APPENDIX - I

Air Traffic Control and Management

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APPENDIX-II

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This is to acknowledge with thanks the help, guidance and support that I have received during the Dissertation.

I have no words to express a deep sense of gratitude to the management of Quest 2 travel (the name of the organization) for giving me an opportunity to pursue my Dissertation, and in particular Mrs. Anjali Thomas (name of external project supervisor), for his able guidance and support.

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APPENDIX - III

A Declaration by the Guide

This is to certify that the Mr. Carlton Fernandes a student of B.Sc Aviation Studies Roll No500012101 of UPES has successfully completed this dissertation report on "Air Traffic Control and Management" under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of B.Sc Aviation Studies

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Abstract

As air travel has become an essential part of modern life, the air traffic control system has become strained and overworked. This problem is occurring because the capacity of the current air traffic control system is severely limited by the capabilities of its human operators. Therefore, if we are to increase the capacity of the air traffic control system, then we must develop new automated systems for air traffic control.

Many studies have been conducted in an attempt to determine the complexity involved in handling an Air Traffic Control (ATC) situation. As the aviation community moves towards a "free flight" environment, traffic complexity may not necessarily increase or decrease, but it will most certainly change. To that end, traffic complexity, as it is perceived by the controllers, who will still be ultimately responsible for traffic separation, becomes increasingly more important to understand. Previous studies of ATC complexity have based their measures on the amount of physical workload experienced by an Air Traffic Specialist (ATS). Unfortunately, many of these studies typically discount the importance of the cognitive activities of the controller, simply because this information is not easily measured. It is our position, however, that the complexity of ATC is better revealed through the analysis of controller strategies and decision making activities (cognitive tasks), and that this type of complexity may not be accurately reflected through measures of physical workload alone. In this paper, we will describe a framework for developing and evaluating a model of the perceived complexity of an air traffic situation, with specific regard to the traffic characteristics that impact the cognitive abilities of the controller. The framework does not depend on any specific type of procedures for ATC, so it may be used to evaluate complexity in both the current and future ATC environments.

The following dissertation takes a looks at the current Air traffic control and Management procedures and techniques used and indentifies its short comings and also shows how a automated system can help improve efficiency and safety.

Chapter 1: Introduction

Basic Function and tasks of ATC

A controller's primary task is to maintain separation. In order to do so, s/he must use aircraft information, information on the airspace, and any other available resources to effectively control and predict potential conflicts that jeopardize this separation. These conflicts can include conflicts between two aircraft, conflicts between aircraft paths and airspace, and conflicts between the demand and capacity of a particular airport. Air traffic control, with respect to conflict resolution, typically has four main processes: planning, implementation, monitoring, and evaluation. These processes, along with a discussion of how they are impacted by air traffic complexity, are presented below.

In the planning process, the controller's goal is to determine the best course of action needed to resolve each traffic conflict. This process typically results in a set of re-routes, vectors, speed assignments, altitude changes, coordination with other controllers, or other control actions. However, as part of this planning process, the controller must also evaluate the impact that a given control action, which is intended to solve one particular conflict, might have on the rest of the system. Once the controller completes the planning process and has determined the necessary control actions to be taken, the controller implements the plan through the use of various communication and data entry tasks. Although this implementation may be viewed as only being a physical task, if the implementation itself requires some sort of planned coordination, then the distinction of whether the implementation is a physical task or a mental task is not entirely clear. After implementation, the controller must then monitor the situation to ensure the conformance of the situation to the plan, and to evaluate the effectiveness of the plan in resolving the conflicts.

In many countries, ATC services are provided throughout the majority of airspace, and its services are available to all users (private, military, and commercial). When controllers are responsible for separating some or all aircraft, such airspace is called "controlled airspace" in contrast to "uncontrolled airspace" where aircraft may fly without the use of the air traffic control system. Depending on the type of flight and the class of airspace, ATC may issue instructions that pilots are required to follow, or merely flight information (in some countries known as advisories) to assist pilots operating in the airspace. In all cases, however, the pilot in command has final responsibility for the safety of the flight, and may deviate from ATC instructions in an emergency.

Although the native language for a region is normally used, the English language must be used on request, as required by the International Civil Aviation Organization (ICAO).

1.1 History of ATC

In 1919, the International Commission for Air Navigation (ICAN) was created to develop General Rules for Air Traffic. Its rules and procedures were applied in most countries where aircraft operated. The United States did not sign the ICAN Convention, but later developed its own set of air traffic rules after passage of the Air Commerce Act of 1926. This legislation authorized the Department of Commerce to establish air traffic rules for the navigation, protection, and identification of aircraft, including rules as to safe altitudes of flight and rules for the prevention of collisions between vessels and aircraft. The first rules were brief and basic. For example, pilots were told not to begin their takeoff until there is no risk of collision with landing aircraft and until preceding aircraft are clear of the field. As traffic increased, some airport operators realized that such general rules were not enough to prevent collisions. They began to provide a form of air traffic control (ATC) based on visual signals. Early controllers, like Archie (one of the first system's flagmen), stood on the field, waving flags to communicate with pilots

As more aircraft were fitted for radio communication, radio-equipped airport traffic control towers began to replace the flagmen. In 1930, the first radio-equipped control tower in the United States began operating at the Cleveland Municipal Airport. By 1935, about 20 radio control towers were operating.

Increases in the number of flights created a need for ATC that was not just confined to airport areas but also extended out along the airways. In 1935, the principal airlines using the Chicago, Cleveland, and Newark airports agreed to coordinate the handling of airline traffic between those cities. In December, the first Airway Traffic Control Center opened at Newark, New Jersey. Additional centers at Chicago and Cleveland followed in 1936.

The early controllers tracked the position of planes using maps and blackboards and little boat-shaped weights that came to be called shrimp boats. They had no direct radio link with aircraft but used telephones to stay in touch with airline dispatchers, airway radio operators, and airport traffic controllers.

In July 1936, en route ATC became a federal responsibility and the first appropriation of $175,000 was made ($2,665,960 today). The Federal Government provided airway traffic control service, but local government authorities where the towers were located continued to operate those facilities.

In 1941, Congress appropriated funds for the Civil Aeronautics Administration (CAA) to construct and operate ATC towers, and soon the CAA began taking over operations at the first of these towers, with their number growing to 115 by 1944. In the postwar era, ATC at most airports was eventually to become a permanent federal responsibility. In response to wartime needs, the CAA also greatly expanded its en route air traffic control system.

The postwar years saw the beginning of a revolutionary development in ATC, the introduction of radar, a system that uses radio waves to detect distant objects. Originally developed by the British for military defense, this new technology allowed controllers to see the position of aircraft tracked on visual displays. In 1946, the CAA unveiled an experimental radar-equipped tower for control of civil flights. By 1952, the agency had begun its first routine use of radar for approach and departure control. Four years later, it placed a large order for long-range radars for use in en route ATC.

In 1960, the FAA began successful testing of a system under which flights in certain positive control areas were required to carry a radar beacon, called a transponder that identified the aircraft and helped to improve radar performance. Pilots in this airspace were also required to fly on instruments regardless of the weather and to remain in contact with controllers. Under these conditions, controllers were able to reduce the separation between aircraft by as much as half the standard distance.

For many years, pilots had negotiated a complicated maze of airways. In September 1964, the FAA instituted two layers of airways, one from 1,000 to 18,000 feet (305 to 5,486 meters)above ground level and the second from 18,000 to 45,000 feet (13,716 m) above mean sea level. It also standardized aircraft instrument settings and navigation checkpoints to reduce the controllers' workload.

From 1965 to 1975, the FAA developed complex computer systems that would replace the plastic markers for tracking aircraft thereby modernizing the National Airspace System. Controllers could now view information sent by aircraft transponders to form alphanumeric symbols on a simulated three dimensional radar screen. The system allowed controllers to focus on providing separation by automating complex tasks.

The FAA established a Central Flow Control Facility in April 1970, to prevent clusters of congestion from disrupting the nationwide air traffic flow. This type of ATC became increasingly sophisticated and important, and in 1994, the FAA opened a new Air Traffic Control System Command Center with advanced equipment.

In January 1982, the FAA unveiled the National Airspace System (NAS) Plan. The plan called for modernized flight service stations, more advanced systems for ATC, and improvements in ground-to-air surveillance and communication. Better computers and software were developed, air route traffic control centers were consolidated, and the number of flight service stations reduced. New Doppler Radars and better transponders complemented automatic, radio broadcasts of surface and flight conditions.

In July 1988, the FAA selected IBM to develop the new multi-billion-dollar Advanced Automation System (AAS) for the Nation's en route ATC centers. AAS would include controller workstations, called "sector suites," that would incorporate new display, communications and processing capabilities. The system had upgraded hardware enabling increased automation of complex tasks.

In December 1993, the FAA reviewed its order for the planned AAS. IBM was far behind schedule and had major cost overruns. In 1994 the FAA simplified its needs and picked new contractors. The revised modernization program continued under various project names. In 1999, controllers began their first use of an early version of the Standard Terminal Automation Replacement System, which included new displays and capabilities for approach control facilities. During the following year, FAA completed deployment of the Display System Replacement, providing more efficient workstations for en route controllers.

In 1994, the concept of Free Flight was introduced. It might eventually allow pilots to use on board instruments and electronics to maintain a safe distance between planes and to reduce their reliance on ground controllers. Full implementation of this concept would involve technology that made use of the Global Positioning System to help track the position of aircraft. In 1998, the FAA and industry began applying some of the early capabilities developed by the Free Flight program.

Current studies to upgrade ATC include the Communication, Navigation and Surveillance for Air Traffic Management System that relies on the most advanced aircraft transponder, a global navigation satellite system, and ultra-precise radar. Tests are underway to design new cockpit displays that will allow pilots to better control their aircraft by combining as many as 32 types of information about traffic, weather, and hazards.

1.2 ATC in India (AAI)

In India air traffic at all the airports and within Indian airspace is managed by Airport Authority of India (AAI).

Figure 1

The Airports Authority of India (AAI) formed by the merger of IAAI and NAA through Airports Authority Act (No.55 of 1994), came into existence on 1st April 1995. AAI manages five international airports, 87 domestic airports and 28 civil enclaves. There are 449 airports/airstrips in the country. Among these, the AAI owns and manages 5 international airports, 87 domestic airports and 28 civil enclaves at Defense airfields and provides air traffic services over the entire Indian airspace and adjoining oceanic areas.

Some of the major objectives of AAI are,

- To control and manage the entire Indian airspace (excluding the special user airspace) extending beyond the territorial limits of the country, as accepted by ICAO.
- Provisioning of Communication and Navigational aids viz. ILS, DVOR, DME, Radar, etc.
- To Design, Construct, Operate and Maintain International Airports, Domestic Airports, and Civil Enclaves at Defense Airports.
- Development and Management of International Cargo Terminals.
- Provisioning of Passenger Facilitation and Information System.
- Expansion and Strengthening of Operational areas viz. Runways, Apron, Taxiways, etc.
- Provisioning of Visual Aids.

Chapter 2: Air Traffic Services

The objectives of the air traffic services shall be to:

- Prevent collisions between aircraft;
- Prevent collisions between aircraft on the maneuvering area and obstructions on that area;
- Expedite and maintain an orderly flow of air traffic;
- Provide advice and information useful for the safe and efficient conduct of flights;
- Notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required.

Air traffic control services have been divided in three parts as follows:

1. Area control service

   The provision of air traffic control service for controlled flights, except for those parts of such flights which are under the jurisdiction of Approach Control or Aerodrome Control to accomplish following objectives:
   - Prevent collisions between aircraft;
   - Expedite and maintain an orderly flow of air traffic;

2. Approach control service

   The provision of air traffic control service for those parts of controlled flights associated with arrival or departure, in order to accomplish following objectives:
   - Prevent collisions between aircraft;
   - Expedite and maintain an orderly flow of air traffic;

3. Aerodrome control service:
   The provision of air traffic control service for aerodrome traffic, except for those parts of flights which are under the jurisdiction Approach Control to accomplish objectives:
   - Prevent collisions between aircraft;
   - Prevent collisions between aircraft on the maneuvering area and obstructions on that area;
   - Expedite and maintain an orderly flow of air traffic;

2.1 Classification of airspaces

ATS airspaces in India are classified and designated in accordance with following.

Class D:
IFR and VFR flights are permitted and all flights are provided with air traffic control service, IFR flights are separated from other IFR flights and receive traffic information in respect of VFR flights. VFR flights receive traffic information in respect of all other flights.

Airspaces in terminal areas, control areas, control zones and aerodrome traffic zones have been classified and designated as class D airspace.

Class E:

IFR and VFR flights are permitted; IFR flights are provided with air traffic control service and are separated from other IFR flights. IFR flights receive traffic information in respect of VFR flights; VFR flights receive traffic information in respect of all other flights, as far as is practical. Class E is not be used for control zones.

Airspaces in designated ATS routes outside terminal areas, control areas and control zones, where air traffic control service is provided, have been classified and designated as class E airspace.

Class F:

IFR and VFR flights are permitted. All IFR flights receive an air traffic advisory service and all flights receive flight information service, if requested.

Airspaces in designated ATS route segments outside terminal areas, control areas and control zones, where air traffic advisory service is provided, have been classified and designated as class F airspace.

Class G:

IFR and VFR flights are permitted and receive flight information service if requested.

Airspaces other than those in Class D, E and F have been classified and designated as class G airspace.

Application of air traffic control service

Air traffic control service shall be provided:
- To all IFR flights in airspace Classes D and E;
- To all VFR flights in airspace Classes D;
- To all special VFR flights;
- To all aerodrome traffic at controlled aerodromes.

SERVICES PROVIDED AND FLIGHT REQUIREMENTS

Class	Type of Flight	Separation Provided	Services Provided	Speed limitation	Radio Communication Requirement ATC	Subject to an ATC clearance
D	IFR	IFR from IFR	Air traffic control service, traffic information about VFR flights (and traffic avoidance advice on request)	250 kt IAS below 10000 ft AMSL	Continuous two-way	Yes
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (and traffic avoidance advice on request)	250 kt IAS below 10000 ft AMSL	Continuous two-way	Yes
E	IFR	IFR from IFR	Air traffic control service and, as far as practical, traffic information about VFR flights	250 kt IAS below 10000 ft AMSL	Continuous two-way	Yes
	VFR	Nil	Traffic information as far as practical	250 kt IAS below 10000 ft AMSL	No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service	250 kt IAS below 10000 ft AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 10000 ft AMSL	No	No
G	IFR	Nil	Flight information service	250 kt IAS below 10000 ft AMSL	Continuous two-way	No
	VFR	Nil	Flight information service	250 kt IAS below 10000 ft AMSL	No	No
* When the height of the transition altitude is lower than 10 000 ft AMSL, FL 100 should be used in lieu of 10 000 ft.						

TABLE 1: ATS AIRSPACE CLASSES

Airport classification

To provide specified services as per the requirement of different type of traffic at different type of airports, airports in India are classifies as follows,

a) International Airports
These are declared as international airports and are available for scheduled international operations by Indian and foreign carriers. Presently, Mumbai, Delhi, Chennai, Calcutta and Thiruvananthapuram are in this category.

b) Domestic Airports
   - Customs Airports with limited international operations - These have customs and immigration facilities for limited international operations by national carriers and for foreign tourist and cargo charter flights. These include Bangalore (CE), Hyderabad, Ahmedabad, Calicut, Goa (CE), Varanasi, Patna, Agra (CE), Jaipur, Amritsar, Tiruchirapally, Coimbatore, and Lucknow.
     (CE - Civil Enclave)

   - Model Airports - These domestic airports have minimum runway length of 7500 feet and adequate terminal capacity (400 passengers or more) to handle Airbus 320 type of aircraft. These can cater to limited international traffic also, if required. These include Bhubaneswar, Guwahati, Nagpur, Vadodara, Imphal and Indore. Rest 6 Nos. of airports, developed under Model Airports concept has graduated to the classification of Customs Airports, given above.

   - Other Domestic Airports - All other 71 domestic airports are covered in this category.

   - Civil Enclaves in Defense Airport - There are 28 civil enclaves in Defense airfields. Twenty civil enclaves are in operation.

The ICAO airport code or location indicator is a four character alphanumeric designation each airport around the world. These codes are defined by ICAO (International Civil Aviation Organization).

All Indian Airports have this ICAO airport code and airports which lie in the same region the airports codes starts with the same alphanumeric character.

- VA – West Zone
- VE – East Zone
- VI – North Zone
- VO – South Zone

Chapter 3: Air Traffic Control Network

There are many phases in a flight such as pre flight, taxi, take-off, departure, en route, arrival, approach and landing. It is practically not possible for one person to handle all these phases by himself. To efficiently control traffic all these phases are controlled by different controllers from different sections of the Air Traffic Control Network.

The network for controlling the air traffic can be divided into the following:

- Aerodrome control
- Flight Data / Clearance Delivery
- Ground Control
- En-route, center or area control
- Approach and terminal control

The methods of traffic control for each system depends upon weather conditions. These are commonly known as visual flight rules (VFR) and instrument flight rules (IFR). If VFR conditions prevail, the air traffic control during the route is practically not required, since the pilots can maintain the desired separation by visual aids. The IFR conditions exist, when the visibility id lower than the limits prescribed for flights under visual flight rules. Rigid traffic control has to be exercised under IFR conditions. The pilot prior to his departure prepares a flight plan which indicates the aircraft destination, the air route to be followed, the desired altitude and the estimated time of departure. Once the flight plan has been approved no changes are allowed without prior approval of the traffic control center.

3.1 Aerodrome Control

The functions of Aerodrome Control are

Aerodrome control towers shall issue information and clearances to aircraft under their control to achieve a safe, orderly and expeditious flow of air traffic on and in the vicinity of an aerodrome with the object of preventing collision(s) between:

- Aircraft flying within the designated area of responsibility of the control tower, including the aerodrome traffic circuits;
- Aircraft operating on the maneuvering area;
- Aircraft landing and taking off;
- Aircraft and vehicles operating on the maneuvering area;
- Aircraft on the maneuvering area and obstructions on that area.

Aerodrome controllers shall maintain a continuous watch on all flight operations on and in the vicinity of an aerodrome as well as vehicles and personnel on the maneuvering area. Watch shall be maintained by visual observation, augmented in low visibility conditions by an ATS surveillance system when available. Traffic shall be controlled in accordance with the procedures set forth herein and all applicable traffic rules specified in MATS 2 / Temporary Local Instructions (TLI) of the concerned airport. If there are other aerodromes within a control zone, traffic at all aerodromes within such a zone shall be coordinated so that traffic circuits do not conflict.

- The functions of an aerodrome control tower may be performed by different control or working positions, such as:
- Aerodrome controller, normally responsible for operations on the runway and aircraft flying within the area of responsibility of the aerodrome control tower;
- Ground controller, normally responsible for traffic on the maneuvering area with the exception of runways;
- Clearance delivery position, normally responsible for delivery of start-up and ATC clearance to departing IFR flights.

Where parallel or near parallel runways are used for simultaneous operations, individual aerodrome controllers should be responsible for operations on each of the runways.

The primary method of controlling the immediate airport environment is visual observation from the airport traffic control tower (ATCT). The ATCT is a tall, windowed structure located on the airport grounds. Aerodrome or Tower controllers are responsible for the separation and efficient movement of aircraft and vehicles operating on the taxiways and runways of the airport itself, and aircraft in the air near the airport, generally 2 to 5 nautical miles (3.7 to 9.2 km) depending on the airport procedures.

Radar displays are also available to controllers at some airports. Controllers may use a radar system called Secondary Surveillance Radar for airborne traffic approaching and departing. These displays include a map of the area, the position of various aircraft, and data tags that include aircraft identification, speed, heading, and other information described in local procedures.

The areas of responsibility for ATCT controllers fall into three general operational disciplines; Local Control or Air Control, Ground Control, and Flight Data/Clearance Delivery—other categories, such as Apron Control or Ground Movement Planner, may exist at extremely busy airports. While each ATCT may have unique airport-specific procedures, such as multiple teams of controllers ('crews') at major or complex airports with multiple runways, the following provides a general concept of the delegation of responsibilities within the ATCT environment.

ALERTING SERVICE PROVIDED BY AERODROME CONTROL TOWERS

- Aerodrome control towers are responsible for alerting the rescue and fire fighting services whenever:

- An aircraft accident has occurred on or in the vicinity of the aerodrome; or,

- Information is received that the safety of an aircraft which is or will come under the jurisdiction of the aerodrome control tower may have or has been impaired; or

- Requested by the flight crew; or

- When otherwise deemed necessary or desirable.

Procedures concerning the alerting of the rescue and fire fighting services shall be contained in local instructions. Such instructions shall specify the type of information to be provided to the rescue and fire fighting services, including type of aircraft and type of emergency and, when available, number of persons on board, and any dangerous goods carried on the aircraft.

Aircraft which fail to report after having been transferred to an aerodrome control tower, or, having once reported, cease radio contact and in either case fail to land five minutes after the expected landing time, shall be reported to the approach control unit, ACC or flight information centre, or to the rescue coordination centre or rescue sub-centre, in accordance with local instructions.

Runway in use

The term "runway-in-use" shall be used to indicate the runway or runways that, at a particular time, are considered by the aerodrome control tower to be the most suitable for use by the types of aircraft expected to land or take off at the aerodrome.
In selecting runway-in-use the unit providing aerodrome control service shall take into consideration, besides surface wind speed and direction, other relevant factors such as the aerodrome traffic circuits, the length of runways, and the approach and landing aids available.

A runway for take-off or landing appropriate to the operation, may be nominated for noise abatement purposes, the objective being to utilize whenever possible those runways that permit airplanes to avoid noise-sensitive areas during the initial departure and final approach phases of flight.

Only one aircraft can be cleared to land on the runway-in-use at any one time except formation flight by military aircraft.

Whenever change of the runway-in-use is necessary the aerodrome controller, after prior consultation with approach control, shall inform to aircraft under his control and other agencies according to local instructions.

INITIAL CALL TO AERODROME CONTROL TOWER

For aircraft being provided with aerodrome control service, the initial call shall contain:

- Designation of station being called;
- Call sign, and for aircraft in the heavy wake turbulence category, the word "Heavy";
- Position; and
- Additional elements, as required by the appropriate ATS authority.

The control tower in response prior to entering the traffic circuit or commencing its approach to land, an aircraft shall be provided with the following elements of information, in the order listed, with the exception of such elements which it is known the aircraft has already received:

- The runway to be used;
- The surface wind direction and speed, including significant variations there from;
- The QNH altimeter setting and, either on a regular basis in accordance with local arrangements or, if so requested by the aircraft, the QFE altimeter setting.

Runway Incursion or Obstructed Runway

In the event the aerodrome controller observes, after a take-off clearance or a landing clearance has been issued, any obstruction on the runway likely to impair the safety of an aircraft taking off or landing, such as a runway incursion by an aircraft or vehicle, or animals or flocks of birds on the runway, appropriate action shall be taken as follows:

- In all cases inform the aircraft concerned of the obstruction and its location on the runway;
- Cancel the take-off clearance for an aircraft which has not started to roll;
- Instruct a landing aircraft to go around.

Wake Turbulence and Jet Blast Hazard

Aerodrome controllers shall, when applicable, apply the wake turbulence separation minima specified in the next Chapter. Whenever the responsibility for wake turbulence avoidance rests with the pilot-in-command, aerodrome controllers shall, to the extent practicable, advice aircraft of the expected occurrence of hazards caused by turbulent wake.

In issuing clearances or instructions, air traffic controllers should take into account the hazards caused by jet blast and propeller slipstream to taxiing aircraft, to aircraft taking off or landing, particularly when intersecting runways are being used, and to vehicles and personnel operating on the aerodrome.

Communication Requirements Visual Signals

At controlled aerodrome vehicles employed on the maneuvering area shall be capable of maintaining two-way radio communication with the aerodrome control tower, except when the vehicle is occasionally used on the maneuvering area and is:

- Accompanied by a vehicle with the required communications capability, or
- employed in accordance with a pre-arranged plan established with the aerodrome control tower.

When communications by a system of visual signals is deemed to be adequate, or in the case of radio communication failure, the signals given here under shall have the meaning indicated therein:

Signal	Aircraft in flight	Aircraft on the ground	Ground vehicles or personnel
Flashing white	N/A	Return to starting point	Return to starting point
Steady green	Cleared to land	Cleared for takeoff	Cleared to cross/proceed
Flashing green	Cleared to approach airport, or return to land	Cleared to taxi	N/A
Steady red	Continue circling, give way to other aircraft	Stop	Stop
Flashing red	Airport unsafe, do not land	Immediately taxi clear of runway in use	Clear the taxiway/runway
Alternating red and green	Exercise extreme caution	Exercise extreme caution	Exercise extreme caution
Blinking runway lights	Vehicles, planes, and pedestrians immediately clear landing area in use		

Table 2: Aviation light signal

Runway Occupancy

When aircraft, persons or vehicles have been given permission to cross or occupy a runway in use, the controller shall, as a positive reminder that the runway is blocked, display a strip(s) or marker(s) on the part of the flight progress board which is used to represent the runway.

At units where flight progress boards are not used, such runway occupancy is to be shown effectively by a suitable method similar to the above.

Control of traffic in Traffic Circuit

Aircraft in the traffic circuit shall be controlled to provide the separation minima outlined by the air traffic controller, except that:

- Aircraft in formation are exempted from the separation minima with respect to separation from other aircraft of the same flight;
- Aircraft operating in different areas or different runways on aerodromes suitable for simultaneous landings or take-offs are exempted from the separation minima;

- Separation minima shall not apply to aircraft operating under military necessity.

Entry of traffic circuit

The clearance to enter the traffic circuit should be issued to an aircraft whenever it is desired that the aircraft approach the landing area in accordance with current traffic circuits but traffic conditions do not yet allow a landing clearance to be issued. Depending on the circumstances and traffic conditions, an aircraft may be cleared to join at any position in the traffic circuit.

An arriving aircraft executing an instrument approach shall normally be cleared to land straight in unless visual maneuvering to the landing runway is required.

Priority for landing

If an aircraft enters an aerodrome traffic circuit without proper authorization, it shall be permitted to land if its actions indicate that it so desires. If circumstances warrant, aircraft which are in contact with the controller may be instructed by the controller to give way so as to remove as soon as possible the hazard introduced by such unauthorized operation. In no case shall permission to land be withheld indefinitely.

In cases of emergency it may be necessary, in the interests of safety, for an aircraft to enter a traffic circuit and affect a landing without proper authorization. Controllers should recognize the possibilities of emergency action and render all assistance possible.

Priority shall be given to:

- An aircraft which anticipates being compelled to land because of factors affecting the safe operation of the aircraft (engine failure, shortage of fuel, etc.);
- Hospital aircraft or aircraft carrying any sick or seriously injured persons requiring urgent medical attention;
- Aircraft engaged in search and rescue operations;
- VVIP aircraft.

Order of priority for arriving and departing aircraft

An aircraft landing or in the final stages of an approach to land shall normally have priority over an aircraft intending to depart from the same or an intersecting runway.

CONTROL OF DEPARTING AIRCRAFT

Departure sequence

Departures shall normally be cleared in the order in which they are ready for take-off, except that deviations may be made from this order of priority to facilitate the maximum number of departures with the least average delay. Factors which should be considered in relation to the departure sequence include, inter alia:

- Types of aircraft and their relative performance;
- Routes to be followed after take-off;
- Any specified minimum departure interval between take-offs;
- Need to apply wake turbulence separation minima;
- Aircraft which should be afforded priority; and
- Aircraft subject to ATFM requirements.

Take-off clearance

Take-off clearance may be issued to an aircraft when there is reasonable assurance that the separation will exist when the aircraft commences take-off.

When an ATC clearance is required prior to takeoff, the take-off clearance shall not be issued until the ATC clearance has been transmitted to and acknowledged by the aircraft concerned. The ATC clearance shall be forwarded to the aerodrome control tower with the least possible delay after receipt of a request made by the tower or prior to such request if practicable.

The take-off clearance shall be issued when the aircraft is ready for take-off and at or approaching the departure runway and the traffic situation permits. To reduce the potential for misunderstanding, the take-off clearance shall include the designator of the departure runway.

In the interest of expediting traffic, a clearance for immediate take-off may be issued to an aircraft before it enters the runway. On acceptance of such clearance the aircraft shall taxi out to the runway and take off in one continuous movement.

CONTROL OF ARRIVING AIRCRAFT

Separation of landing aircraft and preceding landing and departing aircraft using the same runway

A landing aircraft will not normally be permitted to cross the runway threshold on its final approach until the preceding departing aircraft has crossed the end of the runway-in-use, or has started a turn, or until all preceding landing aircraft are clear of the runway-in-use

Clearance to land

An aircraft may be cleared to land when there is reasonable assurance that separation will exist when the aircraft crosses the runway threshold, provided that a clearance to land shall not be issued until a preceding landing aircraft has crossed the runway threshold. To reduce the potential for misunderstanding, the landing clearance shall include the designator of the landing runway.

Landing and roll-out maneuvers

When necessary or desirable in order to expedite traffic, a landing aircraft may be requested to:

- Hold short of an intersecting runway after landing;
- Land beyond the touchdown zone of the runway;
- Vacate the runway at a specified exit taxiway;
- Expedite vacating the runway.

In requesting a landing aircraft to perform a specific landing and/or roll-out maneuver, the type of aircraft, runway length, location of exit taxiways, reported braking action on runway and taxiway, and prevailing weather conditions shall be considered. A HEAVY aircraft shall not be requested to land beyond the touchdown zone of a runway.

If the pilot-in-command considers that he or she is unable to comply with the requested operation, the controller shall be advised without delay.

When necessary or desirable, e.g. due to low visibility conditions, a landing or a taxiing aircraft may be instructed to report when a runway has been vacated. The report shall be made when the entire aircraft is beyond the relevant runway-holding position.

PROCEDURES FOR LOW VISIBILITY OPERATIONS

Control of aerodrome surface traffic in conditions of low visibility

In conditions where low visibility procedures are in operation, persons and vehicles operating on the maneuvering area of an aerodrome shall be restricted to the essential minimum, and particular regard shall be given to the requirements to protect the ILS sensitive area(s) when Category II or Category III A precision instrument operations are in progress.

When there is a requirement for traffic to operate on the maneuvering area in conditions of visibility which prevent the aerodrome control tower from applying visual separation between aircraft, and between aircraft and vehicles, the following shall apply:

At the intersection of taxiways, an aircraft or vehicle on a taxiway shall not be permitted to hold closer to the other taxiway than the holding position limit defined by a clearance bar, stop bar or taxiway intersection marking.

SUSPENSION OF VISUAL FLIGHT RULES OPERATIONS

Any or all VFR operations on and in the vicinity of an aerodrome may be suspended by any of the following units, persons or authorities whenever safety requires such action:

- The approach control unit or the appropriate ACC;
- The aerodrome control tower;

All such suspensions of VFR operations shall be accomplished through or notified to the aerodrome control tower.

The following procedures shall be observed by the aerodrome control tower whenever VFR operations are suspended:

- Hold all VFR departures;
- Recall all local flights operating under VFR or obtain approval for special VFR operations;
- Notify the approach control unit or ACC as appropriate of the action taken;
- Notify all operators, or their designated representatives, of the reason for taking such action, if necessary or requested.

AUTHORIZATION OF SPECIAL VFR FLIGHTS:

When traffic conditions permit, special VFR flights may be authorized subject to the approval of the unit providing approach control service and the following provisions:

- Requests for such authorization shall be handled individually.
- Separation shall be effected between all special VFR flights and between such flights and IFR flights in accordance with separation minima applicable to IFR flights.
- When the ground visibility is not less than 1 500 m, special VFR flights may be authorized to: enter a control zone for the purpose of landing, take off and depart from a control zone, cross a control zone or operate locally within a control zone. Performance Class I, Performance Class II and military helicopters may be authorized to operate special VFR flights when the ground visibility is not less than 1000meters.

VFR flights can flown only if the following weather minima are present if not the flight as has to be carried out as per Instrument flight rules (IFR):

Controlled Airspace		Above 3000 feet MSL or 1000 feet AGL whichever is higher	Below 3000 feet MSL or 1000 feet AGL
Visibility		8 KM	+ 5 KM
Distance form Clouds	Horizontal	1.5 KM	1.5 KM
	Vertical	1000 feet (300 meters)	1000 feet (300 meters)

TABLE 3: WEATHER MINIMA FOR VFR FLIGHTS (CONTROLLED AIRSPACE)

Uncontrolled Airspace		Above 3000 feet MSL or 1000 feet AGL whichever is higher	Below 3000 feet MSL or 1000 feet AGL
Visibility		8 KM	+ 1.5 KM
Distance form Clouds	Horizontal	1.5 KM	Clear of clouds*
	Vertical	1000 feet (300 meters)	
* No VFR if 1000 feet or less ceiling and 5NM Visibility			

TABLE 4: WEATHER MINIMA FOR VFR FLIGHTS (UNCONTROLLED AIRSPACE)

SVFR flights can be conducted if:

- Visibility is less than 5 Km however not less than 1.5 Km
- Clouds less than 1500 feet but not less than 1000 feet

Above 14000 feet all flights have to carried out as per Instrument Flight Rules (IFR)

3.2 Flight Data / Clearance Delivery

AIR TRAFFIC CLEARANCE- An authorization by air traffic control for the purpose of preventing collision between known aircraft, for an aircraft to proceed under specified traffic conditions within controlled airspace. The pilot-in-command of an aircraft may not deviate from the provisions of a visual flight rules (VFR) or instrument flight rules (IFR) air traffic clearance except in an emergency or unless an amended clearance has been obtained. Additionally, the pilot may request a different clearance from that which has been issued by air traffic control (ATC) if information available to the pilot makes another course of action more practicable or if aircraft equipment limitations or company procedures forbid compliance with the clearance issued. Pilots may also request clarification or amendment, as appropriate, any time a clearance is not fully understood, or considered unacceptable because of safety of flight. Controllers should, in such instances and to the extent of operational practicality and safety, honor the pilot's request. 14 CFR Part 91.3(a) states: "The pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft." THE PILOT IS RESPONSIBLE TO REQUEST AN AMENDED CLEARANCE if ATC issues a clearance that would cause a pilot to deviate from a rule or regulation, or in the pilot's opinion, would place the aircraft in jeopardy."

Clearance Delivery is the position that issues route clearances to aircraft, typically before they commence taxiing. These contain details of the route that the aircraft is expected to fly after departure. Clearance Delivery or, at busy airports, the Traffic Management Coordinator (TMC) will, if necessary, coordinate with the en route center and national command center or flow control to obtain releases for aircraft. Often, however, such releases are given automatically or are controlled by local agreements allowing "free-flow" departures. When weather or extremely high demand for a certain airport or airspace becomes a factor, there may be ground "stops" (or "slot delays") or re-routes may be necessary to ensure the system does not get overloaded.

The primary responsibility of Clearance Delivery is to ensure that the aircraft have the proper route and slot time. This information is also coordinated with the en route center and Ground Control in order to ensure that the aircraft reaches the runway in time to meet the slot time provided by the command center. At some airports, Clearance Delivery also plans aircraft pushback and engine starts, in which case it is known as the Ground Movement Planner (GMP): this position is particularly important at heavily congested airports to prevent taxiway and apron gridlock.

Along with clearance delivery start-up time procedures should be contained in the local instructions and should specify the criteria and conditions for determining when and how start-up times shall be calculated and issued to departing aircraft.

Flight Data (which is routinely combined with Clearance Delivery) is the position that is responsible for ensuring that both controllers and pilots have the most current information: pertinent weather changes, outages, airport ground delays/ground stops, runway closures, etc. Flight Data may inform the pilots using a recorded continuous loop on a specific frequency known as the **Automatic Terminal Information Service (ATIS).**

Aerodrome and Meteorological Information

Prior to taxiing for take-off, aircraft shall be advised of the following elements of information, in the order listed, with the exception of such elements which it is known the aircraft has already received:

- The runway to be used;
- The surface wind direction and speed, including significant variations;
- The QNH altimeter setting and, either on a regular basis in accordance with local arrangements or if so requested by the aircraft, the QFE altimeter setting;
- The air temperature for the runway to be used, in the case of turbine-engine aircraft;
- The visibility representative of the direction of take-off and initial climb, if less than 10 km, or, when applicable, the RVR value(s) for the runway to be used;
- The correct time.

Prior to take-off aircraft is advised of:

- Any significant changes in the surface wind direction and speed, the air temperature, and the visibility or RVR value(s)
- Significant meteorological conditions in the take-off and climb-out area, except when it is known that the information has already been received by the aircraft.

Elements of a Proper Clearance
All clearances must include "**CRAFT**" –
Clearance limit / Route / Altitude / Departure Frequency / Transponder.

- Clearance Limit - This is almost always the destination airport, though it could also be an IFR fix, if the aircraft is on a composite IFR / VFR flight plan.
- Route of Flight - This is usually the route of flight filed in the flight plan and could be simply "direct". If the route has been revised, the new route of flight must be issued.
- Altitude - An initial altitude specified by local procedure such as a Letter of Agreement.
- Frequency - At larger airports, the departure controller's frequency is issued in advance to reduce communications after takeoff.
- Transponder - In the real world, transponder codes are computer generated, for our purposes, it should be a code other than the default FS code of 1200 that is designated for VFR operations. Each digit ranges from 0 to 7. There are no 8's or 9's in the transponder code.

3.3 Ground Control

Ground Control (sometimes known as Ground Movement Control abbreviated to GMC or Surface Movement Control abbreviated to SMC) is responsible for the airport "movement" areas, as well as areas not released to the airlines or other users. This generally includes all taxiways, inactive runways, holding areas, and some transitional aprons or intersections where aircraft arrive, having vacated the runway or departure gate. Exact areas and control responsibilities are clearly defined in local documents and agreements at each airport. Any aircraft, vehicle, or person walking or working in these areas is required to have clearance from Ground Control. This is normally done via VHF/UHF radio, but there may be special cases where other processes are used. Most aircraft and airside vehicles have radios. Aircraft or vehicles without radios must respond to ATC instructions via aviation light signals or else be led by vehicles with radios. People working on the airport surface normally have a communications link through which they can communicate with Ground Control, commonly either by handheld radio or even cell phone. Ground Control is vital to the smooth operation of the airport, because this position impacts the sequencing of departure aircraft, affecting the safety and efficiency of the airport's operation.

Uncertainty of position on the maneuvering area

A pilot in doubt as to the position of the aircraft with respect to the maneuvering area shall immediately:

- Stop the aircraft; and
- Simultaneously notify the appropriate ATS unit of the circumstances (including the last known position).

In those situations where a pilot is in doubt as to the position of the aircraft with respect to the maneuvering area, but recognizes that the aircraft is on a runway, the pilot shall immediately:

- Notify the appropriate ATS unit of the circumstances (including the last known position);
- If able to locate a nearby suitable taxiway, vacate the runway as expeditiously as possible, unless otherwise instructed by the ATS unit; and then,
- Stop the aircraft.

A vehicle driver in doubt as to the position of the vehicle with respect to the maneuvering area shall immediately:

- Notify the appropriate ATS unit of the circumstances (including the last known position);
- Simultaneously, unless otherwise instructed by the ATS unit, vacate the landing area, taxiway, or other part of the maneuvering area, to a safe distance as expeditiously as possible; and then,

- Stop the vehicle.

In the event the aerodrome controller becomes aware of an aircraft or vehicle that is lost or uncertain of its position on the maneuvering area, appropriate action shall be taken immediately to safeguard operations and assist the aircraft or vehicle concerned to determine its position.

ESSENTIAL INFORMATION ON AERODROME CONDITIONS

Essential information on aerodrome conditions is information necessary to safety in the operation of aircraft, which pertains to the movement area or any facilities usually associated

Essential information on aerodrome conditions shall include information relating to the following:

- Construction or maintenance work on, or immediately adjacent to the movement area;
- Rough or broken surfaces on a runway, a taxiway or an apron, whether marked or not;
- Snow, slush or ice on a runway, a taxiway or an apron;
- Water on a runway, a taxiway or an apron;
- Snow banks or drifts adjacent to a runway, a taxiway or an apron;
- Other temporary hazards, including parked aircraft and birds on the ground or in the air;
- Failure or irregular operation of part or all of the aerodrome lighting system;

Essential information on aerodrome conditions shall be given to every aircraft, except when it is known that the aircraft already has received all or part of the information from other sources. The information shall be given in sufficient time for the aircraft to make proper use of it, and the hazards shall be identified as distinctly as possible.

When a not previously notified condition pertaining to the safe use by aircraft of the maneuvering area is reported to or observed by the controller, the appropriate aerodrome authority shall be informed and operations on that part of the maneuvering area terminated until otherwise advised by the appropriate aerodrome authority.

Control of Taxiing Aircraft

Taxi Clearance

Prior to issuing a taxi clearance, the controller shall determine where the aircraft concerned is parked. Taxi clearances shall contain concise instructions and adequate information so as to assist the flight crew to follow the correct taxi routes, to avoid collision with other aircraft or objects and to minimize the potential for the aircraft inadvertently entering an active runway.

When a taxi clearance contains a taxi limit beyond a runway, it shall contain an explicit clearance to cross or an instruction to hold short of that runway.

CONTROL OF OTHER THAN AIRCRAFT TRAFFIC

Entry to the Maneuvering Area

The movement of persons or vehicles including towed aircraft on the maneuvering area of an aerodrome shall be controlled by the aerodrome control tower as necessary to avoid hazard to them or to aircraft landing, taxiing or taking off. Persons, including drivers of all vehicles, shall be required to obtain authorization from the aerodrome control tower before entry to the maneuvering area. Notwithstanding such an authorization, entry to a runway or runway strip or change in the operation authorized shall be subject to a further specific authorization by the aerodrome control tower.

In conditions where low visibility procedures are in operation:

- persons and vehicles operating on the maneuvering area of an aerodrome shall be restricted to the essential minimum, and particular regard shall be given to the requirements to protect the ILS sensitive area(s) when Category II or Category III A precision instrument operations are in progress;

- The vehicles shall remain at safe distance from taxiing aircraft.

Priority on the Maneuvering Area

Emergency vehicles proceeding to the assistance of an aircraft in distress shall be afforded priority over all other surface movement traffic. All movement of surface traffic should, to the extent practicable, be halted until it is determined that the progress of the emergency vehicles will not be impeded.

vehicles on the maneuvering area shall be required to comply with the following rules:

- Vehicles, vehicles towing aircraft and pedestrians shall give way to aircraft which are landing, taking off for taxiing;

- Vehicles shall give way to other vehicles towing aircraft;

- Vehicles shall give way to other vehicles in accordance with ATS unit instructions;

- Notwithstanding the provisions of a), b)and c), vehicles and vehicles towing aircraft shall comply with instructions issued by the aerodrome control tower.

When an aircraft is landing or taking off, vehicles shall not be permitted to hold closer to the runway-in use than:

- At a taxiway/runway intersection:- at a runway holding position; and

- At a location other than a taxiway/runway intersection:-at a distance equal to the separation distance of the runway-holding position.

In order guide aircraft all taxiways are name alpha numerically and runways are name as per their magnetic heading.

Some busier airports have Surface Movement Radar (SMR), such as, ASDE-3, AMASS or ASDE-X, designed to display aircraft and vehicles on the ground. These are used by Ground Control as an additional tool to control ground traffic, particularly at night or in poor visibility. There are a wide range of capabilities on these systems as they are being modernized. Older systems will display a map of the airport and the target. Newer systems include the capability to display higher quality mapping, radar target, data blocks, and safety alerts, and to interface with other systems such as digital flight strips.

<u>Operating Procedures for Aerodrome Surface Detection Equipment (ASDE).</u>

ASDE is useful in assisting the Controller to keep continuous check of runway occupancy and taxiway usage during period of low visibility and at night. It also allows rapid appreciation of lighting control requirements and facilitates clearances for aircraft and vehicles.

ASDE is an adjunct and not an alternative to the visual aids and procedures used for the control of aircraft and vehicles on the maneuvering area.

ASDE may be used to augment visual observation of traffic on the maneuvering area and to provide surveillance of traffic on those parts of the maneuvering area which cannot be observed visually.

The following technical limitations may affect the operational efficiency and use of ASDE.

- Aircraft/vehicle size- delectability diminishes with reduction in size.

- Line-of-sight limitations.

- Heavy rain causing clutter and resolution difficulties.

- Shielding - A portion of an aircraft/vehicle may be shielded from the radar by another object or part of the same object, e.g. An offside wing is often not visible when shielded by the fuselage.

- Reflection - Other aircraft/vehicle (s) and large structures such as hangers may reflect some energy away from the radar antenna, e.g. a smooth aircraft fuselage at angles other than a right angle to the radar.

- Rough surfaces or long grass-vehicle delectability is reduced on rough ground, wet or long grass.

- Radar position elongation - Occurs in both range and azimuth, due to radar equipment resolution limitations associated with stronger returns.

- Lack of radar position labels and symbols.

- Shadow area.

Before providing guidance to an aircraft/vehicle based on ASDE derived information, positive identity of the object should be established by use of at least one of the methods specified below :

- Correlating the position of a visually observed aircraft/vehicle to that displayed on ASDE.

- Correlating an ASDE position - Complying with an ATC instruction for a specific maneuver.

- Correlating a displayed ASDE position of an aircraft or vehicle as reported by radio.

- Correlating a displayed ASDE position to an aircraft or vehicle :
  - Entering a runway or taxiway intersection
  - Abeam a building or airfield feature which either shows as a permanent echo on the display or is marked on the video or grid map
  - On a taxiway or runway, provided that there are no other unidentified vehicles or aircraft on that runway or taxiway segment.

Position information of ASDE - Derived aircraft/vehicles position may be relayed by use of the following methods

- Direct designation

- Specifying the location of ASDE derived position by reference to identifiable features displayed on the video or grid map.

The ASDE will be deployed for the surface movement guidance and control when visibility is 2000M or less or RVR is 1500M or less. However, it may be used for the above purposes at night irrespective of the visibility/RVR conditions or at the discretion of the Controller.

In the event of equipment failure when visibility is below 2000M or RVR is below 1500M,the information will be disseminated on ATIS.

The ASDE provided at the workstation of Surface Movement Controller within the limitation of the coverage, may be used for the following purposes:

- To monitor and assist departing and arriving traffic.
- To monitor the position of traffic in order to facilitate switching-on of associated taxiway lights.
- To monitor and assist emergency service vehicles to attend a scene of an incident as necessary.
- To monitor movement of ground vehicles on the movement area to detect unauthorized entry into maneuvering area.
- To monitor pilot compliance with the issued instructions.
- To provide taxi guidance.
- To provide guidance information to an aircraft uncertain of its position.
- To monitor push-back for avoiding conflict with traffic in the area.

ASDE should not be used by ATC to provide heading instructions for taxi-guidance. Taxi guidance instructions using ASDE should be the same as those applicable for visual control.

The use of ASDE for the above listed purposes will not in any way relieve pilots of taxing aircraft or drivers of vehicles or any of their responsibilities in respect of avoiding collision with other objects or structure on the ground.

The ASDE monitor provided at Aerodrome Control workstation may be used for the following purposes:

- To ascertain that departing aircraft are lined up on the correct runway.
- To ascertain that arriving aircraft has vacated the runway.
- To ascertain that aircraft has commenced the take-off run.
- To ascertain that runway is clear of aircraft, vehicles or obstructions prior to a departure or landing.

All airports have airport diagrams publish which a layout of the airport which clearly define the taxiways along with their name, aprons, maneuvering areas and the runways along with the runway number.
These diagrams are used by pilots as reference to follow the taxing instructions provided by ground controllers.

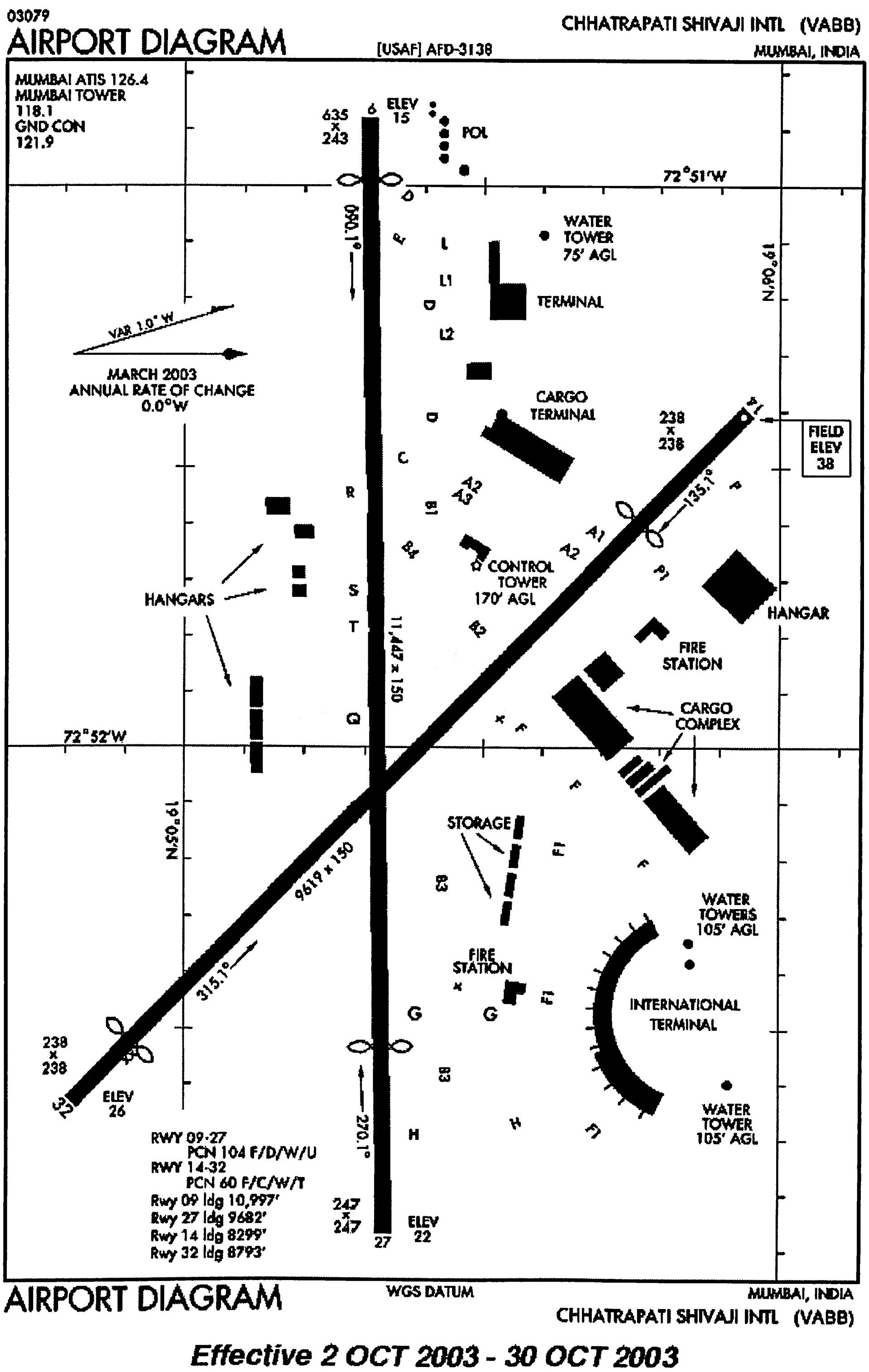


Figure 2: Airport diagram of VABB

3.4 En-route, center or area control

In air traffic control, an Area Control Center (ACC), also known as a Center, is a facility responsible for controlling instrument flight rules aircraft en route in a particular volume of airspace (a Flight Information Region) at high altitudes between airport approaches and departures.

A Center typically accepts traffic from, and ultimately passes traffic to, the control of a Terminal Control Center or of another Center. Most Centers are operated by the national governments of the countries in which they are located. The general operations of Centers worldwide, and the boundaries of the airspace each Center controls, are governed by the ICAO.

In some cases, the function of an Area Control Center and a Terminal Control Center are combined in a single facility. For example, NATS combines the London Terminal Control Centre (LTCC) and London Area Control Centre (LACC) in Swanwick in the UK.

Area control functions

Air traffic controllers working within a Center communicate via radio with pilots of instrument flight rules aircraft passing through the Center's airspace. A Center's communication frequencies (typically in the very high frequency amplitude modulation aviation bands, 118 MHz to 137 MHz, for overland control) are published in aeronautical charts and manuals, and will also be announced to a pilot by the previous controller during a hand-off.

In addition to radios to communicate with aircraft, Center controllers have access to communication links with other Centers and TRACONs. In the United States, Centers are electronically linked through the National Airspace System, which allows nationwide coordination of traffic flow to manage congestion. Centers in the United States also have electronic access to nationwide radar data.

Controllers use radar to monitor the progress of flights and instruct aircraft to perform course adjustments as needed to maintain separation from other aircraft. Aircraft with Center contact can be readily distinguished by their transponders. Pilots may request altitude adjustments or course changes for reasons including avoidance of turbulence or adverse weather conditions.

Controllers can assign routing relative to location fixes derived from latitude and longitude, or from radio navigation beacons such as VORs. See also Airway; VORs, Airways and the Enroute Structure.

Typically, Centers have advance notice of a plane's arrival and intentions from its pre-filed flight plan.

Oceanic air traffic control

Some Centers have ICAO-designated responsibility for airspace located over an ocean such as ZOA, the majority of which is international airspace. Because substantial volumes of oceanic airspace lie beyond the range of ground-based radars, oceanic airspace controllers have to estimate the position of an airplane from pilot reports and computer models (procedural control), rather than observing the position directly (radar control, also known as positive control). Pilots flying over an ocean can determine their own positions accurately using the Global Positioning System and can supply periodic updates to a Center.

A Center's control service for an oceanic FIR may be operationally distinct from its service for a domestic overland FIR over land, employing different communications frequencies, controllers, and a different ICAO code.

Pilots typically use high frequency radio instead of very high frequency radio to communicate with a Center when flying over the ocean, because of HF's relatively greater propagation over long distances.

Area control services in India

GENERAL PROVISIONS:

ATS surveillance systems, such as primary surveillance radar (PSR), secondary surveillance radar (SSR) and automatic dependence surveillance - broadcast (ADS-B) may be used either alone or in combination in the provision of air traffic services, including in the provision of separation between aircraft, provided:

Reliable coverage exists in the area;

- The probability of detection, the accuracy and the integrity of the ATS surveillance system(s) are satisfactory; and
- In the case of ADS-B, the availability of data from participating aircraft is adequate,

PSR systems should be used in circumstances where SSR and/or ADS-B alone would not meet the air traffic services requirements.

SSR system, especially those utilizing mono pulse technique or having Mode S capability, may be used alone, including in the provision of separation between aircraft, provided;

- The carriage of SSR transponders is mandatory within the area; and
- Identification is established and maintained.

ADS-B shall only be used for the provision of air traffic control service provided the quality of the information contained in the ADS-B message exceeds the values specified by the appropriate ATS authority. The provision of ATS surveillance services shall be limited when position data quality degrades below a level specified by the appropriate ATS authority.

Where PSR and SSR are required to be used in combination, SSR alone may be used in the event of PSR failure to provide separation between identified transponder-equipped aircraft, provided the accuracy of the SSR position indications has been verified by monitor equipment or other means.

The number of aircraft simultaneously provided with ATS surveillance services shall not exceed that which can safely be handled under the prevailing circumstances, taking into account:

- The structural complexity of the control area or sector concerned;
- The functions to be performed within the control area or sector concerned;
- Assessments of controller workloads, taking into account different aircraft capabilities, and sector capacity; and
- The degree of technical reliability and availability of the primary and back-up communications, navigation and surveillance system, both in the aircraft and on the ground.

The following types of radar services may be provided to aircraft operating within reliable radar coverage:

Type of radar service	Class of airspace
Radar control service	D & E
Radar Advisory service	F
Radar Flight information service	G

TABLE 5: TYPE OF RADAR SERVICE AS PER AIRSPACE

Before providing radar service to an aircraft, radar identification shall be established and the pilot informed.
Thereafter, radar identification shall be maintained until termination of the radar service.

If radar identification is subsequently lost, the pilot shall be informed accordingly and, when applicable, appropriate instructions issued.

The provision of radar services requires that aircraft remain in direct two way communication with the unit providing the service. However radar separation may be provided between two radar identified aircraft even when only one of the aircraft is in direct communication with the radar unit.

In the event of an aircraft in or appearing to be in, any form of emergency ATC will provide all possible assistance, including the provision of radar service to the extent possible.

