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HUMAN FACTORS IN AIR TRAFFIC CONTROL

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INTRODUCTION

1. This digest deals with Human Factors issues related to air traffic control (ATC). Its objective is to provide practical Human Factors guidance to those concerned with ATC systems. It is intended to show how human capabilities and limitations can influence task performance and safety. Sources of Human Factors knowledge are also identified. The target audience includes air traffic controllers and supervisors, ATC managers and planners, civil aviation administrators and equipment designers. The digest also seeks to provide information that is useful for the whole international aviation community and to introduce the non-specialist to Human Factors issues relevant to ATC.

2. This digest contains the following:

- *Chapter 1* describes the evolution of ATC, including a brief account of how to consider Human Factors within a system;
- *Chapter 2* deals with requirements associated with the design of controllers' workspaces and makes recommendations about them;
- *Chapter 3* explains the Human Factors issues raised by the introduction of automated equipment into ATC workstations;
- *Chapter 4* outlines selection criteria for controllers and discusses issues regarding air traffic controller training;
- *Chapter 5* considers specific human attributes relevant to ATC systems; and
- the *Appendix* provides a list of references and recommended reading.

3. This digest was prepared with the guidance and assistance of the ICAO Flight Safety and Human Factors Study Group. The original draft was prepared by Study Group Advisor Mr. V. David Hopkin, Human Factors Consultant to the United Kingdom Civil Aviation Authority.

4. The other digests in this series are:

- Digest No. 1 — *Fundamental Human Factors Concepts* (Circular 216);
- Digest No. 2 — *Flight Crew Training: Cockpit Resource Management (CRM) and Line-Oriented Flight Training (LOFT)* (Circular 217);
- Digest No. 3 — *Training of Operational Personnel in Human Factors* (Circular 227);
- Digest No. 4 — *Proceedings of the ICAO Human Factors Seminar* (Circular 229);

- Digest No. 5 — *Operational Implications of Automation in Advanced Technology Flight Decks* (Circular 234);
- Digest No. 6 — *Ergonomics* (Circular 238); and
- Digest No. 7 — *Investigation of Human Factors in Accidents and Incidents* (Circular 240).

Chapter 1
THE EVOLUTION OF AIR TRAFFIC CONTROL

HUMAN FACTORS WITHIN SYSTEMS

1.1 An ATC system aims to achieve a safe, orderly and expeditious flow of air traffic and is an example of a large human-machine system[1]. In such systems, humans interact with machines to fulfil the functions of the system. However, individual humans do not usually all have the same tasks, jobs, equipment or functions, although they may have similar professional training and qualifications. A safe and efficient ATC system must include appropriate technology. It must also have trained and knowledgeable professional air traffic controllers who can understand and use all available facilities to provide a satisfactory ATC service.

1.2 In addition to safety, orderliness and expedition, the ATC system can have several less known objectives — fuel conservation; noise abatement; minimum environmental disturbance; cost effectiveness; impartiality towards all users within the rules and regulations; and the granting of users' requests whenever possible. A subsidiary but vital aim is to ensure the continued provision of a workforce of controllers who can fulfil the standards, policies and objectives of ATC with existing and new facilities and equipment.

MATCHING HUMAN AND MACHINE

1.3 Most Human Factors issues in ATC are not new but derive from fundamental human capabilities and limitations. Yet Human Factors has to respond to changes that originate elsewhere, for example in increased air traffic demands or technological advancements. The achievement of the full expected benefits of these advancements requires the successful matching of human and machine, so that humans do not impede technical progress because they have been given tasks beyond their capabilities. The aim of Human Factors in ATC is to match human capabilities and limitations with the specifications and design of the ATC system. This matching of human and system is an active process, the achievement of which may imply changes to either or both. Successful matching requires the correct application of the extensive Human Factors data available.

1.4 Human Factors applies knowledge of how human beings perceive, sense, learn, understand, interpret, process, remember and use information, and also applies knowledge of how to measure human performance and its effects within a functioning system. Human Factors examines the many ways in which the controller and the system can affect each other, and helps to reveal whether the main influence on events is the structure of the ATC system or the actions of individual controllers. Human Factors knowledge is applied to ATC to understand and quantify the interactions between the system and the human. It is used to guide how each should adapt to the other and to suggest how human and system requirements that may appear to differ

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1. For a complete explanation of the concept of systems, refer to ICAO Human Factors Digest No. 1 — *Fundamental Human Factors Concepts*, or No. 6 — *Ergonomics*.

can nevertheless all be met, so that ATC efficiency and safety are optimized without harm to the controller. Thus Human Factors knowledge is applied both to effects of the human on the system and to effects of the system on the human.

1.5 The air traffic controller needs to have an understanding of how the air traffic control system has been designed and can function, in order to interact with it and contribute the benefits of the controller's professional knowledge. The fundamental reason for applying Human Factors to ATC is to improve safety and help prevent accidents.

THE SHEL MODEL

1.6 The SHEL model, described in detail in Human Factors Digest No. 1, provides a unifying theme throughout this series of ICAO Human Factors digests. The model illustrates the main elements and interactions of Human Factors, and is applied to ATC in this digest. Figure 1-1 illustrates the SHEL model. The central human being — liveware, has four main kinds of interaction:

- liveware-hardware: humans and machines including equipment.
- liveware-software: humans and materials, such as documents, procedures, symbols, etc.
- liveware-environment: humans and the environment, including factors internal and external to the workplace.
- liveware-liveware: humans and other humans, including colleagues.

The objective is to optimize these relationships. The SHEL model can be used to identify problem areas, to trace the origins of specific problems and to define appropriate data collection tasks.

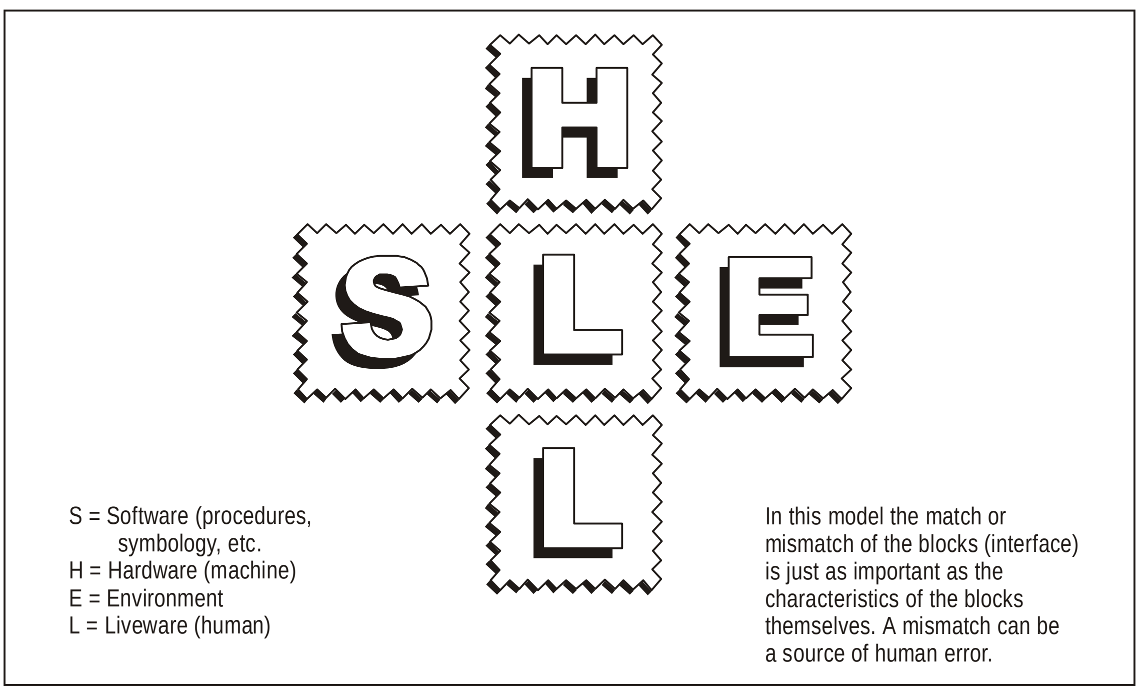

Figure 1-1. The SHEL model (adapted from Hawkins, 1975)

1.7 Throughout the digest, various Human Factors topics are discussed separately as a convenient way to describe them. In practice, these topics are never separate but always interact significantly with each other. No real-life Human Factors issue in ATC can ever be addressed completely under a single heading. For example, any ATC workspace specification will have implications for task design, performance, skill and error, and probably also for training and team functions. The SHEL model includes the main interactions between the human and other aspects of the system, but there can be second and third order interactions also. For example, what a controller (liveware) actually sees on a display can depend on which information is displayed (hardware), how appropriate it is for the task (software), whether it is obscured by glare (environment) **and** what the controller is expecting to see after conversing with the pilot (liveware).

THE EVOLUTION OF AIR TRAFFIC CONTROL

1.8 Although there was some air traffic after the First World War, not until the Second World War did it become necessary to start to regulate it on a global scale. Technological advances affected aircraft design and manufacture as well as control equipment installed on the ground in response to the increase in traffic. Airfields able to handle large numbers of aircraft had been built, and the need to reach agreements to control air traffic became urgent. At an international convention in 1944, governments drafted agreements on principles and arrangements to develop international civil aviation in a safe and orderly manner. On 4 April 1947, this convention was ratified, and ICAO — the International Civil Aviation Organization — came into being. Under its auspices, Rules of the Air and Air Traffic Services were established.

1.9 The airspace round our globe is divided into flight information regions (FIRs) within which States are responsible for providing air traffic services (ATS). Each FIR is divided into controlled and uncontrolled airspace. ATC service is provided for aircraft within airspace classes A to E. The primary objective of ATC is to prevent collisions between aircraft, and the second objective is to maintain and expedite an orderly flow of air traffic. In addition, the ATC service provides information for the safe and efficient conduct of flight, and assists any aircraft in an emergency.

1.10 Controlled airspace (airspace classes A to E) comprises control areas and control zones round certain aerodromes. There are three main categories of air traffic control:

- area control, for flights en route through an area;
- approach control, for aircraft bound for an airport from the point at which the area control centre (ACC) hands over the flight;
- aerodrome control, responsible for landings, movements on the ground, and take-offs;

Departing aircraft are passed from the aerodrome control tower to the approach control office and then to the ACC for the en-route sectors.

1.11 To receive ATC service, the pilot must submit a flight plan. The flight plan includes the aircraft call sign (identity), type, speed, proposed route and level, estimated time of departure, time over en-route positions and estimated time of arrival at destination. The controller relates the aircraft's planned route to other expected traffic and issues a clearance for the aircraft. The flight plan information and all subsequent instructions by controllers during the flight are passed on from one controller to the next. Pilots in controlled airspace must comply with controllers' instructions.

1.12 Controllers and pilots communicate with each other by radio and controllers use radar where available. Primary radar shows the position, track and speed of each aircraft as a series of fading blips on the screen. Secondary radar may display the call sign, level, speed, destination and other unique data, in the form of a label for each aircraft on the radar screen. The controller organizes the air traffic flows along designated routes within which aircraft are separated horizontally or vertically according to internationally agreed standards. The actual standards that are applicable depend on available navigational aids and on the controller's and the aircraft's equipment.

THE FUTURE OF AIR TRAFFIC CONTROL

1.13 Recent years have seen an inexorable growth of air traffic worldwide. The introduction of larger and faster aircraft together with an increasing number of smaller aircraft has required ATC to handle a greater variety of aircraft types. Despite more efficient equipment in the air and on the ground and more intensive and productive use of the ATC system, peaks of air traffic at or near maximum ATC system capacity have become more common and more prolonged.

1.14 In many parts of the world, future air traffic demands are expected to exceed the capacities of current ATC systems, which must therefore evolve or be replaced in order to cope efficiently and safely with these higher demands. Further sectorization of the airspace eventually becomes counter-productive as a solution because of the extra co-ordination and liaison work incurred. Alternative solutions have to be devised, proved and implemented. They include:

- the provision of better data to the controller;
- the replacement of manual functions by automated versions;
- automated data handling and presentation;
- automated assistance for cognitive human tasks such as problem solving and decision making;
- a change from short-term, tactical interventions which solve problems that arise, to strategic pre-planning of efficient traffic flows to prevent problems from arising.

1.15 At times, systems become overloaded and flow controls have to be imposed: air traffic flow management (ATFM) is nowadays a normal process in busy areas to co-ordinate the planning of the flow of air traffic across sectors and FIRs. Although ATFM is basically a strategic tool to prevent overloading of the air traffic control systems, experience as an air traffic controller and thorough knowledge of the area are needed to plan the traffic flows. The objective of ATFM is not to control airborne aircraft but to minimize delays by allocating departure slots and routes to aircraft still on the ground.

