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An Analysis of Controlled-flight-into-terrain (CFIT) Accidents of Commercial Operators 1988 through 1994

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In This Issue

An Analysis of Controlled-flight-into-terrain (CFIT) Accidents of Commercial Operators 1988 through 1994

This special double issue of Flight Safety Digest *presents a ground-breaking report on factors associated with controlled-flight-into-terrain (CFIT) accidents involving commercial aircraft operators, which was produced by the Netherlands National Aerospace Laboratory (NLR).*

The NLR report, which has been edited by the FSF editorial staff, focused on 156 CFIT accidents that occurred from 1988 through 1994. The report found that the landing (descent) phase and the landing (approach) phase together accounted for about 70 percent of the accident sample; and that 75 percent of the accident aircraft were not equipped with ground-proximity warning systems (GPWSs). Procedural, situational-awareness and tactical-decision errors were the dominant crew error types, the report concluded.

The NLR report, conducted under contract for the Netherlands Directorate-General of Civil Aviation (RLD), was launched in association with a Flight Safety Foundation (FSF)-led global industry effort, in counsel with the International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO), to reduce CFIT accidents by 50 percent.

Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of flight safety. Nonprofit and independent, FSF was launched in 1945 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 660 member organizations in 77 countries.

Contents

Tables

Figures (Appendix A)

Abbreviations and Acronyms

ADF	Automatic direction finder
ADREP	Aviation Data Reporting Program (ICAO)
AFR	African Region of ICAO
AIP	Aeronautical information publication
ALPA	U.S. Air Line Pilots Association
APA	Asia/Pacific Region of ICAO
ARP	Aerodrome reference point
ARTS	Automated radar terminal system
ATC	Air traffic control
ATIS	Automatic terminal information service
BASI	Bureau of Air Safety Investigation (Australia)
CAA	U.K. Civil Aviation Authority
CDU	Control display unit
CFIT	Controlled flight into terrain
CO	Communication
DH	Decision height
DME	Distance measuring equipment
EEU	Eastern European Region of ICAO
ER	En route
EUR	European Region of ICAO
FAA	U.S. Federal Aviation Administration
FAF	Final approach fix
FD	Flight director
FMS	Flight management system
FO	First officer
FSF	Flight Safety Foundation
GCAS	Ground-collision avoidance system
GNSS	Global navigation satellite system
GPWS	Ground-proximity warning system
GPS	Global positioning system
HUD	Head-up display
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Associations
IMC	Instrument meteorological conditions
ILS	Instrument landing system
JAA	Joint Airworthiness Authorities
LA	Landing (approach)
LAM	Latin American Region of ICAO
LD	Landing (descent)
LDA	Localizer-type directional aid
LG	Landing (go-around)
LH	Landing (hold)
LOC	Localizer
MC	Monitoring/Challenging
MCTM	Maximum certified takeoff mass
MDA	Minimum descent altitude
MID	Middle East Region of ICAO
MORA	Minimum off-route altitude
MSA	Minimum sector altitude
MSAW	Minimum safe altitude warning
NAM	North American Region of ICAO
NDB	Nondirectional beacon
NE	Navigation error
NLR	National Aerospace Laboratory, Netherlands
NTSB	U.S. National Transportation Safety Board
PAPI	Precision approach path indicator
PAR	Precision approach radar
PE	Procedural error
PF	Pilot flying
PNF	Pilot not flying
RAeS	U.K. Royal Aeronautical Society
RLD	Netherlands Directorate-General of Civil Aviation
SA	Situational awareness
SDF	Simplified directional facility
SO	Systems operation
STAR	Standard terminal arrival route
TAR	Terminal approach radar
TC	Takeoff (climb cruise)
TD	Tactical decision
TI	Takeoff (initial climb)
VASIS	Visual approach slope indicator system
VFR	Visual flight rules
VMC	Visual meteorological conditions
VOLMET	Meteorology information for aircraft in flight
VOR	Very high frequency omnidirectional radio range

Data and Study Limitations

Results of the study should be interpreted in the light of methodological limitations.

Sample size

One limitation was the accident sample size. The sample of 156 accidents represents the majority of CFIT accidents involving commercial aircraft during the study period, but the small number of events limited the analysis to single- and two-factor analysis. Application of this simplistic analytical model to what is acknowledged to be a complex event (i.e., factors involved in aviation accidents) was the only method by which these data could be evaluated. The greater insight that might have been gained from multivariable analysis (i.e., where all factors are held constant while the factor of interest is evaluated) was not possible.

Sample bias

The accident sample is biased because North American accidents accounted for 34.6 percent of the total sample. This is probably because of the ease with which U.S. accident data can be accessed, as well as the level of commercial aviation activity in that area of the world. This bias is probably present only for the air taxi and regional operator samples because accident reporting of major air carriers is believed to be better than that for air taxi and regional air carriers in most of the world. This bias limited the number of two-factor analyses, especially stratifications by ICAO region.

Missing data

Information on many factors of interest was not available, so many accidents had factors coded as “unknown.” This problem also limited some of the two-factor analyses that could be conducted because of problems associated with small numbers. Missing data may represent a serious problem because their influence on the study results is unknown.

Inadequate crew training, misreading instruments, organizational weaknesses, improper crew pairing, fatigue and visual illusions are among the factors that have been strongly associated with CFIT accidents. To the extent that such data were obtained for the accident sample, they have been mentioned. But because those data were missing for such a large proportion of the accidents, no conclusions could be drawn about those factors.

One original goal of this study was to estimate the risk associated with the various factors included in the accident taxonomy. For each factor of interest the corresponding distribution, systemwide, among commercial operators not involved in accidents must also be known. Those data can then be used to determine rates for each of the potential risk factors (Section 3.7). Most of the nonaccident data required were not available (within the limited time frame of the study), so the risk rates associated with many of the parameters of interest could not be calculated.

An Analysis of Controlled-flight-into-terrain (CFIT) Accidents of Commercial Operators, 1988 Through 1994

Seventy-five percent of the accident aircraft, where the data were known, lacked a ground-proximity warning system (GPWS). For scheduled flights of major operators, North America and the Middle East had the lowest CFIT rates. And a significant percentage of CFIT accidents occurred in areas without high terrain.

R. Khatwa and A.L.C. Roelen
Netherlands National Aerospace Laboratory

1 INTRODUCTION

1.1 Background

Air travel is one of the safest means of modern mass transportation, but the safety rate has remained approximately constant in recent years.[1–3] The challenge is to further reduce this safety rate so that the projected increase in air traffic, which is expected to almost double during the next decade, does not increase the number of aircraft accidents.

Accident statistics suggest that controlled flight into terrain (CFIT) remains one of the leading categories of air carrier accidents.[1, 3–5] According to one widely quoted definition, a controlled-flight-into-terrain (CFIT) accident is one in which an otherwise serviceable aircraft, under the control of the crew, is flown (unintentionally) into terrain, obstacles or water, with no prior awareness on the part of the crew of the impending collision.[6]

The escalating costs of each accident in financial and human terms are significant and are not tolerable by the industry or the traveling public. Refs. 1–2 suggest that maintaining adequate aviation safety in the future will require new measures even if the current accident rate continues.

The number of recent CFIT accidents justifies further scrutiny of the problem, which could provide an opportunity for accident prevention and safety enhancement. The initial impulse to conduct CFIT research at the Netherlands National Aerospace Laboratory (NLR) stemmed directly from deliberations with Flight Safety Foundation (FSF) and the Netherlands Directorate-General of Civil Aviation (RLD). The objective of the investigation reported here was to identify and analyze factors associated with CFIT accidents. The research focused on evaluation of 156 CFIT accidents of commercial operators that occurred from 1988 through 1994. A previous NLR study developed a taxonomy of CFIT causal factors.[7] The results of that study provided a convenient starting point for the present investigation.

1.2 CFIT Prevention Activities

In the early 1970s, there was a spate of CFIT accidents, and a number of airline operators voluntarily began installing ground-proximity warning systems (GPWSs) aboard their aircraft. In 1972, the U.S. National Transportation Safety Board (NTSB) recommended to the U.S. Federal Aviation Administration (FAA) that GPWS be mandatory for all U.S. Federal Aviation Regulations (FARs) Part 121 aircraft operations. At that time, U.S. operators were experiencing several CFIT accidents each year. By 1974, GPWS was standard in all new Boeing aircraft. As a result of one accident near Washington, D.C., U.S., in 1974, the FAA required all large turbine aircraft engaged in international operations to be equipped with GPWS within one year. *International Civil Aviation Organization (ICAO) Standard and Recommended Practices* concerning GPWS became applicable Aug. 10, 1978. The Standard in Annex 6, "Operation of Aircraft, Part I, International Air Transport — Aeroplanes," 6.15.1,[8] required aircraft (in international operations), with maximum certified takeoff mass (MCTM) in excess of 33,069 pounds (15,000 kilograms) or authorized to carry more than 30 passengers, for which the individual certificate of airworthiness was issued on or after July 1, 1979, to be equipped with GPWS. Part I, 6.15.2, recommended that such airplanes first certified before July 1, 1979, should be equipped with GPWS. A similar recommendation, but without any reference to dates of certification for airworthiness, was contained in Annex 6, "Part II, International General Aviation Aeroplanes," 6.9.[9] The application varies from country to country, and some countries require GPWS for both domestic and international operations.

Responding to an FSF CFIT Task Force recommendation, ICAO has expanded Annex 6 to apply the requirements described above to a greater proportion of the world's aircraft fleet. The new GPWS standards, effective Dec. 31, 1998, require GPWS in all airplanes in international commercial air service with an MCTM in excess of 12,566 pounds (5,700 kilograms), or authorized to carry more than nine passengers. No exception is made currently for older airplanes. A similar Standard in Annex 6, Part II, will require GPWS in all equivalent airplanes involved in international general aviation operations. This implies raising the status of the requirement from a Recommended Practice to an ICAO Standard. A further amendment to Annex 6, Parts I and II, also specifies the minimum modes in which the GPWS is required to operate.

