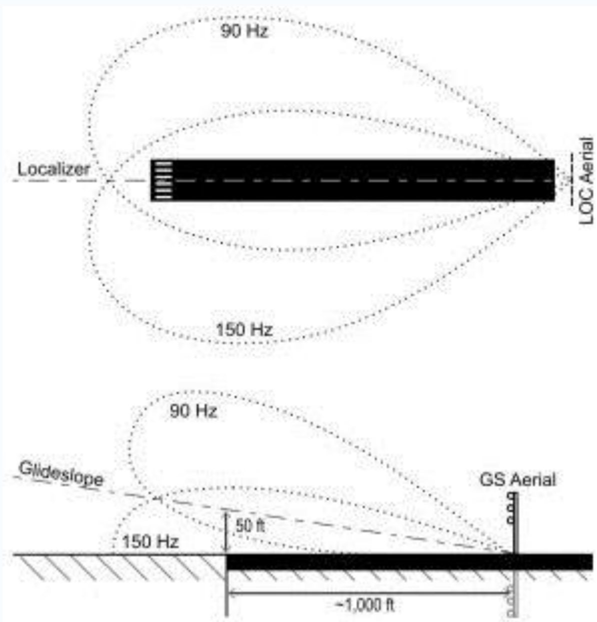
Instrument Landing System

The NDB station co-located with **Middle Marker** of Beijing Capital International Airport **ILS** RWY36L

The **Instrument Landing System** (ILS) is an instrument approach system which provides precise guidance to an aircraft approaching a runway and in some cases along the runway surface.

Principle of operation



The emission patterns of the localizer and glideslope signals. Note that the glideslope beams are partly formed by the reflection of the glideslope aerial in the ground plane.

An ILS consists of two independent sub-systems, one providing lateral guidance, the other vertical guidance to aircraft approaching a runway. A localizer (LOC) antenna array is normally located around 1000 ft from the departure end of the runway and generally consists of 8 or 14 directional antennas such as the Log-periodic antenna or the V-Ring antenna. Two signals are transmitted on a carrier frequency between 108 MHz and 111.975 MHz. One is modulated at 90 Hz, the other at 150 Hz and these are transmitted from separate but co-located aerials. Each aerial transmits a fairly narrow beam, one slightly to the left of the runway centreline, the other to the right. The localizer receiver on the aircraft measures the difference in the depth of modulation of the 90 Hz and 150 Hz signals, when this difference is zero the receiver aerial is on the centreline of the localizer which normally coincides with the runway centreline. Usage of V-ring antennas allows a runway to have a non-precision approach called a localizer backcourse. This lets aircraft land using the signal transmitted from the back of the localizer array. This signal is reverse sensing so a pilot would have to fly opposite the needle indication. Log periodic antennas are highly directional and do not provide a sufficient signal to support a backcourse.

A glideslope (GS) transmitter aerial is sited to one side of the runway touchdown zone. The GS signal is transmitted on a carrier frequency between 328.6 MHz and 335.4 MHz using a technique similar to that of the localizer, the centreline of the glideslope signal being arranged to define a glideslope at approximately 3° above the horizontal.

Localizer and glideslope carrier frequencies are paired so that only one selection is required to tune both receivers. The localizer provides for facility identification by periodically transmitting a 1020 Hz morse code identification signal. For example, the ILS for runway 04R at John F. Kennedy International Airport transmits IJFK to identify itself to users whereas runway 04L is known as IHIQ . This lets users know the facility is operating normally and that they are tuned to the correct ILS. The glideslope transmits no identification signal and relies on the localizer for identification.

Localizer and glideslope signals are displayed on a cockpit instrument, called a Course deviation indicator (CDI), as vertical and horizontal needles (or an electronic display simulating needles). The pilot controls the aircraft so that the needles remain centred on the display, the aircraft then follows the ILS centreline. The signals are also be fed into autopilot systems to allow approaches to be flown on autopilot.

ILS Category

A standard ILS is termed "Category I", allowing landings for suitably equipped aircraft in weather with 2400 ft (732m) visibility or 1800 ft (549m) in case of touchdown and centerline lighting and 200 ft ceiling (cloud base or vertical visibility). More advanced Category II and III systems allow operations in near-zero visibility, but require special additional certification of the aircraft and of the pilot. Category II approaches permit landing with a 100 foot decision height and visibility as low as 1200 ft (366m). Category III is flown by an autoland system on board the landing aircraft, and permit operations even with no decision heights and visibility better than 700ft (Cat IIIa) or between 150ft and 700ft (Cat IIIb). Each operator certified for Cat III operations will have specific decision heights and visibility minima established which are unique to their certification. Some operators are authorized to land in zero/zero conditions (Cat IIIc). Category II/III installations include in-runway centreline and touchdown zone lighting, as well as other aids and enhancements.

Limitations and alternatives

A limitation of ILS is its sensitivity to obstructions in the signal broadcast area. In the 1970s there was a major US & European effort to establish the Microwave Landing System, which are not similarly limited and which allow curved approaches. However, a combination of slow development and airline reluctance to invest in MLS, and the rise of GPS has resulted in its failure to be widely adopted. The Transponder Landing System (TLS) is another alternative to an ILS system that can be used where a conventional ILS system will not work or is not cost-effective.

