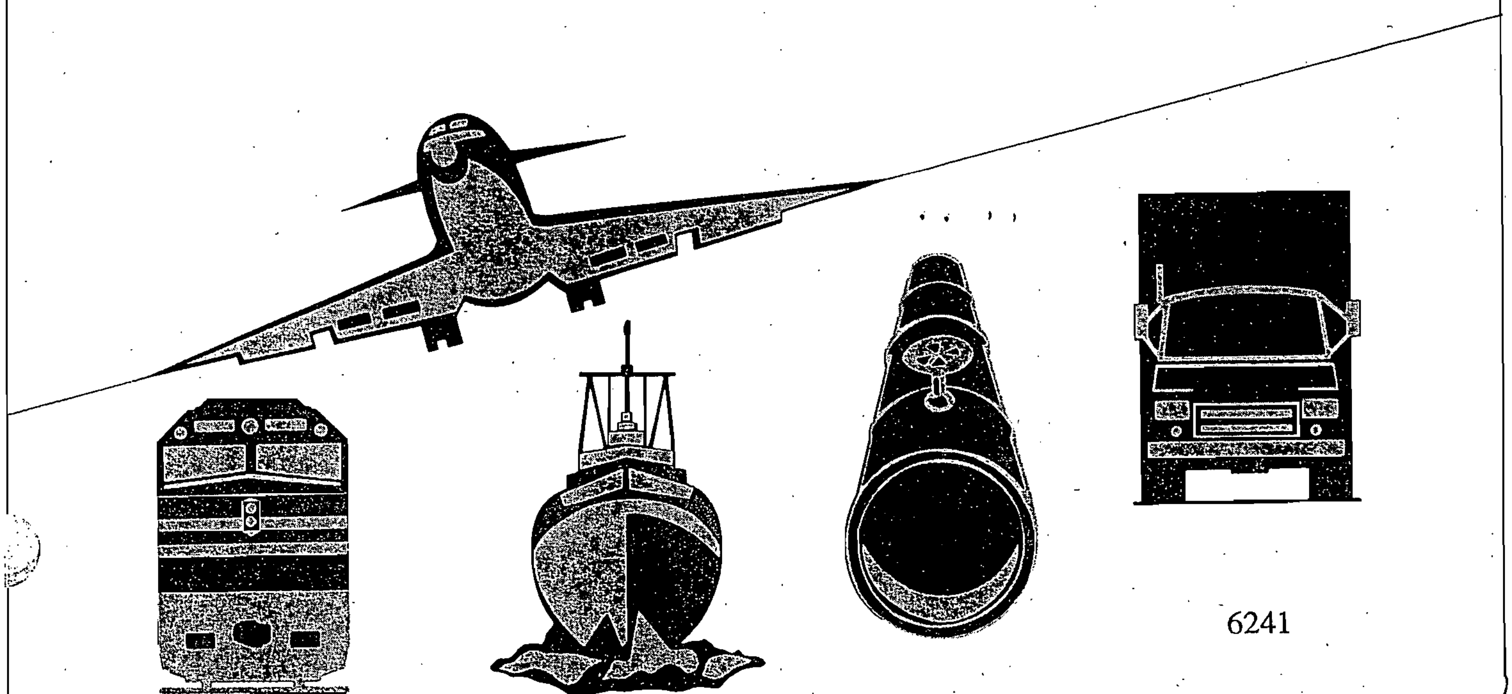
PB94-917001
NTSB/SS-94/01

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SAFETY STUDY

A REVIEW OF FLIGHTCREW-INVOLVED, MAJOR ACCIDENTS OF U.S. AIR CARRIERS, 1978 THROUGH 1990



6241

National Transportation Safety Board. 1994. A review of flightcrew-involved, major accidents of U.S. air carriers, 1978 through 1990. NTSB/SS-94/01. Washington, DC.

U.S. air carrier operations are extremely safe, and the accident rate has declined in recent years. However, among the wide array of factors cited by the National Transportation Safety Board as causal or contributing to airplane accidents, actions or inactions by the flightcrew have been cited in the majority of fatal air carrier accidents. Recognizing that deficiencies in various aspects of the aviation system may adversely influence flightcrew performance, the Safety Board conducted this study to learn more about flightcrew performance by evaluating characteristics of the operating environment, crewmembers, and errors made in major accidents of U.S. air carriers between 1978 and 1990 in which the flightcrew was cited by the Board. Characteristics of the operating environments and flightcrews were identified from information derived from major investigations of 36 accidents and 1 incident. The errors identified were evaluated in light of the contexts in which they occurred. The safety issues discussed in the report are (a) performance of flightcrews when the captain is the flying pilot and the first officer is the non-flying pilot; (b) performance of the non-flying pilot in monitoring and challenging errors made by the flying pilot; (c) adequacy and error-tolerance of checklist procedures during the taxi phase of operation; (d) associations between flightcrew performance and crewmember experience, crewmembers' familiarity with each other, work/rest issues, and flight delays; and (e) adequacy of crew resource management training programs. Safety recommendations concerning flightcrew training and flight operations procedures were made to the Federal Aviation Administration.

The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

Information about available publications may be obtained by contacting:

National Transportation Safety Board
Public Inquiries Section, RE-51
490 L'Enfant Plaza, S.W.
Washington, D.C. 20594
(202)382-6735

Safety Board publications may be purchased, by individual copy or by subscription, from the National Technical Information Service. To purchase this publication, order report number **PB94-917001** from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703)487-4600

A REVIEW OF FLIGHTCREW-INVOLVED, MAJOR ACCIDENTS OF U.S. AIR CARRIERS, 1978 THROUGH 1990

Safety Study

Safety Study NTSB/SS-94/01
Notation 6241

National Transportation
Safety Board

Washington, D.C.
January 1994

Contents

Executive Summary

U.S. air carrier operations are extremely safe, and the accident rate has declined in recent years. However, among the wide array of factors cited by the National Transportation Safety Board as causal or contributing to airplane accidents, actions or inactions by the flightcrew have been cited in the majority of fatal air carrier accidents. Recognizing that deficiencies in various aspects of the aviation system may adversely influence flightcrew performance, the Safety Board conducted this study to learn more about flightcrew performance by evaluating characteristics of the operating environments, crewmembers, and errors made in major accidents of U.S. air carriers between 1978 and 1990 in which the flightcrew was cited by the Board. Characteristics of the operating environments and flightcrews were identified from information derived from major investigations of 36 accidents and 1 incident (for convenience, referred to as an accident). The errors identified in the accidents were evaluated in light of the contexts in which they occurred.

The Safety Board aggregated the information examined in this study from its records of individual accident investigations. Although the data were not analyzed for the purpose of determining trends over time, the Board did identify patterns in the data. In evaluating the results of the study, the Board recognized that major accidents are rare events, and that flightcrew performance during accidents is subject to the simultaneous influences of many operational context variables. Results of this study need to be viewed from this perspective.

The captain was the flying pilot, and the first officer was the non-flying pilot, in more than 80 percent of the 37 accidents. Eleven (73 percent) of the 15 accidents for which information was available occurred on the first day the captain and first officer had flown together. Seven (44 percent) of the 16 accidents for which information was available occurred on the first flight together for the captain and first officer. Seventeen (55 percent) of the 31 accident flights for which information was available had departed late or were operating behind schedule prior to the accident.

Half the captains had been awake more than 12 hours prior to their accidents, and half the first officers had been awake more than 11 hours. Crewmembers who had been awake longer than these median values made more errors overall, and specifically more procedural and tactical decision errors, than did the crewmembers who had been awake for less time.

Regarding flight experience, more than half of the first officers in these accidents were in their first year as a first officer.

Of the 302 specific errors identified in the 37 accidents, the most common were related to procedures, tactical decisions, and failure to monitor or challenge another crewmember's error. Monitoring/challenging failures were pervasive, occurring in 31 of the 37 accidents. In the aircraft accident reports of those 31 accidents, the Safety Board had cited 90 percent of the errors that crewmembers did not challenge as causal or contributing to the cause of the accident; of these, the Board had cited 73 percent as causal. The type of error most frequently unchallenged was a captain's tactical decision error that was an error of omission.

The safety issues discussed in this study are:

- Performance of flightcrews when the captain is the flying pilot and the first officer is the non-flying pilot.
- Performance of the non-flying pilot in monitoring and challenging errors made by the flying pilot.
- Adequacy and error-tolerance of checklist procedures during the taxi phase of operation.
- Associations between flightcrew performance and crewmember experience; crewmembers' familiarity with each other; work/rest issues; and flight delays.
- Adequacy of crew resource management training programs.

As a result of this study, recommendations were issued to the Federal Aviation Administration. The recommendations focus on flightcrew training and flight operations procedures.

Chapter 1

Introduction

In one of the earliest fatal accidents involving a U.S. air carrier, on August 7, 1934, both engines of a Lockheed Electra 10-A failed shortly after takeoff at Milwaukee, Wisconsin. The Bureau of Air Commerce, the Department of Commerce agency responsible for investigating airplane accidents at that time, determined that a probable cause of the accident was "pilot error for failing to attempt to use the right fuel tank...,"[1] which contained more than 50 gallons of fuel. The Bureau also cited two factors that contributed to the error: supervisors had failed to determine the airplane's fuel consumption characteristics before placing it in service, and a fuel tank gauge had failed to function adequately. Consequently, the pilot did not know the amounts of fuel remaining in the airplane's various tanks.

On December 3, 1990, a Douglas DC-9 taxied without clearance onto an active runway at Detroit, Michigan. The DC-9 was struck by a Boeing 727 that was on its takeoff roll. The National Transportation Safety Board determined that a probable cause of the accident was "...a lack of proper crew coordination, including a virtual reversal of roles by the DC-9 pilots, which led to their failure to stop taxiing their airplane...before and after intruding onto the active runway."[2] In addition to flightcrew involvement, the Safety Board cited deficient airport signage, surface markings, and lighting. These factors contributed to the flightcrew's loss of positional awareness while taxiing in conditions of low visibility.

Between the 1934 and 1990 accidents, millions of U.S. air carrier flights were completed safely. Although accidents and accident rates fluctuate from year to year, accident rates have declined markedly. The passenger fatality rate per million enplanements declined from 0.42 in 1970-78, to 0.30 in 1979-85, to 0.18 in 1986-88.[3] Based on the 1986-88 fatality rate, the average

---

[1] Department of Commerce, Bureau of Air Commerce. 1935. Statement of probable cause concerning an aircraft accident which occurred to a plane of Northwest Airlines on August 7, 1934, at Milwaukee, Wisconsin. In: Civil Aeronautics Board Reports. Vol. 1: Air carrier accidents, August 1934 to December 1940. Washington, DC.

[2] National Transportation Safety Board. 1991. Northwest Airlines, Inc., flights 1482 and 299, runway incursion and collision, Detroit Metropolitan/Wayne County Airport, Romulus, Michigan, December 3, 1990. Aircraft Accident Report NTSB/AAR-91/05. Washington, DC.

[3] Oster, C.V.; Strong, J.S.; Zorn, C.K. 1992. Why airplanes crash. New York: Oxford University Press (p. 23).

passenger boarding a U.S. air carrier had a 99.999982 percent chance of surviving the flight. These data indicate that the U.S. commercial air transportation system is extremely safe.

As illustrated by the 1934 and 1990 accidents, an array of environmental, mechanical, and human performance factors cause or contribute to airplane accidents. The Safety Board cited errors[4] by flightcrew members as causal or contributing factors in 124 (42.3 percent) of the 293 total (fatal and non-fatal) Part 121 air carrier[5] accidents that occurred between 1978 and 1990. Flightcrew errors were cited in 29 (55.8 percent) of the 52 fatal Part 121 accidents during this period.[6]

Decades of aircraft accident investigations have shown that accidents in which flightcrew performance is cited typically involve other human, mechanical, and environmental factors as well. When examining the evidence from such accidents, investigators have attempted to understand why flightcrew performance was deficient. The Safety Board has long recognized that air carrier operations are a system, and flightcrews are only one part of the system. Elements of the system well outside the flight deck can contribute to the cause of accidents through their effects on flightcrew performance. For example, in its report on the July 30, 1992, accident involving an aborted takeoff of a Trans World Airlines (TWA) Lockheed L-1011 at John F. Kennedy International Airport in New York, the Board stated that, in addition to the flightcrew's inadequate crew coordination, the probable causes of the accident were "design deficiencies in the stall warning system that permitted a defect to go undetected, [and] the failure of TWA's maintenance program to correct a repetitive malfunction of the stall warning system...."[7]

Recognizing that deficiencies in various aspects of the aviation system may underlie the errors made by flightcrews, the Safety Board conducted this study to learn more about flightcrew performance by evaluating the

---

[4] As used in this report, "error" means a specific instance in which a crewmember responded inadequately to the existing situation. It does not connote improper motivation or intentions on the part of the crewmember.

[5] U.S. air carriers regulated under Title 14 Code of Federal Regulations Part 121 operate aircraft with more than 30 passenger seats or a payload greater than 7,500 pounds.

[6] Source: Safety Board aircraft accident data base.

[7] National Transportation Safety Board. 1993. Aborted takeoff shortly after liftoff, Trans World Airlines, flight 843, Lockheed L-1011, N11002, John F. Kennedy International Airport, Jamaica, New York, July 30, 1992. Aircraft Accident Report NTSB/AAR-93/04. Washington, DC.

characteristics of the operating environments, the flightcrews, and errors made in major accidents of U.S. air carriers between 1978 and 1990 in which the flightcrew was cited by the Board. Information aggregated across these 37 accidents[8] is used to identify and evaluate the characteristics of the operating environments and flightcrews. The errors are evaluated in light of the contexts in which they occurred. Because the study examined previously collected accident data, there was no attempt to perform new analysis of individual accidents or to redefine their probable cause.

Chapter 2 describes the methodology of the study and explains the measures of operational context, flightcrew characteristics, and errors in flightcrew performance. Chapter 3 examines the broad, operational context within which flightcrew-involved accidents occurred. Chapter 4 discusses the characteristics of the flightcrews. Chapter 5 discusses specific errors made by the flightcrews and their association with the circumstances of the accidents and characteristics of the flightcrews, using the results presented in chapters 3 and 4. The last sections present the Safety Board's findings and safety recommendations made as a result of this study.

[8] One case was classified as an incident by the Safety Board. Because it was the subject of a major investigation, equivalent to those received by the accident cases, the incident produced a substantial amount of human performance data; thus, it was included in the study. For convenience throughout the report, it is referred to as an accident.

Chapter 2

Methods

The Safety Board selected for study flightcrew-involved, air carrier accidents that the Board had investigated between 1978 and 1990.[9] Measures of flightcrew characteristics, the operational context within which these accidents occurred, and the specific errors associated with flightcrew performance during these accident flights were extracted from the Safety Board's investigation records and accident reports.

Accident Selection Criteria

An accident was included in the study if all the following criteria were fulfilled: the accident involved a U.S. air carrier[10] operating under Title 14 Code of Federal Regulations (CFR) Part 121, and occurred between 1978 and 1990 (293 accidents); the Safety Board conducted a major investigation of the accident[11] (75 accidents); and the Safety Board cited actions of the flightcrew as a causal or contributing factor in the accident (37 accidents).[12]

Accident selection was limited to air carriers operating under Part 121 because the cockpit voice recorders (CVR) required on airplanes operated under

[9] The study began with accidents that occurred in 1978. Although accident reports were available for accidents that occurred prior to that year, complete information dockets needed to supplement the accident reports were not available.

[10] Safety Board investigations of foreign air carrier accidents occurring in the United States were not included in the study because of potential differences in standard procedures and complications of analyzing foreign language transcripts.

[11] For the study, major investigations were defined as investigations of accidents for which the Safety Board adopted an aircraft accident report or an aircraft accident/incident summary report.

[12] Of the 37 accidents, 23 (62 percent) resulted in fatalities.

Part 121[13] provide documentation of some of the flightcrew's specific actions during the accident sequence and information about the situation at the time the actions occurred. Further, accidents in which the Safety Board conducted major investigations and cited flightcrew actions as causal or contributing factors[14] were selected because these accident investigations include detailed evaluations of flight operations and human performance characteristics, as appropriate to the circumstances of each accident.

The 37 accidents that fulfilled the selection criteria are listed in table 2.1. Although the selected accidents are not necessarily a representative sample of all flights, they do represent all of the flightcrew-involved, Part 121 air carrier accidents for which the Safety Board has conducted a major investigation.

Data Sources

All accident information examined for the study was obtained from the Safety Board's public dockets of the investigations. Five components of each docket were reviewed:

1. Aircraft accident report or summary report;
2. Brief of the accident;
3. Factual report of the operations group chairman;
4. Factual report of the human factors or human performance group chairman; and
5. Factual report of the cockpit voice recorder specialist.

[13] Beginning in 1991, the Federal Aviation Administration required operators under other Parts of the regulations to install CVRs in their aircraft.

[14] Errors also may have been made by flightcrews during accidents in which the Safety Board did not cite flightcrew actions as causal or contributing, but because the flightcrew was not cited, these accidents were not included in the study.

Table 2.1—Aviation accidents included in the safety study

Date of accident	Location of accident	Air carrier
May 8, 1978	Escambia Bay, Pensacola, Florida	National Airlines
July 9, 1978	Rochester, New York	Allegheny Airlines
July 25, 1978	Kalamazoo, Michigan	North Central Airlines
September 25, 1978	San Diego, California	Pacific Southwest Airlines
December 28, 1978	Portland, Oregon	United Airlines
February 12, 1979	Clarksburg, West Virginia	Allegheny Airlines
April 4, 1979	Saginaw, Michigan	Trans World Airlines
June 17, 1979	Hyannis, Massachusetts	Air New England
November 18, 1979	Salt Lake City, Utah	Transamerica Airlines
November 21, 1980	Yap, Western Caroline Islands	Continental Airlines
February 17, 1981	Santa Ana, California	Air California
January 13, 1982	Washington, D.C.	Air Florida
January 23, 1982	Boston, Massachusetts	World Airways
February 16, 1982	King Salmon, Alaska	Reeve Aleutian Airways
January 9, 1983	Brainerd, Minnesota	Republic Airlines
January 11, 1983	Detroit, Michigan	United Airlines
October 11, 1983	Pinckneyville, Illinois	Air Illinois
January 13, 1984	New York, New York	Pilgrim Airlines
May 30, 1984	Chalkhill, Pennsylvania	Zantop International Airlines
June 13, 1984	Detroit, Michigan	USAir
January 9, 1985	Kansas City, Kansas	TPI International Airways
January 21, 1985	Reno, Nevada	Galaxy Airlines
August 2, 1985	Dallas/Fort Worth, Texas	Delta Air Lines
September 6, 1985	Milwaukee, Wisconsin	Midwest Express Airlines
September 25, 1985	Unalaska, Alaska	MarkAir
February 21, 1986	Erie, Pennsylvania	USAir
October 4, 1986	Kelly Air Force Base, Texas	Southern Air Transport
October 25, 1986	Charlotte, North Carolina	Piedmont Airlines
April 13, 1987	Kansas City, Missouri	Buffalo Airways
August 16, 1987	Detroit, Michigan	Northwest Airlines
November 15, 1987	Denver, Colorado	Continental Airlines
December 27, 1987	Pensacola, Florida	Eastern Airlines
August 31, 1988	Dallas/Fort Worth, Texas	Delta Air Lines
September 8, 1989	Kansas City, Missouri	USAir[a]
September 20, 1989	New York, New York	USAir
June 2, 1990	Unalakleet, Alaska	MarkAir
December 3, 1990	Detroit, Michigan	Northwest Airlines

a Aircraft incident.

Establishment of Operational Contexts and Crew Characteristics

Characteristics of the accidents and the circumstances associated with the accident sequences were evaluated to establish the operational context of the accident. Previous accident investigations have identified a large set of operational and human performance factors as being related to the occurrence or seriousness of errors. These factors were examined by the Safety Board for the study and include the following: type of operation; phase of flight; flight delay status; equipment type; crewmember position and function; workload of the crewmember and quality of information available to the crewmember when an error occurred; fatigue; fitness; stress; past performance evaluations; mutual familiarity of the crewmembers; training; experience; and air carrier organizational structure and function.

It was necessary to develop a means of representing each of these operational and human performance factors in a quantifiable way. The development process resulted in defining one or more variables by which each factor could be represented. Next, data were obtained for each variable from the accident investigation dockets. The data were sufficient to examine 24 variables (listed in tables 3.1 and 4.1 of the following chapters). A number of other variables (appendix A) were excluded from further analysis because of missing data or the inability to develop objective and reliable measures from the information available in the accident investigation dockets.

The distributions of the operational context variables and crew characteristics in the accidents were examined and, when feasible, compared with illustrative examples of non-accident flights. The results are presented and discussed in chapters 3 and 4.

Associations between the operational context variables and the number and types of errors were also examined. Although all of the cases examined in the study were accidents, all accidents are not the same. They may be characterized by different types of errors and by different contexts in which the errors were made. To help identify appropriate means of remediation for the various circumstances of accidents that occur, it was relevant to examine subsets of the accidents that shared similar circumstances as reflected in the context variables. These results are presented and discussed in chapter 5. Despite the inherent limitations of accident data,[15] the study identified a

[15] Appendix B discusses limitations of the accident data for comparing flightcrew performance with operational contexts and crewmember characteristics.

number of potentially interesting associations, which are highlighted in the discussions.

Identification of Specific Errors

For this study, an error was defined as a discrete instance in which a crewmember (1) did something that should not have been done, (2) did something inadequately, or (3) did not do something that should have been done. For example, "Did not extend takeoff flaps."

The definition of error was restricted in this study by the limited information that investigators can obtain reliably from an accident. Investigators can infer an inadequate action or inaction by analyzing various components of the accident airplane: the CVR, flight data recorder, control surfaces, instruments, and switches. This type of information was available to accident investigators and used to identify specific errors of action or inaction. But an error in perception, comprehension, attention, knowledge, memory, or reasoning—which may have led to an error of action or inaction—rarely leaves a trace in the wreckage and is difficult to determine conclusively in retrospect. Consequently, these types of errors were not identified.

The 37 accidents were reviewed to identify the specific errors that flightcrews made during the accident sequences. The review methods were developed and validated by a panel comprising the study manager and three other persons with substantial experience and training in both human performance and its application to aircraft accident investigation. Subsequently, the study manager conducted the review of the 37 accidents.

