A Review of Civil Aviation Accidents
Air Traffic Management Related Accidents:1980-1999

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Abstract

The National Aerospace Laboratory NLR was contracted by Air Traffic Control the Netherlands (LVNL) to collect and analyse a selected a number of air traffic management (ATM) related accidents.

The objective of the present study was to quantify the historical safety performance in terms of accident rates of a selected number of ATM related accident types. This information can assist in the determination of target levels of safety.

This paper presents an analysis of ATM related accidents involving commercial civil transport aircraft which occurred worldwide during the period 1980-1999. ATM related accident rates by event type, flight phase and world region are presented and discussed.

1 Introduction

1.1 Background

There is a number of studies available that provide historical data on aviation safety. So far not much attention has been given specifically to Air Traffic Management (ATM) related accident types. EuroControl published one of the few studies on safety minima for ATM[1]. This EuroControl study presents an initial set of ECAC safety minima, based on a historical safety achievement in the ECAC Region. To obtain more insight into the assessment of the historical safety data in the EuroControl study, the National Aerospace Laboratory NLR was contracted by Air Traffic Control the Netherlands (LVNL) to collect and analyse a selected number of ATM related accidents. In this paper the results of this study are presented.

1.2 Research Objectives

The objective of the present study was to quantify the historical safety performance in terms of accident rates by operational flight phases of a selected number of ATM related accident types. This information can assist in the determination of numerical safety standards known as "target level of safety" (TLS[2]). The present study was not limited to accidents in which ATM was a causal factor but covered all accidents that can be related to the ATM system in general. Therefore the results of the present study are more significant when considering the overall ATM system.

1.3 Paper Structure

Section 2 describes the basic approach applied in the study, the data sources consulted, the accident sample inclusion criteria, and the applied accident taxonomy. In section 3 the results are presented and discussed. A trend analysis is presented in section 4. Some final remarks are given in section 5. Section 6 summarises some of the important results. Finally section 7 gives recommendations.

2 Methodology

2.1 Approach

The following approach was used:

- Compilation of a sample of Air Traffic Management related accidents,
- Compilation of exposure data (i.e. number of conducted flights),

[1] "ECAC SAFETY MINIMA FOR ATM", SAFETY REGULATION COMMISSION POLICY DOC 1, EuroControl, Edition 0.01, 14-07-2000.

[2] A TLS specifies a maximum accepted level of risk for an activity.

- Estimation of accident rates.

2.2 Data Sources

Searches were conducted in the NLR Air Safety Database[3]. This database consists of accident data from a large number of sources including, for instance, official international reporting systems (e.g. ICAO ADREP), Accident Investigation Agencies, and insurance companies. These sources provided data for virtually all reported ATM related accidents. Exposure data (e.g. number of flights) were also obtained from the NLR Air Safety Database. The database contains arrival and departure data of commercial aircraft at airports worldwide.

2.3 Accident Sample Inclusion Criteria

Several criteria were used to establish the final accident sample:

1) The selected accident must fulfil the definition in ICAO ANNEX 13 given as follows:

An occurrence associated with the operation of an aircraft which takes place between the time any person board the aircraft with the intention of flight until such time as all persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of:

- being in the aircraft, or
- direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
- direct exposure to jet blast, *except* when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which:

- adversely affects the structural strength, performance or flight characteristics of the aircraft, and
- would normally require major repair or replacement of the affected component, *except* for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin; or

c) the aircraft is missing or is completely inaccessible.

Note 1: For statistical uniformity only, an injury resulting in death within thirty days of the date of the accident is classified as a fatal accident by ICAO.

Note 2: An aircraft is considered to be missing when the official search has been terminated and the wreckage has not been found.

Note 3: According to ICAO, one collision is counted as *two* accidents (one for each aircraft involved), which implies that the probability of the occurrence of an accident could be twice the probability of the occurrence of a collision. The word "*could*" is used here because it is possible that one of the aircraft involved in the collision does not comply with the accident inclusion criteria (e.g. one aircraft could be a small general aviation aircraft). In that case the collision is counted in this study as *one* accident[4].

