NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

AIR TRAFFIC CONTROL

Graduation Project
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This project is dedicated to my parents. They gave me the chance to study in Turkish Republic of Northern Cyprus. With my Father and my Mothers sincere effort it was possible for me to successfully complete Engineering and heading towards a successful life.

before Contents

Abstract

In this project I have attempted to put together theories techniques and procedures which can be used to understand the AIR TRAFFIC CONTROL.

In chapter 1; duties and responsibilities of airtraffic control aircraft communication system has been de scribed using different block diagrams of internal circuits of the instruments. The chapter shows the importance of audio control panel, which is the interior communication system of the aircraft. Failure in the audio control can be a big danger to the aircraft.

In chapter 2, Rules of air traffic control and air space separation, control zone and flight information system are defined in this chapter.

In chapter 3, Navigation aids, DVOR, DME. Distance measuring instrument plays an important role in the field of air traffic control.

In chapter 4, I have tried to clarify some information about the importance of radar. Secondary surveillance radar and the role of radar in air traffic control.

In chapter 5,6,7, the other aspects of the air traffic control system consists of computer radar display, flight and radar data processing, flight plane and conduct of military and civil flights are also discussed is these chapters.

What is Air Traffic Control

"THE AIR TRAFFIC CONTROLLER - PART CHESS GRAND MASTER, PART BATTLEFIELD COMMANDER - IS THE MENTAL HIGH STAKES EQUIVALENT OF AN OLYMPIC ATHLETE; AN ATHLETE WHO CAN NEVER TURN IN LESS THAN A GOLD MEDAL PERFORMANCE..."

"The interaction between the automation and the controller on the ground and the automation and the pilot in the cockpit"

Duties and Responsibilities of the Air Traffic Controller

The primary duties and responsibilities of Air Traffic Control Specialists are to provide for the safe, orderly and expeditious flow of air traffic. Seems pretty cut and dry doesn't it (see the governmentese version below). However, with more than 1,700,000 people boarding U.S. airlines every day, this is usually not an easy task. There are 215,000 privately owned planes. There are 74 million flight operations at tower-equipped airports annually. As a result, an Air Traffic Control Specialist must:

- ...be able to think abstractly
- ...be able to establish priorities; first things first
- ...have automatic recall
- ...be able to look at errors objectively and reconstruct situations
- ...accept the responsibility of the Job!

Air traffic control is without a doubt one of the most challenging occupations available today. There is much to be known and considered when undertaking this profession. An air traffic control specialist is often described as one who provides for the safe, orderly, and expeditious flow of air traffic both in the air and on the ground. This definition may sound simple, but the job is a highly complicated and exacting one. It demands extraordinary men and women with special characteristics.

Talking with controllers, you get the impression that these are a special breed - tough-minded, alert, not-quite-ordinary people. Which figures. It's not an ordinary job.

The air traffic control specialists at Houston Intercontinental ATC Tower and TRACON direct air traffic so it flows smoothly and efficiently. The controllers give pilots taxiing and takeoff instructions, air traffic clearances, and advice based on their own observations and information received from the National Weather Service, other controllers, flight service stations, aircraft pilots, and other reliable sources. They provide separation between landing and departing aircraft on instrument flights to center controllers and adjacent approach controllers when the aircraft leave their airspace, and receive control of aircraft on instrument flights coming into their airspace from controllers at adjacent facilities. They must be able to recall quickly registration numbers of aircraft under their control, the aircraft types and speeds, positions in the air, and also the location of navigational aids in the area.

Virtually all controllers work shift work because IAH ATC Tower and TRACON are operational 24 hours a day. The exact rotation of the schedule changes on a daily basis. Days off rarely fall on weekends. IAH ATC Tower and TRACON remain open on all holidays.

GOVERNMENTESE VERSION:

The primary duties and responsibilities of Air Traffic Control Specialists are to provide for the safe, orderly and expeditious flow of air traffic in accordance with procedures, directives and letters of agreement set up by the Federal Aviation Administration. The controller also provides pertinent weather and airport information as required and recognizes adverse situations and takes corrective actions.

In addition, each controller must communicate with coworkers, system users and the general public in a cooperative and courteous manner with limited need for repetition. The controller is required to use specific phraseology and perform inter/intrafacility coordination in an efficient manner. The controller must listen effectively in order to prevent readback-hearback errors, and ensure complete position relief briefings.

Every Air Traffic Control Specialist is required to complete required training and self-briefing items in a timely manner. On-the-job training (OJT) is provided by Air Traffic Controllers who have successfully obtained full performance level (FPL) status. These training sessions are conducted objectively through instruction, demonstration and practical application in accordance with agency directives and are adequately critiqued and documented.

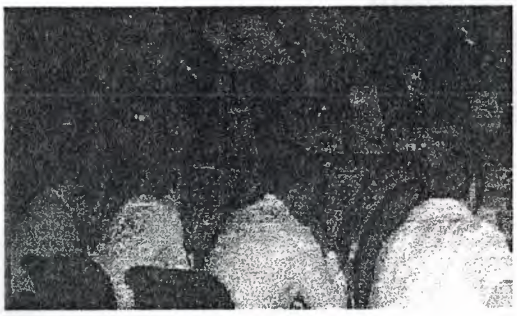
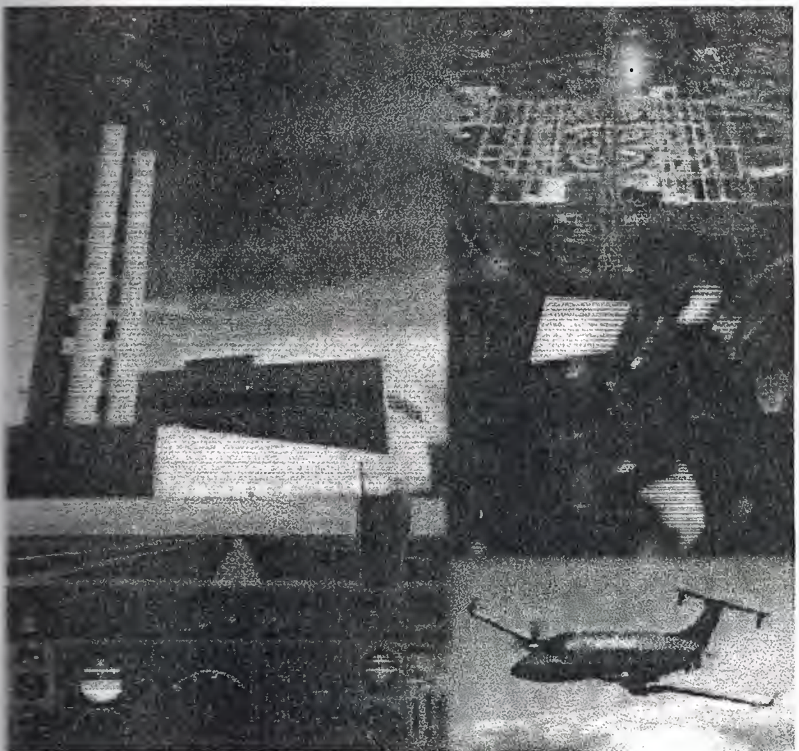


figure no?

The Management of the Airspace

Introduction



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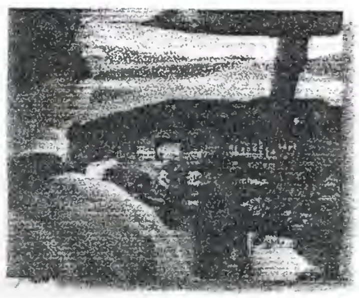


The Management of the Airspace

Introduction

Rules, which are used by air traffic controllers to separate aircraft, it is now essential to describe how the airspace is managed to make the application of these rules possible. However, before commencing to explain the various types of airspace and how it is organized, it might well be of assistance to outline briefly the historical background to airspace management.

In the years immediately preceding the Second World War the increasing use of the air as a practical means of rapid transportation was already begging to require the provision of regulations to avoid for safety in the air and on the ground. A form of air traffic control was also being pioneered, but certainly in Europe, this was largely restricted to a type of positive control which was limited to within the immediate victory of an aerodrome, with an advisory information service, largely conducted by 'wireless telegraphy, outside this area. This generalization is in no way intended to belittle the efforts of the stalwart band of gentlemen who laid the foundations of the present-day sophisticated 'systems'. It would indeed be interesting to place on record their endeavors in some other forum. It is possibly worth recording that in the United Kingdom it was a Department of the then Air Ministry, who were responsible for both the airside and ground side of aviation safety, and who then commenced to build the foundations of the ATC systems of the present day.

It was in fact the cessation of hostilities which acted as a catalyst to concentrate minds upon the need to provide air traffic control services, based upon both the experience which had been gained pre-war and the experience of the handling of large concentrations of aircraft by the Armed Services. The reason for the urgency was, quite simply, that aircraft bad not only undergone rapid development in design and performance characteristics, but bad demonstrated their vast potential in the movement of goods and persons. This potential was readily recognized in support of the occupying forces and of the growing needs of commerce,

Although the example of the awareness to act is quoted as Western Europe, the problem was also recognized internationally, and in 1944 an international meeting was held in Chicago (U.S.A.) where the Provisional Inter-national Civil Aviation Organization was formed (PICAO) and the Chicago Convention was ratified as a basis for the development of international standards and practices fi)r aviation - it was indeed this body that gave as its interpretation of air traffic control, a phrase which still obtains today; that is: 'The safe, orderly and expeditious flow of air traffic.'

It was, however, to be several years before the deliberations of this organization would be able to impact upon the fast-growing aviation scene and therefore states had of necessity to seek some short-term solutions for themselves. It was indeed reasonably easy to provide an air traffic control service within the immediate vicinity of aerodromes and to declare the airspace 'air traffic zones' to which rules could be applied. These rules required aircraft to make contact on R/T or W/T for an air traffic control clearance, or by prior permission obtain authority to enter and leave in accordance with visual flight rules. It was also possible, as was the case with the London area, to encompass several aerodromes within a parent control zone. In the case of London the first of these zones, known as the Metropolitan Control Zone, was a circle of 25 nautical miles radius centered on Westminster Bridge with a prohibited area of 3 nautical miles from the bridge itself Having drawn up the original map myself I was never quite certain why we had to have this prohibited zone, but possibly it was to protect our MPs from the sight of such forward progress.

It has to be remembered that pilots of aircraft, being unfettered at that time in regard to routes to be followed to destination aerodromes, had quite naturally set as direct a course as possible immediately after take-off. They had therefore by force of circumstances established a series of aerial highways linking the capitals of Europe and the Mediterranean states. In accepting the situation that aircraft would, however, enter and leave the control zone at recognized points on the periphery of the circle, it was then reasonably logical to site as near as possible geographically, ground-based navigational aids, which at this stage of development were non-directional beacons (NDB); at these locations. Pilots of aircraft were thus, by using these beacons, able to establish their position in relation to the earth's surface and to report to the controlling authority the time which they estimated to be at the facility and then subsequently their actual time over it. From this information air traffic control were then able to allocate height and times at which the aircraft could be cleared to a particular NDB. The theory was very simple, in that aircraft outbound from aerodromes within the zone were cleared not above 3000 fret and those inbound, not below 4000 feet. Therefore provided the inbound aircraft was not descended below 4000 feet until it reached the holding facility of the aerodrome of intended landing, no conflict existed between departing and arriving traffic within the zone itself. It should be remembered also that, at this time in aviation development, 500 feet was the accepted vertical separation between aircraft, which therefore permitted a reasonably high permutation of level allocation.

Readers with a personal knowledge of these times will I know. realise that the dictates of brevity have obliged me to omit a number of the innovations which occurred prior to the installation of the NDBs, of the truly pioneering efforts of the aerodrome controllers in sorting out arriving and departing traffic, and of the area controllers and telecommunications officers who had to battle away with static-filled WIT, in order to get their instructions across to the sometimes wayward pioneers of the air. The problem however was that in the airspace outside these control zones and aerodrome traffic zones no system existed to be able to provide an air traffic service for the majority of the en-route phase of an aircraft's flight. Each state had its own flight information region (FIR) which covered the entire airspace of a state up to internationally agreed contiguous boundaries. Within these FIRs there existed, as it still does today, a very simple flight safety rule, known as the quadrennial height rule, which operates in respect of all aircraft flying above 3000 feet. The rule requires that aircraft flying in specified quadrants of the compass (360~) should fly at either even levels, or even levels plus 500 feet, if in the opposite quadrant, or odd levels or odd levels plus 500 feet in the reciprocal quadrant. As you will see, the rule provides for a very rough form of separation for aircraft in level flight, in that either approaching head-on or crossing quadrants a theoretical separation of 500 feet vertically should exist between the concerned aircraft.