The Safety Board identified specific errors from the following sources of information:

1. Cause/factor statements in the brief of the accident;

2. Statement of probable cause and conclusions in the aircraft accident report; and

3. Factual material and Safety Board analytical statements in the aircraft accident report.

Errors were also identified in the 37 accidents by cross-referencing factual material about specific aspects of flightcrew performance during the accident sequence with factual information (also contained in the accident investigation dockets) about standard operating procedures (SOP) of the air carrier. For example, one SOP, excerpted in the aircraft accident report for one of the cases, instructed the non-flying pilot to call out "...any significant deviation especially when less than 500 feet above field elevation, [including]... airspeed...10 knots above intended approach speed." Based on radar data, the Safety Board found that the actual airspeed of the airplane was well above the criterion specified in the SOP, requiring a challenge by the non-flying pilot. However, the CVR transcript did not indicate a challenge from the non-flying first officer. Further, the Safety Board concluded the following in its accident report: "Crew coordination was deficient due to the first officer's failure to call the captain's attention to aspects of the approach that were not in accordance with [the airline's] operating procedures." Based on the comparison of factual investigation material with information in the SOP, the first officer's failure to challenge the excessive airspeed was identified, for this study, as an error.

A brief narrative was produced to describe each error identified in the 37 accidents (see appendix C). The narratives contain phrases such as "did not initiate" and "over-rotated." These phrases clearly indicate whether the error was one of omission or commission. For some errors, the narrative could have been worded as either an error of omission or an error of commission. For example, the aviation accident report for one of the cases stated that a causal error was "...continuation of the descent well below decision height...without visual contact with the runway environment." The statement connotes an error of commission (continuation of the descent). On the other hand, the event was a continuation of an ongoing action (descending on the approach) when a new action (a go-around) should have been executed. In that regard, the error was one of omission (a failure to act). Because the error involved a failure to change a course of action, it was re-phrased, for this study, as a failure to execute the action that was required: "Did not execute a go-around at decision height."

To classify the nature of this error and the other errors consistently either as one of omission or commission, the following rule was applied: When explicit statements in the accident report refer to an incorrect action, and that incorrect action served to maintain a previously established course of action, the narrative shall be re-phrased to reflect an error of omission. As the example shows, the meaning of the statements in the Safety Board's accident reports (and other information sources) was not changed in applying this rule.

For each error identified in the 37 accidents, the position of the crewmember who made the error was recorded: captain (C), first officer (FO), and, when appropriate, flight engineer (FE). Also recorded was whether the crewmember was serving as flying pilot or non-flying pilot at the time of the error. Finally, the time in the accident sequence that the error occurred was obtained from the CVR transcript. This time was referenced for extracting information about the operational context associated with the error.

A total of 302 specific errors were identified in the 37 accidents. Names of air carriers and crewmembers were removed from data records prior to analyzing the errors and their operational contexts.

Chapter 3

Characteristics of the Operating Environments and Discussion

This chapter examines the characteristics of the 37 flightcrew-involved accidents. It provides the distributions and descriptive statistics of variables that, along with the flightcrew characteristics presented in chapter 4, embody the operational context in which the flightcrews' errors occurred. The variables that describe the operating environments of the accidents—such as local time of day, non-flightcrew causal and contributing factors, and flight delay status—are shown in table 3.1. The table also provides the number of accidents for which data were available.

Period of Day

Sixteen accidents (43 percent) occurred during the afternoon-evening period, between 1400 and 2159[16] local time (see figure 3.1). Eleven accidents (30 percent) occurred during the overnight period, between 2200 and 0559 the next morning. Ten accidents (27 percent) occurred during the morning-midday period, between 0600 and 1359.

Time-of-day data were obtained for a sample of 214,000 non-accident, Part 121 flights conducted during 1988.[17] Of these, 28,200 (13 percent) operated

[16] Times given in this report are expressed by the 24-hour clock.

[17] Because data were not available to sample from the same period as the accidents (1978-90), the non-accident flights of 1988 are not samples of the population of flights most relevant to the accidents. Consequently, comparisons between accident and non-accident data are illustrative only and serve to highlight apparent differences between accident and non-accident flights.

Table 3.1—Variables used to describe the operational environment of the 37 accidents, and number of accidents for which data were available

Name of variable	Number of accidents for which data were available
Local time of day	37
Type of aircraft	37
Type of operation	37
Phase of operation	37
Weather[a]	37
Mechanical[a]	37
Other (non-flight) personnel[a]	37
Flight delay status	31

[a] The variable was examined in terms of whether it caused or contributed to the accident.

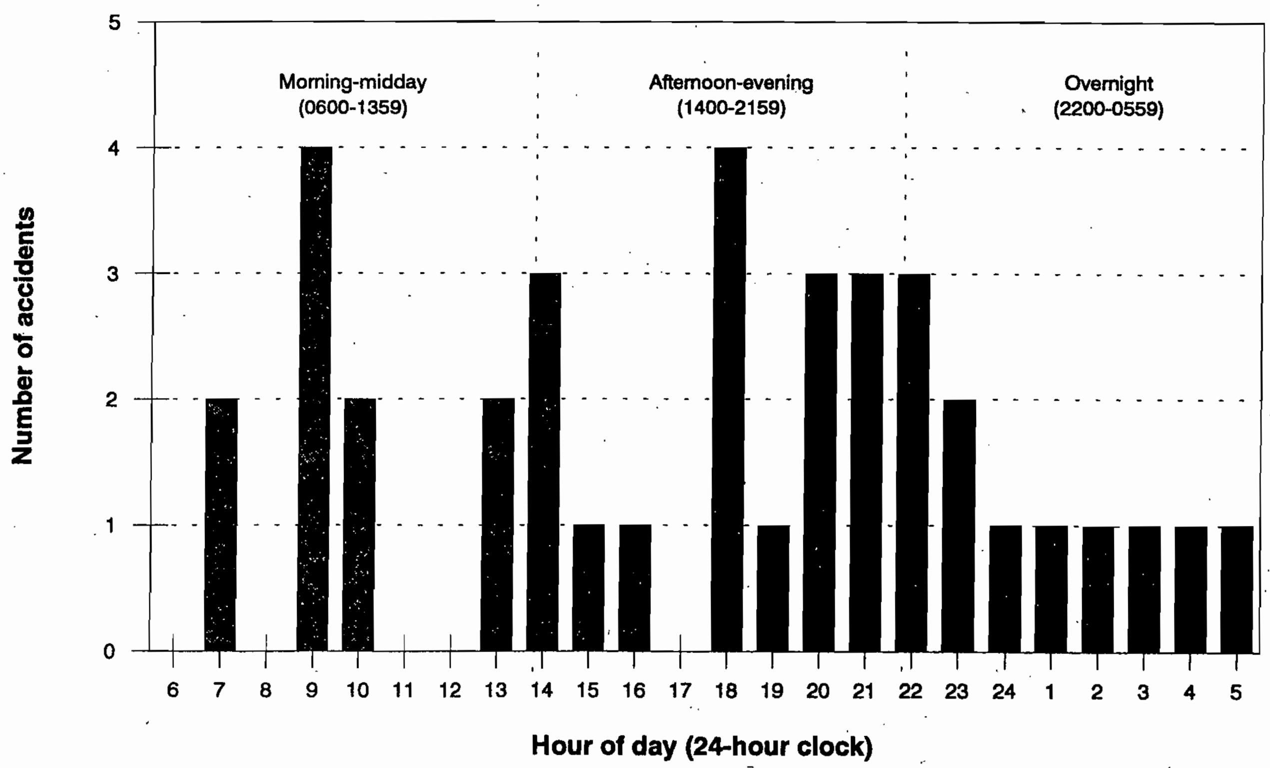


Figure 3.1--Number of accidents by time of day.

between 2200 and 0659,[18] in contrast to the 30 percent of the accidents that occurred during the same overnight period.[19]

It is plausible that operational contexts associated with nighttime flying—including fatigue, and instrument and runway lighting conditions—are responsible for the association between the overnight period and accidents. These contexts were confounded with time of day in the accident data; that is, the data did not permit the unique effects of these operational context variables to be distinguished. The association between time since awakening and the overnight period is discussed in chapter 4.

Type of Operation and Aircraft

Information was obtained on whether each flight was scheduled or non-scheduled (charter), and whether it was a passenger or cargo flight. Thirty of the 37 flights (81 percent) were scheduled passenger flights, and 4 (11 percent) were non-scheduled (charter) passenger flights. Of the three cargo flights, two were non-scheduled; information was not available about whether the remaining cargo flight was scheduled or non-scheduled.

The accidents involved 16 different aircraft types (table 3.2). Twenty-two of the 37 accidents (60 percent) involved two-person crews (a captain and a first officer), and 15 accidents (40 percent) involved three-person crews (captain, first officer, and flight engineer). Turboprop airplanes were involved in 12 of the 37 accidents (32 percent).

Table 3.2 indicates that many of the accidents involved airplane types that are no longer in widespread, Part 121 service in the United States (for example, Boeing 707, Lockheed 188 Electra, and Nord FRK-298). Further,

[18] Data on 1988 air carrier operations reported in the following source: Transportation Research Board, National Research Council. 1991. Forecasting civil aviation activity: methods and approaches. Circular No. 372 (p. 33). Washington, DC.

[19] The time span available in the comparison data included the hours 2200-0559, shown as the "overnight" period in figure 3.1, plus 0600-0659. None of the accidents occurred between 0600 and 0659.

Table 3.2—Types of aircraft involved in the 37 accidents

Type	Number	Percent[a]
Boeing 707	1	2.7
Boeing 727	5	13.5
Boeing 737	7	18.9
British Aero BAC-111	1	2.7
Convair 580	2	5.4
DeHavilland DHC-6	1	2.7
Douglas DC-8	2	5.4
Douglas DC-9	7	18.9
Douglas DC-10	1	2.7
Fokker F-27	1	2.7
Hawker-Siddley HS-748	1	2.7
Lockheed 188	4	10.8
Lockheed 382	1	2.7
Lockheed 1011	1	2.7
Nihon YS-11	1	2.7
Nord FRK-298	1	2.7
Total	37	100.0

[a] Percentages are rounded.

none of the accidents involved the new generation of highly automated, glass-cockpit[20] airplanes.

Although the U.S. air carriers have withdrawn from service some airplane types involved in these accidents, much of the flightcrew performance data obtained from the accidents is relevant to current air carrier operations. The majority of U.S. air carrier airplanes still in service pre-date the glass-cockpit era. The procedures used by the pilots of these airplanes, and the equipment they use for control and navigation, are similar to those used by the accident crews. The Safety Board recognizes the changing role of flightcrews on the highly automated flight decks; nevertheless, many of the basic functions performed by the flightcrews in the older generation airplanes will not be eliminated. For example, more than one pilot will be present on the flight deck for the foreseeable future; consequently, one pilot will continue to be required to monitor the performance of the other pilot and to challenge errors.

Phase of Operation

Each of the 37 accident flights was subdivided into seven phases of operation. The phase of operation during which each accident occurred is shown in table 3.3. The majority of the accidents occurred either during takeoff (27 percent) or landing (51 percent). Frequently, however, errors made by flightcrews in one phase of operation were causal to accidents occurring in a subsequent phase of operation. Relationships between errors and phase of operation are discussed in chapter 5.

[20] "Glass-cockpit" airplanes are equipped with video displays of basic flight, navigation, and systems information. Many of these airplanes are also equipped with flight management systems that integrate flight planning and navigational tasks.

Table 3.3—Phase of operation during which the accidents occurred

Phase of operation	Number of accidents	Percent[a]
Taxi	1	2.7
Takeoff	10	27.0
Maneuvers	1	2.7
Cruise	3	8.1
Descent	3	8.1
Approach/landing	19	51.3
Total	37	99.9

[a] Percentages are rounded.

Involvement of Weather, Mechanical Failures, and Other Persons' Actions

The contributions (as additional causes or contributing factors) of weather, mechanical failures, and other persons' actions were also examined. The term "other persons," in this context, includes air traffic controllers, air carrier and airport management, regulatory authorities, ramp/maintenance personnel, and pilots of other aircraft.

In 29 of the 37 accidents (78 percent), factors in addition to the actions of the flightcrew were cited as causal or contributing. In the remaining 8 accidents, the Board cited only the flightcrew. Weather was cited as a cause in 2 of the 37 accidents (6 percent) and as a contributing factor in 14 of these accidents (38 percent). Mechanical (systems or structural) failure was causal in 5 of the 37 accidents (14 percent) and contributed to the cause of 12 of the accidents (32 percent). The Safety Board also cited non-flightcrew personnel as causal in 5 of the 37 accidents (14 percent), and as contributing to the cause of 13 of the accidents (35 percent). The most common non-flightcrew personnel cited were airline management (cited in 10 accidents), regulatory/surveillance authorities (6 accidents), and air traffic controllers (5 accidents).

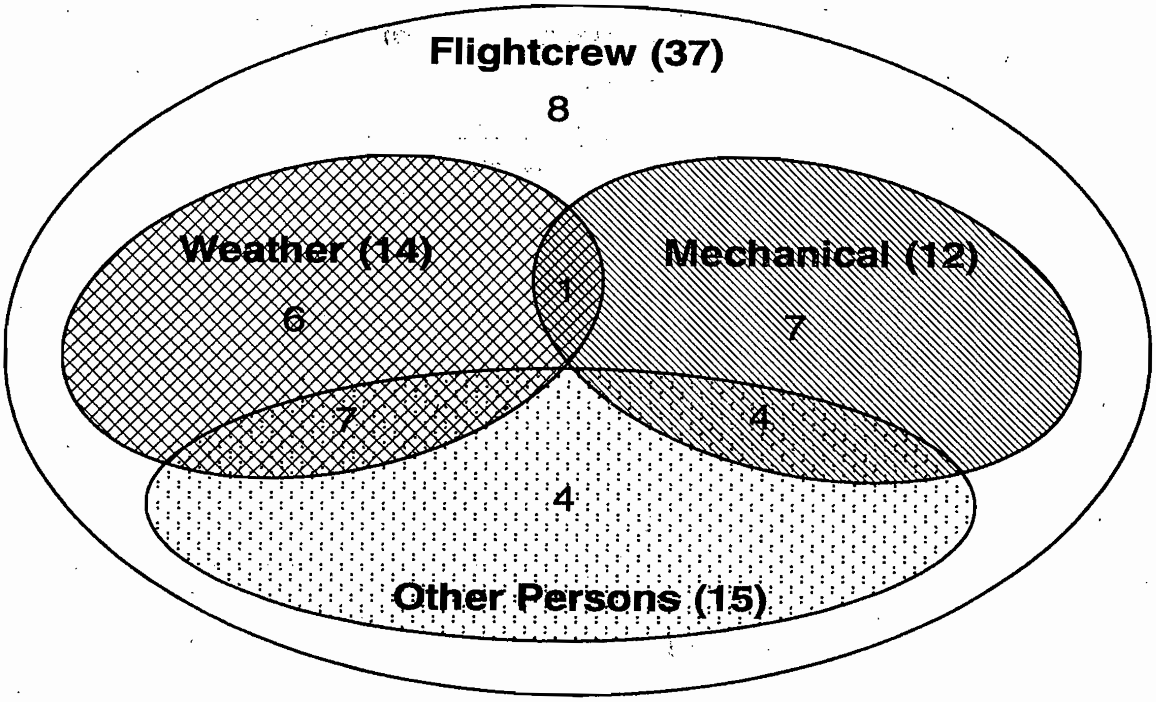


Figure 3.2--Number of the 37 accidents in which causal or contributing factors were cited alone or in combination with each other.

In many accident reports, the Safety Board cites combinations of weather, mechanical failures, and other persons' actions as causal or contributing factors. Figure 3.2 shows the distribution of accidents in which the Board cited these factors, in addition to the flightcrew, in its reports on the 37 accidents reviewed in this study. It also indicates the number of accidents in which each factor was cited in combination with the flightcrew, and in combination with the other factors. Weather, mechanical failure, and other persons were cited in about the same number of accidents (14, 12, and 15 accidents, respectively). The most frequently cited combinations of causal and contributing factors involved other persons: their actions or inactions combined with weather in seven accidents, and with mechanical failure in four accidents. In contrast, the combination of weather and mechanical failure was cited in one accident.

These data illustrate the role of causal and contributing factors that were external to the flight deck in these flightcrew-involved accidents. They also illustrate that the actions or inactions of non-flightcrew personnel frequently combined with weather and mechanical failures to affect the operational environment.

Flight Delay Status

The 37 accidents were examined to determine the number of flights that were delayed at the time of the accident sequence. A flight was considered "delayed" if it had departed the gate more than 15 minutes behind schedule, or if it was delayed in flight prior to the accident sequence such that arrival within 15 minutes of schedule was unlikely. Flight delay information was available for 31 of the 37 accident flights. Of these 31 flights, 17 (55 percent) were delayed.

Although weather was cited as a factor in 14 accidents, the role of weather in causing delays in any of the 37 accident flights was unknown. Of the 17 accident flights known to be delayed, 7 (41 percent) involved weather as a causal or contributing factor. Thus, a majority (59 percent) of the delayed flights did not involve weather as a factor in the accident.

Data from the accident flights were compared with a sample of on-time performance statistics for non-accident flights, collected by the U.S. Department of Transportation (DOT).[21] The non-accident data were from operations at the largest U.S. airports during each December for 1987 through 1992. Because of the large volume of holiday travel and widespread poor weather during December, this non-accident sample likely had poorer on-time records than would be expected from a sample drawn from all 12 months and all airports. Consequently, the non-accident sample provides a conservative estimate of any difference in on-time performance between the accident and non-accident flights.

Data for the non-accident sample are based on DOT definitions of delayed flights: a delayed departure is a flight that leaves the gate 15 minutes or more

[21] U.S. Department of Transportation, Office of Consumer Affairs. 1987-92. Air travel consumer report [Mimeo]. Washington, DC. February editions. Data are for scheduled passenger flights conducted by major air carriers, departing from or arriving at the 27 largest U.S. airports.

behind schedule; a delayed arrival reaches the gate 15 minutes or more behind schedule. In the sample of non-accident flights, late departures ranged between 17 and 28 percent of the flights, and late arrivals ranged between 21 and 35 percent.

Compared to the sample of non-accident flights, a larger proportion (55 percent) of accident flights were running late. This held true whether considering non-accident flights that departed late or arrived late.

In 1987, the first year from which the non-accident sample was drawn, the DOT required the largest air carriers to publicly report their on-time performance. The imposition of these reporting requirements may have prompted air carriers to lengthen the scheduled duration of many flights to achieve better on-time performance. Consequently, the Safety Board wanted to determine if the lower incidence in delays among the non-accident sample, compared to the accident flights, was a result of the change in reporting requirements. Regarding the 31 accident flights for which flight delay data were available, 22 of the flights were conducted prior to the 1987 reporting requirements, and 9 during and after 1987. In both periods (1978 through 1986, and 1987 through 1990), 55 percent of the accident flights had been delayed. On this basis, the relatively higher incidence of delays among the accident flights, compared to the sample of non-accident flights, do not appear to result from the change in on-time reporting requirements.

Flight delays can be a source of perceived time pressure for flightcrews. The Safety Board notes that the difference in flight delay status between the 31 accident flights for which data were available and the non-accident sample is not inconsistent with anecdotal evidence of a relationship between time pressure and flightcrew errors in the air carrier environment. In a recent study of 125 reports submitted by air carrier and commuter airline pilots to the Aviation Safety Reporting System,[22] researchers observed that flightcrews often allowed themselves to be rushed or pressured, events and personnel outside the flight deck often were factors in time-pressure errors, and 90 percent of all time-related errors occurred in the pre-flight and taxi-out phases of flight.[23]

---

[22] The Aviation Safety Reporting System (ASRS) is an incident reporting system administered by the National Aeronautics and Space Administration and the Battelle Memorial Institute. All personnel in the aviation system are able to voluntarily contribute to the ASRS data base reports of safety hazards and to recommend safety improvements.

[23] McElhatton, Jeanne; Drew, Charles R. 1993. Time pressure as a causal factor in aviation safety incidents: the hurry-up syndrome. In: Proceedings, 7th international symposium on aviation psychology; 1993 April 26-29; Columbus, OH. Columbus, OH: The Ohio State University: 269-274.

Chapter 4

Characteristics of the Crewmembers and Discussion

The 37 accidents involved 89 flight crewmembers: 37 captains, 37 first officers, and 15 flight engineers. Because their number was small, flight engineers (six of whom made errors) are excluded from the present analysis. Relevant characteristics of the captains and first officers involved in the accidents included variables such as flight experience in aircraft type, the amount of time since awakening, and duty time on the day of the accident. All of the variables reflective of the crewmember characteristics that were examined, and the number of captains and first officers for whom the data were available, are shown in table 4.1.

Time Since Awakening (TSA)

The number of hours between awakening and the time of the accident was obtained for 17 captains and 15 first officers.[24] The distributions of time since awakening for the captains and first officers are provided in figure 4.1. For captains, the mean TSA was 10.5 hours; the standard deviation (SD) was 4.8. For first officers, the mean was 9.9 hours (SD = 4.6). The Safety Board was interested in whether TSA was associated with other contextual variables,

[24] The Safety Board considered the possibility of a bias in the collection of information during accident investigations, with information on time since awakening being recorded only when it was believed that the pilots had been awake for a long time. If the collection of information were biased, one would expect relatively little missing data for crewmembers whose accidents occurred in the afternoon and overnight periods, because these would be the crews most likely to have been awake for an extended time. No such pattern was observed, however. The 42 captains and first officers for whom TSA information was not reported were involved in accidents that were distributed relatively evenly around the clock. Also, if TSA information was reported for one member of a flightcrew, it was generally reported for all crewmembers. Thus, there was no evidence of bias in the collection of information on time since awakening.

