HUMAN FACTORS GUIDELINES FOR AIR TRAFFIC MANAGEMENT (ATM) SYSTEMS

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and published under his authority*

INTERNATIONAL CIVIL AVIATION ORGANIZATION

AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS				CORRIGENDA			
No.	Date applicable	Date entered	Entered by	No.	Date of issue	Date entered	Entered by

FOREWORD

The safety of civil aviation is the major objective of the International Civil Aviation Organization (ICAO). Considerable progress has been made in increasing safety, but additional improvements are needed and can be achieved. It has long been known that the majority of accidents result from less than optimum human performance, indicating that any advance in this field can be expected to have a significant impact on the improvement of flight safety.

This was recognized by the ICAO Assembly, which in 1986 adopted Resolution A26-9 on Flight Safety and Human Factors. As a follow-up to the Assembly Resolution, the Air Navigation Commission formulated the following objective for the task:

"To improve safety in aviation by making States more aware and responsive to the importance of Human Factors in civil aviation operations through the provision of practical Human Factors material and measures developed on the basis of experience in States, and by developing and recommending appropriate amendments to existing materials in Annexes and other documents with regard to the role of Human Factors in the present and future operational environments. Special emphasis will be directed to the Human Factors issues that may influence the design, transition and in-service use of the [future] ICAO CNS/ATM systems."

One of the results of this initiative has been the incorporation of Human Factors-related Standards and Recommended Practices (SARPs) in several Annexes to the Chicago Convention and in other ICAO documents, including the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8400) and the *Procedures for Air Navigation Services — Rules of the Air and Air Traffic Services* (PANS-RAC, Doc 4444). Table F-1 presents the existing ICAO Human Factors SARPs in the various Annexes that have a relationship with the provision of air traffic services (ATS):

The Recommendation in Annex 10, Volume IV, Chapter 2, 2.2.1, includes the design and certification of automatic dependent surveillance (ADS) systems. Similarly, the references to "communications" in Annex 10, Volume II,

Chapter 5, 5.1.1.3, and in Annex 11, Chapter 2, 2.22.1.1, include both voice and data link communications.

Furthermore, at the ICAO World-wide CNS/ATM Systems Implementation Conference, held from 11 to 15 May 1998 in Rio de Janeiro, Brazil, *inter alia*, the following Conclusions pertaining to Human Factors issues were generated:

- In order to maximize safety and cost-effectiveness of CNS/ATM systems, the pro-active management of Human Factors issues must be a normal component of the processes followed by designers, providers and users of the systems. (Conclusion 6/2)

- The time to address Human Factors issues is during technology design and before the technology is deployed into operational contexts. (Conclusion 6/3)

- Training plays a fundamental role in CNS/ATM systems but should not be used as a mediator of flawed or less-than-optimum human-technology interface design. (Conclusion 6/4)

On the subject of timely consideration of Human Factors and associated safety regulation, the Conference recommended that:

- Human Factors issues be considered before CNS/ATM technologies are deployed, during the process of design and certification of the technology and associated standard operating procedures. (Recommendation 6/11)

- States and organizations which design and provide CNS/ATM systems take into account ICAO guidelines when developing national regulations and incorporate Human Factors Standards in the processes of design and certification of equipment and procedures. (Recommendation 6/12)

The Human Factors-related SARPs in Annexes 10 and 11, as well as the Conclusions and Recommendations of the Rio de Janeiro Conference, underlie the development of this manual of Human Factors guidelines for air traffic management (ATM) systems.

Table F-1.   ATS-related ICAO Human Factors SARPs

Annex	Part and chapter	Paragraph and text of the Standard or Recommended Practice
1 – Personnel Licensing	4.3 Air traffic controller licence	4.3.1.2 *Knowledge* *Human Performance and limitations* d) human performance and limitations relevant to air traffic control;
10 – Aeronautical Telecommunications Volume II – (Communications Procedures including those with PANS status)	Chapter 5. Aeronautical Mobile Service 5.1 General	5.1.1.3 **Recommendation.—** In all communications, the consequences of human performance which could affect the accurate reception and comprehension of messages should be taken into consideration.
10 – Aeronautical Telecommunications Volume IV – Surveillance Radar and Collision Avoidance Systems	Chapter 2. General 2.2. Human Factors considerations	2.2.1 **Recommendation.—** Human Factors principles should be observed in the design and certification of surveillance radar and collision avoidance systems.
11 – Air Traffic Services	Chapter 2. General 2.22 Service to aircraft in the event of an emergency	2.22.1.1 **Recommendation.—** In communications between ATS units and aircraft in the event of an emergency, Human Factors principles should be observed.

The target audience for the manual consists of two main groups: 1) ICAO panels and groups from other organizations that are involved in the development of ATM equipment and/or procedures for ATM purposes; and 2) States and organizations that will acquire and implement ATM systems. Both groups are assumed to be familiar with the CNS/ATM concept.

Note 1.— In several States the provision of air traffic services (ATS) is the responsibility of organizations that in varying degrees operate independently from the government. The governments, however, are still responsible for safety regulation for the ATS-providing organizations. Guidelines in this manual are applicable to regulators and providers alike.

Note 2.— In this manual, the phrase "ATS provider" is used generically, i.e. without distinguishing whether a State or an organization is responsible for the provision of ATS.

The development, acquisition and implementation of an advanced ATM system generally is not a linear but rather an iterative process, involving a high degree of interaction between the manufacturer and the buyer/user. Therefore, this manual consists of a single volume containing guidelines for both target audiences throughout the text.

This manual is designed as follows:

• Chapter 1 contains background information from various sources about the importance of incorporating Human Factors knowledge into the development, acquisition and implementation processes for ATM systems.

• Chapter 2 introduces three essential concepts to guide these processes. This chapter is primarily aimed at the panels and groups involved in high-level development and implementation issues, but it is relevant to ATS providers.

- Chapter 3 provides a description of external data link infrastructure and applications, where "external" indicates that the topics discussed are considered to be outside the influence of those involved in the development, acquisition and implementation of ATM systems. Panels and other groups may take note of the descriptions of the human-machine interfaces (HMIs) for controller-pilot data link communications (CPDLC) on the flight deck in this chapter.

- Chapter 4 discusses design issues for the HMI of advanced, ground-based ATM systems and therefore is mainly aimed at States and organizations that will acquire and implement ATM equipment. Manufacturers of ATM equipment will benefit from this chapter. Members of panels and other groups may find the Appendices to this chapter, in which examples of existing HMI designs are presented, of particular interest.

- Chapter 5 includes findings from the research community related to the early implementation of CPDLC. These findings are in line with operational results from user groups (mainly in the Pacific area) and are presented as background information to support the recommendations in this manual.

- Chapter 6 is mainly aimed at the States and organizations that will acquire and implement ATM systems and presents guidelines on topics related to preparation for the change from present to new systems. Selected topics from this chapter are of interest to panels and other groups as well.

- Chapter 7, Standard operating procedures, is relevant to panels and other groups as well as to States and organizations responsible for the provision of ATS.

- Chapter 8 introduces examples of new flight deck technology that will eventually have an impact on the provision of ATS. This impact on the development and acquisition of ATM systems should be anticipated, hence the inclusion of this chapter.

- Chapter 9 lists sources for further information on the subjects discussed in this manual.

In summary:

- Guidance material for **panels and other development and implementation groups** is included in Chapters 1, 2, 3, 4 and 7. Background information material for this audience is contained in the appendices to Chapter 4 and in Chapters 5, 6 and 8. Chapter 4 is especially relevant for **manufacturers of ATM equipment**.

- **States and organizations** that will acquire and implement ATM equipment will find relevant guidance material in Chapters 1, 3, 4, 6, 7 and 8, with background information material in Chapters 2 and 5.

- Sources for further information are presented in Chapter 9.

This manual is a living document and will be kept up to date. It will be amended periodically as more experience with the new systems and associated procedures is gained, and as new research and increased knowledge on Human Factors issues as they may affect the development, acquisition and implementation of ATM systems become available.

The cooperation of the following organizations in the production of this manual is acknowledged: Airbus, Air Services Australia, the Airways Corporation of New Zealand, Boeing, The European Organisation for the Safety of Air Navigation (Eurocontrol), the Federal Aviation Administration, the Japanese Civil Aviation Bureau and the Radio Technical Commission for Aeronautics.

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ACRONYMS

ACARS	Aircraft communications addressing and reporting system	CNS/ATM	Communication, Navigation, Surveillance/Air Traffic Management
ACC	Area control centre	CPDLC	Controller-pilot data link communications
ACID	Aircraft identification		
ADS	Automatic dependent surveillance	DCDU	Data link control and display unit
ADS-B	Automatic dependent surveillance — broadcast	EICAS	Engine indication and crew alerting system
AFN	ATS facilities notification	EUROCONTROL	Organisation for the Safety of Air Navigation
AIDC	ATS interfacility data communications		
		FAA	Federal Aviation Administration
AIRSAW	Airborne situational awareness	FANS	Future Air Navigation System
ARINC	Aeronautical Radio, Incorporated	FDPS	Flight data processing system
ASAS	Airborne separation assurance system	FDR	Flight data recorder
		FIR	Flight information region
ASRS	Aviation safety reporting system	FL	Flight level
ATC	Air traffic control	FMC	Flight management computer
ATIS	Automatic terminal information service	FMS	Flight management system
ATM	Air traffic management	FO	First officer
ATN	Aeronautical telecommunication network	GNSS	Global navigation satellite system
		HCA	Human-centred automation
ATS	Air traffic services	HF	High frequency
ATSU	Air traffic services unit	HMI	Human-machine interface
CDTI	Cockpit display of traffic information	IAS	Indicated airspeed
CDU	Control and display unit	ICAO	International Civil Aviation Organization
CFL	Cleared flight level	ID	Identification

IFR	Instrument flight rules	RNP	Required navigation performance
ISPACG	Informal South Pacific Air Traffic Services Co-ordinating Group	RTCA	Radio Technical Commission for Aeronautics
JCAB	Japan Civil Aviation Bureau	RVSM	Reduced vertical separation minimum
MCDU	Multipurpose control and display unit (Airbus)		
MCDU	Multifunction control-display unit (Boeing)	SA	Situational awareness
		SARP	Standards and Recommended Practices
MFD	Multifunctional display	SID	Standard instrument departure
MSG	Message		
MSAW	Minimum safe altitude warning system	SITA	Société Internationale de Télécommunications Aéronautiques
NM	Nautical mile	SOP	Standard operating procedure
NOTAM	Notice to airmen	SSR	Secondary surveillance radar
OCS	Oceanic Control System	STAR	Standard instrument arrival
ODIAC	Operational Development of Integrated Surveillance and Air/ground Data Communications	STCA	Short term conflict alert
		TAAATS	The Australian Advanced Air Traffic System
ODP	Oceanic Control Data Processing System	TCAS	Traffic alert and collision avoidance system
OJT	On-the-job training		
PANS	Procedures for Air Navigation Services	TRM	Team resource management
		UHF	Ultra-high frequency
PDC	Predeparture clearance	VDL	VHF Digital Link
PFD	Primary flight display	VFR	Visual flight rules
PNF	Pilot not flying	VHF	Very high frequency
R/T	Radiotelephony	VOR	VHF omnidirectional radio range

Chapter 1

INCORPORATING HUMAN FACTORS KNOWLEDGE

"Automation, of course, is not infallible either. The literature abounds with failures of automation to perform as expected; […] . These failures are among the reasons why humans must be an integral part of the system — they are there to compensate for the imperfections of the automation. They are also there […] to accept responsibility for system safety. If they are to remain in command, they must be involved in system operation — not only when the automation fails, but during normal operations as well, in order to be in the loop when the inevitable failures occur. The human operator is the final line of defence in automated systems, and the new systems proposed for air traffic management are no exception."

Charles E. Billings: *Aviation Automation – The Search for a Human-Centered Approach.*

1.1   In recent years a significant body of knowledge has made a compelling case in support of the incorporation of Human Factors knowledge into air traffic management (ATM) system design from the early stages. This body of knowledge is captured in a number of highly regarded publications. Three such publications are discussed in the following paragraphs.

1.2   The document *Human Factors in the Design and Evaluation of Air Traffic Control Systems*, was developed in 1995 for the Federal Aviation Administration (FAA) by the United States Department of Transportation. This document states:

> "Human error remains the most common contributing factor in aviation accidents and incidents, yet strategies for mitigating their impact are well known and widely documented. Acquisition handbooks and system engineering guides identify equipment design, training and personnel selection, procedures, and organisational structures and management as causal of human-system interface discrepancies. Because each application of new technology poses unforeseen difficulties in these interface areas, technology must be centred on the needs, capabilities and limitations of the user rather than the capabilities of the technology. [. . .] Failing to consider the performance of the human component of

the system increases program cost and schedule, and jeopardises system technical performance. However, ensuring that system designs are human-centred, will lead to enhanced system performance, reduced safety risks, lower implementation and life cycle costs, and a higher probability of program success. It is never efficient to play 'catch-up' with Human Factors in any acquisition.

"Qualified Human Factors support during system design and acquisition provides an engineering perspective to the incorporation of information about human capabilities and limitations related to how people receive and process information, solve problems, and interact with the system and its components. Where sufficient information is not already available to address a concern, the Human Factors discipline also offers an arsenal of methods for obtaining time-tested and objective performance measures. Tools and methods used to analyse system performance with the human component as an integral part can help to provide reliable information on which to base developmental and operational decisions, efficiently.

"One of the main goals of Human Factors engineers is to ensure that the users' interests are considered in all stages of system acquisition and development. In this sense, the goal of the user and the Human Factors specialists are the same — to ensure that the system is usable and operationally suitable to the user, the task, and the environment. However, the role of selecting the optimal human-system interface should not be the sole proprietorship of the user for three reasons. First, **system design decisions [. . .] always involve complex trade-offs among optimal performance, cost, and competing technological alternatives**. These decisions require program management and engineering expertise from a multitude of disciplines, including that of the human engineering community. Second, **decisions and alternatives related to human performance may be counter-intuitive unless scrutinised and analysed by those skilled in quantifying the relationships**. For example, the decision to assign some system diagnostic tasks to an operator or a maintainer may require

detailed analyses of life cycle cost, alternative training strategies, and personnel selection criteria. Third, **users are not always the best judges of what will provide the best operational performance**. For example, users may want many more system features than they will frequently use (such as excess display information) which can lead to distracting clutter, confusion during emergencies, and non-standard interfaces that complicate training and supervision. Having Human Factors engineers involved in the acquisition process helps to ensure that the system is easy to use, unlikely to induce errors, and tolerant of common and uncommon human performance anomalies.

"Human Factors need to be considered early in the process, such as when the requirements are identified. Requirements that are written with systematic and explicit consideration of Human Factors issues lay the foundation for ensuring that these issues are addressed at the earliest possible stage of development (or procurement). Identifying potential Human Factors problems early has the advantage of remedying situations when they are easier and less costly to fix. Too often, Human Factors engineers aren't involved in the process until the developmental or operational testing stage. Addressing Human Factors problems at this stage can lead to costly changes in design, delays in implementation, or degraded performance. While managers in charge of programs are often, and understandably, reluctant to incur additional costs (such as those associated with baselining human-system performance or establishing human-in-the-loop performance criteria), ignoring Human Factors concerns

can prove even costlier when errors are induced by inadequate design."

1.3   This point is made also in a Eurocontrol document entitled *Human Factors Module — A Business Case for Human Factors Investment*. The document identifies three different strategies for dealing with Human Factors issues in the life-cycle of an ATM system:

"As a way of dealing with Human Factors in the life-cycle, three different strategies can be found:

'Do nothing' approach: no initiatives are taken to counter Human Factors problems and only when problems arise will they be addressed.

'Reactive' approach: concern for Human Factors is left to the last stages of the development process.

'Proactive' approach: fix the problems before they occur.

"The cost scenarios of the three different strategies are illustrated in Figure [1-1]. The first ('do nothing') approach illustrates how cost related with human performance issues will increase rapidly over the life-cycle of the system. If some concern for human performance issues is dealt with in the final stages of the development process, the cost scenario will develop in a less aggressive yet increasing manner.
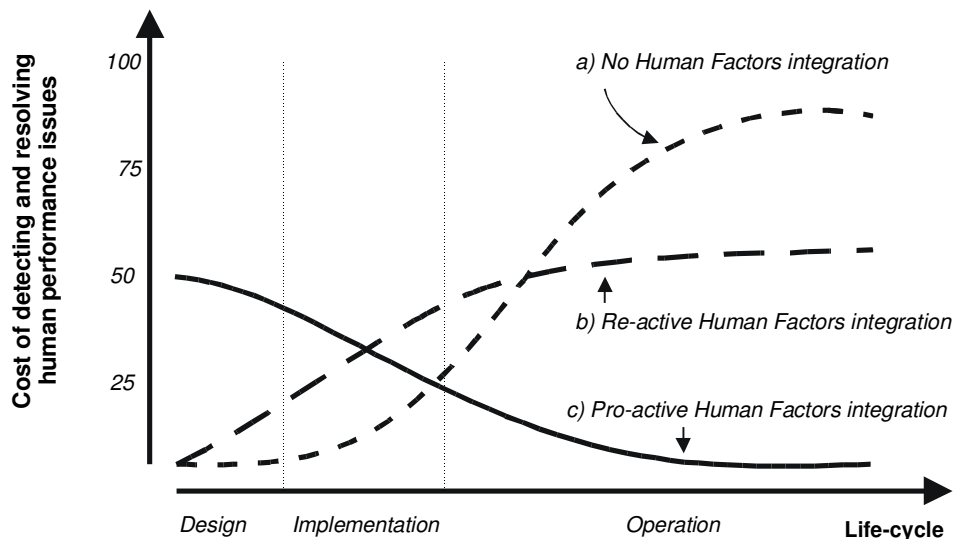

Figure 1-1.   Cost scenarios of three different life-cycle strategies

"However, if an early awareness to the Human Factors and human performance issues is introduced in a pro-active manner, the cost will develop in a rather different manner. The figure illustrates how cost is higher compared to the other approaches due to the investments made early in the process, but also how the early anticipation of problems takes the air out of later and more expensive problems.

"The reluctance to provide the necessary resources to embark on a proactive approach is probably based on the notion that it is better to wait and see where the problems occur and then intervene. While this strategy may, apparently, save some money, especially when the system is being developed, experience shows that the bill will have to be paid later ... with interest.

"Unless Human Factors are emphasised as an important part of the requirements for a new or adapted system, contractors bidding for the contract are likely to leave them out to save cost (and therefore increase the likelihood of winning the contract). Therefore, the requirements from any system development or from making changes to an existing system need to address Human Factors specifically.

"In summary, we can make the following observations:

*   70% of cost are determined in the first 10% of the project;

*   The change of design when the system has been built and is operating will cost 60 to 100 times more than the same change if it takes place during the initial phases of the design.

"To put it briefly, it is a matter of either paying up front for detecting and resolving the problems — or paying more later, which by all accounts, will be significantly more costly."

1.4   The third and final selection in this chapter is taken from the ICAO *Human Factors Training Manual* (Doc 9683-AN/950), where a quotation from Professor Earl Wiener (University of Miami) underscores that, compared to the everyday operating costs induced by inadequate design, the front-end cost associated with human-centred technology in the conceptual stages is negligible:

"There is an 'iron law' that should never be ignored. To consider Human Factors properly at the design and certification stage is costly, but the cost is paid only once. If the operator must compensate for incorrect design in his training program, the price must be paid

every day. And what is worse, we can never be sure that when the chips are down, the correct response will be made."[1]

Conclusion

1.5   The overall safety and efficiency of the aviation system depends on human operators as the ultimate integrators of the numerous system-elements. This dependence is unlikely to decrease, and may even increase in unanticipated ways, as additional advanced technology is implemented. To a greater extent than ever before, understanding and accounting for the role of humans, including their positive and negative contributions, will be important to maintaining and improving safety while improving efficiency.

1.6   This manual provides Human Factors guidance material that will enable global and regional planners and developers to ensure that Human Factors issues are properly considered at the appropriate stages of planning and development. At the same time, this manual provides guidance on Human Factors aspects to States and organizations that are about to acquire and implement CNS/ATM technology for the provision of air traffic services. The objective is to facilitate a successful transition to the CNS/ATM environment.

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Chapter 2

THREE ESSENTIAL CONCEPTS

2.1 INTRODUCTION

2.1.1 In order to provide a common platform for discussions on the development, acquisition and implementation of ATM systems, this chapter introduces three concepts essential to such discussions. These are the concepts of **Human-centred Automation**, **Situational Awareness** and **Error Management**.

2.1.2 Each concept is discussed in detail with special emphasis on its relevance for air traffic management. The discussion on Situational Awareness includes a listing of specific consequences for the design, implementation and operation of ATM systems. The discussions on Human-centred Automation and Error Management include high-level conclusions which should be borne in mind throughout the processes of development, acquisition and implementation of ATM systems.

2.2 HUMAN-CENTRED AUTOMATION

Introduction

2.2.1 Hardly anyone working in a radar environment would want to return to the days prior to the introduction of radar into air traffic control (ATC). There is no question that the display of radar targets eases the burden on the controller of remembering aircraft positions and projecting those positions in relationship to each other. Similarly, despite the uncertainties associated with increased automation, it is beyond argument that additional automation is needed to enhance controllers' abilities to handle increased traffic demands. What is at issue is the specific design of new automated tools and their capabilities.

2.2.2 Automated aids can be designed from a technology-centred perspective or from a human-centred perspective. A technology-centred approach automates whatever functions it is possible to automate and leaves the human to do the rest. This places the operator in the role of custodian to the automation; the human becomes responsible for the "care and feeding" of the computer. In contrast, a human-centred approach provides the operator with automated assistance that saves time and effort; the operator's task performance is *supported*, not *managed*, by computing machinery.

2.2.3 The ICAO *Human Factors Training Manual* (Doc 9683-AN/950), Part 1, Chapter 3, introduces the principles of human-centred automation as developed by Dr. Charles E. Billings. This section applies these general principles to the aviation domain and, in particular, to the ATC domain.

Principles of Human-centred Aviation Automation

Basic Assumptions

- The pilot bears the responsibility for safety of flight.

- Controllers bear the responsibility for traffic separation and safe traffic flow.

Fundamental Principles

- Pilots must remain in command of their flights.

- Controllers must remain in command of air traffic.

Consequences

- The pilot and controller must be actively involved.

- Both human operators must be adequately informed.

- The operators must be able to monitor the automation assisting them.

- The automated systems must therefore be predictable.

- The automated systems must also monitor the human operators.

- Every intelligent system element must know the intent of other intelligent system elements.

Applied Human-centred Automation in ATC

2.2.4   In a technology-centred approach, whatever automated functions that can be provided to the controller to assist in managing aircraft and increasing capacity are provided. This is different from a human-centred approach which aims to provide only those functions that the controller needs, based on information and task requirements. While the goals of the automation remain the same, i.e. to assist the controller in managing aircraft and to improve system performance, the approach taken to automation will determine which functions are automated and how the controller will use these automated functions.

2.2.5   A human-centred approach is applied by systematically mapping user requirements to technical solutions (e.g. hardware and software that will satisfy requirements). A human-centred approach also requires careful evaluation of the usability, suitability and acceptability of the design products. Such an evaluation benefits controllers by ensuring that the tools and capabilities provided by the computer system are in fact the ones needed by controllers to do their jobs.

2.2.6   Possible ways in which human-centred automation can support controllers have been suggested by Charles E. Billings in an analysis of aircraft automation and its effects on flight crews (*Human-centered Aircraft Automation: A Concept and Guidelines*). The following recommendations are based on the conclusions of that report:

• Humans must remain in command of flight and air traffic operations.

• Automation can assist by providing a range of planning and control options.

• Human operators must remain involved in the task.

• Automation can assist by providing better integrated and more timely information.

• Human operators must be fully informed about the purposes and functioning of automated processes. At no time should the controller be wondering, "What is the automation doing" or "why is it doing that?"

• Automation can be designed on the basis of a coherent model of its use, which can be explicitly communicated to users; automation should assist users by providing explanations of its intentions, recommendations and actions.

• Human operators must have the information needed to anticipate and resolve problems. Automation can assist by monitoring trends, providing decision support and making required information accessible when it is needed.

2.2.7   The specification of requirements and review of design products based upon considerations such as those outlined above contribute to ensuring that ATC automation remains human-centred.

High-level objectives

2.2.8   There are three higher-level objectives for ATC automation: usability, operational suitability and workforce acceptance.

2.2.9   **Usability** is a function of measurable ease-of-use outcomes, such as the ease of navigating through a menu structure, ease of remembering data-entry requirements (e.g. command formats and sequences), and ease of locating specific items on a visual display. Overall usability depends on several interdependent factors, such as reliability of system performance, organization of the user interface, and maintainability in the field. Establishing usability goals and evaluating design products against these goals are key system development activities in which controllers, as end-users, should participate.

2.2.10   In order for a design to be **operationally suitable**, it must support the controller's effective and efficient planning, maintenance of situational awareness, separation of aircraft, and performance of other ATC tasks. Support is provided to the controller by the design primarily in the form of information about the ATC situation and the status of ATC equipment and facilities. A design can be usable but operationally unsuitable if it does not meet the controller's requirements for appropriate and timely information. Early indications of operational suitability can surface in systematic field evaluations. The ultimate tests of operational suitability occur later during rigorous site-implementation evaluations.

2.2.11   **Workforce acceptance** derives, in part, from a design's reliability, usability and operational suitability. Acceptance also depends on the impact that new ATC technology has on controller job satisfaction, and in particular, on the intrinsic motivation the job holds for the controller. It may be the case that sources of job satisfaction in the current system, such as opportunities for individual recognition by one's peers and managers, are disrupted or removed by the new technology.

Human Factors objectives for ATC automation

2.2.12   As a basis for ensuring that the design is usable, operationally suitable and acceptable to the work-force, it is useful to specify Human Factors objectives for the new ATC automation and its operation. A set of objectives for automation that should be considered during the specification of requirements and development follows:

- transparency of underlying software operations so that the controller does not need to be aware of the inner workings of the computer but perceives a smooth, responsive operation;

- error-tolerance and recoverability;

- consistency with controllers' expectations;

- compatibility with human capabilities and limitations;

- ease of reversion to lower levels of automation and of returning to higher levels of automation;

- ease of handling abnormal situations and emergencies; and

- ease of use and learning.

2.2.13   For any specific design, these objectives will need to be further specified in terms of individual system functions and operational objectives.

2.2.14   **Transparency of underlying operations.** Internal software operations will not be apparent to the controller if design meets the high-level objective of usability. For example, if it is difficult for the controller to maintain a sense of orientation within a user-interface menu structure, it is likely that programming convenience has taken priority over usability goals.

2.2.15   Software operations will be transparent to the controller if ATC tasks can be performed naturally or intuitively without needing to pay conscious attention to underlying computational structures. Thus, transparency also relates to operational suitability. On the other hand, a non-transparent (or opaque) user interface is likely to have adverse consequences for job satisfaction because it will be difficult to understand and use. It will add complexity to operating the system and distract from the real task at hand, i.e. controlling aircraft. It will foster negative attitudes, such as frustration and resentment. These questions should be dealt with early in design development so that systems deployed in the field for early field evaluation and later site testing will be more usable, operationally suitable and acceptable.

2.2.16   **Error tolerance and recoverability.** The objectives of error tolerance and recoverability fall primarily under operational suitability, but they are related to the other goals as well. Error-tolerant designs allow for the conceptual equivalence of different commands (e.g. Exit and Quit) and will accept any of the pre-defined equivalents. Further, error-tolerant designs anticipate possible user errors in data entry and include capabilities to trap errors before they spread through the system. Error-tolerant designs routinely query the user at critical choice points (e.g. "Are you sure you want to delete this flight plan?"). Under such design, recovery from error is simple and usability is enhanced.

2.2.17   **Consistency with controllers' expectations.** Automation that does not assess a situation in the same way a controller would, or does not take the same actions as a controller would, is likely to elicit scepticism or inappropriate actions from the controller. Controllers will be more likely to accept, trust and use automated functions that handle situations in the same ways as a controller would. To be most useful to the controller, the design of automated functions should take into account air traffic procedures and operations (e.g. airspace and traffic management restrictions, rules for assignment of flight levels), so that the automation does not violate common practices.

2.2.18   **Compatibility with human capabilities and limitations.** People are, by nature, poor monitors of automated processes. Controllers cannot be put in the position of passively monitoring the automation and then be expected to be able to detect a failure, determine the problem, and take appropriate action. On the other hand, people are good at analysing novel or unforeseen situations and selecting strategies to cope with these. Automated functions must be compatible with human capabilities and limitations.

2.2.19   **Ease of reversion to lower levels of automation.** After operating with a highly automated system for some time, returning to lower levels of automation (e.g. as in the case of system degradation or failure) may be problematic for several reasons. First, controllers may experience a loss of proficiency. For example, if an automatic conflict-resolution function is used extensively, controllers may rarely have to resolve potential conflicts between aircraft. Their problem-solving skills and strategies are not likely to be as finely tuned as when they had to prevent and solve the problems with only basic support from automation. Complex skills suffer from disuse. Provisions for maintaining these skills (such as

recurrent training) must be considered in these circumstances. Second, a controller's ability to respond may be affected by a loss of Situational Awareness. Controllers who are left "out of the loop" will lose their Situational Awareness and possibly become bored and inattentive. This will increase the time required for the controller to take over from the automation and will be detrimental to the quality of the controller's response. Automated systems have to include an active, involved role for the controller, so that the controller always retains enough Situational Awareness to handle whatever problems arise. Finally, the controller will not be able to recover from an automation failure if the number and complexity of operations being managed by the automation exceeds basic human capabilities.

2.2.20   **Ease of handling of abnormal situations and emergencies.** Controllers need to have the information and the means that are required to intervene in emergencies or abnormal situations. Controllers should not be denied access to controls or critical information that they may need to respond to these situations. For example, a system designed to automatically handle all communications with aircraft would be unacceptable unless alternative provisions were available for the controller to communicate with aircraft as necessary. Such design should also provide direct controller access to critical flight information regarding all aircraft in the sector.

2.2.21   **Ease of use and learning.** Automated functions should be easy to learn and use. The implications of the use of automated functions on training requirements should be examined. Complex systems may require extensive training on the various operational modes and limitations. Recurrent training may need to address problems that are possible but rare.

ATC automation philosophy

2.2.22   Before evaluating automated systems, it is useful to think in terms of a human-centred philosophy of ATC automation. Such philosophy considers automation as assisting, not replacing, the controller. It recognizes that there is more overlap than ever in the capabilities of the human and the computer. It does not divide tasks between controller and computer according to simplistic approaches depicting computers as "better-than-the-human" at some tasks and humans as "better-than-the-computer" at other tasks. This philosophy advocates a synergistic task-allocation strategy that benefits from the best of controller and computer capabilities, rather than leaving to the controller only those tasks (or bits of tasks) that the designer finds difficult to automate.

2.2.23   The philosophy of human-centred ATC automation emphasizes the need for allocating functions in such a way that the controller's Situational Awareness is continually maintained and updated, and that the controller's expertise and creativity are exercised regularly. It suggests that dynamic or adaptive function allocation be considered as a technical solution. Under adaptive function allocation, the controller can prepare for periods of heavy traffic by allocating normally manual functions to the computer, and the controller can prepare for lighter traffic periods by taking on some functions (or portions of functions) normally accomplished by the computer. Under a static allocation policy, flexibility of assigning functions is not possible.

Human-centred Automation — Summary

2.2.24   The following excerpt from the book *Aviation Automation — The Search for a Human-Centered Approach* by Charles E. Billings provides an appropriate concluding summary to the concept of Human-centred Automation as discussed in this section.

"Although humans are far from perfect sensors, decision-makers, and controllers, they possess three invaluable attributes. They are excellent detectors of signals in the midst of noise, they can reason effectively in the face of uncertainty, and they are capable of abstraction and conceptual organisation. Humans thus provide to the aviation system a degree of flexibility that cannot be attained by computers. Human experts can cope with failures not envisioned by aircraft and aviation system designers. They are intelligent: they possess the ability to learn from experience and thus the ability to respond adaptively to new situations. Computers cannot do this except in narrowly defined, completely understood domains and situations.

"The ability of humans to recognise and bound the expected, to cope with the unexpected, to innovate, and to reason by analogy when previous experience does not cover a new problem are what has made the aviation system robust, for there are still many circumstances, especially in the weather domain, that are neither controllable nor fully predictable. Each of these uniquely human attributes is a compelling reason to retain human operators in a central position in aircraft and in the aviation system. Those humans can function effectively, however, only if the system is designed and structured to assist them to accomplish the required tasks. As technology continues to advance, it will become increasingly urgent that its applications on the flight deck be designed specifically around the

human who must command them; in short, future aviation automation must be human-centered if it is to be a maximally effective tool.

"At the same time, many machines today are capable of tasks that unaided humans simply cannot accomplish. This is true in both the perceptual and cognitive realms. An example today is the calculation of optimal orbital trajectories for systems such as the Space Shuttle; another is the determination of a great circle navigation route. For these tasks, computers and automated systems are an absolute requirement. Competitive pressures in aviation being what they are, it is likely that still more complex automation will be offered in the marketplace, and there will be a tendency to accept it. If this tendency toward greater complexity is to be countered, it must be by the customers: airlines and other operators must decide whether the potential gains are worth the certain costs."

2.3   SITUATIONAL AWARENESS

Introduction

2.3.1   The ICAO World-wide CNS/ATM Systems Implementation Conference, held in Rio de Janeiro, Brazil, in 1998, concluded, *inter alia,* that "the most important Human Factors issue in regards to human-technology interface is the ability of the human operator to maintain situational/system awareness. It is an established fact that human-technology interfaces have not always been intuitive. Non-intuitive, 'opaque' interfaces lead to oper-ational complexity which often forces the operator to allocate increased attention to maintain an adequate mental model of the situation/system status. This becomes the breeding grounds for loss of situational awareness, decreased system performance and eventually human error and safety breakdowns." (*The Role of Human Factors in CNS/ATM Systems Guidelines*, ICAO, 1999.)

2.3.2   True as this statement is, it may not always be clear what exactly is meant by the term "Situational Awareness" (SA). In particular there appears to be confusion between thinking of SA as simply knowing the relative position of other traffic in the vicinity of one's own aircraft (pilots), or "having the picture" or awareness of the traffic situation (controllers), as opposed to knowing what is happening in a far wider sense.

2.3.3   The accepted definition of SA from the scientific community would seem to support the wider interpretation of the phrase: "Situational Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"[1]. The following section discusses in detail the elements that are relevant to SA in the ATC environment. For each element, the relationship to the design, implementation and operation of an ATM system is provided.

Elements of Situational Awareness in ATC

2.3.4   The elements listed below are highly dynamic and present subtle to large changes that may occur at short notice, and that can or will influence the way a controller works at any particular moment. How these changes interact with a controller's SA may only be recognized after having gained considerable experience in ATC in general, and at a specific location in particular:

- personal factors

- weather

- airport infrastructure

- individual differences

- traffic

- operators and pilots

- environment

- navigational aids

- aircraft performance

- equipment

- adjacent units.

Personal Factors

2.3.5   A person's physical and mental state will very much determine the interaction with other persons and will also influence the performance of certain tasks by that person. Simply put, someone who does not feel well will probably be performing in a less-than-optimal fashion.

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1.   Endsley, M., quoted in *Situation Awareness Information Requirements for En Route ATC*, (DOT/FAA/AM-94/27), Office of Aviation Medicine, Washington D.C., December 1994.

2.3.6   In ATC, typical **physical comfort** factors affecting individual performance include the ambient temperature (too cold/too hot), lighting (too bright/too dark), humidity, as well as the noise level at the working place. Knowing that any of these factors is present, or could occur, when at work helps to shape the SA of a controller.

2.3.7   For example: when realizing that the noise level is higher than usual, a controller may wish to give extra care to ensuring that radiotelephony (R/T) readbacks are correct. Similarly, the controller may take more care to ensure that the microphone is close to the mouth.

2.3.8   Another important personal factor is being aware of personal **stress** level. A controller with a high SA will realize when stress (usually caused by external factors) influences performance and may arrange to be relieved from the working position earlier or more often than usual.

2.3.9   The last personal factor discussed in this section is **fatigue.** Recognizing fatigue is not easy, but recognizing the conditions that can cause fatigue increases the SA. The onset of fatigue should be expected after working a high number of consecutive shifts, after a period with intensive physical activity during off-duty hours, or towards the end of a single nightshift. If such conditions apply, it may not be prudent to work the busiest position in the operations room if less busy positions are available. A controller with a high SA will know that when fatigue could be a factor all actions should be double-checked, and high attention-demanding traffic situations should be avoided, if possible.

2.3.10   Consequences for the design, implementation and operation of ATM systems

*   In the design of ATC workstations, and of the entire ATC operations room with multiple workstations, ergonomic principles should be taken into consideration. These ergonomic principles are discussed in the ICAO *Human Factors Training Manual*, in the FAA's *Human Factors Design Guide*, and in the book *Human Factors in Air Traffic Control* by V. David Hopkin.

*   When analysing and developing safety-related working conditions for air traffic controllers, consideration must be given to the reduction of stress- and fatigue-inducing factors. Stress and fatigue in ATC are discussed in the ICAO *Human Factors Training Manual*.

Weather

2.3.11   SA is heightened by knowing the **current** weather and the **forecast** trend for at least the duration of a controller's shift. For example: changes in wind direction may involve runway changes. The busier the traffic, the more crucial becomes the timing for a runway change. A controller will plan strategies to make the change with a minimal disruption to the traffic flow. For en-route controllers, knowing areas of significant weather will help to anticipate requests for re-routings or circumnavigation.

2.3.12   Appropriate knowledge of local weather phenomena (e.g. turbulence over mountainous terrain; fog patterns, intensity of thunderstorms, etc.) and/or sudden weather occurrences like windshear or microbursts contributes towards greater SA. A controller with a high SA will apply more effective solutions in special circumstances.

2.3.13   Consequences for the design, implementation and operation of ATM systems

*   Provisions should be included in systems design so that updated and accurate weather information is available to air traffic controllers at all times.

*   When designing traffic situation displays, available weather data should be integrated in real time and in graphical format on the display.

Airport infrastructure

2.3.14   Constant awareness of **runway availability** at the airport(s) under the jurisdiction of a controller allows adequate response in case of emergencies requiring an immediate diversion. Such awareness should include not only the runway physical characteristics but also information on **work in progress** that might preclude runway use at any particular time.

2.3.15   For aerodrome controllers, awareness of **work in progress** is not limited to runways but must also include taxiways and aprons, as well as special considerations such as temporary obstructions to visibility from the tower by construction work.

2.3.16   Knowing how the airport looks from a pilot's point of view — not just during the approach but also when taxiing — increases the SA of aerodrome controllers. Which **visual aids** (e.g. lighting, signs) can be referred to when explaining a required routing to a pilot? A controller who possesses such awareness will be more successful in transferring routing information.

2.3.17   Consequences for the design, implementation and operation of ATM systems

- Provisions should be included in the design of control facilities so that information on the status of airports under their jurisdiction is available to controllers at all times.

- Training practices should provide the possibility to aerodrome controllers to regularly familiarize themselves with the visual aids at their airport.

Individual Differences

2.3.18   Controller performance is expected to meet minimum standards. Controllers must perform according to these minima, but there are differences in the degree to which each individual controller performs in excess of the minimum standards. At any given facility, controllers are aware of these differences and will subconsciously or even consciously take each other's **strengths and weaknesses** into account when working together.

2.3.19   Humans, unlike machines, do not perform exactly the same way over and over again. One of the ways in which this human attribute manifests itself in ATC is the feeling of "being a little rusty" after not having worked in a certain position for a certain time (even though that time is within the regulatory requirement). Recognition of this variation in **performance level** among people is an important component of SA.