USE OF ATS SURVEILLANCE SYSTEM IN AIR TRAFFIC CONTROL SERVICE:

The information provided by ATS surveillance systems and presented on a situation display may be used to perform the following functions in the provision of air traffic control service;

Provide ATS surveillance services in order to:-

- Improve airspace utilization;
- Reduce delays;
- Facilitate direct routings and more optimum flight profiles;
- Enhance safety

Provide vectoring to:-

- Departing aircraft for expeditious and efficient departure flow and expediting climb to cruising level
- Arriving aircraft for the purpose of expediting descent from cruising level and establishing an expeditious and efficient approach sequence.
- Aircraft for purpose of resolving potential conflict.
- Assist pilot in their navigation.

Provide separation and maintain normal traffic flow when an aircraft experiencing communication failure is within area of coverage.

- Maintain flight path monitoring of air traffic
- Maintain a watch on the progress of air traffic, in order to provide a procedural controller with:
- Improved position information regarding aircraft under control.
- Supplementary information regarding other traffic.
- Any significant deviations by aircraft from their assigned routing or level.

NOTE: *To be considered 'Significant' an aircraft's track deviation should be sufficient to take it beyond the boundary of the route being followed or be assessed by the radar controller as liable to take it beyond the edge of the protected airspace of the route being followed.*

The position indication presented on a situation display may be used to perform the following additional functions in the provision of approach control service:

- Provide vectoring of arriving traffic on to pilot-interpreted final approach aids;
- Provide vectoring of arriving traffic to a point from which a visual approach can be completed;

- Provide vectoring of arriving traffic to a point from which a surveillance radar approach can be made;
- Provide flight path monitoring of other pilot-interpreted approaches;
- In accordance with prescribed procedures, conduct: surveillance radar approaches;
- Provide separation between:
  - Succeeding departing aircraft
  - Succeeding arriving aircraft; and
  - A departing aircraft and a succeeding arriving aircraft.

USE OF SSR TRANSPONDERS AND ADS-B TRANSMITTERS

To ensure the safe and efficient use of Secondary surveillance Radar (SSR) and ADS-B pilots and controllers shall strictly adhere to published operating procedures and standard radiotelephony phraseology shall be used. The correct setting of transponder codes and/or aircraft identification shall be ensured at all times.

Use of SSR without Primary Radar:

SSR information may be used alone in the provision of separation between aircraft provided; aircraft identification is established and maintained by use of discrete SSR codes.

Procedural separation will be applied between transponder-equipped aircraft and an aircraft without a SSR transponder or with a non-functioning SSR transponder.

In the event of an aircraft transponder failure or ATC determining that transponder does not will meet serviceability requirements the aircraft (for whom carriage of Transponder is mandatory)normally be permitted to continue to operate to the next point of landing.

An aircraft (for whom carriage of transponder is mandatory) whose transponder failure is detected before departure may be specifically authorized by ATC to operate without serviceable transponder provided a request is included in the flight plan.

SSR Code management

Uniqueness and continuity criteria are used to provide permanent visibility and identification of individual flights with a minimum of errors and of interruptions.

- Uniqueness: Only one aircraft should respond on a given code in any particular area and at any given time. This measure provides an unambiguous code/call-sign association and consequently an easy identification of flights.
- Continuity: A code assigned to a flight will be retained as long as possible (preferably for the entire duration of the flight). This measure secures permanent display of individual flights, especially for control transfers between adjacent units.

The uniqueness and continuity criteria enhance safety by limiting the likelihood of identification errors due to the presence of several aircraft having the same code or to wrong settings. They assist traffic flow equally well since radar identification and all aspects connected with transfers are facilitated. This results in some reduction of the controllers' workload (Radio-telephony, monitoring for identification, etc.).

The detailed principles governing the use of SSR codes in the Asia/PAC Region are based on the following general principles:

- Mode A/3 codes should be used for ATS purposes only.

- Code assignment practices should be based on the temporary use of codes and permit the most economic code re-cycling. The need for code changes during flight should be minimum and may be resorted to only when essential for the operations of the ATC system/unit having control responsibility.

- Codes are allotted on the basis of duly justified operational requirements, with the actual number derived from the number of aircraft to be handled simultaneously within a specified area and for a determined period of protection (uniqueness) during traffic peaks.

- Codes should be assigned to aircraft as close as possible to their actual departure time, and preferably at the time they receive their start-up clearance. In the case of having to change the code of an aircraft while in flight, the assignment should be made as close as possible to the time the flight is to transfer to the control of the assigning ATS unit/system.

- Codes may be assigned according to the earliest time of release. However, in units assigning codes manually, the cyclical assignment of the codes released should be undertaken instead of an allocation.

Special Purpose Codes:

Specific codes in certain series are reserved for special purposes as follows:

SSR Codes	Purpose
0000	Available as a general-purpose code for domestic use by any State.
2000	Reserved for use on the initiative of pilots to provide recognition of aircraft which have not received ATC instructions regarding which code to squawk.
7500	Reserved for use in the event of unlawful interference.
7600	Reserved for use in the event of radiotelephony communication failure
7700	Reserved for use in the event of emergencies

TABLE 6: SPECIAL PURPOSE TRANSPONDER CODES

USE OF SSR TRANSPONDERS AND ADS-B TRANSMITTERS

To ensure the safe and efficient use of Secondary surveillance Radar (SSR) and ADS-B pilots and controllers shall strictly adhere to published operating procedures and standard radiotelephony phraseology shall be used. The correct setting of transponder codes and/or aircraft identification shall be ensured at all times.

Use of SSR without Primary Radar:

SSR information may be used alone in the provision of separation between aircraft provided; aircraft identification is established and maintained by use of discrete SSR codes.

Procedural separation will be applied between transponder-equipped aircraft and an aircraft without a SSR transponder or with a non-functioning SSR transponder.

In the event of an aircraft transponder failure or ATC determining that transponder does not will meet serviceability requirements the aircraft (for whom carriage of Transponder is mandatory)normally be permitted to continue to operate to the next point of landing.

An aircraft (for whom carriage of transponder is mandatory) whose transponder failure is detected before departure may be specifically authorized by ATC to operate without serviceable transponder provided a request is included in the flight plan.

SSR Code management

Uniqueness and continuity criteria are used to provide permanent visibility and identification of individual flights with a minimum of errors and of interruptions.

- Uniqueness: Only one aircraft should respond on a given code in any particular area and at any given time. This measure provides an unambiguous code/call-sign association and consequently an easy identification of flights.
- Continuity: A code assigned to a flight will be retained as long as possible (preferably for the entire duration of the flight). This measure secures permanent display of individual flights, especially for control transfers between adjacent units.

The uniqueness and continuity criteria enhance safety by limiting the likelihood of identification errors due to the presence of several aircraft having the same code or to wrong settings. They assist traffic flow equally well since radar identification and all aspects connected with transfers are facilitated. This results in some reduction of the controllers' workload (Radio-telephony, monitoring for identification, etc.).

The detailed principles governing the use of SSR codes in the Asia/PAC Region are based on the following general principles:

- Mode A/3 codes should be used for ATS purposes only.

- Code assignment practices should be based on the temporary use of codes and permit the most economic code re-cycling. The need for code changes during flight should be minimum and may be resorted to only when essential for the operations of the ATC system/unit having control responsibility.

- Codes are allotted on the basis of duly justified operational requirements, with the actual number derived from the number of aircraft to be handled simultaneously within a specified area and for a determined period of protection (uniqueness) during traffic peaks.

- Codes should be assigned to aircraft as close as possible to their actual departure time, and preferably at the time they receive their start-up clearance. In the case of having to change the code of an aircraft while in flight, the assignment should be made

International Codes:

International codes are allotted for assignment to aircraft engaged in international flights. They may also be assigned to international flights which overfly, or fly into the, FIR. However, in keeping with the principle of continuity, this action should always be seen as a exception to recommended practice.

International codes are assigned in accordance with the following principles.

Duplication of code assignments by different units in the same FIR is prevented.

Each flight will retain the original code assigned for the entire flight within the originating FIR at least.

Appropriate code protection criteria shall be applied in order to avoid duplication by too early re-assignment of the same code. For most FIRs within the ASIA/PAC Region, a protection period of two hours should be sufficient. However, larger FIRs may need to apply longer protection periods, or protection by some other criteria (i.e. Knowledge of the aircraft having reached its destination or having passed a predetermined point). For reasons of economy, every effort should be made to reduce the length of the protection periods whenever possible.

The protection period needs to be calculated with respect to preventing duplication in adjacent FIRs as well as within the FIR in which the flight originated.

Code changes at FIR boundaries should only be undertaken to meet the essential needs of ATC in the receiving FIR.

Domestic Codes:

Domestic codes are allotted for assignment to aircraft engaged in flights which will remain wholly within the State FIRs.

Domestic codes should be used so that the utmost economy in the number of codes required is achieved. All of the general principles described above and several of those ascribed to international code assignment (i.e. Prevention of duplication, code retention for flight leg, protection period etc.), are relevant with respect to domestic code use.

Except as provided in the above paragraphs pilots shall operate transponders and select modes and codes in accordance with the following procedures.

- Aircraft departing from an aerodrome located in Delhi, Calcutta, Chennai, Mumbai and Guwahati FIR shall be assigned an appropriate SSR code on departure. This SSR code setting shall continue unless instructed otherwise.
- Aircraft engaged in International flight, entering Delhi, Calcutta, Chennai, Mumbai and Guwahati FIR shall continue to maintain the SSR code being squawked in the adjacent FIR. This SSR code setting shall be included in the first position report prior to entering the FIR.
- Aircraft engaged on domestic flight shall operate the transponder on the last assigned code.
- Aircraft not assigned a SSR code shall operate transponder on mode A3 code 2000 before entry into Delhi, Calcutta, Chennai, Mumbai and Guwahati FIR and maintain that code setting until otherwise instructed.
- In order to avoid interference on Radar display, the pilot shall not operate the transponder when the aircraft is on ground except when entering the runway for take-off or till vacating the runway after landing.

Emergency Procedure:

An aircraft encountering a state of emergency may continue to operate the transponder on the previously assigned code, until otherwise advised. Alternatively the transponder shall be set to mode A3 code 7700.

Notwithstanding the procedure mentioned above a pilot may select mode A3 code 7700 whenever the nature of the emergency is such that this appears to be the most suitable course of action.

Radio Communication Failure

In the event of an aircraft radio receiver failure, a pilot shall select mode A3 code 7600 and follow established procedures; subsequent control of the aircraft will be based on those procedures.

Unlawful Interference

Should an aircraft in flight be subjected to unlawful interference, the pilot shall endeavor to set the transponder to mode A3 code 7500 to give indication of the situation unless circumstances warrant the use of mode A3 code 7700.

When a pilot has selected mode A3 code 7500 and is subsequently requested to confirm his code by ATC he shall, according to circumstances either confirm this or not reply at all.

NOTE: The absence of a reply from the pilot will be taken by ATC as an indication that the use of code 7500 is not due to an inadvertent false code selection.

Operation of SSR transponders:

When it is observed that the Mode A code shown on the situation display is different to what has been assigned to the aircraft, the pilot shall be requested to confirm the code selected and, if the situation warrants (e.g. not being a case of unlawful interference), to reselect the correct code.

If the discrepancy between assigned and displayed Mode A codes still persists, the pilot may be requested to stop the operation of the aircraft's transponder. The next control position and any other affected unit using SSR in the provision of ATS shall be informed accordingly.

Aircraft equipped with Mode S having an aircraft identification feature shall transmit the aircraft identification as specified in Item 7 of the ICAO flight plan or, when no flight plan has been filed, the aircraft registration.

Level Information based on the use of pressure altitude information:

Verification of accuracy of level information:

The tolerance value used to determine that pressure altitude-derived level information displayed to the controller is accurate shall be ± 200 ft in RVSM airspace. In other airspace, it shall be ±300 ft. Geometric height information shall not be used for separation.

Verification of pressure altitude-derived level information displayed to the controller shall be effected at least once by each suitably equipped ATC unit on initial contact with the aircraft concerned or, if this is not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure altitude-derived level information is within the approved tolerance value need not be advised of such verification. Geometric height information shall not be used to determine if altitude differences exist.

Note 1: The accuracy of pressure altitude-*derived level information displayed to the controller may be verified based on the level information report given by aircraft*

Note 2: When the accuracy of pressure altitude-derived level information displayed to the controller has been verified by a controller and handoff is made to another controller at the same airport (intra facility), the accepting controller need not verify the pressure altitude-derived level information.

If the displayed level information is not within the approved tolerance value or when a discrepancy in excess of the approved tolerance value is detected subsequent to verification, the pilot shall be advised accordingly and requested to check the pressure setting and confirm the aircraft's level.

If, following confirmation of the correct pressure setting the discrepancy continues to exist, the following action should be taken according to circumstances:

- Request the pilot to stop Mode C or ADS-B altitude data transmission, provided this does not cause the loss of position and identity information, and notify the next control positions or ATC unit concerned with the aircraft of the action taken;

- Inform the pilot of the discrepancy and request that the relevant operation continue in order to prevent loss of position and identity information of the aircraft, and, when authorized by the appropriate ATS authority, override the label-displayed level information with the reported level. Notify the next control position or ATC unit concerned with the aircraft of the action taken.

Determination of level occupancy:

The criterion which shall be used to determine that a specific level is occupied by an aircraft shall be ± 200 ft in RVSM airspace. In other airspace, it shall be ±300 ft.

Aircraft maintaining a level:- An aircraft is considered to be maintaining its assigned level as long as the pressure altitude-derived level information indicates that it is within ±300 ft of the assigned level.

Aircraft vacating a level: - An aircraft cleared to leave a level is considered to have commenced its maneuver and vacated the previously occupied level when the pressure altitude-derived level information indicates a change of more than ±300 ft in the anticipated direction from its previously assigned level.

Aircraft passing a level in climb or descent: - An aircraft in climb or descent is considered to have crossed a level when the pressure altitude-derived level information indicates that it has passed this level in the required direction by more than ±300 ft.

Aircraft reaching a level: - An aircraft is considered to have reached the level to which it has been cleared when the elapsed time of three display updates, three sensor updates or 15 seconds, whichever is the greater, has passed since the pressure altitude-derived level information has indicated that it is within + 300 ft of its assigned level.

Intervention by a controller shall only be required if differences in level information between that displayed to the controller and that used for control purposes are in excess of the values stated above.

PERFORMANCE CHECKS

The controller shall adjust the situation display(s) and carry out adequate checks on the accuracy thereof, in accordance with the technical instructions contained in Manual of Air Traffic Services Part-2.

The controller shall be satisfied that the available functional capabilities of the ATS surveillance system as well as the information presented on the situation display(s) is adequate for the functions to be performed.

The controller shall report, in accordance with local procedures contained in Manual of Air Traffic Services Part-2, any fault in the equipment, or any incident requiring investigation, or any circumstances which make it difficult or impractical to provide ATS surveillance services.

IDENTIFICATION OF AIRCRAFT

Before providing ATS surveillance service to an aircraft, identification shall be established and the pilot informed. Thereafter, identification shall be maintained until termination of the ATS surveillance service.

If identification is subsequently lost, the pilot shall be informed accordingly and, when applicable, appropriate instructions issued.

When a discrete code has been assigned to an aircraft, a check shall be made at the earliest opportunity to ensure that the code set by the pilot is identical to that assigned for the flight. Only after this check has been made shall the discrete code be used as a basis for identification.

ASD-B Identification Procedures

Where ADS-B is used for identification, aircraft may be identified by one or more of the following procedures:

- Direct recognition of the aircraft identification in an ADS-B label;
- Transfer of ADS-B identification;
- Observation of compliance with an instruction to TRANSMIT ADS-B IDENT;

Note: - In automated system, the "IDENT' feature may be presented in different ways, e.g. as a flashing of all or part of the position indication and associated label.

SSR Identification Procedures

Where SSR is used for identification, aircraft may be identified by one or more of the following procedures:

- Recognition of the aircraft identification in a radar label;
  Note: - The use of this procedure requires that the code/call sign correlation is achieved successfully, taking into account the Note following b) below.

- Recognition of an assigned discrete code, the setting of which has been verified, in a radar label;
  Note:- The use of this procedure requires a system of code assignment which ensures that each aircraft in a given portion of airspace is assigned a discrete code.

- Direct recognition of the aircraft identification of a Mode S-equipped aircraft in a radar label;

- By transfer of identification;

- Observation of compliance with an instruction to set a specific code;

- Observation of compliance with an instruction to squawk IDENT;
  Note 1:- In automated radar systems, the "IDENT" feature may be presented in different ways, e.g. as a flashing of all or part of the position indication and associated label.
  Note 2:- Garbling of transponder replies may produce "IDENT"- type of indications. Nearly simultaneous "IDENT" transmissions within the same area may give rise to errors in identification.

When a discrete code has been assigned to an aircraft, a check shall be made at the earliest opportunity to ensure that the code set by the pilot is identical to that assigned for the flight. Only after this check has been made shall the discrete code be used as a basis for identification.

PSR Identification Procedures:

Where PSR is used for identification, aircraft may be identified by one or more of the following procedures:

Position Report Method:

By correlating particular radar position indication with an aircraft reporting its position over or as bearing and distance from, a point shown on the situation display; and by ascertaining that the track of the particular radar position is consistent with the aircraft path or reported heading.

Departing Aircraft Method:

By correlating an observed radar position indication with an aircraft which is known to have just departed, provided that the identification is established within 1 NM from the end of the runway used. Particular care should be taken to avoid confusion with aircraft holding over or overflying the aerodrome, or with aircraft departing from or making a missed approach over adjacent runways.

Transfer of Identification.

The Turn Method:

An aircraft may be identified by ascertaining the aircraft heading, if circumstances require, and following a period of track observation:

- Instructing the pilot to execute one or more changes of heading of 30 degrees or more and correlating the movements of one particular radar position indication with the aircraft's acknowledged execution of the instructions given; or

- Correlating the movements of a particular radar position indication with maneuver currently executed by an aircraft having so reported.

When using these methods, the radar controller shall:

- Verify that the movements of not more than one radar position indication correspond with those of the aircraft; and
- Ensure that the maneuver(s) will not carry the aircraft outside the coverage of the radar or the situation display.

Note 1: Caution must be exercised when employing these methods in areas where route changes normally take place.

Note 2: With reference regarding radar vectoring of controlled aircraft should be referred.

DOUBTFUL IDENTIFICATION:

Controller should use more than one method of identification when proximity of radar position indications, duplication of observed action, or any other circumstances cause doubt as to identification of radar position indication.

If identification is doubtful due to any reason, a controller shall take immediate action to re-identify the aircraft or terminate the radar service.

TRANSFER OF RADAR DENTIFICATION:

Transfer of **identification** from one controller to another should only be attempted when it is considered that the aircraft is within the accepting controller's surveillance coverage.

Transfer of identification shall be affected by one of the following methods:

- Designation of the radar position indication by automated means, provided that only one radar position indication is thereby indicated and there is no possible doubt of correct identification;
- Notification of the aircraft's discrete SSR code or aircraft address;
  Note: - The use of a discrete SSR code requires a system of code assignment which ensures that each aircraft in a given portion of airspace is assigned a discrete code.
- Notification that the aircraft is SSR Mode S-equipped with an aircraft identification feature when SSR Mode S coverage is available;
- Notification that the aircraft is ADS-B- equipped with an aircraft identification feature when compatible ADS-B coverage is available;
- Direct designation (pointing with the finger) of the position indication, if the two situation displays are adjacent, or if a common "conference" type of situation display is used. If parallax is likely to cause an error, an alternative method is to be used;
- Designation of the position indication by reference to, or in terms of bearing and distance from, a geographical position or navigational facility accurately indicated on both situation displays, together with the track of the observed

position indication if the route of the aircraft is not known to both controllers.

- The radar position indication, as seen by the accepting controller, must be within 3 miles of the position stated.
- The distance between the aircraft and the reference point must not exceed:
  - 30 miles, if the aircraft is flying along a published ATS route or direction is given as a bearing in degrees;
  - 15 miles in other circumstances.

Note:- Caution must be exercised before transferring identification using this method, particularly if other position indications are observed on similar headings and in close proximity to the aircraft under control. Inherent radar deficiencies, such as inaccuracies in bearing and distance of the radar position indications displayed on individual situation displays and parallax errors, may cause the indicated position of an aircraft in relation to the known point to differ between the two situation displays.

- Where applicable, issuance of an instruction to the aircraft by the transferring controller to change SSR code and the observation of the change by the accepting controller; or

- Issuance of an instruction to the aircraft by the transferring controller to squawk /transmit IDENT and observation of this response by the accepting controller;

Note:- Use of procedures g) and h) requires prior coordination between the controllers, since the indications to be observed by the accepting controller are of short duration.

POSITION INFORMATION

An aircraft provided with ATS surveillance service should be informed of its position in the following circumstances:

- Upon identification, except when the identification is established:
  - Based on the pilot's report of the aircraft position or within one nautical mile of the runway upon departure and the observed position on the situation display is consistent with the aircraft's time of departure; or
  - By use of ADS-B aircraft identification, SSR Mode S aircraft identification or assigned discrete SSR codes and the location of the observed position indication is consistent with the current flight plan of the aircraft; or
  - By transfer of identification;

- When the pilot requests this information;

- When a pilot's estimate differs significantly from the radar controller's estimate based on the observed position;

- When the pilot is instructed to resume own navigation after vectoring if the current instructions had diverted the aircraft from a previously assigned route,

- Immediately before termination of ATS surveillance service, if the aircraft is observed to deviate from its intended route.

Position information shall be passed to aircraft in one of the following forms:

- As a well-known geographical position;
- Magnetic track and distance to a significant point, an en-route navigation aid, or an approach aid;
- Direction (using points of the compass) and distance from a known position;
- Distance to touchdown, if the aircraft is on final approach; or
- Distance and direction from the centre line of an ATS route.

Whenever practicable, position information shall relate to positions or routes pertinent to the navigation of the aircraft concerned and shown on the situation display map.

When so informed, the pilot may omit position reports at compulsory reporting points or report only over those reporting points specified by the air traffic services unit concerned, including points at which air-reports are required for meteorological purposes. Unless automated position reporting is in effect (e.g. ADS-C), pilots shall resume voice or CPDLC position reporting:

- When so instructed;
- When advised that the ATS surveillance service has been terminated; or
- When advised that identification is lost.

<u>VECTORING</u>

Vectoring shall be achieved by issuing to the pilot specific headings which will enable the aircraft to maintain the desired track. When vectoring an aircraft, a controller shall comply with the following:

- Whenever practicable, the aircraft shall be vectored along tracks on which the pilot can monitor the aircraft position with reference to pilot-interpreted navigation aids (this will minimize the amount of navigational assistance required and alleviate the consequences resulting from an ATS surveillance system failure);
- When an aircraft is given its initial vector diverting it from a previously assigned route, the pilot shall be informed, what the vector is to accomplish and, the limit of the vector shall be specified (e.g. to ... position, for ... approach)
- Except when transfer of radar control is to be effected, aircraft shall not be vectored closer than 2.5 NM, or, where the minimum permissible separation is greater than 5 NM is prescribed, a distance equivalent to one half of the prescribed separation minimum, from the limit of the airspace for which the radar controller is responsible, unless local arrangements have been made to ensure that separation will exist with aircraft operating in adjoining areas;

Controlled flights shall not be vectored into uncontrolled airspace except in the case of emergency or in order to circumnavigate severe weather (in which case the pilot should be so informed), or at the specific request of the pilot; and When an aircraft has reported unreliable directional instruments, the pilot shall be requested, prior to the issuance of maneuvering instructions, to make all turns at an agreed rate and to carry out the instructions immediately upon receipt.

When vectoring an IFR flight and giving an IFR flight a direct routing which takes the aircraft off an ATS route, the controller shall issue clearances such that the prescribed obstacle clearances will exist at all times until the aircraft reaches the point when pilot resumes his own navigation.

Note 1:- When an IFR flight is being vectored, the pilot is often unable to determine the aircraft's exact position and consequently the altitude which provides the required obstacle clearance. .

When ATC provides vectors to a VFR flight, the pilot retains responsibility for terrain clearance.

Report of incidents involving activations of aircraft ground proximity warning systems should be encouraged so that their locations can be identified and altitude, routing and/or aircraft operating procedures can be altered to prevent recurrences.

In terminating vectoring of an aircraft, the controller shall instruct the pilot to resume own navigation, giving the pilot the aircraft's position and appropriate instructions, as necessary, if the current instructions had diverted the aircraft from a previously assigned route.

NAVIGATION ASSISTANCE

An identified aircraft observed to deviate significantly from its intended route or designated holding pattern shall be advised accordingly. Appropriate action shall also be taken if, in the opinion of the controller, such deviation is likely to affect the service being provided.

The pilot of an aircraft requesting navigation assistance from an air traffic control unit providing ATS surveillance services shall state the reason (e.g. to avoid areas of adverse weather or unreliable navigational instruments) and shall give as much information as possible in the circumstances.

INTERRUPTION OR TERMINATION OF ATS SURVEILLANCE SERVICE

An aircraft which has been informed that it is provided with ATS surveillance service should be informed immediately when, for any reason, the service is interrupted or terminated.

Radar service is automatically terminated when an arriving aircraft receiving radar service has been instructed to contact tower frequency. Position of aircraft to touch down should be given to the aircraft before changing over the aircraft to tower.

When the control of an identified aircraft is to be transferred to a control sector that will provide the aircraft with procedural separation, the radar controller shall ensure that appropriate procedural separation is established between that aircraft and any other controlled aircraft before the transfer is affected.

MINIMUM LEVELS

The controller shall at all times be in possession of full and up-to-date information regarding:

- Established minimum flight altitudes within the area of responsibility;
- The lowest usable flight level or levels determined
- Established minimum altitudes applicable to procedures based on tactical radar vectoring.

Unless otherwise specified by the appropriate ATS authority, minimum altitude for procedures based on tactical vectoring with any ATS surveillance system shall be determined using the criteria applicable to tactical radar vectoring.

INFORMATION REGARDING ADVERSE WEATHER

Modern ATS surveillance system and processors are normally designed to suppress weather clutter. Even the most active areas of adverse weather may not be presented on the situation display. An aircraft's weather radar will normally provide better detection and definition of adverse weather than radar sensors in use by ATC.

If, however weather is observed that appears that appears likely to affect the flight, the controller may pass the information to the pilot. (AIP)

If an aircraft is equipped with weather radar and the pilot intends to circumnavigate the adverse weather area observed on his situation display, he should intimate and obtain clearance from controller for his proposed action. This is necessary to ensure that separation which the controller may be providing to any other aircraft is not jeopardized.

In vectoring an aircraft for circumnavigating any area of adverse weather, the controller should ascertain that the aircraft can be returned to its intended or assigned flight path within the available radar coverage, and, if this does not appear possible, inform the pilot of the circumstances.

Note:- Attention must be given to the fact that under certain circumstances the most active area of adverse weather may not be displayed.

REPORTING OF SIGNIFICANT METEOROLOGICAL INFORMATION TO METEOROLOGICAL OFFICES

Although a controller is not required to keep a special watch for heavy precipitation, etc.
information on the position, intensity, extent and movement of significant meteorological conditions (i.e. heavy showers or well-defined frontal surfaces) as observed on situation displays, should, when practicable, be reported to the associated meteorological office.

SEPARATION APPLICATION

Note:- Factors which the controller using an ATS surveillance system must take into account in determining the spacing to be applied in particular circumstances in order to ensure that the separation minimum is not infringed include aircraft relative headings and speeds, ATS surveillance system technical limitations, controller workload and any difficulties caused by communication congestion.

When control of an identified aircraft is to be transferred to a control sector that will provide the aircraft with procedural separation, such separation shall be established the transferring controller before the aircraft reaches the limits of the transferring controller's area of responsibility, or before the aircraft leaves the relevant area of surveillance coverage.

Separation based on the use of ADS-B, SSR and/or PSR position symbol and/or PSR blips shall be applied so that the distance between the centre's of the position symbols and/or PSR blips, representing the positions of the aircraft concerned, is never less than a prescribed minimum.

In no circumstances shall the edges of the position indications touch or overlap unless vertical separation is applied between the aircraft concerned, irrespective of the type of position indication displayed and separation minimum applied.

In the event that the controller has been notified of a controlled flight entering or about to enter the airspace within which separation minima specified is applied, but has not identified the aircraft, the controller may continue to provide ATS surveillance service to identified aircraft provided that:

- Reasonable assurance exists that the unidentified controlled flight will be identified using SSR or ADS-B or the flight is being operated by an aircraft of a type which may be expected to give an adequate return on primary radar in the airspace within which the separation is applied; and
- The separation is maintained between identified flights and any other observed ADS-B and/or radar position indications until either the unidentified controlled flight has been identified or procedural separation has been established.

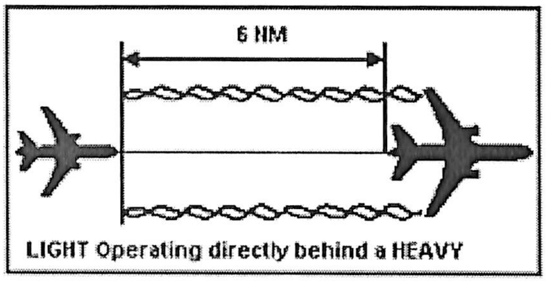
The separation minima specified in Separation minima based on ATS surveillance systems may be applied between an aircraft taking off and a preceding departing aircraft or other identified traffic provided there is reasonable assurance that the departing aircraft will be identified within 1 NM from the end of the runway, and that, at the time, the required separation will exist.

Separation minima specified in Separation minima based on ATS surveillance systems shall not be applied between aircraft holding over the same holding fix. When applying radar separation between holding aircraft and other flights, the controller shall maintain identity of holding aircraft for the provision of separation minima based on radar and/or ADS-B to other flights. No doubt shall exist about the identity of holding aircraft for any reason when such separation is applied. The controller shall also keep in mind the likely maneuvers of the holding aircraft during application of such separation.

Separation minima based on ATS surveillance systems

The following horizontal radar separation minima shall be applied:

- 5 NM horizontal radar separation up to 60 NM from radar head except 6 NM horizontal radar separations to aircraft in the approach and departure phases of flight shall be applied when
  - The LIGHT an aircraft is operating directly behind the HEAVY aircraft at the same altitude or less than 1000 ft below; or
  - The LIGHT aircraft following the HEAVY aircraft using the same runway, or parallel runways separated by less than 760 m or
  - The LIGHT aircraft is crossing behind the HEAVY aircraft, at the same altitude or less than 1000 ft below.
- 10 NM horizontal radar separations beyond 60 NM from radar head.



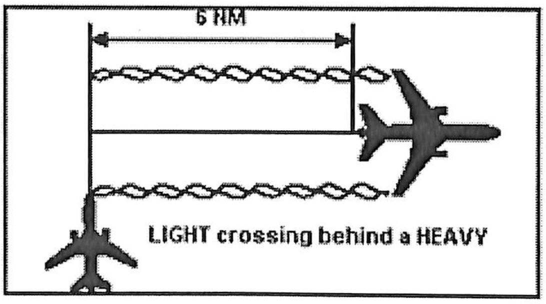


Figure 3: Separation minima based on ATS surveillance systems

TRANSFER OF RADAR CONTROL

Where ATS surveillance service is being provided, transfer of control should be effected, whenever practicable, so as to enable the uninterrupted provision of ATS surveillance service.
Where SSR and/or ADS-B is used and the display of position indications with associated labels is provided for, transfer of control of aircraft between adjacent control positions or between adjacent ATC units may be effected without prior coordination, provided that:

- Updated flight plan information on the aircraft about to be transferred, including the discrete assigned SSR Code or, with respect to SSR Mode S and ADS-B, the aircraft identification, is provided to the accepting controller prior to transfer;

- ADS-B or radar coverage provided to the accepting controller is such that the aircraft concerned is presented on the situation display before the transfer is effected and is identified on, but preferably before, receipt of the initial call;

- When the controllers are not physically adjacent, two-way direct speech facilities, which permit communications to be established instantaneously, are available between them at all times;

  Note: - "Instantaneous" refers to communications which effectively provide for immediate access between controllers.

- The transfer point or points and all other conditions of application, such as direction of flight, specified levels, transfer of communication points, and especially an agreed minimum separation between aircraft, including that applicable to succeeding aircraft on the same route, about to be transferred as observed on the situation display, have been made the subject of specific instructions (for intra-unit transfer) or of a specific letter of agreement between two adjacent ATC units;

- The instructions or letter of agreement specify explicitly that the application of this type of transfer of control may be terminated at any time by the accepting controller, normally with an agreed advance notice;

- The accepting controller is informed of any level, speed or vectoring instructions given to the aircraft prior to its transfer and which modify its anticipated flight progress at the point of transfer.

The minimum agreed separation between aircraft about to be transferred and the advance notice shall be determined taking into account all relevant technical, operational and other circumstances. If circumstances arise in which these agreed conditions can no longer be satisfied, controllers shall revert to the procedure in speed control mentioned below until the situation is resolved.

Where primary radar is being used, and where SSR and/or ADS-B is employed but, the transfer of control of aircraft between adjacent control positions or between two adjacent ATS units may be effected, provided that:

- Identification has been transferred to or has been established directly by the accepting controller;

- When the controllers are not physically adjacent, two-way direct-speech facilities between them are at all times available which permit communications to be established instantaneously;

- Separation from other controlled flights conforms to the minima authorized for use during transfer of control between the sectors or units concerned;

- The accepting controller is informed of any level, speed or vectoring instructions applicable to the aircraft at the point of transfer;

- radio-communication with the aircraft is retained by the transferring controller until the accepting controller has agreed to assume responsibility for providing the ATS surveillance service to the aircraft. Thereafter, the aircraft should be instructed to change over to the appropriate channel and from that point is the responsibility of the accepting controller.

SPEED CONTROL

In order to facilitate sequencing or to reduce the need for vectoring, a controller, subject to consideration of the aircraft performance limitation, may request aircraft to adjust their speed in a specified manner.

Unless a pilot concurs in the use of lower speed, the controller should use the following minima for arriving aircraft operating below 10,000 ft: An IAS not less than 210 knots, except when the aircraft is within 20 flying miles of the runway threshold of the airport of intended landing, an IAS not less than

Aircraft category	Speed
A	90 Knots
B	120 Knots
C	160 Knots
D/E	185 Knots

TABLE 7: AIRCARFT CATEGORY AS PER SPEED

EMERGENCIES, HAZARDS AND EQUIPMENT FAILURES

Emergencies

In the event of an aircraft in, or appearing to be in, any form of emergency, every assistance shall be provided by the controller, and the procedures prescribed herein may be varied according to the situation.

The progress of an aircraft in emergency shall be monitored and (whenever possible) plotted on the situation display until the aircraft passes out of coverage of the ATS surveillance system, and position information shall be provided to all air traffic services units which may be able to give assistance to the aircraft. Transfer to adjacent sectors shall also be affected when appropriate.

Note:- If the pilot of an aircraft encountering a state of emergency has previously been directed by ATC to select a specific transponder code and/or an ADS-B emergency mode, that code/mode will normally be maintained unless, in special circumstances, the pilot has decided or has been advised otherwise. Where ATC has not requested a code or emergency mode to be set, the pilot will set the transponder to Mode A Code 7700 and/or the appropriate ADS-B emergency mode.

Collision hazard information

When an identified controlled flight is observed to be on a conflicting path with an unknown aircraft deemed to constitute a collision hazard, the pilot of the controlled flight shall, whenever practicable:

- Be informed of the unknown aircraft and if so requested by the controlled flight or, if in the opinion of the controller the situation warrants, a course of avoiding action should be suggested; and
- Be notified when the conflict no longer exists.

When an identified IFR flight operating outside controlled airspace is observed to be on a conflicting path with another aircraft, the pilot should:

- Be informed as to the need for collision avoidance action to be initiated, and if so requested by the pilot or if, in the opinion of the controller, the situation warrants, a course of avoiding action should be suggested; and
- Be notified when the conflict no longer exists.

Information regarding traffic on a conflicting path should be given, whenever practicable, in the following form:

- Relative bearing of the conflicting traffic in terms of the 12-hour clock;
- Distance from the conflicting traffic in nautical miles;
- Direction in which the conflicting traffic appears to be proceeding;
- Level and type of aircraft or, if unknown, relative speed of the conflicting traffic,

Pressure altitude-derived level information, even when unverified, should be used in the provision of collision hazard information because such information, particularly if available from an otherwise unknown aircraft (e.g. a VFR flight) and given to the pilot of a known aircraft, could facilitate the location of a collision hazard.

When the pressure altitude-derived level information has been verified, the information shall be passed to pilots in a clear and unambiguous manner. If the level information has not been verified, the accuracy of the information should be considered uncertain and the pilot shall be informed accordingly.

Failure of equipment

Aircraft Radio Transmitter Failure

If two-way communication is lost with an aircraft, the controller should determine whether or not the aircraft's receiver is functioning by instructing the aircraft on the channel so far used to acknowledge by making a specified maneuver and by observing the aircraft's track, or by instructing the aircraft to operate IDENT or to make SSR code and/or ADS-B transmission changes.

Note1:-Transponder-equipped aircraft experiencing radio-communication failure will operate the transponder on Mode A Code 7600.

Note2:- ADS-B-equipped aircraft experiencing radio-communication failure may transmit the appropriate ADS-B emergency and/or urgency mode.

If the action prescribed in above is unsuccessful, it shall be repeated on any other available channel on which it is believed that the aircraft might be listening.

In both the cases covered above any maneuvering instructions shall be such that the aircraft would regain its current cleared track after having complied with the instructions received.

8Where it has been established by the action mentioned above that the aircraft's radio receiver is functioning, continued control can be affected using SSR code/ADS-B transmission changes or IDENT trans-missions to obtain acknowledgement of clearances issued to the aircraft.

Complete Aircraft Communication Failure:

When a controlled aircraft experiencing complete communication failure is operating or expected to operate in an area and at flight levels where an ATS surveillance service is applied, separation specified may continue to be used. However, if the aircraft experiencing the communication failure is not identified, separation shall be applied
between identified aircraft and all unidentified aircraft observed along the expected route of the aircraft with the communication failure, until such time as it is known, or can safely be assumed, that the aircraft with radio communication failure has passed through the airspace concerned, has landed, or has proceeded elsewhere.

Aircraft Transponder Failure in areas where the carriage of a functioning transponder is mandatory:

When an aircraft experiencing transponder failure after departure is operating or expected to operate in an area where the carriage of a functioning transponder with specified capabilities is mandatory, the ATC units concerned should endeavor to provide for continuation of the flight to the aerodrome of first intended landing in accordance with the flight plan. However, in certain traffic situations, either in terminal areas or en-route, continuation of the flight may not be possible, particularly when failure is detected shortly after take-off. The aircraft may then be required to return to the departure aerodrome or to land at the nearest suitable aerodrome acceptable to the operator concerned and to ATC.
In case of a transponder failure which is detected before departure from an aerodrome where it is not practicable to effect a repair, the aircraft concerned should be permitted to proceed, as directly as possible, to the nearest suitable aerodrome where repair can be made. When granting clearance to such aircraft, ATC should take into consideration the existing or anticipated traffic situation and may have to modify the time of departure, flight level or route of the in-tended flight. Subsequent adjustments may become necessary during the course of the flight.

ATS surveillance system failure

In the event of complete failure of the ATS surveillance system where air-ground communications remain, the controller shall plot the position of all aircraft already identified, take the necessary action to establish procedural separation between the aircraft and, if necessary, limit the number of aircraft permitted to enter the area.
As an emergency measure, use of flight levels spaced by half the applicable vertical separation minimum may be resorted to temporarily if standard procedural separation cannot be provided immediately.

Degradation of aircraft position source data

In order to reduce the impact of a degradation of aircraft position source data, for example, a receiver autonomous integrity monitoring (RAIM) outage for GNSS, the appropriate ATS authority shall establish contingency procedures to be followed by control positions and ATC units in the event of data degradation.

Ground radio failure

In the event of complete failure of the ground radio equipment used for control, the controller shall, unless able to continue to provide the ATS surveillance service by means of other available communication channels, proceed as follows:

- Without delay inform all adjacent control positions or ATC units, as applicable, of the failure;
- Appraise such positions or units of the current traffic situation;
- Request their assistance, in respect of aircraft which may establish communications with those positions or units, in establishing and maintaining separation between such aircraft; and
- Instruct adjacent control positions or ATC units to hold or reroute all controlled flights outside the area of responsibility of the position or ATC unit that has experienced the failure until such time that the provision of normal services can be resumed.

3.5 Approach and terminal control

Many airports have a radar control facility that is associated with the airport. In most countries, this is referred to as Terminal Control; in the U.S., it is often still referred to as a TRACON (Terminal Radar Approach Control). While every airport varies, terminal controllers usually handle traffic in a 30 to 50 nautical mile (56 to 93 km) radius from the airport. Where there are many busy airports in close proximity, one consolidated TRACON may service all the airports. The airspace boundaries and altitudes assigned to a TRACON, which vary widely from airport to airport, are based on factors such as traffic flows, neighboring airports and terrain. A large and complex example is the London Terminal Control Centre which controls traffic for five main London airports up to 20,000 feet (6,100 m) and out to 100 nautical miles (190 km).

Terminal controllers are responsible for providing all ATC services within their airspace. Traffic flow is broadly divided into departures, arrivals, and over flights. As aircraft move in and out of the terminal airspace, they are handed off to the next appropriate control facility (a control tower, an en-route control facility, or a bordering terminal or approach control). Terminal control is responsible for ensuring that aircraft are at an appropriate altitude when they are handed off, and that aircraft arrive at a suitable rate for landing.

Not all airports have a radar approach or terminal control available. In this case, the en-route center or a neighboring terminal or approach control may co-ordinate directly with the tower on the airport and vector inbound aircraft to a position from where they can land visually. At some of these airports, the tower may provide a non-radar procedural approach service to arriving aircraft handed over from a radar unit before they are visual to land. Some units also have a dedicated approach unit which can provide the procedural approach service either all the time or for any periods of radar outage for any reason.

Terminal radar approach control responsibilities

TRACONs are responsible for providing all ATC services within their airspace. Generally, there are four types of traffic flows controlled by TRACON controllers. These are departures, arrivals, over flights, and aircraft operating under Visual Flight Rules (VFR).

Departure aircraft

Departure aircraft are received from the control tower from which the aircraft departs and are generally 1,000 feet (300 m) to 2,000 feet (610 m) high, climbing to a pre-determined altitude. The TRACON controller working this traffic is responsible for clearing all other TRACON traffic and, based on the route of flight, placing the departing aircraft on a track and in a geographical location (sometimes referred to as a "gate" or "exit") that is set through agreements with the en-route center. This positioning is designed to allow the en-route center to integrate the aircraft into its traffic flow easily.

Arrival aircraft

Arrival aircraft other than Visual Flight Rules aircraft entering the area are received from the en-route center in compliance with pre-determined agreements on routing, altitude, speed, spacing, etc. The TRACON controller working this traffic will take control of the aircraft and blend it with other aircraft entering the center airspace from other areas or "gates" into a single, parallel or perpendicular final for a runway at any of the airports with the TRACON space. The spacing is critical to ensure the aircraft can land and clear the runway prior to the next aircraft touching down on the runway. The TRACON controller will do a hand-off to pass the flight communication to the approach airport tower. That tower controller may also request expanded spacing between aircraft to allow aircraft to depart or to cross the runway in use.

Over flight aircraft

Over flight aircraft are aircraft that enter the TRACON airspace at one point and exit the airspace at another without landing at an airport. They must be controlled in a manner that ensures they remain separated from the climbing and descending traffic that is moving in and out of the airport. Their route may be altered to ensure this is possible. When they are returned to the en-route center, they must be on the original routing unless a change has been coordinated.

VFR aircraft

If the class of airspace allows flight under VFR, such aircraft are handled as traffic permits. Controllers will provide traffic information to ensure safety with other aircraft, and may even positively separate VFR aircraft from other aircraft, depending on the class of airspace. Controllers spend extra time with these flights in order to avoid vectoring VFR aircraft into IMC. Controllers usually provide information for the pilot about traffic in the immediate vicinity and weather information. This ensures that separation from Instrument Flight Plan (IFR) aircraft is maintained within the controller's coverage area.

Most US airports do not have a TRACON available. In this case, the en-route center will coordinate directly with the tower and provide this type of service where radar coverage permits. In these cases, the separation minimums are greatly increased. In many countries, mid-sized airports without a TRACON have a dedicated Approach Radar Controller based upon the airport itself to sequence inbound flights and to provide radar services to aircraft in the vicinity of the airport.

USE OF RADAR IN THE APPROACH CONTROL SERVICE

General provision:

ATS surveillance systems used in the provision of approach control service shall be appropriate to the functions and level of service to be provided.

General Approach control Procedures using ATS surveillance systems:

The aerodrome controller shall be kept informed of the sequence of arriving aircraft by the approach controller, as well as any instructions and restrictions which have been issued to such aircraft in order to maintain separation after transfer of control to the aerodrome controller.

Prior to, or upon commencement of, vectoring for approach, the pilot shall be advised of the type of approach as well as the runway to be used.

The controller shall advise an aircraft being vectored for an instrument approach of its position at least once prior to commencement of final approach.

When giving distance information, the controller shall specify the point or navigation aid to which the information refers.

The initial and intermediate approach phases of an approach executed under the direction of a controller comprise those parts of the approach from the time vectoring is initiated for the purpose of positioning the aircraft for a final approach, until the aircraft is on final approach and:

- Established on the final approach path of a pilot-interpreted aid; or
- Reports that it is able to complete a visual approach; or
- Ready to commence a surveillance radar approach;

Aircraft vectored for final approach should be given a heading or a series of headings calculated to close with the final approach track. The final vector shall enable the aircraft to be established in level flight on the final approach track prior to intercepting the specified or nominal glide path if an ILS or radar approach is to be made, and should provide an intercept angle with the final approach track of 45 degrees or less.

Whenever an aircraft is assigned a vector which will take it through the final approach track, it should be advised accordingly, stating the reason for the vector.

<u>Vectoring to pilot-interpreted final approach aid</u>

An aircraft vectored to intercept a pilot-interpreted final approach aid shall be instructed to report when established on the final approach track. Clearance for the approach should be issued prior to when the aircraft reports established, unless circumstances preclude the issuance of the clearance at such time. Vectoring will normally terminate at the time the aircraft leaves the last assigned heading to intercept the final approach track.

The controller shall be responsible for maintaining the needed separation between succeeding aircraft on the same final approach, except that the responsibility may be transferred to the aerodrome controller in accordance with procedures prescribed in MATS Part 2 and provided an ATS surveillance system is available to the aerodrome controller.

Transfer of control of succeeding aircraft on final approach to the aerodrome controller shall be effected in accordance with procedures prescribed in MATS Part 2.

Transfer of communications to the aerodrome controller should be affected at such a point or time that clearance to land or alternative instructions can be issued to the aircraft in a timely manner.

<u>Surveillance Radar Approach</u>

<u>General Provisions</u>

During the period that a controller is engaged in giving surveillance radar, he or she should not be responsible for any duties other than those directly connected with such approaches.

Controllers conducting surveillance radar approaches shall be in possession of information regarding the obstacle clearance altitudes/heights established for such approaches.

Prior to commencement of a surveillance radar approach, the aircraft shall be informed of:

- The runway to be used;
- The applicable obstacle clearance altitude/height;
- The angle of the nominal glide path
- The procedure to be followed in the event of radio-communication failure.

When a radar approach cannot be continued due to any circumstance, the aircraft should be immediately informed that a radar approach or continuation thereof is not possible. The approach should be continued if this is possible using non-radar facilities or if the pilot reports that the approach can be completed visually; otherwise an alternative clearance should be given.

Aircraft making a radar approach should be reminded, when on final approach, to check that the wheels are down and locked.

The controller conducting the approach should notify the aerodrome controller or, when applicable, the procedural controller when an aircraft making a radar approach is approximately 8 NM from touchdown. If landing clearance is not received at this time, a subsequent notification should be made at approximately 4 NM from touchdown and landing clearance requested.

Clearance to land or any alternative clearance received from the aerodrome controller or, when applicable, the procedural controller should normally be passed to the aircraft before it reaches a distance of 2 NM from touchdown.

An aircraft making a radar approach should:

- Be directed to execute a missed approach in the following circumstances:
  - When the aircraft appears to be dangerously positioned on final approach; or
  - For reasons involving traffic conflictions; or
  - If no clearance to land has been received from the procedural controller by the time the aircraft reaches a distance of 2 NM from touch-down or such other distance as has been agreed with the aerodrome control tower; or
  - On instructions by the aerodrome controller; or
- Be advised to consider executing a missed approach in the following circumstances:
  - When the aircraft reaches a position from which it appears that a successful approach cannot be completed; or
  - If the aircraft is not visible on the situation display for any significant interval during the last 2 NM of the approach; or
  - If the position or identification of the aircraft is in doubt during any portion of the final approach.

In all such cases, the reason for the instruction or the advice should be given to the pilot.

Unless otherwise required by exceptional circumstances, radar instructions concerning a missed approach should be in accordance with the prescribed missed approach procedure and should include the level to which the aircraft is to climb and heading instructions to keep the aircraft within the missed approach area during the missed approach procedure.

Final approach procedures

A surveillance radar approach shall only be performed with equipment suitably sited and a situation display specifically marked to provide information on position relative to the extended centre line of the runway to be used and distance from touchdown, and where surveillance radar approaches are promulgated.

When conducting a surveillance radar approach, the controller shall comply with the following:

- At or before the commencement of the final approach, the aircraft shall be informed of the point at which the surveillance radar approach will be terminated;
- The aircraft shall be informed when it is approaching the point at which it is computed that descent should begin, and just before reaching that point it shall be informed of the obstacle clearance altitude/height and instructed to descend and check the applicable minima;
- The pilot shall be informed at regular intervals of the aircraft's position in relation to the extended centre line of the runway. Heading corrections shall be given as necessary to bring the aircraft back on to the extended centre line
- Distance from touch-down shall normally be passed at every each NM;
- Pre-computed levels through which the aircraft should be passing to maintain the glide path shall also be transmitted at each NM at the same time as the distance;
- The surveillance radar approach shall be terminated:
  - At a distance of 2 NM from touchdown, or
  - Before the aircraft enters an area of continuous radar clutter; or
  - When the pilot reports that a visual approach can be effected;

  Whichever is the earliest.

Levels through which the aircraft should pass to maintain the required glide path, and the associated distances from touchdown, shall be pre-computed and displayed in such a manner as to be readily available to the controller concerned.

Chapter 4: Separation Methods and Minima

Provision for the separation of controlled traffic

Vertical or horizontal separation shall be provided:

- Between IFR flights in Class D and E airspaces except when VMC climb or descent is involved under the conditions specified
- Between IFR flights and special VFR flights; and
- Between special VFR flights

No clearance shall be given to execute any maneuver that would reduce the spacing between two aircraft to less than the separation minimum applicable in the circumstances.

Larger separations than the specified minima should be applied whenever exceptional circumstances such as unlawful interference or navigational difficulties call for extra precautions. This should be done with due regard to all relevant factors so as to avoid impeding the flow of air traffic by the application of excessive separations.

Note: - Unlawful interference with an aircraft constitutes a case of exceptional circumstances which might require the application of separations larger than the specified minima, between the, aircraft being subjected to unlawful interference and other aircraft.

Where the type of separation or minimum used to separate two aircraft cannot be maintained, another type of separation or another minimum shall be established prior to the time when the current separation minimum would be infringed.

<u>Degraded aircraft performance</u>

Whenever, as a result of failure or degradation of navigation, communications, altimetry, flight control or other systems, aircraft performance is degraded below the level required for the airspace in which it is operating, the flight crew shall advise the ATC unit concerned without delay. Where the failure or degradation affects the separation minimum currently being employed, the controller shall take action to establish another appropriate type of separation or separation minimum.

4.1 Reduction and loss in separation minima

In the vicinity of aerodromes

In the vicinity of aerodromes, the separation minima may be reduced if:

- Adequate separation can be provided by the aerodrome controller when each aircraft is continuously visible to this controller; or
- Each aircraft is continuously visible to flight crews of the other aircraft concerned and the pilots thereof report that they can maintain their own separation; or
- In the case of one aircraft following another. The flight crew of the succeeding aircraft reports that the other aircraft is in sight and separation can be maintained.

In the event of complete failure of radar equipment

As an emergency measure, use of flight levels spaced by half the applicable vertical separation minimum may be resorted to temporarily if standard non-radar separation cannot be provided immediately.

Loss of separation

If, for any reason, a controller is faced with a situation in which two or more aircraft are separated by less than the prescribed minima due to reason other than ACAS RA (e.g. air traffic control errors or difference in the pilot's estimated and actual times over reporting points) controller is to

- Use every means at his / her disposal to obtain the required minimum with the least possible delay; and
- Pass essential traffic information.

Essential traffic information

Essential traffic is that controlled traffic to which the provision of separation by ATC is applicable, but which, in relation to a particular controlled flight is not, or will not be, separated from other controlled traffic by the appropriate separation minimum.

Essential traffic information shall be given to controlled flights concerned whenever they constitute essential traffic to each other.

Essential traffic information shall include:

- Direction of flight of aircraft concerned;
- Type and wake turbulence category(if relevant) of aircraft concerned;
- Cruising level of aircraft concerned and;
  - Estimated time over the reporting point nearest to where the level will be crossed; or

- Relative bearing of the aircraft concerned in terms of the 12-hour clock as well as distance from the conflicting traffic; or
- Actual or estimated position of the aircraft concerned.

4.2 Vertical Separation

Vertical Separation Minimum

- A nominal 1000 feet below FL290 and a nominal 2000 feet at or above FL290, except as provided for in b) below; and
- A nominal 1000 feet when both aircraft are RVSM compliant and operating within designated RVSM airspace.

Cruise climb

Cruise climb is not permitted in Indian FIRs.

Vertical Separation during climb and descent

An aircraft may be cleared to a level previously occupied by another aircraft after the latter has reported vacating it, except when:

- Severe turbulence is known to exist; or
- The aircraft concerned are established at the same holding pattern; or
- The difference in aircraft performance is such that less than the applicable separation minimum may result;

In which case such clearance shall be withheld until the aircraft vacating the level has reported at or passing another level separated by the required minimum.

Pilot in direct communication with each other may, with their concurrence, be cleared to maintain a specified vertical separation between their aircraft during ascent or descent.

Step climb and descents

The step climb/descent procedure may be used for simultaneous climb /descent of the aircraft to vertically separated levels provided that the lower / higher aircraft is progressively assigned levels that provide vertical separation with the higher / lower aircraft.

When applying the step climb or step descent procedures, pilot must be advised that they are subject to a step climb or descent.

VMC climb and descent:

When so requested by an aircraft and provided it is agreed by the pilot of the other aircraft, an ATC unit may clear a controlled flight, including departing and arriving flights, operating in airspace Classes D and E in VMC during the hours of daylight to fly subject to maintaining own separation to one other aircraft and remaining in VMC. When a controlled flight is so cleared, the following shall apply:

- Clearances shall be for a specified portion of the flight at or below 10,000 feet, during climb and descent;

- Essential traffic information shall be passed; and

- If there is possibility that flight under VMC may become impracticable, an IFR flight shall be provided with alternative instructions to be complied with in the event that in VMC cannot be maintained for the term of clearance.

Flight level (FL)

Flight levels are described by a number, which is this nominal altitude ("pressure altitude") in feet, divided by 100. Therefore an apparent altitude of, for example, 32,000 feet is referred to as "flight level 320". To avoid collisions between two aircraft due to their being at the same altitude, their 'real' altitudes (compared to ground level, for example) are not important; it is the difference in altitudes that determines whether they might collide. This difference can be determined from the air pressure at each craft, and does not require knowledge of the local air pressure on the ground.

