Department of Transport and Regional Dedvelopment

Bureau of Air Safety Investigation

Advanced Technology Aircraft Safety Survey Report

Released by the Secretary of the Department of Transport and Regional Development
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ISBN 0 642 27456 8 June 1998

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ACKNOWLEDGMENTS

The Bureau of Air Safety Investigation wishes to acknowledge the contributions of the following organisations and individuals:

- Airbus Industrie
- Ansett Australia
- Cathay Pacific Airways Limited
- Qantas Airways Limited
- The Boeing Company
- Orient Airlines Association (now known as the Association of Asia-Pacific Airlines)
- Dr Barbara Kanki (NASA)
- Dr Ashleigh Merritt (University of Texas)
- Dr Earl Wiener (University of Miami)

ABBREVIATIONS

AAPA	Association of Asia-Pacific Airlines
ACAS	Airborne Collision Avoidance System
AFDS	Autopilot and Flight Director System
A/T	Auto Throttle
ATC	Air Traffic Control
CRM	Crew Resource Management
CRT	Cathode Ray Tube
DME	Distance Measuring Equipment
ECAM	Electronic Centralised Aircraft Monitoring
EOD	End Of Descent
FAA	Federal Aviation Administration (USA)
FLCH	Flight Level Change
FMA	Flight Mode Annunciator
FMC	Flight Management Computer
FMGS	Flight Management Guidance System
FO, F/O	First Officer
HDG SEL	Heading Select Function
IATA	International Air Transport Association
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
kts	Knots
LCD	Liquid Crystal Display
LNAV	Lateral Navigation
LSALT	Lowest Safe Altitude
LVL CHG	Level Change
MCP	Mode Control Panel
MSA	Minimum Safe Altitude
NM	Nautical Miles
NASA	National Aeronautics and Space Administration
SID	Standard Instrument Departure
SOP	Standard Operating Procedures
STAR	Standard Terminal Arrival Route
TCAS	Traffic Alert and Collision Avoidance System
V/S	Vertical Speed
VNAV	Vertical Navigation
VOR	VHF Omni-Directional Radio Range

SYNOPSIS

Jet transport aircraft equipped with basic automated flight control systems and electromechanical displays have given way to new generations of aircraft equipped with highly automated flight management systems and cathode ray tube or liquid crystal displays.

The advent of new technology has significantly changed the work of airline pilots and has had implications for all elements of the aviation system, including safety regulators, air traffic services and air safety investigators.

Each new generation of aircraft has resulted in safer and more efficient flight; however, new technology also has the potential to introduce new challenges and potential operational difficulties. Air safety investigators and researchers worldwide have witnessed the emergence of new human factors problems related to the interaction of pilots and advanced cockpit systems.

Several major airline accidents have been related to such difficulties.

BASI has a role to identify deficiencies before they lead to accidents, and conducted this research into advanced technology aircraft to pro-actively identify safety deficiencies.

With the cooperation of member airlines of the Association of Asia-Pacific Airlines (AAPA) (formerly the Orient Airlines Association (OAA)), BASI developed a survey designed to explore the safety issues of advanced technology aircraft. The survey contained questions designed to evaluate pilot attitudes to advanced technology aircraft and to give pilots the opportunity to provide written comments on their experiences with advanced technology aircraft.

Five thousand copies of the survey were distributed within the Asia-Pacific region; 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.

Crew coordination on advanced technology aircraft remains a potential problem and a significant proportion of respondents reported that they had experienced communication problems with another crew member.

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 continuing incidence of such work-arounds indicates that designers have not yet achieved optimal systems compatibility.

It is apparent that air traffic control systems do not always utilise the advantages of advanced aircraft to their fullest and sometimes impose requirements on advanced aircraft which are not easily achieved. There is scope for greater coordination between air traffic controllers and operators of advanced technology aircraft. In particular, future air traffic control systems and procedures need to be designed to take account of the characteristics of advanced technology aircraft. [for example, 'communications, navigation, surveillance / air traffic management' systems will be included in a new generation of FMGS.]

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.

The report concludes with recommendations addressing issues of system design, training, human factors and the interface between air traffic control and advanced technology aircraft.

INTRODUCTION

Definitions

For the purpose of this study, advanced technology aircraft, or automated aircraft, were defined as aircraft equipped with cathode ray tube/liquid crystal displays and flight management systems, such as Boeing 737-300, 737-400, 767, 747-400, 777, and Airbus A310, A320, A330 and A340.

Automation is the allocation of functions to machines that would otherwise be allocated to humans. Flight-deck automation, therefore, consists of machines which perform functions otherwise performed by pilots (Funk, Lyall & Riley 1996).

Background

Accident, incident and anecdotal evidence indicates that the introduction of new technology to aviation has generally resulted in benefits to safety and efficiency (Norman & Abbott 1988), but has also resulted in a range of new human factors and operational difficulties. BASI's advanced technology aircraft research project was begun in response to a number of perceived problems such as data entry errors, monitoring failures, mode selection errors and inappropriate manipulation of automated systems.

Phase 1 of this project included a literature review which identified major concerns with advanced aircraft, including pilot complacency, potential loss of skills, and loss of situational awareness. There have been several previous surveys concerned with advanced technology aircraft safety issues. Wiener (1989) surveyed errors made by pilots of Boeing 757 aircraft and Wiener and others (1991) compared the DC9 with the MD 80, looking at errors in the operation of both aircraft types. James and others (1991) surveyed over 1,000 pilots on their attitudes to advanced aircraft but focussed on opinions rather than error types. Lufthansa also surveyed A310 pilots (Heldt 1988) with an emphasis on opinion regarding cockpit layout and design. Although advanced systems have the potential to reduce errors and to make the systems more error tolerant, they can also introduce new forms of error. NASA researchers have suggested that advanced systems have the potential to elicit more severe errors than electromechanical systems (Wiener 1989). While reliability has not been a major issue with advanced systems, there have been occasional instances of system irregularities.

Previous international surveys have identified that although pilots have a generally positive view of new technology, some system interface difficulties are occurring with advanced systems. This is reflected in systems behaving in unanticipated ways, pilots inappropriately manipulating automated systems, and 'user errors'. These concerns have also been reinforced by the recent study conducted by the FAA (Federal Aviation Administration 1996). Rather than laying the blame for these problems at the feet of the pilots alone, it is useful to see such difficulties as *system-induced* abnormalities. Although the term 'error' is used throughout this report, it is not intended to imply blame or culpability.

Issues are not necessarily being identified by existing government and airline safety systems for the following reasons: human factor incidents tend to be under-reported; there is often a resistance to reporting for fear of adverse consequences; and, perhaps most importantly, pilots may perceive errors as very minor, perhaps not recognising that they may be indicators of larger problems.

The second phase of the project was commenced with the belief that aviation safety will benefit from the collection and dissemination of information on specific operational problems.

Scope

This report deals with information supplied by respondents to the Advanced Technology Aircraft Safety Survey and provides a detailed analysis of answers to both the 'open' and 'closed' questions.

The accompanying analysis does not include responses to closed questions by second officers or McDonnell Douglas pilots due to their disproportionately low representation within the sample. However, all written comments made by all respondents have been included and analysed.

The survey covers a range of technologies from the early 1980s to the present. However, the survey sought pilots' perceptions of the technology that they were using. Despite any differences in technology, the Bureau believes that the survey results are applicable to aviation in the Asia-Pacific region.

Objectives

The objectives of the phase 2 study were to:

- Determine specific types of human/system interface problems that are occurring on advanced aircraft in service within the Asia-Pacific region;
- Collect information on flight-deck errors;
- Assess the severity of errors;
- Identify design-induced errors; and
- Identify areas where pilots inappropriately manipulate automated systems.

Method

Phase 2 included the drafting and distribution of a questionnaire. Questions were based on:

- personal interviews with flight crew;
- flight deck observation; and
- personal interviews with airline management.

The draft questionnaire was trialed within two Australian airlines and the results were published in a BASI report (Bureau of Air Safety Investigation 1996). The questionnaire was then modified on the basis of comments provided by respondents via a survey critique. Details of the survey questionnaire are included as the final section of this report.

Five thousand and twenty-three survey forms were distributed through the flight safety departments of participating member airlines of the AAPA.

One thousand two hundred and sixty-eight surveys were returned by the specified reply date, representing a 25.24% return. Completed questionnaires were returned in sealed envelopes to BASI via the flight safety departments of participating airlines, or for Australian Airlines, via a prepaid envelope.

The survey contained 42 attitude probes or Likert scale items designed to elicit pilot opinion over seven topics.

> A Likert scale is a standard tool in attitude assessment. It is a form of 'intensity scale', whereby not only the direction but intensity of the response is measured. An item consists of a 'probe', which is a positive or negative statement with which the respondent was asked the degree of agreement/disagreement. The response scale contains an odd number of possible responses, ranging from agree through neutral to strongly disagree. The center response is somewhat ambiguous: it can mean 'no opinion', 'undecided' or a truly neutral

position on the probe. In this study, five response levels were employed: 'strongly agree', 'agree', 'neutral', 'disagree' and 'strongly disagree' (Wiener 1989).

Open-ended questions gave respondents the opportunity to provide detailed comments regarding their opinion on specific subjects.

The results of the 'closed' (Likert scale) questions were recorded in a database before being statistically analysed using the Statistical Package for the Social Sciences (SPSS Version 6 for Windows). The 'hand-written', or 'open', responses were similarly recorded in a database before being manually analysed by a team of six raters.

Participation was voluntary and no incentives were provided to any of the respondents to complete the survey form.

Confidentiality

All volunteers were assured of confidentiality. The survey cover included the following statement:

> 'As this survey does not require you to identify yourself, all information supplied is COMPLETELY CONFIDENTIAL'.

The survey form contained no codes that would allow researchers to identify an individual. Survey responses were entered into a database as they were received and no attempt was made to order surveys returned from any particular flight safety department.

Archiving

All survey forms were retained in accordance with the Australian Government Public Service General Disposal Authority No. 14.24.2.1.

Statistical analysis

All results contained in this report relating to differences between demographic categories (e.g. pilot rank, age, nationality or aircraft manufacturer) are statistically significant. An alpha level of 0.05 was used for all statistical tests.

Report – figure and table numbering

Numbering of figures and tables in the report does not follow the standard. Beginning at chapter 1 of the ANALYSIS, the numbers allocated to figures and tables reflect those allocated to the corresponding questions in the survey form. For example, fig. B2.4 graphically depicts the distribution of the answers to question 2.4 in part B of the survey form.

The sample – summary

The following information summarises the demographic data provided in response to questions in part A of the survey.

The accompanying analysis does not include information pertaining to second officers or pilots of McDonnell Douglas aircraft due to their disproportionately low representation within this sample. However, written comments made by all pilots have been included and analysed.

Table 5.1 shows demographic data for respondents according to pilot rank, age, gender, average experience on type, and average total aeronautical experience.

Table 5.1
Summary of demographic data by pilot rank

	Captain	1st Officer	2nd Officer	Unknown	Total
Respondents	699	457	89	23	1,268
Average age	46	35	32	41	–
Male	697	448	87	6	1,238
Female	1	7	1	0	9
Unspecified gender	1	2	1	17	21
Average experience on type	2,776	1,829	958	2,409	–
Average total aeronautical experience	12,662	6,262	4,396	10,358	–

Table 5.2 indicates the current aircraft type flown by respondents at the time of the survey.

Table 5.2
Current aircraft type

Airbus		Boeing		MD		Other	
A320	87	B747/400	524	MD-11	18	Unknown	11
A310	42	B767	299	DC-10	1		
A340	29	B737	222				
A330	27	B777	2				
A300-600	6						
Total	191		1,047		19		11

- The majority of respondents (68%) were 'line pilots'. The remaining 32% of respondents were represented by management pilots (5%), check pilots (8%), training pilots (8%), supervisory pilots and company test pilots (1%). One hundred and thirty pilots (10%) did not provide their rank.
- Approximately 42% of respondents flew 'international long haul routes'. International long-haul routes were defined as flights crossing more than one international boundary e.g. Manila to London, Tokyo to Los Angeles, Jakarta to Jeddah.
- Pilots reported their nationality as Australian (51%), Singaporean (12%), New Zealander (11%), British (10%), Malaysian (5%), Canadian (3%), Korean (3%), Indonesian (2%), and other (3%).
- The majority of pilots recorded their first language as English (90%), and most (66%) indicated that they did not speak a second language. This figure is influenced by the large number of Australian English speakers in the sample.

ANALYSIS

Introduction

The following analysis has been organised into 12 topical chapters. Each chapter commences with an introduction, followed by an analysis of those elements of the questionnaire that fall under the topic area. Chapter 13 contains recommendations which arise from the preceding analysis, and chapter 14 contains a general conclusion.

Organisation

For the purpose of analysis each of the closed questions contained in the questionnaire was allocated to one of the following 10 groups (see table 1):

Table 1
Organisation of data analysis

Chapter	Question number
1. Air traffic control	2.1, 2.2, 2.3, 2.4, 2.5
2. Automation	1.5, 1.6, 1.7, 7.4
3. Crew resource management	7.1, 7.2, 7.3, 7.4
4. Flying skills	5.1, 5.2
5. General	9.1, 9.2, 9.3, 9.4, 9.5, 9.6
6. Mode	1.10, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8
7. Situational awareness	4.1, 4.2, 4.4, 4.5
8. System design	1.1, 1.2, 1.3, 1.4, 1.8, 1.9, 5.3
9. Training	8.1, 8.2, 8.3, 8.4, 8.5, 8.6
10. Workload	6.1, 6.2, 6.3, 6.4

AIR TRAFFIC CONTROL

Introduction

During the questionnaire design phase some airline managers expressed concern that the safe operation of advanced technology aircraft could be threatened by potential incompatibilities between aircraft automation and ATC procedures, systems and airways design.

The ATC environment in which advanced technology aircraft operate has become increasingly complex. Some ATC systems have undergone technological change comparable to that of the aircraft they are designed to manage. Within the Asia- Pacific region, most ATC centres have made technological changes, or have plans in place to adopt new technologies that include modern radar facilities, remote very high frequency (VHF) communications and computer aided ATC management systems.

This chapter contains a discussion based on pilot perceptions of the relationship between ATC and advanced technology aircraft, together with an analysis of specific events where pilots had difficulty operating their aircraft in accordance with ATC instructions.

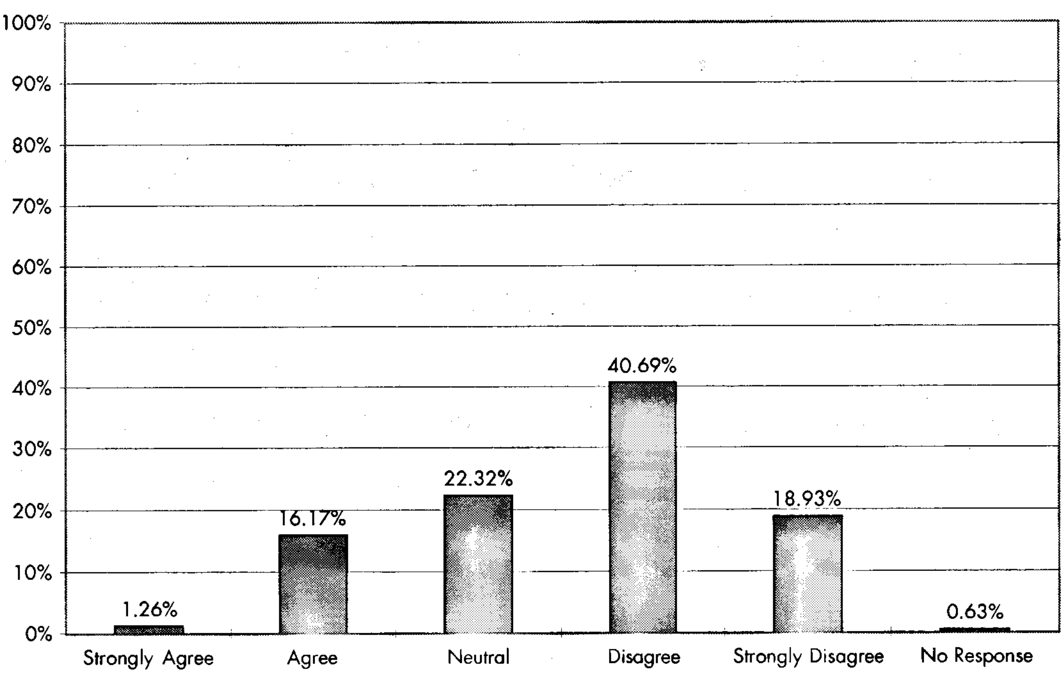
Using the capabilities of advanced technology aircraft

Approximately 60% of respondents considered that ATC did not make use of the capabilities of their aircraft to the fullest (see fig. B2.1).

First officers were observed to be more positive in this respect than captains. Airbus pilots (58%) were more positive than Boeing pilots (61%).

The capabilities available to pilots of advanced technology aircraft include precision flight in both the vertical and lateral planes, enhanced situational awareness through computer generated map displays, and enhanced awareness of other air traffic via the ACAS. Hazardous weather avoidance has also been enhanced by the overlay of airborne weather radar on computer generated map displays. This is particularly important considering that many modern ATC radar displays filter out hazardous weather information.

FIGURE B2.1
Air Traffic Control make use of the capabilities of this aircraft to their fullest



Vertical and lateral navigation systems allow the pilot to program a flight from takeoff to landing in accordance with actual, or expected, ATC clearances. Once the auto-pilot and navigation modes are engaged, the aircraft can follow the programmed route with minimal pilot input or ATC intervention.

The airways system is a complex environment which caters for many different aircraft types and operations. Air traffic controllers are often unable to use the capabilities of advanced technology aircraft to their fullest because they are restricted by other flow control and separation considerations.

On the other hand, some advanced technology aircraft functions do not permit adequate compliance with ATC requirements. For example, anecdotal evidence revealed that some air traffic controllers are aware of the limitations of advanced technology aircraft and have devised their own system 'work-arounds' to ensure timely flow control. During interviews with ATC personnel at Sydney, several staff mentioned that advanced technology aircraft take a longer time to enter and exit holding patterns, compared with earlier model aircraft. Some ATC staff now compensate for this lag in response time by modifying the instructions they issue to these aircraft. For example, if holding is no longer required, ATC may issue the instruction 'cancel holding track direct to'. The aircrew are required to make several keystrokes on the FMC to exit the holding pattern and program a track to the next waypoint. To ensure this process is completed in a timely manner, some ATC staff may issue specific instructions, such as 'cancel holding, turn onto a heading of'. Once the aircraft is established towards the next desired waypoint they will instruct the aircraft to 'track direct to'.

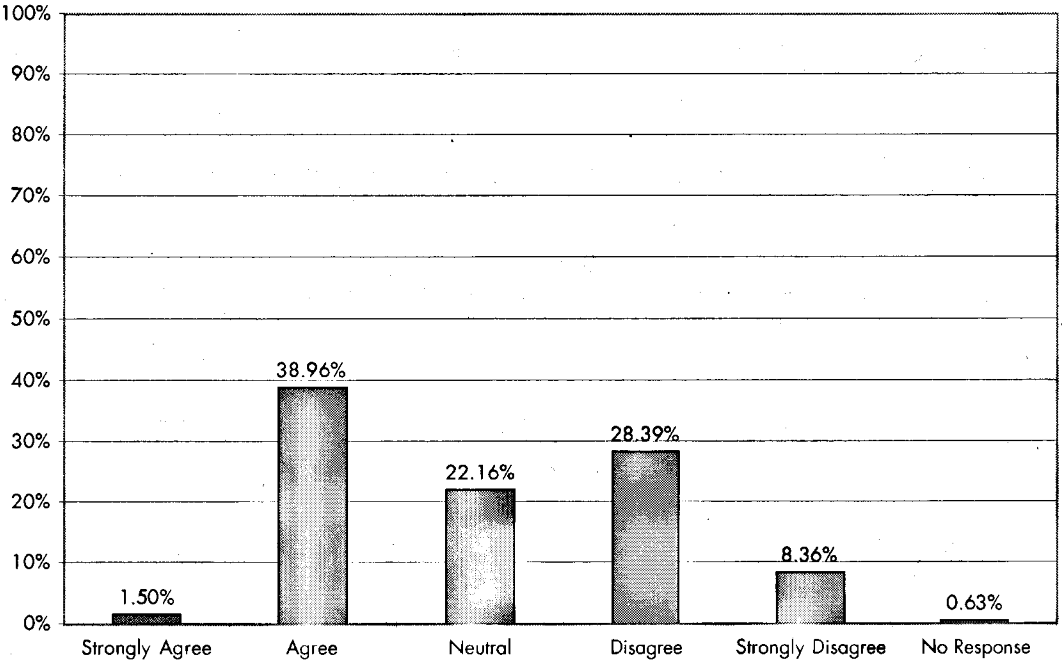
ATC familiarity with modern aircraft aerodynamics

Figure B2.2 shows that 40% of respondents were satisfied with the level of ATC familiarity with their aircraft, while 36% were not satisfied. The results were evenly distributed across pilot ranks, although Airbus pilots were less satisfied than Boeing pilots.

Pilots commonly pointed out that the aerodynamics of modern jet aircraft did not always allow them to reduce airspeed and descend ('slow down and go down') simultaneously. The design and execution of ATC flow control measures needs to take into account the performance and operational characteristics of modern jet aircraft.

There appears to be a general lack of appreciation by both pilots and ATC staff regarding the requirements of each other's operation. Past familiarisation/observation activities have been of limited value, mainly due to the lack of an integrated program where participants are required to observe and report on specific aspects of an operation.

FIGURE B2.2
Air Traffic Control appears to be familiar with the descent profile of my aircraft

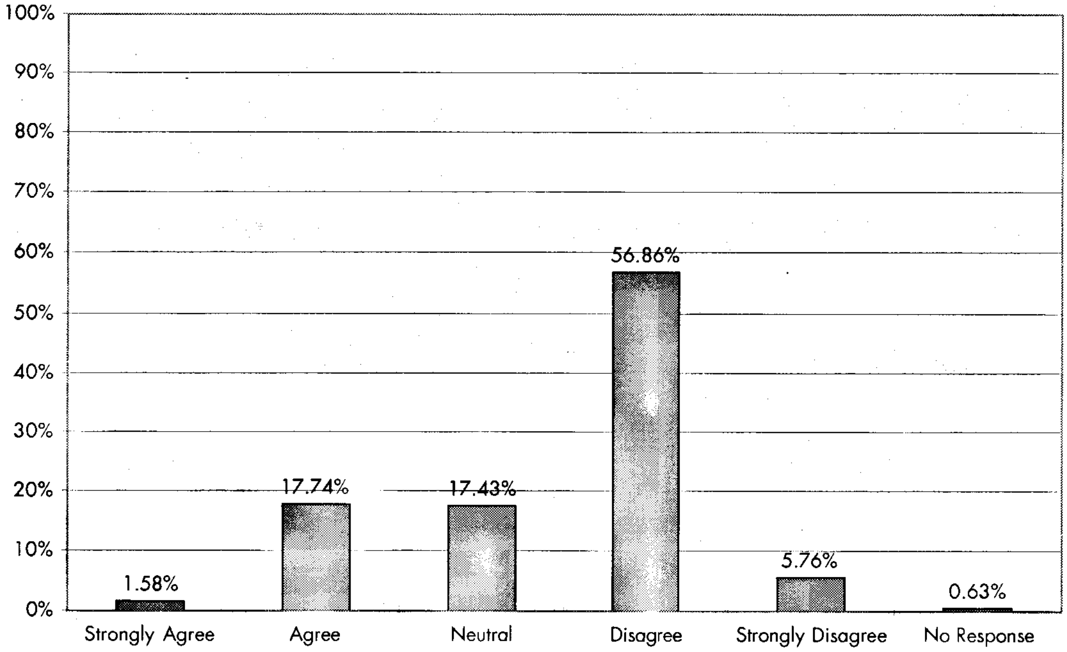


Automation's response to ATC requests for information

Figure B2.3 indicates that most crew did not agree that air traffic controllers sometimes asked for information which is difficult to extract from the FMC/FMGS in a reasonable amount of time.

This finding proved to be contrary to information received during flight deck observations, where pilots expressed their concern that not all air traffic controllers were aware of what the crew were required to do to extract information from an FMC/FMGS in response to ATC queries. Pilots reported that sometimes the most difficult queries to answer relate to time/distance/altitude information while at low altitude following takeoff. There is no suggestion that such requests for information are not justified; however, whereas the response from the crew of an older aircraft may be no better than an educated guess (based on the existing performance of the aircraft), the crew of modern aircraft are more likely to rely on the calculations of the FMC. Difficulty may arise when the crew are required to use data outside the programmed flight-planned data.

FIGURE B2.3
Air Traffic Controllers sometimes ask for information which is difficult to extract from the FMC/FMGS in a reasonable amount of time

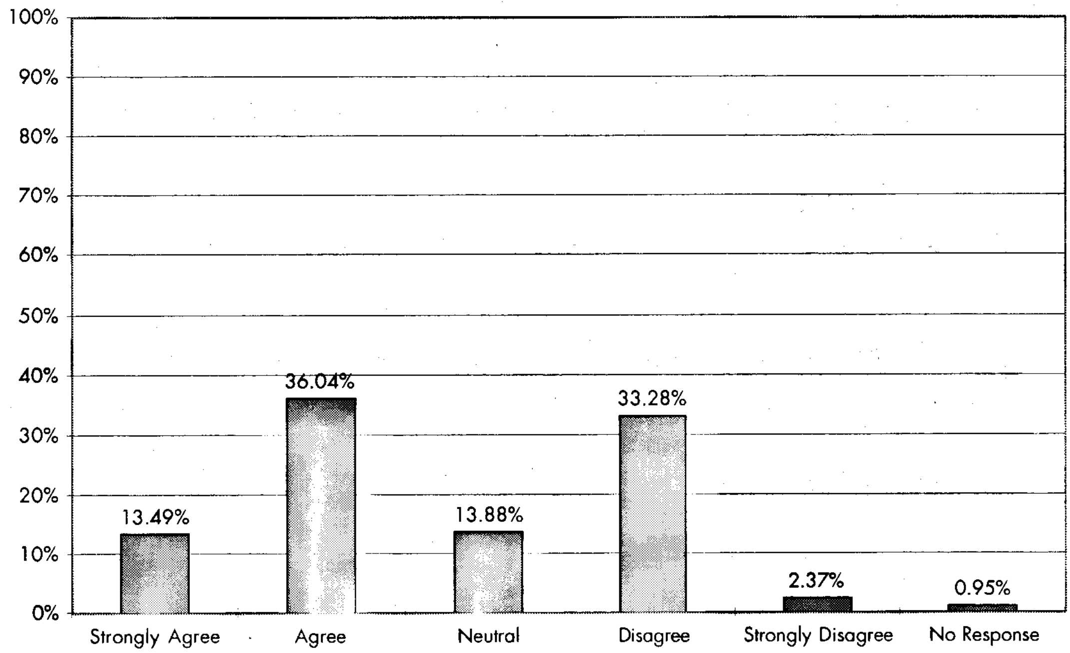


The ability of automation to cope with changes imposed by ATC

Figure B2.4 shows that approximately 50% of crew agreed with the statement that the current level of automation did not cope well with the last-minute changes imposed by ATC. Aircrew expressed the concern that what once may have been a relatively simple task (such as a change of runway, SID, or STAR) may now be much more complicated.

Modern aircraft operate most efficiently when subjected to minimum disruption to ATC clearances (for example, changes to STARs). The intervention service provided by ATC does not seem compatible with the safe and efficient operation of modern automated aircraft. The response to this question highlights the fact that aircraft and airspace/procedures design have not advanced at the same pace.

FIGURE B2.4
The current level of automation does not cope well with the last minute changes imposed by Air Traffic Control

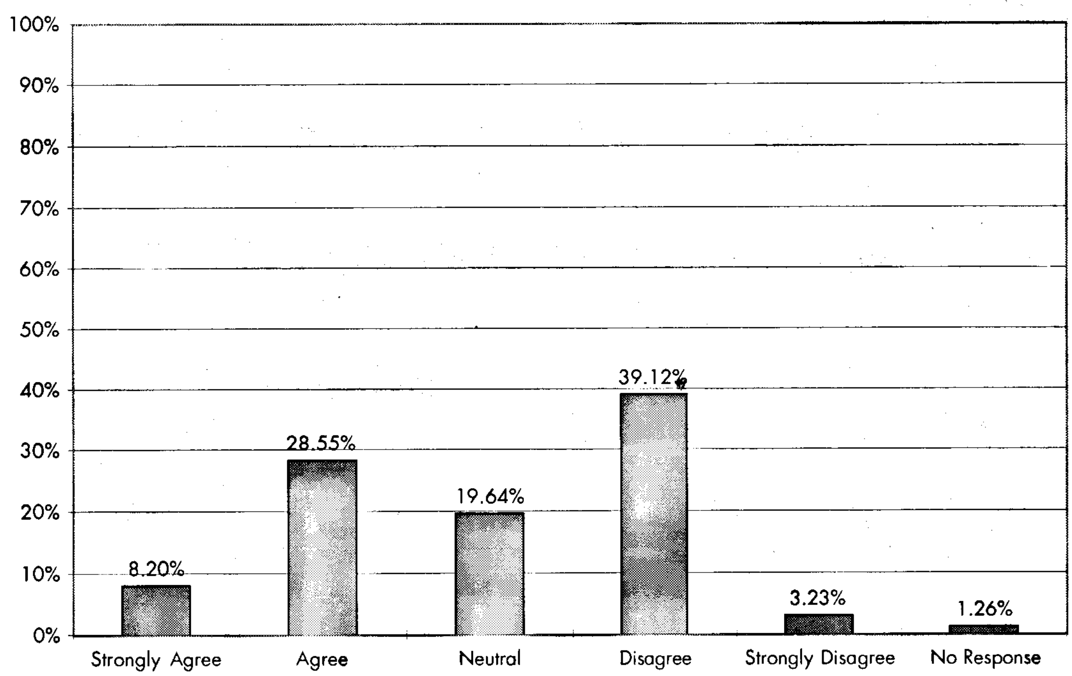


Programming below 10,000 ft

Some pilots (36.75%) were concerned that there was too much programming activity below 10,000 ft (see fig. B2.5).

This question related directly to the way in which ATC processed aircraft, especially during the arrival phase, and the methods by which pilots controlled their aircraft. It also reflected on the familiarity of both pilots and controllers with the complexities of each other's operation.

FIGURE B2.5
There is too much programming going on below 10,000 feet



ATC procedures by geographical area

Approximately 50% of respondents indicated that they were concerned about ATC procedures within a specific geographical area (B2.6).

Respondents were grouped into one of seven categories according to their response to question A2, which asked pilots to nominate which routes they flew. Pilots were free to nominate any geographical location for which they had a concern. This led to a certain amount of overlap as some respondents may have nominated several different ports (for example, Sydney, Melbourne and Perth), whereas others may have nominated a country (for example, Australia).

Table 2.6 summarises the most frequent responses by pilots in each category.

Table B2.6
Most frequently nominated geographical region by routes flown

Route flown	Summary of responses
Domestic routes	Sydney
Domestic & international short-haul & international long-haul routes	Indonesia
Domestic & international short-haul routes	Sydney
Internationol long haul routes	Indio
International short-haul routes	Sydney, China
International short-haul routes & international long-haul routes	India, China and Indonesia

Domestic routes - Flights which do not cross international borders e.g. Sydney to Melbourne.
International short haul routes - Flights to adjoining airspace e.g. Australio to New Zealand, Singapore to Jakarta, Hong Kong to Taipei.
International long haul routes - Flights crossing more than one international boundary e.g. Manila to London, Tokyo to Los Angeles, Jakarta to Jeddah.

The high proportion of Australian based respondents could account for the prominence of Sydney in three of the seven categories.

Some degree of concern was reported from within all seven categories regarding the relationship between the operation of advanced technology aircraft and ATC procedures in various geographical locations. Sixty-one locations were nominated by pilots responding to question B2.6.

These locations incorporate various levels of ATC services, ranging from the most advanced to purely procedural ATC environments. The responses to this question would seem to indicate that advances in technology do not necessarily guarantee better or safer operations.

It should be noted that this survey was conducted prior to the 1996 mid-air collision near New Delhi, India.

Specific events

When asked to outline a specific event where they had difficulty operating an advanced technology aircraft in accordance with an ATC instruction, pilots nominated the following:

- Runway change / late runway change (27%)
- Speed changes / late speed changes (24%)
- STAR / Changes to STAR (17%)

Box 2.7a provides examples of pilot comments concerning programming a change of runway and/or receiving late advice of a change of runway from ATC. This would appear to confirm the responses to part B, question 2.4, where pilots indicated that the current level of automation did not cope well with the last-minute changes imposed by ATC.

The following boxes contain examples from each category.

Change of runway and/or receiving late advice of a change of runway

Box B2.7a

Examples of written responses relating to a change of runway and/or receiving late advice of a change of runway

Arrive into Bangkok, where a request/requirement to change from runway 21R to runway 21C was made. The altitude was 2,000 ft and intercept from the east required a slight 'S' turn to capture the ILS. Some difficulty was encountered changing ILS frequency.

Four runway changes arriving into London on a B747-400 (though it would probably have been difficult in an analogue aircraft). The last two changes were, with localiser captured and the last with both localiser and glide slope captured and auto-pilot engaged.

Several occasions with change of runway and hence SID or STAR in either take-off or arrival situations.

On arrival to Sydney the assigned runway is given too late, as is speed control. These things need to be known before descent begins. Also I believe once a STAR is cancelled it should not be resumed.

Weather at Sydney included heavy rain and low cloud. ATC advised change of runway from 16R ILS to 16 LOC/DME with 18 miles to run. Heavy rain and light/moderate turbulence. Several returns on aircraft radar requiring some manoeuvring. Different runway and approach had to be programmed into FMGC and briefed.