1.16 Further factors can aggravate the difficult circumstances that ATC is facing. The size of the controller workforce may remain about the same, even when more controllers are needed because of the increase of traffic. More controllers may also be needed if new technology allows the applicable separation criteria between aircraft to be lowered, which not only achieves intended increases in the traffic handling capacity of the system but also requires the controller to intervene more quickly if the separation criteria are not maintained. The runway, departure route or approach pattern preferred by the controller or pilot may not be available due to noise abatement restrictions.

1.17 The techniques of air traffic management are constantly changing. New data link and satellite communication methods are evolving, the quality of radar and data processing is improving, collision avoidance systems are being developed, direct routing of aircraft between departure and arrival airports instead of via airways is being explored, and future air navigation systems in the next century are being researched. The further options offered by such technological advances also have to be considered in terms of safety, efficiency, cost effectiveness and compatibility with human capabilities and limitations. These advances change the procedures and practices of ATC, the working environment and the role of controllers, presenting all involved with the challenge not to overlook the Human Factors issues. The paramount requirement of safety must never be compromised in ATC, but maintained and enhanced throughout all future changes.

TRANSFER OF INFORMATION

1.18 The objectives of ATC are to prevent collisions between aircraft and avoid other potential hazards by means which nevertheless promote efficiency of flight. How these are achieved depends on many factors, including:

- the characteristics of each aircraft and its equipment;
- the nature and degree of control over the traffic that is exercised;
- applicable rules, principles and procedures;
- the means for exercising control over air traffic;
- the knowledge, skill and experience of the pilot;
- the knowledge, skill and experience of the controller;
- the quantity, density, and mix of air traffic;
- the information available on each aircraft;
- environmental factors, including ground equipment, terrain and weather.

1.19 Information about aircraft is of two kinds, quantitative and qualitative. Quantitative information — e.g. on position, flight level, speed, heading and manœuvres — can generally be expressed and communicated digitally, and presented on displays. Qualitative information — e.g. on the reliability, validity and trustworthiness of data — is not usually displayed but depends on how the information is sensed and processed, particularly in terms of its frequency of updating, accuracy, precision, and the kinds of error, failure or degradation to which it may be susceptible. The experienced controller learns to recognize and adjust to information of poor quality.

1.20 Qualitative information often determines how closely together aircraft may fly safely, and hence sets the capacity of the ATC system in most circumstances, although other factors such as wake turbulence minima or the number and availability of runways may have an impact on capacity. The permissible separation between aircraft can generally be smaller on final approach in a radar environment (when the information about them is of high quality and frequently updated) than when they are in oceanic flight beyond radar coverage.

Chapter 2
THE CONTROLLER'S WORKSPACE

APPLICATION OF ERGONOMIC DATA

2.1 This topic has been the most traditional Human Factors contribution to ATC. Task performance depends on workspace specification and design, and on matching the demands of air traffic with the equipment and facilities provided to control it. The controller interacts with the system and controls air traffic using the human-machine interface. It must therefore be designed according to correct ergonomic principles to meet all ATC requirements.

2.2 The workspace includes aspects of software, hardware, and the environment, as well as liveware considerations. If existing workspaces impose constraints which make it impossible to implement Human Factors recommendations, the best approximation within the constraints should be adopted. However, there may be no satisfactory Human Factors solution when the constraints are severe. For example, if there is not enough room to accommodate all the flight progress strips or if glare obscures information displays, these problems must be resolved by more drastic system changes. They must not remain unresolved. The ergonomic data in this chapter have been compiled from several sources, including Hopkin (1982), Boff and Lincoln (1988), Rohmert (1973) and Pheasant (1986) (see the Appendix for details).

BUILDINGS

2.3 The broadest application of ergonomic principles to ATC workspaces is environmental, concerning the building where the workspaces are, which should be designed to meet all obvious needs. For example, an ATC unit located within an airport requires extensive sound insulation so that noise does not impair the intelligibility of speech; parking, canteens, rest rooms, toilets and other amenities should be near the workspaces so that rest breaks do not have to be lengthened significantly to include time to use these amenities.

2.4 The layout of the building should foster servicing and maintenance with minimum interference to ATC work, for example by providing easy access for bulky maintenance equipment. There should not be a gross disparity between the lighting of the control room and of its approaches. The approaches to the workspace and the workspace itself should employ sound absorbing materials for the walls and ceilings, and have carpeted floors, to minimize disturbance to the work by those entering or leaving the workspace.

ROOM LAYOUT

2.5 Room layout is also an aspect of the environment. The layout of the room must accommodate all those who work there at the maximum planned staffing level, including controllers, assistants, supervisors and those with other functions. There should be ample room in the workspaces for watch hand-overs, for on-the-job training and assessment without distraction or disturbance of controllers, and for back-up positions used in an emergency or when equipment becomes unserviceable. Safety equipment must always be accessible but never obstruct access.

2.6 The entire range of control and non-control tasks must be specified and the room layout designed to assist them. If ATC workspaces may be continuously staffed, the control room layout must allow regular maintenance and cleaning to be done while some workspaces remain operational. Provision must be made in the room layout for other non-control tasks such as equipment checks and additional data gathering, and for others who may work in ATC environments such as those who modify current systems, plan future ones or deal with quality assurance or aviation safety. The principle is to identify all the needs beforehand and then design room layouts to meet them. If this is not done, some needs cannot be met at all, others will be inefficient, and costly retrospective modifications to the environment will be required, which can rarely be as satisfactory as correct initial planning would have been.

2.7 Air traffic control is often a magnet for visitors. It is sensible to plan the room layouts so that visitors can see the work and have it explained to them without disturbing the work itself. General summary wall-mounted displays in a separate room, or viewing balconies that are soundproofed from the control room can reconcile visitors' wishes to see ATC with the controllers' needs not to be distracted.

SUITES

2.8 The workspaces of individual controllers are grouped into suites, according to the jobs and tasks. Suite design includes environment, software and hardware features. Each work position must contain all the facilities needed for the whole range of duties at that position, including information displays, data input devices and communications, and these must meet all the ergonomic requirements of reach and viewing distances and accessibility.

2.9 Any facilities designed to be shared by adjacent controllers must satisfy the ergonomic requirements of both of them. For example, if two controllers may occasionally share the same input device, it must meet the reach distance requirements of both. A display intended for more than one controller must meet the viewing distance and viewing angle requirements of all involved. Any large wall-mounted information displays intended for general use must be clearly and comfortably visible from every work position at which they are needed, and all controllers must face towards them. If there are no general wall-mounted displays, suites may be grouped within the room primarily to facilitate task sharing, access, supervision and communication between suites. No suite must block any controller's view of essential information. Care must be taken at every work position to prevent glare and reflections. These requirements become more difficult to achieve if suites or workspaces are in small clusters and not in a long row.

2.10 Where the amount of air traffic varies greatly, for example according to time of day or time of year, ATC may have to accommodate gross changes in staffing levels by opening or closing positions, and by splitting or amalgamating jobs. This may be done in different ways, depending on the traffic. The size of the sector for which a controller is responsible may be increased or decreased, or the sectors within an area may be combined or separated. The layout of suites must allow changes in staffing levels to be made smoothly and efficiently, and the hardware and software at each workspace must be appropriate so that tasks and jobs can be split or combined as planned. A supervisor may still need to see every workspace, whatever the staffing levels are. Some workspaces may be continuously occupied and must be designed for this.

TOWERS

2.11 In the air traffic control tower environment, all controllers must have a clear view of all the information necessary for their jobs. Those concerned with aircraft departing or on final approach must be able to see the runways and the aircraft for which they are responsible; this requirement applies to both directions of every runway. Some tower controllers need to see aircraft movements on taxiways and aprons below the tower. A controller's view must not be impeded by other controllers, by equipment within the tower, by stanchions or other features of the tower structure, or by airport buildings.

2.12 The workspace of the tower must be designed to promote the easy and unambiguous flow of information. It should aid the transfer of data and the handover of control responsibility within the tower at busy airports where the work may be divided between approach, departure, supervision, planning and control of ground movements. Flight progress strips must be delivered to the correct controller and handed over correctly from one controller to another. At each handover, the flight progress strip must be placed in a designated position, so that it cannot be mislaid. Even in towers with limited space, flight progress boards (FPBs) must be able to hold flight progress strips representing the maximum possible number of flights. The information from additional displays, such as a ground movement plan or a distance from touchdown indicator, must be correctly integrated with other information sources and always fully compatible with them.

CONSOLE PROFILE

2.13 The console profile, illustrated in Figures 2-1 and 2-2, is the side view of the outline formed by the set of surfaces presented to the controller seated at the work position and which contain the human-machine interface. As a feature of the environment, the profile must meet ergonomic requirements for all body sizes of the controller population, if necessary by making some profile surfaces adjustable. The profile must also promote efficient use of the hardware housed within it and of the software used in conjunction with the hardware. The surface of each main display should be at approximately a right angle to the controller's normal line of sight when busy (the busy controller usually sits forward rather than back, and therefore the anthropometric data corrected for slump should be used to establish normal eye position, viewing angles and distances and reach distances).

Controls for all tasks must be within recommended reach distances for the entire population. The actual recommended reach distances vary somewhat according to the type of control and how it is intended to be touched, grasped or manipulated. Controls that are frequently or continually used should be in the optimum control position, in front of the controller on a console shelf that is horizontal or nearly so, where the shelf can provide some support for the arm or hand and hence help to prevent fatigue. Rarely used controls, such as setting up controls, can be positioned on vertical console surfaces, although they are more tiring to operate because the arm is unsupported.

ANTHROPOMETRY

2.14 Anthropometry measures the range and distributions of standardized physical dimensions of the human body, and combines aspects of all features, especially liveware and environment. Some adjustability of relevant aspects of the workspace is needed in relation to different body sizes. Either the console is adjustable, for example by moving the shelf up and down, or the seat height for the controller is adjustable, or both are adjustable. The shelf should be thin at the front to ensure adequate thigh clearance for every seated controller. Ample room to stretch the legs while seated should be provided under the suite.

