International General Aviation and Corporate Aviation Risk Assessment (IGA-CARA) Project

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Final Report

Prepared for ASSI

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ABBREVIATIONS

AAG	Accident Analysis Group
ALAR	Approach and Landing Accident
(A)NPA	(Advance) Notice of Proposed Amendment
AOC	Air Operator's Certificate
ASSI	Air Safety Support International
ATSB	Australian Transport Safety Bureau
AWOPS	All Weather Operations
CAA	Civil Aviation Authority (UK)
CASA	Civil Aviation Safety Authority (Australia)
CAST	Commercial Aviation Safety Team
CFIT	Controlled Flight into Terrain
CICTT	CAST/ICAO Common Taxonomy Team
CTSB	Canadian Transportation Safety Board
EASA	European Aviation Safety Agency
(E)GPWS	(Enhanced) Ground Proximity Warning System
FAA/FAR	Federal Aviation Administration / Federal Aviation Regulation
FSF	Flight Safety Foundation
GAIN	Global Aviation Information Network
HFACS	Human Factors Analysis and Classification System
IBAC	International Business Aviation Council
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
IGA-CA(RA)	International General Aviation and Corporate Aviation (Risk Assessment)
IS-BAO	International Standard for Business Aircraft Operations
JAA	Joint Aviation Authorities
JSAT	Joint Safety Analysis Team (JSAT)
MNPS	Minimum Navigation Performance Specification
MSAW	Minimum Safe Altitude Warning
MTOW(M)	Maximum Take-Off Weight (Mass)
MTWA	Maximum Total Weight Authorised
NBAA	National Business Aviation Association
NPA	Non Precision Approach
NTSB	National Transportation Safety Board
OT(AR)	Overseas Territories (Aviation Requirements)
PNF	Pilot Not Flying
PRNAV	Precision Area Navigation
RIF	Risk Influencing Factor
RVSM	Reduced Vertical Separation Minimum
SMS	Safety Management System
TAWS	Terrain Awareness and Warning System
UFIT	Un-controlled Flight Into Terrain
VFR	Visual Flight Rules
VLJ	Very Light Jet

GLOSSARY OF TERMS [with source]

Accident [ICAO Annex 13]
An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such 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 or 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.

Business Aviation – Corporate [IBAC, 2005]
The **non-commercial** operation or use of aircraft by a company for the carriage of passengers or goods as an aid to the conduct of company business, flown by a professional pilot(s) employed to fly the aircraft.

Business Aviation – Owner Operated [IBAC, 2005]
The **non-commercial** operation or use of aircraft by an individual for the carriage of passengers or goods as an aid to the conduct of his/her business.

Commercial operation [EASA]
A remunerated aeronautical activity covered by a contract between an operator and a customer, where the customer is not, directly or indirectly, an owner of the aircraft used for the purpose of this contract and the operator is not, directly or indirectly, an employee of the customer.

Complex-motor-powered aircraft [EASA]

i. an aeroplane – with a MTWA exceeding 5,700kg OR with a maximum approved passenger seating configuration > 9 OR certificated for operation with a minimum crew of at least 2 pilots OR equipped with (a) turbojet engine(s); OR

ii. a helicopter with a MTWA exceeding 3,175kg OR with a maximum approved passenger seating configuration > 5 OR certificated for operation with a minimum crew of at least 2 pilots; OR

iii. a tilt rotor aircraft.

Controlled Flight into or Toward Terrain [CICTT, 2005]
In flight collision or near collision with terrain, water, or obstacle without indication of loss of control. Controlled flight into or toward terrain is an occurrence category.

Hazard
A hazard is an event that has the potential to result in damage or injury **[CAP712**].

Incident
An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation. **[ICAO Annex 13]**

Operator [EASA]
Any legal or natural person, operating or proposing to operate one or more aircraft.

Risk
Risk is the product of the likelihood of a particular hazard AND the severity of its consequence (e.g. loss of life, value of property).

Un-controlled Flight into Terrain (UFIT)

UFIT - Control Loss Technical
An aircraft collides with terrain, obstacles or water, whilst not under control of the flight crew, where control of the aircraft is lost due to a technical failure, e.g. Structural failure.

UFIT - Control Loss Non-Technical
An aircraft collides with terrain, obstacles or water, whilst not under control of the flight crew, where control of the aircraft is lost because of other causes e.g. local meteorological conditions, aerodynamic stall etc.

1 INTRODUCTION

1.1 Background

Following the ICAO Safety Oversight Audit Mission of 2000, the UK established ASSI to oversee and discharge UK Government obligations for civil aviation regulation within the overseas territories (OTs). Of particular relevance to this project is its responsibility to produce "…the United Kingdom Overseas Territories' Aviation Requirements (OTARs) and updates to relevant legislation".

Acknowledging the unique profile of aviation activities within the territories, ASSI has identified a need to better understand risks associated with international general aviation and corporate aviation (IGA-CA). This assessment of hazards and quantification of the risks they present are key components of the Regulatory Impact Assessment which is required as part of the consultation phase for any new regulations.

ASSI commissioned Cranfield University (Department of Air Transport) to carry out a Risk Assessment for this sector of aviation, and make recommendations as to which areas require regulation.

1.2 Statement of Objectives

The IGA-CARA Project comprises many diverse activities, which go to make up a coherent whole. The objectives for the project are listed below:

- An assessment of the safety data of the IGA-CA sectors over the past 20 years, using a mix of existing published data and original data search as required.
- Identification of any trends in safety data for these sectors. Helicopters were included in the original project proposal, but were subsequently excluded from detailed analysis
- Gain the views of relevant industry bodies, including accident and incident investigators, corporate aviation operators and maintenance organisations.
- Determine the intentions of other regulatory authorities with regard to regulation of IGA-CA, and what impact this should have on future OTARs for IGA-CA.
- From the above information sources, perform a hazard and risk analysis for the IGA-CA sector in order to recommend what action should be taken by ASSI. This may be bench-marked against risk levels identified in commercial aviation in order to define appropriate discriminants and actions.
- Produce a draft Interim Regulatory Impact Assessment resulting from the project research and recommendations. This is to be in accordance with Cabinet Office Guidelines;
- Recommend what ongoing activities and analysis should be undertaken in order to monitor the effectiveness of the OTARs implemented.

1.3 Format of report

The report aims to describe the activities carried out to complete project activities as described in Section 1.2. Chapter 2 summarises the current literature available in the domain of corporate aviation and risk assessment for flight operations, and indicates the variety of accident data sources. When appropriate, some of these references have been used in this report to estimate the rate of each type of accident.

This is followed by a description of the current safety level within this industry sector in Chapter 3. The latter gives information on the accident data available for both commercial and business/corporate aviation. The work of certain key regulators around the world is described, as is the level of current safety initiatives.

Chapter 4 explains the methodology behind risk assessment in general, and the IGA-CARA in particular. This also includes a section on discriminants in order to define the subject of the risk assessment without ambiguity, i.e. the type of aircraft (MTWA etc) and its operation (corporate, GA etc).

Chapter 5 contains the data analysis that was carried out to facilitate the risk assessment, after which the results and discussion are presented in Chapter 6. Conclusions and recommendations are in Chapter 7. Figure 1 shows a representation of the key project stages.

It should be noted that for the purpose of comparison, results of the risk assessment are also presented for FAR Part 135 unscheduled operations (referred to as "**135**"). This has been carried out in order to provide a benchmark against which results for corporate aviation can be compared.

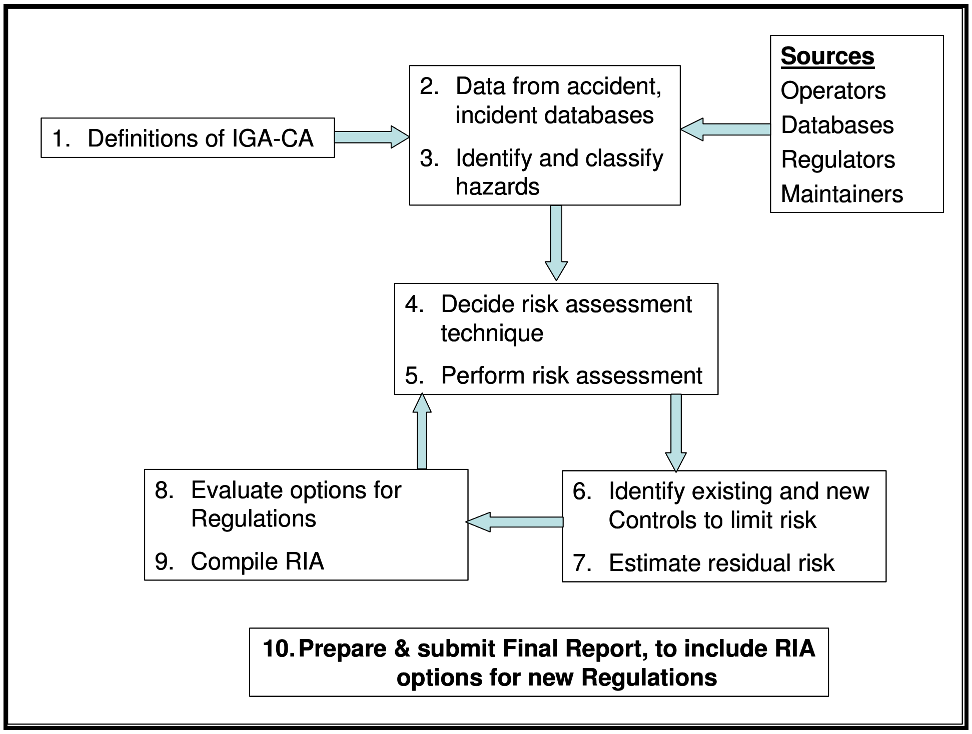

Figure 1: IGA-CARA Sequence of Activities

2 CURRENT LITERATURE & DATA SOURCES

A survey of current literature has been carried out in the areas of risk assessment and Hazard Analysis in the area of Flight operations. This review has been limited to the following areas:

- Risk Modelling in Flight Operations
- Other Aviation-related Applications
- Data Sources

2.1 Risk Modelling in Flight Operations

One of the most promising techniques under development is the Flight Operations Risk Assessment System, known as FORAS **[Hadjimichael & McCarthy, 2004]**. This is a Risk management tool to 'encode' human knowledge about a type of risk and does not depend on statistical probabilities, but on knowledge of variables that constitute risk. The approach employs a 'fuzzy' expert system to identify the factors which have the greatest impact on overall risk.

The methodology is based on five principles **[Hadjimichael & McCarthy, 2004]**:

1. Risk models are based on human expertise
2. A FORAS risk model focuses on preventing accidents, by identifying accident/incident precursors.
3. Risk analyses must be rapid, consistent and independent of bias from individual users.
4. Risk assessments must be quantitative to facilitate comparison and communication.
5. FORAS analysis is intended to be used for communicating risk to all levels in an organisation.

A research project is currently being undertaken with EVA Air to build knowledge based model for Approach to land. However in its current form, the model is only suited for bespoke risk assessment of an enclosed system. The scope of the IGA-CARA project, and timescale available do not permit this approach to be adopted. Nevertheless, the FORAS project will become more widely used, and will become a useful tool for assessing risk of larger systems in the future.

A different approach has been adopted by **[Luxhøj, 2003]** who has developed the Aviation Safety Risk Model (ASRM). This makes use of the Human Factors Analysis & Classification System (HFACS) proposed by **[Wiegmann and Shappell, 2003]**. HFACS is a classification scheme which has been developed to capture and analyse the different types of human error that occur. The framework draws on the work of Reason**,** who developed the so-called "Swiss-cheese" model of accident causation **[Reason, 1990]**. ASRM was originally developed for use by US Naval Aviation, but has since been used more widely within the aviation industry.

The ASRM uses Bayesian Belief Networks to model the uncertainty within the model, using either data or the opinion of "experts". The network is created to represent the dependencies between the different factors identified by applying HFACS. Data has been obtained by examining case studies of accidents, e.g. Air Ontario Flight 1363 **[Luxhøj, 2003].** This technique appears to be still in the design and validation phase, and is once again only being applied to limited accident scenarios. However, models are being created using the extensive HFACS database, and there may be scope for applying it to assess general risk across all aircraft operations.

An additional technique has been adopted by **[Bazargan & Ross, 2004],** who have carried out a risk assessment of General Aviation. This has used the proportionate occurrence of causal factors obtained from accident reports, where fatalities or serious injuries were reported. This information is then combined with expert judgments on the relative importance of the flight attributes using Analytical Hierarchy Process (AHP). The latter allows the development of importance weights for different criteria in a decision process, which in this case are the flight characteristics (e.g. hazards, Flight phase and pilot experience). It was considered that this method for assessing risk would be too time-consuming for use in the IGA-CARA, given the need for considerable expert input and analysis.

With regard to helicopter safety, work carried out in the off-shore helicopter sector has also been undertaken by a number of bodies. One of the most relevant to this project was carried out by the Norwegian Industrial management organisation, SINTEF. The work was published in two reports entitled “Helicopter Safety Study”; (HSS-1) was based on work carried out in 1989/1990, and has since been updated by HSS-2 **[Hokstad et al, 1999].** The work focused on North Sea helicopter accidents and incidents in the period 1990-1998 in order to calculate the risk in terms of fatalities per million person flight hours. This was achievable due to the recording of flight hours and personnel carried by the North Sea operators.

The work also studies the factors that influence risk in terms of Frequency (e.g. Operations Procedures, Air Traffic & Navigational services) and Consequence (e.g. Impact absorption upon hard landings, Stability on sea). These factors are termed Risk Influencing Factors (RIFs). Estimated values for the respective importance of each RIF were elicited by means of a series of expert panels, which then allowed the RIFs with the largest impact on overall risk to be identified. The approach adopted by SINTEF has been selected as a basis for the IGA-CARA study, with certain modifications. This is explained in Section 4.2.

2.2 Other Aviation-related Applications

Other risk assessments studies have also been identified during the course of this work. The FAA carried out a risk assessment for Land & Hold Short operations at Airports **[FAA, 1999]**. The technique adopted was to use quantitative information represented by Fault and Event Tree Analysis (ETA and FTA) in order to calculate risk. This was possible due to the limited nature of the risk assessment and readily defined scope of the assessment.

Other techniques were adopted to calculate public risk in vicinity of Schiphol airport **[RAND, 1993]** and for the risk analysis of aerodrome design rules for the Norwegian CAA **[AEA Technology, 2001].** The work by RAND in modelling risk in the region surrounding Schiphol airport was based on parameters which represented population distribution, flight operations data, aircraft fleet data and aircraft accident rates. The effects of different risk reduction strategies were also included, e.g. adding an additional runway or changing the aircraft fleet mix.

The work to analyse aerodrome design rules **[AEA Technology, 2001]** was based on accident data for runway over-runs and under-shoots, and applied this with the dimensions of the runway available. Dimensions were then calculated to achieve the required Target Level of Safety (TLS) and recommendation made as to remedial action to be taken to reduce risk, if needed.

Further information has been published by the Global Aviation Information Network (GAIN), which has set up Working Group B to promote safety management systems for the aviation industry. This includes fostering the use of existing analytical methods and supporting the introduction of new methods and tools. The published guidance is contained in the "Guide to Methods & Tools for Airline Flight Safety Analysis" **[GAIN, 2003]**, which provides useful advice on a wide range of risk assessment tools. It also contains advice on the use of Fault Tree Analysis (FTA), Event Tree Analysis (ETA), software packages such as @Risk[1] as well as more recent techniques such as FORAS (see above).

2.3 Data sources

2.3.1 Types of Accident

For large aircraft, one the most regular sources of accident data is the Statistical Summary of Commercial Jet Accidents **[Boeing, 2004].** This data represents information drawn from worldwide aircraft operations from 1959 to 2003, but does not focus on (nor in some cases does it include) corporate aircraft/operations as a distinct class. Similar comments may be made on reports by the CAA, which categorises data based on Airline & Air Taxi operations or General Aviation, CAP735 **[CAA, 2002]** and CAP667 **[CAA, 1997]**. It is therefore not possible to identify clearly the accident types and causes in business and corporate aviation.

One of the most recent studies on business aircraft accidents was carried out by [Veillette, 2004]. This work, published in full by FSF [**Veillette, 2004b**], and also in summary in **[Veillette, 2004a]** detailed a study of business **jet** accidents between Jan 1991 - Dec 2002. This included a worldwide survey of fatal and non-fatal accidents, and incidents from the following sources:

- Airclaims
- Australian Transport Safety Bureau, Transportation Safety Board of Canada, UK Air Accidents Investigation Branch, US National Transportation Safety Board
- US Federal Aviation Administration
- NASA Aviation Safety Reporting System

It should be noted that Veillette's study did not consider turbo-prop aircraft or Scheduled FAR Part 135 operators (Commuter), but was focused on fixed wing turbo-jet aircraft. The sectors studied were:

- Unscheduled air-taxi operations (FAR Part 135)
- Corporate/executive operations (flown by professional pilots)
- Business Operations
- Personal, training, maintenance and public-use (government)

The benefit of studying the above work is that it gives a reflection of the types of accident which may be peculiar to business and corporate operation. However, there is no distinction between aircraft flown by a corporate operator and those flown by an Air Taxi. It is therefore not possible to judge whether the proportion of accident types (e.g. CFIT, In-flight collision etc) is the same for each type of operator.

2.3.2 NTSB

The NTSB have produced downloadable databases for all US aircraft accidents from 1982 – 2002, which are available on the Internet. These are in the form of MS Access™ databases that may be sorted by any of the > 50 data fields, including "aircraft manufacturer", "weight"

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[1] @Risk™ (© Palisade) is a software "Add-in" to MS Excel for probabilistic modelling and Monte-Carlo simulation

or “type of operation”, e.g. FAR Part 91, 121 and 135. Other information includes accident narrative, sequence of events, number of fatalities etc.

The NTSB also publishes annual reports for both Commercial – Part 121 and Part 135 **[NTSB, 2004a]** and General Aviation – Part 91 **[NTSB, 2004b],** the most recent of which covers the year 2000. However, web-based data are available up to 2004. These reports summarise findings, but do not analyse results by sub-category of “operation”. For example, the Part 91 category covers Private, medical, corporate and training flight operations

2.3.3 Other sources

When studying corporate accident statistics, an additional source of data is Robert Breiling & Associates **[IBAC, 2003, 2004, 2005**]. The particular benefit is that usage rates (hours flown) have been included, which allow estimates of the accident rate to be made. The data is given in the form of a 5-year average, and includes the total of hours flown in each geographical region of the world. It also distinguishes between Part 135 (unscheduled) and corporate operation, and provides information for estimating accident rates for turbo-prop and business jet aircraft.

The CAA has also been a useful source of data with the Accident Analysis Group (AAG) and Mandatory Occurrence Reporting System (MORS) databases. These are not available in open literature, except in summary report form, e.g. CAP 661 **[CAA, 1998**].

3 IGA-CA SAFETY RECORD

3.1 Accident data

Accident data gained from the NTSB have been plotted to show some of the trends in safety and accident statistics for aircraft operating under FARs. Although FAR-operated aircraft may operate worldwide, these data sources relate mainly to operation within the USA. This represents a large population of aircraft and may therefore be used to draw conclusions on the relative frequency of accidents between the different types of operation.

The data have been used to calculate the five-year moving average for the following categories of operation. The advantage of NTSB data is that it segregates different sizes of operation, e.g. FAR Part 121 and FAR Part 135.

- FAR Part 121 – scheduled air carrier (passenger and freight), Figure 2.
- FAR Part 135 – scheduled commuter air services, Figure 3.
- FAR Part 135 – Non-scheduled Air Taxi operations, Figure 4.
- FAR Part 91 – General Aviation, Figure 5.

Figure 2 shows the accident rate (total and fatal) for Part 121 operators, with the most recent accident rate of 0.25 per 100 000 hrs (fatal 0.015). These figures are calculated from the most recent five-years, with 2004 having 28 accidents (2 fatal) over a total of 17.5M flying hours for FAR 121 operators. The rise in the graph before 1999 is partly due to a re-classification of certain Part 135-type operations under Part 121 that took place in 1997. This re-classification involved the following classes:

(i) Non-Transport category turbo-prop aircraft type certificated after Dec 1964, with a passenger seat configuration of 10–19 seats;
(ii) Transport category turbo-prop aircraft with passenger seat configuration of 20–30 seats; or
(iii) Turbojet engined aircraft with passenger seat configuration of 1–30 seats.

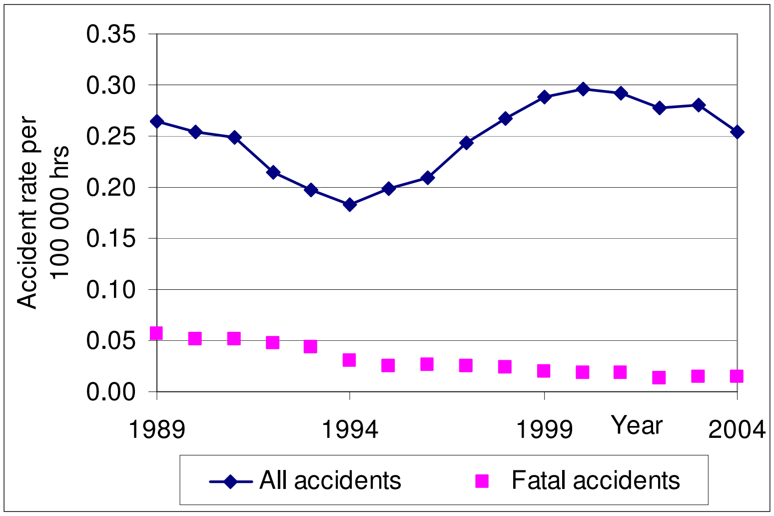


Figure 2: Trend in total accident rate and fatal accident rate for FAR Part 121 operators (NTSB data)

Figure 3 is the corresponding result for scheduled Part 135 operations, often referred to as “Commuter”. This graph also shows an increase around 2002, which could also stem from the Part 135 to Part 121 re-classification. The effect may also be due to the difficulty in capturing the total hours flown for this industry sector; and the number of hours flown have been re-assessed by the FAA.

The graph shows the most recent accident rate of 2.07 per 100 000 hrs (fatal 0.25), calculated from the most recent five-years. For comparison, 2004 contained 5 accidents (non fatal) over 330 000 flight hours. It is these comparatively low figures which are partly responsible for the variable accident rate, i.e. a small variation in the number of accidents has a proportionately larger effect on the accident rate.

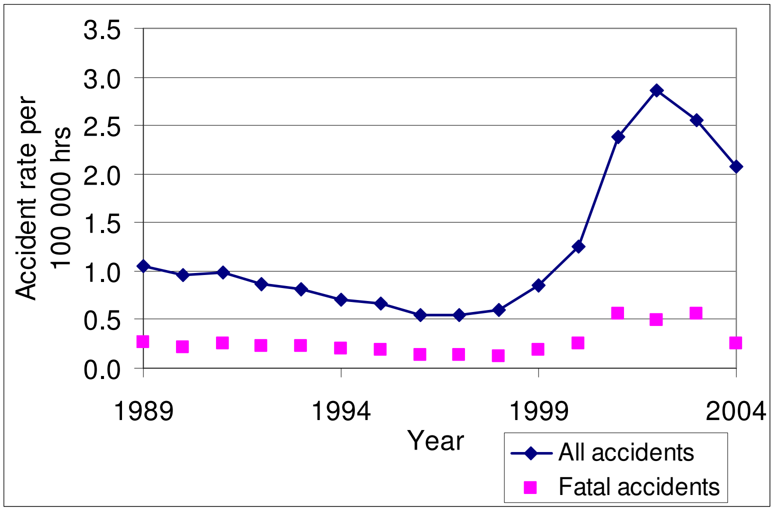


Figure 3: Trend in total accident rate and fatal accident rate for FAR Part 135 Scheduled operators (NTSB data)

Figure 4 shows the falling trend for non-scheduled Part 135 operations, often referred to as “Air Taxi”. It should be noted that the total accident rate is greater than that for scheduled commuter Part 135 operations. The graph shows the most recent accident rate of 2.24 per 100 000 hrs (fatal 0.63) as a five-year moving average. This is due to the fact that this class of operation can include very diverse operations to sometimes remote and/or uncontrolled airfields, including Emergency Medical Services (EMS).

The graph is based on a total of 68 accidents (24 fatal) over 3M flying hours for 2004. This is a factor of 10 greater than the flying hours for Commuter (Figure 3). Hence, variations in the annual number of accidents will have less effect on the overall accident rate.

