Manned Aviation Navigation

Galileo Information Centre for Mexico, Central America and the Caribbean

Implemented by:

TABLE OF CONTENTS

1.1 Introduction

According to widely accepted definition the air navigation is defined as "the process of determining the geographic position and maintaining the desired direction of an aircraft relative to the surface of the earth."

There are three types of navigation:

- Dead Reckoning Navigation
- Visual Navigation
- Electronic Navigation.

DEAD RECKONING NAVIGATION

Dead Reckoning is defined as directing an aircraft and determining its position by the application of direction and speed data from a previous position. It is the basis for all types of air navigation. Navigation is both the history and prediction of an aircraft's flight path. At the heart of DR are its four components: position, direction, time, and speed. Position is a set of coordinates that define the specific location of the aircraft above the earth's surface. Direction is an angular measurement from a reference, which determines the actual flight path from a known starting point. Speed multiplied by time will produce the distance flown (or to be flown). The combination of these four components will allow the aircrew to determine the aircraft's current position or to predict its future position. As with any mathematical relationship, if three of the four components are known, the fourth can be determined.

VISUAL NAVIGATION

Visual Navigation requires maintaining direct visual contact with the earth's surface. Visual navigation supports DR by using ground references to determine current position or to provide steering cues to a destination. Visual navigation is most commonly used for helicopter operations and for high speed/low level flight by tactical aircraft. Its obvious limitation is that it requires sufficient visibility and visual references. Visual navigation is not a stand-alone form of navigation. Without DR, the aviator is likely to misidentify ground references and become lost.

ELECTRONIC NAVIGATION

Electronic Navigation requires the use of electronic devices to determine position. They can be grouped into three general categories. In the first category, electronic signals are received from ground stations (VOR, TACAN, ADF, VORTAC, and VOR/DME). The second category of electronic devices will transmit their own signals (RADAR, DOPPLER). The last group is self-contained and requires the aviator to input the starting location (INERTIAL NAVIGATION SYSTEM or INS). The INS is a high-speed DR computer that does the same thing the aviator does but faster and with greater accuracy. The newest addition to the electronic navigation family is the Global Navigation Satellite System (GNSS). This system receives its input from space-based satellites.

1.2 Manned Aviation Navigation

The Aviation navigation is aimed of getting from point "A" to point "B" in the least possible time without losing your way. In the early days of aviation, navigation was mostly an art. The simplest instruments of flight had not been invented, so pilots flew "by the seat of their pants". Today, navigation is a science with sophisticated equipment being standard on most aircraft.

The type of navigation used by pilots depends on many factors. The navigation method used depends on where the pilot is going, how long the flight will take, when the flight is to take off, the type of aircraft being flown, the on-board navigation equipment, the ratings and currency of the pilot and especially the expected weather.

To navigate a pilot needs to take into account the following factors:

- Starting point (point of departure)
- Ending point (final destination)
- Direction of travel
- Distance to travel
- Aircraft speed
- Aircraft fuel capacity
- Aircraft weight & balance information

With this information flight planning can commence and the proper method of navigation can be achieved.

Pilotage

For a non-instrument rated, private pilot planning to fly VFR (Visual Flight Rules) in a small, single engine airplane around the local area on a clear day, the navigation is simple: the navigation process for such a local trip would be pilotage. (Bear in mind, however that the flight planning and preflight for such a trip should be as thorough as if the pilot is preparing to fly cross-country).

The pilotage method of navigation developed naturally through time as aircraft evolved with the ability to travel increasingly longer distances. Flying at low altitudes, pilots used rivers, railroad tracks and other visual references to guide them from place to place. This method called pilotage is still in use today. Pilotage is mainly used by pilots of small, low speed aircraft who compare symbols on aeronautical charts with surface features on the ground to navigate. This method has some obvious disadvantages. Poor visibility caused by inclement weather can prevent a pilot from seeing the needed landmarks and cause the pilot to become disoriented and navigate off course. A lack of landmarks when flying over the more remote areas can also cause a pilot to get lost.

Using pilotage for navigation can be as easy as following an interstate highway. It would be difficult to get lost flying VFR from Oklahoma City to Albuquerque on a clear day because all a pilot need do is follow Interstate 40 west. Flying from Washington, DC to Florida years ago was accomplished by flying the "great iron compass" also called the railroad tracks.

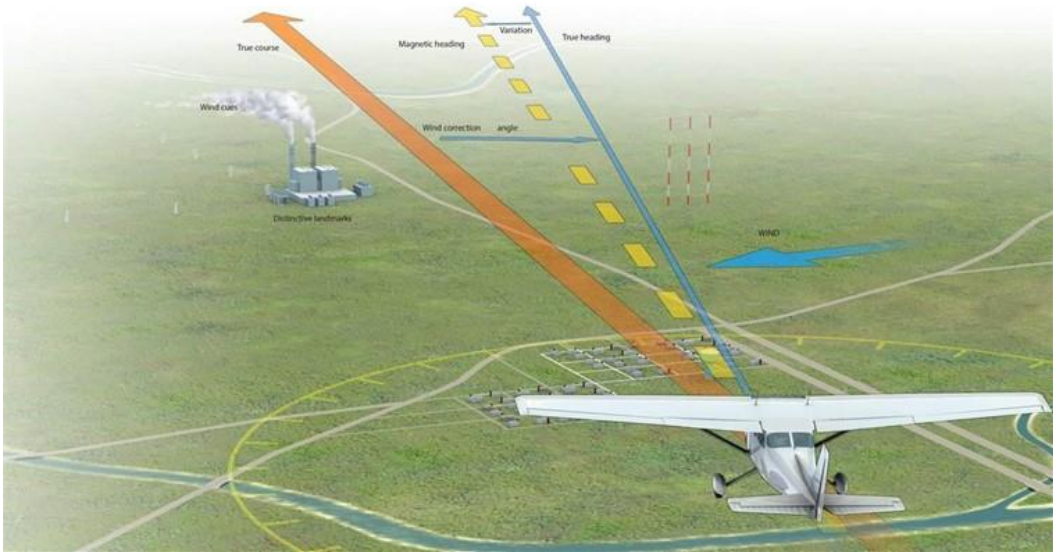


Figure 1: Pilotage navigation technique

Dead Reckoning

The "Dead" Reckoning (or "Ded" for Deductive Reckoning) is another basic navigational method used by low speed, small airplane pilots. It is based on mathematical calculations to plot a course using the elements of a course line, airspeed, course, heading and elapsed time. During this process pilots make use of a flight computer. Manual or electronic flight computers are used to calculate time-speed-distance measurements, fuel consumption, density altitude and many other en route data necessary for navigation.

The Estimated Time En route (ETE) can be calculated using the flight distance, the airspeed and direction to be flown. If the route is flown at the airspeed planned, when the planned flight time is up, the destination should be visible from the cockpit. Navigating using known measured and recorded times, distances, directions and speeds makes it possible for positions or "fixes" to be calculated or solved graphically. A "fix" is a position in the sky reached by an aircraft following a specific route. Pilots flying the exact same route regularly can compute the flight time needed to fly from one fix to the next. If the pilot reaches that fix at the calculated time, then the pilot knows the aircraft is on course. The positions or "fixes" are based on the latest known or calculated positions. Direction is measured by a compass or gyrocompass. Time is measured on-board by the best means possible. And speed is either calculated or measured using on-board equipment.

Navigating now by dead reckoning would be used only as a last resort, or to check whether another means of navigation is functioning properly. There are navigation problems associated with dead reckoning. For example, errors build upon errors. So if wind velocity and direction are unknown or incorrectly known, then the aircraft will slowly be blown off course. This means that the next fix is only as good as the last fix.

The wind triangle is a graphic explanation of the effect of wind upon flight. GS, heading, and time for any flight can be determined by using the wind triangle. It can be applied to the simplest kind of cross-country flight, as well as the most complicated instrument flight. The experienced pilot becomes so familiar with the fundamental principles that estimates can be made that are adequate for visual flight without drawing the diagrams. The beginning student, however, needs to develop skill in constructing these diagrams as an aid to the complete understanding of wind effect. Either consciously or unconsciously, every good pilot thinks of the flight in terms of wind triangle.

If flight is to be made on a course to the east, with a wind blowing from the northeast, the aircraft must be headed somewhat to the north of east to counteract drift.

Figure 2: The principle of dead reckoning wind triangle

Each line represents direction and speed. The long blue and white hashed line show the direction the aircraft is heading, and its length represents the distance traveled at the indicated airspeed for 1 hour. The short blue arrow at the right shows the wind direction, and its length represents the wind velocity for 1 hour. The solid yellow line shows the direction of the track or the path of the aircraft as measured over the earth, and its length represents the distance traveled in 1 hour or the GS.

Suppose a flight is to be flown from E to P. Draw a line on the aeronautical chart connecting these two points; measure its direction with a protractor, or plotter, about a meridian. This is the TC, which in this example is assumed to be 090° (east). From the NWS, it is learned that the wind at the altitude of the intended flight is 40 knots from the northeast (045°). Since the NWS reports the wind speed in knots, if the true airspeed of the aircraft is 120 knots, there is no need to convert speeds from knots to mph or vice versa.

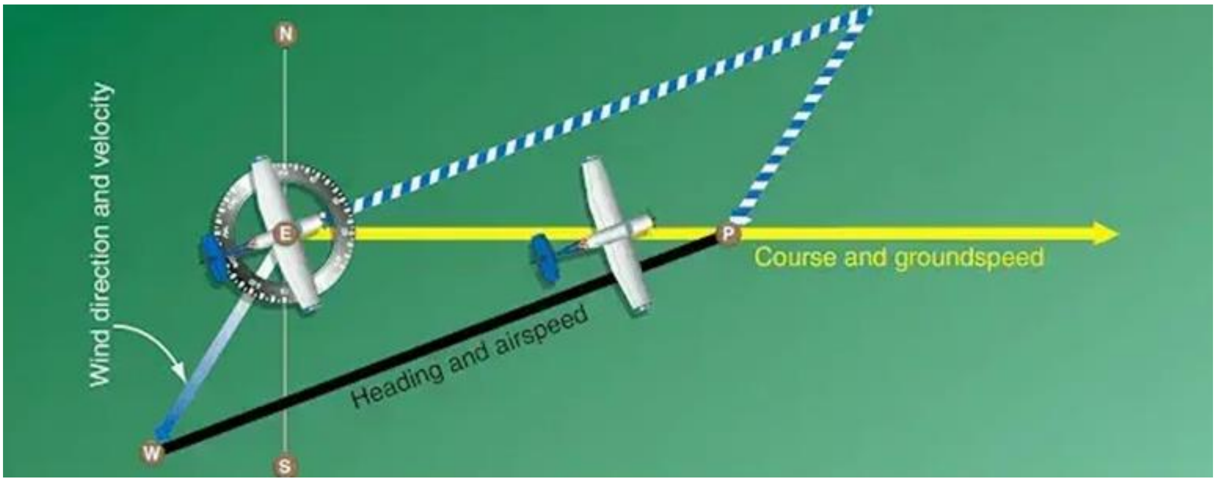


Figure 3: The wind triangle as is drawn in navigation practice

Step 1:

Place the protractor with the base resting on the vertical line and the curved edge facing east. At the center point of the base, make a dot labeled "E" (point of departure) and at the curved edge, make a dot at 90° (indicating the direction of the true course) and another at 45° (indicating wind direction).

Step 2:

With the ruler, draw the true course line from E, extending it somewhat beyond the dot by 90°, and labeling it "TC 090°.

Step 3:

Next, align the ruler with E and the dot at 45°, and draw the wind arrow from E, not toward 045°, but downwind in the direction the wind is blowing making it 40 units long to correspond with the wind velocity of 40 knots. Identify this line as the wind line by placing the letter "W" at the end to show the wind direction.

Step 4:

Finally, measure 120 units on the ruler to represent the airspeed, making a dot on the ruler at this point. The units used may be of any convenient scale or value (such as ¼ inch = 10 knots), but once selected, the same scale must be used for each of the linear movements involved. Then place the ruler so that the end is on the arrowhead (W) and the 120-knot dot intercepts the TC line. Draw the line and label it "AS 120." The point "P" placed at the intersection represents the position of the aircraft at the end of 1 hour. The diagram is now complete

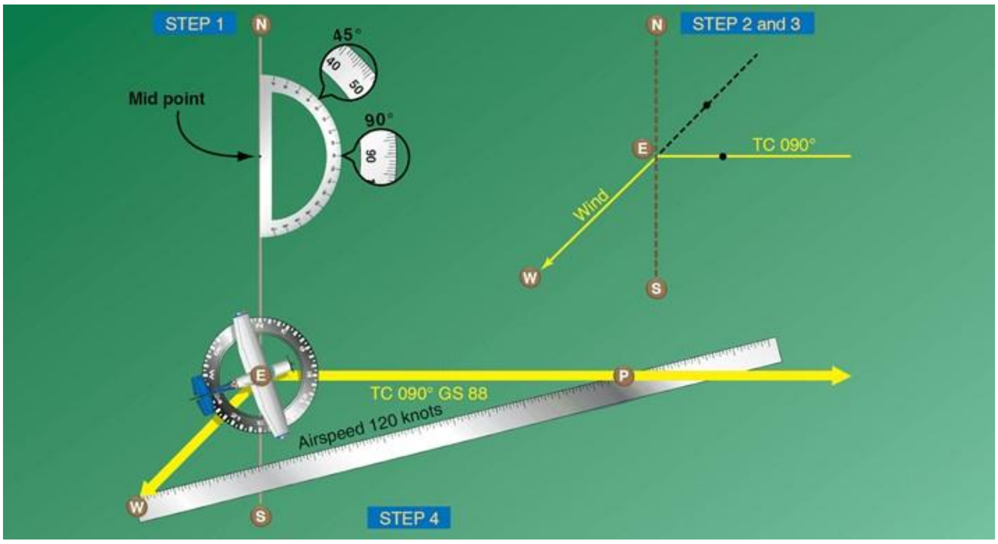


Figure 4: Steps in drawing the wind triangle

Radio Navigation

Radio navigation provides the pilot with position information from ground stations located worldwide. There are several systems offering various levels of capability with features such as course correction information, automatic direction finder and distance measuring.

Most aircraft now are equipped with some type of radio navigation equipment. Almost all flights whether cross-country or "around the patch" use radio navigation equipment in some way as a primary or secondary navigation aid.