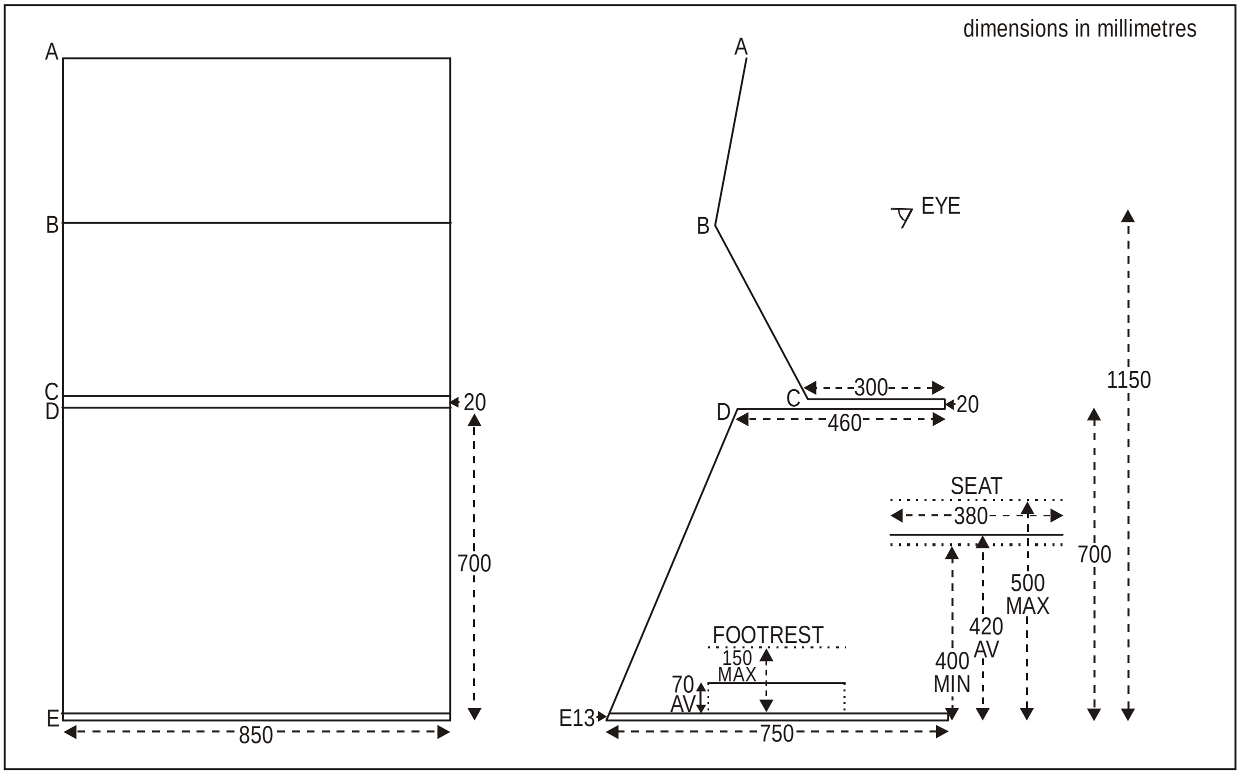

Figure 2-1. Console profile: large display

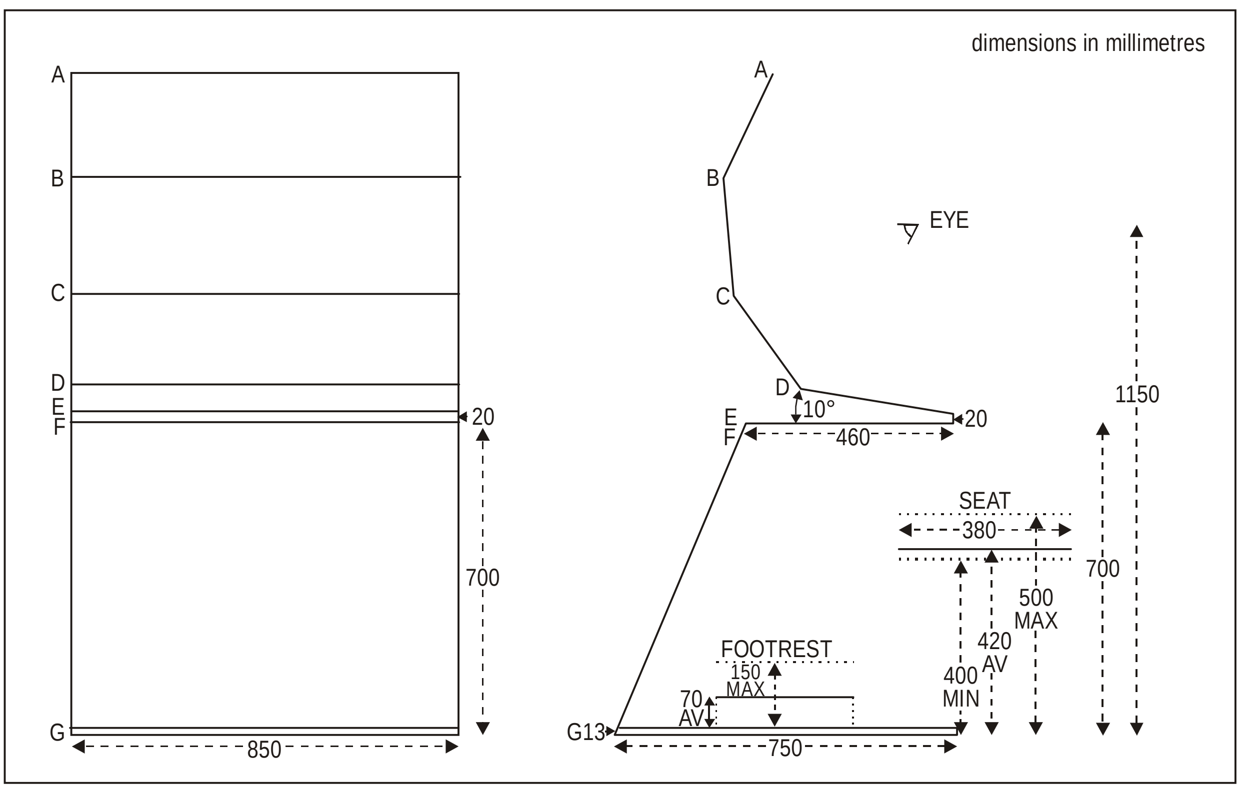

Figure 2-2. Console profile: small displays

2.15 The seat should be adjustable for the predefined range of acceptable body sizes for controllers, should provide good back support, and should incorporate cushioning or padding suitable for continuous occupancy. The seat should be easily moved, preferably on large castors that do not get caught in the floor covering. Armrests are recommended, and should be adjustable. They must be allowed for in the recommended spacing between adjacent seats so that each controller can leave or enter the work position without disturbing immediate neighbours. A minimum centre seat to centre seat spacing of 650 millimetres between adjacent controllers is essential, and 750 millimetres is recommended as the minimum for permanent occupancy, particularly for seats with armrests.

LAYOUT AND RESPONSIBILITIES

2.16 The layout of the equipment in the environment must enable responsibilities to be fulfilled through an effective liveware-liveware interface. For example, if there is a supervisor, the facilities needed for effective supervision must be provided in a usable and efficient form at the supervisor's workspace; otherwise supervision is in name only because the means to exercise real supervision have not been provided. The provision and layout of equipment largely determine the responsibilities that are possible. It is vital that the responsibilities of each workspace can actually be fulfilled there, and are not nominal.

2.17 Equipment should be configured in workspaces to prevent distractions, to emphasize primary activities, and to minimize the frequency and magnitude of major head movements imposed by task designs. If all information that is often needed cannot be on the same display, it should be on closely adjacent ones and the relationship between them must be made obvious. There should not be any gross visual disparities in brightness between different and regularly used information displays within the same workspace.

THE PHYSICAL ENVIRONMENT

Decor

2.18 The decor should be designed as an entity, and not be arbitrary, to provide an optimum visual environment. Surfaces should be matte, not shiny, and should not become shiny as they wear. The colours of walls, floors and furniture should be pastel since saturated colours can interact too much with the colour coding on displays. Pastel beiges, light browns and light greys are often satisfactory while white may often be too bright.

2.19 If the room is large, it should contain visible features that provide some visual structure and convey an impression of the dimensions of the room. Examples are carpet tiles that differ from each other in their appearance slightly but not grossly, or occasional different but not obtrusive vertical features within an extensive wall. Any large room should also be quite high: a low ceiling in a large room can seem oppressive and makes it much more difficult to achieve reasonably uniform ambient lighting throughout the workspaces.

Lighting

2.20 One of the most crucial aspects of the physical environment is the ambient lighting. ATC workspaces are of two distinct kinds. In air traffic control towers, the ambient lighting can vary greatly, from direct sunlight to artificial lighting during the hours of darkness. All the displays and controls must remain usable whatever the ambient lighting is, and must be automatically or manually adjustable so that they do not become too bright in hours of darkness or too dim in bright sunlight. Lighting set within the ceiling, or up-lighters reflecting from the ceiling, can be effective. The latter in particular can prevent obtrusive shadows, although the ceiling must be matte and white or nearly so. No light source such as a filament or a tube should be directly visible from any work position.

2.21 In workspaces dealing with area or approach control, either there is no outside view or the windows are fitted with curtains or blinds to provide a controllable lighting environment. Here, ambient lighting that is optimum for the whole range of visual displays and controls, and for other requirements such as the reading of hard copy, can be employed. It should be specified in terms of its spectrum, intensity, and the type and location of light fittings as an integral aspect of the workspace design and at the same time as the displays are specified, not afterwards. Since the lighting has been designed to be optimum for a fixed visual environment and the displays within it, the required range of adjustment of its intensity is much less than it is for towers. The brightness of individual displays in controllable environments should be adjustable only within the permissible limited range that preserves the planned optimum visibility of the displayed information.

2.22 Glare can be a severe problem in towers where the light level can become very high on a bright day. Towers should be positioned so that controllers does not normally face the sun while viewing the main runways. Glare or reflections from any source in the ATC environment must be prevented. Usually problems of glare have to be tackled in two separate ways: by reducing the ambient light and by modifying the displays. Glare is reduced by constructing tower cabs so that the roof overhangs the floor and the window glass is angled outwards, which also can prevent the impairment and distortion of visibility by rain on the glass but may restrict visibility upwards. Glare is also reduced by coatings or filters on the window glass, by providing adjustable blinds with slats, by minimizing very light surfaces within the room, by cowlings round workspaces or individual displays, and by positioning consoles, workspaces and furniture in the tower so that, as far as possible, direct sunlight never falls on displays. Controllers' sightlines must never be compromised by glare. Because glare reduces the contrasts and readability of displayed information, this must be compensated for by increasing display brightness, by coating or filtering the display surfaces, or by changing the display technology employed. Some modern display technologies, claimed to be suitable for daylight conditions, are still too dim for the exceptionally bright conditions that can occur in some towers.

2.23 The workspaces and the layouts of suites, consoles and displays must be planned in relation to the ambient lighting. Checks can be made to prevent glare and reflections by depicting on plans of the workspace the region of the room reflected in each display when viewed from the normal viewing position. No fitments with directly visible light sources must be placed within this reflected region of the room. Another way to make these checks is to use actual size or small scale mockups of the layouts.

2.24 It may occasionally be necessary to provide extra lighting for particular displays or to reduce the lighting locally to maintain visibility, notably of radar displays (this is not a recommended practice, however, and should not be necessary if the ATC environment has been designed so that all displayed information in it can be viewed in the prevailing ambient lighting). As the controller scans visually round the room, the general level of lighting from every direction should be broadly similar, so that scanning does not induce gross changes in pupil size of the eye. There should not be any pools of darkness or pools of bright light within the room.

Thermal environment

2.25 The thermal environment concerns temperature, humidity and air flow rates. ATC is a shirt-sleeve environment. Most air traffic controllers do not move about much and can therefore be classified as sedentary from the thermal comfort point of view. In towers they may have to stand or move to see around obstructions, but this suggests poor workspace design if it occurs often. Ambient temperatures in the range 21 to 25EC would be a common recommendation for many of the busiest ATC environments. There are national and regional differences in the temperatures which people are accustomed to and accept as comfortable, and these should also be taken into account.

2.26 The relative humidity should be about 50% or slightly higher. Some variation can be tolerated, but very high humidity makes the air seem stuffy and clothing becomes uncomfortable, and very low humidity can lead to dryness in the throat which is undesirable because controllers rely so much on speech.

2.27 The other determinant of thermal comfort is air flow. An air movement rate of about 10 metres per minute is just detectable and makes the air seem fresh without causing draughts. It is necessary to check that the layout of the furniture in the room does not seriously interfere with the planned flow of air through it. The air flow rate must not be achieved by fans or any other devices which generate significant background noise.

Noise

2.28 High noise levels are not conducive to efficient air traffic control, especially during co-ordination and liaison when background noise may be carried via radios or telephones to the pilot in the cockpit or to controllers working in other positions. Loudspeakers in ATC environments are not recommended for routine use. Silent ventilation, carpeting, sound-absorbent plasters and curtains, and good attenuation of the workspace to preclude noise from aircraft or other external sources are the main practical means to reduce the ambient noise level in the room, preferably to 55 dB or thereabouts. If this can be achieved, it brings major benefits because all controllers can then speak quietly to each other and to pilots, and the general sound level in the control room or tower remains low. If people have to shout to be heard, vital messages are heard against a noisy background and the probability of mishearing is increased. The possibility is also introduced that a message intended for one controller or pilot is overheard and erroneously acted upon by someone else. Every practical means should be adopted to keep the prevailing background noise levels low in all ATC workspaces.

VISUAL DISPLAYS

2.29 Visual displays combine all aspects of the SHEL model: the viewer (liveware) the lighting (environment), their physical appearance and adjustability (hardware), and their information content (software). Job and task analyses, which mostly relate to liveware and software but also include other aspects, form the basis for specifying the contents of the displays. System planners and equipment manufacturers can suggest alternative technical means to satisfy these needs. Displays must be chosen in relation to human capabilities of vision, information processing and understanding.

Eyesight

2.30 The detailed contents of all displays must be clear and visible to every controller who needs to see them, even when the equipment is old and due for replacement. The workspace design should specify a viewing distance for all information on displays, and the specifications of each displayed information item should be checked against the applicable viewing distance to ensure that it will remain clearly visible to the controller with the minimum permitted eyesight in the most adverse conditions that can occur. Special visual corrections matched to the workspace may be prescribed to achieve these eyesight standards, and must always be worn at work if they are prescribed.

