Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR TP 97270

Controlled flight into terrain (CFIT) accidents of air taxi, regional and major operators

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DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF. TP 97270 U		SECURITY CLASS. Unclassified

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
Controlled flight into terrain (CFIT) accidents of air taxi, regional and major operators

PRESENTED AT
the Flight Safety Foundation's 9th European Aviation Safety Seminar, March 4-5, 1997, Amsterdam, and at The International Aviation Safety Conference, 27-29 August, 1997, Rotterdam.

AUTHORS	DATE	pp	ref
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DESCRIPTORS

Aircraft accidents	Instrument approach
Airline operations	Pilot error
Collision avoidance	Proximity
Commercial aircraft	Statistical analysis
Flight control	Warning systems
Flight safety	Weather

ABSTRACT
This investigation focused on the identification and analyses of factors that are potentially associated with Controlled Flight Into Terrain (CFIT) accidents involving air taxi, regional and major carriers. The study considered 156 fatal CFIT accidents that occurred in the 1988-1994 time frame. Contributory factors related to flight crew, environment, airport and approach, ATC, aircraft equipment and air carrier (organisational) have been analysed. Results indicate that Africa and Latin America are the ICAO regions with the highes CFIT risk for major operators. Descent and approach phase accidents accounted for around 70% of the total sample. Almost 60% of the approach accidents involve non-precision approaches. A high proportion of the accidents occurred in areas without high terrain. Procedural, situational awareness, tactical decision making and monitoring/challenging were the dominant crew error types. The data shows that one-fifth of the accidents involved inadvertent VFR flight into IMC. One disturbing finding is that 75% of the accident aircraft were not equipped with a Ground Proximity Warning System.

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CONTROLLED FLIGHT INTO TERRAIN (CFIT) ACCIDENTS OF AIR TAXI, REGIONAL & MAJOR OPERATORS

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Abstract

This investigation focused on the identification and analyses of factors that are potentially associated with Controlled Flight Into Terrain (CFIT) accidents involving air taxi, regional and major carriers. The study considered 156 fatal CFIT accidents that occurred in the 1988-1994 time frame. Contributory factors related to flight crew, environment, airport and approach, ATC, aircraft equipment and air carrier (organisational) have been analysed. Results indicate that Africa and Latin America are the ICAO regions with the highest CFIT risk for major operators. Descent and approach phase accidents accounted for around 70% of the total sample. Almost 60% of the approach accidents involved non-precision approaches. A high proportion of the accidents occurred in areas without high terrain. Procedural, situational awareness, tactical decision making and monitoring/challenging were the dominant crew error types. The data shows that one-fifth of the accidents involved inadvertent VFR flight into IMC. One disturbing finding is that 75% of the accident aircraft were not equipped with a Ground Proximity Warning System.

Abbreviations and Acronyms

AFR	African Region of ICAO
APA	Asia-Pacific Region of ICAO
CFIT	Controlled Flight Into Terrain
c o	Communication
EEU	Eastern European Region of ICAO
ER	En-route
EUR	European Region of ICAO
FO	First Officer
FSF	Flight Safety Foundation
IMC	Instrument Meteorological Conditions
LA	Landing - Approach
LAM	Latin American Region of ICAO
LD	Landing - Descent
LG	Landing - Go Around
LH	Landing - Hold
MC	Monitoring/Challenging
MCTM	Maximum Certified Take-off Mass
MID	Middle East Region of ICAO
N	Valid number of observations
NAM	North American Region of ICAO
NE	Navigation Error
NM	Nautical Mile
p	Probability
PE	Procedural Error
SA	Situational Awareness
s o	Systems Operation
SPO	Single Pilot Operation
TC	Take-Off - Climb Cruise
TD	Tactical Decision
TI	Take-off - Initial Climb
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

1 Introduction

While air travel is undoubtedly one of the safest means of modem mass transportation, the actual accident rate has remained approximately constant in recent years [1]. The challenge is to further reduce this rate so that the projected increase in air traffic does not increase the actual number of accidents. Controlled Flight Into Terrain (CFIT) remains one of the leading categories of air carrier accidents [l]. CFIT accidents are those in which an aircraft, under the control of the crew, is flown into terrain, obstacles or water, with no prior awareness on the part of the crew of the impending collision [2].

Since the introduction of the Ground Proximity Warning System (GPWS), the overall CFIT rate has decreased [3-5]. Other features such as expansion of ATC radar, enhancement of flight crew training programmes, improved flight standards, approach lighting, visual approach guidance and superior approach procedures may have contributed directly or indirectly to reducing the CFIT risk. However, these accidents continue to occur today at an unacceptable frequency. Pursual of the CFIT problem could provide an opportunity for safety enhancement.

Currently, various sectors of the industry are focusing on means of further reducing the CFIT risk. The most notable effort is the CFIT Task Force led by the Flight Safety Foundation (FSF) and International Civil Aviation Organisation (ICAO). Since 1992, the group has attempted to improve awareness of CFIT accidents and established measures to further reduce the accident rate [6]. Other efforts involve the development of advanced terrain alerting systems, e.g. Enhanced Ground Proximity Warning System (EGPWS), Ground Collision Avoidance System.

1.1 Study Objectives

The objective of this study was to identify and analyse factors that are potentially associated with CFIT accidents. A more comprehensive account is presented in Ref. 7. This study was initiated in association with the FSF CFIT Task Force and the Netherlands Department of Civil Aviation (RLD).

2 Review of Other CFIT Studies

Although much credible work has been done previously (e.g. Ref. 2-5, 8-18), some of the references date back more than 20 years and may not reflect today's operational environment and current generation aircraft. Most of the studies referred to above, although recognising that multiple agents may contribute to CFIT, have not necessarily conducted a comprehensive analysis of such factors. Ref. 16 does present evidence of the development of an appropriate accident taxonomy.