In the early years of aviation, a compass, a map, and dead reckoning were the only navigational tools. These were marginally reassuring if weather prevented the pilot from seeing the terrain below. Voice radio transmission from someone on the ground to the pilot indicating that the aircraft could be heard overhead was a preview of what electronic navigational aids could provide. For aviation to reach fruition as a safe, reliable, consistent means of transportation, some sort of navigation system needed to be developed.

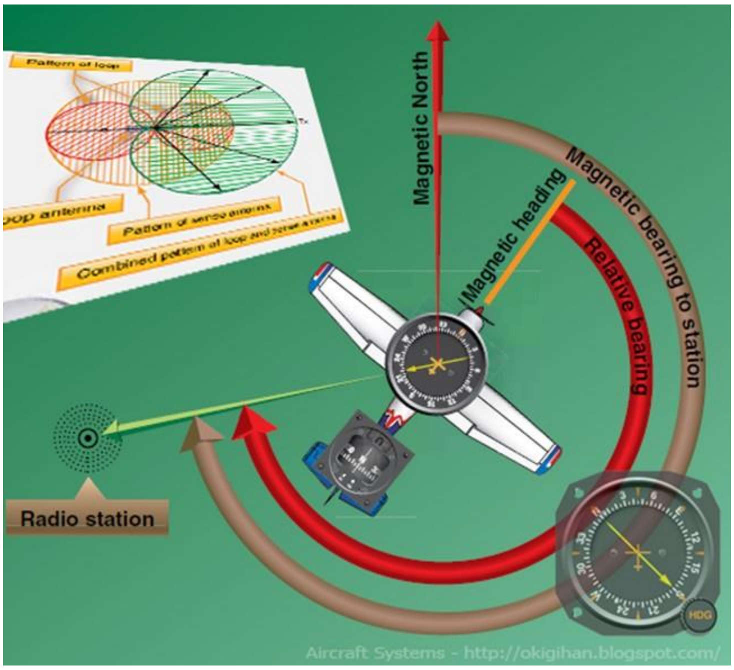


Figure 5: Radio Navigation

Early flight instruments contributed greatly to flying when the ground was obscured by clouds. Navigation aids were needed to indicate where an aircraft was over the earth as it progressed towards its destination. In the 1930s and 1940s, a radio navigation system was used that was a low frequency, four course radio range system. Airports and selected navigation waypoints broadcast two Morse code signals with finite ranges and patterns. Pilots tuned to the frequency of the broadcasts and flew in an orientation pattern until both signals were received with increasing strength. The signals were received as a blended tone of the highest volume when the aircraft was directly over the broadcast area. From this beginning, numerous refinements to radio navigational aids developed.

Radio navigation aids supply the pilot with intelligence that maintains or enhances the safety of flight. As with communication radios, navigational aids are avionics devices, the repair of which must be carried out by trained technicians at certified repair stations. However, installation, maintenance, and proper functioning of the electronic units, as well as their antennas, displays, and any other peripheral devices, are the responsibilities of the airframe technician.

Automatic Direction Finder (ADF)

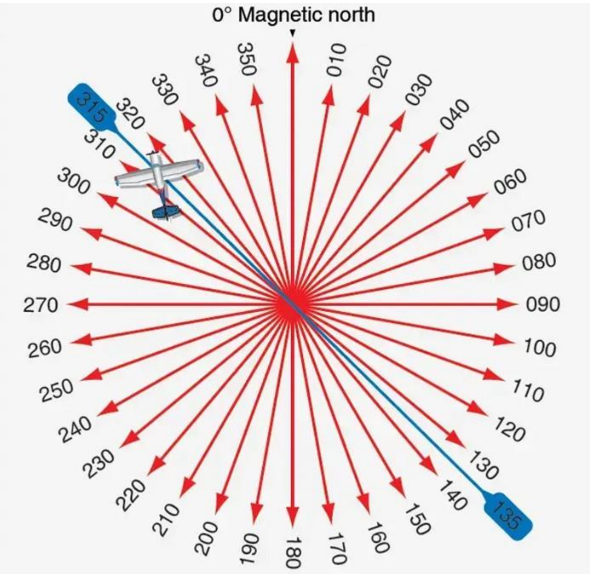
ADF is the oldest radio navigation system still in use. ADF uses Non-Directional Beacons (NDBs) that are simply AM-radio transmitters operating in the Low and Middle Frequency (L/MF) Band from 190 to 535 kHz. These frequencies are below the standard broadcast band. All ADFs can also home in on AM broadcast stations. Pilots can listen to the radio and navigate also. The ADF indicator has a compass rose and an indicating needle. The needle automatically points to the station. "Homing" means following the needle. "Crabbing" to track to the station is more efficient. Crabbing is a method of flying in which the horizontal axis of the airplane is not parallel to the flight path. ADFs have an "HDG" knob where the pilot can dial in the aircraft heading.

Figure 6: ADF Navigation and ADF Indicator

Very High Frequency Omni-directional Range (VOR)

The VOR station transmits two signals, one is constant in all directions, and the other varies the phase relative to the first signal. The VOR receiver senses the phase difference between the two frequencies and the difference identifies 360 different directions or "radials" from the VOR. The aircraft is on one, and only one, radial from the station. The system does not provide distance information. The VOR uses VHF radio waves (108–117.95 MHz) with 50 kHz separation between each channel. This keeps atmospheric interference to a minimum but limits the VOR to line-of-sight usage. To receive VOR VHF radio waves, generally a V-shaped, horizontally polarized, bi-pole antenna is used.

When the appropriate VOR frequency is entered into a navigation radio, the VOR indicator connected to that radio is used to find where the aircraft is relative to the VOR station. The vertical needle called a Course Deviation Indicator (CDI) on the VOR indicator shows whether the aircraft is right or left of the chosen course. A "To/From/Off" indicator indicates whether the aircraft is on the "to" or "from" side. If the aircraft is "abeam the station", an "off" indication is given. To fly toward the station, the Omni Bearing Selector (OBS) is turned until the CDI is centered with a "to" indication. The pilot then flies that heading. To find out where the aircraft is located from that station, center the needle with a "from" indication. If a radial is dialed into the VOR indicator, the CDI will be right or left of the center and either a "to" or a "from" indication will be seen. The heading of the aircraft does not matter.



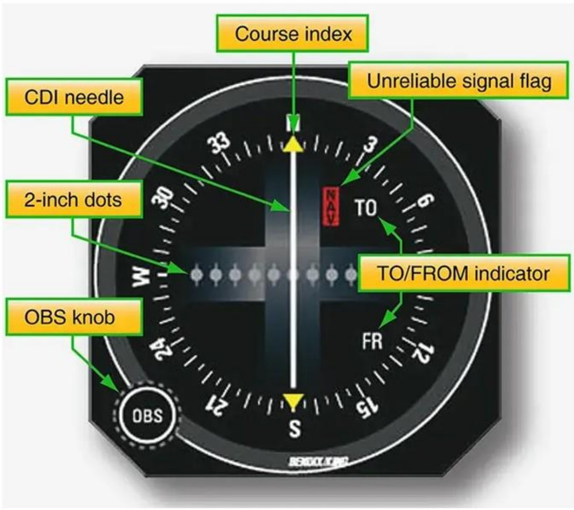


Figure 7: VOR Transmitter and VOR onboard gauge with both CDI and OBS

Distance Measuring Equipment (DME)

DME as its name states is an electronic device that measures "slant range" from the DME station. Slant range is a measure of an aircraft's position relative to the DME station that incorporates the height of the aircraft, its angle from the ground station and its unknown ground range based upon a 90° angle. The farther the aircraft is from the station and the lower the aircraft's altitude, the more accurate the distance reading. An aircraft could be directly over the DME station at an altitude of 10,500 feet above ground level (AGL) and the DME would correctly indicate the aircraft is two miles from the station.

The DME is useful because with the bearing (from the VOR) and the distance to a known point (the DME antenna at the VOR), a pilot can positively identify the location of the aircraft. DME operates in the UHF frequency range from 962 MHz to 1213 MHz A carrier signal transmitted from the aircraft is modulated with a string of integration pulses. The ground unit receives the pulses and returns a signal to the aircraft. The time that transpires for the signal to be sent and returned is calculated and converted into nautical miles for display. Time to station and speed are also calculated and displayed. DME readout can be on a dedicated DME display or it can be part of an EHSI, EADI, EFIS, or on the primary flight display in a glass cockpit.

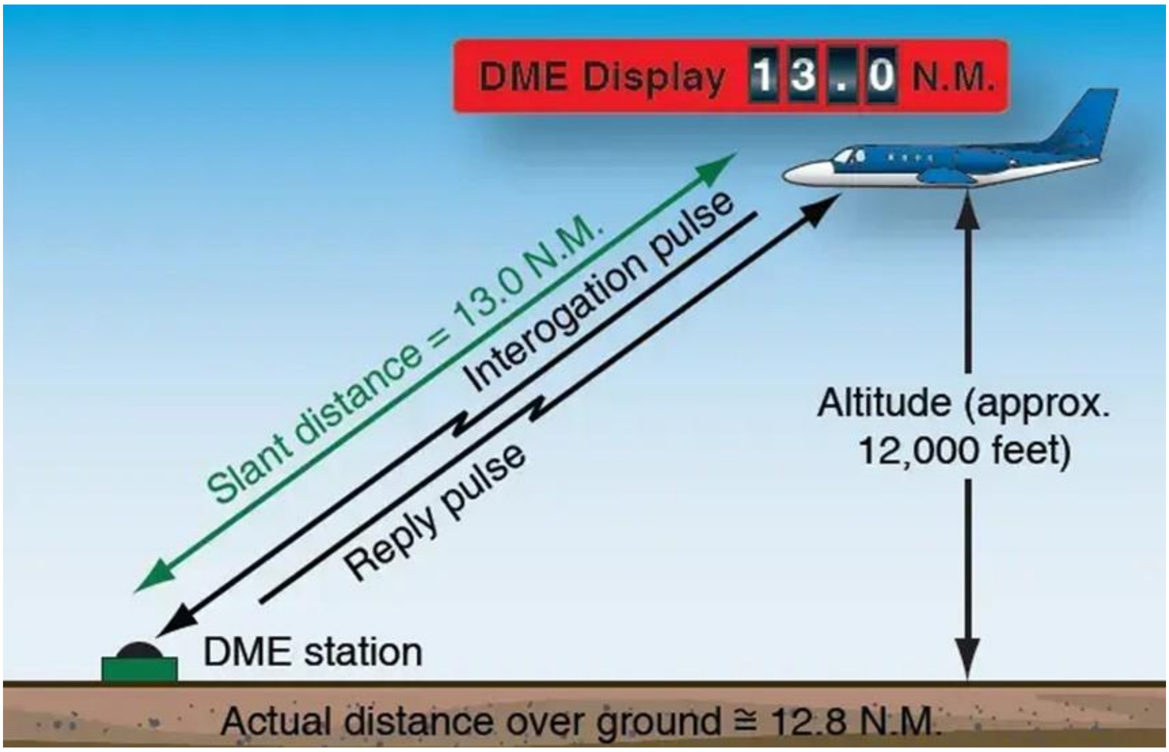


Figure 8: DME actual functioning

Instrument Landing System (ILS)

An ILS is used to land an aircraft when visibility is poor. This radio navigation system guides the aircraft down a slope to the touch down area on the runway. Multiple radio transmissions are used that enable an exact approach to landing with an ILS. A localizer is one of the radio transmissions. It is used to provide horizontal guidance to the center line of the runway. A separate glideslope broadcast provides vertical guidance of the aircraft down the proper slope to the touch down point. Compass locator transmissions for outer and middle approach marker beacons aid the pilot in intercepting the approach navigational aid system. Marker beacons provide distance from-the-runway information. Together, all these radio signals make an ILS a very accurate and reliable means for landing aircraft.

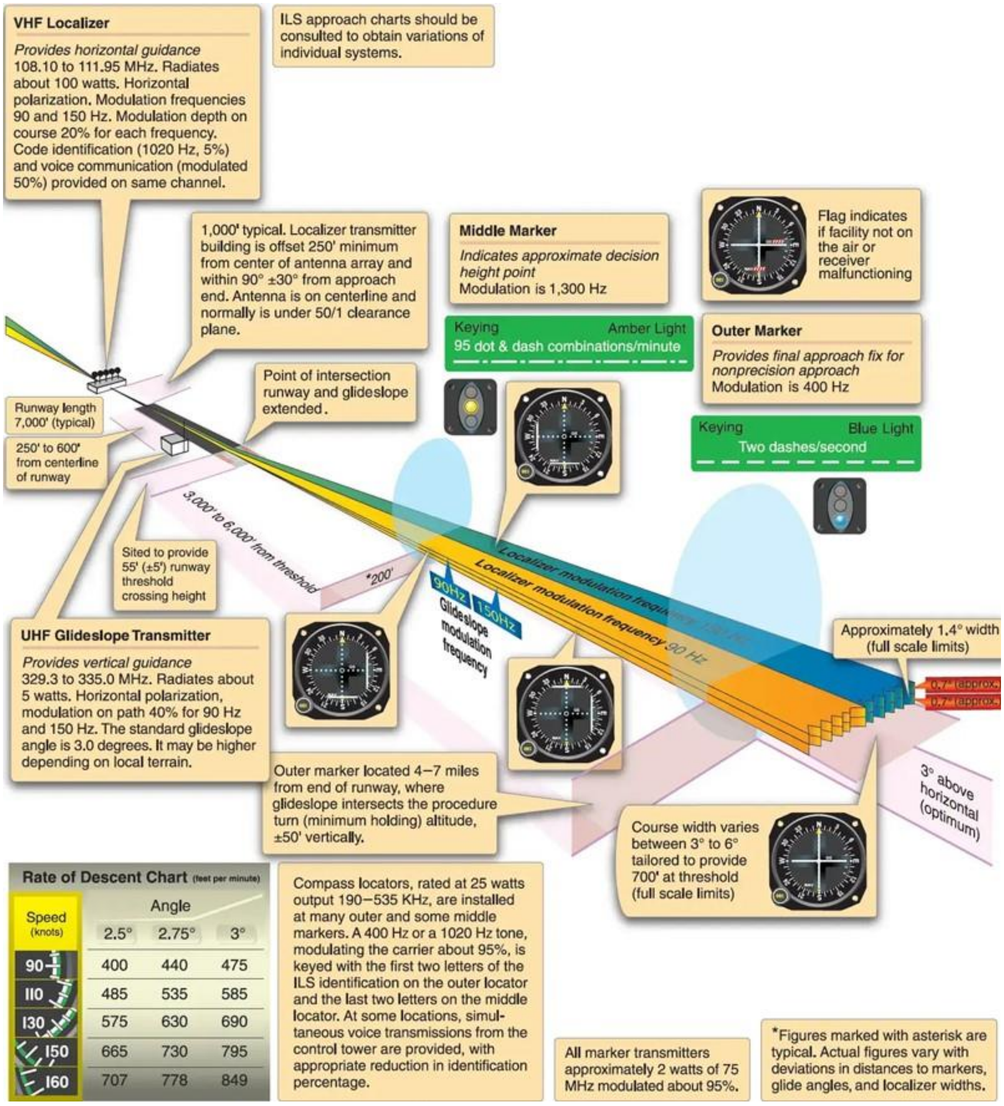


Figure 9: ILS Components

Localizer

The localizer broadcast is a VHF broadcast in the lower range of the VOR frequencies (108 MHz–111.95 MHz) on odd frequencies only. Two modulated signals are produced from a horizontally polarized antenna complex beyond the far end of the approach runway. They create an expanding field that is 21⁄2° wide (about 1,500 feet) 5 miles from the runway. The field tapers to runway width near the landing threshold. The left side of the approach area is filled with a VHF carrier wave modulated with a 90 Hz signal. The right side of the approach contains a 150 MHz modulated signal. The aircraft's VOR receiver is tuned to the localizer VHF frequency that can be found on published approach plates and aeronautical charts.