2.3.20   The **social gradient** influences each specific work situation within ATC facilities. This social gradient is also found in flight decks, where a situation in which a young captain working with an older first officer is different from a situation in which an older captain is working with a younger first officer. Substituting "captain" by "supervisor" and "first officer" by "controller" allows to see how social gradients could affect an ATC work situation and influence SA.

2.3.21   The last discussion item in this section involves on-the-job training (OJT). Knowing that there is **training in progress** at an adjacent position, or at a position or facility with which frequent coordination is necessary, will influence the way a controller works. The degree of influence can be subtle, such as in adopting a slightly more formal phraseology during coordination, or overt, such as in accepting, for the benefit of the training, proposed solutions for traffic conflicts or handovers that normally would be regarded as less favourable.

2.3.22   Consequences for the design, implementation and operation of ATM systems

- ATC training programmes in general should include teamwork training. Training programmes associated with the implementation of advanced systems should in particular include teamwork training. Teamwork training in ATC is described in *Guidelines for Developing and Implementing Team Resource Management* (Eurocontrol).

Traffic

2.3.23   Awareness of the exact traffic **situation** is a very important element of a controller's SA. In addition to "having the picture" of where all aircraft under the controller's jurisdiction are and will be next, it is equally important to be aware of the **development** of the traffic situation. Is it the beginning of a peak period, or is it the end of it? Will there be additional traffic, such as photo-flights, training flights, calibration flights and so forth? Any of these aspects can influence the way in which a controller will handle traffic.

2.3.24   A controller's awareness of the normal traffic **patterns** will help determine options for solving conflicts. These patterns are not necessarily the same as the airways, standard instrument arrivals (STARs) and/or standard instrument departures (SIDs) depicted on maps, which implies that a controller may only learn them over time, or by experience.

2.3.25   A further aspect that may influence a controller's SA is awareness of the **flow** of the traffic under management. If a considerable amount of traffic is expected to move in the same general direction (e.g. to or from one particular aerodrome; north/east/south/westbound; and so forth), solutions different from those when traffic is moving randomly will be applied.

2.3.26   Consequences for the design, implementation and operation of ATM systems

- Design and organizational practices should ensure that all relevant information on the traffic situation and its development is available to the controller at all times.

Operators and Pilots

2.3.27   Viewing surface operations at unfamiliar aerodromes is not unlike being in a strange city for the first time. There are signs providing names and directions, as well as maps with routes, but it takes time to properly

interpret all that information. It is always useful if a person familiar with the place can provide further instructions. Aerodrome controllers, especially ground movement controllers, are often in the role of the "familiar person". If their SA is high, they will recognize operators and pilots with a low **familiarity level** with the local circumstances, and they can provide adequate assistance. (Recognizing potentially unfamiliar operators is relatively easy by looking at the company or aircraft colours or may be evident from the call sign. Recognizing potentially unfamiliar pilots could be more difficult.) To a certain extent this also applies to area and approach controllers, with respect to their familiarity with specific, national or local procedures.

2.3.28 "Corporate culture", in terms of the differences among airlines, has received considerable attention in aviation safety circles over the last few years. Subconscious awareness of these differences exists among controllers, who have learned to take the subjective **performance level** of the various operators into account. Solutions or manoeuvres that are acceptable to (and therefore applied to) one operator are not proposed to other operators. This awareness is part of a controller's SA.

2.3.29 A third aspect, distinct from and yet closely linked to the other two mentioned here, is worth mentioning: a pilot's **R/T level**. Controllers get important cues from the degree of proficiency in R/T that a pilot displays, both in procedure and in vocabulary, and — given the right degree of SA — will adjust their R/T accordingly with respect to the complexity of instructions and/or procedures.

2.3.30 Consequences for the design, implementation and operation of ATM systems

- Training programmes for air traffic controllers should include awareness of the importance of specific aspects of differences between operators and between individual pilots.

Environment

2.3.31 Although the environment could be considered of a semi-permanent nature, and therefore irrelevant as an element of SA, there are certain aspects that are important enough to warrant mention in this section. Aerodrome controllers need, for example, to be aware of the significant **obstacles** at and around their airport. This includes keeping track of new construction in the vicinity and the machinery associated with construction or maintenance work at airports.

2.3.32 Awareness of the **terrain characteristics** could lead a controller to choose different solutions in given situations to those that might have been applied without that awareness. This could relate also to the familiarity level of the operator involved.

2.3.33 Awareness of the **noise sensitivity** of populated areas in the environment of an airport may be a factor when certain runway combinations must be considered. Even when not many options are available, the environment may dictate certain changes in the runway use to be effected at certain times of day (curfews; landing/departure runway change; and so on). Awareness of the part of the environment affected by traffic patterns or runway(s) in use at any time is therefore part of an aerodrome controller's SA.

2.3.34 Consequences for the design, implementation and operation of ATM systems

- When designing traffic situation displays, the inclusion of maps depicting relevant terrain, obstacles and noise sensitive areas should be considered.

- When designing advanced ATM systems, the inclusion of a minimum safe altitude warning (MSAW) system should be considered.

- Organizational procedures should be in place to keep air traffic controllers constantly updated of temporary changes in the surrounding environment.

Navigational aids

2.3.35 An obvious aspect of this element is **availability**, i.e. whether the navigational aid (navaid) is serviceable or not, but there are further considerations. A navaid (or way-point) may be situated in the area for which a controller is responsible, but pilots may not have immediate access to its frequency or coordinates. If a flight is following a standard instrument departure (SID) that is based on specific navaids and is cleared to proceed to a navaid or way-point that is not specified in the SID, the pilots might be unable to locate the navaid. A controller with a high SA either will use navaids and way-points that are likely to be familiar to the pilots concerned or will use radar vectors to overcome these problems.

2.3.36 Similarly, controllers need to consider the **performance level** of navaids. Navaids should work according to operational specifications, but this is not always the case even though the aids meet the required technical specifications. Experienced controllers will

develop awareness of specific conditions impairing navaid performance. This awareness is part of their SA.

2.3.37   Consequences for the design, implementation and operation of ATM systems

Equipment design and organizational procedures should ensure that:

• Information on the status of navigational aids is available to the controller at all times.

• Procedures applicable in case of failure of navigational aids are established.

• Training for air traffic controllers should include proficiency in the application of procedures related to the failure of navigational aids.

Aircraft Performance

2.3.38   Controllers are taught general awareness of **differences** in aircraft performance, e.g. between jets and propeller-driven aircraft. However, there may be more subtle differences. An aircraft serving a destination that is only two hours' flying time from the departure airport has different performance characteristics than a similar aircraft taking off for a ten-hour flight. This difference affects aerodrome and area controllers alike. A controller with a high SA will take cues from the flight plan information available, or even just the call sign (flight number), to assess the expected performance of each flight and will adjust control strategies accordingly.

2.3.39   A further factor may be the way in which an aircraft is usually operated by the various companies. Climb speeds, rates and/or angles may differ although the aircraft type is the same. Familiarity with such differences adds to a controller's SA.

2.3.40   Controllers also need to be aware of potential **degradations** in aircraft performance, either as a result of atmospheric conditions or as a result of technical problems.

2.3.41   Different types of aircraft have different **possibilities** and **limitations**, and awareness about these will increase a controller's SA. For example: modern aircraft have the capability for off-set navigation, to construct non-standard way-points, or can provide accurate wind information. Older aircraft often lack these capabilities and should therefore be handled in a different way. As another example, non-pressurized aircraft will normally not accept altitudes of more than 10 000 ft

(3 050 m) above mean sea level, thus restricting the options for applying vertical separation with such aircraft.

2.3.42   Consequences for the design, implementation and operation of ATM systems

• Organizational procedures should be established to ensure that verified information on the type of aircraft of a flight under a controller's jurisdiction is available to the controller at all times.

• Training programmes for air traffic controllers should include awareness about aspects of differences and variations in aircraft performance.

• Organizational procedures should be established to ensure that controllers have the possibility to make regular familiarization flights to observe from the flight deck the possibilities and limitations of relevant types of aircraft.

Equipment

2.3.43   In line with the previous discussion on navaids, awareness about ATC equipment **availability** is essential. This includes spare (or back-up) equipment and equipment scheduled to be temporarily taken out of service for maintenance.

2.3.44   The **reliability** of the equipment is an important factor. A high number of failures with a certain radarscope will dictate prudent use when working the position, including tactics such as accepting less traffic or applying wider separations than under normal circumstances.

2.3.45   Also similar to the discussion on navaids, the **performance** of the equipment may not be optimal under all conditions. Awareness of these conditions, and the associated **degradations** in performance, increases a controller's SA.

2.3.46   **Degradations** may also occur as a result of technical problems. The ability to recognize the problems, and know what the consequences are, are all part of a controller's SA.

2.3.47   Consequences for the design, implementation and operation of ATM systems

• Organizational procedures should be established to ensure that information on the status of ATC equipment is available to the controller at all times.

- Procedures that are applicable in case of failure of ATC equipment must exist.

- Controller training must include proficiency in the application of procedures related to the failure of ATC equipment.

Adjacent Units

2.3.48   Certain aspects discussed under the heading *Individual Differences* are also applicable to the traffic exchange among ATC units. Awareness of the actual **performance level** of different units, and the ability to compare this to a perceived average performance, are part of a controller's SA and may influence the choice of strategies. In some cases, a shift takeover in an adjacent centre has a significant bearing on the way traffic is handled by that unit and subsequently affects traffic exchange with that unit.

2.3.49   A controller with a high SA will also be aware of possible **limitations** that adjacent units may experience. For example, significant weather may complicate adherence to agreed handover procedures. Another example could be staff shortages or equipment problems. In some cases this may lead the adjacent unit(s) to declare a lower **capacity** than usual.

2.3.50   Consequences for the design, implementation and operation of ATM systems

- Organizational procedures should be established to ensure that information on the status of adjacent centres is available to the controller at all times.

- Organizational procedures should be established to ensure that controllers have the possibility to make regular familiarization visits to adjacent centres in order to observe the working practices in those centres.

Situational Awareness — Summary

2.3.51   Situational Awareness in ATC comprises more than knowing where all the traffic is at a given moment and what is the relative direction of movement of each aircraft. For air traffic controllers SA includes all the elements discussed in this section. Consideration of all elements may be done consciously or unconsciously, and some elements can have a higher importance in one situation than in another.

2.3.52   When designing new systems and supporting procedures that include the goal of "enhancing the Situational Awareness of the controller", care must be taken to address all the elements from this section. As a minimum, the controller should be formally provided with up-to-date information on the traffic, weather, airport infrastructure, navigational aids, the status of the system itself, and the adjacent units. Such information should be available to the controller when required or presented to the controller in case of significant changes.

2.4   MANAGING ERROR

Introduction

2.4.1   The last two decades have witnessed a notable shift in the way the aviation industry regards human error. In the past, it was generally considered that human error was an individual trait that could be prevented by the right training and attitudes. Specific to CNS/ATM systems it was considered that error-free systems could be designed by automating as many human tasks as possible. Reports from aviation incident/accident investigations commonly concluded that "pilot error" or "controller error" was the cause of the event under investigation.

2.4.2   Automation, however, did not eliminate error, and serious accidents kept occurring in aviation as well as in other high-technology environments (e.g. the nuclear, aerospace and oil industries). Studies on safety in "complex socio-technological systems" further demonstrated that automation had a tendency to change the place where human error could occur in the system and sometimes even potentially increased the magnitude of human error as a result.

2.4.3   The model developed by Professor James Reason, of the University of Manchester (UK), provides insight into error generation within organizations and what organizations can do to prevent it. (See Figure 2-1.)

Note.— A detailed discussion of the Reason model is provided in the ICAO Human Factors Training Manual.

2.4.4   The Reason model proposes that accidents seldom originate exclusively from the errors of operational personnel (frontline operators) or as a result of major equipment failures. Instead, they result from interactions of a series of failures or flaws already present in the system. Many of these failures are not immediately visible, and they have delayed consequences.
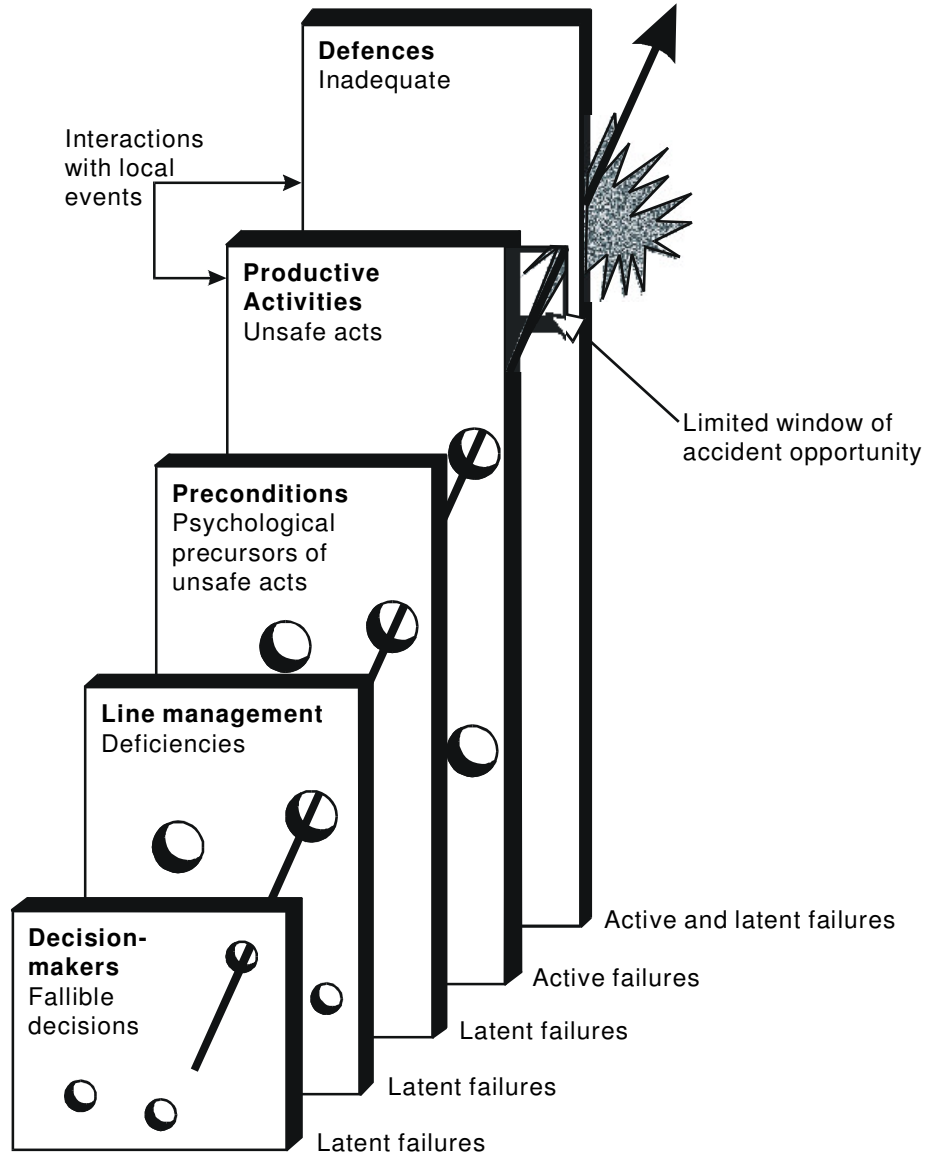
Defences
Inadequate

Interactions
with local
events

**Productive
Activities**
Unsafe acts

Limited window of
accident opportunity

Preconditions
Psychological
precursors of
unsafe acts

Line management
Deficiencies

Active and latent failures

**Decision-
makers**
Fallible
decisions

Active failures

Latent failures

Latent failures

Latent failures

Figure 2-1.   The Reason model

2.4.5   Failures can be of two types, depending on the immediacy of their consequences. An **active failure** is an error or a violation that has an immediate adverse effect. Such errors are usually made by the frontline operator. A **latent failure** is a result of a decision or an action made well before an accident, the consequences of which may lie dormant for a long time. Such failures usually originate at the decision-maker, regulator or line-manager level, that is, with people far removed in time and space from the resulting event. These failures can also be produced at any level of the system by the human condition, for example, through poor motivation or fatigue.

2.4.6   Latent failures, which originate from inevitable downsides of strategic decisions, may interact to create "a window of opportunity" for a pilot, air traffic controller or mechanic to commit an active failure that breaches all the defences of the system and results in an accident. The frontline operators are thus the inheritors of a system's defects. They are the ones dealing with a situation in which technical problems, adverse conditions or their own actions will trigger the latent failures present in a system. In a well-guarded system, latent and active failures will interact, but they will seldom breach the defences.

2.4.7   Based on the work by Reason and others, aviation incident/accident investigators are coming to realize that "human error" is not the end of the investigation process but rather its starting point. The objective of investigations thus becomes to find out why these errors were made, how they could have led to disaster in a particular case and, subsequently, to make recommendations for improving the safety of the overall system.

2.4.8   The aviation industry thus shifted its focus from *eliminating* error to *preventing* and *managing* error. Human error is recognized as an inevitable component of human performance. Complex socio-technological systems therefore should take this into account by design. The concepts of *error tolerance* and *error resistance* in technology design best exemplify this new focus.

2.4.9   The concept of error tolerance can be illustrated by the comparison between a typewriter and a word processor. A typewriter is hardly error tolerant: if a wrong key is struck during the typing of a text, the entire text has to be retyped in order to produce a faultless page. Later models of typewriters include correction facilities to help overcome this problem to a degree, but the corrections made are still noticeable to the trained eye of readers. A computer-based word processor on the other hand is highly error tolerant in this respect: if a wrong key is struck, the backspace key provides a simple but effective means to

correct the problem. In fact, by separating the composition stage and the printing stage, an opportunity to correct a multitude of errors is created.

2.4.10   The concept of error resistance can also be illustrated using the example of a personal computer. Many potentially destructive commands will first trigger a "question" from the computer to confirm that the user really wants the programme to execute that command and often require a second input from the user before the programme performs the action. Examples are: deleting files, formatting disks and terminating applications (programmes) before saving work done with those applications. Personal computers therefore by design can be seen to resist potential user errors that would negate the purpose of using the computers in the first place.

Error management

2.4.11   Error management has two components: *error reduction* and *error containment*. Error reduction comprises measures designed to limit the occurrence of errors. Since this will never be wholly successful, there is also a need for error containment — measures designed to limit the adverse consequences of the errors that still occur.

2.4.12   Error management includes:

- measures to minimize the error liability of the individual or team;

- measures to reduce the error vulnerability of particular tasks or task elements;

- measures to discover, assess and then eliminate error-producing (and violation[2]-producing) factors within the workplace;

- measures to diagnose organizational factors that create error-producing factors within the individual, the team, the task or the workplace;

- measures to enhance error detection;

- measures to increase the error tolerance of the workplace or system;

- measures to make latent conditions more visible to those who operate and manage the system;

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2. In Professor Reason's terms a violation is a deviation from safe operating procedures, standards or rules. Such deviations can be either deliberate or erroneous.

- measures to improve the organization's intrinsic resistance to human fallibility.

2.4.13   Most attempts at error management are piecemeal rather than planned, reactive rather than proactive, event-driven rather than principle-driven. They also largely ignore the substantial developments that have occurred in the behavioural sciences over the last 20 to 30 years in understanding the nature, varieties and causes of human error.

2.4.14   Some of the problems associated with existing forms of error management include the following:

- They address the last error rather than anticipate and prevent the next one.

- They focus on active failures rather than on latent conditions.

- They focus on personal rather than on situational contributions to error.

- They rely heavily on warnings and disciplinary sanctions.

- They employ blame-laden and essentially meaningless terms such as "carelessness", "bad attitude" and "irresponsibility".

- They do not distinguish adequately between random and systematic error-causing factors.

- They are generally not informed by current Human Factors knowledge regarding error and accident causation.

2.4.15   In aviation and elsewhere, human error is one of a long-established list of "causes" used by the press and accident investigators. But human error is a consequence rather than a cause. Errors are shaped and provoked by upstream workplace and organizational factors. As mentioned before, identifying an error is merely the beginning of the search for causes, not the end. The error, just as much as the disaster that may follow it, is something that requires an explanation. Only by understanding the context that provoked the error can there be hope to limit its recurrence.

2.4.16   It is essential to recognize the following basic facts about human nature and error as the foundations of an error management programme:

- Human actions are almost always constrained by factors beyond an individual's immediate control.

- People cannot easily avoid actions that they did not intend to perform in the first place.

- Errors have multiple causes: personal, task-related, situational and organizational.

- Within a skilled, experienced and largely well-intentioned workforce, situations are more amenable to improvement than are people.

2.4.17   Human behaviour is governed by the interplay between psychological and situational factors. This applies to errors as to all other human actions. Such claims raise a crucial question for all those in the business of minimizing potentially dangerous errors: which is the easiest to remedy, the person or the situation?

2.4.18   General practice seems to aim at the person. After all, people can be retrained, disciplined, advised or warned in ways that will make them behave more appropriately in the future — or so it is widely believed. This view is especially prevalent in professions that take pride in their willing acceptance of personal responsibility; among these are pilots and air traffic controllers. Situations, in contrast, appear as given: people seem to be stuck with them. As a consequence, errors in aviation often are suppressed. They go unreported and therefore do not exist. If errors do not exist, they need not and cannot be managed.

2.4.19   A developing trend, however, is to clearly favour the situational rather than the personal approach to error management. There are many reasons for this:

- Human fallibility can be moderated up to a point, but it can never be eliminated entirely. It is a fixed part of the human condition, partly because errors, in many contexts, serve a useful function (for example, trial-and-error learning).

- Different error types, which have different psychological mechanisms, occur in different parts of the organization and require different methods of management.

- Safety-critical errors happen at all levels of the system, not just at the operational end.

- Measures that involve sanctions, threats, fear and appeals have only a very limited effectiveness; in many cases, they can do more harm — to morale, self-respect and a sense of justice — than good.

- Errors are a product of a chain of causes in which the precipitating psychological factors — momentary

inattention, misjudgement, forgetfulness, preoccupation — are often the last and least manageable links in the chain.

- The evidence from a large number of accident inquiries indicates that bad events are more often the result of error-prone situations and error-prone activities than they are of error-prone people.

2.4.20   Error management therefore must be aimed at systemic performance rather than individual performance.

Developments in error management

2.4.21   To conclude this section, a brief mention is made of an emerging development in error management in aviation. Since it is realized that not every human error immediately has a disastrous outcome, the industry has begun to monitor "normal operations". Several airlines are routinely analysing flight data recorders (FDRs) from flights during which no abnormal occurrences happened. The idea behind this is to learn from "successes" (i.e. operations that went as intended) rather than from "failures" (i.e. operations that resulted in incidents or accidents). Of course such "failures", should they occur, are still thoroughly investigated as well, but it is hoped that data from the monitoring of normal operations will provide new insights into human error and, therefore, error management. The overall aim remains to reduce the number of safety occurrences in the aviation industry.

2.4.22   It could be argued that, in order to better understand the nature of normal operations, in addition to the quantitative data from the FDRs there should also be a qualitative analysis of the performance of the human operators. This would, for example, provide an insight into the operational suitability of a system design (see 2.2 — Human-centred Automation). For practical reasons, however, this part of the equation is not routinely included in the monitoring programmes so far, although certain encouraging initiatives are being undertaken.

Managing Error — Summary

2.4.23   Contrary to what was believed in the recent past, human error cannot be avoided by "designing it out of the system" or by disciplining operators. Error is a normal component of human performance. This fact therefore must be incorporated into all stages of the design, implementation and operation of complex systems where safety is the expected outcome. ATM systems are a prime

example. During the development, acquisition and implementation stages of an ATM system, one should always be on the lookout for opportunities for error by the eventual operators and users, in order to reduce those opportunities and/or mitigate the consequences of the resulting errors. The following chapters in this manual provide alternatives to this end.

Conclusion

2.4.24   There is a relationship between the three conceptual topics presented in this chapter. Application of the Human-centred Automation concept will increase the Situational Awareness of the air traffic controller, which in turn becomes a component of the Error Management programme of the air traffic services provider. Controllers with a high Situational Awareness are more likely to detect errors and contain their consequences. Furthermore, a human-centred system design reduces the vulnerability to error of tasks or task elements from operators.

2.4.25   This interrelationship plays an important role throughout the processes of development, acquisition and implementation of ATM systems. In Chapter 4 "The human-machine interface" and in Chapter 7 "Standard operating procedures" more detailed guidelines are provided for the practical application of these concepts.

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Chapter 3

DATA LINK INFRASTRUCTURE AND APPLICATIONS

3.1   INTRODUCTION

This chapter discusses aspects of the data link infrastructure that are relevant to the design and implementation of ATM systems but that are outside the influence of the designers, buyers or operators of the systems. Furthermore the chapter includes an overview of data link applications most relevant for ATS, as well as a description of human-machine interface designs for controller-pilot data link communications (CPDLC) on the flight deck. Designers, buyers and operators of ATM systems should understand and take into account the characteristics of the topics in this chapter.

3.2   DATA LINK

3.2.1   Although CNS/ATM systems are being designed to operate with the aeronautical telecommunication network (ATN), it is quite likely that the ATN will not be fully available before 2005. Until that time, most of the emerging system components will use a provisional network based on the use of the existing aircraft communications addressing and reporting system (ACARS) infrastructure. ACARS was originally designed as a system for airline operators to enable them to communicate via data link with aircraft during flight without having to use scarce VHF voice communication channels. When the first operational trials with automatic dependent surveillance (ADS) and CPDLC were designed, ACARS was chosen as the data link medium to transfer data between the aircraft and ground stations.

3.2.2   To that end, Boeing, Airbus and Honeywell designed avionics packages for selected aircraft types that would transfer the required data from the on-board navigation system (or to be more exact, the flight management system [FMS]) to the ground stations. The Boeing package is called FANS-1 and is available for the B747-400 series, the B767 and the B777. In addition there are also FANS-1 packages for the MD11 and MD90. The Airbus package is called FANS-A and is available for the A330 and A340 series. Both packages provide equipped

aircraft with global navigation satellite system (GNSS) capability, ADS capability and CPDLC capability.

3.2.3   From a technical viewpoint the most important difference between the ACARS network and the ATN is that ACARS is a character-based system (analogue) whereas the ATN is bit-oriented (digital). A bit-oriented system has fewer constraints for data exchange than does a character-based system. One of the key components of the ATN will be the VHF Digital Link Mode 2 (VDL Mode 2) network, which is expected to render the ACARS network obsolete over time. With ACARS, messages from air traffic control "compete" with messages from airlines for transmission space on the network. Although there is a prioritization system to govern this competition, there is a realistic risk that not all messages get through in the required order of priority. With VDL Mode 2 this risk is expected to be significantly reduced, thereby increasing the integrity of the data exchange between all parties involved.

3.2.4   One aspect that will probably not change when ACARS is replaced by VDL Mode 2 is the fact that the communications service is mainly being offered by independent service providers. For ACARS, there are two companies that offer this service globally, i.e. ARINC (Aeronautical Radio, Incorporated) and SITA (Société Internationale de Télécommunications Aéronautiques), and although the market is, in principle, open to other companies, it appears that ARINC and SITA will also be the main providers for VDL Mode 2.

3.2.5   Customers, i.e. the airlines and the air service providers, must subscribe to the services of one of these communications service providers in order to get access to ACARS and/or VDL Mode 2. Subscribing to one does not preclude access to clients using the other. An airline that uses ARINC as its communications provider can successfully establish ADS/CPDLC contacts with an air service provider that uses SITA or vice versa. The only drawback that so far has been identified with ACARS in this respect is that there may be a technical delay of up to six minutes before this cross-provider contact is established. It is expected that this situation will improve with VDL Mode 2.

3.2.6   Other networks that are under development are VDL Mode 3 and VDL Mode 4. Originally, there were also provisions for VDL Mode 1, but since the characteristics of it were at best similar to those of the ACARS network, the lack of market demand for it seems to have forestalled its further development.

3.2.7   A further technological development comprises the use of Secondary Surveillance Radar (SSR) Mode S data link. There are two options available for Mode S data link: Mode S and Mode S Extended Squitter, that in functionality are equivalent to VDL Mode 3 and VDL Mode 4, respectively. The following table gives an overview of the attributes of the VDL Modes and SSR Mode S:

Table 3-1.   Overview of VHF Digital Link and SSR Mode S

Type	Technical characteristics	Specifics
VDL Mode 1	Similar to ACARS	No further development expected
VDL Mode 2	Transfer of data only	Improved speed and distribution compared to ACARS
VDL Mode 3	Transfer of digitized voice and data	Point-to-point transmission (i.e. no broadcast)
VDL Mode 4	Broadcast transfer of data only	Enabling technology for ADS-B
Mode S	Transfer of digitized voice and data	Point-to-point transmission (i.e. no broadcast)
Mode S Extended Squitter	Broadcast transfer of data only	Enabling technology for ADS-B

3.2.8   In the ultimate ATN network environment the technical aspects will be transparent to the end-users. The pilots and controllers will not be required to choose which of the available technical means of communication is best suited under a given circumstance; the ATN technology will do that for them. It is expected, however, that pilots and controllers will be informed (by the system) of what functionalities are available to them at any given time.

3.2.9   Human Factors implications for the design, implementation and operation of ATM systems

•   ATM systems must be able to accommodate both ACARS- and ATN-based data link transmissions. Controllers should have information on which technology is employed by the aircraft under their jurisdiction.

•   ATM systems that are already implemented should be upwardly compatible in order to accommodate progressive developments of the ATN.

•   Operators and users should be made aware of the inherent limitations of any deployed technology.

•   Separation minima must be designed or adjusted in accordance with the capabilities and limitations of the enabling technology.

3.2.10   More detailed guidelines on how this can be accomplished will be provided throughout this manual, and in particular in Chapter 4 "The human-machine interface", Chapter 6 "Preparing for change" and Chapter 7 "Standard operating procedures".

3.3   DATA LINK APPLICATIONS

Automatic Dependent Surveillance (ADS)

3.3.1   ADS offers a potential for the transfer of a vast amount of information from each aircraft to the ground station. Every ADS report contains the following information: the 3-D position of the aircraft (latitude, longitude and level), the time, and an indication of the accuracy of the position data information figure of merit. In addition to this basic information, an ADS report may contain any or all of the information presented in Table 3.2.

3.3.2   It is obvious that to manage this amount of information clear choices will have to be made in the design stage of the system. It is also obvious that depending on the choices made, further choices will follow as a logical consequence. To illustrate this, a choice to make the (extended) projected profile information visible in a graphical format (i.e. as a line on the traffic situation display) will generate requirements different from those generated by a choice to have that same information displayed in a tabular format (i.e. as written text). In the latter case, a choice also has to be made as to whether to display the tabular information on the main screen or on an

Table 3.2   Overview of ADS information categories and content

Information category	*Information content*
Aircraft identification	As in field 7 of the ICAO model flight plan
Ground vector	Track Ground speed Rate of climb or descent
Air vector	Heading Mach or IAS Rate of climb or descent
Projected profile	Next way-point Estimated level at next way-point Estimated time at next way-point (Next + 1) way-point Estimated level at (next + 1) way-point Estimated time at (next + 1) way-point
Meteorological information	Wind direction Wind speed Temperature Turbulence
Short-term intent	Latitude at projected position Longitude at projected position Level at projected position Time of projection
Intermediate intent	Distance from current point to change point Track from current point to change point Level at change point Predicted time to change point
Extended projected profile	Next way-point Estimated level at next way-point Estimated time at next way-point (Next + 1) way-point Estimated level at (next + 1) way-point Estimated time at (next + 1) way-point (Next + 2) way-point Estimated level at (next + 2) way-point Estimated time at (next + 2) way-point … [repeated for (next + 128) way-points]

auxiliary screen. Other important choices to be made include whether such information is to be displayed continually for all flights or only at the discretion of the controller. This is why input from the future users of the system is crucial during the design stage, as many of the choices will depend on local (or national) preferences. As a general rule it would appear that most users are more comfortable working with information displayed in graphical than in tabular format.

3.3.3   This is supported by a recommendation from the RTCA in the document *Human engineering guidance for datalink systems* (DO-238):

"Graphic displays of data should be considered in addition to message text when the graphic format presents the data in a manner that eases the operator's task. When compatible with the operator's task, graphical formats are preferred for redundant display of spatially-oriented route and weather data. If a clearance is represented graphically on a map display, route discontinuities, restricted airspace violations, and other errors may be more apparent than if the clearance is represented in text. Furthermore, icons may capture more information in a smaller space than text."

3.3.4   Figure 3.1 illustrates how information could be displayed to the controller. These experimental labels have been proposed by Eurocontrol and are part of ongoing developmental studies on the human-machine interface (HMI) for advanced ATC workstations.

3.3.5   The label on the left is for a non-data link-equipped aircraft, the one on the right for an aircraft that does have data link capabilities. The box around the call sign (BAW362) in the label on the right denotes this capability. The letters AW indicate the next ATC sector with which this aircraft will work. The figures 290 are the actual flight level (Mode C and/or ADS), the cleared flight level and the transfer flight level. The figures 470 (left) and 475 (right) are the indicated airspeed. CIV is the next way-point (in this case a VOR) in the route of the aircraft. The bottom line of the label on the right gives the heading (135), speed (Mach .81) and vertical change rate (00, to indicate that the aircraft is in level flight). These parameters are derived from the aircraft's flight management system (FMS) through ADS.

3.3.6   Figure 3.2 presents three labels which show a change in heading, speed and vertical change rate, respectively.

3.3.7   The first label (on the left) shows that the aircraft is in a left-hand turn and passing heading 320. In the second label (centre), the aircraft is accelerating through a speed of Mach .745. In the third label (on the right), BAW362 is climbing out of FL 255 for FL 290, indicated on the second line, with a decreasing climb speed of 1 200 feet per minute, which is indicated on the bottom line by a "down arrow" symbol ($\vee$) in front of the figure 12. (Of course, changes in those three parameters may occur simultaneously, in which case the label would show arrows for all three items on the bottom line.)

Note 1.— With respect to the method proposed in the Eurocontrol experiments to denote a change in vertical speed (the label on the right side in Figure 3-2), from a Human Factors perspective it is interesting to see that "$\vee$12" (where $\vee$ is a "down arrow") actually means that the aircraft is climbing, but not as fast as it was before. Confirmation that the aircraft is climbing can be found on the second line of that same label, where the information on the FL is presented ("255 $\uparrow$ 290"). It would not be unlikely for a controller to misinterpret "$\vee$12" to mean that the aircraft is descending at 1 200 feet per minute. This same mismatch could possibly occur when the aircraft is actually descending, but with an increasing rate of vertical change, in which case there would be an "up arrow" symbol ($\wedge$) displayed in front of the figures corresponding with the vertical speed. This design therefore requires further work.

Note 2.— Human Factors guidelines for the design of the human-machine interface are contained in Chapter 4 of this manual.

3.3.8   In order to present those parameters in a meaningful way to the controller, it will be necessary to establish a high update rate for the ADS reports. If, for instance, an update rate of once every 15 minutes were maintained, the changes in heading, speed and vertical change rate would probably be useless to the controller, in which case it could be questioned whether they should be displayed at all. But if an update rate close to that of radar-returns (i.e. once every four to ten seconds) were to be achieved, controllers could make good use of the available information.

3.3.9   One factor that may possibly restrict the freedom of controllers to select a high update rate for ADS reports is the cost of the ADS contract with each individual flight. As mentioned earlier in this chapter, the transmission of the actual data is so far done via the network of one of two commercial service providers, ARINC and SITA, and those companies charge a fee for their services. The more frequently data is exchanged, the higher the fee.
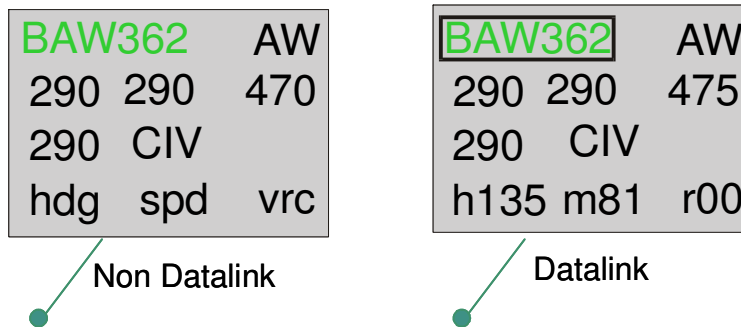
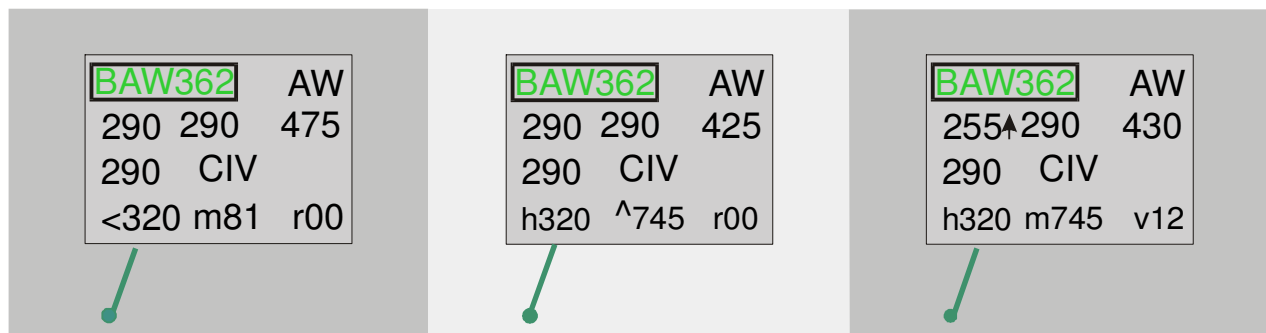**Figure 3-1. Examples of ADS information display labels**

Figure 3-2. Example of ADS information display labels

ADS-Broadcast (ADS-B)

3.3.10   ADS-B is a surveillance application that allows the transmission of parameters, such as position and identification, via a broadcast mode data link for use by any air and/or ground users requiring it. Where ADS reports can be received by a limited number of selected ground stations only, ADS-B reports can be received indiscriminately. This application is envisaged to enable new flight deck technology such as a cockpit display of traffic information (CDTI) and other airborne separation assurance systems (ASAS).

Note.— ASAS and CDTI are discussed in Chapter 8 "New flight deck technology".

3.3.11   Recent trials have been conducted to validate the ADS-B concept. While the first results are encouraging, it remains to be seen whether the aviation industry is prepared to invest in this new technology on a large enough scale for global implementation.

Note.— In other chapters of this manual occasional reference is made to ADS-B, hence its inclusion in this section.

ADS on the flight deck

3.3.12   The ADS capability is fully transparent to the flight crew in that position reports are generated and transmitted automatically from the FMS after a successful data link log on has been accomplished with a suitably equipped ground station. The only physical ADS element available to the flight crew is an "ADS Emergency" push-button, which, when activated, will generate and transmit an emergency ADS report with maximum priority.

CPDLC

3.3.13   Controller-pilot data link communications (CPDLC) is a means of communication between controller and pilot using data link for ATC communication.

3.3.14   The CPDLC application provides air-ground data communication for ATC service. This includes a set of clearance/information/request message elements which correspond to voice phraseology employed by ATC procedures. The controller is provided with the capability to issue level assignments, crossing constraints, lateral deviations, route changes and clearances, speed assignments, radio frequency assignments and various requests for information. The pilot is provided with the capability to respond to messages, to request clearances and information, to report information, and to declare or rescind an emergency. The pilot is, in addition, provided with the capability to request conditional clearances (downstream) and information from a downstream ATS unit (ATSU). A "free text" capability is also provided to exchange information not conforming to defined formats. An auxiliary capability is provided to allow a ground system to use data link to forward a CPDLC message to another ground system.

3.3.15   Controllers and pilots will use CPDLC in conjunction with the existing voice communication. It is expected to be used for routine or frequent types of transactions. Although the initial implementation is intended to conform to existing procedures, it is anticipated that future evolution of the system and procedures will result in the greater automation of functions for both aircraft and ground systems.

