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Flight Crew Reliance on Automation

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List of Effective Pages

Chapter	Page	Date	Chapter	Page	Date
	iii	December 2004			
	iv	December 2004			
	v	December 2004			
	vi	December 2004			
	vii	December 2004			
Chapter 1	1	December 2004			
Chapter 1	2	December 2004			
Chapter 1	3	December 2004			
Chapter 1	4	December 2004			
Chapter 1	5	December 2004			
Chapter 2	1	December 2004			
Chapter 3	1	December 2004			
Chapter 3	2	December 2004			
Chapter 3	3	December 2004			
Chapter 3	4	December 2004			
Chapter 3	5	December 2004			
Chapter 3	6	December 2004			
Chapter 3	7	December 2004			
Chapter 4	1	December 2004			
Chapter 4	2	December 2004			
Chapter 4	3	December 2004			
Chapter 4	4	December 2004			
References	1	December 2004			
References	2	December 2004			
References	3	December 2004			
Annex A	1	December 2004			
Annex A	2	December 2004			
Annex A	3	December 2004			
Annex A	4	December 2004			
Annex A	5	December 2004			
Annex A	6	December 2004			
Annex A	7	December 2004			
Annex A	8	December 2004			
Annex A	9	December 2004			
Annex A	10	December 2004			
Annex A	11	December 2004			
Annex A	12	December 2004			
Annex A	13	December 2004			
Annex A	14	December 2004			
Glossary	1	December 2004			
Glossary	2	December 2004			

Contents

Executive Summary

Modern large transport aircraft have an increasing amount of automation and crews are placing greater reliance on this automation. Consequently, there is a risk that flight crew no longer have the necessary skills to react appropriately to either failures in automation, programming errors or a loss of situational awareness. Dependence on automatics could lead to crews accepting what the aircraft was doing without proper monitoring. Crews of highly automated aircraft might lose their manual flying skills, and there is a risk of crews responding inappropriately to failures. This preliminary report is intended to provide clarification of areas of concern.

A detailed literature search was made to understand the problems identified by previous studies into flight deck automation. In parallel a review of relevant incidents occurring on major aircraft types during 2002 and 2003 recorded in the Mandatory Occurrence Report (MOR) database was conducted. Finally, interviews were held with personnel from the following areas: airline training departments (short and long haul), Type Rating Training Organisations, CAA Personal Licensing Department, CAA Flight Operations Inspectorate, and Crew Resource Management/Human Factors (CRM/HF) specialists. Further work would be needed to refine the database search, conduct a survey with line pilots and discuss these issues with the aircraft manufacturers and equipment vendors.

The research indicated that there was much evidence to support the concern that crews were becoming dependent on flight deck automation. Furthermore, the new human task of system monitoring was made worse by the high reliability of the automation itself. Little research exists to provide a structured basis for determination of whether crews of highly automated aircraft might lose their manual flying skills. However, anecdotal evidence elicited during interviews and a brief mention in the European Collaboration on Transition Training Research for Increased Safety (ECOTTRIS) study indicates that this is a concern amongst practitioners. Finally, several MOR incidents revealed that crews do respond inappropriately having made an incorrect diagnosis of their situation in which the automation fails. For example, disconnecting the autopilot following an overspeed in turbulence then resulted in level busts. If pilots had a better understanding of the automation then it is likely that the need for manual flying could have been avoided and thus the subsequent level bust.

During the course of this research two more fundamental observations were made:

- First, pilots lack the right type of knowledge to deal with control of the flight path using automation in normal and non-normal situations. This may be due to operators making an incorrect interpretation of existing requirements and/or a lack of emphasis within the current requirements to highlight the particular challenges of the use of automation for flight path control.
- Second, there appears to be a loop-hole in the introduction of the requirements for CRM training. This has resulted in many of the training personnel and managers responsible for the ethos and content of training programmes not fully understanding the significance of the cognitive aspects of human performance limitations.

Preface

1 Background

1.1 Risk Identification

The CAA Flight Operations Department, research literature and a number of international teams involving regulatory authorities and industry have identified reliance on aircraft automatics as an area of potential risk. This is documented in numerous research publications and international regulatory authority reports such as the FAA led Human Factors Task Team Report (1996) and a group within the JAA led Joint Safety Strategy Initiative (JSSI) known as the Future Aviation Safety Team (FAST). The latter focused upon predictive techniques to identify new, emergent or foreseeable future risks to public transport operations.

1.2 Issues Highlighted for Investigation by CAA

1.2.1 There is an increasing amount of automation in aircraft and greater reliance on this automation by the crew. Consequently, there is a risk that flight crew no longer have the necessary skills to react appropriately to either failures in automation, programming errors or a loss of situational awareness. The CAA requested investigation of the following areas:

- Firstly, dependence on automatics could lead to crews accepting what the aircraft was doing without proper monitoring. The risk is that if the automatics malfunctioned, or perhaps more likely the Flight Management System (FMS) was wrongly programmed, the crew would not realise the problem until too late.
- Secondly, crews of highly automated aircraft might lose their manual flying skills. It requires a positive intervention from the crew to keep in practice at some manoeuvres and it becomes all too easy to let the aircraft get on with it. The more the pilot becomes out of practice the less inclined he becomes to disconnect the autopilot and fly the aircraft himself. The only requirement for manual flying skills to be tested is during an engine-out ILS, go-around and landing annually during the Licence Proficiency Check. Document 24, Guidance to Examiners, now requires the autopilot to be disconnected prior to the selection of flap and becoming established on the localiser.
- Thirdly, there is a risk of crews responding inappropriately having made an incorrect diagnosis of their situation. This in turn could arise when systems are over-complicated with too many variables to be easily assimilated. There is a risk that with insufficient depth of training, crews would be unable to interpret accurately all the eventualities that might be presented.

2 Introduction

2.1 Scope

The issues highlighted for investigation by CAA cover a large area and it was necessary to define exactly what was and what was not included in the study (Wood, 2004). As a result the study was restricted to the consideration of automation of the task of control of the flight path using an autopilot and a Flight Management System on a fixed-wing 'glass-cockpit' commercial aircraft. A taxonomy of failures was presented that was limited to four classes:

- Automation system failure
- Programming errors
- Organisation errors
- Design errors

2.2 Methodology

2.2.1 A detailed literature search was made to understand the problems identified by previous studies into flight deck automation. In parallel a review of relevant incidents recorded in the MOR and CHIRP databases was made. The search parameters were: Airbus, Boeing, Embraer, FMS, autopilot, automation/automatic problems; 1st January 2002 to 31st December 2003. Interviews with personnel from the following areas: airline training departments (short and long haul), Type Rating Training Organisations, CAA Personal Licensing Department, CAA Flight Operations Inspectorate, and CRM/HF specialists.

2.2.2 Further work has still to be done to refine the database search, conduct a survey with line pilots and discuss these issues with the aircraft manufacturers and equipment vendors. Additionally, the findings of this interim report will be discussed with contemporary researchers working for JSSI.

2.3 Layout of this Preliminary report

2.3.1 The report is divided into four Chapters. Chapter One presents a review of the relevant research literature. The impact of automation on modern aircraft is presented first, followed by a synopsis of previous studies in this area. Chapter Two covers the data that was reviewed. Chapter Three presents a discussion of the findings and Chapter Four presents the conclusions and recommendations.

2.3.2 It must be remembered that this report summarises a brief, preliminary study of the issues. Delays in receiving appropriate incident data has meant that there are few analytical findings presented.

Chapter 1 Review of Literature

1 Introduction

1.1 Given that the task facing today's pilots has changed, have the regulatory requirements for training and the ensuing standards also changed appropriately to meet such a change? Furthermore, as a result of such training, do the pilots have the necessary skills to react appropriately to either failures in automation, programming errors or a loss of situational awareness?

1.2 Equally, the review of modern aircraft automation issues must acknowledge the continual efforts that are being made to reduce error and mitigate the effects of error. Training programmes and material have not stood still over the last 30 years and the general familiarity with automated systems has changed as well. It is with this point firmly in mind that the conclusions of several studies, ranging over a period of 10-15 years have been presented. It should also be understood that we are not dealing with one 'subject'. The 'pilot' in the cockpit is a multi-dimensional subject, for example: status (Captain or First Officer), age (18 – 60 or even 65), experience (200 – 10,000 hrs), or diverse nationality from any JAA member state.

1.3 The following presents a synopsis of the literature review that has been conducted. A more full account is presented at Annex A.

2 Review of the Impact of Automation

2.1 Introduction of Automation to the Flight Deck

We currently have flight deck automation systems that change the task, re-distribute workload for the crew, and present situations that induce an error. The change in role from active, manual control to one of system management has left pilots less proficient in manual skills but still required, on occasions, to take control in time critical situations. The architecture of flight deck automation is based on rationalistic principles that do not readily align with the mental models pilots have for the manual flying task. Pilots have adapted or bridged this gap by adopting 'work-arounds'. The way forward is for the evolution of current designs rather than revolution; however, we still have a problem of mitigating the human-machine problems of extant system designs.

2.2 Automation Dependency - Complacency

2.2.1 Complacency in the automated flight deck represents an important issue. Pilots may become complacent in highly reliable automated environments where the role has become supervisory and lacks practice in direct control. Researchers have reported that when subjects performed multiple flight related tasks simultaneously, with one of the tasks being automated, the consistency and reliability of the automation affected their ability to monitor for automation failure. Detection of automation failures was poor under constant-reliability automation, even following a catastrophic failure. However, monitoring was efficient under variable-reliability automation. These effects do not significantly alter following training.

2.2.2 A further extension of this issue is that the automation need not necessarily 'fail' to cause a problem of cognition for the pilot. The Bangalore crash involving an Air India A320 is a case in point. The system did not fail per se, but it did not behave the way the crew expected it to behave. By the time their effective monitoring alerted them to the problem there was insufficient time to intervene and prevent the impact with the ground.

2.3 Automation Bias

2.3.1 The availability of automation and automated decision aids encourages pilots to adopt a natural tendency to follow the choice of least cognitive effort. When faced with making decisions pilots will rely on these automated aids as a replacement for vigilance, and actively seeking information and processing. This is termed automation bias. Studies have reported that pilots committed errors on 55% of occasions when the automation presented incorrect information in the presence of correct information to cross-check and detect the automation anomalies. Training crews on automation bias or to verify correct automated functioning had no effect on automation-related omission errors, and neither did display prompts that reminded crews to verify correct functioning. However, there was evidence that pilots did perform better depending on the flight critical nature of the event. For example, they were more likely to notice an altitude capture error rather than a radio call error in the cruise. These studies also confirmed the tendency towards over-reliance on reliable automation where pilots were reluctant to correct automation errors despite recognising and acknowledging a discrepancy between what they were expecting and what the automation actually did. Furthermore, an error of commission was committed by nineteen out of twenty experienced crews who followed a false fire indication and shut down an engine despite the lack of any other indications of fire. Additionally, results of questionnaires indicated that these same pilots considered that an automated warning message alone would be insufficient for them to ensure that the fire was real. Pilots believed that they saw information that verified the automated cue; this aspect has profound relevance for the analysis of human factors following incident and accident reports.

2.3.2 Interestingly, after the incorrect decision had been made to shutdown the engine, crews immediately adopted the rule-based behaviour for the shutdown procedure i.e. they then verified that they were shutting down the correct engine. The results of such studies indicate that pilots fail to take into account all of the relevant information that is present in an automated flight deck. The tendency is for pilots to take cognitive short-cuts by pattern matching and using rule-based behaviour wherever possible. Once established in 'familiar territory' the skill-based behaviour completes the task.