Foreground and background information

2.31 ATC electronic displays giving a plan view of the traffic can portray two broad classes of information. Static background information (such as airways, coastlines, restricted flying areas and range rings) should be present but unobtrusive, and depicted by using area fill, very unsaturated colours if colour is employed, and low contrast ratios. Dynamic foreground information may change or move, and much of it, including labels, refers to single aircraft. The brightness contrast ratio between dynamic data and the background should be approximately 8:1.

Colour

2.32 If colours are used, they should generally be pastel and quite unsaturated. Saturated colours should be employed only for vital and temporary information since they can be visually disruptive; even then, they are unsuitable for small visual items or areas. Some saturated colours, especially blue, can also induce problems such as chromatic aberration and should not be used. All colours must meet the brightness contrast requirement, even those with high saturation, and they must be rejected for operational suitability if they do not, no matter what other merits they may seem to have. To avoid confusion, the chosen colours should be clearly different from each other and should all have obvious names so that each colour can be referred to without ambiguity in speech. Tests for colour blindness should always be employed to ensure that all controllers meet the required standards for colour vision, but the colours chosen must allow for any permissible deficiencies in the colour vision of individual controllers.

Symbols and alphanumerics

2.33 Knowledge of brightness contrasts between the information and the background, of the ambient lighting, of the methods of generation of symbols and alphanumerics, of ergonomic recommendations for legibility and readability, and of minimum eyesight standards should be applied to derive minimum sizes and acceptable designs for symbols and alphanumeric characters, and minimum spacings between them. These specifications must not be compromised. Much dynamic ATC information is in the form of symbols or alphanumerics, the readability of which depends on how they are generated. With modern equipment, a minimum character height of about 3 millimetres should be satisfactory for symbol and label information. This size of characters may have to be increased to compensate for old equipment or adverse viewing conditions such as excessive ambient light. The minimum vertical spacing between lines of uppercase alphanumeric characters within the same label should be about 30% of the character height, though the vertical spacing between lines of continuous text on displays should not be less than 60% of the character height. The visual gap between adjacent characters in a line should be at least twice the thickness of the strokes used to form the characters. If character size is employed as a coding dimension, only two sizes should be used, with a large difference between them.

Further requirements

2.34 Visual codings of ATC information may have to meet further requirements. It must always be possible to visually discriminate between shapes and every shape must have an obvious name by which it can be specified verbally. Human visual limitations must be acknowledged: for example, colour as a coding is unsuitable for very small areas, as it may not be possible to discriminate small symbols from each other on the basis of their colour. Ambient lighting should not be coloured, since this can change the appearance of display colours, and must not be so bright that it degrades the portrayed information nor so dim that other vital information such as that on hard copy is difficult to read.

INPUT DEVICES

2.35 The controller initiates and implements all control actions by using input devices. Some of the simplest are switches or keys, such as those employed to select the correct communications channel before speaking. Traditional keyboards, or touch-sensitive surfaces which fulfil similar functions in some more modern systems, allow alphanumeric information to be entered into the system and appropriately updated. Other input devices include roll-balls, mouse, knobs and buttons. Sometimes foot switches are employed, e.g. as on-off switches to transmit on a communication channel. The choice of input devices suited to the task, their layout in relation to each other and to the displays associated with them, and the detailed design of each are main influences on the attainable proficiency, on the efficiency and speed of their use, on the development of skills, and on the kinds of human error that are possible while using them. Standard ergonomic recommendations should be applied to the controller's workspace, including the positioning, spacing, sensitivity, feedback and visual appearance of input devices, and appropriate reach distances and forces required to operate them.

MINIMUM ACCEPTABLE CONDITIONS

2.36 Air traffic control workspaces must remain safe and efficient under the most unfavourable conditions that are permissible. This applies to attributes of liveware (such as minimum eyesight standards), of hardware (such as equipment about to be replaced), of software (such as non-standard procedures), and of environment (such as glare from sunlight). Workspaces must therefore be tested and validated for these conditions and not for average or optimum ones. Each workspace must take account of the information to be portrayed, of the types of controls needed for each task and their layout in relation to each other and to displays, and of the furniture design. This requires the thorough application of proven ergonomic evidence for the positioning, layout, separation and coding of controls and of displayed information. To compromise these principles can lead to poorer performance that takes longer, is more prone to error and can endanger safety.

COMMUNICATIONS

2.37 The communication facilities available at the workspace need to be evident. Communications are primarily software, accessed through hardware. They have to be integrated into the workspace, with a clear and unambiguous indication whenever a communication channel is already in use. They must provide a positive indication of successful transmission. Hitherto much of the information transmitted between one controller and another and between pilots and controllers has been by speech, a liveware-liveware interface, and the message formats have included formal acknowledgement that each message has been received and understood. In the future more information will be transmitted automatically between aircraft and ground systems, between satellites and computers and through various other communication systems, without the direct participation or involvement of the controller. The controller has no knowledge of such information unless deliberate provision for informing the controller has been included. The roles of groups and teams are often reduced when communications are automated, since the human link with the machine through the human-machine interface is usually accessible to one controller but not to a team of controllers.

2.38 For many years to come, ATC systems will continue to contain a mixture of various kinds of communication. ATC must provide a service for types of aircraft which vary greatly in their on-board communications equipment. The controller has to understand and integrate all the kinds of information that may be encountered. If there are automated aids to communications, the controller must know how these function. Different kinds of communicated information can be combined and reconciled only in the ways which are practical within the human-machine interface design.

2.39 To avoid ambiguity and potential sources of error, the content, structure, dialogues, vocabulary and sequences of spoken ATC messages have been standardized as much as possible. Much of this was done many years ago. The ICAO spelling alphabet[1] was the product of extensive research to choose a set of words which would sound as different from each other as possible, even when spoken over noisy and degraded communication channels by people whose native language was not English. The ICAO spelling alphabet has proved to be efficient, and further research on it would be unlikely to achieve significant improvements. (However, its suitability for recognition by humans does not imply its suitability for recognition by machines.)

2.40 The main sources of phonetic confusions and similarities are well established. Aircraft with similar call signs within the same airspace must inevitably be a potential cause of human error, and such circumstances are best avoided by pre-planning. Whenever aircraft may fly in the same area at some stage during their flight, very different call signs should be assigned to those aircraft. Ambiguity can be curtailed by always giving the contents of ATC messages in standard formats and in standard order. This reduces the possibility that one kind of information will be mistaken for another.

2.41 Communications can be improved by good controller and pilot discipline. It is always important to speak slowly and clearly, especially when English is not the native language of either the speaker or the listener. Towards the end of a long shift or a long flight, the controller or pilot may be tired and speech should be particularly slow and clear. Voices become familiar, and it can confuse the pilot if a different controller from the one expected replies, and confuse the controller if parts of a single dialogue with the crew of an aircraft are with different crew members. Transmissions where the start or the end of a message is cut off can be potentially dangerous, especially if the controller is busy, which is when this is most likely to happen. Routine confirmation of messages and requests to repeat them if there is any uncertainty can help to prevent errors. Particular care is needed to counteract the human propensity to hear what is expected rather than what is actually said.

CONTROLLER PROFICIENCY

2.42 ATC requires the performance of many different tasks using the same information or different selections from the information presented. When displays, controls and workspaces are specified, it is therefore important that they be suitable for the whole range of tasks for which they will be employed, and not merely for some of them. As a consequence, they may not be optimum for any single function but must be efficient and safe for every function. Otherwise certain functions in the operational system may be very inefficient or impossible. For example, any visual coding such as colour is likely to assist tasks with which it is directly compatible but hinder tasks which require the collation of information portrayed in different colours. A balance has to be struck across the various tasks, to choose codings that help as many tasks as possible and do not seriously interfere with any task.

2.43 The controller must be able to plan the air traffic control, implement the plans, make decisions, solve problems and formulate predictions. To perform the essential control tasks, the controller must understand the portrayed information, whatever form it takes. The controller must remember what forms of assistance are available and know when it is appropriate to call on each. The controller must know the right course of action in all circumstances. Human Factors addresses the thinking processes that the controller must follow and the effects of equipment changes on them. If necessary, equipment or procedures must be modified to ensure that these thinking processes do not change too much or too quickly. Whenever these thinking processes must change, appropriate controller retraining is essential. This often involves revised liveware-software links.

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1. The ICAO spelling alphabet is: Alfa, Bravo, Charlie, Delta, Echo, Foxtrot, Golf, Hotel, India, Juliet, Kilo, Lima, Mike, November, Oscar, Papa, Quebec, Romeo, Sierra, Tango, Uniform, Victor, Whiskey, X-Ray, Yankee, Zulu.

2.44 If changes are relatively minor, the aim of retraining may be to transfer what was already known. If former control procedures would be totally inappropriate in the new setting, one objective of retraining is to over-learn the new and remove any similarities between old and new, so that the controller never carries over old and inappropriate actions into the new system as a matter of habit. States introducing new systems may learn about appropriate retraining from the experience of other States that have already introduced similar systems.

CLASSES OF INFORMATION

2.45 Information in ATC refers mainly to software, as interpreted by the human (liveware) through the human-machine interface (hardware). ATC obtains information from several sources, which vary according to the type of ATC. The controller must have an adequate understanding of all the information when it has been amalgamated.

2.46 Information obtained through speech is universal: almost every ATC job requires some speech by the controller and includes some information spoken to the controller by pilots or other controllers. Information available in advance about the aircraft including its identity and details of its flight in the form of a flight plan is also almost universal and is the main basis for ATC planning tasks. As the flight progresses, this information is kept up-to-date by annotating flight progress strips or an electronic equivalent of them, and by updating tabular and other relevant information stored in the computer. Information in the form of a current geographical view of the traffic, usually derived from radar, is very common, and is the main basis for tactical air traffic control, particularly when the radar display includes an electronic label for each aircraft under control giving details of its flight. In the future, similar information may be derived from satellites. A further source of information comes from relating aircraft to various fixed facilities on the ground, such as radio aids marking routes. Much ATC information is in the form of actual times such as times over reporting points en route, or estimated times over reporting points or positions where routes intersect or join. Some information is obtained through the workspace itself. For example, the choice and layout of input devices, of displayed information, of the relationships between displays and controls, and of communications facilities help to indicate control functions and remind the controller about available options.

2.47 Information can be derived from various sensors. Much of it requires processing and computation. Future ATC systems will contain more processed information of two broad kinds. One kind is intended to lead to controller action by drawing attention to anomalies, to deviations from track, to potential conflicts or infringements of separation standards, and to information that has changed or been updated automatically. The other kind is intended for ATC planning on the basis of prediction or extrapolation from the current situation. Some aids may show the predicted traffic situation at a designated future time or offer solutions to predicted future problems that have not yet become apparent. Such computations can be impossible for a controller to verify, since such computer assistance far exceeds the speed and accuracy of human computing capabilities.

2.48 While ATC is in a state of transition, information intended for similar functions may be in different parallel forms. Some systems may employ paper flight progress strips, while others use electronic flight progress strips. Some may use data transmitted automatically between air and ground while others use speech between the pilot and the controller. Common Human Factors principles apply to both forms but the Human Factors problems differ. For example, the ergonomic problems of incorporating within a workspace a large FPB or an electronic display of flight progress strips are quite different.

2.49 As in any system which relies on human intervention in the event of system failure, the controller is expected to be ready to take over and maintain a safe ATC service, which implies that the controller's information must be continuously updated and that the controller must maintain a full understanding of the traffic situation. If this requirement is not met, safe reversion to more manual forms of control may not be possible if the system fails. The human cannot be as efficient in the reverted manual mode without computer assistance, but must still remain safe.

2.50 To build and maintain the controller's knowledge of the situation, the following considerations are relevant:

- timing of the presentation of information;
- formats, codings and level of detail of information;
- compatibility of different sources of information so they can be correctly interpreted as a whole;
- depiction of the relationships between different kinds of information;
- the kinds of error associated with each category of information, the means to detect and prevent errors with serious operational consequences and the appropriate procedures for the controller to deal with less serious errors;
- the appropriate degree of accuracy, precision and trustworthiness for each information category and the provision of means to convey this kind of information correctly to controllers;
- the matching of the amount of information and its level of detail with the task requirements so that there is neither too much nor too little detail;
- specification and conduct of training required to use, apply and interpret the information correctly;
- procedures and instructions to be followed and the conditions under which alternative procedures or instructions become permissible or mandatory;
- effects of individual differences between controllers in age, experience, knowledge, ability or other factors, on their interpretation or use of the information provided.

2.51 Decisions about workspaces and design predetermine many of the kinds of human error that are possible and which sooner or later will occur. This applies particularly to decisions about the displays and codings, the types and sensitivities of control and input devices, the layout of equipment in the workspace, communication channels and the means to activate them, and the perceived relationships between displays and input devices.

