# E

# APPENDIX E:

# EXAMPLES OF DERIVATION OF SAFETY TARGETS FOR NAV APPLICATION - METHODOLOGY

# 0 EXECUTIVE SUMMARY

## Introduction

A number of implementation projects within the Navigation Domain have had difficulty in selecting suitable TLSs for their safety assessments. It is understood that these difficulties apply more widely in EATM and indeed outside EUROCONTROL. At the root of these difficulties lie a number of factors such as the difficulty in establishing a comprehensive and unambiguous definition of “ATM” and “ATM direct cause of accidents” (as used in ESARR4) or that projects nominally labelled as “ATM” projects have effects on airworthiness or other areas that lie outside the traditional boundary of ATM.

Thus this document proposes a method for developing TLSs for a full matrix of accident categories and flight phases. These TLSs cover all causes of accidents (Severity Class 1 events - SC1) within these categories. If a project wants to concentrate on ATM specific causes of risk, a method for further partitioning of these TLSs is proposed.

The methodology still needs some additional refinement but it constitutes the first step for deriving systematically suitable and coherent TLSs based on Severity Class 1 events for various Navigation Domain implementations.

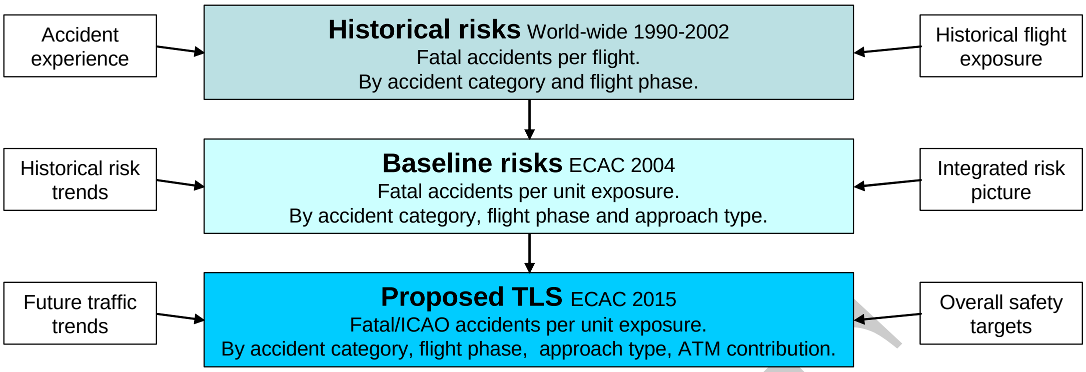
In addition, this methodology needs to be validated prior to its application to the various Navigation Domain implementations. A list of points for discussion is provided in section 8 to facilitate the validation process of the proposed methodology.

In the case that the methodology is approved, further steps are foreseen in order to produce estimates for lower Severity Classifications.

## Proposed methodology

The TLS development method (Figure 1) begins with analysis of the historical risks among a suitable dataset of aviation accidents. To illustrate the methodology a set of fatal accidents on large Western commercial jets world-wide during 1990-2002 has been chosen for the purpose.

**Figure 1 Overview of Proposed Method for TLS Development**




These historical risks can be developed into baseline risk estimates through consideration of historical trends to the year 2004. Where accident experience is insufficient to give risks for certain combinations of accident categories, flight phases and approach types, other risk estimates can be used, such as the analysis of precursor incidents in the ATM Integrated Risk Picture report[1] (Ref 4).

Suitable TLSs are proposed based on the selected dataset for Western commercial jets worldwide that will ensure that the overall safety target (i.e. no increase in numbers of accidents) is maintained despite anticipated future traffic growth. TLSs can be developed for a suitable time horizon such as the year 2015.

Finally, an approach based on the IRP baseline results for estimating the ATM contribution has been proposed. This approach has been applied for illustrative purposes to the derived TLSs for 2015 from the selected dataset. The result is a value of $2.5 \times 10^{-8}$ per flight hour, which is higher than the ESARR4 target but of the same order of magnitude.

[1] The Integrated Risk Picture report is a Eurocontrol initiative that intends to show the relative safety priorities in the gate-to-gate ATM cycle. The main output of this report is a risk model representing the risks of aviation accidents, with particular emphasis on ATM contributions.

# 1 INTRODUCTION

## 1.1 Scope

In this report, a method is proposed for developing Target Levels of Safety (TLSs) in a systematic way from available accident data and risk estimates, so as to provide a consistent set of TLSs for various applications in the Navigation Domain. This document is limited to Severity Class 1 (SC1) events. This method may also be relevant to ATM projects outside the Navigation Domain.

During the RTF/29 meeting it was proposed that a distinction between "design target" and "Annex 11 tolerable level of safety" should be made. A design target is an objective given *a priori* for designing a system with the best possible practices. In this sense, the TLS can be considered as a "design target".

Rather than entering into a conceptual discussion of what a TLS is, this Annex intends simply to provide a statistical analysis of worldwide accident data as an additional element and potential contribution to future safety assessments. The correct application of any derived value following the proposed methodology into a specific safety assessment is the responsibility of the project manager in coordination with the safety manager. The reason is that these values might or might not be used in the elaboration of Navigation Domain safety assessments depending on the needs identified in the safety assessment process and specially the applied risk classification scheme compliant with ESARR4.

## 1.2 Background

A number of implementation projects within the Navigation Domain have had difficulty in selecting suitable TLSs for their safety assessments. It is understood that these difficulties apply more widely in EATM and indeed outside EUROCONTROL. At the root of these difficulties lie a number of factors:

- While the projects may nominally be labelled “ATM” projects, they can have effects on flightdeck safety, airworthiness and other areas that lie outside the traditional boundary of ATM.

- Defining “ATM” and “ATM direct cause of accidents” (as used in ESARR4) is surprisingly difficult to do in a comprehensive, unambiguous manner. The boundaries of ATM are not always clear or are interpreted differently by various groups and may change significantly in the future.

- There are current TLSs that cover more than traditional ATM causes, e.g. ICAO’s mid-air en-route collision target of 5 x $10^{-9}$ fatal accidents per flight hour per dimension. However, when one considers the full matrix of accident categories (mid-air collision, CFIT, runway collisions etc.) and flight phases relevant to ATM projects, it becomes clear that there are many gaps and inconsistencies in the current set of TLSs (Ref 1).

This document presents a systematic way to develop TLSs from available accident data and risk estimates, so as to provide a consistent set for various applications in the Navigation Domain and beyond.