The circuitry specific to standard VOR reception is inactive while the receiver uses localizer circuitry and components common to both. The signals received are passed through filters and rectified into DC to drive the course deviation indicator. If the aircraft receives a 150 Hz signal, the CDI of the VOR/ILS display deflects to the left. This indicates that the runway is to the left. The pilot must correct course with a turn to the left. This centers course deviation indicator on the display and centers the aircraft with the centerline of the runway. If the 90 Hz signal is received by the VOR receiver, the CDI deflects to the right. The pilot must turn toward the right to center the CDI and the aircraft with the runway center line.

Glideslope

The vertical guidance required for an aircraft to descend for a landing is provided by the glideslope of the ILS. Radio signals funnel the aircraft down to the touchdown point on the runway at an angle of approximately 3°. The transmitting glideslope antenna is located off to the side of the approach runway approximately 1,000 feet from the threshold. It transmits in a wedge-like pattern with the field narrowing as it approaches the runway. The glideslope transmitter antenna is horizontally polarized. The transmitting frequency range is UHF between 329.3 MHz and 335.0 MHz. The frequency is paired to the localizer frequency of the ILS. When the VOR/ILS receiver is tuned for the approach, the glideslope receiver is automatically tuned. Like the localizer, the glideslope transmits two signals, one modulated at 90 Hz and the other modulated at 150Hz.

The aircraft's glideslope receiver deciphers the signals like the method of the localizer receiver. It drives a vertical course deviation indicator known as the glideslope indicator. The glideslope indicator operates identically to the localizer CDI only 90° to it. The VOR/ILS localizer CDI and the glideslope are displayed together on whichever kind of instrumentation is in the aircraft. The UHF antenna for aircraft reception of the glideslope signals comes in many forms. A single dipole antenna mounted inside the nose of the aircraft is a common option. Antenna manufacturers have also incorporated glideslope reception into the same dipole antenna used for the VHS VOR/ILS localizer reception.

Compass Locators

It is imperative that a pilot be able to intercept the ILS to enable its use. A compass locator is a transmitter designed for this purpose. There is typically one located at the outer marker beacon 4-7 miles from the runway threshold. Another may be located at the middle marker beacon about 3,500 feet from the threshold. The outer marker compass locator is a 25-watt NDB with a range of about 15 miles. It transmits omnidirectional LF radio waves (190 Hz to 535 Hz) keyed with the first two letters of the ILS identifier. The ADF receiver is used to intercept the locator so no additional equipment is required. If a middle marker compass locator is in place, it is similar but is identified with the last two letters of the ILS identifier. Once located, the pilot maneuvers the aircraft to fly down the glidepath to the runway.

Marker Beacons

Marker beacons are the final radio transmitters used in the ILS. They transmit signals that indicate the position of the aircraft along the glidepath to the runway. As mentioned, an outer marker beacon transmitter is located 4–7 miles from the threshold. It transmits a 75 MHz carrier wave modulated with a 400 Hz audio tone in a series of dashes. The transmission is very narrow and directed straight up. A marker beacon receiver receives the signal and uses it to light a blue light on the instrument panel. This, plus the oral tone in combination with the localizer and the glideslope indicator, positively locates the aircraft on an approach. A middle marker beacon is also used. It is located on approach approximately 3,500 feet from the runway. It also transmits at 75 MHz. The middle marker transmission is modulated with a 1300 Hz tone that is a series of dots and dashes to not be confused with the all dash tone of the outer marker. When the signal is received, it is used in the receiver to illuminate an amber-colored light on the instrument panel.

Some ILS approaches have an inner marker beacon that transmits a signal modulated with 3000 Hz in a series of dots only. It is placed at the land-or-go-around decision point of the approach close to the runway threshold. If present, the signal when received is used to illuminate a white light on the instrument panel. The three marker beacon lights are usually incorporated into the audio panel of a general aviation aircraft or may exist independently on a larger aircraft. Electronic display aircraft usually incorporate marker lights or indicators close to the glideslope display near attitude director indicator.

LORAN-C

Originally just a marine navigation system, LORAN-C determines present position by the intersection of Lines of Position (LOPs) that are hyperbolic curves. At least three stations, (a Master and two Secondaries) are needed. Accuracy is plus or minus 2.5 miles. The LORAN-C uses triangulation to measure the location of an aircraft or boat.

LORAN-C provides:

- Range (RGE)
- Track (TRK)
- Ground speed (GS)
- Estimated time en route (ETE)
- Cross track error (XTD)
- Track angle error (TKE)
- Desired track (DTK)

Advanced navigation equipment being developed by NASA gives pilots more information and freedom to fly in a more efficient manner thus saving fuel and lowering overall flight costs. These controls often combine several indicators into one for a more accurate display. Pilots now use satellite data from global positioning systems for navigation.

Inertial Navigation System (INS)

An INS is very simple in theory but complicated in practice. Put simply, it is a totally self-contained dead reckoning system. Given its starting position, INS keep track of all movements in all directions, so it calculates the aircraft's flight position in relation to that point. To detect movement, the INS uses three accelerometers, one north-south, one east-west, and one up-down mounted on a stable platform. An accelerometer is an electronic device that provides information like a gyroscope. Part of the accelerometer is in a fixed position and the other part is free to move with the aircraft. A magnetic field is produced by electricity between the two parts. Any change in movement by the free part will disturb the magnetic field. This disturbance will be recorded into the on-board computer which reads the data and calculates the amount of movement. The accelerometers use sliding shuttles and can detect accelerations up to a thousandth of a G force. The platform is stabilized using three gyros, one each for pitch, yaw and roll. This way the aircraft's movement is constantly monitored and helps the pilot keep the aircraft on course.

Newer Inertial Navigation Systems use ring laser gyros that are made up of a series of lasers aligned in the same plane and forming a ring. Interference patterns are generated as the aircraft accelerates indicating changes in the airplane's movement. These changes in movement are measured as nautical miles per hour (nmph) Accuracy is within 1.7 nmph. So, after an hour the accuracy is 1.7 nm.

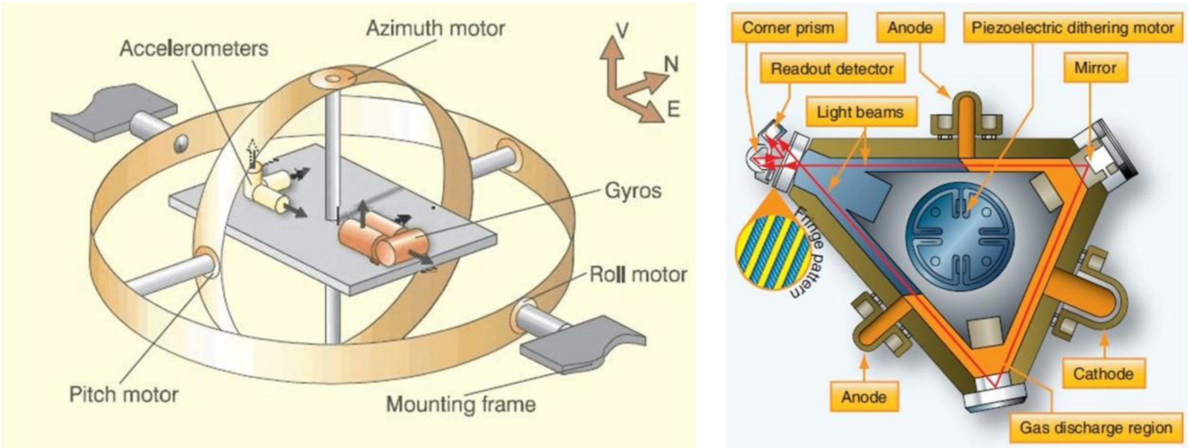


Figure 10: Traditional (left) gyroscope inertial unit vs laser (right) one

The INS must be initialized on the ramp prior to takeoff. The pilot merely enters the aircraft's coordinates and the system performs the calculations since it has an internal clock calendar. Warm-up time and the time it takes for the INS to "sense" north can take from 2.5 to 45 minutes.

This system computes for the pilot the following flight data:

- Track
- Drift angle
- Cross track error
- Distance traveled
- Distance remaining
- Flight time remaining

Separation of Air Traffic and Rules

As in all aspects of life there are rules and regulations that affect flying. Some rules are just good common sense practices while others are habits acquired through specific training. All these rules exist because safety in the skies is the most important consideration of all.

There are some basic flying common-sense rules in which all pilots and air traffic controllers are trained. Some are given below:

- Spend 70% of pilot time scanning the skies using a series of short, regularly spaced eye movements in 10° sections alternately looking both near and far, horizontally and vertically.
- If there is no apparent motion between the aircraft you are piloting and another aircraft, then both are probably on a collision course.
- Be aware of your aircraft's blind spots.
- Before beginning a maneuver, make clearing turns while carefully scanning the area for other aircraft.
- When faced with an aircraft approaching head-on, both aircraft are required to alter the course to the right.
- When overtaking another aircraft flying in the same direction and on the same course, the aircraft being overtaken has the right-of-way, therefore pass well clear of it on the right.
- When two aircraft are converging or approaching from the side, the aircraft to the left must give way to the aircraft on the right.
- A general right-of-way rule states that the least maneuverable aircraft has the right-of-way.
- Over congested areas (city or metropolitan area), aircraft are required to fly 1,000 feet above any obstruction (tall building, for example) within a horizontal radius of 2,000 feet of that aircraft.
- Over uncongested areas (rural land, not open water), aircraft are required to fly at least 500 feet above the surface.

For most small aircraft flying outside controlled airspace in good weather, the pilots are responsible for maintaining a safe distance from other aircraft. This is the "see and be seen" principle otherwise known as VFR or Visual Flight Rules. In this mode of operation, a pilot must keep a continual watch for other aircraft in the sky. When flying above 3,000 feet above ground level (AGL), the pilot must follow VFR cruising altitudes given below (or east/west cruising altitudes).

For jetliners flying inside controlled airspace, pilots are still responsible for maintaining a safe distance from other aircraft. They also must strictly follow IFR or Instrument Flight Rules. In this mode of operation, pilots are flying under reduced visibility and must depend on their instruments for additional guidance and information. Though rules of separation vary depending on the airspace in which a jetliner is flying, in general, air traffic controllers and pilots are required to maintain a horizontal distance of 5 nautical miles between 2 aircraft flying at the same altitude. For altitudes at and below 29,000 feet, vertical separation must be maintained at a minimum 1,000 feet. For altitudes above 29,000 feet vertical separation must be maintained at a minimum of 2,000 feet.

In conclusion the aviation navigation is much more complicated than driving a car. It also involves more than knowing your starting and ending point. A pilot needs to know the flight characteristics and specifications of the aircraft and needs to be able to read an aeronautical chart, plot a course and follow that course. From basic pilotage skills through advanced navigation equipment, navigation means more than taking off and landing. Many calculations are performed, and much planning is required to navigate the skies safely.

1.3 Manned Aviation Navigation and GNSS

The GNSS (Global Navigation Satellite System) satellite technique is applied and implemented in air transport, especially in the area of aerial navigation. Currently, for air navigation, the use of a GNSS sensor allows the use of many methods and techniques of GNSS satellite positioning, in both real time and in post-processing, such as monitoring the state of the atmosphere, researching the quality of GNSS positioning in aviation, and the implementation of the ABAS (Aircraft Based Augmentation System), SBAS (Satellite Based Augmentation System), and GBAS (Ground Based Augmentation System) in air navigation.

The term GNSS is given to a worldwide position, velocity, and time determination system, that includes one or more satellite constellations, receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation. Four implementations of GNSS are currently in existence:

- Global Positioning System (GPS) - USA
- GALILEO - European Union
- Global Orbiting Navigation System (Global'naya Navigatsionnaya Sputnikovaya Sistema GLONASS) - Russia
- BeiDou Navigation Satellite System (BDS) - China:

Global Positioning System (GPS)

The GPS system uses a constellation of 24 or more satellites, 21 plus spares, at an altitude of 10,900 miles, moving 7,500 nmph. Two UHF frequencies, 1.57542 gHz and 1.22760 gHz are used. Ionospheric distortion is measured by the phase shift between the two frequencies. Two modes are available, the "P", or precise mode, and the "C/A" or Coarse/Acquisition Mode. The P mode used by the military transmits a pseudo-random pattern at a rate of 10,230,000 bits/sec and takes a week to repeat. The C/A code is 10 times slower and repeats every millisecond.

Two signals loaded with digitally coded information are transmitted from each satellite. The L1 channel transmission on a1575.42 MHz carrier frequency is used in civilian aviation. Satellite identification, position, and time are conveyed to the aircraft GPS receiver on this digitally modulated signal along with status and other information. An L2 channel 1227.60 MHz transmission is used by the military.

