DOCUMENT
GSM-G-CPL.026

DOCUMENT TITLE

NAVIGATION 1

CHAPTER 11 – GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

Version 2.0
October 2017

CONTENTS

GLOBAL NAVIGATION SATELLITE SYSTEMS

11.1 Satellite Navigation Systems

Satellite navigation systems developed in recent years offer global, all-weather, continuous and highly accurate navigation information. Satellite navigation has the potential to supersede all other navigation aids for approach as well as en-route phases of flight.

This section explains the principles of satellite navigation and describes the American GPS and Russian GLONASS systems. It also describes the development of the European GALILEO satellite navigation system and the approvals of Global Navigation Satellite Systems (GNSS) for day VFR (Visual Flight Rules) flying operations.

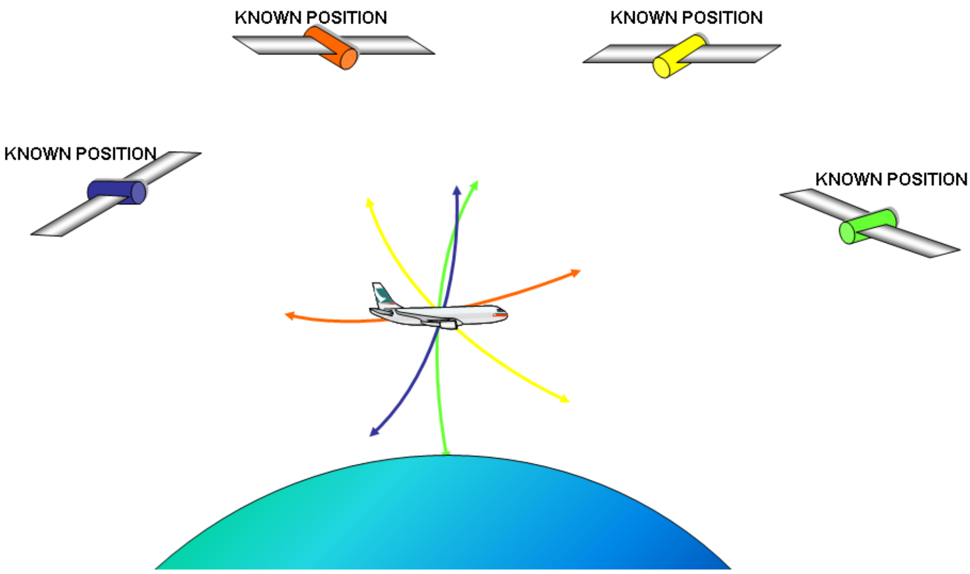
More information on GNSS and the approvals for VFR and IFR (Instrument Flight Rules) flight can be obtained in CAAP 179A-1(1).

11.2 Principle of Satellite Ranging

Satellite navigation receivers fix the position of aircraft by obtaining a number of range position lines. The intersection of the position lines is the three dimensional position of an aircraft.

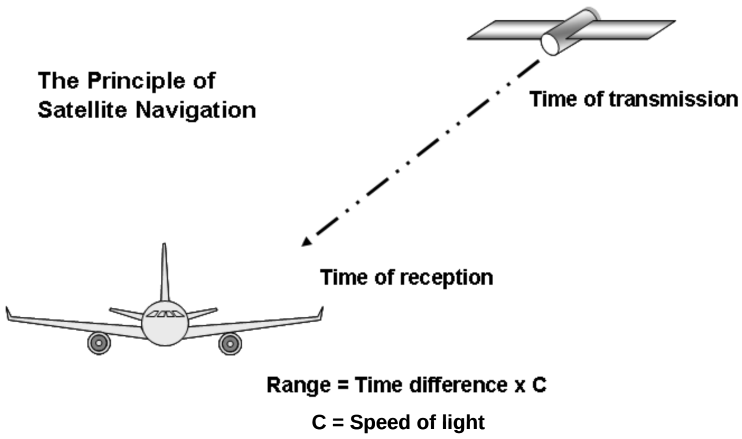
A receiver is required to simultaneously (or sequentially) measure range from several satellites, the positions of which are known from data broadcast by the satellites.

At least **4 satellites** with good geometry are required to obtain a **3D fix**. If only **3 satellites** are in view, a **2D fix** can be obtained if the system is provided with altitude.



Satellite ranging is similar to the principle of Distance Measuring Equipment (DME). Time and speed of radio waves are used to calculate distance. However, unlike DME, GNSS receivers are passive and calculate time duration for the one way journey of the satellite's transmission to the aircraft. To do so accurately, the receiver must know the time of transmission on the basis of a clock exactly synchronised with that of the satellite.

The satellite's transmissions are precisely timed by means of up to four atomic clocks. Unfortunately the receiver's quartz clock is less accurate and there is an unknown time difference between receiver and satellite clocks that GNSS resolves mathematically provided sufficient satellites are in view.



11.3 Global Positioning System

The American satellite navigation system, referred to as GPS (Global Positioning System), consists of three major segments:

- **Space:** Constellation of satellites.
- **Control**: Consists of the master control station in Colorado, USA and a number of monitor stations located around the world.
- **User:** Consists of the user's equipment (receiving, decoding and processing satellite signals).

The original GPS constellation consisted of 24 satellites, including 3 operational, in-orbit spares, orbiting the Earth in just under 12 hours. As of February 2016 there are 32 satellites in orbit of which 31 are operational.