This then was the general world-wide situation in regard to airspace regulation at that point in aviation development. There was, however, one notable exception - that was North America and in particular the United States. The U.S.A., because of its geographical position and of the need to communicate over long distances, had not only fostered the use of aircraft as a method of transport but had developed a system of airways to protect and regulate the flight of aircraft between departure points and destinations. These 'airways', which were the first of the present world network of aerial highways, were 10 miles wide and extended from approximately 3000 feet to 10,000 feet above ground level. The method employed to ensure that pilots of aircraft could locate and navigate along these airways was by the positioning on the ground of a facility known as a radio range. The radio range radiated four legs on a published radio frequency and transmitted the Morse letter 'A' on one side and the Morse letter 'N' on the other. By positioning the legs of the range along the route of the airway, the pilot, by knowing the geographical position of the range and its frequency and by receipt of its either 'A' or 'N' characteristic. was then able to navigate himself from range to range along his predetermined route and also be able to pass, by radio telephony, a position report over the range and give a calculated estimate for the next range In this information, and by the application of rules relating to flight in the airspace encompassed by these airways, lay the beginnings of the application of an air traffic service to aircraft in the airspace away from the aerodromes. It is interesting to observe that communications by air traffic controllers with air-craft in those days was by relaying messages by telephone to the aircraft's company for broadcast on their own discrete company radio, or through an operator physically sited at the radio range site.

Once again it is tempting to write history, but certainly on the American scene I would not have the temerity to try. I wish, however, to make mention of one of the great pioneers of air traffic control in the U.S.A., the late Glen Gilbert, whose book on air traffic control explains most vividly those early days of a system which has since been copied worldwide. I myself was fortunate enough, with a colleague Len Winter, to be seconded in 1949 to the then Civil Aviation Authority (CAA) in the U.S.A. to study the system and then qualify as an en-route controller at the Chicago Air Traffic Control Centre, and on my return to introduce the first of the European airways which ran from a place called Woodley near Reading to Strumble Head on the Welsh Coast, code-named, and still today - 'Green Airway One'.

I appreciate that the temptation to write history is very strong, but I have to limit it to my purpose, that of leading into the management of the airspace.

Rules of the air

Having described, in the introduction, the background to the management of the air-space, I wish now to explain how the airspace is organized to achieve the objective of a safe, expeditious and orderly flow of air traffic.

To channel the flow of air traffic and to obtain the necessary degree of orderliness to apply separation standards between aircraft it is essential to establish a system of airspace's sufficient to protect an aircraft's flight path from take-off to touch-down, and then to apply rules regarding the use of these airspaces which are designed to provide for the safety of all those who fly within them. These rules are known as 'rules of the air' and their origins and general interpretation are set out in Annex 2 of the Convention of the International Civil Aviation Organization.

In regard to the international use of these rules it is interesting to note that they apply to the aircraft itself In practical terms this means that these rules will be obeyed by any aircraft bearing the nationality and registration of any contracting state of ICAO, wherever they may be and provided the rules do not conflict with the rules of any state which has jurisdiction over the territory being overflows. This latter point is important, for it is possible for a variety of reasons that a particular state may have to place a different interpretation on a specific rule. States themselves in fact, as I previously stated, produce their own legislation based on these rules, such as for example, in the U.K. 'The Air Navigation Order', and therefore operators of aircraft are able to acquaint themselves with any differences in interpretation, prior to undertaking flights into or over the concerned territories.

However, whatever the interpretation of a particular rule may be, the objective is common, and that is to ensure the enforcement, by law if necessary of their application, which is to ensure the safety of national and international flight.

As mentioned earlier each state has its own flight information region contiguous with its bordering states, and it is within these FIRs that the various categories of controlled air-spaces are contained. As will doubtless be appreciated from a sight of Figure 3, it is obvious that a great deal of co-operation and co-ordination has to take place between these various states to ensure that not only the rules applicable to the airspace, but also their physical layout, do not conflict one with the other.

The rules of the air cover, of course, many aspects of an aircraft's flight, but from the point of view of the air traffic control service the most important is the rule requiring an air traffic control 'clearance' to be obtained prior to operating a controlled flight. In simple terms this means that no aircraft is allowed to enter controlled airspace without having been given a clearance (instruction) to do so by the air traffic control authority responsible for that airspace. There are some exceptions, in various parts of the world, where flight in accordance with visual flight rules (VFR) is permitted. This rule permits an aircraft to be flown visually in accordance with a set minimum standard of weather conditions and here responsibility for avoidance of collision is vested in the pilot. However, due to the restricted design of modern cockpits in regard to visual look-out and high closing speeds, often of 1000 kts plus, many states, the United Kingdom in particular, apply instrument flight rule (IFR) conditions to their controlled airspaces, irrespective of the weather conditions.

It is these designated airspaces which permit air traffic control to be able to apply the separation standards mentioned in earlier paragraphs

graphs. r should now like to explain in rather more detail how the airspace is managed, starting from an aerodrome and working outwards to the en-route phase of flight.

Control zones

Control zones are established at busy acrodrornes, usually within a terminal area complex, and they extend from ground level to 2500 fi or a level appropriate to the base of the surrounding terminal area. Their purpose is to protect the flight paths of aircraft arriving from the protection of the terminal area or departing into it.

Terminal areas

Terminal areas are established around one or more busy aerodromes and extend usually from 2500 feet or the top of the concerned control zone/s to a height of approximately flight level 245 (the base of the upper airspace which can vary from state to state) and the area extends laterally to connect with the systern of airways serving the terminal area cornplex. Their purpose is to protect the flight paths of aircraft leaving the airways system to land at am aerodrome in the terminal, or alternatively the flight paths of aircraft depaning the terminal for an en-route airway. Their vertical extent is to enable protection to be given to the flight paths of aircraft which may be overflying the terminal to other destinations served by the internal or international airways system.

Airways

Airways are established to connect the main areas of population within a partic~ar geographical area and to *link* up with the major cities of adjacent states. They are usually a minimum of 10 nm wide and generaily have a variable base between 3000 feet and flight level 55, and with some exceptions extend vertically up to flight level 245, the base of the upper airspace. Their purpose is to protect the flight paths of aircraft which are flying en-route between destinations served by the airways net.-work, or to a specified point of departure from the system.

Upper airspace

The airspace above flight level 245 or such other level as determined by a particular state and extending up to flight level 660 is designated a special rules area, and within this area there are upper air routes. The majority of these routes are contiguous with the airways network below that level. The purpose of this airspace is to protect the flight paths of aircraft flying not only on the network of air routes, but also in any part of this particular airspace. In general, however, the majority of aircraft, either civil or military, which are operating in accordance with civil procedures conform to the air-ronte network. The base at which the upper airspace commences can vary' between states, as also can the procedural rules. The foregoing does, however, represent a general interpretation of the intent of this airspace. The international accepted term for this airspace, within which exists the Upper Air Routes and Special Rules

Airspace is the Upper Flight information Region (UIR).

Flight information regions

The airspace outside the control zones, terminal areas, airways and specia] rules areas, but within which these areas are contained, is designated the flight information region. It is not protected airspace and aircraft are free to fly without being subject to control procedures, provided they comply with a set of simple rules for flight in instrument conditions and avoid the air traffic (circuit) zones of aerodromes which do not have protected airspace.

It is appreciated that it may seem rather ambiguous, in a book which is dealing with it.

Navigation and Communication Aids

In previous paragraphs I have made mention of the fact that navigational aids are required not only to enable the pilot of an aircraft to determine his position in relation to the earth's surface, but also to delineate the routes, airways and *airs paces* within which air *traffic* services are provided, and finally to enable him to align his aircraft with the runway in use, and effect a landing at the aerodrome of destination.

Navigational aids come within two broad definitions - 'ground-based' which, as their name implies, are installations on the earth's surface whose geographical position is known and published, and 'airbo'rne', which relates to the equipment carried in an aircraft, which enables the pilot to interrogate and obtain information from the ground-based installations.

There is a third category, called 'on~board' navigation Systems, which enables the aircraft to be navigated without recourse to ground-based aids, such as sateLlite navigation and inertial navigation (INS) but it is not my intention to deal with these systems at this stage. Informed readers will also be aware that 'dead reckoning navigation' and 'astral navigation' still widely used in many of the world's airspaces, that are without adequate ground-based cover. Navigation, as these readers will know, is a very wide and complex subject, best dealt with in the many learned books which have been publtshed; therefore my explanations will be limited to those aids which are generally in use in air traffic systems. In this regard, however, I wish to reiterate a point which I made earlier, which is that, responsibility for the navigation of an aircraft is vested in the pilot-in-command, and only exceptionally -- as for example, when an aircraft is being 'directed' by a radar controller - is this responsibility temporarily transferred.

Radar could also be generally regarded as an aid to navigation, and, of course, it is widely used in modern air transport and military aircraft in a variety of airborne roles. From an air traffic control point of view, which is the aspect I shall be discussing, its role is priniarijy that oC assisting in expediting the flow of air traffic. Because of its importance in this regard I will deal with the principles of radar and bow it is used later in the book

Additional facilities are, however, required for both pilots and controllers to enable them

to carry out their allotted tasks, and in general terms these are known as 'communication aids'. They embrace radio telephony for communication between the air and the ground, telephone networks for rapid communication between controllers and for use as data links, and teleprinter networks for the passing of routine messages and the latest of these communications devices, secondary surveillance radar (SSR

Mode 'S'), which I shall be describing later, and which is to be used as a data link between the aircraft and the ground, without the need to use a radio telephony speech circuit. Computers are also becoming increasingly used as a rapid method of communication, but because they have a special role in their application to air traffic control I propose to deal with this subject separately under the heading of automation.

Having therefore previously explained the separation standards which a controller employs, and the management of the airspace which makes the application of these separations possible, I now propose to explain, against this background, the major facilities which the controller has at his disposal to enable this task to be discharged. I should like to emphasise that not all of the facilities I shall describe are essential at every locality, for much depends upon the level of traffic and also the specific environment of a particular area. Also whilst the basic requirements for navigation and communication will remain fundamental to any system, it is undoubtedly true that the rapid development of technology, particularly in the field of avionics, could well outdate the methods by which these standards are achieved today.

Navigation aids

It is considered it would be helpful to give an explanation of the role of navigation aids in present air traffic control systems and to descnbe how the efficiency of these aids contri

bute towards the safety and expedition of aircraft into and out of the airport environment. You are aware of the airways or en-route networks previously described, which act as links between the major centres of aviation interest and which form the basis of the air traffic control systems outside the immediate environments of terminal areas. These routes rely for their delineation upon the existence of ground-based navigational aids of sufficient accuracy and in sufficient quantity not only to ensure that the aircraft using these airways remain within the confines of the airspace but are also sufficiently accurate for the aircraft to be able to determine its position within a tolerance which will permit air traffic control to use this information for the purpose of separating traffic one from another in time sequence and for confirming or correcting other planned applications of separation standards. It is, then, these navigational aids which mark out the routes and act as three-dimensional traffic lights at which the airborne position of the aircraft can be checked and also at which they can be 'held' if necessary, to regulate the traffic flow on a particular route or at a conflux of routes such as a terminal area.

DVOR/DME

The use of navigational aids for this purpose has progressed from the radio range and its associated fan markers supplemented by MIF non-directional beacons, as described earlier, to the present-day VHF Omni-directional range (VOR) which operates in conjunction with distance measuring equipment (DME). This latter equipment enables the pilot of an aircraft to determine how far away he is from the geographical position of a VOR on a specific radial of that facility. The VOR itself has for some 30 years been the ICAO international short-range navigational aid, and consists of a ground beacon which transmits a signal from which an airborne receiver can determine the Navigation and Communication Aids aircraft's bearing from the beacon. It thus provides a simple means of flying radial paths either from or towards the ground station, More recently the use of airborne navigation computers combined with VOR and DME enables the aircraft to fly desired paths, other than the direct radials, thus providing an area navigation capability.

Doppler VOR (DYOR), so called since the well-known doppler principle is used in generating the ground beacon signals, has considerably improved the VOR system performance since such beacons have much greater immunity from multi-path propagation effects. (A photograph of a typical DVOR installation is shown in Figure 7.)

Multipath effects describe a situation where both direct and indirect signals occur, causing noticeable variations in course indications. Large built-up areas close to the beacon, or mountainous terrain between the beacon and aircraft, are sources of this particular problem, largely overcome by IDVOR. These navigational aids, however, are what is known as point source aids'; that is, they are physically located on the earth's surface and aircraft using their radiated signals will eventually arrive at the same spot on the earth's surface- An exception to this is, as previously explained, the carriage and use of distance measuring equipment (IDME) which together with VOR, permits an aircraft to be navigated, if desirable, using its on-board computers, on a course parallel to the physical position of the associated ground aid. It follows that if all aircraft using an ATC system were capable of lateral tracking, and if the navigational aid in use possessed a high degree of accuracy, it would be possible to separate aircraft on lateral tracks at the same height or level instead of in a line-astern configuration, which is primarily the case at present. This capability within a system is called area navigation. There have been several attempts to establish a practical method of operation, of which, possibly the Decca Navigator is an outstanding example. However, I am certain readers will appreciate that to be effective such a system requires all concerned aircraft to have the same standard of navigational capability. It is undoubtedly the way ahead in which to obtain the economic and flexible use of the airspace, and future advances in aviation technology will hopefully supply an answer tO this problem.