2.4 Recognition of and Reaction to Failure

2.4.1 The point at which a pilot would intervene in an automated process is fundamental to the success of operation i.e. at what point does the automated system stop and require the human to take over? If the point of intervention is too early then there may be too many alerts in normal operation or too little information to make full use of the pilot's experience and problem solving ability. Conversely, if intervention is left too late then the pilot may well be landed in a deteriorating situation that has reached the limits of the automated system's capability. Research has shown that rather than design systems to work on thresholds or specific limits for control there should be a continuous flow of information to the pilot to indicate the difficulty or increasing effort needed to keep relevant parameters on target.

2.4.2 If we find ourselves in an unfamiliar situation then we try to make sense of the disparate data in front of us by using knowledge-based behaviour. However, we will minimise the cost of cognitive effort by pattern matching so that we can adopt previously learnt procedures, rule-based behaviour, wherever possible. Again, once established in 'familiar territory' the skill-based behaviour completes the task.

2.5 Failures and Situation Awareness

A review of 230 ASRS reports classified failures into two broad classes that reflected 'Emergency' and 'Abnormal' malfunctions. Results indicated wide differences in adherence to procedures depending on the type of malfunction. The report suggested that this may be caused by the crew perception of the malfunction, and training. The malfunctions classified as 'Emergency' had well-developed procedures that had been practised in the simulator on many occasions thus leading to rule-based behaviour. However, the Abnormal malfunctions had less well-defined procedures and therefore required the crew to revert to knowledge-based behaviour requiring more time and effort to properly assess and resolve the situation. “This refocusing of tasks likely resulted in reduced levels of procedural accomplishment, communications and situational awareness”. The report concludes that minor anomalies often have no immediate or obvious solution; therefore, the crew may resort to time-consuming thought, and trial-and-error procedures in order to deal with them.

2.6 Manual Flying Skill

There has been very little research published on the subject of the change in manual flying skill experienced by crews of highly automated aircraft. Most of the comments arise from questionnaires and interviews which rely on subjective feedback of the change in perceived skill. However, it is consistently reported that there is a discernible reduction in manual flying skills that is correlated both with the use of automation and whether the operation is long haul or short haul.

3 Previous Studies

3.1 Studies of Pilots' Model and Awareness of the FMS 1989-94

Several studies (Weiner, 1989; Sarter and Woods, 1992 and 1994) indicate that although pilots were competent in normal operational situations there were gaps in the pilots' understanding of the functional structure of the automation which became apparent in non-normal, time-critical situations. Additionally, pilots may not be aware of the gaps in their knowledge about FMS functionality.

3.2 FAA HF Team Report 1996

The team reported concerns regarding pilot understanding of the automation's capabilities, limitations, modes, and operating principles and techniques. Additionally, they reported differing pilot decisions about the appropriate level of automation to use or whether to turn the automation 'on' or 'off' when they get into non-normal situations. The report also highlighted potential mis-matches between manufacturers' assumptions about how the flightcrew will use the automation. Furthermore, the report commented on the vulnerabilities in situational awareness, such as: mode awareness and flightpath awareness, including terrain and energy awareness. The team concluded that these “vulnerabilities are there because of a number of interrelated deficiencies in the current aviation system” (FAA, 1996 p3). They also highlighted the lack of sufficient knowledge and skills of designers, pilots, operators, regulators and researchers. “It is of great concern to this team that investments in necessary levels of human expertise are being reduced in response to economic pressures when two-thirds to three-quarters of all accidents have flightcrew error cited as a major factor” (FAA, 1996 p3).

3.3 BASI Advanced Technology Aircraft Safety Survey Report 1998

Pilots expressed strongly positive views about advanced technology aircraft. Although some reported difficulties with mode selection and awareness on flight management systems, most pilots did not consider that too many modes were available. Many respondents gave examples of system 'work-arounds' where they were required to enter incorrect or fictitious data in order to ensure that the system complied with their requirements. The most common reasons for system 'work-arounds' were to comply with difficult air traffic control instructions and to compensate for software inadequacies during the descent approach phase of flight. The content and standard of instruction was not considered to provide adequate knowledge required to operate their aircraft in abnormal situations. Traditional airline check-and-training systems, developed to maintain flight standards on earlier generations of aircraft, did not necessarily cover all issues relevant to the operation of advanced aircraft. For example, the survey identified that there is the potential for pilots to transfer some of the responsibility for the safety of flight to automated systems, yet problems such as this are not generally addressed by check-and-training systems.

3.4 Assessing Error Tolerance in Flight Management Systems 1998

Courteney (1998) presented the results of a study which reinforces the conclusions of the BASI study by highlighting the predominance of 'work-arounds'. This study raises the question that there are human factors issues beyond the more commonly accepted problems of mode complexity. “This includes crew being distracted by incompatibility between the FMS design and the operating environment, incorrect data and anomalies in the system, as well as training and procedures that are not sufficient for comprehensive system utilisation”.

3.5 ECOTTRIS 1998

The research was designed to improve the existing transition training procedures for pilots moving from conventional to advanced automated cockpits. The study reported a striking lack of standardisation between, and within, manufacturers for design philosophies of automated systems. On top of that airlines then adopt different Standard Operating Procedures regards the use of automation e.g. some airlines prohibit the use of certain modes; however, the trend is for an increasing prescription for the use of automation. Incident and accident reports from both European and US sources were analysed. Contrary to previous studies only 6% of reports were concerned with mode awareness but deficient CRM factors accounted for 39%. This was linked with incorrect settings, monitoring and vigilance, inadequate knowledge of aircraft systems, experience and flight handling.

3.6 ESSAI 2003

The Enhanced Safety through Situation Awareness Integration in training (ESSAI) programme sought to offer potential training solutions for improved safety by enhancing situation awareness and crisis management capability on the flight deck. The results indicated that situation awareness skills could be improved by training using a non-interactive DVD, a classroom activity to reinforce skills presented on the DVD and then two demanding Line Orientated Flight Training (LOFT) scenarios plus instructor led de-briefs.

3.7 HF Implications for Flight Safety of Recent Developments in the Airline Industry 2001

The JAA commissioned a study (Icon, 2001) to determine if there was an impact on flight-deck safety as a result of commercial developments such as: deregulation, liberalisation and privatisation. The report identified three outcomes of commercial developments that have an effect on flightcrew: multicultural flight crew, merging of company cultures, and commercial pressures. Apart from the obvious concerns over differences in languages with multi-national crews there were other potential problems such as: reduced interaction both on- and off-duty, different SOPs, different interpretation of CRM, and differing levels of technical knowledge. It was concluded that when airlines merged or became part of a strategic alliance individual company cultures remained largely unaffected, thus creating the situation of flight-deck crewmembers operating with differing approaches to the overall task. Increases in commercial pressure were deemed to increase fatigue and the potential to reduce training budgets to the absolute minimum to satisfy regulatory requirements. However, the report highlighted mitigation of these concerns through the appropriate development of CRM and SOPs, and the adoption of an appropriate safety culture within the organisation. These commercial factors will therefore influence automation failures attributable to the organisational elements.

4 Training Regulations and Requirements

4.1 General

A review of JAR-FCL 1 (JAA, 2003a), JAR-OPS 1 (JAA, 2003b) and other related material was made and several discussions were held with CAA personnel from the relevant departments to gain an understanding of these documents. A review of such documents is not presented here for obvious reasons; however, the content of these Requirements is discussed in Chapter Three.

Chapter 2 Review of Data

1 Review of Incident Data

1.1 UK CAA MOR

1.1.1 A search of the CAA MOR database was made using the following keywords: Airbus, Boeing and Embraer FMS, autopilot and automation/automatic problems for the period 1st January 2002 to 31st December 2003. The search yielded 147 pages of data which have still to be classified. Unfortunately, the keyword search did not capture all the problems associated with this topic; another search associated with an icing project yielded hitherto un-retrieved reports.

1.1.2 One qualitative observation of the data was apparent: in turbulence, aircraft speed variation resulted in the crew disconnecting the autopilot completely so that they could then fly the aircraft manually to control speed using pitch. This action results in an altitude bust (often the cause of the report in the first place).

1.1.3 An incidental observation was made during the course of this study. The content of the reports is very thin. Reporters do not provide much detail and therefore much valuable information is never recorded. Additionally, keyword searches do not capture all reports of interest to human factors research. It is recommended that a study be undertaken to determine if this valuable tool could be further refined for the purposes of tracking HF issues.

1.2 FODCOM 20/2002

The CAA has issued FODCOM 20/2002 on 29 August 2002. This FODCOM gives additional guidance to crews on the handling of aircraft with advanced instrumentation in turbulent conditions and required operators to review their procedures to take account of the FODCOM. The incident data, which spans 2002 to 2003, will be reviewed to determine if there was a significant change in events of this nature following the issue of this FODCOM.

Chapter 3 Discussion

1 General

1.1 Issues Highlighted for Investigation by CAA

1.1.1 As automation has taken over more and more of the manual skills of the pilot there is a risk that if the automation should fail then the pilot may not have the necessary skills to recognise, decide and take appropriate action to recover the situation. The CAA raised three issues:

- Automation dependency
- Loss of manual flying skills
- Inappropriate crew response to failures

1.1.2 Failures of automation can be grouped into a number of areas. A failure could occur due to the automation system itself failing; a partial failure i.e. one function within a system, or a total failure of a system e.g. loss of autopilot. There could be a failure due to incorrect programming either from the pilot or from a secondary system providing incorrect data. Other failures may originate at an organisation level due to inappropriate procedures or as a result of the procurement of insufficient / inadequate training or education, or, failures may occur as a direct result of the design of the automation itself.

1.1.3 Examples of these different types of failures are given in the following paragraphs. The research indicated that there was much evidence to support the concern that crews were becoming dependent on flight deck automation. Furthermore, the new pilot function of system monitoring was dependent on the reliability of the automation itself. There was little research to provide a structured basis for determination of whether crews of highly automated aircraft might lose their manual flying skills. However, anecdotal evidence elicited during interviews and a brief mention in the ECOTTRIS study indicates that this is a concern amongst practitioners. The term "manual flying skills" is not fully defined and different organisations may use the term to mean slightly different things. Some definition needs to be included at the start of any further investigations such as: which skills are degraded, how can the change be quantified, and which pilot groups are affected. Finally, several MOR incidents revealed that crews do respond inappropriately having made an incorrect diagnosis of their situation in which the automation fails. For example, disconnecting the autopilot following an overspeed in turbulence then resulted in altitude busts.

1.1.4 Additionally, during the course of this research two more fundamental observations were made. First, pilots lack the right type of knowledge to deal with control of the flight path using automation in normal and non-normal situations. This may be due to incorrect interpretation of existing requirements or lack of a comprehensive training curriculum that encompasses all aspects of the published requirements. Second, there appears to be a loop-hole in the introduction of the requirements for CRM training that has resulted in many of the training personnel and managers responsible for the ethos and content of training programmes not fully understanding the significance of the cognitive aspects of human performance limitations. These observations will be discussed further in the following paragraphs.

2 Automation failures

2.1 Normal Operation

2.1.1 The starting point for 'automation failures' is the acknowledgement of the inadequacies of the human-machine relation in the 'normal' case. Even with a fully serviceable system the crew, under certain situations, are already under increased workload to compensate for the design of the system thereby producing a deterioration in situational awareness bought on, in part, by the automation itself (Dekker and Orasanu, 1999). Therefore, the consequence of even the smallest of 'failures' may, depending upon situation, jeopardise the safe conduct of the flight.

2.1.2 Therefore, training should be improved to provide crews with a better understanding of the operation of the automation in the normal case as well as in response to the failure situation.

2.2 Automation System Failure

2.2.1 Consider a 'failure' of either the autopilot, autothrust or the flight management system. There could be a partial failure i.e. one function within a system e.g. altitude hold, or a total failure of a system e.g. loss of autopilot.