The satellites operate in six planes that cross the equator at an angle of 55° with a maximum of 4 satellites in each plane. The orbital planes are at an altitude of about 10,900 nm (20,200 km). The current system allows at least 9 satellites to be in view from any point on the surface of the Earth.

11.3.1 Operation of GPS

GPS operates on two L-band frequencies:

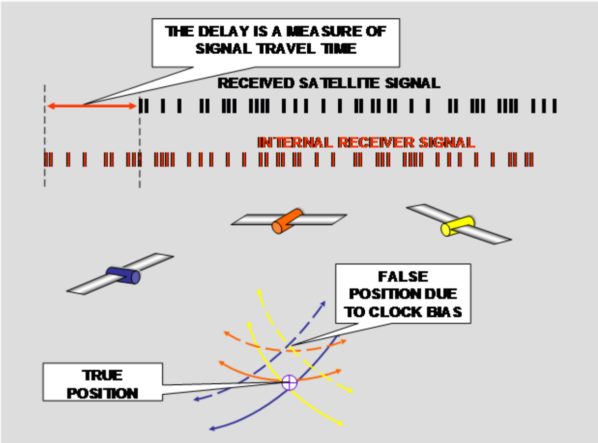
- L1 band (1575.42 MHz) modulated with two pseudo-random codes, P (Precise) for military use only and C/A (coarse acquisition) for civil use. The position accuracy of the C/A code was deliberately degraded to ±100* metres but from May 2000 this process, known as selective availability, was discontinued. The accuracy for C/A code users is now potentially ±30* metres. (* Assuming a PDOP value of 3).
- L2 band (1227.6 MHz) P (precise code only) for military use with an accuracy which is potentially ±6 metres.

The first L5 band (1176.45 MHz) satellite was due to be launched in 2006/7. The L5 band introduces another civilian frequency that can be used with the existing L1 band to reduce Ionospheric errors.

For identification purposes each satellite has its own unique C/A and P digital codes and although it appears to be random, it is well defined and predictable, and known as pseudo-random codes. Satellites use low power transmissions (lower than the background noise at that frequency) and the weak signals are spread over a wide bandwidth making it less susceptible to jamming. The receiver can detect the signals by reproducing an exact copy that it matches with the received signal.

Each satellite's unique pulse train (the pseudo random code) contains the identification code, the satellite position in space and the exact time it was transmitted. The receiver generates an identical C/A code pulse train at precisely the same time but due to the signal travel time it is not synchronised with the transmission.

The receiver automatically slews the pulse train it is generating in order to match the two signals. When they are matched the receiver 'locks on' and the receiver can measure the signal travel time plus or minus the timing error of the receiver's quartz crystal oscillator.



Due to this timing error, the range measured is referred to as 'pseudo-range'. As the timing error or clock bias at the receiver is the same for all pseudo-ranges measured at that time, it can be eliminated by using a number of simultaneous equations.

11.3.2 Positions of the Satellites

The measurements of range can only be used to obtain a fix if the positions of the satellites are known. Long-term predictions of the satellite positions are made in the form of almanac data which is valid for many months.

The ground monitoring stations accurately measure the satellite's current position, altitude and speed and relay that information to the satellites. This information is transmitted by the satellites to the GPS receiver in the form of ephemeris data.

Each satellite transmits almanac data for that satellite and for every other satellite in the system as well as its own ephemeris data. Ephemeris data is the most accurate information on any variations in a satellite's orbit and is unique to each satellite.

Ephemeris data also includes satellite status, current date and time, orbital location and velocity. All the above information is contained within the NAV message transmitted with both C/A and P codes.

11.3.3 Contents of the GPS Navigation Message

The GPS Navigation message contains:

- Clock correction data
- Ephemeris data
- Ionospheric correction index
- UTC time
- Almanac data.

> It takes 12.5 minutes to download all the almanac data.

11.3.4 Speed of Radio Waves

Accurate range calculation from the measured time interval also requires that the speed of the radio signal from the satellite is accurately known. Radio waves travel approximately 300,000 kilometres per second and slows as it passes through the ionosphere and the atmosphere.

The Ionosphere is a layer of electrically charged particles about 150km above the surface of the Earth. Ionospheric slowing depends on time of day (i.e. diurnal variation), season, solar activity, radio frequency and other factors.

This can be partially predicted and corrections are automatically applied. Since the delay is inversely proportional to the square of the frequency, P code receivers using both L1 and L2 frequencies are able to assess the delay and almost eliminate the error. In the atmosphere further slowing also takes place due to the presence of water vapour.

11.4 Accuracy of GPS

Accuracy depends on the user. For users authorised by the US Department of Defence, Precision Position Service is provided by allowing access to the precision code (P) signals. These are generally military users and the resulting accuracy is ±6 metres for 95% of the time.

For Civil Aviation and other general civilian use, Standard Position Service is provided by means of the Coarse/Acquisition code (C/A) signals. Accuracy is downgraded to ±10 metres for 95% of the time. Position Dilution of Precision (PDOP) (par 11.5.3) can further degrade the quoted accuracy.

11.5 Sources of Errors

11.5.1 Survey Datum Discrepancies

The figures quoted for accuracy assume that the position given is referenced to the World Geodetic System 1984 (WGS-84) datum. The point of origin of WGS-84 is the Earth's centre of mass. GPS uses WGS-84 for establishing its position in relation to the Earth's surface and conforms to ICAO, which adopted WGS-84 as a world standard in 1998.

Formerly, various local and regional datums were in use giving rise to discrepancies of several hundred metres. This source of error has been largely eliminated through resurveying.