Future

The advent of the Global Positioning System (GPS) provides an alternative source of guidance for aircraft, however GPS is not sufficiently accurate to provide guidance even to Category I standards without augmentation. Various methods of augmentation are being considered, for example the US Wide Area Augmentation System (WAAS). This can provide guidance to Category I standards.

The use of GPS for Category II and III approaches requires greater accuracy than WAAS can provide. Perhaps the most promising method of providing the increased accuracy is the use of pseudo-satellites (pseudolites) which are a local, ground-based short range device emulating a GPS satellite. The Local Area Augmentation System (LAAS), though currently only a category I system, is under development and a cat II or III system may include the use of pseudolites. Eventually such techniques may replace ILS, though it may be necessary to keep some ILS facilities as backup in the event that the alternative system should fail or in case of interference with the GPS signal or deliberate jamming.

The European Galileo positioning system is intended to provide data accurate enough to permit autoland functions.

Components

A complete ILS system includes additional sub-systems in addition to the localizer and glideslope systems described above.

Marker Beacons

On some installations marker beacons operating at a carrier frequency of 75 MHz are provided. When the transmission from a marker beacon is received it activates an indicator on the pilot's instrument panel and the modulating tone of the beacon is audible to the pilot. The height at which these signals will be received in an aircraft on the correct glideslope is promulgated. Although the following three types of beacon are specified, in practice it is rare to find middle or inner markers and outer markers are no longer universal.

Outer Marker

The outer marker should be located 7.2 km (3.9 NM) from the threshold except that, where this distance is not practicable, the outer marker may be located between 6.5 and 11.1 km (3.5 and 6 NM) from the threshold. The modulation is two dashes per second of a 400 Hz tone, the indicator is blue. The purpose of this beacon is to provide height, distance and equipment functioning checks to aircraft on intermediate and final approach. An NDB may be combined with an outer marker to make a Locator Outer Marker (LOM).

Middle Marker

The middle marker should be located so as to indicate, in low visibility conditions, that visual contact with the runway is imminent. It is modulated with a 1300 Hz tone as alternate dots and dashes.

Inner Marker

The inner marker, when installed, shall be located so as to indicate in low visibility conditions the imminence of arrival at the runway threshold. This is typically the position of an aircraft on the ILS as it reaches Category II minima. The modulation is 3000 Hz dots at 6 per second.

DME

Distance Measuring Equipment (DME) is replacing markers in many installations. This provides more accurate and continuous monitoring of correct progress on the ILS to the pilot, and does not require an installation outside the airport boundary. The DME is frequency paired with the ILS so that it is automatically selected when the ILS is tuned.

Monitoring

It is essential that any failure of the ILS to provide safe guidance is detected very rapidly by the pilot. Monitors are provided that continuously assess the vital characteristics of the transmissions. If any significant deviation beyond strict limits is detected either the ILS is automatically switched off or the navigation and identification components are removed from the carrier. Either of these actions will activate an indication ('failure flag') in the instrument of an aircraft using the ILS.

Other Means of Determining Distance DME, GPS, Radar, and Cross Radials(through use of VOR receivers), a form of triangulation may also be used to determine distance.

Approach Lighting

Most installations include medium or high intensity approach light systems. The approach light system (abbreviated ALS) assists the pilot in transitioning from instrument to visual flight, and to align the aircraft visually with the runway centerline. At many non-towered airports, the intensity of the lighting system can be adjusted by the pilot.

See also

- Instrument flight rules (IFR)
- VHF Omni-directional Range (VOR)
- Distance Measuring Equipment (DME)
- Non-Directional Beacon (NDB)
- Global Positioning System (GPS)
- Transponder Landing System (TLS)
- Local Area Augmentation System (LAAS)
- Wide Area Augmentation System (WAAS)

VHF omnidirectional range

D-VOR (Doppler VOR) ground station, co-located with DME.

VOR, short for *VHF Omni-directional Radio Range*, is a type of radio navigation system for aircraft. VORs broadcast a VHF radio signal encoding both the identity of the station and the angle to it, telling the pilot in what direction he lies from the VOR station, referred to as the *radial*. Comparing two such measures on a chart allows for a *fix*. In many cases the VOR stations have a colocated DME or Distance Measuring Equipment to provide distance measurement allowing for a one-station fix.

VORs became the major radio navigation system in the 1960s, when they took over from the older radio beacon system. The older system retroactively became known as non-directional beacons, or NDBs. VOR's major advantage is that the radio signal provides a to/from bearing to the beacon, allowing pilots to follow a line in the sky more easily than with an NDB. A major network of "air highways", known in the US as *Victor* *airways*, were set up linking the VORs and airports. On any particular part of the journey the airway would say to fly at a specific angle from a particular station, in which case the pilot simply tunes in the station on the VOR receiver, dials that angle into the indicator, and then keeps a pointer centered in a display.