Table 4.1—Variables used to describe characteristics related to crewmembers involved in the 37 accidents, and number of captains and first officers for whom data were available

Name of variable	Number for whom data were available	
	Captain	First Officer
Time since awakening	17	15
Duty hours	31	29
Off-duty hours prior to flight	11	11
Time zone change in past 24 hours	22	22
Total flight hours	37	34
Hours in crew position	7	11
Years in crew position	0	32
Hours in aircraft type	36	30
Hours in type and position	20	29
Hours in 7 days prior	13	11
Hours in 30 days prior	23	19
Hours in 90 days prior	23	17
Past unsatisfactory rating	15	15
Crew assignment (who was flying)	37	37
Captain/First Officer first day together	15	15
Captain/First Officer first flight together	16	16

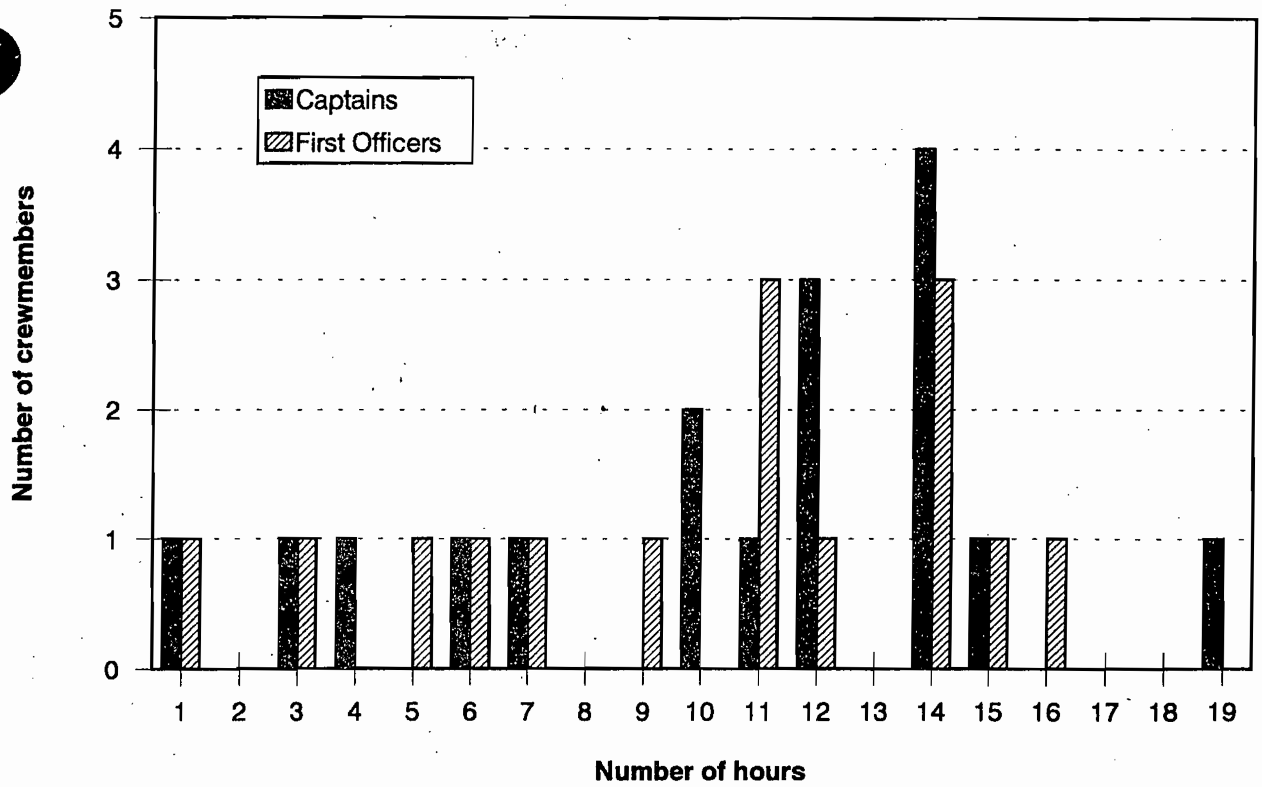


Figure 4.1--Time since awakening prior to the accident.

such as amount of duty time and time of day the accident occurred. To address these questions, captains and first officers were placed into one of two groups depending on whether their time since awakening was above or below the median for all accident pilots in their crew position. The median TSA was 12 hours for captains and 11 hours for first officers. For two first officers and one captain, the TSA was equal to the median value for their crew position. Rather than arbitrarily assign those three crewmembers to the high or low TSA groups, they were excluded from any analysis in which high and low TSA crewmembers were compared.

Captains who had been awake for fewer than the median of 12 hours were coded as "low TSA" captains. The mean TSA for this group of eight captains was 6.5 hours (SD = 3.7). The eight captains who had been awake more than 12 hours prior to the accident were coded as "high TSA" captains. The mean TSA for these captains was 14.3 hours (SD = 2.1).

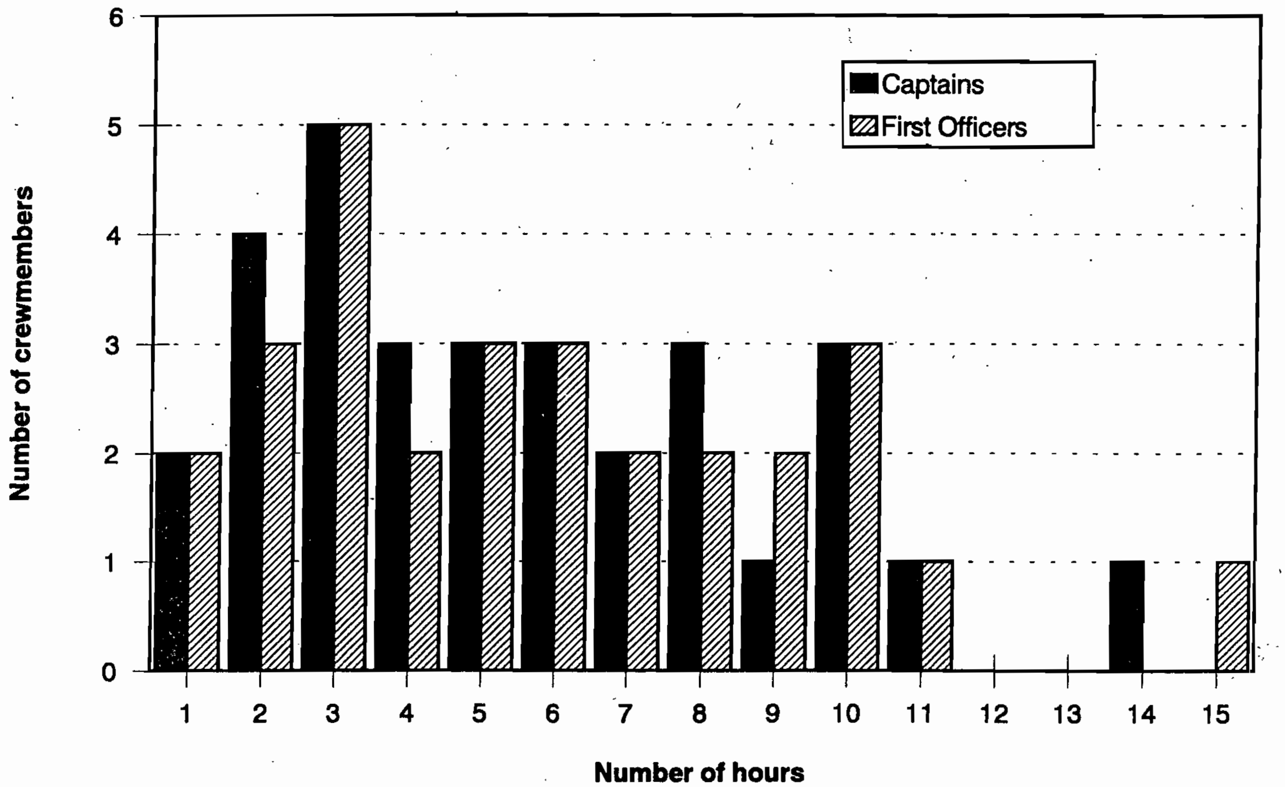


Figure 4.2--Time on duty prior to the accident.

First officers were classified as "low TSA" or "high TSA" in a similar manner, depending on whether their TSA was below or above, respectively, the median of 11 hours for first officers. The six "low TSA" first officers had a mean TSA of 5.2 hours (SD = 2.9). In contrast, the seven "high TSA" first officers had a mean TSA of 13.6 hours (SD = 1.7).

Duty and Pre-Duty Hours.—The amount of time crewmembers had been on duty prior to the accident was obtained for 31 captains and 29 first officers. Duty time was defined as the number of hours elapsed between the crewmember's reporting for duty and the time of the accident.

The distributions of duty time for these crewmembers are provided in figure 4.2. For captains, the mean duty time was 5.6 hours (SD = 3.3); for first officers, the mean was 5.8 hours (SD = 3.5).

Table 4.2—Time since awakening (TSA), pre-duty time, and duty time elapsed when accident occurred, by TSA group and crew position

TSA group[a] and crew position	Mean hours (standard deviation in parentheses)		
	TSA	Pre-duty	Duty
Low TSA:			
Captains (n=8)	6.5 (3.7)	3.8 (3.2)	2.7 (2.0)
First Officers (n=6)	5.2 (2.9)	2.2 (2.0)	3.0 (2.3)
High TSA:			
Captains (n=8)	14.3 (2.1)	8.2 (2.9)	6.1 (1.8)
First Officers (n=7)	13.6 (1.5)	7.8 (3.1)	5.8 (2.4)

[a] Pilots for whom TSA data were available (17 captains and 15 first officers) were placed in one of two groups depending on whether their TSA was above (high TSA) or below (low TSA) the median for all pilots in their crew position. The median was 12 hours for captains, 11 hours for first officers. Because the TSA of 1 captain and 2 first officers equaled the median, these 3 crewmembers are not included in the analysis of TSA.

The record of duty time allows comparison of the amount of time crewmembers had been awake prior to reporting to duty. Time on duty and time since awakening were compared for the 16 captains and 15 first officers for whom all of this information was available and who were classified as high or low TSA crewmembers. Pre-duty hours were calculated by subtracting time on duty from time since awakening. The results, presented in table 4.2, indicate that high TSA crewmembers had been awake substantially longer before reporting for duty, as well as on duty longer, than low TSA crewmembers had been.

Table 4.3—Number of captains and first officers involved in the accidents, by crew position, time-since-awakening (TSA) group, and period of day the accident occurred[a]

Crew position and TSA group	Number involved in accidents during—		
	Morning-midday (0600-1339 hours)	Afternoon-evening (1400-2159 hours)	Overnight (2200-0559 hours)
Captain:			
Low TSA (n=8)	4	4	0
High TSA (n=8)	0	4	4
First Officer:			
Low TSA (n=6)	4	2	0
High TSA (n=7)	0	3	4

[a] Pilots for whom TSA data were available were placed in one of two groups depending on whether their TSA was above (high TSA) or below (low TSA) the median for all pilots in their crew position. The median was 12 hours for captains, 11 hours for first officers.

TSA and Period of Day.—The period of day in which accidents involving high and low TSA crewmembers occurred is presented in table 4.3. As expected, high TSA crewmembers tended to be involved in accidents that occurred later in the day.

Figure 4.3 presents the number of pre-duty and duty hours awake by period of day the accident occurred for the 17 captains and 15 first officers for whom this information was available. The number of duty hours were somewhat more for the crewmembers in accidents that occurred in the afternoon-evening and overnight periods than for crewmembers in accidents that occurred in the morning-midday period. Further, crewmembers involved in afternoon-evening and overnight flights had been awake substantially longer before reporting for duty than crewmembers involved in the morning-midday accidents. These results are consistent with research findings[25] on the behavior of shift workers, which suggest that night shift workers may arise

[25] Tepas, Donald I. 1982. Work/sleep schedules and performance. In: Webb, Wilse B., ed. Biological rhythms, sleep, and performance. New York, NY: John Wiley & Sons, Ltd.: 175-204.

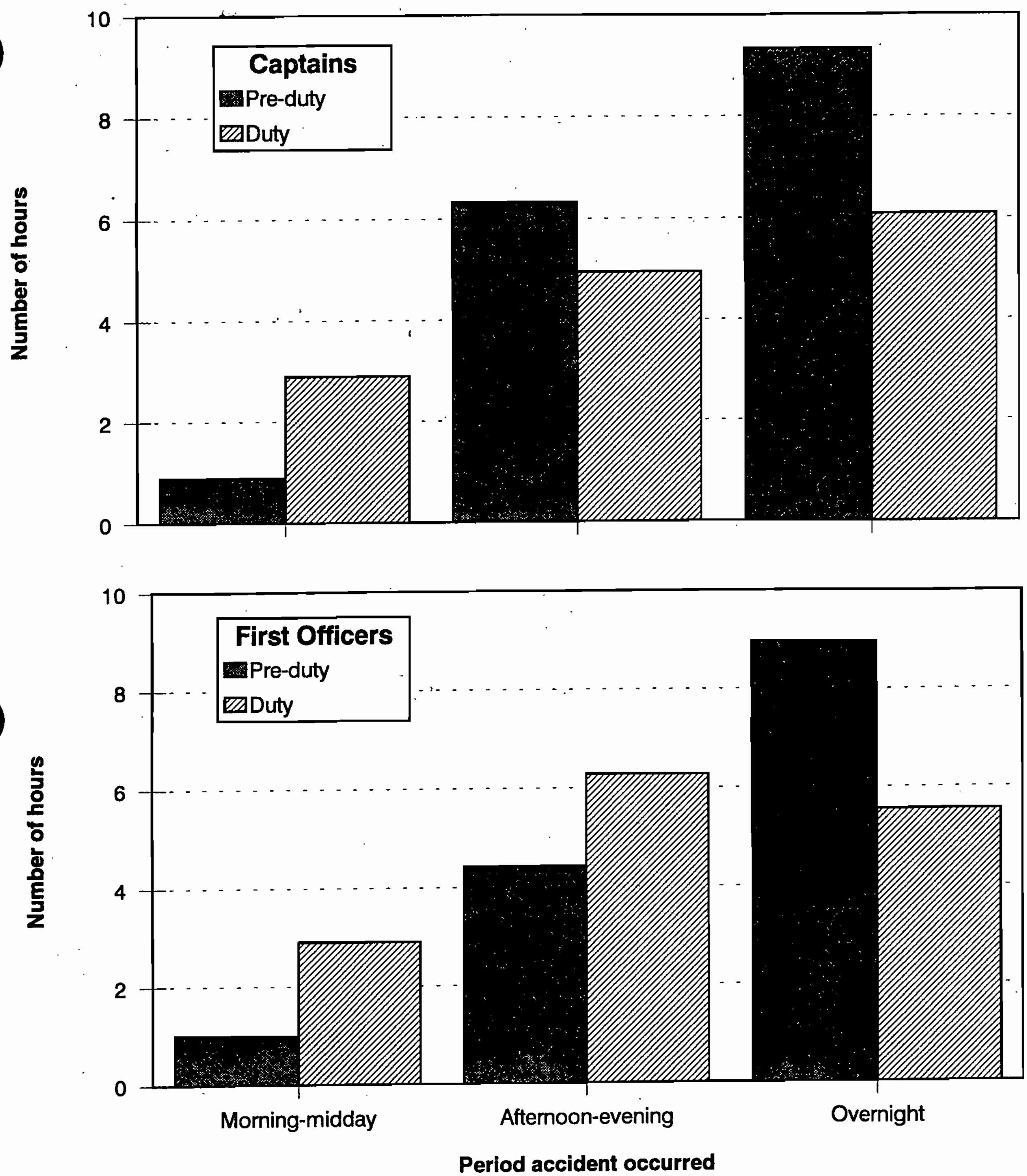


Figure 4.3--Pre-duty and duty time awake by period of day when accident occurred. (Data were available for 17 captains and 15 first officers.)

well before their shift begins to attend to personal activities. The Safety Board is concerned that similar behavior may cause pilots working late shifts to be more subject to the effects of fatigue because they devote the latter part of their period of wakefulness to the work shift.

The Safety Board recognizes that these results do not establish a link between the occurrence of accidents and variables such as TSA and duty and pre-duty times because all of the crewmembers in the study were involved in accidents. Of interest, then, is whether the performance of high TSA pilots was systematically different than the performance of low TSA pilots. The association between the length of time crewmembers had been awake and flightcrew performance, as measured by the number and types of errors made, is discussed in chapter 5.

Flightcrew Experience

Five aspects of flightcrew experience were obtained from the accident data:

1. Total hours of flying experience;

2. Hours of experience in the crew position (captain or first officer) that the person held on the accident flight;

3. Hours of experience in the accident aircraft type[26] (regardless of crew position);

4. Hours of experience in aircraft type and crew position; that is, the person's specific job on the accident flight (for example, Boeing 727 captain); and

5. Years of experience in the crew position that the person held on the accident flight, regardless of aircraft type (available for first officers only).

The ranges of experience for captains and first officers, measured in flight hours, are presented in table 4.4. Mean and median amounts of experience are also given.

[26] Aircraft make and model; for example, Douglas DC-9.

Table 4.4—Flightcrew experience of captains and first officers involved in the accidents, by aspect of experience and crew position

Aspect of experience	Captains	First Officers
	Flight hours	
Total flying experience:		
Range	4,028 - 30,650	1,800 - 10,049
Mean	14,364	5,595
Median	14,000	5,110
Standard deviation	6,702	2,185
(Number of valid observations)	(37)	(34)
Experience in crew position held on accident flight:		
Range	64 - 10,000	8 - 6,143
Mean	2,700	1,212
Median	1,100	474
Standard deviation	3,640	1,849
(Number of valid observations)	(7)	(11)
Experience in accident aircraft type:		
Range	215 - 14,300	8 - 5,800
Mean	4,120	1,383
Median	3,335	882
Standard deviation	3,155	1,503
(Number of valid observations)	(36)	(30)
Experience in aircraft type and crew position:		
Range	64 - 14,300	8 - 4,687
Mean	2,759	900
Median	1,680	419
Standard deviation	3,314	1,111
(Number of valid observations)	(20)	(29)

Total Flight Experience.—Crewmembers gain flight experience in a variety of general aviation, military, and air carrier settings. Total flight hours, however gained, represent each pilot's general seasoning.

Total flight experience was recorded for all 37 captains. The distribution of total flight hours is provided in figure 4.4. Half the captains had logged at least 14,000 hours; the least experienced captain had 4,028 hours.

Total flight experience was obtained for 34 of the 37 first officers (figure 4.5). Half the first officers had logged more than 5,110 hours; the least experienced first officer had 1,800 hours.

Experience in Crew Position (Captain or First Officer).—Many aspects of the job of air carrier captain—such as style and performance as a decisionmaker, commander, and team leader—do not vary greatly among different types of aircraft. Thus, to some extent, general experience gained as a captain is cumulative. Prior command experience, even when gained in a different aircraft type, may have been applicable to the accident flight.

Likewise for an air carrier first officer, prior experience in that crew position—even when gained in a different aircraft type—provides general experience in handling large aircraft and working constructively with other crewmembers. Thus, a crewmember's total experience as a first officer in all aircraft types may have been applicable to the accident flight.

Flight hours data for experience in crew position (regardless of aircraft type) were limited to a small subset of the 37 accidents. As reported in table 4.4, total experience as a captain (all aircraft types) was recorded for only 7 of the 37 captains. Total experience as a first officer (all aircraft types) was recorded for 11 of the 37 first officers.

Although flight hours data were limited for captains and first officers, information was available on the number of years 32 of the 37 first officers had been employed in that crew position by the air carrier. For 17 (53 percent) of the 32 first officers, the accident occurred within their initial year as a first officer for the air carrier.

Experience in Aircraft Type.—Experience in the accident aircraft type can be relevant to a crewmember's familiarity with aircraft handling characteristics and the unique systems, controls, and displays of each type of aircraft.

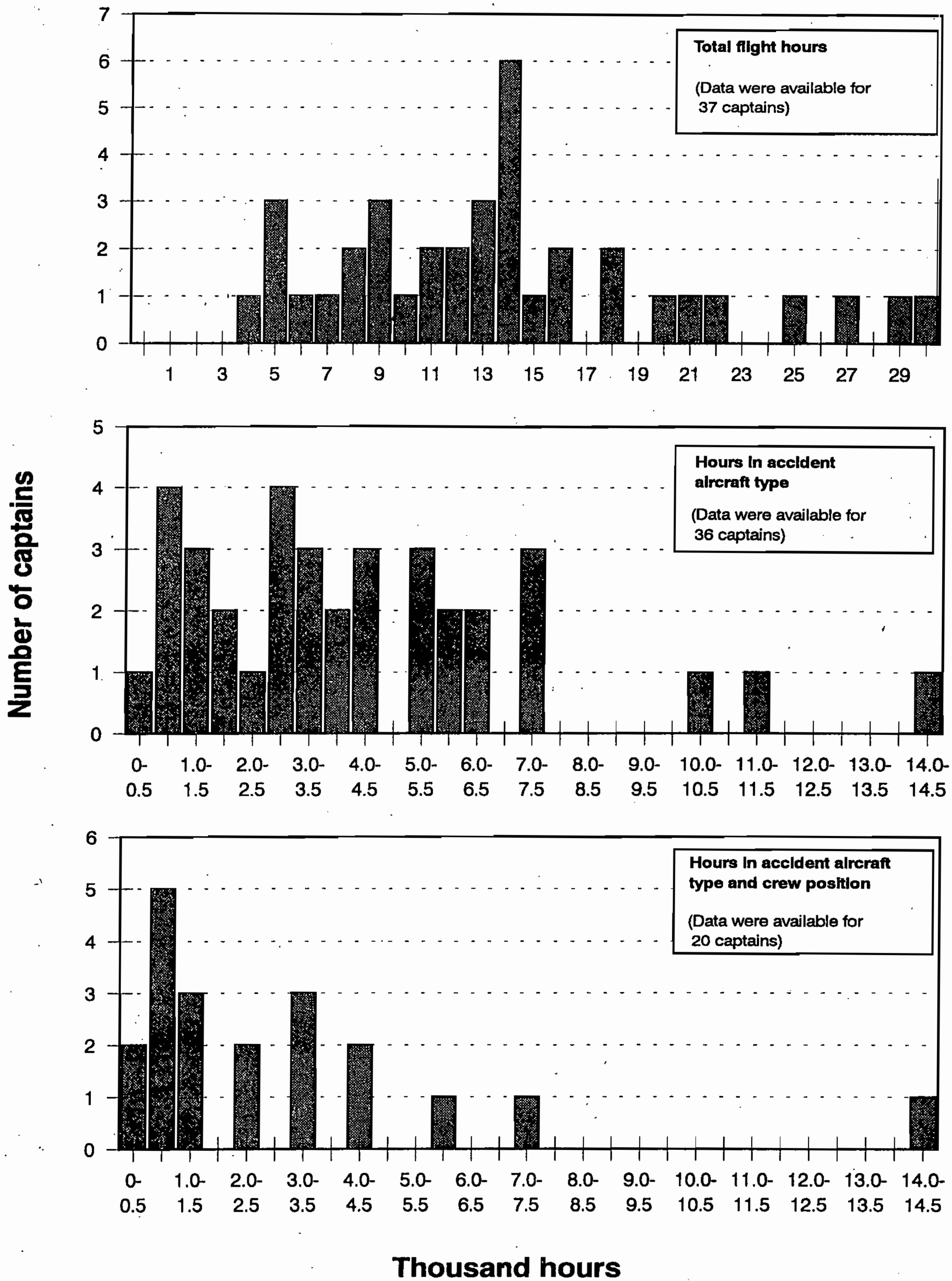


Figure 4.4--Flight experience of captains involved in the 37 accidents.

