INTERNATIONAL CIVIL AVIATION ORGANIZATION

"GUIDANCE MANUAL FOR THE TRAINING OF HUMAN RESOURCES ON THE CNS/ATM SYSTEMS"

Prepared by the Human Resources and Training Task Force

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SECTION I

GENERAL INFORMATION ABOUT THE CNS/SAM SYSTEMS

Chapter 1

INTRODUCTION

1.1 PURPOSE

The Human Resources and Training Requirements Task Force of the GREPECAS CNS/ATM Implementation Coordination Subgroup agreed at its Second Meeting, which dealt with the training requirements of aeronautical personnel in general, that it would be advisable to place emphasis on the training shortcomings that exist in many States, in light of the advent of the new CNS/ATM technology.

It is particularly important to touch upon the human and psychological factors that affect human resources and that are reflected in the functional performance of aeronautical personnel.

The successful implementation of the system is closely related to the success of and motivation provided by training programmes offered by the respective Administrations.

In keeping with the above, this ?Guidance Manual for the Training of Human Resources on the New CNS/ATM Systems" seeks basically to present the topic of CNS/ATM systems to all human resources involved in aviation and operational services, namely:

FLIGHT CREWS

AIR TRAFFIC SERVICES

TECHNICAL SUPPORT SERVICES

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Chapter 2

ORIGIN AND EVOLUTION OF THE CNS/ATM CONCEPT

2.1 SPECIAL COMMITTEE ON FUTURE AIR NAVIGATION SYSTEMS (FANS)

In the early 80s, the International Civil Aviation Organization (ICAO) recognised the growing limitations of the existing communication, navigation, surveillance, and air traffic management (CNS/ATM) systems, as well as the need to make improvements in order to overcome those limitations and meet future needs.

In 1983, the ICAO Council created the Special Committee on Future Air Navigation Systems (FANS) to examine new concepts and technologies and recommend a system for overcoming both existing and future problems and lead aviation into the twenty-first century.

The FANS Committee carried out an extensive study of existing systems and the possible applications of new technologies. It reached the conclusion that current limitations were inherent to the systems themselves and hindered effective air traffic management to such a point that the problems could not be resolved worldwide without applying new CNS concepts and systems. The FANS Committee decided that the only viable and cost-effective solution for overcoming said limitations and meeting future global needs was to take advantage of satellite technology.

In the communications field, it was agreed to introduce data links via VHF, satellite, HF or SSR Mode S.

In the navigation area, the proposal is to use the global navigation satellite system (GNSS) with the appropriate augmentations to eliminate errors in satellite signals.

Flight progress monitoring in airspaces without radar coverage will be carried out using automatic dependent surveillance (ADS), either directional or broadcasting (ADS-B).

Some of the existing systems, such as VHF voice communication and the secondary surveillance radar (SSR), will continue to be useful in appropriate airspaces.

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Chapter 3

THE NEW COMMUNICATION SYSTEM

Voice communication will be used for critical messages, such as vectors for avoiding traffic and landing clearance at airports with heavy traffic. It will also serve as backup for data links.

Data link communication is already being used for non-critical messages, such as pre-departure clearance (PDC), taxiing clearance, request/clearance for flight deviation, ATIS arrival and departure information (ATIS-D), terminal area weather information for pilots (TWIP), NOTAMs, etc.

3.1 REQUIRED TOTAL SYSTEM PERFORMANCE (RTSP) CONCEPT

The CNS/ATM-based system is intended to be seen as the sum total of several components, such as airspace, flight operations, and facilities and services provided. The required communication performance (RCP) and required surveillance performance (RSP) concepts are being developed and, together with the required navigation performance (RNP), are intended as the basis for the required total system performance (RTSP) concept. This should definitively constitute a common standard for measuring the performance of all CNS/ATM elements.

3.2 REQUIRED COMMUNICATION PERFORMANCE CONCEPT (RCP)

The term required communication performance (RCP) refers to a series of communication performance requirements concretely defined in terms of capability, availability, error average, traffic delay, etc. Once an RCP has been specified for an operational scenario in a given airspace, any communication system or combination of systems that complies with the specified parameters can be considered operationally acceptable.

3.3 DATA LINK

The data link (DL) is a basic component of communication between air traffic control units and aircraft. There are two generations of ATS data links:

1) the exchange of text messages; and

2) the more complex and computer-processed messages for FANS uses, which employ ACARS data links.

Data links were initially used only for ACARS communications, but now equipment compatible with ATN communications has been developed, thus improving the efficiency and capacity of aeronautical VHF data channels.

Air Traffic Services (ATS) are formulating requirements for more complicated data link capable of interconnecting with the ATN, in order to meet their needs.

The start-up of ATN routing for VDL (VHF digital link) will also improve the performance of the aeronautical mobile-satellite service (AMSS) link. The introduction of the AMSS has been gradual to allow users to benefit from the increased capabilities. Omnidirectional antennas have been replaced by directional antennas that enable high speed data communications and digitalized voice communications.

The VDL format specifies a protocol for delivering data packets between airborne equipment and ground systems similar to that used in the ACARS system. The difference is that the VDL provides a capacity 10 times greater than that of an equivalent 25 KHz VHF channel.

The ACARS system uses a VHF radio that was designed for voice messages, which restricts it to data encoding using the tones available in current voice communication. In addition, the precision level of the VHF signal does not allow a receiver to decode rapid tone changes; as a result, the average is restricted to 2,400 bauds per second.

The VDL protocol specifies use of a digital modulation system capable of encoding data by changing the VHF signal phase to 10,500 bauds per second.

VHF analogue radios available today are not compatible with this new technology; VDL operation requires a VHF digital radio (VDR).

Migrating from ACARS VHF to VDL requires a changeover from an ACARS routing capability to an ATN routing capability in the aircraft, together with a data link processor to interconnect with ground systems.

VDL is essential for ATN implementation and, consequently, for greater use of ATS data links. Also, the availability of airborne equipment manufactured in series, including digital radios, will make it possible to equip a larger number of aircraft.

The ICAO Aeronautical Mobile Communication Panel (AMCP) has defined four VDL operation modes; modes 1 and 2 already havs the corresponding SARPs:

3.3.1 VDL Mode 1

The use of VHF analogue radios for data exchange was started by airlines in the late 70s. Current airborne VHF radios have been used to transmit data between operators and their aircraft by means of special ground-based stations and interconnection networks. The so-called ACARS system has been developed and has grown considerably, with limited use for ATC communication.

VDL Mode 1 has been especially designed to use ACARS modulation equipment and radio and uses a data link technology called carrier sense multiple access (CSMA).

3.3.2 VDL Mode 2

VDL mode 2 is an improved version of mode 1 and also uses CSMA technology, but is not capable of handling voice communication. Average data transmission is 31.5 kbps.

3.3.3 VDL Mode 3

VDL mode 3 is an integrated digital data and communication system that makes it possible to use four radio channels on a carrier (with a 25 KHz spacing). It uses a data link technology called time division multiple access (TDMA).

3.3.4 VDL Mode 4

It also has navigation and surveillance capacities and uses a data link technology called self-organizing time division multiple access (STDMA).

With VDL mode 4, the stations, on transmitting, send their geographic position together with the data message in time slots that are dynamically modified at frequent intervals.

Before starting a transmission using the STDMA technique, the aircraft keeps a listening watch on the frequency to be used and establishes a track and a table of time slots of all other aircraft. An algorithm in the aircraft transceiver selects a free slot or takes the slot of the most distant aircraft. This modulation system allows distant stations to transmit in the same slot with a minimum of interference. STDMA does not have voice communication capability. Even so, reception of the geographic position of other aircraft gives it a surveillance capability that, combined with precise time information, will enable this mode to be used for navigation.

3.3.5 Data link in Mode S

Mode S allows for an air-ground data link whose use is particularly indicated for airspaces with traffic of high density. It can also operate in a mixed environment, in which aircraft equipped with transponders of different data link capabilities fly.

3.3.6 HF data link (HFDL)

The feasibility of using HF data links for Air Traffic Control communications has been demonstrated. Inasmuch as propagation anomalies rarely affect the entire HF frequency band, it is possible, with a carefully sited system of well-connected ground stations and with a number of adequate frequencies available, to find the best frequency for the transmission of data packets anywhere and at any time. HF data link is also an excellent stand-by system for AMSS in oceanic/remote areas.

3.4 CONTROLLER - PILOT DATA LINK COMMUNICATION (CPDLC)

CPDLC is the means of communication between the controller and the pilot that uses data links for Air Traffic Control communication. In areas where CNS/ATM routes are built and/or where airspaces exist that are outside VHF communication range, CPDLC is the primary means of communication, supplemented by HF and voice satellite links. Messages may be composed through individual utilization or a combination of up to five message elements for clearances, pre-departure clearance, and messages related to Air Traffic Control.

CPDLC will resolve a number of flaws in existing systems:

- it provides an automatic data entry capability, which will permit ground systems and airborne flight management computers (FMC) to enter critical information, such as the flight route. This will cut down on errors caused by manual data entry;

- it permits a significant reduction in transmission time, thus reducing congestion; and

- it eliminates misunderstandings due to a deficienct quality of voice received, propagation problems, dialects, and the impossibility of having instant access to previous voice transmission recordings.

Below is an extract of the CPDLC procedures contained in the **?Asia/Pacific Guidance material for CNS/ATM operations"**:

> **?**A supplement should be published in the AIP of each country to report the CPDLC capability of an ATS unit, together with its log-on. The pilot must specify the CPDLC capability of the aircraft in the flight plan.
>
> Although the CPDLC may be the main means of communication, all aircraft should also be advised of appropriate voice communication frequencies.
>
> Aircraft communicating via CPDLC should do so only with the appropriate air traffic control unit for its route segment. Most ATS systems reject a message if they do not have the corresponding flight plan.
>
> The pilot initiates the CPDLC procedure by sending a contact message containing the four-letter ICAO site designator of the air traffic control unit. The latter will respond with an acknowledgment message.
>
> The recommended procedure when an aircraft enters an airspace where CPDLC is used is for the pilot to send a contact message between 15 and 45 minutes before entering. An automated ATS system will not consider log-on attempts if the flight number or registration used for contact are not exactly the same as those indicated in the flight plan.
>
> Under normal conditions, the relevant air traffic control unit initiates the CPDLC disconnect sequence, sending an uplink end of service message.
>
> In responding to this message, the airborne equipment:
>
> 1) sends a downlink disconnect message. That equipment considers an aircraft as disconnected as soon as the disconnect message is sent, without considering whether or not the message was received by the air traffic control unit; and
>
> 2) disconnect and activate the disconnection. The next air traffic control unit can then

exchange CPDLC messages with the aircraft.

Both the controller and the pilot should bear in mind that it takes up to one minute for a message to be received; this includes the lapse of time in which the pilot (or the controller) analyses and answers the message, and up to one minute for that answer to be received by the other party. Therefore, note should be taken that additional delays could occur between the transmission of a CPDLC message and the response to it.

All CPDLC messages should use as many preset phrases as possible. Free text messages should be used only when no appropriate preset phrases exist.

Clearance request and issuance messages should be of the preset type only. Use of messages of this kind enables better processing by airborne equipment, enabling automatic insertion of some of the clearance components directly into the flight management computer (FMC).

These preset messages allow the controller to answer most rapidly when the ATS system has the capability to automatically link a preset response to a message of the same kind. This process also reduces the risk of making mistakes when entering information into the system."

MESSAGE	MEANING	ANSWER
UNABLE	Means that the ATS cannot comply with the request	WILCO, UNABLE, AFFIRM
REQUEST DEFERRED	Means that the ATS has received the message and will answer it	WILCO, UNABLE, AFFIRM
IMMEDIATELY TURN (direction) HEADING (degrees)	Instruction to immediately turn right or left as specified in the directed course	WILCO, UNABLE
REPORT REMAINING FUEL AND SOULS ON BOARD	Instruction to report the amount of fuel remaining and the number of persons on board	WILCO, UNABLE, AFFIRM
CAN YOU ACCEPT (altitude) AT (time)	Instruction to report whether the specified level can be accepted at the specified time	AFFIRM, NEGATIVE
CHECK STUCK MICROPHONE	A continuous transmission is detected in the specified frequency. Check the microphone button.	ROGER
REQUEST VOICE CONTACT	Request for voice contact	Response required

REQUEST WEATHER DEVIATION TO (position) VIA (route clearance)	Request to deviate due to weather conditions on the route specified	Response required
WHEN CAN WE EXPECT HIGHER ALTITUDE	Request for the closest time when clearance to ascend can be expected	Response required

Table 3-1. Some examples of preset CPDLC messages

3.5PRE-DEPARTURE CLEARANCES

IFR flight departure procedures include clearance limits, route, approved flight level or levels, instrument departure, frequency assignments, departure restrictions, etc. These messages are voice transmitted in VHF, which highly overloads frequencies, since these long authorizations must normally be collated to avoid mistakes or misunderstandings.

To avoid this, some airports are using data links to send their clearances, which are received by crews on the screen of an airborne equipment (could be the FMS). The messages can also be printed and acknowledgment sent via data link.

3.6 DATA LINKS BETWEEN ATS UNITS (AIDC)

The AIDC offers the means for exchanging data during the reporting, co-ordination, and transfer of control phases. AIDC use will largely reduce the need for voice co-ordination.

AIDC message format and procedures are designed for use through any ground-ground circuit, including the AFTN and the future ATN. The following means of communication can be used for the transmission of AIDC messages:

- AFTN
- ATN (when it is developed)
- dedicated data circuits

3.7 AERONAUTICAL MOBILE-SATELITE SERVICE (AMSS)

Because radar surveillance systems and VHF communication equipment are limited to line-of-sight bands, they are not practical for surveillance and communication over oceanic or desert regions; furthermore, they require many means of support, such as electric power and maintenance. In addition, HF communication is not fully acceptable because it is unsafe, of medium quality, and requires too much technical support.

Satellite communications, on the other hand, can provide high-quality voice and data communication services instantaneously, irrespective of the type of airspace involved.

More and more avionics systems are being digitally implemented due to the increased workload in the cockpit, coupled with the desire to improve operational availability, economics, and safety.

Data links are part of that revolution to improve the flow of information between airborne and ground computers for purposes of air traffic services (ATS) and of airline operational control (AOC).

The AMSS transmits data and voice digitally and significantly improves efficiency and effectiveness because it has moreprocessing performance and flexibility. With increased data link use, voice communications will undoubtedly decrease, but will always be available for critical messages.

3.7.1 Basic system considerations

In selecting orbits for mobile communication and navigation service satellites, many factors must be considered. Use of the geostationary orbit for communication satellites and of the intermediate circular orbit for navigation satellites has proven to be the best solution.

The geostationary orbit is the circular orbit on the equatorial plane of the earth, in which the orbital period is equal to the rotation period of the planet. Thus, in placing a satellite in this orbit, it will appear to remain at a fixed point over the equator. The satellite antennas may be placed in such a way that they illuminate the entire terrestrial globe visible from the satellite and, if necessary, certain regions on the earth surface that appear contained in that globe. Thus, the entire planet may be covered with only a few geostationary satellites (equipped with antennas covering the terrestrial sphere) distributed lengthwise as necessary, except in the most distant polar latitudes when they are below the radial horizon.

Geostationary satellites, like the others, are subject to orbital disturbances, such as gravity and other forces that act on them. Therefore, they are equipped with position maintenance devices consisting of microimpellers driven by orders sent from ground control stations if the satellite deviates from its orbit and moves beyond certain limits of the designated orbit position. The fuel that can be carried on board a satellite for its position maintenance manoeuvres is necessarily limited. When it runs out, the satellite moves away from its position and in time becomes useless, irrespective of the condition of its electric and electronic components. In order to lengthen the useful life of the orbiting satellite, care is taken to draw position maintenance plans that require the least fuel consumption. Even so, the end of the useful life of a satellite is due more to the depletion of the fuel used for position maintenance than to failures of the electric or electronic equipment.

One of the advantages of geostationary satellites is that the antennas of ground stations are used only to detect up to the minutest deviation from their nominal position in space. These deviations are defined as position maintenance limits. This simplifies the conception of the antenna considerably. The large-aperture antennas of ground stations, however, constitute one of their most visible and costly features.

3.7.2 The space segment of satellite communications

The minimum space segment needed to establish a world telecommunication system is a constellation of three satellites equipped with earth coverage antennas arranged in geostationary orbits with a 120E longitudinal spacing between them. That constellation facilitates coverage in the band of approximately 80E N to 80E S at aircraft cruising altitude. The main components of satellite communication systems are the transponders

that receive signals from the ground and relay them to the aircraft. Other transponders receive the signals from the aircraft and transmit them to the ground. The remaining satellite components take care of the generation and use of power, management of the transponder and the correction of orbit position.

In practice, the space segment has more than enough satellites to guarantee the necessary integrity of the communication services provided. The other satellites can be arranged in geostationary orbits near the main satellites and share the traffic with them or can be placed in orbit, ready for activation in the event of failure of a primary satellite.

3.7.3 The ground segment of satellite communications

The ground segment of the satellite communication system consists of ground earth stations (GES) and their supporting ground communication infrastructure.

Voice and data services can be provided to aircraft via satellite with a minimum of one ground earth station for each satellite coverage region. In practice, for reasons of system integrity, communication with a given aircraft is possible through at least two ground stations.

Ground earth stations also serve as a means of interconnection, through which flight communication terminals accede to ground communication systems, among them the aeronautical telecommunication network (ATN).

3.7.4 The airborne segment of satellite communications

The airborne segment of the system consists of aircraft earth stations (AES) and their airborne support systems. An aircraft earth station is made up of an antenna and, in high-gain antenna installations, electronic beam guidance components, a transmitter-receiver, and the communication management unit serving as an interface with the airborne systems that route data messages and with audio systems that convey voice communications.

3.7.5 Conception of satellite communication systems

The economics of satellite communication systems requires satellites to operate with minimum power margins. Care must be taken with electric power consumption on board satellites; therefore, an effort is made not to use low energy frequencies except as needed to provide the communication service in question. Although electric power is not so limited on board aircraft, other technological and environmental factors must be considered that affect operating costs. As a result, the aircraft-satellite-aircraft link ratio offers little margin for offsetting the effects of adverse operating conditions, such as the ?shadowing” of the antenna by wings or fuselage during turns. This effect creates some problems for manufacturers of aircraft earth stations (AES), above all with regard to the antennas. The ideal solution would be for the antenna to be able to operate with a satellite at all elevation angles above the aircraft and up to 5E below it.