11.5.2 Ionospheric and Tropospheric Slowing of Signals

The most significant causes of error is the slowing of the satellite signals as they pass through the ionosphere and the atmosphere. P-code users with access to two signals on different frequencies can reduce the Ionospheric component of this error.

Ionospheric and Tropospheric slowing can degrade the calculated position by as much as 11 metres.

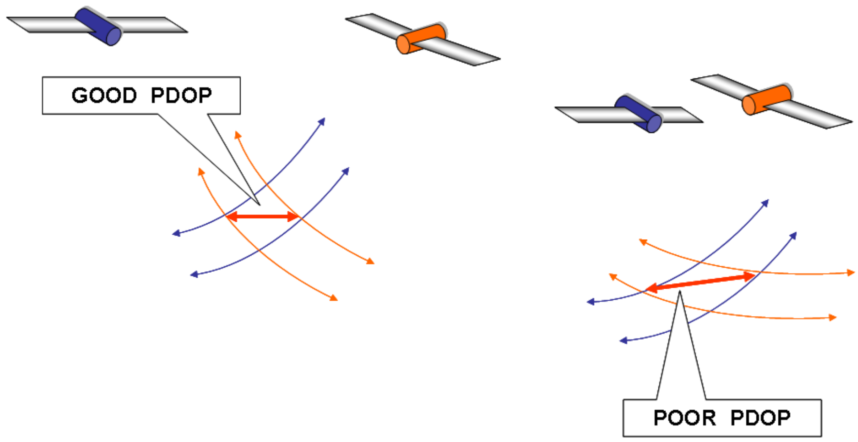
11.5.3 Position Dilution of Precision (PDOP)

If the geometry of the position lines from the available satellites is not ideal, the fixing error due to other causes is magnified. This source of error known as Position Dilution of Position (PDOP) can increase the fixing error from ±10 metres to ±100 metres.

This means the receiver is located in a certain band of distance from the satellite rather than a specific distance. Position Dilution of Precision (PDOP) puts the receiver somewhere inside a box formed by the overlapping bands.

When the satellites used are closer together (refer to the diagram below) the box is elongated and the potential PDOP is greater.

If the available satellites are clustered together, PDOP reduces the accuracy of the fix:



International Civil Aviation Organization (ICAO) has specified that for en-route navigation, a PDOP of less than 6 is required and a PDOP of less than 3 is required for non-precision approaches.

11.5.4 Multipath

Multipath is an error in range measurement resulting from the reflection and refraction of the satellite signals by objects and terrain near the GPS receiver.

Multipath errors can degrade the calculated position by about 3 metres.

The use of a masking function that excludes satellites below a fixed elevation angle relative to the user's horizon limits both multipath and Ionospheric / Tropospheric errors. Equipment that meets the TSO C129 specification uses a mask angle of 7.5°

11.5.5 Clock Errors

Timing errors due to inaccuracies in both the satellite and receiver clocks, as well as relativity effects, can result in small position errors. Relativity effects arise because of relative motion between the satellite and the receiver.

Clock errors can degrade the calculated position by about 3 metres.

11.5.6 Receiver Noise

The satellite signals are wide spectrum, low power transmissions and are generally weaker than the background noise when arriving at the GPS receiver. The weakness of the signal affects the ability of the receiver to match the satellite and receiver generated codes and this can degrade the position by about 1.5 metres.

11.5.7 Ephemeris Error

Satellite ephemeris data is updated as the satellites pass over the earth monitoring stations. However, there is likely to be some small remaining discrepancy between the satellite's true position and the transmitted ephemeris data, causing position errors of about 3 metres.

11.5.8 GPS Error Budget

Sources of error	C/A code users	P code users
Clock errors	2 m	2 m
Ephemeris errors	4 m	4 m
Ionosphere	8 m	1 m
Troposphere	3 m	3 m
Receiver noise	1 m	0 m
Total error	**10 m**	**6 m**

Total errors found by the root mean square method. The accuracy figures quoted above will only apply if there is no position dilution of precision (PDOP). A PDOP of 3 is normally assumed.

11.6 GPS and GLONASS

The United States of America (USA) and Russia both developed satellite navigation systems that have common elements but also some significant differences. Both their commonality and their unique features reflect their military origin. I.e. the USA and Russia attempted to meet military navigation requirements by similar solutions but developed their own systems entirely independently.

The USA launched its first prototype GPS satellite in 1978 and achieved full operational coverage by 1993 with satellites launched from Cape Canaveral at the rate of 5 per year. Full operational coverage consisted of 24 satellites, i.e. 21 active plus 3 spares. Their design life is 7½ years.

The Russians developed GLONASS (Global Navigation Satellite System) to achieve the same purpose and with a similar design. Satellites were launched from a base near the Aral Sea, the most southerly region of Russia. The first was launched in 1982 and Russia continued deployment at the rate of 2 launches per year, each rocket containing 3 satellites. Full operational coverage of 24 satellites was achieved in 1995 but after the collapse of the Soviet Union GLONASS fell into disrepair. It was recovered and restored in 2011.

There are obvious advantages in designing receivers that use both systems. Potentially users will have more satellites in view at all times, increasing system availability and integrity. However, there are significant technical difficulties in building receivers that can simultaneously track GPS and GLONASS satellites.

11.7 Barriers to the Approval of GPS by Civil Aviation Authorities

Aviation authorities have been reluctant to approve GPS as a sole-means navigation source. Lacking both a record of reliability and a built-in integrity monitoring system, authorities have been cautiously approving GPS as a supplementary or primary means of navigation.