3.3.16   Sending a message by CPDLC comprises three steps:

1)   selecting the recipient;

2)   selecting the appropriate message from a displayed menu or by other means that allow fast and efficient message selection; and

3)   executing the transmission.

The received message may be displayed and/or printed. A message sent by a downstream ATSU will be distinguishable from a CPDLC message sent by the current ATS unit.

3.3.17   CPDLC may be used to remedy a number of shortcomings of voice communication, such as voice channel congestion, misunderstanding due to poor voice quality and/or misinterpretation, and corruption of the signal due to simultaneous transmissions.

3.3.18   The following quote from the document *Pilot-Controller Communication Errors: An Analysis of Aviation Safety Reporting System (ASRS) Reports*, illustrates however that CPDLC is not the solution for all communication errors:

"Data link is often touted as a technology that will reduce or eliminate communication errors. Certainly, data link technology presents capabilities for reducing some forms of errors and greatly reducing frequency congestion. However, no technology can resolve all communication errors. Clearly, the pattern of errors will change. Sending clearances directly to the aircraft will eliminate the possibility of the pilot accepting a message intended for another aircraft, however, it is possible for the controller to send the message to the wrong aircraft or make another error in the message sent. For the pilot, seeing clearances in writing has several advantages over hearing them; it gives the advantage of attending to it when the pilot is ready and to double check it whenever necessary. However, it is still possible to misinterpret written clearances (e.g. by transposing numbers). While no communication technology can totally prevent communication errors, careful use of data link is likely to reduce frequency congestion and reduce the likelihood of communication errors. The relative error rates observed with data link (compared to voice) will depend on the design of the equipment and the procedures used to implement it. Careful attention to Human Factors issues in the design and implementation of data link systems will help to realise the benefits of data link without a potentially deleterious increase in controller workload."

3.3.19   Implementation of CPDLC will significantly change the way pilots and controllers communicate. The effect of CPDLC on operations should be carefully studied before deciding the extent to which voice will be replaced by data link.

3.3.20   The following aspects of CPDLC should be taken into account in considering its application and in defining procedures:

a)   the total time required for selecting a message, transmitting the message, and reading and interpreting the message;

b)   the heads-down time for the pilot and controller; and

c) the inability of the pilot to monitor other data link transmissions to and from other aircraft in the same area of operation.

Note.— See also Chapter 5 "Research".

3.3.21   More detailed guidelines on how this can be accomplished will be provided throughout this manual and, in particular, in Chapter 4 "The human-machine interface" and in Chapter 7 "Standard operating procedures".

CPDLC on the flight deck

3.3.22   When designing, implementing and operating CPDLC workstations and procedures for controllers, it is essential to consider how the CPDLC interface with the flight deck is constructed. In the following paragraphs the CPDLC interfaces of three different families of aircraft will be introduced. Although significant differences exist between these interfaces, the ground-based CPDLC systems (i.e. on the ATC side) should handle data link communications with each of the airborne systems without the users noticing any differences. Ideally, it should be transparent to the controller with which type of airborne equipment the CPDLC is taking place.

The CPDLC HMI on the flight deck of the Boeing 747-400

3.3.23   In the Boeing 747-400 (Figure 3-3), the CPDLC functionality is integrated in the Multifunction Control-Display Unit (MCDU), the interface with the FMS. There are three identical MCDUs on the flight deck, but CPDLC cannot be accessed through the rear MCDU.

Illustrations courtesy of Boeing

Figure 3-3.   The flight deck of the Boeing 747-400
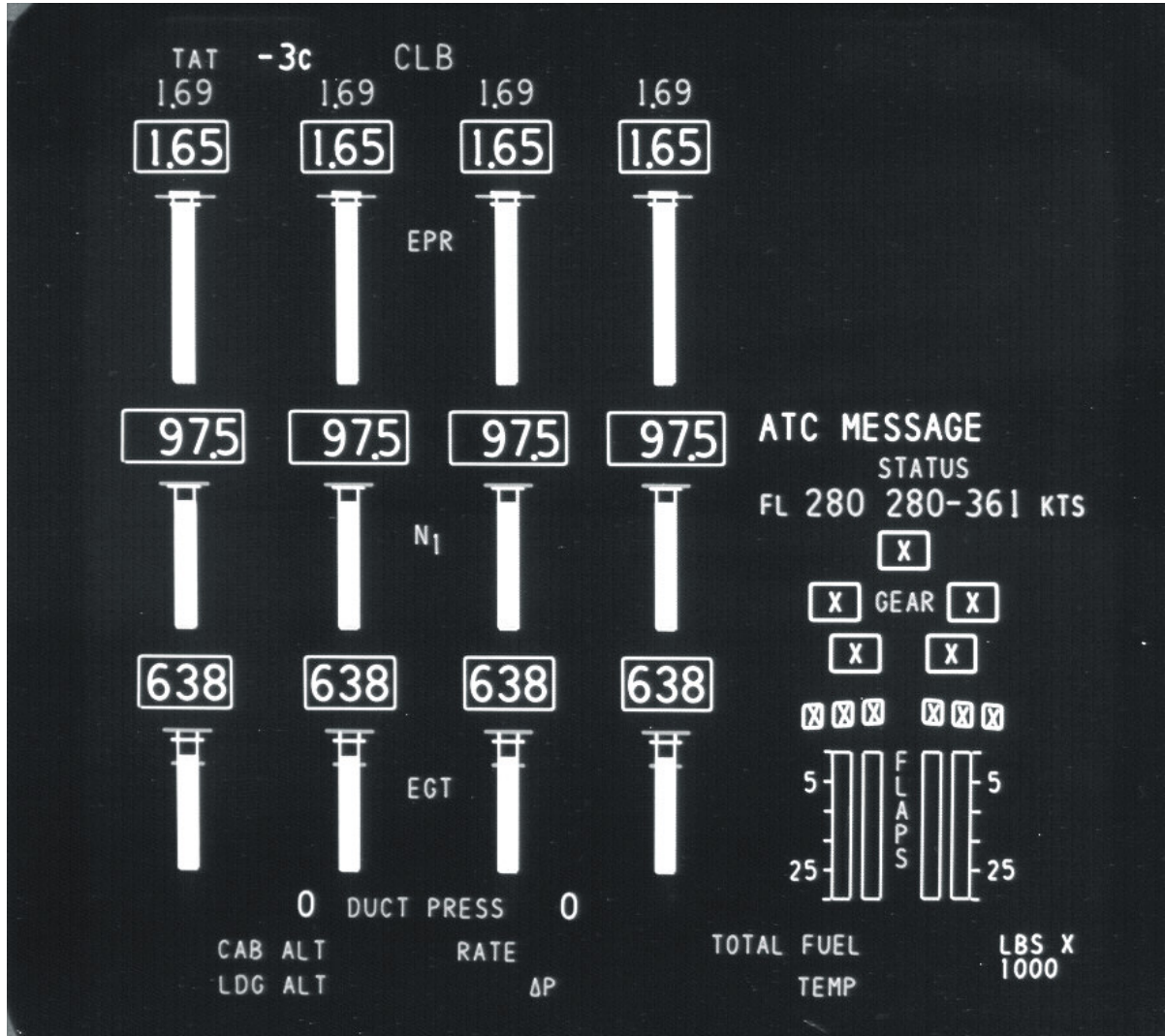
Figure 3-4.   Visual indication of an incoming CPDLC message

3.3.24   The flight crew is alerted to an incoming message by means of by an audio sound which consists of a chime that sounds once when a message is received. This same aural alert is used for a variety of other communications functions. In addition there is a line of text on the EICAS (Engine Indication and Crew Alerting System) screen that reads "ATC MESSAGE" to direct the pilots to the correct response to the sound. The visual memo (the text line) remains on the EICAS screen until the crew responds to the message. FANS-1 does not distinguish between routine and urgent messages.

3.3.25   Figure 3-4 shows a close-up of the EICAS screen. The text "ATC MESSAGE" is in white, while most of the other textual information in this picture is in blue, green or magenta.

3.3.26   The actual message can be viewed at the Multifunction Control-Display Unit (MCDU, i.e. the screen of the interface with the FMS) located on the horizontal panel between the pilots. This MCDU screen (Figure 3-5) is monochrome, so no use is made of colour coding.
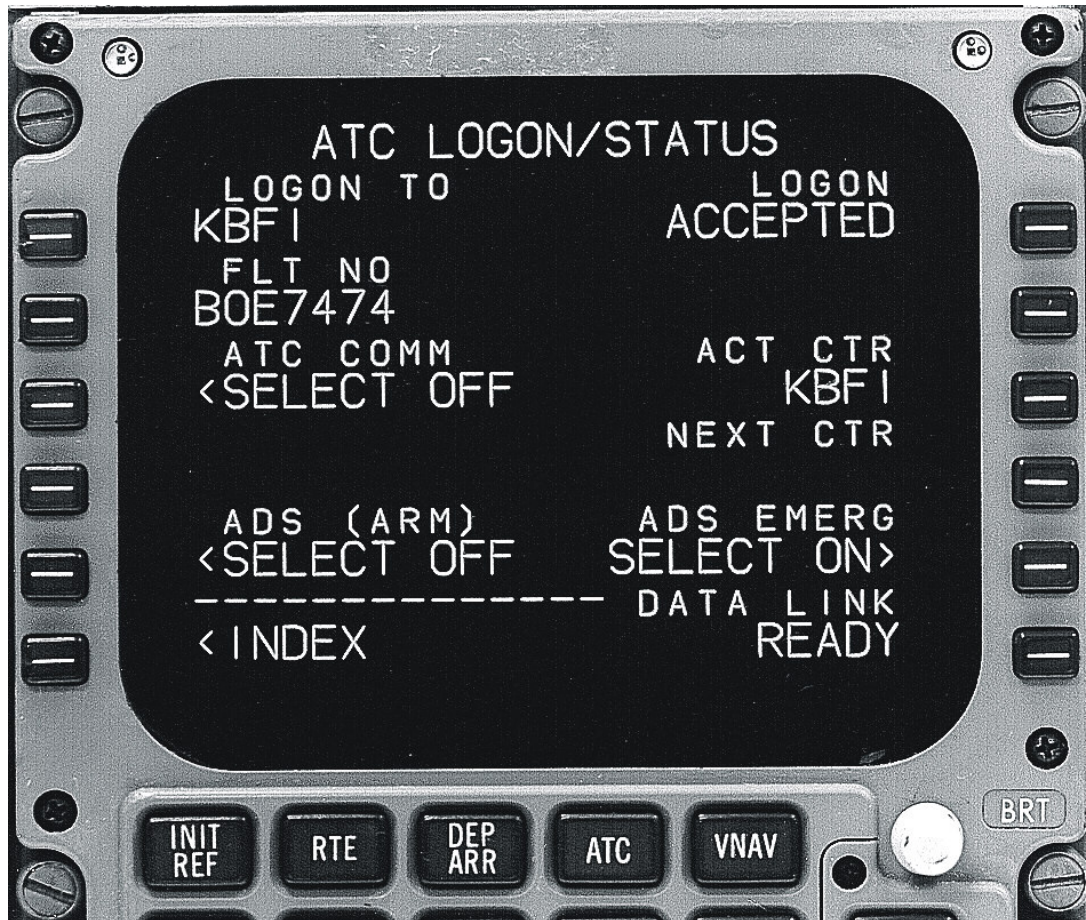
Figure 3-5.   The Multifunction Control-Display Unit

3.3.27   To access the CPDLC interface, the crew has to push the ATC button (just below the screen). They are then presented with the ATC log on/status menu page, as illustrated in Figure 3-5. If the system is already logged on and there is no open uplink (i.e. a message requiring a response), the "ATC INDEX" page is displayed. If there is one open (new or pending) message, the message is displayed on the "ATC UPLINK" page. If there are two or more open messages, the "ATC LOG" is displayed.

3.3.28   Functions for which the crew can make a specific input by the push-buttons on the left and right side of the screen are indicated by a "<" or a ">" symbol on the screen, adjacent to the appropriate button(s). Pushing such a button results in a page change, a status change or a transmission. Additional data can be entered by the "scratchpad" function of the MCDU into various other fields (e.g. the "LOGON TO" line at the top left in the picture.)

3.3.29   Two different font sizes are used on the display. In the menu shown in Figure 3-6 the smaller font is used to indicate fixed text, the larger font is used for variable text.

3.3.30   In other screen pages, such as the one in Figure 3-6, the two font sizes are used to display text that continues over more than one line. In the example, the text "at EPH cleared route clearance" uses three display lines and alternates between the smaller and the larger fonts. Fixed message text is in small font while variables that are inserted into the message are in large font. Furthermore,

Figure 3-6.   Example of message with text in two font sizes

any time the message switches from fixed to variable text or vice versa it is displayed on a new line. The goal of this format is easier interpretation by pilots of what is important in the text.

Note.— Feedback from users has indicated that this goal of the HMI designers is sometimes not achieved, which can lead to potentially unsafe situations. (See Chapter 5 "Research".) Boeing has not adopted the described format in the implementation of CPDLC for the 757/767 series, and a modification is being developed for the 747-400.

3.3.31   With the "LOAD" command the pilot can transfer relevant items from the received clearance directly into the FMS, provided the sender used the correct preformatted message elements. When free text is used, this functionality is not available.

3.3.32   The "ACCEPT" command will generate a "Wilco", "Roger" or an "Affirm" message, as appropriate. The "REJECT" command will transmit a "Negative" or "Unable" message, as appropriate. Before the message is transmitted to the ground system, the crew can review it on a subsequent display page.

Note.— This implies that the system is actually transmitting other words than those initially selected by the pilots. See Chapter 5 "Research".

3.3.33   The indication 1/1 in the top right-hand corner of Figure 3-6 denotes that this message consists of only one page. Messages consisting of more than one page will be indicated as x/y, where x is the number of the displayed page and y is the total number of pages. Related pilot-response prompts are only displayed on the last page of a multipage uplink, so the pilot must go to the end of the message to respond.

Note.— Feedback from CPDLC operations in the Pacific region suggests that flight crews sometimes overlook the fact that a message can consist of more than one page and begin to react to instructions from the first page before reading the following page(s). This may have implications for procedure design as well as for controller and pilot training in the use of CPDLC. (See Chapter 7 "Standard operating procedures".)

3.3.34   A similar though improved CPDLC interface is used in the FANS-1 packages that Boeing developed for the B767, the B757 and the MD90, and it is expected that the FANS-1 package that will be offered for the MD11 will also use this improved method.

The CPDLC HMI on the flight deck of the Boeing 777

3.3.35   In the Boeing 777 (Figure 3-7), the CPDLC function can be displayed on one of three Multi-Functional Displays (MFDs): the inboard display for each pilot and the lower central display. Furthermore, the EICAS display has a dedicated space for incoming messages. The EICAS screen (Figure 3-8) also displays memo messages and alerts associated with the communications function.

3.3.36   The flight crew is alerted to an incoming message by means of a line of text on the EICAS screen that reads "ATC", as well as by an audio sound. The audio signal consists of a two-tone chime that sounds once when a message is received. The visual memo (the text line) remains on the EICAS screen until the message is responded to by the crew. Suitable messages are displayed directly in the ATC Uplink Message Block (also known as Data Block, see Figure 3-9) on the EICAS screen. This message area can handle up to five lines of text with a maximum of 30 characters per line. For each separate message element a new line is used.

Illustrations courtesy of Boeing

Accept/Reject buttons

EICAS

MFD

Figure 3-7.   The flight deck of the Boeing 777

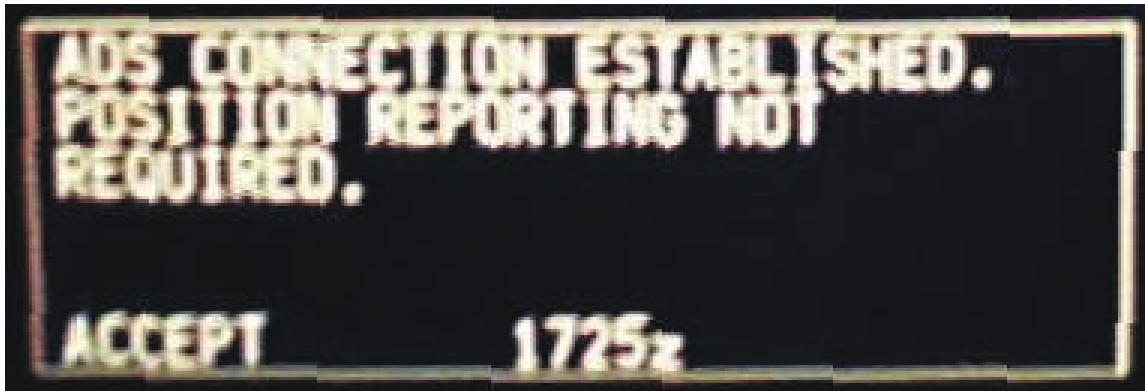**Figure 3-8.   Visual indication of an incoming CPDLC message**

Figure 3-9.   The Boeing 777 ATC Uplink message block

3.3.37   If a message that is too large for the Message Block (e.g. one consisting of multiple elements) or a route clearance message is received, the crew is presented with the text "LARGE ATC UPLINK" in this message block. They subsequently have to use the COMM function on a MFD to read the message. FANS-1 does not distinguish between routine and urgent messages.

3.3.38   The block also displays the responses that are available and the crew can access these by using the ACCEPT or REJECT buttons mounted on each pilot's glare shield. Alternatively, the crew can select the COMM function on an MFD and use the cursor control to select a response prompt in the displayed menu. After selecting and sending a response, for example "ACCEPT", the displayed text changes to "ACCEPTED" and the text colour changes from white to green.

3.3.39   The Message Block furthermore displays what Boeing terms "sidelinks", i.e. when the system automatically downlinks a response to certain incoming messages (e.g. REPORT LEVEL FL350). The downlink is displayed in this area (LEVEL FL350) and the crew is aurally alerted just as if the message were an uplink. This allows validation by the pilots of the automatic response.

3.3.40   Figure 3-10 shows the ATC menu overview from the MFD. Selections are made by means of cursor control. (In the picture the cursor is on the "ATC" button, top left.) When alphanumeric input is required, the input is composed on the Multifunction Control-Display Unit (MCDU, the interface with the FMS) and transferred into the appropriate field on the MFD using the cursor control.

3.3.41   Figure 3-11 shows the Route Request page. It offers the pilots a wide variety of input options that are grouped in a logical order. In the picture the pilot has selected "Route 1" as the requested choice, which is a reference to one of two possible alternative routes the crew can programme in the FMS.

3.3.42   Figure 3-12 shows an example of what a route clearance looks like on the B777 CPDLC display. The fact that the pilot has access to a second page (see the scroll bar on the right of the picture) indicates that this is not the end of the message but no more can be presented on this page. At the bottom of the picture a button with the text "LOAD FMC" is visible. By clicking this button the displayed route clearance is automatically loaded into the flight management computer, thus greatly reducing the chance for input error by the flight crew when compared to having to manually type the way-points.

3.3.43   Another difference between this display and the Boeing 747-400's FMS-based display is that here the font size is consistent for the whole message. The B747-400's FMS-based display uses two different font sizes. For the B777 interface, colour coding is used to distinguish different categories of displayed text. For example, when the crew correctly selects certain numerical values (e.g. altitude clearances, radio frequencies, headings, etc.), these characters turn green as a validation of the correct selection.

3.3.44   Figure 3-13 shows an example of an ATC instruction to "CLIMB TO AND MAINTAIN FL350, REPORT LEAVING FL230." The digits 350 are displayed in green, while the rest of the text is in white.

3.3.45   If flight crews are unable to accept a specific ATC instruction, they have the option to send a message in which they explain why they are unable to accept the instruction. The B777 CPDLC interface provides the crews with a dedicated template from the menu in which several options are preformatted. In addition to those options, the crew may also elect to send a free text message to ATC. Figure 3-14 shows an example of the crew using the latter possibility. Also visible in the picture are three preformatted options.

***The CPDLC HMI on the flight deck
of the Airbus 340***

3.3.46   The flight deck of the Airbus 340 (Figure 3-15) features two dedicated screens for CPDLC called Datalink Control & Display Units (DCDUs).

3.3.47   The DCDU was designed to provide a minimum change in existing flight deck procedures and to allow for a simple reversion to backup voice-based procedures when needed.

3.3.48   On the DCDU colour coding and/or reverse video are used to differentiate between titles, text, main parameters in the text, uplink or downlink messages and closed actions.

3.3.49   The DCDU provides for full time accessibility and readability for both crew members and requires only limited heads-down time.

3.3.50   The flight crew is alerted to an incoming message by means of a flashing blue "ATC MSG" light in two push-buttons on the glare shield (i.e. visual), as well as by a dedicated audio sound. The alert is stopped by

pressing a push-button or by answering the message. For normal messages, the buttons flash and the audio signal is repeated about every 15 seconds (with the first signal delayed by 15 seconds). The message will appear on the DCDU if the screen is empty. If the screen is not empty, a flashing cue (e.g. "MSG 1/2") reminds the crew of the arrival of the message. For urgent messages, the buttons flash, the audio signal is repeated about every five seconds, and the message is displayed on the DCDU regardless of the state of the screen.

3.3.51   Figure 3-16 shows an impression of how an uplinked ATC instruction is displayed on the DCDU. The message text is in white, with the speed instruction (the variable part) in blue. The text "OPEN" in the top right corner indicates that a reply to the message is required.

3.3.52   To reply to a message, the flight crew either uses the standard replies displayed on the DCDU or composes a reply on a menu page from the Multipurpose Control and Display Unit (MCDU, i.e. the interface with the flight management computer). After the message is composed on the MCDU, it is transferred to the DCDU for checking and sending.

3.3.53   Figure 3-17 shows an impression of the DCDU display after the crew has selected the "WILCO" reply. The text "WILCO" appears in reverse video in blue colour in the top right corner, allowing verification of the selected reply before sending it.

3.3.54   After pressing the "SEND" button, the message text and the reverse video change to green colour, and the text "SENDING" is displayed in white in the bottom half of the DCDU. Once acknowledgement of receipt by the ground system is received, this text changes to "SENT". (Figure 3-18)

3.3.55   If the crew wish to initiate a message to ATC, they use the MCDU to compose the message and subsequently transfer it to the DCDU for checking and

sending. Figure 3-19 shows an impression of the DCDU display with a climb request that was just transferred from the MCDU. The message text is displayed in reverse video in blue colour.

3.3.56   After pressing the "SEND" button, the colour of the reverse video changes to green. The text "OPEN" in the top right corner indicates that a reply to the message is required (in this case a reply by ATC).

3.3.57   The same system will be available for the Airbus 330 and, eventually, for the Airbus 320 family. It is designed to be usable within the ATN-based CNS system, for which it will require a software upgrade.

Data link ATIS

3.3.58   The data link automatic terminal information service (ATIS) supplements the existing availability of ATIS as a voice broadcast service provided at aerodromes worldwide. All types of ATIS currently in use (i.e. arrival, departure and combined) are encompassed.

3.3.59   The data link ATIS message will be used to provide an alternative means of transmitting the service to those equipped aircraft which request the message.

3.3.60   Data link ATIS (together with future applications like data link Flight Information Service) has the potential to significantly reduce congestion on voice communication channels at aerodromes and in terminal areas. Especially in environments where most communications between flight crew and ATC are considered to be time-critical (e.g. aerodromes, terminal areas), the implementation of data link ATIS could be more effective than implementing CPDLC. In such environments voice-communications (R/T) will be preferred over CPDLC, so any reduction in frequency congestion achieved by data link ATIS will be regarded as an improvement in communications.
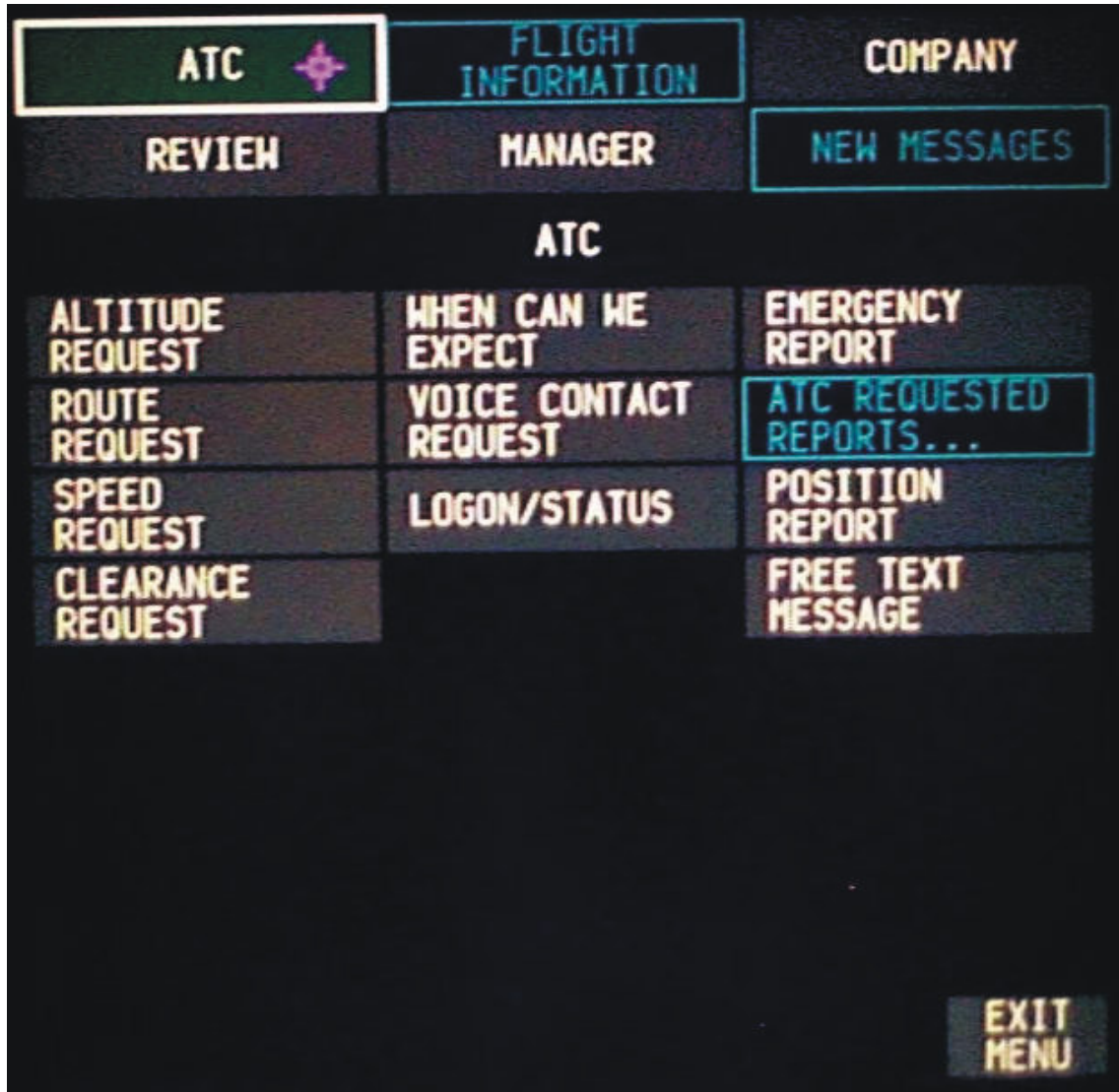
Figure 3-10.   The Boeing 777 CPDLC ATC menu
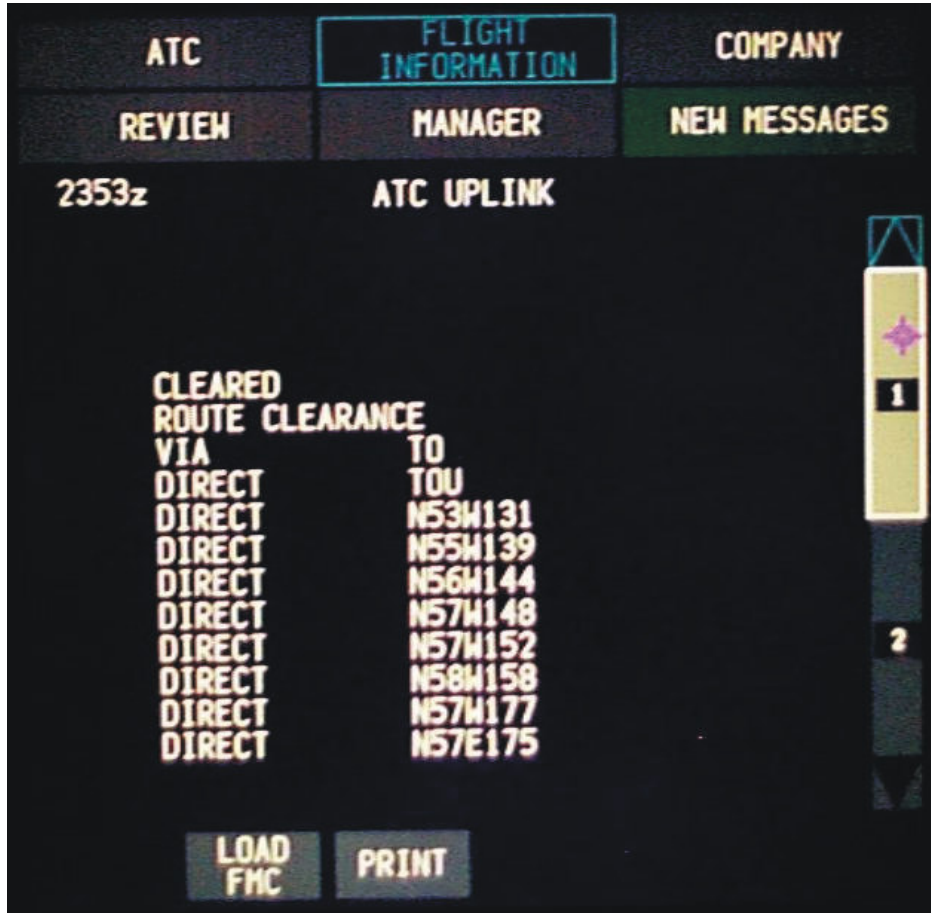
Figure 3-11.   The Boeing 777 Route Request page

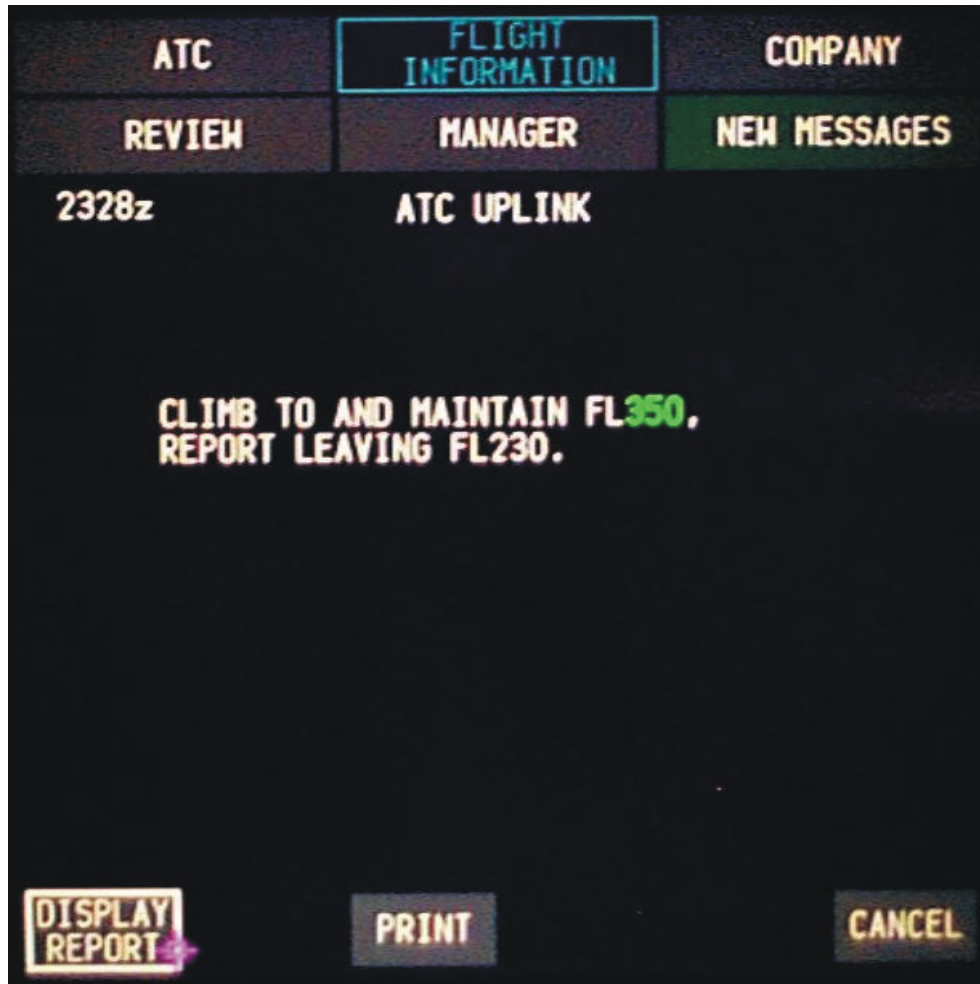**Figure 3-12.   Example of a received CPDLC route clearance**

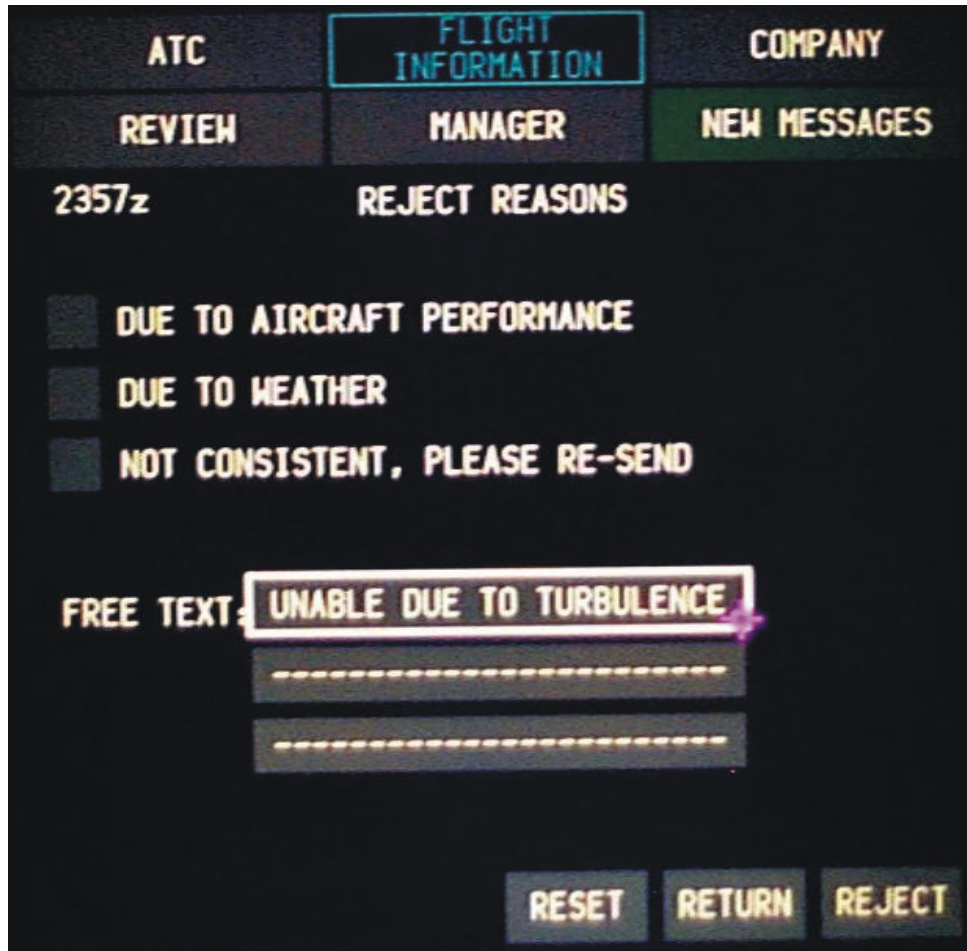**Figure 3-13.   Example of a received CPDLC ATC instruction**

Figure 3-14.   Example of a CPDLC message with free text
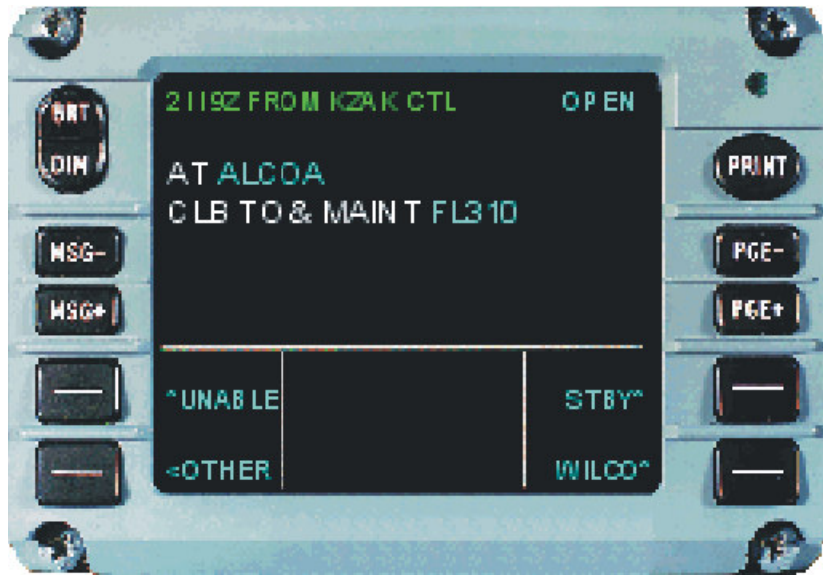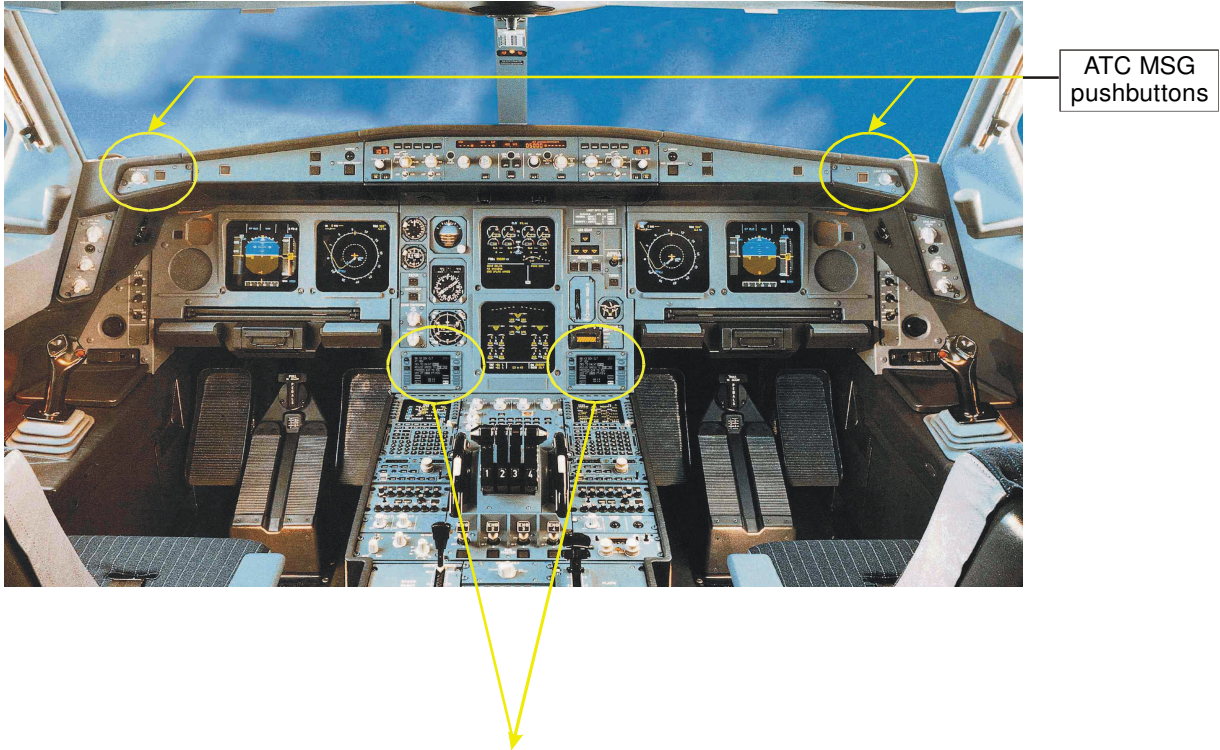
Illustrations courtesy of Airbus Industries

Figure 3-15.   The flight deck of the Airbus 340 and the Airbus 340 Datalink Control and Display Unit
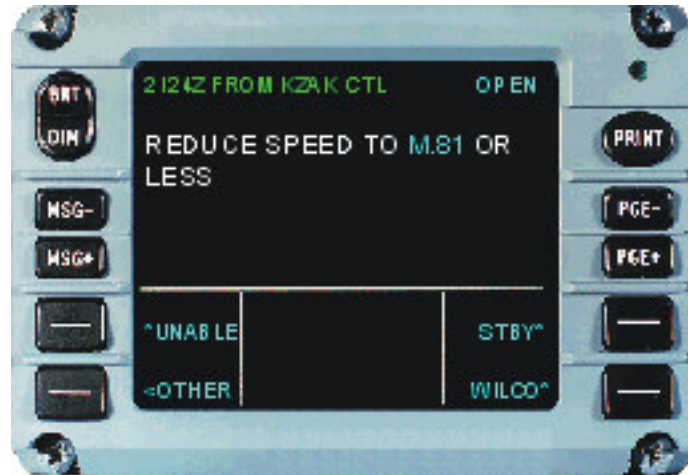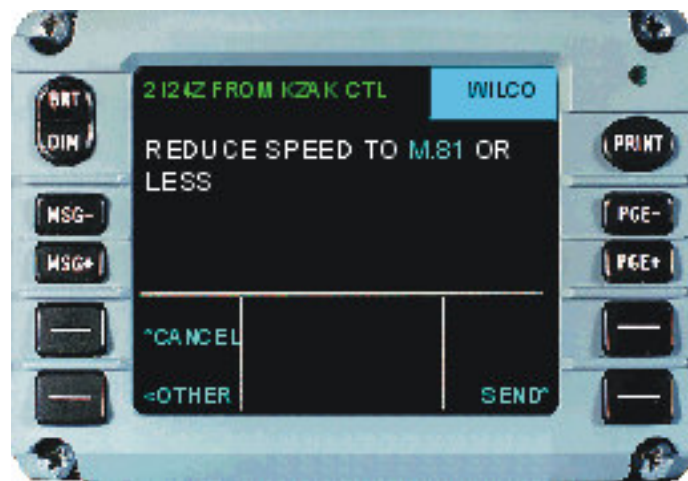
Figure 3-16.   Example of a received CPDLC ATC instruction

Figure 3-17.   Example of a CPDLC reply message (before sending)

Figure 3-18.   Example of a CPDLC reply message (after sending)
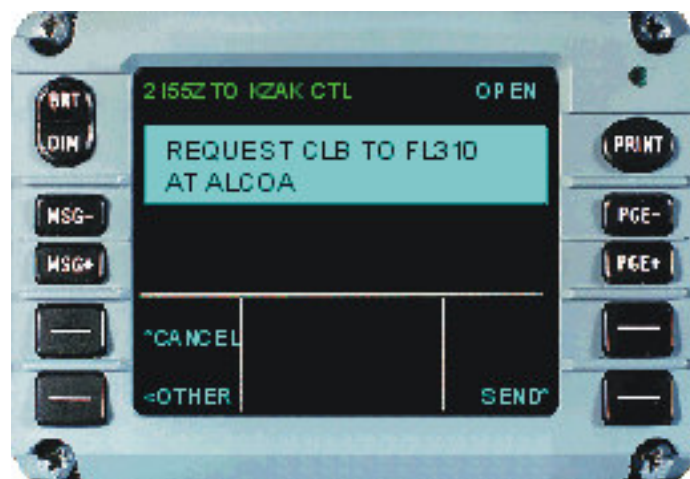
Figure 3-19.   Example of a CPDLC climb request message

Conclusion

3.4   Designers, buyers and operators of ATM systems need to be familiar with the present and future data link infrastructure. They also should be familiar with present and future data link applications. Knowledge and understanding of the HMI design on flight decks of the major airframe manufacturers and how these are used by aircrews will enhance the design and operation of ATM systems. The material presented in this chapter should be considered as basic study material for all those involved in the development, acquisition, implementation and operation of ATM systems.