While ground earth stations (GES) do not have the same weight and power limitations with respect to operating conditions as satellites and the AES, their installation and operation can have major repercussions on system economics and, therefore, on the cost of services. To become a part of the system, all GES have space segment resources, particularly satellite power and aeronautical bandwidth (in which satellite power prevails). Such resources are used to continually irradiate the station system management channel. It is from

that management channel that the GES obtain the station identification, together with other information they need to establish and maintain communication through it. The more GES there are in the system, the more satellite power and aeronautical bandwidth will be used to manage the system.

Proliferation of GES that carry insufficient aeronautical communications is not advisable. In this way, satellite power and aeronautical bandwidth are not distracted from the management channels of the systems that provide full-time service. Consequently, States that have planned to install GES for aeronautical communication within the airspace under their jurisdiction would be better advised to use the services of already existing stations that serve those areas. The establishment of good ground networks between the GES and air traffic control units would guarantee the system sufficient standby elements.

It is also essential to make sure that the satellite communication system will not jeopardise the integrity of the information going through it. To achieve this, error correction without a return channel is used, together with a procedure allowing for the relay of all that part of the message in which an error in the point of destination has been found. Error correction without a return channel entails the encoding of messages in such a way that errors introduced during transmission can be detected and corrected at the point of destination.

3.8 AERONAUTICAL TELECOMMUNICATION NETWORK (ATN)

The various communication sub-networks (AMSS, VHF data link, Mode S data link, etc.) will be interconnected through the aeronautical telecommunication network (ATN).

The satellite-assisted air navigation system concept supported by ICAO allows for more efficient use of the communication, navigation, and surveillance systems in assisting the migration toward an air traffic control that is fully integrated with the air traffic management (ATM) concept.

In computer data interoperation terminology, the necessary infrastructure for supporting the interconnection of automated ATM systems is called inter-network. An inter-network involves the interconnection of computers with gateways or routers through actual sub-networks. This makes it possible to build a virtually homogeneous data network in a common environment from both the administrative and technical viewpoints.

Given the desire to interconnect an ever growing and evolving diversity of aircraft computers and ground-based computers to arrive at this ATM automation, it is obvious that civil aviation requires a global data inter-network. The inter-network infrastructure developed by ICAO to fulfil this purpose is the ATN.

The ATN has been defined as an inter-network architecture that allows for the interoperation of the ground, air-ground, and avionics data sub-networks through the adoption of common interface and protocol services based on the ISO (International Standardization Organization) reference model.

The ATN is designed in such a way that it can offer communication services to different groups of users, such as:

- air traffic services (ATS);
- aeronautical operational control (AOC);

- aeronautical administrative aommunications (AAC); and
- passenger aeronautical communications

The design foresees the incorporation of various air-ground sub-networks, such as, for example, the SSR in Mode S, the aeronautical mobile-satellite service (AMSS), and various ground sub-networks that result in a common data transfer service.

These two aspects are the basis for ATN interoperability and will provide a reliable data transfer service to all users. In addition, the design is such that communication services can be incorporated in an evolutionary way.

In designing the ATN, it is essential to understand how data link communications can interconnect with end systems, both airborne and ground-based. It is therefore necessary to define the operational utilization of data messages. Although, as stated before, different system user groups can be identified, priority should be given mainly to ATS service users. Use of data communications for ATS purposes can vary significantly.

3.9 BENEFITS OF THE NEW COMMUNICATION SYSTEM

With data communications, the links between ground and airborne automated systems will be more direct and effective. Improved data processing and transfer between operators, aircraft, and air traffic service providers will alleviate the congestion of voice channels, reduce the possibility of making mistakes, and allow for a more efficient link between ground and airborne systems, all of which will contribute to air traffic management (ATM).

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Chapter 4

THE NEW NAVIGATION SYSTEM

4.1 THE REQUIRED NAVIGATION PERFORMANCE (RNP) CONCEPT

This term refers to the precision of navigation performance required to operate in a given airspace.

RNP is classified according to the flight path limits--measured in nautical miles--within which the aircraft should remain. Aircraft should be capable of maintaining that navigation precision with 95% probability. As a result, lower RNP values are equivalent to narrower limits, which can be found near the boundaries of terminal areas.

There are four general RNP classifications used for en-route operations, although ICAO is working to extend the concept to cover terminal areas operations, which could include arrivals and departures:

- RNP-1 requires the highest navigation performance, with a containment zone of only 1 nautical mile along the length of a given route. Aircraft that fulfil this requirement should have highly precise position information. RNP-1 will permit a more flexible routing;

- RNP-4 is normally connected with continental airspace and allows for ATS routes or airways based on a limited spacing between radio aids;

- RNP-5 is a less precise derivative of RNP-4, designed to permit operations with the existing navigation equipment without changing the route structure.

- RNP-12.6 allows for limited optimum routing in areas with limited radio aid coverage; and

- RNP-20 is the minimum performance level required for aircraft operating in controlled airspace.

4.2 GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

4.2.1 Definition

The term global navigation satellite system (GNSS) is the generic name used by ICAO to define any world-wide positioning and time-defining system that includes one or more satellite constellations, aircraft receivers, and various integrity monitoring systems, including the corresponding augmentation devices for meeting operational performance requirements.

Services that supply distance information will be provided, at least in the immediate future, by the GPS and GLONASS.

4.3 COMPONENTS

4.3.1 Global Positioning System (GPS)

The GPS is a satellite-based radio navigation system that provides its users with high-precision position and time information on almost any part on earth.

The space segment is composed of 24 satellites with a useful life of approximately 7 and a half years, arranged in 6 orbits of four satellites each at an altitude of 20,200 km.

The control segment has 5 monitoring stations and 3 ground antennas. The monitoring stations use a GPS receiver to track all satellites within its range and store distance data from satellite signals. The information of the monitoring stations is processed at the master station to determine the condition of the satellite clock and the orbit condition and to update the message containing the data (used for navigation purposes) sent by the satellites. This updated information is sent to the latter through ground antennas, which are also used to transmit and receive information about the general condition of the system and its control.

The user segment consists of the antenna and the processor-receiver for receiving and processing the navigation solutions used to provide it with the precise position and time.

The GPS position is based on satellite measurements, for example, using distance measurements made by orbiting satellites to obtain a precise position.

The GPS satellites transmit an extremely precise time signal that is compared by the GPS receiver with the time in its own internal clock. The difference between the time signal received from the satellite and the time on the receiver equipment is the time the signal takes to travel from the satellite to the receiver. Since the speed of the signal is a known fact (speed of light: approximately 297,000 km/sec.), the distance between the receiver and the satellite can be estimated.

In order for the system to function, time measurements must be very precise, as must the clocks used. Within the satellites, that exactness is achieved through the use of very-high-precision atomic clocks. Measurements from at least 4 satellites are needed to establish a 3-D position and time fix. At least three satellites are needed to determine the position in 2 dimensions if the altitude is known.

Precision depends upon the geometry of the satellites used. Five satellites with good geometry are needed to monitor the integrity of the system. Each measurement will contain an error produced by the existing difference between the time on the receiver clock and that of the satellite. This error will be the same for all measurements; therefore, the receiver computer will be able to make a mathematical correction that will allow all of these distance measurements to intersect at a single point. Then the clock error can be calculated and the proper correction made.

GPS satellites are positioned in very precise and predictable orbits. They orbit the earth every 12 hours and pass over some of the monitoring stations at least twice a day. These stations are equipped to calculate satellite positions with precision and to uplink the corrected information to them. They send information to the receiver on their position with respect to the centre of the earth, together with the time signal.

The airborne receiver uses this information to calculate a position with respect to the surface of the earth, which will be presented to the user in terms of latitude and longitude.

The exactness of this system makes it possible to obtain fixes with an error of 100 m (95% probability) and with an error of 300 m (99.99% probability) on the horizontal plane, and with a possibility of error of 156 m (95% probability) on the vertical plane when the selective availability (S/A) is activated.

The geodetic coordinate system it uses is the 1984 World Geodetic System (WGS-84).

4.3.1.1 *Errors*

The United States Department of Defense declared the GPS precision for civil use as being +/- 100 m 95% of the time. But, like all other conventional navigation systems, the GPS is subject to errors that can degrade its precision, including:

- ionospheric error;
- atmospheric error;
- selective availability;
- clock error;
- receiver error;
- satellite ephemeris error; and
- position dilution of precision

The most significant error occurs when the satellite signal goes through the earth ionosphere. This is a layer of electrically charged particles located approximately between 130 and 190 km above the surface of the earth. As the GPS signal travels through the ionosphere, it is slowed down in a proportion that varies according to the time of day, solar activity, and a series of other elements. Ionospheric delays may be forecast and an average correction applied to the GPS position; even so, there will still be some errors generated by this phenomenon.

Another error is caused when the signal goes through the atmosphere. The water vapour in the atmosphere delays the GPS signal and also contributes to degrade the precision of the system.

There is another error that has been introduced directly into the system by the United States Department of Defense. This error is known as ?selective availability”.

Additional errors may include clock errors, receiver errors, and errors in satellite ephemeris (position) data.

Lastly, there is the error known as position dilution of precision (PDOP). The errors existing in the system can be significantly increased, depending upon the geometry of the satellites used to determine a position. When the PDOP is factored in, errors of between 30 and 300 m can occur, depending upon receiver type, relative satellite position, and extent of other errors.

4.3.1.2 *Notices to airmen (NOTAMs)*

When the GNSS (GPS component) is authorized as primary means of navigation in oceanic/remote airspaces, a RAIM-capable airborne receiver is required.

RAIM requires that at least five satellites be visible so as to detect a faulty one. Even with the 24 satellites of the constellation in operation, there will be times when their geometry in space will not be suitable to detect a failure in any one. Furthermore, it is sometimes necessary to remove a satellite from service for maintenance.

It is very important for the pilots to know beforehand when the required number of satellites will not be available for a given segment of the proposed flight route.

In the United States, the Department of Defense sends the FAA and the Coast Guard information about any change in the number of operational GPS satellites. This is done at least 48 hours in advance. This information is entered in a database that can be used by aeronautical information service personnel during pre-flight planning. This generic information about satellites out of service must be converted, through an appropriate automation process, so that pilots can use it in said planning. This will make them aware not only that a satellite will be out of service, but also how that will affect the planned flight.

4.3.2 Global orbiting navigation satellite system (GLONASS)

The Russian Federation has implemented the global orbiting navigation satellite system, its concept quite similar to that of the United States system. It provides for space signals to be sent to properly equipped users for precise determination of position, speed, and time. The space segment consists of 24 satellites (21 operational + 3 standby) orbiting at an altitude of 19,100 Km, with an orbit period of 11 hours and 15 minutes. They are distributed into 3 orbits of 8 satellites each with an operational life of 3 years (5 years in improved versions).

The message transmitted from each satellite for navigation purposes consists of the coordinates of the transmitting satellite, speed vector components, corrections to the time of the GLONASS system, and information about satellite condition. To obtain a fix, a receiver must receive at least 4 satellite signals, either simultaneously or in sequence, and must resolve 4 equations at the same time for the three position and time components.

The ground segment fulfils satellite monitoring and control functions at the same time that it selects the data to be modulated in the encoded signals sent for navigation purposes. This segment includes the master station and monitoring and information delivery stations. The measurement data from each monitoring station are processed at the master station and used to compute the navigation data downlinked to satellites by relay stations.

The operation of the system requires precise synchronization of satellite clocks with the time of the GLONASS system. To this end, the master station provides correction parameters.

The user segment (GLONASS receiver) automatically receives navigation signals from at least four satellites

and measures their speed. Simultaneously, it selects and processes the navigation message from the satellite signals. The computer of the receiver processes all input data and calculates 3 coordinates, 3 speed components, and the precise time.

The precision of this system allows for 50 to 70 m exactness on the horizontal plane and 70 m on the vertical plane (99.7% probability in both cases).

The geodetic coordinate system that it uses is called Earth Parameters 90 (PE-90).

4.4 GEODETIC REFERENCE

Implementation of CNS/ATM systems requires a global geodetic frame of reference to avoid errors in geographic coordinates that might be caused by the location of references in more than one datum. Member States have adopted datums individually over a period of many years to comply with national geodetic and positioning requirements.

The different datums adopted could, however, provide different position information for the same geographic location and fail to meet the requirements of a global reference system for worldwide implementation of CNS/ATM systems.

To solve this problem, ICAO adopted the 1984 World Geodetic System (WGS-84) as the standard global frame of reference for air navigation.

Adoption by a State of the WGS-84 as a geodetic reference is a prerequisite, and the first step, for transition to satellite navigation. Each ICAO member State should plan carefully to ensure the exactness of the position information provided to CNS/ATM system users.

4.4.1 Basic Concept

Geodetics is the branch of applied mathematics that is used to determine, through observation and measurement, the exact position of points, the shape and size of large ground surfaces, the shape and size of the earth, and variations in earth gravity.

In practice, geodetics applies principles of mathematics, astronomy, and physics, together with modern engineering techniques and satellite technology to obtain precise measurements.

4.4.2 The ellipsoid as the figure that depicts the earth

In order to depict the earth on maps and navigation charts, its shape needs to be defined. According to geodetics, it has more than one shape, depending on how it is used and the precision with which its size is defined. In addition to the observations of the physical surface of the earth, geodetics evaluates mathematical or geometric models, making it possible to measure positions and areas.

Considering the earth as flattened at the poles and bulging at the equator, the geometric figure used in geodetics that is closest to its shape is a revolving ellipsoid. This figure can be obtained by revolving an ellipse on its shortest axis. There are many spheroids but they all have different radii and flattening coefficients.

4.4.3 The geoid as the figure that depicts the earth

The geoid is another surface related to geodetic measurements. The geoid is a surface along whose length the gravity potential is always the same and where the direction of the latter is always perpendicular. The geoid also coincides with the surface on which the oceans are formed and is free to adjust to the combined effect of earth mass attraction and the centrifugal force of earth rotation. The angle formed by the plummet line, perpendicular to the geoid, is called ?the vertical”.

In geodetic surveys, the geodetic coordinates of points are calculated on an ellipsoid, which resembles the shape and size of the earth in the area of terrain measured. However, the actual measurements of the surface of the earth using certain instruments are referenced to the geoid.

Because of the uneven distribution of land masses, the geoid surface is irregular, and since the ellipsoid is a regular figure the two will not coincide. The separation between the two figures is known as geoid undulation, geoid height, or separation of the geoid in regard to the ellipsoid.

4.4.4 The deflection from the vertical

The perpendicular to the geoid, also called the vertical, forms an angle with the perpendicular to the ellipsoid, called angle of deviation or deflection from the vertical. This angle depends upon the ellipsoid used. Calculations to determine geoid undulations and deflections from the vertical require many gravity observations.

Normally, such observations are made at mean sea level, assuming that the ellipsoid and the geoid coincide at that point. This means that the deflection from the vertical and the separation between the ellipsoid and the geoid are defined as zero at the origin. Based on this guidance criterion, it is possible to establish the origin of the geodetic datum.

4.4.5 The geodetic datum

A datum is defined as any geometric quantity or set of quantities that serve as a reference or basis for other quantities. A geodetic datum is determined by 5 parameters: latitude, longitude and geoid height to define the datum of origin and the greater and smaller semi-axes to determine the reference ellipsoid.

All horizontal geodetic surveys are referenced to specific original conditions (datums), just as vertical surveys are referenced to an initial quantity or datum. In geodetics, two types of datums can be considered: a horizontal datum that forms the basis for calculating horizontal control surveys, in which the curvature of the earth is considered, and the vertical datum, to which elevations are referenced.

The vertical datum for measuring all elevations is mean sea level. The elevation is the vertical distance (plummet) from a datum (generally mean sea level) to a point on the surface of the earth.

It may be stated that any geodetic point is based on a vertical datum and a horizontal datum. Each country or group of countries that make up a region adopts datums in accordance with the best solution for each area. That is why so many datums exist in the world. When determining positions in a zone covered by different datums, the conversions from one to another can create confusion and inexactness, especially among

navigation chart and map users that are not familiar with the principles of geodetics.

Local datums are based on a spheroid whose theorem does not coincide with the positional value of the centre of the earth. Modern navigation systems, however, including the inertial and satellite-based systems, need to be referenced to the centre of the earth. The ideal solution, then, is to have a common datum projected to the centre of the earth that can be utilised worldwide by any user.

4.4.6 The 1984 World Geodetic System (WGS-84)

The WGS-84 was developed to provide for more precision and continuing updating of geodetic and gravitational data; also to offer means for interrelating positions based on various geodetic systems or datums through a system of coordinates that consider a single earth centre as its fixed system. The WGS-84 represents the model of a geocentric, geodetic, and gravitational earth that uses data and technology available as of 1984. Such system allows the user to relate geographic data, such as coordinates obtained from a source based on a local datum, with another source (for example: map positions with coordinates obtained in real time by inertial navigation systems). The WGS-84 is an ideal system for global navigation applications, such as international air operations.

In the static survey modality, the precision of geodetic latitude and longitude and geoid height of WGS-84 is within +/- 1 meter.

4.5 GNSS IMPLEMENTATION

4.5.1 Development stage

During this stage, the organisational aspects to be borne in mind and the basic requirements for authorizing limited use of the GNSS are described. A GNSS implementation team is also established. A development plan is designed to attain progressive objectives. That plan should include a requirement to permit rapid but, at the same time, limited use of the system. It should also determine the initial capability to be incorporated (en-route operations, non-precision approaches, precision approaches, etc.).

4.5.2 Supplementary stage

This stage covers the requirements to be met for approval of the GNSS as supplementary means of navigation. It identifies the topics of system certification and the creation of suggested operating methods. It also identifies the tests and demonstrations that should be conducted to gain operating experience.

The corresponding authorizations and guidelines are published and augmentations to basic GNSS signals are discussed and analysed in this stage.

4.5.3 Primary stage

The objectives set in the development stage are attained in this stage. A check is made to see whether the objectives have been attained with regard to the use of GNSS for the various categories of precision approaches and the selected augmentation techniques are evaluated.

The steps followed for the certification and final approval of the system are also checked. Needs are identified in terms of both air and ATS service procedures, and the necessary publications are issued to disseminate and regulate the use of the GNSS. Lastly, follow-up mechanisms are established to control the procedures.

4.6 NAVIGATION AID PERFORMANCE REQUIREMENTS

All navigation aids must fulfil four basic performance requirements in order to be certified: continuity, availability, integrity, and precision.

4.6.1 Continuity

It is the ability of the entire system to carry out its function without interruption during the planned operating period.

The continuity risk is the probability that the system will be interrupted and cease to provide guidance information for the proposed operation.

