



Air Traffic Control

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Chapter 1

Air Traffic Control



Airport Traffic Control Towers (ATCTs) at Amsterdam's Schiphol Airport, the Netherlands.

Air traffic control (ATC) is a service provided by ground-based controllers who direct aircraft on the ground and in the air. The primary purpose of ATC systems worldwide is to *separate* aircraft to prevent collisions, to organize and expedite the flow of traffic, and to provide information and other support for pilots when able. In some countries, ATC may also play a security or defense role (as in the United States), or be run entirely by the military (as in Brazil).

Preventing collisions is referred to as separation, which is a term used to prevent aircraft from coming too close to each other by use of lateral, vertical and longitudinal separation minima; many aircraft now have collision avoidance systems installed to act as a backup to ATC observation and instructions. In addition to its primary function, the ATC can provide additional services such as providing information to pilots, weather and navigation information and NOTAMs (*NOTices To AirMen*).

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.

History



Contrails of aircraft entering and leaving Heathrow Airport. Intersecting flight paths are carefully controlled to prevent collisions.

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 League (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 Federal Aviation Administration (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.

Language

Pursuant to requirements of the International Civil Aviation Organization (ICAO), ATC operations are conducted either in the English language or the language used by the station on the ground. In practice, the native language for a region is normally used, however the English language must be used upon request.

Airport control



Inside the São Paulo-Guarulhos International Airport's tower, Latin America's second busiest airport.

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 5 to 10 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.

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.

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.

Local control or air control

Local Control (known to pilots as "Tower" or "Tower Control") is responsible for the active runway surfaces. Local Control clears aircraft for takeoff or landing, ensuring that prescribed runway separation will exist at all times. If Local Control detects any unsafe condition, a landing aircraft may be told to "go-around" and be re-sequenced into the landing pattern by the approach or terminal area controller.

Within the ATCT, a highly disciplined communications process between Local Control and Ground Control is an absolute necessity. Ground Control must request and gain approval from Local Control to cross any active runway with any aircraft or vehicle. Likewise, Local Control must ensure that Ground Control is aware of any operations that will impact the taxiways, and work with the approach radar controllers to create "holes" or "gaps" in the arrival traffic to allow taxiing traffic to cross runways and to allow departing aircraft to take off. Crew Resource Management (CRM) procedures are often

used to ensure this communication process is efficient and clear, although this is not as prevalent as CRM for pilots.

Flight data / clearance delivery

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 pushbacks 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.

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).

Approach and terminal control



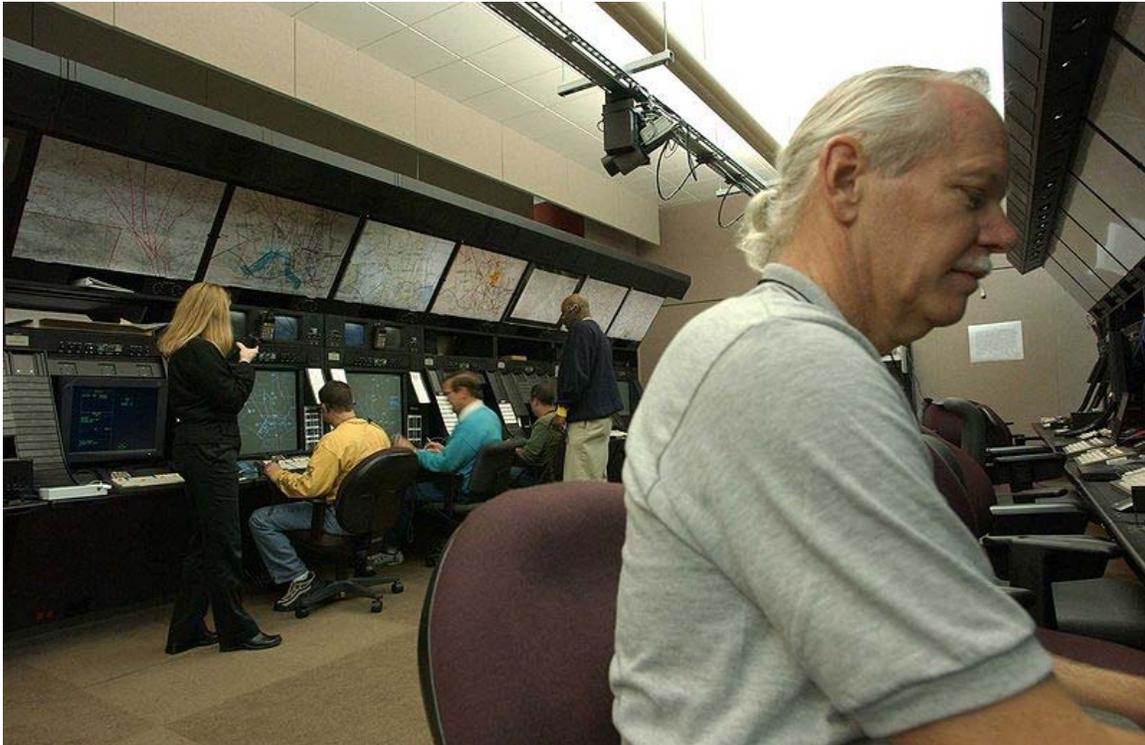
Potomac TRACON, Washington, D.C., United States.

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 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 close together, 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 overflights. 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.

En-route, center, or area control



The training department at the Washington Air Route Traffic Control Center, Washington, D.C., United States.

ATC provides services to aircraft in flight between airports as well. Pilots fly under one of two sets of rules for separation: Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). Air traffic controllers have different responsibilities to aircraft operating under the different sets of rules. While IFR flights are under positive control, in the US VFR pilots can request flight following, which provides traffic advisory services on a time permitting basis and may also provide assistance in avoiding areas of weather and flight restrictions. In the UK, a pilot can request for "Deconfliction Service", which is similar to flight following.

En-route air traffic controllers issue clearances and instructions for airborne aircraft, and pilots are required to comply with these instructions. En-route controllers also provide air traffic control services to many smaller airports around the country, including clearance

off of the ground and clearance for approach to an airport. Controllers adhere to a set of separation standards that define the minimum distance allowed between aircraft. These distances vary depending on the equipment and procedures used in providing ATC services.

General characteristics

En-route air traffic controllers work in facilities called Area Control Centers, each of which is commonly referred to as a "Center". The United States uses the equivalent term Air Route Traffic Control Center (ARTCC). Each center is responsible for many thousands of square miles of airspace (known as a Flight Information Region) and for the airports within that airspace. Centers control IFR aircraft from the time they depart from an airport or terminal area's airspace to the time they arrive at another airport or terminal area's airspace. Centers may also "pick up" VFR aircraft that are already airborne and integrate them into the IFR system. These aircraft must, however, remain VFR until the Center provides a clearance.

Center controllers are responsible for climbing the aircraft to their requested altitude while, at the same time, ensuring that the aircraft is properly separated from all other aircraft in the immediate area. Additionally, the aircraft must be placed in a flow consistent with the aircraft's route of flight. This effort is complicated by crossing traffic, severe weather, special missions that require large airspace allocations, and traffic density. When the aircraft approaches its destination, the center is responsible for meeting altitude restrictions by specific points, as well as providing many destination airports with a traffic flow, which prohibits all of the arrivals being "bunched together". These "flow restrictions" often begin in the middle of the route, as controllers will position aircraft landing in the same destination so that when the aircraft are close to their destination they are sequenced.

As an aircraft reaches the boundary of a Center's control area it is "handed off" or "handed over" to the next Area Control Center. In some cases this "hand-off" process involves a transfer of identification and details between controllers so that air traffic control services can be provided in a seamless manner; in other cases local agreements may allow "silent handovers" such that the receiving center does not require any coordination if traffic is presented in an agreed manner. After the hand-off, the aircraft is given a frequency change and begins talking to the next controller. This process continues until the aircraft is handed off to a terminal controller ("approach").

Radar coverage

Since centers control a large airspace area, they will typically use long range radar that has the capability, at higher altitudes, to see aircraft within 200 nautical miles (370 km) of the radar antenna. They may also use TRACON radar data to control when it provides a better "picture" of the traffic or when it can fill in a portion of the area not covered by the long range radar.

In the U.S. system, at higher altitudes, over 90% of the U.S. airspace is covered by radar and often by multiple radar systems; however, coverage may be inconsistent at lower altitudes used by unpressurized aircraft due to high terrain or distance from radar facilities. A center may require numerous radar systems to cover the airspace assigned to them, and may also rely on pilot position reports from aircraft flying below the floor of radar coverage. This results in a large amount of data being available to the controller. To address this, automation systems have been designed that consolidate the radar data for the controller. This consolidation includes eliminating duplicate radar returns, ensuring the best radar for each geographical area is providing the data, and displaying the data in an effective format.

Centers also exercise control over traffic travelling over the world's ocean areas. These areas are also FIRs. Because there are no radar systems available for oceanic control, oceanic controllers provide ATC services using procedural control. These procedures use aircraft position reports, time, altitude, distance, and speed to ensure separation. Controllers record information on flight progress strips and in specially developed oceanic computer systems as aircraft report positions. This process requires that aircraft be separated by greater distances, which reduces the overall capacity for any given route.

Some Air Navigation Service Providers (e.g. Airservices Australia, The Federal Aviation Administration, NAV CANADA, etc.) have implemented Automatic Dependent Surveillance - Broadcast (ADS-B) as part of their surveillance capability. This new technology reverses the radar concept. Instead of radar "finding" a target by interrogating the transponder, the ADS-equipped aircraft sends a position report as determined by the navigation equipment on board the aircraft. Normally, ADS operates in the "contract" mode where the aircraft reports a position, automatically or initiated by the pilot, based on a predetermined time interval. It is also possible for controllers to request more frequent reports to more quickly establish aircraft position for specific reasons. However, since the cost for each report is charged by the ADS service providers to the company operating the aircraft, more frequent reports are not commonly requested except in emergency situations. ADS is significant because it can be used where it is not possible to locate the infrastructure for a radar system (e.g. over water). Computerized radar displays are now being designed to accept ADS inputs as part of the display. This technology is currently used in portions of the North Atlantic and the Pacific by a variety of states who share responsibility for the control of this airspace.

Precision approach radars are commonly used by military controllers of airforces of several countries, to assist the Pilot in final phases of landing in places where Instrument Landing System and other sophisticated air borne equipments are unavailable to assist the pilots in marginal or *near zero visibility* conditions. This procedure is also called **Talkdowns**.

A Radar Archive System (RAS) keeps an electronic record of all radar information, preserving it for a few weeks. This information can be useful for search and rescue. When an aircraft has 'disappeared' from radar screens, a controller can review the last radar returns from the aircraft to determine its likely position.

Flight traffic mapping

The mapping of flights in real-time is based on the air traffic control system. In 1991, data on the location of aircraft was made available by the Federal Aviation Administration to the airline industry. The National Business Aviation Association (NBAA), the General Aviation Manufacturers Association, the Aircraft Owners & Pilots Association, the Helicopter Association International, and the National Air Transportation Association petitioned the FAA to make ASDI information available on a "need-to-know" basis. Subsequently, NBAA advocated the broad-scale dissemination of air traffic data. The Aircraft Situational Display to Industry (ASDI) system now conveys up-to-date flight information to the airline industry and the public. Some companies that distribute ASDI information are FlightExplorer, FlightView, and FlyteComm. Each company maintains a website that provides free updated information to the public on flight status. Stand-alone programs are also available for displaying the geographic location of airborne IFR (Instrument Flight Rules) air traffic anywhere in the FAA air traffic system. Positions are reported for both commercial and general aviation traffic. The programs can overlay air traffic with a wide selection of maps such as, geo-political boundaries, air traffic control center boundaries, high altitude jet routes, satellite cloud and radar imagery.

Problems

Traffic

The day-to-day problems faced by the air traffic control system are primarily related to the volume of air traffic demand placed on the system and weather. Several factors dictate the amount of traffic that can land at an airport in a given amount of time. Each landing aircraft must touch down, slow, and exit the runway before the next crosses the approach end of the runway. This process requires at least one and up to four minutes for each aircraft. Allowing for departures between arrivals, each runway can thus handle about 30 arrivals per hour. A large airport with two arrival runways can handle about 60 arrivals per hour in good weather. Problems begin when airlines schedule more arrivals into an airport than can be physically handled, or when delays elsewhere cause groups of aircraft that would otherwise be separated in time to arrive simultaneously. Aircraft must then be delayed in the air by holding over specified locations until they may be safely sequenced to the runway. Up until the 1990s, holding, which has significant environmental and cost implications, was a routine occurrence at many airports. Advances in computers now allow the sequencing of planes hours in advance. Thus, planes may be delayed before they even take off (by being given a "slot"), or may reduce speed in flight and proceed more slowly thus significantly reducing the amount of holding.

Weather

Beyond runway capacity issues, weather is a major factor in traffic capacity. Rain, ice or snow on the runway cause landing aircraft to take longer to slow and exit, thus reducing

the safe arrival rate and requiring more space between landing aircraft. Fog also requires a decrease in the landing rate. These, in turn, increase airborne delay for holding aircraft. If more aircraft are scheduled than can be safely and efficiently held in the air, a ground delay program may be established, delaying aircraft on the ground before departure due to conditions at the arrival airport.

In Area Control Centers, a major weather problem is thunderstorms, which present a variety of hazards to aircraft. Aircraft will deviate around storms, reducing the capacity of the en-route system by requiring more space per aircraft, or causing congestion as many aircraft try to move through a single hole in a line of thunderstorms. Occasionally weather considerations cause delays to aircraft prior to their departure as routes are closed by thunderstorms.

Much money has been spent on creating software to streamline this process. However, at some ACCs, air traffic controllers still record data for each flight on strips of paper and personally coordinate their paths. In newer sites, these flight progress strips have been replaced by electronic data presented on computer screens. As new equipment is brought in, more and more sites are upgrading away from paper flight strips.

Call signs

A prerequisite to safe air traffic separation is the assignment and use of distinctive call signs. These are permanently allocated by ICAO on request usually to scheduled flights and some air forces for military flights. They are written callsigns with 3-letter combination like KLM, AAL, SWA, BAW, VLG followed by the flight number, like AAL872, VLG1011. As such they appear on flight plans and ATC radar labels. There are also the *audio* or *Radio-telephony* callsigns used on the radio contact between pilots and Air Traffic Control not always identical with the written ones. For example BAW symbolises British Airways but on the radio you will only hear the word *Speedbird* followed by an alpha-numeric code instead. By default, the callsign for any other flight is the registration number (tail number) of the aircraft, such as "N12345", "C-GABC" or "EC-IZD". The term *tail number* is because a registration number is usually painted somewhere on the tail of a plane, yet this is not a rule. Registration numbers may appear on the engines, anywhere on the fuselage, and often on the wings. The short *Radio-telephony* callsigns for these tail numbers is the last 3 letters only like ABC spoken Alpha-Bravo-Charlie for C-GABC or the last 3 numbers like 345 spoken as TREE-FORE-FIFE for N12345. In the United States the abbreviation of callsigns is required to be a prefix (such as aircraft type, aircraft manufacturer, or first letter of registration) followed by the last three characters of the callsign. This abbreviation is only allowed after communications has been established in each sector.

The flight number part is decided by the aircraft operator. In this arrangement, an identical call sign might well be used for the same scheduled journey each day it is operated, even if the departure time varies a little across different days of the week. The call sign of the return flight often differs only by the final digit from the outbound flight. Generally, airline flight numbers are even if eastbound, and odd if westbound. In order to

reduce the possibility of two callsigns on one frequency at any time sounding too similar, a number of airlines, particularly in Europe, have started using alphanumeric callsigns that are not based on flight numbers. For example DLH23LG, spoken as lufthansa-two-tree-lima-golf. Additionally it is the right of the air traffic controller to change the 'audio' callsign for the period the flight is in his sector if there is a risk of confusion, usually choosing the tail number instead.

Before around 1980 International Air Transport Association (IATA) and ICAO were using the same 2-letter callsigns. Due to the larger number of new airlines after deregulation ICAO established the 3-letter callsigns as mentioned above. The IATA callsigns are currently used in aerodromes on the announcement tables but never used any longer in Air Traffic Control. For example, AA is the IATA callsign for American Airlines — ATC equivalent AAL. Other examples include LY/ELY for El Al, DL/DAL for Delta Air Lines, VY/VLG for Vueling Airlines, etc.

Technology

Many technologies are used in air traffic control systems. Primary and secondary radar are used to enhance a controller's situation awareness within his assigned airspace — all types of aircraft send back primary echoes of varying sizes to controllers' screens as radar energy is bounced off their skins, and transponder-equipped aircraft reply to secondary radar interrogations by giving an ID (Mode A), an altitude (Mode C) and/or a unique callsign (Mode S). Certain types of weather may also register on the radar screen.

These inputs, added to data from other radars, are correlated to build the air situation. Some basic processing occurs on the radar tracks, such as calculating ground speed and magnetic headings.

Usually, a Flight Data Processing System manages all the flight plan related data, incorporating - in a low or high degree - the information of the track once the correlation between them (flight plan and track) is established. All this information is distributed to modern operational display systems, making it available to controllers.

The FAA has spent over USD\$3 billion on software, but a fully-automated system is still over the horizon. In 2002 the UK brought a new area control centre into service at Swanwick, in Hampshire, relieving a busy suburban centre at West Drayton in Middlesex, north of London Heathrow Airport. Software from Lockheed-Martin predominates at Swanwick. However, Swanwick was initially troubled by software and communications problems causing delays and occasional shutdowns.

Some tools are available in different domains to help the controller further:

- Flight Data Processing Systems: this is the system (usually one per Center) that processes all the information related to the Flight (the Flight Plan), typically in the time horizon from Gate to gate (airport departure/arrival gates). It uses such processed information to invoke other Flight Plan related tools (such as e.g.

- MTCB), and distributes such processed information to all the stakeholders (Air Traffic Controllers, collateral Centers, Airports, etc.).
- Short Term Conflict Alert (STCA) that checks possible conflicting trajectories in a time horizon of about 2 or 3 minutes (or even less in approach context - 35 seconds in the French Roissy & Orly approach centres) and alerts the controller prior to the loss of separation. The algorithms used may also provide in some systems a possible vectoring solution, that is, the manner in which to turn, descend, or climb the aircraft in order to avoid infringing the minimum safety distance or altitude clearance.
 - Minimum Safe Altitude Warning (MSAW): a tool that alerts the controller if an aircraft appears to be flying too low to the ground or will impact terrain based on its current altitude and heading.
 - System Coordination (SYSCO) to enable controller to negotiate the release of flights from one sector to another.
 - Area Penetration Warning (APW) to inform a controller that a flight will penetrate a restricted area.
 - Arrival and Departure Manager to help sequence the takeoff and landing of aircraft.
 - The Departure Manager (DMAN): A system aid for the ATC at airports, that calculates a planned departure flow with the goal to maintain an optimal throughput at the runway, reduce queuing at holding point and distribute the information to various stakeholders at the airport (i.e. the airline, ground handling and Air Traffic Control (ATC)).
 - The Arrival Manager (AMAN): A system aid for the ATC at airports, that calculates a planned Arrival flow with the goal to maintain an optimal throughput at the runway, reduce arrival queuing and distribute the information to various stakeholders.
 - passive Final Approach Spacing Tool (pFAST), a CTAS tool, provides runway assignment and sequence number advisories to terminal controllers to improve the arrival rate at congested airports. pFAST was deployed and operational at five US TRACONS before being cancelled. NASA research included an Active FAST capability that also provided vector and speed advisories to implement the runway and sequence advisories.
 - Converging Runway Display Aid (CRDA) enables Approach controllers to run two final approaches that intersect and make sure that go arounds are minimized
 - Center TRACON Automation System (CTAS) is a suite of human centered decision support tools developed by NASA Ames Research Center. Several of the CTAS tools have been field tested and transitioned to the FAA for operational evaluation and use. Some of the CTAS tools are: Traffic Management Advisor (TMA), passive Final Approach Spacing Tool (pFAST), Collaborative Arrival Planning (CAP), Direct-To (D2), En Route Descent Advisor (EDA) and Multi Center TMA. The software is running on linux.
 - Traffic Management Advisor (TMA), a CTAS tool, is an en route decision support tool that automates time based metering solutions to provide an upper limit of aircraft to a TRACON from the Center over a set period of time.