VORs also provided considerably greater accuracy and reliability than NDBs due to a combination of factors in their construction. But these same factors also make VOR transmitters and receivers rather more expensive to install and maintain. In addition VORs have limited maximum ranges of between 25–130 nautical miles (46–240 km), which means that an extensive network of stations needs to be used to provide reasonable coverage along main air routes. The VOR network is a major cost in operating the current air navigation standards.

How the VOR works

Each VOR operates on a radio frequency assigned to it between 108.0 megahertz (MHz) and 117.95 MHz, which is in the VHF (very high frequency) range. The channel width is 50 kHz. VHF was selected because it travels only in straight lines, resisting bending due to atmospheric effects, thereby making angle measurements accurate. However, this also means that the signals do not operate "over the horizon"; VOR is line-of-sight only, limiting the maximum operating radius to 130 nmi (240 km).

VOR systems use the phase relationship between two 30 Hz signals to encode direction. The main "carrier" signal is a simple AM tone broadcasting the identity of the station in morse code. The second 30 Hz signal is FM modulated on a 9960 Hz subcarrier. The combined signal is fed to an array of four omnidirectional antennas, which rotates the signal at 30 times a second. Note that the antennas need not be physically rotating—all VOR beacons use a phased antenna array such that the signal is "rotated" electronically.

When the signal is received in the aircraft, the FM signal is decoded from the subcarrier and the frequency extracted. The two 30 Hz signals are then compared to extract the phase difference between them. The phase difference is equal to the angle of the antenna at the instant the signal was sent, thereby encoding the direction to the station as the narrow beam washed over the receiver.

The phase difference is then mixed with a constant phase produced locally. This has the effect of changing the angle. The result is then sent to an amplifier, the output of which drives the signal pointers on a compass card. By changing the locally produced phase, using a knob known as the **Omni-Bearing Selector**, or **OBS**, the pilot can zero out the angle to a station. For instance, if the pilot wishes to fly at 90 degrees to a station, the OBS mixes in a −90 phase, thereby making the indicator needle read zero (centered) when the plane is flying at 90 degrees to the station.


VORTAC TGO (TANGO) Germany

Many VORs have another navigation aid called DME (distance measuring equipment) at the same location. The combination may be called a VOR-DME or VORTAC, depending on the agency operating the facility; a VORTAC is a civilian VOR co-located with a military TACAN navigation system. Both VOR-DME and TACAN share the same DME system.

DME provides the pilot with the aircraft's *slant* distance from the ground station (i.e. the direct distance, not the ground distance). At lower altitudes and/or at a respectable distance from the DME, the difference is negligible, and so by knowing both the distance and radial from the station, the aircraft's position can be plotted on an aeronautical chart from a single station.

Some VORs are low power for regional navigation and others are high power for high altitude long range navigation.

Using the VOR

A mechanical VOR display

A typical mechanical VOR display consists of a compass dial (usually called a compass card) surrounding a vertical needle and a To/From indicator. Outside the compass dial is a knob called the Omni Bearing Selector (OBS) that rotates the compass dial. All angles are referenced to magnetic north, to allow VOR and compass angles to be easily compared. Magnetic north differs from true north by a number called the magnetic variation, which varies depending on one's location around the world and is available on aeronautical charts and in directories.

If the pilot wants to approach the VOR station from due east he will have to fly due west to reach the station. The pilot will use the OBS to rotate the compass dial until the number 27 (270 degrees) aligns with the pointer at the top of the dial. When the aircraft intercepts the 90 degree radial (due east of the VOR station) the needle will be centered and the To/From indicator will show "To". Notice that the pilot set the VOR to indicate the reciprocal; the aircraft will follow the 90 degree radial while the VOR indicates that the course "to" the VOR station is 270 degrees. The pilot needs only to keep the needle centered to follow the course to the VOR station. If the needle drifts off-center he turns toward the needle until it is centered again. After the aircraft passes over the VOR station the To/From indicator will indicate "From" and the aircraft is then on the 270 degree radial. The needle will generally swing all the way to one side as the aircraft passes over the vicinity of the VOR station but will recenter once the aircraft has flown a short distance beyond the station.

In the illustration above, notice that the compass ring is set at 254 degrees, the needle is centered and the To/From indicator is showing "From" (FR). The VOR is indicating that the aircraft is on the 254 degree radial, west-southwest "from" the VOR station. If the To/From indicator were showing "To" it would mean the aircraft was on the 74 degree radial and the course "to" the VOR station was 254 degrees. Note that there is absolutely no indication of what direction the aircraft is flying. The aircraft could be flying due north and this snapshot of the VOR could be the moment when it crossed the 254 degree radial. However, it is probably safe to assume that the aircraft is flying a course of 254 degrees, has overflown the VOR station and is now flying away from it.

Following a single course with a VOR is much easier than with a NDB. With an NDB only the direction to the station is known, not the radial on which the aircraft lies. This may sound like the same thing, but the key difference is that in order to overfly an NDB the indicator must be centered in the display, the exact location of the aircraft in reference to that station is unknown. In order to find the radial, the NDB pointer must be centered and then referenced to the compass. In addition, as the aircraft approaches the NDB any crosswind will cause the aircraft to drift to one side of the desired course. As the pilot recenters the indicator the aircraft will follow a curved path to the NDB and overfly it from a direction far from the one he started the approach from.