2.2.2 The Flight Crew Operating Manuals and CBT for the B747-400 and the A340 provide information on how the systems works and the basic method for normal operation and hardware failures. Procedures are supplied for use in the event of the display of a warning messages for total failure of the autopilot, autothrust, or flight management systems. Clearly, these failures will present the crew with a rule-based procedure that can be applied to recover or mitigate the situation. It is the role of the manufacturer to provide recommended procedures in the form of checklists; however, these procedures specifically do not include elements of 'airmanship'. Operators should ensure that training programmes include means and standards to be met regarding the interaction of Human Performance and Limitations with changes to the normal operation of the automation. This will, necessarily, be material that is in addition to that provided by the manufacturer. Procedures should be taught and trained in the context of an operating environment i.e. the procedure should not be covered as a button-pushing drill but more to highlight the differences to the workload and management of the operational task.

2.2.3 Both manufacturers stipulate procedures for input of data and cross-checking response of system modes. Airbus have included “Ten Golden Rules” as a result of operational feedback and individual operators have developed and published philosophies of operation to guard against complacency and human errors e.g. long-haul operator - very simple use of automatics; short-haul – AP at 1000 ft after take-off. But the studies discussed previously clearly indicate that pilots, who have access to all these written philosophies and procedures still confuse modes or make inappropriate decisions.

2.3 Programming/Input Failure

2.3.1 A programming failure may a occur when the automation is functioning normally but incorrect data has been input through either incorrect action by the pilot, or where a sub-system or associated system failure provides incorrect data to an automated system. Systematic errors may occur, for example, when databases used for navigation are incorrectly programmed. The very rare nature of these events places the human reaction into the “Complacency – over-reliance on automation” class that was discussed earlier. The Mount Erebus incident is an example of this type of failure.

2.3.2 A further example comes from a recent VOR approach into Addis Ababa, a GPWS warning was received while the raw VOR signal and FMS provided compelling data that the aircraft was on track. In fact a number of factors conspired to place the aircraft some 4.5nm to 7.7nm off track. Disparate data was presented to the crew in the form of an unexpected altitude call-out, and an NDB bearing that was at odds with the VOR/ FM position. As it happened the VOR was in error and this produced an error in the FM position. However, the initial reaction was to believe the VOR because it was in agreement with the FM position and reject (or not use the information) from the NDB. The weighting of belief was in favour of the automation. If the crew had been flying a 'raw' VOR approach then the only other information available, i.e. the NDB, would have featured more prominently as a disagreement.

2.4 Organisation Failure

2.4.1 Organisation failure can occur when the organisation and management controlling the flight operation fails to ensure that the policies and procedures stipulated are coherent with the operational task. For example, incident reports cite cases where the use of ACARS to provide loadsheet information during taxy appears efficient from a commercial point of view but may provide a distraction during a critical moment prior to take-off. Other points were elicited during interviews such as the handling of flight critical data. Efficiencies are technically possible by using ACARS to request take-off data calculations. However, there is a concern that pilots will, in time, become used to merely reading data from one computer output into the input for another computer without 'thinking' about the accuracy or reasonableness of the data. This contrasts with the process of using a manual of tabulated data or graphical data where although the opportunity for mis-reading still exists at least there is a range of data presented. With an ACARS print out there is only the single answer and an incorrect input figure may not be easily apparent. An example was recently presented concerning an A340-600 where the take-off weight was input as 240T instead of 340T. The resulting take-off performance figures were quite reasonable for an A340-300 and therefore familiar to the dual rated crew who failed to notice the error despite careful read-backs and cross-checks (it was the relief pilot who highlighted the error).

2.4.2 Integration of all aspects of human cognitive behaviour and the requirements of a commercial operation are necessary if policies and procedures are to be optimised for safety as well as efficiency considerations. Regulatory explanatory material should provide information to operators on specific areas to include in training programmes and 'best' practice for policies and procedures.

2.5 Design failure

2.5.1 There are substantial obstacles such as lead-time and costs before 'in-service' experience is fed back into new designs. Moreover, current designs have become accepted and indeed form the basis for common type ratings across a number of variants. Therefore, a single change must be incorporated in a variety of platforms. Notwithstanding the importance of continuing work to improve designs there will still be the problem of dealing with the in-service designs that could be with us for the next 30 years. It is for this reason that this report concentrates on the human aspect of automation issues.

2.5.2 As discussed in Couteney's paper known problems promote 'workarounds'; unknown problems require initiative, knowledge and experience to deal with. One of the 'workarounds' quoted in interviews was the conscious decision by one airline to not use the full automation capability of an aircraft on its initial introduction. As experience was gained procedures were adapted and the use of certain functions was trained and encouraged.

3 Regulations for Training Requirements

3.1 JAR FCL

JAR-FCL 1 (JAA, 2003a) was first issued in 1997, with amendments in 2002 and 2003, and was predominantly a harmonisation of existing standards within the JAA area. There was no attempt to conduct a 'training needs analysis' as such to verify that extant standards were effective and comprehensive. However, a review of previous standards reveals little change in philosophy over the years despite the acknowledged changes in the operational task facing pilots. The current Flight Crew Licence requirements indicate what the training courses should achieve in terms of syllabus and learning objectives but there is little guidance on how to achieve the aim. This level of detail is left to the Flight Training Organisations and airlines. The structure of the licence requirements has changed little since the end of the Second World War.

3.2 Initial Stages of Training

3.2.1 During initial training simple aircraft are utilised to concentrate on the basics of aircraft operation. Theoretical knowledge regarding aircraft systems is taught in an academic fashion and each system is treated in isolation during teaching and examination. The examination covers 9 subject areas and the majority of questions are in multiple choice format, with no penalty marking, and a 75% pass mark. Normal operation of aircraft systems and cross-system effects are highlighted during simulator training and reinforced during initial flight training. In parallel, flight skills, flight operations and flight procedures are introduced in the classroom with theoretical knowledge teaching and examination being conducted in the same fashion as aircraft systems. Simulation and initial flight training develop the motor schema required for manual flying (JAA, 2003a).

3.2.2 This learning/training process is consistent in so far as it is applied to the *ab initio* stage where the aircraft systems are simple, the weather is usually benign, the air traffic environment is simple, and the operating task minimal i.e. no time constraints or external commercial pressures. The architecture and operation of the simple aircraft systems can be easily and fully explained in the classroom and the examination process validates the students recall. The simulator and in-flight training allows the student to learn and practise the rule-based behaviour required to manage the systems and, to an extent, increases the students understanding of the systems. Operation and management of the systems requires the same level and type of cognitive activity as that employed during the examination stage i.e. memory recall. In a similar fashion the motor schema required for manual flying are developed through classroom (knowledge) to simulator and flight training (rule). The skill is developed with manual flying practice and is examined in context by performing the operational task. At the end of this stage the pilot can manually fly an aircraft to complete a basic operational task (control of the flight path) and the teaching/training and examination process has validity.

3.2.3 Before proceeding further it is important to understand the process by which we acquire and use knowledge.

3.3 The Concept of Knowledge

The three basic domains of cognition are: perception, memory, and thinking. The boundaries of these domains are indeterminate; however, the processes involved in each have a bearing on how we assimilate and employ knowledge. Studies of amnesia have shown that the brain handles certain types of memory in physically different ways. This results in the classification of two types of knowledge: procedural and declarative. Procedural knowledge is knowing how: to ride a bicycle or how to manually land an aircraft in a cross-wind. Declarative knowledge, in contrast, is knowing that: an aircraft uses Jet A1 fuel or that the auxiliary power unit can be used to replace the loss of an engine electrical generator. Declarative knowledge also includes episodic memory, the memory of a specific event. It should be obvious that one can have procedural knowledge without declarative knowledge of a subject and vice-versa. For example, one can ride a bicycle but it is unlikely that one can explain the principles of conservation of angular momentum that describe why we don't fall off! Equally, Dr. John Fozzard, the lead design aerodynamicist for the Harrier, can explain why a jump-jet can hover but would not relish the opportunity to demonstrate the effect at the controls.

3.4 Requirements for CPL/ATPL

Appendix 1 to JAR-FCL 1.470 sets out the theoretical knowledge requirements for the ATPL (A) licence. These syllabi are expanded in the associated Learning Objectives. Unfortunately, the reality is that students only learn what is required for the exam of the individual module. At present there is little consideration given to the introduction of automation as an integral component of the flight deck task. Rather the topic is treated as a 'system' and as such consigned to the same format as hydraulics, electrics etc. Rignér and Dekker (1999) state: “If the goals of flight education are to make the pilots able to transfer their knowledge (from the training situation to the airline environment), so they can manage both routine and novel situations, training methods that rely on reproductive memory do not make the grade.” So, once the student has gained his ATPL (A) Theoretical Knowledge credits he has acquired a limited level of declarative knowledge but very little procedural knowledge that is relevant to working with the automation of a modern flight deck.

3.5 Type Rating

3.5.1 Once again theoretical knowledge for the Type Rating is presented and assimilated as declarative knowledge. Individual systems and individual multiple choice exam format. Some procedural knowledge is introduced in the form of practical training in the use of autopilot, autothrust and flight management systems. However, the training is limited to use of system in normal mode and with hardware failures only. In fact, the complex nature of these systems means that the limited exposure of these sessions is often accompanied by the phrase “Don't worry about that, you will pick that up on the line”.

3.5.2 During the research for this report a review of CBT packages for the B747-400 and the Airbus A340 autopilot and FMS modules was made. In summary, what was presented amounted to an exposition of the capabilities of the systems themselves. Individual facets of each system were presented with occasional use of the phrase “the use of the equipment will be made clear in the sessions on the simulator or training device”. However, interviews with ground training personnel yielded comments that the normal procedures and non-normal situations, for which there was a published procedure, were covered but there was little, if any, time allocated to the presentation of Human Performance Limitations and the management of the automation in realistic settings. Again, this is dealt with during Line Training. Further interviews with training captains produced comments that during Line Training, opportunities to demonstrate anomalies were limited, unless the situation just happened to present itself. Clearly, at this stage of training, there would be no question of demonstrating automation failures by deliberately downgrading system capability. So at the end of the Type Rating training the pilot is competent to manage the system in a normal situation based on declarative knowledge but has little experience or procedural knowledge of normal operation and even less in the case of failure, i.e. non-normal situations.

3.6 **Proficiency Checks**

3.6.1 The requirements for the Skills Tests contained within JAR-FCL (JAA, 2003a) and amplified in Standards Document 24 (CAA, 2003b) are heavily weighted towards the checking of the manual flying skill of the pilot. Specific guidance is given on the tolerances on flight path parameters that must be achieved and also the manner in which such targets are satisfied. However, the issue of controlling the flight path by means of the autopilot and FMS and the demonstration of such skill is grouped with 'other aircraft systems'. Indeed, one may infer that such skill is deemed of a low priority given that this facet is only required to be evaluated once every three years and there is no stipulation as to the degree of competence that is required.

3.6.2 Standards Document 24 does make specific mention of the use of automation for the departure and arrival phases but this is done in a 'concessionary' manner, viz.

> “Item 3.9.1 - Departure and Arrival Procedures, […] b) Full use of automatics and LNAV if fitted is permitted. Examiners are encouraged to use their imagination to obtain maximum benefit from this item of the test. For example, if LNAV is used, a departure with a close in turn that may require some speed control or a change to ATC clearance that may require some reprogramming of the FMS might be appropriate. […] g) If the arrival procedure contains a hold, this can be assessed. Automatics can be used and therefore value can be obtained by giving a last minute clearance into the hold, or if FMS is fitted, an early exit from the hold to see how the FMS is handled.” (CAA, 2003b p11)

3.6.3 Furthermore, the specific paragraph entitled “Automatics” reinforces this idea that the automation may be used as a concession. These words do little to highlight the complex nature of modern automation and the degree of competence that is necessary for safe and consistent application of this tool across the range of situations that are commonly met in contemporary commercial operations.

