tuned flight schedules—a single flight cancellation or delay can disrupt the flight connections for passengers in many cities. Self- or management-induced pressures to meet schedules may adversely affect pilot performance and decisionmaking. One pilot stated that he believed intimidation was the intent when his airline made computer checks of pilots' maintenance entries in the aircraft logbooks; those who were perceived by management as making too many entries were called into the chief pilot's office and required to justify their actions. The effects of such stress factors are difficult to quantify. See chapter 6 for further discussion of the effects of stress.

Regional/Commuter Airline Operations

According to RAA, consolidation of the commuter and regional airlines is expected to continue into the early 1990s, with two-thirds of currently operating airlines merging or failing and many becoming wholly or partly owned by the large airlines.[50] This development can be beneficial for safety if the parent company imposes strict operating and maintenance requirements on closely linked affiliates. For example, Allegheny Airlines (now USAir) formed the Allegheny Commuter System in 1967 and required that member airlines adhere to standards more stringent than FAA's in return for marketing, scheduling, and financial services. From 1970 to 1980, the Allegheny Commuters had a better safety record than the jet carriers.[51]

Some major carriers have placed regional pilots on their seniority lists and guaranteed future employment opportunities. Pan Am established such an arrangement after purchasing Ransome Airlines (now Pan Am Express); the pilot turnover rate went from 12 percent per year to approximately zero.[52] Continental Airlines, which owns Britt Airways, PBA, Rocky Mountain Airways, and a major interest in Bar Harbor Airways, established a commuter division to coordinate aircraft purchases and pilot training. Continental plans to replace the 20 types of aircraft used by its affiliates with just 3 types and to the standardize the training of mechanics and pilots. Additionally, Continental is using its regional airlines to train pilots for the parent company. For example, some new hires fly as flight engineers on Continental for 1 year, then become co-pilots on a Continental Express aircraft, and finally move up as co-pilots at Continental (although some will fly as captains at the regional first).[53]

One conclusion of FAA's National Air Transportation Inspection program was that ". . . a significant change in operations of an existing carrier, such as a change in range of operation or in size of aircraft flown . . . can provide a warning signal for potential problems."[54] Yet the principal inspector assigned to a Part 135 commuter often is responsible for a number of other airlines. For example, the principal operations inspector for one commuter airline testified before NTSB that he did not have time to carry out his oversight tasks effectively because he was responsible for 20 other certificate holders.[55] While the expected consolidation of regional/commuter airlines may ease some of FAA's workload in the future, the ensuing turmoil as the reorganization takes place warrants close FAA attention. Moreover, the upturn in the commuter accident rate for 1987 is noteworthy; in only one other year since 1978 did the rate increase from the previous year.

[49]R Curtis Graeber, National Aeronautics and Space Administration, "Ames Research Center, personal communication, Mar. 2, 1988.

[50]*Aviation Week & Space Technology,* "Economics, Code Sharing Threaten Survival of Commuter Airlines," Apr. 27, 1987, p. 57.

[51]Clinton V. Oster, Jr. and C. Kurt Zorn, "Commuter Airline Safety," *Deregulation and the New Airline Entreprenuers*, John R. Meyer and Clinton V. Oster, Jr. (eds.) (Cambridge, MA: The MIT Press, 1984), ch. 5.

[52]Tim Cwik, director of operations, Pan Am Express, personal communication, Mar. 10, 1988.

[53]*Aviation Week & Space Technology*, "Regional Airlines Play Key Role in Continental's Pilot Development," Nov. 16, 1987, pp. 40-41.

[54]U.S. Department of Transportation, Federal Aviation Administration, "National Air Transportation Inspection Program," report for the Secretary, Mar. 4- June 5, 1984, p. 36.

[55]Jim Burnett, chairman, National Transportation Safety Board, "Safety Recommendation to Federal Aviation Administration," letter, Oct. 9, 1986, p. 7.