FL starts at 5000 feet

Quadrantal rule for vertical separation

Starts form 3000 feet and goes up till FL140

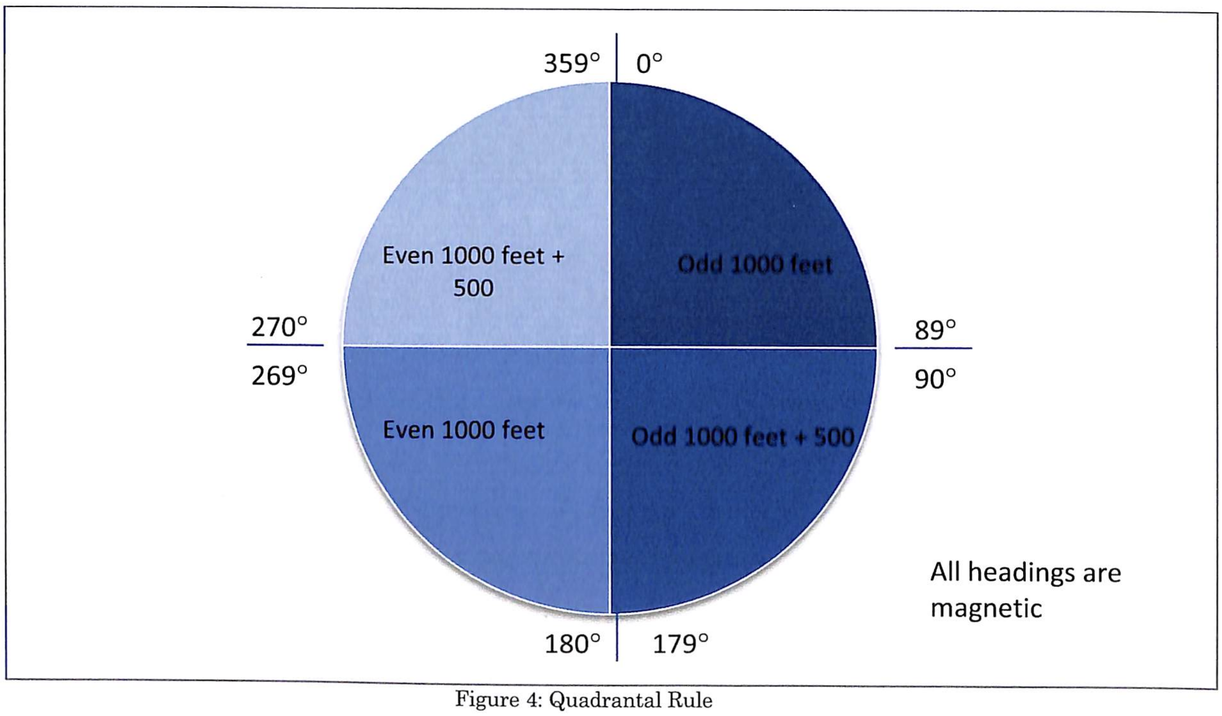


Figure 4: Quadrantal Rule

Semicircular System for vertical separation

Starts from FL 150 to FL 280

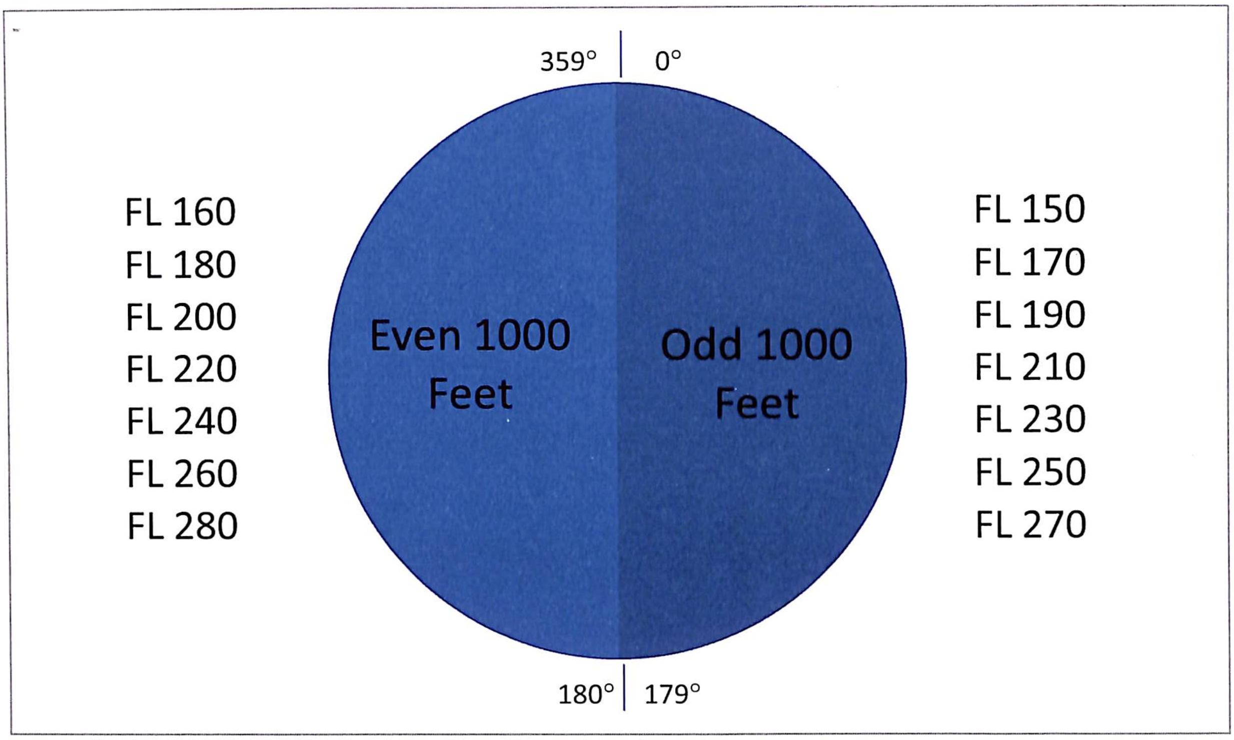


Figure 5: Semicircular system for vertical separation

Flight level 145 is not used because it is a buffer between the quadrantal system and the semicircular system.

Above FL 280 increased separation of reciprocal traffic from 1000 feet to 2000 feet for non RVSM aircraft for RVSM aircraft it remains at 1000 feet separation.

Magnetic Heading	Flight level
000° to 179°	FL 290 FL 330 FL 370 FL 410 FL 450
180° to 359°	FL 310 FL 350 FL 390 FL 430

TABLE 8: VERTICAL SEPARATION FOR NON RVSM AIRCRAFT

Reduced Vertical Separation Minima or Minimum (RVSM)

Reduced Vertical Separation Minima or Minimum (RVSM) is an aviation term used to describe the reduction of the standard vertical separation required between aircraft flying aboveFL285 (28,500 ft.) and up to FL410 (41,000 ft.) from 2,000 feet to 1,000 feet (or between 8,900 meters and 12,500 meters from 600 meters to 300 meters). This therefore increases the number of aircraft that can safely fly in a particular volume of airspace.

Historically, standard vertical separation was 1,000 feet from the surface to FL290, 2,000 feet from FL290 to FL410 and 4,000 feet above this. This was because the accuracy of the pressure altimeter (used to determine altitude) decreases with height. Over time, Air data computers (ADCs) combined with altimeters have become more accurate and autopilots more adept at maintaining a set level, therefore it became apparent that for many modern aircraft, the 2,000 foot separation was too cautious. It was therefore proposed by ICAO that this be reduced to 1,000 feet.

Requirements for RVSM aircraft

Only aircraft with specially certified altimeters and autopilots may fly in RVSM airspace, otherwise the aircraft must fly lower or higher than the airspace, or seek special exemption from the requirements. Additionally, aircraft operators (airlines or corporate operators) must receive specific approval from the aircraft's state of registry in order to conduct operations in RVSM airspace. Non RVSM approved aircraft may transit through RVSM airspace provided they are given continuous climb throughout the designated airspace, and 2,000 ft vertical separation is provided at all times between the non-RVSM flight and all others for the duration of the climb/descent.

"State aircraft", which includes military, customs and police aircraft, are exempted from the requirement to be RVSM approved. Participating states have been requested, however, to adapt their State aircraft for RVSM approval, to the extent possible, and especially those aircraft used for General Air Traffic (GAT).

Minimum safe altitude

VFR flights congested area 1000 feet above highest obstacle with a radius of 2000 feet.

Other places 500 feet over ground or water.

IFR flights
Hilly terrain 2000 feet above highest obstacle within a radius of 5 NM

Non hilly terrain minimum distance of 1000 feet from the highest obstacle within a radius of 5 NM requiring flying on specified tracks which are separated by a minimum amount appropriate to the navigational aid or method employed. Lateral separation between two aircraft exists

4.3 Horizontal separation

The three types of horizontal separation are:

- Lateral separation;
- Longitudinal separation;
- Radar separation.

Lateral separation

Means by which lateral separation may be applied include the following:

By using the same or different geographic locations:

By position reports which positively indicate the aircraft are over different geographic locations as determined visually or by reference to a navigation aid.

By using the same navigation aid or method

By when:

- VOR

Both aircraft are established on radials diverging by at least 15 degrees and at least one aircraft is 15 NM or more from the facility.

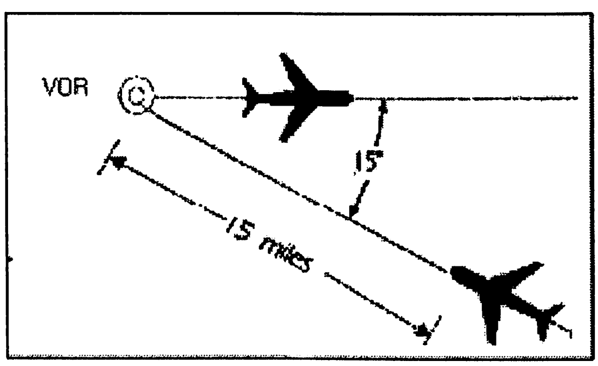


Figure 6a: Lateral Separation using VOR

- NDB

Both aircraft are established on tracks to or from the NDB, which are diverging by at least 30 degrees and at least one aircraft is15 NM or more from the facility.

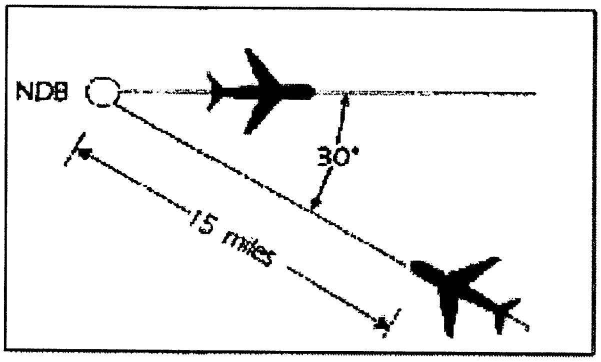


Figure 6b: Lateral Separation using NDB

- DR (dead reckoning)

Both aircraft are established on tracks diverging by at least 45 degrees and at least one aircraft is 15 NM or more from the point of intersection of the tracks, this point being determined either visually or by reference to a navigational aid and both aircraft are established outbound from the intersection.

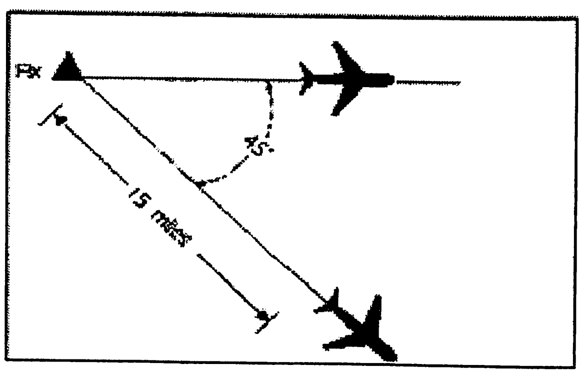
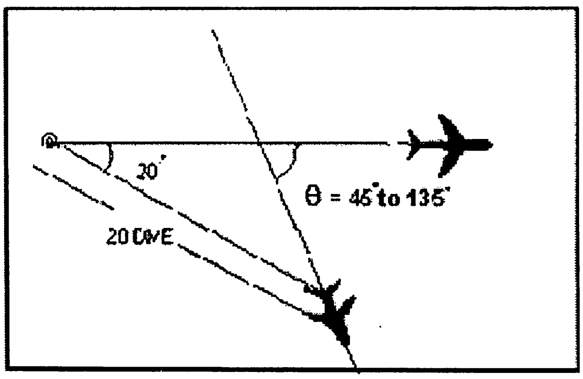


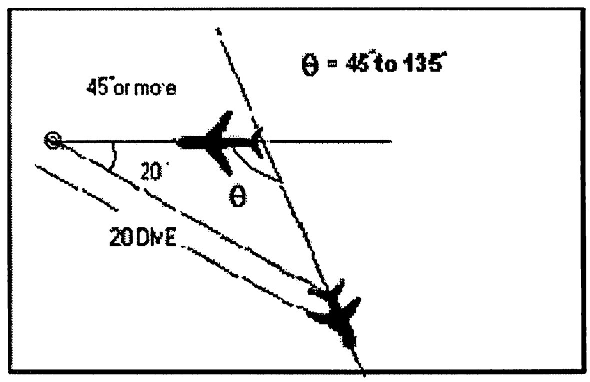
Figure 6c: Lateral Separation using dead reckoning

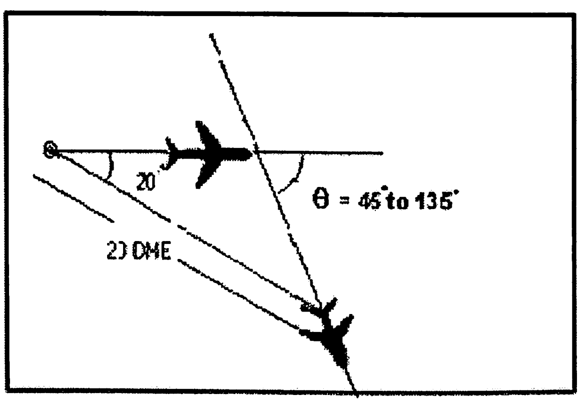
- By using crossing radials of the same VOR:

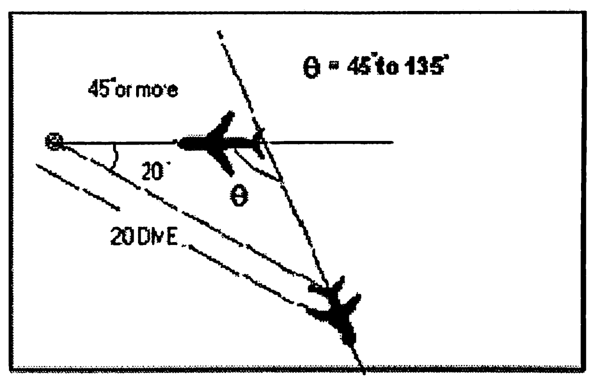
When one aircraft is maintaining a radial from a VOR and other aircraft is crossing its track, and after crossing the angular difference of 45 deg to 135 deg inclusive, aircraft will be deemed to be laterally separated, when the other aircraft

- Has passed the radial of first aircraft; and
- Crossed a radial which is different by at least 20 degrees from the radial of first aircraft; and
- Is 20 DME or more from the VOR used by first aircraft.









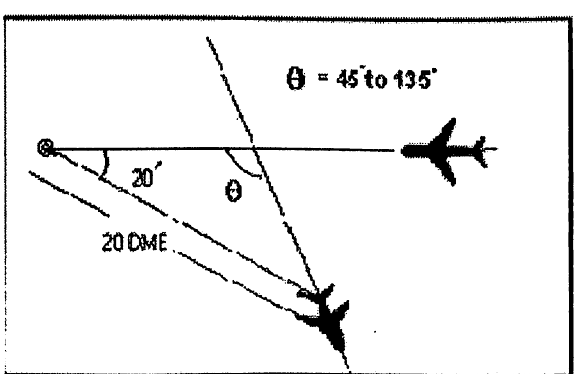


Figure 6d: Lateral Separation using crossing radials of the same VOR

Longitudinal separation

Longitudinal separation shall be applied so that the spacing between the estimated positions of the aircraft being separated is never less than a prescribed minimum.

For the purpose of application of longitudinal separation, the terms same track, reciprocal tracks and crossing tracks shall have the following meanings:

- Same track

Same direction tracks and intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees, and whose protection areas overlap.

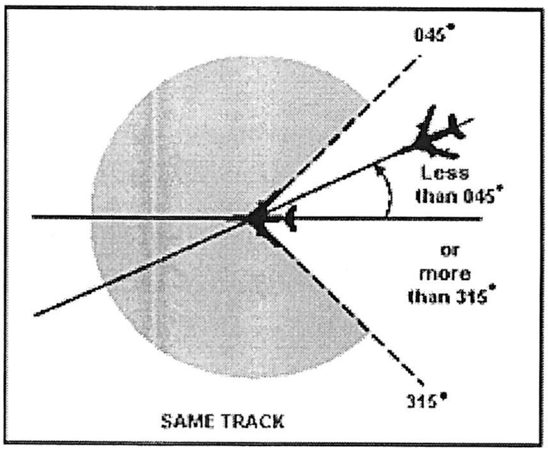


Figure 7a: Longitudinal separation same track

- Reciprocal tracks

Opposite tracks and intersecting tracks or portions thereof, the angular difference of which is more than 135 degrees but less than 225 degrees, and whose protection areas overlap.

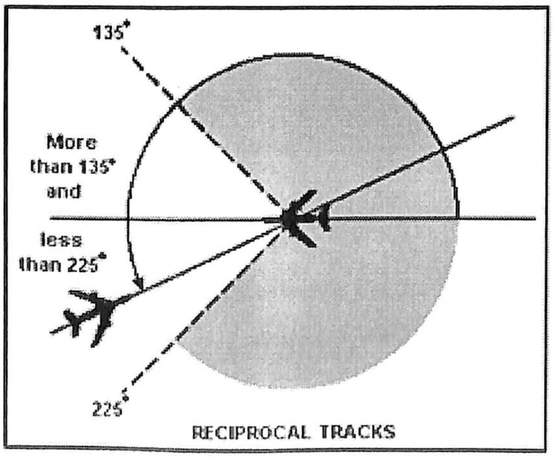


Figure 7b: Longitudinal separation Reciprocal tracks

- Crossing Tracks

Intersecting tracks or portions thereof other than those specified in a) and b) above.

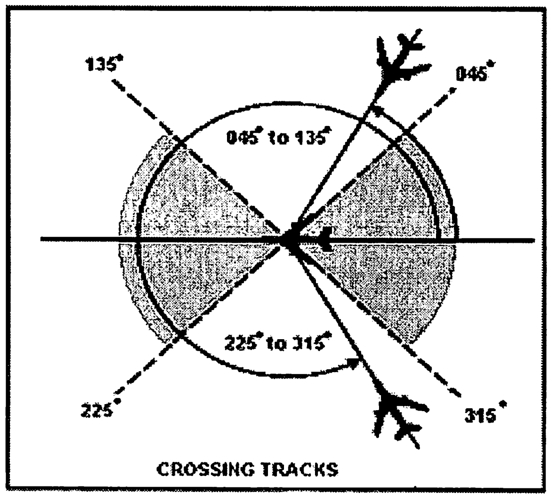


Figure 7c: Longitudinal separation crossing tracks

<u>Longitudinal separation minima based on time:</u>

Cross Check Calculations

- Separation requirements must be cross-checked to ensure the integrity of calculations.
- The cross-check is to validate the initial calculation and to confirm that the calculation is consistent with the traffic disposition.

<u>Separation for Aircraft at the same cruising level</u>

a) Aircraft flying on the same track:

- 15 minutes;
- 10 minutes, if navigation aids permit frequent determination of position and speed;

b) Aircraft flying on crossing tracks:

- 15 minutes;
- 10 minutes, if navigation aids permit frequent determination of position and speed;

Aircraft climbing or descending

a) Traffic on the same track.
   When an aircraft will pass through the level of another aircraft on the same track, the following minimum longitudinal separation shall be provided:

   - 15 minutes while vertical separation does not exist

   - 10 minutes, if navigation aids permit frequent determination of position and speed; has

   - 10 minutes while vertical separation does not exist, provided that such separation is authorized only where navigation aids permit frequent determination of position and speed.

   - 5 minutes while vertical separation does not exist, provided that the level change is commenced within 10 minutes of the time the second aircraft reported over an exact reporting point.

b) Traffic on crossing tracks:

   - 15 minutes while vertical separation does not exist

   - 10 minutes while vertical separation does not exist if navigation aids permit frequent determination of position and speed.

c) Traffic on reciprocal tracks
   Where lateral separation is not provided, vertical separation shall be provided for at least ten minutes prior to and after the time the aircraft are estimated to pass, or are estimated to have passed.

   Provided that it has been determined that the aircraft have passed each other, this minimum need not apply:

Longitudinal separation minima based on distance using DME and/or GNSS

Separation shall be established by maintaining not less than specified distance(s) between aircraft positions as reported by reference to DME in conjunction with other appropriate navigation aids and/or GNSS. This type of separation shall be applied between two aircraft using DME, or two aircraft using GNSS, or one aircraft using DME and one aircraft using GNSS. Direct controller-pilot VHF voice communication shall be maintained while such separation is used.

Note:- *For the purpose of applying GNSS based separation minimum, a distance derived from an integrated navigation system incorporating GNSS input is regarded as equivalent to GNSS distance.*

All distance reports must be made with reference to the same DME station.

When applying these separation minima between any aircraft with area navigation capability, controllers shall specifically request GNSS derived distance.

Note:- *Reason making a pilot unable to provide GNSS distance information may include inadequate onboard equipment, on GNSS input into an integrated navigation system, or a loss of GNSS integrity.*

Aircraft at the same cruising level

a) Aircraft on the same track:

- 20 NM, provided:

  - Each aircraft utilizes,
    - The same "on track" DME station when both aircraft are utilizing DME, or
    - An "on track" DME station and a collocated waypoint when one aircraft is utilizing DME and the other is utilizing GNSS, or
    - The same waypoint when both aircraft are utilizing GNSS, and

  - Separation is checked by obtaining simultaneous DME and/or GNSS readings from the aircraft at frequent intervals to ensure that the minimum will not be infringed.

- 10 NM, provided:

  - The leading aircraft maintains a true airspeed of 20 knots or more faster than the succeeding aircraft;

  - Each aircraft utilizes,
    - The same "on track" DME station when both aircraft are utilizing DME, or
    - An "on track" DME station and a collocated waypoint when one aircraft is utilizing DME and the other is utilizing GNSS, or
    - The same waypoint when both aircraft are utilizing GNSS, and

  - Separation is checked by obtaining simultaneous DME and/or GNSS readings from the aircraft at frequent intervals to ensure that the minimum will not be infringed.

b) Aircraft on crossing tracks:

- 20 NM, provided:
  - Each aircraft reports distance from the DME station and/or collocated waypoint/or same waypoint located at the crossing point of the tracks and that the relative angle between the tracks is less than 90 degrees; and

  - Separation is checked by obtaining simultaneous DME and/or GNSS readings from the aircraft at frequent intervals to ensure that the minimum will not be infringed.

- 10 NM provided:
  - The leading aircraft maintains a true airspeed of 20 knots or more faster than the succeeding aircraft;

- Each aircraft reports distance from the DME station and/or collocated waypoint/or same waypoint located at the crossing point of the tracks and that the relative angle between the tracks is less than 90 degrees; and
- Separation is checked by obtaining simultaneous DME and/or GNSS readings from the aircraft at such intervals as are necessary to ensure that the minimum is established and will not be infringed.

Aircraft climbing or descending

a) Aircraft on the same track

- 10 NM while vertical separation does not exist provided:
  - Each aircraft utilizes,
    - The same "on track" DME station when both aircraft are utilizing DME, or
    - An "on track" DME station and a collocated waypoint when one aircraft is utilizing DME and the other is utilizing GNSS, or
    - The same waypoint when both aircraft are utilizing GNSS, and
  - One aircraft maintains a level while vertical separation does not exist; and
  - Separation is established by obtaining simultaneous DME and /or GNSS readings from the aircraft.

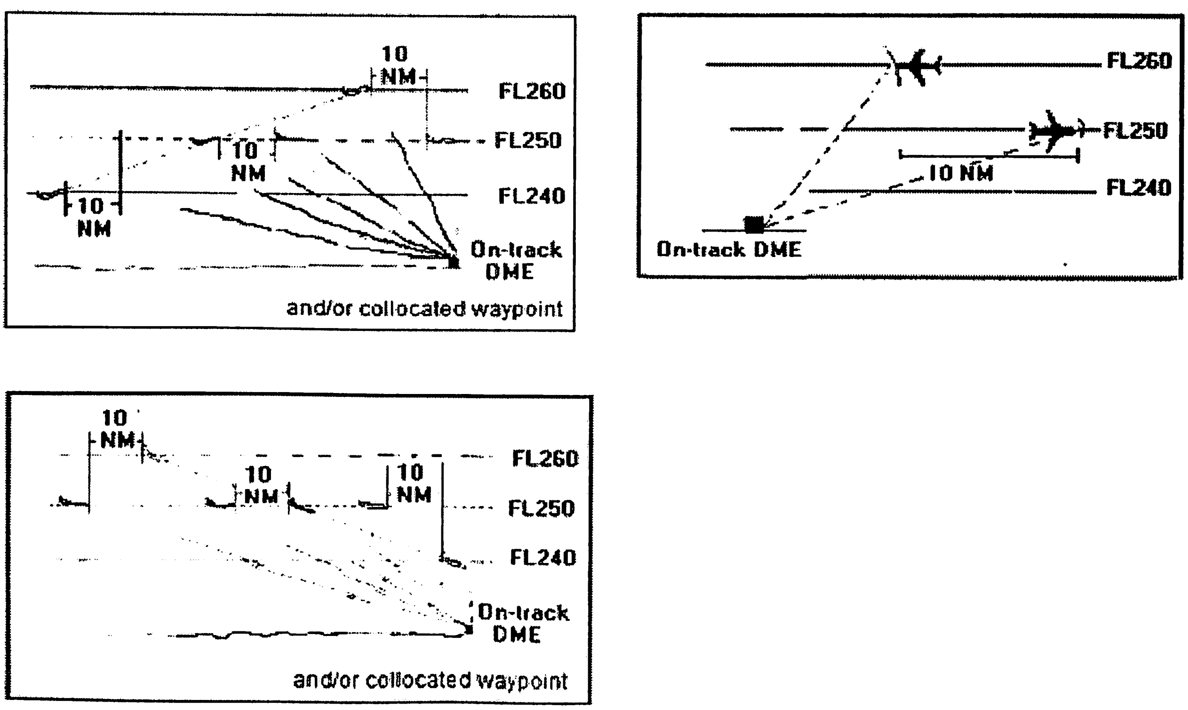


Figure 8: Horizontal Separation (Aircraft climbing or descending on same track)

Note:- To facilitate application of the procedure where a considerable change of level is involved, a descending aircraft may be cleared to some convenient level above the lower aircraft, or a climbing aircraft to some convenient level below the higher aircraft, to permit a further check on the separation that will obtain while vertical separation does not exist.

b) Aircraft on reciprocal tracks

Aircraft utilizing on-track DME and/or collocated waypoint or same waypoint may be cleared to climb or descend to or through the levels occupied by other aircraft utilizing on-track DME and/or collocated waypoint or same waypoint, provided that it has been positively established that the aircraft have passed each other and are at least 10 NM apart.

Longitudinal separation minima with Mach number technique based on time:

The following conditions shall be met when the Mach number technique is being applied:

a) Aircraft Types: Turbojet aircraft only.

b) Routes:

- The aircraft concerned have reported over the same common point and follow the same track or continuously diverging tracks until some other form of separation is provided; or
- If the aircraft have not reported over the same reporting point and it is possible to ensure, by radar, ADS-B or other means, that the appropriate time interval will exist at the common point from which they either follow the same track or continuously diverging tracks.

c) Levels: The aircraft concerned are in level flight, climbing or descending.

Note1:- The Mach Number Technique is applied using True Mach Number

d) Mach number Assignment: A Mach number (or, when appropriate, a range of Mach numbers) shall be issued to each aircraft.

Note: *Turbojet aircraft shall adhere to the Mach number approved by ATC and shall request ATC approval before making any changes thereto. If it is essential to make an immediate temporary change in the Mach number (e.g. Due to turbulence), ATC shall be notified as soon as possible that such a change has been made. If it is not feasible, due to aircraft performance, to maintain the last assigned Mach number during en-route climbs and descents, pilots of aircraft concerned shall advise ATC at the time of the climb/descent request.*

e) Separation Minima

- When Mach number technique is applied, minimum longitudinal separation between turbojet aircraft on the same track, whether in level, climbing or descending flight shall be 10 minutes; or the prescribed minima based on application of differential Mach number on prescribed ATS routes.
- The applicable longitudinal separation minima is maintained by:
  - Ensuring that the spacing between the estimated positions of the

aircraft is not less than the prescribed minimum.

- Continuously monitoring aircraft position reports and updating control estimates along the aircraft's track(s). If after establishing the Mach number technique between aircraft, control information indicates that
  Less than the applicable minima between aircraft may exist, immediately

  - Issue crossing restrictions to ensure the appropriate longitudinal minima at the next significant point, or
  - Assign revised Mach numbers appropriate for the estimated interval, or
  - Establish vertical separation.

NOTE-Control estimates are calculated by the controller using known wind patterns, previous aircraft transit times, pilot progress reports, and pilot estimates.

f) Relative Speeds
The preceding aircraft maintains the same or a greater Mach number than the following aircraft; or If the following aircraft is faster than the lead aircraft, ensure that the appropriate time interval will exist until another form of separation is achieved.

NOTE- The calculation of ground speeds and estimated times over significant points is a time consuming process which, in dense traffic situations, could result in unacceptable delays in issuance of clearances. A "rule of thumb" may be applied which allows clearances to be issued in a timely manner, provided the expected minimum longitudinal separation over the exit point is subsequently confirmed when the calculated flight progress strip data become available. This rule of thumb can be stated as follows: for each 600 NM in distance between the entry and exit points of the area where the Mach number technique is used, add one minute for each 0.01 difference in Mach number for the two aircraft concerned to compensate for the fact that the second aircraft is overtaking the first aircraft (See Table below.)

Application of the Mach Number Technique when the Following Aircraft is Faster					
Difference in Mach	Distance to Fly and Separation (in Minutes) Required at Entry Point				
	001 - 600 NM	601 - 1200 NM	1201 - 1800 NM	1801 - 2400 NM	2401 - 3000 NM
0.1	11	12	13	14	15
0.2	12	14	16	18	20
0.3	13	16	19	22	25
0.4	14	18	22	26	30
0.5	15	20	25	30	35
0.6	16	22	28	34	40
0.7	17	24	31	38	45
0.8	18	26	34	42	50
0.9	19	28	37	46	55
0.10	20	30	40	50	60

Table 9: Longitudinal separation following aircraft is faster (Using Mach no.)

When preceding aircraft is maintaining a true Mach number greater than the following aircraft separation minima of 9 and 5 minutes inclusive, on prescribed minima may be applied in accordance with the following table:

Application of the Mach Number Technique when the Preceding Aircraft is Faster	
Separation Minima in Minutes	Mach Number by which the Preceding Aircraft is Faster
9	0.02
8	0.03
7	0.04
6	0.05
5	0.06

Table 10: Longitudinal separation Preceding aircraft is faster (Using Mach no.)

Separation of aircraft holding in flight

Aircraft established in adjacent holding patterns shall be separated by the applicable vertical separation minimum.

Except when lateral separation exists, vertical separation shall be applied between aircraft holding in flight and other aircraft, whether arriving, departing or en route, whenever the other aircraft concerned are within five minutes flying time of the holding area or within a distance prescribed by the appropriate authority.

Minimum separation between departing aircraft

- One-minute separation if aircraft are to fly on tracks diverging by at least 45 degrees immediately after take-off so that lateral separation is provided.
- Two minutes between take-offs when the preceding aircraft is 40 knots or more faster than the following aircraft and both aircraft propose to follow the same track.

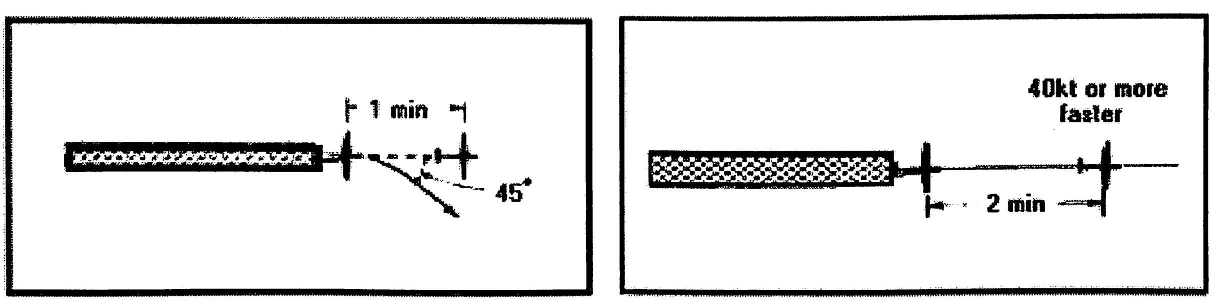


Figure 9a: Minimum separation between departing aircraft

- Five-minute separation while vertical separation does not exist if a departing aircraft will be flown through the level of a preceding departing aircraft and both aircraft propose to follow the same track. Action must be taken to ensure that the five-minute separation will be maintained or increased while vertical separation does not exist.

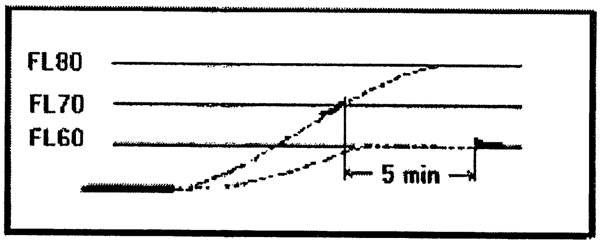


Figure 9b: Minimum separation between departing aircraft

<u>Separation of departing aircraft from arriving aircraft</u>

The following separation shall be applied when take-off clearance is based on the position of an arriving aircraft:

If an arriving aircraft is making a complete instrument approach, a departing aircraft may take off:

- In any direction until an arriving aircraft has started its procedure turn or base turn leading to final approach;

- In a direction which is different by at least 45 degrees from the reciprocal of the direction of approach after the arriving aircraft has started procedure turn or base turn leading to final approach, provided that the take-off will be made at least three minutes before the arriving aircraft is estimated to be over the beginning of the instrument runway.

If an arriving aircraft is making a straight-in approach, a departing aircraft may take off:

- In any direction until five minutes before the arriving aircraft is estimated to be over the instrument runway;

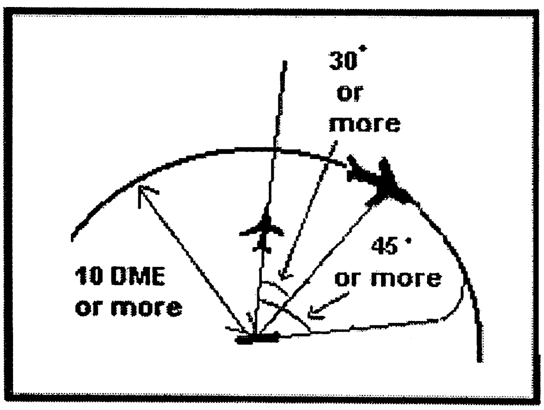
- In a direction which is different by at least 45 degrees from the reciprocal of the direction of approach of the arriving aircraft:
  - Until three minutes before the arriving aircraft is estimated to be over the beginning of the instrument runway, or
  - Before the arriving aircraft crossing a designated fix on the approach track; the location of such fix to be determined by the appropriate ATS authority after consultation with the operators.

Note: Lateral separation is considered to exist between an arriving aircraft that subsequently commenced final approach and the departing aircraft that has established on a course diverging by at least 45 degrees from the reciprocal of the final approach course.

Departing aircraft is maintaining a radial from a VOR and arriving aircraft established on a DME arc:

- Case 1: An arriving aircraft carrying out a DME arc procedure, and a departing aircraft, established on a track which is different by at least 45 degrees from the reciprocal of the direction of final approach track of the arriving aircraft, will be deemed to be laterally separated, when
  - The arriving aircraft is established on a DME arc of at least 10 NM using same VOR and is moving away from the track of the departing aircraft maintaining VOR radial; and
  - The departing aircraft maintaining the VOR radial is crossing the arc of the arriving aircraft from behind; and
  - The arriving aircraft has passed a VOR radial which is different by at least 30 degrees from the radial maintained by departing aircraft.

- Case 2: When a departing aircraft is maintaining a radial from a VOR and arriving aircraft established on a DME arc of at least 10 NM using same VOR, will be deemed to be laterally separated, when the aircraft established on VOR radial is at a DME distance of 10 miles or greater than the DME arc maintained by the arriving aircraft.



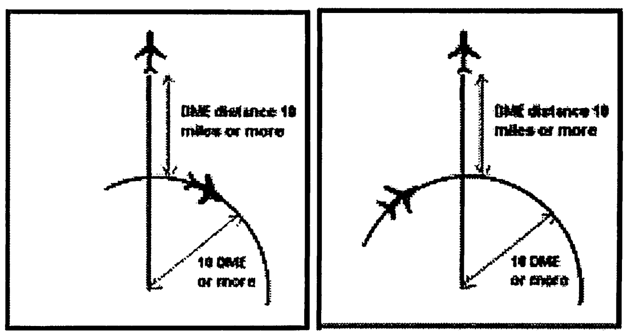


Figure 10: Departing aircraft is maintaining a radial from a VOR and arriving aircraft established on a DME arc

Time-based wake turbulence longitudinal separation minima

Categorization of aircraft: Wake turbulence separation minima should be based on a grouping of aircraft types into three categories according to the maximum certificated take-off mass.

Category	Maximum Certified take off mass
Heavy	1,36,000 kg or more
Medium	Less than 1.36,000 kg but more than 7000 kg
Light	7000 kg or less

Table 11: Aircraft category based on maximum take-off weight

The ATC unit concerned shall not be required to apply wake turbulence separation:

- For arriving VFR flights landing on the same runway as a preceding landing HEAVY or MEDIUM aircraft; and
- Between arriving IFR flights executing visual approach when the aircraft has reported the preceding aircraft in sight and has been instructed to follow and maintain own separation from that aircraft.

Arriving aircraft

The following minima shall be applied to aircraft landing behind a HEAVY or a MEDIUM aircraft:

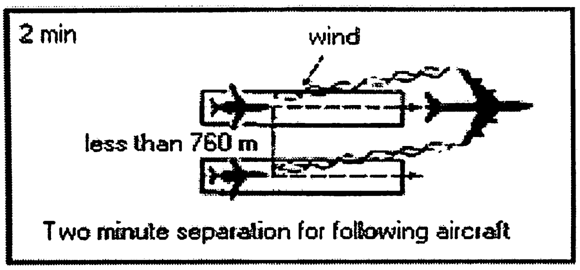
Leading Aircraft	Following Aircraft	Separation Minima
Heavy	Medium	2 min
Heavy or Medium	Light	3 min

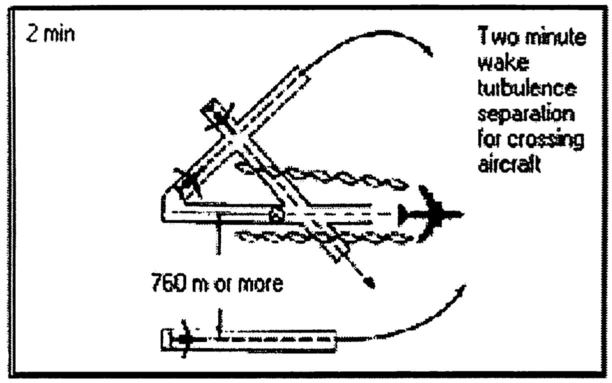
Table 12: Wake turbulence minima for arriving aircraft

Departing aircraft

<table>
<tr><th>Leading aircraft</th><th>Following aircraft</th><th colspan="2">Separation Minima</th></tr>
<tr><td>Heavy</td><td>Medium or Light</td><td rowspan="2">Departing from
a) The same runway
b) Parallel runway separated by less than 760 m
c) Crossing runways if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 1 000 ft below;
d) Parallel runways 2 min separated by 760 m or more, if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 1000ft below.</td><td rowspan="2">2 mins</td></tr>
<tr><td>Medium</td><td>Light</td></tr>
<tr><td>Heavy
(Full length take off)</td><td>Medium or Light</td><td rowspan="2">Departing from
a) An intermediate part of the same runway; or
b) An intermediate part of a parallel runway</td><td rowspan="2">3 mins</td></tr>
<tr><td>Medium
(Full length take off)</td><td>Light</td></tr>
</table>

Table 13: Wake turbulence minima for departing aircraft





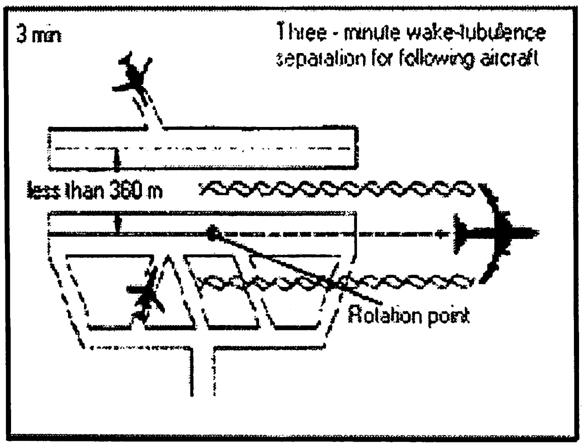


Figure 13: Wake turbulence minima for departing aircraft

<u>Opposite direction</u>

A separation minimum of 2 minutes shall be applied between a LIGHT or MEDIUM aircraft and a HEAVY aircraft and between a LIGHT aircraft and a MEDIUM aircraft when the heavier aircraft is making a low or missed approach and the lighter aircraft is:

- Utilizing an opposite-direction runway for take-off; or
- Landing on the same runway in the opposite direction, or on a parallel opposite-direction runway separated by less than 760 m.

Displaced landing threshold

A separation minimum of 2 minutes shall be applied between a LIGHT or MEDIUM aircraft and a HEAVY aircraft and between a LIGHT aircraft and a MEDIUM aircraft when operating on a runway with a displaced landing threshold when:

- A departing LIGHT or MEDIUM aircraft follows a HEAVY aircraft arrival and a departing LIGHT aircraft follows a MEDIUM aircraft arrival; or
- An arriving LIGHT or MEDIUM aircraft follows a HEAVY aircraft departure and an arriving LIGHT aircraft follows a MEDIUM aircraft departure if the projected flight paths are expected to cross.

Note: Wake Vortex generation begins when the nose wheel lifts off the runway on take-off and continues until the nose wheel touches down on landing.

Chapter 5: Procedures for aircraft arriving and departing an aerodrome

In order to maintain the desired separation in the vicinity of an airport certain procedures and separation minima have to be followed at the same time information on essential local traffic known to the controller shall be transmitted without delay to departing and arriving aircraft concerned.

5.1 Departing aircraft

General

Clearances for departing aircraft shall specify, when necessary for the separation of aircraft, direction of takeoff and turn after take-off; heading or track to be made good before taking up the cleared departure track; level to maintain before continuing climb to assigned level; time, point and/or rate at which a level change shall be made; and any other necessary maneuvers consistent with safe operation of the aircraft.

At aerodromes where standard instrument departures (SIDs) have been established, departing aircraft should normally be cleared to follow the appropriate SID.

Standard instrument departures (SID)

At many busy controlled airports, specific Standard Instrument Departures (SID), now referred to as Departure Procedures (DPs), are published to expedite clearance delivery and to facilitate transition between takeoff and en route operations. The SID provides a standard route from the terminal to the en route structure. There are often transitions which connect the end of the SID with one of several en route possibilities.

SIDs furnishes pilots departure routing clearance information in graphic and textual form. This simplifies the issuance of a departure clearance by allowing ATC to simply specify the SID by name without having to describe, in detail, the route. The clearance may include the basic SID name and number, plus a transition to the en route portion of the flight plan.

SID CHARTS

On the chart below, the Bradford transition is highlighted in red. As you can see, the SID starts at the departure runway, then via radar vectors to the STL VORTAC. At this point, the pilot would be expected to navigate to the SKUTR intersection via the 014° radial and then on to BDF VORTAC via the 198° radial.

In addition to the departure procedures themselves, there is a lot of other information on the SID, such as (A) the name of the facility and the SID, (B) frequencies for communications, (C) navigation aids, including frequencies and identifiers, (D) minimum altitudes, distances and courses, and (E) text descriptions of the procedures and transitions.

SIDs are designed to separate departing traffic from arrivals, provide efficient interception of an outbound course, avoid noise sensitive areas, simplify the issuance of departure clearances, and reduce radio traffic.

There are two basic types of SIDs: pilot navigation, where the pilot is primarily responsible for navigation along the SID course, and vector SIDs, where ATC will provide radar vectors to an assigned route or fix.

If you do not want to fly a SID, a note should be entered in the remark section of the flight plan indicating "no SID".

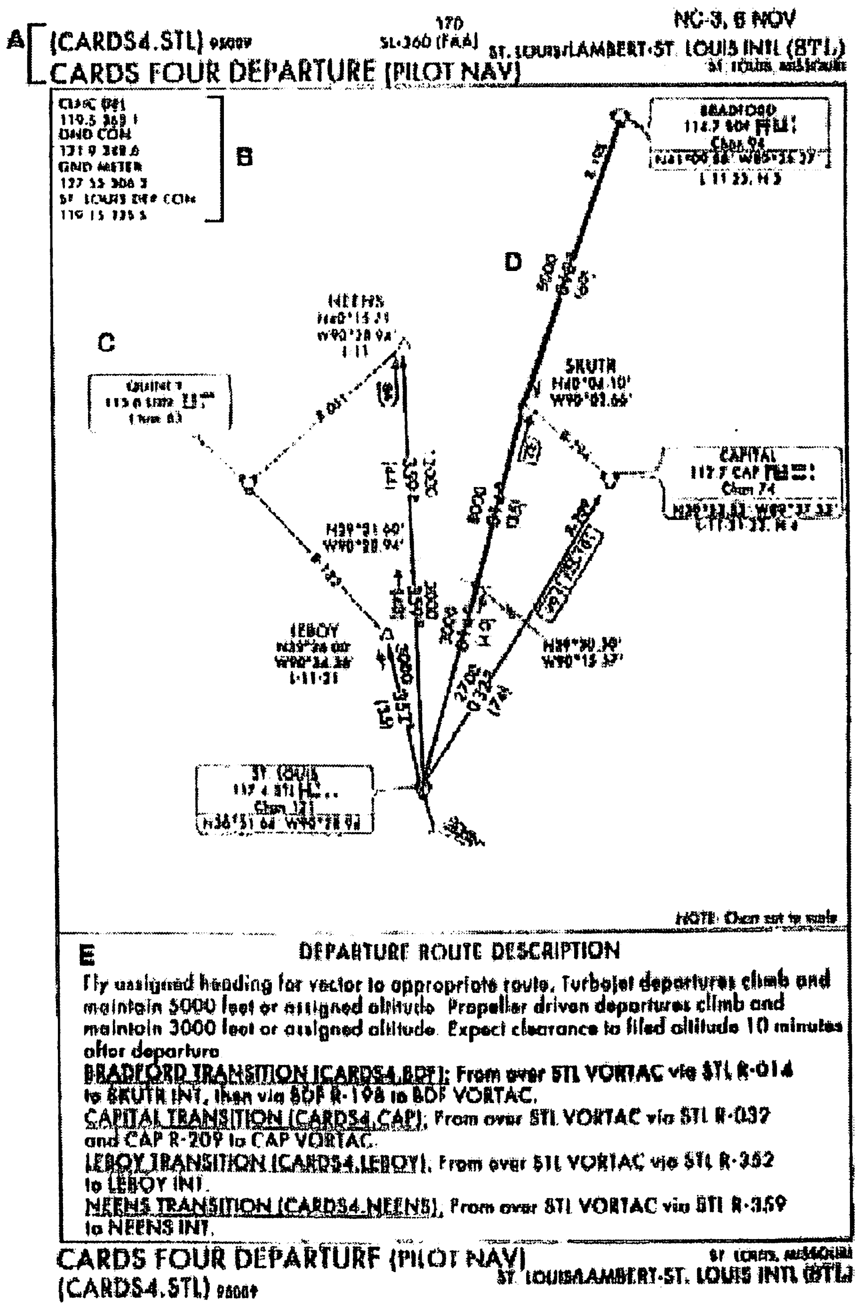


Figure 12: SID Chart

Departure Sequence

Departing aircraft may be expedited by suggesting a take-off direction which is not into the wind. It is the responsibility of the pilot-in-command of an aircraft to decide between making such a take-off or waiting for take-off in a preferred direction.

If departures are delayed, the delayed flights shall normally be cleared in an order based on their estimated time of departure, except that deviation from this order may be made to:

a) Facilitate the maximum number of departures with the least average delay;

b) Accommodate requests by an operator in respect of that operator's flights to the extent practicable.

Air traffic control units should when practicable advise aircraft operators or their designated representatives when anticipated delays are expected to exceed 30 minutes.

Information for Departing Aircraft

- Meteorological conditions

Information regarding significant changes in the meteorological conditions in the take-off or climb-out area, obtained by the unit providing approach control service after a departing aircraft has established communication with such unit, shall be transmitted to the aircraft without delay, except when it is known that the aircraft already has received the information.

Note:- Significant changes in this context include those relating to surface wind direction or speed, visibility, runway visual range or air temperature (for turbine-engine aircraft), and the occurrence of thunderstorm or cumulonimbus, moderate or severe turbulence, wind shear, hail, moderate or severe icing, severe squall line, freezing precipitation, severe mountain waves, sand storm, dust storm, blowing snow, tornado or waterspout.

- Operational status of visual or non-visual aids

Information regarding changes in the operational status of visual or non-visual aids essential for take-off and climb shall be transmitted without delay to a departing aircraft, except when it is known that the aircraft already has received the information.

5.2 Arriving Aircraft

General

When it becomes evident that delays will be encountered by arriving aircraft, operators or designated representatives shall, to the extent practicable, be notified and kept currently informed of any changes in such expected delays.

The controller may request an arriving aircraft to report when leaving or passing a significant point or navigation aid, or when starting procedure turn or base turn, or any other information, to expedite departing and arriving aircraft.

An IFR flight shall not be cleared for an initial approach below the Minimum Sector Altitude (MSA) or Minimum Holding Altitude (MHA) whichever is higher, nor to descend below that altitude unless:

a) The pilot has reported passing an appropriate point defined by a navigation aid or as a waypoint; or

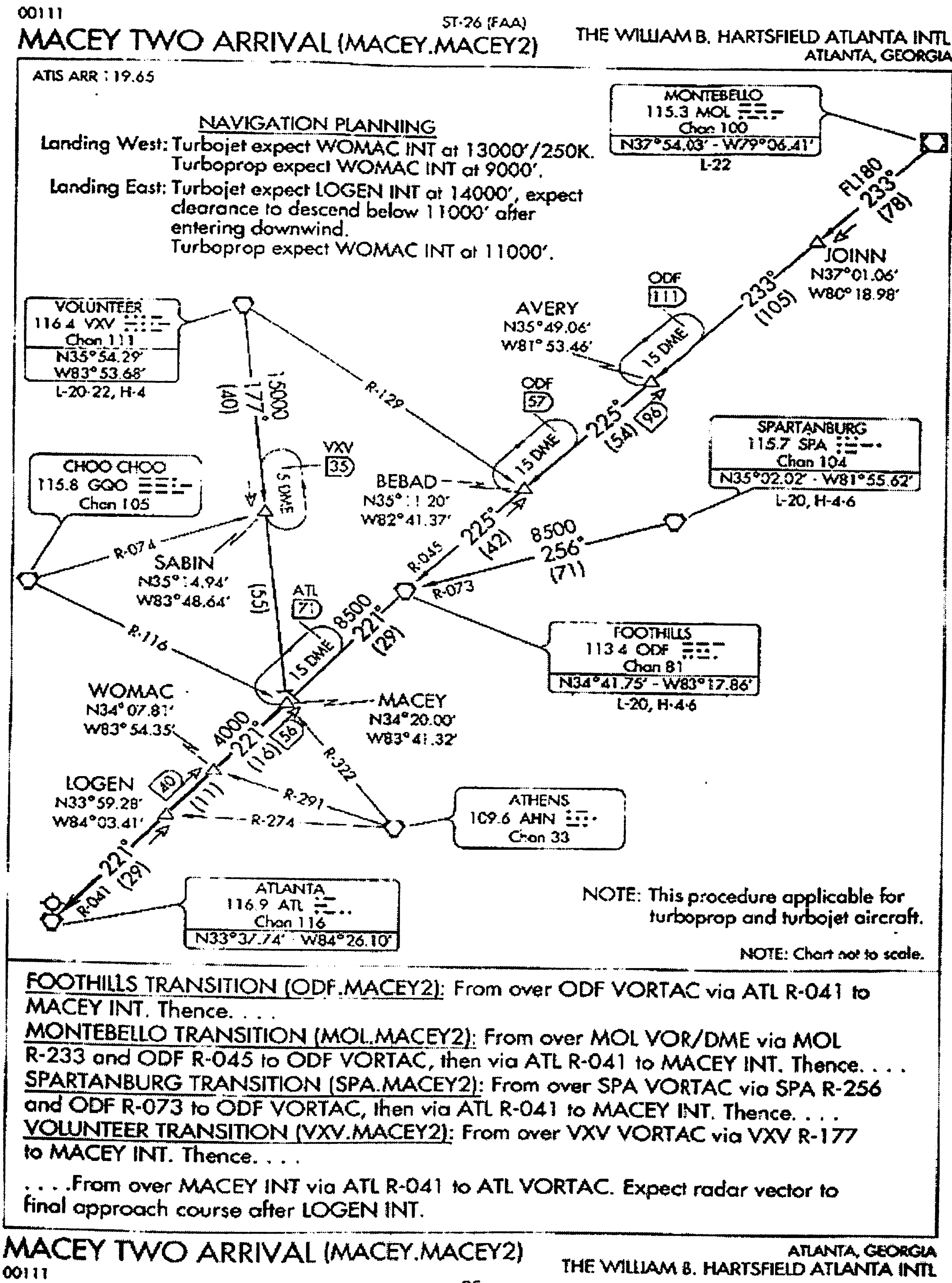
b) The pilot reports that the aerodrome is and can be maintained in sight; or

c) The aircraft is conducting a visual approach; or

d) The controller has determined the aircraft's position by the use of ATS surveillance system, and a lower minimum altitude has been specified for use when providing ATS surveillance services.

At aerodromes where standard instrument arrivals (STARs) have been established, arriving aircraft should normally be cleared to follow the appropriate STAR. The aircraft shall be informed of the type of approach to expect and runway-in-use as early as possible.

Standard Terminal Arrival Route (STAR) Charts are designed to expedite ATC arrival procedures and to facilitate transition between en route and instrument approach operations. They present the pilot a pre planned IFR ATC arrival procedure in graphic and textual form. Each STAR procedure is presented as a separate chart and may serve a single airport or more than one airport in a given geographic location. To accept a STAR, you must have at least a textual description. A STAR has many similarities to the SID and is presented in a similar format.



00111 ST-26 (FAA)

MACEY TWO ARRIVAL (MACEY.MACEY2) THE WILLIAM B. HARTSFIELD ATLANTA INTL ATLANTA, GEORGIA

ATIS ARR : 119.65

NAVIGATION PLANNING

Landing West: Turbojet expect WOMAC INT at 13000'/250K.
Turboprop expect WOMAC INT at 9000'.

Landing East: Turbojet expect LOGEN INT at 14000', expect clearance to descend below 11000' after entering downwind.
Turboprop expect WOMAC INT at 11000'.

NOTE: This procedure applicable for turboprop and turbojet aircraft.

NOTE: Chart not to scale.

FOOTHILLS TRANSITION (ODF.MACEY2): From over ODF VORTAC via ATL R-041 to MACEY INT. Thence. . . .

MONTEBELLO TRANSITION (MOL.MACEY2): From over MOL VOR/DME via MOL R-233 and ODF R-045 to ODF VORTAC, then via ATL R-041 to MACEY INT. Thence. . . .

SPARTANBURG TRANSITION (SPA.MACEY2): From over SPA VORTAC via SPA R-256 and ODF R-073 to ODF VORTAC, then via ATL R-041 to MACEY INT. Thence. . . .

VOLUNTEER TRANSITION (VXV.MACEY2): From over VXV VORTAC via VXV R-177 to MACEY INT. Thence. . . .

. . . .From over MACEY INT via ATL R-041 to ATL VORTAC. Expect radar vector to final approach course after LOGEN INT.

MACEY TWO ARRIVAL (MACEY.MACEY2) ATLANTA, GEORGIA
00111 THE WILLIAM B. HARTSFIELD ATLANTA INTL

P5

SE-4, 22 DEC 2001

Figure 13: Standard Terminal arrival chart

After coordination with the approach control unit, the ACC may clear the first arriving aircraft for approach rather than to a holding fix.