Closer to the environment of the airport, navigational aids of the types previously described play a vital role in the efficient operation of the terminal area surrounding the airport complex. For example, in considering the arrival phase of an aircraft's flight it is a well-known fact that the vagaries of weather, and the requirements to meet passenger demands, inevitably result from time to time in the fact that arriving traffic exceeds the capacity of particular airports to accept aircraft without incurring the penalty of a delay in the landing interval. As a result a continuous descent from cruising level followed by a straight-in approach cannot always be achieved, and therefore the use of the navigational aid must be resorted to, to enable aircraft to hold their positions in a very accurate configuration whilst awaiting their turn to approach the runway in an orderly sequence for landing. The advances in technology previously described permit the safe holding or stacking of aircraft in busy terminal areas, for not only must an aircraft be able to hold its position in space within a tightly prescribed airspace but the controlling authorities must have sufficient confidence in the ground-based aid and the airborne equipment, to accept this fact. The accuracy with which aircraft are able to position themselves in these holding patterns also facilitates the movement of transiting or departing aircraft by enabling them to bypass the holding facility, often at the same level and whilst using a form of lateral separation. This type of separation is applied in the firm knowledge that the navigational aids being used .

Radar

Introduction

The term "Radar" was derive from an acronym of the phase radio deteection and ranging.

In explaining the facilities which a controller has at his disposal, we now come to the most significant advance in technology which, although it had its origins in the Second World War, was not exploited as a 'tool' of air traffic control until the late 1950s, and in fact its major impact as an aid to the separatiqn of aircraft did not really materialise until the mid 196Os. I refer to the advent of radar, both 'primary' and 'secondary'.

The use of radar as a means of assisting aircraft to land, had, however, been pioneered in the United Kingdom by the Royal Air Force, since the first of the ground approach control (OCA) sets arrived in this country from the U.S.A. in 1942 accompanied by its mentors, Dr Alvarez and Dr Comstock. In fact, prior to the development of the instrument landing system (ILS) referred to in the earlier chapter, the talkdown controller, as he became popularly known, was a key member of the approach control team at many international civil airports, and it was indeed a very famous sight to see the two OCA caravans moving from one runway to another, whenever a change of wind also dictated a change of runway. To pay tribute to this past band of stalwart talkdown controllers and technicians, I should mention that at that stage of development the OCA trucks, which were prime movers, had to be very precisely positioned alongside the runway in use. Working inside the operational truck, which was very small indeed, took place in almost total darkness and controlling was conducted from two cathode ray tubes, each 6 inches only in diameter. One tube was used for a 360 surveillance of the immediate vicinity of the aerodrome and was used by the director to locate the aircraft and feed it into the azimuth and elevation funnel of the talkdown controller's display. The talk-down controller was assisted by a 'tracker' whose task was to servo the two aerials (azimuth and elevation) onto the aircraft's response, and then the controller, who was able to view the aircraft's response in glide angle and displacement from the runway centre-line through an ingenious arrangement of silvered mirrors, literally did talk the aircraft down onto the runway. In the early days of aviation expansion all of the staffs of these OCA trucks did a magnificent job, and I count myself fortunate to have been amongst them. We did not, of course, in those days concern ourselves overmuch with the 'Factories, Shops and Railway Premises Act'. Later developments, however, enabled the runway guidance elements (azimuth/elevation) of the OCA to be remoted to the approach control rooms, where it be- lets. A particular phenomenon is the effect of temperature creating a radio duct, resulting in mirror images of targets from a longer distance being shown at a shorter range; these are popularly known as 'angels'. Much of this unwanted 'clutter' can, however, be suppressed by sophisticated processing of the returning signals within the radar. The range at which a target can be detected depends upon a number of parameters, of which the power output of the transmitter, the frequency of the signal, the gain of the antenna and the quality of the receiver are most important. The radar set generates bursts of radio energy, known as pulses, and it is the frequency at which these pulses occur, known as the pulse recurrence frequency (PRF), allied to the power output, which characterises the radar.

Many readers wilt no doubt have heard of the tertns 'X band', 'S band', 'L band' to describe the different frequencies of operation. In very general terms:

(I) J *and KU Band* represent very short microwaves and would be used in equipment such as ground surface movement detection (e.g. aircraft and vehicles moving on the surface of an aerodrome, where very high definition is required). This frequency, however, suffers high attenuation in rain and is therefore a short-range device.

(2) X *Band* represents short microwaves and is used in precision approach radar (PAR) and marine systems, where good detinition is needed and only medium range.

(3) S *Band* represents medium microwaves and would be used in equipment such as terminal and approach control radars (e.g. for the sequencing of arriving and departing aircraft, where it represents a corn-promise between good definition and medium range).

(4) *L Band* represents long microwaves and would be used in equipment such as area or en-route radar (e.g. for the control of aircraft over long distance such as airways, where long range and immunity from weather are more important than high definition).

Radar signals are 'line of sight', which means that the further away an aircraft is from the transmitting antenna, the higher it must fly to remain within radar cover. Also the shape and size of the antennas are extremely critical to the task the radar is required to perform, and to the desired vertical and longitudinal coverage.

These then arc some of the factors which have to be taken into consideration both by the manufacturers and users of radar.

Through the courtesy of one of these manufacturers, Plessey Radar Ltd, Figure II shows a modem radar antenna, which operates on 'S' band frequencies, and would be typically used for approach and terminal area radar control purposes. Mounted on top of the primary radar antenna is a secondary surveillance radar (SSR) antenna, which is a subject discussed later in this chapter.

It is emphasised, however, that the foregoing is a very abbreviated and simplified

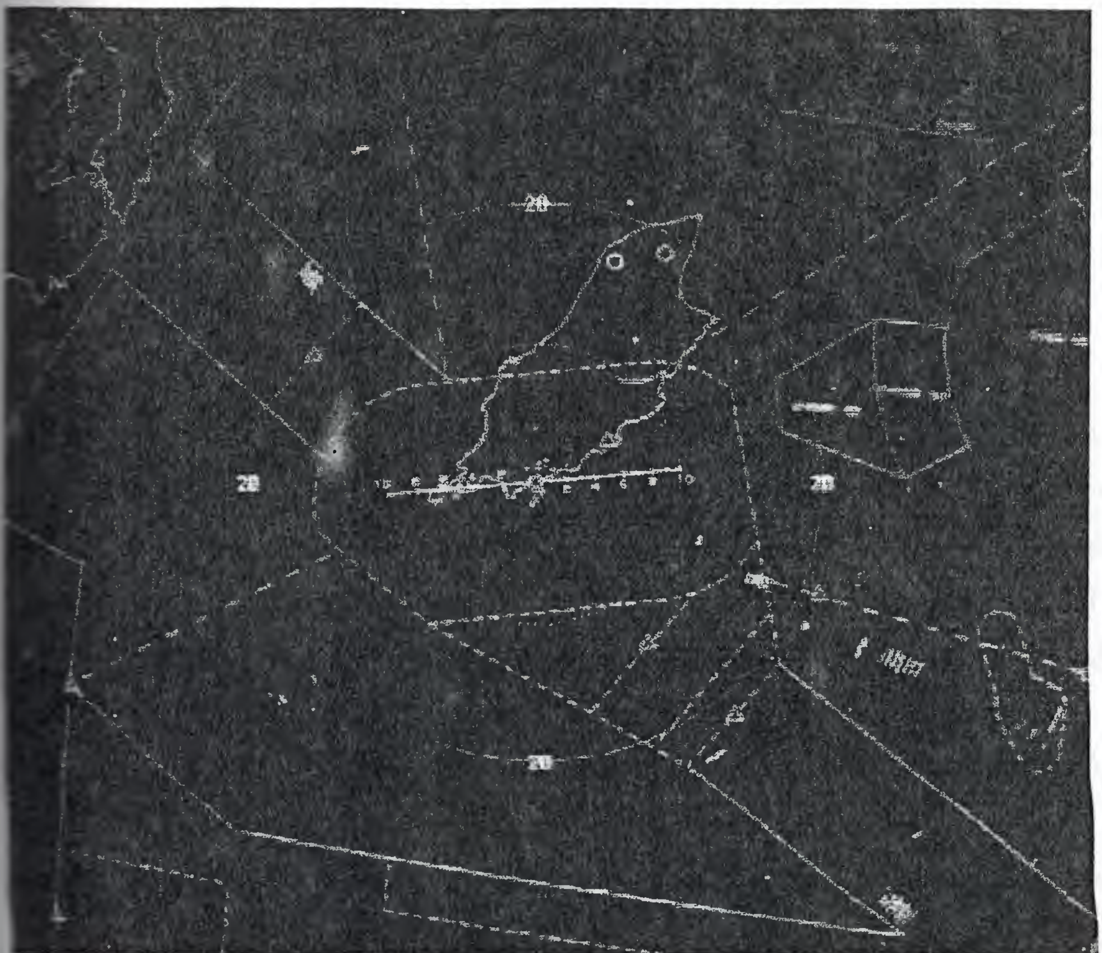


figure no?

explanation indeed of the properties of radar, and a reader or student who wishes greater knowledge is advised to read the many excellent textbooks on radar theory.

Radar displays

The purpose of the radar is to provide the radar operator with an indicator or display upon which the information made available by the radar system can be interpreted by him as easily as possible. The best known of these displays is called the plan position indicator (PPI), which in effect is a radar map of the area of coverage. The radar antenna represents the centre of the map and the radar echoes or 'blips' appear as bright spots of light on the surface of the display. Whilst radar displays have today reached a highly sophisticated stage using digitized/computerized techniques, it is considered it would be of more general interest at this level of introduction to use as an example the standard form of display based upon the cathode ray tube (CRT) (Figure lOb).

The cathode ray tube, which is also used in domestic television sets, is a device which produces electrons in the form of a stream, from a source called an 'electron gun'. This stream of electrons can be controlled in such a manner that the information derived from the radar can be displayed on the screen. The stream of electrons is first focused into a narrow beam which appears as a bright spot on the fa£e of the tube and can then be moved about by the use of deflection coils, and therefore made to follow the movement of the antenna. The gun can be switched off to simulate those areas where there are no signals, and then switched on again when an echo is received, so indicating its position on the tube. The inside ~urface of the face of the tube is usually coated with phosphorus, permitting sufficient 'afterglow' to permit the most recent position of the spot to persist for a short time, and thus show the track of the aircraft. This will, however, be accomplished in the future by the use of digital memory techniques.

The plan position indicator uses a cathode ray tube to provide a plan view of the reflected responses from aircraft. This plan view is obtained, as was explained earlier, from a knowledge of the range and bearing information sent from the antenna. As the antenna is continuously rotated it is possible to introduce onto the display range circles which illuminate on every sweep of the antenna. This sweep around the tube face is known as the 'time base' (Figure12) it is then possible to introduce, onto the display, bearing mark lines, which enable the radar operator to determine the bearing of the echo from the antenna (Figure 13), also a map outline known as a video map which can show features such as coastlines or the position of airways, airports and navigational aids. Thus the radar operator is able to establish the precise position of the target aircraft, and having carried out an identification procedure, direct the aircraft to any position within the coverage of his radar. A more detailed description of the facilities which are available on a modern radar display console, is given in Chapter 8, 'Automation and Air Traffic Control', in the section dealing with 'The display of radar-derived data'.

The basic principles of secondary surveillance radar (SSR)

Fascinating as primary radar may be, it is the advent of secondary surveillance radar (SSR) that has escalated the techniques for the processing of radar data and the application of computer technology, towards the development of automated air traffic control systems. In fact, from the point of view of controlling air traffic the introduction of SSR has been the most significant advance since the application of primary 'radar.

As stated earlier, primary radar works by reflection, from an aircraft, of radio pulses transmitted by a radar station on the ground. From this reflection can be detected the direction from which it returned and the time taken to return. The returning echo is, however, extremely weak, and requires considerable boosting and refining before it can be processed through to the radar display. The greater the range of the aircraft the higher the transmitted power must be, to try to achieve as many strikes (pulses) upon the aircraft as possible.

There are, however, penalties associated with increases in power output, which are rather complex to detail in this explanation, but whilst there exist some very good counters to these penalties, high-technology solutions are equally highly priced. Even so, primary radar alone is no longer able to satisfy the requirements of modern ATC systems, which must have instantly available information that is both accurate and reliable. This requirement is able to be satisfied by the fact that the aircrafi itself is able to co-operate with the ground-based radar system. That is, it can carry its own airborne equipment, known as a 'transponder', which is capable of communicating with the ground-based SSR system.

The 'transponder' is one of the well-known 'black boxes' which is caffled in the aircraft and operates in much the same way as the wartime 1FF (identification friend or foe), but now gives more information to the controller. The transponder is activated by pairs of pulses transmitted by a ground interrogator, and its reaction is to transmit a 'train' of pulses on a different radio frequency to the SSR interrogator receiver on the ground.

Because the transponder is not relying upon reflected energy from the aircraft to provide a radar echo, but is making a full-blooded reply itself, this enables the transmitters on the ground to be of lower power and employ simpier and cheaper technology and also ensure a certainty of signal return, unaffected by weather or other clutter factors.

Also the returning train of pulses from the aircraft can be coded to contain data pertinent to that specific aircraft such as, for example, the identity of the aircraft and the height at which it is flying. This factor gives the SSR receiver and its computer processor the ability to separate and identify different targets in a manner that the primary radar cannot do, and then be able to compute additional information such as the speed of the aircraft and its flight attitude, all without recourse to any radio telephony speech with the pilot, other than an initial request to select a special group of code numerals on his SSR select panel in the cockpit. Figure 14 provides some idea of the type of information which can be presented on radar displays, where SSR is being used, either singly or in conjunction with primary radar.