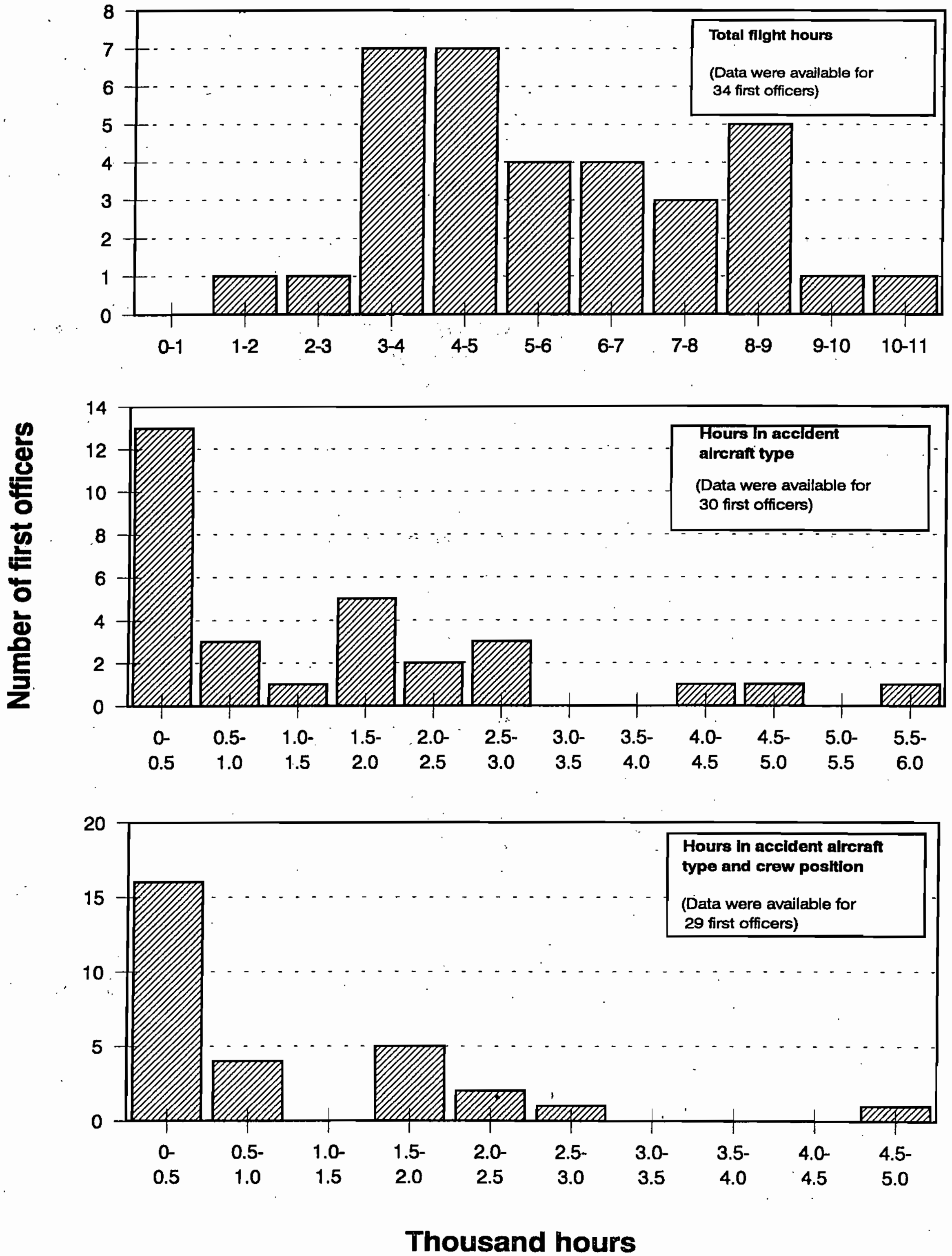


Figure 4.5--Flight experience of first officers involved in the 37 accidents.

Experience in the accident aircraft type was recorded for 36 of the 37 captains. Half the captains had logged at least 3,335 hours. Figure 4.4 shows the distribution of captains' hours in type.

Experience in type was recorded for 30 of the 37 first officers. The distribution of first officers' hours is provided in figure 4.5. Of the 30 first officers for whom information was available, 13 had less than 500 hours of experience in type. Of these, 9 had less than 200 hours, and 4 had less than 100 hours in type.

Experience in Accident Aircraft Type and Crew Position.— Experience in type and position, the aspect of experience most specific to the accident flight, was recorded for 20 of the 37 captains. The distribution of captains' hours in type and position is presented in figure 4.4. The median was 1,680 hours.

Experience in type and position was recorded for 29 of the 37 first officers. The distribution of first officers' hours is shown in figure 4.5. The median was 419 hours, and 5 of the 29 first officers (17 percent) had less than 100 hours in type and position.

Based on the information disclosed regarding experience, the Safety Board was interested in comparing the experience of first officers involved in the accidents with illustrative data from non-accident flights. To illustrate the experience levels of a group of current first officers, the Board obtained the number of hours in position and type for 1,649 first officers flying on a randomly selected day in 1993 at four U.S. air carriers: two major airlines; a small, passenger airline; and a small, all-cargo airline. The number of first officers in each airline's sample follows:

U.S. air carrier	Number of first officers in non-accident sample
Major airline #1	529
Major airline #2	1,073
Small, passenger	25
Small, all cargo	22
Total	1,649

Comparisons of experience in type and crew position between first officers involved in the accidents and those in the non-accident sample are shown in figure 4.6. First officers in the accident group were highly weighted toward

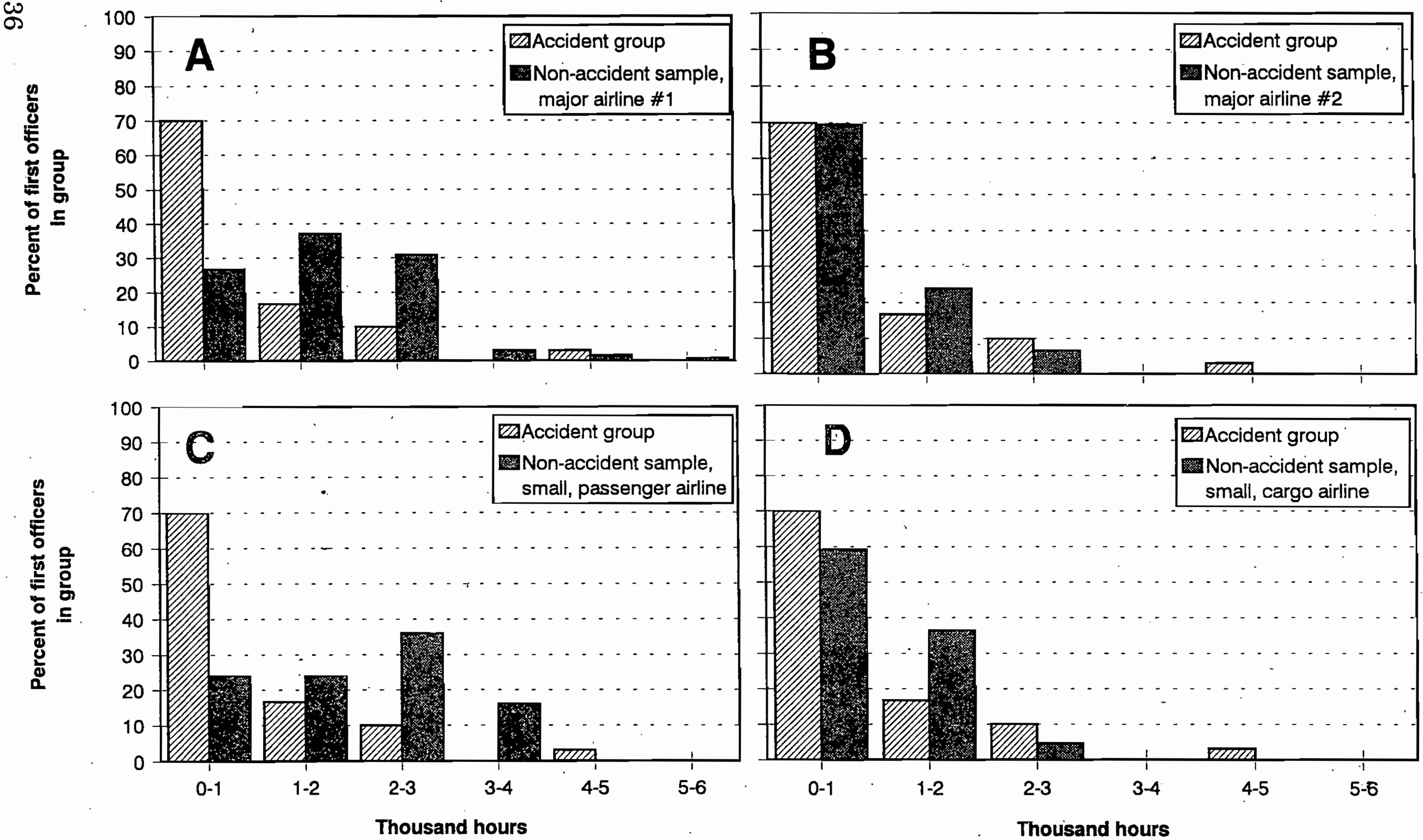


Figure 4.6--Comparison of flight hours in airplane type and crew position for first officers involved in the accidents with non-accident sample: (A) major airline #1; (B) major airline #2; (C) small, passenger airline; (D) small, cargo airline.

less experience compared to those at major airline #1; however, the distribution of their experience was comparable to that of first officers at major airline #2 (figure 4.6A and B, respectively). The distribution of experience for first officers in the accident group was different from that at the small, passenger airline but was similar to that at the small, all-cargo airline (figure 4.6C and D, respectively).

Thus, distributions of first officer experience were not consistent among the four air carriers providing non-accident data. The differences likely can be attributed to different hiring patterns, expansion rates, and fleet compositions. The resulting variability among the non-accident samples makes it difficult to draw any conclusions about the relative experience level of first officers who were involved in the accidents.

The distribution of experience for accident-involved first officers may reflect patterns in the air carrier industry during the 1978-90 period from which the study's accidents were selected. Rapid growth and turnover may have led to lower levels of first officer experience, at least for a portion of time and at certain air carriers. For example, when an air carrier experiences rapid growth or expansion, a first officer is likely to spend a relatively short time before making a transition to another aircraft type or qualifying as captain. Alternatively, the distribution of the accident group may indicate that the first year of experience is critical for first officer performance. This topic is discussed further in chapter 5, where dynamics of the captain/first officer relationship are examined.

Recent flight experience.—The Safety Board obtained data on flight experience of captains and first officers during the 7, 30, and 90 days prior to the accident. Their hours of recent flight experience were consistent with the Board's expectations for flightcrew utilization in the air carrier industry. The median hours are shown in table 4.5.

Crew Assignment

Captains and first officers usually alternate flying the airplane, either by swapping duties on alternate flights or by following another regular pattern. Thus, on about half of all air carrier flights, the captain is the flying pilot and the first officer is the non-flying pilot. For convenience in this report, this combination of flightcrew positions and duties is referred to as crew assignment 1. On the other flights, the first officer is the flying pilot and the captain is the non-flying pilot; this is referred to as crew assignment 2.

Table 4.5—Recent flight experience of captains and first officers involved in the accidents

Period of experience	Captains	First Officers
	- - - - Median flight hours - - - -	
7 days before the accident	13.7	10.6
(Number of valid observations)	(13)	(11)
30 days before the accident	61.9	52.0
(Number of valid observations)	(23)	(19)
90 days before the accident	174.0	146.0
(Number of valid observations)	(23)	(17)

The flying pilot's primary duty is to manipulate the controls. The non-flying pilot's duties are to assist the flying pilot with auxiliary instruments and controls; to perform checklists and callouts that enhance the flying pilot's situational awareness; and to challenge errors made by the flying pilot before the errors threaten flight safety.

Crew assignment at the time of the accident (the end of the accident sequence) was determined for all 37 accidents. In 30 of the 37 accidents (81 percent), crew assignment 1 (captain flying/first officer non-flying) prevailed when the accident occurred.

Because this percentage was greater than would be expected, considering that about half of all flights are flown with crew assignment 2 (first officer flying/captain non-flying), the Safety Board wanted to ascertain if the greater percentage was a result of circumstances, such as being in a certain phase of flight operation or in adverse weather, that might have favored captains to be the flying pilot when the accident occurred.[27] Consequently, the Board

[27] (a) The captain usually is the "flying" pilot during the taxi phase because the captain's seat, on most air carrier airplanes, has sole access to the ground steering tiller. On a flight for which the first officer is to be the flying pilot, the first officer usually takes the controls at (continued...)

identified the accidents whose circumstances might have favored crew assignment 1, then excluded those accidents from a subsequent examination of crew assignment at the time of the accident.

In 22 of the 37 accidents, operation of the airplane involved one or more circumstances that might have favored crew assignment 1: 3 cases in which the captain took over the controls during the accident sequence;[28] 10 cases in which causal errors were made during the taxi phase of the flight;[29] and 14 cases in which weather was a causal or contributing factor.[30]

After excluding these 22 accidents, the Safety Board reexamined crew assignments in the remaining 15 of the 37 accidents. Because these 15 accidents did not involve circumstances that may have favored a particular crew assignment, the normal 50/50 distribution between crew assignments 1 and 2 would be expected. However, crew assignment 1 prevailed when 13 (87 percent) of these 15 accidents occurred.

The patterns of errors associated with crew assignment 1 are discussed in chapter 5.

---

[27](...continued)
the beginning of the takeoff roll and returns control to the captain during the landing roll. Thus, alternation of crew assignments for a flight usually occurs only on the portion of a flight between takeoff and landing. (b) Weather is a factor that can influence crew assignment, either at the captain's discretion or as a matter of company policy. Captains may reserve flights to be made in difficult weather for themselves, and air carriers may require captains to fly during takeoffs and landings in poor weather.

[28] In two of the three accidents, causal errors were made prior to the captain's takeover. In all three, causal errors were also made after the captain took over the controls. Because these three accidents exhibited a mixture of both crew assignments, they were excluded from the subsequent examination of crew assignments that prevailed when the accidents occurred.

[29] In 1 of the 10 cases, the captain took over the controls from the first officer during a subsequent phase of flight. That case was counted as one of the three cases in which the captain took over.

[30] Because of the prevailing weather in one of these cases, company policy required the captain to be at the controls. In the other cases in which weather was a factor, it could not be determined if the weather affected crew assignment; consequently, these cases were excluded from the subsequent examination of crew assignments. Four of the 14 cases already had been counted as a captain takeover or as an accident in which causal errors were made during the taxi phase of operation.

Crew Familiarity

In 1986, researchers at the National Aeronautics and Space Administration compared the performance of crews who had recently flown together in air carrier operations (familiar crews) with crews who had not (unfamiliar crews).[31] A controlled scenario was given to both groups using flight simulators. In these scenarios, the familiar crews performed significantly better than the unfamiliar crews; particularly, they made fewer serious errors.

For its study of flightcrew-involved accidents, the Safety Board identified two measures of crew familiarity: whether the captain and first officer were on their first day flying together; and whether they were on their first flight together. Crews on their first day or flight together were presumed to have less familiarity flying with each other than were crews who had more than one day or flight together.

In 11 (73 percent) of the 15 accidents for which data were available, the accident occurred on the crew's first day flying together; and in 7 (44 percent) of the 16[32] accidents for which data were available, the accident flight was the crew's first flight together.[33]

The Safety Board's understanding of industry practices related to air carrier crew scheduling suggests that the percentages of accident crews who were on their first flight or first day together are greater than would be expected. To illustrate, the Safety Board obtained from four air carriers the number of flights and days that, on average, crews were paired together during

---

[31] Foushee, H. Clayton; Lauber, John K.; Baetge, Michael M.; Acomb, Dorothea. 1986. Crew factors in flight operations. III: The operational significance of exposure to short-haul transport operations. NASA Technical Memorandum 88322. Moffett Field, CA: NASA Ames Research Center.

[32] In one accident, the crew had flown together earlier in the day, but it could not be determined whether the crew had flown together on previous days.

[33] The data were examined for evidence of possible confounding between crew familiarity and crew assignment variables. The Safety Board recognizes that many captains assign themselves to be the flying pilot on their first flight paired with a first officer. However, of the 12 captain-flown flights for which crew familiarity data were available, 7 were not the first flight together for the crew. Further, two of the three first officer-flown flights for which crew familiarity data were available were the first flight together for the crew. Thus, among the accident flights, the captain's assignment as the flying pilot does not appear to be a function of the flight's being the first together for the crew.

a randomly selected month in 1993. It was then necessary to convert the average duration of a crew pairing into an estimate of the percentage of crews who would be newly paired together on any given flight or day.

The probability of a particular flight or day being the crew's first one together can be estimated as 1/n, where n is the average duration of the crew pairing by flights or days, respectively.[34] The resulting estimates for duration of crew pairing at the four air carriers are as follows:

U.S. air carrier crews	Estimated percentage of crews for whom a given: Flight is first flight together	Day is first day together
Major airline #1	2.8	6.8
Major airline #2	3.9	Not available
Small, passenger	10.5	30.3
Small, all cargo	7.1	Not available

The incidence of accident crews who were on their first flight together (44 percent) was substantially greater than that estimated for crews at the four air carriers (which ranged from 2.8 to 10.5 percent). Similarly, the incidence of accident crews who were on their first day together (73 percent) was substantially greater than that estimated for crews at the two air carriers for whom data were available (6.8 and 30.3 percent).

The greater-than-expected incidence of newly paired captains and first officers on the accident flights draws attention to the performance of these crews who were relatively unfamiliar with each other. Because these flightcrews had been cited in the accidents, their performance, in combination with their relative unfamiliarity, lends support to the NASA flight simulator study, in which familiar crews made fewer serious errors.

[34] This relationship strictly holds if new crew pairings (that is, crews on first flights or first days together) are randomly distributed over time. Although this may not be true for any particular day or air carrier, the Safety Board suggests that it is a reasonable working assumption for the industry in general.

Past Unsatisfactory Rating

The performance of air carrier crewmembers is evaluated repeatedly during their careers. They must successfully complete simulator/airplane checkrides and ground school tests to qualify in each new crew position and equipment type. In addition, captains are required to complete proficiency checks every 6 months,[35] line checks every year, and company and FAA inspections on a random basis. First officers are required to complete proficiency checks annually.

The Safety Board is well aware that crewmembers who receive an unsatisfactory rating on any evaluation are required to demonstrate proficiency before they may continue flying. Thus, every crewmember engaged in air carrier flying can be considered to meet the minimum proficiency standards. The Board also recognizes that subjectivity of checkrides, differences between air carriers in pass/fail, retraining, and rechecking policies, and variability in recordkeeping may prevent prior ratings from validly predicting subsequent performance.

Nevertheless, a crewmember's history of checkrides and tests is the only available record of pilot proficiency, and a greater incidence of prior unsatisfactory ratings for the accident crewmember group could suggest that the air carriers did not deal effectively with crewmembers whose previous unsatisfactory ratings had identified them as needing additional training, checking, or supervision.

The accident data were reviewed to determine how many captains and first officers had received an unsatisfactory performance rating for an airline ground school exam, type rating check, or proficiency check prior to their accidents. This information was available for both the captain and the first officer in 15 of the 37 accidents.

Of these 15 accidents, seven captains (47 percent) had received at least one unsatisfactory rating prior to the accident, and five first officers (33 percent) had received an unsatisfactory rating. In 3 of the 15 accidents, both the captain and first officer had received an unsatisfactory rating in the past.

---

[35] Some air carriers have received exemptions from the FAA to substitute an annual simulator training session in lieu of one of the semiannual proficiency checks.

The Safety Board does not believe that the results were produced by a data collection bias. In each of the 15 accidents for which data were available, the information was obtained for both crewmembers regardless of whether the crewmembers had a past unsatisfactory rating. Likewise, satisfactory/unsatisfactory rating information was consistently missing for all crewmembers in the remaining 22 accident cases. Thus, the pattern of available and unavailable data in the 37 accidents showed that accident investigators were no more likely to report an unsatisfactory rating than a satisfactory rating. Collection of the unsatisfactory rating information likely was a function of availability of records, and not a function of the existence of an unsatisfactory rating.

No information was available from the FAA or the air carrier industry that was directly comparable to the accident data on past unsatisfactory ratings. For this reason, and because of the limitations of these ratings as predictive measures of flightcrew performance, the Safety Board was unable to draw any conclusions from its findings in this area.

Chapter 5

Errors and the Contexts in Which They Occurred

Number of Errors Per Accident

A total of 302 errors were identified in the 37 accidents. The number of errors per accident ranged from 3 to 19; the median per accident was 7. The distribution of errors per accident is provided in figure 5.1.

Classification of the Errors

Each of the 302 identified errors was classified into one of nine types of errors adapted from an error classification scheme used by NASA.[36] Each error was also designated as either an error of omission or commission.[37]

The nine error types are defined and illustrated below.

Primary Errors.—Eight of the nine descriptive types of errors are considered primary errors; that is, they are not dependent on making a prior error.

1. <u>Aircraft handling:</u> Failing to control the airplane to desired parameters.

   Examples: Stalled aircraft after rapid climb during missed approach.
   Did not re-trim to relieve pitch-up tendency.

---

[36] Ruffell Smith, H.P. 1979. A simulator study of the interaction of pilot workload with errors, vigilance, and decisions. NASA Technical Memorandum 78482. Moffett Field, CA: NASA Ames Research Center.

[37] See appendix C for the classification of each error.

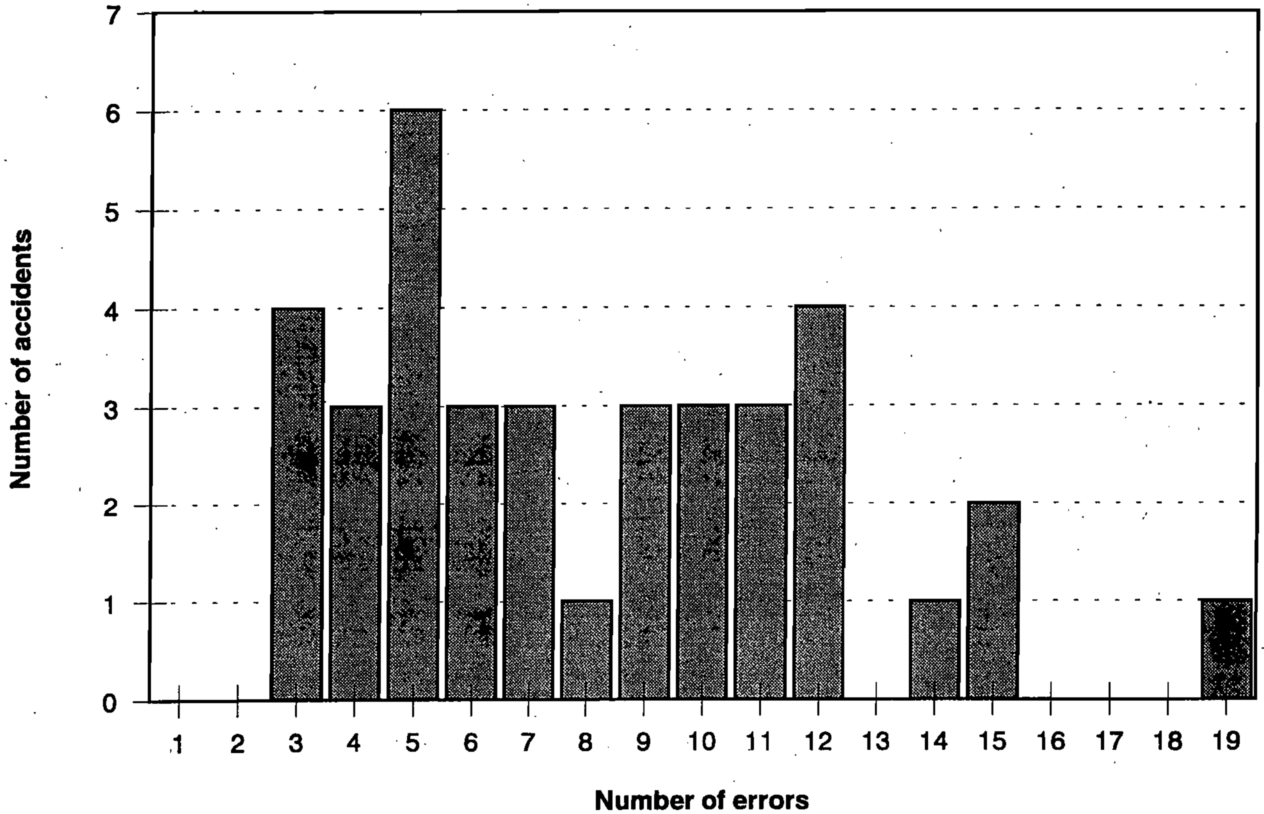


Figure 5.1--Number of errors per accident.