The recent thrust of industry activities related to CFIT by organisations such as FSF and ICAO, and the fact that no recent similar study of CFIT causal factors (with similar objectives) could be identified, makes the current study timely and appropriate.

3 Methodology

3.1 Study Approach

The overall approach employed in this study was to:

(a) Identify a sample of CFIT accidents using world-wide sources;
(b) Identify potential CFIT factors using the accident data;
(c) Develop an appropriate taxonomy for the collation and analysis of the information; and
(d) Analyse 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

Searches were conducted using the following databases/sources:

- AirClaims;
- AlliedSignal CFIT database;
- Australian Bureau of Air Safety Investigation (BASI);
- UK Civil Aviation Authority (CAA) [19];
- Flight International;
- Flight Safety Foundation;
- CFIT Task Force accident database;
- ICAO database;
- Lawrence Livermore National Laboratory [20];
- US National Transportation Safety Board (NTSB):
- NLR's accident database; and
- Netherlands Aviation Safety Board.

These sources enabled compilation of a virtually complete listing of all CFIT accidents of major operators that fulfil the criteria in Section 3.3. CFIT accident data of regional and air taxi operators is not as easily accessible. The NTSB database provided a rather complete list of US CFIT accidents for regional and air taxi operators. Those accidents were included in the sample at the cost of potentially biasing the sample by overrepresenting accidents to US operators.

3.3 Accident Inclusion Criteria

(a) **The** accidents involved fixed-wing aircraft; turbojet, turboprop and piston engined aircraft; and aircraft in all weight categories.
(b) The accident flights had the following characteristics:

- engaged in public transport;
- world-wide (no geographical restriction);
- both scheduled and non-scheduled flights;
- freight, passenger and positioning flights; and
- both international and domestic flights.

(c) The accidents occurred during 1988 through 1994.
(d) The accidents resulted in loss of life.

Excluded were executive/corporate operations, general aviation, training flights and experimental/test flights. Application of the above criteria resulted in a sample of 156 accidents, presented in Appendix A.

3.4 **Accident Causal Factor Taxonomy**

The accident record suggests that accidents rarely have a single cause but, instead are the result of a series of contributory factors. The accident taxonomy applied herein also attempted to account for multiple contributory factors. The taxonomy was developed by using accident reports and other related literature and consists of 7 main parameter groups:

- basic data;
- flight crew;
- environment;
- airport and approach;
- ATC;
- aircraft equipment; and
- air carrier (organisational).

The *basic data* category contains parameters such as date, local time, flight phase, etc. The resulting taxonomy, which contains a total of 85 factors, is presented in Ref. 7.

3.4.1 Definitions

It was difficult to obtain explicit definitions of *major*, *regional/commuter* and *air taxi* operators that apply world-wide. The following based on US operations were loosely applied to categorise operator type.

(a) Major operator. Have similar characteristics to carriers currently operating under FARs, Part 121. The aircraft operated generally have more than 30 seats.
(b) Regional/Commuter. Provide scheduled and non-scheduled short-haul passenger and freight services. Typically a wide range of both jetprop and turbojet aircraft with 19 to 100 seats are used.
(c) Air taxi. Transport persons, property and mail, generally using small aircraft (fewer than 30 seats). In the US these carriers operate in accordance with FARs, Part 135. Much of the operation is based on an *on-demand* basis as opposed to a published flight schedule.

The following flight phase definitions are based on those used by the UK CAA [19] and AirClaims.

(a) TI Take-Off - Initial Climb. From lift-off until first power reduction or 1500 ft.
(b) TC Take-Off - Climb Cruise. From end of initial climb until first en-route altitude.
(c) ER En-route. From top of climb to commencement of descent.
(d) LD Landing - Descent. From top of descent to 1500 ft.
(e) LH Landing - Hold. Holding during descent.
(f) LA Landing - Approach. From 1500 ft to the runway threshold.
(g) LG Landing - Go Around.

Flight crew error definitions were derived from Ref. 21. The main goal was to record the number of accidents in which each error type occurred. *Primary errors* are independent of any prior error. The six primary error types are defined below.

(a) Communication (CO): Incorrect read-back, hear-back; failing to provide accurate information; providing incorrect information.
(b) Navigational (NE): Selecting wrong frequency for the required radio navigation station: selecting the wrong radial or heading; misreading charts.
(c) Procedural (PE): 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.
(d) Situational awareness (SA): Controlling aircraft to wrong parameters.
(e) Systems operation (SO): Mishandling engines or hydraulic, brake, and fuel systems; misreading and mis-setting instruments; disabling warning systems.
(f) Tactical decision (TD): 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.

In contrast, a *secondary* error is dependent on another crew member previously or simultaneously making a primary error [21].

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

3.5 Accident Data Coding Protocol

The accident was coded using the values included in the CFIT taxonomy [7]. With the exception of a few US and European complete accident reports, accident summaries/narratives were generally employed. The coding protocol precluded interpretation of the accident report or narrative to complete the variable (especially where a subjective judgement could be applied, e.g. fatigue, improper crew pairing etc.). Where information was not provided, or was not complete enough to make an accurate assessment, the value was coded as 'unknown'. Some information may have been lost using this procedure, but it reduced the risk of a coding bias and ensured consistency of coding across all accidents.

3.6 Analytical Processes Employed

One of the original desires of this study was to estimate the risk associated with the various factors included in the accident taxonomy. To accomplish this, an understanding of the underlying prevalence of those individual factors, system-wide, among commercial operators not *involved in accidents* is also essential. These data could then be used to determine rates for each of the potential risk factors (see Ref. 22). However, much of the non-accident data for many parameters in the taxonomy were not available. Unfortunately this meant that risk rates could not be calculated.

The major steps included in the analysis are listed below.

(a) A digital version of the database was accomplished, and the data were evaluated through simple single variable analysis. Single population *qualitative* data was analysed using χ^2 tests.

