CRANFIELD UNIVERSITY

R W SEARS

BUSINESS JET SAFETY AND ACCIDENT STUDY

SCHOOL OF ENGINEERING

M PHIL
Academic Years: 2007 - 2013

Supervisor: Dr J HUDDLESTONE
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ABSTRACT

As world transport has grown in complexity, so has public pressure for safe flight. The scheduled airline industry has a consistently good safety record. Unfortunately, the business jet industry has not kept pace with the airline safety statistics and lags far behind. During safety surveys and reports over the past 5 years there has been increasing comment and concern over the perceived safety standards of business jets operations compared with normal scheduled airline services. The UK Civil Aviation Authority (CAA) has reported that based on flight hours flown, the fatal accident rate for smaller jet aircraft below 15 tonnes was twice that for large passenger aircraft (CAA 2006a). The CAA also identified that the majority of the accidents occur during the approach and landing phase of the flight.

There is however, a lack of research concerning business jet operations. Due to the unique and varied style of operations, business jet flights have many factors that differentiate it from normal scheduled airline operations. Business jet accidents have been reported but they have not been further investigated for any overall causes. The study described in this thesis, a Grounded Theory analysis of accident data was conducted to develop a model of the factors that contributed to the accidents. The model that was developed demonstrated that Pilot skills, Command and Crew Resource management are the key central elements, with the ground organisations such as engineering and ground operations personnel as a contributory influence.

As piloting skills were determined as a key factor in the accident statistics and the accident model, a simulator trial was also conducted to assess the manual flying skill levels of business jet pilots. The trial was both a challenging manual flying task and a profile that is included as part of the Pilot Skill test prior to the issue of a commercial pilot's licence. The simulator trial confirmed that although all the pilots were correctly tested and certified commercial pilots, a significant proportion did not fly an accurate airspeed on approach within the CAA examination tolerances.

The simulator trial data and the grounded theory model found that there are concerns for the piloting skills of business jet pilots in their ability to fly an accurate airspeed on approach.

The results from this investigation yield findings concerning the piloting skill and accuracy of the business jet pilots that had not previously been identified. The results also emphasise the need to include adequate testing and supervision during business jet operations. It is recommended that further research be conducted to evaluate actual piloting skill and accuracy during the licence skill test.

Keywords:

Accident Analysis, CRM, Piloting skills, Operational Environment, Control strategy, Simulator.

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LIST OF ABBREVIATIONS

AAG,	Accident Analysis Group
AAIB	Air Accident Investigation Branch
AGL	Above ground level
ALT	Alternator
AOC	Air Operators Certificate
AOPA,	Aircraft Owners and Pilots Association
APU	Auxiliary Power Unit
ARINC,	Aeronautical Radio Incorporated
ATC	Air Traffic Control
ATQP	Alternative Training and Qualification Programme
ATPL	Air Transport Pilot Licence
AUW	All Up Weight
BALPA	British Airline Pilots’ Association
BPS	British Psychological Society
CAA	Civil Aviation Authority (United Kingdom)
CAT 1,	Category One Approach (to 200 feet above runway)
CFS	Central Flying School (RAF)
CPL	Commercial Pilots Licence
CAP	Civil Air Publication
CRM	Crew Resource Management
CU	Cranfield University
DEP.	Direct Entry Pilot.
DH	Decision height
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
EGKK	London Gatwick Airport
EHSI	Electronic Horizontal Situation Indicator
ETOPS	Extended Twin Engine Operations
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FBO,	Engineering Base Operations
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FODCOM	Flight Operations Department Communication
FMS	Flight Management System
FMGS	Flight Management and Guidance System
FTD	Flight Training Device
FSF	Flight Safety Foundation
GROUND PROX	Ground Proximity Warning System
HFACS	Human Factors Analysis and Classification System
HP	High pressure fuel cock
Hz	Hertz
IBAC	International Business Aviation Council
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions

IOS	Instructors Operating Station
IPA	Independent Pilots' Association
IS BAO	International Standard for Business Jet Operations
JAA	Joint Aviation Authorities
KETX,	Telluride Airport, Colorado
Kn	Knots, airspeed
LB	Pound Weight
LP	Low Pressure fuel cock
LOSA	Line operational Safety Audits
LOFT	Line Orientated Flight Training
LPC	Licence Proficiency Check
LST	Licence Skill test
MCC	Multi Crew Co-operation
MDA	Minimum Descent Altitude
MQTG	Master Qualification Test Guide
NATS	National Air Traffic Service
NTSB	National Transportation Safety Board
NOTECHS	Non-Technical Skills
PIC	Pilot in Command
PF	Pilot Flying
PLA	Power Lever Angle
PM	Pilot Monitoring
PNF	Pilot not flying
PPL	Private Pilot's Licence
PTU	Power Transfer Unit
RAF	Royal Air Force
RIL	Rifle Airport, Garfield County Regional, CO, USA.
RPM	Revolutions per Minute
QNH	Sea Level Atmospheric Pressure
QRH	Quick Reference Handbook
SD	Standard Deviation of Error
SFI	Synthetic Flight Instructor
SMS	Safety Management System
SRG	Safety Regulation Group
SOP	Standard Operating Procedures
TRE	Type Rating Examiner
UK	United Kingdom
USA	United States of America
Vapp	Approach Airspeed
VOR	VHF Omnidirectional Range, navigation beacon
Vref	Aircraft approach/landing airspeed
WBA	World Business Jet Association
ZFW	Zero Fuel Weight

1 INTRODUCTION

1.1 **Rational for the Research**

In 2004, the following was published in Business & Commercial Aviation (April 2004).

> "High profile accidents, often involving celebrities, unfortunately can leave the misimpression that business jets are somewhat less safe and piloted by less professional aircrews than the major airlines. Such accidents provoke the question, "how safe is business jet aviation and where do we need to improve?" (Veillette 2004).

The article was a review of the business jet accident statistics from 1991 to 2002 which found that business jet flights were not as safe commercial airline flights (Veillette 2004).

Over the last few years the situation has not improved (IBAC 2008, 2010, 2011, 2012). The number of globally operating business jets has risen from 17,382 in 2009 (IBAC 2010) to 18,460 in 2011 (IBAC 2012). As the fleet of privately owned and operated business jets continues to grow, their relatively poor safety record has continued to be a concern. The UK Civil Aviation Authority (CAA) has commented on the situation and raised it concerns as part of its Safety Plan 2006/7-2010-11 (CAA 2009b). However, the primary causes of the business jet poor safety record are uncertain (CAA 2009b, CAA 2006a).

The study set out in this thesis has undertaken to consider the particular operating conditions and regulations relevant to business jets and has conducted a study to suggest "where do we need to improve".

1.2 **Aim and objectives of the Study**

The aim of the study was to investigate business jet operations and determine operational areas in need of improvement. This study has 3 research objectives:

- Review and discuss the business jet operations, regulations, operating conditions, accident data, and crew skills compared to commercial airline operations.
- Conduct a study of the business jet accident data, to create an overall accident model relevant to their operating conditions.
- Carry out a simulator trial assessment of business jet pilots' operating skills.

2 LITERATURE REVIEW

2.1 **Background to the Study and Literature Review**

This study is an investigation into the safety of small passenger carrying jet powered aircraft, termed “Business Jets”. The aircraft size varies from approximately 4700 kg (such as Cessna 525), to 42,400 kg (Bombardier Global Express). Also, in order to be classed as business jets and not as scheduled airliners, they may not be operated to a fixed schedule or timetable (FAA 2010). Therefore, business jet operations are conducted either by the aircraft owner, a corporation or company or by a charter company granted a licence by the regulators and the regulations are discussed in the following Chapter. As noted above, business jet operations are becoming a large part of the international aviation scene, with over 18,000 aircraft operating around the world (IBAC 2012).

The initial research objective was to review the unique style of business jet operations in comparison with commercial airlines and from the literature the major topics of concern were:

- CAA and FAA Regulations
- Airfield Categories and limitations
- Pilot Performance
- Pilot Training
- Pilot Crew Resource Management
- Safety Data
- Safety Initiatives
- Regulatory Oversight
- Previous Research
- Technical Failures and Outside Support

It is notable that studies have been conducted into military operations, civilian flying in both General aviation and Commercial scheduled operations, such as Orlady (1999) Human factors in Multi-crew Operations, Soeters (2000) Culture and Flight safety in Military Aviation and Wood (2004) Flight Crew Reliance on

Automation. More recently, Keller (2013) has reported concerns of the decay in piloting skills for instrument flying and approaches for General Aviation, (which includes private pilots and turbo prop aircraft). Also, the rail and electricity generating industry has included both human factors and Crew Resource Management (CRM) in its safety studies (Wilson et al. 2005, Strater 2005, Sheridan 1997). However, apart from safety concerns dating back to 1991 (Veillette 2004) it was not possible to reference material directly concerning business jet operations apart from the papers from Cranfield University (2005) and the CAA (2009a).

2.2 **CAA and FAA Regulations**

Business jets do not operate to a fixed schedule or to a fixed number of destinations, in the same way as commercial airlines. The aircraft may be operated by a charter company to a destination of the customer's choice or on behalf of a company or aircraft owner to various destinations for their own use. Therefore, for all passenger operations, each aircraft's state of registration regulates commercial passenger flights, including both airlines and smaller operators. (In some states, the smaller operators are often termed "Air Taxi or On Demand"). The following is a review of the regulations in the USA, the UK and Europe.

In the USA, the Federal Aviation Administration (FAA) uses Federal Aviation Regulations (FAR) to define the various types of operation. Airline operators are FAR Part 121 (FAA 2010). This regulation is for scheduled Air Carrier operations such as Airlines, which offer a schedule or timetable of pre-planned flights designated by both destination and departure time (FAA 2010). FAR Part 121 also limits the operations to controlled airspace and controlled airports including, specific weather limitations, navigational, operational and maintenance support. The CAA has a similar designation for airline operations, in that a Type A Route Operating licence is issued for scheduled and non-scheduled operations for aircraft with more than 20 seats (CAA 2010a, FAA 2010).

FAR part 135 covers the less restrictive operations in 2 types. The first is “Scheduled Part 135” which allows scheduled passenger carrying operations to smaller airports that do not provide the high level of support required for FAR Part 121. This is commonly referred to as commuter airlines and includes air carriers flying smaller jet and turbo prop aircraft. The second type of operation is “On Demand Part 135” which allows commercial passenger carrying flights (including medical evacuation flights), for which the departure location, arrival location and time are all negotiated by the customer (FAA 2010). The customer may charter the entire aircraft or book a single seat on an air taxi. Part 135 does however; limit the number of return trips between the same fixed points to less than 5 per week. This is directly comparable to the CAA Type B licence which permits operations, for aircraft with fewer than 20 seats and/or weighing less than 10 tones (this class covers almost all business jet aircraft). The type B licence may be issued for either scheduled or non-scheduled operations in the same way that FAR 135 designates non-scheduled as “On Demand”. Finally FAR 91 is the class equivalent of General Aviation in the UK.

It is worth noting that not all passenger carrying aircraft are covered by these FAR. Aircraft owned and operated by their owners or for company use are governed by FAR part 91 (General Aviation). Most of the FAR 91 operators own the aircraft and do not carry fare paying passengers and are therefore subject to far less stringent regulations. The overriding consideration for both FAR 91 and General Aviation is that the flights must not be for a fee or payment. FAR set the regulations for the conduct of passenger carrying operations; they do not however, distinguish by the type of aircraft but rather by the type of activity carried out.

In the UK a commercial company is governed by the grant of an Air Operators Certificate (AOC) and is subject to the appropriate regulations, such as Civil Air Publication (CAP) 371 which governs duty time limits and the avoidance of fatigue in pilots (CAA 2004). The AOC is specific to the type of operation, for example scheduled or non-scheduled, cargo or passenger. The AOC also defines and limits the operations, some of the conditions include; the type and number of aircraft, minimum weather conditions, and the geographical area allowed for the operation (CAA 2010a). Another condition is when a company or corporation operates their own aircraft that is not for “Hire or Reward”, then an AOC is not required and it is regulated as General Aviation (CAA 2010a). A table showing the FAA and CAA requirements is shown in Appendix A. The European Aviation Safety Agency (EASA) is also setting out its regulations and has issued an initial definition for commercial operations, which does not limit or define the size and type of passenger carrying operations (EU OPS 2008).

In summary, business jet operations are regulated by the major authorities but in a less stringent manner by not defining the routes, timetables and weather limitations. The business jets are also not limited to fixed destinations, in the same way as established commercial airlines, as these are dictated by the customer. So, the business jets have a more varied itinerary yet apparently less regulation and, as reported by the National Business Aviation Association (NBAA), are often operated by small companies with the majority having only one or two aircraft.

2.3 **Airfield Categories and limitations**

It is part of CAA and European Regulations (CAA 2010a, EU OPS 2008) that all airfields are categorised according to the type of terrain, approach aids available and any special considerations required. This airfield designation system specifies the experience level and training required for each crew in order to operate into each airfield. For example a Category A airfield has all the normal instrument approach aids (such as Air Traffic Control (ATC) radio facilities and Radar) and is without undue terrain or approach hazards. Category B airfields do not provide the Category A airfield facilities. Also, there may be limitations due to local conditions that required extra caution.

Finally a category C airfield requires special training and operating conditions, with detailed company records of all pilots qualified for that airfield. For example the airport of Chambery, in France, due to its relatively steep approach into a deep valley, has a requirement for special simulator training. Also, the captain should operate into the airfield under the supervision of a training captain prior to his/her first operational flight. A full Joint Aviation Authority (JAA) airfield category description is shown in Appendix B. In the UK, the CAA Operations Inspectors ensure that each airline maintains training records, thus confirming adherence to the procedures. For the smaller and more diverse operators, it could be difficult to ensure the specialist training is conducted prior to the flight. The CAA has raised their concerns and cited the difficulty of regulatory oversight, and considers this may be one of the causal factors for the business jet poor safety record (CAA 2009a). Furthermore, since the destinations are chosen by the customer, it may not be possible to confirm whether extra training is required. Business jet operators routinely send aircraft, with only a 2 pilot crew, to wide ranging destinations and, as part of a flight safety campaign, the International Business Aviation Council (IBAC) has a safety programme. This programme includes prescribing standards of operation, company monitoring procedures and company flight safety audits, to monitor companies to improve the operating standards across the industry. The results are published in their annual accident reviews (IBAC 2008a, 2010, 2011, 2012).

2.4 **Pilot Performance**

The CAA regularly conducts research programmes and one area of concern is that of pilot performance (Courteney 2009). Periodically, the pilots are required to demonstrate adequate flying skills to maintain their licence, during the Licence Skill test (LST) (CAA 2010c). However, in order to complete the mandatory licence requirements, there is rarely any remaining training time to practice other flying skills. During the periodic testing and recurrent training, the time dedicated to manual flying may be the minimum required (CAA 2009a). The tests include pilot skill and closed loop flying tasks such as engine failures and an approach and go-around in instrument flying conditions. This aspect of Commercial airline pilot performance has already been the subject of research by Ebbatson (2007, 2009) and Wood (2004) but there is a paucity of research concerning business jet pilots.

Since the introduction of Extended Twin Engine Operations (ETOPS) in 1985, engine reliability has improved to such an extent that the rate of engine shut down or failure in flight has reduced to less than 2 per 100,000 engine flight hours (Airbus 2010). For this reason, it is most unlikely that pilots today will ever face an engine malfunction that is sufficiently serious to warrant an engine shut down. Even though the engine failure rate has improved, all aircraft certified for passenger carrying must demonstrate safe and acceptable emergency handling characteristics, as required by the regulators (CAA 2012a, FAA 2010). Despite the aircraft design requirements, the rate of accidents, primarily due to incorrect crew response, following an engine failure has remained constant (Airbus 2010). Safety studies have confirmed that although the majority of failures were handled correctly, the more obscure malfunctions were harder to identify and resolve, since most pilots had no experience of actual failures. However, in order to obtain a licence all pilots are expected to demonstrate their competence after an engine failure as part of their final examination. Also, the LST examination procedures closely follow the engine handling procedures and techniques that are fully listed in the procedures manuals (AOPA 1987, 1994, Airbus 2010, Boeing 2003, Hawker 2008).

In the busy ATC controlled airways and airport airspace, passenger aircraft are only separated by 1000 feet vertically. So, when under strict ATC control, altitude deviations constitute a flight safety hazard. However, the CAA and the National Air Traffic Service (NATS) has reported the rate of “Level Busts” by business jets, when compared to the number of incidents from scheduled airlines (Riley 2009). (A Level bust is when an aircraft deviates by 300 feet or more from its assigned altitude when under radar control or in controlled airspace). For example although business jets only account for 6.12% of flights within the UK airspace but during the period January 2006 to December 2008 business jet reports were 19.63% of all incidents. In comparison, scheduled airlines which flew 92.96% of flights, reported only 76.73% (Riley 2009). Furthermore, a lower percentage, 3.64% of incidents were due to military flights (Riley 2009). All Level Busts are investigated and allocated a level of severity by a NATS working group, “Work stream”. This group determined that from January 2007 to December 2007, the business jet community accounted for 10 out of the 19 most serious level busts. This was 52% of the serious level busts recorded by UK registered aircraft. The working group then considered whether there was a clear need to focus the industry and improve the response within the business jet community (Riley 2009).

From accident report evidence, IBAC (2012) concluded that pilot experience was not necessarily a primary factor in the accidents that were reviewed. Although IBAC did not find that pilot experience was a factor, Todd and Thomas (2012) found that the level of accident risk was significant below 5000 pilot flying hours and stable above 10,000 pilot flying hours. It may be that experience could be considered a factor for the business jet community, since the CAA business jet pilot survey (CAA 2009a) reported that the average pilot flying experience was 2800 flying hours, well within the significant level below 5000 hours, reported by Todd and Thomas.

Furthermore, even though pilot flying experience may not be directly linked to flying ability, an IBAC business jet accident analysis identified that skill based pilot ability was a causal factor in 149 out of 232 accidents (IBAC 2008a).

The categories were;

- Knowledge based (No standard solution) 37
- Rule based (need to modify behaviour) 46
- Skill based (routine practised tasks) 149

In summary, although IBAC (2012) did not link pilot experience with primary accident factors, the overall fleet experience (CAA 2009a) may be relevant, since the business jet pilot flying hours are predominantly within the zone of significant risk, below 5000 hours (Todd & Thomas 2012). In addition, pilot ability, whether related to experience or not, should be further considered, since it a major factor in the 2008 accident review (IBAC 2008a).

2.5 **Pilot Training**

2.5.1 Initial Training

At present the recruitment of commercial pilots is competitive, with the most sought after places being with the major airlines. Some airlines will sponsor their pilot candidates and provide all the necessary training. Apart from those pilots entering commercial aviation following a military career, (Direct Entry Pilots), there are still many pilots, without sponsorship, wishing to fly commercially. (Harris 2006) The majority of these will have to pay for their own training either through a recognised course established by a training provider or by gaining each qualification as time and money allows (Harris 2006). These 2 training styles are defined in CAP 804 (CAA 2013) as either Modular or Integrated:

- Modular flying training course. The course consists of modules, which may be taken separately or combined.
- Integrated flying training course. The integrated course shall complete all the instructional stages in one continuous course of training. (Cap 804 Appendix 6)

Once the newly qualified pilots seek employment, they often join an Air Taxi Company or fly for a business jet operator. However, the CAA has raised concerns over the levels of training provided, as the new pilots would have the minimum of experience and may not obtain further operational or systems knowledge working with their new companies (CAA 2009a). The pilot training industry considered what may be required to improve the standard of both the candidate and the training (Petteford 2009). Petteford did not consider that the training organisations were at fault. However, he did suggest that the content of the courses could be re-examined, to improve any recognised deficiencies.

Due to the high cost of flying training, it is understandable that most only cover the minimum requirements (Harris 2006). Therefore, new pilots seek a commercial position, often with the minimum of experience, and training. Some of these pilots are operating business jets or Air Taxi operations all around the world. As noted by the CAA (2009a) many pilots felt ill prepared to commence work as a corporate or business jet pilots due to lack of training in the additional duties of corporate work. In contrast, military and major airline junior pilots undergo a long and intensive period of supervision and training prior to being declared fully operational.

2.5.2 Recurrent Training

After the initial examinations to obtain a commercial pilot's licence, each pilot must undergo recurrent training, including both annual and bi-annual examinations in flying skills, the LST. The simulator exercises are often planned to mimic the normal operations and are termed Line Oriented Flight Training (LOFT). Unfortunately, for some types of business jet in the UK, either a simulator was not available for the type of aircraft operated (for example, Citation Excel) or the simulator was of limited use (CAA 2009a). With the apparent lack of simulators or adequate facilities to improve pilot handling, the investigation by the CAA Accident Analysis Group (CAA 2009a) listed the causal factors in the 59 worldwide fatal accidents to business jets for the years 2000 to 2007. The investigation confirmed that Flight Handling was responsible for 27% of the accidents and the lack of positional awareness (in air) was responsible for 19%. Furthermore, over 50% of accidents were during the approach and landing phase (CAA 2006a, 2009a).

The CAA Business Jet Safety research (2009a) report included comments from a pilot questionnaire, which had been distributed to pilots holding CAA professional pilot licences, UK Business jet companies and their senior/training pilots. The questionnaire included approximately 30% questions about training methods and experience levels. Many of the respondents were happy with the standard of the initial training received, (an example is the syllabus in AOPA 1994) but raised concerns over the level of pre course study material available and the lack of further, follow up training once allocated to a company and commencing flying operations. It was noted that only 40% of all respondents had completed the requisite Multi Crew Co-operation (MCC) course that is required prior to operating commercially on a multi crew aircraft. The aim of the MCC is to instruct on the principles of CRM and train the pilots for multi – pilot airline operations, including the safe crew co-operation by maintaining a standard set of operating rules (SOPs). It is not surprising, therefore, that there were many comments concerning the lack of SOPs and the poor standard of CRM among the Captains. Some pilots also commented on the poor standard of re-current training in that it was often repetitive and nothing new was learnt from the previous year, unless a safety notice required a new emphasis. Other respondents reported that simulators used for recurrent training, were unable to reproduce major failures and were therefore of limited training value. This is in contrast with major airline operators, where a sophisticated simulator should be available (CAA 2011c) and the airline training organisation would provide new training scenarios for each summer and winter operating period. A serious concern was raised by the company senior pilots/trainers was that some pilots had no understanding of the required planning/actions in the event of a failure, such as engine failure on take-off (CAA 2009a).

2.5.3 Training for Emergencies

Once an engine has failed, this aircraft would lose 50% of its available thrust and its capability is dependent on the airspeed, configuration and drag of the aircraft. It is therefore desirable to fly accurately, especially if there are limiting conditions when a safe go-around, from a baulked landing is not assured (ref Hawker Beechcraft 2008, page 2-28).

The Hawker Pilots' Manual is quite specific on the importance of maintaining the correct airspeed and this is emphasised in the Pilot's manual section on single engine flying.

> "Basic Single Engine Procedures.
>
> 1. Maintain airplane control and a safe airspeed at all times.
> 2. **THIS IS CARDINAL RULE NUMBER ONE** "
>   (Hawker 2008, Section VII, page 21).

Similar training and advice is also part of the commercial pilot training and is included in the Boeing and Airbus Flight crew training manuals (Airbus 2010, Boeing 2003). The Airbus training manual quotes, with a special reference to smooth power changes for accuracy:

a) Once safely established in a visual or instrument circuit, aeroplane performance must be considered before reconfiguring for landing. Is sufficient excess performance available to cope with the extra drag of gear and flap? At high mass and/or ambient temperature some multi engine aeroplanes may not be able to maintain level flight with the gear down.

b) Power changes can be kept to a minimum by using gear and flap selection to assist in the control of speed and flight path.

Thrust settings and the resultant airspeeds will always be linked to the correct pitch attitude for a constant glide path (CFS 1995). Once the final configuration of undercarriage and flap for landing has been set and the 3 degree glideslope attained, the primary airspeed control is thrust, with commensurate minor pitch adjustments as the speed changes. However, once established keep engine handling smooth and power changes slowly and only as required. So, what could be a good control strategy? The following quote from the Private Pilot's Licence (PPL) course guidance illustrates the point.

"The key to a smooth approach is to make corrections as soon as they are judged required. A series of minor corrections is greatly preferred to a couple of major changes of power and attitude." (AOPA, 1994)

2.5.4 Training Standards

Although pilot training is quoted as paramount in safety (FAA 2012), there is little evidence of investigation into the standards. It is further relevant that pilots have commented on the lack of training for adverse weather operations (CAA 2009a). However, in a further study of business jet accidents, pilot experience and fatigue were listed as non-contributory factors (IBAC 2012). However, the International Business Aviation Council (IBAC, 2012) findings did also conclude that runway length, low cloud ceilings or poor visibility and day /night were not significant issues. In contrast, IBAC (2012) did list the following 4 major causes of runway accidents.

- Poor speed control and unstable approaches, most prevalent
- Incorrect or lack of reported runway conditions.

- Crosswinds and gusts in bad weather.
- Poor runway conditions and snow clearance.

From a training perspective, both the regulators and the pilots in all types of operations have stated their concerns that their manual flying skills are diminishing (CAA 2009a, Ebbatson 2007). During several data surveys and interviews, most pilots believed their flying skills were degrading (CAA 2009a, Veilllette & Decker 1995). Since an autopilot is normally required and utilised in controlled airspace (CAA 2010d) some pilots had stated the need to manually fly the aircraft whenever possible in order to maintain their flying skills (Ebbatson 2007). Furthermore, in 2004 the CAA acknowledged the need to maintain manual flying skills. An operations department communication was issued by the CAA (Vivian 2004), which considered that manual flying was acceptable, provided it was adequately briefed and discussed beforehand. However, it was agreed the most sensible place for training was the simulator, not the aircraft on line operations (Vivian 2004, Ebbatson 2007). Also, in order to improve both the scope and the validity of training, operators were given the opportunity to provide innovative and more operator specific recurrent training under the Alternative Training and Qualifications programme (ATQP) (CAA 2011c).

2.6 **Pilot Crew Resource Management**

Good crew behaviour, such as co-operation and effective leadership are an essential element for the safety of flight operations (Flin 2003). The monitoring of crew behaviour “Crew Resource Management” has been established by the CAA and is included in the pilot licencing requirements (CAA 2006 b). The appropriate skills for crew behaviour are separate from the technical knowledge and flying skills required by pilots. As such they are annotated as “NOTECHS” and are included in the pilot training syllabus (CAA 2006b). It is now accepted that a pilot may possess adequate flying skills yet their personal behaviour and relationship with the other crew members could pose a flight safety risk (CAA 2006b). Subsequently several behavioural types, including two social skills, (Co-operation, Leadership and Management), and two cognitive skills, (Situation awareness and Decision Making), have been established for use in pilot assessment. Airline operators regularly review crew CRM in regular safety audits to improve flight safety and crew situation awareness during Line operational Safety Audits (LOSA) (Helmreich 2001). The importance attributed to CRM by the FAA and NTSB can be inferred from its inclusion as a major requirement in the “Most Wanted List” for 2003, 2004 and 2009 (NTSB 2009b). The FAA has now increased the requirement for CRM training (FAA 2012).

All aircraft operators, both airline and business jet, are required to have a system of CRM training and assessment, to provide feedback to the crew and identify any need for retraining and improve CRM and safety (CAA 2006b, JAA 2001). In spite of the requirements, since the regulating authorities have included CRM in the pilot syllabus, reporting by the FAA and NTSB has shown that there is a lack of effective CRM in the business jet community (NTSB 2009b).

2.7 **Safety Data**

Annually, the CAA, FAA and NTSB issue annual safety updates and accident data for all types of flying. The data normally covers everything from the smallest hang glider accident to the accidents of the largest airliner. However, only data for commercial passenger flights will be considered with special interest in the comparison between scheduled airlines and business jet operations.

In 2007, the CAA Safety regulation Group (SRG) commissioned the Business Jet Safety Research paper with regard to operations in the United Kingdom (CAA 2009a). The CAA report discussed the operations and safety aspects from the SRG Accident Analysis Group (AAG) Annual review of 2006. This included data on the aircraft normally utilised in business jet and corporate aviation. The concern was the disproportionately high number of fatal accidents involving this type of aircraft.

In 2008, the safety record for the previous ten years has been consistent, with similar fatal accident records for business jets (CAA 2008). The CAA 2006 safety review also contains similar statistics (CAP 776). The CAA Flight Safety accident rates quoted are for fatal accidents per million hours. For example, the 2006 global fatal accident data shows that airline operators achieved a rate of 0.65 accidents per million hours but a much higher rate for business jets operations at 1.27 accidents per million for large business jets, above 27 tonnes and 0.88 for the smaller jets between 15 and 27 tonnes (CAA 2006a). The overall rate of 1.27 was almost twice the accident rate of commercial airlines.

The CAA data noted above, supported that of other agencies including the NTSB (NTSB 2007) and IBAC, Summary of Global Accident Statistics 2006-2010 (IBAC 2011). The safety incident rate per million flying hours for scheduled airline flights is far lower than commuter jets and Air Taxi or "On demand "operations. In 2005, Air Taxi operators had approximately 10 times more safety incidents than scheduled airlines. The trend is worse for fatal accidents per million flight hours (NTSB 2007). In 2008, the Scheduled Airline rate was 0.15 per million hours but for small commuter jets it was 2.88 per million hours or almost 20 times greater (NTSB 2009a). Another 3 year FAA survey of all General Aviation, on demand operators and business jets considered that 65% of business jet operations are in the USA and the distribution of operators was representative of the world fleet (IBAC 2012). When the data from the European fleets was applied, the sensitivity analysis tables concluded a difference ranging from 0.01% to 0.08% in the fatal accident rates, which demonstrates acceptable level of error for the comparison purposes intended by the statistics (IBAC 2012). Therefore, for the purposes of this study, the FAA accident data may be considered as representative of the world fleet.