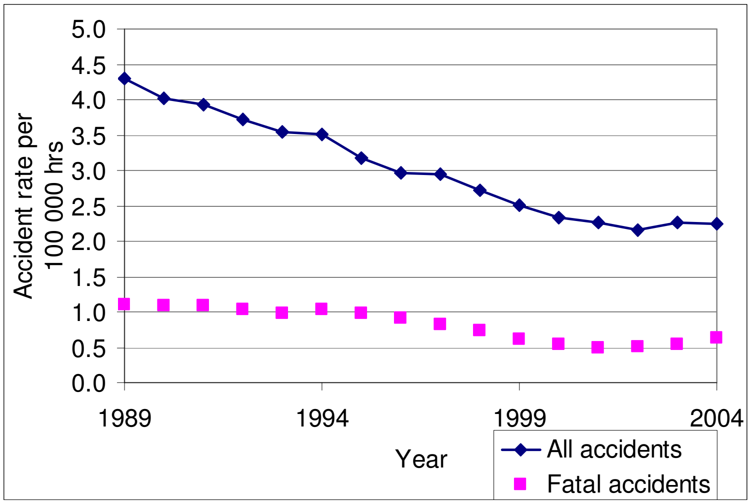


Figure 4: Trend in total accident rate and fatal accident rate for FAR Part 135 Non-Scheduled operators (NTSB data)

Figure 5 shows the total and fatal accident rates for General Aviation conducted under FAR Part 91. The most recent figure is 6.62 accidents (1.29 fatal) per 100 000 hours. The total accident rate is a factor of 3 larger than that for Part 135 non-scheduled operation, and the fatal accident rate is double.

These results are based on a total of 1 600 accidents for 26M flying hours, and represent a large and diverse population of aircraft and pilots. These include all small and home-built aircraft as well as high performance jet aircraft operated in the corporate and executive role. In the latter case data collected by **[Veillette, 2004]** shows the number of accidents for business jets as a separate category, Figure 6. Combining the number of accidents (21) with the estimated number of hours flown – 4.8M for 2002 (Section 4.4.1) - gives an accident rate of 0.44 per 100 000hrs.

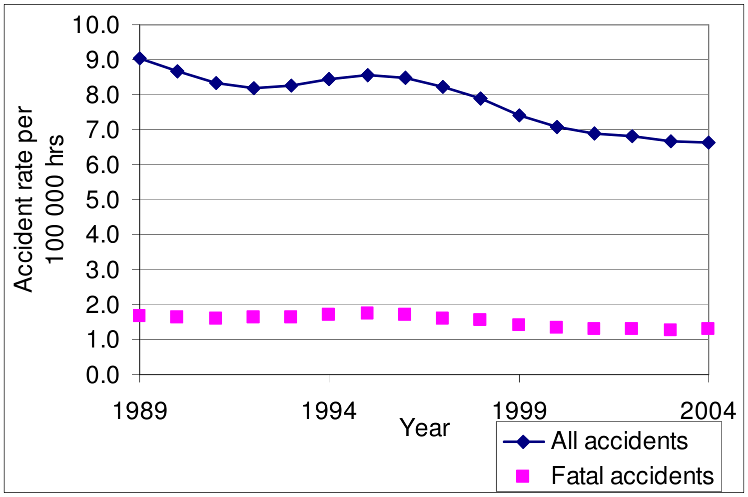


Figure 5: Trend in total accident rate and fatal accident rate for FAR Part 91 General Aviation (NTSB data)

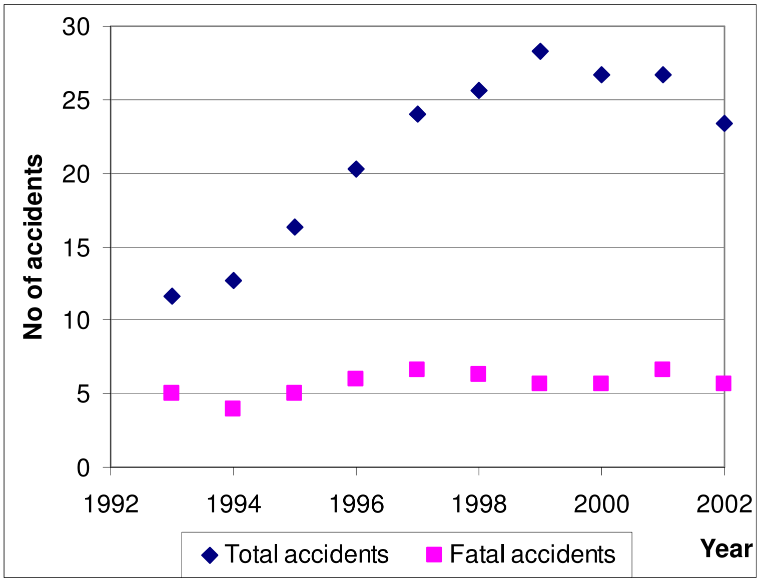


Figure 6: Business Jet accidents by year [Veillette, 2004]

Figure 7 shows a comparison of Accident rate for different types of operation using data from the NTSB and NBAA. This has separated the accident rates for Corporate/executive, Part 121, Part135 (Commuter) and Part 135 (Air Taxi). The data shows that the accident rate for Corporate/executive is at a similar level to that for scheduled air carrier, operating under FAR Part 121. Some of the reasons for this low accident rate could be the low average age of aircraft used, professional two-crew operation, and a high level of standardisation in each company, e.g. Operations Manual, simulator training etc. All these factors mentioned are present in larger Airlines, which could explain why the accident rates are similar.

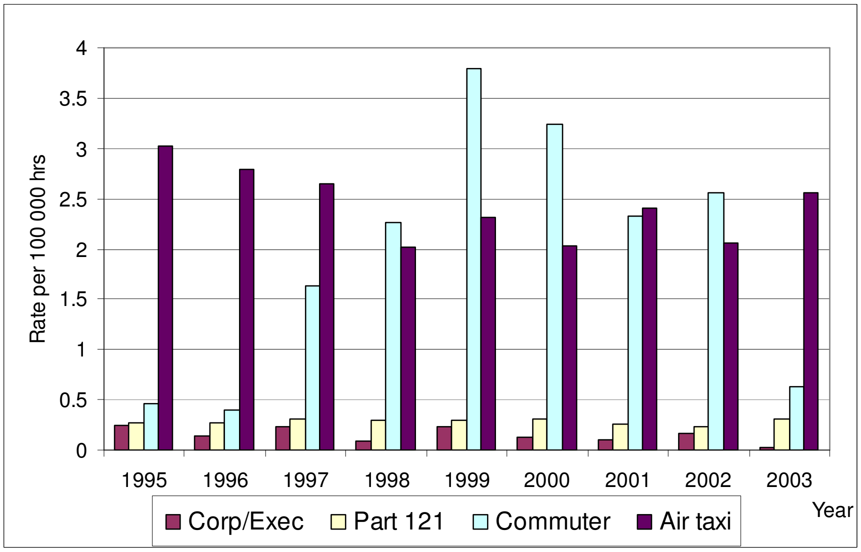


Figure 7: Comparison of Accident rate for different types of operation [Data from NTSB, NBAA]

3.2 Accident Causation

Accident causation can be complex subject that is not well described by statistics. Simply stated, the notion of single-cause accidents in complex sociotechnical systems such as aviation has largely been discounted. However, those statistics designed to break down causal factors into categories often focus on the ‘primary cause’ or even sometimes the ‘cause’ even when the official investigation has not cited a primary cause (or indeed in some states, not used the word cause at all). This observation reminds of the need for caution in deriving causal trends from many of the freely available statistical summaries.

Similarly, while there is a clear benefit in using causal trends to try and predict future accident causes, it should be noted that many causes have been reduced either through intervention or education and are unlikely to recur with such frequency. This notwithstanding, certain causes seem to recur in spite of interventions – for example, the continued prevalence of human factor issues such as loss of situational awareness in spite of widespread Crew Resource Management (CRM).

Boeing’s Commercial Aircraft Accident Summary **[Boeing, 2004]** published annually and focusing on the western-built commercial fleet provides a broad overview of the trends in accident type from its own database. Its most frequently cited graph, plotted from primary cause accident data highlights the prevalence of flight crew error as a cause of accidents. While this seems compatible with the general view that human factors is the primary cause of 60-80% of accidents in aviation (and indeed most industries), the statistics can be misleading. For example, the number of accidents that cite air traffic control as primary cause may draw the reader away from the fact that, when analysed, ATC events also demonstrate a similar proportion of human factors failings within the category.

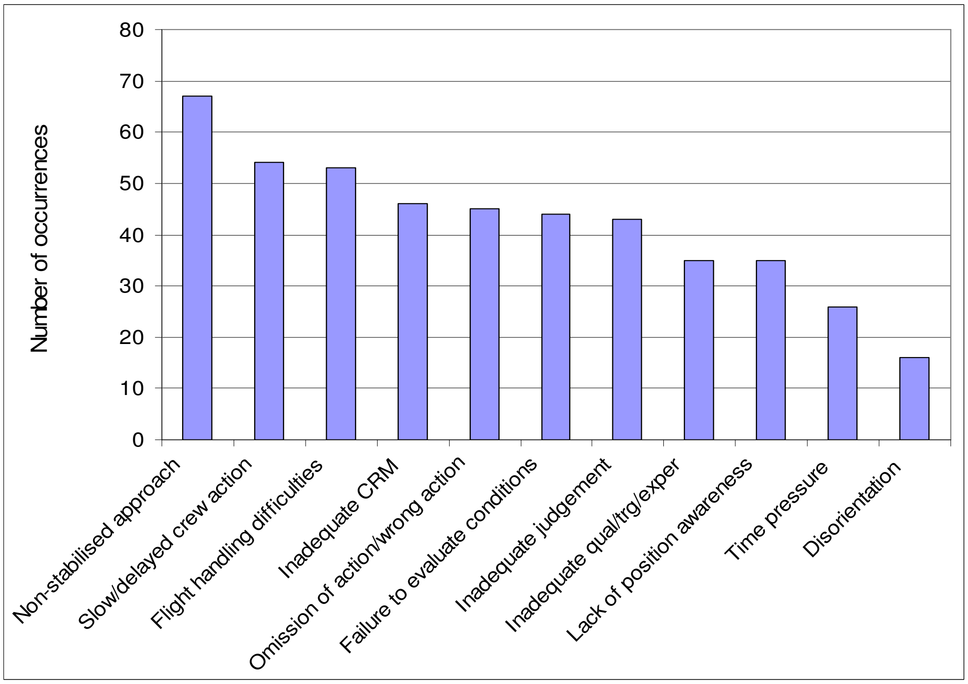


Figure 8: Causal factors for Approach & Landing Accidents (104 in survey) [Veillette, 2004]

The Boeing data is clearly focused on large, commercial aircraft and hence does not offer directly transferable statistics for examining risk within the IGA-CA sector. However, in offering a reference group for comparison, it is useful for establishing where IGA-CA is either below or above the safety levels for commercial aviation. Indeed some of the aircraft types operating as corporate aircraft are of a size that would warrant inclusion in Boeing's study which increases its relevance.

Take-off and landing accidents account for the majority of accidents involving commercial jet aircraft. During the period 1994 – 2003, take-off and initial climb accounted for 17% of all accidents (and 22% of fatalities) whereas initial and final approach, and landing accounted for 51% of accidents (and 31% of fatalities). Does this point to issues of poor infrastructure or crew performance? The answer is of course, a complex combination of the two.

Although Boeing cite loss of control in flight and controlled flight into terrain (CFIT) as the two leading sources of accidents and fatalities (2,131 and 1,701 fatalities respectively), the categorisation does not easily lend itself to understanding the hazards involved. For example, CFIT is generally a consequence of factors such as loss of situational awareness or mode confusion, rather than a cause per se. This view is supported by the work of the Flight Safety Foundation in examining Approach and Landing accidents **[FSF, 1998, 1999].**

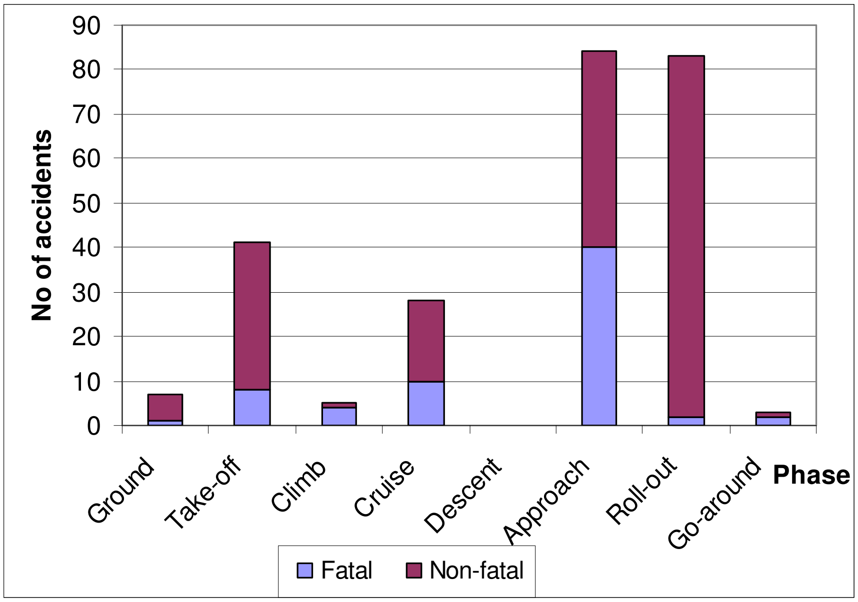


Figure 9: Business Jet accidents by phase of flight
[Veillette, 2004]

3.3 Accident Investigation

Accident investigation continues to evolve as a discipline and with it, the emphasis or depth of investigations has also changed. Whilst most accident investigations are conducted under the guidance of the Standards And Recommended Practices (SARPS) laid down in ICAO Annex 13, the focus of investigations is seen to alter between member states. For example, the Australian Transport Safety Bureau (ATSB) and Canadian Transportation Safety Board (CTSB) are well-known for their emphasis on deeper psychological and organisational issues whereas the UK Air Accidents Investigation Branch (AAIB) and US National Transportation

Safety Board (NTSB) are renowned for their technical prowess. The practical effect of these differences is potential bias in the accident statistics. For example, the ATSB and its predecessor the Bureau of Air Safety Investigation (BASI) have not used the term ‘cause’ or ‘causal factor’ for 20 years, so many databases rely on arbitrary decisions in coding to classify Australian accidents.

The work of Organisation Psychologist, Professor James Reason has been widely publicised by ICAO through its Human Factors Digest series as being the accepted model of accident causation. In simple terms, Reason points out that the failures which occur immediately prior to the accident (often referred to as active failures or unsafe acts) are only able to occur because of preceding failures higher up in the organisation or separated in time from the final accident sequence. These are generally referred to as latent conditions and may include policies and procedures that were in place months or years before an event. High profile, catastrophic accidents across a wide range of domains (such as the Challenger and Columbia shuttle disasters, Chernobyl fire, Herald of Free Enterprise capsize, Kings Cross Fire, Barings Bank collapse and Clapham rail disaster) have validated this way of thinking.

Modern safety management systems acknowledge the complexity of accident causation by using multiple strategies to identify and assess risk, to report and investigate occurrences and to provide support and resources for changing safety behaviour. However, all of the work on safety management systems remains dependent on the culture or context in which it occurs, not least the strategic direction of senior management. Where staff see no real need for ‘additional safety’ or where they perceive a reward for taking particular risks, “risk compensation” will occur. This has the effect of skewing the understanding of accident causation from statistics alone and emphasises the need for the insights of accident investigators to be gained as part of this study.

Indeed, many potentially contributing factors to accidents may go unrecorded by investigators because of lack of definitive evidence. The difficulties that have been experienced in trying to introduce corporate manslaughter legislation illustrate the difficulties of proof, although safety investigators generally do not have to work to the same levels of proof that the legal system does.

The emphasis placed on ‘senior management commitment’ in establishing a safety management system is an implicit indication of the role that management and organisational culture have to play in aircraft accidents. Certain high-profile investigations have allowed this role to be more clearly understood, although the message has not always been popularly received. The Royal Commission into the accident involving Air New Zealand at Mount Erebus in 1979 and Commission of Inquiry into the accident involving Air Ontario at Dryden in 1989 are clear examples.

The salient point to be made is that accident statistics in isolation do not necessarily give a reliable indication of the areas of risk to be examined by this study. The theory behind accident causation points at deeper, and therefore more influential factors that lie behind most occurrences – those factors relating to the management of an organisation and the regulatory system it operates within. Indeed, many ICAO states have only recently dared to cite deficiencies within the regulatory system as being significant contributors to accidents and incidents.

This is stated by **[Hadjimichael & McCarthy, 2004]** who state that “accidents are a poor measure of performance” as they reflect an outcome rather than the true risk that may be present during a flight. The underlying factors behind accidents (e.g. corporate culture) may be identified by reviewing the Human Factors Analysis and Classification System (HFACS – see section 6.5). The review of incident data may seem to be a better approach to gain a picture of potential accidents; however, reporting of incidents is heavily biased by the culture of both the nation and operator, and is unreliable as a measure of the sources and occurrence rate of flight crew error. Hence, it was decided that the IGA-CARA study would start by focusing on the categorisation of accidents which occur in the business and corporate sector. The factors which influence these accidents will then be examined to detect underlying risk factors to identify the areas to be targeted by the new OTARs.

3.4 Work of Regulators and Industry Bodies

The status of business and corporate aviation is at many different levels among the different regulatory bodies around the world. This section gives an indication of the current (and intended) level of activity.

In the UK, corporate aviation is considered and regulated as General Aviation, provided there is no hire or reward (referred to as “valuable consideration”) for carrying passengers or goods. Hence a company aircraft operator does not require an Air Operator’s Certificate (AOC). The CAA will be affected by the new EASA rules regarding Operations, see Section 3.4.1, and has also recently begun a study to review the accident rates for business/corporate aviation.

In the JAA, consultation work has been undertaken by the Operations Sectorial Team (OST). The latter worked closely with the Aerial Work and General Aviation Sub-group (AWGAS) and the Helicopter Steering Group (HSG) in the lead up to the new regulations as quoted below. This may lead to the issue of a Notice of Proposed Amendment (NPA) for JAR (Ops) 0, 2 and 4 in 2005.

- JAR-OPS 0 for General Operating Rules
- JAR-OPS 2 for General Aviation (including Aerial work) - Aeroplanes
- JAR-OPS 4 for General Aviation (including Aerial work) - Helicopters

In the FAA, Business and Corporate aviation currently conducted under Part 91 (General Aviation), see Appendix B. There are a number of particularly relevant parts:

- Sub-part F for large aircraft (jet powered or above 5 700kg)
- Sub-part K for fractional ownership.

Many of the key regulations from Sub-part K were derived from Part 135, as there was considerable controversy as to whether or not fractional ownership **[Federal Register, 2003]** should be classed as Commercial aviation. The latter is the case in the UK and OTs at present. However studies being undertaken the European Civil Aviation Conference (ECAC) may influence that view in the near future.

Dialogue with the FAA (K Perfetti) indicated that a Rule Review was due to take place for FAR parts 125 and 135. At present any turbojet used for scheduled service has to be operated under Part 121. However any aircraft used for Part 121 has to be certified to Part 25 – this excludes VLJs as they are under the MTWA limit. The Rule Review should in future allow VLJs with less than 10 seats to be operated under Part 135 instead of Part 121 as at present. However, the rules governing corporate aviation (i.e. non-commercial) are not due to change.

3.4.1 EASA

Opinion 3 of 2004 (proposed EASA rule amendment to 1592/2002) has shown that EASA intend to regulate the areas of operations for EU states in the future (estimated date 2007).

The basis for future regulation is that regulation of non-commercial aviation should be adapted to the complexity of aircraft rather than the type of operation.

EASA propose the introduction of a definition of **complex motor-powered aircraft** to draw a line between the aircraft categories used for non-commercial aviation. The term includes:

- an aeroplane – with a MTWA exceeding 5,700kg **OR** with a maximum approved passenger seating configuration > 9 **OR** certificated for operation with a minimum crew of at least 2 pilots **OR** equipped with (a) turbojet engine(s); **OR**
- a helicopter with a MTWA exceeding 3,175kg **OR** with a maximum approved passenger seating configuration > 5 **OR** certificated for operation with a minimum crew of at least 2 pilots; **OR**
- a tilt rotor aircraft.

For the Implementation Rules (IR) for non-commercial operations with non-complex aircraft Draft JAR-OPS 0 will be reviewed. For the IR for non-commercial operations with complex motor-powered aircraft, draft JAR-OPS 0 and 2 will be reviewed. Draft JAR-OPS 0 and 4 will also be reviewed for the aerial work regulation. The timeframe for this work is 2005 – 2007.

3.4.2 Transport Canada

Regulations for corporate aviation in Canada are issued under the heading of CAR Part VI - General Operating and Flight Rules. Of particular note is the Private Operator’s Certificate (POC) scheme, administered by Canadian Business Aviation Association (CBAA) on behalf of Transport Canada. See Appendix B.

The Part VI - Subpart 4 is entitled ”Private Operator Passenger Transportation” and has a corresponding Standard 624 “Private Operator Passenger Transportation Standards”. The latter outlines the standards that must be met to comply with the requirements of Subpart 604. Subpart 4 applies to the operation of a Canadian aircraft for the transport of passengers, for the following:

- An aircraft which is a **turbine-powered pressurized aeroplane or a large aeroplane (> 5 700kg)**; and
- An aircraft which is not required to be operated under Subpart 6 of Part IV (Flight training) or under Part VII (Commercial Air Transport).

3.4.3 CASA, Australia

The Australian regulatory authority is in the process of consulting on, and producing draft regulations for, the following areas. Dialogue has been initiated with regard to the new Part 132, which includes corporate operations.

Part 132 [Source http://rrp.casa.gov.au/casrcreate/132.asp]

CASR Part 132 will stipulate the regulatory requirements and standards for the approval of operators that provide air experience flights in Australian-registered aircraft, other than those operations that are conducted under a CASR Part 149 (Recreational aviation) organisation. In the context of this Part, the term 'air experience' includes 'joy flights' and 'adventure flights' in either normal or limited category aircraft (e.g. 'warbirds').

CASR Part 132 will also define regulatory requirements and standards for the approval of certain corporate operations. This is specified by CASA as a flight that is operated by or on behalf of a company or a group of companies, or by or on behalf of the owner or owners of the aircraft, which involves the carriage of passengers or cargo for business purposes other than air transport operations.

Currently, some regulatory standards for small aircraft passenger charter operations do exist. However, this is substantially a new set of regulations for operations that would otherwise be classified as 'Air Transport' under CASR Parts 135 and 133 (Air transport & aerial work operations - rotorcraft). Part 132 operations may be classified as either 'General Aviation', or as 'Aerial Work' requiring an Operating Certificate (OC), depending on the type and complexity of the operation. The Part will include:

- Procedure for the application and issue of a Part 132 Operating Certificate (where required);
- Obligations and privileges of OC holders;
- Operational requirements and standards to be complied with by OC holders;
- Aircraft maintenance requirements and standards to be complied with by OC holders;
- Qualifications of Flight Crew involved in Part 132 operations; and
- Contents of an OC holder's Operations Manual.

One of the most significant features of the proposed Part 132 rules is that an Operating Certificate (OC) will be required for operations classified as Aerial Work.

CASR Part 121 [Source http://rrp.casa.gov.au/casrcreate/121.asp]

CASR Part 121 will consolidate into one Part of the regulatory requirements for the operation of large aeroplanes used in Air Transport Operations that apply, in addition to, or in substitution for, the general operating and flight rules prescribed in Part 91. It will require operators to establish procedures to ensure compliance and incorporate those procedures into operations manuals. The split between Part 121 and 135 will be based on 5 700kg MTWA only, rather than dual break points of 5700kg and 9 passengers as originally proposed. This is to bring the requirements into line with the certification standards, CASR Parts 23 and 25.

CASR Part 91 [Source http://rrp.casa.gov.au/casrcreate/091.asp]

CASR Part 91 is designed to replace Civil Aviation Regulations (CARs) 1988 and Civil Aviation Orders (CAOs) that relate to general operating and flight rules. It will form a complete set of operating rules for private operations and will be supported by a number of Advisory Circulars (ACs). This will supplement the operating rules applicable to aerial work and air transport operations. The Part primarily consolidates and retains most of the existing rules with little change. However, a small number of new rules have been included to further ICAO compliance and enhance aviation safety.

CASR Part 135 [Source http://rrp.casa.gov.au/casrcreate/135.asp]

CASR Part 135 will specify the requirements for the operation of small aeroplanes engaged in air transport operations that apply in addition to, or substitution for, Part 91 general rules. The part sets a common level of safety for Charter and Regular operations, and will particularly affect charter operators in areas such as:

- flight crew training;
- proficiency checks and supervision;
- over-water operations for approved single engine aeroplanes; and
- more flexible take-off and landing performance.