(b) Next, the 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 χ^2-test of a contingency table. The tests for *quantitative* data involving two or more populations included the Krusskal-Wallis test for completely randomised design (i.e. independent samples).

4 Results and Discussion

Unless otherwise stated, all percentages are based on the total sample (N = 1.56). N denotes the number of valid cases. In the tables that follow, 'Yes' denotes the number of accidents in which a particular factor was present, and 'No' indicates accidents where it was not a factor.

4.1 Basic Data

4.1.1 Accident Rates

Accident *rates* were generally difficult to estimate due to lack of aircraft movement data. Based on ICAO movement data of *scheduled* air traffic [7], CFIT accident rates per year of *major* operators are presented in Fig. 1. The average CFIT rate (world-wide) over the period 1988-1994 was 0.24 accidents per million flights.

On average around 4 accidents involved international operations per year, in contrast to 14 for domestic operations. Using ICAO movement data [7], the CFIT accident rate for *scheduled international* flights of *major* operators was estimated as 0.43 accidents per million flights. This is 3.8 times higher than the rate for domestic flights (0.11 accidents per million flights).

Regional and air taxi operations together accounted for around 13 accidents on average per annum, whereas major operators suffered an average of 5 accidents.

4.1.2 Time of Occurrence

Table 1 presents the data when the time of accident is stratified across operator type.

Table 1 Local Time of Accident (N=87)

PERIOD	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%)	27 (100%)	34 (100%)

Ref. 21 provides time-of-day data for a sample of

214,000 non-accident flights conducted by major US operators during 1988. Of those, 13% operated between 2200 and 05.59, which compares with the major and regional operators data in Table 1 (15.4% and 11.1% respectively). However, 29.4% of air taxi accidents occurred in the same time period. If activity levels of non-accident flights for air taxi operators are comparable to those for major operators, then this finding may suggest that an increased risk is associated with overnight air taxi operations.

4.1.3 Accident ICAO Region

Fig. 2 presents the distribution of the CFIT accidents among the major ICAO regions. North America (NAM) accounts for 34.6% of the total accident sample - this reflects the accessibility of US accident data as well as the high commercial aviation activity level.

Based on ICAO movement data, CFIT accident rates per region for *scheduled* flights of *major* operators are presented in Fig. 3. Africa has the highest CFIT rate followed by Latin America and Asia Pacific. North America and Middle East have the lowest CFIT rates.

4.1.4 Accident Site Relative **to Runway**

Fig. 4 presents the distance of the aircraft crash location relative to the runway threshold for accidents occurring in the approach and landing phase (N = 80). Almost 60% of those accidents occurred within 5 NM from the runway threshold, and 90% within 15 NM. The progressive increase in the number of accidents with decreasing distance to the runway threshold is also reported in Ref. 4,9,12.

4.1.5 **Phase of Flight**

As Fig. 5 shows most accidents occurred in the landing approach phase (47.7%). followed by 21.9% in the descent phase - combined total is 69.6%. The en-route phase accounted for around one-fifth of the accidents. The difference between the relative frequencies of occurrence is statistically significant (χ^2 = 142 and p c 0.01).

Fig. 5 also shows that in those cases for which data were known, 93% of the en-route accidents were attributable to air taxi and regional operators. The majority of aircraft types engaged in such operations cruise at significantly lower altitudes than those used by major operators.

Although major and air taxi operators suffered their greatest losses in the landing-approach phase (61.1% and 48.9% respectively, p c 0.01) the regional operators encountered the largest percentage of accidents in the en-route phase (32.6%, p c 0.01).

4.2 **Flight Crew Variables**

4.2.1 Pilot Flying

Fig. 6 shows the pilot flying (PF) distribution. Data were missing in 50% of the sample. Single pilot operations (SPO) accounted for 30.8% of the sample. This high number is associated with the large number of air taxi cases in the accident sample. For operations where there were at least two crew members, the Captain was PF (denoted by CAPT in Fig. 6) in 11 (7.1%) cases, whereas the First Officer was PF (FO in Fig. 6) in at least 13 (8.3%) accidents. This difference is not statistically significant.

4.2.2 **Flight Crew Experience**

The basic statistics associated with flight crew experience are shown in Table 2.

Table 2 Flight Crew Experience

EXPERIENCE	CAPT.	FO
Total hours		
Range (hrs)	480- 16000	425-15639
Mean (hrs)	5097	3084
Standard dev. (hrs)	3707	4220
N	66	13
Hours accident aircraft		
Range (hrs)	4-4500	4-1100
Mean (hrs)	1046	182
Standard dev. (hrs)	1134	300
N	52	12
Total Instrument hours		
Range (hrs)	16-3764	38-389
Mean (hrs)	600	214
Standard dev. (hrs)	839	248
N	37	2

Half the Captains had less than 4000 hrs *total* experience (N = 66). In the cases where data were known (N = 12), more than half the First Officers had less than 2000 hrs *total* experience.

In 67% of the accidents, the Captain had less than 1000 hours of experience on *type*, whilst more than 42% had fewer than 500 hours (N = 52). For all but one First Officer, experience on *type* was fewer than 500 hours (N = 12).

Where data were available (N=37), 73% of Captain subjects had fewer than 500 hours of *instrument* flight time. In one-half the cases these subjects had fewer than 220 hours instrument time.

4.2.3 **Flight Crew Errors**

Fig. 7 presents a distribution of the percentage of accidents in which the flight crew errors occurred. The monitoring/challenging (MC) error is not applicable in 48 SPOs. Data were unknown in a high number of accidents. Nevertheless, the following observations can be made:

- at least 11 accidents included a communication (CO) error (7.1%);
- 18 accidents involved a navigational error (NE) (11.5%);
- 53 involved a procedural error (PE) (34%);
- 70 involved a situational awareness (SA) error (44.9%);
- 13 included a systems operation (SO) error (8.3%);
- 69 involved a tactical decision (TD) error (44.2%); and
- 31 involved a monitoring/challenging (MC) problem (28.7% of the relevant cases).