Schedules are determined that will not exceed the specified arrival rate and controllers use the scheduled times to provide the appropriate delay to arrivals while in the en route domain. This results in an overall reduction in en route delays and also moves the delays to more efficient airspace (higher altitudes) than occur if holding near the TRACON boundary is required to not overload the TRACON controllers. TMA is operational at most en route air route traffic control centers (ARTCCs) and continues to be enhanced to address more complex traffic situations (e.g. Adjacent Center Metering (ACM) and En Route Departure Capability (EDC))

- MTCO & URET
 - In the US, User Request Evaluation Tool (URET) takes paper strips out of the equation for En Route controllers at ARTCCs by providing a display that shows all aircraft that are either in or currently routed into the sector.
 - In Europe, several MTCO tools are available: iFACTS (NATS), VAFORIT (DFS), New FDPS (MASUAC). The SESAR Programme should soon launch new MTCO concepts.

URET and MTCO provide conflict advisories up to 30 minutes in advance and have a suite of assistance tools that assist in evaluating resolution options and pilot requests.

- Mode S: provides a data downlink of flight parameters via Secondary Surveillance Radars allowing radar processing systems and therefore controllers to see various data on a flight, including airframe unique id (24-bits encoded), indicated airspeed and flight director selected level, amongst others.
- CPDLC: Controller Pilot Data Link Communications — allows digital messages to be sent between controllers and pilots, avoiding the need to use radiotelephony. It is especially useful in areas where difficult-to-use HF radiotelephony was previously used for communication with aircraft, e.g. oceans. This is currently in use in various parts of the world including the Atlantic and Pacific oceans.
- ADS-B: Automatic Dependent Surveillance Broadcast — provides a data downlink of various flight parameters to air traffic control systems via the Transponder (1090 MHz) and reception of those data by other aircraft in the vicinity. The most important is the aircraft's latitude, longitude and level: such data can be utilized to create a radar-like display of aircraft for controllers and thus allows a form of pseudo-radar control to be done in areas where the installation of radar is either prohibitive on the grounds of low traffic levels, or technically not feasible (e.g. oceans). This is currently in use in Australia, Canada and parts of the Pacific Ocean and Alaska.
- The Electronic Flight Strip system (e-strip): A system of electronic flight strips replacing the old paper strips is being used by several Service Providers, such as NAV CANADA, MASUAC, DFS, being produced by several industries, such as Indra Sistemas, Thales Group, Frequentis, Avibit, SAAB etc. E-strips allows controllers to manage electronic flight data online without Paper Strips, reducing the need for manual functions.

- **Screen Content Recording:** Hardware or software based recording function which is part of most modern Automation System and that captures the screen content shown to of the ATCO. Such recordings are used for a later replay together with audio recording for investigations and post event analysis.
- **Communication Navigation Surveillance / Air Traffic Management (CNS/ATM)** systems are communications, navigation, and surveillance systems, employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global air traffic management system.

Major accidents

A list of recent accidents can be found in this list.

On July 1, 2002 a Tupolev Tu-154 and Boeing 757 collided above Überlingen near the boundary between German and Swiss-controlled airspace when Skyguide-employed controller Peter Nielsen (who was murdered by a relative of people who died in the crash), unaware that the flight was receiving instruction from the on-board automatic Traffic Collision Avoidance System software to climb, instructed the southbound Tupolev to descend.

The deadliest mid-air crash, the 1996 Charkhi Dadri mid-air collision over India, partly resulted from the fact that the New Delhi-area airspace was shared by departures and arrivals, when in most cases departures and arrivals would use separate airspaces. However investigations later found that the causative factor for this mid air accident was non adherence to air traffic control instructions by not maintaining **the assigned flight level** during descent phase by the pilot.

The deadliest collision between airliners took place on the ground, on March 27, 1977, in what is known as the Tenerife disaster, although ATC is only partly to blame for this incident.

Air navigation service providers (ANSPs) and traffic service providers (ATSPs)

The regulatory function remains the responsibility of the State and can be exercised by Government and/or independent Safety, Airspace and Economic Regulators depending on the national institutional arrangements. Often you will see a division between the Civil Aviation Authority (CAA) (the Regulator) and the ANSP (the Air Navigation Service Provider).

An Air Navigation Service Provider — The air navigation service provider is the authority directly responsible for providing both visual and non-visual aids to navigation within a specific airspace in compliance with, but not limited to, International Civil Aviation Organization (ICAO) Annexes 2, 6, 10 and 11; ICAO Documents 4444 and

9426; and, other international, multi-national, and national policy, agreements or regulations.

An Air Traffic Service Provider is the relevant authority designated by the State responsible for providing air traffic services in the airspace concerned. *Air traffic services* is generic and can mean: flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service), etc.

Both ANSPs and ATSPs can be public, private or corporatized organisations and examples of the different legal models exist throughout the world today. The world's ANSPs are united in and represented by the Civil Air Navigation Services Organisation (CANSO) based at Amsterdam Airport Schiphol in the Netherlands.

In the United States, the Federal Aviation Administration (FAA) provides this service to all aircraft in the National Airspace System (NAS). With the exception of facilities operated by the Department of Defense (DoD), the FAA is responsible for all aspects of U.S. Air Traffic Control including hiring and training controllers, although there are contract towers located in many parts of the country. A contract tower is an Airport Traffic Control Tower (ATCT) that performs the same function as an FAA-run ATCT but is staffed by employees of a private company (Martin State Airport in Maryland is an example). DoD facilities are generally staffed by military personnel and operate separately but concurrently with FAA facilities, under similar rules and procedures. In Canada, Air Traffic Control is provided by NAV CANADA, a private, non-share capital corporation that operates Canada's civil air navigation service.

-  Albania - Agjencia Nazionale e Trafikut Ajror
-  Armenia - Armenian Air Traffic Services (ARMATS)
-  Austria - Austro Control
-  Australia - Airservices Australia (State Owned Corporation) and Royal Australian Air Force.
-  Belarus - Republican Unitary Enterprise "Белэронавигация (Belarusian Air Navigation)"
-  Belgium - Belgocontrol
-  Brazil - Departamento de Controle de Tráfego Aéreo (Military Authority) and ANAC - Agência Nacional de Aviação Civil
-  Bulgaria - Air Traffic Services Authority
-  Canada - NAV CANADA - formerly provided by Transport Canada and Canadian Forces
- Central America - Corporación Centroamericana de Servicios de Navegación Aérea
 -  Guatemala - DGAC (Dirección General de Aeronáutica Civil)
 -  El Salvador
 -  Honduras
 -  Nicaragua
 -  Costa Rica - Dirección General de Aviación Civil

-  Belize
-  Colombia - (UAEAC) Aeronáutica Civil Colombiana
-  Croatia - Hrvatska kontrola zračne plovidbe (Croatia Control Ltd.)
-  Cuba - IACC (Instituto de Aeronáutica Civil de Cuba)
-  Czech Republic - Řízení letového provozu ČR
-  Denmark - Naviair (Danish ATC)
-  Dominican Republic - IDAC (Instituto Dominicano de Aviación Civil)
"Dominican Institute of Civil Aviation"
-  Estonia - Estonian Air Navigation Services
-  Europe - Eurocontrol - (European Organisation for the Safety of Air Navigation)
-  Finland - Finavia
-  France - Direction Générale de l'Aviation Civile (DGAC) : Direction des Services de la Navigation Aérienne (DSNA) (Government body)
-  Georgia - SAKAERONAVIGATSIA, Ltd. (Georgian Air Navigation)
-  Germany - Deutsche Flugsicherung (German ATC - State-owned company)
-  Greece - Hellenic Civil Aviation Authority (HCAA)
-  Hong Kong - CAD (Civil Aviation Department)
-  Hungary - HungaroControl Magyar Légiforgalmi Szolgálat Zrt.
(HungaroControl Hungarian Air Navigation Services Pte. Ltd. Co.)
-  Iceland - ISAVIA
-  Indonesia - Angkasa Pura II
-  Ireland - IAA (Irish Aviation Authority)
-  India - Airports Authority of India (AAI) (under Ministry of Civil Aviation, Government Of India)
-  Italy - ENAV (Italian ATC)(Ente Nazionale Assistenza al Volo - Italian ATC)
-  Jamaica - JCAA (Jamaica Civil Aviation Authority)
-  Latvia - LGS (Latvian ATC)
-  Lithuania - ANS (Lithuanian ATC)
-  Macedonia - DGCA (Macedonian ATC)
-  Malaysia - DCA-Department of Civil Aviation
-  Malta - Malta Air Traffic Services Ltd
-  Mexico - Servicios a la Navegación en el Espacio Aéreo Mexicano
-  Nepal - Civil Aviation Authority of Nepal
-  Netherlands - Luchtverkeersleiding Nederland (LVNL) (Dutch ATC)
-  New Zealand - Airways New Zealand (State Owned Enterprise)
-  Norway - Avinor (State-owned private company)
-  Pakistan - Civil Aviation Authority (under Government of Pakistan)
-  Peru - Centro de Instrucción de Aviación Civil CIAC Civil Aviation Training Center
-  Philippines - Civil Aviation Authority of the Philippines (CAAP) (under the Philippine Government)
-  Poland - PANSAs - Polish Air Navigation Services Agency
-  Portugal - NAV - NAV (Portuguese ATC)
-  Romania - Romanian Air Traffic Services Administration - (ROMATSA)

-  Russia - Federal State Unitary Enterprise "State ATM Corporation" - (State ATM Corporation)
-  Saudi Arabia - General Authority of Civil Aviation (GACA)
-  Singapore - CAAS (Civil Aviation Authority of Singapore)
-  Serbia - Serbia and Montenegro Air Traffic Services Agency Ltd. (SMATSA)
-  Slovakia - Letové prevádzkové služby Slovenskej republiky
-  Slovenia - Slovenia Control
-  South Africa - Air Traffic and Navigation Services. (ATNS)
-  Spain - AENA (Spanish ATC and Airports)
-  Sweden - The LFV Group (Swedish ATC)
-  Switzerland - Skyguide
-  Taiwan - ANWS Civil Aeronautical Administration
-  Thailand - AEROTHAI (Aeronautical Radio of Thailand)
-  Trinidad and Tobago - TTCAA (Trinidad and Tobago Civil Aviation Authority)
-  Turkey - DGCA (Turkish Directorate General of Civil Aviation)
-  United Arab Emirates - General Civil Aviation Authority (GCAA)
-  United Kingdom - National Air Traffic Services (49% State Owned Public-Private Partnership)
-  United States - Federal Aviation Administration (Government Body)
-  Ukraine - Ukrainian State Air Traffic Service Enterprise (UkSATSE)
-  Venezuela - INAC (Instituto Nacional de Aviación Civil)

Proposed changes

In the United States, some alterations to traffic control procedures are being examined.

- The Next Generation Air Transportation System examines how to overhaul the United States national airspace system.
- Free flight is a developing air traffic control method that uses no centralized control (e.g. air traffic controllers). Instead, parts of airspace are reserved dynamically and automatically in a distributed way using computer communication to ensure the required separation between aircraft.

In Europe, the SESAR (Single European Sky ATM Research) Programme plans to develop new methods, new technologies, new procedures, new systems to accommodate future (2020 and beyond) Air Traffic Needs.

Many countries have also privatized or corporatized their air navigation service providers.

Change in regulation in admittance for possible A.T.C.'s regarding their eye-refraction and correction thereof by technology has been proposed.

USA specificities

FAA Control Tower Operators (CTO)/Air Traffic Controllers use FAA Order 7110.65T as the authority for all procedures regarding air traffic. For more information regarding Air Traffic Control rules and regulations, refer the Federal Aviation Administration's (FAA) website?

Chapter 2

Airfield Traffic Pattern

An **airfield traffic pattern** is a standard path followed by aircraft when taking off or landing, while maintaining visual contact with the airfield.

At an airport, the pattern (or **circuit** in the Commonwealth) is a standard path for coordinating air traffic. It differs from "straight-in approaches" and "direct climb-outs" in that aircraft using a traffic pattern remain close to the airport. Patterns are usually employed at small general aviation (GA) airfields and military airbases. Many large controlled airports avoid the system, unless there is GA activity as well as commercial flights. However, some kind of a pattern may be used at airports in some cases, such as when an aircraft is required to go around — but this kind of pattern at controlled airports may be very different in form, shape and purpose to the standard traffic pattern as used at GA airports.

Wind direction

Pilots prefer to take off and land facing into the wind. This has the effect of reducing the aircraft's speed over the ground (for the same given airspeed) and hence reducing the distance required to perform either maneuver.

The exception to this rule is at alpine airports (altiports) where the runway is on a severe slope. In these instances, takeoffs are usually made downhill and landings uphill, with the slope aiding in acceleration and deceleration.

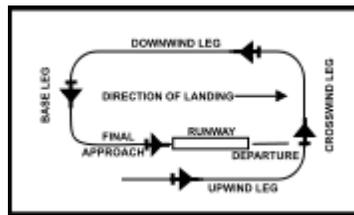
Many airfields have runways facing a variety of directions. The purpose of this is to provide arriving aircraft with the best runway to land on, according to the wind direction. Runway orientation is determined from historical data of the prevailing winds in the area. This is especially important for single-runway airports that don't have the option of a second runway pointed in an alternative direction. A common scenario is to have two runways arranged at or close to 90 degrees to one another, so that aircraft can always find a suitable runway. Almost all runways are reversible, and aircraft use whichever runway in whichever direction is best suited to the wind. In light and variable wind conditions, the direction of the runway in use might change several times during the day.

Layout

Traffic patterns can be defined as left-hand or right-hand, according to which way the turns in the pattern are performed. They are usually left-hand turns because most small airplanes are piloted from the left seat (or the senior pilot or pilot-in-command sits in the left seat), and so the pilot has better visibility out the left window. Right-hand patterns will be set up for parallel runways, for noise abatement or because of ground features (such as terrain, towers, etc.). In USA, the non-standard (i.e. right-hand) patterns are noted in the Airport/Facilities Directory or on a sectional chart, in other countries they may be indicated in that nation's similar document, e.g. Canada Flight Supplement. Unless explicitly indicated otherwise, all traffic patterns at non-towered airports are to the left.

Helicopters are encouraged, but not required, to use an opposite pattern from fixed-wing traffic due to their slower speed and greater maneuverability.

Because the active runway is chosen to meet the wind at the nearest angle (with take-offs and landings upwind), the pattern orientation also depends on wind direction. Patterns are typically rectangular in basic shape, and include the runway along one long side of the rectangle. Each leg of the pattern has a particular name:

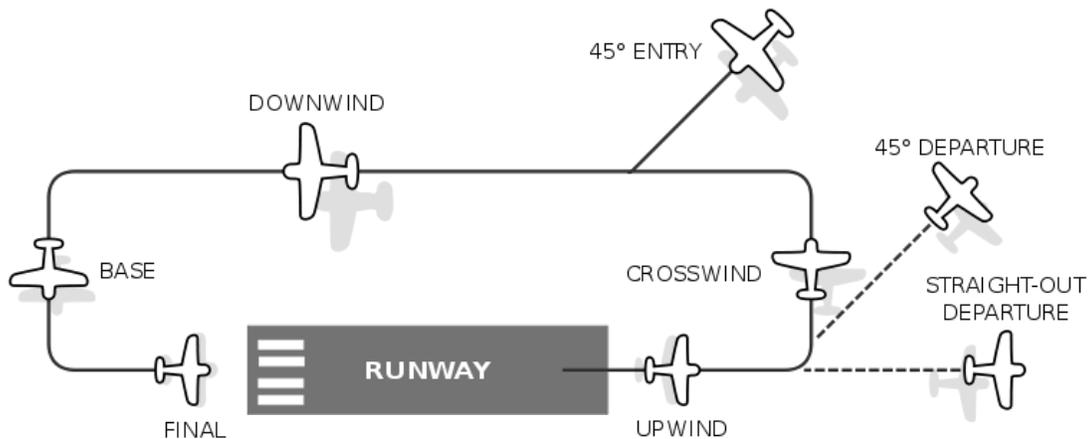


Components of a Traffic Pattern. Fig. 4-3-1 from FAA AIM.

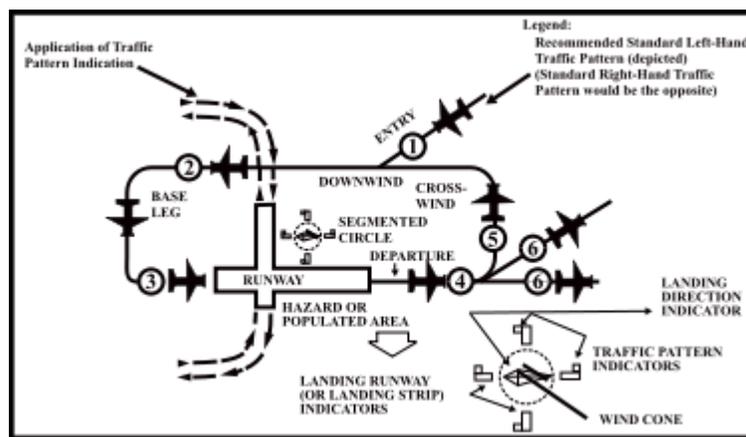
- *Upwind leg.* A flight path parallel to and in the direction of the landing runway. This can be above the runway, as in a "low and over" or when practicing a "missed [instrument] approach," or offset to the upwind side as when inspecting the field prior to landing.
- *Crosswind leg.* A short climbing flight path at right angles to the departure end of the runway.
- *Downwind leg.* A long level flight path parallel to but in the opposite direction of the landing runway. (Some consider it to have "sub-legs" of early, mid and late. Certainly a plane giving a position report of "mid-downwind" can be visually located easily.)
- *Base leg.* A short descending flight path at right angles to the approach end extended centerline of the landing runway.
- *Final approach.* A descending flight path in the direction of landing along the extended runway centerline from the base leg to the runway. The last section of the final approach is sometimes referred to as *short final*.

- *Departure leg.* The climbing flight path along the extended runway centerline which begins at takeoff and continues to at least 1/2 mile beyond the runway's departure end and not less than 300 feet below the traffic pattern altitude. It is a special case of an upwind leg.

The names of the legs are logical and based on the relative wind as seen looking down a runway facing into the wind. An aircraft flying *upwind* heads into the wind, flying *crosswind* heads across the wind, flying *downwind* heads in the direction of the wind just like blown smoke.



While many airfields operate a completely standard pattern, in other cases it will be modified according to need. For example, military airfields often dispense with the crosswind and base legs, but rather fly these as circular arcs directly joining the upwind and downwind sections.