Change of runway in poor visibility at SFO from runway 28R to runway 28L. I was new on the fleet and took a long time to change the ILS frequency, new route/overshoot etc. The B747-300 was definitely faster and easier.

Speed changes, and/or late speed changes where nominated by 24% of respondents, followed by STARs, and/or changes to STAR procedures (17.57%) as the next most difficult events (see box B2.7b).

Speed changes and/or late speed changes

Box B2.7b

Examples of written responses relating to speed changes and/or late speed changes

Last minimum speed and height restrictions. FMC can cope aircraft cannot. ATC knowledge not 100%

The B737-300 does not like to go down and slow down. ATC issue too many speed restrictions, too late.

Speed reduction on descent being given after descent commenced with a restrictive altitude requirement of 8,000 ft. Some difficulty meeting this requirement as VNAV had been programmed for optimum descent profile.

In San Francisco they require us to slow down, descend to a lower altitude and expect an early turn to final approach. On top of this a change in runway occurred while we were intercepting the initial runway. The workload had increased a lot and the FMC took a long time to be reprogrammed, i.e. stand-by mode kept popping up.

Being required to maintain 250 kts for separation on descent then required to expedite descent. The two are incompatible.

Requested 350-kt descent to initial approach fix by ATC, input info into FMC, descent commenced. Half-way down radar instructed us to contact approach. Upon change-over told to reduce airspeed to 250 kts putting us very high on profile.

STARs and/or changes to STAR procedures

Box B2.7c

Examples of written responses relating to STARs and/or changes to STAR procedures

STAR arrival Sydney - three changes to STAR in 10 minutes.

Reloading STARs, with last minute changes due poor ATC.

Last minute changes, STAR or descent speed changes especially if involving new track and or altitude crossing required as STAR has to be entered into FMC and verified.

Arriving into Melbourne on the new STARs (20 June 1996) the speed control changes made, make the altitude requirement difficult.

Late changes to a STAR clearance into Sydney, require a new entry in the FMGS then a confirmation from the Jeppesen chart that the correct procedure is inserted. This takes both pilots to confirm the entry. Meanwhile the new STAR requirements still have to be met and you are not aware of them at this point.

Arrival in Tokyo STAR was pre-programmed and we were cleared via a different arrival. This made for some heads down. On an older plane you would just track to the appropriate VOR or WPT.

To a lesser degree pilots nominated the following as also being difficult to comply with:

- changes to instrument approaches (7%);
- holding patterns (4%);
- unanticipated navigational requirements (4%);
- low altitude level-off (3%); and
- changes to SIDs (3%).

Pilot comments

Changes to instrument approaches

Box B2.7d

Examples of written responses relating to changes to instrument approaches

Direct to VOR then told to intercept 9 DME ARC for a VOR approach (Perth). Aircraft not programmed for that approach and too difficult to program at late stage.

Landing New Delhi, delayed descent way above ILS GS, late clearance into LOC, very late frequency changes with no response on first contact with ATC.

An instruction to discontinue an ILS approach (LOC and GS captured) due conflicting traffic and then a parallel runway side step, to another ILS in marginal (IMC) weather. Equipment not user-friendly and workload high.

Changes of instrument approach of runway at very late notice.

When an aircraft on final approach is 'logged on or captured' on runway 20C and glide slope and ATC requires a change of runway or side-step to a parallel runway.

When fully established on an ILS approach, asked to change over to another runway at short final.

Unanticipated navigational requirements

Box B2.7e

Examples of written responses relating to unanticipated navigational requirements

Instruction to intercept a radial which is not expected. The only sure and safe method is to use raw data and once on the radial use the direct intercept to and then engage LNAV.

Intercepting a VOR radial is sometimes a little difficult on the B767.

Inbound to Sydney on LETTI STAR. At around 40 NM from Sydney, told to track to CALGA and be at or below 7,000 ft by 20 DME. It took us a while to program CALGA (which is not a waypoint but an NDB). Also descent profile was shot to bits by re-route. (Perhaps this is more a case of ATC asking us to do things which exceed quick execution in an FMC aircraft.)

Given direct tracking to a point not in FMC while in terminal area. Had to ask for vectors. Problem with CAA not supplying Jeppesen with new way-points.

Intercepting and track outbound on a VOR radial. Requires a lot of button pushing to fly in LNAV. As there is no VOR LOC mode, only other alternative is increased workload of flying and intercept in HDG mode.

Intercepting a VOR radial is almost impossible on short notice. The aircraft has to be flown in heading select up a fix line or a waypoint and a track built.

When given a 'direct to' clearance to a point I am not familiar with or not on my flight plan, without ATC HDG steer I have to look for the point and enter it into the FMS. I am uncomfortable with the length of time to do it. I have had to ask for initial HDG steer whilst ascertaining the position.

Low altitude level-off

Box B2.7f

Examples of written responses relating to low altitude level-off.

Low altitude level-off i.e. 1,500 ft, 2,000 ft, 3,000 ft.

On departure from a short runway requiring high power, we were given a very low initial level-off altitude. Just after rotation the aircraft captured the assigned altitude but the thrust stayed in THRUST HOLD. Some quick MCP selections were required to stop an overspeed of the flaps occurring.

Level-off after takeoff is an area of concern for me as this causes problems with speed control.

Low altitude level-off after takeoff during turning departure.

ATC runway heading maintain 2,000 ft. Must be very quick with AT, CAB commands to overspeeds/excursions.

Departure Cairns (B767) ATC, maintain 2,000 ft, after takeoff to level off, and keep speed within limits that was beyond the capability of the automatics.

Changes to SIDs

Box B2.7g

Examples of written responses relating to changes to SIDs

Change of departure SID on line up, request to immediate roll, also change of level restriction.

ATC changed the ATC clearance during initial take-off phase.

Sudden last minute changes to departure clearances at Brisbane. Low level altitude restrictions, sudden changes to headings all at odds with initial departure clearance.

Taxiing for departure Sydney with runway change. Figures extracted prior to engine start are now calculated under increased pressure with most cases the captain not checking the figures. Runway change below 10,000 ft Sydney. 8 NM final with runway change from runway 16L to 16R, this requires the support pilot head down in the box for a while.

On departure from Shanghai Airport, given last minute different SID with take-off clearance. Too many changes to FMC.

Frankfurt, last minute change of departure runway to one with minimal taxi time. ATC expected us to be able to just 'line up and go' and were not aware of need to re-calculate data and then re-program the FMC.

The common theme among these comments appears to be that pilots can at times experience difficulty changing a preprogrammed component of the flight. The later the pilot receives the advice of the change, the more difficult it becomes to program the particular change, assimilate new information, accommodate changes and maintain situational awareness. The degree of difficulty may be greater when these changes are carried out in adverse weather conditions. Several situations were reported where it was impossible for the pilot to reprogram the FMC prior to landing. In these cases the pilots elected to go around or hand-fly the aircraft.

Summary and conclusions

Aircraft and ATC systems have undergone significant advances in recent decades. However, the results of this survey suggest that some of these developments have occurred in an uncoordinated fashion and that issues of system compatibility between airborne and ground-based systems have not always been addressed.

Many pilots considered that air traffic controllers do not take full advantage of the capabilities of modern aircraft and sometimes impose unrealistic requirements on pilots. It appears that the design philosophy and aerodynamic characteristics of advanced technology aircraft have not always been considered by the designers of ATC procedures.

Of particular concern are the reports that pilots are sometimes required to disconnect automated systems to comply with ATC requirements, particularly on approach. Automated systems have the potential to improve the safety and efficiency of flight and unnecessary reversions to manual operation are not desirable.

Some individual air traffic controllers appear to be unfamiliar with the descent profiles of advanced technology aircraft. A program of controller familiarisation flights on the flight decks of advanced technology aircraft (or in full-flight simulators) could help to provide this knowledge.

The survey identified the most frequent situations in which pilots had difficulty complying with ATC instructions. These were late changes of runway, speed changes, STARs and changes to STARs, changes to instrument approaches, difficulties with holding patterns, unanticipated navigational requirements, low altitude level-offs and changes to SIDs. As can be seen, most of these difficulties occurred on approach rather than departure. When considering potential improvements in ATS procedures, designers would do well to give particular attention to making approach procedures more compatible with the characteristics and capabilities of advanced technology aircraft.

When asked to identify a location where ATC procedures were of concern, pilots nominated a large range of geographical areas, including regions with advanced ATS systems and regions with less advanced systems. These results will to some extent reflect the pilots' familiarity with various regional ATC systems and the frequency with which they fly in these regions. Nevertheless, the responses to this question seem to indicate that advances in ATC technology do not necessarily guarantee a higher level of pilot satisfaction with the system.

Contrary to anecdotal evidence, the majority of pilots do not agree that controllers sometimes ask for information which is difficult to extract from the FMC/FMGS in a reasonable amount of time. This may reflect the nature of the initial inquiry and the pilot's skill in retrieving information from the FMC. Pilots revealed that their main concerns related to any non-essential requests shortly following takeoff, and requests involving off-track waypoints or navigation aids. These involved considerably more input into the FMC than when pre-programmed data was queried.

There are many aspects of flight operations which affect the analysis of question B2.6 ('I am concerned about the ATC procedures within the following geographical area'), for example, the frequency of flights and familiarity with ATC procedures. Notwithstanding these considerations, the results are not as clear-cut as might be expected. The responses to this question would seem to confirm that advances in technology do not necessarily guarantee a better or safer operating environment.

By nominating specific events where they had difficulty operating their aircraft in accordance with an ATC instruction, pilots have identified several areas where potential mistakes can be made:

- programming a change of runway and/or receiving late advice of a change of runway from ATC;
- speed changes, especially late speed changes;
- STARs, and/or changes to STAR procedures;
- changes to instrument approaches;
- difficulties with holding patterns;
- unanticipated navigational requirements;
- low altitude level-off; and
- changes to SIDs.

Developing an 'automation policy' by airline operators and ATC, or addressing these difficulties through clear and concise standard operating procedures, may minimise the risk of errors.

Recommendations

The Bureau of Air Safety Investigation recommends that Airservices Australia (R980024) and the Civil Aviation Safety Authority (R980025):

Review their airways and procedures design philosophies to:

(a) ensure that STAR, SID and airways design is compatible with aircraft FMS programs;

(b) allow a +/- 10-kt range with respect to descent speed below 10,000 ft to allow for the tolerances of FMS-equipped aircraft, with the aim of reducing the requirement for system work-arounds;

(c) provide ATC personnel with the information on aerodynamic and performance characteristics of advanced technology aircraft; and

(d) seek the co-operation of airline operators for a program of advanced technologies flight-deck observation for all ATC personnel during both their initial and recurrent training.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980026):

Consider a program of flight crew observation of ATC operations during both initial and recurrent flight crew training. Such a program could be incorporated into the syllabus of training and include subjective elements requiring observation and assessment.

AUTOMATION

Introduction

Since 1910 aircraft systems have become progressively more automated. Major developments in automation have included the gyroscopic stabiliser, coupled navigation (DC6), flight management systems (B767), and fly-by-wire with envelope protection (A320).

This chapter analyses the results relating to the current level of automation in advanced technology aircraft and considers the evidence for the existence of cases where the flight crew were not aware of the mode characteristics or aircraft response (automation surprise) and the unconscious transfer of aircraft control and command (passive control) to automation.

The extent of automation

Contrary to anecdotal evidence, only 10% of respondents agreed that 'they've gone too far with automation' (see fig. B1.5).

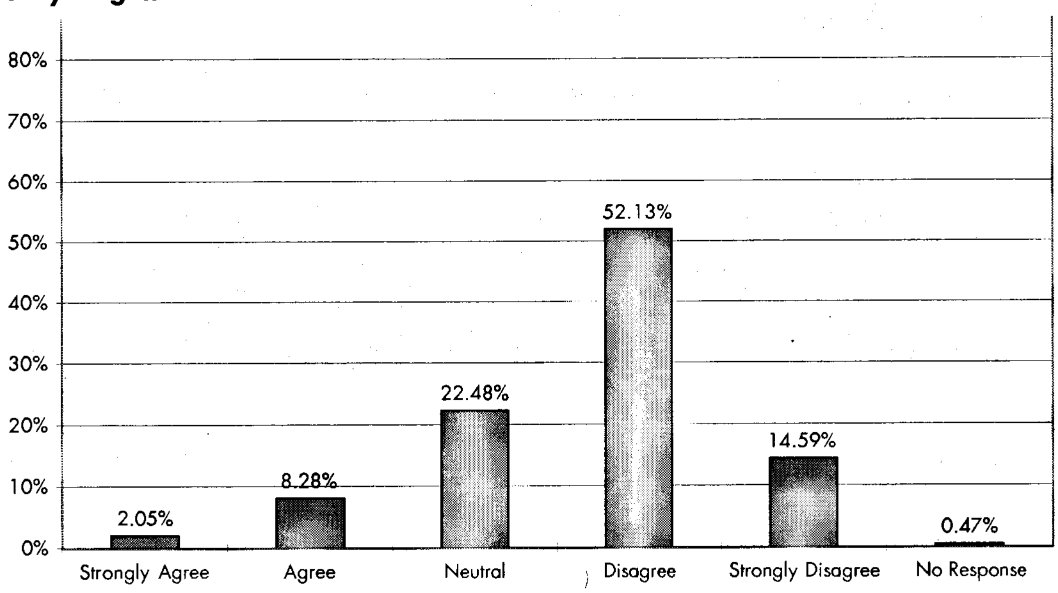
These results are in accordance with the findings of Wiener (Wiener 1989, see chapter 11) and are also consistent with responses received to question B3.5 ('There are too many modes available on the FMC/FMGS'), where only 9% of respondents felt that there were too many modes available on the FMC/FMGS.

Table B1.5 indicates the proportion of pilots who agreed that 'they've gone too far with automation'. A statistically significant difference was observed between the response of first officers and captains, with captains being more likely than first officers to consider that automation had 'gone too far'.

Table B1.5
'They've gone too far with automation.'

	Captain	First officer
Airbus	16%	8%
Boeing	11%	7%

FIGURE B1.5
They've gone too far with automation



Automation surprise

Figure B1.6 shows that 61% of respondents agreed that with automation there are still some things that took them by surprise. Automation surprise can be defined as a weakness in a pilot's mental model of the automated environment that results in the pilot being 'surprised' by the difference between the expected and actual performance of the aircraft. For example, subtle mode reversion (commonly between Vertical Speed mode and Flight Level Change mode) may result in an unexpected change in aircraft performance from what was expected by the pilot. Common verbal responses to automation surprise are 'What is it (the aircraft) doing now?', and 'Why did it (the aircraft) do that?' This weakness has been attributed to a lack of mode awareness and inadequacies in training. Sarter and Woods (1995) have discovered weaknesses in the mental models pilots had developed of how the FMS functions in specific situations. They concluded that training must go beyond teaching how to operate the automated systems to teaching how the automated systems operate. Ongoing learning programs are also needed to help pilots refine their mental models of how automation works.

Table B1.6.1 summarises the responses of those pilots who agreed with the statement, 'With automation there are still some things that take me by surprise'. A statistically significant difference was observed between the responses of Airbus and Boeing pilots. Airbus pilots were more likely to report experiences of automation surprise than Boeing pilots. It should be noted that Boeing pilots had considerably more experience on type than Airbus pilots (see table B1.6.2), and this may account for some of the differences between groups.

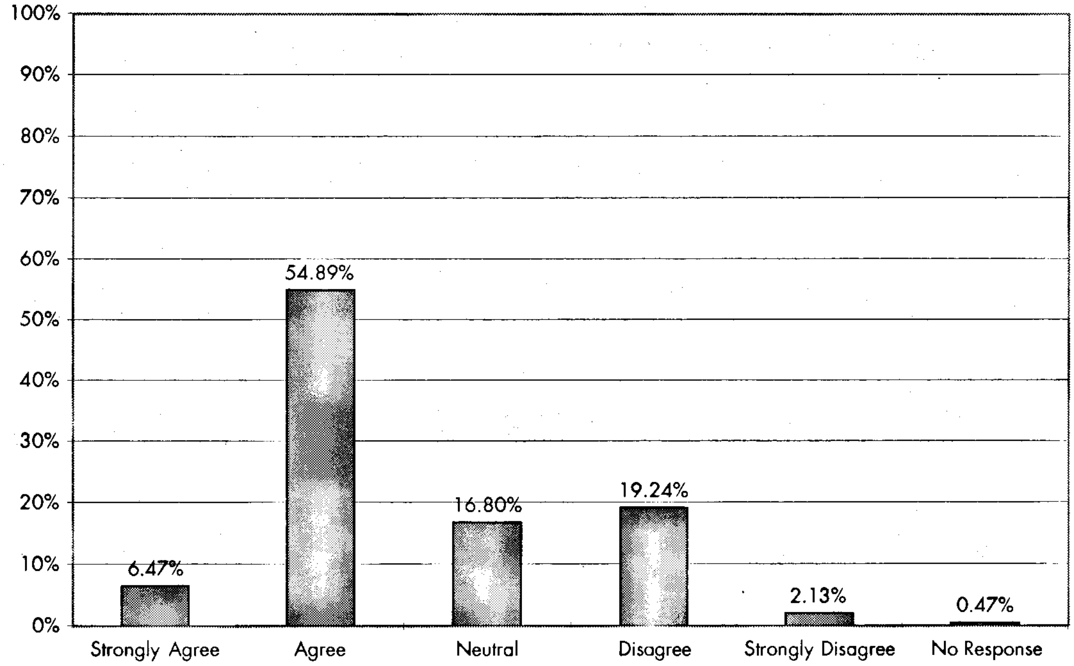
Table B1.6.1
'With automation there are still things that take me by surprise.'

	Captain	First officer
Airbus	68%	73%
Boeing	55%	65%

Table B1.6.2
Hours on type by aircraft manufacturer

	Mean hours on type	Minimum recorded hours on type	Maximum recorded hours on type
Airbus	1,789	5	6,800
Boeing	2,379	10	9,999

FIGURE B1.6
With automation there are still some things that take me by surprise

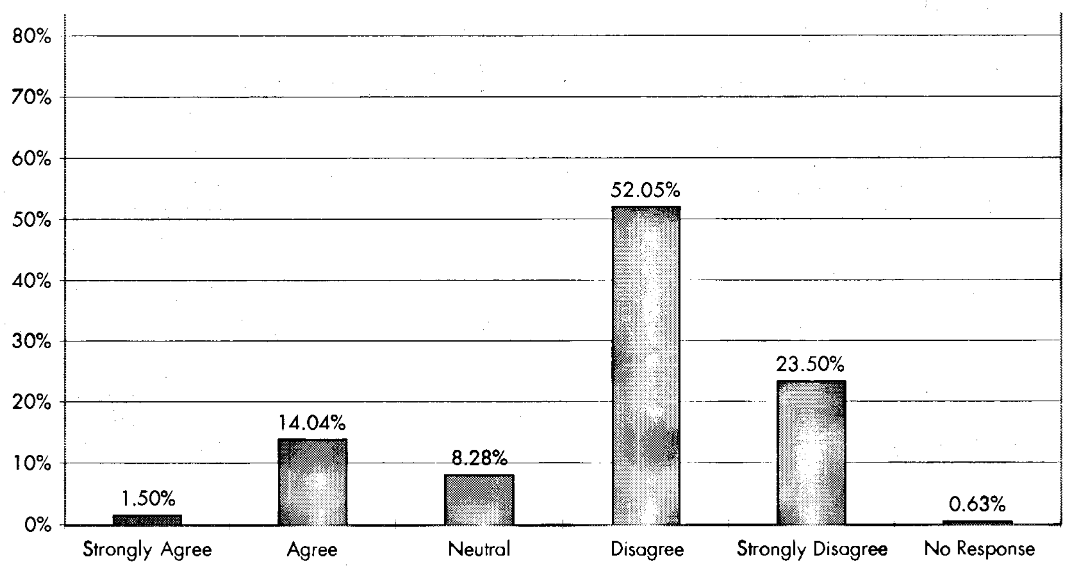


Altitude capture

The weakness in the mental model is not necessarily the fault of the pilot. Poorly annunciated mode changes can leave the pilot several steps behind the aircraft. The pilot anticipates that the aircraft will respond to the last selected mode, whereas the aircraft may have reverted to a sub-mode and will behave in a different manner than expected.

As in the previous question (B1.6), this also provides evidence of a weakness in the pilot's mental model, particularly in relation to mode awareness. Fifteen per cent of respondents indicated that the FMC/FMGS sometimes fails to capture an altitude as they expect (see fig. B1.7).

FIGURE B1.7
The FMC/FMGS sometimes fails to capture an altitude as I expect



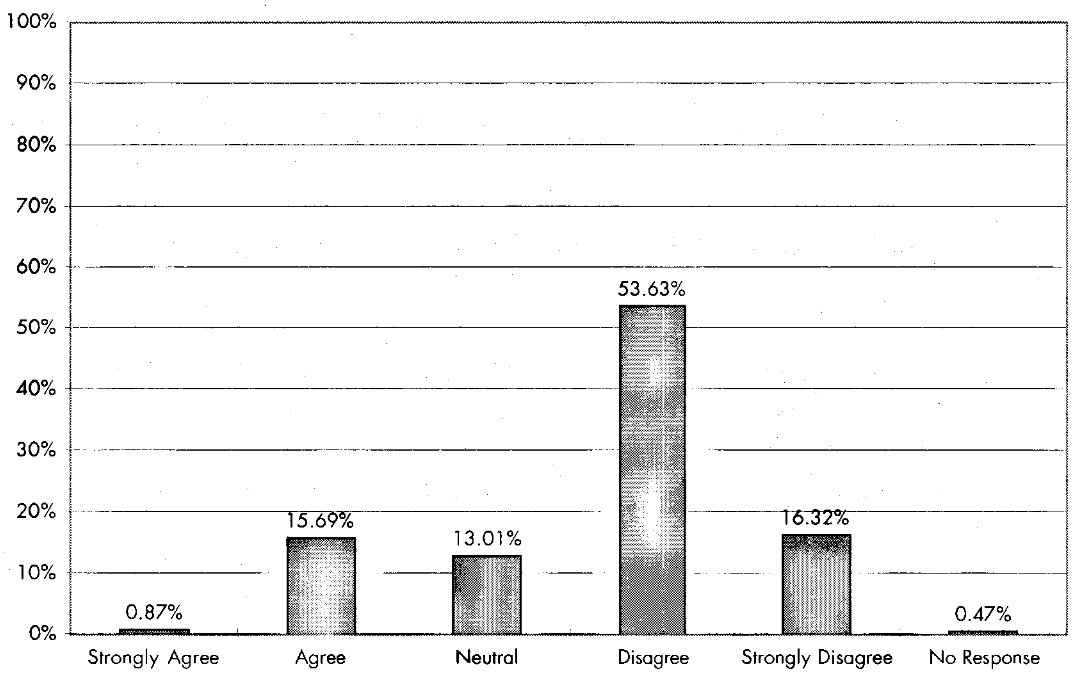
Passive command

The development of automation has also produced instances where the crew have unconsciously relinquished their command responsibilities momentarily to the automated systems. In such situations, pilots may unconsciously become 'observers' rather than 'controllers' of aircraft systems.

Figure B7.4 indicates that while most respondents did not have a problem with passive command, 16% had experienced this phenomenon during flight.

Analysis of this result revealed that this phenomenon is apparent across all aircraft types, pilot ranks, age categories and experience levels.

FIGURE B7.4
I sometimes find the automated systems taking over command of the aircraft



Automation policy

This chapter has outlined several comments made by respondents in relation to the quality of training staff, manuals, simulator instruction, line training and the quality of training. Several pilots requested greater standardisation and expressed the need to discuss automation philosophy prior to their simulator training. Investigation revealed that very few airlines have addressed automation philosophy in their company manuals. The lack of specific policy has promoted a plethora of personal opinion and may cause check-and-training staff to avoid making comment during initial and recurrent training activities.

Aviation safety could be improved by incorporating specific policy guidelines regarding the operation of automated aircraft. Such policy should be incorporated into standard operating procedures and become a reference document for all operational staff.

The following information is provided as an example of the results of two airlines' efforts to formulate an automation policy:

1. Delta Air Lines Inc.

The following is taken from the Delta Air Lines, Inc. Flight Operations Manual, chapter 4: 'General Policy', page 8:

General

Automation is provided to enhance safety, reduce pilot workload and improve operational capabilities. Automation should be used at the most appropriate level.

Pilots will maintain proficiency in the use of all levels of automation and the skills required to shift between levels of automation. The level used should permit both pilots to maintain a comfortable workload distribution and maintain situational awareness. The following guidelines apply to the use of automation:

- If any autoflight system is not operating as expected, disengage it.
- All pilots should be aware of all settings and changes to automation systems.
- Automation tasks should not interfere with outside vigilance.
- Briefings should include special automation duties and responsibilities.
- The PF must compare the performance of the autoflight systems with the flight path of the aircraft.

2. Cathay Pacific Airways Limited

Automation policy is mentioned in Cathay Pacific's Flight Training Manual, vols 1, 3 and 7, part 1:

It is Cathay Pacific Airways policy to regard Automation as a tool to be used, but not blindly relied upon. At all times, flight crew must be aware of what automation is doing, and if not understood, or not requested, reversion to basic modes of operation must be made immediately without analysis or delay. Trainers must ensure that all CPA flight crew are taught with emphasis how to quickly revert to basic modes when necessary. In the man-machine interface, man is still in charge.

Conclusions

These results establish the existence of an unacceptably high degree of 'automation surprise'. Of concern is the number of pilots who completed their engineering course prior to 1993 and still report that they experience this problem. Most airline recurrent training and checking programs do not adopt a holistic approach to consolidating, or developing, a pilot's knowledge and understanding of aircraft operation. Often such programs are restrained by regulatory requirements. Future research should identify specific instances of 'automation surprise' in order to minimise occurrences. The fact that most pilots indicated that 'the FMC/FMGS captures an altitude' as they expected may reflect the routine nature of this manoeuvre. However, this result should not mask the importance of the pilot maintaining a correct mental model of the aircraft environment at all times.

Similarly, these results confirm the subtle phenomenon of 'unconscious transfer of command to automation' or 'passive command'. Airlines should take appropriate action to alert pilots to the existence of this phenomenon. Further research should identify the stage of flight in which this occurs and assess the risk to safe flight operations.

Recommendations

The Bureau of Air Safety Investigation recommends that airline operators (R980027):

1. Ensure that flight crew of advanced technology aircraft are educated in the concept , and safety implications, of Passive Command Syndrome.
2. Include a comprehensive statement of automation policy in their general operations manual and/or airline policy documents.

CREW RESOURCE MANAGEMENT

Introduction

Crew Resource Management (CRM) may be defined as 'the management and utilisation of all people, equipment and information available to the aircraft. It is in principle no different from the management and utilisation of people in any other workplace involving skilled activities in a technological environment'.

CRM was first seriously considered within the aviation industry in 1972 following an accident involving Eastern Airlines Flight 401 (Florida Everglades). In 1975, IATA held its landmark Human Factors Conference in Istanbul, Turkey, and in 1977 KLM developed the KLM Human Factors Awareness Course (KHUFAC) following the fatal accident involving KLM and Pan Am aircraft at Teneriffe, Canary Islands.

CRM concepts have developed significantly since the early training courses of the 1970s.

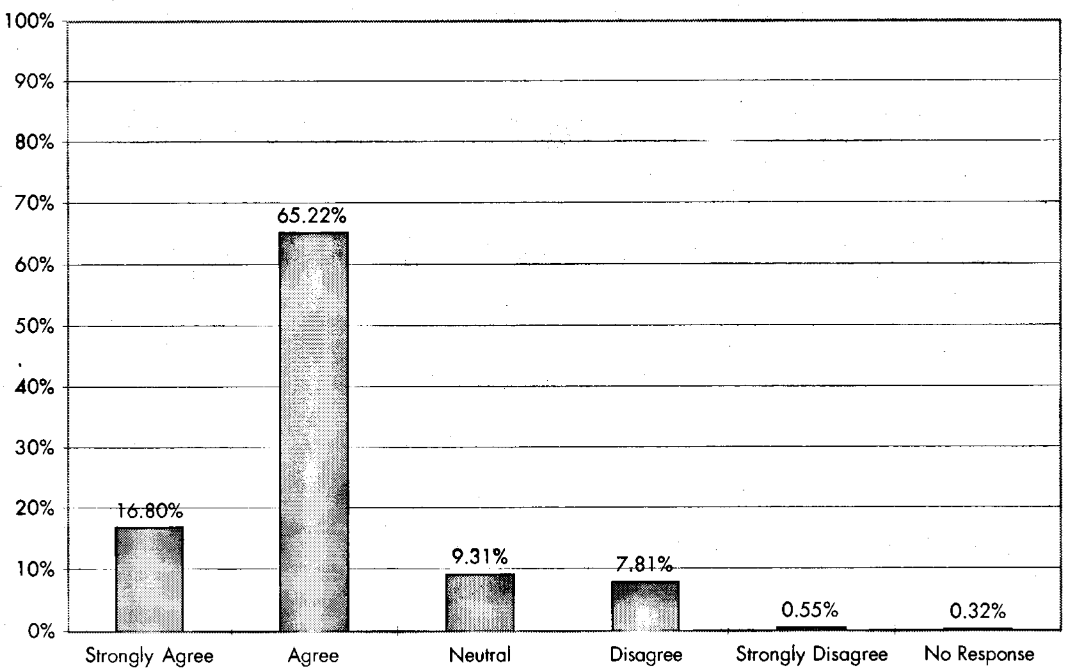
Helmreich (1996) has identified five generations of CRM encompassing the initiation of CRM programs, team building, focusing on specific skills and behaviours, integrating CRM into technical training and focusing on the management of human error and training in the limitations of human performance.

This chapter addresses the role of the pilot, crew communication, and crew management on automated aircraft, and their effect on CRM.

Well-defined roles

Figure B7.1 shows that 82% of respondents felt that the roles of the pilot flying (PF) and the pilot not flying (PNF) are always clear. Analysis of the negative responses (n = 102) revealed no statistically significant results.

FIGURE B7.1
On this aircraft, the role of the pilot flying (PF) and pilot not flying (PNF) is always clear



Communication

Thirty-seven per cent of respondents reported that there had been times when the other pilot had not told them something they needed to know for the safe conduct of the flight (see fig. B7.2).

A statistically significant difference was observed between the responses of Australian and Singaporean pilots (on the basis of nationality). Singaporean pilots were more satisfied with the level of communication than Australian pilots. This may reflect differences in cultural traits between Anglo-Europeans and Asian groups (see Hofstede 1980).

FIGURE B7.2
There have been times when the other pilot has not told me something I needed to know for the safe conduct of the flight

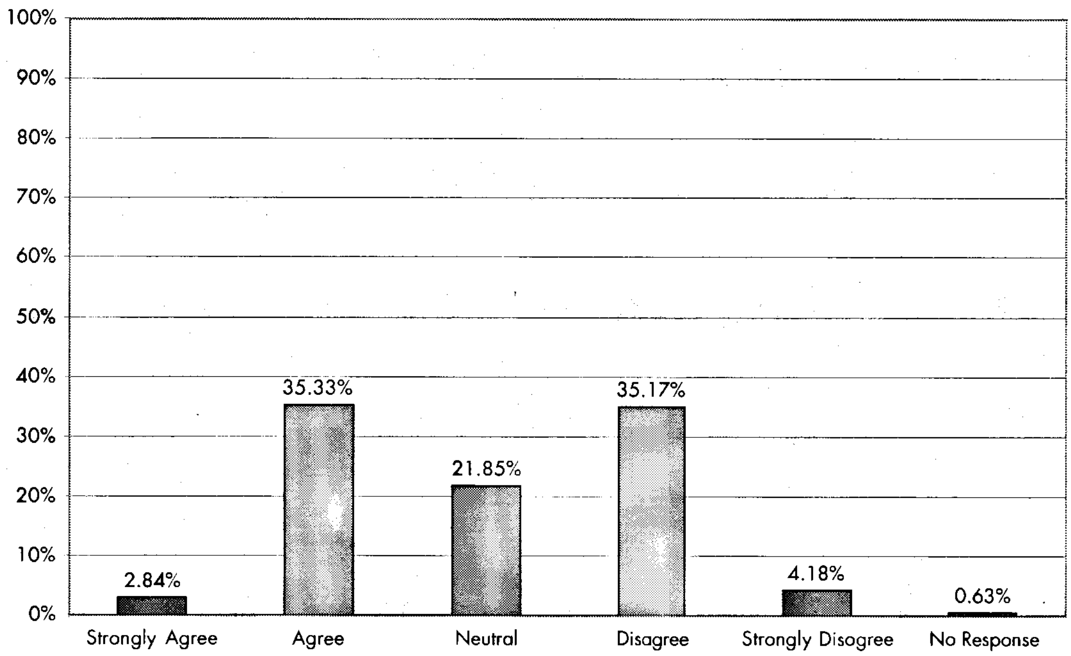


Table B7.2 suggests a trend toward a significant difference (0.07522) between pilots with different first languages. Captains who spoke English as their first language tended to perceive more communication difficulties when compared to captains who spoke an Asian language. The reasons for this difference are not clear; however, the difference in the sample size may have affected the reliability of this result.

Table B7.2
'There have been times when the other pilot has not told me something I needed to know for the safe conduct of the flight.'