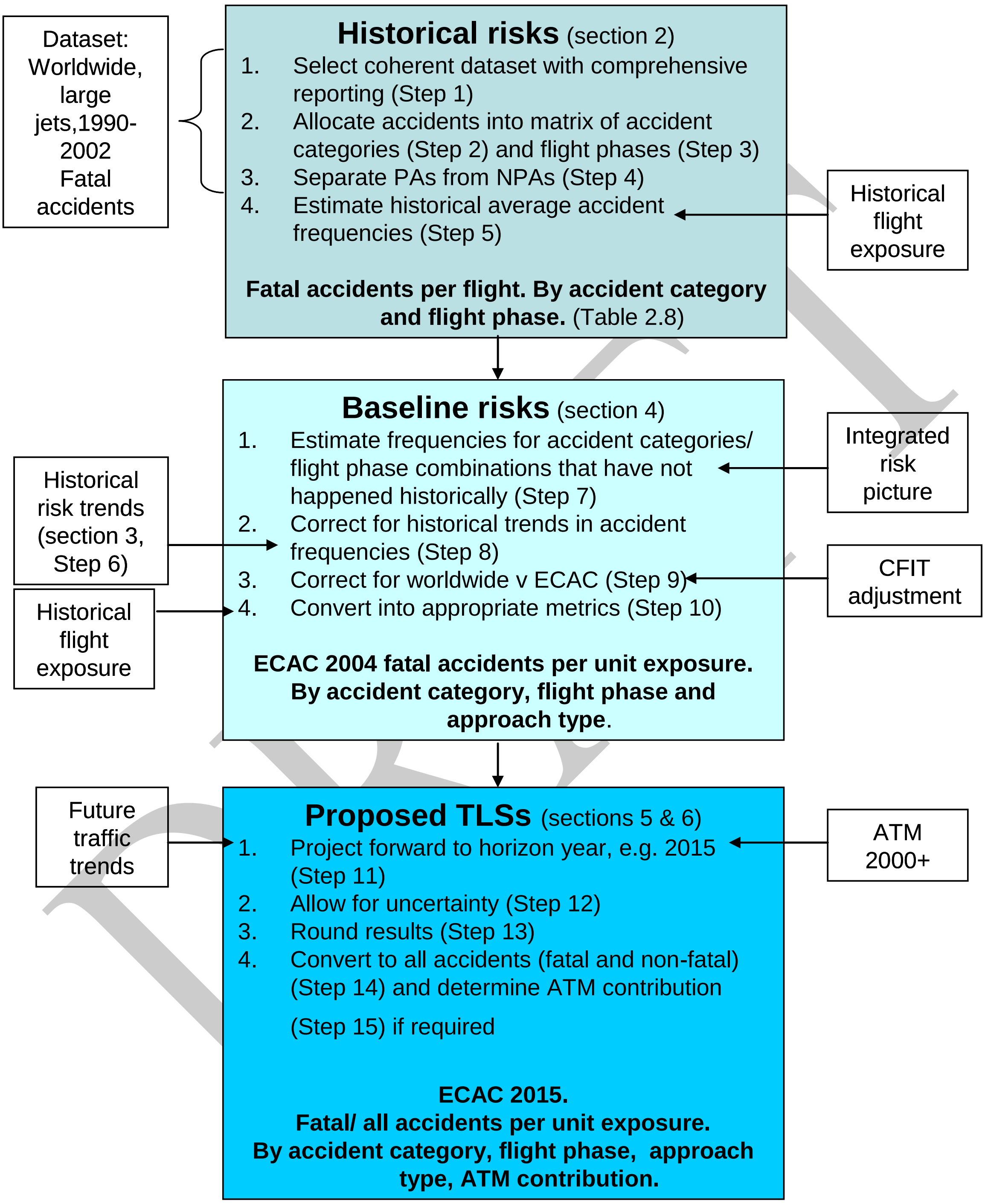
## 1.3 Document Structure

The report addresses the following key steps:

- Analysis of historical accident rates in a selected dataset (Section 2).
- Analysis of historical trends in accident frequencies (Section 3).
- An approach to estimating baseline accident risks in 2004, making allowance for trends and limitations in the historical dataset (Section 4).
- Projection of risk targets to a horizon year (e.g. 2015) to form suitable TLSs (Section 5).
- An approach to estimating the contribution from ATM direct causes (Section 6).
- A list of assumptions made (Section 7).
- Discussion points (Section 8).
- A list of references (Section 9).

These steps are detailed in the flowchart in Figure 1.1 below.

**Figure 1.1 Flowchart of Key Steps**



# 2 REVIEW OF HISTORICAL PERFORMANCE

## 2.1 Outline of Approach

The review of historical accident rates involves the following key steps:

- Selection of a coherent dataset, with comprehensive reporting of all relevant accidents among a defined population (Step 1).
- Allocation of accidents into a matrix of flight phases (Step 2) and accident categories relevant to the NAV domain (Step 3).
- Separation of precision approaches from non-precision approaches (Step 4).
- Estimation of historical average accident frequencies (Step 5).

These steps are now discussed in turn.

## 2.2 Choice of Dataset (Step 1)

### 2.2.1 Overview

A suitable dataset for estimating accident frequencies must have a complete set of accidents occurring among a defined population. The dataset should be as large as possible, but should also cover operations that are as homogenous as possible. Apportionment into different accident types usually requires a dataset that describes each accident individually, rather than simply providing statistical analysis. In practice, it is the availability of population exposure data that most severely limits the choice.

Sources of data recommended in this step are Boeing annual *Statistical Summary of World Jet Airplane Accidents* (Ref 2) and Airclaims World *Aircraft Accident Summary* (Ref 3).

Important issues to take into account in this step are:

- Exclusion of specific aircraft types (e.g.. piston engine aircraft) and certain flights (e.g. experimental test flights).
- Identification of fatal accidents. Fatal accidents are defined as those causing at least one death within 30 days of the accident. This includes deaths in accidents involving the aircraft, caused by the aircraft, or personal accidents occurring on-board, but excludes health effects or deaths from self-inflicted injuries. It includes deaths among passengers, crew, people on other aircraft, airport workers and other members of the public outside the airport, but excludes stowaways.
- Counting of fatal accident *involvements* in consistency with normal aviation practice for mid-air, runway and taxiway collisions. This method consists in identifying and counting how many of the two aircraft *involved* in the identified fatal accidents are in the list of selected aircraft types. Hence any collision involving two such selected

aircraft types would be counted as two fatal accident *involvements.* In the case that only one such aircraft is involved, one fatal accident *involvement* will be counted. This is appropriate for any TLS based on the accident frequency using metrics such as collision involvements per flight or per flight hour.

### 2.2.2 Example of Dataset (1990- 2002)

In order to illustrate the proposed methodology, an accident dataset has been chosen comprising a set of fatal accidents on large Western commercial jets, world-wide, during 1990-2002. Flight exposure for these aircraft has been supplied by Boeing, and is the same as used in their annual *Statistical Summary of World Jet Airplane Accidents* (Ref 2). Accidents have been obtained primarily from the Airclaims *World Aircraft Accident Summary* (Ref 3), but checked using data from Boeing and the Aviation Safety Network (http://aviation-safety.net/index.php).

Selection criteria for the dataset are explained as follows:

- The time period 1990-2002 has been selected as giving a reasonable balance between dataset size and relevance of aircraft and flight safety practices.
- Large jets are those over 27 tonnes (60,000 lb) maximum gross weight. This includes types such as F-28 and RJ-70, and excludes Bombardier CRJ and Embraer ERJ as well as all turboprops and piston-engine aircraft.
- Western jets exclude those manufactured by the CIS/Soviet Union.
- Commercial aircraft are defined as excluding commercial types in military service. Passenger and cargo services are included, together with ferry, positioning, training, demonstration and maintenance test flights. Experimental test flights are excluded, as they are not considered representative of in-service risks.
- Fatal accidents are identified according to the ICAO definition.
- In the case of collisions, accident *involvements* are counted, for consistency with normal aviation practice. Thus, where two large Western commercial jets collided (Detroit, 3 Dec 90) is counted as two fatal accident involvements. Cases of collision involving a large Western commercial jet and another aircraft are included as a single involvement. The three cases where the fatalities all occurred on the other aircraft (Charles de Gaulle, 25 May 00; St Louis, 22 Nov 94; Atlanta, 18 Jan 90) are included in this way as the *accident* was fatal. The effect on the results if they were excluded could be considered as a sensitivity test.

The resulting dataset consists of 129 fatal accidents on large Western commercial jets during 1990-2002. Breakdowns of this total are provided in the Integrated Risk Picture (IRP) baseline report for 2004 (Ref 4). Accident categories relevant for the NAV domain are analysed in the following sections.

## 2.3 Accident Categories (Step 2)

### 2.3.1 Overview

The main accident categories relevant for the NAV domain are:

- Mid-air collision
- Controlled flight into terrain (CFIT)
- Landing accident

In addition, the following accident categories are of interest for ATM in general, and may be relevant for the NAV domain:

- Wake turbulence accident
- Runway collision
- Taxiway collision

The above accident categories (except landing accidents) have already been analysed as part of the IRP 2004 baseline report (Ref. 4).

The following definitions are provided to clarify what events are covered by these accident categories:

- **Mid-air collision** is where two aircraft come into contact with each other while both are airborne. This includes any in-flight collision between an aircraft and another flying vehicle, whether commercial, military or general aviation, including microlights, hang-gliders, gliders and balloons. It excludes collisions caused by hostile attack (i.e. terrorism, hijack, sabotage or military attack) but includes collisions caused in all other ways. This is consistent with the CAST/ICAO common terminology for mid-air collision (Ref 5).

- **Controlled flight into terrain (CFIT)** is an in-flight collision with terrain, water or another obstacle without prior loss of control. This excludes intentional flight into terrain/buildings due to hostile attack. It also excludes cases where the aircraft lands short or to one side of the runway (covered under landing accidents). It includes cases where the CFIT follows or is caused by an in-flight disruption such as a fire or engine failure, provided that flight control is maintained. This is consistent with the CAST/ICAO occurrence category “controlled flight into or toward terrain”.

- **Landing accidents** include all types of accidents during the landing phase of flight (see below), other than collision. This includes abnormal runway contacts (e.g. hard landings, gear-up landings), loss of control on the runway (e.g. due to wind-shear or surface contamination), runway incursions (e.g. by animals, vehicles or people, but not aircraft), runway excursions (e.g. veer-off, overrun), off-runway touchdown (e.g. undershoot, overshoot and offside touchdown). It includes external causes (e.g. snow/ice/rain and wind-shear), technical causes (e.g. gear failure) and human causes (e.g. flight crew misjudgements). It includes cases where the landing accident follows or is caused by an in-flight disruption such as a fire or engine failure, provided that sufficient control is maintained to attempt a normal or emergency landing. It includes cases where the landing accident is followed by collision with another aircraft outside the runway. There is no specific CAST/ICAO equivalent for this term.