It will be dealing with the application of automation later in the book, under which heading I will endeavour to explain how the information derived from SSR forms the basis of modem ATC systems. However, to give an idea of the vast difference between primary radar only, and primary plus secondary, I have included two figures. Figure 15 shows a typical primary display of aircraft targets. It is interesting to note that in the early days of the application of radar the standard method of achieving identification was to request the pilot to make a 90 turn from his present course, hold it for 1 minute and then make a further
turn, back onto his original course. To confirm that the radar response was in fact the concerned aircraft, both turns had to be observed by the radar controller who then, using a chinagraph pencil, marked the face of his display with the aircraft's identity and continued to plot its course on the display. It is easy to imagine that pilots were none too keen to follow this tedious manoeuvre, and it is only surprising to recall that so many did so, to assist in the development of ATC techniques. As a complete contrast Figure 16 shows a modern digitised radar display, upon which appears not only the outlines of the geographical area under radar surveillance but also, alongside the aircraft's radar response, its identity and the height at which it is flying. There were of course many stages of development before ATC arrived at these techniques, but it is a truly remarkable development by any stan-dards.

The role of radar in air traffic control

Before leaving the subject, and although I will be dealing with its detailed application later, it might be worthwhile to consider the role of radar in the control of air traffic. In the section dealing with 'Separation standards' I mentioned radar separations, and in regard to their application it is essential to recognise the two following fundamental principles.

(I) radar is primarily used by air traffic control to reduce the separation between aircraft and by so doing enable more air traffic to be controlled in a given airspace; and

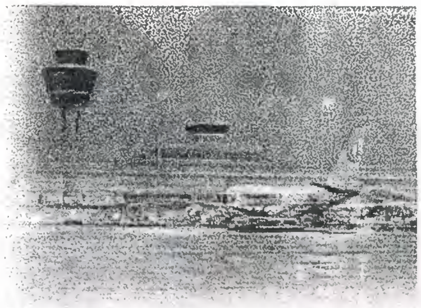
(2) there haS to be in existence a basic ATC system which can be readily employed in the event of the failure of the radar element or part thereof.

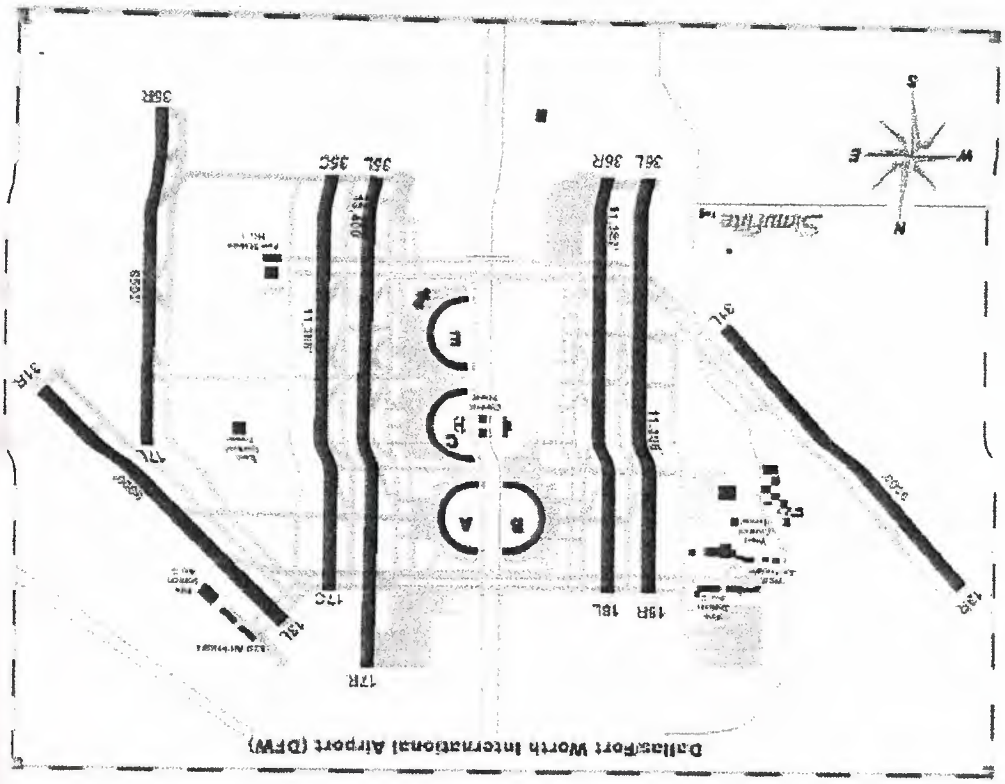
In general terms the operational role of an approach/terminal area radar can be described as the provision of a service for:

IC control of air traffic overilying or trantting the approach terminal area;
te guidance and sequencing of arriving affic, either onto a pilot-interpreted inrument landing system or a precision aproach radar (PAR);
te sequencing of aircraft departing from te aerodrome until either handed over to ~ area control centre, or until clear of the.)proacb/terminal area, or until control is ansferred to a military air traffic air dence authority;
e provision of an approach control 5cr-cc to one or more adjacent aerodromes
e provision of a radar advisory service, here this is required, within the area of dar cover.
rry out these tasks, not only is an area of ry radar cover of approximately 60 nautiiles up to a height of 30,000/45,000 feet, but also the radar must have the ility to detect

- ***assists***

  in the development of airport capacity to meet growing demand;





responses from aircraft ',h 'fixed' and 'moving' clutter returns.
mentioned previously 'fixed' clutter is ced from energy sent out by the transmit3ich is then reflected back to the receiver, tionary objects such as airport buildings the immediate vicinity of the aerial or high ground which penetrates the 'PC of the transmitted power. 'Moving' is usually produced by weather, such as lection of energy from rain droplets.

Vital for the safe control of air traffic, radar separation is being provided, that dar sensor which is being used for this je has the ability to continue to detect sponses from aircraft targets through ireas of clutter returns. Of equal import-the capability of the radar to be able to ['mate between aircraft targets, throughie range of the primary radar cover, d by a manufacturer. For, apart from riety of speed ranges of modern aircraft, radar reflecting area can vary from a 'odied passenger aircraft to a light private aircraft, or in a military sense from a heavy air transport to a supersonic fighter aircraft. But whatever the size of the target aircraft may be; it is the responsibility of air traffic control, when providing a radar service, to ensure the safety of that aircraft in relation to all other air users within the area of responsibility of the particular authority. To do so the radar controller requires continuous and precise target information and the elimination of as much of the unwanted interference as modern technology can provide.

Secondary surveillance radar (SSR/IFF) does, of course, materially assist in the resolution of these problems, but provision still has to be made for good solid primary radar cover, in the approach/terminal area environment, for a variety of reasons, including those occasions where the carriage of transponders may not yet be a legal requirement, or where from a military point of view the radar is required to operate in a hostile or semi-hostile environment.

It has to be accepted, however, that most modern air traffic control systems, both civil and military, rely heavily upon the fact that the air traffic for which they are responsible is cooperative; that is to say, that the aircraft are fitted with an airborne transponder. In fact many states now require aircraft flying at or above certain heights to carry a serviceable transponder as mandatory equipment for receiving an air traffic control service.

The foregoing principles apply equally to area radar control, that is the airspace outside the approach and terminal areas, which contain the airways and air routes. The primary radar, however, needs a much greater power output to achieve the desired range and height. It is nonetheless interesting to observe in this regard that, apart from the understandable military requirement of long-range primary radar cover, civil air traffic control authorities are likely in future systems, to rely upon the extended cover provided by SSR to cater for

their area radar requirements. For example, the quoted range of primary radar cover which I gave for an approach/terminal area radar of 60 nautical miles, would be extended to between 120 and 150 nautical mites with the addition. of an associated SSR installaflon therefore, as modern ATC systems are becoming increasingly dependent upon the carriage by aircraft of SSR transponders, it seems sen-

sible and economic to take advantage of the increased range of cover, which is provided by this facility.

In my Preface I made mention of the fact that tht control of air traffic is operating in a continually changing environment, and readers may find that this paragraph on radar underhnes that statement more than any other.

Flight Planning and Flight Data

The prior notification, by the pilot of an aircrafi, of the details of a proposed flight, has two basic purposes.

(1)That should he desire to, or be required to, receive an air traffic service, prior information is essential for the provision of that service; and

(2)In the event of an accident or incident the information contained in this notification is vital to the success of the search and rescue services (SAR)~

This notification of the pilot's intentions can either be *'booking-out'* if he does not wish to, or is not required to, receive an air traffic service, or the filing of a *flight plan;* which is a mandatory requirement for certain types of flight. Apart from this mandatory requirement pilots can still file a flight plan, and are certainly advised to do so, if intending to fly more than to nautical miles from the coast, or over sparsely populated or mountainous terrain The difference between 'booking-out' and filing a 'flight plan' is that with a flight plan all of the information it contains is passed to the air traffic services units concerned with the routc the flight, whereas the information contained in the booking-out procedure remains at the aerodrome of departure.

As, however, we are concerned with explaining the provision of air traffic services, it is those categories of flight, which are required to submit a flight plan which are our concern.

I sho4ld make the point, before proceeding to detail what a flight plan is and how it is used, that a pilot who has not filed a flight plan at his departure aerodrome can still file an airborne flight plan, provided he gives adequate warning and passes the required information to the concerned air traffic services unit (ATSU).

The flight plan

The application of air traffic control is dependent upon a knowledge of the aircrafl's present position and the intentions of the pilot-in-command. A vital factor in the provision of this service, and one from which all subsequent data acquired during the course ofan aircraft's flight corrects or amends, is the filing ofa flight pian~

The flight plan is an internationally agreed document, which, for ease of transmission and understanding on a world-wide basis, is prepared in a standard format. The types of flights which are required to submit flight plans are also agreed internationally and are set out in ICAO rules of the air (Annex 2). As a general guide however, the requirement can be described as follows:

A flight plan shall be submitted prior to operating:

(I) any flight, or portion thereof, to be provided with an air traffic control sen'ice;

(2) any instrument flight rule ([FR) flight, within advisory airspace;

(3) any flight within or into designated areas, or along designated routes, when so required by the appropriate ATS authority, to facilitate the pronsion of flight information, alerting and search and rescue services;

(4) any flight across international borders.

These rules may vary somewhat in interpretation by the contracting states of ICAO when translated into a particular state's air navigation orders (A~O), but my experience is that these variations are minor in nature and the intent of the rCAO rules are applied worldwide.

I should like to underline the fact that the wording says 'prior to operating'. As I have previously stated ATC requires to have prior information of a pilot's intentions, therefore the submission of a flight plan before the departure of an aircraft is required to take place at least 30 minutes prior to the estimated departure time (ETD) of the concerned aircraft. In fact some states, of which the United Kingdom is one, require 1 hour's notification, if the aircraft's flight is operating into or through that country's complex route network.

I shall be dealing at a later stage with the application of automation, but as it will occur to readers, particularly those who fly by scheduled airlines, that many of these flights are repetitive in nature and operate on a published timetable, the filing of a flight plan for each flight would be a very cumbersome process. To

assist in this administrative requirement many states have adopted a procedure whereby, if the flight has a high degree of stability and operates at the same time/s of day(s) of consecutive weeks and on at least ten occasions without change of details, then a single repetitive plan can be filed. There is a further procedure which provides for the amendment of such flight plans and for the notification of the change of details to the other states which are concerned with that particular flight~ One of the advantages of this method of flight planning is that, where a computer is being used to assist the air traffic services, the information can be placed in what is termed the 'bulk store' and the computer programmed to bring the relevant details forward at a predetermined time.

I should now like to explain the details which a pilot or his representative is required to insert on the flight plan. they are:

(1)Aircraft identification;

(2)SSR data (code etc.);

(3)The type of flight rules under which the pilot proposes to operate;

(4)Type of flight (e.g. scheduled/general aviation/military);

(5)The aircraft type;

(6)The aircraft's callsign;

(7)The aerodrome of departure;

(8)The estimated time at the FIR boundaries;

(9)The aircraft's cruising speed;

(10)The desired flight levels;

(11) The proposed route of flight;

(12)The aerodrome of destination;

(13)The alternate aerodromes;

(14)Other information pertinent to the flight such as the aircraft's endurance, the number of passengers. the type of survival equipment carried.

Figure 17, which has been reproduced with the kind permission of ICAO, is a completed copy of a flight plan, depicting a flight from Rotterdam (EHRD) to Lisbon (LPPT). In the

paragraph dealing with the teleprinter network I mentioned that it is through this system that flight plans are addressed to all the ATC authorities concerned with the conduct of a specific flight. The route followed by this aircraft takes it through the airspaces controlled by Amsterdam (EHAM), Brussels (EBEB), Paris (LEFF) Biarritz (LFBZ) and Madrid (LECM) and you will note that all of these units are addressees of the message. I should mention that the four-figure codes which are used are the international designators of the telecommunications network, usuatly in this instance, aerodromes and air traffic control centres.