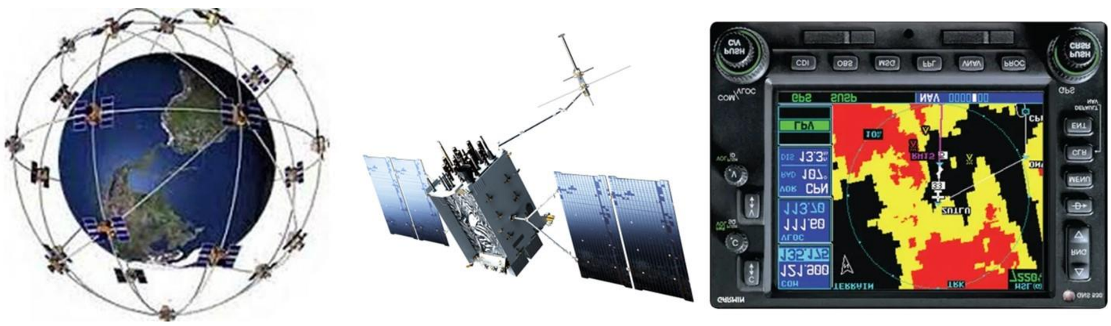


Figure 11: GPS orbit, GPS Satellite and GPS onboard unit

The GPS receiver synchronizes itself with the satellite code and measures the elapsed time since transmission by comparing the difference between the satellite code and the receiver code. The greater the difference, the greater the time since transmission. Knowing the time and the speed of light/radio, the distance can be calculated. The timing comes from four atomic clocks on each satellite. The clocks are accurate to within 0.003 seconds per thousand years. The GPS satellites correct for receiver error, by updating the GPS receiver clock.

The GPS satellite also transmits its position, its ephemeris, to the GPS receiver so it knows where it is relative to the satellite. Using information from four or more satellites the GPS receiver calculates latitude, longitude, and altitude. (The math involves matrix algebra and the solution of simultaneous equations with four unknowns. Computers do that sort of computation very well).

GPS receivers provide all needed navigational information including:

- Bearing
- Range
- Track
- Ground speed
- Estimated time en route (ETE)
- Cross track error
- Track angle error
- Desired track
- Winds & drift angle

The accuracy of current GPS is within 20 meters horizontally and a bit more vertically. This is sufficient for en route navigation with greater accuracy than required. However, departures and approaches require more stringent accuracy. Integration of the wide area augmentation system (WAAS) improves GPS accuracy to within 7.6 meters and is discussed below. The future of GPS calls for additional accuracy by adding two new transmissions from each satellite. An L2C channel will be for general use in non-safety critical application. An aviation dedicated L5 channel will provide the accuracy required for category I, II, and III landings. It will enable the NEXTGEN NAS plan along with ADS-B.

Wide Area Augmentation System (WAAS)

To increase the accuracy of GPS for aircraft navigation, the wide area augmentation system (WAAS) was developed. It consists of approximately 25 precisely surveyed ground stations that receive GPS signals and ultimately transmit correction information to the aircraft. WAAS ground stations receive GPS signals and forward position errors to two master ground stations. Time and location information is analyzed, and correction instructions are sent to communication satellites in geostationary orbit over the NAS. The satellites broadcast GPS-like signals that WAAS enabled GPS receivers use to correct position information received from GPS satellites. A WAAS enable GPS receiver is required to use the wide area augmentation system. If equipped, an aircraft qualifies to perform precision approaches into thousands of airports without any ground-based approach equipment. Separation minimums are also able to be reduced between aircraft that are WAAS equipped. The WAAS system is known to reduce position errors to 1–3 meters laterally and vertically.

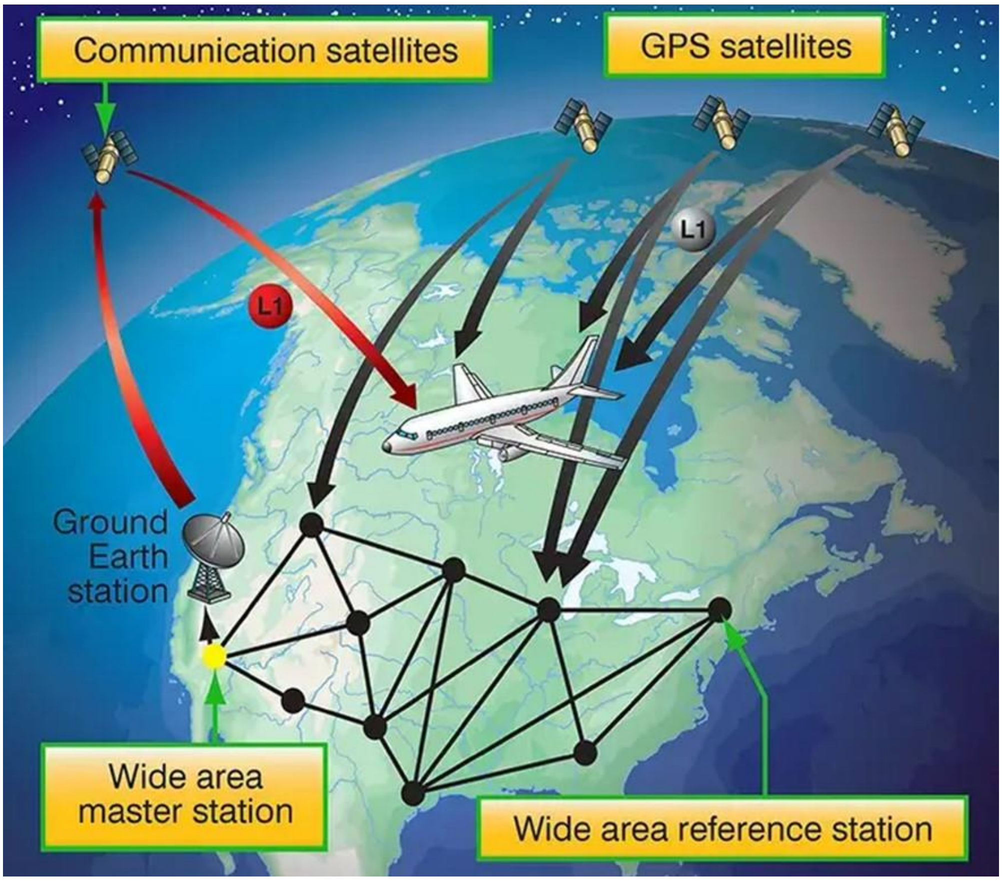


Figure 12: WAAS Schematic for North America

Differential GPS or DGPS

DGPS uses a ground station to correct the code received from the satellites for 5-meter accuracy. DGPS could be used for Precision approaches to any airport. Most people think that once they're on the ground, the flight is over. Believe it or not, many pilots feel this is the most dangerous and stressful part of the route. NASA is now working on a project called the Taxiway Navigation and Situation Awareness System (T-NASA) that will speed up ground operations and aid flight safety in bad weather.

T-NASA blends Global Positioning Satellite (GPS) abilities with virtual reality technology to create displays that help pilots move around the airport quickly and safely. GPS pinpoints the exact location of the aircraft on the ground. Then the GPS information is downlinked to the T-NASA system, which displays it on a real-time moving map and a heads-up-display (HUD) in the cockpit.

The map shows the pilot the aircraft's exact position, a cleared route, and any other traffic on the taxiways. When looking through the HUD, the pilot sees a virtual representation of the airport surface. The image is projected on a piece of glass, but it looks like it's part of the world. The pilot follows virtual cones that are along the edge of the taxiway showing the route that he or she is cleared to follow.

So far, the results with this system are extremely exciting. After a flight test in Atlanta, researchers found that the workload for pilots and controllers goes way down. They also found that the pilots were much more aware of their exact position and the position of other traffic on the surface. All this translates into significant performance benefits and improved safety.

Whether it's seeing through fog or booming 1600 miles an hour, new technologies are giving pilots a clear view of what's ahead.

Figure 13: DGPS T-NASA HUD integrated within aircraft cockpit

GALILEO

The Galileo project began the submission of concepts in 1999 before being officially initiated in 2003. Two experimental satellites (GIOVE-A and B) were launched in 2005 and 2008 to validate the in-orbit segment of the system as well as the ground-based architecture. Two pairs of Galileo-IOV (In-Orbit Validation) satellites, launched in 2011 and 2012, were used to demonstrate the finalized design of the navigation payloads and the operational capabilities of the spacecraft and ground segment. One of the IOV satellites has since failed on orbit. The five-billion Euro project is named after Italian astronomer Galileo Galilei and headquartered in Prague, Czech Republic with operations centers in Germany and Italy. The overall aim of Galileo is to provide navigation services to European nations independent of GPS and GLONASS services which could be disabled for civilian users in the event of war or other extreme situations. Unlike GPS and GLONASS, Galileo will offer its highest possible accuracy to civilian customers.

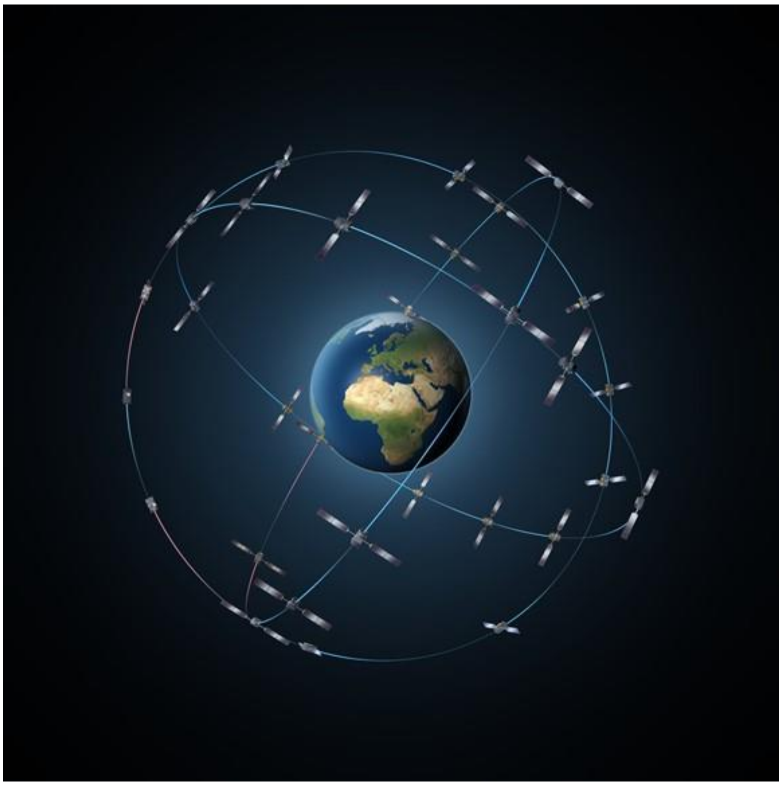


Figure 14: Galileo orbit

The operational Galileo Satellite constellation is very similar to the American GPS, the Russian GLONASS and the Chinese BeiDou navigation systems – all operating by having spacecraft in different orbital planes in Medium Earth Orbit so that any given observer on Earth sees at least three satellites. Galileo uses three orbital planes – spaced 120° with each plane containing nine active satellites plus one spare for a total of 30 satellites being part of the constellation at any given time. The Galileo satellites operate in an orbit of 23,222 Kilometers at an inclination of 56 degrees. This orbit is higher in altitude and inclination than that of GPS, GLONASS and BeiDou which enables Galileo to provide services at higher latitudes with more accuracy.

Figure 15: Galileo Satellite

Galileo provides horizontal and vertical position measurements with sub-meter accuracy. Basic services with a lower precision will be available for free and open to anyone with a receiver compatible with Galileo. Full accuracy services will be available for government and military users, but also to all paying commercial customers. The Galileo constellation also provides global Search and Rescue Function with feedback to the user. The Galileo satellites are built by OHB Systems while the payloads are manufactured by Surrey Satellite Technology Limited, SSTL. Each Galileo FOC satellite weighs 732.8 Kilograms and measures 2.91 by 1.7 by 1.4 meters in dimensions when its solar arrays are stowed – the core satellite body is 2.5 by 1.2 by 1.1m in size. In orbit, with both arrays extended, the satellite has a span of 14.67 meters from tip to tip.

The satellite consists of seven modules including a plug-and-play propulsion module for a simplified production and integration as part of the serial production of Galileo satellites. Power to the satellite is provided by two solar arrays, each consisting of two panels and employing triple-junction Gallium Arsenide solar cells for a total End-of-Life power output of 1,900 Watts. The solar arrays are installed on rotating booms driven by Solar Array Drive Mechanisms to track the sun for optimized power generation. Power is stored in a 3.8 Kilowatt-hour Li-Ion battery and dedicated power conditioning and distribution electronics condition the main 50-Volt power bus that interfaces with all satellite systems. Bus protection and battery management is also provided by the power system electronics.

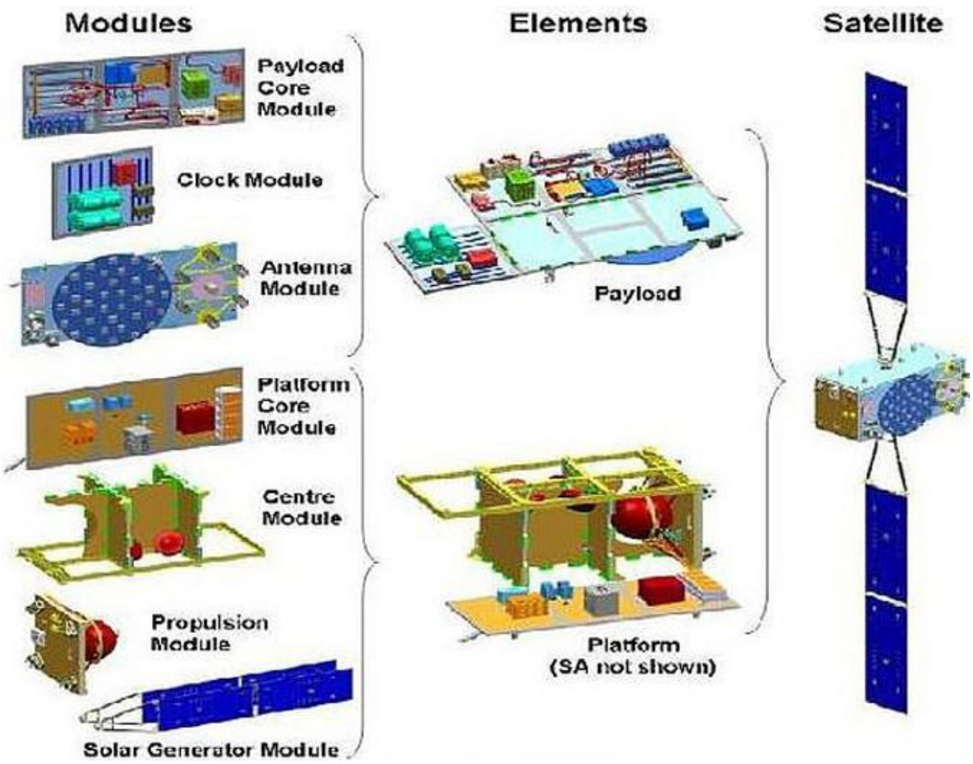


Figure 16: Galileo Satellite Modular Architecture

The satellites use a three-axis stabilization system featuring reaction wheels for attitude control as well as magneto torquers for momentum dumps from the wheels. Navigation data is provided by coarse and fine sun sensors, infrared Earth sensors and a gyro unit that measures body rates. Thermal control uses passive multilayer insulation and heaters to keep all components at acceptable operating temperatures. Heat pipes and external radiators are used to radiate excess heat from the electronics into space. The Galileo satellites are equipped with a Hydrazine monopropellant propulsion system consisting of a central Hydrazine tank and two thruster banks, each containing four 1-Newton thrusters. The propulsion system is used for orbit adjustments and constellation maintenance, attitude control and the maneuver to a disposal orbit at the end of the satellite's mission.