To achieve sole-means approval, a navigation system must satisfy five basic performance characteristics: accuracy, availability, reliability, coverage and integrity.

Supplementary means it must be used in conjunction with a sole means navigation system, whereas for primary means it must meet accuracy and integrity requirements but need not meet full availability and continuity of service requirements.

Availability and integrity are the major reasons preventing the use of GPS as a sole means of navigation and are defined as follows:

- <u>Availability</u>. The ratio of the total time a facility is operationally available to the total time in a specified period.

Current minimum operational standards require there to be a minimum of 5 satellites in view above a mask angle of 7.5°. For short periods of time, in some places, GPS with full operational coverage does not meet this requirement.

- <u>Integrity</u>. The trust that can be placed in the correctness of information from a system. The term includes the ability of a system to provide timely warnings to users when a system should not be used for navigation.

Individual GPS satellites are not continuously monitored and considerable time could elapse before a ground station detects and corrects a problem. Meanwhile receivers may continue to use the erroneous signal resulting in navigation errors.

11.8 GPS Developments

There are a number of developments that can overcome the availability and integrity limitations of GPS. These are listed and described below.

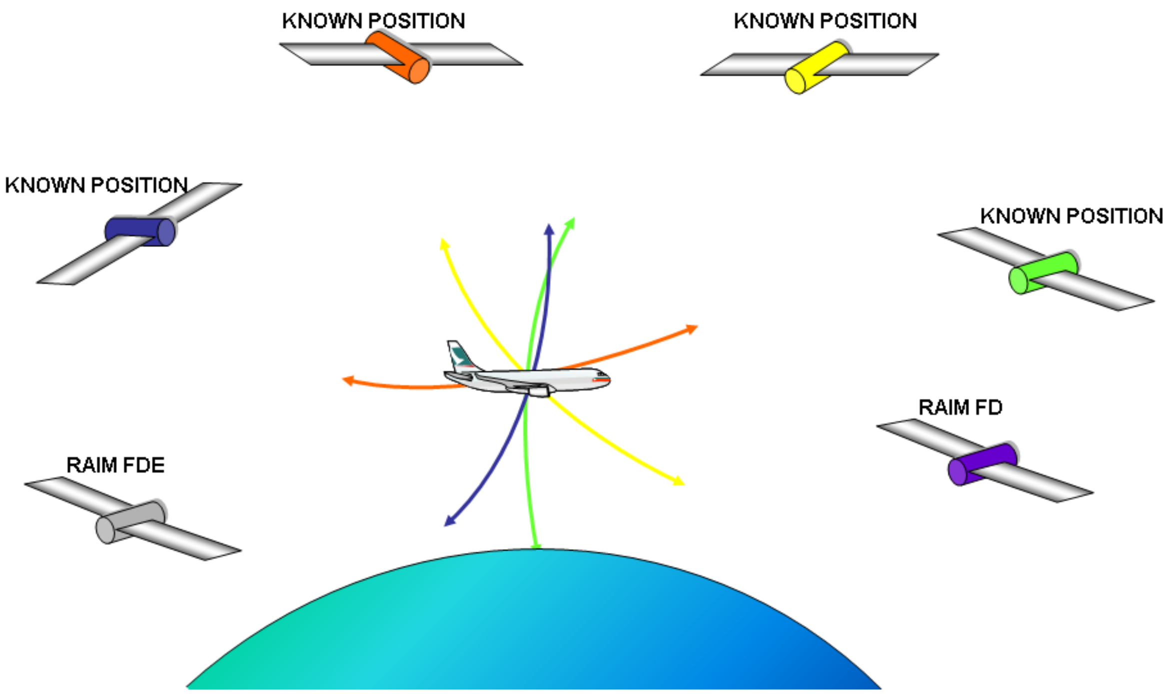
11.8.1 Receiver Autonomous Integrity Monitoring (RAIM)

RAIM detects the failure of a GPS satellite by comparing position and time information from various combinations of four satellites in a set of at least five visible satellites. In this way a faulty satellite can be detected and a warning provided to the pilot.

A minimum of six satellites must be visible for the RAIM function to continue following the detection of a faulty satellite. GPS, even with full operational coverage (FOC), does not meet the integrity requirements by means of RAIM at all times and places.

RAIM can be assisted by means of Barometric Aiding (see below) which effectively adds a further position line, reducing the requirement for visible satellites by one.

The RAIM limit for en-route operations is 2nm, for terminal operations it is 1nm and for non-precision approaches it is 0.3nm.



11.8.1.1 RAIM Outage

RAIM outages (holes) are occasions when there are limited satellites, with the required geometry for integrity monitoring, in view by the receiver.

RAIM outages can be predicted for flight planning purposes and the information is available at www.airservicesaustralia.com.