The IBAC Safety Summary, (IBAC 2011) reported the global accident rate for business jets. Although the accident rate is reported at a rate per 100,000 hours rather than as previously discussed, per million hours, the business jet safety record is still significant. Table 1 Illustrates the Business Jet Global Accident rate per 100,000 hours. The accident rate is broken down to show the difference between the Commercial Air Taxi operators that provide aircraft "as required “ and the owner operated/ corporate operations. The reported accident rate of 0.17 is a great improvement on the previous 5 year value (2003-2007) of 1.09 but is still far above that of commercial aircraft operations. The overall rate for the owner operated and corporate aircraft is the lowest at 0.03 as these aircraft tend to be limited in geographical area and type of operations compared to the Air Taxi operations which may operate world-wide. Even though IBAC considers the difference in operations within the business jet organisations, there is no breakdown geographically or for airfield facilities and environment.

Table 1 Business Jet Global accident rate per 100,000 flight hours 2006-2010 (Adapted from IBAC 2012)

Type of business jet operation	Accidents per 100,000 flight hours
Commercial Air taxi	0.44
Corporate Operations	0.03
Owner operated	0.11
All Business Aircraft	0.17

The global data for all accidents are widely reported and is summarised in CAP 776. The regions are considered as large geographical areas, for example the whole of Africa is one zone. Also there is no further information concerning the airport environment, such as high terrain or the standard of the runway approach aids. The global distribution of business jets is shown at Table 2

Table 2 Global Business Aircraft Population (Adapted from IBAC 2012)

Geographical Area	Percentage of world population
North America	65%
North America, without the US	8%
South and Central America	7%
Europe	11%
Rest of the world	9%

There is no related information for business jets regarding the type of operating environment, terrain, weather or airport facilities in order to make a reasonable comparison and define safety concerns. For example, two airfields with very similar operating conditions, (such as mountainous terrain, single runway and limited runway approach aids) are Taba in Egypt and Aspen in Colorado but they have very different accident statistics. Taba is a tourist destination for commercial airline operators with annual passenger numbers of 210,000 to 340,000 and no reported accidents in the last 12 years. However, Aspen is mainly a business jet destination with approximately, 40,000 aircraft movements per year, yet has had several accidents, including 18 fatalities in 2001 (NTSB 2012a). Taba is only one example of the many tourist destinations for commercial airlines, which also include the winter skiing resorts in Europe that are very similar in terrain and access to Aspen. However, the commercial airlines retain a better overall safety record.

All the accident statistics quoted so far have been based on flying hours accumulated by the various types of passenger carrying operations. However, the most prevalent business jet accident by phase of flight from 2003 to 2012 has been during the landing phase (IBAC 2008 a, 2011, 2012). Similarly of the 552 jet and turbo prop accidents recorded between 1998 and 2003; there were 72 approach accidents and 111 landing accidents (A rate of 33% overall, R. Woodhouse. 2006). The business jet accident data for 2006-2010 confirms that approach and landing remains the critical phase of flight with 10.6% of all accidents on approach and 54.4% during landing (IBAC 2011). The approach phase has shown a consistent level of accidents and the most recent data confirms that 60% of all accidents have occurred during the approach and landing (IBAC 2012). The 2012 Accident summary for phase of flight is shown at Table 3.

Table 3 Business jet accident summary by phase of flight. (Adapted from IBAC 2012)

Taxi	Take off	Climb	Cruise	Descent	During manoeuvre	Approach to land	Landing	TOTAL
10.9%	6.9%	8.3%	3.2%	2.6%	0.6%	8.3%	52.2%	100%

With the majority of accidents occurring during the landing phase, and as all departures and normally finish with a landing, the fatal accident rate per 100,000 departures is the next consideration. The relative safety record of the business jets is still apparent in the following statistics.

The fatal accident average, 2006 - 2011 per 100,000 departures has been 0.18 for all business jets and 0.034 for Scheduled Commercial aviation (IBAC 2012). However, the Corporate owned aircraft tend to be limited in operations related to the company place of business and are therefore more stable in the their operations and have a rate of 0.01 per 100,000 departures. Table 4 shows the IBAC 2012 comparison summary of the 5 year fatal accident rates.

Table 4 Summary of 5 year Fatal Accident rates (Adapted from IBAC 2012)

AVIATION SECTOR	FATAL ACCIDENT RATE PER 100,000 DEPARTURES
ALL BUSINESS AIRCRAFT (jet & turbo prop), Note 1	0.44
CORPORATE AVIATION (Jets), Note 1	0.01
ALL BUSINESS JETS, Note 1	0.18
BOEING ANNUAL REPORT- JET AIRCRAFT OF MCTOM OVER 60,000 LBS. (engaged in commercial scheduled passenger operations) Note 2	0.034

Note 1: Rate is IBAC 5 Year average

Note 2: Boeing Statistical Summary of Commercial jet Airplane Accidents, Worldwide operations 1959-2011, dated July 2012. Rate is for Scheduled Commercial Operations for a 10 year period.

In summary, whether reported per flying hour or by departure rate, and when operating away from Class A airports, the business jets do not match the safety record of commercial passenger carrying operations and the majority of accidents occur in the approach and landing phase of flight.

2.8 **Safety Initiatives**

Part of the IBAC safety initiative was to recommend the implementation of a Safety Management System (SMS). The safety Management system is a method of reviewing every part of the company in order to audit safety levels and operating procedures for any possible errors; oversights or failures that could in any way contribute to an incident or accident. Once the safety review procedures are in place and any improvements implemented, there should then be a periodic review of improvements in working practices to further maintain safety awareness. In all major flying organisations and large airlines, there exists some central authority for Command and Control or overall responsibility. It is essential, therefore, that any flying organisation has a positive attitude to safety and operations that reflects throughout the staff both air and ground based (CAA 2010a). This is the safety culture and a poor safety culture or attitude would be detrimental to safety and appears to be lacking in the business jet community. This attitude had been confirmed in a quote from an accident report by an NTSB Board member.

> “When asked about the flight department's standard operating procedures (SOPs), the chief pilot advised that they did not have any…” (NTSB 2009 b)

IBAC has completed a study to monitor trends and proposed a safety initiative and code of practice (IBAC 2008b). In April 2008 the World Business Jet association announced a new programme of SMS. Also, a planning toolkit was proposed, the International Standard for Business Aircraft operations (IS-BAO) (IBAC 2008b). Subsequently, assessments were made to assess the possible impact of the improved SMS and code of practice on 500 accidents between 1998 and 2003 (IBAC 2008a). This study concluded that an improved SMS and good company practice would be conducive to improved flight safety.

The EASA safety plan 2011 to 2014 has listed safety initiatives to address concerns in major areas (EASA 2011), including the increasing numbers of Loss of Control incidents and the increasing number of runway overruns (I.e. when an aircraft cannot stop on the runway and continues off the end of the prepared surface). Other factors in the Safety Plan are concerning pilot handling, for example high airspeeds on landing , high on approach path, poor decision making, poor braking techniques and lack of runway performance knowledge (EASA 2011). Unstable approaches have also been identified as possible safety hazards. An unstable approach is when the aircraft is either much faster than required or in the wrong configuration prior to landing, between 1000 ft. and 500 ft. above touchdown (FSF 1998).

The IBAC (2008a) study compared the probability of accident prevention with regard to some human factors designations. The analysis of deliberate violations, inadvertent violations and mistakes confirmed the high number of failures to follow defined procedures. The most significant (40% combined) was concerning adherence to procedures and pilot monitoring.

The safety initiatives are indicative of the regulator's concerns with the safety of business jet operations. The EASA safety plan for 2011 /2014 again emphasises issues with Loss of Control, Runway performance, pilot handling. Similarly, IBAC has an almost constant programme to improve company safety standards and the adherence to procedures.

2.9 **Regulatory Oversight**

Business jet operators are becoming more diversified and many companies are choosing to register the aircraft operation in a country of convenience. The aircraft operator may hold a worldwide AOC, allowing world operations and never returning to the country of registration. Once the AOC is issued and operations commence, it is almost impossible for the flight operations inspectors to oversee every aircraft operator. For example, the CAA UK 2009 Register Database listed 219 aircraft in the categories of light, light/medium, medium and heavy business jets. All these aircraft could operate under an UK AOC with the right to fly anywhere in the world (CAA 2012b).

With the conditions listed above, this is extremely difficult to monitor with a non-domiciled operator. This is recognised in the CAA (2009b) safety report "Producing a complete picture of these aircraft in the UK is further complicated by the fact that many of the resident aircraft in this group are not on the UK register" and is therefore registered elsewhere. The UK register is growing in this aircraft category. During June 2005, there were 98 registered aircraft of the business jet type between 5700 kg and 10000 kg. In May 2008 the total was 208 (CAA 2012b). As discussed in Para 2.2, there is a group of operators who do not carry fare-paying passengers (operated by the owners or flown purely on company business). These operators do not require an AOC; therefore it is difficult for the regulating authorities to have effective oversight.

EASA has shown concern over the management oversight of operations, since reports have confirmed that some operators are no longer applying a safety margin (15%) when calculating landing distances required (EASA 2011). Part of the basic flying skill required of any pilot is to touch down accurately in the landing zone. Unfortunately, practice suggests that pilots are making long landings when the runway is very long or attempting to land very close to their runway turn off point, with hazardous results (EASA 2011). Runway performance may be critical, especially since the operations manual performance data is not normally certified and is advisory only. (EASA 2011)

There is a requirement for aircraft over 27 tonnes to have an on board system of Flight Data Monitoring (FDM) (CAA 2003). The FDM allows the flight to be recorded and the flight parameters (such as speed and configuration) to be verified after landing. Commercial airlines are required to monitor the FDM and address any possible flight safety hazards, such as excess speed on approach. However, business jets are primarily below this weight category and are therefore exempt. Therefore, any routine violations or persistent skill errors as defined by Wiegmann & Schappell (2003) would be difficult to monitor during normal operations. By monitoring all the flight parameters, situations such as poor flying technique or not following the correct flight profiles could be examined (EASA 2011).

The CAA safety plan 2011 -2013 (CAA 2011) raised similar safety concerns, highlighting ‘Significant Seven’ Safety Issues (in priority order);

1. Loss of Control
2. Runway Excursion
3. Controlled Flight into Terrain
4. Runway Incursion

5. Airborne Conflict
6. Ground Handling
7. Airborne and Post-Crash Fire

The CAA has initiated a Flight Safety programme of actions and publicity to improve safety in these seven areas. Another safety initiative has identified deficiencies in Business Jet operations, with the intention gaining a desired safety outcome as follows (CAA 2011).

1. Reduce the number of and relative contribution to level busts in UK airspace by business jets.
2. Reduce the proportion of incorrect response to Aircraft Collision Alerting System (ACAS) RA warnings by business jet pilots.
3. Extend Alternative Training and Qualification Programmes (ATQP) into business jet operations.

The safety initiatives proposed by the regulators cover all aspects of passenger carrying operations and may not be specific to business jets. However, many of the regulators' concerns are focused on the flight safety aspects discussed in the business jet safety data, Para 2.8.

2.10 **Previous Research**

The CAA has already been involved in a simulator trial to ascertain a method of assessing pilot manual flying skills. In this study, the Instrument Landing System (ILS) tracking data was utilised to measure pilot performance (CAA 2009c). One reason for the pilot performance study was the consideration that the use of automation in modern passenger aircraft was affecting the pilot's ability to retain essential flying skills (Wood 2004). Most modern jet transport aircraft utilise an auto-flight system which has the flight profile programmed or selected rather than the aircraft being controlled by manual pilot inputs. With much more use of automation, it may be that during an aircraft failure or degradation, poor pilot skills would pose a flight safety hazard (Ebbatson 2009). In general aviation, Keller (2013) has reported concerns for the decay in instrument flying skills on approach since more than half of instrument approach accidents occurred within three and a half months of the last instrument flying test.

The Cranfield (2005) paper concerning risk assessment and the 2007 NTSB safety review both quote pilot handling as major factors in reported accidents and incidents. The Air Accident Investigation Branch (AAIB) (2009) database lists 795 cases of accidents or incidents where Pilot handling is quoted as a factor. Also, as previously discussed pilot handling and training is one of the major influences on business jet safety.

Commercial Airline operations have an established system of safety audits. In some airlines, the primary flight operations audit is the LOSA. For these audits, the pilots are observed on routine line flights and any safety concerns are reported. The findings of the NTSB safety review were supported by Helmreich (2000, 2001) during an evaluation of Commercial Airline flights during a LOSA. Even though the LOSA was devised around airline operations, these same problem areas are evident from the business jet accident reports (IBAC 2012).

The inter-reaction with agencies such as maintenance and ATC could be the most difficult for the crew to manage and Klinect (2002) found for commercial airlines that during the approach phase, outside threats associated with ATC resulted in errors or undesired aircraft states. The most frequent were incorrect aircraft configuration, vertical deviations and excess speed (Helmreich 2001).

In general, for the inter-reaction of man and the environment, Harris & Thomas (2006) found the central spheres of the Human, Machine and Mission were influenced by the spheres of influence of the Management and the Medium. For example, for an airliner to perform its mission the management must obtain the aircraft, which must be capable of the task in the physical medium and the pilot must comply with the medium of licences and capability. The pilot performs a defined goal in flying from A to B, the union of man and machine. For the safe operation, the management and requirements demanded by society need to be actioned accordingly. In the framework of the operation, all aspects are influenced and controlled by the surrounding aspects (Harris & Harris 2004).

Previous research has concentrated on the operational aspects commercial airliners, with little research conducted into business jet operations. As discussed in the Safety Data, Para 2.8, there are annual safety reviews and accident data statistics, without further research into business jet the operations.

2.11 **Technical Failures and Outside Support-**

Flight operations are dependent on other agencies and individuals involved in the support of the flights, maintenance, ATC etc. (Helmreich 2001). The business jets operate throughout the world. In Europe and North America, engineering support to a high standard is normally available. However, once farther afield in Africa or Asia, this may be increasingly scarce. In extremes this would ground the aircraft awaiting repair or operating with reduced efficiency to return. Also, maintenance errors have caused equipment failures in flight, which required emergency action by the crew. The inter-reaction of ATC and Ramp Maintenance with the pilots, who could not operate in isolation but needed to inter-react, was discussed by Li (2007).

The effect of technical failure was reported in CAP 776, which discussed the number of accidents that occurred after an in-flight failure. Even though the aircraft manufacturers provide procedures and drills for dealing with failures, (Airbus 2008, Boeing 2003, Hawker 2008) the report contained emphasis on the subsequent loss of control after engine failure/malfunction. In addition, the 2 highest circumstantial factors were inadequate regulatory oversight and the failure of company oversight and management (CAA 2009b). The company commitment to flight safety and organisational culture also had an overall influence on many accidents (Cranfield 2005).

2.12 **Summary of Findings**

Business jet operations do not operate to a fixed schedule, or a fixed set of destinations. So, when compared to the scheduled airlines, they have a more varied itinerary and a different set of licencing regulations. By the very nature of the operation, business jets are more difficult to oversee and regulate (CAA

2009 a). The disparity of global operations, which may require extra training and the possible lack of supervision, has raised concerns within the industry and the regulators. (CAA 2009a, IBAC 2008b)

Piloting skills are regularly tested as part of the annual licensing requirements, yet compared to the airlines the training and standard of simulation has come into question (CAA 2009a, Ebbatson 2007, 2010). In the IBAC and the CAA accident safety data (IBAC 2012, CAA CAP 776), the approach and landing phase is reported as a major accident statistic. Engine reliability has greatly improved, possibly after the introduction of ETOPS in 1985. However, on those occasions when an engine has failed there was evidence of incorrect crew response or poor pilot handling (CAA 2006a).

CRM, training and assessment is required for professional pilots and is a major part of airline training (Flin 2003, Helmreich 2001). Unfortunately, both pilot reports (CAA 2009a) and industry feedback confirm a low standard of CRM in business jet operations.

The 5 year average for Fatal Accident rates confirms that business jets have a poorer safety record than scheduled airlines (IBAC 2012). Moreover, the safety data from as far back as 2003 have consistently shown the same safety record. There are now at least 18400 business jets in global use, but apart from the concerns expressed by the regulating authorities and the Safety Initiatives from the industry, there is no evidence of a deeper investigation into Business Jet Operations.

Even though business jets are supervised and subject to the same safety criteria as scheduled airliners, the operations do not have the same safety record. Overall, with the same pilot licences, training and syllabus there exists an imbalance in the proportion of accidents during the landing phase, especially when there is a technical failure. Also, commercial airlines are regularly inspected and conduct LOSA to report on the level of flight safety. However; there has not been a formal investigation into business jet operations. Therefore, in order to further understand business jet operations and the accident rate, an in depth study of the accident history was conducted and is reported in Chapter 3. Further, a simulator trial was conducted to obtain pilot handling data on a representative task that would emulate the majority of reported accidents. This is reported in Chapter 4.

3 ACCIDENT DATA INVESTIGATION

3.1 Introduction

The purpose of this Chapter is to follow on from the Literature Review and explain the rationale for the next stage of the accident investigation. This Chapter addresses the second research objective as listed in Para 1.2. This Chapter examines the business jet accident history to build a representative accident model which then provides a link to the simulator phase of the study.

The CAA has raised it concerns for the safety of business jets as part of its Safety Plan 2006/7-2010-11 (CAA 2009b). Previous research has already outlined the types of accidents. However, the primary causes of the business jet safety record are uncertain (CAA 2009b, CAA 2006a). Subsequently, there was no clear indication of how the business jet operation varied from the relatively safe scheduled airline operations.

The safety of Scheduled Airline operations has already been the subject of research in several key areas. LOSA have been conducted by monitoring flight crews during normal operations (Helmreich 2001, Klinect 2002), which did highlight critical safety concerns during the approach and landing phase. Airline pilot attributes and behaviours have also been the considered for CRM and a crew assessment system created (Flin 2003).

However, even though LOSA have not been reported for the business jets, in 2009, the CAA Accident Analysis Group reported the primary causal factors in the 59 worldwide fatal business jet accidents from 2000 to 2007. In the reported data “Flight Handling” was responsible for 27% of the accidents, followed by the “Lack of Positional Awareness (in air)” being responsible for 19%. In the same summary, the data confirmed that over 50% of accidents occurred during the approach and landing phase (CAA 2009a).

3.1.1 Data Investigation Rationale

Several taxonomies exist for investigating the human factors which contribute to an accident. The Human Factors Analysis and Classification System (HFACS), Wiegmann & Schappell (2003) has often proven to be the first step to accident analysis. HFACS is organised upon 4 hierarchical levels and each level is sub divided into specific sub elements. The primary 4 levels are;

1. Organisational influences.
2. Unsafe supervision.
3. Preconditions for unsafe acts.
4. Unsafe acts of the operator.

For an investigation into flying skill errors or deficiencies, the area of concern would be in level 4 under “Unsafe Acts”, which is then divided into three types of error 1) Decision errors 2) Skill-based errors, and 3) Perceptual errors. Subsequently, the skill based error would cover hand flying or “stick and rudder”, which are basic flight skills as a continual process, without significant conscious thought (Wiegmann & Shappell 2003). However, there are many more factors within this one task that could have an influence and the levels of the HFACS system would need to be amplified to include these factors. For example, poor instrument scanning or poor technique may be evident. An accepted model for performance levels and skill learning is offered by Reason (1990). For a skill - rule – knowledge based performance, the lowest level is to follow the knowledge based actions, and then as experience grows the rule based behaviour takes over. This is especially pertinent where a pilot has very little experience and may have an incomplete or erroneous knowledge base for the situation thus becoming overwhelmed by the task.

Further Human Factors analysis may prove useful in evaluating accidents and defining the accident causality (Shappell & Wiegmann 2006). Typically there are a multitude of factors which contribute to an accident. Studies have associated a number of causal factors in the following areas, Environment, Human, Machine and Task (Harris 2006, Wiegmann 2003). Evidently, it may prove difficult to isolate each single event or factor. In support of taking several factors into account, Helmreich (2001) validated the importance of operating skills into essential groups, Team Climate, Planning, Task execution and reviewing. These essential groups improve the level of accident investigation outside the initial levels proposed by HFACS. Also, HFACS can be limiting in that it can be difficult to collate information about the latent conditions or inter-relation of conditions in the accident reports. The deeper investigation of human factors in accidents has shown the value of going beyond HFACS by gaining a broader insight into the crew actions and developing a central theme that links the human factors of each accident, such as CRM or training where several aspects all link together (Li 2007). For example, Li (2007) found that accidents rarely involved a single error and overall it was possible to show as many as eight individual errors linked across the HFACS framework. CRM was often found to be a major factor and was then linked across three out of four categories at the HFACS level one framework. Therefore a broader approach was considered that would provide a representative accident model of business jet operations.

It was considered that an accident data analysis such as the Grounded Theory approach, suggested by Strauss & Corbin (1990) would establish an accident model that was pertinent to the particular operations of business jets. For example, when utilising HFACS, in order to assess an unsafe act, the researcher must first designate it to either an Error or Violation. If the example is an error, then it must be allocated to one of the next sub sets of Skill, Decision or Perceptual based errors. In contrast, when the evidence is collated by the Grounded Theory method, it is grouped by type or similarity of context and content, with minimal researcher input or opinion. Once all the initial groups or categories are created, then further assessment is completed to refine the model and establish similarity of action or groups that could improve the definition of the final analysis. Furthermore, the evidence “speaks for itself” and the groups or categories are created by the facts themselves. So, groups like Team, Task, Skill or Environment become self-evident and as noted above overall effects, such as CRM may become apparent. Therefore, for these reasons, Grounded Theory study was considered advantageous over HFACS in gaining an objective view of the business jet accident record.

3.1.2 Data Origin

As stated earlier, a CAA study had evaluated the accident data prior to 2007. So, the accident analysis in this Chapter continues from the year 2007. The accident analysis was further refined to a specific flight phase from the data reported in the annual safety summaries. In particular, IBAC (2008a, 2011, and 2012) reported that the majority of accidents of business jet accidents occur during the approach and landing phase of flight (over 60% in 2012). IBAC further list the 4 major causes of runway accidents, including, poor speed control, unstable approaches, runway conditions and crosswinds. The approach phase was further considered representative, since the EASA safety plan 2011 to 2014, proposed safety initiatives to address factors such as high landing speeds, high approach paths, unstable approaches and poor braking techniques. Also, when operating to smaller, less sophisticated airports, some operators were not allowing sufficient landing distance margins or the pilots are landing too far down the runway to stop safely (EASA 2011). The basic flying skill required of any pilot is a safe and accurate touch down in the correct part of the runway, yet pilot skills, including loss of control, were identified in several safety initiatives (EASA 2011, CAA 2011). Considering the safety concerns of the regulators and the majority of landing accidents during business jet operations, it was identified that the approach and landing phase was the critical area of interest.

The data for this Chapter was obtained from the NTSB accident data statistics for the years 2007 to 2010 in the flight phase “Approach and Landing” for all business jet listed accidents (NTSB 2012a). The NTSB database is an independent organisation with reports for all accidents within their domain and all aircraft with a United States registration, to the accepted standards as define ICAO annex 13 (NTSB 2012b, ICAO 2012). Also, during 2010, the North American fleet represented 63.7% of the global business jet fleet, whereas Europe only 13.9% (IBAC 2011). Other accident investigation organisations were also considered. Although the AAIB is of equal merit it is only responsible for the investigation of the accidents occurring to UK registered aircraft and foreign registered aircraft whose accidents occur in the UK (AAIB 2009). During the years 2007 to 2010 NTSB reported a total of 59 landing accidents, whereas for the same period the AAIB reported only 5 business jet accidents, in all categories (AAIB 2009).

3.2 **Methodology**

The study was based on the procedures for data gathering and coding as outlined by Strauss and Corbin (1990) (format listed in Figure 1), in order to develop an accident model that could reflect the particular operations of the business jets.

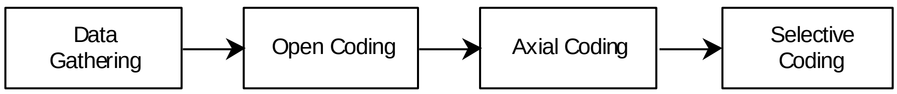

Figure 1 Grounded theory application steps (from Strauss and Corbin, 1990).

3.2.1 Data Gathering

The data were collected from the NTSB accident data files for the years 2007 to 2010. In order to gather the evidence, a set of qualitative statements from the NTSB accident investigation reports were collated, verbatim, into a database. This was followed by a line by line analysis as described by Strauss & Corbin (1990). The accident and incident data from all the approach/landing categories listed in NTSB data files were broken down into individual phrases or sentences, which referred to a single incident or observation concerning the facts of the accident.

For each phrase, the sampling criteria were that it should contain evidence of the following:

1. Statements and evidence from either the crew or witnesses.
2. Description of the conditions pertaining to the accident. For example; the weather reports, the aircraft state (either fully serviceable or with

equipment failures), the runway in use, Air Traffic Control reports and the runway conditions (either wet or dry etc.)
3. The relevant operating drills or procedures that were required or recommended by the manufacturer.
4. The evidence of the investigating officer.

3.2.2 Open Coding

In accordance with the procedure defined by Strass & Corbin (1990), the Open Coding category list was established as follows; the tabulated data groups were obtained by from a line by line analysis of the lines of text from the NTSB accident reports to gather items of evidence or witness comments.

Each item was then examined in order to consider a relevant category. The analysis was conducted using the constant comparison technique (Partington 2002). In the process each line of text was compared with the preceding examples to see if it repeated the same phenomenon as stated in one of the previous lines. If this were true, then it could be allocated to an existing category, if not, then a new category was required and allocated to that line of text. This procedure was followed by the first rater and an initial set of coding categories was created. During this phase each phrase had been given an identifier linking to the original report, so that it may be read and cross checked in its original context, if required. Subsequently, the complete listing, along with its identifiers plus the original NTSB reports, was passed to a second rater. The second rater was asked to repeat the procedure outlined above, where each phrase would be compared with the preceding examples and either included in a new category or added to an existing category. In order to check for inter-rater reliability, once the second rater had created an independent list, the differences in coding were discussed by the two raters and a consolidated list of categories was agreed.

3.2.3 Axial Coding

Following the procedures outlined in Strauss & Corbin (1990) axial coding was the next stage of proceedings. Axial coding specifies the properties and dimensions for a higher level of coding. Strauss views axial coding as building a ‘dense texture of relationships around the axis of a category’. Thus it begins the development of a higher order category although it may be at an early stage of development. Initially, the open coding results were further examined to confirm that each phrase was in the appropriate category. This was done by comparing the content of each phrase against the other phrases in the same category. The open coding categories were then arranged into groupings containing similar or linked content. This new format became the basis for the High order categories.

3.2.4 Selective Coding

The final segment of Strauss & Corbin defines Selective Coding as

“The process of selecting the core category (and) systematically relating it to other categories”

During the Selective Coding process the categories identified by the axial coding were further examined to identify if there were relationships between these categories to develop a core model of the accident data. The high level groups in isolation would not completely build a working model for accident analysis. For example, the pilot may have lacked the ability to land in the prevailing conditions, yet the weather had not been considered prior to the accident. So, the skill of the pilot could be listed as a cause of the accident, even though, the situation could also be the responsibility of the commander, who ignored weather conditions. The core strategy was therefore established to show the overall model and demonstrate the relationship of the higher order categories.

3.3 **RESULTS**

3.3.1 Open Coding

The data were taken from the NTSB on line data base for all Final Factual reports for Turbo jet and Turbo fan engine business jets (NTSB 2012a). This yielded a total of 47 accidents which fulfilled the sampling criteria.

The NTSB data included two fatal accidents where the aircraft was completely destroyed and the facts of the accident could not be determined. Therefore, these 2 accidents were excluded from the listing. In 2 other reports of accidents, the aircraft was either parked or taxiing and in each case the crew could not affect the outcome. For example, one aircraft was parked prior to start up and a refuelling truck drove into the wingtip. Since these accidents did not involve any flight crew action or inaction, these reports were excluded.

3.3.2 Open Coding: Category Descriptions.

During the open coding process, 164 phrases fulfilled the sampling criteria and from these phrases 15 open coding categories were established. The list of open coding categories, with the number of phrases allocated to each category is shown in Table 5. After the table, each category is described in detail.

Table 5 Initial Open Coding Categories.

CATEGORY	Phrases allocated
Pilot skill or accuracy.	31
Systems awareness	23
Captain’s command or judgement	8
Failure to follow a drill or procedure	16
Maintenance Error	15
Actions reported as correct, in the situation.	14
Understanding the aircraft’s runway performance	12
Aircraft systems knowledge	9
Examining the Conditions	3
CRM or company CRM policy	9
Ground Personnel	6
Operational Procedures	8
Reluctance, uncertainty or confusion	3
Rules or Regulations	5
Outside the aircraft Clearance	2
TOTAL PHRASES	164

3.3.3 Piloting Skill or Accuracy

Aspects of the pilots' flying abilities were listed in several reports. An example is shown in the following quote where a co-pilot is having difficulty achieving the required approach and makes several inputs to correct the situation. However the aircraft was damaged during the hard landing and subsequent go-around.

> "The first officer then saw the runway threshold, and as he descended below the MDA (Minimum Descent Altitude), the airplane was high and indicating an airspeed of 150 knots. The first officer momentarily deployed the speed brakes, but stowed them about 200 feet AGL, (above ground level) and reduced the engine power to flight idle. About 20 feet AGL, the airplane descended at an excessive rate and impacted the runway. The airplane drifted right, bounced, and the first officer initiated a go-around."

3.3.4 System Awareness

The category for "System Awareness" contained examples of crews that did not seem aware of the aircraft state for the safe conduct of the flight. An example is where the aircraft ran out of fuel following several attempts to land in poor weather conditions. Here is the report extract showing that the Captain did not appear to appreciate the severity of the situation. The aircraft crashed once the engines had stopped due to a lack of fuel.

