From Sight and Radio Beacons to Satellites

The Importance of GPS in Aviation is Growing

GPS provides location information on the Earth with a high degree of accuracy. In height, however, it is much less accurate. This is one of the reasons that, until recently, it has had a minor role in navigation in the air. On an airfield, a beacon with a GPS signal can make a difference. Nico Peursum, Airbus 320 captain, tells us more.

By Job van Haaften

The cockpit of an Airbus 320 with the Navigation Display in the middle, left and right. The two Control and Display Units a little lower an almost next to each other and the IRSs top left. The importance of GPS in aviation is increasing. Source: www.airbus.com

Aviation started with visual navigation and the use of a compass and map. Position was checked by overflying prominent landmarks or, for instance, following railroad tracks. Nico Peursum: "After some time pilots wanted to fly in clouds or above them, and at night. Beacons were placed on the ground, and in the cockpit an Automatic Direction Finder (ADF) pointed the bearing to the beacon. By following the beacons, the aircraft was brought near the airfield where the pilot navigated visually to a safe landing. This developed into more complex beacons that indicate the radial the plane flies on and the distance to the locator beacon. These are called VHF Omnidirectional Range (VOR) and Distance Measuring Equipment (DME). The aircraft sends a radio signal to the beacon which returns it after a certain processing time. The time it takes to get the signal returned gives the distance to the beacon."

Accelerometers and Gyroscopes

More and more ways of navigating and back up systems were used, mostly in combination to provide additional accuracy. Peursum: "In former days they flew from Europe to the United States over Scotland, Iceland and Greenland by following the radio beacons. On a flight over the North Pole they needed a navigator who, from a cupola (a transparent dome on top of an airplane where the navigator can make celestial observations), navigated using the stars. Even in the early Boeing 747s there is room for a kind of viewer to shoot the stars. This way of navigating airplanes was used until the 1970s. Then came the Inertial Reference System (IRS) based on three gyroscopes and three accelerometers. They measure rotation and acceleration in all three axes and thereby continually calculate position and speed.
This is still the basis of navigation in aviation. Nowadays laser gyroscopes are used which, unlike the old mechanical gyroscopes, have no moving parts. In a triangle a laser beam is introduced and split. One beam goes around clockwise, the other counterclockwise. A rotation causes a phase difference as the speed of light is absolute. The information from the IRS is also used for the artificial horizon on the pilots' instrument panel. As even the modern IRSs may shift one nm (nautical mile) per hour, position accuracy can be improved by overflying a radio beacon while simultaneously inserting the correct position of that beacon into the system. Most aircraft use three IRSs, from which a mix position is calculated. If one of the IRSs develops a fault and shifts, in general the two IRSs that are closest together will be correct."

A Difference of 10 Miles

One always needs to check the position that the IRSs provide. Peursum: "Like once when we were flying over Nairobi. The three IRS determinations differed 10 miles, two with a difference of 1mile and the third 10 miles out of line. Usually you rule out the one with the biggest difference. En route over Africa most beacons did not work. However, one beacon 200 nm north of Nairobi did work. Navigating over the beacon, we found out the one stray IRS was actually correct, while

Nico Peursum: "The first civil airplanes using GPS to update the IRS came around 1992."

the other two had both developed a fault in the same direction. A very odd chance! "

No more Maps

In the early 1980s updating became automated and real time. Peursum: "In older aircraft like the early 747s, one needs a map just to know where you are, by referencing to the beacons selected on the instruments. On long flights, we often fly with an augmented crew. When I returned to the cockpit after a rest period, I actually needed a few minutes to orientate myself. In modern planes like the Airbus 320 I can see on a screen exactly where I am. Aircraft like the later model 747s, such as the 400 series and other aircraft developed in that era, started to use a database containing all the runways of major airports, radio beacons and airway routes.
You program your flight in the Control and Display Unit (CDU) and the Flight Management System (FMS) selects two beacons for a cross bearing, preferably using DME, which is quite accurate."