It is evident that PE, SA, TD and MC are the dominant error types. Despite the high proportion of missing data, the percentages quoted above are based on the total sample. If only those accidents with available data are considered (i.e. 'yes' and 'no' in Fig. 7), then it is evident that the PE, SA, TD and MC error types occurred in the majority of accidents. Communication errors appear to be relatively less of a problem (Fig. 7 indicates that in 37.2% of the accidents communication errors did not contribute). Ref. 2 1 reported similar trends for a sample of 37 Part 121 US accidents.

4.2.4 **VFR Flight into IMC**

In 30 cases (19.2% of the total sample) inadvertent flight from VFR into IMC was a factor. Data was missing in 67 cases (43%). Twenty one of the 30 accidents involved single pilot operation flights and this association was significant at the 95% confidence level. The mean instrument time for the accident pilots was 611 hours (N = 14).

Most of the accidents (for which data are available, N= 79) involved regional and air taxi operators (p = 0.006). See Table 3 ('No' indicates accidents where this was not a factor).

Seventeen of the VFR into IMC accidents occurred in the en-route phase (Table 4), and this association is significant at the 95% confidence level.

Table 3 VFR into IMC Stratified Across Operators

	YES	NO
MAJOR	1	20
REGIONAL	13	15
AIR TAXI	11	19

Table 4 VFR into IMC Stratified Across Flight Phase

PHASE	YES	NO
Take-Off - Initial Climb	0	3
Take-Off - Climb Cruise	1	2
En-Route	17	5
Landing - Descent	6	11
Landing - Approach	6	34
Landing - Go-Around	0	4

4.3 **Aircraft Variables**

4.3.1 Ground Proximity Warning System (GPWS)

Where data were available (N = 108), in only 27 accidents was a GPWS fitted aboard the accident aircraft, i.e. 75% of the aircraft were not fitted with a GPWS. Twenty two of these GPWSs were aboard major operator aircraft, one on a regional and none were on air taxi. Table 5 shows 21 (78%) were early mark I and II types.

Table 5 GPWS Equipment

GPWS mark	Number
I	12
II	9
III	2
V	2
Unknown	2

Of the 27 GPWS equipped aircraft, 15 (55.6%) sounded valid alerts prior to the accident, whereas in 9 cases the GPWS did not sound any alert. Six of the latter accidents occurred on non-precision approaches.

Table 6 summarises the crew response to the GPWS alerts. In only 12 accidents was it known whether the crew reacted to the GPWS signal. Despite the small sample, it is remarkable that in 8 of those accidents there was no crew reaction to the GPWS alert. In the four accidents where an escape manoeuvre was initiated, the recovery was non-optimal (e.g. turns, failure to level wings) and in two of these accidents the crew response to the GPWS alert was not instantaneous (Table 6). In some quarters it has been argued that some of the accident crews had received little, if any, terrain recovery training.

Table 6 Crew Response to GPWS Alerts

	YES	NO	UNKNOWN
GPWS warning given	15	9	3
Crew initiated escape manoeuvre	4	8	15
Crew response on time	2	2	23
Escape manoeuvre correct	0	4	23
GPWS disabled by crew	1	4	22

The aircraft were divided into three classes based on the applicability of current and future (applicable 1999) ICAO GPWS requirements [23]. The requirements are a function of aircraft weight, number of passengers carried and date of certificate of airworthiness (see ICAO Annex 6). They apply only to international operations. The following definitions were formulated.

(a) Small - aircraft not required to be equipped with GPWS in accordance with current or future ICAO requirements outlined in ICAO Annex 6 and Ref. 23 respectively.
MCTM < 5,700 kg and in future, aircraft that in addition carry more than 9 passengers.

(b) Medium - aircraft that will be required to be equipped with GPWS in the future, if engaged in international operations, but currently not required to do so.
5,700 kg c MCTM < 15,000 kg. Airplanes less than MCTM 15,000 kg are currently required to carry GPWS if they carry more than 30 passengers.

(c) Large - aircraft that must be equipped with GPWS in accordance with current ICAO requirements (and in the future) if engaged in international operations. MCTM > 15,000 kg.

Applying these definitions to the accident sample aircraft produces the data in Fig. 8. Data were missing in only 33 cases. An important issue is the percentage of accident aircraft that may benefit from the new ICAO regulations. The ‘small’ aircraft category accounted for 61 accidents, whereas the ‘medium/domestic’ and ‘large/domestic’ categories each accounted for 25 accidents. These latter three categories will not benefit from the new requirements. In total 71% of the accident aircraft would not be required to be fitted with a GPWS in future if the above weight classification is strictly applied. Note that some states (e.g. USA) have extended the basic ICAO regulations to include domestic operations and this should be taken into account in the interpretation of the data. The CFIT Task Force has made recommendations to require the installation of GPWS for domestic operations [24]. Resolution A3 1-9, adopted by the 3 1 st Session of the ICAO Assembly in 1995, urges states to take similar action.

4.4 Environment Variables

Ninety three cases (87% of available data, N=107) involved IMC, compared with 14 accidents in VMC.

Fig. 9 presents the distribution for the light conditions. In 114 cases where data were known, half occurred in dark conditions and 46% in light conditions. Light condition stratified across basic weather for 86 cases is shown in Table 7. Whatever the light condition, IMC prevailed in a high proportion of the accidents.

Table 7 Light as a Function of Basic Weather

	DARK	LIGHT	DUSK
IMC	33	37	2
VMC	5	9	0
TOTALS	38	46	2

4.5 Airport and Approach Variables

Table 8 provides the distribution of the airport variables. Only accidents that occurred during the landing phase of flight (N = 116) are considered.