3.7 **Knowledge of Manual Flying vs Automatic Control**

3.7.1 From the initial stages of flying training pilots develop skills to manually control the flight path in a feed-forward type of behaviour. This means that when recognising an error in the flight path performance the pilot makes a control input in anticipation of a desired response – they think ahead in a pro-active manner. However, studies have shown that pilots operating modern automation for flight path control do not have the knowledge or understanding to predict the behaviour of the automation based on detection of an error and selection of a control input. They cannot always predict the behaviour or feedback cues of the systems modes; as a result it may be said that they behave in a feedback or reactive manner - they are behind the aircraft.

3.7.2 As illustrated above there is a recognisable difference in the way humans (pilots) handle certain types of knowledge. The basic skills associated with 'manually flying' an aircraft are predominantly based on procedural knowledge i.e. how to achieve the task. However, the use of automation to control the flight path of an aircraft is taught as declarative knowledge. Pilots are required to manage systems based on a knowledge that the autoflight system works in a particular fashion. So, the pilot is faced with the same operational task of controlling the flight path but employs two different strategies of cognitive behaviour depending upon whether the task is manually or automatically executed. As discussed above the current requirements for licence and type rating issue prescribe standards and experience in the procedural knowledge of manual control of the flight path; however, there are no similar requirements to ensure appropriate standards and experience for the procedural knowledge of control of the flight path using automation.

3.7.3 It may be concluded that pilots lack the right type of knowledge to deal with control of the flight path using automation in normal and non-normal situations. This may be due to incorrect interpretation of existing requirements or lack of a comprehensive training curriculum that encompasses all aspects of the published requirements. It suggested that there should be a shift in emphasis in the way automation for flight path control is taught and trained. Further research is required to identify the cause and provide a solution.

3.8 Crew Resource Management

3.8.1 Crew Resource Management (CRM) was introduced into commercial aviation during the late 1970's. It was initially based upon concepts adapted from business management behaviour programmes in the US. Predominantly, initial CRM topics were limited to behavioural and physiological aspects. These concepts were refined during the 1980's to include psychological topics and mandated as part of the licence requirements following AIC 18/1991 (CAA, 1991). All licence holders prior to 1st January 1992 were exempt from the Human Performance and Limitations exam but were required to undergo an Initial CRM course on joining a new company and to undergo recurrent training on an annual basis. Since then the emphasis for CRM has strengthened in terms of the practical application of the behavioural marker system, NOTECHs etc., resulting in the recently published Standards Document 29 (CAA, 2001) and accompanying CAP 737 (CAA, 2003c). However, the areas relating to the practical application of the cognitive elements of human performance, in particular in relation to the human-machine operations, have not been as widely promoted nor understood.

3.8.2 Training and management pilots who are required to implement JAR-OPS requirements are, for the most part, in the category of licence holders who were exempt from the Human Performance and Limitations exam. Following interviews they appeared to fall into two classes that either thoroughly endorse all aspects of Human Performance and Limitations i.e. behavioural, physiological and cognitive limitations, or still view CRM as limited to behavioural aspects of flight deck operation. All requirements and regulations are subject to 'interpretation'. It appears that the requirements for training in, and the application of, the cognitive elements of human performance on the flight deck and their impact on the operations of highly automated systems has been better understood by some than others. It is only by obtaining a thorough understanding of the cognitive limitations of pilots in the flight deck environment that operational policies and procedures can be effectively implemented.

3.8.3 It may be concluded that there was a loop-hole in the introduction of the requirements for CRM training that has resulted in many of those responsible for the oversight of training programmes not fully understanding all the cognitive aspects of human performance limitations.

3.9 Line Oriented Flight Training

Interviews with training personnel revealed that the principles of LOFT are included in design of OPC / LPCs; however, LOFT as an exercise in itself was only included as part of the recurrent training schedule if time and resources were available. However, LOFT is a valuable tool for examining and training procedural knowledge of how to fly the aircraft using automation and yet may not be fully included in training budgets.

Chapter 4 Conclusions and Recommendations

1 Dependency on Automatics Leads Crews to Accept what the Aircraft is doing without Proper Monitoring

1.1 Summary

1.1.1 The availability of automation and automated decision aids encourages pilots to adopt a natural tendency to follow the choice of least cognitive effort. Training crews on automation bias or to verify correct automated functioning had no effect on automation-related omission errors, and neither did display prompts that reminded crews to verify correct functioning. However, there was evidence that pilots did perform better when the event was flight critical in nature.

1.1.2 There are two distinct types of knowledge that pilots have:

a) Declarative knowledge – the knowledge that the system works in a certain way.

b) Procedural knowledge – knowing how to use the system in context.

The use of automation to control the flight path of an aircraft is taught mainly as declarative knowledge. Pilots are required to manage systems based on a knowledge that the autoflight system works in a particular fashion, this is different for manual flying skills.

Manual Flying
The current requirements for licence and type ratings issue prescribe standards and experience in the procedural knowledge of manual control of the flight path, pilots are required to know and demonstrate how to control the flight path manually.

Automated Flying
There are no similar licensing or type rating requirements, to ensure appropriate standards and experience for the procedural knowledge of how to control the flight path using automation. Pilots are taught that the automation works in a particular way but their ability to use it is not checked to anywhere near the extent of checks for manual flying skills.

1.1.3 Therefore, it may be concluded that pilots lack the training and checking for control of the flight path using automation in normal and non-normal situations. Document 24 requires demonstration of the task of flight path control; however this is heavily weighted towards manual skills. Demonstration of proficiency in controlling the flight path using the automation is included as a secondary concern for the departure and arrival without detailed guidance on manoeuvres or tolerances to be achieved, which is in contrast to the guidance provided for the manual skill check.

1.1.4 The point at which a pilot would intervene in an automated process is fundamental to a successful outcome. This is not a well defined training goal and how and when decisions are made is variable within flight crews and organisations. The level busts resulting from disconnection of the autopilot during a turbulence induced overspeed event is evidence of incorrect intervention strategy.

1.1.5 Type rating training is limited to use of autopilot and FMS system in normal mode and with hardware failures only. CBT packages for the B747-400 and the Airbus A340 autopilot and FMS modules amount to an exposition of the capabilities of the systems themselves. Without adequate knowledge it is more likely that flight crews will accept what the aircraft is doing because they do not always have the knowledge or experience to predict the results of the automation targets and modes displayed.

1.2 Conclusions

1.2.1 The current training does not adequately prepare crews to properly monitor the automated functions of the aircraft in all foreseeable situations or when to intervene in an automated process. Neither does it prepare crews to conduct an adequate range of tasks using the automation.

1.2.2 There should be a shift in emphasis in the way automation for flight path control is taught and trained. This may involve moving from 'declarative' to 'procedural' training, i.e., less 'this is how it works' and more 'this is how to do it'. The assumption that much training can be carried out 'on the line' should be questioned. Operators are unable to demonstrate a full range of circumstances or effects during passenger flights.

1.2.3 The regulatory standards and checking requirements for the evaluation of the appropriate knowledge and skills for the use of automation are significantly less well defined compared with manual flying skills.

1.3 Recommendation

1.3.1 Further research is required to determine what training is needed in the use of automation and the best methods for delivering such training.

1.3.2 Document 24 should be reviewed in the light of such research. This should ensure that appropriate training and assessment standards, for use of automation, are adequately addressed.

2 Crews of Highly Automated Aircraft Lose Manual Flying Skills

2.1 Summary

There has been very little research published on the subject of the change in manual flying skill experienced by crews of highly automated aircraft. However, it is reported consistently that there is a discernible reduction in manual flying skills that is correlated both with the use of automation and whether the operation is long haul or short haul.

2.2 Conclusion

The term “manual flying skills” is not fully defined and the loss of manual flying skills is not covered by previous research.

2.3 Recommendations

Further investigation is required to establish; which skills are degraded, how can the change be quantified and which pilot groups are affected.

A range of possible mitigating actions should be considered, including increased practice, increased system reliability, safety reclassification of imposed manual flying (e.g. to alert ATC), and increased automation training to avoid the necessity for reversion to manual flight.

3 Inappropriate Response to Failures

3.1 Summary

3.1.1 Abnormal malfunctions have less well defined procedures compared with emergency situations and therefore crew revert to knowledge-based behaviour requiring more understanding of the system, plus time and effort to properly assess and resolve the situation. This refocusing of tasks results in reduced levels of procedural accomplishment, communications and situational awareness, i.e. relatively minor failures can absorb both crew members in a way that is disproportionate to the significance of the problem. Published aircraft procedures specifically do not include elements of 'airmanship'.

3.1.2 System design is not always appropriate to keep pilots in the loop. (Research has shown that rather than design systems to work on thresholds or specific limits for control there should be a continuous flow of information to the pilot to indicate the difficulty or increasing effort needed to keep relevant parameters on target.)

3.2 Conclusions

3.2.1 The current level of training does not adequately prepare crews to recognise or deal with all situations that might arise.

3.2.2 Crews may fail to recognise failures because a) they do not have sufficient understanding of 'normal' automated operation to be able to detect what is abnormal and b) they do not receive training in recognition of situations from the symptoms as they appear to the pilot. Thus they may not realise there is a problem or may believe the problem is different to the real situation. Further, even when they do correctly recognise the situation, they may not have sufficient system knowledge to respond appropriately.

3.2.3 As noted under Risk 1 current training does not include practice at recognising a situation from the flight deck symptoms, for example, a programming input error or a navigation database error. Frequency of recognition errors in accidents suggests that such training would be justified.

3.3 Recommendation

Research should investigate practical ways of incorporating the cognitive elements of CRM into automation training such that failure recognition and recovery are improved.

4 CRM Requirements

4.1 Summary

4.1.1 Airline training and management pilots who are required to implement JAR-OPS requirements are, for the most part, in the category of licence holders who were exempt from the Human Performance and Limitations exam (pre 1992). Following interviews they appeared to fall into two classes that either thoroughly endorse all aspects of Human Performance and Limitations i.e. behavioural, physiological, and cognitive limitations, or still view CRM as limited to behavioural aspects of flight deck operation.

4.1.2 CAP 737 and Doc 29 contain good information but have only been released recently. Comments in interviews indicate that much of the cognitive aspects of CRM and the application of Human Performance and Limitations to the use of automation may not be fully understood nor implemented as anticipated.

4.2 Conclusions

4.2.1 The requirements for training in, and the application of, the cognitive elements of human performance on the flight deck and their impact on the operations of highly automated systems have been understood better by some pilot groups than others.

4.2.2 There is a real risk that Doc 29 will be interpreted as a requirement only to implement a behavioural marker system in OPC/LPC and Line Check events.

4.3 Recommendations

4.3.1 Investigate appropriate methods to ensure effective communication of the cognitive aspects of the “Human Performance and Limitations” message to pre 1992 licence holders.

4.3.2 Investigate methods to monitor uptake, promote understanding and encourage full implementation of CAP 737 and Doc 29 requirements.

References

BASI, (1998). *Advanced Technology Aircraft Safety Survey Report (Department of Transport and Regional Development, Bureau of Air Safety Investigation).* Civic Sq, ACT, AUS: Author.

Billings, C. E. (1997). *Aviation Automation. The Search for a Human-Centered Approach.* Mahwah, NJ, USA: Lawrence Erlbaum Associates.

CAA. (1991). Introduction of a new subject (Human Performance and Limitations) into the examination syllabus for professional flight crew licences and the private pilot's licence instrument rating. *United Kingdom Aeronautical Information Circular, AIC 18/1991 (White 47) 21 February.* Cheltenham: UK CAA.