Standard airport traffic pattern. Fig. 4-3-2 from FAA AIM.

Procedures in the pattern

Aircraft are expected to join and leave the pattern, following the pattern already in use. Sometimes this will be at the discretion of the pilot, while at other times the pilot will be directed by air traffic control.

There are conventions for joining the pattern, used in different jurisdictions.

- In the United States, aircraft usually join the pattern at a 45° angle to the downwind leg and abeam midfield. Although aircraft may legally join the pattern at any point, the AIM clearly states that the only approved pattern entry is the 45.
- In Canada, aircraft at uncontrolled airports usually cross the airport at midfield at pattern altitude from the upwind side, turning onto the downwind leg. At controlled airports, the tower typically directs aircraft to join the downwind leg, base leg, or straight in to the final leg.
- In the UK and South Africa, a Standard Overhead Join is recommended.
- In Europe, aircraft usually join the pattern at a 45° angle to the downwind leg, in the beginning of the downwind leg.
- Fast aircraft, for example military jets, may enter the pattern with a run-and-break. The aircraft flies at speed along the final leg, and makes a sharp, high-G turn above midfield to lose speed and arrive on the downwind leg at pattern altitude and in landing configuration.

Similarly, there are conventions for departing the pattern.

- In the United States, aircraft usually depart the pattern either straight out along the runway heading, or with a 45° turn in the direction of the crosswind leg.
- In Canada, aircraft usually depart straight out along the runway heading until at circuit altitude, at which point they may turn as desired. At controlled airports, the tower typically gives instructions for what turn to make on departure.

There is also a procedure known as an "orbit", where an aircraft flies a 360° loop either clockwise or anticlockwise. This is usually to allow greater separation with other traffic ahead in the pattern. This can be the result of a controller's instruction. If at the pilot's initiative, the pilot will report e.g. "(tail ID number or flight number) making one left-hand orbit, will advise complete".

Contra-rotating circuit patterns

In cases where two or more parallel runways are in operation concurrently, the aircraft operating on the outermost runways are required to perform their patterns in a direction which will not conflict with the other runways. Thus, one runway may be operating with a left-hand pattern direction, and the other one will be operating with a right-hand pattern direction. This allows aircraft to maintain maximum separation during their patterns, however it is important that the aircraft do not stray past the centerline of the runway when joining the final leg, so as to avoid potential collisions. If three or more parallel

runways exist, as is the case at Bankstown Airport in Australia, then the middle runway(s) can, for obvious reasons, only be used when either a straight in approach is used or when the aircraft joins the pattern from a very wide base leg.

Altitudes

An airfield will define a **circuit height** or **pattern altitude**, that is, a nominal level above the field at which pilots are required (recommended in the US, FAA AC90-66A Para. 8c) to fly while in the circuit. Unless otherwise specified, the standard recommended pattern height is 1000 ft AGL (above ground level), although a pattern height of 800 feet above ground level is relatively common. Helicopters usually fly their pattern at 500 feet above ground level. Extreme caution is exercised by pilots flying the published traffic pattern altitude as this may contribute to mid air collisions.

Benefits

The use of a pattern at airfields is for air safety. Rather than have aircraft flying around the field in a haphazard fashion, by using a pattern pilots will know from where to expect other air traffic, and be able to see it and avoid it. GA pilots flying under Visual Flight Rules (VFR) will not be separated by air traffic control, and so the pattern is a vital way to keep things orderly. However, at tower-controlled airports air traffic control (ATC) will provide traffic advisories for VFR flights on a work-load permitting basis.

A pilot undergoing training will often fly many patterns, one after another. Usually, each landing is followed immediately by a take off and further pattern; this is called a touch and go. Pilots executing Touch and Go landings should declare the intention to do so when calling the final approach leg. After landing and once airborne again the Touch and Go pilot should declare that the aircraft is On the Go. The pilot should not declare that the aircraft is on an Upwind as that term is not applicable to non-towered airports and is not appropriate for aircraft departing from a runway end.

Helicopters

Helicopter pilots also prefer to land facing the wind and are often asked to fly a pattern on arrival or departure. Many airfields operate a special pattern for helicopters to take account of their low airspeed. This is usually a mirror image of the fixed-wing pattern, and often at a slightly lower standard height above surface level; as noted above this altitude is usually 500 feet above ground level. However due to helicopters' unique maneuverability, helicopter pilots often choose not to enter the pattern, and make a direct approach to the helipad or apron they wish to land on.

Other patterns

If an aircraft intending to land must be delayed, the air traffic control (ATC) may decide to place it in a holding pattern until the airport is prepared to permit the landing. Commercial aircraft on hold will generally fly slow, racetrack-shaped patterns which

differ considerably from the airfield traffic pattern that will be commenced once the approval has been given to land. Although an aircraft in a holding pattern may similarly circle the airport, ATC may designate a distant location in which to circle.

Chapter 3

Aircraft Warning Lights



Emley Moor transmitting station using a red warning beacon

Aircraft warning lights are high-intensity lighting devices that are attached to tall structures that are used as collision avoidance measures. Such devices make structures more visible to passing aircraft and are usually used at night, although they may be used during the day as well. These lights need to be of sufficient brightness in order to be visible for miles around the structure.

Lamp types



Structure using a white strobe



Structure using a Red/White Strobe



Closeup of an aircraft warning light on top of a highrise in Changzhou, China



Structure using high intensity white lights and a medium intensity white strobe

The lights generally come in two forms:

- Red lamps that are either constantly illuminated or turn on and off slowly in a cycle of a few seconds.
- White xenon discharge flashers.

Both types were in use in the United Kingdom until recently, however new regulations stipulate the use of red lamps at nighttime only. Xenon flashers are therefore gradually being phased out.

In the United States and Canada, there are several types of lights:

- Obstruction lights (that are constantly illuminated)
- Red Beacons/Red strobes
- High Intensity White (Strobe) Lights
- Medium Intensity White (Strobe) Lights

Traditionally, red lamps (or beacons) use incandescent filament bulbs. In order to improve the otherwise quite short lifespan, they are made with a ruggedised design and

are run below normal operating power (under-running). A recent development has been the use of arrays of high power red LEDs in place of incandescent bulbs, which has only been possible since the development of LEDs of sufficient brightness. LED based lamps have a significantly longer lifespan than incandescent bulbs, thus reducing maintenance costs and increasing reliability. Several manufacturers have also developed medium intensity white strobes based on LED technology to replace Xenon.

Xenon flashers, whilst more visually impressive, tend to require frequent replacement and so have become a less favoured option. However, with the advent of LEDs, white strobes are still somewhat desired.

It is common to find structures with white xenon flashers/white strobes during the daytime, and red lights at night. Red lights are commonly found to be used in urban areas, since it is easier for pilots to spot them from above. White strobes (that flash 24/7) may also be used in urban areas. However, it has been recommended that flashing white strobes should not be used in densely populated areas; the lights usually merge with background lighting at nighttime, making it difficult for pilots to spot them and thereby aggravating the hazard. In addition, residents near the lit structure will complain of light trespass.

In rural areas, red beacons/strobes may also be used during nighttime. However, white strobes are (sometimes) preferred since it reduces maintenance cost (i.e. no maintenance of painting, no red side lights) and there are no background lights that would blend with the strobes.

For white strobes, there is a medium intensity white strobe and a high intensity white strobe. Medium Intensity White Strobes are usually used on structures that are between 200–500 feet (61-152.4 meters). If a medium white strobe is used on a structure greater than 500 feet (152.4 meters), the structure *must* be painted.

The common medium white strobe flashes 40 times in a minute, at an intensity of 20,000 candelas for daytime/twilight, and 2,000 candelas at nighttime.

A high intensity white strobe light is used on structures that are greater than 500 feet (152.4 meters). These lights provide the highest visibility both day and night. Unlike a medium strobe, a high intensity strobe doesn't provide 360° coverage; this requires the use of at least 3 high strobes at each level. On the other hand, it reduces maintenance costs (i.e. no painting). If the structure has an antenna at the top that is greater than 40 feet, a medium intensity white strobe light must be placed above it rather than below.

The common high white strobe flashes 40 times in a minute, at an intensity of 270,000 candelas for daytime, 20,000 candelas at twilight, and 2,000 candelas at night-time.

Dual lighting is where a structure is equipped with white strobes for daytime use, and red beacons/strobes for nighttime use. In urban areas, these are commonly preferred since it usually exempts a structure from the requirement of having to be painted. One advantage

to the dual system is that when the uppermost red lights fail, the lighting switches onto its *Backup* lighting system, which uses the white strobes (at its night intensity) for nighttime. In the United States and Canada, red beacons are slowly going out of commission and being replaced with red strobes. In addition, some medium strobes are equipped to flash the white light for daytime and red light for night in a single strobe (unlike the old type which had two different lights).

For high tension power lines, the white strobes are equipped to flash 60 times per minute, using the same intensities as stated above. Unlike the common white strobes, these strobes are specified not to flash simultaneously. The flash pattern should be middle, top, and bottom to provide "a unique system display".

On aircraft



An antenna tower stands 446 feet tall in Springfield, MO with its red and white aircraft warning paint clearly visible in the setting sun.

Aircraft use collision avoidance lighting systems to warn other aircraft of their presence. These lights include landing lights, white beacons, wingtip strobes, and wingtip navigation lights. The wingtip navigation lights are required to consist of a red light on the left wingtip and a green light on the right wingtip. Landing lights are used during the descent and approach to landing, and at other times if deemed necessary by the flight crew or operator.

Use and positioning

These lights can generally be found attached to any tall structure such as broadcast masts and towers, water tanks located on high elevation, electricity pylons, chimneys, tall buildings, cranes and wind turbines. Shorter structures that are located close to airports may also require lighting. The International Civil Aviation Organization (ICAO) sets standards, usually adopted worldwide, for the performance and characteristics of aviation warning lamps.

Lights are usually arranged in clusters of two or more around the structure at specific heights on the tower. Frequently there will be a set at the top, and then one or more sets equally spaced down the structure. England's Belmont mast (the tallest construction in the European Union) has nine clusters of red lamps spaced equally along the full height of the mast.

Non-standard aircraft warning lights

On some tall structures there are or were non-standard aircraft warning lights installed.

- The mast of Deutschlandsender Herzberg/Elster had no aircraft warning lamps installed. It was instead lit by skybeamers mounted on small masts near the tower. This method was chosen as the mast was a mast radiator insulated against ground and for feeding the lamps on the mast otherwise special devices like Austin transformers would be required.
- Stuttgart TV Tower carries rotating lamps like used on lighthouses. Such lamps were also used on other towers in earlier days.
- Blosenbergturm in Beromünster has a rotating lamp above the cabin. In opposite to Stuttgart TV Tower it is less bright and only operated in the dawn.
- The main mast of Mühlacker radio transmitter and the former Konstantynow Radio Mast has or have also aircraft warning lights at the outmost bases of their anchor guys.
- Conductor marking lights and Balisors are sometimes used for marking power lines.
- The Obstacle Collision Avoidance System allows the standard lights to remain off until an aircraft is in within a given radius, allowing for a significant decrease in light pollution. The OCAS system also provides audio warnings.

Aircraft warning paint

Aircraft warning paint usually consists of red and white paint at equal lengths on the antenna tower or mast. This paint scheme is usually required on towers over 300 feet tall, but may vary from state to state and near airports internationally. Because such a paint scheme is expensive to apply, antenna towers and masts are often built to heights just below the level of requirement. Antenna towers and masts often also have other aircraft warning features located at equal distances along their height and at their tops. These may include high powered strobe lights or LED lights in either red, white, or both colors in an alternating pattern. In such a case red is employed at night, while a white strobe is usually used during daylight hours.

Chapter 4

Radar Tracker

A **radar tracker** is a component of a radar system, or an associated command and control (C2) system, that associates consecutive radar observations of the same target into tracks. It is particularly useful when the radar system is reporting data from several different targets or when it is necessary to combine the data from several different radars or other sensors.

Role of the radar tracker

A classical rotating air surveillance radar system detects target echoes against a background of noise. It reports these detections (known as "plots") in polar coordinates representing the range and bearing of the target. In addition, noise in the radar receiver will occasionally exceed the detection threshold of the radar's Constant false alarm rate detector and be incorrectly reported as targets (known as false alarms). The role of the radar tracker is to monitor consecutive updates from the radar system (which typically occur once every few seconds, as the antenna rotates) and to determine those sequences of plots belonging to the same target, whilst rejecting any plots believed to be false alarms. In addition, the radar tracker is able to use the sequence of plots to estimate the current speed and heading of the target. When several targets are present, the radar tracker aims to provide one track for each target, with the track history often being used to indicate where the target has come from.

When multiple radar systems are connected to a single reporting post, a **multiradar tracker** is often used to monitor the updates from all of the radars and form tracks from the combination of detections. In this configuration, the tracks are often more accurate than those formed from single radars, as a greater number of detections can be used to estimate the tracks. In addition to associating plots, rejecting false alarms and estimating heading and speed, the radar tracker also acts as a filter, in which errors in the individual radar measurements are smoothed out. In essence, the radar tracker fits a smooth curve to the reported plots and, if done correctly, can increase the overall accuracy of the radar system. A **multisensor tracker** extends the concept of the multiradar tracker to allow the combination of reports from different types of sensor - typically radars, secondary

surveillance radars, identification friend or foe (IFF) systems and electronic support measures (ESM) data. A radar track will typically contain the following information

- Position (in two or three dimensions)
- Heading
- Speed
- Unique track number

In addition, and depending on the application or tracker sophistication, the track will also include:

- Civilian SSR Modes A, C, S information
- Military IFF Modes 1, 2, 3, 4 and 5 information
- Call sign information
- ADS-B information
- Track reliability or uncertainty information

General approach

There are many different mathematical algorithms used for implementing a radar tracker, of varying levels of sophistication. However, they all perform steps similar to the following every time the radar updates:

- Associate a radar plot with an existing track (plot to track association)
- Update the track with this latest plot (track smoothing)
- Spawn new tracks with any plots that are not associated with existing tracks (track initiation)
- Delete any tracks that have not been updated, or predict their new location based on the previous heading and speed (track maintenance)

Perhaps the most important step is the updating of tracks with new plots. All trackers will implicitly or explicitly take account of a number of factors during this stage, including:

- a model for how the radar measurements are related to the target coordinates
- the errors on the radar measurements

- a model of the target movement
- errors in the model of the target movement

Using these information, the radar tracker attempts to update the track by forming a weighted average of the current reported position from the radar (which has unknown errors) and the last predicted position of the target from the tracker (which also has unknown errors). The tracking problem is made particularly difficult for targets with unpredictable movements (i.e. unknown target movement models), non-Gaussian measurement or model errors, non-linear relationships between the measured quantities and the desired target coordinates, detection in the presence of non-uniformly distributed clutter, missed detections or false alarms. In the real world, a radar tracker typically faces a combination of all of these effects; this has led to the development of an increasingly sophisticated set of algorithms to resolve the problem. Due to the need to form radar tracks in real time, usually for several hundred targets at once, the deployment of radar tracking algorithms has typically been limited by the available computational power.

Plot to track association

In this step of the processing, the radar tracker seeks to determine which plots should be used to update which tracks. In many approaches, a given plot can only be used to update one track. However, in other approaches a plot can be used to update several tracks, recognising the uncertainty in knowing to which track the plot belongs. Either way, the first step in the process is to update all of the existing tracks to the current time by predicting their new position based on the most recent state estimate (e.g. position, heading, speed, acceleration, etc.) and the assumed target motion model (e.g. constant velocity, constant acceleration, etc.). Having updated the estimates, it is possible to try to associate the plots to tracks.

This can be done in a number of ways:

- By defining an "acceptance gate" around the current track location and then selecting:
 - the closest plot in the gate to the predicted position, or
 - the strongest plot in the gate
- By a statistical approach, such as the Probabilistic Data Association Filter (PDAF) or the Joint Probabilistic Data Association Filter (JPDAF) that choose the most probable location of plot through a statistical combination of all the likely plots. This approach has been shown to be good in situations of high radar clutter.

Once a track has been associated with a plot, it moves to the **track smoothing** stage, where the track prediction and associated plot are combined to provide a new, smoothed estimate of the target location.

Having completed this process, a number of plots will remain unassociated to existing tracks and a number of tracks will remain without updates. This leads to the steps of **track initiation** and **track maintenance**.

Track initiation

Track initiation is the process of creating a new radar track from an unassociated radar plot. Obviously, when the tracker is first switched on, all of the initial radar plots are used to create new tracks, but once the tracker is running, only those plots that couldn't be used to update an existing track are used to spawn new tracks. Typically a new track is given the status of **tentative** until plots from subsequent radar updates have been successfully associated with the new track. Tentative tracks are not shown to the operator and so they provide a means of preventing false tracks from appearing on the screen - at the expense of some delay in the first reporting of a track. Once several updates have been received, the track is **confirmed** and displayed to the operator. The most common criterion for promoting a tentative track to a confirmed track is the "M-of-N rule", which states that during the last N radar updates, at least M plots must have been associated with the tentative track - with M=3 and N=5 being typical values. More sophisticated approaches may use a statistical approach in which a track becomes confirmed when, for instance, its covariance matrix falls to a given size.

Track maintenance

Track maintenance is the process in which a decision is made about whether to end the life of a track. If a track was not associated with a plot during the plot to track association phase, then there is a chance that the target may no longer exist (for instance, an aircraft may have landed or flown out of radar cover). Alternatively, however, there is a chance that the radar may have just failed to see the target at that update, but will find it again on the next update. Common approaches to deciding on whether to terminate a track include:

- If the target was not seen for the past M consecutive update opportunities (typically M=3 or so)
- If the target was not seen for the past M out of N most recent update opportunities
- If the target's track uncertainty (covariance matrix) has grown beyond a certain threshold

Track smoothing

In this important step, the latest track prediction is combined with the associated plot to provide a new, improved estimate of the target state as well as a revised estimate of the errors in this prediction. There are a wide variety of algorithms, of differing complexity and computational load, that can be used for this process.

Alpha-beta tracker

An early tracking approach that assumed fixed Gaussian errors and a constant-speed, non-maneuvering target model to update tracks.

Kalman filter

The role of the Kalman Filter is to take the current known state (i.e. position, heading, speed and possibly acceleration) of the target and predict the new state of the target at the time of the most recent radar measurement. In making this prediction, it also updates its estimate of its own uncertainty (i.e. errors) in this prediction. It then forms a weighted average of this prediction of state and the latest measurement of state, taking account of the known measurement errors of the radar and its own uncertainty in the target motion models. Finally, it updates its estimate of its uncertainty of the state estimate. A key assumption in the mathematics of the Kalman filter is that measurement equations (i.e. the relationship between the radar measurements and the target state) and the state equations (i.e. the equations for predicting a future state based on the current state) are linear - i.e. can be expressed in the form $y = A.x$ (where A is a constant), rather than $y = f(x)$.

The Kalman filter assumes that the measurement errors of the radar, and the errors in its target motion model, and the errors in its state estimate are all zero-mean Gaussian distributed. This means that all of these sources of errors can be represented by a covariance matrix. The mathematics of the Kalman filter is therefore concerned with propagating these covariance matrices and using them to form the weighted sum of prediction and measurement.