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Chapter 4

THE HUMAN-MACHINE INTERFACE (HMI)

4.1 INTRODUCTION

"The increased complexity and added workload that has resulted from the system is already surfacing as an important issue, even in the low traffic volumes of the current single sector. Future functionality and complexities as well as busier sector traffic volumes will serve to heighten this concern. We recommend testing the current configuration and future multisector version of the software in simulations of heavier traffic. When identifying solutions, we recommend that changes in the design of the HMI be considered as a higher priority than training or other interventions."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

The human-machine interface (HMI) consists of physical components as well as software and tailored standard operating procedures (SOPs). The physical components of the HMI include the parts of the system, i.e. the computer screens and output and input devices, that support the transfer of information and instructions between the computer and the human. This chapter will discuss issues for the design and use of input devices, visual displays, menus, colour, data entry, electronic flight progress strips, user guidance, visual alerting and auditory alerts. Specific recommendations for the design of the HMI for CPDLC are also included. The Appendices to this chapter contain examples of existing HMI designs for CNS/ATM technology. An example of a checklist with Human Factors considerations for the ATC HMI is also included as an attachment to this chapter.

Note.— Standard operating procedures are discussed in Chapter 7.

4.2 INPUT DEVICES

4.2.1 Several issues need to be considered in the design and use of input devices. Some of these issues are common across devices, while others are unique to each device. Such devices include keyboards, touchscreens, mice, lightpens and trackballs (rolling balls). Although the selection of a specific type of input device will depend upon the task at hand, in no case should an overall design of input devices require frequent switching between devices. Frequent switching between devices induces errors and adds to the controllers' workload.

"The input devices used with the system are a keyboard and a trackball with pushbuttons. Many controllers expressed concern about the difficulty of using the trackball. The trackball has three pushbuttons that are used for performing many functions. The left and right trackball buttons have multiple and sometimes inconsistent purposes. Some trackball commands do not seem like they would be very easy to remember. Some people were observed using two hands at times to operate the trackball and press its pushbuttons. Also, some users said it is too slow. Another complaint was that the trackball does not have a long enough cord. This makes it difficult for the controllers to arrange the workstation as they like. Finally, the trackball pointer does not disappear when text is entered into data entry fields. The pointer blocks the text being entered in the field."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.2.2 The main Human Factors issues related to the design of input devices are **usability** and **operational suitability**. At issue is not only whether a controller can use a device to perform a task, but also whether the device promotes optimal task performance. The following example illustrates this point. In a tower, a controller could use a keyboard to enter or manipulate data. However, the need to maintain Situational Awareness outside the tower suggests that input devices requiring less heads-down time would be more appropriate or operationally suitable.

4.2.3 Controllers frequently update information in the computer and exchange information with other controllers through the computer system. Consequently, any change in the input device needs to be carefully examined because it affects critical aspects of ATC performance.

4.2.4   Assessment of input devices for use in ATC should focus on two key questions:

• Does the device meet the needs of the controller?

• Do new capabilities change the ways controllers organize their tasks?

4.2.5   To ensure that the performance of the device matches the needs of the controller, positioning accuracy and time lag between input and output should be taken into account when evaluating the device. Performance parameters must be assessed on tasks that closely resemble those performed by air traffic controllers, and the participants in the evaluation should be controllers who are representative (e.g. in level of skill) of the user population.

4.2.6   A thorough evaluation of any input device should include assessment of basic Human Factors issues (i.e. usability and operational suitability) and testing of performance parameters that are valued in ATC operational environments (e.g. system response times and feedback). Because certain Human Factors issues and performance parameters might not have the same relevance in different contexts, findings from the research literature should be generalized with caution. The nature of the task that is analysed, the purpose, and the situation in which controls are employed, are some of the considerations that must be taken into account when evaluating the relevance of research findings. Although research literature may suggest what the results could be, there is no substitute for actual usability testing with controllers who are representative of the workforce.

4.3   VISUAL DISPLAYS

"Much of the complexity and display clutter problem is caused by the fact that the interface is made up of several windows that can be customised in size and placement. Also, a lot of unnecessary information and commands are provided in the display. Other issues that add to the complexity of the system's HMI are the large number of menu buttons and information coding types."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.3.1   In ATC environments, the best display is the one that most consistently and accurately enables the controller to achieve the goals associated with the task being performed. This is why it is necessary to understand task objectives and related information requirements before designing the display format or symbology.

4.3.2   Before a display is designed, a task analysis should be conducted to answer the following questions:

• What is the objective of the task that must be performed with this display? What other tasks will be performed concurrently?

• What information does the controller need at each stage of performing the task?

• What errors is the controller likely to make in conducting this task? What are the consequences of these errors?

• What other displays will the controller be working with? The symbology, layout, controls and other characteristics of the new display must be compatible with those of other displays in use.

• How critical is it for this task to be completed immediately?

4.3.3   The selection and presentation of information for displays must be managed so that the displays provide **only** the information that is needed, **when** it is needed, and **how** it is needed (i.e. in a form that is useful and operationally suitable). Ergonomic standards and guidelines are available to aid in meeting this objective, and these issues must be resolved within the context of the controllers' individual and team tasks. Prototype visual displays must be evaluated for usability, operational suitability and acceptability within the ATC context.

"When aircraft messages appear on the aircraft list they appear in alphabetical order and not by urgency. This requires the controller to scan the entire list of messages awaiting acknowledgement and determine which is the most urgent. It was also noted that the level of urgency for various urgency codes was not well understood by users."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.3.4   Visual displays may be technically usable but not operationally suitable or acceptable; that is, their physical and perceptual aspects, such as formatting and use of colour graphics, may comply with guidelines, but their content and their sequential presentation of information to the controller may be deficient. If visual displays do not meet criteria for operational suitability, it is unlikely that they will be acceptable to the workforce. Field evaluations, developmental testing, operational testing and evaluation, and site testing are required to identify suitability and acceptability issues and to assess usability.

4.3.5   In summary:

•   Displays must be designed for the tasks they need to support and the environment in which they will be used.

•   The entire set of displays that a controller will use must be designed and evaluated as a whole and not as a combination of parts.

"The use of separate subsystems and components adds complexity, requires the same data to be entered several times, and divides controller and supervisor attention among the components. Lack of integration also results in inconsistent HMI designs across subsystems. When users require a variety of data to complete a task it is important that those data be provided in an integrated display and not partitioned in separate windows or on separate systems."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.3.6   For an ATC environment where surveillance data (radar and/or ADS) and communications (CPDLC) both need to be displayed, the issue arises whether to apply dedicated visual displays for each function or to integrate both functionalities on a single display. When formulating a decision, careful consideration must be given to the tasks that are being performed by the users of the display(s) and the environment in which the display(s) is/are to be used.

4.3.7   Experience from systems in operation suggests that, in case a choice is made to apply dedicated displays for each modality, it is appropriate to enable access to certain functions from both (or all) displays. In particular, the traffic situation display, used by controllers to monitor and plan the traffic for which they have responsibility, should allow access to often-used functions for communication (CPDLC) and coordination (AIDC).

4.4   MENUS

4.4.1   A menu is a list of *options* from which a user makes a *selection* or selections. An *option* is one of the selectable items in a menu. *Selection* is the action a user makes in choosing a menu option.

4.4.2   Three types of menus are *permanent*, *pull-down* and *pop-up*. Permanent menus are always "opened", that is, the menu options are continuously displayed on the screen. Pull-down and pop-up menus conserve screen area by only showing the available options at the user's request. Pull-down menus are activated by selecting a menu title that

describes the menu. Several menu titles are usually available on the menu bar of a window or application. Pop-up menus are typically accessed by pressing a special mouse button while the cursor is on a graphical symbol or hot spot.

Note.— For an example of pull-down menus, see Appendix 1 to this chapter; for an example of pop-up menus, see Appendix 2 to this chapter.

4.4.3   The windows used for data entry or to specify command parameters may contain graphical controls called command buttons to initiate or cancel data processing and command execution. Command buttons are also called push-buttons because of their physical appearance. Push-buttons may be shaded or coloured to appear three-dimensional. This coding enables them to show a pushed-in (i.e. activated) versus pushed-out state on the visual display, depending on whether they have been selected or deselected via an input device.

4.4.4   Frequently, a menu option or push-button command can be executed using keyboard short cuts, such as function keys or key combinations (e.g. "Enter" key to activate the currently highlighted push-button or "Alt" and "F4" to close an open window). Before the widespread use of the mouse, function keys were used extensively as the only or primary method to activate menu options.

4.4.5   Another method used to execute commands within today's applications is by directly manipulating graphical objects on the screen, an example of which is included in the "Data entry" section later in this chapter (see also Appendix 2 to this chapter).

4.5   MENU DESIGN

"Many menu buttons seemed to be rarely used and unnecessary to the controllers. Some of the commands were rarely used because the controllers found little benefit in using them. Others, the controllers believed, were un-necessary features. It was understood that some of the commands would be useful to controllers in other sectors with different types of air traffic."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.5.1   Menu design requires careful consideration. Issues facing the designer include:

•   the number of options to offer;

- how to phrase and format the options;

- how to organize options within the menu;

- the number of levels to use;

- how to help the user maintain a sense of orientation within the menu structure.

4.5.2   Research on menu design has shown that design solutions to these issues are important in terms of human performance. Both direct and indirect costs can be reduced, and benefits can be increased through menu design that complements human capabilities and protects against errors.

4.5.3   **Number of options.** This issue has received a great deal of research attention. There is, however, no single answer to the question of how many options to present because the answer varies from one context to another. For example, the number of options in a "coordination" menu for an approach control unit will probably be lower than that for a large area control centre. Where possible, four to six options are considered optimal because this limits the demand on working memory. Having too many options in a menu increases the time it takes to find any one option. Having fewer than four probably means that levels of the underlying menu structure could be combined so that more options could be offered in one place. With few options in a given menu, the user may be required to select options from several lower-level menus in order to reach a specific location in the menu structure.

4.5.4   In contrast to these general recommendations, research on so-called "vast" menus suggests that a menu can contain up to 200 options if they are organized into logical groups. With large numbers of options, however, problems arise in developing a menu structure and graphic layout that reflect the underlying structure of the domain information. For example, if the underlying structure is a hierarchy, the menu structure should be hierarchical, i.e. organized as a multi-level, branching structure of smaller menus in which an option in a higher level menu is the name of another menu at the next lower level. The options in the lowest level menus are such things as commands or values; they are not the names of other menus.

4.5.5   Large hierarchies are difficult to traverse efficiently, therefore hierarchical menus should be organized and labelled to guide the user within the hierarchical structure (e.g. when a user selects an option from a menu, the menu and the selected option remain on display with the selected option highlighted, and the lower-level menu that results from the selection is displayed adjacent to the selected option). Users should always be able to return to the next higher menu level with one simple action, as well as always be able to return to the top-level menu from anywhere in the hierarchy with one simple action.

4.5.6   **Phrasing menu options.** Research has shown that vague, ambiguous wording of menu options confuses the user and detracts from performance. The purpose of careful phrasing is clarity; this allows users to understand the meanings of the options in terms of how the system will respond. For options that are to be executed immediately upon selection, a general recommendation is to use wording that reflects the actions to be executed. Notice that the emphasis is on action. Actions are denoted by verbs or verb phrases, not by nouns or noun phrases. Common actions that might be offered in an ATC hand-over menu include Accept, Deny, Initiate and Retract.

4.5.7   Two other types of options are: 1) routings that display a window or a cascading submenu; and 2) settings that are used to define parameters or to specify an application state. Routing options, such as Search, Customize, Sort or Save As, should be followed by three dots (an ellipsis) to indicate that another small window, called a dialog box, will open when this option is selected. The purpose of the dialog box is to present further choices that are related to the higher-level action, for user selection before the system can proceed. For example, before carrying out a command to sort metering advisories, the system may need to know the criteria on which the sort is to be based. The alternatives should be presented in a dialog box.

4.5.8   The wording used in menus should be consistent with ATC vocabulary as it is used in the ATC environment. New terminology or ATC terms that mean something different from what controllers understand them to mean should be avoided. This requires that designers and developers survey ATC facilities and become familiar with operational concepts to identify terms that are commonly used for system actions.

4.5.9   Option labels should be concise and used consistently from one menu to another. They should be distinctive and mutually exclusive (non-overlapping). Controllers can provide expert assistance in the development and review of menu phrasing.

4.5.10   **Formatting menu options.** Menu options can be formatted in a linear (vertical or horizontal) list or presented in a spatial format. Although most menus tend to

be presented as lists, some sets of menu options might best be represented in a rectangular or circular format. Spatial menus for ATC might take advantage of existing spatial formats, such as the geometry of sectors within an area.

4.5.11   Whether a menu is linear or spatial, each word in a menu should be presented in upper and lower case with the first letter capitalized. When a vertical menu is displayed, the location cursor should be on the first available option closest to the top of the list. When a horizontal menu is displayed, the location cursor should be on the first available option to the left.

4.5.12   Menu options presented in a vertical list should be left-justified, never centred in relation to each other. Left justification allows the user's eye to follow a direct line, rather than a jagged line, in searching for a particular menu option. Other forms of justification increase search time and contribute to visual fatigue.

4.5.13   A window that contains a hidden pop-up menu or menus should indicate the availability of these menus to the user. One way to do this is to highlight the portion of the display that can be selected to access the hidden menu. Another way is to provide a textual message indicating that a hidden menu is available. A third approach is to change the shape of the cursor when it is located in a "clickable" or selectable area. When a pop-up menu is selected, it should be displayed in context, that is, close to associated information. For example, if there is a pop-up menu for each radar target, the menu should be displayed near the associated target, not halfway across the screen.

4.5.14   An option or set of options that is never available to the user should not appear in the menu. If an option is temporarily unavailable, it should be displayed in its normal place in the menu but subdued in intensity (dimmed down or greyed out).

4.5.15   **Organizing menu options.** There are three acceptable ways to organize menu options:

• in logical or functional groupings with clear titles;

• by frequency of usage, with the most frequently used options at the top or beginning of the list;

• in alphabetical, numerical or chronological order.

4.5.16   Logical or functional grouping of menu options is recommended because it is more meaningful than the other methods. A meaningful order is easier to work

with than an arbitrary order. If frequency of usage is the basis for organizing menu options, the less frequently used options and destructive commands (such as Delete or Exit) should be placed at the bottom of the menu.

4.5.17   To protect against accidental activation, menu options that initiate opposing actions (such as Save and Delete) should not be placed next to each other.

4.5.18   For the sake of positive transfer, similar options that appear in different menus should be ordered consistently from one menu to the next. Any cascading menus should appear to the right of the parent menu or below the parent menu if there is insufficient space to the right.

4.5.19   The process of organizing menu options should always occur in the context of the tasks to be performed by the controller. A menu organization that properly supports one set of tasks may not be as good for a different set of tasks.

4.5.20   **Number of levels.** Research has shown that when more than three to four levels are included in a menu structure, users tend to feel lost or disoriented. To reduce the likelihood that this will happen, menu users should not be required to move more than three to four levels down into a menu structure to locate a desired option.

4.5.21   Sometimes it may be necessary to make a trade-off between the recommendations on number of options (menu breadth) and number of levels (menu depth). In such a case, evidence indicates that it is better to increase the number of options per level than to add to the number of levels.

4.5.22   If the menu structure includes more than a few levels, designers should consider providing a way for the experienced user to by-pass intermediate levels. Using fast-action keys, controllers can then go directly to specific locations in the overall structure without having to step through intermediate menus.

4.5.23   **Supporting user navigation.** When working within a large, multi level menu structure, users often lose their bearings, forgetting where they are and which levels they have traversed. To some extent, this disorientation relates to the limits of working memory because it is difficult to keep in mind one's position four or more levels down in a menu structure while also concentrating on the task at hand. To assist users in navigating easily within a menu structure, graphical or textual aids should be provided.

4.5.24   A graphical aid may take the form of a small schematic representation of the menu structure with the path already taken highlighted. This miniature menu map may be displayed continuously in a corner of the screen or made available from a pull-down menu. An alternative to the menu map is a sequential list of the options that have been selected. If they are not displayed continuously, menu navigation aids should be available in the help function.

4.5.25   **Resolving detailed design issues.** This discussion has surveyed major issues in menu design, but many other detailed issues will need to be resolved. Tentative menu designs should be subjected to systematic testing with representative groups of controllers. The key objectives of menu design, testing and redesign are to minimize search-and-selection time and to minimize navigational errors.

4.6   USE OF COLOUR

4.6.1   The effective use of colour on a display requires careful attention to the definitions of the colours used and the ways in which the colours are used. The development of a coding scheme begins with an understanding of the tasks to be performed and the identification of subtasks for which colour coding may be particularly helpful (such as immediate identification of certain streams of traffic). From this identification of tasks and the information required to complete the tasks, we can construct a hierarchy of display information. Such a hierarchy would include all of the information to be displayed ranging from the background information (e.g. a map), which should be present but unobtrusive, to critical components of a display (e.g. warnings that require immediate action, the cursor) that require some form of highlighting.

4.6.2   While this hierarchy of display information will help to determine how the information is colour-coded, the first decision must be the choice of a background colour. Black (or other very low luminance) backgrounds are very good for colour identification and help to minimize display flicker, but they can suffer from noticeable glare. Light grey backgrounds minimize glare, but colour identification can suffer and flicker is more apparent (and potentially distracting) at higher lighting intensity. The selection of a background colour should consider the task and operational environment. In a dark environment, a dark background is usually preferred. In high ambient light (such as in an ATC tower), with a display that uses minimal colour coding, a light grey background may be preferred. In office level lighting, either light or dark backgrounds are usable when properly designed.

4.6.3   Once a background colour is selected and a hierarchy of information has been constructed, colour names can be assigned to specific groups of information. While user input is important at all stages of display development, an efficient strategy is to have structured user input at the first stages of design (e.g. the construction of the information hierarchy) and then again at the final stages (evaluating the prototype displays). Human Factors specialists are in a better position than users to design the prototype colour schemes, since their designs will be based on Human Factors "best practices" rather than user preferences. There is a tremendous amount of variation in personal preferences for selection of display colours. However, the colours that users prefer are not necessarily the ones that will optimize their performance. Thus, having a prototype colour scheme based on Human Factors guidance not only minimizes variability, but also precludes designs that may have a detrimental effect on performance.

4.6.4   Once a colour scheme that matches colour names to groups of information has been developed, these colour names will need to be defined to be optimally distinct for a specific monitor. Once the colour set has been defined, it should be validated by testing to ensure that no two colours in the set can be confused and none of the colours in the set adversely affect legibility. Again, these are tasks for Human Factors engineers. The next and final steps are a critical review of the colour scheme by users and, finally, operational testing and evaluation.

4.6.5   In developing a prototype colour scheme, it is very useful to examine the colour schemes used by other air traffic organizations. It could be argued that since specific colour schemes have been in use at other ATC facilities with no disastrous outcomes, the same colour scheme should be applied elsewhere. However, since no two air traffic control facilities have exactly the same amount, mix and complexity of traffic, it could be a mistake to adopt similar colour schemes without adequate operational testing.

4.6.6   The use of color must be considered cautiously. However, colour remains an effective, compelling and attractive method for coding visual information on a display. The use of colour in ATC displays presents opportunities as well as challenges. Colour, when used properly, is an extremely useful tool for organizing complex information. Well-designed colour displays for ATC are likely to have profound advantages over monochromatic displays. The careful design and testing of specific colour-coding schemes with attention to the guidelines presented here will help to realize the potential benefits of the use of colour while minimizing the potential drawbacks:

- Whenever colour is used to code critical information it must be used along with another method of coding, such as reverse video or the use of different sizes of text or symbols (see 4.10 "Visual alerting", later in this chapter).

- When colour is used to assign a unique meaning to specific colours (such as red for emergencies or green for aircraft under one's control), it is imperative that no more than six colours be used.

- Care must be taken to ensure all colour-coded text and symbols are presented in sufficient contrast.

- Cultural colour conventions (such as red for danger and yellow for warnings) should not be violated.

- Pure blue should not be used for text, small symbols, fine detail or as a background colour.

- Bright, highly saturated colours should be used sparingly.

- Colour use needs to be consistent across all of the displays that a single controller will use.

- The specific colours that are selected for a display must take into account the ambient environment and the capabilities of the specific monitor.

- Any implementation of colour needs to be tested in the context of the tasks that it is designed to support and the environment in which it is intended to be used.

4.6.7   As a final point concerning the use of colour it should be noted that results of ATC simulations indicate that where colour coding of data blocks is used to divide aircraft into groups (e.g. departure and arrival, or own traffic versus other traffic) controllers may not notice potential conflicts between two aircraft colour-coded differently. In other words, the controllers tend to look for conflicts only between aircraft pairs with labels in the same colour. They tend to miss conflicts between aircraft whose labels are coloured differently. This suggests that colour coding of data blocks should only be applied in combination with a short term conflict alert (STCA) or similar device.

4.7   DATA ENTRY

4.7.1   The simplest data entry method is free text entry into a large field (e.g. for a data link message to be transmitted to a pilot). Generally, little or no data entry restrictions are placed on such a field, and the computer performs little data validation.

4.7.2   A fill-in-the-blank form allows the user to enter data into predefined, labelled fields. Labels should be used consistently within and throughout all forms and should use specific, user-oriented wording (e.g. accepted ATC terminology). Data entry items should be logically ordered and arranged according to user expectation. This method facilitates computer validation of the entered data.

4.7.3   When the same set of data must be entered for several entities (e.g. aircraft flight information for all current traffic), a table is often the best data entry form. Labels are required for both columns and rows. The first column should contain the most salient discriminating feature that identifies and distinguishes the row (e.g. flight number or aircraft identifier). There should be row and column scanning aids (e.g. on every third row/column a blank or shaded row/column). If the user needs to run a finger down the table or hold a ruler up to it, this is indicative of poor table design. The table (and other forms) used for data entry should be compatible with, or identical to, display data on tabular and other displays.

4.7.4   In general, another sign of poor design is the "sticky" note posted in or around the workstation area. If controllers need to post notes, the design has failed to capture and provide all necessary information.

4.7.5   Data entry may also be achieved via direct manipulation of graphic objects on the screen. For example, to enter a revised flight route for the pilot to fly, the controller could select points on a map (e.g. by pointing with the cursor/mouse and selecting by pressing and releasing the mouse button) or could "bend" the pilot's currently planned flight path (e.g. by selecting a point on the route and pressing and holding the mouse button while moving the mouse). Direct manipulation interfaces support a highly natural flow of communication between the user and the computer and therefore could be a useful means to help realize a human-centred design.

4.7.6   Figure 4-1 shows an example of a direct manipulation interface for a route revision from The Australian Advanced Air Traffic System (TAAATS). A graphic re-route is in progress, indicating a change to the north of the original route. The internal flight plan in the system is automatically updated with the new way-points, and the new clearance (preformatted by the system) may be uplinked by CPDLC to the aircraft.

Figure 4-1.   Example of a direct manipulation interface

4.7.7   For cluttered screens, where many selectable graphic objects are in close proximity, it helps to provide users the ability to zoom (or enlarge) a portion of the display for precise pointing. Usually, the selectable objects remain the same size while other information (e.g. a background map) is magnified so that selectable objects appear farther apart.

4.7.8   Once selected, a graphical object should be highlighted, so that the user knows the next action will be applied to it. For certain transactions, the user should be able to select a set of objects (e.g. by holding the Shift key and clicking on several objects or drawing a box around a grouping or specifying a characteristic shared by all objects in a group). Once the grouping is specified, the user can initiate a transaction on all group members. For example, the controller may want to transmit the same message to several aircraft.

4.8   ELECTRONIC FLIGHT PROGRESS STRIPS

4.8.1   Although the introduction of electronic flight progress strips to replace the traditional paper versions is regarded by many controllers as a controversial issue, it would be a mistake not to consider their use when designing an advanced ATM system. Electronic flight progress strips have significant potential in terms of automated assistance to the controller in maintaining Situational Awareness — but so do paper flight progress strips. The challenge for system designers therefore is to identify what elements of the controller's Situational Awareness provided by paper strips can be transposed to an electronic format and how best to achieve that.

4.8.2   Electronic flight progress strips can be an integral part of an ATM system featuring flight data processing, i.e. dynamically keeping track of flight parameters derived from flight plan data and surveillance information. With paper strips, controllers write down changes in these parameters on each strip (which, as an action, serves to help them maintain Situational Awareness) and often must coordinate such changes with other controllers. Electronic strips can be updated automatically by the system, and changes can be displayed at all affected working-positions of the system. Furthermore, automated exchange of data with other ATM systems for coordination becomes a possibility, thus potentially reducing controller workload.

4.8.3   It is important for system designers to preserve as much as possible the Situational Awareness-enhancing attributes from paper strips when introducing electronic flight progress strips. Yet this does not necessarily imply that every checkmark or annotation currently utilized by controllers should be mimicked for the electronic version.

Designers rather should attempt to capture the **essence** of the checkmark or annotation, and provide an alternative for it in the new system. Is the mark on the paper strips there to denote the completion of an action, or is it there to indicate that an action still has to be taken? Is the position of the mark on the strip of relevance to the controller, and if so, why? Once these and other questions have been answered, it will be possible to look for means and methods to provide the controller with similar functionalities in the new system.

Note.— Such means and methods are discussed in Section 4.10 "Visual alerting", later in this chapter.

4.8.4   One specific issue for designers to consider is the importance of crossed-out items on paper strips and how to retain that same importance in an automated system with electronic flight progress strips. For example, after clearing an aircraft to a higher flight level, a controller normally writes down the new level and crosses out the previously assigned level. Yet if the level change was a tactical decision from the controller in order to resolve a conflict, the aircraft may later be cleared back to its original flight level based on the crossed-out value on the strip. This would imply that in an automated environment the controller must have access to the original value of the flight level even after the new level is displayed by the system. One possible way of doing this is by displaying the actual flight level, the assigned flight level and the filed or requested flight level, all at the same time.

4.8.5   If the new system features a traffic situation display and this was not available in the old system, it may be possible to "transfer" some of the Situational Awareness-enhancing attributes from paper strips to the labels on the traffic situation display. (See as an example Appendix 2 [ODIAC] to this chapter.)

4.8.6   Figure 4-2 shows an example of an electronic flight progress strip from The Australian Advanced Air Traffic System (TAAATS).

4.8.6.1   The first box on the left of the strip contains an orientation indicator (a green triangle indicating a northbound flight), the controlling sector and the flight plan state.

4.8.6.2   The second box from the left shows the call sign (QFA12 — Qantas 12), CPDLC status (colour coded call sign), wake turbulence category (H — Heavy), SSR code (1211), aircraft type (B744 — Boeing 747-400), departure point (YBBN — Brisbane), destination (NZAA — Auckland) and departure time (0000).

4.8.6.3   The third box shows the true airspeed (N0475 — 475 knots), the pilot reported level (304) and the FIR exit time (0116).

4.8.6.4   The fourth box contains the requested flight level (330), the cleared flight level (330) and the coordination flight level (330).

4.8.6.5   Box five shows the previous fix (DUDID), the next fix (PONEL), the next fix plus one (LHI), the actual or estimated time over the fix (0028/0034/0051) and the profile level (330).

4.8.6.6   The sixth box, at the bottom left of centre, contains other information or remarks (/AUSEP, to indicate that the aircraft is qualified for specific national separation criteria).

4.8.6.7   The seventh box, to the right of the previous one at the bottom, shows the FIR entry time (in this case 0000 as the flight departs from an aerodrome within the FIR).

4.8.6.8   The final box, on the bottom right, is a scratchpad area where a controller can add notes, if required.

Figure 4-2.   Example of an electronic flight progress strip

4.9   USER GUIDANCE

"For the keyboard there is a problem with the meaning of the function keys. A few controllers said that it is difficult to remember the meaning of each of the function keys. This is made more complicated because the meaning of the function keys changes under different system modes."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.9.1   User guidance includes alarms, prompts, labels, error messages and instructions provided to guide the user's interaction with the computer. Effective user guidance contributes to meeting several of the HMI design's general objectives:

•   consistency of operational procedures

•   efficient use of full system capabilities

•   limited memory load on the user

•   reduced learning time

•   flexibility in supporting different users.

4.9.2   Because it is often difficult for a software developer to create messages that are clear to the user community, it is recommended that a team including a software developer, a Human Factors specialist and a controller representative collaborate on guidance message development.

4.9.3   Guidance messages should provide any required context information (e.g. a history of previous entries). Both on-line and hard copy forms of a dictionary of abbreviations and legends for all symbols and codes should be provided. In addition to on-line help, the controller should have access to a complete list of error messages with detailed explanation in hard copy form (e.g. within the user manual).

"The feedback for some errors was found to be too vague to be meaningful or helpful to the users. An example of a cryptic error feedback message is "Bad Format", which is received after the user enters data that is not in a proper format. A more detailed feedback message about the format error and the necessary solution would be useful to the user. It was understood that some error messages could be clicked on to get more information about the format errors, but most controllers did not seem to be aware of this feature. The problem with this type of feature is that there

is no indication that the user needs to click the message to get the information. In addition, the messages provided with this feature were often not very helpful."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.9.4   Typically, users commit two types of errors: expert errors and novice errors. An expert error or "slip" occurs when the user knew what should have been done but inadvertently performed the wrong action. This can occur without direct awareness and is not likely to be remembered. In such a case, the user needs the computer to report the user's action. A novice error or "mistake" occurs when the user knew the action, but thought that the action sequence was correct when in fact it was not. In such an instance, the intention is flawed and the user needs to know what action should have been taken. Any user is likely to commit both types of errors, although with experience novice errors will be less prevalent. To address both types of errors, messages should summarize the problem and propose a solution. Expert users may choose to downsize an error message window so that only the problem statement is in view. When an error is detected, the computer should display an error message stating both what is wrong and what can be done. When the set of acceptable responses is small, these should be provided.

4.9.5   To address the needs of both the novice and the expert as well as an individual's specific needs, the computer should support multiple levels of error messages. There are many ways to accomplish this:

•   A controller-defined capability may be provided to set the message level as abbreviated or detailed;

•   An error message window may be provided that can be sized so that only the beginning of a message (which should be the most informative part) is shown;

•   A capability may be provided with each message to expand the text with explanations, examples and perhaps illustrations; or

•   Messages may be tied closely to a help application (e.g. an on-line user manual where the controller can click on "hotspots" to jump to various topics and/or tutorials) so that the controller can quickly transfer into the appropriate area of help. For example, each message window can include a "Help" push-button through which the controller can access specific information associated with the current problem.

Specifically:

- Error messages should always be written in the active voice and be as specific as possible while, at the same time, minimizing wordiness.

- Error messages that are too generic (e.g. "Invalid Entry" or "Invalid Drive Path Specification") or too obscure (e.g. "Error #E211A07") should be avoided.

- Error messages should describe the problem and the recommended solution(s) in very specific terms, that is, they should tie the problem to a process, object, action, file, data entry field or other data element.

- Terms used in error messages should be task oriented and familiar to controllers.

- Error messages should be unique (i.e. only one possible message for each error) and should not be redundant (i.e. each error generates only one message).

- Guidance messages should promote the idea of the computer as a tool, not a person, and should affirm the controller's sense of being in charge.

- Wording of feedback messages should reflect fact rather than make value judgements (e.g. instead of "Flight Conditions = Excellent," state "Visibility = 50 miles").

- Prompts should indicate a ready mode (e.g. an "I"-shaped beam for data entry) rather than telling the controller what to do (e.g. ENTER DATA>).

- The computer can prompt the controller for a logical action (e.g. "Save training session Alpha before Exit?") but should never automatically perform a task or switch the controller into or out of a mode without being explicitly instructed by the controller to do so.

4.9.6   Since part of the user population may be unfamiliar with computers or may be accustomed to modern day "friendly" applications, computer messages should be constructive phrases written in a positive tone. Messages should be worded in the affirmative, not the negative. They should instruct the controller on what can be done, rather than on what is wrong or not possible. Any blame should be placed on the computer, not the user; e.g. a value should be described as "Unrecognized" or "Not within range" rather than "Illegal" or "Invalid."

4.9.7   Message wording and tone are key components in error message development. Historically, computerized messages were written in condemning and extreme language. It was not uncommon to get a "FATAL" or even "CATASTROPHIC" error or have a "RUN ABORTED" or "TERMINATED." (Messages were often in all capitals to further emphasize the severity of the error.) User actions and entries were deemed "Bad," "Illegal," in "Error" or "Invalid." This approach can be unsettling to a person not familiar with the programming world in which operating systems and compilers, even today, commonly display harsh messages. Wording should reflect the controller's understanding of the system and avoid any codes, references to computer user manuals, or other information that may not be readily available.

4.9.8   In general, users prefer mixed upper and lower case. People can read mixed case messages more quickly than messages in all capitals, and mixed case makes error messages appear less harsh. Messages should preserve consistency in grammatical form, terminology, phrasing, abbreviations, punctuation and other grammatical elements. Visual format and placement should also be consistent. Error messages may be presented in a pop-up message window, which the controller should be able to quickly dismiss, for example, by pressing a confirmation push-button, or perhaps by clicking anywhere on the screen. Error messages can also be presented as a closable message-log window, which should be displayed upon log on unless otherwise specified by the controller, or via an audible beep.

4.9.9   Audible "beeps" provide one alternative to textual error messages. These are most appropriate for minor errors committed by expert users, who need to be informed of the problem's occurrence but not given the solution. The sound of the audible tone should be subtle and pleasant. Since users often find an audible cue to be embarrassing or annoying, they should be able to turn off the tone or replace it with a visual cue, for example, very brief dimming of the screen. If the controller repeats the error two or more times successively, a textual message should be provided.

4.9.10   Error   messages   should   be   presented immediately after the error's occurrence. In order not to disrupt the user's task, the computer should allow the controller to finish entering data in a field before the computer validates the entry, e.g. the user indicates completion by moving to another field. A special key (e.g. a function key or the "Return" key) can be used to allow the controller to move quickly to the next erroneous field using the keyboard. Guidance messages should present a series of actions in the sequence that the controller would normally follow.

4.9.11   The following are some areas where computer messages or feedback should be provided:

- Processing delay: acknowledge receipt of request, specify process and length of delay, indicate per cent of processing complete and provide feedback when processing is complete.

- Limits not met or exceeded: specify appropriate range.

- Unrecognized command action (e.g. mouse click) or data entry value.

- Status information (e.g. current mode).

- Prompting for logical action (e.g. save before exit).

- Confirmation of destructive entry, especially if the action is irreversible (e.g. delete).

- Cautionary messages or highlighting for questionable entries.

4.9.12   To maintain consistency and promote ease of error message evaluation, a single file of computer messages should be created. This allows software developers to access a common set of computer messages or to create new ones using templates provided in this file, e.g. "[task type] processing will be complete in [time value] [minutes or seconds unit of measure]".

4.9.13   The complete set of computer messages should be reviewed by controllers who are only minimally familiar with the new system (e.g. not those who have been involved in system development). Evaluation and redesign of messages should occur where appropriate to eliminate uncommon or unclear words, phrases, abbreviations and acronyms. The following evaluation methods are suggested:

- Show an error message and ask a controller to describe the problem that caused it and the solution to remedy it. This will determine whether the message is intuitive with explicit remedies or needs to be changed to make it more readily understood.