Before leaving the subject of the flight plan I mentioned that it was also possible to file an airborne flight plan. This situation usually occurs where an aircraft, in flight, wishes to cross or join an airway or penetrate controlled airspace for the purpose of transitting or landing at an aerodrome within the confines of that airspace. Also, in some parts of the world aircraft are permitted to fly in some designated airspaces, in accordance with visual flight rules (VFR); however, due to either traffic density or adverse weather conditions a pilot can decide to change the nature of his flight and seek the protection of an air traffic service. In these circumstances the pilot is required to give minimum notice, usually not less than 10 minutes, of a request for an air traffic clearance. The information which the pilot is required to pass to the ATC authority is in the form of an abbreviated flight plan and the content will depend upon the traffic circumstances existing at the material time and the complexity of the routeing desired by the pilot.

Flight data

The word 'Data' is relatively new in dictionary terminology but as far as its use in our particular aspect of aviation is concerned, it means the gathering of intelligence, in regard to the flight of an aircraft, both prior to and during the course of that flight. It is the gathering of this intelligence and the actions based upon it that forms the fabric of a system whereby control can be exercised. In this context there are two basic forms of 'data', 'radar data' and 'flight data'.

From the earlier paragraph on radar, readers will be aware of the manner in which intelligence is gathered, by both primary and secondary radar, and then presented to the controller on his display. This intelligence is known as radar data. However, radar data alone would be almost incomprehensible to the controller without the existence of flight data, to enable him to interpret the information presented to him on his radar display. At this point in the development of air traffic control systems it is also necessary to draw attention to the fact that many parts of the world, and even parts of sophisticated systems, do not enjoy the benefit of radar coverage, but nonetheless, an efficient and safe ATC system must operate within these areas. It does so because of the presence of the flight data which exists as a basic foundation of any system.

Whilst I shall be detailing later the various air traffic services which are the responsibility of air traffic control, they can for the purpose of this chapter of the book be broad-banded as follows:

(1) aerodrome control; (2) approach control;

(3) terminal area and area control.

To underline the importance of flight data, I wish to point out that it is only the first of these, 'aerodrome control', where the controller physically sees the aircraft he is controlling. in all other aspects of the services he provides, the controller has td 'imagine' the aircraft he is responsible for, by building up a mind picture of the air situation under his controi and from this mind picture, assisted by a flow of data from various sources.

Automation and Air Traffic Control

Before I proceed to explain how the facilities and procedures which I have previously described come together to provide an air traffic control service it would, I consider, he of value to examine the role of the computer in its application to modern air traffic control systems.

~r first problem is to ranonabse the words 'automation' and 'computer'. The dictionary describes 'automation' as, 'a piece of mechanism with concealed motive power' and 'computer as 'a calculating device'. Personally I think both these descriptions are in need of revision and therefore, whilst risking the wrath of linguistic experts, I propose for our purpose to regard automation in this context as the result of the application of computer techniques to specific Arc processes. The second problem is how to approach an explanation of the subject. There are so many computer devices available today, even for application to domestic appliances and leisure games, that I suggest the only reasonable way is to approach it from the point of view of the user. In other words, what is the computer and its resultant automation doing for the controller.

In Chapter 5, I explained the principles of primary and secondary radar and how secondary radar can be used to provide the controller with information on the identity and height regarding those aircraft responses which are of concern to him. Coflectively this information is known as *radar datd.* In Chapter 6, 1 cxplained about *flight data'* and how computers are used to assist in the prepa~ation of flight progress strips, and in the low of information between those air traffic control units which are concerned with the conduct of the flight of a particular aireraff. It is then these two elements, radar data and flight data, which form the basic ingredients for the application of computer technology, and I now propose to explain how these elements, when computer-assisted, form the basic foundations of an automated ATC system. For ease of understanding and to eliminate continuous back-referencing, there will of necessity be some reiteration of pans of the information contained in previous chapters in the explanation that follows.

The computer

The computer, although a versatile machine with an immense capability, is inherThe computer ently an unintelligent device, which cannot
of a standard foundation. It is advisable also that the associated 'hardware' and 'software' philosophy should, if possible, be based upon a 'stage-by-stage' build-up principle. The advantageS of this approach benefit not only the operators and technicians who have to use and maintain the system but also those ATC authorities who do not require fully advanced sophisticated systems, either for air traffic or economic reasons, at a specific point in time, but who would be able to build-up their system further should occasion so demand.

It should not be necessary to install the complete system before any advantage can be obtained from it. Every attempt should be made to design the first stage so that by development and addition, rather than replacement, the system can be made capable of performing more functions, or
of performing them in a different manner.

This sounds a very simple and logical statement to make, particularly as computers are relatively expensive pieces of hardware in economic terms, and the preparation of their related software routines, equally demanding in hours of dedicated manpower. Regrettably, however, it is a statement which is oflen overlooked, possibly for good reason, by both the customer, the concerned aviation authority, and the provider, the avionics industry. I appreciate that it is not always possible to follow good intentions, particularly when they are formed for international application. However, I hope that at least by discussing, in this chapter, the application of automation to air traffic control, concerned readers will gain an understanding of the major elements which are of concern in this development of automation and its associated avionics, for these developments perform even a single function without being told, in almost infinite detail, precisely what to do in a logical step-by-step manner. Telling the computer what to do in the form of a 'program', translated into computer language, requires that the 'functions' to be programmed are understood and examined in detail. These programs, when translated into computer language, are known as *'sofiwaTe'* and the computers themselves are, not surprisingly known as *'hardware'*.

In considering the application of the techniques of automation to the processes of air traffic control it is essential to have an understanding of the basic Arc system of operation and of those functions to which it is intended to apply these techniques. It is also desirable to appreciate why the need for automation exists and what the advantages are, to both controllers and pilots, of its introduction into an air traffic control system. From an air traffic control point of view these advantages can be briefly summarised as the handling of repetitive tasks, to ensure that the right data, in the right form, are in the right place at the right time, with the objective of reducing the workload on the controller by relieving him of these repentive manual tasks.

As a generalisation there are three recognisable elements in the application of automation to this particular discipline. they are:

.(1) Flight data processing;

(2) Radar data processing; and

(3) The correlation or marriage of flight data Processing

(4) And radar data processing.

Within each of these stages there are variants and the stages can he, and often are, telescoped and, of course, the air traffic Automation and Air Traffic Control be successful in the future, to replace this ubiquitous piece of paper by, for example, an electronic data display (EDD) but as the present flight progress strip represents to the controller a three-dirnensional display in time, height and geographical position, continuously updated by 'live' information, it will be apparent that its replacement promotes a challenging problem both for the computer software routines and the controller/computer interface.

Flight data processing

The foregoing sections have set out, in general terms, the functions of air traffic control and the relationship of the flight plan and flight data to these functions. The reason for so doing, is to try to illustrate that they are functions which are general to any location, and therefore should be capable of forrning the basic foundation of any approach to system automation; from this software routines can then be developed to suit the requirements of specific locations.

Flight data processing, then, is that function which is concerned with the input into the computer of the flight data which have originally been extracted from the flight plan, and thereafter the updating of this computer information by reference to the 'live' or 'active' situation, and readers will recall that a detailed explanation of the computer's role in flight $ata processing was given in Chapter 6. The activation of the computer can be carried out manually, by a controller or other member of the control team, either by the use of an 'input' keyboard, known as an ANK (alpha-numeric

keyboard) or alternative devices, such as, for example, a TWD (touchwire device). Whatever the system used, however, the person operating 'input' device must in the first instance identify to the computer the particular aircraft's flight data, which are stored in its memory, and to which the update message is to be addressed.
It is also possible to activate and update the flight data carried in the computer automatically, by correlating it with the radar data which are being received by the radar sensors. How this is achieved, and the consequences of this marriage of flight data and radar data, will be subsequently explained.

Radar data processing

The term 'radar', an acronym of the phrase radio detection and ranging, and the range and bearing signals which are received by the antenna are in 'analogue' form. Whilst all signals so received require to be processed before being transmitted to a radar display, the term 'radar processing' used in this chapter is in respect of the processing of the received radar signals and their relationship in regard to computers. Technically, computers are concerned only with those radar signals which relate to responses from aircraft, and it is therefore unnecessary and uneconomic to feed them with all of the unwanted echoes which occur as a radar antenna sweeps through 360~, out to the range of its transmitted power. To be able to achieve this situation the radar signals of the concerned targets require to be convened into a digitised foirnat. In this form the radar signals, or radar data, can be fed into a computer, to be either displayed directly onto a radar display or, if the computer has the capacity or is linked to an additional computer containing the relevant flight data, then both types of data can be correlated before being funher processed onto the controller's display. In this regard there are many occasions where the radar transmitters and receivers are located at a considerable distance from the control positions. In these

control systems to which they are applied will vary from state to state and often within states themselves. There are, however, within the ATC and flight radar data functions a sufficient number of common factors which, when evaluated, form the basis when radar was first introduced to assist in the control of air traffic, the standard controller's viewing unit was a cathode ray tube (see Chapter 5' 'Radar') upon which the echoes of aircraft appeared as 'blobs' of light, known as radar 'responses'. Identification of these responses, to ensure that they were indeed the aircraft of concern to

laborious business of through 90' and then Direct observation of

the controller, was a turning the aircraft turning it back again. the viewing unit and notation of *borh* turns was essential to confirm that the response was indeed that of the concerned aircraft

The prime objective of the use of automation in this regard is to assist in this process of identity, by placing alongside the particular response a *'label'* which carries, in written characteristics, the identity of the response and other pertinent data, which will be explained later.

To be fully effective the concerned aircraft needs to carry an airborne SSR transponder and in many areas of the world's airspace the carriage of this equipment is increasingly becoming a mandatory requirement.

Methods do exist, however, for alerting computers to the requirement to display responses from aircraft not so equipped, or alternatively for overlaying responses from transponder equipped aircraft on viewing units which are displaying radar responses, of both primary and secondary targets.

The radar viewing units have also changed dramatically from the original cathode ray tube. It is usual, in ATC units to which this type of automation is being applied, to use a synthetic' type of radar display. Synthetic displays, whilst being a processed representation of the signals which are being received by the radar sensors, have the advantage that all responses, irrespective of the weakness of the returned signal, can be displayed at a constant level of brilliance and clarity.

In fact, the displays which are available today, for use by radar controllers, are truly remarkable pieces of equipment and although I shall be explaining their operational setting in Chapter 9, 'The ATC environment', I consider it would be of assistance, in this present chapter on automation, to spend a short time on a brief explanation of the main characteristics of a modern radar controller's display console, for without the facilities which these display systems provide it would not be possible to apply the automated techniques described in this chapter.

In describing these facilities, it is essential to include not only the display upon which is portrayed the air traffic, and which is the controller's 'viewing' unit, but also the furniture in which the display is housed, known as a console. The console of the type of equtpment I am describing contains a high proportion of the avionics which are essential to provide the controller with the interface between his operating position and the radar data and flight data contained within the ATC system, and also with the capability to interpret, alter or add to the information on his display, and to co-ordinate automatically with other operational positions contained within the system. Therefore the display and the console are an integral unit and, not surprisingly and quite simply, are referred to as the 'display console'. With the kind permission of the Displays Division of Plessey Electronics Systems Ltd I have included the photograph in Figure 23 which clearly demonstrates the integrated nature of the display and the console, Figure 24 shows a close-up view of the control function keys and the input keyboard, associated with the display console.

This particular equipment contains within the console its own computer, which is capable

The Air Traffic Control Environment

Before proceeding to give an explanation of the control of the flight of a civil aircraft operating within an air traffic control system, I should like to try to convey something of the environment within which air traffic control operates. In the previous chapters 1 have explained the rules, the procedures and the technical equipment, which must all come together to form a foundation for the application of the art of the control of air traffic. Not all of the facilities described are of course necessary at all of the ATS units providing air traffic control services. These facilities can range from radio telephony and the telephone. at a small aerodrome operating within its aerodrome traffic zone, to the availability of instrument landing facilities, radar, computers and sophisticated communications and air trafbc displays at the busier aerodromes and at air traffic control centres situated in a complex of airways and terminal areas/control zones However, for the purpose of conveying an atmosphere, it is necessary for me to use as a background the latter situation. To do so I will proceed from aerodrome control to approach control and then to area control. It should also be appreciated that the operating positions I describe will doubtless vary from one location to another. A further factor which I should mention at this stage is that in some states, and the United Kingdom is one, all aircraft which are operating within controlled airspace must do so in accordance with instrument flight rules. What this means is that, irrespective of the weather conditions which are being encountered by aircraft, they must receive and adhere to an air traffic control clearance, and the separations standards explained in Chapter 2 are applied even though there may be unlimited visibility and not a cloud in the sky. Before the knowledgeable take me up on this point, there is one exception, and that is 'special VFR' flights, where, under certain specified weather conditions, visual flight is permitted in controlled airspace. These flights are described by 1CAO as 'a controlled VFR flight authorised by ATC to operate within a control zone under meteorological conditions below the visual meteorological conditions'. The authorisation of such a flight by ATC is dependent upon the traffic conditions which exist at that particular time, and a controller having issued a special VFR clearance is required to provide separation between that aircraft and all other special VFR flights in accordance with the minima prescribed by the appropriate ATS authority. Additionally he is required to provide separation between these flights and all other IFR flights in accordance with the separation minima as described in Chapter 2 ('Separation standards'). Other states do permit a mixture of VFR flights and IER flights within certain of their controlled airspaces. Pilots flying in accordance with visual flight rules, however, are only permitted to do so in weather conditions which accord with laid-down standards of forward visibility and of distance/height from cloud. These weather conditions must, of course, be maintained to continue VFR flight. But what it does also mean is that under these conditions the responsibility for avoidance of collision rests with the pilot of the VFR aircraft. Where an air traffic unit does have a radar capability they can, and . do, assist the pilots of IFR aircraft by passing information, known as 'radar advisories' on this VFR air traffic. A radar advisory is the passing of ~nformation usually in accordance with the 'clock code' in regard to the plan position of the target aircraft and details of its probable intended flight path, as observed from the radar display.