CAA. (1992). CAP 360. Air Operators' Certificates. Part One, Operation of Aircraft, 6th Edition. London, UK: Civil Aviation Authority

CAA. (2000). *CAP 701. Aviation Safety Review 1990 – 1999.* Strategic Safety and Analysis Unit, Safety Regulation Group, UK CAA.

CAA. (2001). *Guidance notes for Accreditation Standards for CRM Instructors and CRM Instructor Examiners Standards Document 29.* Flight Operations Department, Safety Regulation Group, UK CAA

CAA. (2003a). *Flight Crew LASORS.* Personnel Licensing Department, Safety Regulation Group, UK CAA.

CAA. (2003b). *Guidance to Examiners: Multi-Pilot Aeroplanes (MPA) Type Rating Skill Tests and Proficiency Checks Standards Document 24, Version 04.* Flight Operations Department, Safety Regulation Group, UK CAA

CAA. (2003c). CAP 737. Crew Resource Management (CRM) Training. London, UK: Civil Aviation Authority.

Chidester, T. (1999). Introducing FMS aircraft into airline operations. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 7-27). Aldershot, UK: Ashgate.

Courteney, H. (1998). Assessing error tolerance in flight management systems. *Proceedings of the second international conference on engineering psychology and cognitive ergonomics.* Oxford, UK.

Courteney, H. (1999). Human factors of automation: The Regulator's challenge. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 7-27). Aldershot, UK: Ashgate.

Dekker, S. W. A. (1995). From meaningless toil to soporific monitoring: seven lessons that perhaps were not applied to aviation automation after all. Or: the latent failure in the latent failure approach. *Eighth International Symposium on Aviation Psychology, April 24-27, 1995. Columbus, OH, USA.*

Dekker, S. and Orasanu, J. (1999). Automation and situation awareness – pushing the research frontier. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 69-85). Aldershot, UK: Ashgate.

Dekker, S. and Woods, D. (1999a). Automation and its impact on human cognition. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 7-27). Aldershot, UK: Ashgate.

Dekker, S. and Woods, D. (1999b). Extracting data from the future – Assessment and certification of envisioned systems. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 7-27). Aldershot, UK: Ashgate.

Dekker, S. W. A. and Woods, D. D. (2002). MABA-MABA or Abracadabra: Progress on human-automation co-operation. Journal of Cognition, Technology and Work, 4(4), 240-244.

ECOTTRIS, (1998). *European collaboration on transition training research for improved safety: Final Report.* European Community DG-VII (Transport) Contract AI-96-SC.201.

ESSAI, (2003). *Enhanced Safety through Situation Awareness Integration in training: Final Report*. European Community Competitive and Sustainable Growth Programme (1998-2002). Contract No. 2000-RD.10450.EC DG-VII (DG-TREN).

FAA, (1996). *The interfaces between flightcrews and modern flight deck systems. (Federal Aviation Administration Human Factors Team Report.)* Washington, USA: Author.

Flight International. (2004). System Failures*. Flight International, 20-26 Jan 2004, (pp. 34-42).*

Green, R. G., Muir, H., James, M., Gradwell, D. and Green, R. L. (1996). *Human factors for pilots 2nd Edition.* Aldershot: Ashgate.

Howard, M. (1999). Visualising automation behaviour. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 55-67)*.* Aldershot, UK: Ashgate.

Hollnagel, E. (1999). From function allocation to function congruence. In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit. (pp 29-53).* Aldershot, UK: Ashgate.

ICAO. (1995). Operational Implications of automation in advanced technology flight decks. *Human Factors Digest No.5.*

Icon. (2001). *The human factors implications for flight safety of recent developments in the airline industry.* A research study for the JAA. Final Report. London, UK: Icon International Services Ltd.

JAA. (2003a). JAR-FCL 1 Flight Crew Licensing (Aeroplane), Amendment 3, 1 Jul 2003. Hoofddorp, NL: JAA

JAA. (2003b). JAR-OPS 1: Commercial Air Transportation (Aeroplanes), Amendment 6, 1 Aug 2003. Hoofddorp, NL: JAA

Mårtensson, L. and Singer, G. (1998). *Warning systems in commercial aircraft: An analysis of existing systems* (TRITA-IEO-1998:01). Stockholm, Sweden: Royal Institute of Technology.

Mosier, K. L., Skitka, L. J., Heers, S. and Burdick, M. D. (1998). Automation bias: Decision making and performance in high tech cockpits. *The International Journal of Aviation Psychology. 8 (pp. 47-63).*

Mosier, K. L., Skitka, L. J., Dunbar, M. and McDonnell, L. (2001). Aircrews and automation bias: The advantages of teamwork? *The International Journal of Aviation Psychology. 11 (pp. 1-14).*

Norman, D. A. (1988). *The psychology of Everyday Things.* New York, USA: Basic Books

Orasanu, J. and Connolly, T. (1993). The reinvention of decision making. In G. Klein, J. Orasanu, R. Calderwood, and C. E. Zsambok (Eds.) *Decision making in action: Models and methods* (pp. 3-20). Norwood, NJ, USA: Ablex.

Reason, J. (1990). *Human error.* Cambridge, UK: CUP

Rignér, J. and Dekker, S.W.A. (1999). *Modern flight training – managing automation or learning to fly?* In Dekker, S and Hollnagel, E. (Eds.) *Coping with computers in the cockpit* (pp 145-151). Aldershot, UK: Ashgate.

Sarter, N. B. and Schroeder, B. (2001). Supporting decision-making and action selection under time pressure and uncertainty: The case of in-flight icing. *Human Factors, 43 (pp 581-590).*

Sarter, N. B. and Woods, D. D. (1994). Pilot interaction with cockpit automation II: An experimental study of pilots' mental model and awareness of the Flight Management System (FMS). *International Journal of Aviation Psychology,* 4, (pp. 1-28).

Singh, I. L., Molloy, R. and Parasuraman, R. (1993). Individual differences in monitoring failures in automation. *The Journal of General Psychology. 120 (3), (pp 357-373).*

Singh, I. L., Molloy, R. and Parasuraman, R. (1997). Automation-induced monitoring inefficiency: role of display location. *The Journal of Human Computer Studies. 46 (pp 17-30).*

Singh, I. L., Sharma, H. O., and Parasuraman, R. (2001). Effects of manual training and automation reliability on automation induced complacency in flight simulation task. *Psychological Studies. 46 No. 1-2. (pp 21-27). National Academy of Psychology, India.*

Singer, G. and Dekker, S. W. A. (2000). Pilot performance during multiple failures: An empirical study of different warning systems. *Transportation Human Factors,* 2(1), (pp 63-76). Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Singer, G. and Dekker, S. W. A. (2001). The ergonomics of flight management systems: fixing holes in the cockpit certification net. *Applied Ergonomics 32 (pp 247-254).*

Sumwalt, R. L. and Watson, A. W. (1995). What ASRS incident data tell about flight crew performance during aircraft malfunctions. *Proceedings of the Eighth International Symposium on Aviation Psychology.* Columbus OH, USA: Ohio State University.

Wood, S. J. (2004). Scope of clarification study into issues associated with safety intervention 03/06. Internal paper, Research Management Group, Safety Regulation Group, UK CAA.

Woods, D. D. (1992). *Cognitive activities and aiding strategies in dynamic fault management (Series of three cognitive Systems Engineering Laboratory reports).* Columbus, OH, USA: Department of Industrial System Engineering, Cognitive Systems Engineering Laboratory.

Woods, D. D., Johannesen, L. J., Cook, R. I., and Sarter, N. B. (1994). *Behind human error: Cognitive systems, computers, and hindsight.* Dayton, OH, USA: Crew Systems Ergonomic Information and Analysis Center (CSERIAC).

Woods D. D. (1996). Decomposing Automation: Apparent Simplicity, Real Complexity. In Parasuraman, R. and Mouloua, M. (Eds.) *Automation and Human Performance: Theory and Applications* (pp. 3-17). Hillsdale, NJ, USA: Lawrence Erlbaum Associates.

Woods, D. D. (1997). Basic concepts in supervisory control (Internal paper ISE 773). Columbus, OH, USA: Industrial and Systems Engineering, The Ohio State University

Woods, D. D. and Sarter, N. B. (1998). *Learning from automation surprises and 'going sour' accidents: Progress on human-centered automation (report ERGO-CSEL-98-02).* Columbus, OH, USA: Institute for ergonomics, The Ohio State University.

Annex A Literature Review

1 The Role of Automation

1.1 General

Technology has led the aviation industry. Better materials, manufacturing processes and the use of automation has generally helped aviation achieve improvements in safety and reductions in costs. It is almost as if we accept that newer technology must offer an improvement. Unfortunately, the safety critical nature of the flight deck means that the human-automation relationship must be developed and optimised to ensure that certificated equipment is designed to accommodate the human limitations.

1.2 Intentions versus Reality

Society has been driven by a desire to advance through the implementation of technology. Progress is measured in 'bytes per second'. The “labour saving” adage of the fifties and sixties has been extended to virtually all areas of life. We now have television systems that not only present hundreds of channels but also allow the viewer to programme what is presented and when it is presented, and then to participate via an 'interactive' mode. More is good. Each element is treated in isolation which, in turn, engenders an isolationist approach to the task; the technology drives the task instead of the technology serving the task. How often will someone spend minutes searching the back of the sofa looking for the remote instead of walking across the room to change the channel manually? “Our fascination with the possibilities afforded by technology in general often obscures the fact that new computerised and automated devices also create new burdens and complexities for the individuals and teams of practitioners responsible for operating, troubleshooting, and managing high-consequence systems” (Woods, 1996 p. 3).

1.3 Changing role of Flight Deck Crewmember

Thirty or forty years ago major airlines were operating aircraft with "fly-by-cable" and simplex systems that we could all understand from a few synoptic charts and wiring diagrams. Aircraft accident and incident statistics for the 1950's and 60's show that pilots faced emergencies which required the use of their hands-on piloting skill and manual system management. Now, in the twenty-first century, improved designs and materials have allowed the provision of redundant systems which can be monitored and switched automatically by microprocessors to provide fail-safe operation. The task of operating transport aircraft has changed and increased significantly; not only do pilots have to fly their aircraft but also manage their aircraft through various computer interfaces and displays in a more complex air traffic environment.

1.4 Effect of Automation on Workload

1.4.1 Woods (*op cit.*) argues that the introduction of technology produces changes along several dimensions. Automation can be considered as: more autonomous machine agents; an increase in flexibility; more computerisation; and an increase in coupling across diverse parts and agents of a system. Often, the introduction of technology is justified by claims such as “the new system will reduce workload”, “help practitioners focus on the important part of the job”, and, “decrease errors”. However, rarely are these claims challenged and research (Billings, 1997; Woods *et al,* 1994; Woods and Sarter, 1998) has shown that the introduction of such systems actually created new complexities and new types of error traps. Chidester (1999) reported a decrease in workload for an increase in automation under 'normal' conditions but when experiencing 'abnormal' conditions the workload increased when either hand-flying the aircraft or using the higher levels of automation that required programming. See Figure 1.