4.6.2 Availability

This is the ability of a navigation aid to transmit signals of the required quality most of the time. This is a critical requirement in landing guidance and for this reason standby equipment is added to the ground-based aids.

The GPS needs to have 4 satellites on the horizon simultaneously in order to obtain a 3-D position fix, but this is not enough to provide a navigation solution with sufficient integrity.

4.6.3 Integrity

This is the ability of a navigation aid to warn the pilot that it has failed or is giving incorrect bearings.

GPS satellites are not monitored continuously and several hours can go by before a failure is detected and corrected, although in fact most error warnings are issued within 30 minutes.

4.6.4 Precision

This is the ability of a navigation aid to guide the path of an aircraft within pre-defined tolerances.

The GPS component of the GNSS has a precision of 100 m on the horizontal plane 95% of the time. The signals available for civil users are, for security reasons, degraded 100 m precision-wise using selective availability (S/A). It is estimated that GLONASS signals can be manipulated in a similar fashion.

The U.S. Air Navigation Plan sets the possible margin of error of a GPS fix at +/- 100 horizontal meters by +/- 156 vertical meters, the latter being the most critical value for consideration in the case of a precision approach.

It should also be borne in mind that a satellite fix in space is an ellipsoid in which the vertical axis of error is almost 50% larger than the horizontal axis of error.

These percentages are very far from the minima allowed for precision approaches. To correct them, augmentation or differential correction techniques have been developed.

4.7 THE THREE NAVIGATION SYSTEMS

4.7.1 Supplementary navigation system

This is the navigation system that must meet the precision and integrity requirements, but not the availability and continuity requirements.

Approval for using a supplementary navigation system in a given flight phase requires having a sole means of navigation system on board.

4.7.2 Primary navigation system

This is the navigation system approved for a given operation or flight phase that must meet the precision and integrity requirements, but not with those of availability and continuity. Safety is achieved by limiting flights to specific periods of time and establishing certain procedural restrictions.

4.7.2 Sole means navigation system

This is the navigation system approved for a given operation or flight phase that must meet, for that operation or flight phase, the four navigation system performance requirements: continuity, availability, integrity, and precision.

4.8 DATABASES

Airlines and other organisations that provide flight planning and aeronautical chart services maintain internal navigation databases, from which they extract the necessary data to plot flight routes and to design aeronautical charts.

These databases should be compiled based on information supplied by States, in keeping with ICAO Annex 15 **?**Aeronautical Information Services". Therefore, the States are responsible for the precision of said information.

With the appearance on the market of flight management equipment (FMS), airlines need to update, on a monthly basis, the on board data bases used for navigation purposes. This information is taken from the central data base that these organisations keep.

4.9 AUGMENTATIONS

The GPS (and presumably the GLONASS) does not have enough continuity, availability, integrity, and precision to allow for its use as the sole means of navigation for all flight phases. In order to meet operational

requirements, augmentations must be applied to basic GPS signals to eliminate the errors they contain.

Three basic categories of augmentations have been proposed: airborne-based augmentation systems (ABAS), ground-based augmentation systems (GBAS), and satellite-based augmentation systems (SBAS).

4.9.1 Airborne-based augmentation systems (ABAS)

4.9.1.1 Receiver autonomous integrity monitoring (RAIM)

This technique can be used if there are more than 4 satellites with the appropriate geometry within range of the receiver. With 5 satellites, 5 independent positions can be computed; if these do not match, the receiver infers that one or more of the satellites is supplying incorrect information and a warning light will turn on on the equipment panel.

If there are 6 or more satellites within range, more independent positions can be calculated and the receiver will be able to identify the defective satellite and exclude it from positioning calculations.

The RAIM technique may be assisted by a process known as barometric aiding. Aircraft barometric altitude information is taken from the GPS receiver, which can simulate a satellite placed directly over the user.

With this process, the requirement for 5 or 6 satellites can be reduced to 4 or 5, respectively.

4.9.1.2 Aircraft autonomous integrity monitoring (AAIM)

Other types of on-board augmentations can be used. An INS can replace the GNSS at times when their antennas are shielded (during turns, for example) or when the number of satellites within range of the receiver is inadequate.

Other airborne-based augmentation techniques can include a more precise time reference, a given combination of sensor input information through filtering techniques, etc.

4.9.2 Ground-based augmentation systems (GBAS)

These systems are used to enhance the continuity, availability, integrity, and precision of GNSS signals within a reduced geographic area.

They consist of a ground monitoring station whose location is known with precision. This station evaluates the information received from GNSS satellites, detects clock and other errors, and sends a corrective signal to airborne receivers through a VHF data link.

Precisions on the order of 5 meters can be achieved with ground-based augmentation systems, which makes them suitable for Cat. II/III instrument approaches. The advantage of the GBAS lies in the fact that it can serve all airport runways within a range of 30 nautical miles from the ground monitoring station.

4.9.2.1 Special Category 1 ILS (SCAT-1) equipment

A version of the GBAS known as SCAT-1 (Special Category 1 ILS) has been developed in the United States. This SCAT-1 equipment is certified for each specific airport and for each type of aircraft. It must also be compatible with airborne avionics, making its use very specific and not open to general aviation.

4.9.3 Satellite-based augmentation systems (SBAS)

The GBAS will not be able to provide coverage for all flights because of its range limitations. An effective means of overcoming this limitation has been devised, using geostationary satellites to transmit messages to correct GNSS signals on a broad geographic area.

4.9.3.1 European geostationary navigation overlay service (EGNOS)

This system is based on the provision of three services combined in a single signal:

- range expansion, whereby a GPS-type signal is broadcast by the transponder, giving the satellite a broader range;
- geostationary integrity channel, through which information is provided about the status of all GPS and GLONASS satellites; and
- broad area differential corrections, with information for correcting errors generated when GPS signals cross the ionosphere, as well as satellite clock errors.

a) Spatial navigation segment

This segment consists of the GPS constellation, the GLONASS constellation, and the geostationary satellites (usually two).

b) Ground segment

This segment is composed of:

- ranging and integrity monitoring stations (RIMS), which act as data collection points. They also transmit the data collected from the MCC.
- master control centre (MCC), which includes:
- central control facilities (CCF), that monitor and control the system;
- central processing facilities (CPF), that compute, distribute, and validate the transmission of adjustments and data corrections. They also ensure end-to-end integrity of the corrections transmitted;
- navigation land earth stations (NLES), which are used to modulate the message generated

by the CPF, synchronize the signal and uplink the data to the geostationary satellites; and

- a communication network, that is needed to interconnect all of the elements of the ground segment.

c) Functions

- Ranging capability over each GEO signal;

- Dissemination of navigation data concerning the satellites used (GPS, GLONASS, and GEO), which are used to control the integrity in the so-called GIC (ground integrity channel) function and to enhance integrity; and

- The WAD (wide area differential) function to enhance precision, which includes information about ionospheric delays;

These services give rise to three levels of service in the AOC:

- Service level 1, RANGING, which will improve the GPS navigation function, based on the transmission of a GPS-type signal, which will increase the availability of the navigation service (positioning and RAIM); EGNOS will give two ranging signals through the GEO INMARSAT III AORE and IOR;

- Service level 2, GIC, which will add to the improvements brought about by Service level 1, an enhancement of the integrity function, based on the transmission of additional integrity data supplied from the ground, over the GPS, GLONASS, and GEO; and

- Service level 3, WAD, which will give users the same service as Level 2 plus the transmission of differential corrections and ionospheric delay data in order to improve the precision services provided by the GPS.

The functions that EGOS will furnish to cover the cited services are:

- Data collection;

- Determination of satellite orbits;

- Determination of corrections to be applied to each satellite;

- Provision of data on the integrity of each satellite;

- Determination of ionospheric corrections;

- Independent verification of the data;

- Independent data verification;

- Provision of unified time to the systems network;
- Provision of ranging service in the signals in space and dissemination of navigation messages;
- Provision of system communications; and
- Monitoring and control.

d) EGNOS receiver

This receiver will be capable of receiving GPS/GLONASS signals and of processing the adjustment data from the GNSS integrity channel and the differential corrections sent by geostationary satellites. It will also use a RAIM algorithm to complete the integrity verification.

The EGNOS receiver is also expected to be interoperable with the other satellite-based augmentation systems (WAAS, MTSAT, etc.).

4.9.3.2 Multifunctional transport satellite (MTSAT)

Japan is evaluating projects for applying new generation CNS systems, based on the MTSAT. The MTSAT is scheduled to be launched into space in mid 1999.

It has communication and navigation capabilities. The two-way communication link capability enables message relaying between the pilot and the air traffic control unit and to send automatic ADS aircraft position reports to the appropriate ground unit.

Pilot-controller two-way communications can include data messages, with one satellite acting as relay. This allows for the exchange of large amounts of data over a relatively short period of time while avoiding errors and enabling a highly efficient service.

The overlay and differential augmentation capabilities of the MTSAT will improve the information supplied by the GPS. In order to determine its position, an aircraft needs at least four GPS satellites with the appropriate geometry; but these satellites are not geostationary and, as a result, there are times and positions when that information cannot be obtained. The overlay capability of the MTSAT, which is geostationary, will be capable of supplementing the GPS by providing unique position information.

The differential capability monitors GPS satellite operation from the earth and informs aircraft of any problem, while correcting any position information obtained through the GPS.

With these functions, air traffic controllers will be able to determine the position of an aircraft precisely, thus increasing the capacity of a given airspace.

There will also be advantages for aircraft flying at low altitudes that are presently unable to maintain an efficient radio link due to interruptions caused by geographic obstacles.

Consequently, the MTSAT will allow routes to be established freely, thus providing flights with more economic and efficient paths.

4.9.3.3 Wide area augmentation system (WAAS)

The United States is implementing a version of the SBAS known as the wide area augmentation system (WAAS).

The WAAS fulfils 3 functions:

- Integrity for all flight phases through CAT I landings;
- Adjustment signals to improve availability for all flight phases through CAT I landings; and
- Improved precision with DGPS through CAT I landings.

The WAAS network will consist of 24 wide area reference stations, to be installed in predetermined positions, which will evaluate GPS satellite signals.

This information will be sent to 2 wide area master stations that calculate the correction algorithms and evaluate the reliability and integrity of GPS signals sent by the satellite within range of the reference stations.

The master station will format the information in a message that it will send to the corresponding geostationary satellite of the 3 that cover the United States. This satellite will relay the information to airborne GPS receivers that are capable of accepting such corrections.

4.10 BENEFITS OF THE NEW NAVIGATION SYSTEM

The availability of an improved guidance and position capability in any part of the world will enhance operational efficiency, reducing flight time and the fuel required through navigation that is more precise than it is today and, where applicable, the adoption of routes requested by the user. Flights with some weight limitation can benefit from the reduction of fuel requirements, including contingency reserves, thus increasing payload and profits.

Consideration must also be given to the availability of non-precision guidance for runways lacking ground navigation aids or that are served by unreliable navigation aids; this will reduce delays, alternates, overflights and cancellations due to bad weather. The availability of a GNSS-supported precision approach capability, whether through ground-based or satellite-based augmentation systems, coupled with airborne ones, will also offer operational advantages over existing equipment.

Consequently, the capability of providing approach guidance for more airports could attract traffic from those where delays due of congestion are common. By reducing such delays, operators will save flight time and required fuel.

Use of the GNSS 4-D navigation capability will permit more precise positioning of incoming flights over an approach fix. The ability to comply with a required time of arrival (RTA) will contribute to increase airport

capacity and also to reduce delays.

Eventual use of the GNSS for all flight phases will result in savings for operators due to the reduction of airborne equipment types. It will also reduce maintenance and capital costs. Advanced integration techniques with inertial reference systems (IRS) will make it possible to operate with less expensive inertial sensors.

The availability of satellite navigation will enable the gradual deactivation and dephasing (eliminación eventual) of ground aids. This will reduce costs, at least in the medium and long terms, allowing service providers and users significant savings.

4.10.1 Expected operational benefits

Progressive implementation of satellite navigation will be required in order to take early advantage of GNSS operational benefits.

The use of GPS as a supplementary means of en-route navigation and as a primary means of navigation over oceanic/remote airspaces, as well as overlay approaches and autonomous GPS approaches provide users with operational advantages by giving them direct contact with the GNSS.

Regarding the relevant bodies, this is an excellent opportunity for gaining experience in the operation of the GPS equipment, in-flight inspection procedures, application of the WGS-84, etc.

4.10.1.1 Use of the GPS as a supplementary means of en-route navigation

The global positioning system (GPS) can be used as a supplementary means of IFR en-route navigation.

The GPS receiver used for IFR flights should meet the technical requirements specified in the FAA Technical Standard Order (TSO) C-129a and should be installed in keeping with FAA Circular AC-20-138.

The GPS IFR receivers possess the airborne RAIM augmentation technique and have a built-in navigation database, which cannot be manually accessed during flight in order to avoid insertion errors.

4.10.1.2 Use of the GPS as primary means of navigation in oceanic/ remote airspaces

International Civil Aviation Organization Circular NE 267-AN/159 ?Guidelines for the Introduction and Operational Use of the Global Navigation Satellite System” stipulates in paragraph 6.1.1, item C) that ?in light of the availability of an improved navigation integrity, together with reduced availability requirements for flights over oceanic airspaces, the use of satellite-based systems would be allowed as the primary means of navigation for this flight phase”.

Aircraft will have to be equipped with receivers that comply with the FAA TSO C-129a standard and must also meet the requirements of FAA Notice N.8110.60 ?GPS as a primary means of navigation for oceanic/remote operations”.

4.10.1.3 Overlay approaches

In this type of non-precision approaches, the final approach segment of the procedure is extracted from the GPS receiver, instead of being based on ground radio aid bearings. An overlay programme is not complicated to carry out, for it only requires one airborne C-129-compliant GPS receiver.

The first step consists of selecting the non-precision approaches to be overlaid. There should be only one approach per runway and it should be the one that is most closely aligned with the final path.

The coordinates of the points that mark the beginning of the approach segments to be overlaid (IAF, IF, FAF, and MAPt.) will then be converted to the WGS-84 Geodetic System.

A database for the overlay approach will have to be developed, with the points surveyed in the WGS-84, and sent to a database provider for the preparation of a data card in keeping with FAA Circular AC NE 97-2 ?Data base standardization for the GPS overlay programme". The provider should be informed of the type of equipment to be used, since card formats differ according to the type of equipment involved.

The requirement for a printed database is intended to keep the pilot from programming the approach manually and thereby avoid data input errors. The receivers are equipped with an automatic sequence device to protect the integrity of the database. No data can be entered once the approach mode has been selected. The IAF will appear on the equipment screen, followed automatically by all of the points that define the approach segments, up to the missed approach point (MAPt).

Once it receives the data card, the Flight Inspection Department will use the procedure in flight in order to validate it.

4.10.1.4 GPS stand-alone approaches

GPS non-precision stand-alone approaches that are not the overlay of a traditional approach are the step following the overlay approaches.

The sequence of waypoints that define the procedure is encoded in the airborne GPS receiver (129a standard-compliant) database. These points include the initial approach fix (IAF), the intermediate approach fix (IF), the final approach fix (FAF), the missed approach point (MAPt), the missed approach turn fix, and the missed approach holding fix. This sequence of waypoints that appears on the airborne equipment screen should be identical to the sequence shown on the GPS approach card.

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Chapter 5

THE NEW SURVEILLANCE SYSTEM

The secondary surveillance radar (SSR), augmented with Mode S when traffic conditions so warrant, will continue to be used, especially in high traffic density airspaces.

In other places, such as oceanic airspaces and remote areas over the earth, surveillance will be done using automatic dependence surveillance (ADS).

5.1 REQUIRED SURVEILLANCE PERFORMANCE (RSP) CONCEPT

This concept defines the surveillance requirements according to the airspace involved. These can be categorised as follows:

- The surveillance system must provide the updated aircraft position in order to ensure a safe separation:

  1) in low-traffic oceanic/remote airspaces, position information should be updated every 12 seconds;

  2) in high-traffic airspaces (routes and terminal areas), position information should be updated every 4 seconds;

- The surveillance system should allow users to select the preferred en-route flight path and conform fully to emergency procedures;

- The surveillance system should contribute to search and rescue operations; and

- The precision of the surveillance system should allow for the application of separation in a defined airspace.

5.2 AUTOMATIC DEPENDENT SURVEILLANCE (ADS)

Through the ADS, the aircraft automatically transmits, via data link, its identification and 3-D position (supplied by the airborne navigation systems, which obtain it from the GNSS) to the air traffic control units.

ADS allows controllers to observe, in a pseudo-radar display, the position of aircraft and possible deviations from the assigned flight paths.

The design of the ADS should allow its implementation without disrupting air traffic services. It should also be sufficiently flexible and capable of expanding to fulfil the following objectives:

- adaptability to local regulations and ATS special requirements;
- flexibility for incorporating future changes in functional requirements and possibility of integrating new technological developments;
- ability to move, with sufficient safety, to other forms of ATC services if the system fails or is degraded;
- capability of providing a minimum service to all duly equipped aircraft; and
- possibility of becoming part of an ATS architecture that takes full advantage of the ADS.

5.2.1 ADS-A (Addressed)

This system operates only in the air-ground mode and at the request of the air traffic control unit; it is the controller who determines which reports are necessary for controlling each aircraft.

5.2.1.1 Basic principles

Communication contracts must first be established between airborne equipment and the ground systems before being able to receive any ADS report. The controller determines which reports are necessary to control each aircraft in the flight segments under the control of a given air traffic control unit.

The contract may include the issuance of basic ADS reports at periodic intervals defined by the ground system, with one or more blocks of additional data containing specific information.

The contract can also specify ADS reports made at geographically defined points, such as waypoints and intermediate points, in addition to reports triggered by specific occurrences.

Certain types of airborne equipment (FANS-1/A) have the capability to maintain contracts with four or five ATC units simultaneously. These aircraft will also send automatic position reports, in keeping with the ADS contract made by the ground system.

At a given time or distance, before reaching the boundaries of a flight information region (FIR), which can vary depending on the ground system, the FANS - 1/A creates and allots the appropriate ADS contracts for the aircraft. The latter will immediate prepare and transmit ADS reports addressed to the ground system in keeping with the pre-established contracts.

In some systems, the controller has the capability to replace the ADS contract, if necessary. The ground system will issue the appropriate messages to start the modification of existing contracts.

5.2.1.2 Conformity monitoring

Automated ground systems can use the ADS position reports and other data groups from the ADS message to provide automated flight tracking in accordance with the flight plan.