Visual Approach:

- Visual approach is an approach by an IFR flight when either part or all of an instrument approach procedure is not completed and the approach is executed in visual reference to terrain.
- Clearance for an IFR flight to execute a visual approach may be requested by the pilot or initiated by the controller.
- The controller shall not initiate a visual approach when there is a reason to believe that the flight crew concerned is not familiar with the aerodrome and its surrounding terrain.
- Controller should take into consideration the prevailing traffic and meteorological conditions before initiating visual approach.
- Aircraft may be cleared for direct base leg/final, if there is reasonable assurance that visual approach and landing can be completed.
- Separation shall be provided between an aircraft cleared to execute a visual approach and other arriving and departing aircraft.
- When clearance to execute visual approach has been issued, it shall be the responsibility of pilot to maintain terrain clearance.

Visual approach by a flight crew:

A flight crew may request visual approach if he has runway in sight and the pilot can maintain visual reference to terrain subject to the following conditions only:

a) The reported ceiling is at or above initial approach level i.e. minimum holding altitude at the facility associated with the instrument approach procedure; or the pilot finds at the initial approach level or at any time during the instrument approach procedure that the meteorological conditions are such that with reasonable assurance a visual approach and landing can be completed;

b) The ground visibility is not below the 'Aerodrome Operating Minima' of non precision approach available at the aerodrome and which aircraft is capable of carrying out at the time visual approach is requested,

The pilot at the time of requesting for visual approach should give position report.

The pilot shall advise the controller immediately when

a) Weather has deteriorated and unable to keep the terrain in sight; or

b) Unable to continue flight following the preceding aircraft; or

c) Additional spacing is required from preceding aircraft.

Visual approach initiated by a procedural controller:

The procedural controller may initiate visual approach subject to following conditions

a) Ground visibility is not below the aerodrome operating minima of non precision approach available at the aerodrome and which aircraft is capable of carrying out,

b) Concurrence of the flight crew is obtained, and

c) The reported ceiling is at or above the approved initial approach level

Clearance to execute a visual approach shall only be issued provided the aircraft can maintain visual reference to terrain and has the aerodrome or the runway in sight.

Phraseologies:

- ADVISE ABLE TO ACCEPT VISUAL APPROACH RUNWAY (number);
- EXPECT VISUAL APPROACH RUNWAY (number), REPORT RUNWAY IN SIGHT;
- CLEARED VISUAL APPROACH RUNWAY (number), REPORT (position in the traffic circuit).

Visual approach initiated by a radar controller:

The radar controller may initiate visual approach subject to the following conditions

a) Ground visibility is not below the aerodrome operating minima of non precision approach available at the aerodrome and which aircraft is capable of carrying out,

b) Concurrence of the flight crew is obtained, and

c) The reported ceiling is at or above the minimum altitude applicable to radar vectoring and meteorological conditions are such that, with reasonable assurance, a visual approach and landing can be completed.

Clearance for visual approach shall be issued, provided the aircraft can maintain visual reference to terrain and has the aerodrome or, runway in sight, at which time radar vectoring would normally be terminated.

Phraseologies:

- ADVISE ABLE TO ACCEPT VISUAL APPROACH RUNWAU (number)
- (vectoring instruction) VECTORING FOR VISUAL APPROACH RUNWAY (number), REPORT RUNWAY IN SIGHT
- (vectoring instruction) VECTORING FOR) (position in the traffic circuit), REPORT RUNWAY IN SIGHT
- CLEARED VISUAL APPROACH RUNWAY (number), REPORT (position in the traffic circuit)

If the pilot does not sight the runway, the aircraft will either be vectored for pilot interpreted final approach aid /surveillance radar approach or the aircraft will be climbed to minimum holding altitude associated with landing nav-aid and cleared for IAL procedure of the nav-aid.

Successive visual approaches:

For successive visual approaches, separation shall be maintained by the controller until the pilot of a succeeding aircraft reports having the preceding aircraft in sight. The aircraft shall then be instructed to follow and maintain own separation from the preceding aircraft and report runway in sight.

Phraseologies:

- REPORT NUMBER (number) (aircraft type and position) IN SIGHT
- CLEARED VISUAL APPROACH RUNWAY (number) MAINTAIN OWN SEPARATION FROM PRECEDING [CAUTION WAKE TURBULANCE]
- REPORT RUNWAY IN SIGHT

When both aircraft are of a heavy wake turbulence category, or the preceding aircraft is of heavier wake turbulence category than the following, and the distance between the aircraft is less than the appropriate wake turbulence minimum, the controller shall issue caution of possible wake turbulence.

Phraseology: CAUTION WAKE TURBULANCE

The pilot-in-command of the aircraft concerned shall be responsible for ensuring that the spacing from a preceding aircraft of a heavier wake turbulence category is acceptable. If it is determined that additional spacing is required, the flight crew shall inform the ATC unit accordingly, stating their requirements.

Transfer of communication to the Aerodrome controller should be effected at such a point or time that information on essential local traffic, if applicable, and clearance to land or alternative instruction can be issued to the aircraft in a timely manner.

The aerodrome controller should endeavor to sight the aircraft and upon sighting should inform the pilot so. The landing clearance should be issued by the controller only after sighting the aircraft.

Instrument approach

The approach control unit shall specify the instrument approach procedure to be used by arriving aircraft. A flight crew may request an alternative procedure and, if circumstances permit, should be cleared accordingly.

If a pilot reports or it is clearly apparent to the ATC unit that the pilot is not familiar with an instrument approach procedure, the initial approach level, the point (in minutes from the appropriate reporting point) at which base turn or procedure turn will be started, the level at which the procedure turn shall be carried out and the final approach track shall be specified, except that only the last mentioned need be specified if the aircraft is to be cleared for a straight-in approach. The frequency (ies) of the navigation aid(s) to be used as well as the missed approach procedure shall also be specified when deemed necessary.

If visual reference to terrain is established before completion of the approach procedure, the entire procedure must nevertheless be executed unless the aircraft requests & is cleared for a visual approach.

Holding

In the event of extended delays, aircraft should be advised of the anticipated delay as early as possible and, when practicable, be instructed or given the option reduce speed en route in order to absorb delay.

When delay is expected, the ACC shall normally be responsible for clearing aircraft to the holding fix , and for including holding instructions, and expected approach time or onward clearance time, as applicable, in such clearances.

After coordination with the approach control unit, the ACC may clear arriving aircraft to visual holding location to hold until further advised by the approach control unit.

After coordination with the aerodrome control tower, the approach control unit may clear arriving aircraft to visual holding location to hold until further advised by the aerodrome control tower.

Holding and holding pattern entry shall be accomplished in accordance with published procedures. If entry and holding procedures have not been published or if the procedures are not known to a flight crew, the appropriate air traffic control unit shall specify the designator of the location or aid to be used, the inbound track, radial or bearing, direction of turn in the holding pattern as well as the time of the outbound leg or the distances between which to hold.

Aircraft should normally be held at a designated holding fix. The required minimum vertical, lateral or longitudinal separation from other aircraft shall be provided. Criteria and procedures for the simultaneous use of adjacent holding patterns shall be prescribed in local instructions.

Levels at holding fix or visual holding location shall as far as practicable be assigned in a manner that will facilitate clearing each aircraft to approach in its proper priority. Normally, the first aircraft to arrive over a holding fix or visual holding location should be at the lowest level, with following aircraft at successively higher levels.

When extended holding is anticipated, turbojet aircraft should, when practicable, is permitted to hold at higher levels in order to conserve fuel, whilst retaining their order in the approach sequence.

If an aircraft is unable to comply with the published or cleared holding procedure, alternative instructions shall be issued.

For the purpose of maintaining a safe and orderly flow of traffic, an aircraft may be instructed to orbit at its present or at any other position, provided the required obstacle clearance is ensured.

Approach sequence

The following procedures shall be applied whenever approaches are in progress.

The approach sequence shall be established in a manner which will facilitate arrival of the maximum number of aircraft with the least average delay. Priority shall be given to:

a) An aircraft which anticipates being compelled to land because of factors affecting the safe operation of the aircraft (engine failure, shortage of fuel, etc.);

b) Hospital aircraft or aircraft carrying any sick or seriously injured person requiring urgent medical attention;

c) Aircraft engaged in search and rescue operations; and

d) VIP I (President), VIP II (Vice President), VIP III (Prime Minister) and VIP V (Foreign Heads of State/Govt.) aircraft.

Succeeding aircraft shall be cleared for approach:

a) When the preceding aircraft has reported that it is able to complete its approach without encountering instrument meteorological conditions; or

b) When the preceding aircraft is in communication with and sighted by the aerodrome controltower and reasonable assurance exists that a normal landing can be accomplished, or

c) When timed approaches are used, the preceding aircraft has passed the defined point inbound and reasonable assurance exists that a normal landing can be accomplished;

d) When the required longitudinal spacing between succeeding aircraft, as observed by radar, has been established.

In establishing the approach sequence, the need for increased longitudinal spacing between arriving aircraft due to wake turbulence shall be taken into account.

If the pilot of an aircraft in an approach sequence has indicated an intention to hold for weather improvement, or for other reasons, such action shall be approved. However, when other holding aircraft indicate intention to continue their approach-to-land, the pilot desiring to hold will be cleared to an adjacent fix for holding awaiting weather changes or re-routing
Alternatively, the aircraft should be given a clearance to place it at the top of the approach sequence so that other holding aircraft may be permitted to land. Coordination shall be effected with any adjacent ATC unit or control sector, when required, to avoid conflict with the traffic under the jurisdiction of that unit or sector.

When establishing the approach sequence, an aircraft which has been authorized to absorb a specified period of notified terminal delay by cruising at a reduced speed en route, should, in so far as practicable, be credited with the time absorbed en route.

Expected approach time

An expected approach time shall be determined for an arriving aircraft that will be subjected to a delay of 10 minutes or more. The expected approach time shall be transmitted to the aircraft as soon as practicable and preferably not later than at the commencement of its initial descent from cruising level. A revised expected approach time shall be transmitted to the aircraft without delay whenever it differs from that previously transmitted by 5 minutes or more, or such lesser period of time as agreed between the ATS units concerned.

An expected approach time shall be transmitted to the aircraft by the most expeditious means whenever it is anticipated that the aircraft will be required to hold for 30 minutes or more.
The holding fix to which an expected approach time relates shall be identified together with the expected approach time whenever circumstances are such that this would not otherwise be evident to the pilot.

Onward clearance time

In the event an aircraft is held en route or at a location or aid other than the initial
approach fix, the aircraft concerned shall, as soon as practicable, be given an expected onward clearance time from the holding fix . The aircraft shall also be advised if further holding at subsequent holding fix is expected.

Note:- "Onward clearance time" is the time at which an aircraft can expect to leave the fix at which it is being held.

Information for arriving aircraft

As early as practicable after an aircraft has established communication with the unit providing approach control service, the following elements of information, in the order listed, shall be transmitted to the aircraft, with the exception of such elements which it is known the aircraft has already received:

a) Type of approach and runway-in-use;

b) Meteorological information, as follows:
   - i. surface wind direction and speed, including significant variations;
   - ii. Visibility and, when applicable, runway visual range (RVR);
   - iii. present weather;
   - iv. Cloud below 5000 ft or below the highest minimum sector altitude, whichever is greater; cumulonimbus;
   - v. Air temperature;
   - vi. Dew point temperature;
   - vii. Altimeter setting(s);
   - viii. Any available information on significant meteorological phenomena in the approach area; and
   - ix. Trend-type landing forecast, when available.

c) Current runway surface conditions, in case of precipitants or other temporary hazards;

d) Changes in the operational status of visual and non visual aids essential for approach and landing.

If it becomes necessary or operationally desirable that an arriving aircraft follow an instrument approach procedure or use a runway other than that initially stated, the flight crew shall be advised without delay.

At the commencement of final approach, the following information shall be transmitted to aircraft:

a) Significant changes in the mean surface wind direction and speed;
   Note:- If the controller possesses wind information in the form of components, the significant changes are:

   - Mean head-wind component: 10 knots
   - Mean tail-wind component: 2 knots
   - Mean cross-wind component: 5 knots

b) The latest information, if any, on wind shear and/or turbulence in the final approach area;

c) The current visibility representative of the direction of approach and landing or, when provided, the current runway visual range value(s) and the trend, if practicable, supplemented by slant visual range value(s), if provided.

During final approach, the following information shall be transmitted without delay:

a) The sudden occurrence of hazards (e.g. unauthorized traffic on the runway);

b) Significant variations in the current surface wind, expressed in terms of minimum and maximum values;

c) Significant changes in runway surface conditions;

d) Changes in the operational status of required visual or non-visual aids;

e) Changes in observed RVR value(s), in accordance with the reported scale in use, or changes in the visibility representative of the direction of approach and landing.

Chapter 6: Phraseology

Introduction

Radiotelephony {RTF} provides the means by which pilots and ground personnel communicate with each other. Used properly the information and instructions transmitted are of vital importance in assisting in the safe and expeditious operation of aircraft. On the other hand, the use of non-standard procedures and phraseology can cause misunderstanding. Incidents and accidents have occurred in which a contributing factor has been the misunderstanding caused by the use of poor phraseology. The importance of using correct and precise standard phraseology cannot, therefore, be over-emphasized.

Transmitting Technique

The following transmitting techniques will assist in ensuring that transmitted speech is clearly and satisfactorily received:

a) Before transmitting listen out on the frequency to be used to ensure that there will be no interference with a transmission from another station.

b) Be familiar with good microphone operating techniques.

c) Use a normal conversational tone, speak clearly and distinctly.

d) Maintain an even rate of speech not exceeding 100 words per minute. When it is known that elements of the message will be written down by the recipient, speak at a slightly slower rate.

e) Maintain the speaking volume at a constant level.

f) A slight pause before and after numbers will assist in making them easier to understand.

g) Avoid using hesitation sounds such as "er".

h) Depress the transmit switch fully before speaking and do not release it until the message is completed. This will ensure that the entire message is transmitted.

Be aware that the mother tongue of the person receiving the message may not be English. Therefore, speak clearly and use standard RTF words and phrases wherever possible.

One of the most irritating and potentially dangerous situations in radiotelephony is a "stuck" microphone button. Operators should always ensure that the button is released after a transmission and the microphone placed in a appropriate place that will ensure that it will not inadvertently be switched on.

Familiarity with Radiotelephony Procedures

The communication procedures shall be in accordance with Volume II of Annex 10, and pilots, ATS personnel and other ground personnel shall be thoroughly familiar with the radiotelephony procedures.

ICAO Phonetics

Pronunciation of numbers:

Numeral or numeral element	Pronunciation
0	ZE-RO
1	WUN
2	TOO
3	TREE
4	FOW-er
5	FIFE
6	SIX
7	SEV-en
8	AIT
9	NIN-er
Decimal	DAY-SEE-MAL
Hundred	HUN-dred
Thousand	TOU-SAND

Table 13a: Pronunciation of numbers:

Pronunciation of Spelling Alphabets

Letter	Word	Pronunciation
A	Alfa	AL FAH
B	Bravo	BRAH VOH
C	Charlie	CHAR LEE or SHAR LEE
D	Delta	DELL TAH
E	Echo	ECK OH
F	Foxtrot	FOKS TROT
G	Golf	GOLF
H	Hotel	HO TELL
I	India	IN DEE AH
J	Juliett	JEW LEE ETT
K	Kilo	KEY LOH
L	Lima	LEE MAH
M	Mike	MIKE
N	November	NO VEM BER
O	Oscar	OSS CAH
P	Papa	PAH PAH
Q	Quebec	KEH BECK
R	Romeo	ROW ME OH
S	Sierra	SEE AIR RAH
T	Tango	TANG GO
U	Uniform	YOU NEE FORM or OO NEE FORM
V	Victor	VIK TAH
W	Whiskey	WISS KEY
X	X-ray	ECKS RAY
Y	Yankee	YANG KEY
Z	Zulu	ZOO LOO

Table 13b: Pronunciation of Spelling Alphabets

Transmission of numbers in Radiotelephony:

All numbers shall be transmitted by pronouncing each digit separately. The following examples illustrate the application of the procedure exception to this rule are also provided in the given examples:

Aircraft call Sign AIC 238 JAI242	**Transmitted as** Air India **two three eight** Jet Airways **two four two**
Flight levels FL 180 FL 200	**Transmitted as** flight level **one eight zero** flight level **two zero zero**
Headings 100 degrees 080 degrees	**Transmitted as** heading **one zero zero** heading **zero eight zero**
Wind direction and speed 200 degrees 70 knots 160 degrees 18 knots gusting 30 knots	**Transmitted as** wind **two zero zero** degrees **seven zero** knots wind **one six zero** degrees **one eight** knots gusting **three zero** knots
Transponder codes 2400 4203	**Transmitted as** Squak **two four zero** Squak **four two zero three**
Altimeter setting 1010 1000	**Transmitted as** QNH **one zero one zero** QNH **one zero zero zero**
Altitude 800 3400 12,000	**Transmitted as** **Eight hundred** **Three thousand four hundred** **One two thousand**
Cloud height 2200 4300	**Transmitted as** **Two thousand two hundred** **Four thousand three hundred**
Visibility 1000 700	**Transmitted as** Visibility **one thousand** Visibility **seven hundred**
Runway visual range 600 1700	**Transmitted as** RVR **six hundred** RVR **one thousand seven hundred**

Table 14: Transmission of numbers in Radiotelephony

All numbers used in the transmissions of altitude, cloud height, visibility and runway visual range (RVR) information, which contain whole hundreds and whole thousands, shall be transmitted by pronouncing each digit in the number of hundreds or thousands followed by the word HUNDRED or THOUSAND as appropriate. Combinations of thousands and whole hundreds shall be transmitted by pronouncing each digit in the number of thousands followed by the word THOUSAND followed by the number of hundreds followed by the word HUNDRED. The following examples illustrate in the last 4 examples of table 14 illustrate the application of this procedure.

Call signs for aeronautical stations

Aeronautical stations are identified by the name of the location followed by a suffix. The suffix indicates the type of unit or service provided.

Unit or service	Call sign suffix
Area control center	CONTROL
Radar [in general]	RADAR
Approach Control	APPROACH
Approach control radar	APPROACH RADAR
Area Control Radar	CONTROL RADAR
Aerodrome control	TOWER
Surface movement control	GROUND
Flight information service	INFORMATION
Apron control /management service	APRON
Clearance Delivery	DELIVERY
Company dispatch	DISPATCH
Aeronautical Station	RADIO

Table 15: Call signs for aeronautical stations

Standard words and phrases

The following words and phrases shall be used in radiotelephony communications as appropriate and shall have the meaning given below:

WORD/ PHRASE	MEANING
ACKNOWLEDGE	Let me know that you have received and understood this message
AFFIRM	Yes.
APPROVED	Permission for proposed action granted.
BREAK	I hereby indicate the separation between portions of the message. {TO be used where there is no clear distinction between the text and other portion of the message.}
BREAK BREAK	I hereby indicate the separation between messages transmitted to different aircraft in a very busy environment.
CANCEL	Annul the previously transmitted clearance.
CHECK	Examine a system or procedure. {No answer is normally expected.} Specified.

CLEARED	Authorized to proceed under the conditions
CONFIRM	I request verification of (clearances , instruction, action, information)
CONTACT	Establish communication with ....
CORRECT	True or Accurate
CORRECTION	An error has been made in the transmission (or message indicated). The correct version is...
DISREGARD	Ignore
GO AHEAD	Proceed with your message Note: Not used whenever the possibility exists of misconstruing "GO AHEAD" as authorization for an aircraft to proceed.
HOW DO YOU READ	What is the readability of my transmission?
MAINTAIN	Continue in accordance with the condition(s) specified or in its literal sense, e.g. MAINTAIN VFR
MONITOR	Listen out on (frequency)
NEGATIVE	"NO" or "Permission not granted" or "That is not correct" or "Not capable"
OVER	"My transmission is ended and I expect a response from you" Note: Not normally used in VHF communication
OUT	"This exchange of transmission is ended and no response is expected" Note: Not normally used in VHF communication
READ BACK	"Repeat all, or the specified part, of this message back to me exactly as received"
RECLEARED	"A change has been made to your last clearance and this new clearance supersedes Your previous clearance or part thereof"
REPORT	"Pass me following information"
REQUEST	"I should like to know..." or "I wish to obtain...." Note: Under no circumstances to be used in reply to a question requiring "READ BACK" or a direct answer in the affirmative (AFFIRM) or negative(NEGATIVE)
ROGER	"I have received all of your last transmission." Note: Under no circumstances to be used in reply to a question requiring "READBACK" or a direct answer in the affirmative (AFFIRM) or negative (NEGATIVE).
SAY AGAIN	"Repeat all, or the following part, of your last transmission"
SPEAK SLOWER	"Reduce your rate of speech"
STANDBY	"Wait and I will call you" Note: The caller would normally re-establish contact if delay is lengthy. STANDBY is not an approval or denial.
UNABLE	"I cannot comply with your request, instruction, or clearance" Note: UNABLE is normally followed by a reason
WILCO	(Abbreviation for "will comply") "I understand your message and will comply with it."
WORDS TWICE	a) As a request: "Communication is difficult. Please send every word, or group of words twice." b) As information: "Since communication is difficult, every word, or group of words, in this message will be sent twice."

Table 16: Standard words and phrases

Aircraft call signs

An aircraft radiotelephony call sign shall be one of the following types:

Type	Example	Example abbreviated form
a) Character corresponding to the registration marking of the aircraft	**VTEJP or CESSNA VTEJP**	**VJP or CESSNA VJP**
b) The telephony designator of the aircraft operating agency, followed by the last four characters of the registration marking of the aircraft	**INDAIR TEPJ**	**INDAIR PJ**
c) The telephony designator of the aircraft operating agency, followed by the flight identification	**INDAIR 809**	No abbreviated form

Table 17: Aircraft call signs full and abbreviated

After satisfactory communication has been established, and provided that no confusion is likely to occur, aircraft call signs may be abbreviated as shown in table 17.

Establishment and condition of communications

When establishing communications, an aircraft should use the full call sign of both the aircraft and the ground station.

When a ground station wishes to broadcast information to all aircraft likely to receive it, the message should be prefaced by the call "All Stations".

No reply is expected to such general calls unless individual stations are subsequently called upon to acknowledge receipt.

If there is doubt that a message has been correctly received, a repetition of the message shall be requested either in full or in part.

If there is doubt that a message has been correctly received, a repetition of the message shall be requested either in full or in part.
The following phrases can be used:

- Say again means Repeat entire message
- Say again ... [item] means Repeat specific item
- Say again all before... (The first word message satisfactorily received) means repeat part of the message.
- Say again all after .... (The last word message satisfactorily received) means repeat part of the message.
- Say again all between.... And .... message means repeat part of the message

When a station is called but is uncertain of the identification of the calling station, the calling station should be requested to repeat its call sign until identification is established.

When an error is made in a transmission, the word "CORRECTION" shall be spoken, the last correct group or phase repeated and then the correct version transmitted.

If a correction can best be made by repeating the entire message, the operator shall use the phrase "CORRECTION I SAY AGAIN" before transmitting the message a second time.

When it is considered that reception is likely to be difficult, important elements of the message should be spoken twice.

Issue of clearance and read-back requirements

Controller should pass a clearance slowly and clearly since the pilot needs to write it down and wasteful repetition will thus be avoided. Whenever possible a route clearance should be passed to an aircraft before start up. In any case controllers should avoid passing clearance to a pilot engaged in complicated maneuvers and on no occasion should a clearance be passed when pilot is engaged in line up or take-off maneuvers.

An ATC route clearance is not an instruction to takeoff or enter an active runway. The words "TAKE OFF" are used only when an aircraft is cleared for takeoff, or when canceling a take-off clearance. At times the word "DEPARTURE" or "AIRBORNE" is used.

Read back requirements have been introduced in the interests of flight safety. The stringency of the read back requirement is directly related to the possible seriousness of a misunderstanding in the transmission and receipt of ATC clearances and instructions. Strict adherence to read back procedures ensures not only that the clearance has been received correctly but also that the clearance was transmitted as intended. It also serves as a check that the right aircraft, and only that aircraft, will take action on the clearance.

The flight crew shall read back to the air traffic controller safety-related parts of the clearances and instructions which are transmitted by voice. Following items shall always be read-back:

a) ATC route clearance;

b) Clearances and instructions to enter, land on, take off on, hold short of, cross taxi and back track on any runway; and

c) Runway-in-use, altimeter settings, SSR codes, level instructions, heading and speed instructions and, whether issued by the controller or contained in ATIS broadcasts, transition levels e.g. Air Traffic services: (aircraft call sign) "**SQUAWK THREE FOUR TWO FIVE**". Aircraft reply: "**SQUAWK THREE FOUR TWO FIVE**, (aircraft call sign)".

The controller shall listen to the read-back to ascertain that the clearances has been correctly acknowledged by the flight crew and shall take immediate action to correct any discrepancies revealed by the read-back.

Take-off procedures:

At busy aerodromes with separate GROUND & TOWER functions aircraft are usually transferred to TOWER at or approaching the holding position. Since misunderstandings in the granting and acknowledgement of take-off clearances can result in serious consequences, meticulous care should be taken to ensure that the phraseology employed during the taxi maneuvers cannot be interpreted as a take-off clearance.

To reduce the potential for misunderstanding, the take-off clearance shall include the designator of the departure runway when more than one runway is in use.

Except for reasons of safety no transmission shall be directed during take-off.
For traffic reasons it may be necessary for the aircraft to take-off immediately after lining up.

In poor visibility, the controller may request the pilot to report when airborne.

When a pilot abandons the take-off maneuvers, he should as soon as practicable, inform the control tower that he is doing so and assistance or taxi instructions should be requested, as required.

Final approach and landing

Except for reasons of safety no transmission shall be directed during the last part of the final approach or during the landing roll.
If and when turn on to final is made at a greater distance, "LONG FINAL" report is made. If the aircraft is making a straight-in-approach, a "LONG FINAL" report is made at about 8 NM from touchdown. If no landing clearance is received at that time, a "FINAL" report is made at 4NM from touchdown.
"FINAL" report is made when an aircraft turns onto final within 4NM from touchdown.

A pilot may request to fly past the control tower or other observation point for the purpose of visual inspection from the ground.

After landing

Unless absolutely necessary, controllers should not direct taxi instructions to pilots until the landing roll is completed. Unless otherwise advised pilots should remain on tower frequency until the runway is vacated.

Chapter 7: Navigation aids

Radio navigation encompasses the radio navigation facilities available for the navigation of aircraft during departure, en route and approach and the radar facilities used for the control of aircraft and for in flight safety.

The ground and airborne radars will continue to be an essential feature of aviation; however, it is intended in the medium term to replace all other radio navigation facilities with global navigation satellite systems.

The radio theory mentioned below are essential knowledge for the understanding of the reason why particular frequencies are used for particular radio navigation facilities and the advantages and limitations they impose. Central to this is understanding of the nature of electromagnetic radiation and knowledge of the frequency bands in the radio part of the electro-magnetic spectrum. Also essential is a knowledge and understanding of the different propagation modes used and available within the radio band.

Radio theory

1. Phase angel and the phase comparison can only be carried out between two radio waves at the same frequency, and that the measurement is made from the reference wave to the variable wave.

   To determine the phase difference diagrammatically, start from an easily identifiable point on the reference wave, in this case assume 0 phase and measure the change in phase angle of the reference wave between this point and the 0 phase point on the variable wave. The change in phase of the reference wave between the two points is 270°, so the phase difference is stated as 270°

2. The factors affecting propagation especially attenuation, reflection, refraction and the causes of fading.

3. Propagation: It should be noted that space wave exists at all frequencies and that in LF and MF both sky wave and ground wave exist, since the presence of all propagation modes affects the problems that arise with the systems operating in these frequency bands. An understanding of the properties of the ionosphere and its effect on the transit of radio waves is essential for both terrestrial and space based systems.

4. The two types of modulation (AM and FM) are relevant, when discussing bandwidth it should be noted that the specified bandwidth is at a specified power level and that outside the specified frequencies, power is still being radiated which can interfere with other transmissions. this is a factor in ILS, DME and SSR.

5. The knowledge of polar diagrams for various aerial types is fundamental to the use of ADF, VOR, ILS and radars.

Frequency band	Frequencies	Wavelength	Propagation Characteristics	Uses
Very Low Frequency (VLF)	3-30 KHz	100-10 Km	Ducting	No civil use
Low frequency (LF)	30-300 KHz	10-1 Km	Surface wave (Skywave)	ADF, DECCA, LORAN C
Medium Frequency (MF)	300-3000 KHz	1000-100 m	Surface wave (Skywave	ADF, Long range communications
High Frequency (HF)	3-30 MHz	100-10 m	Skywave (Surface Wave)	Long range communications
Very High Frequency (VHF)	30-300 MHz	10-1 m	Space Wave	Short range communications, VDF, VOR, ILS Localiser, Marker Beacons
Ultra High Frequency (UHF)	300-3000 MHz	100-10 cm	Space Wave	ILS Glideslope, DME, SSR, SATCOM, SATNAV, Long range radars
Super High Frequency (SHF)	3-30 GHz	10-1 cm	Space Wave	MLS, RAD ALT, AWR, Doppler radars, Short range radars
Extremely High Frequency (EHF)	30-300 GHz	10-1 mm	Space Wave	No civil use

Figure 18: Radio portion of the Electro Magnetic Spectrum

During VFR weather conditions, the flight is usually conducted by visual recognition of the object on the ground. Instrument rules are used when the visibility is inadequate during night or due to cloudy or foggy weather. During low visibility conditions the following air traffic control aids are always available to the pilot during the flight:

a) En route aids or airways aids

b) Landing aids

Radio navigation or radio navigation is the application of radio frequencies to determine a position on the Earth. Like radiolocation, it is a type of radio determination.

The basic principles are measurements from/to electric beacons, especially

a) Directions, e.g. by bearing, radio phases or interferometry,

b) Distances, e.g. ranging by measurement of travel times,

c) Partly also velocity, e.g. by means of radio Doppler shift.

7.1 ADF and NDB

The automatic direction finder (ADF), an airborne receiver with controls, antennas and indicator(s), operates in upper LF and lower MF band. In conjunction with ground based non-directional beacon (NDB) it continuously provides relative bearings on an indicator. The system is based on principle of bearing by loop direction finding (DF) which is also known as bearing by null method.

Advantage of use of frequencies between 190 kHz to 1750 kHz is to obtain higher ranges at lower levels. Coastal NDBs operating on these frequencies can also be used both by ships and aircraft. Based on their signal strength, the NDBs are used for navigation - along airways, for out to sea, terminal aid at airfields and locators for instrument landing system (ILS).

LOOP DF. If plane of vertical loop aerial is 90° to incoming radio waves, no signal is received or current induced, as both vertical members receive signal at same phase. But when plane of loop is along the path of radio waves maximum signal is received. Thus by turning the loop to a position of minimum (null) signal direction of beacon (transmitter) on ground can be determined.

Use of a single loop aerial suffers from directional ambiguity of 1800. That is, null may be to any direction and it's opposite. To distinguish this, a sense (Omni directional) aerial input is combined with signal of loop aerial and combined polar (field strength) diagram is in shape of cardiod, with single minimum. In modern equipment effect of a rotating loop is created electronically by two fixed loops placed 900 to each other.

The non directional radio beacon (NDB) is a ground-based radio transmitter that transmits radio energy in all directions. The ADF, when used with an NDB, determines the bearing from the aircraft to the transmitting station. The indicator may be mounted in a separate instrument in the aircraft panel. The ADF needle points to the NDB ground station to determine the relative bearing (RB) to the transmitting station. It is the number of degrees measured clockwise between the aircraft's heading and the direction from which the bearing is taken. The aircraft's magnetic heading (MH) is the direction the aircraft is pointed with respect to magnetic north. The magnetic bearing (MB) is the direction to or from a radio transmitting station measured relative to magnetic north.

NDB Components

The ground equipment, the NDB, transmits in the frequency range of 190 to 535 kHz. Most ADFs will also tune the AM broadcast band frequencies above the NDB band (550 to 1650 kHz). However, these frequencies are not approved for navigation because stations do not continuously identify themselves, and they are much more susceptible to sky wave propagation especially from dusk to dawn. NDB stations are capable of voice transmission and are often used for transmitting the automated weather observing system (AWOS). The aircraft must be in operational range of the NDB. Coverage depends on the strength of the transmitting station. Before relying on ADF indications, identify the station by listening to the Morse code identifier. NDB stations are usually two letters or an alpha-numeric combination.

Identification: ground stations must be positively identified by their Morse code. Long range coastal stations use keying break in transmission for this purpose, while most others are amplitude modulated (AM) transmissions. To hear the modulated code signal, a Beat Frequency Oscillator (BFO) is used in the airborne receiver. Position of this facility switch, sometimes referred as Tone is required to be properly selected on the control unit as under;

Emission Type	BFO Selection		
	Initial Tuning	Code Identification	Obtaining Bearing
NON A1A	ON	ON	OFF
NON A2A	ON	OFF	OFF
A2A	OFF	OFF	OFF

Table 19: BFO selection

ADF Components

The airborne equipment includes two antennas, a receiver, and the indicator instrument. The "sense" antenna (non-directional) receives signals with nearly equal efficiency from all directions. The "loop" antenna receives signals better from two directions (bidirectional). When the loop and sense antenna inputs are processed together in the ADF radio, the result is the ability to receive a radio signal well in all directions but one, thus resolving all directional ambiguity. The indicator instrument can be one of four kinds: fixed-card ADF, rotatable compass-card ADF, or radio magnetic indicator (RMI) with either one needle or dual needle. Fixed-card ADF (also known as the relative bearing indicator (RBI)) always indicates zero at the top of the instrument, with the needle indicating the RB to the station. Figure 7-3 indicates an RB of 135°; if the MH is 045°, the MB to the station is 180°. (MH + RB = MB to the station.)

ADF controls

After switching on the equipment, selecting the required frequency, fine tuning and identification should be done on ANT (antenna or receiver REC) position, with BFO position correctly selected. Bearing must only be monitored with function control on ADF position. Test position may be used to deflect the pointer on bearing indicator and check that it returns to correct and original indication on reselection to ADF.

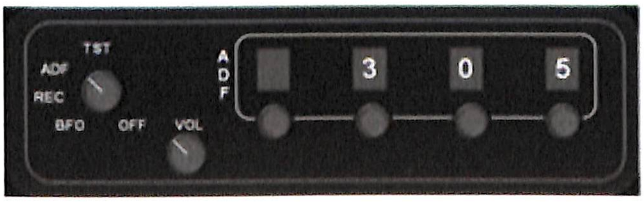


Figure 14: ADF controls

Indicators

A fixed card or radio compass indicator always shows relative bearings which are with fore and aft axis of the aircraft as datum. Therefore, it is called Relative Bearing Indicator (RBI) also.

Rotatable-Card ADF
On some indicators a knob (HDG) is provided to rotate the compass card of the indicator manually and set the present heading. When pilot manually sets the magnetic heading of the aircraft, then the indicator pointer shows homing to the station.

Radio Magnetic Indicator

On RMI the underlying dial moves in synchronization with magnetic heading that is always indicated against an index (shown in figure by the top triangle). As movement of the dial adds heading to the relative bearing, the ADF pointer always indicates the direction to the station - homing or QDM.

Generally RMI has two pointers, one each for ADF and VOR. If more than one ADF or VOR receiver is available then any particular combination of the nav aids for indication is possible.

Fixed card indicators

Moveable card indicator

Figure 15: ADF Indicators

Radio Magnetic Indicator

Homing and Tracking.

RBI or ADF Indicator

Direction to fly to the station - homing or QDM can be obtained by adding magnetic heading and relative bearing. Three illustrations are here.

Brg (M) to station = Hdg (M) + Brg (R)

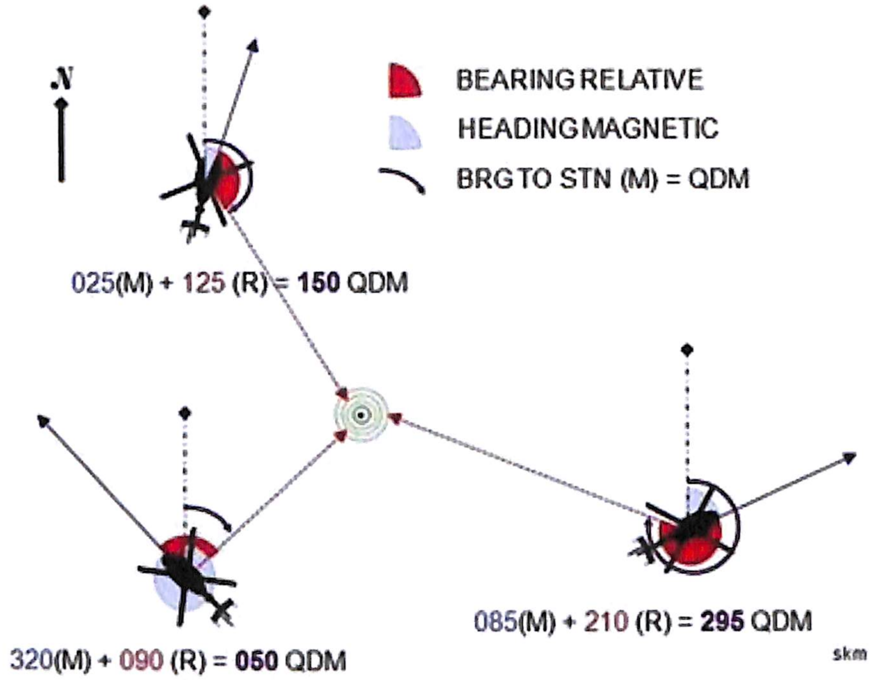


Figure 16: Calculating QDM

Homing to an NDB while flying in cross wind component condition and trying to keep ADF reading 000, results in continual change in heading and following a curved path to station. This is depicted in figure on the left. A better procedure is tracking to or out of a station. This is achieved by flying a heading with proper allowance for the drift and following a direct track to the station. Drift correction depends on wind velocity, TAS and required track of aircraft. This may be calculated by using navigation computers, or estimated from known information using pilot navigation thumb rules.

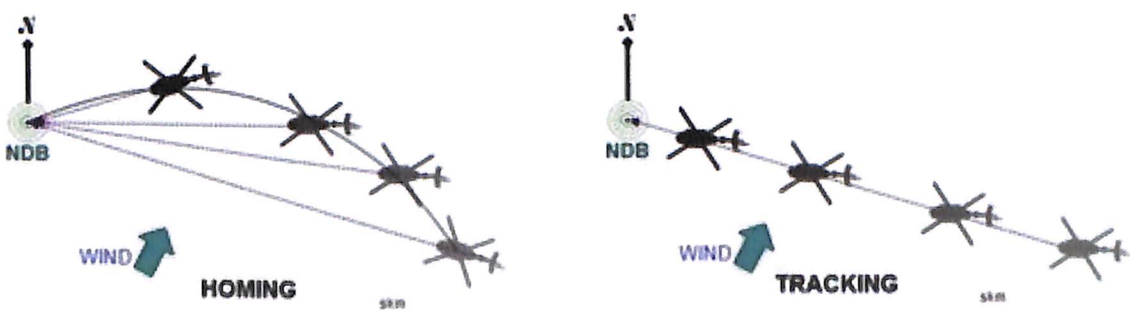


Figure 17: Homing and tracking

RMI and Rotatable-card ADF Indicator

Head of ADF pointer on RMI and on Rotatable-Card ADF, if heading has been set, will always indicate magnetic bearing to station (QDM). The tail end of this pointer shows the radial (QDR). Its interpretation is quite straight forward, and it is easy to visualize the relative orientation of aircraft with respect to the NDB.

Keeping on Track to station

When the aircraft is off the desired track, options are:

a) Fly direct to or from NDB on new radial or

b) Regain original track and maintain the same.

While flying to keep the aircraft on the radial, trend of ADF pointer is a useful cue. Simple method is to correct by flying double the error till the track is regained, and then turn half of the correction in opposite direction. As an example if RBI is indicating 010 that is position ten degrees to left, alter heading by 20 0 to right. Once on track - indicated now by ADF bearing 340 (R), change heading to left only by 10°, to make allowance for drift of 10° port.

If incorrect drift application has been made you will drift off to one side of the track. This will result in RBI and bearing to the station not remaining steady. With a constant heading being flown divergence from desired track will be seen by gradual change in relative bearing. Suppose a heading allowing for 15° S drift is being flown and the actual drift is less than that expected. Aircraft position will be slowly moving to the left of the required track to the station, and relative bearing will gradually increase. Appropriate correction either to fly direct to station or regain track based on distance to go should be carried out.

When uncertain of wind effect, best method is to fly initially track as heading that is, make no allowance for the drift. After a while, effect of wind will be obvious by deflection of ADF pointer to left or right. Carry out double the angle correction as explained above.

Tracking out from station

With no cross wind, flying the track as heading would be fine and ADF will remain steady on 1800. In cross wind conditions allowance for drift is required. A drift of 50 P and positioned on desired track the indication would be 175° on the ADF. It is easier to relate to tail end of pointer which would read 355° and show 5° left, when applied drift and actual drift are same. In case estimated drift is incorrect, track made good (TMG) and desired tracks would differs. A constant indication on RBI while keeping same heading does not confirm position on desired track. Sum of heading magnetic and ADF reading should equal the desired track.

Keeping track in crosswind

In case you are required to track out without the knowledge of drift, initially fly track as heading. After a while, the ADF needle will not remain constant and its tail end will indicate the side the aircraft is in relation to the desired track. Tail end reading 3450 means track error is 15° P. A turn 30° - double the error - to the right is required. Once on desired track, indicated by tail end of pointer showing same angle as the correction made, that is 330° (360 -30), turn in opposite direction and fly a heading with allowance for estimated drift.

Intercepting a track

Suppose you are on heading 350° and RMI indicates 070. It is required to intercept radial 270 (that is 090 track to the NDB). Magnetic bearing to NDB is 070. Imagine the aircraft position pointing in direction of the heading and at tail end of ADF pointer, and the NDB at centre of the dial. Visualize the aircraft along the desired track of 090 to the NDB as shown on grey dotted pointer in the figure. The required track with respect to present radial is ahead and a turn to the right will be required to reach station.

Angle to Intercept

Suitable heading to intercept is based on angle to intercept the desired track (or radial). While 90^0 intercept (heading 360 in the Example above) will make it earliest to intercept the required track, hardly any distance towards the station is covered. A shallower angle say 30^0 or 45^0 would close in faster, both to the track required and the NDB.

An intercept angle of double the track difference for smaller angles and distances may be used. Just short of the required track a turn equal to the intercept angle to left or right and allowance for drift would have to be made.

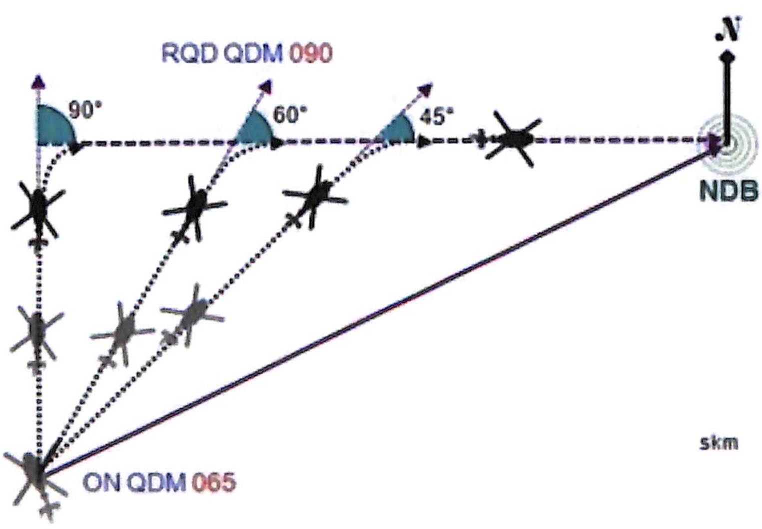


Figure 18: Angle to Intercept

Intercepting the radial using ADF Indicator

On ADF indicator (RBI) when tracking in, this would be indicated by pointer deflection equal to the intercept angle to right or left of 000. If tracking out same indication would be with reference to 180. Figure below illustrates this point. Inbound track is depicted on the left while the aircraft is on track 080 (radial 260) to NDB and flying 075 heading to allow for 5° S drift. To intercept the radial 285 (track 105) at 60° it alters heading to 045 (105 - 60). ADF pointer gradually starts falling from 030 to 060, as flight progresses. Just before reaching 060 a turn to right on heading 100 is made to follow the radial with 5° S drift.

On the right of the figure procedure to track out from on radial 100 when flying on the radial 070 is shown. The aircraft is flying 065 heading to allow for 5° S drift. Change in heading to 130 is made to intercept the radial 100 at 30°. ADF pointer reading 185 would read 120 when heading is just changed to 130 from original 065. Tail end of the pointer will rise from 300 to 330 as required radial is approached. Just before reaching the radial turn to left is made on heading 095 giving allowance for expected drift of 5° S.

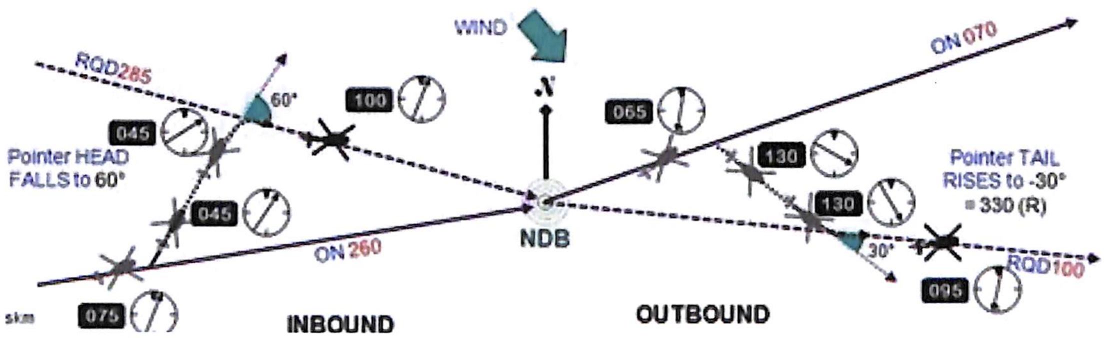


Figure 19: Intercepting the radial using ADF Indicator

Intercepting the radial using RMI

It is easier to use the RMI for tracking in or out. The pointer over the moving dial always shows the QDM (magnetic track to the station). Therefore, information on the current radial is readily available by reading the tail end of pointer. Figure below displays the same two cases that have been explained above using RBI. On the left in the figure below, a an aircraft is on the 260 radial and is required to intercept and track in on radial 285 (track 105). With a turn to the left on heading 045 and flying on this heading the QDMs gradually change from 080 to 105. Just before reaching the track right turn to follow the radial is initiated.

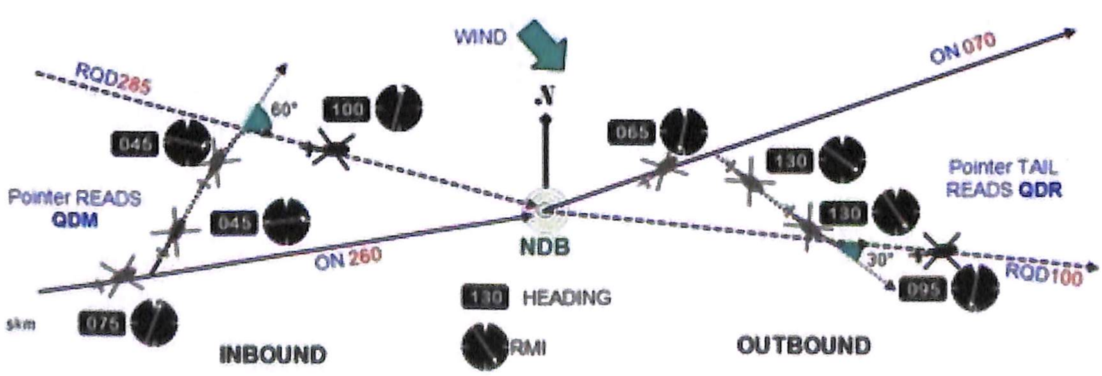


Figure 20: Intercepting the radial using RMI

On the right in the figure case of intercepting a specified radial and tracking out is shown. The aircraft is to track out on the radial 100 while presently is on 070. A turn on heading 130 is made to intercept at 30°. Radial indication, read off tail of the pointer change from 070 to 100. Final heading flown is with allowance for the drift as usual.

Errors and Limitations of ADF/ NDB

- Night effect
  Main path of radio waves from the NDB to the airborne ADF receiver is known as ground wave and is along the surface of the earth. At night Ionospheric changes take place and radio waves transmitted sky wards are refracted back to earth. The mixing of indirect sky wave and ground wave causes distortion of the polar diagram of loop aerial. As a result ADF needle wanders and no steady indications are available. The effect is most pronounced at dawn and dusk and long ranges as ground wave is attenuated. This effect is also known as Sky Wave Interference. Protected ranges published in AIP are not valid for night. Sometimes day and night ranges of NDB are separately given in Aeronautical publications, latter being less in range. Increased power of NDB does not reduce the night effect. Locator beacons with limited coverage are considered free of this effect.

- Coastal Refraction
  Radio waves passing the coastline at small angles suffer refraction due to different conducting and reflecting properties over land and sea. A false bearing indication is obtained at the aircraft flying over sea and taking bearings from NDB located over land. The effect is less for an NDB on coast than one inland and on a bearing 90° to coastline then at an oblique angle. Hence, given the choice use beacon at coast and rely on bearings perpendicular to the coastline.

- Static
  Considerable electrical disturbance is created by thunderstorms for attenuated NDB signals at long ranges. Lightening from the thunderstorms produces strong signals and cause the ADF pointer to swing from direction of NDB towards electrical storm. Totally incorrect indications may be obtained during such adverse weather conditions.

- Quadrantal Error
  NDB signals may reach the receiver aerial directly and also after being reflected by the aircrafts body. Due to electrical circuits and current flowing through them there is an electromagnetic field surrounding the aircraft, in general alignment with its body. This causes the incident radio waves to deflect near the ADF receiver aerial. The mixed signal affects the null position and the bearing indicated may be with large error. The maximum effect is at quadrantal relative bearings - 045,135, 225 and 315 relative to heading. Modern installations are compensated for this error.

- Terrain and Mountain effect
  Over mountainous regions and sandy deserts range of NDB signal is relatively lesser than that over the sea. Reliable range from an NDB located at shore may vary in directions. Reflection and diffraction of the radio waves in mountainous areas mixed with ground wave may cause fluctuations in signal. The bearings indicated may be in error or change rapidly over such regions. Use

of higher frequency in such cases may reduce the problem.

- Synchronous transmission or station interference
  If two NDBs operate at frequencies close to each other then the bearings obtained at the ADF would be in error. This is caused due to mixing of the radio signals, particularly at night with long range of undesired sky waves also being received on same frequency from a distant station. In such cases the NDBs with adjacent or same frequencies are geographically well separated in their location.

Accuracy and Range

Airborne equipment accuracy is to the order of ± 2° which combined with that of the system and NDB reduces to ± 5° within the protected range of the beacon. The factors affecting the range are:

- Sky wave interference or Night Effect reduces the reliable range to about 70 nm.

- Range is proportional to square root of the transmitter power. Therefore to double the range power should be increased by four times.

- Lower frequencies have lesser attenuation of the surface wave therefore give higher range.

- Type of emission also decides the maximum range because transmission power is used for modulation of the signal. N0N A1A has greatest and A2A the least range.

- Over sea and smooth surface range is more than over dry and sandy land as the attenuation is less in first case.

Uses of NDB

- **Airways**
  A bearing is a line passing through the station those points in a specific direction, such as 270 degrees (due West). NDB bearings provide a charted, consistent method for defining paths aircraft can fly. In this fashion, NDBs can, like VORs, define "airways" in the sky. Aircraft follow these pre-defined routes to complete a flight plan. Airways are numbered and standardized on charts; colored airways are used for low to medium frequency stations like the NDB and are charted in brown on sectional charts. Green and red airways are plotted east and west while amber and blue airways are plotted north and south. There is only one colored airway left in the continental United States. It is located off the coast of North Carolina and is called G13 or Green 13. Alaska is the only other state in the United States to make use of the colored airway systems. Pilots follow these routes by tracking radials across various navigation stations, and turning at some. While most airways in the United States are based on VORs, NDB airways are common elsewhere, especially in the developing world and in lightly populated areas of developed countries, like the Canadian Arctic, since they can have a long range and are much less expensive to operate than VORs.
  All standard airways are plotted on aeronautical charts, such as U.S. sectional charts, issued by the National Oceanographic and Atmospheric

Administration (NOAA).

- Fixes
NDBs have long been used by aircraft navigators, and previously mariners, to help obtain a fix of their geographic location on the surface of the Earth. Fixes are computed by extending lines through known navigational reference points until they intersect. For visual reference points, the angles of these lines can be determined by compass; the bearings of NDB radio signals are found using RDF equipment.
Plotting fixes in this manner allow crews to determine their position. This usage is important in situations where other navigational equipment, such as VORs with distance measuring equipment (DME), have failed. In marine navigation, NDBs may still be useful should GPS reception fail.

- Determining distance from an NDB station
To determine the distance in relation to an NDB station in nautical miles, the pilot uses this simple method:

  a) Turns the aircraft so that the station is directly off one of the wingtips.

  b) Flies that heading, timing how long it takes to cross a specific number of NDB bearings.

  c) Uses the formula: Time to station = 60 x number of minutes flown / degrees of bearing change

  d) Uses the flight computer to calculate the distance the aircraft is from the station; time * speed = distance.

- Apart from **Morse Code Identity** of either 400 Hz or 1020 Hz, the NDB may broadcast:
  - Automatic Terminal Information Service or **ATIS**
  - Automatic Weather Information Service, or **AWIS**, or, in an emergency i.e. Air-Ground-Air Communication failure, an Air Traffic Controller using a Press-To-Talk (PTT) function, may modulate the carrier with voice. The pilot uses their ADF receiver to hear instructions from the Tower.
  - Automated Weather Observation System or **AWOS**
  - Automated Surface Observation System or **ASOS**
  - Meteorological Information Broadcast or **VOLMET**
  - Transcribed Weather Broadcast or **TWEB**
  - **PIP** monitoring. If an NDB has a problem, e.g. lower than normal power output, failure of mains power or standby transmitter is in operation, the NDB may be programmed to transmit an extra 'PIP' (a Morse dot), to alert pilots and others that the beacon may be unreliable for navigation

- Instrument landing systems
NDBs are most commonly used as markers or "locators" for an instrument landing system (ILS) approach or standard approach. NDBs may designate the starting area for an ILS approach or a path to follow for a standard terminal arrival procedure, or STAR. In the United States, an NDB is often combined with the outer marker beacon in the ILS approach (called a locator outer marker, or LOM); in Canada, low-powered NDBs have replaced marker beacons entirely.

Marker beacons on ILS approaches are now being phased out worldwide with DME ranges used instead to delineate the different segments of the approach.

- NDB approaches
  A runway equipped with NDB or VOR (or both) as the only navigation aid is called a non-precision approach runway; if it is equipped with ILS it is called a precision approach runway.