2) The accidents involved aircraft operated by commercial operators, including and limited to:

- Freight operators and air carriers involved in public transport,
- Scheduled and non-scheduled flights,
- Freight, passenger, training and positioning flights,

[3] More information about the NLR Air Safety Database can be found in NLR Report CR-98167. Note that an update of the information provided in NLR Report CR-98167 is currently in progress.

[4] For this reason *collision* rates cannot be obtained by simply dividing the *accident collision* rates (presented in this study) by a factor two.

- International and domestic flights,
- Turbojet, turboprop and piston-engine fixed-wing aircraft,
- Aircraft in the takeoff weight category of 5,670 kg or higher.

but excluding:

- Experimental/test flights,
- Accidents with helicopters.

3) Accidents caused by sabotage, terrorism and military actions were excluded.

4) Russian-built and business jet aircraft could not be included due to lack of complete and accurate flight exposure data for these aircraft for a sufficiently long period.

5) The accidents occurred during 1980 through 1999. This time frame was considered large enough to provide a statistically acceptable number of accidents. The available data for 2000 were incomplete and therefore not selected.

6) Accidents of the following type only were considered in the analysis:

- Wake vortex induced accidents[5],
- Accidents involving two or more aircraft,
- Accidents involving one aircraft and one or more ground vehicles,
- Accidents involving problems with landing aids[6].

These accident types were considered to be ATM related. ATM *related* does not necessarily mean that ATM was a causal factor in the accident.

7) Accidents in the flight phase *standing*[7] were excluded.

There is no restriction to the geographical location at which the accident occurred. Selection criteria 2, 4, and 5 were also applied to the exposure data.

2.4 Accident taxonomy

A taxonomy was used to record all accidents fulfilling the inclusion criteria. This taxonomy consisted of the following items:

- Accident date,
- Aircraft type (including manufacturer),
- Accident location,
- Region in which the accident occurred,
- Operator name,
- Flight phase (according to the year 2000 CAST/ICAO COMMON TAXONOMY TEAM definitions[8], which are available from the author),
- Event type,
- Onboard fatalities.

The following event types were considered in this study:

- AIRCRAFT ENCOUNTERED VORTEX/WAKE TURBULENCE,
- COLLISION / NEAR COLLISION WITH AIRCRAFT -BOTH AIRBORNE[9],
- COLLISION WITH AIRCRAFT -ONE AIRBORNE,
- COLLISION WITH MOVING AIRCRAFT ON GROUND,
- COLLISION WITH STANDING AIRCRAFT ON GROUND[10],
- COLLISION WITH VEHICLE,
- LANDING AIDS RELATED ACCIDENT[11].

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[5] Wake vortex = A disturbance caused by a pair of counter rotating vortices trailing from the wing tips of an aircraft.

[6] Landing aids such as (but not limited to) ILS, MLS, PAR, PAPI, VASI and approach lights.

[7] STANDING: After the first person boards the aircraft with the intention of flight until pushback or, if pushback does not apply, until taxiing from the gate or parking position. Subsequently, from engine shut down upon reaching the gate or parking position after flight until the last person exits the aircraft.

[8] CAST: Commercial Aviation Safety Team.

[9] Near mid-air collisions can result in damage to the aircraft and/or fatal injuries to the occupants resulting from an evasive manoeuvre conducted to avoid the collision. Also note that mid-air collisions *do not* necessarily result in fatalities among the occupants of the involved aircraft.

[10] This should NOT be confused with the flight phase *standing* which is excluded in this study.

3 Results

3.1 Exposure data

Queries were made in the NLR Air Safety Database for the period 1980-1999. Selection criteria 2, and 4 from section 2.3 were also applied to the query. The query resulted in a total of 420 million flights[12]. The distribution of the flights by world region is shown in Figure 1. The majority of all flights were conducted in North America and Western Europe.