	English	Asian	European
Captain	41.5% (261/628)	25.6% (11/43)	52.6% (10/19)
First officer	35.5% (148/417)	36.3% (12/33)	–

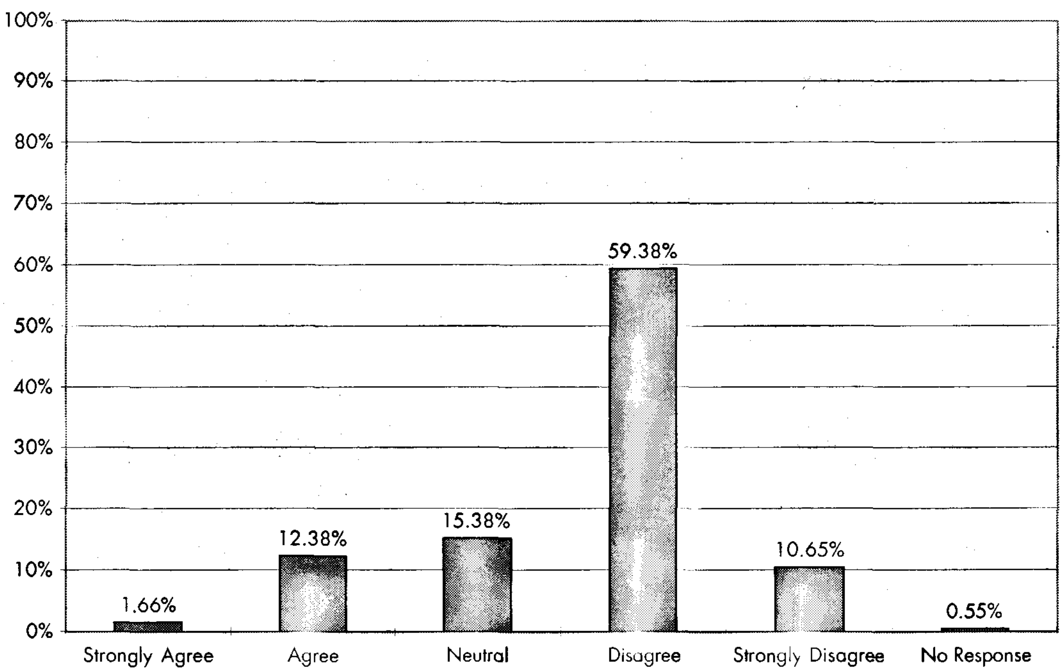
Crew management

Most of the respondents reported that crew management was not a problem on advanced technology aircraft (see fig. B7.3). Thirteen per cent, however, had experienced difficulty with crew management. Table B7.3 presents a breakdown of pilot rank and aircraft flown by those respondents who found CRM to be a problem on advanced technology aircraft. More Airbus pilots (19%) reported a problem than Boeing pilots (12%).

Table B7.3
'Crew management is a problem on advanced technology aircraft.'

	Captain	First officer
Airbus	19.7%	18.2%
Boeing	12.9%	12.6%

FIGURE B7.3
Crew management is a problem on advanced technology aircraft



The development of automation has also produced instances where the crew have unconsciously relinquished their command responsibilities momentarily to the automated systems. In such situations, pilots have unconsciously become 'observers' rather than 'controllers'.

Figure B7.4 (page 22) indicates that 16% of respondents recognised the existence of this phenomenon during flight.

Analysis of this result revealed that this phenomenon is apparent across all aircraft types, pilot ranks, age categories and experience levels.

Table B7.4 indicates a relatively even distribution across pilot ranks and aircraft manufacturers.

Table B7.4
'I sometimes find the automated systems taking over command of the aircraft.'

	Captain	First officer
Airbus	17.4%	14.8%
Boeing	13.7%	18.5%

Conclusions

Pilots agree that their roles (pilot flying and pilot not flying) are well defined and that crew management is generally not a problem on advanced technology aircraft.

There is evidence of 'passive command', and while the percentage of pilots who reported this problem is relatively low (16%), this phenomenon requires continued monitoring. The topic deserves to be addressed in CRM courses and during conversion/recurrent training.

One of the aims of CRM training is to create a cockpit environment where both crew can communicate openly and effectively. The designers of CRM programs have recognised this and attempted to minimise the effects of cross-cockpit gradient (age, pilot rank and cultural differences between crew members) which may inhibit communication. The responses to question B7.2 ('There have been times when the other pilot has not told me something I needed to know for the safe conduct of the flight') suggest that more effort needs to be put into the improvement of communications between crew. In the absence of historical data we are unable to assess whether technology has specifically aided communication in the cockpit.

Recommendation

The Bureau of Air Safety Investigation recommends that airline operators (R9800028):

Employ appropriate methods and examples during initial and refresher CRM training to enhance the transmission of safety information between flight crew members during flight. Such training should stress the consequences of not communicating essential flight safety information.

FLYING SKILLS

Introduction

The opportunities for pilots to maintain their manual flying skills have decreased significantly since the introduction of advanced technology aircraft; for example, improvements in autopilot and autoland systems, airline policies, and long-haul operations have reduced the opportunities for hand-flying. Some airlines have introduced additional simulator sessions to allow pilots to practise their manual flying skills.

This chapter discusses how pilots perceive the effect of automation on their manual flying skills.

Skill retention

Figure B5.1 indicates that 85% of respondents prefer to hand-fly part of every trip to retain their skills. A statistically significant difference was noted between the responses of captains and first officers, with first officers more likely to prefer to 'hand-fly part of every trip' than captains (see table B5.1).

FIGURE B5.1
I prefer to hand-fly part of every trip to keep my skills up

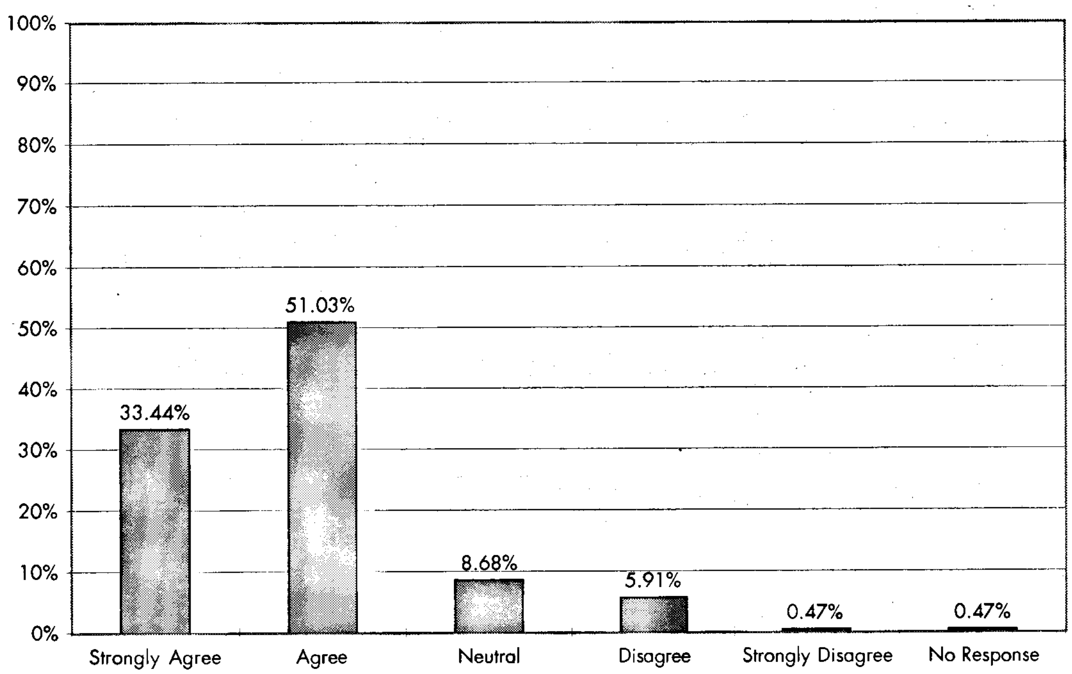


Table B5.1
'I prefer to hand-fly part of every trip to keep my skills up.'

	Captain	First officer
Airbus	85%	92%
Boeing	81%	90%

Skill assessment

Forty-three per cent of pilots considered that their manual flying skills had declined since they started flying advanced technology aircraft (see fig. B5.2).

FIGURE B5.2
My manual flying skills have declined since I started flying advanced technology aircraft

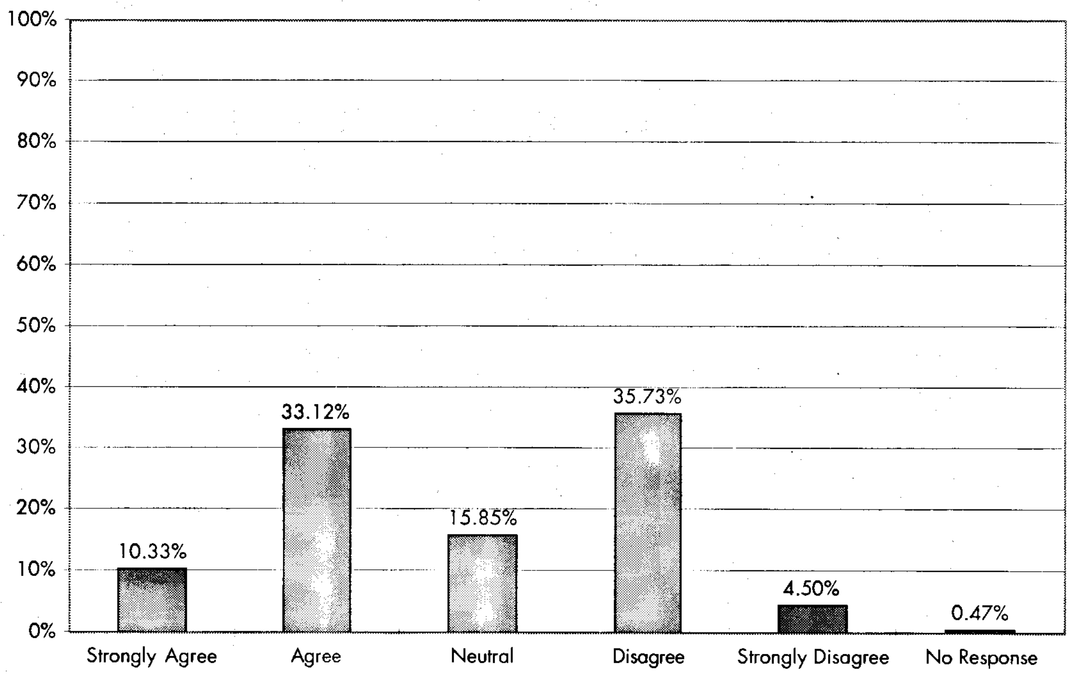


Table B5.2 presents a breakdown by pilot ranks and aircraft types flown by those pilots who agreed that their flying skills had declined since they started flying advanced technology aircraft. These results are relatively evenly distributed between pilot ranks and aircraft manufacturers.

Table B5.2
'My manual flying skills have declined since I started flying advanced technology aircraft.'

	Captain	First officer
Airbus	45.5%	48.2%
Boeing	40.5%	45.2%

Conclusion

Most pilots hand-fly their aircraft at some stages of each flight to maintain an acceptable skill level. Anecdotal evidence indicates that the main reasons for this are a pilot's natural satisfaction in performing manual flying tasks, the requirement to perform manual flying exercises during simulator sessions (including recurrent training and licence renewal) and the need to be able to manually fly the aircraft should the automated systems fail to function as expected (see page 22, 'Automation policy').

It would appear that the attempts of both the pilots and their airlines have not succeeded in maintaining a perceived level of manual skills. Of concern are pilots who continue to manually control an aircraft with a diminishing level of skill. This has been recognised by some airlines who have implemented supplementary simulator programs to compensate for a perceived loss of manual flying skills.

Some airlines have required pilots to demonstrate their manual flying skills during simulator exercises to fulfil the requirements set down by regulatory authorities. These requirements (for example, manually flown instrument approaches or emergency descents) are often outdated and thus not appropriate for the current level of technology.

Further research is needed to determine how pilots can best maintain their manual flying skills, the reliability of autopilot systems, and the appropriateness of licence renewal procedures.

Recommendation

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority (R980029):

Ensure that all recurrent and rating renewal simulator exercises are appropriate considering the level of automation fitted to the aircraft type. Such exercises should reflect the level of serviceability which the pilot may be expected to encounter during line operations.

GENERAL

Introduction

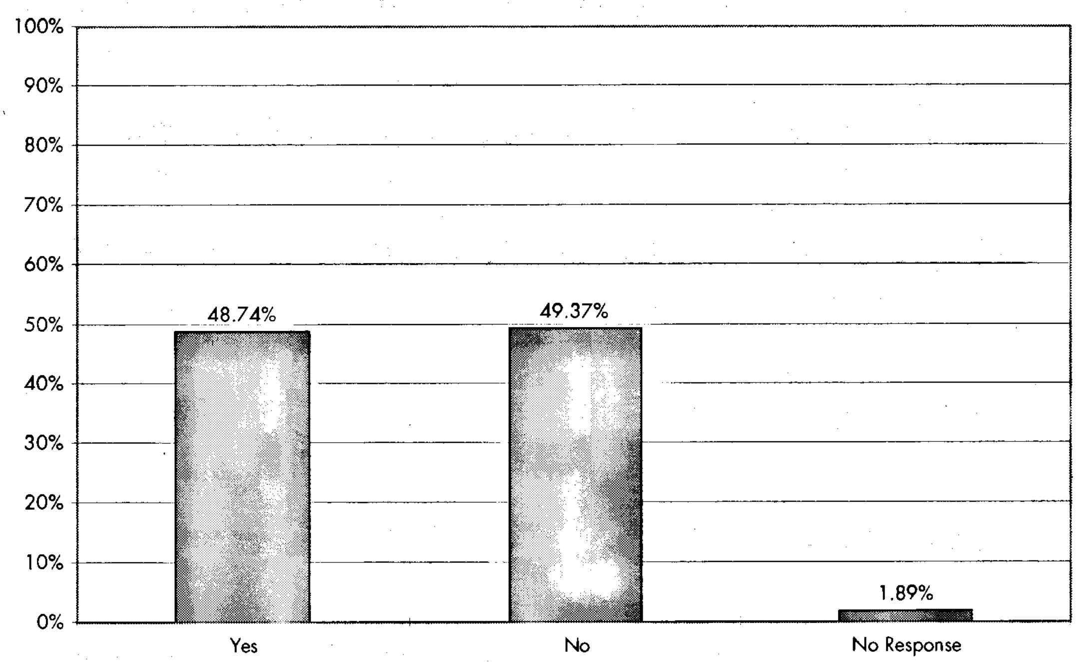
This chapter analyses the results of the General section of the survey which comprised six unrelated questions addressing automation reliability, database errors, teaching techniques, flight-crew alertness, and perceived difficulties during conversion training. Five of these questions gave respondents the opportunity to give a written response.

Encountering abnormal/emergency situations

Forty-eight per cent of respondents had experienced an abnormal or emergency situation while flying their current aircraft in operations excluding simulator sessions and base training.

Analysis of the type of emergencies pilots had experienced reveals that flight control problems (17%) were mentioned most often, followed by engine failure/shutdown (13%), FMC/FMGS malfunctions (10%), emergencies involving engines other than failure/shutdown (10%), hydraulics (8%), electrical (7%) and in-flight emergencies involving warnings and messages (7%).

FIGURE B9.1
Have you ever encountered an abnormal/emergency situation while flying your current aircraft (excluding simulator or base training) ?



The percentage of pilots who indicated that they had encountered an abnormal or emergency situation was higher than expected.

The list of emergencies and abnormal situations provided by pilots answering this question included several situations which are unique to automated aircraft. These were FMC failure (including double FMC failures) and false electronic warnings. It could not be determined from the data provided whether the high percentage of flight control problems can be attributed to an automated system. Most flight control problems related to the flap system, with pilots reporting asymmetric, partial or flapless landings. For example:

'Asymmetric flaps on landing'.

'Flap failed to deploy below Flap 5, Flap 5 landing'.

'Flap malfunction, flaps locked, followed ECAM, landed with slats only'.

Less frequent reports concerned navigation failures (Inertial Reference System), emergencies involving TCAS and problems attributed to personal electronic devices (PEDs). (PEDs include carry-on electronic items such as laptop computers and mobile phones, which may interfere with the aircraft's electronic systems. Most airlines restrict the use of PEDs to the cruise phase of flight.)

This information should be of special interest to training departments and regulatory authorities when formulating training requirements for initial and recurrent training exercises.

Database errors

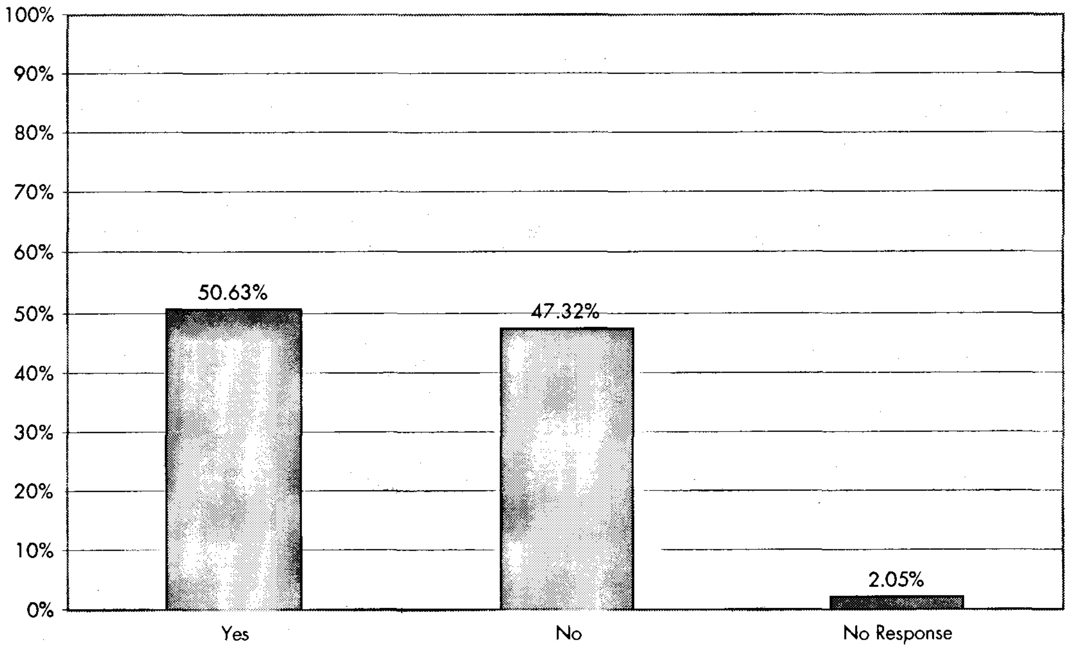
The integrity of the computerised navigation and performance systems rests on the quality of the FMC/FMGS database. Avionics and aircraft manufacturers and regulatory authorities have recognised the potential for entering incorrect data through the FMC/FMGS. Flight crew are therefore required to make minimal manual input to advanced systems, compared to navigation and performance systems of previous generations of navigation systems such as Inertial Navigation System. Databases are updated on a regular basis (approximately every 28 days). If an error is detected in the database, the operator advises the pilots of the error and relies on them to manually correct those errors that apply to the route they are flying. Such errors may stem from an authority providing outdated or incomplete data to the aircraft manufacturer, from data-entry errors, or from electronic data transfer faults. Most airlines require the crew to cross-check the information in the database against printed information contained in en-route charts, instrument approach charts and NOTAMs. Currently, aircraft manufacturers are researching the concept of a 'paperless' cockpit, wherein this cross-checking process may not be available.

Fifty per cent of respondents reported that they had detected database errors.

Pilots reported that the most common database problems were errors in SID information, followed by incorrect waypoint information (latitude/longitude), and STAR information. Pilots also highlighted inconsistencies in route/track data, the use of outdated databases, and incorrect Navaid information. To a lesser extent, some information was missing from the database altogether or was at variance with chart information. Errors were also found in instrument approach data, aerodrome data (including gate position), and in holding pattern and runway information.

Pilot responses are summarised in fig. B9.2 below.

FIGURE B9.2
Have you detected any FMC/FMGS data base errors (waypoint Lat/Long, SID or STAR route/restriction errors etc)?



A majority of pilots have encountered errors in database information including errors in aerodrome information, SID, en-route and STAR data.

The final safety net in the process of checking the accuracy of database information currently lies with the pilot who should cross-check electronic data against printed data. Evidence suggests that human performance during such cross-checking tasks deteriorates over time; therefore there is the likelihood that even with the best policy and intentions, this process could be compromised and database errors could be missed by the pilot. Furthermore, pilots have indicated (question B4.1) that they refer to their en-route charts far less on new-technology aircraft than on aircraft without an FMC/FMGS. This may further weaken the cross-checking process.

This deficiency needs to be addressed by both aircraft manufacturers and regulatory authorities if the goal of a paperless cockpit is to be attained.

Using previous accidents and incidents as a training aid

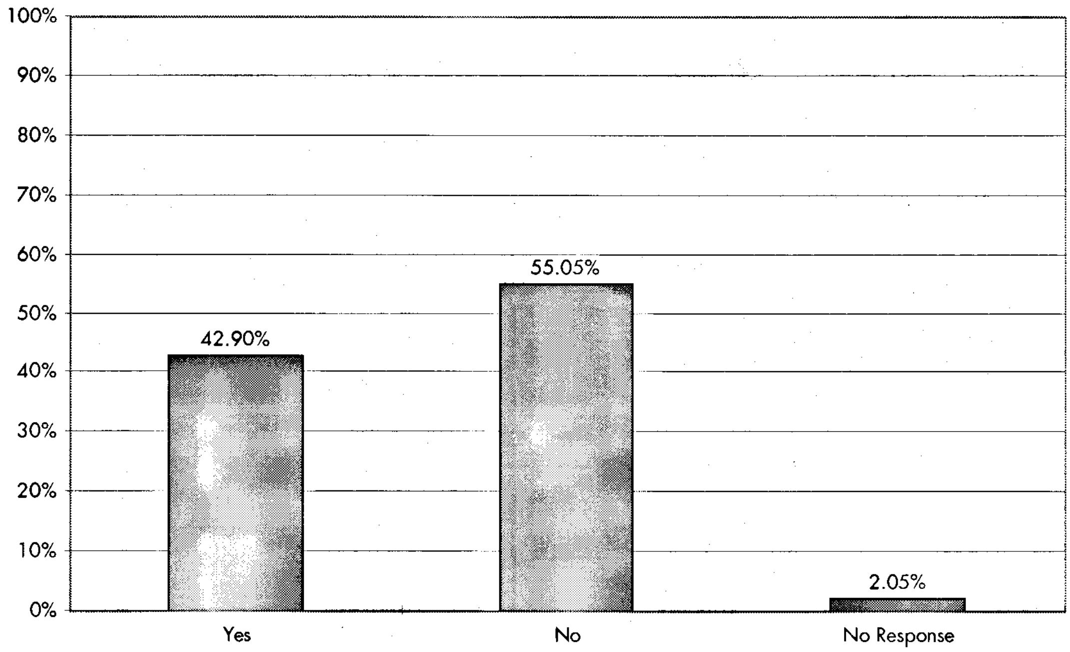
Discussion with airline managers revealed that some airlines considered that they effectively used accident and incident information in either initial endorsement training or during CRM refresher courses. Some respondents confirmed that they had discussed accident or incident scenarios during their recurrent/CRM training sessions. However, only 42% of respondents stated that they had ever discussed any advanced technology aircraft accidents or incidents during their conversion training (see fig. B9.3).

When asked to list the accidents and incidents which were discussed during conversion training (see table B9.3), respondents listed a total of 28 identifiable accidents or incidents.

Table B9.3
Most commonly listed accidents and incidents discussed during conversion training

Category	Result
Accidents involving Airbus aircraft	20%
Bangalore (Airbus)	17%
Cannot recall details of discussion	9%
Nagoya (Airbus)	7%
Habshiem (Airbus)	7%
Kegworth (Boeing)	6%
Strasbourg (Airbus)	6%
Other (< 12 responses per category)	28%

FIGURE B9.3
Did you discuss any advanced technology aircraft accidents or incidents during your conversion training?



These results tend to confirm that some companies are discussing aircraft accident and incident data during conversion training programs, although more use could be made of the educational value of occurrences. Pilots are generally able to recall events which have been discussed during their training. Approximately 10% of pilots, however, recorded that they only had a vague recollection of accident or incident details, or that they had forgotten the details altogether.

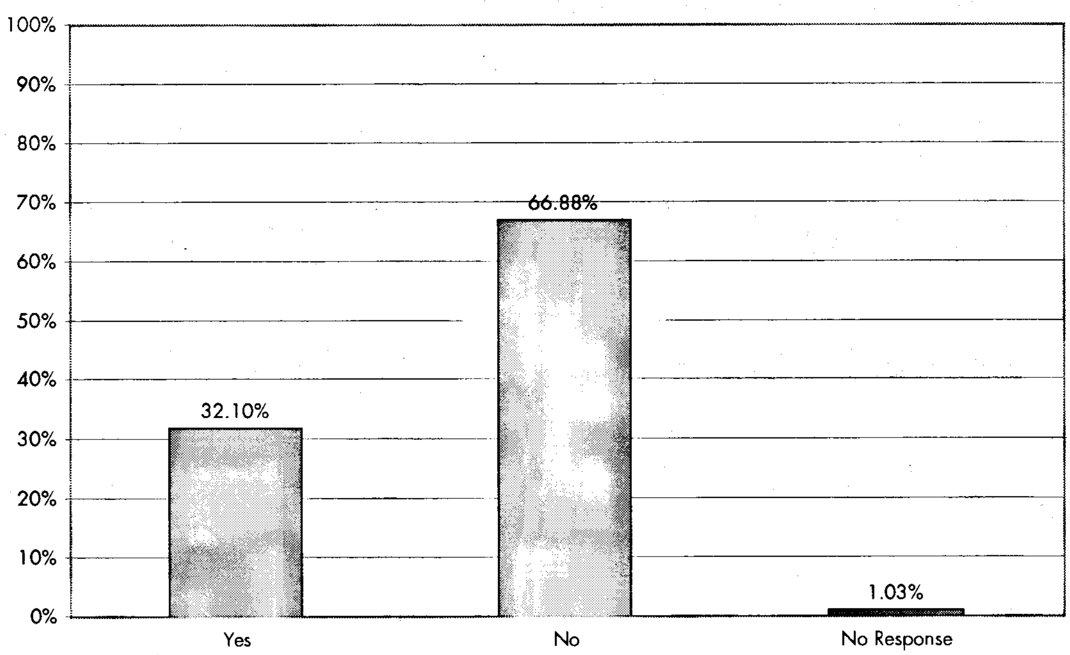
It also seems significant that very few pilots recorded the fact that they discussed accident and incident data pertaining to their own company, 'company incidents—engine failures, hydraulic pump failures and fleet specific information', as one pilot stated. Another pilot stated that he had only discussed 'other operators experiences'.

Another aspect of these responses is that the accidents and incidents which have been nominated are now reasonably old. While the Nagoya accident, which occurred on 26 April 1994, ranks fourth in discussion topics, only three pilots mentioned discussing the B757 accident near Cali, Colombia (12 December 1995). This may confirm the notion that pilots seldom discuss accident and incident scenarios which are not related to the specific type of aircraft they are operating. There are no B757 aircraft operating in the Asia-Pacific region. Often the same problem or scenario is repeated in various accidents or incidents and reinforcement with new material can be an effective teaching tool. Also, as automated aircraft develop, new lessons may be learnt which need to be regularly presented to aircrew.

Flight-deck fatigue

Figure B9.4 shows that 32% of respondents acknowledged that they had, at one time or another, inadvertently fallen asleep on the flight deck of an advanced technology aircraft. This may relate to question B6.1 ('Times of low workload are boring') where 36% of respondents indicated that times of low workload in an automated aircraft were boring. Anecdotal evidence suggests that automation may make times of high workload more difficult and times of low workload even less arousing. However, in the absence of comparative figures for older generation aircraft, it is not possible to conclude that fatigue is a greater problem on advanced technology aircraft. Nevertheless, there is a clear message that airlines and regulator need to address the problem of pilot fatigue.

FIGURE B9.4
Have you ever inadvertently fallen asleep on the flight deck of an advanced technology aircraft?



The focus of this question was on the concept of 'inadvertent sleep', as opposed to programmed rest or in-flight relief.

Some airlines have addressed this situation by installing pilot-alertness monitors. These systems monitor pilot input to the FMC, autopilot and radio transmissions. If the pilots fail to make inputs within a given period of time, the monitoring system will call for a response by the pilot such as responding to a message on the FMC screen. If a response is not made within a specified time, the level of response is increased, culminating in an aural alarm which must be cancelled by the pilot. Furthermore, in some airlines cabin staff regularly visit the cockpit to check on the alertness of the pilots.

With developing automation the level of activity during the cruise phase of flight is continuing to reduce. Navigation and communication tasks have significantly reduced compared with the previous generation of aircraft.

Conversion difficulties

Pilots were asked to nominate the most difficult part of their conversion to advanced-technology aircraft. A significant proportion (63%) of respondents answered this question. Their responses are summarised in table B9.5 below.

Table B9.5
Difficult aspects of conversion to advanced technology aircraft

Difficulty	%
FMC/FMGS	42%
Autopilot / auto throttle mode selection	13%
CRT instrumentation / instrument scan	10%
Understanding automation philosophy	8%
Information overload	6%
Mode control panel	5%
Other	16%

To express their difficulties pilots employed terms commonly used to describe a new learning experience:

- *Accepting* FMC data;
- *Adapting* to the FMC and MCP;
- *Assimilating* all the information;
- *Becoming* familiar with the FMC;
- *Coming* to grips with (to terms with automation concepts);
- *Finding* information in the FMC;
- *Getting* used to the FMC;
- *Learning* different manipulative skills; and
- *Understanding* and operating the FMC.

Such language supports the hypothesis that the challenge faced by pilots during conversion training on an automated aircraft is largely conceptual rather than physical.

The areas in which pilots experienced most difficulty during their conversion training correlate closely with their responses to question B8.7, in which pilots were asked what could be done to improve the training they received on their aircraft. Of the respondents (n = 157) who specifically addressed automation, 58% stated that they would like more 'hands on' training and the provision of an FMC trainer or fixed-base simulator. They then suggested that in-depth training on automated systems (19%), teaching about automation philosophy (14%) and more training on mode characteristics would have improved their training.

The request for more hands-on training is not necessarily a request for more hands-on flying experience, but reflects the need to further explore, or consolidate, systems knowledge. Approximately 9% of pilots responding to question B9.5 commented upon the large amount of information they were expected to assimilate in such a short period of time.

It appears that much of the training provided to pilots is focussed on the physical skills needed to comply with standard operating procedures, with minimum emphasis being given to systems knowledge. Safety could be enhanced if during the initial stages of training, pilots were provided with a thorough systems knowledge and an awareness of the design philosophies which guided the makers of automated systems.

Recommendations

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority (R980030):

Review the minimum standards for the quality of information provided in FMC databases with the aim of eliminating FMC database errors.

The Bureau of Air Safety Investigation recommends that airline operators (R980031):

1. Include in the ground-training phases of pilot endorsement courses:
   (a) sufficient technical knowledge of aircraft systems; and
   (b) knowledge of the design philosophies employed by aircraft system manufacturers;

   to give the pilots sufficient systems understanding to permit analysis of system abnormalities and to determine appropriate responses in situations for which checklists are not available.

2. Consider the safety lessons from discussions of incident and accident scenarios during all initial, recurrent and CRM training programs.

The Bureau of Air Safety Investigation recommends that aircraft design authorities and airline operators (R980032):

Consider effective systems and procedures to ensure that flight crew of automated aircraft do not inadvertently fall asleep during flight.

MODE

Introduction

Automated aircraft provide pilots with a large number of functions and options for carrying out control tasks under varying circumstances. Appropriate mode selection should be underpinned by knowledge of systems operations (and the operation of the system) in order to satisfy new monitoring and attentional demands to track which mode the automation is in and what it is doing to manage the underlying processes. Failure to support these new cognitive demands may result in mode error (Sarter & Woods 1995)

The modern automated aircraft may be controlled by the autopilot system from approximately 400 ft after takeoff to the completion of the landing roll following an automatic landing. Modes are selected via the MCP, while mode engagement is confirmed via the FMA. Some vertical modes may be further defined through the FMC, for example VNAV SPEED.

This chapter discusses the responses of pilots in relation to mode selection, mode awareness, mode transition, and indication. We also report responses regarding the number of available modes, whether there are modes which are not understood, and whether the airlines set clear guidelines for the selection of modes during line operations.

Mode indication

Approximately 80% of respondents looked at the FMA when they wanted to know what the aircraft was doing (fig. B1.10). The FMA indicates to the pilot which mode is engaged. These annunciations will also confirm that the mode the pilot selected has actually engaged and secondly, indicate mode reversion or transition.