Most automated ground systems compare the aircraft position reported by the ADS with the position foreseen by the ground system, taken from the flight plan. The ground system will prepare and show the controller the appropriate messages in the event that the ADS report does not match the position foreseen by the ground system. This conformity monitoring capability makes it possible to verify whether the flight is proceeding according to its flight plan.

Furthermore, aircraft equipped with FANS - 1/A are capable of doing their own monitoring and of making an automatic report in case of significant flight variations, when so required by an appropriate occurrence contract. The ground system will include, together with the request for an ADS occurrence contract, the values that triggered these reports.

5.2.1.3 ADS contracts

There are three types of contract, each of them operating independently of the others:

- The periodic contract;
- The occurrence contract; and
- The demand contract

a) The periodic contract

A request for a periodic contract defines the contract requirements to be included in the reports and reporting frequencies.

Through an uplink, an ATS unit initiates a periodic report request. This request allows an ATS unit to include the optional data groups in the basic ADS report, also specifying its frequency of inclusion. The controller can modify the periodic reporting average up or down in order to accommodate special situations, such as traffic density. Information about the minimum reporting averages recommended for each type of aircraft can be obtained from the manufacturer’s manual.

Only one periodic contract can be established. If another is to be established, then the previous contract will be replaced. The periodic contract will remain in force until modified or cancelled.

b) The occurrence contract

An occurrence contract specifies a report request to be sent by the aircraft if certain occurrences take place. These can be:

- A variation in the ascent or descent regime, triggered when it is above or below a value defined in the contract;
- A lateral deviation, triggered when the current position of the aircraft exceeds a lateral distance value determined on the basis of the position foreseen in the activated flight plan;
- A change in altitude, triggered when the aircraft altitude exceeds the maximum or minimum altitude value stipulated in the contract defined by the ground system; and
- A change in reporting point, triggered by a change in the next or one after the next reporting point. This change is normally produced by the reporting point sequence. It will also be triggered, however, by a modification in a reporting point not stipulated in the ATC clearance, but entered by the pilot for operational reasons. Only one occurrence contract may be established each time between the aircraft and the ground system; even so, the contract may contemplate different types of occurrences.

c) The demand contract

The demand contract request is a single request from the ground system for the airborne equipment to send an ADS report containing the data specified in the request. A demand contract may be requested by the ground system at any time. A request for such contract will not affect any other that exists.

d) The emergency mode

This mode may be activated or cancelled by the pilot only. Once activated, the emergency mode connects the aircraft with all ground systems that have established periodic or occurrence contracts with it.

Any periodic contract that is taking place will be suspended when the emergency mode is activated. Even so, occurrence or demand contracts will not be affected by said mode.

When the pilot cancels the emergency mode, the on board equipment will send a cancellation message to each ground station that received this message.

5.3 AUTOMATIC DEPENDENT SURVEILLANCE - BROADCASTING (ADS-B)

ADS-B is a new aeronautical surveillance concept by virtue of which the aircraft transmits its position (generally derived from an airborne GNSS receiver) through a data link. The position information is received by nearby aircraft, which enables all users to be informed about their own position and the position of all other nearby traffic. The position information may be displayed in the cockpit of aircraft thus equipped to allow for a new possibility of detecting traffic.

Ground vehicles and facilities can also be equipped to receive and transmit position data, making it possible to monitor all types of traffic through two-way data links.

Aside from position information, the data link allows additional data to be relayed. These may include the aircraft identification and speed, normally obtained from the GNSS receiver.

ADS-B will play an important role in the cockpit environment, for it will keep the pilot informed about all the traffic nearby (the aircraft flight number/registration will appear automatically on the screen).

The cockpit display is used to show the position and intentions of all aircraft within a 200-mile radius. The equipment is called cockpit display of traffic information (CDTI) or traffic situation display (TSD).

Pilots can use the screen to monitor nearby traffic and, for the first time, will have available the same traffic surveillance overview as the air traffic controller.

Cockpit display will permit other manoeuvres, such as following another aircraft while maintaining a given separation, irrespective of weather conditions, or overtaking manoeuvres in low traffic oceanic airspace. This does not mean taking away from air traffic controllers the responsibility for maintaining separation between aircraft, but it allows them to share part of their workload with the pilot.

The CDTI/TSI will also enable crews to maintain what in radiotelephony is called a ?listening watch", in order to get a mental picture of surrounding traffic. Pilots are concerned that the implementation of controller-pilot data link communications (CPDLC) will take away the possibility of getting an idea of the surrounding traffic through a radio listening watch. However, the ADS-B allows to keep a visual display of all traffic.

On the ground, the ADS-B will offer air traffic control new surveillance capabilities at a fraction of the cost of a conventional SSR. An ADS-B ground station is a transmitter/receiver station without the complex and costly rotary antennas of radar systems. Unlike those systems, an ADS-B ground station does not need to make high-precision measurements of the aircraft position, thus reducing the cost of ground equipment considerably.

The ADS-B concept is independent of the type of link used for data transmission. The information can be relayed by VHF, satellite, or SSR Mode S. Therefore, ADS-B will be an advanced and relatively low-cost system (in comparison with the SSR) that will provide:

- High-quality flight surveillance information with a coverage from the beginning to the end of the flight and not the partial coverage that exists today, since the quality of radar coverage varies, depending upon the flight phase and antenna site;

- Low cost. There will be no separate surveillance system, as it will be a part of the already installed communication structure;

- Flexibility. The average surveillance reporting can be modified based on the requirements. Approach monitoring, for example, can have a higher reporting average than en-route applications;

- More precise data. GNSS position data have a precision of a few meters if differential corrections are available for the GNSS receiver. This precision is much greater than that obtained by means of conventional radar systems. Speed information provided by a GNSS receiver is also more precise than that obtained from consecutive radar tracks;

- More complete surveillance information. For example, additional data obtained from the FMS or other airborne computers can be transmitted to other users by data link;

- Capability to support new applications. A general-purpose data link can be used to transmit additional surveillance information or support new applications;

- Identical surveillance information is available to all users, on ground or air. Aircraft could use this data for autonomous control in low-traffic remote/oceanic airspaces; and

- Available for all flight phases. This includes air and surface movement surveillance.

The ADS-B will also send a message to ground control units within a radius of 95 NM around the transmitting aircraft.

5.4 MAIN COMPONENTS

5.4.1 Pilot interface

The pilot interface has the means to monitor system operation. The transfer of communications to another ground earth station is automatic, but manual override capability is available when circumstances so require.

For emergency situations, there is a report system that indicates its cause and a basic ADS report (aircraft identification). A voice capability also exists if emergency or special messages need to be sent.

5.4.1.1ADS Messages

ADS messages contain the following data:

- latitude and longitude;
- altitude;
- time;
- track;
- ground speed (G/S);
- vertical situation (ascent/descent);
- magnetic heading;

- Mach number or indicated airspeed (IAS);
- next route reporting point;
- estimated altitude at the next reporting point;
- second-to-the-next reporting point;
- upper wind direction;
- upper wind velocity; and
- temperature

5.4.2 Avionics

5.4.2.1 Flight Management System

The FMS offers a complete GPS/RNAV solution for worldwide 4-D aircraft navigation in the oceanic/remote, en-route, terminal area, and approach flight phases. It includes a series of navigation and flight planning devices, with the possibility for programming user-defined reporting points, and has a large database of routes, airports, and navigation aids and the capability to create and modify the flight plan.

It has an automatic multimode satellite-based area navigation capability and the possibility of receiving short- and long-range navigation aids. Other input data include air data and heading. Based on these navigation aids and the route data obtained from the navigation database, all flight progress, guidance, and heading information is considered with reference to the reporting points of the activated flight plan.

The navigation aid normally used is selected automatically by the navigation system, depending upon the flight phase and the availability and quality of each aid. The operator can select or discard any available navigation aid.

Under normal conditions, the available aids will be selected in the following order of priority, based on the precision of rated performance and assuming good satellite geometry:

- GPS
- DME/DME
- DME/VOR
- VLF

When the FMS equipment is used as the primary or supplementary means of GNSS navigation (having GNSS integrity information available), the GPS will be the preferred source of navigation. When GPS integrity is not sufficient, GPS navigation will continue; nonetheless, the position derived from the GPS will be compared with that derived from the aids approved for the flight phase in question. An alert message will appear when a difference of position exceeding the limits predefined for that flight phase is detected. Failure to receive a navigation aid being used will result in the automatic selection of the closest available aid, provided that it is approved for that flight phase and that it has an acceptable quality factor.

In the unlikely case that the GPS and all the other means of navigation are unavailable, the FMS navigation system will shift to dead reckoning (DR) navigation mode, using true airspeed (TAS), heading information, and the last estimated wind value. An alert message will show on the screen to inform the user that this navigation mode is being used.

The pilot can obtain information on the status of all navigation aids and determine which is being used by means of the multifunction control and display unit (MCDU), which is the primary equipment control and which also allows for interconnection with other aircraft sub-systems. GPS parameters may be observed on request and can include the number of visible satellites and which ones are being tracked by the equipment, the limits of GPS vertical and horizontal integrity, and its precision. Radio aids in use and their operational status can also be verified when the radio navigation mode is activated. When the aircraft position derived from the GPS or other navigation aids fails to comply with the required navigation performance for the flight phase being flown, an alert message will appear.

The FMS can also select the standard instrument arrival routes (STARs), STAR transitions, GPS autonomous and overlay approaches, and the missed approach procedures for the arrival airport, which are automatically entered in the flight plan.

a) Required time of arrival (RTA)

The required time of arrival (RTA) is a function of FMS equipment whereby true airspeed (TAS) is computed in order to comply with a given crossing time over a position, bearing in mind also the effect of unforecast winds on the estimated time of arrival (ETA).

The air traffic controller, through an uplink and using CPDLC, sends a message requesting the aircraft to be at a specific point at a given time. If the pilot accepts it, the message is entered in the FMS, which first determines whether the aircraft will be able to fulfil the request. If so, the FMS will manage the aircraft systems to ensure passage within the specific time.

5.4.2.2 FANS 1

The navigation system known as FANS 1 is certified for use in the Boeing 747-400 and 777, among other models.

It uses the GPS as input information for a multi-sensor area navigation system (RNAV) that includes tripled inertial reference system (IRS) equipment, double FMS, two double GPS and DME receivers.

It has been designed for use in remote or oceanic, en-route, and terminal areas and in non-precision

approaches.

5.4.2.3 FANS A

The FANS A equipment has been developed by the AIRBUS company for use in models A310/A320/A330 and A340. It is designed to be employed as a primary means of navigation in the appropriate airspaces. It draws on GPS precision and aircraft autonomous integrity monitoring (AAIM) techniques, backed by the integrity verification capability built into the FMS.

The aircraft integrity monitoring functions are based on the GPS/ADIRS configuration, which is the GPS connected to the inertial air data system, which uses all available navigation sources to monitor GPS operation, ensuring the highest levels of precision, integrity, and availability. With the FANS A system, GPS signals are used as much as possible for navigation, keeping in mind the satellite coverage of the airspace flown.

5.4.2.4 FANS B

The FANS B equipment is being developed by the AIRBUS company for use in models A 330 and A 340 and possibly other models, as well.

FANS B introduces an ATN-based communication and surveillance capability to allow for operations in high traffic density airspace; CPDLC and ADS links are also made through the ATN.

5.4.2.5 Satellite communication equipment (SATCOM)

SATCOM equipment provides voice capability by means of a digital telephone that is available on some aircraft through the INMARSAT geostationary satellite network. Each geostationary satellite has 600 voice channels, which are not intended for aeronautical purposes exclusively.

Most SATCOM equipment has been installed in the cabin of passenger aircraft as an added service and to generate more income. There is single-channel and multi-channel equipment. Depending on the installation, some SATCOM equipment is also integrated into the intercommunication system of the cockpit.

SATCOM equipment operators have to establish contracts with the various service providers in order to be able to use their ground earth stations (GES) to connect up to a ground telephone. The aircraft must connect to the appropriate GES for the region over which it is flying, bearing in mind that some regions may have more than one satellite or GES available. This makes air-ground calls easier to effect than ground-air calls.

In the case of a satellite link, the ground connection consists of the ground earth station (GES), which is part of the fixed satellite service or of the aeronautical mobile-satellite service, located at a given fixed point on the ground.

5.4.3 Data link

ADS operational requirements are being effectively backed up by the complete data link sub-system that connects air traffic service units with properly equipped aircraft.

The links used can be VHF, Mode S, or HF, in addition to exclusively satellite links. The different links will be used bearing in mind the airspace involved and in keeping with a cost-benefit analysis, since these vary according to the link used.

The air-ground link includes the capability to exchange data or voice messages, with the latter being reserved for emergency or special communication situations.

5.4.4 Communication interface

This interface connects air traffic services units with the ground earth stations, one of whose functions is to direct ADS messages to end users (ATS).

5.4.5 Controller interface

This interface has the capability for:

- displaying the traffic situation so that the controller can monitor it with a minimum effort (user friendly);
- alerting the controller to potential conflicts or a decrease in the separation;
- enabling the controller to compose and transmit message by means of the selected data link, using free or preset formats;
- displaying the messages sent by the pilot;
- allowing for rapid access to a voice channel that can be used for special and emergency communications; and
- arranging for a rapid voice response to a pilot request.

5.4.6Automation applied to ADS

Air Traffic Control using ADS information must have the capability to automate the following functions:

- flight data validation, a function whereby the route proposed by the aircraft (reporting points) and entered into its navigation system, is compared with the authorized route. Any discrepancies will be reported to the pilot;
- conformity monitoring, whereby reported or foreseen aircraft positions are compared with the route laid out in the flight plan. The system will alert the controller to any deviation

exceeding reasonable tolerances;

- automatic tracking, which monitors aircraft flight progress between each position report;
- detection of potential conflicts, which projects aircraft positions into the future, making an evaluation to detect possible violations of separation minima;
- conflict resolution, which offers the controller a possible solution to a potential traffic conflict, for use or modification; and
- display of relevant processed data.

5.5 BENEFITS OF THE NEW SURVEILLANCE SYSTEM

With the use of ADS, air traffic control applied in airspaces without radar coverage (based on pilot voice reports and pilot/controller estimates of passage time) will evolve to a point where services will be furnished that are very similar to those provided by radar control, including aircraft position display on a ground screen (pseudo-radar display).

ADS use leads to a reduction of separation minima used in non-radar airspaces. The existing regulatory separation over oceanic airspaces (10 minutes longitude and 60 NM lateral) may be reduced by one-half, thus doubling the capacity of oceanic routes.

ADS use also adds operational flexibility to air traffic control, for controllers are able to respond better to user flight preferences.

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Chapter 6

AIR TRAFFIC MANAGEMENT

The term Air Traffic Management (ATM) is used to describe airspace and traffic management activities that are carried out jointly by aeronautical authorities concerned with the planning and organisation of the effective use of airspace and its movements within their regions of responsibility.

The ATM operational concept must have a visionary scope and be referred to the concepts of endurance of flight, shared separation assurance, and situational awareness in the cockpit.

6.1 OBJECTIVES

The general objective of ATM is to allow aircraft operators to comply with the estimated times of departure and arrival and to follow preferred flight profiles with a minimum of limitations and without jeopardising the agreed level of safety.

The ATM should:

- maintain or increase the existing level of safety;
- increase system capability and use it fully, as needed, to meet traffic demands;
- dynamically incorporate the flight paths preferred by the user in 3 or 4 dimensions;
- allow for the use of all types of aircraft and different capabilities of airborne equipment;
- provide the user with better information (weather conditions, traffic situation, available facilities and services, etc.);
- improve navigation and landing capabilities in order to be able to carry out optimised arrival and departure procedures;
- increase the involvement of users in decision-making, resorting even to computer air-ground dialogue for in-flight negotiations;
- create an unrestricted airspace, insofar as possible, in which its divisions are transparent for the user;
- organise the airspace according to ATM provisions and procedures;

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- reduce delays and holding patterns to a minimum and adjust flight path programming to achieve efficient traffic movement and airspace and airport use; and
- achieve a better strategic ATS planning so that the need for involvement of the ATS system is reduced to a minimum in the future in cases of aircraft conflicts or for tactical conflict resolution.

6.2 COMPONENTS

It consists of an air and a ground component, both closely integrated through well-defined procedures and interfaces.

6.2.1 Ground component

The ground component is made up of airspace management (ASM), air traffic flow management (ATFM), and air traffic services (ATS).

6.2.1.1 Airspace Management (ASM)

Its purpose is to maximise use of available airspace within a given airspace structure.

In designing the future airspace structure, its boundaries and divisions should not impede the effective use of automated conflict detection and resolution techniques or the use of the advanced avionics equipment with which modern aircraft are equipped.

The purpose of dividing the airspace into sectors is to develop an optimum configuration, combined with the use of other appropriate methods for enhancing ATC capabilities.

When using the airspace, close co-ordination and supervision are essential in order to meet the contrasting and legitimate requirements of all users and minimise any restriction on operations.

6.2.1.2 Air Traffic Flow Management (ATFM)

Although ATM is designed to accommodate the maximum traffic demand and can be expanded to respond to predicted growth, it should be borne in mind that it may not be possible to meet excessive maximum air traffic demands. For that reason, ATM has a co-ordinated sub-system called air traffic flow management (ATFM).

In order to develop it, data on probable future demand forecasts, based on available background, are collated with the development foreseen by airports and airlines, aircraft manufacturer order books, and macroeconomic trend forecasts of the domestic and other State economies.

The ATFM function is to balance traffic demand and ATC capacity. The task of ATFM focuses on a general picture of traffic and on the planning strategy required to ensure efficient use of airport and airspaces in specific areas that are prone to ?bottlenecks”.

ATS units must provide the ATFM with information about traffic management capability.

The ATFM should also have access to the airline flight database to obtain up-to-date information about long- and short-term programming. Common databases are needed to provide a consistent AFTM service.

Finally, ATFM units should plan for the introduction and start-up of automated systems.

6.2.1.3 Air traffic services (ATS)

The implementation of CNS elements improves ATS services, incorporating advanced technology into existing or basic functions instead of merely replacing them.

Consideration should be given to using the operational functions and new elements of the system in parallel with the existing ones for a limited period of time, in order to evaluate their operational application and familiarise pilots and controllers with the new procedures.

Automated aids will be introduced, such as a conflict prediction and resolution advisory capability. Standards, recommended practices and procedures to be introduced should facilitate the operation of aircraft with different equipment in the same ATS environment.

During the transition phase, an evaluation is made of the incorporation of 3/4-D flight profiles preferred by users and their effect on the total traffic situation. Procedures should be agreed upon by the users.