The split between Part 121 and 135 is now based on 5700kg maximum take-off weight only, rather than dual break points of 5700kg and 9 passengers as originally proposed.

3.4.4 New Zealand CAA

In New Zealand, the Scholtens Report was completed in December 2002 and identified 17 recommendations for changes to be made to the NZ CAA's rule development process. The report included Recommendations 5 and 6 as follows:

- Recommendation 5 - For all remaining issues [**those not filtered out as unsuitable**] a process of problem identification and preliminary risk assessment is recommended to test whether the issue qualifies for further attention.

- Recommendation 6 **-** Risk management process and solution choice: after the problem is identified and articulated, it should be subject to a standardised risk management process and appropriate feasible solution should be identified and evaluated before a solution is selected.

A Rules Review Implementation Project was subsequently initiated, which aims to apply AS/NZS standard for Risk Management (AS/NZS4360:1999) to:

- Establish a more efficient and effective rule making process that delivers aviation safety at reasonable cost.
- Ensure that process improvements are identified and implemented as quickly as possible.
- Create a basis for the ongoing improvement of the rule process; and
- Ensure that the rule making process has the ongoing support and confidence of the aviation community and politicians by true consultation and engagement.

3.5 Initiatives

3.5.1 Commercial Aviation Safety Team (CAST)

The Commercial Aviation Safety Team (CAST) was set up in response to the US White House Commission on Aviation Safety (1997). It was formed from an amalgamation of the aviation industry and FAA Safer Skies Initiatives. The goal is to carry out a data-driven and consensus-based development of an integrated strategic safety plan. This is currently working and supported by Government and Industry.

The current "recommended - highest priority" interventions can be grouped into the following general categories:

- Install TAWS-EGPWS
- Ensure CFIT prevention programs are developed, published, and implemented
- Implement flight operations quality assurance
- Expand availability and utilization of precision approach capability
- Maximize the effectiveness of MSAW
- Ensure ATC awareness/training/procedures include CFIT prevention programs

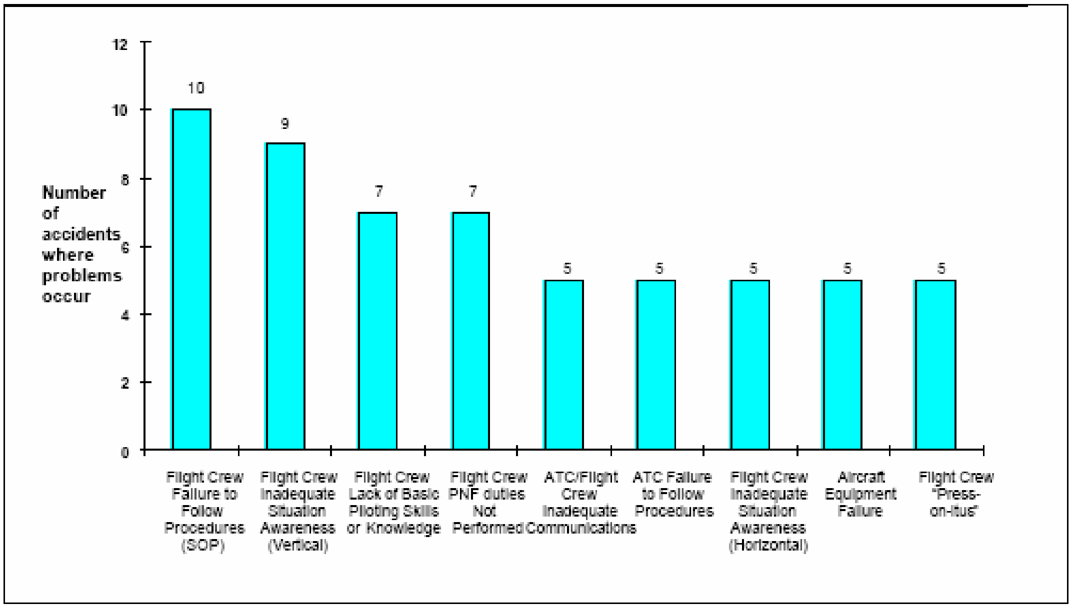


Figure 10: Most common problems from CFIT accidents (12 in sample) [JSAT, 1998]

3.5.2 Flight Safety Foundation and ALAR/CFIT Initiatives

The Flight Safety Foundation has been instrumental in all areas regarding aviation safety and regularly publishes relevant information in the monthly Flight Safety Digest. Of particular relevance is the Approach-and-landing Accident Reduction (ALAR) Task Force, which was created in 1996. This group produced a useful guide to these risk areas in the FS Digest "Killers in Aviation" **[FSF, 1998, 1999]**. FSF have now produced a "CFIT Checklist" **[FSF, 1994]**, which allows an operator to assess all the risk factors which could lead to CFIT and provides a "score" relating to the risk present. Allied with this is the "Approach-and-Landing Risk reduction Guide **[FSF, 2000],** which lists those factors which should be considered when seeking to identify and reduce ALAR.

The above (CFIT and ALAR) are considered to be the largest risk sectors. The FSF have also been responsible for disseminating results from **[Veillette, 2004]** which have been used by this study. Additional work to reduce the occurrence of CFIT has also been carried out for General Aviation by the North America Free Trade Association (NAFTA). This is known as the NAFTA Tri-national CFIT Working Group Initiative, set up by FAA Civil Aerospace Medical Institute, Transport Canada and Direccion General de Aeronautica Civil, Mexico. Extracts from one of their publications "Prevention of CFIT In General Aviation Operations" **[FAA, TC & DGAC, 2002]** have been reproduced in Appendix C.

3.5.3 IBAC - International Business Aviation Council

The International Business Aviation Council represents all the national and international organisations for business and corporate operators. They have been instrumental in promoting an Industry (non-mandatory) code-of-practice known as the International Standard for Business Aviation Operations **[IBAC, 2002].** The concept behind IS-BAO is to combine the best and most appropriate elements of a traditional flight safety program with quality management practices **[Rohr, 2004]**. This can be applied to any size of organisation, and seeks to establish the principles of a safety management system (SMS) at every level of the flight operation.

The goal of IS-BAO (and SMS in general) is to identify and manage safety-risks as effectively as practicable. In order to do this, it must be applied by an organisation in a pro-active manner at all levels. Steps within the implementation of the standard include the identification of hazards and risks, and the mitigation already in place to reduce risk. Where necessary, additional measures may need to be adopted to reduce risk identified during this process.

3.5.4 Industry Best Practice

During the course of this project, several corporate operators were approached with a view to discovering their approach to safety in the corporate sector. One such operator requires their contractors to produce and maintain a verifiable Safety case for all parts of their operation. This includes the adoption of a pro-active Safety management system, such as that recommended by IS-BAO. In the case of rotary wing operations, a safety improvement program was implemented, which includes improvements to operating procedures and also additional equipment, e.g. mandating the use of EGPWS.

With the widening use of IS-BAO, operators who wish to be accredited as being in compliance with IS-BAO are audited for their adherence to the standard. It has also been proposed that IS-BAO could become an ISO standard; this would give it more widespread and official recognition as an operating standard for best practice in this sector of aviation.

4 METHODOLOGY

4.1 Introduction

The aircraft included in the sector 'International General Aviation' overlap several traditional classifications – covering as it does aircraft from light twins and helicopters up to large jets such as the Boeing BBJ series. A primary objective is to define what comprises international general aviation and specifically the corporate aircraft within this group. The definition is to facilitate the use of relevant accident data and latterly to target any possible regulatory interventions. A hard and fast definition at the start of the project was difficult – indeed many organisations have struggled to define this sector of aviation for years. A working definition was developed based upon a review of existing classifications and the availability of accident data. A 'perfect' definition that is not supported by available data may actually be of negative value so some flexibility was considered prudent.

Having established a definition of the sector under consideration, the actual risk assessment was designed around the system safety process advocated by the FAA in its System Safety Handbook **[FAA, 2000].** The basic steps are as outlined in Figure 11 – see also the FAA Order 8040.4 for Safety Risk Management **[FAA, 1998]**. The order of activities from the latter, together with the FAA System Safety Process **[FAA, 2003]**, provides a useful framework upon which to order the activities of the IGA-CARA project.

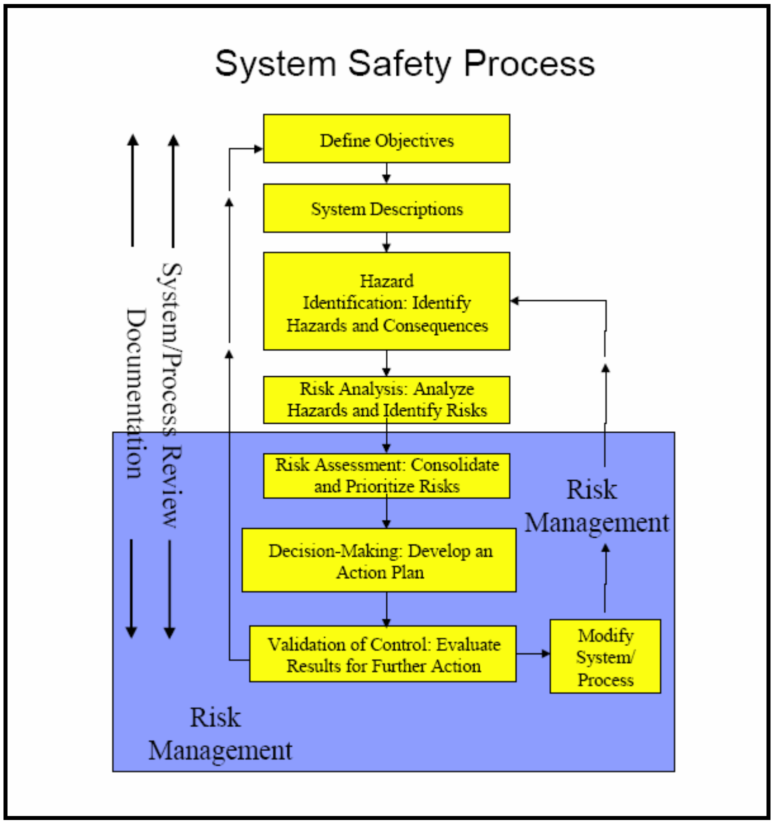


Figure 11: System Safety Process [FAA, 2003]

1. **Define Plan and Objectives**

   Case-specific plan for the analysis and assessment of risk in relation to the project concerned before new Regulations are drafted. This includes the definition of objectives.

2. **System Description**

   Produce a System description that gives the scope for the safety assessment, and includes descriptions of the data available.

3. **Hazard Identification**

   The hazards that contribute to each accident must be clearly stated. In the presence of an "Accident Trigger" or undesirable system state, such hazards may give rise to an accident (Figure 12). This list may be referred to as a Preliminary Hazard List (PHL). The consequence of each accident should also be assessed.

4. **Risk Analysis: Analyse Hazards and Identify Risks**

   In this stage, each risk is characterised for its severity and likelihood. It must be noted that lack of historical data and/or the inability to quantify a particular hazard does not exclude any hazard from such analysis **[FAA, 1998]**.

5. **Risk assessment: Consolidate & prioritise risks**

   The risk assessment process is the method of analysing the impact all risks to a system and comparing them to a risk target.

6. **Decision making: develop action plans**

   This involves determining how to address each risk (as required), by adopting one of the four options – transfer, eliminate, accept, mitigate (TEAM). As an example in engineering, the order would be **[FAA, 1998]:**

   - Design for minimum risk
   - Incorporate safety devices
   - Provide warning devices
   - Develop procedures and training

7. **Validations and Control: Evaluate results of action plan**
8. **Modify system/process – if needed**

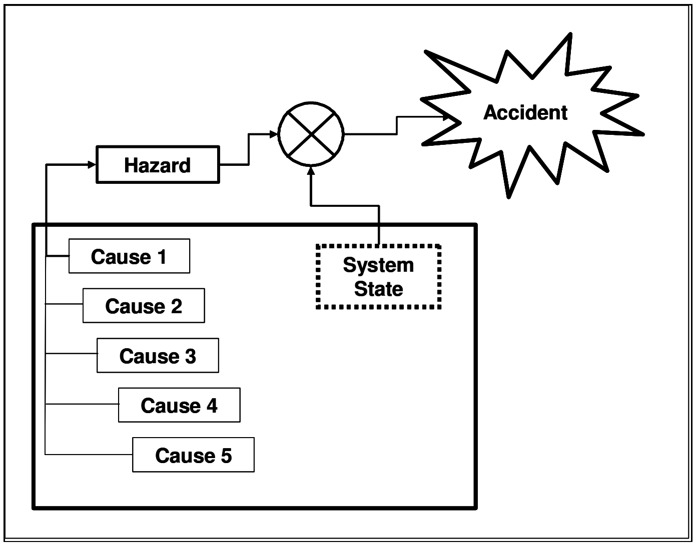
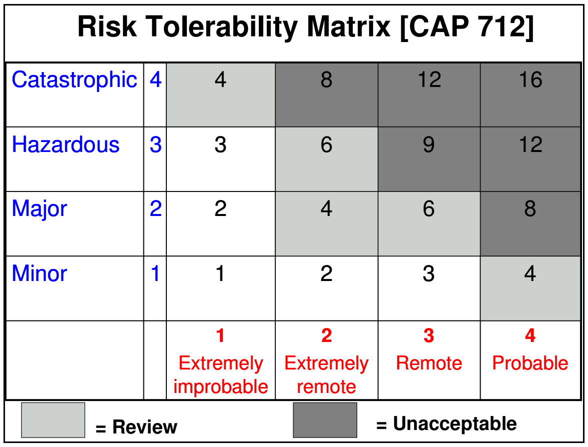


Figure 12: Accident Causation Sequence [FAA, 2000]

Steps 3-5 are expanded in Section 4.3 which describes the exact process by which accident rates and values of risk are estimated. The method used for the risk assessment is based on that used for offshore helicopter safety as developed by SINTEF **[Hokstad et al, 1999]**, and is explained in Section 4.2.

The risk assessment will enable ASSI to make informed decisions as to where improvements in international GA and Corporate Aviation must be made. One of the aims is to be able to "plot" the frequency and consequence of each accident type, as per the Risk matrix shown in Figure 13. Following the above steps, the Regulatory Impact Assessment of future OTARs will be able to draw information and conclusions from the risk assessment.



Risk Tolerability Matrix [CAP 712]

Catastrophic	4	4	8	12	16
Hazardous	3	3	6	9	12
Major	2	2	4	6	8
Minor	1	1	2	3	4
		1 Extremely improbable	**2** Extremely remote	**3** Remote	**4** Probable

▨ **= Review** ■ **= Unacceptable**

Figure 13: Example Risk Assessment matrix [CAA, 2002]

4.2 Risk Assessment Technique

The method of risk assessment adopted is similar to that used by SINTEF in their two reports for helicopter safety for North Sea, off-shore operations **[Hokstad et al, 1999]**. This method (referred to here as the 'SINTEF model' was chosen as it gives a Top-down approach capable of showing an appropriate level of detail with the data available. It analyses Risk Influence Factors (RIFs) for each Accident, and allows these to be assessed and quantified where data permits. The RIFs also enable the contribution of different parameters to the overall risk to be assessed. The overall hierarchy as used by **[Hokstad et al, 1999],** but here adapted for fixed wing aircraft, is shown in .

This project focuses on the first (Operational) level of RIFs, since these have the most influence on the accident rate, and therefore risk. However, the outcome of the IGA-CARA project may produce effects at the Organisational Level – such as changes to corporate culture via Regulations - and the Regulatory Level(National Authorities) levels ().

0. Main cause level	**1. Operational level**
Aircraft technical dependability	Design & Continuous airworthiness
	Maintenance
Aircraft operations dependability	Physical/technical environment
	Condition of Flight Crew
	Personnel factors
Other conditions	ATC/Ground aids
	Airport infrastructure
	Environment

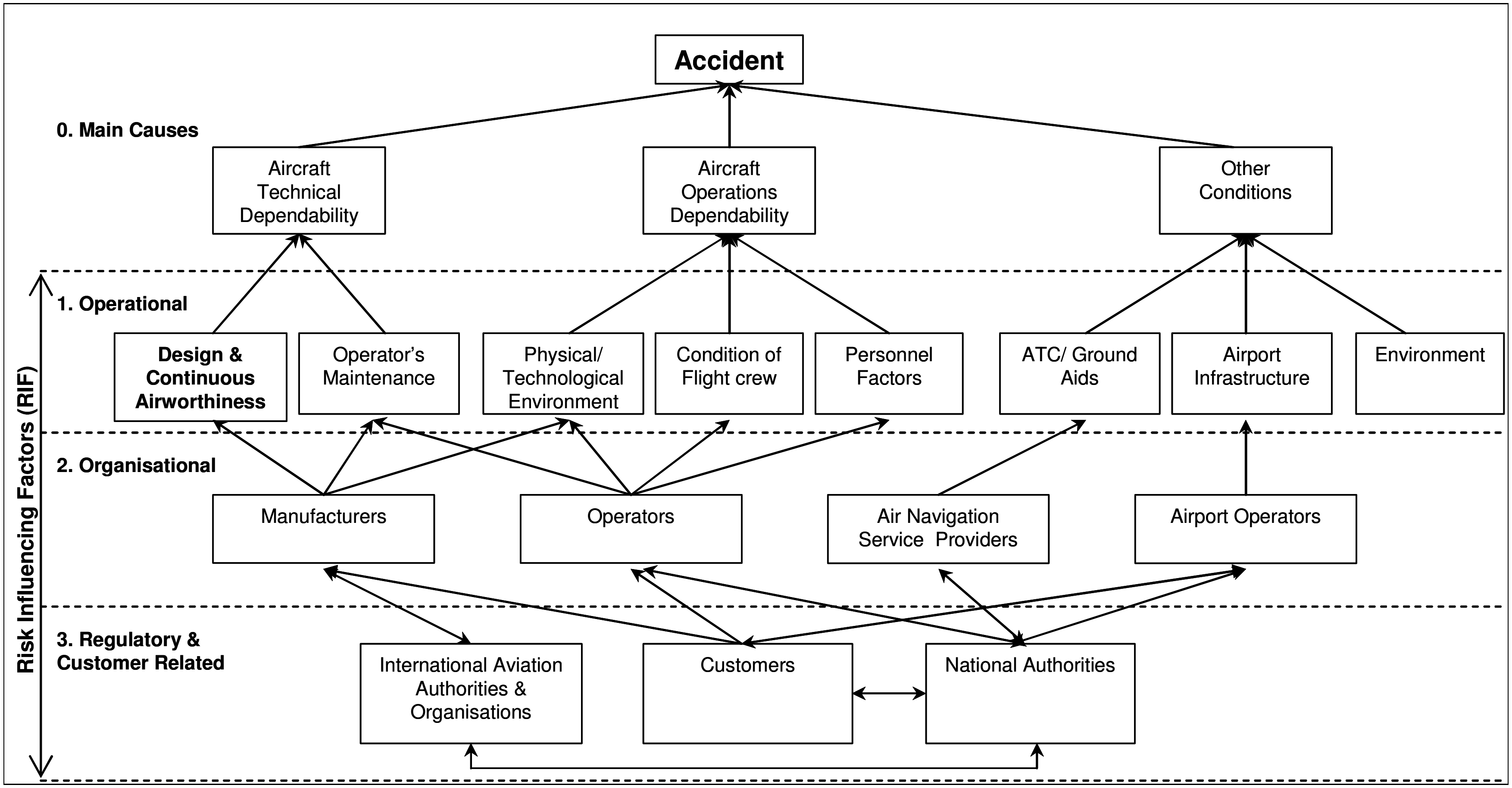


Figure 14: Influence Diagram for frequency [Hokstad et al, 1999]

4.3 Steps 3-5 - Hazard identification and Risk Assessment

Applying the SINTEF model allows the contribution of each RIF to be estimated. Each RIF (Operations, Maintenance, Environment etc) has an influence on both Frequency and Consequence. The RIFs for Frequency cover all those factors that influence the precursors to accidents and incidents, see **Figure 15**. The RIFs for Consequence are those factors that determine the severity of the accident/incident once it has occurred.

Most risk reduction strategies aim to prevent accidents occurring rather than reducing the consequences of an accident. This is the approach adopted by the IGA-CARA Project, which seeks to determine the factors that determine accident frequency. In the current study, the accident “hierarchy” has been reduced to focus on the levels as shown in **Figure 15**). Examples of factors that would affect Frequency of each RIF include the following:

- Application of EGPWS to reduce the likelihood of controlled flight into Terrain (CFIT)
- Application of Crew Resource Management, Incident reporting system.

Factors that would affect Consequence could include the following **[Hokstad et al, 1999**]:

- Making structures more crashworthy, e.g. impact absorption.
- Airport preparedness for Emergency situations
- Crew and passenger preparedness for Emergency situations
- Search & Rescue operations, in particular for helicopter off-shore flight.

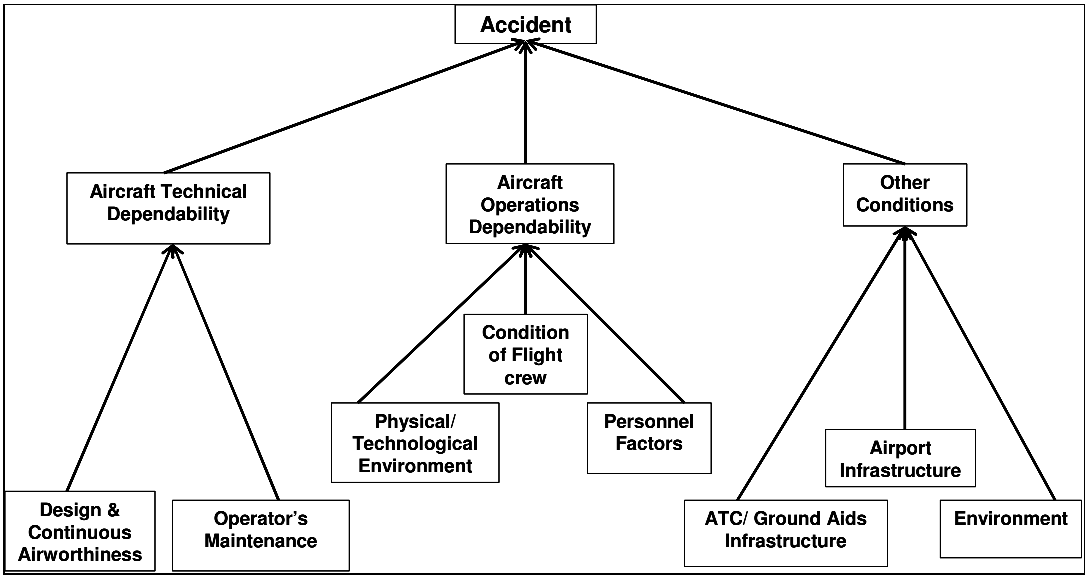


Figure 15: RIFs at operational Level [Hokstad et al, 1999]

The Steps 3-5 from the overall Methodology (Section 4.1) have been expanded to explain how accidents were assessed and risk estimated. The Hazard identification and Risk Assessment steps were conducted as follows:

A. Identify relevant accidents in respect to business aviation and corporate operators. This was completed by referring to accident and safety reports (see Section 6.1). These were numbered as Accidents no 1-10.

B. Estimate the relative frequency of Accidents no 1-10 based on safety and accident reports, plus search of relevant databases.

C. Derive the estimated value of accident rate for each of the following categories

Ref	**Business jet**	**Turboprop aircraft**
“135”	Part 135 On-demand	Part 135 On-demand
“A”	Business Aviation – Corporate	Business Aviation – Corporate
“B”	Business Aviation – Owner Operated	Business Aviation – Owner Operated

D. Combine the results from (B) and (C) above to estimate the accident rate for Accidents no 1-10 for the above 6 categories. For example, if Accident No 1 comprises 10% of all accidents, and the total accident rate for “**135-jet**” was 2 per 100 000 hrs:

Accident 1 occurrence rate for **135-jet** = 10% x 2 = 0.2 per 100 000 hrs.

E. Estimate the consequence for each Accident No 1-10. Here this is expressed in terms of fatalities, but this could also be financial cost of damage to property or reputation.

F. Results from (D) and (E) can then be used to estimate risk for each accident type and each type of operation, e.g. Runway Over-run for Corporate Operator with Turboprop aircraft.

G. Identify which Risk Influencing Factors (RIFs) contribute to which accident type, e.g. Maintenance RIF contributes to UFIT - Control-Loss Technical, but does not contribute to CFIT.

H. The RIFs for each Accident 1-10 are quantified by estimating their contribution to each accident type, e.g. the respective weightings for Operations, ATC and Environment RIFs for a CFIT accident could be 80%, 10%, 10%.