Since the introduction of the GPWS, the overall CFIT accident rate has decreased.[10–12] The implementation of the minimum safe altitude warning (MSAW) feature of the automated radar terminal system (ARTS III), expansion and upgrading of air traffic control (ATC) radar, enhancement of flight crew training programs, improved flight standards, approach lighting, the visual approach slope indicator system (VASIS) and superior approach procedures may have contributed directly or indirectly to reducing the CFIT risk. There have also been significant improvements in the basic GPWS design since its introduction. Nevertheless, the current accident record suggests that the problem is far from eliminated, and these accidents continue to occur today with unacceptable frequency.[1, 4–5]

Currently, various sectors of the industry are focusing on means of further reducing the accident risk. These involve both long- and short-term strategies. The short-term strategies are required to bring about an immediate reduction in the current CFIT rate using low-cost, easily implemented concepts. The most notable effort is the FSF CFIT Task Force. Since 1992, the FSF-led aviation industry task force, in counsel with the International Air Transport Association (IATA) and ICAO, has attempted to improve awareness of CFIT accidents and establish measures to further reduce the accident rate.[13–23]

Other, longer-term efforts involve the development of advanced ground-collision avoidance systems (GCASs). Advanced systems with a forward-look capability could provide crews with earlier alerts of a CFIT threat. Some of these systems are being developed with terrain displays to enhance flight crew terrain awareness. Enhanced and synthetic vision systems are also under scrutiny.

The introduction of high-integrity terrain data bases, data storage devices, global positioning system (GPS)/global navigation satellite system (GNSS), head-up displays (HUDs), high-speed data processing hardware and new sensors has accelerated the interest. Some of the concepts have had previous military applications, and it is widely accepted that further research into the feasibility of such systems for civilian cockpits is needed. New technology, by its nature, is a longer-term solution.

1.3 Study Objectives

The overall objective of this study was to identify and analyze factors associated with CFIT accidents in commercial aviation. Identifying differences among CFIT accidents of major operators, regional operators and air taxi operators (Section 3.4.2.1 [a]–[c]) was central to the research.

2 PREVIOUS CFIT ACCIDENT ANALYSES

The concept of analyzing CFIT accidents is not original, and there is no shortage of literature, for example refs. 6–7, 10–13 and 24–36. Although much credible work has been done, some of the references date back more than 20 years (e.g., refs. 6 and 24–25) and may not reflect today's operational environment and current-generation aircraft. The more recent literature (e.g., refs. 10–13) indicate that a number of measures have been introduced over the years to prevent CFIT. The data suggest that the overall rate at which these accidents occur has decreased, but the current rate remains unacceptable. When comparing the analyses from the 1960s and 1970s (e.g., refs. 6 and 24–25) with more recent literature (e.g., refs. 10–13), it is evident that despite the preventive measures taken, some factors have continued to contribute to CFIT accidents. Some of these factors are related to flight crew (e.g., use of nonstandard phraseology, noncompliance with procedures, fatigue and visual illusions), ATC (e.g., erroneous vectors), weather and organizational issues. Other factors, such as confusing aeronautical charts and nonoptimal approach procedure designs, have also been implicated. Refs. 6 and 30 stress that CFIT is related heavily to organizational failures.

Other publications (such as refs. 26, 29 and 34) concentrate on GPWS performance. Ref. 34 says that the drawback of GPWS is that it treats an outcome, namely unsafe terrain proximity or closure, rather than addressing how the crew allowed this unsafe condition to develop. It notes that the GPWS is an attempt to break the last link in the chain of events leading to CFIT, and that a better prevention strategy might be to intervene earlier.

Most of the studies referred to above, although recognizing that multiple agents may contribute to CFIT, have not necessarily conducted a comprehensive analysis of such factors. Ref. 32 does present evidence of the development of an appropriate accident taxonomy. That study was conducted primarily for defining flight crew information requirements. Information deficits that occurred in a limited sample of incidents and accidents were identified, so that changes in cockpit equipment and procedures could be proposed. The present study attempts to expand on the ideas presented in ref. 32 so that problems external to the cockpit can also be identified.

The recent thrust of industry activities related to CFIT by organizations such as FSF, ICAO, IATA and the International Federation of Air Line Pilots' Associations (IFALPA), and that no recent, similar study of CFIT causal factors with similar objectives could be identified, makes the current study timely and appropriate. The FSF effort has produced considerable insight into CFIT accidents, which has supported this investigation.

3 METHODOLOGY

3.1 Study Approach

The overall approach employed in this study was to:

(a) Identify a sample of CFIT accidents appropriate to the study objectives, using statistical and narrative accident data from worldwide sources;

(b) Identify potential CFIT factors using the accident narratives and literature;

(c) Develop an appropriate taxonomy for the collation and analysis of the information; and,

(d) Analyze the gathered information to determine what factors and to what degree they were associated with CFIT accidents in the study sample.

3.2 Data Sources

Accident data were acquired for two primary purposes:

(a) To apply the criteria in Section 3.3 to establish the accident sample; and,

(b) To compile specific information on each of the accidents according to the accident taxonomy described in Section 3.4.

Searches were conducted using the following data bases and sources:

- AirClaims Ltd.;
- AlliedSignal (formerly Sundstrand) CFIT data base;
- Australian Bureau of Air Safety Investigation (BASI);
- U.K. Civil Aviation Authority (CAA) World Airline Accident Summary;[37]
- *Flight International* annual review of accident statistics;[38]
- FSF publications;
- FSF CFIT Task Force accident data base;
- ICAO Aviation Data Reporting Program (ADREP) data base;
- Lawrence Livermore [U.S.] National Laboratory;[39]
- NTSB;
- NLR's accident data base (Flight Safety and Flight Testing Department); and,
- Netherlands Aviation Safety Board — Accident and Incident Investigation Bureau (NASB — AIIB).

These sources provided sufficient data to compile a virtually complete listing of CFIT accidents of major operators that fulfill the criteria in Section 3.3. Compiling a complete list of CFIT accidents of regional and air taxi operators was more difficult because of data limitations. Nevertheless, the NTSB data base was comprehensive enough to allow compilation of a nearly complete list of U.S. CFIT accidents for regional and air taxi operators. Those data were included in the accident sample, at the cost of biasing the sample by overrepresenting accidents to U.S. operators, because that information was more available.

Another challenge was collecting specific data for parameters of interest for each accident. Accessing accident investigation reports for each accident in the final accident sample was very difficult. Except for a few U.S. and European complete accident reports, accident summaries/narratives provided by the sources listed above were generally applied. Even where there were multiple data sources for an accident, the quality of data obtained was inferior to that found in well-documented accident investigation reports.

3.3 Accident Inclusion Criteria

Criteria used to establish the final accident sample, analyzed in this investigation, were as follows:

(a) The accidents involved CFIT.

For this study a slightly altered definition was applied to CFIT from that given on page 1:

A CFIT accident is one in which an aircraft, under the control of the crew, is flown (unintentionally) into terrain, obstacles or water with no prior awareness on the part of the crew of the impending collision.

Therefore, this study excluded collisions with terrain or water caused by problems such as:

- Hard landings;
- Unstabilized approaches;
- Gear-up landings or failures of landing gear;
- Runway overruns;
- Emergency descents;
- Fuel exhaustion;
- Downdraft/wind shear/wake vortex;
- Icing on airframe or wings;
- Bird strikes;
- Loss of power;
- Control-system problems;
- Pilot incapacitation;
- Sabotage/hijacking;
- Military action; and,
- Intoxication or drug use.

These exclusions were adopted because it is sometimes argued that many accidents involving collision with terrain are wrongly classified as CFIT.

(b) The accidents involved:

  - Fixed-wing aircraft (helicopters were not considered);
  - Turbojet, turboprop and piston-engine aircraft; and,
  - Aircraft in all weight categories.

(c) The accident flights included those that were:

  - Engaged in public transport;
  - Both scheduled and unscheduled operations;
  - Freight, passenger and positioning flights; and,
  - Both international and domestic operations.

There was no restriction on geographical location.

Excluded were:

  - Executive/corporate operations;
  - General aviation;
  - Training flights;
  - Experimental/test flights;
  - Aerial application/survey flights; and,
  - Construction-work flights.

(d) The accidents occurred during 1988 through 1994.

This period is considered large enough to provide a statistically acceptable number of accidents, and the data are applicable to present-day aviation. The FSF CFIT Task Force used the same period for its accident data base. On the assumption that most of the 1995 data are still incomplete and preliminary, data from the most recent accidents were not used.

(e) The accidents resulted in loss of life.

Details of nonfatal accidents and incidents are not widely available in some countries. Therefore, only accidents that resulted in loss of life were included in the final accident sample. A preliminary examination suggested that most CFIT accidents involved at least one fatality, so the majority of CFIT accidents are probably included.

Application of the criteria resulted in a sample of 156 accidents, listed in Appendix B.

3.4 Accident Causal Factor Taxonomy

3.4.1 Development of a taxonomy

The accident record suggests that accidents rarely have a single cause but, instead, are the result of a series of contributory factors. Reason[40] argues that accidents should not be considered as isolated, infrequent events, but as the consequences of active and latent failures, sometimes acting in combination with external environmental factors, which facilitate a failure of the system. The taxonomy applied here also attempted to account for multiple contributory factors.

In a previous CFIT study,[7] NLR developed a comprehensive taxonomy of causal factors by using accident reports and related literature. That taxonomy consists of eight main parameter groups:

- Flight (basic parameters such as date, local time, flight phase, etc.);
- Flight crew;
- Environment;
- Airport and approach;
- ATC;
- Aircraft equipment;

- Air carrier (organizational); and,
- Regulatory issues.

The original CFIT taxonomy was considered too detailed to allow collection of many of the data items, a problem also encountered in the recent FSF/NLR study into approach-and-landing accidents.[41]

Therefore, the original CFIT taxonomy was simplified. The resulting taxonomy, which contains 85 factors, is presented in Appendix C. Many of the items discarded in this simplification are not unimportant causal factors. Nevertheless, the main groups referred to above have been preserved.