- Describe a problem with several potential error messages and have the controller select the best one.

- Present a problem and an error message and have the controller note any aspect of the message that is confusing, superfluous or incomplete. Once error messages are implemented on the ATC computer, a

performance data collection routine can be implemented to run in the background. This routine could record the frequency of each error message. Any message that occurs frequently in a session or across controllers points to user-interface issues that need to be redesigned.

4.9.14 Guidance messages should provide any required context information, e.g. a history of previous entries. Users should have access to an on-line and hard copy dictionary of abbreviations and legends for all symbols and codes.

4.10   VISUAL ALERTING

"The large number and variety of coding dimensions results in added complexity to the HMI and possible confusion to the users. The requirement to remember all the coding dimensions can interfere with the controllers' main task."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.10.1   There are many factors that affect the effectiveness of visual alerts and coding techniques. Some of these factors are related to the physical parameters (e.g. brightness, location) of an alert and others are related to its functional parameters (i.e. does it perform as it was intended to perform). The goals of visual alerts and coding techniques are to effectively direct the controller's attention to important information that might otherwise be missed or to critical situations that might otherwise take longer to recognize. Both the physical and functional parameters of alerts should be evaluated in order to ensure that the alert is effective and useful.

4.10.2   It is important that the alert be useful to controllers and not be an annoyance. The alert must provide the controller with useful information in a timely manner. If the controllers consider an alert to be annoying, then the alert needs improvement. The problems with the alert may be related to its physical parameters (e.g. the location, blink rate or contrast of the alert) or to its functional parameters (e.g. it does not activate when it should, or it goes off when it should not). In either case, the problem will have implications for human performance. For example, any alert that generates a high percentage of false alarms will be considered annoying and, eventually, controllers may begin to ignore it. Similarly, an alert that continues to be activated after it is no longer needed is unnecessarily distracting.

4.10.3   The following coding and emphasis techniques can be used to attract attention to specific information or to categorize information on a display:

- blinking or flashing

- reverse video

- use of different sizes (of text or symbols)

- colour

- location.

4.10.4   All coding techniques have advantages and disadvantages. For example, flash coding is good for attracting attention, but flashing text is difficult to read. The critical importance of specific information can be indicated by a separate blinking symbol placed near the information that must be read. The controller should always be able to turn off blinking or flashing. The blink rate should be between 0.1 to 5 Hertz (Hz), with 2 to 3 Hz preferred. No more than two levels of blinking should be used because more will be difficult for controllers to discriminate. Flash coding or blinking should be used sparingly and should never be used for text or numbers that are critical or that the controller needs to read quickly.

4.10.5   Critical, abnormal or updated data should be emphasized or highlighted using such techniques as reverse video, shadows, brightness or colour coding. In each case, the levels of shadows or brightness used (as well as different colours) need to be distinctive and easily identified in order to be effective highlighting tools.

4.10.6   Overuse of a coding technique or the combined use of too many techniques can result in unacceptably "busy" visual designs. If size coding is used, it is recommended using only two widely different sizes. Emphasis should be placed on simplicity and clarity.

4.10.7   Colour coding is especially useful for highlighting or categorizing information on a display. Highlighting must be used sparingly so that emphasized items will actually "pop out" from the others. If too many items are emphasized, none will pop out. Use of colour is discussed in detail in the next three sections of this chapter.

4.10.8   The location of information on a display is a function of both the physical area of the display surface and the position of the eyes relative to the display screen. Visual alerts will be recognized more quickly when placed in the area of the visual field that has the best visual acuity than they would if placed in the periphery.

4.11   AUDITORY ALERTS

4.11.1   With respect to auditory alerts it is important to observe the following "dos and don'ts":

- Do not overload the auditory channel: In any situation, it should be impossible for more than a few auditory alerts to be presented simultaneously. If there is one underlying problem, rather than activating multiple alarms, the problem should produce one high-level alarm message indicating the root cause. As an example of overloading, the Three Mile Island nuclear crisis activated over 60 auditory warnings in the power plant's control room, adding to the confusion.

- Avoid conflict with previously used signals: Where practical, newly installed signals should agree in meaning with previous ATC system signals.

- Promote intuitiveness: Auditory alerts should make use of natural or learned relationships familiar to controllers, e.g. wailing signals mean emergency.

- Promote discernability: Auditory alerts should be easily recognized among the other signals and noise. Use of synthetic speech or tones of varying frequencies will usually create a highly distinct warning.

- Do not overload short-term, working memory: The auditory alert should not provide more information than is necessary.

- Promote consistency: The same signal should always be used to indicate the same information and should not be used for any secondary purpose. The meanings of specific auditory alerts should be documented in a design standard or style guide to ensure consistency in their implementation.

- Avoid extremes of auditory dimensions: For example, a high intensity alarm could startle the controller and disrupt performance. All alarms should be of moderate intensity (or volume). Alarm signals should be spaced relatively far apart and kept within a moderate range.

- Establish intensity relative to ambient noise level: Signal volume should be loud enough to be heard over background noise.

- Use interrupted or variable signals: To minimize perceptual adaptation, use interrupted or variable signals rather than steady signals.

- Test the signals to be used: Use a representative controller sample to make sure users can detect the signals in their working environment. Signals should be tested in realistic ATC work conditions to ensure distinctiveness. They should also be evaluated for suitability and acceptability.

- Facilitate changeover from previous display: When auditory alerts are replacing visual warnings, use both simultaneously during the transition period. In some cases, it is preferable to maintain both permanently, for example, a visual display to illustrate spatial relations and a voice message to provide a verbal reference.

- The controller should be able to cancel auditory signals: A capability to cancel signals will help to minimize annoyance caused by auditory alerts and prevent possible disruption to the controller's processing of other information.

4.11.2   In summary, auditory signals need to be distinctive, concise, clear, audible and invariant. Testing is necessary to ensure that they meet these usability criteria.

4.12   SPECIFIC RECOMMENDATIONS FOR THE CPDLC HMI

"One concern is that the large number of message composition steps causes controllers to pay attention to system-generated tasks and be distracted from the true task at hand, which is to keep aircraft separated. Another concern is that the number of steps is cumbersome and time consuming."

Computer-Human Interface Evaluation
of the Oceanic Data Link System (FAA, 1997)

4.12.1   This section includes functional and design requirements for the CPDLC HMI. When developing data link systems, the need for error protection should be balanced against the need for ease of use. This is a fundamental trade-off, to the extent that automated error detection cannot trap every possible critical error. It is critical that the content of CPDLC clearances and clearance requests be checked for reasonableness and implications to flight safety. However, because the system will be used frequently, the process of entering data into the system and transferring data to and from the system needs to be as easy as possible in order to reduce the total number of keystrokes that should be made and the amount of attention that should be paid to CPDLC operations. The HMI design should reflect trade-offs made between ease of use and error protection.

4.12.2   These objectives can be achieved by adhering to the following recommendations:

- The air traffic controller should have information to determine which aircraft have a data link capability and the level of that capability. It is recommended that data link system availability should be indicated only when the aircraft has the capability to receive and process all data link services provided by the air traffic controller. The use of unique indications for multiple levels of data link capability is not precluded. However, empirical research should be undertaken to ensure that the larger number of indications does not degrade air traffic controller performance. For air traffic controller positions operating with a traffic situation display, indications of an aircraft's data link system status should be associated with the aircraft's label or position symbol.

- The data link system should provide capabilities for message generation such as the following:

  — form-filling — either controller entry or retrieval of stored parameters to fill in predefined message templates;

  — free-form message text entry;

  — selection of predefined messages and phrases from a menu;

  — entry of commands or use of function keys to quickly format messages;

  — selection of computer-generated message data.

- The data link system should provide feedback for every user input in time to prevent doubt about the status of the input.

- Any unrecognized or unreasonable entry should prompt an error message from the system and should not result in any data changes. The system should provide the information needed to assist the controller in determining the nature of the error and how the error could be corrected.

- The HMI should clearly distinguish between the various functions and modes of the system and indicate the type and format of data expected. To the extent possible, data link systems should ensure that data intended for one purpose cannot be used erroneously for a different purpose.

- The HMI should clearly differentiate functions that are available for use from those that are not available, based on the current context of the system or message status. For example, applicable response options should be indicated when a specific message is selected by the controller.

- If speech generation technology is used to present CPDLC messages, it should be used redundantly with a visual display, unless research demonstrates that such redundancy is not required. Speech generation applications should meet or exceed current levels of intelligibility and comprehensibility achieved with voice radio without increasing controller workload. If speech generation is provided, the controllers should be able to select it on and off, have the message replay, mute the message, and adjust the speech rate and volume through headsets and speakers. It is further recommended that speech presentations of messages be preceded by an aural pre-alert such as a tone or aircraft call sign to orient the controller to attend to the message.

- The controller should not be required to enter the same information multiple times. In addition, it is desirable that data link systems be designed to facilitate sharing of information needed for multiple functions.

- Control logic for CPDLC operations should permit completion of frequent or urgent data link-related operations with a minimum number of actions and keystrokes and minimum controller memory load. Only one action should be required to see the next or previous display page of a CPDLC message.

- Lines of text should be broken only at spaces or other natural delimiters. Parameters associated with text should be adjacent to and grouped with their descriptive or explanatory text or labels and should be on the same page. If the complete message cannot be presented on the same page, there should be a clear indicator to the controller that the message continues.

- A minimal number of inputs should be required to compose or respond to a message.

- The CPDLC system should provide a preview of all messages as they are composed and before the controller sends them; the system should support editing of controller-composed messages.

- To reduce workload and data entry errors, common messages and message response options should be predefined or composed by entering data into predetermined formats.

- For messages that require a controller response, the CPDLC system should indicate the set of appropriate response options as established in current procedures.

- For clearance requests from the flight deck, the CPDLC system should generate and present an appropriate clearance as a response option for controller review and uplink.

- For controllers, the CPDLC HMI should facilitate message composition by providing a predefined set of frequently used messages tailored to the position's operation.

- To the extent possible, the system should automatically manage designation of the message addressee. This should not preclude controller designation of the message addressee.

- When multiple CPDLC messages are waiting, the system should facilitate responses by order of urgency first and age second. More urgent messages should be answered before less urgent messages. Within levels of urgency, messages should be displayed and answered in order of oldest to newest, based on sending time. The controller should be able to manually select messages for display.

- When a previously issued clearance or clearance request can be identified as having been superseded by a new message, the previous message should be visually tagged as being superseded. If the message that is being superseded has not been displayed to the controller it may be automatically cleared from the queue; however, the crew should be notified that the message has been cleared and should acknowledge this notification.

- A new message should not automatically cover and displace a message currently being displayed. Disruption due to automatic overwriting of a message being processed by the controller should not be possible, and errors due to the association with a new message of a response intended for an old message should not be possible.

- It should not be possible to inadvertently respond to a message so soon after it appears that it could not have been read; a minimum two-second delay between the appearance of the message and its response should be implemented. All of the message should have been displayed before a positive or negative response is allowed.

- CPDLC implementations should minimize any increase in controller visual attention to display locations that will interfere with attention to high priority tasks.

- In order to minimize controller re-entry of data, it is recommended that the CPDLC system be integrated with appropriate ATS system functions.

- CPDLC installations should not prevent the controller from performing other high priority tasks by either requiring excessive devotion of the controller's attention or by tying up the equipment needed for the other tasks with data link functions.

- The alerting function for incoming CPDLC messages should be easily distinguishable from any other alerts presented at the controller's workstation.

- Maximum use of data link should not impose undue competition for display or control resources. Data link systems should not preclude access to other functions or unduly conflict with higher priority operations.

- Use of colour for CPDLC message display should be consistent with established standards for air traffic controller workstation colour coding.

- The controller should be able to suspend ongoing data link functions to access other functions at any time and resume the suspended data link function at the point at which it was suspended. Clear indication should be provided of where the controller is in the suspended operation.

- If data link operations share display and control equipment with other functions, one controller's use of data link functions should not impede another controller's use of other equipment functions, particularly if there is only one of the equipment at the workstation.

- All information required in a data link operation should be available for display during the data link operation. The controller should not be required to rely solely on memory at any point during the transaction.

Conclusion

4.13   The HMI is the most important part of the system for the user. Throughout the lifespan of the system, which typically is in the range of 10 to 15 years, the user will use the HMI to make the system work and to get support from the system in the user's task execution. As was argued earlier (see Chapter 1 "Incorporating Human Factors knowledge"), it will pay off in the end, both in time and money, to invest adequate resources during the design phase of the HMI. The guidance provided in this chapter will help to achieve an optimal HMI design for advanced ATM systems.

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Cardosi, K. and D. Hannon, Hannon Consulting, *Guidelines for the Use of Color in ATC Displays*, United States Department of Transportation, Research and Special Programs Administration, John A. Volpe National Transportation Systems Administration, Cambridge, MA, 1999. (DOT/FAA/AR-97/ DOT-VNTSC-FAA-98-5.)

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Human Engineering Guidance for Data Link Systems. RTCA, Inc., Washington, DC, 1997. (RTCA/DO-238.)

Appendix 1 to Chapter 4

THE NEW ZEALAND
OCEANIC CONTROL SYSTEM (OCS)

1. Phase 2 of the Oceanic Control System (OCS) that was commissioned in 1999 by the Airways Corporation of New Zealand consists of an integrated flight data processing system (FDPS), a datalink communications system (for both CPDLC and ATC Inter-facility Data Communications [AIDC]), a traffic situation display, electronic flight progress strips, a meteorological and NOTAM database and a conflict probe.

2. The workstation (Figure 4-A1-1) has two displays (2 000 × 2 000 pixels). One is the Traffic Situation Display and on the other are the communication message queues, electronic flight progress strips, coordination and clearance windows, the AFN log-on window and a conflict summary window. The Situation Display can be zoomed in (i.e. the range can be decreased), and a window can be superimposed on either display.

3. The Traffic Situation Display shows aircraft symbols much like a contemporary radar display does, but the symbols represent either a radar-derived aircraft position, an ADS-derived aircraft position or a "projected position" (i.e. a position computed by the OCS, based on position reports, estimates and flight plan data). For each of these categories of position information a different symbol is used to represent the aircraft concerned.

4. Each symbol is connected with a label in which the controllers can see the most relevant control parameters for the flight. The labels include mandatory and optional fields: call sign, CPDLC log-on indicator, destination, special code (e.g. RNP [Required Navigation Performance] certified, RVSM [Reduced Vertical Separation Minima] certified, etc.), reported flight level, climb/descent indicator, cleared flight level, lower block flight level, upper block flight level, Mach number or True Airspeed, ground speed, SSR [Secondary Surveillance Radar] code/mode, distance-based separation flag, Mach number separation flag. Additionally, the label will show alerts such as "position report due", "coordination due" or "coordination in progress".

The ADS interface

5. In the permanently displayed ATS Facilities Notification (AFN) Window (see Figure 4-A1-2) the controller can see the status of the data link connections between the OCS- and FANS-1/A-equipped aircraft. The log-on sequence for an aircraft starts with establishing an AFN connection, normally followed by establishing ADS contracts. Subsequently, the CPDLC connection may be established.

6. The OCS automatically establishes two default contracts for a flight: a Periodic Report contract and a Waypoint Event contract. The controller can modify a contract whenever necessary. To do so, the controller clicks on the "Edit ADS…" button at the bottom of the AFN window, after which the controller gets access to a template for the desired contract type (i.e. Periodic, Event or On Demand).

7. As an example, the Periodic Contract template is shown in Figure 4-A1-3. The call sign of the flight to which the contract pertains (QFA36 – Qantas 36) is displayed at the top of the template. Below that are eight items that may be included in the periodic reports. In the example the frequency for the ADS reports is set at 15 minutes and 00 seconds, which in reality means it will be at 14 minutes and 56 seconds (the OCS corrects the frequency entered by the controller to the nearest possible periodic reporting rate). Of the seven remaining items, one (the Airframe ID) is not available which is indicated by "greying out" the option in the list. All other six items are selected for inclusion in the reports. The "modulus" column gives the controller the option to set how often each item should be included in consecutive reports. In the example all values are set to "1", which means that in every report each item will be included. If a value were set at "3", this would imply that the related item would only be included in every third ADS report from the aircraft.

8. The item "Earth Reference" comprises the aircraft's true track, ground speed and vertical rate. The

item "Air Reference" comprises the true heading, Mach number and vertical rate. Both items are normally not displayed to the controller, unless the parameters are out of conformance (i.e. exceeding a pre-set tolerance value).

9.   By clicking the "Send" button at the bottom, the controller activates the contract with the (avionics of the) aircraft.

10.   Similar templates are available for Event contracts and On Demand contracts.

Note.— For an explanation of the different categories of ADS contracts, see the Manual of Air Traffic Services Data Link Applications, *(ICAO Doc 9694) Part III, Chapter 3.*

The CPDLC interface

11.   The OCS features pull-down menus in a Message Processing window to generate CPDLC messages for uplinking to the aircraft. An example of the Message Processing window is depicted in Figure 4-A1-4.

12.   The top line in the window shows the call sign of the aircraft with which the message is exchanged (DL001). Immediately below that is an area where downlinked (i.e. incoming) messages are displayed.

13.   In the example this area is empty. Next is a horizontal bar with twelve menu headers where the item "Vertical Clr" has been activated to display five related categories. Each of those options will open a subsequent menu, from which the desired CPDLC message element eventually can be selected.

14.   Here the "Expect" category was activated, opening a menu with thirteen available message elements. Each element is preceded by a number which corresponds to the accepted FANS-1/A message set and also to the CPDLC message set in ICAO Doc 4444 (Appendix 5). Those numbers are used by the flight deck automation to generate logical default responses for the pilots to down-link, if acceptable.

15.   In the example the controller selected message number 6 "EXPECT (alt)", as can be seen on the left side below the horizontal menu bar. In the field following the selected message, the controller inputs the desired flight level (F350) by using an alphanumeric keyboard. The result of the "message under construction" is displayed in the Message Editing Area, below the input field. The phrase "DUE TO TRAFFIC" in the example was also added by using the input field.

16.   Once the message is completed, it will be displayed in its final form in the Message Review Area at the bottom of the window. By finally clicking the "Send" button, the controller activates the CPDLC transmission and the message is sent to the aircraft. If the message is a clearance or instruction, the OCS will conduct a conflict probe prior to sending the message. If a conflict is detected, the message is not sent, which gives the controller the opportunity to change the clearance or instruction.

Other features

17.   The OCS has an audio signal to alert controllers to incoming CPDLC emergency messages. There is also a visual alert, i.e. a different colour for the emergency messages in the queue.
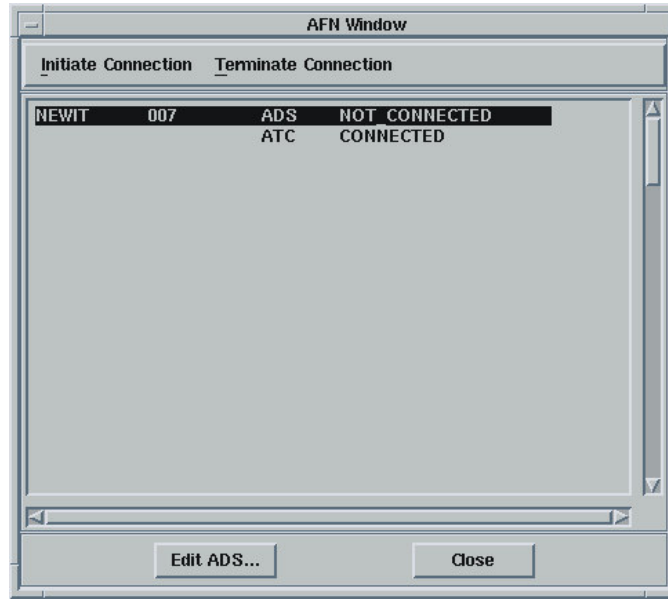
Figure 4-A1-1.   OCS workstation

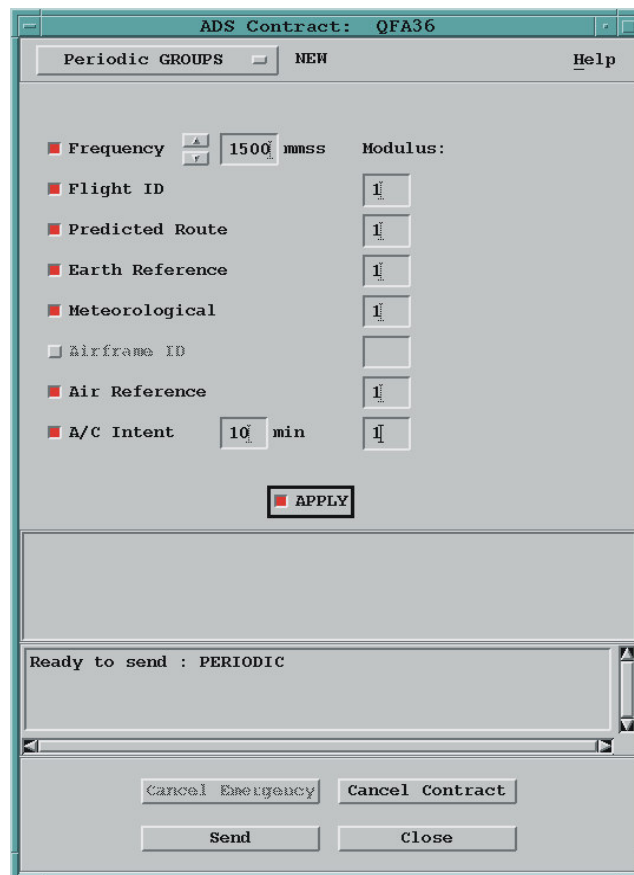**Figure 4-A1-2.   ATS facilities notification window**

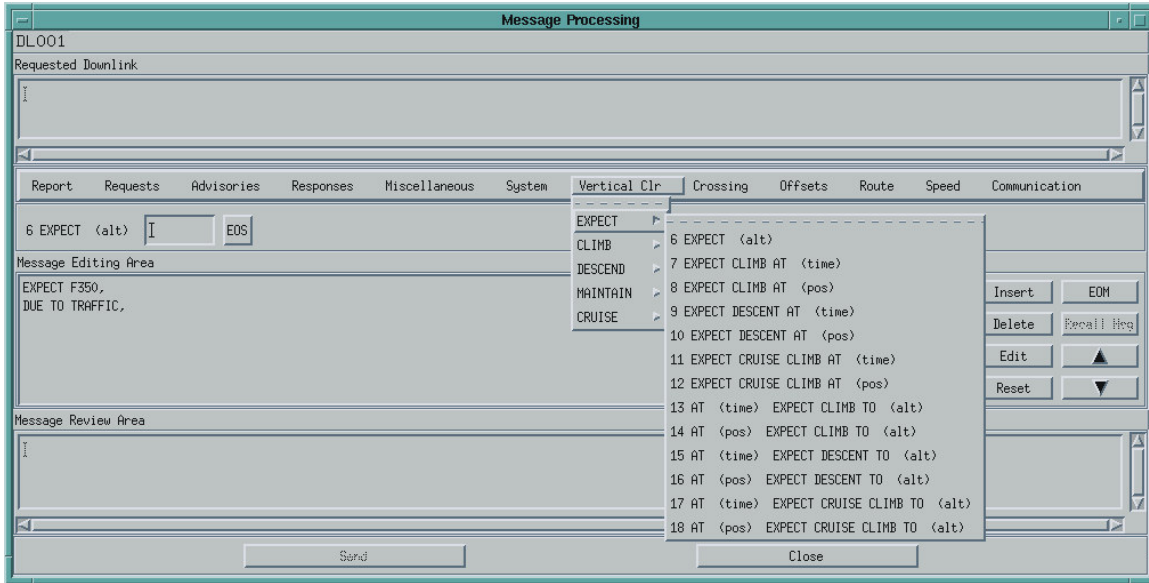**Figure 4-A1-3.   Periodic contract template**

Figure 4-A1-4.   CPDLC message processing window

Appendix 2 to Chapter 4

OPERATIONAL DEVELOPMENT OF INTEGRATED SURVEILLANCE AND AIR/GROUND DATA COMMUNICATIONS (ODIAC)

1.   INTRODUCTION

1.1   The HMI features described in this section were designed by Eurocontrol's ODIAC (the Operational Development of Integrated Surveillance and Air/ground Data Communications) Subgroup to support the air/ground data link functionality as described by ODIAC. In the ODIAC philosophy, data link communications will not substitute for voice communications but rather supplement and support them.

1.2   The ODIAC HMI is incorporated in this manual as an example of what is technically possible and to demonstrate the need for careful integration of Human Factors knowledge. This example should be considered neither to be exhaustive, nor to present the ideal solution for the problems associated with HMI design.

2.   INDICATION OF CDPLC CAPABILITY

2.1   The indication on the radar display or ADS display of an air/ground data link aircraft is very simple. Only aircraft which have logged on to perform CPDLC are indicated. The indication is a framing around the call sign in the display label. The colour of the framing indicates the status of the CPDLC.

2.2   In Figure 4-A2-1 the label on the left represents an aircraft without CPDLC capability. The label colour is black (the standard label colour). The central label is for an aircraft with CPDLC capability that has not logged on to the Air Traffic Services Unit. This label is coloured blue, including the framing around the call sign. The label on the right represents an aircraft with CPDLC capability that has successfully logged on to the ATS Unit, which is distinguished from the central label by the black colour of the framing.

Note.— ODIAC elected to not use the aircraft position symbol to distinguish between aircraft capabilities. In all *presented examples the position symbol is a dot. Other systems, however, could consider indicating CPDLC capability by using different symbols for appropriate aircraft, e.g.* $\nabla, \Delta, \square, \otimes$*, etc.*

3.   THE SELECTED LABEL

3.1   When a controller wants to access the label of a particular flight (e.g. in order to transmit a clearance via CPDLC to that flight), a mouse or trackball is used to position a pointer (arrow) over the symbol or label of that flight. This will trigger the label to change from the standard content to a more comprehensive version (see Figure 4-A2-2).

3.2   The standard label shows the call sign (BAW362), the actual flight level (290, derived from Mode C in a radar environment, or from the FMS in an ADS environment) and the next control sector where this flight will go (AW). The black framing of the call sign indicates that this aircraft is in CPDLC contact with the ATS Unit. The selected label shows the call sign in a differing colour (green) and has additional fields to denote the cleared and requested flight levels (290), the airspeed (420), the routing (RP2) and the type of aircraft (B737). The information in the bottom line of the selected label is discussed in Chapter 3 "Data link infrastructure and applications".

4.   COMMUNICATING A CLEARANCE VIA CPDLC

4.1   The following example describes the sequence of events involved in issuing a flight level clearance via data link. Similar sequences will apply when issuing direct/heading, speed and vertical rate of change clearances. In Figure 4-A2-3, flight BAW362 is being cleared to climb from flight level 260 to flight level 290.

4.2   The sequence initiated by the controller is the following:

- The controller inputs the new flight level 290 via the cleared flight level (CFL) field in the selected label.

    Note.— A button click with the pointer activates a local menu that shows flight levels that are "logically" related to the actual flight level of the aircraft. By scrolling, other flight levels are accessible as well, when required.

- The input value is framed in black, a message is displayed in the "Message OUT" window (see Figure 4-A2-4) and the clearance is transmitted to the aircraft.

- The pilot transmits a "Wilco" message.

When the "Wilco" message is received:

- The frame around the CFL field disappears.

- The message in the "Message OUT" window disappears.

4.3   Figure 4-A2-4 shows a detail of the "Message OUT" window that can be positioned at another part of the controller's traffic situation display (i.e. radar screen or ADS screen) or on a separate display.

4.4   In case the pilot does not transmit a "Wilco" message, but sends a "Standby" or an "Unable" message instead, this will be presented to the controller as depicted in Figures 4-A2-5 and 4-A2-6, respectively.

4.5   When a "Standby" message is received, the framing around the field to which the message refers changes colour to white. The white frame remains until another message from the pilot is received, i.e. "Wilco" or "Unable".

4.6   When an "Unable" message is received, the framing around the field to which the message refers changes colour to yellow and the message "UNABLE" is displayed in yellow above the call sign.

Note.— It would seem logical to expect that this response will be followed by a further exchange, probably involving the "free text" option provided by CPDLC. Alternatively, the controller could elect to switch to voice communication in order to discuss other options with the pilot.

4.7   The absence of a reply from the pilot will trigger the display of a warning in the standard label (see Figure 4-A2-7).

4.8   A yellow "warning colour" frame highlights the field to which the message refers. Take, for example, a situation where a climb clearance is sent to the aircraft and a pilot reply is expected but not received. After a time out (which is a system parameter), the absence of the pilot reply results in a yellow frame around the CFL field, and a warning message "NO REPLY" is displayed in yellow above the call sign.

Note.— When no reply is received by CPDLC from a pilot, the controller would normally try to establish contact by voice communication in order to resolve the issue at stake.

5.   NEGOTIATING A PILOT REQUEST VIA CPDLC

5.1   The next example describes the sequence of events involved in requesting a flight level change via data link. Similar sequences will apply when requesting direct, heading and speed clearances.

5.2   When the pilot request is received by the ground system, the background of the call sign field changes to white in the standard label and in the corresponding line of the "Message IN" window. The request is displayed in the "Message IN" window (Figure 4-A2-8).

5.3   The possible answers (cleared FL 330, Standby or Unable) are available in the "Message IN" window.

- A click on the downlinked (i.e. from aircraft to ground) requested flight level "330" displays the CFL menu, with the cursor defaulted on that particular level; a second click uplinks (i.e. from ground to aircraft) the clearance to climb from flight level 290 to flight level 330.

- A click on "Standby" uplinks that message to the pilot and the display is changed to a white framing of the call sign.

- A click on "Unable" uplinks that message to the pilot and the request is then cancelled. The message in the "Message IN" window is removed and the white background of the call sign is removed as well.

5.4   The controller can also respond to the request through the CFL menu (as described in Section 4 "Communicating a clearance via CPDLC") in the selected label. If a new CFL is entered, the white background of the call sign is removed.

6.   LOGICAL ACKNOWLEDGEMENT

6.1   The Logical Acknowledgement is a technical message, normally not displayed to the controller, confirming that the message sent has been received by the airborne systems and will be displayed to the pilot.

6.2   Only when a Logical Acknowledgement is not received within a certain time is a warning displayed to the controller in the standard label (Figure 4-A2-9).

6.3   A yellow "warning colour" frame highlights the field to which the message is referring. If, for example, a clearance to climb from FL260 to FL290 is sent to the aircraft, a Logical Acknowledgement is expected as with all messages. After a time out (which is a system parameter), the absence of the Logical Acknowledgement triggers a

yellow frame around the CFL field, and a warning message "DL ERROR" is displayed in yellow above the call sign.

Note.— After a data link error, the controller would either have to re-send the message (assuming that the data link connection still exists) or, possibly, alert the pilot by voice communication that the data link connection has been lost. In the latter case, the pilot could subsequently attempt to log on again.

7.   CONDITIONAL CLEARANCES

The ODIAC HMI has no provisions (yet) for the transmission of conditional clearances. The main reason for this is that the design was aimed specifically at the use of CPDLC in areas with high-density traffic and radar coverage. It was felt that in that environment there would be very little use of conditional clearances (as compared to a procedural environment, e.g. oceanic airspace, where conditional clearances are more commonly used).

References

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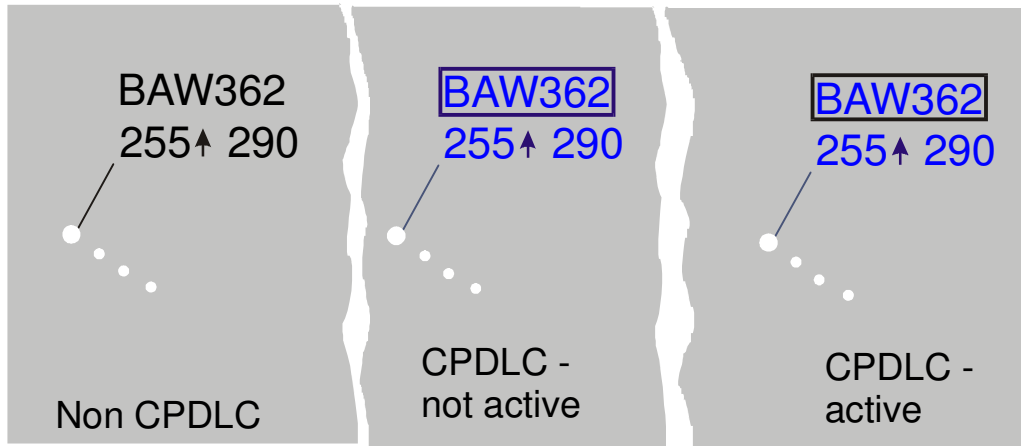
Figure 4-A2-1.   Indication of CPDLC capability
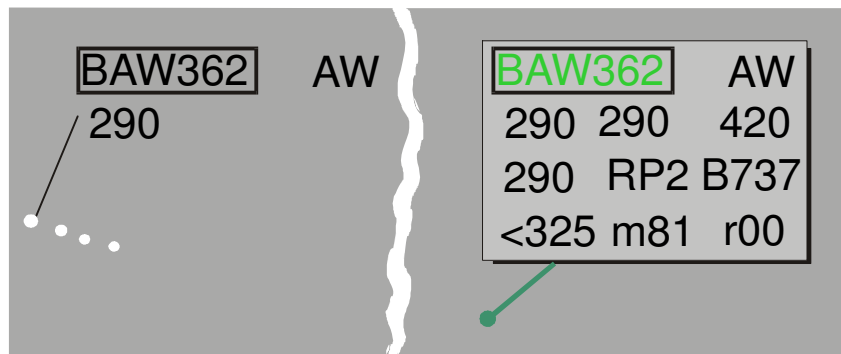
Figure 4-A2-2.   ODIAC label options
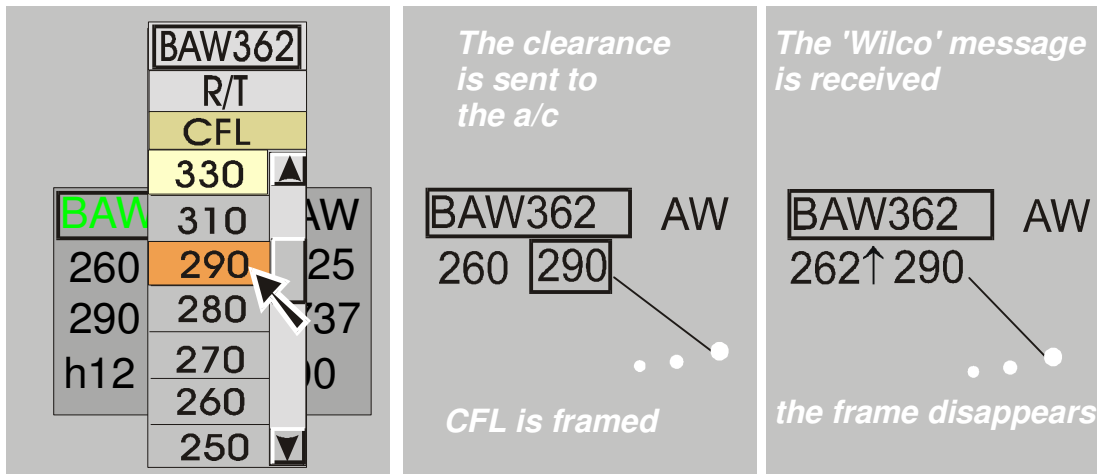
Figure 4-A2-3.   Communicating a flight level clearance via CPDLC
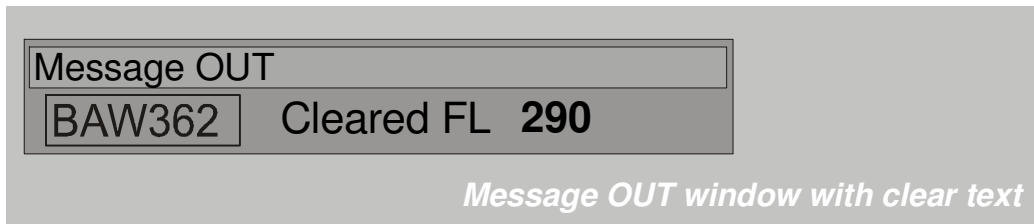

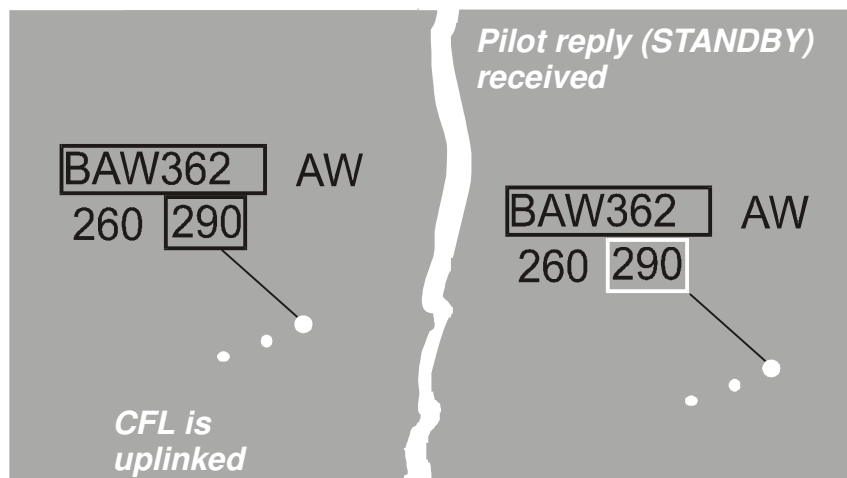**Figure 4-A2-4.   The "Message OUT" window**

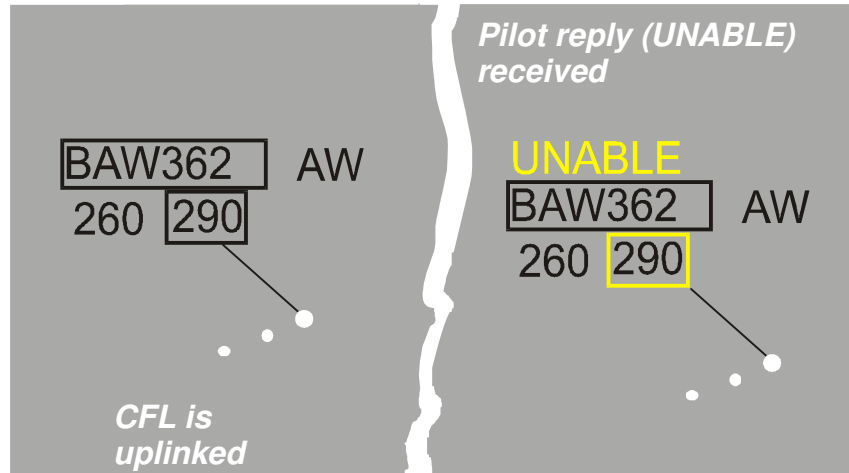**Figure 4-A2-5.   Presentation of use of the "Standby" message**
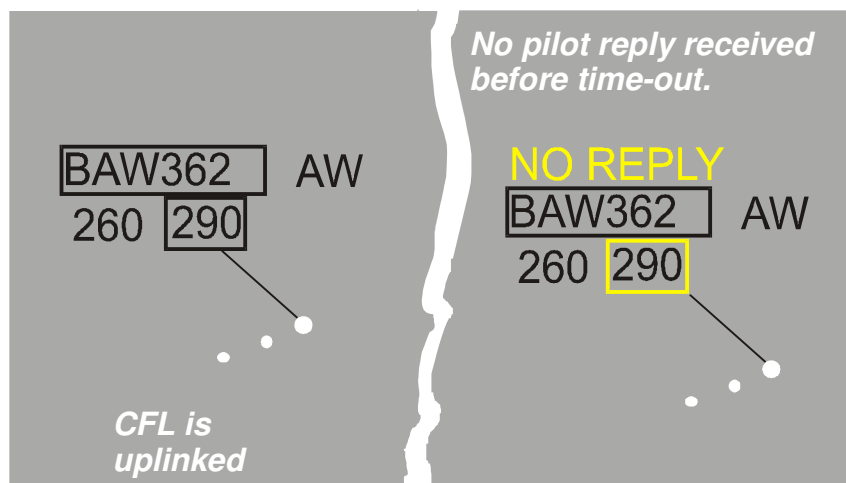
Figure 4-A2-6.   Presentation of use of the "Unable" message
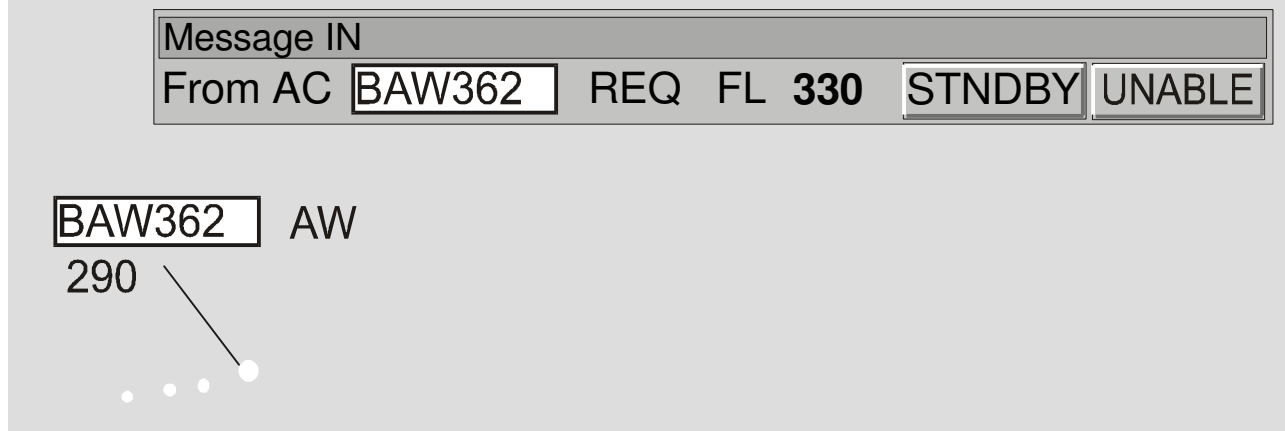

Figure 4-A2-7.   Presentation of the "Absence of reply" warning
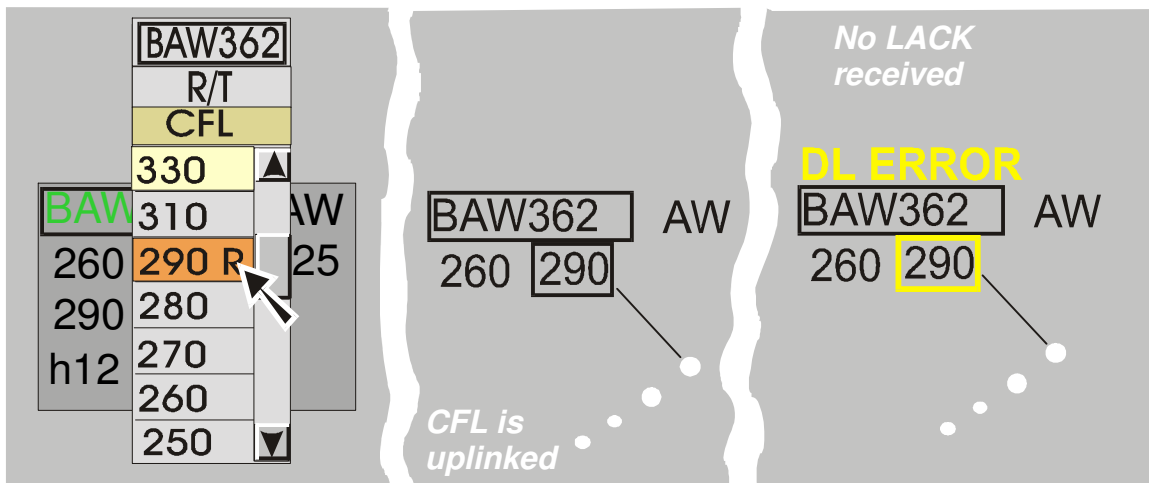
Figure 4-A2-8.   The "Message IN" window

Figure 4-A2-9.   Presentation of the "Absence of logical acknowledgement" warning

Appendix 3 to Chapter 4

THE AUSTRALIAN ADVANCED AIR TRAFFIC SYSTEM (TAAATS)

1. The Australian Advanced Air Traffic System (TAAATS) is a fully integrated airspace management and air traffic control system that has been incrementally becoming operational since 1998. It combines computer, radar and communications technologies in a system that makes all flight information available to controllers in two Flight Information Regions and two Flight Data Regions, comprising two en-route control centres, four terminal control units and 29 aerodrome control towers. The area covered by TAAATS represents 11 per cent of the earth's surface.