FIGURE B1.10
I look at the FMA when I want to know what the aircraft is doing

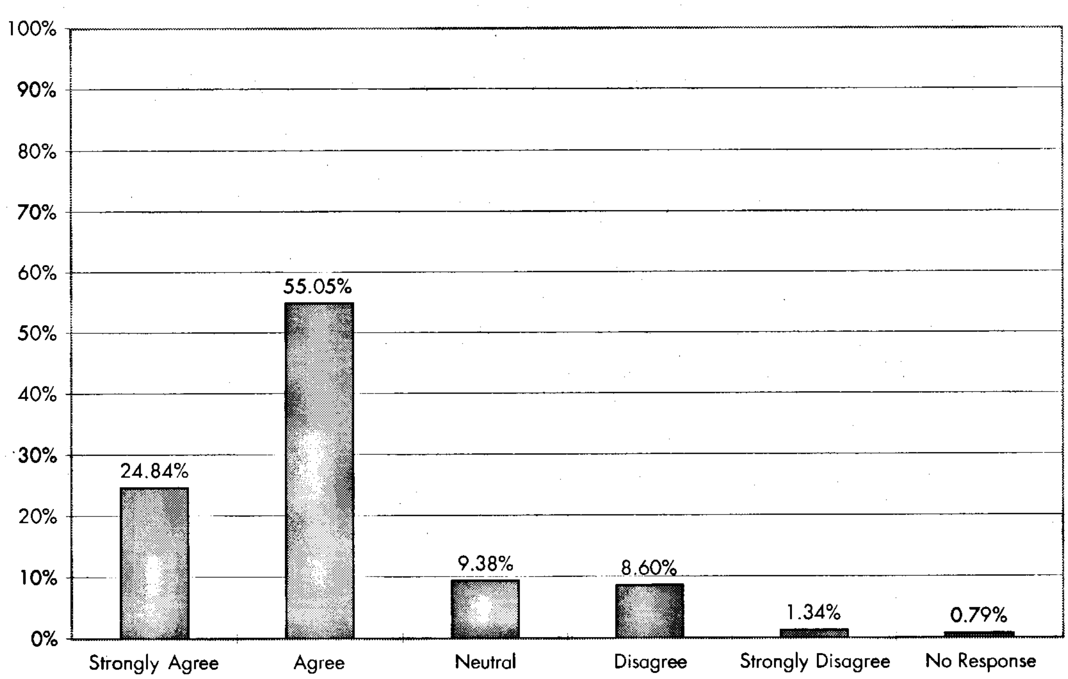


Table B1.10 addresses pilot rank and aircraft manufacturer, and indicates the proportion of pilots who do not look at the FMA when they want to determine what mode the aircraft is in. Further analysis revealed a statistically significant difference between the responses of Boeing pilots compared to Airbus pilots, with Boeing pilots less likely to refer to the FMA than Airbus pilots. Also of concern are approximately 20% of respondents who either did not refer to the FMA or were unsure of the procedure they employed to determine what the aircraft was doing.

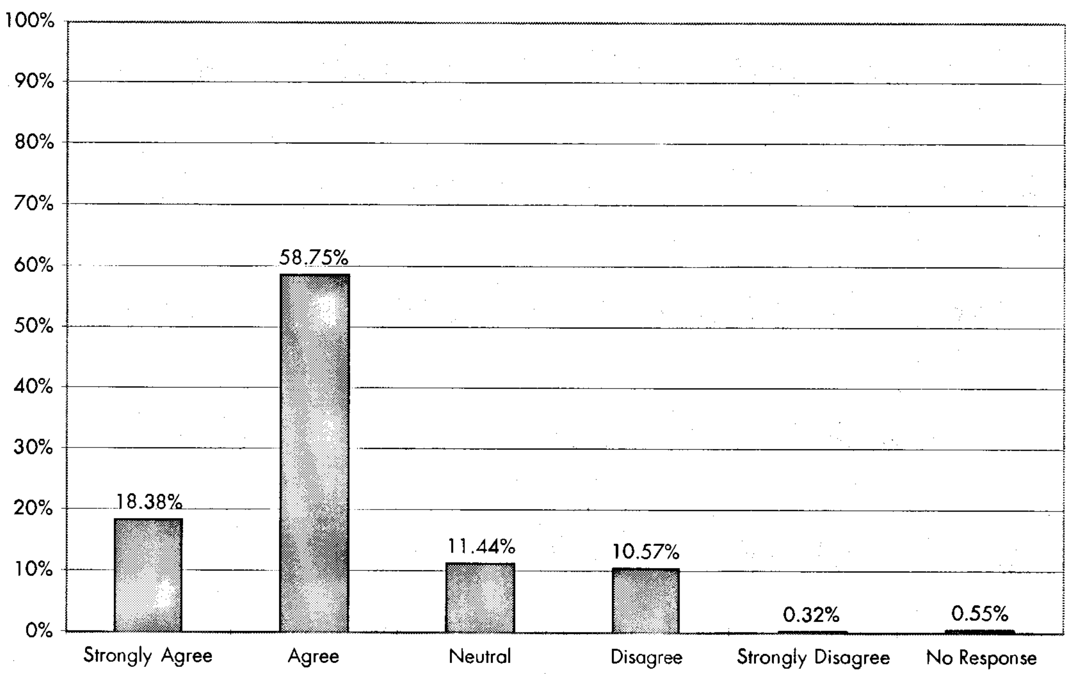
Table B1.10
'I do not look at the FMA when I want to know what the aircraft is doing.'

	Captain	First officer
Airbus	10%	5%
Boeing	12%	8%

Mode awareness

Approximately 11% of respondents reported that they did not always know what mode the autopilot, autothrottle and flight director was in (see fig. B3.1). Those respondents who did not know what mode the autopilot/autothrottle/flight director was in were relatively evenly distributed across pilot rank and aircraft manufacturers.

FIGURE B3.1
I always know what mode the autopilot/autothrottle/flight director is in.



Of the 1,268 respondents only 33 gave negative responses to both question B1.10 and B3.1 (2.6%), saying that they did not look at the FMA when they wanted to know what the aircraft was doing, and that they did not always know what mode the autopilot / autothrottle / flight director was in.

Mode annunciation

Twenty-one per cent of pilots indicated that they were concerned that the automated systems might have been 'doing something' they didn't know about (see fig. B3.2). Many functions which have, in the past, been controlled and monitored by the aircrew are now automatic, for example, the automatic transfer of fuel to maintain the optimum centre-of-gravity position and the automatic tuning of navigation aids. These functions may operate normally without warning or indication. Billings (1991) discusses the essential characteristics of human-centred automation:

> *To command effectively, the human operator must be involved and informed. Automated systems need to be predictable and be capable of being monitored by human operators. Each element of the system must have knowledge of the others' intent.*

Therefore it is not surprising that such a significant percentage of pilots may be suspicious of systems over which the pilot has inadequate systems knowledge and little or no control.

FIGURE B3.2
It worries me that the automated systems may be doing something that I don't know about

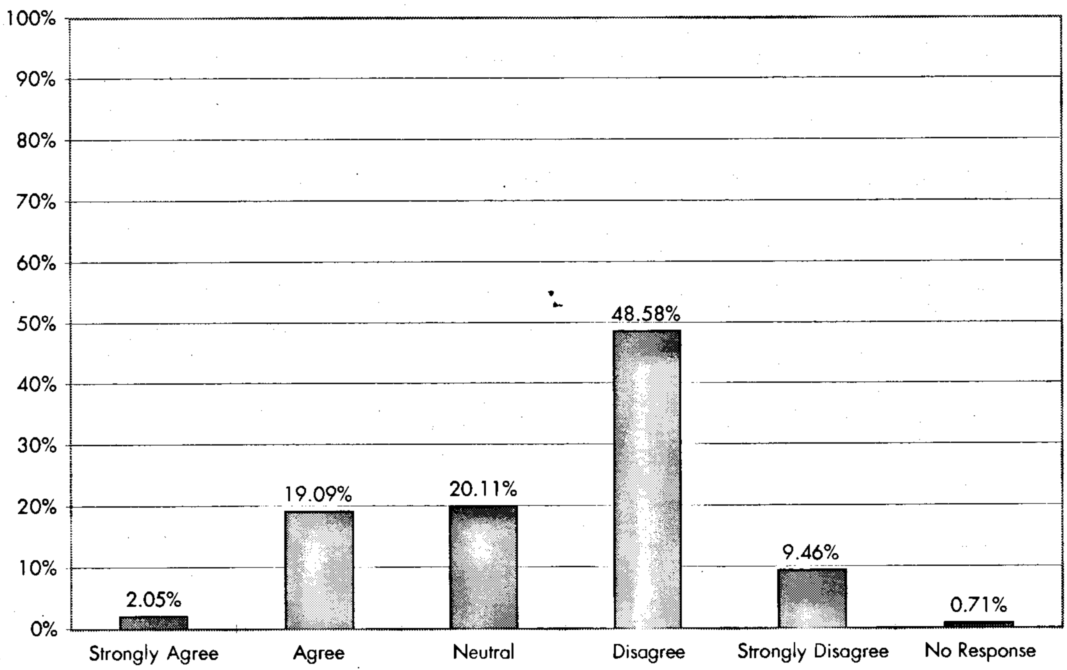


Table B3.2 indicates the proportion of respondents who were worried that the automated systems might have been doing something that they didn't know about. Further analysis revealed that there was a statistically significant difference between the responses of Boeing pilots compared to Airbus pilots. Boeing pilots were less concerned about this issue than Airbus pilots.

Table B3.2
'It worries me that the automated systems may be doing something that I don't know about.'

	Captain	First officer
Airbus	33%	35%
Boeing	16%	20%

Mode selection

Figure B3.3 indicates that 73% of respondents had inadvertently selected a wrong mode.

FIGURE B3.3
On occasion I have inadvertently selected the wrong mode

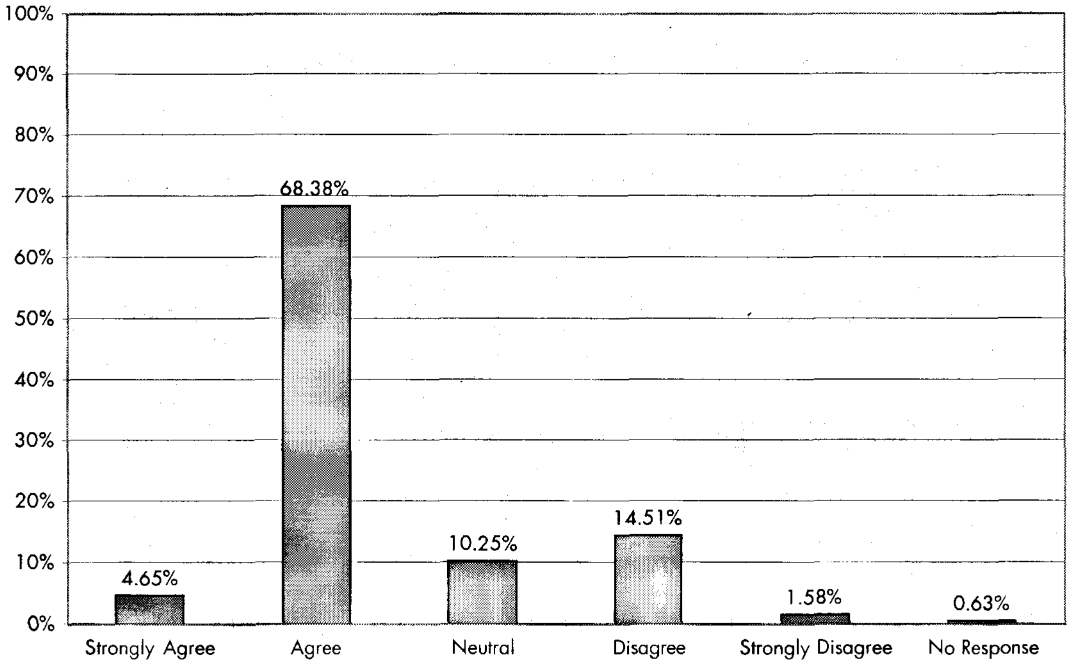


Table B3.3 shows the proportion of respondents who had inadvertently selected the wrong mode, comparing pilot rank by aircraft manufacturer. Specifically, Airbus crews were more likely to report that they selected an incorrect mode than Boeing pilots.

Table B3.3
'On occasion I have inadvertently selected the wrong mode.'

	Captain	First officer
Airbus	76%	83%
Boeing	72%	74%

Further analysis revealed that Asian-based pilots were less likely to have selected an incorrect mode than pilots based in Australia and New Zealand. This may correspond with the results of question B3.7 which noted that most Asian-based pilots reported that when it came to mode selection, their company set clear guidelines and procedures.

Subtle mode changes

Thirty-one per cent of respondents reported that mode changes can occur without adequate indication (see fig. B3.4). This relates to the adequacy of visual and aural warnings associated with mode changes. Pilots reported that mode changes in the vertical plane (e.g. V/S to FLCH) were particularly subtle and often went unnoticed for long periods. For example, when asked to outline the details of a specific event where they had difficulty with mode selection, mode awareness or mode transitions, pilots made the following written responses:

Subtle changes from VNAV PATH to VNAV SPEED during descent.

The subtle changes or noticeability of mode changes on the FMA.

With VNAV path disconnect aircraft goes silently into control wheel steering mode.

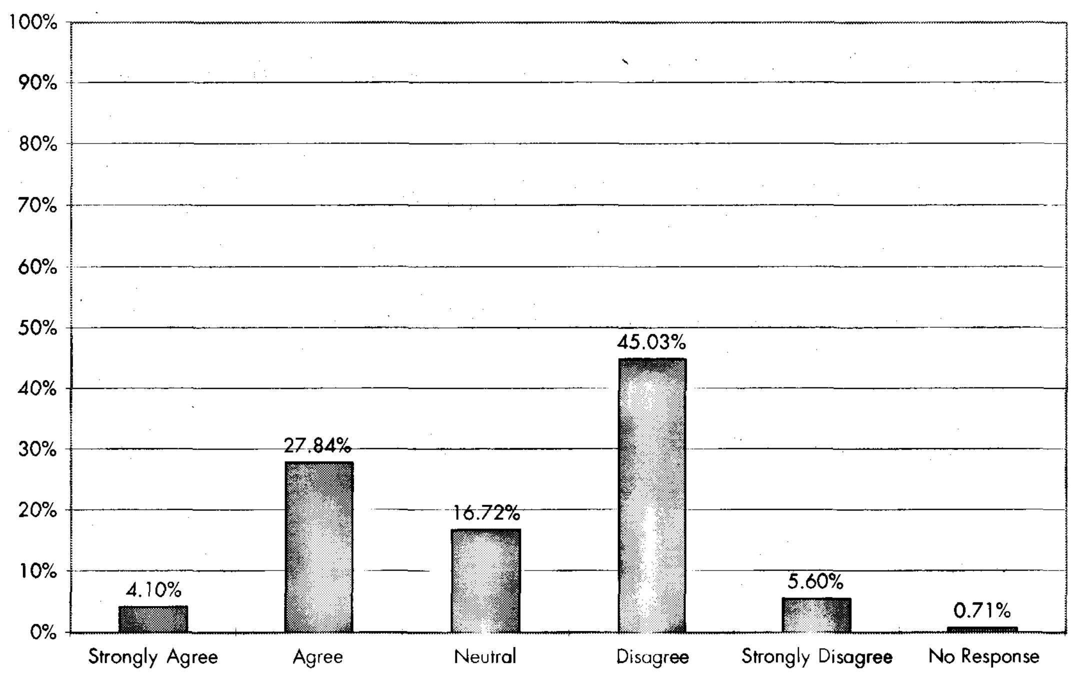
FMA annunciations on Saab better than on B747-400. Saabs flash, where Boeing places a box around the changed mode.

There are several situations in which the mode changes subtly causing annoyance, e.g. during descent in IDLE OPEN plus LNAV, an ATC instruction to adopt a HDG causes a reversion to VS, which was not a pilot instructed mode.

Mode transition from VNAV PATH, SPEED to VNAV SPEED, idle if the aircraft leaves the path the FMC changes are subtle, i.e. VNAV PATH looks too much like VNAV SPEED.

Sometimes a mode selection will inadvertently disconnect itself with no aural warning.

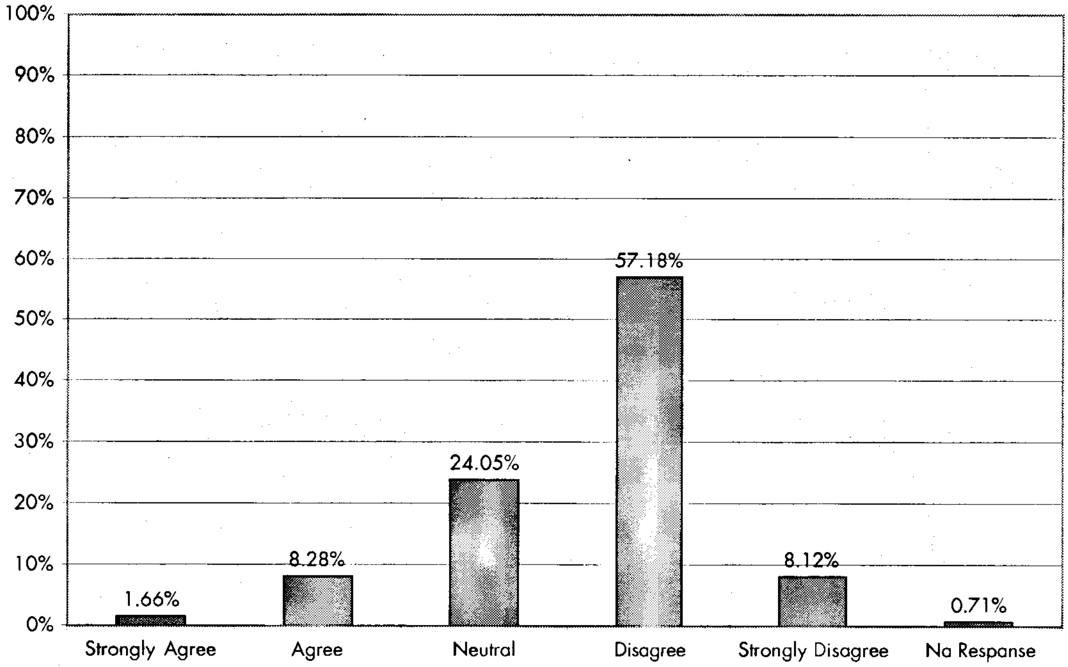
FIGURE B3.4
Mode changes can occur without adequate indication



Too many modes?

Authorities in the field of human/computer interaction (e.g. Norman) have warned that a large number of modes may work against the useability of automated systems. Yet contrary to this, only 9% of respondents agreed that there were too many modes available on the FMC/FMGS (see fig. B3.5).

FIGURE B3.5
There are too many modes available on the FMC/FMGS



Understanding mode functions

Fifteen per cent of respondents indicated that there were still some modes that they did not understand (see fig. B3.6).

Table B3.6a shows that pilots operating Airbus aircraft were less satisfied with their knowledge of various modes than pilots operating Boeing aircraft.

Table B3.6a
'There are some modes that I still don't understand.'

	Captain	First officer
Airbus	22%	18%
Boeing	11%	15%

Further research needs to establish whether the modes which are not well understood by pilots are seldom used, or whether they are fundamental to the safe operation of the aircraft.

FIGURE B3.6
There are some modes that I still don't understand

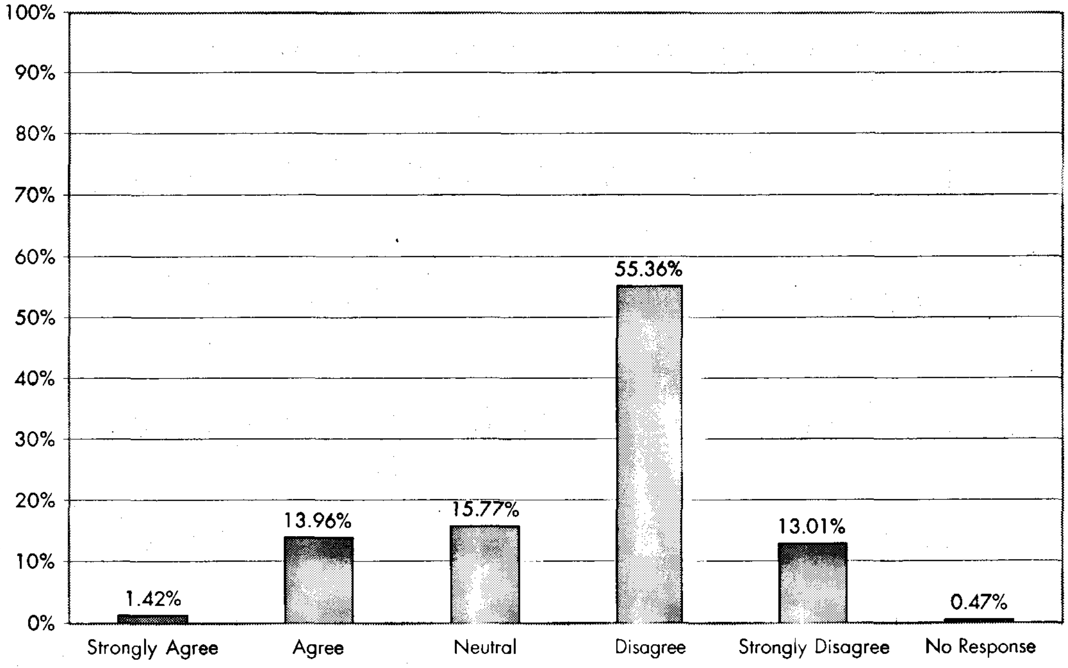


Table B3.6b
'There are some modes that I still don't understand.'

Engineering course completed	Captain		First officer		Second officer	
	Airbus	Boeing	Airbus	Boeing	Airbus	Boeing
1996	4	8	4	5	–	3
1995	8	6	3	22	1	12
1994	5	13	1	6	–	3
1993	–	6	1	9	–	–
1992	1	4	–	10	–	1
1991	1	7	–	2	–	–
1990	3	6	–	3	–	1
1989	4	4	–	1	–	2
1988	1	3	–	–	–	–
1987	2	1	–	–	–	–
1986	–	3	–	–	–	–
1985	–	1	–	–	–	–
1983	–	–	–	1	–	–

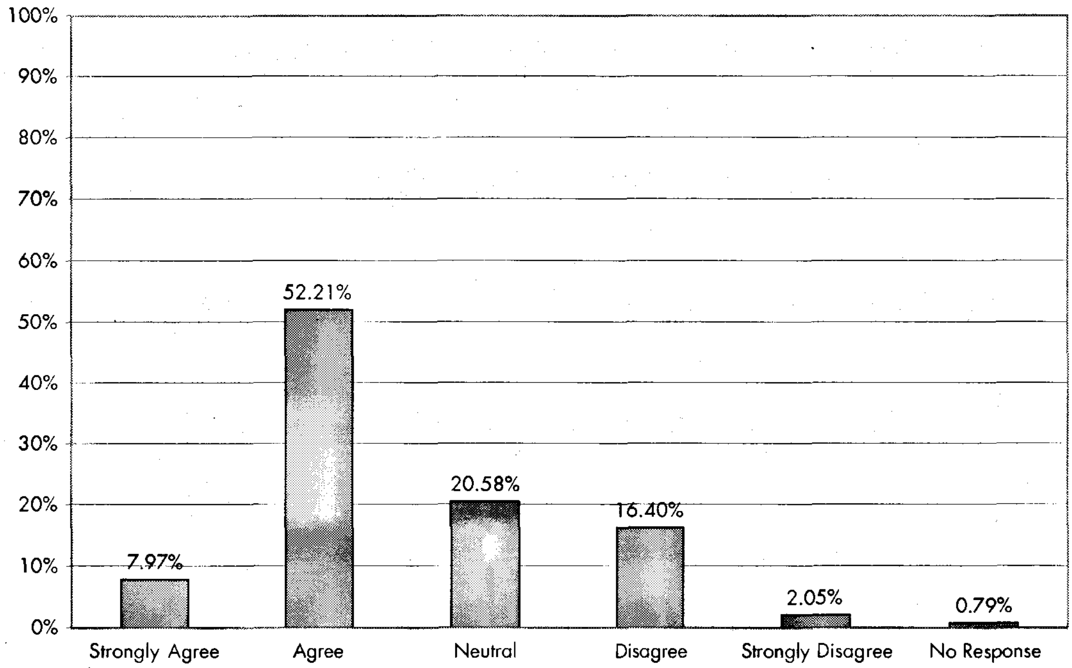
Table B3.6b lists 182 respondents (n = 195; valid cases for analysis = 182) who reported that there were still some modes that they didn't understand. The table shows that even pilots who had completed an engineering course prior to 1995 had gaps in their knowledge or understanding. Although these figures are relatively small, they may indicate deficiencies in recurrent training and line check programs.

Mode selection guidelines

Mode selection guidelines are a function of the aircraft manufacturer's and company's training philosophy. Interviews with airline management revealed that some airlines set rigid guidelines for mode selection, whereas others permitted pilots to make their own judgement about mode selection.

Eighteen per cent of respondents were concerned that their company did not set clear guidelines and procedures for mode selection (see fig. B3.7).

FIGURE B3.7
When it comes to mode selection, the company sets out clear guidelines and procedures

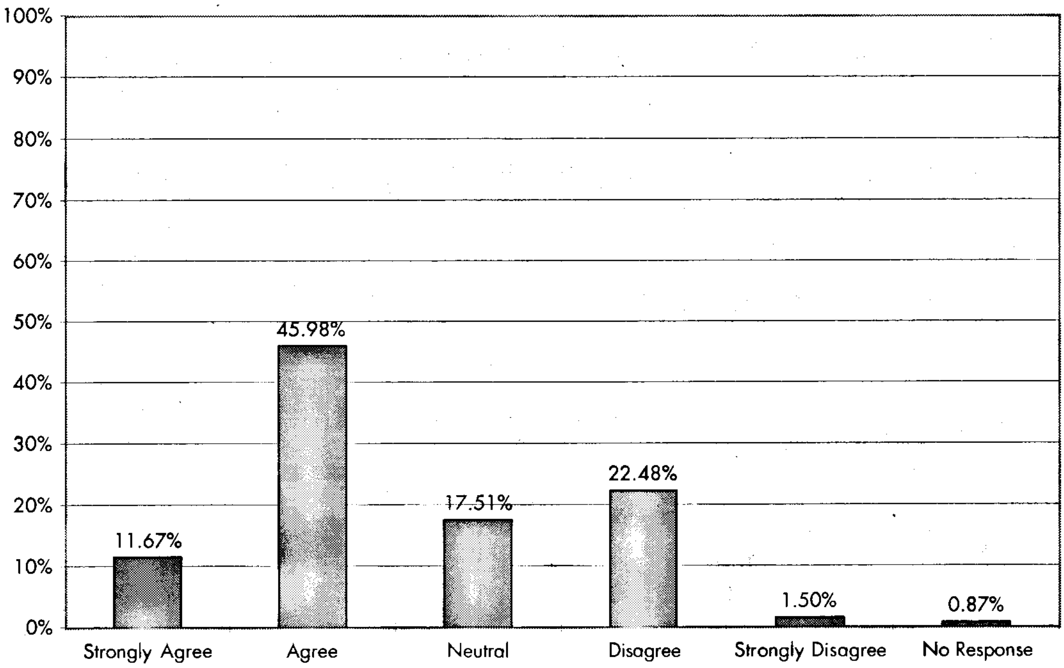


Communicating mode selection

Twenty-four per cent of respondents did not agree that a good crew briefing would always include what modes are to be used (see fig. B3.8).

These results are probably dependent upon the company's training philosophy; however, the importance of pre-planning and communicating intended mode selection is seen as a further safety net in the overall approach to safe operating practice. Mode selection is just as important as navigation aid selection. Incorporating this facet of the operation into the briefing structure reinforces the check and cross-check process.

FIGURE B3.8
A good crew briefing will always include what modes will be used



Specific events

Question B3.9 gave pilots the opportunity to outline the details of a specific event where they had difficulty with mode selection, mode awareness or mode transitions.

Three hundred and thirty-eight pilots (26%) provided a valid response to this question. Pilot responses were analysed against three criteria: the difficulty experienced, the mode, and the phase of flight (see tables B3.9.1–3).

Table B3.9.1
Nominated difficulty

Difficulty	Response
Unaware of mode characteristics / poor training / difficulty learning	28%
Mode reversion / not aware / subtle / poor annunciation / uncommanded mode changes	21%
Pilot failed to select mode	6%
Other	35%

Table B3.9.2
Nominated mode

Mode	Response
TOGA / max. continuous thrust	30.02%
Approach mode	25.73%
Vertical speed	20.32%
VNAV	13.09%
Other	10.84%

Table B3.9.3
Nominated phase of flight in which difficulty was encountered

Phase of Flight	Response
Descent	44%
Approach (precision)	18%
Go Around	16%
Approach (non-precision)	9%
Other	10%

These results are of concern as the majority of accidents have been shown to occur during the final approach and landing phases of flight. As can be seen from table 3.9.3, descent and approach were the phases of flight in which most mode difficulties occurred.

Conclusion

A thorough theoretical and practical understanding of mode function is essential for the pilot of a modern automated aircraft. This was highlighted in the report concerning the accident involving an A300B4-622R aircraft at Nagoya, Japan, in 1994 (Aircraft Accident Investigation Commission 1996), which listed the following as two of the twelve causes of the accident:

(2) The crew engaged the autopilot while go-around mode was still engaged, and continued the approach; and

(6) The captain and first officer did not sufficiently understand the flight director mode change and the autopilot override function.

Survey results presented in this chapter have revealed various inadequacies in both aircraft design and training.

Over 30% of respondents reported that mode changes could occur without adequate indication. Aircraft manufacturers need to ensure that mode changes (especially automatic mode transitions) are adequately annunciated. Preferably, mode changes should be accompanied by a discrete audible tone.

Mode selection is an important aspect of controlling an automated aircraft. A comprehensive understanding of mode selection, mode function and the consequences of inappropriate mode selection are required by the crew. Traditionally, pilots have been required to obtain a 100% pass in the fuel, and weight and balance sections of the type-rating examinations. Failure to uplift sufficient fuel, or the incorrect loading of an aircraft, is potentially disastrous. Similarly, a lack of knowledge regarding mode usage is equally dangerous. Mode operation (both practical and theoretical) should be considered as important as fuel and loading calculations for a modern automated aircraft.

Some airlines do not set clear guidelines and procedures when it comes to mode selection. They view the setting of guidelines as contradicting the freedom of the operating pilot to use an appropriate mode for the in-flight situation. There are two important issues here. The first includes the recognition that guidelines, rules or policies are valuable aids to the pilot, especially when newly endorsed on type. The second includes the importance of a consistent policy which flows from the initial simulator training through to line operations. Similarly, it would appear that briefings could be improved by including the intended use of modes during any given phase of flight.

The written responses to question B3.9 ('Please outline the details of a specific event where you had difficulty with Mode Selection, Mode Awareness or Mode Transition') provide a valuable insight into the mode difficulties experienced by pilots. Those respondents who reported that they had been unaware of mode characteristics appeared to have either poor training and/or had difficulty in learning. Difficulty with the Take-Off Go-Around (TOGA) mode or maximum continuous thrust mode was the most commonly reported problem.

The following comment summarises one pilot's perception of an event.

The area that causes the greatest problem is a go-around. It is a real problem for two reasons: We never practice normal two-engine visual go-arounds, even in the simulator. It all happens so fast it is difficult to keep up with the FMA changes and level out at a low (2,000 ft) altitude.

Possibly one remedy to this situation would be the extension of a 'free play' simulator session where pilots can practice or explore whatever event they wished. Alternatively, specific exercises could be included in line-orientated flight training (LOFT) exercises.

Recommendations

The Bureau of Air Safety Investigation **recommends that aircraft design authorities (R980033):**

Consider a requirement to ensure that all FMGS mode changes are visually and aurally annunciated.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980034):

Review their procedures with regard to mode selection and consider:

(a) if flight crews should state intended mode selection during all flight crew briefings;

(b) if flight crews should announce and acknowledge all mode changes during flight;

(c) refresher training regarding mode mechanics and mode usage on a regular basis; and

(d) clear and consistent guidelines regarding mode usage.

The Bureau of Air Safety Investigation recommends that **the Civil Aviation Safety Authority** (R980035):

Review the achievement requirements for aircraft technical examinations with the aim of improving the knowledge pilots possess regarding mode characteristics and application.

SITUATIONAL AWARENESS

Introduction

Helmreich & Foushee (1993) identify situational awareness as an 'outcome rather than a specific set of mission management behaviours'. They nominate *preparation, planning, vigilance, workload distribution and distraction avoidance* as key factors when considering effective situational awareness.

Orasanu (1993) describes situational awareness as the interpretation of 'situational cues'. The crew must analyse these cues to determine whether a problem exists which may require a decision or action. Successful interpretation relies on knowledge and experience. For example, airborne weather radar provides the crew with vital cues regarding en-route weather. If an area of hazardous weather is indicated on the radar, the crew must evaluate their situation with respect to their training and previous knowledge and make a decision. If they decide to track clear of the hazardous weather they must also consider other information such as conflicting traffic and surrounding terrain.

In response to question B9.3 (concerning which advanced technology accidents were discussed during conversion training) pilots nominated many accidents which related to inadequate situational awareness. One such example was that of American Airlines Flight 965 which, during a scheduled service between Miami International Airport and Cali Colombia, and operating under instrument flight rules (IFR), crashed into mountainous terrain during descent. The aircraft impacted terrain at approximately 8,900 ft above mean sea level (AMSL) near the summit of El Deluvio. One hundred and fifty-nine of the 163 passengers and crew sustained fatal injuries as a result of the accident. Colombian authorities (Aeronautica Civil of the Republic of Colombia 1996) cite the following as the probable cause of the accident:

- the flightcrew's failure to adequately plan and execute the approach to runway 19 at Cali and their inadequate use of automation;
- failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach;
- the lack of situational awareness of the flightcrew regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids; and
- failure of the flightcrew to revert to basic radio navigation at the time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight.

This accident illustrates the dangers of poor situational awareness.

One of the problems facing pilots flying modern automated aircraft is that to gain adequate information they must consult several sources. In older aircraft the pilot obtained all necessary information from printed material (maps, charts, aircraft performance manuals, and company policy); in an automated aircraft some of this information is contained within the FMC, some in printed performance manuals and some on charts.

The FMC does not incorporate all the information provided in aircraft documentation. The navigation system does include information about SIDs, en-route navigation, STARs, runways and airfield data. However, these systems do not often incorporate data which is essential for well-rounded situational awareness. For example, terrain features, LSALT, MSA and crossing airways are often excluded, or not highlighted, in computer generated information.

Situational awareness en-route

Figure B4.1 indicates that 60% of respondents refer to their en-route charts far less on new-technology aircraft than on aircraft without an FMC/FMGS. Figure B4.5 shows that 16% of respondents refer to their instrument approach charts far less on new technology aircraft than those on aircraft without an FMC/FMGS. It is unrealistic for pilots of aircraft with FMC/FMGS to believe they can rely on computer data to provide adequate information to build a complete mental model of their environment. It is important for pilots to realise that technology is not yet at the point where it has completely and satisfactorily replaced 'paper' information.