Employee Selection and Training

Aviation professionals—pilots, controllers, mechanics, and others—are the key components of the air safety system. Their skills and flexibility prevent countless mishaps each day, while their mistakes are dominant factors in aircraft accidents and incidents. Employee selection and training are important methods used by the airlines and the Federal Government for controlling human errors, though they are not panaceas (see chapter 6). Airline flight crew selection and training have changed markedly in the past decade.

Selection

Although flight crew hiring declined between 1979 and 1982, strong traffic growth brought record demand for pilots, and more pilots have been hired since 1983 than in the period from 1967 to 1983. Data collected by the Future Aviation Professionals of America indicate that, on average, a greater percentage of new hires have no military experience, have less than 2,000 hours total flight-time, have no jet or turboprop experience, and have no airline transport pilot or flight engineer certificate. Airlines are also relaxing requirements for age, education, eyesight, and physical size.

Examined by airline type, these changes are more pronounced (see table 5-7). The most notable change[56] for the major carriers is that new hires with less than 2,000 total flight-hours have increased from less than 2 percent to more than 13 percent. For the nationals, the number of new cockpit crew members with military experience[57] has dropped from 82 to 34 percent. At other jet carriers and regional airlines, 29 percent of the new hires have no jet or turboprop experience, compared to less than 3 percent at the larger airlines. Finally, the number of new pilots at the regional carriers with less than 2,000 hours of total flight-time increased from less than 9 percent to 29 percent.

Flight-time or military background, although used for years by the airlines, are only rough estimates of actual pilot skills. Developments in aircraft and training technologies may correct some deficiencies in pilot experience. Accident statistics for the large airlines show no correlation with pilot experience; no aircraft involved in an accident since 1976 was flown by a captain with 2,500 hours or less of flight-time. Actual experience in a specific aircraft type and airline might be more predictive of accident risk. However, OTA is aware of no studies in this area, though NTSB and FAA have warned against pairing inexperienced captains with inexperienced copilots.

The rapid growth of the large carriers has meant increased competition for limited resources, a battle the regional/commuter can rarely win. The demand for more commercial airline pilots places additional pressure on the regional/commuters: they must compete for new hires and at the same time see a large number of their trained pilots leave for the high paying majors. Some small airlines have experienced pilot turnover rates exceeding 100 percent per year.

Training

A comprehensive analysis and qualitative comparative assessment of employee training programs across the airline industry is beyond the scope of this study. The best source for such information would be FAA inspections and audits; however, these data are presently unavailable or inaccessible.

[56] All changes are for the period 1983 to 1986.

[57] The airlines regard military backgrounds highly. The military services have rigorous pilot selection and training requirements; only the most skilled and motivated pilots earn their wings.

However, from the aspect of cockpit management and decisionmaking, the "can do" attitude instilled in the military flyer is not appropriate if applied to commercial passenger operations.

Table 5-7.—Qualifications of New-Hire Commercial Flight Crews (percent, by year)

Pilots with	Major airlines 1983	Major airlines 1986	National airlines 1983	National airlines 1986	Other jet airlines 1983	Other jet airlines 1986	Regional airlines 1983	Regional airlines 1986
Less than 2,000 hours total flight time	1	13	0	11	14	12	9	29
No military experience	46	56	18	66	55	70	83	88
No jet or turboprop flight time	1	2	1	6	24	29	32	28
No air transport pilot certificate and no flight engineer certificate	18	26	24	41	42	56	77	76

SOURCE: Office of Technology Assessment based on Future Aviation Professionals of America data, as of May 1987.

OTA relied upon case studies of selected carriers and the responses to survey questionnaires for insight on quality differences over time and among the airlines.