Work on the specifications for the automation of air traffic services should be performed in close co-operation with ATFM.

6.2.2 Air component

The transition to airborne systems compatible with CNS/ATM concepts should offer a good cost-benefit ratio for all user categories; the benefits to be obtained should offset the implementation cost of the new equipment as soon as possible.

Airborne equipment should have the capability to perform the necessary functions in a given flight phase and meet RNP criteria according to the airspace used.

The automated function capability of the airborne equipment should be such that ATM automation requirements of the airspace used are fulfilled.

The capabilities of airborne systems should be applied so as to derive the benefits from available ATM services, such as, for example, facilitating dynamic flight planning during aircraft operations.

6.3 FREE FLIGHT/AUTONOMOUS FLIGHT

The concept of free flight/autonomous flight developed in the United States and originally conceived to give aircraft more manoeuvering capacity, with the support of available new technologies. It also emphasises the need for users to decide on their own upon their flight schedules, routes, and altitudes, thus reducing delays and costs.

The most important thing is the principle of maintaining a safe separation between aircraft. This principle is based upon two strips of airspace, known as protection and alert strips, whose dimensions are determined by the aircraft speed, performance, and communication, navigation, and surveillance equipment. The protected zone--the one closest to the aircraft--can never overlap with the protected zone of another aircraft. The alert zone extends beyond the protected zone and the aircraft can manoeuvre freely until its alert zone touches that of another aircraft. If that happens, the controller can give one or both pilots heading vectoring or other restrictions in order to ensure the separation.

Eventually, most of the orders will be sent by data link, which will be integrated into an air-ground communication network. Furthermore, airborne computers and GPS satellites will enable pilots, assisted by controllers, to use cockpit displays of traffic information (CDTI) to select the best separation options.

6.3.1 Benefits of the free flight option

- Improved safety through advanced conflict detection and resolution techniques;
- More flexibility for managing flight operations and better prediction of airspace conditions and their effects on such operations;
- Better tools for decision-making by pilots, air traffic controllers, and flight dispatchers;
- Savings from reduced fuel consumption and lower aircraft operating costs;
- Reduced use of flow control;
- Environmental improvements due to a reduction in exhaust emissions in en-route flights, approaches, and at airports;
- Obtention of a more precise time and position; and
- Possibility of sharing information between pilots and controllers.

RNAV ROUTES	AIR REQUIREMENTS	GROUND REQUIREMENTS	NOTES
RNAV Routes	RNAV capability		Currently available in the Asia/Pacific Regions
Flexible paths	FMS or RNAV	Tracking capability	Currently available in the Asia/Pacific Regions
Parallel one-way RNAV route structures	RNAV capability		Currently available in the Asia/Pacific Regions
CNS/ATM ROUTES			
Fixed routes	CNS/ATM-certified aircraft	Possible DCPC (voice or data) requirement	Additional requirements may be included
Flexible routes	CNS/ATM-certified aircraft	Possible DCPC (voice or data) requirement	Additional requirements may be included
Dynamic re-routing	CNS/ATM-certified aircraft with: FMS (IRS), CPDLC, data links. Directly updated flight plans	CPDLC. Air-ground data links, flight plan development, display of traffic situation to controller	Use depends upon airspace complexity
Free flight/autonomous flight	Aircraft with autonomous equipment	ATM system interoperable with automated airborne equipment	Concept being defined by ICAO. Use will depend upon airspace complexity.

Table 6-1. AIR AND GROUND REQUIREMENTS FOR THE ESTABLISHMENT OF AREA NAVIGATION AND CNS/ATM ROUTES

SECTION II

TRAINING SYLLABUS

Chapter 1

GENERAL

1.1 Communications

Future communications under the CNS/ATM concept will be based on an extensive use of data exchange.

The system architecture will provide both air traffic service providers and users with the various data link media, such as HFDL, VDL, secondary surveillance radar Mode S, aeronautical mobile satellite service (AMSS), etc.

Voice communication capabilities will be retained and will be reserved for exceptional or emergency situations.

The link media will permit an seamless connection between ground-ground and ground-air equipment and will be integrated through a global Aeronautical Telecommunications Network (ATN).

1.2 Navigation

Future navigation for all flight phases will be based on the reception of satellite-generated signals, and it is foreseen that satellite-based augmentations (SBAS) will be required, both ground-based (GBAS) and aircraft-based (ABAS), to meet the requirements as the only navigation system.

1.3 Surveillance

Future surveillance systems will include, in addition to radar as currently envisaged, Automatic Dependent Surveillance (ADS).

The use of ADS will permit surveillance in those airspaces that currently do not have radar coverage. As a result, safety will be enhanced and it will be possible to reduce the separation minima in such a way that a greater number of aircraft will be able to use a given airspace while meeting surveillance performance requirements.

1.4 Air Traffic Manageme nt

Air Traffic Management is the activity that involves the administration of airspace and the handling of air traffic by aeronautical authorities, in relation to the planning and organisation for the effective use of airspace. This permits the rationalisation and optimisation of resources and aircraft movements within the regions under their responsibility.

Chapter 2

TRAINING SYLLABUS

2.1 Assignment

Introduction to CNS/ATM systems.

2.2 Objective

To give students the required systematic knowledge on the essentials, principles and functions of the new technology called "CNS/ATM systems" and its different components.

2.3 Contents

KEY	UNIT 1	HOURS
CNS/ATM	**ORIGIN AND EVOLUTION OF THE SYSTEM** E.O.: That the student identify the most relevant aspects of the origin and evolution of CNS/ATM systems. 1.1. Limitations of the current system. 1.2. Measures adopted by the ICAO Council. 1.3. Measures adopted by the FANS Committee.	

Table 2.3.1

KEY	UNIT 2	HOURS
CNS/ATM	**COMMUNICATIONS** E.O.: That the student describe the most relevant aspects of the new communication system. 2.1 Required communication performance (RCP) concept. 2.2 Terms referred to: ✈ Direct controller/pilot communications (DCPC) ✈ Controller pilot data link communications (CPDLC). ✈ ATS interfacility data communications (AIDC). ✈ Aeronautical mobile satellite service (AMSS). 2.3 Aeronautical telecommunication network (ATN). 2.4 Benefits of the new communications system.	

Table 2.3.2

KEY	UNIT 3	HOURS
CNS/ATM	**NAVIGATION** E.O.: That the student describe the most relevant aspects of the new navigation system. 3.1 The Global Navigation Satellite System (GNSS). 3.2 Global Positioning System (GPS). 3.3 Global Orbiting Navigation Satellite System (GLONASS). 3.4 Geodetic system used by the GPS. ✈ Basic concepts of geodesy. ✈ The ellipsoid as the figure that depicts the earth. ✈ The geoid as the figure that depicts the earth. ✈ The deflection from the vertical. ✈ The representation of the geodetic datum. ✈ The world geodetic system, WGS – 84. 3.5 The required navigation performance concept (RNP). 3.6 Navigation aids performance requirements. 3.7 The three basic navigation systems. 3.8 The augmentation systems. 3.9 Benefits of the new navigation system.	

Table 2.3.3

KEY	UNIT 4	HOURS
CNS/ATM	**SURVEILLANCE** E.O.: That the student describe the most relevant aspects of the new surveillance system. 4.1 The new surveillance system. 4.2 The required surveillance performance (RSP) concept. 4.3 Use of the secondary surveillance radar (SSR) Mode S. 4.4 Use of automatic dependent surveillance (ADS). 4.5 Use of automatic dependent surveillance-broadcasting (ADS-B). 4.6 The flight management system (FMS). 4.7 The FANS 1 and FANS A navigation systems. 4.8 The satellite communications equipment (SATCOM). 4.9 Benefits of the new surveillance system.	

Table 2.3.4

KEY	UNIT 5	HOURS
CNS/ATM	**AIR TRAFFIC MANAGEMENT (ATM)** E.O.: That the student identify the air traffic management (ATM) components. 5.1 Meaning of air traffic management. 5.2 Objectives of ATM. 5.3 Components of ATM: Air Traffic Flow Management (ATFM), Airpace Management (ASM) and Air Traffic Services (ATS). 5.4 The free flight concept. 5.5 Benefits of Air traffic Management.	

Table 2.3.5

Chapter 3

SPECIFIC TRAINING PROGRAMME

COMMUNICATIONS	NAVIGATION	SURVEILLANCE	AIR TRAFFIC MANAGEMENT
Use of data link DCPC CPDLC AMSS SATCOM ATN Avionics ***Contingencies***	GNSS (GPS/ GLONASS/ Civil constellations) Augmentations: *ABAS *GBAS *SBAS FMS INS/ IRS Avionics ***Contingencies***	ADS/ B SSR Mode S Avionics ***Contingencies***	Operational concept RNP concept and application Flexible paths Dynamic re-routing Separation reduction: *Vertical *Lateral *Longitudinal Free flight concept/ Autonomous flight ***Contingencies***

3.2 **AIR TRAFFIC CONTROLLERS**

COMMUNICATIONS	**NAVIGATION**	**SURVEILLANCE**	**ATM**
Use of data link DCPC CPDLC AMSS SATCOM AIDC ATN ***Contingencies***	GNSS (GPS/ GLONASS/ Civil constellations) Augmentations: *ABAS *GBAS *SBAS INS integration ***Contingencies***	ADS/ B SSR Mode S Procedures: • RDR/ ADS/ Non- RDR • ACAS ***Contingencies***	Operational concept Detection of conflicts ASM/ATFM/RNP *Flexible paths *Dynamic re-routing *Preferential routes *Separation reduction *Vertical *Lateral *Longitudinal Free flight concept/ Autonomous flight ***Contingencies***

3.3 TECHNICAL PERSONNEL

COMMUNICATIONS	NAVIGATION	SURVEILLANCE	ATM
Use of data link DCPC CPDLC AMSS SATCOM ATN Avionics ***Contingencies***	GNSS (GPS/ GLONASS/ Civil constellations) Augmentations: *ABAS *GBAS *SBAS Certification Calibration Avionics ***Contingencies***	ADS/ B SSR Mode S RDR/ ADS integration Avionics ***Contingencies***	ATM operational concept ***Contingencies***

Chapter 4

RECCOMENDATIONS

4.1 FLIGHT CREW

4.1.1 Communications

The use of new communications systems will require that flight crew receive adequate training of their qualification in the use of state-of-the- art onboard communications equipment. Likewise, they should have a general knowledge on how the different components interconnect within the new COM environment. A flight crew qualified for the operation of the new on-board communications equipment must have received training and demonstrated competence in their management.

4.1.2 Navigation

Future navigation, mostly satellite-based, will require that flight crews have a thorough knowledge of the systems' operating principles. Training in the use of same should be well structured so as to ensure flight safety during the transition period. Their training should include a programme to enable them to use on-board satellite navigation equipment. A duly qualified flight crew should be trained to efficiently and safely operate the new satellite navigation systems.

4.1.3 Surveillance

The use of ADS (ADS-B Broadcasting) will provide, through data links, surveillance capability on oceanic airspace and continental routes currently lacking radar control services. Automatic transmission of aircraft position through the ADS will replace pilot voice position reporting (VPR), thus reducing the work load in the cockpit and enabling a reduction in the separation minima,, increasing flight safety and better accommodating the flight profiles preferred by users.
The flight crew must be familiar with the operational principles of ADS/ADS-B, as well as with the limitations inherent to the system.

4.1.4 Air Traffic Management

It is expected that the ATM, in its final concept, will permit flight crews to dynamically select the flight path according to their needs, based on decisions supported by meteorological and traffic information, available services, etc. These decisions will be the result of the crew's processing of the information received and constantly updated by modern data link equipment, which will be the cornerstone of all these future systems. Consequently, the flight crews will need to be fully informed on the use and limitations of these systems.

New equipment manufacturers will also have to bear in mind the feedback that users may give in the design process of the systems.
Due to the complexity and the great number of different equipment that will be necessary to operate under the ATM concept, aircraft operators will have to take special periodical training measures for the flight crews to keep updated in their use.

4.2 AIR TRAFFIC CONTROLLERS

4.2.1 Communications

Air traffic service providers should bear in mind the training that will need to be provided to their air traffic controllers in relation to control using the new communication systems. An air traffic controller duly qualified to operate the new communication systems should have received training and shown proficiency in their use.

4.2.2 Navigation

Air traffic service providers should give air traffic control personnel the necessary training to maximise the benefits offered by GNSS and its augmentations. A duly qualified air traffic controller should have received in the training programme orientation with regard to the operation of the new navigation systems.

4.2.3 Surveillance

Air traffic service providers should give air traffic control personnel the necessary training to maximise the benefits offered by ADS and other future surveillance systems. A duly qualified air traffic controller should have approved a training course with a structured programme on the operation of the new surveillance systems.

4.2.4 Air Traffic Management

Air traffic service providers should give air traffic control personnel the necessary training to maximise the benefits of the new C, N and S systems, in order to optimise air traffic management. An air traffic controller should have approved an ATM introductory course that includes a thorough understanding of the operation of the new C, N and S systems.

4.3 TECHNICAL PERSONNEL

4.3.1 Communications

The new communication systems will extensively use data link technology and, as such, the technical preparation of personnel supporting these systems will be critical. Air traffic service providers should take steps to keep their personnel trained in the installation and maintenance of same.

4.3.2 Navigation

Air traffic service providers should bear in mind the training to be given to their technical support personnel with regard to installation and maintenance of the new augmentation systems, including on-board equipment. Technical support personnel should be trained in electronics for the efficient installation and maintenance of ground and on-board navigation equipment based on the GNSS and its augmentations.

4.3.3 **Surveillance**

Air traffic service providers should take into account the training to be given to their technical support personnel with regard to installation and maintenance of the new surveillance systems, including on-board equipment.

4.3.4 **Air Traffic Management**

Air traffic service providers should bear in mind the training to be given to their technical support personnel with regard to the installation and maintenance of all systems and equipment supporting the ATM concept.

4.4 **GENERAL RECOMMENDATIONS**

4.4.1 **Selection of instructors**

The instructors selected for the "Introductory course to CNS/ATM systems" should have, at least, five years of experience in any of the areas concerned, vouch for a course on training techniques or its equivalent, and have a sound background in CNS/ATM concepts.

4.4.2 Current status of the National Implementation Plan

The student should be well acquainted with the reality of the organisation to which he/she belongs, as concerns the National CNS/ATM Systems Implementation Plan.

4.4.3 Schedule

The schedule will be defined on the basis of the professionals who will receive the training. Each State, through its corresponding Training Centre, will have the faculty of assigning the number of hours it deems advisable for the different training levels.

4.4.4 **Evaluation**

It is recommended that, at least, two written mid-term evaluations and one final, be given.

SECTION III

"IMPACT OF CNS/ATM AUTOMATION ON HUMAN RESOURCES"

PREFACE

Currently, a great number of new Communications, Navigation, Surveillance and Air Traffic Management (CNS/ATM) systems are being proposed to improve aviation globally. These systems are recommended for it is felt that they will produce significant changes, including:

- *more information;*
- *greater precision of available information;*
- *reduction of work load for human operators.*

If these changes are actually introduced, more efficient operational procedures will be implemented, thus improving operational safety. Therefore, the Free Flight concept, allowing pilots to more freely determine their flight plans, will be closely linked to the successful introduction of the new CNS/ATM systems.

Nevertheless, the use of these new systems could bring about new types of human error. While some of them will be reduced (for example, the introduction of data links could reduce errors in the reception/collation of messages), the possibility exists that other errors arise, some of them resulting from the design of the new systems.

As detailed in this Section, many errors could be due to an inadequate presentation of the information (for example, a deficient man-machine interface). These types of errors can be related to the amount of information presented (in the event that same is greater to what the human operator can understand), the way in which it is presented (if it is difficult to interpret properly), if the human operator does not understand the "intentions" of the system, and if the human operator cannot remember, due to the many options, the meaning of the various operation codes (for example, if a code in a graphical display indicates that the aircraft is being surveilled through the use of ADS, or if another code shows that the aircraft is still not in radar contact, etc.).

Errors could also be caused by an unforeseen use of the new systems, surely one not envisaged by the designers. For example, an air traffic controller using a new system in a manner not contemplated during training could enter into unexplored territory, since the designers may have not taken into account all the possible variations in its use.

Another problem analysed in this Section is the possibility of a negative reaction by human operators to these new systems. The reasons for such a behaviour could be, inter alia, the concern for job cutbacks, lack of confidence in the precision of the proposed solutions (in the case of systems that support decision-making), over-dependence on automation, or fear of change.

This Section identifies some basic stages that civil aviation administrations could follow to reduce such negative reactions. Special emphasis is placed on training as a means to get operators acquainted with the operation and advantages to be derived from the new systems, through an efficient management of same.

Meanwhile, it is advisable to use experienced instructors; problems such as the following could arise:

- *most instructors would not have the required experience, more so being recently incorporated systems; and*

- *a greater number of operators would need to be trained in a limited period of time, without the possibility of counting with instructors highly experimented in the new systems, due to the aforementioned reasons.*

To correct these deficiencies, it is suggested that the "train the trainer" methodology be applied, whereby a group of highly experienced instructors trains a small group of controllers from a given unit, who will then train the rest of the controllers.

Supposing that, at least initially, a small number of instructors trained in the operation of these new CNS/ATM systems will be available, the training programmes should be rather simple. Also, the operational procedures should be widely tested and detailed beforehand, for which training should not only emphasise how they work, but also how they should be operated, in order to achieve the originally planned benefits.

Another way to reduce negative reactions to these new systems and diminish (but not eliminate) the possibility of finding unknown errors, is to allow human operators to participate in their development. Also, the use of certain techniques, such as highly realistic operational simulations (to demonstrate the new interfaces) and maintenance simulations in the chain of events (to permit human operators to compare alternate designs and develop operational procedures), will surely improve the quality of the end product and, at the same time, increase the human operator's confidence. For example, the knowledge that other colleagues are participating in the development of a new system could increase the level of confidence of the other controllers.

Finally, despite the efforts made to the contrary, it is likely that civil aviation administrations will encounter such resistance. Consequently, it should be anticipated.

While it would not be possible to completely avoid it, the uncertainty of human operators should be soothed through:

- *designs fully tested and approved by the human operators;*
- *intensive training; and*
- *seminars for disseminating the purpose of the new CNS/ATM systems.*

To achieve the aforementioned, a first, but not least important, stage is to consider human factor aspects in the development of the new CNS/ATM systems.