FIGURE B4.5

I refer to my instrument approach charts far less on new technology aircraft than on aircraft without an FMC/FMGS

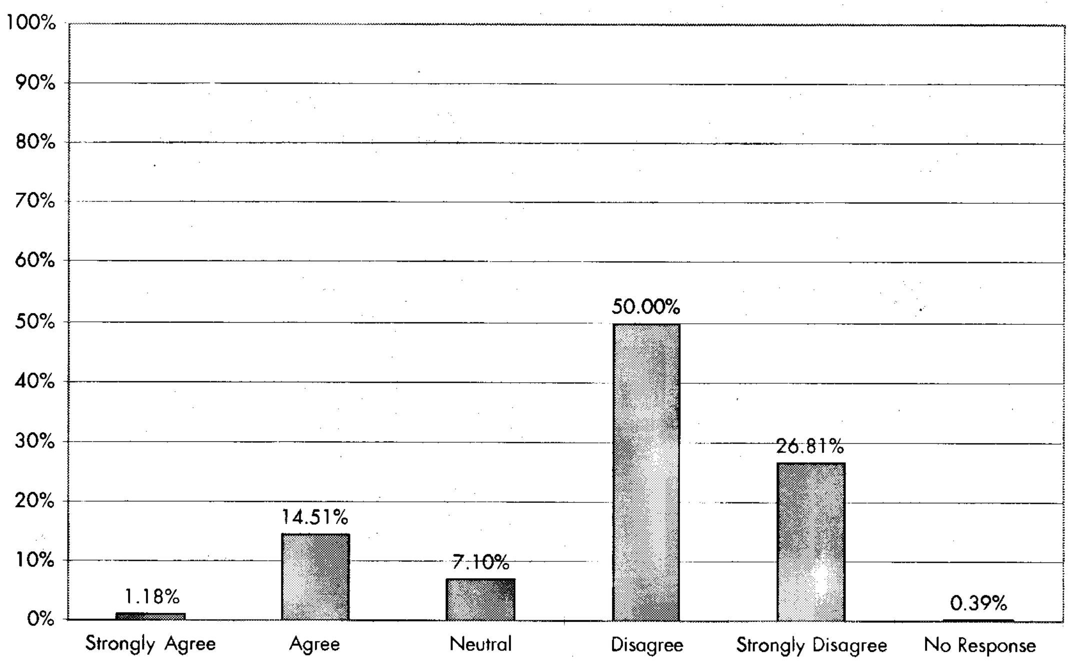
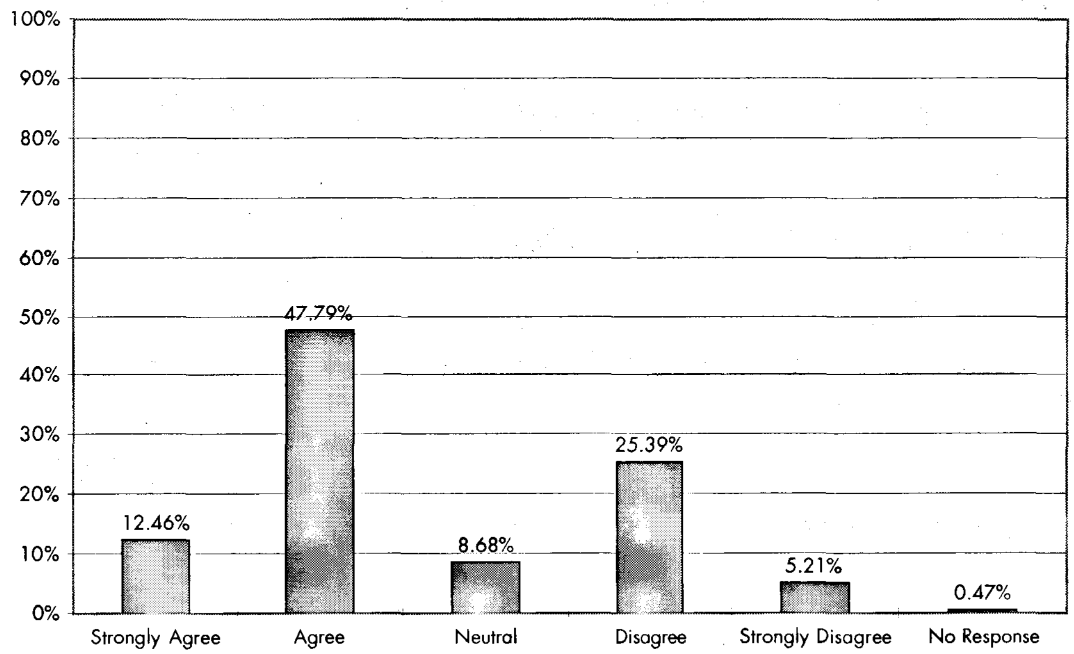


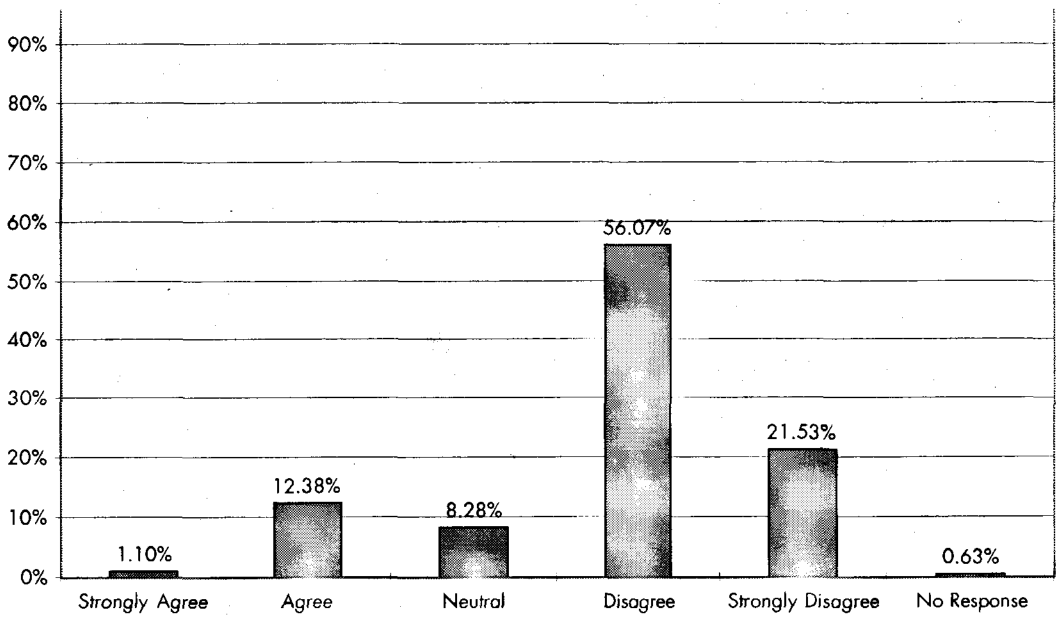
FIGURE B4.1
I refer to my enroute charts far less on new technology aircraft than on aircraft without an FMC/FMGS



Understanding the limitations of the FMC/FMGS

Thirteen per cent of respondents believe that all the information they need for the safe conduct of a flight is contained within the FMC/FMGS (see fig. B4.2). This view cannot be supported at this time. Clearly, aircraft manufacturers are developing the 'paperless' cockpit by incorporating electronic checklist and system information in their databases. Often, whether the operator includes this information in its database is an economic decision and is not related to flight operations or safety.

FIGURE B4.2
All the information I need for the safe conduct of the flight is contained within the FMC/FMGS



ATC and situational awareness

Fourteen per cent of respondents reported that they relied on ATC to provide terrain clearance (see fig. B4.3).

Analysis revealed a statistically significant difference between the opinions of captains and first officers. First officers were more likely to rely on ATC to provide adequate terrain clearance than captains.

FIGURE B4.3
I rely on Air Traffic Control to provide adequate terrain clearance

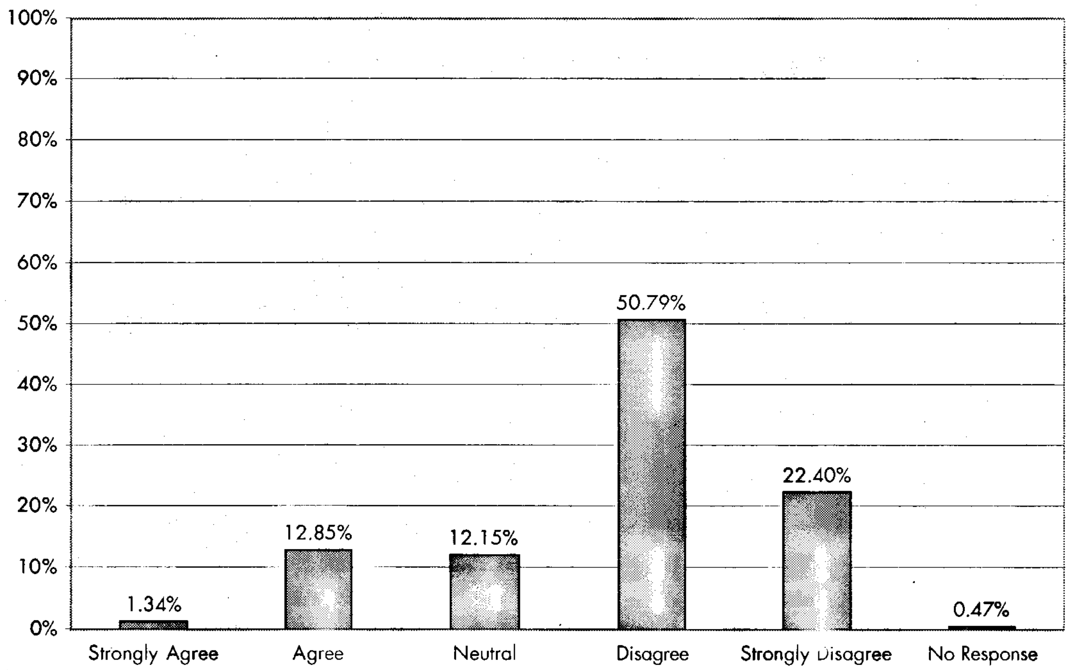


Table B4.3 shows the distribution of pilot rank by aircraft manufacturer of those aircrew who rely on ATC for adequate terrain clearance.

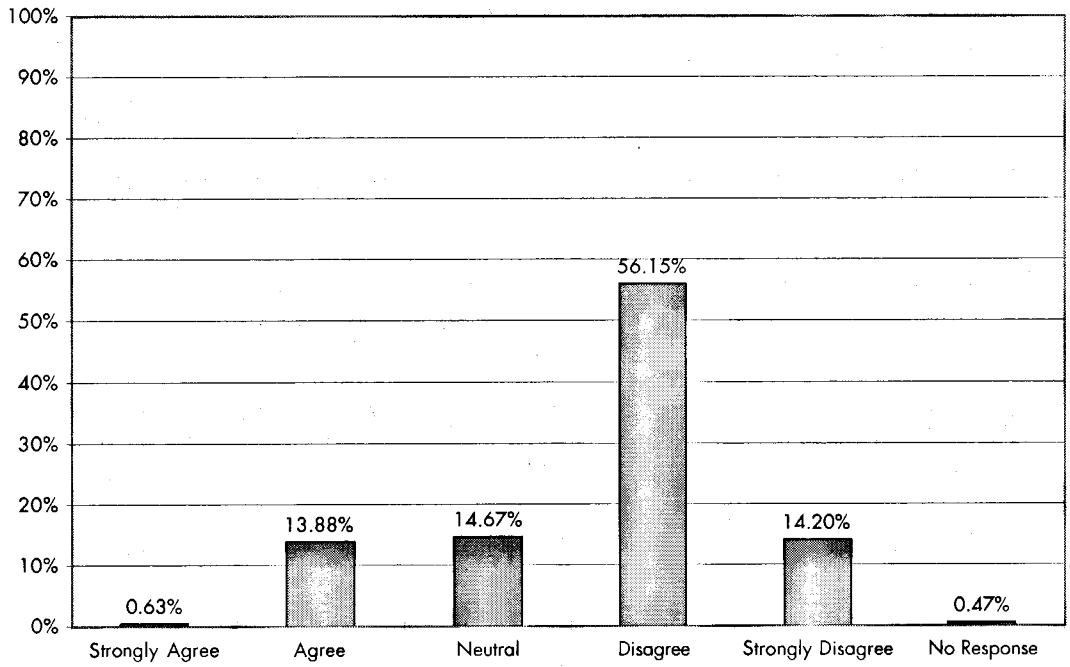
Table B4.3
'I rely on ATC to provide adequate terrain clearance.'

	Captain	First officer
Airbus	15 (11%)	9 (16%)
Boeing	68 (12%)	76 (19%)

Terrain awareness

Fourteen per cent of respondents reported having been surprised to find their aircraft closer to terrain than they had thought (see fig. B4.4). Such events clearly reflect a lack of situational awareness.

FIGURE B4.4
At times I have been surprised to find the aircraft is closer to terrain than I thought



Further analysis revealed 43 respondents who reported relying on ATC to provide terrain clearance and having at times been surprised to find the aircraft closer to terrain than they thought. This does not imply that ATC have failed in their traffic management function, nor does it imply that the aircraft was at risk of collision with terrain.

A significant difference was noted between the responses of captains and first officers. First officers were more likely to find the aircraft closer to terrain than expected, possibly because they were relying on the captain and ATC to ensure the safety of the flight. Hence first officers may benefit from specific training in situational awareness techniques.

Conclusions

Situational awareness relies on the pilot using all the available cues, assessing their significance and taking appropriate action. The pilot must be aware that the source of information, or cues, may differ from aircraft to aircraft, and from flight to flight. Like many CRM concepts, situational awareness may have become a vague concept to many pilots. Therefore, safety would be enhanced by providing pilots with specific situational awareness training during their initial conversion training and during recurrent training exercises.

The responses recorded in this chapter appear to support the concern that some pilots rely solely on computer-generated data as their reference for making decisions. There is no doubt that reliance on a single source of information rarely contributes to safe operations in any environment. Airlines could enhance safety by emphasising to pilots the information which is incorporated in the FMC and the information which must be obtained from other sources.

In other situations, pilots have reported relying on ATC to provide adequate terrain clearance. Controllers are clearly of the opinion that the safety of the aircraft remains the responsibility of the pilot. In this case ATC is one of the cues or aids that are available to the pilot when making decisions regarding terrain clearance.

Recommendation

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980036):

Review their pilot training to consider:

(a) specific training to pilots regarding situational awareness;

(b) differences that may exist between printed and electronic flight information;

(c) responsibilities of ATC regarding the provision of terrain clearance; and

(d) clear policy regarding the use of en-route charts and instrument approach charts during flight.

SYSTEM DESIGN

Introduction

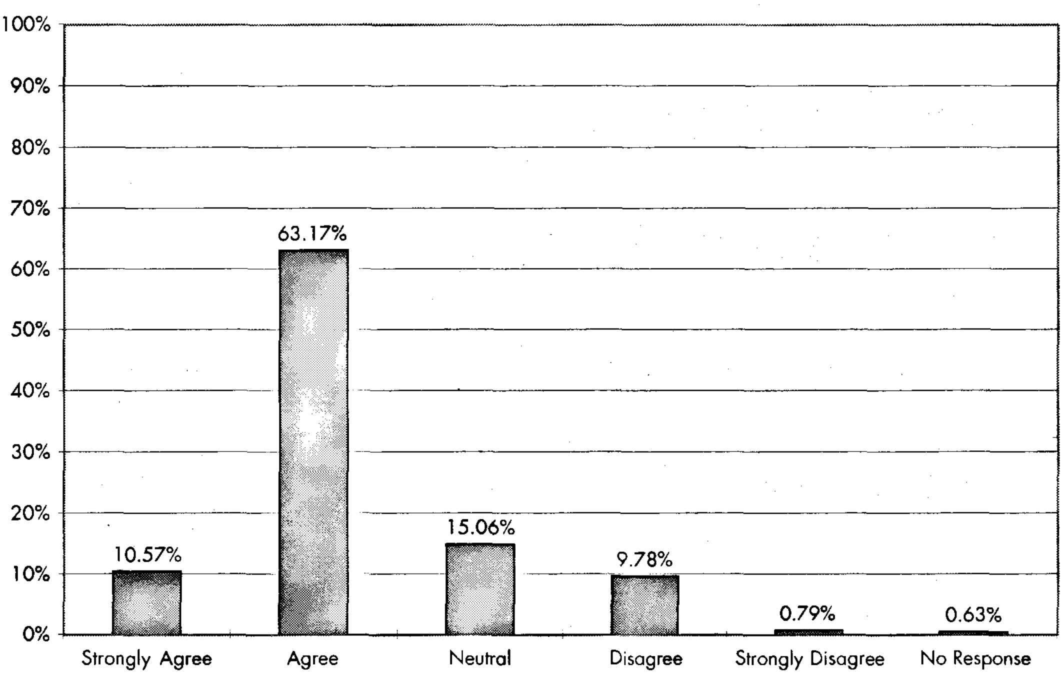
Research and development in ergonomics, metallurgy, fibre-optics, computer hardware and software, and human factors have contributed to the increased safety and efficiency of modern automated aircraft. System design benefits from computer-aided design (CAD) programs which are incorporated in pre-production 'debugging'. Also, manufacturers continue to receive input from airline personnel and interest groups within the aviation industry. However, even the most extensive pre-production testing has not been able to eliminate errors and potential errors from automated hardware and software.

This chapter discusses the responses of pilots in relation to automated system hardware and software, including the user-friendliness of controls, data entry error detection and correction, crew awareness and communication, and the ability of the FMC/FMGS to cope with last-minute changes.

User-friendly controls

Contrary to anecdotal evidence, 73% of respondents indicated that the FMC/FMGS and associated controls are 'user-friendly' (see fig. B1.1). Past design issues, such as the adoption of a non-QWERTY keyboard, touch-sensitive screens, and non-ergonomic design do not seem to be reflected in this result.

FIGURE B1.1
The FMC/FMGS and associated controls are user friendly



A statistically significant difference between both pilot rank and aircraft manufacture was noted in the response to this question. First officers were likely to be more satisfied with the user-friendliness of the controls than captains. Airbus pilots were likely to be less satisfied than were Boeing pilots (see table B1.1).

Table B1.1
'The FMC/FMGS and associated controls are not user-friendly.'

	Captain	First officer
Airbus	27%	21%
Boeing	9%	6%

Similarly, statistically significant differences were noted between the responses of pilots from different national groups. As expected, significant differences were also noted between pilots on the basis of their home port.

- *National groups.* Asian groups, Singaporeans and Australians were more positive regarding the user-friendliness of controls compared to New Zealand, British and European pilots.
- *Home port.* Pilots based in Asian ports (excluding Singapore and Hong Kong), Australia and Singapore were more positive regarding the user- friendliness of controls than pilots based in New Zealand, Europe and Hong Kong.

Data entry error detection

Twenty-seven per cent of respondents stated that it was difficult to detect when incorrect data had been entered into the FMC/FMGS (see fig. B1.2).

There are two aspects to this question. Firstly, the acceptance of incorrect data by the FMC/FMGS, and secondly, the detection of incorrect data.

Tests completed throughout the course of this study revealed that it is possible to insert incorrect data into the FMC/FMGS. For example, researchers found that it was possible to insert and execute an end-of-descent point below the elevation of an airfield. However, airline standard operating procedures prohibited pilots from flying VNAV approaches below the initial approach altitude.

Data error detection is the other aspect of this question. The pilot is left with only two methods of error detection, namely, human detection (including physical sensation) or electronic detection. Through a process of cross-checking, pilots may realise their mistake, or the FMC/FMGS may generate a warning message or fail to accept some erroneous data.

Either approach highlights a degree of inconsistency. The FMC/FMGS will accept some erroneous data whereas it will not accept others. The pilot may pick up some mistakes whilst others may not be discovered. For example:

Wrong runway inserted for Brisbane. Not detected until initial turn off track (due ATIS change).

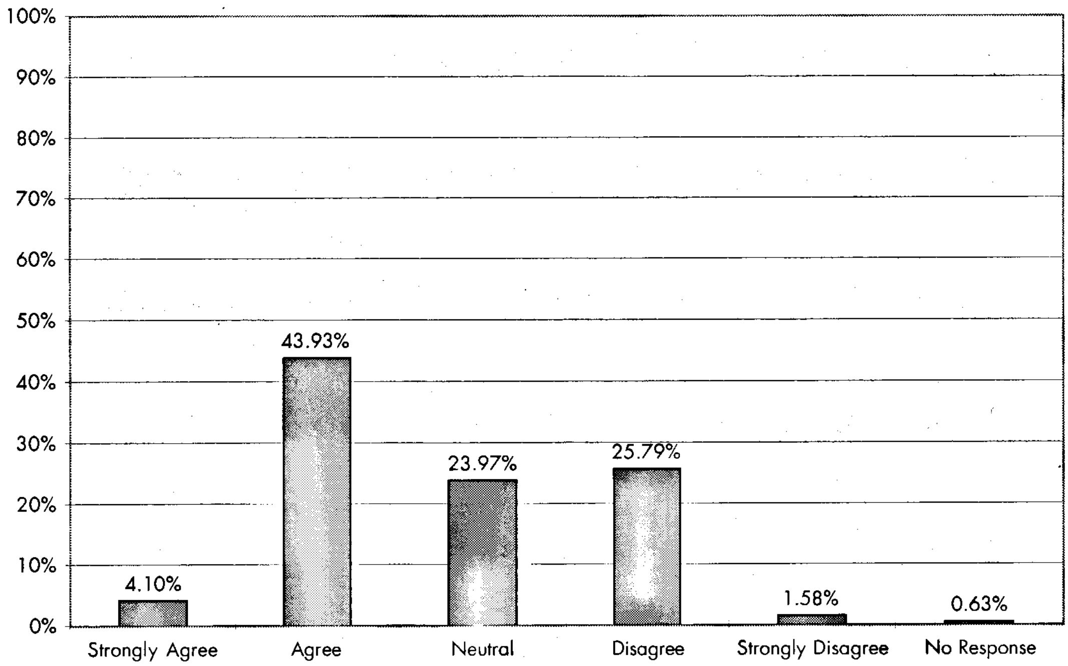
An incorrect OAT was entered into FMC and not picked up in check. This resulted in the auto-throttles not bringing sufficient power for takeoff. Manually overridden and corrected during take-off roll with no further incident.

Pacific random track crossing requiring manual entry of waypoints. Waypoint entry error by first crew combination, followed by duty hand-over prior to random track entry. Error was not detected until aircraft had left correct waypoint towards incorrect waypoint–but before substantial navigation anomaly occurred. Procedures for manual entry and cross-check of navigation have deteriorated with increased automation.

Putting in a wrong departure in the FMS. Both pilots missed the entry. The wrong departure was flown until ATC spotted it. PON 1D was inadvertently entered instead of PON 3B departure. PON 1D was a new departure included into the database, something which the pilots didn't realise.

Information is presented to pilots on CRT or LCD screens. It is possible that pilots experience the same difficulties during the input of information as computer operators do when editing information on-screen. The development and application of advanced system logic would minimise the opportunity for pilots to 'execute' unintentional mistakes.

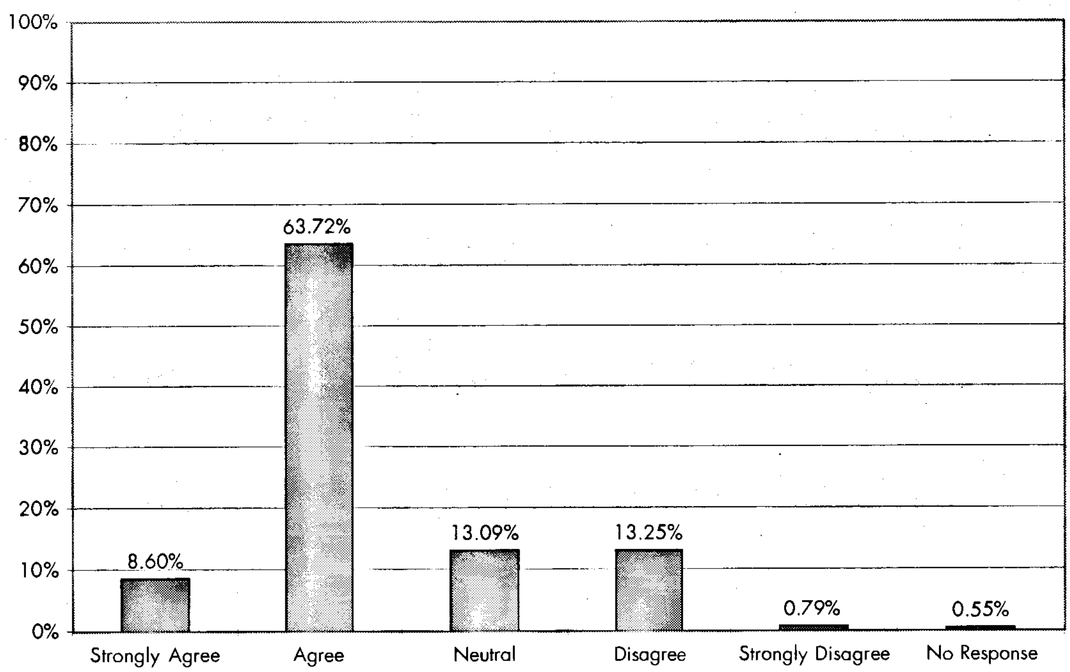
FIGURE B1.2
It is easy to detect when incorrect data has been entered by mistake



Correcting mistakes

Fortunately, most data entry errors are detected before they are 'executed'. Seventy-two per cent of respondents reported that incorrect data entered by mistake was easily corrected (see fig. B1.8).

FIGURE B1.8
Incorrect data entered by mistake is easily corrected



The following responses contain examples where incorrect data was corrected:

Upon receiving a route modification the captain selected the position to the top of the second page and executed without realising the error. Picked up by second officer.

Overly 'snappy' FMC pre-flighting led to cost index 1,000 instead of cost index 100 being loaded (key pad bounce perhaps). The higher speed climb was detected airborne.

Wrong data entered for runway due to last-minute change.

When altering the legs page to track direct to a waypoint we passed over a waypoint causing the incorrect point being taken to the top of the legs. The error was recognised prior to it being entered.

Crew awareness

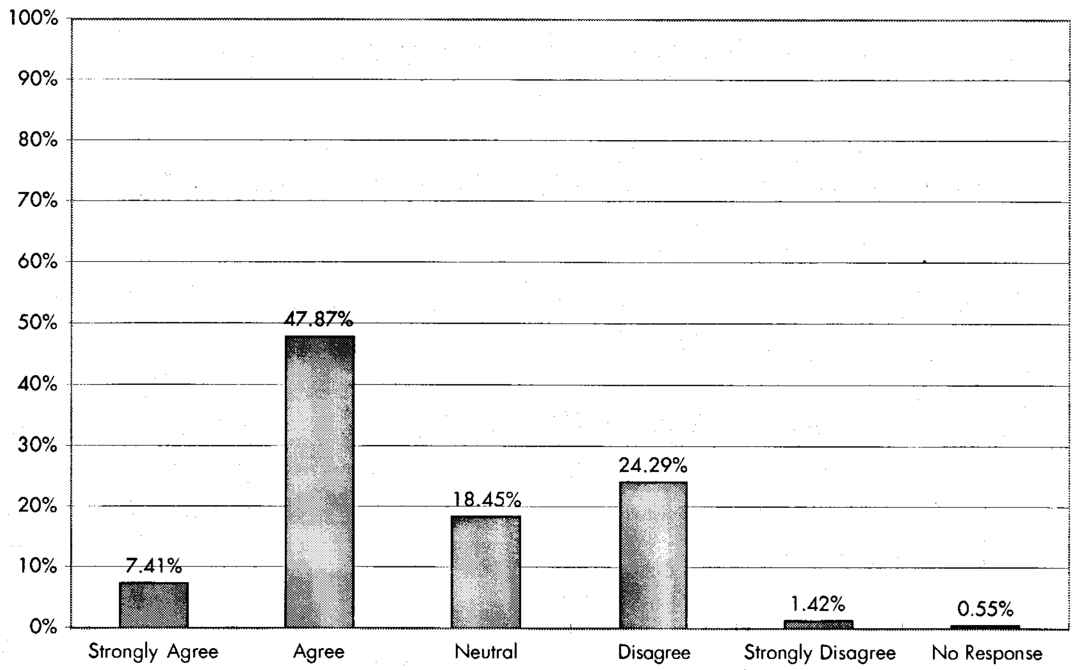
System design and cockpit layout should enhance communication and awareness of crew activities. It is important that each crew member is aware of the other crew member's control inputs, including those involving computer/automated controls.

Figure B1.3 indicates that 25% of respondents reported that they did not always know what the other crew member was doing with the automated systems. Some pilots commented that the other crew member had 'executed' automated functions without informing them. For example:

On descent into Sydney where VNAV was engaged by the PF without the PNF being informed.

The ATC requires a minimum rate of climb shortly after t/off. The PF immediately selected v/s on the MCP without advising the other pilot, resulting in thrust reduction immediately.

FIGURE B1.3
I always know what the other crew member is doing with the automated systems



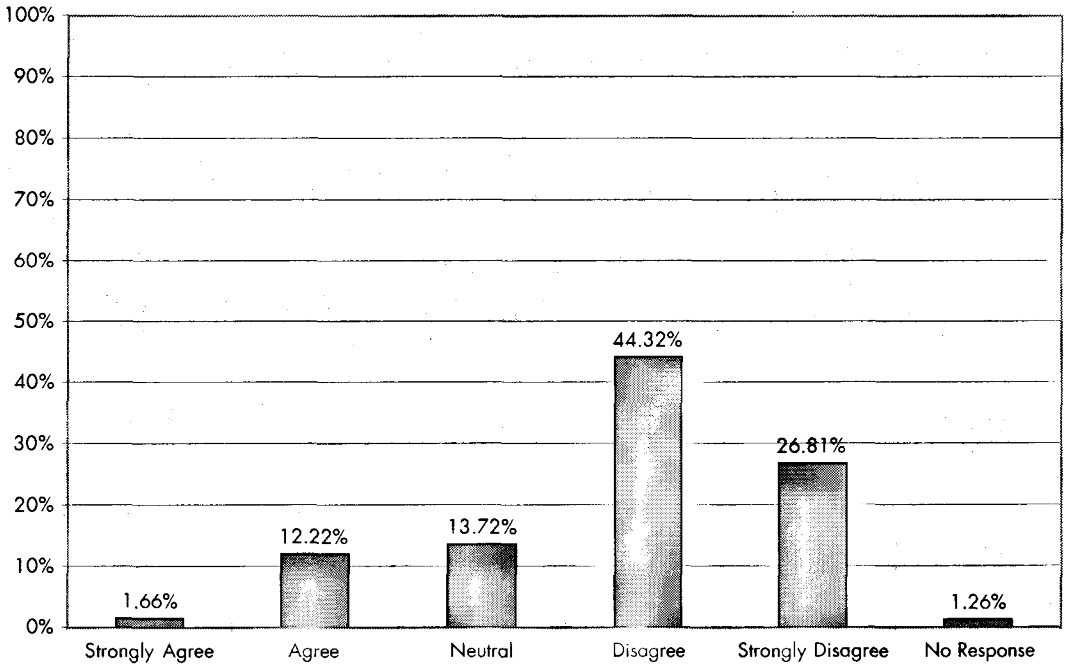
Pilot control inputs

Figure B1.4 shows that 13% of pilots had been surprised to find the pilot not flying (PNF) making flight control inputs. Boeing and Airbus pilots were equally likely to report this problem.

Some reported accidents and incidents have occurred in which both operating crew made simultaneous flight control inputs. Aircraft manufacturers are currently addressing the problem of providing feedback to the pilots when dual inputs are being made. In the case where simultaneous inputs are 'summed', it is possible that one input will negate the other.

In some cases, pilots may 'instinctively' make control inputs, for example, when encountering severe turbulence. A dedicated training program may be warranted to address this undesirable situation.

FIGURE B1.4
At times I have been surprised to find the pilot not flying (PNF) making flight control inputs

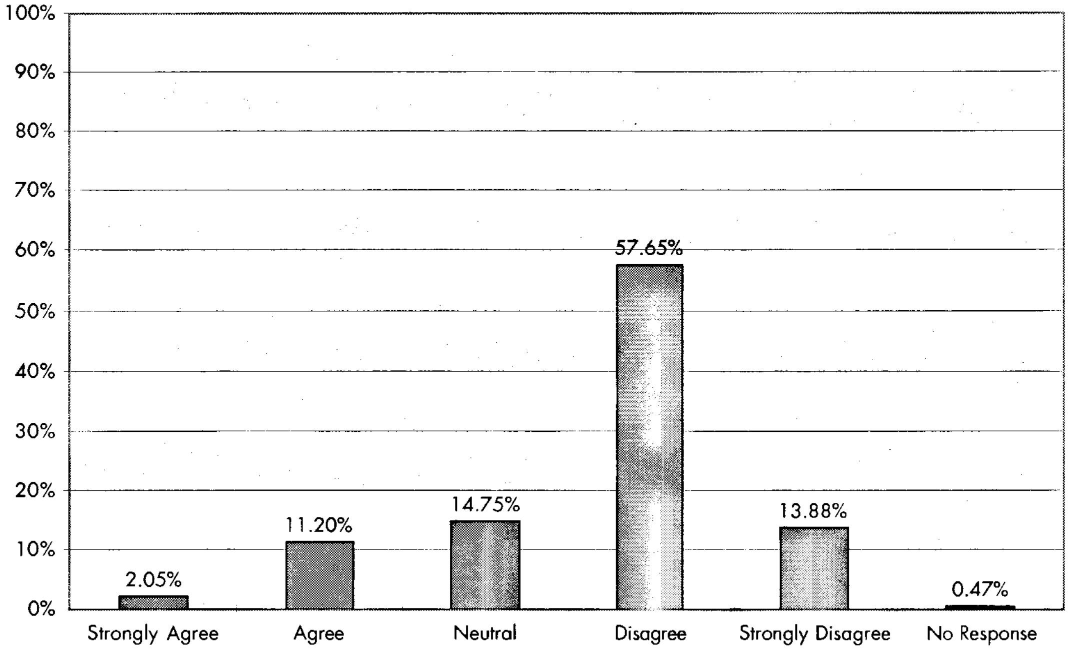


Understanding the language of the FMC/FMGS

Thirteen per cent of respondents sometimes found it hard to understand the language or technical jargon in messages presented by the FMC/FMGS (see fig. B1.9).