3.2 Accident data

A total of 193 ATM related accidents were found that fulfilled the accident inclusion criteria of section 2.3. There were in total 2340 accidents that fulfilled all criteria of section 2.3 except criterion 6. Hence 8.2% of this total are considered ATM related. A number of different frequency distributions of the accident sample are discussed in the following sections.

3.2.1 Flight phases

In Figure 2 the distribution by flight phase is shown. The majority of all ATM related accidents in the sample took place in the taxi phase.

3.2.2 Event types

The frequency of event types is shown in Figure 3. The majority of all events in the accident sample concern collisions with vehicles on the ground (33.2%), followed by collisions with standing (21.8%) and moving (20.2%) aircraft on the ground. The majority of these three event types occurred during the taxi flight phase.

3.2.3 Fatalities

There were 27 (14%) fatal ATM related accidents recorded in the sample with a total of 873 fatalities. In total there were 613 fatal accidents that fulfilled all criteria of section 2.3 with the exception of criterion 6. Hence the share of ATM related fatal accidents is 4.4%[13].

Figure 4 shows the number of fatal ATM related accidents with the event type. The distribution of fatalities with the event type is shown in Figure 5. The majority of the fatalities were caused by mid-airs (71 %). The wake vortex encounter event type is the only one in which there were no fatalities reported[14].

3.2.4 Accident data by world region

It is known from statistical data that North American and Western European operators have a significantly better safety performance than operators from other regions[15]. Because the present study is concerned with ATM related accidents, a sub-division by operator region is not useful. Instead a sub-division is made by world region itself because of the differences in ATM standards and quality between the different world regions. In Figure 6 the number of accidents by world region is shown. The number of accidents is not a very useful safety metric but is given here for the sake of completeness. Number of accidents is more meaningful when it is combined with the corresponding exposure data. This is discussed in section 3.3.

3.3 Estimation of accident rates

The estimation of ATM related accident rates was the prime objective of this study. The accident rate was calculated using a maximum likelihood estimator (number of accidents

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[11] Accident that was related to e.g. the failure or incorrect functioning of landing aids.

[12] One flight consists of one takeoff and one landing. Therefore one flight is equal to two movements.

[13] This number does not necessarily correspond with the share of *causal/contributing* factors presented in studies such as "Civil Aviation Safety Statistical Summary - World-wide commercial operators 1980-1999", prepared by NLR, published by the Dutch Civil Aviation Authorities NLA, 2000 or in other similar studies.

[14] During the considered time frame (1980-1999) three wake vortex related accidents have been recorded with fatal injuries to the occupants. Two of these accidents occurred with a B757 as leading aircraft and business jets as following aircraft. These accidents occurred in 1992 and 1993. In the present study accidents with business jets were excluded from the analysis. Note that in 1996 the Federal Aviation Administration (FAA) implemented new aircraft separation standards for the B757 following these accidents. In the third fatal accident due to a wake vortex, a Yakolev YAK-40 was involved. This is a Russian-built aircraft. These types of aircraft were excluded from the present analysis (see section 2.3).

[15] See for instance: "Civil Aviation Safety Statistical Summary - World-wide commercial operators 1980-1999", prepared by NLR, published by the Dutch Civil Aviation Authorities NLA, 2000.

divided by the number of flights[16]). In the next sections several accident rates are presented and discussed.

3.3.1 Overall ATM related accident rate

The accident rate per region for all flight phases and event types is given in Figure 7, including the 95% confidence intervals. The overall ATM related accident rate of 0.46 per million flights for all regions is also shown in this figure for comparison. A number of observations can be made from Figure 7. First there is apparently not much difference among the accident rates per region. Tentatively it can be expected that regions with poor ATM infrastructures (e.g. Africa) would have higher accident rates than for instance North America of Western Europe. A number of explanations can be given why the accident rates appear to be the same for each region[17].