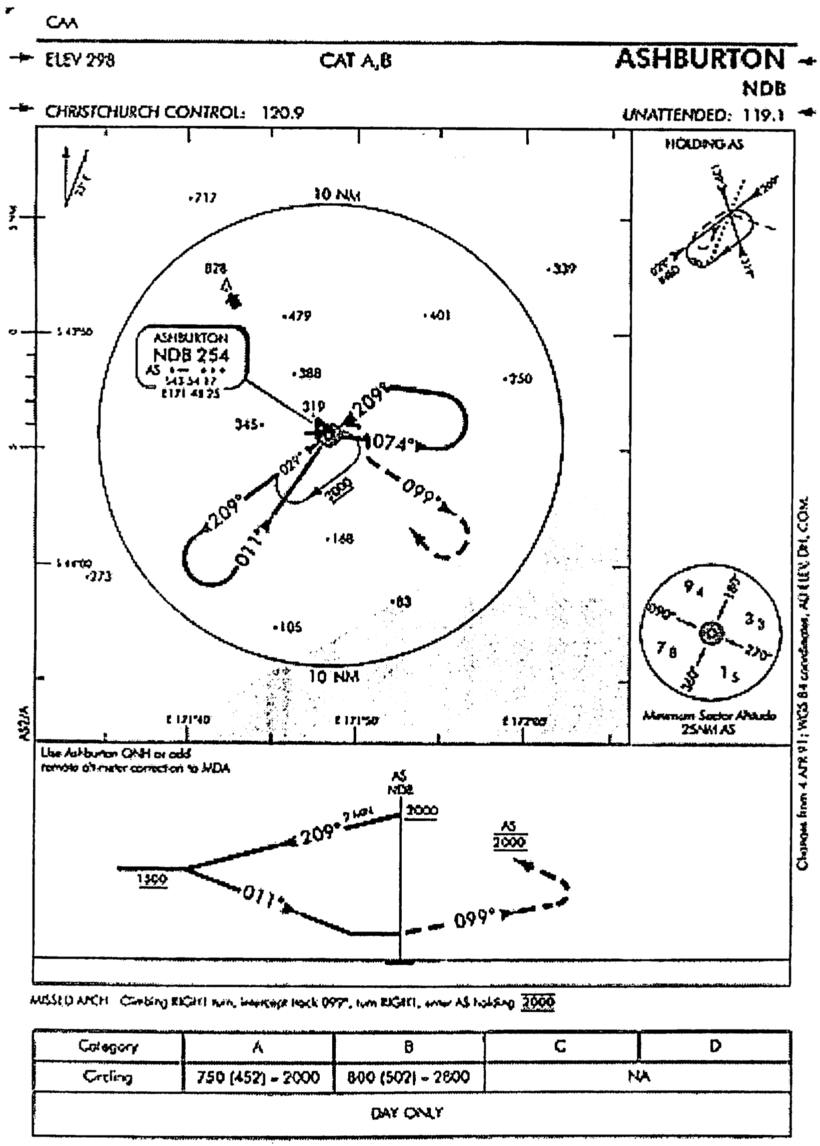


Figure 21: NDB approach plate

7.2 VOR

VHF Omni-directional Radio Range, popularly known as VOR, is a short range navigation aid operating in the VHF band of the radio spectrum. It is practically free from static and night effect therefore is a reliable navigational aid by day and night. It provides bearing information in form of radials (QDR) and QDMs (magnetic bearings to the station) throughout 360° of the ground transmitter.
Operating principle of VOR is bearing by phase comparison.

<u>Ground Equipment</u>

Transmitter

Out of 160 individual frequencies available between 108.0 and 117.95 MHz, ground beacon transmits two horizontally polarized separate radio signals on any one channel. One is Frequency Modulated signal at 30 Hz (shown in the figure by dotted curve) and is called the reference signal. Its phase is same in all directions at any instant. The second signal (shown as solid curve), is known as variable signal. It is produced by transmissions from a rotating loop at 30 rotations per second along with a non-directional transmitter. By virtue of rotation, a combined signal transmission at 30 Hz Amplitude Modulated is radiated. The transmission is such arranged that the phase difference between two signals in direction of magnetic north is zero and in all other directions equals the value of the radial. At the airborne receiver both signals are received and their phase difference, which corresponds to magnetic direction from the VOR station, is displayed on different indicators appropriately as magnetic bearing to or from the VOR station.

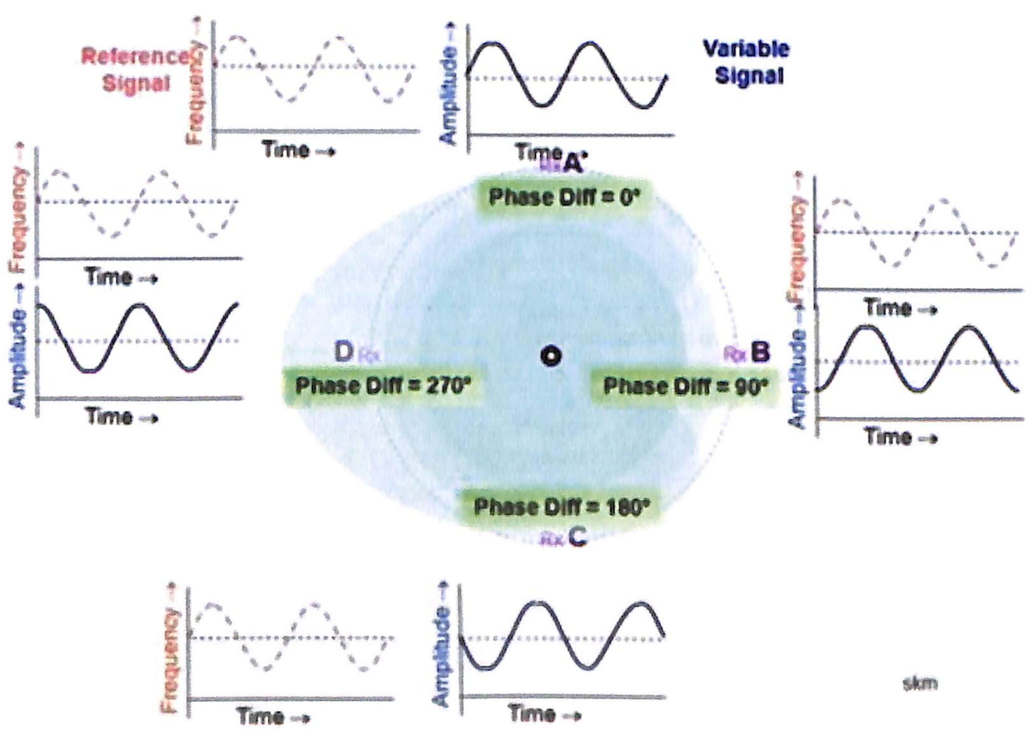


Figure 22: VOR Phase angle relationship

Station Identification

A Morse code amplitude modulated signal comprising normally three letters is transmitted every ten seconds for positive identification of the VOR by aircrew. Some VORs carry voice transmission also for automatic terminal information service (ATIS) and identification. Limited voice communication one way facility by ground control may also be available in event of communication failure on normal VHF. During maintenance a test signal or no identification may be received. Pilots using VOR must always positively identify the station before use and continue to monitor the same.

Cone of confusion

Ground transmitters radiate signals in elevation 60° to 80° above horizon. A gap over head in the form of an inverted cone is left with no or weak radiation. Flying through this region causes confusion in indications in the airborne equipment. Passing through this zone the indications flick rapidly. To determine precisely the overhead position is difficult but positive and stable indication thereafter confirm passage of the station.

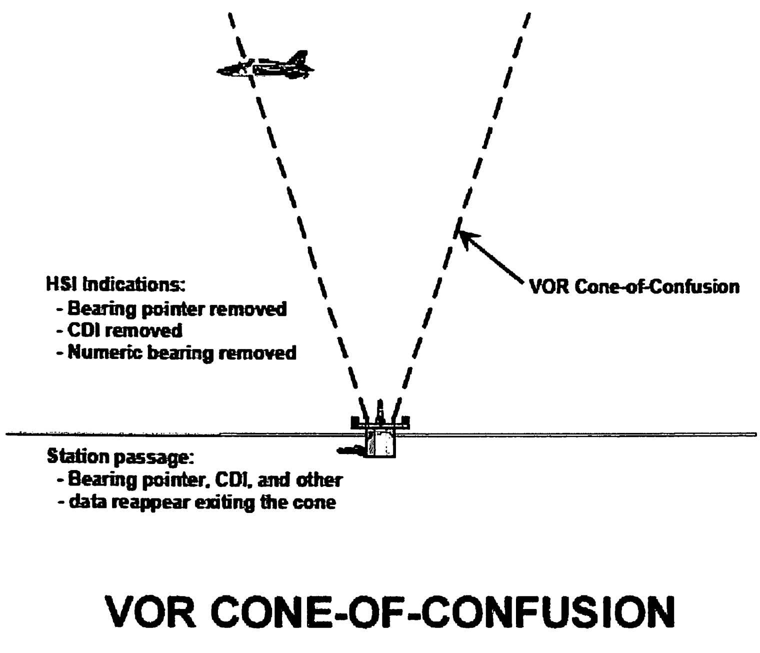


Figure 23: VOR Cone of Confusion

Monitoring

A monitor unit near the transmitter on ground is located within area of radiation of the VOR transmitter. The monitor continuously compares the received signal with specified parameters. In event of any of the following, the monitor switches off the VOR transmitter or withholds the identification and navigation signal transmission.

a) Received bearing is in error by more than 1°

b) Either of the signals - reference or variable fall below 15% in strength

c) Monitor itself fails.

A standby transmitter is provided to takeover in case of malfunction, but it takes some time to stabilize its transmission. Therefore, it is emphasized that pilots must listen for identification of the code for sake of safety

.

<u>Airborne Equipment</u>

Control Unit

Various types of control units are in use but with basic function of selection of VHF frequency for the VOR. Units with provision to select a standby frequency for immediate changeover to another station through a toggle switch are available. Some units have common selection panel and controls for the VHF communication and VOR. Two of these control units that are quite common are shown here.

Indicators

Many types of VOR cockpit displays are in use, however all are similar in operation and interpretation. Typical display is usually referred to as a VOR
indicator or Omni Bearing Indicator (OBI). Using the Omni bearing selector (OBS), a small knob, the pilot selects the radial (From) or track to (QDM) the VOR station. This selection may be indicated by rotation of the card against index marks and/or by counters displaying three digits as shown in the left diagram below. On other instruments, as shown on the right a pair of two triangles may move by turning OBS against a fixed 360° dial. A TO/ FROM indicator and Course Deviation Indicator (CDI) also form part of this display as illustrated in the figure. The CDI vertical bar moves to the left or right vertically over a dial. Sometimes it is pivoted on top and swings to the left or right for indication. Normally there are five dots on either side of the centre mark. As a caution about failure of equipment, no reception or malfunction and while equipment is off a red (or red and white) flag may appear.

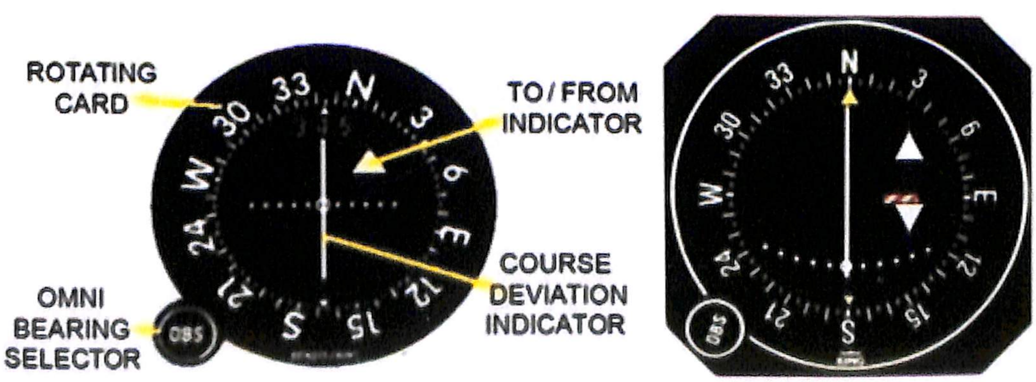


Figure 24: VOR Indicator

RMI

Another indicator where information on VOR bearings is available is Radio Magnetic Indicator (RMI), which has been discussed in notes on ADF. Against the index on top, a rotating dial displays the magnetic heading being flown. The pointer(s) always indicate magnetic bearing to the NDB or VOR. Based on number of ADF and VOR receivers available on board, selection can be made for indication of specific combination of ADF and VOR. The indicator shown on here can display information from one ADF and one VOR (on any of the two pointers), or two ADFs or two VORs.

Interpretation of VOR displays

CDI

The track selected by OBS controls the display of the CDI and TO/ FROM indicators in conjunction with aircraft's line of position in respect to VOR station. Note that VOR cockpit display is not heading sensitive. VOR indication in all three aircrafts on different headings as shown in the figure is the same. OBS has been selected to the inbound track of 240.

The CDI bar shows how far (angular error) the aircraft's position is from the selected track. Maximum scale defection corresponds to 10° or more, and each dot represents 2° of difference. On some indicators first dot may be indicated by a circle in the centre. A point to remember is if aircraft maintains position on a radial (or track), the VOR indication does not change with alteration in heading. In the figure the OBS selection is 045 and 225, but as the two aircraft positions are on radial 234 the indications in both cases is 4.5 dots (representing 9°) Fly Left with To and From displayed respectively.

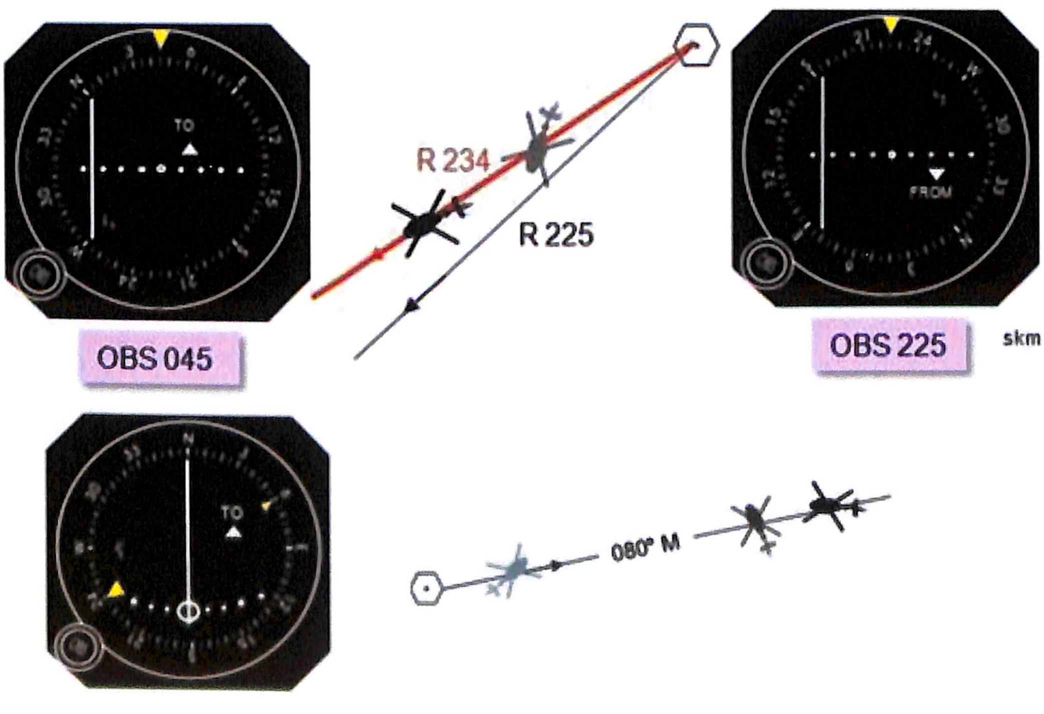


Figure 25: Interpretation of the CDI in a VOR display

Finding distance off track

When distance from the station is known (by DME or a position line) CDI dots indication can be used to determine nm off the required track using 'one in sixty' rule. If in the example above it is known that 4.5 dots deflection to left is at 45 nm from the station, distance off track would be from expression:

Deg = (Short side x 60)/ Long Side
Or 9°= (Off Dist x 60) / 45
Or Off Dist = (9 x 45)/60 = 7 nm

Determining CDI deflection and TO/FROM indication

As shown in the figure, with station at the centre there are four sectors combining TO/ FROM and CDI indications of Fly Left and Fly Right. The sectors are decided by the track selected by the OBS. No reliable indication of TO/ FROM is available within ±10° to the either side of the perpendicular to OBS track. A step by step method to visualize the VOR indication is;

a) Draw the OBS direction (240 in figure) through the station and mark direction of the track with (double) arrow.

b) Through the station draw a perpendicular and ±10° radials on either side.

c) Label 160° sector with track leading to VOR as TO and the other 160° as FROM.

d) Label 180° sector to the left of OBS (track) as FLY RIGHT and the other 180° sector to FLY LEFT.

e) Mark position of the aircraft as the radial or track based on available information.

f) Interpret the indication in terms of TO or FROM and CDI Fly Left or Fly Right and number of dots, when within 10° or less from OBS.

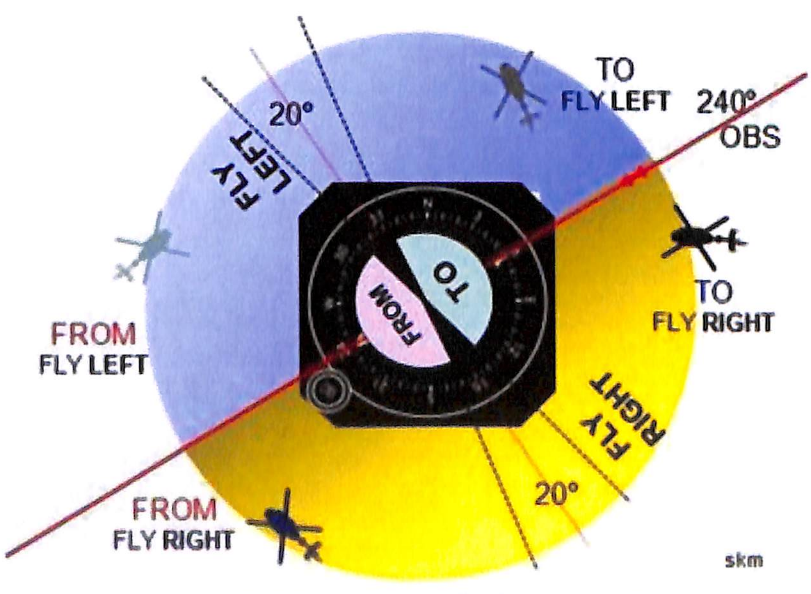


Figure 26: CDI deflection and TO/FROM indication

Orientation using CDI

To determine the radial of the aircraft in flight the pilot should

a) Rotate the OBS till CDI becomes central and

b) Note the TO/ FROM flag indication.

If the CDI is centralizes while OBS reading is 225 and To/From indication is From. Hence, radial is 225 and track to the VOR is 045. CDI would also be centralized with OBS at 045 but TO indication.

Therefore, it may be noted that if the indication is From, OBS reading is the radial else reciprocal of OBS is the radial.

Using two NAV AIDS to fix position

Position (radio-fix) of the aircraft in flight can be determined by intersection of two or more radio bearings. It must be remembered that for the fix to be reliable the two lines of positions must intersect at least at an angle of 45° and ideal angle is 90°. In absence of two VHF Nav systems onboard, quick retuning to second VOR station can be made. The figure here shows three different combinations of position fixing using two nav aids.

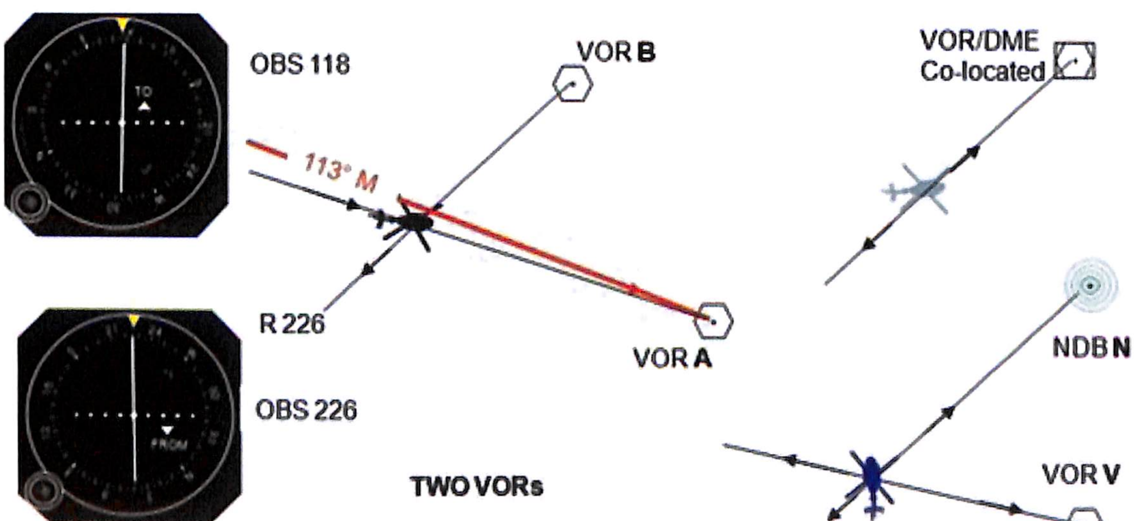


Figure 27: Using two NAV AIDS to fix position

Tuning and Orientation

To tune the VOR equipment, turn on the power switch, select the required frequency, and adjust the volume until the VOR beacon aural identification signal can be clearly heard and identified as the required beacon. Ensure that the OFF alarm flag has disappeared as this indicates that the visual indicators are serviceable. Now turn the Omni Bearing Selector (OBS) until the Deviation Indicator is centered and TO is shown by the TO/FROM indicator. The bearing then shown in the Bearing Selector Window is the magnetic bearing to the VOR beacon.

Homing Directly to the VOR Beacon

After orienting the aircraft as detailed above, turn the aircraft onto the magnetic heading shown in the Bearing Selector Window and then, changing heading as necessary, maintain the Deviation Indicator in the central position. With the TO/FROM Indicator showing TO, the aircraft heading should be changed toward the Deviation Indicator to re-centre it if it deviates from the central position as the Deviation Indicator shows the position of the Radial relative to the aircraft. If a cross-wind component exists, this will be indicated by the Deviation Indicator's moving to the side from which the wind is blowing. The drift angle is the difference between the aircraft heading necessary to maintain the Deviation Indicator in the central position, and the bearing being maintained. Continue flying with the Deviation Indicator central along the bearing towards the VOR beacon until the Deviation Indicator swings from side to side. The aircraft is now over the VOR beacon, and, if flight is continued on the same heading the Deviation Indicator will return to the central position and the TO/FROM indicator will show FROM.

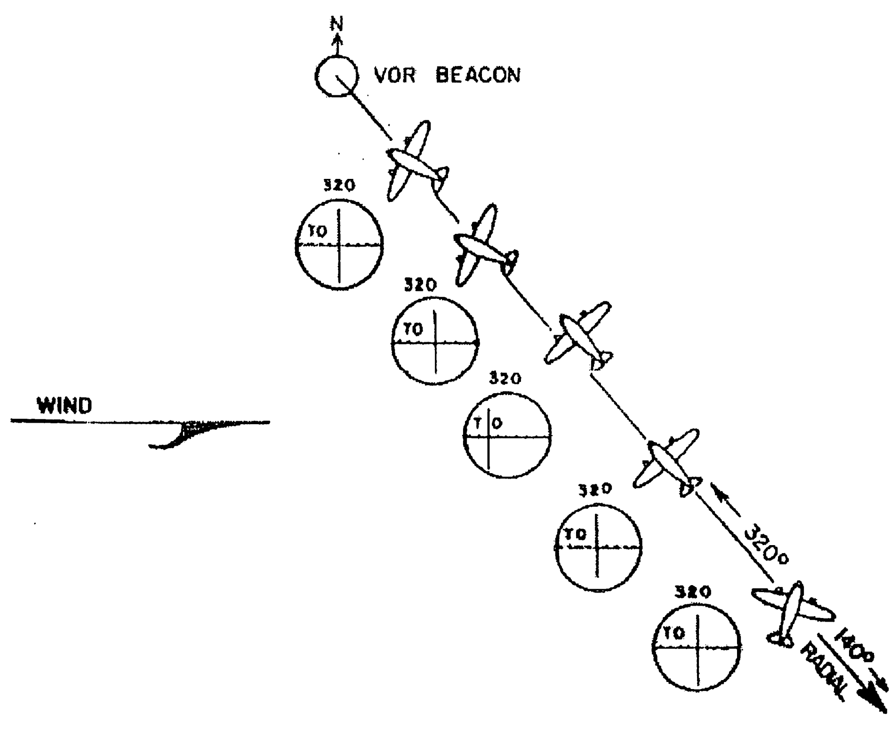


Figure 27: Homing Directly to the VOR Beacon

Interception of an Inbound Track

Tune and identify the required VOR beacon and orient the aircraft to ascertain the magnetic bearing of the aircraft to the beacon. Then rotate the OBS until the required inbound track is shown in the Bearing Selector Window. The TO indicator should then be visible (If FROM appears, either the wrong track has been set or the aircraft is on the other side of, or has passed the beacon—see Interception of an Outbound Track). The aircraft should then be turned in the direction of the Deviation Indicator on to a suitable intercept heading, which is determined from the position of the aircraft as visualized from the information available from the orientation. Closure of the required track is shown by the Deviation Indicator moving towards the central position, and when this occurs, the aircraft should be turned onto the same heading as the required inbound track (see Figure 29). The track should be maintained as described in Homing Directly to the VOR Beacon.

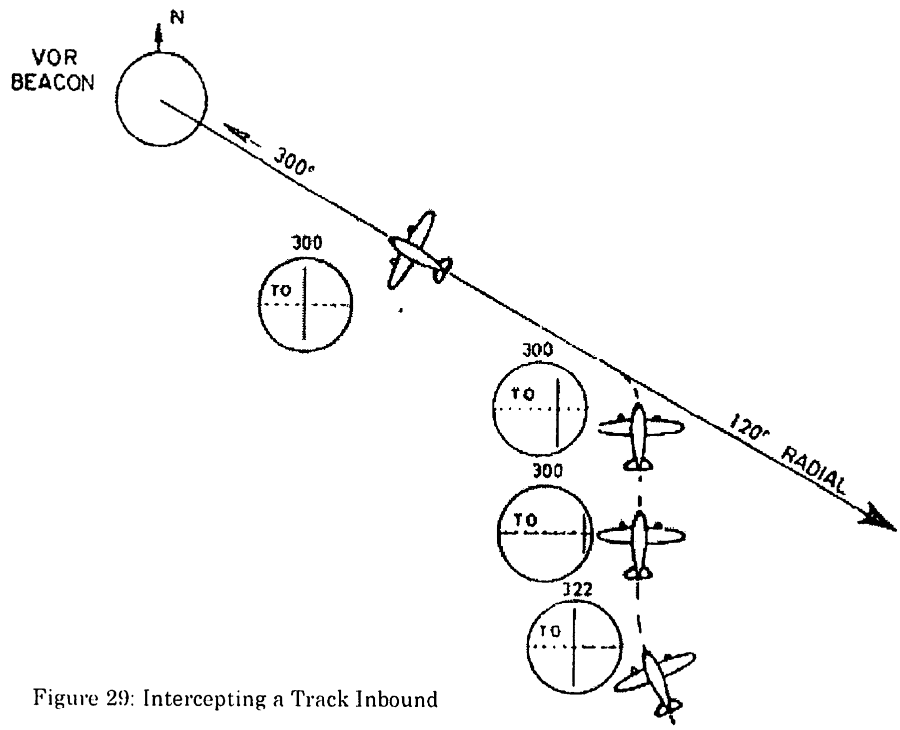


Figure 29: Intercepting a Track Inbound

Interception of an Outbound Track

The procedure for intercepting an outbound track differs from the procedure for intercepting an inbound track only in that FROM rather than TO appears in the TO/FROM Window (see Figure 30).

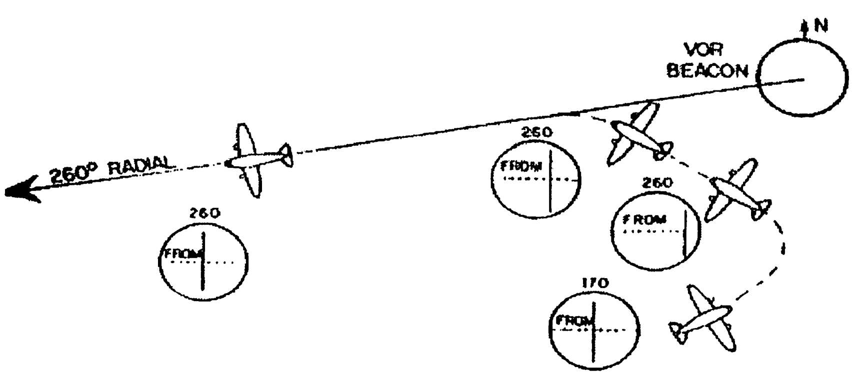


Figure 30: Interception of an outbound track

Range and Accuracy

Range

En route VORs transmitting with a power output of about 200 Watt may be received at ranges around 200nm. Terminal VORs (TVOR) generally radiating at 50 watt have for less range. VOR transmissions being VHF, height of receiver and transmitter decide the expected range, which is given by expression;

Distance (nm) = $1.25 (\sqrt{Tx} + \sqrt{Rx})$
Where Tx and Rx are respective height of transmitter and receiver in feet.

Line of sight range of a transmitter located at sea level and the aircraft at 5,000 feet would be about 88 nm and that at 10,000 feet about 125 nm. DOC (Declared Operational Coverage) is generally less than these figures.

Accuracy

Transmission accuracy is less than ± 3° but with all errors combined including airborne equipment will be within ± 5°

Types of VOR stations

Doppler VOR

DVOR has reduced site error and is based on Doppler principle for signal emission. The variable signal is frequency modulated and reference signal is amplitude modulated - just opposite of conventional VOR. No change in the airborne equipment is required as radiation on ground is made to rotate in the opposite direction.

Test VOR (VOT)

Transmitter installed for testing the airborne equipment during pre-flight checks. On tuning the frequency and centralizing CDI the reading should be within ±4° of 000° FROM or 180° TO, anywhere on the aerodrome. This is not to be used for any navigational information.

TVOR

Terminal VOR are low powered transmitters usually located at major aerodromes for arrival and departure navigation.

BVOR

Weather Broadcast VOR transmits in voice weather information of selected aerodromes in between the identification signals.

VORTAC

A co-located VOR and TACAN (military nav aid combing bearing and distance information compatible to civil DME), that can be used by civil aircraft as VOR/DME combination.

DB VORTAC

A weather broadcasting Doppler VOR co-located with a TACAN

PVOR

A precision VOR.

Errors and Limitations

BEACON ALIGNMENT or GROUND STATION ERROR

Signal accuracy can be affected by error in the generation of the signal and alignment of 360 radial with local magnetic north. Regular calibration of ground equipment and alignment of signals are carried out with changes in local variation.

SITE ERRORS

Physical obstacles, terrain, even over grown grass around the transmitter site affect directional propagation of VOR signals. The sites around transmitters are maintained and accuracies monitored to limit error within ± 1°.

PROPAGATION ERROR

Signals arriving at the aircraft can be distorted by spurious signals that have been reflected by uneven terrain or obstructions during propagation. Mixed signals received at airborne equipment cause error in display. When this causes oscillations in indications it is called scalloping.

AIRBORNE EQUIPEMENT ERROR

Manufacturing inaccuracies and imperfections in the airborne equipment produce small differences between the detected bearing and its display on the instrument. The equipment should be periodically checked and error contained within ± 2°.

PILOTAGE ERROR

Although this is not an equipment or system error, while calculating the total accuracy of VOR signal the difficulty of holding the radial by pilot is also taken in account.

Total effect all factors causing errors is combined and called Aggregate Error of the VOR. Although a variable value, generally it is taken to be ± 5°, which is acceptable for IFR and non-precision approaches.

Uses of VOR

a) Marking the BEGINNING, the END and CENTERLINE of airways. In short word, VOR guide an aircraft from point A to point B.
b) As a holding point for aircraft
c) As a source of en-route navigational position lines.
d) Position fix using two VOR's
e) As a let-down aid at airport based on procedures.(VOR based Non precision Approaches)

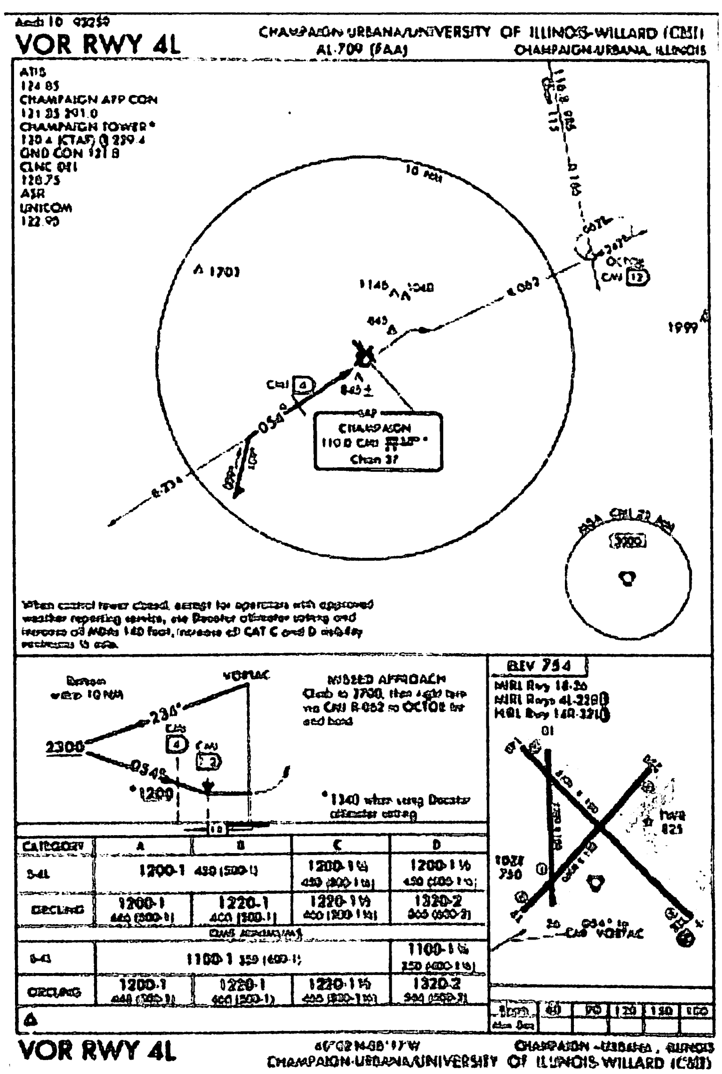


Figure 31: VOR Approach plates

7.3 DME

Distance Measuring Equipment operates on principle of secondary radar. A ground beacon continuously responds to trigger pulses received from airborne interrogators. Airborne equipment receives all responses, determines the ones related to its transmissions and finds time duration between firing of interrogation pulses and corresponding reply pulses. This duration is displayed as slant (direct) range at the airborne equipment as distance from the ground station.

Principle of operation

Basic principle of operation of DME is Range by pulse technique. Airborne equipment transmits pulse pairs in all directions on the receiver frequency of the ground transponder station. Ground station, activated by the interrogation pulses, transmits pulse pairs in all directions on the receiver frequency of the airborne equipment. At the airborne equipment, time interval between transmission of interrogation pulses and reception of reply pulses is determined. It is converted to range in nautical miles and displayed on the indicator.

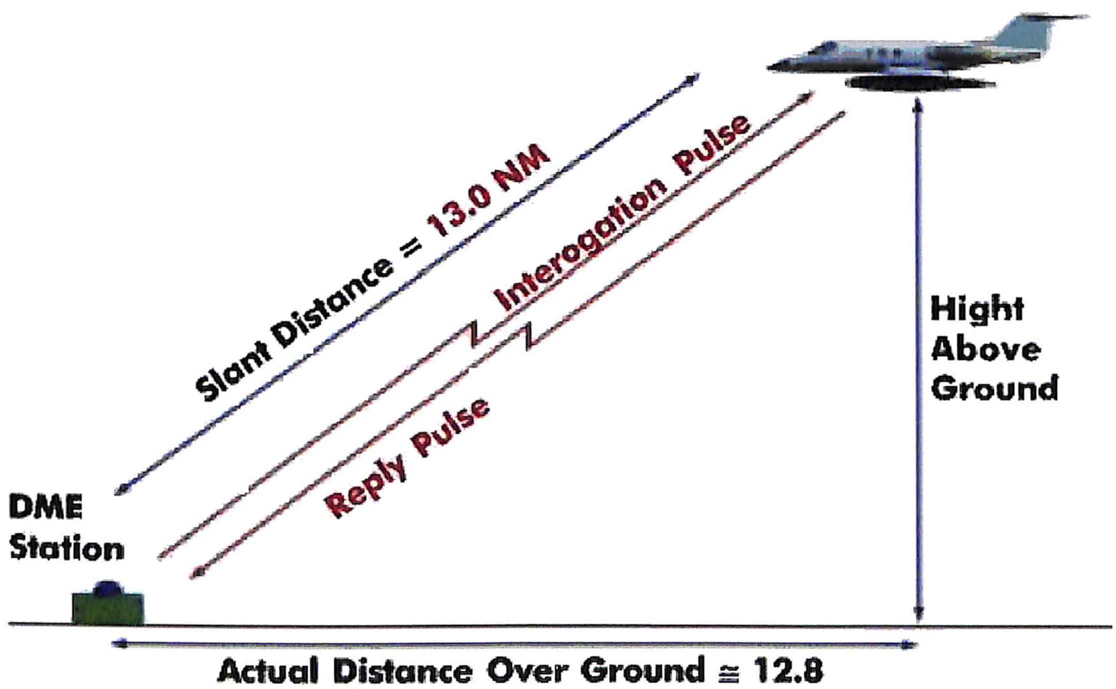


Figure 32: DME operation

Equipment

Ground transmitter beacons of DME are co-located with VOR and ILS equipment at all major aerodromes and en route reporting points. The system operates on frequencies between 960 MHz and 1215 MHz on the UHF band. Therefore, it can provide line of sight range as in the case of VOR. Each ground station transmits its unique aural Morse code identification signal comprising three letters.

Single DME ground station can respond to a maximum of 100 airplanes at one time before reaching saturation. Jittering (randomly changing) the airborne equipment's pulse repetition rate, ensures that it rejects the responses meant for other airplanes.

There are 126 channels available for civil use. Each channel using a unique paired set of airborne and ground beacon frequencies. The pairing has been formulated by ICAO and used as such throughout the world. Pilots need not know the exact frequency details, since the combination is automatically selected by his selection of a VHF frequency associated with either a VOR or ILS localizer transmitter. DME airborne equipment can also be used with military TACAN (tactical air navigation) system for range information. This system is not available in India.

VOR/ DME Pairing

When co-located, although operating on the different frequencies - VOR on VHF and DME on UHF, both navigational aids have same Morse code identification. However, the higher pitched one and with longer inter-spread is for the DME, which is heard twice in a minute. Between the DME identifications, two or three identifications of VOR may be received. In case only one of them is heard, the pilot can discern from the pitch and number of times the identification is heard in a minute, which of the transmitters is operating.

ILS/ DME Pairing

Now most localizers (track guidance component of ILS system) are paired with a DME located very close to landing threshold of the runway. This provides accurate and continuous distance information during an instrument approach to land. The identification Morse code in such cases generally consists of four letters - usual there, prefixed by an 'I'. Examples for Delhi and Mumbai are: IPLM, IDLH, IDGM, IDMR, IDEL, ISCZ, IBBY, IBOM. Many ILS instrument approach procedures commence with flying a constant distance arc based on DME.

DME controls and indicators

Typical equipment consists of a combined control unit and an indicator. The indicator displays distance in nm along with speed and time to fly to the beacon. The DME frequencies on this control unit can be locally selected by combination of two concentric knobs and associatedbuttons. Selection of paired VOR or ILS frequency by the pilot on the control unit automatically selects the paired UHF frequencies of the DME. Remote selection at VHF-Nav set also is provided, which makes quick changeover possible between two stations. When a steady distance value is obtained and displayed, DME is said to have a lock on. Initially, while the interrogator is searching for the range and if the signal is reduced below acceptable level, the indicator displays dashes in place of the readings as shown in the figure. If signals are lost for a short duration of few seconds, with memory circuit equipment continues to display changes in the respective values based on the latest rate of change computed and stored.

The indicator displays the groundspeed as rate of closure of the aircraft with the ground station based on rate of change in the DME range. If the aircraft is either tracking in or out of the beacon this would be same as the ground speed - very useful information for pilot navigation. Some indicators also display time to station in minutes considering the closure rate as ground speed. It must be remembered that indications, both the ground speed and the time to the station will be in error if the aircraft is not tracking in or out of DME station.

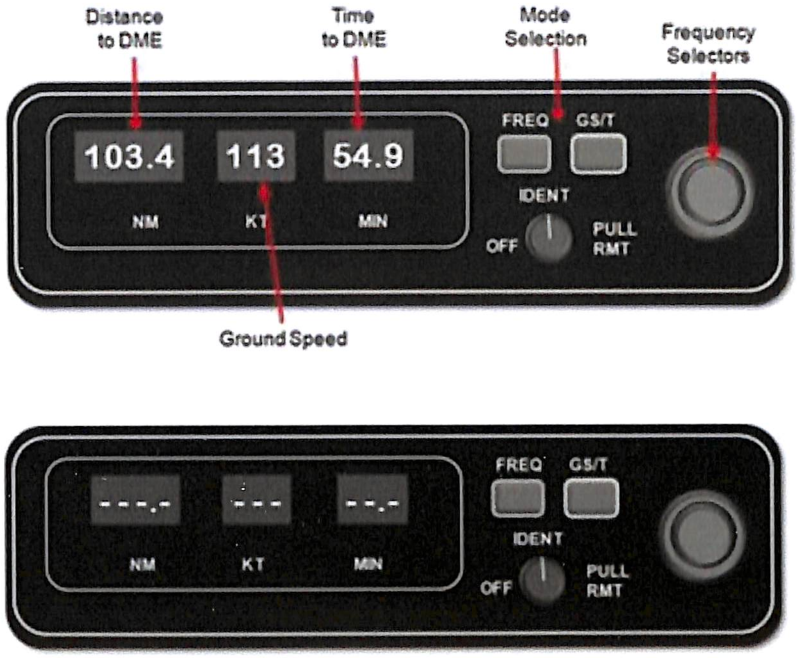


Figure 33: DME controls

Slant vs Ground Range

It is pertinent to note, flying overhead DME station will not indicate zero range, but the height above ground as the distance to beacon. As a thumb rule, the error is insignificant, if slant range is 1nm/ 1000 feet of height above ground. That is to say at 5000 feet agl beyond 5 nm, the difference in the two ranges is negligible.

An ILS paired DME is designed to provides precise ground ranges along the runway centre line from the touchdown. It means that distances provided in other directions from such a DME are in slight error.

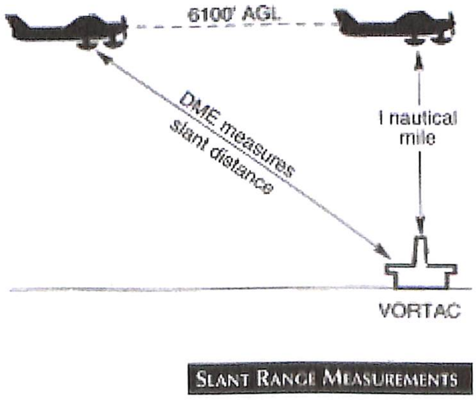


Figure 34: Slant range

Chart depiction of DME station

Some examples of different ways the DME is portrayed on Jeppesen charts are illustrated here.

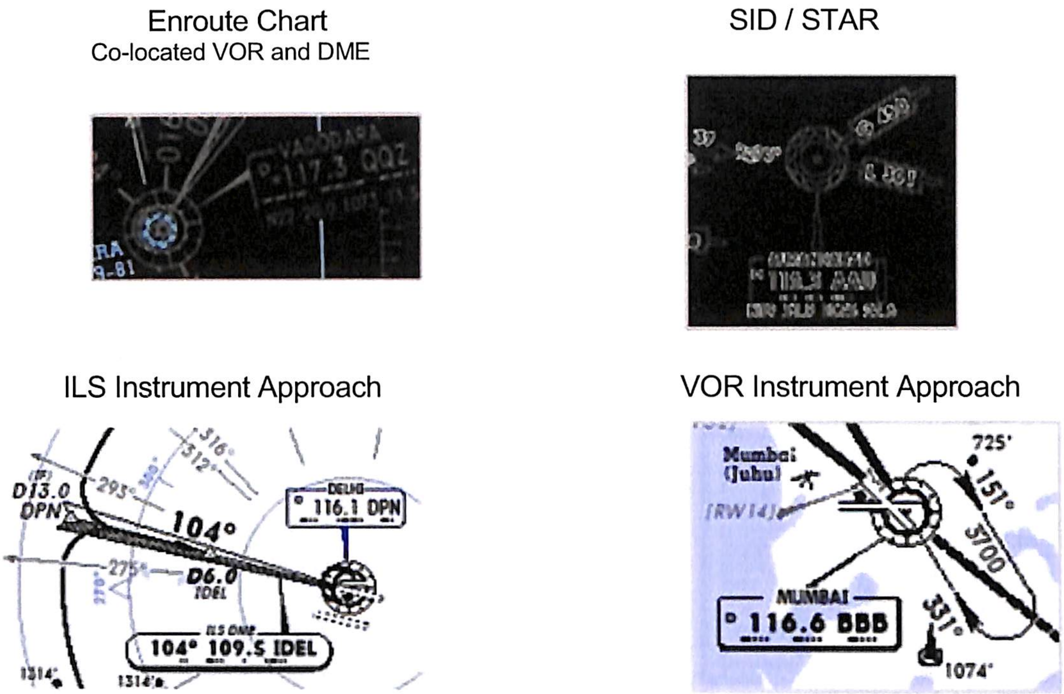


Figure 35: Chart depiction of DME station

Notice small 'D' in navaid facility boxes prefix to frequency and identification indicates co-located DME. On ILS Instrument Approach Chart four letter identification of paired ILS DME can be noticed.

Use of DME Range

DME ground speed

As stated, some indicators show closure rate to the station. In event of the aircraft tracking in or out of the station, this rate is the ground speed itself. In absence of a ground speed read out, while tracking in or out of DME station, the ground speed can be found by a simple calculation using distance and time.

Example

At 1007 DME range is 27.0 nm. At 1013 it increases to 36.5 nm and the aircraft is tracking out.

Ground speed = (9.5 nm / 6 min) x 60 min = 95 kts.

Indications over DME

In case the aircraft is flying directly to DME, its position overhead DME is indicated by rapid decrease in distance up to its height in nm or by a dropout of the indications. If not tracking to or away from a DME station, the closure rate will decrease gradually and read zero, when the aircraft reaches an abeam position. At this point the distance indicated will be minimum. If continued, closure rate would increase with increasing distance.

Fixing position with DME

The DME range is a circular position line with the station as its centre and the range as the radius. Combining it with another suitable position line a radio fix can be obtained. Co-located VOR/DME always provides the best angle of cut of 90° and therefore a good fix. Accuracy of fix may be degraded if another VOR or NDB is used for the second position line. Angle of cut less than 45° or using two DME, either side of track, would result in a radio fix with doubtful accuracy.

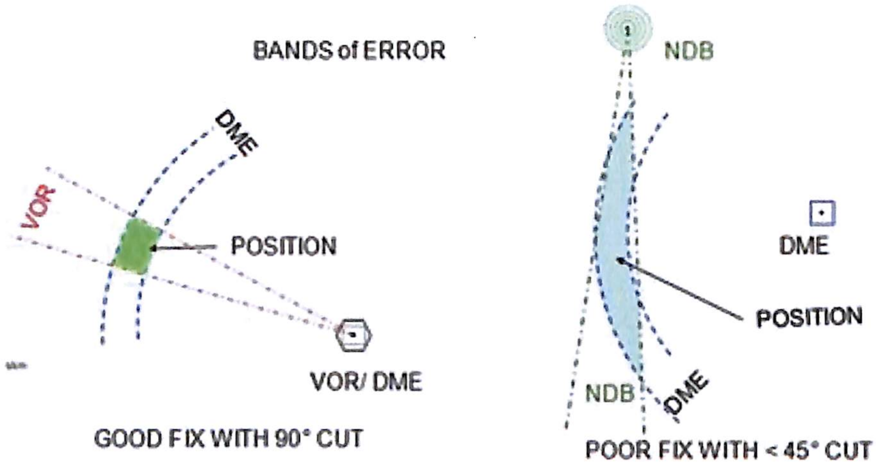


Figure 36: Fixing position with DME

DME Homing

As a last option for homing and in absence of bearing information, once at abeam position the pilot can turn 90° towards station, and notice the distance readings reducing. In case, after turn the distance starts increasing the turn has been made on to the wrong side.

Track keeping

If DME is located to one side of the track, abeam position thus determined can be gainfully used to establish the aircraft's ground position with respect to required track. Distance found to be less than the planned one indicates the position off track and towards the side the station is located and vice versa.

Example: On a planned route, DME beacon XRY is 27 nm port of track. In flight DME observations of XRY decreased up to 30 nm and then increased. What is the aircraft's position with respect to track?

Abeam position is at 30 nm, that 3 nm off track.

DME is to the felt, hence the aircrafts is 3 nm starboard of track.

DME as an Instrument Approach Aid

A relatively recent introduction for many Approach Procedures is the DME Arc. The DME is used, in a sense, as a tracking device. By following a fixed distance from a DME, the aircraft ends up flying an arc centered on the DME itself.

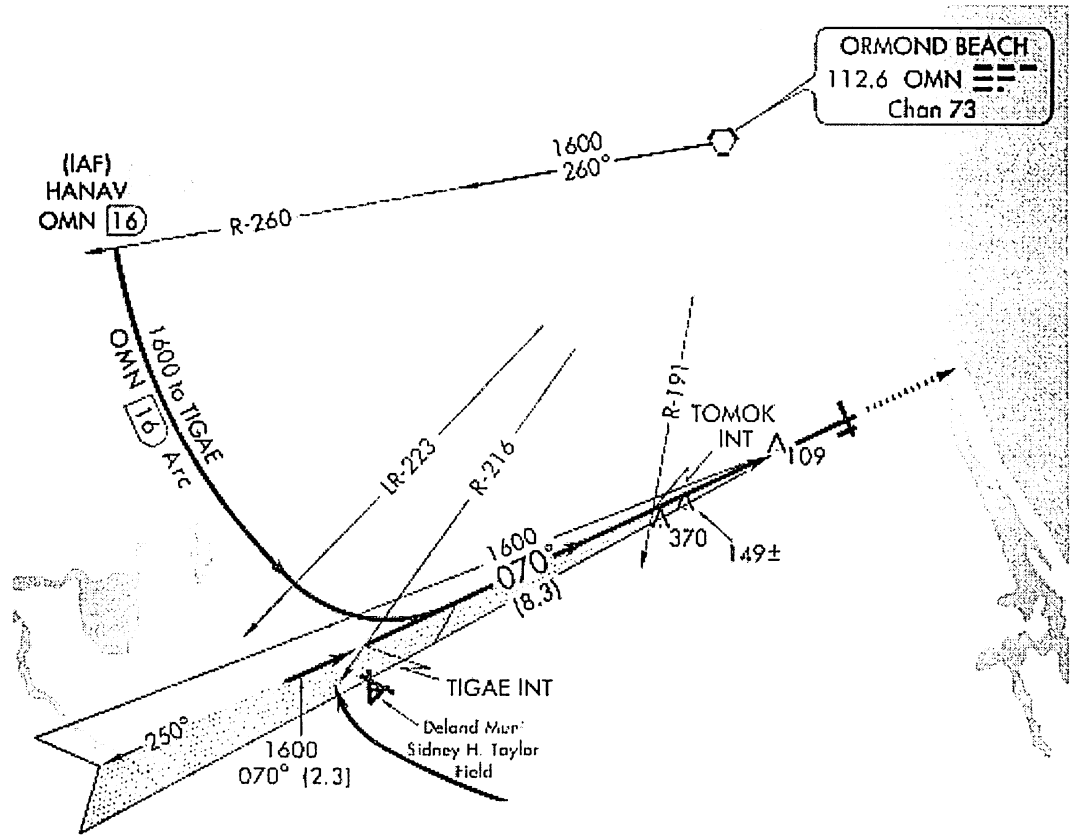


Figure 37: DME arc Instrument approach aid

DME Range and rated coverage

Operating at UHF, maximum range expected are optical range that can be calculated by the formula given in notes for VOR. However rated coverage specified in aeronautical publication may be less than the calculated values. These may have taken terrain shielding and other preparation factors in consideration.

Accuracy

DME is most accurate nav aid amongst the ones providing bearing or distance for route navigation. Its accuracy is ± 0.5 nm, or 3% of the indicated distance if greater. That means up to 17 nm the error is within half a nm and beyond ±3% of the distance.

DME Errors

A DME/DME fix (a location based on two DME lines of position from two DME stations) provides a more accurate aircraft location than using a VOR and a DME fix.

DME signals are line-of-sight; the mileage readout is the straight line distance from the aircraft to the DME ground facility and is commonly referred to as slant range distance.

Slant range refers to the distance from the aircraft's antenna to the ground station (A line at an angle to the ground transmitter. GPS systems provide distance as the horizontal measurement from the WP to the aircraft. Therefore, at 3,000 feet and 0.5 miles the DME (slant range) would read 0.6 NM while the GPS distance would show the actual horizontal distance of .5 DME. This error is smallest at low altitudes and/or at long ranges. It is greatest when the aircraft is closer to the facility, at which time the DME receiver will display altitude (in NM) above the facility. Slant range error is negligible if the aircraft is one mile or more from the ground facility for each 1,000 feet of altitude above the elevation of the facility.

7.3 ILS

Instrument Landing System (ILS) assists a pilot to fly along a precise path, defined in three dimensions, during approach to land on a specific runway using radio guidance signals transmitted by ground equipment.
It is a precision approach

ILS works on basic principle of bearing by lobe comparison.

A typical ILS has following components:

- **Localizer**: - It provides Azimuthal guidance along extended centre line of runway. A vertical equi-signal reference plane produced by two lobes (directional beams) transmitting on either side of the runway centerline with an overlap.

- **Glide slope**: - Guidance to touch down zone in elevation is provided by two overlapping lobes producing on inclined plane of equi-signal.

- **Marker beacons**: - Accurate distance along the approach path from the runway over two points - outer and middle markers generally - is provided by respective beacons during an approach to land. Low powered NDB -compass locator may be co-located for tacking in/ out of marker. A DME transmitter may be associated with localizer to render the marker redundant.

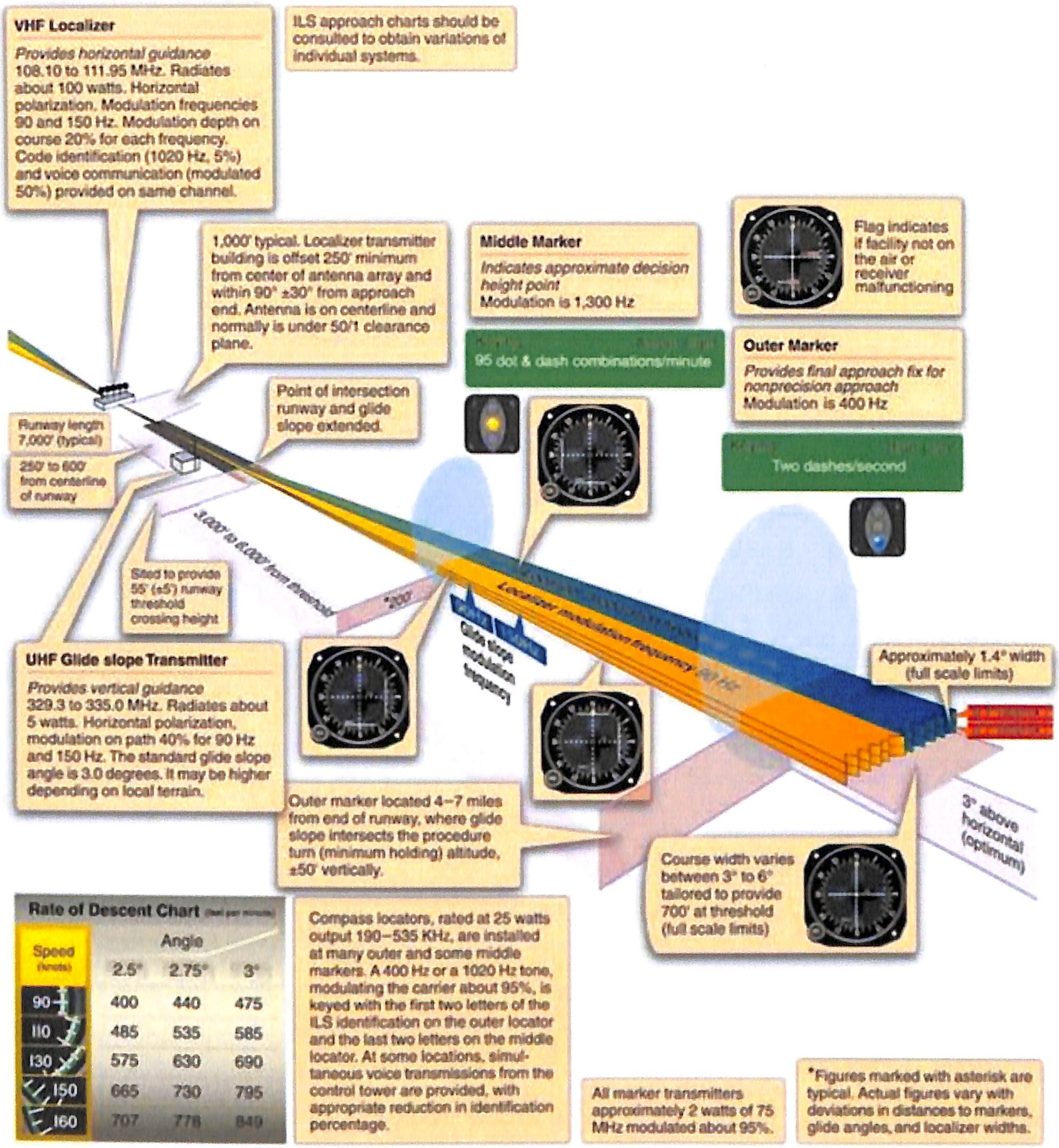
- **Lighting system**: - Runway approach lights, touch downzone, and other lights providing visual reference for landing may also be associated with ILS functioning.