In just over a quarter of the sample, significant terrain features were present in the vicinity of the airfield, but in almost 40% there was no high terrain. This indicates that CFIT accidents do occur in areas without high terrain. In around a quarter of the cases approach lights and visual approach guidance (Visual Approach Slope Indicator System (VASI)/Precision Approach Path Indicator (PAPI)) were not present, while there was no Terminal Approach Radar (TAR) for 37.0% of the accidents. A recent study [22] found that lack of TAR was associated with a threefold increase in risk of accidents compared to approaches conducted with TAR present. In 35% of the descent and approach accidents, weather update information from Automatic Terminal Information Service (ATIS) or Meteorology Information for Aircraft in Flight (VOLMET) was not available.

Table 8 Airport and Approach Variables

AIRPORT VARIABLE	% YES	% NO	% UNKNOWN
Terrain	26.7	37.9	35.3
ATISNOLMET	37.1	35.3	27.6
Approach Lights	32.7	25.9	41.4
VASI/PAPI	36.2	22.4	41.4
TAR	31.0	37.0	31.9

Fig. 10 presents the instrument approach aid type data (N = 66, data unknown in 50 accidents). Rates could not be estimated due to unavailability of movement data. Almost 60% of the approaches were non-precision. Twenty-five percent (17 cases) of the total sample were VOR/DME approaches. Ref. 22 concluded that the risk of an accident while flying a non-precision approach is about five times greater than that associated with flying a precision approach (world-wide, other factors constant).

5 Other Casual Factors - Missing Data

Many of the parameters with a high proportion of missing data were excluded from the analysis. Several are mentioned here as they have been reported elsewhere as important contributory factors to CFIT accidents. The relevant factor and the number of accidents in which it was involved are given below.

- 25 accidents - management/organisational deficiencies.
- 23 accidents - inadequate crew training.
- 9 accidents - visual or physical illusion (black *hole* approaches and somatogravic illusions).
- 7 accidents - pairing two crew members with inappropriate experience levels.
- 5 accidents - fatigue.
- 5 cases - barometric altimeter set incorrectly.
- 4 accidents - FMS/autoflight related.
- 1 case - barometric altimeter was read incorrectly.

6 Data and Study Limitations

The sample of 156 accidents represent the majority of fatal CFIT accidents involving commercial aircraft during the study period, but the small number of events limited the analysis to simple single- and two-factor analysis. Application of this simplistic analytical model to what is acknowledged to be a very complex event was the only method by which these data could be evaluated. The greater insight that might have been gained from multivariable analysis was not possible.

The accident sample is considered biased as North American accidents accounted for 34.6% of the total sample. This is probably because of the accessibility of US accident data, as well as the high commercial aviation activity levels. This bias limited some of the two-factor analyses that could be conducted.

Information on many factors of interest was not available. This problem also limited some of the two-factor analysis that could be conducted (problems associated with small numbers). Missing data may represent a serious problem because their influence on the study results is unknown. Missing data resulted in the study team having to abandon certain planned analyses because of the risk of misrepresentation. As movement data were unable (see Section 3.6) 'risk rates' could not be estimated.

7 Conclusions

(a) Seventy five percent of 108 aircraft for which data were available, were not fitted with a GPWS. Three quarters of the GPWS equipped aircraft (27 in total) were fitted with early mark I and II types. In 9 cases (on non-precision approaches) an alert was not generated by the GPWS. In the majority of 15 accidents with valid GPWS alerts, flight crew response was non-optimal.

(b) A large proportion of the accident sample (nearly 70%) would not be required to be fitted with a GPWS if new ICAO regulations are strictly applied.

(c) Procedural, situational awareness, tactical decision making and monitoring/challenging errors were the dominant crew error types, whereas those related to communication appear to be relatively less of a problem.

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

(e) Whilst major and air taxi operators suffered their greatest losses in the landing-approach phase, the regional operators encountered the largest losses en-route.

(f) Almost 60% of the 66 approach phase accidents where data were known involved non-precision approaches. Twenty five percent (17 cases) of all approaches were of the VOR/DME type.

(g) Almost all (90%) approach and landing phase accidents occurred within a radius of 15 NM from the runway threshold.

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

(i) In 30 accidents (one-fifth of the total sample) inadvertent VFR 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 (56.7%) VFR into IMC accidents occurred in the en-route phase.

(j) When the data for scheduled flights of major operators are considered, Africa appears to be the region with the highest CFIT rate, followed by Latin America and Asia Pacific. North America and the Middle East regions 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) Eighty seven percent of 107 cases where weather status was known involved IMC. Around half of the accidents occurred in conditions of darkness.

(m) The level of analysis detail possible was limited by the scarcity of data.

8 Recommendations

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

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

(c) CFIT risk-reduction should include not only major air carriers, but also air taxi and regional operations.

(d) Any means of reducing flight crew procedural, tactical decision making, monitoring/challenging errors is encouraged. Whether this involves training and/or improved cockpit discipline, or other measures such as error-tolerant design of check-lists and procedures is for further study. Operators are strongly encouraged to adopt the CFIT Training Aid, as recommended by the CFIT Task Force.

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

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

(f) The international sharing of accident and incident data should be encouraged, to facilitate addressing safety problems quickly and effectively.

Acknowledgements

This study was conducted under a contract awarded by the Netherlands Department of Civil Aviation (RLD). The constructive input from the FSF CFIT Task Force is greatly appreciated. The following organisations readily provided CFIT data, namely AlliedSignal, UK CAA, FSF, ICAO, US NTSB, BASI and Netherlands Aviation Safety Board.