- First a large number of the ATM related accidents that occurred in North America and Western Europe involved collisions in the taxiing to/from runway flight phase. Such occurrences are more likely to take place at large airports with significant number of ground movements. Such airports can especially be found in North America and Western Europe. A useful parameter to confirm this is the average number of taxiways per airport in the different world regions. A high average is an indication of significant ground movement activity. In table 1 an overview is given of the average number of taxiways per airport by world region. It is clearly shown that a difference exists among the world regions in the number of taxiways, which is an indication of the number of ground movements. This difference will be even higher when only the larger airports in North America and Western Europe are considered.

- Secondly the confidence intervals of the accident rates for North America and Western Europe are relatively much smaller than those of other regions. This means that the accuracy of the estimated accident rates is less for the other regions compared to the accident rates estimated for North America and Western Europe.

In the remainder of this report accident rates will be calculated for the regions North America and Western Europe combined. These regions have a comparable ATM infrastructure and the same mix of operators. Accident rates for other regions will be presented for completeness and not necessarily for comparison.

3.3.2 Accident rates by event type

Figure 8 shows the accident rate per event type, including the 95% confidence intervals. The "collision with vehicle" has the highest rate for the North America - Western Europe region. The landing aids related accident rate for the North America - Western Europe region is low and significantly less than for the other regions. This could be an indication of the quality and reliability of the landing aids equipment at the airports located in the North America and Western Europe. The fact that the North America -Western Europe region has a higher wake vortex accident rate is likely caused by the high traffic density on the airports and the associated minimum spacing used to obtain sufficient capacity.

3.3.3 Accident rates by flight phase

In Figure 9 the accident rate by flight phase is shown. The taxi phase is by far the most critical followed by the approach and en route phase.

[16] This estimate is subject to chance fluctuations in the population from which the observations are taken and can therefore never be exact. To provide an indication of the variability contained in the estimate a confidence interval can be calculated. The confidence interval gives a range of values around the estimate where it is expected that the "true" (population) probability is located (with a given level of certainty). For this study a 95% level of certainty is applied to calculate the confidence intervals. The calculation is in accordance with NEN 1047, "Confidence interval for one probability", using the "exact" method based on a F-distribution.

[17] Reporting bias in safety related events is a known factor in non-western regions. However, the type occurrences analysed in this study are believed to be less influenced by reporting biases than for instance minor incident type of events.

4 Trends in ATM related accidents

All the data discussed so far referred to the full time frame 1980-1999. A potential trend in the ATM share of accidents was not considered. To see whether there was a trend in the data an analysis was made of the ATM share in the overall number of accidents. There were 2340 accidents in total that fulfilled all criteria of section 2.3 except for criterion 6 which is specifically valid for ATM related accidents. To avoid large fluctuations due to chance in the data, 3-year blocks were used instead of single year observations. The results are shown in Figure 10. The data do not show a systematic up- or down-going trend in the ATM share of accidents in the studied period 1980-1999. The variations in each 3-year block of data are well within the 95% accuracy of the estimated relative share.
A similar trend analysis was conducted for the ATM share in fatal accidents. In total there were 613 fatal accidents that fulfilled all criteria of section 2.3 except criterion 6. The result of the trend analysis is shown in Figure 11. Again the data do not show a systematic up- or down-going trend in the ATM share in the studied period 1980-1999.

5 Final remarks

The following remarks are made in the relation to the presented results:

- The accident types considered in the present study are not necessarily caused by ATM[18]. However they can be related to the ATM system in general. The results of the present study are therefore more significant when considering the overall ATM system. It is for instance the responsibility of the ATM system to avoid mid-air collisions with aircraft[19]. However, a collision could be caused by a pilot error only. Although this accident is not ATM caused it does fall within the context of the accidents considered in this study.