I. The RIFs for Consequence (e.g. crashworthiness, emergency preparedness) have not been considered. Only the RIFs for Frequency have been included.

J. Perform the sum of each RIF to establish:
- Influence of each RIF on total accident frequency
- Influence of each RIF on total accident risk

K. the results from (J) can then be used to determine the most influential RIF (that with the largest contribution) as an aid to deciding which risk-reduction strategy to implement.

4.4 Accident Data

Aircraft accidents are rare events and as such the use of accident statistics for plotting future trends needs some care. Where the population under consideration is small, specific accidents may carry loud statistical noise. Ffor example, the loss of a Concorde near Paris in 2000 had a profound effect on the safety record for that aircraft type. To try and smooth the data, options include widening the population (if possible) or considering data collected over a longer period. In considering the safety performance of international general aviation and specifically corporate aircraft on the OT registers, the small sample (fleet) size could be dealt with by:

- considering accidents over a long time period, or
- drawing upon a larger population (for example, US or rest of the world data) and testing whether the results are generalisable to aircraft operating in the OTs.

The difficulty of the former is the effect of time series data – in other words, the threats that may have been present in aircraft 20-30 years ago are likely to have changed. Long sample periods may not take account of changes in technology and training that have occurred during this time leading to skewness.

Although the focus of this project is the UK Overseas Territories, it was clear from the outset that the most reliable picture of safety performance within this sector would come from global data, whilst acknowledging that certain aspects of the IGA-CA sector would be of particular interest to the OTs. Specific threats that the OTs may face were considered, but due to their small size and the comparative lack of data, they are presented as 'Points to Note' (Section 6.7) rather than quantitative data.

The aircraft registered in OTs may be operated by any company, or any individual, anywhere in the world. For this reason it was decided to assess global accident data and US data when the former are not available. The possible bias in using US data is justified since it is reported that North America represents 72% of the global fleet of business aircraft **[IBAC, 2005].**

The data used for Hazard Identification was obtained by assessing the most frequent categories of accident and incident. These are based upon reports compiled by the following:

- UK CAA – Accident Analysis Group (AAG) for worldwide accidents **[CAA, 1998]** and Mandatory Occurrence Report System (MORS) for UK incidents and accidents.

- USA NTSB - Accident data reviewed directly from database and from other researchers, in particular **[Veillette, 2004]** and Robert Breiling & Associates [**IBAC, 2005].**

- NASA ASRS – Incident data reviewed by **[Veillette, 2004].**

4.4.1 Assumptions

- The most recent data for accident rate **[IBAC, 2005**] covers the five-year period 1999-2003. However the data for the proportion of the different types of accidents for business jets [**Veillette, 2004**] are based on a 12-year spread of data over the period 1991 – 2002. Hence the proportion of accidents may be different, e.g. the proportion of CFIT may have reduced with the advent of EGPWS.

- The proportion of the different types of accidents for business jets has been applied for turbo-props. This may not be the case, as turbo-props may be more prone to icing, for example. However, within the limited data available this is deemed to be an acceptable approximation.

- The split of hours between business jet and turboprop aircraft is estimated as 55% / 45%. This has been taken from operations data for years 2001 – 2003 **[IBAC, 2003, 2004, 2005**], quoted as:

2001	Business jet	4 870 564 hours	56 %
	Turboprop aircraft	3 905 814 hours	44 %
2002	Business jet	4 766 230 hours	53 %
	Turboprop aircraft	4 187 280 hours	47 %
2003	Business jet	4 741 355 hours	55 %
	Turboprop aircraft	3 975 609 hours	45 %

- Little data was available to estimate the consequences of each Accident type. Judgement was therefore used, based on the likely number of people on board each aircraft type.

4.4.2 Data from Accident Analysis Group (AAG)

The work of the CAA Accident Analysis Group (AAG) has proven very useful for their Causal analysis of world-wide accidents. Each year, the accident reports for all fatal accidents are analysed by an independent panel - comprising operations, engineering, Regulatary and accident investigation staff. The most recent report, CAP 681, considered 621 fatal accidents over the period 1980 to 1996 **[CAA, 1998]**. Of these, 589 accidents had sufficient information for causal factors to be allocated. The scope of the analysis includes:

- Fatal accidents
- Operations for Public transport, Business aviation, commercial training and ferry/positioning
- Fixed wing aircraft with MTWA > 5 700kg

The following were excluded from the AAG analysis:

- Piston-engined aircraft
- Rotorcraft
- Terrorism or sabotage
- Third party fatalities not caused by aircraft or its operation
- Aircraft and operators from Commonwealth of Independent States (CIS) pre-1990
- Military operations and test flights

For each report, the AAG list the Causal factors, which are events that are "judged to be directly instrumental in the causal chain of events leading to an accident" **[CAA, 1998].** Circumstantial factors are also listed, which are events judged to have possible contributed to the accident. These are not directly causal but could have had an influence on the outcome.

4.4.3 FSF data

A survey of worldwide accident data for business jets was carried out by the Flight Safety Foundation **[Veillette, 2004].** This was based on an analysis of 251 accidents (67 fatal) between 1991 and 2002, and included reports from:

Accident reports	Airclaims Australian Transport Safety Bureau, Transportation Safety Board of Canada, UK Air Accidents Investigation Branch US NTSB, FAA

<u>Incident reports</u> NASA Aviation Safety Reporting System

The data does not consider turbo-prop aircraft and omits scheduled commuter Part 135 operations, but is very useful for providing insights regarding the types and relative frequencies of accidents.

4.4.4 <u>IBAC data</u>

The International Business Aviation Council (IBAC) has produced a summary of global accident statistics which focuses on accidents of business type jets and turbo-prop aircraft over a five-year period **[IBAC, 2005]**. The most useful parts of this information are used in the IGA-CA risk assessment - these include accident rate data for both business jet and turbo-prop aircraft. The usage data is based on data drawn from AvData and aircraft manufacturers, and has been analysed by Robert Breiling & Associates **[IBAC, 2005].**

4.5 <u>Definition of IGA-CA</u>

The requirement for a definition of "International General Aviation and Corporate Aviation" (IGA-CA) has always been recognised by ASSI. The discriminants used within the definition are required for two reasons:

- **To specify categories of aircraft and/or operation for searching incident and accident databases.**
- **To specify categories of aircraft and/or operation to which new Requirements (OTARs) should apply.**

It was considered inadvisable to choose hard and fast definitions at an early stage of the project. Such a move could have lead to the omission of incident and accident data that could be useful to the identification of hazards and risks. The two attributes to define IGA-CA are the (a) physical type of aircraft and (b) the type of operation where they are used, see Table 1 and Figure 16.

Aircraft type	Operation type
MTWA	Scheduled Commercial Air Transport (FAR Part 121)
Certification Specification, e.g. CS-25	Commuter Commercial Air Transport (FAR Part 135)
Type of Power plant - Turbojet, turbine, piston, No of engines	Aerial work
Pressurised/un-pressurised	Business Aviation – Commercial – On demand charters (Air Taxi)
Two-crew/ single pilot operation	Business Aviation – Corporate
Max configuration of passenger seats	Business Aviation – Owner Operated
Payload	Other General Aviation
Operator utilizes more than one aircraft at a time	
Requirement for the operator to hold a specific approval (MNPS, PRNAV, RVSM, AWOPS or similar requirements	

Table 1: Possible Discriminants for IGA-CARA Project

The different types of operation have been classified as below. The definitions for Business Aviation listed in No 4, 5 and 6, and in Figure 16 have been taken from **[IBAC, 2005]**.

1. **Commercial Air Transport** (ref FAR Part 121)

   Commercial passenger and/or cargo transportation in aircraft with passenger seat configuration > 30 and payload of greater than 7 500lb, and turbo-jet aircraft
2. **Commercial Air Transport** (ref FAR Part 135)

   Commercial passenger and/or cargo transportation in aircraft with passenger seat configuration of 30 seats or fewer and payload of 7 500lb or less
3. **Aerial work [ICAO Definition]**

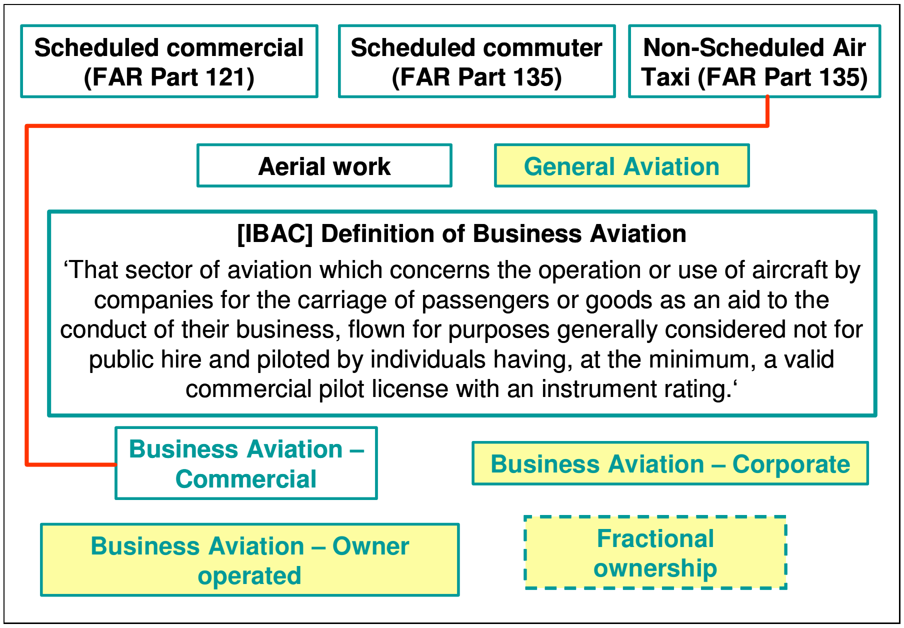
   An aircraft operation in which an aircraft is used for specialised services such as agriculture, construction, photography, surveying, observation and patrol, search and rescue, aerial advertisement, etc.
4. **Business Aviation – Commercial -** On demand charters (Air Taxi) - ref FAR Part 135.

   The commercial operation or use of aircraft by companies for the carriage of passenger or goods as an aid to the conduct of their business and the availability of the aircraft for whole aircraft charter, flown by a professional pilot(s) employed to fly the aircraft.
5. **Business Aviation – Corporate**

   The non-commercial operation or use of aircraft by a company for the carriage of passengers or goods as an aid to the conduct of company business, flown by a professional pilot(s) employed to fly the aircraft.
6. **Business Aviation – Owner Operated**

   The non-commercial operation or use of aircraft by an individual for the carriage of passengers or goods as an aid to the conduct of his/her business.
7. **Other General Aviation**.

   This category includes all other types of aviation activity, in particular recreational and flying training.



‘That sector of aviation which concerns the operation or use of aircraft by companies for the carriage of passengers or goods as an aid to the conduct of their business, flown for purposes generally considered not for public hire and piloted by individuals having, at the minimum, a valid commercial pilot license with an instrument rating.‘

Figure 16: Types of Operation of Aircraft

4.6 Choice of Discriminants

A definition of IGA-CA has been chosen from the characteristics listed in Table 1. These are expanded in the following sections, and are discussed further in Section 7. The initial set is based on:

- Discriminants that are currently used or proposed by other regulatory bodies
- Analysis of safety and accident data.

4.6.1 Aircraft type

Fixed wing aircraft below 2250kg / 5000lb MTWA have been excluded from the study. This weight is the limit for reporting accidents to ICAO (Annex 13), and is a useful limit to remove light single and twin-engine aircraft from the data. For rotary wing, a limit of 3175kg / 7000lb MTWA will be used. This will exclude lightweight single piston engine helicopters (e.g. training) and small turbine helicopters, e.g. Bell Jet Ranger, see Appendix E.

The study suggests amending the term "**complex-motor-powered aircraft**", as proposed by EASA rule amendment to [1592/2002]. The term "turbojet" has been replaced with the word "**turbine**" in order to include high performance single-engine aircraft, e.g. PA-46, PC-12. It is suggested that the latter, and similar aircraft, could be used in the corporate aviation sector, and should therefore be subject to similar operating rules when employed in this role.

4.6.2 Operation type

The selected operation types are those listed in Table 1, which relate to:

A. Business Aviation – Corporate
B. Business Aviation – Owner operated
C. Other General Aviation. The GA category is that which corresponds to the aircraft that are categorised in Section 4.6.1.

It was also deemed to be advisable to use additional operator discriminants to focus correctly the new OTAR requirements. These are operators with more that one aircraft in service, and those operators that require specific approvals. These were proposed by the JAR OPS 2 working group.

4.6.3 IGA-CA Discriminants

It is proposed that the new OTAR for IGA-CA should apply to (a) to (f) as follows. For the following definitions A = Business Aviation (Corporate) and B = Business Aviation (Owner Operated):

a. Operations [A] or [B] conducted with aeroplanes:
  - MTWA more than 5,700 kg; **or**
  - with a maximum approved passenger seating configuration of more than 9 **or**
  - certificated for operation with a minimum crew of at least 2 pilots **or**
  - equipped with (a) turbine engine(s);

b. Operations [A] or [B] conducted with helicopters:
  - MTWA more than 3,175kg; **or**
  - with a maximum approved passenger seating configuration of more than 5 **or**;
  - certificated for operation with a minimum crew of at least 2 pilots;

c. Operations [A] or [B] conducted with a tilt rotor aircraft

d. Operator [A] or [B] with an operational fleet of more than one aircraft;

e. Operator [A] or [B] who is required to hold a specific approval (MNPS, PRNAV, RVSM, AWOPS etc).

f. Other non-commercial operation (non-A or B) of "complex-motor-powered aircraft" [see Glossary].

The selection of the above discriminants has been based on discussion with other regulatory and industry bodies and the study of accident data. Commonality with the proposed EASA definition of "complex-motor-powered aircraft" has been chosen to assist in promoting harmonisation between regulatory bodies. The **exception** to this is the use of the term **turbine** in_Sub-clause (**a**) in order to include turbo-prop aircraft less than 5 700kg (e.g. PC-12, Cessna Caravan). This broadening of the EASA definition is proposed due to the higher accident rate of turbo-prop aircraft.

However, the IGA-CARA project (and future OTAR) is not targeted at turbo-prop aircraft with MTWA below 5 700kg in private ownership. The chosen discriminants in Sub-clause (**f**) have been chosen to include the new Very Light Jet (VLJ) type aircraft, but excludes turbo-prop aircraft with MTWA below 5 700kg.

From the Operations aspect, the definitions promoted by IBAC have been chosen, as these appear to correctly distinguish between categories. The only point to be noted is the possible ambiguity posed by Fractional Ownership schemes. These are currently viewed as private operation by the FAA (Part 91 sub-part K), but as commercial by ASSI, CAA and others. However, studies are currently underway by the Industry Working Group on Business Aircraft Operations (IWG-BAO), which will report to European Civil Aviation Conference (ECAC). This may influence the view of Fractional Ownership in the near future.

The choice of discriminants for the new OTARs could also benefit from additional dialogue with key stakeholders, e.g. regulatory authorities and industry bodies including IBAC.

5 ACCIDENT DATA AND CAUSAL ANALYSIS

5.1 Modelling Data

5.1.1 Data from IBAC

Based on the five year period 1999-2003 **[IBAC, 2005]**, the mean accident rate for business jets is calculated to be **0.53 per 100 000 hours**, and that for turbo-props is **1.89 per 100 000 hours**. For fatal accidents, the rates are 0.18 and 0.65 per 100 000 hrs, respectively, see Figure 17.

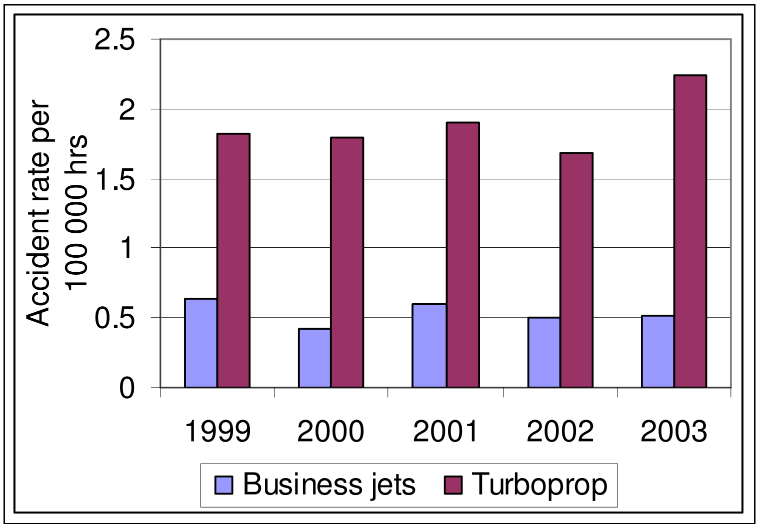


Figure 17: Worldwide accident rate [IBAC, 2005]

Also used in the risk assessment is information relating to the type of operation, listed in Table 2 (Business jet) and Table 3 (turbo-prop). These tables show the number of accidents per type of operation, assessed from global statistics, for business jet and turbo-prop aircraft separately. The data contained in **[IBAC, 2005]** is used in the risk assessment to calculate the accident rates for business jet and turbo-prop aircraft in the categories listed below.

- Part 135 non-scheduled Air Taxi
- Corporate aviation
- Owner operated

Operation	**Total accidents (5 yrs)**	**Fatal accidents (5 yrs)**	**Percentage of global total**	
			All	**Fatal**
Commercial	68	26	60%	68%
Corporate	16	4	14%	11%
Owner operated	16	5	14%	13%
Public/Gov	6	3	5%	8%
Fractional	7	0	6%	0%
TOTAL	**113**	**38**	**100%**	100%

Table 2: Global Business jet accidents 1999-2003 [IBAC, 2005]

Operation	**Total accidents (5 yrs)**	**Fatal accidents (5 yrs)**	**Percentage of global total**	
			All	**Fatal**
Commercial	220	44	61%	55%
Corporate	27	5.4	7%	9%
Owner operated	103	20.6	29%	34%
Public/Gov	10	2	3%	2%
Manufacturer	1	0.2	0%	0%
TOTAL	**361**	**72.2**	100%	100%

Table 3: Global Turbo-prop accidents 1999-2003 [IBAC, 2005]

5.1.2 Data from NTSB and FSF

NTSB data (downloaded from NTSB web-site) was also analysed for years 2000-2004. The database was searched on the basis of type of operation - FAR parts 91 (GA) and 135 (Commuter/Air taxi). Figure 18 summarises the records for:

- Part 91 operations – fixed wing > 4950 lb MTWA (2 250kg) - total 406 accidents.
- Part 135 operations - fixed wing > 4950 lb MTWA (2 250kg) - total 114 accidents.

The figure allows comparisons between Part 135 and Part 91 accident types to be made. For example, the proportion of accidents due to Loss of Control (UFIT – Non-technical) for Part 91 operation was 1.7 times that for Part 135 over this 5 year period. This could be due to the limited experience of Part 91 pilots when compared with Part 135 pilots.

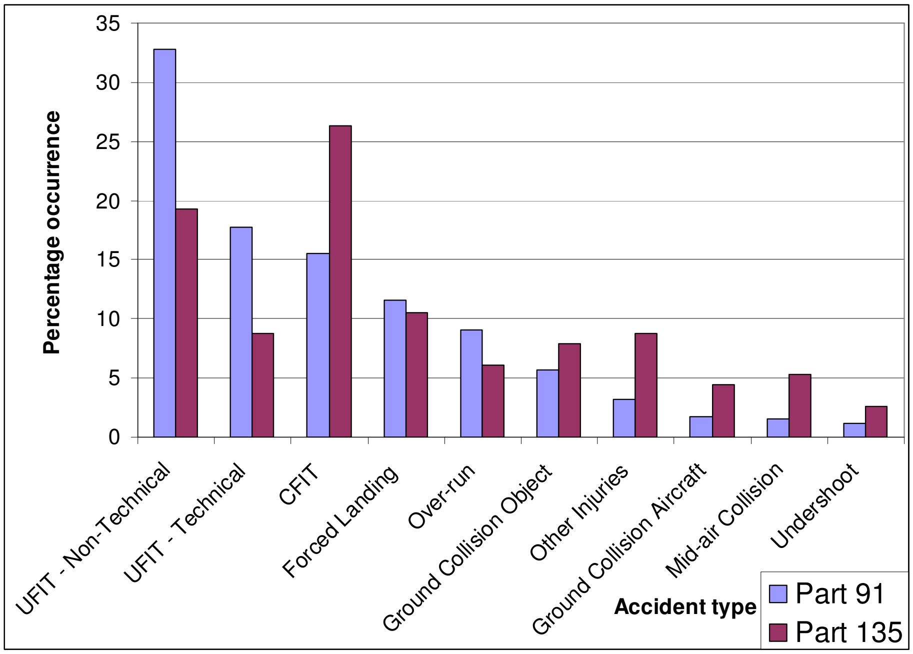


Figure 18: FAR Part 91 and Part 135 Accident types 2000 - 2004 [source NTSB]

The situation is reversed for CFIT, with a larger proportion of Part 135 aircraft suffering this type of accident. This could be due to the increased possibility of Part 135 flights taking place in IFR conditions.

Although a useful source of accident data, the NTSB data does not always clearly record the sub-category of operation within Part 91 (e.g. training, private, corporate flight). For this reason, data from **[Veilette, 2004]** has been used in this study. The latter has produced data for the number of accidents by phase of flight, see Figure 9, and the categorisation of accident types is in Figure 19.

Accident type		Total No	Fatal
Controlled Flight into Terrain		27	27
➢ Non-precision approach (NPA)	13		
➢ Precision	4		
➢ Visual	4		
➢ Not known	6		
Approach and landing (ALA)		104	10
➢ Runway over-runs	59		
➢ Runway undershoots	14		
➢ (10 fatal) Loss of Control	11		
➢ Hard landings	10		
➢ Failure to extend gear	7		
➢ Collisions with objects	3		
Mechanical failure		51	5
Take-off		30	9
Ground collisions		7	1
Animal strike		9	0
Mid-air collision		3	2
Pilot incapacitation		3	2
SAM		2	2
Unknown		8	7
Other		7	2
TOTAL		**251**	**67**

Table 4: Global Business jet accidents 1991-2002 [Veillette, 2004]

The accident types listed in Table 4 have been used as one of the inputs to the hazard Identification process (Section 5.3), and the proportion of each accident type has been used as data for the risk assessment calculation, summarised in Section 6.1. This entailed re-classifying some of the data into different categories – Accident types 1-10. For example, the CFIT category required no change, since this is listed as Accident type 1. However, Loss of Control and Take-off accidents were grouped together under the heading of “UFIT – Control-loss Non-technical”.

The work of **[Veillette, 2004]** contains a limited assessment of the causal factors involved with each accident type. However, there was no data found to correlate the causal and contributory factors by either size (weight) of aircraft or type of operation (e.g. FAR Part 91 or 135). In the case of approach and landing accidents, Table 17 in Appendix D.2 gives the factors which lead to 104 (41%) of the accidents studied. This assessment of causal factors is also shown in Figure 8.

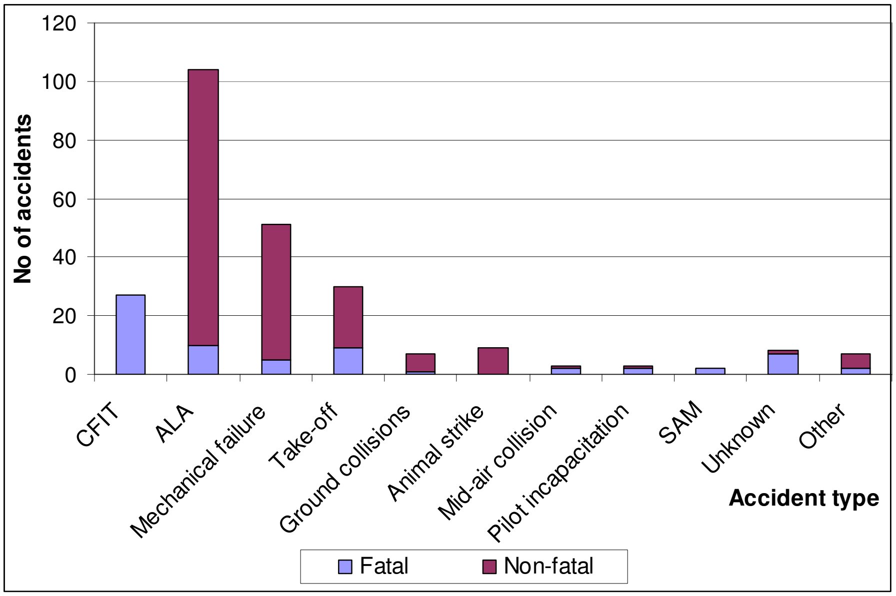


Figure 19: Accident types for 251 Business jets accidents from 1991-2002 [Veillette, 2004]

5.1.3 Data from Accident Analysis Group (AAG)

Figure 20 gives the relative frequency of fatal accident types for Business jet and Turbo-prop fatal accident types 1996 – 2004, from the 45 reports collected by the AAG **[source CAA].** The proportions of the different accident types differs substantially from the data in Figure 19 since the AAG only collects data for fatal accidents. If the **[Veillette, 2004]** data is altered to reflect only the fatal accidents, the proportions of the top three accident types are very similar. This comparison is made later in the report, see Section 6.1.