3.4.2 Definitions

3.4.2.1 Flight variables

It was difficult to obtain explicit definitions of major, regional and air taxi operators that would apply worldwide. The following definitions, based on U.S. operations, were loosely applied to categorize operator type:

(a) **Major operator**. Operators that have similar characteristics to carriers currently operating under FARs, Part 121. The aircraft generally have more than 30 seats.

(b) **Regional operator**. Air carriers that generally provide scheduled and nonscheduled short-haul passenger and freight services. Typically a wide range of both turboprop and turbojet aircraft with seating capacities of 19 to 100 are used.

(c) **Air taxi operator**. Air carriers that transport persons, property and mail, generally using small aircraft (fewer than 30 seats). In the United States, these carriers operate in accordance with FARs, Part 135. Much of the operation is on-demand, as opposed to following a published flight schedule.

The following flight phase definitions, based on those used by the U.K. CAA[37] and AirClaims, were adopted for this investigation:

(a) **Takeoff (initial climb)**. From liftoff until first power reduction or 1,500 feet (458 meters);

(b) **Takeoff (climb cruise)**. From end of initial climb until first en route altitude;

(c) **En route**. From top of climb to commencement of descent. Included are changes of level en route, en route holding, etc.;

(d) **Landing (descent)**. From top of descent to 1,500 feet (458 meters);

(e) **Landing (hold)**. Holding during descent;

(f) **Landing (approach).** From 1,500 feet (458 meters) to the runway threshold; and,

(g) **Landing (go-around)**.

3.4.2.2 Flight crew variables

The flight crew error definitions were derived from ref. 42. The main goal was to record the number of accidents in which each error type occurred. Therefore, even when a particular error occurred more than once in an accident, the error was recorded as a single event. This approach was adopted because of the limited information provided in most of the accident summaries.

Primary errors are independent of any prior error. The six primary error types are:

(a) **Communication**: Incorrect read-back, hear-back; failing to provide accurate information; providing incorrect information.

Examples:

- Did not read back frequency change.
- Misinformed tower of aircraft position.

(b) **Navigational**: Selecting the wrong frequency for the required radio navigation station; selecting the wrong radial or heading; misreading charts.

Example:

Used distance measuring equipment (DME) rather than cross-bearing for desired intersection.

(c) **Procedural**: Failing to make required call-outs, making inaccurate call-outs; 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 (305 meters) above field level.

(d) **Situational awareness**: Controlling aircraft to wrong parameters.

Examples:

- Descended below 3,000 feet (915 meters) prior to being established on the localizer.
- Commenced descent to minimum descent altitude (MDA) prior to reaching the final approach fix (FAF).

(e) **Systems operation**: Improper operation of engines or hydraulic, brake and fuel systems;

misreading and mis-setting instruments; disabling warning systems.

Examples:

- Turned off GPWS.
- Stated incorrect reading of fuel quantity gauges.

(f) **Tactical decision:** Improper decision making; failing to revise action in response to signal to do so; failing to heed warnings or alerts that suggest a revision of action.

Examples:

- Continued to hold; accepted a vector away from the airport.
- Descended below decision height (DH) prior to sighting runway environment.

In contrast, a *secondary error* depends on another crew member previously or simultaneously making a primary error.[42]

(g) **Monitoring/challenging:** Failing to monitor and/or challenge faulty action or inaction (primary error) by another crew member.

Example:

- The primary error was made by the captain, who was the pilot flying (PF). The captain did not execute a go-around on reaching DH in instrument meteorological conditions (IMC). The monitoring/challenging error, made by the first officer, who was pilot not flying (PNF), entailed not challenging descent below DH.

3.5 Accident Data Coding Protocol

An accident was included in the sample only when it clearly satisfied the CFIT definition in Section 3.3(a). Several accidents were listed as CFIT occurrences in a particular data base, but the accident summary (or accident investigation report) did not support a CFIT classification according to the definition used in this study. Those accidents were not included, ensuring a more homogeneous sample.

The general procedure for coding the data from each accident included reviewing the appropriate accident summary or report. The accident was coded in terms of the CFIT taxonomy. Only those variables with clear information cited in the report or summary were coded. The coding protocol precluded interpretation of the report narrative by the analysts to complete the variable (especially where a subjective judgment could be applied, e.g., fatigue, improper crew pairing, etc.). Where information was not provided, or was not complete enough, the value was coded as “unknown.” Some information may have been lost, but this procedure reduced the risk of coding bias, improved coding reliability and ensured consistency of coding across all accidents.

3.6 Airport Data

For the accidents that occurred in the landing (descent) and landing (approach) phases of flight, airport-specific data were demanded by the taxonomy.

Data sources were principally the Jeppesen Airways Manual and other aeronautical information publications. In addition, navigational documentation published by major airlines was consulted.

The only common feature of these data sources is that they are used for navigation and they are periodically updated with an amendment service. Therefore, these data must be considered biased because they represent a November 1995 snapshot of available resources at the airports, and it is assumed that this snapshot describes the situation throughout the 1988–1994 time span. This assumption is plausible considering the time and investments required to significantly upgrade airport facilities; the level of facilities offered in 1995 differ significantly from the 1988–1994 situation for only a few airports.

The data items required fall into two categories: airport and runway variables. *Airport variables* describe the airport as a whole and hold true for all runway-ends at that airport; *runway variables* describe an individual runway.

Data regarding the following airport variables were collected:

(a) The presence of significant terrain features in the airport vicinity. Significant terrain is defined as “any spot elevation or obstacle more than 2,000 feet (610 meters) above the aerodrome reference point (ARP) elevation within a circle of six nautical miles (NM) (6.9 statute miles/11.1 kilometers) around the ARP or 6,000 feet (1,830 meters) within a circle of 25 NM (28.75 statute miles/46.26 kilometers) around the ARP.” A similar definition is used by Jeppesen to determine whether to include colored contours in its approach plates,[43] and was employed in the recent FSF/NLR airport safety study;[41]

(b) The availability of the latest weather observations to the pilot via automatic terminal information service (ATIS) or meteorology information for aircraft in flight (VOLMET);

(c) The presence of terminal approach radar (TAR); and,

(d) The presence of published arrival routes from the airways to the FAF of the standard terminal arrival route (STAR).

For every runway-end, information about these runway variables was collected:

(e) The presence of an approach lighting system;

(f) The presence of a visual glidepath-indicating system such as precision approach path indicator (PAPI) or VASIS;

(g) The most precise published instrument approach procedure to the runway-end; and,

(h) Whether the instrument approach has a constant descent gradient from FAF to the runway threshold that can be monitored by the crew during the approach.

3.7 Analytical Processes

One goal of this study was to estimate the risk associated with the various factors included in the accident taxonomy. To accomplish this, it is also essential to understand the underlying prevalence of those individual factors, systemwide, among commercial operators *not* involved in accidents. These data could then be used to determine rates for each of the potential risk factors. This approach has been successfully adopted elsewhere (e.g., in the FSF/NLR approach-and-landing aids study).

Nevertheless, two major difficulties were encountered during this study. First, many of the nonaccident data for many parameters in the CFIT taxonomy were unavailable. Second, when nonaccident data were available, they were often incomplete and could not be used to estimate rates. For example, worldwide movement data for scheduled flights of major operators were available, but data were impossible to obtain for nonscheduled flights and for air taxi operations within a number of ICAO regions. These difficulties meant that risk rates associated with many parameters of interest could not be calculated.

The major steps included in the analysis for this study are listed below:

(a) A digital version of the data base was accomplished, and the data were evaluated through simple single-variable analysis. This included developing frequency distributions for each variable, looking at the geographic distribution of accidents and performing other simple explanatory analyses that provided a basic understanding of the accident data. Single-population qualitative data were analyzed using chi-square (χ^2) tests; and,

(b) After the basic evaluation was completed, relationships among various parameters were evaluated. For qualitative data, the comparison of two or more populations and the analysis of the relationship between two variables were facilitated by the use of a χ^2 test of a contingency table. The tests for quantitative data involving two or more populations included the Krusskal-Wallis test for completely randomized design (i.e., independent samples).

4 RESULTS AND DISCUSSION

Unless otherwise stated, all percentages are based on the total sample (N = 156), presented in Appendix B. *N* denotes the number of valid cases.

The level of significance, α, is set at 0.05.

4.1 Missing Data

Analyzing parameters with a large proportion of missing data would not lead to very useful results (especially because the accident sample size was limited). Therefore, the data set was examined to identify variables with significant missing data. Those parameters are presented in Appendix D. Although most of those parameters were excluded from subsequent analysis, several were retained because they have been reported elsewhere as important contributory factors to CFIT accidents.

4.2 Flight Variables

4.2.1 Year of accident

The distribution of the absolute number of accidents per year for the period under study did not show any striking trend. Rates were difficult to estimate because of lack of aircraft movement data. Nevertheless, based on movement data of scheduled air traffic published by ICAO,[44–50] it was possible to calculate approximate CFIT accident rates per year for scheduled flights of major operators (Figure 1, page 21).

When the raw data are stratified across domestic/international flights and operator type, the resulting trends are shown in Figure 2 (page 21) and Figure 3, (page 22) respectively. An average of about four accidents per year involved international operations, in contrast to an average of 14 for domestic operations. Regional and air taxi operations together accounted for about 13 accidents per year on average, whereas major operators suffered an average of five per year.

4.2.2 Time of accident

Figure 4 (page 22) shows the distribution of the times the accidents (N = 101) occurred. About 42 percent of the accidents occurred in the morning-midday period (0600–1359 hours), 47 percent during the afternoon-evening period (1400–2159) and 12 percent in the overnight period (2200–0559). (These definitions are derived from ref. 42.) As time-of-day data for a sample of nonaccident flights were not available, rates could not be determined. The small number of accidents in the overnight period probably reflects the lower activity levels during that period.

Table 1 presents the time-of-accident data stratified across operator type. The overnight period accounted for 15.4 percent of major-operator accidents. Ref. 42 provides time-of-day data for a sample of 214,000 nonaccident flights conducted by major U.S. operators during 1988. Of those, 13 percent operated between 2200 and 0559, which is comparable to major operator accidents in this study. The regional operators also accounted for a small proportion of accidents in the overnight period. Nevertheless, 29.4 percent of air taxi accidents occurred in the overnight period. If activity levels of nonaccident flights for air taxi operators are comparable to those for major operators, this finding may suggest that an increased risk is associated with overnight air taxi operations.