- **Wake turbulence accidents** are where the aircraft encounters wake turbulence from a preceding aircraft. This is important only if the encounter is sufficiently severe to cause consequences such as loss of control, landing accident, structural accident or personal accident on board. This occurrence would normally be considered a cause of such events, rather than an accident category in its own right. However, its potential importance for ATM justifies identifying it in this way, otherwise it would be concealed among many less relevant causes of these events. There is no precise CAST/ICAO equivalent for this term, as it is a sub-set of the occurrence category "turbulence encounter".

- **Runway collision** is where two aircraft come into contact with each other on a runway, including cases where one aircraft is on the runway and the other is in flight close to the ground. It excludes collisions caused by hostile attack, and excludes landing/take-off accidents that result in collision with another aircraft outside the runway. It excludes cases where the aircraft collides with people, animals, vehicles or other objects on the runway (these should be covered in future TLSs). There is no precise CAST/ICAO equivalent for this term, but it is a consequence of the occurrence category "runway incursion - aircraft".

- **Taxiway collision** is where two aircraft come into contact with each other on the airport manoeuvring area, i.e. other than the runway. This includes cases where an aircraft is parked, being pushed back from the stand, under tow, or taxi up to the point of runway entry. It excludes collisions caused by hostile attack, and excludes landing/take-off accidents that result in collision with another aircraft outside the runway. It excludes cases where aircraft collide with people, animals, vehicles or other objects on the taxiway (these should be covered in future TLSs). This corresponds to the CAST/ICAO occurrence category "ground collision".

It is important to note that the accident categories have to be selected in accordance with the nature of the proposed safety assessments. The categories above are the ones considered of most relevant to NAV projects.

After a relevant set of accident categories has been selected, the accident dataset has to be split into these accident categories. For that purpose, the information provided by Airclaims and the Aviation Safety Network, or other authoritative descriptions, is critical.

As for step 1, in the case of mid-air, runway and taxiway collisions, the number of selected aircraft types that were *involved* in every collision has to be clearly identified and counted accordingly.

### 2.3.2 Application of Step 2 to the proposed dataset

Concerning the proposed dataset, fatal accidents have been split in the proposed accident categories following the information provided in the abovementioned sources. Furthermore, only the number of *involvements* of large Western commercial jets has been considered for the derivation of the TLS. Any collision involving two such aircraft is counted as *two involvements*, in the case that only one such aircraft is involved, *one involvement* is counted.

Therefore, the numbers of fatal accidents on large Western commercial jets during 1990-2002 in the above accident categories are:

- 7 fatal runway collision involvements (of which 3 had fatalities on board)
- 3 fatal mid-air collision involvements (all 3 had fatalities on board)
- 1 fatal wake turbulence accident
- 34 fatal CFITs
- 20 fatal landing accidents
- 0 fatal taxiway collision involvements

This set of 65 accidents excludes loss of control, single-aircraft take-off accidents, structural accidents, fire/explosion, hostile attack and personal accidents, which contribute to the full set of 129 accidents (Section 2) but are not significantly influenced by ATM.

The individual events are listed in Tables 2.1 to 2.5 below.

**Table 2.1 Fatal Runway Collision Involvements**

| DATE | TYPE | LOCATION | FLIGHT PHASE | NOTES |
|---|---|---|---|---|
| 18-Jan-90 | 727 | Atlanta, GA, USA | Landing | Fatalities on other aircraft |
| 03-Dec-90 | DC9 | Detroit, MI, USA | Taxi | |
| 03-Dec-90 | 727 | Detroit, MI, USA | Take-off | Fatalities on other aircraft |
| 01-Feb-91 | 737-300 | Los Angeles, CA, USA | Landing | ATM causes |
| 22-Nov-94 | MD82 | St Louis, MO, USA | Take-off | Fatalities on other aircraft |
| 25-May-00 | MD83 | Charles de Gaulle, France | Take-off | Fatalities on other aircraft |
| 08-Oct-01 | MD87 | Milan, Italy | Take-off | |

**Table 2.2 Fatal Mid-Air Collision Involvements**

| DATE | TYPE | LOCATION | FLIGHT PHASE | NOTES |
|---|---|---|---|---|
| 22-Dec-92 | 727 | Tripoli, Libya | Arrival (intermediate app) | Flight phase varies in different sources [**A1**][2] |
| 12-Nov-96 | 747-100 | Delhi, India | Departure (climb to cruise) | |
| 01-Jul-02 | B757 | Uberlingen, Germany | En-route | |

**Table 2.3 Fatal Wake Turbulence Accidents**

| DATE | TYPE | LOCATION | FLIGHT PHASE | NOTES |
|---|---|---|---|---|
| 12-Nov-01 | A300-600 | Queens, NY, USA | Departure (climb to cruise) | |

[2] Assumptions in text are referenced as A1, A2 etc and detailed in Annex I

**Table 2.4 Fatal CFIT Accidents**

| DATE | TYPE | LOCATION | FLIGHT PHASE | APPROACH |
|---|---|---|---|---|
| 14-Feb-90 | A320 | Bangalore, India | Final approach | NPA |
| 14-Nov-90 | DC9 | Zurich, Switzerland | Final approach | Precision[3] |
| 04-Dec-90 | 707 | Nairobi, Kenya | Final (missed approach) | Precision |
| 05-Mar-91 | DC9 | Trujillo, Venezuela | Arrival (initial approach) | NPA |
| 16-Aug-91 | 737-200 | Imphal, India | Arrival (intermediate app) | Precision |
| 20-Jan-92 | A320 | Strasbourg, France | Final approach | NPA |
| 24-Mar-92 | 707 | Athens, Greece | Final approach | NPA |
| 22-Jun-92 | 737-200 | Cruzeiro do Sul, Brazil | Arrival (intermediate app) | NPA |
| 31-Jul-92 | A310 | Kathmandu, Nepal | Final (missed approach) | NPA |
| 28-Sep-92 | A300 | Kathmandu, Nepal | Final approach | NPA |
| 19-May-93 | 727 | Medellin, Colombia | Arrival (initial approach) | NPA |
| 01-Jul-93 | F28 | Sorong, Indonesia | Final approach | NPA |
| 26-Jul-93 | 737-500 | Mokpo, S Korea | Final approach | NPA |
| 13-Nov-93 | MD82 | Xinjang, China | Final approach | Precision |
| 21-Dec-94 | 737-200 | Coventry, UK | Final approach | NPA |
| 29-Dec-94 | 737-400 | Van, Turkey | Final approach | NPA |
| 11-Jan-95 | DC9 | Cartagena, Colombia | Arrival (initial approach) | NPA |
| 09-Aug-95 | 737-200 | San Salvador, El Salvador | Arrival (initial approach) | Precision |
| 30-Nov-95 | 707 | Baku, Azerbaijan | Arrival (manoeuvring) | NPA |
| 20-Dec-95 | 757 | Cali, Colombia | Arrival (initial approach) | NPA |
| 29-Feb-96 | 737-200 | Arequipa, Peru | Final approach | NPA |
| 06-Aug-97 | 747-300 | Agana, Guam | Final approach | NPA |
| 26-Sep-97 | A300 | Medan, Indonesia | Arrival (intermediate app) | Precision |
| 02-Feb-98 | DC9 | Mindanao, Philippines | Arrival (initial approach) | NPA |
| 19-Mar-98 | 727 | Kabul, Afghanistan | Arrival (initial approach) | NPA |
| 20-Apr-98 | 727 | Bogota, Colombia | Departure (climb to cruise) | |
| 25-Sep-98 | BAe146 | Melilla, Morocco | Arrival (intermediate app) | NPA |
| 07-Jul-99 | 727 | Kathmandu, Nepal | Departure (climb to cruise) | |
| 19-Apr-00 | B737-200 | Samal Island, Philippines | Final approach | NPA |
| 24-Nov-01 | RJ100 | Zurich, Switzerland | Final approach | NPA |
| 27-Nov-01 | B747-200 | Port Harcourt, Nigeria | Final approach | NPA |
| 28-Jan-02 | B727 | Volcan Cumbal, Colombia | Arrival (intermediate app) | NPA |
| 15-Apr-02 | B767 | Pusan, Korea | Final (missed approach) | NPA |
| 07-May-02 | B737-500 | Tunis, Tunisia | Final approach | NPA |

**Table 2.5 Fatal Landing Accidents**

| DATE | TYPE | LOCATION | FLIGHT PHASE | APPROACH |
|---|---|---|---|---|

[3] Future work could break down precision approaches into CAT I, CAT II, CAT III providing historic data is available. However, overall method needs to be agreed before further sub-division.