In situations where the target motion conforms well to the underlying model, there is a tendency of the Kalman filter to become "over confident" of its own predictions and to start to ignore the radar measurements. If the target then manoeuvres, the filter will fail to follow the manoeuvre. It is therefore common practice when implementing the filter to arbitrarily increase the magnitude of the state estimate covariance matrix slightly at each update to prevent this.

Multiple hypothesis tracker (MHT)

The MHT allows a track to be updated by more than one plot at each update, spawning multiple possible tracks. As each radar update is received every possible track can be potentially updated with every new update. Over time, the track branches into many possible directions. The MHT calculates the probability of each potential track and typically only reports the most probable of all the tracks. For reasons of finite computer memory and computational power, the MHT typically includes some approach for deleting the most unlikely potential track updates. The MHT is designed for situations in which the target motion model is very unpredictable, as all potential track updates are considered. For this reason, it is popular for problems of ground target tracking in Airborne Ground Surveillance (AGS) systems.

Interacting multiple model (IMM)

The IMM is an estimator which can either be used by MHT or JPDAF. IMM uses two or more Kalman filters which run in parallel, each using a different model for target motion or errors. The IMM forms an optimal weighted sum of the output of all the filters and is able to rapidly adjust to target maneuvers. While MHT or JPDAF handles the association and track maintenance, an IMM helps MHT or JPDAF in obtaining a filtered estimate of the target position.

Nonlinear tracking algorithms

Non-linear tracking algorithms use a Non-linear filter to cope with the situation where the measurements have a non-linear relationship to the final track coordinates, where the errors are non-Gaussian, or where the motion update model is non-linear. The most common non-linear filters are:

- the Extended Kalman filter
- the Unscented Kalman filter
- the Particle filter

Extended Kalman filter (EKF)

The EKF is an extension of the Kalman filter to cope with cases where the relationship between the radar measurements and the track coordinates, or the track coordinates and the motion model, is non-linear. In this case, the relationship between the measurements and the state is of the form $h = f(x)$ (where h is the vector of measurements, x is the target state and $f(\cdot)$ is the function relating the two). Similarly, the relationship between the future state and the current state is of the form $x(t+1) = g(x(t))$ (where $x(t)$ is the state at time t and $g(\cdot)$ is the function that predicts the future state). To handle these non-linearities, the EKF linearises the two non-linear equations using the first term of the Taylor series and then treats the problem as the standard linear Kalman filter problem. Although conceptually simple, the filter can easily diverge (i.e. gradually perform more and more badly) if the state estimate about which the equations are linearised is poor.

The unscented Kalman filter and particle filters are attempts to overcome the problem of linearising the equations.

Unscented Kalman filter (UKF)

The UKF attempts to improve on the EKF by removing the need to linearise the measurement and state equations. Although it retains the assumption that the filter errors are Gaussian distributed, rather than model these as covariance matrices, it instead chooses an explicit sample of those Gaussian errors by choosing a small number (typically 5 or so) of different state estimates that have the required mean and variance.

These points are then propagated directly through the non-linear equations, and the resulting five updated samples are then used to calculate a new mean and variance. This approach then suffers none of the problems of divergence due to poor linearisation and yet retains the overall computational simplicity of the EKF.

Particle filter

The Particle Filter could be considered as a generalisation of the UKF. It makes no assumptions about the distributions of the errors in the filter and neither does it require the equations to be linear. Instead it generates a large number of random potential states ("particles") and then propagates this "cloud of particles" through the equations, resulting in a different distribution of particles at the output. The resulting distribution of particles can then be used to calculate a mean or variance, or whatever other statistical measure is required. The resulting statistics are used to generate the random sample of particles for the next iteration. The particle filter is notable in its ability to handle multi-modal distributions (i.e. distributions where the PDF has more than one peak). However, it is computationally very intensive and is currently unsuitable for most real-world, real-time applications.

Chapter 5

Procedural Control

Procedural control is a method of providing air traffic control services without the use of radar. It is used in regions of the world, specifically sparsely-populated land areas and oceans, where radar coverage is either prohibitively expensive or is simply not feasible. It also may be used at very low-traffic airports, or at other airports at night when the traffic levels may not justify staffing the radar control positions, or as a back-up system in the case of radar failure.

Separation

In air traffic control, the risk of aircraft colliding is managed by applying separation rules. These rules require aircraft to be separated by either a minimum vertical distance, or if vertical separation is not feasible, by a minimum horizontal distance defined by various means. One of the means of determining horizontal separation is by a controller observing the radar returns of the aircraft to be at least a minimum horizontal distance apart. This is the essence of radar control and is probably the form of air traffic control most familiar to lay people.

However in times gone by radar was not very common, and in certain parts of the world today it still is not common, on grounds of cost or technical feasibility. Procedural control is a form of air traffic control that can be provided to aircraft in regions without radar, by providing horizontal separation based upon time, the geography of pre-determined routes, or aircraft position reports based upon ground-based navigation aids, for those aircraft that are not vertically separated.

Techniques



A strip rack at a high-altitude procedural sector in Indonesia

The central rule of procedural control is that each aircraft is cleared onto a predetermined route (airway), and no aircraft traveling on the same or intersecting routes at the same level shall come within 10 minutes' flying time of another (or sometimes 15 minutes depending on the accuracy of the available radio navigation beacons).

Using procedural control, the controller must maintain a mental picture of the location of aircraft based on each aircraft's flight progress strip, which contains its route, altitude and estimated times over reporting points. That information is compared against all other aircraft in the sector to determine if there are any conflicts. For aircraft that conflict, the controller issues an altitude, speed or routing change that both separates the conflicting aircraft from each other, while still remaining separated from all others. After all conflicts have been resolved in this way, the sector is considered "separated" and the controller only needs to check again for conflicts when new aircraft are added, if an aircraft needs to change its altitude, or if the aircraft reaches a reporting point significantly earlier or later than previously estimated.

There are two main techniques controllers use to organize flight progress strips in order to best detect conflicts: grouped together by *altitude*, or grouped together by route

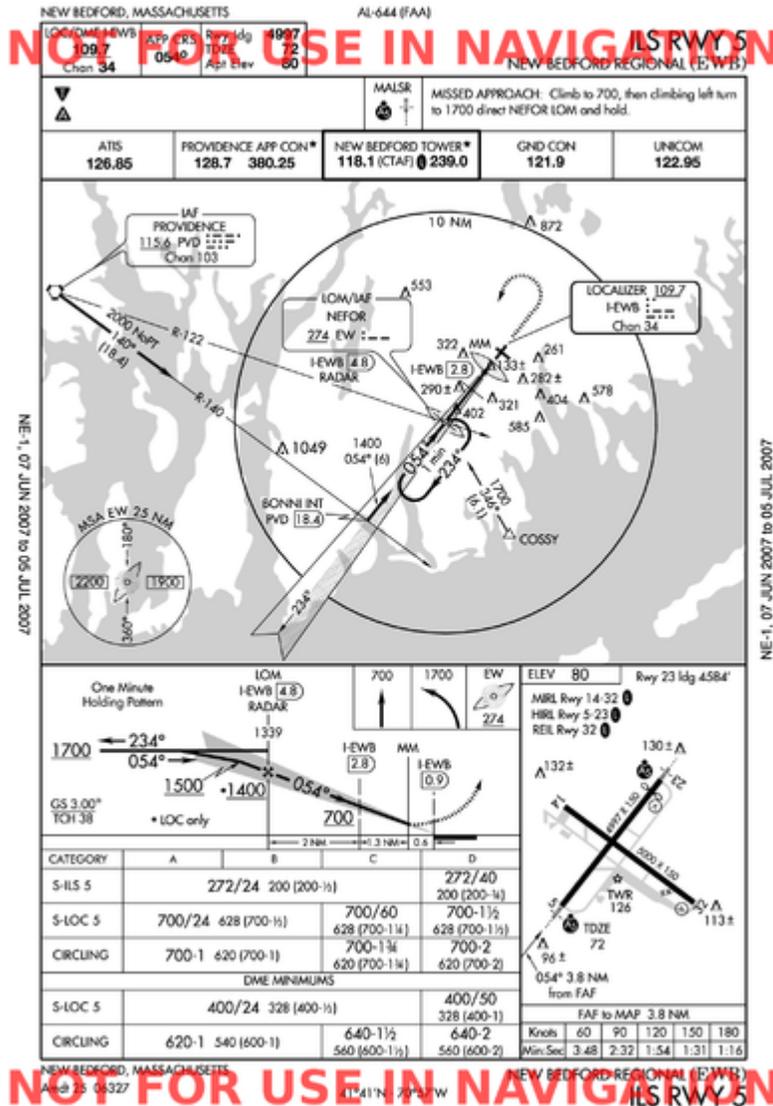
intersection points (*fix posting area*). Altitude grouping is the easiest and most common method when most aircraft in the sector tend to be level at a cruising altitude, such as in trans-oceanic sectors. Each aircraft's strip is placed in a "bay" (labeled section of the strip rack) depending on its altitude. Because aircraft cruising at different altitudes will never conflict regardless of route of flight or estimated times, they don't need to be checked against each other. Only aircraft at the same altitude (i.e. in the same bay) need to be further evaluated. If an aircraft needs to transition to a new altitude (whether changing cruising level, or descending to or climbing from an airport), it only needs to be checked against others in the bays between the current altitude and destination altitude.

The *fix posting area* method is easier however when there are a lot of altitude changes because of numerous departures and arrivals within the sector. This is a more obscure method today because most airports around the world with significant enough traffic to warrant this technique have at least a radar covering the climbout and arrival area, and only need procedural control for points between (in which case altitude grouping is likely more efficient).

Nevertheless, the *fix posting area* method was the main technique used in U.S. en route system prior to the 1960's, for example, when en route radar became more widespread. This method evolved from similar techniques used in railroad dispatch. It simplifies conflict detection because aircraft on different routes can only possibly conflict at intersection points with other routes, or with aircraft on the same route. Each intersection point ("fix posting area") in the sector is made into a separate bay on the strip rack, and multiple strips are printed for each aircraft, one per bay. The controller then sorts strips within each bay by the estimated time the aircraft is expected over that point. Only aircraft estimated to cross within 10 minutes of each other are considered possible conflicts, at which point altitudes are then compared to determine if there actually is a conflict. Aircraft on the same route however (in either direction) must be checked for conflict regardless of time over the intersection.

As new altitudes are issued, all of the strips for that aircraft must be annotated with the new data and separation checked again at all of the intersections it passes through. This is more laborious than the altitude method of grouping where only one strip is needed, but possible conflicts between multiple aircraft climbing and descending are easier to discern or discard this way since all intersection points and times are precalculated and laid out separately. With the altitude grouping method, if two aircraft are determined to conflict based on altitude, the controller must then manually determine the intersection points and times to further determine or rule out the conflict.

Procedural approaches



The approach plate for an ILS approach shows the pilot the tracks (as defined by nav aids) and levels to be flown during the approach.

Every runway used by IFR aircraft normally has a procedural approach defined and published. This generally involves the aircraft flying over a nav aid (or 'beacon') on or close to the airport (where the aircraft can hold if necessary), flying away from the airport on a set track whilst descending (going 'beacon outbound'), then at some point approximately ten miles from the airport turning back towards the airport aligned with the runway to make an approach (becoming 'inbound track established' or just 'established').

In procedural approach control, separation is maintained by only allowing one aircraft to be making an approach at any one time -- the proceeding aircraft must either be in visual contact by the airport's control tower, or have reported that it has landed before the next aircraft is allowed to leave the hold and commence the approach.

At airports equipped with radar, procedural approaches are only normally used in the event of an aircraft suffering a radio failure, or for training purposes. At non-radar airports or when radar is not available, these become the only means of IFR flights making approaches to the airport.

At some non-radar airports the procedural approach may be combined with aerodrome control, thus providing a control service for all aircraft at the airport, and all in and outbound flights within its terminal airspace. As most aircraft will be flying to/or from the same point within this airspace (i.e. the airport), procedural controllers use a variety of separation standards to achieve a safe and expeditious flow of air traffic to and/or from the airport. One commonly used separation in these locations is track separation, which states that two aircraft on different tracks to/from a navigational aid will be separated from each other provided at least one is a minimum distance from the navaid. The distance needed will vary dependent on how far apart the tracks are. For example, two aircraft on tracks that are 60° apart do not have to be far from the navaid to be clear of each other in comparison to two aircraft whose tracks are, say 13° apart.

Airspace capacity

En-route jet aircraft tend to fly at roughly 8nm per minute: therefore 10-15 minutes' flying time separation using procedural control would equate to around 80-120nm distance between aircraft at the same altitude. This contrasts with standard separation on radar whilst en-route, which is only 5nm. Likewise a typical procedural approach might allow one aircraft to land only every 5-10 minutes, whereas with radar this could be less than one landing every 90 seconds. It is therefore easy to see what a large increase in airspace capacity the provision of radar-based air traffic control gives.

Chapter 6

Wake Turbulence



This picture from a NASA study on wingtip vortices qualitatively illustrates the wake turbulence.

Wake turbulence is turbulence that forms behind an aircraft as it passes through the air. This turbulence includes various components, the most important of which are wingtip vortices and **jetwash**. Jetwash refers simply to the rapidly moving gases expelled from a jet engine; it is extremely turbulent, but of short duration. Wingtip vortices, on the other hand, are much more stable and can remain in the air for up to three minutes after the

passage of an aircraft. Wingtip vortices make up the primary and most dangerous component of wake turbulence.

Wake turbulence is especially hazardous during the landing and take off phases of flight, for three reasons. The first is that during take-off and landing, aircraft operate at low speeds and high angle of attack. This flight attitude maximizes the formation of dangerous wingtip vortices. Secondly, takeoff and landing are the times when a plane is operating closest to its stall speed and to the ground, meaning there is little margin for recovery in the event of encountering another aircraft's wake turbulence. Thirdly, these phases of flight put aircraft closest together and along the same flightpath, maximizing the risk of encountering the phenomenon.

Fixed wing – level flight

At altitude, vortices sink at a rate of 90 to 150 metres per minute and stabilize about 150 to 270 metres below the flight level of the generating aircraft. For this reason, aircraft operating greater than 600 metres above the terrain are not considered at risk.

Helicopters

Helicopters also produce wake turbulence. Helicopter wakes may be of significantly greater strength than those from a fixed wing aircraft of the same weight. The strongest wake can occur when the helicopter is operating at lower speeds (20 to 50 knots). Some mid-size or executive class helicopters produce wake as strong as that of heavier helicopters. This is because two blade main rotor systems, typical of lighter helicopters, produce stronger wake than rotor systems with more blades.

Parallel or crossing runways

During takeoff and landing, an aircraft's wake sinks toward the ground and moves laterally away from the runway when the wind is calm. A 3 to 5 knot crosswind will tend to keep the upwind side of the wake in the runway area and may cause the downwind side to drift toward another runway. Since the wingtip vortices exist at the outer edge of an airplane's wake, this can be dangerous.

Hazard avoidance

Wake vortex separation



Wake vortices from a landing Airbus at Oakland Airport interact with the sea as they descend to ground level

ICAO mandates separation minima based upon wake vortex categories that are, in turn, based upon the Maximum Take Off Mass (MTOW|MTOM) of the aircraft.

These minima are categorised as follows:

- Light – MTOW of 7,000 kilograms (15,000 lb) or less;
- Medium – MTOW of greater than 7,000 kilograms, but less than 136,000 kilograms (300,000 lb);
- Heavy – MTOW of 136,000 kilograms or greater.

There are a number of separation criteria for take-off, landing and en-route phases of flight based upon these categories. Air Traffic Controllers will sequence aircraft making instrument approaches with regard to these minima. Aircraft making a visual approach are advised of the relevant recommended spacing and are expected to maintain their own separation.

The FAA does not use the ICAO categories for wake turbulence separation, instead using the following:

"Appendix A is being revised to harmonize FAA weight category standards with those of the International Civil Aviation Organization (ICAO). All aircraft with a maximum certificated takeoff weight of more than 41,000 pounds but less than 300,000 pounds maximum certificated takeoff weight will now be classified as a "Large" aircraft according to FAA standards. Aircraft with a maximum certificated takeoff weight of 300,000 pounds or more will now be classified as a "Heavy" aircraft according to FAA and ICAO weight classification standards. This change reclassifies all B757 aircraft as "Large" aircraft; however, controllers are required to apply the special wake turbulence separation criteria as specified in paragraph 5-5-4. This change cancels and incorporates N JO 7110.525, Appendix A, Aircraft Information Fixed-Wing Aircraft, effective April 8, 2010."

- Super - A separate designation that currently only refers to the Airbus A380
- Heavy - Aircraft capable of takeoff weights of 300,000 pounds (140,000 kg) or more whether or not they are operating at this weight during a particular phase of flight.
- Large - Aircraft of more than 41,000 pounds (19,000 kg), maximum certificated takeoff weight, up to but not including 300,000 pounds (140,000 kg) .
- Small – Aircraft of 41,000 pounds or less maximum certificated takeoff weight.

Common minima are:

Take-off

An aircraft of a lower wake vortex category must not be allowed to take off less than two minutes behind an aircraft of a higher wake vortex category. If the following aircraft does not start its take off roll from the same point as the preceding aircraft, this is increased to three minutes.

Landing

Preceding aircraft Following aircraft Minimum radar separation

	Super	4 NM
Super	Heavy	6 NM
	Medium	7 NM
	Light	8 NM
Heavy	Heavy	4 NM
	Medium	5 NM
Medium	Light	6 NM
	Light	5 NM

Staying on or above leader's glide path

Incident data shows that the greatest potential for a wake vortex incident occurs when a light aircraft is turning from base to final behind a heavy aircraft flying a straight-in approach. Light aircraft pilots must use extreme caution and intercept their final approach path above or well behind the heavier aircraft's path. When a visual approach following a preceding aircraft is issued and accepted, the pilot is required to establish a safe landing interval behind the aircraft he was instructed to follow. The pilot is responsible for wake turbulence separation. Pilots must not decrease the separation that existed when the visual approach was issued unless they can remain on or above the flight path of the preceding aircraft.

Warning signs

Any uncommanded aircraft movements (such as wing rocking) may be caused by wake. This is why maintaining situational awareness is so critical. Ordinary turbulence is not unusual, particularly in the approach phase. A pilot who suspects wake turbulence is affecting his or her aircraft should get away from the wake, execute a missed approach or go-around and be prepared for a stronger wake encounter. The onset of wake can be insidious and even surprisingly gentle. There have been serious accidents where pilots have attempted to salvage a landing after encountering moderate wake only to encounter severe wake turbulence that they were unable to overcome. Pilots should not depend on any aerodynamic warning, but if the onset of wake is occurring, immediate evasive action is vital.

Incidents involving wake turbulence



XB-70 62-0207 following the midair collision on 8 June 1966.