After a series of highly publicized incidents and increased attention by labor unions to airline training programs, FAA announced an initiative to examine FARs dealing with pilot training. Whether or not the quality of training at some airlines has declined recently, over the past 15 years training has substantially improved. Sophisticated, full-motion simulators used by all the major carriers, or other advanced training devices, allow training scenarios (e. g., flight into severe weather, engine fires, or other extreme emergencies) that could never be permitted in actual training aircraft. Cockpit crew management is a significant factor in a number of air carrier accidents, and crew coordination training, used in conjunction with simulations of operational flights with full crews, adds an important dimension to the background of the modern airline pilot.

At least three U.S. carriers are establishing programs at universities to take pilot candidates with no aviation experience and prepare them for airline careers. General aviation training has dwindled in recent years—the number of private pilot certificates that were issued in 1986 represented a 35 percent drop from the 52,000 issued in 1982. This reduction has come at a time when the airlines are drawing fewer of their pilots from the military. Moreover, early training and experience has a strong influence on a pilot's future performance—even after he has received advanced training.[58]

While most airlines claim to have cockpit resource management or line oriented flight training programs, OTA's research indicates that relatively few pilots experience them. United Airlines and Pan Am are the only carriers with formal, annual crew coordination training programs using full mission simulation for all flight crew members. Most of the pilots surveyed felt that present recurrent training programs are insufficient; however, all confirmed that the training is consistent with current regulations.

Mechanics from three airlines indicated to OTA that they believed that present Federal standards for maintenance training are too low–for example, recurrent training is not required for aircraft mechanics or inspectors. At one carrier, the number of maintenance instructors was cut by 75 percent.

[58]Frank Monastero, T.M. Monitor Corp., personal communication, Mar. 7, 1988.

MANAGEMENT POLICIES

"Safety begins at the top" is an accepted maxim throughout aviation. Senior corporate officials set the safety framework within their organizations by the policies they establish. Although airline and government officials alike profess a willingness to pay any price for safety, in reality, this is impractical. While safety is an important passenger concern, convenience and cost are the primary variables that determine demand for air transportation.[59]

Cost control is critical to the success of any organization, and safety, like fuel, maintenance, or advertising, has a cost. However, safety costs are rarely defined clearly, since management of each element in a system plays a role in safety.

In recent years, a number of airlines have eliminated or cut back engineering, weather, medical, and safety departments, thereby shifting some safety responsibilities within the company and moving other tasks outside the company. While changing aspects of a redundant safety system may reduce safety, a number of questions need to be answered before such actions cause undue alarm. If marginal improvements in other safety areas balanced the loss, two layers of redundancy in 1988 could be more effective than three layers in 1978, for example.

Since corporate actions are many steps removed from accident rates, identifying a clear cause-and-effect relationship may be impossible, although one

[59]Robert W. Simpson, Flight Transportation Laboratory, Massachusetts Institute of Technology, "A Theory for Domestic Airline Economics," unpublished manuscript, January 1977.

measure of corporate safety policy might be relative compliance with safety regulations. Adherence to Federal regulations gives an indication of corporate attitude or competence, both critical with regard to safety. While FAA has records of the enforcement actions taken against carriers that violated regulations, no records have been kept on the amount of inspection activity each carrier experienced over time, preventing calculation of a valid violation rate.[60]

@For further information on the potential uses of Federal Aviation Administration inspection data records for measuring airline safety, see U.S. Congress, General Accounting Office, *Aviation Safety: Measuring How Safely Individual Airlines Operate,* GAO-RCED-88-61 (Washington, DC: March 1988).

CONCLUSIONS AND POLICY OPTIONS

On the basis of its review of accident data, OTA concludes that commercial aviation safety in the 1980s continues to be excellent. However, human errors are the predominant causes of over 65 percent of all accidents that do occur, and this distribution has not changed in recent years. Moreover, weather-related accidents from unexpected severe conditions often involve faulty decisionmaking or communications. Aircraft component failures, factors in over 40 percent of total accidents, are often compounded by human error.