Analysis revealed a statistically significant difference between the responses of Airbus and Boeing pilots. Airbus pilots found it harder to understand the language or technical jargon in messages presented by the FMC/FMGS. Automation terminology is currently being addressed by aircraft manufacturers with the aim of agreeing on standard terms for automated components, modes and messages. These results seem to confirm that a common language of automated hardware and software would be beneficial to all users.

FIGURE B1.9
I sometimes find it hard to understand the language or technical jargon in messages presented by the FMC/FMGS



Coping with last-minute changes

Approximately 50% of respondents agreed that automation did not cope well with the last-minute changes imposed by ATC (see fig. B2.4 on page 11). The ATC aspect of this statement has been addressed in chapter 1; however, this statement deserves further comment from the aspect of system design.

When asked to outline a specific event where they had difficulty operating an advanced-technology aircraft in accordance with an ATC instruction, pilots reported difficulty with programming runway changes, speed changes, and changes to STARs. Particular difficulty was experienced with last-minute changes.

Advances in FMC software have seen the addition of 'alternate route' pages which allow pilots to anticipate and program different routes or approach criteria. While this assists with accelerating the 'change process', pilots perceive that further improvements should be made to assist them in coping with ATC requirements.

System work-arounds

Forty-two per cent of respondents confirmed that they sometimes employed system work-arounds to achieve a desired result from the FMC/FMGS (see fig. B5.3).

An analysis of the information contained in table B5.3 reveals that the results are almost evenly distributed across aircraft manufacturer (44% Airbus and 42% Boeing). However, there is a statistically significant difference between pilot ranks, in that first officers (48%) are more likely to be required to 'trick' the FMC/FMGS than captains (39%). Pilot reports suggest that they are required to enter erroneous data into the FMC/FMGS to overcome deficiencies in aircraft performance, especially during VNAV control. These procedures, which in many cases have evolved into a form of standard operating procedure (SOP) are not addressed by airline operational policies and procedures.

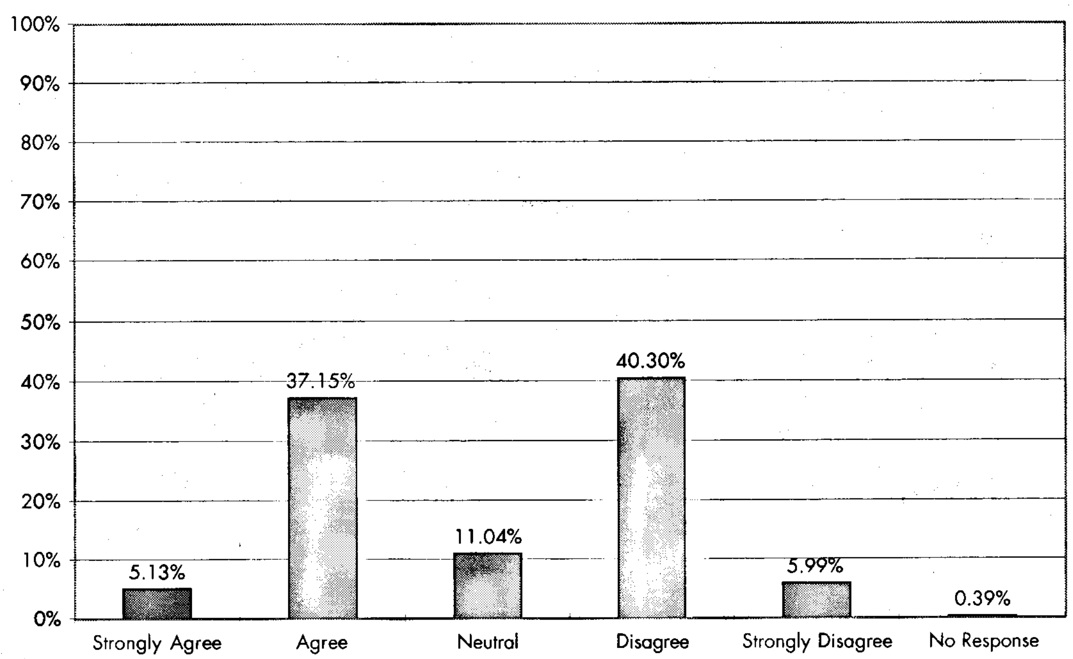
Table B5.3
'I am sometimes forced to 'trick' the FMC/FMGS by entering erroneous data to achieve a desired result.'

	Captain	First officer
Airbus	38%	51%
Boeing	38%	47%

When asked to outline the details of a FMC/FMGS system work-around, pilots revealed that the most common objective of work-arounds was to ensure an accurate descent profile (69%), followed by refining speed management during the cruise or holding manoeuvre (8%), and providing accurate speed control during descent (7%). Their most frequent *strategies* were to manipulate the end of descent point or distance/altitude window (43%), insert a different speed or mach number (24%), or to insert a different wind component than forecast (9%). Approximately 80% of these manipulations applied to the descent phase of flight while 15% took place in cruise.

These results confirm the responses to question B1.12 where pilots revealed that the feature they liked least of all was the VNAV function.

FIGURE B5.3
I am sometimes forced to 'trick' the FMC/FMGS by entering erroneous data to achieve a desired result. (For example, I enter 240 knots to ensure the aircraft maintains 250 kts etc.)



Conclusions

The results support the current industry concern of ensuring sufficient quality control and pre-flight testing of automated products, especially automation software. The requirement for pilots to engage in FMC/FMGS work-arounds is an indication of the continuing shortfall in some aspects of software/hardware design. Although many of these deficiencies have been rectified in subsequent software releases, 'working around' a known problem is a poor solution, and represents a significant safety concern. Airline operators passively participate in this process by failing to address the practice of system work-arounds through their policy and procedure documents. It would appear that an undesirable subculture has developed amongst aircrew which needs to be addressed by both aircraft manufacturers and airline management.

System work-arounds are most commonly performed to achieve a desired descent profile which often reflects the incompatibility between advanced-technology aircraft and the current ATC environment.

Similarly, the ability to enter incorrect data, which may or may not by identified, represents a serious safety concern. Aircraft manufacturers should ensure that the ability of systems to accept illogical data is reduced and preferably eliminated.

Further research is needed to determine the circumstances in which non-flying pilots make flight-control inputs. This factor has been a contributing factor in at least one accident and one serious incident within the Asia-Pacific region. Although aircraft manufacturers have taken steps to address a shortfall in hardware design, the human factors aspect of this phenomenon has not yet been fully explored.

Recommendations

The Bureau of Air Safety Investigation **recommends that airline operators (R980037):**

Review their standard operating procedures (SOP) and airline policy to require only one crew member to make control inputs at any one time unless stated to the contrary in an emergency/abnormal procedure, and emphasise the consequences of multiple simultaneous flight control inputs.

The Bureau of Air Safety Investigation recommends that **aircraft design authorities consider requirements for (R980038):**

(a) a means of alerting the pilot when incorrect data has been entered into the FMC/FMGS;
(b) all data entries being able to be corrected easily by flight crew;
(c) common industry terminology for automation hardware and software;
(d) FMS software and hardware to accommodate the various changes which are imposed by ATC on an advanced technology aircraft during all phases of operation;
(e) quality control procedures for FMC software with the aim of eliminating the need for system work-arounds; and
(f) the position, design and tactile differences of the frequently used mode selectors (such as heading and speed), with the aim of eliminating any confusion regarding the use of these controls.

TRAINING

Introduction

The introduction of automated aircraft systems has been accompanied by significant changes to pilot training methods. Computer based training (CBT) has largely replaced the traditional classroom. Some ground training courses have been reduced from 6 weeks to 14 days duration. Much of the 'nice to know' information, which in the past provided the pilot with a well-rounded understanding of aircraft systems, has been narrowed to a 'need to know' level. Also, in some cases, aircraft 'base training' has been replaced by zero flight time (ZFT) simulation.

This chapter contains a discussion of respondents' answers to six attitude probes relating to pilot training on advanced technology aircraft, and a detailed analysis of the written responses to question B8.7 ('What could be done to improve the training you received on this aircraft?'). An analysis of 'previous aircraft types' revealed that only 25% of respondents had previously flown an advanced technology aircraft. These responses account for the majority of pilots who were transitioning to an automated aircraft for the first time, possibly without previous biases toward automation or training procedures.

Training standards

Twenty-six per cent of respondents indicated that training for their current aircraft was inadequate when compared to past training (see fig. B8.1).

Significantly more Airbus pilots were dissatisfied with their training than Boeing pilots (see table B8.1). This possibly reflects the fact that Boeing has a longer history of training pilots than Airbus Industrie.

Table B8.1
'Training for my current aircraft was inadequate.'

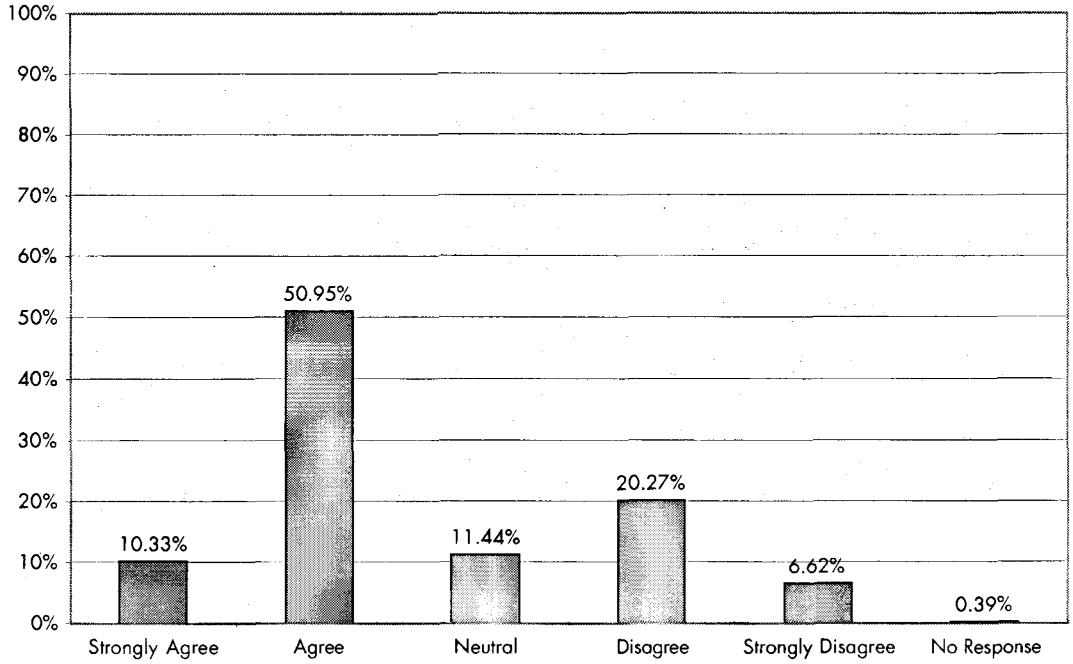
	Captain	First officer
Airbus	41.1%	27.3%
Boeing	28.9%	19.9%

Table B8.1.1 indicates that a degree a dissatisfaction was present across all age groups but that dissatisfaction was directly related to age, so whereas 17% of 21–30 year olds were dissatisfied with their training, 39% of 51–65 year olds were dissatisfied.

Table B8.1.1
'Training for my current aircraft was inadequate.'

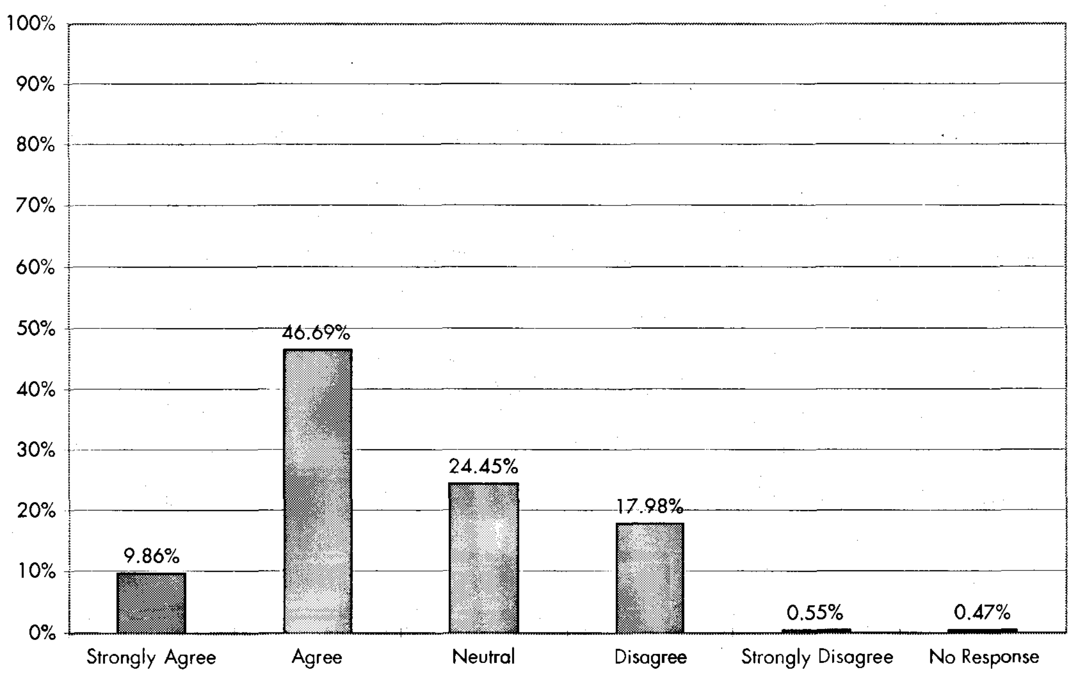
	21–30 years	31–40 years	41–50 years	51–65 years
Percentage	17	22	29	39
Total in age group	134	449	439	497

FIGURE B8.1
Training for my current automated aircraft was as adequate as any training that I have had



Understanding of aircraft systems

FIGURE B8.2
I would like to have a deeper understanding of aircraft systems



The majority of respondents (55%) considered that they would have liked a deeper understanding of the aircraft systems (see fig. B8.2). Of this group only 22% indicated that they had previously flown an advanced technology aircraft (n = 717; advanced technology aircraft types = B737, B757, B767, A310, A320 and A330). This result may reflect a change in training philosophy for advanced technology aircraft in which information is provided on a 'need to know' basis. While this training provides a pilot with sufficient information to deal with the more predictable emergency/abnormal situations, it may not adequately prepare pilots to deal with situations requiring deeper systems knowledge, for example, the UA232 accident, Sioux City.

Technical manuals

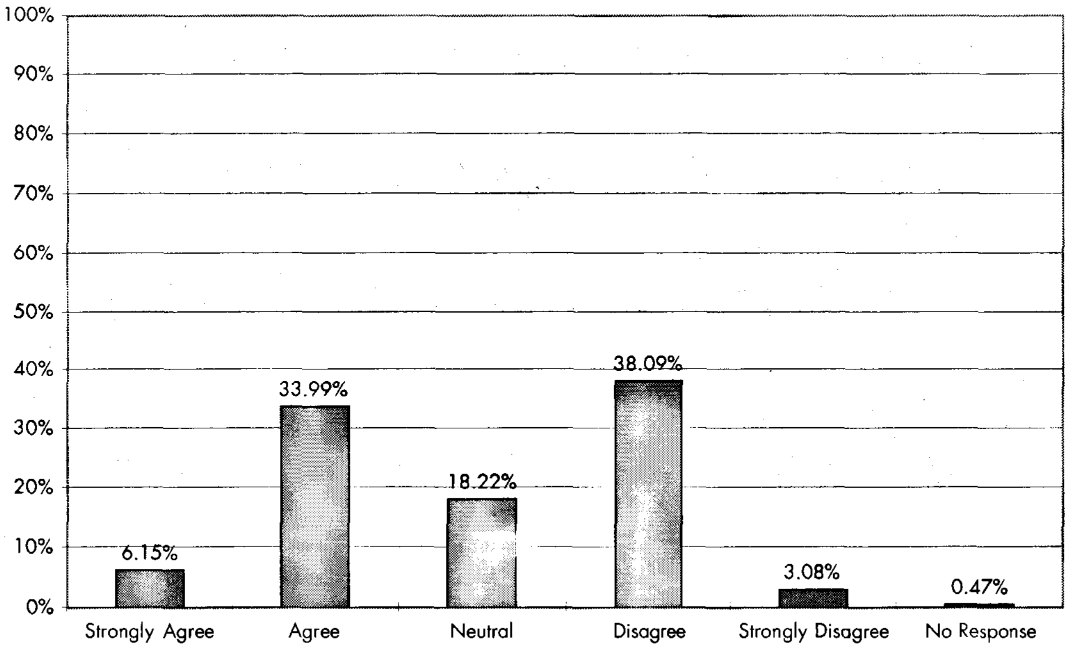
Many of the respondents (40%) sometimes had difficulty understanding information in the technical manuals associated with their aircraft (see fig. B8.3).

Table B8.3 indicates that pilots operating Airbus aircraft had more difficulty understanding information in the technical manuals associated with their aircraft than pilots operating Boeing aircraft. Further analysis revealed that this result was highly statistically significant.

Table B8.3
'I sometimes have difficulty understanding information in the technical manuals associated with this aircraft.'

	Captain	First officer
Airbus	63%	58%
Boeing	32%	38%

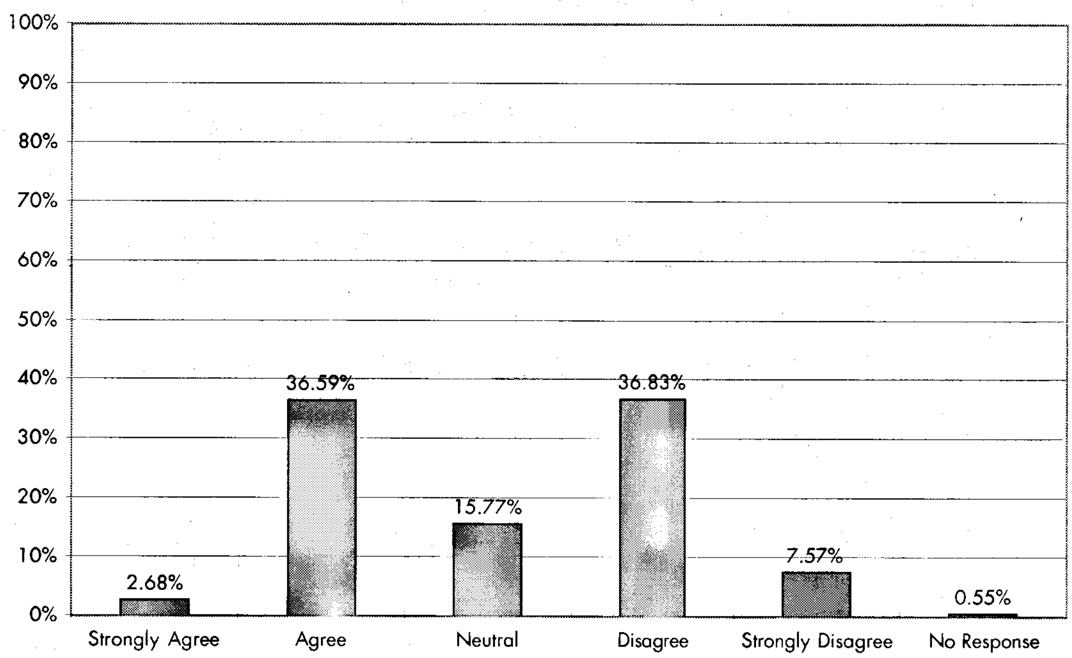
FIGURE B8.3
I sometimes have difficulty understanding information in the technical manuals associated with this aircraft



Quality of training manuals

Similarly, fig. B8.4 indicates that 39% of respondents were unable to find all the information they needed for their training in the aircraft or company technical manuals. Training manuals should be tailored to the needs of the flight crew. The question arises that if the pilots needed to find some information and it was not contained in the manual or training notes, where did they obtain the information? Relying on opinion or personal experience seriously degrades the quality of information received by the pilot and hence degrades the safety of flight operations.

FIGURE B8.4
I was able to find all the information I needed for my training in the aircraft/company technical manuals



Effective training

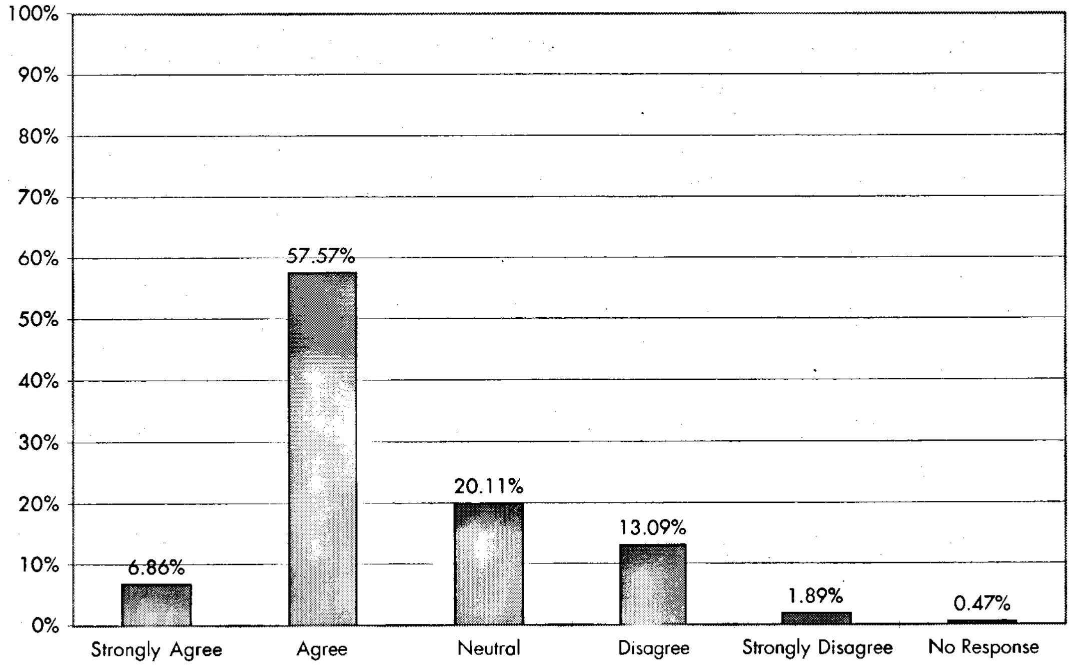
Most pilots (64%) indicated that their training prepared them well to operate their current aircraft (see fig. B8.5). This result is consistent with overall survey scores which indicate that pilots had responded favourably to automation.

Only 14% of respondents felt that their training had not prepared them well to operate their current aircraft (see fig. B8.5). This result is relatively evenly distributed across pilot rank and aircraft manufacturer (see table B8.5).

Table B8.5
'My training did not prepare me well to fly this aircraft.'

	Captain	First officer
Airbus	15.9%	17.9%
Boeing	16.3%	13.7%

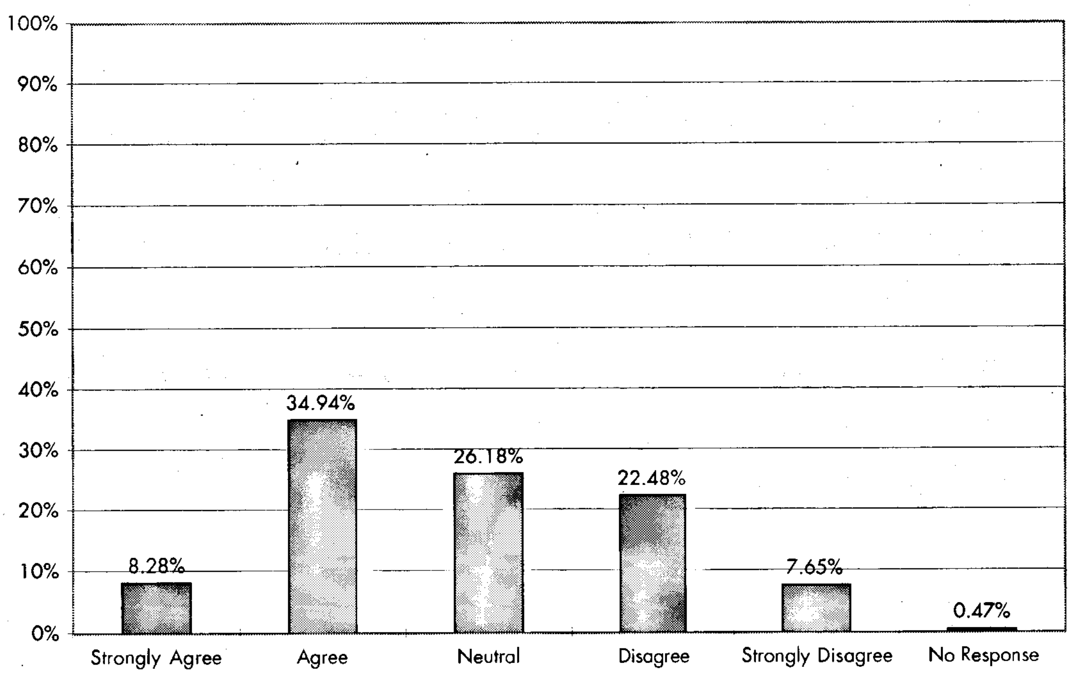
FIGURE B8.5
My training has prepared me well to operate this aircraft



Computer-based training versus traditional teaching methods

Forty-three percent of pilots preferred computer-based training, while 30% preferred traditional teaching methods (see fig. B8.6).

FIGURE B8.6
I prefer computer based training over traditional teaching methods



Further analysis revealed a statistically significant difference between the preference of Boeing pilots when compared to Airbus pilots (see table B8.6). Boeing pilots had a higher preference for computer based training than Airbus pilots. However, at the time this survey was conducted, not all Airbus pilots may have experienced computer based training.

Table B8.6
'I prefer computer based training over traditional teaching methods.'

	Captain	First officer
Airbus	34%	23%
Boeing	45%	39%

Training improvements

A significant number of pilots (711 or 56%) responded to the question B8.7. 'What could be done to improve the training you received on this aircraft?' To enable these written responses to be analysed, each question was allocated to one of the following categories, which are listed in order of significance:

1. automation
2. simulator
3. teaching methods
4. training quality
5. training quantity
6. manuals
7. line operations
8. training staff
9. comments regarding check/training.

Automation

The subject of automation was addressed by 156 respondents in relation to improving their training.

- Approximately 40% of this subgroup suggested that more 'hands on' training (FMC/FMGS, MCP), or being allowed more time to use an FMC/FMGS training aid, would have enhanced their training:

More hands-on practice with the training FMC.

Much more training is necessary on ground based trainers for managing the FMC and data input.

Free-play FMC training should be mandatory.

- Other significant comments called for in-depth training on automated systems:

More explanation of modes and their relationship to each other.

Mode annunciation and speed protection modes are only explained after completion of ground school. They are not part of the training package.

More detail on autopilot / flight director modes and annunciations.

- Similarly, pilots suggested that the provision of a fixed-base FMC/FMGS trainer, or fixed-base simulator, would have improved their training experience:

An FMGC in the classroom, to be able to understand its programming and become familiar with all its features prior to commencing line training. Otherwise your attention during flight is diverted away from flying the aircraft.

Improved FMC simulator.

Provision of a FMGS for hands-on training.

- Equally important was the suggestion that 'automation philosophy' should be explained during the early stages of conversion training:

A course on logic behind the development of the automated systems.

Simulator

One hundred and ten respondents commented on aspects of their simulator training. Comments were classified according to duration and quality of simulator training.

The majority of comments relating to the duration of training stated that more simulator training should be scheduled. For example:

More simulator sessions, with emphasis on teaching rather than assessing the student.

Similarly, most pilots stated that the quality of simulator exercises needed improvement. Specifically, pilots suggested improving the quality of simulation, providing better simulator training programs (especially regarding rostering), an even flow of information ('too much too quickly'), more comprehensive briefings by the instructor prior to the simulator session and practical demonstrations throughout the session, and the use of a standard syllabus. For example:

Better use of simulator. There is a tendency to try and cover too much in too short a time. We are expected to be proficient without sufficient training time being allocated to really feel comfortable with abnormal operations.

Pilots offered three significant suggestions as to how their simulator training could be improved:

1. More time should be spent concentrating on normal operations including takeoff, descent, circuits and manual flying. For example:

More emphasis during ground school and SIM endorsement on a normal line flight, with some ATC constraints, in order to become more familiar with the FMGC.

More normal operations training in simulator during initial endorsement.

2. There should be more emphasis on automation, especially the use of various 'modes'. For example:

Much more simulator time concentrating on mode changes and mode awareness.

More SIM time at first on mode use of MCP in upper air work.

More time could be spent practising in the simulator with the automatic modes. Too often we seem to be asking 'What's it doing now?'

Training was well structured and prepared pilots well. However, a little more simulator experience in basic flying using all the FMA modes would have been helpful without additional pressure of non-normal situations to manage.

Hands-on training in the simulator on profiles requiring FMC selection/manipulation and mode control panel selection/operation.

3. Free time, or free-play simulator sessions would have improved their training. Some (8%) commented that post-training simulator practice or self-help sessions would have been beneficial:

Free-time simulation sessions during which individual pilots could practice the aspect of flight they feel needs improving.

Having time in simulators to experiment without being graded or rated in training records.

Simulator available for self-help programs is very good improvement.

Teaching methods

One hundred and four pilots made specific comments regarding the method of teaching during their training.

Most of those who made comments would have preferred face-to-face lectures, presentations, and discussion groups during their ground training. Conversely, 21 pilots preferred computer-based training (CBT). Interestingly, 13 pilots suggested that CBT and 'chalk and talk' should be integrated:

Face-to-face teaching with technical specialists of the aircraft's systems will help in the safe operation of the aircraft.

Greater use of multimedia PC-tech for systems and procedures training.

Computer based training requires back-up lectures by a well trained, experienced lecturer.

Quality of training

Sixty-one respondents commented on the quality of their training. Most of these pilots reported that their training was superficial, lacking in-depth system/software information. This comment corresponds to those made regarding 'manuals':

Better systems knowledge. It is amazing how little I know about the B767 but am still required to operate it to a high standard.

Pilots also commented that the information presented throughout their course was often out of date or inadequate:

More accurate up-to-date information.

The training handouts are nearly all out of date, some by 5 or 6 years.

Quantity of training (general)

Sixty pilots made specific comments regarding the quantity and duration of their training with regard to specific topics or areas.

Most respondents suggested they should have received more training, while only five pilots would have been satisfied with less training.

Most pilots suggested that more training should be available to those pilots transitioning from older technology aircraft, while 13 specified more time during the engineering-course and ground-school phase. Pilots specifically suggested that they would have benefited from more time spent discussing automation, particularly the FMC/FMGS functions. Also more time could have been spent in the simulator. These comments are consistent with previous comments.

Manuals

This subgroup comprised 52 respondents. Comments related to the reference manuals available to pilots in the course of their training and during their subsequent operational duties. Three significant issues arose from these comments:

1. Pilots considered that manuals should provide more detailed information. For example:

   Information provided (manuals, checklist etc.) are on a need-to-know basis. Information which is 'good to know' should also be included. Information provided should be concise and easy to interpret.

2. Manuals are not 'user-friendly' and the overall presentation requires improvement (index, colour coding, layout, cross reference system):

Improved tech manuals, explanations, documentation. The technical manuals do not always present information in a user-friendly way, especially as there can be a number of manifestations of the same problem. Automated features each require different treatment.

Manuals provided for my fleet type are below standard, new procedures are passed by inter-office memos or more often than not, by hearsay. Most inappropriate.

Line training

Forty-four pilots commented on the quantity, content/syllabus and organisation of their line training.

Of those who commented on the duration of line training, all stated that more line training (more sectors) would have been beneficial. For example:

More line training. There was not enough time available during line training to learn about the systems in more detail.

More sectors as pilot flying.

More sectors for those who have not done FMC work before.

Comments on the content or syllabus of line training were almost equally distributed across the following issues:

- greater emphasis on automation/systems;
- more dynamic training;
- more informative training;
- greater emphasis on crew roles (PF/PNF); and
- more information on company procedures.

Comments concerning the organisation of line training suggested allowing more observer/supernumerary flights, and providing better training blocks/schedules.

Training staff

This subgroup comprised 37 responses. These comments addressed the selection of ground-training staff, the quality of instruction, and aspects of the training program relating to both ground, simulator and line-training personnel.

Five respondents believed that the selection process for instructors was inadequate. All indicated that instructors were not necessarily selected or appointed according to their instructional abilities:

Six years in an airline and 100 years as a captain does not qualify a pilot to train.

Most of these respondents were dissatisfied with the ability of their instructors (knowledge, language, experience), while some suggested that instructors should undergo specific training in instructional techniques, or that the company should provide better instructor training. The following comments illustrate this view:

Better instructors. On this aircraft conversion I was given no training which I could discern as training. Basically I completed the course finding out as I went along by myself. This airline's concept of training is 'It's in the book'. Read the book and you'll find out.