2. Communication: Incorrect readback, hearback; failing to provide accurate information; providing incorrect information.

   Examples: Did not read back frequency change.
   Misinformed tower as to position of the aircraft.

3. Navigational: Selecting wrong frequency for the required radio navigation station; selecting the wrong radial or heading; misreading charts.

   Examples: Used DME rather than crossbearing for desired intersection.
   Taxied toward runway instead of turning onto taxiway.

4. Procedural: Failing to make required callouts, making inaccurate callouts; not conducting or completing required checklists or briefs; not following prescribed checklist procedures; failing to consult charts or obtain critical information.

Examples: Did not request updated weather information.
Did not call out 1,000 feet above field elevation.

5. Resource management: Failing to assign task responsibilities or distribute tasks among crewmembers; failing to prioritize task accomplishment; overloading crewmembers; failing to transfer/assume control of the aircraft.

   Examples: Failed to assign monitoring of fuel state to a crewmember.
   Did not provide a clear command for transfer of control.

6. Situational awareness: Controlling aircraft to wrong parameters.

   Examples: Descended below 3,000 feet prior to being established on the localizer.
   Commenced descent to MDA prior to reaching the final approach fix.

7. Systems operation: Mishandling engines or hydraulic, brake, and fuel systems; misreading and mis-setting instruments; failing to use ice protection; disabling warning systems.

   Examples: Turned off GPWS.
   Stated incorrect reading for fuel quantity gauges.

8. Tactical decision: Improper decisionmaking; failing to change course of action in response to signal to do so; failing to heed warnings or alerts that suggest a change in course of action.

   Examples: Initiated rejected takeoff above V_1.
   Continued to hold and accepted a vector away from the airport.

Secondary Errors.—In contrast to a primary error, a secondary error (the ninth descriptive error type) is dependent on another crewmember previously or simultaneously making a primary error.

9. Monitoring/challenging: Failing to monitor and/or challenge faulty action or inaction (primary error) by another crewmember.[38]

---

[38] Every primary error was not linked to a secondary error (failure to monitor or challenge the primary error). Some of the primary errors were challenged; thus, no secondary error was made. Other primary errors were not challenged, but there was insufficient evidence to (continued...)

Example: (The primary error, made by captain who was flying pilot.) Did not execute go-around on reaching decision height in instrument meteorological conditions.

(The monitoring/challenging error, made by first officer who was non-flying pilot.) Did not challenge descent below decision height.

Distribution of Errors Among Error Types

The distribution of errors by error type is presented in table 5.1. Procedural, monitoring/challenging, and tactical decision errors were the most prevalent types, accounting for 73 (24 percent), 70 (23 percent), and 51 (17 percent) of the 302 errors, respectively.[39]

The most common procedural errors identified were failures to make required callouts, failures to initiate required checklists, and the improper conduct of checklists. The failures to make required callouts typically were observed in accidents that occurred during approach and landing, whereas failures to initiate required checklists or the improper conduct of checklists were most frequent in accidents that occurred during takeoff. The most common tactical decision error made was the failure to execute a go-around, or missed approach, during an unstabilized approach. Monitoring/challenging errors, particularly those concerning a failure to challenge a tactical decision error, are discussed in detail later in this chapter.

The number of errors identified, by type of error and per accident, is provided in appendix D.

---

[38](...continued)
document a secondary error. Also, in some cases, a monitoring/challenging failure was associated with multiple primary errors that were similar and occurred at nearly the same moment. For analytical purposes, these monitoring/challenging failures were linked to only one of the primary errors.

[39] These results are generally consistent with the results of a Boeing study of commercial aircraft accidents: Boeing Commercial Airplane Group, Airplane Safety Engineering. 1993. Accident prevention strategies. Seattle, WA.

Table 5.1—Distribution of errors identified in the 37 accidents, by type of error

Type of error	Number of errors	Percent	Number of accidents in which error type occurred
Primary error:[a]			
Aircraft handling	46	15.2	26
Communication	13	4.3	5
Navigational	6	2.0	3
Procedural	73	24.2	29
Resource management	11	3.6	9
Situational awareness	19	6.3	12
Systems operation	13	4.3	10
Tactical decision	51	16.9	25
Secondary error:[b]			
Monitoring/challenging	70	23.2	31
Total	302	100.0	

[a] Error not dependent on making a prior error.
[b] Error dependent on making a prior primary error.

Errors of Omission and Commission

As explained previously, each primary error was designated as an error of omission or commission.[40] Errors of omission included inaction or untimely action by a crewmember when an action was required. In contrast, errors of commission included selecting the wrong action from a set of alternatives, starting but not completing a correct action, or manipulating controls incorrectly while trying to execute a correct action.

[40] By definition, the 70 monitoring/challenging failures are errors of omission. Given this identity and that they are secondary errors (dependent upon the occurrence of a primary error), the monitoring/challenging failures are not included in the designation of errors into errors of omission or commission.

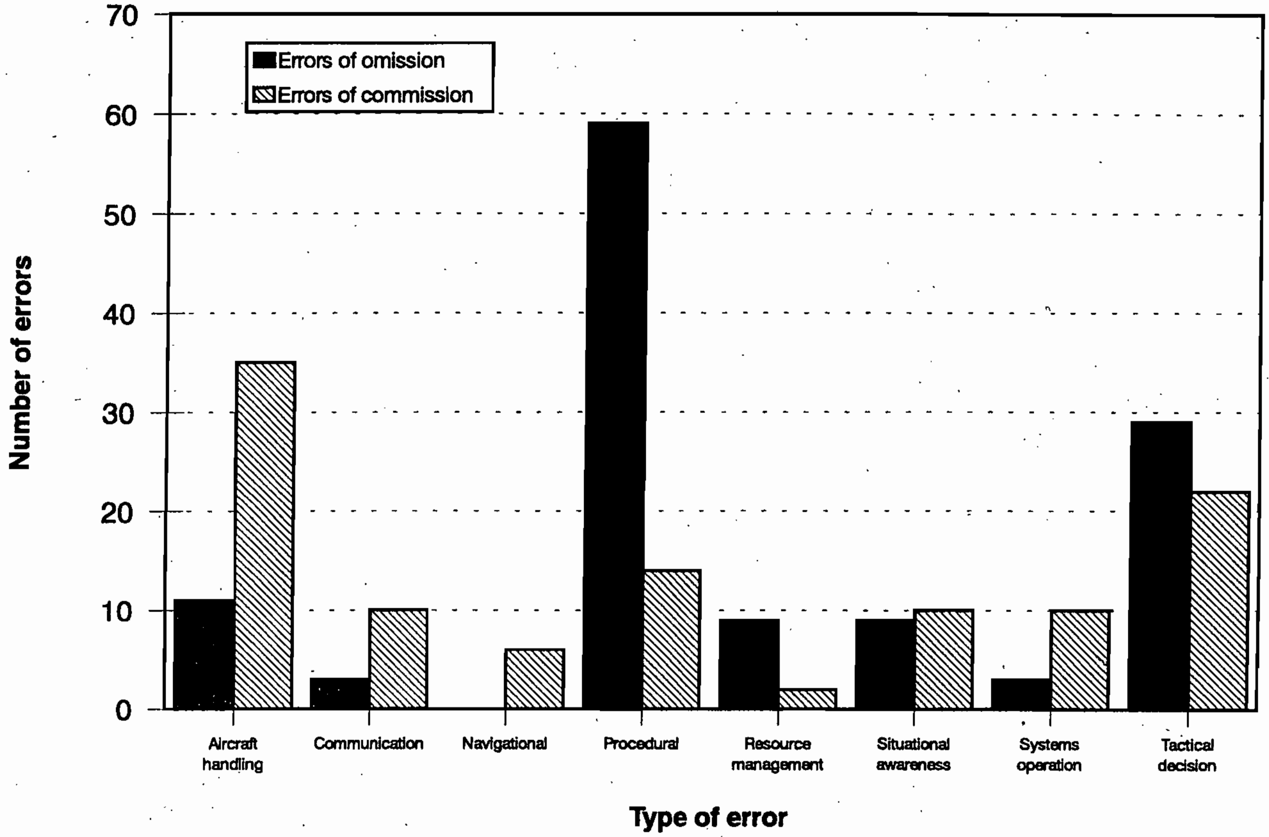


Figure 5.2--Number of primary errors, by type and nature of error.

Of the 232 primary errors identified, 123 (53 percent) were errors of omission, and 109 (47 percent) were errors of commission. Figure 5.2 shows the eight types of primary errors by whether they were errors of omission or commission. Procedural and resource management errors were largely errors of omission, whereas most of the aircraft handling, communication, and systems operation errors were errors of commission. All of the navigational errors were errors of commission.

Error Types and Carryover of Causal Errors to Subsequent Phase of Operation

Only one accident occurred during the taxi phase of operation (see table 3.3). However, errors made during the taxi phase of operation were more consequential than would be suggested by considering only the phase of flight in which the accident actually occurred. For example, 8 of the 10 accidents that occurred during the takeoff phase were caused, in part, by errors made during the preceding taxi phase.[41]

Of the 8 takeoff accidents that involved causal errors made during the taxi phase, 6 included procedural errors that were causal: uninitiated or inadequately performed checklists.[42] These checklist-related errors resulted in attempted takeoffs with the following airplane configurations: mis-trimmed control surfaces (2 accidents), flaps not extended (2 accidents), incorrect use of engine anti-ice systems (1 accident), and locked controls (1 accident).

The Safety Board has previously addressed the need for improved checklists. As a result of its investigation of the August 1987 crash of a Northwest Airlines DC-9-82 at Detroit Metropolitan Wayne Airport in Romulus, Michigan, in which the flaps were not extended for takeoff, the Board issued the following safety recommendation to the FAA:[43]

> Convene a human performance research group of personnel from the National Aeronautics and Space Administration, industry, and pilot groups to determine if there is any type or method of presenting a checklist which produces better performance on the part of user personnel. (A-88-68)

In response to this 1988 safety recommendation, the FAA contracted with the Volpe National Transportation Systems Center (VNTSC), a facility of the

---

[41] The remaining 2 of the 10 accidents involved engine failures that occurred immediately after takeoff.

[42] The remaining 2 of the 8 accidents involved tactical decision errors related to icing conditions or equipment.

[43] National Transportation Safety Board. 1988. Northwest Airlines, Inc., McDonnell Douglas DC-9-82, N312RC, Detroit Metropolitan Wayne County Airport, Romulus, Michigan, August 16, 1987. Aircraft Accident Report NTSB/AAR-88/05. Washington, DC.

Research and Special Programs Administration within the DOT, to study checklist design and usage. The VNTSC reported its results to the FAA in April 1991.[44] Effective June 30, 1991, the FAA revised its Air Transportation Operations Inspector's Handbook to provide additional guidance to principal operations inspectors (POIs) for evaluating the acceptability of air carrier checklists.

In a May 28, 1992, letter to the FAA, the Safety Board stated, "Although [it] agrees with the intent of the revisions, the Board believes that the POIs, without human factors expertise and specific checklist design guidelines, cannot be expected to adequately address this complex problem." In the letter, the Safety Board classified Safety Recommendation A-88-68 "Closed—Unacceptable Action."

The Safety Board recognizes that, as a result of research already completed on checklists, many of the shortcomings in traditional checklist design and usage have been identified. The 1991 report on checklists concluded that "there are some [air] carriers who are operating with poorly designed checklists and manuals, and who have flightcrews who are not well trained in the use of these aids and who admit to not using them when they were expected to." The report made 11 recommendations to the FAA to further conduct research in several areas, including checklist presentation methods, checklist format, typography, readability, and user behavior. It recommended the development of prototypes using human factors principles, standard terminology, and the application of new technology.

NASA has sponsored several studies of checklist design and usage.[45] One of the NASA studies recognized that "the human factors of a paper checklist as a display...is only the outer shell of the problem." The study identified "the core of the problem...as the design concepts and the social issues surrounding the use of the checklist that have led some pilots to misuse it or not use it at

[44] Turner, John W.; Huntley, M. Stephen, Jr. 1991. The use and design of flightcrew checklists and manuals. Report No. DOT/FAA/AM-91/7. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

[45] The research includes the following: (a) Degani, A.; Weiner, E.L. 1990. Human factors of flight-deck checklists: the normal checklist. NASA Contractor Report 177549. Moffett Field, CA: NASA Ames Research Center. (b) Degani, A.; Weiner, E.L. 1991. Philosophy, policies, and procedures: the three P's of flight-deck operations. In: Jensen, R.S., ed. Proceedings, 6th international symposium on aviation psychology; 1991 April 29-May 2; Columbus, OH. Columbus, OH: The Ohio State University: 184-191. Vol. 1. (c) Linde, C.; Goguen, J. 1991. Checklist interruption and resumption: a linguistic study. NASA Contractor Report 177460. Moffett Field, CA: NASA Ames Research Center.

all."[46] The study concluded with 16 general guidelines for the design and use of checklists.

However, because of the recurrence of causal errors involving checklists made during the taxi phase of operation, the Safety Board believes that the FAA should apply the results of research conducted to date on the design and use of checklists to improve the error-tolerance of air carrier checklist procedures for taxi operations, by enhancing flightcrew monitoring/challenging of checklist execution, providing cues for initiating checklists, and considering technological or procedural methods to minimize overlooking any item on a checklist. Further, once these procedures have been developed, the Safety Board urges the FAA to provide specific guidance to air carriers for implementing them.

Only one other phase of operation, descent, generated causal errors that carried over to subsequent phases of flight. Of the 19 accidents that occurred in the approach/landing phase, 4 (21 percent) involved causal errors (primarily failures to initiate a go-around) made during the descent phase.

Error Types and Crew Position

As discussed in chapter 4, captains fulfilled the flying pilot function, and first officers the non-flying pilot function, on more than 80 percent of the accident flights. The number of errors made by captains and first officers while performing the flying and non-flying functions mirrored the crew assignments, as table 5.2 indicates.

The distributions of error types for captains, first officers, and flight engineers are presented in figure 5.3. Of the 168 errors made by captains, 49 (29 percent) were tactical decision errors, the most common error type attributed to captains. The 49 tactical decision errors made by captains accounted for 96 percent of the 51 tactical decision errors made by all crewmembers, which is consistent with the captains' ultimate responsibility for decisions. Procedural (23 percent) and aircraft handling (20 percent) errors were the second and third most common error types made by captains. The 33 aircraft handling errors made by captains accounted for 72 percent of the

[46] Degani and Weiner (1990, p. 4).

Table 5.2—Number of errors made by captains and first officers in the accident flights, by crew position and crew function

Crew function	Captains	First Officers
Flying pilot	147	27
Non-flying pilot	21	92
Total	168	119

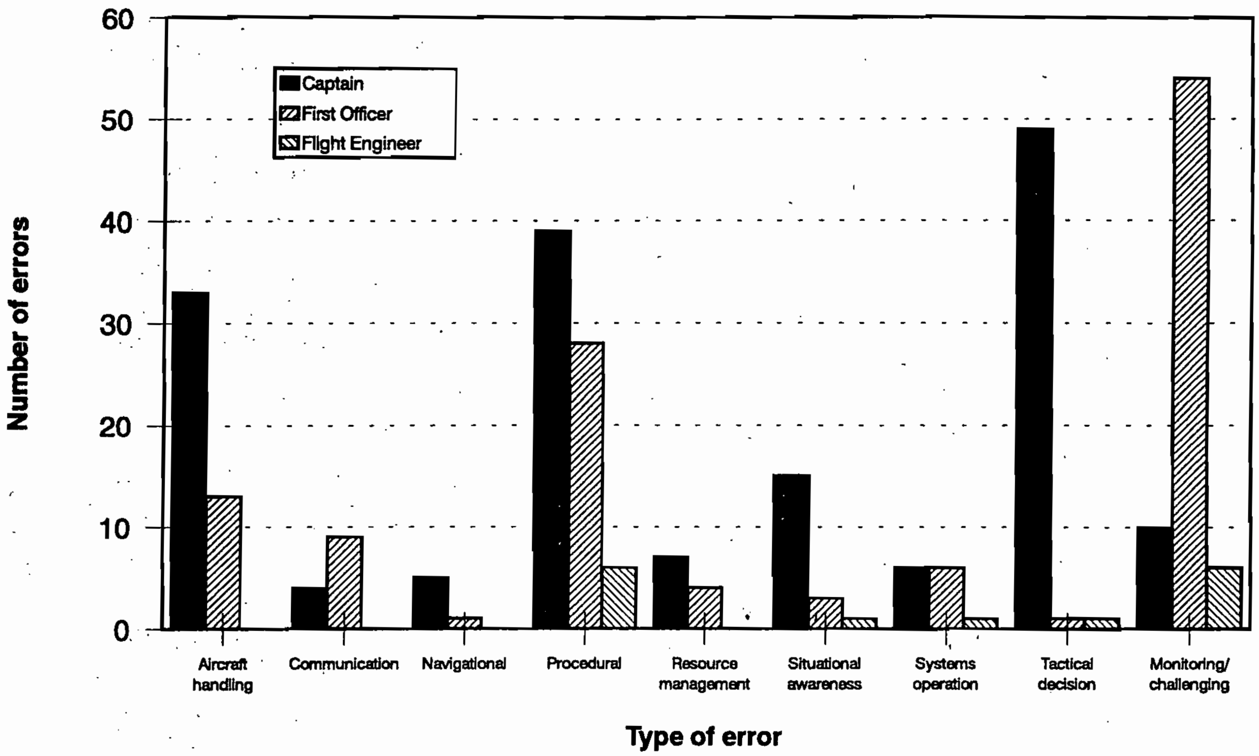


Figure 5.3--Number of errors, by type of error and crew position.

46 aircraft handling errors made by all crewmembers, which is consistent with the captains' serving as the flying pilot on more than 80 percent of the accident flights.

Of the 49 tactical decision errors made by captains, 44 (90 percent) were made while serving as flying pilot; 26 (59 percent) of these were errors of omission. Thus, the most common tactical decision error was the failure of a captain/flying pilot to take action when the situation demanded change.

Of the 26 tactical decision errors made by captains that were errors of omission, 16 (62 percent) involved the captain's failure to execute a go-around during approach. These 16 errors were made during 10 different accident sequences. Of the 16 failures to execute a go-around, 8 involved an unstabilized approach.[47]

Of the 119 errors made by first officers, 54 (45 percent) were monitoring/challenging errors, 29 (24 percent) were procedural, and 13 (11 percent) were aircraft handling. The 54 monitoring/challenging failures by first officers represented 77 percent of the 70 monitoring/challenging errors made by the accident crews, which is consistent with first officers' non-flying pilot function on more than 80 percent of the accident flights. First officers also made 9 of the 13 communication errors (69 percent).

Of the 15 errors made by flight engineers, 6 (40 percent) were procedural errors, and 6 were monitoring/challenging errors.

Monitoring/Challenging Errors

Monitoring the results of one's actions is an important ingredient in consistent, excellent performance of complex tasks. In flying, self-monitoring allows a pilot to recognize inadequate performance, observe changes in the operational environment, and take corrective action. Self-corrections may range from adjusting control inputs to reversing decisions.

---

[47] Air carrier SOPs establish discrete points during approaches (for example, 500 feet above ground) at which flight parameters (rate of descent, airspeed, and airplane configuration) must fall within stated limits for the approach to be continued. Exceeding the limits at a discrete point is a cue that the approach is unstabilized and a go-around should be executed. In two accidents, the captain did not execute a go-around at more than one of these discrete points.

In air carrier operations, the monitoring task is shared by two or more crewmembers. This task is well-defined in the SOP of most air carriers; for example, by cross-checking instruments and through the challenge/response formats of critical checklists. The flying pilot is responsible for monitoring his or her own procedures and control inputs. In addition, operational redundancy is provided by the non-flying crewmember, who is given the task of monitoring the flying pilot. Similarly, because captains are responsible for final decisionmaking, the first officer (and flight engineer, if present) is given the task of monitoring the captain's decisions. In moving from only self-monitoring to monitoring another crewmember, whether monitoring a flying pilot's control inputs or a captain's decisions, the monitoring crewmember must also challenge the crewmember perceived to be making an error.

When this challenge is made, the error is caught. When, alternatively, an error is not challenged, the failure to challenge is, itself, an error made by the crewmember who did not monitor or challenge the earlier error. This monitoring/challenging failure is associated with the primary error that it failed to catch, yet it is a distinct error made by a different crewmember.

For the monitoring/challenging errors that were identified from the records of the 37 accidents, it was not possible to determine if primary errors were not caught because one crewmember did not detect or comprehend the other's error, or because one crewmember detected but did not challenge the other's error. The 37 accidents, nevertheless, yielded a substantial record of errors and associated failures by the monitoring crewmember(s) to challenge them.

Of the 302 errors identified in the 37 accidents, 70 (23 percent) were monitoring/challenging errors. This type of error was identified in 31 (84 percent) of the 37 accident sequences.

Most of the errors that were not monitored or challenged played very important roles in the accidents. For example, in one accident the captain did not equate the airplane's remaining fuel with time and distance from the airport, an error that was cited by the Safety Board as causal to the accident. Concurrently, the first officer failed to catch this causal error by not expressing his concern, in a timely manner, about the time remaining to fuel exhaustion. Among all 37 accidents, 53 (76 percent) of the 70 monitoring/challenging errors failed to catch errors that the Safety Board had identified as causal to the accident. An additional 12 monitoring/challenging failures (17 percent) were failures to catch errors that contributed to the cause of the accident.