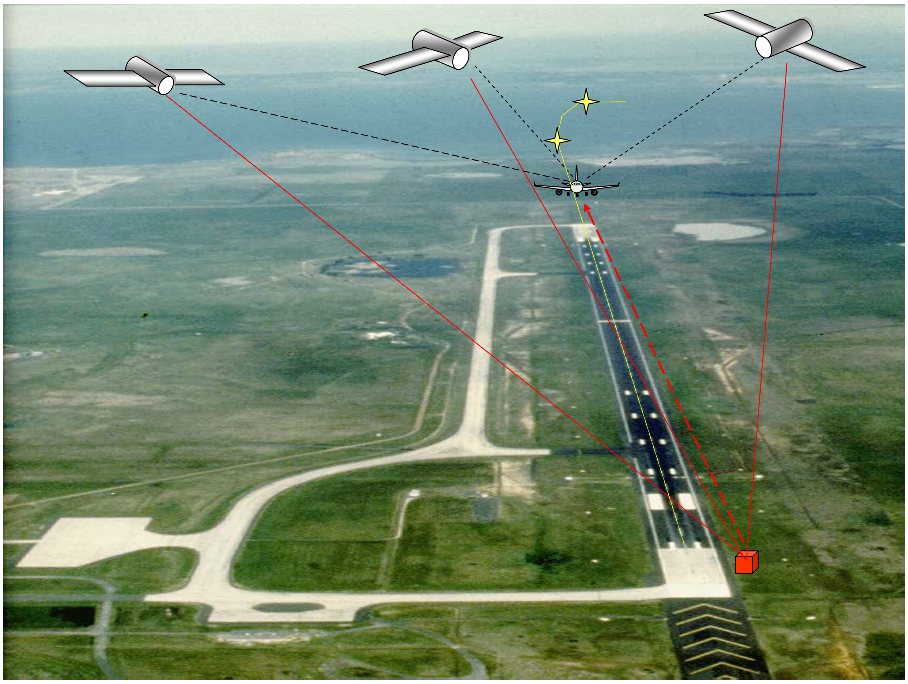
CASA cautions the use of the GPS receiver's built in RAIM prediction function for flight planning, as it may lack data forming the basis of the Air Services predictions.

11.8.2 Differential GPS - Approach Phase and Wide Area (WADGPS)

Differential systems use ground based monitoring equipment at accurately surveyed locations to determine the error in the GPS signal. A differential correction can be computed by comparing the GPS position with the surveyed position of the monitoring station and the correction relayed to the aircraft's navigation system.

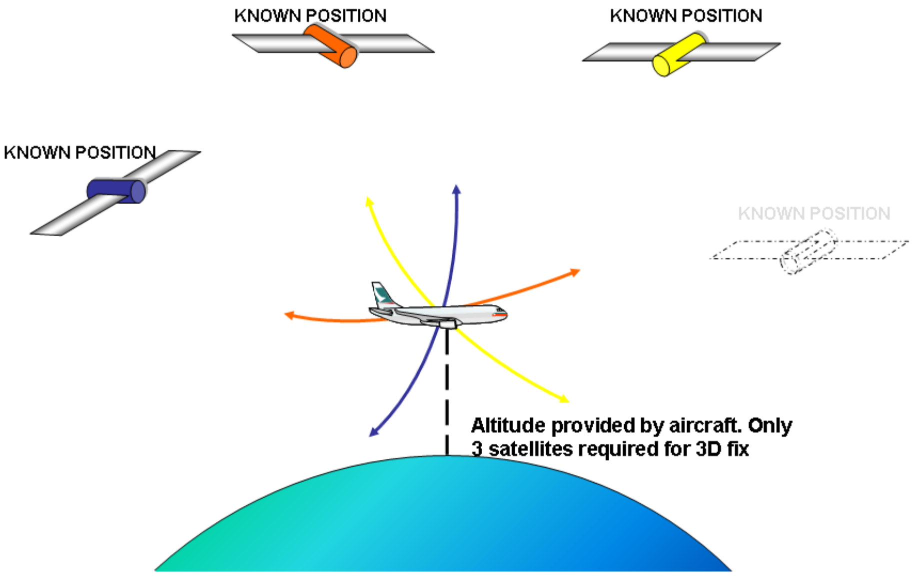
Differential GPS can be used to achieve the accuracy required for a precision approach by means of a monitor located at the airport. It can also be used as Wide Area Differential GPS (WADGPS) to provide a correction service to an entire continent by relaying information to users via a geostationary satellite.

Integrity and differential monitoring can also be described as augmentation systems, either as Ground Based (local area) Augmentation Systems (GBAS) and Space Based (wide area) Augmentation Systems (SBAS). Wide area augmentation is being developed by the US, Europe and Japan.



11.8.3 Barometric Aiding

With barometric aiding the GPS receiver obtains another measured range by using the output of the pressure altimeter or SSR (Secondary Surveillance Radar) mode C, therefore one less satellite is required.



11.8.4 Other Global Navigation Satellite Systems

The coverage of the American GPS satellites alone may not meet the integrity and availability requirements of civil aviation in all locations and at all times. At times there have been ‘worm holes’ in the coverage, lasting from a few minutes to a few days, that have caused degradation of accuracy or even total loss of GPS service.

GLONASS can be used to supplement GPS coverage, but other navigation satellite systems are also under development.

The European Navigation Satellite System, known as GALILEO, has been offering Early Operational Capability (EOC) in December 2016, and is expected to reach Full Operational Capability (FOC) by 2019 with the complete 30-satellite system expected in 2020.

GALILEO will have 30 satellites in three different circular orbits, inclined at 56° to the equator. There will be 9 satellites in each orbital plane and GALILEO is expected to be fully compatible with GPS so that receivers will be able to combine signals and achieve greatly increased accuracy.

China has indicated that it intends to expand its regional navigation system, termed Beidou Navigation Satellite System (BDS) or Northern Dipper, into a global navigation system by 2020. Beidou-2 (formerly known as COMPASS) supersedes the Beidou-1 system and will consist of 30 satellites in medium Earth orbit and five satellites in geostationary orbit.