Chapter 3
AUTOMATION IN AIR TRAFFIC CONTROL

FULL OR PARTIAL AUTOMATION

3.1 Many modern ATC systems include some functions, for example in data gathering and processing, which are fully automated with no direct human intervention. These functions may have significant indirect Human Factors implications, for example if the controller is not able to discover whether fully automated functions have occurred or have been successful. If any of these fully automated functions were previously fulfilled by the controller, the absence of the knowledge formerly gained by fulfilling them may be experienced by the controller as an apparent loss of understanding of the traffic situation.

3.2 This chapter is primarily concerned with a different form of automation in ATC, in which the automation of a function is partial or incomplete and intended to assist the controller. The Human Factors implications of such forms of automation are direct and immediate. They pose problems of human-machine relationships which have to be identified and resolved during the system design process, with subsequent confirmation that the operational objectives of the automation have been achieved. They relate primarily to the liveware-software interface.

REASONS FOR AUTOMATION

3.3 There are several reasons for the progressive introduction of automation into ATC systems. One concerns technological and navigational advances which provide more accurate, precise, reliable and up-to-date data about the position of each aircraft, its plans and intentions, its flight level and speed, and the progress of its flight. These developments are often accompanied by advances in display technology which enhance the depiction of aircraft on ATC displays, and by advances in automated assistance for problem solving, predictions and decision making. The gathering, storage, compilation, integration, presentation and communication of information are essential processes in ATC, and all of them can be aided by automation.

3.4 Air traffic is expanding world-wide. The information about aircraft is improving in quantity and quality, and must do so to allow greater numbers of aircraft to fly within the same airspace as safely as they do now. Because there are more aircraft and there is more information about each aircraft, the amount of ATC information is expanding beyond the capacities of existing systems to handle it. Yet safety and efficiency must be maintained. The problems cannot always be solved by further sectorization of airspace and the employment of more controllers because at some stage the additional liaison, co-ordination and communications burdens eventually outweigh other benefits. Long-term trends are for more information about each aircraft, less permissible delay in dealing with it because aircraft are closer together, and less time for controllers to devote to each aircraft.

3.5 ATC information and tools for the controller are evolving through paper (flight progress strips), electronic displays (radar), data handling (computer assistance), and automation (computer implementation).

This evolutionary process has reached very different stages in different States. It has been concluded[1] that increased automation in ATC is inevitable. The issues are therefore about when, where and how automation should be introduced, not if it should be introduced.

3.6 Two examples illustrate forms of automation applicable to ATC. One example is data links: equipment has to be installed not only in the ground systems but also in aircraft receiving the ATC service. The other example is satellite-derived information that can be used for navigation and surveillance. The system is in principle accessible everywhere, and it offers opportunities to plan and control traffic more globally in systems that transcend national boundaries, provided that the forms and use of data are standardized and agreed internationally.

GOALS OF AUTOMATION

3.7 If properly used and employed, automation can be a great boon. It can aid efficiency, improve safety, help to prevent errors and increase reliability. The task is to ensure that this potential is realised, by matching automated aids with human capabilities and by mutual adaptation of human and machine to take full advantage of the relative strengths of each. Depending on the type of traffic (traffic density, type of aircraft) and the ground equipment (communication and navigation means), different types of tools can be developed to achieve these goals:

1) tools providing additional information without inducing any major changes in working methods, e.g. a TV network;

2) partial or full automation of existing non-expert tasks, e.g. transmitting control data via data link or using secondary radar (SSR) to correlate a paper flight progress strip and a radar reply by displaying the aircraft identity close to the reply;

3) tools which provide information that introduces a radical change in working methods, e.g. radar or automatic dependent surveillance (ADS);

4) automation of so-called expert tasks, using either expert systems or tools which can calculate and negotiate 4D conflict-free trajectories within an air-ground integrated system, e.g. planning of traffic flows, conflict resolution or sequencing traffic within the terminal area.

3.8 The influence of Human Factors considerations on the efficiency of the tools increases from type 1 to type 4. Many ATC services all over the world are already equipped with tools of types 1 to 3, and have some experience of the Human Factors issues that they introduce, but it is necessary to consider carefully the issues arising from tools of type 4. In most automated systems the human will remain the key element of the system: the machine will assist the human and not the contrary. The human-machine collaboration must be studied very early in the development of any tool; if it is not, the tool may not be used as intended or not used at all, which may prejudice the efficiency or the safety of the system.

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1. Wise, Hopkin and Smith (1991). *Automation and Systems Issues in Air Traffic Control.*

CONSTRAINTS

3.9 The human functions within the ATC system have to be described clearly. Various constraints must be overcome, including the following:

- The level of human expertise must be maintained. Even highly reliable systems can fail, and the system must remain safe, though not necessarily efficient, in the event of failure. The controller should remain able to deal with the traffic without machine assistance even if this induces a very high workload. If the automated system shuts down, the human controller must still be able to handle the traffic, at least until all aircraft present in the sector have landed or left the area of responsibility, if necessary without the normal pilot/controller relationships.

  Whenever it is possible for automated functions to revert to human functions in the event of failure, it must also be possible, while the system is functioning manually, to restore the automated functions when the failure has been repaired. Human expertise is particularly important when automating expert tasks such as conflict resolution. Expertise can be maintained only by regular practice as it is gradually lost if there are never any opportunities to use it.

- The controller's mental picture of the traffic should be maintained. This picture may become less detailed and more vague if the controller becomes less actively involved in control processes and does not need to have such a detailed understanding of the air traffic in order to control it.

- The workload of the controller must remain between a minimum and a maximum threshold. Too little work induces boredom, inattention and loss of skill, and this can be dangerous in low traffic density periods. Beyond the overload threshold the controller may no longer ensure safety. Automation may induce, in certain conditions, extra tasks which generate additional workload. There is still no satisfactory way to quantify workload in such a complex process as air traffic control. Workload may be generated by different parameters which cannot easily be aggregated, including the number of aircraft and the complexity of the traffic situation, which is not a simple function of aircraft numbers.

- Different kinds of workload are not equivalent. Time saved by reducing one kind of workload cannot always be allocated to another kind. For example, reducing the requirements for data entry does not necessarily result in more time for decision making. Tasks which require different skills and abilities may not be interchangeable. Functions that have been automated may need human verification.

- Job satisfaction must be maintained. This requires effort, challenge and use of skills. Automation may well reduce the effort required for certain tasks and the stress associated with them, but may lead to loss of job satisfaction by taking away some of the intrinsic interest of the job and the perceived control over certain functions. This is particularly important in relation to problem solving, decision making, prediction and planning (i.e. with tools of type 4).

- The controller must be able to understand and trust the automatic system. It must be reliable or at least the controller must know when it may not be — this knowledge can be an aspect of controller proficiency, e.g. to recognize under what circumstances there could be a false alarm. A tool that is not trustworthy should not be introduced: if it is, it may be ignored or misused.

- Task sharing and the division of responsibilities between controllers must be unambiguous. Effective task sharing requires rigorous planning and correct work-space design. Each controller must always know which tasks are his or her own responsibility to be done manually, which tasks are done entirely by the automated system, which tasks are done entirely by other controllers with or without the automated system, and which tasks are shared with other controllers. If planning and executive control functions are physically separated, it may be impossible for each to fulfil the main functions of the other in the event of system failure.

- Information is transmitted from human to system and from system to human, and the human-machine co-ordination process must be carefully defined. It is necessary to be sure that transmitted information is acted upon by the controller and by the system, or by the pilot in the case of, for example, a data link. Furthermore, human-machine co-ordination does not consist only of exchanging information. There must be no interference between automated decision processes and actions taken by the controller. It is particularly difficult to achieve this when decisions may be implemented by a succession of actions and not by a single action at a fixed time. Although it might be quite easy for the controller to use a device such as electronic flight progress strips to inform the machine about human actions, it may be much more difficult to inform the system about future human intentions. A goal is to convey human intentions to the machine so that the machine can help the human to fulfil them.

3.10 It is a mistake to develop systems first and then try to devise a way for the human to use them. This is why the participation of controllers is necessary throughout the system development, from its initial specification until it becomes operational. The human-machine interface should integrate different automated tools while improving the presentation of information to the human and communications between human and machine. It is not necessary (and may even be dangerous) to present too much information, as is always possible in highly automated systems. The aim is to present timely and relevant information when it is needed. Alternative input devices may be more suitable for some dialogues and interactions than for others.

THE APPLICATION OF AUTOMATION

3.11 The extent of the application of automation currently and in the near future varies greatly between States because of the differences in ATC demands, in the airspace and in the resources devoted to ATC. The initial forms of automatic assistance consisted of the gathering of data automatically, its storage, and some selectivity in summarizing and presenting information to the individual controller by adjusting its level of detail to the task requirements. A later development was the use of the gathered data to make various computations, to collate different information sources, to make checks and to extrapolate in the form of predictions. Forms of assistance were thus devised to indicate if an aircraft was diverging too far from its planned route and to show whether two aircraft, if they continued to fly as planned, would be in potential conflict with each other at some future time. At this stage, computer assistance indicated potential problems to the controller but did not suggest solutions.

3.12 As data were sensed and updated automatically and more frequently, they rapidly exceeded in quantity and level of detail the amount which the human controller could see and understand within the time available. Therefore they had to be collated, condensed and presented more selectively in a form suitable for the specific tasks of the controller, as determined by task analysis of the controller's information needs. A further development, with origins in intelligent knowledge-based systems and aspects of artificial intelligence and expert systems, was the introduction of forms of assistance which would aid the controller in taking decisions, solving problems, making predictions and scheduling future work. These were based on computations from automatically sensed data, and their value — and indeed their feasibility — depends on the availability of such data and the power to make these computations. These aids can handle more data, faster, more often and more reliably than a human being can. They are helpful because they allow the human controller to do more in less time. If they fail, however, the human controller taking their place will use much less information, make poorer decisions, be slower, or omit some functions. Therefore one of the problems of automation is the extent to which the human can act as a backup in the event of failure. The more helpful the automated assistance is when it is functioning normally, the more difficult it becomes for the controller to compensate for it if it fails.

3.13 One problem in ATC has always been the integration of different kinds of information from different sources. The incompatibility between the information about a flight on a paper flight progress strip in a holder on a FPB and other information about the same flight in the form of a label related to a blip on a radar display is obvious. The whole structure of these two kinds of information is so different that they have always been difficult to integrate. Flight progress strips cannot be laid out in the same relative positions as the radar blips, and they contain too much information to be condensed onto a label on a radar display without incurring insuperable problems of label overlap, clutter and ambiguities in interpretation. Therefore automation in ATC has often sought better ways to integrate and cross-reference the two kinds of data.

3.14 Paper flight progress strips do not enter any information into a computer. Wherever they are used, the controller must keep the information on them up-to-date manually, but may also have to update the corresponding information in the computer so that all the calculations based on that information and presented in the form of computer assistance are correct. If the controller has too much work, updating information may suffer because it can be postponed, though it then becomes more and more difficult to catch up. Duplication of tasks by updating the same information in two different forms seems wasteful. However, doing the same task in two forms may help to prevent errors that are typical of one form only, and may also help to reinforce understanding and memory. Such issues need to be addressed so that the avoidance of duplication does not generate further problems.

3.15 Various forms of automated flight progress strips are currently being tried. They seek to replace paper flight progress strips and to help the controller by minimising task duplication, by facilitating the entry into the system of the controller's actions and decisions and by helping to integrate radar information and tabular information on flight progress strips. Electronic flight progress strips exemplify the aim of automation to reduce routine work and increase the time available to each controller for controlling aircraft. Progress is being made but it is proving to be a more complex problem than was originally envisaged, because paper flight progress strips fulfil a more complex range of ATC functions than was at first realised.

FURTHER IMPLICATIONS OF AUTOMATION

3.16 Different philosophies can be adopted, corresponding to different respective roles for human and machine in automated tasks. For example, if the machine is advisory, alternative solutions may be calculated and proposed to the controller in an order of preference that depends on performance criteria. The controller has the responsibility to validate the proposed solutions and to select one of them, or, if none seems correct, to devise and apply an alternative solution. The controller may also define additional constraints that the proposed solutions must fulfil: in a sequencing process in a terminal area, for instance, the controller may impose for a given aircraft an arrival time that any computed solution must comply with. In some cases, the controller may delegate the application of a solution to the machine. In an advisory role the machine can never make a decision without controller agreement.