| DATE | TYPE | LOCATION | FLIGHT PHASE | APPROACH |
|---|---|---|---|---|
| 20-Feb-91 | BAe146 | Puerto Williams, Chile | Landing | NPA |
| 26-Jun-91 | BAC 1-11 | Sokoto, Nigeria | Landing (emergency) | NPA |
| 21-Dec-92 | DC10 | Faro, Portugal | Landing | NPA |
| 14-Sep-93 | A320 | Warsaw, Poland | Landing | Precision |
| 26-Oct-93 | MD82 | Fujian, China | Landing | NPA |
| 27-Apr-94 | 727 | M'Banza Congo, Angola | Landing (undershot) | NPA |
| 01-Jul-94 | F28 | Tidjikja, Mauritania | Landing | NPA |
| 28-Apr-95 | DC8 | Guatemala City, Guatemala | Landing | NPA |
| 13-Nov-95 | 737-200 | Kaduna, Nigeria | Landing | NPA |
| 23-Oct-96 | 707 | Buenos Aires, Argentina | Landing (undershot) | NPA |
| 14-Feb-97 | 737-200 | Carajas, Brazil | Landing | NPA |
| 08-May-97 | 737-300 | Shenzhen, China | Landing | NPA |
| 29-Jul-97 | BAC 1-11 | Calabar, Nigeria | Landing | NPA |
| 22-Mar-98 | A320 | Bacolod, Philippines | Landing | NPA |
| 01-Jun-99 | MD82 | Little Rock, AR, USA | Landing | Precision |
| 22-Aug-99 | MD11 | Hong Kong | Landing | Precision |
| 21-Dec-99 | DC10 | Guatemala City, Guatemala | Landing | NPA |
| 06-Oct-00 | DC9 | Reynosa, Mexico | Landing | NPA |
| 05-Jan-01 | B727 | Dundo, Angola | Landing | NPA |
| 16-Jan-02 | B737-300 | Yogyakarta, Indonesia | Landing (emergency) | NPA |

## 2.4 Flight Phases (Step 3)

### 2.4.1 Overview

The following flight phases are distinguished for the NAV domain TLS:

- Taxi
- Take-off
- Departure (terminal area)
- En-route
- Arrival (terminal area)
- Final approach
- Landing

The following definitions are used, based on ADREP and CAST/ICAO (Ref 6), adjusted in order to match accident data categorisations used by Airclaims:

- **Taxi** includes push-back, tow and taxi to/from the runway.

- **Take-off** is from runway entry until 1500 ft above the runway or the first power reduction.

- **Departure (terminal area)** is taken to be the “climb to cruise” phase in the ADREP definitions, since the terminal areas are in reality variable in size. Climb to cruise is from 1500 ft above the runway or the first power reduction to the first cruise level.

- **En-route** is from the arrival at initial cruise altitude, including changes of cruise level, and normal descent to the initial approach fix.

- **Arrival (terminal area)** is from the initial approach fix until the point of interception with the final approach. This includes both initial and intermediate approach, and also any holding at arrival and miscellaneous manoeuvres near to the ground.

- **Final approach** is from the point of interception with the final approach (localiser and glideslope for a precision approach, or final track of a visual approach procedure) until landing flare. For present purposes, missed approaches are included in this phase.

- **Landing** is from the flare (transition from nose-down to nose-up attitude just before landing), through touchdown until the aircraft exits the runway or comes to a stop.

There will be cases when the accident category might not fit clearly into these flight phases. This method proposes to categorise it according to the last flight phase in which it was established.

### 2.4.2 Application of Step 3 to the proposed dataset

The accident dataset has been split into flight phases based on the categorisation provided by Airclaims, modified where necessary based on available authoritative descriptions (e.g. detailed descriptions in Aviation Safety Network, reports from NTSB and European accident investigation boards). The numbers of fatal accidents on large Western commercial jets during 1990-2002 in the above flight phases are shown in Table 2.6.

**Table 2.6 Fatal Accident Involvements Broken Down by Flight Phase and Accident Category**

| FLIGHT PHASE | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT | TOTAL |
|---|---|---|---|---|---|---|
| Taxi | 1 | | | | | 1 |
| Take-off | 4 | | | | | 4 |
| Departure | | 1 | 1 | 2 | | 4 |
| En-route | | 1 | 0 | 0 | | 1 |
| Arrival | | 1 | 0 | 13 | | 14 |
| Final approach | | 0 | 0 | 19 | | 19 |
| Landing | 2 | | | | 20 | 22 |
| TOTAL | 7 | 3 | 1 | 34 | 20 | 65 |

Cases that do not fit clearly into these flight phases are categorised according to the last flight phase in which they were established, as follows:

- A CFIT during a low pass for visual inspection of the undercarriage from the ground (30 Nov 95) is categorised as the arrival phase since no final approach was conducted.

- Two cases of CFIT associated with a late turn onto final approach (16 Aug 91 and 22 Jun 92) are categorised as the arrival phase since the final approach was not established.
- Three cases of CFIT associated with a missed approach (4 Dec 90, 31 Jul 92 and 15 Apr 02) are categorised as the final approach phase since a final approach had previously been established.
- Two cases of landing accidents during emergency landing (26 Jun 91 and 16 Jan 02) are categorised as the landing phase.
- Two cases of landing accidents where the aircraft undershot the runway on final approach (27 Apr 94 and 7 May 02) are categorised as the landing phase.

## 2.5 Final Approach into Precision and Non-Precision Approaches (Step 4)

### 2.5.1 Overview

Of relevance to the Navigation Domain is the separation between Precision and Non-Precision Approaches.

A precision approach is defined as a standard instrument approach procedure using a ground-based system in which an electronic glideslope is provided (EATM glossary). Glideslope information may be provided by an instrument or microwave landing system, ILS/ MLS (potentially GBAS in the future), or precision approach radar (PAR).

Non-precision approaches rely on visual identification of the runway markings/lighting, and navigational aids such as non-directional beacon (NDB) and distance measuring equipment (DME). In poor weather, a procedural approach is used, beginning overhead the NDB at the runway threshold, and flying a standard procedure that involves a 180º turn and descent to the minimum descent altitude (MDA), at which a missed approach must be executed if the runway is not visible.

Information from Airclaims, the Aviation Safety Network and other authoritative descriptions can be used as sources to facilitate the classification of the approaches. When no information is available on the accident, additional information on the airport landing infrastructure can be used to identify the likely approach type.

### 2.5.2 Application of Step 4 to the proposed dataset

As proposed in the method, final approaches in the accident dataset have been split into the above types based on Airclaims, the Aviation Safety Network and other authoritative descriptions. Where no information is available on the accident directly, information about the airport from www.landings.com has been used to deduce the likely approach type. The numbers of fatal accidents on large Western commercial jets during 1990-2002 during final approach in the above approach types are shown in Table 2.7.

**Table 2.7 Fatal Accident Involvements Broken Down by Flight Phase, Approach Type and Accident Category**

| FLIGHT PHASE | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT | TOTAL |
|---|---|---|---|---|---|---|
| Taxi | 1 | | | | | 1 |
| Take-off | 4 | | | | | 4 |
| Departure | | 1 | 1 | 2 | | 4 |
| En-route | | 1 | 0 | 0 | | 1 |
| Arrival | | 1 | 0 | 13 | | 14 |
| Final (PA) | | 0 | 0 | 3 | | 3 |
| Final (NPA) | | 0 | 0 | 16 | | 16 |
| Landing (PA) | 1 | | | | 3 | 4 |
| Landing (NPA) | 1 | | | | 17 | 18 |
| TOTAL | 7 | 3 | 1 | 34 | 20 | 65 |

## 2.6 Accident Frequencies (Step 5)

### 2.6.1 Overview

Having considered the split of accidents by accident categories and flight phases it is possible to develop accident frequencies specific to each cell of the matrix.

For that purpose, the number of flights within the selected dataset period of time is used to form the historical accident frequencies. The use of more appropriate metrics for the TLS is considered in Section 4.

Uncertainties can be substantial in these frequencies, since they are usually based on small datasets. A 90% confidence level can be generated extending from a lower (5%) to an upper (95%) confidence level, defined in terms of a chi-square distribution. If the number of failures/ events is 5, the 90% confidence range extends from 0.4 x accident frequency value up to 2 x accident frequency value. In many cases, values are based only on a single event, implying a 90% confidence range of 0.05 to 5 x the accident frequency value.

### 2.6.2 Application of Step 5 to the proposed dataset

The flight exposure by large Western commercial jets world-wide during 1990-2002 has been supplied by Boeing as 207.4 million departures and 378.5 million flight hours. This implies an average of 1.8 hours per flight. The number of flights is used to form the historical accident frequencies as shown in Table 2.8. Only the figures in bold in Table 2.8 are based on more than 5 events.