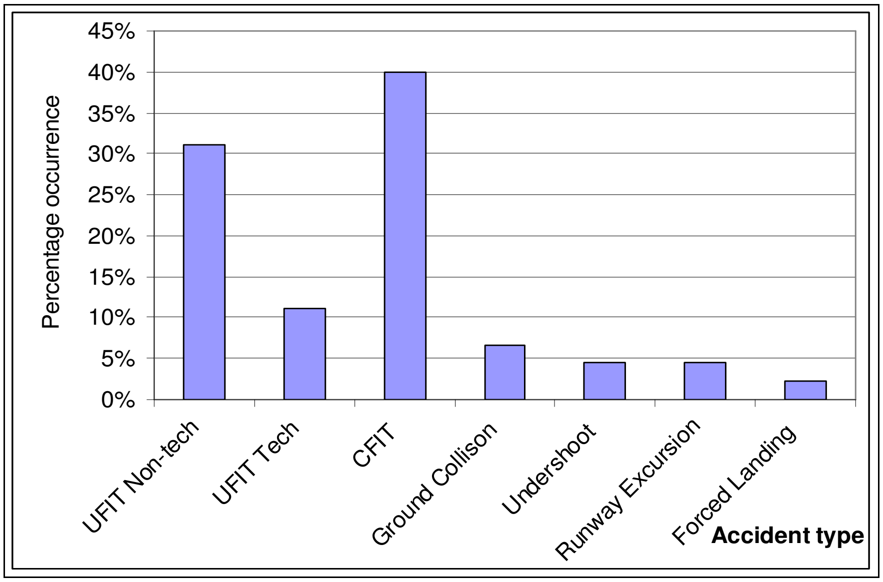


Figure 20: Business jet and Turbo-prop Fatal Accident types 1996 - 2004 [source CAA]

The Primary Causes of these accidents are listed in Table 5. For each fatal accident, the Primary cause is the one considered the most significant factor among what is often a series of causes. However, the information given does not allow further analysis of more deep-rooted factors. An example of this would be a lack of training or recency that could have led to "Omission of Action/Inappropriate action"

Accident Type	Primary Causal Factor	No	Total
UFIT Control loss Non-technical	Flight Handling	6	
	Omission of Action/ Inappropriate Action	3	
	Poor Professional Judgement/ Airmanship	2	
	Deliberate Non-Adherence to Procedures	1	
	Lack of Positional Awareness in Air	1	
	Press-on-itis	1	14
UFIT Control loss Technical	Maintenance or Repair Error/ Oversight/ Inadequacy	2	
	Engine Failure or Malfunction	1	
	Engine Fire or Overheat	1	
	System Failure – Other	1	5
CFIT	Lack of Positional Awareness in Air	13	
	Omission of Action/ Inappropriate Action	2	
	Deliberate Non-Adherence to Procedures	1	
	Lack of Awareness of Circumstances in Flight	1	
	Poor Professional Judgement/ Airmanship	1	18
Ground Collision	Flight Handling	2	
	Omission of Action/ Inappropriate Action	1	3
Undershoot	**Omission of Action/ Inappropriate Action**	1	
	Slow and/ or Low on Approach	1	2
Runway Excursion	Flight Handling	1	
	Fast and/ or High on Approach	1	2
Forced Landing	**Omission of Action/ Inappropriate Action**	1	1
Total			45

Table 5: Primary causes of Fatal Accident types shown in Figure 20
1996 - 2004 [source CAA]

A survey was also carried out to record the occurrence of all causes (not just Primary), and this is shown in Figure 21. It should be noted that many factors will be cited as causal more than once. One note of caution when studying these tables is that the AAG group reviewing each accident report only have access to a limited amount of information. There may therefore be other Factors underlying the "causes" which were not reflected in the Accident Investigation report, and hence be unreported by the AAG.

Notwithstanding the above, it is important to note that 9 of the top 13 causal factors quoted for fatal business and turbo-prop accidents relate to Human Factors issues on the flightdeck. These include Poor judgement/airmanship, Non-adherence to procedures etc. The most common factor quoted is Lack of positional awareness.

The corresponding "Circumstantial factors" for the 55 Business jet and Turbo-prop fatal accidents (1994 – 2004) are also given in Figure 22. These are those factors that are judged to have possible contributed to the accident. They are not directly causal but could have had an influence on the outcome. The same note of caution should also be sounded as for Causal Factors above, i.e. the dependence on the original accident report which could have been compiled to varying degrees of details and depth by the National Investigating Agency (NIA). However, there may also be bias introduced by the AAG, which could be limited by the actual knowledge surrounding the background of each accident.

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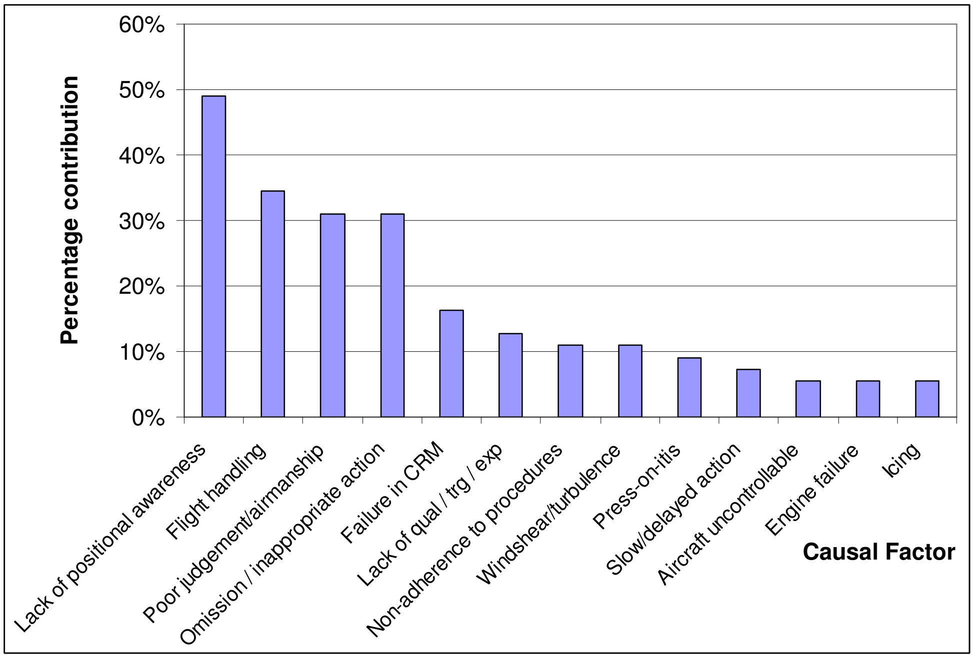

Figure 21: Causal Factors for 55 Business jet and Turbo-prop Fatal Accidents 1994 - 2004 [source CAA]

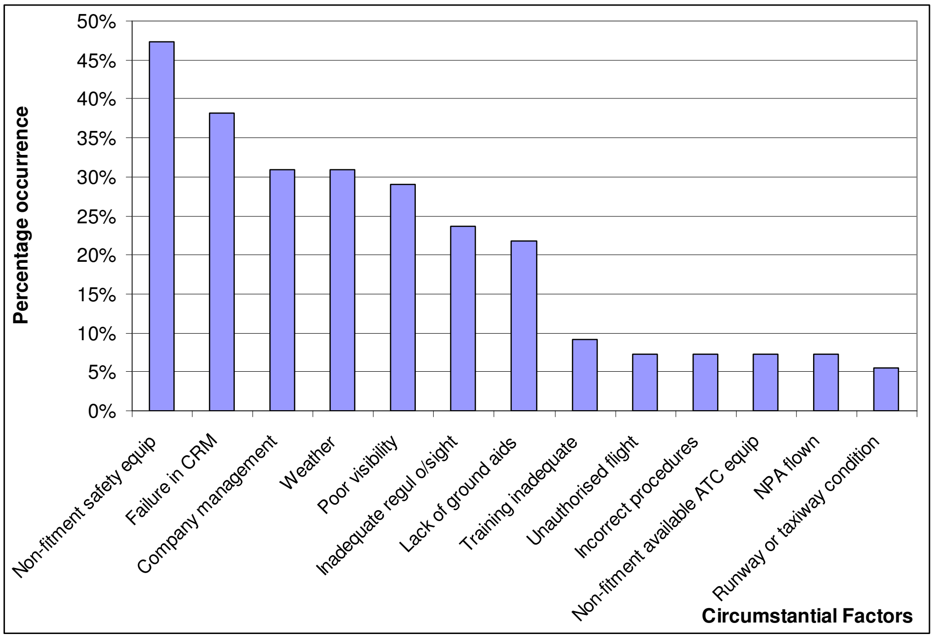

Figure 22: Circumstantial Factors for 55 Business jet and Turbo-prop Fatal Accidents 1994 - 2004 [source CAA]

5.2 Primary Causal Factors

The complex interaction of contributing factors that combine to create an accident is never more apparent than when trying to understand and quantify the influence of human performance. As an essential component of the aviation system, the human has often been cited as the weakest link in the chain. Indeed many accident statistics appear to demonstrate an overwhelming proportion of 'flight crew' or 'human factors' accidents. However, a more balanced view demonstrates that as arguably the most flexible link, the human is best able to adapt to changes in circumstance or unpredicted events and hence provides a mantle of safety beyond that of technology. Indeed it is this 'last line' defence capability which means that when an accident happens, there is a temptation to point to the human as the cause of failure rather than just the final defence to be breached.

One of the limitations of traditional aircraft accident investigation has been the depth to which human performance issues have been explored. At best the approach has been sporadic with the consequence that unless the data are interpreted with some context, it is easy to allocate resources to inadequate or inappropriate solutions. Early generations of cockpit and crew resource management (CRM) were good examples of where interventions were targeted at an 'area' without a full understanding of the problems to be solved. Considering the factors that influence the preconditions of unsafe acts is vital to the process of selecting strategies to eliminate, trap or manage the risk from human performance limitations.

Primary Causal Factors	**Fatal Accidents**	**Percentage of total number of accidents (589)**	
Lack of Positional Awareness in Air	123	20.9	**Crew Ops category** **67%**
Omission of Action/ Inappropriate Action	116	19.7	
Flight Handling	76	12.9	
Press-on-itis	46	7.8	
Poor Professional Judgement/ Airmanship	22	3.7	
Deliberate Non-Adherence to Procedures	14	2.7	
Design Shortcomings	13	2.2	
Windshear/ Upset/ Turbulence/ Gusts	12	2.0	
Maintenance or Repair Oversight/ Error/ Inadequate	10	1.7	
System Failure - Affecting Controllability	10	1.7	
Most frequently identified primary causal factors	442	**75%**	

Table 6: Most common Primary Causes of 589 Fatal Accidents 1980 – 1996, source CAP 681 [CAA, 1998]

Lack of positional (or situational) awareness in the air is cited as a primary cause in 123 (21%) of the accidents considered in the Safety Regulation Group study **[CAA, 1998**], Table 6. **[Endsley, 1995]** defines situational awareness as "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Loss of situational awareness tends to be the consequence of three possible failure modes:

a) failing to correctly perceive the situation; the consequence of fallible perception – perhaps due to an individual's ability, performance state or illusions);

b) failure to comprehend the situation; the result of an individual's ability to interpret a situation or information – often a function of experience); or

c) failure to project the situation. An individual's failure to perceive and comprehend a situation and then take appropriate actions at the right time in the future. This may be the result of distraction, lack of co-ordination or other performance-limiting conditions such as fatigue.

This information highlights the secondary human factors that are not necessarily apparent at first glance. For example, the influence of fatigue on the ability of a human to perceive, comprehend and react to a situation is well documented in the research literature. However, the exact nature and magnitude of this influence is much harder to quantify, especially within the specific category of aircraft accidents. Fatigue is difficult to accurately measure, especially during the accident investigation when evidence may have been destroyed.

Several strategies for reducing lack / loss of positional awareness exist – a feature of its insidious threat to safe aviation. In terms of training interventions, the two key strategies are the use of crew resource management (CRM) training, particularly in terms of crew interaction, cross-checking and communication; and Line Oriented Flight Training (LOFT). The difficulty with both CRM and LOFT is the concept of evaluation, not least because they have tended to be introduced as non-jeopardy training. Broad and varied definitions of both concepts means that even where evaluation is desired, it is difficult to quantify the effect of either CRM or LOFT even though there is strong anecdotal evidence of their benefit and indeed regulatory requirements for their application in certain sectors.

In terms of technical interventions, Ground Proximity Warning Systems (GPWS and EGPWS), Airborne Collision Alert and Avoidance Systems (ACAS and TCAS) and Head-up Displays (HUDs) have all demonstrated the ability to restore or enhance situational awareness although none of them are totally infallible. Indeed even advanced technology can be rendered ineffective where flightcrew choose to override a warning that they perhaps misinterpret as false or nuisance.

Loss of positional / situational awareness remains an insidious threat to aviation safety in spite of a number of possible intervention strategies. A combined approach of training and technical solutions appears to offer the greatest potential for managing the risk. However, the threat is an evolving one as advanced technology aircraft are susceptible to introducing new challenges such as mode confusion. For specific operators, accurate measurement of the threat can come from Flight Data Monitoring (FDM) and voluntary reporting by crews.

According to the CAA data, Table 6, the second-largest (19.7%) category of preconditions for unsafe acts (by primary cause) was "omission of action / inappropriate action". This was also ranked as the number one primary causal factor for Business Jets, accounting for 23.4% of primary causes. The category mainly referred to instances where "…crew continuing their descent below the Decision Height or Minimum Decision Altitude without visual reference or when visual clues were lost." Issues of crew decision-making are complex, not least because the clarity of hindsight provided after an accident can often give the impression that a decision was much clearer cut that the circumstances on the day actually made it.

The development of the University of Texas' Line Oriented Safety Audit (LOSA), which is endorsed by ICAO as "…a tool for monitoring normal flight operations and developing countermeasures against human error" **[ICAO, 2002]** has helped paint a clearer picture of how flightcrew errors occur. By examining a large number of normal flights with trained observers, the study team has managed to better understand the types of errors crews make, their relative frequency and consequences. Most errors that occur on a routine flight are trapped before they become consequential, either by the originator or a fellow crewmember. Indeed, following 1,310 US airline flight observations, the LOSA team presented the following data [**FSF, 2005**]:

- 64% of flights recorded one or more errors
- The most frequent errors involved hand-flying (21%); checklists (20%); and communication / coordination between flight crew and air traffic control.
- Most errors (43%) occurred during descent, approach and landing.
- The second highest proportion of errors occurred before departure (27%)
- The third highest proportion of errors occurred on takeoff (22%)

Further breakdown reveals multiple error types, specifically:

- Intentional non-compliance errors
- Procedural errors
- Communication errors
- Proficiency-based errors
- Operational decision errors

The consequence of these errors depends upon whether they are trapped, exacerbated or ignored by the flightcrew. The 'normal operations' assessments demonstrate that those errors that lead to an accident may be complex and numerous. Caution needs to be applied in targeting solutions at the specific error highlighted in an accident investigation as a more general approach may better manage the range of possible errors.

There a number of possible training and technical interventions that can help to reduce the hazard of "omission of action / inappropriate action". CRM, and in particular the ability for crew members to communicate assertively where appropriate, an emphasis on cross-checking and strict adherence to Standard Operating Procedures (SOPs) can help defend against inappropriate actions or at least provide a mitigation should such an error occur. Pre-eminent to this, appropriate SOPs also need to exist to cover the situations that crews are likely to encounter and in turn these SOPs need to be supported by training. In terms of technical interventions, equipment such as TCAS and GPWS, as well as other aircraft systems such as gear and configuration alerts, provide defences to trap errors before they become consequential, but generally do not protect against an inappropriate action being made in the first place. Such actions tend to be predominantly a function of an individual's training, experience and mental state and in turn, can be influenced by factors as diverse as corporate pressure, situational awareness or personality clashes.

In third place in the CAA study, the category of 'flight handling' refers to the manipulation or 'stick and rudder' skills of flight crew. This is a direct function of training, experience and familiarity with aircraft type. Lack of operational experience can be addressed to a degree by simulator training, but the quality of this is dependent upon availability of simulators, their fidelity and the nature of training conducted in the simulator. Operators with access to high-fidelity simulators with structured training programmes (such as LOFT) will see commensurate improvement in flight handling skills.

Whilst each category within the CAA study is discrete, there are several which highlight the fact that safety interventions can have a positive effect on several possible causal factors. For example, CRM is a strategy that has potential to reduce loss or lack of positional / situational awareness, to reduce inappropriate actions or at least to increase the likelihood that such errors would be trapped and mitigated before they became consequential. Whilst there is a separate category cited in the study as 'failure in CRM (cross-check / co-ordinate)', improvement in CRM skills may also have a positive effect on categories such as 'poor professional judgement / airmanship', 'press-on-it is' and even 'slow / delayed action'.

Some preconditions for unsafe acts that were cited in the dataset highlight the fact that certain hazards may be obscured by the limitations of considering accidents in terms of a 'primary cause'. For example, of the 589 fatal accidents that were examined, only one demonstrated 'slow and / or low on approach' as a primary cause, but 112 recorded it as a causal factor. This is likely to be on account of the fact that slow and / or low on approach is likely to be symptomatic of another failure such as lack of positional awareness, flight handling or slow / delayed reaction.

5.2.1 Fatigue

Other preconditions recorded lower scores than the research literature may lead the reader to expect currently. Fatigue was only cited a causal factor in 13 of the 589 accidents, yet many regulatory agencies, pilots associations and research institutions are placing considerable resources into dealing with this threat. The reasons for this apparent disparity are two-fold.

Firstly, as mentioned earlier, the investigation of fatigue during an accident investigation is notoriously difficult, not least when flight crew have been fatally injured. Few national investigating agencies (NIAs) have investigators who are trained human performance specialists. Even when such specialists are used, there are several schools of thought as to how to measure fatigue following an accident. Secondly, the threat posed by fatigue is changing as factors such as increased aircraft range, airspace congestion and the rise of low cost carriers with tighter turnarounds all have an influence. The effects of fatigue are varied, but are often associated with a reduction in cognitive performance and impaired motor skills. In turn this is likely to effect areas such as risk-assessment, decision-making and flight handling.

Quantifying the influence of fatigue on aircraft accidents is difficult, largely because of the challenge of collecting hard evidence, particularly when the pilot has been fatally injured. Notwithstanding this, various expert groups highlight the importance of fatigue as a causal factor of accidents. For example in a consensus statement of 28 leading sleep scientists published in 2000, fatigue was cited as the "…largest identifiable and preventable cause of accidents in transport operations (between 15 and 20% of all accidents)" **[Akerstedt et al, 2000]**.

NASA Ames Research Centre has also considered the role of fatigue in accidents and noted "…the contributory or causal role that fatigue may play in an accident is often underestimated or potentially ignored" **[Rosekind et al, 2000]**. The US National Transportation Safety Board has listed fatigue as one of its 'most wanted' safety improvements continually since 1996.

5.3 Hazard Identification

Based on information from **[Veillette, 2004**] in Figure 19, and [**CAA, 1998**] in Table 5, plus searches of AAG and NTSB databases, accident types have been categorised in Table 7 (Fixed wing) and Rotary wing (Table 8). The accident types have been numbered 1 to 10, within three bands corresponding to the risk matrix in Figure 13 - Catastrophic, Hazardous, Major, as defined by CAP 712 **[CAA, 2002].**

Although the categorisation may appear to quite coarse, this has been necessary since the actual number of accidents on which the analysis is relatively small (251). If greater detail were applied, e.g. sub-dividing the "Loss of Control" category, the results could be misleading. It should also be noted that the risk assessment has only been pursued beyond this point for fixed wing aircraft.

<u>Catastrophic</u> (Loss of the aircraft, Multiple fatalities)

1. **Controlled** Flight into terrain (CFIT) is described in detail in Appendix C and is the subject of a focussed campaign by CAST and FSF. It occurs when an aircraft collides with terrain, obstacles or water whilst under the control of the flight crew, but generally with little or no warning.

2. **Un-Controlled** Flight into terrain (UFIT) is where an aircraft collides with terrain, obstacles or water whilst not under control of the flight crew. For <u>Control Loss Technical</u>, control of the aircraft is lost due to a technical failure of the aircraft, e.g. structural failure, engine fire.

3. **UFIT** (as above) may also occur due to <u>Control Loss Non-Technical</u>, where control of the aircraft is lost because of non-technical causes, e.g. local weather conditions, poor handling by the crew etc.

4. Mid-air Collision, a collision in-flight

<u>Hazardous</u> (Large reduction in safety margins, Serious or fatal injury)

5. Ground Collision with other aircraft. This category includes:

   - Very late Go-Arounds due to traffic on the runway.
   - Clearances given to enter runways with other aircraft landing or departing.
   - Inappropriate use of land and hold short operations (LAHSO).

6. Ground Collision with object/ obstacle

7. Over-run/Runway excursion, due to (for example) rejected take-off, Excessive landing speed and Landing deep. Possible causes include incorrect flap settings, incorrect power settings, incorrect load distribution, high-speed and low-speed rejected take-offs, deep landings, reduced braking (thrust reverser, spoiler and braking deficiencies) and steering difficulties.

8. Undershoot/Runway excursion. Causes include incorrect flap settings, incorrect power settings, incorrect load distribution, landing short, reduced braking (thrust reverser, spoiler, braking deficiencies) and steering difficulties.

9. Forced landing – land or water

<u>Major</u> (Significant reduction in safety margins)

10. Fire/smoke during operation/other injury to passengers. Sources of fire include electrical failures, fuel spillages, FOD, ground equipment/vehicles and terminal fires.

Category	Potential Accident	Description
Collision	CFIT	An aircraft collides with terrain whilst under the control of the flight crew.
	Collision with terrain/water/ obstacle	UFIT - Control Loss Technical An aircraft collides with terrain, obstacles or water, whilst not under control of the flight crew, where control of the aircraft is lost due to a technical failure, e.g. Structural failure.
		UFIT - Control Loss Non-Technical An aircraft collides with terrain, obstacles or water, whilst not under control of the flight crew, where control of the aircraft is lost because of other causes e.g. local meteorological conditions, aerodynamic stall etc.
	Mid-air Collision	An aircraft collides with another aircraft whilst in flight.
	Ground Collision with other aircraft	An aircraft collides with other aircraft whilst manoeuvring on the ground within the aerodrome including on the runway (take-off or landing roll).
	Ground Collision with object/ obstacle	An aircraft collides with objects (ground equipment, vehicles etc) whilst manoeuvring on the ground within aerodrome including on the runway (take-off or landing roll).
Excursion	Over-run/Runway excursion	An aircraft departs the paved surface of the runway during the take-off or landing roll.
	Undershoot/Runway excursion	An aircraft departs the paved surface of the runway during landing.
	Forced landing – land or water	An aircraft is forced to land due to system failure (includes Fuel exhaustion)
Fire/Smoke/ Evacuation	Fire/smoke during operation	An aircraft is affected by fire occurring during operation from which subsequent fatalities could result.
Other causes	Security/ Other causes	An aircraft is destroyed through threats arising from security failures; ranging from lapses in Terminal Security to operating within regions of military conflict.

Table 7: Fixed Wing Aircraft Accident Type Categories

Category		Potential Accident	Description
Collision	CFIT	In-flight collision with object	**A helicopter collides with object whilst in flight:** • Airport/helipad/fence/building • Wire/pole/tower • Trees, brush, aircraft
	UFIT	In-flight collision with terrain/water	UFIT - Control Loss Technical A helicopter collides with terrain/water, whilst not under control of the flight crew where control of the helicopter would be lost due to a technical failure such as: • Loss of engine power. • Structural failure. • Airframe/component/system failure/malfunction
			UFIT - Control Loss Non-Technical A helicopter collides with terrain/water, whilst not under control of the flight crew where control of the helicopter would be lost because of other causes e.g. local meteorological conditions etc. • Loss of Control • Weather/local conditions
		On-ground/water collision with object/ terrain/water	**A helicopter collides with an object, terrain or water whilst manoeuvring on the ground/water:** • Hard landing • Rollover/nose-over • Forced landing – land or water
Other Injuries to passengers		Fire/smoke during operation	A helicopter is affected by fire occurring during operation from which subsequent fatalities could result. Sources of fire include: electrical failures, fuel spillages, FOD, ground equipment/vehicles and terminal fires.
		Rotor contact - person	
Security/ Other causes			A helicopter is destroyed through threats arising from security failures; ranging from lapses in Terminal Security to operating within regions of military conflict.