2. A TAAATS workstation (Figure 4-A3-1) consists of an air situation display (2 000 × 2 000 pixels, central in the picture), an auxiliary flight data display (on the right in the picture), a weather radar display (top left in the picture) and a voice communications control panel (bottom left in the picture). The weather radar display also is connected to a networked PC, which provides access to static graphics (e.g. airport diagrams, approach and departure procedure diagrams) and to hypertext linked documents such as controller manuals and checklists. Input devices are a keyboard, one mouse for both the air situation display and the auxiliary flight data display, and a second mouse for the weather radar display. The communications control panel inputs are made by a touch-screen. In Figure 4-A3-1, the object to the left of the keyboard is a unique hand-operated push-to-talk switch that was designed specifically for TAAATS. It is colloquially called a "ferret". Like the mice, the ferret can be moved around the working surface to suit left- and right-handed controllers. In addition to the ferret, there is an R/T footswitch located on a footrest under the console.

3. The air situation display shows aircraft symbols much like a contemporary radar display does, but the symbols represent either a radar-derived aircraft position, an ADS-derived aircraft position or a "flight plan track" (i.e. a position computed by TAAATS, based on position reports, estimates and flight plan data). For each of these categories of position information a different symbol is used to represent the aircraft concerned.

4. Figure 4-A3-2 shows, from left to right, a label for a radar track, an ADS track and a flight plan track. Each label can be displayed as a normal label or as an extended label (which contains more information) at the discretion of the controller. In Figure 4-A3-2 the radar track label is a normal label, while the other two are extended labels.

5. The contents of the normal radar track label are: the call sign (AVN11), the wake turbulence category (M — medium), an indication (*) that there is relevant information to be found in the "other information" field, the mode C-derived flight level (350), an attitude indicator (>), the cleared level (350), the ground speed in tens of knots (41, i.e. 410 knots) and a free text line (RWY 16L, i.e. assigned runway 16 left).

6. The contents of the extended ADS track label are: an indication that coordination has been completed (C), the call sign (QFA46), the CPDLC connection status (-), the wake turbulence category (H — heavy), an indication (*) that there is relevant information to be found in the "other information" field, the ADS-derived flight level (350), the cleared level (350), the ground speed in tens of knots (45, i.e. 450 knots), the destination (YSSY — Sydney) and the aircraft type (B744 — Boeing 747-400). There also is a free text line, which in Figure 4-A3-2 is empty.

7. The contents of the extended flight plan track label are: the call sign (QFA104), the wake turbulence category (H — heavy), an indication (*) that there is relevant information to be found in the "other information" field, the pilot-reported flight level (390), the cleared level (390), the ground speed in tens of knots (38, i.e. 380 knots), the destination (YSSY — Sydney) and the aircraft type (B762 — Boeing 767-200). There also is a free text line, which in Figure 4-A3-2 is empty.

8. All labels on the TAAATS air situation display are interactive, which means they provide the controller with access to pop-up menus for the most relevant air traffic control actions. Figure 4-A3-3 shows an example of a pop-up menu for a cleared flight level entry in the system.

9.   By clicking on the cleared flight level in the label (350), the controller is presented with a menu in which the current cleared flight level is indicated by inverted video. The next four levels above and below the current level are displayed in the menu, while other levels can be accessed by clicking a "-" or a "+" symbol. The number of symbols on the buttons indicates the desired range from the current level.

10.   The controller selects the desired level and clicks on it, thus entering the new value in the label on the air situation display. TAAATS automatically and simultaneously updates all other fields on other displays (including electronic flight progress strips) that contain the cleared flight level for this particular flight.

11.   In case the change in flight level is transmitted by CPDLC to an aircraft, TAAATS automatically updates the related values on all displays as soon as the expected acknowledgement "Wilco" is received from the aircraft. This means the controller does not have to make the same input twice for the system.

The ADS interface

12.   The types of ADS contracts and default periodic reporting rates are initialized automatically by the ground system. The controller can manually modify the periodic reporting rate for a period of time through the ADS contract window depicted in Figure 4-A3-4. This window is one of the display options of the air situation display or the auxiliary flight data display. Like all other windows it can be moved to any position on either of the two screens at the controller's discretion. The controller can elect to have the window displayed permanently or just to bring it up when needed.

13.   The window shows the aircraft identification (ACID) for the flight to which the ADS contract pertains (UAL815 – United Airlines 815). Also presented are the parameters that the controller can select as required. The "Escape" button allows the controller to **not** activate the changes that were about to be made to the contract and to return to the screen that was used before. The "One shot" button is the TAAATS equivalent of an On Demand contract.

14.   As can be seen in Figure 4-A3-5, the ADS contract windows in TAAATS also feature pop-up menus with context-specific values.

The CPDLC interface

15.   To manage CPDLC messages, the controller has a CPDLC Message Editor window, a Current Messages window and an Error Messages window. (The Error Messages window is also used for system error messages that are not related to CPDLC.) These windows can be positioned on the air situation display or the auxiliary flight data display at the controller's discretion.

16.   When a downlink message is received, the controller is alerted by a single audible "beep" and the message is displayed in the Current Messages window. Colour coding is applied in TAAATS to distinguish messages that have been responded to from messages that still require action from the controller. The controller generates a response through the Message Editor window. Once sent, the message is displayed in the Current Messages window. When a reply is received from the flight deck, the message changes colour again to indicate the change in status to the controller.

17.   The CPDLC Message Editor window is organized in a hierarchical menu structure (see Chapter 4 "The human-machine interface"). The controller is presented with several message categories (e.g. Climb, Descend, Speed, SSR, Route, Free Text, etc.) that each give access to a specific menu with related message elements. The controller selects the desired message elements, which are subsequently displayed in a dedicated section of the window. After each element, the window provides a "clear" button that allows the controller to remove and edit a specific element without having to compose the whole message again. The Message Editor features a "suspend" button to allow the controller to attend to other tasks while retaining the selected elements from the message under construction. When the controller returns to the Message Editor window, the composition of the message can be resumed at the point where it was suspended.

18.   After completing the message, the controller clicks the "Send Message to: (call sign)" button, or alternatively, clicks the "Escape" button to cancel the message without sending it. By repeating the call sign of the aircraft to which the message will be sent on the "Send Message" button, enhanced assurance is provided against inadvertently sending a message to the wrong aircraft.

19.   Emergency messages in TAAATS are colour coded red in the Current Messages window and are accompanied by a continuous audible "beep". Also, an emergency indication is generated on the corresponding track label (see Figure 4-A3-6) by adding a box around the label. The box contains the mnemonic EMG for emergency.

(The octagonal shape around the aircraft position symbol indicates that the controller has designated the track with the mouse to apply a subsequent function — in this case probably to cancel the aural alarm.)

Electronic flight progress strips

Note.— The electronic flight progress strips from TAAATS were used as an example in the main text of this chapter and are described there in detail.

20.   In TAAATS the electronic flight progress strips are displayed in a window either on the air situation display or on the auxiliary flight data display, at the controller's discretion. Paper strips are not used in the system. Like the labels on the air situation display, the electronic strips are interactive. Selected areas on the strips provide the controller with access to pop-up menus for the most relevant air traffic control actions.

21.   Figure 4-A3-7 shows an example of a way-point estimate entry by means of a pop-up menu. After the controller enters the revised estimate, all estimates for subsequent way-points are automatically updated by the system.

22.   Colour coding of the border and call sign of a strip indicates that, for the system, the flight is in a warning status. The type of warning (e.g. "no response") is indicated by a mnemonic in the corresponding track label, similar to the emergency indication (see Figure 4-A3-6), except that the colour is yellow rather than red.

Other features

23.   TAAATS features a highly user-friendly direct manipulation interface for route revisions. This particular interface is described in Section 4.7, Data Entry, in the main text of this chapter.
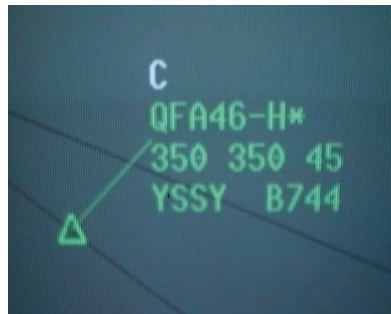
Figure 4-A3-1.   TAAATS workstation
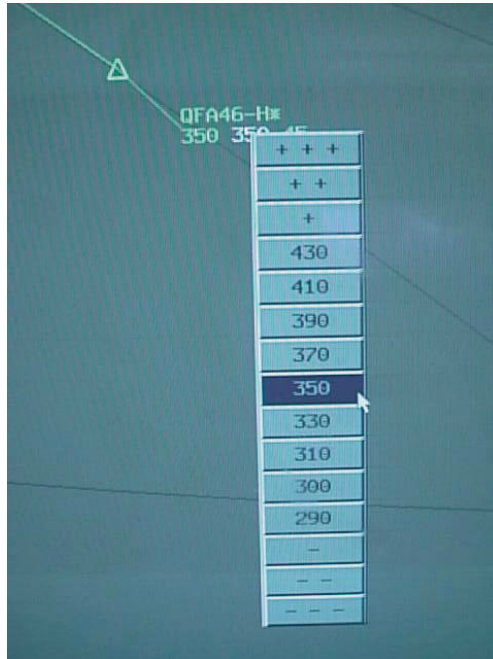

Figure 4-A3-2.   Position symbol categories

Figure 4-A3-3.   Example of a pop-up menu

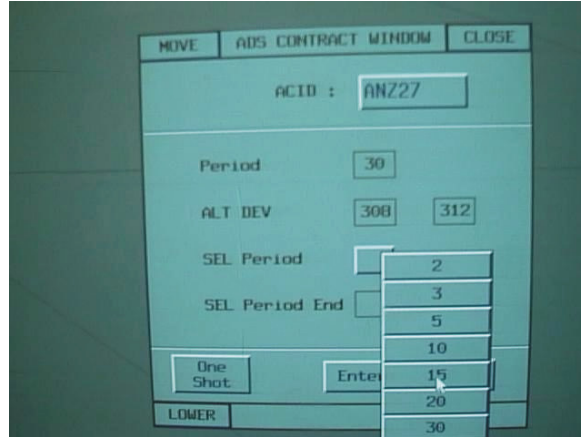**Figure 4-A3-4.   The ADS contract window**

Figure 4-A3-5.   Pop-up menu in an ADS contract window

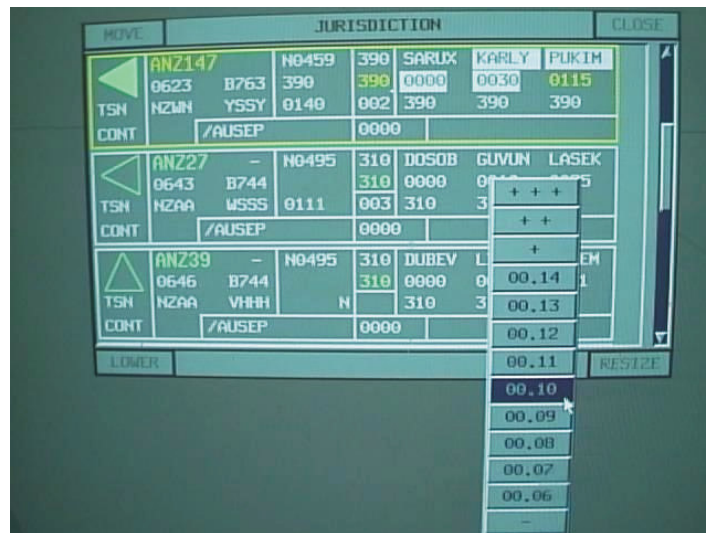**Figure 4-A3-6.   Track label with emergency indication**

Figure 4-A3-7.   Example of a way-point-estimate entry

Appendix 4 to Chapter 4

THE JAPAN OCEANIC CONTROL DATA PROCESSING SYSTEM (ODP)

1. Tokyo Area Control Centre has been operating version 2.5 of the Oceanic Control Data Processing System (ODP) since 1997. The current version includes a data link function, and it is expected that version 3 of the ODP, which will become operational in 2000, will feature electronic Flight Progress Strips.

2. The Traffic Situation Display shows aircraft symbols for two categories of data, i.e. ADS-derived tracks and way-point projected time from Flight Data Processing (procedural tracks). Position symbols in different colours are used for each of these categories, and colour coding is used also to distinguish RVSM-certified aircraft. In case no more ADS data is received from an aircraft, the symbol on the Traffic Situation Display changes to that for a FDP-derived track. Position data for FDP-derived tracks are obtained by High Frequency voice communications or by CPDLC position reports.

3. Labels may be displayed in two ways, i.e. with limited or full data presentation. Full data consist of the call sign, RNP certification (e.g. "R10" indicates compliance with RNP 10 requirements), RVSM certification ("R" indicates the aircraft is RVSM certified), aircraft status[1], assigned altitude, reported altitude, climb/descent indicator, cruising speed, altitude block, altitude limitation and destination. In a limited label, a selection of these items is presented, including mandatory items such as call sign and altitude.

4. The parallel diagonal lines on the Traffic Situation Display (Figure 4-A4-1) are air routes. The colour-coded rectangular shapes in front of the position symbols are called separation boxes.

The ADS interface

5. In the Air Communication Status window (Figure 4-A4-2), the controller can see the status of data link connections between the ODP and FANS-1/A-equipped aircraft.

6. After an aircraft establishes an AFN log on, the ODP automatically transmits a Periodic Report contract and an Event Report contract to the aircraft. The controller can modify a contract when necessary by changing items in a dedicated window on the display. There are windows for modifying Periodic contracts, Event contracts and Demand contracts. Figure 4-A4-3 shows the Event contract window, with several items that can be modified.

7. Deviation and Vertical Rate can be set by using the keyboard or by using the increase/decrease buttons adjacent to the boxes for the numerical values. By clicking the SEND button at the bottom of the window the controller activates the contract with the (avionics of the) aircraft. The CANCEL CNT button is used to cancel an existing contract.

8. Figure 4-A4-4 shows a Periodic Report window in which received ADS reports are presented as analytical data. At the top of the window, the call sign (ANA901) and the internal FDP registration number (0012) of the flight to which the contract relates are displayed.

The CPDLC interface

9. On the Traffic Situation Display is a message monitoring field. In Figure 4-A4-5 a request for altitude change is shown in the downlink message display area (top left side of the window). Since this is a request message, the ODP recognizes that the avionics remain in an "open" status (i.e. a reply is required to close the communication loop). This is indicated to the controller by displaying a "Y" at the beginning of the line with the message (not visible in Figure 4-A4-5).

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1. Aircraft status comprises alerts for delayed position reports, AIDC transfer information and receipt of CPDLC messages.

10.   By clicking with the right mouse button on the message, a menu appears with related reply categories. The controller selects the required elements and thus composes a reply message. Sending this message will close the "open" status of the avionics. At the same time, the "Y" at the beginning of the message line changes into an "A" in case of an altitude request message and into a "/" for other request messages. When the controller initially replies by sending a STANDBY message, the "Y" changes into an "S".

11.   During the composition of a reply message to a climb request, the ODP rejects values that represent a lower altitude than the present altitude of the aircraft. By default it will display possible values up to +5 000 ft of the present altitude of the aircraft, since it is not expected that the controller will receive a request for an altitude change of more than 5 000 ft.

12.   Colour coding is used to indicate the technical status of transmitted messages (e.g. message assurance received yes/no).

Other features

13.   The ODP has both a visual and an audio alert to indicate incoming CPDLC emergency messages to the controller. Furthermore, the ODP features a conflict alert that will warn the controller whenever the separation between two aircraft is foreseen to become less than the required minimum.

14.   Figure 4-A4-6 shows workstations from version 3 of the ODP, which will become operational in 2000. One sector consists of three working positions.
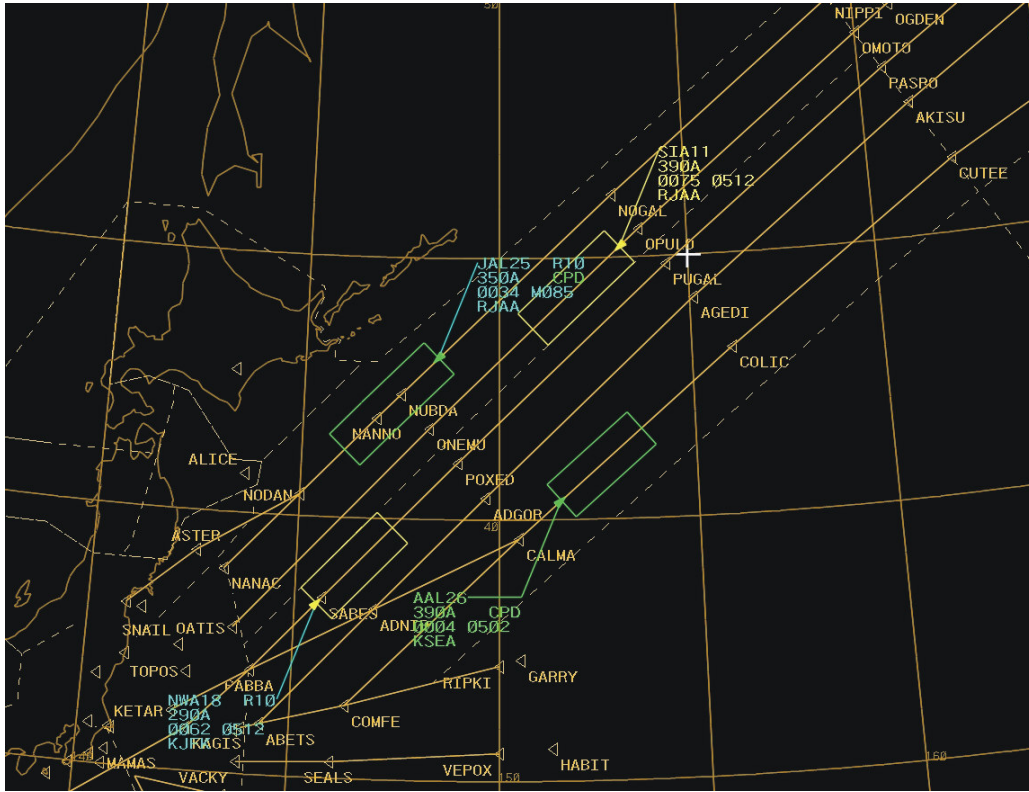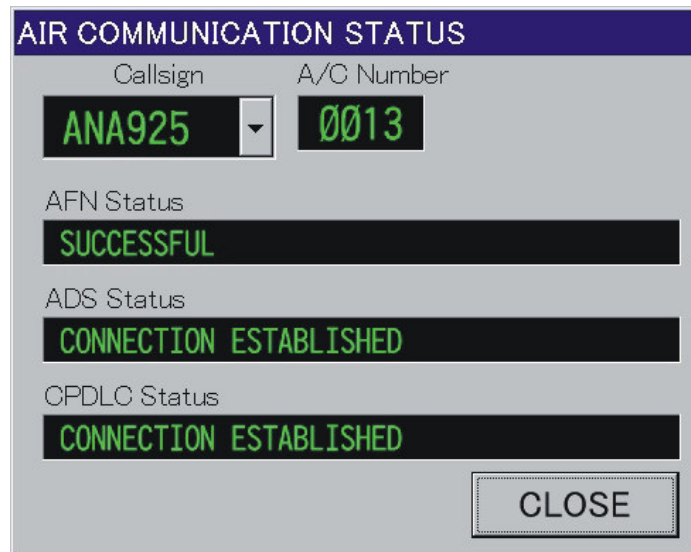
Figure 4-A4-1.   Traffic Situation Display

Figure 4-A4-2.   Air Communications status window

Figure 4-A4-3.   Event contract window

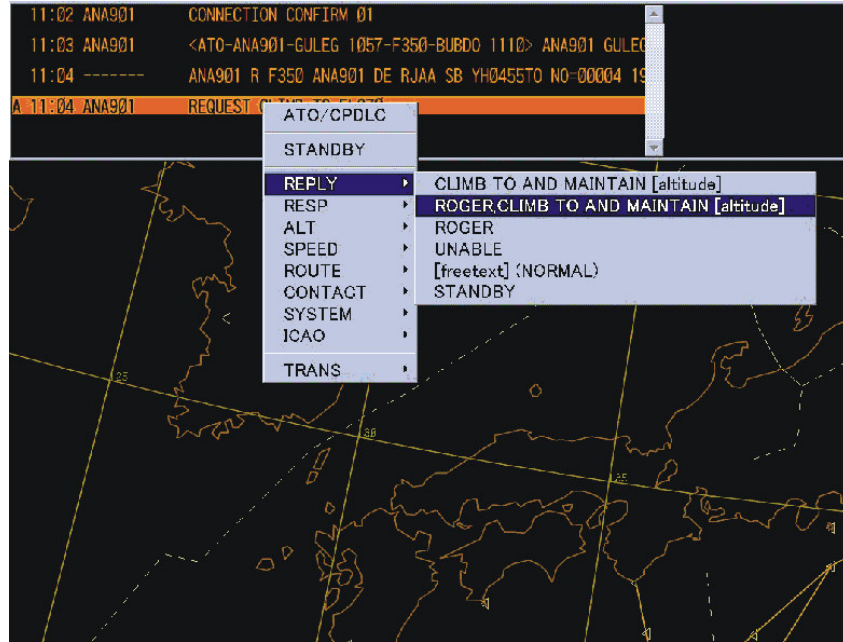**Figure 4-A4-4.   Periodic Report window**

Figure 4-A4-5.   Request for altitude change

Figure 4-A4-6.   ODP workstations

Attachment to Chapter 4

AN EXAMPLE OF A CHECKLIST WITH HUMAN FACTORS CONSIDERATIONS FOR THE ATC HUMAN-MACHINE INTERFACE

The following checklist is excerpted from the final report on *Human Factors in the Design and Evaluation of Air Traffic Control Systems*, by Kim M. Cardosi and Elizabeth D. Murphy (1995), of the U.S. Department of Transportation Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, for the Federal Aviation Administration (FAA).

"Note.— Checklist items marked by shading indicate items that must be assessed with equipment and/or by referring to the specifications documentation.

"I. VISUAL DISPLAYS

A. General

1. Information does not disappear from the screen without being intentionally deleted or suppressed by the controller.

2. The computer responds quickly so that the controller is not kept waiting for information (i.e., in less than one second for simple, frequently performed tasks; within four seconds for more complex processing; and within 12 seconds for infrequent, highly complex processing).

3. Essential ATC information is never blocked or obstructed by other information.

4. All information that a controller needs to accomplish a task that is essential and time-critical is located on a single page or in a single window.

5. Visual displays provide necessary information in a usable form when it is needed.

6. Display clutter is not a problem.

7. The meaning of each icon is immediately apparent to the controller or it is labelled.

8. Symbols chosen for the display are intuitive so that the controller can interpret them quickly and accurately.

9. Controllers can change the amount of task-related detail that is presented.

10. When the meaning of the colour is critical, colour is used redundantly with another type of visual cue, such as shape, text, or size. For example, all yellow objects have a triangular shape.

11. The controller is able to recognise and differentiate between colour codes under all anticipated lighting conditions.

12. The controller will not need to identify more than five colours (to interpret the meaning of the colour when it stands alone).

13. Colour displays are readable and adequately bright under all anticipated lighting conditions.

14. When the controller must distinguish between the colour of characters and symbols, small blue characters and symbols are not used.

15. Saturated (i.e., vivid) colours are used only for critical or temporary information.

16. Saturated (i.e., vivid) colours are not used for small objects or areas.

17. Saturated (i.e., vivid) red and blue are never presented next to each other.

18. Colours are far enough apart in perceptual terms that they are not confusable even when "washed out" by sunlight, if applicable.

19. Characters and symbols can be read easily under all anticipated lighting conditions (e.g., from dim light to direct sunlight, if applicable).

20. Computer displays and controls are clearly visible and easy to use under all anticipated lighting conditions (e.g., from dim light to direct sunlight, if applicable).

21. To acquire needed information, the controller only needs to look at a single, localised display.

22. The position and form of displayed objects appear the same to the controller seated directly in front of the object and to team members, when they view the display from other anticipated viewing angles.

23. If windows are used, the controller can scroll the underlying data set.

24. If windows are used, the controller can move windows.

25. If windows are used, the controller can resize windows.

26. If windows are used, the controller can iconify display pages.

27. If windows are used, the controller can open and close windows.

28. The active window is highlighted to distinguish it from inactive windows.

29. The relationship between different windows is clear to the user.

30. All information that a controller needs to accomplish a given task is located in a single window or within a small number of related windows.

31. Abnormal data are emphasised effectively so that it attracts the controller's attention.

32. Updated data are emphasised effectively so that it attracts the controller's attention.

33. Acronyms in the new display system have the same meanings as in the previous system.

34. Terms in the new display system have the same meanings as in the previous system.

35. Symbols in the new display system have the same meanings as in the previous system.

36. Symbol size can be adjusted by the controller.

37. Visual displays and their labels are sufficiently visible under all anticipated lighting conditions.

38. If size coding is used, it is limited to two widely different sizes.

39. Graphic displays are used only to present information that is naturally pictorial and to present dynamic data.

40. Placement of standard data fields is consistent from one display to another.

41. Formats used within data fields are consistent from one display to another.

42. Labels, terms, and abbreviations are used consistently across the display set.

43. Only one abbreviation is used for each word or item and abbreviations are used consistently on all visual displays.

44. Punctuation is used conservatively and consistently.

45. Continuous text is presented in mixed upper-and-lower case.

46. Computer printouts (in upper and lower case) are available for lengthy text.

47. Visual displays maintain good image quality even at the dimmest possible setting.

48. According to the display monitor manufacturer's report, the display refreshes at a rate of 65 cycles (or more) per second so that the display does not appear to flicker.

49. According to the display monitor manufacturer's report, a displayed object moves no more than .0002 times the viewing distance (in inches) in one second so that no display jitter can be detected.

50. The heights and widths of characters appearing at the centre and the four corners of the displays do not vary by more than 10 percent.

51. When the centre of the display is compared to an edge, brightness uniformity does not vary by more than 50 percent.

52. The luminance of dynamic text and symbols are eight times that of the static background.

53. All colours are 8 times brighter than the static background symbology.

54. When the controller must distinguish between the colour of characters, character height is at least 21 minutes of arc.

B. Visual alerts

1. Information that the controller must read and understand quickly, such as alarms or critical error messages, never blinks or flashes rapidly (greater than 3 Hz).

2. High-priority alerts and other critical information are located within the central display area (i.e., the central 15 degrees of the area where the controller normally looks, given the normal viewing position).

3. Highlighting and blinking are used sparingly.

4. The colour red is used only for warning/danger.

5. Yellow is used to indicate caution.

6. Green is used to indicate for normal/ready status.

7. The same colour coding strategy is applied to every display used by the same controller.

8. No more than two levels of blinking are used.

9. If blinking is used, it is cancellable by the controller.

10. For a time-critical warning system (such as a conflict detection or resolution advisory), the controller response time has been measured and is within acceptable limits.

11. This design effectively directs the controller's attention by means of alerting, coding, and emphasis techniques.

12. If size coding is used it is limited to two widely different sizes.

13. Alerts have a low incidence of false alarms.

14. Information that is blinking, has an "on" period that is at least as long as the "off" period.

15. If blinking is used, the blink rate is between 2 and 3 Hz.

"II.   AUDITORY ALERTS

A. General

1. Auditory alerts are used only when necessary.

2. The number of auditory alerts is sufficient, that is, auditory alerts are included wherever they are needed.

3. The meanings of auditory alerts are readily apparent.

4. All proposed auditory alerts have been tested and evaluated in a realistic environment by a representative set of controllers.

5. The auditory alert does not nag, or otherwise annoy, the controller.

6. Auditory signals (and speech messages) are not masked by other auditory alerts or background noise.

7. For any situation, it is impossible for more than a few auditory alerts to be presented simultaneously.

8. The number of auditory signals (e.g., warnings, alerts) that the controller may need to identify is fewer than five.

9. Auditory alerts are easily discernible from other signals or noise.

10. Auditory alerts do not provide more information than is necessary.

11. The same auditory signal always indicates the same information.

12. Auditory alerts are consistently implemented throughout the system.

13. The information contained in an auditory alert is also displayed visually.

14. Auditory alerts are only used when immediate action is required.

15. Auditory alerts are cancellable by the controller.

16. A modulated signal emits from one to eight beeps per second.

17. A warbling sound varies from one to three times per second.

18. The frequency of all auditory signals is between 500 and 3 000 Hz so that they are well within the band of frequencies that humans are most sensitive to.

19. In general, auditory alerts sound for at least a 0.5 second duration.

20. The pause between repetitions of an auditory signal is less than or equal to three seconds.

21. Auditory alerts are at least 10 dB above ambient noise or have been demonstrated to be sufficiently intense for a specific working environment.

B.   Speech messages

1.   A detection signal display (for example the sound of static on the line) precedes a voice warning, unless a distinctive synthesised voice is used.

2.   Speech messages are short enough to be easily remembered.

3.   Brief speech messages are available to the controller when there is the need to explain the specific nature of alarm and warning signals.

4.   Speech displays are distinct from and not easily confused with other voices in the control room.

5.   The controller does not need to remember more than one or two speech messages at a time in order to accomplish any of his or her ATC tasks.

6.   Speech messages are not masked by other auditory alerts or background noise.

7.   If important messages are produced by synthetic speech, they are at least 8 Db above the surrounding noise.

"III.   DATA ENTRY PROCEDURES

A.   General

1.   The number of keystrokes (or other control actions) necessary to input data is kept to a minimum and the amount and complexity of data entry is about the same as was required in the previous system.

2.   With this system, data-entry errors can be caught and corrected before they propagate through the system.

3.   The design assists the controller in detecting and correcting errors in data entry.

4.   This system makes it easy to recover from data-entry errors.

5.   Keystrokes or other data-entry actions are echoed immediately on the screen, that is, there is no delay in providing a legible representation of what has been entered.

6.   The data entry method helps to minimise errors and provides for quick, simple data editing and correction.

7.   This user interface system queries the controller at critical choice points, e.g., "Are you sure you want to delete this flight plan?".

8.   A particular data item, such as assigned altitude, must be entered only once; the computer can retain this value and enter it in other fields, as appropriate.

9.   The controller receives appropriate feedback on data acceptance or rejection.

10.   The computer does not erase all or part of any erroneous data entry.

11.   The controller controls the pace of data entry, that is, the computer does not impose time limits or time outs.

12.   The computer does not restrict the order in which data items are entered.

13. The computer prompts the controller for data that have been deferred for entry.

14. Data processing is initiated only after an explicit command from the controller.

15. Boundaries indicate where to enter the data and show maximum field length.

16. A cursor appears to indicate data-entry mode and location.

17. The controller can edit all or part of a data field.

18. The controller is not required to enter leading zeroes for numeric entries.

19. When delimiters, such as punctuation, are required to partition long entries, the computer provides the required format and prompts for the order of data entry.

20. Field labels use accepted ATC terminology and are used consistently.

B.   Commands and Command Execution

1. Command execution requires minimal controller action.

2. The consequences of destructive commands (e.g., "Delete") are explained.

3. Destructive commands (e.g., "Delete") require controller confirmation of intention before they are executed.

4. Command execution always occurs by explicit controller action, never as a by-product of another action.

5. The controller can suspend/interrupt or cancel/undo a transaction in progress.

6. Command ordering is consistent from screen to screen/window to window.

7. Command labels use accepted ATC terminology and are used consistently.

8. The relevant command set is displayed to show the controller which commands are currently available.

9. Commands are consistent in their placement across multiple screens, panels, or windows; in their wording; and in their method of activation.

10. The computer indicates the current operational mode.

11. Entry of long sequences of command parameters is not required.

12. Upper- and lower-case letters are accepted as equivalent when the controller is entering a command or command parameter.

13. Feedback is always given to indicate that the computer has initiated a command.

14. Commands should be stated in the affirmative; that is, they should tell the controller what to do, rather than what not to do.

C.   Menus

1. Menu options are phrased to reflect the action executed and worded in user vocabulary.

2. Options that perform opposing actions are not placed adjacent to each other.

3. The number of menu options is between three and ten (five to six options is optimal).

4. If an option, or set of options, is never available to the user, the option(s) is not in the menu.

5. If an option is temporarily unavailable, it is displayed in the menu, but dimmed.

6. Menu options are organised in logical or functional groupings with clear titles.

7. If not in logical groups, order is by frequency of usage, with most frequently used options at the top.

8. If not in logical groups or by frequency, options are in alphabetical or numerical order.

9. Less frequently executed options and destructive commands are at the bottom of the menu.

10. If similar options are in different menus, the options are ordered in a consistent manner.

11. Each word in the menu is presented in upper and lower case with the first letter capitalised.

12. Cascading submenus appear to the right of the parent menu (below, if space to the right is limited).

13. When a menu is displayed, the location cursor is in the first available option.

14. When a pop-up menu appears, it appears near the element with which it is associated.

15. A window containing a pop-up menu provides an indication that the menu is available.

16. If they are presented in a vertical list, menu options are left justified.

17. Menu organisation supports specific controller tasks.

18. Graphical or textual aids are provided to assist controllers in navigating through menu structures.

19. The controller is required to traverse no more than four levels in a menu structure.

20. When a trade-off is required between menu breadth (i.e., number of options at a level) and menu depth (i.e., number of levels), the design increases breadth rather than depth.

D. Error Messages and User Guidance

1. Error messages are provided whenever needed.

2. Each error message briefly summarises the specific problem and proposes a specific solution.

3. Error messages are direct and precise.

4. Error messages are presented immediately after an error's occurrence.

5. Error messages are not redundant.

6. Guidance messages are presented in mixed upper and lower case.

7. Messages about limits not met or exceeded specify the appropriate range for data entry.

8. Questionable data entries elicit cautionary messages.

9. Feedback regarding processing delays specifies the process, the length of the delay, and completion of the process.

"IV.   DATA ENTRY AND CONTROL DEVICES

A. General

1. Input devices work in ways that are compatible and consistent with the controller's tasks.

2. The overall design of input devices does not require frequent switching between devices.

3. The input device(s) is/are appropriate for performing the necessary functions (e.g., alphanumeric data entry; selection of displayed objects; cursor positioning).

4. Input devices have been compared not only for speed and accuracy, but also for factors such as induced fatigue, resolution capability, and space requirements.

5. Controls and their labels are sufficiently visible under dim lighting conditions.

6. Input devices meet operational requirements for accuracy, force, feedback, precision, and manipulation.

B. Keyboards

1. Alphanumeric keys are arranged consistently on all keyboards that the controller will use. (The preferred arrangement is the QWERTY layout.)

2. Keyboards are readable under all operating conditions and backlit, if necessary.

3. If a numeric keypad is provided, it is visually separated from the main keyboard and arranged in a 3 X 3 + 1 matrix.

4. Function keys are provided for frequently used commands.

5. Function keys are clearly labelled to indicate their function.

6. The functions invoked by the function keys are consistent throughout the system.

7. Keys on keyboards and keypads have no more than two functions.

8. Non-active keys are left blank (i.e., not labelled).

9. The key used to initiate a command is clearly labelled "Enter".

10. Keyed data are displayed quickly (echoed) on the screen.

11. Tactile and auditory feedback are provided in response to keystrokes.

12. The main keyboard is located directly in front of and below the associated visual display, at a comfortable distance from the seated controller's position.