3.17 If the machine is always adequate, the controller may develop excessive trust in it and accept proposed solutions routinely without checking. However, if the machine seems inadequate in any respect, it might not be used at all. All forms of automated assistance for the controller must be highly reliable, but this can induce human complacency. Human expertise may gradually be lost and, if the machine fails, the controller may accept an inappropriate solution or become unable to formulate a satisfactory alternative.

3.18 This advisory role can be more suitable for planning functions which consist largely in manipulating constraints. The planning controller could define constraints that have not been taken into account by the tool and transmit them to the machine. If the machine has been suitably designed, true human and machine co-operation may be achieved, retaining human expertise. Such human-machine co-operation already occurs, e.g. in certain sequencing tools in terminal areas. **The most appropriate forms of human-machine relationship depend on the type of task which is automated and particularly on the interaction between planning and executive functions.** Examples of planning functions are the allocation of flight levels in an en-route sector, inter-sector co-ordination, and the sequencing of aircraft into a terminal area, whereas conflict detection/resolution, monitoring and surveillance are executive functions. It may be easier to design satisfactory tools for planning controllers than it is for controllers with specific executive functions such as collision prevention.

3.19 In another role, the system may recognize classes of problems that it can resolve entirely. For example, in a conflict detection/resolution process it might resolve conflicts involving two aircraft but not those involving three. Tasks may be allocated either to the human or to the machine, provided that the machine can accept a problem allocated to it. The allocation process can help avoid extremes of controller workload. The successful implementation of machine roles that can resolve problems entirely requires thorough development work.

3.20 The automation of data can lead to Human Factors problems, since it can deprive the controller of important information about the reliability and durability of information. For example, because much information conveyed through speech cannot be expressed in digital terms, it is omitted in the automation process; thus while it may contain important *quantitative* information, it may no longer contain the *qualitative* component (the “party-line effect”) needed by the controller in order to make the best use of it. The significance of such qualitative information must be established before it is taken away, and alternative methods of providing it may have to be adopted.

3.21 Whenever tasks are done automatically rather than manually, what the individual controller understands and remembers about the traffic under control can change. Acknowledgement of this before automation is introduced allows it to be compensated for if the resultant changes in understanding and memory are not acceptable. The performance of routine ATC tasks aids memory, which is not the case if these tasks are done automatically for the controller. This may be acceptable as long as it has been recognized in advance and the system and tasks have been planned to take account of it.

TEAM FUNCTIONS

3.22 Automation can affect some liveware-liveware interfaces in ATC, and as a consequence some methods of verification and supervision can change. A manual ATC system is open to inspection and checking; a supervisor or colleague can see all that a controller does, form a judgment of his or her competence, help a controller who is overloaded, and draw attention to problems which may have remained undetected. Such functions become more difficult when there is automated assistance for problem-solving, decision-making and prediction, because these functions are much less immediately observable by others. If independent supervision or confirmation is still needed it may have to be provided in other forms. Although a supervisor may oversee several controllers, it may no longer be possible, for example, to personally annotate a controller's flight progress strip to indicate that the supervisor has made the amendment.

3.23 The team roles and functions in automated systems differ from those which can be exercised in manual systems. Controllers in more automated systems are more self-sufficient and autonomous and fulfil more tasks by interacting with the machine rather than with colleagues or with pilots. There is less speech and more keying. This affects the feasibility and development of traditional team functions such as supervision, assistance, assessment and on-the-job training.

3.24 When jobs are done by members of a closely co-ordinated team, a general consensus about the relative merits of individual performance can form the basis not only of professional respect and trust but also of promotions or assignments of further responsibilities. The evidence to make such decisions may, however, be changed by the automation of tasks, as may the evidence available for the assessment of individual performance. If ATC consists of accepting computer decisions, then this does not itself confirm how competent the individual controller is. Other means may have to be found to check that the controller's proficiency and professional knowledge have been maintained. ATC simulations may meet such needs, just as flight simulators do for some pilots.

STANDARDIZATION

3.25 One issue raised by automation concerns standardization, especially in communications. Messages between controllers and pilots have standardized formats, wordings and sequences. Messages for some other communications, such as those with ground vehicles, have less complete standardization. Quite often, non-standard practices and procedures that have become entrenched among the controllers at particular ATC locations can lead to problems if they are incompatible with standardized forms of computer assistance being introduced throughout the system, either to replace human speech or to present the content of human speech in alternative forms such as visual words or synthesised auditory messages.

3.26 Verbal communications are safest when everyone adheres to the standard language, standard formats, standard message sequences and standard acknowledgements intended for universal use. Exceptions can lead to errors and misunderstandings, and must be discouraged. Although most current forms of automation seem rigid and inflexible, automation may in principle be able to accept more flexibility in message forms, content and language than humans can, and this raises anew the issue of how much standardization is desirable for safety.

3.27 Automation proposes one best way to control air traffic. Yet different controllers have traditionally had some flexibility in their choice of control techniques. Alternative techniques can be broadly equivalent in terms of safety and efficiency, with none obviously superior to all others. An automated system may discourage human flexibility and impose standardization. The recommendation with present forms of automated assistance is to apply rigid standardization and not to introduce any variations or shortcuts since these are likely to lead to a new crop of human errors or misunderstandings.

HUMAN-MACHINE INTERFACE AND HUMAN ERROR

3.28 The human-machine interface mainly consists of liveware-software and liveware-hardware links. Traditionally, most information has been conveyed from the machine to the human by means of visual displays and from the human to the machine by means of input devices and controls. Automation changes what is transmitted through the human-machine interface, either leading to some information not being transmitted at all or changing the format of transmitted information, such as from human speech to keyboard entry, which in turn changes the kinds of human error which are possible while entering any given message. Speech errors are often caused by phonetic confusions (sounds which are too similar to be reliably distinguished). Visual errors and misreadings can be caused by alphanumeric characters which look similar to each other, lines of data which can be mistaken for each other, blocks of data which look alike, visual labels for keys which give a misleading impression of their functions, and so on.

3.29 Although the kinds of human error are not all the same, their general nature can often be predicted in advance, because decisions about the choice of method of input or about the form and content of displayed information are also decisions about human error. It may not be possible to predict who will make a particular error under what circumstances, but it is possible to predict, before a change in the system is made, which human errors can no longer occur and which new kinds of error are now possible and must therefore be prevented. One of the most important applications of Human Factors to any form of automated assistance is this identification of new kinds of human error — especially those which might be dangerous — that can arise as a consequence of change.

Chapter 4
THE SELECTION AND TRAINING OF AIR TRAFFIC CONTROLLERS

SELECTION OF APPLICANTS

4.1 Air traffic control is a demanding profession — its safety and efficiency depend on selecting those who will become most capable of doing the jobs within it. A good selection procedure eliminates unsuitable candidates at an early stage and saves training costs. Selection and training are mostly concerned with liveware, although they are influenced to some extent by all other interfaces within the SHEL model.

4.2 For the selection procedure to be effective, the number of applicants must exceed the number of vacancies by a substantial margin. A prerequisite for a successful selection procedure, therefore, is that ATC be viewed as a desirable profession, attracting many applicants. National publicity and positive advertising may be needed to encourage enough suitable applicants to apply. The more stringent the criteria for selection are, the larger the proportion of applicants rejected will be, and the larger the initial pool of qualified applicants must be. Given suitable applicants, the selection process is the first vital step towards producing proficient air traffic controllers. An impartial selection procedure based on Human Factors principles is essential.

4.3 Analysis of the ATC jobs within a particular context establishes the skills, abilities and knowledge needed to perform them and the degree of commonality among them. If there is a high degree of commonality, the same selection procedure can be used for all ATC jobs; if the commonality is low, different jobs may require different selection procedures. Various local system requirements or ATC characteristics may point to further relevant human attributes that could be included; these include the amount and patterns of traffic, the nature of the terrain, the navigational and other aids, the geographical relationships between nations, and climatic and meteorological factors.

TESTS

4.4 Detailed task analyses are used to identify many of the measurable human performance attributes that contribute to success. When the relevant human attributes have been defined, tests that measure them are administered to all applicants. The tests should be standardized, and the scoring of test results must be impartial. All the attributes measured by specific tests may not be equally important to ATC, and so some test scores may be more important than others. Some tests may measure a general human ability known to be relevant to many aspects of ATC. Others may measure a more specific ability required for particular ATC tasks.

4.5 Numerous human abilities, measurable by standardized tests, seem to have some predictive value in the selection of controllers. These include general intelligence, spatial reasoning, abstract reasoning, arithmetical reasoning, task sharing, verbal fluency and manual dexterity. All form part of some selection procedures but none has gained universal acceptance. No single test approaches the levels of prediction that would be needed to justify total reliance on it for controller selection. Many of the most widely available personality tests have also been tried experimentally in controller selection, but none is widely used and their role has generally been limited to interpreting other measures or indicating a need to gather more evidence about an applicant.

4.6 The scores on some tests may be emphasized more than the scores on others. Test validation procedures can be used to suggest appropriate weighting for each test to maximize the predictive value of the whole test battery. The processes of presenting and scoring tests are becoming more automated, and it is an administrative advantage (and more objective) if impartial automated presentation and scoring can be used. Candidates must receive practice and familiarization with the automated testing procedures, however, so that their test performance is not reduced due to unfamiliarity with human-machine interfaces and computer dialogues.

4.7 The selection process is not static but should evolve as the jobs, tasks and equipment in ATC change. Appropriate modifications of the selection procedures may be introduced when properly conducted and validated research has shown that additional testable human dimensions are relevant.

OTHER DATA

4.8 Procedures and data other than testing are also important in the selection process. Age, medical history, eyesight, hearing, emotional stability and educational attainments are all relevant to becoming a controller. Even basic anthropometric requirements may form part of the selection procedure — it may be impossible, for example, to accommodate exceptionally tall or short people within the ATC workspace. Some ATC workspaces, notably those in towers, may be inaccessible to disabled people. Controllers must maintain their medical fitness and therefore those who have a medical condition with a potentially unfavourable prognosis may not be selected. Drug or alcohol dependence is usually a disqualifying condition.

4.9 Previous knowledge of aviation, previous coaching and practice in tests similar to those used to select controllers, or previous ATC experience (for example as a military controller or as an air traffic control assistant) might seem to be advantageous, but in fact their benefits and relevance are often disappointing, and States differ in the value they attach to such experience. One difficulty is that those with most experience are likely to be older, and those who are older than about 30 are less likely to complete ATC training successfully. Previous related experience may be a better predictor of the motivation to become a controller than of the ability to become one, and more applicable to dealing with emergencies than to routine ATC.

4.10 An interview helps to confirm that candidates can express themselves clearly when they speak, an essential attribute since much ATC is conducted by speech. An interview may help to reveal how well each applicant relates to other people, another essential attribute when most ATC work is not done alone but in groups and teams. The interview should be standardized, structured, and demonstrably fair to all candidates in its conduct and scoring.

TRAINING

4.11 The objective of air traffic controller training is to ensure that controllers possess the required knowledge, skills and experience to perform their duties safely and efficiently, and to meet national and international standards for ATC. A controller must be able to understand and assign priorities to the relevant information, to plan ahead, to make timely and appropriate decisions, to implement them and to ensure compliance with them.

4.12 Training is a matter of learning, understanding and remembering. It relates what the controller already knows to the information that the system provides about current and pending traffic. It relates the information which the system presents automatically to the controller to the information which the controller must remember unaided, and it provides guidance on how human memory can be strengthened and made more reliable. Training also relates the principles for learning and displaying ATC information to the capabilities and limitations of human information processing and understanding. The aim is to make the best use of human strengths and capabilities and to overcome or circumvent human inadequacies or limitations, particularly in relation to knowledge, skill, information processing, understanding, memory and workload.

TRAINING CONTENT AND TEACHING

4.13 Two essential aspects of training are training content and the teaching process. With regard to training content, it is beneficial to divide the training into a series of courses or phases. These start with basic principles and practices, and progress on successful completion of each phase towards more complex aspects of ATC. This approach requires mastery of the basic principles and practices first, which helps to ensure that the later stages of training build on knowledge already acquired. Separate courses coupled with impartial assessments provide benchmarks of training progress and a form of quality assurance applicable to training. This can be particularly helpful to demonstrate that changes in the training, whether in its content or in the teaching methods such as the introduction of automated teaching aids, have been successful and beneficial.

4.14 It is possible to deduce from envisaged tasks what the content of training must be and what the controller must learn, only to discover that it cannot be taught or that controllers cannot learn it. In introducing changes in systems for whatever reason, therefore, it is vital to establish what new knowledge the controller must acquire and to show that it can be taught and learned. New forms of automated assistance must be teachable; if they are not, the expected benefits will not materialize and new forms of human error may arise because the automated assistance is not completely understood.