This subject of visual flying is one I shall return to in Chapter (1 on 'Airborne threat alert and collision-avoidance systems', but I have made reference to it at this stage, to add to the sccnario that does exist in many pans of the world, and which affects the general atmosphere of operation particularly at a busy aerodrome/approach control facility.

That having been said, my following explanation, and the narrative on the control of the flight of a civil aircraft that follows, ts set against the background of busy AT(: units, located within a close-controlled ATC system:

that is, where all aircraft in the system operate on an air traffic clearance irrespective of the weather conditions.

Aerodrome control

The modern aerodrome control room sits on the top of a concrete stalk, or on the top of a brick building, placed at as high an elevation as is permissible within the clearance angles of the aerodrome's runways. It is usually built entirely of non-reflective glass and the discerning airline passenger can often see disembodied heads constantly moving to and fro. Visitors are not normally welcome, for the very good reason that the room is surprisingly much smaller in area than one would imagine, and any unwanted physical presence not only adds to the congestion, but more importantly can obstruct the line of sight of the controller. Seeing, by eye, what is actually happening within the immediate environment of the aerodrome and on its surface is what this part of the ATC service is all about.

safety at aerodrome there would be two controllers: the air controller and the ground controller. From the division of duties between these two controllers which I described in Chapter 7 you will be aware that the *air controller* is responsible for aircraft which are flying in the vicinitv of the aerodrome traffic zone and for aircraft taking off and landing. As he is the officer responsible for issuing the clearances to aircraft to take off and land, he must ensure visually that his runway is unobstructed before issuing such a clearance. In many locations this can involve a single runway for the use of both departures and arrivals, and therefore it is a fine judgement whether or not to permit a departure in between a sequence of arriving aircraft which are due to land on the same runway. Re has to bear in mind not only that he has the correct spacing between the arriving and departing traffic but must also be aware of the route which the departing aircraft will he following immediately after take-off, and whether or not it is subject to wake turbulence in regard to its weight category, relative to the previous departing aircraft. To assist in this decision the problems in regard to their use in the close-in human eye can be aided by the distance from touchdown indicator (DFTI). This is a cathode ray tube type of display which is clearly view-able in daylight conditions and upon which the distance from the end of the runway is indicated by the response of the arriving aircraft, being displayed as a symbol on the tube, relative to the extended centre-tine of the runway in use. The centre-line is marked on the tube in distances from the runway threshold, and therefore the position of the aircraft's response will clearly indicate whether or not the controller has sufficient time in which to clear a departing aircraft from the runway, before the next arriving aircraft. To help him in this task the air controller will normally have the services of an air traffic control assistant, who will be receiving all details of the sequence of arriving aircraft from approach control, amending where necessary the flight plan information previously received, and in regard to departing aircraft, advising the parent air traffic control centre of the departure time, either by telephone or via a computer terininal.

As technology progresses in regard to the ability to view radar displays in daylight conditions. more and more visual control rooms will become equipped with surveillance radar displays, to assist the air controller in his observation of what the air situation is like in his immediate vicinity. Figure 25 shows such a display in use in the aerodrome control room of Austria's Vienna airport, and demonstrates the advance which has been made in this type of display in recent years. The display shown however in the photograph is a 'digitized' display, which is more easily adaptable to these conditions. Digitizing means that the radar responses from aircraft, have been electronically processed, usually at the radar transmitter and receiver, and as a result of this processing the aircraft's targets are reproduced as symbols on the radar controller's display. There are certain environment of an aerodrome, foremost amongst which is probably track titter', Track jitter is where the trail dots which appear be-hind an aircraft's position symbol to indicate its previous flight path history, move from side to side. This phenomenon can be disconcerting to controllers when they are radar-directing aircraft in the approach sequencing phase of flight. However, the advent of Monopulse SSR, which is described in Chapter 11, and the resultant improvement in tracking accuracy, which is clearly demonstrated in Figure 39, could matenally affect the use of digitised displays in the aerodrome environment. It has to be remembered, however, as stated earlier, that this display cannot be used for radar control purposes by the air controller, unless a separate controller is provided to carry out this task or alternatively the air controller's other duties. Additionally, the air controller must ensure that all arriving traffic is aware of any pertinent essential aerodrome mformation and also initiate any emergency action should this be necessary.

The *ground movements controller* is, as his designation implies, responsible for all movements on the surface of the aerodrome. He has to liaise with the aerodrome management in regard to the position at the passenger terminal, which is vacant to receive an arnving aircraft; pass this information to the aircraft and similarly give permission for engine startup and clearance to manoeuvre to the runway in use, in respect of departing aircraft. Like the air controller, it is essential for him to see as much as possible of the surface of the aerodrome, including its taxiways and exit points from the runway/s in use. To assist him he has usually the services of an air traffic control assistant, who will be receiving information on the flight plans of departing aircraft and liaismg with area control, for the essential en-route air traffic clearance, which has to be issued to the aircraft once it has started its engines .

Detailed Description of the Control of the Flight of a Civil Aircraft

In the earlier chapters 1 have explained the rules, the procedures and the technical facilities which are required to provide an air traffic service. In doing so I have emphasised that the level of facilities available to the controller depends to a large degree upon the amount and complexity of air traffic for which he is required to provide a service. However, for me to be able to describe as many as possible of the air traffic services and the technical support facilities, it is essential for me to use as a background a busy location. I have therefore chosen for this purpose the United Kingdom's London (Heathrow) International Airport, including its surrounding terminal area and airways route network. For international readers I apologise for the use of this particular geographical location, but it is an area with which I am familiar and therefbre should enable me to provide a reasonably accurate account of a somewhat complex operation. However, whilst certain of the procedures which I shall describe may vary at other geographical locations, the basic principles remain the same, and subject to minor procedural differences, the examples which follow reflect how air traffic is controlled on a world-wide basis, in a similar type of environment.

To enable me to provide a detailed description of the ATC operations I propose to take you through, in narrative form, the following phases of the aircraft's flight.

Departure - London to Manchester

(I) Pre-flight planning.

(2) Departure clearance - (aerodrome control ground movements controller).

(3) Runway departure - (aerodrome control -~ air controller).

(4) Terminal area transit - (area control - terminal area controller).

(5) En-Route airway flight - (area control - air-ways sector controller).

.(6) Manchester terminal area (Manchester sub-centre terminal area/approach controlicr).

(7)Manchester airport arrival - (Manchester air controller and Manchester ground movements controller).

Arrival - Paris to London (Heathrow)

(I) Pre-notification of aircraft's flight - (Area control - Paris and London airways sector controllers).

(2)En-Route airways flight - (Area control -the Paris/London inbound sector airways controller).

(3)Terminal area - (area control - terminal area controller).

(4)Approach phase - (approach control No.1 and No.2 radar directors).

(5)Aerodrome arrival - (aerodrome control -air controile?) (aerodrome control - ground movements controller).

Note:- Reference to Figure 22 (Chapter 7) demonstrates the ATC functions associated with these phases of an aircraft's flight.

In the previous chapter, 'The air traffic contro~ environment', I tried to convey something of the atmosphere which pertains in the locations which will be concerned with the phases of the aircraft's flight which I shall describe. Therefore it is my hope that this present chapter, when read in conjunction with its predecessor, will bring together in an understandable form, the various elements, previously described, which are essential to the art of the control of air traffic.

Also as this book is concerned with the control of military and civil air traffic, I propose, following the next chapters which deal specifically with the problems of civil/military co-ordination, to provide a detailed description of the air traffic control operations concerned with the flight of a military aircraft. The geographical location of this flight will also be the United Kingdom and I propose to link it to the description of the London - Manchester flight, described later, as one method ofdemonstrating the co-ordination of civil and military air traffic.

Finally 1 would ask readers to bear in mind that whflst the situation described, and the facilities and procedures employed, are correct at the time of writing, the application of new technologies and the requirements of increasing traffic may well alter the methodology of the events described. Also for the sake of the clarity of the narrative, only the main principles of the ATC operations are described. There are many detailed operating and co-ordination procedures specific to each ATS unit and to individual operating positions within that unit, but their inclusion would be confusing without adding to an understanding of the events described. I make the point, however, for my more learned readers, who will be aware of the multitude of unit supplementary instructions which, as their name implies, supplement the national instructions *(Manual of Air Traffic **Control)*** that exist to cater for the specific requirements of particular ATS units and/or for specific operating positions within those units.

The flight plan

All aircraft which are either required by law or who wish voluntarily to participate in the United Kingdom's national air traffic service are required to obtain, in advance, a clearance to do so. This prior notification normally takes the form of the filing of a 'flight plan'. The flight plan is a statement of the pilot's intentions and contains such information as the type of aircraft, its callsign, speed performance, destination and the height and route he wishes to follow. The flight plan is usually filed at the pilot's aerodrome of departure but provision is also made for filing 'in-flight' for aircraft who wish to enter the ATC system whilst airborne of the Control of the Flight of a Civil Aircraft from destinations which may not be served directly by the system.

Many airline operators do, of course, fly regularly over the same route, and to prevent continuous paper repetition of this data, information on these flights are permanently stored in computer memories. Similarly, to assist in the extraction and presentation of this flight data to air traffic control, computer techniques as described in Chapter 6, are now used to carry out many of these tasks which were previously discharged on a manual basis. The use of flight plans and associated computer techniques is somewhat complex and subject to considerable variation from one locality to another. To try to illustrate the workings of the ATC system in a reasonably simplified manner it is therefore proposed, as stated in the Introduction, to describe a flight departing from Heathrow bound for Manchester and a flight arriving at Heathrow that originated in Paris. In both of these examples computer technology plays a vital role, and I hope to demonstrate how aviation authorities endeavour to provide their ATC services with the latest in modern methods to assist in the discharge of their functions.

Heathrow departure

For a departure of a scheduled airline operator from Heathrow to Manchester a copy of the flight plan will have been stored in the computer memory and that memory will have been programmed to activate the flight plan approximately 40 minutes before the estimated time of departure, which had previously been inserted on the flight plan, to concur with the operator's published timetable. The computer is housed at the London air traffic control centre, West Drayton, and the manner in which it reacts to this memory activation is to print out fight progress strips at each sector through which the aircraft will fly on its route to Manchester, including one for the ground movements controller in the tower at Heathrow Airport, where a tail-off from the parent computer is positioned. These flight progress strips provide the controllers with the basic data they need to plan the movements of air traffic prior to the application of radar techniques. The information printed on them by the computer enables the controller to see at a glance the identity of the aircraft, its departure point and destination, the height at which the aircraft would like to cruise, and the speed at which it will be flown.

When the passengers are aboard the aircraft and it is ready to move out from the terminal buildings the pilot initiates a radio telephony call to the ground movement controller in the tower. The ground movement controller, who has already been alerted to the pending aircraft movement by the computer, issues to the pilot taxiing instructions in regard to the route to be follqwed to the runway in use and also the secondary radar code (SSR) which the pilot is required to select to establish his identity when airborne. Whilst the aircraft is in the process of taxiing the controller obtains from the terminal departure controller, who is situated at the London centre, a clearance for the aircraft to depart in accordance with the pilot's flight-planned request.

At an aerodrome such as Heathrow, which has a very high movement rate, there are detailed variables to this procedure which are arranged to prevent an aircraft starting its engines too early, or to regulate the traffic where delays in the system may require flow control to be imposed. Also the procedure for requesting an individual clearance from the terminal area departure controller can be dispensed with. which permits aircraft to free-flow on the appropriate standard instrument departure (SID). This procedure is based upon the premise that the terminal area radar controllers can accept all of the departures which the aerodrornes can generate. Resort to individual requests for departure clearances, then onlyoccur if there is any reason to anticipate any overload either upon the terminal area sectors or the airways sectors which they serve. The individual request for a departure clearance has, however, been described to demonstrate the link between the aerodrome and the area control centre. The clearance when issued will contain instructions to the pilot stating the route he has to take out of the terminal area, the navigational aids to follow and the height at which to cross them; also when he can cornmence climb to his cruising flight level and the airways to proceed along on his flight to Manchester. Within the London area these clearances arc standardised and are known as standard instrument departure clearances (SIDs). They are published in documents avail-able to pilots and alleviate the need for lengthy R/T messages. These Sibs also contain any noise-abatement procedures which may be conditional to the use of a particular runway. On arrival at the holding point for the particular runway which is in use for departing traffic, control of the aircraft will he transferred from the ground movement controller to the air controller. The air controller is in charge of the 'live' runway and it is his task to instruct the aircraft when to enter the runway for take-off This instruction will depend upon a variety of factors such as, for example, the route which is being followed by the aircraft which immediately preceded the departure. The fundamental basis of the air traffic control system is that aircraft are separated one from another either by height, by time or by geographical position. The intervals between aircraft departing tYom the runway are therefore an essential element of the controller's plan to achieve separation between this particular departure and any other aircraft which may he flying on the same routc or flying through the terminal area.