11.8.5 Multi Sensor Systems

Availability and integrity problems can be overcome by combining GPS with another system. Various combinations have been proposed including GPS/MLS and GPS/IRS. GPS used in conjunction with an Inertial Reference System (IRS) provides an optimum solution that makes use of IRS position and velocity data during periods when insufficient satellites are available. It effectively combines the long term accuracy of GPS with the short term accuracy of IRS.

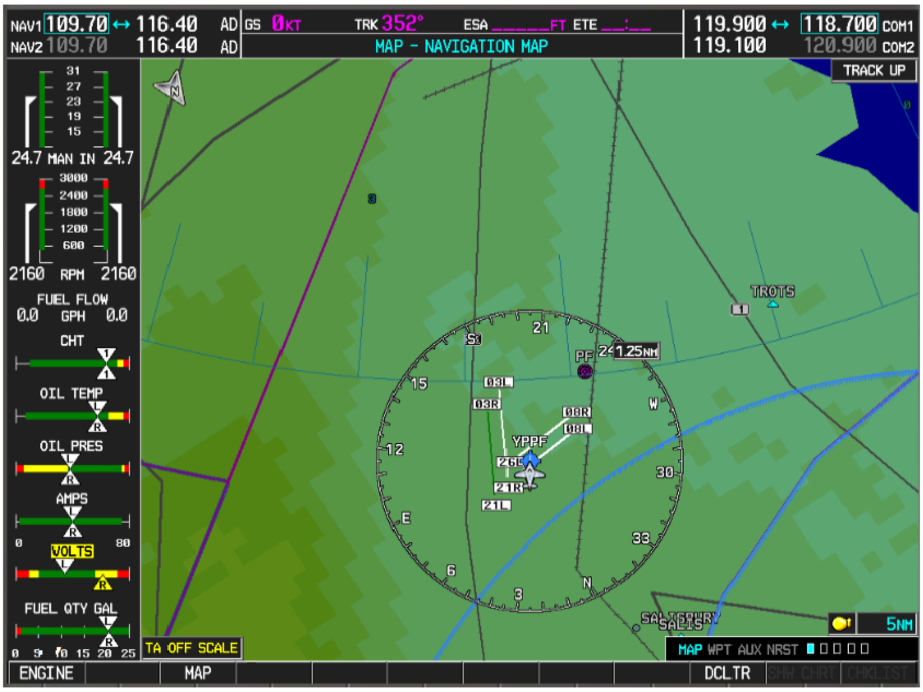
11.9 Typical GPS Receiver

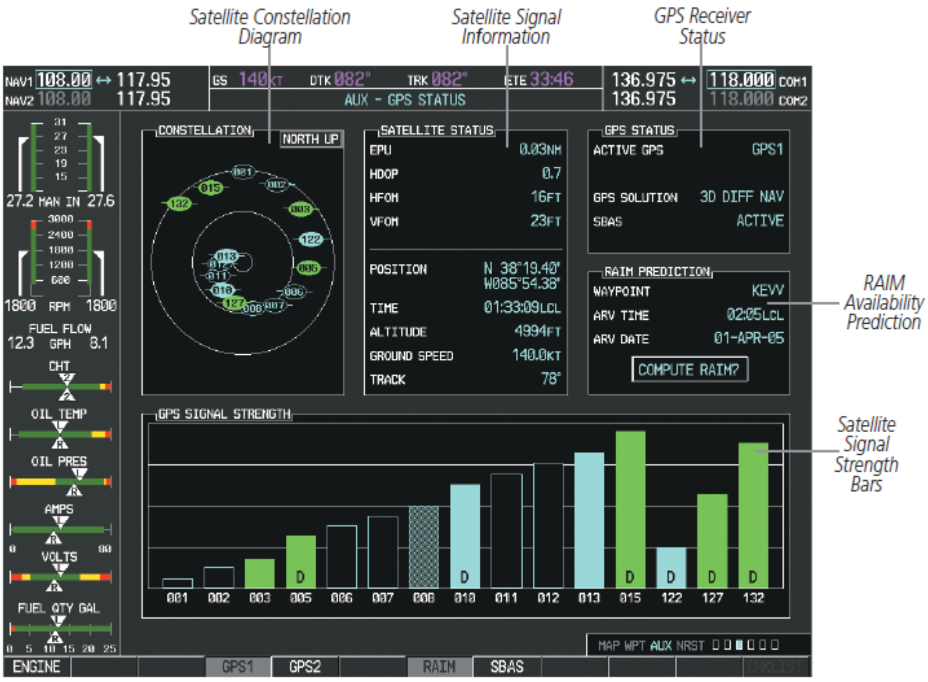
Illustrated below are two GPS pages from the GARMIN G1000 receiver, as installed in the DA40 Diamond Star training aircraft used by FTA.

The first picture is the navigational moving map display and the second is the GPS status page. The system provides the following:

- Current position
- Waypoint navigation
- Dilution of precision information
- Current and future satellite coverage
- Evaluation and selection of best satellites
- Dead-reckoning during coverage gaps and various other data
- RAIM prediction.

The operating procedures for the G1000 will be covered in a mass brief during the flying phase.