**Table 2.8 Fatal Accident Involvement Frequencies (per flight) by Flight Phase and Accident Category**

| FLIGHT PHASE | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT | TOTAL |
|---|---|---|---|---|---|---|
| Taxi | 4.8E-09 | | | | | 4.8E-09 |
| Take-off | 1.9E-08 | | | | | 1.9E-08 |
| Departure | | 4.8E-09 | 4.8E-09 | 9.6E-09 | | 1.9E-08 |
| En-route | | 4.8E-09 | 0.0E+00 | 0.0E+00 | | 4.8E-09 |
| Arrival | | 4.8E-09 | 0.0E+00 | **6.3E-08** | | **6.8E-08** |
| Final approach | | 0.0E+00 | 0.0E+00 | **9.2E-08** | | **9.2E-08** |
| Landing | 9.6E-09 | | | | **9.6E-08** | **1.1E-07** |
| TOTAL | **3.4E-08** | 1.4E-08 | 4.8E-09 | **1.6E-07** | **9.6E-08** | **3.1E-07** |

# 3 TREND ANALYSIS (STEP 6)

## 3.1 Outline of Approach

The historic values from an accident dataset need to be trended in order to generate an accurate risk picture for current day operations. This then provides a solid basis for projecting forward into the future.

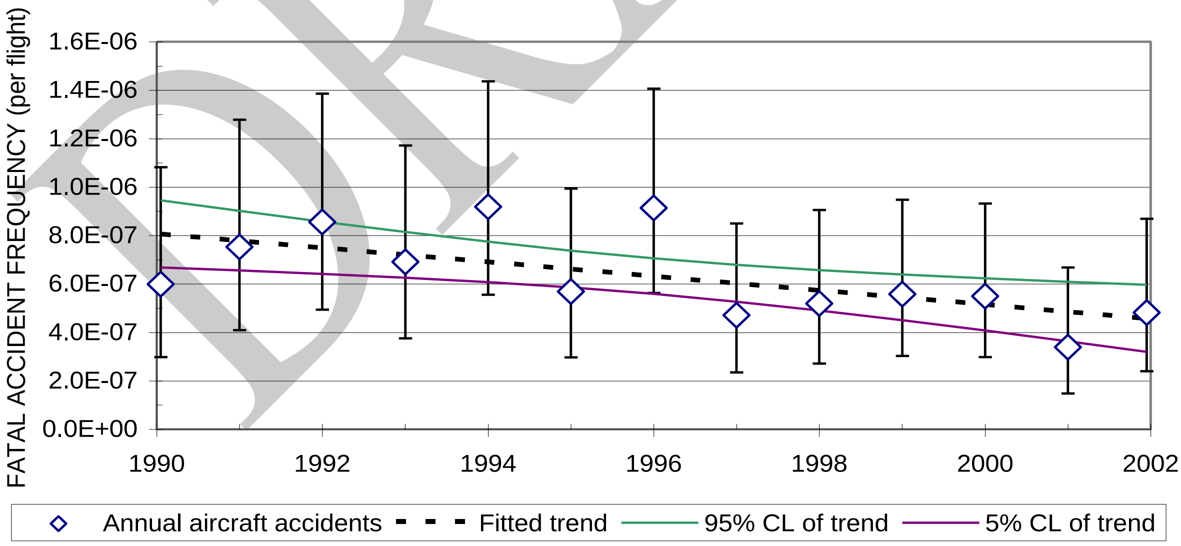
It is first proposed to estimate the overall accident frequency trend with the corresponding 90% confidence limits. A model fitting the trend line will provide the best-estimate underlying frequency in 2004. However, the same trend may not be applicable to all accident categories. Additional fit trends can be produced for the individual categories based either on accident frequencies or accident precursor frequencies.

## 3.2 Application of Step 6 to the proposed dataset

### 3.2.1 Overall Accident Frequency Trend

Figure 3.1 shows the accident frequencies for large Western commercial jets broken down by year of occurrence during 1990-2002. Hostile acts and personal accidents are excluded. Despite the scatter, a downward trend is apparent. The fitted trend indicates an average reduction of approximately 4.5% per year. The plot shows the 90% confidence limits on the fit, which indicate that the downward trend is significant, despite the scatter in the data.

**Figure 3.1 Trend in Overall Worldwide Accident Frequency**

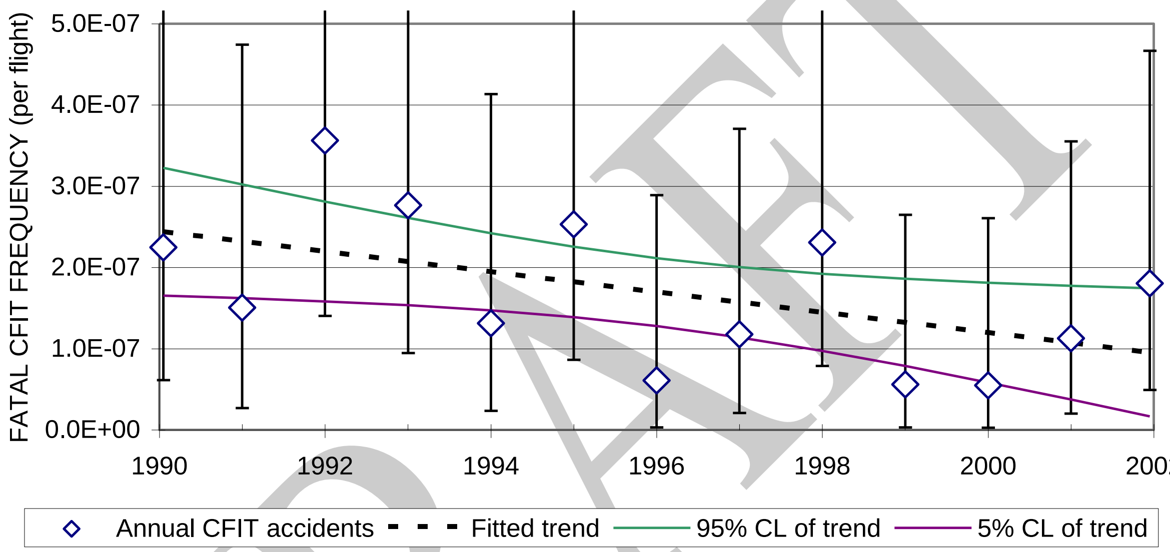



Based on the fitted trend line, the underlying frequency in 2004 was approximately $4.2 \times 10^{-7}$ per flight, which is approximately 69% of the average frequency of $6.2 \times 10^{-7}$ per flight for the period 1990-2002.

### 3.2.2 CFIT Accident Frequency Trend

Figure 3.2 shows the CFIT accident frequencies for large Western commercial jets during 1990-2002. The scatter is much greater than on Figure 3.1, due to the smaller number of events (34 versus 129). The plot shows the frequencies for each year, together with their 90% confidence limits, which clearly show that the year-on-year variations are not significant due to the small numbers of events. A constant frequency would lie within the scatter of the annual values. However, the best fit trend indicates an average reduction of approximately 8% per year. This is not statistically significant (the confidence limits on the trend are omitted for clarity). Nevertheless, it is considered a plausible model of the underlying trend [**A2**].

**Figure 3.2 Trend in Worldwide CFIT Accident Frequency**



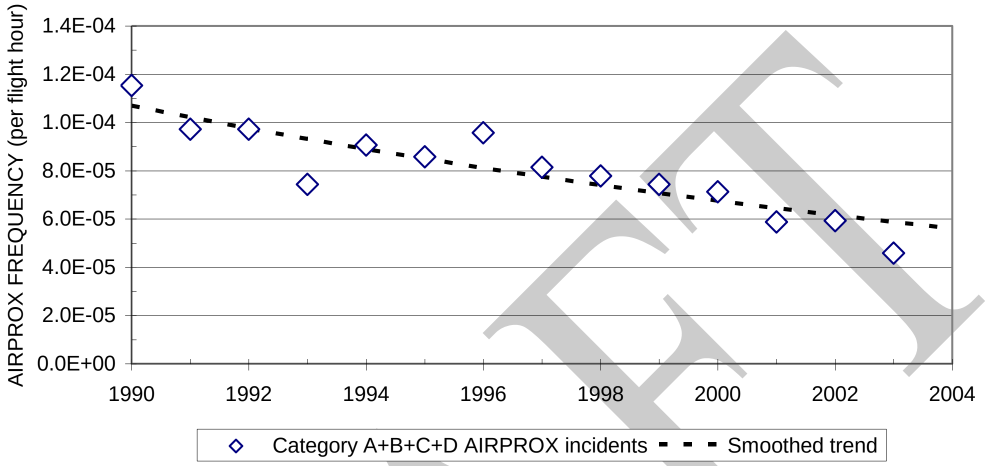

### 3.2.3 AIRPROX Incident Frequency Trend

It is clearly impractical to obtain trends in the other accident categories that are of interest to the NAV domain, because the numbers of events are much smaller than for CFIT. Another approach might be to consider frequencies of incidents that might be the precursors of the accidents. Any trend in these incident frequencies might suggest similar trends in the accident risks.