The last error cited by the Safety Board as causal in an accident sequence often occurred at the time of the crew's final chance to avert the accident, or

Table 5.3—Distribution of unchallenged errors, by type of error, and comparison with the distribution of all primary errors

Type of error	Unchallenged errors		All primary errors[a]	
	Number of errors	Percent	Number of errors	Percent
Aircraft handling	9	12.9	46	19.8
Communication	5	7.1	13	5.6
Navigational	3	4.3	6	2.6
Procedural	11	15.7	73	31.5
Resource management	0	0	11	4.7
Situational awareness	13	18.6	19	8.2
Systems operation	1	1.4	13	5.6
Tactical decision	28	40.0	51	22.0
Total	70	100.0	232	100.0

[a] Primary errors are not dependent on making a prior error.

it was the primary error that made the accident inevitable. In 19 of the 37 accidents (51 percent), a monitoring/challenging error followed the last causal, primary error. For example, the captain's failure to level off at the minimum descent altitude (MDA) in one accident was the last in a sequence of errors that the Safety Board described as an "unprofessionally conducted non-precision instrument approach." In this accident, the first officer did not challenge the captain's descent below MDA. In 8 of the 19 accidents in which a monitoring/challenging error followed the last causal, primary error, the Safety Board also had included the monitoring/challenging failure in the probable cause. Thus, breakdowns in the monitoring/challenging function often were failures to correct the most serious errors made by flightcrews.

For each of the 70 monitoring/challenging failures, information was obtained on the nature and type of error that was not challenged. Regarding the nature, errors of omission accounted for 39 of the unchallenged errors (55 percent), whereas errors of commission accounted for 31 of the unchallenged errors (44 percent). Regarding types of errors, the highest percentage (40 percent) of the unchallenged errors were tactical decision errors, followed by situational awareness errors (nearly 19 percent) and procedural errors (about 16 percent) (table 5.3).

This distribution of unchallenged errors among error types was different from the overall distribution of primary errors. Table 5.3 shows the percentage of all primary errors made, by each error type, compared with the percentage of those errors that were not challenged. Most striking is that tactical decision errors (such as, "continued to hold and accepted a vector away from the airport") and situational awareness errors (such as, "failed to establish a time limit for beginning approach") constituted a much greater proportion of the unchallenged errors than they did of all primary errors.

Crew Assignment and Pattern of Errors

As discussed in chapter 4, more than 80 percent of the accidents involved crew assignment 1, in which the captain was the flying pilot and the first officer was the non-flying pilot. Even when the subset of accidents believed to be least biased toward crew assignment 1 was examined, 13 of the remaining 15 accidents (87 percent) involved crew assignment 1. In contrast, crew assignment 1 prevails during about 50 percent of all non-accident flights, based on the common practice among air carrier pilots of swapping flying duties on alternate flight legs.

Because such a small percentage of the accidents examined in this study involved crew assignment 2, it was not possible for the Safety Board to analyze differences in flightcrew performance with respect to crew assignment. In addition, the Safety Board was unable to determine any particular significance to, or draw any conclusions from, the high percentage of accidents that involved crew assignment 1. Nevertheless, many of the accidents involving crew assignment 1 demonstrated a consistent pattern of errors by captains and first officers.

Crew Assignment and Captain Decisionmaking.—The error type observed most frequently for captain/flying pilots in the 37 accidents was a tactical decision error (see figure 5.3). When serving as the flying pilot, captains must devote at least some of their attention and other cognitive resources to aircraft control. Research on captain decisionmaking suggests that captains take significantly more time to make decisions while flying the airplane than when they are the non-flying pilot. As part of a full-mission simulation experiment, NASA tested captains for the amount of time required to decide to shut down a malfunctioning engine.[48] Captain/flying pilots took more time to make the decision than captain/non-flying pilots.

Also, a captain/flying pilot who decides to make a change must perceive a need to change, then must alter his or her own current plan and behavior. The decision to change a course of action may be inhibited by overconfidence in ability or the earlier decision to engage in the ongoing course of action.[49] These dynamics probably were relevant in the eight accidents involving a failure to execute a go-around during unstabilized approaches.

Crew Assignment and First Officer Monitoring/Challenging.— Tactical decision errors were the error type most frequently associated with monitoring/challenging failures. Fifty-one tactical decision errors were identified in 25 of the 37 accidents; 28 of these errors were not challenged. Of these 28 unchallenged errors (which were identified in 17 of the accidents), 20 (71 percent) were errors of omission. The 20 tactical decision/errors of omission were identified in 13 accidents.

The tactical decision/errors of omission may be particularly difficult to catch, especially for first officers. In monitoring and challenging a captain's tactical decision error, a first officer may have difficulty both in deciding that the captain has made a faulty decision, and in choosing the correct time to question the decision. A first officer may be concerned that a challenge to a decision may be perceived as a direct challenge to the captain's authority. For example, challenging a captain's failure to execute a go-around may be much more difficult for a first officer to do, in a timely fashion, than challenging a straightforward procedural error whose correction is unarguable, such as failure to turn on a transponder prior to takeoff.

The error of omission (absence of action) may not call attention to itself as an error as readily as an error of commission. Also, in many situations there may be a period of seconds or minutes when action could be taken. Thus, there may be no distinct signal or cue that *now* is the time to speak up about another crewmember's error of omission, and a challenge may be deferred in hope that the error will be corrected soon.

---

[48] Ruffell Smith (1979).

[49] Nagel, David C. 1988. Human error in aviation operations. In: Weiner, Earl L.; Nagel, David C., eds. Human factors in aviation. San Diego, CA: Academic Press, Inc.: 263-303. Chapter 9.

Strategies for Improving the Dynamics of Captain Decisionmaking and First Officer Monitoring/Challenging

The pattern of error types observed in many of the accidents involving crew assignment 1 indicates that improvements are needed in the monitoring/challenging function of crewmembers, especially as related to challenges by first officers of the errors made by captains. The Safety Board recognizes that monitoring/challenging procedures generally are included in air carrier SOPs and training programs. In addition, many air carriers address this subject in crew resource management (CRM)[50] programs they voluntarily provide to their flightcrews. Most of these programs emphasize pre-flight briefings, better intra-cockpit communication, and better standard operating procedures. As a result, the performance of many flightcrews has likely been enhanced. However, the specific monitoring/challenging problem areas identified in this study—particularly decisionmaking errors, errors of omission, and errors made during the taxi phase of operation—warrant special attention. Further, the Safety Board believes that air carriers could enhance flightcrew performance in these areas with strategies designed for use in conjunction with crew resource management and initial operating experience. Also, flight deck automation has potential to improve the monitoring/challenging function.

Crew Resource Management Programs.—A comprehensive CRM program is one tool an air carrier can use to improve both decisionmaking and monitoring/challenging by crewmembers. The CRM programs currently implemented by some air carriers attempt, in addition to other objectives, to enhance crewmembers' skills in monitoring and challenging.

The Safety Board has previously addressed crew resource management as a result of its investigations of several air carrier and regional airline accidents. In a safety recommendation issued on January 9, 1990, the Board asked the FAA to:

---

[50] In this study, the Safety Board uses the term crew resource management rather than cockpit resource management. Crew resource management has been widely adopted by the FAA and industry to describe a philosophy of CRM that includes the management of resources outside the cockpit (such as flight attendants and dispatchers) as well as the resources inside the cockpit. In keeping with this philosophy, many CRM programs allow for joint participation between flightcrew and non-flightcrew personnel.

> Require 14 CFR Part 121 operators to develop and use CRM programs in their training methodology by a specified date. (A-89-124)

In its response of April 12, 1990, the FAA indicated that it was considering proposed rulemaking to require CRM training. About a year later, on June 17, 1991, the FAA informed the Safety Board that it had issued special regulations to establish alternative methods for air carrier training (the Advanced Qualification Program, or AQP). Air carriers have the option of adopting AQP's alternate training and checking methods, which stress CRM and line operational simulations. The FAA also reiterated in its 1991 response that proposed rulemaking to require CRM training was still under consideration. On December 11, 1991, the Safety Board classified Safety Recommendation A-89-124 as "Open—Acceptable Response," based on the AQP information from the FAA and pending further action to require CRM training.

Crew resource management was also addressed as a result of the Safety Board's investigation of a June 8, 1992, GP Express regional airline accident at Anniston, Alabama.[51] Following the investigation, the Board recommended that the FAA:

> Develop guidance and evaluation criteria for principal operations inspectors to use to ensure that airline cockpit resource management training programs adequately address crew interaction, decision-making process, information gathering, flightcrew communication, and leadership skills. (A-93-37)

In its June 16, 1993, response to Safety Recommendation A-93-37, the FAA indicated that "guidelines for developing, implementing, reinforcing, and assessing crew resource management programs" are provided in Advisory Circular (AC) 120-51A, which the FAA issued on February 10, 1993.

Through the advisory circular, the FAA provides non-regulatory guidance to air carriers regarding the content of CRM programs. According to AC 120-51A, CRM programs should include three components to develop and maintain crew resource management skills. First, *initial indoctrination and awareness* training introduces the concepts of CRM through classroom lectures, group exercises, and videotape presentations. Second, *recurrent practice and feedback* sessions reinforce CRM by placing full crews in realistic flight scenarios (using simulators or flight training devices) and giving them feedback about their

---

[51] National Transportation Safety Board. 1993. Controlled collision with terrain, GP Express Airlines, Inc., flight 861, a Beechcraft C99, N118GP, Anniston, Alabama, June 8, 1992. Aircraft Accident Report NTSB/AAR-93/03. Washington, DC.

performance from videotaped segments of their sessions. Third, *continuing reinforcement* of CRM must be provided throughout training and line operations by check airmen, instructors, and managers who are attuned to and supportive of CRM.

In a reply to the FAA on November 19, 1993, the Safety Board indicated its support of the guidance provided in AC 120-51A and agreed that the AC was appropriate guidance for FAA principal operations inspectors to use in evaluating air carrier CRM programs. Accordingly, the Board classified Safety Recommendation A-93-37 "Closed—Acceptable Action."

The Safety Board notes that the FAA makes the following statement in the AC, based on research conducted by NASA and the FAA: "...when there is no effective reinforcement of CRM concepts by way of recurrent training, improvements in attitudes observed after initial indoctrination tend to disappear, and individuals' attitudes tend to revert to former levels." The three components of CRM, as described in AC 120-51A, form a comprehensive CRM program, and the Safety Board concurs with the FAA that flightcrews should receive all three components to improve their crew resource management performance. Further, because of the patterns of errors observed in this safety study, the Board concludes that comprehensive CRM training should be mandatory. Therefore, the Safety Board urges the FAA to require U.S. air carriers operating under 14 CFR Part 121 to provide, for flightcrews not covered by the AQP, a comprehensive crew resource management program as described in Advisory Circular 120-51A. The Board also classifies Safety Recommendation A-89-124 "Closed—Acceptable Response/Superseded" by the new recommendation issued as a result of this study.

The Safety Board is concerned about the high incidence, in the accident flights, of first officer failures to challenge decision errors made by the captain/flying pilots. The high incidence highlights a need for air carrier training programs to devote additional attention to the monitoring/challenging function of crewmembers. Literature about CRM addresses monitoring/challenging as principles of inquiry, advocacy, and assertion. The FAA describes this aspect of CRM, in Advisory Circular 120-51A, as "training in the potential benefits of crewmembers advocating the course of action that they feel is best, even though it may involve conflict with others." The Safety Board recognizes that many of the current CRM programs use classroom lectures and role-playing exercises to address inquiry, advocacy, and assertion.

The Board believes that a positive attitude toward monitoring/challenging and effective use of monitoring/challenging procedures can be developed and enhanced with appropriate training. In addition to training crewmembers in such matters under classroom conditions, air carriers could maximize the effectiveness of the training by providing crewmembers opportunities to practice monitoring and challenging under the realistic conditions of line operational simulations (LOS).

According to FAA Advisory Circular 120-35B, "Line Operational Simulations," LOS includes line-oriented flight training (LOFT), special purpose operational training (SPOT), and line operational evaluation (LOE). LOFT and SPOT could provide opportunities for pilots to practice monitoring and challenging other crewmembers' errors.

The AC defines LOFT as, "...training in a simulator with a complete crew using representative flight segments which contain normal, abnormal, and emergency procedures that may be expected in line operations." LOFT is no-jeopardy,[52] full-mission, simulator training in which crews are provided with an opportunity to practice technical and CRM skills during routine and abnormal flight conditions. With regard to the practice of CRM skills during LOFT, the AC states:

> LOFT scenarios should contain CRM skills, whereby crewmembers utilize and reinforce various CRM concepts. CRM skills should be integrated into each operator's maneuver/procedure learning objectives. In addition, focused CRM training could be provided independently during separate Special Purpose Operational Training.

Monitoring/challenging could be practiced in LOFT scenarios designed to increase the likelihood of operational errors by the flying pilot resulting from high workload, distractions, or complacency. The Safety Board supports emphasis in LOFT briefings and debriefings on the monitoring and challenging of errors that occur during the course of the session. However, given that the flying pilot might perform reasonably or even flawlessly under such conditions, this approach does not guarantee that pilots will have experienced an opportunity to practice monitoring and challenging of errors under realistic conditions.

One way to ensure that the non-flying pilot has an opportunity to practice monitoring/challenging is through the intentional introduction of a procedural or decision error by the flying pilot in the LOFT scenario. This technique would make certain that the non-flying pilot is confronted with the opportunity to detect and challenge the error made by the flying pilot. There may be some concern, however, that instructing the flying pilot to generate an error deliberately during LOFT violates the underlying premise that LOFT be

---

[52] AC 120-35B states, "LOFT is 'no-jeopardy' training; i.e., the instructor does not issue a passing or failing grade to a participating crewmember."

conducted under realistic conditions. The intentional generation of errors by participants represents a departure from standard air carrier training practice, and it would have to be executed with due regard to the possibilities for transferring negative habits to line flight operations. However, it is the Board's opinion that the benefits of practicing monitoring/challenging under realistic conditions outweigh the potential negative aspects of artificial interruption of LOFT scenarios and deliberate introduction of errors by LOFT participants.

As an alternative to, or in conjunction with LOFT, training in monitoring/challenging also could be provided to pilots through SPOT, which AC 120-35B defines as training, conducted in a simulator or advanced training device, designed specifically to target unique areas of concern, including CRM skills. Like LOFT, SPOT is operationally-oriented flight training, utilizing scenarios that are real-world and real-time. SPOT is also no-jeopardy training and places emphasis on instructor feedback and critique. Unlike LOFT, SPOT may be conducted on a wide range of flight simulators or training devices. Further, SPOT allows for direct instruction and the interruption of the scenario by the instructor.

Many air carriers provide LOFT or LOS training to various crewmembers at various times; for example, as initial (new hire) training, when being upgraded to a new crew position, when making a transition to a new aircraft type, or during recurrent training. Air carriers with more extensive CRM programs provide LOS training that is oriented around the briefing, practice, and debriefing of CRM concepts, usually on an annual basis during recurrent training. All air carrier pilots are not currently provided such training. As discussed in the earlier section on flightcrew experience (chapter 4), 53 percent of the first officers involved in the accidents had not yet completed their first year of service in the first officer position. Thus, any CRM-oriented LOS training that was to be provided them during forthcoming recurrent training would not have occurred prior to the accident flight. The behavior of first officers, including inquiry and assertion, has been viewed as heavily influenced by the personality, attitudes, and resource management style of captains.[53] The Safety Board supports the attention given by CRM programs to captains' resource management. However, CRM-oriented LOS training, if provided, could have positive effects on the ability of subordinate crewmembers—first

---

[53] See, for example, the following publication: Foster, Gramer C.; Garvey, Michael C. 1979. Left seat command or leadership? Flight leadership training and research at North Central Airlines. In: Cooper, George E.; White, Maurice E.; Lauber, John K., eds. Resource management on the flight deck: Proceedings, NASA/industry workshop; 1979 June 26-28; San Francisco, CA. NASA Conference Publication 2120. Moffett Field, CA: NASA Ames Research Center: 133-151.

officers and flight engineers (when applicable)—to interact successfully with captains. Further, such training may be especially helpful in dealing with problems associated with crew unfamiliarity.

The FAA does not maintain a data base of information about which air carriers provide CRM-oriented LOS training, what crew positions receive the training, when the training is provided, or what specific educational objectives, if any, are incorporated in LOS training scenarios. Consequently, it is impossible to know the percentage of all first officers currently receiving LOS training in skills such as monitoring and challenging when they are newly hired or upgraded to the first officer position.

The Safety Board obtained information about the training practices of a limited number of air carriers from a 1993 survey sent by the Air Line Pilots Association (ALPA) to its safety representatives at member airlines. Of the 13 responses received by ALPA from its safety representatives at the time this report was completed, 8 were known to pertain to Part 121 carriers. According to the survey responses, three (38 percent) of the eight air carriers do not provide LOFT as part of their first officer upgrade training.[54] Four of the eight air carriers hire pilots directly into the first officer position. Two of those four do not provide first officers with LOFT as part of their new-hire training program.

The results from the survey suggest that no industry standard exists for CRM-oriented LOFT or LOS training. Based on the pattern of errors associated with crew assignment, the high incidence of first officers who were serving their first year in that crew position, and the high incidence of crew unfamiliarity among the accident flights, the Safety Board believes that the FAA should require air carriers to provide, for flightcrews not covered by the AQP, LOS training during each initial or upgrade qualification into the flight engineer, first officer, and captain position that allows flightcrews to practice, under realistic conditions, non-flying pilot functions, including monitoring and challenging errors made by other crewmembers.

Data analyzed in this study also highlight the need for LOS training that addresses other specific educational objectives. As discussed in earlier sections, the accidents involved a high incidence of decision errors that were errors of omission and causal errors made during the taxi phase of operation. Consequently, the Safety Board believes the FAA should also require that air carrier LOS training be designed to attune flightcrews to the hazards of

[54] One of the three air carriers that does not provide LOFT to upgrading first officers, according to its ALPA safety representative, provides LOFT for new-hire flight engineers, which is followed by annual, recurrent LOFT.

tactical decision errors that are errors of omission, especially when those errors are not challenged, and to include practice in monitoring and challenging errors during taxi operations, specifically with respect to minimizing procedural errors involving inadequately performed checklists.

Initial Operating Experience (IOE):—As a result of its investigation of the November 15, 1987, crash of a Continental Airlines DC-9-14 at Stapleton International Airport in Denver, Colorado,[55] the Safety Board issued several safety recommendations. One of the recommendations asked the FAA to take the following action:

> Amend 14 CFR 121.434 to require that a second-in-command pilot complete initial operating experience for that position while actually performing the duties of a second-in-command under the supervision of a check pilot. (A-88-138)

On March 23, 1993, the FAA issued a Notice of Proposed Rulemaking (NPRM) that addresses pilot operating experience and requirements.[56] The NPRM includes a requirement for first officers of all Part 121 air carriers to obtain initial operating experience while actually performing the duties of the second-in-command. The Safety Board indicated support for the proposed requirement in comments on the NPRM submitted to the FAA on June 23, 1993. Under current regulations, a first officer is provided IOE credit for observing a second-in-command performing the duties of first officer during a flight. In its comments to the FAA, the Board stated that IOE obtained by passive observation in the cockpit is not as effective as IOE obtained by performing the duties under the supervision of a check pilot. Accordingly, the Board further stated that "passive observation should not be allowed as credit toward meeting the required supervised operating experience hours." On November 19, 1993, the Safety Board classified Safety Recommendation A-88-138 "Open—Acceptable Response," pending final rulemaking on requirements for first officer IOE.

The Safety Board suggests that the proposed requirement for first officers to receive their IOE while performing, rather than observing, the duties of the position is, in addition to CRM training with LOS exercises, an excellent opportunity for air carriers to instill monitoring and challenging habits in their new first officers. During IOE, all crewmembers—not just the new first

---

[55] National Transportation Safety Board. 1988. Continental Airlines, Inc., flight 1713, McDonnell Douglas DC-9-14, N626TX, Stapleton International Airport, Denver, Colorado, November 15, 1987. Aircraft Accident Report NTSB/AAR-88/09. Washington, DC.

[56] Federal Register, Vol. 58, No. 54, dated March 23, 1993, page 15730.

officer—may be more inclined to form good habits and be responsive to comments from the check airman. Consequently, the Safety Board believes that the FAA should require air carriers to structure their IOE programs to include: (a) training for check airmen who provide IOE in enhancing the monitoring and challenging functions of captains and first officers; (b) sufficient experience for new first officers in performing the non-flying pilot role to establish a positive attitude toward monitoring and challenging errors made by the flying pilot; and (c) experience (during IOE and annual line checks) for captains in giving and receiving challenges of errors.

Flight Deck Automation.—None of the accidents examined in this study involved airplanes equipped with the latest generation of glass-cockpit flight deck automation, such as the Airbus A-320, Boeing 747-400, or McDonnell Douglas MD-11. The Safety Board is aware that a major research effort is underway by government, universities, and the private sector to understand the human performance implications of flight deck automation and develop human-centered automation designs.[57]

The Safety Board recognizes that the highly automated flight deck has potential for affecting the monitoring/challenging function of crewmembers; for example, the reduction of the flying pilot's aircraft control workload may allow the flying pilot to engage in more self-monitoring and more observation of the performance of the automation system. Research also indicates that flight deck automation may cause monitoring/challenging to be more difficult under some circumstances; for example, one pilot cannot easily observe the other pilot's keyboard inputs pertaining to flight management systems, and automation mode selection and changes impose an additional monitoring burden on the pilots.[58] Although human-centered flight deck automation has the potential to resolve some of the monitoring/challenging issues identified in this study, monitoring and challenging will remain an important element of flightcrew performance as long as the flightcrew complement is greater than one.

---

[57] Wiener, Earl L. 1993. Crew coordination and training in the advanced-technology cockpit. In: Wiener, Earl L.; Kanki, Barbara G.; Helmreich, Robert L., eds. Cockpit resource management. San Diego, CA: Academic Press, Inc.: 199-229. Chapter 7.

[58] Wiener, Earl L. 1989. Human factors of advanced technology ("glass cockpit") transport aircraft. NASA Contractor Report 177528. Moffett Field, CA: NASA Ames Research Center.

Time Since Awakening and Performance

As described in chapter 4, individual crewmembers were classified as high or low TSA depending on whether their time since awakening was above or below the median for their crew position. This classification enabled an examination of performance, measured by the number and types of errors made, as a function of the length of time crewmembers had been awake prior to the accident.

Captains who were in the high TSA group (TSA greater than 12 hours) made slightly more errors overall than did captains in the low TSA group (TSA less than 12 hours): 6.6 errors and 5.0 errors, respectively. Small differences were observed in the average number of errors made by first officers in the high TSA group (more than 11 hours) versus those in the low TSA group (less than 11 hours): 4.7 errors and 4.0 errors, respectively.

High and Low TSA Crews.—The classification of captains and first officers into high and low TSA groups allowed a designation of crews according to whether they comprised a low TSA captain/low TSA first officer (low/low), low TSA captain/high TSA first officer (low/high), high TSA captain/low TSA first officer (high/low), or high TSA captain/high TSA first officer (high/high). After excluding crews for which there were missing data or for which the TSA value of an individual equaled the median for the crew position, 12 of the 37 crews could be classified as either high or low TSA crews. Six of these crews comprised a low TSA captain and a low TSA first officer, and are referred to as low TSA crews. The remaining six crews comprised a high TSA captain and a high TSA first officer, and are referred to as high TSA crews.