11.9.1 Good Practices When Using GNSS

Recommended GNSS practices:

- Plan the route using charts suited to the type of flight.
- Enter the navigation planning data into the GNSS unit or retrieve a saved plan from volatile memory.
- Check the information in the GNSS database and user waypoint information against a chart or a flight plan containing waypoint names, identifiers, latitude/longitude, tracks and distances. (Cross checking both latitude/longitude information and bearing/distance information will prevent a charted error being carried over to the GNSS.)
- When entering data manually, get a crew member to check that the data is entered accurately. If the information seems to be incorrect, reference it against appropriate documents. For single pilot operations, do cross checking by comparing GNSS computer tracks and distances with current chart data.
- Use ‘Flight plan mode’ to compare GNSS-derived distance and bearing information with the pre-flight planning.
- Check each route leg for input errors.
- Customise the worldwide database to only access information from a particular region, thus reducing the amount of waypoint scrolling, e.g. Australia.

11.9.1.1 Occasions to Check Data during Flight

Check the manually entered and database derived position tracking information:

- Before each compulsory reporting point
- At or before arrival at each en route waypoint
- Every hour during area type operations, especially when deviating from established routes
- After insertion of new data e.g. creating a new flight plan
- Check GNSS NOTAMs and other warning information
- Check that the database is current (displayed after the GARMIN G1000 is powered on)
- Ensure the presence of the GNSS operating manual for the unit during the flight.

11.9.1.2 Use of the DIRECT TO Function

The 'DIRECT TO' or 'GO TO' function is used to navigate directly from the current position to a nominated waypoint. This function is useful when ATC instructs an aircraft to route direct (track direct) from present position, or when a weather diversion is required.

Beware of the proximity to controlled airspace and restricted area boundaries when using this function, cross check against current maps, charts and NOTAM information.

The 'DIRECT TO' function may cause the aircraft to track away from a published ERC airway track; the pilot will need to reassess the lowest safe altitude along the revised track.

11.9.1.3 Use of the NEAREST AIRPORT Function

GNSS equipment can present a list of the nearest airports, VORs, NDBs, intersections and approaches. The nearest airport function is used to search for the nearest landing area in the event of an in-flight emergency.

11.9.2 System Warnings and Messages

Currently there are no specific design guidelines that manufacturers of GNSS displays need to comply to, the types and method of depicting warning or notification messages differ from receiver to receiver.

Users of GNSS equipment are expected to be familiar with the meaning and severity of impact on integrity of navigation data, the different types of warning messages displayed and corrective actions to be taken for each message.

Certain messages are provided for informational purposes only and require no user interaction, whilst others notify the user of a critical failure or loss of integrity.

TSO-specified GNSS equipment uses internal and external message lights to convey special messages. New messages are indicated by a flashing light. Press the message key to access the message. The unit will store messages relevant to the current stage of the flight and the message light will remain steadily illuminated. Press the message key to sequence through all messages stored. When the unit no longer deems the messages relevant, it deletes the messages and the light goes off.

Discussed below are examples of typical warning and status messages, their meaning and implications for the flight.

11.9.2.1 Loss of Integrity

When the receiver loses the RAIM function, integrity cannot be guaranteed Different units have different messages to indicate this situation. Users should familiarise themselves with the receiver before using it in IMC (Instrument Meteorology Conditions). If RAIM is lost, navigation should not be based on the GNSS solution. This may require climbing to LSALT or following navigational aid (navaid) failure procedures.

11.9.2.2 RAIM Errors and Failures

Various warnings are displayed when RAIM detects a failure in the navigation solution. Certain units may disable the navigation display, requiring the use of another means of navigation.

11.9.2.3 2D Navigation

The equipment is no longer tracking the minimum amount of satellites to provide a 3-dimensional navigation solution and RAIM is not available. With aircraft altitude information either automatically or manually entered, the equipment may provide a very basic navigation function. The accuracy and integrity can however not be guaranteed and the equipment may not be used for IFR navigation.

11.9.2.4 Dead Reckoning Mode

The receiver cannot locate the minimum amount of satellites to establish a positive fix. It is possible to enter heading and ground speed data, which will provide a DR navigation function. The receiver may continue to display navigation information, although it is not suitable for IFR use.

11.9.2.5 Database Out of Date

The installed database (i.e. data card) has expired. Although a current database is required for navigation approvals, it is possible to acknowledge the message and continue using the out-of-date data.

11.9.2.6 Database Missing

The database card is missing or not properly installed. Switch off the equipment and insert a database card or remove and re-insert the existing card. Follow the manufacturer's instructions when handling data cards. GNSS equipment and their data cards may be damaged by attempting to remove or install the card whilst the unit is switched on.

11.9.2.7 GPS Fail or Receiver Fail

Warnings appear when the GNSS electronics has detected an internal failure. It is necessary to have the equipment repaired by a manufacturer or authorised service centre.

11.9.2.8 Barometric Input Fail

The automatic barometric aiding function has failed. The equipment will prompt you to manually input altitude data and continue to provide navigation information. However, the equipment will not meet the requirements for IFR navigation.

11.9.2.9 Power or Battery Fail

Equipment may continue to function if internal backup batteries are installed. Use the aircraft checklists for such a failure.

11.9.2.10 Parallel Offset On

The parallel tracking mode is selected and the equipment guides the aircraft along the selected offset track, e.g. tracking around a thunderstorm. In controlled airspace do not use parallel tracking mode without an ATC (Air Traffic Control) clearance. In Class G airspace advice ATS (Air Traffic Services) of any intention to operate on offset track.

11.9.2.11 Satellite Fail

The receiver's RAIM function has detected a satellite failure. If the receiver is receiving a signal from sufficient satellites the faulty satellite can be deselected and it may be possible to continue navigation with RAIM.