Table 1
Time of Accident Stratified Across Operator Type, Study Data Base

Time	Major	Regional	Air Taxi
Morning–midday (0600–1359)	15 (57.7%)	12 (44.4%)	11 (32.4%)
Afternoon–evening (1400–2159)	7 (26.9%)	12 (44.4%)	13 (38.2%)
Overnight (2200–0559)	4 (15.4%)	3 (11.1%)	10 (29.4%)
Totals	26 (100.0%)	27 (100.0%)	34 (100.0%)

N = 87

Source: Netherlands National Aerospace Laboratory (NLR)

4.2.3 Accident site

4.2.3.1 ICAO region

Figure 5 (page 23) presents the CFIT accident distribution among the major ICAO regions. North America accounts for 34.6 percent of the total accident sample. What appears to be a disproportionate number of accidents in North America is because of the accessibility of U.S. accident data, as well as the commercial aviation activity level. This bias is probably present only for the air taxi and regional operators; accident reporting of major air carriers is believed to be better in most areas of the world. Because of this bias and the unavailability of movement data, it was not possible to calculate accurate accident rates for air taxi and regional operators.

Based on movement data of scheduled air traffic published by ICAO,[44–50] it was possible to calculate CFIT accident rates per region for scheduled flights of major operators (Figure 6, page 23). A composite rate is presented for Europe (combining the rates for Europe and Eastern Europe ICAO regions). The rates calculated are compared with rates presented by the Boeing Commercial Airplane Group,[14] and risk multipliers presented in the FSF CFIT Checklist[20] are shown in Table 2. The magnitudes of the accident rates are not identical for a given region when comparing the data from the current study with that from ref. 14. This is probably because the rates estimated here are based on scheduled flights, whereas those in ref. 14 include nonscheduled operations as well. Nevertheless, in all three columns of Table 2, Africa appears to have the highest CFIT rate, followed by South America and Asia/Pacific. North America and the Middle East have the lowest CFIT rates.

Table 2
CFIT Rates for ICAO Regions
(Accidents per Million Flights)

ICAO Region	This Study	Ref. 14	Risk Multiplier, FSF CFIT Checklist
Africa	0.70	2.40	8.0
Asia/Pacific	0.57	1.00	3.0
Europe	0.27	0.45	1.3
South America	0.63	1.14	5.0
Middle East	0.00	0.00	1.1
North America	0.00	0.03	1.0

Source: Netherlands National Aerospace Laboratory (NLR)

In ref. 35, CFIT losses are presented for both major operators and regional operators in Europe and the United States, as average losses per year over the 10-year period 1984–1993. In Table 3 (page 9) those results are compared to the average annual losses established in this study. Those numbers correspond closely, except for the annual loss for regional operators in Europe — the magnitude presented in ref. 35 is almost five times higher than that of this study. Part of the discrepancy may be because of dissimilar definitions for the term "regional operator." Ref. 35 does not provide an explicit definition.

4.2.3.2 Distance from the accident to the runway threshold

Figure 7 (page 24) presents the distance from the aircraft accident location to the runway threshold for accidents occurring in the landing (approach) phase (N = 80). The progressive increase in the number of accidents with decreasing distance to the runway threshold shown in Figure 7 is also reported elsewhere (for example, refs. 25 and 51). The shape of this curve is similar to that of a plot of undershoot and terrain-collision accidents published by ICAO.[25] The ICAO plot, however, shows more accidents occurring closer to the runway threshold

Table 3
CFIT Annual Losses in Europe and the United States

Average Annual CFIT Loss	Major Operator Ref. 35	Major Operator This Study	Regional Operator Ref. 35	Regional Operator This Study
Europe	1.2	1.1	2.8	0.6
United States	0.2	0.0	3.0	2.7

Source: Netherlands National Aerospace Laboratory (NLR)

because the ICAO data also include non-CFIT accidents. A similar trend is shown in ref. 11 for 40 CFIT accidents that occurred during the five-year period 1986–1990. All those accidents occurred within a radius of approximately 15 NM (17.25 statute miles/27.76 kilometers) from the runway threshold, and this is comparable to the data in Figure 7.

When the accident location data were scrutinized as a function of operator type, there were no notable trends.

4.2.4 Aircraft

4.2.4.1 Aircraft type

Appendix B lists the aircraft types involved in the accidents. Table 4, derived from those data, provides a more general picture of the aircraft categories. Business aircraft types accounted for 40 percent, commuter types for 25 percent and transport aircraft for 35 percent of the total sample.

Table 4
Accident Aircraft Categories, Study Data Base

Aircraft Category	Number	Percent
Business piston*	48	30.8
Business turboprop*	12	7.7
Business jet*	2	1.3
Commuter turboprop	37	23.7
Commuter jet	2	1.3
Transport turboprop	18	11.5
Transport jet	37	23.7

*Business aircraft types being used in commercial operations.

Source: Netherlands National Aerospace Laboratory (NLR)

For this study, the aircraft were also divided into three classes based on the applicability of current and future ICAO GPWS requirements (Section 1.2). The ICAO requirements are a function of aircraft weight and apply only to international operations. The following definitions were based on ICAO weight classes:

(a) **Small** — aircraft not required to be equipped with GPWS in accordance with current or future ICAO requirements outlined in ref. 21. MCTM: less than 12,566 pounds (5,700 kilograms).

(b) **Medium** — aircraft that will be required to be equipped with GPWS in the future, if engaged in international operations, but are currently not required to be GPWS-equipped. MCTM: 12,566 pounds (5,700 kilograms) – 33,069 pounds (15,000 kilograms).

(c) **Large** — aircraft that must be equipped with GPWS in accordance with current ICAO requirements if engaged in international operations. MCTM: greater than 33,069 pounds (15,000 kilograms).

Applying these definitions to the accident sample aircraft produces the data in Figure 8 (page 24). Comparing the frequencies of the various weight classes is not very useful because the sample is biased (e.g., 42 of the 61 small aircraft were U.S. registered).

More important, perhaps, is the percentage of accident aircraft that may benefit from new ICAO requirements when the weight classification described above is applied. The small-aircraft category accounted for 40 percent of the total sample and will not benefit from the new requirements. The medium- and large-aircraft categories must be stratified as a function of international/domestic operations to reveal any additional protection offered by the new requirements. Data were missing in only 33 cases.

The data for applicability of future GPWS standards are shown in Figure 8. Twenty-five medium-category aircraft (63 percent) would not be covered, whereas 25 large-category aircraft (45 percent) would be excluded. In total, 71 percent of the accident aircraft would not be required to be fitted with a GPWS in the future if the weight classification system described above is strictly applied.

Some countries (e.g., the United States) have extended the basic ICAO requirements to include domestic operations, and this should be taken into account in interpreting the data. The Aircraft Equipment Committee of the FSF CFIT Task Force has made specific recommendations to require the installation of GPWS for domestic operations.[23]

4.2.4.2 Aircraft damage

Table 5 shows the distribution for aircraft damage. In 86.5 percent of the sample (or 97 percent of the cases where data were known), the aircraft was completely destroyed. This illustrates the high level of kinetic energy associated with fatal CFIT accidents.

Table 5
Accident Aircraft Damage, Study Data Base

Damage	Number	Percent
Destroyed	135	86.5
Substantial	4	2.6
Minor	0	0
None	0	0
Unknown	17	10.9

Source: Netherlands National Aerospace Laboratory (NLR)

4.2.5 Phase of flight

Figure 9 (page 25) shows the flight-phase distribution of the accidents. (In five accidents the data were unknown). Most accidents occurred in the landing (approach) phase (47.7 percent), followed by 21.9 percent in the landing (descent) phase, for a combined total of 69.6 percent. The en route phase accounted for about one-fifth of the accidents. The difference between the frequencies of occurrence was found to be statistically significant ($\chi^2 = 142$ and $p < 0.01$).

Figure 9 shows a stratification in terms of operator type. Caution must be exercised in comparing operator types for a given flight phase because of the sample bias. In those cases for which data were known, 93 percent of the en route accidents were attributable to air taxi operators and regional operators. This is probably because the majority of aircraft types engaged in such operations cruise at significantly lower altitudes than those used by major operators.

Figure 10 (page 25) shows an alternative distribution of the flight phases for each operator type. Although major operators and air taxi operators suffered their greatest losses in the landing (approach) phase (61.1 percent and 48.9 percent, respectively, $p < 0.01$), the regional operators encountered the largest percentage of accidents in the en route phase (32.6 percent, $p < 0.01$).

4.2.6 Type of operation

Table 6 shows the distribution by type of operation. Nonscheduled flights accounted for at least 43 percent of the sample (44.9 percent were scheduled). At least 65.4 percent of the accident sample involved passenger flights, whereas 26.3 percent were cargo flights. Ten flights involved repositioning. Because movement data were unavailable, accident rates could not be calculated.

In accidents where data were known ($N = 123$), 20.3 percent of the flights were international, whereas almost 80 percent were domestic. Based on movement data of scheduled air traffic published by ICAO,[44–50] it was possible to calculate CFIT accident rates for scheduled international and scheduled domestic flights of major operators (Figure 11, page 26). The CFIT accident rate for international flights was 3.8 times higher than the CFIT accident rate for domestic flights. The increased CFIT danger for international flights is recognized by FSF, and the FSF CFIT Checklist[20] includes a risk multiplier of 3 for international flights, compared to 1 for domestic flights.

4.2.6.1 ICAO operator region

The ICAO operator region was based on the country in which the operator was registered. Figure 12 (page 26) presents the distribution of the ICAO operator regions. The disproportionate representation of North American operators, caused by the accessibility of U.S. data and U.S. commercial aviation activity levels, is evident. Comparing Figure 12 and Figure 5 (accident ICAO regions) suggests no significant differences in accident aircraft ICAO operator regions.