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Appendix A Accident Sample Listing

Date (dmy)	Location	Aircraft
02/01/88	Izmur, Turkey	B737-200
08/01/88	Monroe (LA), USA	L-36
03/02/88	Helena (MT), USA	Ce42 l
10/02/8 8	Stratfort(CT), USA	PA-34
27/02/88	Ercan. Cyprus	B727-200
17/03/88	Cucuta, Colombia	B727-1000
07/04/88	Coffs Harbour, Australia	PA-3 I
19/04/88	Bagdarin, USSR	Let 410
06/05/88	Broennoeysund, Norway	DHC7
18/05/88	Skenton,(AK),USA	PA-32
09/06/88	Maralinga, Australia	Ce-3 IO
12/06/88	Posadas, Argentina	MD-8 l
2 I/07/88	Lagos. Nigeria	B707-320
17/08/88	Mt Torbet (AK), USA	Ce-402
26/08/88	Irkutsk, USSR	Lct 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, USA	PA-60 l
14/11/88	Ilmajoki, Finland	EMB 110
12/01/89	Dayton (OH), USA	HS 748
12/01/89	Caracas, Venezuela	Be-200
08/02/89	Azores. Portugal	B707-300
19/02/89	Orange County (CA), USA	Ce402
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	Tcgucigalpa, Honduras	DC-7
22/03/89	Jacksonville (FL). USA	PA-600
10/04/89	Valencc, France	F-27
19/04/89	Pelican (AK). USA	DHC-2
10/05/89	Azusa (CA),USA	Be-200
07/06/89	Paramaribo, Surinam	DC-8-62
11/06/89	Waipio Valley (HI). USA	Be-18
11/06/89	Vereda El Salitrc, Colombia	DHC-6
27/07/89	Tripoli, Libya	DC-IO
30/07/89	Haines (AK), USA	PA-3 I
3 1/07/89	Auckland. New Zealand	CV 580

Date (dmy)	Location	Aircraft
03/08/89	Samos, Greece	SD 330
07/08/89	Nome (AK), USA	Ce-402
07/08/89	Gambella, Ethiopia	DHC-6
28/08/89	Lynchburg (VA), USA	PA-31
26/09/89	Terrace (BC), Canada	SA-227
28/09/89	Roma, Australia	Be-95
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), USA	DHC-6
01/11/89	Fort Myers (FL), USA	PA-60
02/11/89	Apopka (FL), USA	PA-60
22/12/89	Beluga River (AK), USA	PA-31
16/01/90	San Jose, Costa Rica	C-212
05/02/90	Baker (OR), USA	Ce-402
14/02/90	Bangalore, India	A-320
17/02/90	Cold Bay (AK). USA	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	Willmington (NC), USA	Nomad
11/05/90	Cairns, Australia	Ce-500
06/06/90	Altamira, Brazil	F-27
25/06/90	Aialak Bay (AK), USA	Ce-207
02/07/90	Asford (WA), USA	Ce-210
01/08/90	Stepanakert, USSR	Yak 40
13/08/90	Cozumel, Mexico	AC-I 121
21/09/90	Flagstaff (AZ), USA	PA-31
14/11/90	Zurich, Switzerland	DC-g-30
21/11/90	Samui island, Thailand	DHC-8
04/12/90	Nairobi, Kenya	B707
18/12/90	Evanston (WY). USA	PA-31
18/12/90	Thompson (UT), USA	Ce-182
07/02/91	Munford (AL). USA	PA-31
08/02/91	Mirecourt, France	Be-200
08/02/91	Stansted. UK	Be-200
05/03/91	Santa Barbara, Venezuela	DC-9-30
29/03/91	Homer (AK), USA	Ce-206
04/07/91	El Yopal, Colombia	DHC-6
14/08/91	Uricani, Romania	Il-18
14/08/91	Gustavus (AK), USA	PA-32
16/08/91	Imphal, India	B737-200
20/08/91	Ketchikan (AK), USA	BN-2
17/09/91	Djibouti, Djibouti	L-100
27/09/91	Guadalcanal. Solomon Islands	DHC-6
16/11/91	Destin (FL), USA	Ce-208
10/12/91	Temple Bar (AZ), USA	PA-31
18/12/91	Albequerque (NM), USA	Cc-210
20/01/92	Strasbourg, France	A-320
03/02/92	Serra Do Taquari, Brazil	EMB 110
09/02/92	Kafountine, Senegal	CV 640
21/02/92	Castle Rock Peak, Australia	Ce-310
24/02/92	Unionville (PA), USA	cc-310
26/02/92	Morganton (NC), USA	Be-18
24/03/92	Athens, Grcccc	B707-300
17/04/92	Hamburg (PA). USA	PA-23
22/04/92	Maui, (HI), USA	Be-19
08/06/92	Anniston (AL). USA	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), USA,	PA-42
09/11/92	Boise (ID), USA	Ce-210
19/11/92	Elk City (ID), USA	Ce-207
19/11/92	Tehachapi (CA), USA	Ce-172
13/12/92	Coma, Zaire	F-27
06/01/93	Paris, France	DHC-8
13/01/93	Sellafield, UK	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), USA	Be-18
02/03/93	Oakley (UT), USA	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), USA	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), USA	JS-31
30/12/93	Dijon. France	Bc-90
14/01/94	Sydney, Australia	AC-690
18/01/94	Kinshasa. Zaire	L-24
24/01/94	Altenrhein, Switzerland	Cc-425
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 DC, USA	L-25
22/06/94	Juneau (AK), USA	DHC-3
26/06/94	Abidjan, Ivory Coast	F-27
17/07/94	Forte de France, Martinique	BN-2
07/08/94	Kodiak (AK), USA	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	Saumcr, France	UC-90
22/11/94	Bolvovig. Papua N. Guinea	BN-2
10/12/94	Koyut (AK), USA	cc-402
17/12/94	Tabubil, Papua N. Guinea	DHC-6
21/12/94	Coventry, UK	B737-200
29/12/94	Van, Turkey	B737-400