11.10 Human Factors

As with all automated systems, GNSS may decrease workload in some areas while increasing it in others. It delivers gains in reliability, accuracy and system monitoring ability but is open to gross mistakes that are difficult to detect.

Ergonomic problems with the units, a lack of standardisation and the effect of technology on what human factors specialists call "liveware", i.e. the user, are among the sources of human error.

GNSS may distract the user from other tasks, e.g. controlling the aircraft, scanning instruments and maintaining a good lookout for other aircraft.

Automated systems can lull users into a false sense of security and take you ‘out of the loop’, at least until you have your first problem with it. It is near impossible to maintain situational awareness if you are not aware of what it is the system is doing.

It can even erode your basic navigational skills through lack of use. Cross checking, an appreciation of the technology’s limitations and the ability to revert quickly to traditional navigational techniques are countermeasures that can be used.

With their small control keys, GNSS units are prone to data entry errors. The displays of many units are also quite small, creating the possibility of display reading errors. System warnings, including RAIM warnings, are often indicated by relatively small symbols or lights. Panel mount your unit in a prominent, central position and familiarise yourself with the displays.

Mode errors are also a risk. GNSS units have different modes of operation, including “GO TO”, “DIRECT”, “WAYPOINT”, “ALERTS” and “SYSTEM STATUS”, and the function inputs can mean different things in different modes. Some systems do not display the current mode, forcing you to remember which one you are in.

11.10.1 Liveware

When you monitor a system like GNSS rather than control it directly, you are less likely to pick up and act on errors. In the long term, being out of the loop can erode skills like map reading, so you should maintain your basic navigation skills and not become so dependent on the system that you are unable to resume navigation in the event of a system failure.

Another liveware problem is that GNSS can breed complacency, especially among trusting pilots who have never encountered problems with it. The brain’s information processing capacity can be exceeded during high workload phases of flight, and pilots sometimes shed tasks to focus on ones they think are more important.

You might lose situational awareness if you are struggling with GNSS technology in flight, e.g. flicking through manuals, or pressing keys randomly hoping to find the page with the function/information you require.

Familiarise yourself with the technology and do as much preparation as possible, such as entering the waypoints for alternates on the ground to cut the in-flight workload.

11.10.1.1 Examples of GNSS and Human Error Related Incidents

To illustrate the problems associated with GNSS and human error related issues, included below are some extracts of actual incidents that have occurred involving misuse of GNSS around the world.

Extract 1: "The crew of an outbound aircraft had climbed through the altitude specified by ATC. Their aircraft was only 500ft vertically distant and 1.25nm horizontally distant from an inbound aircraft before ATC advised immediate descent. The investigation report explained that the pilot had given over his attention to the co-pilot who was struggling to reprogram their 'broken down' GPS unit.

Extract 2: "The accident report of a collision between two aircraft stated that the pilot of one of the aircraft became preoccupied with programming his GPS unit and impacted the other aircraft, the pilot of which was practising ground reference manoeuvres at the time."

Extract 3: "The pilot of an aircraft, which was destroyed when it struck trees on departure from an airport, told the investigator that his handheld GPS receiver had fallen from the instrument panel during the take-off roll and jammed the flight controls."

Extract 4: "The pilot was using a GPS receiver to navigate when, about 10 minutes before arrival, the receiver batteries failed. Becoming disoriented, the pilot then used up the remaining fuel trying to locate the airport, eventually making a forced landing into a parking lot."

11.11 GNSS Approvals

Since its inception GNSS has evolved into one of the principle means of navigation in Australia. There are limitations, depending on the sophistication of the receiver, of which users must be aware.

The first limited approvals for GPS were published in 1994, and since then CASA has gradually increased the list of approved operations. Most recently, the appearance of TSO-C145/C146 avionics has eliminated dependence on conventional navaids in some circumstances.

Details of the approvals are in the AIP and current regulations. CASA also publishes advisory material and pilots should refer to CAAP 179A-1(1) for the latest information.

11.11.1 Approvals for Day VFR Navigation

Pilots can use GNSS under the VFR in the following applications:

- Visual navigation
- Night VFR RNAV (Radio Navigation).

Pilots operating under the VFR may use GNSS to **supplement** map reading and other visual navigation techniques. This is not an approval to replace visual navigation techniques with GNSS.

Blind faith in GNSS has been blamed for a sharp rise in the number of violations of controlled and restricted airspace by VFR aircraft. Pilots should also be aware of the human factors and technical standards issues associated with different types of receivers and installations, as described in CAAP 179A-1(1).

11.11.2 Approvals for Night VFR Navigation

In addition to the use of GNSS to supplement visual navigation, pilots may train and obtain qualifications to use GNSS equipment as a night VFR navigation aid in Australian domestic airspace.

If GNSS performance degrades to the point at which an alert is raised, or there is other cause to doubt the integrity of GNSS information, the pilot in command must discontinue GNSS use and carry out appropriate navaid failure procedures.

11.11.3 Approvals for IFR Navigation

CASA approves the use of GNSS for a variety of IFR applications. These include:

- DR substitute
- IFR RNAV
- RNAV(GNSS) non-precision approach
- Oceanic RNAV
- GNSS landing system (GLS).

As in the case of VFR, if GNSS performance degrades to the point at which an alert is raised or there is other cause to doubt the integrity of GNSS information, the pilot in command must discontinue the use of GNSS and carry out appropriate navaid failure procedures.

Refer to CAAP 179A-1(1), for further information regarding IFR flight approval and the use of GNSS.