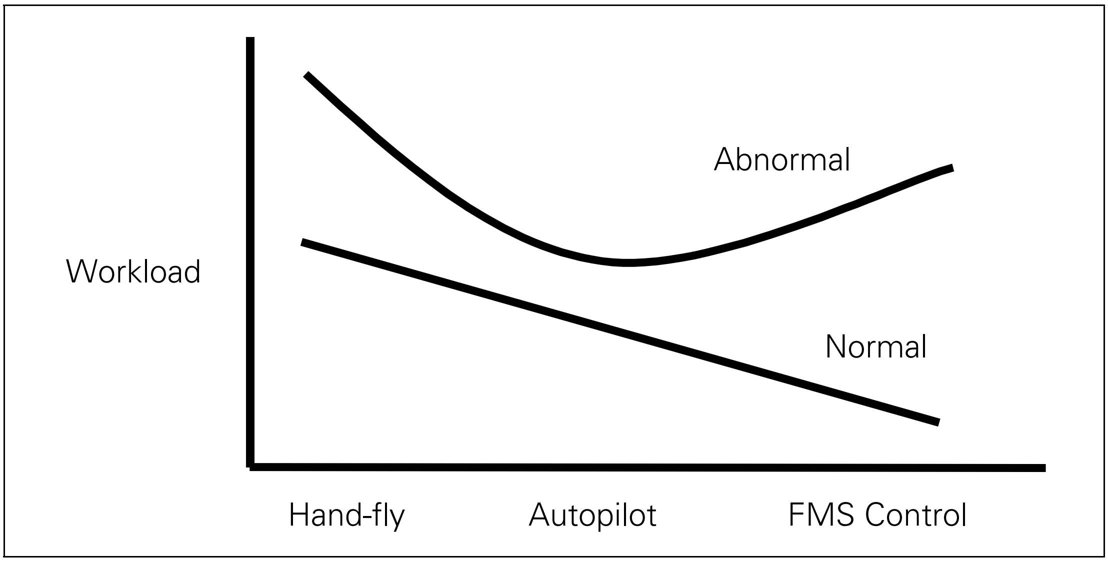

Figure 1 Automation and workload (after Chidester, 1999)

1.5 Changing the Task – New Problems

1.5.1 Our view of the introduction of technology and automation to a task is usually that it must make life easier for us – why else would it be introduced? However, research has shown that introduction of automation into complex processes and systems shifts the responsibility of the human operators regarding the monitoring and management functions (Billings, 1997). The processes become composites of man and machine, a team. Unfortunately, the automation often fails to 'behave' as a team player. This occurs when the automation behaves in an autonomous manner, or provides poor feedback, or when it adds cognitive demands on the operator during periods of high workload, or when it is time consuming for the operator to re-direct the automation task in response to environment changes (Norman, 1988; Sarter and Woods, 1994; Dekker and Woods, 1999a). Systems with these characteristics create new problems for the human operator and new forms of systems failures.

1.5.2 Furthermore, recent studies (Mumaw, et al, 2003) have reported that autoflight/FMS mode awareness was affected by both failures to verify mode selections and an inability to understand the implications of autoflight mode on the aircraft's performance.

1.6 Functionality – Good or Bad?

Norman (1998) provides an example of how the simple function of a wristwatch has become complex with the advent of technology. Digital watches can present many functions and yet these added functions cause problems in design, which are constrained by limitations of size, cost, and complexity. “Whenever the number of functions and required operations exceeds the number of controls, the design becomes arbitrary, unnatural and complicated” (Norman, ibid p. 31). Modern autopilots / flight management systems provide various means of achieving similar tasks, for example, there can be up to five means of achieving a change in altitude depending on various environmental conditions or task criteria. Is this choice of functionality a good or bad attribute? One viewpoint is that it allows the operator to choose the best mode for the task in hand. However, a contrary position highlights that such complexity adds workload in terms of increased knowledge base requirements and increased cognitive demands (Woods, 1996). Furthermore, modern aircraft automation tends to reduce activity during low periods of workload e.g. the cruise, and yet increases workload during periods of high workload e.g. approach (Chidester, 1999). Deficiencies such as these create opportunities for new kinds of human error and new paths to system or process breakdown that did not occur in simpler systems (Woods *et al.*, 1994).

1.7 Function Allocation

1.7.1 Function allocation addresses the division of labour between man and machines. As previously discussed, the introduction of automation on to the flight deck has created a system that comprises man and machine. The task of flight operation is now achieved by this 'system'. The task, which comprises goals and functions, is now executed by the team of man and machine. Some functions are better served by machines and some goals are better achieved by man (Dekker and Woods, 2002); however, the responsibility for the task will always remain with the pilot (Billings, 1997). A common starting point for the discussion of function allocation is the substitution assumption i.e. that a human function can be replaced by a machine function. However, Hollnagel (1999) challenges this assumption. Machine functions are based on iterative steps of execution, an algorithmic approach. Unfortunately, there is plenty of evidence that humans do not perform well in this manner, e.g. following instruction sets repeatedly, or following procedures, checklists etc. “Yet replacing part of human functions by machines means precisely that humans are forced to behave machine-like in order to interact with machines, and therefore embraces the substitution principle” (Hollnagel, 1999 p31). When a human is given a task it is usually described in terms of the goals required, i.e. what is required. The human will then decide how to achieve the goal. In contrast we must always tell (program/design) the machine how to achieve the task and, subject to reliability issues, expect a repeatable outcome of goal achievement. Furthermore, human capability or performance is subject to variation over time and with respect to environment conditions. Therefore, we should only automate those functions that can be fully automated for all conditions. The disparate processes involved in human versus machine function means that if and when substitution takes place, by necessity this has an impact on the environment or conditions in which the human approaches the remaining functions within the task, or system, as a whole. The allocation of function within the process and the control by which by the process is executed must be co-ordinated or, as Hollnagel proposed, that we should strive for function congruence.

1.7.2 A similar situation exists in ATC automation where proposal for the next generation of control will see the advent of 'Air Traffic Managers' who will standby to intervene to resolve conflicts. Controllers will work in a mode of management by exception. In future ATC architectures, automated tools for conflict detection and resolution are supposed to take a greater role in picking up much of the routine work of keeping aircraft on their tracks and away from one another. Controller intervention will only be necessary when the automation is not able to resolve potential manoeuvres that might interfere with other aircraft, when traffic density preludes route flexibility, or when flight restrictions are considered necessary for safety (RTCA, 1995 as cited in Dekker and Woods, 1999b). However, how will controllers be trained and practised in this new role? They will, by definition, be less practised but be required to act in time critical, complex situations. Automation does not substitute for human work; it changes it. The modern flight deck requires a pilot to work in a mode of supervisory control (Woods, 1997; ECOTTRIS, 1998) and as the level of automation of the task increases so too does the element of management by exception.

1.8 The Design of Automation

1.8.1 The engineering involved in the design of flight deck automation requires a rationalistic or deductive approach. Engineers working individually or in co-ordinated groups aim to model a process and predict the outcome of a system given a clearly defined set of input parameters and environment or state conditions. In doing so, a specification or set of requirements is established prior to the design being formalised. The actual design and production is then concerned with the fulfilment of the requirements, without necessarily questioning the validity of them. Effective use or employment of such designs then requires a rationalistic approach; it is assumed that the input data must be precise according to the situation and it is assumed that output data will be fully understood. This is a reasonable approach - for an engineer working in an ordered environment with time to reason and apply a deductive approach. Unfortunately, pilots work in dynamic, event driven environments where the input / output transformation of the system maybe entirely appropriate in one set of conditions and yet be quite inappropriate in another. Furthermore, the pilots do not have the vast engineering training and experience of the design team and necessarily have a somewhat reduced overall awareness of the principles of design. There is a mis-match between the process of the design of flight deck automation and the process in which the system will be used.

1.8.2 Howard (1999) argues that automation should be designed from the point of view of “quality in use” rather than the more traditional rationalistic approach of decomposing the task into individual functions and establishing a technical specification for each element. This line of reasoning opens up a new approach to automation design. Automation on the flight deck should be designed to provide a visualisation of the process and permit interaction with the process. “Central tasks are not being able to read individual pieces of data, but to see aggregates, trends, and relations; to recognise patterns and behaviour, in order to know when and how to act. A move from data-oriented towards process-oriented views means a shift from communicating numbers and values to communicating issues and ideas” (Howard, *ibid*, p66). The advent of the total system i.e. the teaming of the human and machine has yet to be fully accepted into the design of flight deck automation.

1.9 Certification of Automation

Courteney (1999) and Singer and Dekker (2001) both highlight the current lack of human factors certification of modern aircraft flight deck systems. Work is in hand to address these issues but by their very nature there will be much discussion before workable regulations are in place. However, there is an interesting point to be made regarding the philosophy of the extant airworthiness regulations: Aircraft Performance criteria have been well established and the means of demonstrating compliance have evolved with time and technology into a robust objective process. Similarly, both flying and handling qualities requirements have developed with advances in technology. However, 'aircraft systems' requirements have been assessed primarily with respect to their reliability and failure modes analysis as mechanical systems. Singer and Dekker (*ibid.*) highlight the austerity of current human factors requirements that, in practice, result in an evaluation process that is limited to a subjective evaluation by a restricted group of evaluators and conditions. Modern flight deck systems have been designed to assist the pilot in the fulfilment of the operational task. However, as has been mentioned earlier, the introduction of these systems has brought both benefits and problems. As Courteney (*ibid.*) points out, this is not to say that the current regulatory proposals are inappropriate or wrong but rather that they are incomplete. Surveys (FAA, 1996; BASI, 1998; Courteney, 1998) indicate that contemporary flight management systems' designs result in pilot's adopting 'workarounds' to achieve the task, and equipment that increases the pilot's workload in certain situations. Part of the problem lies in the gap between the design model used by the manufacturer and the model of operation that is held by the pilot. Future requirements may well have to incorporate some form of specific training requirements and in-service feedback to bridge this gap.

1.10 Automation Issues – Summary

We currently have flight deck automation systems that change the task, re-distribute workload for the crew, and present error traps. The change in role from active manual control to one of system management has left pilots less proficient in manual skills but required, on occasions, to take control in time critical situations. Designs are based on rationalistic principles that do not readily align with the mental models pilots have for the manual flying task. Pilots have adapted or bridged this gap by adopting 'work-arounds'. The way forward is for the evolution of current designs rather than revolution; however, we still have a problem of mitigating the human-machine problems of extant system designs.

2 Recognition of and Reaction to Failure

2.1 Forming an Intention

The basic theory of the processes by which a pilot recognises and reacts to a failure are covered in the sections of Aviation Psychology contained in various texts of Human Performance and Limitations. Woods, *et al* (1994) show that 'intention errors' are made during the process of forming intentions, how people decide what to do as opposed to the processes involved in going from intention to action. Intention formation refers to the cognitive processes involved in information gathering, situation assessment, diagnosis, and response selection. This distinction is important because when an erroneous intention is formed pilots may omit correct actions but they may also carry out actions that are appropriate given the perceived situation but are in fact incorrect given the actual situation.

2.2 The Point of Intervention

As previously discussed, the design of flight deck automation is based on principles of rationalistic processes employing deductive reasoning. However, pilots work in a time limited, dynamic, event driven environment where such a deductive approach is inappropriate. “The problem facing the pilot is not to be able to trace the correct theoretical origins of an encountered situation, but to handle it successfully. Practitioners do not solve problems; they manage situations.” (Howard, 1999, p59). The point at which a pilot would intervene in an automated process is fundamental to the success of operation i.e. at what point does the automated system stop and require the human to take over? If the point of intervention is too early then there may be too many alerts in normal operation or too little information to make full use of the pilot's experience and problem solving ability. Conversely, if intervention is left too late then the pilot may well be landed in a deteriorating situation that has reached the limits of the automated systems capability. For example, descending in vertical speed mode a subsequent ATC request for a higher rate of descent may cause an overspeed with attendant autopilot disengagement. In the worse scenario this could leave the pilot confused, on the edge of the aircraft's envelope and also failing to satisfy the ATC clearance.

2.3 Decision Making (Establish Goals, Procedure/Strategy)

2.3.1 Decision-making involves some or all of the following steps: cue detection, cue interpretation/ integration, hypothesis generation/ selection, and action selection. Several factors can affect performance at these different stages. A lack of, or poor quality of, cues can make it difficult for pilots to generate a reasonable hypothesis about the nature and severity of a problem. Time pressure and stress can lead to perceptual narrowing and a reduction in working memory capacity, which can lead to decreased vigilance and reduce the utilisation of available cues. In high workload periods, such as descent and approach to landing, pilots may not have the time or the attentional resources that are required to examine and evaluate multiple hypotheses. Both the hypothesis and action generation stages require retrieval of information from long-term memory, such as prior experience with similar conditions, which may not be available, especially with novice pilots or in case of a novel situation. These factors affect pilots' performance during flight operations into high-density air traffic areas (Sarter and Schroeder, 2001).