OTA examined numerous nonaccident safety databases for indications of changes in safety risk. While inadequacies in data collection and management or the nature of the safety events limit the validity of such data, nonaccident databases in three categories—ATC environment, aircraft reliability, and human performance—can contribute to aviation safety policy decisionmaking. For example, while data on aircraft component failures indicate improving aircraft system reliability, airline flight operations, especially scheduling and timing, have caused record levels of air traffic and controller workload in recent years. Increases in commercial aviation traffic correspond closely to the rise in reported NMACs, suggesting that future traffic growth is a cause for concern.

The four major causal factors in commercial aviation accidents are human performance, weather, aircraft component failure, and the air traffic environment. OTA concludes that the greatest potential for additional safety problems lies in the areas of air traffic, as continued vigorous traffic growth and increased traffic densities for longer periods of time at more airports could outstrip the capabilities of the traffic system. However, continuing gains in aircraft mechanical reliability and in understanding and coping with severe weather could well outweigh the effect of even a sizable decline in air traffic safety. The rate of pilot error-caused accidents has remained constant for the past decade and few data on pilot performance have been collected and analyzed from the operating environment, making reliable predictions of future trends difficult.

OTA concludes that if Congress wishes to improve commercial aviation safety significantly, enhancing human performance is a top priority. Civilian aviation in the United States lacks a long-term human performance research and development program. While innovative research is best done outside of a regulatory agency, FAA could serve as the focal point and catalyst for cooperative efforts at understanding human performance and the factors influencing it and communicating the findings to the aviation system operators and managers. In the short term, the resources and understanding within FAA, NASA, the Department of Defense, universities, industry, and special interest groups could be combined in advisory working groups. These could provide guidance for developing and disseminating training procedures for upgrading crew coordination and decisionmaking.

An important research area is the optimal design and procedures for use of automation in the cockpit and in ATC facilities. Analyses of human errors and their causes need to be implemented in the airworthiness and operating standards for aviation systems and organizations.

Increasing the capability to predict and detect severe weather such as windshear and communicate this information to the cockpit is another pri-

ority. Data also indicate that air traffic safety will be further improved with the introduction of collision avoidance equipment and the expansion of Mode C transponder requirements. Safety could be upgraded through the addition of conflict alert capabilities at large radar terminals and the development of ground collision alert and runway intrusion detection systems for airports.

Airline management operating practices, along with the ATC system, are the control valves for commercial aviation safety. Maintenance expense data show increased spending (in constant dollars) across the industry during the past 5 years. Some airlines have lowered hiring standards, increased duty time, and increased employee stress through reorganizations and wage cuts. However, the effects of these and other management practices on human performance, and subsequently on system safety, are difficult to quantify. FAA's inside view of airline management procedures through periodic and unannounced audits and inspections is critical for assessing the relative safety value of airline management procedures and any changes over time.

OTA concludes that Federal oversight, through standards, inspections, and enforcement is key to upholding air carrier maintenance reliability and operating safety. Three FAA responsibilities need continued support: the training program for in-0 specters, work force levels sufficient to match changes in industry operating patterns, and auto**mated systems for tracking and analyzing FAA. collected data and airline computerized records.** Based on the operating and marketing changes underway, the Part 135 commuter industry warrants the most critical FAA oversight during the shakeout expected over the next few years. While it is too early to draw conclusions regarding patterns or causes for 1987 commuter accidents, last year's upturn in accidents is noteworthy; in only one other year since 1978 did the accident rate increase from the previous year.

improved safety data collection and analysis by FAA would permit better Federal understanding of developing aviation safety problems. While FAA analyzes air traffic safety data and is upgrading its collection and management of inspection data, the agency could benefit greatly from analysis of air carrier-related safety data, such as operating practices and all types of incidents. FAA principal inspectors have a good understanding of their respective air carriers' safety postures; but they are often unaware of the activities at other airlines. Additionally, FAA requires only that airlines meet minimum Federal standards; FAA might consider encouraging airlines to strive to improve their safety posture above the base level. **A program to consolidate and communicate the safty 'knowledge from each principal inspector and airline would do much to enhance safety.**