- June 8, 1966 - an XB-70 collided with an F-104. Though the true cause of the collision is unknown, it is believed that due to the XB-70 being designed to have an enhanced wake turbulence to increase lift, the F-104 moved too close, therefore getting caught in the vortex and colliding with the wing.
- May 30, 1972 - Delta Air Lines Flight 9570 crashed at the Greater Southwest International Airport while performing "touch and go" landings behind a DC-10. This crash prompted the FAA to create new rules for minimum following separation from "heavy" aircraft.
- December 15, 1993 - a chartered aircraft with five people on-board, including In-N-Out Burger's president, Rich Snyder, crashed at John Wayne Airport. The aircraft followed a Boeing 757 in for landing, became caught in its wake turbulence, rolled into a deep descent and crashed.
- September 8, 1994 - USAir Flight 427 crashed near Pittsburgh, Pennsylvania in 1994. This accident was believed to involve wake turbulence, though the primary cause was a defective rudder control component.
- September 20, 1999 - JAS 39A Gripen from Airwing F 7 Såtenäs crashed into Lake Vänern in Sweden during an air combat maneuvering exercise. After passing through the wake vortex of the other aircraft, the aircraft abruptly changed course, and the pilot, Capt. Rickard Mattsson, got a highest-severity

- warning from the ground-collision warning system. He ejected from the aircraft, and landed safely by parachute in the lake.
- November 12, 2001 - American Airlines Flight 587 crashed into the Belle Harbor neighborhood of Queens, New York shortly after takeoff from John F. Kennedy International Airport. This accident was attributed to pilot error in the presence of wake turbulence from a Japan Airlines Boeing 747 that resulted in rudder failure and subsequent separation of the vertical stabilizer.
 - November 3, 2008 - Airbus A380 wake turbulence event, Sydney Airport, Australia. Wake turbulence of an Airbus A380-800 causing temporary loss of control to a Saab 340 on approach to a parallel runway during high crosswind conditions.
 - November 4, 2008 - Mexican Government LearJet 45 XC-VMC, carrying Secretary of the Interior Juan Camilo Mouriño, crashed close to Paseo de la Reforma avenue before turning for final approach to runway 05R at Mexico City International Airport. The airplane was flying behind a Mexicana Airlines 767-300 and above a heavy helicopter. The pilots were not told about the type of plane that was approaching before them, neither did they reduce to minimum approach speed. (This has been confirmed as the official stance by the Mexican Government as stated by Luiz Tellez, the Secretary of Communications of Mexico.)

Measurement

Wake turbulence can be measured using several techniques. A high-resolution technique is doppler lidar, a solution now commercially available. Techniques using optics can use the effect of turbulence on refractive index (optical turbulence) to measure the distortion of light that passes through the turbulent area and indicate the strength of that turbulence.

Audibility

Wake turbulence can occasionally, under the right conditions, be heard by ground observers. On a still day, heavy jets flying low and slow on landing approach may produce wake turbulence that is heard as a dull roar/whistle. Often, it is first noticed some seconds after the direct noise of the passing aircraft has diminished. The sound then gets louder, sometimes becoming as loud as was the original direct sound of the aircraft. Nevertheless, being highly directional, wake turbulence sound is easily perceived as originating a considerable distance behind the aircraft, its apparent source moving across the sky just as the aircraft did. It can persist for 30 seconds or more, continually changing timbre, sometimes with swishing and cracking notes, until it finally dies away.

Chapter 7

Terminal Doppler Weather Radar



Airports with a TDWR in the US. Another in San Juan, Puerto Rico, is not on this map.

Terminal Doppler Weather Radar (TDWR) is a doppler weather radar system used primarily for the detection of hazardous wind shear conditions on and near major airports in the United States. As of 2009, there are 45 such radars across United States, and a number have been sold to other countries, such as China (Hong Kong). Funded by the United States Federal Aviation Administration, TDWR was developed in the early 1990s at Lincoln Laboratory, part of the Massachusetts Institute of Technology, to assist air traffic controllers by providing real-time wind shear detection and high-resolution precipitation data.

The primary advantage of TDWR over previous radars is that it has a finer range resolution—meaning it can see smaller areas of the atmosphere. The reason for the resolution is that the TDWR has a narrower beam than traditional radar systems, and that it uses a set of algorithms to reduce ground clutter.

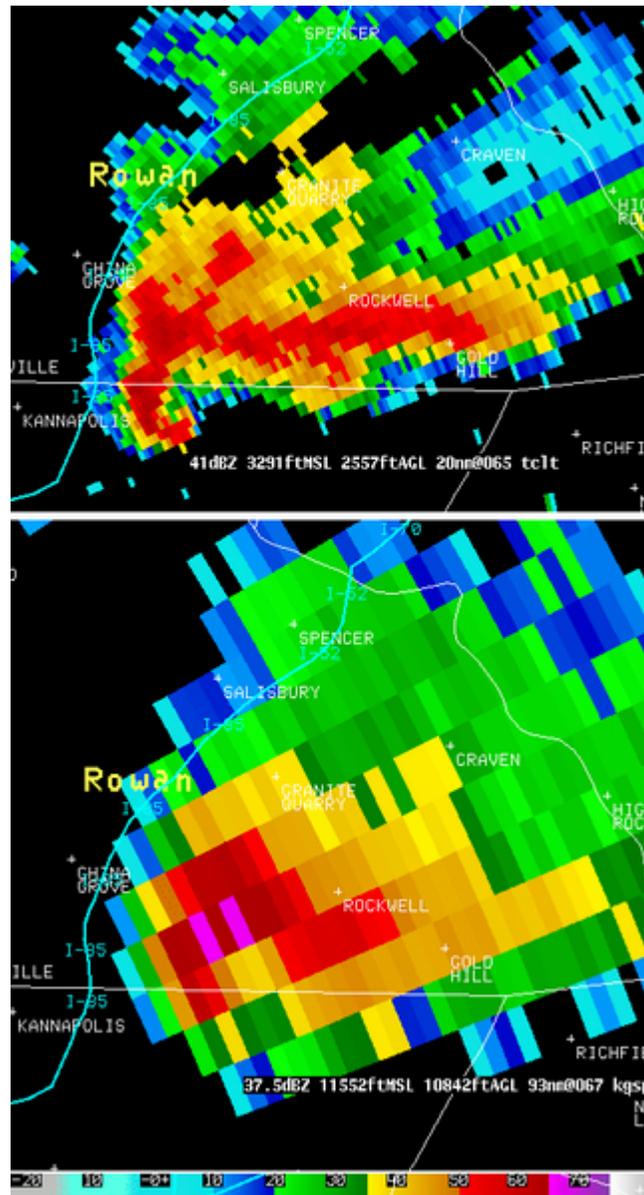
Characteristics

The TDWR uses a 5 cm wavelength carrier wave with an angular resolution beam of 0.55 degrees. In reflectivity, the resolution in distance is 150 meters within 135 kilometers of the radar and 300 meters from 135 km to 460 km to the radar. The reason for this difference is that the width resolution being angular, at larger range the width of the beam becomes quite large and to obtain a better averaging of data in a resolution volume, one has to increase the number of range pulse bins. This cut off is arbitrarily set for the software at 135 km.

In radial velocities, data are available up to 90 km from the radar with the full angular resolution of 0.5 degrees and range resolution of 150 meters. Because of the Pulse Repetition Frequency used, there is aliasing and the maximum non-ambiguous velocity is 20 to 30 knots.

TWDR can perform near-surface scans at a 0.1-0.3 degree angle of inclination from the Earth's surface every minute. It can also perform composite scans in which the radar observes at several different angles of inclination in order to obtain a fuller picture of the atmospheric conditions; each such composite scan requires 6 minutes.

Comparison with NEXRAD



Located in near identical locations, a TDWR return (top) and NEXRAD return (bottom) showing the improved resolution in reflectivity, but also showing the attenuation in the TDWR due to absorption from heavy precipitation as a black gap.

Advantages

A NEXRAD weather radar currently used by the National Weather Service is a 10 cm wavelength radar capable of a complete scan every 4.5 to 10 minutes, depending on the number of angles scanned. Its resolution is 1.25 degrees in width and 250 meters in range. The non-ambiguous radial velocity is 62 knots up to 230 km from the radar.

The range resolution of the TDWR is nearly twice the one of the NEXRAD. This will give much better details on small features in precipitation patterns, particularly in thunderstorms, in reflectivity and radial velocity. However, this finer resolution is only available up to 135 km from the radar; beyond that, the resolution is close to that of the NEXRAD.

Shortcomings

The shorter 5 cm wavelength, which is closer to the size of a raindrop than the 10 cm wavelength, is partially absorbed by precipitation. This is a serious drawback to using TDWR, as the signal can be strongly attenuated in heavy precipitation. This attenuation means that the radar cannot "see" very far through heavy rain and could miss severe weather such as strong thunderstorms which may contain the signature of a tornado, when there is heavy rain falling between the radar and that storm. When heavy rain is falling on the radome, the range of the TDWR is further limited. Finally, hail in a thunderstorm scanned by a TDWR can entirely block the signal as its size is larger than the wavelength. So a total attenuation behind a storm should raise the possibility of hail in the observer's mind.

A second problem is the smaller non-ambiguous radial velocity or Nyquist velocity. In the case of the TDWR, this means the velocity of precipitations moving at a speed beyond 30 knots away or toward the radar will be analyzed incorrectly because of aliasing. Algorithms to correct for this do not always yield the proper results. NEXRAD has a threshold that is twice as high (62 knots) and thus less processing and interpretation are needed. Because of this, the resolution of radar reflectivity for small scale features such as mesocyclones might be better in TDWR, but the velocity resolution may be worse.

Thus, it is best to use the TDWR in conjunction with a traditional NEXRAD nearby to ensure that nothing is missed.

Data processing improvements

The National Severe Storms Laboratory (NSSL) has a program of development and improvement of radar products extracted from data obtained from TDWR and NEXRAD radars. The *Severe Weather Warning Applications and Technology Transfer* (SWAT) group is sponsored by the National Weather Service and the FAA. It is working in 2009 on better filtering of non-weather echoes, better dealiasing algorithms of velocities, techniques to extract horizontal the wind field from one or multiple radars. NSSL has been providing TDWR data to NWS office since the late 1990's.

Chapter 8

Transponder (Aviation)

Transponder



A Cessna ARC RT-359A transponder (the beige box), beneath a Bendix/King KY197 VHF communication radio mounted in the instrument panel of a 1970 model American Aviation AA-1 Yankee aircraft. In this example, the transponder code selected is 1200 for VFR flight.

A **transponder** (short-for *Transmitter-responder* and sometimes abbreviated to XPDR, XPNDR, TPDR or TP) is an electronic device that produces a response when it receives a radio-frequency interrogation. In aviation, aircraft have transponders to assist in identifying them on radar and on other aircraft's collision avoidance systems.

Air traffic control units use the term "squawk" when they are assigning an aircraft a transponder code, e.g. "Squawk 7421". Squawk or squawking thus can be said to mean "select transponder code" or "I have selected transponder code xxxx".

History

The aviation transponder was originally developed during World War II by the British and American military as an "Identification friend or foe" (IFF) system to differentiate friendly from enemy aircraft on radar. The concept became a core of NORAD technology in the defence of North America during the Cold War.

This concept was adapted in the 1950s by civil air traffic control using secondary surveillance radar (beacon radar) systems to provide traffic services for general aviation and commercial aviation.

Secondary Surveillance Radar

Secondary Surveillance Radar is referred to as "secondary", to distinguish it from the "primary radar" that works by passively bouncing a radio signal off the skin of the aircraft. Primary radar works best with large all-metal aircraft, but not so well on small, composite aircraft. Its range is also limited by terrain, rain or snow and also detects unwanted objects such as automobiles, hills and trees. Furthermore not all primary radars can estimate the altitude of an aircraft. Secondary radar overcomes these limitations but it requires a radio transponder in the aircraft to respond to interrogation signals from the ground station to make the aircraft more visible and to report the aircraft's altitude.

Transponder modes

Operation

A pilot may be requested to squawk a given code by the air traffic controller via the radio, using a phrase such as "Cessna 123AB, squawk 0363". The pilot then selects the 0363 code on their transponder and the track on the radar screen of the air traffic controller will become correctly associated with their identity.

Because primary radar generally gives bearing and range position information, but lacks altitude information, mode C and mode S transponders also report pressure altitude. Some lower-end altimeters do not normally have a built in encoder and so a modified Gray code, called a Gillham Code, is used to pass altitude information to the transponder. Around busy airspace there is often a regulatory requirement that all aircraft be equipped with an altitude-reporting mode C or mode S transponders. In the United States, this is known as a Mode C veil. Mode S transponders are compatible with transmitting the mode C signal, and have the capability to report in 25 foot increments. Without the pressure altitude reporting, the air traffic controller has no display of accurate altitude information, and must rely on the altitude reported by the pilot via radio.. Similarly, the Traffic Collision Avoidance System installed on large aircraft as a last resort safety net needs the altitude information supplied by transponder signals.

Ident

All mode A, C, and S transponders include an "ident" button, which activates a special "thirteenth" bit on the mode A reply known as Ident, short for Identify. When radar equipment receives the Ident bit, it results in the aircraft's blip "blossoming" on the radar scope. This is often used by the controller to locate the aircraft amongst others by requesting the ident function from the pilot (e.g., "Cessna 123AB, squawk 0363 and ident").

Ident can also be used in case of a reported or suspected radio failure to determine if the failure is only one way and whether the pilot can still transmit *or* receive but not both (e.g., "Cessna 123AB, if you read, squawk ident").

Transponder codes

Transponder codes are four digit numbers transmitted by the transponder in an aircraft in response to a secondary surveillance radar interrogation signal to assist air traffic controllers in traffic separation. A discrete transponder code (often called a squawk code) is assigned by air traffic controllers to uniquely identify an aircraft. This allows easy identity of the aircraft on radar.

Squawk codes are four-digit octal numbers; the dials on a transponder read from zero to seven inclusive. Thus the lowest possible squawk is 0000 and the highest is 7777. Four octal digits can represent up to 4096 different codes, which is why such transponders are often called "4096 code transponders." Because these squawks are sensitive, care must be taken not to squawk any emergency code during a code change. For example, when changing from 1200 to 6501 (an assigned ATC squawk), one might turn the second wheel to a 5 (thus *1500*), and then rotate the first wheel backwards in the sequence 1-0-7-6 to get to 6. This would momentarily have the transponder squawking a hijack code (*7500*), which might lead to more attention than one desires. Pilots are instructed not to place the transponder in "standby mode" while changing the codes as it causes the loss of target information on the ATC radar screen, but instead to carefully change codes to avoid inadvertently selecting an emergency code. Additionally, modern digital transponders are operated by buttons to avoid this problem.

The use of the word "squawk" comes from the system's origin in the World War II Identification Friend or Foe (IFF) system, which was code-named "Parrot".

Routine codes

- 0000:
 - military intercept code (in the US)
 - mode C or other SSR failure (in the UK).
 - shall not be used – is a non-discrete mode A code (Europe)
- 0021: VFR squawk code for German airspace (5000 feet and below) - from 15 March 2007 replaced by the international 7000 code for VFR traffic.

- 0022: VFR squawk code for German airspace (above 5000 feet) - from 15 March 2007 replaced by the international 7000 code for VFR traffic.
- 0033: Parachute dropping in progress (UK)
- 0041 to 0057: In Belgium assigned for VFR traffic under Flight Information Services (BXL FIC)
- 0100: In Australia: flights operating at aerodromes (in lieu of codes 1200, 2000 or 3000 when assigned by ATC or noted in the Enroute Supplement Australia)
- 1000:
 - Instrument Flight Rules (IFR) flight below 18,000' when no other code has been assigned (Canada)
 - non-discrete mode A code reserved use in Mode S radar / ADS-B environment where the aircraft identification will be used to correlate the flight plan instead of the mode A code
- 1200:
 - Visual flight rules (VFR) flight, this is the standard squawk code used in North American airspace when no other has been assigned.
 - In Australia civil VFR flights in class E or G airspace.
- 1201:
 - Visual flight rules (VFR) glider flight, this is the standard squawk code used in United States airspace for transponder equipped gliders when no other has been assigned.
- 1400: VFR flight above 12,500'ASL when no other code has been assigned (Canada) .
- 2000:
 - The code to be squawked when entering a secondary surveillance radar (SSR) area from a non-SSR area used as Uncontrolled IFR flight squawk code in ICAO countries
 - In Canada for uncontrolled IFR at or above 18,000'
 - In Australia: civil IFR flights in Class G airspace.
- 2100: Australia: Ground testing by aircraft maintenance staff.
- 3000: Australia: Civil flights in classes A, C and D airspace, or IFR flights in Class E airspace.
- 4000:
 - Aircraft on a VFR Military Training Route or requiring frequent or rapid changes in altitude (US)
 - In Australia: civil flights not involved in special operations or SAR, operating in Class G airspace in excess of 15NM offshore.
- 4400 to 4477: Reserved for use by SR-71, YF-12, U-2 and B-57, pressure suit flights, and aircraft operations above FL600 (USA only).
- 5000: Aircraft in Military Operations
- 6000: Australia: Military flights in Class G airspace.
- 7000:
 - VFR standard squawk code when no other code has been assigned (ICAO)
 - UK: this code does not imply VFR; 7000 is used as a general conspicuity squawk.

- 7001:
 - Sudden military climb out from low-level operations (UK)
 - Used in some countries to identify VFR traffic (France, ...)
- 7004: Aerobatic and display code in some countries.
- 7010: VFR circuit traffic code in the UK
- 707X: Paratroop activities in France (7070, 7071, 7072...)
- 7615: Australia: civil flights engaged in littoral surveillance.
- 7777:
 - military interception (US) (*"Under no circumstances should a pilot of a civil aircraft operate the transponder on Code 7777. This code is reserved for military interceptor operations."*)
 - non-discrete code used by fixed test transponders (RABMs) to check correctness of radar stations (BITE). (US, Germany, Netherlands, Belgium, ...)

Emergency codes

- 7500: Unlawful Interference (i.e., Aircraft hijacking)
- 7600: Lost Communications
- 7700: General Emergency

Codes assigned by ATC

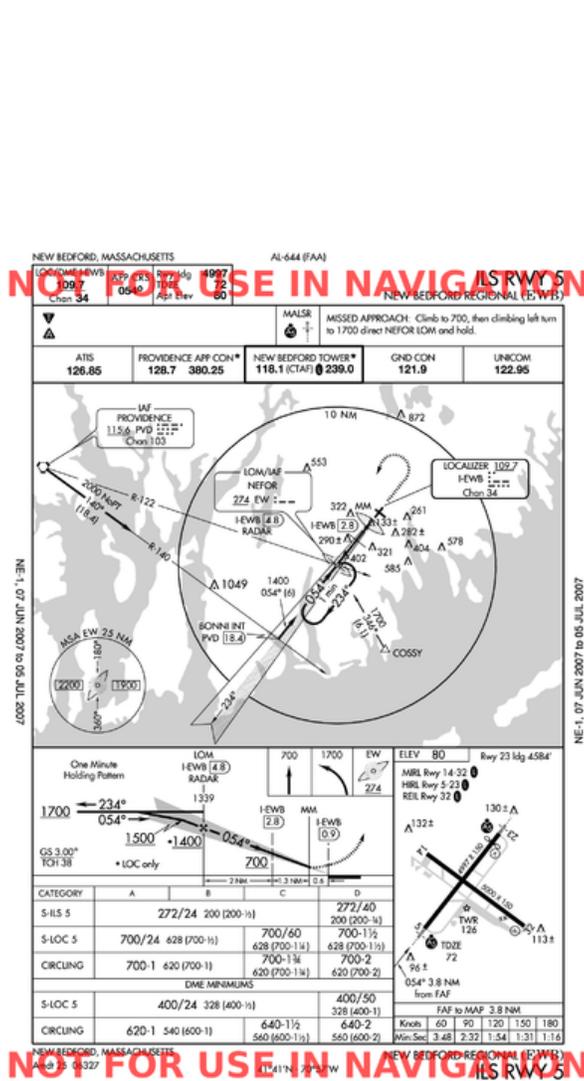
Most codes above can be selected by aircraft if and when the situation requires or allows it, without permission from ATC. Other codes are generally assigned by ATC units. For IFR flights, the squawk code is typically assigned as part of the departure clearance and stays the same throughout the flight. VFR flights, when in uncontrolled airspace, will "squawk VFR" (or conspicuity code in the UK)(1200 in the US, 7000 in Europe). Upon contact with an ATC unit, they will be told to squawk a certain unique code. When changing frequency, for instance because the VFR flight leaves controlled airspace or changes to another ATC unit, the VFR flight will be told to "squawk VFR" again.