Table 6
Accident Aircraft Types of Operation, Study Data Base

Type of Operation	Yes	No	Unknown
Scheduled (no = nonscheduled)	67 (42.9%)	70 (44.9%)	19 (12.2%)
Passenger (no = freight)	102 (65.4%)	41 (26.3%)	3 (8.3%)
International (no = domestic)	25 (16.0%)	98 (62.8%)	33 (21.2%)

Source: Netherlands National Aerospace Laboratory (NLR)

4.2.6.2 Operator type

Table 7 presents the distribution of air taxi, regional and major operations. As mentioned earlier, the accident sample is biased because U.S. regional and air taxi operator CFIT accident data are more easily accessible than those of many other areas of the world. Therefore, the true contribution of regional and air taxi operator accidents is probably even higher than that shown in Table 7. Official sources appeared to reinforce that supposition. Rates could not be estimated because movement data were unavailable.

Table 7
Accident Aircraft Operator Types, Study Data Base

Operator Type	Number	Percent
Major	36	23.1
Regional	46	29.5
Air taxi	47	30.1
Unknown	27	17.3

Source: Netherlands National Aerospace Laboratory (NLR)

Stratification across ICAO regions was inconclusive because of the biased data. Nevertheless, the U.S. data are considered reliable, and for the United States air taxi operator accidents accounted for 61 percent of the sample, regional operator accidents for 35 percent and major operator accidents for only 4 percent. Again, these are not rates.

Stratification of the operator type data as a function of domestic/international flights and scheduled/nonscheduled operations is presented in Figure 13 (page 27) and Figure 14 (page 27), respectively. By their nature, most air taxi and regional operations were domestic. Domestic flights, for which GPWS is not mandated by ICAO, accounted for 39 percent of the major operators' flights. Figure 14 indicates that a substantial proportion of flights in the major and regional operator categories were scheduled (69 percent and 70 percent, respectively).

Figure 15 (page 28) presents the operator data as a function of passenger and freight operations. Passenger flights accounted for the bulk of major operator flights (69 percent), whereas about one-half (49 percent) of air taxi operations comprised passenger flights. Eighty-seven percent of regional operations were passenger flights.

4.2.7 Fatalities

There were 3,177 fatalities in the total sample of 156 accidents. In three-fourths of the accidents the fatality rate (the percentage of the aircraft occupants who were fatally injured) was 100 percent. The mean fatality rate was 91 percent, another indication of the extreme kinetic energy associated with CFIT accidents.

4.3 Flight Crew Variables

4.3.1 Number of flight crew

Figure 16 (page 28) presents the distribution for the number of flight crew in the accident aircraft. In 48 accidents (30.8 percent), the flight was a single-pilot operation, while 44 (23.1 percent) of the flights were conducted by at least a two-person crew. Data were missing in 41.0 percent of the sample. An operator type stratification is made in Figure 17 (page 29). Where data were known, the major operator flights were piloted by at least a two-person crew and the majority of air taxi flights were single-pilot operations, but the regional operator sample was divided between those two categories.

4.3.2 Pilot flying

Figure 18 (page 29) shows the pilot flying (PF) distribution for the accident sample. For half the accident sample data were missing. Single-pilot operations flown by a captain (CAPT1) accounted for 30.8 percent of the sample. The high number associated with a single pilot reflects the large number of air taxi operations included in the accident sample.

It has been said that a large number of CFIT accidents occurred while the first officer was the PF. In this accident sample, for operations where there were at least two crew members, the captain (denoted by CAPT in Figure 18) was the PF in 11 (7.1 percent) of the cases, and the first officer (FO in Figure 18) was the PF in at least 13 (8.3 percent) of the flights. This difference is not statistically significant.

Stratification of the data as a function of operator type was inconclusive because of the small sample size (compounded by the missing data).

4.3.3 Flight crew experience

The basic statistics associated with flight crew experience are shown in Table 8 (page 12).

4.3.3.1 Total hours of flying experience

As might be expected, the means of the total hours of flying experience of the captains and first officers in the sample differed significantly ($p = 0.005$) where data were available. The distributions of flight experience for the captains and first officers are presented in Figure 19 (page 30) and Figure 20 (page 30), respectively. Almost 76 percent of the captains in accidents where data were

Table 8
Flight Crew Experience, Study Data Base

Aspect of Experience	Captain	First Officer
Total flying experience (hours)		
Range	480–16,000	425–15,639
Mean	5,097	3,084
Standard deviation	3,707	4,220
N	66	13
Experience in accident aircraft type (hours)		
Range	4–4,500	4–1,100
Mean	1,046	182
Standard deviation	1,134	300
N	52	12
Total instrument flying experience (hours)		
Range	16–3,764	38–389
Mean	600	214
Standard deviation	839	248
N	37	2

Source: Netherlands National Aerospace Laboratory (NLR)

known (N = 66), had less than 6,000 total hours of experience — 6,000 hours is the upper limit of the 95 percent confidence interval. Half the captains had less than 4,000 hours of experience. In the accidents where data were known (N =12), more than half the first officers had less than 2,000 total hours of experience.

Table 9 shows the data for captains when stratified across operator type. The major operator captains were the most experienced, the regional operator captains were next and the air taxi operator captains had the least total hours of flying experience. These differences were statistically significant at the 95 percent confidence level (p = 0.0018). A similar stratification was not possible for the first officer data because of the small sample size.

Table 9
Captains' Total Experience, Study Data Base

	Major	Regional	Air Taxi
Mean (hours)	10,378	5,869	3,743
Standard deviation (hours)	3,537	4,084	2,474
N	5	22	33

Source: Netherlands National Aerospace Laboratory (NLR)

4.3.3.2 Hours on aircraft type

Not surprisingly, the difference between the mean hours on type for captains and first officers was significant (p = 0.0002), where data were available (Figure 21, page 31 and Figure 22, page 31). In 67 percent of these accidents, the captain had fewer than 1,000 hours of experience on type. More than 42 percent of the captains had fewer than 500 hours of flight time on type. For all but one first officer, experience on type was fewer than 500 hours (N = 12).

Table 10 shows the data as a function of operator type for the captains. These means did not differ significantly at the 95 percent confidence level (p = 0.2319). Similar data for the first officers could not be calculated because of the small numbers.

Table 10
Captains' Experience on Aircraft Type, Study Data Base

	Major	Regional	Air Taxi
Mean (hours)	2,182	1,124	982
Standard deviation (hours)	1,654	1,216	1,036
N	3	21	23

Source: Netherlands National Aerospace Laboratory (NLR)

4.3.3.3 Instrument flight hours

Where data were available (N = 37, Figure 23, page 32), almost 73 percent of captains had fewer than 500 hours of instrument flight time. In about one-half the accidents the captains had fewer than 220 hours. Instrument flight times for major operator accidents were missing. The regional and air taxi operator captains' mean instrument times were found not to differ significantly at the 95 percent confidence level (p = 0.5090).

Data for first officers were available in only two accidents and are presented in Table 8.

4.3.4 Crew compatibility — improper crew pairing

Improper pairing of crews means inappropriate pairing of two pilots according to their relative levels of experience. Despite the large missing data set (87.0 percent of the relevant cases), this parameter is included because it has been an issue in some recent accidents. In seven accidents (6.5 percent of the relevant accidents, which are dual-pilot operations), improper crew pairing was cited as a contributing factor.

4.3.5 Fatigue

Again, a high proportion (63.4 percent) of the data were missing, but the data available are presented for reasons similar to those outlined in 4.3.4. In five accidents, (3.2 percent) fatigue was cited as a contributory factor, whereas in one-third of the total sample, fatigue was known not to have been a factor.

4.3.6 Visual and physical illusions

Visual and physical illusions refer to phenomena such as “black hole” approaches and somatogravic illusions, respectively. Data for approximately one-half the sample (54.5 percent) were missing. In nine accidents (5.8 percent), a visual or physical illusion contributed to the accident, but it is known that such illusions did not play a role in 39.7 percent of the accidents.

4.3.7 Flight crew errors

Figure 24 (page 32) presents a distribution of the number of accidents in which flight crew errors occurred. In a very high percentage of accidents the data were unknown, and therefore any comparison of the frequency of occurrence must be made with extreme caution. Nevertheless, the following observations can be made:

- At least 11 accidents included a communication error (7.1 percent);
- 18 accidents involved a navigational error (11.5 percent);
- 53 involved a procedural error (34 percent);
- 70 involved a situational-awareness error (44.9 percent);
- 13 included a systems-operation error (8.3 percent);
- 69 involved a tactical-decision error (44.2 percent); and,
- 31 involved a monitoring/challenging problem (28.7 percent of the relevant accidents — 48 accidents involved single-pilot operations where this error category is not applicable).

Although it is difficult to draw conclusions from the data about the relative frequencies of occurrence, because of the high proportion of missing data, it is evident that procedural, situational-awareness and tactical-decision errors are dominant, whereas communication errors were probably less of a problem. (Figure 24 also indicates that in 37.2 percent of the accidents, it is known that communication errors were not a factor.) Ref. 42 reported similar trends for a sample of 37 Part 121 U.S. accidents.

Despite the large percentage of missing data, an attempt was made to identify any association between the error types and the following variables:

(a) Single- vs. multiple-crew operation;

(b) Operator type (major, regional or air taxi);

(c) PF for multiple-crew operations (first officer vs. captain); and,

(d) Approach type (precision vs. nonprecision).

For (a), the only finding was that no systems-operation errors were reported in the single-pilot operations, and this association was significant at the 95 percent confidence level. Stratification (b) showed that the systems-operation errors were all made by the regional and major carriers. Virtually all monitoring/challenging errors involved major and regional operators. This result is not surprising, because most of the air taxi operations were single-pilot flights. No association was demonstrated between crew error and approach type (p = 0.094), but the contingency table for situational-awareness error is shown in Table 11. Data were available in 42 of the 66 landing (approach) phase accidents, and in virtually all those, situational-awareness error was present.