> "On the third missed approach, the No. 1 engine shut down and the pilots requested a vector from air traffic control (ATC) for a fourth approach. The first officer then stated to ATC that they were low on fuel. In the report, the captain stated that the airplane "ran out of fuel"

3.3.5 Captain's Command & Judgement

The accident data contained evidence of situations where the captain's decisions could prejudice a safe flight, such as uploading insufficient fuel for the flight or continuing to land in adverse weather conditions. The category for "Captain's Command or judgement" was included. In one particular accident, a captain landed in adverse conditions, even though the evidence confirms that the information was passed to the pilot. The following quotation from the accident investigator, in this accident, lists several of the facts (including evidence from ATC and the Flight Data Recorder) plus the comments about a slippery runway by the Pilot in Command (PIC). In the event, the aircraft could not stop on the runway and ran off the far end.

> “They stated that the airplane appeared "high and fast" as it crossed over the runway threshold The data revealed the airplane's groundspeed at touchdown was about 140 knots The PIC reported that he thought the runway might be covered with an inch or two of snow, which did not concern him. The co-pilot reported encountering light snow during the approach. At 0904:23, the PIC stated, “now expect it to be icy and slippery okay so..”

3.3.6 Failing to Follow a Drill or Procedure

During several flights, the incident had been initiated by a system or component failure on the aircraft. In this situation, the crew would have been expected to complete the required failure or emergency drill/procedure in preparation for landing. As will be listed in the next paragraph, this would normally be the case. However, it became apparent that a further category of “Failing to follow a drill or procedure” was required. The particular crew, in this extract, could not stop on landing after a hydraulic system failure, since they did not complete the drill and the emergency brakes were not selected “on”.

> “The flight crew did not evaluate the auxiliary hydraulic pump to see if it could restore system pressure, and continued to trouble shoot the fluid loss without following the checklist. During the flight crews evaluation of the hydraulic system, the A side pump was turned on and the PTU circuit breaker was engaged which enabled the normal landing gear extension. The flight crew did not complete the Landing checklist.”

(Note: the PTU is a Power Transfer Unit, part of an emergency system.)

3.3.7 Maintenance Error

During the statement collation there were 12 phrases or statements that illustrated an accident or incident that was directly attributable to maintenance error. In 2 other statements there was evidence of material or design failure. In these 2 situations the components failed in flight but were causes which could not be influenced by any flight crew action or inaction. However, it was noted that in the majority of cases the flight crew dealt correctly with the situation and safely recovered the aircraft. Since the correct actions and all other consequences were already covered in other categories, these phrases were included in the category of “Maintenance Error”. For example, in one accident report, an engine cover did not have the correct fasteners and was not securely re-fitted following engine overhaul. Subsequently, the panel opened in flight and the crew made an emergency landing.

3.3.8 Actions Reported as Correct for the Situation

Although, there were 13 entries in the category for the crew failure to follow a drill, there were still 10 cases of correct crew action followed by a safe/ uneventful landing (“Actions reported as correct for the situation”). As in the following example, accident reports of correct crew action were often very short with few comments.

> “The pilots shut-down the left engine and declared an emergency. The airplane diverted to Palm Springs where it made an overweight, single-engine landing without further incident.”

3.3.9 Understanding Aircraft Runway Performance.

Included in the investigation, several accident reports contained references to the crew landing or taking off when the runway conditions and /or length were unsuitable. Therefore a category for “Understanding of the aircraft’s runway performance” was included. The following example, demonstrates a crew using a runway of less than 5000 feet, when the manufacturers quoted performance required a far longer distance.

> "The required landing distance on a runway contaminated with 1-inch of snow, at a Vref of 110 knots was approximately 5,800 feet. At Vref + 10 knots, the required landing distance increased to about 7,750 feet. (Actual runway 4800 feet)"

3.3.10 Aircraft Systems Knowledge

The runway performance and capabilities of the aircraft was not the only area demonstrating a lack of crew knowledge. The next category of "Aircraft systems knowledge" became necessary when the accident reports contained instances of crew apparently not having the knowledge or understanding of essential aircraft systems. In the report extract a pilot reported he could not lower the landing gear (undercarriage), so landed with it retracted. However, the investigator found that the serviceable emergency system had not been utilised.

> "Airplane and Systems, also noted that the landing gear was electrically controlled and hydraulically operated, and that there was an emergency extension system that could be actuated by a red AUX GEAR CONTROL, T-handle located under the pilot's instrument panel."

3.3.11 Examining all the Conditions

Even though some crews appeared to complete their pre-flight briefing actions, there was evidence that all the relevant conditions, (such as the changing weather conditions, whether the destination airfield was suitable and if adequate landing aids were available), had not been considered. The category of "Examining all the conditions" was included. This extract demonstrates that a captain used a runway that was too short for the weather conditions and afterwards admitted that he knew the requirements.

> "The pilot remembered observing a weather report that reported light rain at RIL; however, the report was not current after the flight departed Scottsdale. The pilot "did not use wet runway performance numbers",

> [and] did note the 135 landing distance requirements as an aid for safety margin; approximately 6,600 feet."

(Note: 135 refers to the FAA rule for obtaining an adequate safety margin for landing)

3.3.12 CRM or Company CRM Policy

As discussed earlier the actions and the attitudes of the captain may impact on the safe conduct of the flight. It is generally accepted that good CRM is essential to maintaining situation awareness; preventing breakdown of teamwork and helping prevent the wrong decisions leading to an accident (CAA 2006b). Unfortunately, accident report extracts highlighted the lack of CRM, which led to the next category for "CRM or Company CRM policy". In one case 2 Captains were flying together, with neither knowing who was in command (PIC), as shown in the following quote.

> "When queried as to who was in command of the flight, the pilot stated that he was confused as to who was the PIC and advised that both he and the captain were "co-captains." When asked about the flight department's standard operating procedures (SOPs), the chief pilot advised that they did not have any, and that the flight department had started out as just one pilot and one airplane, He believed that there was a lack of CRM, and advised that there were no SOPs or "company manual" and that the chief pilot "kind of takes over."

3.3.13 Ground Personnel

Pilots do not operate in isolation and require the assistance and support from other agencies. For example, Air traffic control is required for flight clearances and control; also the ground operations staffs provide the planning and weather information for the crews. The accident data provided several cases of influence or action by these support agencies. In one particular case, Air Traffic Control tried to avert an incident by persuading a crew to divert to another airfield where the weather conditions were more suitable. The crew did not however accept the advice and persisted in their landing attempts until the fuel was exhausted. Further reports reflected the type of operations carried out by some business jets operators. In contrast to the scheduled airlines, business jets do not always operate flights to large established airfields. Rather, they operate charters to remote or unmanned airfields then returning to their home base outside the normal operating hours. In the following instance it is apparent that airport staffs were normally available but the aircraft arrived outside their operating hours and the crew did not receive adequate warning of the snow and ice prior to landing.

> "He reported that N165TW arrived several hours after the airport staff had left for the evening. Prior to the accident, the airport crew arrived and found the runway covered with ice and snow, December 21, 2008, at about 0100 Eastern Standard Time."

In the example quoted above, Air traffic control had considered the weather conditions at the various airfields and by offering their support and advice attempted to avert an accident. In contrast during the particular style of business jet operations, where adequate and responsible support was not forthcoming from the airfield personnel, this had directly attributed to a landing accident. Therefore, the category of "Ground Personnel" was included.

3.3.14 Operational Procedures

The next group shows evidence of pilot actions that did not appear to follow normally accepted operational procedures. This category was labelled "Operational Procedures". The following extract lists how the base engineers offered advice concerning the snow and ice, then witnessed the aircraft taxi out to the runway, even getting stuck in a ditch and powering its way out. Finally the aircraft crashed on take-off. The accident report did not, however, contain details or explanation for the crew actions.

> "The pilot declined to have the airplane de-iced when asked by the FBO. (Engineering Base Operators) He also noticed the airplane was not on

the taxiway as it taxied, but rather on the grass area on the south side of the asphalt taxiway. At that time the ground was covered with snow and ice."

3.3.15 Reluctance Uncertainty or Confusion

The importance of good crew relations and CRM has already been discussed with regard to the Captain's responsibilities and decision making. However another aspect of crew co-operation and understanding came from the transcript evidence of the on board voice recorder. There were instances of the Pilot Flying (PF), often the co-pilot, showing their concern or apprehension but being urged on by the pilot who is not actually flying (PNF), the Captain. Although this may reflect on the crew CRM at the time, it is included as a separate category since it demonstrates the co-pilot situation and their treatment by the captains. This category was listed as "Reluctance, uncertainty or confusion" and is demonstrated in the following report extract.

> PNF asks the PF if she would like to try to circle the airplane down to land.
>
> The PF starts by saying "I don't..." but is cut off by the PNF saying "circle this way."
>
> The PF says "uuhhh...," followed by the PNF replying, "try it."
>
> The PF responds "No, I don't see anything yet." The PNF states "There's the runway".
>
> The PF replies, "Oh <expletive>, are you kidding me?"

3.3.16 Rules or Regulations

The safe flight of an aircraft is often governed by relevant rules and procedures. Although it has already been stated, several incidents or failures were correctly handled by the crews. Some other, instances included crews not following the applicable "Rules or Regulations", such as continuing to operate even though the weather conditions were below the prescribed minima. In the accident report quoted below, this crew utilised a flap setting that was not authorised for use.

> “The crew reported that the landing was performed utilizing a flap setting of 30 degrees based on the landing conditions, with a landing approach speed of 135 knots. The airplane was certified for normal landings with the flap system at 45 degrees only, and there was no flight test data to certify the airplane to land with the flap system not at 45 degrees during normal operations.”

3.3.17 Outside the Aircraft Clearance

The final category is where pilots go outside the certification and clearance capabilities of the aircraft. Passenger carrying aircraft are not certified or cleared for aerobatic manoeuvres. However, this pilot carried out an aileron roll at high altitude, lost control, recovered at 5000 feet and damaged the aircraft. This category is listed as “Outside the Aircraft Clearance”

> “The captain reported the airplane was "functioning normally" prior to the intentional aileron roll manoeuvre. The captain stated that the "intentional roll manoeuvre got out of control" while descending through flight level 200 (20,000 feet).”

3.4 **Inter – Rater Reliability**

Different raters can disagree about the results from the same object of evidence by difference in interpreting the meanings or expected results. In order to improve the rater reliability, reduce the experimenter’s bias and improve the consensus of the results, the open coding was repeated by a second, fully qualified rater and the results reviewed and compared.

After the initial coding, the NTSB data files of accident and incident reports were passed to an RAF and Civil Aircraft Industry Test Pilot, experienced in accident investigation. An independent review of all the accident information and coding groups was completed by the second investigator, using the same accident data as the first rater. The results were collected and discussed at length to determine any differences from the open coding process. A comparison of the open coding categories and phrases allocated is shown in Table 6.

Table 6 Inter-rater reliability. Comparison of coding categories

OPEN CODING CATEGORY	FIRST RATER	SECOND RATER
Pilot skill or accuracy.	31	23
Systems awareness	23	19
Captain's command or judgement	8	16
Failure to follow a drill or procedure	16	13
Maintenance Error	15	14
Actions reported as correct for the situation.	14	10
Understanding of the aircraft's runway performance	12	11
Aircraft systems knowledge	9	9
Examining all the Conditions	3	4
CRM or company CRM policy	9	5
Ground Personnel	6	5
Operational Procedures	8	7
Reluctance, uncertainty or confusion	3	4
Rules or Regulations	5	3
Outside the aircraft Clearance	2	2
TOTAL PHRASES	164	145

The first point for discussion was the total number of statements in the final listing. Of the 164 phrases obtained from the sampling criteria, the second rater determined that 38 phrases were duplicate statements of the same fact from the evidence and therefore only categorised 145 phrases.

The initial discussion was centred on the phrase contents to explain the difference in the numbers of comments. Since the comments were extracted verbatim from the accident reports, in some instances the same aspect was described by two or more witnesses or the crew repeated an action. Since the first rater considered this pertinent part of the accident report, these comments were initially included as part of the data set. For example:

a. Crew Statement: “One crew member stated that the approach was flown faster than the planned approach speed.”

b. Findings of the Aircraft data recorder: The aircraft airspeed was analysed, confirming the speed was higher than that required by the aircraft weight and configuration.

However, there were now two separate phrases from different sources showing the same fact. The second rater had listed these phrases but annotated them as a single entry. All the phrases were re-checked and any duplicated facts consolidated into one entry. It was evident that the categories for Systems awareness, Maintenance Error and Failure to Follow a Drill or procedure, required the phrases to be amended.

During the review a further case of duplication was considered, in the category Rules or Regulations. One of the accident reports contained details of a crew completing an approach to an airfield, even though the weather conditions were below the prescribed minima. Since the visibility was very poor, the crew could not see the runway to land, so they carried out a “go around” to fly back to the initial navigation beacon and commence a second attempt to land. The first rater considered this to be two statements for violation of the rules, yet the second rater only considered this as one reportable occurrence. This was discussed and agreed that only one reportable statement for each occurrence would be included. Once this was agreed, further review confirmed that the categories for Actions reported as correct, Ground Personnel and CRM or Company CRM Policy also contained duplicated statements.

The next point of discussion was that the first rater had included 31 phrases for Pilot skill or accuracy and only 8 for Captain’s command or judgement. However, the second rater had allocated only 23 to Pilot skill or accuracy and

16 to Captain’s command or judgement. The category for Piloting skill or accuracy was a cause of further discussion due to 8 of the statements listed by the first rater. However, the second rater had allocated these statements to Captain’s command or judgement. The difference of opinion being that the second rater considered that the crew were placed in a difficult situation due to poor leadership rather than due to poor skill on the part of the pilot actually flying the aircraft. This was shown in several accident reports. In this example, just as the aircraft came in to land, the Captain says "I know you don’t want to listen to me put it down...don't float it...put it down”. This accident occurred on landing as the aircraft actually touched down 20 feet off the side of the runway. During the data review, the question of skill level was considered and whether the captain’s attitude had a detrimental effect on the crew’s performance. Finally, it was agreed that the Captain’s actions could strongly influence the final outcome, since the Commander should be aware of the crew abilities and therefore act accordingly. Each of the 8 statements was discussed at length and agreement reached for their inclusion in the category Captain’s Command or judgement.

Following on from the Piloting Skill discussion, it was obvious that the accident reports contained several statements concerning the flying ability of the crews, such as a hard landing causing damage. There were also accidents where inaccurate speed control on approach was quoted as a factor but the evidence also confirmed that there was damage on landing. For example, in an accident where airspeed was apparently too high, the evidence further confirmed that the landing tyre marks were off the side of the runway, on the grass. Therefore, the category Piloting skill or accuracy was further assessed, as the reports contained evidence of both failure to fly an accurate airspeed and difficulties during the landing itself. All the examples were re-examined and the contents were considered by both the raters. Finally, it was decided that sub categories of “Flying faster than optimum on approach” and “Pilot skill”, should be included as sub groups of the primary category Pilot skill or accuracy. This was considered possible, since the airspeed was accurately reported and could be isolated as the criterion for the category. For example:

> “In one accident, although the FAA had cleared an airfield approach for all aircraft flying at up to 120 knots and turning with a maximum of 30 degrees of bank angle, the aircraft data recorder confirmed the crew utilized upwards of 48 degrees of bank with airspeeds varying from 132 to 147 kn.”

Finally, in each of the categories: “Understanding of the aircraft’s runway performance”, “Operational procedures “, and “Reluctance, uncertainty or confusion” there were phrases which needed more discussion and agreement. These phrases were finally included in the category “Examining all the Conditions.” There was agreement in the entries for “Aircraft System knowledge” and “Outside the Aircraft Clearance”.

The accident reports initially provided 164 phrases or statements of evidence. Once the duplicated statements and the conditions for repeat occurrences were removed, the number allocated to the Open Coding was 143. Ultimately, the statements were coded according to their content and are shown with the number of statements listed for each category in Table 7.

Table 7 Final Open Coding Categories

CODING	CATEGORY DEFINITION	NUMBER OF STATEMENTS
1	Pilot skill or accuracy.	23
1A	Pilot skill	(1 A = 15)
1B	Flying faster than optimum on approach.	(1 B = 8)
2	Systems awareness	19
3	Captain's Command or Judgement	16
4	Failure to follow a drill or procedure	13
5	Maintenance Error	12
6	Actions reported as correct for the situation.	10
7	Understanding of the aircraft's runway performance	11
8	Aircraft systems knowledge	9
9	Examining all the conditions	7
10	CRM or company CRM policy	5
11	Ground Personnel	5
12	Operational procedures	4
13	Reluctance, uncertainty or confusion	4
14	Rules or Regulations	3
15	Outside the aircraft Clearance	2
	TOTAL STATEMENTS	143

3.5 **Axial Coding**

The Axial coding investigation examined the possible links between the Open Coding Categories. The first area to be examined was the largest category of Piloting Skills. This was followed by Captain's Command and then Crew Resource Management.

3.5.1 Skills and Knowledge

During the open coding phase, the categories "Pilot skill or accuracy" was the leading category, with its two subgroups, "Pilot skill" and "Flying faster than optimum on approach.” Several accident reports contained evidence of approaches flown at airspeed above that required and the excess speed quoted as one of the significant accident factors. In another accident, the pilot was high on the normal approach path, attempted to correct but landed harder than normal and damaged the aircraft. However, even though pilot accuracy and skills were reported factors of the accidents, all the accident reports confirmed that the crews were correctly licensed and had passed the relevant skill tests and examinations for the award of a licence.

Also, the 2 categories, “Understanding of aircraft performance” and “Aircraft systems knowledge” contained several failures of the crew to safely operate the aircraft. In one example, a crew required approximately 7000 feet of runway, yet landed on a 4800 feet runway and therefore could not stop in the runway length available. In another case, the aircraft crashed due to lack of fuel. The captain was just able to reach the runway but the undercarriage would not lower normally. Although, the normal systems ceased to function, the crew did not operate the emergency undercarriage system, thus landing on the belly of the aircraft. The investigation did confirm that the undercarriage was serviceable and available on the emergency system. It could not be determined from the reports, what level of crew training was achieved or what had been the crew reasoning in each case, either for not using a longer runway or for failure to use an aircraft emergency system.

Since these accident reports contained comments on the skill or ability of the pilots, it was considered that the crews lacked either the skills or knowledge that was required. Therefore, the following categories were included in the high level category “Skills and knowledge”.

- Pilot skill
- Flying faster than optimum on approach
- Understanding of the aircraft’s runway performance
- Aircraft systems knowledge

3.5.2 Command and Decision Making

During the preparation of the open coding stage, the Captain's command and leadership was identified as one of the top 3 categories. However, command and leadership was also considered as a component of several other categories such as those instances when the crew did not comply with either the required rules or the operational procedures. The extracted statements in all the remaining categories were reviewed to identify if the Captain's attitude was reflected in the crew actions. Comments from the categories; "Systems awareness", "Failure to follow a drill or procedure.", "Rules or Regulations" and "Captain's command or judgement" were re-examined.

In the accident, where the aircraft ran out of fuel, the captain did not seem to be aware of the aircraft low fuel state (systems awareness). Also, the report concluded that "the crew do not take into consideration the amount of distance and time to complete the flight" (operational procedures). In the 13 accidents listed under "Failure to follow drill or procedure", there were reports of incomplete crew actions. One crew landed on the aircraft belly, as they did not complete the drill. In another a crew landed but did not select a back-up pump for the wheel brakes and could not stop.

The captain is responsible for the conduct and planning of a flight. However, during another accident the captain did not collect adequate weather information, attempted to land outside the weather limits and subsequently crashed. (Examining all the conditions and Rules or Regulations) For the category, "Captain's Command or judgement", there were other examples of Captains continuing in adverse conditions. One Captain continued to land even though ATC had passed the fact that there was snow and ice.

All these examples reflect on the poor standard of command and leadership. There were, however examples of good leadership and as noted in the category "Actions reported as correct for the situation" and this was considered. The safe outcome of these particular flights demonstrated good levels of crew co-operation and high quality leadership could be effective.

Finally, one further category was also added to the analysis under the command sector. One of the business jet pilots rolled the aircraft upside down in an unauthorised aerobatic manoeuvre and lost control. This was in the category "Outside the aircraft clearance" and was an example of poor judgement by the captain

Therefore, by reviewing the comments included in these categories a high level category was included for the actions and decisions of the Captain. "Command and Decision Making" was identified as a high level category and the following open coding categories were included:

- Systems awareness
- Failure to follow drill or procedure
- Actions reported as correct for the situation
- Captain's command or judgement
- Examining all the conditions
- Rules or Regulations
- Operational Procedures
- Outside the aircraft Clearance

3.5.3 Crew Resource Management

In aircraft operations, the role of the Captain is primary in the conduct of the aircraft and its safe operation. However, the Captains perception of the role as commander is affected by many factors, including, company organisational culture and national social norms. In the reports there were several different command styles observed by crew members. An example of good leadership is from open and affirmative captains, who state their intentions and manage the flight. These captains are more likely to enlist the cooperation and assistance of the crew than those who are overbearing and autocratic (CAA 2006b). It is this balance between "Leadership" and "Followership" that establishes the "Command Gradient" across the flight deck, generally from the Captain in the left seat to the co-pilot in the right seat. A steep gradient would be a situation where all decisions are made by the captain and the other crew members have little or no choice but to agree.

In the first case there was an obvious disregard for the regulations and conditions. For example, a crew flew an approach to an airfield even though the reported weather conditions prohibited the approach. Consequently, they were unable to land but repeated the profile in another attempted landing.

> "On arrival at KTEX, the weather was reported to be below minimums, so a missed approach back to the VOR [radio beacon] and a further approach requested"

In the second case the Captain urged an unwilling co-pilot to continue landing even though the co-pilot was uncertain or unable to comply. The following extract is from the NTSB report, the Pilot Not Flying (PNF) is the Captain and the Pilot Flying (PF) is the co-pilot.

> "20 seconds prior to touchdown the PNF tells the PF "just put it down. Put it down". The PF replies "I'm trying, where is it?" Eight seconds prior to touchdown the PNF says "I know you don't want to listen to me …put it down…don't float it …put it down".

During the investigation, the effect of an over bearing or forceful Captain was considered regarding the efficiency and ability of the crew. In the transcripts, there was no evidence of co-pilot input either to question the captain's decisions or raise concerns prior to the impending accident. The crew co-operation and working attitudes were assessed and a comparison technique was applied to the initial categories, in order to confirm if the data supported this view. Subsequently, the comments concerning the role of the commander and his/her relationship and command style during the conduct of the flight were compared to other categories such as "Reluctance, uncertainty or confusion" and "CRM or company CRM policy".

In the example case of Captain urging an unwilling co-pilot to continue, there is an apparent lack of consideration for the other crew member even though the co-pilot is uncertain and may not be able to see the runway;

> "Co-pilot "I'm trying, where is it?" followed by Captain "I know you don't want to listen to me."

The following extract from the cockpit voice recorder is further example of confusion and reluctance by a co-pilot;

> "….don't..." but is cut off by the Captain saying, "circle this way." The co-pilot says "uuhhh...," followed by "Oh <expletive>, are you kidding me?"

Since these examples contained evidence of poor crew co-operation and inter pilot reactions on the flight deck, the following categories were consolidated into the high level category, "CRM".

- Reluctance, uncertainty or confusion
- CRM or company CRM policy

3.5.4 Support Environment

Finally, the categories of "Ground Personnel" and "Maintenance Error" were reviewed. Consideration was given to the essential requirements for operating an aircraft. This included such support aspects as aircraft maintenance, the operational support of the company personnel and the interaction with Air Traffic control. For example, the crew would be reliant on the maintenance team for the serviceability of the aircraft. Also, all the Flight Planning data (flight plan routeing, fuel plan, time, total distances and weather information) would be provided by dedicated ground personnel. Finally, the following categories were combined into the high level category of "Support Environment".

- Maintenance error
- Ground Personnel

3.5.5 Axial Coding – High Level Categories

As described above, the final Axial Coding High Level categories were:

- Skills and knowledge
- Command and Decision Making
- Crew Resource Management
- Support Environment

The final results from the Axial Coding phase are shown at Table 8.

Table 8 Axial Coding High level Categories and Sub Categories.

HIGH LEVEL CATEGORY	SUB CATEGORY
COMMAND AND DECISION MAKING	Systems awareness
	Failure to follow drill or procedure
	Actions reported as correct for the situation
	Captain's command or judgement
	Examining all the conditions
	Rules or Regulations
	Operational Procedures
	Outside the aircraft Clearance
SKILLS OR KNOWLEDGE	Understanding of the aircraft's runway performance
	Aircraft systems knowledge
	Pilot skill
	Flying faster than optimum on approach
CRM	Reluctance, uncertainty or confusion
	CRM or company CRM policy.
SUPPORT ENVIRONMENT	Ground Personnel.
	Maintenance error

3.6 **Selective Coding**

Selective coding level is the final task to obtain a higher level of group attribution in refining the categories and their relationship. From this new attribution, a linking can be defined for all the accident codes or groups that have already been developed. Therefore, the business jet accident safety model will show the overriding relationship between all of the aspects (factors) of the high level categories defined in the axial coding process.

3.6.1 Linking CRM with Skills and Knowledge

In this investigation CRM was evident as a factor from the accident reports; this was especially applicable for the co-pilots behaviour and the captain's actions. In the reports it was apparent that the co-pilots could not provide input or comments nor were they considered as part of the team. Furthermore, poor consideration of the co-pilot's skill is shown in an accident report, where the captain urges the co-pilot to land saying "I know you don't want to listen to me- just put it down." Upon investigation, it was found that the aircraft had touched down on the grass at the side of the runway, yet the captain's evidence stated "the landing was normal". In contrast, there was an example of good pilot skill supported by good CRM, when a large bird struck the nose of an aircraft immediately after take-off. The captain elected to continue the 20 minute flight to the intended destination, completed all the drills, flew an approach without incident and landed safely.

In these examples, the CRM plus Skills and Knowledge factors are linked and both influence the final safety of the flight. In order to demonstrate this, the 2 spheres of influence for the factors are linked as shown in Figure 2.

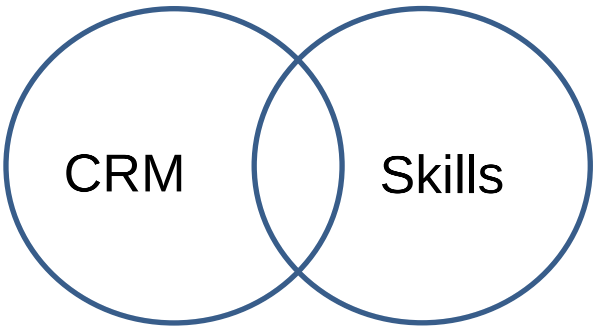

Figure 2. The Linked Spheres of influence for CRM with Skills and Knowledge

3.6.2 Linking Command and Decision Making with CRM

As stated, the accident reports contained examples of poor leadership, management and flying skills. Some crews did maintain the required performance standards (correct speed on approach). Others did not follow or maintain procedures (incomplete checklists). Another consideration for flight safety is Situation Awareness, such as an appreciation of .the external environment. This may be whether the pilot collects relevant information e.g. weather, traffic, etc., or if the pilot ignores the information. In two accident reports, one captain did not load sufficient fuel for the planned flight. In the second, prior to commencing a flight; the captain had operated to his destination several times and was “very comfortable with the weather” but could not stop on landing due to the wet runway. As these Captains demonstrated poor leadership, there is also a lacking of CRM and teamwork which would allow the co-pilots to voice their opinions. This was re-enforced in the accident when an aircraft ran out of fuel on approach, by the co-pilot informing ATC that they could not divert as they were low on fuel. However, there was no evidence that he discussed this or that any contingency plan was considered by the captain. The captain also demonstrated a lack of leadership and CRM as immediately after the co-pilot had informed ATC of the fuel state, he requested a further attempt to land in the prevailing weather conditions.

As shown in the quoted accident reports, the factors of Command and Decision Making together with CRM jointly influence the crew actions and the safe conduct of the flight. Therefore, the spheres of influence are shown linked together as in Figure 3

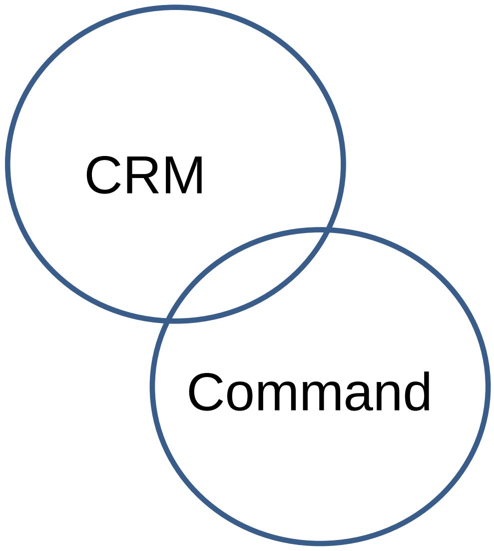

Figure 3. The Linked Spheres of CRM and Skills or Knowledge

3.6.3 Linking Skills and Knowledge with Command and Decision Making

It is a requirement that all pilots are required to demonstrate adequate flying skills to obtain their licence. The testing includes elements of emergency training, such as the ability to land safely after an engine failure. However, in the Open Coding process, the major category was Pilot Skills. For example, an accident occurred following a hydraulic failure and the crew "continued to troubleshoot the failure without following the checklist ". During this sequence of events the checklist was not completed and the wheel brakes were inoperative on landing. Furthermore, the captain demonstrated a lack of command and leadership when the landing checklist was not completed. In this instance, the Captain compounded the in- flight emergency by accepting poor standards of both skills and knowledge.

The captain is ultimately responsible for the safe conduct of the flight. Therefore, it is within his or her remit to decide whether a course of action is both safe and within the skill levels of the crew. This is demonstrated in the accident, where the pilot deliberately rolled an aircraft upside- down and lost control. The pilot statement after the accident confirmed that "the intentional roll manoeuvre got out of control while descending through 20,000 feet." The aircraft commander attempted a manoeuvre that was beyond the skill of the pilot and outside the performance clearance of the aircraft.