In order to avoid confusion over assigned squawk codes, ATC units will typically be allocated blocks of squawk codes, not overlapping with the blocks of nearby ATC units, to assign at their discretion.

Not all ATC units will use radar to identify aircraft, but they assign squawk codes nevertheless. As an example, London Information – the Flight Information Service station that covers the lower half of the UK – does not have access to radar images, but does assign squawk code 1177 to all aircraft that receive a FIS from them. This tells other radar equipped ATC units that that specific aircraft is listening on the London Information radio frequency, in case they need to contact that aircraft.

Chapter 9

Instrument Approach



Terminal procedures for an ILS approach in the United States. (The disclaimers shown in red in the illustration do not appear on the original approach plate.)

For aircraft operating under instrument flight rules (IFR), an **instrument approach** or **instrument approach procedure (IAP)** is a series of predetermined maneuvers for the orderly transfer of an aircraft under instrument flight conditions from the beginning of the initial approach to a landing, or to a point from which a landing may be made visually.

There are two main classifications for IAPs: **precision** and **nonprecision**. A third type of approach, available only to IFR flights but not considered a true instrument approach, is discussed below. Precision approaches utilize both lateral (localizer) and vertical (glideslope) information. Nonprecision approaches provide lateral course information only.

The publications depicting instrument approach procedures are called Terminal Procedures, but are commonly referred to by pilots as approach plates. These documents graphically depict the specific procedure to be followed by a pilot for a particular type of approach to a given runway. They depict prescribed altitudes and headings to be flown, as well as obstacles, terrain, and potentially conflicting airspace. In addition, they also list missed approach procedures and commonly-used radio frequencies.

In the past, the requirement for large land-based navigation aid (NAVAID) facilities has generally limited the use of instrument approaches to land-based (i.e. asphalt, gravel, turf, ice) runways (including those aboard aircraft carriers). However, recent advances in GPS approach technology have permitted the creation of instrument approaches at water aerodromes such as Rangeley Lake Seaplane Base in Maine, USA.

Basic principles

Instrument approaches are generally designed such that a pilot of an aircraft in instrument meteorological conditions (IMC), by the means of radio, GPS or INS navigation with no assistance from air traffic control, can navigate to the airport, hold in the vicinity of the airport if required, then fly to a position from where he or she can obtain sufficient visual reference of the runway for a safe landing to be made, or execute a missed approach if the visibility is below the minimums required to execute a safe landing. The whole of the approach is defined and published in this way so that aircraft can land if they suffer from radio failure; it also allows instrument approaches to be made procedurally at airports where air traffic control does not use radar or in the case of radar failure.

An instrument approach procedure may have as many as four separate segments depending on how the approach procedure is structured. These segments include:

- **Initial approach:** The segment between the initial approach fix (IAF) and the intermediate fix (IF), or the point where the aircraft is established on the intermediate course or final approach course.
- **Intermediate Approach:** The segment between the IF or point, and the final approach fix (FAF).
- **Final approach:** The segment between the FAF or point, and the runway, airport, or missed approach point (MAP).
- **Missed approach:** The segment between the MAP or the point of arrival at decision height and the missed approach fix at the prescribed altitude.

When aircraft are under radar control, air traffic controllers may replace some or all of these phases of the approach with radar vectors (the provision of headings on which the

controller expects the pilot to navigate his aircraft) to the final approach, to allow traffic levels to be increased over those of which a fully procedural approach is capable. It is very common for air traffic controllers to vector aircraft to the final approach aid, e.g. the ILS, which is then used for the final approach. In the case of the rarely-used Ground-Controlled Approach (GCA), the instrumentation (normally Precision Approach Radar) is on the ground and monitored by a controller, who then relays precise instructions for adjustment of heading and altitude to the pilot in the approaching aircraft.

Low visibility approaches

Many instrument approaches allow for landing in conditions of low visibility. ICAO classifies ILS approaches as being in one of the following categories:

ILS Categories			
Category	Decision Height (above threshold)	RVR limit	Visibility
I	200 ft	550m or 2400 ft	800m
II	100 ft	300m or 1200 ft	N/A
IIIa	DH < 100 > 50 ft	200m	N/A
IIIb	DH < 50ft to No DH	75m	N/A
IIIc	No DH	No RVR	N/A

Cat III minima depend on Roll Out Control & Redundancy of the Autopilot.

Smaller aircraft will generally only be equipped to fly a cat I ILS.

For larger aircraft it is typical that these approaches are under the control of the flight control system with the flight crew providing a supervisory role.

A Head-up display allows the flight crew to fly the aircraft using the guidance cues from the ILS sensors so that if such a large deviation were seen, the pilot would be able to respond in an appropriate and safe manner. This is becoming increasingly popular with "feeder" airlines and most manufacturers of regional jets are now offering HUDs as either standard or optional equipment. In addition a HUD can provide a low visibility take off capability.

For both automatic and HUD landing systems, the equipment requires special approval for its design and also for each individual installation. The design takes into consideration all of the additional safety requirements for operating an aircraft close to the ground and takes into consideration the ability of the flight crew to react to a "system anomaly." Once installed, the equipment also has additional maintenance requirements to ensure that it is fully capable of supporting reduced visibility operations.

For all cat II or III approaches, additional crew training is required for such approaches, and a certain number of low visibility approaches must either be performed or simulated in a set period of time for pilots to stay 'current' in performing them.

For practical reasons Category IIIc approaches are rare, but category IIIb approaches are relatively common at major airports.

There are also air traffic control considerations with low visibility approaches: when using ILS, the integrity of the signal must be protected, which requires that certain areas of the airport close to the installations being free of other aircraft and vehicles. Also there must be bigger gaps between aircraft on final approach to both protect the ILS signal and to cope with slower runway vacation times. In addition, the airport itself has special considerations for low visibility operations including different lighting for approach, runways, and taxiways as well as the location of emergency equipment.

Precision approaches and systems

- ILS - Instrument landing system
- MLS - Microwave Landing System
- PAR - Precision Approach Radar (Military)
- LAAS - Ground based augmentation system (GBAS) for Global Satellite Navigation Systems (GNSS)
- JPALS - Joint Precision Approach and Landing System
- GCA - Ground-Controlled Approach (mostly military)
- GLS - GNSS Landing System

Nonprecision approaches and systems

- Localizer
- VOR
- Non-Directional Beacon or NDB with complementary Automatic Direction Finder (ADF) installed on board
- Localizer Type Directional Aid or LDA
- Simplified Directional Facility or SDF
- GPS (with or without vertical navigation *via* WAAS, EGNOS, or other signal correction systems) - Global Positioning System
- TACAN
- SRA - Surveillance Radar Approach (known in some countries as an ASR approach)
- ASR - Airport Surveillance Radar (Military designation for SRA)

Concepts in detail

Decision height or altitude

A decision height (DH) or decision altitude (DA) is a specified height or altitude in the precision approach at which a missed approach must be initiated if the required visual reference, such as the runway or runway environment, to continue the approach has not been acquired. This allows the pilot sufficient time to safely re-configure the aircraft to climb and execute the missed approach procedures while avoiding terrain and obstacles.

Minimum descent altitude

The minimum descent altitude (MDA) is the lowest altitude (in feet MSL) to which descent is authorized on final approach, or during circle-to-land maneuvering in execution of a nonprecision approach. Unlike a DH, a missed approach need not be initiated immediately upon reaching the altitude; that decision can be made at any time before reaching the missed approach point (MAP). A pilot flying a non-precision approach may descend to the MDA and maintain it until reaching the MAP, then initiate a missed approach if the required visual reference was not obtained. An aircraft must not descend below the MDA until visual reference is obtained, which differs slightly from a DH in that while the missed approach procedure must be initiated at or prior to the DH, because of its vertical momentum, during a precision approach an aircraft may end up descending slightly below the DH during the course of the missed approach.

If a runway has both precision and non-precision approaches defined, the MDA of the non-precision approach is almost always greater than the DH of the precision approach, due to the lack of vertical guidance of the non-precision approach: the actual difference will also depend on the accuracy of the navaid upon which the approach is based, with ADF approaches and SRAs tending to have the highest MDAs.

Reverse Sensing

Reverse sensing is an instrument error only associated with the localizer. It occurs when the aircraft flies a "localizer back course" approach. The CDI in the aircraft will cease to function as a command instrument and instead will read the opposite of what the pilot is to fly; that is, the CDI will command you to fly left when the aircraft in fact needs to fly right to intercept the approach course, and vice versa. Reverse sensing is not a factor in aircraft equipped with a Horizontal Situation Indicator (HSI).

Multipathing

Multipathing is the second error associated with the ILS. In this case, unlike reverse sensing, it is associated with both the glideslope and the localiser. This occurs when distortions of the glide slope or radio waves are received by the aircraft. Distorted signals can reach the aircraft when a large metal object moves into the radiation zone of the transmitter. For instance an aircraft ahead of you or a taxiing aircraft or truck on the taxi way will produce a distorted signal.

Reversal procedure

If conducting approach, and the pilot is not lined up for a Straight-in Approach, then a course reversal may be necessary. This can be used on either a VOR, ADF or ILS approach. The idea of a reversal is to turn the aircraft around by 180 degrees therefore lining the aircraft up with the runway. This will line the aircraft up for final, and can be accomplished in three different ways: Procedure Turn, Holding Pattern, or Teardrop Course Reversal.

- *Procedure turn*: Standardized way of reversing course to get lined up on final approach. The approach chart must indicate that a procedure turn is authorized for the approach, via a procedure turn barb. Note that when a procedure turn exists for an approach, the maximum speed of the aircraft should never exceed 200 knots IAS. This is typically entered by tracking the localizer outbound, and then turning 45 degrees off of the localizer. After that, the pilot extends the leg, and conducts a roughly 180-degree turn, depending on the wind, and then flying back toward the localizer path and reintercepting it, so the pilot can track the localizer inbound.
- *Holding pattern*: commonly referred to as the racetrack pattern. It is another method of course reversal, but it can also be used for losing altitude within protected airspace. Only one circuit within the holding pattern is approved. ATC must be advised if the pilot needs more circuits, and ATC must approve the request prior to doing so. A holding pattern used for this purpose will be depicted in U.S. Government publications as the "hold-in-lieu-of-PT" holding pattern symbol.
- *Teardrop procedure turn*: If the controlled airspace is extremely limited, a teardrop may be used to reverse the direction of the aircraft and permit the aircraft to lose altitude. This procedure is shaped like a teardrop, hence the name. The approach chart, usually the profile view section, will give limitations as to how far you can get from the VOR. So, this method of course reversal is all about perception. The pilot must use timing, given a known airspeed, or DME to remain within the limits described on the approach chart.

Direct Approach

A Direct instrument approach requires no procedure turn or other reversal course procedures for alignment (NoPT), as the arrival direction coincides with the final approach course. The direct approach can be finished with a straight-in landing or circle to land procedure, if necessary and published.

Circling To Land

A circle to land maneuver is the opposite of a straight-in landing. It is a maneuver used when a runway is not aligned within 30 degrees of the final approach course of the instrument approach procedure or the final approach requires 400 feet of descent (or more) per nautical mile, and therefore requires some visual maneuvering of the aircraft in the vicinity of the airport after the instrument portion of the approach is completed for the aircraft to become aligned with the runway to land.

It's very common for a circle to land maneuver be executed during a straight-in approach to a different runway, e.g. an ILS approach to one runway, followed by a low-altitude pattern flying, ending in a landing on a different runway. This way, approach procedures to one runway can be used to land on any runway at the airport, as the other runways may lack instrument procedures or their approaches cannot be used for other reasons (traffic considerations, navigation aids being out of service, etc.).

Circling to land is considered more difficult and less safe than a straight-in landing, especially under Instrument meteorological conditions, due to the fact that the aircraft is at a relatively low altitude and must remain within a small distance from the airport in order to be assured of obstacle clearance (often only a couple of miles, even for larger, faster aircraft). In any case, the pilot must maintain visual contact with the runway at all times - loss of visual contact must result in an immediate climb to the published safe altitude.

Instrument Currency

In some countries Instrument Rated Pilots are required to perform a minimum number of instrument approaches in a set period to remain current. Pilots may also have to fly a certain number of low visibility approaches (Cat 2 or Cat 3) to remain current at performing these. When practicing instrument approaches in visual meteorological conditions, a safety pilot will be required if the pilot practicing instrument approach wears a view limiting device, which restricts his field of view to the instrument panel. A safety pilot's basic role is to observe and help to avoid traffic. Logging instrument approaches toward license currency has long been an area of much confusion. The regulations have been revised and rewritten many times to meet the needs of pilots.

Back Course Approach

A back course approach is a type of approach in which a pilot flies the localizer on the opposite (back) side from the original direction it was primarily designed to be flown. Usually, when one flies a front course approach, the shaded side of the localizer will be on the right on an approach plate. However, if flying a back course approach, the shaded side of the localizer would be on the left, due to the back course heading. By flying the back course, the Course Deviation Indicator (CDI) needle will deflect to the opposite side, depending on what type of equipment exists in the aircraft. If the needle starts to move away from center, the aircraft would be flown away from the needle in order to re-intercept the correct inbound track; turning toward the needle, such as is required on a front course, would cause the aircraft to deviate further from the correct inbound track.

The localizer transmits on both sides, making this approach possible. Because the glide slope is not transmitted on the back side of the localizer, a back course approach is classed as a non-precision approach as it has no vertical guidance. Any (false) movements of the glideslope needle during a back course approach must always be ignored.

This type of approach typically is found at smaller airports that do not have ILS approaches on both ends of the runway, where often the older localizer antennas are less directional. These transmit a signal from the back that is sufficient enough to be used in a back course approach. Newer localizer antennas are highly directional, and often cannot be used for a back course approach.

Simultaneous close parallel approaches

At some airports, multiple parallel runways are available for operations, but are so closely spaced (less than 4300 feet between centerlines) that they present a hazard for simultaneous use under ordinary conditions. Simultaneous operations on such runways can be carried out using ILS and special Precision Runway Monitor radars and three controllers, with special procedures known as simultaneous close parallel approaches.

In this type of approach, two aircraft approach and land simultaneously on closely-spaced parallel runways, with extra air traffic controllers assigned to monitor each approach path on special PRM radar. A zone between the runways is designated as the No Transgression Zone (NTZ), and if either of the aircraft nears or strays into this zone, the other approaching aircraft is told to break off by the PRM controller, at which point that aircraft must veer away from the approach path (without the use of autopilot). The aircraft must have two radios, one tuned to the tower controller in the usual way, and another tuned (for monitoring only, no transmission) to the PRM controller.

If runways are less than 3000 feet apart but at least 750 feet apart, simultaneous offset instrument approaches (SOIAs) may be used. The procedure is similar to that described above, except that one aircraft flies the ILS/PRM approach, and the other flies an offset LDA/PRM approach at an angle to the runway centerline. The aircraft flying the LDA/PRM approach with glide path is positioned to be behind the ILS/PRM aircraft, and must have the ILS/PRM aircraft in sight before beginning a visual segment to the approach at or before the missed approach point. During the visual segment, the LDA/PRM aircraft must keep the ILS/PRM aircraft in sight as it aligns with the centerline of the runway.

Visual Approach

A visual approach is a precision approach carried out using visual references to the runway, when weather conditions permit. While it is not an instrument approach in the strict sense, visual approach clearances are issued only to IFR flights (because VFR flights must *always* approach and land visually).

A visual approach may be requested by the pilot or offered by ATC. Visual approaches are possible when weather conditions permit continuous visual contact with the destination airport. They are issued in such weather conditions in order to expedite handling of IFR traffic.

A pilot may accept a visual approach clearance as soon as he has the destination airport in sight. ATC must ensure that weather conditions at the airport are above certain minima (in the U.S., a ceiling of 1000 feet AGL or greater and visibility of 3 statute miles) before issuing the clearance. Once the pilot has accepted the clearance, he assumes responsibility for separation and wake turbulence avoidance and may navigate as necessary to complete the approach visually.

Visual approaches are very commonly used for IFR flights at some airports that routinely experience good visual meteorological conditions.

Airport Requirements

In the United States, the requirements for an airport to offer instrument approaches is contained in FAA Order 8200.97 AIRMAN AND AIRCRAFT APPROVAL FOR REDUCED VISIBILITY FLIGHT OPERATIONS, INCLUDING CATEGORY II/III OPERATIONS.

Chapter 10

Automatic Dependent Surveillance-Broadcast

Automatic Dependent Surveillance-Broadcast (ADS-B) is a cooperative surveillance technique for air traffic control and related applications being developed as part of the Next Generation Air Transportation System (NextGen). Australia is the first country with full, nationwide ADS-B coverage. The United States will require the majority of aircraft operating within its airspace to be equipped with some form of ADS-B out by January 1, 2020.

Description

An ADS-B-equipped aircraft determines its own position and periodically broadcasts this position and other relevant information to potential ground stations and other aircraft with ADS-B-in equipment. Position data is usually derived from a global navigation satellite system, or, less commonly, from an aircraft's inertial reference system. ADS-B can be used over several different data link technologies, including Mode-S Extended Squitter (1090 ES) operating at 1090 MHz, Universal Access Transceiver (978 MHz UAT), and VHF Data Link (VDL Mode 4).

ADS-B provides accurate information and frequent updates to airspace users and controllers, and hence supports improved use of airspace, reduced ceiling/visibility restrictions, improved surface surveillance, and enhanced safety, for example through conflict management.

Under ADS-B, a vehicle periodically broadcasts its own state vector and other information without knowing what other vehicles or entities might be receiving it, and without expectation of an acknowledgment or reply. ADS-B is *automatic* in the sense that no pilot or controller action is required for the information to be issued. It is *dependent surveillance* in the sense that the surveillance-type information so obtained depends on the suitable navigation and broadcast capability in the source vehicle. International aviation standards for the individual ADS-B data link technologies have been standardized by the International Civil Aviation Organization (ICAO). The basic concept

of broadcasting aircraft position based on an onboard navigation data source goes back to least 1973 when the U.S. Federal Aviation Administration sponsored a study that investigated alternate data link channel access techniques, including a broadcast mode, for the transmission of Automatic Dependent Surveillance reports. The use of GPS as the primary onboard navigation data source and the three alternative air-ground data links were developed and evolved through the national and international standards organizations in the 1990s leading to the first generation ADS-B standards in the late 1990s with further refinements subsequently developed, based on results from technical evaluations and limited operational experience, and incorporated into updated standards.

A similar solution is the Automatic Identification System (AIS), a system used by ships and Vessel Traffic Services.

Theory of operation

ADS-B consists of three components:

- A transmitting subsystem that includes message generation and transmission functions at the source, e.g. airplane.
- The transport protocol, e.g. VHF (VDL mode 2 or 4), 1090ES, or 978 MHz UAT.
- A receiving subsystem that includes message reception and report assembly functions at the receiving destination, e.g. other airplanes, vehicle or ground system.