2.3.2 Historically, formally models of decision making were proposed based on an algorithmic approach. These processes assume full knowledge of all available alternatives and after a period of consideration of each a final choice was made to ensure optimum outcome. Clearly, this process is not applicable in the flight deck environment, nor is it particularly relevant to everyday life. Orasanu and Connolly (1993) proposed an alternative model called naturalistic decision making (NDM). This model is based on a schema driven process rather than the algorithmic approach: i.e. situations are considered in relation to a mental library of situations and successful or expedient outcomes; appropriate actions are then chosen.

2.3.3 As mentioned earlier, the point at which a pilot would intervene in an automated process is fundamental to the success of operation. Let's expand the scenario presented earlier: a pilot selects a 'vertical speed' mode to commence a descent. Initially, all may be well; however, ATC may instruct the pilot to increase the rate of descent to say 3000 ft per min to avoid a conflict ahead. It may well be that this aircraft cannot descend at this rate and still maintain the selected speed because it does not have sufficient drag. At this point the pilot is faced with a speed target that the automation is failing to satisfy and yet the system is behaving as per design. This will induce confusion and, if left unattended, could result in the aircraft continuing to increase speed until it reaches its limiting speed, at which point most autopilots are designed to reduce the vertical speed to maintain the structural speed limit. Of course, now the aircraft will not satisfy the original constraint demanded by ATC plus the aircraft is also not flying the commanded speed target. The pilot is left to not only control his aircraft back away from the speed limit but also reconfigure the aircraft (deploy speedbrake?) to satisfy the original ATC constraint. Research (Sarter and Woods, 1992; 1994; 1998; Billings, 1997) has shown that rather than design systems to work on thresholds or specific limits for control there should be a continuous flow of information to the pilot to indicate the difficulty or increasing effort needed to keep relevant parameters on target. The pilot could interrogate the system to determine the nature of the difficulty, investigate the problem, and finally intervene to achieve overall safety. This type of co-operative design would dictate the requirements for feedback cueing and decision support architecture.

2.4 Warning Systems Design

On the flight deck warnings serve three purposes: 1) to alert the pilot that something is wrong, 2) to report what is wrong, and 3) to guide the pilot in what to do (Mårtensson and Singer, 1998). However, these intents must be placed in the context of the time distributed, multi-task process that is known as airline operation. Put simply the pilot must deal with not only the failure itself but also the impact of such a failure on the actual flight that lays ahead, or in other words, fault management in a dynamic environment. A study by Singer and Dekker (2000) demonstrated that human performance benefits, in terms of response times and error rates in identifying the failure, are associated with warning systems that sort failures, display them selectively and go on to guide the pilot in what to do next. Similar benefits were found in systems that contain the fault or re-configure the system and display what functionality remains to the pilot. Therefore, it may be concluded that pilot performance in response to a failure is predicated on the information and manner in which it is displayed.

2.5 Presentation of Information

2.5.1 Work has been done to determine the benefits of decision support systems in the flight deck environment (Billings, 1997; Woods, 1992; Woods and Sarter, 1998). Basically, decision support systems can provide status information or command information. This categorisation highlights the similarity with contemporary autopilot and flight management systems designs that may have unwittingly transgressed the boundaries of both these classifications thus providing conflicting cueing for pilots. Status displays present information about the state of the system or environment but leave the decision entirely to the pilot. However, as mentioned previously, the pilot can only work with the cueing that he perceives; hence, presentation, feedback etc. all influence the outcome for any given situation. Command displays recommend appropriate actions and thus save the crew the cognitive step from diagnosis to action selection. Both status displays and command displays involve benefits and disadvantages that need to be weighed carefully against one another.

2.5.2 One of the biggest concerns with status and command displays, and with decision aids in general, is their potential for creating automation biases. Operators may show signs of excessive trust in, and reliance on, an automated decision support system. Research has shown that both status and command displays are beneficial to users; as long as accurate information is presented. When unreliable or inaccurate information or advice is provided, performance reduces. This effect is more pronounced with command (as compared with status) displays, which lead to faster, but also more often inaccurate responses to a problem (Sarter and Schroeder, 2001).

2.6 Skill, Rule, Knowledge Behaviour (Execution)

Knowledge-based behaviour is the realm of the human. We can make sense of disparate data, we can reason, we can learn. This ability comes at a price and we will minimise the cost of cognitive effort by pattern matching and using rule-based behaviour wherever possible. Once established in 'familiar territory' the skill-based behaviour completes the task. As yet automation on the flight deck is limited to functions that start at the rule-based behaviour and, as with humans, the machines can employ/be employed for inappropriate functions. However, once the correct or appropriate function has been determined then the equivalent skill-based behaviour is more consistently and, usually, more accurately achieved by the machine.

2.7 Failures and Situation Awareness

2.7.1 A review of 230 ASRS reports submitted between May 1986 and August 1994 identified 10 items that could be construed as symptoms of a loss of situational awareness when dealing with aircraft malfunctions (Sumwalt and Watson, 1995). The study classified malfunctions into two broad classes that reflected 'Emergency' and 'Abnormal' malfunctions. Results indicated wide differences in adherence to procedures depending on the type of malfunction. The report suggested that this may be caused by the crew perception of the malfunction, and training. “When faced with major malfunctions such as engine fires or a complete loss of major aircraft systems, crews typically resorted to highly practised rules-based procedures, CRM principles and some degree of heightened awareness” (p. 761). The malfunctions classified as 'Emergency' had well developed procedures that had been practised in the simulator on many occasions thus leading to rule-based behaviour. However, the 'Abnormal' malfunctions had less well defined procedures and therefore required the crew to revert to knowledge-based behaviour requiring more time and effort to properly assess and resolve the situation. “This refocusing of tasks likely resulted in reduced levels of procedural accomplishment, communications and situational awareness” (p. 762). The report concludes that minor anomalies often have no immediate or obvious solution; resolving them may require time-consuming thought, and trial-and-error procedures.

2.7.2 This report was written in 1995 and interviews with training personnel conducted during this study have indicated that, since then, the lessons outlined have been applied to training for dealing with aircraft systems' malfunctions in general. However, the area of automation failures has been less well addressed. As discussed earlier, automation failures can be due to many causes, the least of which is a failure of the system that results in a warning message and associated published procedure. Therefore, by default, most automation failures will result in the crew reverting to knowledge-based behaviour requiring more time and effort to properly assess and resolve the situation. “This refocusing of tasks likely resulted in reduced levels of procedural accomplishment, communications and situational awareness”. This finding has important ramifications for training to deal with automation failures.

2.8 Automation Dependency - Complacency

2.8.1 Complacency in the automated flight deck represents an important issue. Pilots may become complacent in highly reliable automated environments where the role has become supervisory and lacks practice in direct control. Singh, Molly and Parasuraman (1993; 1997) reported that when subjects performed multiple flight related tasks simultaneously, with one of the tasks being automated, the consistency and reliability of the automation affected their ability to monitor for automation failure. Detection of automation failures was poor under constant-reliability automation, even following a catastrophic failure. However, monitoring was efficient under variable-reliability automation. Therefore, automation related inefficiency in monitoring is in part a function of the reliability and consistency of the automation itself. Furthermore, limited research by Singh, Sharma and Parasuraman (2001) indicated that these effects do not significantly alter following training.

2.8.2 Previous studies (Langer, 1989 as cited in Singh, Molloy and Parasuraman, 1993) have proposed a notion of 'premature cognitive commitment' which refers to an attitude that develops when a person first encounters a device in a particular context; that attitude is then reinforced when it is re-encountered in the same way. This can occur in situations of routine repetition and extremes of workload. “When people make a public commitment that an operating gauge is inoperative, the last thing they will consider is that the gauge is operating. Had they not made the commitment, the blind spot would not be so persistent.” (Weick, 1988 p. 310 as cited in Singh, Molloy and Parasuraman, 1993).

A further extension of this issue is that the automation need not necessarily 'fail' to cause a problem of cognition for the pilot. The Bangalore crash involving an Air India A320 is a case in point. The system did not fail *per se,* but it did not behave the way the crew expected it to behave. By the time their effective monitoring alerted them to the problem there was insufficient time to intervene and prevent the impact with the ground.

2.9 Automation Bias

2.9.1 The availability of automation and automated decision aids encourages pilots to adopt a natural tendency to follow the choice of least cognitive effort. When faced with making decisions pilots will rely on these automated aids as a replacement for vigilance, and actively seeking information and processing. This is termed *automation* bias. A simple example of this is to rely on the FMS prediction of the top of descent point rather calculate the point based on altitude, wind etc. Automation bias leads to two types of error: omission errors that occur when the pilot fails to take action when required because of a lack of prompting from the automation; and, commission errors that occur when a pilot follows an inappropriate procedure recommended or directed by the automation despite contradiction from other sources.

2.9.2 In studies by Mosier *et al* (1998, 2001) it was reported that pilots committed errors on 55% of occasions when the automation presented incorrect information in the presence of correct information to cross-check and detect the automation anomalies. Training crews on automation bias or to verify correct automated functioning had no effect on automation-related omission errors, and neither did display prompts that reminder crews to verify correct functioning. However, there was evidence that pilots did perform better depending on the flight critical nature of the event. For example, they were more likely to notice an altitude capture error rather than a radio call error in the cruise. These studies also confirmed the tendency towards over-reliance on reliable automation where pilots were reluctant to correct automation errors despite recognising and acknowledging a discrepancy between what they were expecting and what the automation actually did.

2.9.3 The study (Mosier *et al*, 2001) included only one event that would contribute to an error of commission: a false fire indication. Nineteen out of twenty experienced crews followed the commanded drill to shut down the engine despite the lack of any other indications of fire. Additionally, results of questionnaires indicated that these same pilots considered that a warning message alone would be insufficient for them to ensure that the fire was real. Pilots believed that they saw information that verified the automated cue; this aspect has profound relevance for the analysis of human factors following incident and accident reports.

2.9.4 Interestingly, after the incorrect decision had been made to shutdown the engine, crews immediately adopted the rule-based behaviour for the shutdown procedure i.e. they then verified that they were shutting down the correct engine. The results of such studies indicate that pilots fail to take into account all of the relevant information that is present in an automated flight deck. The tendency is for pilots to take cognitive short-cuts by pattern matching and using rule-based behaviour wherever possible. Once established in 'familiar territory' the skill-based behaviour completes the task.

2.10 Manual Flying Skill

There has been very little research published on the subject of the change in manual flying skill experienced by crews of highly automated aircraft. Most of the comments arise from questionnaires and interviews which rely on subjective feedback of the change in perceived skill. However, it is consistently reported that there is a discernible reduction in manual flying skills that is correlated with the use of automation and the task, whether it be long haul or short haul.

3 Previous Studies

3.1 A Study of Pilots' Model and Awareness of the FMS 1992/4

Sarter and Woods (1994) report the second part of a two-stage study into pilot-FMS interaction. The first part (Sarter and Woods 1992) gathered reports of problems noted by crews transitioning from conventional to glass cockpit aircraft. These reports formed the basis for a categorisation of problems associated with pilot mental models and mode awareness of FMS behaviour. The second part involved 20 experienced pilots executing scenarios based on the problems identified using FMS part-task trainers. The results, which were consistent with other research (Norman, 1990, Weiner, 1989) up to this point, indicated that although pilots were competent in normal operational situations there were gaps in the pilots' understanding of the functional structure of the automation which became apparent in non-normal, time-critical situations. Additionally, pilots may not be aware of the gaps in their knowledge about FMS functionality.