The average amount of time since awakening for the six high TSA crews was 13.8 hours for captains and 13.4 hours for first officers. For the six low TSA crews, the average time since awakening was 5.3 hours for captains and 5.2 for first officers.

Performance of High and Low TSA Crews.—The number and types of errors made by the six high TSA crews were contrasted with those made by the six low TSA crews. Table 5.4 presents the average number of overall errors, errors of omission, errors of commission, and monitoring/challenging failures made by low and high TSA crews. Overall, high TSA crews made an average of 40 percent more errors than low TSA crews (about 12.2 errors versus 8.7 errors). Moreover, this difference was almost exclusively due to the high TSA crews' making more errors of omission than the low TSA crews (5.5 errors

Table 5.4—Errors made, by nature of the error and by low and high time-since-awakening (TSA) crews[a]

Nature of the error	Mean errors (standard deviation in parentheses) made by—	
	Low TSA crews	High TSA crews
Among the types of primary errors:[b]		
Error of omission	2.00 (1.67)	5.50 (2.67)
Error of commission	4.33 (4.41)	3.50 (1.64)
Monitoring/challenging failure	2.33 (1.21)	3.17 (1.47)
Overall	8.67 (5.57)	12.17 (3.19)

[a] Captain-first officer pairs were placed in one of two groups depending on whether the TSA of both individuals in a pair was above (high TSA crew) or below (low TSA crew) the median for their respective crew positions. For the low TSA crews, the mean time since awakening was 5.3 hours for captains and 5.2 for first officers. For the high TSA crews, the mean was 13.8 hours for captains and 13.4 for first officers. Of the 37 crews involved in the accidents, 6 were high TSA crews and 6 were low TSA crews. The remaining 25 crews could not be designated because individual TSA data were missing or because the TSA value of a crewmember equaled the median for the crew position.

[b] The types of primary errors are aircraft handling, communication, navigational, procedural, resource management, situational awareness, systems operation, and tactical decision.

versus 2.0 errors). As an example of an error of omission made by a high TSA crew, the captain, awake for 14 hours prior to the accident, did not call for the taxi checklist. The accident sequence of that flight included 12 errors of omission.

The types of errors made by high and low TSA crews are presented in table 5.5. High TSA crews made significantly more procedural errors and tactical decision errors than did the low TSA crews. There were no other statistically significant differences observed between the TSA groups for other

Table 5.5—Mean errors made by low and high time-since-awakening (TSA) crews, by type of error[a]

Type of error	Low TSA crews	High TSA crews
Primary error:[b]		
Aircraft handling	1.17	1.50
Communication	1.67	.33
Navigational	.50	.17
Procedural	.83	3.00[c]
Resource management	.33	.33
Situational awareness	.67	1.00
Systems operation	.17	.67
Tactical decision	1.00	2.00[c]
Secondary error:[d]		
Monitoring/challenging	2.33	3.17

[a] Captain-first officer pairs were placed in one of two groups depending on whether the TSA of both individuals in a pair was above (high TSA crew) or below (low TSA crew) the median for their respective crew positions. For the low TSA crews, the mean time since awakening was 5.3 hours for captains and 5.2 for first officers. For the high TSA crews, the mean was 13.8 hours for captains and 13.4 for first officers.

[b] Error not dependent on making a prior error.

[c] Differs significantly ($p < .05$).

[d] Error dependent on making a prior primary error.

error types. These results suggest that the decrements in performance by high TSA crews tended to be in the form of ineffective decisionmaking, such as "failed to perform a missed approach," and procedural slips, such as "did not make altitude awareness callouts," rather than a deterioration of aircraft handling skill.

The number and types of errors made by crews varied with the total length of time crewmembers had been awake prior to the accident. The median periods of wakefulness were quite high for the crewmembers involved in the accidents: 12 hours for captains and 11 hours for first officers. Crews comprising pilots who had been awake longer than the median length of time for their crew position made more decisionmaking errors and procedural errors than did crews who had been awake for less time.

Fatigue and Flightcrew Performance

Prior wakefulness, characterized in this study as time since awakening prior to the accident, is one of several factors researchers have associated with increased vulnerability to fatigue.[59] Where possible, other fatigue-related factors were explored for their possible influence on flightcrew performance. These other factors include time of day, time zone crossings, and changing work schedules.

Time since awakening was somewhat confounded with the time of day the accidents occurred. All of the high TSA crews had their accidents during either afternoon-evening or overnight flights. It is possible that unique characteristics of flying later in the day are responsible for the differences in performance between high and low TSA crews. However, when the entire set of 37 accidents was examined, there was only one significant relationship between the time of day the accidents occurred and the errors made by crewmembers: crews flying during the afternoon-evening period made significantly more tactical decision errors than crews flying in the morning-midday period (1.9 errors versus 0.56 errors). No significant differences in the number or types of errors made were observed between crews whose accidents occurred overnight and crews whose accidents occurred during other periods of the day.

Research has indicated that there may be an interaction between work schedules and sleep schedules that affects human performance.[60] Detailed information on the pilots' duty and sleep schedules during the period just prior to the accidents was not available for analysis in this study. However, information on whether the pilots had been off duty for one or more days prior to the day of the accident was recorded for 29 captains and 29 first officers. No differences in the number or types of errors made were observed between pilots who had been off duty one or more days and pilots who had been on duty the day prior to the accident.

Flightcrews are subject to circadian desynchronization when they cross multiple time zones. The 37 accidents, however, were relatively short-haul

---

[59] Rosekind, Mark R.; Ganda, Philippa H.; Connell, Linda J. [In press]. Crew factors in flight operations: X. Strategies for alertness management in flight operations. NASA Technical Memorandum. Moffett Field, CA: NASA Ames Research Center.

[60] Tepas (1982).

operations with fewer than two time zone changes.[61] Overall, there were no differences in the number or types of errors made by crews as a function of cumulative time zone changes.

Of the factors regarded as contributing to an increased vulnerability to the effects of fatigue, significant differences in performance, in terms of the number and types of errors made by pilots, were observed only for the measure of prior wakefulness; that is, time since awakening. This observation is perhaps expected given that variability on many of the other factors was restricted by federal regulations (for example, flight time restrictions) and by the domestic, relatively short-haul flights included in the study.

On May 12, 1989, as a result of its review of and concern about the rising number of accidents in all modes of transportation attributable to human fatigue, the Safety Board issued the following recommendations to the U.S. Department of Transportation:

> Expedite a coordinated research program on the effects of fatigue, sleepiness, sleep disorders, and circadian factors on transportation system safety. (I-89-1)
>
> Develop and disseminate educational material for transportation industry personnel and management regarding shift work; work and rest schedules; and proper regimens of health, diet, and rest. (I-89-2)
>
> Review and upgrade regulations governing hours of service for all transportation modes to assure that they are consistent and that they incorporate the results of the latest research on fatigue and sleep issues. (I-89-3)

Currently, the three safety recommendations are classified "Open—Acceptable Response." In response to recommendation I-89-1, the DOT formed the Transportation Human Factors Coordinating Committee, comprising representatives from each of the DOT modal agencies, who regularly brief the Safety Board on the progress of the committee and action taken by each modal agency to address these recommendations. In a briefing held in September 1993, a representative of the FAA informed the Safety Board of fatigue research currently being sponsored by the FAA.

The Safety Board recognizes that an extensive body of useful knowledge exists about the factors that contribute to a pilot's vulnerability to fatigue and

[61] The criteria for inclusion in this study limited the accidents to those involving U.S. air carriers on U.S. territory. All of the accidents in the study were domestic flights.

associated performance decrements. Programs such as the Fatigue Countermeasures Program at NASA Ames Research Center have used this information to develop integrated educational and training modules on fatigue in flight operations and strategies for alertness management. This training provides participants with a general understanding of the physiological mechanisms underlying fatigue, the performance decrements that accompany fatigue, and applied strategies for maintaining alertness. The Safety Board believes that the FAA should require air carriers to include, as part of pilot training, a program similar to the NASA-Ames Fatigue Countermeasures Program, to educate pilots about the detrimental effects of fatigue, and strategies for avoiding fatigue and countering its effects.

Comments on Systemic Effects on Flightcrew Performance

The genesis of this study was the Safety Board's long-term recognition that errors made by flightcrews do not occur in a vacuum. Characteristics of a flight's operating environment and crewmembers, many of which are determined by various elements of the aviation system, affect the performance of the crew both positively and negatively. Just as the Safety Board recognizes that elements of the aviation system can make errors more likely to occur or more likely to result in an accident, the Board also recognizes the safety-enhancing effects of redundancy throughout the aviation system. Errors often occur during routine air carrier operations, but only very rarely do they result in accidents. This suggests that, on the whole, the aviation system is relatively error-tolerant.

Using data obtained from all its major investigations of flightcrew-involved, Part 121 air carrier accidents that occurred during a 12-year period, the Board sought to identify associations between flightcrew performance (measured as errors made during accident sequences) and the contexts in which the accidents occurred and errors were made (defined as the available set of operating environment and crewmember characteristic variables).

Several of these variables had distributions in the accident data that differed from the Safety Board's expectations for non-accident flights, implying a possible association between the variable and flightcrew-involved air carrier accidents. Associations were also found between types of errors and subsets of accidents that shared individual contexts, such as crewmembers who had been awake for a relatively long time, and crew assignments consisting of a captain/flying pilot and a first officer/non-flying pilot.

Because accident contexts may be determined by elements of the aviation system beyond the accident airplane's flight deck (including organizational factors and equipment design), these associations between context variables may identify areas of remediation in the aviation system that may, in turn, improve flightcrew performance. For example, training programs and standard operating procedures developed by aircraft manufacturers and air carriers, and approved by the FAA, are capable of improving the monitoring/challenging function of crewmembers. Similarly, the crew scheduling policies adopted by air carriers, and approved by the FAA, can affect the interaction between the captain and first officer through the effects of these policies on crew familiarity and experience.

The findings of the Safety Board's retrospective review of 1978-90 accident data may suggest areas for further human factors research and underscore the importance of the National Plan for Aviation Human Factors,[62] which the Board believes should receive high priority from the FAA. As explained in chapter 2, the accident data available for the Board's study permitted only some of the elements of the aviation system to be addressed. Elements that could not be studied may also suggest areas for research under the auspices of the National Plan. Although identification of all of the factors that influence the performance of vehicle operators is a major emphasis of the Board's investigation process, past investigations have not always gathered all of the information needed to evaluate total system influences on flightcrew performance. The Safety Board will, as a separate process, use this study to enhance its ability to identify and analyze the effects of the entire aviation system on flightcrew performance.

---

[62] The National Plan for Aviation Human Factors was established by the Aviation Safety Research Act of 1988 (P.L. 100-591).

Findings

1. In more than 80 percent of the 37 accidents reviewed for this study, the captain was the flying pilot and the first officer was the non-flying pilot. The Safety Board was unable to determine any particular significance to, or draw any conclusions from, this finding.

2. Procedural, tactical decision, and monitoring/challenging errors were the most common types of errors identified in the 37 accidents reviewed for this study; and of the primary errors identified, errors of omission were more frequent than errors of commission.

3. Monitoring/challenging failures were identified in 31 of the 37 accidents reviewed in this study.

4. A pattern common to 17 of the 37 accidents was a tactical decision error by the captain (with more than half constituting a failure to initiate required action), followed by the first officer's failure to challenge the captain's decision.

5. Errors made in the taxi phase of operation were causal in 8 of the 10 accidents that occurred during takeoff; 6 of the 10 involved inadequate performance of checklists.

6. Of the 31 accident flights for which information was available, 55 percent were running late. In contrast, between 17 and 35 percent of an illustrative sample of non-accident flights were running late.

7. Of the 15 accidents for which information was available, 73 percent occurred during the first duty day together for the captain and first officer, and of the 16 accidents for which information was available, 44 percent occurred during the crew's first flight together.

8. Half the captains for whom data were available had been awake for more than 12 hours prior to their accidents. Half the first officers had been awake more than 11 hours. Crews comprising captains and first officers whose time since awakening was above the median for their crew position made more errors overall, and significantly more procedural and tactical decision errors.

9. In the 29 accidents for which data were available, the median number of flight hours accumulated by first officers in the accident-involved crew position and aircraft type, while employed by the air carrier, was 419 hours. In the 32 accidents for which data were available, 53 percent of the first officers were in their initial year as a first officer for that air carrier.

10. The data analyzed in this study suggest the need for mandatory, comprehensive crew resource management training; and for CRM-oriented line operational simulation training and initial operating experience structured for the attainment of specific educational objectives.

Recommendations

As a result of this safety study, the National Transportation Safety Board made the following recommendations to the Federal Aviation Administration:

Apply the results of research conducted to date on the design and use of checklists to improve the error-tolerance of air carrier checklist procedures for taxi operations, by enhancing flightcrew monitoring/challenging of checklist execution, providing cues for initiating checklists, and considering technological or procedural methods to minimize the omission of any items on a checklist. Provide specific guidance to air carriers for implementing these procedures. (Class II, Priority Action) (A-94-1)

Require U.S. air carriers operating under 14 CFR Part 121 to provide, for flightcrews not covered by the Advanced Qualification Program, a comprehensive crew resource management program as described in Advisory Circular 120-51A. (Class II, Priority Action) (A-94-2) (Supersedes A-89-124)

Require U.S. air carriers operating under 14 CFR Part 121 to provide, for flightcrews not covered by the Advanced Qualification Program, line operational simulation training during each initial or upgrade qualification into the flight engineer, first officer, and captain position that: (1) allows flightcrews to practice, under realistic conditions, non-flying pilot functions, including monitoring and challenging errors made by other crewmembers; (2) attunes flightcrews to the hazards of tactical decision errors that are errors of omission, especially when those errors are not challenged; and (3) includes practice in monitoring and challenging errors during taxi operations, specifically with respect to minimizing procedural errors involving inadequately performed checklists. (Class II, Priority Action) (A-94-3)

Require that U.S. air carriers operating under 14 CFR Part 121 structure their initial operating experience programs to include: (a) training for check airmen in enhancing the monitoring and challenging functions of captains and first officers; (b) sufficient experience for new first officers in performing the non-flying pilot role to establish a positive attitude toward monitoring and challenging errors made by the flying pilot; and (c) experience (during initial operating experience and annual line checks) for captains in giving and receiving challenges of errors. (Class II, Priority Action) (A-94-4)

Require U.S. air carriers operating under 14 CFR Part 121 to include, as part of pilot training, a program to educate pilots about the detrimental effects of fatigue, and strategies for avoiding fatigue and countering its effects. (Class II, Priority Action) (A-94-5)

By the National Transportation Safety Board

Carl W. Vogt
Chairman

Susan M. Coughlin
Vice Chairman

John K. Lauber
Member

John A. Hammerschmidt
Member

James E. Hall
Member

Adopted: January 19, 1994

Appendix A

Operational Context Variables Excluded From Analysis

A number of variables were excluded from analysis because of missing data or the inability to develop objective and reliable measures from the information available in the accident investigation dockets. Given the nature of data collection during accident investigations, it was not always possible to obtain all of the information that would have been optimal for this study's type of analysis. All of the information necessary for the Safety Board to evaluate the causes, factors, and circumstances of each individual accident was collected, however.

Variables that could not be analyzed because of missing data (more than 90 percent of the observations were missing):

- Habitual use or non-use of a relevant SOP by the air carrier's pilots.
- Crewmember's time since last meal.
- Meal nutritive contents (protein, complex carbohydrate).
- Crewmember's detailed schedule of off-duty/duty periods prior to accident.
- Crewmember's sleep times prior to accident.
- Crewmember's life stress factors: marital conditions, signs of maturity or stability, recent engagement to be married, recent or concurrent major career decision, professionalism in approach to flying, conduct of interpersonal relationships, disciplinary record, and peer relationships.
- Crewmember's prior receipt of simulator training for the situation in which the error occurred.
- Crewmember's flight time in turbojet, turboprop, piston-powered equipment.
- Number of pilots employed by air carrier.
- Ratio of check airmen to pilots at crewmember's domicile.
- Air carrier had established an independent safety department.
- Months since most recent major labor disturbance.
- Months since most recent corporate merger.
- Months since most recent pilot layoff.

Variables that could not be analyzed because of inadequate data variance (more than 90 percent of the observations were identical):

- Existence of a threat to the crewmember's life: from weather, systems or structural failure, previous crew error, or imminent collision.
- Prior air traffic control error.
- Risk of Federal Aviation Regulation violation due to error action/inaction.
- Effect of error action/inaction on crewmember's paycheck.
- Deviation from an established SOP involved in the error.
- Crewmember on overtime shift.
- Crewmember's fitness for duty: incapacitation, alcohol/drug use, pre-existing illness.
- Crewmember's prior Federal Aviation Regulation violation.
- Crewmember's prior receipt of CRM classroom training.
- Crewmember's prior receipt of CRM training that fulfilled AC-120-51 or -51A, including line operational simulations.
- Flight deck instrument display type.
- Level of control automation.
- Function of flight deck equipment that failed.
- Failure mode of flight deck equipment that failed.

Variables that could not be measured objectively using the available information:

- Quality of external information cues (true, ambiguous, false...).
- Error situation presented cues to change plan of action.
- Change in safety margin due to error action/inaction.
- Change in delay/inconvenience due to error action/inaction.
- Need to critique or correct another crewmember avoided by error.
- Task complexity or workload: visual, auditory, motor task, and cognitive.
- General applicability of SOPs to the situation in which the error occurred.
- Establishment of a relevant SOP by the air carrier.
- Crewmember's theory of the situation.

External information basis (inadequate cues/false information) for false theory of the situation.
Internal information basis (memory, knowledge, habit pattern) for false theory of the situation.
SOP enabled/interfered with monitoring or challenging an error.
Workload enabled/interfered with monitoring or challenging an error.

Appendix B

Limitations of Accident Data for Comparing Performance With Operational Contexts

The Safety Board notes that, with the single exception of the time-since-awakening measure, it was not able to associate differences in the number and types of crewmember errors with differences in the operational contexts or crewmember characteristics. Although past research has linked some of these variables to pilot performance, it is not surprising that such associations were not observed in the current study. Generally, the effects reported in past research studies have been obtained in the relatively controlled environment of the flight simulator. In simulator studies, there are repeated trials in which all but a limited number of critical variables are held constant or controlled through experimental manipulation. In contrast, air carrier accidents are extremely rare events, and the conditions under which they occur vary widely from accident to accident. Further, a retrospective study of human performance in accidents, such as the current study, must necessarily focus on those usually discrete and discontinuous failures of performance, called errors in this report, rather than the richer measures of the range of performance usually available in simulator or laboratory studies. Also with regard to the current study, when the accident data were divided into subsets based on values of the operational context variables, often there were insufficient observations in one or more subsets to make a comparison of performance.

Flightcrew performance during accidents is subject to the simultaneous influences of many operational context variables, including variables evaluated in this study, as well as others that could not be evaluated. Because of data limitations—a small number of air carrier accidents (due to their rarity), and missing data (due to the nature of the evidence in accident investigations)—the interactions between operational context variables and flightcrew performance could not be analyzed in a multivariate context.

As noted in the introduction of this report, air carrier operations are extremely safe. The rarity of accidents required an extended time span for the study, 1978-90. During this period, many changes occurred in air carrier operating equipment, procedures, and training. These changes may have confounded the effects of variables, although no individual operational context variable was strongly associated with time. In addition, because of changes in accident investigation methods between 1978 and 1990, it was not appropriate to analyze the data for the purpose of determining trends over time.

The Safety Board also found it difficult to measure some of the operational context data in the retrospective study. For example, laboratory research indicates that workload affects human performance. Workload varies throughout both normal and accident flights. However, it was not possible to reliably measure workload from the data available in the accident records. As a result, workload could not be evaluated in the study, although it may have confounded the effects of other operational context variables that could be measured.

The scope of the study limited the flights examined to those resulting in an accident. Further, the evaluation of crew performance focused on the errors made during the accident sequence. Thus, behavioral comparisons were not possible between successful and unsuccessful flights, or between successful and unsuccessful crew performance during flight.

Appendix C

Narrative Description of Errors Made

The safety study identified 302 separate errors, which are listed in this appendix. The sources of information and methods used to identify the errors are explained in chapter 2.