The heart of the Galileo satellites are four clocks – two passive hydrogen maser clocks and two Rubidium clocks. The hydrogen maser clocks are atomic clocks that use the ultra-stable 1.4 GHz transition in hydrogen atoms to achieve a timing accuracy of under 0.45 nanoseconds of drift over a 12-hour period. Rubidium atomic clocks are commonly used in space applications due to their robustness and reliability, but they achieve a lower accuracy of <1.8 nanoseconds over 12 hours. The satellites are configured to run one hydrogen maser clock in primary mode and a Rubidium clock as hot backup. Should the hydrogen maser encounter any problem, an instantaneous switchover to the Rubidium clock would be performed.

In case of a failure of the primary hydrogen maser, the two spare clocks would automatically start up. On ground command, the secondary hydrogen maser could be activated to take over within a period of days as part of a highly redundant system that ensures that the satellites provide continuous timing signals. A Clock Monitoring and Control Unit builds the primary interface of the clocks with the Navigation Signal Generator Unit NSU. It validates that the timing signals from the primary clock and the hot backup are in phase so that the spare can take over instantly should the master clock fail for some reason.

The clocks provide the precise timing solutions needed for the calculation of the time delay from the moment the signal is sent and the arrival at the receiver which in turn allows the calculation of the distance to the satellite. Three simultaneous distance measurements to three different satellites are needed for the receiver to calculate its precise position. Galileo satellites use up to ten different signals in three bands known as L1, E5a & b, and E6 all in the 1,100 to 1,600 MHz range. This variety of signals is needed to provide the different Galileo services: open (OS), safety-of-life (SOL), commercial (CS) and public regulated services (PRS).

Signals sent by the satellites include pilot signals which are data-free signals that only include a ranging code, not modulated by a navigation data stream. The ranging code is a Pseudo-Random Noise (PRN) sequence of 0s and 1s that allow the receiver to determine the signal's travel time. Data signals include binary-coded messages containing information on the satellite ephemeris (position and velocity), clock bias parameters for error correction, satellite health status and other complementary information.

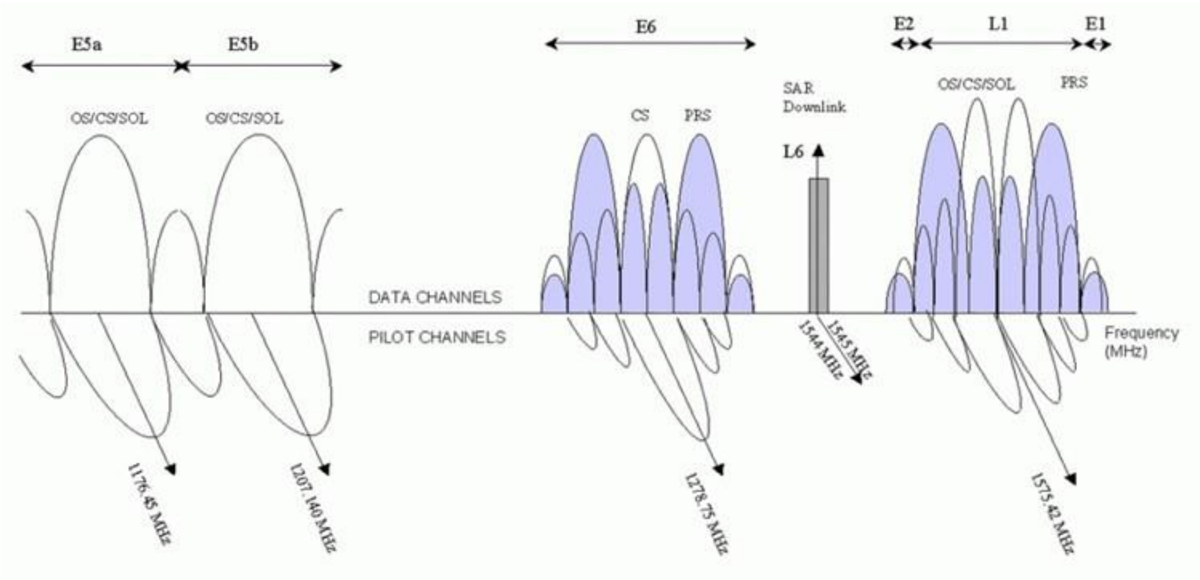


Figure 17: Galileo Satellite Signals

Open Services are provided via the L1 and E5 bands – single, dual and triple-frequency applications are possible depending on the purpose of the navigation measurement. The L1 channel at a carrier frequency of 1,575.420 MHz includes a pilot signal (L1c) and a data signal (L1b) both used for open and commercial services and the safety of life services. The L1a channel is used for public regulated services. The L1 channel operates at the same frequency as the GPS L1 band.

To avoid interference, Galileo uses BOC (1,1) signal modulation – Binary Offset Carrier of rate (1,1). Having both L1 carriers at the same frequency will make future use of the combined Galileo and GPS signals less complex. The open L1 signals use a code frequency of 1.023 MHz and a primary PRN code length of 4092. The pilot channel operates at 250 symbols per second and the data channel transmits a secondary PRN code with a length of 25. The L1a band uses a different type of BOC modulation known as (15,2.5) at a sub-carrier frequency of 15.345 MHz and a code frequency of 2.5575 MHz. The signal is encrypted to avoid unauthorized access.

The E5a band at 1,176.45 MHz is divided into the E5a-I and E5a-Q signals for data and pilot signals. E5b is also divided into E5b-I and E5b-Q, using a carrier frequency of 1,207.14 MHz. The E5 band uses AltBOC (15,10) modulation, a sub-carrier frequency of 15.345 MHz and a code frequency of 10.23 MHz. The primary PRN code length is 10,230 and the data rates used are 50 symbols per second for E5a and 250sps for the E5b data channel with secondary code lengths of 20 and 4. The two pilot channels use code lengths of 100.

Having different code lengths allows receivers to be optimized for their purpose and also allows single, dual and triple-signal operation which increases the accuracy of the navigation solutions. An issue for navigation measurements is the ionospheric delay that is introduced as the radio signals travel through the ionosphere. To account for that delay, single-signal receivers use models based on static data that can increase accuracy by a factor of two, but not eliminate the error entirely. Dual-channel mode allows the receiver to precisely calculate the ionospheric delay and subtract it to provide more precise data as the ionospheric delay is depending on the frequency of the signal. Triple-signal mode can yield even more precise data as larger frequency differences lead to more accurate ionospheric delay estimates.

The E6 band containing three signals is used for commercial and public regulated services. E6b (pilot) and E6c (data) are used for commercial services using a frequency of 1,278.75 MHz. These signals use a primary PRN code length of 5115, the pilot channel operates at 1000sps and the data channel transmits a secondary PRN code with a length of 100. The two channels use BPSk modulation. E6a utilizes BOC (10,5) modulation and a sub-carrier frequency of 10.23 MHz. The Search and Rescue transponder of the Galileo satellite is capable of receiving distress signals from portable UHF transmitters operating at 406 MHz.

Up to 150 active beacons can be received by one satellite simultaneously. The distress message is then modulated onto the L6 signal at 1,544 MHz and transmitted to dedicated ground stations with a latency of less than ten minutes. The position of the distress beacon is calculated with an accuracy of at least five Kilometers and can reach an accuracy of a few meters if the terminal is equipped with a Galileo receiver. Unique to Galileo is that the satellites provide feedback to the distress beacons acknowledging the reception of the signal.

The Galileo satellites use S- and C-Band for housekeeping communications. Two S-Band antennas are installed on the satellite for the transmission of telemetry data to ground stations and the uplink of commands for satellite operations. The S-Band terminal also receives and transmits ranging signals that provide precise orbit determination. C-Band is used to uplink mission data from Galileo uplink stations including clock bias data and integrity data about how well each satellite is functioning. These messages are relayed via the data signals in the navigation bands to allow receivers to correct for known errors.

Galileo vs. GPS and Other Positioning Constellations

Since Galileo works with GPS, navigation is improved as there are always satellites “in view,” providing more accurate and reliable positioning for the receiving device, particularly for dual-frequency service. Even though it just started full commercial service, Galileo accounts for most of the satellites broadcasting in the E1/E5a frequency band, providing a significant contribution to the dual-frequency (high-precision) service landscape. This contribution is also particularly important for navigation in cities, where satellite signals can often be blocked or echoed (multipath) by buildings. With satellites' time references based on rubidium and passive hydrogen masers, Galileo delivers better timing with 30-nanosecond accuracy, enabling more resilient synchronization for time-critical events, including aviation, telecommunications, financial transactions, and power distribution networks. Galileo's Search and Rescue service cuts the time to detect emergency distress signals to around 10 minutes compared to 3 hours for other constellations. With the distress beacon position also determined more accurately, distress events, such as those at sea or in the mountains, can be located and receive help faster and more reliably.

With 26 satellites in orbit (including reserves) and over 1.5 billion devices worldwide enjoying the benefits of high-precision navigation, Galileo is already slated for upgrades with a new generation of satellites and terrestrial infrastructure to ensure quality service for decades to come. Following the decision to accelerate the development of "Galileo Next Generation," ESA asked European manufacturers in 2020 to start submitting bids for the first set of the second generation (G2) Galileo satellites. They are expected to be placed in orbit around 2024. The next generation is being specified to be ultra-flexible with more software-defined and fewer dedicated hardware features.

Use Cases of Galileo for the Internet of Things

Galileo is designed with a tiered business model to better support traditional positioning and navigation applications and foster innovation. Additionally, Galileo signals — L1, E5A and E5B — are compatible with the existing L1 GPS signal and the new L5 signal.

Services are sectioned into five groups:

1. Open Service (OS)

   As the name suggests, OS is free for use in the general IoT and consumer markets. It includes timing and positioning with about a meter precision and similar civil access codes as used by GPS and GLONASS.

2. Safety of Life (SoL)

   SoL service is part of OS, available free of charge and not encrypted. Applications developed for it can leverage an integrity monitoring feature that warns of signal disruption problems. An application use case could be, for example, a tracker on cold-chain containers with COVID-19 vaccines, relying on minimal signal integrity for a given degree of accuracy. If something goes wrong with the satellite signals, the Galileo receiver notifies the application for an alarm or other appropriate action by the device and provider.

3. Public Regulated Service (PRS)

   PRS is higher precision and encrypted for use primarily by public safety and civil authorities. Applications and devices developed for this service require the provider to secure permission for use and even testing since decryption is required for navigation, positioning or timing data to be accessed via the receiver.

4. Search and Rescue (SAR)

   SAR is a space-based service in which terrestrial devices can transmit an emergency beacon skyward. It is then picked up by any of the satellites in view, relayed and backhauled to Galileo monitoring centers and routed for action according to the application and provider. SAR is an improved solution from other constellations in terms of the latency between when the distress beacon is activated and when the application operations center receives the alert message.

5. Commercial Authentication Service (CAS)

   CAS is encrypted and has high accuracy to the centimeter level with a service guarantee SLA compared to the OS's best effort. Device operators and providers utilizing this level of service must pay usage and subscription fees. This service category is unique to Galileo, which was created first for commercial and civilian use. Others like GPS were primarily military endeavors with commercial and consumer use delivered as an afterthought.

GLONASS

GLONASS was developed by the Soviet Union as an experimental military communications system during the 1970s. When the Cold War ended, the Soviet Union recognized that GLONASS had commercial applications, through the system's ability to transmit weather broadcasts, communications, navigation, and reconnaissance data. The first GLONASS satellite was launched in 1982 and the system was declared fully operational in 1993. After a period where GLONASS performance declined, Russia committed to bringing the system up to the required minimum of 18 active satellites. Currently, GLONASS has a full deployment of 24 satellites in the constellation.

The GLONASS constellation provides visibility to a variable number of satellites, depending on your location. A minimum of four satellites in view allows a GLONASS receiver to compute its position in three dimensions and to synchronize with system time.

The GLONASS space segment consists of 24 satellites, in three orbital planes, with eight satellites per plane. The GLONASS constellation geometry repeats about once every eight days. The orbit period of each satellite is approximately 8/17 of a sidereal day so that, after eight sidereal days, the GLONASS satellites have completed exactly 17 orbital revolutions.

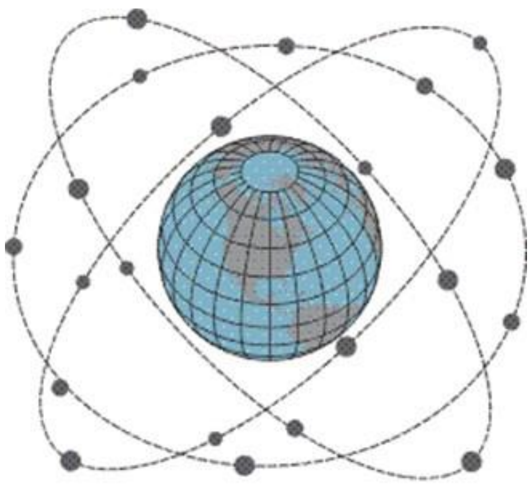


Figure 18: GLONASS Satellite Orbit

Each orbital plane contains eight equally spaced satellites. One of the satellites will be at the same spot in the sky at the same sidereal time each day. The satellites are placed into nominally circular orbits with target inclinations of 64.8 degrees and an orbital radius of 19,140 km, about 1,060 km lower than GPS satellites.

The GLONASS satellite signal identifies the satellite and includes:

- Positioning, velocity and acceleration information for computing satellite locations.
- Satellite health information.
- Offset of GLONASS time from UTC (SU) [Coordinated Universal Time Russia].
- Almanac of all other GLONASS satellites.