- The EuroControl study (mentioned in the introduction of this paper) presented accident rate information that cannot directly be compared to the accident rates of the present study. The EuroControl study considered aircraft and helicopters with a maximum takeoff weight of greater than 2,250 kg. The present study only considered fixed wing aircraft with a takeoff weight of 5,670 kg or higher. Other selection criteria applied by EuroControl were not clear. From the information provided in the EuroControl study it can be concluded that business jets were included whereas the present study excluded these type of aircraft. The same is likely for military aircraft since these are not excluded from the exposure data used in the EuroControl study. It appears that EuroControl used only one accident data source (ICAO ADREP). This source was also one of the data sources used in the present study. However, during the data collection process it became clear that ADREP did not cover all accidents that have occurred. Experience from the present and earlier studies indicated that approximately 85% of all accidents are recorded in ADREP. It is not unlikely that other selection criteria applied in the present study also do not match with the EuroControl selection criteria.

- Collisions with vehicles are the most frequent ATM related accident types found (see Figure 3). The number of fatalities related to these accidents is very low (see Figure 4). However, the vehicles involved tend to cause sufficient damage to the aircraft for selection criterion 1b to be fulfilled.

- All presented rates are per flight. However, it can be argued that one flight has two taxi operations. Therefore when looking at the risk of ground events *per taxi operation* it should be based on a denominator that is *twice* the number of *flights*. For reason of consistency the accident rates of all event types analysed in this report are based on the number of *flights* only as denominator.

[18] The overall risk of an accident is normally the result of many individual and interrelating factors. An accident that has ATM as the causal factor will in general have other causal factors as well.

[19] See e.g. "Rules of the Air and Air Traffic Services", ICAO DOC 4444-RAC/501, 1999.

6 Summary of important results

- In total 193 ATM related accidents were identified for the period 1980-1999 worldwide,
- ATM related accidents have a share of 8% in all accidents,
- ATM related accidents have a share of more than 4% in all fatal accidents,
- Collisions and near collisions between two airborne aircraft cause the majority of the number of onboard fatalities in ATM related accidents,
- The overall worldwide ATM related accident rate is 0.46 per million flights,
- No systematic trend was found in the share of ATM related accidents for the studied period 1980-1999.

7 Recommendations

- It is recommended to conduct a study into accidents in which ATM was a causal or contributing factor.

Table 1: Average number of taxiways by world region.*

Region	Average number of taxiways per airport
AFRICA	5
ASIA	8
AUSTRALIA / PACIFIC	8
CENTRAL/SOUTH AMERICA	6
E-EUROPE	6
MIDDLE-EAST	6
NORTH-AMERICA	20
W-EUROPE	15

*Source: NLR Air Safety Database

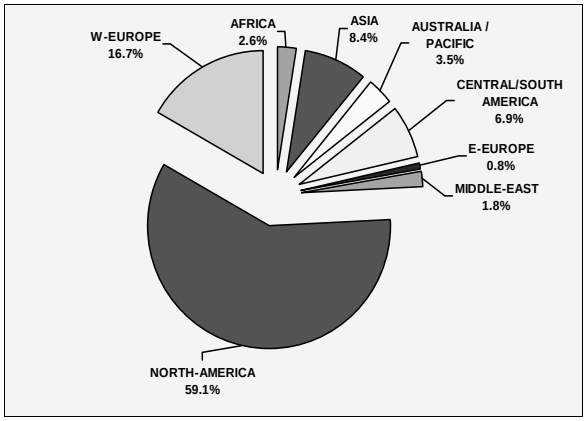

Figure 1: Distribution of flight exposure by world region.

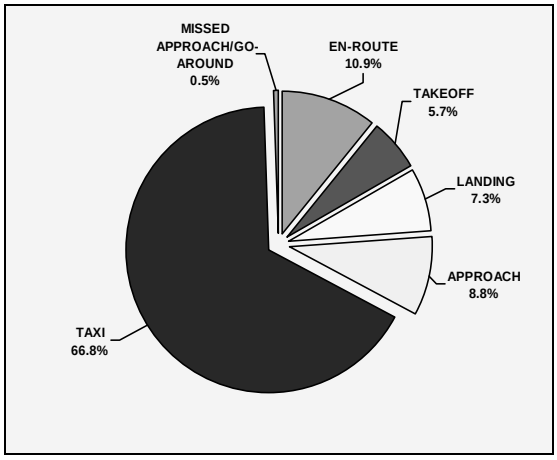

Figure 2: Distribution by flight phase.