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Chapter 1

INTRODUCTION

The factors directly or indirectly involved in the CNS/ATM systems that affect human resources, as highlighted in this Section, are varied and some of their consequences unpredictable or simply still unknown. Such diversity and lack of knowledge prevent the establishment of specific mechanisms for eliminating or lessening their impact on human beings. For that reason, this Section contains general information based on professional experience that will help the States to implement local policies to accomplish the desired purposes.

One of the benefits of implementing the CNS/ATM systems in the CAR/SAM Regions will be the establishment of areas where air traffic will be managed in an efficient, seamless, homogeneous, safe, and reliable manner, in such a way that the user will not perceive the physical boundaries between States.

The implementation of CNS/ATM systems entails, from the very beginning, the introduction of automated techniques aimed at their better management, understanding that one of the impacts of such implementation is the so-called "resistance to change".

The introduction of the new technologies available to human beings for the provision and reception of services has many times caused confrontation and an involuntary resistance to change because of a fear of the application of automated systems, which are only intended to provide a safer and more reliable service. It should be borne in mind that technology that relies heavily on automation, while keeping the operator in an important position, helps to prevent incidents and accidents.

The systems in use today are operated by human resources that are, on average, highly experienced in their management. When the migration to the new CNS/ATM equipment described in Section I of the Guidance Manual takes place, a process of training in the new equipment should be started in order to standardise the knowledge of existing experts and those being trained. It is during this transition period that States should invest decidedly in providing the human resources related to aviation and operational services with training in the use of these technologies.

It should be kept in mind that there are papers by eminent experts on the subject, which were consulted in drawing up this Section, to help not only flight crews, traffic controllers and technical personnel, but also Civil Aviation Administration executives in the CAR/SAM Regions understand this important aspect. Since they are the decision-makers, they will be able to provide direct and timely support that will make it possible to continue with this aeronautical development consisting of the implementation of the new technologies for the XXIst century.

Chapter 2

GENERAL INFORMATION

In the transition to the CNS/ATM systems, the participation of human beings should be taken into account, assuming that they will be in charge of the safe and efficient operation of the systems. To that end, it is necessary and advisable to have information available that will allow them to perform their activities appropriately.

Human resources will play a very important role in the implementation and subsequent use of these systems and it is therefore felt that their involvement in the different stages of such process will ensure that the planning and implementation phases are carried out in a better way. According to the experience with similar transitions to the new systems in different parts of the world, their involvement will also facilitate their adaptation to the new technologies and the chances of error or failures will be reduced.

The corresponding training will help to minimise the impact of changes in technology and processes, in an effort to avoid failures. Training of itself will not guarantee that such failures will not occur, inasmuch as other, closely linked elements are involved, particularly as regards human factors, and for that reason not only the skills, but also the attitudes of the personnel should be addressed.

To achieve this, it is absolutely necessary for the members of the different organisations to be aware of their own responsibilities. Consequently, a awareness-raising phase should first be defined, followed by a CNS/ATM training programme aimed, among other things, at attaining a proper knowledge of those technologies so that, irrespective of each person's area of specialisation, knowledge will be standardised. All of this will contribute qualitatively to the planning and implementation processes.

As a result, the impact of the automation inherent in the new technologies on human resources will be reduced and will not involve a regression but, more likely, a step forward.

Chapter 3

HUMAN FACTORS

"Will automation always be beneficial? ***Data obtained from experiments in which performance controls and work load measurements were used, showed that many automated systems will not be used as intended, or will just not be used, especially when the work load is heavy."***

(Jorna, 1997)

3.1 PRELIMINARY CONSIDERATIONS

Air traffic control is made up of many complex subsystems; it is affected by weather conditions; it is also operated by different human beings (each one with specific behaviours), with the latent possibility of making mistakes. The end result is a system with many minor discrepancies and possibilities for potential errors, most of which never become incidents--due to the influence exerted by human operators as a result of their ability to adapt to different situations.

The existing Air Traffic Management (ATM) system is broad-based, complex, and almost organic, and human interactions are the glue that holds it all together. Controllers and pilots handle and manage not only complex subsystems in real time, but also the inherent risks through adaptable and flexible interactions at critical moments. These factors add to the complexity inherent in the development and design of the new CNS/ATM systems.

The fact that these systems have some components that are closely united and others that are not so much adds to the complexity of the task of defining, designing, and implementing changes aimed at increasing the capacity while maintaining the required safety levels. It is this desire to obtain more capacity that is driving the transition. Inasmuch as human beings are at the centre of this process, as already stated, it may be inferred that the migration to a system capable of accommodating larger volumes of air traffic will be accompanied by major changes in the role played by human operators and, hence, in the tasks they perform.

3.2 INCORPORATION OF HUMAN FACTORS

The study of human factors is a key element in determining how best to manage the changes that will take place in the role of the human operator in order to accommodate larger volumes of traffic while maintaining the required safety levels.

The role played by human factors in the development of these new systems should not be limited to a modification of primary design characteristics in order to obtain their acceptance by users. If the rendering of human capabilities (and their limitations) is not taken into account from the very beginning of the concept definition, designs may be created that are not fully appropriate, thus seriously jeopardising the productivity of the entire system and it could also affect operational safety to some extent.

Experts in human factors should be members of the interdisciplinary teams responsible for developing and designing the new CNS/ATM systems from the very beginning of the development stage, so as to factor in both the strengths and the weaknesses of the human subsystem in the final design. In fact, such experts will act as intermediaries between the designer and the end user.

It should be noted that sometimes these end users tend to become atypical because of their participation in the development process and, for that reason, periodic reapplications with more representative end users will be required.

The multidisciplinary design teams should work in close coordination throughout the development process, which includes the formulation of the initial concept, analysis and assignment of functions, preliminary design, development of the first prototypes and system evaluation, with special emphasis on the verification of the provision of human services.

3.3 HUMAN FACTORS IN THE IMPLEMENTATION, EDUCATION, AND TRAINING

The participation of human factors should continue beyond the design stage into that of implementation. There is a tendency to allow the end user to make modifications to the final design in order to facilitate the implementation. This should be carefully controlled through the participation of similar numbers of human factor experts and end users. It is very easy to lose all or part of the effectiveness sought in the original design concept by making final modifications that are out of balance or that are based on an inadequate processing of the information, which could lead to a loss of efficiency and, maybe, safety problems.

The new systems require fully developed implementation plans, which includes the training of operators in the logic, capacity and rationality of said systems, as well as a clear statement of the role they will play in the overall ATM system.

The operators of a system will also tend to consider the changes or modifications in the design as resulting from or constituting improvements in existing operational practices (used in the equipment in operation today) and could fail to take into account the need to incorporate new or different tasks or procedures in order to obtain greater productivity, thereby improving safety levels.

In the absence of a positive and proactive training programme, there is the possibility that old attitudes and working methods will be passed on in what is known as negative transfer.

In developing an implementation plan, special attention should be given to the possible transfer of working habits used in the old system, which, if continued in the new system, could seriously jeopardise efficiency and safety. That negative transfer becomes very apparent when operators have a heavy work load.

3.4 SYSTEMS TO SUPPORT HUMAN OPERATORS

Systems to support human operators cover different types and levels of automation, aimed at facilitating decision-making.

3.4.1 Systems to support decision-making

When designing automated collaborative decision-making tools, the capability of explicitly showing human operators the limits of the system insofar as operating conditions are concerned should be included among the operational options. Human operators should not be tasked with finding out or surmising on their own the status and limitations of the system, especially under exceptional conditions when they must undertake the functions that the system should have performed automatically but which, for some reason such as a failure, for example, it is unable to accomplish.

The most important aspect to be kept in mind in considering these collaborative tools, especially in automated systems that create their own action plan (in an effort to help human operators process the data that is available to them), is how to keep human operators informed about the system plans, especially if said human operators are the standby "system".

The effectiveness of collaborative decision-making tools, therefore, will be limited unless they know the *intentions* of pilots and controllers. The advantages of these automated systems are based on a sharing of intentions and the subsequent formulation of a corresponding action plan.

3.5 INTENTIONS

The word *"intentions"* is used to describe the picture that is held of the future; it is through such intentions that an effort is made to foretell the future. Consequently, intentions involve prediction and predetermination elements.

Airborne technology has reached such a state of development that it is possible to predict the future, from the viewpoint of the aircraft, with a high degree of probability. This is achieved through the Flight Management System (FMS), which ensures that predictions become a reality and ensures conformity. With the FMS, future situations become attainable goals.

Intentions are not limited to the aircraft and its planning; they are also an important aspect of the management method used by controllers within their areas of responsibility. The intentions of the controller are a projection in time of the dynamics of the present situation, with an identification of where modifications should be made to ensure safety and comply with pilot requests.

Air traffic control takes place mainly through the controllers, who combine all the individual intentions of pilots with their own, contained within a broad action plan, and who act as arbitrators when such intentions are in conflict. Thus, information on intentions becomes a requirement which each pilot and controller seeks to fulfil.

When controllers speak of "having an overview," they refer not only to the existing situation and how it is expected to develop (their intentions), but also to the future action plan: they are fully aware of the situation.

Currently, the intentions of controllers exist only in their own minds. Ground-based collaborative decision-making tools need to know the controller's intentions in order to help execute the tactical plan.

These aspects are harder to solve in the airspaces under the responsibility of Approach Control and the Control Tower because of the specific nature of the operations that take place therein. Controllers serving in these units process many decisions in short periods of time and tend to have a heavy work load of mechanical tasks.

This places heavy demands on collaborative decision-making tools designed for use in those airspaces, particularly with regard to the work load and maintaining situation awareness.

3.6 STRUCTURE-ORIENTED AIR TRAFFIC MANAGEMENT

More potential conflicts arise in a terminal area airspace than in the long-range cruise flight phase because of the uncertainty over aircraft vertical performance and the lack of appropriate information about air traffic intentions. It is potential conflict that increases the work load of controllers. Whenever aircraft are ascending or descending on paths that could exceed separation minima, the need arises to manage uncertainty through surveillance (radar equipment/ADS) and, perhaps, through the direct involvement of the human operator (controller), until traffic is no longer a factor.

The response of controllers (as determined by existing regulations) to an increase in traffic volume is to impose some type of structure on the traffic flow within the airspace under their responsibility. The imposition of different kinds of structured restrictions is an attempt to manage the complex task of controlling many pilots, each with different demands. As traffic load increases, controllers tend to vary their way of operating, going from the processing of individual requests to the accommodation of each aircraft within a given structure.

Examples of this would include:

ATS routes/airways, standard instrument departures and arrivals (SIDs/STARs);

letters of operational agreement among the different air traffic control units; and

the imposition of flow controls for a given portion of airspace.

The favoured strategy today for reducing the work load generated by conflict prediction/resolution is to direct air traffic toward the aforementioned structures.

Lastly, before implementing any plans that call for removing or modifying any of the structures being currently used to handle uncertainty, there must be an understanding of the way in which controllers evaluate and manage uncertainty.

A proper knowledge of human factors is required to determine the possible impact of modifying airspace structure with reference to a system (*e.g.* CNS/ATM systems), which will have less structure than the current one.

Chapter 4

LIKELY IMPACT OF AUTOMATION

In 1801, José María Jacquard developed an automated loom operated by punch cards similar to those used in offices up to 35 years ago.

The workers, who had become extremely skilled in carding and weaving, were suddenly confronted by a completely new technology that was capable of doing their work faster and with a higher level of precision.

The fear and frustration caused by such automation reached such a pitch that by 1811 the areas around Nottingham and Lancashire in England were the sites of violent riots in which mills and machinery were destroyed.

This reaction has occurred over and over for more than 200 years every time that machines of different kinds, like automobiles, railroads, computers, and robots, have for ever changed the way human beings work.

Carrying our example into the area of the new CNS/ATM systems, we will start our analysis from a common premise: automation, an integral part of the new systems, enables a better and more effective use of the capabilities offered to us.

Therefore, it is necessary to be fully aware of the impact, at both an operational and managerial level, that automation will have on human resources, which include the decision-makers for the planning, procurement, and implementation of the new equipment.

The migration to the new systems should be accompanied by a thorough preparation of human resources, providing them with appropriate training and sufficient motivation so that during the transition period they are duly aware of what is happening and human beings (us) are not bypassed in the sequence of events.

Planners should be aware that the introduction of automation represents a major change for a large number of the operational personnel and that, contrary to what some may think, this process does not reduce training requirements: human beings must surely continue to know how to operate complex systems, including those that are highly automated.

The necessary training to prepare us for this change should begin as soon as possible, by providing a basic knowledge of computer science and automation. It is frequently the case that experienced personnel who are being instructed on how to operate the new equipment, with the inevitable element of automation involved, will resist the change. This is another challenge that planners must anticipate and face.

Below, we will briefly discuss some of the aspects to be considered in addressing this issue, namely:

- the human-machine interface;
- situation awareness;
- information processing; and
- psychological impact.

4.1 HUMAN-MACHINE INTERFACE

CNS/ATM systems use state-of-the-art technology, which includes a considerable number of automated devices.

Those in charge of planning and implementing the CNS/ATM systems could draw from the broad experience of the aeronautical industry in introducing new technology, which dates back to the introduction of aircraft equipped with advanced cockpit systems. That experience could be transferred to the CNS/ATM field with highly beneficial results, for important lessons could be learned from the studies of the impact on pilots (human beings) of the automation of advanced cockpit system, in order to improve such situation with respect to CNS/ATM systems.

A number of problems related to the human-technology interface arose during the introduction of such aircraft. The problems were of such a dimension that experts in that area initially proclaimed that the design of said automated systems could be a factor leading to accidents.

4.1.1 Aspects to be borne in mind in considering human-machine communication

It was only after analysing that statement to determine its validity, based on a host of operational statistics, that the conclusion was reached that the degree of communication between human and technology could be behind all of these events.

The following conclusions were reached:

- the technological design contained no inherent error;
- most of the communication problems between human and technology were due basically to defective interfaces; and
- the proper moment for resolving interface problems is during the stages of design and certification of the new equipment.

4.2 SITUATION AWARENESS

One of the most important elements with regard to human resources and technology is the ability of the human being to keep abreast of the situation and the system, an ability that is known as situation awareness.

A key aspect of situation awareness is the ability to know when to act and then to identify the act itself if so required.

In order to perform their task, air traffic controllers generally formulate a “tactical plan” (planning), which is then carried out and which can be modified in real time.

For such planning to be effective, sufficient information must be available for processing in due time. If such information is not available or cannot be accessed, the tactics should be changed. This capability of identifying what should be present but is missing should be a function built into the design of the collaborative tool; if the information necessary for decision-making is not available, some type of warning should be activated.

The whole matter of situation awareness--what it is, where it comes from, what information is needed (to support it), etc.--is not yet fully understood. The incorporation of a collaborative decision-making tool into an environment of uncertainty, as would be the case if the equipment were unable to process all the variables affecting a given operational situation, is an option that should be approached with great caution.

4.2.1 Mode errors

A secondary consequence of a poor understanding of the situation is a mode error. Mode errors are defined as failures in the overall person-machine system, whereby the human being stops understanding the existing configuration of the machine, and the machine interprets the operator's instructions differently from what is expected.

If the interface is not user-friendly, the system operator must take a long time to create an adequate mental model of the situation and of the current status of the system. This can generate a loss of situation awareness, preventing operators from deriving all the benefits from the automated equipment available to them.

Consequently, human factor problems that arise during the start-up and operation of the new CNS/ATM systems are due mainly to human-equipment interface problems.

4.3 INFORMATION PROCESSING

"System designers, regulators, and operators should recognise the existence of an over-dependence (on automated devices) and should fully understand its causes and consequences."

(Parasurman, 1997)

The human-machine interaction, which in the final analysis will determine the effectiveness of using automated devices, will depend upon how the information available to human beings is processed.

It al begins when the human being generates sensorial pulses and mentally processes all the information within reach. The following level is that of decision-making: the most appropriate option will be chosen from a host of options.

The degree of interrelationship between the human being and the automated device during the cited information gathering process can range from an absolute disregard of those devices to considering them flesh and blood persons.

Automation can also frighten people because of its apparently complex functions. This is even worse when the individual does not know how automated devices operate and the improvements that may be achieved through their rational use; in that case, people will tend to ignore it.

At the other extreme, people may believe that automation (through its different functions) is able to "think" on its own and perform more tasks than those for which it is programmed. In that case, they will rely on automation in detriment of the processing of the available information. We must not lose sight of the fact that automation is a servant that obeys all orders, bar none; no more than that should be expected.

It is clear that such automation brings about a response in controllers and pilots that is very similar to that of other beings, generating a growing dependency on it. This has a strong impact on how the role of human beings evolves in air traffic control systems.

This dependency can feed not only on growing trust in the system, but also on a lack of knowledge of how it works without such automation. Therefore, it is the new operators who, lacking the skill and experience of the more experienced operators, are more likely to rely heavily on such automated functions. This growing dependency can work against the human operator, particularly if the system is degraded, such as when there are failures, errors, and different contingencies.

It is essential to consider that dependency not only during the development, design, and implementation stages, but also during the certification procedures, when the availability, reliability and redundancy of the new systems are evaluated.

As a compromise between the two extremes described, the point or moment as of which the human being is most likely to interrupt the processing of available information should be identified. This could bring about unfavourable consequences, for this could be a quick and easy way to lose situation awareness: where we are, what the machine is doing, where we are going.

This can be aggravated by the fact that we, human beings, are poor supervisors because, among other things, we are easily distracted, our concentration is frequently interrupted, and we get bored unless we remain active.

Our minds can analyse, extrapolate and distinguish new ideas, but we can only interpret and think about one thing at a time. Furthermore, we cannot process very large amounts of basic information in a short period of time; nor can we perform complex tasks in a limited time frame.

As a result, the more automation there is, the less manual tasks have to be carried out. It should be kept in mind, however, that during critical situations (for example, when the controller is communicating with several aircraft and establishing different types of separations, providing radar vectoring, etc.), mental activity can become overloaded and memory saturated. This would bring about the paradox of apparent (manual) inactivity, while mental work load approaches a saturation level.

4.3.1 Possible solutions

But how are we to make sure, from the managerial viewpoint, that our human resources will have an optimum performance in an automated environment, particularly those who will be making the transition from a previous generation of air traffic control systems?

There are basically three ways to accomplish this:

- by bearing in mind the many factors that can affect the work of a person in an automated environment;
- by changing our opinion about automation, no longer considering it frightening, but helpful in following the proper sequence of events so that the benefits of such automation be used realistically and appropriately; and
- by modifying and expanding training programmes to encourage efficient and safe use of automation.