In the accidents quoted above, the commander should have considered the skill levels of his crew in order to operate safely. In this way Command and Decision Making together with Skills and knowledge are jointly influential on the conduct of the flight. The spheres of influence are shown linked in Figure 4

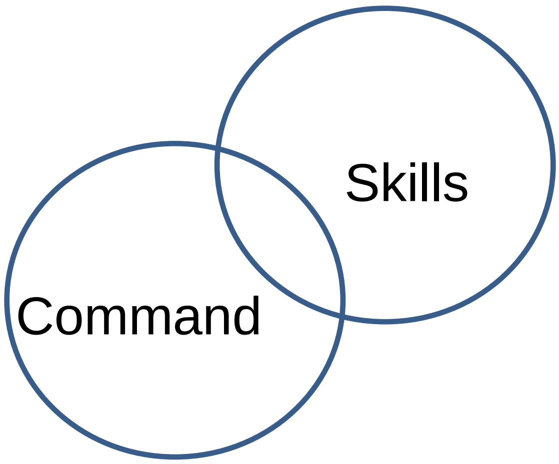

Figure 4 The Linked Spheres of Command and Decision Making with Skills and Knowledge.

3.6.4 The Linking of all Three Factors

The following accident report extract demonstrates the interdependence of CRM, Skills and Decision Making with Command and Decision Making on the flight deck. From the factual evidence of the accident it may be argued that this was a pilot skill and handling accident but it has all the indicators of the other groups.

“The approach was flown at a speed higher than that allowed by the procedure. Once visual, the aircraft was out of position and too high for a safe landing, so the Captain suggested an orbit (360 degree turn) to reposition for the landing. However, this is not prescribed in the procedures. Once re-aligned with the runway the co-pilot could not see the runway and did not want to continue, but was coerced by the captain to continue following his verbal instructions down to the runway. Finally over the runway, at a higher speed than normal for landing, the co-pilot has difficulty getting the aircraft to land and touch down. The captain made further comments to encourage the co-pilot to land. Finally the aircraft touched down but too fast and too far down the runway to stop". (NTSB 2012a)

This evidence indicates that every aspect should be considered before allocating a primary cause. The report contains the following elements that are all significant in the outcome of the accident.

- Failure to follow regulations (Command)
- Approaching too fast to land (Skills)
- A 360 turn this goes outside the normal procedures (Command)
- Captain leadership in poor judgement to continue (Command)
- Poor CRM talking the co-pilot into his actions (CRM)
- Poor CRM, the co-pilot's comments were ignored and did not feel capable of deciding himself (CRM)
- Lack of performance knowledge, landing too far along the runway (Skills)

As shown previously, the individual factors of CRM, Command and Decision Making plus Skills and Knowledge are each coupled together for their influence on flight safety. Moreover, during the accident quoted above, the initial decision by the captain to conduct an approach outside the regulations was poor command. However, by coercing the co-pilot to orbit was a demonstration of poor CRM. Ultimately, the captain failed in his responsibility by urging the co-pilot to continue an ill judged and poorly flown landing. In fact, the captain demonstrated a lack of Command and CRM and also failed to take into account the co-pilot's flying skills. This inter relationship is represented in the diagram by the intersection of the circles representing the three factors.

Thus, this final accident demonstrates that the 3 elements of CRM, Command and Skills are all influential on the outcome. Therefore, considering the previous pairing of the 3 elements, the next stage of the business jet accident model should also demonstrate the conditions when all the factors combine, as shown by the intersection of the circles in Figure 5.

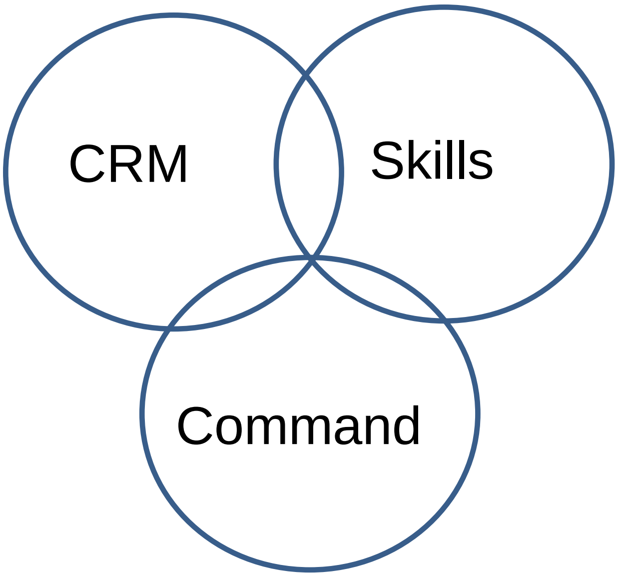

Figure 5 The Linked Spheres of CRM, Command and Skills.

3.6.5 Support Environment

The final aspect of the core model is “Support Environment”, since the flying operation cannot be considered in isolation. All flights are dependent, to varying degrees, on aircraft maintenance, the operations and planning departments, airport weather information and other support organisations such as Air Traffic Control. The importance of safety support is included in the Open Coding and Axial Coding categories. Several reports contained evidence for the lack of support from ground personnel, directly involved with the operations and maintenance. For example the ground crew finished duty and left without informing the arriving crew of the icy runway (CRM and good team work should also apply to ground personnel). In other reports, maintenance errors caused equipment failures in flight, which required skilful emergency action by the crew. In one case an engine cover was incorrectly fitted and came loose in flight. Fortunately, this was correctly handled by the crew and a safe landing ensued. In another case, whilst attempting to land in poor weather conditions, the Air Traffic Control offered the crew an alternative airport, (with better weather conditions), but were ignored by the aircraft commander. Since the coded categories were outside the crew control (Maintenance Error and Ground Personnel); they should stand outside the normal crew actions and responsibilities.

However, all the support concerning the flight, whether good (ATC assistance) or bad (Maintenance Error) reflects on the crew actions and may be considered as a two way path or flow of information. The information depends on crew inter reaction with the ground personnel, such as an in - flight emergency due to an aircraft fault, aircraft equipment failures corrected after being reported. Similarly it may be timely advice and assistance, such as a weather or airport information update from ATC that is acted upon for a safe landing. The two way flow of information does not link to a specific area and may have further implications. For example, information from ATC may be of no use to the crew if the co-pilot feels unable to voice an opinion, even if the situation warrants it. Similarly, the captain may elect to depart with insufficient fuel, against the operations and ATC reports of weather or airport availability. In one accident report, the captain considered the weather and disregarded any advice, then found the conditions beyond his or the co-pilots skill level. In another instance, the pilots reported that there were no SOPs and the chief pilot “kind of takes over”. Thus, the two way flow was still relevant between the pilots and the management but was flawed since the pilots felt unable to use the two way flow of information to set better standards and improve the SOPs.

Therefore, the two way flow of information may be represented by two way arrows linking all the high level categories, with equal merit and include “Support Environment” with additional influence on the overall operation. The final business jet accident model is shown as the Selective Coding Model at Figure 6. This demonstrates the previous relationship of CRM, Skills and Command, but now includes the influence of the Support Environment.

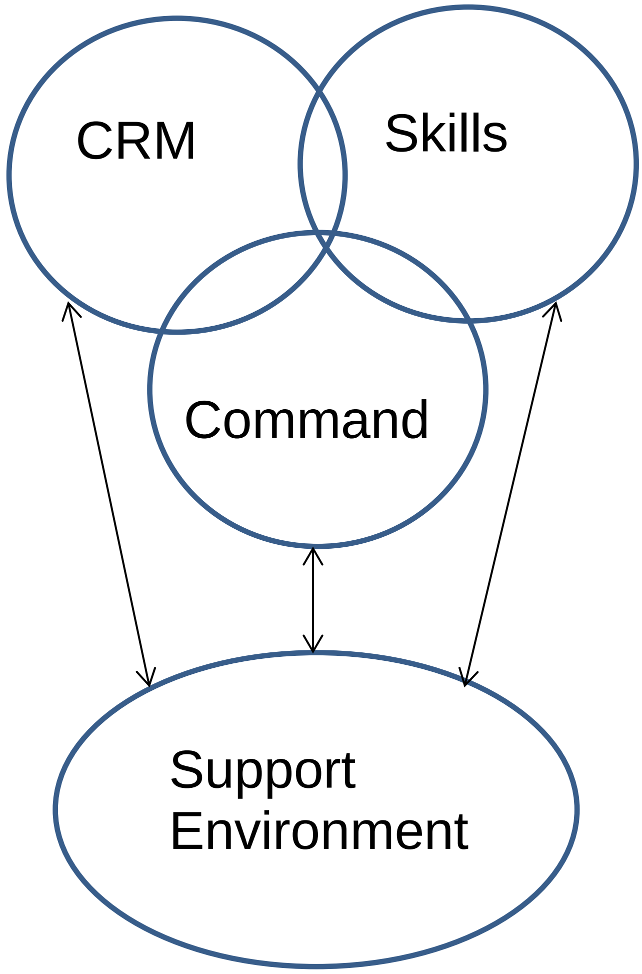

Figure 6 Business jet Accident Model.

3.7 **Discussion**

The core model of the business jet accident profile, shown at figure 6 demonstrates the linking and interdependence of the CRM, Skill and Command categories found in the accident report evidence. The main theme of the model is constant inter-reaction between the 3 central aspects. Good CRM is essential for the safe and effective operation of the crew (CAA 2006b). Pilots are tested prior to the issue of a licence to ensure that they possess the minimum flying skills to operate the aircraft (CAA 2013). The Captain as the aircraft Commander is ultimately legally responsible for the safe conduct of the flight and he/she must therefore take responsibility for all command decisions (CAA 2010d).

The final model established from the accident reports included these crew responses. However, the consequences were always linked to the other central categories, sometimes the link was across all three categories. The flight operation was also shown to be dependent on support from other agencies involved in the "Support Environment" (maintenance, ATC etc., Helmreich 2001). These factors for crew interaction and working issues with both ATC and Ramp Maintenance were in agreement with Li (2007). Considering the actions of the crew and the influence of outside agencies, this thesis model supports the Five M model of Harris & Thomas (2006), where the central spheres of the HuMan, Machine and Mission are influenced by the spheres of influence of the Management and the Medium. It is also consistent with CAP 737 (CAA 2006a) explanation of CRM, command and outside agencies;

> "In order to be effective, team members must be able to talk to each other, listen to each other, share information and be assertive when required. Commanders should take particular responsibility for ensuring that the crew function effectively as a team. Whilst the emphasis in CRM is primarily upon the cockpit crew, and how they work as a team, it is also important to look at wider team effectiveness, namely the whole flight crew. CRM principles may also extend to situations where ATC, maintenance, company experts, etc., are considered to be part of the team (especially in emergency situations)." (CAA 2006a)

All aircraft operators, both airline and business jet, are required to have a system of CRM training and assessment, to provide feedback to the crew and identify any need for retraining and improve CRM and safety (CAA 2006b, JAA 2001). This is especially applicable for the co-pilots, who were unable to provide feedback or were not taken into account as part of the team. This aspect is further emphasised by the JAA regulations.

"The flight crew must be assessed on their CRM skills in accordance with a methodology acceptable to the Authority and published in the Operations

Manual. The purpose of such an assessment is to: provide feedback to the crew collectively and individually and serve to identify retraining; and be used to improve the CRM training system." (JAA 2001, Para 1.965).

Furthermore, the CRM attributes in the core model were closely in agreement with findings of Flin (2003) and Van Avermaete (1998) for the development of the Non - Technical marking system (NOTECH). For example; 2 social skills, (Co-operation, Leadership and Management), and 2 Cognitive skills, (Situation awareness, Decision Making), were established as behavioural markers. (A listing of CRM and behavioural markers is at Appendix C). CRM is also considered an essential safety element by the NTSB and FAA as it is quoted as one of major requirements in the "Most Wanted List" in 2003, 2004 and 2009 (NTSB 2009b). Significantly, the FAA has now increased the requirement for CRM training (FAA 2012).

Several examples of poor practice by the Captains contained in the business jet accidents reports are reflected in "Considering Others." In the accident example quoted in Selective coding (where an orbit was suddenly included in the profile), the Captain did not consider the condition of the other crew member, even when the co-pilot openly expressed doubts about continuing. This supports the examples of poor practice evident in the NOTECH coding elements (Flin 2003). (An example of CRM Co-operation elements is shown at Appendix D.)

The accident reports concerning leadership and management skills also include poor practices. Some crews did maintain the required performance standards (correct speed on approach). Others did not follow or maintain procedures (incomplete checklists). Similarly for Situation Awareness the good and bad practice includes the external environment and whether the pilot collects relevant information e.g. weather, traffic, etc., or the pilot ignores the information (Flin 2003). These failings are reinforced by Helmreich (2001) during an evaluation of Commercial Airline flights during a LOSA. Even though the LOSA was devised around airline operations, these same problem areas are evident from the business jet accident reports.

Although the Business Jet Accident Model has been developed purely from the evidence in the business jet accident database, it could be relevant to commercial airline operations since it contains the essential elements for a safe operation. However, as the business jet commercial operation is dictated for time and destination by the customer, there are essential differences in the type of operation. For instance commercial airlines do not normally operate to airports without ground personnel and engineering support. So the instance of the pilots arriving un-announced onto an ice covered runway is extremely unlikely. Also, as some airlines operate LOSA as part of their SMS, the pilots are more closely monitored during normal operations. The feedback from LOSA surveys and the routine flight data recorded by FDM would quickly highlight any inconsistencies, such as high airspeeds or inaccuracies on approach.

Pilots are required to demonstrate adequate flying skills during the LST (CAA 2010c) but the simulator training time could be limited (CAA 2009a). During the periodic testing and recurrent training, the time dedicated to manual flying may be the minimum required. This may be the tests involving engine failures, including an engine failed approach and go-around (Ebbatson 2007, 2008).

3.8 **Summary of the main findings**

From the accident reports, it is evident that CRM, Leadership and Skill are the essential actions of the crew in completing the task or mission. However, they are not operating in isolation and the many outside factors and influences are evident in the accident reports.

The importance of the outside influences and the attitudes of the company is re-enforced by the initiatives of the IBAC safety programme – the International Standard for Business Aviation (ISBAO). (IBAC 2008b)

The parallel between the safety initiatives and new airline training schemes and the core model, adds support and validity to the model. It confirms the primary areas of concern and yet is representative of business jet operations. The model could therefore be instrumental in suggesting improvements to the components of CRM, SKILL and COMMAND, with an increased awareness of the importance of the SUPPORT ENVIRONMENT.

As noted, both the CAA (CAA 2006a, 2009d) and IBAC (2012) reported that the majority of accidents have occurred during the approach and landing phase. Similarly, there was reference to the level of Pilot Skill and control during the approach. Therefore, the next Chapter reports on the assessment of pilot skills conducted in a business jet full mission simulator.

4 SIMULATOR STUDY

4.1 **Introduction**

The literature review indicated the concern for pilot performance on approach and landing. There has been research into the manual flying skills of airline pilots but not for those of business jet pilots. In a study of airline pilots, Wood (2004) found anecdotal evidence suggesting that pilots were very dependent on the automation and the autopilot and as a result their manual flying skills decay. As discussed in Chapter 2 the majority of accidents and incident occur during approach and landing. The Grounded Theory derived accident model presented in Chapter 3, highlighted the concerns for Pilot Skills and manual skills during the landing phase. Moreover, even though the majority of aircraft accidents have not only been on approach but also associated with an emergency or an engine failure (CAA 2006a), there has not been any business jet orientated research. Therefore, a study of business jet pilots handling skills during an approach was required in order to measure and record actual pilot performance under realistic conditions. A simulator trial was conducted with business jet pilots, who flew an instrument approach and this Chapter reports the findings of the trial.

4.2 **Method**

The first consideration was how to plan a trial for an aircraft on the approach to land, with an engine emergency. Although it may be desirable to replicate this by deliberately attempting several landings on an aircraft with one engine disabled, it was considered that the attendant risks were too high. Therefore a flight simulator would be the safest trial option. In addition, it would not be possible to guarantee sufficient repeatability on a real aircraft trial, since the conditions such as the weather, wind, temperature, aircraft weight and runway availability may not be constant. So, in order to obtain control and repeatability of the assessment, the decision was taken to evaluate the pilots in a full flight simulator training device.

To ensure that the pilots were representative of the business jet pilot community, it was determined that all flight crew would be licenced and operational within the business jet arena. However, although all the pilots would be correctly qualified for the trial, the level of recent flying experience and opportunity to practice manual flying which may provide various levels of expertise (Ebbatson et al. 2010). Similarly, the role of the commercial pilot has changed and in many ways the Captain is more of a manager, in contrast military flying has always concentrated on the “hands on stick and throttle” for piloting skills (Harris 2006), so there may be a variation among the pilots from different backgrounds. As the pilots are required to be at the required standard for the LST, this would set a benchmark level for the pilots prior to the trial. Therefore, the trial was during a specially organised additional 30 minute segment at the end of their annual Licence Proficiency Check (LPC).

In line operations there are several approach options (depending on the weather conditions) For example, the pilots could fly visually and align with the runway to land. Another possibility is to use a radio beacon on or close to the airfield as the navigation aid for line up and complete a landing. During both of these approaches there is not an accurate tracking task that could be measured or recorded, since the visual approach could be from a curved or straight approach without a means of accurately tracking the required descent profile. Similarly, the radio aid approach utilises target altitudes along the approach with the descent profile at the pilot’s discretion. The ILS however is a precision approach aid designed for bad weather and poor visibility in instrument flying conditions, with both the lateral and vertical guidance displayed to the pilot. The deviation from the runway centreline and the descent profile is displayed and can be recorded. Each airfield and runway aid combination have their operational limits and weather operating minima so that the aircraft may be flown down to the approach minimum, normally 200 feet above the runway. At this point (the Decision Height, DH) the pilots would take over visually once they could see the runway, without further reference to the ILS. In terms of piloting skill, a critical point in the landing is the final touch down. However, this final landing segment is a visual landing task and would be flown depending on the individual pilot judgement and flying style. Therefore, compared to the fixed centreline and glideslope reference on the ILS it would be difficult to determine satisfactory measures for the final few feet down to the runway. For this reason, the trial recording was terminated on the ILS at the decision height of 200 feet above touchdown.

The participants were required to perform standard instrument approach in instrument meteorological conditions and with the aircraft in an asymmetric thrust condition (Flight with one engine inoperative). As discussed in Chapter 2, previous evidence had suggested that the most critical phase of flight was not only during the approach but also following an emergency procedure (CAA 2009b, 2011), such as after an engine failure. Also, an earlier study (Ebbatson et al. 2010), had found that a simple lateral control task was insensitive to differences in experience and it was recommended that a more demanding lateral task, such as asymmetric thrust approaches required. Therefore, the flying task incorporated an operationally representative but demanding manual flight task for the short time available in the simulator.

A major business jet training and Type Rating company based in the UK agreed to provide the use of their facilities, including the use of a high fidelity Hawker 800 XP flight simulator, the flight simulator instructors, engineering data support and briefing facilities.

4.3 **Description of the Flying Task**

The task began from straight and level flight at 3000 feet, with the aircraft in the clean configuration at 210 knots (gear and flaps retracted), positioned to intercept the localiser and glideslope. From the ATC clearance the candidates were required to perform a standard terminal manoeuvring exercise and follow the ILS profile. From the initial conditions, the crew were required to use their judgement and reduce to the planned approach speed, to reconfigure correctly (according to their SOPs) for the approach and landing, then intercept and follow the localiser / glideslope. The candidates were briefed that the autopilot and auto-throttle systems would not be available for the approach, so it would be a flown manually. The rest of the cockpit systems were set for normal operations, with the flight director available for use, the electronic flight information system (flight instrument display) was configured to show the flight data for the ILS display and the horizontal situation indicator set to display the aircraft position on the navigation map. Finally, the weather conditions at the decision altitude would prevent a visual acquisition of the runway; so that a single engine missed approach procedure would be necessary.

This exercise would provide a suitably demanding but operationally pertinent flying tasks, whilst within the spirit of the simulator LST. Tracking the ILS has been demonstrated as a good discriminator for piloting skills (Veillette 1995, Ebbatson et al. 2006) yet remaining valid for normal manual flying operations. Although, the simulated failure of an engine, provided an increase in the workload for the pilots it should be well within their capabilities, since it had been practiced and tested as part of the LST. The localiser and glideslope are examples of a closed loop tracking task representative of the piloting skills required to fly a constant angle of descent on a safe approach path for landing. Similarly, the closed loop task of maintaining the required airspeed on approach requires judgement of the drag changes due to selecting the gear and flap, whilst setting and monitoring the appropriate engine RPM. The cockpit systems and controls would all affect the closed loop dynamics and response for the task. In order to reduce briefing time and ensure that all candidates were familiar with the profile, London Gatwick was chosen for the ILS as it had been flown during the training details. (Runway 08 R, London Gatwick)

Most importantly, the exercise can be easily measured using the chosen recorded parameters. The main instrument display, electronic horizontal situation indicator would display an expanded ILS display and other flight parameters, requiring a good standard of instrument scanning. Overall the task that was essential for the licence examination, representative of the real world and the majority of reported accident statistics (CAA 2006a).

4.4 **Equipment**

The trial was conducted on 2 identical Flight Safety International Inc. Raytheon Hawker 800 XP simulators. (An external view of the simulator is shown at figure 7). The company full flight simulators were complete with 6 degrees of freedom motion simulation cueing system with control loading and a Vital 9, 180 degree by 40 degree colour visual system, with a day/night/dusk capability). The simulators were approved to JAR STD 1A level D (JAA 2003) and were approved for training by the CAA and the FAA. The JAR STD simulator requirements are shown in Appendix E.

Figure 7 Hawker 800 XP Simulator, external view.

The simulators were completely representative of the Hawker aircraft and a photograph of the Hawker flight deck is included in Figure 8.

Figure 8 Hawker 888 XP, simulator cockpit.

An instructor control station was loaded with a customised trial profile, which was available for the end of the LPC training session. The instructor console was loaded with the start conditions and the configuration for the trial scenario and was able to initialise the data recording. (Data were taken in real time and recorded during each run). A single selection repositioned, set the aircraft position, configuration for fuel and weight along with weather and airfield for the start of the approach. Once the trial run was terminated, the simulator was frozen and held in position to indicate the end of the exercise. Data were saved and then converted off line into ARINC 717 format raw data bit streaming. (ARINC 717 is the standard data format for flight data and quick access recorders)

4.5 **Pre-trial Assessment**

Normally, the line pilot would not critique the aircraft handling characteristics as the simulator was already certified to the required CAA standards. However, in this instance a test pilot was able fly the profile and review the pilot skills required and to confirm that there were no adverse handling characteristics or procedural issues compared to other types, previously flown.

The pre-trial assessment was conducted by an Airline Training Captain (The author), who was rated on the Boeing 757 and Boeing 767 (with over 12900 flying hours), and was also an experienced military test pilot and simulator acceptance pilot. Although the test pilot was not rated on the Hawker, he had flown several business jets including the Hawker 125 (Dominie) the Lear-jet and the Mystere Falcon. The pre -trial run was conducted to review the procedure and test the data recording system. The Test pilot results for Localiser, glideslope and airspeed are shown in Table 9.

Table 9. Test Pilot Profile, including the mean, SD, minimum and maximum values of airspeed, engine RPM, ILS tracking of the localiser and the glideslope.

	MEAN	SD	MINIMUM	MAXIMUM
AIRSPEED	145.3	1.0	143.2	148.3
LOCALISER	0.01	0.3		
GLIDESLOPE	0.01	0.1		
ENGINE RPM	74.0	2.1	71.1	80.6

The test pilot flew the profile as briefed for the Hawker SOPs in the exercise and the results were within the CAA limits set out in the Guidance to Examiners Document (CAA 2010c). The airspeed profile on the ILS from 3000 feet to 200 feet is shown in Figure 9.

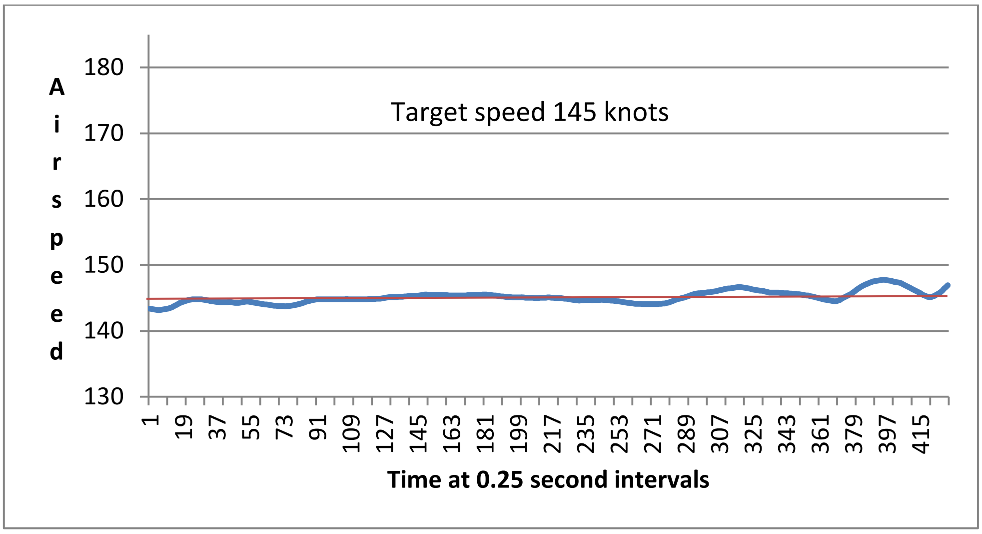

Figure 9 Simulator Trial, Test Pilot, Airspeed tracking from 3000 feet to 200 feet on the ILS

The test pilot also noted that the engine response to inputs was well simulated with no perceptible lag between throttle input (Power lever angle, PLA) and engine response. The plot of the engine RPM response to PLA during the assessment run from 3000 feet to 200 feet is shown at Figure 10.

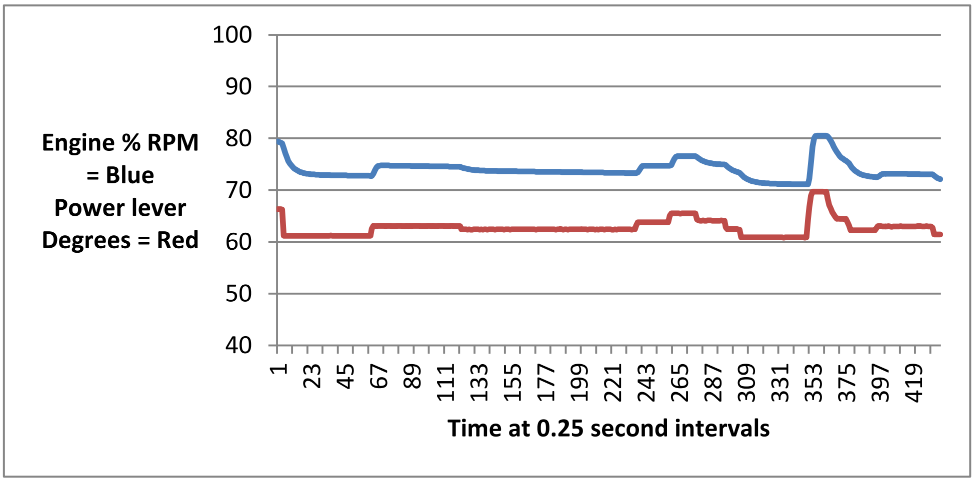

Figure 10 Simulator Trial, Test Pilot Time history plot of Engine RPM, (Blue) against Power Lever Angle (RED), from 3000 feet to 200 feet.

The engine response to pilot input was also confirmed from the engine data. The data recording was at a rate of 4 samples per second. So each data point is separated by a maximum of 0.25 seconds. Once a pilot PLA input is set, the data confirmed that the engine responded within one recorded data frame, thus the response was a maximum of 0.25 second. This is shown in Figure 11, for a step input of the PLA, the engine RPM responds rapidly and is increasing by the next data point.

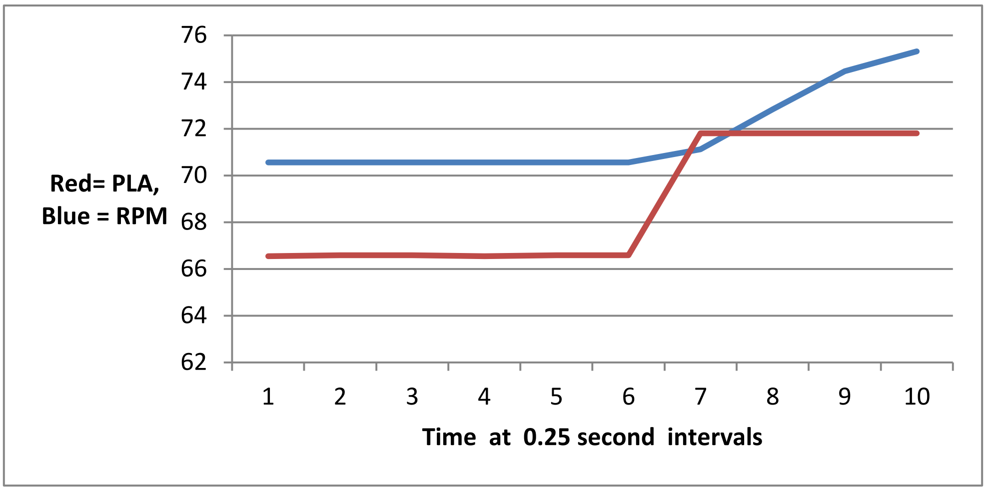

Figure 11. Simulator data for engine RPM response to pilot PLA input.

The test pilot considered that the simulator did not display any flight simulation or control anomalies and the profile should be well within the capabilities of the average pilot. Also, the profile was representative of the procedures proposed in the Hawker Pilot's Manual (Hawker 2008) for an engine failed approach. Finally, it was assessed that the approach represented both the pilot closed loop tracking task on the ILS and provided a representative workload to maintain the airspeed on the approach.