The GLONASS system uses 24 satellites to achieve global positioning services, which provides high-precision three-dimensional (3D) space and velocity information, as well as timely service. In contrast to GPS frameworks, the GLONASS framework utilizes a frequency-division multiple access strategy. Each GLONASS satellite broadcasts L1-frequencies ($L1 = 1602 + 0.5625 * k$ (MHz), with $k = 1 \sim 24$) and L2-frequencies ($L2 = 1246 + 0.4375 * k$ (MHz)) signals.

Between 1982 and 1985, three simulated stars and 18 prototype satellites were launched for testing. The life of these test satellites by the Soviet Union was only 1 year, and the true average on-orbit life is only 14 months. The construction of the GLONASS system began in 1985, and till 1986, six real GLONASS satellites were launched. These satellites improved the timing and frequency standards of the prototype satellites and enhanced the frequency stability. Their life span is still poor, with an average life span of about 16 months. Since then, 12 satellites that were continually improved had been launched, but half of the satellites were lost due to launch accidents. These new satellites had a designed life of 2 years and an actual average life of 22 months.

Thus, in 1987, the GLONASS system launched a total of 30 satellites, including early prototype satellites. Nine satellites were available in orbit, and the prospects were bright. The satellite launched in 1988 was a further improved version, which was commonly known as the GLONASS satellite. These satellites weigh 1400 kg and use triaxial stabilization technology and precision cesium atomic clocks, and their design life had been further increased to 3 years. Between 1988 and 2000, this version of the GLONASS satellite launched as many as 54 satellites. These satellites were launched into orbit using a proton rocket from the Baikonur launch center.

Figure 19: GLONASS-K Satellite

All three of the first-generation GLONASS (also known as Uragan) satellites were axial stationary vehicles that typically weighed 1250 kg and had a modest propulsion system for transfer within the satellite group. Over time, they were upgraded into block IIAs, IIBs, and IIV vehicles, each of which was undergoing evolutionary improvement. The development of GLONASS-M began in 1990 and was launched for the first time in 2003. The life span of these satellites was quite 7 years, and they weighed a little over 1480 kg. Their diameters were approximately 2.4 m and height 3.7 m. The GLONASS-K is much better than its previous generation. It is the first no pressurized GLONASS satellite, with a much smaller mass (just 750 kg compared to the GLONASS-M with a mass of 1450 kg). Its operating life span is 10 years, which is more than the 7-year life span of the second-generation GLONASS-M.

Figure 20: GLONASS Satellite Family

The GLONASS control segment consists of the system control center and a network of command tracking stations across Russia. The GLONASS control segment, like that of GPS, monitors the satellites health, determines the ephemeris corrections, as well as the satellite clock offsets with respect to GLONASS time and UTC (Coordinated Universal Time). Twice a day, it uploads corrections to the satellites.

Each GLONASS satellite transmits on a slightly different L1 and L2 frequency, with the P-code (HP code) on both L1 and L2, and the C/A code (SP code), on L1 (all satellites) and L2 (most satellites). GLONASS satellites transmit the same code at different frequencies, a technique known as FDMA, for frequency division multiple access. Note that this is a different technique from that used by GPS. GLONASS signals have the same polarization (orientation of the electromagnetic waves) as GPS signals, and have comparable signal strength.

The satellites can share the frequencies by having antipodal satellites transmitting on the same frequency. Antipodal satellites are in the same orbital plane but are separated by 180 degrees. The paired satellites can transmit on the same frequency because they will never appear at the same time in view of a receiver on the Earth's surface.

Figure 21: GLONASS Antipodal Satellites

As the current GLONASS-M satellites reach the end of their service life, they will be replaced with next generation GLONASS-K satellites. The new satellites will provide the GLONASS system with new GNSS signals. The first block of GLONASS-K satellites (GLONASS-K1) broadcasts the new civil signal, designated L3, centered at 1202.025 MHz. Unlike the existing GLONASS signals, L3 is based on CDMA which will ease interoperability with GPS and Galileo. The first GLONASS-K1 satellite was launched in February 2011.

The second block of GLONASS-K satellites (GLONASS-K2) adds two more CDMA based signals broadcast at the L1 and L2 frequencies. The exiting FDMA L1 and L2 signals will continue to be broadcast as well to support legacy receivers. GLONASS-K2 satellites are planned to be launched starting in 2023. The third block of GLONASS-K satellites (GLONASS-KM) will add an L5 signal to the GLONASS system and is currently planned by 2030.

<u>BeiDou</u>

China's BeiDou experienced three phases of construction, with the third phase fully deployed in July 2020.

- BeiDou started as the now-decommissioned BeiDou-1, with only three satellites, in 2000.
- The second phase, also known as COMPASS, became operational in 2012 with only 16 satellites covering Asian-Pacific regions. Unlike GPS, which started working after being fully set, BeiDou's staged strategy made early commercial use of the system accessible. Besides, experience gained in the second phase led scientists to make a better design for BeiDou-3.
- The third step of BeiDou was launched in 2015 with complete global coverage, using 35 satellites.

The project started providing global navigation services in 2018. The last satellite launched in 2020 was the latest in the series of 30 BDS-3 satellites. Compared with previous generations of the BeiDou, satellites have been providing increased bandwidth and accuracy. The system upgraded its performance after completing its third phase, reaching accuracy at 1 m for public use and 1 cm for encrypted military use.

The system is a two-way communication system, allowing it to identify the locations of receivers. BeiDou-compatible devices can transmit data back to the satellites, even in text messages of up to 1,200 Chinese characters. By completing BeiDou, China now has its navigation system, which will compete with GPS developed by other countries. Out of these navigation systems, the GPS is the most widely used for both personal navigation and for more sensitive military purposes. Significantly, as ties between the U.S. and China deteriorate, it becomes more important for China to have its own navigation system that the U.S. does not control.

China completed its satellite navigation system named BeiDou, one of four global satellite navigation networks alongside the US GPS, Russia's GLONASS, and Galileo's E.U., Indian Constellation (NavIC), in 2020. China's domestically developed BeiDou Navigation Satellite System is now offering worldwide coverage, allowing global users to access its high-accuracy positioning, navigation, and timing services.

China's BeiDou experienced three phases of construction, with the third phase fully deployed in July 2020. BeiDou started as the now-decommissioned BeiDou-1, with only three satellites, in 2000. The second phase, also known as COMPASS, became operational in 2012 with only 16 satellites covering Asian-Pacific regions. Unlike GPS, which started working after being fully set, BeiDou's staged strategy made early commercial use of the system accessible. Besides, experience gained in the second phase led scientists to make a better design for BeiDou-3. The third step of BeiDou was launched in 2015 with complete global coverage, using 35 satellites.

The BeiDou Space Segment will consist of a constellation of 35 satellites, which include 5 geostationary orbit (GEO) satellites and 30 non-GSO satellites; 27 in Medium Earth Orbit (MEO) and 3 in Inclined Geosynchronous Orbit (IGSO), with a worldwide coverage. As of December 2011, the Initial Operation Service was officially declared providing initial passive positioning navigation and timing services for China service area.

The nominal constellation includes 35 satellites, 5 GEOs, 3 IGSOs and 27 MEOs. The number of IGSO orbits is 3, with one IGSO per plane. The intersection node is 118E. The MEOs are deployed as a Walker constellation; 24 MEOs in 3 planes plus 3 spares. The orbital parameters of the final constellation are shown in the following figure.

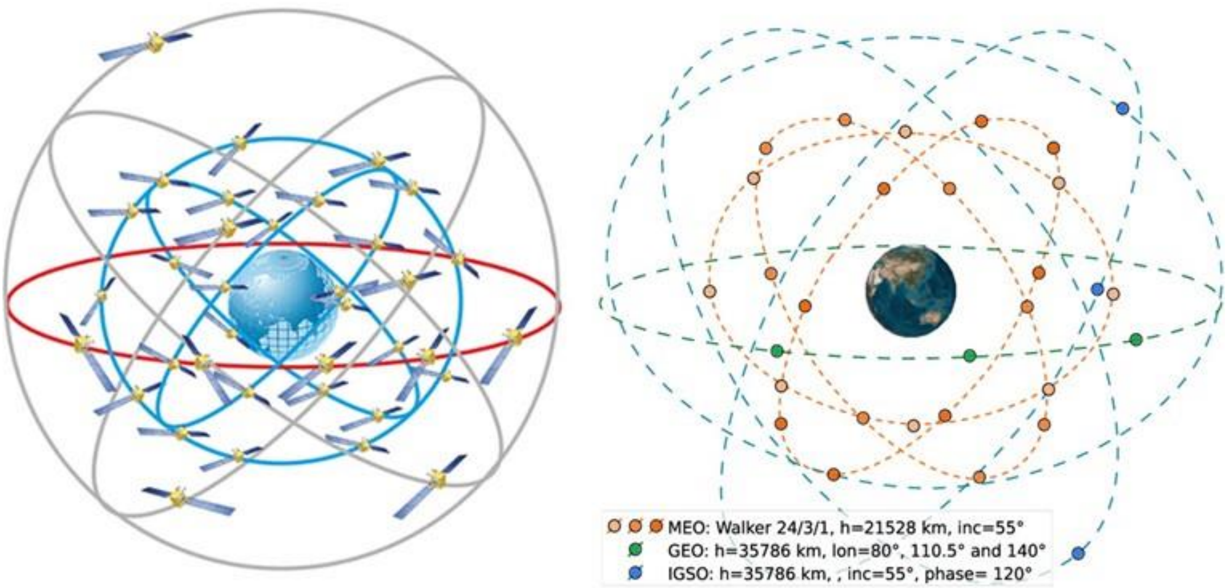


Figure 22: BeiDou Satellite Orbits

Even if it is difficult to provide a single description of the wide BeiDou satellite family, since there are different designed spacecrafts for different orbital assets, as follows there is a brief introduction of the main feature of the MEO family.

The 27 Beidou-3M satellites deployed to a 22,000-Kilometer Medium Earth Orbit inclined 55° are using a newly developed Navigation Satellite Bus that is more compact than the large DFH-3 satellite bus but still uses a number of heritage components to match DFH-3 capabilities & reduce risk. The three-axis stabilized satellites have a launch mass of 1,014 Kilograms including 280 Kilograms for the navigation payload, measuring 2.25 by 1.0 by 1.22 meters in size.

Two power-generating solar arrays deliver 1,500 Watts of electrical power for the satellite systems and navigation payload. The satellites only use the RNSS communications payload. The MEO segment operates in a 55-degree orbit with three planes that each host nine satellites to guarantee global coverage.

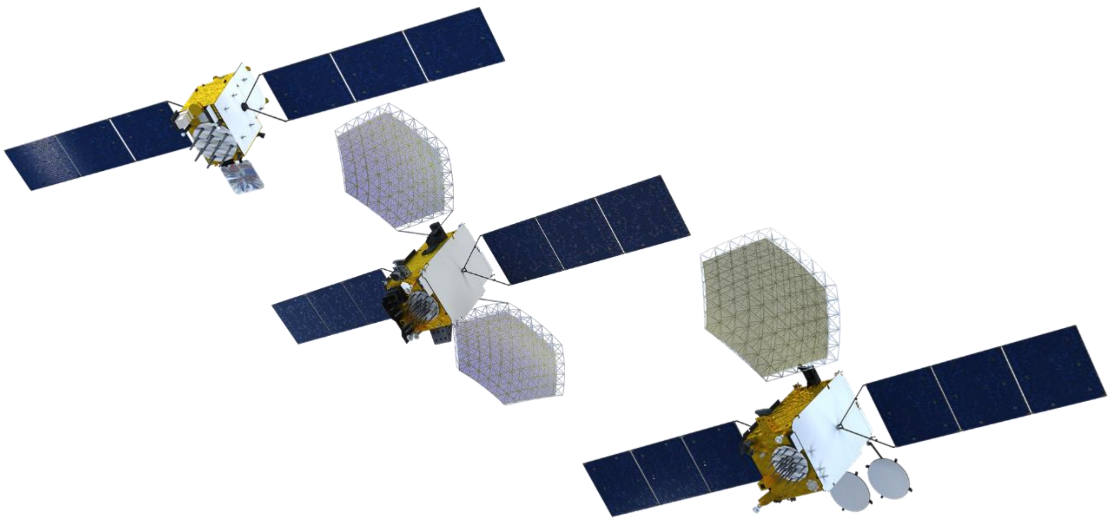


Figure 23: BeiDou Satellites Family (Left MEO, Center GEO and Right IGSO)

The Beidou-3M satellites can be launched as single spacecraft atop the Long March 3C rocket with YZ-1 upper stage, as pairs on CZ-3B/YZ-1 or four at a time on Long March 5 plus appropriate upper stage.

BeiDou military and commercial implications

BeiDou has become a vital part of President Xi Jinping's strategy to develop a smarter military. Notably, the Chinese armed forces are now less reliant on GPS. BeiDou satellites, in the event of a conflict, will enable China to identify, track and strike enemy ships, increasing their tracking ability by 100 to 1,000 times. China can deploy precision-guided munitions in large quantities to strike accurately. Accordingly, the success rate of attacks by the PLA's navy and air force will be significantly increased. Security experts believe that BeiDou could pose a security risk by allowing China's government to track users with malware transmitted through either its navigation signal or messaging function (via a satellite communication channel), once the technology is in widespread use.

Via the short messaging service chinese fishing vessels can send instant alarms to fishing departments when emergencies arise, while a vessel management system allows them to request assistance from nearby vessels. All the features mentioned above are particularly relevant to the ongoing disputes in the South China Sea and Beijing's plan to regain Taiwan by force.

Based on the American forecast, GNSS use will grow 7 percent annually on average through 2023, with 3.6 billion GNSS devices in use worldwide. The total output of China's navigation service sector exceeded 25 billion dollars in 2015. It is expected that BeiDou will generate 298 billion dollars by 2020.

In 2012 the United States led with 31 percent of the total downstream GNSS industry, followed by Japan with 26 percent, Europe with 25.8 percent, and China with 7 percent. BDS's penetration rate in China is still very low: 95 percent of the domestic market is dominated by GPS. However, this situation will change once BeiDou offers global coverage.

China aims to reach 60 percent of the domestic GNSS market to become globally competitive by 2020. Chinese press reports tout a variety of uses for BDS, including public security, transportation, fishing, energy, forestry, disaster reduction, smart cities, social governance and more. Numerous pilot projects have already been tested. A new BeiDou -related supply chain of more than 14,000 enterprises and 45,000 employees is emerging.