4.4 PSYCHOLOGICAL IMPACT

Before delving into the psychological impact on human resources of the implementation and start-up of the new Communication, Navigation, and Surveillance and Air Traffic Management (CNS/ATM) Systems, it is necessary to state the mission of the aeronautical authority, which may be known by different names in the various countries (Civil Aviation Bureau, Federal Aviation Administration, etc.), although the mission it fulfils is basically similar, to wit: *"Planning, regulating and controlling civil air navigation in a given territory, as well as building, operating, and maintaining airports, aerodromes, heliports, and other services and facilities, in order to raise air traffic safety levels and promote the development of commercial and private civil aviation. That aeronautical authority should also support the establishment and operation of training centres in the different areas of specialisation that constitute the aeronautical professions. Lastly, it must apply and control the standards and procedures that will ensure effective flight protection, as provided for in the different standards and regulations in force."*

That mission covers all branches of civil aeronautical activity and, for that reason, human resources are a key element in each one of the aeronautical processes, both present and future. It is on the basis of this notion that people form part of organisations and the study of those persons is the basic element for understanding those organisations.

In order to gain a better understanding of such possible impact, it is necessary to briefly describe the present status of air navigation and the new trends in that field.

Currently, aircraft obtain their position from ground-based navaids, such as VOR, DME, ILS, etc. Position reporting is done through a voice communication channel (VPR), while its movement is observed on a graphical display (radar screen) by the air traffic controller.

The different areas of specialisation or technical positions are present in all of these processes and, in one way or another, contribute to the attainment of the desired results. These may be grouped into three large non-exclusive areas:

flight crews;

air traffic controllers; and

technical support personnel.

In addition, the existing CNS systems have many limitations, among them, range problems, the impossibility of placing them in remote sites, frequency saturation during peak hours, etc.

The new technology, based mainly but not exclusively on advanced satellite systems, is here to overcome these shortcomings. These systems have their own processes and navigation aids which are quite different from the existing ones, thus substantially changing air traffic management.

Staffing will be reduced with the introduction of highly automated processes, while satellite navigation will permit the phasing out of ground-based radio aids, with the consequent reduction in the number of technical personnel assigned for their maintenance.

This major step of migrating from traditional systems to other highly innovative and, above all, safer ones, bears with it a countless number of changes in existing processes well established among human resources. Thus, the desired change in culture will be extremely laborious, since, as expected, job positions will change, new ones will appear, others will disappear, completely different processes will emerge and the organisational structure will change substantially in order to adjust to the new expectations of users.

4.4.1 Alternatives to consider

Two alternate approaches should be considered for properly dealing with human resources:

1. study them as people, endowed with a personality, individuality, aspirations, values, attitudes, motivations, and individual objectives; or

2. study them as resources, endowed with abilities, capabilities, skills, and knowledge that are needed to perform the assigned tasks.

Consequently, it is understood that the first point, which is closely related to the psychological aspect and will most likely be affected by the implementation and start-up of said systems, must be defined or clarified. Thus, we must take special account of aspects of personality, individuality, values, motivations, etc.

4.4.2 Assumptions

We shall analyse two basic assumptions in order to understand possible human behaviour in the face of the implementation of the CNS/ATM systems within an organisation:

1. Human behaviour is derived from all events that coexist around it, which, in this particular case, are related to the processes resulting from the introduction of the new CNS/ATM systems; and

2. These coexisting events have the nature of a dynamic field, called the psychological field, where each part depends upon its dynamic interrelationship with the other parts.

This psychological field constitutes the vital environment, which encompasses the individual and its psychological environment. The psychological or behavioural environment is what the individual perceives or interprets as the external environment (in this case, the CNS/ATM technology) but, more than that, it is the environment associated with his/her existing and future needs.

The new CNS/ATM environment, with all the systems it contains, could acquire values in the psychological sphere and determine a dynamic field of psychological forces. The value is positive when it can or seeks to meet the needs of the individual, and negative when it can or seeks to cause some damage.

We believe that the implementation of such CNS/ATM systems will be charged with positive value, for it will tend to attract the individual. However, consideration should also be given to those specific cases of some human resource components, where a negative value could exist, inasmuch as they could reject or adapt poorly to these systems. Attraction is a force or vector aimed at the object (CNS/ATM), person, or situation, while rejection is a force or vector that spurs a retreat in an attempt to escape from the object, person, or situation.

In keeping with the foregoing, the implementation of these cutting-edge systems will create vectors that could generate a movement in either of the two cited directions.

As explained in the previous paragraphs, it is estimated that if the safety of air operations and the guarantees offered by the new CNS/ATM systems are placed before their possible psychological impact on our human resources, this latter consequence will not be too significant, although this will depend upon how many elements of the menu of new technologies each State adopts, a matter that has not yet been fully defined.

Human beings, by nature, fear change and the new CNS systems involve a major change in the equipment and the ways it is used. They will also make it necessary for people to change their behaviour, for if we conceive human beings as such, they resist new situations, from conception itself, through birth, childhood, maturity, and death. Transferring this to the workplace, this resistance to change will be defined as any disruption in a work situation or environment.

It is anticipated that the new systems will generate antagonistic feelings in human resources, such as suspicion, mistrust, and also fear, since the application of these new systems involves entering uncharted terrain. This could also be accompanied by a feeling of insecurity with respect to change, expressed through individual insecurity and a loss of self-confidence; this will enable us to measure how flexible or adaptable our organisation is.

Other features within the psychological aspect that could affect human resources are the cultural beliefs and rules of behaviour that emerge in any organisation; these include cultural beliefs related to the need to perpetuate certain practices that influence the attitudes of people. Feelings of trust and loyalty related to the change depend largely upon the trust placed in superiors, co-workers, and the organisation as a whole.

Our human resources will respond in different ways when confronted by these situations arising from the implementation of the new systems. These responses will range from acceptance (expressed through cooperation and enthusiastic support), through reluctant cooperation under the pressure of superiors, to passive resignation. Other possible responses could be indifference, apathy, or loss of interest in the job, as reflected in the performance of only those tasks that are specifically assigned.

Other behaviours that could arise include passive resistance (encompassing regressive behaviour, failure to learn, protesting, working by the book, etc.), as well as active resistance (doing the least possible work, reducing the pace of work, personal withdrawal, mistakes, damage to equipment, etc.).

Based on the foregoing, and assuming that the culture of human resources in each organisation is known in advance, and in the understanding that opposition to change should be minimised, efforts should be based on a process which considers the possibility of active and total resistance, moving through more passive and subtle behaviours, to indifference, so as to finally induce them to acceptance. In any case, the safety of air operations should always prevail, although human resources should at all times be considered the heart of an organisation, in the understanding that they are proactive beings, who seek effective results.

4.4.3 Suggested courses of action for the transition (in the psychological area)

The constant and dynamic world of aviation requires that organisations continuously seek mechanisms for improvement and development; to that end, it is essential for human beings to be conceived as the basic pillar of their structure. Unfortunately, this notion has not been fully assimilated by the leaders of some organisations, particularly in the West. On the other hand, Eastern organisations view people as basic entities of development and this approach has enabled them to raise their levels of efficiency, productivity, and motivation, thereby generating a logical job satisfaction and better standards of living. We understand that each State should assimilate these experiences so that it can face up to the major challenge of implementing the CNS/ATM systems.

The success or failure of the new CNS/ATM systems will depend largely upon human resources, who, at times, carry with them a culture that will have to be modified to accept and embrace the new vision of the organisation with all of its processes, inasmuch as it encompasses behavioural, emotional, and cognitive aspects reflecting the overall psychological operation of the group or organisation.

The change that the transition to the new CNS/ATM systems will bring about in human resources, particularly with regard to the psychological and cultural aspects, constitutes a process of creative reorientation: the change does not start with the new, but as of the moment the old systems begin to be shut down.

4.4.4 Implementation stages

In order to guarantee an optimum migration, all the States should join efforts to coordinate the implementation, so as to effectively attain the expected results. It is understood that this change will not take place suddenly, but will be a gradual migration with three basic stages, that will affect human resources in different ways.

The first of these stages is marked by the initial deactivation of the traditional systems. In the case of navigation components, this would begin when the first ground-based radio aids are removed from service, with the resulting emotional burden of evaluation and mourning, inasmuch as this will inevitably involve changes in the processes, jobs, functions, tasks, etc.

The second is the intermediate stage, applicable to the period during which the two systems operate in parallel. This is perhaps one of the most difficult periods, which has often been compared to being in no man's land, as having no firm grounding. It is during this stage that the old rules no longer apply--at least as a whole--, nor the new ones, although specific guidelines may exist.

The third and last stage of the transition period is the change itself, the new beginning, the innovation. This stage must be duly planned down to the last detail in order to reduce most of the impact it could have on our human resources.

Although the transition to these new technologies is being planned with great care, with emphasis on its technical aspect, the area of human resources must not be neglected, particularly the psychological and cultural factors involved. By way of example, it could be said that we know the port we want to reach, but do not know how to process the meteorological information to have a full knowledge of the weather, how to guide the ship in order to avoid the storms, the condition of the ship before beginning the journey, etc.

The unavoidable preparations should revolve around the analysis of the organisation from the viewpoint of the changes to be made and the projection not only of the sequence of said changes, but also of the transitions that will be needed for those changes to take place. This process must be very objective, for the strengths of the areas involved must be enhanced and the weaknesses reduced so as to assess their readiness and flexibility to face the coming changes.

The individuals and groups that will be affected by the changes will be identified here. It is understood that the technical changes that could occur must be made clearly known in order to project the psychological aspects, so that these will not constitute an obstacle but, rather, a driving force that will help us attain the desired objective, which is the implementation of CNS systems.

To that end, the new skills and knowledge required to begin the transition must be identified and then the training programmes for providing them created or acquired. The existing communication channels will be reviewed and the necessary changes made so that the human resources are duly informed and appropriate settings will be created to receive their comments so that they are properly taken into account; this is an ongoing process. The system of incentives must be reinvented in order to recognise those human resources that act in keeping with the demands posed by the new situations that arise. Plans must also be made from the beginning to celebrate the different phases of transition, not only the major landmarks, but also the small accomplishments, as true indicators that we are moving ahead on the expected course.

Even if the transition stage is planned down to the very last detail, it will not be possible to foresee all the effects of change or the reactions of individuals or groups, especially in the psychological aspect. For that reason, each organisation should have a Transition Planning Committee made up of members of the different areas representing the various levels of activity, whose basic function will be to remain alert to the changes, so that all human resources are properly advised about them. In short, the aim is to keep morale high in an effort to reinvent organisational culture. To do this, this Committee needs the support of top management and the recognition of all the members of the organisation.

This type of activity requires that the directors, bosses, and managers have an adequate level of awareness so as to understand and accept the fact that the new CNS systems, which they assume are better than the existing ones, may not be so understood nor accepted by the human resources involved. It is basically a matter of understanding the uncertainty, fear, or anger of individuals, while patiently orienting them toward the future so that they stop considering changes as definitive. These top and mid-level managers must resort to their inter-personal communication skills to get the necessary feedback and handle objections and resistance, so as to guide human resources towards the future changes.

A key task of management will be to review what has been done, assess whether or not it works, in order to make the necessary adjustments or changes, or to reapply it. An ongoing weekly review will make it possible to determine whether what was done was what had been agreed upon and whether it had had the desired effect. If so, it is reapplied and becomes a page in the success story. The latter is the clearest indication of the commitment to and respect for the culture that an organisation can receive during the transition process.

4.4.5 Learning

Learning is another aspect worth bearing in mind to reduce the psychological and cultural problems resulting from the transition to the CNS systems. It can be carried out mainly through four fields of action:

4.4.5.1 *Educational programmes*

These are prepared for the specific purpose of developing the knowledge, skills and attitudes of the participants, with a view to their subsequent application in their workplace, and should be carried out in an area within the organisation that is specifically used for training purposes.

4.4.5.2 *On-the-job training*

It should take place at the individual's own work environment and should be provided by someone who has been duly trained for that purpose.

4.4.5.3 *Development of human processes*

Systemic thinking, the technique of personal domination, mental models, the shared vision, and finally the technique of team learning--all required for the implementation of state-of-the-art technology--should be disseminated to favour learning.

4.4.5.4 *Design and implementation of information technology systems*

This should be done in order to capitalise, develop, and favour the use of knowledge in the organisation. It involves the search, collection, classification, interconnection, filing, distribution of and easy access to knowledge.

4.4.6 Integration between the workplace and educational activities

A concept that reinforces the synergy of the four aforementioned areas is the integration between the workplace and educational activities, where the following is stressed:

Putting working experience to profitable use as a basic source for the development of knowledge and skills to compound the exogenous incentives provided by the instructor and audiovisual teaching methods;

Applying the results of educational activity in the workplace--in other words, bringing about an effective change in behaviour in the workplace, the so-called "transfer to the workplace";

Selecting from among the knowledge and skills offered by the educational activity those that have true added value for the participant;

Identifying from among that knowledge and skills, those that are being effectively applied to the indicated degree--in other words, making a diagnosis of the real work situation as compared to the model proposed by the educational activity;

Based on this diagnosis, preparing a plan of changes that seeks specific measures for improving those areas that are worthwhile; and

Following up that plan and reflecting on the experience, thus reinforcing the learning cycle.

4.4.7 Summary

If the change has already been incorporated into the life of the organisation, as it should be, the challenge will be to make sure it reinforces the latter. To that end, it will be necessary to design transitions that will enable the organisational cultures to capitalise on their strengths, instead of wasting them.

We assume that organisations are intelligent, for the work problems today are those that will enable them to develop the necessary capabilities to resolve future problems. The idea is to maximise personal learning for the benefit of both individuals and the organisation as a whole.

If the proposed disciplines are applied as they should be, we will surely have an even stronger organisation, for not only will the personnel feel more satisfied and motivated, but we will also have taken steps toward the attainment of our objectives.

The proposal underlines the importance of personal behaviour and of inter-personal relations, in opposition to organisational change undertakings in which strategy, structure, and systems are basically involved.

Therefore, it is understood that the most appropriate approach will be a systemic approach that pays attention to both the architecture and the human processes and their mutual circular relationship.

Chapter 5

FINAL CONSIDERATIONS

5.1 RESISTANCE TO CHANGE

Resistance to change is a human phenomenon like any other. In the face of the "resistance" variable, several points are worth making:

> The concept of resistance to change in this particular context could be defined as *"any individual or group attitude or behaviour that is more or less unconscious and whose effect is, in the end, to obstruct, in order to impede the process of change"*.
>
> As a concept, resistance refers to behaviour or attitude, in the broadest sense of the two terms. This behaviour or attitude may be that of a group or of an individual, in cases where a single person emerges from a given collective, and so long as that collective expresses itself through that person. The unconscious condition must be explained by a duly trained external observer.
>
> There may be attitudes or behaviours that are consciously in opposition, but in that case the unconsciousness is not to be found in the resistance itself, but must be sought in the object towards which that attitude is directed. Why is that object being rejected? What does it represent for the individual or the collective in question? What particular kind of relational configuration is being updated?, etc.

In any case, the key questions for unveiling the mystery of resistance are, in principle:

> Why and for what purpose is this individual or group of individuals adopting this behaviour?
>
> What unconscious complicity is at stake in the hatching of this resistance phenomenon by all of the actors?
>
> What special meaning does permanent change have for this collective or individual?
>
> The updating of what element of the unconscious conflicts is being sought in this special relational configuration?

5.2 PARTICIPATION

"Participation is not only information."

Information is often confused with participation, but it is not the same. An organisation may keep its staff perfectly informed about its decisions and yet may not be participatory at all; in fact, it may even report down to the last detail and at the exact moment and still not care about the opinion of the staff. That is not participation.

Participation implies an opening of the decision-making process to the exchange of ideas and honest discussion before, during, and after the strategic decision is made. It involves a collective that is relevant to the process and, at the same time, broadly representative of all levels of the system and all lines of technical and professional opinion. The confrontation of ideas does not have to be pleasant. It is enough for it to be effective and efficient.

The collective construction of the strategic decisions of the organisation is a method that feeds on diversity and not on similarity.

5.4 INFORMATION PROCESSING

The process startts when the machine delivers data to the human element. This information acts as a spur to induce the human being to generate a sensorial, cognitive, and affective process between the reception of the stimulus, its processing, and the product, the motor and verbal response.

The human being transforms the data (input) into relevant information for decision-making (process by-products) so as to then generate the final product, which is the motor and verbal response.

5.5 AUTOMATION

Automation refers to a process whereby human resources, gradually or suddenly, decide to delegate to the machines all or part of the functions they had been performing on their own.

The definition given by the Oxford Dictionary which is cited in ICAO Compendium No. 5 on "Automation in the cockpit" (also applicable to air traffic control since both contain state-of-the-art technology) states the following:

"Automatic control of the manufacture of a product through successive stages; use of automatic equipment to save physical and mental efforts."

In other words, there is a prior decision by human resources to delegate to the machine all or part of the functions inherent in them. On the other hand, the end purpose is to reduce or attenuate the physical and mental demands of the process that is being automated.

All of the cases recorded to date cite as advantages of automation those already mentioned, together with the ensuing increase in effectiveness and efficiency resulting from such automated processes.

So we can do no less than applaud the interaction between technological development and the satisfaction of the needs of the systems that benefit from technology. The benefits are real and tangible.

5.5.1 Challenges posed by automation

In the case of aviation, this is obviously not the disappearance of jobs. On the contrary--and here perhaps the experience with human factors can prove very helpful--, jobs in automated environments tend to generate more professionalism and specialisation of the human resources and a significantly greater appreciation of the system.

5.5.2 Human-automation interactions

The main idea is to generate training and retraining processes for the technical personnel so that a link between the human element and the machine with as few imbalances as possible can be created. The human element and the machine should be able to interact to fulfil the objectives of the job, obviously more effectively than before automation. Interacting is not just any word and does not mean just anything. It is worth stopping to examine it.

The human element does not advance as rapidly as technological development. It is known that the human element needs to adapt to any process of change, even more so when changes are both significant and rapid.

If the transition periods between the beginning and the end fail to consider the limitations inherent in the human element, there will be no dynamic field of interaction between the machine and the human resource. There can be strong resistance, reluctance to use the equipment with its new tools, absolute dependence by the human element on the machine; in all cases, the possibility of a true interaction is hindered.

Retraining programmes, then, are aimed at allowing the human element to maintain its essential capabilities and competencies, although now these are also the capabilities and competencies of the machine. Under such conditions, the human resource and the machine generate an interface that is beneficial to the system, a delicate interface in which safety is dependent upon a successful human-machine link.