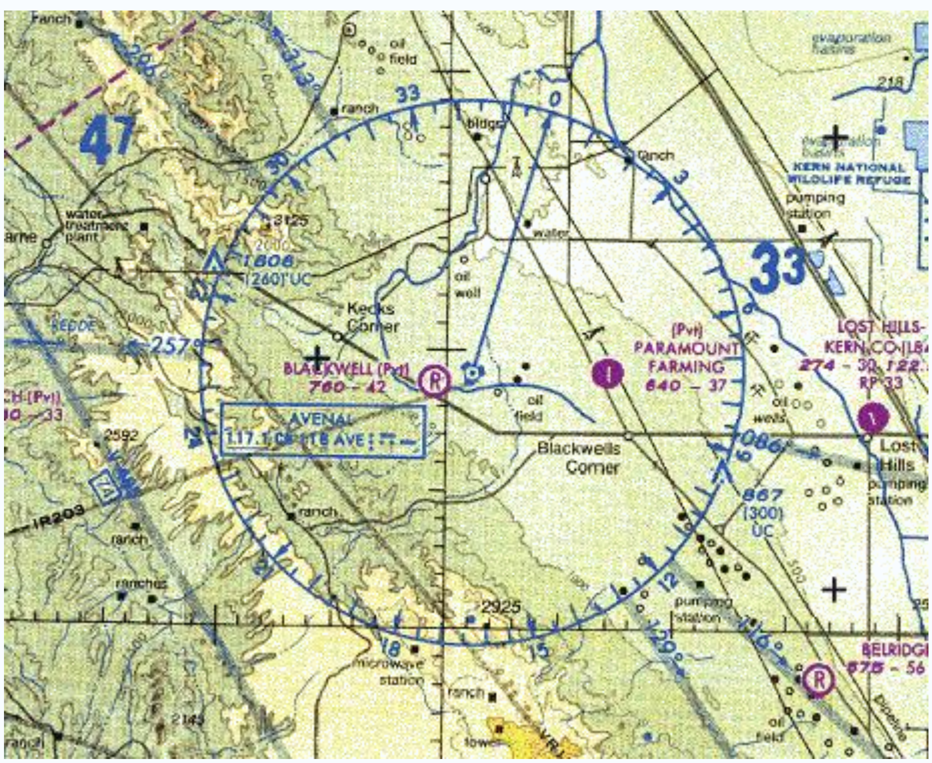
When the aircraft passes overhead a VOR station, it enters the cone of confusion, an imaginary inverted cone, where it cannot correctly identify its radial (and distance for DME). Once the aircraft has passed through this area, the VOR will indicate the "From" radial that is now being flown; the pilot continues to navigate by keeping the pointer centered in the display. With an NDB the pointer will suddenly "flip over" as the station is passed, and in order to continue flying the same direction the pilot has to reverse all corrections. This is often very difficult.

Taking a position fix with a VOR is no easier than with an NDB however. In both cases two stations must be tuned in and their directions found and plotted on a chart. The VOR does offer somewhat better accuracy in this case due to the nature of the signals, but offsets this slightly by the need to rotate the OBS in order to find the direction to the station.

Navigating along lines between stations, as opposed to over them, also remains a difficult problem for either system. In this case the radials change as the aircraft moves, and the only reasonable way to do this manually is to plot the course and sample fixes along it before flight. Errors in navigation can be very difficult to correct, requiring a fix and then comparing that to one of the sample fixes plotted earlier.

Electronics can solve this problem, and Area Navigation (RNAV) systems makes such tasks almost foolproof. An RNAV system is an analog computer that is attached to several VOR receivers and can use both VOR and DME data in order to continually calculate a fix. Flight paths can be selected as the pilot wishes, and the electronics will continually calculate the direction needed to stay on that path, just as if the pilot was flying a VOR radial.

VORs and aerial highways



The Avenal VOR shown on a sectional aeronautical chart. Notice the light blue airways radiating from the VOR. (click to enlarge)

VOR stations are used as intersections along airways. A typical airway will hop from station to station in straight lines. As you fly in a commercial airliner you will notice that the aircraft flies in straight lines occasionally broken by a turn to a new course. These turns are often made as the aircraft passes over a VOR station. There are also navigational reference points where two radials from different VOR stations intersect. These intersections may or may not lie along mapped airways.

Most instrument-rated aircraft have two VOR receivers. As well as providing a backup to the primary receiver the second receiver allows the pilot to easily follow a radial toward one VOR station while watching the second receiver to see when he crosses a certain radial from another VOR station.