In conclusions the rise of the BeiDou system is not simply positioning service in competition with the U.S, but also a strategic challenge for the U.S. "Selective availability" technology which introduced intentional error into non-military GPS receivers to retain the best accuracy for military use is not a cause of superiority for the U.S since the existence of the other GPSs especially BeiDou. Along with 5G, the system is called by Beijing "The Two Pillars of a Great Power."

	Number of satellites	Positioning accuracy	Military controlled (civil and military use)	Time frame of the project	Coverage
GPS	31	Civil: 1-2.2 meters. Military: 0.1-0.2 meters (with the use of augmentation systems: within centimeters)	Yes	Initiated in 1978, global coverage since 1995	Global
Galileo	21 (6 satellites are to be added)	Civil:1 meter (public) 1 cm (encrypted)	No (designed only for civil use)	Initiated in 2005, global coverage since 2016 (still in pilot phase)	Global
GLONASS	24	Civil: 2.8 meters Military:1.2 meters	Yes	Initiated in 1982, global coverage since 1996 with breaks	Global
BDS	39 (including 24 BDS-3 satellites)	Civil: 2-3.6 meters in China, 10 meters in other regions. In China BDS-3 has achieved a positioning accuracy of 2-5 cm. Military: 0.4 meters	Yes	Initiated in 1994. Since 2012 coverage in China, Asia and the Middle East. Starting from 2020, global coverage	Global

Table 1: GNSSs comparison table

1.4 Manned Aviation Navigation Regulation in Mexico

Aviation in Mexico is regulated by the Secretariat of Communication and Transportation (SCT), as part of the Federal executive branch. In this optic the SCT is the administrative body the can issue rules and regulations in the field of both private and public aviation in Mexico. The Federal Civil Aviation Agency or *Agencia Federal de Aviaciòn Civil* (AFAC) advises the SCT in all matters pertaining to the Air Transportation, as also for airports and complementary services, their facilities and equipment, as well as with the respect of the issuance of air operator certificates. concessions, permits, and authorizations concerning the provision of regular, non-regular and private air transportation services.

Civil aviation in Mexico is regulated by the Civil Aviation Law and its regulations, which rule the exploitation and use of the Mexican air space with the respect to the provision and development of State and civil air transportation services. Since the Mexican airspace is considered a general means of communication, it is also subject to the General Means of Communication Law of National Property. From a procedural standpoint, the Federal Law of Administrative Proceedings, the Code of Commerce, the Federal Civil Code and the Federal Proceedings Code are also applicable to air navigation matters.

Mexico is also a party to the 1999 Montreal Convention for the Unification of Certain Rules for International Carriage by Air.

The U.S. Federal Aviation Administration (FAA) announced May 25, 2021, that it had downgraded Mexico from Category 1 to Category 2 after finding that it didn't meet standards set by the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations. "The FAA identified several areas of noncompliance with minimum ICAO safety standards," the aviation authority said in a statement at the time. The downgrade prevented Mexican airlines from adding new flights to the United States. The National Air Traffic Controllers Union subsequently acknowledged that its members lack training.

1.5 Space Environmental Effects on Manned Aviation Navigation

The impact of Space Weather on Aviation. The Space weather phenomena refers to natural perturbations coming from the sun or from space that can influence the performance and reliability of space-borne, ground-based or airborne systems and can endanger human life or health.

According to various sources (Skybray and others) the solar activity is not constant and, from time to time, eruptions appear on the sun's surface which result in an abnormal level of radiation and of particle ejection. The radiation and particles are thrown into space and, if directed towards the earth, will arrive after a certain interval. Three different space weather events which effect the earth are:

- CME's (Coronal Mass Ejections)
- SEP's (Solar Energetic Particles)
- Solar Flares.

These vary in times to reach the earth from as little as 8 minutes with solar flares travelling at the speed of light up to a day with CME's.

The occurrence and severity of these eruptions follows an 11-year period are quite low (but unfortunately not equal to zero), followed by a higher solar activity period called the solar maximum. This cycle can be characterized using the sunspot number (SSN), which is the arithmetic sum of the visible dark spots on the solar surface. The disruption caused on Earth is a result of these highly charged particles from the sun interacting with the upper atmosphere and disrupting the magnetic field of the earth.

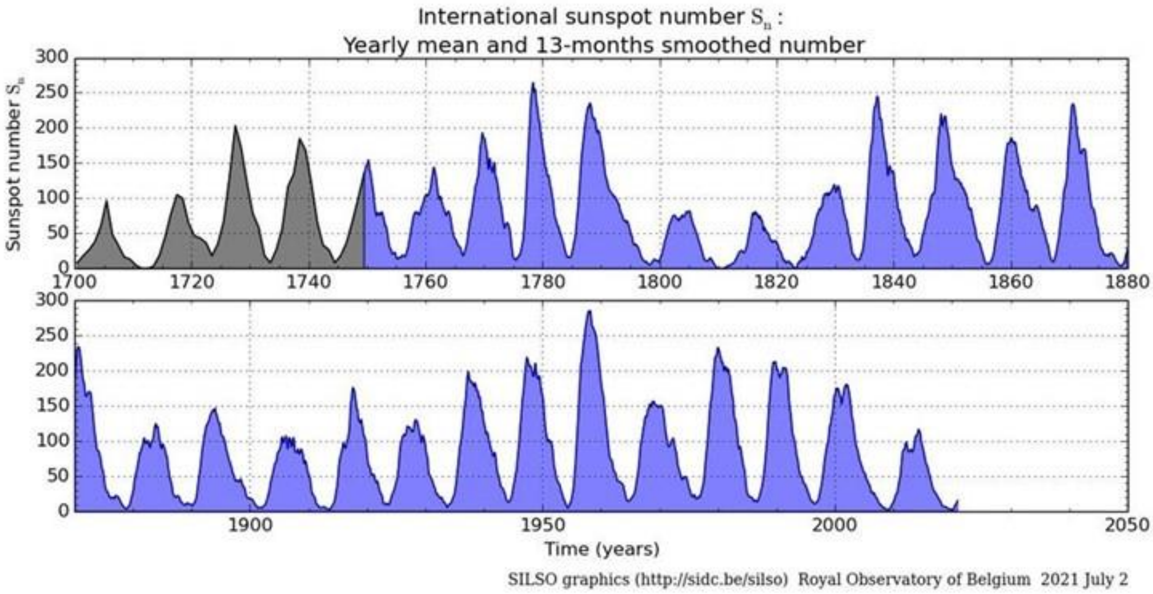


Figure 24: Monthly sunspots number evolution

The above Figure shows solar activity as indicated by the monthly SSN and highlights that some of the solar cycles have a higher peak than others. However, the intensity of the solar cycle is not directly linked to the severity of eruptions. Once the period of minimum solar activity of the previous solar cycle has been reached, prediction of the next solar cycle becomes reliable.

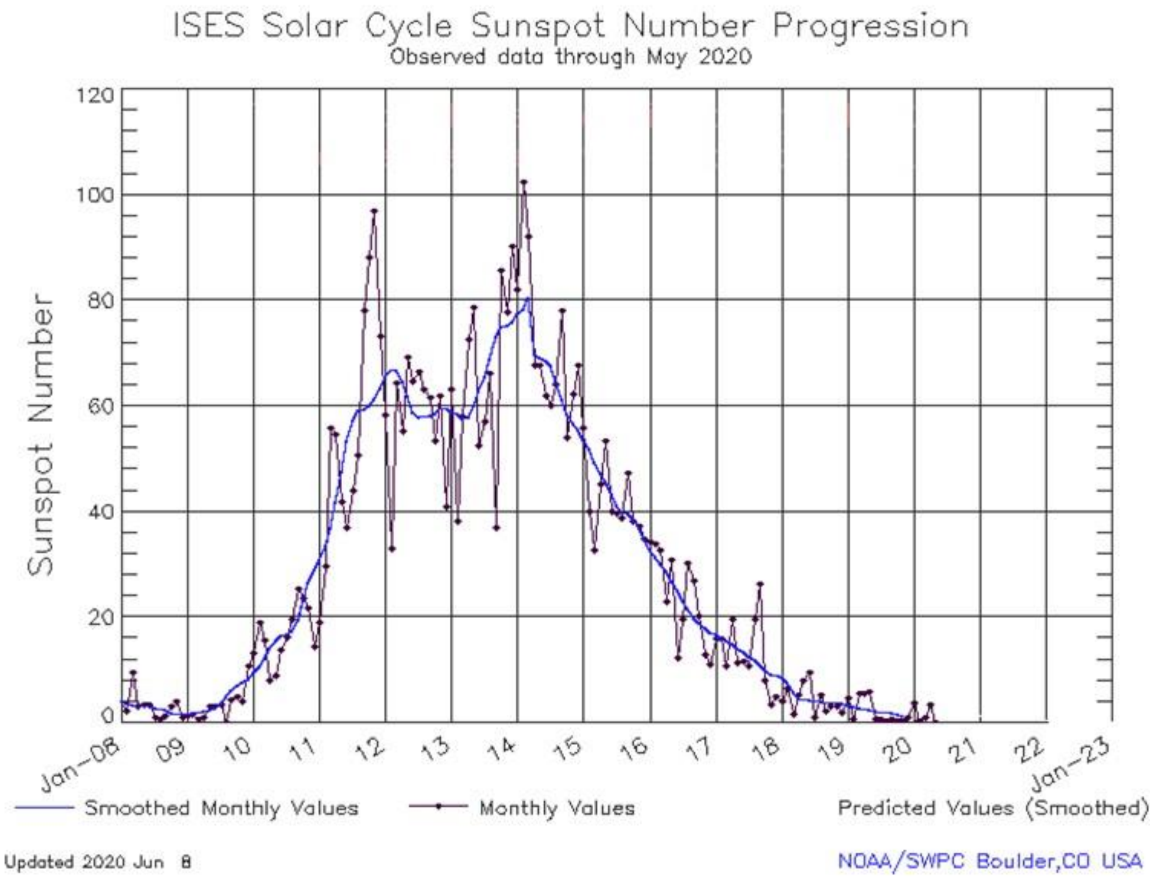


Figure 25: Solar cycle sunspot number progression from ISES

The above Figure shows the latest prediction of the current solar cycle, known as solar cycle 24. The intensity of this solar cycle was relatively modest, and the peak of maximum solar activity was observed in early 2014. As the solar eruptions are most likely to appear during the period of maximum solar activity but also during the decreasing phase, the occurrence and severity of solar eruptions was highest in the period from 2011 to 2017.

When a space weather event occurs, a wide range of effects can result. The main impacts on aviation are listed below.

- **Degradation of radio/satellite communication**: During solar events, some disturbance may happen on HF and satellite communications, which would have side effects on CPDLC, ADS-C, AOC…. In any case, line of sight VHF communication are not fully impacted.

- **Onboard system failure due to radiation**: During a radiation storm, when striking a sensitive node, radiation may induce shortcuts, change of state, or burnout in onboard electronic devices. This phenomenon is called the "single event effect". Its impact may vary a lot from unnoticeable to a complete failure of the system. This kind of failure may become more frequent in the future because modern electronic equipment is more vulnerable to radiation due to the smaller size of their devices, let alone the possibility to have fully electrical propulsion aircrafts is near term future.

- **Radiation doses**: During radiation storms, unusually high levels of ionizing radiation may lead to an excessive radiation dose for air travelers and crew. The dose received by passengers and crew is higher at higher altitudes and latitudes. Cosmic ray doses on flight crew is an ongoing project, with civil aircrew flying above 15 km of altitude (not so likely in reality) requiring cosmic ray detection equipment to be worn.

- **GNSS based aviation operation**: High-energy particles ejected by the sun may cause strong disturbances in the upper layers of the atmosphere, mainly in the layer called the Ionosphere. This layer is composed of charged particles and is particularly sensitive to the particles ejected by the sun. The GNSS radio signals emitted by satellites travel through this layer and, under severe disturbance, could be strongly affected. As a result, unexpected position and timing errors can occur at the level of the user receiver. In extreme cases, the GNSS receiver can lose reception of the satellite altogether and the position can no longer be computed. As a side effect, GNSS-based surveillance applications may be unavailable. SBAS or GBAS augmented services, used for approach and landing, are more demanding in terms of accuracy and integrity than the En-Route/TMA GNSS-based navigation. Therefore, the safety monitors of those systems are also more sensitive to space weather events and the unavailability of these services would be more frequent. More operators of commercial air transport are introducing RNAV GNSS type approaches. With the retirement of several ground based navigation aids there is a greater chance of conducting a GNSS approach with no ground based navigation aids as backup and therefore an accurate assessment of the risk from a space weather event should be completed before flight and very accurate monitoring of the system on an approach is required with a contingency procedure decided in the event of a loss of GPS data to continue the approach.

- **Magnetic based equipment and compasses**: Due to a change in the earth's magnetic field caused by the magnetic fields of the charged particles from the sun, any magnetic based equipment are not accurate for the duration of the solar event.

- **Aircraft electrical systems**: Solar electrical coupling mechanisms, in particular the consequences of vertical conduction-current through clouds, have been observed to charge cloud droplets at the upper and lower boundaries of layer (Stratiform) clouds. This charging may only have influences on the microphysical processes in clouds, indirectly causing variability on the macroscopic level, and it is unsure whether or not the charging is significant enough to affect aircraft (helicopter and/or fixed wing) electrical and/or communication systems.