Table 11
Situational-awareness Error Stratified Across Approach Type, Study Data Base

	Yes	No
Precision	13	3
Nonprecision	26	0

Source: Netherlands National Aerospace Laboratory (NLR)

4.3.7.1 Visual meteorological conditions (VMC) flight into IMC

In 30 accidents (19.2 percent of the total sample), inadvertent flight from VMC into IMC was a factor. Data were missing in 67 cases (43 percent). When these 30 cases are stratified across single- and dual-/multiple-crew operations, it is seen that 21 accidents occurred in single-pilot operations, and this association is significant at the 95 percent confidence level. When the instrument flight time of pilots involved in VMC-into-IMC accidents is compared to those who were not involved in such accidents, the difference is not significant for the available data set (p = 0.9533). The mean instrument time for the accident pilots was 611 hours (N = 14).

Table 12 (page 14) shows the available data (N = 79) stratified across operator type.

Most of the accidents were for regional and air taxi operators (p = 0.006).

The data available are shown as a function of flight phase in Table 13 (page 14). Seventeen of the 30 VMC-into-IMC accidents occurred in the en route phase, and this association is significant at the 95 percent confidence level.

Table 12
VMC-into-IMC Accidents Stratified Across Operator Type, Study Data Base

	Yes	No
Major	1	20
Regional	13	15
Air taxi	11	19

IMC = Instrument meteorological conditions
VMC = Visual meteorological conditions
Source: Netherlands National Aerospace Laboratory (NLR)

Table 13
VMC-into-IMC Accidents Stratified Across Phase of Flight, Study Data Base

	Yes	No
Takeoff (initial climb)	0	3
Takeoff (climb cruise)	1	2
En route	17	5
Landing (descent)	6	11
Landing (approach)	6	34
Landing (go-around)	0	4

IMC = Instrument meteorological conditions
VMC = Visual meteorological conditions
Source: Netherlands National Aerospace Laboratory (NLR)

4.3.7.2 Minimum altitude not maintained

This error refers to the pilot/crew descending below an ATC clearance, the minimum sector altitude (MSA), the minimum off-route altitude (MORA) or a specific altitude associated with the approach procedure (e.g., stepdown on a very high frequency [VHF] omnidirectional radio range [VOR]/distance measuring equipment [DME] approach). In at least 54 accidents (35 percent of the total sample) it was known that this error played a role, with data unavailable in the other cases. Stratification of the data as a function of single- and dual-/multiple-crew operations and flight phase is not significant ($p = 0.257$ and $p = 0.059$, respectively).

4.3.7.3 Response to GPWS alerts

Table 14 summarizes the crew responses to the GPWS alerts. In only 12 accidents (44.4 percent of the GPWS-equipped aircraft — 27 in all), was it known whether the crew reacted to the GPWS signal. This sample size is too small to draw any firm conclusions, but it is remarkable that in eight of those accidents (29.6 percent of the GPWS-equipped aircraft) there was no crew reaction to the GPWS.

Table 14
Crew Response to GPWS Alert, Study Data Base

	Yes	No	Unknown	Total
GPWS alert given	15	9	3	27
Crew initiated escape maneuver	4	8	15	27
Crew responded in time	2	2	23	27
Escape maneuver correct	0	4	23	27
GPWS disabled by crew	1	4	22	27

GPWS = Ground-proximity warning system
Source: Netherlands National Aerospace Laboratory (NLR)

Because of the lack of data, it is not possible to draw any conclusions about the delays associated with crew response, the correctness of the escape maneuver and possible disabling of the GPWS by the crew.

4.3.7.4 Barometric altimeter setting/reading

The incorrect setting or reading of the barometric altimeter has been associated with some CFIT accidents.[52–54] The necessary data were available in only 16.0 percent of the accident reports or summaries. In five accidents (3.2 percent of the total sample), the barometric altimeter was set incorrectly. In only one accident (0.6 percent), was the barometric altimeter read incorrectly.

4.4 Environment Variables

4.4.1 Basic weather

Figure 25 (page 33) shows the basic weather data. Ninety-three accidents (87 percent of the sample for which data were available, N = 107) involved IMC, compared with 14 accidents in VMC.

4.4.2 Light/Dark conditions

Figure 26 (page 33) shows the distribution for the light/dark conditions at the accident time. Where data were known (N = 114), one-half the accidents occurred in dark conditions, whereas 46 percent involved light conditions. The light/dark condition data were stratified across basic weather (N = 86), where data were available (Table 15, page 15). Whatever the light/dark condition, IMC prevailed in a high proportion of the accidents. Nine accidents occurred, surprisingly, in the light/VMC combination. When the narratives of these accidents were closely examined, it appeared that although the basic conditions may have been reported as VMC, there was cloudiness in the vicinity of the accident sites. Seven of these nine accidents involved regional and air taxi flights.

Table 15
Light/Dark Conditions as a Function of Basic Weather, Study Data Base

	Dark	Light	Dusk
IMC	33 (87%)	37 (80%)	2 (100%)
VMC	5 (13%)	9 (20%)	0
Totals	38 (100%)	46 (100%)	2 (100%)

IMC = Instrument meteorological conditions
VMC = Visual meteorological conditions

Source: Netherlands National Aerospace Laboratory (NLR)

4.4.3 Fog

Data on the presence of fog at the accident location was missing in 50 percent of the sample. Where data were available (N = 78), fog was present at the accident location in 55 accidents (71 percent).

4.4.4 Precipitation

Figure 27 (page 34) shows the distribution of the type of precipitation present at the accident location. Data were missing in 47.4 percent of the accidents. In almost one-fourth of the accident sample, rain was present.

4.4.5 Cloud base

Where the cloud base data were known (N = 49), the cloud base was at or below 1,000 feet (305 meters) in 31 accidents (63.3 percent).

4.4.6 Visibility

Where the visibility was known (N = 54), the visibility was less than 0.5 NM (0.58 miles/0.92 kilometers) in 27.8 percent of the accidents.

4.5 Airport and Approach Variables

Table 16 shows the distribution of the airport and approach variables. Only accidents that occurred during the landing (descent) and landing (approach) phases of flight (N = 116) are considered here.

In just over one-fourth of the sample, significant terrain features were present in the vicinity of the airfield, but in almost 40 percent there was no high terrain. This indicates that CFIT accidents do occur in areas without high terrain. In about one-fourth of the cases approach lights and visual approach guidance (VASIS/PAPI) were not present, and there was no TAR for 37.0 percent of the accidents. In the recent FSF/NLR study of approach-and-landing safety[41], it was found that lack of TAR was associated with a three-fold increase in risk of accidents compared to approaches conducted with TAR present.

In about one-fifth of the sample herein, the approach procedure design to the applicable runway was not stabilized. In 35 percent of the landing (descent) and landing (approach) accidents, weather update information from automatic terminal information service (ATIS) or meteorology information for aircraft in flight (VOLMET) was not available. Ref. 41 concluded that lack of ATIS/VOLMET was associated with a four-fold increase in risk compared to approaches conducted with ATIS/VOLMET available.

In Figures 28–32 (pages 34–36), the airport and approach data are presented as a function of ICAO region. The higher frequencies associated with the presence of VASIS/PAPI, TAR, etc. for North America and Europe are presumably because airports in those regions are better equipped generally than their counterparts in South America, Africa and Asia. Lack of nonaccident data made it impossible to draw conclusions about the effectiveness of ATIS, approach lights, visual approach guidance and approach radar for the reduction of CFIT accidents.

Table 16
Airport and Approach Variables, Study Data Base

Variable	Yes	No	Unknown
Terrain	31 (26.7%)	44 (37.9%)	41 (35.3%)
ATIS/VOLMET	43 (37.1%)	41 (35.3%)	32 (27.6%)
Approach Lights	38 (32.7%)	30 (25.9%)	48 (41.4%)
VASIS/PAPI	42 (36.2%)	26 (22.4%)	48 (41.4%)
Stabilized approach procedure design	42 (36.2%)	23 (19.8%)	51 (44.0%)
TAR	36 (31.0%)	43 (37.0%)	37 (31.9%)

ATIS = Automatic terminal information service VOLMET = Meteorology information for aircraft in flight TAR = Terminal approach radar
VASIS = Visual approach slope indicator system PAPI = Precision approach path indicator

Source: Netherlands National Aerospace Laboratory (NLR)

Further stratification of the airport parameters across variables such as crew error, light/dark conditions, basic weather conditions, etc., proved to be inconclusive because of small numbers.

Figure 33 (page 37) presents the data for instrument approach aid type (N = 66, data unknown in 50 accidents). Rates could not be estimated because movement data were unavailable. Almost 60 percent of the approaches were nonprecision. Twenty-five percent (17 accidents) of the total sample were VOR/DME approaches. Ref. 41 concluded that precision approaches confer a risk advantage of about five over nonprecision approaches worldwide, with other factors constant.

4.6 Aircraft Equipment Variables

4.6.1 Ground-proximity warning system

Where data were available (N = 108), in only 27 accidents was a GPWS fitted aboard the accident aircraft, i.e., 75 percent of the aircraft were not fitted with a GPWS. Twenty-two of these GPWSs were aboard major operator aircraft, one was on a regional aircraft and none were on air taxi aircraft. Table 17 shows that 21 (78 percent) were early — Mark I and Mark II — systems. The latest — Mark V — systems were both aboard major operator aircraft.

Table 17
GPWS Equipment Type, Study Data Base

Ground-proximity Warning Systems Mark	Number
I	12
II	9
III	2
V	2
Unknown	2

Source: Netherlands National Aerospace Laboratory (NLR)

Of the total sample of GPWS-equipped aircraft (N = 27), 55.6 percent (15 accidents) of the GPWSs sounded valid alerts prior to the accident, whereas in one-third of the sample the GPWSs did not sound any alert (see also Table 14, page 14). Six of the accidents without GPWS alerts occurred on nonprecision approaches.

4.6.2 Flight management system (FMS)/ Autoflight

FMS/autopilot problems are often said to be one of the most important causal factors in CFIT accidents.[34] In four accidents (2.6 percent of the total sample), FMS/autoflight-related problems were described as contributing factors to the accidents. FMS-related problems were not present in 25.0 percent of the accidents, and in 72.4 percent of the accidents it was not known whether FMS-related problems were causal factors in the accidents. These findings should be treated with caution because many of the accident aircraft, especially in air taxi operations, were probably not equipped with an FMS.