4.6 **Participants**

4.6.1 Ethics

As an encouragement to crew participation and reduce the stress on performance associated with crew testing, it was emphasised that it would be conducted after all the licence testing standards had been met and that the extra flight profile would be another training or practice opportunity. Also, the trial was conducted in accordance with ethical guidelines (BPS 2006). The candidates were fully briefed on the purpose of the research. The relaxed atmosphere for the trial was established to represent normal line flying operations, however, it was noted that crew performance whilst undergoing testing may be likely to exceed the unsupervised standards, especially for any abnormal, emergency, profiles (Baker and Dismukes, 2002). As the recurrent training had been the initial part of the session, it was normal to take a break prior to the trial for the crews to relax and conduct a final research trial briefing.

The research was approved by the Cranfield University School of Engineering Ethics committee (The ethics proposal is shown at Appendix F) and conformed to the British Psychological Society's guidelines (BPS 2006) All the candidates confirmed their consent to participate by signing a consent form (A copy is shown at Appendix G). The trial participation was entirely voluntary and was undertaken on a non-jeopardy basis, as the trial was supplementary to the recurrent training and the results would not be annotated on their training records.

4.6.2 The participating Pilots

The participants were 41 professional commercial pilots. All the pilots held a valid commercial pilots or air transport pilot licence and held a Hawker 800 XP type endorsement.

A business jet training organisation provided access to a large range of candidates from varied backgrounds and experience. The licence renewal dates and roster requirements of the air operator/company dictated which pilots were available for the trial. Therefore the candidate's selection was completely random. The proposed flight crew were pilots conducting either their Licence renewal periodic training or completing their type rating on for the Hawker 800 XP. The candidates were allocated for training in pairs as captain and co-pilot. It was, however, a requirement that each pilot had passed their proficiency testing and was not undergoing a LPC retest. By allocating the pilots as they completed their recurrent training, a diverse sample of pilots could be provided from the existing business jet pilot workforce.

It was noted that all the pilots would have completed a minimum of two days training and testing for their proficiency check prior to the assessment, it may be that their performance may be normalised. However, it was felt that the research aim to investigate pilot performance would still be possible, since the methodology measures for the population would still be representative of the work-force in attaining their licence prior to unsupervised line operations.

Following the pre – trial briefing, the candidates provided their individual pilot qualifications, training and experience details. A copy of the background details proforma is shown at Appendix H. Data was recorded for proximal pilot flying practice i.e. .the number of approaches in the preceding days and if applicable, the number of days since the last flight to ascertain whether there was a prolonged period without flying. (The independent variables of the study). The CAA work and fatigue limitations define required resting periods for flight crew and all crew are required to have days every 7,14 and 28 days. (CAA 2004) Therefore, the questionnaire for flight recency data was defined accordingly. For this research, a manually flown approach is considered to be when the autopilot is disconnected prior to or at the final approach fix and the aircraft flown manually until the landing or go-around for a missed approach. Distal manual flying practice was evaluated from the information given on pilot’s total flying experience.

4.7 **Measures**

4.7.1 Demographic Variables

The participants were asked to provide their background data including their career history, age and total number of flying hours their training history and standard demographic information (E.g. age, sex, experience).

4.7.2 Flight Data Derived Performance Measures (Dependant Variables)

The simulator Master Qualification Test Guide (MQTG) (ICAO, 2003) profile was used to store the initial set up, run and data store for all the data. The MQTG file recorded all the normal parameters that would be required for the simulator acceptance, however, many of the data points were not considered essential for the trial. From the MQTG file an essential listing of 22 parameters was annotated and a sample rate of 4 per second was utilised for the trial. (The simulator parameters are listed in Appendix I) The standard aircraft parameters were recorded from the flight data. However, the pilot ILS display was formatted to indicate deviation from the centreline of the runway and a descent angle of 3 degrees to the horizontal. The instrument analogue display is marked for the optimum, centre point with two markings for half and full offset from the ideal, (Left and right for the localiser; above and below for the glideslope). The half and full deflection are referred to as 1 or 2 “dots” deviation. The pilot tracking task is to maintain the central tracking index, an offset reading of zero. The simulator parameter was therefore set to a maximum scale of plus or minus 2 as a representation of the pilot display and tracking task. The pilot’s control inputs for pitch, roll, yaw and thrust were also recorded.

The simulator data were recorded from the initial point of release, until climbing through the altitude of 500 feet on the go-around. The simulator propriety information was then collected, collated and stored prior to being assessed. The final data format required conversion off line, since the initial simulator output was in ARINC 717 format. This was the format for aircraft quick access recorders which are used for analysis in flight monitoring programmes and was not suitable for statistical analysis. The simulator data format was re-written into an Excel format for the final data reduction. The data set was defined for each run and the data set refined into 3 tasks, Airspeed control (maintaining the planned approach speed of 145 kn.), Localiser Tracking, Glideslope tracking

The pilot tracking data were extracted from the once the ILS conditions were satisfied. The start point was defined as;

- Tracking the localiser to within 0.5 dots displacement.
- Tracking the glideslope to within 0.5 dots displacement.
- Descending more than 50 feet below the initial 3000 feet altitude.

The end point for the ILS task was passing the Decision Height of 200 feet above the runway.

The performance metrics were assembled in an SPSS data file, along with the biographical and career data analysis.

The outer loop, flight path performance metrics computed were the arithmetic mean and standard deviation of lateral and vertical deviations from the ideal flight path on the approach and the mean and standard deviation of airspeed error relative to the target approach speed.

4.7.3 Pilot Handling Experience (Independent Variables)

In order to gain details of the pilot qualifications, experience and demographic data, a pro-forma was developed. Data were recorded for proximal pilot flying practice i.e. the number of approaches in the preceding days and if applicable, the number of days since the last flight to ascertain whether there was a prolonged period without flying (The independent variables of the study). CAP 371 paragraph 4.6 (CAA 2004) prescribes the fatigue limitations for flight crew such that all crew are required to have periods of rest every 7,14 and 28 days. Therefore, the questionnaire for flight recency data was defined accordingly. This data was the basis for relating recent experience and current practice in manual flying, to investigate any possible effects of recent exposure on pilot performance For this research, a manually flown approach is considered to be when the autopilot is disconnected prior to or at the final approach fix and the aircraft flown manually until the landing or go-around for a missed approach. Distal manual flying practice was evaluated from the information given on pilot's total flying experience. Other factors were also gathered which may have had an impact on the piloting ability, for example whether any recreational or aerobatic flying was being conducted by the candidate, the flying training and licence qualification undertaken and the demographic information, including age, sex and experience.

4.8 **Procedure**

4.8.1 Experimental Procedure

4.8.1.1 Simulator set up and start point.

The Type Rating Examiner (TRE) conducting the candidate crew's training detail volunteered to co-ordinate and observe the trial runs. Initially, the candidates were provided with the airfield approach briefings, a weather brief and aircraft mass and configuration data essential for the task. They were then allowed time to familiarise themselves and if necessary ask any final questions. The candidates were briefed to fly a standard terminal area approach, with a manually flown ILS commencing from straight and level flight, prior to the Final Approach Fix, 15 nautical miles from touchdown. The instructor briefing is shown at Appendix J, which lists the initial actions prior to the simulator release. In this way, although the Starboard engine was shut down, the crew were able to confirm the emergency drills were completed prior to flying the approach:

- Emergency contingencies and crew briefing were complete.
- Emergency Check List procedure had been completed.
- Engine, fuel and generator controls were appropriate for the failed engine.
- ILS, Decision Altitude and approach parameters were set and briefed.

- The aircraft weight and configuration inputs for the Flight Management Computers were all entered.

4.8.1.2 Simulator release for the ILS

The candidates were an established crew of a Captain and a co-pilot so they were briefed to perform the exercise using their SOPs. In this context; "established", denotes a crew utilising a standard set of drills and procedures. The procedure should be to reduce speed, select the required Flap position (25 degrees of flap), extend the landing gear and fly the ILS at the planned approach speed of 145 knots, as they would on any operational flight. The duties of Pilot Flying (PF) and Pilot Monitoring (PM) were randomly assigned by the crew deciding who would fly the first profile.

The flight task was initialised by the instructor at the initial point, but was "frozen", in that the position, all controls and the aircraft response were all held fixed. The instructor completed his briefing. Once the crew was ready, the simulator was released in straight and level flight, gear and flap retracted at 210 knots and 3000 feet altitude. However, the initial position was held at a fixed distance from touchdown while the PF disconnected the autopilot and auto-throttle in order to settle into the aircraft condition, set the trim and thrust ready for the asymmetric approach. When the PF was quite ready the position released and the following Air Traffic Control instructions were given.

> "Cleared to establish on the ILS and descend on the glide path. Reduce speed at your discretion. You are cleared to land. If you go around, climb straight ahead to 3000 feet."

4.8.1.3 Flying the ILS

The reported weather conditions were above the Category One (CAT 1) minima required legally for the ILS, with the crew expecting a visual transition to land below the Decision Altitude. At the 4 nm distance from touchdown, the TRE passed an ATC repeat of the landing clearance and a weather update of the latest weather conditions. However, the simulated cloud-base and visibility had been set below the minima. Therefore, the crew would be forced to fly a missed approach as they would not be able to see the runway for landing. Upon passing a height of 200 feet above the runway elevation, the crew performed a go around. The exercise was terminated once the crew was established in the climb away.

4.8.1.4 Completion of the run

After the first run, the simulator was reset to the initial conditions and reconfigured for the next run. The crew re – briefed ready for a repeat of the trial, with roles of PF and PM reversed. The exercise was repeated but the instructor commented that the weather condition had been re-set and it was hoped that a go around would not be required. (Note: the outside environment had not been changed). Once the simulator session was complete, the crew vacated the simulator and moved to a debriefing area. The participants were asked to complete the demographic feed- back pro-forma. Time was taken for feedback and discussion concerning the trial and the candidates were thanked for their participation.

4.9 **Results**

4.9.1 Sample Characteristics

The participants were 41 professional pilots (all male), comprising 28 captains and 13 first officers. The imbalance between captains and first officers was because some companies employed several captains who also flew as first officers. All held either Air Transport Pilot Licences (ATPL) or Commercial Pilot Licences (CPL) or the equivalent from the CAA, FAA, JAA or the RAF and they were all rated to fly the Hawker 800 XP (The summary of licence qualifications is shown in Table 10). Their mean age was 40 years, (SD 11 years) and had accumulated a range of experience from 800 flying hours to 16000 flying hours. (Mean 6143 hours, SD 4786). There was a large variation in experience, with a median of 4500 hours. Nine of the candidates had less than 2000 flying hours, in comparison with eleven of the candidates who had in excess of 10,000 flying hours. Similarly, there was a variation in the flying experience on the Hawker 800 XP, with a mean of 1483 flying hours (SD 1283) and a spread of experience ranging from pilots new to the type with 90 to 200 hours to a senior captain with 8000 hours on type. The overall range of flying experience, from newly qualified pilots to experienced captains, was representative of the pilots that were conducting their recurrent training on the Hawker 800 XP.

Table 10 Summary of Pilot Candidate Qualifications.

PILOTS RANK	LICENCE AUTHORITY	GRADE OF LICENCE
Captains 28	CAA = 19	ATPL = 28
	FAA = 3	CPL = 13
First Officers 13	JAA = 13	
	RAF = 6	

As explained in Chapter 1, there are 3 main methods of accepted training schemes for gaining a commercial pilot's licence. The courses are; an Integrated course, a Modular course or Military training. The candidates initial flying training courses were varied, but the representation was distributed as shown in Table 11.

Table 11 Initial Flying Training: Number of Candidates from each course.

Type of Initial Flying Training.	Number of Candidates
Integrated Course	15
Modular Course	10
Military Course	16

4.9.2 Flight Data Derived Performance Measures

The simulator trial initially yielded 43 runs but 2 runs were removed from the results due to data capture failures, yielding 41 effective runs. The Flight data Performance measures (dependant variables) were recorded in ARINC 717 format. This was imported into an Excel format for data analysis. The outer loop flight path performance metrics computed were the arithmetic mean and standard deviation of lateral and vertical deviations from the optimum ILS flight path. Also, the mean and standard deviation airspeed error relative to the target approach speed. The data set was defined for each run and the data set refined into 3 tasks, Airspeed control (maintaining the planned approach speed of 145 kn.), Localiser Tracking, Glideslope tracking. The data files were listed and co-related from the start of the ILS, (with less than 0.5 localiser and glideslope deviation) and descending from 3000 ft. to the minimum Decision Height of 200 feet above the runway. Table 12 contains the summary of results from the sample size of 41 runs achieved during the trial.

Table 12 Summary performance data for flight path tracking metrics for the ILS approach from 3000 feet to 200 feet.

Metric Parameter	N	Minimum	Maximum	Mean	SD
Localiser – mean error (dots)	41	-0.34	0.20	0.1	0.09
Localiser – Standard Deviation of error (dots)	41	0.06	0.37	0.2	0.1
Glide slope – mean error (dots)	41	-0.18	0.44	0.02	0.09
Glide slope Standard deviation of error (dots)	41	0.06	0.51	0.15	0.08
Airspeed mean (knots)	41	143.3	163.5	148.2	3.7
Airspeed Standard deviation of error (knots)	41	0.86	12.4	4.8	2.9

The ILS instrument display is set to show the angle of error with regard to the central index. As explained earlier, the ILS tracking is recorded in “dots” deflection on the display. The pilot tracking data for full scale deflection, 2 dots, of the localiser is 2.5 degrees. Therefore at 10 nautical miles from touchdown 0.5 dot deflection is actually 654 feet displaced from the centreline. At two miles from touchdown this equivalent lateral displacement is down to 130 feet. So, the pilot gain required as the approach progresses must increase as the lateral displacement is reducing, for the same instrument “dot” displacement. However, the change of gain required did not appear to present handling challenges to the pilots, as the localiser and glideslope mean error was 0.1 and 0.02 respectively. A localiser deviation of 0.1 dots is only 9 feet of error at the decision altitude of 200 feet, barely the width of the cabin or less than ½ a wing span. In practical terms, for an instrument approach, this is a very narrow margin of error and would be more than adequate to allow a pilot to land in the centre of the runway.

4.9.3 Pilot Tracking Task: Localiser.

For the Localiser a positive value was deviation to the right and a negative value an offset to the left. With 2 dots of deviation showing the maximum tracking error, the trial resultant Localiser mean was 0.1 dots with a Standard deviation of 0.09, as shown in Table 12. The mean localiser value for each run is shown at Figure 12, and the localiser SD for each run is shown at Figure 13.

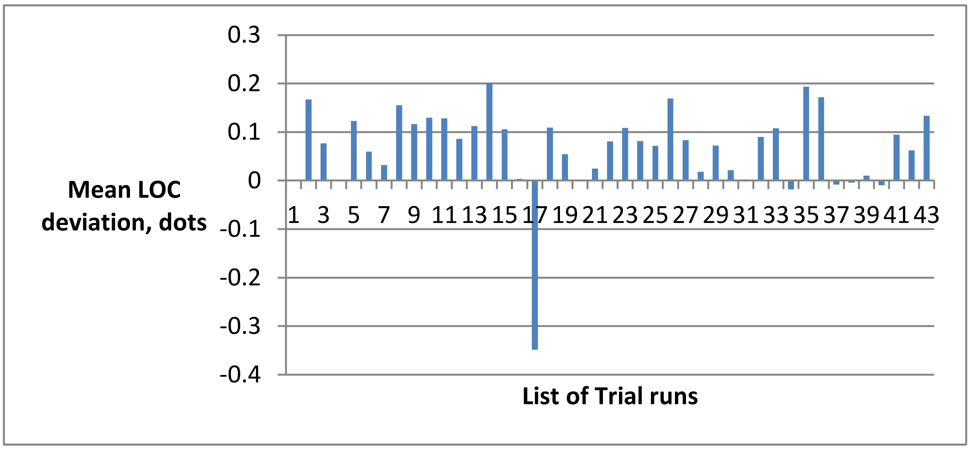

Figure 12 . The mean localiser value for the trial runs.

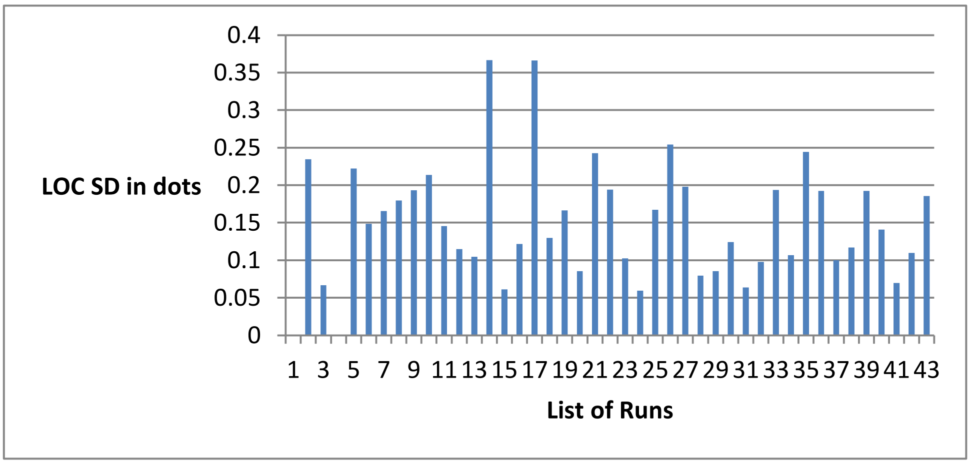

Figure 13 .Value of Localiser Standard Deviation for each candidate.

It is noticeable that candidate number 17 had a mean of - 0.348 and an SD of 0.366 and this is discussed under the section for CAA tolerance. Furthermore, it was notable that this candidate was alone in having a negative value mean, i.e. an offset to the left. Since the starboard engine was inoperative, the resultant asymmetric power from the left side normally causes a bias to the right on approach, as shown by the other candidates. Also, another candidate displayed a large variation in performance was candidate number 14 who had a mean of 0.201 and an SD of 0.366. However, even with a relatively high SD value (compared with the rest of the candidates), which suggests a large variation in tracking performance; this candidate did remain within the CAA tolerance.

4.9.4 Localiser Data in Comparison with CAA Tolerance

The data confirmed that the majority of candidates tracked the Localiser to within 0.5 needle deflection and were within the CAA tolerance to pass the Licence Skill test for ILS localiser tracking. The CAA tolerance on both the localiser and the glide path for the Licence skill test (CAA 2010 c) is a deflection of 0.5. However, the assessment of the maximum excursions determined that 3 runs were outside the CAA tolerance. (With one run just at the CAA limit, value 0.505). The final localiser deviations, for the candidates that exceeded the CAA tolerance are shown in Table 13 and the localiser deviations from 3000 feet to 200 feet on the approach for runs 17, 43 and 5 are shown at figures 14, 15 and 16 respectively.

Table 13 Localiser values for the runs that exceeded the CAA tolerance.

Run number	Localiser Mean	Localiser SD	Localiser Maximum
17	-0.35	0.37	0.74
43	0.13	0.18	0.55
5	0.12	0.22	0.50

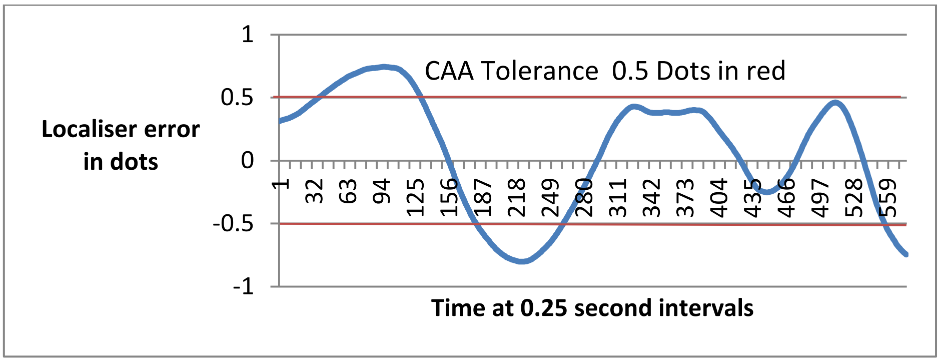

Figure 14 . Run 17, Localiser variation from 3000 ft. to 200 ft.

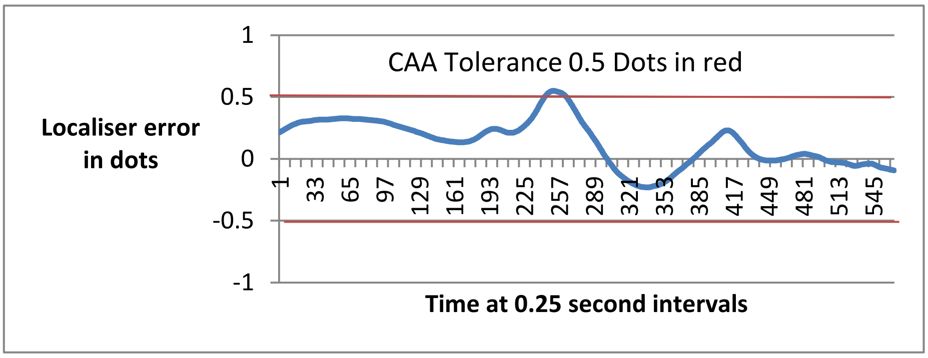

Figure 15 Run 43, Localiser variation from 3000 feet to 200 feet

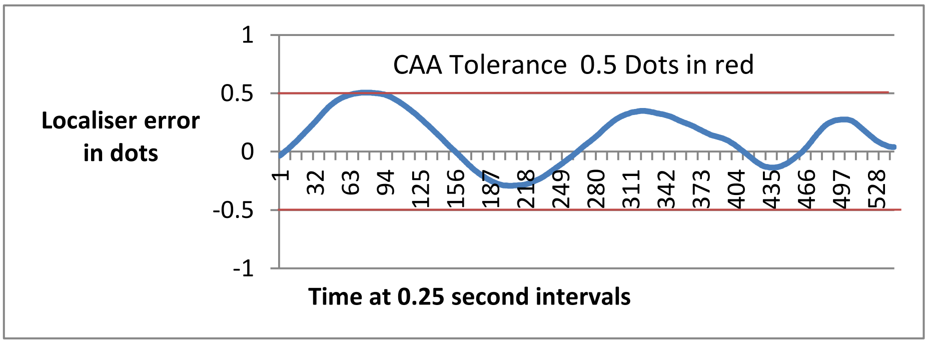

Figure 16 Run 5, Localiser variation from 3000 ft. to 200 ft.

4.9.5 Pilot Tracking Task: Glideslope

The Glideslope display is a needle deflection, up or down, representing a deviation from the ideal glide path angle of 3 degrees, with the horizontal. On the Glideslope the positive value was above the glideslope and a negative value represented a displacement below. The majority of candidates achieved glideslope value less than 0.5 dots displacement. (With only one exception) The trial mean glideslope deviation was 0.021 with an SD of 0.093, as shown in Table 12. The Glideslope Mean and Standard deviation values for each run are shown Figures 17 and 18 respectively.

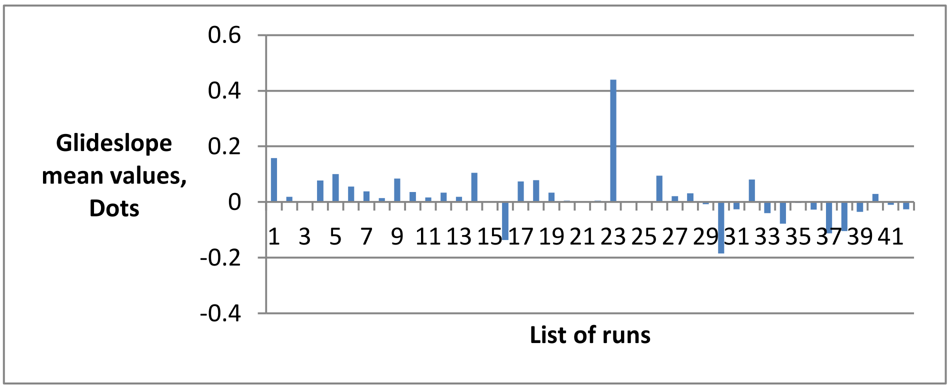

Figure 17 The Mean Glideslope value for each run

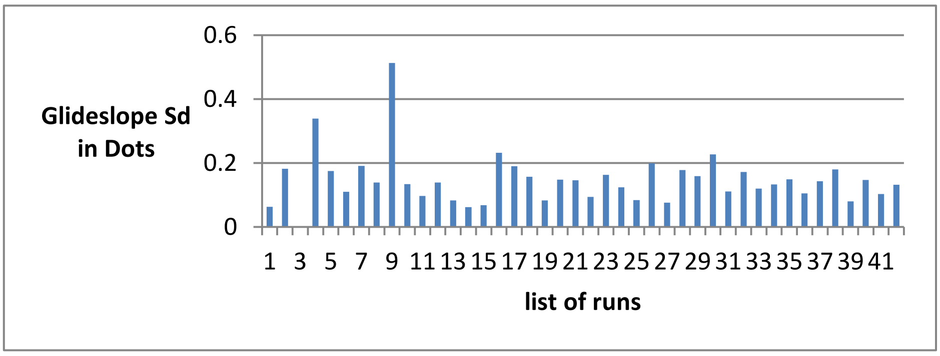

Figure 18 The SD of glideslope value for each run

The highest mean value was recorded for run number 24 (mean = 0.44). This run did, however, record a SD of only 0.17 and the run remained within the CAA tolerance. The greatest SD value was for run number 10, which attained a mean of 0.08 and a SD of 0.51 but it also remained within the CAA tolerance.

4.9.6 Glideslope Data in Comparison with CAA Tolerance

The only run which surpassed the CAA tolerance of 0.5 dots was run number 31, where the glideslope varied throughout the run with 2 periods outside the CAA limit. The glideslope values, for run number 31 are shown in Table 14 and glideslope deviations from 3000 feet to 200 feet on the approach are shown at Figure 19.

Table 14 Glideslope values for run number 31.

Run number	Glideslope Mean error, dots	Glideslope SD, dots	Glideslope Maximum error, dots
31	-0.18	0.23	-0.68

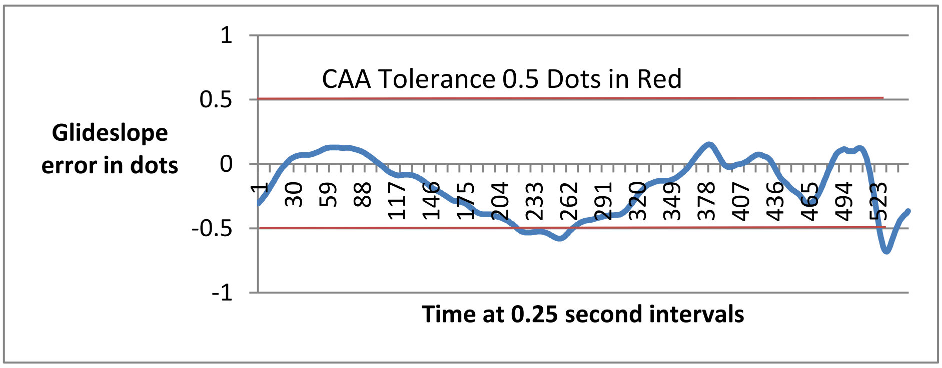

Figure 19 Run 31 Glide-slope variations from 3000 ft. to 200 ft.

4.9.7 Pilot Tracking Task: Airspeed

The data were analysed for speed control with regard to the planned approach speed of 145 knots. For each run the mean of the candidate's airspeed and the Standard Deviation for the airspeed during the run was calculated. The airspeed mean for each run is shown in Figure 20, with the required approach speed of 145 knots highlighted in red.

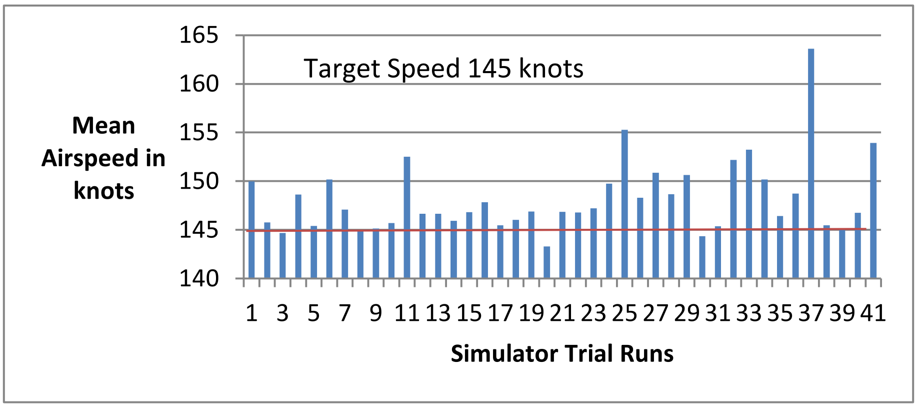

Figure 20 Mean Airspeed for the trial runs.

The majority of runs achieved mean airspeeds above the target airspeed of 145 knots, with 4 candidates having a mean below the target approach speed. The highest mean airspeed was for run number 39 which recorded a mean airspeed of 163.59 knots. The Standard deviation for each run is shown in Figure 21.

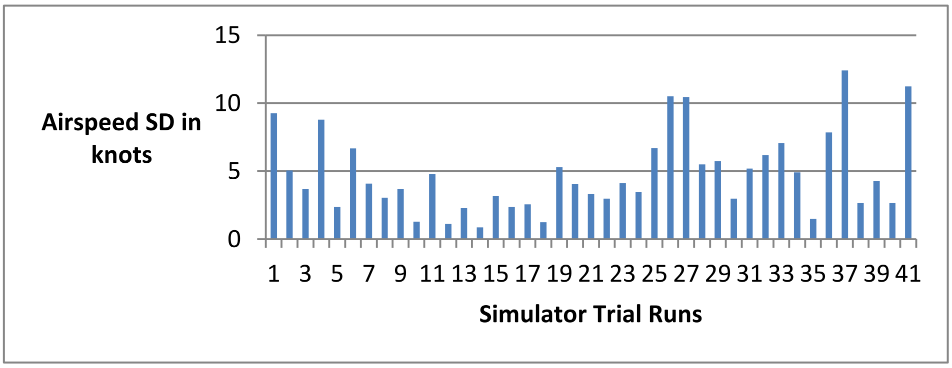

Figure 21 Airspeed Standard Deviation, in knots for each simulator run

The results confirmed that during 10 runs the candidates attained a mean speed of 150 knots or greater, with 4 further runs attaining a standard deviation in excess of 10 knots. For example run 39 recorded a mean speed of 163 knots and a standard deviation of over 12 knots. Even though for 31 runs (75%) the mean airspeed was within 5 knots of the target airspeed, on 10 runs (24%)

there was a greater variation of airspeed. The maximum recorded was 180 knots. The table of Maximum and minimum airspeeds is at Appendix K.