The following supplementary elements, though not specific components of the system, may be incorporated to increase safety and utility:

- Compass locators: - Provides transition from en route NAVAIDs to the ILS system and assisting in holding procedures, tracking the localizer course, identifying the marker beacon sites, and providing a FAF for ADF approaches.

- DME:- When collocated with the GS transmitter providing positive distance-to-touchdown information or DME associated with another nearby facility (VOR or stand- alone), if specified in the approach procedure.

ILS approaches are categorized into three different types of approaches based on the equipment at the airport and the experience level of the pilot.



Speed	Angle 2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Figure 38: Instrument landing system

Ground Equipment

Localizer

A VHF transmitter emitting highly directional lobes is located typically 1,000ft (300 meters) beyond the stopping end of the runway. The two lobes are amplitude modulated; the one to the right at 150 Hz and the other to the left at 90Hz on one of the carrier frequency between 108.10 MHz and 111.95 MHz. As even decimal frequencies in this range are used for the VOR, only odd frequencies are for the localizer. Thus there are 40 channels available for ILS localizer.

The transmission is so arranged that along the extended centre line and in the vertical plane, the depth of signal from both lobes is equal. The CDI deflection of the airborne indicator is controlled by the difference in depth of modulation between two lobes at the position of receiver. Therefore, along the centerline, CDI remains central. When the aircraft is off the centre line the CDI deflects to show the sector (but not the direction) pilot should turn to be on centerline.

The carrier wave also carries amplitude modulated (A2A) ILS identification as three or four letters in Morse code and voice transmission of airfield information. In event of an emergency ATC may also pass instructions. Some localizers may transmit an identical signal in the take off direction also, which is known as back beam and may be used for limited guidance.

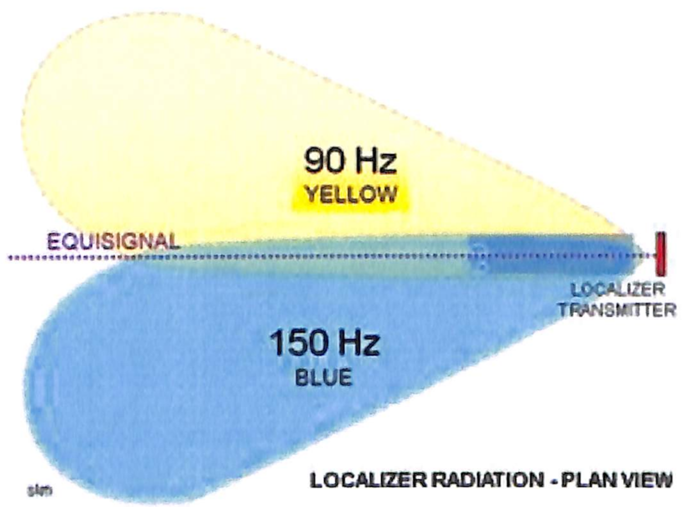


Figure 39: Localizer radiation- Plan view

Glide Path

The transmission of the lobes for vertical guidance is in UHF band between frequencies 329.30 and 335.0 MHz with 150 KHz spacing, providing 40 channels. With standard pairing of glide slope and localizer frequencies, pilots need to select only the VHF localizer frequency. Paired glideslope UHF frequency is automatically tuned at the receiver. The radiation is arranged such that 150 Hz modulated signal lobe is below the 90 Hz modulated lobe and the plane of equi-signal thus formed, normally defines a slope of 3° to the horizontal. Local conditions govern this angle which may differ in some cases for reasons of safety.

A slope of approximately 3° intersects the runway at approximately 300 meters (1,000 ft) from its beginning and provides a descent of 300 feet for every one nm of forward travel. This translates to a gradient of 5.2 % or 1 in 20.

A thumb rule for rate of descent required to maintain 3° glide slope is;

ROD= 5 x Ground Speed
[As example: 600 feet/ min is ROD for ground speed of 120 knots.]

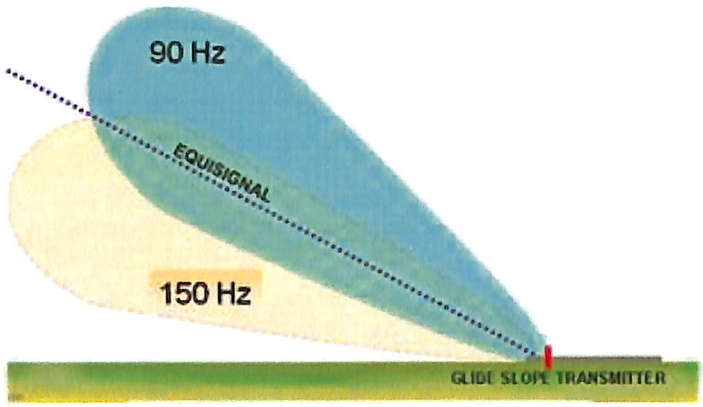


Figure 40: Glide Slope radiation- Plan view

Marker Beacons

Directional transmissions in form of inverted cone at 75 MHz are provided at markers' locations to confirm exact range from the runway when the aircraft is crossing over them. Visual and audio indications in the cockpit are there to confirm this. Compass locator (low powered NDB) may be co-located with a marker if required for initial tracking in to the particular marker beacon.

'Outer Marker' is placed at a range between 3.5 to 6 nm from the touch- down to provide adequate time for functional check of equipment and to commence final descent on the approach. 'Middle Marker', located at about 1 km, is the point where visual reference should be available (that is, at about DH - decision height of Cat I equipment) to runway to continue with instrument approach. Third optional 'Inner Marker', if provided is just short of the runway threshold, also the position for a Cat II DH. An illustration here indicates horizontal polar diagram (cross section) of the three markers, designed to provide signal for sufficient duration for identification when passing over them.

As glide slope transmitter is placed along the runway to one side, the glide slope passes over the threshold at about 50 feet. This point over the threshold is called 'ILS Reference Point' the height as TCH (threshold crossing height). If a precision DME forms part of the installation, it is co-located with glide slope transmitter. Such a DME provides accurate ground ranges from touch-down point and in localizer approach area. Elsewhere the DME readings may be in error. Each component of the ground equipment has its monitoring system, which may switch off either its related transmitter or identification code during any malfunction.

Compass Locator

Compass locators are low-powered NDBs and are received and indicated by the ADF receiver. When used in conjunction with an ILS front course, the compass locator facilities are collocated with the outer and/or MM facilities. The coding identification of the outer locator consists of the first two letters of the three-letter identifier of the associated LOC. For example, the outer locator at Dallas/Love Field (DAL) is identified as "DA." The middle locator at DAL is identified by the last two letters "AL."

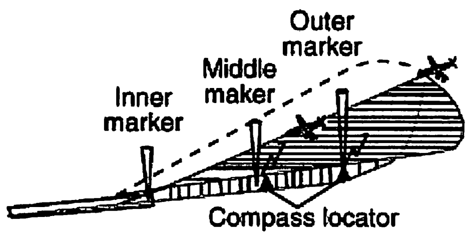


Figure 41: Compass locator

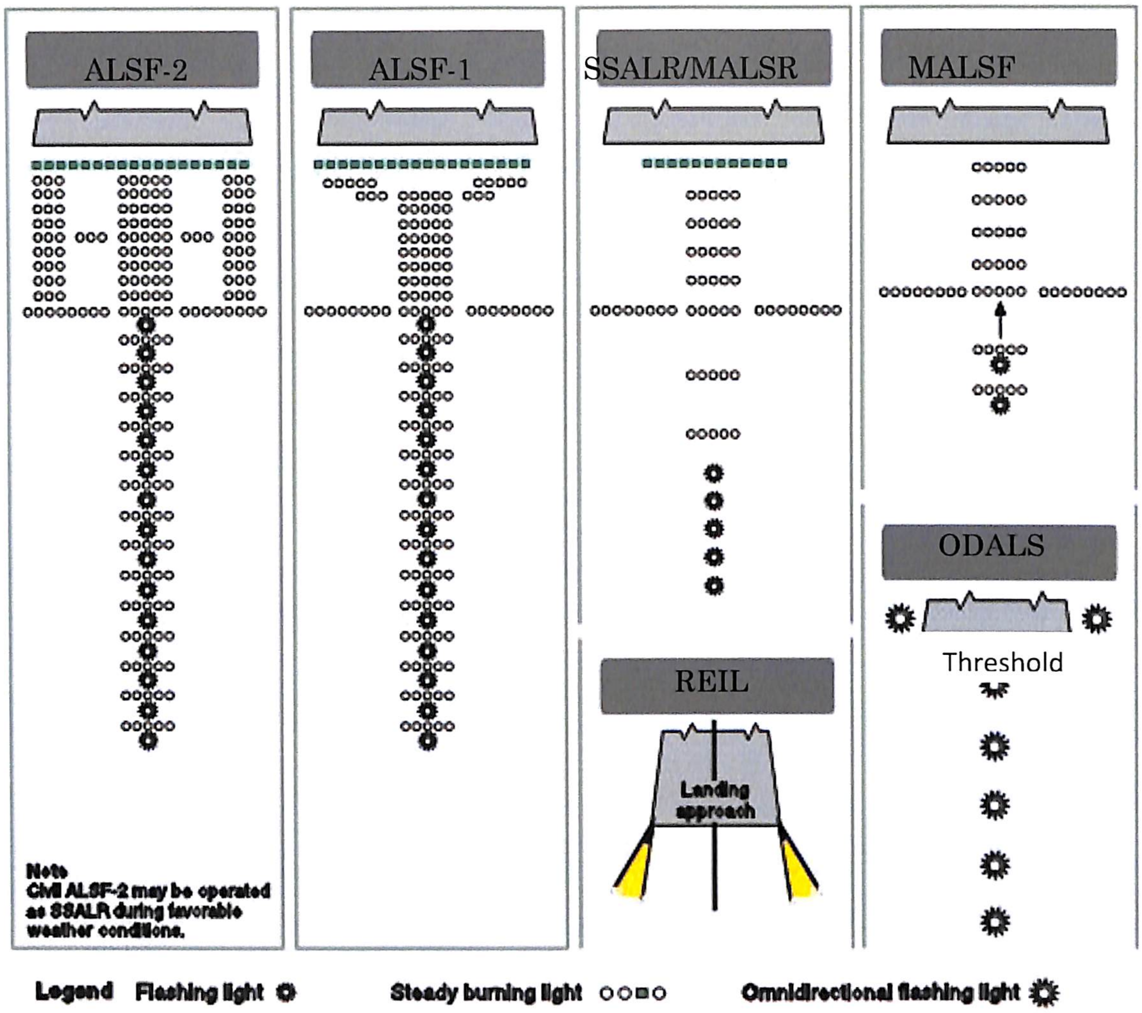
Approach Lighting Systems (ALS)

Normal approach and letdown on the ILS is divided into two distinct stages: the instrument approach stage using only radio guidance, and the visual stage, when visual contact with the ground runway environment is necessary for accuracy and safety. The most critical period of an instrument approach, particularly during low ceiling/visibility conditions, is the point at which the pilot must decide whether to land or execute a missed approach. As the runway threshold is approached, the visual glide path will separate into individual lights. At this point, the approach should be continued by reference to the runway touchdown zone markers. The ALS provides lights that will penetrate the atmosphere far enough from touchdown to give directional, distance, and glide path information for safe visual transition.

Visual identification of the ALS by the pilot must be instantaneous, so it is important to know the type of ALS before the approach is started. Check the instrument approach chart and the A/FD for the particular type of lighting facilities at the destination airport before any instrument flight. With reduced visibility, rapid orientation to a strange runway can be difficult, especially during a circling approach to an airport with minimum lighting facilities, or to a large terminal airport located in the midst of distracting city and ground facility lights. Some of the most common ALS systems are shown in Figure 41.

A high-intensity flasher system, often referred to as "the rabbit," is installed at many large airports. The flashers consist of a series of brilliant blue-white bursts of light flashing in sequence along the approach lights, giving the effect of a ball of light traveling towards the runway. Typically, "the rabbit" makes two trips toward the runway per second.

Runway end identifier lights (REIL) are installed for rapid and positive identification of the approach end of an instrument runway. The system consists of a pair of synchronized flashing lights placed laterally on each side of the runway threshold facing the approach area.



ALSF: - Approach light system with sequenced flashing lights
SSALR: - Simplified short approach light system with runway alignment indicator lights
MALSR: - Medium intensity approach light system with runway alignment indicator lights
REIL: - Runway and identification lights
MALSF: - Medium intensity approach light system with sequenced flashing lights and runway alignment
ODALS: - Omni directional approach light system

Figure 42: Approach Lighting Systems (ALS)

Airborne Equipment

A common antenna with VOR is used for localizer reception. Another UHF antenna for glide slope and a combined receiver for all the three components, namely localizer, glide slope and markers is used. Panel mounted Control Unit is generally integrated with VHF communication set. Navigational information derived from ILS signals may be displayed on different instruments.

OBS Display

On an OBI with an extra horizontal bar and vertical dots, the glide slope indications are also made available on the same display for VOR and ILS. In case of glide slope the maximum deflection either way for five dots shows 0.7° of deviation. That is, each dot corresponding to 0.14°. Half a scale deflection of 'fly up' indication of glide slope bar is considered significant deviation. As a thumb rule vertical scale deflection from the glide slope equals 24 feet/ dot/ nm of deviation. Therefore, maximum deflection of horizontal bar at 10 nm would be 700 feet (24 x 5 x 10) or at 3 nm 210 feet.

CDI scale gets four times more sensitive than VOR indications when used with a localizer. Each dot shows 0.5° deviation from the centre line and full scale deflection corresponds to 2.5° or more. Roughly, one dot deviation is equivalent to 50 feet/ nm of off distance from the centre line. As an example, at 7 nm to touchdown, indication of '2 dots fly right' would mean 100 feet off the centerline. In ILS mode, OBS selection has no effect on CDI indications. But selection of inbound track is a good reminder and useful practice if sometimes one is required to use HSI.

The CDI gives only positional information independent of the aircrafts heading. Therefore, any indications of azimuth and elevation displacement do not depend on heading. Failure of localizer signal renders the complete installation unusable, but with failure of only the glide slope, a non precision approach may be carried out.

HIS (Horizontal situation indicator)

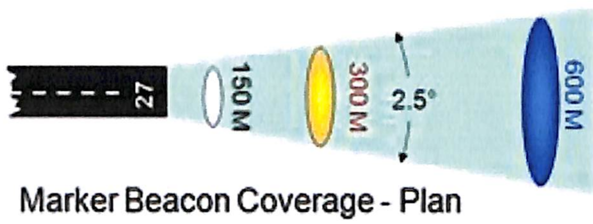
A rotating compass card indicating heading and CDI are combined in HSI. Selecting the inbound localizer track makes the presentation meaningful. Track arrow and CDI are carried around with moving compass card as the aircraft's heading changes. With OBS setting the dots too move and remain perpendicular to broken arrow showing OBS. As the CDI moves parallel to the broken arrow of OBS setting and TO/FROM indication is available, the HSI remains as the command ('what to do') instrument throughout. With the aircrafts symbol in the centre, unambiguous picture in the plan view by HSI greatly simplifies interpretation and interception of the localizer and any required radials. The glide slope indication is given by a wide pointer moving over vertical scale and may be either on one side or both sides of the indicator. A knob to set the heading bug on the compass card as reminder is also there. The width of the bug assists in making small corrections to heading close to the runway on approach.

OBS HSI

Figure 43: OBS and HSI indicators

Marker Beacon Indicator

A set of colored lights which flash to indicate the aircraft's passage over the markers is installed on the instrument panel. Simultaneous Morse code identification in the headsets (and speaker) is also available. Salient details of all markers are depicted and tabulated below.



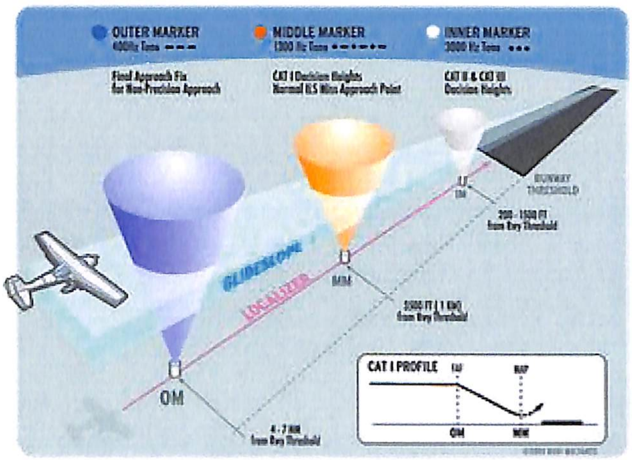


Figure 44: Marker beacon

Marker	Light Colour	Morse/ Sec	Pitch
OM	Blue/ Purple	Two Dashes	400 Hz
MM	Amber	Dot dash	1,300 Hz
IM	White	Six dots	3,000 Hz

Table 15: Marker Beacon

Use of DME

In case of a co-located DME with ILS, airborne DME equipment automatically gets switched on when VHF frequency selection for the localizer is made on the control unit. In absence of marker beacon or as an additional and regular check of the distance to runway, DME readings can be used for the range. This can confirm position in relation to the glide slope by comparison of height (or altitude) with distance to touchdown.

System coverage and Limitations

The volume of airspace within which accurate indications must be available are defined by ICAO for different components of ILS.

Localizer

The indications for the localizer signals received should be accurate up to 7° in elevation above the aerodrome level. The horizontal coverage of this airspace should extend to ±35° of approach centerline and up to a distance of 18 nm. Beyond this; up to range of 25 nm the coverage should be within ±10° of the extended centerline of the runway, as is shown in the figure here.

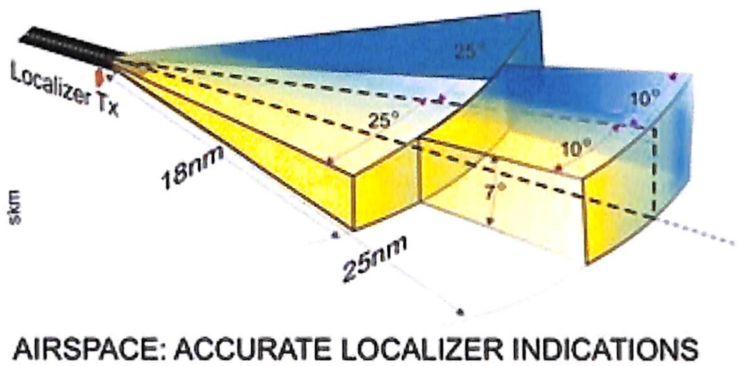


Figure 45: Localizer coverage

Glide Path

The volume of airspace where accurate indication of glide path is available extends up to 10 nm range. Its coverage in elevation is based on the glide slope angle and extends above runway from 0.45 θ to 1.75 θ, where θ represents the descent angle for approach. Therefore, for a 3° nominal angle of approach the coverage in elevation extends from 1.35° above aerodrome to 5.25°.The coverage in the horizontal plane extends to 8° either side extended centerline of the runway.

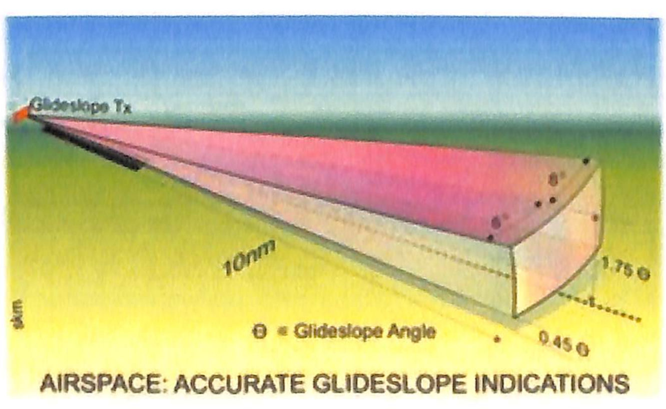


Figure 46: Glide path coverage

Back Beam Approaches

Localizer radiation pattern is replicated in take-off direction as well and can be used for tracking out in take-off direction or carrying out a non-precision approach on the opposite runway. On simple indicators, it must be noted that indications are opposite in sense. The approach may be carried out only if such a procedure is published and authorized.

False Glide slope

The emission of lobes at glide slope transmitter gets repeated due to antenna design. A steep and false glide slope above the actual one would occur at twice the normal angle. The indications with false glide slope will be in reverse. The procedures are designed to intercept the glide slope from below to avoid a possibility of following the false glide slope which also demands a high rate of descent.

Beam Bending

An apparent bending of the localizer beam may be caused by presence of aircraft, vehicles or other obstructions near the transmitter. Although the signal due to diffraction may go around obstructions, its modulation is affected, causing the apparent kinks. Separate holding points are designated for aircraft holding while precision approaches are taking place.

Operational Errors

1) Failure to understand the fundamentals of ILS ground equipment, particularly the differences in course dimensions. Since the VOR receiver is used on the localizer course, the assumption is sometimes made that interception and tracking techniques are identical when tracking localizer courses and VOR radials. Remember that the CDI sensing is sharper and faster on the localizer course.

2) Disorientation during transition to the ILS due to poor planning and reliance on one receiver instead of on all available airborne equipment. Use all the assistance available; a single receiver may fail.

3) Disorientation on the localizer course, due to the first error noted above.

4) Incorrect localizer interception angles. A large interception angle usually results in overshooting, and possible disorientation. When intercepting, if possible, turn to the localizer course heading immediately upon the first indication of needle movement. An ADF receiver is an excellent aid to orient you during an ILS approach if there is a locator or NDB on the inbound course.

5) Chasing the CDI and glide path needles, especially when you have not sufficiently studied the approach before the flight.

ILS Approach Categories

The performance category of the complete ILS installation and the operating criteria together decide the minima - decision height and the visibility to which a pilot may operate carrying out an ILS instrument approach to land. The performance includes the reliability, technology and accuracy of all the components of system including special equipment and traffic control procedures. Operating criteria includes factor like; accuracy and reliability of the airborne equipment, runway category, pilot's special training and recency, with wind component and runway surface condition at time of approach. ICAO has stipulated ILS categories based on operational objectives in terms to allow aircraft to approach a runway and be in a position to land are tabulated below:

Category	Decision Height	Visibility	RVR
I	60 m (200 ft)	not < 800 m	not < 550 m
II	60 to 30 m (100 ft)	-	not < 350 m
III A	30 m or less	-	not < 200 m
III B	15 m (30 ft) or less	-	between 200 and 50 m
III C	No cloud base or visibility restrictions		

Table 21: ILS categories

TYPICAL ILS APPROACH

Instrument approach charts for ILS Rwy 09 by Jeppesen, with annotations are available on the next two pages. General format of Approach Procedure Chart has four sections; Heading, Approach Plan View, Profile View and Landing Minimums. On major airports - like the one shown here, the procedures may be covered in two pages.

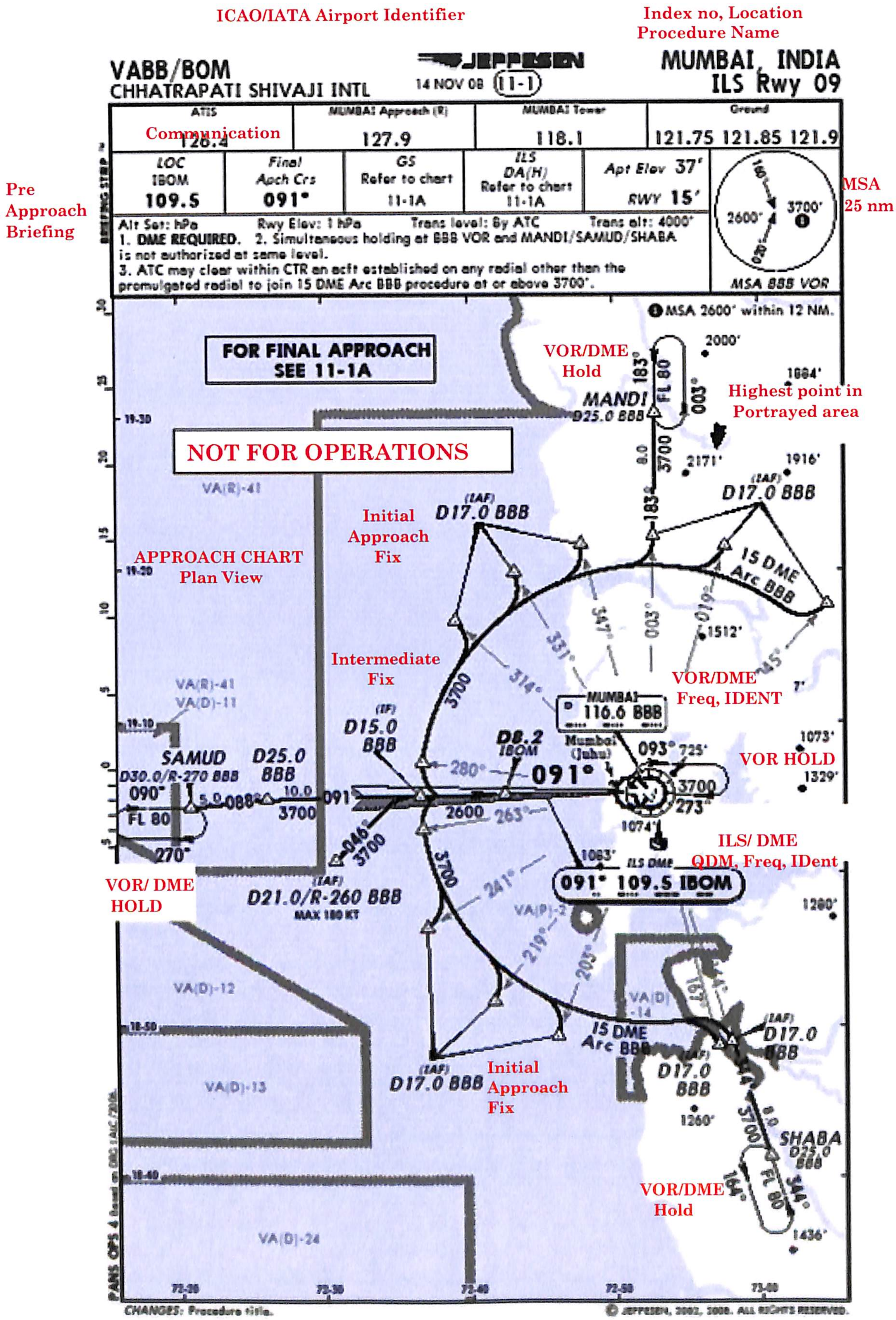


Figure 47: ILS Approach plate – Plan view

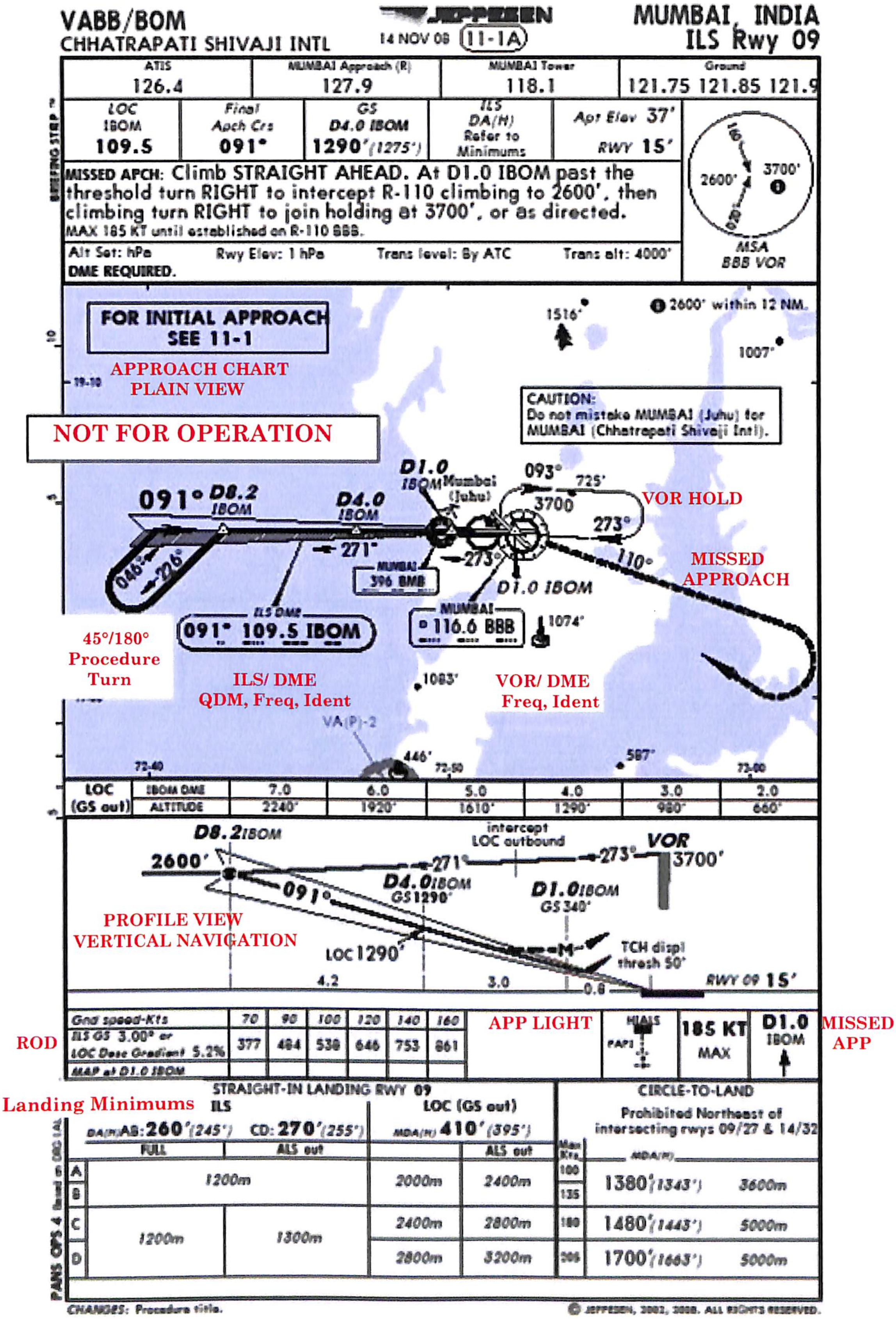


Figure 48: ILS Approach plate – Plan view/Profile view

7.4 Global Positioning System (GPS)

GPS also known as Navstar is a Satellite based navigation system, controlled and operated by the US Department of Defense. With help of transmissions from satellites orbiting in space, the system is capable of providing an accurate position fix anywhere over the world. GLONASS (Global Orbiting Navigation Satellite System) is another similar system by Russia is now operational. Generic term used by ICAO for such systems is GNSS (Global Navigation Satellite System). The system is used to establish the position of a radio receiver in three dimensions, correlate it to Earth's reference and compute accurate time after receiving signal broadcasts from number of orbiting satellites in space.

Principle of Operation

Basic principle of operation is; position by ranging method. Travel times of radio signals from respective satellites to the receiver are measured and converted to corresponding ranges at a common time. With the each satellite's position in its orbit and distance from the receiver at a particular time known, three such ranges are geometrically combed to determine the receiver's position in x, y and z coordinates in space, with centre of the Earth being the origin. The Cartesian coordinates are then converted to latitude and longitude of the receiver's position over the Earth for navigational use. The height above the ground below is computed by making allowance for the eccentricity in shape of the Earth.

The GPS has three functional elements; Space Segment comprising number of orbiting satellites in space, Ground Control Segment for monitoring and functional control of the complete system and User Segment comprising airborne receivers used for standalone air navigation.

Function of GPS

GPS operation is based on the concept of ranging and triangulation from a group of satellites in space which act as precise reference points. The receiver uses data from a minimum of four satellites above the mask angle (the lowest angle above the horizon at which it can use a satellite).

The aircraft GPS receiver measures distance from a satellite using the travel time of a radio signal. Each satellite transmits a specific code, called a course/acquisition (CA) code, which contains information about satellite position, the GPS system time, and the health and accuracy of the transmitted data. Knowing the speed at which the signal traveled (approximately 186,000 miles per second) and the exact broadcast time, the distance traveled by the signal can be computed from the arrival time. The distance derived from this method of computing distance is called a pseudo-range because it is not a direct measurement of distance, but a measurement based on time. In addition to knowing the distance to a satellite, a receiver needs to know the satellite's exact position in space, its ephemeris. Each satellite transmits information about its exact orbital location. The GPS receiver uses this information to establish the precise position of the satellite.

Using the calculated pseudo-range and position information supplied by the satellite, the GPS receiver/processor mathematically determines its position by triangulation from several satellites. The GPS receiver needs at least four satellites to yield a three-dimensional position (latitude, longitude, and altitude) and time solution. The GPS receiver computes navigational values (distance and bearing to a WP, groundspeed, etc.) by using the aircraft's known latitude/longitude and referencing these to a database built into the receiver.

The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) to determine if a satellite is providing corrupted information. RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter baro-aiding to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate a corrupt satellite signal and remove it from the navigation solution.

Generally, there are two types of RAIM messages. One type indicates that there are not enough satellites available to provide RAIM and another type indicates that the RAIM has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Aircraft using GPS navigation equipment under IFR for domestic en route, terminal operations, and certain IAPs, must be equipped with an approved and operational alternate means of navigation appropriate to the flight. The avionics necessary to receive all of the ground-based facilities appropriate for the route to the destination airport and any required alternate airport must be installed and operational. Ground-based facilities necessary for these routes must also be operational. Active monitoring of alternative navigation equipment is not required if the GPS receiver uses RAIM for integrity monitoring. Active monitoring of an alternate means of navigation is required when the RAIM capability of the GPS equipment is lost. In situations where the loss of RAIM capability is predicted to occur, the flight must rely on other approved equipment, delay departure, or cancel the flight.

GPS Segments

Space Segment

This segment comprises a constellation of 24 (including three as standby) satellites orbiting the earth every 12 hours at height of 20,200 km and in six different orbits. These orbits are inclined at 55° to Earth's axis in order to provide a geometrical configuration such that at least five satellites are in view at any point over the earth. All satellites consecutively transmit on the same frequency in UHF band with their individual codes known as PRN (pseudo random noise number). Each satellite carries four atomic clocks with accuracy of one billionth of a second in time keeping and makes a transmission every millisecond. The PRN is used by GPS transmitters for their identification and by receivers to track a particular satellite for ranging. There are two types of this PRN.

- C/A Code (course acquisition)
  Also referred to as SPS (standard positioning service) is available for use by all receivers at 1575.42 MHz frequency with degraded accuracy.

- P Code or PPS (precise positioning service).
  Provides extremely accurate position. Earlier it was meant for military use only, but now is available for civil use as well.

The transmission from all satellites has the following information.

- Time transmission is made
- Ephemeris - precise orbital information and the
- Almanac - information on health and orbital details on entire GPS constellation.

Ground Control segment

US Department of Defense constantly monitors and tracks the orbits and transmissions of all satellites through monitoring stations at Hawaii, Kwajalein, Ascension Island and Colorado Springs (master control station). Civilian use of the system is available subject to deliberate degradation in accuracy by the US. The use of SPS (not precise positions) accessed via C/A code is known as Selective Availability. The monitoring stations, located across the world, track satellites in their view and pass information to the master station. Control on satellites clocks, orbits and navigational information is exercised by the master station's computer and atomic clock through monitoring stations. Navigational data used by satellites for transmission is regularly uploaded with necessary corrections and any unserviceable messages. Orbits of the satellites are regularly corrected and the satellites are periodically about every ten years replaced.

User Segment (Airborne receiver)

Pseudo Ranging:- Once switched on the receiver recalls data, used earlier before last shut down, from computer's memory to determine which satellites would be in view and suitable for use. Alternately, it receives and processes data from all satellites which takes longer as transmission of ephemeris takes about six seconds and that of the almanac about 13 seconds. Using the C/A codes, the receiver determines rough ranges from number of satellites. Combining this information with knowledge of the exact locations of the satellites, it computes its own position. This process is called pseudo ranging.

Accurate Position: - Accurate ranging needs highly accurate time reference. Requirement of an onboard costly atomic clock is dispensed with by using reception of signals from at least four or more appropriately positioned satellites. With combination of three ranges at a time, number of positions is found which would be different mainly due to error in time reference. A common correction to ranges is computed to bring all of them to a single position. This correction is attributed to error in time or clock bias at receiver. Once corrected for clock bias, subsequent positions and tracking are accurate.

Airborne Receiver: - Category of the receiver - operating sequentially on single channel or more expensive ones operating simultaneously on multi channel, decides the capability, accuracy and cost of the airborne equipment. For IFR operations multi channel capacity with RAIM (receiver autonomous integrity monitoring) facility is required.

RAIM:- As a primary navigation aid criterion, the receiver must be independently able to detect when its information is unreliable. Minimum five satellites are required to
be in view to analyze the signal integrity and independently evaluate the positions, using this feature. Six satellite signals are required to isolate the signals from the satellite causing anomaly - called FDE (failure detection and exclusion). RAIM facility ensures minimum level of required navigation accuracy for the related phase of flight. An error in position caused due to geometrical disposition of satellites and the receiver which is known as position PDOP (position dilution of precision) or GDOP (geometric dilution of precision) is detected when this facility available. This is illustrated in the figure.

Altimeter Input: - Digitized data from pressure altimeter can be used by the GPS receiver to simulate a range from centre of the Earth. This facility provides additional input, particularly when less than five satellites are in for use with RAIM, and also extends navigational coverage.

Masking: - Satellites in view, but at low angle of elevation should not be used for the fact that their signals have to travel through greater distances in ionosphere and troposphere, suffering higher degree of refraction. Passing through longer distances in the ionosphere they suffer higher attenuation. Such weak signals, generally at 7.5° elevation are discarded at the receiver by masking function.

Receiver Displays:- Variety of control and display units is commercially available. Data for flight planning may be entered manually via a keypad on the control unit. Alternately, extensive aeronautical information on airports, facilities, communication and airspace may be stored through data card and utilized as and when required. Regular updating of all information that is needed for GPS receiver operation is required to be carried out. Most displays include navigational information on present position (latitude / longitude or bearing and distance to fix/ nav aid), track, ground speed, EET, Wind Velocity and TAS, if CAS is input. A CDI and/ or digital display to show directions and position on moving map of the terrain is also included in many indicators. CDI deflection in most of the equipment is controlled automatically. Full scale deflection in en route phase corresponds to 5 nm, in terminal navigation to 1 nm and during a GPS assisted approach to 0.3 nm. The receiver equipment can also be integrated with other electronic display systems like flight director or attitude direction indicator (ADI). Inputs from GPS receiver may be provided to external CDI or horizontal situation indicator (HIS), radio magnetic indicator (RMI), area navigation system (RNAV), external moving map display system and others. Flexibility of instantly making changes in the planned route or direct flight to destination exists. Performance monitoring of the system can be done any time by a check on its status.
Following sections attempt to provide a glimpse on two commonly used airborne GPS sets.

a) **Bendix/King 89(B)**

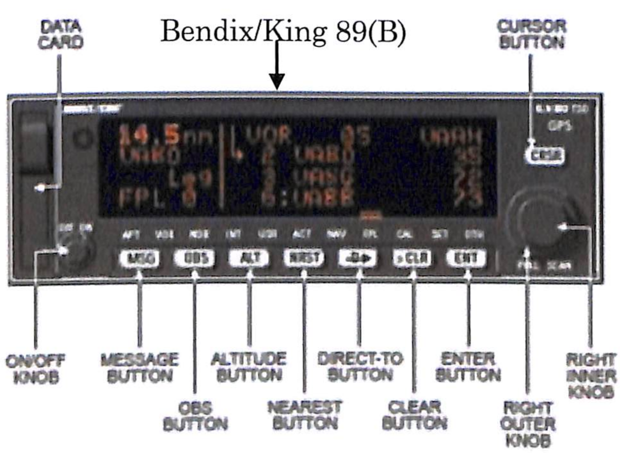
An illustration of typical control and Display Unit of is illustrated here. This display may be visualized as chapters and pages of a book. With the different buttons and knobs the user accesses these and inputs data where needed. The figure shows the FPL (flight plan) page of the display showing the current flight segment for the route from Ahmedabad to Mumbai. Next waypoint, Vadodara is 14.5 nm to go and the destination, Mumbai is 73 nm from previous waypoint (No 5). Most of the captions and button labels are self explanatory, but reference to pilot's guide for operation is strongly recommended.

b) Garmin 500W.

Second GPS equipment shown here displays the FPL (flight plan) page of Garmin 500 set. The flight plan details - required track, leg distance and cumulative distance for the route from Mumbai to Ahmedabad via Daman and Vadodara can be seen on the screen's main panel. Vertical panel on the left has current leg details and the ground position in reference to required track in form of track error angle and off track distance. ETA to next waypoint Daman is also indicated.

The second figure on the Nav page graphically displays the required track and aircraft position with partial compass rose on an overlay of the aeronautical chart. Some of the other navigational details available on this page are; desired track from present position, ground speed, distance and time to next waypoint, and CDI indication at the bottom. Comparison of figures in the vertical panel on the left with the corresponding ones of the previous figure, clearly indicate the progress of the flight. It is obvious that the track error has increased.

The third figure displays a page in TERRAIN (terrain) mode with overlay of the topographical map and airspace boundaries. Partial compass rose, aircraft symbol and magenta colored track required present comprehensive horizontal position. The scale may be zoomed in or out by the RNG button on right top and present value is indicated by a label 'Zoom 20 nm'. The CDI shows required track to be to the right about 2 nm - full scale being 5 nm in en route mode. Exact value of XTK 1.79 nm can be seen at left bottom. All other navigational parameters on the screen indicate current values.



Garmin 500w Flight plan View

Garmin 500 w NAV page (graphical display)

Garmin 500W Terrain view

Figure 49 : GPS Receiver Displays

GPS Instrument Approches

There is a mixture of GPS overlay approaches (approaches with "or GPS" in the title) and GPS stand-alone approaches in the United States.

NOTE: GPS instrument approach operations outside the United States must be authorized by the appropriate country authority.

While conducting these IAPs, ground-based NAVAIDs are not required to be operational and associated aircraft avionics need not be installed, operational, turned on, or monitored; however, monitoring backup navigation systems is always recommended when available.

Pilots should have a basic understanding of GPS approach procedures and practice GPS IAPs under visual meteorological conditions (VMC) until thoroughly proficient with all aspects of their equipment (receiver and installation) prior to attempting flight in instrument meteorological conditions (IMC).

All IAPs must be retrievable from the current GPS database supplied by the manufacturer or other FAA-approved source. Flying point to point on the approach does not assure compliance with the published approach procedure. The proper RAIM sensitivity will not be available and the CDI sensitivity will not automatically change to 0.3 NM. Manually setting CDI sensitivity does not automatically change the RAIM sensitivity on some receivers. Some existing non precision approach procedures cannot be coded for use with GPS and will not be available as overlays.

GPS approaches are requested and approved by ATC using the GPS title, such as "GPS RWY 24" or "RNAV RWY 35." Using the manufacturer's recommended procedures, the desired approach and the appropriate IAF are selected from the GPS receiver database. Pilots should fly the full approach from an initial approach waypoint (IAWP) or feeder fix unless specifically cleared otherwise. Randomly joining an approach at an intermediate fix does not ensure terrain clearance.

When an approach has been loaded in the flight plan, GPS receivers will give an "arm"

annunciation 30 NM straight line distance from the airport/heliport reference point. The approach mode should be "armed" when within 30 NM distance so the receiver will change from en route CDI (±5 NM) and RAIM (±2 NM) sensitivity to ±1 NM terminal sensitivity. Where the IAWP is within 30 NM, a CDI sensitivity change will occur once the approach mode is armed and the aircraft is within 30 NM. Where the IAWP is beyond the 30 NM point, CDI sensitivity will not change until the aircraft is within 30 NM even if the approach is armed earlier. Feeder route obstacle clearance is predicated on the receiver CDI and RAIM being in terminal CDI sensitivity within 30 NM of the airport/heliport reference point; therefore, the receiver should always be armed no later
than the 30 NM annunciations.

Pilots should pay particular attention to the exact operation of their GPS receivers for performing holding patterns and in the case of overlay approaches, operations such as procedure turns. These procedures may require manual intervention by the pilot to stop the sequencing of WPs by the receiver and to resume automatic GPS navigation sequencing once the maneuver is complete. The same WP may appear in the route of flight more than once and consecutively (e.g., IAWP, final approach waypoint (FAWP), missed approach waypoint (MAWP) on a procedure turn). Care must be exercised to ensure the receiver is sequenced to the appropriate WP for the segment of the procedure being flown, especially if one or more fly-over WPs are skipped (e.g., FAWP rather than IAWP if the procedure turn is not flown). The pilot may need to sequence past one or more fly-over's of the same WP in order to start GPS automatic sequencing at the proper place in the sequence of WPs.

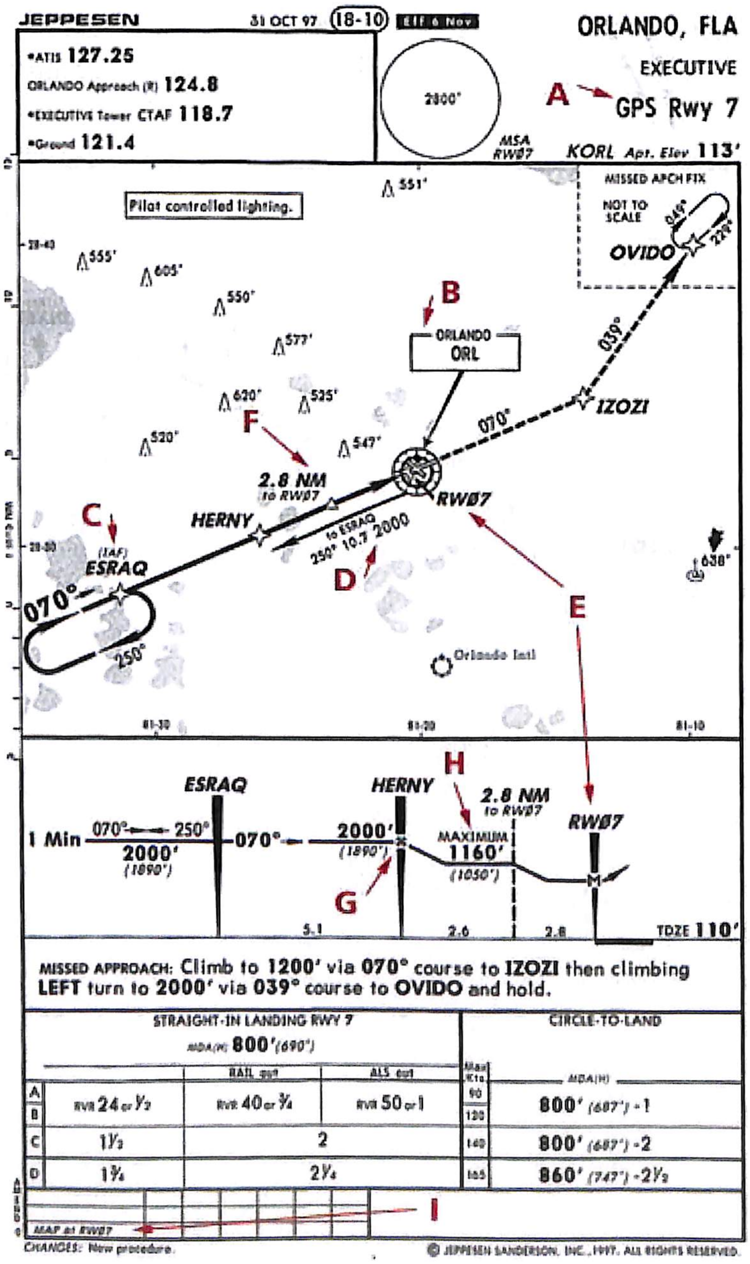
When receiving vectors to final, most receiver operating manuals suggest placing the receiver in the non sequencing mode on the FAWP and manually setting the course. This provides an extended final approach course in cases where the aircraft is vectored onto the final approach course outside of any existing segment which is aligned with the runway. Assigned altitudes must be maintained until established on a published segment of the approach. Required altitudes at WPs outside the FAWP or step-down fixes must be considered.

Calculating the distance to the FAWP may be required in order to descend at the proper location. When within 2 NM of the FAWP with the approach mode armed, the approach mode will switch to active, which results in RAIM and CDI sensitivity changing to the approach mode. Beginning 2 NM prior to the FAWP, the full scale CDI sensitivity will change smoothly from ±1 NM to ±0.3 NM at the FAWP. As sensitivity changes from ±1 NM to ±0.3 NM approaching the FAWP, and the CDI not centered, the corresponding increase in CDI displacement may give the impression the aircraft is moving further away from the intended course even though it is on an acceptable intercept heading. If digital track displacement information (cross-track error) is available in the approach mode, it may help the pilot remain position oriented in this situation. Being established on the final approach course prior to the beginning of the sensitivity change at 2 NM will help prevent problems in interpreting the CDI display during ramp-down. Requesting or accepting vectors, which will cause the aircraft to intercept the final approach course within 2 NM of the FAWP, is not recommended.

Incorrect inputs into the GPS receiver are especially critical during approaches. In some cases, an incorrect entry can cause the receiver to leave the approach mode. Overriding an automatically selected sensitivity during an approach will cancel the approach mode annunciation. If the approach mode is not armed by 2 NM prior to the FAWP, the approach mode will not become active at 2 NM prior to the FAWP and the equipment will flag. In these conditions, the RAIM and CDI sensitivity will not ramp down, and the pilot should not descend to minimum descent altitude (MDA), but fly to the MAWP and execute a missed approach. The approach active annunciator and/or the receiver should be checked to ensure the approach mode is active prior to the FAWP.

A GPS missed approach requires pilot action to sequence the receiver past the MAWP to the missed approach portion of the procedure. The pilot must be thoroughly familiar with the activation procedure for the particular GPS receiver installed in the aircraft and must initiate appropriate action after the MAWP. Activating the missed approach prior to the MAWP will cause CDI sensitivity to change immediately to terminal (±1 NM) sensitivity, and the receiver will continue to navigate to the MAWP. The receiver will not sequence past the MAWP. Turns should not begin prior to the MAWP. If the missed approach is not activated, the GPS receiver will display an extension of the inbound final approach course and the along track distance (ATD) will increase from the MAWP until it is manually sequenced after crossing the MAWP.

Missed approach routings in which the first track is via a course rather than direct to the next WP require additional action by the pilot to set the course. Being familiar with all of the required inputs is especially critical during this phase of flight.



Key:-

A - Tell us this is the GPS Rwy 7 approach to Orlando Executive

B - Indicates the Orlando VOR which is ORL

C - Shows us our IAF as the GPS waypoint called ``ESRAQ"

D - Depicts a feeder route from ORL.

E - Illustrates our MAP, a GPS waypoint called ``RW07"

F - Depicts another waypoint which is simply ``2.8NM to RW07"

G - Is the FAF at the GPS waypoint ``HERNY". ``

H - You see that it says ``MAXIMUM 1160ft". On normal altitudes, like 2000ft to HERNY, we can fly any altitude at or above 2000ft. In this case however, we must be right at 1160ft, no higher. This is because this approach crosses the approach path to Orlando International

I - tells us that our MAP is at RW07

Figure 50: GPS approach

Departures and Instrument Departure Procedures (DPs)

The GPS receiver must be set to terminal (±1 NM) CDI sensitivity and the navigation routes contained in the database in order to fly published IFR charted departures and DPs. Terminal RAIM should be provided automatically by the receiver. (Terminal RAIM for departure may not be available unless the WPs are part of the active flight plan rather than proceeding direct to the first destination.) Certain segments of a DP may require some manual intervention by the pilot, especially when radar vectored to a course or required to intercept a specific course to a WP. The database may not contain all of the transitions or departures from all runways and some GPS receivers do not contain DPs in the database. It is necessary that the aircraft procedures be flown at 70 knots or less since aircraft departure procedures and missed approaches use a 20:1 obstacle clearance surface (OCS), which is double the fixed-wing OCS. Turning areas are based on this speed also. Missed approach routings in which the first track is via a course rather than direct to the next WP require additional action by the pilot to set the course. Being familiar with all of the required inputs is especially critical during this phase of flight.

System Status

The status of GPS satellites is broadcast as part of the data message transmitted by the GPS satellites. GPS status information is also available by means of the United States Coast Guard navigation information service: (703) 313-5907, or on the internet at http://www.navcen.uscg.gov/. Additionally, satellite status is available through the Notice to Airmen (NOTAM) system.
The GPS receiver verifies the integrity (usability) of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) to determine if a satellite is providing corrupted information. At least one satellite, in addition to those required for navigation, must be in view for the receiver to perform the RAIM function; thus, RAIM needs a minimum of five satellites in view, or four satellites and a barometric altimeter (baro-aiding) to detect an integrity anomaly. For receivers capable of doing so, RAIM needs six satellites in view (or five satellites with baro-aiding) to isolate the corrupt satellite signal and remove it from the navigation solution.
RAIM messages vary somewhat between receivers; however, there are two most commonly used types. One type indicates that there are not enough satellites available to provide RAIM integrity monitoring and another type indicates that the RAIM integrity monitor has detected a potential error that exceeds the limit for the current phase of flight. Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

Selective Availability

Selective Availability (SA) is a method by which the accuracy of GPS is intentionally degraded. This feature is designed to deny hostile use of precise GPS positioning data. SA was discontinued on May 1, 2000, but many GPS receivers are designed to assume that SA is still active. New receivers may take advantage of the discontinuance of SA based on the performance values in ICAO Annex 10, and do not need to be designed to operate outside of that performance.

GPS Errors and Limitations

a) **Clock-bias error** and its resolution, degradation in accuracy due to satellite geometry (PDOP) and use of selective availability (SA) have been already discussed. Other errors affecting overall performance are enumerated here.

b) **Ephemeris Error**: - Transmitted data defining satellites current position is based on predicted values of gravity of earth, sun, moon and other planets. This may further be modified by other celestial bodies and debris in space. Minor malfunctions, delay in their detection and subsequent rectification can also contribute to error in the ephemeris information. The error may be within ± 4mtrs.

c) **Multi Path Error**: - Ranging error may be caused by radio signals reaching the receiver after reflection from Earth's surface or parts of aircraft like its fin. Aircrafts flying at low altitudes may be relatively susceptible to this error due to mountains, high structures and even tall trees in case of signals from satellites at low elevation angle. Signals received via different paths may cause error to order of ± 0.6 meters.

d) **Ionosphere and Troposphere Refraction**: - Radio signals passing through Ionospheric layers particularly at shallow angles even in the UHF band may suffer refraction and slow down during propagation. The combined error is called Ionospheric Group delay and the error is about 5 meters. In lower regions of atmosphere, water vapor causes reduction in speed of radio waves and results in ranging error. Compensation for this however can be built in the computer of GPS receiver.

e) **Measurement Error at receiver**:- Manufacturing limitations and tolerances accepted for the receivers give rise to small inaccuracies in computed positions. These are rather small and in order of ± 0.3 meters.

f) **Interference**: - Extremely weak signals of GPS having travelled thousands of kilometers are received mixed with electromagnetic interferences of all kinds - VHF, high powered radar, TV and FM broadcasts. Radio spectrum is becoming crowded and the problem is likely to increase. Deliberate action of 'jamming' is also being possible. Doubt on GPS integrity or loss of RAIM should be reported to appropriate authorities whenever observed.

g) **Satellite availability**: - With 30 satellites in operation, the GPS constellation is expected to be available continuously worldwide. Whenever there are fewer than 24 operational satellites, GPS navigational capability may not be available at certain geographic locations. Loss of signals may also occur in valleys surrounded by high terrain, and any time the aircraft's GPS antenna is "shadowed" by the aircraft's structure (e.g., when the aircraft is banked).