4.7 Organizational Issues

4.7.1 Management issues

Management factors have been considered central causal factors in CFIT accidents.[19, 30] Management issues were identified as factors in 25 accidents (16.0 percent of the total sample). Management issues did not contribute in seven accidents (4.5 percent), and in the majority of accidents (79.5 percent) the relevant data were missing.

4.7.2 Flight crew training

Flight crew training was reported as inadequate in 23 accidents (14.7 percent), and in 4.5 percent of the sample, training was reported as adequate. For 80.8 percent of the sample, training data were unavailable.

5 CONCLUSIONS

(a) Seventy-five percent of 108 accident aircraft, for which data were available, were not fitted with a GPWS. Virtually all the 27 aircraft fitted with a GPWS belonged to the major operator category, and just over three-fourths of these GPWSs were early (Mark I and Mark II) types. In at least nine accidents (33 percent) an alert was not generated by the GPWS;

(b) Seventy-one percent of the accident aircraft were in one of two groups:

  (i) An MCTM category below 5,700 kilograms, involved in either international or domestic operations; or,

  (ii) Heavier aircraft involved in domestic operations.

Most of the aircraft above (i) are not authorized to carry more than nine passengers. This suggests that a very large proportion of the accident sample (nearly 70 percent) would not be required to be fitted with a GPWS in the future, if the new ICAO requirements are strictly applied;

(c) Procedural errors, situational awareness errors and tactical decision errors were the dominant crew-error types, whereas those related to communication appear to be less of a problem. In the special case of landing (approach) phase accidents, virtually all the accidents involved a situational awareness error;

(d) The landing (descent) phase and landing (approach) phase accidents together accounted for almost 70 percent of all accidents, whereas the en route phase accounted for about 20 percent. Where data were known, 93 percent of the en route accidents were attributable to air taxi and regional operators;

(e) Major and air taxi operators suffered their greatest losses in the landing (approach) phase, and the regional operators encountered the largest percentage of accidents in the en route phase;

(f) Almost 60 percent of the 66 landing (approach) phase accidents where data were known involved aircraft flying nonprecision approaches. Twenty-five percent (17 cases) of all approaches were of the VOR/DME type;

(g) Almost all landing (approach) phase accidents (90 percent) occurred within a radius of approximately 15 NM (17.25 statute miles/27.76 kilometers) from the runway threshold;

(h) In almost 40 percent of the landing (descent) phase and landing (approach) phase accidents, significant terrain features were absent in the vicinity of the airfield. This indicates that CFIT accidents do occur in areas without high terrain;

(i) In 30 accidents (one-fifth of the total sample), inadvertent VMC flight into IMC was a factor. Most of these accidents occurred in single-pilot operation flights, involving regional and air taxi operators. Seventeen of the 30 VMC-into-IMC accidents (56.7 percent) occurred in the en route phase;

(j) When the data for scheduled flights of major operators are considered, Africa appears to be the ICAO region with the highest CFIT rate, followed by South America and Asia/Pacific. North America and the Middle East have the lowest CFIT rates;

(k) For major operators, the CFIT accident rate for scheduled international flights was 3.8 times higher than that for scheduled domestic flights;

(l) For international operations, there were an average of four accidents per year, in contrast to 14 per year for domestic operations. Regional and air taxi operations together accounted for an average of 13 accidents per year, whereas major operators suffered an average of five per year;

(m) In 97 percent of the 139 accidents where data were known, the aircraft was completely destroyed. Total fatalities amounted to 3,177. The mean fatality rate (the percentage of the aircraft occupants who were fatally injured) was 91 percent;

(n) Eighty-seven percent of 107 accidents involved IMC where weather status was known. About one-half of the accidents occurred in conditions of darkness; and,

(o) The level of analytical detail was limited by the scarcity of data for factors that are significant in accident causation.

6 RECOMMENDATIONS

(a) All operators should comply with current and future ICAO requirements pertaining to the installation of GPWSs. Furthermore, the use of GPWSs for domestic operations, as recommended by the FSF CFIT Task Force, should be observed;

(b) International support should be given to reducing the CFIT risk variances among the different ICAO regions;

(c) CFIT risk-reduction efforts must include not only the major air carriers, but also regional and air taxi operations;

(d) Any means of reducing flight crew procedural and tactical decision-making errors should be encouraged. Whether this involves training and/or improved cockpit discipline, or other measures such as error-tolerant design of checklists and procedures, is for further study;

(e) Improving terrain situational awareness is encouraged. In this respect, the FSF CFIT Task Force recommends:

  - The use of colored contours to present either terrain or minimum flight altitudes on instrument approach charts;
  - Technological developments that give the flight crew a visual display of the terrain; and,
  - A radio altitude call-out facility to improve crew awareness of proximity to terrain. Where altitude call-out is not available, or where a GPWS is not fitted, radio altimeter raw data can be used to enhance terrain awareness; and,

(f) The international sharing of accident and incident data should be encouraged to quickly and effectively address safety problems. The difficulty of obtaining complete and accurate information about accidents was a major problem in this study and is an ongoing problem for safety analysts.

7 ACKNOWLEDGMENTS

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About the Authors

Ratan Khatwa is a research scientist at the Netherlands National Aerospace Laboratory (NLR) in Amsterdam, Netherlands. He has a doctorate in aerospace engineering from the University of Bristol, England. His primary research areas include human factors, cockpit development and flight safety. Khatwa is a member of FSF's CFIT Task Force and FSF's European Advisory Committee.

Ir. Alfred Roelen is a research scientist at the NLR. He has a master's degree in aerospace engineering and a postgraduate diploma in aircraft design from the Technical University of Delft, Netherlands. His main research topics are human factors and flight safety.

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Appendix A
Figures

Figures are reproduced directly from the original report. For an explanation of abbreviations used in the figures, see Abbreviations and Acronyms, page v.

GRAPHICS TOO LARGE
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PAGES 21–37

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Appendix B
Accident Sample

Date (dmy)	Location	State	Aircraft
02/01/88	Izmir	Turkey	B737-200
08/01/88	Monroe, LA	United States	L-36
03/02/88	Helena, MT	United States	Ce-421
10/02/88	Stratford, CT	United States	PA-34
27/02/88	Ercan	Cyprus	B727-200
17/03/88	Cucuta	Colombia	B727-100
07/04/88	Coffs Harbour, NSW	Australia	PA-31
19/04/88	Bagdarin	USSR	Let 410
06/05/88	Broennoeysund	Norway	DHC-7
18/05/88	Skenton, AK	United States	PA-32
09/06/88	Maralinga	Australia	Ce-310
12/06/88	Posadas	Argentina	MD-81
21/07/88	Lagos	Nigeria	B707-320
17/08/88	Mt. Torbet, AK	United States	Ce-402
26/08/88	Irkutsk	USSR	Let 410
04/10/88	Batagai	USSR	An-12
17/10/88	Rome	Italy	B707-300
19/10/88	Gauhati	India	F-27
19/10/88	Ahmedabad	India	B737-200
02/11/88	Houston, TX	United States	PA-601
14/11/88	Ilmajoki	Finland	EMB 110
12/01/89	Dayton, OH	United States	HS 748
12/01/89	Caracas	Venezuela	Be-200
08/02/89	Santa Maria, Azores	Portugal	B707-300
19/02/89	Orange County, CA	United States	Ce-402
19/02/89	Kuala Lumpur	Malaysia	B747-200
23/02/89	Altenrhein	Switzerland	AC 690
24/02/89	Helsinki	Finland	SA-226
25/02/89	Tegucigalpa	Honduras	DC-7
22/03/89	Jacksonville, FL	United States	PA-600
10/04/89	Valence	France	F-27
19/04/89	Pelican, AK	United States	DHC-2
10/05/89	Azusa, CA	United States	Be-200
07/06/89	Paramaribo	Suriname	DC-8-62
11/06/89	Waipio Valley, HI	United States	Be-18
11/06/89	Vereda El Salitre	Colombia	DHC-6
27/07/89	Tripoli	Libya	DC-10
30/07/89	Haines, AK	United States	PA-31
31/07/89	Auckland	New Zealand	CV 580
03/08/89	Samos	Greece	SD 330
07/08/89	Nome, AK	United States	Ce-402
07/08/89	Gambella	Ethiopia	DHC-6
28/08/89	Lynchburg, VA	United States	PA-31
26/09/89	Terrace	Canada	SA-227
28/09/89	Roma	Australia	Be-95

Appendix B
Accident Sample (continued)

Date (dmy)	Location	State	Aircraft
20/10/89	Leninakan	USSR	Il-76
21/10/89	Tegucigalpa	Honduras	B727-200
26/10/89	Hualien	Taiwan	B737-200
28/10/89	Molokai, HI	United States	DHC-6
01/11/89	Fort Myers, FL	United States	PA-60
02/11/89	Apopka, FL	United States	PA-60
22/12/89	Beluga River, AK	United States	PA-31
16/01/90	San Jose	Costa Rica	C-212
05/02/90	Baker, OR	United States	Ce-402
14/02/90	Bangalore	India	A-320
17/02/90	Cold Bay, AK	United States	PA-31
21/03/90	Tegucigalpa	Honduras	L-188
28/04/90	Tamanrasset	Algeria	Be-90
30/04/90	Moosonee	Canada	Be-99
04/05/90	Wilmington, NC	United States	Nomad
11/05/90	Cairns	Australia	Ce-500
06/06/90	Altamira	Brazil	F-27
25/06/90	Aialak Bay, AK	United States	Ce-207
02/07/90	Asford, WA	United States	Ce-210
01/08/90	Stepanakert	USSR	Yak 40
13/08/90	Cozumel	Mexico	AC-1121
21/09/90	Flagstaff, AZ	United States	PA-31
14/11/90	Zürich	Switzerland	DC-9-30
21/11/90	Samui Island	Thailand	DHC-8
04/12/90	Nairobi	Kenya	B707
18/12/90	Evanston, WY	United States	PA-31
18/12/90	Thompson, UT	United States	Ce-182
07/02/91	Munford, AL	United States	PA-31
08/02/91	Mirecourt	France	Be-200
08/02/91	Stansted	United Kingdom	Be-200
05/03/91	Santa Barbara	Venezuela	DC-9-30
29/03/91	Homer, AK	United States	Ce-206
04/07/91	El Yopal	Colombia	DHC-6
14/08/91	Uricani	Romania	Il-18
14/08/91	Gustavus, AK	United States	PA-32
16/08/91	Imphal	India	B737-200
20/08/91	Ketchikan, AK	United States	BN-2
17/09/91	Djibouti	Djibouti	L-100
27/09/91	Guadalcanal	Solomon Islands	DHC-6
16/11/91	Destin, FL	United States	Ce-208
10/12/91	Temple Bar, AZ	United States	PA-31
18/12/91	Albuquerque, NM	United States	Ce-210
20/01/92	Strasbourg	France	A-320
03/02/92	Serra Do Taquari	Brazil	EMB 110
09/02/92	Kafountine	Senegal	CV 640