When the aircraft has been given instructions to take off control is transferred when the aircraft is airborne to the London air traffic control centre.

The London air traffic control centre is responsible for [he control of the London terminal area and the airways and upper air route network that links London with internal centres of population such as Birmingham. Manchesten Glasgow. etc.. and with its adjacent foreign neighbours Holland, Belgium. France, the Channel Islands. Eire, Denmark. and the North Atlantic. which serves the routes fbr aircraft bound for North America. The organisation of the London centre is extremely complex hut in simple terms the airspace for which it is responsible is divided into a number of sectors with a team of controllers responsible for the control of aircraft within the sector, which is their direct concern. The terminal area is divided into two sectors, one north and one south, and it is to the departure controller ofthe northern terminal area that control of the aircraft will be transferred by the air controller at Heathrow. Prior, however, to the transfer of control of the aircraft the Heathrow' R/T frequency on which the instruction to take off was issued will have been monitored by an air traffic control assistant at the London centre and the information on the aircraft's movement is recorded on a screen placed in front ofa television camera. .4 closed-circuit television display of this information is positioned adjacent to the terminal departure controller, who is thus alerted to the fact that the aircraft in respect of which he had previously received from the computer a warning flight progress strip, has departed Heathrow and is about to enter his sector. At the same time as the aircraft is airborne. the actual time of departure is entered into the computer from a keyboard adjacent to the Heathrow air controller's position. This input message activates the computer to produce new flight progress strips for the terminal area north sector and the Daventm' sector through which the aircraft will fly on its route to Manchester. The computer having been previously programmed with the aircraft's profile, i.e. its climb/descent/cruise,

The Civil/Military Air Traffic Problem

In trying to rationalise the problems associated with civil and military air operations it is essential to accept, from the outset, the differing roles of these two types of flying activity and to recognise that the majority of military operations are, by their very nature, not amen-able to the strict rules and procedures which apply to civil passenger-carrying air [raffle. Exempted from this statement are those occasions where military aircrat't operate within controlled or special rules airspace, when they comply with the rules and procedures applicable to those airspaces. Also air traffic control at military aerodromes is exercised in much the same manner as explained in the ibregoing chapters.

To look at the problem from a military viewpoint it is also essential to try to assess how the impact of the use of the am for commercial purposes impacts upon their operational role. In the early 1950s civil aviation commenced to expand very rapidly, on a world-wide basis, and continued to do so at an annual growth rate of approximately 0 per cent until the late 1970s; even in the period of economic recession of the early 1980s this ex
pansion continued, albeit at a slower annual rate of approximately 3 per cent. The aircraft itselt, both in performance and size, demonstrated an equally rapid evolution. In particular the introduction into passenger-carrying service of jet-powered air transport meant that for both operational and economic reasons these aircraft were required to operate in the higher levels of the airspace; an area which had previously

been almost exclusively used by military jet aircraft.

Additionally, as you will be aware from the reading of previous chapters in this book, it was essential to create controlled airspace structures to protect the flight paths of these aircraft and within which mandatory rules and procedures could be applied. In this regard. if you refer again to Figure 3 (which shows the upper air routes over pan of north-west Europe) I think you will appreciate this diagram illustrates very graphically the problem which faces both of these types of flying. To illustrate the problem further, let us consider for one moment one of the world's congested airspaces, the United Kingdom's London terminal area. As I have mentioned earlier at London Heathrow airport alone, aircrafl take off and land in peak hours in excess of one a minute, and the terminal area itself handles approximately 3500 controlled flights in a period of 24 hours. Of this latter number a high proportion will be overflying the terminal area to other destinations and will be occupying the higher flight levels from approximately FL 250 (25,000 feet) to FL 370 (37,000 feet). Similarly, *aircraft* bound for and departing from aerodromes within the terminal area will be descending from or climbing to these flight levels. The airways en-route networks spread out from the terminal like three-dimensional motorways to link up not only with the major internal cities of the United Kingdom but also with the major capitals of continental Europe and beyond.

This abbreviated picture of civilian aerial activity is repeated to a larger or lesser degree throughout the aviation world, and it is therefore against this background that military aviation is required to conduct its operations in such a manner that they do not constitute a hazard to the safe conduct of flight. In this regard the tasks facing military aviation are many and varied, and most of them do not fall readily into the fairly rigid concept of control as practised in a civil capacity. Also the tactical role of military aviation is subject to changes dependent upon the 'threat analysis'. For example in recent years there has been a gradual shift of emphasis from the upper air space to low-level operations, and whilst in terms of airspace congestion this has introduced problems for the co-ordination of military aircraft with general aviation and aviation sports, such as hang-gliding and parachuting, it has reduced the conflict between military aircraft and civil commercial air traffic. Therefore the co-ordination procedures must be sufficiently flexible in application to be able to react to these changes and be subject to constant review by both organisations. It is appreciated that the successful planning and operational application of co-ordination procedures does create an extra work-load for both military and civil ATC authorities. However, the service pilot is as much concerned for the safety of himself and his aircraft, as is his civil counterpart, and therefore recognises that where a conflict may arise for the use of the airspace, co-ordination and co-operation must exist to provide for the protection of both types of flying.

To try to summarise, therefore, from a military viewpoint, the creation, by many states, of an air traffic control system of airways with their associated terminal areas and control zones, allied to the rapid expansion of the numbers of aircraft movements and their performance characteristics, has further complicated the question of civil/military coexistence, and the ability of each to carry out its differing tasks within the world's air-spaces.

Further, it has to be accepted that on the one hand the civil operators demand the rigid application of separation standards between aircraft and protection by law of much of the airspace in which they fly, and therefore, by implication, acceptance of control of their flight paths by a ground organisation. From a military point of view, however, the adherence to predetermined flight paths and stringent separation rules, such as those required by passenger-carrying aircraft, negate the role for which they exist, which is one of freedom of movement and tactical flexibility It is then the co-existence of both of these types of air traffic within shared airspace to which solutions have to be found. To assist in the resolution of this dilemma it is suggested that it is desirable for states to have in existence civil and military traffic control organisations capable of co-ordinating these two types of flying, to ensure not only that their respective roles can be carried out safely and with the minimum of interference, but also that the world's airspace, which stubbornly refuses to get any bigger, can be used as flexibly and economically as possible.

The international aspect of the civil/ military air traffic problem

In the previous chapter on the International Civil Aviation Organisation I referred to the fact that it was this organisation which provided the international link between civil and military air traffic, and in this regard I trust the foregoing introduction clearly indicates the need for states to take action on the deliberations of this body of world opinion.

To achieve this objective ICAO in its AnnexII to the Convention deals both with coordination between military and civil air traffic services and with the co-ordination of activities which may be potentially hazardous to civil aircraft. Because the role of military aviation varies considerably from state to state, ICAO wisely does not try to advise states how this coordination should be carried out in detail, but leaves it to the concerned state to adopt procedures which are directed towards satisfying these objectives. However, to assist readers to appreciate not only the difficult task of international 'drafting', but also the manner in which ICAO has tried to place on record the difficult areas of civil/military co-ordination, I have reproduced, with their kind permission, a copy of the actual wording which is contained in Annex II.

The Organisation for the Co-ordination of Civil and Military Air Traffic

As stated in the previous chapter the International Civil Aviation Authority, when re-commending that co-ordination between civil and military authorities should take place, did not for the reasons stated, say how this should be accomplished.

In practical terms it is not possible, certainly at this time, to propound an overall world-wide organisational solution to this problem. It is, however-. reasonable to suggest that there are three main definitions, and then to indicate by example how an organisation can be established to create the system to ensure the existence of co-ordination. These definitions are considered to he:

(I)*Total integration* That is where a single unified service provides air traffic services to a!! airerafi irrespective of the operating authority of the aircraft concerned.

(2)*Partial integration* That is where the organisation is composed of staffs belonging

to both civil and military services and where the air traffic services are provided jointly by both authorities.

(3)Procedural co-ordination That is where air traffic services are provided separately by the civil and military authorities and where co-operation exists entirely through co-ordination procedures.

Probably the outstanding example of total integration is that practised in the United States of Amenca, where a single authorily, the civijianbased Federation Aviation Agency (FAA) has an organisation which provides air traffic services to all air users of their national ATC system. However, even in this example there are exceptions, in that the military' authorities provide air traffic services at most of the miiitary aerodromes. The co-ordination of civil and military air traffic could therefore be re-garded as a mixture of. (1) *total integration* in respect of military aircraft which are participating in the national air traffic system, and (2)
Methods of co-ordination of civil and military air traffic *procedural co-ordination* in respect of the requirements for co-ordination in regard to operations from military aerodromes, where any conflict may arise between the two types of flying activity. I am making this comment at this stage, for whilst it is necessary for me to explain the systems definitions of how co-ordination can be achieved, it does underline the point that the requirements of military and civil air operations can and do vary. even within a state's own airspace. Therefore a flexible approach towards the solution of these problems is often preferable to the rigid application of a particular system.
'Partial integration', as the above explanation implies, is a compromise solution based upon the willingness of both parties, civil and miiitary to co-operate in practical terms

to achieve the objectives of ICAO, which were set out in the previous chapter. On an international basis it is suggested that partial integration is the solution most likely to appeal to both authorities responsible for this type of flying. for it enables each to retain its autonomy and independence of action away from those areas where co-ordination requires joint action.

The principle of this type of co-ordination is not to try to co-ordinate all types of flying, but to concentrate upon those areas where the two types offlying would otherwise conflict one with the other and, as a result, develop an organisation and procedures which, whilst providing for safe operation, can also minimise interference and delay to both flying operations.

In developing the methods by which this desirable state of affairs can be achieved it is necessary to bear in mind that within a state it may be necessary to adopt differing methods in relation to specific co-ordination problems. For example, in a busily congested terminal area which has a predominant civil activity, or on busy air routes, it may be desirable to physically locate a military controller alongside his civilian counterpart; whereas in a busy military area crossed by air routes of low traffic density such physical presence would not be necessary, and co-ordination can be discharged at long range bynotification procedures. In other words, examine what the co-ordination problem is, and then apply the most suitable solution.

Before proceeding to examine the methods of co-ordination which can be applied I should like to make the point that no-one has a proprietary right to postulate these solutions but can only offer, from experience. examples of how this can be achieved under a given set of circumstances. In writing internationally it is essential to recognise that military aviation, in particular. varies considerably according to the role it has to adopt in the state of its origin, and also the organisations employed by these states to control aviation activities are equaLly varied. The concern. however, of all of these states is how to implement the ICAO recommendations in regard to the safe operation of flight, and my purpose in writing this chapter is to explain some of the methods which have been employed by one state. the United Kingdom, to achieve the co-ordination of civil and military air traffic. I have chosen the United Kingdom not as an example of how things should be done, but because it is an area with which

I am familiar and for which at one time I was operationally responsible. Before doing so I wish to make the point that although the majority of air traffic services to civil pilots are provided by the Civil Aviation Authority. the military air traffic operations provide some services in certain circumstances to civil aircraft, in addition to their co-ordination responsibilities. I therefore propose to describe the services which they provide and how the military and civil staffs co-ordinate together. and the organisation which has been developed to manage this application of partial integration

Methods of co-ordination of civil and military air traffic

The United Kingdom has a 'National Airmilitary air traffic operations (MATO) have the mandate to co-ordinate aerodrome patterns and procedures where necessary and to authorise the agreed procedures. Provision is made for civil aircraft to receive an air traffic control service, on request from these aerodromes, in the lower air space below flight level 10.

At each air traffic control centre the military. staff provide distress and diversion facilities both to civil and military aircraft, in conjuction with the rescue co-ordination centres, HM Coastguard and mountain rescue units. They operate a 24-hour service monitoring the miiitary and civil emergency R/T frequencies (243.0 MHz and 121.5 MHz) and are supported by a comprehensive and immediate telephone network.

Service Provided By Military Air Traffic Operations

he services provided by military air traffic operations are as follows.'

Emergencies

By virtue of the radar and R/T cover they have available through co-location, the miiitary controllers at the air traffic control centres and joint radar units are in an excellent position to provide initial response in respect of aircraft emergencies.

Upper airspace

The upper airspace in the United Kingdom commences at flight level 245 and in the airspace above this level all military aircrafi with the exception of those operating in militarv training areas, are required to receive a mandatory service from the military controllers within the coverage of the respective radars. The radar cover equates to that available to the civil controller.

Airways crossing

Military controllers provide an airways crossing service to military aircraft using either radar or a negotiated procedural clearance.

Middle airspace service

Military controllers provide an advisory radar service within the coverage of their equipment to military and civil aircraft flying outside the airways and terminal areas.

Lower airspace

Military controllers located at aerodromes provide a radar penetration service to aircraft in the lower airspace who wish to transit their traffic patterns en-route to destination.

Research and development flights

Military controllers provide a service as required to research and development flights within the coverage of their radar equipments.