4.15 Various teaching methods can be employed in ATC training. Classroom instruction of principles and theories according to traditional academic methods, common in the past, is currently diminishing, partly because more active participation is favoured, partly because the relevance of theory is often disputed and partly in response to financial pressures. Instruction based on real-time simulation, some of which can be quite rudimentary, is strongly favoured as a practical means of training groups of students, and fundamental reliance on simulation training is common. In on-the-job training, a student already instructed in the principles of ATC learns its practical aspects from other controllers directly in centres and towers. Soon there will be more self-training packages for the student to practise particular procedures and skills on a computer.

4.16 On-the-job training is not a replacement for simulation training but is generally considered to be essential at some stage, to show that the student can cope with the strains of controlling real, as distinct from simulated, air traffic, and to build the student controller's experience of real air traffic while an instructor or experienced controller is present. On-the-job training also reveals the high standards of professionalism and competence which the controller must achieve to gain the trust and respect of colleagues. The task of the on-the-job coach is a demanding one. Not all controllers make good coaches, nor do all controllers want to become coaches. The controller who coaches must want to teach, must be proficient and confident in his or her own skills, and must be able to handle a traffic situation through another person, teaching skills to that person while at the same time maintaining over-all command of the situation. There are principles and techniques in coaching which all who coach should be aware of so that the coaching is efficient and the standard of air traffic services is maintained. Coaching is a specialist task, one that is carried out in addition to controlling aircraft. For this reason, it will be seen that a certain amount of operational experience is necessary before a controller commences coaching.

4.17 There are national differences in policy on the range of ATC jobs that each individual controller should be qualified to do, which are reflected in the forms and duration of training. A knowledge of basic ATC practices and procedures is essential even in sophisticated systems, since safety may depend on such knowledge in the event of some forms of system failure. Regular additional training may be needed to maintain the controller's proficiency in the manual functions needed should the system fail. Refresher training and competency checks can be employed to ensure that the controller retains the professional knowledge and skills that are not used frequently in more automated systems but may still be needed.

4.18 The efficiency of learning depends on teaching methods, content and presentation of material, attributes and motivation of the student and on whether the instruction is provided by a human or a machine. It also depends on whether the instruction is theoretical or practical, general or specific. The content of what is taught, the sequence in which items are taught, the pace of teaching and the amount of reinforcement and rehearsal of taught ATC information should all be established according to known learning principles. Knowledge of results and of progress is essential for successful learning.

4.19 The proficient controller needs to know and understand:

- how ATC is conducted;
- the meaning of all presented information;
- the tasks to be accomplished;
- the applicable rules, procedures and instructions;
- the forms and methods of communication within the system;
- how and when to use each tool provided within the workspace;
- Human Factors considerations applicable to ATC;
- the ways in which responsibility for an aircraft is accepted and handed over from one controller to the next;
- the ways in which the work of various controllers harmonizes so that they support rather than impede each other;
- what changes or signs could denote system degradations or failures;
- aircraft performance characteristics and preferred manoeuvring;
- other influences on flight and routes, such as weather, restricted airspace, noise abatement, etc.

ASPECTS OF TRAINING

4.20 ATC is not self-evident. The typical ATC workspace contains no instructions or guidance about what it is for, what the tasks are, what the facilities are, what the displayed information actually means, what the controls and other input devices do, what constitutes success or failure or what should be done next after each task has been completed. Even in quite automated systems, ATC cannot function without human presence — it is reliant on controller intervention and will remain so for the foreseeable future. Hence the importance of identifying all that the controller needs to know and ensuring that it is known, all that the controller needs to do and ensuring that it is done, and all that the controller needs to say and ensuring that it is said clearly and correctly and at the right time. These are essential objectives of training.

4.21 Training should follow recommended Human Factors procedures and practices. It should be flexible enough to be adaptable to the needs of individual controllers. It should incorporate a basic understanding of Human Factors so that controllers have some insight into their own capabilities and limitations, particularly with regard to possible human errors and mistakes. Controllers should know enough to be able to select the most appropriate aids in their workspace to improve their task performance and efficiency, especially in choosing display options.

4.22 Training must also ensure that the controller can cope with the workload required to control the traffic offered. This means knowing what the correct actions and procedures are in all circumstances, as well as executing them properly. The controller also needs to be able to learn how to schedule work efficiently. Training aims to teach the controller how to plan ATC and to deal successfully with any unexpected situations. Important objectives of training are to instil good skills, knowledge and habits, and to reinforce them so that they are durable and retained. They have to be maintained actively because skills degenerate, knowledge is forgotten and habits are broken if rarely used. Over-learning can be helpful in the form of extra training and practice deliberately intended to reinforce what has already been learned.

4.23 Training should not only encourage certain actions but discourage or prevent others. An important part of training is to break bad habits or prevent them from arising. For example, the controller must give priority to an emergency and offload other tasks. Yet the controller must never become so totally absorbed in a single problem as to fail to notice what else is happening. This might entail breaking the habit of concentrating on a single task until it has been completed and forming the new habit of frequent scanning of the radar screen or other displays to check that all is well. Training must encourage this constant scanning and alertness.

4.24 It is vital that the controller be capable and confident in handling high levels of traffic so that these tasks do not become excessively demanding or burdensome. Training must be related to the maximum handling capacity of the system for which the controller is being trained. Positive intervention by the controller to forestall an overload condition is just as important as the ability to keep aircraft separated. Training should also prepare the controller for conditions of underloading, when there is little traffic but the control positions must still be staffed, and the controller must be alert and able to detect any unexpected events at once.

4.25 Training engenders self-confidence through achieved performance. Illness or lack of well-being from whatever cause has to be remedied if its consequences render the controller inefficient or even potentially unsafe. Training which has successfully generated sound knowledge and confidence in applying that knowledge can help to sustain controllers through events which might lead to stress in others who lack such training.

TRAINING AND SYSTEM CHANGES

4.26 Wherever possible, any changes made in ATC systems should allow the existing skills and knowledge of controllers to remain applicable. Any major change in the ATC system that affects what the individual controller should do or needs to know, such as a new form of automated assistance, should normally be associated with a careful redefinition of all the consequent changes in the controller’s knowledge, skills and procedures. Appropriate retraining should be given **before** the controller encounters the changes while controlling real air traffic. The benefits of any changes to the ATC system that affect the controller will be gained fully only if the corresponding changes in the controller's knowledge and skills have been instilled through appropriate retraining. It should be normal for controllers to have regular refresher training, during which knowledge and skills are practised and verified and changes are introduced if needed.

4.27 Issues which should be addressed by specific Human Factors training for controllers include:

- learning and understanding all the rules, regulations, procedures, instructions, scheduling, planning and practices relevant to the efficient conduct of ATC;
- procedures for liaison and co-ordination with colleagues and pilots;
- recognition and prevention of human error;
- matching the machine to the controller so that any human errors are noticed, prevented and corrected;
- verification of the training progress of each student by impartial assessments that are accepted as fair by all;
- identification of individual weaknesses that require extra training or practical experience and the provision of appropriate extra training and support to overcome these weaknesses and to correct faults and sources of error;
- acquisition of knowledge about professional attitudes and practices within ATC, which are the hallmark of professional competence;
- acceptance of the professional standards that prevail and the personal motivation always to attain and exceed those standards.

4.28 The initial training of the new controller and the retraining of qualified controllers following system changes are not always the same. Initial training builds on the foundation of a knowledge of the principles and practices of ATC; retraining may entail not only the learning of new knowledge and practices appropriate to the new system but the unlearning and discarding of familiar knowledge and inappropriate practices.

Chapter 5
THE HUMAN ELEMENT — SPECIFIC ATTRIBUTES

RECOGNITION OF THEIR SIGNIFICANCE

5.1 The traditional emphases of Human Factors, and still perhaps the most influential ones, are on the tasks performed by each individual controller (liveware-software), on the equipment provided (liveware-hardware), and on the effects of system features on the safety and efficiency of that performance (liveware-environment). These features include the facilities and tools available, the workspace, displays, input devices, communications, forms of computer assistance and human-machine interface specifications. In air traffic control, however, many other Human Factors issues also have to be considered.

5.2 Some human attributes (liveware) have no apparent machine equivalent. Though they are highly pertinent, these attributes can seem irrelevant because human-machine comparisons cannot be applied to them, and they may therefore be omitted when the allocation of responsibilities to human or machine is considered. Early Human Factors studies often neglected such human attributes, because their significance was not recognized or because too little was known about them to be of practical use. However, their importance is now acknowledged and much more is known about many of them. They must no longer be ignored. They form two broad categories, depending on their origins and on how they can be changed.

5.3 One category of human attributes concerns the effects of ATC on those who work within it. This category therefore covers issues that can be influenced by changes in ATC procedures, environments and conditions. It includes such topics as stress, boredom, complacency and human error, which can be construed as effects on the controller of predisposing influences within the ATC system and which can therefore be changed by modifying the system.

5.4 The second category refers to fundamental and universal human attributes which are relatively independent of specific aspects of ATC environments and to which ATC must therefore be adapted. This category includes the needs of people at work, individual differences, human competence in specific tasks such as monitoring, and characteristics of human information processing, thinking, decision-making and remembering. ATC cannot change such attributes but must adapt to them by utilizing their advantages and circumventing their constraints. It is important to realize in resolving Human Factors problems that the direction of causality is not always the same, and that therefore the most successful solutions of particular problems may differ in kind. In both categories, the practical outcome is a mismatch between the system and the human which may have to be resolved by changes to either or both. The preferred solution depends on the category.

STRESS

5.5 Stress is primarily a liveware issue although any of the SHEL interfaces may be relevant to it. The incidence of stress-related illnesses among air traffic controllers compared with more general populations varies in different contexts and may not be the same in all States. It has long been contended that air traffic controllers endure excessive stress because of their occupation. This has been attributed to aspects of ATC jobs such as high task demands, time pressures or responsibilities, or inadequate equipment. Occasionally, it has been attributed to environmental influences or liveware-liveware interfaces such as conditions of employment, poor relationships between management and controllers, insufficient appreciation of controllers' skills, the allocation of blame for failure, excessive hours of work, inadequacies in training, disappointed career expectations or ill-informed and unfair public disparagement of ATC.

5.6 Two other factors may contribute to stress. One is shift work, which can disrupt sleep patterns and affect domestic and social relationships. The other is the modern lifestyle, which seems to induce stress-related symptoms in some individuals almost regardless of their jobs. A controller with stress-related symptoms may have to be removed from active duties. This can be a costly but essential remedy since the safety and efficiency of ATC must not be put at risk and problems of stress can be difficult to solve. It is much better to prevent them by good workspace and task design, sensible working hours and work patterns, supportive and understanding management and concern for individual health and welfare. Because stress can have so many different causes, the successful prevention or reduction of stress in any given circumstances depends on the correct diagnosis of its origins.

5.7 The following possibilities should be examined. If the ATC demands of a particular job are excessive for nearly everyone doing that job, the demands must be reduced by redesigning tasks and re-allocating responsibilities. If the ATC demands of a particular job have become excessive for an individual controller but not for most controllers, the individual should be transferred to a less demanding job. If conditions of employment such as the working hours or work-rest cycles rather than the ATC itself impose unavoidable stress on individual controllers, the remedy is to adjust the hours of work, the work-rest cycles or other stress-inducing conditions of employment. If the rostering and shift patterns, including occasional or regular night work, are far from optimum and lead to domestic difficulties or disrupted sleep, changes are needed in those areas.

5.8 Caution is required regarding the expected effects of alleviating stress. There may be compelling medical or humanitarian reasons for doing so, and cost benefits may accrue through reduced staff turnover rates and consequent lower recruitment and training costs. There may be safety or performance benefits but stress conditions are not always closely correlated with incidents and accidents and the reasons for the alleviation of stress are not confined to performance and safety. There have been many extensive studies of stress in ATC but it remains a lively and contentious issue, not yet fully resolved.

BOREDOM

5.9 Compared with stress, there has been much less work in ATC on the subject of boredom, also a liveware issue. Although it is often a problem, all its causes and consequences are not well understood. Not every common sense assumption about the causes and effects of boredom seems correct. Boredom may occur when there is little activity: the remedy is to provide more work. Boredom may occur when there is substantial activity but it has all become routine, requiring little effort and devoid of challenge and interest: the remedy is to maintain direct and active involvement in the control loop. Boredom tends to increase as skill and experience increase: the remedy is to design tasks with a hierarchy of required skills, since opportunities to exercise high-level skills can help to prevent boredom.