The source of the state vector and other transmitted information as well as user applications are not considered to be part of the ADS-B system.

Relationship to surveillance radar

Radar directly measures the range and bearing of an aircraft from a ground-based antenna. Bearing is measured by the position of the rotating radar antenna when it receives a response to its interrogation from the aircraft, and range is measured by the time it takes for the radar to receive the interrogation response.

The antenna beam becomes wider as the aircraft gets further away, making the position information less accurate. Additionally, detecting changes in aircraft velocity requires several radar sweeps that are spaced several seconds apart. In contrast, a system using ADS-B creates and listens for periodic position and intent reports from aircraft. These reports are generated based on the aircraft's navigation system, and distributed via one or more of the ADS-B data links. The integrity of the data is no longer susceptible to the position of the aircraft or the length of time between radar sweeps.

Primary Surveillance Radar does not require any cooperation from the aircraft. It is robust in the sense that surveillance outage failure modes are limited to those associated with the ground radar system. Secondary Surveillance Radar depends on active replies from the aircraft. Its failure modes include the transponder aboard the aircraft. Typical

ADS-B aircraft installations use the output of the navigation unit for navigation and for cooperative surveillance, introducing a common failure mode that must be accommodated in air traffic surveillance systems.

Type	Independent?	Cooperative?
Primary surveillance radar (PSR)	Yes: surveillance data derived by radar	No: does not depend on aircraft equipment
Secondary surveillance radar (SSR)	Yes: surveillance data derived by radar	Yes: requires aircraft to have a working ATCRBS transponder
Automatic dependent surveillance (ADS-B)	No: surveillance data provided by aircraft	Yes: requires aircraft to have working ADS-B function

Today's ATC systems do not rely on coverage by a single radar. Instead a multiradar picture is presented via the ATC system's display to the controller (ATCO). This improves the quality of the reported position of the airplane, provides a measure of redundancy, and makes it possible to verify the output of the different radars against others. This verification can also use sensor data from other technologies, such as ADS-B and multilateration.

Relationship to ADS-A/ADS-C

There are two commonly recognized types of ADS for aircraft applications:

- ADS-Addressed (ADS-A), also known as ADS-Contract (ADS-C), and
- ADS-Broadcast (ADS-B).

ADS-B differs from ADS-A in that ADS-A is based on a negotiated one-to-one peer relationship between an aircraft providing ADS information and a ground facility requiring receipt of ADS messages. For example, ADS-A reports are employed in the Future Air Navigation System (FANS) using the Aircraft Communication Addressing and Reporting System (ACARS) as the communication protocol. During flight over areas without radar coverage (e.g. oceanic and polar), reports are periodically sent by an aircraft to the controlling air traffic region.

The transmission delay caused by protocol, satellites, etc., is significant enough that significant aircraft separations are required. The cost of using the satellite channel leads to less frequent updates. Another drawback is that no other aircraft can benefit from the transmitted information.

Relationship to other broadcast services

The ADS-B link can be used to provide other broadcast services, such as TIS-B and FIS-B.

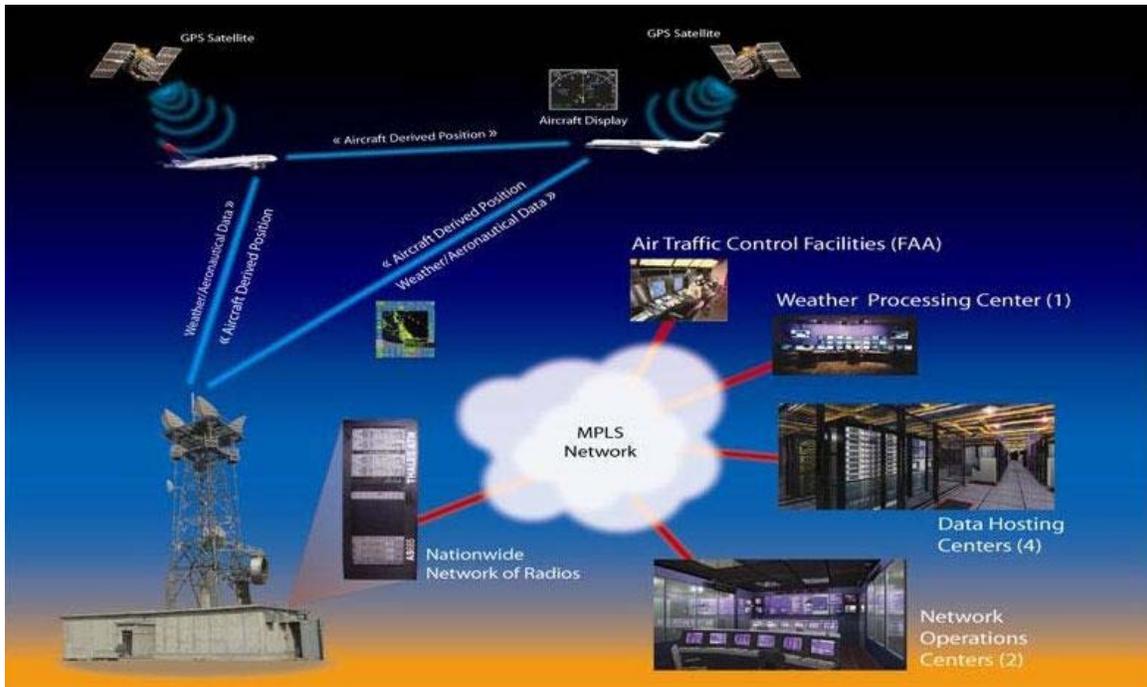
Another potential aircraft-based broadcast capability is to transmit aircraft measurements of meteorological data.

ADS-B and General Aviation

The Automatic Dependent Surveillance-Broadcast system (ADS-B) is an essential part of the planned NextGen airspace upgrade and will create better aircraft visibility at a lower overall cost than before. ADS-B equipment is built to meet one of two sets of US government standards, DO-260B and DO-282B.

By the year 2020 all aircraft operating in the airspaces listed below will be required to carry equipment that produces an ADS-B out broadcast. The FAA has published a rule requiring ADS-B transmitters in many types of airspace (ADS-B Out) in 2020, but there is no mandate for ADS-B In, which receives data and provides it to in-cockpit displays.

Airspace	Altitude
A	All Aircraft
B	All Aircraft
C	All Aircraft
	Above 10,000 ft MSL
E	but Not Below 2,500 ft AGL



ADS-B system

ADS-B will offer increased safety, efficiency and environmental awareness for pilots and air traffic controllers at a lower overall cost than the current radar system. Companies have already begun selling and developing aircraft hardware systems to allow general aviation aircraft owners to equip at an affordable cost. These companies include Avidyne, Aviation Communication and Surveillance Systems (a joint venture of L-3 Communications and Thales), Garmin and Rockwell Collins.

ADS-B physical layer

Two link solutions are being used as the physical layer for relaying the ADS-B position reports:

- Universal Access Transceiver (UAT)
- 1090 MHz Mode S Extended Squitter (ES);

Universal Access Transceiver (UAT)

The term Universal Access Transceiver refers to a data link intended to serve the majority of the general aviation community. The data link is approved in the US FAA's "Final Rule" for use in all airspace except class A (above 18,000 ft. MSL). UAT is intended to support not only ADS-B, but also Flight Information Service - Broadcast (FIS-B), Traffic Information Service - Broadcast (TIS-B), and, if required in the future, supplementary ranging and positioning capabilities. Due to the set of standards required for this rule, it is

seen as the most effective application for general aviation users. UAT will allow aircraft equipped with "out" broadcast capabilities to be seen by any other aircraft using ADS-B "in" technology as well as by FAA ground stations. Aircraft that are equipped with ADS-B "in" technology will be able to see detailed altitude and vector information from other ADS-B "out" equipped aircraft as well as FIS-B and TIS-B broadcasts. The FIS-B broadcast will allow receiving aircraft to see weather and flight service information including AIRMET's, Convective SIGMET's, SIGMET's, METAR's, SPECI, National NEXRAD, Regional NEXRAD, D-NOTAM's, FDC-NOTAM's, PIREP's, Special Use Airspace Status, Terminal Area Forecasts, Amended TAF's, Winds and Temperature Aloft. These broadcast serve to provide early adopters of the technology with benefits as a way to incentives more pilots to use the technology before the required 2020 date. Aircraft receiving traffic information through the TIS-B service will see other aircraft in a manner very similar to how all aircraft will be seen after they have equipped in 2020. The availability of a non subscription weather information service, FIS-B provides general aviation users with a great alternative to other, monthly or annual fee based services.

The UAT system is specifically designed for ADS-B operation. UAT is also the first link to be certified for "radar-like" ATC services in the U.S. Since 2001, it has been providing 5 NM en-route separation (the same as radar) in Alaska. UAT is the only ADS-B link standard that is truly bi-directional: UAT users have access to ground-based aeronautical data (FIS-B) and can receive reports from proximate traffic (TIS-B) through a multilink gateway service that provides ADS-B reports for 1090ES equipped aircraft and non-ADS-B equipped Radar traffic. UAT equipped aircraft can also observe each other directly with high accuracy and minimal latency. Viable ADS-B UAT networks are being installed as part of the U.S. FAA NextGen air traffic system.

1090ES

In 2002, the Federal Aviation Administration (FAA) announced a dual link decision using 1090 MHz ES and UAT as media for the ADS-B system in the United States, with the 1090 MHz extended squitter ADS-B link for air carrier and private/commercial operators of high performance aircraft, and Universal Access Transceiver (UAT) ADS-B link for the typical general aviation user.

Europe has not officially chosen a physical layer for ADS-B. A number of technologies are in use. However, the influential Eurocontrol CASCADE program uses 1090ES exclusively.

With 1090ES, the existing Mode S transponder (TSO C-112 or a stand alone 1090 MHz transmitter) supports a message type known as the extended squitter (ES) message. It is a periodic message that provides position, velocity, time, and, in the future, intent. The basic ES does not offer intent since current flight management systems do not provide such data – called trajectory change points. To enable an aircraft to send an extended squitter message, the transponder is modified (TSO C-166A) and aircraft position and other status information is routed to the transponder. ATC ground stations and aircraft equipped with Traffic collision avoidance system (TCAS) already have the necessary

1090 MHz (Mode S) receivers to receive these signals, and would only require enhancements to accept and process the additional Extended Squitter information. As per the FAA ADS-B link decision and the technical link standards 1090ES does not support FIS-B service.

Final Rule

Background

While there is currently a drop in air travel due to a general economic downturn, delay and congestion continue to build in the nation's busiest airports and the surrounding airspace. The FAA must not only address current congestion, but also be poised to handle future demand that will surely return as the nation's economy improves. The FAA has been developing the Next Generation Air Transportation System (NextGen) for the purpose of changing the way the National Airspace System (NAS) operates. NextGen will allow the NAS to expand to meet future demand and support the economic viability of the system. In addition, NextGen will improve safety and support environmental initiatives such as reducing congestion, noise, emissions and fuel consumption through increased energy efficiency.

System

ADS-B consists of two different services: ADS-B Out and ADS-B In. ADS-B Out periodically broadcasts information about each aircraft, such as identification, current position, altitude, and velocity, through an onboard transmitter. ADS-B Out provides air traffic controllers with real-time position information that is, in most cases, more accurate than the information available with current radar-based systems. With more accurate information, ATC will be able to position and separate aircraft with improved precision and timing.

Summary of Final Rule

This final rule will add equipment requirements and performance standards for ADS-B Out avionics. ADS-B Out broadcasts information about an aircraft through an onboard transmitter to a ground receiver. Use of ADS-B Out will move air traffic control from a radar-based system to a satellite-derived aircraft location system. Operators will have two options for equipment under this rule—the 1090 megahertz (MHz) extended squitter(ES) broadcast link or the Universal Access Transceiver (UAT) broadcast link. Generally, this equipment will be required for aircraft operating in Classes A, B, and C airspace, certain Class E airspace, and other specified airspace.

The FAA has concluded that this rule will require only the performance requirements necessary for ADS-B Out. While certain requirements adopted in this rule will support some ADS-B In applications, the FAA is not adopting the higher performance standards that would enable all of the initial ADS-B In applications. Pilots should be aware that in accepting the FAA's positions regarding antenna diversity and position source accuracy,

compliance with this rule alone may not enable operators to take full advantage of certain ADS-B In applications. Operators may voluntarily choose equipment that meets the higher performance standards in order to enable the use of these applications.

This system will make radar based ATC obsolete, moving the nation to a satellite derived aircraft location system.

This will make ADS-B the backbone of the NextGen ATC system coming online in 2020.

Benefits of ADS-B for General Aviation

Improved situational awareness

Pilots in an ADS-B equipped cockpit will have the ability to see other traffic operating in the airspace as well as access to clear and detailed weather information. They will also be able to receive pertinent updates ranging from temporary flight restrictions (TFR's) to runway closings.

Improved visibility

Even aircraft only equipped with ADS-B out will be benefited by air traffic controllers ability to more accurately and reliably monitor their position. Other fully equipped aircraft using the airspace around them will be able to more easily identify and avoid conflict with ADS-B out equipped aircraft.

Reduced environmental impact

ADS-B technology provides a more precise report of an aircraft's position. This allows controllers to guide aircraft into and out of crowded airspace with smaller separation standards than it was previously possible to do safely. This reduces the amount of time aircraft must spend waiting for clearances, being vectored for spacing and holding. Estimates show that this is already having a beneficial impact by reducing pollution and fuel consumption.

ADS-B is intended to increase safety and efficiency. Safety benefits include:

- Improved visual acquisition especially for general aviation under visual flight rules (VFR).
- Reduced runway incursions on the ground.

ADS-B enables increased capacity and efficiency by supporting:

- Enhanced visual approaches
- Closely spaced parallel approaches
- Reduced spacing on final approach
- Reduced aircraft separations

- Enhanced operations in high altitude airspace for the incremental evolution of the "free flight" concept
- Surface operations in lower visibility conditions
- Near visual meteorological conditions (VMC) capacities throughout the airspace in most/all weather conditions
- Improved ATC services in non-radar airspace
- Trajectory-based operations providing a gently ascending and descending gradient with no step-downs or holding patterns needed. This will produce optimal trajectories with each aircraft becoming one node within a system wide information management network connecting all equipped parties in the air and on the ground. With all parties equipped with NextGen equipage, benefits will include reduced gate-to-gate travel times, increased runway utilization capacity, and increased efficiency with carbon conservation.

Traffic information services-broadcast (TIS-B)

TIS-B supplements ADS-B air-to-air services to provide complete situational awareness in the cockpit of all traffic known to the ATC system. TIS-B is an important service for an ADS-B link in airspace where not all aircraft are transmitting ADS-B information. The ground TIS-B station transmits surveillance target information on the ADS-B data link for unequipped targets or targets transmitting only on another ADS-B link.

TIS-B uplinks are derived from the best available ground surveillance sources:

- ground radars for primary and secondary targets
- multi-lateration systems for targets on the airport surface
- ADS-B systems for targets equipped with a different ADS-B link

Multilink gateway service

The multilink gateway service is a companion to TIS-B for achieving interoperability in low altitude terminal airspace. In some airspaces, aircraft that primarily operate in high altitude airspace are equipped with 1090ES, and aircraft operating primarily in low altitude airspace are equipped with UAT. These aircraft cannot directly share air-to-air ADS-B data. In terminal areas, where both types of ADS-B link are in use, ADS-B/TIS-B ground stations use ground-to-air broadcasts to relay ADS-B reports received on one link to aircraft using the other link.

Flight information services-broadcast (FIS-B)

FIS-B provides weather text, weather graphics, NOTAMs, ATIS, and similar information. FIS-B is inherently different from ADS-B in that it requires sources of data external to the aircraft or broadcasting unit, and has different performance requirements such as periodicity of broadcast.

In the US, FIS-B services will be provided over the UAT link in areas that have a ground surveillance infrastructure.

ADS-B supported applications

The ADS-B data link supports a number of airborne and ground applications. Each application has its own operational concepts, algorithms, procedures, standards, and user training.

Cockpit display of traffic information

A Cockpit Display of Traffic Information (CDTI) is a generic display that provides the flight crew with surveillance information about other aircraft, including their position. Traffic information for a CDTI may be obtained from one or multiple sources, including ADS-B, TCAS, and TIS-B. Direct air-to-air transmission of ADS-B messages supports display of proximate aircraft on a CDTI.

In addition to traffic based on ADS-B reports, a CDTI function might also display current weather conditions, terrain, airspace structure, obstructions, detailed airport maps, and other information relevant to the particular phase of flight.

Airborne collision avoidance

ADS-B is seen as a valuable technology to enhance ACAS operation. Incorporation of ADS-B can provide benefits such as:

- Decreasing the number of active interrogations required by ACAS, thus increasing effective range in high density airspace.
- Reducing unnecessary alarm rate by incorporating the ADS-B state vector, aircraft intent, and other information.
- Use of the ACAS display as a CDTI, providing positive identification of traffic.
- Extending collision avoidance below 1000 feet above ground level, and detecting runway incursions.

Eventually, the ACAS function may be provided based solely on ADS-B, without requiring active interrogations of other aircraft transponders.

Conflict management

ATS conformance monitoring

Other applications

Other applications that may benefit from ADS-B include:

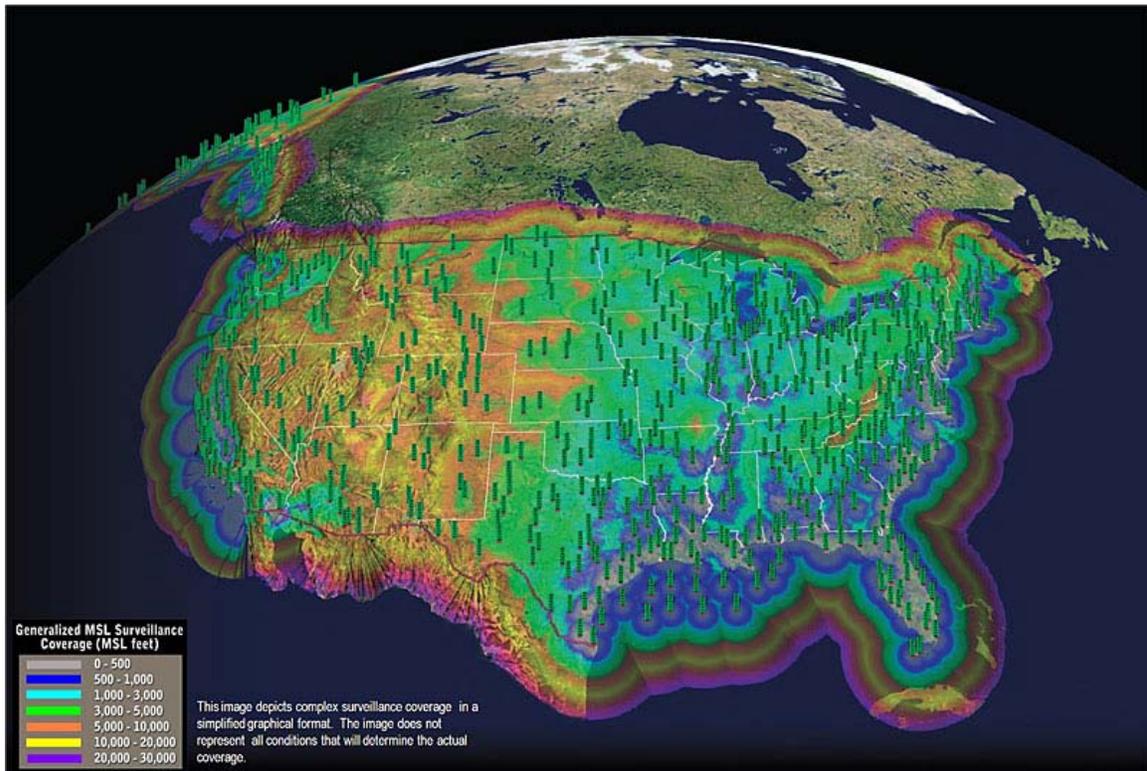
- Improved search and rescue - although ADS-B can transmit "aircraft down" data, the FAA has stated that there is no intention to perform even a study of ADS-B's effectiveness in an "aircraft down" situation simply based on the fact that ADS-B equipment has no requirement to be crash worthy, as compared to the current "black box" recorder.
- Enhanced flight following
- Lighting control and operation
- Airport ground vehicle and aircraft rescue and firefighting vehicle operational needs
- Altitude height keeping performance measurements
- General aviation operations control

U.S. implementation timetable

The Federal Aviation Administration (FAA) ADS-B implementation is broken into three segments each with a corresponding time line. Ground segment implementation and deployment is expected to begin in 2009 and be completed by 2013 throughout the National Airspace System (NAS). Airborne equipment is user-driven and is expected to be completed both voluntarily based on perceived benefits and through regulatory actions (Rulemaking) by the FAA. The cost to equip with ADS-B Out capability is relatively small and would benefit the airspace with surveillance in areas not currently served by radar. The FAA intends to provide similar service within the NAS to what radar is currently providing (5 NM en route and 3 NM terminal radar standards) as a first step to implementation. However, ADS-B In capability is viewed as the most likely way to improve NAS throughput and enhance capacity.