Accuracy and Integrity

A user should appreciate the intricacies and uncertainness in the combined effect that the factors enumerated above have on the final GPS position. Expecting the same accuracy all the time and everywhere is impractical. Operators should monitor the status page and correlate the accuracy. Exhaustive details on sky view of satellites, accuracy of the fix, receiver status, relative strength of signal from each satellite being received, and exclusion of any satellite. Figure below shows a sample of the Status Page.

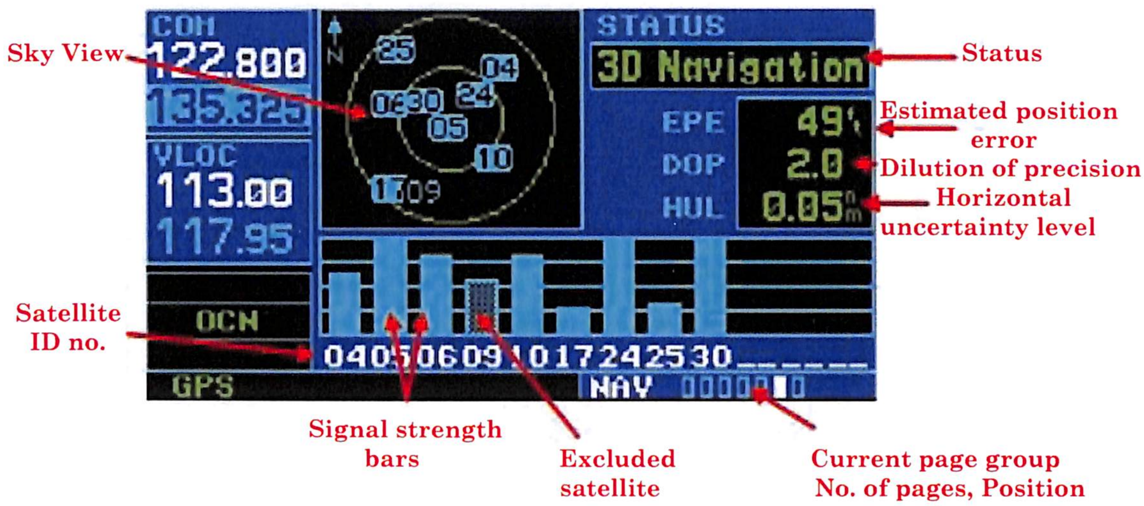


Figure 51: GPS status page

Positional accuracy of ±30 meters at 95% of occasions in C/A mode is expected in horizontal position with CA signal. Computed vertical position relatively is less accurate and may be within ±500 ft at 95% of the time. Typical magnitudes for the error quoted for DGPS are of the order of ±3 meters and with P Code operating to be ±17 meters.

Other Operational systems

- **GLONASS**
  As mentioned earlier, Russian equivalent system of GPS is known as GLONASS (Global Orbiting Navigation Satellite System) and operates with 21 satellites orbiting the Earth every 12 hours. The difference is in the orbital altitude and inclination of about 19,000 feet and 66° compared to GPS. In transmitting navigational data each satellite uses a different frequency and facility of selective availability is not provided. Common receivers for GPS and GLONASS are available which minimize the error due to PDOP with larger number of satellites in view from both systems. The system is expected to have 24 operational satellites by 2010.

- **Differential GPS**
  Accuracy, much higher than that is available with conventional GPS equipment is required during approach and departure procedures. An ingenious modification to improve the accuracy is adaptation in DGPS (differential GPS). A ground GPS receiver is installed at accurately surveyed location in the terminal area. The

difference in actual geographical position and the one found by GPS computer is continually determined. Considering same difference applies to all airborne equipment in the area, suitable correction through data links is passed on to the other users. The figure illustrates this simple concept. Correction when applied to the computed position of airborne receiver's results in accuracy enhancements between +1 to -10 meters. This is acceptable for non-precision aerodrome approach procedures only. Claims on improvement in accuracy and work in enhancing the capability to carry out precision approaches have already been made.

- **WAAS GPS (Wide Area Augmentation System GPS)**

  WAAS is meant for use in precision flight approaches providing required positional accuracies. The system consists of approximately 25 ground reference stations positioned across North America. With two master stations, located on either coast, data from the reference stations is collected and a GPS correction message created. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. WAAS GPS also provides vital integrity information regarding the health of each GPS satellite. The corrected differential message is then broadcast through one of two geostationary satellites that are satellites with a fixed position over the equator. The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the signal. The figure here explains the basic concept. Available in North America, WAAS GPS provides extended coverage both inland and offshore compared to the land-based DGPS system. Another benefit of WAAS is that it does not require additional receiving equipment, while DGPS does.

  Other states are continually developing similar systems or variants of the WAAS GPS to achieve better accuracies. The European system is EGNOS (European geostationary navigation over lay service). Japan's Mass (multi functional transport satellite augmentation system) and India's GAGAN (GPS aided Geo Augmented Navigation) projects are in advance stages towards completion. The system depicted here also illustrates the concept which aims to improve global navigation, communication, surveillance and air traffic management in future. Installation of eight Indian Reference Stations (Ingress) and link to MCC at Bangaluru were completed in 2007. With launch of three GAGAN payloads with GSAT series of satellites starting in 2010, the system will be operational.

Chapter 8: TCAS

The Functional Requirement

TCAS is a system of last resort and hence should have the following characteristics:

- Should only intervene when all "normal" means of separation have failed
- Should not be disruptive to "normal" separation means
- Should have minimum reliance on other systems
- Should work anywhere – even remote or oceanic areas
- Should ensure complementary maneuvers are employed by the aircraft in conflict
- Should have a very high probability of successful conflict resolution.

Basis of operation

TCAS provides "last ditch" collision avoidance by detecting and tracking aircraft proximate to own aircraft. The relative movement of threat aircraft to own aircraft is assessed. TCAS generates a Traffic Alert (TA) for aircraft which are predicted to come unhealthily close approximately 45 seconds before Closest Point of Approach (CPA). The TA draws the flight crew's attention to the situation and assists their visual acquisition of the threat aircraft. If the situation continues to deteriorate, at about 30 seconds before CPA, TCAS issues a Resolution Advisory (RA). Resolution is always in the vertical plane. The RA may be passive (don't climb, don't descend) or active (climb, descend). TCAS communicates the RA to other TCAS equipped aircraft to ensure complementary maneuvers. The flight crews are expected to enact the RA without delay. If followed correctly, the RA can be expected to cause a vertical separation between the aircraft of 300 to 800 feet. TCAS continues to reassess the geometry once per second and if required will vary the RA (increase climb, adjust vertical speed). When the threat has passed, TCAS removes the RA and advises "Clear of Conflict". The flight crew should return the aircraft to the ATC assigned level. The maneuver is usually sufficiently gentle that for most passengers it goes unnoticed. TCAS comprises a number of functions; surveillance, collision avoidance, crew alerting and co-ordination with other TCAS units. TCAS is implemented as an extension of the aircraft ATC Transponder installation.

System description

TCAS involves communication between all aircraft equipped with an appropriate transponder (provided the transponder is enabled and set up properly). Each TCAS-equipped aircraft interrogates all other aircraft in a determined range about their position (via the 1,030 MHz radio frequency), and all other craft reply to

other interrogations (via 1,090 MHz). This interrogation-and-response cycle may occur several times per second.
The TCAS system builds a three dimensional map of aircraft in the airspace, incorporating their range (garnered from the interrogation and response round trip time), altitude (as reported by the interrogated aircraft), and bearing (by the directional antenna from the response). Then, by extrapolating current range and altitude difference to anticipated future values, it determines if a potential collision threat exists.

TCAS and its variants are only able to interact with aircraft that have a correctly operating mode C or mode S transponder. A unique 24-bit identifier is assigned to each aircraft that has a mode S transponder Identification friend or foe Modes.

The next step beyond identifying potential collisions is automatically negotiating a mutual avoidance maneuver (currently, maneuvers are restricted to changes in altitude and modification of climb/sink rates) between the two (or more) conflicting aircraft. These avoidance maneuvers are communicated to the flight crew by a cockpit display and by synthesized voice instructions.

A protected volume of airspace surrounds each TCAS equipped aircraft. The size of the protected volume depends on the altitude, speed, and heading of the aircraft involved in the encounter. The illustration below gives an example of a typical TCAS protection volume.

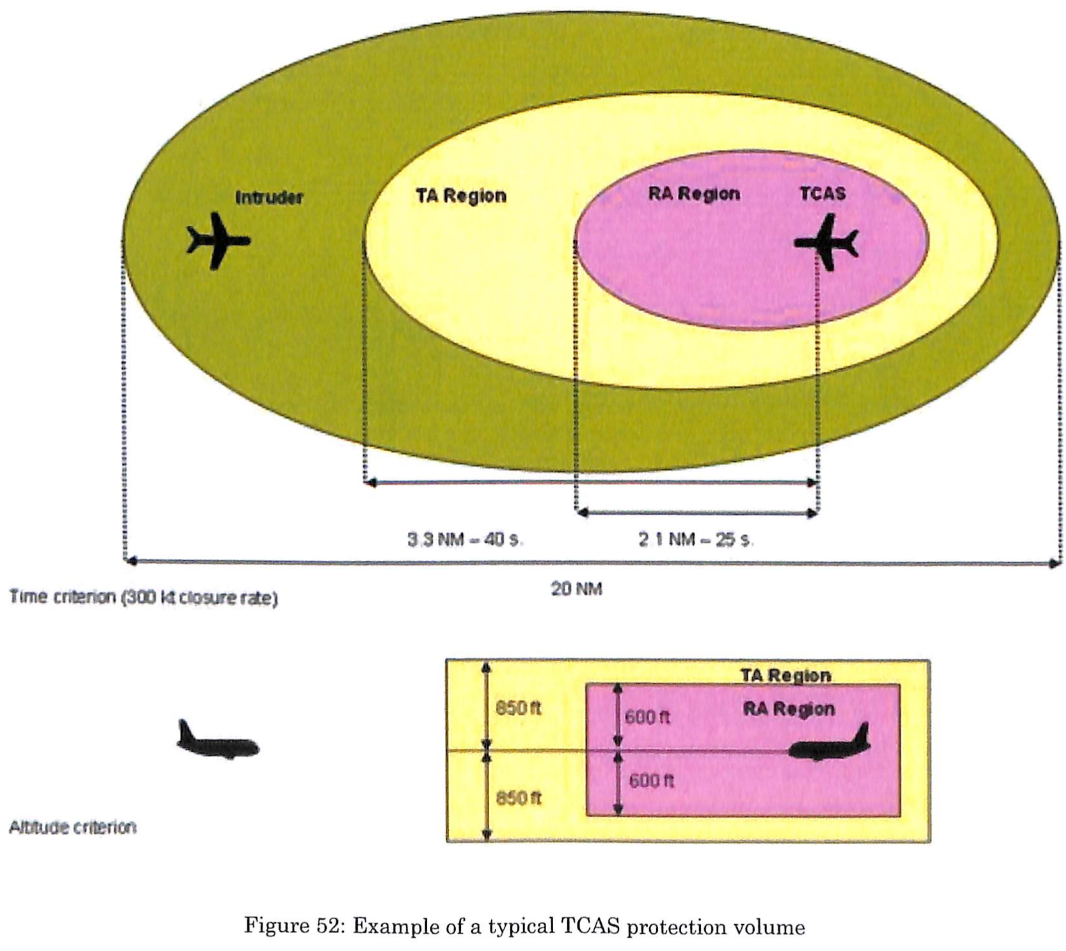


Figure 52: Example of a typical TCAS protection volume

TCAS operation modes

TCAS II can be currently operated in the following modes:

- **Stand-by**
  Power is applied to the TCAS Processor and the mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.

- **Transponder**
  The mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in stand-by.

- **Traffic advisories only**
  The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. However, TCAS will only issue traffic advisories (TA), and the resolution advisories (RA) will be inhibited.

- **Automatic (traffic/resolution advisories)**
  The mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue traffic advisories (TA) and resolution advisories (RA), when appropriate.
  TCAS works in a coordinated manner, so when an RA is issued to conflicting aircraft, a required action (i.e., *Climb Climb*) has to be immediately performed by one of the aircraft, while the other one receives a similar RA in the opposite direction (i.e., *Descend. Descend.*).

TCAS alerts

TCAS II issues the following types of aural annunciations:

- **Traffic advisory (TA)**
  When a TA is issued, pilots are instructed to initiate a visual search for the traffic causing the TA. If the traffic is visually acquired, pilots are instructed to maintain visual separation from the traffic. The pilot training programs also indicate that no horizontal maneuvers are to be made based solely on information shown on the traffic display. Slight adjustments in vertical speed while climbing or descending, or slight adjustments in airspeed while still complying with the ATC clearance are acceptable.

- **Resolution advisory (RA)**
  When an RA is issued, pilots are expected to respond immediately to the RA unless doing so would jeopardize the safe operation of the flight. This means that aircraft will at times have to maneuver contrary to ATC instructions or disregard ATC instructions. In these cases, the controller is no longer responsible for separation of the aircraft involved in the RA until the conflict is terminated.
  On the other hand, ATC can potentially interfere with the pilot's response to RAs. If a conflicting ATC instruction coincides with an RA, the pilot may assume that ATC is fully aware of the situation and is providing the better resolution. But in reality ATC is not aware of the RA until the RA is reported by the pilot.

Once the RA is reported by the pilot, ATC is required not to attempt to modify the flight path of the aircraft involved in the encounter. Hence, the pilot is expected to "follow the RA" but in practice this does not yet always happen.
Some States have implemented "RA downlink" which provides air traffic controllers with information about RAs posted in the cockpit obtained via Mode S radars. Currently, there are no ICAO provisions concerning the use of RA downlink by air traffic controllers.
The following points receive emphasis during pilot training:

- Do not maneuver in a direction opposite to that indicated by the RA because this may result in a collision.
- Inform the controller of the RA as soon as permitted by flight crew workload after responding to the RA. There is no requirement to make this notification prior to initiating the RA response.
- Be alert for the removal of RAs or the weakening of RAs so that deviations from a cleared altitude are minimized.
- If possible, comply with the controller's clearance, e.g. turn to intercept an airway or localizer, at the same time as responding to an RA.
- When the RA event is completed, promptly return to the previous ATC clearance or instruction or comply with a revised ATC clearance or instruction.

- Clear of conflict

Version of TCAS

TCAS I

TCAS I is the first generation of collision avoidance technology. It is cheaper but less capable than the modern TCAS II system, and is mainly intended for general aviation use. TCAS I systems are able to monitor the traffic situation around a plane (to a range of about 40 miles) and offer information on the approximate bearing and altitude of other aircraft. It can also generate collision warnings in the form of a "Traffic Advisory" (TA). The TA warns the pilot that another aircraft is in near vicinity, announcing *"Traffic, traffic"*, but does not offer any suggested remedy; it is up to the pilot to decide what to do, usually with the assistance of Air Traffic Control. When a threat has passed, the system announces *"Clear of conflict"*.

TCAS II

TCAS II is the second and current generation of instrument warning TCAS, used in the majority of commercial aviation aircraft (see table below). It offers all the benefits of TCAS I, but will also offer the pilot direct, vocalized instructions to avoid danger, known as a "Resolution Advisory" (RA). The suggestive action may be "corrective", suggesting the pilot change vertical speed by announcing, *"Descend, descend"*, *"Climb, climb"* or *"Adjust Vertical Speed Adjust"* (meaning reduce vertical speed). By contrast a "preventive" RA may be issued which simply warns the pilots not to deviate from their present vertical speed, announcing, *"Monitor vertical speed"* or *"Maintain vertical speed, Maintain"*. TCAS II systems coordinate their resolution advisories before issuing commands to the pilots, so that if one aircraft is instructed to descend, the other will typically be told to climb maximizing the separation between the two aircraft.

As of 2006, the only implementation that meets the ACAS II standards set by ICAO was Version 7.0 of TCAS II, produced by three avionics manufacturers: Rockwell Collins, Honeywell, and ACSS (Aviation Communication & Surveillance Systems; an L-3 Communications and Thales Avionics company).

After the Überlingen mid-air collision (July 1, 2002), studies have been made to improve TCAS II capabilities. Following extensive Eurocontrol input and pressure, a revised TCAS II Minimum Operational Performance Standards (MOPS) document has been jointly developed by RTCA (Special Committee SC-147) and EUROCAE. As a result, by 2008 the standards for Version 7.1 of TCAS II have been issued and published as RTCA DO-185B (June 2008) and EUROCAE ED-143 (September 2008).

TCAS II Version 7.1 will be able to issue RA reversals in coordinated encounters, in case one of the aircraft doesn't follow the original RA instructions (Change proposal CP112E). Other changes in this version are the replacement of the ambiguous *"Adjust Vertical Speed, Adjust"* RA with the *"Level off, Level off"* RA, to prevent improper response by the pilots (Change proposal CP115).; and the improved handling of corrective/preventive annunciation and removal of green arc display when a positive RA weakens solely due to an extreme low or high altitude condition (1000 feet AGL or below, or near the aircraft top ceiling) to prevent incorrect and possibly dangerous guidance to the pilot (Change proposal CP116).

Studies conducted for Euro control, using recently recorded operational data, indicate that currently the probability of a mid-air collision in European airspace is 2.7 x 10^{-8} which equates to one in every 3 years. When TCAS II Version 7.1 is implemented, that probability will be reduced by a factor of 4.

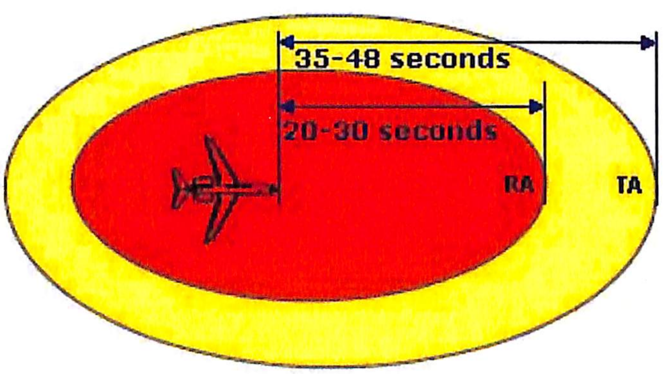


Figure 23: TCAS II typical envelope

Upward sense			Downward sense		
RA	Required vertical rate (FT/MIN)	Aural	RA	Required vertical rate (FT/MIN)	Aural
Climb	1500	Climb, Climb	Descend	-1500	Descend, Descend
Crossing Climb	1500	Climb, Crossing Climb; Climb, Crossing Climb	Crossing Descend	-1500	Descend, Crossing Descend; Descend, Crossing Descend
Maintain Climb	1500 to 4400	Maintain vertical speed, Maintain	Maintain Descend	-1500 to -4400	Maintain vertical speed, Maintain
Maintain Crossing Climb	1500 to 4400	Maintain vertical speed, Crossing Maintain	Maintain Crossing Descend	-1500 to -4400	Maintain vertical speed, Crossing Maintain
Reduce Descent	0 -500 -1000 -2000	Adjust vertical speeds, adjust	Reduce climb	0 500 1000 2000	Adjust vertical speeds, adjust
Reversal climb	1500	Climb, Climb NOW; Climb, Climb NOW	Reversal Descend	-1500	Descend, Descend NOW; Descend, Descend NOW
Increase Climb	2500	Increase Climb, Increase Climb	Increase Descend	-2500	Increase Descend, Increase Descend
Preventive RA	No change	Monitor Vertical speed	Preventive RA	No change	Monitor Vertical speed
RA Removed	-	Clear of Conflict	RA Removed	-	Clear of Conflict

Table 22: TCAS II types of RA

TCAS III

Originally designated TCAS II Enhanced, TCAS III was envisioned as an expansion of the TCAS II concept to include horizontal resolution advisory capability. TCAS III was the "next generation" of collision avoidance technology which underwent development by aviation companies such as Honeywell. TCAS III incorporated technical upgrades to the TCAS II system, and had the capability to offer traffic advisories and resolve traffic conflicts using *horizontal* as well as vertical maneuvering directives to pilots. For instance, in a head-on situation, one aircraft might be directed, "turn right, climb" while the other would be directed "turn right, descend." This would act to further increase the total separation between aircraft, in both horizontal and vertical aspects. Horizontal directives would be useful in a conflict between two aircraft close to the ground where there may be little if any vertical maneuvering space.

TCAS III attempts to use the TCAS directional antenna to assign a bearing to other aircraft, and thus be able to generate a horizontal maneuver (e.g. turn left or right).

However, it was judged by the industry to be unfeasible due to limitations in the accuracy of the TCAS directional antennas. The directional antennas were judged not to be accurate enough to generate an accurate horizontal-plane position, and thus an accurate horizontal resolution. By 1995, years of testing and analysis determined that the concept was unworkable using available surveillance technology (due to the inadequacy of horizontal position information), and that horizontal RAs were unlikely to be invoked in most encounter geometries. Hence, all work on TCAS III was suspended and there are no plans for its implementation. The concept has later evolved and been replaced by TCAS IV.

TCAS IV

TCAS IV uses additional information encoded by the target aircraft in the Mode S transponder reply (i.e. target encodes its own position into the transponder signal) to generate a horizontal resolution to an RA. Obviously, this requires the target aircraft to have some data link capability at a minimum. In addition, some reliable source of position (such as Inertial Navigation System or GPS) is needed on the target aircraft in order for it to be encoded.

TCAS IV has replaced the TCAS III concept by the mid 1990s. One of the results of TCAS III experience has been that the directional antenna used by the TCAS processor to assign a bearing to a received transponder reply is not accurate enough to generate an accurate horizontal position, and thus a safe horizontal resolution. TCAS IV uses additional position information encoded on an air-to-air data link to generate the bearing information, so the accuracy of the directional antenna would not be a factor.

TCAS IV development continued for some years, but the appearance of new trends in data link such as Automatic Dependent Surveillance - Broadcast (ADS-B) have pointed out a need to re-evaluate whether a data link system dedicated to collision avoidance such as TCAS IV should be incorporated into a more generic system of air-to-air data link for additional applications. As a result of these issues, the TCAS IV concept was abandoned as ADS-B development started.

Chapter 9: Controller Pilot Data Link Communications (CPDLC)

General

The CPDLC application provides a means of communication between the controller and pilot, using data link for ATC communication.

This application includes a set of clearance / information / request message elements which correspond to · the phraseologies used in the radiotelephony environment.

Ground and airborne systems shall allow for messages to be appropriately displayed, printed when required and stored in a manner that permits timely and convenient retrieval should such action be necessary.

Where applicable, the communication procedures for the provision of CPDLC shall be in accordance with Annex 10, Volume III, Part I, Chapter 3. Message element intent and text and associated procedures are, in general, consistent with Chapter 6 - Phraseologies.

The standard method of communication between an air traffic controller and a pilot is voice radio, using either VHF bands for line-of-sight communication or HF bands for long-distance communication (such as that provided by Shanwick Oceanic Control).

One of the major problems with voice radio communications used in this manner is that all pilots being handled by a particular controller are tuned to the same frequency. As the number of flights air traffic controllers must handle is steadily increasing (for instance, Shanwick handled 391,273 flights in 2006, an increase of 5.4% - or 20,000 flights - from 2005[1]), the number of pilots tuned to a particular station also increases. This increases the chances that one pilot will accidentally override another, thus requiring the transmission to be repeated. In addition, each exchange between a controller and pilot requires a certain amount of time to complete; eventually, as the number of flights being controlled reaches a saturation point, the controller will not be able to handle any further aircraft.

Traditionally, this problem has been countered by dividing a saturated Air Traffic Control sector into two smaller sectors, each with its own controller and each using a different voice communications channel. However, this strategy suffers from two problems:

- Each sector division increases the amount of "handover traffic". That is the overhead involved in transferring a flight between sectors, which requires a voice exchange between the pilot and both controllers, plus co-ordination between the controllers.
- The number of available voice channels is finite, and, in high density airspace, such as central Europe or the Eastern Seaboard of the USA, there may not be a new channel available.

In some cases it may not be possible or feasible to further divide down a section.

A new strategy is needed to cope with increased demands on Air Traffic Control, and data link based communications offers a possible strategy by increasing the effective capacity of the communications channel.

9.1: Establishment of CPDLC

<u>General</u>

CPDLC shall be established in sufficient time to ensure that the aircraft is communicating with the appropriate ATC unit. Information concerning when and, where applicable, where, the air or ground systems should establish CPDLC, shall be published in Aeronautical Information Publications.

<u>Airborne-initiated CPDLC</u>

When an ATC unit receives an unexpected request for CPDLC from an aircraft, the circumstances leading to the request shall be obtained from the aircraft to determine further action.

When the ATC unit rejects a request for CPDLC, it shall provide the pilot with the reason for the rejection using an appropriate CPDLC message.

<u>ATC unit-initiated CPDLC</u>

An ATC unit shall only establish CPDLC with an aircraft if the aircraft has no CPDLC link established, or when authorized by the ATC unit currently having CPDLC established with the aircraft.

When a request for CPDLC is rejected by an aircraft, the reason for the rejection shall be provided using CPDLC down link message element NOT CURRENT DATA AUTHORITY or message element NOT AUTHORIZED NEXT DATA AUTHORITY or ICAO FACILITY DESIGNATION of CURRENT DATA AUTHORITY, as appropriate. Local procedures shall dictate whether the reason for rejection is presented to the controller. No other reasons for airborne rejection of ATC unit-initiation of CPDLC shall be permitted.

<u>Implementation</u>

Today, there are two main implementations of CPDLC:

- The FANS-1/A System that was originally developed by Boeing, and later adopted by Airbus, is primarily used in oceanic routes by wide bodied long haul aircraft. It was originally deployed in the South Pacific in the late 1990s and was later extended to the North Atlantic. FANS-1/A is an ACARS based service and, given its oceanic use, mainly uses satellite communications provided by the Inmarsat Data-2 (Classic Aero) service.

- The ICAO Doc 9705 compliant ATN/CPDLC system, which is operational at Euro control's Maastricht Upper Airspace Control Centre and has now been extended by Euro control's Link 2000+ Programme to many other European Flight Information Regions (FIRs). The VDL Mode 2 networks operated by ARINC and SITA are used to support the European ATN/CPDLC service.

9.2: Exchange of operational CPDLC messages

General

The controller or pilot shall construct CPDLC messages using the defined message set, a free text message or a combination of both.

The use of long messages or messages with multiple clearance elements, multiple clearance request elements or messages with a combination of clearances and information should be avoided where possible.

When CPDLC is being used, and the intent of the message is included in the CPDLC message set contained in Appendix 5 PANS ATM DOC 4444, the associated message shall be used.

Except as provided below, when a controller or pilot communicates via CPDLC, the response should be via CPDLC. When a controller or pilot communicates via voice, the response should be via voice.

Whenever a correction to a message sent via CPDLC is deemed necessary or the contents of a message needs to be clarified, the controller or pilot shall use the most appropriate means available for issuing the correct details or for providing clarification.

Note:- The following procedures may be applied by the controller, in terms of correcting clearances, instructions or information, or by a pilot, in terms of correcting a reply to an uplink message or correcting previously advised requests or information.

When voice communications are used to correct a CPDLC message for which no operational response has yet been received, the controller's or pilot's transmission shall be prefaced by the phrase: "DISREGARD CPDLC (message type) MESSAGE, BREAK" — followed by the correct clearance, instruction, information or request.

Note:- It is possible that, at the time the voice communicated clarification is transmitted, the CPDLC message being referred to has not yet reached the recipient, or has reached the recipient but not acted upon, or has reached the recipient and acted upon.

When referring to, and identifying, the CPDLC message to be disregarded, caution should be exercised in its phrasing so as to avoid any ambiguity with the issuance of the accompanying corrected clearance, instruction, information or request.

Note: - For example, if SAS445, maintaining FL290, had been instructed via CPDLC to climb to FL350, and the controller needs to correct the clearance utilizing voice communications, the following phrase might be used:

SAS445 DISREGARD CPDLC CLIMB CLEARANCE MESSAGE, BREAK, CLIMB TO FL310.

If a CPDLC message that requires an operational response is subsequently negotiated via voice, an appropriate CPDLC message closure response shall be sent, to ensure proper synchronization of the CPDLC dialogue. This could be achieved either by explicitly instructing the recipient of the message via voice to close the dialogue or by allowing the system to automatically close the dialogue.
Attributes of CPDLC message

Message attributes dictate certain message hand-ling requirements for the CPDLC user receiving a message. Each CPDLC message has three attributes: Urgency, Alert and Response.

URGENCY

The urgency attribute delineates the queuing requirements for received messages that are displayed to the end-user. Urgency types are presented as:

Type	Description	Precedence
D	Distress	1
U	Urgent	2
N	Normal	3
L	Low	4

Table 23: Urgency attributes (uplink and downlink)

ALERT

The alert attribute delineates the type of alerting required upon message receipt.
Alert types are presented in following table:

Type	Description	Precedence
H	High	1
M	Medium	2
L	Low	3
N	No alerting required	4

Table 24: Alert attributes (uplink and downlink)

RESPONS

The response attribute delineates valid responses for a given message element. Response types for uplink messages are presented in Table 14- A for uplink messages and Table 26 for downlink messages.

When a multi-element message requires a response and the response is in the form of a single message element, the response shall apply to all message elements.

Note:- For example, given a multi-element message containing CLIMB TO FL310 MAINTAIN MACH .84, a WILCO response applies to, and indicates compliance with, both elements of the message.

When a single message element clearance or any part of a multi-element clearance message cannot be complied with, the pilot shall send an UNABLE response for the whole message.

The controller shall respond with an UNABLE message that applies to all elements of the request when no element(s) of a single or multi-element clearance request can

be approved. The current clearance(s) shall not be restated.
When a multi-element clearance request can only be partially accommodated, the controller shall respond with an UNABLE message applying to all the message elements of the request and, if appropriate, include a reason and/or information on when a clearance may be expected.

Note: - A separate CPDLC message (or messages) may subsequently be transmitted to respond to those elements that can be accommodated.

When all elements of a single or multi-element clearance request can be accommodated, the controller shall respond with clearances corresponding to each element of the request. This response should be a single uplink message.

Note:- For example, whilst messages containing multi-element clearance requests are to be avoided, a multi-element downlink message containing the indicated message elements:

REQUEST CLEARANCE YQM YYG YYT YQX TRACK X EINN FPL EDDF
REQUEST CLIMB TO FL350
REQUEST MACH 0.84

Could be responded to with

CLEARED YQM YYG YYT YQX TRACK X EINN EDDF
CLIMB TO FL350
REPORT MAINTAINING
CROSS YYG AT OR AFTER 1150Z NO SPEED RESTRICTION

When a CPDLC message contains more than one message element and the response attribute for the message is Y, when utilized, the single response message shall contain the corresponding number of replies and in the same order.

Note:- For example, a multi-element uplink message containing

CONFIRM SQUAWK
WHEN CAN YOU ACCEPT FL410

Could be responded to with

SQUAWKING 5525
WE CAN ACCEPT FL410 AT 1636Z.

Response attributes (uplink)

Type	Response required	Valid responses	Precedence
W/U	Yes	WILCO, UNABLE, STANDBY, NOT CURRENT DATA AUTHORITY, NOT AUTHORIZED NEXT DATA AUTHORITY, LOGICAL ACKNOWLEDGMENT (only if required), ERROR	1

A/N	Yes	AFFIRM, NEGATIVE, STANDBY, NOT CURRENT DATA AUTHORITY, NOT AUTHORIZED NEXT DATA AUTHORITY, LOGICAL ACKNOWLEDGMENT (only if required), ERROR	2
R	Yes	ROGER, UNABLE, STANDBY, NOT CURRENT DATA AUTHORITY, NOT AUTHORIZED NEXT DATA AUTHORITY, LOGICAL ACKNOWLEDGMENT (only if required), ERROR	3
Y	Yes	Any CPDLC downlink message, LOGICAL ACKNOWLEDGEMENT (only if required)	4
N	No, unless logical acknowledgement required	LOGICAL ACKNOWLEDGMENT (only if required), NOT CURRENT DATA AUTHORITY, NOT AUTHORIZED NEXT DATA AUTHORITY, ERROR	5

Table 25: Response attributes (uplink)

Response attributes (downlink)

Type	Response required	Valid responses	Precedence
Y	Yes	Any CPDLC uplink message, LOGICAL ACKNOWLEDGEMENT (only if required)	1
N	No, unless logical acknowledgement required	LOGICAL ACKNOWLEDGMENT (only if required), SERVICE UNAVAILABLE, FLIGHT PLAN NOT HELD, ERROR	2

Table 26: Response attributes (downlink)

Transfer of CPDLC

When CPDLC is transferred, the transfer of voice communications and CPDLC shall commence concurrently.

When an aircraft is transferred from an ATC unit where CPDLC is available to an ATC unit where CPDLC is not available, CPDLC termination shall commence concurrent with the transfer of voice communications.

When a transfer of CPDLC results in a change of data authority, and there are still messages for which the closure response has not been received (i.e. messages outstanding), the controller transferring the CPDLC shall be informed.

If the controller needs to transfer the aircraft without replying to any downlink message(s) outstanding, the system shall have the capability to automatically send the appropriate closure response message(s). In such cases, the contents of any automatically sent closure response message(s) shall be promulgated in local instructions / MATS II.

When the controller decides to transfer the aircraft without receiving pilot responses to any uplink message(s) outstanding, the controller should revert to voice communications to clarify any ambiguity associated with the message(s) outstanding.

Free text messages

The use of free text messages by controllers or pilots, other than pre-formatted free text messages, should be avoided.

Note: - Whilst it is recognized that non-routine and emergency situations may necessitate use of free text, avoidance of utilizing free text messages is intended to reduce the possibility of misinterpretation & ambiguity.

Note: - Provisions concerning the use of pre-formatted free text messages are contained in Annex 10, Volume II,

Emergencies, hazards

When a CPDLC emergency message is received, the controller shall acknowledge receipt of the message by the most efficient means available.

When responding via CPDLC to a report indicating unlawful interference, uplink message ROGER 7500 shall be used.

When responding via CPDLC to all other emergency or urgency messages, uplink message ROGER shall be used.

When a CPDLC message requires a logical acknowledgment and/or an operational response, and such a response is not received, the pilot or controller, as appropriate shall be alerted.

Failure of CPDLC

The controller and pilot shall be alerted to the failure of CPDLC as soon as the failure has been detected.

When a controller or pilot is alerted that CPDLC has failed, and the controller or pilot needs to communicate prior to CPDLC being restored, the controller or pilot should revert to voice, if possible, and preface the information with the phrase: CPDLC FAILURE.

Controllers having a requirement to transmit information concerning a complete CPDLC ground system failure to all stations likely to intercept, should preface such transmission by the general call ALL STATIONS CPDLC FAILURE, followed by the identification of the calling station.

Note: - No reply is expected to such general calls unless individual stations are subsequently called to acknowledge receipt.

When CPDLC fails and communications revert to voice, all CPDLC messages outstanding should be considered not delivered and the entire dialogue involving the messages outstanding should be recommenced by voice.

When CPDLC fails but is restored prior to a need to revert to voice communications, all messages out-standing should be considered not delivered and the entire dialogue involving the messages outstanding should be recommenced via CPDLC.

Intentional shutdown of CPDLC

When a system shutdown of the communications network or the CPDLC ground system is planned, a NOTAM shall be published to inform all affected parties of the shutdown period and, if necessary, the details of the voice communication frequencies to be used.

Aircraft currently in communication with the ATC unit shall be informed by voice or CPDLC of any imminent loss of CPDLC service.

Failure of a single CPDLC message

When a controller or pilot is alerted that a single CPDLC message has failed, the controller or pilot shall take one of the following actions as appropriate:

a) via voice, confirm the actions that will be undertaken with respect to the related dialogue, prefacing the information with the phrase:
CPDLC MESSAGE FAILURE;

b) Via CPDLC, reissue the CPDLC message that failed.

Discontinuation of the use of CPDLC pilot requests

When a controller requires all stations or a specific flight to avoid sending CPDLC requests for a limited period of time, the following phrase shall be used:

((call sign) or ALL STATIONS) STOP SENDING CPDLC REQUESTS [UNTIL ADVISED] [(reason)]

Note;- Under these circumstances, CPDLC remains available for the pilot to, if necessary, respond to messages, to report information and, to declare and cancel an emergency.

The resumption of the normal use of CPDLC shall be advised by using the following phrase:

((call sign) or ALL STATIONS) RESUME NORMAL CPDLC OPERATIONS

Testing of CPDLC

Where the testing of CPDLC with an aircraft could affect the air traffic services being provided to the aircraft, coordination shall be effected prior to such testing.

Chapter 10: Air crash Cases involving ATC error

Air crash Overview

Although flying is generally a safe method of transportation, accidents occasionally happens whether through human error, mechanical failure, or criminal activity. Over the last two decades, there have been between 30 and 65 fatal aircraft accidents per year worldwide. These, and lesser accidents, have to be investigated scientifically in order to gain important lessons about aircraft performance and safety.

The International Civil Aviation Organization (ICAO) requires that a civil aircraft accident be investigated by an independent body belonging to the country where the accident took place. Each country has its own organization taking responsibility for this.

ICAO and the regulator bodies of respective countries have set up a number of policies and procedures in order to insure air safety. Hence when an air crash does occur is it because of multiple failures is procedures, mechanical, weather issue or human error.

Human error is one the most common cause of air crashes

Errors

One of the more common error forms, decision errors, represents conscious, goal-intended behavior that proceeds as designed; yet, the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation or misuse of relevant information. In contrast to decision errors, the second error form, skill-based errors, occurs with little or no conscious thought. Just as little thought goes into turning one's steering wheel or shifting gears in an automobile, basic flight skill such as stick and rudder movements and visual scanning often occur without thinking. The difficulty with these highly practiced and seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures. As a result, skill-based errors such as the breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgot- ten intentions, and omitted items in checklists often appear. Even the manner (or skill) with which one flies an aircraft (aggressive, tentative, or controlled) can affect safety. While, decision and skill-based errors have dominated most accident databases and therefore, have been included in most error frameworks, the third and final error form, perceptual errors, has received comparatively less attention. No less important, perceptual errors occur when sensory input is degraded, or "unusual," as is often the case when flying at night, in the weather, or in other visually impoverished environments. Faced with acting on imperfect or less information, aircrew run the risk of misjudging distances, altitude, and decent rates, as well as a responding incorrectly to a variety of visual/vestibular illusions.

We will review a few air crashes where ATC error played a major contributing factor.

Then main duty of ATC is insure proper separation between aircraft hence in most cases Mid air collision are due to lapse in ATC procedures.

10.1 Case 1

USAir Flight 1493 and SkyWest Flight 5569 Collision

Accident summary

Date: - February 1st 1991
Type: - Runway collision caused by ATC error and negligence
Location: - Los Angeles Int'l Airport
Total Injured: 30
Total fatalities: 37
Total Survivors: 67

First Aircraft

Type: - Boeing 737-300
Operator: - US Air
Passengers: - 83
Crew: - 6

Second Aircraft

Type: - Fairchild Swearingen Metroliner
Operator: - Sky West Airlines
Passengers: - 10
Crew: - 2

Accident details

The Los Angeles Airport consisted of four parallel runways. There were two runways north of the terminal and a set of runways south of the terminal. The runways and taxiways to the north of the terminal were called the North Complex and contained the northernmost runway 24R along with 24L which was closest runway to the terminal on the north side. There was no parallel taxiway between the runways, but there were several taxiways that let aircraft that landed on 24R to cross the inboard runway. Runways 25L and 25R were in the South Complex. To reduce taxi time, flights typically would try to depart from whichever complex was closest. Due to their northerly route of flight, Skywest 5569 was cleared to taxi to Runway 24L instead of the closer Runway 25R. The departure from the gate and taxi were normal and uneventful. They taxied from gate 32 to the runway via taxiways Kilo, 48, Tango, and 45 on a predetermined route called the north route. The taxiways have since been re-designated Charlie, Quebec, Delta, and Delta10 respectively. The flight was briefly not visible from the tower on taxiway 48 between Kilo and Tango in the area known as no man's land.
Immediately prior to SkyWest reaching runway 24L, a Wings West aircraft had landed on 24R and was holding short of 24L. The local controller attempted to cross the Wings West aircraft downfield but the crew had changed frequencies and did not answer, distracting the controller in her attempt to reestablish communications. Shortly after 6 PM local time, as USAir 1493 was making its final approach to LAX, SkyWest Airlines Flight 5569, a twin-engine Fairchild (N683AV), a commuter flight bound for Palmdale with 10 passengers and two crew members on board, was cleared by LAX air traffic control (ATC) to taxi into its takeoff position at the intersection of taxiway 45, some 2,200 feet (670 m) from the runway threshold. After four attempts by the controller, the Wings West aircraft finally responded to the tower and apologized for switching frequencies. The local controller cleared them to cross runway 24L downfield. The same local controller cleared US1493 to land on the same runway with SkyWest still holding in position. Another Wings West aircraft called the tower reporting they were ready for takeoff. The tower controller queried this aircraft, another Metroliner,

about their position, and they stated they were holding short of 24L behind a Southwest 737. The flight progress strip for this flight was still with the clearance delivery controller (another position in the control tower), and the local controller mistakenly thought this Metroliner was SkyWest 5569 and that the runway was clear of all aircraft. The first officer of USAir 1493 recalled hearing this conversation, but did not remember anyone being cleared to hold on the runway.
USAir 1493 touched down near the runway threshold and as the nose was being lowered, the first officer noticed the SkyWest plane on the runway and applied maximum braking. USAir 1493 shortly thereafter slammed into the Skywest aircraft. Both aircraft skidded down the runway with the Metroliner crushed beneath the 737's fuselage. The aircraft veered off the left side of the runway between the extended centerlines of taxiways 48 and 49 and the wreckage came to rest on the far side of the taxiway against a closed fire station building where it caught fire. Large debris from the Metroliner including its tail, wings, and right engine were found on the runway and between the runway and the abandoned fire station.

Aftermath

The first officer, who was the pilot flying the 737 during the accident leg, reported that he did not see the Skywest Metroliner until he lowered the nose of the aircraft onto the runway after landing. He also said that he applied the brakes, but did not have enough time for evasive action. Statements made by passengers who survived the crash were consistent with this testimony.

The Local Controller who cleared both aircraft to use the same runway testified before the NTSB and accepted blame for causing the crash. She said she originally thought the landing USAir plane had been hit by a bomb, then "realized something went wrong... I went to the supervisor and I said, 'I think this (the SkyWest plane) is what USAir hit.'" She testified that rooftop lights in her line of sight caused glare in the tower, making it difficult to see small planes at the intersection where the SkyWest plane was positioned. Just before the accident, she confused the Skywest plane with another commuter airliner that was on a taxiway near the end of the runway. Making matters more difficult, the ground radar at LAX was not working on the day of the accident.

The NTSB's investigation of the crash revealed that the cockpit crew of the landing USAir jet could not see the commuter plane, which blended in with other airport lights. The NTSB cited LAX's handling of the runways which placed much of the responsibility for the runways on the local controllers which directly led to the loss of situational awareness by the local controller. The NTSB also noted that during the previous performance review a supervisor had noted four deficiencies in the controller who ultimately worked the accident aircraft. These deficiencies were not addressed prior to the accident, and two of the deficiencies were apparent in the accident sequence—loss of situational awareness and aircraft misidentification.
At the time of the accident, air traffic controllers at LAX used all four runways for takeoffs and landings. One of the NTSB recommendations was that the runways be segregated with only landings or departures taking place on an individual runway. This recommendation was implemented, but not until after another incident, when on 19 Aug 2004 a B747 landing on 24L came within 200 ft vertically of a B737 holding on the same runway before executing a go around. LAX now uses the outboard runways (24R and 25L) for landings and the inboard runways (24L and 25R) for departures.

Before this accident, the Federal Aviation Administration (FAA) issued a ruling that required airlines to upgrade the flammability standards of materials on board, but the USAir plane had been built before the effective date of those requirements and had not yet been modernized. It was scheduled to be upgraded within the next year. By 2009, all aircraft operating in the United States were compliant.

Conclusion

The safety issues raised by the investigation where:

1. **Air traffic management and equipment at LAX International airport.**

2. Aircraft exterior lighting and conspicuity.

3. Pilot situational awareness during takeoff and landing operations on airport surface.

4. **Air traffic controller workload, performance and supervision.**

The major cause of this accident was the inability of the Air traffic controller to maintain separation which was caused by work overload and lack of necessary equipment.

10.2 Case 2

Bashkirian Airlines Flight 2937 DHL Flight 611 Collision

Accident summary

Date: - July 2st 2002
Type: - Mid air collision caused by ATC and crew error
Location: - Mid air Uberlingen Germnay
Total fatalities: 70
Total Survivors: 0

First Aircraft

Type: - Tupolev Tu-154M
Operator: - Bashkirian Airlines
Passengers: - 57
Crew: - 12

Second Aircraft

Type: - Boeing 757-23APF
Operator: - DHL
Passengers: - 0
Crew: - 2

Accident

The two aircraft were flying at flight level 360 (approximately 36,000 feet (11,000 m) above Mean Sea Level) on a collision course. Despite being over Germany, the airspace was controlled from Zürich, Switzerland by the private Swiss airspace control company Skyguide. The only air traffic controller handling the airspace, Peter Nielsen, was working two workstations at the same time. He did not realise the problem in time and thus failed to keep the aircraft at a safe distance from each other. Only less than a minute before the accident did he realize the danger and contacted Flight 2937, instructing the pilot to descend by a thousand feet to avoid collision with crossing traffic (Flight 611). Seconds after the Russian crew initiated the descent, however, their traffic collision avoidance system (TCAS) instructed them to climb, while at about the same time the TCAS on Flight 611 instructed the pilots of that aircraft to descend. Had both aircraft followed those automated instructions, it is likely that the collision would not have occurred.

Flight 611's pilots on the Boeing jet initially followed the TCAS instructions and initiated a descent, but could not immediately inform the controller due to the fact that he was dealing with Flight 2937. About eight seconds before the collision, Flight 611's descent rate was about 2,400 feet per minute (12 m/s), not as rapid as the 2,500 to 3,000 ft/min (13 to 15 m/s) range advised by TCAS. The Russian pilot on the Tupolev disregarded the TCAS instruction to climb and instead began to descend, as instructed by the controller, thus both planes were now descending.
Unaware of the TCAS-issued alerts, Nielsen repeated his instruction to Flight 2937 to descend, giving the Tupolev crew incorrect information as to the position of the DHL plane. Maintenance work was being carried out on the main radar system, which meant that the controllers were forced to use a slower system.
The aircraft collided at almost a right angle at an altitude of 34,890 feet (10,630 m), with the Boeing's vertical stabilizer slicing completely through Flight 2937's fuselage

just ahead of the Tupolev's wings. The Tupolev exploded and broke into several pieces, scattering wreckage over a wide area. The nose section of the aircraft fell vertically, while the tail section with the engines continued, stalled, and fell. As the nose section of the Tupolev fell at such speed, the flight deck crew soon lost consciousness. The crippled Boeing, now with 80% of its vertical stabilizer lost, struggled for a further seven kilometers (four miles) before crashing into a wooded area close to the village of Taisersdorf at a 70 degree downward angle. Each engine ended up several hundred meters away from the main wreckage, and the tail section was torn from the fuselage by trees just before impact. All 69 people on the Tupolev, and the two on board the Boeing, died.

ATC factors

Only one air traffic controller, Peter Nielsen of ACC Zurich, was controlling the airspace through which the aircraft were transitioning. The other controller on duty was resting in another room for the night. This was against the regulations, but had been a common practice for years and was known and tolerated by management. Due to maintenance work, Nielsen had a stand-by controller and system manager on call. Nielsen was either unaware of this or he chose not to use either of the two additional air traffic controllers available to him. When Nielsen realised that the situation had subtly increased beyond his span of control, it was too late to summon assistance.

In the minutes before the accident, Nielsen was occupied with an Airbus on a delayed Aero Lloyd Flight 1135 approaching Friedrichshafen Airport. Handling two workstations at once, Nielsen struggled with the malfunctioning phone system that he was trying to use to call the Friedrichshafen airport to announce the approaching Aero Lloyd. The main phone lines at Skyguide were down due to maintenance work, and the backup line was defective. This caused Nielsen to spend more time than he anticipated coordinating the Airbus late arrival into Friedrichshafen, and to miss several calls from aircraft. The faulty phone lines also prevented adjacent air traffic controllers at Karlsruhe from phoning in a warning. Due to these distractions he did not spot the danger until about a minute before impact. Had he been aware of the dangerous situation earlier, he could have kept the aircraft at a safe distance from each other. They would have been separated and their collision avoidance systems would not have issued instructions.

Additionally, after Nielsen instructed the Russian crew to descend, he returned to the situation with the Airbus bound for Friedrichshafen, and did not hear the DHL aircraft TCAS report of its descent.

Another factor was that the ground-based optical collision warning system, which would have alerted the controller to imminent collisions early, had been switched off for maintenance; Nielsen was unaware of this. There still was an aural STCA warning system, which released a warning addressed to workstation RE SUED at 21:35:00 (32 seconds before the collision); this warning was not heard by anyone present at that time, although no error in this system could be found in a subsequent technical audit; whether this audible warning is turned on or not, is not logged technically. Even if Nielsen had heard this warning, he might have misinterpreted it until the next radar update 12 seconds later became visible or until the TCAS descent notice by the DHL crew came in; at that time finding a useful resolution order by the air traffic controller is difficult to impossible.

Conclusion

The following immediate causes have been identified:

- The imminent separation infringement was not noticed by ATC in time. The instruction for the TU-154M to descend was given at a time when the prescribed separation to the Boeing 757-200 could not be ensured anymore.

- The Tu-154M crew followed the ATC instruction to descend and continued to do so even after TCAS adviced them to climb. This maneuver was performed contrary to the generated TCAS RA.

The following systemic causes have also been identified:

- The integration of ACAS/TCAS II into the system aviation was insufficient and did not correspond to all points with system philosophy. The regulation concerning ACAS/TCASII published by ICAO and as a result the regulation of national aviation authorities, operational and procedural and partially contradictory.

- Management and quality assurance of the air navigation service company did not ensure that during the night all open workstations were continuously staffed by controllers.

- Management and quality assurance of the air navigation service company tolerated for years during times of low traffic flow at night only on controlled worked the one retired to rest.

10.3 Case 3

British Airways Flight 476 Inex-Adria Aviopromet Flight 550

Accident summary

Date: - September 10th 1976
Type: - Mid-air collision caused by ATC error
Location: - over Vrbovec, SR Croatia, and Yugoslavia
Total fatalities: 176
Total Survivors: 0

First Aircraft

Type: - Hawker Siddeley Trident 3B
Operator: - British Airways
Passengers: - 54
Crew: - 9

Second Aircraft

Type: - Douglas DC-9
Operator: - Inex-Adria Aviopromet
Passengers: - 108
Crew: - 5

Accident

On entering Yugoslav airspace from Austria, flight 476 established radio contact with the Zagreb ACC upper-sector controller Gradimir Tasić at 10:04:12 UTC, informing him that they were at flight level 330 and expected to reach the Zagreb VOR at 10:14. The controller responded by instructing them to select transponder code 2312, and to call again on reaching the VOR.

This was the last communication with the Trident aircraft before the accident.
At around the same time, JP550 contacted middle-sector controller Bojan Erjavec asking for a higher flight level; the aircraft was at flight level 260, or 26,000 feet. FL280 and FL310 were unavailable, so Erjavec informed JP550 of the situation and offered FL350, which the pilots accepted. To get clearance for a higher level, it was necessary to obtain the permission of the upper-sector controller. Erjavec waved his hand to get Tasić's attention, but Tasić (who was working the upper sector on his own, as Mladin Hochberger had gone to search for Tepeš) was far too busy to be interrupted. Middle sector controller Gradimir Pelin was then instructed to co-ordinate the climb out for the DC-9 with Tasić.

According to Pelin, he walked to the upper sector console holding JP550's flight progress strip. He asked Tasić if the DC-9 could climb to FL350. Tasić took the strip from Pelin and looked at it, then asked where the aircraft was at the moment. Pelin then pointed to a blip on the screen approaching Kostajnica. Tasić's response was 'yes, it could climb'. Pelin then noticed an aircraft on the screen coming from the direction of Metlika and asked Tasić about it, who said 'wait until they cross'. Pelin referred to the middle-sector screen to make sure that he had identified the DC-9 positively on the upper-sector screen. He then returned to Tasić and they both watched the targets pass each other, at which point Tasić authorized JP550 to climb. Pelin then called out to Erjavec and said 'yes, climb it'. Upon Erjevec receiving the OK from Pelin, he instructed the DC-9 to climb to FL350. That was at 10:07:40.

At 10:12:03, JP550 called the Zagreb middle-sector controller to inform them that the aircraft was out of flight level 310. The last instructions given by Erjavec to JP550 were to call the upper-sector controller on 134.45 MHz and to stop squawking the assigned squawk code. By instructing JP550 to squawk Standby, Erjavec simply released a code allocated for the middle sector. The data tag for the DC-9 would now disappear from his screen and the aircraft would become merely a point among many others. If everything about this handover had been normal, the DC-9 would have been given a new code on initial contact with the upper sector controller and would have been positively identified on the upper sector screen with its flight number and altitude readout. But this had not been a normal handover because of the ill-handled coordination for the climb. Also, Tasić was busy with other traffic and JP550 did not immediately contact the upper-sector controller. This could have been because the frequency was busy, but the pilots might also have delayed the call for some unknown reason.

By the time JP550 contacted the upper-sector controller at 10:14:04 it had reached the Zagreb VOR and was already climbing through flight level 325. The controller immediately asked for confirmation of the aircraft's level.

Realizing the imminent danger of collision, Tasić instructed the JP550 to stop climbing. In doing so, he reverted to his native Serbo-Croatian language, contrary to the regulations. Unfortunately, this meant that the British Airways plane, even if they overheard this conversation, would have very little chance of understanding their own imminent danger. The controller's last moment attempt to avert catastrophe turned what would have been a near miss into the collision he was trying to prevent. For, by the time JP550 had leveled off it was at flight level 330, exactly the same level as BE476.
Half a minute later, Tasić called BEA476 and instructed it to report passing the next waypoint at Našice.
Tasić continued to call BE476 and JP550, ignoring calls from other aircraft, but to no avail.
A Lufthansa Boeing 737 travelling eastbound on UB5 at level 290 towards Zagreb, was positioned only 15 miles behind the Trident. The co-pilot saw the collision as a flash of lightning and afterwards, out of a ball of smoke, two aircraft falling towards the ground. The Boeing 737 commander, Captain Josef Kröse, reported the sighting to Erjavec, the middle-sector controller.
The two aircraft had collided over the town of Vrbovec. The last 5 meters of the DC-9's left wing sliced through the Trident's cockpit section and forward passenger compartment. The DC-9 went into an immediate nose dive; the Trident remained in flight for a short while before going down. All 63 people aboard flight 476 and 113 people aboard flight 550 were killed.

ATC Factors

Contrary to ATC instructions, a flight progress strip was not produced for JP 550 for a part of the flight within the Upper Sector of Zagreb ACC. This resulted in the Sectors overlooking of the previous information about this flight and untimely planning and safe control.

The Upper Sector Assistant Controller was absent from his duty post from 10:05until 10:10 and probably until 10:13 hours during a period when the Sector Controllers work load was high.
The chief of the shift should have noticed the absence of the Upper Sector Assistant Controller and taken the appropriate measures. However he did not do so. The upper controller was overloaded and this with the absence of the appropriate flight progress strip, lead to the overlooking and late recognition of a conflict situation.

The Upper Sector Controller accepted the coordination on JP 550 to climb to FL 350 without providing adequate procedural separation against BE 475.

The use of Secondary Radar Height Filtering System and no usage of its specific possibilities for tracking of aircraft in other sectors as well prevented the Upper Sector Controller to sight in time and follow vertical movement of JP 550 and to carry out the separation procedure.

There was a critical delay prior to the first call from JP 550 to the upper controller due the volume of RTF traffic on the Upper Sector frequency. Shortly before the collision the crew of JP 550 was warned that they had an aircraft from left to right at FL 335. However the instructions of the Upper Sector Controller for the purpose of achieving any vertical separation between the two aircraft were not sufficiently precise and accurate.

Occasional use of the Serbocroatian language by the Upper Sector Controller in the critical situation, prevented the crew of BE476 from monitoring the RTF conversation between the Upper Sector Controller and JP 550. However, the crew of BE 476 must have heard at 10:14'10 and 10:14'17 the conversation in the English language, in immediate vicinity of Zagreb VOR, i.e. that it estimated to cross Zagreb VOR in the current minute.