13. Forearm and wrist supports are provided.

14. Alphanumeric keys meet standards for dimensions, displacement, and separation.

15. Keyboard design includes guards to reduce inadvertent key activation.

16. If alternative keyboards are featured, they have been tested for usability and operational suitability.

17. The slope of the keyboard is adjustable between 15 and 25 degrees from the horizontal.

18. Keyboard height is adjustable between 23 and 32 inches.

C. Touchscreens

1. If a touchscreen is used, it is suitable for the task(s) to be performed by the controller.

2. Controllers can achieve sufficient touch accuracy with the touchscreen.

3. Touchscreen displays can be read easily under all anticipated lighting conditions.

4. The touch input strategy (e.g., land-on; first contact; lift-off) is compatible with the controller's task objectives.

5. Touchscreen displays meet standards for required finger pressure (displacement), separation of touch areas, and resistance.

D. Trackballs

1. The trackball can move the cursor in any direction without causing cursor movement in the opposite direction.

2. The trackball allows the controller to move the cursor quickly across relatively large distances and also to precisely position the cursor within a small area.

3. The trackball meets standards for physical dimensions, resistance, and clearance.

E. Control Grip Devices

1. Any input device meant to be held and operated by a standing controller can be held comfortably for a period of three to four hours.

F. Mice

1. If a mouse is part of the design, it can be used compatibly with all of the tasks the controller is supposed to perform.

2. Controllers can easily and smoothly position the cursor with the mouse.

3. Movement of the mouse produces cursor movement in the same direction on the display. For example, if the mouse is moved to the left, the cursor moves to the left on the display.

4. The mouse is equally usable with the left or right hand.

5. The mouse has no sharp edges and meets standards for width (1.5 to 3 in.), length (3 to 5 in.), and thickness (1 to 2 in.).

G. Graphics Tablets

1. Movement of the stylus in any direction on the tablet surface produces smooth movement of the cursor in the same direction.

2. When the stylus is placed at any point on the tablet, the cursor appears at the associated co-ordinates on the display screen and maintains that position until the stylus is moved.

3. If the stylus and tablet are to be used for free-hand drawing, the device generates a continuous line as the stylus is moved.

4. If a graphics tablet is used, frequent switching to the keyboard is not necessary.

5. The graphics tablet can be located on the workstation within a comfortable distance from the controller.

H. Pushbuttons (Actual and Virtual)

1. Mechanical pushbuttons are sized and spaced to support activation but to prevent accidental activation.

2. The surfaces of "hard" pushbuttons are rough or concave.

3. Labelling of virtual pushbuttons is consistent.

4. The active and inactive states of virtual pushbuttons are visually distinct.

5. The on-off status of software-generated togglebuttons is made clear through the use of labels and graphic indicators.

6. Mechanical pushbutton resistance is in the range recommended for single-finger operations (10-40 oz.).

I. Foot Switches and Pedals

1. Positive feedback is provided to indicate activation of the foot switch.

2. The controller is not required to operate more than one switch or pedal with the same foot.

3. Foot switches are positioned for operation by the toe or ball of the foot.

4. Foot switches/pedals meet requirements for dimensions, resistance, and displacement."

Chapter 5

RESEARCH

5.1 INTRODUCTION

The empirical lessons from the early implementation of CNS/ATM systems (mainly in the Pacific region) have been supplemented by several scientific studies on the effects of using CPDLC. These studies are either research-oriented or conducted in response to analysis of reports received through confidential safety reporting systems in the aviation industry. This chapter focuses on research on the *communication speed*, the *party line effect* and the *potential vulnerability to human error* of CPDLC. The recommendations from these studies complement the guidelines contained in Chapter 4 "The human-machine interface" and Chapter 7 "Standard operating procedures" of this Manual.

5.2 COMMUNICATION SPEED

5.2.1 High Frequency voice communication has served the aviation community for over five decades. As a consequence of its inherent propagation characteristics, however, it often takes considerable effort from flight crews or ground-based radio operators to successfully exchange messages. More to the point, establishing and sustaining two-way contact often proves difficult and requires a significant amount of time. The actual exchange of words normally takes place in a relatively short time.

5.2.2 CPDLC is expected to bring improvements in this area, especially when the ATN is available. VHF digital link (VDL modes 2, 3 and 4, see Chapter 3 "Data link infrastructure and applications") will enable more reliable technical means to exchange messages between ATC and flight crews. Yet it should be realized that with CPDLC a *written* message is sent from controller to pilot or vice versa, and this message requires composing by the sender and reading by the receiver. So although the transmission of CPDLC messages may be faster than establishing contact by HF voice, the time needed to compose, read and interpret the messages may actually be longer.

5.2.3 If no contact is established using HF voice, it will be apparent to the party trying to make contact that no message (e.g. a report, a request, a clearance, etc.) can be exchanged. Time spent on making contact is spent "off-line", as no actual communication is taking place. With CPDLC, however, the party initiating the transmission expects a reply from the other party almost immediately after sending the message. If the other party requires some time to reply, or elects not to attend to the incoming message immediately, the sender will experience the delay as time lost "on-line". The time required to complete the communication may therefore appear longer than when using HF voice.

5.2.4 A number of scientific studies have looked at the amount of time or the number of transmissions required to complete a communication when using data link versus voice communication. It was shown that total transaction time (i.e. the entire time span when a controller would be concerned with a given communication) was twice as long for data link as for voice. This can be explained by various factors such as the possibility of delayed responses to data link messages or by more time being required to compose data link messages. Also, the ability to delay attending and responding to an incoming message, until competing task demands allow for it, can create problems with respect to the timeliness and relevance of information.

5.2.5 Such delays may be a consequence of normal distractions, either on the flight deck or in the ATC facility. Other studies have shown that distractions occuring on the flight deck after the crew has accessed the message (i.e. brought it up on the screen, but not yet completely read or interpreted it), have a potentially large impact on message acknowledgement times. Handling of other tasks after accessing the data link message also seemed to be procedurally problematic. Half of the messages with distractions were not acknowledged by the flight crews, and the remaining messages had acknowledgement times almost three times longer than considered desirable.

5.2.6 Several airlines have meanwhile introduced the flight deck procedure to first print the content of an

incoming FANS-1/A CPDLC message. The pilot not flying (PNF) then reads it out aloud, and both pilots discuss and interpret the message before composing and sending a reply to ATC. This obviously affects the total transaction time for the communication.

5.2.7   The shift to processing messages to the visual modality from the auditory channel may lead to increased modality competition between accessing ATC information content and the already visually laden flight deck environment. This modality shift in the presentation of ATC information appears to fundamentally change the role of the PNF in the communication cycle. The PNF becomes the primary distributor of the ATC message content in data link compared to acknowledging and verifying information transfer in the present voice system. Results from one study suggest that the amount of message content the PNF makes available within the flight deck can affect both the understanding and timing of the overall message.

5.2.8   In summary, the existing potential for delays in the flow of communication suggests that current data link implementations may not be well suited to handling the majority of transmissions in the future ATM environment, where most communication can be expected to be time-critical so as to support the planned tactical approach to traffic management. Many researchers and practitioners agree that even in the current ATC system, data link should not be used to transmit time-critical, immediate action messages.

5.2.9   Recommendations:

•   Air traffic controller training for the use of CPDLC should include awareness of related flight deck procedures used by operators in their area of jurisdiction; and

•   Standard operating procedure design and training for controllers must incorporate the fact that voice communications are the preferred option for transmitting time-critical immediate action messages.

5.3   PARTY LINE EFFECT

5.3.1   The phrase "party line information" has its origins in a commercial telephone service that has been offered in several countries by high-tech entrepreneurs since the late 1980s. This service, called the "party line", makes it possible for a high number of individual callers to engage in a group conversation on the same telephone line.

Every participant can hear what the others say, even if they themselves are not actually taking part in the discussion.

5.3.2   The conventional radiotelephony (R/T) system used in aviation possesses this same attribute. Pilots who are not actively involved in an R/T conversation can overhear what is being said by other pilots and by ATC. Consciously but also subconsciously this provides them with information that they will use in subsequent stages of their flight(s).

5.3.3   An example of consciously received party line information via R/T could be a report by a preceding aircraft of turbulence at a certain position or level. Overhearing this report allows a crew to anticipate the turbulence and possibly even plan an alternative strategy to avoid the area.

5.3.4   Subconsciously received R/T party line information can simply be the notion that it is very busy on the frequency. Yet this notion will likely cause pilots to be more alert to what is said on the R/T in general, and for calls to their flight in particular. At the same time it will keep them from making extra requests to ATC, and when they do communicate, they will keep their messages as short as possible without having to be asked to do so.

5.3.5   When the research community began to study the differences that could possibly occur as a result of the introduction of CPDLC, they adopted the phrase "party line information" to describe the effects mentioned above. The studies that so far are available seem to indicate that the loss of party line information, in an environment where R/T communications are replaced by CPDLC, is something that cannot be ignored. This leads to the following conclusions:

"The presentation of information currently available from party line information must be a consideration during implementation of data link communications. The importance of party line information was found to be significantly higher in the busier and higher density phases of flight near the airport, suggesting any initial implementation of data link communications in Terminal Area control sectors will need to be well compensated for party line information loss.

"Specific Traffic and Weather party line information elements were identified as critical. These results, combined with the common citing of these two types of information as necessary for 'The Big Picture' suggest Traffic and Weather information is required for pilot global Situational Awareness." *(Variations in "Party Line" information importance between pilots of different characteristics.)*

5.3.6 Recommendation:

- Design of CPDLC systems and associated procedures must include provisions to compensate for the loss of party line information as compared to conventional R/T communications.

5.3.7 It could be argued that the traffic information element eventually will be compensated for by the cockpit display of traffic information (CDTI, see Chapter 8 "New flight deck technology"), a tool that will be enabled by ADS-Broadcast (ADS-B, see Chapter 3 "Data link infrastructure and applications"). Yet it should be realized that the implementation of CPDLC will precede the possible implementation of CDTI and ADS-B by a significant time span. States that are about to introduce CPDLC into their airspace may have to find other ways to compensate for the loss of party line information.

5.3.8 Recommendation:

- When introducing CPDLC, alternative procedures must be developed for those cases where no technological means of compensation are available for the loss of party line information as compared to conventional R/T communications.

5.3.9 These alternative procedures could take different forms, depending on the situation to which they apply. A State might decide to authorize CPDLC for use in the en-route phase of flights only; it might decide to authorize CPDLC only as a back up for conventional R/T communications (which would probably lead to increased workload for controllers and pilots); or it might decide to authorize CPDLC only for the transfer of *information* while the transfer of *instructions* would still be via R/T communications. It is emphasized that these examples should not be seen as limiting or restricting the options available to States.

Note.— See also Chapter 7 "Standard operating procedures".

5.3.10 It should be realized that similar provisions will need to be in place even once the use of VDL Mode 3 (transfer of digitized voice and data, see Chapter 3 "Data link infrastructure and applications") has become an integral part of the ATN. VDL Mode 3 communications are point-to-point transmissions, which means that no stations other than the sender and the receiver can hear any voice communication in progress.

5.4 VULNERABILITY

5.4.1 This section uses two case studies to demonstrate CPDLC's potential vulnerability to human error. Both case studies are based on reports from the Aviation Safety Reporting System (ASRS, USA). In both cases the type of aircraft involved was a Boeing 747-400. For the sake of readability, the abbreviated format of the original narratives is replaced by the full words.

5.4.2 *Case Study 1: Flight crew misunderstanding of a conditional altitude clearance.*

5.4.2.1 The following narrative is from the ASRS incident report filed by the flight crew:

"We were 3200 lbs. behind our flight plan fuel forecast, and because of aircraft reluctance to climb, I requested an off course climb to FL350, a more efficient altitude for us. The following clearance was received from ATC, 'cleared direct 1510N 150W, direct 12N 156W, direct 05N 164W, at 150W climb and maintain FL350, report reaching FL350'. We both somehow missed the 'at 150W' restriction and began a climb to FL350 on the new heading. After reporting level at FL350 we received a message from ATC, 'your clearance was to climb at 150W, not before, verify alt.' We were both surprised by this message.".

5.4.2.2 The reporter goes on to describe what the crew did, then speculates about what might have led them to overlook a crucial part of the clearance:

"I feel several factors contributed to the error. [1:] Both the FO and I had little actual experience using FANS since our original training in late 1995, and this was our first time seeing the ATC uplink clearance format. [2:] The new clearance was quickly accepted using the accept prompt, this action changed the screen to the verify response page, and diverted us from the print prompt which should have been selected before sending the accept message. [3:] If just the CDU screen is used to read the clearance, the critical word "at" is in small font, and very easy to overlook with dim screens and tired eyes. [4:] The correct operational procedure is to "print and read aloud" and had we followed the procedure, the incident would not have occurred. However, nearly 1 year has elapsed since initial FANS training. This long period of time without actual hands on experience presents an opportunity for procedural errors."

5.4.2.3 The reporter identifies four contributing factors:

1) crew unfamiliarity with the data link interface;

2) disappearance from view of the "print" prompt (and the "at 150W" phrase) when the CDU page changes;

3) mixed font formats that make the short word "at" even harder to notice; and

4) a long interval (roughly ten months) between training and initial use that made trained procedures difficult to remember.

5.4.2.4   One additional factor was not apparent to the captain nor to anyone else until a few additional incidents were reported. The flight crew had asked for (and were eager to receive) a climb clearance. They were not expecting the conditional restriction "at 150W" that delayed the clearance to FL350 and overlooked it when reading the ATC uplink message on the CDU.

5.4.2.5   Although conditional clearances may also be misunderstood or forgotten in voice communications, the readback requirement and opportunity for the controller or radio operator to emphasize the conditional restriction make it less likely that an error will occur.

5.4.2.6   Recommendation:

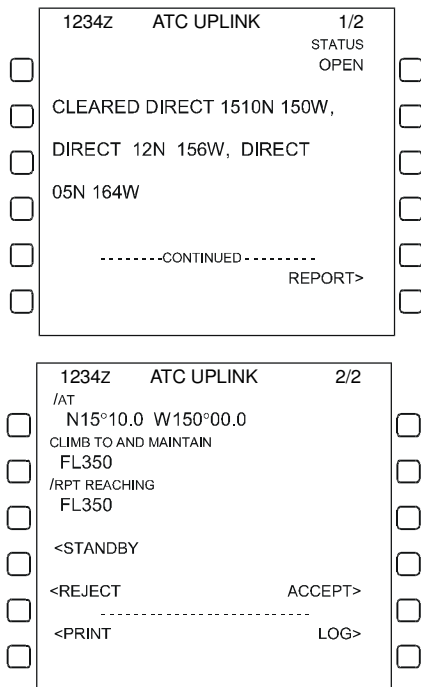• CPDLC procedures should avoid conditional clearances; and

Figure 5-1.   Re-creation of the ATC Uplink CDU pages described in Case Study 1

• ATS CPDLC operator training should include information on the opportunities for human error when issuing conditional clearances by CPDLC.

5.4.2.7   Perhaps the most interesting conclusion from this example is that the significance of the conditional element in this data link clearance was not recognized until a number of similar incidents had occurred. System designers, message set developers, Human Factors analysts, fleet training personnel and trained flight crews did not detect or immediately recognize the vulnerability of conditional elements in data link clearance messages. This was a lesson waiting to be learned from operational experience.

5.4.3   *Case Study 2: Significance of "accept" and "reject" as data link response labels.*

5.4.3.1   The flight in this case study was cleared to operate in a block altitude from FL290 to FL330. After three hours the crew was asked to "say time able FL350". Shortly after responding to this message, the aircraft received a subsequent clearance by data link as described in the narrative part of the ASRS report filed by the crew:

"At xxxxZ we received the following CPDLC message: 'xxx ATC clears aircraft x descend to and maintain FL310 report reaching. Descent necessary due to opposite direction company traffic'. The ACARS provided 2 prompts ("accept" or "reject") for response to this message. The way it is presented to the pilot makes it seem that you do have an option. The lower altitude was unfavorable and because we were down on our fuel score I felt that I needed to reject the clearance. A few minutes later we were selcalled. They wanted to know why we didn't want to descend. I told them because of fuel burn concerns. In the meantime, we started to re-evaluate the higher altitude."
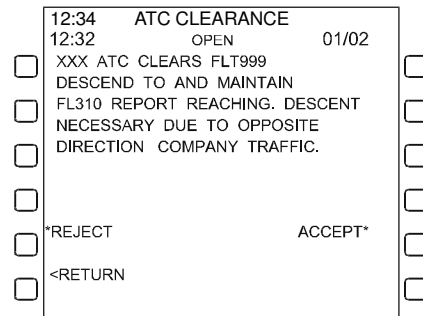

Figure 5-2.   Re-creation of the ACARS display described in Case Study 2

5.4.3.2   In an ASRS callback interview, the reporter again told the analyst that: ..."he believed the ACARS machine (CPDLC) gave a clearance which could be accepted or rejected because that is what the options were on the selection menu of the aircraft's receiver".

5.4.3.3   The captain certainly has the authority to reject any clearance that is felt to be unsafe, and concern about fuel burn is a good reason to reject the descent clearance. So it is interesting to note that the reporter suggests — not once, but twice — that the labels on the prompts for responses influenced the decision.

5.4.3.4   The example shows how standard message formats, interface labels and transmission delays might distort communication between the pilot and controller in the data link message exchange. In this case, the crew apparently felt that the controller had offered them a choice of accepting or rejecting the descent clearance, and the controller may have felt the crew was being uncooperative — refusing to either climb or descend from their current altitude.

5.4.3.5   Finally, the example illustrates some of the unintended side effects of changing from voice to data link for pilot-controller communication. One of these conse-quences is increased difficulty in conducting any dialogue or negotiation that requires more than a simple question-reply exchange.

Note.— Boeing has not adopted the described format in the implementation of CPDLC for the 757/767 series, and a modification is being developed for the 747-400.

5.4.3.6   Recommendations:

- Training for ATS CPDLC operators should include awareness of the capabilities and limitations of the CPDLC interfaces on the flight deck of relevant aircraft types; and

- Procedures including the use of voice communications should be established as alternative to the use of CPDLC for complex dialogues or negotiations.

Conclusion

5.5   The two case studies demonstrate some of the negative side effects of changing from voice to data link for pilot-controller communication: conducting a dialogue becomes more difficult; the absence of readback oppor-tunities removes an important error-trapping mechanism; the intent of the communication can be affected by the mechanics of data link. The importance of the system

interface in data link communication was also demonstrated: message presentation format and function labels played a significant role in both ASRS incidents.

5.6   Standard phraseology and voice communication protocols are replaced in data link by standardized message sets (often based on voice phraseology) and new interface conventions. As both examples show, data link messages are not directly equivalent to voice clearances, and attempts at direct translation cannot guarantee that safeguards evolved over years of radio voice communication will successfully transfer to data link. Both examples demonstrate that new problems are encountered with data link communication and different safeguards must be developed.

5.7   Finally, to quote research: "Although the focus of the studies has been on exploring problems encountered with use of FANS-1 CPDLC, early survey results indicate that pilots find it a great improvement over HF voice for most oceanic communications with air traffic control. The discussion has offered some preliminary lessons that can be learned from operator experiences with the system. However, it is not the intent to suggest that CPDLC is inferior to voice for pilot-controller communication." *(An assessment of flight crew experiences with FANS-1 ATC data link.)*

5.8   Recommendation:

- Use of the available confidential reporting mechanisms to describe operator experiences must be encouraged so that the operational problems encountered can be thoroughly analysed and the system improved. Submission of such reports should not divert crews from submitting reports to their organizations in support of FANS Interoperability Team efforts to improve the system as a whole.

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Chapter 6

PREPARING FOR CHANGE

6.1   INTRODUCTION

The development, acquisition and implementation of CNS/ATM systems for ATS are complex processes with many facets. States and organizations that make the transition to new technology and new procedures need to prepare for this change several years ahead of the envisaged transition day. In this preparation all aspects related to the transition must be considered. This chapter addresses:

— writing of system specifications;

— development of a Human Factors plan;

— the operating philosophy;

— changing team roles;

— early prototyping;

— planning and timing of training;

— training content; and

— regulatory aspects.

6.2   WRITING SYSTEM SPECIFICATIONS

6.2.1   One common feature of recent successfully completed programmes to introduce new ATC equipment is that early in the process a multidisciplinary team was formed to guide the procurement of the new equipment. Such a project team comprises a mix of technical and operational expertise from the groups that ultimately will be using the new system. Engineers, air traffic controllers, flight data personnel, flow controllers, software experts and trainers are all represented on the team. The individual team members are selected because of their personal interest and motivation to make the new system happen. For certain stages of the process, the team may be expanded to include safety-occurrence investigators, simulator operators and/or data analysts. The project team should include a human performance specialist.

6.2.2   The following excerpt from *Human Factors in the Design and Evaluation of ATC Systems* provides an adequate insight into the need for a team approach:

"When a Human Factors evaluation of a system or subsystem is warranted, it should be designed by a team that includes Human Factors specialists and operations specialists. Since there is no licensing procedure for Human Factors specialists, they can only be judged by their credentials and previous experience. A successful (i.e., helpful) Human Factors specialist is likely to have an advanced degree (in an area of experimental or engineering psychology, Human Factors, or a related field) and experience in a specific area (e.g., ATC). Operations specialists are intimately familiar with the operational environment (e.g., a specific cockpit or ATC facility). They represent the potential users and are usually operators (e.g., pilots or controllers). As long as they are operationally current (i.e., knowledgeable of current issues, procedures, and practices), they are the most appropriate source for information on user preferences and suggestions for symbology, terminology, display layout, and other factors.

"Even the most experienced users should not be solely responsible for the user-machine interface, however. In fact, many years of experience can occasionally be a liability in making such decisions, since the skills and knowledge that develop with extensive experience can often compensate for design flaws that may then remain unnoticed.

"For these and other reasons, it is important for operations specialists to work with Human Factors specialists in the planning and conduct of a Human Factors test. Human Factors specialists are intimately familiar with the capabilities and limitations of the human system, testing methods, and appropriate data analysis techniques. They can point out potential problems that operational specialists might overlook. Working together, the two types of specialists can predict problems and head them off before they occur in actual operations. Together, Human Factors specialists and operations specialists are equipped to decide exactly what needs to be tested and how it should be tested."

6.3   HUMAN FACTORS PLAN

6.3.1   The development of a formal Human Factors plan ensures that Human Factors considerations are fully incorporated into system design. This plan addresses the human performance and staffing parameters for programme and design alternatives. The plan is first developed at the very start of the project and updated during each subsequent acquisition phase. The initial Human Factors plan outlines the issues, tasks and strategies associated with human performance considerations in the operation, maintenance and support of system options. Subsequent updates to the plan further define and refine the human parameters of the programme and ensure the identification and resolution of Human Factors problems and issues in the programme. The Human Factors plan should be designed to be a living document; it should be tailored to the specific programme requirements, procurement strategy, key decision points and acquisition phase as well as to customer considerations of the programme. It imposes only the necessary and reasonable requirements to achieve the objective effectiveness of human performance during system operation, maintenance and support, and the efficient use of personnel resources, skills, training and funds.

6.3.2   Table 6-1 contains the content and format for a Human Factors plan.

6.4   OPERATING PHILOSOPHY

6.4.1   Being part of the procurement process of new equipment presents participants with the opportunity to introduce basic requirements or aspects into the system. But before going into detail about what certain system elements should or should not look like, it is recommended for the procurement team to formulate an *operating philosophy* that should govern the design of the entire system.

6.4.2   An example of such a philosophy could be that in the new system "users will have all the available information displayed to them at all times". This philosophy will no doubt result in a system design that is different from one that is built on the philosophy that "users will have access to all available information without having to go through more than three levels of menus at all times".

6.4.3   These are but simple examples. In reality there may be a requirement to formulate several of such philosophies to govern the design of the system. One philosophy would be for the access to information, a second would be for the use of one display screen versus multiple screens, a third would be for the available and applicable level or levels of automation, a fourth would be for the (de)centralized control of the system configuration, and so forth. It may be necessary to assign a certain level of importance to each of the philosophies in order to be able to determine which has priority over another and thus avoid conflicts. For example, a philosophy that "users will have all the available information displayed to them at all times" would probably conflict with a philosophy "to only have one display screen at the working positions".

6.4.4   It will be one of the most important tasks of the procurement team to coherently formulate the operating philosophies for the system. Admittedly this will take some time at the very beginning of the process, but it will be time well invested. During the subsequent lifetime of the process it will be possible to refer to the agreed philosophies and verify that every step about to be made, or that has just been completed, is compatible with those philosophies – which in fact is the main reason for having them.

6.4.5   By applying the principles of Human-centred Automation (see Chapter 2 "Three essential concepts") to the operating philosophies, the end-result should be a system that supports the users in their operational tasks, removes non-essential tasks, reduces workload, improves performance and increases efficiency. Such a system enhances the safety element of the users' tasks, in addition to the job satisfaction of the users.

6.5   CHANGING TEAM ROLES

6.5.1   Most forms of computer assistance in ATC are to support the tasks of individual controllers although traditionally many functions have been performed by teams or by individuals working within teams. The purpose of introducing computer assistance is to help each single controller and to improve the efficiency and safety of ATC. Any associated changes in team roles are considered incidental consequences instead of stated objectives.

6.5.2   Most of the changes in team functions are a consequence either of the reduced observability of controller actions and effectiveness or of the failure to devise forms of computer assistance that can be applied collaboratively by teams to ATC. Many of the traditional roles of teams become more difficult for controllers to fulfil as team members if the available forms of computer assistance only help their individual tasks. Examples include discerning the controlling style of colleagues, the allocation of responsibilities among team members, and the identification of training needs.

Table 6-1.   Human Factors plan content and format

Headings		*Content*
Background	Programme Summary	• Brief description of the programme • Concept of operation and maintenance
	Programme Schedule	• Overview of system acquisition schedule
	Target Audience	• Identify the user and maintainer • Demographics • Biographical data • Previous training • Aptitudes • Task-related experience • Anthropometric data • Physical qualifications • Organizational relationships • Workspace requirements (Appendix if data are lengthy)
	Guidance	• Summarize any guidance received
	Constraints	• State if additional staffing is required by the new system • State whether an existing job series will be used or a new one created • Post limits on the amount of time that can be afforded for training • Establish standards on the working conditions that will be acceptable when the new system is fielded
Issues and Enhancements	Issue Description	• Describe the issue or problem background, importance and consequences or task to be done to support the acquisition
	Objectives	• Identify Human Factors Programme objectives • Provide performance measures and criteria in terms of time and accuracy to perform tasks to evaluate resolution of issue • When human performance thresholds are known, identify tasks for the developer to be done early enough in the acquisition process to influence requirements and system engineering • Identify the actions to be taken to resolve each issue • Show the current status of each issue
	Actions	• Identify actions to be taken to resolve issues • Show current status of each action
Activities	Activity Description	• Identify any tasks, studies or analyses that must be performed to resolve the issues
	Activity Schedule	• By acquisition phase, describe the Human Factors tasks in terms of who, what, when and how (resources) • Identify feeds to and dependencies on logistics support, training and test and evaluation programs

Headings		*Content*
Strategy	Goals and Requirements	• Strategy should be derived from the major concerns, issues, schedule, tasks, guidance, constraints, objectives and approach for the Human Factors Programme • Answer the question, "What objectives does the organization wish to achieve?" • Answer the question, "How will the organization accomplish these objectives?"
	Approach	• Define who will be responsible for the Human Factors Programme • Set out the extent of contractor support required • Define how the Human Factors coordinator will support the acquisition team
	References	• Identify relevant references needed for a full understanding of the Human Factors plan (Use appendix if appropriate.)
Review, Approval and Distribution	Review/Approval	• Identify administrative handling procedures • Identify update schedule and procedure • Identify review and approval authority and procedures
	Distribution	At a minimum, the Human Factors plan and each update should go to system engineering representatives and personnel with oversight responsibilities

6.5.3   Controllers may have less evidence available to detect when a colleague is tired, incapacitated or inexperienced, and fewer possibilities to intervene even when such judgements are still possible with some validity. Each controller's picture of the traffic tends to be confined more within the individual region of responsibility. This is because the reduced contact with other team members tends to remove opportunities to supplement the picture with a framework of broader information about the traffic in other regions. As a result, the controller's Situational Awareness (see Chapter 2 "Three essential concepts") is reduced, although the aim of advanced systems usually is to enhance Situational Awareness.

6.5.4   To avoid this situation the effects of the new system on team functions should be taken into account early in the design process. This is particularly relevant when it is foreseen that, in the new system, two persons will operate ATC functions that were the responsibility of a single controller in the old system. An example of this situation could be the introduction of ADS into an environment where previously only procedural control was available. If the ATS provider elects to have the ADS workstations manned by two controllers, it should be clear from the outset what the individual responsibilities of each controller are, as those responsibilities will have a direct impact on the design of each working position.

6.5.5   One initiative that has been developed to help the transition to new technology is that of team resource management (TRM) training for ATC. Within Europe, this initiative has fostered the development of various approaches from a teamwork perspective. Topics include safety practices, teamwork, the roles within the team and issues such as collective Situational Awareness, decision making and stress management.

Note.— More information on TRM can be found in the Eurocontrol Guidelines for Developing and Implementing Team Resource Management.

6.6   EARLY PROTOTYPING

Experience from ATS providers who recently accomplished a successful transition to an advanced ATM system indicates that there can be significant benefits from employing early prototypes of (components of) the new system. An "early prototype" of a system or system component is normally a first developmental version of the manufacturer's interpretation of the design specifications. By showing this first version to the end-users, i.e. the controllers (or other operators) who will ultimately work with the new system, and inviting them to interact with and

comment on the prototype, valuable feedback can be obtained. This feedback can be used to improve or modify the design where necessary. At the same time the early exposure to the new system will promote user acceptance, in particular when comments from the user population are seen to be taken seriously. To that end it should be ensured that feedback on the use of the received comments is provided to the end-users throughout the process.

6.7   PLANNING AND TIMING OF TRAINING

6.7.1   One of the lessons learned from the introduction of new and complex ATM technology is that generally not enough time appears to have been reserved for a proper training programme for the operators to learn how to use the new equipment. For a variety of reasons most of the systems were delivered only after a considerable delay in time which meant the original planning for the implementation could not be met. Since usually those systems were overdue to replace the previously used systems, there was considerable pressure on the ATC providers to start using the new systems almost immediately after the manufacturers had finished the technical installation.

6.7.2   As a result, training programmes for the conversion from the old system to the new sometimes are started before the final development of the system has been completed. Testing of the system, and adding modifications to the system, is taking place in parallel with the training of the staff who will use the system eventually. This is illustrated in Figure 6-1.

6.7.3   A major drawback of this situation of course is that at the time of implementation (i.e. actual use) of the new system, few (if any) operators will have received any training on the operation of the system in its final form. Sometimes subsystems may not have been available during training at all, so that the first time the operators see the
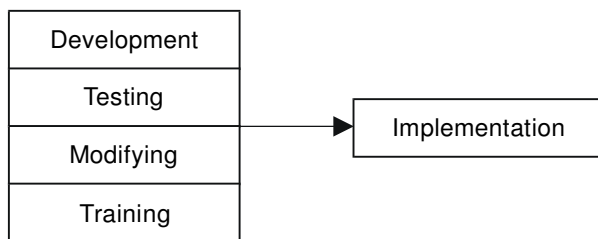

Figure 6-1.   Actual or observed situation

complete system is the day they are expected to start using it. There may be significant differences in the quality and fidelity of training received by individual operators. Not surprisingly, it will take the operators several days or even weeks to sufficiently acquaint themselves with the new system(s). Until the time they feel comfortable operating the system(s), they are likely to handle traffic more conservatively than envisaged by the designers of the system and probably even more conservatively than they did using the old system, which in turn will detract from optimum system performance. By more careful planning of the process, this undesirable situation could have been avoided for all.

6.7.4   The following quote from *Computer-Human Interface Evaluation of the Oceanic Data Link System* demonstrates that the situation described above is not a hypothetical one: "The primary training issues appear to be that training is conducted on a simulator that is not identical to the system to be used in operations, there is minimal controller exposure to the new system, and there is limited refresher training. Due to the frequent changes in the new system (particularly command labels), controllers find that much of what they have learned is no longer accurate and they must use trial and error to identify new or modified commands."

6.7.5   Experience shows that it is unrealistic to expect a new system to be ready for use the day the manufacturer releases it to the customer (the ATC service provider). Despite the fact that at that moment the system formally meets the specifications to the satisfaction of the customer, preparations by the customer for several minor or major modifications to the system (usually in the software) will already have been made. The reason for adding those modifications only after having formally become the owner of the system, rather than during the installation phase, is purely financial. Were they to be done during the installation, the manufacturer would have probably considered them to be a deviation from the original specifications, for which there normally would follow a charge. By doing the modifications after accepting the system from the manufacturer, the new owners may not have to pay such additional costs.

6.7.6   Ideally, training of the operators would only commence after those modifications have been incorporated into the system. At that point in time all developmental work and testing should have been completed and the system will be in its operational state. All operators receive training on the most recent version of the system and will soon feel comfortable using it. There will probably still be a requirement to allow for a minimal transition time, during

which the organization will start using the new system and stop operating the old one, which may cause some disruption to normal operations in the airspace concerned. Through a careful information campaign, the airspace users can be informed of this in advance though, and they in turn can plan for the inconvenience, too.

6.7.7   It should be realized that the linear time-schedule from Figure 6-2 does not imply that preparations for the training cannot start before completion of the system. In fact, as argued before (see 6.3.1), those preparations should start as early as the writing of the system specifications. If the system features a training simulator, which with advanced and complex systems is normally the case, the specifications for this simulator and its connection with the operational system should be included in the system specifications. Also, by involving trainers from the early stages onward in the design and development of the project, they will obtain a good understanding of the various aspects of the system, which will enable them to transfer relevant knowledge to the training programme.

6.8   TRAINING CONTENT

6.8.1   When implementing new equipment and/or new procedures, the main focus of associated training programmes obviously will be on the HMI features of the new equipment and application of the new procedures. What is less obvious, however, is that for optimal operator performance it is necessary as well to address other aspects in such training programmes. These aspects include understanding of the applied philosophies in the system design, understanding of the (changing) team roles within the ATS unit, understanding of the interaction of the new equipment with other equipment, and understanding of concepts such as Situational Awareness and Error Management (see Chapter 2 "Three essential concepts").

6.8.2   Previous chapters in this manual suggest various items for incorporation into training programmes related to the implementation of ATM systems. For convenience, these items are summarized below:

Chapter 2 — Three essential concepts/Situational Awareness

- ATC training programmes in general should include teamwork training. Training programmes associated with the implementation of advanced systems should in particular include teamwork training.

- Training programmes for air traffic controllers should include awareness of the importance of specific aspects of differences between operators and between individual pilots.

- Training for air traffic controllers should include proficiency in the application of procedures related to the failure of navigational aids.

- Training programmes for air traffic controllers should include awareness about aspects of differences and variations in aircraft performance.

- Controller training must include proficiency in the application of procedures related to the failure of ATC equipment.

Chapter 3 — Data link infrastructure and applications

- Operators and users should be made aware of the inherent limitations of any deployed technology.

Chapter 5 — Research

- Air traffic controller training for the use of CPDLC should include awareness of related flight deck procedures used by operators in their area of jurisdiction.
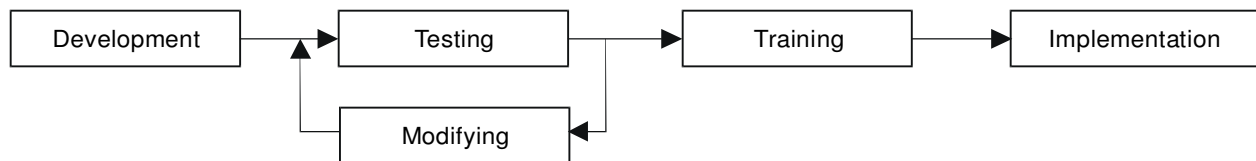

Figure 6-2.   Ideal or desired situation

- Standard operating procedure design and training for controllers must incorporate the fact that voice communications are the preferred option for transmitting time-critical immediate action messages.

- ATS CPDLC operator training should include information on the opportunities for human error when issuing conditional clearances by CPDLC.

- Training for ATS CPDLC operators should include awareness of the capabilities and limitations of the CPDLC interfaces on the flight deck of relevant aircraft types; and

- Procedures including the use of voice communications should be established as alternatives to the use of CPDLC for complex dialogues or negotiations.

6.9   REGULATORY ASPECTS

6.9.1   The implementation of a new and advanced ATM support system may require certain actions from the State's air safety regulatory authority. In particular the regulator may wish to become involved in the *certification* of the new equipment, as well as in defining specific *licensing* criteria for the operators of the new system(s).

Certification

6.9.2   The certification of ATM equipment is a relatively new area in air safety regulation. Historically, ATM systems have by design been rather autonomous pieces of technology. Requirements that needed to be fulfilled for interactions with other systems (both airborne and on the ground) were fairly basic and mainly consisted of precise technical specifications. In essence, ATM systems were designed to operate independently of airborne equipment (with the notable exception of transponders), and the airborne equipment was designed to operate independently of the ATM equipment. The introduction of CPDLC and ADS brings a major change to this practice. ATM equipment and airborne equipment become interdependent (CPDLC), or ATM equipment even becomes largely dependent on airborne equipment (ADS — hence the name Automatic **Dependent** Surveillance).

6.9.3   This implies that air safety regulators in principle become responsible for the correct functioning of ATM equipment in conjunction with airborne equipment. In fact this is not a new responsibility, since the regulators have always been ultimately responsible for the correct functioning of ATM equipment. Yet that responsibility has not always resulted in a formal certification process for ATM equipment. With the implementation of, for example, CPDLC and ADS-based services in a State, it becomes necessary to establish such a formal certification process in order to ensure compatibility of the new equipment with that in adjacent States as well as with airborne equipment (avionics).

6.9.4   It goes beyond the scope of this Manual to offer detailed information on the certification process for ATM equipment. For the purpose of this chapter it suffices to identify the requirement for certification of the equipment. The graph in Figure 6-3 illustrates where certification fits in the time-schedule presented earlier.

Licensing

6.9.5   The graph in Figure 6-3 also illustrates where licensing fits in the time-schedule for the implementation of new ATM equipment. The introduction of CPDLC and/or
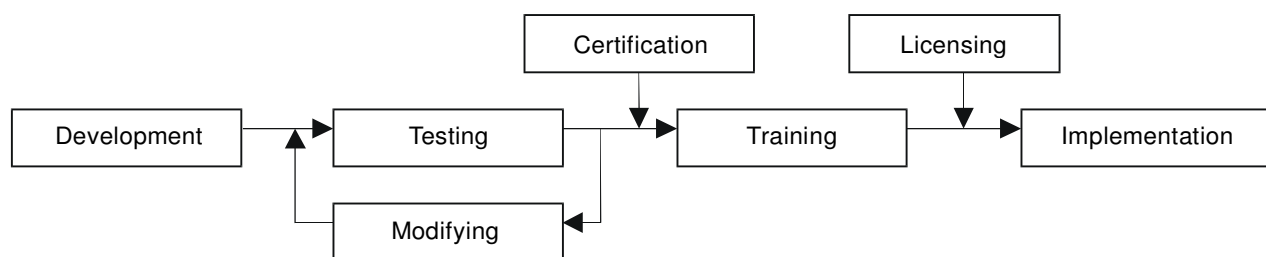
Figure 6-3.   Time-schedule including certification and licensing

ADS-based air traffic services will require licensing authorities to review their existing licensing schemes. Just as not every person who can speak is thereby qualified to use radiotelephony (R/T) communications, it should not automatically follow that any person who is qualified to use R/T is also qualified to use CPDLC. For the provision of ADS-based air traffic services, which fundamentally differ from both procedural control and radar control, it is evident that operators will first need to have obtained an adequate level of knowledge and skills relevant to these services.