It is obvious that an automated system *"thinks and performs tasks on its own"*. What is not implied in this statement is that the human element must necessarily cease to think and to perform other activities that are qualitatively different; the human element does not have to, nor should become, an extension of the machine. In all cases, the two elements of the system, together with the software, the environment, and the group dynamics, should create a dynamic field as harmonious as possible, with only one purpose: **to maximise safety.**

5.5.3 Reasons for introducing automation

Automation is not the consequence of human mediocrity in performing demanding jobs. If we were to insist upon this assertion, we would be unfair to all the forerunners of aviation and its rich history.

Automation arose out of the need of the systems to be increasingly effective and efficient, an undertaking in which the presence of the human element is indispensable. Only the human being has the flexibility to resist, but also to adapt to changing situations. Machines cling with extreme rigidity to specific guidelines that drive their thinking and problem-resolution. It is the human being that is highly trained and therefore a good supervisor, who, together with the machine, determines in the final instance the result of the process.

It should also be borne in mind that if one or several of the interacting factors--the human element, machine, software, intra- and inter-group relationship--undergo a change, no matter how small, this will generate qualitative modifications in the rest of the factors, which in turn will have an overall effect on the system. It is these changes and their effects that we must be on the lookout for in an attempt to reduce those that work against the aims of the system.

5.6 THE CHOSEN SOLUTION

The most important solution is to design training and retraining programmes that protect the harmony of the interfaces foreseen in the SHELL model and keep the human resources in a condition to interact smoothly with the machine in an automated environment.

5.6.1 Other considerations

Some authors on modern management propose the concept of "*humanising management*".

If the future is change and this, in turn, is produced in the market, it can logically be assumed that it is generated by the individual.

By that token, three aspects should be considered in the process of change:

the pace, referring to the speed of the process of change;

the timing, which is the particular moment that said process starts up; and

the emotions involved in the management of human resources, which are the feelings within the context of the organisation.

It is possible to envisage an organisation in which the individuals themselves are the ones who make the changes required by the market, public policies, or the context, instead of merely talking about them. Therefore, the idea is to design an organisation in which, instead of accumulating proposals, decisions are made without trying to hide or distort emotions.

It is important for organisations, when designing their strategy, to incorporate pace and timing criteria, taking into account the emotional aspect as well as any other indicators. The organisation should be disciplined in regard to the choice of the pace and timing in the implementation of its strategy.

Modern management proposes the incorporation of emotions in directing organisations and people.

A farmer does not throw the seeds on cement and then water them because he knows that nothing will grow there. In order for his toil to yield the expected fruits, he needs fertile soil and inputs to carry out his activity. The fertile soil in organisations is the individuals who comprise them. This soil must be worked, fertilised, and left fallow when needed; it is the only possible terrain for the success or failure of organisations, particularly in times of change.

Finally, it should be noted that the new context in which we find ourselves requires a careful observation of the behaviour, attitudes, and skills of people (human operators); this means learning to appreciate their individual cultural, generational, or gender differences.

Chapter 6

RECOMMENDATIONS

One of the main objectives of automation should be to eliminate non-essential and secondary tasks, allowing the human being to concentrate on the more important ones.

Automation, through well-defined and known interfaces, should help the human being to achieve the objective of maximum operational safety and efficiency.

Any device, function, or equipment that tends to replace the human being,, taking on the role of main operator and relegating this human being to a secondary role, should be analysed and studied carefully to avoid results that are directly opposed to those sought.

Inasmuch as automation is not infallible and can fail at any moment, the design of any system, no matter how complex it is intended to be or how many functions it is expected to perform, should not exclude from its operational options the possibility for the human operator to take charge under given exceptional circumstances.

On such occasions, the human being must necessarily intervene to correct the errors of the automated systems.

To that end, a direct and effective interrelationship between the human being and automation (technology) should be achieved.

The human-machine interface should therefore be user-friendly.

The introduction of automation represents a radical change for operating personnel and, contrary to the opinion of some people, this process does not reduce training requirements. As a result, programmes must be set up to provide training in those technologies.

These programmes should contemplate possible contingencies due to specific failures of the automated systems, such as: mode error, database errors, programming errors, software problems, hardware failures, etc.

- The various Administrations should do their utmost to reduce the psycho-social impact of an unequal understanding by the human resources (appointed to work in the CNS/ATM environment) of all of the factors to be considered.

APPENDIX A

GLOSSARY OF TERMS

Guidance Manual on Human Resource Training in CNS/ATM Systems

GLOSSARY OF TERMS

The following glossary of terms relating to CNS/ATM has been compiled from several different sources. It should be kept in mind that some subject areas are still being developed and therefore several of these definitions are still provisional. Furthermore, certain definitions should be considered an aid to the reader's general understanding and not necessarily as having been officially approved by ICAO.

Aeronautical Mobile-Satellite Service (AMSS) - Air-ground communication system *via* satellite, which uses a frequency band allocated for aeronautical purposes.

Aeronautical Telecommunication Network (ATN) - Inter-network architecture that allows ground-ground, air-ground, and avionics data sub-networks to operate by adopting common services and interface protocols based on the International Standardization Organisation's (ISO) open systems interconnection (OSI) reference model.

Airborne Autonomous Integrity Monitoring (AAIM) - Airborne augmentation technique for improving the availability of the navigation function.

Airborne Collision Avoidance System (ACAS) - Airborne system based on the signals of the secondary surveillance radar (SSR) responder system, which operates independently of the ground equipment to provide the pilot with information about possible conflict with aircraft equipped with SSR responders.

Aircraft Earth Station (AES) - Aircraft avionics equipment needed to process satellite communications.

Aircraft-Based Augmentation System (ABAS) - Augmentation systems incorporated into airborne GNASS equipment, and which can be RAIM or AAIM-type.

Aircraft Communications Addressing and Reporting System (ACARS) - Communication system for air-ground data link communication system *via* VHF channels assigned for that purpose.

Airspace Management (ASM) - ATM component, whose purpose is to maximise use of the available airspace within the structure of a given airspace.

Air Traffic Control Service - Service supplied to prevent aircraft collisions in the manoeuvring area between aircraft and obstacles and to expedite and keep air traffic movement orderly.

Air Traffic Flow Management (ATFM) - Service intended to guarantee optimum air traffic movement toward or through areas during hours when demand exceeds or is expected to exceed the available capacity of the ATC system.

Air Traffic Management (ATM) - Widely defined function that encompasses Air Traffic Services (ATS), Air Traffic Flow Management (ATFM), and Airspace Management (ASM) Services. Its objective is to enable airline operators to meet their scheduled times of arrival and departure and to fly preferred flight levels.

Air Traffic Services (ATS) - Generic term applied to Flight Information, Warning, Air Traffic Advisory, and Air Traffic Control (Area, Approach, or Aerodrome) Services, as the case may be.

Area Navigation (RNAV) - Navigation method that enables aircraft to operate in any convenient flight path covered by ground navigation aids, or within the capacity limits of autonomous aids, or a combination of the two. RNAV that uses these capacities only on the horizontal plane is called two-dimensional area navigation (2-D RNAV). RNAV that incorporates a vertical guide is called 3-D RNAV or VNAV. If time navigation (TNAV) is added to 3-D systems, these are called 4-D RNAV.

ATS Inter-facility Data Communications (AIDC) - Means by which information is exchanged between and within ATS facilities when notifying, co-ordinating, and transferring control of an aircraft.

Augmentation - Technique that provides the system with input data and information from the main constellation(s) in service, in order to furnish new distance information or corrections or improvements to the input data. This allows the system to improve its performance as compared to that obtained from satellite raw data only.

Automatic Dependent Surveillance (ADS) - Surveillance system through which the aircraft automatically transmits, through a data link, data from navigation and airborne positioning systems, which include its identification, 4-dimensional position, and other appropriate data.

Automatic Dependent Surveillance - Broadcast (ADS-B) - Surveillance system whereby an aircraft transmits its position automatically. That position can then be received by aircraft located within a radius of approximately 150 NM, using equipment generically called CDTI.

Availability - The availability of a navigation system is the percentage of time system services can be used. Availability is an indication of the system's capability to provide useful service within a given area of coverage. Signal availability is the percentage of time navigation signals are transmitted from outside sources for use. Availability is a function of the physical characteristics of the environment and of the technical capability of transmission facilities.

Barometric aid - Process that employs altitude information to simulate a GNSS satellite situated directly over the receiver antenna (reduces by one the number of satellites needed to perform a given function).

Cockpit Display of Traffic Information (CDTI) - Airborne equipment capable of receiving ADS-B messages from other aircraft and of displaying them on the screen (EFIS or similar type).

Communications, Navigation and Surveillance (CNS) - System that encompasses the communications, navigation, and surveillance functions, all of which are needed in order for an aircraft to reach its destination safely and efficiently.

Contingency fuel - Any extra fuel loaded before flight to cover possible incorrect meteorological forecasts and ATC restrictive procedures (inappropriate flight levels, en-route holding, diversions, etc.).

Continuity - The system's capability to function without interruption during the operation foreseen. Continuity risk is the likelihood that the system may be interrupted and that no guidance information will be provided for the operation foreseen.

Controller-Pilot Data Link Communication (CPDLC) - Means of controller-pilot communication using data link (with free or preformed messages) for air traffic control communications.

Data Link (DL) - Improvement of the capabilities of airborne and ground systems could be made complementary in order to maximise efficient use of airport and airspace resources. Operational use of an air-ground data link plays an essential role. It is considered that the VHF (VDL) will be the primary data link sub-network, with the SATCOM or HF (HFDL) as alternate when beyond VHF coverage.

Direct Controller-Pilot Communication (DCPC) - Method of communication between air traffic control and the cockpit that allows for instantaneous voice answers by both parties, making it possible to reduce aircraft separations.

European Geostationary Navigation Overlap Service (EGNOS) - GPS and GLONASS augmentation system through the use of geostationary satellites, whose purpose is to improve the performance of these two systems.

Flight Management System (FMS) - An interactive computer and navigation display system to assist the pilot in flying the aircraft as economically as possible, on a previously planned route with defined waypoints and altitude changes. The system continuously updates the exact position according to the data received from several navigation aids.

Free Flight - ATM system used in the United States of America that allows pilots, whenever possible, to choose their own routes and submit flight plans with the most efficient and cost-effecive routes.

Geocentric - Relative to the Earth as the centre, measured from the centre of the Earth.

Geodesy - The science concerned with determining the size and shape of the Earth (geoid) through direct measurements, such as triangulation, levelling, and gravimetric observations, to find out the Earth's external gravitational field and, to a certain extent, its internal structure.

Geostationary - An equatorial satellite orbit leading to a constant fixed satellite position above a particular point of reference on the Earth's surface (GPS satellites are not geostationary). Geostationary satellites are used in satellite-based augmentation systems.

Global Navigation Satellite System (GNSS) - Name given by ICAO to a global system for determining position and time, which includes one or more satellite constellations, aircraft receivers, and system integrity surveillance. Augmentations can be made as necessary to support the required navigation performance corresponding to the effective operational phase. The GPS and GLONASS will provide the GNSS with distance measurement services, at least in the medium term.

Global Orbiting Navigation Satellite System (GLONASS) - Navigation system based on satellite signal transmissions, provided and maintained by the Russian Federation and available to civil aviation users.

Global Positioning System (GPS) - Navigation system based on satellite signal transmissions that is provided and maintained by the United States of America and is available for civil aviation users.

Ground-Based Augmentation System (GBAS) - Limited coverage augmentation systems that will use ground facilities to transmit augmentation signals to the user (*e.g*. SCAT-I).

Ground Earth Station (GES) - Facility that is part of the fixed satellite service or of the aeronautical mobile-satellite service (AMSS), which is located at a fixed point on the ground, inteded to supply a connection link to the satellite constellation.

Ground segment - The portion of the Global Positioning System (GPS) that is on the ground (5 monitoring stations and 3 antennas).

IFR GPS Equipment - The GPS equipment for IFR flights is classified as follows, according to FAA Order TSO-129a:

Class A - The equipment incorporates a GPS sensor and navigation capacity, as well as the RAIM technique.
Class A1 - Includes en-route, terminal area, and non-precision approach capabilities.
Class A2 - Includes en-route and terminal area capabilities only.
Class B - The equipment consists of a GPS sensor that feeds data into an integrated navigation system (FMS, Multi-Sensor Navigation System, etc.).
Class B1 - Includes RAIM and provides en-route, terminal area, and non-precision approach capabilities.
Class B2 - Includes RAIM and en-route and terminal area capabilities only.
Class B3 - Requires the integrated navigation system to provide a GPS integrity level equivalent to RAIM and is apt for en-route, terminal area, and non-precision approach operations.
Class B4 - Requires the integrated navigation system to provide a GPS integrity level equivalent to RAIM and offers en-route and terminal area capabilities only.
Class C - The equipment consists of a GPS sensor that feeds data into an integrated navigation system (FMS, Multi-Sensor Navigation System, etc.) that offers improved guidance to an automatic pilot or flight director in such a way that technical flight errors are reduced.
Class C1 - Includes RAIM and provides en-route, terminal area, and non-precision approach capabilities.
Class C2 - Includes RAIM and provides en-route and terminal area capabilities only.
Class C3 - Requires the integrated navigation system to provide a GPS integrity level equivalent to RAIM and can be used in en-route, terminal area, and non-precision approach operations.
Class C4 - Requires the integrated navigation system to provide a GPS integrity level equivalent to RAIM and offers en-route and terminal capabilities only.

Inertial Navigation System (INS) - Autonomous navigation system that uses one or more inertial navigation sensors to determine aircraft position by precisely following all of its movements from a known starting point. In time, the precision of an inertial sensor becomes degraded. The position obtained through an inertial system can be degraded at an average of 2 NM per hour in flights lasting more than 10 hours.

Inertial Reference System (IRS) - Navigation equipment that determines the aircraft position by detecting any accelerations through the use of a gyrostabilised platform that furnishes data to the RNAV equipment.

Integrity - Characteristic referring to the trust that can be placed in the correctness of the data furnished by the total system. Integrity includes the capability of a system to provide timely and valid warnings to the user in those cases in which the system should not be used for the planned operation.

Local Area Augmentation - Augmentation that offers additional satellite signals over a reduced geographic area, so as to improve GNSS integrity and/or availability and/or accuracy. A data link is needed to transmit the augmentation services to the user.

Multichannel receiver - A GPS receiver capable of receiving more than one satellite signal at a time.

Multifunction Transport Satellite (MT SAT) - Japanese geostationary satellite with a meteorological mission and an aeronautical mission, which can include ADS capability, data link, and a GPS integrity/overlay channel.

Precision - Capability of the whole system to maintain the aircraft's position within the error limits of the total system (TSE = total system error), with a 95% probability at each point of the specified procedure, so that it is kept within the external performance limits.

Primary navigation system - Navigation system approved for a given operation or flight phase, which must meet precision and integrity requirements, but not full availability and service continuity requirements. Safety is assured by limiting flights to specified periods and applying appropriate restrictions.
Note - There is no requirement to have a single means navigation system on board to support a primary navigation system.

Receiver Autonomous Integrity Monitoring (RAIM) - Airborne augmentation technique whereby a GPS receiver/processor determines the integrity of GPS navigation signals through the use of GPS signals only, or by augmenting such signals with altitude data. This determination is made by continuously verifying the signals received. At least one other satellite, in addition to those used for navigation purposes, should be within reach of the receiver in order to carry out RAIM.

Required Communication Performance (RCP) - Set of communication performance requirements specified for a given airspace operating scenario.

Required Navigation Performance (RNP) - Indication of the navigation performance parameters needed to operate in a given airspace. ICAO specifies the navigation performance, but does not indicate any specific type of equipment.

Required Surveillance Performance (RSP) - Series of surveillance performance requirements stipulated according to the airspace in question and the traffic density and complexity.

Required Time of Arrival (RTA) - Time at which an aircraft is requested by ATC to pass over a given waypoint and that can be programmed by specific navigation equipment. It should be kept in mind that RTA precision will depend upon the precision of the wind forecast and of the flight time available for making the necessary speed adjustments.

Required Total System Performance (RTSP) - Standard for measuring the performance of all the elements of the CNS system. Includes the Required Communication Performance, the Required Navigation Performance, and the Required Surveillance Performance.

Satellite-Based Augmentation System (SBAS) - Wide-range augmentation systems, such as the EGNOS (European), the MTSAT (Japanese), and the WAAS (U.S.), that use communication satellites to transmit augmentation signals to the user.

Single means navigation system - A single means navigation system for a given flight phase should give the aircraft the possibility of meeting, during that flight phase, the four basic performance requirements for navigation systems: continuity, availability, accuracy, and integrity.
Note - This does not mean that other navigation systems may not be carried on board. Any single means navigation system may include one (autonomous installation) or several sensors, possibly of different types (multi-sensor installations).

Spatial segment - The portion of the Global Positioning System (GPS) that is in space (the satellites).

Supplementary navigation system - A navigation system that must be used jointly with a single means navigation system. Approval of a supplementary navigation system for a given flight phase requires that a single means navigation system be carried on board for that phase. A supplementary navigation system for a given flight phase must meet the same performance requirements as to accuracy and integrity as the single means system. Availability and continuity requirements do not have to be met.
Note - Operationally speaking, so long as the accuracy and integrity requirements are being met, the supplementary means navigation system may be used without the need to cross-reference with the single means system. Any navigation system approved as a supplementary system may involve the use of a single (autonomous installation) or several sensors, possibly of different types (multi-sensor facilities).

Time Navigation (TNAV) - An RNAV equipment function (*e.g.*, FMS) that provides the capability of reaching/leaving a waypoint at a given time.

Vertical Navigation (VNAV) - An RNAV equipment function (*e.g.* FMS) through which a vertical profile or path is estimated, displayed, and guidance thereon is provided.

Wide Area Augmentation - Augmentation that offers additional satellite signals above an extensive geographic area, so as to improve GNSS integrity and/or availability and/or accuracy.

World Geodetic System (WGS) - A prefixed set of parameters that describe the size and shape of the Earth, the positions of a network of points in reference to the centre of the Earth's mass, and the conversions based on larger geodetic datums.

APPENDIX B

LIST OF REFERENCES

Guidance Manual on Human Resource Training in CNS/ATM Systems

LIST OF REFERENCES

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6) Annex 6 to the ICAO International Civil Aviation Convention

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8) Federal Aviation Administration Notification 8110.60 "GPS as a primary means of navigation for oceanic/remote operations"

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12) Canadian Marconi's operating handbook for FMS CMA 200 equipment

13) ICAO Circular Letter 249-AN/149 Compendium of human factors Number 11 "Human factors in the CNS/ATM Systems"

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