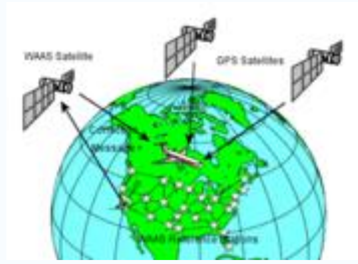
Accuracy

The predictable accuracy of the the VOR system is ±1.4°. However, test data indicates that 99.94% of the time a VOR system has less than ±0.35° of error. VOR systems are internally monitored so that it will shutdown if the station error exceeds 1.0°.[1]

Future

Like many other forms of aircraft radio navigation currently used, it is likely that VOR systems will be replaced by some form of space based navigational system such as GPS. VOR is specifically in jeopardy because of the need for numerous stations to cover a large area. The Wide Area Augmentation System appears to be more cost effective since it can cover most of North America and it is sufficiently accurate for en route usage. The Local Area Augmentation System is planned to use the same VHF frequency band for its correction message. This would require some existing VOR facilities to be shutdown or there could be interference issues. [2]

Wide Area Augmentation System



WAAS Operation

The **Wide Area Augmentation System** (**WAAS**) is a system that improves the precision and accuracy of global positioning system (GPS) signals. It uses a combination of specialized satellites and ground-based stations to send correction signals to GPS receivers, as well as providing integrity information for each satellite's signal, equivalent or better than RAIM (receiver autonomous integrity monitoring), thereby improving the accuracy of the GPS signal by approximately 5 times. The European Geostationary Navigation Overlay System (EGNOS) is the European parallel to this United States system. In Asia, it's the Japanese Multi-Functional Satellite Augmentation System (MSAS). The International Civil Aviation Organization (ICAO) calls this type of system a Satellite Based Augmentation System (SBAS).

Approaches

WAAS was jointly developed by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT), beginning in 1995, to provide precision approach capability for aircraft. Without WAAS, ionospheric disturbances, clock drift (timing), and satellite orbit errors create too much error in the GPS signal for aircraft to perform a precision approach. A "precision approach" is one that is always aligned with the runway, and provides lower minimum weather requirements than non-precision approaches. It provides course guidance, distance from the runway, and elevation information.

The only precision approach currently used by civilian aviation today is the ILS (Instrument Landing System), which is a combination of a localizer, a glidepath, marker beacons and DME (Distance Measuring Equipment). The localizer gives course guidance, lining the aircraft up with the runway; the glidepath tells the pilot how far he/she is above or below the ILS glideslope; and the DME tells the pilot how far away he/she is from the DME equipment on the ground, usually co-located with the airfield. In short, the ILS gives three-dimensional information to the pilot, although in a manner specifically suited for an approach.

The MLS (Microwave Landing System), an effort that began in the 1980s, was intended to be a higher-precision replacement for the ILS, but was rapidly overshadowed by the far less-expensive (per aircraft) WAAS technology, and the FAA has since discontinued MLS capability throughout the United States.

By providing sufficiently accurate information, WAAS enables pilots to make a precision approaches based on GPS signals and an on-board database without relying on an instrument landing system or other ground-based signals. It also enhances GPS capability for en-route navigation. When a pilot files for "area navigation," or "RNAV" using GPS capability, he/she can bypass existing aviation navigation systems such as VOR, TACAN and NDB, and proceed directly from the departure point on his/her instrument departure termination point to the initial approach point for the approach to his/her destination. This direct routing saves both time and fuel.

In addition, because of its ability to provide information on the accuracy of each GPS satellite's information, aircraft equipped with WAAS are permitted to fly at lower en-route altitudes than was possible with ground-based systems, which were often blocked by terrain of varying elevation. This enables pilots to safely fly at lower altitudes, not having to rely on ground-based systems. For unpressurized aircraft, this conserves oxygen and enhances safety.

In order to actually fly an LPV (Lateral Precision with Vertical Guidance) approach, the pilot's WAAS-enabled GPS needs to be Class 3 or 4 TSO-C146 compliant.

Accuracy

The accuracy of WAAS is phenomenal between one and two meters horizontally and between two to three meters vertically throughout most of the continental United States and large parts of Canada and Alaska. It's also been stated as being "better than three meters 95% of the time."

The following table lists the accuracy of the historical GPS systems:

100 meters: Original GPS system accuracy. This is the advertised accuracy of the GPS system with the Selective Availability (SA) option turned on. SA was an imposed error designed to thwart an enemy's use of GPS for its own purposes. SA was employed by the U.S. Government until May 1, 2000 but has not been used since. According to the Inter Agency GPS Executive Board (IGEB), "The United States has no intent to ever use SA again. To ensure that potential adversaries do not use GPS, the military is dedicated to the development and deployment of regional denial capabilities in lieu of global degradation." [1]

15 meters: This is the best non-SA accuracy. It's considered the "normal" accuracy for the GPS system. 2001 FRS states this as ≤ 13 m horizontally and ≤ 22 m vertically.

< 10 meters: This is the Differential GPS (DGPS) accuracy. According to the 2001 Federal Radionavigation Systems (FRS) report published jointly by the US DOT and DOD, accuracy degrades with distance from the facility and can be < 1 m but will normally be < 10 m. Maritime DGPS was implemented in the 1990's, and is used in various seaports and inland waterways to provide pinpoint navigation for shipping. It has been superseded by the National DGPS (NDGPS) program. NDGPS will expand the existing system for railway and highway usage. NDGPS is stated to have accuracy of < 1 m with high end equipment and < 10 m with standard equipment.