Conclusion

This collision was caused by a failure:

- To provide the prescribed separation between the aircraft.
- Untimely recognition of conflict situation
- Application of unprecise measures for prevention of the collision.

This resulted from the following:

- Non- application of rules and regulations by the competent air traffic controllers.
- The overloading of the Upper Sector Controller in a critical situation due to the absence from his post of the Upper Sector Assistant controller.

10.4 Case 4

Saudi Arabian Airlines Flight 763 Kazakhstan Airlines Flight 1907

Accident summary

Date: - November 12th 1996
Type: - Mid-air collision caused by Pilot error and miss communication
Location: - over Charkhi Dadri, Haryana, India
Total fatalities: 349
Total Survivors: 0

First Aircraft

Type: - Boeing 747-168B
Operator: - Saudi Arabian Airlines
Passengers: - 289
Crew: - 23

Second Aircraft

Type: - Ilyushin Il-76
Operator: - Kazakhstan Airlines
Passengers: - 27
Crew: - 10

Accident

Flight SVA 763 departed Delhi at 6:32 PM local time. Flight KZK 1907 was, at the same time, descending to land at Delhi. Both flights were controlled by approach controller VK Dutta. The crew of flight 763 consisted of Captain Khalid Al Shubaily, First Officer Nazir Khan, and Flight Engineer Evris Arabia. On Flight KZK 1907, Gennadi Cherepanov served as the pilot and Yegor Repp served as the radio operator.

Flight KZK 1907 was cleared to descend to 15,000 feet (4,600 m) when 74 miles (119 km) from the airport while Flight SVA 763, travelling on the same airway as Flight KZK 1907 but in the opposite direction, was cleared to climb to 14,000 feet (4,300 m). About eight minutes later, around 6:40 PM, Flight KZK 1907 reported having reached its assigned altitude of 15,000 feet (4,600 m) but it was actually lower, at 14,500 feet (4,400 m), and still descending.[2] At this time, Dutta advised the flight, "Identified traffic 12 o'clock, reciprocal Saudia Boeing 747, 10 miles (16 km). Report in sight."

When the controller called Flight KZK 1907 again, he received no reply. He warned of the other flight's distance, but it was too late—the two aircraft had collided. The tail of KZK 1907 sliced through the left wing of SVA 763. Flight SVA 763 had lost its horizontal stabilizer in its left wing and as a result, went into spiral motion towards the ground with fire trailing from the wing. The aircraft disintegrated under the stress before the wreckage hit the ground at almost 1135 kilometers per hour. The fuselage of Flight KZK 1907 remained structurally intact as it went in a steady but rapid and uncontrolled descent until it crashed in a field. Rescuers discovered four critically injured passengers from the IL-76 but all died soon afterward. In the end, all 312 people on board Flight SVA 763 and all 37 people on Flight KZK 1907 perished.

Investigation

The crash was investigated by the Lahoti Commission, headed by then-Delhi High Court judge Ramesh Chandra Lahoti. Depositions were taken from the Air Traffic Controllers Guild and the two airlines. The flight data recorders were decoded by Kazakh Airlines and Saudia under supervision of air crash investigators in Moscow and Farnborough, Hampshire, England, respectively.

The commission determined that the accident had been the fault of the Kazakh Il-76 commander, who (according to FDR evidence) had descended from the assigned altitude of 15,000 feet (4,600 m) to 14,500 feet (4,400 m) and subsequently 14,000 feet (4,300 m) and even below that. The report ascribed the cause of this serious breach in operating procedure to the lack of English language skills on the part of the Kazakh aircraft pilots; they were relying entirely on their radio operator for communications with the ATC who in turn did not have his own flight instrumentation but had to look over the pilots' shoulders for a reading. Kazakh officials stated that the aircraft had descended while their pilots were fighting turbulence inside a bank of cumulus clouds. Also, a few seconds from impact, the Kazakh plane climbed slightly and the two planes collided. This was due to the fact that only then did the radio operator of Kazakh 1907 discover that they did not fly at 15000 ft. Had the Kazakh pilots not climbed slightly, it is likely that they would have passed under the Saudi plane. He asked the pilot to do so and the captain gave orders for full throttle and the plane climbed, only to hit the oncoming Saudi plane. The tail of the Kazakh plane clipped the left wing of the Saudi jet, severing both parts off their respective planes. The counsel for the ATC Guild denied the presence of turbulence, quoting meteorological reports, but did state that the collision occurred inside a cloud. This was substantiated by the affidavit of Capt. Place, who was the commander of the aforementioned Lockheed C-141B Starlifter which was flying into New Delhi at the time of the crash. The members of his crew would file similar affidavits. The ultimate cause was held to be the failure of Kazakhstan Airlines Flight 1907's pilot to follow ATC instructions, whether due to cloud turbulence or due to communication problems.

Indira Gandhi International Airport did not have secondary surveillance radar, which produces exact readings of aircraft altitudes by reading transponder signals; instead the airport had outdated primary radar, which only produced readings of distance. In addition, the civilian airspace around New Delhi had one corridor for departures and arrivals. Most areas separate departures and arrivals into separate corridors. The airspace had one civilian corridor because much of the airspace was taken by the Indian Air Force. Due to the crash, the air-crash investigation report recommended changes to air-traffic procedures and infrastructure in New Delhi's air-space: Separation of in-bound and out-bound aircraft through the creation of 'air corridors', installation of a secondary air-traffic control radar for aircraft altitude data, mandatory collision avoidance equipment on commercial aircraft operating in Indian airspace and reduction of the airspace over New Delhi which was formerly under exclusive control of the Indian Air Force.

The Civil Aviation Authorities in India made it mandatory for all aircraft flying in and out of India to be equipped with an ACAS (Airborne Collision Avoidance System). This was the first time in the world that ACAS was mandatory.

Conclusion

The following immediate causes have been identified:

- Pilot error on part of the IL-76 Pilot to maintain the assigned altitude.
- Mis-communication and a delay in communication as the IL-76 commander was not familiar with English and had to get information passed on from the radio operator.

The following systemic causes have also been identified:

- Absence of Secondary surveillance radar at Delhi airport.
- Congested air corridors

Recommendations

Air-ground communication with ATC may be governed as follows:-

- In general, the emphasis should be on direct Pilot-Air Traffic Controller Communications at all times irrespective of crew composition.
- In the terminal control area, the Pilot must have communication with Air Traffic Controllers to avoid time lag in compliance of ATC instructions.
- In the en route phase, a crew other than pilots may handle ratio communications with ATC subject to basic flying instruments being in his view and that he is appropriately qualified.

Chapter 11: Free Flight

Summary

Free Flight is more than just freely roaming the sky. It is about jobs, technology, money, politics, economics, and ecology. It will be a difficult task to get these diametric fields together and work on the common goal of Free Flight. From a pilot's perspective, Free Flight is full of direct-to, self-separation en-route, circum flying tall clouds without needed clearance, optimized trailing of other aircraft, and more. In short: saving fuel and gaining time.

Accurate navigation is a prerequisite for all involved systems to supervise and recognize traffic, as well as predict future routing conflicts. Further up-grades of airborne systems are required: an FMS that can process up-linked data, better displays to provide a traffic situation picture, and extended digital communications. All this needs again to be fitted into a redesigned cockpit layout that will have evolved from a pure flying seat to a flight management workplace.

A center-piece of technology that enables Free Flight is the self-separation unit. It relieves the ATC controller of his duty to separate aircraft, and will do it faster and more accurate. Separations will not contain excessive additional distances, and the more traffic is in the vicinity, the advantage of a network-centric design in contrast to the human-centric ATC will become apparent.

Therefore, ATC will go thru radical changes as well. However, it is not about to dismiss ATC personnel, but more about a continuing change of the profession's duties such as area, departure or arrival control. Fewer controllers in the classical sense will be needed, but new jobs will be created in a Free Flight environment, which certainly opens new prospects.

It will be maybe too late if Free Flight arrives in 20 years or more. This means that the concept of Free Flight was embraced at a very late point of time, which let many years pass by without having benefited from reduced costs of running nav aids, from optimizing and standardizing airspaces, and from getting rid of other short-comings of the current ATC system (e.g. delays). It also means that it will very likely have to be introduced in a rush. The mentioned predictions demand a faster pace. Instead of going different ways on many continents, it is mandatory that all stakeholders act soon together.

To summarize, this chapter tries to provide insight information into the whole thematic and calls for accelerating the pace from all stakeholders to work towards the goal of Free Flight.

11.1 Scope

It has been talked about it for years, but progress to this noble goal has been slower than expected, and some major hurdles are still to be overcome. There are many Free Flight related sub-projects in the U.S., in Europe, and elsewhere, which tackle the progress of aviation in different ways. From time to time and worldwide are specific meetings being held, conferences organized, articles written and even thesis made. Free Flight is a big and hotly debated subject in circles of specialized commissions like Europe's EUROCONTROL, the U.S. Federal Aviation Authority (FAA) and the Requirements and Technical Concepts for Aviation (RCTA)commission, from where again many professional air traffic and airline employees get their information and background knowledge.

Acquiring more and more information about Free Flight for this thesis, there is always more and more to discover and write about. But time is running out fast for delivering this thesis. So not all what is out there could be incorporated, or could be investigated in-depth. But this leaves it open to continue on the subject for someone else sometime.

For readers who are not pilots or have nothing to do with aviation, this thesis will also gives a fair insight to aviation and an airline pilot's working day.
For a professional aviator, this shall be an interesting documentation of current airplane and air traffic systems and about the potential changes in the future. For the air traffic specialist, this thesis will probably not contain lots of new information, maybe evensome speculation that seems to be far-fetched. The intention is to look at Free Flight from the cockpit seat. Some concepts will be explained thoroughly, others are only grazed. Maybe some have even been missed to mention. Hopefully, though, this thesis will generate some discussions, and constitutes another (small) step towards Free Flight.

What is Free Flight?

"Free Flight is an innovative approach for a modern ATM system[3] born out of the need for increased user[4] flexibility, operating efficiencies, and safety to meet the growing demand of air transportation" (RTCA, 2002).

With the Free Flight concept, pilots under IFR have the freedom to select their flight path and can adjust their speed any time. But they also bear the responsibility for separation. ATC, however, could impose restrictions to ensure separation, preclude exceeding airport capacity, prevents flying through restricted areas, and ensure the safety of flights. Free Flight will embrace the entire range of aviation operations and will address the interest of all users. It will not only include the free flying part of 'operation flight', but also the concept of free filing of flight plans (for AOCs) and free flowing of traffic (for ATMs).

It will not be easy to switch from the established, conventional ATC system to a Free Flight system. Avionics in the cockpit and the whole ATC infrastructure will be affected.

Questions like

- "Why will Free Flight be inevitable",
- "Is such a chaotic system not dangerous?",
- "Who will bear the responsibility of separation?",
- "How will it be paid for?", or
- "What and when is the best way to introduce it?"are not entirely answered yet.

Today, commercial air traffic worldwide is straining with the burdens of today's system. The aviation community cannot afford to wait for long-term development initiatives to produce needed benefits. If more and more restrictions of today can be removed, the sooner flying will be 'free' again.

11.2: Obstacles to Overcome

Required Changes

Psychological Aspects

Humans tend to be quickly satisfied once things go steadily and smoothly. One possible argument is "why change a proven system?'" If it becomes necessary to perform a change in one way or the other, it is natural to resist it as long as one can. If, however, unavoidable changes are recognized and understood, it is best to tackle them early enough to lessen the pain of change.

McKenna (2000) summarizes in the chapter 'Organizational Change and Development' in his student's handbook 'Business Psychology and Organizational Behavior': The sources of resistance to change at the organizational level are over-determination, narrow focus of change, group inertia, threatened power. At the individual level they were identified as habit, security, economic considerations, fear of the unknown. Approaches to controlling resistance to change were identified as education and communication, participation, facilitation and support, negotiation and agreement. Free Flight will be a quantum leap for aviation. Aircraft and ground equipment have to evolve with computing power and with human friendly interfaces. Pilots will get the ability to enjoy (mostly) unrestricted flying with the additional responsibility of controlling and avoiding other traffic safely which changes their workplace to one of a manager and supervisor of the flight.

Controllers work with tools that will cope with more traffic, will mainly manage traffic volumes and will, rarely, but then vigorously, interfere with separation issues. These workplace-related changes of the directly involved professionals should not be underestimated. A too fast approach could endanger the willingness to change. First, it must be explained and made clear in a neutral way that with the 'old' way of handling air traffic sooner than later more capacity problems will arise. Secondly, a convincing, open strategy that not only emphasizes the benefits, but deals with the temporarily negative effects as well, must put in place. Only with developing a common vision the goal of a safe Free Flight system can be reached.

Incompatible Standards

Many things in this world make you wonder how this came about in the first place. So why was there no standardization? There are two main reasons:

- Short-term thinking: local calculations of costs and benefits did not anticipate a boom of worldwide travel spreading its standard.

- Commercial interest: it was purposely done so to protect the own market from a foreign product that had gained worldwide acceptance and could damage the own industry or national know-how.

And what are the consequences in the long term? Everyone has higher costs by adapting to the situation, has more design constraints for a product to meet all respective standards, and finally annoy the end-users.

All this is also true in aviation as these examples show:

- Altimeter: millimeters Hg / hPa
- Lengths: inches / meters
- Weights: lbs / metric tons
- Pressure: PSI / Pa
- Thrust: lbs / N
- Visibility: statute miles / meters
- Altitude: feet / meters
- Procedures: TERPS / PANS-OPS

Not only in aviation have unit mix-ups caused confusion, waste, and sometimes fatalities, but also in space. Everybody agrees that life would be much easier if there were not so many various standards. But is it easy to change? And if the intention would be there, how should it be approached? In these numerous workshops, conferences from governmental organizations, NGOs, and ICAO meetings that are held, this subject is addressed frequently but usually turns into endless discussions with no progress is reached. Other ways of defining a standard is with a new generation of a product (e.g. aircraft family) replacing an old standard. Or, in a more 'darwinistic' way, when market forces reign and a certain standard becomes the dominating one - even if it is not the better standard (e.g. PC market). If our world had more equally strong nations they would more easily be ready to find common grounds on standardizations. Free Flight would cope with the aching ATC system. With collaboration and incremental implementation a new aviation standard can be established.

National Interests

Difficulties arise when it comes to a border-crossing system. This stems usually not from a technical side but from a political side.
The most cited excuses are for not being able to cooperate for the sake of all:

- Loss of control of sovereign airspace.
- Restrictions for the own Air Force.
- 'National security!'
- Not being 'Number 1' anymore.
- Fear of losing know-how and jobs.
- Protecting the domestic industry from competition.

Many parliaments fear the loss of power should any ratifications come from foreign nations. So some nations proceed with own projects aiming for improvements in their aviation system. In the U.S., the FAA way of preparing the ATM system is the SWIMS. The Europeans will digitalize all flight related information with the FDM project. The navigation standard for Europe will be P-RNAV starting from October 29, 2005. In the U.S., the goal will be performance-based navigation. Two RNP standards are the result. "A solid global RNP regulatory requirement needs to be created!"
The current FAA administrator, Marion C. Blakey, indicated in an interview that the U.S. has a tremendous advantage of having pioneered much of what now exists in aviation and of having the largest, most complex aviation system in the world.

The U.S. wants to maintain its leadership in building a safe, global ATC system, but, contradictorily, this would not mean U.S. control. Most of the advanced safety technologies will be exported by U.S. companies, especially to new key parts of the world like China or India (AW&ST, Raising the Safety Bar).
Knowing all the backdoors of a global ATC system could mean, when remembering recent wars, that infiltration into ATC systems (e.g. providing false targets, hide traffic or shutting it down) would be dangerously easy.
Contrary in Switzerland, any drive to create advanced systems are hindered by a monopolistic ATS environment, almost broke airlines and a very conservative federal civil aviation bureau (FOCA) which is still struggling with reorganization after it neglected safety standards and oversight duties (van de Geest et al, 2003) and was confronted with sleaze.

A major issue for Free Flight will be certification. If different nations strive for incompatible solutions, then a global oversight committee should act up to define a single standard. In mind comes ICAO or even the U.N. - but these agencies have a weak reputation to set new standards; rather, they just take over existing norms and declare them applicable worldwide.

11.3: Future Techniques

Universal Navigation

When all aircraft will have the same accurate navigation capability this would benefit especially terminal areas where the airspace could be highly optimized:

- Flight tracks are more precise and therefore more trustworthy and predictable.
- Flexible airport access routes will have less constrains due to less separation to traffic and obstacles, even in poor weather situations. Throughput can then be increased.
- Punctuality then becomes Swiss-clock like.
- Delays are out of the ordinary. In short, this would make it more time and cost efficient and all this with gain of safety.

Approaches into an airport would be the same everywhere: no non-precision, no ILS approaches anymore, but GNSS provided RNAV or LPV approaches. No navigations ground stations will be required except GBAS ground stations near airports for high precision automatic landings. Since all routings will be user-preferred no published routes will need to exist and some waypoints will only be needed for the respective approaches / departures and possible holding fixes. All other navigational fixes that are required for filing a flight plan or negotiating an in-flight rerouting would be named according to the geographic coordinates.

Airspace Redesign

To still permit GA VFR flights without satellites and ATC control two kinds of airspaces are eventually required: One for VFR and the other for IFR traffic.VFR airspace is normally defined up to around 3000m, in mountainous regions maybe 4000m. On the other hand, around terminal areas VFR traffic would be vastly restricted to permit dynamic approach and departure paths. However, properly equipped VFR traffic will be able to penetrate IFR airspace without hassles. Another necessity will be that entire regions have a unified airspace. This will make it easier to enforce changes and shorten any kind of bureaucratic hindrances. On the other hand, a too centralistic approach could be insecure. Power shortages, natural disasters, and so on, necessitate having several ATM centers that can back up others. Should Free Flight be introduced in steps, there could be the situation that a Free Flight airspace lies next to a 'conventional' airspace, and coordination for Free Flight capable traffic in and out could become a burden. Imaginable would be a time / altitude / speed constraint to merge such traffic. This task is done already when entering the OTS, so no new difficulties are expected here. Once all airspace is 'free', this coordination will eventually cease to exist.

Directional Freedoms

Even before airways are abolished, user-preferred routings and profiles of the flight path will be possible to file, fly and alter. The AOC would have to calculate (or let calculate for smaller airlines) an optimized routing in space and time. This flight plan would be filed with ATC, which in turn will determine if airspace saturation anywhere would occur. If so, a slot would be assigned (e.g. too many aircraft departing at the same time), or in case of an en-route 'overload' a re-routing would be suggested.
The advantage is manifold. Shorter routings, optimized with the prevailing winds and temperatures, cruising on the optimal flight altitude. In-flight alteration could be flown in case of circumstances like flying around thunderstorms, avoiding restricted or turbulent areas, a.s.o. Should a conflict arise because of such a change of direction or altitude the necessary separation system must be available.

Managing own Separation

Until today, it is the pilot's responsibility to ensure the safety of flight by avoiding collisions with other aircraft by:

- Maintain traffic situational awareness (from sources like traffic information from the controller; the 'party line' effect in voice communications; the TCAS traffic display; vigilant out-the-window monitoring; and the flight crew's prior experience);

- Follow the controller's clearances and instructions

- See and avoid other traffic;

- Use TCAS, if installed.

On the other hand, the controller uses instructions and clearances to preserve spacing in time, distance, or altitude. In the future, thanks to better sharing of traffic information between aircraft and ATC, the pilots can become greater involved in managing traffic separation. Because separation can then reliably be reduced to the respective minima, increase in airspace capacity and even safety can be accomplished.
The airborne separation assurance system (ASAS) is a new tool that provides flight information concerning surrounding traffic, and assists the flight crew to maintain separation of their aircraft from one or more aircraft (ASAS Action Plan 1, 2001). ASAS will not be based on SSR signals and data but entirely on extensive ADS derived information. Such an in-flight separation system will require major reliance on aircraft avionics and changes to present responsibilities and procedures to ensure aircraft separation. It will require rigorous safety analysis and validation and will need to demonstrate conclusively that the ASAS application meets or exceeds the required safety levels before implementation. Also, equipment failure and human error must be considered and methodologies and guidelines will need to be agreed at the international level.

There are three iterations of ASAS developments, package I, II, III. They are differentiated by the amount of ASAS applications they contain (based on the experience of the previous package) and each of them is planned with a consecutive timeframe in mind.

Four ASAS application categories have been defined by the FAA-EUROCONTROL R&D committee that take into account conceptual, operational procedures, human factors, aircraft systems, enabling technologies and users' perspective and implementation. They are:

- **Airborne Situational Awareness**
  These applications are aimed at enhancing the flight crew's knowledge of the surrounding traffic situation, both in the air and on the airport surface, and thus improving the flight crew's decision process for the safe and efficient management of their flight. No changes in separation tasks or responsibility are required for these applications.

- **Airborne Spacing**
  These applications require the flight crews to achieve and maintain a given spacing with designated aircraft, as specified in a new ATC instruction. Although the flight crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged. An example would be in-trail spacing in the OTS.

- **Airborne Separation**
  In these applications, the controller delegates separation responsibility and transfers the corresponding separation tasks to the flight crew, who ensures that the applicable airborne separation minima are met. The separation responsibility delegated to the flight crew is limited to designated aircraft, specified by a new clearance, and is limited in time, space, and scope. Except in these specific circumstances, separation provision is still the controller's responsibility. Implementation of these applications will require the definition of airborne separation standards.

- **Airborne Self-Separation**
  These applications require flight crews to separate their flight from all surrounding traffic, in accordance with the applicable airborne separation standards and rules of flight. This is the ultimate goal of ASAS. However, ASAS must be safe without relying on TCAS, and alerts should be clearly distinguishable from each other. Situations are also imaginable where ASAS needs to suppress TCAS alerts (e.g. in a parallel approach), and on the other hand when TCAS is the ultimate tool to 'safe the day'.

Expected Benefits

Airspace users may realize different benefits according to each ASAS application and environment in which it is used. Some benefits are: '

- **Safety**

  - **Situational awareness** presenting the flight crew with flight information concerning surrounding traffic together with a navigation display and possibly surface map. This would
    - Assist flight crews with see-and-avoid duties.
    - Assist flight crews in avoiding blunders or errors.

- Provide information to facilitate correct decision-making.
- Provide flight crews with information consistent with that available to the controller.

➢ **Automation**
ASAS would use various sources of position and intent data. ASAS would support actions without reliance on controller by generating guidance to the crew for safe and timely resolution of conflicts or maintenance of safe separation.

➢ Guidance presented directly to flight crew ASAS guidance would not depend on ground-to-air communication. This should prevent the common hazard of missed or garbled radio communications.

- User flexibility and flight efficiency ASAS would support to fly preferred routes or trajectories, which are more fuel or time- efficient, than can be allowed with current ATC practices and traffic levels. This capability would be supported by ASAS providing a monitoring or separation function that supplements or replaces ATC separation.

- Increased throughput / capacity benefits ASAS could support increases in aircraft throughput at an airport or passing through a volume of airspace. Arrival or departure capacities, or sector traffic limits, often cause severe bottlenecks that limit the capacity of the ATM system. It is anticipated that significant capacity benefits could result from implementation of ASAS. Many of these capacity improvements could be enabled in part by reductions in workload for controllers and flight crews. Examples include:

  ➢ Reduced communications between flight crews and controllers.
  ➢ Automated monitoring and alerting in the cockpit.
  ➢ Delegation of specific separation responsibilities and the transfer of the associated tasks to the flight crew.
  ➢ Make environmental benefits possible

- Environmental benefits ASAS supports to fly preferred routes and altitudes thus permitting to fly optimum profiles which reduced exhaust emissions and noise. However, there is a cost associated with the introduction of ASAS. For AOCs and ATSPs the benefits must be sufficient to justify the investments costs. "The use of incentives or, where appropriate mandates, as a way to accelerate deployment, should be considered." (ASAS-TN, 2004).

<u>Current Concerns</u>

ASAS installed on a flight deck has various implications and will face numerous challenges. Generally, it is agreed that the human must be in control and must be able to monitor such automatic systems. This is called human-centric design. (A summary about automation of leading researchers can to be found in appendix F).For Pilots, safety is paramount, but then again nothing is perfect, so they are willing to use ASAS. Pilots need to have ASAS integrated in to the present automation systems, get proper training for equipment and procedures, and build up trust that this system performs as designed. However, workload to manage ASAS should not be distracting.

TCAS warnings must work independently and will aid in a worst-case scenario. Because of ASAS's constant checking of up-coming conflicts, almost no TCAS TAs and even RAs should be trigged, fortunately. From the controller's perspective, delegation of responsibility must first be accepted. The usual workload will be reduced, and the controller becomes more of a 'traffic supervisor'. On the other hand, in an out-of-normal situation intervention from the controller must be possible. With new systems new errors are generated, therefore the human being will have to cover any shortcomings. ASAS needs to be placed as part of a holistic concept (Dr. Smoker, ASAS-TN). Implementation must come in steps, such as in separate low-density airspaces and with one ASAS application after each other.

Right now there is some lack of commitment to ASAS. ATC is reluctant to press ahead (human factors, task transfer, etc.) while airlines and aircraft manufacturers do not want to invest (no global certification, required aircraft retro-fitting, etc.) in an immature system yet. However, the needed economic drive to abandon the old, expensive system will eventually convince both parties to proceed further with ASAS. By applying more and more functions to ASAS in an iterative way, it will not be too complex from the beginning for all stakeholders and thus permit acceptance and commitment. However, as Dr. Smoker mindfully noted, "one must not underestimate the amount of work that needs for implementation to obtain certification!"

Interesting Free Flight Studies

An interesting study about airborne separation in a Free Flight environment has been done by the NLR (Hoekstra, van Gent & Ruigrok, 2001). They started off with two the allegations "Free Flight with airborne separation will result in an uncontrolled, dangerous jungle without a firm, central controlling element such as ATC!", and "Pilots haven't got the time, the training nor the mental resource available to function as ATC on top of flying the aircraft!"

Then they tested the en-route Free Flight goals of having more airspace capacity and reduced costs via user preferred routing with the concept of

- No ATC control.
- All aircraft fullyequipped with a air-to-air data link (e.g. ADS-B) and a EFIS with CDTI.
- Full user preferred routing, speed and cruise altitude.

Comparing the task for a pilot in an ATC controlled flight vs. a non-controlled environment (Free Flight), the time used to communicate with ATC was replaced with separation tasks, thus not affecting the pilot's workload. Having an ASAS with a comfortable prediction mode would even prevent getting into a zone of imminent required actions. Three different ATM concepts that permitted Free Flight and non-Free Flight traffic to mingle had been tested:

- Flight level division: where above a certain altitude only Free Flight aircraft were allowed.

- Protected Airways: controlled aircraft had to stay on airways but enjoyed the right of way.

- Fully mixed: ATC used longer 'look ahead' times, so equipped aircraft have the 'right of way'.

The results showed that the fully mixed ATM condition was best from the pilot's perspective and the flight level division was most optimal in the controller's opinion. Furthermore, the flight deck crew was able to handle higher traffic densities than the ground controller.

Another, even more interesting simulation has been executed by the same Dutch engineers, proving that in high density situations the power of distributed systems (ASAS) is far more effective than centralized control (by ACC). They simulated conflicts with a programmed module that had a conflict look-ahead time of 5 minutes with several aircraft in various scenarios.
When two targets were released against each other, both maneuvered cooperatively like two magnetic balls repelling each other. This was achieved by small vertical speed, heading and speed changes. In reality, with such subtle maneuvers passenger comfort is not affected at all. Then they increased the amount of traffic. They noted that when increasing traffic density three-fold, conflicts rose nine-fold, but were resolved all perfectly! Even a super-conflict was created: 8 aircraft with the same speed, at the same level, towards the same point in space and time. For test reasons any vertical evasion was not permitted (e.g. to simulate a restricted airspace above or below). After some initial conflicts the situations solved it selves quickly. It was a demonstration of the power of parallel systems and showed that per aircraft the number of conflicts was quite low. An ATC controller would not have been able to cope with such a situation at all.

They then exposed airline pilots to these scenarios on flight simulators after a few hours of training and concluded:
"No significant increase in workload had been found during this cruise phase. The acceptability was surprisingly high and, further, the subjective safety was equal or better than today's situation. In summary, none of the sub-studies could refute the feasibility of airborne separation, even under extremely dense and constrained traffic situations." (Hoekstra et al, 2000).

Approach Trajectories

Free Flight in the cruise phase with self-separation is easy compared to an optimum trajectory during descent and approach until short final. Here a ground based, intelligent systems needs to assign speeds and 3D-trajectories to sequence inbound traffic and optimize separation according wake-turbulence category. This individual solution for an approaching aircraft would be up-linked so that the FMS has the necessary dynamic approach path with all turns and speed adjustments to enable a speedy and still safe approach. Each arriving traffic would have a different approach trajectory, depending on its direction it is coming from, altitude, and sequence it has to merge with other traffic. Traffic would be guided to a point about 5 NM short of the active runway.
In this way even multiple active runways could be operated. If a runway needs to be closed, a swift rerouting could be assigned, and all involved aircraft would adjust their

approach trajectory. ASAS would be aware of this flexible-pipe-like approach path and would not trigger any nuisance traffic separation suggestions. TCAS would be still the last barrier should some aircraft not follow the assigned trajectory and endanger other traffic.
In situations such as winter operations or Thunderstorms in the vicinity or even overhead the airfield, a method to channel traffic is still the holding pattern. When approaches can be resumed or the number increased again, traffic that is short of fuel can be prioritized or traffic from different holding patterns can be merged e.g. According to spent time in the holding stack. The ATC controller would manage traffic by using tools to provide an efficient and safe arrival and departure flow. He would merely supervise the solutions such a ATC approach system calculates and would monitor the compliance of the aircraft as well.

Radical Cockpit Layout

In a current, modern cockpit there are multiple screens and sources a pilot has to observe which concerns navigation:

- PFD (horizon),
- ND (tracking / navaids / TCAS),
- MCDU (FMS flightplan / CPDLC inputs),
- DCDU (CPDLC messages),
- And charts and maps.

And it seems to get even more complex: Screens for ASAS, which depicts the traffic in the neighborhood better than the ND, would be installed somewhere in the cockpit as well. The solution lies in two single, large screens for each pilot, and a retractable keyboard (with a track ball) from below the screens that is integrated in the small working table.

The screen could even provide a 3D / holographic display, showing the dynamic approach 'pipe' better. On these screens all interaction with ATC, FMS, the electronic flight-bag (no paper charts), even limited Internet access for emailing and reporting, would be performed in different windows on the 'desktop'.

On the first screen, vital flight information like the PFD would always be displayed. On the second one, windows of different tools could be viewed, and in case of an incoming clearance or other alert the more important window would come up to the front.

A further necessity is to permit ASAS to communicate with the FMS. ASAS needs flight plan and aircraft performance data to operate properly, and vice versa in case of a required separation resolution, the avoidance flight path information will be imbedded into the flight plan in split seconds and flown by the autopilot accordingly. Having such a futuristic working-place, one thing with new flight deck technology may not be omitted: Safety. The human factor is still the biggest
In creating but also preventing errors. An article with the title 'Human Factors Aspects of Flight Deck Design' summarizes this as follows:
"It has been demonstrated by analysis of accidents that the primary risk to flight safety is 'human error' [e.g. CAP 681]. It is also well established that the design of the aircraft flight deck and other systems can strongly influence the likelihood, and result,

of an error by the crew. Therefore the design of the flight deck should be assessed to limit the risks arising from human performance considerations [including error]. This should be a priority in addressing safety standards of aircraft design.
Action is needed even to sustain existing safety levels because there are radical new changes in technology, especially the flight deck, in current JAA certification projects. These changes will affect the interaction between the aircraft and the flight crew and this may impact safety." (JAA, 2001)

New Controller Tools

The work of a controller will consist less with talking and tactic control but with managing and strategic control. He will become air traffic managers applying many new tools. Currently, more of them are getting in the field, as this example shows:
"The Future Area Control Tools Support (FACTS) R&D project aims to develop advanced computer assistance tools using trajectory prediction and medium-term conflict detection. It is intended to support the future operation of The New En Route Centre (NERC) at Shanwick and the New Scottish Centre (NSC) at Prestwick, in particular by providing extra capacity to meet increasing traffic demand. The objective of providing assistance from such tools to the sector controller team is to reduce the workload associated with each flight as it passes through the sector, and thus enable an increase in the sector capacity." (Whysall, 1998).
Future technical concepts for ATM and tools give the controller the knowledge of an aircraft's intentions along its route allows the controller to approve or issuing conflict free trajectories based on the user-preferred routing. 4D-trajectories can be difficult for the controller to interpret manually, so computer assistance is needed for helping to foresee conflicts and design a solution with a minimum intervention.
Other tools will include improved spacing due to wake turbulence in approach, expeditious paths selection on departure, and greater use of CPDLC. But one thing is sure: it will get more complex, and also human factors on ground will be a big issue.

Human Interface

With using new technologies it will be the human who will commit most errors. All newly designed avionics, programmed tools, and installed terminals and antennas will have an important function in this new worldwide ATC network. It needs to be designed in a human friendly way - nothing missing, but without unnecessary gadgets with error-causing potential.
Next to rigorous testing of all hard- and software an eye must be laid on how all participants work with it.

Pilots will bear more responsibility. Flying will still be the most important task, but e.g. During an approach, concentrating on the traffic around will add to the workload. Also, pilots will have more 'head-down' time, watching screens and monitor the automatic or decide about the suggested solution. A psychology study in a simulator performed by people from University of Illinois revealed that pilots with a traffic situation screen located within the cockpit had a head-down time of 25%, and when forced to evade traffic preferred climbs versus descends or turns and speed adjustments (Wickenset al, 2002).

ATC controllers have less normal separation tasks to manage, but they need to be ready when immediate intervention should be required. Maybe bottlenecks will just shift to other places, like airport congestion, which then controllers need to handle by steering the traffic volume.

However, studies have revealed that some aspects of Free Flight can significantly hinder the controller's situation awareness and performance because of being 'out-of-the-loop'. New and better procedures will inevitably come around. Training, checking and obtaining qualification will be mandatory for all involved. It may even come down to different selection processes for pilots and controllers.

Security and Safety

Not to be neglected is the security aspect! What happens if several GNSS satellites will get damaged after an extensive solar outburst? Or a nuclear detonation in space renders half of them useless? Aircraft would be without electronic navigation capabilities, and would need to fall back to dead-reckoning - weather permitted!
Less serious events could occur if ADS connection is lost and such traffic becomes 'invisible'; or someone tampers with the data and false targets are displayed. These and more security related issues must be solved. Regarding navigation, a proposed back-up system is to leave all DMEs in service and even build new ones in newly strategically locations. With two DME stations it is quickly possible to determine a quite exact position, especially if they are located perpendicular from each other. Therefore, with a future Free Flight project, a safe (and cheap) navigation back-up system like DME/DME must be available.
On the safety side are all stakeholders responsible to ensure that they meet their safety parameters. Only a safe system is being trusted. Here as well: safety first!

Labor Resistance

With more automation, a controller's job will shift focus on managing than controlling. One troubling item will be who bears responsibility of the flights: is it the controller, or is it the 'machine'? The controller's union IFATCA supports the CNS/ATM philosophy, but stresses that the responsibility for separation should be ground based and humans must remain at the center of the control loop.
Controllers want to possess and maintain all relevant information of a flight from gate-to-gate and want to be able with the help of automation to provide conflict free trajectories. A fear is that controllers might lose their monitoring ability, the 'picture'.

Two question are being asked (IFATCA, 2003):

- How, if at all, can a system failure under peak traffic load be managed using manual fallback procedures?

- Will a controller possess or retain the ability to check safety critical information provided by automated systems?

IFATCA thinks that the controller will be unable to do so in both cases. Should even a considerable part of ATC employees be redundant, a massive opposition of such unions can be expected. They certainly will take action if a change towards Free Flight is against its member's interests. One possible excuse could be that it will never be as safe as with a human controller in front of a screen. Controllers must therefore be convinced that an automated system (except in emergencies, of course) can handle more traffic safely than before - in all conceivable situations!
However, introducing Free Flight in a quick manner or in steps will in the beginning require more people. Eventually, over several years, a reduced work force could be possible. It will be as in many professions: a slow change will alter a job's character with time.

11.4 Investments

In the U.S. in 1994, the FAA cancelled a prestigious ATC modernization project, the Advanced Automation System (AAS). It encountered numerous cost overruns, delays and failures. It sounded so good:"...it combines high availability, extensibility, and extraordinary functionality into a single distributed system, running at multiple locations. By requirement, the AAS must execute continuously without error, without interruption for upgrades or maintenance, and with the complete trust and confidence of air traffic controllers using it at over twenty centers. Each ATC center uses the same application software coupled with varying quantities of hardware and an extensive base of data to tailor the center to its unique geography and operational procedures." (Deblack et al, 1995).

With Free Flight, there are many possible ways to get it done. Some are hasty and probably unsafe, others meticulous and very time consuming. Surely the lessons from the above project cancellation have been drawn. There will be some tremendous initial costs for this futuristic ATC system. The best chance for success is when the user (customer) is being convinced that this will be the best future of the aviation industry and keep him in the clear. E.g. should the price for oil continue to increase, fuel savings made possible with Free Flight will desperately be wanted. Concerns about safety of such an automatic system must also be proven and dispelled. Both users and providers will benefit from a higher throughput at less cost and at least the same safety standards.
During the transition phase, expenses mount for the current system with all the ugly side effects (delays, higher fuel costs, etc.) and investment costs are required for upgrading to the Free Flight system. However, no astronomical cost ought to fall on top of the user and provider. Luckily, the GNSS system costs are practically paid for. What remains are costs for:

- Navigation ground infrastructure
- Flight-planning upgrades
- ATM equipment
- Flight deck avionics / software
- Sound testing
- Training and checking
- Parallel running of systems
- Developing temporary fall-back procedures
- De-installation of navaids

Since the ultimate benefit will be higher than if we stay with the current system, there should be incentives to lessen the cost burden during the transition. Also, the time frame should be kept reasonable small. Who would participate in sharing these costs? Could it be feasible to acquire first users and providers with a 'launch customer' price tag? The manufacturers of Free Flight avionics and ATM hard- and software who dare to invest in it will certainly be a trendsetter and dominate the market. In our capitalistic world, stakeholders want to see a certain benefit potential before they invest. For aircraft operators, there will be a Free Flight benefit, however, ATSPs are not so convinced and see especially ASAS impacting their business.

But there are numerous benefits by improving communications, navigation, surveillance, and by introducing Free Flight:

- Benefits of the communication system will be the links between ground and airborne automated systems will be more direct and effective. Improved data processing and transfer between operators, aircraft and ATS providers will alleviate the congestion of voice channel, reduce the possibility of making mistakes and allow for a more efficient link between ground and airborne systems.

- Benefits of the new navigation system will be the availability of an improved guidance and position capability in any part of the world will enhance operation efficiency, reducing flight time and the fuel required through navigation. The availability of the NPA for runways lacking ground navigation aids or that are served by unreliable navigation aids: will reduce delays, alternates, over flights and cancellations due to bad weather. The availability of a GNSS-supported PA through GBAS or SBAS coupled with airborne ones will also offer advantages over existing equipment. The capability of providing approach guidance for more airports could attract from those where delays due to congestion are common. By reducing such delays, operators will save flight time and fuel. Eventually use of the GNSS for all phases will result saving for operator due to the reduction of airborne equipment types. It will also reduce maintenance and capital costs. Advance integration techniques with inertial reference systems (IRS) will make possible to operator with more precise approach i.e. CAT-II and III. The availability of satellite navigation will enable the gradual deactivation and phasing out of conventional ground aids, which will provide significant saving to ATSPs.

- Benefits of the new surveillance system will come with use of ADS. ADS applied in airspace without radar coverage will evolve to a point where services will be furnished that are very similar to those provided by radar control, including aircraft position display on a ground screen. ADS use leads to a reduction of separation minima used in non- radar airspaces. The exiting regulatory separation over oceanic airspace may be reduces by one-half, thus doubling the capacity of the oceanic routes. ADS users also add operational flexibility to ATC for controllers are able to respond better to user flight preferences.

- Finally, benefits of the Free Flight concept will improve safety through advanced conflict detection and resolution technique. It will allow more flexibility for managing flight operations and better prediction of airspace conditions and their effects on such operation, better tools for decision making by pilots, air traffic controller, and flight dispatchers, saving from reduced fuel consumption and lower aircraft operating costs, reduced use of flow control, environmental improvements due to reduction in exhaust emissions in en-route flights, approaches at airports, more precise position and time and possibility of sharing information between pilots and controllers.

In the eyes of a pilot, these changes have various implications. In the upper airspace, it will be quite beneficial and not such a giant leap from the present system. En- route, savings will mean less flight time and less fuel burn around airports, however, technological breakthroughs will be much harder to achieve. Additionally, local airport restrictions such as noise areas, runway layout and airport capacity could the longed for benefits. Hubs need to streamline an increased of traffic else they will be a cause for bottlenecks. Usually such airports have outdated structures, use over-safely procedures, or face political pressure. Because of constraints, plus daily and seasonal peaks, CFMU restrictions will also exist in the future, unfortunately. However, Free Flight will reduce en-route and approach holdings, thus avoiding ATM 'ripple effects' and reduce indirect costs such as increase of fuel consumption, missed connections, hi-speed cruise of following flight to catch up time, etc. And if an AOC will be informed in due time of upcoming airspace limitations, decisions can be made to file for another routing or increase the fuel reserves in foresight. The potential benefits of agreeing on standards are also important for the aviation sector, because aviation activities are global. It starts in the supplier industry: reduced development risks, standardized product lines, and having a market without protectionism. The global stakeholders (mainly airlines, avionics suppliers, military, space-faring organizations and ATSPs) could share a common flight data standard to facilitate a global airspace control.

This in turn makes procurement of any aviation related system easier: simpler specifications, reduced development timescales, more competition and choice. In short: interoperability. A new project that airspace users are leading is SESAME. The intention is to develop a harmonized ATM master plan within 2 years that focuses on standardized systems allowing seamless information exchange and better co-operation that lead to simplifications which in turn reduce cost and workload for increased safety. This will accommodate future growth (Martis, 2005). It is clear this cannot happen by tomorrow. But with foresight, some global rules can now be made to permit a future harmonization. Obviously a gradual change would allow getting accustomed to a new standard. But too long transition period would give reason for confusion and even aversion. A bad example would be the German language reform - resulting in a standardization chaos. A good example would be the Euro currency: over night, a new standard was enacted. In aviation this could be done by mandates for new aircraft and for all others an incentive or subsidy should be made available to outfit / retrofit them with required avionics.

Ultimately, a new standardized ATC system covering the entire world would improve the way ATC works, safety would be increased and for aircraft operators this will drive down costs. This perfect 'window of opportunity' for Free Flight will not be open for too long.

11.5 Conclusion

Worldwide traffic growth indications predict a steady annual increase of which the current air traffic system cannot cope with. Although in Europe, ATSPs try with new projects to come to grips with it. Nevertheless, some day, a more revolutionary system must replace the current inconsistent, complex and often antiquated ATC system. It needs to manage considerable more traffic, allow economic growth, cost less, and - most important - be as equal or even safer in operation. With the Free Flight concept, rules, regulations and restrictions can be reduced. Flight routes can be planned more flexible and flown more economical and in less time. ATC guidance and communication will be diminished by the appliance of an in-flight separation system and a two-way digital, text-based communication. Not only will Free Flight be conducted in cruise and remote areas, but also in high-density traffic areas and on departure and arrival routings.

Free Flight builds up on CNS/ATM, which will simplify the ground infrastructure variations for navigation, allow clear and precise communication, and allows surveillance by ground entities and airborne traffic. Safety is improved thru advanced detection and resolution techniques, especially in high-density traffic situations, even with utilizing optimized separation limits.

It must be realized that with the introduction of timed steps in the near future, the Free Flight concept will not only meet the required quality (well tested, correctly certified, and thoroughly trained), but will replace the expensive ATC system of today by reducing direct and indirect costs (fees and delays). Not all stakeholders share the same expectations with Free Flight, though. It also stirs up some fears: People thinking of Free Flight the first time, they have the impression that it is a chaotic and even unsafe system (like flies buzzing around a lamp). But the contrary has been proven for ASAS: better have a safe chaotic system than an unsafe dangerous order.

Pros and Cons

Many advantages of Free Flight have been presented. Some of them have been already achieved with FANS, some benefits can only be reached by fully implementing Free Flight:

- Fuel savings in the single figure percentage range compared to today (with immediate climbs to the optimum level, cruising on user- preferred MTT tracks, and approaches on optimum idle-descend angles).
- Time savings (enabling less fuel consumption, less maintenance cost, permitting to generate more business by being airborne again earlier).
- Closer separation (less in-trail distance that is vortex dependant, early, comfortable conflict resolution).
- Less communication (therefore clearer, without confusion, reliable, timely, and no direct-to or level-change requests).

- Accurate navigation (GNSS-based, precise, all airfields CAT I, most airports CAT 3 capable).

- ATC controls the 'big picture' (performs traffic management, issues departure slots, steers the merging of arrival traffic, handles emergencies, gives assistance, and can interfere with decision-makings (e.g. in unusual weather situations).

- Improved safety (automatic systems perform better in high traffic load situations).

- More cost benefits (no conventional nav aids to maintain, less costly rotary radar antenna).

- More earnings (throughput is higher, generates more income of ATC fees).

- Airlines gain (are able to grow, have lower costs).

- Environmental advantages (assuming the same number of movements, less emissions and noise is produced).

There is also a backside of the coin:

- The current downturn in aviation (groundings, Chapter Eleven, soaring fuel costs) is delaying growth by half a decade, so Free Flight is not that urgent.

- Labor resistance could be fierce if lay-offs should occur.

- GBAS/SBAS installations need to be paid for by nations and airports.

- The testing and certification of ASAS will need time and requires a flawless performance.

- Retrofitting of current aircraft, new cockpit instrumentation of future aircraft must be paid for.

- Worldwide implementation must be synchronized

- The better or at least same safety factor must be reached for all stakeholders.

- The security of the aviation industry must be safeguarded against intentional (e.g. terrorism, military auscultating) or unintentional (e.g. Natural disasters, human error).

- A navigational back-up system must be available over land (DME/DME) and over oceans (IRS) all the time.

- More airport problems (congestions, runway occupation time, movement restrictions, etc.) could arise and should be tackled first.

- FMS enhancements that work tightly together with ASAS, allowing up-load of flight plans, newest wind data, 4D-trajectories on approach, etc.

- Political hurdles must be solved from the highest instances. Thru U.N. mandates all nations are required to adapt their aircraft, airports and ATSPs.

- Non-participating aircraft must fit into the system, and special cases need to be addressed.

- The ATC controller needs to be on top of things with new tools and skills.

- An implementation schedule for planning reasons needs to be agreed to by defining a timeframe.

- The certification process will take due time.

- The environment could take more damage with more traffic, until the global oil resources are depleted (hopefully, a kerosene replacement will be available, soon).

From a Pilot's View

Will a pilot still be able to fly an airplane by hands in the future? Of course! As today, the first and last few minutes of a flight are usually hand-flown, the other flight phases with the autopilot. Executing ASAS maneuvers will also be delegated to the autopilot, which carries them out smoothly. Since with Free Flight no steady cruise flight level needs to be flown, 'parabolic' flight profiles become possible. A change of heading to avoid a growing cumulus cloud, climbing higher than optimal to fly on-top of a cloud layer and avoiding a bumpy ride, would immediately reassess the probability of encountering threats by ASAS and will warn the pilot if necessary.
During approach, the merging of traffic is already done by the approach controller today, and will occur more or less the same with a 4D-trajectory approach system. Instead of getting vectors and speed requirements verbally, this would be dynamically uploaded in real-time into the FMS and could be followed automatically with optimum separation. Regarding fuel planning, contingency fuel will certainly be needed for the occasional, slight deviation due to an ASAS intervention and for the unforeseeable approach trajectory (length, speed and altitude) at the time of pre-flight planning as well. Bigger fuel saving will be gained during the optimum cruise routing
To work with Free Flight new procedures, certified tools and systems must be learned. Using ADS and CPDLC is already common today, but working with ASAS screens and procedures will take some simulator sessions. Further fall-back procedures will be needed to be quickly available, like

- What if ASAS quits? There must be one or even two back-up unit.

- What if ADS-B creates problems? There must be separate receiving and transmitting channels, and also back-up units.

- What if GPS reception is distorted? With DME/DME (or IRS) a position fix can still be made.

- What if CPDLC is out of order? Voice communication is still an option.

- What if an emergency arises? Enabling the 'mayday mode' and ASAS demands priority from all other traffic. ATC can be contacted over CPDLC, voice, or SATCOM.

- And a total electrical power loss? ATC has the projected flight path stored and transmits the missing signal via TIS-B to other traffic, or uses primary radar to track the target and also up-links TIS-B data to everyone. The flight crew might have the means to broadcast their intentions on guard frequency, providing inputs for ATC.

Weighing the pros with the cons, Free Flight wins out. It has the potential to renew the aviation industry and permits a global harmonized and a cost-reduced ATM system. Controllers have been and will still be the pilot's 'guardian angels' - just on another, new level. Keeping the key elements of automation (in mind, Free Flight will also please controllers. But they also fear that their job might be endangered. This fear is baseless: to supervise and provide assistance in case of communication failure or emergency, humans controlling the situation are irreplaceable. Most probably fewer controllers will be needed, but on the other hand more specialists dealing with flow management, tool support and analysis, and many newly created professions will be required. So only a shift (or continuing education) to other high-profile jobs with responsibilities will occur. To sum this up, a safe, reliable aviations system is also an enabler for economic development. For airlines, and all involved companies, this means sustainable working places and return on investments.

Recommendations

Based on the information that has been collected and presented in this thesis, it appears that there is a certain way to accomplish the goal of a global Free Flight system. It seems that it would be too time consuming and expensive to first unify all ATC centers worldwide, some of which would resist to unify or lack the willingness and financial ability to modernize. Fewer ATM centers would be required. But on a national level a domestic agency would monitor traffic for complying with the filed routes, charge them with over flight fees, and manage and enforce local restricted airspaces. The idea is to make all aircraft Free-Flight-ready, then at a certain point switch over to designated new ATC centers, with re-trained ATSP employees. Some air traffic agency propose a quick and radical change, which is too hasty, others are very reluctant and are afraid to even name a time-frame for implementation, which seems to be too conservative. A big accelerator would be from the aviation market itself: supposing that the economical need for change will increase, the faster everyone will demand an improvement of the aviation environment.
3rd-World countries would need support from U.N. or ICAO, but surely would not refuse it once being offered. In such a way, the spread of Free Flight will make the concept globally acceptable and worth.

These steps should be followed:

1. By 2015: Extend Navigation and Surveillance capabilities.
    - Navigation will steadily be based on GPS and SBAS information. With the GALILEO system running some day, a second, independent GNSS system will provide a precision that will lead to the dismantling of

en-route nav aids. However, the airway system would be retained for now. In terminal areas, GBAS installations and RNP approaches will replace all non-precision approaches, precision approaches and other nav aids on airports. STARs will still lead to these RNP approaches, and SID will guide traffic away from airports.

- ADS-B will become the uni-solo surveillance standard and prime enabler for a new ATM. For high performance aircraft and for new GA aircraft, this will not be that expensive, and for older GA aircraft the installation of a mode S transponder for ABS-B-out should at least be mandatory. To support these retro- fittings or new acquaintances financial incentives should be granted. This could be done by the way of tax relief, or by a one-time cash payout. Parallel to that, ATC should make ADS-B in cruise 'the' standard. Radar surveillance will still be used, especially to monitor GA traffic with transponders, or by the military, but would not be necessary for other traffic due to the transmission of more precise GPS-derived position reports. As a direct effect, the separation limitations can be reduced, and controllers will receive ADS- derived 'intent data' as well.

- Communication would still be done in most areas without CPDLC, requiring ATC controllers to retain the obligation to separate traffic and issuing clearances.

2. By 2020: Upgrade of avionics and airspace redesign.

- New airplanes will only roll out with advanced cockpit displays and new features. Utilizing ADS-B, the traffic situation around him is now also visible for the pilot. Trailing of traffic can now be accurately performed by the flight crew, in cruise, or on approach. Older airliners will be retrofitted so that on their ND's not only TCAS information will be shown, but also surrounding traffic. In this way, both pilots and controllers have a situational awareness.

- Airspace layout will be simplified: only two airspaces will exist. Around terminal areas and above an altitude of 3000m (mountainous areas 4000m), a class I airspace exists for IFR traffic. The class V airspace will be used by GA for VFR flights. However, a transponder of ADS-B is mandatory (and will be required to operate), thus ATC is able to see them. Such traffic can be displayed on radar screen, with TIS-B on high performance aircraft's cockpit displays as well. This will enable general aviation traffic to cross controlled airspace when cleared to do so. Restricted areas can be designated in either kind of airspaces.

- Nav aids will not be required anymore: all ILS's, NDBs, VORs will be history. An exception will be DMEs - they will be retained to provide back-up navigation in case of e.g. GNSS receiver failures.

- Communication will largely occur via screens with CPDLC, for non-equipped aircraft via voice.

3. By 2020: ASAS matures and approaches become dynamic.

   - SIDs will be replaced from each runway by simple straight-out flight path and turns to various departure waypoints to permit a rapid take-off scheme.

   - Airborne separation will be introduced, thus transferring basic separation responsibility from the controller to the flight deck for ASAS equipped aircraft. Free routing becomes available including level and speed selection according to e.g. desired fuel consumption or turbulence. ATC will initially observe conflict resolutions and stand-by to provide aid. TCAS is still the last resort for flight crews in case ASAS commands do not comply with. For non-ASAS aircraft, the controller will do the look-ahead function and will assure separation.

   - New tools for the ATC controller will enable him to follow the traffic situation, intervene when deemed necessary, manage upcoming congestions by issuing slots, or even assign aircraft to holding patterns, e.g. for weather related approach delays.

   - Arrivals are dynamically allocated. With no traffic, straight-in's to a 5NM final will be provided. With lots of inbound traffic a handle, autonomous merging of traffic will take place, always considering e.g. Vortex separation and aircraft-type speed constraints. Graphical presentations of their inbound track will be drawn not only on cockpit displays, but the approach controller can follow the dynamic approach system on his screen as well and could issue commands to prioritize certain traffic, e.g. Ambulance flights or aircraft in a low fuel situation.

Final conclusion

Free Flight "...establishes a globally harmonized, uniform ATM system that allows users to make operational decisions based on their own economic business case while enabling the safe, orderly, and expeditious flow of traffic."Business reasons will determine if the world should go for the Free Flight concept. Due to the rising fuel price airlines will most certainly look for further ways to save fuel. With Free Flight, a tremendous amount can be saved, comparable with newly engineered jet engines. For us pilots, and airlines, the total cost of it must be lower than with today's ATC system. Sighting all mentioned sources, the conclusion can be made that the huge amount of money spent every day with delays, etc. and the usage of more fuel will justify the change.

If the aviation industry would be forecasted not to grow, it would even then pay off. But with such growth figures, it is imperative.
The crowded global airspace system will become ever more complex for ATC controllers to handle. A solution lays in abolishing airways, but with this, their 'picture' will become chaos-like and even more difficult to control.

Therefore, advanced, computer-supported systems such as ASAS will take over the duty for safe separation. In simulations and in-flight tests, ASAS was proved theoretically to be safe. This important prerequisite is one of the cornerstones of Free Flight. It is speculated that with Free Flight the next bottleneck will be the airports. With improved departure and arrival techniques, as well as with more high-speed turn-offs, airports can accommodate the increase of traffic. Since aircraft will produce less noise in the future (maybe with even novel propulsion systems in 30+ years), noise restrictions could be minimized, and diversified take-off and approach tracks will spread any noise equally. To benefit from what Free Flight brings along, we must not only push technology, but must also devote our aims towards the political aspect. Free Flight cannot be lead to success by a small country alone. With mandates from political leaders, positive effects can be generated: the aerospace industry can better anticipate, plan with frozen standards, and target specific goals.

ATSP's must work together and recognize the need, as well as the opportunities for it.
Airlines will need to invest in Free Flight and someday will be rewarded with lower costs.
Nations who start to devote themselves seriously to Free Flight will lead the others and determine standards, giving spin to the 'economic dynamo'. Involved companies will acquire leading knowledge and obtain patents that can be useful for other products. Such a big task can be accomplished if all the players are willing to pull on the same rope - for the sake of aviation, ecology, economy and the welfare of humankind. The future of aviation is Free Flight. The sooner this impressive concept is pursued, the better for aviation.