4.10 **Mean Airspeed with Experience and Recent Flying**

4.10.1 Pilot Experience

There were no measures that correlated significantly with total flying experience. There was no evident improvement in pilot performance with increasing experience (ranging from 800 to 16000 hours). In fact the correlation of mean airspeed with regard to the total flying experience was as follows;

$r(39) = 0.09, p = 0.278$

Therefore, there was no statistical evidence of an increase in accuracy with an increase in experience. The comparison of mean airspeed with experience is shown in Figure 22.

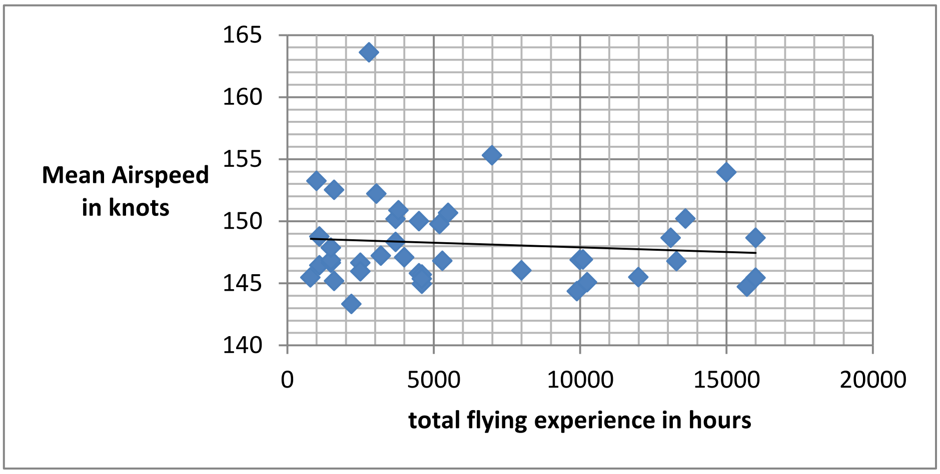

Figure 22 Mean airspeeds related to total flying experience.

4.10.2 Pilot Short term Flying History

The pilot background data also requested the pilot's details of the number of manually flown approaches in the previous 7, 14 and 28 days. The data for the pilot experience during the previous month is shown in table 15. The candidate's recent experience was very varied, as can be seen from the 28 day data, the mean was 4.68 but with a SD of 7.19, within a total experience ranging from nil up to 40 sectors.

Table 15 Pilot Short Term Flying History

	MEAN	SD	MAXIMUM	MINIMUM
Approaches in the last 7 days.	1.13	1.77	6	0
Approaches in the last 14 days.	2.27	4.07	20	0
Approaches in the last 28 days.	4.68	7.19	40	0

There correlations for mean airspeed in relation to the sectors flown in the preceding periods were non-significant, as shown in Table 16.

There was, however, a significant correlation between the airspeed SD and the sectors during the 7 day flying period.

$$r\ (39) = 0.42,\ p < 0.001$$

Thus, the data suggests that the pilots displayed slightly less airspeed variation, depending for increasing practice in the preceding week.

Table 16 Correlation Values for the mean airspeed against the sectors in the preceding days.

Preceding flying period	Value of r (39)	Value of p
7 Days	0.26	0.102
14 days	0.05	0.74
28 days	0.023	0.88

4.11 **Comparison of Training background with Airspeed**

The information provided by the candidates confirmed the type of training undertaken by each candidate. The training backgrounds were; the Integrated course, the Modular course and Military trained pilots. The Integrated course pilots displayed less deviation from the target airspeed of approximately 1 to 2 knots over the other groups. Also, the integrated group SD of 5.6 knots was a small improvement over the other 2 groups. The Military trained demonstrated slightly poorer speed control with an SD of 6.9 knots. Whereas it was 6.4 knots for the Modular trained group. The actual difference in mean airspeeds achieved was small. (Integrated 147.0 knots, Military 148.7 knots and Modular 148.4 knots)

A one – way between groups analysis of variance was conducted between the groups, according to their initial flying training background. There was no statistically difference in mean airspeeds for the 3 groups

$$F\ (2,\ 38) = 1.25,\ p > 0.05$$

The comparisons of the training backgrounds against the airspeed mean are shown in Figure 23.

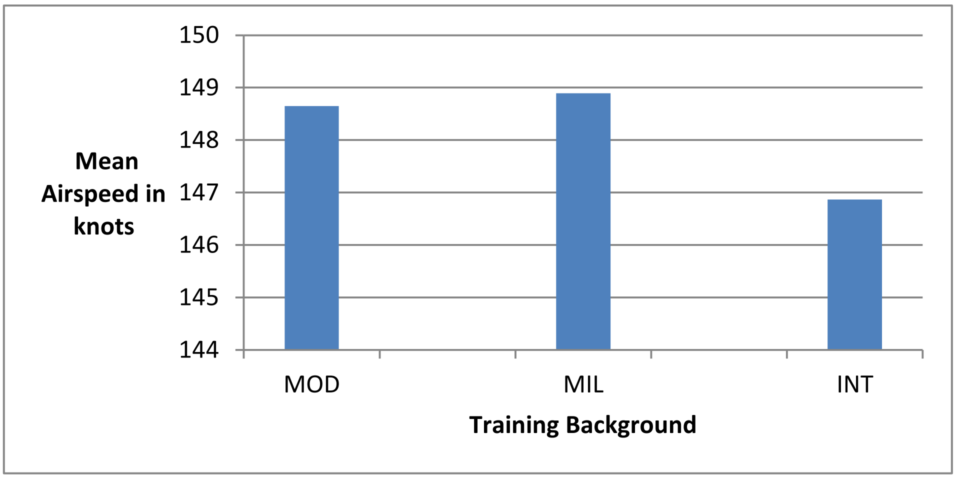

Figure 23 Mean Airspeed for Modular, Military Trained and Integrated Course Pilots.

4.12 **CAA Licence Skill Test Tolerance for Airspeed**

The CAA tolerance for Licence Skill tests for single engine flying is an allowance from the planned/required approach speed. The tolerance allows for a variation of Minus 5 knots up to a maximum of plus 10 knots (CAA 2010c). The planned approach speed for the aircraft weight and configuration was 145 knots. Therefore, the candidates would have an airspeed range from a minimum of 140 knots up to a maximum of 155 knots.

The range of values shown in table 16 indicates the failure rate to remain within the CAA tolerance during the ILS procedure. The table also includes the failure rates with a high airspeed for the start of the ILS at 3000 feet and finally the low airspeed limit at the Decision Altitude, 200 feet above ground level.

Table 17. Failure rates for the Maximum and Minimum Airspeeds on approach compared with the CAA Tolerance

	Below the CAA tolerance of 140 knots	Above the CAA tolerance of 155 knots.	Above the CAA tolerance at 3000 feet	Below the CAA tolerance at Decision Altitude
Number of runs with a speed outside tolerance	11	27	22	9
Percentage of runs outside CAA tolerance	26.8%	65.8%	53.6%	21.9%

During one run, the airspeed varied from a minimum of 132 knots to a maximum of 181 knots. This is a variation of 13 knots below and 36 knots above the planned airspeed of 145 knots. As the trial profile emulated part of the Licence skill test, the candidate would fail, if they exceeded the allowable tolerance i.e.to fly below 140 knots and above 155 knots. The requirement to pass the LST is to remain within the tolerance and therefore have no time outside these values.

The time period, for which each candidate was outside the tolerance, can be extracted from the data by annotating each time element outside the tolerance and then recording the percentage of the total time. From this definition, only 11 runs achieved a zero value for time outside the tolerance and would have been acceptable for the licence test. In contrast, 30 runs were outside the tolerance with 27 flying above the required speed 12 below (9 runs were both above and below the tolerance). The distribution of those exceeding the CAA tolerance, including the successful runs with a zero score, is shown in Figure 24. The run mean and standard deviations for the percentage of the time outside the tolerance, during the approach are shown in Table 18.

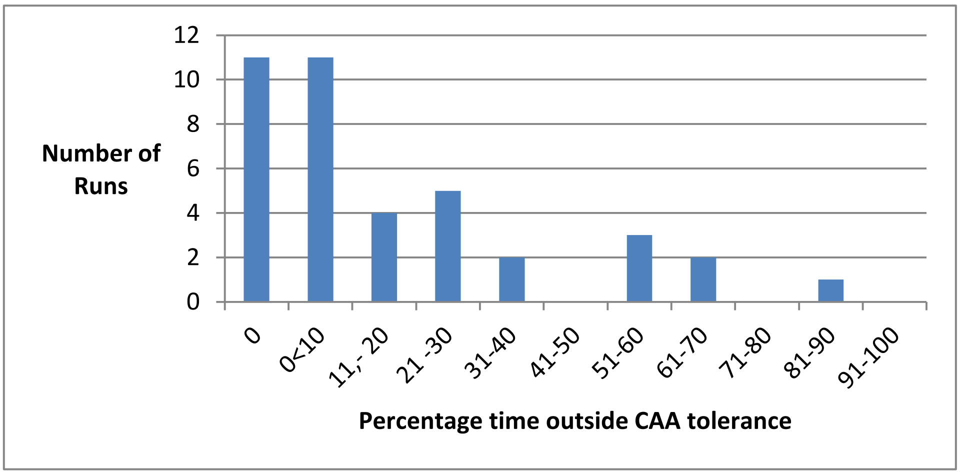

Figure 24 The run listing of percentage times outside the CAA tolerance, including the runs with a score of zero.

Note: there were no runs showing an error for the zones between 41<50, 71<80 and 91< 100.

Table 18 The listing of the Mean and SD for the Percentage Time outside the CAA airspeed tolerance.

	N	Mean percentage time outside limits	SD of percentage time outside limits
Runs outside CAA tolerance	30	18.5	2.0
Runs above CAA tolerance	27	20.2	19.6
Runs below CAA tolerance	12	5.8	9.2
Runs above and below the CAA tolerance	9	48.7	22.0

The pass fail rate varied across the 3 types of training, Integrated, Modular and Military training. The military and the integrated course groups both had a pass rate of 5 trial runs. However, the modular course trainees only attained 1 pass during the trial. The pass/failure rate for the trained groups is shown at table 19 and CAA criteria for each run are shown at Appendix M.

Table 19 The Pass or Failure rate for each trained group.

Initial Training	Modular Course	Military Trained	Integrated course	Total
PASS	1	5	5	11
FAIL	9	11	10	30

Ch. Sq. (2, 41) = 2.43, p = 0.29

The Chi-Square test did not show a statistical significance for the pass rates in the groups. However, it should be noted that there are cells with less than the expected frequency of 5. Therefore, the results are likely to be unreliable. If anything, this may show a conservative result, i.e. It fails to show a significant effect where one may actually exist.

4.13 **Airspeed commencing the ILS**

The simulator profile was planned to represent a high gain task, by commencing at 3000 feet at 210 knots and 15 miles from touchdown, as reducing airspeed and increasing drag on approach, requires a certain level of energy management by the pilot. However, this should have been within the capabilities of the candidates since the task was representative of the CAA LST. Unfortunately, the candidates did not achieve this level of control. In fact, 20 candidates (48.7%) commenced the approach at least 10 knots above the datum speed at 3000 feet, with a maximum airspeed recorded of 181 knots.

Since the aircraft is in an emergency condition, with one engine failed, it is good airmanship and flying skill not to extend the undercarriage and flaps too early and risk slowing towards the stall. The procedure would normally consist of an early reduction towards the final speed, with a low flap setting prior to the glideslope. Once established for the approach, the final flap setting and the undercarriage would be selected. This is elaborated in the Pilots' manual, Hawker Beechcraft Pilots operating manual. (Hawker 2008, P/N 140-590032-007. Section V Flight Handling). During the more accurate runs, this procedure was followed, as shown by the candidate in Figure 25, who was able to extend the undercarriage and flaps and reduce speed towards 145 knots for the approach.

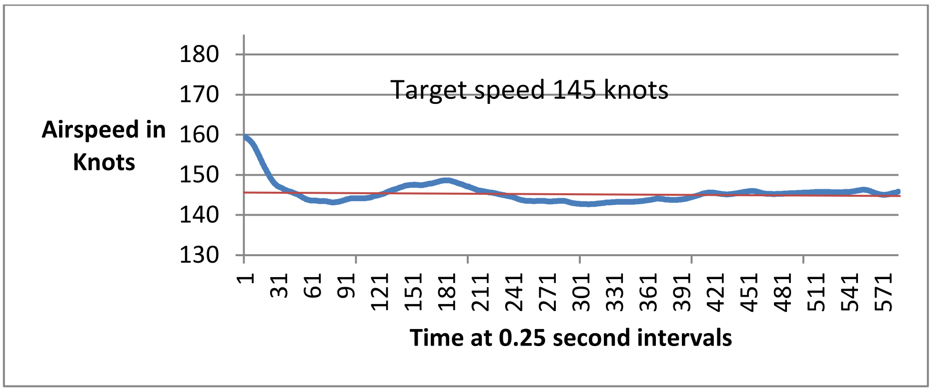

Figure 25 Simulator Trial, candidate Pilot, Airspeed from 3000 feet to 200 feet.

In contrast, as the drag increased, other candidates were unable to maintain the airspeed, whilst it gradually decayed towards or below the approach speed. (An example is shown in Figure 26) The extremes of approach speed were evident during the approaches, with candidates commencing the approach well above the planned speed and often decaying to below the approach speed at the decision height (200 feet above touchdown).

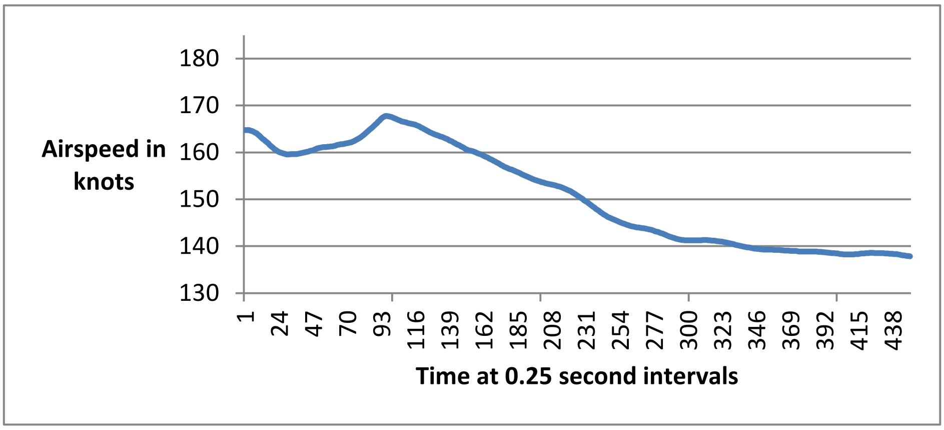

Figure 26 A candidate display of airspeed management from 3000 feet to 200 feet. In that the speed is initially above 145 knots then reducing below it.

4.14 **Minimum Airspeed on Approach.**

From the CAA all aircraft accident data (CAA 2006a) the loss of airspeed and subsequent loss of control after engine failure is listed as a major factor in fatal accidents. It is essential that the pilot should monitor the airspeed and prevent a reduction of airspeed near the stall. Yet as shown in Figure 27, only 4 candidates maintained the airspeed at or above 145 knots for the whole approach. It is notable that 3 candidates were 10 knots or more below 145 knots.

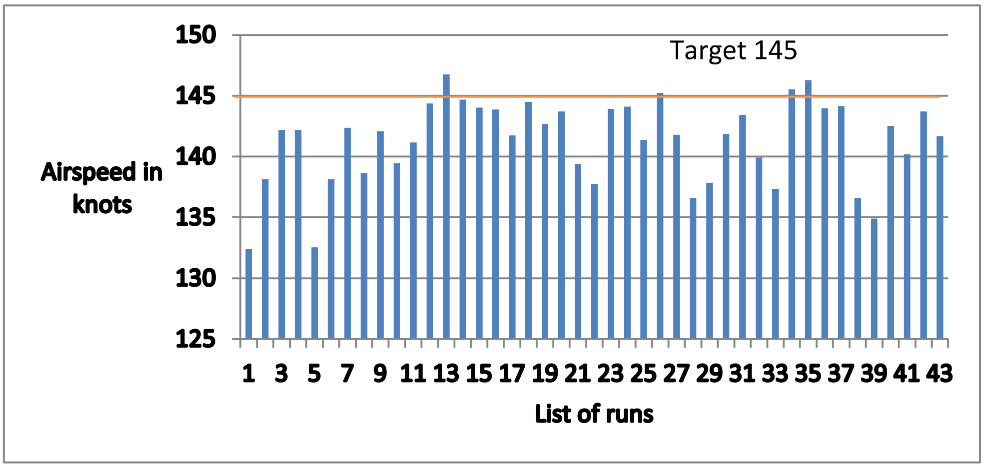

Figure 27 Minimum Airspeed recorded during each run

Accurate airspeed control is essential for a safe approach and landing and the flight procedures allow a margin for error. For example, the Hawker recommended single engine approach speed with 20 degrees of flap is 145 knots, which is 20 knots above the planned minimum speed on for the configuration (Vref). Thus the minimum Vref is 125 knots which also includes further safety factor as it is a minimum of 1.2 times the stall speed (VS.). The calculated stall speed for the aircraft is therefore 104 knots. However, by reducing speed to 132 knots as shown by 2 candidates in Figure 27, the candidates have reduced the safety margin to 28 knots. Since the margin is reduced, a turn with 45 degrees of bank would place the aircraft very close to the stall. Also, in turbulence the aircraft would only have a margin of 1.4 g. above the stall.

Some of the candidates may have accepted that being single engine could be critical and it may be preferable to keep speed in hand early in the approach to guarantee remaining safe. It would then be reasonable to assume that the final segment to landing could be flown at the correct speed. As the plot of airspeed at the critical 200 feet decision height demonstrates, Figure 28, this was not the case. In the final segment a total of 20 pilots were below 145 knots and 9 of those were below 140 knots. Notably, for an aircraft limited by 50% thrust descending below 200 feet whilst below the approach speed severely restricts the aircraft performance (Hawker 2008).

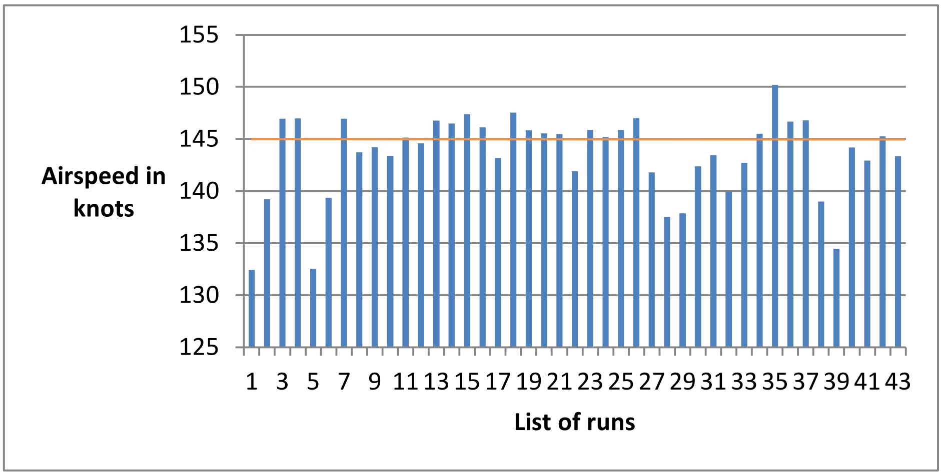

Figure 28 Airspeed at 200 feet above touchdown

4.15 **Engine Handling Data**

Once the aircraft is configured for the approach, gear and flap extended, the airspeed is primarily controlled by the variation of engine thrust. The range of engine RPM measured during the trial varied from 49% to 95%. However, the mean engine RPM had a much lower range of values, from a minimum of 67% to a maximum of 76%. Also, the RPM standard deviation ranged from 1.3% to 9.2%. Thus, some pilots were using more RPM variation than others. During the runs which passed the CAA criteria there was a mean variation of engine RPM of 13%, whereas the mean variation of engine RPM for the failure runs was between 20% and 30%. The mean variation of 30% was on the run which achieved speeds outside the tolerance for 90% of the approach.

There was an increase in RPM SD with an increase in time outside the CAA tolerance, as shown in Figure 29. There was a strong correlation between the time outside the CAA tolerance and the variation of RPM used, so the data suggests that the pilots who remained within or just outside the CAA tolerance utilised a narrower RPM range.

$$r\ (39) = 0.71,\ p<0.001$$

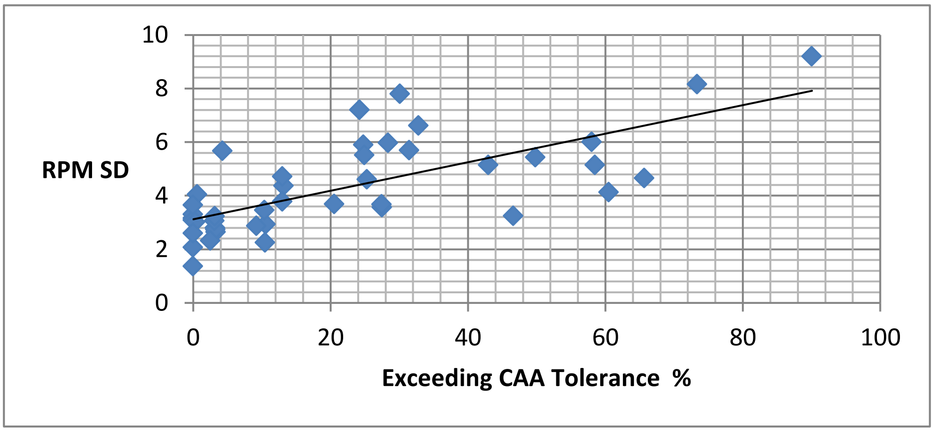

Figure 29 Plot of engine RPM SD against the percentage time outside the CAA tolerance.

4.16 **Modulus**

The modulus of the airspeed error from the required value of 145 knots, gives an overall comparison for all runs, which is not linked to the CAA tolerance levels. Also, the standard deviation of the RPM would demonstrate the level of smoothness of the pilot (Ebbatson et al. 2010). The relationship between the mean airspeed error and the SD of the engine RPM demonstrated that the range of RPM utilised increases with the increase in airspeed error, as shown in Figure 30. There was a strong correlation for the mean modulus of airspeed error against the standard deviation of the mean engine RPM.

$$r\ (39) = 0.72,\ p< 0.001$$

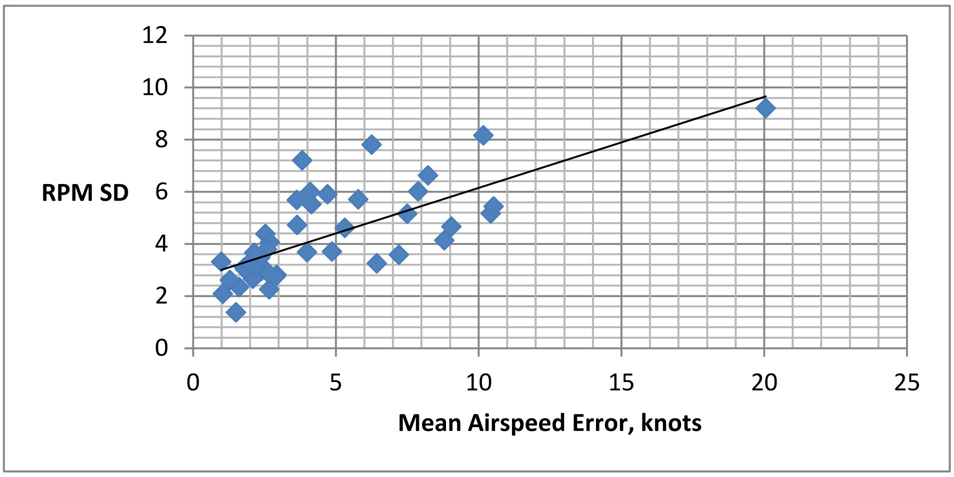

Figure 30 The plot of the engine RPM SD against the Mean Airspeed Error, from 145 knots.

However, the statistical values and trends did not illustrate the engine handling for all cases. For example there is an isolated value of 20 knots mean airspeed error shown in Figure 30. In this example on run 39, there was an extreme error of approximately 35 Knots for most of the approach, as shown in Figure 31. During this approach the airspeed reduced from the maximum of 180 knots to a final airspeed well below the planned approach speed of 145 knots. However, as the airspeed did not stabilise, this can be to the reducing engine RPM on the approach.

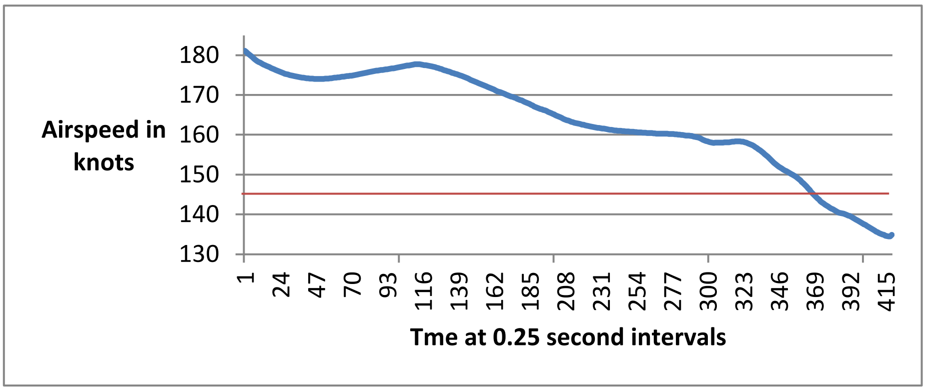

Figure 31 Candidate 39 Trial run, Airspeed variation with time from 3000 feet to 200 feet on the ILS.

Initially, the engine RPM utilised was held at 80%, followed by a prolonged period at 65%. This is shown at Figure 34. Finally the RPM was reduced to 59% and the airspeed decayed to approximately 10 knots below the planned approach speed. (Mean RPM: 68%, SD: 9.1%). In this case, the large variation of RPM is reflected in the high SD of 9.1%. As the SD could be a utilised as an indicator of smoothness, the relatively high SD is indicative of broad power changes and it is represented by large airspeed errors.

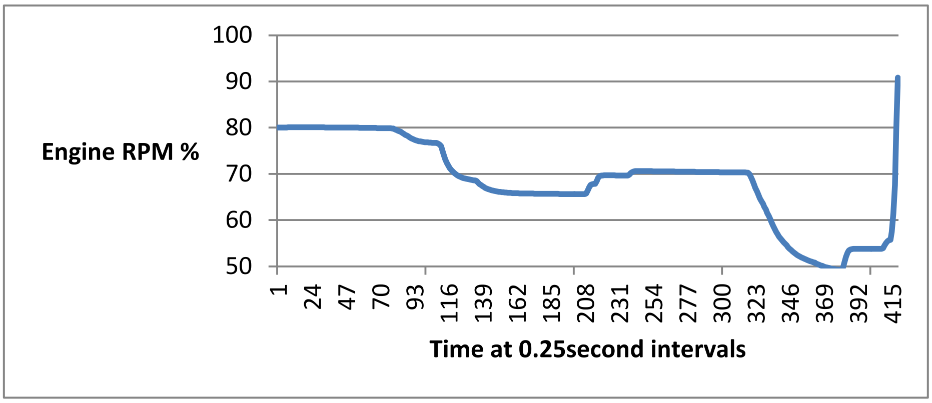

Figure 32 Run 39 Engine RPM time history, from 3000 feet to 200 feet.

As shown in an example plot at Figure 32, the variation of engine RPM utilised were varied across the trial and are related to engine handling techniques. The runs which achieved a CAA pass had a mean engine RPM standard deviation of 2.75. In comparison, the runs which failed for more than 60% of the time there was an RPM mean SD of 6.5%, a clearer indication of engine utilisation and thrust settings could be demonstrated by plotting the real time RPM values for the approach as discussed in the next paragraph.

4.17 **Engine Control Strategy**

Even though the statistical data defines the RPM range for each run, a clearer understanding of their control strategy is available. The candidates utilised various engine control strategies, which was reflected in the airspeed accuracy. The candidates, who passed the CAA criteria, applied a reducing RPM as the target speed was approached and adjusted to a stable RPM at the approach speed.

However, as the less accurate candidates applied a broad series of Power Lever (throttle) inputs to control the airspeed, the possibility of poor engine response or control delays must be considered. Fortunately, as shown in the pre-trial assessment, the data confirmed that the engine response time following an input was less than 0.25 sec. All the engine input/engine response characteristics were examined and even for the most inaccurate, there was no perceptible lag between the pilot inputs and the RPM. Thus the data confirmed a large variation of engine control strategy across the pilot population was representative of the pilot inputs.

The more accurate pilots were able to utilise a smaller RPM range and achieve a more concise control of the airspeed. From the airspeed data, there were 7 candidates who were the most accurate, and remained well within the CAA tolerance, for the duration of the approach. By plotting the RPM parameters during the profile, it can be seen that relatively small adjustments were made and a narrow RPM band was utilised. The stable RPM for each candidate was a setting of approximately 70% to 72% RPM, with fine adjustments around this figure. The engine rpm time histories for the most accurate candidates on approach are shown in Figure 33.