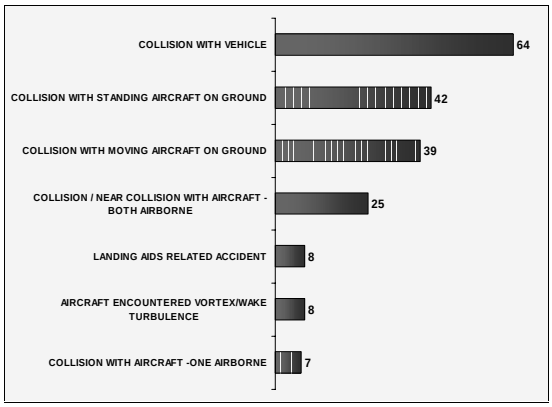

Figure 3: Frequency of event types in the accident sample.

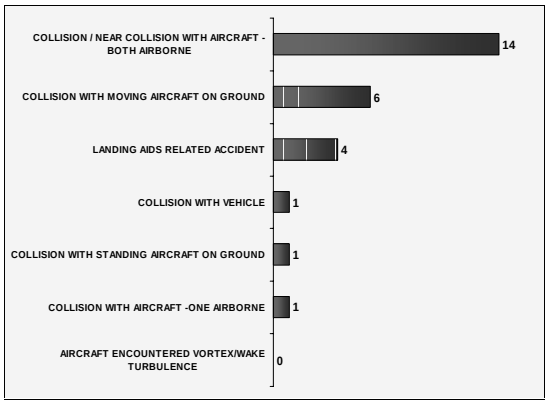

Figure 4: Number of fatal ATM related accidents by event type.

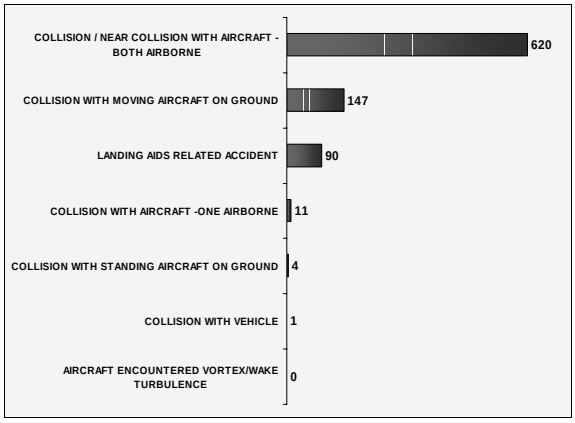

Figure 5: Distribution of total number of fatalities with event type.

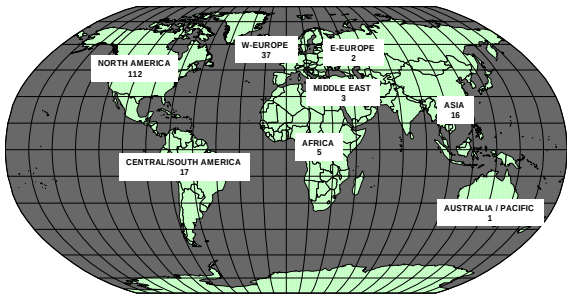

Figure 6: ATM related accident frequency by world region.

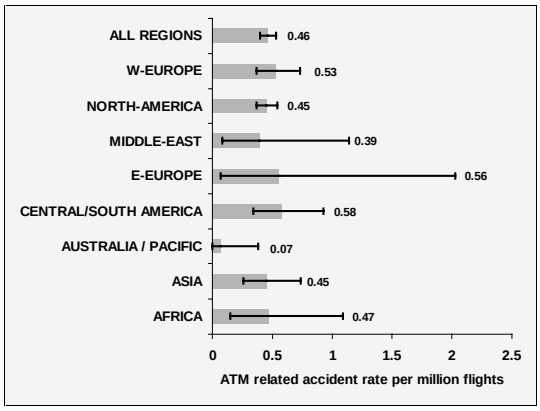

Figure 7: ATM related accident rates by region (all flight phases and event types).