Table 8: Helicopter Accident Type Categories

6 RESULTS & DISCUSSION

The methodology of Section 4 is now applied to perform the risk assessment and Steps A to K from Section 4.3 were followed for the estimation of risk. The accident type and usage data were merged to calculate the proportion of accident types for Business jets and turbo-props, according to their use in business and corporate operation. The Part 135 (unscheduled) Air Taxi results were calculated throughout in order to give a "bench-mark" against which the results could be compared.

6.1 Accident and Consequence data

Accident rate data from [**IBAC, 2005**] has been used to derive separate rates for the types of operation shown in Table 9. For the purpose of comparison, results of the risk assessment are also presented for FAR Part 135 operations (referred to as "**135**")

	Hrs in 5 yrs			**Total accidents**	
Operator type	Total	Business jet	Turbo-prop	Business jet	Turbo-prop
135 - Commercial (Air taxi)	9.15E+06 [1]	5.03E+06	4.12E+06	68	220
A Corporate	1.55E+07	8.52E+06	6.97E+06	16	27
B Owner operated	1.58E+07	8.70E+06	7.12E+06	16	103

Table 9: Operations and Accident Data

The data in Table 9 has been created by using the percentage of flight hours given by **[IBAC, 2005]** for the USA, and using this for global operations. This approximation has been justified on the basis that the USA accounts for 72% of the global total, so reducing the effect of the possible bias. The respective flight hour break-down used is:

Part 135 non-scheduled Air Taxi	22.6%
Corporate aviation	38.3%
Owner operated	39.1%

The total global flight hours in 2003 is quoted as 4 741 355 hours for business jet and 3 975 609 hours for turbo-props, a split of 55%/45%. This has been applied for the three types of operation. In reality this may not be the case, e.g. there may be proportionally more hours flown by turboprops than business jets in Air Taxi operations. For this level of analysis however, the split will still produce an indication of the higher risk areas. As an example of the procedure for each calculation, for Commercial (Air taxi), the accident rate is:

$$\text{Accident rate (135 jet)} = \frac{68}{5.03E06} = 1.35 \text{ per } 100\,000\text{hrs}$$

Operator type		Accident rate per 100 000 hrs		
		Total	Business jet	Turbo-prop
135	Commercial (Air taxi)	**3.15**	1.35	5.35
A	Corporate	**0.28**	0.19	0.39
B	Owner operated	**0.75**	0.18	1.45

Table 10: Accident data Calculated for each Type of Operation

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[1] 9.15E+06 is the mathematical representation for 9.15 x 10^6, which is 9 150 000

The sources from which accident data were obtained were listed in Sections 2.3 and 4.4, and the data obtained is listed in Table 11. Data from FSF **[Veillette, 2004]** have been used to estimate the proportion of total accidents as well as fatal accidents. It is useful to compare these (column 2) with the fatal accident data from AAG (column 5) and observe the close correlation for Accident types 1-3. Data from the NTSB have been used to calculate the proportion of different accident types for FAR Part 91 (MTWA > 2 250kg) and Part 135 operation. However, these data contain a mix of different operations and are therefore not used in the risk calculation.

- Part 91 – Private operator, corporate aviation
- Part 135 – Commuter airline, Non-scheduled Air Taxi

Data from column 1 (FSF) is used for the risk assessment calculations. This is specific to corporate and business aviation, and has been based on a world-wide survey of accident reports from verified sources.

No	**Accident type**	**FSF** [1]	**FSF** [1] **fatal**	**NTSB** [2] **Part 91**	**NTSB Part 135**	**AAG** [3]	Fatalities [4] per accident
	Catastrophic	**Proportion of accidents**					
1	CFIT	**10.8%**	40.3%	15.5%	26.3%	40%	6.5
2	UFIT - Control Loss Technical	**20.3%**	7.5%	17.7%	8.8%	11%	5
3	UFIT - Control Loss Non-Technical	**16.3%**	28.4%	32.8%	19.3%	31%	5
4	Mid-air Collision	**1.2%**	3%	1.5%	5.3%	0	20
	Hazardous	**Proportion of accidents**					
5	Ground Collision with other aircraft	**2.8%**	1.5%	1.7%	4.4%	3.5%	2
6	Ground Collision with object/ obstacle	**4.8%**	0	5.7%	7.9%	3.5%	1
7	Over-run/Runway excursion	**23.5%**	0	9.1%	6.1%	4%	1
8	Undershoot/Runway excursion	**5.6%**	0	1.2%	2.6%	4%	1
9	Forced landing on land or water	**7.6%**	3%	11.6%	10.5%	2%	1
	Major	**Proportion of accidents**					
10	Other Injuries to passengers	**7.2%**	16.4%	3.2%	8.8%	1%	1

Notes:

1. FSF data **[Veillette, 2004**] relates only to business jets
2. Aircraft with MTWA > 2 250 kg
3. AAG data relates only to fatal accidents.
4. Estimated from accident reports/judgement

Table 11: Accident data from sources used for IGA-CARA

Also shown in the last column of Table 11 is estimated data for the Consequence of each accident. The number of fatalities for CFIT for business aircraft has been estimated from **[Veillette, 2004].** The latter quoted 174 deaths over the 27 CFIT accidents, which gives an average of approximately 6.5 per accident. However, although the total number of fatalities per year is available, in-depth review of accidents reports to determine average fatalities for other accident types has not been carried out.

The figures quoted have been drawn from a judgement of the likely number of persons on board a typically small executive jet or turboprop used for transporting high profile and senior people. The number of fatalities is not shown in the display of results in the Risk matrix, see Table 13, which uses the Consequence categories of Catastrophic, Hazardous and Major.

6.2 Accident rate results

The data used in the risk analysis is based on the accident types in Table 4, and is displayed in Figure 23 to allow a visual inspection of the relative frequencies to be made. The most frequent accident type is Runway over-run (Accident No 7), followed UFIT Control-Loss (Technical), then UFIT Control-Loss (Non-technical).

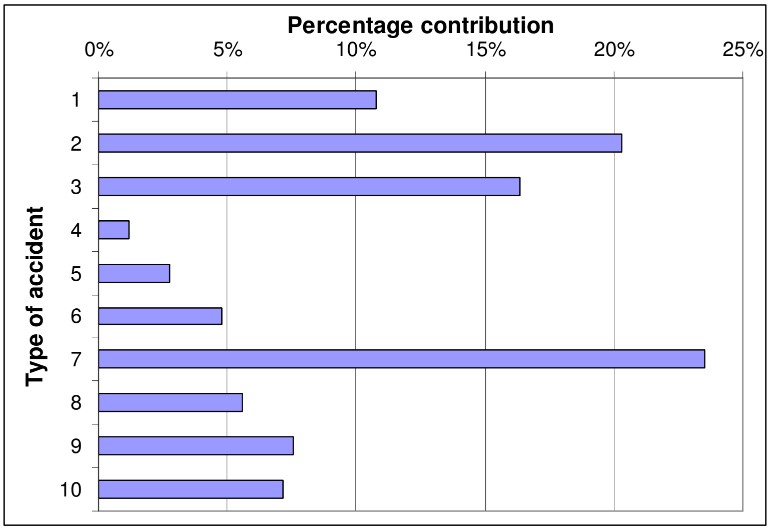

Figure 23: Contribution of each accident type to total Accident rate Business Jet data [Veillette, 2004]

These accident rates are apportioned in respect to aircraft type and operation, in the following manner. For example, if $\mathbf{p_1}$ is the proportion of Accident type 1 among all accidents, and $\mathbf{r_{135jet}}$ is the total accident rate for Business jets in Part 135 operation:

Accident 1 frequency (Business jets in Part 135 operation) = $\mathbf{p_1} \times \mathbf{r_{135jet}}$
Accident 2 frequency (Business jets in Part 135 operation) = $\mathbf{p_2} \times \mathbf{r_{135jet}}$

Similarly

Accident 1 frequency (Turbo-prop aircraft in Corporate operation) = $\mathbf{p_1} \times \mathbf{r_{A\ turbo}}$
Accident 2 frequency (Turbo-prop aircraft in Corporate operation) = $\mathbf{p_2} \times \mathbf{r_{A\ turbo}}$

Accident No	135 jet	A jet	B jet	135 turbo	A turbo	B turbo
1	0.146	0.020	0.020	0.577	0.042	0.156
2	0.274	0.038	0.037	**1.085**	0.079	0.294
3	0.220	0.031	0.030	0.871	0.063	0.236
4	0.016	**0.002**	**0.002**	0.064	**0.005**	0.017
5	0.038	**0.005**	**0.005**	0.150	0.011	0.041
6	0.065	**0.009**	**0.009**	0.257	0.019	0.069
7	0.318	0.044	0.043	**1.256**	0.091	0.340
8	0.076	0.011	0.010	0.299	0.022	0.081
9	0.103	0.014	0.014	0.406	0.029	0.110
10	0.097	0.014	0.013	0.385	0.028	0.104

Table 12: Results for Accident Frequency (per 100 000 hrs) for Business Jet and Turbo-prop Aircraft

The results appear as in Figure 24 for Catastrophic (Accident types 1-4) and Figure 25 for Hazardous (Accident types 5-9) events. Purely on the basis of frequency, the operation of FAR 135 Air Taxi turbo-prop aircraft is estimated to have the highest frequency for Accident types 1-3, as shown in Table 12. The next highest accident rates are estimated for Business Aviation – Owner operated for turbo-prop aircraft. These are underlined in the table of results and are in the "Probable" column in Table 13. The lowest frequency accidents predicted are for the seven categories highlighted in bold, and fall within the "Extremely remote" column in Table 13.

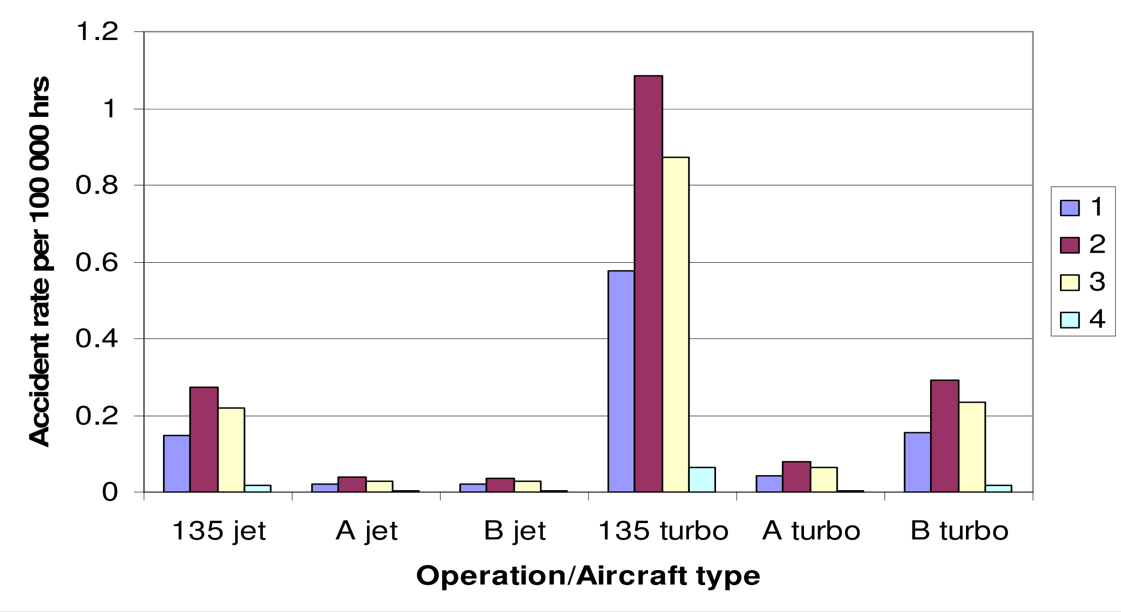

Figure 24: Summary of Estimated Accident Rate (Catastrophic)

Table 12, Figure 24 and Figure 25 show that the highest frequency accident for the six combinations of aircraft type/operation is Accident type 7, runway over-run. The occurrence rate of Accident types 1-10 within each category (e.g. corporate operation of business jet) do not vary since the proportion of accidents has been assumed to the same. Hence, although the absolute rate for CFIT (accident type 1) for "135 turbo" is 13.7 times that for corporate operators, this is purely because the **overall** accident rate (5.35 per 100 000hrs) is 13.7 times the accident rate for corporate operators (0.39 per 100 000hrs), see Table 10.

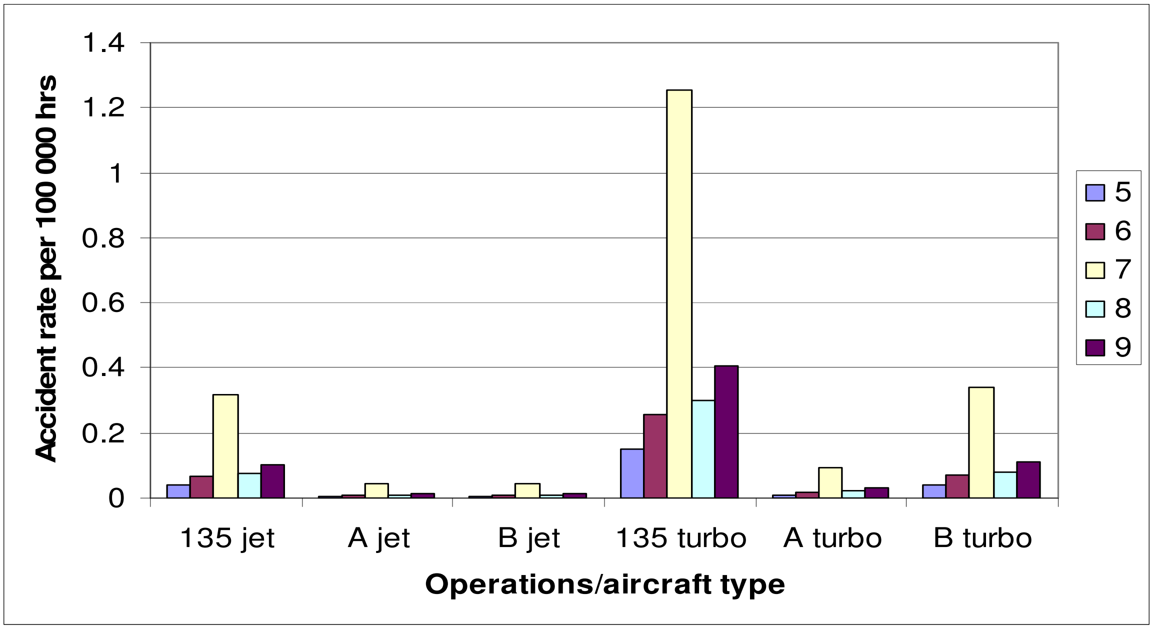

Figure 25: Summary of Estimated Accident Rate (Hazardous)

6.3 Risk Assessment results

Based on results in Table 12, the risk matrix in Table 13 has been presented to show graphically the relative positions of accident types within Frequency-Consequence parameters. Most are seen to be estimated in the "Remote" band, which represents a frequency of between 0.01 and 1 per 100 000hrs. The exceptions are UFIT (Control-Loss Technical) and Over-run for FAR Part 135 Air taxi with turbo-prop, both of which are estimated as greater than 1 per 100 000hrs. The matrix can be used to view the highest risks according to type of aircraft operated and type of operation.

The classification of the risks show that although the estimated rate of occurrence of the catastrophic accident types appears low, that risk reduction action should still be considered. From Appendix D of CAP712 **[CAA, 2002],** a risk tolerability matrix lists any risk in the Catastrophic/Remote or Hazardous/Remote category as being Unacceptable, and requiring risk reduction measures to be taken.

Catastrophic				
CFIT			**135/A/B jet** **135/A/B turbo**	
UFIT - Control Loss Technical			**135/A/B jet** **A/B turbo**	**135 turbo**
UFIT - Control Loss Non-Technical			**135/A/B jet** **135/A/B turbo**	
Mid-air Collision		**A/B jet** **A turbo**	**135 jet** **135/B turbo**	
Hazardous				
Ground Collision with other aircraft		**A/B jet**	**135 jet** **135/A/B turbo**	
Ground Collision with object/ obstacle		**A/B jet**	**135 jet** **135/A/B turbo**	
Over-run/Runway excursion			**135/A/B jet** **A/B turbo**	**135 turbo**
Undershoot/Runway excursion			**135/A/B jet** **135/A/B turbo**	
Forced landing on land or water			**135/A/B jet** **135/A/B turbo**	
Major				
Other Injuries to passengers			**135/A/B jet** **135/A/B turbo**	
Per flight hour	$< 10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-5}	$> 10^{-5}$
Per 100 000 hrs	$< 10^{-4}$	10^{-4} to 10^{-2}	10^{-2} to 1	> 1
	Extremely improbable	**Extremely remote**	**Remote**	**Probable**

Table 13: Results of Risk Assessment as part of Risk matrix

Based on estimated fatalities for each type of accident, the risk may now be estimated as in Table 14 Figure 26 and Figure 27. This reflects a different order of precedence for FAR 135 Air Taxi aircraft compared to Figure 24. Whereas the highest frequency accident was runway over-run (Accident No 7), the highest risk accidents are due to (in descending order), UFIT - Control Loss Technical, UFIT - Control Loss Non-technical, then CFIT.

Accident No	135 jet	A jet	B jet	135 turbo	A turbo	B turbo
1	0.949	0.132	0.129	3.753	0.272	1.015
2	1.372	0.191	0.187	5.426	0.393	1.468
3	1.102	0.153	0.150	4.357	0.315	1.179
4	0.324	0.045	0.044	1.283	0.093	0.347
5	0.076	0.011	0.010	0.299	0.022	0.081
6	0.065	0.009	0.009	0.257	0.019	0.069
7	0.318	0.044	0.043	1.256	0.091	0.340
8	0.076	0.011	0.010	0.299	0.022	0.081
9	0.103	0.014	0.014	0.406	0.029	0.110
10	0.097	0.014	0.013	0.385	0.028	0.104

Table 14: Results for Estimated Risk (fatalities per 100 000 hrs)

The results should be treated with a degree of caution, as there are several sources of uncertainty. The main issue is the difficulty of estimating the expected number of fatalities per accident type. Certain accident types, e.g. Mid-air collision, are rare but could involve aircraft that differ greatly in the number of people on board. An attempt to estimate the mean number of fatalities per Mid-air collision should consider a large sample, which is not possible due to the positive effect of procedural ATM procedures, ground radar and TCAS etc.

Similar comments could also be made about the difficulty of estimating fatalities for ground collisions. Although more frequent than mid-air collisions, the variability in consequence is also large. A small scale, low-speed collision could result in major injuries and no fatalities, whereas the accident at Linate in 2001 (Cessna Citation colliding with MD-87) resulted in 118 deaths.

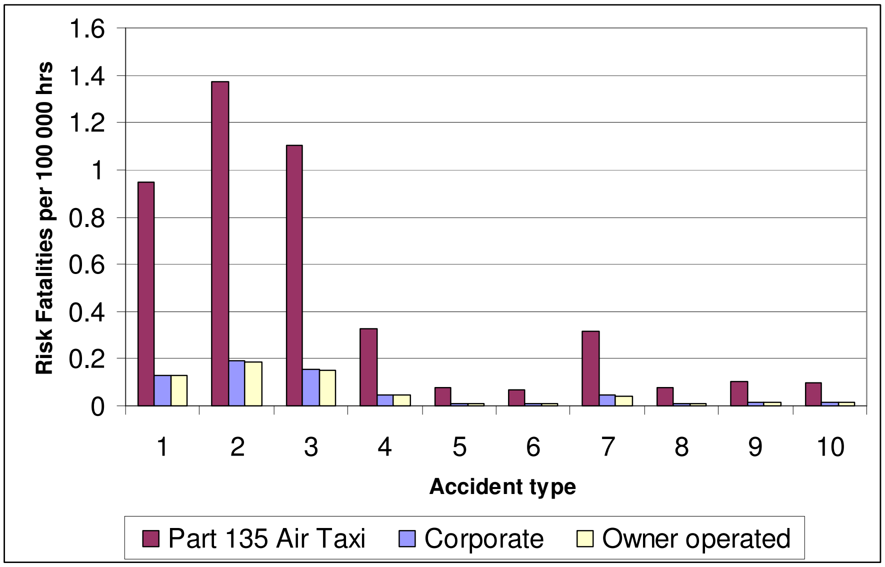

Figure 26: Summary of Estimated Risk for Business Jet

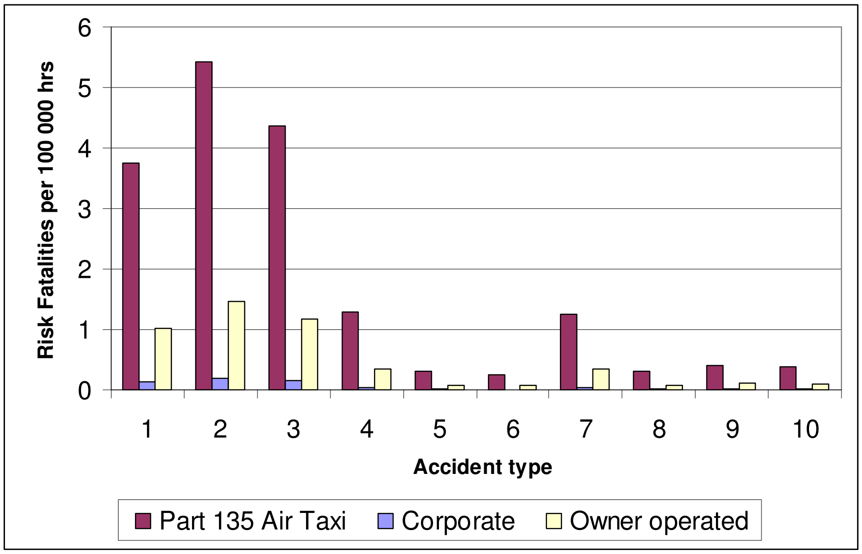

Figure 27: Summary of Estimated Risk for Turboprop Aircraft

The next highest risk results are estimated for Owner operated (referred to as Operator type 'B') for turbo-prop aircraft. Again, the order of risks is the same as that above for Part 135 operation and the consequences have a large amount of uncertainty associated with them.

Figure 26 refers to the risk from Business jet aircraft and can be compared directly with Figure 27 which is for turbo-prop aircraft. It is observed that the risks are greater due to the higher accident rate for turbo-prop aircraft generally. However, the relative position of each risk is the same as that for business jet, since the proportions of accidents for each category was assumed to be the same, see section 4.4.1.

6.4 Contribution of Risk Influencing Factors

The contribution of each RIF to the overall frequency of each Accident type has been estimated using judgement based on accident surveys and reports. For the limited scope of this project, the number of Risk Influence Factors (RIFs) has been reduced to five, when compared to Figure 15:

Aircraft Technical Dependability

- Design & Continuous Airworthiness RIF – any aspects of the aircraft design or modifications which may have been carried out.
- Operator's Maintenance RIF – any aspects of maintenance carried out to the aircraft.

Aircraft Operations Dependability

- Operations – this includes Environmental Factors, Condition of Flight Crew and Personnel factors (see Table 16). This also refers to the company procedures, rostering, culture, training, experience, recency and other factors which may underlie the human performance.

Other Conditions

- ATC/Airport RIF – any aspects of ATC facilities, instructions and airport operations or ground facilities.
- Environment RIF – any aspects of external factors, e.g. weather.

The contributions of each of the five RIFs are shown for Accidents 1 to 10 as percentages in Table 15 for Part 135 operation with Business Jets. Columns in the table should be read vertically. For example, Accident type 1 (CFIT) has an estimated frequency of occurrence of 0.146 per 100 000hrs for Part 135 business jet operation. The estimated consequence per accident is 6.5 fatalities. The estimated contribution of each RIF is then listed in each column, and the sum must add to 100%:

Design and Continuous Airworthiness	0%
Operator's maintenance	0%
Flight crew operations	80%
ATC/Airport	10%
Environment	0%

Further tables were also created for the other categories of operation and aircraft. However, the proportional contribution of each RIF is estimated to be the same for each combination.

The results in Figure 28 are presented in terms of percentages, and therefore apply for Business jet/Turbo prop aircraft for each operator type. The results show that the highest contributor to accident rate, and estimated accident risk, is the Operations RIF. Figure 28 also shows the contribution of each RIF to total accident frequency, and risk. After the Operations RIF the next largest RIF is that for Maintenance, showing the importance of high integrity in this function.