Figure 3.3 shows the AIRPROX incident frequencies for commercial aircraft in the UK during 1990-2003 (Ref 7). The scatter is much less than on Figure 3.1, due to the larger number of events (1260 versus 129). This large number of events shows a significant trend (the confidence limits on the trend are omitted for clarity), which is exactly consistent with average reduction of 4.5% per year estimated for the overall accident frequency. This is considered a plausible model of the underlying trend for mid-air collision risks based on available data. If additional data is obtained (e.g. from other ECAC states) this could be updated. However, in this document it is fed through into the baseline risk estimates.

There are several possible explanations for the observed trends, including the introduction of ACAS requirements, and a possible change in the categorisation of ACAS-averted events. Investigation of such matters might provide greater insight into the causes of AIRPROX incidents and hence mid-air collision risks. Similar investigations could be made of the effects of other safety nets such as the increasing fitment of GPWS on CFIT risks. In principle, the results could be represented in a causal model (as implemented in the IRP for 2004) and combined to obtain a theoretical representation of the observed overall accident frequency trend. This provides a possible method of obtaining distinct trends for each accident category.

**Figure 3.3 Trend in UK AIRPROX Incident Frequency[4]**






[4] CAT A = Risk of Collision, CAT B = Safety not Assured, CAT C = No Risk of Collision, CAT D = Risk not Determined

# 4 BASELINE RISK ESTIMATES FOR 2004

## 4.1 Outline of Approach

The historical frequencies from Section 2 can be converted into current risk estimates, using 2004 as the baseline year, using the following steps:

- Estimation of accident frequencies for accident category and flight phase combinations that do not appear in the historical record (Step 7).
- Correction for trends in accident frequencies during the historical period (see Section 3) (Step 8).
- Correction for differences between the aircraft types and world-wide operations analysed in the historical data and the types and operations for which the TLS may be applied (Step 9).
- Conversion of the accident frequencies per flight into frequency metrics appropriate for each individual flight stage and approach type (Step 10).

For simplicity, these corrections are all considered to be independent, and hence can be applied in any order.

The steps above would enable estimates to be made for current risk levels for each relevant accident category and flight phase.

## 4.2 Accident involvements - Application of Step 7 to the proposed dataset

Some accident categories (mid-air collision, CFIT, wake turbulence accident) can occur in any flight phase, although some have not occurred in the historical dataset used.

In order to obtain a TLS for all relevant flight phases, the missing frequencies can be estimated from analysis of near-miss incidents (e.g. air proximity incidents, wake turbulence encounters). In the absence of that information, the IRP 2004 baseline provides complementary information that can be used either to estimate the taxiway accident frequency or the flight phase distributions.

### 4.2.1 Taxiway Accident Frequency

In the accident category of taxiway collisions, there have not been any fatal accidents involving large Western commercial jets during 1990-2002. In such cases, it is appropriate to use risk analysis techniques to estimate the risk. This approach was used by the IRP (Ref 4, section VI.4.1.1), which estimated the risk to be equivalent to "0.7" taxiway collision involvements during 1990-2002.

### 4.2.2 Flight Phase Distributions

For the present work, flight phase distributions are obtained from the IRP 2004 baseline (Ref 4, section VI.4.1.1), as shown in Table 4.1.

At present these show no mid-air collisions during final approach, but a larger dataset of UK Airproxs shows 1 out of 27 involvements were on final approach, and hence the value of 4% is adopted for the present work. As more data becomes available, e.g. from other ECAC states, these fractions could be checked.

**Table 4.1 Flight Phases for In-Flight Fatal Accidents and Incidents**

| FLIGHT PHASE | MID-AIR COLLISION | WAKE ACCIDENT |
|---|---|---|
| Departure | 21% | 8% |
| En-route | 36% | 17% |
| Arrival | 39% | 25% |
| Final approach | 4% | 50% |
| TOTAL | 100% | 100% |

The values in Table 4.1 could be used to re-distribute the numbers of mid-air collisions and wake turbulence accidents, as shown in Table 4.2. In the absence of any better data, mid-air collisions and wake accidents are assumed equally likely on precision and non-precision approaches [**A3**], and hence are distributed in the same ratio as approach experience (see below).

**Table 4.2 Estimated Worldwide Fatal Accident Involvements**

**(decimals introduced by adjustments for where we have no historical events, see above)**

| FLIGHT PHASE | TAXIWAY COLLISION | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT |
|---|---|---|---|---|---|---|
| Taxi | 0.7 | 1 | | | | |
| Take-off | | 4 | | | | |
| Departure | | | 0.63 | 0.08 | 2 | |
| En-route | | | 1.08 | 0.17 | 0 | |
| Arrival | | | 1.17 | 0.25 | **13** | |
| Final (PA) | | | 0.11 | 0.46 | 3 | |
| Final (NPA) | | | 0.01 | 0.04 | **16** | |
| Landing (PA) | | 1 | | | | 3 |
| Landing (NPA) | | 1 | | | | **17** |
| TOTAL | 0.7 | **7** | 3 | 1 | **34** | **20** |

## 4.3 Historical Trends – Application of Step 8 to the proposed dataset

Some accident categories have shown distinct declining trends during the period of data collection (Section 3). Hence the current risks are probably lower than the historical averages. It is desirable to reflect these historical trends in the frequencies; otherwise the TLS would form a weak standard for these accident types.

The following historical trends are assumed:

- **Mid-air collision** - reduction at 4.5% per year during 1990-2002 (Section 3).
- **CFIT** - reduction at 8% per year during 1990-2002 (Section 3).
- **Wake turbulence accident** - reduction at 4.5% per year during 1990-2002 (Ref 4).

No trends have yet been demonstrated for the other accident types (Ref 4).

Accumulated trend factors, sufficient to convert the average frequencies for 1990-2002 into frequency estimates for 2004 are $0.955^8 = 0.69$ for mid-air collisions and wake turbulence accidents and $0.92^8 = 0.51$ for CFIT. These are the same as used in the IRP 2004 baseline. In the absence of any better data, they are assumed to be valid for all flight phases and approach types [**A4**].

The adjustment factors are summarised in Table 4.3.

## 4.4 Accident Datasets – Application of Step 9 to the proposed dataset

The chosen accident dataset of world-wide large Western commercial jets (Section 2) does not precisely match the aircraft types for which the TLS will be applied, i.e. all IFR traffic in ECAC. This will include smaller regional and business jets, turboprops, some Eastern-built jets and even some commercial piston-engine aircraft, but will not include operations outside Europe.

Accident frequencies for modern turboprops are estimated to be approximately 20% higher than for jets (Ref 13). Regional jets are likely to be similar, although no data sources are known. Accident frequencies for business jets, Eastern-built jets and piston-engine aircraft are significantly higher, although sources vary. However, these comprise a small fraction of traffic for most ECAC applications, and it is not considered appropriate to increase the TLS to allow for them.

There are no authoritative estimates of the differences between ECAC and world-wide accident frequencies, due to the relatively small number of accidents in the ECAC region. However, comparisons can be made as follows:

- For CFIT, only 7 out of 34 (21%) accidents were in ECAC, compared to 29% of flight exposure (Ref 4). Hence the average CFIT frequency per flight in ECAC is estimated as 0.21/0.29 = 0.72x the world average.
- For mid-air collisions, the 26 year gap between the collisions in Zagreb and Überlingen indicates an average return period of 0.038 per year. World-wide flight exposure during this period has been 106 million flights, equivalent to an average of 4.1 million per year. Assuming that 29% of this was in ECAC, the average mid-air collision frequency per flight in ECAC is estimated as $0.038/(0.29 \times 4.1 \times 10^6) = 3.2 \times 10^{-8}$ per flight. This is higher

than the world-wide frequency of 1.4 x $10^{-8}$ per flight (Table 2.8), but the number of events is too small to justify a correction for this.

The CFIT factor is adopted here, while the frequencies of other accident categories are assumed equal to world average (Table 4.3).

**Table 4.3 Frequency Adjustments for ECAC in 2004**

| ACCIDENT CATEGORY | HISTORICAL TREND TO 2004 | ECAC vs WORLD-WIDE |
|---|---|---|
| Taxiway collision | x1 | x1 |
| Runway collision | x1 | x1 |
| Mid-air collision | x0.69 | x1 |
| Wake accident | x0.69 | x1 |
| CFIT | x0.51 | x0.72 |
| Landing accident | x1 | x1 |

## 4.5 Frequency Metrics (Step 10)

### 4.5.1 Overview

Most TLS applications consider only single accident categories, flight phases and approach types. Hence the metric of accident frequency per flight may not be optimal. Instead, the frequency should refer to the specific flight phase and approach type within which the accident category may occur.