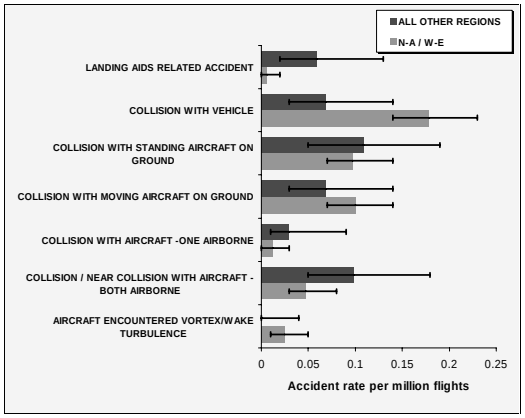

Figure 8: ATM related accident rate by event type.

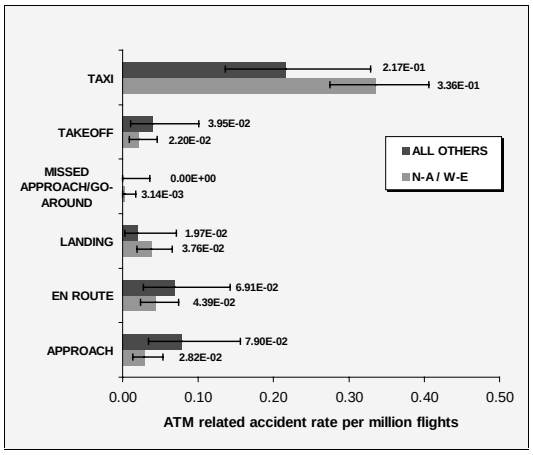

Figure 9: ATM related accident rate by flight phase.

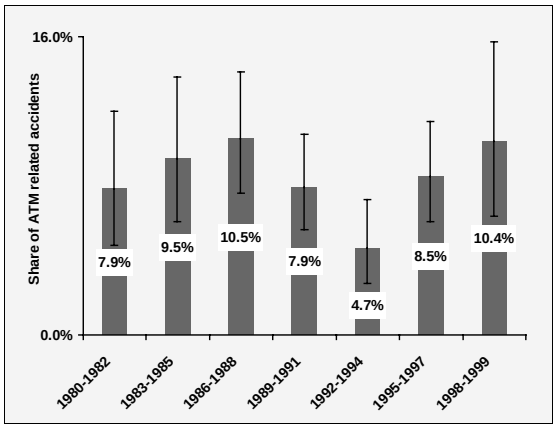

Figure 10: Trend analysis of ATM accident share (all regions).

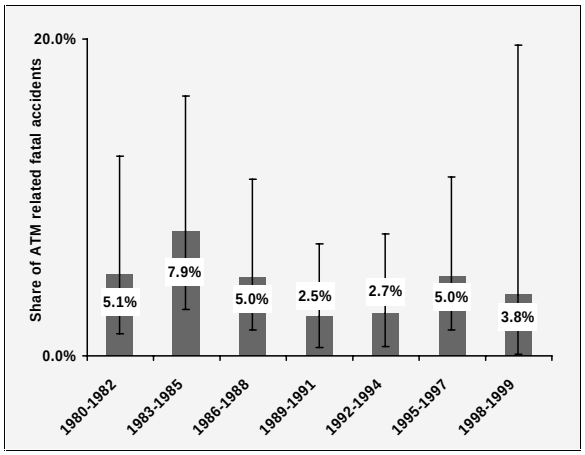

Figure 11: Trend analysis of ATM fatal accident share (all regions).

Author biography

Gerard van Es is a research engineer working for the flight testing and safety department at the National Aerospace Laboratory NLR, the Netherlands. He has been involved in numerous aviation safety studies. He is also involved in flight data monitoring, aircraft accident/incident investigation, and flight operational issues. He is a member of the CAST/ICAO common taxonomy team and of the JAA performance sub-committee on contaminated runway operations.