The co-ordination methods employed in the application of military air traffic operations

Where the application of the services listed in the previous paragraph may affect the flight of an aircraft which is being provided with a civilian air traffic control service it is essential that co-ordination is carried out between the concerned military and civil controllers or ATS units, to ensure the safe and flexible operation of both types of flying. I therefore propose, under the headings of the services previously appreciated that in-doing so my explanations are in general terms, and I trust readers will appreciate tbat each action in itself may be complex and the subject of detailed operating procedures. However, to assist in an understanding of these co-ordination procedures I intend to describe, in the next chapter, details ofthe flight ofa military aircraft from one aerodrome to another and in that chapter I shall endeavour to involve as many of these services as is possible.

Emergencies

Emergencies occurring to military' aircraft are handled exclusively by military personnel other than the possible exception ofa military aircraft operating on the airw'ays system where initial action would be taken by the concerned civilian controllers. However, in regard to an emergency being handled by a military controller, co-ordination would take place on a direct speech circuit between the military and civil controller responsible for the specific airspace, if the action in respect of the emergency should require deviation ofan aircraft under civil control. Military' controllers also provide a service to civil aircraft flying 'off-route' in the flight information region, who may require navigational assistance or diversion facilities in an emergency. Co-ordination would take place hetween the military and civil ATC supervisors to provide the most expeditious solution to the emergency.

The upper air space

Within the United Kingdom a special rules airspace has been established from flight level 245 up to and including flight level 660. The rules governing this airspace are somewhat complex but the main difference between this airspace and that below flight level 245 is that throughout the entire airspace aircraft, both civil and military, are required to operate on a 'known' and co-ordinated basis. Within the upper airspace is contained a network of upper air routes used primarily by civil aircraft, and to which the same rules and procedures apply as for aircraft operating on the airways system immediately below, and which are usually contiguous with the upper air routes. Within this airspace there are also military training areas (MTA) which are designated for specific military activity. They are marked on the international charts and the upper air routes are aligned to avoid these areas. A large part of this airspace is covered by the National Air Traffic Service's radar installations, and within this cover it is mandatory for military aircraft to receive a radar/procedural service from NATS military controllers. Co-ordination between civil and military controllers takes the following form:

(1) *Upper air routes.* At the present time the major part of the upper air space cover is provided from a variety of radars both on site and remoted and joint air traffic control radar units (JATCRUs) have been estahlished at some of these sites. At these JATC.RUs military and civil controllers operate from the same operations room and use a common traffic display upon which details of all traffic in their concerned areas of responsibility is displayed. To avoid unnecessary re-routing of passenger-carrying aircraft the standard procedure is for the military controller to initiate co-ordination with his civil colleague. If avoiding action is necessary, it is normally the military aircraft which will give way. Co-ordination can and does take place whenever this would result in advantage to the military controller such as the use of height separation.

(2) *Special flights.* There are special categories of military flights of a non-deviating status where co-ordination between both controllers must take place where a conflict of flight

Detailed Description of the Control of the Flight of a Military Aircraft

In the previous chapter I explained how civil and military air traffic is co-ordinated and thc air traffic services which are provided by miiitary air traffic operations (MATO) to achieve this objective.Chapter 10 provides a description of the air traffic control functions associated with a civil passenger-carrying aircraft, and it is now intended to describe the manner in which the flight of a military aircrafl is co-ordinated with civil air traffic and how the military air traffic services as detailed in Chapter 14 operate.

To illustrate, as clearly as possible, the coordination that takes place between civilian and military controllers, I intend to use as an example the flight of a Phantom (at the time of writing a front-line fighter aircraft of the Royal Air Force) from its base in East Anglia, which is situated in eastern England, to RAF aerodrome St Mawgan in

Cornwall, in south-west England.

Reference to Figure 5, 'Airways in the United Kingdom's airspace', will show that the track the aircraft has to follow will cross the busy airways and upper air routes between the London and Manchester terminal areas, also Green Airway One and Amber Airway Twenty-Five. Readers of Chapter 10 will recognise that the track of the Phantom will thus take it across the track being followed by our example passenger-carrying aircraft, on its flight from London's Heathrow airport to Manchester airport.

The flight plan

A military flight of the type being described carries out flight-planning in much the same manner as a civil passenger-carrying aircraft; that is, at least 30 minutes prior to the intended departure of the Phantom a flight plan is filed giving the details as listed in Chapter 6. This flight plan is then transmitted to all of the air traffic control agencies who will be concerned with providing a service to the aircraft throughout the course of its flight. These agencies are:

(I) *Eastern radar-joint air traffic control radar unit (JA TCR U)* Eastern radar provides a centralised approach control (CAC) service, in regard to the initial departure phase of the flight and thereafter arc responsible for its conduct until the aircraft is handed over to the London joint area organisation.

(2) *London joint area organisation (LJA 0)* The LJAO is responsible for providing the ajrcrafi with a safe flight path to cross the busy airways and upper air routes which lie on its track between the London and Manchester terminal areas until the aircraft is handed over to the military area services.

(3) Military' area services (AlAS) Following transfer of control from LJAO, MAS are responsible for providing the aircraft with an ATC service on its track to its destination, which may include crossing clearances for Airways Green One and Amber Twenty-Five. Also in the final stages of its flight MAS provide a centralised approach control (CAC) service, until handing over control to the destination aerodrome. St Mawgan, when the aircraft is approximately 30 nautical miles away from the aerodrome.

(4) . *RAF aerodrome St Mawgan* Following handover of control from the MAS (CAC service) ATC at St Mawgan are responsible for the final approach and landing phase of flight.

These then are the ATC agencies who are concerned with the conduct of the flight of the Phantom and to whom the flight plan has been addressed prior to the departure of the flight from its base aerodrome.

It is now intended to follow the flight of the Phantom from the aerodrome of departure to the destination aerodrome, and in doing so, to explain how the concerned military air traffic services operate and how the co-ordination of ctvil and military air traffic is accomplished.

The conduct of the flight

As the Phantom taxies out to the runway in use, at its base aerodrome in East Anglia. the ground controller who is situated in the control tower advises eastern radar, by a direct telephone circuit, that the flight will shortly become active.

Eastern radar, who already have the Phantom's flight plan details, will handle the aircraft on the dedicated combined approach control (CAC) console and allocate to the aircraft a secondary radar code (SSR) which will discretely identify the aircraft as being controlled frnm this CAC position, and the l{/T frequency, to be selected for use, following hand-off to them.

Shortly after thc aircraft is airborne, the approach controller at the base aerodrome contacts eastern radar on the direct telephone circuit and identifies it to them by reference to the position of the radar response and the SSR code, which the pilot will have selected either whilst taxiing or immediately after becoming airborne. When identification has taken place the aircraft is instructed to change his R/T frequency and to call the eastern radar controller.

The eastern radar controller continues the climb of the aircraft and provides a radar advisory service. This involves passing the p0sition, by clock code, and range, and the flight level, if known, of all conflicting traffic, and giving avoiding action. The pilot will usually accept the avoiding action unless he is in visual contact with the conflicting aircraft and content to continue. There is no distinction in the service given between flight in IMC or VMC, but clearly the pilot is more likely to follow the avoiding action in [MC. As the flight progresses the eastern radar controller contacts the LJAO military controller, who is positioned on carry out the MAS task, throughout this area of responsibility, there are 17 radar consoles and extensive use is made of advanced computer and electronic technology, to assist the military controllers in their task. rn fact this unit is possibly the first to use electronic data displays (EDD) for traffic purposes, in an operational environment. Instead of using the commonly accepted principle of a paper flight progress strip, as portrayed at Figure 7, flight details are manually extracted from the flight plan and entered into a computer and are then presented electronically on a display at the position occupied by the controller concerned with a particular flight. The controller has an input device associated with the computer, known as a touch wire display (TWD) and is therefore able to update the original flight plan data as flights proceed in the live environment. Closed-circuit television is also used extensively for the relay of other data concerned with the conduct of flights.

Returning once again to the flight of the Phantom, the LJAO military controller, as stated earlier, makes contact with the allocated MAS controller as the aircraft approaches the western boundary of the Daventry sector's airspace. The MAS controller will have had details of the Phantom's flight displayed to him on his EDD at least 15 minutes prior to this contact, and is therefore pre-warned of the requirement for his services. The aircraft is identified to the MAS controller by reference to the position of its radar response and SSR code identity. The pilot of the Phantom is then instructed to change his SSR code and RIT frequency to that of the MAS controller and transfer of control is thus completed.

The MAS controller outside of controlled air space, will provide the same radar advisory service as his colleagues at eastern radar gave before the aircraft reached the Daventry sector. He may achieve separation from potentially conflicting traffic by contacting the controller, either civil or military, controlling the other traffic, and agreeing a course of action to ensure separation between the two aircraft. This latter course of action is termed 'co-ordination' and in practice most conflicts within the airspace for which the London air traffic control centre is responsible, are resolved in this manner. As a result it is exceptional for the MAS controller to have to resort to the vectoring of aircraft to achieve separation.

Once the Phantom has cleared Airway (ireen One, Airway Amber Twenty-Five and any related upper air routes on its track the This glossary is limited to terms which have a specific meaning in civil aviation. pilot is instructed to commence descent from his cruising flight level. During the course of the aircraft's descent the MAS controller will provide the centralised approach control service which may be required in regard to any air traffic associated with arrivals and departures from other aerodromes related to the aerodrome of destination (St Mawgan). When the Phantom is within approximately 30 nautical miles of St Mawgan aerodrome the MAS controller contacts, by telephone, the approach controller in the tower at St Mawgan. As the Phantom will now be within range of St Mawgan's own aerodrome radar, the MAS controller identifies the Phantom to the approach controller by reference to the position of the aircraft's radar response. The St Mawgan approach controller is already in possession of the flight plan which was initiated by the aerodrome of departure, and which has since been updated by the military area services controller as the flight proceeded through their airspace. The approach controller is therefore fully aware of this progress of the flight and able to respond to the telephonic contact from the MAS controller. Once identification of the radar target of the Phantom has been accepted by the St Mawgan approach controller the MAS controller instructs the pilot to change his RIT frequency to that of St Mawgan, and it is then the responsibility of that unit to ensure the safe conduct of the flight of the Phantom to landing and final stop engines in its specified dispersal bay.

List of Abbreviation

Aerodrome Any area on land or water set apart or commonly used for affording facilities for the landing and departure of aircrafl.

Aerodrome traffic zone The airspace extending from the surface to a height of 2000 ft above the level of the aerodrome and within a distance of 1+ nm of its boundaries, except any part of that airspace which is within the aerodrome traffic zone of another aerodrome which is notified as being the controlling aerodrome.

Air-ground communications Two-way communications between aircraft and stations or locations on the surface of the earth.

Air traffic control centre A term used in the United Kingdom to describe a unit combining the functions of an area control centre and a flight information centre.

Air traffic control clearance Authorisation for an aircraft to proceed under conditions specified by an air traffic control unit,

Airway A control area or part ofa control area established in the form of a corridor equipped with radio navigational aids.

Alternate aerodrome An aerodrome specified in the flight plan to which a flight may proceed when a landing at the intended destination becomes inadvisable.

Altitude The vertical distance of a level, a

point or object considered as a point, measured from mean sea level.

Apron The part of an aerodrome provided for the stationing of aircrafl for the embarkation and disembarkation of passengers, the loading and unloading of cargo, refuelling and for parking.

ATS route A specified route designed for channelling the flow oftraffic as necessary for the provision of air traffic services.

Clearance limit The point to which an aircrafl is granted an air traffic control clearance.

Code (SSR code) The number assigned to a particular multiple pulse reply signal transmitted by a transponder.

Control area (CTA) A controlled airspace extending upwards from a specified limit above the surface of the earth.

Control zone (CTR) A controlled airspace extending upwards from the surface of the earth to a specified limit.

Controlled airspace An airspace of defined dimensions within which air traffic control service is provided to IFR flights.

Cmising level A level maintained during a significant portion of a flight.

Data processing A systematic sequence of operations performed on data.

Decision height A specified height at which a missed approach must be initiated if the required visual reference to continue the approach to land has not been established.

Elevation The vertical distance of a point or level on, or affixed to the surface of, the earth, measured from mean sea level.

Entry point The first airways reporting point over which a flight passes on entering an FIR.

Estimated time of arrival The time at which the pilot estimates that the aircraft will be over a specified location.

Exit point The last airways reporting point over which a flight passes before leaving the FIR.

Flight information service A service provided for the purpose of giving information useful for the safe and efficient conduct of flights.

Flight levels *(FL)* Surfaces of constant atmospheric pressure which are related to a specific pressure datum 1013.2 mitlibars and are separated by specific pressure intervals.

Flight plan (FPL) Specified information provided to air traffic services units relative to an intended flight or portion of a flight of an aircraft.

CONCLUSION

This Project is the work for the Air Traffic Control Automation. A critical aspect of this project is to examine the interaction between the automation and the controller on the ground and the automation and the pilot in the cockpit. Specifically, we plan to project future tasks and examine the consequences of automation on them, assess possible changes in the pattern of controller work and the potential effects on performance, and evaluate procedures needed for the smooth evolution of the national airspace system.

We hope the readers of this Project will encompass a broad audience, including those interested in the air traffic control system and its operation and policy as well as those interested in general issues of aviation psychology research and air safety. We direct the attention of our policy readers to the executive summary with our conclusions and recommendations, the chapters on system management and automation, and the final sections of each chapter that contain a brief discussion of the major points covered.

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