In December 2008 Acting FAA Administrator Robert Sturgell gave the go-ahead for ADS-B to go live in southern Florida. The south Florida installation, which consists of 11 ground stations and supporting equipment, is the first commissioned in the USA, although developmental systems have been online in Alaska, Arizona and along the East Coast since 2004. The completed system will consist of 794 ground station transceivers. The December 2008 action is in compliance with a late-term Executive Order from George W. Bush which mandated accelerated approval of NextGen.

FAA segment 1 (2006-2009)



ADS-B Coverage as of 2010 (Segment 1).

ADS-B deployment and voluntary equipment, along with rule making activities. Pockets of development will exploit equipment deployment in the areas that will provide proof of concept for integration to ATC automation systems deployed in the NAS. It is being developed at the FAA's technical center in Egg Harbor, New Jersey.

FAA segment 2 (2010-2014)

ADS-B ground stations will be deployed throughout the NAS, with an In-Service Decision due in the 2012-13 time frame. Completed deployment will occur in the 2013-2014 time frame. Equipment rules have been finalized and the current standards are DO-282B for UAT and DO-260B for 1090ES. :

- Airport Situational Awareness – A combination of detailed airport maps, airport multilateration systems, ADS-B systems and enhanced aircraft displays have the potential to significantly improve Airport Surface Situational Awareness (ASSA) and Final Approach and Runway Occupancy Awareness (FAROA).
- Oceanic In-trail – ADS-B may provide enhanced situational awareness and safety for Oceanic In-trail maneuvers as additional aircraft become equipped.

- **Gulf of Mexico** – In the Gulf of Mexico, where ATC radar coverage is incomplete, the FAA is locating ADS-B (1090 MHz) receivers on oil rigs to relay information received from aircraft equipped with ADS-B extended squitters back to the Houston Center to expand and improve surveillance coverage.
- ADS-B is currently in service for two terminal airspace areas, Louisville, KY and Philadelphia, PA.

FAA segment 3 (2015-2020)

ADS-B In equipment will be based on user perceived benefit, but is expected to be providing increased situational awareness and efficiency benefits within this segment. Those aircraft who choose to equip in advance of any mandate will see benefits associated with preferential routes and specific applications. Limited radar decommissioning will begin in the time frame with an ultimate goal of a 50% reduction in the Secondary Surveillance Radar infrastructure.

On May 27, 2010 the FAA published its final rule mandating that by 2020 all aircraft owners will be required to have ADS-B Out capabilities when operating in any airspace that currently requires a transponder (airspace classes A, B, and C, and airspace class E at certain altitudes).

Worldwide

- **Australia** - Australia is the first country with full, nationwide ADS-B coverage, though only above FL300. There are 57 ground stations operating at 28 sites.
- **Canada** - Nav Canada commissioned operational use of ADS-B in 2009 and is now using it to provide coverage of its northern airspace around Hudson Bay, most of which currently has no radar coverage. The service is also being extended to cover some oceanic areas off the east coast of Canada and Greenland. The service is expected to be later extended to cover the rest of the Canadian Arctic, and to the rest of Canada.
- **China** - An American Company, ADS-B Technologies created one of the largest and most successful ADS-B system in the world (an 8 station, 350+ aircraft network that spans more than 1,200 NM across Central China). This was also the first UAT installation outside the U.S.. As of March, 2009, more than 1.2 million incident/failure free flight hours have been flown with these ADS-B systems.
- **Sweden** - LFV Group in Sweden has implemented a nationwide ADS-B network with 12 ground stations. Installation commenced during spring 2006, and the network was fully (technically) operational in 2007. An ADS-B supported system is planned for operational usage in Kiruna during spring 2009. Based on the VDL Mode 4 standards, the network of ground stations can support services for ADS-B, TIS-B, FIS-B, GNS-B (DGNSS augmentation) and Point-to-Point

communication, allowing aircraft equipped with VDL 4-compliant transceivers to lower fuel consumption and reduce flight times.

- **United States**
 - **Cargo Airline Association** - Cargo carriers, notably United Parcel Service (UPS). They operate at their hub airports largely at night. Much of the benefit to these carriers is envisioned through merging and spacing the arriving and departing traffic to a more manageable flow. More environmentally friendly and efficient area navigation (RNAV) descent profiles, combined with CDTI, may allow crews to eventually aid controllers with assisted visual acquisition of traffic and limited cockpit-based separation of aircraft. The benefits to the carrier are fuel and time efficiencies associated with idle descent and shorter traffic patterns than typical radar vectoring allows.
 - **Embry-Riddle Aeronautical University** - ERAU has equipped their training aircraft at its two main campuses in Florida and Arizona with UAT ADS-B capability as a situational safety enhancement. The University has been doing this since May 2003, making it the first use in general aviation. With the addition of the G1000 to their fleet in 2006, ERAU became the first fleet to combine a glass cockpit with ADS-B.
 - **University of North Dakota** - UND has received an FAA grant to test ADS-B, and has begun to outfit their Piper Warrior fleet with an ADS-B package.
- **United Arab Emirates** - UAE commissioned three operational redundant ADS-B ground stations in early 2009 and is now using ADS-B to provide enhanced coverage of its upper airspace in combination and integrated with conventional surveillance radars.
- Use of ADS-B and CDTI may allow decreased approach spacing at certain airports to improve capacity during reduced-visibility operations when visual approach operations would normally be terminated (e.g. ceilings less than MVA +500).

System design considerations of ADS-B

A concern for any ADS-B protocol is the capacity for carrying ADS-B messages from aircraft, as well as allowing the radio channel to continue to support any legacy services. For 1090ES, each ADS-B message is composed of a pair of data packets. The greater the number of packets transmitted from one aircraft, the lesser the number of aircraft that can participate in the system, due to the fixed and limited channel data bandwidth.

System capacity is defined by establishing a criterion for what the worst environment is likely to be, then making that a minimum requirement for system capacity. For 1090ES, both TCAS and ATRBS/MSSR are existing users of the channel. 1090ES ADS-B must not reduce capacity of these existing systems.

The FAA national program office and other International aviation regulators are addressing concerns about ADS-B non-secure nature of ADS-B transmissions. ADS-B messages can be used to know the location of an aircraft, and there is no means to guarantee that this information is not used inappropriately. Additionally, there are some concerns about the integrity of ADS-B transmissions. ADS-B messages can be produced, with simple low cost measures, which spoof the locations of multiple phantom aircraft to disrupt safe air travel. There is no foolproof means to guarantee integrity, but there are means to monitor for this type of activity. This problem is however similar to the usage of ATCRBS/MSSR where false signals also are potentially dangerous (uncorrelated secondary tracks).

There are some concerns about ADS-B dependence on satellite navigation systems to generate state vector information, although the risks can be mitigated by using redundant sources of state vector information, e.g. GPS, GLONASS, Galileo or multilateration.

There are some General Aviation concerns that ADS-B removes anonymity of the VFR aircraft operations. The ICAO 24-bit transponder code specifically assigned to each aircraft will allow monitoring of that aircraft when within the service volumes of the Mode-S/ADS-B system. Unlike the Mode A/C transponders, there is no code "1200"/"7000", which offers casual anonymity. Mode-S/ADS-B identifies the aircraft uniquely among all in the world, in a similar fashion as a MAC number for an Ethernet card or the IMEI (International Mobile Equipment Identity) of a GSM phone. However, the FAA is allowing UAT equipped aircraft to utilize a random self-assigned temporary ICAO address in conjunction with the use of beacon code 1200. 1090ES equipped aircraft using ADS-B will NOT have this option.

ADS-B technical and regulatory documents

MASPS = Minimum Aviation System Performance Standards

MOPS = Minimum Operational Performance Standards

- DO-242A - ADS-B MASPS
 - Describes system-wide operational use of ADS-B.

Chapter 11

Control Tower



The 109-meter tall control tower of Vienna International Airport, Austria.



Inside the control tower at Misawa Air Base, Japan.

A **control tower**, or more specifically an **air traffic control tower**, is the name of the airport building from which the air traffic control unit controls the movement of aircraft on and around the airport. Control towers may also refer to the operations center to control the traffic for other forms of transportation such as rail transport, sea port or moveable bridges. Most of the world's airports are non-towered or mandatory frequency — only a minority of airports have enough traffic to justify a control tower, though some airports may open temporary tower units during special events like an airshow.

Permanent control tower structures generally rise high above other buildings at an airport to give air traffic controllers a view of aircraft moving on the ground and in the air around the airport, though temporary tower units may operate from trailers or even portable radios outside.

Medium-traffic airports may have only one controller staffing the control tower, and may not keep the tower open 24 hours per day. Busier airports usually have space for several controllers and other support staff, and operate 24 hours per day, 365 days per year.

Features



Field-deployable control tower

Full control tower structures usually have windows that circle the entire top floor, giving all round vision. The windows are usually tilted outwards at 15 degrees, because otherwise the controllers would see the reflection of their equipment. The ceiling may also be painted black.

Control towers typically contain the following:

- radios for communication with aircraft, linked to controllers' headsets or to microphones and speakers;

- a telephone system that connects dedicated voice lines and public telephone lines via quick-dial systems to controllers' headsets, allowing them to talk to other controllers and outside parties;
- a strip board allowing Flight Progress Strips to be used (however in some towers these have been replaced by a computerised system);
- a light gun for communication with aircraft via aviation light signals in the event of a radio failure;
- wind and pressure gauges.
- Cab glass may be impact resistant laminated, or the typical insulated annealed glass. Testing includes the determination of acceptable tolerances regarding double imaging.

Other equipment may include the following:

- a rotating beacon;
- an aerodrome traffic monitor, which is a small radar display that is not used for separation purposes but allows controllers to see the aircraft flying in the vicinity of the airport;
- a surface movement radar displaying aircraft and vehicles on the airport to assist controllers at night and in poor visibility;
- computerized meteorological information, flight data and briefing systems.

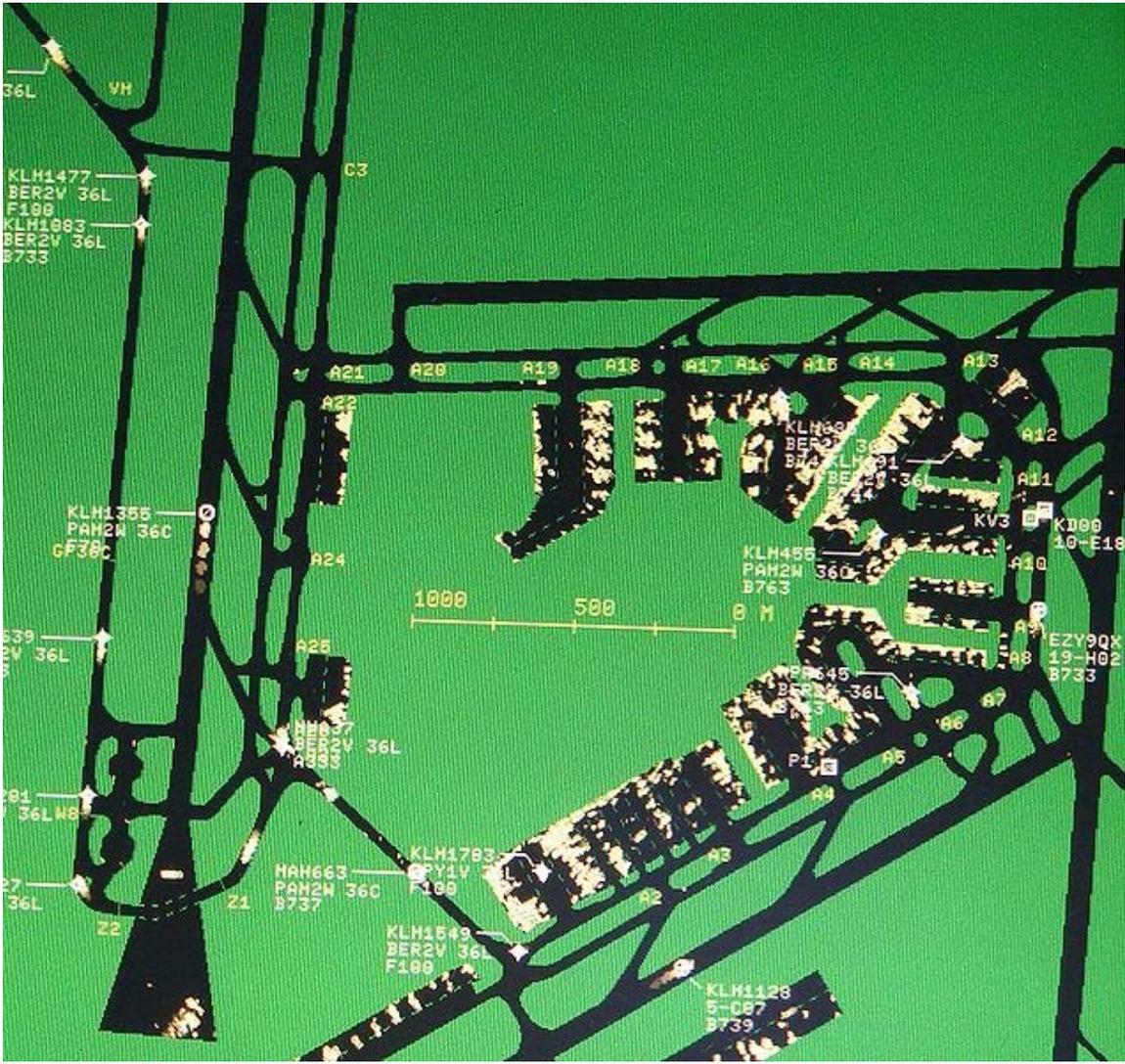
Records

The world's highest control tower is Vancouver Harbour Control Tower, situated on top of the 142 meter skyscraper 200 Granville Square, in downtown Vancouver, Canada. The world's tallest free standing control tower is the 132.2 m (434 feet) Suvarnabhumi Airport control tower, 25 km east of Bangkok, Thailand.

The very first control tower for an airport was built in 1925 in Cleveland Hopkins International Airport.



The distinctive tower at Nuremberg Airport



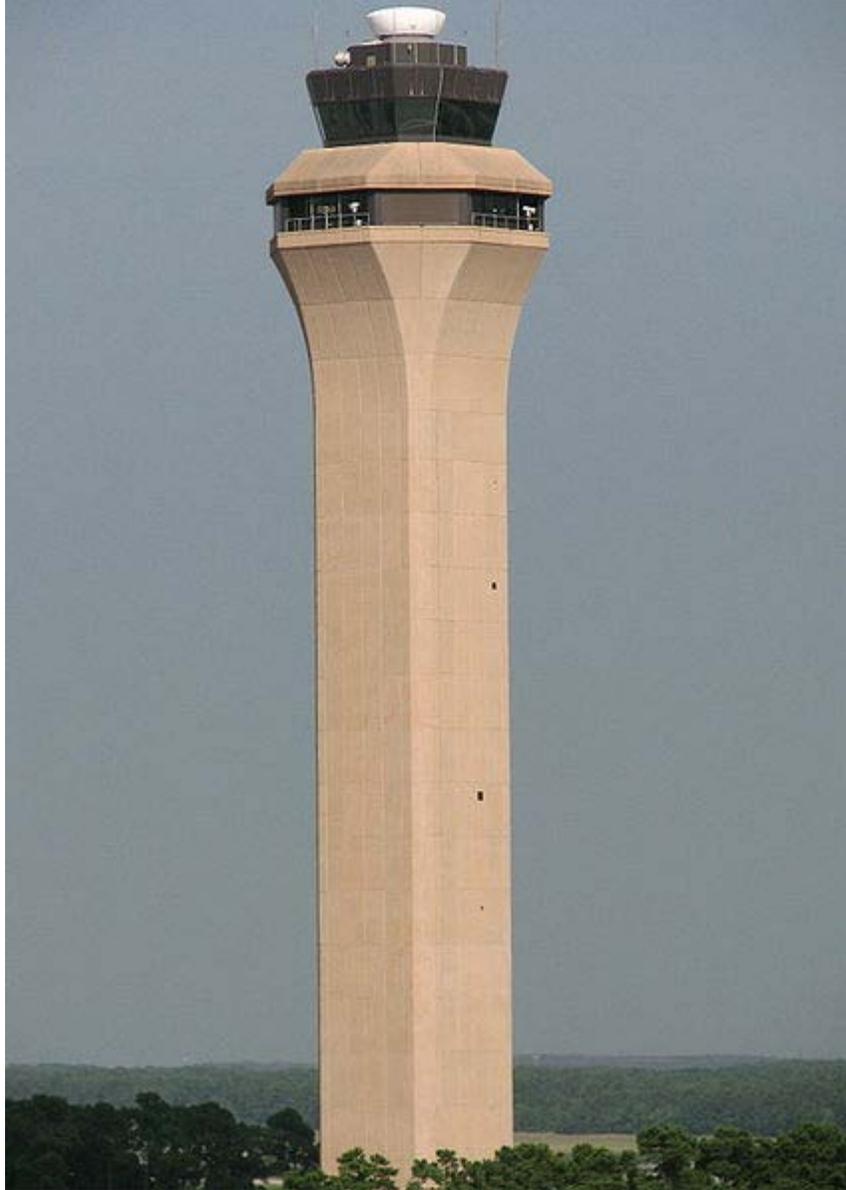
A surface movement radar at Schiphol airport, used to assist tower controllers at night or in poor visibility



London Luton Airport control tower



Stockholm-Arlanda Airport



George Bush Intercontinental Airport control tower



Oslo airport, Gardermoen control tower at 91 meters



Sydney Airport control tower



The control tower of a small airfield: Kemble Airport, England



The interior of the tower at Seattle-Tacoma International Airport