< 3 meters: This is the figure currently being given for WAAS accuracy in the vertical plane. WAAS accuracy in the horizontal plane is less than 2 meters. WAAS is capable of achieving Category I precision approach accuracy of 16 m laterally and 4 m vertically.

< 1 meter: Local Area Augmentation System (LAAS). As of 2001, LAAS was capable of achieving a Category I ILS accuracy of 16 m laterally and 4 m vertically. The goal of the LAAS program is to provide Category III ILS capability. This allows aircraft to land with zero visibility utilizing 'autoland' systems and indicates a very high accuracy of < 1 m.

Operation

WAAS begins with approximately twenty-five ground stations positioned throughout the United States which compare the GPS signal with known (surveyed) coordinates. These ground stations send their findings to a WAAS Master Station (WMS) using a land-based communications network. The WMSs then broadcast a correction signal to the two WAAS satellites covering the U.S., which in turn broadcast that correction signal on a per-satellite basis to each WAAS-enabled GPS receiver. The WAAS-enabled GPS receiver adds the correction factor to the GPS signals to derive a corrected GPS signal which is far more accurate than the original GPS signal.

The Future of WAAS

On July 10, 2003, the WAAS signal was activated for general aviation, covering 95% of the United States, and portions of Alaska offering 350ft minimums. The FAA indicates that LPV capability will be enabled for WAAS in September 2003, enabling 250-ft minimums.

In March 2005, the FAA finalized the Geostationary Satellite Communications Control Segment contract with Lockheed Martin for WAAS geostationary satellite leased services through 2016. Two additional satellites, PanAmSat Galaxy XV and Telesat Anik F1R, were launched in 2005 and plan to be operational in late 2006. The Telesat was launched September 9, 2005. This will enhance coverage of North America and all but the northwest part of Alaska. Satellites will be positioned in slots at 54W, 107W, 125W and 178E.

In 2006, WAAS is projected to be available nearly all the time (over 99%), and its coverage will encompass the full continental U.S. and most of Alaska.

Non-directional beacon

A **non-directional beacon (NDB)** is a radio broadcast station in a known location, used as an aviation or marine navigational aid. NDB usage for aviation is standardized by ICAO Annex 10 which specifies that NDBs be operated on a frequency between 190 kHz and 1750 kHz. Each NDB is to be identified by a two or three-letter Morse code group. With the advent of VOR systems and GPS navigation, NDBs are decreasing in use; however, they are still the most widely-used navigational aid in use today.

NDBs have one major advantage over the more-sophisticated VOR. The signals follow the curvature of the earth so NDB signals can be received at much greater distances at lower altitudes. However, the NDB signal is affected more by atmospheric conditions, mountainous terrain, coastal refraction and electrical storms, particularly at long range.

Automatic direction finders

NDB navigation actually consists of two parts – the *Automatic Direction Finder* (or ADF), equipment on the aircraft that detects an NDB's signal, and the NDB's transmitting unit itself. The ADF can also locate transmitters in the standard AM broadcast band (535 kHz to 1615 kHz).

ADF equipment as implemented today uses a rotating solenoid to determine the direction to a broadcast signal. Equipment then plots the direction to the station on a compass card found on the instrument panel of the aircraft. The pilot follows the needle to fly toward the station. In better-equipped aircraft, such as complex singles, twins, and airliners, ADF equipment may plot the bearing to a station on a so-called *horizontal situation indicator*.

When flying in crosswinds and navigating by ADF the pilot has to compensate for crosswinds. For example, with the VOR, if the pilot keeps the needle centered he will follow a straight line to the VOR transmitter. With the ADF, if the pilot keeps the nose of his aircraft pointed at the radio transmitter, the aircraft will drift left or right in any crosswind. As the pilot compensates by repointing the nose of the aircraft at the transmitter he will follow a curving path, first drifting to one side of the NDB then making an increasingly tight turn before overflying it. Therefore, the pilot must compensate for crosswinds and point his aircraft to the left or right of the NDB to follow a straight track to it.

The principles of ADFs are not strictly limited to NDB usage; such systems are also used to detect the location of a broadcast signal for many other purposes, such as the location of emergency beacons.

Usage of NDBs

NDBs provide rudimentary navigation – essentially, the ability to fly a line through the sky. However, with the advent of VOR navigation, NDBs have found their niche in several applications.

Radials and airways

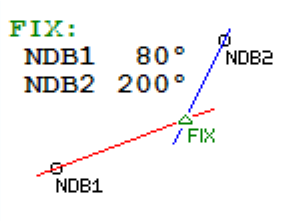
First, using the compass equipment on his aircraft, a pilot can track a specific *radial* over the station. A radial is a line passing through the station that points in a specific direction, such as 270 degrees (due West). NDB radials provide a charted, consistent method for defining paths aircraft can fly.