Some of the background of the associated Human Factors is presented and discussed in Section 6.5. The contribution of each RIF to accident types has been estimated only for the initial study. Further work is required to analyse the accident reports more deeply in order to assess the significance of each RIF in turn. Sensitivity studies are then required in order to provide a more complete assessment. However, given the scope of this project, it is viewed that the above results give a first approximation of the key risk factors.

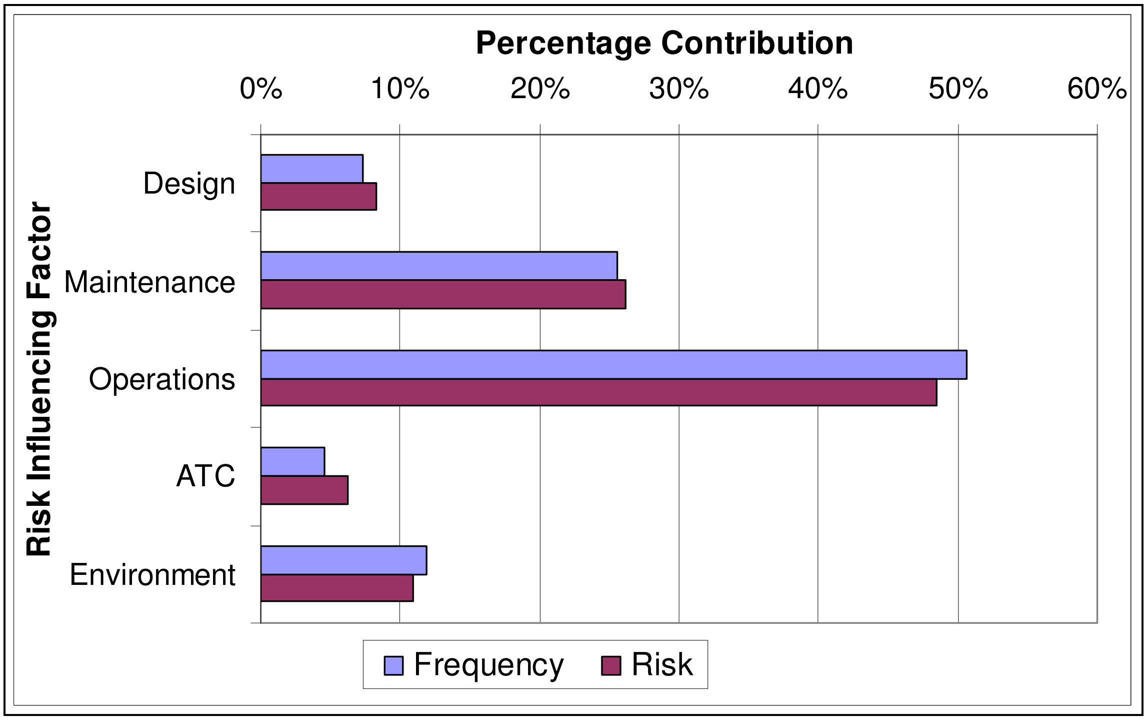

Figure 28: Contribution of Risk Influencing Factors to Total Accident rate and Total Risk

Frequency per accident type [1]		0.146	0.274	0.220	0.016	0.038	0.065	0.318	0.076	0.103	0.097	Percentage Of total	
Fatalities per accident type [2]		6.5	5	5	20	2	1	1	1	1	1		
RIFs	**RIFs for frequency**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Freq**	**Risk**
Design	Design & Continuous airworthiness		25%							10.0%	20.0%		
	Frequency		0.069							0.010	0.019	7.3%	
	Risk		0.343							0.010	0.019		8.3%
Maintenance	Maintenance		75%							80.0%	60.0%		
	Frequency		0.206							0.082	0.058	25.6%	
	Risk		1.029							0.082	0.058		26.1%
Operations	Operations	80%		80%	40%	40%	40%	80%	80%	10.0%	20.0%		
	Frequency	0.117		0.176	0.006	0.015	0.026	0.254	0.061	0.010	0.019	50.6%	
	Risk	0.759		0.881	0.130	0.030	0.026	0.254	0.061	0.010	0.019		48.4%
ATC/Airport	ATC/Ground aids	10%			40%	40%	40%						
	Frequency	0.015			0.006	0.015	0.026					4.6%	
	Risk	0.095			0.130	0.030	0.026						6.3%
Environment	Environment	10%		20%	20%	20%	20%	20%	20%				
	Frequency	0.015		0.044	0.003	0.008	0.013	0.064	0.015			11.9%	
	Risk	0.095		0.220	0.065	0.015	0.013	0.064	0.015				10.9%
TOTAL												**1.353**	**4.481**

Table 15: Results from Part 135 Business jet operation

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[1] Frequency per accident type from Table 12

[2] Fatalities per accident type from Table 11

6.5 Operational Human Factors

The previous section indicated that the so-called “Operations RIF” is the most influential in terms of both frequency of accidents, and the risk associated with those accidents. Although these may be summarised as Unsafe acts (Errors and Violations), the only way to analyse the underlying factors is to expand the work in terms of the preconditions for these unsafe acts. The analysis may then go deeper into the supervisory and organisational pre-conditions, as follows.

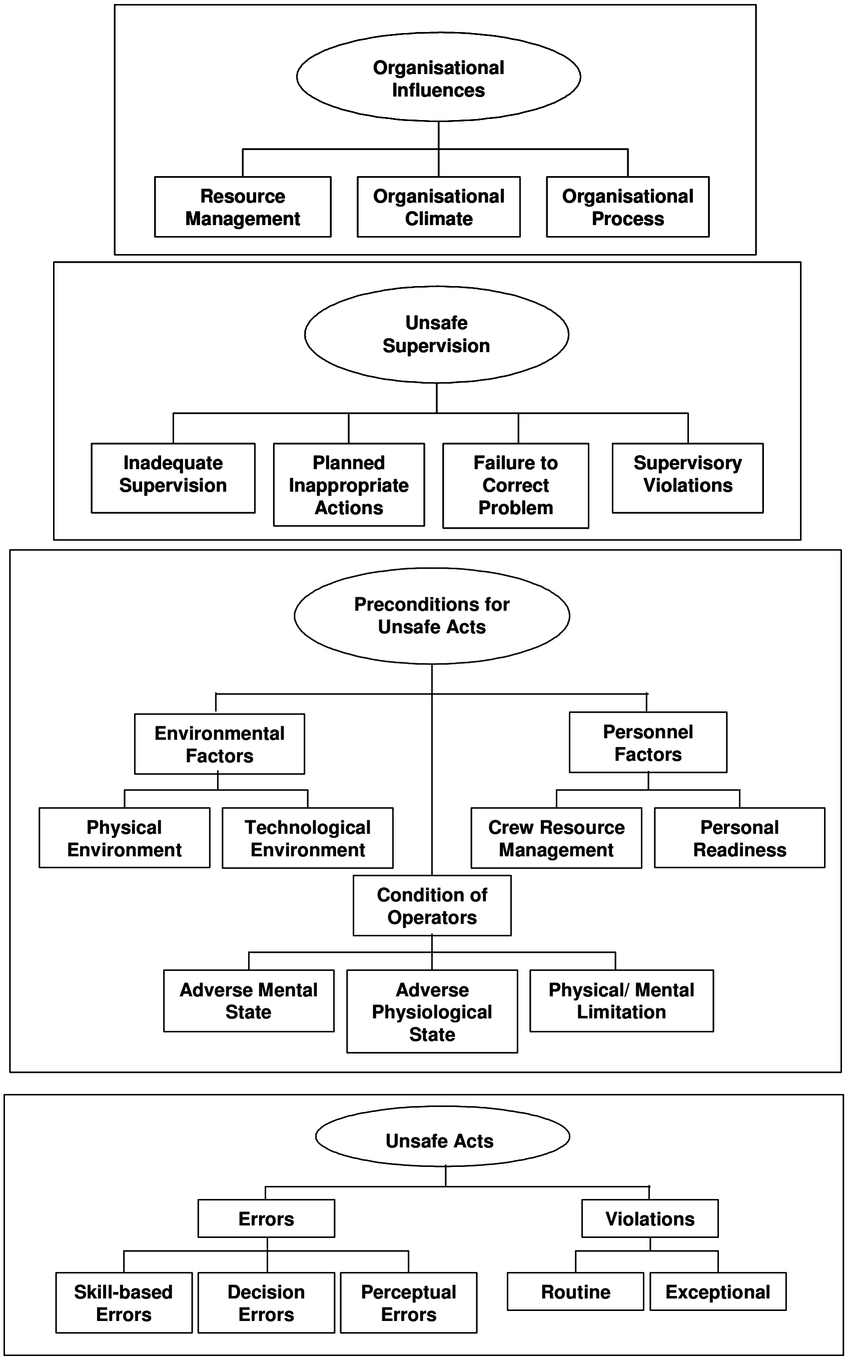

Figure 29: Human Factors Analysis & Classification System (HFACS) [Wiegmann & Shappell, 2003]

Human performance, particularly within the ‘operational’ areas of aviation is acknowledged to be the largest single area of threat. However, it is an area of considerable debate, particularly in the classification of errors and violations, the preconditions that lead to them and the local or organisational factors which in turn influence the preconditions.

The work of organisational psychologists such as Rasmussen, Reason and Dekker has helped clarify (and occasionally confuse) the industry’s understanding of the human factors behind accident causation. More recently the work on the HFACS – Human Factors Analysis and Classification System **[Wiegmann and Shappell, 2003]** has helped to define a common framework, see Figure 29.

Condition of Operator

Adverse Mental States
- Loss of situational awareness
- Complacency
- Stress
- Overconfidence
- Poor Flight Vigilance
- Task Saturation
- Alertness (drowsiness)
- Get-home-itis (time pressure)
- Mental Fatigue
- Circadian dysrhythmia
- Channelised Attention
- Distraction

Adverse Physiological States
- Medical Illness
- Hypoxia
- Physical Fatigue
- Intoxication
- Motion Sickness
- Effects of OTC Medications

Physical/ Mental Limitations
- Visual Limitations
- Insufficient Reaction Time
- Information Overload
- Inadequate experience for complexity of situation
- Incompatible Physical Capabilities
- Lack of Aptitude to Fly
- Lack of Sensory Input

Personnel Factors

Crew Resource Management
- Failed to Conduct Adequate Brief
- Lack of Teamwork
- Lack of Assertiveness
- Poor Communication/ Coordination within & between Aircraft/ ATC etc
- Misinterpretation of Traffic Calls
- Failure of leadership

Personal Readiness
- Failure to adhere to Crew Rest requirements
- Inadequate Training
- Self-medicating
- Over-exertion while off-duty
- Poor dietary practices
- Pattern of poor risk judgement

Environmental Factors

Physical Environment
- Weather
- Altitude
- Terrain
- Lighting
- Vibration
- Toxins in the Cockpit

Technological Environment
- Equipment/ Controls Design
- Checklist Layout
- Display Interface Characteristics
- Automation

Table 16: Examples of Preconditions of Unsafe Acts
[Table 3.2, Wiegmann & Shappell, 2003]

Utilised by the US military, Canadian Transport Safety Board and about to be adopted by a number of NIA’s, HFACS provided a logical framework for the consideration of human factors issues behind the operational accidents in this study. In particular, HFACS reminds the reader that unsafe acts – those errors and violations often associated with front-line operators and the final failed filter in an accident sequence – are the consequence of preconditions and influences further back in the system (Table 16). Indeed such preconditions and influences can go as far back as the regulatory system as shown in Level 3 of the SINTEF **[Hokstad et al, 1999]** model diagram (), and by “Organisational Influences” in Figure 29. However for the purposes of this study, it is all but impossible to quantify the level of effect.

One of the values of the HFACS model is to remind the reader of the risk mitigations that may be directed at the highest levels of the aviation system. Safety culture is a classic example in that whilst being hard to define, there is considerable evidence of its role in assuring the safety of a system. Some of the risk management strategies that may be employed by the OTs may target the highest levels through an integrated safety management system. The direct effect is hard to measure, but the research literature strongly supports such interventions and regulators such as CAA and CASA have endorsed such an approach.

6.6 Managing Human Performance Threats

The study of accidents is essentially reactive in nature, even though the stated aim of investigation under ICAO Annex 13 is to prevent future recurrence. The investigation of incidents as well as accidents is well recognised as a way of accessing far more data and indeed sometimes a way of accessing data that would just not be possible following an accident. Various regulatory authorities, operators and charitable trusts offer incident reporting options; mandatory and voluntary; confidential and open etc. Current thinking on Safety Management Systems, for example CAP 712 **[CAA, 2002**] highlights the importance of reporting systems as part of the system to achieve safety oversight. In particular, the need for an operator to supplement the regulatory authority’s Mandatory Occurrence Reporting scheme with its own internal scheme is stressed.

The low number of occurrence reports currently received within the OTs is unlikely to be solely a function of a lack of occurrences. Lack of reporting may reveal a lack of reporting-culture or indeed a wilful intent to hide problems. In contrast **[Hudson, 2000]** refers to the concept of ‘chronic unease’, associated with generative safety cultures. For the latter, a lack of reports would cause concern for an operator who accepts that there will always be problems to be fixed and wants to know what they are.

No reporting system can operate in isolation. There also needs to be a process for investigation and trend analysis leading to rectification actions where appropriate. Reporting systems should be confidential and could initially be “no-blame”. However, the adoption of the “just-culture” model is considered to be the best way forward since wilful violations should not be tolerated.

However, as incidents are generally self-reported and prone to reporting biases, the information recorded is not necessarily a full reflection of the underlying problems. Similarly, incident reporting systems are susceptible to what **[Maurino, 2003]** refers to as ‘**normalisation of deviance**’. This occurs when over time, workarounds, local procedures and shortcuts aimed at dealing with design or procedural deficiencies become ‘normal’ and therefore never reported. As a consequence, and recognising the fact that many problems will go unreported simply because no-one is aware of them at the time, Flight Data Monitoring (FDM) has become an essential safety management tool for major carriers.

Mature FDM technology for recording and analysing operational and engineering performance against defined criteria has demonstrated success over a number of years. JAR OPS 1 has now mandated FDM systems for commercial operators with aircraft above 27 tonnes MTOW since 1st January 2005.

CAP 739 **[CAA, 2003]** provides guidance for operators including a discussion of costs and benefits. Despite a typical cost for a Quick Access Recorder (QAR) at £10,000 per unit, installation costs of £2,000 per unit and decoding hardware and software at £50,000 - £150,000, CAP 739 cites a UK operator who demonstrated an overall annual saving of £1,600 per aircraft. In short, most major operators have found that the investment in an FDM system is more than balanced out through cost savings. As the technology continues to mature, cheaper and smaller recorders and the possibility of analysis by a third-party mean that smaller fleets and smaller aircraft are able to benefit from FDM.

Apparently limited samples of data (from small operators) can be offset against pooling data with other operators. As the CAA points out, there is no 'one-size fits all' system and as FDM has grown in popularity, so the options for potential customers have increased. Whilst mandatory fitment for IGA-CA aircraft as a category would be all but impossible at present, encouraging operators to work towards an FDM programme as part of their Safety Management System would seem beneficial.

6.7 General Discussion

6.7.1 OT Advantages

The fact that the majority of ICA-GA aircraft on the OT registers are to be found in Bermuda and Cayman Islands is not coincidence. There are clear attractions in placing aircraft on the register in these places. **[Malcolm, 2004]** observes that the Bermuda register offers the following benefits:

- Administration, rated category 1 by FAA, that is prepared to accept more than one internationally recognised set of airworthiness requirements and various crew licences for validation;
- A low-profile registration mark – of particular value when operating in areas of the world where security or political stability may be an issue;
- A responsive, fully-featured administration with limited administrative bureaucracy;
- No requirement that the aircraft be based or primarily used within the territory;
- Fuel price advantages when operating into certain countries;
- Limited taxes imposed on Bermudan companies or its overseas shareholders.

Similar attractions exist within Cayman Islands, but the important question is whether these factors present any specific risks that are different to those within the world population of IGA-CA aircraft?

Those attracted to the register by virtue of a low-profile registration mark may, by inference, want to operate the aircraft in areas of security threat or political instability. However, there is little evidence that corporate aircraft are a particular target and most safety statistics tend to exclude events that are the result of terrorism. This issue is not felt to be a significantly different threat for OTs. Those attracted to the register by virtue of the fact that they do not have to base or operate their aircraft in the territories may present a heightened threat although this is not necessarily the case.

The limited access by the OT authorities to some of the aircraft on their register was noted as a concern by staff interviewed during this study. Although in theory, states into which the aircraft fly are allowed to conduct inspections, in practice, such surveillance is sporadic around the world. Those who wish to operate their OT registered aircraft in parts of the world where regulatory oversight is limited are not restricted from doing so by the existing OT requirements. As such this is a level of threat specific to the OTs and should be considered in the application of OTARs.

6.7.2 IGA-CARA Summary

The challenges for the IGA-CARA assessment have included:

(a) The diversity of the operational environment where OT-registered aircraft may be used (e.g. geography, climate, population, facilities)
(b) Transferability of world accident statistics to OT registers
(c) Small sample sizes within each OT register
(d) Availability of data / expert opinion

The safety performance of the IGA-CA sector is comparable with that for airline operations. However, the safety performance may be largely as a result of key operators and is no guarantee of homogeny across the sector. The relatively small sample size may lead to loud statistical noise in the event of even low numbers of accidents.

The largest risks associated with IGA-CA are displayed in the Risk matrix (Table 13) and show that most accident frequencies fall with the “Remote” region, i.e. between 0.01 and 1 per 100 000 hours. It is suggested that the low accident rate for corporate aviation is due to the use of up-to-date aircraft, professional pilots and pre-existing company procedures (e.g. Operations Manual) by major operators in this class. Discussions with Shell Aircraft International and TAG Aviation would appear to support this reasoning.

The methodology chosen has allowed a top-down analysis to be performed to estimate the relative effect of the Risk Influencing factors (RIFs). This approach is limited to only a limited number of factors, and would benefit from more in-depth analysis using a finer categorisation. This would include a sensitivity study to determine the key elements of a future safety management system that could reduce accidents.

During the search of the UK CAA MORS database, no quantitative data was found from incident reports that related to flight operations errors. An incident reporting system operated in USA by NASA, the Aviation Safety Reporting System (ASRS) did produce some anecdotal evidence of operator errors **[Veillette, 2004]**. However, it is not possible to estimate a rate of occurrence for such errors, possibly due to a reluctance to report errors. It is therefore proposed that a “no-blame” incident reporting system would be useful in the IGA-CA sector.

7 CONCLUSIONS & RECOMMENDATIONS

1. The IGA-CARA has been produced to meet ASSI's requirement that future regulation of business and corporate aviation should be based on a full risk assessment. This has allowed full visibility of the associated risks to be gained and the priorities for OTARs to be set.

2. Part 135 Air taxi-type operations has the largest risks but is not the primary focus of this study. The results were estimated for this sector in order to bench-mark the results for Business - Corporate and Business - Owner operated aircraft.

3. The safety performance of the IGA-CA sector is largely as a result of key operators and is no guarantee of homogeny across the sector. The relatively small sample size may lead to loud statistical noise in the event of even low numbers of accidents.

4. Most accident frequencies for the IGA-CA sector fall with the "Remote" region, i.e. between 0.01 and 1 per 100 000 hours.

5. It is suggested that the low accident rate for corporate aviation is due to the use of up-to-date aircraft, professional pilots and pre-existing company procedures, e.g. Operations Manual by major operators in this class.

6. No data were found that would enable any categorisation to be made between the causal and contributory factors of accidents, by either size (weight) of aircraft or type of operation (e.g. FAR Part 91 or 135).

7. The **discriminants** used for IGA-CA should be based on the following definition. Part of this has modified the EASA definition of "complex-motor-powered aircraft" to include turbo-prop aircraft:

   a Operations [A] or [B] conducted with aeroplanes:
      - MTWA more than 5,700 kg; **or**
      - with a maximum approved passenger seating configuration of more than 9 **or**
      - certificated for operation with a minimum crew of at least 2 pilots **or**
      - equipped with (a) turbine engine(s);

   b Operations [A] or [B] conducted with helicopters:
      - MTWA more than 3,175kg; **or**
      - with a maximum approved passenger seating configuration of more than 5 **or**;
      - certificated for operation with a minimum crew of at least 2 pilots;

   c Operations [A] or [B] conducted with a tilt rotor aircraft

   d Operator [A] or [B] with an operational fleet of more than one aircraft;

   e Operator [A] or [B] who is required to hold a specific approval (MNPS, PRNAV, RVSM, AWOPS etc).

   f Other non-commercial operation (non-A or B) of "complex-motor-powered aircraft" [see Glossary].

   A = Business Aviation (Corporate) and B = Business Aviation (Owner Operated)

8. The application of the term “**turbine**” in order to include turbo-prop aircraft should be reviewed. The IGA-CA study is not aimed at the General Aviation owner/pilot of turbo-prop aircraft < 5 700kg.

9. Further work is required to analyse the corporate aircraft accident reports more deeply in order to assess the significance of each Risk Influencing Factor (RIF) in turn. Sensitivity studies are then required in order to provide a more complete assessment. However, given the scope of this project, it is viewed that this report gives a first approximation of the key risk factors.

10. The Risk Influencing Factor with the largest influence is that for Operations (nearly 50%) which includes Environmental Factors, Condition of Flight Crew and Personnel Factors. This may be influenced by (for example) procedures, rostering, company culture, training, experience, recency and other factors which underlie human performance.

11. The OTARs must be focussed on areas influenced by the Operations RIF, as described by the Human Factors Analysis & Classification System (HFACS). This must include requirements to address crew resource management, operations standards, flight time limitations and influence corporate culture.

12. The development of the OTARs would benefit from consideration of the work underpinning FAR Part 91 Sub-part K, CAR 604 and the Draft CASR Part 132.

13. The OTARs required for IGA-CA must focus on formalising the good practices adopted by some corporate operators into regulations. A strong area would be the emphasis on safety management systems, as included in the IBAC-initiated International Standard for Business Aircraft Operations (IS-BAO).

14. The development of the OTARs would benefit from a thorough review of the salient features of industry best practice, notable IS-BAO. These include:
    - Safety Management Systems
    - Training and Proficiency, including Crew Resource Management
    - Flight Operations, including Standard Operating Procedures
    - Aircraft Equipment Requirements
    - Aircraft Maintenance Requirements
    - Company Operations Manual
    - Emergency Response Plan

15. The development of the OTARs should monitor the work within JAA and EASA to ensure that opportunities for standardisation, where appropriate and desired, are realised.

16. The OTARs required for IGA-CA must address the risk associated with CFIT and Control-loss, to review the additional requirements for risk reduction strategies e.g. EGPWS, CRM training etc. This should draw on the work carried out by CAST and FSF.

17. During the review for additional OTARs required for IGA-CA, ASSI should review the feasibility of Flight data monitoring (FDM) for exceedance and incident monitoring in IGA-CA. Such a program could be carried out by a third party on behalf of the operator as part of an integrated safety management system.

18. No quantitative data was found from incident reports from the UK MORS database. However, a “no-blame” incident reporting system would be useful in the IGA-CA sector.