5.10 Unless there is excessive repetition of training content, boredom does not occur much during training because the workload can be controlled by matching the level of task demands with the controller's abilities. Highly skilled task performance is not immune from boredom if the skilled performance can be achieved without close attention, but attempts to relieve boredom in such circumstances can incidentally degrade highly skilled performance. Boredom is not always related to safety although commonsense suggests that it must be.

5.11 People do not like to be bored. Time drags and they may invent tasks, procedures or diversions to make the time pass more quickly. This is not in the fundamental interests of ATC efficiency. One relevant factor is the extent to which the human is driven by the system, which may result in boredom, or has some control over it and can exercise initiatives, particularly in relation to task demands and workload. Many forms of automated assistance in ATC may have the unintended effect of increasing boredom.

5.12 The following recommendations may prevent or alleviate boredom:

- allow controllers as much freedom as possible to control and schedule their own workload;
- try to keep staffing levels adjusted so that there is always sufficient skilled work to do;
- design workspaces, equipment and tasks so that they promote a hierarchy of skills, and provide opportunities to use those skills;
- try to ensure that individuals are not alone at work, for the prevalence and consequences of boredom are often less serious among groups than individuals.

CONFIDENCE AND COMPLACENCY

5.13 Confidence and complacency are mainly liveware issues. In a job which requires rapid problem-solving and decision-making, confidence in one's own abilities is essential. There is no place for indecisive persons in ATC. However, confidence can lead to over-confidence and complacency. If a job never tests an individual's limitations, every difficulty may seem familiar and every problem foreseeable — this can induce complacency. Complacency may be reduced partly by reasonably high (though not excessive) work levels, by control over the scheduling of tasks and by training and assessment through the presentation off-line of difficult and challenging problems.

ERROR PREVENTION

5.14 Every effort is made — in the design of systems, workspaces, human-machine interfaces, tasks and jobs; in predicting task demands; in matching skills and knowledge with jobs; and in specifying conditions of employment — to ensure that the controller will attend to the work continuously and commit as few errors as possible. The success with which this is achieved depends on adequate Human Factors contributions during the formative stages of the system planning and design. In this way, potential sources of error and inattention are detected soon enough to be removed. Most of the kinds of human error that are possible and will occur are predetermined by aspects of the system design (hardware, software, environment), which is why their general nature is often predictable. However, liveware issues usually are the main predisposing causes of each particular error. Human beings are fallible, and air traffic controllers remain fallible and subject to error no matter how experienced and proficient they become. While every effort should be made to prevent human error, it is not sensible to predicate the safety of the ATC system on the assumption that every human error can be prevented. Some errors will occur and the system must remain safe when they do, by being designed to be error-tolerant.

5.15 Many types of error can be predicted from task and job analyses, from characteristics of the displays, input devices, communications and human-machine interface and from ATC requirements. Sometimes humans can detect errors as they make them and correct them straightaway. Sometimes, in a team environment, colleagues can detect a controller's errors and point them out. Sometimes machines can be programmed to detect and prevent human errors by not accepting or not implementing actions that are incorrect or invalid, or by compensating automatically for their adverse consequences.

5.16 In speech, the main sources of error are phonetic confusions, omissions, false expectations and non-standard sequencing of items. In tabular information, one line or block of data can be mistaken for another, and characters and shapes which are insufficiently different may be misidentified. Poor labelling, misalignments between displays and controls, and lags between actions and feedback are among the sources of error in display-control relationships. The only errors that the controller can make are those permitted by the human-machine interface design.

5.17 Various classifications of human error in ATC have been compiled. Among the most comprehensive are those based on reported air traffic incidents, since many reports contain details of human errors that have actually occurred. An alternative approach starts with an error classification based on general evidence about characteristics of human information and thought processes, and makes distinctions, for example about errors in planning or in execution, and about errors attributable to deficient knowledge, to applying the wrong rules, or to attention failures. The classes of error that could occur in ATC can be categorized according to such distinctions, which can then guide the formulation of appropriate procedures to remove them or prevent their more serious consequences.

FATIGUE

5.18 An important liveware issue is that of controllers becoming tired or fatigued, because when people are over-tired, their judgement can be impaired, and the safety and efficiency of the ATC service can be put at risk. This is unacceptable, in terms both of safety and performance and of occupational health and well-being. Controllers must not become over-tired because of excessive working hours or unreasonable task demands, and so the prevention of fatigue among controllers should exert an important influence on management decisions. Remedies include splitting jobs, adjusting staffing levels, curtailing shift lengths, improving work-rest cycles, giving further training, providing more computer assistance and installing modern equipment.

5.19 Staffing levels have to make provision for adequate rest breaks during each shift. The maximum recommended continuous work period without a break is normally about two hours, especially under high traffic demands. Rest should be away from the ATC environment — sitting back and trying to relax within the work environment is not the same as rest, since the controller is still on duty and may have to resume work quickly at any time. The controller must not have any ATC responsibilities during the rest period. Even if traffic demands have been light and the controller has been under-loaded and bored, rest breaks are still needed. Under-activity is never a satisfactory substitute for a real rest break.

5.20 Provision for meal breaks is necessary within shifts. The maximum shift length depends on traffic demands, on whether the shift includes periods on call but not actually working, and on various logistic factors. It is not prudent to end any shift, particularly a night shift, at a time when the tired controller has to drive a car home through rush-hour traffic. Even with rest and meal breaks, more than about eight hours continuous work is not normally recommended unless the air traffic is light or intermittent. Controllers who work a statutory number of hours may prefer longer shifts in order to have longer continuous periods away from work, and rostering that results in several consecutive days off duty at regular intervals is often highly prized, but must not be achieved at the expense of severe fatigue through excessive shift lengths.

5.21 ATC commonly includes some shifts at night. The relevant evidence is contentious but on the whole favours rotating shift patterns rather than several consecutive nights working. Shifts should rotate later — that is, a morning shift may be followed by an afternoon shift the next day, but an afternoon shift should not be followed by a morning shift the next day. Age must be considered; older controllers may become more tired by shift work, particularly if they have to return to shift work after a spell of normal day work. Less night work may be advisable as controllers approach retirement age. While no recommendation can be applicable to all individuals, it is advisable to reallocate controllers, if necessary, to jobs that remain within their capabilities as they become older. Their greater experience may compensate for age-related deterioration in performance to some extent, but continuous sustained high levels of effort may be more tiring for them.

NEEDS AT WORK

5.22 A liveware attribute relevant to ATC is that the human has specific needs from work which are fundamentally different from those of machines. As we know, a machine can tolerate protracted idleness, but a human cannot. A machine can be employed indefinitely on routine, unskilled, undemanding, repetitive tasks, but these are not suitable for the human. A machine can monitor endlessly without becoming overtired, bored, distracted or sleepy, but a human is not an efficient monitor for long periods with little happening. A machine seems indifferent to other machines whereas the controller seeks the good opinion and respect of colleagues and others.

5.23 Human controllers have job and career expectations; they need to be able to plan their futures. They can become disillusioned if their actual career or their career prospects are below their expectations, even though their expectations may seem unrealistic to others. ATC jobs now and in the future should recognize human aspirations for job satisfaction. Among the most effective advocates of ATC as a profession are the controllers themselves, provided that their jobs seem satisfying and meet basic human needs at work. If ATC is to thrive when it becomes more automated, controllers' attitudes towards its automated forms should be as favourable as they are towards its more manual forms.

ATTITUDES

5.24 Performance can be influenced by conditions of employment, by professional ethos, norms and standards, by morale through working as a member of a professional team, and by the attitudes of controllers, all aspects of liveware. Controllers form attitudes to:

- the ATC system itself;
- their profession;
- those for whom they work, such as management or employers;
- those who can influence their conditions of employment;
- colleagues;
- pilots;
- those who design ATC systems and facilities;
- those who service and maintain the system;
- the equipment and facilities with which they are provided.

Attitudes to equipment are influenced by its suitability to their tasks, how error-free it is, and how modern it is. The provision of up-to-date equipment is often interpreted as a symbol of the value and status accorded to ATC.

5.25 Some further influences affect the whole ATC community. These include attitudes towards and relations with:

- the international ATC community;
- international authorities concerned with standards and practices;
- other professions with which controllers compare their own;
- the aviation community;
- passengers;
- the general public;
- those in positions of power and influence;
- the media.

5.26 Controllers' attitudes towards these further influences depend on whether they perceive them as supportive to ATC or not. Wherever possible, management should seek to promote favourable attitudes to air traffic controllers on the part of these influences and vice versa. It is unhelpful if, for example, ATC is blamed for delays or aggravation for which it is not directly responsible.

FUNCTIONS OF TEAMS

5.27 Most forms of computer assistance seek to aid individual tasks rather than team tasks which depend on liveware-liveware interfaces. An incidental consequence of various forms of computer assistance can be a reduction in team roles and functions. This includes the capability of supervisors, colleagues or others to observe, interpret, or assess the conduct, understanding and processes of ATC adopted by individual controllers. If there has been extensive automation of tasks it may be more difficult for less experienced controllers to learn and profit from working alongside colleagues with greater experience and proficiency. Controllers may also be less able to notice a mistake or error by a colleague. The effects of such changes can be substantial and it may become necessary to redesign workspaces and to revise selection and training methods to restore an optimum match between the human and the machine.

5.28 Computer assistance reduces the observability of control activities by others and makes it more difficult to judge the performance of the individual controller by on-the-job assessments, which are used for decisions about career development, promotion, retraining, allocation of tasks, and appropriate instructions and procedures. The introduction of computer assistance may require the reappraisal of all such factors.

INDIVIDUAL DIFFERENCES

5.29 The large individual differences between people are an aspect of liveware and a primary concern of selection procedures. These differences include medical differences, differences in physique, in abilities, in aptitudes and perhaps in personality. A group of successful candidates can be expected to differ less than the original group of applicants from which they were selected. The training processes then seek to reduce further the remaining individual differences among those selected. In this way, the safety and efficiency of the ATC service do not depend significantly on which individual controllers are on operational duty at a given time.

5.30 Selection and training both have the effect of reducing individual differences. Yet some differences remain, and they can be very beneficial. They can form the basis for career development and for allocating controllers to different jobs. In the future, automation may adapt more to the individual controller by making the best use of individual strengths and compensating for individual weaknesses, whereas the current practice is to discount individual differences and to build on general human strengths and circumvent general human weaknesses. This trend may become particularly important if a shortage of available applicants forces the selection of candidates who initially have more varied potential abilities and backgrounds.

A GENERAL HUMAN FACTORS VIEW

5.31 ATC has to take account of the basic cognitive capabilities of people, how they think, how they decide, how they understand and how they remember. Jobs and tasks must be designed within these capabilities and training must be devised to maximize them. People need to be able to use their cognitive capacities well and sensibly, in ways which they recognize as worthwhile and not demeaning.

5.32 The conditions of employment of controllers vary. There is a need to periodically review and make recommendations about the total hours of work, rostering and shift patterns, and the maximum permissible period of continuous work with no rest break. The designs of the workspace must not induce any occupational health hazards such as visual or postural difficulties during the performance of ATC tasks. There must always be provision for the early retirement of individual controllers on medical grounds.

5.33 ATC is dynamic and expanding. The future rate of expansion is difficult to predict, being subject to factors totally beyond the direct influence of ATC, such as global and national economic conditions, the availability and cost of fuel, and the travelling public's perception of how safe it is to fly. Nevertheless, all projections expect air traffic to increase so substantially in the longer term that most existing ATC systems will have to be replaced, extended or further developed because they were never designed to handle so much traffic.

5.34 The applicability to ATC of technological innovations such as satellite-derived information, data links, colour coding, artificial intelligence and direct voice input has to be appraised, to assess their helpfulness and their optimum forms in relation to ATC. It is necessary to identify all the Human Factors consequences of such changes, and to resolve the associated problems not only of display, control, integration, interfaces, communications, understanding and memory, but also of team roles, attitudes, norms and ethos.

Appendix
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— END —

ICAO TECHNICAL PUBLICATIONS

The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

International Standards and Recommended Practices are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

Procedures for Air Navigation Services (PANS) are approved by the Council for world-wide application. They contain, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome.

Regional Supplementary Procedures (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.

Technical Manuals provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

Air Navigation Plans detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

ICAO Circulars make available specialized information of interest to Contracting States. This includes studies on technical subjects.

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Order No. CIR241
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