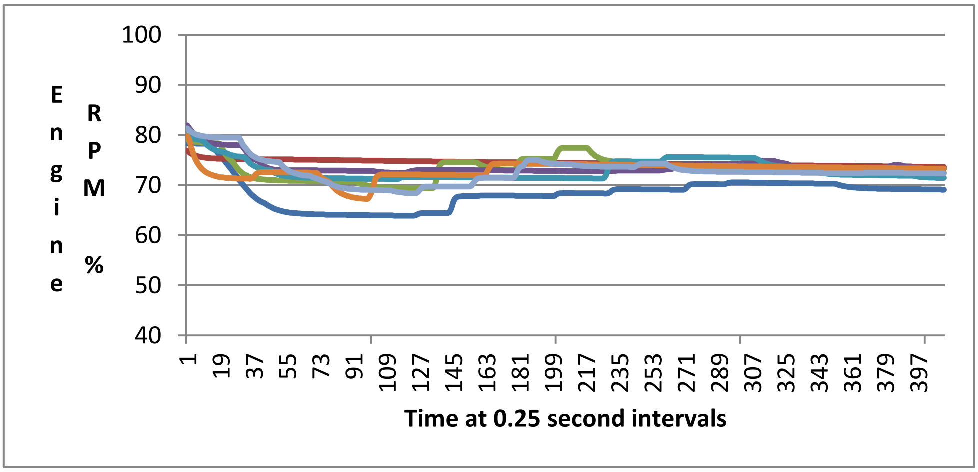

Figure 33 RPM settings for the seven strongest candidates, from 3000 feet to 200 feet.

However, in comparison, the RPM settings were more varied for the candidates with the highest airspeed variation. Therefore, the RPM settings for the 7 weakest candidates who failed the CAA tolerance by the greatest margin, from 90% to 42% were considered and are shown at Figure 34. The overall engine response varies from above 90% to below 50%, with large variations and very short time periods of stable RPM.

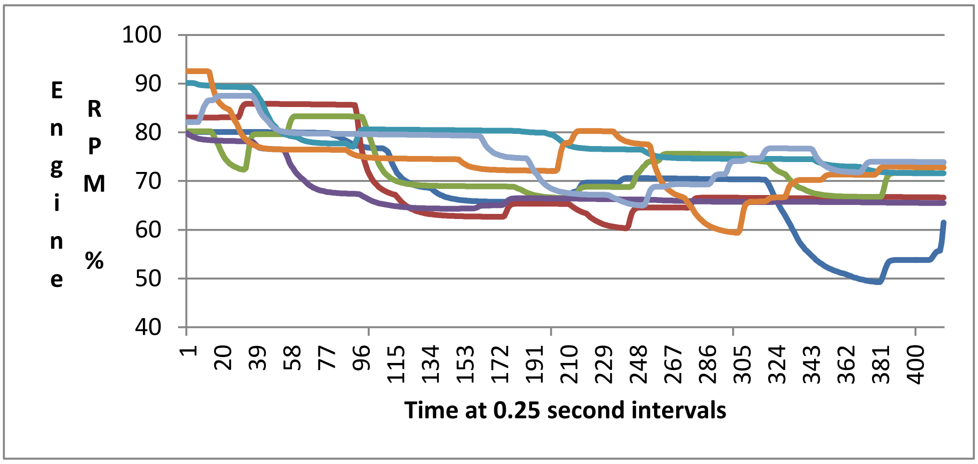

Figure 34 RPM settings for the seven weakest candidates, from 3000 feet to 200 feet.

In conclusion, it can be demonstrated by Figures 33 and 34, that the more accurate pilots were able to establish what RPM was required very quickly on the approach. In contrast, there did not appear to be a consolidated strategy for the less accurate pilots as they did not establish a final RPM, to maintain the target airspeed. The RPM inputs for the weakest candidates varied throughout the approach by as much as 20%.

4.18 **Discussion**

The simulator trial was successful in recording piloting skills, including pilots of CAA, FAA and JAA licence qualifications, during an operational task that was representative of line operations. Even though only 41 runs were achieved, this was considered to be adequately representative of the pilot population.

Significantly, all the candidates had completed the required skill tests for their licence renewal and were expected to have achieved the required standards.

4.18.1 Localiser and Glide slope

The tracking accuracy for the Localiser and glide path was within limits for all but 3 of the candidates and one had only had a momentary lapse of standards outside the tolerance of 0.5 dots displacement. All the other candidates performed well with recorded overall localiser mean of 0.069 dots (SD of 0.089) and a glideslope mean of 0.021 dots (SD of 0.09).

4.18.2 Airspeed Tracking and CAA Test Tolerance

The airspeed tracking task was indicative of the pilot performance in a representative emergency situation. However, the airspeed mean of 148.18 knots and the SD of 4.81 knots did not fully illustrate the overall pilot performance with regard to the single engine flying task. Even though the candidates had passed their LST, during 30 (73%) runs there was failure to meet the CAA tolerance. Also, 8 runs were below 140 knots at 200 feet above touchdown (at the Decision Height), which is consistent with previous accident reports, where pilot handling or loss of airspeed were significant factors (CAA 2006a, CAA 2009b). One run was as slow as 132 knots, 13 knots below the planned speed. Is it possible that they had lost or did not have the required skills to fly accurately, even though they had passed the LST on the same day? The pilots had each completed their recurrent training and had completed less than 4 hours duty for the simulator session prior to the trial. As a consideration for possible fatigue, the total duty was organised to be well within the regulated duty periods allowed. In fact, for the worst case of an overnight duty and 8 sectors, the regulations would have allowed up to 9 hours of duty. An extract of Cap 371 (CAA 2004) is shown at Appendix M. Therefore, a 4 hour duty period, with several simulator sectors and a final approach to land could be considered very representative of a normal working day and not unduly stressful.

4.18.3 Pilot Training Background, Recent Flying and Experience

For the three pilot training backgrounds, included in the pilot sample, the group mean airspeeds varied by less than two knots across the training types. As the pilots should have received comparable engine and airspeed control training, this was reflected in the group statistics and there was little statistical difference in performance across the three groups. With the pilot experience ranging up to 16000 hours, the data did not provide evidence of increasing accuracy with the gaining of experience. However, this supports the evidence of previous studies with Commercial Airline Pilots (Todd et al. 2012). The evidence also suggests that for up to 28 days, the pilot performance accuracy was not significantly affected by the number of approaches in the preceding days.

4.18.4 Minimum and Maximum Airspeed

The simulator data supported the Accident Data Investigation derived in Chapter 3, where pilot skill, specifically airspeed control was listed as a major factor. Part of the simulator task was the requirement to manage the aircraft speed and configuration prior to commencing the ILS. However, several candidates were up to 20 to 35 knots fast at the 3000 feet point for the ILS. With such an excess of speed as they initiated the glide-slope descent, it is perhaps not surprising that airspeed control became a problem. Furthermore, the importance of maintaining the correct airspeed has been discussed in Chapter 2 and as a reminder, the cardinal rule is “Maintain airplane control and a safe airspeed at all times” (Hawker 2008). If the airspeed is so important, why so many fail the “cardinal rule number one” and only 3 candidates maintained speeds above 145 knots for the approach? Essentially, the performance of the majority of the candidates was below the required CAA criteria.

4.18.5 Engine Control Strategy

Flying a passenger aircraft with asymmetric thrust this requires a different control strategy to balanced two engine flights, in that the pilot should be conservative in both thrust and configuration changes. The most critical is the configuration change and the extra drag created by the undercarriage and flaps, once they are extended. The trial procedure was established according to the standard approach profile for the Hawker, with a speed reduction and a drag increase approaching the ILS. Once the landing configuration is attained, the engine thrust setting is varied to maintain the airspeed. During the trial, the engine RPM demonstrated significant variations, the larger the airspeed error, the greater the RPM spread.

Although beyond the scope of this accident study, the type of engine control strategy among business jet pilots could be evaluated in future simulator trials, pilot opinion surveys or during line flying.

The training background of the pilots did not demonstrate a clear separation in tracking accuracy or engine control strategy, with mean airspeeds that varied by only 2 knots.

4.18.6 TRE Tasks and Responsibilities

During simulator training and testing, the examiner is required to set and run the simulator, monitor the pilots actions, including CRM and at the same time act as the ATC controller. For the examiner, an LST involves checking that all the tolerances have been met, such as localiser and glideslope tracking or heading and radio beacon tracking plus monitoring airspeed and altitude accuracy. As the test progresses, there would be several tasks such as monitoring the candidates' procedures, and observing the flying accuracy, from a position behind the crew seats. It may be that the conditions make it difficult to make accurate observations or notice minor deviations whilst conducting the test and running the simulator. The recorded simulator data provided sufficient real time data to determine the candidate's performance within the tolerance parameters and decide the pass/fail criteria. The examiners task could be similarly simplified by setting the prescribed limitations and presenting a pass/fail on the instructor console.

4.18.7 Flight Data Monitoring

The trial did represent a standard approach under benign conditions, and in accordance with normal SOPs but for 30 runs the pilots did not achieve the

CAA standards. However, it is not possible to predict the pilot standards once the crews return to line operations. In scheduled airline operations, aircraft above 27 tonnes are required to maintain a FDM programme (CAA 2003), where such a set of parameters are recorded for post flight evaluation. The Hawker trial aircraft is below the regulated weight limit for mandatory FDM and is therefore not a regulatory requirement. The airspeed tracking result has highlighted and supports the latest CAA initiative for its 7 Significant Safety concerns, where increased pilot training and improved in flight monitoring is advocated (CAA 2011b).

4.19 **Summary**

The skills of business jet pilots were investigated to review any weakness in pilot handling. The data was consistent with the findings of the accident model described in Chapter 2, where pilot skill was a major factor in the final model. An area that was highlighted was the airspeed tracking task, within the limits laid down for the Commercial Licence qualification, although all the pilots had passed this test. As the simulator data could define a pass / fail parameter, an automatic method could be proposed for assessing the pass/fail pilot performance during the Licence Skill tests. The lack of proper airspeed control has been significant in the accident data, on one side by flying too slowly and losing control on the other side, by attempting to land too fast, where it has contributed to the overrun accidents (IBAC 2012, EASA 2013). Even though the principles of engine control are included in early pilot training by both the military (CFS 1995) and civilian schools (AOPA 1994), further research could examine the type of engine control training received by pilots and suggest improvements.

In terms of the HFACS definitions, a lack of accuracy could be considered under “Unsafe Acts”. However, it is debatable whether they constitute “Skill Errors” or “Inadequate Supervision” (Wiegmann & Schappell 2003). Command and leadership was considered a significant figure in the Accident Data Investigation in Chapter 3. So if the captains accept poor standards of flying and do not demand accuracy from the co-pilots, then this could be accepted as the norm and perpetuated among the pilots. However, long term Skill fade has been reported among airline pilots (Wood 2004) and in a study of General Aviation accidents, Keller (2013) reported evidence of pilots failing to maintain airspeed and maintain control from as few as 100 days after their instrument licence test. However, the trial candidates had passed the LST within hours of flying the trial; so long term skill fade could be unlikely.

If skill fade is unlikely, to continue the concept of expected crew capabilities, Chapter 3 contained evidence that the captains were prepared to accept poor standards of drills and flying. Similarly, if the simulator instructor does not demand high standards and rate accordingly, do the pilots strive to improve? From the simulator trial it is not possible to identify the causes. There may be several aspects including; training, handling procedures, and skill levels. The results, therefore suggest that further research into business jet piloting skills would be beneficial. Also, the statistical analysis of recording the mean and standard deviation did not immediately illustrate the real time task and the measure of pilot performance with regard to the accepted limits. The measure of allowable tolerance and maximum deviation was more successful in both simulator and aircraft data monitoring, to provide an appropriate measure for pilot accuracy.

5 CONCLUSION

5.1 Introduction

This chapter first provides a recap of the thesis background and then presents summaries of the 3 key research studies, followed by a summary of the simulator trial limitations. Finally it presents the overall conclusion of the research.

As discussed in the opening paragraph of this thesis, business jet operations have a poorer long term safety record than scheduled airline operations (IBAC 2008, 2010, 2011, 2012). Also the CAA had noted the situation, as part of its Safety Plan (CAA 2009b). This Business jet Safety and Accident study supports this concern and proposes guidance to remedial action. The study provides substantive evidence of the concerns and has investigated the manual flying skills of the crews.

As stated in the introduction, the aim of the study was to investigate Business jet Operations and determine operational areas in need of improvement, with the following 3 key research objectives:

- Review and discuss the business jet operations, regulations, operating conditions, accident data, and crew skills compared to commercial airline operations.
- Conduct a study of the business jet accident data, to describe an overall accident model relevant to their operating conditions.
- Carry out a simulator trial assessment of business jet pilots' operating skills.

The Study presented in this thesis has successfully addressed each of these principal objectives. The literature and accident data review has provided an overview of business jet operations, regulations, operating conditions, accident data and crew skills compared to commercial airline operations. The accident data investigation then provided an accident data model that was pertinent to the particular style of business jet operations and highlighted the major areas of concern.

Subsequently, considering the results from the accident data review and the proposed accident model, a pilot simulator trial study was devised to provide the final area for study, an assessment of business jet pilots' operating skills.

5.1.1 STUDY ONE: Review Business Jet Operations

The review of business jet operations and accident data provided background and information on the particular type of operations. Several key topics were presented in the literature review, in Chapter 1, and from these topics, the following was amplified during the study.

There are at least 18000 business jets in use around the world. In contrast to the major airlines where large numbers of aircraft are operated from established airports, with established facilities and support, the business jets are often part of small operations from smaller airfields. For example in 2010, 75% of the company operators had only one aircraft and 12% had just two aircraft, with only 13 % having 3 or more aircraft (NBAA 2010).

The lack of compliance with the rules and regulations was demonstrated by crew operating outside the weather limits, where pilots also conducted operations from runways that were unsuitable or too short. Business jet operations are not conducted along defined routes and timetables. Therefore, the operators are not limited to fixed destinations, as these are dictated by the customer. So, the business jets have a more varied itinerary and would present difficulties for the regulator. At present the EASA is setting out its regulations and has issued an initial definition for commercial operations, which does not limit or define the size and type of passenger carrying operations (EU OPS 2008), so this may be influential on future business jet operations.

The airfield categories was noted a factor, as the lack of facilities and the problems associated with business jets operating to smaller, less sophisticated airfields was evident in the accident data.

The pilot performance, with special regard to flying skills and airspeed control was a major factor in the accident data, especially during the approach and landing phase of flight. The pilot performance with regard to landing ability, stable approaches and poor crew CRM was all evident in the accident reports and is further reflected in both Chapters 2 and 3.

The accident data investigation statistics were for 2007 to 2010 but the data for the following year, 2011 supports this study and highlights the pressing need for improvement. The 2011 statistics for both United States registered and Non United States registered business jets were; a total of 27 accidents, with 17 (62%) on landing where 14 lost control and 8 had airspeed as a factor (IBAC 2012). There were also 4 accidents with US registered aircraft that were technical faults or failures.

The 2011 accident data for both the USA registered and non- USA registered aircraft, as presented by IBAC (2012), is included at Appendix N.

The several safety initiatives by both the regulators and the business jet associations (e.g. IBAC), have concentrated on the operational aspects found in the review, such as pilot skills, rushed approaches, requisite landing conditions, (wet, snow, ice etc.). Business jet operators routinely send aircraft; with only a pilot crew, to wide ranging destinations so the IBAC has a safety programme in place which monitors companies in an attempt to improve the operating standards across the industry. The results are published in their annual accident reviews (IBAC 2008b)

With over 18000 aircraft in use world-wide, regulatory oversight could be an onerous task. Also, as discussed in Chapter 1, the CAA has raised their concerns and cited the difficulty of regulatory oversight, and considers this may be one of the causal factors for the business jet poor safety record (CAA 2009a).

The apparent lack of support in some areas and technical failures was supported by this thesis and The Accident data investigation for the proposed accident model. The Grounded Theory model outline included Outside Support as it proved representative of the business jet operations. This aspect is further reflected in the 2011 accident data which includes 4 technical failures (IBAC 2012).

5.1.2 STUDY TWO: Accident Data investigation

The Accident Data Investigation and Grounded Theory accident model revealed the interlinking of several major factors in the accidents. The business jet core model was able to consolidate the evidence to show an overview of the operation as a whole. Furthermore, the primary crew factors of CRM, Command and Skills, with a further influence of the Support Environment are in agreement with the findings of Harris (2006) and Klinect (2001) who found similar crew factors during routine airline operations. This Grounded Theory study found that the apparent lack of CRM among the crews directly affected performance. This is in accord with the CRM and NOTECHs procedures proposed by Flin (2003).

The inclusion of Pilot Skills in the final model supports the findings of previous annual safety reviews (CAA 2008). However, the piloting skill was not limited to purely “stick and rudder”, but was also demonstrative of lacking systems and performance knowledge among the crews.

5.1.2.1 CRM

The results of the Grounded Theory and the proposed accident model suggest that CRM was a major safety factor in business jet operations. The accident reports highlighted examples of actions by the Captains that were listed as poor standards as set out in the NOTECHs for crew behaviour. This again, supports the findings of Flin (2003) .The results of the study also support the principles of CRM (CAA CAP 737). In addition, the actions of the captains and the co-pilots’ reluctance to act both supports previous research and re-enforces the FAA directives which state the importance of CRM training (FAA 2012).

5.1.2.2 Command

The findings of this grounded theory study suggested some captains displayed good leadership, closely followed the drills, briefed the crews and achieved a safe conclusion. However, further accident report evidence disclosed inadequate actions or supervision by other captains, such as running out of fuel, failing to comply with the regulations and deliberately attempting manoeuvres outside the aircraft and crew capabilities. This reflects on the standard of command and supports the CAA requirements (CAA 2010d, 2011c). The findings of this study have supported the inclusion of Command as a significant factor.

5.1.2.3 Skills

The pilot's capabilities varied across the range of experience. This supports the findings of Ebbatson (2009). Furthermore, the skill retention and dependency on automation of airline pilots has been reported by Wood (2004) and Ebbatson (2007) but this has not been investigated for business jet pilots. Although, the study has offered an accident model that proposes concern for the piloting skills, the evidence also proposed a greater understanding of the aircraft was equally important. Even though piloting skills was a major factor, the evidence suggests crew deficiencies in both understanding the aircraft's runway performance and also the aircraft systems and supports the CAA accident data summary (CAA 2006a).

5.1.2.4 Support Environment

The final factor in the consolidation of the business jet accident model was Support Environment. As they are frequently operating to minor, less established or even unmanned airfields, the business jet operational arena is more varied than that of scheduled airline operations. Moreover, aircraft operations may not be considered in isolation. External factors such as ATC, aircraft maintenance and operational planning support are essential. An element of the support environment personnel could link directly to the CRM discussion above, as the operations and maintenance personnel should be considered part of the overall "team members". Similarly, this study reflects the proposed safety initiatives, such as an improved SMS for all operators (IBAC SMS) to promote a better level of safety awareness.

5.1.3 STUDY THREE Simulator Trial

The third study used the results of the previous 2 studies to define a task that was both challenging, and met the expectations of every commercial pilot. However, the simulator trial indicated that the performance of the majority of pilots, according to the regulations (CAA 2010c), would have been a licence failure. The simulator study suggested that when a piloting task is considered, it is not only the manual tracking tasks that should be investigated but also the cognitive aspects. As the aircraft had an engine failed, it would not be able to sustain level flight with the flaps and undercarriage deployed ready for landing. Therefore, an element of the task is the judgement and capability to understand the planning required for the profile, without losing airspeed and becoming dangerously slow. This would provide extra workload, as the pilot was required to reduce speed and deploy the undercarriage and flaps, commensurate with the reduced thrust available whilst monitoring the flight parameters to join the ILS. This supports the findings of Ebbatson (2009). The inner loop close control of aircraft attitude and short term trajectory in the ILS tracking proved adequate for the simulator. The outer loop control of aircraft performance and airspeed due to the reduced thrust requires a different control strategy in the long term, deploying gear and flaps, and the short term, speed control on the ILS.

The energy management consideration, both commencing and ending the ILS proved to be a challenge for some crews who were either fast at 3000 feet or slow at 200 feet. Although the metrics of airspeed and ILS tracking were statistically evaluated, it was the more fundamental measures of airspeed variation and maxima that revealed the real crew capabilities. The pilots' performance was consistent with a lack of appropriate long term energy philosophy, as shown by the extremes of airspeed at 3000 feet, (up to 180 knots). For the short term airspeed tracking task, the accurate pilots refined the engine setting very quickly and stabilised the airspeed. In contrast, the performance of the less accurate pilots was consistent with an inappropriate engine strategy being applied. The poor standard of airspeed accuracy was not limited to the less experienced and the increase in experience was not commensurate with increased accuracy. In comparison with commercial airline pilots, this supports the findings of Todd & Thomas (2013).

5.1.3.1 Performance Measures

The majority of the candidates (38) were very consistent, with for both the localiser and glide path tracking, remaining well within the CAA tolerance limit of 0.5 dot displacement. However, three candidates failed to maintain the CAA tolerance for the localiser and glide path tracking tasks for short periods. It was considered that the outer loop tracking task of the aircraft trajectory and tracking the vertical and lateral flight path was satisfactorily achieved. This supports the findings of Ebbatson (2009) in that the average ILS tracking error was very close to zero for most of the subjects.

The second relatively complex outer loop task of configuration control and energy management ready for landing (Lowering the undercarriage and the flap) was reflected in the relatively large airspeed variation. It was in closer, inner loop task of airspeed control that required further investigation. Although the control strategy metrics and control input frequencies were not evaluated, the initial validation of the airspeed against the CAA standard illustrates the actual performance.

Whilst each pilot had received identical training profiles and testing regimes prior to the trial, there was a large variation of engine management. Moreover, there was a broad range of experience, varied career paths among the candidates and the higher experience levels did not reflect in improved performance. Also the 3 basic pilot training backgrounds demonstrated similar performance and similar engine management.

The degree of RPM and throttle input combined with the outer loop performance measures could suggest reliable measure of piloting skills. As the more accurate pilots utilised a narrower RPM band, this supports the hypothesis of Ebbatson (2009) that confirmed that more skilled performance was shown by a reduction in control input across all frequency bands.

5.1.3.2 Energy management

Since the aircraft is in an emergency condition, with one engine failed, it could be good airmanship and flying skill not to extend the undercarriage and flaps too early and risk slowing towards the stall. The procedure would normally consist of an early reduction towards the final speed, with a low flap setting prior to the glideslope. Once established for the approach, the final flap setting and the undercarriage would be selected (Hawker 2008). The simulator profile was planned to represent a high gain task, in that reducing airspeed and increasing drag on approach, requires a certain level cognitive skill by the pilot. However, this should have been within the capabilities of the candidates since the task was representative of the CAA licence skill test. The candidates did not achieve this level of control. In some cases, as the drag increased, the candidates were unable to maintain the airspeed, whilst it gradually decayed towards or below the approach speed. The extremes of approach speed were evident during the approaches, with candidates commencing the approach well above the planned speed and often decaying to below the approach speed at the final decision height.

From the accident data (CAA 2006a) the loss of airspeed and subsequent loss of control after engine failure is a major category for fatal accidents. It is essential that the pilot should monitor the airspeed and prevent a reduction of airspeed near the stall. Yet, only 4 candidates maintained the airspeed at or above 145 knots for the whole approach. Thus some candidates were recording very low airspeeds during an emergency approach, in cloud. Finally, at the decision point only 200 feet above the runway, the aircraft is in a poor condition, slow and low, with little time or height in which to recover. Critically, this is representative of previous accident data (CAA 2006a).

5.1.3.3 Pilot skills and training

The results of the simulator trial also support the accident data evidence (CAA 2006a) in that a major factor in both fatal and non-fatal accidents is pilot handling, resulting from the lack of adequate airspeed control. Similarly, it is considered that the performance distribution of performance issues is commensurate with the complexity of the task, requiring a more complex mental model, for example, and landing with an engine failure (Veillette 1995). The simulator trial demonstrated, for future trials, that consideration should be given to designing a task which is challenging to both the cognitive aspects of pilot performance as well as the physical tracking tasks. It is uncertain whether the failings are due to skill errors or a lack of adequate training and this should be further investigated. However, the quality of simulator training and lack of manual flying practice has already been raised by the CAA (CAA 2009a, Vivian 2004) An improved recurrent training programme (ATQP) has already been instigated for airline operators, this may have benefits for the business jet operators, providing that manual flying skills are adequately addressed. Moreover, Wood (2004) reported that design of modern aircraft and the ATC environment rarely allows for manual flying in preference to full use of the autopilot. Finally, the findings of the investigation support earlier subjective evidence concerning the loss of manual flying skills. (Curry 1985, Wiener 1989, Wood 2004, Ebbatson et al. 2007).

5.1.3.4 TRE rating and examination

For the training and examination criteria, it is notable that the pilots had attained a pass grade for their LST within hours of the simulator trial. However, for the trial, several candidates exceeded the CAA tolerance for more than 40% of the approach. Significantly, the criteria for the trial included that all candidates would have passed their recurrent training and therefore had already performed to the required standards. During normal operations, AOC holders are responsible to the CAA for the crew standards and the CAA inspectors may observe crews and critique company operations (CAA 2010d). Unfortunately, it was not possible to observe the training sessions prior to the trial procedure. Therefore the pre-trial training cannot be commented on in the study.

In order to conduct a LST, the TRE is required to monitor several parameters during the approach (e.g. Localiser, Glideslope, Airspeed, flap, undercarriage, Air Traffic Control calls). Therefore, an automatic data recording function to show a pass/ fail for all the parameters would aid the test process whilst recording the candidate’s performance.

5.1.3.5 Simulator trial limitations

The simulator trial was conducted on a Level D, CAA and FAA approved simulator. The candidates were taken from the pool of pilots undergoing recurrent training for their licence renewal. However, the time opportunities were limited as the simulator was in almost constant use, which restricted the time available. The Simulator Company was, however, very supportive and enabled the successful runs to take place over a 2 year period. However, as each candidate had received the required training and achieved the required standard, it was considered that the sample could be considered as representative.

The simulator trial was limited in that the approaches were all conducted on one aircraft type (Hawker 800 XP). Ideally, it would have been preferable to conduct a series of trials across several aircraft types and a larger sample of pilot candidates. Under the actual time and simulator constraints this was not possible but should be considered for further trials of this type.

Furthermore, it would have been desirable to obtain further data and observe the full training details. From the review of the trial data, further data runs, especially for the LST would have been beneficial. Unfortunately, due to the constraints, this was not possible.

5.2 **Conclusion**

This Business Jet safety and accident thesis has achieved the research aims proposed in Chapter 1 by identifying the major factors in business jet accidents.

The Literature Review has confirmed the different operating environment of the business jets, often operating at short notice to a destination of the customer’s choice, that may be isolated and lacking in some ATC or airfield facilities. In contrast, the airlines are have regular schedules predominantly to major well supported airports. Many business jet operations have less than three aircraft (NBAA 2010), only a few pilots and lack the full ground support available to the major airlines. This evidence suggests that the supervision and regulation of such a large and varied aircraft fleet across the globe presents unique problems. The annual safety data published by the CAA and IBAC illustrates that the business jet safety record has consistently been below the level of commercial airlines. This has been recognised and several safety initiatives have been proposed by both the regulators and the industrial organisations (CAA 2011b, IBAC 2008b). In both the commercial airline and the business jet industry training improvements such as ATQP (CAA 2011c) have been implemented to broaden the recurrent training in a manner more appropriate to the individual operator. Also, both the CAA and EASA has publicised safety issues such as the loss of aircraft control and excess airspeed an approach for all operators, regardless of aircraft type (CAA 2011b, EASA 2011).

In the Accident Data Investigation the influence of Command and CRM in the accident reports, especially including failures to adhere to regulations were significant flight safety concerns. Although the primary factors were crew related, the outside influence of the Support Environment and inputs from the outside agencies were still significant and safety initiatives are being implemented to improve these areas.

The pilots' skills simulator trial has amplified previous work by Wood (2004) and Ebbatson (2009) by raising the concerns for pilot skills during routine line flying. Although previous research has investigated pilot operations, there has not been any similar investigation to record pilot handling performance during a simulated emergency on a commercial licence qualification profile. Since the LST is common to all commercial pilot recurrent training, it would be beneficial to conduct an identical trial among airline pilots. Subsequently further information could be gained concerning the quality of training for the fundamental tasks such as engine control strategies. The simulator results have suggested that even though the fundamentals of aircraft performance and engine control is taught at the first stages of pilot training, there is an apparent degradation of ability. The dominance of poor airspeed control reported in the loss of control related accidents (CAA 2006a) and the results of this thesis should provide the emphasis for improved engine and airspeed management either by improved training or monitoring the standards of licence examination.

This thesis has shown the importance of a reliable measuring technique to evaluate pilot performance with regard to the statutory licence requirements. The simulator results were able to track the pilot performance to within one knot and provide the TRE with an immediate measure of the pilot capability. Furthermore, the results demonstrate the need to improve aircraft control by including the inner loop input measures (RPM management) as a training requirement and thus better refine the measurement of the outer- loop tracking task (Airspeed)

The direct comparison of the airspeed data with the CAA examination tolerances gave an immediate and accurate measure of the pass or fail time period for each candidate. This method, therefore, gave a more measured indication of the candidates' performance with regard to the actual task and highlighted major failings in both energy management and flying ability.

The training and evaluation system should ensure that every pilot is up to the task;

> Can the pilot fly the aircraft and land safely with an engine failed?

5.3 **Suggested future research**

This study has identified the major factors associated with the particular aspects of business jet operations. However, considering that only one aircraft type was evaluated, a broader scope with more evidence of actual aircraft operations would be beneficial as well as an appraisal of airline pilot skills. Therefore, the following considerations are suggested for future research:

5.3.1 Training and Simulation

- The scope of this study was limited to the approach and landing phase of flight, since there are also significant flight phases that have not been included, (e.g. Take-off), it is suggested that further investigation is conducted to include airline operations and all flight phases.
- The pilot skill of airspeed tracking was identified as weak during the trial, therefore it is suggested that further research be conducted into the pilot training for engine/airspeed control and strategy.
- The major factors of Command and CRM were of equal status alongside Skills in the Accident Data Investigation. It is suggested that further research is conducted to determine the training areas that are lacking in Command and CRM.
- Business jet training should include more pilot handling emphasis and promote ATQP for pilot recurrent training.