6.9.6   By adding appropriate requirements for knowledge and skills related to CPDLC and ADS-based air traffic services, the licensing authorities will ensure that the new services are only provided by qualified operators.

6.9.7   In a proposal for a European Manual of Personnel Licensing for Air Traffic Controllers, the concept of distinguishing ratings for tower, approach and area control is introduced based on whether or not the service is provided with the aid of surveillance equipment. In case surveillance equipment is used, the type of equipment for which the licence holder is qualified is specified in what has been provisionally labelled an "endorsement" to the rating. Such an endorsement could also be used to indicate on the licence that the holder is qualified to use CPDLC, both for the Procedural and the Surveillance ratings. (See Figure 6-4.)

6.9.8   This concept offers States and regulatory authorities flexibility to adapt their licensing schemes to the operating practices of the air traffic service providers. It also allows for the future introduction of other means of surveillance by simply adding an endorsement to the scheme where appropriate.

Note.— See also the ICAO Manual of Procedures for Establishment and Management of a State's Personnel Licensing System *(Doc 9379).*

6.10   RECOMMENDATIONS

* A multidisciplinary project team should be formed to guide the procurement of new equipment.

* The project team should consider the development of a formal Human Factors plan.

* The project team should formulate an operating philosophy to govern the design of the new system. This operating philosophy should be based on the concept of Human-centred Automation.

* The effects of the new system on team functions should be taken into account early in the design process.

* The project team should consider the use of "early prototyping".

* All operators must receive training on a version of the system that is similar to the operational version.

* Training for operators should not be restricted to the HMI features of the new equipment and application of the new procedures. It should include such aspects as understanding of the applied philosophies in the system design, understanding of the changing team roles within the ATS unit, understanding of the interaction of the new equipment with other equipment, and under-standing of concepts such as Situational Awareness and Error Management.

* States and regulatory authorities must consider the implications for certification of ATM equipment and for ATC licensing schemes in a timely manner when implementing CNS/ATM systems and/or related services.
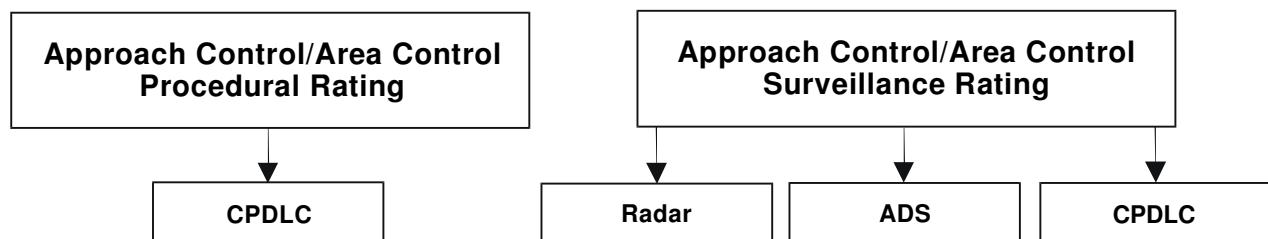
```
┌─────────────────────────────┐      ┌─────────────────────────────────────────────┐
│  Approach Control/Area Control │      │       Approach Control/Area Control           │
│       Procedural Rating       │      │            Surveillance Rating                │
└─────────────────────────────┘      └─────────────────────────────────────────────┘
              │                          │              │              │
              ▼                          ▼              ▼              ▼
         ┌─────────┐              ┌──────────┐   ┌─────────┐   ┌─────────┐
         │  CPDLC  │              │  Radar   │   │   ADS   │   │  CPDLC  │
         └─────────┘              └──────────┘   └─────────┘   └─────────┘
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Figure 6-4.   Sample endorsements to ratings

Summary

6.11   The flow chart in Figure 6-5 provides a schematic summary of the items discussed in this chapter and incorporates the recommendations listed above. The chart contains a reference to standard operating procedures, which are discussed in Chapter 7.

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Cardosi, Kim M. and Elizabeth D. Murphy. (eds.), *Human Factors in the Design and Evaluation of Air Traffic Control Systems*, United States Department of Transportation, Research and Special Programs Administration, John A. Volpe National Transportation Systems Administration, Cambridge, MA, 1995. (DOT/FAA/RD-95/3 DOT-VNTSC-FAA-95-3.)

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Guidelines for Developing and Implementing Team Resource Management, Eurocontrol, Brussels, 1996. (HUM.ET1.ST10.1000-GUI-01.)

European Manual of Personnel Licensing — Air Traffic Controllers. Draft edition version 5.1, Eurocontrol, Brussels, 1999.

Hopkin, V. David, *Human Factors in Air Traffic Control*, Taylor & Francis, London, UK, 1995. (ISBN 0 7484 03574.) (ISBN 0 85066 823 9.)

Manual of Procedures for Establishment and Management of a State's Personnel Licensing System, ICAO, Montreal, 1983, reprinted 1996. (Doc 9379.)

Process	Output / Input
Form multidisciplinary team	→ Human Factors Plan
Determine operating philosophies	← Human-Centred Automation
Write system specifications	→ System specifications
Develop system	← Team functions
Test and modify system	← Early prototyping
Develop Standard Operating Procedures (Chapter 7)	→ Standard Operating Procedures
Certification	
Train operators	← HMI, SOPs, design philosophies, team roles, interaction with other equipment, SA, error management
Licensing	
Implement system	

Legend

Tangible output

Methodology or input

Action of Regulatory Authority

Figure 6-5.   A schematic summary of items and recommendations from Chapter 6

Chapter 7

STANDARD OPERATING PROCEDURES

7.1 INTRODUCTION

7.1.1 The introduction of CNS/ATM technology generates the requirement to develop and implement new standard operating procedures which reflect the needs and constraints of the operational context in which the technology will be deployed.

Note.— In this chapter the term "procedures" is used to indicate standard operating procedures.

7.1.2 ICAO has developed Standards and Recommended Practices (SARPs) related to CNS/ATM, but due to the asynchronous and incremental introduction of the various (sub)systems in different regions and States it is unavoidable that initial procedures for the application of new technology will sometimes have to be developed regionally, nationally or even locally.

7.1.3 This chapter presents general guidelines on procedure development and specific guidance concerning standard operating procedures for CPDLC, ADS, pre-departure clearance (PDC) and GNSS-based instrument approaches.

7.2 REQUIREMENTS FOR PROCEDURE DEVELOPMENT

7.2.1 It is of paramount importance to incorporate Human Factors knowledge in the procedure development as well as in the procedure implementation.

7.2.2 Procedures must be based on the concept of the users' operation. These operating concepts should evolve into work policies and practices that specify how to operate the system efficiently. In general, procedures should specify:

- what the task is;

- when the task should be conducted (time and sequence);

- by whom it should be conducted;

- how the task should be done (action);

- the sequence of actions; and

- the feedback necessary.

Furthermore, procedures should:

- be written carefully;

- be error-resistant and error-tolerant;

- be unambiguous;

- be comprehensive;

- not contradict each other;

- be easy to understand and apply.

7.2.3 Procedures should clearly state who is responsible for their application, and when procedures contain listings of conditions, it should be clear what is to be done and by whom in cases where not all of the conditions are met.

7.3 HARMONIZATION OF STANDARD OPERATING PROCEDURES

For ease of interoperability, on a national level there should be as little discrepancy between local procedures as possible, just as on a regional level there should be as little discrepancy from national procedures as possible. To that end, States and organizations involved in the implementation of CNS/ATM-related standard operating procedures should coordinate their activities on a regional level as early as is feasible.

7.4   STANDARD OPERATING PROCEDURES FOR CPDLC

Note.— General procedures for the use of CPDLC are contained in the Manual of Air Traffic Services Data Link Applications *(ICAO Doc 9694).*

7.4.1   From a Human Factors perspective, and based on feedback from early implementation as well as from the research community, it is possible to offer the following observations concerning the use of CPDLC:

- The differences in characteristics and capabilities of the available FANS-1/A avionics should be known to the ATS providers and in particular to the controllers.

- When implementing CPDLC it may be advisable to initially use a limited subset of the available message elements only.

- It may be advisable, due to differences in interpretation between ATS units, to exclude the use of certain message elements.

- Not all available message elements can be accommodated by the different FANS-1/A avionics.

- It may be useful to add locally frequently-used phrases to the message set of the ground system, even though the airborne systems will consider these phrases to be free text.

- The use of free text should be limited to those cases for which no preformatted message elements exist.

Note.— The use of preformatted message elements allows on-board data processing such as the automatic insertion of the clearance information into the flight management computer. It also allows the controller to respond more quickly when the ATS system has the capability to automatically link a preformatted request to a preformatted response. Additionally, this process minimizes the risk of input errors.

- The use of long messages should be avoided.

- The use of messages with multiple clearance elements should be avoided.

- The use of conditional clearances should be avoided.

- Procedures for data link failure (i.e. CPDLC communications failure) must be established.

Unresolved issues

7.4.2   The ICAO CPDLC message set is initially published in English only. There is, however, nothing to prevent States, organizations and/or operators from translating this message set into any other language. The potential for incompatibility between end-users, and the resulting errors and degraded safety, is obvious. Therefore there may be a growing requirement for the formal certification of the software containing such translated message sets before they are put into operational use.

7.4.3   For the development of the current ICAO CPDLC message set, a conscious choice was made to adhere as much as possible to the existing ICAO R/T phraseology. It should be realized, however, that the R/T phraseology was designed for use with voice communications via HF, VHF or UHF radio. The R/T phraseology contains words and sounds that are optimally suited for transmission and interpretation via these media. With CPDLC there no longer are any sounds transmitted between controllers and pilots, and some of the words used in R/T may therefore not be strictly required anymore in CPDLC. An example are the simple words "yes" and "no", that in R/T were substituted by "affirm" and "negative", respectively. It may be possible to design a future CPDLC message set in which words and phrases are used that are optimally suited for transmission and interpretation via data link. The effect of the differences in the two sets of phraseologies (R/T and data link) should be carefully analysed and understood before such a change in philosophy is effected.

7.5   STANDARD OPERATING PROCEDURES FOR ADS

Note.— General procedures for the use of ADS are contained in the Manual of Air Traffic Services Data Link Applications *(ICAO Doc 9694).*

7.5.1   From a Human Factors perspective, and based on feedback from early implementation, it is possible to offer the following observations concerning the use of ADS:

- Most ground systems, whether manually or automatically, will establish ADS contracts on completion of a successful AFN log on. However, the establishment of an ADS contract by a ground system does not require the current controlling authority to forward the address of that particular facility to the aircraft. As such, it is imperative that a priority system for ADS connections be strictly adhered to;

- FANS-1/A-equipped aircraft can have up to four ADS connections established, each with a different ground facility. As no priority is assigned to these connections, the highest priority for an ADS connection must be given to the current controlling authority, followed by the next authority with direct control responsibilities for the aircraft (see Figure 7-1);

Figure 7-1: An ADS contract was required by ATSU 2 to allow the aircraft's progress near the FIR boundary to be monitored. To ensure that the next unit with direct control responsibility for the aircraft had priority over the ADS connections, an AFN log on to ATSU 3 was initiated by ATSU 1 prior to the aircraft being instructed to log on to ATSU 2.

- Ground automation and system design features differ between FIRs. Some systems cannot process flights which do not enter their FIR, whether or not they are in possession of a flight plan. Additionally, some systems will connect both CPDLC and ADS automatically on receipt of an aircraft's AFN log on. For these systems, when connecting as the adjacent FIR for the monitoring of an aircraft close to a boundary, the CPDLC connection request will be refused by the aircraft as the FIR will not have been notified as being the Next Data Authority;

- To guard against the situation where an aircraft is required to generate reports at a rate faster than can be sent by the ACARS system, only the ATS facility currently controlling the flight should initiate a high periodic reporting rate with the aircraft. Any adjacent or subsequent ATS facility requiring a high reporting rate (five minutes or less) with that aircraft should coordinate with the current controlling authority prior to increasing the periodic reporting rate.

Unresolved issues

7.5.2   There are no ICAO provisions pertaining to ADS vectoring (as opposed to radar vectoring). Still it will be very tempting for a controller with an ADS-derived traffic situation display to resolve certain conflicts by issuing heading instructions to aircraft. Since the source of the position information and the update rate of the position reports differ significantly between ADS and radar, it is yet

ATSU 1 (ADS)
Current Controlling Authority

ATSU 2 (ADS)
Adjacent FIR

ATSU 3 (ADS)
Next Controlling Authority
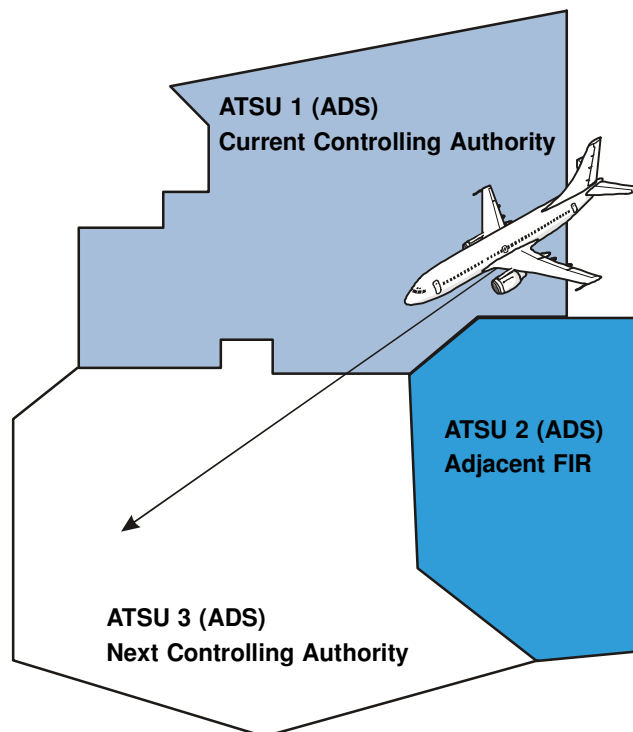
Figure 7-1.   Example of an ADS connection sequence

to be demonstrated that ADS vectoring is a safe option. The appropriate authorities and/or the ATS providers should ensure that ADS vectoring is not applied unless procedures are developed and conditions exist under which it is considered safe to do so by all parties involved.

7.6   STANDARD OPERATING PROCEDURES FOR PRE-DEPARTURE CLEARANCE (PDC)

7.6.1   Pre-departure clearance (PDC) is a system that allows pilots to obtain IFR clearances via data link prior to engine start, thus reducing or even eliminating the need for verbal communication on clearance delivery frequencies. PDC has been implemented operationally or in trial versions at various airports around the world. The data link medium used so far is the ACARS network, though in the future the ATN will be used.

7.6.2   Issues that have arisen from the application of PDC include: confusion on the flight deck concerning the content of PDC messages; flights departing without having received their PDC; and inconsistencies in the formats of PDC messages used by different facilities. On the ATC side, it has been noted that the addition of a PDC terminal that was not integrated in the existing (automated) system significantly increased the workload of the controllers.

Content and format

7.6.3   According to ICAO Annex 11 — *Air Traffic Services*, an air traffic control clearance is an "authorization for an aircraft to proceed under conditions specified by an air traffic control unit". An air traffic control clearance shall indicate:

- the aircraft identification as shown in the flight plan;

- the clearance limit;

- the route of flight;

- the level(s) for the entire route or part thereof and changes of levels if required; and

- any necessary instructions or information on other matters such as approach or departure manoeuvres, communications and the time of expiry of the clearance.

7.6.4   At many airports where frequent IFR departures are handled, standard instrument departures (SIDs) are used

to indicate the initial route to be followed after departure and often contain the initial level to climb to. This reduces the requirement for controllers to read lengthy and complicated routing instructions and also reduces the requirement for pilots to copy and read back such instructions.

7.6.5   An example of the text of a PDC transmitted via voice communication is: "Flight 123 is cleared to Los Angeles via MOGUL1A departure, squawk 4530". In this example MOGUL1A is the designator of a SID that includes an initial altitude restriction. The pilot is required to read back the complete text and the controller will confirm to the pilot that the readback was correct. It is obvious that when routing instructions consisting of several way-points and/or airway designators are used instead of SIDs, the potential for error increases.

7.6.6   In the previous example, the pilots from Flight 123 additionally will have to obtain information on the weather conditions and the assigned departure runway, which is normally received from the automatic terminal information service (ATIS). Confirmation of receipt and validation of this information is also passed by voice communication between pilot and controller.

7.6.7   A format for PDC via data link that is becoming widely accepted in the industry was developed by ARINC as part of their Specification 623. The contents of this format consist of (in this specific order): a message type identifier, time and date, ATC identifier, clearance indicator and number, flight identifier, cleared destination, cleared runway, departure and route, squawk notification, departure time notification, next frequency notification, current ATIS notification and optional free text.

7.6.8   An example of the text of a PDC transmitted via data link in accordance with this format is:

"CLD 1035 990802 EGKK PDC 146
BAW123 CLRD TO KJFK OFF 26R VIA DTY5V
SQUAWK 5023 ADT 1022 NEXT FREQ 134.550
ATIS I
EXPEDITE IF POSSIBLE".

Items that are underlined are "fixed text", i.e. non-variable standard items in the PDC. The avionics of the aircraft receiving a data link PDC subsequently generate a "read-back downlink message". This message is almost identical to the PDC received, except that the message type identifier is different. By transmitting this message, the pilot enables the ATC system to process the acknowledgement of the PDC.

7.6.9   In case it is necessary to amend a PDC already received by a flight, the new clearance is transmitted in accordance with the same format and the text "RECLEARANCE #" (where # represents a numeric indication of the appropriate reclearance sequence) included as the first part of the free text area of the message.

Note.— At certain locations where PDC trials have been conducted based on the use of ACARS, it was decided to only amend PDCs by R/T since with ACARS there is no guarantee that messages are delivered in the same order in which they are sent. The possibility exists that a reclearance could reach a flight crew before the original clearance is received, which is a potential source of confusion. Once the ATN is available, this situation will be remedied.

Integrity

7.6.10   Due to existing differences in the way these clearances are generated within ATC units, as well as to existing differences in the processes by which clearances are provided to flight crews, it is not possible to present here a detailed procedure for data link PDC delivery that is applicable in all situations. Some aerodrome control units have to first contact an area control centre (ACC) before they physically have all elements of the PDC available. Other units immediately have the full PDC available and can issue it to pilots upon demand, after which they only require (silent) endorsement of the clearance contents from the ACC. In some facilities, the PDC is communicated by ATC to the airline operations centres, who in turn communicate it to their pilots before departure. Yet the following general guidelines apply:

*   Procedures need to be in place to ensure that the ATC clearance received and used by the flight crew is identical to that issued and used by ATC.

*   The automated system must indicate that a flight is requesting a PDC, and it must present the controller with a proposed PDC for that flight.

*   At the same time, it must provide an opportunity for the controller to modify the proposed PDC where and when necessary before the message is transmitted to the aircraft.

*   The system must indicate that the PDC was received and acknowledged by the flight crew.

*   At a given time before take-off, verification of receipt of the correct PDC shall be accomplished by voice communication between pilots and ATC. The form of such verification shall be established by the appropriate authorities and may consist of readback of the transponder code, or readback of the clearance indicator and number, or other acceptable means.

Note 1.— If readback of the transponder code is considered as a means of PDC verification, this implies that in any subsequent reclearances the code must be changed.

Note 2.— Flight crews may apply an internal procedure that involves printing of the PDC via the ACARS printer on the flight deck. It should be noted that the integrity of this printer is — by specification — of a lower standard than that of the visual displays on which the PDC is presented. In some cases this may lead to discrepancies between the printed text and that on the displays, which may go unnoticed by the flight crew concerned. This is particularly the case when numerical strings (e.g. latitude/longitude way-points) are used in the PDC. Controllers should be trained to be alert for apparent deviations from PDC routings or levels transmitted by data link.

An example of a data link PDC HMI

7.6.11   Figure 7-2 shows an example of the screen of an ATC data link PDC application. This screen is an experimental version from Brussels (Belgium). Extensive use is made of colour coding to distinguish the various categories of information on the screen. ATIS information is visible on the right side of the screen. It may be technically possible to transmit this information together with the PDC, thus reducing the number of separate actions that pilots have to perform before departure.

Note.— One aspect that emerged as a lesson from several data link PDC implementation trials is that the controller-PDC interface should be an integrated part of the automated ATC system. If controllers are required to operate dual systems, their workload often increases to unacceptable levels which results in one of the systems (usually the data link PDC) not being attended to anymore. (See also Chapter 4 "The human-machine interface".)

7.7   STANDARD OPERATING PROCEDURES FOR GNSS-BASED INSTRUMENT APPROACHES

As with other instrument approaches, it is expected that with approaches based on the GNSS the role of ATC will

Figure 7-2.   Example of a data link pre-departure clearance HMI

be to clear the aircraft to the starting point for the approach as well as to clear it for the subsequent procedure. ATC will be the authority to determine whether the requested approach procedure can be used. To that end ATC will have to be provided with technical information concerning the availability and integrity of the GNSS signals. Furthermore, procedures need to be in place in case the GNSS-based approach cannot be used for technical reasons.

- When GNSS-based instrument approaches are used, ATC must be provided with technical information concerning the availability and integrity of GNSS signals; and

- Procedures must be in place in case the GNSS-based instrument approach cannot be used for technical reasons.

Conclusion

7.8   Standard operating procedures enable the conversion from a theoretical operational concept to its practical application; technology should assist and support the operators to achieve this conversion. However with the introduction of data link technology, originally designed to overcome shortcomings in voice R/T communications, new possibilities arise that warrant a change in existing procedures when applied. CPDLC, ADS and other data link applications bring fundamental changes in the way air traffic controllers work — and are trained to work. By applying Human Factors knowledge in CNS/ATM procedure design, these changes will remain manageable, provided adequate training is given to the operators before the systems are put into operational use.

Note.— Training aspects are discussed in Chapter 6 "Preparing for change".

References

ARINC, *Character-Oriented Air Traffic Services (ATS) Applications*. Specification 623, 1999.

Isaac, A. and B. Ruitenberg, *Air Traffic Control: Human Performance Factors*, Ashgate Publishing Ltd., Aldershot, Hants, UK, 1999. (ISBN 0-291-39854-5.)

ISPACG, *South Pacific Operations Manual*. Version 2.6, 1999.

Manual of Air Traffic Services Data Link Applications. ICAO, Montreal, 1999. (Doc 9694-AN/955.)

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Chapter 8

NEW FLIGHT DECK TECHNOLOGY

8.1 INTRODUCTION

8.1.1 The ideal way to change operations begins with defining a concept, followed by developing procedures to support the concept, and subsequently designing technology to support the procedures. However, this is not how change is always introduced in aviation. Quite often changes in aviation procedures and indeed in operational concepts have been brought about by emerging new technologies.

8.1.2 This chapter introduces the concept of Airborne Situational Awareness and presents new designs for flight deck technology that may eventually have an impact on air traffic services and ATC procedures. Implementation of this technology may still be years away, and some of it may not be implemented at all, yet designers of ATM systems should consider allowing for future incorporation of relevant aspects of new flight deck technology in their systems.

8.2 AIRBORNE SITUATIONAL AWARENESS (AIRSAW)

8.2.1 Airborne Situational Awareness (AIRSAW) is defined as the aircrew mental picture of the aircraft state and outside operational environment, including information on the terrain, aircraft position, weather, traffic situation and air traffic management. The AIRSAW concept aims at enhancing the aircrew mental picture of its outside environment in order to improve its ability to manage the flight safely and efficiently within the current and foreseen operational environment.

8.2.2 To provide enhanced AIRSAW, improved data on aircraft position, weather, terrain, surrounding traffic and ATM information need to be fed on board the aircraft. This can be done through the implementation of data link services and other airborne tools in order to globally enhance aircraft functions.

8.2.3 Those enhanced aircraft functions will also constitute a set of functionalities that can be regrouped

under the term of airborne separation assurance capability. Such capability can be defined as the set of communication, navigation and airborne surveillance functions on board an aircraft which enable the aircrew to ensure that their flight remains separated from others (in accordance with minimum separation standards) and from other hazards (e.g. terrain, obstacles, vehicles, etc.), in all types of weather.

8.3 AIRBORNE SEPARATION ASSURANCE SYSTEMS (ASAS)

8.3.1 By increasing the Situational Awareness of flight crews it is envisaged that new concepts (e.g. Free Flight) and new procedures (e.g. In-trail Climb, and Station-keeping) will become feasible. An important feature of these concepts is that the responsibility for separation between aircraft will be delegated in part or fully from the ground (i.e. ATC) to the flight deck (i.e. pilots). The generic name for systems that support this delegation of responsibility is Airborne Separation Assurance Systems (ASAS).

8.3.2 The Research and Development community has made significant efforts to develop tools for improving and supporting the Situational Awareness of flight crews. The cockpit display of traffic information (CDTI) is a tool that has resulted from these efforts. Another innovation consists of integrating a CPDLC message display with a navigation display on the flight deck. Examples of new tools are discussed in the following paragraphs.

Cockpit display of traffic information

8.3.3 A cockpit display of traffic information (CDTI) is a generic avionics device on the flight deck that is capable of displaying the position information of nearby aircraft. It may also include ground reference points and navigation information to increase the AIRSAW. The example described here (Figure 8-1) was developed by the
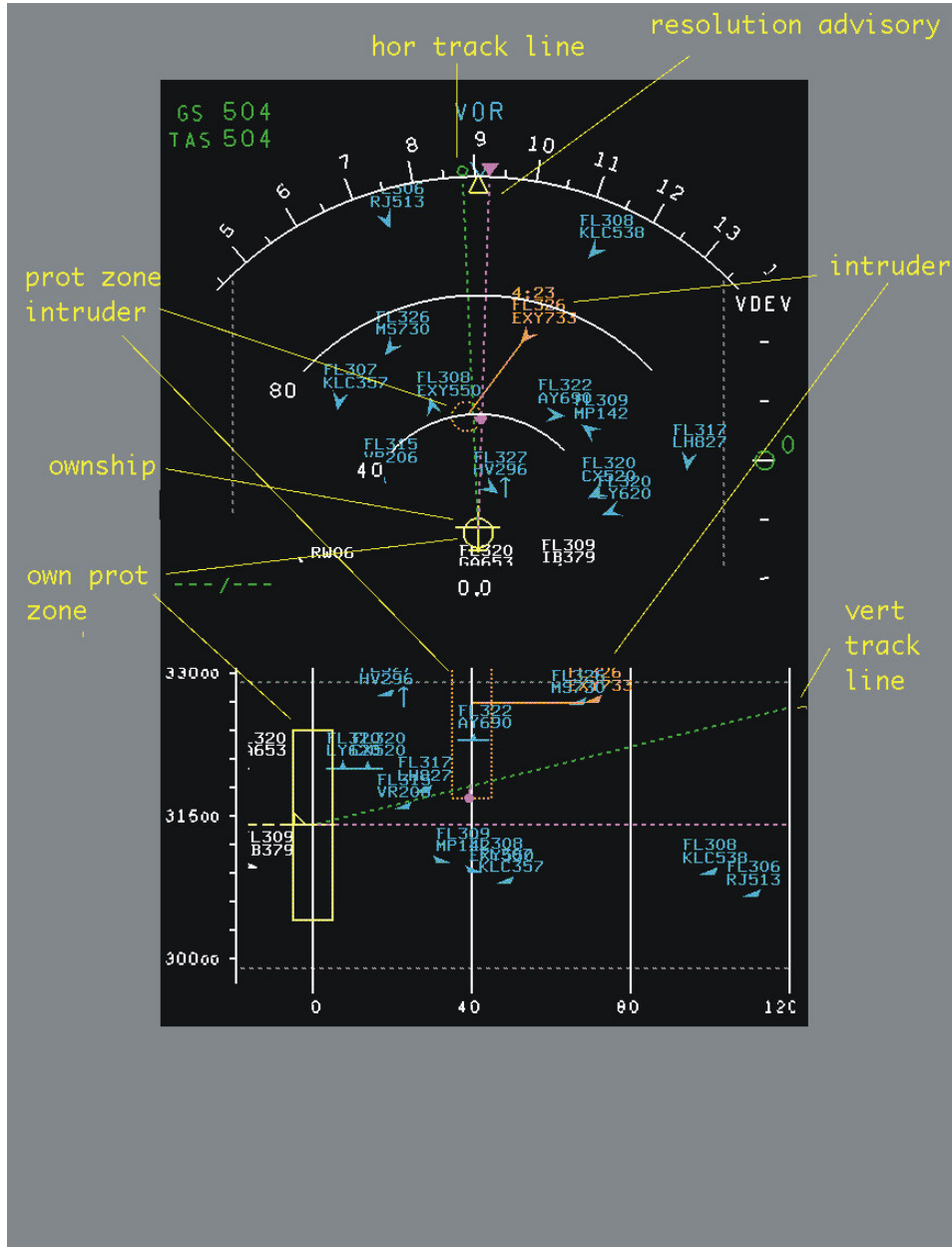
Figure 8-1.   Example of a cockpit display of traffic information

Dutch Aerospace Laboratory (NLR). It represents a state-of-the-art experimental design of a CDTI.

8.3.4   The traffic information, obtained via ADS-B, is displayed on the navigation display. Because of the relative importance of vertical manoeuvres, a vertical navigation display is integrated below the normal horizontal navigation display. In contrast to a conventional TCAS display, different symbology is used because of the extra information available. The extra information consists of:

- traffic call sign

- heading

- altitude

- ground speed

- climbing or descending arrow

- horizontal and vertical track lines

- predicted intrusion of protected zone of target, and

- time to intrusion.

8.3.5   The first six items can be toggled on or off by using a display control panel. The horizontal, vertical and clipping range of the navigation display can also be controlled by means of the display control panel.

8.3.6   When a conflict occurs with a time to maximum intrusion of less than five minutes, an aural alert sounds and the following sequence of display changes are shown:

1. The position of traffic is shown (in amber);

2. When a conflict is predicted, the incursion of the protected zone of the traffic is shown;

3. The traffic resolution is shown on the NAV display; and

4. For ten seconds after the conflict is resolved, the position of the traffic is shown in the colour of the conflict.

8.3.7   If, during the above sequence, the time to maximum intrusion becomes less than three minutes, the traffic symbols will be shown in red together with an increase in the aural alerting level.

Predictive ASAS

8.3.8   An important issue associated with ASAS concepts is whether or not to provide traffic intent information. In a situation in which no intent knowledge is communicated, surprises and short-term conflicts can occur when aircraft unexpectedly turn or initiate a vertical manoeuvre. Many people see the communication of intent as the solution. Concepts are being proposed which would communicate mode control panel data such as altitude, heading and speed settings or flight management system data, such as next way-point and/or optimal cruise level. However, it is not always clear which of the data should be used. The flight crew has no direct connection with the ADS-B set-up and can suddenly change the parameters by which the aircraft is flying. Therefore NLR has tried to tackle the problem from a different perspective. The goal of using intent is to avoid sudden manoeuvres that would trigger short-term conflicts. If the crew/aircraft knows what manoeuvre would trigger a short-term conflict, they could avoid such conflicts by not initiating any such manoeuvres. Adding a "rule of the road" stating that no such manoeuvres are allowed would theoretically eliminate the problem of short-term conflicts. At NLR a so-called "Predictive ASAS" has been developed which shows the crew on the primary flight display (PFD) and the NAV display which manoeuvre (if any) will trigger a conflict within five minutes. Figure 8-2 shows the PFD with "Predictive ASAS".

8.3.9   As long as the aircraft is flying in a straight line (and other aircraft obey the above-mentioned rule) no conflict will be triggered at less than five minutes (the look-ahead time used by the NLR). If a manoeuvre is called for (e.g. at the top of descent), the crew is expected to avoid manoeuvres which would trigger a conflict at short notice. This is achieved by selecting parameters that are outside the amber and/or red regions on the heading, speed and vertical speed scale of the PFD.

8.3.10   Figure 8-3 shows a display that combines a CDTI with a navigation display and a weather-radar picture. Aircraft are presented as symbols with vectors, indicating the direction in which they move. Relevant additional parameters of aircraft from which ADS-B information is available are also displayed. This display is one of the designs used in the Cargo Airline Association's ADS-B evaluation programme.

8.4   UNRESOLVED ISSUES

8.4.1   For most ASAS concepts and CDTI applications it is expected that the formal responsibility for aircraft
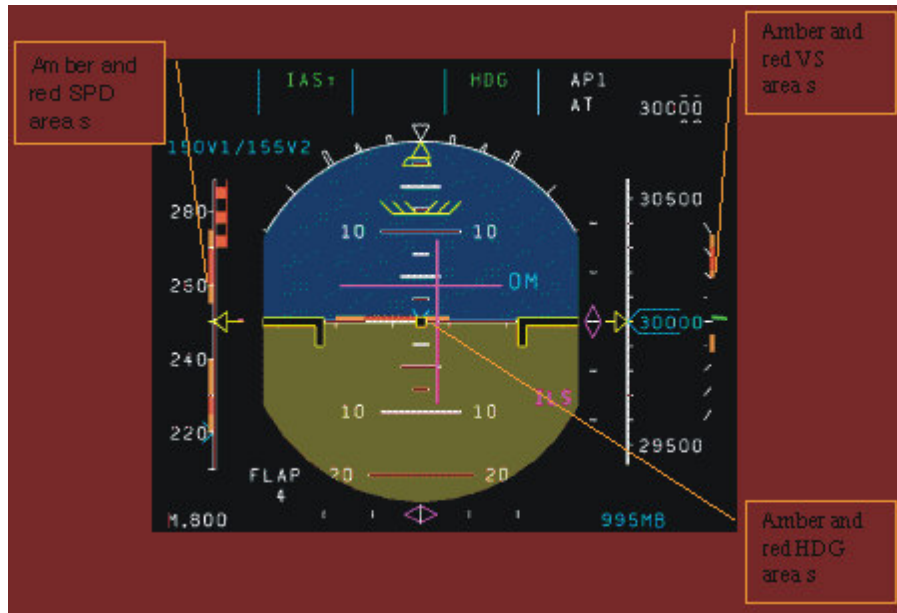
Figure 8-2.   Example of a primary flight display with predictive ASAS

separation will still be with the ground, i.e. with air traffic control. Therefore ASAS concepts must be developed in which controllers are kept "in the loop" even though their role may be more passive than in today's system. Developers of ASAS concepts face the challenge of ensuring that controllers at all times and under all circumstances can safely resume full responsibility for aircraft separation. This includes system degradations, malfunctions and aircraft emergencies.

8.4.2   Other issues that will require careful thought are the training and licensing aspects involved with the implementation of ASAS and CDTI. One obvious training aspect, for example, is aircrew familiarity with the three-letter identifications for flight operators (airlines) presented on their displays. These three-letter codes usually differ from the call sign for that operator as used in R/T communications. (For example, BAW, the identifier for British Airways, is associated with the call sign "Speedbird".) If pilots operate in a foreign environment there may be several unfamiliar three-letter codes on their displays, which will make it difficult for them to correlate visual targets with aural information. This could lead to an increase in workload both on the flight deck and for ATC,

since the flight crew may require more clarification from ATC before comprehending the traffic situation.

8.4.3   On the licensing side it needs to be clarified whether pilots require a formal qualification to assume partial responsibility (delegated by ATC) for separation from other flights. In the current system, pilots have a similar-looking responsibility under visual flight rules (VFR), but the difference is that no prescribed standards for VFR separation exist other than "see-and-avoid". If ASAS concepts are adopted in which flight crews are to apply self-separation with the same standards as existing standards for radar-separation, this will require skills that are different from those of pilots today.

8.4.4   This latter point also has implications for legal liability, e.g. in case of loss of separation. If separation in a given situation becomes less than the prescribed (i.e. legal) standard, and one or more of the flight crews involved are using ASAS/CDTI with the consent of ATC, who will be held legally responsible? For operator acceptance (both airborne and on the ground) of the ASAS concepts, it will be important to resolve this legal issue **before** any systems or procedures are implemented.

Figure 8-3.   Example of a navigation display with an integrated CDTI and weather radar

8.5   CONSEQUENCES FOR ATM

8.5.1   In view of the fact that equipping aircraft with ASAS and CDTI will require a considerable investment by airline operators, it is expected that there will be pressure from those operators on ATS providers to offer a service that will accommodate the use of this technology. Since equipping of aircraft with ASAS and CDTI will most probably be an evolutionary rather than a revolutionary process, ATS providers will at some point have to cater to traffic that either is or is not ASAS/CDTI-equipped. In other words, ATS providers will have to sustain operations in a mixed environment (as far as ASAS/CDTI equipage is concerned) for what could be a considerable length of time.

8.5.2   One related Human Factors concern is that flight crews in ASAS/CDTI-equipped aircraft may be under the impression that they can "see" all traffic in their vicinity, whereas in reality they only have information on ADS-B-equipped aircraft and lack information on other aircraft. This may lead to an increase in communications between flight crews and ATC, thus adding to the workload of both sides. In some cases flight crews, based on the information available on their CDTI, could even initiate actions that are jeopardizing the separation with aircraft that are not visible on their display. Procedures need to be developed and implemented to minimize or preferably eliminate such events.

8.5.3   The introduction of ASAS/CDTI will also have consequences for ATC training. Controllers will need to be proficient in procedures for delegating responsibility for separation to flight crews and for resuming this responsibility when required. This applies to both routine and emergency situations.

8.5.4   A further and less obvious area that could be affected is the user charges. Where ATS providers charge a fee for services provided to flights in their area, flight operators with ASAS/CDTI-equipped aircraft may claim that they should be charged a reduced fee because their flight crews can provide their own separation. The cumulative effect of this potential loss of revenue could significantly affect corporatized ATS providers and should therefore be considered at the early stages of an ASAS concept implementation.

Conclusion

8.6   Developments in flight deck technology will continue to drive changes in ATM operational concepts. When developing and implementing ATM systems and procedures, consideration should be given to the future incorporation of such changes. More importantly, those involved in the development of ATM operational concepts should weigh whether a concept should fit the technology or the technology should support the concept.

Chapter 9

SOURCES FOR ADDITIONAL INFORMATION

Postal addresses

For more information on topics discussed in this manual, the following addresses are suggested:

Eurocontrol
96 Rue de la Fusée
B-1130 Brussels
Belgium

Federal Aviation Administration
800 Independence Avenue SW
Washington, DC 20591
United States of America

RTCA, Inc.
1140 Connecticut Ave., NW, Suite 1020
Washington, DC 20036
United States of America

CD-ROM

The FAA document *Human Factors in the Design and Evaluation of Air Traffic Control Systems* (Cardosi and Murphy, 1995) is available on CD-ROM from the National Technical Information Service, Springfield, Virginia 22161, United States of America.

Internet addresses

An increasing amount of information on topics related to CNS/ATM systems implementation is available on the Internet. Since providers of such information sometimes modify the internal structure of their websites, only the generic addresses for accessing the sites are reproduced here. Most websites contain menu structures for subsequent navigation through the available information. Furthermore, several of the listed agencies offer the option of ordering documentation (in electronic or conventional format) via the Internet.

Air Services Australia	www.airservices.gov.au
Airways Corporation New Zealand	www.airways.co.nz
ARINC	www.arinc.com
Cargo Airlines Association	www.ads-b.com
Eurocontrol (main menu)	www.eurocontrol.be
Eurocontrol (Research and Development)	www.eurocontrol.fr
FAA Human Factors	www.hf.faa.gov
FAA Human Factors Design Guide	www.tc.faa.gov
IATA	www.iata.org
ICAO	www.icao.int
North European ADS-B Network	www.lfv.se
RTCA	www.rtca.org
SAE	www.sae.org