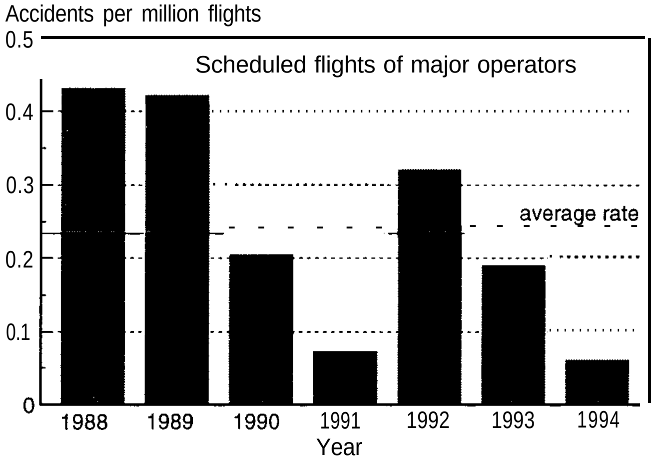

Figure 1 CFIT accident rate annual distribution

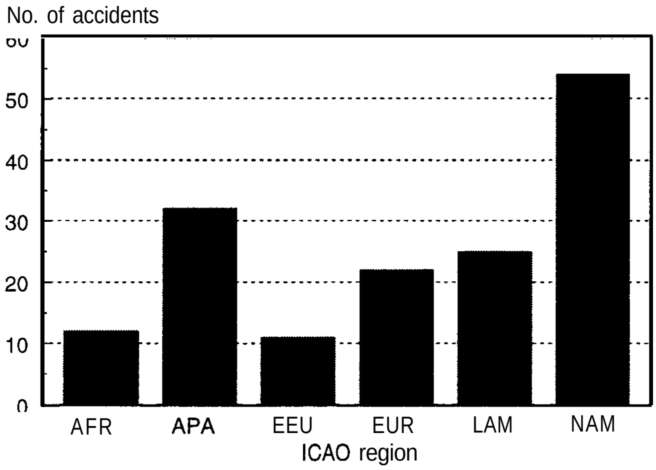

Figure 2 Accidents among ICAO regions

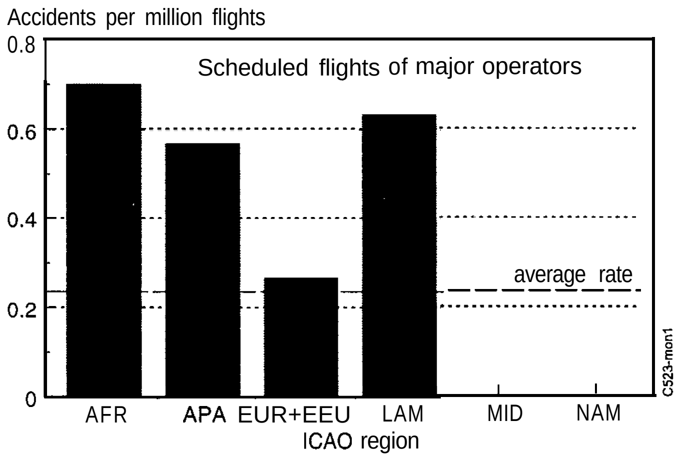

Figure 3 Accident rate among ICAO regions

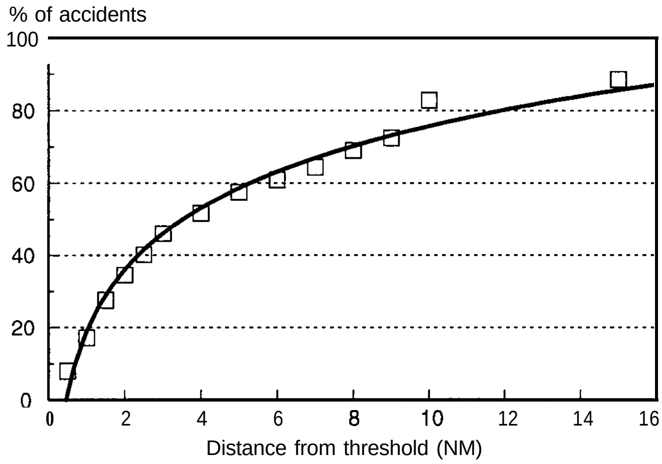

Figure 4 Accident location relative to runway threshold

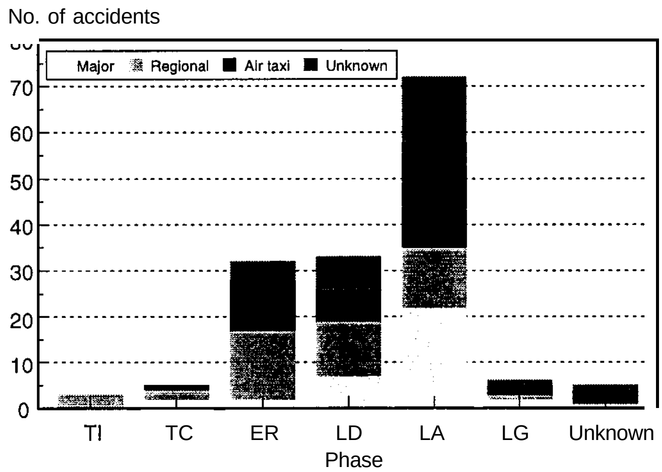