Educate the trainer in teaching methods.

Train the training pilots. A line captain is made a training captain and is not even given a brief on what is required.

Approximately half of the respondents suggested that training personnel should be specialist, full-time and qualified instructors. Other answers centred around three suggestions: that programs should also use line personnel to bring a sense of practicality to the training course; that the company provide for continuity of instructors; and that all instructors should use a set syllabus and standard procedures, and should agree on what is to be expected of flight crew throughout the course. The following comments illustrate this view:

Use specialist instructors who can answer questions instead of Audio Visual training.

Require a formal syllabus of training and qualified flying instructors. •

Better continuity of instructors.

Having all the flight instructors and simulator instructors agree on what is expected of line crew. If one or two instructors try to impose their methods as requirements, it merely confuses trainees and line crew. Even our chief pilot is party to this, so I guess there is no hope.

Comments regarding check-and-training

The following 10 comments were received regarding the check-and-training process on advanced technology aircraft:

Serious cultural problem, the current culture is a become-orientated rather than a learning culture. CRM training is a token sham, the result being that local pilots prefer flying with expatriates.

More training and demonstration, less 'checking'. It is easy for training to simply become a verification process.

Receive better and more continuation training than currently receiving, instead of only a checking element. A better training component prepares you better for a check.

Be exposed to more than one training captain. There are so many ways to operate this aircraft, you need to see other people operating it to decide what does and does not work for you.

Less emphasis in the simulator on 'tests' and more on training.

A more constructive check pilot attitude to simulator checking.

More training and reviewing and less checking would be highly desirable after qualifying.

A more consistent overall training effort by all crew – a culture which encourages more crew to be formally involved in training.

Less checking and more training.

We were over-checked.

More training as against an emphasis on checking instead – i.e. too much of the training captain waiting for and criticising mistakes rather than advising what may be expected.

Conclusion

In the past, each new generation of jet aircraft was an evolutionary development of the previous type. A pilot transitioning from one aircraft type to another could transfer many of the skills learnt on the previous type and tailor them to the new aircraft type or model. This is not the case with many of the pilots transitioning to advanced technology aircraft. Approximately 75% of respondents had not previously operated an automated aircraft and hence were faced with learning many new skills during their transition period.

Most pilots stated that their training had adequately prepared them to operate their aircraft. The majority also indicated that they preferred computer-based training over traditional teaching methods. These responses are consistent with the overall tone of the survey which indicates that pilots have generally adapted well to automation.

Other responses, however, pointed towards improvements which could be made in training procedures.

Pilots clearly expressed their desire to obtain a deeper understanding of aircraft systems.

The depth of training, the provision and availability of training aids and the quality of training manuals should equip flight crew to adequately deal with skill-based, rule-based and knowledge-based operational errors. Respondents perceived that one effect of new training regimes had been to reduce their knowledge of aircraft systems. It appears that the modern concept of requiring pilots to possess less systems knowledge than would have been the case with less automated aircraft types, may become problematic if instruction manuals are of poor quality, and frustrate further personal study.

Pilots suggested several ways of improving the training they received on their current aircraft and the implementation or improvement of the following areas could be beneficial:

1. Ensure that pilots are familiar with the aircraft manufacturer's automation design philosophy and the airline automation policy. Examples of two airline automation policies are provided in chapter 12.
2. Ensure that all ground, simulator and flight instructors are suitably qualified and comprehensively trained in modern instructional/teaching techniques.
3. Provide automation training aids.
4. Ensure training manuals provide up-to-date, in-depth information in a user-friendly presentation.

Several airlines have recognised the benefits of 'free-play' simulator sessions where pilots are free to nominate the scenarios they wish to explore. Several respondents suggested that their training could have been improved by 'free-play' simulator sessions or by the provision of desktop and fixed-base automation simulators. Currently, NASA is researching the effectiveness of personal computer (PC) based training programs, particularly those related to FMC/FMGS training. Early results suggest that this method of training, which is portable and conducted in the pilot's own time and at the pilot's own pace, may significantly contribute to automated training programs.

It is important that pilots receive reliable technical data/information. Although modern teaching methods generally provide information on a need-to-know basis, it is clear that pilots continue to 'fill in the gaps' by procuring information from various sources. The traditional, and sometimes dubious, sources of information have been expanded through various avenues including the Internet. Information gained through this method is often only opinion, or orientated to experience which is very difficult to verify. While many valuable discussion groups have been promoted over the Internet, it is also clear that a significant level of in-flight experimentation is occurring worldwide. Airline training departments can offer a high degree of quality assurance by providing adequate information through trained staff using quality manuals or electronic means.

Anecdotal evidence suggests that regulatory authorities may be hindering the advancement of training programs, especially simulator training programs, by insisting on rigid programs which are required to meet licence issue and renewal criteria. There is a concern that regulators are not able to keep pace with technological changes taking place within the aviation industry. The analysis of written responses highlights the need for training programs to be much more flexible, allowing some ability to adapt to the needs of the student. Those airlines and authorities that exercise some degree of flexibility have made significant advancements in their approach to training regimes.

Recommendations

The Bureau of Air Safety Investigation recommends that Civil Aviation Safety Authority (R980039):

1. Consider the need for:
   - (a) simulator and flight instructors to be trained in instructional/teaching techniques at a recognised educational facility;
   - (b) ground, simulator and flight instructors to undergo regular refresher training in instructional/teaching techniques at a recognised educational facility; and
   - (c) ground, simulator and flight instructors to demonstrate their ability as an instructor/teacher on a regular basis.
2. Assess the quality of printed and electronic training/reference material with respect to advanced technology aircraft.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980040):

Review the qualifications of all ground, simulator and flight instructors, and where necessary provide training in instructional/teaching techniques with the aim accrediting instructional/teaching staff.

WORKLOAD

Introduction

The term *'mental workload'* refers to the difference between the amount of information processing resources required by a situation and the amount of such resources available to the person at the time (Wickens 1992). The more that the demand approaches capacity, the greater the workload. When the demand reaches a level such that the person's performance is significantly affected, then a person can be said to be 'overloaded'.

A high workload level can have a variety of influences on human performance. The majority of these effects can be considered as attempts by the person to reduce demands by simplifying them. For example, a high workload can lead to a narrowing of the perceptual information a person attends to and a narrowing of the number of tasks a person attempts to perform. A person generally focuses on those information sources and tasks which he or she thinks to be the highest priority. However, this prioritisation process is subjective and may not necessarily be optimal. Working memory and decision making processes are also limited by high workload. These limitations can exacerbate a variety of decision making biases, and lead to a focus on certain aspects of tasks (e.g. speed) in opposition to others (e.g. accuracy).

If multiple tasks are being performed simultaneously, the performance of each of the tasks often deteriorates to some extent. The amount of interference between tasks increases if the same stages of information processing, input modalities, processing codes and types of response are involved. Another commonly discussed means of reducing task demands involves reverting to stereotyped patterns of behaviour. In addition, there is a tendency to focus on simpler tasks and responses, which generally but not always are the more established patterns of behaviour.

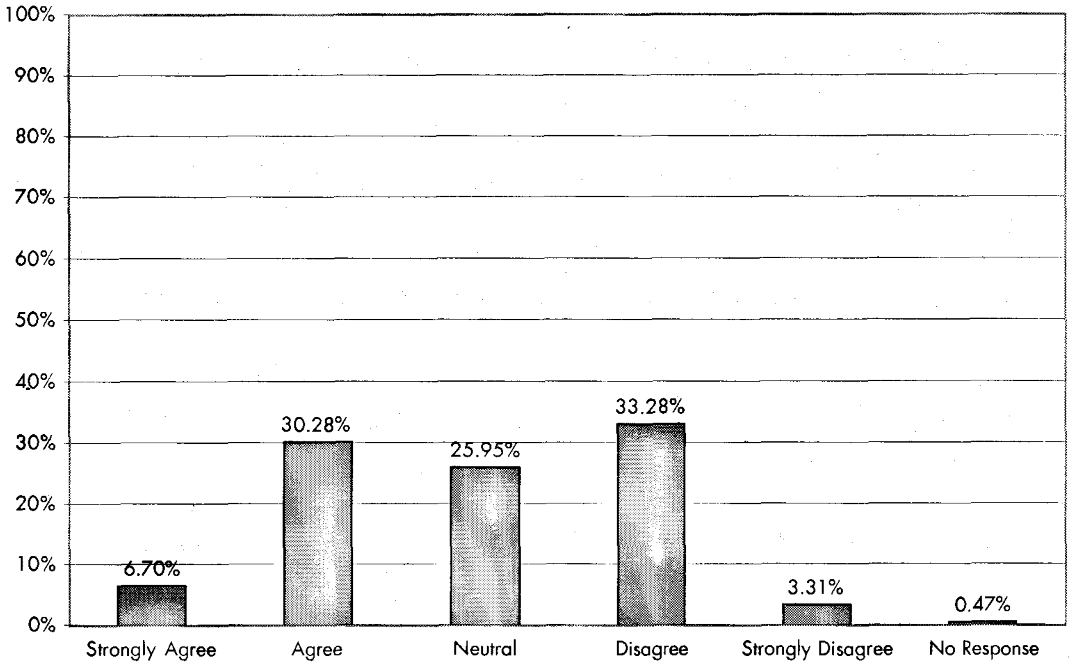
High workload can have negative influences on all aspects of human information processing. It can also be associated with the physiological responses associated with an increased perception of threat or stress. The maintenance of a high workload over a sustained period of time can therefore be associated with a variety of other negative influences.

This chapter discusses the responses of pilots regarding their perception of the effect of automation on workload. The questions in this section address periods of low workload, emergency situations and total workload. Pilots were also asked to assess the effect of automation on fatigue.

Workload and boredom

Thirty-six per cent of respondents considered that times of low workload in an automated aircraft were boring (see fig. B6.1). This supports anecdotal evidence that suggests that automation accentuates times of low workload. It also relates to question B9.4 where 32% of respondents indicated that they had inadvertently fallen asleep on the flight deck of an advanced technology aircraft.

FIGURE B6.1
Times of low workload in an automated aircraft are boring



Analysis revealed a significant difference between the responses to this question when considering both pilot rank and aircraft manufacturer. First officers considered times of low workload to be more boring than did captains, while Boeing pilots considered times of low workload more boring than did Airbus pilots (see table B6.1).

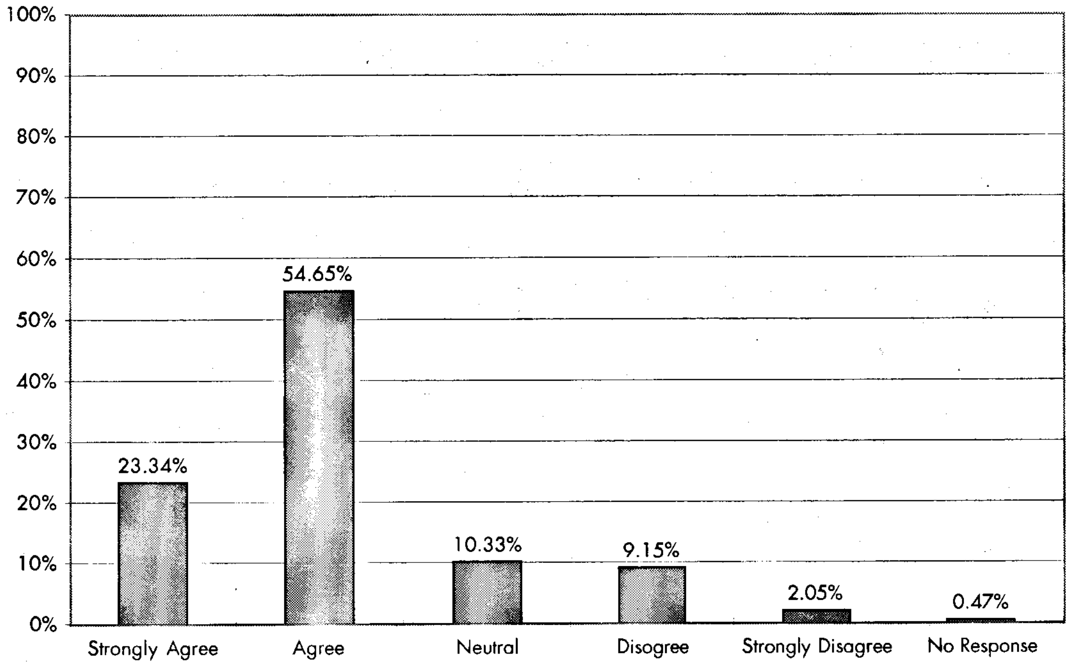
Table B6.1
'Times of low workload are boring.'

	Captain	First officer
Airbus	25%	25%
Boeing	36%	42%

Workload and emergencies

The majority of respondents (77%) considered that in an emergency, automated systems reduced their workload (see fig. B6.2). This result is contrary to anecdotal evidence which points to automation escalating periods of high workload. Further analysis revealed statistically significant differences in the responses to this question by pilot rank and aircraft manufacturer. More Boeing pilots than Airbus pilots considered that automation had reduced their workload in an emergency situation, and first officers responded more positively than captains. An analysis of the previous types flown by current Boeing and Airbus pilots revealed that approximately the same proportion of each group had previously flown jet transport aircraft such as BAe 146, and larger aircraft (Boeing pilots = 79%, Airbus pilots = 78%). The mean hours on type for Boeing pilots (2,379 hours) was approximately 30% greater than for Airbus pilots (1,789 hours). It may be that the more familiar a pilot becomes with automated functions, the greater he/she perceives their contribution to a reduction in workload. Further research is needed to determine if any specific differences between aircraft types might contribute to aviation safety.

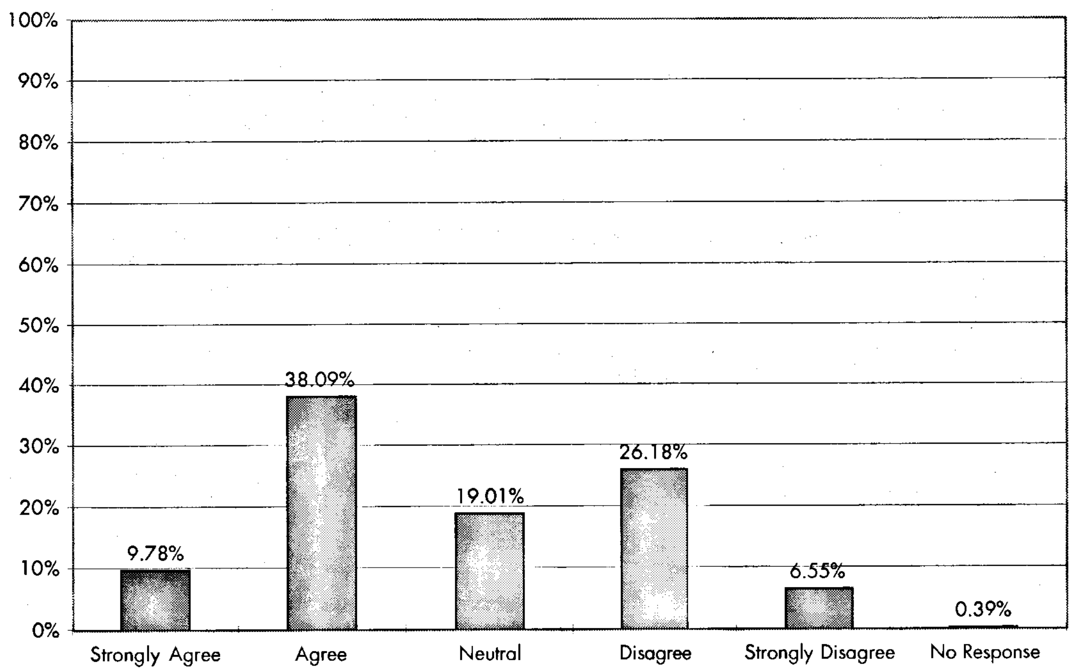
FIGURE B6.2
In an emergency, automated systems reduce my workload



Automation's effect on in-flight fatigue

Forty-eight percent of respondents considered that the introduction of automation had reduced the effect of fatigue during flight (see fig. B6.3).

FIGURE B6.3
The introduction of automation has reduced the effect of fatigue during flight



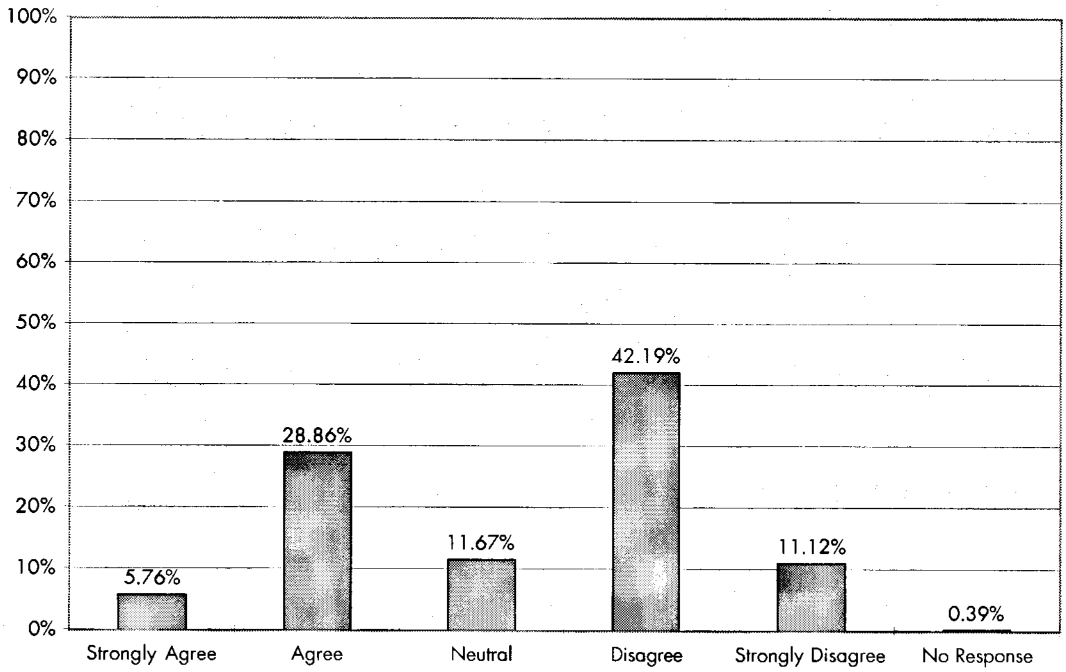
Hawkins (1993) outlines the difficulty in defining fatigue. It may reflect inadequate rest, disturbed or displaced biological rhythms (often described as jet lag), excessive muscular or physical activity, or may result from a sustained period of demanding cognitive activity. Like workload, fatigue affects human performance and therefore must be managed to ensure satisfactory performance levels are maintained throughout a duty period.

Pilots responding to question B6.5 nominated several phenomena which directly reduce the effect of fatigue during flight. Compared to aircraft without FMC/FMGS, pilots operating automated aircraft perceived that they were required to engage in less mental activity, make fewer mental calculations and make fewer references to aircraft manuals (9.38%, n = 224). Approximately 12% indicated that less physical activity was required to fly automated aircraft and 8% that pilots assumed more of a monitoring role.

Automation and total workload

The majority of respondents consider that automation reduced total workload (see fig. B6.4).

FIGURE B6.4
Automation does not reduce total workload



Written responses

Question B6.5 asked pilots to explain how automation had affected their workload. Seven hundred and fifty-eight pilots (59%) responded to this question.

Four hundred and forty-seven pilots indicated that their workload was less when compared to aircraft without FMC/FMGS. For example:

> *Reduced due better planning of track miles to touchdown, better autopilot gives more precise speed and navigation control, better confidence in autoland, better confidence in non-precision approach, clearer raw data.*

One hundred and forty-eight pilots concluded that their workload was mixed (some aspects increased, some decreased) or their workload priorities had been rearranged or altered. For example:

Normal ops automation is very beneficial, non-normal ops workload is extremely high due to two crew ops brought about by automation

Some respondents indicated that their workload had increased while others considered that their workload was the same as when flying non-automated aircraft.

Reduced workload

Of the 447 pilots who indicated that their workload had reduced, 75 made comments regarding a specific phase of flight. Of these, 22% experienced reduced workload during descent, approach, terminal area operations or during holding manoeuvres. Seventeen per cent of this subgroup (n = 75) indicated that although their overall workload had decreased, they had detected an increased workload with regard to emergency situations / late ATC changes / holding / navigation and diversion. Significantly, 16% of the subgroup recorded the opposite opinion, namely that they had detected a decreased workload with regard to emergency situations / late ATC changes / changes general and diversion.

Two hundred and twenty-four pilots nominated why they thought their workload had decreased. Of these, 62% attributed the decrease in workload to automation hardware (for example, FMC, autopilot, navigation systems) or the way in which information from these systems was displayed. The next two categories related to the consequences of automation with 9% attributing the decrease in workload to 'less mental activity / mental calculations / looking up manuals', and 8% highlighting that 'pilots now take on a monitoring role'.

One hundred and fifty-seven pilots commented on the consequences of a reduced workload with 75% indicating that they had more time to manage/monitor/concentrate on the flight.

Workload mixed/rearranged/altered

Approximately 20% (n = 148) of the respondents who provided written comment on workload indicated that some aspects of their workload had increased while other aspects of their workload had decreased.

Of this group, 105 nominated a specific phase of flight in which their workload had been affected. Forty-five per cent perceived that workload in relation to emergency situations / late ATC changes / changes general and diversion had increased. Thirteen per cent indicated that their workload during pre-flight/ground/takeoff and SID had increased, while 12% commented that their workload during pre-flight/ground/takeoff and SID had increased but had decreased during cruise / in flight or en route.

Forty pilots from this subgroup nominated why they thought their workload had altered. Twenty-five per cent commented that pilots currently assumed a monitoring role, while 25% commented that the cockpit crew had been reduced to two pilots.

Only five pilots from this subgroup commented on the consequences of an altered workload with three pilots indicating that they had more time to manage / monitor / concentrate on the flight.

Conclusion

Pilots can suffer from performance degradation at both ends of the workload spectrum. The pilot's ability to perform tasks necessary for flight is degraded with too little stimulation just as it is through excessive stimulation or workload.

Pilots appeared satisfied that automation had reduced the excessive physical and mental workload normally encountered during emergency situations. However, the majority of flight operations are conducted under normal conditions during the cruise phase of flight (especially in long haul operations). The results of this survey indicate that an optimum workload during normal operations had not been achieved. This phenomenon is recognised by airlines that have installed crew alertness monitoring equipment on automated flight decks. Developments such as the future air navigation systems (FANS) have the possibility of further reducing pilot stimuli within the cockpit.

Similarly, while pilots generally agreed that automation had reduced fatigue during flight, it appears that further advancement needs to be made in this area. It is essential that any safety enhancements produced through automation are not negated by a failure to address the issue of fatigue. The combination of automation, ergonomic design and aircraft environmental control (including noise control) should be considered together with in-flight duty patterns to control levels of fatigue.

Further research might establish whether the automation of other aspects of the aviation industry (e.g. maintenance procedures) would reduce workload and fatigue and hence reduce overall error rates.

A COMPARISON WITH PREVIOUS STUDIES

Introduction

Ten of the questions included in this survey were based on attitude probes developed by Wiener for his study of human factors in advanced technology aircraft during the late 1980s (Wiener 1989, used with permission). The purpose of this was to compare the responses of pilots within the Asia-Pacific region to those of their North American counterparts.

Wiener asked a volunteer sample of B757 pilots from two companies to answer two separate questionnaires which were mailed to each pilot 1 year apart (1986 and 1987). Thirty-six identical attitude questions were included in both questionnaires. The following charts (see figs. 11.1 to 11.10) represent the results of Phase 1 and Phase 2 of Wiener's study (labelled Wiener 1 and Wiener 2), followed by the BASI results of 10 similar attitude questions. The BASI results are then reported for Boeing pilots and Airbus pilots.

Table 11.1 reports the characteristics of the samples quoted in this chapter.

Table 11.1
Summary data

	Wiener 1 & 2	BASI
Captains	58.7%	56.1%
First officers	41.3%	36.7%
Second officers	0%	7.2%
Total aeronautical experience (average)	11,000 hours	9,667 hours
Hours on type (average)	Wiener 1 = 500 hours (B757) Wiener 2 = 1,100 hours (B757)	BASI = 2,264 hours (all types) Airbus = 1,789 hours Boeing = 2,379 hours

It is reasonable to expect that time, culture, technological advancement, training and experience would have had an effect on the attitudes of pilots, and that the responses from the two surveys would be significantly different.

Contrary to this expectation, the results from the BASI study were not significantly different to the findings of Wiener.

System design and automation

FIGURE 11.1
Wiener - I think they've gone too far with automation
BASI - They've gone too far with automation

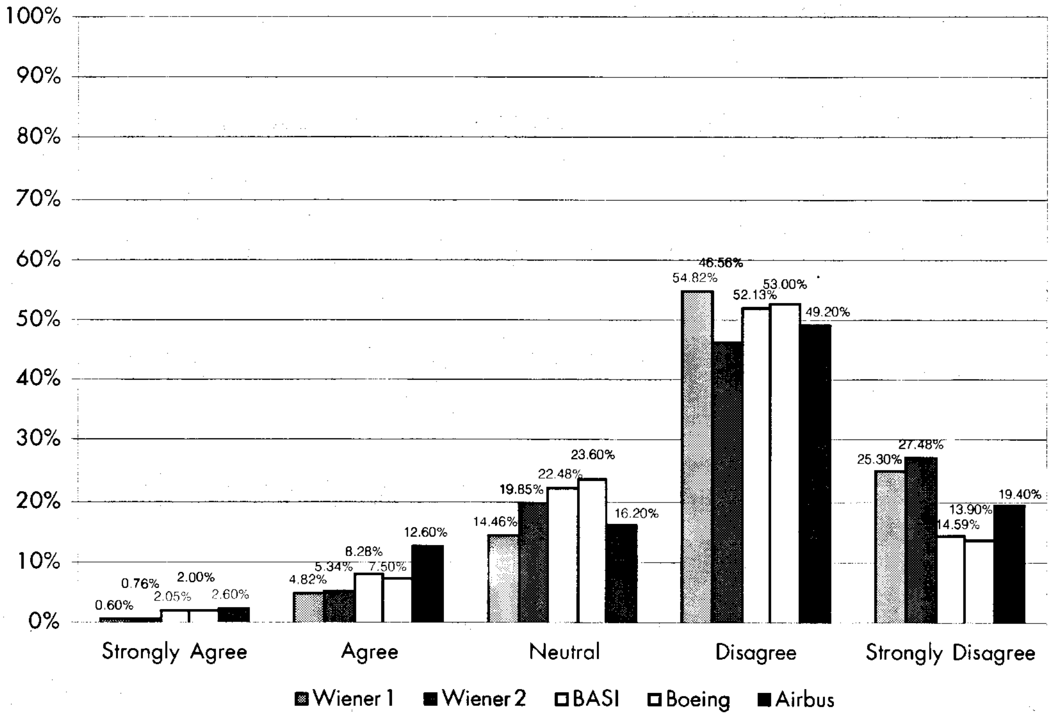
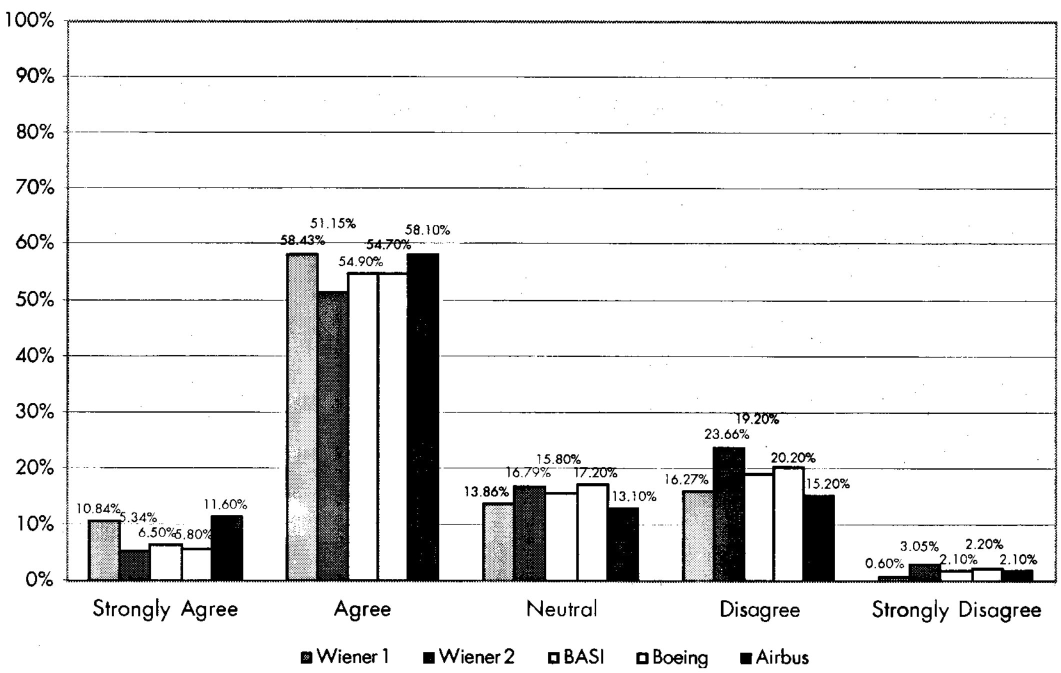
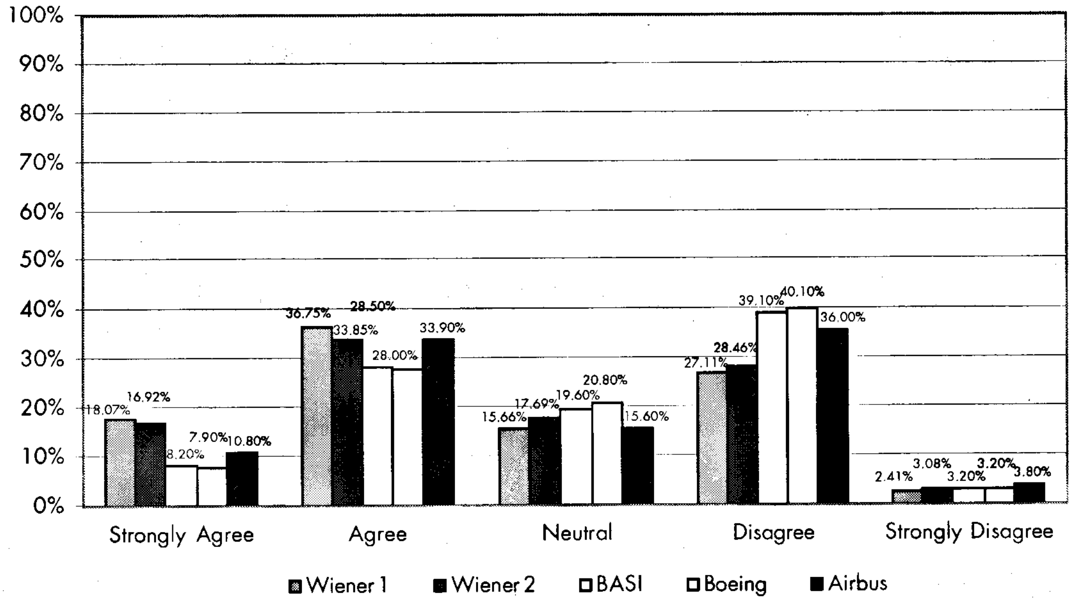


FIGURE 11.2
Wiener - In B757 automation, there are still things that happen that surprise me
BASI - With automation, there are still some things that take me by surprise



Air Traffic Control

FIGURE 11.3
Wiener - In the B757 there is too much programming going on below 10,000 feet and in the terminal area
BASI - There is too much programming going on below 10,000 feet



Modes

FIGURE 11.4
Wiener - I always know what mode the autopilot / flight director is in
BASI - I always know what mode the autopilot / autothrottle / flight director is in