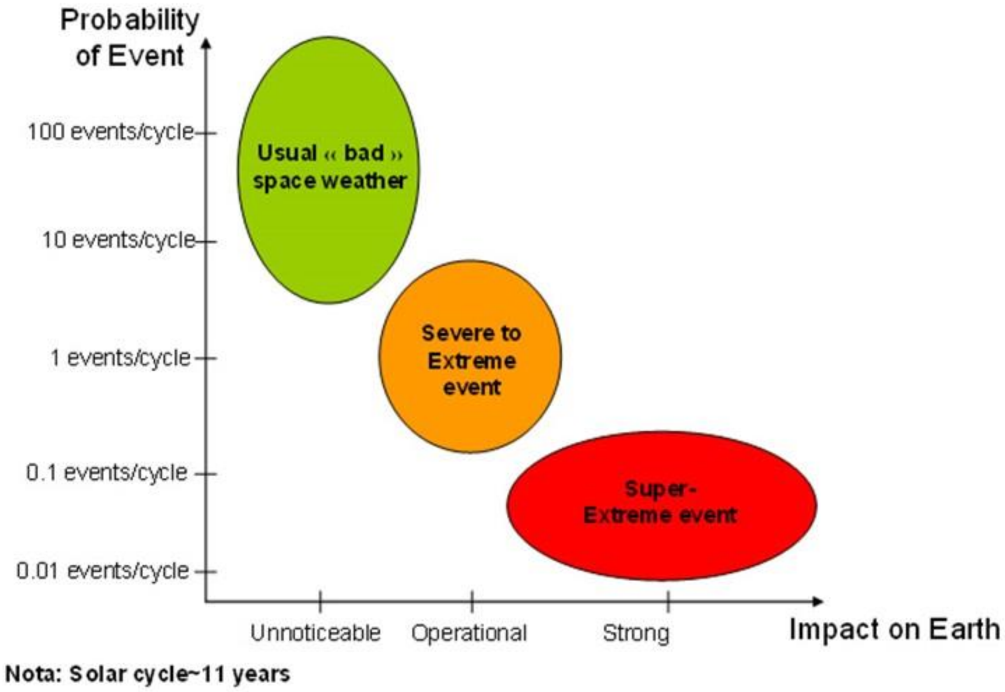


Figure 26: Probability of space weather events versus impact on Earth (source Skybrary)

The above figure introduces the probability of occurrence depending on the magnitude of the event. Events have been separated into three different categories:

- *Usual bad space weather*: these events are quite common (several times a year) during the period of high solar activity, but the impact on earth infrastructures is very low, if noticeable at all.
- *Severe to Extreme event*: these events occur between one and five times per 11-year solar cycle. The impact may be significant on infrastructure.
- *Super-Extreme event*: these events are very rare and may happen only once every 100 to 500 years. One such event was recorded in 1859.

As follows the possible impact of a *severe to extreme space weather* event:

- **Communication**: HF and, potentially, satellite communication may be degraded or temporally lost. As an example, on 7 September 2005, solar activity severely impacted all HF communications over the US. However, line of sight VHF was not significantly impacted.

- **Satellite failure**: Potential loss of one or more satellites. Depending on which satellites are lost, the impact may vary significantly. As an example, the March 1989 space weather event may have caused the loss of four US Navy satellites.

- **GNSS-based navigation**: En-route GNSS-based navigation might be lost in a contained area for a limited duration. GNSS-based landing systems (SBAS, GBAS) may be unavailable for tens of hours. As an example, in October 2003 the US SBAS system (named WAAS) was unavailable for 9 and 15 hours.

- **Surveillance**: As a side-effect, GNSS-based surveillance applications may be degraded.

- **Power failure**: Potential power failure over part of a country for tens of hours. As an example, at 2.45 a.m. on 13 March 1989 the entire Quebec power grid collapsed, and 6 million people suffered a power black-out for 9 hours.

- **Increase in the radiation level**: Passenger and crew flying at high altitude and latitude may be exposed to a higher radiation level than usual. This increased level of radiation might also lead to onboard system failure. Actual impact is difficult to assess.

As follows possible impact of a *super-extreme space weather* event:

- **Communication**: HF and, potentially, satellite communication could be temporally lost. However, line of sight VHF may not be impacted.

- **Satellite failure**: From experts' assessment, up to 50% of the space vehicles may be lost. Depending on which space vehicles are lost, impact can vary significantly.

- **GNSS-based navigation**: Space vehicle failure combined with ionosphere storms may lead to a partial or complete loss of GNSS services.

- **Surveillance**: As a side-effect, GNSS-based surveillance applications may be unavailable.

- **Power failure**: Simulations on the US power grid estimated that 50% of the US may be under a power black-out. Similar results may happen over Europe.

The recovery time may vary between dozens of hours to months, depending on the system failure.

- **Increase in the radiation level**: Passenger and crew flying at high altitude and latitude may be exposed to a higher than usual radiation level. This increased level of radiation may also lead to onboard system failure. Actual impact is difficult to assess.

Even if it is impossible to prevent and stop the solar activities effects (and even forecasting them is very difficult) as follows there are some solution in order to mitigate the most disruptive effects of space weather issues:

- **Satellite failure and GNSS-based applications**: A back-up to satellite communication and navigation should remain available. Depending on the flight phase, area and aircraft equipment, this back-up could be HF/VHF/SATCOM voice communication, ground based navigation, radar vectoring, inertial navigation, etc.

- **Power failure**: Air traffic control centers have alternate power generation in case of power failure to ensure the safety of air navigation.

- **Increase in the radiation level**: As the radiation dose is higher at higher altitude and latitude, a possible solution is to decrease the aircraft altitude and latitude. However, the geographic and altitude limit are difficult to determine. Currently, airlines are not flying polar routes when a radiation storm is in progress.

- **Forecasting for Aviation**. The Met Office in the UK have recently created a Space Weather Centre to monitor and inform flight crews of space weather related events and risks. This will be expanded over the coming years.

1.6 Future Developments and Commercial Opportunities

Environment

In a near future perspective the most important impact of the further GNSS application will be environmental since it will save aviation fuel and reduce the environmental impact of flight. To tell this tale, we begin by discussing a parallel development: the eco-routing of automobiles.

Following this ground-based discussion, the subsection Optimized Enroute Flight extends the discussion to oceanic paths that adapt to weather conditions on a seasonal, daily, or even hourly basis.

Optimized Routes

The GNSS also enables advanced procedures for aircraft in enroute or oceanic flight by considering distance, winds, and convective weather. While eco-routing on the road is limited to choosing the best route using existing highways, eco-routing in the air can go one step further, choosing efficient routes that break free from the traditional highways in the sky. Assisted by GNSS, aircraft can now safely fly routes that deviate from the fixed air traffic service (ATS) routes, realizing significant fuel savings and emissions reductions, while simultaneously saving time and reducing conflicts.

Flexible track systems

The simplest form of optimized routing in the sky is the flexible track system. Operators design and fly an optimized track between a pair of cities, a route that is predicted to be more efficient than the traditional ATS route based on general meteorological forecasts and a representative aircraft performance model. This optimized track becomes the route for all flights between the paired cities and is updated seasonally. Demonstrating the potential inefficiency of the old fixed tracks, and the potential savings that can be realized by switching to flexible track systems, a trial of 592 Emirates Airlines flights between Dubai and Melbourne/Sydney resulted in an average fuel savings of 1,000 kg per flight, and an average of 6 min saved per flight.

User-preferred routes (UPR)

User-preferred routes are like flexible track systems, but they are updated for individual flights based on short-term, specific forecasting. They consider the specifications of the aircraft that will be flying, and the most up-to-date information about the wind and convective weather for the specific date and time the aircraft will be flying. UPRs optimize the track for a single flight, which can be significantly different from the optimal track for the same flight flown by a different aircraft at a different time on the same day. As a result of this flight-specific optimization, UPRs have even greater fuel-saving potential than flexible-track systems. In UPR flight tests between New Zealand, and Japan and China, Air New Zealand obtained a savings of 616 kg of fuel savings per flight, adding up to savings of 1.09 million kg of fuel and 3.44 million kg of CO2 per year. In a model of 15 million flights over the course of a year in the United States national airspace, optimizing for wind resulted in an average fuel savings of 95 kg per flight, and an estimated time saving of 2.7 min per flight. In addition, there was an estimated 29% reduction in conflicts because of route diversification, meaning that UPRs could potentially improve safety in addition to fuel economy.

Dynamic airborne reroute procedure (DARP)

Dynamic airborne reroute procedures are like FTS and UPR, but they can be updated during the flight, based on short-term, specific forecasting. DARP flights begin with a UPR route but update this route enroute based on the current weather. Based on its DARP flight tests between Auckland (AKL) and SFO, Air New Zealand reports that 58% of their AKL–SFO flights have the potential to benefit from DARP, and that for AKL–SFO flights utilizing DARP, the average fuel savings is 450 kg.16 For comparison, the entire fuel burn for a 737-800 flying from AKL to SFO is approximately 35,000 kg, and so these fuel savings are between 2% and 3% of the entire burn.

Safety

As described above, satellite navigation holds much promise for improving flight efficiency and reducing fuel use and greenhouse gases. GNSS does this by providing an RNAV capability. No longer will aircraft be constrained to fly point-to-point paths defined by ground-based navigation aids or overly restrictive air traffic zones.

Aircraft will not need to dive-and-drive when approaching airports; they will descend continuously toward the airport, maximizing aerodynamic efficiency. In the fullness of time, aircraft will also be able to make carefully timed turns to join the queue of aircraft approaching an airport. They will adapt their speed while enroute to synchronize this coordinated merge with their flying colleagues. Their enroute flight will also be optimized based on the likely or current weather.

Required Navigation Performance (RNP)

Satellite navigation supports RNAV, but this is not sufficient. For full benefit, GNSS must also provide RNP. The RNP comprises four tightly woven requirements on the safety of flight.

Accuracy

It describes the day-to-day or nominal error performance of the system. As described below, it is measured at the 95% level, and has two components: navigation sensor error (NSE) and flight technical error (FTE). NSE measures the performance of the navigation sensor, while FTE measures the performance of the human pilot or automatic pilot.

Performance monitoring

It protects the navigation sensor from rare events. In contrast to accuracy, it is measured at the 10^{-5} 10^{-7}, or 10^{-9} level. In the case of GNSS, NSE monitoring must detect human-made faults, space weather, and bad actors. All of these are described in the sections that follow, along with the augmentation systems that detect these events and broadcast worst-case error information in real time.

Reliability of the aircraft equipment

It measures the ability of the navigation system to provide navigation without interruptions. Air navigation systems must be reliable; the meantime between-failure of the airborne hardware shall be greater than 100,000 h. Such reliability is difficult to achieve with a single string of electronics, and so GNSS avionics are duplicated, triplicated, or even arranged in a dual–dual configuration. The avionics manufacturer and the air framers are responsible for the resulting reliability of the airborne equipment.

Signal-in-space

It refers to the signals from the core GNSS constellations and the augmentation signals sent as part of performance monitoring. The constellation service providers (i.e., Europe for Galileo) are responsible for the quality of the GNSS signals. The air navigation service providers (ANSP) are responsible for the integrity of the augmentation signals. As an example, the ANSP in the United States is the Federal Aviation Administration (FAA).

Manned Drones

One of the most promising sectors of the general civil aviation is the one liked to the manned drones' exploitation. For manned drone it is intended a flying VTOL-like vehicle with autonomous guide and able to carry a certain number of passengers from point to point within the same town or from town to town in most complex and evolute scenarios. Autonomously guided flying vehicle are heavily depending by several onboard sensors (video, radar, lidar, I/R, etc.) as also on GNSS technology.

In a future scenario when manned drones will flying across the skies the increasing safety parameters and the IA-driven interactions among the ATC (Air Traffic Control) and the USSP (U-Space Service Provider, where the U-Space is the sum of the flight layers where drones, manned or unmanned, will operate) will generate a real GNSS "data hunger" that could be solved only by a multi-constellation approach. Since only the interpolation of multiple constellation navigation data will ensure the navigational accuracy associated with the level of safety needed when passengers are onboard.

The above considerations are obviously worldwide valid, but there is more than an aspect that could specifically regard the Center and Latin America area:

- The reduced cost of manned drone's vs general aviation players (aircrafts and helicopters).
- The reduced environmental impact of manned drone's vs general aviation players (aircrafts and helicopters).

- The ever-increasing touristic demand especially toward archeological and vacations area in Center and Latin America, that manned drones could and would better satisfy respect the traditional general aviation's players. Let alone the capability of cross islands of such vehicles.

- The intrinsically VTOL (Vertical Take off and Landing) of the manned drones that will make up for the scarcity of good autoroutes or the lack of airports/airfields once at destination.

- Finally, the manned drones will be also utilized to transport people in emergency (Heli ambulance) or to provide relief means or evacuation means in case of natural disasters (e.g. floods, earthquakes, volcanoes activity).

As reference it is possible to introduce the ICARUS project conducted by Telespazio (Leonardo and Thales-Alenia Space joint venture): ICARUS has been set the great challenge of defining the so-called Common Altitude Reference System (CARS), an altitude monitoring system applicable both to drones (or Unmanned Aerial Systems - UAS) and to manned aircraft within airspace known as VLL, an acronym that stands for Very Low Level - i.e. lower than 120 meters.

ICARUS responds to these needs with an innovative solution based on satellite positioning systems (Global Navigation Satellite Systems, GNSS) receivers which are already installed on drones. By using multi-constellation and multi-frequency GNSS signals, also integrated with weather and geoinformation data, ICARUS is able to offer sub-metric accuracy in measuring height relative to ground level and therefore to enable flight operations in environments with high traffic density.

In particular, ICARUS makes it possible to accurately and precisely measure the vertical distance from the ground itself and from obstacles on the ground, sending alerts to the pilot if there is the possibility of collision with other aircraft or the surrounding environment. The solution also offers pilots of drones and civil aircraft an altitude conversion system, from barometric to geometric altitude and vice-versa.

With its innovative approach, therefore, ICARUS has the capability to win the new challenges of integrating drones within VLL airspace, and not only. The solution also uses drones to advance new paradigms for the entire aviation sector. Once the solution's functionalities within the UAS context have been demonstrated, the project plans to also use the platform in manned aviation in both the VLL environment and - prospectively - also beyond this limit, enabling integration between manned and unmanned aircraft.

The drone sector - or more correctly the remotely piloted aircraft sector - is one of the main challenges that Telespazio has taken on in its drive towards future growth. This will be pursued both by developing innovative new business solutions and end-to-end services and also by supporting the definition of the new U-Space world, the basis of the future development of the drone market, through the company's participation in research and development projects promoted by SESAR JU, for example ICARUS and AURA.

In this context the company is one of the founders of D-Flight, established in 2018 with ENAV and Leonardo to develop the first national UTM Unmanned Traffic management system with the ability to cater both to traditional air traffic requirements and the growing application needs of UAS.

As part of a desire to increase its portfolio of services also in new sectors like UAS, Telespazio successfully tested T-DROMES - a platform designed to manage drone fleets and to cover all phases of a mission - in a series of test flights carried out in collaboration with Leonardo, ENAC and the Bambino Gesù Children's Hospital. Aided in particular by T-Dromes, the drones flew between two hospital locations over 30 km apart, between the S. Marinella test centre and the Palidoro analysis center and back, using an automatic control mode beyond the visual line of sight (BVLOS) of the operator.

In conclusion is possible to affirm that both future developments and commercial opportunities in GNSS applications for manned aviation will be tightly connected. As also the Big Data management issue linked to the next manned drones revolution and the multi-constellation needing.

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