RNAV

As air traffic density was increasing during the 1990s, there was a requirement to increase the number of routes with the result that Area Navigation (RNAV) was introduced. Until then all routes ran via radio beacons. Navigation by IRS, with automatic updating, now became a requirement. En route the required accuracy is five nm. The FMS calculates its own accuracy.
Peursum: "Until recently RNAV was only used for en route navigation. Arrival and departure routes to and from airports were still flown using radio beacons. The routes were programmed into the FMS, but one still had to check the 'raw data' of the radio beacons. Since 2002 RNAV departures and arrivals have been in use at some airports. Required accuracy is one nm. This can still be flown without GPS. The advantage is that it has all turns and heights programmed to approach or depart from a certain airport taking into account noise levels and population density.
Approaches to the runway are made by using a radio beacon, while the last part has to be flown visually or by using the Instrument Landing System (ILS). This is a radio navigation system for performing a precise approach and landing. It provides the position of the aircraft in relation to the ideal course and angle. It also indicates the distance to the optimal landing point on the runway. This system can be used when visibility is more than 75 metres and when airport and aircraft systems meet all requirements. It leads you to follow a radial and a glide path and is visible on the instruments as two needles which you have to keep in one line."

The Use of GPS

At the beginning of the 1990s GPS came into the picture. Peursum: "The first civil airplanes using GPS to update the IRS came around 1992. IRS is still the main navigation system because GPS is not always available, particularly close to airports where errors can be introduced due to reflections caused by buildings or mountainous terrain. On board civil airplanes there are usually two FMSs. Each makes a calculation of the position using the three IRSs and combines this information with the GPS-given position. The IRS is more stable but less accurate. It takes the IRS seven minutes to warm up during which time the FMS tracks the GPS. In the CDU we insert the route or flight plan, which consists of three letter codes for the beacons and five letter codes for the waypoints. The dispatcher prepares the flight plan for us a few hours before the actual flight and checks it in at air traffic control." For Europe it is also checked in at central air traffic control in Brussels where the flight plan is distributed to all relevant air traffic controls across Europe.
Peursum: "The GPS is generally so accurate that other aircraft, flying on the same route, pass overhead or underneath along exactly the same track."
GPS is only used to augment the position of the aircraft and is not used for height, which is measured by levels of air pressure. If air is cold, the pressure level is lower than when it is warm but because all airplanes use the same method the relative height differences are correct. At airports air pressure is measured to an accuracy of one millibar, which corresponds to an accuracy of eight meters. The measurement at the airport is used to correct the altitude meter in the plane. Peursum: "During departure, depending on the surrounding terrain, the altimeter is set to standard (1013hp) at the 'transition altitude'. It is customary to have an altitude separation of 1000 feet (300 metres) between routes of different airplanes. For precision approaches in the last 200 feet, a radio altimeter is used, which works the same as a depth meter on a ship. With GPS update of the IRSs it is now permissible to fly non-precision approaches without referring to the beacon. However, the airline has to thoroughly check the FMS programming of the approach, which is quite a bit of work, and often dispensed with."

Detail of the Primary Flight Display on the left and Navigation Display. Flying on 35,000 ft, speed 0,78 Mach. Arnos is the active waypoint, the route is over Austria with Zagreb (ZDA) and Split (SPL) on the way.

Close up of a Control and Display Unit, on the display a part of the flight plan.

WAAS

In the USA they are working on a combination of GPS and WAAS to heighten the accuracy of aerial navigation. Because GPS by itself does not meet all demands of the Federal Aviation Administration (FAA) for precision, integrity and availability, WAAS is being developed through cooperation of the FAA and the Department of Transportation (DOT). WAAS corrects the GPS signals using beacons or land-based satellites (pseudolites) that send GPS signals so height can be included with the other data for navigation. Peursum: "Using WAAS support increases accuracy up to 10 feet which is enough for a safe landing. It is ideal for flying over water and open land. So far, there have been tests with WAAS and mainly private business airplanes."

Another development since 1997 is Forward Looking Infrared (FLI) and Head Up Display (HUD), already used in military airplanes. HUD is a type of display that presents data without blocking the user's view. It gives a projection of the view with an infrared camera. Peursum: "You can see through clouds and fog however opaque. It is still expensive so it will take some time before airline companies implement FLI, especially when all main airports can be approached with ILS. For private business airplanes that use smaller and remote airports, it pays off much sooner."

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Nico Peursum started as a pilot for Martinair in 1994, after completing his training, as a pilot on Boeing 747 and 767. Later followed by the Airbus 320 and he is captain on the Airbus since 2003. Peursum has 7,300 flying hours.