Appropriate measures of exposure for the flight phase and approach type are:

- **Taxi** - the number of ground movements.
- **Take-off** - the number of take-offs, i.e. the number of flights.
- **Departure** - the number of departures, i.e. the number of flights. In some cases, the number of flight hours in the departure phase may be more relevant.
- **En-route** - the number of flight hours in the en-route phase.
- **Arrival** - the number of arrivals, i.e. the number of flights. In some cases, the number of flight hours in the arrival phase may be more relevant.
- **Final approach (precision approach**) - the number of precision final approaches.
- **Final approach (non-precision approach**) - the number of non-precision final approaches.
- **Landing** - the number of landings, i.e. the number of flights.

### 4.5.2 Application of Step 10 to the proposed dataset

The following measures of exposure for the flight phase and approach type are proposed for current dataset:

- **Taxi** - This is approximately 2x the number of flights.
- **Take-off –** This is the number of flights.
- **Departure** - In this case the number of flight hours in the departure phase has been applied. This is estimated as 14% of the flight time, based on Boeing (Ref 2) for climb with flaps up. Combining with the 1.8 hour average flight duration (Section 2), this is 0.25 hours per flight.
- **En-route** - This is estimated as 68% of the flight time, based on Boeing data for cruise and descent. Combining with the 1.8 hour worldwide average flight duration, this is 1.22 hours per flight. For ECAC, where an average flight is 1.5 hour, the enroute time is assumed to be reduced by 0.3 hours to 0.92 hours.
- **Arrival –** This estimation is based on the number of flight hours in the arrival phase. This is estimated as 12% of the flight time, based on Boeing data for initial approach. Combining with the 1.8 hour average flight duration, this is 0.22 hours per flight.
- **Final approach (precision approach**) - This is estimated as 91.7% of final approaches, based on Enders *et al* (Ref 10), i.e. 0.917x the number of flights.
- **Final approach (non-precision approach**) - This is estimated as 8.3% of final approaches, based on Enders *et al*, i.e. 0.0813x the number of flights. [5]
- **Landing –** This is the number of flights.

The values are summarised in Table 4.4.

[5] If missed approaches were to be split out from final approaches, it would be interesting to identify missed approaches following PA and following NPA.

### Table 4.4 Exposure Metrics

| FLIGHT PHASE | METRIC |
|---|---|
| Taxi | 2 ground movements per flight |
| Take-off | 1 take-off per flight |
| Departure | 1 departure per flight or 0.25 hours per flight |
| En-route | 1.22 hours per flight worldwide, 0.92 hours per flight in ECAC |
| Arrival | 1 arrival per flight or 0.22 hours per flight |
| Final approach (PA) | 0.917 precision approaches per flight |
| Final approach (NPA) | 0.083 non-precision approaches per flight |
| Landing (PA) | 0.917 landings from precision approach per flight |
| Landing (NPA) | 0.083 landings from non-precision approach per flight |

After applying the corresponding exposure metrics and corrections, the current risk estimates for ECAC in 2004 have been obtained (see Table 4.5). It is important to note that in this and subsequent tables, the different units for each flight phase and approach type mean that the “total” row is not simply the sum of the rows above.

### Table 4.5 Estimated Fatal Accident Involvement Frequencies for ECAC in 2004

| FLIGHT PHASE | TAXIWAY COLLISION | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT |
|---|---|---|---|---|---|---|
| Taxi (per movement) | 1.7E-09 | 2.4E-09 | | | | |
| Take-off (per take-off) | | 1.9E-08 | | | | |
| Departure (per departure) | | | 2.1E-09 | 2.7E-10 | 3.6E-09 | |
| En-route (per hour) | | | 3.0E-09 | 4.6E-10 | 0.0E+00 | |
| TMA arrival+dep (per hour) | | | 1.3E-08 | 2.3E-09 | 5.7E-08 | |
| Arrival (per departure) | | | 3.9E-09 | 8.3E-10 | 2.3E-08 | |
| Final (per PA final) | | | 4.0E-10 | 1.7E-09 | 5.8E-09 | |
| Final (per NPA final) | | | 4.0E-10 | 1.7E-09 | 3.4E-07 | |
| Landing (per PA landing) | | 5.3E-09 | | | | 1.6E-08 |
| Landing (per NPA landing) | | 5.8E-08 | | | | 9.9E-07 |
| Total (per flight) | 3.4E-09 | 3.4E-08 | 1.0E-08 | 3.3E-09 | **6.1E-08** | **9.6E-08** |

# 5 PROPOSALS FOR TARGET LEVELS OF SAFETY

## 5.1 Outline of Approach

Proposals for target levels of safety (TLS) could be developed from the 2004 baseline risk estimates above (Section 4) using the following steps:

- Consideration of required future trends (Step 11).
- Allowance for uncertainty (Step 12).
- Rounding of results (Step 13).

## 5.2 Required Future Trends (Step 11)

### 5.2.1 Overview

When setting a TLS, there is a link between the traffic levels and the accident frequencies, imposed by the ATM 2000+ objective that the number of ATM induced accidents shall not increase. In effect, this objective requires the accident frequencies to reduce in proportion to the traffic growth rate.

Eurocontrol medium-term forecasts for numbers of IFR flight movements in Europe can be used as the basis for the selection of the growth value. It is advised to use the higher growth scenario when setting the TLS, so as to ensure that safety targets are satisfied in the event of high growth occurring. This will also allow a safety margin in the more likely case of medium growth. If this proves excessively demanding, the likelihood of the high growth scenario could be reviewed.

It should be noted applying the same trend to all accident categories, flight phases and approach types is a very coarse approach to setting Target Levels of Safety. It involves no understanding of the causes of risks, and hence may fail to achieve more substantial safety gains that such insights might provide. It is no substitute for a more strategic approach, based on careful consideration of how various safety enhancements could reduce risks and whether they would be cost effective. For example, rather than ensuring that precision approaches meet the trended risk target, thus minimising risks that are already small, it might be more effective to accelerate the provision of precision approach aids, because these are an effective way of reducing key causes of risk. Although, this can be addressed by using the IRP to set the TLS, it would require the IRP for 2012, which is not yet available.

### 5.2.2 Application of Step 11 to proposed dataset

EUROCONTROL medium-term forecasts for numbers of IFR flight movements in Europe are for average annual growth between 2005 and 2011 of 2.4% to 5.3%, with a most likely value of 3.7% (Ref 11). The most likely value is similar to the historical growth during 1990-2004 (Section 3). This range is wider than previously used in guidance on setting ATM safety minima (Ref 12).

Hence the TLS should be reduced by 5.3% per year compared to the 2004 baseline risk results shown above. Therefore, the TLS for 2015 should be a factor $0.947^{11}$ = 0.55x the 2004 baseline risk results. Table 5.1 summarises the trended risk estimates for ECAC in 2015.

**Table 5.1 Estimated Fatal Accident Involvement Frequencies for ECAC in 2015**

| FLIGHT PHASE | TAXIWAY COLLISION | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT |
|---|---|---|---|---|---|---|
| Taxi (per movement) | 9.3E-10 | 1.3E-09 | | | | |
| Take-off (per take-off) | | 1.1E-08 | | | | |
| Departure (per departure) | | | 1.2E-09 | 1.5E-10 | 2.0E-09 | |
| En-route (per hour) | | | 1.6E-09 | 2.6E-10 | 0.0E+00 | |
| TMA arrival+dep (per hour) | | | 7.0E-09 | 1.3E-09 | 3.1E-08 | |
| Arrival (per departure) | | | 2.1E-09 | 4.6E-10 | 1.3E-08 | |
| Final (per PA final) | | | 2.2E-10 | 9.2E-10 | 3.2E-09 | |
| Final (per NPA final) | | | 2.2E-10 | 9.2E-10 | 1.9E-07 | |
| Landing (per PA landing) | | 2.9E-09 | | | | 8.7E-09 |
| Landing (per NPA landing) | | 3.2E-08 | | | | 5.4E-07 |
| Total (per flight) | 1.9E-09 | 1.9E-08 | 5.5E-09 | 1.8E-09 | 3.3E-08 | 5.3E-08 |

## 5.3 Allowance for Uncertainty (Step 12)

### 5.3.1 Overview

The risk estimates used to develop the TLSs are uncertain. When setting a TLS, it might be appropriate to make allowance for this uncertainty. If the risks are under-estimated, it is possible that even if the TLS is met the number of accidents would still increase, implying that the TLS should be made somewhat lower than the risk estimates. On the other hand, if the risks are over-estimated, the TLS may be excessively strict and expensive to comply with. In general, where there is uncertainty, it is preferable to err on the side of safety, and therefore the TLS should be set lower than the accident risks. The reduction should in principle reflect the degree of uncertainty in the risk estimates.

In practice the uncertainty ranges could be so large, that adopting the lower end of the 90% confidence range, for example, would lead to impractically strict TLSs. Such practical issues will become clearer once the quantitative analysis has been carried out.