Column Key:

Crewmember: C = captain, FO = first officer, FE = flight engineer.
Error Types: AH = aircraft handling, CO = communication, MC = monitoring/challenging, NV = navigation, PR = procedural, RM = resource management, SA = situational awareness, SO = systems operation, TD = tactical decision.
Nature, omission/commission (primary errors only): OM = omission, COM = commission.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
1	C	AH	COM	Permitted the airplane to bank toward the inoperative engine.
2	C	RM	COM	Commanded FO to "call the tower."
3	C	PR	OM	Did not call out "gear up -- check for feather or fire."
4	FO	MC	—	Did not challenge C's failure to command gear retraction.
5	C	TD	OM	Did not execute a missed approach prior to entering a cumulonimbus cloud that contained visible lightning.
6	FO	MC	—	Did not challenge continuation of approach.
7	FE	MC	—	Did not challenge continuation of approach.
8	FO	SA	COM	Retarded power to idle and unspooled engines, in response to performance-increasing windshear.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
9	FO	SA	COM	Retarded power again to continue descent on glideslope, after windshear encounter.
10	C	TD	OM	Did not command go-around during or after windshear encounter.
11	FO	AH	COM	Permitted a rapid nose-down pitch rate to develop.
12	FO	AH	COM	Relaxed pull force on control column in response to stick shaker activation, which made ground contact inevitable.
13	C	PR	OM	Did not consult the landing analysis chart for runway 24 at Erie.
14	FO	PR	OM	Did not consult the landing analysis chart for runway 24 at Erie.
15	C	TD	OM	Did not execute missed approach when informed of tailwind component.
16	FO	MC	—	Did not challenge continuation of approach.
17	C	AH	COM	Maintained V_{ref} plus 13-18 knots below 500 agl.
18	FO	MC	—	Did not challenge excessive airspeed.
19	C	AH	COM	Deviated above glideslope at decision height.
20	C	TD	OM	Did not execute missed approach after deviating above glideslope.
21	FO	MC	—	Did not challenge continuation of the approach to a long landing.
22	C	AH	OM	Delayed maximum deceleration effort after touchdown.
23	FO	PR	OM	Did not remove and secure the elevator control block.
24	C	PR	OM	Did not familiarize the FO with the elevator control block.
25	FE	PR	OM	Did not familiarize the FO with the elevator control block.
26	C	PR	OM	Did not verbalize checklist responses.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
27	FO	PR	OM	Did not verbalize checklist responses.
28	FE	PR	OM	Did not verbalize checklist responses.
29	C	TD	COM	Added a 20 knot margin to V_{ref} for the condition of a quartering tailwind shearing to near calm.
30	FO	AH	OM	Did not acknowledge or perform the "gear down" command when it was issued.
31	C	SA	OM	Failed to configure the aircraft for landing prior to crossing the FAF.
32	FO	MC	—	Did not call out deviations from airspeed/configuration standards.
33	C	PR	OM	Did not arm speedbrake and call for "Landing Checklist down to flaps."
34	C	TD	OM	Failed to initiate go-around when the approach was unstable below 500 agl.
35	FO	MC	—	Failed to call out airspeed and glideslope deviations below 500 agl.
36	C	AH	OM	Delayed manual speedbrake deployment.
37	FO	MC	—	Did not challenge speedbrake non-deployment.
38	C	AH	COM	Did not maintain maximum steady brake pressure.
39	C	PR	OM	Did not contact clearance delivery or ground control prior to taxiing from the gate to the deice pad.
40	C	CO	COM	Accepted clearance to the deice pad as a clearance to the active runway.
41	FO	MC	—	Did not challenge C's acceptance of clearance to deice pad.
42	C	TD	OM	Did not order a second deicing with more than 20 minute delay.
43	C	PR	OM	Did not inspect the wing for ice.
44	FO	PR	OM	Did not inspect the wing for ice.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
45	C	TD	COM	Allowed the FO to perform the takeoff.
46	FO	AH	COM	Rotated the aircraft twice as rapidly as normal and to an excessive pitch attitude.
47	C	MC	—	Failed to arrest the FO's rapid rotation.
48	C	PR	OM	Did not make altitude awareness callouts on approach.
49	FO	MC	—	Did not challenge C's failure to make callouts.
50	C	AH	COM	Leveled off over approach lights (full scale glideslope deflection).
51	C	TD	OM	Failed to perform a missed approach when unstabilized.
52	C	AH	COM	Maneuvered such that a large sink rate developed.
53	FO	MC	—	Did not challenge sink rate deviation in timely manner.
54	C	AH	COM	Performed an improper flare.
55	FO	PR	COM	Initiated non-pertinent conversations.
56	C	RM	OM	Did not enforce sterile cockpit.
57	FO	PR	OM	Did not extend flaps/slats after clearing ramp.
58	C	PR	OM	Did not call for Taxi Checklist.
59	FO	PR	OM	Did not extend flaps/slats after No. 3 engine start.
60	C	PR	OM	Did not call for Before Takeoff Checklist.
61	FO	PR	COM	Gave incorrect response to "flaps" checklist challenge.
62	C	MC	—	Did not verify flap position.
63	FE	PR	OM	Failed to advise C that the auto pack trip light did not illuminate, when throttles were advanced.
64	C	AH	COM	Continued to increase angle of attack after stickshaker began.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
65	C	AH	OM	Delayed command for full power.
66	C	SO	OM	Did not detect mis-trimmed rudder by pedal offset, tiller position, rudder control force, or trim indicator positions.
67	C	AH	OM	Failed to hold short of crossing taxiway.
68	FO	MC	—	Did not challenge C's failure to hold short of taxiway.
69	C	PR	COM	Gave incorrect response to "stabilizer and trim" challenge.
70	FO	MC	—	Did not detect mis-trimmed rudder by trim indicator position.
71	C	TD	COM	Did not use auto-brake for takeoff.
72	FO	CO	OM	Did not communicate to C his directional control difficulties.
73	C	TD	COM	Used nosewheel steering tiller rather than rudder deflection to maintain directional control at high speed.
74	FO	SO	COM	Pressed auto-throttle disengage button instead of TOGA button.
75	C	SO	OM	Did not make final adjustments to left throttle.
76	C	RM	OM	Delayed assumption of control from the FO.
77	C	PR	OM	Did not provide airspeed callouts.
78	C	RM	COM	Did not provide a clear command for transfer of control.
79	C	TD	COM	Initiated rejected takeoff above V_1.
80	C	AH	OM	Delayed maximum braking application during rejected takeoff.
81	FO	PR	OM	Did not brief the C on the visual aids associated with the approach to be flown.
82	C	MC	—	Did not obtain or request information about visual aids.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
83	C	TD	OM	Did not execute a missed approach when not established on localizer at the final approach fix.
84	FO	MC	—	Did not challenge continuation of the approach.
85	C	TD	OM	Failed to discontinue the approach with full deflection of the localizer while inside the final approach fix.
86	FO	MC	—	Did not challenge continuation of the approach.
87	C	SA	COM	Descended below 3,000 feet prior to being established on the localizer.
88	FO	MC	—	Did not challenge premature descent.
89	FO	PR	COM	Called "runway in sight" when looking at other ground lights.
90	C	PR	COM	Verified "runway in sight" by a similar misidentification.
91	C	TD	COM	Descended below MDA while still outside the visual descent point.
92	FO	MC	—	Did not challenge premature descent below MDA.
93	C	SA	COM	Misjudged final visual descent path to presumed runway location.
94	FO	MC	—	Delayed challenge of improper visual descent path.
95	FE	PR	COM	Engaged in non-pertinent conversation.
96	C	PR	COM	Engaged in non-pertinent conversation.
97	FO	PR	COM	Engaged in non-pertinent conversation.
98	FE	PR	COM	Engaged in non-pertinent radio conversation with company operations personnel.
99	FO	RM	OM	Did not point out the Cessna to the C, FE or jumpseat occupant.
100	FO	AH	COM	Did not keep the Cessna in sight while under a maintain-visual-separation clearance.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
101	C	SA	OM	Did not visually track the Cessna while under a maintain-visual-separation clearance.
102	FE	SA	OM	Did not visually track the Cessna while under a maintain-visual-separation clearance.
103	C	PR	OM	Did not convey the loss of visual contact to the controller.
104	FO	CO	COM	Misinformed C that he was familiar with the airport.
105	FO	CO	COM	Misinformed C that he was a Lt. Colonel, that he had combat experience and had bailed out of airplanes twice.
106	FO	CO	COM	Directed C to parallel the taxiway centerline on the ramp.
107	C	NV	COM	Did not join taxiway centerline in time to identify the intersection.
108	FO	CO	COM	Directed C to turn onto the Outer taxiway rather than O-6.
109	C	NV	COM	Turned onto the Outer taxiway rather than O-6.
110	C	MC	—	Did not crosscheck taxiway bearing with magnetic heading indicators.
111	FO	MC	—	Did not crosscheck taxiway bearing with magnetic heading indicators.
112	FO	CO	COM	Misinformed ground controller that DC-9 was on O-6.
113	C	MC	—	Did not challenge FO's incorrect statement.
114	FO	CO	COM	Misinformed ground controller that DC-9 was on Foxtrot.
115	C	MC	—	Did not challenge FO's incorrect statement.
116	FO	CO	COM	Directed C to turn right on O-4 instead of X-ray.
117	C	NV	COM	Turned right onto O-4 instead of X-ray.
118	FO	CO	COM	Misinformed C that the runway ahead was 9-27.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
119	C	RM	OM	Did not make an independent assessment of DC-9 position.
120	FO	CO	OM	Did not tell ground controller that the DC-9 was "stuck" as commanded three times by C.
121	C	TD	COM	Taxied onto the active runway.
122	C	SO	COM	Transmitted warnings over interphone rather than to the ground controller.
123	C	TD	COM	Accepted dispatch release to Dutch Harbor when its runway was contaminated with standing water.
124	C	TD	OM	Did not execute a go-around when airspeed reached V_{ref} + 15 knots.
125	C	SA	COM	Flew a flat descent gradient.
126	FO	MC	—	Did not challenge C's glidepath or aim point.
127	C	AH	COM	Landed short of the runway threshold.
128	C	RM	OM	Did not assign a time limit to the flight attendant for cabin preparations.
129	C	SA	OM	Failed to establish a time limit for beginning approach.
130	C	RM	OM	Failed to assign monitoring of fuel state to a crewmember.
131	C	SA	OM	Failed to equate the fuel remaining with time and distance from the airport.
132	FO	MC	—	Failed to express timely concern about time remaining to fuel exhaustion.
133	FE	MC	—	Failed to express timely concern about time remaining to fuel exhaustion.
134	C	TD	OM	Continued to hold and accepted a vector away from the airport.
135	FO	MC	—	Did not challenge the continued hold.
136	FE	MC	—	Did not challenge the continued hold.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
137	C	SO	COM	Stated an incorrect reading for fuel quantity gauges.
138	C	SA	COM	Extended leading edge slats 2,3,6, and 7.
139	C	AH	COM	Did not initiate timely flight control input to counter slat asymmetry.
140	C	PR	COM	Erased CVR tape.
141	C	TD	COM	Descended below MDA prior to sighting runway environment.
142	FO	MC	—	Did not challenge premature descent below MDA.
143	FO	AH	OM	Delayed extension of flaps to 40°.
144	C	AH	COM	Over-corrected to right in attempt to align aircraft with centerline.
145	C	TD	OM	Failed to execute a go-around when proper runway alignment could not be attained.
146	FO	NV	COM	Incorrectly stated definition of LENEX intersection, using an "11.1 DME" fix.
147	FO	PR	OM	Did not brief the missed approach.
148	C	MC	—	Did not challenge the use of DME to define LENEX and the FO's failure to brief the missed approach.
149	C	NV	COM	Used MKC DME rather than ANX crossbearing for LENEX.
150	FO	SA	OM	Did not begin descent when intercepting the final approach course.
151	C	MC	—	Did not challenge FO's failure to descend.
152	FO	SO	COM	Incorrectly configured the communications radio.
153	C	TD	COM	Chose to execute a circling maneuver without visual contact with the airport.
154	FO	MC	—	Did not challenge the circle in IMC.
155	FE	MC	—	Did not challenge the circle in IMC.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
156	C	AH	COM	Stalled aircraft after rapid climb during missed approach.
157	FO	RM	OM	Did not take over control of aircraft to recover from approach to stall, after C did not respond to challenges.
158	FO	SO	COM	Isolated the right generator after the left generator failed.
159	C	TD	OM	Did not divert to nearest airport after dual generator failure.
160	C	PR	OM	Did not initiate generator failure or load-shedding procedures.
161	C	TD	OM	Did not divert to nearest airport when unable to restore either generator.
162	FO	MC	—	Did not suggest diversion.
163	C	TD	COM	Continued instrument flight based on nicad battery voltage readings of 20-22 volts.
164	FO	MC	—	Delayed challenge of continued instrument flight based on nicad battery voltage readings of 20-22 volts.
165	C	TD	OM	Did not divert to VFR airport when attempting to conduct flight below clouds.
166	FO	MC	—	Did not suggest diversion.
167	FO	PR	OM	Delayed isolation of right and left generator busses.
168	C	TD	COM	Commanded re-connection of right and left generator busses and use of unnecessary electrical equipment.
169	FO	MC	—	Did not challenge C's decisions to maintain high electrical load.
170	C	SA	OM	Failed to configure aircraft for approach outside descent point but within 6 miles of airport.
171	C	SA	COM	Established an excessive descent rate.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
172	FO	ET	—	Failed to provide C with airspeed/descent rate deviation challenges.
173	FE	MC	—	Failed to provide C with airspeed/descent rate deviation challenges.
174	FO	PR	OM	Failed to provide C with required altitude callouts.
175	C	PR	OM	Failed to check radar altitude in response to GPWS alert.
176	FO	PR	OM	Failed to check radar altitude in response to GPWS alert.
177	C	TD	OM	Failed to execute go-around in response to GPWS alert.
178	FE	SO	COM	Turned off GPWS.
179	C	SA	OM	Delayed landing gear extension.
180	C	TD	OM	Failed to level off at MDA.
181	FO	MC	—	Failed to challenge descent below MDA.
182	C	AH	COM	Did not stabilize approach speed.
183	C	TD	OM	Did not execute a go-around when greater than 1,000 FPM descent rate was required to track glideslope.
184	FO	MC	—	Did not challenge C's failure to execute a go-around.
185	FO	PR	OM	Did not call out 1,000 agl.
186	C	TD	OM	Did not execute a go-around when GPWS warning sounded.
187	FO	PR	OM	Did not call out 500 agl, airspeed, and rate of descent.
188	FO	MC	—	Did not challenge unstabilized approach below 500 agl.
189	C	TD	OM	Did not execute a go-around when crossing the threshold at V_{ref} + 61 knots
190	FO	MC	—	Did not challenge airspeed deviation at threshold.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
191	C	AH	COM	Applied brakes before main landing gear touchdown.
192	C	TD	OM	Did not execute a go-around after touchdown.
193	C	TD	OM	Did not order a second deicing of the aircraft.
194	C	PR	OM	Failed to ensure that wings were clear of ice and snow before commencing takeoff roll.
195	FO	MC	—	Failed to challenge captain's decision to take off.
196	C	AH	COM	Rotated to stall angle of attack.
197	FO	AH	COM	Entered a spiral dive.
198	FO	AH	COM	Failed to recover properly from the unusual attitude.
199	C	AH	COM	Failed to recover properly from the unusual attitude.
200	C	AH	COM	Deviated below glideslope.
201	C	TD	OM	Failed to execute a go-around at decision height.
202	FO	PR	OM	Failed to call out "runway in sight/no contact" at DH.
203	FO	MC	—	Failed to challenge descent below DH.
204	FO	RM	OM	Failed to take control of the aircraft.
205	FO	AH	COM	Flew erratic headings.
206	C	SO	COM	Interpreted partial electrical failure as total electrical failure.
207	C	AH	COM	Entered a spiral dive.
208	FO	MC	—	Did not challenge deviation or recover control.
209	C	AH	COM	Applied control force that overstressed the airframe.
210	C	PR	COM	Initiated non-essential conversation/activity.
211	C	SA	COM	Flew a low and flat final approach segment.
212	C	AH	COM	Reduced thrust to idle at 50 agl.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
213	C	AH	COM	Flew approach at V_{ref} + 20-30 knots and did not square turn to final.
214	C	AH	COM	Unspooled engines on final approach.
215	C	TD	OM	Delayed initiation of go-around.
216	FO	MC	—	Did not challenge C's failure to go around.
217	C	PR	COM	Commanded landing gear retraction without positive climb.
218	FO	MC	—	Did not challenge premature gear retraction.
219	C	PR	OM	Did not verify that the airplane was free of ice and snow accumulation.
220	C	TD	COM	Used reverse thrust to assist pushback.
221	C	PR	OM	Did not turn on engine anti-ice.
222	FO	MC	—	Did not challenge anti-ice "off."
223	C	TD	COM	Used other airplanes' exhaust to melt ice.
224	C	TD	COM	Initiated takeoff with snow/ice on airfoils.
225	C	TD	OM	Failed to reject takeoff when notified of anomalous engine instrument indications by FO.
226	FO	MC	—	Did not suggest rejected takeoff.
227	FO	AH	COM	Did not arrest the rapid rotation caused by ice contamination.
228	C	MC	—	Delayed application of maximum power.
229	FO	AH	OM	Delayed application of maximum power.
230	FO	SO	COM	Turned off fuel heat.
231	FO	SO	OM	Did not restore fuel heat in response to power loss.
232	C	MC	—	Did not restore fuel heat in response to power loss.
233	FO	PR	OM	Did not reset longitudinal trim after landing.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
234	C	PR	OM	Did not set trim during turnaround checklist.
235	C	PR	OM	Did not perform final trim check during taxi-out checklist.
236	FO	MC	—	Did not identify out-of-trim condition on the Before Takeoff Checklist trim check.
237	FE	MC	—	Did not identify out-of-trim condition on the Before Takeoff Checklist trim check.
238	C	TD	COM	Suggested that FO and FE swap duty stations.
239	FO	TD	COM	Encouraged FE to swap duty stations.
240	FE	TD	COM	Accepted duty station swap.
241	FO	PR	OM	Did not identify out-of-trim condition at 80-knot control check.
242	FO	AH	COM	Over-rotated at liftoff.
243	FO	AH	OM	Did not re-trim to relieve pitch-up tendency.
244	C	RM	OM	Did not make timely intervention to control the airplane.
245	C	PR	OM	Did not use engine anti-ice when icing conditions were encountered.
246	C	TD	OM	Failed to order deice when there was substantial ice on wing leading edges.
247	C	PR	OM	Failed to inspect engine inlet surfaces for ice.
248	C	SO	COM	Used engine anti-ice without continuous ignition when residual ice on inlet surfaces was likely.
249	C	PR	OM	Did not pre-brief for possible thunderstorm/wind shear encounter.
250	C	PR	OM	Did not request updated weather information.
251	FO	PR	OM	Did not request updated weather information.
252	C	TD	OM	Did not execute a go-around when presented with known thunderstorm conditions.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
253	FO	MC	—	Did not challenge continuation of the approach.
254	C	AH	COM	Did not rotate above 15° to the stick shaker in order to avoid ground contact.
255	C	TD	COM	Abandoned the missed approach by reducing power and pitch attitude.
256	C	PR	OM	Did not process the weight and balance control forms.
257	C	PR	OM	Did not respond to checklist items.
258	FE	PR	OM	Skipped checklist items.
259	C	TD	COM	Reduced power below maximum on all engines.
260	C	TD	OM	Did not restore maximum power when vibration continued, until too late.
261	FO	MC	—	Did not challenge airspeed reduction and flightpath.
262	C	PR	OM	Did not call out "max power" or "ignition override-check fuel system."
263	FO	PR	OM	Did not call out the malfunction.
264	C	AH	COM	Applied rudder input that yawed the aircraft toward the dead engine.
265	FO	MC	—	Did not challenge C's incorrect rudder input.
266	C	AH	COM	Applied nose-up elevator control sufficient to produce a 1.8G loading.
267	C	PR	OM	Did not call for After Start Checklist.
268	FO	CO	OM	Did not read back communications frequency change.
269	FO	PR	OM	Did not extend flaps when aircraft taxied away from ramp.
270	C	PR	COM	Initiated non-pertinent conversation with flight attendant.
271	C	PR	OM	Did not call for Taxi Checklist.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
272	FO	MC	—	Did not ask for Taxi Checklist when it was not called for by C.
273	C	NV	COM	Taxied towards runway 21C instead of turning on taxiway Charlie.
274	FO	MC	—	Did not challenge C's failure to turn onto taxiway until after the taxiway was missed.
275	C	PR	OM	Did not extend flaps or perform Taxi Checklist.
276	FO	PR	OM	Did not extend flaps or perform Taxi Checklist.
277	C	PR	OM	Did not call for Before Takeoff Checklist.
278	C	TD	OM	Did not initiate a rejected takeoff or check flaps when autothrottles would not engage.
279	FO	MC	—	Did not suggest a rejected takeoff or check flaps when autothrottles would not engage.
280	C	PR	OM	Did not extend flaps (part of stall recovery procedure) when given stick shaker indication.
281	C	AH	COM	Maintained airspeed below stick shaker speeds.
282	C	SA	OM	Did not intercept the glideslope.
283	FO	MC	—	Did not challenge glideslope deviation.
284	FO	PR	OM	Did not call out 1,000 feet above field elevation.
285	FO	MC	—	Did not call out time and altitude over outer marker.
286	FO	PR	OM	Did not call out 500 feet above field elevation.
287	FO	PR	OM	Did not call out "runway not in sight" at DH.
288	C	TD	COM	Descended below DH in IMC.
289	FO	MC	—	Did not challenge descent below DH in IMC.
290	C	TD	COM	Responded to ATC altitude alert with continued descent based on radar altitude.
291	FO	PR	OM	Did not familiarize himself with ATIS/field condition information.

Error No.	Crew-member	Error Type	Nature, Om/Com	Error
292	C	SO	COM	Used autothrottle/speed control when it was out of tolerance.
293	C	AH	OM	Did not disengage autothrottle and manually reduce airspeed to V_{ref} + 5 knots at the threshold.
294	FO	MC	—	Did not challenge excessive airspeed at the threshold.
295	C	AH	OM	Delayed application of full reverse thrust by approximately 5 seconds (9 seconds after touchdown).
296	C	PR	COM	Did not completely brief the intended course reversal or brief the final approach fix definition.
297	C	CO	COM	Stated incorrect DME distance for the descent below 1,500 feet—three times.
298	FO	MC	—	Did not challenge incorrect statements of the final approach fix.
299	C	SA	COM	Descended below 3,000 prior to being established on the localizer course.
300	FO	MC	—	Did not challenge premature descent below 3,000.
301	C	SA	COM	Commenced descent to MDA prior to reaching the final approach fix.
302	FO	MC	—	Did not challenge the premature descent to MDA.

Appendix D

Number of Errors by Type and Accident

Table D.1—Number of errors identified in each of the 37 accidents reviewed in the safety study, by type of error

Accident number	Aircraft handling	Commu-nication	Naviga-tional	Proce-dural	Resource manage-ment	Situational awareness	Systems operation	Tactical decision	Monitoring/ Challenging	Total
1	0	0	0	3	0	3	1	2	3	12
2	2	0	0	2	0	0	0	4	3	11
3	1	0	0	1	1	0	0	0	1	4
4	1	0	0	5	1	2	0	0	0	9
5	0	0	0	0	2	2	1	1	4	10
6	1	0	0	1	0	0	0	1	1	4
7	1	0	0	1	1	0	0	1	1	5
8	3	0	0	0	0	0	1	0	1	5
9	1	0	0	1	0	1	0	0	0	3
10	1	0	0	1	0	1	0	0	0	3
11	2	0	0	1	0	0	0	1	2	6
12	2	0	0	2	0	0	0	4	3	11
13	0	0	0	0	0	0	2	0	1	3
14	2	0	0	4	1	0	0	3	2	12
15	2	0	0	0	0	0	0	2	1	5
16	0	0	0	2	0	0	1	1	0	4
17	1	0	0	3	0	0	0	2	1	7
18	1	0	2	1	1	1	1	1	4	12
19	0	0	0	2	0	0	1	5	4	12
20	3	0	0	0	0	0	0	0	0	3
21	2	0	0	1	0	0	1	0	1	5
22	0	0	0	3	0	0	0	2	1	6
23	2	0	0	0	0	2	0	2	2	8
24	2	0	0	2	0	0	0	0	1	5
25	0	0	0	6	0	0	0	0	0	6
26	3	0	0	1	0	1	0	2	3	10
27	1	0	0	0	0	1	0	2	1	5
28	3	0	0	2	0	0	0	2	3	10
29	1	1	1	8	0	0	0	1	3	15
30	1	1	0	3	0	0	0	2	2	9
31	0	0	0	3	0	1	0	2	3	9
32	3	0	0	1	0	0	0	1	2	7
33	2	0	0	7	1	0	0	0	1	11
34	2	1	0	2	2	0	3	3	2	15
35	0	0	0	3	0	2	0	3	6	14
36	0	1	0	1	0	2	0	0	3	7
37	0	9	3	0	1	0	1	1	4	19
Total	46	13	6	73	11	19	13	51	70	302

* U.S. G.P.O.:1994-300-644:80018