In this fashion, NDBs (and VORs as well) create 'airways' in the sky. Aircraft, jets in particular, follow these pre-programmed routes to complete a flight plan. Airways, or *vectors*, are numbered and standardized on charts; for example, J24 (jet) is a high-altitude airway, and V119 (victor) is a low-altitude airway. Pilots follow these routes by tracking radials across various navigation stations, and turning at some. While most airways in the United States are based on VORs, NDB airways are common elsewhere, especially in the developing world and in lightly-populated areas of developed countries, like the Canadian Arctic, since they can have a long range and are much less expensive to operate than VORs.

All standard airways are plotted on aeronautical charts, such as U.S. sectional charts.

Fixes

The ability to intercept fixes is a long-used application of NDBs. A fix is, literally, a point in the sky. These fixes are computed by drawing lines through navigation stations until they intercept, creating a triangle with the fix as one vertex:



Plotting fixes in this manner allows a pilot to determine his rough horizontal location. This usage is important in situations where other navigational equipment, such as VORs with distance measuring equipment (DME), have failed.

Instrument landing systems


The NDB station co-located with Middle Marker of Beijing Capital International Airport ILS RWY36L

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

Technical

NDBs typically operate in the frequency range from 190 kHz (kHz) to 535 kHz (although they are allocated frequencies from 190 to 1750 kHz) and transmit a constant carrier at modulations of either 400 or 1020 Hz. NDBs have a variety of owners, mostly governmental agencies and airport authorities.

Common errors

Navigation using an ADF to track NDBs is subject to several common errors:

twilight error
: radio waves can be reflected back by the ionosphere can cause fluctuations 30 to 60 nautical miles (60 to 110 km) from the transmitter, especially just before sunrise and just after sunset (more common on frequencies above 350 kHz)

terrain error
: high terrain like mountains and cliffs can reflect radio waves, giving erroneous readings; magnetic deposits can also cause erroneous readings

electrical error

electrical storms, and sometimes also electrical interference (from a ground-based source or from a source within the aircraft) can cause the ADF needle to deflect towards the electrical source

shoreline error
: low-frequency radio waves will refract or bend near a shoreline, especially if they are close to parallel to it

bank error
: when the aircraft is banked, the needle reading will be offset

While pilots study these errors during initial training, trying to compensate for them in flight is difficult; instead, pilots generally simply choose a heading that seems to average out any fluctuations.

Monitoring NDBs

Besides their use in aircraft navigation, NDBs are also popular with long-distance radio enthusiasts (DXers). Because NDBs are generally low-power, typically between 25 and 100 watts, they normally cannot be heard over long distances, but favorable atmospheric conditions can allow NDB signals to travel much further than normal. Because of this, radio monitors interested in picking up distant signals can gain considerable enjoyment in listening for and logging faraway NDBs. Also, because the band allocated to NDBs is free of broadcast stations and their associated interference, and because NDBs do little more than transmit their own Morse Code callsign, they are easy to listen to and identify, making NDB monitoring a very accessible and fun niche within the radio hobby.

The NDB band runs approximately 200-530 kHz, ending at the lower end of the AM radio dial in the US. A few NDBs can therefore be heard on older radios that can tune slightly below the official 530 kHz (such as the "OS" and "HEH" NDBs in Columbus, Ohio, at 515 and 524 kHz respectively), but for the most part the NDB band requires a general communications receiver or other radio that will tune within that band.

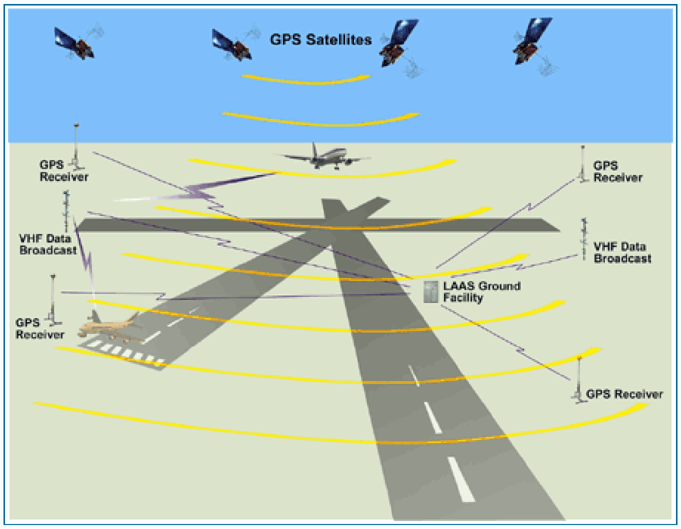
It's also worth noting that most AM radios, while close (within a few miles) to an NDB, can tune to the harmonics of that NDB frequency on a standard AM dial. (In fact, the occurrence of hearing repeated morse code over the standard AM band has been a mysterious phenomenon for years, with many possible sources. However, it is usually NDBs.

Radios which can receive the longwave broadcasting band are especially suitable for reception NDBs. Especially some older radios can also receive the range between 281 kHz and 353 kHz, which is not used for broadcasting purposes any more.