8 REFERENCES

1. AEA Technology, Final Report on the Risk Analysis in support of Aerodrome Design Rules, Report No AEAT/RAIR/RD02325/R/002 Issue 01 (2001).
2. Akerstedt T (Ed) Consensus Statement: Fatigue and Accidents in Transport Operations, Journal of Sleep Research 9, 395 (2000).
3. AS/NZS Risk Management (AS/NZS4360:1999)
4. AS/NZS Risk Management – Guidance Material HB436-2004
5. Bazargan M & Ross D L, A Comparative Risk Measure for General Aviation, presented at MCDM, Whistler, B C Canada Aug 6-11, 2004
6. Boeing, Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations 1959-2003, May 2004.
7. CAA Safety Regulation Group, Safety Plan Issue One, 2005
8. CAA Safety Regulation Group, CAP 667 Review of General Aviation Fatal Accidents 1985-1994, Civil Aviation Authority, Gatwick (1997)..
9. CAA Safety Regulation Group, CAP 681 Global Fatal Accident Review 1980-1996. Civil Aviation Authority, Gatwick (1998).
10. CAA Safety Regulation Group, CAP 701 Aviation Safety Review 1990-1999. Civil Aviation Authority, Gatwick (2000).
11. CAA Safety Regulation Group, CAP 712 Safety Management Systems for Commercial Air Transport Operations. Civil Aviation Authority, Gatwick (2002).
12. CAA Safety Regulation Group, CAP 735 Aviation Safety Review 1992 – 2001. Civil Aviation Authority, Gatwick (2002).
13. CAA Safety Regulation Group, CAP 739 Flight Data Monitoring, Civil Aviation Authority, Gatwick (2003).
14. Carlisle D, Controlled Flight into Terrain, in Business & Commercial Aviation, April 2001.
15. EASA, General acceptable means of compliance for airworthiness of products, parts and appliances AMC-20, Decision No. 2003/12/RM of EASA 5 Nov 03.
16. Endsley, M.R, Towards a Theory of Situation Awareness in Dynamic Systems. Human Factors, Vol 37 (1), (1995).
17. FAA, Pilot Safety brochure, “Prevention of Controlled Flight into Terrain In General Aviation Operations”, ref DOT/FAA/AM-400-02/2
18. FAA, Land and Hold Short Operations Risk Assessment, Sep 1999.
19. FAA, Transport Canada and DGAC Mexico, Prevention of CFIT In General Aviation Operations, DOT/FAA/AM-400-02/2, 2000.
20. FAA, Safety Risk Management, Order No 8040.4 Jun 1998.
21. FAA, System Safety Handbook, 30 Dec 2000.
22. FAA, System Safety Process Steps, Rev 1, Feb 2003.
23. Federal Register, Department of Transportation, Vol 68 No 180, Sep 2003.
24. FSF, Approach-and-Landing Risk Reduction Guide, Rev 1.1. FSF, Arlington (2000).
25. FSF, CFIT Checklist, Rev 2.3. FSF, Arlington (1994).
26. FSF, Killers in Aviation: FSF Task Force presents facts about Approach-and-Landing and Controlled-Flight-into-Terrain accidents, in Flight Safety Digest. FSF, Arlington (Nov-Dec 1998, Jan-Feb 1999).
27. FSF, Line Operations Safety Audit (LOSA) Provides Data on Threats and Errors, in Flight Safety Digest. FSF, Arlington (2005).
28. GAIN Guide to Methods & Tools for Airline Flight Safety Analysis, 2nd edition, 2003.

29. Hadjimichael M & McCarthy J, Implementing the Flight Operations Risk Assessment System, in 57th International Air Safety Seminar Shanghai, China, Nov 2004.
30. Hokstad P, Jersin E, Hansen G K, Sneltvedt J and Sten T, Helicopter Safety Report 2, SINTEF Report No STF38 A99423, 1999
31. Hudson, P T W, Safety Culture and Human Error in the Aviation Industry: In Search of Perfection. In Hayward, B. J. and Lowe, A. R. (Eds) Aviation Resource Management. Ashgate, Aldershot (2000).
32. IBAC, An International Standard for Business Aviation Operations (2002).
33. IBAC, Business Aviation Safety Brief, Summary of Global Accident Statistics 1997-2001, Issue 01 (2003).
34. IBAC, Business Aviation Safety Brief, Summary of Global Accident Statistics 1998-2002, Issue 02 (2004).
35. IBAC, Business Aviation Safety Brief, Summary of Global Accident Statistics 1999-2003, Issue 03 (2005).
36. International Civil Aviation Organisation (ICAO) (2002) Line Operations Safety Audit (LOSA). Document 9803. ICAO, Montreal.
37. Joint Safety Analysis Team (JSAT), Controlled Flight Into Terrain (CFIT) Results and Analysis, Rev A, 20 Nov 1998
38. Luxhøj, J T, “Probabilistic Causal Analysis for System Safety Risk Assessments in Commercial Air Transport,” in Proceedings of the Workshop on Investigating and Reporting of Incidents and Accidents (IRIA), Williamsburg , VA, Sep 2003.
39. Malcolm, D. H. (2004) Flying High – The Bermuda Aircraft Register. Offshore Investment Magazine (September).
40. Maurino, D. E. (2003). Aviation Safety and Human Factors: The Years to Come. In Edkins, G and Pfister, P. (Eds) Innovation and Consolidation in Aviation. Ashgate, Aldershot.
41. NTSB, US Air Carrier Operations Calendar Year 2000, Annual Review of Aircraft Accident Data, Report No NTSB/ARC-04/01 (2004a).
42. NTSB, US General Aviation Calendar Year 2000, Annual Review of Aircraft Accident Data, Report No NTSB/ARG-04/01 (2004b).
43. RAND, Airport Growth & Safety, A study of the External Risks of Schiphol Airport and possible Safety-Enhancement Measures, 1993.
44. Reason J, Human error, New York, Cambridge University Press, 1990.
45. Rohr R, Safety Management Systems for Business Aviation, in BART International Aug-Sep 2004.
46. Rosekind M R, Gregory K B, Miller D L, Co E L, Lebacqz J V and Brenner M, Examining Fatigue Factors in Accident Investigations: Analysis of Guantanamo Bay Aviation Accidents (2000)
47. Veillette P R, Most Fatal US Commercial Helicopter Accidents Occur in Instrument Meteorological Conditions, in Flight Safety Digest, Flight Safety Foundation Vol 22 no 1, Jan 2003.
48. Veillette P R, Twelve Years of Business Jet Accidents, in Business & Commercial Aviation, April 2004 (2004a).
49. Veillette P R, Controlled Flight into Terrain takes Highest Toll in Business Jet Operations, in Flight Safety Digest, Flight Safety Foundation Vol 23 no 5 (2004b)
50. Wiegmann D A & Shappell S A, A Human Error Approach to Aviation Accident Analysis, Ashgate, 2003.

Appendix A: Project Contacts

The following people have been contacted as part of this Project, and grateful thanks are extended to all for their contribution.

Regulatory Authorities

Eric Sivel, EASA Daniela Schladebach	Responsible for development of EASA IRs EASA Rulemaking Officer
George Rebender, JAA Mike Harrison, JAA	Chair of Operations Sectorial Team Responsible for development of JAR Ops 0, 2, 4
Hazel Courteney David Beaven Tim Whittle Joji Waites	CAA Research and data CAA GA department CAA MORS database CAA Accident Analysis Group (AAG) database
Steve Smith Katherine Perfetti Bob Matthews	FAA Office of System Safety Development of FAR part 91, sub-parts F and K FAA Accident investigation
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Malcolm Read	CASA Australia
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Research/Academic sources

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Massoud Bazargan	Embry - Riddle Aeronautical University
Rudolf Fonseca	Flight safety study in Brazil
Steve Bond	City University
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Ioannis Markou	Member of JAA Human Factors Steering Group
Patrick Veillette	Pilot and FSF author

Industry sources

Bill Boucher	CBAA
Don Spruston	IBAC
Bill Stein	NBAA
Mark Wilson, John Batty	BBGA
Ron Swanda	GAMA
Bob Sheffield, Steve Fisher	Shell Aircraft International
Ken New	TAG Aviation (UK)
Mike Jenvey, Kevin Harling	Corporate pilots

Appendix B: FAR and CAR Regulations for Corporate Aviation

Appendix B.1 - 14 CFR Part 91 Subparts F and K

Subpart F	**Large and Turbine-Powered Multiengine Airplanes**
This subpart prescribes operating rules, in addition to those prescribed in other subparts of this part, governing the operation of large airplanes of U.S. registry, turbojet-powered multiengine civil airplanes of U.S. registry, and fractional ownership program aircraft of U.S. registry that are operating under subpart K of this part in operations not involving common carriage.	
91.501	Applicability
91.503	Flying equipment and operating information.
91.505	Familiarity with operating limitations and emergency equipment.
91.507	Equipment requirements: Over-the-top or night VFR operations.
91.509	Survival equipment for overwater operations
91.511	Radio equipment for overwater operations.
91.513	Emergency equipment.
91.515	Flight altitude rules.
91.517	Passenger information.
91.519	Passenger briefing.
91.521	Shoulder harness.
91.523	Carry-on baggage.
91.525	Carriage of cargo.
91.527	Operating in icing conditions.
91.529	Flight engineer requirements.
91.531	Second in command requirements.
91.533	Flight attendant requirements.
91.535	Stowage of food, beverage, and passenger service equipment during aircraft movement on the surface, takeoff, and landing.

Subpart K	**Fractional Ownership Operations**
91.1001	Applicability.
91.1002	Compliance date.
91.1003	Management contract between owner and program manager.
91.1005	Prohibitions and limitations.
91.1007	Flights conducted under part 121 or part 135 of this chapter.
91.1009	Clarification of operational control
91.1011	Operational control responsibilities and delegation
91.1013	Operational control briefing and acknowledgment.

91.1014	Issuing or denying management specifications.
91.1015	Management specifications.
91.1017	Amending program manager's management specifications.
91.1019	Conducting tests and inspections
91.1021	Internal safety reporting and incident/accident response.
91.1023	Program operating manual requirements
91.1025	Program operating manual contents
91.1027	Recordkeeping.
91.1029	Flight scheduling and locating requirements
91.1031	Pilot in command or second in command: Designation required.
91.1033	Operating information required.
91.1035	Passenger awareness.
91.1037	Large transport category airplanes: Turbine engine powered; Limitations; Destination and alternate airports.
91.1039	IFR takeoff, approach and landing minimums.
91.1041	Aircraft proving and validation tests.
91.1043	[Reserved]
91.1045	Additional equipment requirements.
91.1047	Drug and alcohol misuse education program.
91.1049	Personnel
91.1051	Pilot safety background check.
91.1053	Crewmember experience
91.1055	Pilot operating limitations and pairing requirement.
91.1057	Flight, duty and rest time requirements: All crewmembers.
91.1059	Flight time limitations and rest requirements: One or two pilot crews.
91.1061	Augmented flight crews
91.1062	Duty periods and rest requirements: Flight attendants
91.1063	Testing and training: Applicability and terms used.
91.1065	Initial and recurrent pilot testing requirements
91.1067	Initial and recurrent flight attendant crewmember testing requirements.
91.1069	Flight crew: Instrument proficiency check requirements.
91.1071	Crewmember: Tests and checks, grace provisions, training to accepted standards.
91.1073	Training program: General.
91.1075	Training program: Special rules
91.1077	Training program and revision: Initial and final approval.
91.1079	Training program: Curriculum.

91.1081	Crewmember training requirements.
91.1083	Crewmember emergency training.
91.1085	Hazardous materials recognition training.
91.1087	Approval of aircraft simulators and other training devices.
91.1089	Qualifications: Check pilots (aircraft) and check pilots (simulator).
91.1091	Qualifications: Flight instructors (aircraft) and flight instructors (simulator).
91.1093	Initial and transition training and checking: Check pilots (aircraft), check pilots (simulator).
91.1095	Initial and transition training and checking: Flight instructors (aircraft), flight instructors (simulator).
91.1097	Pilot and flight attendant crewmember training programs.
91.1099	Crewmember initial and recurrent training requirements.
91.1101	Pilots: Initial, transition, and upgrade ground training.
91.1103	Pilots: Initial, transition, upgrade, re-qualification, and differences flight training.
91.1105	Flight attendants: Initial and transition ground training.
91.1107	Recurrent training
91.1109	Aircraft maintenance: Inspection program
91.1111	Maintenance training.
91.1113	Maintenance record keeping.
91.1115	Inoperable instruments and equipment.
91.1411	Continuous airworthiness maintenance program use by fractional ownership program manager.
91.1413	CAMP: Responsibility for airworthiness.
91.1415	CAMP: Mechanical reliability reports.
91.1417	CAMP: Mechanical interruption summary report.
91.1423	CAMP: Maintenance organization.
91.1425	CAMP: Maintenance, preventive maintenance, and alteration programs.
91.1427	CAMP: Manual requirements.
91.1429	CAMP: Required inspection personnel
91.1431	CAMP: Continuing analysis and surveillance.
91.1433	CAMP: Maintenance and preventive maintenance training program.
91.1435	CAMP: Certificate requirements.
91.1437	CAMP: Authority to perform and approve maintenance.
91.1439	CAMP: Maintenance recording requirements.
91.1441	CAMP: Transfer of maintenance records.
91.1443	CAMP: Airworthiness release or aircraft maintenance log entry.

Appendix B.2 Canadian Aviation Regulations CAR Part VI

Subpart 4 - Private Operator Passenger Transportation

See also - Standard 624 - *Private Operator Passenger Transportation Standards* which outline the standards that must be met to comply with the requirements of Subpart 604.

For ease of cross reference, the divisions and numbers of the standards are assigned to correspond to the regulations. Hence Standards 624.13 would reflect a standard required by Section 604.13 of the Canadian Aviation Regulations.

- **Division I - General**
    - 604.01 - Application
    - 604.02 - Aircraft Operation
    - 604.03 and 604.04 Reserved
- **Division II - Certification**
    - 604.05 - Issuance or Amendment of Private Operator Certificate
    - 604.06 - Contents of a Private Operator Certificate
    - 604.07 - General Conditions of a Private Operator Certificate
    - 604.08 and 604.09 Reserved
- **Division III - Flight Operations**
    - 604.10 - Checklist
    - 604.11 - Operational Flight Data Sheet
    - 604.12 - VFR Flight Minimum Flight Visibility - Uncontrolled Airspace
    - 604.13 - No Alternate Aerodrome - IFR Flight
    - 604.14 - Take-off Minima
    - 604.15 - Instrument Approach Procedures
    - 604.16 - Flight Attendant Requirement
    - 604.17 - Cabin Safety Procedures
    - 604.18 - Briefing of Passengers
    - 604.19 - Safety Features Card
    - 604.20 to 604.25 Reserved
- **Division IV - Flight Time and Flight Duty Time Limitations and Rest Periods**
    - 604.26 - Flight Time Limitations
    - 604.27 - Flight Duty Time Limitations and Rest Periods
    - 604.28 - Split Flight Duty Time
    - 604.29 - Extension of Flight Duty Time
    - 604.30 - Unforeseen Operational Circumstances
    - 604.31 - Delayed Reporting Time
    - 604.32 - Requirements for Time Free from Duty

  - 604.33 - Flight Crew Positioning
  - 604.34 to 604.37 Reserved
- **Division V - Emergency Equipment**
  - 604.38 - Survival Equipment
  - 604.39 - First Aid Kits
  - 604.40 - Protective Breathing Equipment
  - 604.41 - Hand-held Fire Extinguishers
  - 604.42 to 604.47 Reserved
- **Division VI - Maintenance**
  - 604.48 - Maintenance Control System
  - 604.49 - Description of Maintenance Control System in Operations Manual
  - 604.50 - Person Responsible for Maintenance Control System
  - 604.51 - Maintenance Personnel and Facilities
  - 604.52 - Defect Reporting and Rectification Control Procedures
  - 604.53 - Service Difficulty Reporting
  - 604.54 - Technical Dispatch Instructions
  - 604.55 - Service Information Review
  - 604.56 - Maintenance Agreements
  - 604.57 - Maintenance Training
  - 604.58 to 604.64 Reserved
- **Division VII - Personnel Requirements**
  - 604.65 - Designation of Pilot-in-command and Second-in-command
  - 604.66 - Crew Member Qualifications
  - 604.67 - Check Authority
  - 604.68 - Validity Period
  - 604.69 to 604.72 Reserved
- **Division VIII - Training**
  - 604.73 - Training Program
  - 604.74 - Training and Qualification Records
  - 604.75 to 604.79 Reserved
- **Division IX - Manuals**
  - 604.80 - Requirements relating to Operations Manual
  - 604.81 - Contents of Operations Manual
  - 604.82 - Distribution of Operations Manual
  - 604.83 - Aircraft Operating Manual
  - 604.84 - Standard Operating Procedures
  - 604.85 to 604.89 Reserved

Appendix C: Prevention of CFIT in General Aviation Operations

[Extracts from Ref DOT/FAA/AM-400-02/2]

Controlled flight into terrain (CFIT), as defined by FSF, occurs when an airworthy aircraft under the control of the flight crew is flown unintentionally into terrain, obstacles or water, usually with no prior awareness of the crew. This type of accident can occur during most phases of the flight, but CFIT is more common during the "**approach-and-landing**" phase:

- Start - when an airworthy aircraft under the control of the flight crew descends below 5000 ft above ground level (AGL) with the intention of conducting an approach.
- Finishes – when the landing is complete or the flight crew flies the aircraft above 5000 ft AGL en route to another airport.

The FAA stated that CFIT Accidents occur most frequently in GA operations, comprising 4.7% of all GA accidents and 32% of GA accidents in IMC. On average there are 1.4 fatalities per CFIT accident, versus 0.33 fatalities per GA accident overall.

- 17% of all GA fatalities are due to CFIT
- CFIT accidents are fatal 58% of the time.
- CFIT accidents occur 64% of the time in daytime and 36% at night
- 51% of CFIT accidents occur in IMC, 48% in VMC and 1% unknown.
- Impacted terrain was flat 45% and mountainous 55%.

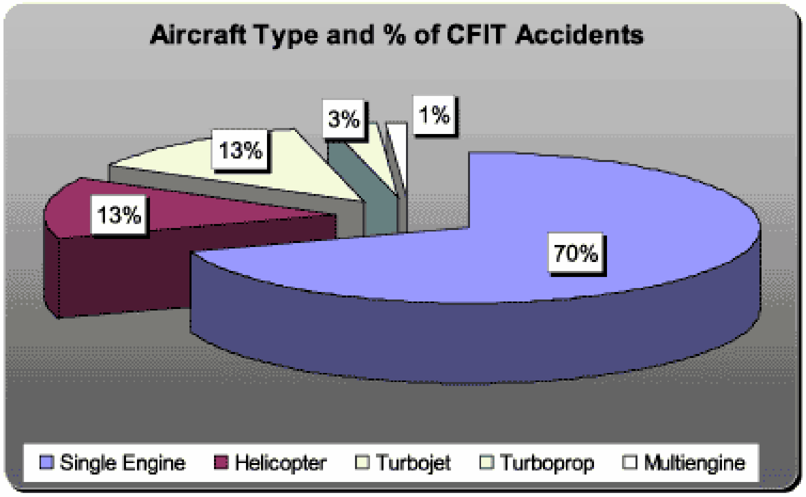

Figure 30: Composition of CFIT accidents [FAA]

The Human Factors Analysis and Classification System (HFACS) has been applied to CFIT accidents. More fatal than non-fatal accidents were associated with violations. Decision errors were more often associated with non-fatal CFIT accidents. When weather was a factor, more CFIT accidents were associated with violations and decision errors.

Note that the HFACS data shows 50% of CFIT accidents were due to pilot judgment errors, thus we need to improve pilot decision making (education, practical test standards, written exam questions).

Analysis also shows 30% skill based errors (feedback to CFIs, designated flight examiners, FBOs). With 30% of CFIT accidents due to violations, we have existing FAA responses to violations, but we also need to educate pilots that violations during conditions conducive to CFIT risk are major contributors to death.

Finally, with 20% of CFIT accidents due to perceptual associations, we must continue to emphasize the illusions and hazards of flight due to spatial disorientation.

Analysis also shows 30% skill based errors (feedback to CFIs, designated flight examiners, FBOs). With 30% of CFIT accidents due to violations, we have existing FAA responses to violations, but we also need to educate pilots that violations during conditions conducive to CFIT risk are major contributors to death. Finally, with 20% of CFIT accidents due to perceptual associations, we must continue to emphasize the illusions and hazards of flight due to spatial disorientation and visual illusions.

Figure 31: HFACS Analysis of 164 Fixed-Wing Accidents

Type of unsafe act		Percentage of total
Errors	Skill-based Error	30
	Decision Error	50
	Perceptual Errors	30
Violations	Routine & Exceptional	20

Appendix D: Approach-and-Landing Accidents

D.1 Elements of a Stabilised Approach

Note: A suggested definition or policy that might be considered by operators could be as follows:

"All flights shall be stabilised by 1,000 feet height above touchdown (HAT) in instrument meteorological conditions (IMC) and by 500 feet HAT in visual meteorological conditions (VMC)."

An approach is considered stabilised when all of the following criteria are met:

1. The aircraft is on the correct flight path
2. Only small changes in heading and pitch are required to maintain that path
3. The aircraft speed is not more than Vref + 20 knots indicated airspeed (KIAS) and not less than Vref
4. The aircraft is in the proper landing configuration (approach configuration for small twins)
5. Sink rate is maximum 1,000 feet per minute; if an approach requires a sink rate greater than 1,000 feet per minute, a special briefing is to be performed
6. Power setting appropriate for configuration and not below the minimum power for approach as defined by the aircraft operations manual
7. All briefings and checklists have been performed
8. Specific types of approaches are considered stabilised if they also fulfil the following:
    - Instrument landing system (ILS) approaches – must be flown within one dot of the glideslope or localiser; a category II or III approach must be flown within the expanded localiser band.
    - Visual approaches – wings must be level on final when the aircraft reaches 500 feet HAT.
    - Circling approaches – wings must be level on final when aircraft reaches 300 feet HAT
9. Unique approaches such as the 'old' Hong Kong airport, and the DCA (Washington, D.C.) river visual approach to Runway 18 require a special briefing

Source: FSF Approach-and-Landing Accident Reduction Task Force [quoted by ATSB Air Safety Occurrence Report No 200302172, 2004]

D.2 Assessment of Causal factors from Approach and Landing accidents

Causal Factor	No	Percentage of total*	Contributing factors
Failure to conduct stabilised approach	67	64.4%	Rushed approach (81%) Inadequate crew co-ordination (72%) Demanding ATC clearance (66%) Inadequate automation management (62%) Inadequate energy management (60%) In-flight icing (30%) Wind-shear/turbulence/gusts (26%)
Slow/delayed crew action	54	51.9%	
Flight handling difficulties Loss of Control (LOC)	11	10.6%	Failure to maintain adequate airspeed (9) Unstabilised approach (9) Restricted visibility (8) Icing conditions (6) Circle to land manoeuvres (5) Decrease in airspeed during flare (3) Wake turbulence (2)
Runway Over-runs	32	30.8%	
Hard landings	10	9.6%	
Inadequate CRM (cross-check/ co-ordinate)	46	44.2%	
Omission of action/ inappropriate action	45	43.3%	
Failure to evaluate conditions adequately	44	42.3%	
Inadequate judgement	43	41.3%	
Inadequate qualification/ training/experience	35	33.7%	
Lack of position awareness	35	33.7%	
“Press-on-itis”/ Time pressure	26	25.0%	
Disorientation	16	15.4%	

Table 17: Most Frequently cited Causal Factors in 104 Business Jet ALAs 1991-2002 [Table 15, Veillette, 2004]

*** Many of the above ALA reports quoted more than one causal factor.**

Appendix E: Example Aircraft Types with MTWA

Aircraft Type – Fixed wing		**Powerplant**	**MTWA (lbs)**	**MTWA (kg)**
MTWA < 2250kg (4950lb) Outside scope of study	Piper Warrior III	Single piston	2 440	1 107
	Cessna Skyhawk R172	Single piston	2 450	1 111
	Piper Seneca V	Twin piston	4 750	2 155
2 250 kg < **Small** < 5 700kg (12 500lb)	Piper Meridian PA-46 (6-seats)	Single turbo-prop	5 092	2 310
	Cessna Caravan (max 12 pass seats)	Single turbo-prop	8 785	3 985
	Pilatus PC-12 (max 9 pass seats)	Single turbo-prop	9 920	4 500
5 700 kg < **Medium** < 15 900kg (35 000lb)	Cessna Citation CJ3	Twin jet	13 870	6 291
	BAE Jetstream 31	Twin turbo-prop	16 204	7 350
	Learjet 45	Twin jet	20 500	9 298
Large > 15 900kg (35 000lb)	Cessna Citation X	Twin jet	36 100	16 375
	BAE Systems ATP	Twin turbo-prop	52 200	23 678
	Bombardier BD700 Global Express	Twin jet	95 000	43 091
	Boeing BBJ	Twin jet	171 000	77 565
	DC-6B	4 piston (radial)	107 000	48 534

Aircraft Type – Rotary wing		**Powerplant**	**MTWA (lbs)**	**MTWA (kg)**
MTWA < 1 360 kg (3 000 lb)	Robinson R44	Single piston	2 500	1 134
1 360 kg < **Small** < 3 175 kg (7 000lb) Outside scope of study	Bell 206B-3 Jet Ranger III	Single turbo-shaft	3 350	1 519
	MD Explorer	Twin turbo-shaft	6 900	3 129
3 175 kg < **Medium** < 5 450kg (12 000lb)	Eurocopter EC 145	Twin turbo-shaft	7 903	3 585
	Eurocopter AS 365N Dauphin 2	Twin turbo-shaft	9 369	4 250
	Sikorsky S-76	Twin turbo-shaft	11 700	5 307
Large > 5 450kg (12 000lb)	Sea King (S-61)	Twin turbo-shaft	21 500	9 752
	Boeing 234	Twin turbo-shaft	48 500	22 000

Note that some fixed & rotary wing aircraft in Small and Medium category will fall into the next bracket due to their performance (Eclipse MTWA 2 558 kg, 5 600 lb) and/or seating capacity (Cessna Caravan with 12 seats).