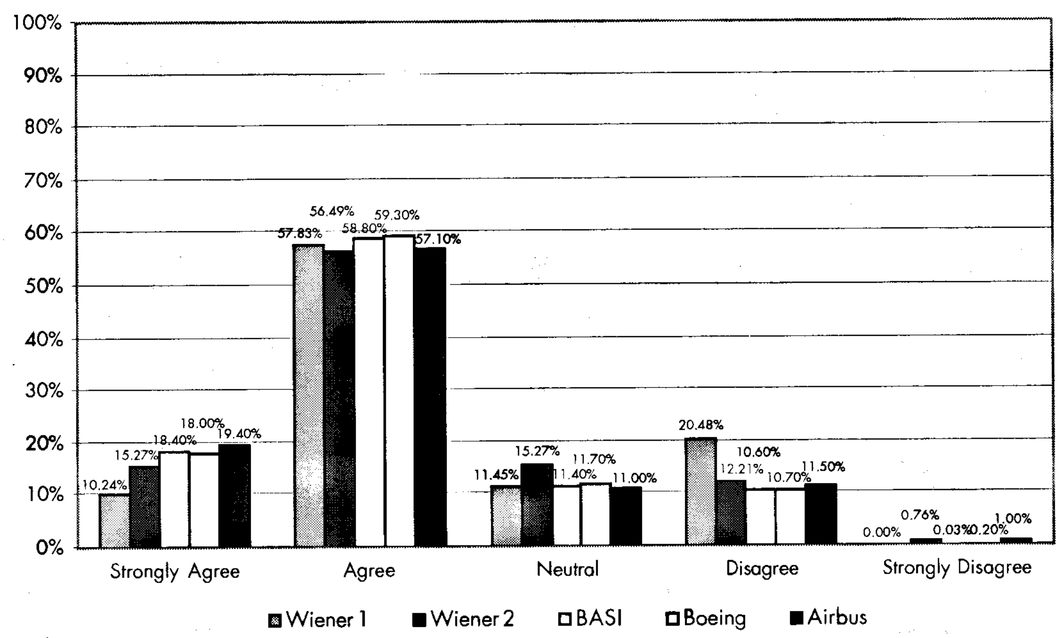
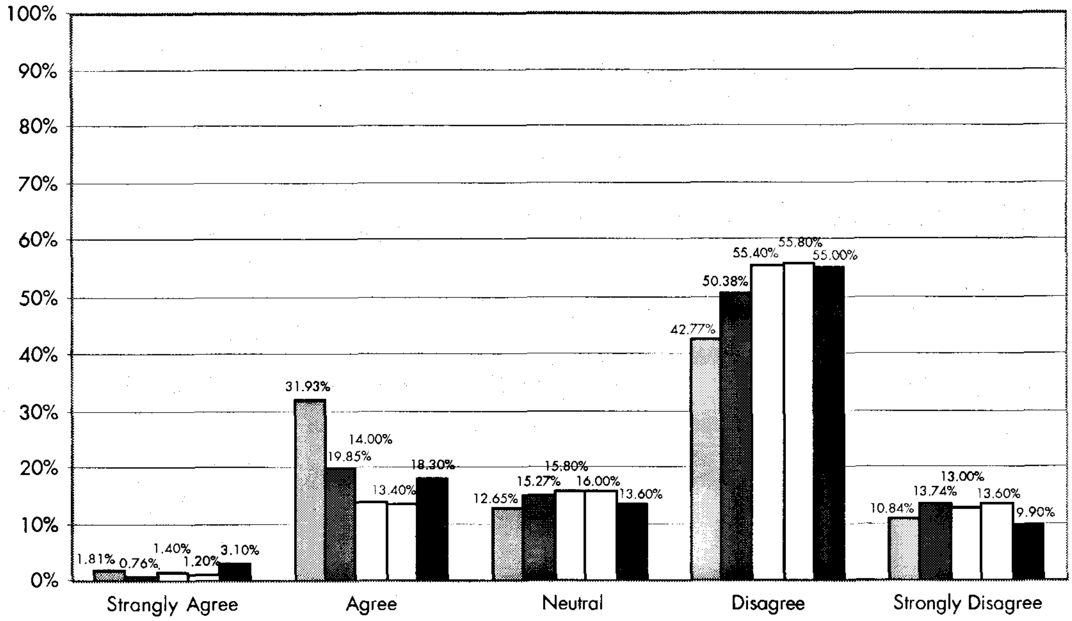
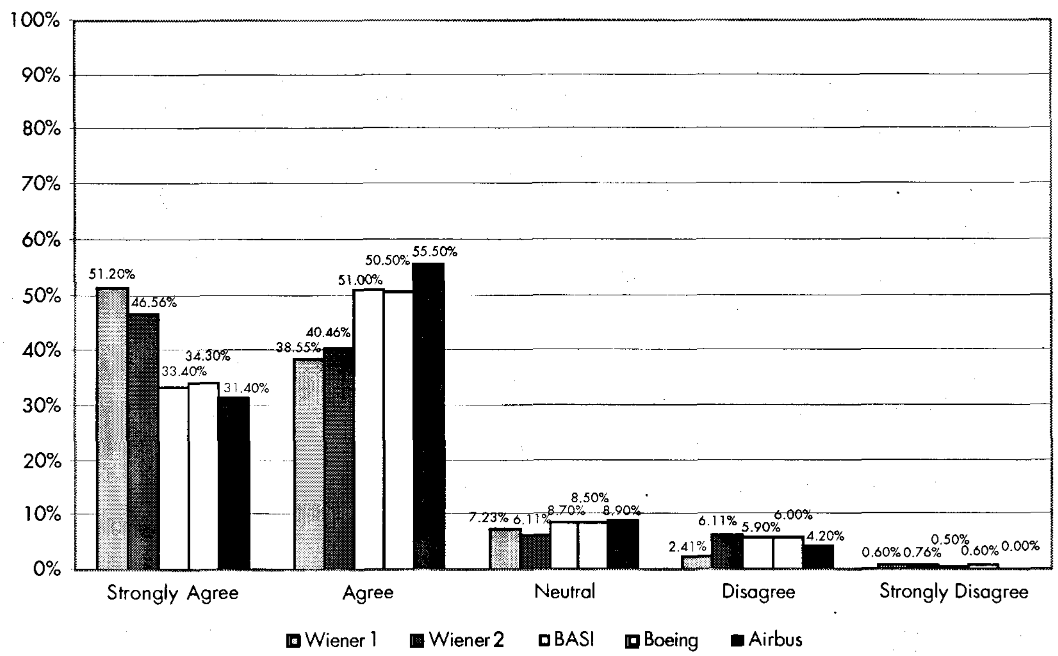


FIGURE 11.5
Wiener - There are still modes and features of the B757 FMS that I don't understand.
BASI - There are some modes that I don't understand



Flying skills

FIGURE 11.6
Wiener / BASI - I prefer to hand fly part of every trip to keep my skills up



Workload

FIGURE 11.7
Wiener - Overall, automation reduces pilot fatigue
BASI - The introduction of automation has reduced the effect of fatigue in flight

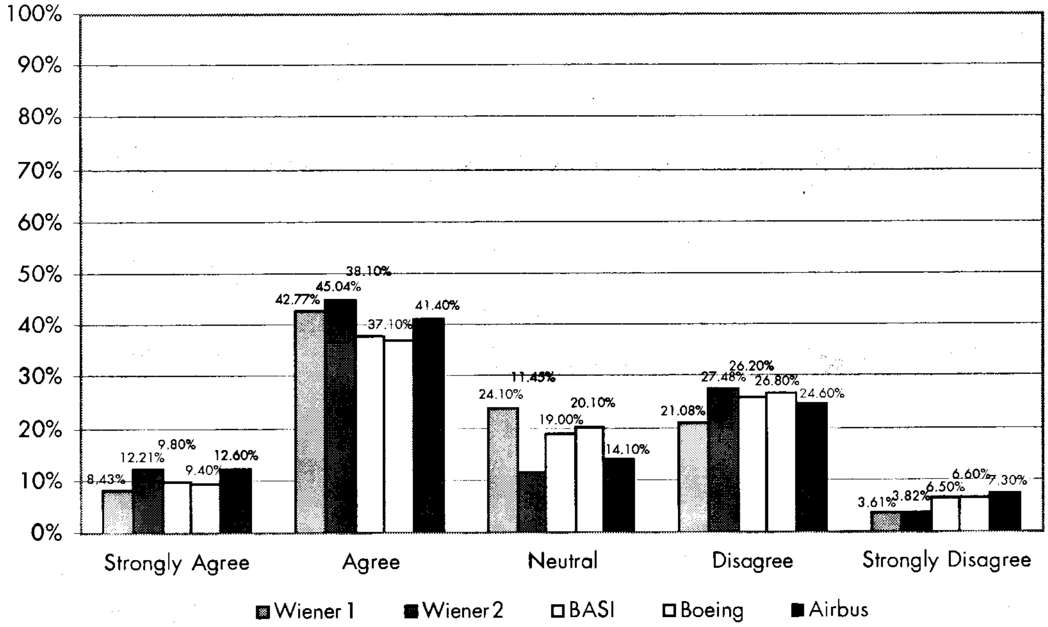
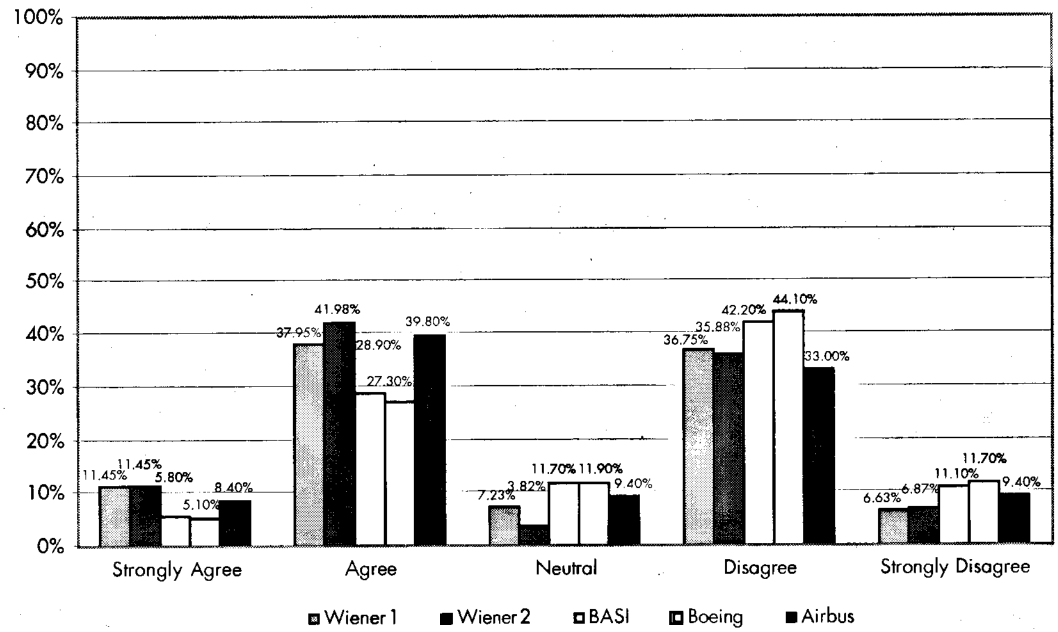
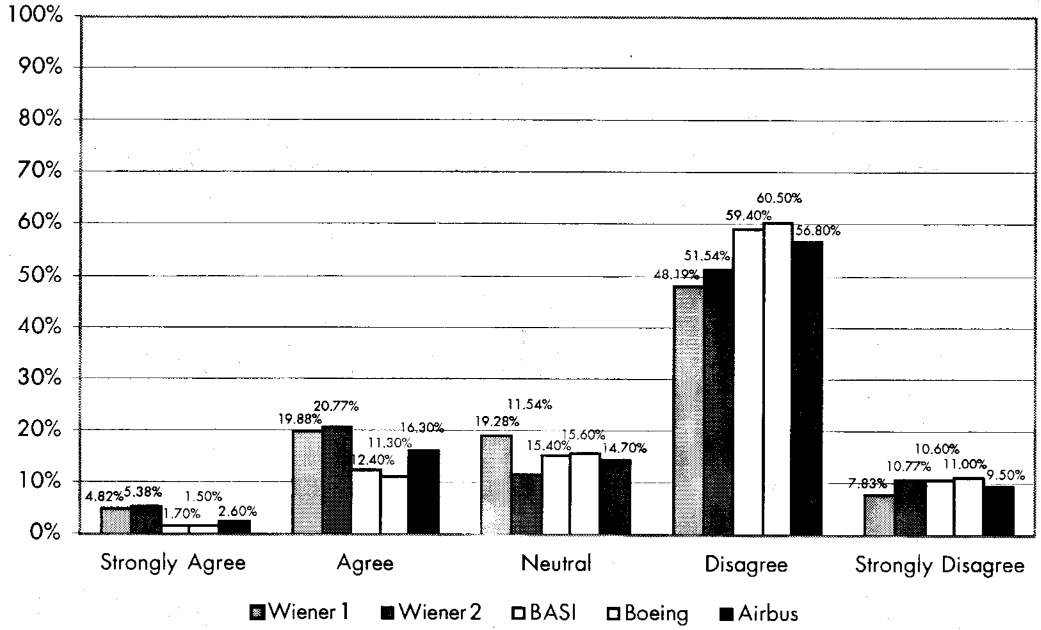


FIGURE 11.8
Wiener - Automation does not reduce total workload, since there is more to monitor now
BASI - Automation does not reduce total workload



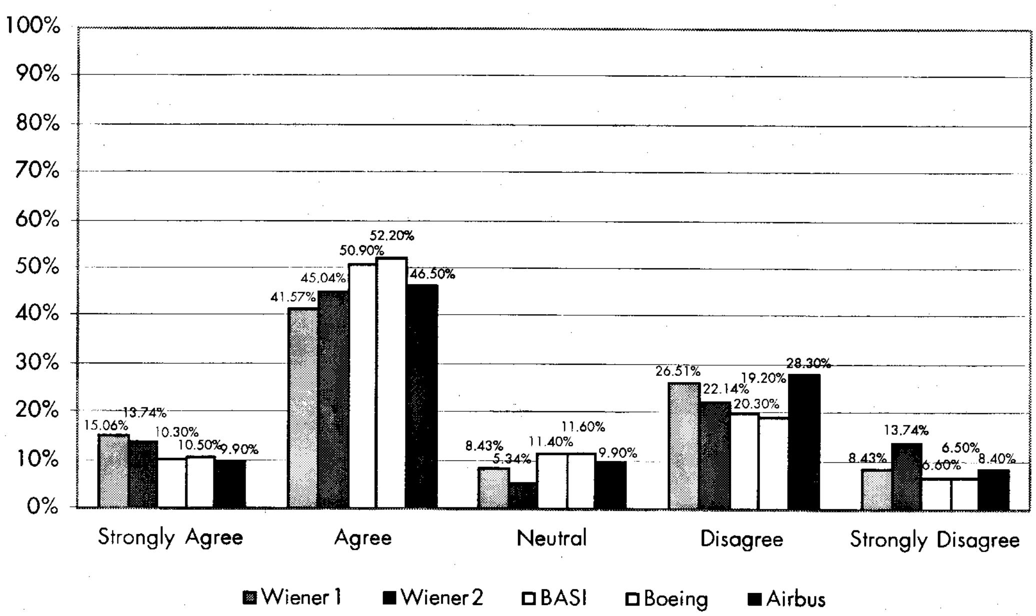
Crew resource management

FIGURE 11.9
Wiener - Crew coordination is more difficult in the B757
BASI - Crew management is a problem on advanced technology aircraft



Training

FIGURE 11.10
Wiener - Training on the B757 was as adequate as any training that I have ever had
BASI - Training for my current automated aircraft was as adequate as any training that I have had



Conclusion

Although this comparison is limited to only 10 attitude probes, figs 11.1–11.10 indicate that pilot attitudes towards automation are remarkably similar, despite differences in culture, technological advancement, training, and experience.

It would appear that after approximately 10 years, the efforts of the aircraft manufacturers and airline training departments have not adequately addressed the issue of automation surprise, the lack of mode awareness, and deficiencies in systems knowledge.

To summarise the results of the 10 attitude probes:

1. Automation surprise was common across all groups.
2. An average of 11% of pilots did not always know what mode the autopilot / autothrottle / flight director was in.
3. An average of 9% of pilots agreed that there were some modes that they did not understand.
4. The majority of all pilots preferred to hand-fly part of every trip to keep their skills up.
5. Most pilots agreed that automation had reduced the effect of fatigue in flight.
6. Pilots were polarised on the issue of the effect of automation on workload reduction.
7. The majority of pilots did not agree that crew management was a problem on advanced technology aircraft.
8. Most agreed that their training had been adequate.

GENERAL CONCLUSION

The purpose of this survey was to evaluate the human/system interface of advanced technology aircraft in service within the Asia-Pacific region, to collect information on flight deck errors, to assess the severity of those errors, to identify design-induced errors, and to identify areas where pilots inappropriately manipulate automated systems.

The success of the study was attributed to the cooperation of many of the airlines that form the Orient Airlines Association (recently renamed 'Association of Asia-Pacific Airlines') and the overwhelming amount of information supplied by pilots who were flying advanced technology aircraft. The study has also been enthusiastically supported by the manufacturers of advanced technology aircraft.

General findings

In general, the pilots who participated in this study possessed positive attitudes to automation. However, several problem areas were identified. These are summarised below.

Human/system interface problems.

'System interface' is used here to relate to specific automated components (e.g. the MCP) and in a larger context to relate to the relationship between automated aircraft and the ATC system.

This study highlighted the following safety issues:

1. Database errors, data entry errors, error detection and correction continue to limit the safety benefits of automation software.
2. Some pilots reported having difficulty understanding the language or technical jargon in messages presented by the FMC/FMGS. Aviation safety would benefit from a common language base for all software applications. FMC messages should lead the operator intuitively to the source of a problem.
3. Systems interface is partly dependent upon the quality of training. Some pilots perceived that the quantity and quality of training they received for their current aircraft was inadequate. Pilots also commented on the experience and qualification of instructional staff. Training, and hence safety, could be enhanced by airline operators ensuring staff (ground, simulator and flight instructors) are trained in appropriate educational techniques.
4. It would appear that aircraft automated systems and the ATC environment have largely developed independently. The results of this survey indicate that ATC does not make use of the capabilities of automated aircraft, that ATC is not always familiar with the aerodynamic characteristics of modern automated aircraft, and that last-minute changes imposed by ATC increase pilot workload. Both pilots and ATC personnel need to be aware of the limitations of each other's environment. Future development should improve the macro interface between aircraft and ATC with the aim of improving ATC procedures. Government and environment groups need to appreciate that their actions may jeopardise the quality of aviation safety.

Flight-deck errors

The results of this study raised the following concerns relating to flight-deck errors:

1. The results highlighted occasions of simultaneous control inputs by both pilots. This phenomenon has been cited as a contributing factor in a number of accidents or incidents within the Asia-Pacific region. These results are not limited to aircraft equipped with side-stick controls. Aircraft manufacturers should evaluate the design philosophy of modern automated control systems, as recent system modifications do not adequately address the case of unannounced simultaneous control inputs by both pilots. Standard operating procedures and airline policy should clearly address this issue.
2. The majority of respondents reported that they had on occasion inadvertently selected the wrong mode. Further research is required to determine the cause of this phenomenon and its impact on aviation safety. Incorrect mode selection may indicate a lack of mode awareness, poor training, vague SOPs, inadequate airline policy or in-flight briefings which do not address which modes are to be selected in a particular manoeuvre.
3. A significant proportion of respondents indicated that there had been times when the other pilot had not told them something they needed to know for the safe conduct of the flight. Pilots need to be aware of the safety implications of not effectively communicating during flight especially considering future ATC procedures which will further reduce the amount of verbal communication on the flight deck.

Design-induced errors

The FMC, FMA and MCP are all major components of the human/system interface. Any limitation or design fault in any of this automated hardware could potentially cause errors.

Respondents to this study reported that they often transpose the heading select knob and the command airspeed bug knob on the MCP. Aircraft manufacturers should evaluate the position, size, shape and tactile cues of these controls.

Mode awareness is necessary for the safe operation of advanced technology aircraft. Some pilots reported that mode changes can occur without adequate indication.

System work-arounds

Respondents confirmed the widespread practice of entering erroneous information into the FMC/FMGS to manipulate the performance parameters of the aircraft. The majority of cases were recorded during the descent and approach phase of flight for the purpose of achieving a desired descent profile. This may reflect partly on poor ATC procedure design, and partly on the inability of current software programs to accurately control aircraft performance. Of greater importance were the cases in which pilots entered erroneous data to override warning messages such as 'INSUFFICIENT FUEL'. Such actions are not addressed in airline policy documents or SOPs, and seem to be encouraged by flight training staff and aircraft manufacturers. Although there is no evidence to suggest that safety is being compromised by these actions, there is a strong argument to the effect that this action promotes bad habits and negates the professionalism of pilots generally. If this attitude were to be incorporated in other areas of flight operation it could constitute a serious safety concern.

Final conclusion

The results of this study have established a base-line of information regarding the operation of advanced technology aircraft within the Asia-Pacific region. Automation appears to have contributed to the overall safety health of airline operations and is generally accepted by pilots; however, these results also point to the existence of specific automation-induced errors that could result in safety hazards. Some of these errors are more easily corrected than others. Some may be addressed through airline policy and SOPs, while others are insidious, latent and extremely costly and time-consuming to address.

SUMMARY OF RECOMMENDATIONS

Introduction

The following recommendations are organised according to their corresponding chapter. Where applicable, recommendations have been addressed to:

- Airservices Australia;
- the Civil Aviation Safety Authority (Australia);
- aircraft design authorities;
- airlines within the Asia-Pacific region; and
- airlines around the world.

However, this does not restrict the applicability of the recommendations to the above-mentioned agencies. BASI encourages foreign agencies, both government and civil, to adopt all, or any, of the following recommendations in the interests of improving aviation safety throughout the international aviation industry.

Traditionally, recommendations flowed from 'reactive' investigations where active or latent failures were found to have directly contributed to an accident or incident. In response, government authorities, aircraft manufacturers and airline operators made changes to various aspects of their operation with the aim of limiting further occurrences. Unlike reactive investigations, much of modern research is framed in a proactive sense. Researchers are given the difficult task of finding potential problems before they arise. Fortunately, safety professionals within the aviation industry are embracing proactive remedies, although ever so slowly. TCAS is a good example of a proactive safety tool that some airline operators were reluctant to implement. Safety professionals now often quote the accidents which have been avoided by responding to a TCAS message.

The objectives of this project are largely proactive. Our task has been to determine specific errors and assess the severity of those errors. Consequently, some of the following recommendations are phrased in a proactive sense. Regulatory authorities, aircraft manufacturers and airline operators are now required to do the same, basing their response on the evidence provided by 1,268 pilots, many of whom are line pilots with considerable experience. Our concern is that appropriate mechanisms and an appropriate mindset are not yet in place to assess proactive recommendations. This is the greatest challenge currently before the aviation industry.

1. ATC

The Bureau of Air Safety Investigation recommends that Airservices Australia (R980024) and the Civil Aviation Safety Authority (R980025):

Review their airways and procedures design philosophies to:

(a) ensure that STAR, SID and airways design is compatible with aircraft FMS programs;

(b) allow a ±10-kts range with respect to descent speed below 10,000 ft to allow for the tolerances of FMS-equipped aircraft, with the aim of reducing the requirement for system work-arounds;

(c) provide ATC personnel with information on the aerodynamic characteristics of advanced technology aircraft; and

(d) seek the co-operation of airline operators for a program of advanced technology flight deck observation for all ATC personnel during both their initial and recurrent training.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980026):

Consider a program of flight crew observation of ATC operations during both initial and recurrent training. Such a program should be incorporated into the syllabus of training and include subjective elements requiring observation and assessment.

2. AUTOMATION

The Bureau of Air Safety Investigation recommends that airline operators (R980027):

1. Ensure that flight crew of advanced technology aircraft are educated in the concept , and safety implications, of passive command syndrome.
2. Include a comprehensive statement of automation policy in their general operations manual and/or airline policy documents.

3. CREW RESOURCE MANAGEMENT

The Bureau of Air Safety Investigation recommends that airline operators (R980028):

Employ appropriate methods and examples during initial and refresher CRM training to enhance the transmission of safety information between flight crew members during flight. Such training should stress the consequences of not communicating essential flight safety information.

4. FLYING SKILLS

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority (R980029):

Ensure that all recurrent and rating renewal simulator exercises are appropriate considering the level of automation fitted to the aircraft type. Such exercises should reflect the level of serviceability which the pilot may be expected to encounter during line operations.

5. GENERAL

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority (R980030):

Review the minimum standards for the quality of information provided in FMC databases with the aim of eliminating FMC database errors.

The Bureau of Air Safety Investigation recommends that airline operators (R980031):

1. Include in the ground-training phases of pilot endorsement courses:
   (a) sufficient technical knowledge of aircraft systems; and
   (b) knowledge of the design philosophies employed by aircraft system manufacturers;

   to give pilots sufficient systems understanding to permit analysis of system abnormalities and to determine appropriate responses in situations for which checklists are not available.
2. Consider the safety lessons from discussions of incident and accident scenarios during all initial, recurrent and CRM training programs.

The Bureau of Air Safety Investigation recommends that aircraft design authorities and airline operators (R980032):

Consider effective systems and procedures to ensure that flight crew of automated aircraft do not inadvertently fall asleep during flight.

6. MODES

The Bureau of Air Safety Investigation recommends that aircraft design authorities (R980033):

Consider a requirement to ensure that all FMGS mode changes are visually and aurally annunciated.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980034):

Review their procedures with regard to mode selection and consider:

(a) if flight crews should state intended mode selection during all flight crew briefings;

(b) if flight crews should announce and acknowledge all mode changes during flight;

(c) refresher training regarding mode mechanics and mode usage on a regular basis; and

(d) clear and consistent guidelines regarding mode usage.

The Bureau of Air Safety Investigation recommends that the Civil Aviation Safety Authority (R980035):

Review the achievement requirements for aircraft technical examinations with the aim of improving the knowledge pilots possess regarding mode characteristics and application.

7. SITUATIONAL AWARENESS

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980036):

Review their pilot training to consider:

(a) specific training to pilots regarding situational awareness;

(b) differences that may exist between printed and electronic flight information;

(c) responsibilities of ATC regarding the provision of terrain clearance; and

(d) clear policy regarding the use of en-route charts and instrument approach charts during flight.

8. SYSTEM DESIGN

The Bureau of Air Safety Investigation recommends that airline operators (R980037):

Review their standard operating procedures (SOP) and airline policy to require only one crew member to make control inputs at any one time unless stated to the contrary in an emergency/abnormal procedure, and to emphasise the consequences of multiple simultaneous flight control inputs.

The Bureau of Air Safety Investigation recommends that aircraft design authorities consider requirements for (R980038):

(a) a means of alerting the pilot when incorrect data has been entered into the FMC/FMGS;

(b) all data entries being able to be corrected easily by flight crew;

(c) common industry terminology for automation hardware and software;

(d) FMS software and hardware to accommodate the various changes which are imposed by ATC on an advanced technology aircraft during all phases of operation;

(e) quality control procedures for FMC software with the aim of eliminating the need for system work-arounds; and

(f) the position, design and tactile differences of the frequently used mode selectors (such as heading and speed), with the aim of eliminating any confusion regarding the use of these controls.

9. TRAINING

The Bureau of Air Safety Investigation recommends that Civil Aviation Safety Authority (R980039):

1. Consider the need for:
   (a) simulator and flight instructors to be trained in instructional/teaching techniques at a recognised educational facility;
   (b) ground, simulator and flight instructors to undergo regular refresher training in instructional/teaching techniques at a recognised educational facility; and
   (c) ground, simulator and flight instructors to demonstrate their ability as an instructor/teacher on a regular basis.
2. Assess the quality of printed and electronic training/reference material with respect to advanced technology aircraft.

The Bureau of Air Safety Investigation recommends that airline operators within the Asia-Pacific region (R980040):

Review the qualifications of all ground, simulator and flight instructors, and where necessary, provide training in instructional/teaching techniques with the aim accrediting instructional/teaching staff.

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SURVEY QUESTIONNAIRE DETAILS

NOTE:
The following is not a reproduction of the survey form but contains all the questions that were included plus a description of the responses requested.

PART A

Part A sought information about the respondent, his/her employment and experience.

1. TICK the boxes which describe your position in the company

   Captain
   First Officer
   Second Officer
   Cadet Pilot

   Management Position
   Check Pilot
   Training Pilot
   Supervisory Pilot
   Company Test Pilot
   Line Pilot

   Qualified
   Under Training

2. I fly *domestic routes* (flights which do not cross international borders e.g. Sydney to Melbourne)

   international short haul routes (flights to adjoining airspace e.g. Australia to New Zealand, Singapore to Jakarta, Hong Kong to Taipei)

   international long haul routes (flights crossing more than one international boundary e.g. Manila to London, Tokyo to Los Angeles, Jakarta to Jeddah)

3. I am Male / Female
4. My age is
5. My nationality is
6. My first language is
7. My second language is
8. My home port (base) is
9. What type of aircraft do you currently fly
10. When did you complete your engineering course/ground school course for this aircraft?
11. Approximately how many hours have you logged on your current aircraft type?
12. What was your previous aircraft type?
13. In what capacity did you fly that aircraft?
    Captain / First Officer / Second Officer / Cadet Pilot
14. Approximately how many flight hours have you logged (Total Aeronautical Experience)?
15. Approximately how many sectors have you flown as 'Pilot Flying' in the last 90 days? (A sector is a flight between any two points where you have conducted the takeoff and/or landing). .... Sectors

PART B

Part B sought the respondent's views on matters concerning advanced technology aircraft. The questions were of three types:

(a) phrased as statements to which the respondent indicated agreement or disagreement and the intensity of feeling (Likert Scale responses);

(b) requests for narrative responses; and

(c) requests for YES/NO answers and amplification of YES responses.

SYSTEM DESIGN AND AUTOMATION

Questions 1.1 to 1.10 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

1.1 The FMC/FMGS and associated controls are 'user friendly'.

1.2 It is easy to detect when incorrect data has been entered by mistake.

1.3 I always know what the other crew member is doing with the automated systems.

1.4 At times I have been surprised to find the pilot not flying (PNF) making flight control inputs.

1.5 They've gone too far with automation.

1.6 With automation there are still some things that take me by surprise.

1.7 The FMC/FMGS sometimes fails to capture an altitude as I expect.

1.8 Incorrect data entered by mistake is easily corrected.

1.9 I sometimes find it hard to understand the language or technical jargon in messages presented by the FMC/FMGS.

1.10 I look at the FMA when I want to know what the aircraft is doing.

Please complete the following sentences in your own words:

1.11 On this aircraft, the automated feature I like most is;

1.12 On this aircraft, the automated feature I like least is;

1.12.1 Please describe in detail a mistake which you made, or saw someone make, which you think could be attributed to automation. Describe specifically what happened and why it happened.

AIR TRAFFIC CONTROL

Questions 2.1 to 2.5 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

2.1 Air Traffic Control makes use of the capabilities of this aircraft to its fullest.

2.2 Air Traffic Control appears to be familiar with the descent profile of my aircraft.

2.3 Air traffic controllers sometimes ask for information which is difficult to extract from the FMC/FMGS in a reasonable amount of time.

2.4 The current level of automation does not cope well with the last minute changes imposed by Air Traffic Control.

2.5 There is too much programming going on below 10,000 feet.

2.6 I am concerned about the Air Traffic Control procedures within the following geographical area:

2.7 Please outline a specific event where you had difficulty operating an advanced technology aircraft in accordance with an ATC instruction.

MODES

Questions 3.1 to 3.8 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

3.1 I always know what mode the autopilot / autothrottle / flight director is in.

3.2 It worries me that the automated systems may be doing something that I don't know about.

3.3 On occasions I have inadvertently selected the wrong mode.

3.4 Mode changes can occur without adequate indication.

3.5 There are too many modes available on the FMC/FMGS.

3.6 There are some modes that I still don't understand.

3.7 When it comes to mode selection, the company sets out clear guidelines and

3.8 Good crew briefing will always include what modes will be used.

3.9 Please outline the details of a specific event where you had difficulty with Mode Selection, Mode Awareness or Mode Transitions.

SITUATIONAL AWARENESS

Questions 4.1 to 4.5 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

4.1 I refer to my enroute charts far less on new technology aircraft than on aircraft without an FMC/FMGS.

4.2 All the information I need for the safe conduct of the flight is contained within the FMC/FMGS.

4.3 I rely on Air Traffic Control to provide adequate terrain clearance.

4.4 At times I have been surprised to find the aircraft closer to terrain than I thought.

4.5 I refer to my instrument approach charts far less on new technology aircraft than on aircraft without an FMC/FMGS.

4.6 Please outline any specific event which caused you to question your position in relation to terrain, or other aircraft.

FLYING SKILLS AND SYSTEM SOFTWARE

Questions 5.1 to 5.3 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

5.1 I prefer to hand fly part of every trip to keep my skills up.

5.2 My manual flying skills have declined since I started flying advanced technology aircraft.

5.3 I am sometimes forced to 'trick' the FMC/FMGS by entering erroneous data to achieve a desired result. (For example, I enter 240 knots to ensure the aircraft maintains 250 knots etc).

5.4 Please outline the details of a specific event where you were required to 'trick' the FMC/FMGS by the input of false data.

WORKLOAD

Questions 6.1 to 6.4 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

6.1 Times of low workload in an automated aircraft are boring.

6.2 In an emergency, automated systems reduce my workload.

6.3 The introduction of automation has reduced the effect of fatigue during flight.

6.4 Automation does not reduce total workload.

6.5 Please explain how automation has affected your workload.

CREW RESOURCE MANAGEMENT AND SAFETY

Questions 7.1 to 7.5 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

7.1 On this aircraft, the role of the pilot flying (PF) and the pilot not flying (PNF) is always clear.

7.2 There have been times when the other pilot has not told me something I needed to know for the safe conduct of the flight.

7.3 Crew management is a problem on advanced technology aircraft.

7.4 I sometimes find the automated systems taking over command of the aircraft.

7.5 At this airline, fleet management have a good awareness of the day to day issues faced by pilots operating advanced technology aircraft.

TRAINING

Questions 8.1 to 8.6 sought Likert Scale responses.

Strongly Agree *Agree* *Neutral* *Disagree* *Strongly Disagree*

8.1 Training for my current automated aircraft was as adequate as any training that I have had.

8.2 I would like to have a deeper understanding of the aircraft systems.

8.3 I sometimes have difficulty understanding information in the technical manuals associated with this aircraft.

8.4 I was able to find all the information I needed for my training in the aircraft/company technical manuals.

8.5 My training has prepared me well to operate this aircraft.

8.6 I prefer computer based training over traditional teaching methods.

8.7 What could be done to improve the training you received on this aircraft?

GENERAL

Questions 9.1 to 9.4 sought YES / NO answers and, if YES, requested amplifying information.

9.1 Have you ever encountered an abnormal/emergency situation while flying your current aircraft (excluding simulator base training)

If YES please describe the situation.

9.2 Have you detected any FMC/FMGS database errors (waypoint, Lat/Long, SID, or STAR route/restriction errors etc)

If YES please describe these errors.

9.3 Did you discuss any advanced technology aircraft accidents or incidents during your conversion training?

If YES please list the accidents or incidents which were discussed.

9.4 Have you ever inadvertently fallen asleep on the flight deck of an advanced technology aircraft?

9.5 What was the most difficult part of your conversion to advanced technology aircraft?

9.6 Further comments or suggestions. You may care to comment on the aspects of automation which have not been specifically covered in this survey.