4 FAA HF Team Report 1996

4.1 As a result of the Nagoya accident, A300-600 26 April 1994, and other incidents that highlighted the difficulties in flight crew interacting with flight deck automation, the FAA conducted a study to evaluate the interfaces between flight crew members and the automation found in modern aircraft (FAA, 1996). The team reported concerns regarding pilot understanding of the automation's capabilities, limitations, modes, and operating principles and techniques. Additionally, they reported differing pilot decisions about the appropriate level of automation to use or whether to turn the automation 'on' or 'off' when they get into non-normal situations. The report also highlighted potential mis-matches between manufacturers' assumptions about how the flight crew will use the automation. Furthermore, the report commented on the vulnerabilities in situational awareness, such as: mode awareness and flightpath awareness, including terrain and energy awareness.

4.2 The team concluded that these “vulnerabilities are there because of a number of interrelated deficiencies in the current aviation system” (FAA, 1996 p3).

- Insufficient communication and co-ordination between organisations such as research, design, regulation and operators
- Processes used for design, training, and regulatory functions inadequately address human performance issues
- Insufficient criteria, methods and tools for design, training, and evaluation to promote human-centred automation and minimise hazardous situations
- Insufficient knowledge and skills of designers, pilots, operators, regulators and researchers. "It is of great concern to this team that investments in necessary levels of human expertise are being reduced in response to economic pressures when two-thirds to three-quarters of all accidents have flightcrew error cited as a major factor" (FAA, 1996 p3).
- Insufficient understanding and consideration of cultural differences in design, operations, and evaluations.

4.3 BASI Advanced Technology Aircraft Safety Survey Report 1998

The Australian Bureau for Air Safety Investigation report (BASI, 1998 p.ix) presents the results of a survey which was distributed within the Asia-Pacific region. “Of the 5000 copies distributed 1,268 (approximately 25%) completed surveys were returned. Pilots expressed strongly positive views about advanced technology aircraft; however, several potential problems were identified. Pilots reported some difficulties with mode selection and awareness on flight management systems. However, most pilots did not consider that too many modes were available. Many respondents gave examples of system 'work-arounds' where they were required to enter incorrect or fictitious data in order to ensure that the system complied with their requirements. The most common reasons for system 'work-arounds' were to comply with difficult air traffic control instructions and to compensate for software inadequacies during the descent approach phase of flight. [...] Pilot technical training, although frequently conducted using advanced computer-based methods, is not necessarily providing pilots with all the knowledge required to operate their aircraft in abnormal situations. The skills and training of instructors also emerged as an issue of concern to some pilots, particularly as many instructors have had no training in instructional techniques. Traditional airline check-and-training systems, developed to maintain flight standards on earlier generations of aircraft, do not necessarily cover all issues relevant to the operation of advanced aircraft. For example, the survey identified that there is the potential for pilots to transfer some of the responsibility for the safety of flight to automated systems, yet problems such as this are not generally addressed by check-and-training systems.

4.4 Assessing Error Tolerance in Flight Management Systems 1998

Courteney (1998) presented the results of a study spanning eight fleets of three major UK operators and 2066 sectors by crews experienced in FMS operations. The survey reported 'operational events' using the classification of: 'Work-around' 33%, Incompatible with environment 19%, Automation discarded 16%, System logic not clear 11%, Automation adds to workload 9%, Anomaly in display 8%, Loss of situation awareness 3%, Feedback inadequate 1%. This study reinforces the conclusions of the BASI study by highlighting the predominance of 'work-arounds' indicating that pilots develop their own procedures that were not discussed or presented in training to adapt the FMS function to the operational environment. This study raises the question that there are human factors issues beyond the more commonly accepted problems of mode complexity. “This includes crew being distracted by incompatibility between the FMS design and the operating environment, incorrect data and anomalies in the system, as well as training and procedures that are not sufficient for comprehensive system utilisation”.

4.5 ECOTTRIS 1998

4.5.1 ECOTTRIS (European Collaboration On Transition Training Research for Increased Safety) was a two year project (1996-8) initiated and sponsored by the European Commission / Directorate General for Transport. The research was designed to improve the existing transition training procedures for pilots moving from conventional to advanced automated cockpits. The study reported a striking lack of standardisation between, and within, manufacturers for design philosophies of automated systems. On top of that airlines then adopt different Standard Operating Procedures regards the use of automation e.g. some airlines prohibit the use of certain modes; however, the trend is for an increasing prescription for the use of automation. Incident and accident reports from both European and US sources were analysed. Contrary to previous studies only 6% of reports were concerned with mode awareness but deficient CRM factors accounted for 39%. This was linked with incorrect settings, monitoring and vigilance, inadequate knowledge of aircraft systems, experience and flight handling.

4.5.2 Fifty-eight structured interviews were carried out at a number of European airlines to gauge the opinion of pilots and trainers regarding the current training practices. Predominant views were: insufficient time between end of flying on one type before starting a course on another – no time for preparation; more understanding of systems; better problem solving skills and prioritisation rules to avoid head-down time; requirement for improved documentation; more simulator (or any synthetic training device) time to become familiar with autopilot operation.

4.5.3 Interestingly, this report highlighted the need to address the requirement for manual flying skills – without providing any details or supporting data.

4.6 ESSAI 2003

The Enhanced Safety through Situation Awareness Integration in training (ESSAI) programme sought to offer potential training solutions for improved safety by enhancing Situation Awareness (SA) and Crisis Management (CM) capability on the flight deck. The investigation consisted of a group of 32 participants, half of which were given the proposed training and the other half acted as a control group and were given a standard LOFT exercise. The proposed training comprised a non-interactive DVD, a classroom activity to reinforce skills presented on the DVD and then two demanding LOFT scenarios plus instructor led de-briefs. The results indicated a significant improvement in Situation Awareness skills but little impact was reported on the Crisis Management skills. However, the study did demonstrate that improvements could be made, in the training of cognitive aspects of operating modern automated aircraft, within the existing framework of current airline training programmes.

4.7 HF Implications for Flight Safety of Recent Developments in the Airline Industry 2001

The JAA commissioned a study (Icon, 2001) to determine if there was an impact on flight-deck safety as a result of commercial developments such as: deregulation, liberalisation and privatisation. The report identified three outcomes of commercial developments that have an effect on flight crew:

- multicultural flight crew;
- merging of company cultures; and
- commercial pressures.

Apart from the obvious concerns over differences in languages with multi-national crews there were other potential problems such as: reduced interaction both on- and off-duty, different SOPs, different interpretation of CRM, and differing levels of technical knowledge. It was concluded that when airlines merged or became part of a strategic alliance individual company cultures remained largely unaffected, thus creating the situation of flight-deck crew members operating with differing approaches to the overall task. Increases in commercial pressure were deemed to increase fatigue and the potential to reduce training budgets to the absolute minimum to satisfy regulatory requirements. However, the report highlighted mitigation of these concerns through the appropriate development of CRM and SOPs, and the adoption of an appropriate safety culture within the organisation. These commercial factors will therefore influence automation failures attributable to the organisational elements.

Table 1 Summary Table

Issue	Regulatory position	Possible Shortcomings	Potential Actions
Regulatory Material	Doc 29 and CAP 737 cover and recommend best practice	Previous advice and requirements do not appear to have been fully heeded or used.	Monitor and encourage full implementation
Manual Flying Skills	Assumed that manual reversion is always possible and safe	Manual control often only arises in safety critical situations. Practice is infrequent and omits 'mental surprise' element.	Research needed to quantify the loss of manual skill in pilots
	Manual flying is defined as the motor control skills required to physically control the aircraft	May be poor understanding of how automation works that leads to reverting to manual flight.	Improved training in use of automation may reduce the need for manual flying skills
	Assumed pilots will continue with mental approach of 'reality checks' and challenging information	Evidence suggests that pilots do not challenge information presented by automated source	Definition of 'manual flying skills' should be reviewed and broadened to include mental / planning skills and reality checking
		Training does not succeed in standardising the criteria pilots use to decide when to intervene in an automated process.	Improve guidance for pilots on when to abandon automation
Licensing / Knowledge	Ensures competence in operation of automation in the majority of normal situations.	Fails to prepare pilots for operation of automation in many non-normal and some normal situations	Explore range of non-normal situations and best options for action for each group of circumstances
	Provides 'declarative' system knowledge i.e. 'how it works'	Fails to provide 'procedural' knowledge of how to deal with control of the flight path using automated features in an operational context i.e. 'how to do it'	Review training syllabus Define and produce training material to bridge this gap
Situation Recognition	Training allows pilots to practice responding to specific predetermined events	No practice in recognising situation (including those due to previous crew errors) and selecting appropriate responses.	Define and implement training that would bridge this gap

Table 1 Summary Table

Issue	**Regulatory position**	**Possible Shortcomings**	**Potential Actions**
Training Formula	Initial training assumes further instruction. Assumed that pilots can learn and practice full range of situations 'on the line'	Automation is treated as a system rather like electrics or hydraulics rather than an integral component of the flight deck task	Explore possibilities for improved training and practice in context
	Training Captains are experienced on Type and assumed to therefore be capable of providing adequate supplementary training in automation	Unable to generate or demonstrate full range of circumstances or effects of actions during passenger flights	Define and produce training material for Training Captains e.g. a DVD on how to train automation
		No requirement for Training Captains to posses in-depth knowledge of automation nor knowledge of human performance and optimal training methods for effective learning	
Organisation	Good Crew Resource Management (CRM) and Human Performance and Limitations (HP&L) training now implemented throughout industry	Many senior airline staff responsible for policy decisions qualified before these improvements were introduced ('pre '92 man'). Such individuals may have a limited (and tainted) view of the value of CRM and HP&L approaches.	Require all pilots and management pilots to undergo the current CRM (and HP&L?) training Or Define and produce training material for 'pre '92 man'
System Design	Aircraft systems are assessed during Type Certification for their airworthiness, vulnerability to failure and (to some extent) their usability within the confines of the aircraft	Complex systems may work perfectly but have incompatibilities with the world beyond the aircraft itself e.g. the Air Traffic System and / or information systems that are provided to the crew. This results in “work arounds” that increase workload and may have unforeseen consequences.	Reinforce to certification staff the use of new regulatory material (INT/POL/25/14 and imminent NPA) to ensure that compatibility with external environment is considered during Type Certification.

Glossary

AP	Auto Pilot
ACARS	Aircraft Communicating And Recording System
ASRS	Air Safety Reporting System (USA)
ATC	Air Traffic Control
ATPL	Air Transport Pilots License
BASI	Bureau Air Safety Investigation (Australia)
CAA	Civil Aviation Authority
CAP	Civil Aircraft Publication
CBT	Computer Based Training
CHIRP	Confidential Human Factors Incident Reporting Programme
CRM	Crew Resource Management
GPWS	Ground Proximity Warning System
HF	Human Factors
MOR	Mandatory Occurrence Report
ECOTTRIS	European Collaboration on Transition Training Research for Increased Safety
ESSAI	Enhanced Safety through Situation Awareness Integration
FAA	Federal Aviation Administration
FAST	Future Aviation Safety Team
FCL	Flight Crew Licensing
FMS	Flight Management System
FODCOM	CAA Flight Ops Dept Communication
ILS	Instrument Landing System
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
JSSI	Joint Strategic Safety Initiative
LNAV	Lateral Navigation
LOFT	Line Orientated Flight Training
LPC	License Proficiency Check
NDB	Non Directional Beacon
OPC	Operational Proficiency Check
OPS	Operations

SOP	Standard Operating Procedure
SRG	Safety Regulation Group (CAA)
VOR	VHF Omni Range finding