Appendix B
Accident Sample (continued)

Date (dmy)	Location	State	Aircraft
21/02/92	Castle Rock Peak	Australia	Ce-310
24/02/92	Unionville, PA	United States	Ce-310
26/02/92	Morganton, NC	United States	Be-18
24/03/92	Athens	Greece	B707-300
17/04/92	Hamburg, PA	United States	PA-23
22/04/92	Maui, HI	United States	Be-19
08/06/92	Anniston, AL	United States	Be-99
22/06/92	Cruzeiro do Sul	Brazil	B737-200
24/07/92	Ambon	Indonesia	Viscount
31/07/92	Kathmandu	Nepal	A-310
27/08/92	Ivanovo	Russia	Tu-134
28/09/92	Kathmandu	Nepal	A-300
31/10/92	Grand Junction, CO	United States	PA-42
09/11/92	Boise, ID	United States	Ce-210
19/11/92	Elk City, ID	United States	Ce-207
19/11/92	Tehachapi, CA	United States	Ce-172
13/12/92	Goma	Zaire	F-27
06/01/93	Paris	France	DHC-8
13/01/93	Sellafield	United Kingdom	EMB 110
30/01/93	Medan	Malaysia	SC-7
07/02/93	Iquacu	Brazil	Be-90
08/02/93	Lima	Peru	PA-42
23/02/93	Lemont, PA	United States	Be-18
02/03/93	Oakley, UT	United States	Ce-402
18/03/93	Trijillo	Peru	Be-90
19/03/93	Dagali	Norway	Be-200
23/03/93	Cuiabo	Brazil	EMB 110
19/05/93	Medellin	Colombia	B727-100
05/06/93	El Yopal	Colombia	DHC-6
11/06/93	Young	Australia	PA-31
25/06/93	Atinues	Namibia	Be-200
01/07/93	Sorong	Indonesia	F-28
26/07/93	Mokpo	Korea	B737-500
31/07/93	Bharatpur	Nepal	Do-228
27/09/93	Lansing, MI	United States	Be-300
25/10/93	Franz Josef Glacier	New Zealand	Nomad
27/10/93	Namsos	Norway	DHC-6
10/11/93	Sandy Lake	Canada	HS 748
14/11/93	Urumgui	China	MD-82
20/11/93	Ohrid	Macedonia	Yak 42
01/12/93	Hibbing, MN	United States	JS-31
30/12/93	Dijon	France	Be-90
14/01/94	Sydney	Australia	AC-690
18/01/94	Kinshasa	Zaire	L-24
24/01/94	Altenrhein	Switzerland	Ce-425

Appendix B
Accident Sample (continued)

Date (dmy)	Location	State	Aircraft
23/02/94	Tingo Maria	Peru	Yak 40
09/03/94	Tamworth	Australia	SA-226
06/04/94	Latacunga	Ecuador	DHC-6
25/04/94	Nangapinoh	Indonesia	BN-2
13/06/94	Uruapan	Mexico	SA-226
18/06/94	Palu	Indonesia	F-27
18/06/94	Washington, D.C.	United States	L-25
22/06/94	Juneau, AK	United States	DHC-3
26/06/94	Abidjan	Ivory Coast	F-27
17/07/94	Fort-de-France	Martinique	BN-2
07/08/94	Kodiak, AK	United States	DHC-2
13/09/94	Abuja	Nigeria	DHC-6
18/09/94	Tamanrasset	Algeria	BAC 1-11
29/10/94	Ust-Ilimsk	Russia	An-12
04/11/94	Nabire	Indonesia	DHC-6
19/11/94	Saumur	France	Be-90
22/11/94	Bolvovig	Papua New Guinea	BN-2
10/12/94	Koyut, AK	United States	Ce-402
17/12/94	Tabubil	Papua New Guinea	DHC-6
21/12/94	Coventry	United Kingdom	B737-200
29/12/94	Van	Turkey	B737-400

Source: Netherlands National Aerospace Laboratory (NLR)

Appendix C
Accident Data Coding Protocol

Codes:
n = no
na = not applicable
u = unknown
y = yes

1 Flight Variables

Date of accident

Local time

Crash site – geographical location (city, state)
– ICAO region AFR/APA/EEU/EUR/LAM/MID/NAM
– location relative to airport/runway in nm

Aircraft – type
– operator and country of origin
– damage: destroyed/substantial/minor/none/u

Flight phase – TI/TC/ER/LD/LH/LA/LG/u

Type of operation – air taxi/regional/major operator
– scheduled/nonscheduled/u
– passenger/freight/u
– domestic/international flight/u
– repositioning/u

Total number of crew and passengers onboard

Total number fatalities (crew and passengers)

2 Flight Crew Variables

No. of flight crew

Pilot Flying – FO/CAPT/u

Experience	FO	CAPT	Other
Total hours			
Hours on type			
Total instrument time			

Crew compatibility – improper pairing of crews – y/n/u

Fatigue-related – yes/no

Illusions – Visual (e.g. black hole approaches) – y/n/u
– Physical (e.g. somatogravic illusion) – y/n/u

Crew Errors:

(1) Communications issues (CO)
– pilot-pilot – y/n/u
– pilot-controller – y/n/u
(2) Navigation error (NE) – y/n/u
(3) Procedural errors (PE) – y/n/u
(4) Situational awareness (SA) – y/n/u
(5) Systems operation (SO) – y/n/u
(6) Tactical decision (TD) – y/n/u
(7) Monitoring/Challenging (MC) – y/n/u

Specific crew errors:

Navigational aid programmed correctly/incorrectly/u

Attempting visual flight in instrument conditions – y/n/u

Descended below minimums prior to acquiring visuals – y/n/u

Minimum altitude not maintained (e.g. ATC clearance, MSA, MORA, IFR procedure, stepdown altitude on VOR/DME approach) – y/n/u

Response to GPWS

– crew initiated escape maneuver – y/n/u/na

If "yes" – crew response on time (i.e. no delay) – y/n/u/na
– escape maneuver correct – y/n/u/na
(Incorrect would include turns, inadequate pitch rate, failure to level wings)

If "no" – no crew action – y/n/u
– disabled GPWS – y/n/
– other – y/n/u

Barometric altimeter
– set incorrectly – y/n/u
– read incorrectly – y/n/u

3 Environment Variables

Light/dark conditions – Dark/twilight/light/u

Weather data – basic weather: IMC/VMC/u
– ATIS/VOLMET available – y/n/u
– fog – y/n/u
– winds/gusts – y/n/u
Precipitation – none/u/snow/rain/hail-ice
– cloud base (feet)
– visibility (statute miles)

4 Airport and Approach Variables

High terrain around airport – y/n/u/na

Lighting
- runway lights – y/n/u/na
- approach lights – y/n/u/na
- VASIS/PAPI-equipped – y/n/u/na

Runway used for approach

VFR approach/landing: – None/y/u/na
(“Yes” includes traffic pattern/straight-in/valley-terrain following/go-around)

Type instrument approach flown (multiple entry):
- None/u/na
- ADF/NDB
- LOC type aid: SDF/LDA/ILS-LOC
- VOR
- DME
- ILS full/ILS backcourse
- ASR/PAR
- visual/circling/sidestep
- other (specify)

Navaid (ground facility)-related problems – y/n/u/na

Approach
- Procedure design:
  stabilized approach – y/n/u
- If nonprecision, average approach slope:

5 ATC Variables

Airport and approach control capabilities
- Terminal approach radar – y/n/u

Clearance instructions
- Radar vectoring to final approach – y/n/u
- Vectoring error – y/n/u

Controller communication issues – y/n/u
Controller experience issues – y/n/u
Controller fatigue issues – y/n/u

6 Aircraft Equipment Variables

GPWS
- was it required to be equipped ? – y/n/u
- was it equipped ? – y/n/u

GPWS characteristics (if equipped):
- mark
- inoperative due to mechanical problem

GPWS warning characteristics (if equipped):
- sounded warning – y/n/u/na
- GPWS alarm – false/nuisance/valid/u

Radio altimeter – y/n/u

Autoflight/FMS/flight director-related – y/n/u/na
(e.g. mode confusion, FD attentional tunnelling)

7 Air Carrier Variables

Company management/organizational issues – y/n/u

Crew training – adequate/inadequate

Maintenance issues – y/n/u

8 Regulatory Issues

Operator surveillance inadequate – y/n/u

Appendix D
Variables Excluded From Analysis

It was not always possible to obtain all of the information that would have been optimal for the current investigation. Variables that have not been analyzed because of the large proportion of missing data are listed below:

- Navigation aid (ground facility) problems;
- Controller communication issues;
- Controller experience;
- Controller fatigue;
- Navigation aid programmed incorrectly;
- Radio altitude read incorrectly;
- Radio altimeter set incorrectly;
- Descending below minimums prior to acquiring visual contact;
- Presence of strong winds/gusts;
- Management issues;
- Maintenance issues; and,
- Inadequate regulatory authority surveillance.

Nevertheless, some of these factors are referred to in the body of the text for comparison with other sources.

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For more information contact J. Edward Peery, FSF.
Telephone: (703) 739-6700
Fax: (703) 739-6708

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