### 5.3.2 Application of Step 12 to proposed dataset

There are likely to be many sources of uncertainty in the risk estimates of the proposed dataset. The main ones are identified as follows:

- ***Statistical uncertainties*** arising from the small datasets – these are already alluded to in Table 2.8.

- ***Choice of dataset*** – this could have effects up to 30% as illustrated in Table 4.3.

- ***Historical trends*** - within individual accident types these trends are very uncertain. If these effects were not included, the changes would be up to a factor of 2, as shown in Table 4.3.

- ***Categorisation uncertainties*** **–** these include whether to include runway collisions that cause fatalities in other aircraft, whether to split missed approaches out from final approach, which flight phase rare events (such as mid-air collisions) occurred in and how the split between NPAs and PAs has been carried out.

## 5.4 Rounding of Results (Step 13)

### 5.4.1 Overview

Given the large uncertainties, a TLS should avoid appearing too precise, which implies that it should be quoted to no more than 2 significant figures, and preferably rounded to only one significant figure. Derivation based on trending current risks require the calculations to be relatively precise, and so rounding should be systematically applied as the final step.

### 5.4.2 Application of Step 13 to proposed dataset

For the selected dataset, rounded to a whole number has been adopted. Table 5.1 summarises the resulting TLS values for 2015.

**Table 5.2 Proposed Target Levels of Safety for ECAC for 2015, Expressed as Fatal Accident Involvement Frequencies**

| FLIGHT PHASE | TAXIWAY COLLISION | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT |
|---|---|---|---|---|---|---|
| Taxi (per movement) | 9 E-10 | 1 E-09 | | | | |
| Take-off (per take-off) | | 1 E-08 | | | | |
| Departure (per departure) | | | 1 E-09 | 1 E-10 | 2 E-09 | |
| En-route (per hour) | | | 2 E-09 | 3 E-10 | 0 E+00 | |
| TMA arrival+dep (per hour) | | | 7 E-09 | 1 E-09 | 3 E-08 | |
| Arrival (per arrival) | | | 2 E-09 | 5 E-10 | 1 E-08 | |
| Final (per PA final) | | | 2 E-10 | 9 E-10 | 3 E-09 | |
| Final (per NPA final) | | | 2 E-10 | 9 E-10 | 2 E-07 | |
| Landing (per PA landing) | | 3 E-09 | | | | 9 E-09 |
| Landing (per NPA landing) | | 3 E-08 | | | | 5 E-07 |
| Total (per flight) | 2 E-09 | 2 E-08 | 5 E-09 | 2 E-09 | 3 E-08 | 5 E-08 |

# 6 CONTRIBUTION FROM ATM DIRECT CAUSES

## 6.1 Outline of Approach

In order to compare the targets produced in Section 5 with the ESARR4 value two further steps are needed:

- Convert the fatal accident frequencies in Section 5 into the frequency of all accidents, as defined by ICAO (Step 14); and
- Determine the ATM direct contribution to these accident targets (Step 15).

## 6.2 Application of Step 14 to the proposed dataset

Step 14 is required to ensure common units. One method of determining the accident frequencies (fatal and non-fatal) would be to use the IRP results (Ref. 4) as these give the ratios between ICAO and fatal accident frequencies as shown in Table 6.1.

**Table 6.1 Frequency Ratios for ICAO Defined Accidents and Fatal Accident Frequencies**

| ACCIDENT CATEGORY | ICAO/FATAL FREQUENCY (per flight) |
|---|---|
| Taxiway collision | 97.1 |
| Runway collision | 1.3 |
| Mid-air collision | 1.0 |
| Wake accident | 9.1 |
| CFIT | 1.3 |
| Landing accident | 11.9 |

## 6.3 Application of Step 15 to the proposed dataset

Step 15 could be addressed directly using an appropriate accident dataset. However, currently this is impractical because of the relatively small number of such accidents due to ATM. Alternatively, the IRP 2004 baseline results could be used, as these give the contributions of ATM to the overall accident frequencies as shown in Table 6.2. The contribution of ATM to landing accidents has not yet been estimated within IRP, but for present purposes is assumed to be 1% [**A5**].

**Table 6.2 Contributions of ATM to Direct Causes of Accidents**

| ACCIDENT CATEGORY | ATM DIRECT CONTRIBUTION (%) |
|---|---|
| Taxiway collision | 10.0% |
| Runway collision | 18.1% |
| Mid-air collision | 72.0% |
| Wake accident | 6.9% |
| CFIT | 4.3% |
| Landing accident | 1% (assumed) |

From these, TLS values can be determined, using the same approach as described in Section 5. Table 6.3 shows the results. The selection of the ATM contribution offsets some of the increase that occurred when converting from fatal to ICAO accident frequencies.

**Table 6.3 Target Levels of Safety for 2015, Expressed as ATM Contributions to ICAO Accident Frequencies for ECAC**

| FLIGHT PHASE | TAXIWAY COLLISION | RUNWAY COLLISION | MID-AIR COLLISION | WAKE ACCIDENT | CFIT | LANDING ACCIDENT |
|---|---|---|---|---|---|---|
| Taxi (per movement) | 9 E-09 | 3 E-10 | | | | |
| Take-off (per take-off) | | 2 E-09 | | | | |
| Departure (per departure) | | | 8 E-10 | 9 E-11 | 1 E-10 | |
| En-route (per hour) | | | 1 E-09 | 2 E-10 | 0 E+00 | |
| TMA arrival+dep (per hour) | | | 5 E-09 | 8 E-10 | 2 E-09 | |
| Arrival (per arrival) | | | 2 E-09 | 3 E-10 | 7 E-10 | |
| Final (per PA final) | | | 2 E-10 | 6 E-10 | 2 E-10 | |
| Final (per NPA final) | | | 2 E-10 | 6 E-10 | 1 E-08 | |
| Landing (per PA landing) | | 7 E-10 | | | | 1 E-09 |
| Landing (per NPA landing) | | 8 E-09 | | | | 6 E-08 |
| Total (per flight) | 2 E-08 | 4 E-09 | 4 E-09 | 1 E-09 | 2 E-09 | 6 E-09 |

## 6.4 Comparison with ESARR4 value

These proposals are now compared with the ESARR4 value.

The ESARR4 value for ATM directly contributing to an ICAO-defined accident is 1.55 x 10-8 per flight hour for 2015. The total of the currently proposed TLSs for the ATM contributions to the 6 accident categories is 3.7 x 10-8 per flight. Based on a 1.5 hour average flight duration this becomes 2.5 x 10-8 per flight hour. This is a factor of 1.6 higher than the ESARR4 value, which can be considered a good agreement due to the uncertainties in the derivation.

# 7 ASSUMPTIONS

When applying the proposed method to a specific dataset, it will be necessary to make a certain number of assumptions and judgements. Those assumptions and judgements should be checked periodically, e.g. every two or three years, to assess whether they are either still robust or require updating.

The list of specific assumptions made in this document concerning the example calculations is the following:

A1 We assume that the description of the Tripoli mid-air collision (1992, Table 2.2) in Aviation Safety Network is accurate in indicating that the flight phase was "Arrival (intermediate approach)". Airclaims indicates it was on final approach but provides much less detail. If it is possible to obtain a more detailed accident report this assumption could be checked.

A2 Although the downward trend in CFITs is not statistically significant at the 90% confidence level, a best fit trend of 8% reduction a year is assumed to be a plausible model and it used in obtaining the best estimate baseline risks in 2004 (Section 3).

A3 It is assumed that mid-air collisions and wake turbulence accidents are equally likely on precision and non-precision approaches (Section 4).

A4 The historical trends in Section 4 are assumed to apply equally to all flight phases and equally to precision and non-precision approaches.

A5 A 1% contribution of ATM to landing accidents is assumed (Section 6).

# 8 DISCUSSION POINTS

This methodology needs to be validated prior to its application to the various Navigation Domain implementations. A list of points for discussion it is provided in this section to facilitate the validation process of the proposed methodology.

In the review of this proposed method, the following points need to be considered:

- Choice of basic dataset in Section 2.
- Categorisation of accidents and flights phases in Section 2.
- Accident trends in Section 3 and implicit inclusion of safety nets in these trends.
- Method for allowing for zero events in Section 4.
- Use of a UK dataset of near-miss incidents for the mid-air collision distributions for final approach on Section 4.
- Adjusting CFIT rate for ECAC in Section 4 but no other accident categories.
- Use of ATM 2000+ in Section 5 to drive all TLSs down at equal rate. It would improve the process if strategic input was obtained for the step from 2004 baseline values to 2015 TLSs. The approach of reducing every TLS in line with traffic growth is very unlikely to be the optimal approach from the viewpoint of effective risk management
- How should these TLSs be fitted into an AFARP (reducing risk As Far As Reasonably Practicable) framework.
- List of assumptions in Section 7.

In the case that the methodology is approved, further steps are foreseen to develop a full risk classification scheme for lower Severity Classifications.

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