Figure 5 Flight phase distribution

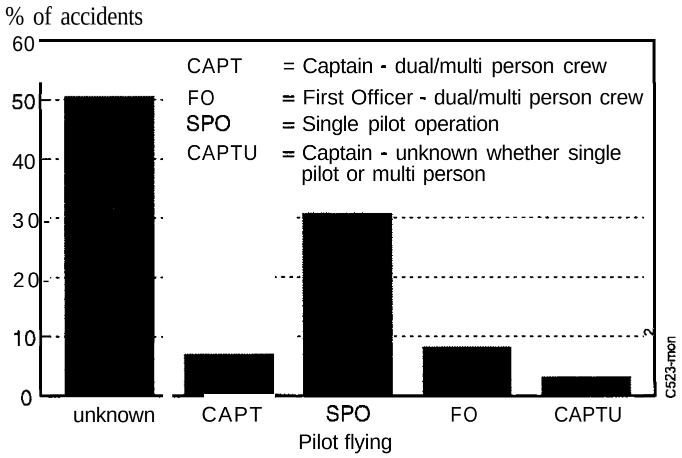

Figure 6 Pilot flying distribution

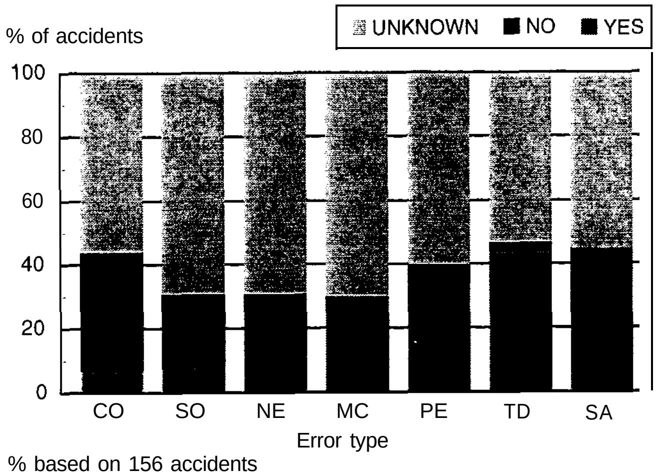

Figure 7 Flight crew errors

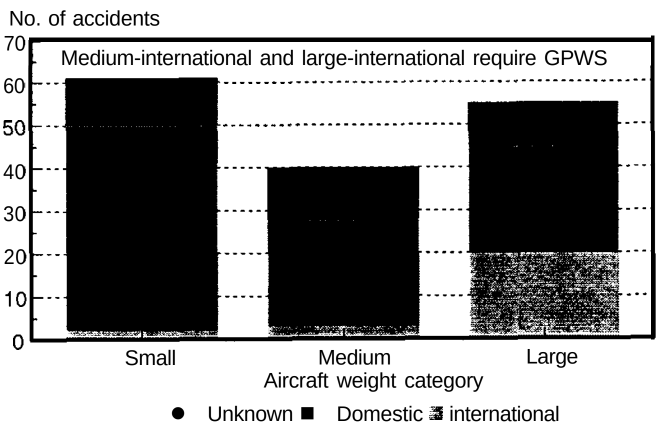

Figure 8 Applicability of future GPWS standards

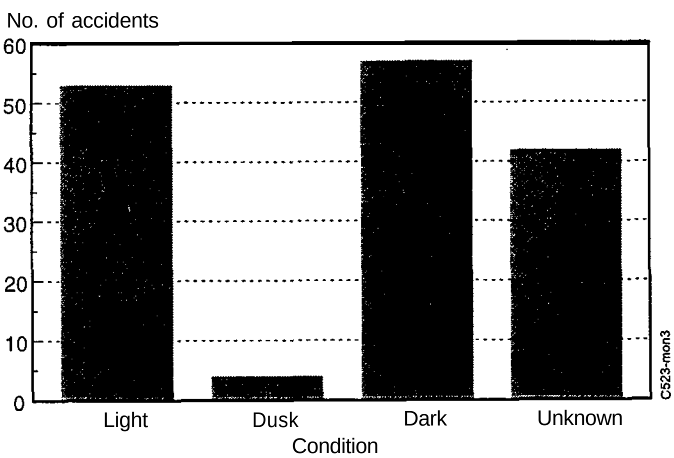

Figure 9 Light conditions

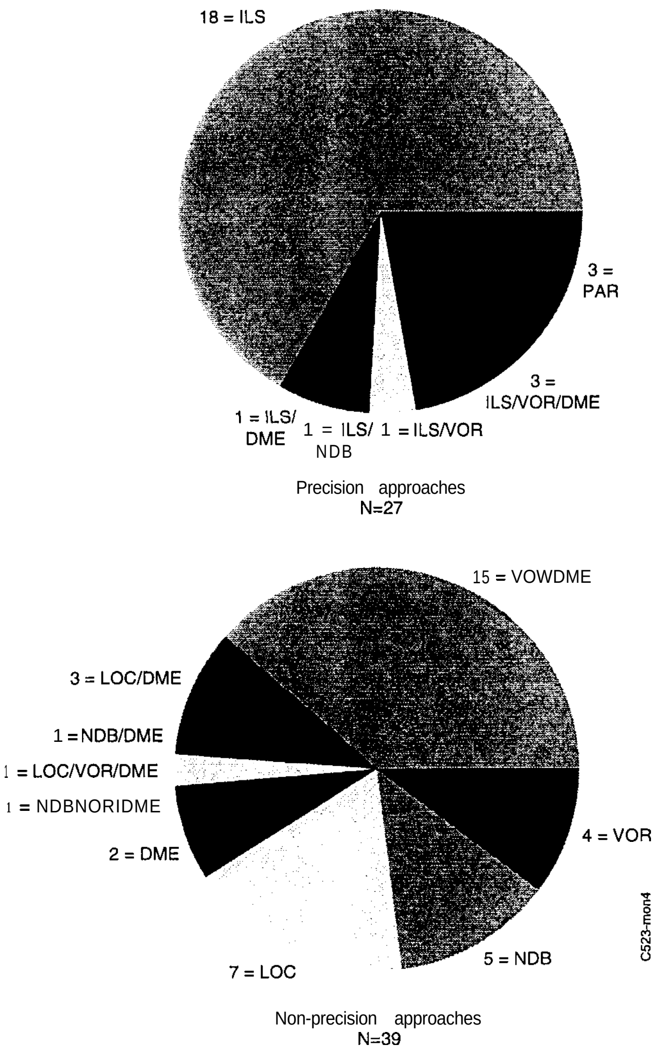

Figure 10 Approach aid types