5.3.2 Licence Skill Test and Flight Data Monitoring.

- It is suggested that research be conducted to investigate an automated system for pilot tracking during the critical phases of the LST in order to provide an automatic pass/fail result for the TRE
- Further research into a monitoring programme for evidence of piloting skills from real world derived data would also be beneficial. The analysis could show improvements in engine handling and also demonstrate pilot skill levels in the business jet community. This may be integrated into an improved FDM category to include the lighter business jets, at present below the 27 tonne minimum.

5.3.3 Support Environment and Pilot Opinion.

- It is suggested that a pilot survey among the business jet community, should be conducted to obtain data and feedback on the particulars of their operations, and background information on engine management philosophy.

- The Support Environment, such as ground operations, maintenance and Air Traffic Control, was a major influence and it is suggested to research the effect of on-going safety initiatives such as the IBAC improved SMS programme.

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APPENDICES

Appendix A : CAA / FAA Regulations for passenger Aircraft.

FAA	FAR 121	FAR 135	FAR 135 ON DEMAND	FAR 91
	Airline Operators: Large transport airplanes operating Scheduled/non-scheduled revenue flights. Regulations limit Part 121 operations to controlled airspace and controlled airports that have available specific weather, navigational, operational, and maintenance support.	A scheduled passenger-carrying operation that flies to smaller airports not providing the services required to support Part 121 operations. Includes commercial air carriers flying smaller jet and turboprop aircraft	Commercial Operators, where air travel is at the request of the traveller in both time and destination. This is restricted to less than 5 round trips per week, between 2 or more points, on published flight schedules.	Operations where no fee or payment is involved. Including: Ferrying, Aerial work. Demonstration & training Company flights
CAA	TYPE A ROUTE LICENSE	TYPE B ROUTE LICENSE-SCHEDULED	TYPE B LICENSE NON-SCHEDULED	GENERAL AVIATION
	Airline operators: The Type A Operating License is granted to companies permitted to carry passengers, cargo and mail on aircraft with 20 or more seats for both scheduled and non-scheduled (Charter) operations	The Type B Operating License is granted to companies permitted to carry passengers, cargo and mail on aircraft with fewer than 20 seats and/or weighing less than 10 tones.	The Type B Operating License is granted to companies permitted to carry passengers, cargo and mail on aircraft with fewer than 20 seats and/or weighing less than 10 tones**.**	General aviation and industry. Similar constraints and type of flights as per FAR 91. The overriding consideration must be not for Hire or reward.

Adapted from FAR 21, 91 , 135 and CAA 2010 a.

Appendix B Airfield Categories

The Airfield Categories and conditions are as follows (JAROPS 1, 2008):

(a) Category A. An airfield which satisfies all of the following requirements:

(i) An approved Instrument approach procedure.

(ii) At least one runway with no performance limited procedure for take-off and/or landing.

(iii) Published circling minima not higher than 1000 ft. above the airfield level. (AAL) and

(iv) Night operations capability.

(b) Category B

An airfield which does not satisfy the Category A requirements or which requires extra considerations such as:

(i) Non-standard approach aids and/or approach patterns;

Or (ii) unusual local weather conditions.

Or (iii) unusual characteristics or performance limitations.

Or (iv) any other relevant considerations including obstructions, physical layout, lighting etc.

(c) Category C

A Category C airfield that requires additional considerations to a Category B airfield and requires the extra training restrictions listed below.

Pilot operations to a category A airfield are unrestricted. However, prior to operating to a Category B airfield, the pilot in-command should be briefed, or self- briefed by means of programmed instruction, on the Category B airfield(s) concerned. It is a requirement that he/she should also certify these instructions by annotating the company Flight Report accordingly.

Prior to operating to a Category C airfield, the pilot-in-command should be briefed and visit the airfield as an observer and/or undertake instruction in a flight simulator approved by the Authority for that purpose. The observation and/or simulator instruction SHALL be recorded on the pilot's training record. (JAR OPS 1, 2008)

Appendix C CRM Elements and Behavioural markers

Categories and Elements of NOTECHS (Adapted from Flin 2003)

CATEGORY	ELEMENT
1.CO-OPERATION	-Team building and maintaining -Considering Others -Supporting others -Conflict Solving
2. LEADERSHIP AND MANAGERIAL SKILLS	-Use of authority and assertiveness -Providing and maintaining standards -Planning and co-ordination -workload management
3. SITUATION AWARENESS	-Awareness of aircraft systems -Awareness of external environment -Awareness of time
4. DECISION MAKING	-Problem definition and diagnosis -Option generation -Risk assessment and option selection -Outcome review

Appendix D CRM Co-operation Elements

Co-operation category: elements and behavioural markers (Adapted from Flin 2003)

Element	Good practice	Poor practice
Team building and maintaining	Establishes atmosphere for open communication	Blocks open communication
	Encourages inputs and feedback from others	Keeps barriers between crewmembers (CM)
	Does not compete with others	Competes with others
Considering others	Takes notice of the suggestions of other CM even if s/he does not agree	Ignores suggestions of other CM
	Takes condition of other CM into account	Does not take account of the condition of other CM
	Gives personal feedback	Shows no reaction to other CM
Supporting others	Helps other CM in demanding situations	Hesitates to help other CM in demanding situations
	Offers assistance	Does not offer assistance
Conflict solving	Keeps calm in interpersonal conflicts	Overreacts in interpersonal conflicts
	Suggests conflict solutions	Sticks to own position without considering a compromise
	Concentrates on what is right rather than who is wrong	Accuses other CM of making errors

Appendix E JAROPS STD 1A Simulator Requirements

Appendix 1 to JAR –STD 1A 0.30 (continued) Section 1 Minimum technical requirements for qualifying JAA Level A, B, C and D Flight Simulators

Qualification Level	General Technical Requirements	Maximum Credits
A	The lowest level of flight simulator technical complexity. An enclosed full scale replica of the aeroplane cockpit/flight deck including simulation of all systems, instruments, navigational equipment, communications and caution and warning systems. An instructor's station with seat shall be provided as shall be seats for the flight crewmembers and one seat for inspectors/observers. Control forces and displacement characteristics shall correspond to that of the replicated aeroplane and they shall respond in the same manner as the aeroplane under the same flight conditions. The use of class specific data tailored to the specific aeroplane type with fidelity sufficient to meet the objective tests, functions and subjective tests is allowed. Generic ground effect and ground handling models are permitted. Motion, visual and sound systems sufficient to support the training, testing and checking credits sought are required. The visual system [shall] provide at least 45 degrees horizontal and 30 degrees vertical field of view per pilot. A night scene is acceptable. The response to control inputs shall not be greater than 300 milliseconds more than that experienced on the aircraft. Wind shear need not be simulated.	Suitable for: – Crew procedures training. – Instrument flight training. – Transition/conversion training, testing and checking except for take-off and landing manoeuvres. – Recurrent training, checking and testing (type and instrument rating renewal/revalidation)
B	As for Level A plus: Validation flight test data shall be used as the basis for flight and performance and systems characteristics. Additionally ground handling and aerodynamics	As for Level A plus: – Recency of experience (three take-offs and landings in 90 days).

	programming to include ground effect reaction and handling characteristics shall be derived from validation flight test data.	– Transition/conversion training for take-off and landing manoeuvres. – Transition/conversion testing and checking except for take-offs and landings.
C	The second highest [l] level of [flight] simulator performance. As for Level B plus: A daylight/twilight/night visual system is required with [a] continuous, cross-cockpit, minimum collimated visual field of view providing each pilot with 180 degrees horizontal and 40 degrees vertical field of view. A six axes motion system shall be provided. The sound simulation shall include the sounds of precipitation and other significant aeroplane noises perceptible to the pilot and shall be able to reproduce the sounds of a crash landing. The response to control inputs shall not be greater than 150 milliseconds more than that experienced on the [aeroplane]. Wind shear simulation shall be provided.	As for Level B plus: – Transition/conversion testing and checking of take- offs and landings for flight crewmembers whose minimum experience level is defined by the Authority.
D	The highest level of flight simulator performance. As for Level C plus: There shall be complete fidelity of sounds and motion buffets.	As for Level C plus: – Transition/conversion testing and checking of take-off and landings for flight crews, who may be required to meet a minimum experience level defined by the Authority.

Appendix F Ethics Proposal

Proposal Submitted by: Rodney Sears . Department of Systems Engineering and Human Factors

School of Engineering r.sears@cranfield.ac.uk

Supervised by: John Huddlestone

Date: 9 June 2010

The proposed study is scheduled to commence 2 August 2010.

BACKGROUND

The growth of air transport since the Second World War has allowed much more freedom to travel. One major area has been the increase in the use of private jets or business jets by private individuals and companies. There are now in excess of 16600 business jets in use according to the Flight Global listing for 2009. Modern scheduled air transport has been made safer over the years and now has a very good safety record for fatal accidents. Unfortunately the statistics for the business jet operations are far worse. The poor safety record was highlighted as long ago as 1994 and shows no sign of improving. The NATS report, US accident rate 2008 states the accident rate per 100,000 hours for scheduled airlines (FAR 121) was 0.145 but the comparable rate for non-scheduled flights (FAR 135) was 2.410. The situation is repeated by the IBAC in their global accident survey 2003 to 2007 showing a high global rate for all business jet operations of 1.09, which is far higher than the rate of 0.145 for Airlines reported by the NTSB.

Although there have been several safety initiatives and attempts to improve standards across the industry, the poor accident record continues. Pilot performance is often quoted as a concern in both Human factors (including CRM related accidents) and pilot flying skills. In CAP 776, World Accident Data 2006, figure 8 lists the accidents by phase of flight. The approach, landing and go-around phases accounted for 47% of all fatal accidents and 42% of all on board fatalities.

AIM

The Aim of the study is to:

a. Study the level of flying skill of Business Jet Pilots.

b. Study the training background of Business Jet pilots.

It is proposed to conduct a simulator trial of an approach and go-around that is representative of both the accident data and the required standards for the issue of a commercial pilot licence. It is hoped that the study will give some insight into the pilot skills of the business jet operators. It may also be possible to compare the skill levels with regard to the accident rates of scheduled and non-scheduled operators.

A pilot background questionnaire will be administered prior to the simulator session to make a similar comparison of experience levels.

METHODOLOGY

A licensing requirement for all UK air transport pilots is to complete a BI-annual simulator proficiency check. Whilst this check is being conducted, an extra approach will be flown

The simulator trial will address this by running a single engine ILS profile and recording relevant control inputs and flight parameter errors including localiser and glide-slope. In this way the flight data can be assessed and the pilot performance reviewed. The ILS profile is already part of the regulatory Licence Skill Test (LST), so the licence examiners conducting the simulator session will be asked to provide observational assessments of the pilot performance. Subsequently, the participating pilots will be asked to provide their career background and experience information. This will be an anonymous information pro-forma, following the simulator session.

ETHICAL CONSIDERATIONS

Informed Consent

As the participants report for the pre-flight briefing, and at a time, which does not interfere with the normal pre-briefing activities, the instructor (an airline or simulator examiner or licensed instructor) will introduce the research. Also, he/she will provide full information in the form of a briefing and introductory letter, requesting their participation and explaining how the data they provide will be used. The participants will be asked to provide written consent if they wish to participate in the research. It must be emphasised that the study will not affect the LST and that non-participation would not be viewed negatively.

Both the British Airline Pilots Association (BALPA) and the Independent Pilot's Association (IPA) have been briefed and given their consent to approach the pilots.

The simulator profile is a standard approach and one that must be completed within 6 months of a previous validation. This profile will be flown on a voluntary basis after all aspects of the LST have been completed, so does not prejudice the licence renewal.

Deception

There is no requirement or intention to deceive the participants. During the briefing, the participants will be informed that the general purpose of the research is to investigate pilot handling performance. This will not detail the specific phases of the profile in order to avoid influencing the response. Any further information will be given at the final debrief.

Freedom of participation – It is the free choice of every pilot whether he/she participates or not. However, every pilot will be encouraged to participate with an initial letter containing information about the study.

Confidentiality – All information and data is collected anonymously and there will not be a possibility to trace individual answers back to individuals. Data sets will be identified and collated according to their time and date when obtained and will be treated with strict confidence. Any published data will be anonymous and as part of an aggregated set. Results will be reported in form of a comprehensive report and the thesis. Every response is handled with great confidentiality and no individual data record will ever be presented.

Risk to Participants – There is no physical danger associated with the proposed research, neither is there any likelihood of psychological harm. The proposed study already uses the existing licence test profile and therefore does not alter any procedure or standard by which pilots are assessed and will take place in the environment in which pilots are currently trained. This means that existing health and safety policies and procedures will apply.

Protection of Participants– The participants will be assured of confidentiality and briefed on the data processing. Any data downloaded will be de-identified and stored securely at Cranfield University. They will also be encouraged to contact the researcher if they wish to discuss any concerns.

Right to Withdraw from the investigation – During the briefing, it will be stressed that participants have the right to withdraw from the research at any time and that any data collected up to that time will be destroyed. This right to withdraw is assured and respected. However, due to the fact that data will be recorded anonymously, it will not be possible to identify an individual response to withdraw from the study once the data has been extracted from the simulator. Since it will have been de-identified and aggregated with other data.

Debriefing – The pilots will be given the opportunity to debrief and make any comments concerning the trial profile. They will also be debriefed on the exact nature of the study and be provided with a written explanation of the research. Pilots will receive a letter containing the contact details of the researcher, should they require any further information and will contain thanks for their participation. Participants will also be asked to refrain from discussing the research with other potential participants to avoid biasing their performance.

Observational work – Observations will be conducted with the participants during their simulator check. However, observations are a normal part of the assessment for the LST and would be expected by the examinee. The observers in the simulator will be either qualified type rating instructors or type rating examiners as is normal for Licence Skill Test.

Professional Conduct – All research work will be conducted in a professional manner, as would be expected to uphold the continued reputation of Cranfield University. Any commitment made to participants when soliciting their co-operation will be respected. The researcher will maintain professional standards to ensure the continued support of the pilot community and associated companies for similar work.

Prior to the study, final approval will be obtained from the Cranfield University Ethics Committee.

Appendix G Candidates Consent Form

PARTICIPANT NUMBER: _____________

I, ____ (please print your name in block capitals) confirm that I agreed to participate in the Cranfield Flight Simulator Study.

I understand that Cranfield University will only use the data collected for research purposes as part of the Investigation into Business Jet Safety. All data collected will be stored in accordance with the UK Data Protection Act (1998).

I understand that all personal information that I provide will be treated with the strictest confidence and I have been provided with a participant number to ensure that all information remains anonymous. I understand that although the information I provide will be used by Cranfield University for research purposes, it will not be possible to identify any specific individual from the data provided during the simulator study

I understand that I am free to withdraw from the study at any stage during the session simply by informing a member of the research team. I also understand that I will not be able to withdraw my data after the session has been completed.

If you have any questions about the research, please do not hesitate to ask a member of the research team.

I confirm I have read and completely and fully understand the information provided on this form and therefore give my consent to taking part in this research.

Signature: _________________________

Date: _________________

Full name: __________________________

Contact number: _________________________

OR

Address: ____________________________

____

Email address: _________________________

(Number and mail both optional)

Appendix H Pilot Questionnaire

Cranfield UNIVERSITY

Pilot Questionnaire

This data form is part of the Cranfield University's Human Factors Department study of the operations and safety aspects of Business jet operations. Even though all the data will be anonymous, we would like a representative sample of pilots. (You will not be required to provide your identity) So, we would be grateful if you would participate in the research and provide the following information. Thank you very much for your help.

Candidate Number ☐

Rank CAPT , FO ……….Licence, JAA / CAA / FAA. Age ☐

Were you pilot flying during the 1st or 2nd ☐ ☐ run

Total Flying Hours (fixed wing) *Hrs. (to the nearest 100)* ☐☐☐☐☐

Hours on Current Type *Hrs. (to the nearest 100)* ☐☐☐☐☐

Approximate number of sectors flown as PF within the past 7 days *sectors* ☐

Approximate number of sectors flown as PF within the past 14 days *sectors* ☐

Approximate number of sectors flown as PF within the past 28 days *sectors* ☐

Beginning with the most recent, please list the previous aircraft types you have operated (only list type variants individually if their flight decks differ significantly), together with the corresponding number of flying hours and type of operation e.g.. Corporate, Private Charter, Low Cost, Freight etc.

Aircraft Type	*Number of Hours(To nearest 100)*	*Type of Operation*

Please identify the training route you undertook to achieve your current licence (tick one box)

☐ Integrated *ab initio* course with flight training organisation

☐ Modular courses with flight training organisation(s)

☐ Conversion following flying career in the military

☐ Other, brief explanation please ……………………………………………

Recent Flying Experience

Please consider your flying experiences whilst acting as the PF over the previous 6 months

At what altitude do you typically engage the autopilot following take-off? *ft.* ☐

At what altitude do you typically disengage the autopilot prior to landing? *ft.* ☐

Approximately what percentage of the approaches that you flew during this period were classified as Precision Approaches? ☐

Please consider the definition of a '<u>manual approach</u>' to be an approach where the autopilot is disengaged either before or upon commencing the final approach (i.e. requiring a prolonged period of manual flight). The approach may be flown with or without the use of auto throttle or flight director systems.

Approximately how many days have passed since <u>you</u> last flew a manual approach? ☐

Approximately how many manual approaches have <u>you</u> flown in the past 7 days? ☐

Approximately how many manual approaches have <u>you</u> flown in the past 14 days? ☐

Approximately how many manual approaches have <u>you</u> flown in the past 28 days ? ☐

Do you regularly participate (or have you previously participated) in flying activities outside of work or initial training? (Please tick the appropriate boxes and indicate how frequently/when you participated)

	Approximate hours	Dates (E.g. 1997-present)
☐ Gliding (non aerobatic)		
☐ GA powered, fixed wing (non aerobatic)		
☐ GA rotary wing		
☐ Aerobatics (powered or gliding)		
☐ Flight instruction (powered or gliding)		
☐ Other (please describe)..		

Appendix I Simulator Parameters

<u>Data at Initial Release</u>

Time	
Gross Weight (Lbs.) 22500.0000	Centre of gravity (%MAC) 23.4326
Flap Deflection (Deg) 0.0732	Flap Lever Position, (DEG)
Gear Position (0=Up, 1=Dn) 0.0000	Gear Lever Position
Weight on Right Gear (Lbs.)	Nose Gear Position
Calibrated Airspeed (Kits) 220.0011	Ground Speed (Kits)
Mach Number	Pressure Altitude (Ft) 2999.9937
Radar Altitude (Ft)	Angle of Attack (Deg)
Outside Temp (Deg C) 0.0000	Fuel Weight (Lbs.) 5000.0000
Elevator Tab (Deg) 0.3592	Column Position, Pitch
Elevator (Deg) -2.4822	
Aileron Tab (Deg) 0.1735	Wheel position, Roll
Average Aileron (Deg) 0.0000	
Rudder Tab (Deg) -6.7878	Rudder (Deg) 6.0755
Pedal Position (Deg)	Yaw Damper (0=Off, 1=On) 1.0000
Wind Speed (kn.) 15.0000	Wind Direction (Deg) 120.0000
Rate of Climb (FPM) -0.0013	Pitch Attitude (Deg) 2.9155
Bank Angle (Deg) 0.0000	True Heading (Deg) 130.0000
Sideslip Angle (Deg)	X, Y, Z, Acceleration
Left Engine N1 (%) 76.1301	Left Engine Thrust Reverse NIL
Left Engine Power Lever 76 %	
Right Engine N1 (%) 10.9733	Right Engine Thrust Reverse. NIL.
Right Engine Power Lever idle	
Localiser (NilDot)	Glideslope (NgDot)
Total 43	

<u>Simulator trial Recorded Parameters</u>

Time	KCAS	Angle of Attack
Aileron Position	Wheel Position	
Column Position	Elevator Position	
Rudder Position	Rudder Pedal Position	
Left Engine N1 %	Left Power Lever Angle	
Right Engine N1 %	Right Power Lever Angle	
Flap Deflection	Ground Speed	Pitch Attitude
Pressure Altitude	Radar Altitude	Sideslip angle
Gear Position		
Localiser error, Dot	Glideslope Error, Dot	

Total 22

Appendix J FSI Hawker Instructor Briefing Notes

Simulator Trial - Initial set up.

Aircraft initial position: Approximately 15 miles from touchdown.

Heading 130 deg. 220 Kn. IAS Set at 3000 FT QNH, on intercept heading for a manually flown ILS.

The FMC should be set for an approach at Gatwick but the route and NAV display is not required for the ILS. EGKK approach ILS 08R / 110.9, INBOUND 079

Initial conditions: QNH 1013, Surface temperature 15 deg. C

Wind 120/15. Weather CAT ONE

FUEL 5000 LB ZFW 17500 LB

AUW 22500 LB.

FLAP 25 APPROACH. V-REF 125, V-APP 145

Crew Instructions and confirm initial cockpit set-up:

Start APU

Select Chart Display if required CAT1 DA 400 FT

Gear and Flap retracted

Single engine, N1 Approximately 80%

Number 2 Engine- HP Cock OFF

LP Cock OFF

Wing Cross Feed Open.

Main Air No 1 closed / no 2 closed

Right ALT OFF GROUND PROX FLAP OVERRIDE

Right Gen. TRIP

Yaw damper on

Select Auto-pilot prior to commencing run and disconnect once stable after simulator release: Allow simulator to trim and settle down.

ATC instructions: **Cleared to establish on the ILS and descend on the glide path. Reduce speed at your discretion. Cleared to land. If you go around, climb straight ahead to 3000 feet.**

Release simulator freeze: Once stable, then disconnect auto-pilot and continue for the ILS.

Pilot flown approach.

Reduce to 180 Kn, clean at 3000 ft.

Reduce to 160 Kn, Flap 15 establish on Localiser.

Once glide-slope at 1 Dot, Gear down, and Flap 25, reduce to 145 kn.

Go Around

At 200 ft. above touchdown, Go Around

Press GA button. Flap 15.

Positive climb Gear Up.

Select heading 079, Flight level change.

Straight ahead climb to 3000 ft.

When above 1000 ft., above touchdown 180 Kn Flap up.

Stop trial run during climb out. Set Simulator stop and freeze at the end of the trial. If required set up for second run with the second pilot.

Appendix K Simulator Results: Maximum and Minimum Airspeeds

Run	Airspeed at 3000 ft.	Maximum Airspeed	Airspeed at Decision Height	Minimum Airspeed
2	165.74	165.74	139.21	138.13
3	156.86	156.86	146.93	142.19
5	150.7	156.97	132.55	132.55
6	161.84	163.9	139.37	138.13
7	147.96	150.97	146.95	142.36
8	152.68	163.88	143.72	138.66
9	156.29	156.29	144.21	142.07
10	151.34	151.34	143.37	139.44
11	157.23	157.23	145.12	141.15
12	150.57	150.75	144.59	144.37
13	156.54	161.37	146.75	146.75
14	147.13	149.7	146.47	144.67
15	154.7	154.7	147.36	144.03
16	144.88	147.64	146.11	143.86
17	154.98	154.98	143.16	141.75
18	152.87	152.87	147.51	144.49
19	159.56	159.56	145.83	142.69
20	145.42	148.1	145.54	143.71
21	150.29	157.93	145.46	139.41
22	144.43	152.36	141.91	137.75
23	155.55	158.03	145.88	143.93
24	158.48	158.48	145.19	144.11
25	153.24	155.15	145.88	141.36
26	152.24	155.89	146.99	145.24
27	162.13	163.04	141.78	141.78
28	163.36	165.71	137.52	136.61
29	164.77	167.76	137.84	137.84

30	156.1	158.82	142.38	141.87
31	161.04	161.24	143.43	143.43
32	154.33	154.33	139.93	139.93
33	156.09	157.8	142.69	137.34
34	174.36	174.36	145.51	145.51
35	167.86	167.86	150.2	146.29
36	153.11	159.47	146.67	143.97
37	149.82	149.84	146.8	144.16
38	166.43	166.43	139	136.59
39	181.14	181.14	134.43	134.9
40	150.61	150.61	144.17	142.53
41	154.87	154.87	142.92	140.19
42	157.18	157.18	145.25	143.71
43	180.09	180.18	143.34	141.69

Appendix L Airspeed Exceeding CAA Tolerance

This table shows the percentage time for each run that was either above 155 knots or below 140 knots and the total percentage time outside the CAA tolerance.

Per cent time above 155 knots	Per cent time below 140 knots	Per cent time outside CAA tolerance
33	23	56
2.2	0	2.2
2.2	0	2.2
33	24	57
		Pass
23.8	2.5	26.3
3	0	3
0	7	7
9.2	0	9.2
		Pass
39.7	0	39.7
		Pass
		Pass
		Pass
		Pass
		Pass
2.2	0	2.2
		Pass
10.9	8.8	19.7
0	17.6	17.6
9.3	0	9.3
2.6	0	2.6
3.1	0	3.1
12.2	0	12.2
56.6	0	56.6
32.6	30.5	63.1
42	25	67
17.8	0	17.8
25.2	0	25.2
0	1	1
6.9	14.2	21.1
24	0	24
31.9	0	31.9

22.4	0	22.4
		Pass
26.9	13.7	40.6
81.6	6.1	87.7
		Pass
		Pass
1.6	0	1.6
49.1	0	49.1

Appendix M CAP P 371 EXTRACT

Extract from CAP 371 (The Avoidance of Fatigue In Aircrews)

The following are the definitions for duty periods that would be allowed under the existing regulations. For example, a crew member must be well rested and not suffering from “jet lag due to change of time zones , so the term acclimatised is defined prior to commencing a duty.

(Unless otherwise defined below all words, phrases, definitions, and abbreviations, have identical meanings to those described in Article 129 of the Air Navigation Order 2000, as amended.)

1) 'Acclimatised'

When a crew member has spent 3 consecutive local nights on the ground within a time zone which is 2 hours wide, and is able to take uninterrupted nights sleep. The crew member will remain acclimatised thereafter until a duty period finishes at a place where local time differs by more than 2 hours from that at the point of departure.

The maximum Flight duty period (FDP) is set down with regard to the time of day for the duty commencing and the number of sectors planned for the duty. 13.1 Standard reporting times prior to flight must be specified by an operator. Pre-flight

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13.3 Tables A and C apply when the FDP starts at a place where the crew member is acclimatised; Table B applies at other times.

Table A Two or more flight crew - Acclimatised

13.3 Tables A and C apply when the FDP starts at a place where the crew member is acclimatised; Table B applies at other times.

Table A Two or more flight crew - Acclimatised

Local time of start	Sectors							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8 or more**
0600-0759	13	12¼	11½	10¾	10	9½	9	9
0800-1259	14	13¼	12½	11¾	11	10½	10	9½
1300-1759	13	12¼	11½	10¾	10	9½	9	9
1800-2159	12	11¼	10½	9¾	9	9	9	9
2200-0559	11	10¼	9½	9	9	9	9	9

Table B Two or more flight crew - Not Acclimatised

Length of preceding rest (hours)	Sectors						
	1	**2**	**3**	**4**	**5**	**6**	**7 or more**
Up to 18 or over 30	13	12¼	11½	10¾	10	9¼	9
Between 18 and 30	11½	11	10½	9¾	9	9	9

NOTE: The practice of inserting a short duty into a rest period of between 18 and 30 hours in order to produce a rest period of less than 18 hours, thereby taking advantage of the longer FDP contained in Table B, is not permitted.

Appendix N NTSB data (2011) adapted from IBAC 2012

2011 Accident data	US Registered Aircraft, Brief Description	Flight Phase
JANUARY	A/C LANDED HARD IN VMC	LANDING
FEBRUARY	OVERRUN HYDRAULIC FAILURE	LANDING
MARCH	OFF SIDE OF RUNWAY	LANDING
APRIL	CRASHED ON TAKE OF, TEST FLIGHT.	TAKE OFF
APRIL	WING STRUCK RUNWAY	LANDING
MAY	DITCHED, IN CLIMB, TECHNICAL	TAKE OFF
MAY	LANDED GEAR UP, TECH FAULT	LANDING
MAY	SKIDDED OFF RUNWAY,	LANDING
JUNE	GEAR UP, GO AROUND GEAR DOWN, LAND	LANDING
JUNE	OVERSHOT LANDING	LANDING
JULY	WING STRUCK RUNWAY, WIND SHEAR	LANDING
SEPTEMBER	CRASHED ON LANDING	LANDING
OCTOBER	TAXI INTO DITCH	ON GROUND
OCTOBER	BRAKE FAIL, OVERSHOT RUNWAY	LANDING
DECEMBER	TO ABORT, OVERSHOT, GEAR COLLAPSED	TAKE OFF

2011 NON US REGISTERED ACCIDENTS

2011 Accident data	Non US Registered Brief Description	Flight Phase
FEBRUARY	CRASHED TO, SNOW, LOW CLOUD	TO/LOC
FEBRUARY	OVERSHOT RWY ON TO	TO/LOC
FEBRUARY	LOST CONTROL APPROACH, DAY VMC	LANDING
MARCH	LOST CONTROL ON TO	TO/LOC
MARCH	STRUCK LIGHTS LOC ANTENNA, IMC	LANDING
MARCH	TSUNAMI, ON GROUND	GROUND
MARCH	DISAPPEARED ON LOCAL FAM FLIGHT?	CRUISE
JUNE	LANDED OFF SIDE OF RUNWAY	LANDING
JULY	OVERSHOT ON LANDING	LANDING
OCTOBER	TAXI BRAKES FAILED	GROUND
OCTOBER	OVERSHOT ON LANDING	LANDING
DECEMBER	VEERED OFF RWY, INTO RAVINE	LANDING

Summary of accident data ; Total 27.

Including, On ground	3	On Landing	17
Loss of control	14	Airspeed related	8