Further reading

- International Civil Aviation Organization (2000). *Annex 10 — Aeronautical Telecommunications*, Vol. I (Radio Navigation Aids) (5th ed.).
- U.S. Federal Aviation Administration (2004). *Aeronautical Information Manual*, § 1-1-2. Available online at http://www.faa.gov/ATpubs/AIM/
- Southern Avionics Company, *Non-Directional Radiobeacons (NDB) and their Place in a Worldwide Navaid System*. Available online at http://www.southernavionics.com/sac1g.htm

Local Area Augmentation System



LAAS Architecture

The **Local Area Augmentation System (LAAS)** is an all-weather landing system based on real-time differential correction of the GPS signal. Local reference receivers send data to a central location at the airport. This data is used to formulate a correction message, which is then transmitted to users via a VHF data link. A receiver on an aircraft uses this information to correct GPS signals, which then provides a standard ILS-style display to use while flying a precision approach. The International Civil Aviation Organization (ICAO) calls this type of system a Ground Based Augmentation System (GBAS).

History

LAAS is designed to correct some of the aviation-related problems of GPS. One problem is the lack of a real-time, rapid-response monitoring system. ILS systems have built-in monitoring equipment that will shut the system down if the monitor detects problems. Category I equipment will normally alert the user of the problem within six to ten seconds of an alarm. GPS has no such rapid-warning system. For example, if a satellite develops a clock problem, there is no way to rapidly warn the user not to use that satellite. WAAS, LAAS and other differential solutions fix this problem and provide GPS system integrity. Another problem is positional accuracy. Sources of error such as satellite clock drift or ionospheric delay can introduce several meters of error in an aircraft's position. These errors must be corrected in real time for a precision approach where there is little or no visibility.

Ten Category I-capable LAAS systems were ordered from Honeywell in 2003. According to the Federal Aviation Administration (FAA) fact sheet, four systems will be for testing and evaluation while the other six will be used at major airports in the US to duplicate existing approaches.[1]

Operation

Local reference receivers are located around an airport at precisely surveyed locations. The signal received from the GPS constellation is compared to the surveyed location then sent to a central location at an airport. This data is used to formulate a correction message which is then transmitted to users via a VHF data link. A receiver on the aircraft then uses this information to correct the GPS signals it receives. This information is used to create an ILS-type display for the user to land with.

LAAS is designed exclusively for aircraft and is only intended for use within 20 to 30 miles of the airfield it is located at. Because LAAS is primarily for aircraft, there are no 'consumer-grade' LAAS-capable GPS receivers.

Accuracy

As of 2001, LAAS was capable of achieving a Category I ILS accuracy of 16 m laterally and 4 m vertically. The goal of the LAAS program is to provide Category III ILS capability. The FAA has not specified the required minimum accuracy for lateral and vertical error of a Cat. III system. However, a Category III approach allows aircraft to land with zero visibility utilizing 'autoland' systems and indicates a very high accuracy of < 1 m.[2]

Benefits

One of the primary benefits of LAAS is that a single installation at a major airport can be used for multiple precision approaches within the local area. For example, if Chicago O'Hare has 12 runway ends each with a separate ILS, all 12 ILS facilities can be replaced with a single LAAS system. This represents a significant cost savings in maintenance and upkeep of the existing ILS equipment.

Another benefit is the potential for approaches that are not straight in. A GPS with LAAS capability can guide an aircraft on any approach necessary to avoid obstacles or to decrease noise levels in areas surrounding an airport.

The FAA also contends that only a single set of navigational equipment will be needed on an aircraft for both LAAS and WAAS capability. This lowers initial cost and maintenance per aircraft since only one receiver is required instead of multiple receivers for NDB's, DME, VOR, ILS, MLS and GPS. The FAA hopes this will result in decreased cost to the airlines and passengers as well as general aviation.

Drawbacks

As of 2005, LAAS has a Category I precision approach capability. This is similar to the WAAS program, but since it covers most of North America, WAAS is far more cost effective. LAAS only covers a 20 to 30 mile area surrounding a single airport. However, research is underway to increase LAAS to Category III and support precision approaches in zero visibility.

LAAS's VHF uplink signal is currently slated to share the frequency band from 108 MHz to 118 MHz with existing ILS localizer and VOR navigational aids. Some existing navaids will need to be turned off because of congestion in the band. Additionally, before LAAS is fully implemented, users may be required to have multiple sets of radio equipment to support all possible situations.

Another drawback of LAAS, is the potential for a single point of failure. If the GPS system is interfered with it could result in serious problems if there is no backup method to land at the airport. Interference could be certain weather conditions, solar activity or malicious jamming of the GPS signal. It is possible that the FAA or local airports will keep existing ILS equipment to provide a backup in the event that the LAAS system should fail or if GPS is jammed. Requiring backup navigational equipment would seem to negate the justification of cost savings since redundant radios on the aircraft would cost users more than the current system. This also makes frequency management difficult because LAAS shares frequency space with its backup.

In order to mitigate these problems, the resulting national system will likely have LAAS capability at major airports, WAAS capability for the rest of North America with a limited amount of conventional navaids as a national backup.

Variations

The Joint Precision Approach and Landing System (JPALS) is a similar system for military usage.

Future

It is likely that the FAA's goal for LAAS is to replace the existing ILS equipment for all categories of precision approaches. Due to the similarity between JPALS and LAAS, the FAA may chose to adopt JPALS instead of LAAS.